GEMINI OBSERVATORY

observing time request summary

Semester: 2015A **Observing Mode:** Fast Turnaround **Gemini Reference:**

Instruments: NIRI

Time Awarded: NaN **Thesis:** No

Band 3 Acceptable: No

Title: **AGB Star Dust Production at Extremely Low Metallicity**

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Reviewer: M. L. Boyer

Partner Submission Details *(multiple entries for joint proposals)*

		PI Request		NTAC Recommendation			
Partner	**Lead**	**Time**	**Min**	**Reference**	**Time**	**Min**	**Rank**
	Total Time	*3.3 hr*	*3.3 hr*		*0.0 hr*	*0.0 hr*	

Abstract

We propose imaging of Sextans A in the near-infrared with NIRI on Gemini North. This galaxy is very metal-poor, and it is unclear how this low metallicity affects dust production by Asymptotic Giant Branch (AGB) stars. More than 20 dusty AGB candidates have been recently identified in Sextans A with Spitzer, and data in the H and K_s bands is crucial for (1) eliminating interlopers, (2) estimating the dust-production rates, and (3) measuring the fundamental stellar parameters. These observations will confirm whether these metal-poor stars are capable of producing dust with the same efficiency seen in the Magellanic Clouds at higher metallicity. If so, they may be significant contributors to the large dust reservoirs seen in high redshift quasars. Obtaining these observations now is critical since we will choose targets among the stars observed here for follow-up infrared spectroscopy with the James Webb Space Telescope to investigate AGB dust properties at low metallicity. This is a pilot program to test this strategy for JWST target selection among other nearby galaxies with variable AGB candidates. For these, observations during Semesters 2015B and 2016A/B will allow for simultaneity with new Spitzer observations.

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TAC Category / Keywords

Extragalactic / AGB stars, Stellar populations, Dwarf galaxies, Dust, Carbon stars

Scheduling Constraints

Observation Details (Band 1/2)

Observation	RA	Dec	Brightness	Total Time *(including overheads)*
SexA	10:10:57.581	-04:42:47.535		3.3 hr
Conditions: CC 70%/Cirrus, IQ 70%/Good, SB Any/Bright, WV Any **Resources:** NIRI None f/6 (0.12"/pix, 120" FoV) H (1.65 um)+K(short) (2.15 um)				

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

Summary: NIRI images will enable accurate measurements of the dust-production rates (DPRs) of Asymptotic Giant Branch (AGB) stars in Sextans A to assess the efficiency of dust production at very low metallicity. This is a pilot program for similar observations in additional galaxies.

The origin of the large dust reservoirs in high-redshift quasars is a matter of debate (e.g., Bertoldi et al. 2003, Robson et al. 2004, Beelen et al. 2006). In the nearby Universe, AGB stars may be the dominant stellar dust producers, contributing significantly to the total dust budget of the Magellanic Clouds (MCs; Matsuura et al. 2009, Boyer et al. 2012, Zhukovska & Henning 2013, Schneider et al. 2014), but it is unclear how the low metallicity at high redshift affects AGB dust production. Some models suggest that AGB stars produce significantly less dust as metallicity decreases (e.g., Mattsson et al. 2014). Currently, only 5 dusty AGB stars more metal-poor than those in the MCs ([Fe/H] < -1, $\gtrsim 1$ $M_\odot$) have been carefully studied (Sloan et al. 2012), and these may show a small, though not conclusive, decrease in dust production at low metallicity.

The survey of Dust in Nearby Galaxies with *Spitzer* (DUSTiNGS; Boyer et al. 2015) imaged 50 nearby galaxies to search for dust-producing AGB stars and identified hundreds of candidates via their variability in the mid-infrared, but very little can be inferred from only their 3.6 and 4.5 μm fluxes. *We propose to image a subset of these candidates with NIRI in H and $K_{\rm S}$ to enable modeling of the full spectral energy distribution (SED) for estimating the DPRs and fundamental properties of the stars. Comparisons to similar, but more metal-rich, stars in the MCs will reveal what effect, if any, that metallicity has on AGB dust production.*

From the DUSTiNGS sample, we select Sextans A for NIRI imaging for the following reasons: (1) it harbors a large dust-producing AGB population, (2) at [Fe/H] $= -1.85$, its AGB stars are among the most metal-poor known, and (3) complimentary $UBVRI$ optical data are available to complete the SEDs (Massey et al. 2007). With one NIRI pointing, we will obtain the full SEDs of $\sim$20 metal-poor dusty AGB candidates. *This pilot program will assess this strategy for other DUSTiNGS galaxies.*

With the NIRI data, we will:

– **Determine the chemistry of each star (oxygen- or carbon-rich).** Stellar evolution models for metal-poor AGB stars show that while O- and C-rich AGB stars are indistinguishable by their *Spitzer* [3.6] – [4.5] color, the near-infrared colors can efficiently separate C- and O-rich AGB stars (Fig. 1; e.g., Cioni et al. 2006).

– **Estimate the stellar fundamental properties.** By sampling at and blueward of the SED peaks, we can measure the bolometric luminosities and effective temperatures, allowing us to determine the conditions required to produce and drive a stellar wind at these metallicities (Fig. 1). Comparisons to stellar evolution models will provide estimates of the stellar masses.

– **Measure the DPRs** via radiative transfer modeling of the SEDs, allowing us to estimate the total stellar dust input into these galaxies and facilitating a direct comparison to similar stars in the MCs. The "extreme" AGB stars are expected to dominate the dust input (Figs. 1,2).

– **Eliminate contamination.** Stars not detected as variable in *Spitzer* cannot be differentiated from background galaxies and foreground dwarf stars at present. In addition, variable background active galactic nuclei can masquerade as dusty AGB variables in *Spitzer* colors. These interlopers can be eliminated via the shape of their SEDs.

– **Select targets for spectroscopy with the James Webb Space Telescope** to investigate differences in the dust composition between these and more metal-rich stars.

References:

Beelen, A., et al. 2006, ApJ, 642, 694
Bertoldi, F., et al. 2003, A&A, 406, L55
Boyer, M. L., et al. 2012, ApJ, 748, 40
—. 2015, ApJS, 216, 10
Cioni, M.-R., et al. 2006, A&A, 448, 77
Massey, P., et al. 2007, AJ, 133, 2393
Matsuura, M., et al. 2009, MNRAS, 396, 918
Mattsson, L., et al. 2014, in preparation
Robson, I., et al. 2004, MNRAS, 351, L29
Schneider, R., et al. 2014, MNRAS, 442, 1440
Sloan, G. C., et al. 2012, ApJ, 752, 140
Zhukovska, S. & Henning, T. 2013, A&A, 555, A99

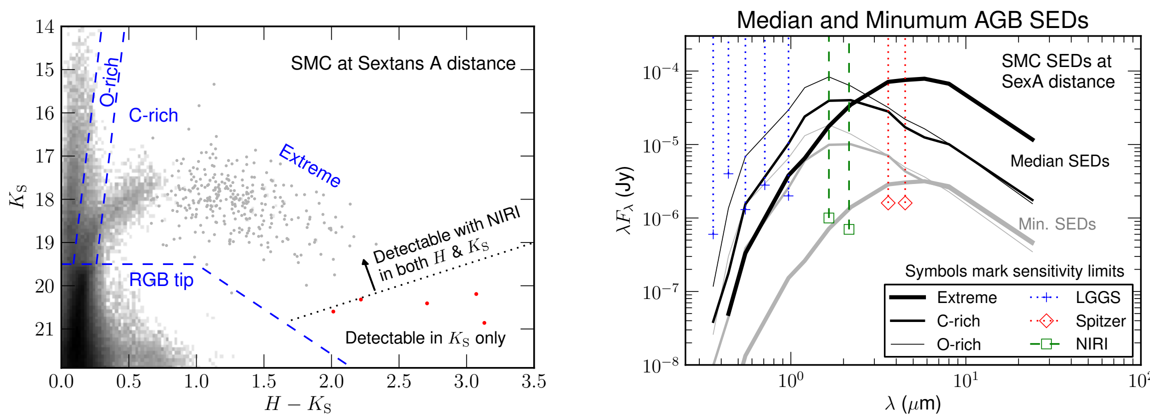

Figure 1: *Left:* H vs. K_S color-magnitude diagram for the SMC, adjusted to the distance of Sextans A. The $H - K_S$ color can be used to distinguish O-rich and C-rich stars. "Extreme" stars are so dusty that they are optically obscured. *Right:* SEDs of SMC dusty AGB stars, adjusted to the distance of Sextans A. All stars here show some evidence of dust production (Boyer et al. 2012). Vertical lines mark the wavelengths we have in the optical (blue, LGGS), IR (red, *Spitzer*), and the proposed NIRI wavelengths (green). The NIRI H and K_S fluxes are essential for sampling the SED peaks for the less-dusty stars and to sample the blue tail of the SED for the dustiest stars. Without NIRI wavelengths, we cannot derive robust DPRs and stellar parameters.

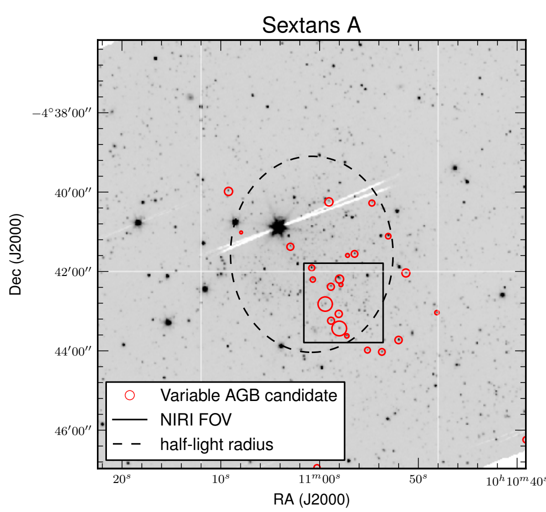

Figure 2: 3.6 μm map of Sextans A with variable AGB candidates circled (identified via 2-epoch imaging). Larger circles signify more infrared excess. Based on the estimated size of the total AGB population, we expect to capture with NIRI at least twice the number of red sources shown here.

Experimental Design *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. (Limit text to one page)*

We propose to image one field in Sextans A to obtain H and K_S magnitudes for a large number of dust-producing AGB candidates at low metallicity. The targets are selected from the DUSTiNGS program, which used 2-epoch *Spitzer* imaging to identify candidate dust-producing AGB stars via their infrared (IR) variability. These dusty AGB candidates (circled in red in Fig. 2) are high-likelihood dust-producing AGB stars, but there may be some contamination from variable background active galactic nuclei. The shape of the SED will be used to eliminate these interlopers. Since each dusty "extreme" AGB star contributes significantly to the total dust budget (e.g., Boyer et al. 2012), their detection in the near-IR is crucial, and eliminating interlopers will have a dramatic effect on the estimated total dust input.

We have chosen the position of the field to achieve a balance between including the maximum number of dusty AGB candidates and the reddest variable sources identified with *Spitzer* (see Fig. 2). In total, the field includes 10 variable dusty AGB candidates, and we expect to detect at least twice this number, based on a comparison of the estimated size of the whole AGB population and the number of detected variable sources (Boyer et al. 2015). These additional sources were not identified as variable with *Spitzer* due to non-optimal separation between the epochs.

We will perform point-spread function photometry using DAOphot, with which the team has extensive experience. We will calibrate fluxes to 2MASS, which picks up the brightest stars, and also to the UKIRT Infrared Deep Sky Survey (UKIDSS), which goes to 18.3 mag in K. NIRI data will reach much fainter magnitudes (see Technical Description and Fig. 1), enabling the detection of the vast majority of the expected dust-producing AGB stars in Sextans A.

We select the H and K_S filters (1) to sample the SEDs at and blueward of their peaks (Fig. 1), (2) to facilitate direct comparison to 2MASS observations of AGB stars in the MCs, and (3) for separation of the C- and O-rich AGB stars. We choose the H filter instead of J to guarantee detection at a wavelength shorter than the SED peak for the dustiest "extreme" AGB stars. The J band would suffice for most AGB stars, but the dustiest sources will be too faint in J for detection with NIRI (based on MC AGB stars). *These extreme stars dominate the dust input, so it is crucial that we detect as many as possible with NIRI.* Since the less dusty stars are detected at optical wavelengths by Massey et al. (2007), the Wien side of their SEDs is already covered, so J is unnecessary.

Filling in the gap between the optical and IR data is crucial for 3 reasons. First, it will ensure that the correct source is matched at each wavelength. Without sampling the peak of the SED, it is difficult to know whether we are seeing the same star at optical and IR wavelengths or two different sources that lie along the same line of sight. Second, a red *Spitzer* color could indicate either a bright star with molecular absorption in the 3.6 μm band or a faint star with excess at 4.5 μm. Without knowing the peak flux, we therefore cannot estimate the stellar luminosities. Third, without sampling the peak of the SED, an AGB star can easily be mistaken for a background galaxy, since galaxy SEDs tend to rise steadily from optical to IR wavelengths.

Proprietary Period: 18 months

Use of Other Facilities or Resources *(1) Describe how the proposed observations complement data from non-Gemini facilities, including those available through NOAO. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program. (2) Do you currently have a grant that would provide resources to support the data processing, analysis, and publication of the observations proposed here?*

We will use these data together with Spitzer 3.6/4.5 μm imaging (Boyer et al. 2015) and $UBVRI$ imaging from the Lowell Observatory Local Group Galaxies Survey (LGGS; Massey et al. 2007) to construct the stellar SEDs (Fig. 1). Both the *Spitzer* and optical surveys cover the full areal footprint of the proposed NIRI observations (Fig. 2). With these data, we will confirm likely member AGB stars and measure their DPRs. In addition, the PI has been awarded cycle 11 *Spitzer* time to obtain 6 new epochs of IR imaging for determining the stellar pulsation periods and amplitudes. The first epochs of the new *Spitzer* data coincide with the NIRI Fast Turn Around time available in March/April 2015. The near-simultaneous imaging at NIR and IR wavelengths and using the period/amplitude information obtained with *Spitzer* will mitigate uncertainties in the SED fitting due to stellar variability.

Obtaining this data in Semester 2015A is of paramount importance. A central aim of the DUSTiNGS program is to obtain mid-IR spectroscopy with JWST to characterize AGB dust composition at extremely low metallicities for the first time. The JWST spectral analysis will clear up remaining questions about dust production and dust properties at low metallicity, and the NIRI observations are an essential step for follow up preparation. These data will act as a pilot for using near-IR imaging to assist in JWST target selection in other DUSTiNGS galaxies. Having Sextans A NIR images observed and analyzed now will assist in designing similar programs for other DUSTiNGS galaxies during Semesters 2015B and 2016A/B, when they can be coincident with additional Spitzer cycle 11 observations. With this timeframe, we will have all observations finished prior to the preparation of JWST programs, which begins in 2016–2017.

The PI is supported by the NASA JWST postdoctoral fellowship through 2015, which has sufficient resources necessary to support data processing and analysis.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the last 2 years for regular proposals, and at any time in the past for survey proposals (including participation of the PI as a Co-I on previous NOAO surveys), together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. Please include original proposal semesters and ID numbers when available.*

The PI has had no NOAO programs in the last 2 years.

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the exposure times, and the constraints requested (seeing, cloud cover, sky brightness, and, if appropriate, water vapor). If applying for instruments on both Gemini North and South, state the time request for each site. If a Band 3 allocation is acceptable, give the Band 3 time requested from each partner.*

To detect dusty AGB stars at the distance of Sextans A in the near-IR with sufficient signal-to-noise (S/N), we require an 8-m class telescope. With NIRI on Gemini North, we can detect a large fraction of the dust-producing stars in each galaxy in essential bandpasses.

Instrument Setup: We will use the f/6 camera because the large field of view ($120'' \times 120''$) is necessary to maximize the number of AGB stars observed (Fig. 2). One field ensures coverage of *at least* 10 dust-producing AGB candidates. We choose the H (1.65 μm) and K_S (2.15 μm) filters (see Experimental Design section).

Required on-source integration: 1.5 hour total integration per filter yields S/N $\gtrsim$ 4 at $H = 22.3$ mag and $K_S = 22.6$ mag under minimally restrictive observing conditions (see attached estimates from the NIRI ITC). This guarantees detection of all dusty stars in K_S and detection of the vast majority of these stars in H (Fig. 1).

Sky background: We will include $10''$ dithers (180 frames, 30 s integrations) for estimation of the sky background. We have placed the field so that some of the frame falls off the crowded inner region of the galaxy.

Saturation: Source/sky saturation will not be an issue with 30 s integrations. The chosen field avoids bright foreground stars.

Overheads: One 6 min acquisition every 1.5 hours yields 12 minutes total for acquisition. Image overheads are 2.78 s + (0.7s $\times N_{\rm frames}$) = 2.15 min total for each field/filter, or a total of 2.15 min $\times$ 2 filters $\times$ 1 field = 4.3 min. To allow for dark current instability, we will reject the first frame from each series and add an extra frame to make up the difference for a total extra 1 min overhead.

Total Requested Time: We request 3 hours on source + 12 min acquisition + 4.3 min image overheads + 1 min for an extra frame = **3.3 hr total**.

Required observing constraints: To achieve the necessary S/N, we require 70%-ile image quality and 70%-ile cloud cover. Any water vapor and sky brightness conditions are acceptable. See attached results from the NIRI ITC.

Seeing: Based on the *Spitzer* data, crowding will not be a problem with typical seeing. Optical and *Spitzer* beamsizes are near $1''$, so AO with ALTAIR is not necessary.

Guiding: We will guide with one of the peripheral wavefront sensors. There are several suitable guide stars ($R < 14$ mag)to choose from within $7'$of the center of the field, allowing for stable guiding without vignetting of the field.

Band 3 Plan *If applying for queue time and it is acceptable for the proposal to be scheduled in Band 3, describe the changes to be made to allow it to be successful in Band 3 (limit text to half a page). Band 3 observations are used to fill the queue when no Band 1 or 2 programs are available. Successful Band 3 programs generally use poorer than median observing conditions, have targets away from the most popular regions of the sky, do not require strict timing or other constraints, and do not require special instrument configurations.*

This program is not suitable for band 3.

Classical Backup Program *If applying for classically scheduled time, describe the program you will pursue should the weather be worse than the requested observing conditions (limit text to half a page).*

Justify Target Duplications *If your targets have been previously observed by Gemini using similar or identical setups to those proposed here, justify the duplication below. Duplicate observations can be identified through a search of the Gemini Science Archive.*

The GSA search revealed no duplicate observations

ITC Examples *Attach representative Gemini ITC output for each instrument requested.*

Gemini Integration Time Calculator
NIRI version 4.2

Click here for help with the results page.
software aperture diameter = 0.90 arcsec
fraction of source flux in aperture = 0.61
enclosed pixels = 47.59

derived image size (FWHM) for a point source = 0.76 arcsec.

Contributions to total noise (e-) in aperture (per exposure):
Source noise = 30.13
Background noise = 2181.13
Dark current noise = 18.89
Readout noise = 241.45

Total noise per exposure = 2194.74
Total signal per exposure = 908.17

Intermediate S/N for one exposure = 0.41

S/N for the whole observation = 3.92 (including sky subtraction)

Requested total integration time = 5400.00 secs, of which 5400.00 secs is on source.

Observation is background noise limited.

The peak pixel signal + background is 99995. This is 49% of the full well depth of 200000.

Input Parameters:
Instrument: NIRI

Source spatial profile, brightness, and spectral distribution:
The z = 0.0 point source is a 22.3 mag K0III star in the H band.

Instrument configuration:
Optical Components:
- Filter: H
- Fixed Optics
- Camera: f6
- Detector - 1024x1024-pixel ALADDIN InSb array
- Read Mode: medNoise
- Detector Bias: lowWell

Pixel Size: 0.116

Telescope configuration:

- silver mirror coating.
- side looking port.
- wavefront sensor: pwfs

Observing Conditions:

- Image Quality: 70.00%
- Sky Transparency (cloud cover): 70.00%
- Sky transparency (water vapour): 100.00%
- Sky background: 100.00%
- Airmass: 1.50

Frequency of occurrence of these conditions: 48.99%

Calculation and analysis methods:

- mode: imaging
- Calculation of S/N ratio with 180 exposures of 30.00 secs, and 100.00 % of them were on source.
- Analysis performed for aperture that gives 'optimum' S/N and a sky aperture that is 1.00 times the target aperture.

Gemini Integration Time Calculator
NIRI version 4.2

Click here for help with the results page.
software aperture diameter = 0.83 arcsec
fraction of source flux in aperture = 0.61
enclosed pixels = 40.21

derived image size (FWHM) for a point source = 0.70 arcsec.

Contributions to total noise (e-) in aperture (per exposure):
Source noise = 21.11
Background noise = 1045.57
Dark current noise = 17.36
Readout noise = 221.95

Total noise per exposure = 1069.21
Total signal per exposure = 445.76

Intermediate S/N for one exposure = 0.41

S/N for the whole observation = 3.95 (including sky subtraction)

Requested total integration time = 5400.00 secs, of which 5400.00 secs is on source.

Observation is background noise limited.

The peak pixel signal + background is 27207. This is 13% of the full well depth of 200000.

Input Parameters:
Instrument: NIRI

Source spatial profile, brightness, and spectral distribution:
The z = 0.0 point source is a 22.6 mag K0III star in the K band.

Instrument configuration:
Optical Components:
- Filter: Kshort
- Fixed Optics
- Camera: f6
- Detector - 1024x1024-pixel ALADDIN InSb array
- Read Mode: medNoise
- Detector Bias: lowWell

Pixel Size: 0.116

Telescope configuration:

- silver mirror coating.
- side looking port.
- wavefront sensor: pwfs

Observing Conditions:
- Image Quality: 70.00%
- Sky Transparency (cloud cover): 70.00%
- Sky transparency (water vapour): 100.00%
- Sky background: 100.00%
- Airmass: 1.50

Frequency of occurrence of these conditions: 48.99%

Calculation and analysis methods:
- mode: imaging
- Calculation of S/N ratio with 180 exposures of 30.00 secs, and 100.00 % of them were on source.
- Analysis performed for aperture that gives 'optimum' S/N and a sky aperture that is 1.00 times the target aperture.

NOAO/Gemini observing proposal LaTeX macros v1.1.