OBSERVING REQUEST
University of Arizona Observatories

Year: 2017 **Term:** Jul–Dec **Proposal type:** short-term⋆

NIR Imaging of the JWST North Ecliptic Pole early-science GTO program.

P.I.: Christopher Willmer (SO; *cnaw@as.arizona.edu*; 520-626-0805)

CoI(s): Rolf Jansen (ASU), Rogier Windhorst (ASU), Marcia Rieke (SO), Seth Cohen (ASU), Brenda Frye (SO), Teresa Ashcraft⋆ (ASU), Bhavin Joshi⋆ (ASU)

Abstract of Scientific Justification

We are requesting 1.5 nights with MMT/MMIRS to complete the Y, J, H and K Near-Infrared imaging of the JWST–North Ecliptic Pole field. These observations combined with LBT/LBC $U_{spec}griz$ data will be used to (1) identify sources such as brown dwarf candidates, and outer Solar System bodies whose emission peaks at much redder wavelengths than covered by the LBC; (2) increase the temporal baseline to identify variable and high-proper motion objects; (3) improve the spectral classification of stars thanks to the larger wavelength coverage; (4) improve the separation between stars and galaxies and (5) improve the calculation of photometric redshifts for galaxies in the field. The combined visible and NIR observations will be essential to provide an independent cross-check for the astrometric and photometric calibration of the JWST data. The photometric redshifts will allow identifying large-scale structures and potential groups and clusters that could serve as lensing sources for high redshift background galaxies. This region of the sky is located $\sim$ 3.8°from the Ecliptic Pole and in the continuous viewing zone of JWST. This is the **only** region where JWST can observe a clean extragalactic deep survey field (free of bright foreground stars and with low A_V) all year round and at arbitrary orientation, which is critical for, e.g., high redshift SNe searches and monitoring.

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	MMT	f/5	MMIRS	*		1.5	bright	Aug-Sep	Aug-Oct	yes	yes

Scheduling constraints and unusable dates *(up to 4 lines)*: None

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	JWST–NEP Survey Field	17:23:01.46	+65:49:37.4	$\mathrm{m}_{AB}(Y, J, H, K) < 24$

Approval for Instrument Use from PI: see last page

Graduate students *(provide the following information if student is PI on the cover page or if this is a 2nd-year or Thesis program. Send confirmation email to TAC chair in place of signature.)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis
Teresa Ashcraft	Rogier Windhorst		no	no
Bhavin Joshi	Rogier Windhorst		no	no

Scientific Justification

The James Webb Space Telescope will be inserted in an Earth-Sun L2 orbit late 2018, and a few months later the Guaranteed Time Observations (GTO) and Guest Observer(GO) programs will begin execution. Because of the combination of Sun avoidance, shielding of the cryogenic telescope and the IR background, there are time constraints as to when certain positions on the sky can be observed. However, within about 5°of the Ecliptic poles, there is a Continuous Viewing Zone (CVZ) which will be accessible to JWST any time of the year at different roll angles.

As part of the JWST GTO time, co-I Windhorst and the Webb Medium Deep Field team will carry out a medium depth survey at the North Ecliptic Pole (NEP), which will use NIRCam imaging in 7 wide-band filters and parallel slitless grism spectroscopy with JWST/NIRISS. The high sensitivity of the JWST/NIRCam makes this an extremely efficient instrument to detect very faint objects in a relatively large field of view ($2 \times 2.2' \times 2.2'$). This sensitivity combined with a location on the sky that is accessible any time of the year, make the NEP survey an ideal field to carry out time-domain observations, such as of very high-z SNe, where the time-dilation can spread the variability over several years.

At the start of JWST's science operations, the on-orbit characterization of the geometric distortion of the cameras may not be in place yet. This issue hampered the alignment of HST/WFC3 ERS images with existing HST/ACS images for over 4 years after launch (Kozhurina-Platais et al. 2013, WFC-ISR 2013-14; Kozhurina-Platais 2014 WFC-ISR 2014-12). The lesson learned is that ground-based images of the intended target region must be acquired to a sufficient depth ($m_{AB} <$ 25.7 mag) that the numerous faint K, M stars in our own Galaxy, sampled by different NIRCam detectors and NIRISS for the different orientations, can serve as an astrometric reference for both instruments, while the ground-based imagery can be accurately tied to an existing all-sky WCS (e.g., 2MASS, WISE, GAIA). At the same time, the high sensitivity of NIRCam also means that latent charge due to persistence after the observation of bright sources can be a source of contamination and the ideal field for the JWST-NEP survey needs to be devoid of any bright (K < 15) stars.

In order to identify the optimal location for the JWST-NEP survey, Co-I Jansen examined the distribution of WISE 3.4 μm and 4.5 μm objects close to the NEP to select regions with a low density of bright sources. The most promising region was observed by Co-I Jansen over a half-night in 2016-A with the LBT/LBC in the U_{spec}, g, r, and z bands. The 2016-A observations allowed selecting a $\sim 14'$diameter field (outer dashed grey circle in Fig.1) that reaches down to the required flux level, contains no bright stars, has enough faint stars for astrometric calibration and is suitable for deep and wide-field extragalactic surveys. This area also overlaps a region covered by the VLA in 3, 8 and 12 Ghz.

We are requesting 1.5 nights to complete the near-infrared (NIR) photometry in the Y, J, H and K bands for the JWST-NEP with MMIRS on the MMT. These observations will complement NIR data to be acquired in 2017-A, and will ensure uniform coverage in the NIR for this field. The combined NIR data will add a new time-step to the temporal baseline that will be used to identify variable and high-proper motion objects. The NIR photometry will enable the detection of very cold sources such as scattered outer Solar System bodies (KBOs, Oort Cloud Objects) and brown-dwarf candidates (e.g., Finkelstein et al. 2015, ApJ 813, 78), whose emission peaks at much redder wavelengths than attained by the LBC. The NIR data combined with the $U_{spec}griz$ observations by co-Is Jansen and Ashcraft will be essential to identify high confidence stellar sources (e.g., Hejazi et al. 2015, AJ, 149, 140), and critical to characterize the astrometric calibration of JWST images. The larger wavelength coverage will also enable an improved calculation of photometric redshifts, and will allow identifying potential large-scale structures, high-density regions that can serve as good lensing candidates, magnifying background galaxies at much higher redshifts.

Because of the wavelength overlap between the MMIRS NIR bands with the NIRCam short-wavelength filters, an efficient cross-matching between sources can be made, providing an independent initial photometric calibration of the NIRCam data. The MMIRS observations will also add accurate Y,J,H,K photometry for sources in the deep JWST images (m_{AB} <16), with with count rates that place them in the non-linear NIRCam regime, thereby expanding the dynamic range of the near-IR survey.

The planned survey at the NEP will combine NIRCam imaging with NIRISS slitless spectroscopy taken in parallel, and the NIRCam observations will have over 90% overlap with the NIRISS footprint. The observations we are proposing will cover a region large enough to include the footprint of both instruments for any orientation (outer circle in Figure 1). The MMIRS observations will complete the first (ground-based) time-domain baselines for IR objects to M_{AB}<25 mag, on which JWST will then build in the decade starting with 2019, and increasing the depth to m_{AB}< 29 mag.

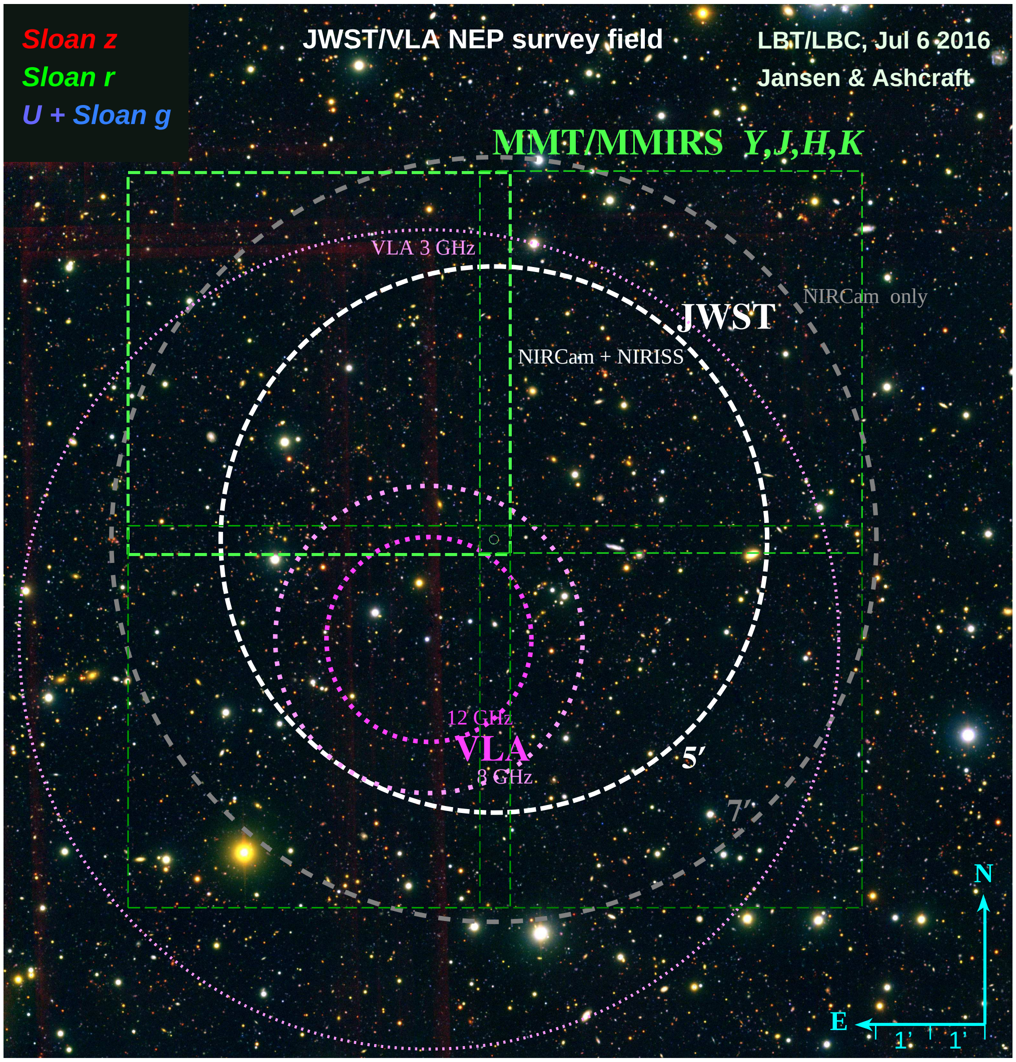

Figure 1: Color image of the NEP field from combined data taken in 2016-A by Co-Is Jansen and Ashcraft. The footprint of a single MMIRS field is outlined by the green dashed box. The white dashed circle contains the region where both NIRCam imaging and NIRISS parallels will be taken, while the grey circle shows the boundary that will only have NIRCam imaging during the GTO cycle. The magenta circles represent the areas with VLA coverage in 3 Ghz (outer), 8 Ghz and 12 Ghz (inner); these are centered on the position of the AGN and radio source NVSS J172314+654746 which serves as phase calibrator for the VLA observations. Almost the entire JWST/NIRCam survey area is efficiently covered by a 2 $\times$2 pattern of MMIRS exposures.

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science.* ***(up to one page)***

We are requesting 1.5 nights in 2017 B with MMT/MMIRS to complete the NIR imaging in the JWST/NEP field. The complete survey will cover the selected 14′ diameter field in the NEP with a mosaic of four 6.9′× 6.9′ MMIRS pointings (see Figure 1). We plan to obtain photometry down to m_{AB} = 24 in the the Y, J, H and K filters. This limit translates to Vega magnitudes of (Y=23.4, J=23.1, H=22.6, K=22.1), and requires exposure times per filter per field of (3370, 3493, 5451, 8053) seconds for a 5 σ detection of a point source assuming the default seeing of 0.75″ FWHM and sky counts of the MMIRS Exposure Time Calculator. Although these limits are brighter than the optical observations with LBT/LBC ($m_{AB} \lesssim$ 25.7 per filter), with the exception of blue stars, this should enable detecting the majority of the visible sources and uncover extremely cool galactic and very high-redshift extragalactic sources.

According to the MMIRS instrument manual (http://hopper.si.edu/wiki/mmti/MMTI/MMIRS/ObsManual, Table1) the readout time for a single frame is 1.475 seconds and the recommendation in Section 4.11 of the manual is that the maximum exposure times per dither ("exposure") should be at most 30 seconds for H and K, which translates into 20 frames of 1.475 seconds. For Y and J and the longest exposures should be of the order 200 seconds, but in this case using the "Logain/ramp_4.5s" readout mode. This translates into 44 frames of 4.5 seconds. In both cases, the observations will follow a random dither pattern. To estimate the overheads (which can be from 7 to 17 seconds according to Table 1 of the instrument manual) we adopt the pessimistic value of 17 seconds. Table 1 below summarizes the exposure time required to attain the limiting magnitude, the number of frames per exposure, the number of exposures, the estimated overheads and the total time per MMIRS footprint. The total time required to image a single pointing including overheads is 28,748 seconds ($\sim$ 8 hours). To complete the mosaic of four pointings a total of about 32 hours or just over 4 nights are needed. The 1.5 nights added to the 3 nights awarded 2017A will allow us to complete this survey. Because this proposal targets a single field, it can be completed efficiently under the queue mode adopted for MMIRS observations on the MMT.

Table 1: Breakdown of exposure time and overheads per MMIRS footprint

band	mag$_{lim}$ (vega)	on sky sec	No. frames	No. exposures	overhead sec	total time sec
Y	23.4	3370	44	17	289	3659
J	23.1	3493	44	18	306	3799
H	22.6	5451	20	185	3145	8596
K	22.1	8053	20	273	4641	12694

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

This is the fourth request for UAO time by the joint ASU/UofA team to target this region of the sky. A half-night was awarded in 2016 July to co-I Jansen on LBT to carry out imaging in the visible just before summer shutdown and data were taken under non-photometric conditions, but with good transparency and seeing ranging from $\sim 0.7''$ to $1.4\,''$. Data in U_{spec}, g, r and z were taken, and the result is shown in Figure 1. A preliminary analysis by co-Is Ashcraft and Jansen shows that the $m_{AB} > 25$ was attained in all bands but z; no data were taken in i. A second half-night was awarded in 2016-B to co-I Jansen to complete the the z and i band imaging, but no data were taken due to poor weather.

We were awarded 3 nights on MMT/MMIRS that will be taken during the months of June as part of the MMIRS queue. Because of the time-critical nature of these observations, we are applying for 1.5 nights to complete the survey, which requires a total observing time of about 32 hours (or ∼4 nights in June). In case we are weathered out during 2017A, these nights will allow us to acquire a subset of the data.

Co-I Jansen is also submitting a proposal for 2017-B to complete the LBT/LBC photometry for this region of the sky in the visible bands.

The observations we are proposing will complete the first epoch of deep ground-based imaging of the JWST/NEP, which will be followed up by at least 3 GTO teams with JWST during Cycle 1. The combined LBT and MMT data will provide the first temporal baseline for variability studies, and identification of potentially interesting objects. These data will have an important legacy value once JWST data become available, enabling follow-up studies using UAO and other ground and space-based facilities. The plan of the team is to release the reduced data of the complete survey from both ground-based telescopes to the community on a short time-scale as possible to allow other researchers prepare observations in this area of the sky both from the ground and from space.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). (**up to one page**)*

$\star$ PI Willmer was awarded 3 nights for 2017A for this project which will take place in May/June 2017, after the proposal deadline.

PI Willmer was awarded 3 nights in 2014-A to identify the counterparts of low redshift C IV absorbers detected on HST/COS spectra. All data were taken and reduced. The results so far indicate that the detection of C IV absorbers is affected by the type of environment in which objects are located.

PI Willmer was awarded 1.5 nights of MMT+Hectospec in 2016-A to identify the counterparts of QSO absorbers along three lines of sight that intercept 5 clusters of galaxies. The data have been reduced and are currently being used to compare the properties of circumgalactic gas of galaxies located in clusters with galaxies in the less dense field and groups of galaxies. The data are being used to characterize the effect of the intra-cluster medium on the evolution of galaxies as measured from their circum-galactic medium.

$\star$ co-I Jansen was awarded two half-nights – one in 2016-A and another in 2016-B – to carry out optical imaging in the U_{spec}, g, r, i and z bands in this field. The 2016-A data have already been reduced and the expected depth was attained in the U_{spec}, g and r bands (see Figure 1). The data taken in z are shallower than required and no i data were obtained. No data in 2016-B were taken.

Other Information *Provide any additional program-related information including, for example, relation of current program to externally funded research, to the development of expanded capabilities for UA telescopes, or to individual timescales (e.g. PI is finishing postdoc appointment and this request would complete program). (**up to one page**)*

| View as HTML

Subject: Re: using MMIRS on MMT for 2017B
From: "McLeod, Brian" <bmcleod@cfa.harvard.edu>
Date: Wed, March 29, 2017 09:27
To: "Christopher Willmer" <cnaw@as.arizona.edu>
Priority: Normal

```
Yes, please proceed.

On Wed, Mar 29, 2017 at 12:19 PM, Christopher Willmer <cnaw@as.arizona.edu>
wrote:

> Hi Brian,
>
> I would like to put in a proposal to complete the photometric survey of a
> 10 by 10 square arc min region in the North Ecliptic Pole, for which I was
> awarded 3 nights-worth of MMIRS time in 2017-A. I am asking for an
> additional 1.5 nights. Do I have your permission to use the instrument ?
> I am attaching the proposal so you know what we are up to...
>
> Thanks !
>
> Christopher
>
>
> --
> Christopher Willmer
> Steward Observatory, University of Arizona
> 933 North Cherry Avenue, Tucson AZ, 85721, USA
> (520) 626-0805
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Attachments

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