

# Tentative co-orbital submillimeter emission within the Lagrangian region $L_5$ of the protoplanet PDS 70 b

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## ABSTRACT

**Context.** High-spatial resolution ALMA data have revealed a plethora of substructures in protoplanetary disks. Some of those features are thought to trace the formation of embedded planets. One example is the gas and dust accumulated in the co-orbital Lagrangian regions  $L_4/L_5$ , which were tentatively detected in the recent years and might be the pristine material for the formation of Trojan bodies.

**Aims.** This work is part of the TROY project, whose ultimate goal is to find robust evidence of exotrojan bodies and study their implications in the exoplanet field. Here, we focus on the early stages of the formation of these bodies by inspecting the iconic system PDS 70, the only confirmed planetary system in formation.

**Methods.** We re-analyse archival high-angular resolution Band 7 ALMA observations from PDS 70 by doing an independent imaging process to look for emission in the Lagrangian regions of the two detected gas giants protoplanets, PDS 70 b and c. We then project the orbital paths and visually inspect emission features at the regions around the  $L_4/L_5$  locations as defined by  $\pm 60^\circ$  in azimuth from the planet position.

**Results.** We find emission at a  $\sim 4\text{-}\sigma$  level ( $\sim 6\text{-}\sigma$  when correcting from JvM effect) at the position of the  $L_5$  region of PDS 70 b. This emission corresponds to a dust mass in a range of  $0.03\text{--}2 M_{\text{Moon}}$  potentially accumulated in this gravitational well.

**Conclusions.** The tentative detection of the co-orbital dust trap that we report requires additional observations to be confirmed. We predict that we could detect the co-orbital motion of PDS 70 b and the dust presumably associated with  $L_5$  by observing again with the same sensitivity and angular resolution as early as February 2026.

**Key words.** Planet-disk interactions - Planetary systems - Planets and satellites: detection, formation - Protoplanetary disks - Stars: early-type - Techniques: interferometric

## 1. Introduction

Trojan asteroids are common inhabitants of the Solar System. They are minor bodies<sup>1</sup> populating the  $L_4$  and  $L_5$  Lagrange regions of a planet, leading and trailing it  $60^\circ$  apart in the same orbital path. Laughlin & Chambers (2002) theoretically demonstrated that Trojans as massive as the main planet could be long-term stable, thus inspiring the concept of co-orbital planets. The fact that the stability condition for co-orbitals is met for pairs of bodies with similar masses opens the possibility of searching for exotrojans using the same methods and instruments as for the currently confirmed exoplanets (e.g., radial velocities, Giuppone et al. 2012, Leleu et al. 2015; transit timing variations, Haghhighipour et al. 2013; transits themselves, Hippke & Angerhausen 2015; or the combination of transit and radial velocity data, Leleu et al. 2017). However, the efforts in the search for exotrojan planets have resulted in a handful of non-confirmed

candidates so far (Lillo-Box et al. 2014; Hippke & Angerhausen 2015; Lillo-Box et al. 2018a; Lillo-Box et al. 2018b).

Several numerical and hydrodynamical simulations on the evolution of planets embedded in protoplanetary disks agree in converging to solutions compatible with Trojan formation. These simulations show that dust particles preferentially accumulate at the  $L_4$  and  $L_5$  regions of the protoplanet (e.g., Laughlin & Chambers 2002; Beaugé et al. 2007; Montesinos et al. 2020). The enhanced dust growth at these locations can form planetesimals and, eventually, rocky bodies with masses as high as those of super-Earths (e.g., Lyra et al. 2009). Therefore, Trojans might be a natural byproduct of planetary formation through in-situ formation mechanisms. Their assembling could be studied at the earliest stages, when protoplanets are still embedded within protoplanetary disks. Furthermore, they might be unique targets to study what protoplanet interiors are made of, since Trojans and planets are most likely formed simultaneously (e.g., Bae et al. 2019 results suggest that grains find difficulties to accumulate in the Lagrangian regions once the planet has carved a gap).

<sup>1</sup>The largest known is the Jupiter Trojan (624) Hektor with  $\sim 220$  km of diameter (Marchis et al. 2014).

High-angular resolution observations of protoplanetary disks (mainly in the submillimeter range) have shown that the presence of substructures such as gaps and rings is very common (e.g., Garufi et al. 2018; Andrews 2020; Benisty et al. 2022). In particular, two of those disks show continuum emissions that could be explained by dust accumulations in the Lagrangian regions of non-detected planets, thus becoming an indirect hint for the presence of such young protoplanets. One case is HD 163296, which shows a well-defined arc-like feature inside a gap satisfactorily reproduced by simulations of dust co-rotating with a potential protoplanet (Isella et al. 2018; Rodenkirch et al. 2021; Garrido-Deutelmoser et al. 2023). The other is LkCa 15, for which Long et al. 2022 have reported two emissions at  $\sim 10\text{-}\sigma$  significance separated  $120^\circ$  in azimuth with shapes comparable to those found in simulations (e.g., Zhang et al. 2018). These claims are an indirect method to infer the presence of (yet undetected) protoplanets, and also the first evidence of exotrojan formation.

The K7 T-Tauri star PDS 70 (Pecaut & Mamajek 2016; Müller et al. 2018) is a unique target for planetary formation studies since it harbors the only robust detection of two protoplanets. It is surrounded by a highly structured protoplanetary disk with a wide inner cavity presumably carved by the planets. Both planets have been observed at infrared and submillimeter wavelengths and at different epochs (e.g., Keppler et al. 2018, Wagner et al. 2018, Haffert et al. 2019, Isella et al. (2019), Benisty et al. 2021). This has enabled modelling their orbits, which appear to be migrating into a 2:1 mean motion resonance (Bae et al. 2019; Wang et al. 2021). As an example of how insightful this system is for planet formation studies, Benisty et al. 2021 recently reported the detection of emission co-located with PDS 70 c, possibly the first detection of a circumplanetary disk (CPD).

In this letter, through a re-analysis of archival public ALMA data, we search for excess emission compatible with dust accumulation in the Lagrangian regions of both protoplanets around PDS 70. This work is part of the TROY<sup>2</sup> project (Lillo-Box et al. 2018a), which is devoted to hunting the first exotrojans and studying their impact in planetary systems. In Sect. 2 we describe the observational data, and we present the results of our search in Sect. 3. Section 4 is dedicated to discussing a potential detection of dust accumulation in the  $L_5$  region of PDS 70 b. We provide our conclusions along Sect. 5.

## 2. Observations

In this work, we use as starting point the combined self-calibrated ALMA dataset used by Benisty et al. (2021). They included submillimeter continuum data in Band 7 at wavelength  $855\ \mu\text{m}$  from program IDs 2018.A.00030.S, 2015.1.00888.S, and 2017.A.00006.S. In particular, we worked with their combination of three observations gathered at different epochs and different baselines. For more details on the calibration, and centering of these datasets, we refer the reader to the seminal publication.

The difference between the combined image showed in Benisty et al. (2021) and the one from this work is the imaging procedure. We used the Common Astronomy Software Applications package (CASA; McMullin et al. 2007) version 6.1.1. We imaged the visibilities of their self-calibrated data using the

task `tclean`, a Multi Frequency Synthesis mode and a multi-scale clean deconvolution algorithm with scales of 0, 1, and 2 times the beam FWHM. Briggs weighting (Briggs & Cornwell 1992) was tested using different robust parameters, finally, we chose  $r = 1.7$  since it provided the best trade-off between sensitivity and angular resolution with the best signal to noise ratio (see Appendix A). A map size of  $2000 \times 2000$  pixels was produced, with a pixel size of  $0.005''$ . The final image was corrected from the primary beam response showing a synthesized beam size of  $0.058'' \times 0.052''$  a position angle of  $58.71^\circ$ , and a root mean square (*rms*) equal to  $11\ \mu\text{Jy beam}^{-1}$  calculated as the standard deviation in the whole image not corrected from primary beam but excluding the disk. In order to follow a very conservative analysis of the data, we perform our analysis without applying the JvM correction (Jorsater & van Moorsel 1995; Czekala et al. 2021) that was used in Benisty et al. (2021). Yet, we also show in Appendix A the impact of the robust parameter for JvM corrected images.

## 3. Results

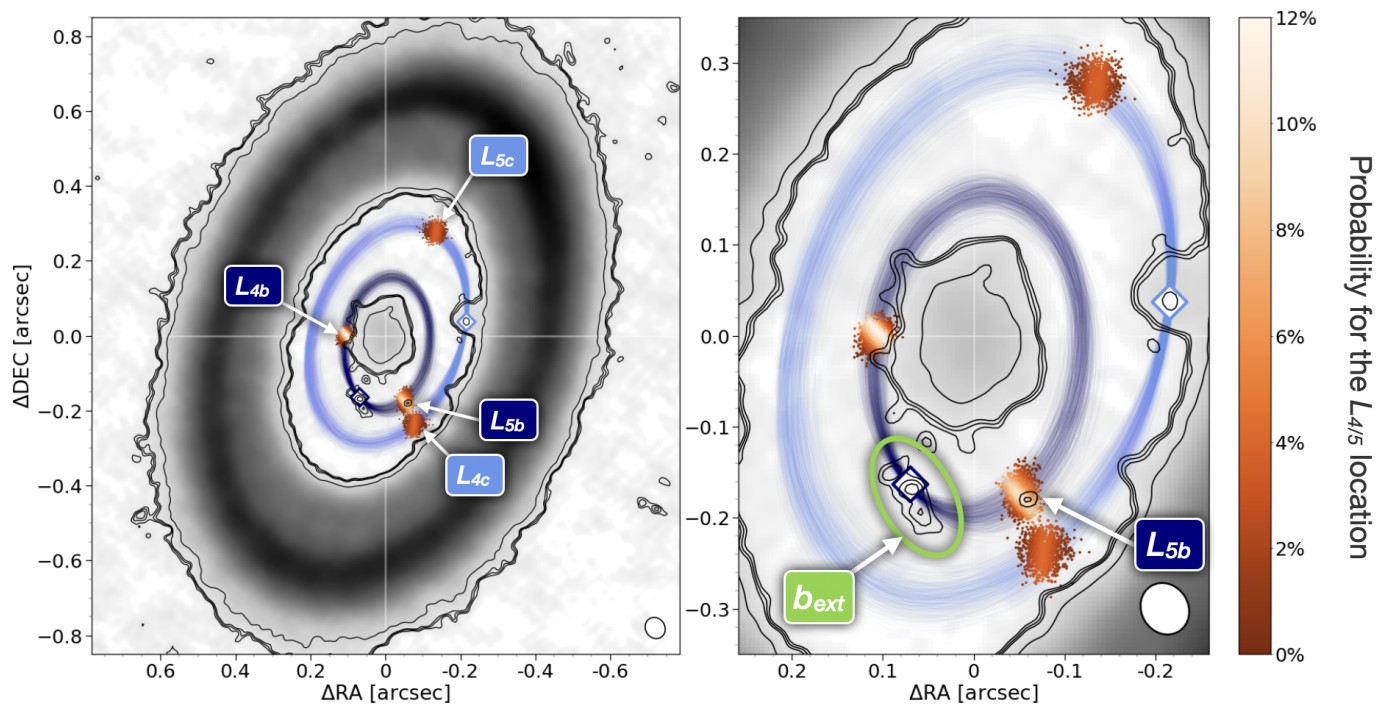
The center of the combined ALMA image in the original publication (Benisty et al. 2021) is defined by the center of an ellipse fitting the emission maximum of the outer ring in the image plane. In order to avoid any effect induced by different cleaning processes, we center the orbit using as criterion that the reported position by the authors of the planet c must match the maximum of its submillimeter emission. This corresponds with an offset with respect to the center of the observations of  $\Delta\text{RA} = 9.5\ \text{mas}$  and  $\Delta\text{DEC} = 12.5\ \text{mas}$  (center marked with white lines on Fig. 1), which is compatible with their uncertainties and also is in good agreement with the offset reported by the authors when modelling the outer disk with the `frank` (Jennings et al. 2020) package ( $\Delta\text{RA} = 12\ \text{mas}$  and  $\Delta\text{DEC} = 15\ \text{mas}$ ).

We project the orbits of PDS 70 b and c onto the image based on the orbital parameters derived by Wang et al. (2021). We generate  $10^3$  random orbits for each planet taking normal distributions centered in the dynamically stable parameters within  $1\text{-}\sigma$  (see Table 3 from their work). Additionally, we restrict to those that cross the positions of the submillimeter peak emissions associated with both planets in our image (as reported by Benisty et al. 2021). For each of the orbits, we locate the corresponding minimum of the gravitational well of the  $L_4$  and  $L_5$  points, at  $\pm 60^\circ$  in azimuth from those peak intensities within the orbits. In Fig. 1 we show the PDS 70 continuum image with the contour lines corresponding to 3, 3.5, 4, and  $8\text{-}\sigma$ , where  $\sigma$  is the *rms* of the image as stated in Sect. 2. The Table B.1 from Appendix B lists the positions for the maximum of the submillimeter emission associated with the planets and their Lagrangian points at the time of the long baseline observations (July 2019).

From Fig. 1, we visually find a match between a submillimeter unresolved compact emission detected with a significance of near  $4\text{-}\sigma$  ( $\sim 6\text{-}\sigma$  with the JvM corrected image, see Appendix C) and the expected position of the  $L_5$  point of the submillimeter extended emission associated with PDS 70 b (hereafter  $L_{5b}^3$ ). Conversely to planet c, the peak of the submillimeter emission associated to PDS 70 b is shifted from the infrared centroid as already discussed by Isella et al. (2019) and Benisty et al. (2021). In Appendix D we repeat the same exercise but considering the infrared position of the planet, concluding that this new compact

<sup>2</sup><https://www.troy-project.com/>

<sup>3</sup>We use equivalent notation for the other Lagrangian regions.



**Fig. 1.** PDS 70 ALMA observations with the projected planetary orbits and Lagrangian points ( $L_4$  and  $L_5$ ) distributions. The background image (inverted grayscale) corresponds to the continuum observations from the combined ALMA data (see Section 2). The locations for the corresponding  $L_4/L_5$  points for each orbit (total of  $10^3$  for each planet) are plotted with dots, whose density is represented by the colors of the right-hand side bar (note that lighter colors denote a higher density of points/probability for the location). The origin of coordinates is shown with white lines. The synthesized beam ( $0.058'' \times 0.052''$ , PA =  $58.71^\circ$ ) is represented on the bottom right of each panel by a white ellipse. Diamond-shaped markers indicate the planets locations. Contours correspond to 3, 3.5, 4, and 8- $\sigma$ . *Left:* global picture of PDS 70. *Right:* zoom to the inner cavity to inspect the  $L_5$  region of PDS 70 b. In green is indicated the extended emission associated with planet b reported by Isella et al. 2019.

emission is fully compatible with dust librating within the  $L_{5b}$  region.

We find this new emission using the same dataset published in Benisty et al. (2021) as the result of carrying out a cleaning focused on maximizing the signal to noise ratio within the disk cavity. Their goal was the analysis of the CPD around PDS 70 c whose emission is noticeably stronger and thus they did not require a cleaning so close to the noise level. To reach the required sensitivity for this tentative detection, it has been key to use the combined data from the three different epochs. We have checked that over these epochs no effect is expected due to the motion of the emission in  $L_{5b}$ . Between August 2016 and July 2019 the motion following the orbit of planet b should have been around half of the beam size, thus not being sensitive to it.

We can do a rough estimation of the dust mass potentially trapped in the  $L_{5b}$  region by using the equation derived by Hildebrand (1983), for which the dust mass ( $M_d$ ) scales with the flux density ( $F_\nu$ ):

$$M_d = \frac{F_\nu d^2}{\kappa_\nu B_\nu(T)}, \quad (1)$$

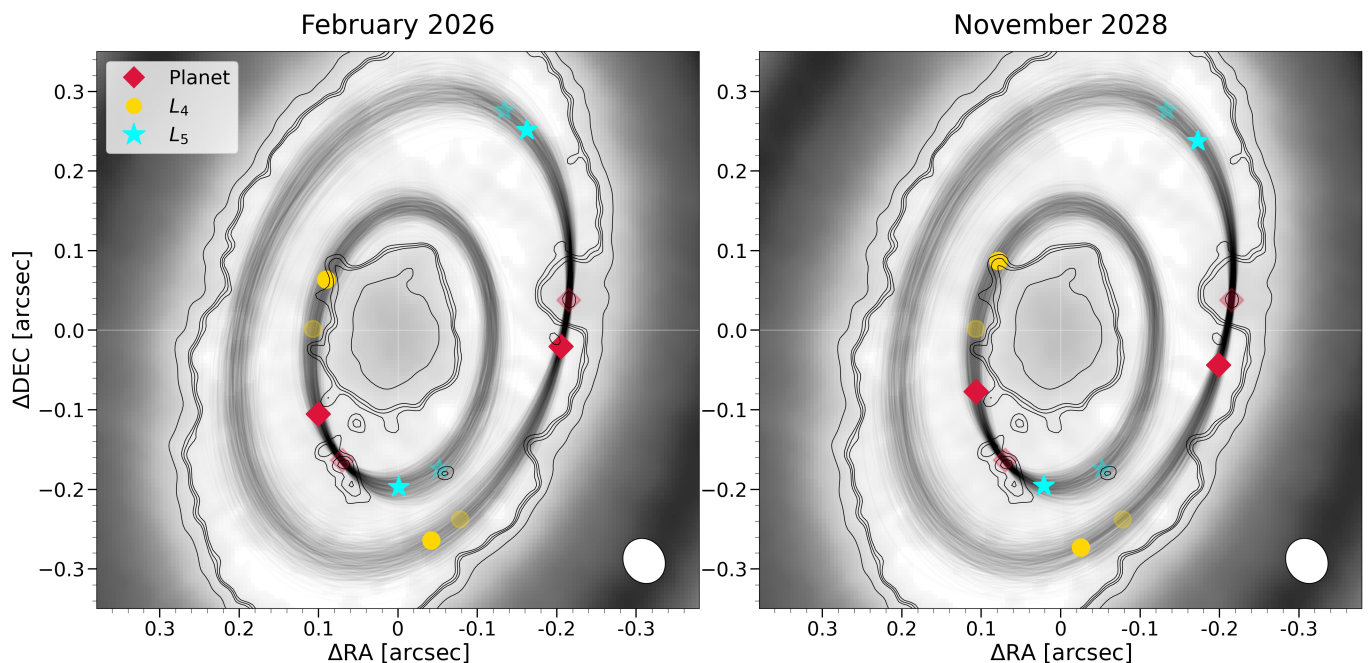
where  $d$  is the distance to the source,  $\kappa_\nu$  the dust opacity, and  $B_\nu(T)$  the black-body emission for a source with an effective temperature  $T$ . We assume that the emission at  $855 \mu\text{m}$  is optically thin and it comes from dust thermal emission. The estimated flux density of the compact emission (which is the same as the peak intensity for an unresolved source) is  $40 \mu\text{Jy}$ . We assume a dust temperature of 19 K as estimated by Keppler et al.

(2019) due to the stellar irradiation at the separation of PDS 70 b ( $\sim 22$  au), and use the dust opacity from Birnstiel et al. (2018) at a close frequency as an approximation ( $\kappa_{0.88 \text{ mm}} = 3.6 \text{ cm}^2 \text{ g}^{-1}$ ). We consider an uncertainty in the temperature of  $\pm 5$  K, a 25% in the dust opacity, and  $\sqrt{rms^2 + \Delta F_{calib}^2}$  for the density flux, where we take  $\Delta F_{calib} = 10\%$  of the measured density flux. Thus, the dust mass traced at this wavelength is in the range of  $0.0004 - 0.02 M_\oplus$ , or equivalently  $0.03 - 2 M_{Moon}$ .

## 4. Discussion

Detecting the co-orbital motion of both the planet and the  $L_{5b}$  emission along the expected orbital path would provide additional evidence in favor of the exotrojan dust scenario. We consider a minimum spatial separation equal to the synthesized beam to be able to detect motions of planets and Trojans between two epochs (considering that the size of the synthesized beam is larger than the absolute astrometric accuracy, which in a very unfavorable scenario of poor atmospheric phase stability could be  $\sim 0.02''$  for a 4- $\sigma$  detection). Assuming that additional data of similar quality (at least the same sensitivity and spatial resolution) are obtained in the near future, we have studied the epoch when the orbital motion will be enough to move to a projected distance equivalent to the beam size. In Table B.1 and Fig. 2 we compare the July 2019 positions of the planets and their Lagrangian regions with their expected locations in February 2026 and November 2028. In the case of PDS 70 b, it will have moved a projected distance of  $0.065''$  by February 2026.





**Fig. 2.** Prediction for the positions of the planets and their Lagrangian points at different epochs. *Left:* minimum observing date to detect the co-orbital motion in the orbit of planet PDS 70 b. *Right:* equivalent for the orbit of planet PDS 70 c. Transparent symbols are the position in the current image epoch (July 2019) while solid symbols are for the epoch in the title. Same ALMA continuum image with same projected orbits as in Fig. 1. Contours are 3, 3.5, 4, and 8- $\sigma$ .

This is the earliest that we will be able to detect the motion of the three relevant locations of the orbit (planet b,  $L_{4b}$ , and  $L_{5b}$ ). This date is 6.6 years after the epoch of the ALMA image used in this work,  $\sim 6\%$  of its orbital period ( $P_b = 113 \pm 19$  years). This would be possible from Cycle 12 onwards due to spatial resolution considerations following the ALMA observatory long-term configuration schedule<sup>4</sup>.

We warn that this exercise is most favorable when performed at similar frequencies (i.e., Band 7). Dust grains with different sizes have different degrees of coupling to the gas and thus different dynamics (e.g., Lyra et al. 2009; Montesinos et al. 2020), and the extension and center of the emission may change. Indeed, this could explain the shift in the putative Trojan emissions detected in LkCa 15 when comparing Band 6 and 7 data by Long et al. (2022). Hence, to study the future orbital motion of the reported dust emission, it is better to perform observations at similar frequencies to guarantee that we are tracing the same dust population. If the Trojan nature of the  $L_{5b}$  emission is confirmed, observations at different frequencies could provide complementary information, valuable to understand the evolution of different dust grain-size populations in the co-orbital regions. These data would be very helpful to test different model predictions investigating the dust population at the two Lagrangian regions. For instance, two independent authors (Montesinos et al. 2020, Rodenkirch et al. 2021) predict that  $L_4$  region tends to harbor smaller dust grains than  $L_5$ .

Seminal works using these data speculate on the unclear nature of the extended emission associated with planet b (shown in green on the right panel of Fig. 1). Isella et al. (2019) proposed different scenarios: circumplanetary dust, trace of dust particles

<sup>4</sup><https://almascience.nrao.edu/observing/observing-configuration-schedule/long-term-configuration-schedule>

trapped in  $L_5$ , or a jet similar to those detected in accreting protostars. In this work, we identify an additional emission spatially compatible with the potential gravitational well of  $L_{5b}$ . Hence, it supports the trace of dust from the trailing Lagrangian point hypothesis. In particular, a plausible explanation for this extended emission could be that planet b dominates over the gravity of the forming Trojan and, therefore, it can be stealing the material from the surroundings leading to the starvation of its companion (e.g., Cresswell & Nelson 2009 argue that gas accretion increases the mass difference between the co-orbital pair).

It is important to highlight that the co-orbital motion does not necessarily mean orbiting in the surroundings of the minimum of the gravitational wells of the Lagrangian points  $L_4/L_5$ . Indeed, the libration amplitude can even enclose at the same time both of these points as well as  $L_3$ , what is known as a horseshoe orbit. For this reason, other substructures that are in the orbital path of the planets but do not exactly fall at the minimum of the gravitational wells could also be dust trapped in co-rotation. In the case of planet b, some substructures are seen coming out from the inner disk and near the location of  $L_{4b}$ . Nonetheless, this region is so close to the inner disk that prevents us from extracting any conclusion about its nature. Similarly, halfway between planet c and  $L_{4c}$  there is a prominence in the inner edge of the outer disk that falls in the orbital path of the outer planet. Higher angular resolution observations would be required to test if this emission could be separated from the outer disk and whether it moves in co-rotation with PDS 70 c. The fact that the most convincing of the signatures compatible with co-orbital dust is at the  $L_5$  region rather than  $L_4$  might be consistent with the theoretical results found in previous works. For instance, Montesinos et al. 2020 points out that planets create an overdensity in  $L_5$  compared to  $L_4$  that results in an asymmetry in the total bulk mass always in

favor of the trailing Lagrangian region, thus being expected to find more massive bodies there than in the leading one.

## 5. Conclusions

We re-analyse the combined ALMA observations of PDS 70 presented in Benisty et al. (2021) by doing an independent cleaning to search for dust accumulation in the Lagrangian regions of its two detected protoplanets. We find tentative emission at  $\sim 4\text{-}\sigma$  significance at the expected position of the Lagrangian region  $L_5$  of planet PDS 70 b, thus being a candidate precursor for the formation of a co-orbital body, or even the leftovers of a massive Trojan body already formed. This would be the third claim of dust trapping in a Lagrangian region of a protoplanet (the former were in HD 163296 and LkCa 15 disks). Nonetheless, this is the first time the position of such emission can be associated with the expected location of the Lagrangian region of a confirmed planet. For the sake of confirming or rejecting the Trojan candidate, we propose future ALMA observations to revisit the system. Since the orbit of PDS 70 b is known, we have shown that beyond 2026 we may be able to resolve the co-orbital motion.

If confirmed, this work represents observational support to the hypothesis of Trojan bodies being a common consequence of planetary formation. It encourages further surveys to find them in both young and evolved systems. Their existence and properties (chemical and dynamical) would provide additional hints for understanding the evolution of planetary systems as a whole. On the other hand, although ALMA is currently making such discoveries possible, its planned Wideband Sensitivity Upgrade (the top priority initiative for the ALMA2030 Development Roadmap) will be crucial to perform these studies in a much more efficient way.

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## Appendix A: Gallery of images for different Briggs robust values

In Fig. A.1 we show a gallery of images changing the Briggs robust parameter in the CASA cleaning routine. In all of them the emission at  $L_{5b}$  is found with a significance between 3 and 4- $\sigma$ , increasing for higher robust parameters since the sensitivity improves. The image shown in this work (see Fig. 1) uses  $r = 1.7$ . This is the value that maximizes the signal to noise ratio for our image in the inner cavity and hence provides the highest significance for the tentative detection. In Table A.1 we summarize the beam,  $rms$ , peak intensity and significance of the emission for each of those images.

**Table A.1.** Properties for the images with different robust values shown in Fig. A.1.

JvM corrected	Briggs Parameter	Beam [mas $\times$ mas, $^\circ$ ]	$rms$ [ $\mu\text{Jy beam}^{-1}$ ]	Peak intensity $L_{5b}$ [ $\mu\text{Jy beam}^{-1}$ ]	Significance $L_{5b}$ emission
No	-0.5	21 $\times$ 21, 29.66	25.2	79.0	3.1- $\sigma$
	0.0	28 $\times$ 25, 40.96	17.3	56.4	3.3- $\sigma$
	0.5	44 $\times$ 36, 51.78	12.7	41.4	3.3- $\sigma$
	1.0	54 $\times$ 47, 57.33	11.3	38.3	3.4- $\sigma$
	1.5	58 $\times$ 51, 58.60	10.9	39.6	3.6- $\sigma$
	1.7	58 $\times$ 56, 58.71	10.9	39.9	3.7- $\sigma$
	2.0	59 $\times$ 52, 58.77	10.9	38.4	3.5- $\sigma$
Yes	-0.5	21 $\times$ 21, 29.66	18.9	59.3	3.1- $\sigma$
	0.0	28 $\times$ 25, 40.96	11.3	36.7	3.3- $\sigma$
	0.5	44 $\times$ 36, 51.78	7.36	25.4	3.4- $\sigma$
	1.0	54 $\times$ 47, 57.33	3.77	16.7	3.4- $\sigma$
	1.5	58 $\times$ 51, 58.60	3.08	18.0	5.8- $\sigma$
	1.7	58 $\times$ 56, 58.71	3.22	18.5	5.7- $\sigma$
	2.0	59 $\times$ 52, 58.77	3.01	14.9	5.0- $\sigma$

## Appendix B: Predicted astrometry to detect the co-orbital motion

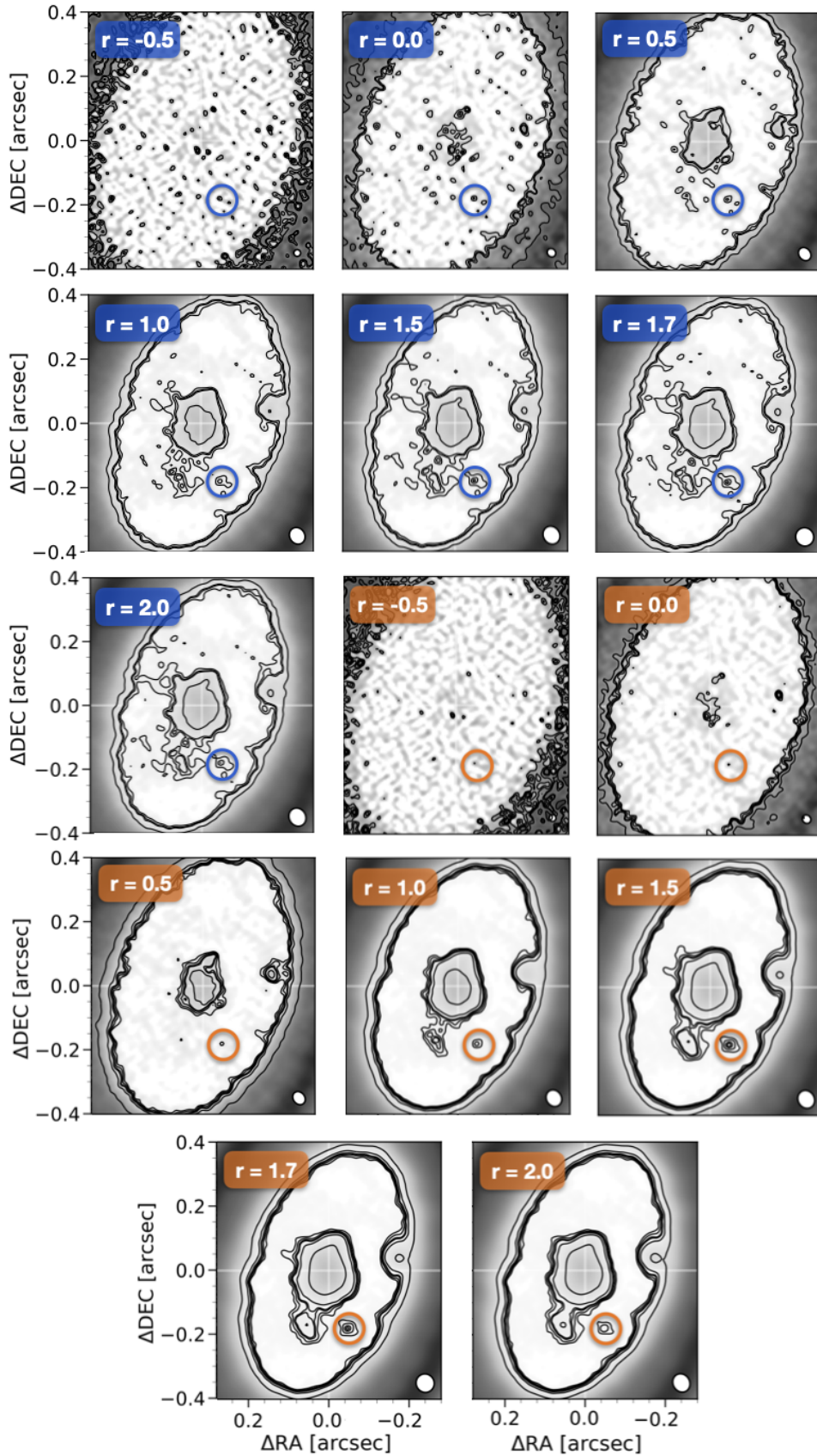
**Table B.1.** Coordinates with respect to the center of our image for the peak submillimeter emission of PDS 70 b and c and their  $L_4$  and  $L_5$  Lagrangian points. July 2019 is the epoch of the long baseline observation used in the composed image of this work. February 2026 and November 2028 are the minimum predicted dates to measure the co-orbital motion in PDS 70 b and c orbits respectively.

	July 2019		February 2026		November 2028	
	$\Delta RA$ [mas]	$\Delta DEC$ [mas]	$\Delta RA$ [mas]	$\Delta DEC$ [mas]	$\Delta RA$ [mas]	$\Delta DEC$ [mas]
PDS 70 b	70.1 $\pm$ 2.5	-163.0 $\pm$ 3.4	100.3 $\pm$ 5.0	-105.4 $\pm$ 7.0	106.5 $\pm$ 6.0	-77 $\pm$ 11
$L_{4b}$	107.0 $\pm$ 9.0	2.8 $\pm$ 9.0	90 $\pm$ 10	63 $\pm$ 10	79 $\pm$ 11	87 $\pm$ 10
$L_{5b}$	-51.8 $\pm$ 9.0	-174 $\pm$ 15	-0.9 $\pm$ 5.0	-196 $\pm$ 11	21.4 $\pm$ 8.0	-194.5 $\pm$ 9.0
PDS 70 c	-215.1 $\pm$ 1.8	37.8 $\pm$ 3.7	-205.2 $\pm$ 4.0	-19.9 $\pm$ 5.0	-199.0 $\pm$ 5.0	-43.7 $\pm$ 6.0
$L_{4c}$	-77 $\pm$ 13	-238 $\pm$ 14	-42 $\pm$ 12	-264 $\pm$ 13	-25 $\pm$ 15	-273 $\pm$ 15
$L_{5c}$	-134 $\pm$ 13	275 $\pm$ 13	-162 $\pm$ 10	251 $\pm$ 14	-173 $\pm$ 11	237 $\pm$ 12

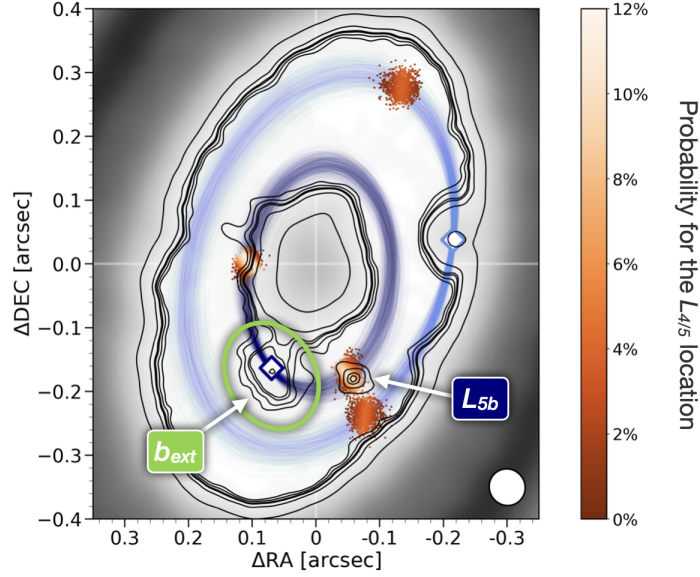
## Appendix C: JvM corrected image

In the cleaning process, the final image is the result of combining the model and the residual images. Nonetheless, there is a mismatch between the units of both images (Jy/CLEAN beam and Jy/dirty beam, respectively). Thus, the resulting flux scale is incorrect (Jorsater & van Moorsel 1995). Following the methodology of Czekala et al. (2021), we correct from this JvM effect by rescaling the residual image by the CLEAN beam/dirty beam volumes ratio before combining it with the model. We show the cleaned image in Fig. C.1. In particular, the emission falling in our interest region  $L_{5b}$  turns out to be at a 5.7- $\sigma$  level since the  $rms$  when using this correction is 3.2  $\mu\text{Jy beam}^{-1}$  and the peak intensity is 18.5  $\mu\text{Jy beam}^{-1}$ .





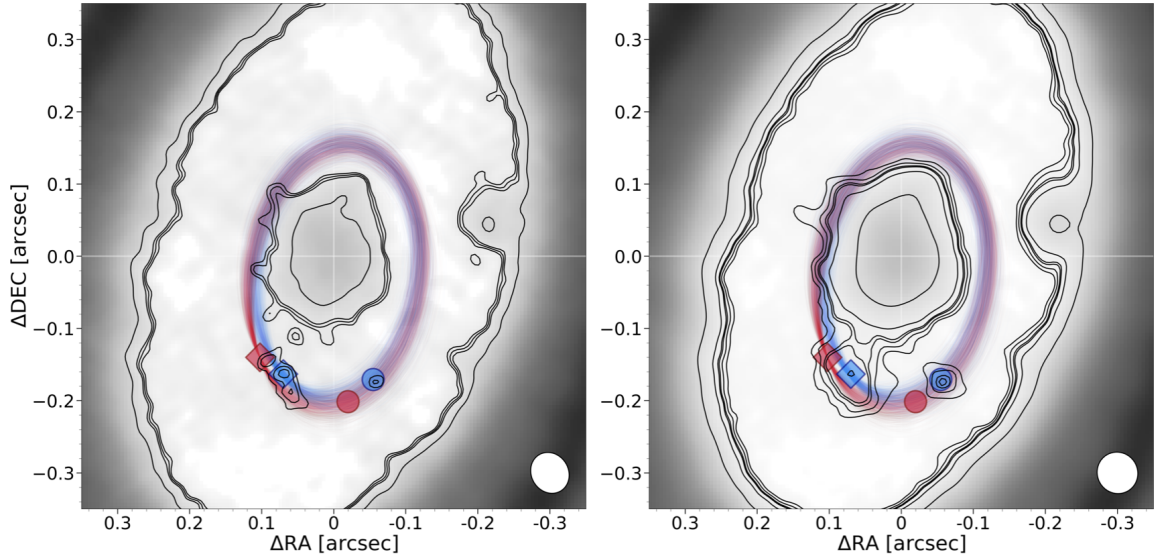
**Fig. A.1.** Gallery of images with different robust values as indicated in the upper left corner of each panel. The circle indicates the position of the  $L_{5b}$  emission. Panels with blue colors correspond with the image without the JvM correction, which contours are 2, 3, 3.5, and  $8\text{-}\sigma$ . Panels with orange colors are JvM corrected images and their contours indicate 3, 4, 5, 5.5, 8, and  $22\text{-}\sigma$ .



**Fig. C.1.** Same image as in Fig. 1 but applying the JvM correction. Contours are 3, 4, 5, 5.5, 8, and 22- $\sigma$ .  $L_{5b}$  submillimetric emission here is detected at  $\sim 6\text{-}\sigma$  of significance.

#### Appendix D: Shift between submillimeter and infrared emission of PDS 70 b

In order to consider the reported shift between the infrared and submillimeter positions for planet b, we have derived the location of the  $L_5$  point associated to the infrared position of the planet. We have used the position inferred in Wang et al. (2021) from the GRAVITY observations in the K-band, taken at the same epoch than the ALMA long baseline observations (July 2019):  $\Delta RA = (102.61 \pm 0.09)$  mas and  $\Delta DEC = (-139.93 \pm 0.24)$  mas. In Fig. D.1 we compare the orbits of planet b when restricting to the location of the planet in the infrared (red), and to the maximum of the submillimeter emission as in the main text (blue). The locations of the  $L_5$  points for each case are indicated with solid circles. As discussed in the main text, the blue circle perfectly matches the compact emission tentatively detected, while it is  $\sim 5^\circ$  in azimuth backward of the  $L_5$  point associated to the PDS 70 b infrared position. The orbital paths in both cases (blue and red) cross the detected emission. Hence, this compact emission perfectly lies within the Lagrangian region of the planet, and might be dust trapped in its potential well, co-orbiting with PDS 70 b, and librating in its  $L_5$  point.



**Fig. D.1.** Same ALMA image and contours than in Fig. 1 (left) and Fig. C.1 (right, which is JvM corrected). Diamond markers indicate the infrared position of PDS 70 b (in red) and the maximum of the submillimeter emission associated with PDS 70 b (in blue). The orbits are restricted to those crossing the position of the markers in each case. The big solid circles represent the location of the  $L_5$  points associated to the infrared position of the planet (in red) and to the peak of the submillimeter emission (in blue), respectively.