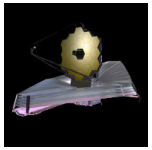

3629 - Direct detection of molecular gas reservoir in the circumgalactic medium of a brightest cluster galaxy

Cycle: 2, Proposal Category: GO

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OBSERVATIONS

Folder	*Observation*	*Label*	*Observing Template*	*Science Target*
Observation Folder				
	1	MRS_BCG_tail	MIRI Medium Resolution Spectroscopy	(1) MACS1931.8-2635-BCG-TAIL
	2	MRS_Sky	MIRI Medium Resolution Spectroscopy	(4) DEDICATED-SKY

ABSTRACT

We seek to conduct a pilot observation with MIRI/MRS to map the warm molecular hydrogen in the circumgalactic medium (CGM) of the brightest cluster galaxy (BCG) of MACS1931-26. The target harbours one of the largest known H2 reservoir in a cluster core revealed by ALMA. Its cold gas,

as traced by CO, is spatially extended over a tail of ~30kpc beyond the BCG core. Submillimeter observations using single-dish and interferometry reveal extreme thermal and excitation conditions in the CGM gas: the dust and gas is thermally decoupled, and the CGM is unusually highly excited. A plethora of evidence points to a drastically different condition in the CGM than typical gas found in galaxies: the thermal gas states are dominated by highly energetic particles rather than FUV-photons from young stars as in galaxies.

JWST/MIRI is uniquely capable of revealing a potentially massive warm H2 reservoir in the CGM. We propose a pilot observation with MIRI/MRS to map the 3D structure of the warm molecular gas in the BCG core and the extended CGM tail of MACS1931, in order to: (1) detect and map the spatial extent and temperature distribution of the warm H2 emission; (2) compare the warm H2 emission to the cold H2 emission mapped by CO. The H2 0-0 S(1) and S(5) line maps will enable us to measure the total gas mass and temperature distribution. By probing the CGM gas across a range of temperatures, we will scrutinize the impact of AGN feedback on the baryon cycle, and assess the role of shocks and turbulence in the heating and cooling of the CGM.

OBSERVING DESCRIPTION

Choice of MIRI/MRS:

The MIRI/MRS is the unique instrument that conduct the pro- posed H2 observations. At the target redshift of z = 0.352, our driving science case is to detect the rotational H2 J = 3 1 or S(1) in short for the following reasons. The H2 S(0) line is redshifted out of the MIRI filters and not observable by JWST. The S(1) line falls in the centre of the MIRI MRS medium grating in Channel 4 (Fig. 4b). The S(1) line is preferred over higher energy transitions, as it probes lower temperatures and thus the bulk of the warm H2 mass. The S(1) line is generally the most luminous line for a range of tem- perature distributions (e.g. Appleton et al. 2017 and Fig 3), and ortho-H2 lines are more luminous than para-H2 lines (Burton et al. 1992; Appleton et al. 2017). By using the MRS medium grating, the MRS will cover the following lines of interest at the target redshift: H2 S(5) in Channel 2, PAH 11.3 micron complex in Channel 3, and H2 S(1) and PAH 17.7 micron complex in Channel 4 (see Figure 4). The medium grating will provide observations of two H2 lines: the S(1) line is important for fitting the overall normalization of the col- umn density and thus warm H2 mass distribution; and the S(5)-to-S(1) line ratio provides a measure of the temperature distribution of the gas. The spectral resolution of the medium grating ranges from R 1680 3750, corresponding to 80 180 km/s. If we conservatively assume that the H2 lines are as broad as the CO (1-0) line with FWHM 110 km/s (Fogarty et al. 2019), the medium grating will be sufficient to resolve the emission line profiles into several resolution elements to probe any velocity gradient.

Mosaicking:

A mosaic with the MRS is required to fully cover the extent of the CGM gas (about 30 kpc or 6 towards the NW direction from the BCG core; see Figure 4a). We request a 6-pointing mosaic (3 rows × 2 columns) with slight shifts applied to cover the BCG core and its extended tail, such that both Ch2 and Ch4 will have continguous spatial coverage over the tail. While a 3-pointing mosaic (3 rows × 1 column) is more time-efficient, the orientation of the mosaic is very restrictive (rotation angle 60 ± 10) and renders the observation unschedulable. We thus opt for the 6-pointing mosaic without any position angle restriction to optimize schedulability.

Dedicated Sky Observation:

Our science target is faint and extended, and fills most of the MRS IFU. Given that the most important spectral line, H2 S(1), is observable at the reddest channel of MIRI, the dominant sources of background noise are zodiacal background and telescope thermal emission. It is thus crucial to obtain a Dedicated Sky Observation with the MRS, so that in post-processing we can accurately model and subtract the background on a pixel-by-pixel basis. A location free of bright MIR sources as seen in WISE is identified for the Dedicated Sky Observation, about 1.2 away N from the science target. The Dedicated Sky Observation will have identical setup (grating, readout, exposure time) as the science target following the observatory's recommendation for faint and extended sources.

Dithering:

We use a 4-point dither pattern for science observations to improve spatial sampling and mitigate bad pixels for all wavelengths observed with the MRS. Based on MIRI commissioning data, the 4-point dither pattern yields better performance than 2-point patterns. For the Dedicated Sky Observation, no dither is required.

MIRI Simulataneous Imaging:

MIRI imaging will be obtained "for free" simultaneously with the MRS observations to improve astrometric solutions of individual MRS exposures. Given that the Dedicated Sky Observations also come with MIRI imaging, we request to restrict the Orientation Angle of the MIRI imaging to be conducted simultaneously with the Sky MRS observations, such that MIRI broadband imaging will cover the science target. We request to use the F2100W filter for the simultaneous imaging, as it covers the H2 S(1) line well away from other potential strong lines expected in the CGM/ICM. The F2100W filter has a PSF of FWHM 0.674, equivalent to 3.3kpc at the target redshift. The spatial resolution of the MIRI imaging is sufficient to

resolve the bright MIR continuum of the BCG AGN from the extended, continuum-free CGM spanning over 30 kpc in length. The MRS and the MIRI imaging will be used in conjunction for accurate measurements of the continuum of the host galaxy. Importantly, the MIRI imaging will provide a much larger field of view of two regions over the cluster, each spanning 74 × 113 (367 kpc × 561 kpc at the target redshift). The MIRI imaging thus has the potential to reveal a much more extended distribution of warm H2 gas near the cluster core, if present.

Exposure time calculation

The exposure time calculation for this pilot detection experiment is driven by the objective to detect the H2 S(1) emission line over the 30-kpc tail over the BCG (see Fig. 2). A total mass of (1.9 ± 0.3) × 1010 M of cold H2 is reported for the BCG+tail, of which 10% is found over the extended tail based on the CO line ratios as reported in Fogarty et al. 2019. We further assume that 10% of the cold H2 mass is found in the warm phase detectable by the rotation H2 lines with MIRI, on par with values reported for SINGS galaxies (Togi & Smith 2016). We follow the formalism in Togi & Smith 2016 and approximate the temperature distribution of the warm H2 gas to follow a continuous power-law temperature distribution, dN TndT, where dN is the column density of H2 between excitation temperatures T and T + dT . A power-law index of n = 4.5 is used which agrees well with the values for the SINGS galaxies (n = 3.8 6.4). The warm H2 mass can be converted to total number of H2 molecules, and knowing the distance (i.e., redshift) and solid angle we obtain the H2 column density. The temperature distribution allows us to populate the different energy levels and predict the line flux of a given rotational H2 transition. We predict an integrated S(1) line flux of 3.5 × 1014 erg cm2s1. The line is expected to be similar in width as the observed CO emission in the tail, where FWHM 120kms1. We estimate the exposure time using the ETC, assuming conservatively that the flux is evenly spreaded over 2/3 of the mosaic region. An exposure time of 1110 seconds per pointing (100 groups per integration × 1 integration per exposure × 4 dither positions) will yield a line SNR of 6 per PSF at the wavelength of the S(1) line. Should the signal be fainter than estimated here (e.g. broader line width than assumed; lower warm H2 gas mass), we will spatially bin the IFU cube to improve signal to noise to achieve our objective of detecting the H2 line.

Special Requirements

The Dedicated Sky Observation is required to be executed right after the science observations to capture the real-time background for optimal calibration.
The MIRI Simulteanous Imaging that accompanies the Dedicated Sky Observation is restricted to a range of rotation angles, such that the MIRI imaging will cover the science target.

Proposal 3629 - Targets - Direct detection of molecular gas reservoir in the circumgalactic medium of a brightest cluster galaxy

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous
(1)	MACS1931.8-2635-BCG-TAIL	RA: 19 31 49.5580 (292.9564917d) Dec: -26 34 29.29 (-26.57480d) Equinox: J2000	Epoch of Position: 2015.5	
Comments: *Category=Galaxy* *Description=[Active galactic nuclei, Active galaxies, Brightest cluster galaxies, Radio jets, Starburst galaxies]* *Extended=YES*				
(4)	DEDICATED-SKY	RA: 19 31 50.6600 (292.9610833d) Dec: -26 33 18.90 (-26.55525d) Equinox: J2000		
Comments: *Category=Calibration* *Description=[Telescope/sky background]* *Extended=YES*				

Observation

Proposal 3629, Observation 1: MRS_BCG_tail Wed Jul 19 02:00:29 GMT 2023

Diagnostic Status: Warning

Observing Template: MIRI Medium Resolution Spectroscopy

Background Observations:[MRS_Sky (Obs 2)]

Diagnostics

(MRS_BCG_tail (Obs 1)) Warning (Form): Imager Filter overlap.

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

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous
(1)	MACS1931.8-2635-BCG-TAIL	RA: 19 31 49.5580 (292.9564917d) Dec: -26 34 29.29 (-26.57480d) Equinox: J2000	Epoch of Position: 2015.5	

Comments:
Category=Galaxy
Description=[Active galactic nuclei, Active galaxies, Brightest cluster galaxies, Radio jets, Starburst galaxies]
Extended=YES

Acquisition

#	Target
1	NONE

Template

AcqFilter	Primary Channel	Simultaneous Imaging	Imager Subarray	Grating Wheel Direction
F560W	ALL	YES	FULL	NEUTRAL

Mosaic

Rows	Columns	Row Overlap %	Column Overlap %	Row shift (deg)	Column shift (deg)	Tile Order
2	3	10.0	10.0	20.0	20.0	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	F2100W	SLOWR1	12	1	1	Dither 1	4	4	1146.716	
1	MEDIUM(B)	MRSLONG		FASTR1	104	1	1	Dither 1	4	4	1154.417	145157
1	MEDIUM(B)	MRSSHORT		FASTR1	104	1	1	Dither 1	4	4	1154.417	145157

Special Requirements	Sequence Observations 1, 2, Non-interruptible

Observation

Proposal 3629, Observation 2: MRS_Sky Wed Jul 19 02:00:29 GMT 2023

Diagnostic Status: Warning

Observing Template: MIRI Medium Resolution Spectroscopy

Background Observation For: [MRS_BCG_tail (Obs 1)]

Comments: Aperture position angle restricted to ensure that the MIRI imaging covers the science target (BCG+tail); this reduced schedulability

Diagnostics

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

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous
(4)	DEDICATED-SKY	RA: 19 31 50.6600 (292.9610833d) Dec: -26 33 18.90 (-26.55525d) Equinox: J2000		

Comments:
Category=Calibration
Description=[Telescope/sky background]
Extended=YES

Acquisition

#	Target
1	NONE

Template

AcqFilter	Primary Channel	Simultaneous Imaging	Imager Subarray	Grating Wheel Direction
	ALL	YES	FULL	NEUTRAL

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	F2100W	SLOWR1	12	1	1	None	1	1	286.679	145157
1	MEDIUM(B)	MRSLONG		FASTR1	104	1	1	None	1	1	288.604	
1	MEDIUM(B)	MRSSHORT		FASTR1	104	1	1	None	1	1	288.604	

Special Requirements	
	Aperture PA Range 70 to 97 Degrees (V3 70.0 to 97.0) Sequence Observations 1, 2, Non-interruptible