ACCURATE FLUX CALIBRATION

for 21st Century Astrophysics

October 22-25, 2024

STScI

Advances in space telescope technology and all-sky surveys are driving the need for more precise and accurate flux calibration across the observable spectrum. The Space Telescope Science Institute is hosting a workshop in October 2024 to evaluate the current state of flux calibration for both ground-based and space observatories.

Workshop Objectives

- Identify issues affecting cross-mission calibration and their impact on the Hubble, Webb, and Roman Space Telescopes as well as surveys like Gaia and Rubin.
- Improve the consistency of flux calibration across the electromagnetic spectrum, with an emphasis on the ultraviolet to the mid-infrared.
- Address the limiting factors for calibration between ground-based and space observatories.
- Improve and assess the relative strengths and weaknesses of the models used for different classes of standards.

Workshop Significance: STScI last hosted a calibration workshop over a decade ago. A workshop planned for March 2020 did not take place due to the pandemic. With new telescopes, new technologies, and new scientific requirements, the need has grown for the astronomy community to meet, assess the current state of the art, and develop new collaborations to improve our current flux calibration.

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Workshop Schedule

STScI

TUESDAY, OCTOBER 22ND

TIME	*TITLE*	*SPEAKER*
8:45 AM	*STScI's Director Welcome Message/Introductory Talk*	*Jen Lotz*

Session 1A:

9:00 AM	**Astronomical Flux Calibration- An Overview**	**Chris Stubbs**
9:30 AM	**Improving the Absolute Calibration Across the Visible and Mid-infrared** ***&*** ***New approaches to improving the absolute flux calibration of standard stars***	**George Rieke & Susana Deustua**
10:10 AM	**The James Webb Space Telescope Absolute Flux Calibration: Program Design and Calibrator Stars**	**Karl Gordon**
10:30 AM	AM Coffee Break & Poster Session ***(Zhen-Kai Gao, Andreea Petric, Charles Proffitt, and Kevin Volk)***	

Session 1B:

11:00 AM	***Status of JWST NIRSpec Flux calibration***	**Charles Proffitt**
11:20 AM	***The Status of the JWST/NIRCam Absolute Flux Calibration***	**Martha Boyer**
11:40 AM	***Absolute flux calibration in the mid-IR: Lessons from the MIRI Medium Resolution Spectrometer***	**David Law**
12:00 PM	*Session Discussion*	
12:30 PM	*Lunch Break*	

TIME	*TITLE*	*SPEAKER*

Session 2A:

1:30 PM	***CALSPEC Basics***	**Ralph Bohlin**
1:50 PM	***New Photometric Calibration of the Wide Field Camera 3 Detectors***	**Annalisa Calamida**
2:10 PM	***Time Dependent Sensitivity of ACS/WFC***	**Gagandeep Anand**
2:30 PM	***Update on the Absolute Flux Recalibrations of the HST/STIS modes***	**Svea Hernandez**
2:50 PM	***Establishing the Absolute Flux Calibration for NASA's SPHEREx All-Sky Spectroscopic Survey***	**Matthew Ashby**
3:10 PM	*PM Coffee Break & Poster Session* ***(Roberto Avila, Mariarosa Marinelli, TalaWanda Monroe, and Matthew Siebert)***	

Session 2B:

3:40 PM	***Refining the CALSPEC Catalog of Standards with TESS***	**Thomas Dutkiewicz**
4:00 PM	***Rapidly Changing HST/STIS Time Dependent Sensitivity in the NUV***	**Daniel Stapleton**
4:20 PM	***Evaluating HASP Flux Calibration Using CALSPEC Models to Enable High-quality Spectral Data from HST***	**Lauren Miller**
4:40 PM	*Session Discussion*	
5:10 PM	***Close Out***	

WEDNESDAY, OCTOBER 23RD

TIME	*TITLE*	*SPEAKER*
	Session 3A:	
8:30 AM	**A Decade of Improvements in Calibration and Needed Improvements for Supernova Cosmology**	**Daniel Scolnic**
9:00 AM	***Toward Millimag Photometry with the Rubin Observatory Legacy Survey of Space and Time***	**Eli Rykoff**
9:20 AM	**ALTAIR High-Altitude Micro-Airships for Precision Rubin Observatory Calibration (and Beyond): Status & Plans**	**Justin Albert**
9:40 AM	**Roman-WFI: characterization of widefield chromatic response**	**Eric Switzer**
10:00 AM	**Euclid photometric calibration - The first year in space**	**Mischa Schirmer**
10:20 AM	AM Coffee Break & Poster Session ***(Justin Albert, Evan Bray, Ami Choi, Dario Fadda, and Sanjib Sharma)***	
	Session 3B:	
10:50 AM	***Cross-calibrating HST and 2MASS for Evolved Star Distances***	**Meredith Durbin**
11:20 AM	***The absolute sky seen through the lens of calibration spectra***	**Michael Weiler**
11:40 AM	***CALSPEC and the Gaia photometric system***	**Jesus Maiz Apellaniz**
12:00 PM	*Session Discussion*	
12:30 PM	*Lunch Break*	

TIME	TITLE	SPEAKER
Session 4A:		
1:30 PM	***Absolute Calibration Across the Spectrum***	Luca Casagrande
2:00 PM	***Accurate flux scale for multifilter surveys with the white dwarf locus***	Carlos Lopez - Sanjuan
2:20 PM	***A library of high-fidelity spectra with the MUSE integral field spectrograph***	Valentin Ivanov
2:40 PM	***Observing Faint Suns in Clusters for Photometric Calibration***	Everett Schlawin
3:00 PM	***Photometric calibration strategy for the Near-Earth Object (NEO) Surveyor mission***	*Sean Carey*
3:20 PM	*PM Coffee Break & Poster Session* ***(Emma Godden, Karl Gordon, Olena Kompaniiets, Angelle Tanner, and Alex Zhang)***	
Session 4B:		
3:50 PM	***The Definition of the Magnitude System For James Webb Space Telescope Photometry***	Kevin Volk
4:10 PM	***The NASA Landolt Mission Overview***	Peter Plavchan
4:30 PM	***The International Astronomical Consortium of High Energy Calibration: Method and Activity***	Kristin Madsen
4:50 PM	***Session Discussion***	
5:20 PM	***Close Out***	
5:30 PM	***SDAS Beer and Snacks Reception***	

THURSDAY, OCTOBER 24TH

TIME	*TITLE*	*SPEAK*
	Session 5A:	
8:30 AM	**The Future of SN Ia Cosmology with the Nancy Grace Roman Space Telescope**	**Rebekah Hounsell**
9:00 AM	***The trouble with K giants: A challenging class of mid-infrared standard stars***	**Greg Sloan**
9:20 AM	**NIST-traceable Optical Flux Calibration using the SNIFS CALibration Apparatus (SCALA)**	**Daniel Kusters**
9:40 AM	**What does SI traceability mean for stellar spectral flux calibration?**	**Joseph Rice**
10:00 AM	**Blackbody Stars for Accurate UV-VIS-IR Flux Calibration**	**Nao Suzuki**
10:20 AM	AM Coffee Break & Poster Session ***(Peter Brown, Susana Deustua, Eunkyu Han, and William Kenworthy)***	
	Session 5B:	
10:50 AM	***Reaching 2% Local Flux Precision with HST COS & STIS to Enable AGN Reverberation Mapping***	**Rachel Plesha**
11:10 AM	***The calibration requirements of the Ultraviolet Explorer (UVEX)***	**Hannah Earnshaw**
11:30 AM	***ALMA Flux Calibration***	**Ruediger Kneissl**
11:50 PM	*Session Discussion*	
12:20 PM	*Group Photo outside of the Muller Building*	
12:30 PM	*Lunch Break*	

TIME	TITLE	SPEAKER

Session 6A:

1:20 PM	***The characterisation of atmospheric effects on ground-based astronomical observations***	Florian Kerber
1:50 PM	***A novel absolute photometric calibration based on fitting the system and atmosphere transmission***	Simone Garrappa
2:10 PM	***Towards blind telluric correction***	Alain Smette
2:30 PM	***Toward a Homogeneously Flux-Calibrated EXTernal Ground Based Dataset for the Euclid Mission***	Joseph Mohr
2:50 PM	***Methods and issues with flux calibration methods employed by student researchers and amateur astrono***	*Brian Kloppenborg*
3:10 PM	*PM Coffee Break & Poster Session* ***(Kathleen Kraemer, Andreea Petric, Diego Reyes, and Ian Wong)***	

Session 6B:

3:40 PM	***A Deep Dive into the Variability and Calibration of the JWST MIRI Imager***	Mary Anne Limbach
4:00 PM	***Current Flux Calibration Limits Stellar Age Estimates***	Jamie Tayar
4:20 PM	***Single-lined Eclipsing Binaries Become Benchmark Binaries with Better Flux Calibration***	Daniel Stevens
4:40 PM	***Session Discussion***	
5:10 PM	***Close Out***	
6:00 PM	***Workshop Thank You Reception in STScI's Café***	

FRIDAY, OCTOBER 25TH

TIME	*TITLE*	*SPEAKER*
Session 7A:		
8:30 AM	**The Potential of Cool Stars as Flux Calibrators**	**Carlos Allende Prieto**
9:00 AM	**Calibrating the Effective Temperatures & Linear Radii Scales for Giant Stars**	**Gerard van Belle**
9:20 AM	**The Updated BOSZ Synthetic Stellar Spectral Library**	**Szabolcs Meszaros**
9:40 AM	**A network of cool white dwarfs as standards for flux calibration**	**Abbigail Elms**
10:00 AM	AM Coffee Break & Poster Session ***(Ellyn Baines, Susana Deustua, Peter Nemeth, David Rubin, and Prasenjit Saha)***	
Session 7B:		
10:30 AM	***All-sky Faint DA White Dwarf Spectrophotometric Standards for Observatories and Surveys***	**Abhijit Saha**
10:50 AM	***DAmodel: Hierarchical Bayesian Modelling of DA White Dwarfs for Spectrophotometric Calibration***	**Ben Boyd**
11:10 AM	***Checking the JWST/MIRI Imager absolute flux calibration using four nearby white dwarfs***	**John Debes**
11:30 AM	*Wrap up/Session Discussion*	
12:00 PM	*Workshop Conclusion*	

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Workshop Abstracts

STScI

Invited Talks

The Potential of Cool Stars as Flux Calibrators

Carlos Allende Prieto
Instituto de Astrofisica de Canarias, Spain

In the quest for astronomical light sources that are stable, fill a wide spectral range, and show smooth spectra easy to model, flux standards are mainly metal-poor halo turn-off stars, A-type stars, and white dwarfs. Nevertheless, cooler stars have their strength on their higher number densities, closer distances (and smaller implied interstellar absorption), and relative brightness in the infrared. This presentation will make an attempt to be quantitative on the value of cool stars, giants and dwarfs, as flux standards for demanding astronomical applications, based on data from HST, DESI and the astrometric missions from ESA: Hipparcos and Gaia.

Absolute Calibration Across the Spectrum

Luca Casagrande
Australian National University

Accurate and consistent absolute calibration from the ultraviolet to the infrared is critical for addressing a wide range of astrophysical questions, ultimately enabling precise inference of physical quantities. In this talk, I discuss an alternative approach that leverages a physical quantity —stellar effective temperature— to establish the zero-point for absolute calibration using solar twins. I present a formalism for deriving photometric zero-points at various wavelengths by benchmarking against stars with well-known effective temperatures, thereby bypassing the need for absolute spectrophotometry. Applications of this methodology to recent (spectro)photometric surveys in the near ultraviolet and optical are discussed, highlighting its implications for improving calibration consistency across the spectrum.

Cross-calibrating HST and 2MASS for Evolved Star Distances

Meredith Durbin
University of California at Berkeley

Spaceborne observatories operating in the near-infrared, which are not subject to the constraints of atmospheric transmission windows, often have filter systems that diverge significantly from their ground-based counterparts. These differences are doubly impactful for cool stars, whose dramatic molecular SED features can make even subtle filter differences salient. I will discuss two complementary efforts to directly link the HST WFC3/IR filter system to that of 2MASS, one via synthetic photometry and one via a pure parallel program in the Magellanic Clouds, with an emphasis on results for evolved stars often used in distance scale work.

New approaches to improving the absolute flux calibration of standard stars

Susana Deustua
NIST

A few, very bright stars have SI-traceable absolute flux determinations, defined as calibrated against physical standards. Historically, these efforts focused on the spectral energy distribution measurements in the visible - between about 400 nm to 900 nm - of Vega (plus a few other stars). Some experiments made photometric measurements in infrared (longward of 1000 nm) of Vega, Sirius (and a few more bright stars), with uncertainties ranging between 1-5%. Today, requirements for science investigations in, for example, cosmology, exoplanets, and stellar astrophysics push to sub-percent uncertainties in the absolute fluxes of standard stars. This has led to new projects to improve the accuracy of astronomical calibrators and increase the number of stars with direct SI-traceable flux measurements. This talk describes the current state of the art in absolute flux calibration.

The Future of SN Ia Cosmology with the Nancy Grace Roman Space Telescope

Rebekah Hounsell
NASA/Goddard Space Flight Center

The Nancy Grace Roman Space Telescope (Roman) will conduct a monumental time-domain experiment, with a focus on Type Ia supernovae (SNe Ia). Given the wide area, wavelength coverage, and depth that the Roman mission is able to achieve, the SN Ia data collected will likely be some of the most detailed and well defined of our generation. Roman SN Ia data is therefore sure to have a significant impact on our understanding of the nature of dark energy, but in order to achieve this accurate flux calibration is required. In this talk I will discuss the impact of various systematic on Roman SN Ia data, how our knowledge of these have evolved for the mission, and how specific uncertainties can possibly alter the design of a given survey strategy.

The characterisation of atmospheric effects on ground-based astronomical observations

Florian Kerber
NIST

In this invited talk I will describe some of the impacts that variable properties of the atmosphere have on ground-based astronomical observations and what can be done to mitigate or correct them. This will help to illustrate and understand the challenges of achieving highly accurate absolute and relative flux calibration in ground-based data, which differ from those faced by space-based missions. Specifically, I will report on the planning for an ESO-led campaign for a comprehensive characterisation of the atmosphere above the ESO observatory sites in Northern Chile. Together with our partners, the US National Institute of Standards and Technology (NIST) and the Cherenkov Telescope Array (CTA) and supported by the Upper air network GRUAN as well as MeteoSwiss we will deploy various instruments in addition to the atmospheric site monitoring system permanently installed at Paranal observatory. We plan for two 10-day/night campaigns during 2025 combining remote sensing data with in-situ measurements by balloon-borne radiosondes, the gold standard in atmospheric research and compare the results with state-of the art forecasting models of the atmosphere and weather. This research will inform our work for the up-coming science operations of ESO's Extremely Large Telescope (ELT) - the technical first light of the world's biggest eye on the sky is planned for 2028 - but can also serve as a basis for a closer collaboration between ground- and space-based observatories in their respective calibration efforts.

Improving the Absolute Calibration Across the Visible and Mid-infrared

George Rieke
Steward Observatory, the University of Arizona

Historically, infrared absolute calibrations have been based on very bright stars, making them hard to apply accurately at the levels of real observations, and have also been quoted with accuracies of order 2% because of concerns about systematic errors. The visible calibration is largely based on the 1995 review by Megessier. This talk will summarize work that has improved the infrared calibration to an accuracy of better than 1%. The issue of systematic errors has been minimized by employing a large number of approaches, and is verified in the use of the calibration to estimate stellar diameters with high accuracy compared with interferometric ones. The work also includes selection of suitable stars to extend the calibration across the sky and down to observable flux levels. The Megessier calibration has been reviewed and augmented. If Sirius is used as the zero-color defining star (preferred because it is a slow rotator with no known infrared excesses), then the theoretical spectrum for it matches the calibrations from the visible through the mid-infrared, establishing a consistent basis for absolute calibration over this full spectral range.

A Decade of Improvements in Calibration and Needed Improvements for Supernova Cosmology

Daniel Scolnic
Duke University

In this talk, I will go over a number of ways calibration has improved over the last decade. This includes wavelength-dependent flux calibration, new spectrophotometric standards, cross-survey calibration and better understanding of detector effects. I will show that a remaining challenge is still book-keeping given the large number of surveys and tremendous amount of data available. I will also explain how various systematic effects propagate to recovery of cosmological parameters with Type Ia supernovae, and show what's needed in the decade to come.

Astronomical Flux Calibration- An Overview

Chris Stubbs
Harvard University

I will provide a brief overview of astronomical flux calibration. I'll begin with some inspirational scientific motivation, and then review why it's a (surprisingly?) hard measurement problem. If successful, this talk should provide an overall framework for the interesting talks and discussion that will take place over the course of the workshop.

Contributed Talks

ALTAIR High-Altitude Micro-Airships for Precision Rubin Observatory Calibration (and Beyond): Status

Justin Albert
University of Victoria

ALTAIR (Airborne Laser for Telescopic Atmospheric Interference Reduction, https://projectaltair.org) is a project and campaign of lightweight, propelled high-altitude balloon payloads containing in-situ precisely calibrated and monitored sources across the optical spectrum (and beyond), to fly in observer-controlled paths (with full and complete observer authority over payload source RA, dec, colors, and radiant flux as functions of time) over observatories at altitudes of approximately 20 km. ALTAIR is presently funded by Canada's National Research Council (NRC), Department of National Defence (DND), and Natural Sciences and Engineering Research Council (NSERC). ALTAIR will be able to provide forefront, ultra-high precision (0.1%) calibration for the later years of LSST at Rubin, in addition to for other upcoming surveys. ALTAIR will work synergistically in concert with satellite-based means of calibration: the former will be above the large majority, but not all, of the atmosphere; whereas the latter fundamentally will have far less flexible flight paths / orbits, are far more expensive and thus will be very much more limited in number; and can only be calibrated at ultimate precision within the laboratory before, rather than also after, each flight (in addition of course to both having precise onboard-detector-based in-situ calibration and monitoring). The current status and the major upcoming plans for the ALTAIR project, including polarimetry calibration for CMB-S4 and beyond, and also unprecedented commercial communication and Earth-observing capabilities, in addition of course to forefront optical photometric calibration for ground-based astronomy, will be presented.

Time Dependent Sensitivity of ACS/WFC

Gagandeep Anand
Space Telescope Science Institute

Yearly observations of white dwarf standard stars with ACS/WFC allow the instrument team to monitor the CCD for changes to photometric sensitivity. Previous work has shown a post-SM4 sensitivity loss rate of 0.061%/yr for all filters, which is currently propagated through to the header keywords which determine the instrumental zeropoint magnitudes. Here we present updates on the ACS/WFC time-dependent sensitivity, including from an longer baseline of data, as well as results with a new photometric reduction pipeline.

Establishing the Absolute Flux Calibration for NASA's SPHEREx All-Sky Spectroscopic Survey

Matthew Ashby
Center for Astrophysics | Harvard & Smithsonian

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CALSPEC Basics

Ralph Bohlin
Space Telescope Science Institute

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DAmodel: Hierarchical Bayesian Modelling of DA White Dwarfs for Spectrophotometric Calibration

Ben Boyd
University of Cambridge

We use hierarchical Bayesian modelling to calibrate a network of 32 all-sky faint DA white dwarf (DAWD) spectrophotometric standards ($16.5 < V < 19.5$) alongside the three CALSPEC primary standards, from 1100 Å to 1.8 µm. The model is the first of its kind to jointly infer photometric zeropoints and WD parameters (log g, T_eff, Av, Rv) by simultaneously modelling both photometric and spectroscopic data. We model panchromatic HST/WFC3 UVIS and IR fluxes, HST/STIS UV spectroscopy and ground-based optical spectroscopy to sub-percent precision. The model jointly infers changing zeropoints across HST cycles, as well as the F160W count rate non-linearity, and is being extended to JWST/NIRCam wavelengths. The hierarchical nature of the model also allows for the unique opportunity to perform population dust analysis on the set of WDs to validate priors. Inferred SEDs from this model will be useful for calibrating the next generation of surveys including the Vera Rubin Observatory's Legacy Survey of Space and Time, the Nancy Grace Roman Observatory's wide-area and time-domain surveys, and the Euclid Wide and Deep surveys.

The Status of the JWST/NIRCam Absolute Flux Calibration

Martha Boyer
Space Telescope Science Institute

We review the results of the JWST cross-instrument flux calibration program for all NIRCam observing modes: imaging, coronagraphy, wide-field slitless, and time series. Several standard stars were observed in each mode with every pupil and filter wheel element available for science on all 10 detectors. Analysis shows uncertainties <1% for most imaging filters and detectors and very small detector-to-detector offsets and subarray offsets. Coronagraphy and grism uncertainties are slightly higher, at about 2%. We also discuss the photometric stability of the instrument and plans for improving the flux calibration in future cycles.

New Photometric Calibration of the Wide Field Camera 3 Detectors

Annalisa Calamida
Space Telescope Science Institute

I will present the new photometric calibration of the WFC3 UVIS and IR detectors based on observations for four white dwarfs, namely GRW+705824, GD153, GD71, G191B2B, and a G-type star, P330E. These calibrations include recent updates to the Hubble Space Telescope primary standard white dwarf models and a new reference flux for Vega.

Time-dependent inverse sensitivities for the two WFC3-UVIS chips, UVIS1 and UVIS2, were calculated for all 42 full-frame filters, after accounting for temporal changes in the observed count rates with respect to a reference epoch in 2009. We also derived new encircled energy values for a few filters and improved sensitivity ratios for the two WFC3-UVIS chips by correcting for sensitivity changes with time. Updated inverse sensitivity values for the 20 WFC3-UVIS quad filters and for the 15 WF3-IR filters were derived by using the new models for the primary standards and the new Vega reference flux and, in the case of the IR detector, new flat fields. However, these values do not account for any sensitivity changes with time. The new calibration provides a photometric internal precision better than 0.5% for the wide-, medium-, and narrow-band WFC3-UVIS filters, 5% for the quad filters, and 1% for the WFC3-IR filters. As of October 15, 2020, an updated set of photometric keywords are populated in the WFC3 image headers.

Photometric calibration strategy for the Near-Earth Object (NEO) Surveyor mission

Sean Carey
NASA Exoplanet Science Institute Caltech/IPAC

The Near-Earth Object (NEO) Surveyor mission is a NASA observatory planned for launch in 2027 and designed to discover and characterize near-Earth asteroids and comets with a primary objective of finding the majority of objects greater than 140m in diameter. The NEO Surveyor observatory is a 50 cm, passively cooled, off-axis TMA with two wide field cameras (1.7 by 7.1 degrees) with bandpasses centered on 4.6 and 8.0 um. The cameras each use an array of 4x1 H2RG detectors. The mission has a 7% requirement on the absolute photometric calibration to achieve the necessary accuracy on the effective spherical diameters of the detected NEOs.

We describe the planned photometric calibration strategy, which is based on the calibration methodologies used for Spitzer/IRAC (Reach et al. 2005, Carey et al. 2012) and WISE (Jarrett et al. 2011). A set of calibration stars in common with those missions has been selected for cross-calibration. We will present the current spectral templates being used as well as plans to update the templates using JWST observations. A particular challenge for NEO Surveyor is ensuring the photometric calibration of the cool (<330 K) sources of interest which are NEOs, main belt asteroids, and comets. We will discuss the transfer of the stellar calibrations via color correction to the cooler sources and the prospects of checking the calibration through diameter measurements using radar and occultations.

Checking the JWST/MIRI Imager absolute flux calibration using four nearby white dwarfs

John Debes
Space Telescope Science Institute

We use hierarchical Bayesian modelling to calibrate a network of 32 all-sky faint DA white dwarf (DAWD) spectrophotometric standards (16.5 < V < 19.5) alongside the three CALSPEC primary standards, from 1100 Å to 1.8 µm. The model is the first of its kind to jointly infer photometric zeropoints and WD parameters (log g, T_eff, Av, Rv) by simultaneously modelling both photometric and spectroscopic data. We model panchromatic HST/WFC3 UVIS and IR fluxes, HST/STIS UV spectroscopy and ground-based optical spectroscopy to sub-percent precision. The model jointly infers changing zeropoints across HST cycles, as well as the F160W count rate non-linearity, and is being extended to JWST/NIRCam wavelengths. The hierarchical nature of the model also allows for the unique opportunity to perform population dust analysis on the set of WDs to validate priors. Inferred SEDs from this model will be useful for calibrating the next generation of surveys including the Vera Rubin Observatory's Legacy Survey of Space and Time, the Nancy Grace Roman Observatory's wide-area and time-domain surveys, and the Euclid Wide and Deep surveys.

Refining the CALSPEC Catalog of Standards with TESS

Thomas Dutkiewicz
Space Telescope Science Institute

The HST/CALSPEC catalog of flux standards is of enormous importance for cross-instrument and cross-telescope calibration. However, flux standards are only viable calibrators if the stars are constant in brightness; given the ubiquity of these standards, it is essential to constrain and monitor their variability. The high-precision, high-cadence observations from the Transiting Exoplanet Survey Satellite (TESS) make even minor variability easy to detect. TESS's high precision also enables us to set upper limits on potential variability, improving the versatility of CALSPEC for observatories with differing calibration requirements. We have analyzed roughly 100 CALSPEC stars that were observed by TESS and report on their variability, providing periods and amplitudes for positive detections and upper limits on amplitudes otherwise.

The calibration requirements of the Ultraviolet Explorer (UVEX)

Hannah Earnshaw
California Institute of Technology

The Ultraviolet Explorer (UVEX) is the latest of NASA's Explorer missions, expected to launch in 2030. It will be a generational improvement on previous ultraviolet capabilities, with wide-field NUV and FUV imaging creating an ultraviolet survey of the entire sky, moderate-resolution long-slit spectroscopy, and the ability to respond swiftly to targets of opportunity. We present the photometric and spectroscopic requirements for UVEX that will enable accurate determination of colors and line ratios, reliable repeat measurements, effective complementarity to deep surveys in other bands, and cross-calibration with previous and existing UV spectrometers. We also outline our calibration target needs and strategy for calibrating UVEX in space. Finally, we discuss the general calibration needs for time domain science in the coming decades, and where UVEX sits within the bigger picture of multiwavelength study of a dynamic universe.

A network of cool white dwarfs as standards for flux calibration

Abbigail Elms
University of Warwick

We have entered a pioneering era of space telescopes and instruments, which will provide previously unattainable data for objects in our Galaxy and beyond, especially at infrared (IR) wavelengths. It is of paramount importance that observations are flux calibrated accurately so that astrophysical and cosmological studies reach accurate conclusions. Currently, three hot (Teff > 30 000 K) hydrogen atmosphere (DA) white dwarfs comprise the primary white dwarf flux standards and CALSPEC absolute flux scale. We propose to add a new network of 17 cooler (Teff < 20 000 K) white dwarfs as standards as these are more reliable IR flux calibrators than hot white dwarfs. As demonstrated in Gentile Fusillo et al. (2020), they do not suffer from non-local thermal equilibrium (NLTE) effects in continuum flux or UV metal line blanketing, have a larger sky density, and their energy distributions peak in the optical or NIR. Using the latest grid of 3D DA LTE atmosphere models, we successfully predict the observed STIS and WFC3 fluxes to within 3% over most of the range between 1450 − 16000 A. Fitting the white dwarf spectral energy distributions and Balmer lines independently yields similar atmospheric parameters, demonstrating the predictive power of the models for our white dwarf network.

A novel absolute photometric calibration based on fitting the system and atmosphere transmission

Simone Garrappa
Weizmann Institute of Science

Transforming the instrumental photometry of ground-based telescopes into a calibrated physical flux in a well-defined passband is a major challenge in astronomy. Along with the intrinsic instrumental difference between telescopes sharing the same filter, the effective transmission is continuously modified by the effects of the variable atmosphere of the Earth. Motivated by determining an absolute calibration for the Large Array Survey Telescope (LAST), we have developed a new approach to the absolute photometric calibration that simultaneously treats instrumental and atmospheric effects on an image-by-image basis by fitting the system transmission. This is possible thanks to the large sample of Gaia spectroscopic measurements that provide a significant number of diverse calibrators for each observation. This approach aims at breaking the 1% accuracy which limits current calibration methods. In this contribution, I will present our proposed calibration method and its versatility to be applied to any astronomical ground-based system. Moreover, we present its performance on real data obtained with LAST, where we achieve an accuracy of 5-8 mmag and high stability over long temporal scales.

The James Webb Space Telescope Absolute Flux Calibration: Program Design and Calibrator Stars

Karl Gordon
Space Telescope Science Institute

It is critical for James Webb Space Telescope (JWST) science that instrumental units are converted to physical units. We detail the design of the JWST absolute flux calibration program that has the core goal of ensuring a robust flux calibration internal to and between all the science instruments for both point and extended source science. This program is observing a sample of calibration stars that have been extensively vetted based mainly on Hubble Space Telescope, Spitzer Space Telescope, and Transiting Exoplanet Survey Satellite observations. The program uses multiple stars of three different, well-understood types (hot stars, A dwarfs, and solar analogs) to allow for the statistical (within a type) and systematic (between types) uncertainties to be quantified. The program explicitly includes observations to calibrate every instrument mode, further vet the set of calibration stars, measure the instrumental repeatability, measure the relative calibration between subarrays and full frame, and check the relative calibration between faint and bright stars. For photometry, we have set up our calibration to directly support both the convention based on the band average flux density and the convention based on the flux density at a fixed wavelength. The current status of the absolute flux calibration of the JWST instruments will be summarized.

Update on the Absolute Flux Recalibrations of the HST/STIS modes

Svea Hernandez
Space Telescope Science Institute

The Space Telescope Imaging Spectrograph (STIS) has been in orbit for approximately 26 years as one of the 2nd generation instruments on the Hubble Space Telescope (HST). With a wide range of both imaging and spectroscopic capabilities and a broad wavelength coverage (from the Far-UV to the Near-IR), STIS continues to be a unique resource to the astronomical community. In the last few years, the HST/STIS team has been working on an ambitious update to improve the absolute flux calibration of both the spectroscopic and imaging modes. This initiative is primarily driven by the release of the improved stellar atmospheric models of the primary HST standard stars, G 191-B2B, GD 71, and GD 153, included in the CALSPEC v11 database. The team prioritized the most widely used modes and has derived sensitivity curves and throughputs which have been made available to the community through a series of data releases. These updates will be presented, specifically for the low and medium resolution spectroscopic modes, as well as imaging modes, highlighting the impact of these improvements of the order of 1-3% on the final Far-UV to Near-IR calibrated observations.

A library of high-fidelity spectra with the MUSE integral field spectrograph

Valentin Ivanov
ESO

The accurate and precise flux calibration is a challenge, especially for wide field surveys that cover large footprints on the sky and multi-year observing campaigns under diverse weather conditions. The recent trend is toward fainter calibrator stars, driven by the increasing size of survey telescopes. However, brighter stars still minimize the calibration time and there are some specific cases, like calibration of narrow band filters that greatly benefit from bright standard stars. The stars from the MUSE spectral library (MSL) meet this requirement. The MSL, originally including 35 stars, was intended as a source of spectra of different spectral classes with reliable continuum shapes, because the integral field spectroscopy is free from slit losses and such spectra are in demand for many problems from spectral typing to continuum removal when weak emission lines are searched for. We verified the continuum shape of our spectra with synthetic broadband colors derived from the spectra, comparing them with the apparent magnitudes of the stars. Further verification came from the space missions that are known to yield accurate and stable photometry. Our spectra cover nearly the entire visual band ($\lambda \sim$ 4800-9300 Å). We review the historic data for variability, and select as potential flux calibrators only the stars that are stable to various degrees, e. g., bellow 0.5 or 1 percent.

Methods and issues with flux calibration methods employed by student researchers and amateur astrono

Brian Kloppenborg
AAVSO

This talk will explore the methods and challenges associated with flux calibration techniques used by student researchers and amateur astronomers for photometric and spectroscopic observations. For photometry, most amateur astronomers use all-sky differential or in-frame differential techniques which are highly susceptible to catalog inconsistencies and different implementations of photometric calibration equations. For spectroscopy, most amateur data is corrected for instrumental response, but seldom calibrated to an absolute flux scale using reference stars. By examining these issues in detail, I hope to elucidate discussions on how the next-generation of photometric and spectroscopic calibration methods can be adapted for use by students and amateur astronomers alike.

ALMA Flux Calibration

Ruediger Kneissl
ALMA / ESO

The Atacama Large Millimeter/Submillimeter Array (ALMA) has a challenging flux accuracy requirement of 1-3% relative and 5% absolute, for a ground-based radio telescope operating at short wavelengths, 8.6-0.3mm. I will discuss technical conditions and explain the operational approach to providing the polarized flux density calibration. ALMA has recently improved the observational scheme of monitoring secondary flux calibrators via more flexible scheduling, higher cadences, wider range of bands including high frequency, and an adjusted flux estimation algorithm. I like to report on the lessons learnt about operational efficiencies, the improved flux accuracy and the quality of the accessible solar system object primary flux calibrators.

NIST-traceable Optical Flux Calibration using the SNIFS CALibration Apparatus (SCALA)

Daniel Kusters
UCB / DESY

Motivated by the stringent flux calibration demands of cosmology using Type Ia supernovae, we are engaged in an effort to transfer flux calibration from a physical system based on NIST-traceable photodiodes to the three primary CALSPEC white dwarfs across the 350-950 nm wavelength range. We use the SuperNova Integral Field Spectrograph (SNIFS) on the University of Hawaii 2.2m telescope on Maunakea to observe standard stars, and calibrate SNIFS using the SNIFS CALibration Apparatus (SCALA) dome-mounted projection system. In previous work we have demonstrated that SNIFS can obtain spectrophotometry that is as internally consistent as spectroscopy from HST STIS. We have upgraded SCALA since its original installation to suppress out-of-band light using a double monochromator, improve the baffling, recoat the mirrors, and mount NIST-traceable photodiodes on each of the 18 SCALA beams. The latter required the design of very sensitive and sturdy picoammeters and a sophisticated facility for performing the wavelength-spatial-angular calibration transfer between NIST photodiodes and our 18 photodiodes. We will discuss a number of interesting technical challenges encountered throughout this calibration effort, and how they have been overcome. We will present a first analysis of the optical spectroscopic flux calibration subsequently obtained with SNIFS and SCALA.

Support: This research has been supported by a NIST Precision Measurement Grant to UC Berkeley, by the United States Department of Energy, by the Physics Department at UC Berkeley, and by engineering support and lab space at the Deutsches Elektron-Synchrotron, Zeuthen.

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Absolute flux calibration in the mid-IR: Lessons from the MIRI Medium Resolution Spectrometer

David Law

Space Telescope Science Institute

Calibration of the MIRI Medium Resolution Spectrometer (MRS) is challenging; when dispersed at moderate resolution traditional spectrophotometric standard stars are faint at wavelengths longer than 20 micron, while the thermal background contributed by JWST is bright. Likewise, the effective responsivity of the instrument varies substantially over time, evolving by over a factor of two at the longest wavelengths since launch. Even accounting for these effects, photometric calibration vectors derived from different standard stars can differ by a few percent, with systematic differences between spectral classes that may imply uncertainties in the model spectra. This presentation describes our current approach to flux calibration of the MIRI MRS using a combination of traditional standards, asteroids, and exodisks, and comments on the reliability of these methods and potential calibration systematics in the 5-28 micron wavelength regime.

A Deep Dive into the Variability and Calibration of the JWST MIRI Imager

Mary Anne Limbach

University of Michigan

In this talk, we delve into the intricacies of the MIRI Imager, utilizing data from our MIRI Exoplanets Orbiting White Dwarfs (MEOW) survey and publicly available MIRI data. We begin by examining the time-dependent variability in the MIRI flatfield, discussing how this variability may offer insights into the underlying cause of the MIRI Reduced Count Rate. Next, we present our measurements of persistence on the MIRI imager, exploring how this phenomenon can affect precision flux measurements. We then use our MEOW sample of white dwarfs to derive an independent absolute flux calibration for the MIRI imager at 7.7, 18, and 21 microns. This calibration is compared with the STScI calibration, which employs a different class of standard stars at the longest wavelengths. Our findings indicate that accurate flux calibration at the 0.5% level might be achievable with the MIRI imager, which could potentially enable groundbreaking science, including significantly improving our searches for exoplanets around white dwarfs. Finally, we discuss how our flux measurements of extremely faint sources appears systematically low and investigate potential causes for this offset.

Accurate flux scale for multifilter surveys with the white dwarf locus

Carlos Lopez-Sanjuan
Centro de Estudios de Física del Cosmos de Aragón (CEFCA)

The J-PAS (Javalambre Physics of the Accelerating Universe Astrophysical Survey) is observing thousands of square degrees of the northern sky with 54 filters of 14 nm width, covering the optical range from 380 to 910 nm. J-PAS will provide a low-resolution (R ~ 50) spectra for 100 million galaxies and 40 million stars in the Milky Way with i < 22.5. The half-CCD dithering pattern in the J-PAS observation strategy, with four exposures per pointing, lead to a precision in the photometric calibration of 2 mmg at lambda > 400 nm and 4 mmg for the bluer filters. However, can we ensure that the J-PAS photometry is in the AB scale? The repeated observation of photometric standard stars takes a prohibitive amount of time, so a different strategy is needed. We present the white dwarf locus technique, able to provide the AB scale for J-PAS colors with a 1% accuracy using neither additional observations nor external data. We developed and tested the methodology with J-PLUS (Javalambre Photometric Local Universe Survey), a precursor of J-PAS that has already observed 3200 deg^2 with 12 optical filters (ugriz + 7 medium bands; J0378, J0390, J0410, J0430, J0515, J0660, J0861). After the homogenization of the photometry in J-PLUS DR3 using Gaia DR3 BP/RP spectra as reference, we selected 109 high-quality white dwarfs in the surveyed area. We restricted the sample to distances closer than 100 pc, where the interstellar extinction can be neglected. We performed a simultaneous Bayesian modeling of the 11 independent (X − r) versus (g − i) color-color diagrams in J-PLUS, with the r band used as the absolute reference in the process and X being the filter to calibrate (including g and i). We confronted the theoretical locus for H- and He-dominated atmospheres against the observations to estimate the best parameters that model the observed color-color distribution of the white dwarfs. The most relevant parameter in the model is the offset needed to match the theoretical locus and the observations, noted DX, that translates the Gaia scale to the AB scale. We found a broad agreement with the Gaia scale, with differences below 0.04 mag. We also identified a trend, with the offsets changing from Du = 0.034 mag to DJ0430 = -0.038 mag, then increasing again to Dz = 0.010 mag. We tested the absolute flux calibration in J-PLUS DR3 by comparing the final photometry with the synthetic photometry of the spectroscopic standard star GD 153. We found a remarkable 1% agreement in all the passbands between the reference spectra and the J-PLUS data. The white dwarf locus technique will be applied to J-PAS when the observed area provides a large enough number of white dwarfs, ensuring a 1% absolute accuracy for 54 narrow bands across the optical range.

The International Astronomical Consortium of High Energy Calibration: Method and Activity

Kristin Madsen
GSFC

The IACHEC aims to provide standards for high energy calibration and supervise cross calibration between different missions. This goal is reached through working groups, where IACHEC members cooperate to define calibration standards and procedures. The scope of these groups is primarily a practical one: a set of data and results (eventually published on refereed journals) will be the outcome of a coordinated and standardized analysis of references sources (“high-energy standard candles”). Past, present and future high-energy mission can use these results as a calibration reference.

CALSPEC and the Gaia photometric system

Jesus Maiz Apellaniz
Centro de Astrobiología

We obtained STIS long-slit spectroscopy of extremely red objects and added them to the CALSPEC library to verify the uniformity and stability of the Gaia photometric system. We show that there is a significant variation in some of the G+BP+RP passbands between DR2 and EDR3, an effect that is also detectable without the use of external spectrophotometry. The use of the new spectra improves the passband calibration. A comparison between CALSPEC and Gaia XP spectrophotometry illustrates the limitations of each.

The Updated BOSZ Synthetic Stellar Spectral Library

Szabolcs Meszaros
ELTE Gothard Astrophysical Observatory

The modeling of stellar spectra observed by the Hubble and James Webb Space Telescopes (JWST) requires a large synthetic spectral library that covers a wide atmospheric parameter range. The aim of this talk is to present an updated version of the BOSZ synthetic spectral database originally calculated for the flux calibration of JWST. These new LTE models incorporate both MARCS and ATLAS9 model atmospheres, updated continuous opacities, and 23 new molecular line lists. The new grid has been calculated with Synspec using LTE approximation covering metallicities, [M/H] from -2.5 to 0.75 dex, [alpha/M] from -0.25 to 0.5 dex, and [C/M] from -0.75 to 0.5 dex, providing spectra for 336 unique compositions. Calculations for stars between 2800 and 8000 K use MARCS model atmospheres; and ATLAS9 is used between 7500 and 16,000 K. The new BOSZ grid includes 628,620 synthetic spectra from 50 nm to 32 microns with models for 495 Teff, log g parameter pairs per composition and per microturbulent velocity. Each spectrum has eight different resolutions spanning a range from R = 500 to 50,000 and also at the original resolution of the synthesis. The microturbulent velocities are 0, 1, 2, and 4 kms. The new BOSZ grid extends the temperature range to cooler temperatures compared to the original grid, because the updated molecular line lists make modeling possible for cooler stars. A publicly available and consistently calculated database of model spectra is important for many astrophysical analyses, e.g. spectroscopic surveys and determination of stellar elemental compositions.

Evaluating HASP Flux Calibration Using CALSPEC Models to Enable High-quality Spectral Data from HST

Lauren Miller
Space Telescope Science Institute

The Hubble Advanced Spectral Products (HASP) program provides unparalleled coadded spectral data from the Hubble Space Telescope's Cosmic Origins Spectrograph (COS) and Space Telescope Imaging Spectrograph (STIS). By automating the coaddition of available COS and STIS data from the entirety of the Mikulski Archive for Space Telescopes (MAST), HASP seamlessly integrates new and archival data with the latest calibrations. This innovation is crucial for addressing the flux calibration challenges highlighted in this workshop, offering extended wavelength coverage with data products spanning the UV, optical, and near-IR.

We present comparisons between HST CALSPEC models and observational SEDs and HASP products of flux standards on the HST system to highlight the accuracy of these user-friendly products. HASP's meticulous multi-stage filtering and coaddition of spectra across different central wavelengths and instruments are crucial in enhancing the quality and scope of observational data. HASP's improved signal-to-noise ratios and expanded wavelength coverage enable more precise measurements of the spectral energy distributions of stellar objects for various spectral types, from M dwarfs to white dwarfs.

Toward a Homogeneously Flux-Calibrated EXTernal Ground Based Dataset for the Euclid Mission

Joseph Mohr
LMU Munich

The Euclid Mission is currently carrying out deep VISual band and Y, J and H NIR band imaging over 15,000 deg^2 of the extragalactic sky that will be employed for cosmological and legacy science studies and released to the world astronomy community. This space-based imaging is complemented by (u)griz band ground based EXTernal imaging that will enable galaxy photometric redshift measurements and VISual stellar photometry to support VISual PSF modeling. To achieve the forecast weak gravitational lensing based cosmological constraints, the photometric zeropoints of the ground based EXT data must be stable to better than 1% over the full survey, and stellar colors must be stable to 0.5% over the scale of the Euclid FOV (0.5 deg^2). To achieve these requirements we are adopting the Gaia stellar spectroscopy and photometry as a standard. In the current implementation, we use the bandpasses from each of the ground based surveys (UNIONS+DES+HSC) together with the Gaia spectroscopy to extract corrected stellar photometry, which then serve as absolute constraints for the detrended ground based single-epoch-frame images (SEFs). Relative constraints extracted from overlapping SEFs of the same band and these absolute constraints are combined to solve for zeropoints and zeropoint uncertainties for the ensemble of SEFs. Tests against the initial calibrations of each of the EXTernal surveys show improvements in the quality of the photometric dataset. Internal cross-checks allow us to check for systematic errors in the detrended SEFs, in the survey bandpasses and to constrain the variation of the bandpasses across the ground based camera FOVs. These calibrated EXTernal SEFs are then coadded into deeper EXTernal imaging, and the PSFs are modeled for each source prior to their being passed on to another element of the Euclid Science Ground Segment where they are MERged with the separately flux calibrated VIS and NIR imaging.

The NASA Landolt Mission Overview

Peter Plavchan
George Mason University

The NASA Landolt mission is an astrophysics PIONEERS program 12U small satellite that will provide significant improvement in the accuracy of photometric measurements of absolute stellar fluxes. This will be accomplished with a NIST-calibrated suite of single-mode fiber-fed laser beacons. The satellite will be placed in a geosynchronous orbit with a one-year primary mission with launch in 2028 or 2029. After commissioning, Landolt will point to scheduled ground-based observatories including designated ground stations and a guest observer program for calibration observations. Landolt has a level 1 mission requirement improve the photometric accuracy to <0.5% at two visible and two near-infrared wavelengths for >60 target stars. Such measurements can only be achieved by a space-based orbiting artificial "star", where the emitted physical photon flux is accurately known. Accuracy of absolute flux zero points is now the leading error budget term in the characterization of stars, be they standard stars or exoplanet host. Landolt will enable the refinement of dark energy parameters, improve our ability to assess the habitability of terrestrial worlds, and advance fundamental constraints on stellar evolution.

Reaching 2% Local Flux Precision with HST COS & STIS to Enable AGN Reverberation Mapping

Rachel Plesha
Space Telescope Science Institute

As part of the Space Telescope and Optical Reverberation Mapping 2 (STORM 2) campaign, the AGN Mrk 817 was observed with both HST/COS (every other day) and HST/STIS (every four months) from November 2020 through February 2022. Additionally, the calibration standard star WD 0308-565 was observed with COS on a monthly basis to perform a custom flux calibration, achieving a 2% local flux precision for our COS medium resolution observations. For our STIS low resolution observations, we leveraged an archival special calibration program that observed WD 0308-565 with STIS in 2020 to both reach a 2% local precision and to utilize a uniform flux calibration stellar model across the HST wavelength regime. To achieve these precision levels for both COS and STIS, we encountered several obstacles and identified potential improvements for the teams at STScI and the community to consider. Here, we present those challenges and how we aim to make the custom flux calibration process more accessible for the average scientist who requires more precise flux levels at local scales with the HST COS and STIS instruments than the current standard calibration provides.

Status of JWST NIRSpec Flux calibration

Charles Proffitt
Space Telescope Science Institute

We review the flux calibration status for each of the NIRSpec observing modes, including recent improvements to the calibration files and algorithms, as well as a description of remaining issues and limitations. For the fixed slit modes, we discuss how the overlap of the PSF with the background regions affects the flux calibration of nod-subtracted exposures, and how to correct for this. For the narrower slits we also discuss the throughput corrections that need to be applied for off-center sources. With these corrections, absolute flux calibration at a level of 1% or better should be possible for this mode. For the IFU mode, variations in the field dependence and the exact centering of a point source in a slice can cause variations in flux of a few percent at various dither positions. We demonstrate the current accuracy that can be expected. For the Multi-Object Spectrograph (MOS) mode, we show current information for the field dependence of the throughput over the field of view and as a function of position within the MOS shutter. This field dependence is currently well established only for the PRISM, and we discuss the extent to which these results can be applied to other modes. We also discuss other limitations of current flux standard observations for NIRSpec MOS, and plans for acquiring new observations to ameliorate these limitations. For all modes, we also discuss how the current resampling algorithm may limit the achieved accuracy and compare with 1D spectral extractions done using both the un-resampled CAL files and improved resampling algorithms.

What does SI traceability mean for stellar spectral flux calibration?

Joseph Rice
NIST

During the five decades since Oke and Schild (1970) and Hayes, Latham, and Hayes (1975) measured the flux from Vega with traceability to the kelvin using a blackbody-based scale,1,2 higher-accuracy alternatives have been developed, and dissemination technology has greatly improved. In particular, cryogenic electrical substitution radiometers have been highly developed and are in wide use at National Measurement Institutes (NIST in the U.S.,3 NPL in the U.K, PTB in Germany, etc) for realizing spectral-radiometric "detector-based" scales with traceability to the watt and the meter. As a result, the standard uncertainty achievable for spectral power responsivity measurements of laboratory detectors is of the order of 0.02 %, and that for spectral flux (a.k.a. spectral irradiance) reference sensors is of the order of 0.05 % (between 380 nm and 950 nm), just what we need for current and future stellar observations. I will describe the techniques involved in establishing such scales and extending farther into the infrared,4,5 review the current status of such detector-based spectral flux scales and comparisons to "source-based" (i.e. blackbody) scales, and discuss the challenges involved with transferring this accuracy to standard stars.

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Toward Millimag Photometry with the Rubin Observatory Legacy Survey of Space and Time

Eli Rykoff
SLAC National Accelerator Laboratory

The photometric calibration requirements for the Rubin LSST are quite strict (5 mmag in uniformity and repeatability), with some science goals (in particular Type Ia Supernovae) requiring calibration at the mmag level. I will discuss the Project plans for hardware and software that will allow us to meet the project goals in the first year, and what additional work will be necessary to reach 1 mmag photometry at the end of the 10 year LSST survey. These include special instrumental signature removal (ISR) for LSSTCam; a new Collimated Beam Projector (CBP) fed by a tunable high-power laser to measure system throughput; and synthetic SED-matched flat fields. Combined with careful attention to foreground subtraction and chromatic multi-band photometric calibration with the Forward Global Calibration Method (FGCM), we should be able to exceed the project requirements for photometric calibration.

All-sky Faint DA White Dwarf Spectrophotometric Standards for Observatories and Surveys

Abhijit Saha
NOIRLab

Hot DA white dwarfs (DAWDs) have fully radiative pure hydrogen atmospheres that are the least complicated to model. Pulsationally stable, they are fully characterized by their effective temperature Teff and surface gravity log(g), which can be deduced from their optical spectra and used in model atmospheres to predict their spectral energy distributions (SEDs). Based on this, three bright DAWDs have defined the spectrophotometric flux scale of the CALSPEC system of the Hubble Space Telescope (HST). We have added 32 new fainter ($16.5 < V < 19.5$) DAWDs spread over the whole sky and within the dynamic range of large telescopes. Using ground-based spectra and panchromatic photometry with HST/WFC3, a new hierarchical analysis process demonstrates consistency between model and observed fluxes above the terrestrial atmosphere to <0.004 mag rms from 2700 to 7750 Å and to 0.008 mag rms at 1.6 µm for the total set of 35 DAWDs. These DAWDs are thus established as spectrophotometric standards with unprecedented accuracy from the near-ultraviolet to the near-infrared, suitable for both ground- and space-based observatories. They are embedded in existing surveys like the Sloan Digital Sky Survey, Pan-STARRS, and Gaia, and will be naturally included in the Large Synoptic Survey Telescope survey by the Rubin Observatory. With additional data and analysis to extend the validity of their SEDs further into the ultra-violet and the infrared: specifically, these spectrophotometric standard stars could be used for JWST, as well as for the Roman and Euclid observatories.

Euclid photometric calibration - The first year in space

Mischa Schirmer
Max-Planck-Institute for Astronomy

Euclid has relative and absolute flux calibration requirements of 1% and 3%, respectively, which it must meet over 14000 square degrees and 6 years of mission duration. Its orbit around Lagrange Point L2 is uniquely suited for high-precision and accurate photometry. The in-flight conditions, however, required us to adjust our observing and calibration strategies in the presence of optical straylight, high-energy space weather, and molecular outgassing. In my talk I highlight these challenges and how we responded to it to meet our core scientific goals.

Observing Faint Suns in Clusters for Photometric Calibration

Everett Schlawin
The University of Arizona

JWST and ground-based near-infrared-capable telescopes are providing new scientific breakthroughs due to their deep sensitivity to the faintest objects in the Universe. However, these telescopes' sensitivities comes with the flip side that they are often easy to saturate on the bright targets where infrared calibrations are most directly tied to photometric standards. The distant open cluster NGC 2506 offers a solution to the problem as an alternative to a network of faint white dwarf stars. The cluster is distant enough that G2 V stars stay below the saturation limits for full frame imaging in most JWST imaging filters. It is also low in extinction ($A_V < 0.3$) considering its 3 kpc distance. We present a collection G2V stars within these clusters that have been identified from colors and optical spectroscopy. We also present high-quality photometry from Gaia, Pan-STARRS, UKIRT and Spitzer and model solar spectra we use to cross check JWST fluxes with these faint solar analogs.

The trouble with K giants: A challenging class of mid-infrared standard stars

Greg Sloan
Space Telescope Science Institute, UNC Chapel Hill

K giants were the go-to class of standard stars in the infrared for decades, because they are bright and numerous, but their use as standards has had a rocky history. We now know that stellar models of K giants consistently underpredict the strength of their molecular bands in the mid-infrared, and as a consequence, JWST does not use them as standards. We have observed four K giants with the Medium-Resolution Spectrometer (MRS) on JWST that served as primary standards for the Infrared Spectrograph (IRS) on the Spitzer Space Telescope, with two goals. First, the new spectra provide an immediate cross-mission calibration check. The MRS spectra are consistently fainter than the IRS by ~5%. We suspect that the issue is with the calibration of the IRS. Second, the new data have sufficient spectral resolution to resolve the line structure in bands produced by CO, SiO, and OH, so that the physical properties of the absorbing molecular layers can be determined and compared to predictions from stellar models. These results will lead to improved models for the atmospheres of evolved stars.

Towardss blind telluric correction

Alain Smette
ESO - Chile

Dedicated telluric line correction tools, such as molecfit (Smette et al. 2015), allow users to derive an accurate transmission spectrum thanks to the use of a radiative transfer code (e.g., LBLRTM), by fitting the science spectrum directly. This approach works well if at least a few lines from each relevant molecule can be properly fitted to determine the molecular abundance, which requires that the lines are not blended with intrinsic target features.

Here we describe how a radiometer - to provide the abundance of water vapor - and twilight observation of telluric standard stars - for other molecules - can be used by molecfit to derive the transmission spectrum of the atmosphere for any observation. This approach will allow to provide telluric line correction for all spectra at the VLT - and later at the ELT - for which the wavelength calibration and the line spread function are well known.

Rapidly Changing HST/STIS Time Dependent Sensitivity in the NUV

Daniel Stapleton
Space Telescope Science Institute

The Space Telescope Imaging Spectrograph (STIS) covers the far-ultraviolet to the near-infrared and is an essential resource for astronomy at these wavelengths. STIS spectrophotometric fluxes provide a basis for all HST (and some JWST) flux calibrations, which makes the flux calibration of STIS data especially important. The STIS team monitors the time dependent sensitivity (TDS) of the instrument to ensure the optimal corrections are performed based on the changes of the throughput of each observing mode with time. I will present a general overview of the current STIS TDS corrections our pipeline performs for each detector: NUV-MAMA, FUV-MAMA, and CCD. I will also present a few recent developments in the TDS. For example, our TDS monitors began showing sudden changes in sensitivity as much ~5% between early 2022 and now (mid-2024). The most prominent change appears as a decrease in sensitivity between ~4-5% for the NUV between 1800 and 2100 Angstroms. This decrease is found in all STIS modes that cover those wavelengths, and is therefore independent of detector (NUVMAMA vs CCD). I will present the findings of our TDS calibration programs, as well as how the STIS team have altered the TDS corrections at these and other wavelengths to improve sensitivity calibration by up to ~5%.

Single-lined Eclipsing Binaries Become Benchmark Binaries with Better Flux Calibration

Daniel Stevens
University of Minnesota Duluth

For decades, bright double-lined eclipsing binaries (DLEBs) have been the "gold standard" for calibrating stellar models and empirical relations: observations of the eclipses and both stars' radial velocity orbits permit individual mass and radius measurements, often to 1-3% accuracy. Compared to DLEBs, single-lined eclipsing binaries (SLEBs), such as F-M EBs, offer key advantages due to the highly unequal mass, radius, and luminosity ratios. Although high-precision space-based eclipse observations now permit measurements of a SLEB primary star's density to 1% precision, the much larger systematic error floors in stellar temperatures and bolometric fluxes prohibit determinations of SLEB stars' individual masses and radii to percent-level accuracy. I will show how these systematic errors propagate through to the errors on the radii and masses and demonstrate how the current achievable precision on these physical parameters exceeds the achievable accuracy. I will preview how improved flux calibration from the Landolt mission can reduce these errors to the 1-3% needed to turn SLEBs into benchmark laboratories for stellar astrophysics, specifically in the contexts of assessing "radius inflation" in low-mass stars and performing comparative analyses of different stellar atmosphere models.

Blackbody Stars for Accurate UV-VIS-IR Flux Calibration

Nao Suzuki
Florida State University / Lawrence Berkeley National Lab

Serendipitously, featureless blackbody stars were identified in the Sloan Digital Sky Survey archive. They had been targeted and classified as quasars. Their spectra are consistent with blackbody radiation from UV (GALEX), VIS (Pan-STARRS), and IR (WISE). We conducted follow-up observations with the Hubble Space Telescope on the best seven stars, enabling us to predict accurate flux in any filters/wavelengths to a sub-percent level using only two parameters without relying on a stellar model. With GAIA DR3 data, we identified new potential blackbody stars, and spectral follow-ups are being conducted by 3-4 meter telescopes. The nature of blackbody stars is understood as a special case of DB white dwarfs at a certain "magic" temperature. We discuss future applications as primary standards for accurate flux calibration for Roman, LSST, and JWST in a covariance matrix form.

Roman-WFI: characterization of widefield chromatic response

Eric Switzer
NASA Goddard

Characterization of filter transmission is essential to control systematic chromatic errors in photometric surveys. Widefield surveys employ large filter optics viewed from high angles of incidence. Large optics may have variations in edge wavelength definition across their surface, and their spectral response shifts at high incidence angles. I will describe the characterization of the band definitions for the Wide Field Instrument of the Roman Space Telescope as part of its thermal vacuum test campaigns and through preparatory work. The measurement approach and analysis enable joint retrieval of chromatic response variations across the filter and focal plane. Additional tests probe out-of-band response and thermal straylight paths.

Current Flux Calibration Limits Stellar Age Estimates

Jamie Tayar
University of Florida

Understanding stars and stellar evolution is critical for our ability to understand the masses and ages of extrasolar planets, and the archeological record of our own and other galaxies. However, our actual understanding of the luminosities of stars has an uncertainty of order 2% because of our lack of accurate flux calibration. I will show that these flux uncertainties propagate to significant uncertainties in stellar mass (5%). I will also show how they are amplified by current differences between stellar models, which then add even larger uncertainties (10-100%) to our understanding of the ages of large samples of stars. Finally, I will discuss how the upcoming Landolt mission can improve our underlying flux calibration, and how those changes can propagate to our understanding of the Milky Way's evolution.

Calibrating the Effective Temperatures & Linear Radii Scales for Giant Stars

Gerard van Belle
Lowell Observatory

Bolometric flux determinations, in conjunction with direct measurements of angular size, allow for exquisite, empirical calibration of effective temperature scales. Directly determine values for effective temperature (T_EFF), in addition to radius (R), for 191 giant stars were based upon angular size measurements from optical interferometry at the Palomar Testbed Interferometer (PTI). The median diameter of these measures is 2.4 milliarcseconds, with a median error of 45 microarcseconds. Bolometric fluxes for these stars were established by fitting template spectral energy distributions (SEDs) to narrow- and wide-band photometry data. The SED fits allowed for homogeneously establishing an assessment of spectral type and dereddened V0-K0 color for our sample; these two parameters are used as calibration indices for establishing trends in T_EFF and R. Spectral types range from G0III to M7.75III, V0-K0 from 1.9 to 8.5. For the V0-K0 = {1.9, 6.5} range, median T_EFF uncertainties in the fit of effective temperature versus color are found to be less than 50K; over this range, T_EFF drops from 5050K to 3225K. The median bolometric flux error was 2.1% and was one of the limiting factors in establishing T_EFF. Linear sizes are found to be largely constant at 11 R_sun from G0III to K0III, increasing linearly with subtype to 50 R_sun at K5III, and then further increasing linearly to 150 R_sun by M8III. Examples of the utility of this data set are presented: first, a fully empirical Hertzsprung-Russell Diagram is constructed and examined against stellar evolution models; second, values for stellar mass are inferred based on measures of R and literature values for log g.

The Definition of the Magnitude System For James Webb Space Telescope Photometry

Kevin Volk
Space Telescope Science Institute

The primary photometric calibration of the Jame Webb Space Telescope (JWST) imaging is the determination of the conversion from the measured count rates (in units of ADU/s) to physical units (the mean flux density in Jansky or the equivalent mean surface brightness in MJy/ster). It is also useful to define a magnitude system for the JWST imaging observations, to allow easy comparison with observations either from the ground or from other space missions. The definition of the magnitude system in JWST is done very differently from the approach used, for example, in the 1950's and 1960's to define the Johnson UBVRIJKLM magnitude system, or for the later definition of the 2MASS JHK magnitude system. As is done for the Hubble Space Telescope (HST) photometry, a single, bright, well-studied star is used to define the magnitude system. HST uses "Vega magnitudes" which take the star Vega to define magnitude 0.0 in all instruments and filters. The properties of Vega are such that it is a poor choice for use as the primary magnitude reference at infrared wavelengths. As an alternative, a magnitude system based on defining the star Sirius to have a fixed magnitude in all JWST imaging filters has been adopted. Sirius has advantages compared to Vega in the ease of producing an accurate stellar model for the spectral energy distribution which is the key element for defining the photometric system in this manner. The JWST magnitude system and a comparison of the results of using Sirius instead of Vega as the primary magnitude standard will be discussed, along with how the magnitude definition may be improved in the future by working to use much fainter stars instead of Vega or Sirius. The proper characterization of fainter stars for this purpose is an important goal for future photometric calibration in the optical to infrared wavelength range.

The absolute sky seen through the lens of calibration spectra

Michael Weiler
IEEC / Universitat de Barcelona

Absolute flux calibration, that is the conversion of instrumental fluxes (in the case of spectroscopy) or integrated fluxes (in the case of filter photometry) to standard SI-based units, requires known spectral energy distributions for some astronomical objects, serving as calibration spectra. The unavoidably limited set of calibration spectra available to derive the transformation between instrumental and absolute fluxes introduces fundamental limitations to the absolute flux calibration. These limitations can result in considerable systematic errors in the calibration, depending on the instrument, the observed astronomical objects, and the random noise involved. We consider the mathematical mechanisms causing these limitations in the concrete cases of the reconstruction of photometric response curves and the flux calibration of low-resolution spectrophotometry. We demonstrate how these effects affect the flux calibration of different kinds of astronomical objects observed by currently operational astronomical space missions. Based on the results, we propose criteria for the selection of calibration spectra that minimise potential systematic errors.

Posters

Laser Photometric Ratio Stars: Ultra-Precise Photometric Calibration Using the Earth's Sodium Layer

Justin Albert
Session 3A
Electronic Poster Screen #1
University of Victoria

An ultra-precise (0.01%-level uncertainty) constraint on relative photometry between wavelengths in vacuum of 589.16 nm and 819.71 nm can be achieved in upcoming surveys, for example in the later years of LSST at Rubin, via mountaintop-located laser sources providing a laser-guide-star-like (however utilizing a separate sodium excitation) two-color artificial star source in the Earth's upper atmospheric sodium layer. Such an artificial star will have identical -- to an unprecedented precision of better than approximately one part in 10,000! -- radiant output at wavelengths in vacuum of 589.16 nm and 819.71 nm, and thus can provide a major handle on relative photometry at those two wavelengths, for future SNe Ia and other surveys. Details of this new technique are described in the three publications MNRAS 508, 4399 (2021) (https://arxiv.org/abs/2001.10958); MNRAS 508, 4412 (2021) (https://arxiv.org/abs/2010.08683); and Nat. Sci. 2, e20220003 (2022) (https://arxiv.org/abs/2203.07556).

This poster will elucidate this new technique, describe how such incredibly tiny uncertainties can be feasibly and economically achieved for this particular photometric ratio (and the immense resulting benefits for SNe Ia cosmology), and detail the optomechanics required to construct a future laser photometric ratio star (LPRS) at Rubin and/or elsewhere.

Advanced Camera for Surveys Solar Blind Channel Lifetime Performance

Roberto Avila
Session 2A
Electronic Poster Screen #1
Space Telescope Science Institute

We present a report on the lifetime performance and latest flux calibration of the Advanced Camera for Surveys Solar Blind Channel (ACS/SBC). The SBC is a FUV detector with a spectral response ranging from 1150Å - 1700Å. The sensitivity of the detector has shown an overall decline of ~10% after 22 years of operations, with slight variations depending on the filter. Recently, a slight increase in sensitivity has been observed in the redder filters. This detector also has low-resolution spectroscopic capabilites accomplished with the use of prisms. We present a new set of wavelength and flux calibrations for these modes, which have not been revised since their initial release in 2005. The new calibration deliveries have been designed to work with slitlesslutils, the new multi-object spectroscopic extraction Python package. Additionally, the low frequency L-flats have been re-analyzed, incorporating five more years worth of observations of the calibration field.

High-Precision Stellar Sizes and Temperatures from Optical/Infrared Interferometry

Ellyn Baines
Session 7A
Electronic Poster Screen #1
Naval Research Laboratory, Washington, DC, USA

Two of the most vital properties that we can study for celestial objects are the sizes and temperatures of stars. These measurements represent the ground floor for understanding stellar astrophysics, which then reaches into any number of other astronomical fields, from improved understanding exoplanets and their environments to nova explosions to variable stars and ever on. A sample of reliable radii and temperatures is absolutely required for calibrating empirical relationships. Optical and infrared interferometry has been used to obtain such measurements, and here we present information on the nearly 300 angular diameter and temperature measurements we obtained using the Navy Precision Optical Interferometer.

E. K. Baines, H. R. Schmitt, J. M. Stone, J. H. Clark III, B. I. Kingsley

Roman-WFI: Spectral characterization of the Grism and Prism slitless spectrometers

Evan Bray
Session 3A
Electronic Poster Screen #2
NASA

The Roman Space Telescope Grism and Prism assemblies will allow the wide-field instrument (WFI) to perform slitless, multi-object spectroscopy across the complete field of view. These optical elements play a critical role in the High Latitude Wide Area and High Latitude Time Domain Surveys, which are designed to produce robust spectroscopic redshifts for millions of objects over the mission lifetime. During the WFI thermal vacuum campaign, a dedicated series of measurements were performed over the full range of operational wavelengths and field angles in the interest of characterizing features such as dispersion scale, bandpass edges, dispersion clocking, and radiometry of Grism diffraction orders. This presentation shall give an overview of the methods and results from this portion of the test campaign.

Interpreting Flux from Broadband Measurement

Peter Brown
Session 5A
Electronic Poster Screen #1
Texas A&M University

The Roman Space Telescope Grism and Prism assemblies will allow the wide-field instrument (WFI) to perform slitless, multi-object spectroscopy across the complete field of view. These optical elements play a critical role in the High Latitude Wide Area and High Latitude Time Domain Surveys, which are designed to produce robust spectroscopic redshifts for millions of objects over the mission lifetime. During the WFI thermal vacuum campaign, a dedicated series of measurements were performed over the full range of operational wavelengths and field angles in the interest of characterizing features such as dispersion scale, bandpass edges, dispersion clocking, and radiometry of Grism diffraction orders. This presentation shall give an overview of the methods and results from this portion of the test campaign.

Roman-WFI: Tackling detector nonlinearities with the simplified Relative Calibration System

Ami Choi
Session 3A
Electronic Poster Screen #3
NASA/Goddard Space Flight Center

The Roman Space Telescope will explore the origins of the accelerated expansion of the Universe through measurements of supernovae, weak gravitational lensing, and baryon acoustic oscillations. To do so requires stringent control of systematic errors, including the precise calibration of linearity for the 18 H4RG-10 detectors in Roman's Wide Field Instrument (WFI). The supernovae program, in particular, demands an exceptional understanding of nonlinearities, with the calibration required to be 0.3% over 4.5 decades of flux. Studies of earlier generations of HxRG devices have identified count-rate dependent nonlinearity (CRNL) as a significant systematic for supernova cosmology analyses. The simplified Relative Calibration System (sRCS) was designed and built as an internal WFI subsystem to achieve our strict calibration requirements. The sRCS facilitates in-flight characterization and monitoring of CRNL by providing flatfield illumination across a range of light levels and wavelengths. Recently, Roman's WFI completed an extensive ground test campaign in a thermal vacuum environment to evaluate, characterize, and trend its performance. I will present results from the tests specific to the sRCS, including characterization of CRNL, and the path forward towards accurate and precise flux calibration throughout Roman's mission.

New approaches to improving the accuracy of absolute flux calibration

Susana Deustua

Session 5A

Electronic Poster Screen #2

NIST

A few, very bright stars have SI-traceable absolute flux determinations, defined as calibrated against physical standards. Historically, these efforts focused on the spectral energy distribution measurements in the visible - between about 400 nm to 900 nm - of Vega (plus a few other stars). Some experiments made photometric measurements in infrared (longward of 1000 nm) of Vega, Sirius (and a few more bright stars), with uncertainties ranging between 1-5%. Today, requirements for science investigations in, for example, cosmology, exoplanets, and stellar astrophysics push to sub-percent uncertainties in the absolute fluxes of standard stars. This has led to new projects to improve the accuracy of astronomical calibrators and increase the number of stars with direct SI-traceable flux measurements. This talk describes the current state of the art in absolute flux calibration.

Establishing Standard Stars for Dark Energy (ESSEX) - an explorer concept

Susana Deustua

Session 7A

Electronic Poster Screen #2

NIST

The quest to understand dark energy drives many investigations using multiple probes, e.g. Type Ia supernovae, weak lensing, baryon acoustic oscillation, cluster surveys, etc. Yet modern dark energy experiments have stringent requirements on the control of systematic uncertainties to obtain the precision necessary to meaningfully test the models. Time domain, wide-field surveys with new space and ground based telescopes (Roman, Rubin) are designed to provide essential SNe Ia measurements. The largest source of systematics is flux calibration, specifically, the absolute color calibration which needs uncertainties up to 10 times smaller than achieved to date. One solution that supports these science objectives is to establish a large set of reference stars whose spectral energy distributions have high accuracy, direct SI- traceablity to physical standards between 300 nm and 2000 nm. Stable stars are good flux standards: they are always available, always on (self -powered), and have a wide range of brightness and color. Achieving the precision and accuracy needed for sensitive dark energy experiments suggests moving the laboratory above the Earth's atmosphere, into space. We describe such a mission, consisting of an artificial star paired with a telescope. CANDLE (Calibration using an Artificial star with NIST-traceable Distribution of Luminous Energy), is a high-precision SI-traceable, artificial star that provides calibrated light between 300 nm and 2000 nm using single mode fiber lasers, reflected sunlight plus a monochromator. Star Catcher is a telescope in orbit with CANDLE at a distance of 600 km and is equipped with a spectrograph. CANDLE is funded by a NASA APRA grant. The ESSEX concept study received philanthropic funding.

Touchstone fields for calibrating the Roman Space Telescope Wide-Field Instrument

Dario Fadda

Session 3A

Electronic Poster Screen #4

Space Telescope Science Institute

Precision astrometry, high photometric accuracy, and accurate temporal tracking of the detector responses are essential requirements to achieve the main scientific goals of the Roman mission. Because of its wide field of view, characterization and calibration of the Wide-Field Instrument's (WFI) 18 detectors pose unprecedented challenges. For accurate astrometric and spectro-photometric calibration, a number of stellar fields will be selected in order to provide a uniform and high density distribution of point sources spanning a magnitude range adequate to provide a homogeneous photometric and color calibration for the different bands across the entire array of detectors. These "Touchstone" fields will also be visible for most of the year to enable tracking temporal variations in the photometric response during both commissioning and throughout science operations. Here, we discuss the criteria used to identify suitable fields along with observing time estimates. The selection of the Touchstone fields is expected to be completed by Fall 2024.

Customized JWST Data Reduction Pipeline for Cosmological Fields

Zhen-Kai Gao

Session 1A

Electronic Poster Screen #1

Institute of Astronomy and Astrophysics, Academia Sinica (ASIAA)

The James Webb Space Telescope (JWST) official pipeline provides crucial steps for reducing and calibrating NIRCam imaging data. However, challenges persist, particularly in artifact removal and computational efficiency during Stage 3 processing. To address these issues, we present enhanced Stage 3 calibration steps that significantly improve both data quality and processing efficiency. Our improvements begin with the development of a comprehensive mask in Stage 3-1. This mask encompasses sources, snowballs, bad pixels, and persistence-prone and wisp regions, enabling accurate measurement of 1/f noise and pedestal background while avoiding biased regions. In Stage 3-2, we refine image astrometry using TweakRegStep with custom absolute reference catalogs, incorporating modifications to handle guide star failures. Artifact removal is addressed in Stage 3-3 through the implementation of the method proposed by Robotham et al. (2023). This approach effectively eliminates image artifacts, enhancing the overall quality of the processed data. We then tackle the computational challenges in Stage 3-4, focusing on outlier detection. By parallelizing the resampling process and optimizing median stacking, we achieve a dramatic reduction in computational time – from over 24 hours to under 30 minutes for PRIMER-COSMOS (PID: 1837). The final stage of our enhanced process, Stage 3-5, deals with efficient mosaicking. We parallelize the resampling process and provide an option to skip the memory-intensive context array. These modifications not only enable the mosaicking of large fields such as COSMOS-Web (PID: 1727) but also significantly reduce processing time on a machine with 500 GB RAM. These enhancements collectively address key challenges in the JWST pipeline, offering a more efficient and effective approach to processing NIRCam imaging data.

Authors: Zhen-Kai Gao, Adarsh Ranjan**,** Bovornpratch Vijarnwannaluk**,** Wei-Hao Wang, Chian-Chou Chen

Accurate commensal photometry for ground-based time-domain spectroscopy with the Global Jet Watch

Emma Godden
Session 4A
Electronic Poster Screen #1
University of Oxford

Accurate photometric and astrometric measurements are essential for a wide range of astronomical studies. A common issue in photometric studies is the undersampling of the point-spread-function (PSF), causing significant intra-pixel position bias on the measured fluxes and centroids of sources. This talk presents a detailed analysis of the effect of intra-pixel position bias in lightcurves from commensal cameras on the Global Jet Watch (GJW) telescopes . GJW is a network of five observatories spread longitudinally across the globe which provide round the clock spectroscopy and commensal photometry. We have developed a custom pipeline to construct the lightcurves of sources within the GJW field of view, which requires precise measurements for both photometry and astrometry. We show how effective PSF fitting techniques can significantly reduce the systematic errors in our lightcurves. Obtaining precise photometric measurements enables us to calibrate our fibre-fed spectroscopy, illustrating the value of accurate photometry for ground-based time-domain spectroscopy.

Mid-Infrared Instrument Imaging and Coronagraphy Absolute Flux Calibration

Karl Gordon
Session 4A
Electronic Poster Screen #2
Space Telescope Science Institute

The absolute flux calibration of the Mid-Infrared Instrument (MIRI) Imaging and Coronagraphy is based on observations of multiple stars taken during the first two years of JWST operations. The observations were designed to ensure the flux calibration was valid for a range of flux densities, different subarrays, and different types of stars. Variations in the calibration factor with time, flux density, background level, subarray, integration time, and well depth were investigated and the only significant variations were with time and subarray. Using observations of the same star taken approximately every month, the time dependent sensitivity loss was measured to have a 22% amplitude in the longest wavelength band F2550W and decreasing to very small/negligible amplitudes by F1130W and shorter wavelength bands. This sensitivity loss fits an exponential model quite well with time constants between 200-250 days and band dependent scatter about the model of 0.3 to 1.2%. Based on observations of the same star taken with difference subarrays, lower fluxes of 1 to 3% were found when compared to FULL frame observations. After correcting for the time and subarray dependencies, the scatter in the calibration factor ranges from 2 to 4%. The formal uncertainties on the flux calibration for MIRI Imaging and Coronagraphy range from 0.4 to 1.2% depending on the number of stars observed in each band.

Properties of the Roman WFI optical elements and comparisons with JWST/NIRcam, HST/WFC3, and 2MASS

Eunkyu Han
Session 5A
Electronic Poster Screen #3
Space Telescope Science Institute

We present an overview of the optical elements of the Roman Wide-Field Instrument (WFI), and compare them with other comparable instruments such as the Hubble Space Telescope (HST) Wide Field Camera 3 (WFC3) IR channel, the James Webb Space Telescope (JWST) NIRCam, and the Two Micron All Sky Survey (2MASS) arrays. The WFI carries eight imaging filters that provide throughput between 0.48 and 2.3 microns, with seven wide-band filters (RzYJHKs + F184) and one extra-wide filter (F146) stretching from approximately 0.9 to 2.0 microns. The WFI also carries two spectral dispersers that provide much of the same wavelength range as the imaging filters, with a grism covering 1.0 to 1.93 microns at a resolution of R ~ 461 and a prism covering 0.75 to 1.83 microns at a resolution around R ~ 80 - 180. The Roman WFI will provide the same spectral coverage as WFC3/IR and the NIRCam short wavelength channel but with some important differences in design, e.g., the absence of narrow-band filters in the WFI.

Dovekie and Whimbrel: Cross-calibrating the Zwicky Transient Facility for next generation cosmology

William Kenworthy
Session 5A
Electronic Poster Screen #4
Oskar Klein Center, Stockholm University

With the release of the recent DESI and DES results hinting at evolution in the dark energy equation-of-state, it is imperative that the next generation of cosmological surveys control systematic uncertainties to challenge or verify these results. The release of the Zwicky Transient Facility sample of Type Ia supernovae promises to increase constraining power with an order of magnitude more cosmological supernovae at redshifts less than 0.15. Here we present cross-calibration of the ZTF with other surveys, including DES and PanSTARRS. We introduce several mitigations to account for the characteristics of the ZTF camera. Additionally, we propagate these calibration uncertainties into light-curve modeling with the SALTShaker code and cosmology. We also introduce novel techniques to reduce impact of these uncertainties on light-curve modeling. Lastly, we show how an extension to the SALT model improves our ability to constrain and measure calibration uncertainties.

Spitzer IRAC 3.6 and 4.5 um Photometry for the IRS Calibration Standards

Kathleen Kraemer

Session 6A

Electronic Poster Screen #1

Boston College

Observations of over 60 Spitzer IRS calibration standards with IRAC at 3.6 and 4.5 um during the post-cryogenic phase of the mission demonstrate that the IRAC and IRS photometric calibrations agree to better than 1%. The IRS wavelength range has only a small overlap with the 4.5 um band, so we created synthetic spectra to bridge the gap to the 3.6 um band. We then compared the IRAC measurements to photometry generated from the synthetic spectra. For the 16 A dwarfs, the photometry agrees within 0.5%, and for the 37 K giants, the agreement is better than 1%. Our IRAC photometry is also within 0.5% of an independent assessment of archival Spitzer photometry of potential JWST calibrators for the 5 A dwarfs we have in common. Three of these are currently being used as calibrators for MIRI: del UMi, HR 5467, and HD 163446, and eta1 Dor was observed by NIRCAM during commissioning. Thus, this work helps tie together the flux calibration of Spitzer and JWST, a particular challenge given the different sensitivity ranges of the instruments on the two telescopes.

This work was supported by NASA grant NNX17AF23G.

Multiwavelength analysis of the nearby isolated galaxies including Milky Way twin, NGC 3521.

Olena Kompaniiets

Session 4A

Electronic Poster Screen #3

Main Astronomical Observatory of the National Academy of Sciences of Ukraine

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O. Kompaniiets[1], O. Pastoven[2], I. Vavilova[1], D. Dobrycheva[1]

Advances in space telescope technology and all-sky surveys drive the need for more precise and accurate flux calibration across the observable spectrum. In the era of all-sky surveys, we have an excellent opportunity for multiwavelength analysis, enabling the estimation of the physical properties of galaxies with unprecedented detail. Utilizing data from GALEX, SDSS, 2MASS, WISE, SPITZER, HERSCHEL, and VLA, we aim to build and analyze spectral energy distributions (SED) using CIGALE software.

We are focused on galaxies that have not undergone a merger for at least a few billion years, providing a unique laboratory for studying astrophysical processes without the complicating factors of recent mergers or dense environments. This study also extends to isolated AGNs, offering valuable insights into galaxies' evolution and activity concerning the Universe's large-scale structure. Key objectives include understanding how the environment affects the accretion of matter onto supermassive black holes, the role of star formation and nuclear activity in galaxy evolution, and the impact of localization in voids or filaments on galaxy properties at low redshifts. Additionally, studying the nearby isolated galaxy NGC 3521, a Milky Way twin, will help us better understand the history of our galaxy. We have used an optimal baseline mode for NGC 3521 which describes the emission from gas and stars, considering both dust attenuation and dust emission. The resulting parameter values are the mass of the stellar component, $M_{star} = 2.54 \times 10^{10}\ M_{Sun}$; the mass of dust, $M_{dust} = 8.36 \times 10^{7}\ M_{Sun}$; and the star formation rate, SFR = 1.26 M_{Sun}/year, with a corresponding statistical value of χ^2/ d.o.f = 2.

One of the main challenges we face is obtaining aperture photometric data for each galaxy in several electromagnetic spectrum bands. This is because sky survey catalogs usually provide fluxes for relatively small regions, which are much smaller than the size of the galaxies.

Time-Dependent Sensitivity of the WFC3/IR Detector (2009 - 2023)

Mariarosa Marinelli
Session 2A
Electronic Poster Screen #2
Space Telescope Science Institute

The WFC3/IR detector has experienced a cumulative photometric sensitivity loss of ~1-2 % since installation, indicating that time-dependent corrections are necessary for highest accuracy photometry. The WFC3 team evaluated the changing photometric sensitivity using staring mode observations of globular clusters, scanning mode photometry of an open cluster, and grism observations of four CALSPEC standard white dwarf stars. Staring mode observations of CALSPEC standards were used for testing and validation. Sensitivity changes appear to be wavelength-dependent, with the greatest losses in the bluest filters. A new IMPHTTAB reference file, with updated inverse sensitivities, will be delivered in 2024. We also provide factors users can apply to manually correct their photometry.

Characterization of the HST/STIS Echelle Spectral Blaze Shifts

TalaWanda Monroe
Session 2A
Electronic Poster Screen #3
Space Telescope Science Institute

The HST/STIS echelle gratings provide simultaneous coverage of multiple, overlapping spectral orders in the FUV and NUV at medium and high resolving powers (R~25,000-110,000). Accurate flux calibration of the echelle gratings requires careful, detailed characterization of the spectral blaze functions, or relative sensitivity of each spectral order. On-orbit sensitivity curves for each echelle mode were derived from observations of a spectrophotometric standard white dwarf following HST's Servicing Mission 4, with some modes receiving recent updates from improvements in the stellar atmospheric model. However, the blaze functions are subject to temporal shifts and shape changes that impact the flux calibration accuracy with time, particularly near the edges of the overlapping spectral orders. Over time the blaze functions can shift with respect to the wavelength scale, resulting in flux mismatches in overlapping spectral regions of up to ~10%. Here we discuss efforts to optimize the relative and absolute flux calibration of the echelle modes over time. We present work to measure the time dependence of the blaze function shifts and updates to CALSTIS reference files to improve the relative flux calibration of adjacent orders.

Decoding Binary Composite Spectra: An Empirical Approach Using Synthetic Spectra

Peter Nemeth
Session 7A
Electronic Poster Screen #3
Astroserver.org

Composite stellar spectra are treasure troves of astronomical data, enabling precision studies of binaries and multiples. However, for that precision, one needs to apply specialized methodologies and address the high level of degeneracy encoded in the spectral data. One such method combines synthetic spectral models of both components to reproduce the observed spectral properties and spectral energy distributions. Various constraints can be applied, such as stellar radii derived from eclipses, orbital separation from astrometry, or stellar rotation rates from independent measurements. The presented methodology is suitable for decomposing a binary from a single observed spectrum, which is advantageous when limited observing time is available. When multiple measurements become available and the orbital period is covered, wavelength space decomposition combined with Fourier disentangling can reveal both the binary orbital parameters and the members' spectral properties. I present a purely spectroscopic empirical decomposition of hot subdwarf (sdO, sdB) - main-sequence (F/G/K type) binary composite spectra, utilizing high-resolution VLT/UVES spectra, where only the mass ratio is known from radial velocity measurements. This approach has significant implications for advancing our understanding of stellar evolution, improving the accuracy of stellar parameter measurements, and refining models of binary systems. The quality of measurements largely depends on the accuracy of flux calibration. In particular, metal abundances and stellar radii are sensitive to flux calibrations. Binaries with very diverse components, such as sdO stars with cool companions, provide a sweet spot for instrument calibrations thanks to their distinct UV and IR flux peaks, while their composite spectra are easily attainable in the optical range from the ground.

Wide-Field Multiplexed Spectroscopy with JWST MIRI

Andreea Petric
Session 1A
Electronic Poster Screen #2
Space Telescope Science Institute

Optical and near-infrared wide-field spectroscopy with Hubble and JWST have revolutionized our understanding of galaxies by allowing simultaneous studies of the impacts of environment, mass, and the presence of AGNs on the evolution of galaxies. The JWST MIRI slitless mode has been a fantastic asset for time-series observations of exoplanets. This talk describes efforts to develop a new wide-field slitless spectroscopy capability for MIRI, including strategy, limitations, and calibration plans. We will focus on the spectral trace and distortion as a function of source position and how those compare with optical models. Furthermore, we will discuss how using multiple roll angles and imaging is required to decompose source spectra in crowded or complex fields and can even decompose extended and compact emissions such as an AGN and its host galaxy.

Empirical Point Spread Function for the MIRI Low-Resolution Spectrometer

Andreea Petric

Session 6A

Electronic Poster Screen #2

Space Telescope Science Institute

The JWST MIRI Low-Resolution Spectrometer (LRS) has the wavelength coverage and spectral resolution to detect bright rest-frame optical emission lines in high-redshift galaxies and the stability to carry out transit, eclipse, and phase-curve spectroscopy of exoplanetary atmospheres. To further improve the signal-to-noise observers can achieve with MIRI LRS spectral extraction, the LRS team has obtained and analyzed sub-pixel dither observations with which to construct empirical point spread functions (ePSFs) that can facilitate PSF-based extractions and background subtractions. This presentation investigates the ePSFs as a function of wavelength, nod position, observing cycle, and LRS mode (slit or slitless), compares them with modeled PSFs, and explores spectral-extraction algorithms that leverage the ePSF.

JWST NIRSpec Observations of Flux Standards

Charles Proffitt

Session 1A

Electronic Poster Screen #3

Space Telescope Science Institute

As parts of the NIRSpec commissioning and calibration programs and the JWST cross-instrument flux calibration program, a number of standard stars have been observed with NIRSpec. In this poster we present the first assessment of the systematic errors via comparison of multiple flux calibration stars. In addition, we show the first cross-mode calibration, comparing the same objects observed in NIRSpec's Fixed Slits, MOS, and IFU. In detail, four standard stars have been observed using all of the grating/filter settings with the S1600A1, as well as with most settings using the IFU mode, while an additional 7 standards have been observed with the S1600A1 using the NIRSpec PRISM which covers the full wavelength range at low dispersion, and three standard stars have been observed with the IFU + PRISM. Additionally, we present the results of our monthly throughput monitor, highlighting excellent stability over the course of the mission thus far. We then discuss the intrinsic accuracy of the NIRSpec observations, the limiting signal-to-noise that can be achieved with current calibrations and pipeline algorithms, and the implied accuracy of the individual SED models.

ORCASat: Lessons Learned from the First Optical Source Satellite Mission for Observatory Calibration

Diego Reyes
Session 6A
Electronic Poster Screen #3
University of Victoria

The ORCASat (Optical Reference Calibration Satellite, https://www.orcasat.ca) 2U CubeSat, funded by the Canadian Space Agency, was constructed in 2019-2022 and launched from Kennedy Space Center to the International Space Station (ISS) onboard commercial resupply mission CRS-26 on Nov. 26, 2022. ORCASat was then deployed out of the ISS into its own low-Earth orbit, initially at an altitude of approx. 405 km ASL, on Dec. 29, 2022. ORCASat's optical payload consisted of 660 nm and 840 nm laser diodes, each with approx. 100 mW of output optical power, both directed into a single 2" inner diameter integrating sphere and output toward the Earth's surface. After a campaign of observation attempts using DECam at the NOIRLab Blanco 4m and MegaCam at the CFHT 4m, ORCASat re-entered the Earth's atmosphere on Jul. 7, 2023. We will discuss the design of and the main lessons learned from this mission. In particular, ORCASat was extremely successful in that communication and operational control during its mission was consistently well-established between the satellite and its ground station on the University of Victoria campus. Also, potential future calibration satellites in LEO, very similar to ORCASat, have great promise for forefront calibration of major wide-angle surveys. However, the three main (and achievable without great expense or challenge) lessons learned from ORCASat are that: 1) Brighter optical sources, with optical output power of 1 W or greater, are needed (rather than ~100 mW sources); 2) An improved (i.e. more reliable) onboard attitude control system is also needed; and 3) A slightly higher low-Earth orbit, in order to obtain a mission lifetime of 3 to 5 years, rather than of ~6 months, is additionally needed.

Fundamentally More: Quadrupling the sample of CALSPEC fundamental white dwarfs

David Rubin

Session 7A

Electronic Poster Screen #4

University of Hawai'i at Mānoa

Photometric calibration well below 1% is a requirement for many current and future programs. The best current spectrophotometric system for UV- optical-NIR calibration is CALSPEC, tied to the NTLE atmosphere models of three pure-hydrogen (DA) white dwarfs (GD 71, GD 153, G 191-B2B) that are in the Local Cavity and thus show very little interstellar extinction. STIS observations of these stars are required to match NLTE model atmospheres, on average, and with this calibration in hand, dozens of STIS-observed stars of many types have been added to CALSPEC. However, the STIS observations of the three white dwarfs do not show the same agreement with the white-dwarf atmosphere models. These differences of up to 1% translate into large differences in forecasted cosmological constraints. These particular three fundamental white dwarfs are a historical choice and other excellent DA white-dwarf calibrators could have been chosen; we identify 11 additional stars that have not already been observed with STIS spectrophotometry. Observing these new stars with STIS thus increases by more than 4x the number of calibrator stars, providing a true statistical sample spanning temperature and gravity. We compare these observations to the model atmosphere grid of Bohlin et al. 2020. With our larger sample, we examine the residuals vs. temperature and gravity. The resulting reduction and quantification of uncertainties will benefit the cosmology community.

AB in the new SI

Prasenjit Saha

Session 7A

Electronic Poster Screen #5

NOIRLab

A probably unintended (but fortunate) consequence of the 2019 redefinitions of the International System of units (SI) is that AB magnitude is exactly equivalent to spectral photon flux on a logarithmic scale. Advantages of this equivalence are (among others) that (i) spectra keep their shape when redshifted, and (ii) the values are convenient to round -- zero magnitude in a typical broad band is about 10 billion photons per square metre per second.

Update of the TVAC analysis

Sanjib Sharma
Session 3A
Electronic Poster Screen #5
Space Telescope Science Institute

The Wide Field Instrument (WFI) of the Nancy Grace Roman Telescope, scheduled for launch by May 2027, was fully assembled for the first time at Ball Aerospace (BAE Systems) in September 2023. Following its assembly, the WFI entered the Titan test chamber for its initial Thermal Vacuum Integration and Testing Campaign (TVAC1), which lasted nearly two months. The insights and data gathered during TVAC1 were instrumental in refining the subsequent testing campaign, TVAC2, which took place from Spring 2024 to May 2024. The Science Operations Center (SOC) at the Space Telescope Science Institute is responsible for generating various calibration reference files for the WFI's imaging mode, to be used during commissioning. This poster details how the SOC is using data from both TVAC1 and TVAC2 to create these calibration reference files. Additionally, we discuss how this work lays the foundation for routine long-term characterization and trending of the WFI.

Recent Improvements in the Calibration of HST/STIS Echelle Modes

Matthew Siebert
Session 2A
Electronic Poster Screen #4
Space Telescope Science Institute

The Space Telescope Imaging Spectrograph (STIS) is a versatile instrument capable of observing at FUV and NUV wavelengths with 44 different echelle settings at medium to high resolution. Recent improvements to stellar atmospheric models have merited updated flux calibration for high priority STIS observing modes. The STIS team has derived sensitivity curves based on the new CALPSEC model of G191-B2B for several echelle modes improving absolute flux calibration by ~3% for observations taken post-Servicing Mission 4 (SM4; in 2009). However, the necessary calibration data to make these improvements are significantly lacking for pre-SM4 observations. I will present a simple alternative method, which implements a throughput scaling based on the ratio of new vs old CALSPEC model continua, that the STIS team has used to improve the flux calibration of pre-SM4 echelle observations by ~0.5 - 2.4% across the FUV to NUV. I will also discuss a new method developed for the derivation of echelle mode traces. Echelle "secondary" modes, that were designed to cover specific absorption or emission lines, have traces previously-defined with straight line fits to each spectral order. Our new method uses Gaussian process regression and better-characterizes the curvature of each order, especially at the detector edges. These improvements have increased throughput by ~4% in these regions in both pre- and post SM4 observations.

The Landolt Mission and Exoplanets

Angelle Tanner
Session 4A
Electronic Poster Screen #4
Mississippi State University

The Landolt Mission will provide improved stellar absolute flux uncertainties which will have a significant impact on our knowledge of the properties of extrasolar planets. The term "Know thy star, know thy planet" is well established in the exoplanet community. This rings especially true for planets detected by the transit method. While the transit signal geometrically reveals the radius of the planet, that value and the planet's mass depend on the flux of the star and its distance, radius and temperature. Now that Gaia has provided improved distances and cutting-edge echelle spectrographs are reaching RV precisions below 1 m/s, the error on the flux of the star can be the dominant source of uncertainty for some planet properties. Flux uncertainties also impact estimates of stellar ages thus impeding our ability to study planetary properties as a function of time. This poster will illustrate how the Landolt mission, which was recently selected as a NASA Pioneers program, will improve our understanding of planetary systems. For instance, we expect that for some systems, the uncertainties in planet radius could improve from 5% to 0.5% with potential ramifications for the interpretation of the planet-radius gap. I will also discuss our initial attempt at an exoplanet host star target list and the mission's plan for a General Observers (GO) program intended to expand the impact of the mission. This includes a web application which will guide proposers to the observability of the spacecraft and the potential for yet unexplored applications of the mission to exoplanet science.

Cross-Instrument Photometric Comparison for the NIRISS and NIRCam Instruments

Kevin Volk
Session 1A
Electronic Poster Screen #4
Space Telescope Science Institute

Both the NIRISS instrument and the NIRCam instrument provide imaging capability for the James Webb Space Telescope. NIRISS has a smaller set of available filters, 11 out of 12 of which are very close analogues of filters that are available in NIRCam. This provides the opportunity to compare the count rates of stars observed by both instruments in the "same" filter as a sensitive test of how well we can carry out forward modeling of the photometry from the two instruments, and how well the JWST reduction pipeline and the calibration reference files perform together to give consistent photometric results. The results of inter-comparing measurements of some photometric standards as well as those of stars in common fields, particularly the Large Magellanic Cloud astrometric field, will be presented.

Calibrating the LRS on JWST: Lessons learned and open questions

Ian Wong
Session 6A
Electronic Poster Screen #4
Space Telescope Science Institute

The Low-Resolution Spectrometer (LRS) on JWST's Mid-Infrared Instrument (MIRI) offers spectroscopy at a spectral resolving power ranging from 40 at 5 um to 200 at 12 um. The slit and slitless modes provide a myriad of use cases, including high-cadence time-series observations, which have established the instrument as a powerful tool for transiting exoplanet spectroscopy. Throughout the first two years of science operations, the flux calibration of LRS has seen major improvements, and work is ongoing to further refine our understanding of instrument throughput, wavelength calibration, detector response, and point-spread functions. This presentation will focus on recent efforts to re-evaluate the performance of LRS. Spectrophotometric updates are based on detailed analyses of A- and G-type standard star observations obtained in Cycles 1 and 2. Issues to be addressed for a proper flux calibration include background subtraction, fixed-pattern noise, time-variable behavior, and assessing the quality of the CALSPEC models.

Absolute calibration of broad-band UV optical system responsivities for the Carruthers mission

Alex Zhang
Session 4A
Electronic Poster Screen #5
Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign

The Carruthers Geocorona Observatory is a NASA Heliophysics Science Mission of Opportunity that will investigate structure and dynamics of Earth's exosphere following its launch in April 2025. The Carruthers mission's primary payload is the GeoCorona Imager (GCI), which consists of two co-aligned imagers (channels) that simultaneously measure scattered solar Lyman-α (121.6nm) emission by exospheric hydrogen atoms at different global scales and spatial resolutions in order to determine the underlying H density distribution. A prerequisite of the H density retrieval is accurate on-orbit and cross-calibration of the two sensors' radiometric responsivity at Lyman-α. We adopt the conventional approach to determine the GCI responsivity at Lyman-α using on-orbit observations of so-called "Lyman-α" stars whose spectra are dominated solely by narrowband Lyman-α emission. Because the GCI channel incompletely suppresses long wavelength (out-of-band) emission from Earth's limb and disk, accurate isolation of Lyman-α emission from the lower exosphere requires precise on-orbit estimation of the GCI responsivity across the full channel passband. In order to determine the wavelength-dependent GCI responsivity independently for each channel, we use an inverse theoretic "source-separation" technique constrained by observations of diverse broad-band (blackbody) spectra from bright EUV stars. To demonstrate the feasibility of our approach to absolute calibration at Lyman-α and across the full passband, we conduct numerical experiments with simulated GCI observations of realistic stellar targets based on reported photon flux data acquired by the Short Wavelength Primary camera onboard the International Ultraviolet Explorer.