The First Year of JWST Science Conference

September 11 - 14, 2023

Conference Agenda
and
Abstracts

Agenda

Monday, September 11

Session 1: Introduction (Chair: Massimo Stiavelli)

8:00	***Breakfast***	
9:00	Welcome & Logistics	Marc Postman / Conference Chairs
9:10	Status of the observatory	Jane Rigby
9:30	Science timeline & future plans	Macarena Garcia Marin
9:50	Instrument Round Table Session	Marcia Rieke, Gillian Wright, Rene Doyon, Roberto Maiolino
10:30	***Coffee***	

Session 2: Galaxies I: High z (Chair: Marc Rafelski)

11:00	Galaxies in the Early Universe with CEERS and NGDEEP	Micaela Bagley (Invited, remote)
11:30	The Crown Jewels of JWST PEARLS: Project Overview and Main First Year Results	Rogier Windhorst
11:45	An unprecedented view of galaxies during the EoR with COSMOS-Web	Maximilien Franco
12:00	Galaxy Luminosity Functions at z>11 and Constraints on the Epoch of Reionization	Haojing Yan
12:15	*Poster pops*	
12:30	***Lunch***	

Session 3: Galaxies II: High z (Chair: Jeyhan Kartaltepe)

1:30	Starbursts Dominate The Star Formation Histories of 6<z<12 Galaxies	Alan Dressler (remote)
1:45	Finding and characterising the first galaxies in the Universe with JWST	James Trussler (remote)
2:00	A joint NIRSpec/IFU+ALMA view on massive galaxy assembly in the first 1Gyr of cosmic time	Mauro Stefanon
2:15	UV continuum slopes and their redshift evolution with PEARLS GTO and public JWST NIRCam imaging	Duncan Austin
2:30	Substantial gas reservoirs in young, star-forming galaxies at z=9-11	Kasper Heintz (remote)
2:45	Abundance of high z UV bright galaxies and implications for early stages of galaxy evolution	Andrey Kravtsov
3:00	***Coffee***	

Session 4: Exoplanets I (Chair: TBC)

3:30	Direct Detection of Exoplanets with JWST: a new opportunity to study solar-age giant exoplanets	Elisabeth Matthews (Invited)
4:00	The JWST ERS Program for the Direct Imaging and Spectroscopy of Exoplanetary Systems	Sasha Hinkley (remote)
4:15	A JWST Spectrum of a Habitable-zone Sub-Neptune	Nikku Madhusudhan
4:30	First comparative exoplanetology with JWST	Jacob Bean
4:45	Direct Imaging Spectroscopy of Substellar Companions with JWST	Kielan Hoch
5:00	***Close***	

Tuesday, September 12

Session 5: Solar System & Exoplanets II (Chair: Naomi Rowe-Gurney)

8:00	***Breakfast***	
9:00	Studying Small Bodies with JWST: New Insights into Solar System History Near and Far	Ian Wong (Invited)
9:30	The Atmosphere and Surface of Titan from JWST and Keck Observations	Conor Nixon
9:45	High-Contrast Science Performance with JWST NIRCam	Jarron Leisenring
10:00	Characterizing NIR Spectra of Flares from TRAPPIST-1 During JWST Transit Spectroscopy Observations	Ward Howard
10:15	***Coffee***	

Session 6: Exoplanets III (Chair: TBC)

10:45	Search for a secondary atmosphere on the temperate rocky exo-Earth TRAPPIST-1 d	Caroline Piaulet
11:00	Mid-infrared maps of exoplanets: from hot Jupiters to sub-Earths	Michael Zhang
11:15	The MANATEEs Year-Long Journey: Swimming Through New Chemical Species in Exo-Atmospheres with JWST	Luis Welbanks
11:30	First year views of gas giant exoplanet atmospheres in the mid-infrared with JWST/MIRI	Polychronis Patapis
11:45	*Poster pops*	
12:00	***Lunch***	

Session 7: Galaxies III: Lensing+ (Chair: Taylor Hutchison)

1:00	JWST and the Hubble tension	Adam Riess (Invited)
1:30	Unveiling the faintest galaxies over 6<z<15 with JWST	Hakim Atek (Invited)
2:00	What's going on inside star-forming galaxies? results from JWST IFU observations of lensed galaxies	Jane Rigby
2:15	Spatially Resolving the Distant Universe with JWST	Brian Welch
2:30	Resolving star formation processes at 100s pc resolution in distant galaxies with JWST	Adelaide Claeyssens (remote)
2:45	*Poster pops*	
3:00	***Coffee***	

Session 8: Galaxies IV: Structure (Chair: Marc Rafelski)

3:30	The Structural Evolution of Galaxies in the Early Universe	Jeyhan Kartaltepe
3:45	Morphology and Size Evolution of Galaxies to z~9 in the JWST Public Fields	Elizabeth McGrath
4:00	JWST MSA slit-stepping to reveal the emergence of the modern Hubble sequence	Ivana Barisic
4:15	PASSAGE: Parallel Application of Slitless Spectroscopy to Analyze Galaxy Evolution	Kalina Nedkova
4:30	The first massive quiescent galaxies	Adam Carnall (remote)
4:45	Discovery of a (mini-)quenched galaxy at z=7.3 and more evidence for bursty SFHs in the first Gyrs	Tobias Looser
5:00	***Close***	

Wednesday, September 13

Session 9: AGN I (Chair: Jeyhan Kartaltepe)

8:00	***Breakfast***	
9:00	Insights into Early SMBH Growth from the CEERS Survey	Dale Kocevski (Invited)
9:30	AGN selection and demographics: a new chapter with JWST/MIRI	Jianwei Lyu
9:45	A Crisis at Early Epochs?- Discovery of the Furthest Obscured RL AGN Candidate at z>7 in COSMOS-Web	Erini Lambrides
10:00	JWST CEERS & JADES Black Holes at z = 4-7: Implications for the High-z M-Mstar Relation and Seeding	Fabio Pacucci
10:15	First look of sub-arc dual quasars at z~2: spatially-resolved spectroscopy with JWST and ALMA	Yuzo Ishikawa
10:30	***Coffee***	

Session 10: AGN II (Chair: Massimo Stiavelli)

11:00	Early galaxies unveiled by the JADES and GA-NIFS surveys: infant black holes and pristine systems	Roberto Maiolino (remote)
11:15	EIGER: Detecting the host galaxies of luminous quasars at z>~6	Minghao Yue
11:30	Emission-line properties of simulated galaxies: high-redshift predictions for JWST	Michaela Hirschmann (remote)
11:45	Building Semi-Analytic Black Hole Seed Models to Analyze Seeding Conditions using IllustrisTNG	Analis Evans
12:00	Evolution in metallicity and ISM properties of galaxies across the cosmic time unveiled by JWST	Mirko Curti
12:15	Poster pops	
12:30	***Lunch***	

Session 11: Star formation, stellar populations & ISM I (Chair: Chris Evans)

1:30	On the importance of radiative feedback from massive stars: results from the PDRs4All ERS project.	Olivier Berne (Invited)
2:00	Interstellar Dust Extinction for JWST	Karl Gordon
2:15	H2 emission in the Orion Bar as observed with JWST	Ameek Sidhu
2:30	PDRs4All: Sulfur elemental abundance in the Orion Bar	Asuncion Fuente (remote)
2:45	*Poster pops*	
3:00	***Coffee***	

Session 12: Star formation, stellar populations & ISM II (Chair: Ryan Lau)

3:30	JWST observations of the compact object and 3D morphology of SN 1987A	Josefin Larsson
3:45	The PHANGS-JWST Treasury Survey: Star Formation, Feedback, & Dust Physics at High Angular Resolution	Janice Lee
4:00	MIRI's transformative view of ISM structure in nearby galaxies: Dust filament networks everywhere!	David Thilker
4:15	Resolving the Crowded Center of M33 into Stars with JWST	Adam Smercina
4:30	Star formation in extreme environments: Accretion onto pre-main sequence stars in NGC 3603.	Ciaran Rogers
4:45	JWST imaging and spectroscopic observations of the Ring Nebula, NGC 6720	Roger Wesson (remote)
5:00	***Close***	

Thursday, September 14

Session 13: SNe & GRBs (Chair: Ryan Lau)

8:00	***Breakfast***	
9:00	Peering into Supernova Explosions with JWST	Tea Temim (Invited)
9:30	Unraveling Cosmic Dust Origins: JWST Revelations from Supernovae	Melissa Shahbandeh
9:45	Serendipitous detection of the dusty Type IIL SN 1980K with JWST/MIRI	Szanna Zsiros
10:00	JWST's eye glimpses the progenitors of the two brightest gamma-ray bursts	Benjamin Schneider
10:15	Poster pops	
10:30	***Coffee***	

Session 14: Star formation & disks I (Chair: Chris Evans)

11:00	Stars like the sun take longer to form when the metallicity is low	Guido de Marchi
11:15	Young Stellar Objects at Low Metallicity in NGC346	Nolan Habel
11:30	Direct Imaging of YSOs: Observing five circumstellar disks to search for forming planets	Camryn Mullin
11:45	High contrast imaging of the debris disk around Beta Pictoris	Marshal Perrin
12:00	MIRI MRS Observations of the Beta Pictoris System	Kadin Worthen
12:15	Ions and complex molecules in space ice: insights from JWST Observations of Young protostarS (JOYS+)	Will Rocha
12:30	***Lunch***	

Session 15: Star formation & disks II (Chair: TBC)

1:30	MIRI maps a molecular disk wind, CO, and water in an edge-on protoplanetary disk	Nicole Arulanantham
1:45	JWST MIRI/MRS IFU Spectroscopy discovers a spatially resolved disk wind	Naman Bajaj
2:00	Probing gas composition and conditions in the inner au of protoplanetary disks: the first year of JW	Sierra Grant
2:15	JWST reveals excess cool water near the snowline in compact disks, consistent with pebble drift	Andrea Banzatti
2:30	Water in T Tauri protoplanetary disks after the first year of MINDS	Danny Gasman
2:45	The MIRI Excesses Around Degenerates (MEAD) Survey	John Debes
3:00	***Coffee***	

Session 16: Galaxies V: Dusty Galaxies (Chair: Taylor Hutchinson)

3:30	First look at the JWST/MIRI 7.7um sources in COSMOS-Web	Santosh Harish
3:45	Insights into HST-dark Star Formation from NIRCam and NIRSpec	Vasily Kokorev
4:00	MIRI-only sources in the MIRI Deep Imaging Survey (MIDIS)	Iris Jermann
4:15	Statistics for Galaxy Outflows at z~6-9 Identified with NIRCam and NIRSpec	Yechi Zhang
4:30	Uncovering the MIR emission of quiescent galaxies with JWST	David Blanquez
4:45	Closing Remarks	

Abstracts

Session 2: Galaxies I: High z

The Crown Jewels of JWST PEARLS: Project Overview and Main First Year Results

Rogier Windhorst

We give an overview and describe the main first-year results from the JWST project PEARLS (``Prime Extragalactic Areas for Reionization and Lensing Science''). PEARLS used up to eight NIRCam filters to survey 13 prime extragalactic survey areas: two fields at the North Ecliptic Pole (NEP); seven gravitationally lensing clusters; two high redshift proto-clusters; and the iconic backlit VV 191 galaxy system to map its dust attenuation. PEARLS also includes NIRISS spectra for one of the NEP fields and NIRSpec spectra of two high-redshift quasars. The main goal of PEARLS is to study the epoch of galaxy assembly, AGN growth, and First Light. Five fields, the JWST NEP Time-Domain Field (TDF), IRAC Dark Field (IDF), and three lensing clusters have been observed in up to four epochs over a year, designed to find faint variable objects such as weak AGN, high-redshift supernovae (at z>2), and cluster caustic transits. Observations from the first spoke in the NEP TDF and IDF are public, as as those of the the overlapping galaxy pair VV191, the most massive cluster El Gordo at z=0.87, and the TNJ1138 protocluster at z=4.1. PEARLS has found a lensed Supernovae up to z=1.78 and more than a dozen caustic transits of luminous stars beyond z=1--2, including the first luminous Red Super Giant discovered at cosmological distances. The El Gordo and CLG1212 clusters revealed a number of highly lensed dusty star-forming galaxies at z=2.3--4.3 at pc resolution, and a lensed proto-cluster or -group at z=4.3. The TNJ1138 protocluster shows a very high jet-induced SFR in one of the most massive radio galaxies known at z=4.1. VV191 shows reddening law in a local spiral with R~1.1-2 suggesting a different grain population than in our Galaxy. Galaxy-galaxy lensing is not uncommon in PEARLS. Finally PEARLS presents the 0.9--4.5 micron galaxy counts and their Integrated Galaxy Light; analyzing the JWST sky brightness in 13 NIRCam filters yields our first strong constraints to truly diffuse light at 0.9--4.5 micron. PEARLS is designed to be of lasting benefit to the community.

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An unprecedented view of galaxies during the EoR with COSMOS-Web

Maximilien Franco

I will present the first results from the JWST COSMOS-Web survey. This program maps a contiguous 0.6 deg^2 area using NIRCam (f115w, f150w, f277w, f444w), and a 0.2 deg^2 area with MIRI (f770w). This is the most ambitious JWST program both in terms of area covered at this depth and time allocated. With only 50% of the observations (the remaining half is arriving next December), we have already detected several tens of galaxies at z>9 and we are building the UV luminosity function (UVLF) of this field, finding an excess of bright galaxies compared with expectations. We are focusing our analysis on determining the origin of this excess by measuring the physical properties of z>8 galaxies (including SFR, star formation history, emission line strength, dust attenuation, UV slope, ionizing photon production efficiency, etc), and link derived properties to the large-scale environment of these very high redshift galaxies (on 10Mpc scales), leveraging the uniquely large size of COSMOS-Web. I will also outline the next steps for COSMOS-Web: the detection of thousands of galaxies at redshift greater than 6 - during the epoch of reionization - is expected, reaching most likely more than half a million galaxies across all redshifts. This will give us an unprecedented view of the formation and evolution of galaxies during the 500 Myrs after the Big Bang. In particular, the number

and properties of very high redshift galaxies will allow us to challenge different cosmological models of galaxy formation, estimate the size and growth of ionization bubbles, and constrain the speed of reionization of the Inter-Galactic Medium.

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Galaxy Luminosity Functions at z>11 and Constraints on the Epoch of Reionization

Haojing Yan

The Cycle-1 JWST data have revealed a large number of z > 11 candidate galaxies, suggesting that galaxy number density is much larger than expected. While the vast majority of them are still yet to be confirmed of their nature, the few spectroscopically identified cases at z > 11 already confirm that there is a discrepancy. Using all the available public Cycle-1 NIRCam data suitable for probing the z > 11 universe, we derive the galaxy luminosity functions at z ~ 11-20 under different contamination scenarios and show that they are all at least an order of magnitude higher than the existing theoretical predictions. Considering the UV slopes of these galaxies, it is highly likely that the reionization happened at z ~ 17, which is in line with the EDGES result but is inconsistent with the Planck result. To reconcile with the latter, a non-instantaneous reionization is necessary.

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Session 3: Galaxies II: High z (Chair: Jeyhan Kartaltepe)

Starbursts Dominate The Star Formation Histories of 6<z<12 Galaxies

Alan Dressler

I describe a study (arXiv:2306.02469) of the star formation histories (SFHs) of 6 < z < 12 galaxies derived from spectral energy distributions (SEDs) of ~1000 galaxies with deep JWST/NIRCam imaging of the JADES program for a GOODS-S field. A new code -- SEDz* -- assembles stellar population templates dominated by the light of A-stars to match observed SEDs. Excellent SED fits for most of our sample demonstrates the suitability of these present-epoch templates to generations of stars in the first galaxies. We confirm earlier work (2023 ApJ 947, L27) that identified four types of star formation histories: burst, stochastic, `contiguous,' and `continuous.' Remarkably, single-epoch starbursts of 10^8 -- 10^9 Msun make up 55% of the new large new sample, and another 20% have two well-separated bursts. We conclude that starbursts, both single and multiple, play the lead role in this critical period of cosmic history, even though less common, longer SFHs lasting 0.5-1.0 Gyr produce comparable stellar mass. SFHs of this intensity have not been anticipated, so this and similar studies should provide strong constraints for theoretical modeling of galaxy growth in the first billion years of cosmic history.

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Finding and characterising the first galaxies in the Universe with JWST

James Trussler (remote)

JWST has opened the possibility of discovering and characterising the very first galaxies to form in the Universe. In these early days, it is therefore imperative to establish the feasibility and best practices for identifying these primordial systems. Firstly, in this talk, I will thus introduce a set of photometric and spectroscopic diagnostics that I have developed to identify potential first galaxy candidates, i.e. chemically pristine Population III galaxies in the EoR. I will show how a combination of NIRCam and MIRI photometry offers the most robust identifier of potential Pop III candidates. However, as MIRI detections will require very deep data, I will highlight how NIRCam medium-band imaging surveys, that can search for high equivalent width (EW) He II λ1640 emitters in photometry, may be a viable alternative. Using the most comprehensive JWST dataset thus far (combining both public and PEARLS GTO data), I will reveal whether any convincing Pop III candidates have been identified from the first year of Webb data. Secondly, I will present a set of z ~ 10 galaxy candidates which appear to exhibit a Balmer break in their photometry

and thus potentially host evolved stellar populations (> 100 Myr). I will discuss the physical properties of these galaxies, their number abundance and star formation histories, highlighting how the evolved stellar populations in these Balmer break galaxies provide valuable indirect constraints on the onset of star formation in the Universe.

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A JOINT NIRSPEC/IFU+ALMA VIEW ON MASSIVE GALAXY ASSEMBLY IN THE FIRST 1GYR OF COSMIC TIME

Mauro Stefanon

The first batches of JWST data are unveiling significant numbers of bright galaxies observed just few hundred Million years after the Big Bang. These fascinating results are providing a transformative view of galaxy assembly, prompting questions on how efficiently galaxies built up in the early universe. While future follow-up studies will ascertain the nature of these tantalizing objects, significant progress can already be achieved now. In this talk, we present the first results from a NIRSpec IFU R100 program targeting 12 bright, spectroscopically-confirmed, especially high-mass galaxies at just 750Myr of cosmic time ($6.5<z<8.5$). Remarkably, this sample also benefits from [CII] and dust continuum estimates from the ALMA large program REBELS making this a unique sample in the panorama of high-redshift studies. The unprecedented high spatial resolution view of both their stellar mass and star formation rates allow us to evaluate the efficiency of star formation in galaxies at early times, determine the impact of merger-driven star formation, and explore correlations between a variety of physical properties from the JWST+ALMA synergy. This dataset will establish a reference sample of reionization epoch galaxies with unique panchromatic information for the JWST era and beyond.

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UV CONTINUUM SLOPES AND THEIR REDSHIFT EVOLUTION WITH PEARLS GTO AND PUBLIC JWST NIRCAM IMAGING

Duncan Austin

I present an analysis of our Manchester-led EPOCHS sample of >200 high-redshift galaxies at $z>6.5$ from a combination of public GO, ERS and PEARLS GTO data produced using our independent data reduction pipeline implemented in the soon to be released python package 'galfind'. This comprises one of the largest samples of NIRCam selected high-redshift galaxies to date, covering >110 square arcmin at 5σ depths up to 30.3 mags. We calculate UV continuum slopes from a power law fit to the rest frame UV photometry, finding several ultra-blue galaxies with UV slopes $\beta<-3$ characteristic of either metal-free Pop. III stellar populations or Lyman continuum leakage; these galaxies may provide an important contribution to the reionization of the Universe. In addition, we analyse the redshift evolution of β with MUV finding minimal change in the slope of the relation over cosmic time. We also observe strong increasing trends with both stellar mass and SFR, determined using the Bayesian SED fitting code bagpipes with lognormal SFH, which may point to the changing impact of SNe feedback in dust production and expulsion in galaxies at early times. Our results, especially those in our recent NGDEEP paper, show the power of probing continuously deeper into the Universe with JWST and lead the way to future high-redshift Universe studies.

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SUBSTANTIAL GAS RESERVOIRS IN YOUNG, STAR-FORMING GALAXIES AT Z=9-11

Kasper Heintz (remote)

The onset of galaxy formation is thought to be initiated by the infall of neutral, pristine gas onto the first protogalactic halos. However, direct constraints on the abundance of neutral atomic hydrogen (HI) in galaxies have been difficult to obtain at early cosmic times. In this talk, I will present recent results from spectroscopic observations with JWST of three galaxies at redshifts $z = 8.8 - 11.4$, about 400–600 Myr after the Big Bang, that show strong damped Lyman-α absorption from HI in their local surroundings. This damping is an order of magnitude in excess of the Lyman-α absorption caused by the fully neutral intergalactic medium at these redshifts. Consequently, these early galaxies cannot be contributing significantly to reionization, at least at their current evolutionary stages. These results will be placed into context with the overall picture of the now observed chemical "dilution" of early galaxies, showing significant metallicity offsets from the fundamental-metallicity relation of later galaxies. Supported by state-of-the-art simulations, these findings indicate that we have now started to uncover galaxy formation in progress, probing the first epoch of rapid gas accretion and assembly.

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Abundance of high z UV bright galaxies and implications for early stages of galaxy evolution

Andrey Kravtsov

I will present a galaxy formation model that is calibrated on results of galaxy formation simulations and that reproduces properties of nearby L<L* galaxies very well. I will show that this model can also match UV luminosity function evolution measured by the HST and JWST from z=5 to z=13 remarkably well, including abundance of the UV bright galaxies. I will discuss implications of the model results for the high-z galaxy-halo connection and for the shape of the UV LF at z>13 that is yet to be measured robustly.

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Session 4: Exoplanets I (Chair: TBC)

The JWST ERS Program for the Direct Imaging and Spectroscopy of Exoplanetary Systems

Sasha Hinkley (remote)

I will showcase how our JWST Early Release Science (ERS) Program unveiled JWST's first-ever direct images and spectroscopy of extrasolar planetary mass companions. Our 55-hour program is one of the two ERS programs dedicated to the study of extrasolar planets, and has provided some of the first examples of the high contrast imaging modes of JWST, resulting in the first-ever direct observations of an exoplanet at wavelengths longer than 5 microns. Our program has also returned the highest fidelity spectrum to date of a planetary mass object, showing evidence for disequilibrium chemistry, as well as the first-ever definitive direct detection of silicate clouds in the atmosphere of a planetary mass companion. Our coronagraphic observations demonstrate that JWST is exceeding its nominal predicted performance by up to an order-of-magnitude in some cases, and JWST's unprecedented sensitivity will make sub-Jupiter extrasolar planets (analogues of our own ice giant planets) accessible for direct characterization for the first time. In addition to leading to the development of several public data processing tools, our program has also allowed us to make clear recommendations to the community of best observing practices going forward, both of which will allow our community to put forward the best possible proposals in future Cycles.

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A JWST Spectrum of a Habitable-zone Sub-Neptune

Nikku Madhusudhan

Atmospheric characterisation of habitable-zone exoplanets is a major frontier of exoplanet science. The detection of atmospheric signatures of habitable Earth-like exoplanets is challenging due to their small planet-star size contrast and thin atmospheres with high mean molecular weight. Recently, a new class of habitable sub-Neptune exoplanets, called Hycean worlds, have been proposed, which are expected to be temperate ocean-covered worlds with H2-rich atmospheres. Their large sizes and extended atmospheres, compared to rocky planets of the same mass, make Hycean worlds significantly more accessible to atmospheric spectroscopy. Several temperate Sub-Neptunes have been identified in recent studies as candidate Hycean worlds orbiting nearby M dwarfs that make them highly conducive for transmission spectroscopy with JWST. Here we present the first broadband transmission spectrum of a candidate Hycean world observed with JWST in Cycle 1. The spectrum reveals multiple spectral features indicative of molecular absorption in the planetary atmosphere, and is the first spectrum of a temperate sub-Neptune exoplanet with such features. We will discuss inferences of the molecular composition of the atmosphere and constraints on the temperature structure, clouds/hazes, atmospheric extent, chemical disequilibrium and the possibility of a habitable ocean underneath the atmosphere. Our findings demonstrate the unprecedented potential of JWST for characterising Hycean worlds, and temperate sub-Neptunes in general, and open a new era of atmospheric characterisation of habitable-zone exoplanets with JWST.

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First comparative exoplanetology with JWST

Jacob Bean

I will present results from a large JWST GTO program focused on measuring atmospheric metallicities and carbon-to-oxygen ratios for a sample of canonical hot Jupiters. These parameters are fundamental tracers of planet formation but have been challenging to determine accurately using previous facilities. Our data have enabled the first JWST comparative planetology results and a new, high-precision view of long sought-after statistical trends in these parameters. Using simple, model-independent comparisons of spectra we have shown definitively that hot Jupiters exhibit a surprising diversity in their atmospheric compositions. These results are further reinforced by detailed retrieval modeling, which suggests that there is significant scatter in the mass-metallicity relationship for hot Jupiters, and that hot Jupiters can have very low carbon-to-oxygen ratios. Ultimately, the results indicate that a large survey of exoplanets is needed to capitalize on the promise of using atmospheric compositions to inform how planets form and evolve.

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Direct Imaging Spectroscopy of Substellar Companions with JWST

Kielan Hoch

JWST has opened the door to spectroscopy of directly imaged exoplanets beyond 3 microns, offering a new landscape for measuring their fundamental properties, assessing atmospheres, and using them to test planet formation theories. Direct imaging of exoplanets has revealed a population of Jupiter-like objects that orbit at large separations (~10-100 AU) from their host stars. These planets, with masses of ~2-14MJup and temperatures of ~500-2000 K, remain a mystery for the two main planet formation models—core accretion and gravitational instability. Observations that probe elemental abundances in the atmospheres of these young gas giants can shed light on their formation. We present results from cycle 1 programs that have pioneered the use of the NIRSpec IFU to obtain higher resolution spectra of substellar companions close to sunlike stars. For the brown dwarf companion HD 19467 B, NIRSpec IFU G395H spectra show detections of CO, CO2, CH4, and H2O. We forward model the moderate resolution (R~2,700) spectra from 3-5 microns using custom atmospheric model grids to constrain the abundances of these molecules, the C/O ratio, and non-equilibrium chemistry. For the multi planet system YSES-1, with two young Jovian planets at wide separations from a sunlike star, we have obtained one of the most comprehensive datasets of a multi-planet system ever imaged with spectral coverage of both companions from 1-12 microns using NIRSpec and MIRI, revealing many spectral features and allowing direct spectral comparison of sibling planets in unprecedented detail. These spectra show a direct detection of silicate clouds in the 6 MJup exoplanet YSES-1 c. Ongoing detailed atmospheric modeling will better constrain C/O, non-equilibrium chemistry, and cloud composition, increasing our understanding of substellar atmospheres and formation. These observations have demonstrated the superb capabilities of the NIRSpec IFU to achieve detailed spectral characterization of substellar companions directly seen even at high contrast close to bright host stars.

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Session 5: Solar System & Exoplanets II (Chair: Naomi Rowe-Gurney)

The Atmosphere and Surface of Titan from JWST and Keck Observations

Conor Nixon

The launch of JWST in 2022 heralded a new era in infrared astronomy, and provided a revolutionary capability for the investigation of planetary bodies in our solar system. Saturn's moon Titan was amongst the first targets to be viewed in year one of science operations, as part of a large Guaranteed Time Observations (GTO) project for solar system science. The observations took place in two epochs: the trailing hemisphere in November 2022, with NIRSpec and NIRCam only; and the leading hemisphere in July with NIRSpec, NIRCam and MIRI. Initial imaging show clouds at mid and high northern latitudes, in line with expectations from global circulation models (GCMs). Near-simultaneous imaging observations were acquired for both epochs with Keck NIRC-2 to provide additional insights into temporal evolution of clouds, which persisted over at least three consecutive nights in 2022 at the same location. Analysis of the spectroscopic data is also underway, and appears to show new bands of existing molecules in the near and mid-infrared, with the possibility of new gas detections as well. In this presentation the latest JWST/Keck results for Titan will be discussed, aloing with plans for observations in future years.

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High-Contrast Science Performance with JWST NIRCam

Jarron Leisenring

Coronagraphic imaging with JWST NIRCam offers unmatched sensitivities for wavelengths at 2 – 5 µm, exceeding commissioning requirements by over an order of magnitude in contrast. This exceptional performance can be primarily attributed to the observatory's cold, thermally stable environment with the telescope exhibiting wavefront error variations of ~2 nm RMS over a 24-hour period. Combined with precision pointing accuracy and ~1 mas line-of-sight jitter, the ultra-stable thermal conditions enable NIRCam's coronagraphic and imaging modes to produce unprecedented contrasts and sensitivities. We explore this unique discovery space relative to ground-based adaptive optics by discussing recent and upcoming results, especially highlighting those led by early career researchers.

NIRCam's high-contrast capabilities have created new opportunities to detect and characterize sub-Saturn mass exoplanets, investigate the dust and ice properties around protoplanetary and debris disks, and reveal the large-scale emission of quasar host galaxies. Our team has executed several programs probing a range of evolutionary states of planetary systems: observing circumstellar disks exhibiting evidence of in-situ planet formation (PID 1179), characterizing the atmospheres of known low-mass companions (PIDs 1189, 1194, 1412), searching for faint companions around nearby M-Dwarfs (PIDs 1184), and investigating the dust morphology in debris disks (PID 2780). We further discuss enhancements to NIRCam coronagraphy during the first year of science operations (such as dual-channel coronagraphy), lessons learned and best practices, as well as current challenges and future improvements to push the limit of NIRCam's high-contrast observations.

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Characterizing NIR Spectra of Flares from TRAPPIST-1 During JWST Transit Spectroscopy Observations

Ward Howard

We present the first analysis of near-infrared JWST spectroscopy of stellar flares from TRAPPIST-1 during transits of rocky exoplanets. Four flares were observed with NIRISS and NIRSpec during transit spectroscopy observations of TRAPPIST-1b, f, and g. Flares emit across the entire electromagnetic spectrum and must be considered as a key source of stellar contamination. Although not previously observed at wavelengths of 1-5µm, continuum emission is expected to be the dominant source of flare contamination. We strongly detect continuum in all four flares across the wavelength range of the instruments. We also characterize the He I infrared triplet and Paschen and Brackett series lines observed in the flares in order to identify which lines are likely to impact transit spectra from 1-5µm. The degree of flare contamination is quantified as a function of flare size and wavelength, with contamination levels at 2µm of 2100±400 and 500±450 ppm observed for the TRAPPIST-1f and b transits, respectively. We model the line and continuum emission of the flares to discover that up to 80% of flare contamination can be

removed, with mitigation most effective from 1-1.8 and 2.1-2.4µm. Our results suggest flare mitigation is a viable pathway to increase the scientific impact of transit observations of small planets around active stars.

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Session 6: Exoplanets III (Chair: TBC)

Search for a secondary atmosphere on the temperate rocky exo-Earth TRAPPIST-1 d

Caroline Piaulet (remote)

The nearby TRAPPIST-1 system, with its seven small rocky planets orbiting a small M8 star, offers the unprecedented opportunity to search for secondary atmospheres on potentially habitable worlds. While TRAPPIST-1 b's dayside emission suggests that it does not have an atmosphere or efficient heat transport, it is yet to be determined whether any of the other planets that are less irradiated by the star harbor a thin gas envelope. In particular, the low insolation (1.14xEarth) of TRAPPIST-1 d makes it more favorable for atmosphere survival, while also placing it close to the inner edge of the habitable zone for synchronously-rotating M-dwarf planets. In addition, while the inferred volatile content of TRAPPIST-1 planets generally increases with orbital distance, TRAPPIST-1 d has an inferred volatile content even larger than the next planet TRAPPIST-1 e, which suggests a different water delivery mechanism than the other planets and makes it a fascinating prospect for atmospheric study. Here, we present the first detailed JWST observation of TRAPPIST-1 d in transmission from 0.6-5.3 µm. The precision of our observations enables us to search for secondary atmospheres dominated by species such as nitrogen, water, or carbon dioxide, and search for traces of methane, ammonia, and even sulfur dioxide. The wide wavelength coverage also allows us to probe beyond the spectral region where hazes can mute molecular bands. Our TRAPPIST-1 d observations provide the first insight into the range of plausible secondary atmospheres on a nearby temperate exo-Earth.

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Mid-infrared maps of exoplanets: from hot Jupiters to sub-Earths

Michael Zhang

Among many other exoplanet observations, MIRI has made one-dimensional maps (phase curves) of the hot Jupiter WASP-43b, the warm mini-Neptune GJ 1214b, and the hot sub-Earth GJ 367b. These thermal phase curves have allowed us to infer dayside and nightside temperatures, albedos, heat redistribution coefficients, and atmospheric compositions for three very different exoplanets. This talk will summarize what MIRI has observed on these planets, including the cloudy and methane-poor nightside of WASP-43b, GJ 1214b's surprisingly reflective aerosols, and the bare, low-albedo surface of GJ 367b.

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The MANATEEs Year-Long Journey: Swimming Through New Chemical Species in Exo-Atmospheres with JWST

Luis Welbanks

We are excited to present results from the MANATEE Guaranteed Time Observations program. The MANATEE survey aims to characterize the atmospheres of nine transiting exoplanets – warm terrestrial, sub-Neptunes, and Jovian worlds below 1000 K – with the NIRCam and MIRI instruments. Executed within the first year of JWST operations, this unique and comprehensive survey has significantly expanded our knowledge about the atmospheric chemistry and evolution of exoplanets. MANATEE has used NIRCam and MIRI to measure precise 2.4 - 11+ micron atmospheric spectra at high precision for our targets. We detect and constrain several chemical species that were previously elusive in exoplanetary atmospheres, including methane (CH4), ammonia (NH3), sulfur dioxide (SO2), carbon monoxide (CO), and carbon dioxide (CO2), alongside several precise water (H2O) measurements.

Atmospheric retrievals performed on these data provide insights into the dynamics, chemistry, and climatic conditions of these distant worlds, as well as their metallicities. They also provide the relative elemental ratios (C/O, N/O, N/S) necessary to better understand the formation and evolution pathways of planetary systems. We will present our progress in robustly and accurately processing JWST TSO data, modeling advancements, and reliably inferring the complete chemical inventory of our diverse

exoplanet sample. Our findings underscore the transformative power of JWST and pave the way for future, in-depth atmospheric investigations of a larger exoplanet population.

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First year views of gas giant exoplanet atmospheres in the mid-infrared with JWST/MIRI

Polychronis Patapis

One of the amazing promises of JWST was opening a new window into exoplanet atmosphere characterisation in the mid-infrared that was previously not accessible from other observatories. The mid-infrared gives access to multiple molecular bands -most notably ammonia- , silicate clouds features, and information on the temperature structure of the atmosphere; all key ingredients to truly understand the nature of gas giants. We present the results from the MIRI European Consortium Exoplanet GTO program, that observed a wide range of gas giant worlds with the goal to characterise their atmospheres in detail. We highlight findings from ultra-cool brown dwarfs that show clear atmospheres full of molecular absorption features and newly discovered molecule isotopologues, young directly imaged and transiting companions that show evidence for photochemistry, clouds, and provide insights into the process of planet formation.

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Session 7: Galaxies III: Lensing+ (Chair: Taylor Hutchison)

What's going on inside star-forming galaxies? Results from JWST IFU observations of lensed galaxies

Jane Rigby

The Cycle 1 programs to study bright lensed galaxies provide opportunities to see how distant galaxies formed their stars, at superior spatial resolution than is possible for field galaxies. I will summarize results from the Early Release Science program TEMPLATES, which observed four of the brightest gravitationally-lensed galaxies known, to determine, at spatial scales better than 100pc, where stars form in galaxies and the physical conditions of star formation, and to compare multiple extinction--robust diagnostics of star formation rate. TEMPLATES has spatially resolved dust emission at z=4, measured the ionization conditions of the nebular gas, detected auroral metallicity tracers, and traced star formation using the extinction-robust Paschen alpha emission line. TEMPLATES has also demonstrated how to handle JWST IFU data (from NIRSpec IFS and MIRI MRS), including publishing data reduction cookbooks. Through TEMPLATES and other Cycle 1 programs to study lensed galaxies, JWST is revealing the inner workings of distant galaxies in a way never before possible.

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Spatially Resolving the Distant Universe with JWST

Brian Welch

Gravitational lensing magnifies distant galaxies, enabling observations of smaller spatial scales and of intrinsically fainter objects than would be visible in field galaxies. Combining lensing with JWST imaging and spectroscopy enables detailed studies of the physical conditions within distant galaxies, which can shed light on the processes that drive galaxy evolution over cosmic time. I will present results from two JWST programs investigating highly magnified distant galaxies. I will discuss the imaging and MOS spectroscopy of the Sunrise Arc, a highly magnified galaxy at Cosmic Dawn. JWST has revealed that this galaxy hosts multiple stellar populations in compact star clusters, including older globular cluster precursors and young massive star clusters with strong emission line features. I will also present direct auroral line chemical abundance measurements for two galaxies from the TEMPLATES ERS program. Together, these JWST observations are providing a more detailed picture of the evolution of galaxies over cosmic time.

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Resolving star formation processes at 100s pc resolution in distant galaxies with JWST

Adelaide Claeyssens (remote)

High redshift galaxies present a very irregular morphology dominated by compact sub-structures called “clumps”. The physical properties of these high-z star-forming systems remain relatively unexplored and their role in galaxy formation and evolution is not clear. The first detections of UV-bright clumps from z=8 to z=1 indicate that these star-forming clumps could be a major mode of star formation and galaxy assembly.
However, resolving structures at 10-100s pc scales in high redshift galaxies (z>1) is hardly achievable with current telescopes even with space-based observations. Combining the unprecedented sensitivity and spatial resolution of JWST with the natural gravitational lens telescopes is the only way to reach hundred/sub-hundred pc resolutions in hundreds of galaxies, necessary to resolve individual star-forming systems and star clusters at UV-optical wavelengths. I will present the first results on resolved high redshift star formation processes obtained from JWST/NIRCam observations of strongly lensed galaxies observed in multiple galaxy cluster fields : SMACS0723 (Claeyssens et al. 2023), WHL0137 (Vanzella, Claeyssens et al. 2023) and Abell2744 (UNCOVER program). The optical restframe, probed with the JWST, enables us to measure physical properties of >2000 clumps (age, mass, extinction). We derive effective radii from <10 to 100s pc and masses ranging from 10^5 to 10^9 Msun, overlapping with massive star clusters in the local universe. Comparing these results with the most recent hydrodynamical simulations of galaxies, we can understand the physical processes involved in the formation and evolution of these clumps (such as gas turbulence, stellar feedback, galaxy mergers and bulge formation). This study shows the potential of JWST observations for understanding the conditions under which galaxies assembly and evolve across the cosmic time and allow us to study for the first time the formation and the role of star clusters in rapidly evolving galaxies.

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Session 8: Galaxies IV: Structure (Chair: Marc Rafelski)

The Structural Evolution of Galaxies in the Early Universe

Jeyhan Kartaltepe

One of the stunning surprises from JWST's first year of observations of the extragalactic sky is that not only are we detecting large numbers of galaxies in the early universe but that many of these galaxies are resolved and show great structural detail. For the first time, we can quantify the morphological structure of galaxies well into the epoch of reionzation and constrain how these galaxies grew over cosmic time. I will present an analysis of the morphological and size evolution of galaxies in the early universe, from z=6-12+, using deep multi-band NIRCam imaging from several public survey fields including CEERS, NGDEEP, PRIMER, and COSMOS-Web. Our morphological measurements include quantitative measures, such as surface brightness profile fitting and non-parametric fits, visual morphologies, and machine learning approaches. We find that galaxies at this early epoch have a wide diversity of morphologies, including compact unresolved sources, disky structures, irregular features and multiple components, and a significant fraction that appear to be involved in a merger.

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Morphology and Size Evolution of Galaxies to z~9 in the JWST Public Fields

Elizabeth McGrath

I will discuss the morphological evolution of galaxy shape and size from z~9 to the present using results from a parametric fitting of galaxy morphology in the CEERS, PRIMER, and NGDEEP fields. For the first time, we are able to trace the stellar mass distribution using rest-frame optical light over this entire redshift range. We find that galaxies with low-Sersic index dominate all redshift bins. Beyond z~2.5, even the most massive galaxies transition from spheroid to disk-dominated, highlighting an important era where JWST is revealing key structural changes in galaxies. Size evolution is evident for all galaxy types out to the highest redshifts. I will discuss new results on the evolution in the slope and intercept of the size-mass relation to z~9. Finally, we also find a significant population of unresolved sources at higher redshifts, z>5. These are characterized by redder colors and may be linked to the growth of AGN activity at early times, as discussed in a number of other recent studies.

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JWST MSA slit-stepping to reveal the emergence of the modern Hubble sequence

Ivana Barisic

Reliable kinematic data during galaxies' formative epochs is crucial to identify the role of accretion and feedback in the transition of galaxy populations from irregular clump structures to ordered thin disks. Spatially resolved integral field spectroscopy (IFS) has proven instrumental in characterizing galaxy kinematics and resolving disk scale radii.

GO-2136 NIRSpec MSA slit-stepping survey is first to provide high resolution pseudo-IFU observations at the epoch of modern thin disks emergence ($0.5 < z < 1.5$). We sample the main diagnostic rest-optical emission lines of 43 main sequence galaxies, totaling 21 hours and thus achieving a remarkable time efficiency of approximately 30 minutes per source. In contrast, an equivalent IFU survey would require 8 hours per source to reach the same sensitivity. The MSA slit-stepping technique proves to be over 15 times more efficient than IFU. Customized data reduction pipelines and original software for cube building were developed to handle the program's complexity.

Our early science results demonstrate remarkable kinematic measurements at redshift ~1. As modern thin disk galaxies are characterized by small local velocity dispersions, 2D velocity field maps derived from our high-resolution pseudo-IFU (0.1" x 0.2" spatial resolution) enable the establishment of redshift and mass scales at which thin disks emerge. Additionally, emission line ratio maps provide insight into kpc-resolved dust-corrected star formation rate (SFR) maps and the characterization of metallicity gradients.

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PASSAGE: Parallel Application of Slitless Spectroscopy to Analyze Galaxy Evolution

Kalina Nedkova

We present a status update and overview of PASSAGE, a cycle 1 pure-parallel NIRISS program. Over the first full year of JWST observations, PASSAGE constructed an unbiased spectroscopic survey of galaxies, with no photometric pre-selection, covering up to 68 independent fields to overcome cosmic variance. This program is enabling global and spatially resolved properties to be reliably measured for large, uncorrelated, and unbiased galaxy samples. We share examples of our initial processed data that will allow us to (1) extend the "main sequence" SFR-M relation down to ~10x less massive galaxies than currently measured at z~2, (2) measure the mass-metallicity relation (MZR) in new regimes by expanding the low-mass samples by over an order of magnitude, reaching stellar masses as low as 10^6.5 Msun, and pushing out to z~3.5, (3) robustly measure variations in the strengths and ratios of diagnostic emission lines in different regions of galaxies, such as clump and interclump regions, that may show different modes of star formation, (4) spectroscopically discover some of the brightest Ly-alpha line emitters at the epoch of reionization, and (5) detect Ly-break galaxies at z >8. Parallel NIRISS programs, like PASSAGE, are revolutionizing our understanding of galaxy evolution at high redshifts in the important low mass regime by assembling some of the largest spectroscopic galaxy samples.

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The first massive quiescent galaxies

Adam Carnall (remote)

Over the past decade, evidence has mounted for the existence of massive galaxies during the first 2 billion years of cosmic history (redshift, $z > 3$) that have already shut down, or quenched, their star-formation activity. Such galaxies are not well reproduced by current cosmological simulations, pointing to an incompleteness in our understanding of early star-formation, black-hole growth and associated feedback during the first billion years. With the advent of the James Webb Space Telescope (JWST), we have the opportunity to select truly representative samples of early massive galaxies for the first time. Furthermore, we can also aspire to study the physical properties of these objects in detail using the spectroscopic capabilities of JWST. I will present an update on the search for the earliest massive quiescent galaxies using the first imaging data from JWST, which suggests that such objects are much more numerous than previously thought. I will also present the NIRSpec spectroscopic

confirmation of a massive quiescent galaxy at redshift 4.658, just 1.25 Gyr after the Big Bang, from my own Cycle 1 programme. This galaxy formed its stellar population over a ~200 Myr period, before quenching just 800 Myr after the Big Bang, demonstrating unambiguously that massive galaxy formation and quenching were already well underway during the first billion years. I will finally also introduce my JWST Cycle 2 programme, the Early eXtragalactic Continuum and Emission Line Science (EXCELS) survey, which will greatly expand the availability of medium-resolution JWST spectroscopy for massive galaxies from cosmic noon back to the first billion years, including ~20 massive quiescent galaxies at z > 3.

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Discovery of a (mini-)quenched galaxy at z=7.3 and more evidence for bursty SFHs in the first Gyrs

Tobias Looser

Directly observing the first quenched galaxies - i.e. galaxies with no or negligible star formation activity at the epoch of observation - and determining the causes which quenched them (perhaps only temporarily), is of utmost importance to constrain models of galaxy formation and transformation. To date, quenched galaxies have been identified out to z<5; and are all found to be massive (M⋆ > 10^10 M⊙). I will present the discovery of a of a quenched, post-starburst galaxy at z=7.3 from the JWST JADES GTO survey. This galaxy exhibits a Lya drop, a Balmer break and complete absence of any emission lines. Its SFH consists of a short and intense burst terminating only 10-40 Myr before the time of observation. Crucially, this galaxy has a stellar mass of only 4–6×10^8 M⊙. This is a significantly lower stellar mass than any known high-redshift quiescent galaxy (redshifts 3<z<5), yet it is much larger than the maximum mass of reionization-quenched dwarf galaxies in simulations. This suggests that likely different physical mechanisms were dominantly responsible for quenching this galaxy. This galaxy lies in a pivotal mass range between 'bursty' and stable SFHs, and in which feedback from a primordial black hole or star formation might drive powerful outflows leading to (temporary) quiescence. Additional to this discovery, I will present more observational evidence for a strongly stochastic evolution of high-redshift and low-mass galaxies based on inferred SFHs of ~200 galaxies (0.6<z<11) from deep NIRSpec prism spectra.

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Session 9: AGN I (Chair: Jeyhan Kartaltepe)

AGN selection and demographics: a new chapter with JWST/MIRI

Jianwei Lyu

We present the first results on the AGN identifications across a wide range of redshift, luminosity, obscuration level and host galaxy properties with the JWST MIRI GOODS-S/HUDF survey. Combining the MIRI data with the NIRCam data and HST data at short wavelengths, we report ∼340 SED-identified AGN candidates over a sky area of ∼30 arcmin2. Despite the extensive pre-JWST efforts of AGN search with the deepest panchromatic data from the X-ray to the radio for the same field, about 85% of our MIRI AGNs are newly found, demonstrating the unique power of JWST, especially the 5–25 µm observing capability provided by MIRI. This MIRI AGN sample include 215 AGNs in normal galaxies (M_star > 10^9 M⊙) at z=0–4, 108 AGN candidates in dwarf galaxies (M∗ < 10^9 M⊙) and 18 high-z AGN candidates at z=4–6, where the latter two populations have been poorly charted in the past. Combined with the super deep Chandra X-ray and VLA radio data, we build the most complete AGN sample in terms of bolometric luminosity and put various constraints on the AGN properties.

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A Crisis at Early Epochs?- Discovery of the Furthest Obscured RL AGN Candidate at z>7 in COSMOS-Web

Erini Lambrides

The vast majority of super-massive black hole growth (SMBH) at high redshifts is heavily obscured. Yet, almost every z>7 powerfully accretting SMBH (hereinafter, QSO) reported is un-obscured or only mildly attenuated. This presents major uncertainties in contextualizing the role of QSOs in their host-galaxies at the epoch of reionization (EOR) and testing competing models of SMBH seed formation. Thus, it is paramount to uncover heavily obscured QSOs in the early Universe to gain a complete picture of early SMBH evolution. In this talk, I will discuss our the discovery of of the furthest, heavily obscured, radio-loud QSO candidate via JWST NIRCAM/MIRI, mid-IR and sub-mm emission in the 0.54 sq. deg. COSMOS-Web field. In conjunction

with deep ground- and ancillary space based data and the un-precendented resolution and sensitivity of JWST - we find a robust, singular solution photo-z estimate of z = 7.3. Furthermore, the second most distant bona-fide RL obscured AGN (z=6.8) is also in the COSMOS field. Finding one of these sources in the COSMOS field, according to space density estimates, already is incredibly statistically unlikely - let alone two. Both of these powerful sources existing at similar redshifts within 2 sq degrees is currently, and very excitingly, unexplainable in current theoretical models of growing SMBHs. I will discuss the implications of these results and future prospects for spectroscopic follow-up.

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JWST CEERS & JADES Black Holes at z = 4-7: Implications for the High-z M-Mstar Relation and Seeding

Fabio Pacucci

JWST observations are revolutionizing our understanding of the high-z Universe by expanding the black hole horizon, looking farther and to smaller masses. New detections of high-z systems offer unprecedented insights into the formation of the first black holes and their early co-evolution with galaxies. By examining new JWST observations in the JADES and CEERS fields, which host Halpha-detected black holes at z=4-7, this research investigates two key aspects: (i) the high-z M-Mstar relation and (ii) the low-mass end of the black hole distribution.

Our findings reveal a high-z M-Mstar relation that significantly deviates (at >3sigma) from the local relation, suggesting black holes are overmassive by approximately ~ 10x compared to their local counterparts in similar galactic hosts. Moreover, our analysis predicts the existence of tens more black holes with mass <10^6 solar masses in current JWST surveys, particularly at z ~ 4-5. These lighter black holes are expected to be preferentially located in galaxies with a mass of ~10^9 solar masses in stars. A search of low-mass black holes in existing JWST surveys will test the M-Mstar relation. Notably, at z ~ 6, our inferred high-z M-Mstar relation yields a number higher by a factor of ~2 when compared to local relations.

The current JWST fields represent a treasure trove of black hole systems at z = 4-7; their detection will provide crucial insights into their early evolution and co-evolution with their galactic hosts.

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First look of sub-arc dual quasars at z~2: spatially-resolved spectroscopy with JWST and ALMA

Yuzo Ishikawa

The formation and growth of SMBHs remain an unsolved problem. Although obtaining spatially resolved observations that capture the early stages has been difficult, many ideas have been proposed (e.g. direct collapse of gas, formation of massive seeds, mergers of massive seeds, super-Eddington accretion). Galaxy mergers may be an important route to fuel SMBHs and produce SMBH pairs, which evolve into a bound binary and inspiral until coalescence. Actively accreting SMBH pairs can be observed as a dual quasar, which are vital probes of SMBH growth. However, there are essentially no studies of dual quasars on galaxy scales at cosmic noon. Here we present the 1st detailed study of kpc-scale dual quasars at cosmic noon, which were identified using a novel Gaia astrometric selection technique. We obtained spatially resolved spectroscopy with JWST NIRSpec IFU and ALMA of the dual quasars. For the first time, we not only resolve the quasar pairs but also detect the faint host galaxy. IFU analyses suggest that the quasars within each pair have very similar properties (masses and accretion rates), suggesting possible symbiotic growth. We also detect a large rotating host galaxy, and we explore the dynamical history of the system. We combine molecular gas observations from ALMA with JWST to build a comprehensive study of dual quasars and their host environments. Detailed studies of dual quasars at cosmic noon may provide insights into the galaxy and SMBH evolution.

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Session 10: AGN II (Chair: TBC)

Early galaxies unveiled by the JADES and GA-NIFS surveys: infant black holes and pristine systems

Roberto Maiolino

JWST has enabled a giant sensitivity leap, especially in terms of near-IR spectroscopy, which has opened a totally new discovery space. The early spectroscopy surveys during the first year of observations have certainly not disappointed the expectations, with a sequel of fantastic discoveries. Within this context, the JADES and GA-NIFS GTO surveys have played a key role, by providing some of the deepest spectra, breaking the spectroscopic redshift frontier and discovering new classes of sources. I will discuss some of the most fascinating cases unveiled by NIRSpec-MSA and NIRSpec-IFS spectroscopy through these surveys. Specifically, in the first part of the talk I will present the recently discovered new population of low-luminosity AGN in the early Universe, including the spectacular case of GN-z11, which is found to host the most distant accreting black hole known so far, only 440 Myr after Big Bang. The population of black holes found by JADES and GA-NIFS is diverse and quite different from those that were known at high redshift prior to JWST. These include black holes as small as a few times 10^5 Msun (i.e. in the realm of the so-called Direct Collapse Black Holes), merging black holes, black holes accreting at super-Eddington rates, and black holes hosted in unevolved galaxies. These findings set tight constraints on the seeding and formation scenarios of early black holes. I will also illustrate that most of these black holes are hosted in very low metallicity environments. The most spectacular of these is GN-z11 at z=10.6, which is hosted in a galaxy with low metallicity and high C/O abundance ratio, which can possibly be explained in terms of recent enrichment by Population III stars. Within this context, extremely exciting is the discovery of HeII emission in the halo of GN-z11 (both via MSA and IFS spectroscopy), which may be the first signature of Population III stars, formed out of pocket of pristine gas in the surrounding of GN-z11, as expected by some recent theories and cosmological simulations.

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EIGER: Detecting the host galaxies of luminous quasars at z>~6

Minghao Yue

High-redshift quasars and their host galaxies are among the most extreme systems at cosmic dawn. The stellar emission of high-redshift quasar host galaxies encodes critical information about the coevolution of SMBHs and their hosts in the early universe, which is nevertheless very challenging to detect. The unprecedented spatial resolution and infrared coverage of JWST have enabled the detection of high-redshift quasar host galaxies in the rest-frame optical for the first time. Here we present the host galaxy measurements for high-redshift quasars in the Emission-line galaxies and Intergalactic Gas in the Epoch of Reionization (EIGER) project. Using deep NIRCam imaging, we successfully detect the host galaxy emission of two luminous quasars at z>~6. These quasar hosts have stellar masses of 10^10~10^11 M_sun and are among the most massive galaxies at their redshifts. The M_BH/M_star ratio of these quasars is ~15%, about 100 times larger than the local relation, which indicates an early SMBH growth compared to their host galaxies' star formation. We will also discuss how we can use NIRSpec IFU to probe the nebulae emission lines (e.g., Hbeta, [O III]) of the quasar hosts and improve the measurements of their physical properties (stellar masses, star formation history, metallicity, etc.).

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Emission-line properties of simulated galaxies: high-redshift predictions for JWST

Michaela Hirschmann (remote)

We present a first, direct comparison of rest-frame optical and UV emission-line properties of high-redshift galaxies and AGN, observed with JWST, with mock cosmological simulations. For that, we have constructed synthetic emission-line catalogues of simulated galaxy populations out to z=10, by coupling, in post-processing, both the cosmological IllustrisTNG simulations and the SantaCruz model with new-generation nebular-emission models, accounting for line emission from young stars, Post-AGB stars, and accreting BHs. Compared to new NIRSpec data, the optical emission-line properties of simulated galaxies reflect the observed increase in [OIII]/Hβ at fixed [NII]/Hα and fixed galaxy stellar mass, the observed increase [OIII]/[OII] at a given ([OIII]+[OII])/Hb (primarily driven by the higher ionisation parameter of higher redshift galaxies) as well as the observed evolution of the [OIII]λ5007 luminosity function out to z=6. At z>3, we also find that classic BPT diagnostic diagrams cannot be used to robustly identify AGN, as they are indistinguishable from SF galaxies, consistent with first JWST data of high-z AGN.

Instead, we highlight 10 UV-diagnostic diagrams able to robustly identify the dominant ionizing sources in high-redshift galaxies. We also provide novel optical and UV diagnostics for AGN luminosities and for ratios of BH accretion to SFR. Finally, we show that the vast majority of predicted line-ratio calibrations for metallicity estimates strongly evolve with redshift, consistent with first metallicity estimates derived via the direct-T method from NIRSpec spectra of z=6-8 galaxies. This motivated us to derive associated high-z metallicity calibrations — potentially useful for the interpretation of on-going and future spectroscopic surveys of high-redshift galaxies with NIRSpec.

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Building Semi-Analytic Black Hole Seed Models to Analyze Seeding Conditions using IllustrisTNG

Analis Evans

Using the cosmological magneto-hydrodynamical IllustrisTNG simulations, we construct theoretically motivated, post-processing, semi-analytic models (SAMs) that efficiently produce black hole (BH) formation and growth histories for many possible seeding criteria. BH population constraints from AGN observations are uncertain, especially past redshift ~6. However, we find that several of our seeding criteria produce BH populations comparable with those from empirical results. Our models also predict a significant fraction of light BH seeds at high redshifts. While these are going to be difficult to directly observe even with JWST, future gravitational wave facilities such as LISA can potentially detect them via their mergers and provide better constraints on BH seeding.

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Evolution in metallicity and ISM properties of galaxies across the cosmic time unveiled by JWST

Mirko Curti

I will discuss the emerging picture on the evolution of the ISM and chemical properties of early (z~3-10) galaxies in the context of the observations taken within the first year of JWST, with specific focus on the joint NIRCam-NIRSpec GTO Survey JADES. Exploiting JADES ‘deep' (up to 28 hours with prism and 7 hours with medium resolution grating configurations) and ‘medium' (up to 3 hours) spectroscopy of hundreds of galaxies we characterise the evolution in their emission line properties, the metallicity scaling relations, and their constraints on the assembly and star formation history of galaxies in the early Universe. I will also present the first results from the 'Measuring Abundances at high Redshift with the Te Approach' (MARTA) Survey, an 'extremely deep' (33 hours on source in G140M/F100LP; 7 hours in G235M/F170LP; 3 hours in G235H/F170LP), recently completed Cycle 1 GO NIRSpec/MSA programme (PI Curti) aimed at studying in detail the ISM properties of galaxies at the cosmic noon (z~2-3).

By simultaneously measuring multiple emission lines in individual spectra, including the elusive temperature-sensitive auroral lines like [O III]4363, [O II]7320,30, and [S III]6312, we aim at robustly characterising the metallicity (with the Te method), ionisation, density, and dust properties of these sources, assess the presence of outflows (from R2700 observations), and provide one of the most detailed pictures of ISM physics in z~2-3 galaxies to date.

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Session 11: Star formation, stellar populations & ISM I (Chair: Chris Evans)

Interstellar Dust Extinction for JWST

Karl Gordon

Dust extinction measurements provide important constraints on the size, composition, shape, and abundance of dust grains and an empirical model to account of the effects of extinction on astrophysical objects. Most extinction measurements covering the JWST near- and mid-infrared (IR) wavelengths have historically been based on photometry. These photometric extinction curves do not cover the full JWST wavelength range and are often based on large samples that mix diffuse and dense ISM environments. Fortunately, recent spectrocsopic work has produced the first fully spectroscopic extinction curves for the entire JWST wavelength range. I will present these extinction mesurements based on IRTF/SpeX spectra from 0.8 to 5 micron (Decleir et al. 2022) and based on Spitzer/IRS spectra from 5 to 32 micron (Gordon

et al. 2021). These measurements reveal the near-IR extinction is well represented as a power-law, the mid-IR extinction is dominated by strong, asymmetric silicate absorption at 10 and 20 microns, and the diffuse extinction curve is lower than most existing measurements that probe denser regions. We have combined these two studies with results covering the ultraviolet and optical to produce the first fully spectroscopic R(V) dependent extinction relationship from 912 A to 32 micron (Gordon et al. 2023). This provides our best understanding of dust extinction over the full JWST wavelength range. I will discuss and present prelminary results on how this work is being enhanced with new JWST observations as part of the WISCI and MEAD cycle 1 programs. The JWST observations provide higher spectral resolution extinction curves allowing dust composition diagnostic absorption features in the near- and mid-IR to be studied.

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H2 emission in the Orion Bar as observed with JWST

Ameek Sidhu

We present a comprehensive study of the molecular hydrogen (H2) emission within the Orion Bar, a nearby photodissociation region (PDR) observed with the Near Infrared Spectrograph (NIRSpec) and the Mid-Infrared Instrument (MIRI) onboard JWST. The study is a part of the Early Release Science program PDRs4All (ID: 1288) in which the Orion Bar has been observed edge-on across the HII region, the ionization front, the atomic PDR, and the H2 dissociation fronts.

Our observations reveal widespread H2 emission throughout the field of view. Owing to the unprecedented sensitivity and spectral resolution of MIRI-MRS and NIRSpec IFU, we are able to detect ~90 H2 emission lines. These lines include ro-vibrational lines originating from levels up to v = 6 and pure rotational lines originating from higher J levels up to 19 in v = 0 and v = 1 states. We find that the H2 is excited by collisions with H and H2 in the atomic and molecular gas and by fluorescent pumping by the ultraviolet starlight from theta 1 Ori C. We note that the H2 emission in the HII region originates from the background PDR in the molecular cloud OMC1. Given the large number of observed H2 lines, we are also able to assess the importance of collisional-excitation on level populations relative to UV pumping.

The multitude of observed H2 lines offers insights into the physical conditions of the emitting environment. To interpret the H2 emission, we construct excitation diagrams using the PDR Toolbox (PDRT). The analysis of the excitation diagrams of the 0-0 S(1-6) lines observed with MIRI indicates that these lines are thermalized, and their level population can be described by a single temperature component of gas. As a result, we derive detailed maps of the kinetic temperature, density, ortho-to-para ratio, and the warm H2 column density across the Orion Bar. We also leverage the observed H2 lines to evaluate the effect of dust extinction on the observed line intensities. The derived temperature and density structure allows us to assess the energy balance of the gas in the Orion bar at a scale of 0.0004 pc (1.2x10^15 cm). We will use these observations to validate theoretical PDR models.

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PDRs4All: Sulfur elemental abundance in the Orion Bar

Asuncion Fuente (remote)

Sulfur is the tenth most abundant element in the Universe and is known to play a significant role in biological systems. However, there are still a lot of open questions about the its relative distribution between gas and solids in the interstellar medium. While gas-phase sulfur accounts for its total cosmic abundance in diffuse regions [1,2], the sum of the abundances of the detected sulfur molecules in gas and ice constitutes <5 % of the expected amount in cold cores [3]. It has been suggested that the so-called depleted sulfur might be in neutral atomic form, which is not observable at (sub-)mm wavelengths. Alternatively, it canbe locked in an unknown volatile compound or semi-refractory material [4,5]. To measure the amount of atomic sulfur in molecular clouds would greatly help to answerthis question. Thus far, the [SI] 25 microns line had only been detected in bipolar outflows.

The James Webb Space Telescope (JWST) ERS “Radiative feedback from massive stars” program (PDRs4All) has observed the Orion Bar using the NIRSpec and MIRI instruments as a template of a photon-dominated region (PDR). The unprecedented angular resolution and sensitivity of the JWST has provided the first ever detection of [SI] 25 microns line in a photon-dominated region (PDR), thus opening the possibity to estimate the abundance of atomic sulfur in a molecular cloud. The comparison of the NIRSpec and MIRI JWST observations with the predictions of CLOUDY and the Meudon PDR code have allowed us to determine the amount of sulfur in gas phase in the ionized, atomic, and molecular phases. In particular, the [SIV] 10.5 microns and [SIII] 18.7 microns lines have been modeled to derive the sulfur abundance in the ionized gas located in the Orion veil and

within the HII region. The [SI] 25 microns line is probing the hot molecular phase in the surface of the molecular cloud where most of the carbon is locked in CO. Finally, the JWST data are combined with previous observations of the sulfur radio recombination lines [6], which probe the atomic phase, to follow the track of sulfur in the transition from the ionized gas to the molecular cloud in this prototypical massive star forming region. For the first time, the complete picture of the sulfur evolution through then different layerst of a giant molecular cloud is unveiled.

[1] Neufeld et al., 2015, 577, 49
[2] Kim et al., 2023, A&A 670, 111
[3] Fuente et al., 2019, A&A 624, 105
[4] Fuente et al., 2023, A&A 670, 114
[5] Cazaux et al. 2022, A&A 657, 100
[6] Goicoechea & Cuadrado, 2021, A&A 647, L7

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Session 12: Star formation, stellar populations & ISM II (Chair: Ryan Lau)

JWST observations of the compact object and 3D morphology of SN 1987A

Josefin Larsson

In 1987, the nearest supernova (SN) since the advent of modern telescopes occurred in the Large Magellanic Cloud, providing us with a unique opportunity to study the explosive death of a massive star and the birth of a SN remnant. Our Cycle 1 JWST NIRSpec and MRS IFU observations of SN 1987A have greatly improved our understanding of this iconic event. The observations show the presence of narrow lines from highly ionised argon and sulphur at the very center of the remnant, which provides the first clear electromagnetic signal from the compact object created in the explosion. The emission can be explained by photoionisation of the central ejecta by the thermal spectrum from the hot neutron star surface or the non-thermal spectrum from a pulsar wind nebula. Furthermore, the NIRSpec observations have allowed for 3D reconstructions of the larger scale metal-rich ejecta and the reverse shock, which gives new insights into the properties of the explosion itself and the progenitor star.

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The PHANGS-JWST Treasury Survey: Star Formation, Feedback, & Dust Physics at High Angular Resolution

Janice Lee

The PHANGS collaboration has been building a reference dataset for the multi-scale, multi-phase study of star formation and the interstellar medium in nearby galaxies. With the successful launch and commissioning of JWST, we are now conducting an imaging survey with NIRCam and MIRI in 8 bands from 2-21µm of 19 nearby spiral galaxies. For the first time, the high-resolution and sensitivity of JWST allow for a census of the youngest stellar populations and dust emission on the scales of star clusters and molecular clouds (~5-50 pc) in galaxies beyond the Local Group. The PHANGS-JWST survey is designed to enable a complete inventory of star formation, accurate measurement of the mass and age of star clusters, identification of the youngest embedded stellar populations, and characterization of the physical state of small dust grains. When combined with Hubble catalogs of star clusters, MUSE spectroscopic mapping of HII regions, and ALMA-identified molecular clouds, it becomes possible to measure the timescales and efficiencies of the earliest phases of star formation and feedback, build an empirical model of the dependence of small dust grain properties on local ISM conditions, and test our understanding of how dust-reprocessed starlight traces star formation activity, all across a diversity of galactic environments. In this talk, I will give an overview of the PHANGS-JWST Treasury survey, and present key results based on the remarkable imaging obtained in JWST's first year of science operations.

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MIRI's transformative view of ISM structure in nearby galaxies: Dust filament networks everywhere!

David Thilker

PHANGS-JWST mid-infrared (MIR) imaging of 19 nearby spiral galaxies has revealed ubiquitous, intricately detailed filaments of dust emission crisscrossing the disk. For the first time, we have systematically mapped the dust filament network (DFN) at multiple scales down to the resolution limit (<~25-50 pc) in all PHANGS-JWST targets. We quantify the fraction of MIR flux contained in the DFN; and the fraction of HII regions, young star clusters and associations occupying the DFN. We examine the dependence of these quantities with the physical scale at which the DFN is extracted. With our highest resolution DFN maps, we find that ~30% of the MIR flux is associated with the DFN; and that 75-80% of HII regions and 60% of star clusters younger than 5 Myr are contained within the DFN. However, the DFN at this scale is anti-correlated with looser associations of stars younger than 5 Myr identified using PHANGS-HST near-UV imaging. We interpret the DFN as: (1) both precursor to and a product of star formation events cyclically linked to stellar feedback, and (2) a finely sculpted record of dynamically-formed morphological features (e.g. bar inflows and associated feeding streamers, inter-arm spurs).

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Resolving the Crowded Center of M33 into Stars with JWST

Adam Smercina

As a member of the Local Group, the prototypical late-type spiral galaxy M33 has been studied extensively at nearly all wavelengths, including a large HST program to resolve its stellar populations. Despite its proximity, the central region of M33 have remained difficult to study with HST, due to high stellar densities - hampering measurements of the evolutionary history of its most central metal-rich populations, the origin of its nuclear star cluster, and the properties of a central supermassive black hole. Owing to JWST's transformative angular resolution and sensitivity, in the first year of its science operations, we have successfully resolved the crowded central regions of M33 for the first time with NIRCam imaging. Covering a ~2.2 kpc x ~1.7 kpc (~0.02 deg^2) region in M33's center, we detect stars well below the Red Clump across the entire footprint, allowing the calculation of detailed ancient star formation histories. Within M33's central 100 pc, these NIRCam observations are nearly 4 magnitudes deeper than the deepest existing HST observations, which are severely limited by stellar crowding. We have even, for the first time, resolved M33's nuclear star cluster, providing a new window onto determining the presence of a central black hole. These observations are not only a powerful early demonstration of JWST's ability to study stellar populations in nearby galaxies, but will also provide unprecedented, novel insight into the evolution of this already well-studied nearby galaxy.

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Star formation in extreme environments: Accretion onto pre-main sequence stars in NGC 3603.

Ciaran Rogers

The majority of stars form in clusters that contain a population of massive stars. The massive stars dominate the radiation field and dynamics of the cluster, but the exact impact they have on star formation is unclear. We have obtained NIRSpec spectra of 100 stars in the massive star forming region NGC 3603 using the microshutter array in high resolution mode. The targets consist of a combination of young and old pre-main sequence stars, selected from a HST catalogue of stars with H alpha excess emission, along with main sequence stars. The spectra exhibit a rich variety of absorption and emission lines that we can use to determine spectral type, metallicity, and accretion luminosity in the case of the pre-main sequence stars. We find evidence of stars still accreting material with ages of more than 10 million years, contrary to what is expected in an environment with such harsh UV radiation. We detect Paschen alpha strongly in emission in many cases, which we can use to derive a new empirical relationship between Paschen alpha and the accretion luminosity. We detect CO bandhead emission in a number of sources and see evidence that high levels of accretion scales inversely with CO bandhead equivalent width, in agreement with current models. We have also obtained 600 nebular spectra in order to measure the complex nebulosity of the region. With these spectra we have derived a new extinction law based on the hydrogen recombination line decrements, which is greyer than previous estimates using optical photometry.

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JWST imaging and spectroscopic observations of the Ring Nebula, NGC 6720

Roger Wesson (remote)

The iconic Ring Nebula is a bright and relatively nearby (780 pc) planetary nebula. It presents an astrophysical laboratory with a single very hot (125,000 K) source of ionising radiation and a well-defined geometry, in which the physics of dense molecular clumps in an energetic irradiated environment can be studied.

We have obtained images and spectra of the nebula with JWST. Images in four NIRCAM and nine MIRI filters provide detailed maps of the ionised, neutral and molecular components of the nebula. The bright ring contains numerous dense clumps which provide an environment suitable for molecule formation and survival. The images reveal a series of concentric structures just outside the main bright ring; one possibility is that these represent the imprint on the AGB mass loss of a binary companion with a separation of about 40-75 AU.

We have observed two regions of the nebula with the MIRI-MRS and NIRSPEC - one containing an individual clump within the harsher environment of the central cavity, and another in the denser main ring. We have measured and identified several hundred emission lines in both regions. The spectra are dominated by lines of molecular hydrogen; level population diagrams indicate that the H2 is collisionally heated to up to about 2,900 K in both regions. Recombination lines of ionised hydrogen and helium, and collisionally excited lines of heavier elements are also detected, and show that the inner region is more highly ionised than the outer region.

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Session 13: SNe & GRBs (Chair: Ryan Lau)

Unraveling Cosmic Dust Origins: JWST Revelations from Supernovae

Melissa Shahbandeh

Dust has seeded the Cosmos with galaxies, stars, and planets since the Universe was young. Despite its critical role, the origins of this cosmic dust have remained shrouded in mystery. AGB stars were originally considered the primary candidates for dust production, but large dust reservoirs have been observed to exist before AGB stars had time to produce them. Core-collapse supernovae (CCSNe) resulting from the death of massive, short-lived stars, offer an alternative explanation, but prior to JWST, we had no instrument with both the sensitivity and wavelength coverage required to test this theory. The focal point of this presentation will be JWST observations of several CCSNe that span from dust precursors formation to massive dust accumulation decades post-explosion. Previously, measurements of molecular dust precursors and dust reservoirs over five years post-explosion have only been achievable for SN 1987A due to its exceptional proximity. We will present NIRSpec and MIRI early spectroscopy of a “once in a decade” nearby stripped-envelope supernova (SESN), SN 2023dbc, which, remarkably, has captured the emergence of dust precursors CO and SiO and allowed us to uniquely probe the poorly constrained ejecta composition of SESNe (DD-4436, PI: Shahbandeh). We will also present JWST observations of two other early-stage SNe, SN 2023ixf and SN 2022acko (DD-4522, GO-2122, PI: Ashall), as well as late-stage observations of SN 2004et and SN 2017eaw (GO-2666, PI: Fox), all four of which are nearby extragalactic Type IIP SNe. Our analysis of MIRI images of these two late-stage SNe reveals the highest SN dust mass observed since SN 1987A. SN 2004et is particularly notable, because its dust reservoirs rival those of SN 1987A, despite being significantly younger. These JWST observations have helped us constrain the geometry, origin, and heating mechanism of dust and support the theory that supernovae played a key role in supplying dust to the early Universe.

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Serendipitous detection of the dusty Type IIL SN 1980K with JWST/MIRI

Szanna Zsiros

Core-collapse supernovae (CCSNe) are unique astrophysical laboratories that play a fundamental role in the cosmic dust cycle and have been long considered one of the primary stellar sources of interstellar dust. Nevertheless, there are still several open questions related to their contribution. The James Webb Space Telescope (JWST) offers an outstanding opportunity to explore the dust and circumstellar (CSM) interaction in the close environment of CCSNe in details never seen before.

We present mid-infrared (mid-IR) imaging of the Type IIL SN 1980K obtained with the JWST more than 40 yr post-explosion and the analysis of dust formation in its close environment. The SN is located in the nearby (~ 7 Mpc) so-called 'Fireworks Galaxy' NGC 6946 and captured in JWST/MIRI images taken of the field of SN 2004et in the same galaxy. Its advantageous location and

evolutionary stage make the SN a promising candidate for examining the transitional phase between young SNe and older SN remnants. Additionally, we re-analyzed all available archive Spitzer data of the SN to investigate the late-time mid-IR light curve and constrain upper limits on shorter wavelengths.

We fit analytical dust models to the mid-IR spectral energy distributions (SED), computed numerical SED dust models, and also model the late-time optical spectrum obtained recently with Keck to conclude the physical properties of the assumed dust in the environment of the SN. The SED models reveal a surprisingly large amount (≈ 0.002 M_⊙) of silicate-dominated dust at ~150 K (accompanied by a hotter dust/gas component), whilst the optical line-profile models disclose two orders of magnitude higher dust masses. We propose two plausible scenarios for the SN 1980K observed with the JWST: i) we may see pre-existing CSM-dust heated collisionally similarly to the equatorial ring of SN 1987A, or ii) the mid-IR component of the newly-formed dust with much colder dust located in the ejecta.

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JWST'S EYE GLIMPSES THE PROGENITORS OF THE TWO BRIGHTEST GAMMA-RAY BURSTS

Benjamin Schneider

Gamma-ray bursts (GRBs) are extreme cosmic explosions, ranked among the most energetic phenomena in the Universe. They originate from the coalescence of two compact objects, such as two neutron stars, or from the violent death of a massive star. The high resolution and sensitivity of JWST offer the potential to study the GRB afterglow emissions in detail, and provide new insights into the nature of these extreme objects. In this talk, we will present our JWST photometric and spectroscopic observations of the two brightest gamma-ray bursts ever detected. The high signal-to-noise spectrum of GRB 221009A, the brightest of all time, observed at ~12 days post burst revealed a redder power-law spectrum than expected. This spectrum significantly constrained the viable afterglow model of the source, and ruled out the existence of a bright supernova associated with this burst. The JWST observations of the long-duration GRB 230307A afterglow provided the first nebular phase observations of a kilonova – a thermal transient powered by the radioactive decay of r-process synthesised heavy elements. These observations revealed spectral features consistent with the three r-process peaks (Tungsten, Selenium, and Tellurium), and confirmed the central role of GRB in producing heavy elements across the Universe.

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Session 14: Star formation & disks I (Chair: Chris Evans)

STARS LIKE THE SUN TAKE LONGER TO FORM WHEN THE METALLICITY IS LOW

Guido de Marchi

Using JWST/NIRSpec, we studied 20 pre-main sequence (PMS) star candidates previously identified with Hubble photometry in the low-metallicity NGC 346 cluster, the most massive starburst region in the Small Magellanic Cloud. These objects have ages in the range 1 -30 Myr. Our spectra show for the first time strong hydrogen recombination lines in the Paschen and Brackets series in the spectra of these sources and reveal mass accretion rates of about 1E-8 Msolar/year for PMS stars as old as 20-30 Myr. These rates are about two orders of magnitude higher than those measured for stars of similar age in the Milky Way. The spectra also reveal prominent H2 ro-vibrational lines, witnessing molecular winds associated with shocks and outflows in the circumstellar discs of all these PMS stars, even those 20-30 Myr old. No such features are seen at comparable ages in Galactic star forming regions. JWST spectroscopy and photometry also reveal NIR excess from these PMS stars, clearly showing that circumstellar discs are still surrounding even the oldest of these PMS objects, providing more time for planets to form and grow than in the Milky Way. We conclude that in these low-metallicity environments, similar to those at high redshift, star and planet formation proceed differently from what we currently know.

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YOUNG STELLAR OBJECTS AT LOW METALLICITY IN NGC346

Nolan Habel

We present NIRCam and MIRI imaging and photometry of the low-metallicity star-forming region NGC 346 located in the Small Magellanic Cloud. With a metallicity (~1/5 Z solar) analogous to that of cosmic noon, the peak era of star formation in the early universe (z = ~2), this active star forming region provides a local laboratory to test theories of early star and planet formation in unprecedented detail. In a 13 hour GTO program (proposal ID 01227), we imaged this nearby (60kpc) region in 11 wavelength bands from 1.15 to 21 microns across the two instruments. We reach photometric depths over 10 magnitudes below Spitzer and 2 magnitudes below HST at comparable wavelengths. We detect sources with masses as low as ~0.1 solar masses, and find evidence of ongoing low-mass star formation concentrated along dust filaments. We find at least 500 YSOs and pre-main sequence stars, including those showing IR excess and evidence of accretion. Such evidence suggests that even at low metallicities, the dust required for the creation of rocky planets is already present, indicating that they may have formed earlier in the universe than previously thought. Using the new tool Starbug II, built specifically for crowded fields with complex diffuse emission such as NGC 346, we extract PSF photometry in 6 NIRCam bands and aperture photometry in 5 MIRI bands. We identify dusty, deeply-embedded YSOs with detections at both NIRCam and MIRI wavelengths, rising SED slopes at 21 microns and 10 micron absorption indicative of dusty silicates in their protostellar envelopes. For these sources, we create model-fitted SEDs, making measurements of their radii, temperatures, luminosities and masses, and suggest them as candidates for upcoming NIRSpec and MIRI MRS spectroscopic studies.

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Direct Imaging of YSOs: Observing five circumstellar disks to search for forming planets

Camryn Mullin

Planets form in circumstellar disks around young stellar objects (YSOs). Several circumstellar disks have observed substructure such as rings, gaps, and spiral arms, suggesting candidate protoplanet companions. Direct observations of protoplanets are crucial to test fundamental planet formation theories – filling in the gap between disk morphology and exoplanet demographics.

In our Guaranteed Time Observation program “Direct Imaging of YSOs” (PID 1179), we used JWST/NIRCam to gather images of five circumstellar disks. We utilized four filters; two for observing spectral line emission (F187N, F405N), and two for continuum emission (F200W, F410M). These five targets were selected for their compelling evidence of companion-induced morphologies: spiral arms (MWC758 and SAO206462), rings and gaps (HLTau and TWHya), and previous confirmed protoplanet detections (PDS70). JWST has unparalleled sensitivity when compared to ground-based imaging, which is vital in our observations of outer disk regions where the companions are predicted to lie.

For each target, we resolved disk structures and searched for candidate planets. In our two spiral targets, we resolved the spiral arms and explored the possibility of them being planet driven. We obtained high-resolution images of HLTau’s envelope and outflow, previously observed from a wider field of view with Hubble. With JWST’s exquisite sensitivity, we reached the deepest limits observed for MWC758 and SAO206462, allowing us to probe as low as 1 MJup within the highly obscured circumstellar environment. These results from our five targets further our understanding of planet-driven disk morphology, and planet formation and evolution.

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High contrast imaging of the debris disk around Beta Pictoris

Marshal Perrin

The prominent disk around the star Beta Pictoris is one of the best studied due to its proximity (19 pc), extended size (up to 1800 au) and large surface brightness. Since the first imaging observation in 1984 by Smith and Terrile, the astronomical community has thoroughly investigated this system, finding large amounts of dust and gas, exocomets, and two planets. All of this makes it the perfect laboratory to investigate the dynamics and chemistry of the late stages of planet formation. The JWST GTO 1411 program was designed to investigate the dust component at near- and mid-infrared wavelengths, providing new insights on the dust morphology, composition, and distribution. The combination of the high sensitivity of the on board instruments with the 4QPM and Lyot coronagraphs allows for the most detailed images of the Beta Pictoris disk so far at this wavelength range, revealing new features and details in the dust distribution. In this talk, I will present JWST NIRCam and MIRI coronagraphic images, ranging from 1.82 to 23 microns. I will also summarize the analysis of the new observed disk features, and compare it to previous ground and space based observations at multiple wavelengths.

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MIRI MRS Observations of the Beta Pictoris System

Kadin Worthen

The young (~20 Myr old) star Beta Pictoris is host to an edge-on debris disk and two confirmed giant planets, Beta Pic b and Beta Pic c. This makes it a great laboratory for investigating the late stages of planet formation. We present MIRI MRS observations from the JWST GTO 1294 program of the Beta Pic system, which was designed to study the composition and spatial distribution of the dust as well as to perform high-contrast imaging to study the atmosphere of Beta Pic b. The Spitzer Space telescope found evidence for a hot dust population emitting at 5 microns as well as silicate features at 10, 18, and 23 microns from sub-micron sized particles. With JWST, we detect hot dust from the inner regions of the system and we spatially resolve the dust disk at 5 microns for the first time, resulting in a newly discovered population of spatially extended hot dust. We find that the 18-micron silicate feature seen with Spitzer has disappeared and that the shape of the 10-micron feature has changed during the 18 years between Spitzer and JWST observations. Since the 18-micron silicate features seen with Spitzer was best fit by small grains, we postulate that these dust grains were radiatively driven out of the system in the 18 years between Spitzer and JWST observations. The location of the spatially resolved hot dust (~450 K) at 5 microns indicates that the dust grains are small and are thus also below the blow-out size of the system. We also perform PSF subtraction and detect Beta Pic b in our MRS data. We extract a low-resolution spectrum of the planet detect water in its atmosphere at ~6-microns. This is the first mid-infrared spectrum of a directly imaged planetary mass substellar companion and the first use of high-contrast imaging techniques with the MIRI MRS.

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Ions and complex molecules in space ice: insights from JWST Observations of Young protostarS (JOYS+)

Will Rocha

A new chapter in our understanding of astrophysical ices is being written with the most recent observations with the James Webb Space Telescope (JWST). Combining two GTO programs, named JWST Observation of Young protostarS (JOYS+) program, about 30 low- and high-mass sources are being observed with the MIRI/MRS instrument, providing results about the ice chemical complexity toward many sources. Our results reveal simple ices expected for these sources (e.g., H2O, CO2, NH3, CH4), ice species not seen previously for low-mass sources (SO2), ions that are likely part of salts (OCN-, HCOO-, NH4+), and methanol (CH3OH). In addition, compelling signatures (at least two vibrational modes) of complex organic molecules (COMs; CH3CH2OH, CH3CHO, CH3OCHO, and CH3COOH) were likely discovered in several of these protostars. Remarkably, this marks the first time such COMs have been detected in interstellar ices. The derived ice column densities and abundances for the simple molecules are consistent with ground- and space-based observations. In addition, we derive robust column densities of these COMs for the first time.

Three striking conclusions are: (1) the formate ion (HCOO-) dominates the absorption features 7.2 and 7.4 micron bands, common toward several protostars, which supports acid-base reactions in interstellar ices; (2) the CH3CH2OH/CH3CHO ratio in ices corresponds to that seen in gas-phase observations of hot cores which points to a solid-phase formation of these two molecules; (3) COMs/H2O ratios are lower in the comet 67P/G-C compared with protostellar ices, which is consistent with previous analysis for CH4, CO and CH3OH ices. In addition, for the first time, we derive robust COMs abundances relative to CH3OH ice and compare them with the comet 67P/G-C. Our results indicate that COMs/CH3OH are higher in protostellar ices, which may suggest the formation of even more complex molecules detected in the comet. This finding unveils new insights into the evolution of protostars and the chemical processes shaping interstellar and solar system ices.

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Session 15: Star formation & disks II (Chair: TBC)

MIRI maps a molecular disk wind, CO, and water in an edge-on protoplanetary disk

Nicole Arulanantham

The environments in which planets form are compendiums of distinct physical systems, including warm gas-rich inner disks, cold icy outer regions, photoevaporative and magnetically driven winds, and jets. Mid-infrared spectroscopy serves as a tool to directly characterize each of these components from the emission lines of atomic and molecular gas. With the medium-resolution spectrometer (MRS) on JWST-MIRI, we can now spatially and spectrally resolve these features for the first time. We present MIRI MRS observations of the edge-on disk around the sub-solar mass star Tau 042021, which map the radial and vertical distributions of warm H2, CO, and H2O. We image a bipolar H2 wind launched from the inner disk and measure opening angle of ~60 degrees in both directions. Emission from H2O and CO is detected at radii as large as r ~ 25, 50 au respectively, with a spatial distribution that is consistent with scattering on large dust grains of line emission formed within ~1 AU in the inner disk. This effect is most visible in edge-on systems, where the optically thick disk midplane masks the warm dust emission and allows only scattered light to escape. The MIRI observations provide an early look into the properties of infrared molecular emission from edge-on planet-forming disks, and their ability to trace volatiles in the comet-forming region.

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JWST MIRI/MRS IFU Spectroscopy discovers a spatially resolved disk wind

Naman Bajaj

Understanding the process underlying circumstellar disk dispersal is crucial to constrain the time left for planet formation and migration. Thermal winds powered by high-energy stellar photons have long been recognized as the driver for this dispersal. However, observational evidence is currently based on blueshifts (~ 5 km/s) in spectrally resolved [NeII] lines which do not exclude MHD winds that contribute to evolution but not dispersal. We report JWST MIRI/MRS IFU spectroscopy of T Cha, a transition disk with a large dust gap (~ 30 au) likely undergoing disk dispersal. We detect three forbidden lines, [NeII] at 12.8 µm, [NeIII] at 15.5 µm, and [ArII] at 6.98 µm, of which [NeII] is known to trace the wind based on a blueshift in the ground-based data. We use line intensity ratios to constrain the type of high-energy stellar photons driving the ionization. Furthermore, we perform continuum as well as PSF subtraction on the IFU cube and discover an extension in the [NeII] emission that is compatible with a disk wind. This is the first image of wind in the [NeII] line. We conclude by discussing whether the origin of the disk wind from T Cha is photoevaporative or MHD and its implications for disk evolution and dispersal. This work acts as a pathfinder for future observations aiming at investigating disk dispersal.

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Probing gas composition and conditions in the inner au of protoplanetary disks: the first year of JW

Sierra Grant

In the first year of science, the sensitivity and spectral resolution of JWST-MIRI MRS is providing a detailed characterization of gas and dust in the inner few au of protoplanetary disks, tracing the building blocks for terrestrial planets. Here we present results from the MIRI mid-INfrared Disk Survey (MINDS) GTO program, which is the largest JWST protoplanetary and debris disk survey so far. To date ~30 disks in our sample have been observed and show a great diversity in gas and dust features. Early results include large variations in water line strengths, the first detection of water in the planet-forming disk PDS 70, and rich hydrocarbon chemistry seen in the disk around a very low-mass star. We will highlight these results, looking both at individual targets and at trends across the sample, and we will also look toward the future.

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JWST reveals excess cool water near the snowline in compact disks, consistent with pebble drift

Andrea Banzatti

Previous analyses of mid-infrared water spectra from young protoplanetary disks observed with the Spitzer-IRS found an anti-correlation between water luminosity and the millimeter dust disk radius observed with ALMA. This trend was suggested to be evidence for a fundamental process of inner disk water enrichment, used to explain properties of the Solar System 40 years ago,

in which icy pebbles drift inward from the outer disk and sublimate after crossing the snowline. Previous analyses of IRS water spectra, however, were very uncertain due to the low spectral resolution that blended lines together. We present new JWST-MIRI spectra of four disks, two compact and two large with multiple radial gaps, selected to test the scenario that water vapor inside the snowline is regulated by pebble drift. The higher spectral resolving power of MIRI-MRS now yields water spectra that separate individual lines, tracing upper level energies from 900 K to 10,000 K. These spectra clearly reveal excess emission in the low-energy lines in compact disks, compared to the large disks, establishing the presence of a cooler component with T≈ 170-400 K and equivalent emitting radius Req≈ 1-10 au. We interpret the cool water emission as ice sublimation and vapor diffusion near the snowline, suggesting that there is indeed a higher inwards mass flux of icy pebbles in compact disks. Observation of this process opens up multiple exciting prospects to study planet formation chemistry in inner disks with JWST.

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Water in T Tauri protoplanetary disks after the first year of MINDS

Danny Gasman

The mid-infrared wavelength ranges probed by MIRI MRS at a resolution of 3500 to 1500 from 5-28 microns allow us to study the compositions of the inner regions of the disks from 0.1 to 10 AU. It is in these regions that terrestrial planets are likely to form. Therefore, the gas composition in this region dictates what species are available for accretion, and what the composition of the planets will be. The JWST MIRI mid-INfrared Disk Survey (MINDS) is a Guaranteed Time Observation Programme (PI: T. Henning) that will observe a sample of 33 T Tauri disks with the MIRI Medium-Resolution Spectrometer, among other objects. Currently, 16 of these T Tauri disks have been observed and the data have revealed an exciting variety of water line strengths between the different disks. We compare dust disk sizes, masses, and substructures to water line fluxes in the current sample of 16 T Tauri disks, in order to understand the conditions under which a disk might be rich in water emission. Water is not only essential for life on Earth and a major oxygen carrier, but may also play an important role in the planet formation process. It is therefore imperative to understand what disk properties could result in abundant water in the inner disk. MIRI/MRS covers the ro-vibrational bending modes in the shorter wavelengths (5 to 8 micron), to the pure rotational lines towards the mid-infrared regions (10 micron and onwards). Due to this large spread in excited wavelengths, it has been suggested that different parts of the spectrum probe different parts of the disk. Detection and/or non-detection of specific lines may then correlate with the structure of the disk and stellar properties. Large gaps in outer regions of the disk may prevent icy pebbles from drifting inwards, inhibiting the formation of gaseous water from sublimation. Additionally, water can chemically form from OH. In reverse, photodissociation of water results in OH. The water lines in the inner disk can therefore provide critical information about the dominant chemical processes in the inner disk, along with providing an indication of pebble migration and the radiation environment.

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The MIRI Excesses Around Degenerates (MEAD) Survey

John Debes

In 2004, Cycle 1 of Spitzer observed ~100 white dwarfs (WDs) in the mid-IR where a handful of IR excesses were detected. This sparked an entire field of WD study looking at remnant planetary systems around dead stars that touches many areas of astrophysics today. With the launch of JWST, we are faced with a very similar situation-- hardly any known WDs have their photospheres detected beyond 8 micron, giving JWST the opportunity to conduct the first wide and shallow survey of the 25 pc WD sample with the Cycle 2 MIRI Excesses around Degenerates (MEAD) Survey. For modest completion frequencies, we expect to detect IR excesses from cool brown dwarfs, young Jupiters, optically thin dust disks from shredding exo-planetesimals, and cyclotron emission from magnetic white dwarfs with unprecedented sensitivity. With JWST's absolute flux calibration requirement of 2%, we also will find other departures from the expected, such as the additional opacity seen in cool WDs from collision-induced absorption. Whatever is out there, this survey will define white dwarf science (and other fields) with JWST two decades after Spitzer first pointed toward a bright white dwarf.

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Session 16: Galaxies V: Dusty Galaxies (Chair: Taylor Hutchinson)

First look at the JWST/MIRI 7.7um sources in COSMOS-Web

Santosh Harish

COSMOS-Web is the largest JWST Cycle 1 Guest Observer program, both in terms of contiguous area on the sky and total prime time allocation, which will image the COSMOS field at near- and mid-infrared wavelengths, adding on to the existing rich, multi-wavelength observations in this region. Roughly half of the program has been observed to date. In this work, we present an overview of the MIRI F770W observations and reductions using the JWST Science Calibration Pipeline including some additional steps for an improved reduction. We also provide 5-sigma depth estimates as well as number counts based on the entire MIRI coverage so far, and a comparison with the Spitzer/IRAC CH4 observations for bright sources in the field. In addition, preliminary efforts on the selection and characterization of extreme emission line galaxies based on broadband colors will also be presented.

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Insights into HST-dark Star Formation from NIRCam and NIRSpec

Vasily Kokorev

The last few decades of observations with HST have revealed a population of dust obscured, optically faint, star-forming galaxies. Objects like these are thought to be common in the early Universe, and yet are missed even by the deepest surveys due to their dusty nature, challenging our understanding of galaxy evolution. Most recently, unparalleled sensitivity and wavelength coverage of JWST has enabled us to identify a growing number of these highly obscured dusty main-sequence galaxies. Will JWST then be able to account for all the previously missed dusty populations at high-z? So far, it does not seem likely.

I will present a first spatially resolved JWST/NIRCam overview of a lensed HST-dark galaxy, spectroscopically confirmed with ALMA at z=2.58. While being largely invisible at ~1 μm with NIRCam, except for sparse clumpy sub-structures, the object is well-detected and resolved in the long-wavelength bands with a spiral shape clearly visible in F277W. Thanks to the synergy between JWST and ALMA, the spatially resolved analysis of the HST-dark galaxy reveals a largely uniform Av ∼ 4 area, which spatially matches to the ALMA 1 mm continuum emission. Most importantly, accounting for the limits of current JWST surveys, unlensed analogs of our HST-dark object at z>4 will only be detectable in F356W and F444W, becoming totally JWST-dark at z~6. This implies that discovering typical dusty star-forming galaxies in the Epoch of Reionization is a challenging task for JWST.

Full understanding of these objects, however, requires spatially resolving them in the sub-mm. To this end I will discuss my work in the UNCOVER survey to study the lensed ALMA-detected HST-dark galaxies in the A2744 field. Finally, metallicities and other line properties of optically dark galaxies are still shrouded in mystery, as such I will conclude with my ongoing work to systematically study the HST-dark sources by using more than 5000 JWST/NIRSpec spectra from the public programs.

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MIRI-only sources in the MIRI Deep Imaging Survey (MIDIS)

Iris Jermann

With the launch of the JWST in December 2021 we are now able to detect and study the first galaxies deep into the Cosmic Dawn Epoch and to study the nature of HST/optically hidden galaxies. Whether these are high-z candidates or dusty-obscured galaxies, dozens of new galaxies have been photometrically detected with JWST/NIRCam and spectroscopically confirmed with JWST/NIRSpec. However, the MIRI instrument observes at even longer wavelengths (> 5 microns), probing the rest-frame optical emission of the first galaxies at z>10 and offering a brand-new mid-IR view of the universe. The MIRI-GTO team has obtained the deepest MIRI image to date in the 5.6 microns band reaching a depth of 29.6 covering a part of the Ultra-Deep Field. We co-analyse our unique dataset with the deep ancillary HST and JWST NIRCam images with similar depth and identify a handful of candidates of galaxies only detected in the MIRI 5.6 microns band, the so-called MIRI-only sources. Moreover, we investigate deep ALMA data to determine whether a MIRI-only source has an ALMA counterpart. In this talk, I will first present our exclusive sample of MIRI-only candidates and explain how we have identified them. Then, I will show the results of several Spectral Energy Fitting (SED) codes on individual MIRI-only sources, but also on the stacked MIRI-only sources, because by stacking our sample they appear significantly in more bands. I will discuss the limits of using SED codes for such sources. The main characteristic we want to constrain is the redshift, but other quantities such as the mass or the star formation rate are crucial to understanding the nature of the MIRI-only population. Last, I will review our findings in a broader picture, pointing out the implication of these results in our understanding of galaxy formation and evolution in the early universe.

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Statistics for Galaxy Outflows at z~6-9 Identified with NIRCam and NIRSpec

Yechi Zhang

We present statistics of z~6-9 galaxy outflows indicated by spatially-extended gas emission and broad lines. With a total of 61 spectroscopically confirmed galaxies at z~6-9 in the JWST CEERS, GLASS, and ERO data, we find five galaxies with [Oiii]+Hb ionized gas emission significantly extended beyond the kpc-scale stellar components based on the emission line images constructed by the subtraction of NIRCam broadband (line on/off-band) images. By comparison with low-z galaxies, the fraction of galaxies with the spatially extended gas, 5/61, at z~6-9 is an order of magnitude higher than those at z~0-1, which can be explained by events triggered by frequent major mergers at high redshift. We also investigate medium- and high-resolution NIRSpec spectra of 30 galaxies at z~6-9, and identify five galaxies with broad (140-800 km/s) lines in the [Oiii] forbidden line emission, suggestive of ongoing galaxy outflows. One galaxy at z=6.38 shows both the spatially-extended gas emission and the broad lines, while none of the galaxies with the spatially-extended gas emission or broad lines present a clear signature of AGN either in the line diagnostics or Type 1 AGN line broadening (>1000 km/s), which hint outflows mainly driven by stellar feedback. The existence of galaxies with/without spatially-extended gas emission or broad lines may suggest that these are galaxies in the early, late, post phases of galaxy outflows at high redshift, where the relatively large fractions of such galaxies indicate the longer-duration and/or more-frequent outflows at the early cosmic epoch.

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Uncovering the MIR emission of quiescent galaxies with JWST

David Blanquez

"We present one of the first studies of the mid-IR (MIR) emission of quiescent galaxies (QGs) beyond the local universe. Using deepJWST imaging in the SMACS-0723 cluster field we identify a mass limited (M∗ > 10^9 M⊙) sample of intermediate redshift QGs(0.2 < z < 0.7) and perform modeling of their rest-frame UV to MIR photometry. We find that QGs exhibit a range of MIR spectrathat are composed of a stellar continuum emission and a dust component that is 1-2 orders of magnitude fainter to that of star forminggalaxies. The observed scatter in the MIR spectra, especially at λrest > 5 µm, can be attributed to different dust continuum levelsand/or the presence of Polycyclic Aromatic Hydrocarbons (PAHs) features. The latter would indicate enhanced 11.3- and 12.7 µmPAHs strengths with respect to those at 6.2- and 7.7 µm, consistent with the observed spectra of local ellipticals and indicative ofsoft radiation fields. Finally, we augment the average UV-to-MIR spectrum of the population with cold dust and gas emission in the far-IR/mm and construct a panchromatic UV-to-radio SED⋆ that can serve as a template for the future exploration of the interstellar medium of z > 0 QGs with ALMA and JWST."

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