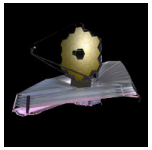

5298 - Catching a cat by the tail: Tracing Dust Dynamics in the Beta Pictoris Debris Disk in the Aftermath of Giant Collisions

Cycle: 3, Proposal Category: GO

INVESTIGATORS

Name	*Institution*
Dr. Marshall Perrin (PI)	**Space Telescope Science Institute**
Dr. Chris Stark (CoI)	NASA Goddard Space Flight Center
Dr. Christine Chen (CoI)	The Johns Hopkins University
Dr. Andras Gaspar (CoI)	University of Arizona
Julien Girard (CoI)	Space Telescope Science Institute
Dr. David A. Golimowski (CoI)	Space Telescope Science Institute
Dr. Dean C. Hines (CoI)	Space Telescope Science Institute
Dr. Kielan K. W. Hoch (CoI)	Space Telescope Science Institute
Jens Kammerer (CoI) (ESA Member)	European Southern Observatory - Germany
Dr. David R. Law (CoI)	Space Telescope Science Institute
Dr. Kellen Dunn Lawson (CoI)	NASA Goddard Space Flight Center
Dr. Cicero Lu (CoI)	NOIRLab - Gemini North (HI)
Dr. Laurent Pueyo (CoI)	Space Telescope Science Institute
Isabel Rebollido (CoI) (ESA Member)	ESA-European Space Astronomy Centre
Dr. Emily Rickman (CoI) (ESA Member)	Space Telescope Science Institute - ESA - JWST
Dr. Aki Roberge (CoI)	NASA Goddard Space Flight Center
Prof. Sara Seager (CoI)	Massachusetts Institute of Technology
Dr. Greg Sloan (CoI)	Space Telescope Science Institute
Dr. Roeland P. van der Marel (CoI)	Space Telescope Science Institute
Dr. Kimberly Ward-Duong (CoI)	Smith College
Kadin Worthen (CoI)	Space Telescope Science Institute

Name	*Institution*
Dr. Marie Ygouf (CoI)	Jet Propulsion Laboratory

OBSERVATIONS

Folder	*Observation*	*Label*	*Observing Template*	*Science Target*
Observation Folder				
	1	beta Pic - MRS on cats tail + imager on backgr ound	MIRI Medium Resolution Spectroscopy	(3) BETA-PIC-disk-offset-cats-tail
	2	beta Pic - MRS on back ground + imager on tar get	MIRI Medium Resolution Spectroscopy	(2) BETA-PIC

ABSTRACT

JWST cycle 1 MIRI observations of the Beta Pictoris system yielded several complete surprises, in particular the discovery of a curved "tail" of material apparently arcing sharply away from the disk, and complex surrounding mid-IR nebulosity. These features may arise from streamers of debris from recent collisions. Along with dramatic changes in the inner disk's mid-IR spectrum over the last 19 years, these discoveries reinforce a picture of the Beta Pic system as the site of dust-producing massive collisions among large planetesimals, perhaps more frequently than expected. The most promising physical model to explain the cat's tail and related nebulosity requires these features to be composed of porous refractory organic-rich dust, to be sorted in size such that the smallest particles (being blown out most rapidly) are at the tip of the tail, and for the tail to be moving outwards at high speed. MIRI observations, in particular MRS spectroscopy of the tail region, can directly test all of these predictions, and thereby confirm or refute the proposed models. The newly-discovered and totally unexpected "tail" appears to offer a new window for understanding dust production and outflow within debris disks. MIRI is the only instrument capable of determining what the dust there is made of, whether it is indeed being blown out of the system, and testing the proposed models for the physical processes that formed it.

OBSERVING DESCRIPTION

SUMMARY:

We propose MIRI MRS imaging spectroscopy of Beta Pic to obtain the first mid-IR spectra of the newly-seen extended "cat's tail" feature to determine the physical properties of the dust in this feature, and thereby enable a direct test of proposed mechanisms for its formation.

During the required off-source MRS background observations, {we will efficiently also obtain an additional epoch of MIRI imaging of Beta Pic to test the predicted fast motion of the tail away from the star, 150-200 milliarcsecs per 2 years predicted if the tail is indeed outflowing debris from recent dust-producing events.

OBSERVATION DESIGN:

The observation plan follows standard MRS methods, using all three grating settings to obtain complete spectral coverage, and with 4-point dithers optimized for all wavelengths to improve spatial sampling.

Obs 1 observes the ``cat's tail" and adjacent main disk plane, using a two-position mosaic for sufficient spatial coverage across both disk component, with the "extended source" dither pattern. The MIRI imager will simultaneously obtain offset sky background images for use in calibrating the imager observations taken in Obs 2.

Obs 2 is an MRS offset sky background observation, plus simultaneous imaging on Beta Pic.
The "Primary channel = Imager" option is used to position B Pic in the MIRI imager, along with the "Background" optimized dither pattern that optimizes PSF sampling in the imager while obtaining the necessary sky backgrounds. A PA Range special requirement ensures that the observing geometry will offset the MRS FOV nearly perpendicular away from the disk, allowing a clean sky background. The specified PA range also ensures that diffraction spikes from the saturated stellar PSF will not fall onto the cat's tail region.

EXPOSURE TIMES:

ETC calculations used a model spectrum for refractory organics scaled to the observed surface brightness in F2300C at the midpoint of the tail, which is about 0.2 mJy/arcsec^2.These outer regions are ~100 times fainter than the inner disk, so it is not practical to achieve comparable S/N per spectral channel as the cycle 1 obs; instead we will bin to lower spectral resolution. Binning to R=300 will suffice for SNR >30 across MRS Channel 3 from 12 - 18 micron, but binning down to R=30 will be needed for Ch.4 with low sensitivity, and for wavelengths below 10 micron where we expect the dust SED to be steeply falling. We set the exposure time to achieve predicted SNR >10 at R=30 from 9 to 25.5 micron, which requires 1330 s per grating (and achieves SNR > 50 at R=300 from 13-18 micron). Ensuring SNR >10 down to >= 10 micron is especially important since the steep spectral slope in that region provides a very sensitive probe of dust compositions. The brightness along the tail varies within a factor of only ~8, so this depth will yield sufficient SNR across the full length of the tail. See ETC workbook 172452 calcs 5-13, and/or local ETC scripting calcs

Jupyter notebook available from Perrin.

For the imager, ETC calculations using the above dust model yield expected SNRs of 13, 600, and 80 in F770W, F1500W, and F2550W respectively. ETC workbook 172452 calcs 14-16. The selected settings avoid saturation on the much brighter inner end of the cats tail and inner main disk as well. ETC workbook 172452 calcs 29-31. The inner ~0.7 arcsec will saturate hard on the star but this is acceptable. Given the superb stability of JWST PSFs for MIRI, the high brightness of the disk relative to the star, and the >6 arcsec separation of the cats tail, archival PSFs and/or WebbPSF models will suffice for simple PSF subtractions to remove systematics from the outer wings of the stellar PSF.

POSITION ANGLES:
We set position angle requirements in order to (a) ensure the move to the offset MRS background observation moves the MRS away nearly orthogonally to the disk midplane, (b) ensure the obs 1 mosaic field coverage is as desired over the cat's tail and adjacent main disk, and (c) a secondary goal, for the imager observations avoiding the diffraction spikes from the central star pointing right onto the area of interest.

In particular we want at least some small rotation of the MRS and MIRIM aperture PA relative to the disk, to ensure the diffraction in the +V3 direction from segment edges, and e for the imager the cruciform artifact in F770W at a closely similar angle, are not right on top of the main disk plane. Simulations using WebbPSF indicate that this can be accomplished by rotation of MIRI apertures by -16 +- 8 degrees relative to the disk midplane at PA=29.1 degrees.

==========
**Note re APT error, as reported in JDox. **

As of October 2023, there is a bug in APT version 2023.5.2: when the Primary Channel = Imager option is chosen, the tool reports a spurious error that says, "This target requires similar background exposures that are linked in a non-interruptible sequence". After confirming that science and background observations are otherwise similar, proposals may be submitted with this error.

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous
(2)	BETA-PIC	RA: 05 47 17.0877 (86.8211988d) Dec: -51 03 59.44 (-51.06651d) Equinox: J2000	Proper Motion RA: 4.65 mas/yr Proper Motion Dec: 83.10 mas/yr Parallax: 0.05144" Epoch of Position: 2000	
Comments: Beta Pictoris, set up as a background target to be used for offset background observation with MRS, while the imager points on target to Beta Pic. *This is tagged as "Calibration" target which is true for the MRS sky data, but is used as a science target in the imager.* *Follows methods described in JDox for achieving imager on source during MRS backgrounds, from this page:* *https://jwst-docs.stsci.edu/jwst-mid-infrared-instrument/miri-operations/miri-dithering/miri-mrs-dedicated-sky-observations* *Proper motions listed here are from DR2, but agree within <1 mas/year to DR3, and to the USNO Bright Star Catalog.* *Category=Calibration* *Description=[Telescope/sky background]* *Extended=YES*				
(3)	BETA-PIC-disk-offset-cats-tail	RA: 05 47 16.5000 (86.8187500d) Dec: -51 04 4.90 (-51.06803d) Equinox: J2000	Proper Motion RA: 4.65 mas/yr Proper Motion Dec: 83.10 mas/yr Parallax: 0.05144" Epoch of Position: 2022.9	
Comments: Offset coordinates toward the location of the "Cat's Tail" as measured in the 2022 December cycle 1 observations. *The specific coordinates were chosen to position the Obs 2 MRS mosaic spatial coverage across the cats's tail and adjacent main disk midplane.* *Proper motions listed here, for Beta Pic, are from DR2, but agree within <1 mas/year to DR3, and to the USNO Bright Star Catalog.* *The epoch of this target is *intentionally* set to 2022.9, the epoch of the cycle 1 MIRI coron observations in program 1411, e.g. visit 1411:3:1 and adjacent.* *Category=Star* *Description=[Debris disks]* *Extended=YES*				

Observation

Proposal 5298, Observation 1: beta Pic - MRS on cats tail + imager on background Thu Nov 14 14:00:10 GMT 2024

Diagnostic Status: Warning

Observing Template: MIRI Medium Resolution Spectroscopy

Background Observations:[beta Pic - MRS on background + imager on target (Obs 2)]

Diagnostics

(beta Pic - MRS on cats tail + imager on background (Obs 1)) Warning (Form): Imager Filter overlap.

(beta Pic - MRS on cats tail + imager on background (Obs 1)) Warning (Form): Imager Filter overlap.

(Visit 1:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.

(beta Pic - MRS on cats tail + imager on background (Obs 1)) Informational (Form): The Visit Planner and Spike may produce different schedulability results.

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous
(3)	BETA-PIC-disk-offset-cats-tail	RA: 05 47 16.5000 (86.8187500d) Dec: -51 04 4.90 (-51.06803d) Equinox: J2000	Proper Motion RA: 4.65 mas/yr Proper Motion Dec: 83.10 mas/yr Parallax: 0.05144" Epoch of Position: 2022.9	

Comments: Offset coordinates toward the location of the "Cat's Tail" as measured in the 2022 December cycle 1 observations.
The specific coordinates were chosen to position the Obs 2 MRS mosaic spatial coverage across the cats's tail and adjacent main disk midplane.

Proper motions listed here, for Beta Pic, are from DR2, but agree within <1 mas/year to DR3, and to the USNO Bright Star Catalog.

*The epoch of this target is *intentionally* set to 2022.9, the epoch of the cycle 1 MIRI coron observations in program 1411, e.g. visit 1411:3:1 and adjacent.*
Category=Star
Description=[Debris disks]
Extended=YES

Acquisition

#	Target
1	NONE

Template

AcqFilter	Primary Channel	Simultaneous Imaging	Imager Subarray	Grating Wheel Direction
FND	All MRS	YES	FULL	Allow Auto Reorder

Mosaic

Rows	Columns	Row Overlap %	Column Overlap %	Row shift (deg)	Column shift (deg)	Tile Order
1	2	10.0	10.0	0.0	0.0	DEFAULT

Dithers

#	Dither Type	Optimized For	Direction
1	4-Point	EXTENDED SOURCE	NEGATIVE

Spectral Elements

#	Wavelength Range	Detector	Filter	Readout Pattern	Groups/Int	Integrations/Exp	Exposures/Dith	Dither	Total Dithers	Total Integrations	Total Exposure Time	ETC Wkbk.Calc ID
1		IMAGER	F2550W	FASTR1	8	13	1	Dither 1	4	52	1287.619	
1	LONG(C)	MRSLONG		SLOWR1	15	1	1	Dither 1	4	4	1433.395	
1	LONG(C)	MRSSHORT		SLOWR1	15	1	1	Dither 1	4	4	1433.395	
2		IMAGER	F1500W	FASTR1	9	12	1	Dither 1	4	48	1320.919	
2	MEDIUM(B)	MRSLONG		SLOWR1	15	1	1	Dither 1	4	4	1433.395	
2	MEDIUM(B)	MRSSHORT		SLOWR1	15	1	1	Dither 1	4	4	1433.395	
3		IMAGER	F770W	FASTR1	12	9	1	Dither 1	4	36	1287.619	
3	SHORT(A)	MRSLONG		SLOWR1	15	1	1	Dither 1	4	4	1433.395	
3	SHORT(A)	MRSSHORT		SLOWR1	15	1	1	Dither 1	4	4	1433.395	

Special Requirements

Aperture PA Range 0 to 16 Degrees (V3 0.0 to 16.0)

Sequence Observations 1, 2, Non-interruptible
Same V3 PA 1, 2 (Aperture PAs differ)

Observation

Proposal 5298, Observation 2: beta Pic - MRS on background + imager on target Thu Nov 14 14:00:10 GMT 2024

Diagnostic Status: Warning

Observing Template: MIRI Medium Resolution Spectroscopy

Background Observation For: [beta Pic - MRS on cats tail + imager on background (Obs 1)]

Diagnostics

(Visit 2:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.

(beta Pic - MRS on background + imager on target (Obs 2)) Informational (Form): The Visit Planner and Spike may produce different schedulability results.

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous
(2)	BETA-PIC	RA: 05 47 17.0877 (86.8211988d)	Proper Motion RA: 4.65 mas/yr	
		Dec: -51 03 59.44 (-51.06651d)	Proper Motion Dec: 83.10 mas/yr	
		Equinox: J2000	Parallax: 0.05144"	
			Epoch of Position: 2000	

Comments: Beta Pictoris, set up as a background target to be used for offset background observation with MRS, while the imager points on target to Beta Pic.

This is tagged as "Calibration" target which is true for the MRS sky data, but is used as a science target in the imager.

Follows methods described in JDox for achieving imager on source during MRS backgrounds, from this page:
https://jwst-docs.stsci.edu/jwst-mid-infrared-instrument/miri-operations/miri-dithering/miri-mrs-dedicated-sky-observations

Proper motions listed here are from DR2, but agree within <1 mas/year to DR3, and to the USNO Bright Star Catalog.
Category=Calibration
Description=[Telescope/sky background]
Extended=YES

Acquisition

#	Target
1	NONE

Template

AcqFilter	Primary Channel	Simultaneous Imaging	Imager Subarray	Grating Wheel Direction
	Imager	YES	FULL	Allow Auto Reorder

Dithers

#	Dither Type	Optimized For	Direction
1	4-Point	BACKGROUND	NEGATIVE

Spectral Elements

#	Wavelength Range	Detector	Filter	Readout Pattern	Groups/Int	Integrations/Exp	Exposures/Dith	Dither	Total Dithers	Total Integrations	Total Exposure Time	ETC Wkbk.Calc ID
1		IMAGER	F2550W	FASTR1	8	13	1	Dither 1	4	52	1287.619	
1	LONG(C)	MRSLONG		SLOWR1	15	1	1	Dither 1	4	4	1433.395	
1	LONG(C)	MRSSHORT		SLOWR1	15	1	1	Dither 1	4	4	1433.395	
2		IMAGER	F1500W	FASTR1	9	12	1	Dither 1	4	48	1320.919	
2	MEDIUM(B)	MRSLONG		SLOWR1	15	1	1	Dither 1	4	4	1433.395	
2	MEDIUM(B)	MRSSHORT		SLOWR1	15	1	1	Dither 1	4	4	1433.395	
3		IMAGER	F770W	FASTR1	12	9	1	Dither 1	4	36	1287.619	
3	SHORT(A)	MRSLONG		SLOWR1	15	1	1	Dither 1	4	4	1433.395	
3	SHORT(A)	MRSSHORT		SLOWR1	15	1	1	Dither 1	4	4	1433.395	

Special Requirements

Sequence Observations 1, 2, Non-interruptible
Same V3 PA 1, 2 (Aperture PAs differ)