Blowing in the wind: An ALMA multiband study of dust in two protostellar winds

2022.1.00216.S

ABSTRACT

The aim of this proposal is to study the interface between protostellar disks and jets, and test the hypothesis that dust can be carried away at this interface via a wind. We have undertaken an extensive search of the ALMA Science Archive, and we found promising evidence for dust continuum extensions in a handful of sources, that we now wish to expand with consistent observations in terms of angular resolution (corresponding to 20 au) and multi-band coverage. Beyond the question of "is dust being launched into protostellar winds?" we seek to address how much dust can be launched into a wind, as compared to the mass of the disk; how far from the disk this dust can be observed; and the dust grain size distribution in the wind launching region. Not only do we aim to constrain if winds can remove dust grains from a disk, but quantify at what level winds affect early disk formation and evolution. The scenario probed here has important impacts on the mass, composition, and evolution of the disk, which is ultimately the reservoir for planet formation. ALMA is the only facility with sufficient angular resolution and multi-band coverage for this study of sub-mm-size dust grains.

SCIENCE CATEGORY:	ISM, star formation and astrochemistry				
ESTIMATED 12-M TIME:	**6.2 h**	**ESTIMATED 7-M TIME:**	**0.0 h**	**ESTIMATED TP TIME:**	**0.0 h**
DUPLICATE OBSERVATION JUSTIFICATION:					

REPRESENTATIVE SCIENCE GOALS (UP TO FIRST 30)

SCIENCE GOAL	POSITION	BAND	ANG.RES.(")	LAS.(")	ACA?
B228 B9	ICRS 15:43:02.2100, -34:09:07.700	9	0.130	4.000	N
B228 B5	ICRS 15:43:02.2100, -34:09:07.700	5	0.130	4.000	N
B228 B8	ICRS 15:43:02.2100, -34:09:07.700	8	0.130	4.000	N
B335 B9	ICRS 19:37:00.7000, 07:34:08.000	9	0.130	4.000	N
B335 B5	ICRS 19:37:00.7000, 07:34:08.000	5	0.130	4.000	N
B335 B8	ICRS 19:37:00.7000, 07:34:08.000	8	0.130	4.000	N
Total # Science Goals : 6					

SCHEDULING TIME CONSTRAINTS	NONE	**TIME ESTIMATES OVERRIDDEN ?**	No

1 Scientific justification

ALMA has been transformational for observing disks in the earliest stages of star formation. Notably, the large program DSHARP revealed diverse substructures, including rings, spirals, and some combination of the above in protoplanetary disks, pointing to planet formation. Since then, disk studies have targeted younger and younger disks, most importantly revealing that substructure in disks – and possibly even planets – form early in the star formation process [e.g. 15]. Still, the disk is one component of a more extensive and complex system, with each component playing a critical role in the process of star formation (Fig. 1). Among these, an early signpost of star formation are so-called protostellar jets [8], where the combination of gravity, rotation, and magnetic fields conspire to eject material from the surface of a protoplanetary accretion disk into the surrounding envelope. These jets sweep up material into a molecular outflow, and in the process redistribute significant amounts of material, remove angular momentum from the system, and effectively permit stars to grow by accretion via the disk.

While this jet is apparently an important phenomenon, the exact launching mechanism is not yet fully understood. The various theories differ mainly in the region where material is being accelerated: (i) a 'stellar wind' emanating from the poles of the protostar [6], (ii) an 'X-wind' resulting from the interaction between the protostellar and disk magnetic fields [17; 16] and (iii) a 'disk wind' ejected magnetically across an extended region of the disk [2]. The disk wind scenario has gained in popularity in recent years, but a combination of the different models is likely needed to match all of the observations [8].

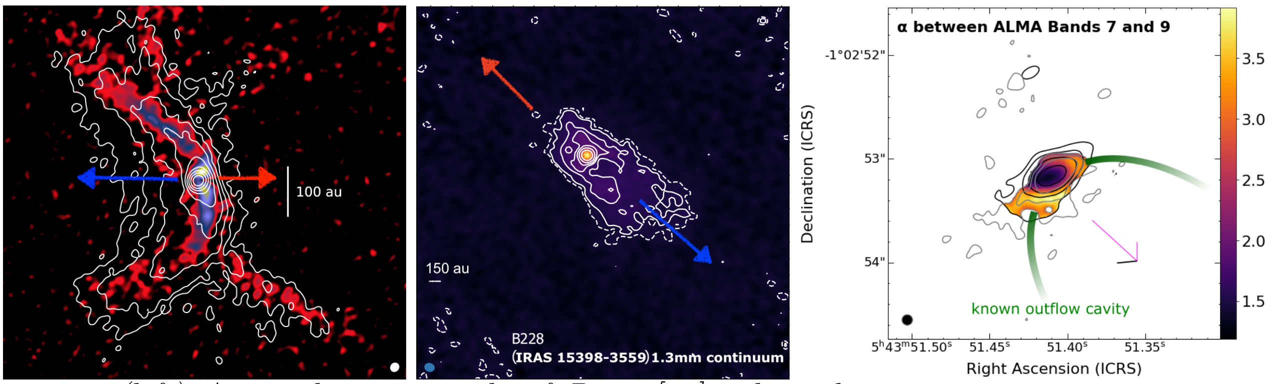

Figure 1: *(left) A tantalizing example of B335 [24], where dust continuum emission traces the shape of the known molecular outflow. (center) Continuum in B228 (IRAS 15398) re-imaged from 2013.1.00879.S [23]. Blue/red arrows indicate the outflow axis. (right) Preliminary analysis of HH212 case study; the spectral index, α, measured using archival band 7 and 9 data, shows an extension coincident with the outflow cavity and with a α value different from the disk.* ***Here we propose to extend our similar spectral index study mapping study to include B228 and B335.***

Only in a few sources has it been possible to directly observe the jet launching region, including Class I sources TMC1A [3] and DG Tau B [7], wherein an extended launching region up to 25 au is implied, supporting the previously mentioned 'disk wind' scenario. A few younger protostellar outflows have been observed at high angular resolution, such as Class 0 sources HH 212 [13; 18] and B335 [4], as well as Class I source BHB07-11 [1]. Observations of HH212 are consistent with both a 'disk wind' or 'X-wind' scenario, depending on the molecular tracer used. B335 meanwhile shows a wide-angle outflow, yet launching is estimated to be confined to the inner 0.07 au from the protostar [4].

Jets/outflows have generally been studied via molecular gas emission, while disks have been studied via gas and dust. *With this proposal, we plan to study the interface between disk and jet for two* *protostars identified for their extraordinary continuum morphologies on small scales, and test the hypothesis that dust can be carried away at this interface via a wind.* We have identified B228 and B335 as two promising sources to add to preliminary analysis of HH212 (Fig. 1) in order to observationally constrain this scenario.

Why ALMA? Under the assumption that the dust thermal emission at a given wavelength is roughly proportional to the size of the dust grains, ALMA's ability to observe in different bands at a range of wavelengths allows it to probe the grain size distribution (via the spectral index) in a target protostellar disks. Given that larger grains are expected to settle towards the disk midplane and central region [11; 20], then smaller grains should preferentially be lifted from the disk face via winds [9; 5; 10; 14]. We performed preliminary analysis of HH212 archival data in Bands 7 and 9, and B228 and B335 in Bands 6 and 7, searching for observational evidence for dust being launched into protostellar winds.

Here, we propose to extend the waveband coverage for the latter two sources, and measure **how much, from where, and with what size distribution** the dust is launched into protostellar winds, compared to respective disk masses. Specifically, we require higher-frequency observations (Bands 8-9) for B228 and B335, as well as a lower band, ideally Band 5, to anchor the spectral index calculations. (Band 3 is likely too faint, and no significant detection was seen for the pilot study HH212.) In this study, we will not only constrain the ability of winds to remove dust grains from disks, but also quantify at what level winds can affect early disk evolution. The scenario probed here, if effective, will have important impacts on the mass, composition, and evolution of the disk, which is ultimately the reservoir for early stage planet formation.

2 Description of observations

2.1 Source selection

To prepare this proposal and preliminary analysis, we carefully selected sources based on an extensive archival search of the ALMA Science Archive (ASA). We developed a pipeline to programmatically query the archive for observations that meet several criteria: (1) keywords 'Outflows, jets and ionized winds','Disks around low-mass stars','low-mass star formation'; (2) angular resolution better than $0.2''$, which is better than about 100 au, even for the farthest sources (note that this angular resolution criterion was for search purposes only, and this proposal requests a higher angular resolution).

Based on the resulting list, we retained any sources with known outflows, based on the literature, or based on spectral line images in the ASA. We excluded perfectly face-on sources, as any continuum extension along the outflow axis will not be distinguishable from the disk. Then, we inspected continuum data products for any sources that have observations in at least two bands, prioritizing those that have observations in higher ALMA bands.

Our team developed a machine learning algorithm to ingest FITS images and compare the source morphology to a bivariate Gaussian model, flagging any cases where deviation from the model was apparent. As a result, we selected 3 sources for more thorough inspection: HH212, B228 (IRAS 15398-3359), B335. Preliminary extensions are seen in Fig. 1 for B228 and B335, and multi-band reimaging of HH212 (Fig. 2) revealed extension in higher ALMA bands. In our unbiased search, only young (Class 0, early class I) targets were found, and none in known binary systems. They are considered excellent candidates for scenarios in which dust is being lifted into the outflow via a disk wind. The existence of a disk wind is established in HH212 [13; 19], while the launching region has not been entirely resolved towards B335 [4] or B228 [21].

As a proof of concept, we selected HH212 as the source with the most available data in the ASA to carefully re-image with optimized parameters; Fig. 2 shows bands 3, 6, 7, and 9 (available bands with high enough angular resolution in the ASA). A dust extension is apparent in Bands 7 and 9, for which we also map the spectral index (Fig. 1). The spectral index map displays evidence for smaller grains (higher spectral index) precisely in the extension coincident with the wind. For the cases of B335 and B228, we already see ample dust extension in Bands 6 and 7 (Fig. 1), and we request to extend the observations to Band 5 to probe potentially larger grains. Bands 8 and 9 are crucial for detecting smaller grain structures that may be launched farther. Band 8 is important as an intermediate between Bands 7 and 9, thus minimizing the error bars on the spectral index calculation. *This will the the first such thorough, systematic spectral index campaign to date.*

Table 1: *Requirements for each source and band.*

Source	Band	Requested			Archival Data		
		Beam		Sensitivity**	Exists?***	Meets θ?	Meets rms?
		($''$)	(au)*	(mK)	Y|N	Y|N	Y|N
B228	5	0.13	20	50	N		
B228	6	0.13	20	90	Y	Y	Y
B228	7	0.13	20	240	Y	Y	Y
B228	8	0.13	20	380	Y	N	
B228	9	0.13	20	1800	N		
B335	5	0.12	20	50	Y	N	
B335	6	0.12	20	90	Y	Y	Y
B335	7	0.12	20	240	Y	Y	Y
B335	8	0.12	20	380	Y	N	
B335	9	0.12	20	1800	N		

* Assumed source distances: B228 at 153 pc [21]; B335 at 160 pc [22].
** Sensitivity requirement depends on distance, as well as number of requested beams within extent of dust emission.
*** Orange indicates that additional observations are requested in current proposal (any row with 'N'); green indicates current ALMA data are satisfactory.

2.2 Specifications for complementary observations

Bands and spectral setup: We require observations in Bands 5, 8, 9 (and complement with Bands 6 and 7 available in ASA, see Table 1). Based on our inspection of archival data, significant dust emission is not expected in lower bands, as it would would require dust grain sizes of > 1 mm. We do, however, see evidence of dust extensions in Band 6 and above.

Resolution: We require observations with a *spatial resolution of 20 au* in order to probe the wind launching region of each respective disk (based on observations of TMC1A; [3]). This corresponds to $0.13''$, $0.12''$ in B228 and B335, respectively (see Table 1). With such resolution, we will be able to discern spatial variations of the spectral index in the regions where emission extends beyond the edge of a disk, as well as in the disk itself. On the other hand, we don't require any higher angular resolution, because otherwise we will lose sensitivity, as well as resolve out larger angular scales.

Sensitivity: Sensitivity required for each band is determined based on a respective mass threshold. For each system, *we aim to detect dust extension corresponding to 5-10% of the mass of the disk*. We base thresholds on the HH212 case (Fig. 2), and scale to the (nearer) distances of B228 and B335.

2.3 Analysis Methodology

We have presented a proof of concept for HH212 (Fig. 2), and once we obtain uniform, multi-band data for B335 and B228, we can follow the same procedure as we did for HH212: First, we fit a Gaussian model to the disk, and to measure the total flux in the regions both beyond (i.e. in extensions) and within this mask. From this emission, we calculate the dust mass, and we distinguish between the mass within the mask (primarily disk), and any extension outside of the mask that is also coincident with the wind. Such features will be compared with archival data showing gaseous emission know to trace disk winds (e.g. ^{12}CO).

We plan to measure the dust mass, based on the emission in each band. Opacities are taken into account following [12]. By observing across the proposed bands in particular, we will be able to calculate the spectral index (α), and subsequently constrain the dust grain size distribution. In HH212, preliminary analysis shows $\alpha \sim 1.5$ in the disk region, and a notable shift towards $\alpha \sim 3.5$ at the edge of the disk and into the extension (see Fig. 1, right panel). We found that the change in α is coincident with the CO and C^{34}S emission in the outflow cavity walls (using data from [19]). However, these are tentative detections only based on available data for HH212, and we require the consistent observations proposed here in order to constrain our hypothesis for additional sources.

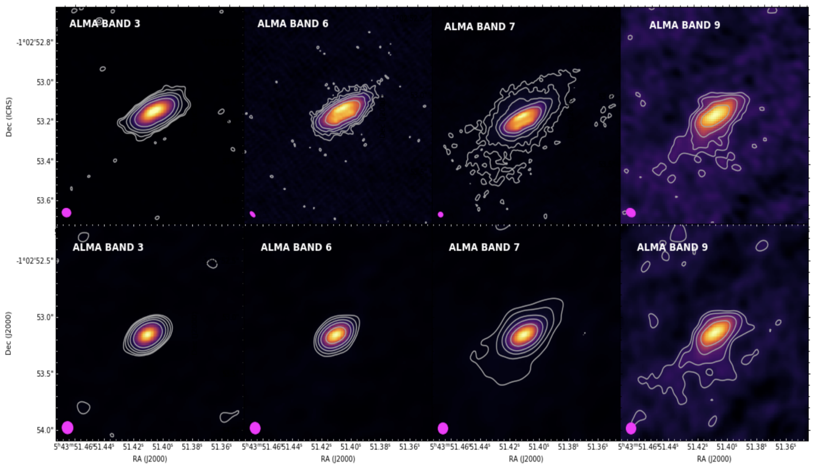

Figure 2: *HH212 continuum observed in ALMA bands. Contours begin at 3σ for each respective image. Top row shows native resolution, and bottom row shows images smoothed to a common 0.1″ beam.* ***An extension is apparent in Bands 7 and 9. The current proposal requests Bands 5, 8, and 9 to complement Bands 6 & 7 for two other sources.***

References: [1] Alves, F. O., et al. 2017, A&A, 603, L3. · [2] Blandford, R. D., Payne, D. G. 1982, MNRAS, 199, 883 · [3] Bjerkeli, P., et al. 2016, Nature, 540, 406. · [4] Bjerkeli, P., et al. 2019, A&A, 631, A64. · [5] Booth, R. A., Clarke, C. J. 2021, MNRAS, 502, 1569 · [6] Bouvier, J., et al. 2014, in Protostars and Planets VI, p. 431. · [7] de Valon, A., et al. 2020, A&A, 634, L12. · [8] Frank, A., et al. 2014, in Protostars and Planets VI, p. 451. · [9] Franz, R., et al. 2020, A&A, 635, A53 · [10] Franz, R., et al. 2022, A&A, 657, A69 · [11] Johansen, A., et al. 2014, PPVI, 547. · [12] Lin, Z.-Y. D., et al. 2021, MNRAS, 501, 1316. · [13] Lee, C.-F., et al. 2017, Nat. Ast., 1, 0152. · [14] Rodenkirch, P. J., Dullemond, C. P. 2022, A&A, 659, A42 · [15] Segura-Cox, D. M., et al. 2020, Nature, 586, 228. [16] Shang, H., et al. 2006, ApJ, 649, 845. · [17] Shu, F., et al. 1994, ApJ, 429, 781. [18] Tabone, B., et al. 2017, A&A, 607, L6. · [19] Tabone, B., et al. 2020, A&A, 640, A82. · [20] Testi, L., et al. 2014, PPPVI, 339. [21] Vazzano, M. M., et al. 2021, A&A, 648, A41. · [22] Watson, D. M. 2020, RNAAS, 4, 88. · [23] Yen, H.-W., et al. 2017, ApJ, 834, 178. · [24] Yen, H.-W., et al. 2020, ApJ, 893, 54.

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SG : 1 of 6 B228 B9 Band 9

Science Goal Parameters

Ang.Res.	LAS	Requested RMS	RMS Bandwidth	Rep.Freq.	Cont. RMS	Cont. Bandwidth	Poln.Prod.
0.1300"	4.0"	11.777 mJy, 1.8 K	6536.173 km/s, 15 GHz	687.997711 GHz	566.563 µJy, 86.6 mK	15.000 GHz	XX,YY

Use of 12m Array (43 antennas)

t_total(all configs)	t_science(C-4)	t_total(C-1)	Imaged area	#12m pointing	12m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate
1.0 h	0.1 h	0.4 h	2.8 "	1	offset	8.5 "	460.7 s	54.0 GB	21.7 MB/s

Use of ACA 7m Array (10 antennas) and TP Array

t_total(ACA)	t_total(7m)	t_total(TP)	Imaged area	#7m pointing	7m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate

Spectral Setup : Spectral Line

BB	Center Freq Rest GHz	spw name	Eff #Ch p.p.	Bandwidth	Resolution	Vel. Bandwidth	Vel. Res.	Res. El. per FWHM
1	687.997711	continuum 1	3840	1875.00 MHz	1.129 MHz	817.0 km/s	0.492 km/s	2
2	685.997718	continuum 2	3840	1875.00 MHz	1.129 MHz	819.4 km/s	0.493 km/s	2
3	689.997705	continuum 3	3840	1875.00 MHz	1.129 MHz	814.7 km/s	0.490 km/s	2
4	691.997698	continuum 4	3840	1875.00 MHz	1128.906 kHz	812.3 km/s	0.489 km/s	2

1 Target

No.	Target	Ra,Dec (ICRS)	V,def,frame --OR--z
1	1-B228	15:43:02, -34:09:07	5.10 km/s,lsrk,RADIO

Expected Source Properties

	Peak Flux	SNR	Linewidth	RMS (over 1/3 linewidth)	linewidth / bandwidth used for sensitivity	Pol.	Pol. SNR
Line	1.00 mJy	0.0	1 km/s	79.34 mJy, 12.1 K	0.0002	0.0%	0.0
Continuum	5.00 mJy	8.8				0.0%	0.0

Dynamic range (cont flux/line rms): 0.1

1 Tuning

Tuning	Target	Rep. Freq. Sky GHz	RMS (Rep. Freq.)	RMS Achieved
1	1	687.986007	566.54 µJy, 86.6 mK	549.07 uJy - 650.97 uJy

Sensitivity Comments

Note that one or more of the S/N estimates are < 3. Please double-check the RMS and/or line fluxes entered and/or address the issue belo
Note that the bandwidth used for sensitivity is larger than 1/3 of the linewidth.
The S/N achieved for a resolution element that allows the line to be resolved will be lower than that reported.

Justification for requested RMS and resulting S/N (and for spectral lines the bandwidth selected) for the sensitivity calculation.

Sensitivity is based on our extensive archival search, selecting the B7 observations for each image, scaling to the other bands, and checking with any available data in the corresponding bands (correcting for angular resolution differences).

We also have to take into account the extent of the emission, in order to calculate brightness (mJy/beam) from flux density (mJy), for the given resolution element. We estimate, based on our inspection of multi-band archival data for HH212, that the dust may extend out to a distance equal to 50\% the major axis of the Gaussian component of the dust continuum emission. Hence, where we see the disk fit with a Gaussian mask with a semi-major axis of 0.3", then we account for a dust extent outside the disk mask to cover the area of A*pi(0.15")^2. Accordingly, we calculate how many beams (0.05") fit within the extension, in order to achieve the minimum mass at a 5sigma level. We require a 5sigma level detection of the same mass threshold in each band in order to generate spectral index maps (realizing that the lower bands require deeper observations to reach the same mass threshold due to the spectral index).

Justification of the chosen angular resolution and largest angular scale for the source(s) in this Science Goal.

The angular resolution is chosen to correspond to 20 au at the distance of each respective source. Largest angular scale is based on inspection of archival data, noticing the width and extent of continuum emission coincident with the cavity wall (see Figure 1). We do not need ACA for extended emission beyond what the 12m-array can recover (few arcsec).

Correlator Comments

Note that the spectral resolution is larger than 1/3 of the the spectral line width and that your line may not be resolved.

Justification of the correlator set-up with particular reference to the number of spectral resolution elements per line width.

For each band, we selected the spectral setup to obtain maximum continuum bandwidth (7.5 GHz), while also using FDM for high enough spectral resolution (0.53 km/s, depending on band) to strategically observe specific spectral lines simultaneously. Channels with spectral line emission will be identified and excluded for continuum analysis (line widths are expected to be narrow, and will not dominate the continuum bandwidth).

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SG : 2 of 6 B228 B5 Band 5

Science Goal Parameters

Ang.Res.	LAS	Requested RMS	RMS Bandwidth	Rep.Freq.	Cont. RMS	Cont. Bandwidth	Poln.Prod.
0.1300"	4.0"	30.477 µJy, 50 mK	10706.874 km/s, 7.5 GHz	210.000000 GHz	30.141 µJy, 49.4 mK	7.500 GHz	XX,YY

Use of 12m Array (43 antennas)

t_total(all configs)	t_science(C-6)	t_total(C-3)	Imaged area	#12m pointing	12m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate
1.0 h	0.2 h	0.3 h	9.2 "	1	offset	27.7 "	816.4 s	76.9 GB	32.2 MB/s

Use of ACA 7m Array (10 antennas) and TP Array

t_total(ACA)	t_total(7m)	t_total(TP)	Imaged area	#7m pointing	7m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate

Spectral Setup : Single Continuum

Center Freq (Sky)	Center Freqs. SPWs	Eff #Ch p.p.	Bandwidth	Resolution	Vel. Bandwidth	Vel. Resolution	RMS
203.000000	196.000000	3840	1875.00 MHz	1.129 MHz	2867.9 km/s	1.727 km/s	68.89 µJy, 129.7 mK
	198.000000	3840	1875.00 MHz	1.129 MHz	2838.9 km/s	1.709 km/s	65.5 µJy, 120.9 mK
	208.000000	3840	1875.00 MHz	1.129 MHz	2702.5 km/s	1.627 km/s	61.3 µJy, 102.5 mK
	210.000000	3840	1875.00 MHz	1.129 MHz	2676.7 km/s	1.612 km/s	60.95 µJy, 100.0 mK

1 Target

No.	Target	Ra,Dec (ICRS)	V,def,frame --OR--z
1	1-B228	15:43:02, -34:09:07	5.10 km/s,lsrk,RADIO

Expected Source Properties

	Peak Flux	SNR	Linewidth	RMS (over 1/3 linewidth)	linewidth / bandwidth used for sensitivity	Pol.	Pol. SNR
Line	0.00 uJy	0.0	0 km/s			0.0%	0.0
Continuum	5.00 mJy	165.9				0.0%	0.0

Dynamic range (cont flux/line rms): N/A

Justification for requested RMS and resulting S/N (and for spectral lines the bandwidth selected) for the sensitivity calculation.

Sensitivity is based on our extensive archival search, selecting the B7 observations for each image, scaling to the other bands, and checking with any available data in the corresponding bands (correcting for angular resolution differences).

We also have to take into account the extent of the emission, in order to calculate brightness (mJy/beam) from flux density (mJy), for the given resolution element. We estimate, based on our inspection of multi-band archival data for HH212, that the dust may extend out to a distance equal to 50\% the major axis of the Gaussian component of the dust continuum emission. Hence, where we see the disk fit with a Gaussian mask with a semi-major axis of 0.3", then we account for a dust extent outside the disk mask to cover the area of A*pi(0.15")^2. Accordingly, we calculate how many beams (0.05") fit within the extension, in order to achieve the minimum mass at a 5sigma level. We require a 5sigma level detection of the same mass threshold in each band in order to generate spectral index maps (realizing that the lower bands require deeper observations to reach the same mass threshold due to the spectral index).

Justification of the chosen angular resolution and largest angular scale for the source(s) in this Science Goal.

The angular resolution is chosen to correspond to 20 au at the distance of each respective source. Largest angular scale is based on inspection of archival data, noticing the width and extent of continuum emission coincident with the cavity wall (see Figure 1). We do not need ACA for extended emission beyond what the 12m-array can recover (few arcsec).

Justification of the correlator set-up with particular reference to the number of spectral resolution elements per line width.

For each band, we selected the spectral setup to obtain maximum continuum bandwidth (7.5 GHz), while also using FDM for high enough spectral resolution (0.53 km/s, depending on band) to strategically observe specific spectral lines simultaneously. Channels with spectral line emission will be identified and excluded for continuum analysis (line widths are expected to be narrow, and will not dominate the continuum bandwidth).

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SG : 3 of 6 B228 B8 Band 8

Science Goal Parameters

Ang.Res.	LAS	Requested RMS	RMS Bandwidth	Rep.Freq.	Cont. RMS	Cont. Bandwidth	Poln.Prod.
0.1300"	4.0"	861.514 µJy, 380 mK	5551.712 km/s, 7.5 GHz	404.998653 GHz	145.452 µJy, 64.2 mK	7.500 GHz	XX,YY

Use of 12m Array (43 antennas)

t_total(all configs)	t_science(C-5)	t_total(C-2)	Imaged area	#12m pointing	12m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate
1.0 h	0.1 h	0.4 h	4.8 "	1	offset	14.4 "	453.5 s	26.4 GB	11.0 MB/s

Use of ACA 7m Array (10 antennas) and TP Array

t_total(ACA)	t_total(7m)	t_total(TP)	Imaged area	#7m pointing	7m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate

Spectral Setup : Spectral Line

BB	Center Freq Rest GHz	spw name	Eff #Ch p.p.	Bandwidth	Resolution	Vel. Bandwidth	Vel. Res.	Res. El. per FWHM
1	404.998653	continuum 1	3840	1875.00 MHz	1.129 MHz	1387.9 km/s	0.836 km/s	1
2	402.998659	continuum 2	3840	1875.00 MHz	1.129 MHz	1394.8 km/s	0.840 km/s	1
3	392.998693	continuum 3	3840	1875.00 MHz	1.129 MHz	1430.3 km/s	0.861 km/s	1
4	390.998699	continuum 4	3840	1875.00 MHz	1128.906 kHz	1437.6 km/s	0.866 km/s	1

1 Target

No.	Target	Ra,Dec (ICRS)	V,def,frame --OR--z
1	1-B228	15:43:02, -34:09:07	5.10 km/s,lsrk,RADIO

Expected Source Properties

	Peak Flux	SNR	Linewidth	RMS (over 1/3 linewidth)	linewidth / bandwidth used for sensitivity	Pol.	Pol. SNR
Line	1.00 mJy	0.1	1 km/s	18.77 mJy, 8.3 K	0.0002	0.0%	0.0
Continuum	5.00 mJy	34.4				0.0%	0.0

Dynamic range (cont flux/line rms): 0.3

1 Tuning

Tuning	Target	Rep. Freq. Sky GHz	RMS (Rep. Freq.)	RMS Achieved
1	1	404.991763	145.45 µJy, 64.2 mK	145.45 uJy - 228.47 uJy

Sensitivity Comments

Note that one or more of the S/N estimates are < 3. Please double-check the RMS and/or line fluxes entered and/or address the issue belo
Note that the bandwidth used for sensitivity is larger than 1/3 of the linewidth.
The S/N achieved for a resolution element that allows the line to be resolved will be lower than that reported.

Justification for requested RMS and resulting S/N (and for spectral lines the bandwidth selected) for the sensitivity calculation.

Sensitivity is based on our extensive archival search, selecting the B7 observations for each image, scaling to the other bands, and checkinį with any available data in the corresponding bands (correcting for angular resolution differences).

We also have to take into account the extent of the emission, in order to calculate brightness (mJy/beam) from flux density (mJy), for the given resolution element. We estimate, based on our inspection of multi-band archival data for HH212, that the dust may extend out to a distance equal to 50\% the major axis of the Gaussian component of the dust continuum emission. Hence, where we see the disk fit with a Gaussian mask with a semi-major axis of 0.3", then we account for a dust extent outside the disk mask to cover the area of A*pi(0.15")^2. Accordingly, we calculate how many beams (0.05") fit within the extension, in order to achieve the minimum mass at a 5sigma level. We require a 5sigma level detection of the same mass threshold in each band in order to generate spectral index maps (realizing that the lower bands require deeper observations to reach the same mass threshold due to the spectral index).

Justification of the chosen angular resolution and largest angular scale for the source(s) in this Science Goal.

The angular resolution is chosen to correspond to 20 au at the distance of each respective source. Largest angular scale is based on inspection of archival data, noticing the width and extent of continuum emission coincident with the cavity wall (see Figure 1). We do not need ACA for extended emission beyond what the 12m-array can recover (few arcsec).

Correlator Comments

Note that the spectral resolution is larger than 1/3 of the the spectral line width and that your line may not be resolved.

Justification of the correlator set-up with particular reference to the number of spectral resolution elements per line width.

For each band, we selected the spectral setup to obtain maximum continuum bandwidth (7.5 GHz), while also using FDM for high enough spectral resolution (0.53 km/s, depending on band) to strategically observe specific spectral lines simultaneously. Channels with spectral line emission will be identified and excluded for continuum analysis (line widths are expected to be narrow, and will not dominate the continuum bandwidth).

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SG : 4 of 6 B335 B9 Band 9

Science Goal Parameters

Ang.Res.	LAS	Requested RMS	RMS Bandwidth	Rep.Freq.	Cont. RMS	Cont. Bandwidth	Poln.Prod.
0.1300"	4.0"	11.777 mJy, 1.8 K	6536.173 km/s, 15 GHz	687.979837 GHz	662.375 µJy, 101.2 mK	15.000 GHz	XX,YY

Use of 12m Array (43 antennas)

t_total(all configs)	t_science(C-4)	t_total(C-1)	Imaged area	#12m pointing	12m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate
1.0 h	0.1 h	0.4 h	2.8 "	1	offset	8.5 "	460.7 s	54.0 GB	21.7 MB/s

Use of ACA 7m Array (10 antennas) and TP Array

t_total(ACA)	t_total(7m)	t_total(TP)	Imaged area	#7m pointing	7m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate

Spectral Setup : Spectral Line

BB	Center Freq Rest GHz	spw name	Eff #Ch p.p.	Bandwidth	Resolution	Vel. Bandwidth	Vel. Res.	Res. El. per FWHM
1	687.979837	continuum 1	3840	1875.00 MHz	1.129 MHz	817.0 km/s	0.492 km/s	2
2	685.979895	continuum 2	3840	1875.00 MHz	1.129 MHz	819.4 km/s	0.493 km/s	2
3	689.979778	continuum 3	3840	1875.00 MHz	1.129 MHz	814.7 km/s	0.490 km/s	2
4	691.979720	continuum 4	3840	1875.00 MHz	1128.906 kHz	812.3 km/s	0.489 km/s	2

1 Target

No.	Target	Ra,Dec (ICRS)	V,def,frame --OR--z
1	1-B335	19:37:00, 07:34:08	8.30 km/s,lsrk,RADIO

Expected Source Properties

	Peak Flux	SNR	Linewidth	RMS (over 1/3 linewidth)	linewidth / bandwidth used for sensitivity	Pol.	Pol. SNR
Line	1.00 mJy	0.0	1 km/s	92.76 mJy, 14.2 K	0.0002	0.0%	0.0
Continuum	5.00 mJy	7.5				0.0%	0.0

Dynamic range (cont flux/line rms): 0.1

1 Tuning

Tuning	Target	Rep. Freq. Sky GHz	RMS (Rep. Freq.)	RMS Achieved
1	1	687.960790	662.29 µJy, 101.2 mK	640.94 uJy - 766.66 uJy

Sensitivity Comments

Note that one or more of the S/N estimates are < 3. Please double-check the RMS and/or line fluxes entered and/or address the issue belo
Note that the bandwidth used for sensitivity is larger than 1/3 of the linewidth.
The S/N achieved for a resolution element that allows the line to be resolved will be lower than that reported.

Justification for requested RMS and resulting S/N (and for spectral lines the bandwidth selected) for the sensitivity calculation.

Sensitivity is based on our extensive archival search, selecting the B7 observations for each image, scaling to the other bands, and checkin with any available data in the corresponding bands (correcting for angular resolution differences).

We also have to take into account the extent of the emission, in order to calculate brightness (mJy/beam) from flux density (mJy), for the given resolution element. We estimate, based on our inspection of multi-band archival data for HH212, that the dust may extend out to a distance equal to 50\% the major axis of the Gaussian component of the dust continuum emission. Hence, where we see the disk fit with a Gaussian mask with a semi-major axis of 0.3", then we account for a dust extent outside the disk mask to cover the area of A*pi(0.15")^2. Accordingly, we calculate how many beams (0.05") fit within the extension, in order to achieve the minimum mass at a 5sigma level. We require a 5sigma level detection of the same mass threshold in each band in order to generate spectral index maps (realizing that the lower bands require deeper observations to reach the same mass threshold due to the spectral index).

Justification of the chosen angular resolution and largest angular scale for the source(s) in this Science Goal.

The angular resolution is chosen to correspond to 20 au at the distance of each respective source. Largest angular scale is based on inspection of archival data, noticing the width and extent of continuum emission coincident with the cavity wall (see Figure 1). We do not need ACA for extended emission beyond what the 12m-array can recover (few arcsec).

Correlator Comments

Note that the spectral resolution is larger than 1/3 of the the spectral line width and that your line may not be resolved.

Justification of the correlator set-up with particular reference to the number of spectral resolution elements per line width.

For each band, we selected the spectral setup to obtain maximum continuum bandwidth (7.5 GHz), while also using FDM for high enough spectral resolution (0.53 km/s, depending on band) to strategically observe specific spectral lines simultaneously. Channels with spectral line emission will be identified and excluded for continuum analysis (line widths are expected to be narrow, and will not dominate the continuum bandwidth).

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SG : 5 of 6 B335 B5 Band 5

Science Goal Parameters

Ang.Res.	LAS	Requested RMS	RMS Bandwidth	Rep.Freq.	Cont. RMS	Cont. Bandwidth	Poln.Prod.
0.1300"	4.0"	30.477 µJy, 50 mK	10706.874 km/s, 7.5 GHz	210.000000 GHz	30.183 µJy, 49.5 mK	7.500 GHz	XX,YY

Use of 12m Array (43 antennas)

t_total(all configs)	t_science(C-7)	t_total(C-4)	Imaged area	#12m pointing	12m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate
1.2 h	0.2 h	0.3 h	9.2 "	1	offset	27.7 "	889.0 s	82.0 GB	29.2 MB/s

Use of ACA 7m Array (10 antennas) and TP Array

t_total(ACA)	t_total(7m)	t_total(TP)	Imaged area	#7m pointing	7m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate

Spectral Setup : Single Continuum

Center Freq (Sky)	Center Freqs. SPWs	Eff #Ch p.p.	Bandwidth	Resolution	Vel. Bandwidth	Vel. Resolution	RMS
203.000000	196.000000	3840	1875.00 MHz	1.129 MHz	2867.9 km/s	1.727 km/s	69.78 µJy, 131.4 mK
	198.000000	3840	1875.00 MHz	1.129 MHz	2838.9 km/s	1.709 km/s	66.01 µJy, 121.8 mK
	208.000000	3840	1875.00 MHz	1.129 MHz	2702.5 km/s	1.627 km/s	61.34 µJy, 102.6 mK
	210.000000	3840	1875.00 MHz	1.129 MHz	2676.7 km/s	1.612 km/s	60.95 µJy, 100.0 mK

1 Target

No.	Target	Ra,Dec (ICRS)	V,def,frame --OR--z
1	1-B335	19:37:00, 07:34:08	8.30 km/s,lsrk,RADIO

Expected Source Properties

	Peak Flux	SNR	Linewidth	RMS (over 1/3 linewidth)	linewidth / bandwidth used for sensitivity	Pol.	Pol. SNR
Line	0.00 uJy	0.0	0 km/s			0.0%	0.0
Continuum	5.00 mJy	165.7				0.0%	0.0

Dynamic range (cont flux/line rms): N/A

Justification for requested RMS and resulting S/N (and for spectral lines the bandwidth selected) for the sensitivity calculation.

Sensitivity is based on our extensive archival search, selecting the B7 observations for each image, scaling to the other bands, and checking with any available data in the corresponding bands (correcting for angular resolution differences).

We also have to take into account the extent of the emission, in order to calculate brightness (mJy/beam) from flux density (mJy), for the given resolution element. We estimate, based on our inspection of multi-band archival data for HH212, that the dust may extend out to a distance equal to 50\% the major axis of the Gaussian component of the dust continuum emission. Hence, where we see the disk fit with a Gaussian mask with a semi-major axis of 0.3", then we account for a dust extent outside the disk mask to cover the area of A*pi(0.15")^2. Accordingly, we calculate how many beams (0.05") fit within the extension, in order to achieve the minimum mass at a 5sigma level. We require a 5sigma level detection of the same mass threshold in each band in order to generate spectral index maps (realizing that the lower bands require deeper observations to reach the same mass threshold due to the spectral index).

Justification of the chosen angular resolution and largest angular scale for the source(s) in this Science Goal.

The angular resolution is chosen to correspond to 20 au at the distance of each respective source. Largest angular scale is based on inspection of archival data, noticing the width and extent of continuum emission coincident with the cavity wall (see Figure 1). We do not need ACA for extended emission beyond what the 12m-array can recover (few arcsec).

Justification of the correlator set-up with particular reference to the number of spectral resolution elements per line width.

For each band, we selected the spectral setup to obtain maximum continuum bandwidth (7.5 GHz), while also using FDM for high enough spectral resolution (0.53 km/s, depending on band) to strategically observe specific spectral lines simultaneously. Channels with spectral line emission will be identified and excluded for continuum analysis (line widths are expected to be narrow, and will not dominate the continuum bandwidth).

2022.1.00216.S

SG : 6 of 6 B335 B8 Band 8

Science Goal Parameters

Ang.Res.	LAS	Requested RMS	RMS Bandwidth	Rep.Freq.	Cont. RMS	Cont. Bandwidth	Poln.Prod.
0.1300"	4.0"	861.514 µJy, 380 mK	5551.712 km/s, 7.5 GHz	404.988131 GHz	157.168 µJy, 69.3 mK	7.500 GHz	XX,YY

Use of 12m Array (43 antennas)

t_total(all configs)	t_science(C-5)	t_total(C-2)	Imaged area	#12m pointing	12m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate
1.0 h	0.1 h	0.4 h	4.8 "	1	offset	14.4 "	453.5 s	26.4 GB	11.0 MB/s

Use of ACA 7m Array (10 antennas) and TP Array

t_total(ACA)	t_total(7m)	t_total(TP)	Imaged area	#7m pointing	7m Mosaic spacing	HPBW	t_per_point	Data Vol	Avg. Data Rate

Spectral Setup : Spectral Line

BB	Center Freq Rest GHz	spw name	Eff #Ch p.p.	Bandwidth	Resolution	Vel. Bandwidth	Vel. Res.	Res. El. per FWHM
1	404.988131	continuum 1	3840	1875.00 MHz	1.129 MHz	1387.9 km/s	0.836 km/s	1
2	402.988189	continuum 2	3840	1875.00 MHz	1.129 MHz	1394.8 km/s	0.840 km/s	1
3	392.988482	continuum 3	3840	1875.00 MHz	1.129 MHz	1430.3 km/s	0.861 km/s	1
4	390.988541	continuum 4	3840	1875.00 MHz	1128.906 kHz	1437.6 km/s	0.866 km/s	1

1 Target

No.	Target	Ra,Dec (ICRS)	V,def,frame --OR--z
1	1-B335	19:37:00, 07:34:08	8.30 km/s,lsrk,RADIO

Expected Source Properties

	Peak Flux	SNR	Linewidth	RMS (over 1/3 linewidth)	linewidth / bandwidth used for sensitivity	Pol.	Pol. SNR
Line	1.00 mJy	0.0	1 km/s	20.28 mJy, 8.9 K	0.0002	0.0%	0.0
Continuum	5.00 mJy	31.8				0.0%	0.0

Dynamic range (cont flux/line rms): 0.2

1 Tuning

Tuning	Target	Rep. Freq. Sky GHz	RMS (Rep. Freq.)	RMS Achieved
1	1	404.976918	157.18 µJy, 69.3 mK	157.18 uJy - 258.69 uJy

Sensitivity Comments

Note that one or more of the S/N estimates are < 3. Please double-check the RMS and/or line fluxes entered and/or address the issue belo
Note that the bandwidth used for sensitivity is larger than 1/3 of the linewidth.
The S/N achieved for a resolution element that allows the line to be resolved will be lower than that reported.

Justification for requested RMS and resulting S/N (and for spectral lines the bandwidth selected) for the sensitivity calculation.

Sensitivity is based on our extensive archival search, selecting the B7 observations for each image, scaling to the other bands, and checking with any available data in the corresponding bands (correcting for angular resolution differences).

We also have to take into account the extent of the emission, in order to calculate brightness (mJy/beam) from flux density (mJy), for the given resolution element. We estimate, based on our inspection of multi-band archival data for HH212, that the dust may extend out to a distance equal to 50\% the major axis of the Gaussian component of the dust continuum emission. Hence, where we see the disk fit with a Gaussian mask with a semi-major axis of 0.3", then we account for a dust extent outside the disk mask to cover the area of A*pi(0.15")^2. Accordingly, we calculate how many beams (0.05") fit within the extension, in order to achieve the minimum mass at a 5sigma level. We require a 5sigma level detection of the same mass threshold in each band in order to generate spectral index maps (realizing that the lower bands require deeper observations to reach the same mass threshold due to the spectral index).

Justification of the chosen angular resolution and largest angular scale for the source(s) in this Science Goal.

The angular resolution is chosen to correspond to 20 au at the distance of each respective source. Largest angular scale is based on inspection of archival data, noticing the width and extent of continuum emission coincident with the cavity wall (see Figure 1). We do not need ACA for extended emission beyond what the 12m-array can recover (few arcsec).

Correlator Comments

Note that the spectral resolution is larger than 1/3 of the the spectral line width and that your line may not be resolved.

Justification of the correlator set-up with particular reference to the number of spectral resolution elements per line width.

For each band, we selected the spectral setup to obtain maximum continuum bandwidth (7.5 GHz), while also using FDM for high enough spectral resolution (0.53 km/s, depending on band) to strategically observe specific spectral lines simultaneously. Channels with spectral line emission will be identified and excluded for continuum analysis (line widths are expected to be narrow, and will not dominate the continuum bandwidth).