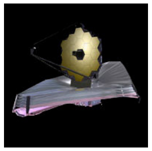

1202 - The NIRISS Survey for Young Brown Dwarfs and Rogue Planets

Cycle: 1, Proposal Category: GTO

INVESTIGATORS

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OBSERVATIONS

Folder	*Observation*	*Label*	*Observing Template*	*Science Target*
N1333-F1				
	1	N1333_KH	NIRISS Wide Field Slitless Spectroscopy	(1) NGC-1333

ABSTRACT

How far down in mass the stellar initial mass function (IMF) extends is a fundamental, unresolved question in astrophysics. The shape of the IMF at the lowest masses will not only establish the boundary between objects that form `like stars' and those that form `like planets', but also distinguish among competing theoretical models for the origin of brown dwarfs. Thanks to extensive surveys by us and others, the IMF is now reasonably well characterised in several nearby star-forming regions down to about 10 Jupiter masses, but not below. While these surveys suggest that free-floating planetary-mass objects are relatively scarce, recent microlensing studies claim they may be twice as common as stars. The stark contrast between the two results could be reconciled if there is a large population of hitherto undetected 1-5 Jupiter mass objects in star forming regions, possibly formed in protostellar disks and subsequently ejected. Here we propose to use NIRISS in the WFSS mode to survey a nearby young cluster to unprecedented

depth, in order to (1) establish firmly the shape of the IMF below the Deuterium-burning limit, (2) investigate the fragmentation limit for `star-like' formation, and (3) quantify the population of isolated planetary-mass objects. Our proposed observations of NGC 1333 will not only identify and confirm objects down to 1-2 Jupiter masses, but also provide a first estimate of their temperature, and thus mass. Follow-up high-resolution spectroscopy with NIRSpec could improve Teff/mass estimates, derive C/O ratios to trace the formation mechanism, look for accretion features, and test atmosphere models, while follow-up MIRI photometry would look for disk emission.

OBSERVING DESCRIPTION

Science Case

Brown dwarfs are substellar objects with masses too low to sustain stable hydrogen burning, at any age. They fill the gap between low-mass stars and giant planets. The formation process of brown dwarfs (BDs) is one of the key problems in stellar astrophysics. For an isolated BD to form, a substellar Jeans mass is required, which implies high densities typically not found in molecular cloud cores (Whitworth et al. 2007). Possible ways to overcome this obstacle are dynamical ejections from stellar multiple systems or turbulent fragmentation ('star-like' formation), disk fragmentation followed by ejection ('planet-like' formation), or hybrid scenarios (Bate 2012, Chabrier et al. 2014, Stamatellos et al. 2011, Basu \& Vorobyov 2012). Accounting for the formation of a substantial number of BDs has been one of the main drivers in the development of the simulations of star and planet formation over the past decade.

Deep surveys in star forming regions are the fundament for testing the outcomes from simulations. Star forming regions host a significant number of substellar objects down to masses comparable to giant planets (Zapatero Osorio 2000, Lucas \& Roche 2000). In 2006 we initiated a ground-breaking survey for young BDs, named SONYC (short for {\it Substellar Objects in Nearby Young Clusters}). Predominantly carried out with 8-m class telescopes (Subaru, VLT, Gemini) our survey is extremely deep and unbiased. The results of SONYC are published in nine peer-reviewed papers (e.g., Scholz et al. 2009, 2012, Muzic 2012, 2015). Our unique survey features comprehensive spectroscopic follow-up for our candidates using multi-object instruments like FMOS and VIMOS, which is crucial to free the samples from contamination. The low mass limit of around 5 Jupiter masses is set by the sensitivity of low-resolution spectrographs at 8-m telescopes. To find objects with lower masses is prohibitively expensive in terms of telescope time, due to the steep mass-luminosity relation in the planetary domain.

With SONYC and a few comparable projects by other groups (Andersen et al. 2008, Alves de Oliveira et al. 2013, Luhman et al. 2009, Lodieu et al. 2013) the substellar mass function is now well characterised down to 5-10 Jupiter masses (depending on extinction). All star forming regions surveyed thus far show a star-to-BD ratio of 2-5, i.e. for 10 stars about 2 to 5 BDs are formed. The mass spectrum is consistent with a single power-law slope from 0.5 solar masses or down to the Deuterium burning limit around 15 Jupiter masses, and also consistent with a log-normal form. Planetary-mass objects with masses below the Deuterium burning limit are not common and the power-law slope shows indications for a turnover in the planetary mass domain (see Fig. 1). It is worth noting that objects with masses of a 5-15 Jupiter masses are also rare in orbits around stars. The most straightforward interpretation is that high-mass BDs are the extension of the stellar mass spectrum, form by the same processes as stars, with a low-mass limit defined by the opacity limit for fragmentation, predicted to occur around 3-10 Jupiter masses. In the free-floating population in clusters we have not seen yet the transition from star to planet formation.

There are strong incentives to explore the mass domain below 5 Jupiter masses: Microlensing surveys indicate that the number of free-floating planetary mass objects may be about as high as the number of stars (Sumi et al. 2011, see also Clanton \& Gaudi 2016). The microlensing results come with a number of caveats, for example, the estimate includes objects on wide orbits around stars, and should therefore be interpreted as an upper limit. Dynamical simulations of clustered star formation (Parker \& Quanz 2012) suggest more modest numbers for the number of ejected free-floating planets (10 per 100 stars, depending on assumptions). These estimates widely exceed the numbers we have detected so far in direct surveys like SONYC (less than 2-5 per 100 stars). From these arguments, we expect to find a large population of isolated planetary mass objects with masses between 1 and 5 Jupiter. This sample would almost certainly have formed in a different way than the BDs found by SONYC and other surveys, most likely by core accretion or gravitational instability in protoplanetary disks followed by ejection. They would constitute the free-floating siblings of the giant planets found in exoplanet surveys and should be called 'rogue planets'.

Directly detecting of the first rogue planets in star forming regions and thus establishing the boundary between low-mass star formation and giant planet formation are prime tasks for the James Webb Space Telescope. JWST will provide greatly improved sensitivity compared with current ground-based instruments across the entire near- and mid-infrared domain, which is critical for a characterisation of ultracool objects. All JWST instruments are expected to contribute to these goals -- NIRCAM with new, ultradeep imaging surveys, NIRSPEC with follow-up spectroscopy at medium resolution, and MIRI for the exploration of disks around ultra-low mass objects. NIRISS with its unique ability to take slitless spectra for all objects in a field can be a 'trail blazer' into the world of rogue planets.

Technical Case

We propose to use NIRISS for the first, unbiased, spectroscopic exploration of the rogue planet domain in a star forming region. Our target of choice, the cluster NGC1333 (age 1\,Myr, distance 250\,pc) combines a number of advantages: It is the best studied region down to 5-10 Jupiter masses, thanks to our SONYC survey which has revealed a rich population of brown dwarfs (Fig. 1). This is an essential feature and allows detailed crossanalysis between stars, brown dwarfs, and the newly identified rogue planets. Compared to the more distant star forming regions (ONC, NGC2024), the planetary-mass population in NGC1333 will be sufficiently bright for follow-up with large ground-based facilities and for MIRI at JWST. NGC1333 is also close enough to obtain direct distance estimates for (bright) brown dwarfs with Gaia DR2. Compared to the nearer star forming regions the cluster is very compact, with a cluster radius of only about 5 arcmin. The object density in NGC1333 is in a 'sweet spot' for slitless spectroscopy -- sufficiently high to generate a large sample, but not too high to cause excessive source confusion (Fig. 2).

We want to carry out a WFSS survey of about 45 square arcmin (i.e. 9 pointings) down to H-band magnitudes of 22, obtaining low-resolution HK spectra with signal-to-noise ratios of at least 10 for all relevant objects in the field. The scope of the survey would cover most of the dense cluster regions and about half of the known cluster members, and therefore gives us a robust assessment of the planetary mass population over the entire cluster. The magnitude limit corresponds to around 1 Jupiter masses for the distance of NGC1333, at an extinction of $A_V \sim 5$ (typical for the members in this cluster). With our ground-based surveys, we have demonstrated that low-resolution near-infrared spectra are sufficient to unambiguously identify planetary mass objects and provide a first estimate of temperature and thus mass -- the water and methane absorption in ultracool atmospheres turn the infrared spectrum into a characteristic 'landscape', dramatically different from the blackbody slope seen in stars (Fig. 1). NIRISS spectra will allow us to easily distinguish planetary-mass objects from more massive brown dwarfs, embedded stars, and reddened background stars, the main sources of contamination.

We selected nine 2.2×2.2\,arcmin WFSS fields from our own deep near-infrared JK-band imaging, which is about 2\,mag shallower than the WFSS spectroscopy. We have designed a 4×4 grid of 16 WFSS fields, and deselected 7 of these fields that are either affected by bright stars and high background emission or devoid of known cluster members. With integration times per field of 2900\,sec in F150 (H-band) and 1700\,sec in F200 (K-band) we can reach the required signal-to-noise ratio (according to estimates based on the Exposure Time Calculator, February 2017), a total photon collection time of 12.9 hours. We choose a 4 point MEDIUM dither pattern, 1 integration per filter, and 17/10 groups per integration for H/K-band. For source identification, we add direct imaging in H- and K-band. According to APT version 25.0, the total required wall-clock time for this setup is 19.0 hours (observing efficiency of 63\%). If needed, the program can be de-scoped by 4\,h by dropping 2 fields with lower object density at the margins of the cluster. The exact exposure times will be updated as ETC and APT improve.

In Fig. 2 we show results from Grizli simulations for this project. As a basis, we use our existing K-band images, which are complete down to K=19.5. By extrapolating our catalogue to the limiting magnitude of the planned NIRISS integrations we estimate that we will find 50 objects per square arcmin, roughly twice as many as in the current imaging data. To account for that, we inserted additional sources at random positions into the simulations shown in Fig. 2. The plots illustrate that source confusion is minimal in the simulated frames, as long as the nebulosity in the center is avoided. Most of the faint sources are well isolated and clean spectra are to be expected. We plan to observe at a V3 position angle between 248 and 252 degrees, which is estimated from APT for the visibility window from Aug 16 2019 to Oct 8 2019.

If the aforementioned microlensing result is correct, we should see 50-100 detections, the first sizable and spectroscopically confirmed population of free-floating planets with good quality spectra. Even with the more modest predictions, we expect to find dozens of confirmed rogue planets. This will be the first test for formation scenarios in this mass domain. This is a stand-alone project and no further follow-up is needed to answer the fundamental questions posed by our science case. In contrast to the expected work with NIRCAM/NIRSPEC in the richer, but more distant star forming regions, every single object we find will be highly interesting for further follow-up (e.g., study of accretion, disks, kinematics), and lead to a flurry of studies, as shown by the recent discoveries of very few free-floating planets with higher masses (e.g., Delorme et al. 2012). In conclusion, this constitutes an excellent early science case for JWST.

Parallel observations

We propose to complement the NIRISS/WFSS program with Coordinated Parallel observations using NIRCAM. While our WFSS fields are covering the core of the cluster NGC1333, NIRCAM will be pointing towards fields at the margins and just outside the margins of the same cluster. In our preferred setup, 20\% of the WFSS field will also be covered by NIRCAM; the remainder of the NIRCAM field is additional field towards the northwest of the WFSS fields. We propose to obtain multiple deep integrations of these NIRCAM fields in wide- and medium-band filters. This survey design gives us a chance to tackle two distinct problems:

1. Does the population of free-floating planets in NGC1333 extend beyond the radius of the cluster? For our WFSS survey we focus on the regions of the cluster with known stellar and substellar members. If planetary mass objects have a different dynamical history, for example, because they are ejected from their planetary systems early on, they may be expected to populate a larger volume than the more massive cluster members. In other words, the mass function might be spatially varying once we reach the planetary domain. With the NIRCAM fields we can directly test this hypothesis.

2. In the regions where WFSS and NIRCAM fields overlap we will acquire spectra and multi-filter photometry for substellar and planetary mass objects. This is an excellent opportunity to calibrate colour criteria that can be used to distinguish young ultracool objects from background stars and embedded young stars. Finding efficient selection criteria for the lowest mass free-floating objects prior to spectroscopy is a key issue in surveys of this type, and so far we simply do not have very young template spectra for objects in this mass domain. Therefore, this unique dataset will help not

only this proposal, but also NIRCAM brown dwarf surveys conducted by other groups.

Our WFSS observations comprise 6 integrations -- 2 for the deep spectroscopy in 2 bands, plus 4 shallow imaging integrations, bracketing the spectroscopy. We have designed matching integrations for the NIRCAM parallels. Parallel to the WFSS spectroscopy, we will take NIRCAM images in the medium-band filters F140M and F182M in the SW module and F335M and F300M in the LW module. Comparisons with model spectra shows that the combination of these bands gives a good handle on effective temperature and gravity for ultracool objects. Parallel to the WFSS imaging, we will collect NIRCAM images in F115W in SW and F277W in LW. These two filters are selected to complement the medium-band filters to build up a spectral energy distribution from 1 to 3.5 microns. Matching the exposure times from WFSS yields s/n >10 for all 6 bands and >50 for all bands except F115W, for our target depth of H=22. We will fit the observed SEDs for all objects in the fields with model spectra for young, low-gravity objects, varying Teff, logg, and Av. These fits will be calibrated using the parameters estimated from the WFSS spectra for the overlapping regions. This allows us to construct a robust mass function for the NIRCAM fields which can be compared with the results obtained from the primary observations.

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous
(1)	NGC-1333	RA: 03 29 3.0000 (52.2625000d) Dec: +31 21 0.00 (31.35000d) Equinox: J2000		

Comments:
Category=Stellar Cluster
Description=[Young star clusters]

Observation

Proposal 1202, Observation 1: N1333_KH

Mon Jul 03 23:00:31 GMT 2023

Diagnostic Status: Warning

Observing Template: NIRISS Wide Field Slitless Spectroscopy

Comments: We only want to observe with one grism - our simulations show that overlap will not be a problem, increasing survey area is much more important than using two grisms per field.

Diagnostics

(N1333_KH (Obs 1)) Warning (Form): Use of only one of GR150R or GR150C may result in spectral overlap from multiple sources that can't be corrected. Users should address this issue in their proposal text.
(Visit 1:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.
(Visit 1:2) Warning (Form): Overheads are provisional until the Visit Planner has been run.
(Visit 1:3) Warning (Form): Overheads are provisional until the Visit Planner has been run.
(Visit 1:4) Warning (Form): Overheads are provisional until the Visit Planner has been run.
(Visit 1:5) Warning (Form): Overheads are provisional until the Visit Planner has been run.
(Visit 1:6) Warning (Form): Overheads are provisional until the Visit Planner has been run.
(Visit 1:7) Warning (Form): Overheads are provisional until the Visit Planner has been run.
(Visit 1:1) Informational (Form): Visit schedulable, but most scheduling windows are when JWST is pointed in direction of greatest micrometeoroid impact risk. This is likely due to scheduling special requirements.
(Visit 1:2) Informational (Form): Visit schedulable, but most scheduling windows are when JWST is pointed in direction of greatest micrometeoroid impact risk. This is likely due to scheduling special requirements.
(Visit 1:3) Informational (Form): Visit schedulable, but most scheduling windows are when JWST is pointed in direction of greatest micrometeoroid impact risk. This is likely due to scheduling special requirements.
(Visit 1:4) Informational (Form): Visit schedulable, but most scheduling windows are when JWST is pointed in direction of greatest micrometeoroid impact risk. This is likely due to scheduling special requirements.
(Visit 1:5) Informational (Form): Visit schedulable, but most scheduling windows are when JWST is pointed in direction of greatest micrometeoroid impact risk. This is likely due to scheduling special requirements.
(Visit 1:6) Informational (Form): Visit schedulable, but most scheduling windows are when JWST is pointed in direction of greatest micrometeoroid impact risk. This is likely due to scheduling special requirements.
(Visit 1:7) Informational (Form): Visit schedulable, but most scheduling windows are when JWST is pointed in direction of greatest micrometeoroid impact risk. This is likely due to scheduling special requirements.

Fixed Targets

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Comments:
Category=Stellar Cluster
Description=[Young star clusters]

Mosaic

Rows	Columns	Row Overlap %	Column Overlap %	Row shift (deg)	Column shift (deg)	Tile Order
3	3	0.0	0.0	-10.0	-10.0	ROW_MAJOR

Dithers

#	Image Dithers	Pattern Size
1	4	MEDIUM

Direct Image

#	Exposure Type	Filter	Grism	Readout Pattern	Groups/Int	Integrations/Exp	Two Extra Dithers	Total Dithers	Total Integrations	Total Exposure Time	ETC Wkbk.Calc ID
1	DIRECT	F200W		NISRAPID	2	5	NO	1	5	161.052	
2	DIRECT	F200W		NISRAPID	2	5	NO	1	5	161.052	
3	DIRECT	F150W		NISRAPID	2	5	NO	1	5	161.052	
4	DIRECT	F150W		NISRAPID	2	5	NO	1	5	161.052	

Proposal 1202 - Observation 1 - The NIRISS Survey for Young Brown Dwarfs and Rogue Planets

Spectral Elements

#	Exposure Type	Filter	Grism	Readout Pattern	Groups/Int	Integrations/Exp	Total Dithers	Total Integrations	Total Exposure Time	ETC Wkbk.Calc ID
1	GRISM	F200W	GR150C	NIS	18	1	4	4	3135.137	24908
2	GRISM	F150W	GR150C	NIS	18	1	4	4	3135.137	24908

Special Requirements

Group Visits within 53.0 Days
Aperture PA Range 244.430014 to 254.430014 Degrees (V3 243.86874683 to 253.86874683)
Visits Same PA
No Parallel Attachments