

Searching for a cometary belt around Trappist-1 with ALMA

Marino, S.; Wyatt, M. C.; Kennedy, G. M.; Kama, M.; Matrà, L.; Triaud, A. H. M. J.; Henning, Th

DOI:
[10.1093/mnras/staa266](https://doi.org/10.1093/mnras/staa266)

License:
None: All rights reserved

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (Harvard):
Marino, S, Wyatt, MC, Kennedy, GM, Kama, M, Matrà, L, Triaud, AHMJ & Henning, T 2020, 'Searching for a cometary belt around Trappist-1 with ALMA', *Monthly Notices of the Royal Astronomical Society*, vol. 492, no. 4, pp. 6067–6073. <https://doi.org/10.1093/mnras/staa266>

[Link to publication on Research at Birmingham portal](#)

Publisher Rights Statement:

This article has been accepted for publication in *Monthly Notices of the Royal Astronomical Society* ©: 2020 The Author(s). Published by Oxford University Press on behalf of the Royal Astronomical Society. All rights reserved.

General rights

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.



Searching for a dusty cometary belt around TRAPPIST-1 with ALMA

S. Marino^{1b}, ^{1★} M. C. Wyatt^{2b}, G. M. Kennedy^{3b}, ³ M. Kama^{2b}, ² L. Matrà^{4b},
A. H. M. J. Triaud⁵ and Th. Henning¹

¹Max Planck Institute for Astronomy, Königstuhl 17, D-69117 Heidelberg, Germany

²Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK

³Department of Physics, University of Warwick, Gibbet Hill Road, Coventry CV4 7AL, UK

⁴Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

⁵School of Physics & Astronomy, University of Birmingham, Edgbaston, Birmingham B152TT, UK

Accepted 2020 January 24. Received 2020 January 21; in original form 2019 September 19

ABSTRACT

Low-mass stars might offer today the best opportunities to detect and characterize planetary systems, especially those harbouring close-in low-mass temperate planets. Among those stars, TRAPPIST-1 is exceptional since it has seven Earth-sized planets, of which three could sustain liquid water on their surfaces. Here we present new and deep ALMA observations of TRAPPIST-1 to look for an exo-Kuiper belt which can provide clues about the formation and architecture of this system. Our observations at 0.88 mm did not detect dust emission, but can place an upper limit of 23 μ Jy if the belt is smaller than 4 au, and 0.15 mJy if resolved and 100 au in radius. These limits correspond to low dust masses of $\sim 10^{-5}$ to 10^{-2} M_{\oplus} , which are expected after 8 Gyr of collisional evolution unless the system was born with a >20 M_{\oplus} belt of 100 km-sized planetesimals beyond 40 au or suffered a dynamical instability. This 20 M_{\oplus} mass upper limit is comparable to the combined mass in TRAPPIST-1 planets, thus it is possible that most of the available solid mass in this system was used to form the known planets. A similar analysis of the ALMA data on Proxima Cen leads us to conclude that a belt born with a mass $\gtrsim 1$ M_{\oplus} in 100 km-sized planetesimals could explain its putative outer belt at 30 au. We recommend that future characterizations of debris discs around low-mass stars should focus on nearby and young systems if possible.

Key words: methods: numerical – techniques: interferometric – planets and satellites: dynamical evolution and stability – circumstellar matter – stars: individual: TRAPPIST-1 – planetary systems.

1 INTRODUCTION

In recent years, the study of planetary systems around low-mass stars has received great attention. This is partly due to low-mass planets being easier to detect via transits around low-mass stars, but also because their occurrence rate is higher compared to planets around FGK stars (e.g. Mulders, Pascucci & Apai 2015; Hardegree-Ullman et al. 2019). Moreover, because of the lower luminosity of M stars, close-in planets could harbour liquid water in these systems. One example of such systems is TRAPPIST-1, a M8 dwarf star at 12 pc hosting at least seven Earth-sized planets (Gillon et al. 2016, 2017; Luger et al. 2017), all within 0.06 au. Three of these planets lie at a distance from the star where long-lived liquid water could exist on their surfaces (O’Malley-James & Kaltenegger 2017), although constraints on the composition of these planets are still

very uncertain despite major efforts (e.g. de Wit et al. 2016, 2018; Dorn et al. 2018; Grimm et al. 2018; Moran et al. 2018; Burdanov et al. 2019; Wakeford et al. 2019). The composition of these planets is highly dependent on how these planets formed. For example, if they formed *in situ* these planets might be water poor (e.g. Hansen & Murray 2012), while if they formed further out and migrated in, as suggested by the near-resonant chain, then these planets might contain significant amounts of water (e.g. Cresswell & Nelson 2006; Terquem & Papaloizou 2007; Ormel, Liu & Schoonenberg 2017; Schoonenberg et al. 2019).

Moreover, volatile delivery through impacts of icy material formed further out (e.g. Kral et al. 2018; Marino et al. 2018; Schwarz et al. 2018; Dencs & Regály 2019) could also affect the composition of their atmospheres and surfaces. How much icy material lies exterior to a planetary system can be constrained by infrared observations which are sensitive to circumstellar dust that is continually replenished through the collisional breakup of km-sized planetesimals (i.e. debris discs, see reviews by Wyatt 2008; Krivov

* E-mail: sebastian.marino.estay@gmail.com

2010; Hughes, Duchêne & Matthews 2018). Thanks to *Spitzer* and *Herschel*, we know that at least 20 per cent of A–K type stars host exo-Kuiper belts that are orders of magnitude brighter (and likely more massive) than the Kuiper belt (Eiroa et al. 2013; Matthews et al. 2014; Montesinos et al. 2016; Sibthorpe et al. 2018). However, the constraints on planetesimal discs around M type stars are poorer due to several factors, including small grain removal processes (Plavchan, Jura & Lipsky 2005) and observational biases and low sensitivity (e.g. Wyatt 2008; Lestrade et al. 2009; Binks & Jeffries 2017; Kennedy et al. 2018).

Thanks to ALMA’s unprecedented sensitivity at sub-mm wavelengths, it is now possible to search for planetesimal discs around low mass stars at greater depth, and constrain the architecture of planetary systems around low mass stars. In this paper we report deep ALMA observations of TRAPPIST-1. While previous to our observations there was no evidence for the presence of dust around TRAPPIST-1, the efficient planet formation in this system, its potentially young age (highly unconstrained until recently) and its proximity made it an ideal target to look for a planetesimal belt. This paper is organized as follows. In Section 2, we describe the ALMA observations and place upper limits on dust emission levels. Then, in Section 3, we compare these dust upper limits with collisional evolution models. Finally, in Section 4, we summarize our results and conclusions.

2 ALMA OBSERVATIONS

We observed TRAPPIST-1 using ALMA band 7 (0.88 mm) as part of the project 2017.1.00215.S (PI: S. Marino). The observations were split into six blocks that were executed between 2018 May 3 and 2018 August 20, with a total time on source of 4.5 h. Observations were taken using a total of 44–48 antennas, with baselines ranging between 35 and 240 m (5th and 80th percentiles), which allows to recover structure on angular scales ranging between 0.37 and 5 arcsec (4.6 and 62 au projected in the sky). The average PWV ranged between 0.4 and 0.7 between the six blocks. The spectral set-up was divided into four windows to observe the continuum, centred at 334.6, 336.5, 348.5, and 346.6 GHz. The first three had a total bandwidth of 2 GHz and a channel width of 15 625 kHz, while the latter a total bandwidth of 1.875 GHz and a channel width of 488.281 kHz (effective spectral resolution of 0.845 km s^{−1}) to look for CO 3–2 line emission. Finally, the observations were calibrated using CASA and the standard pipeline provided by ALMA.

We image the continuum with the task *tclean* in CASA, using natural weights to produce a reconstructed image with the lowest possible noise. Fig. 1 presents the clean image, corrected by the primary beam and with a noise level or rms of 7.7 $\mu\text{Jy beam}^{-1}$ at the centre. We do not find any emission arising from circumstellar material around TRAPPIST-1. The only detected source ($>5\sigma$) is a marginally resolved object with a total flux 0.8 mJy that is likely sub-mm galaxy given ALMA number counts (we expect ~ 0.3 sources within the primary beam with a flux equal or larger than 0.8 mJy, Carniani et al. 2015; Simpson et al. 2015; Aravena et al. 2016). We also search for extended emission from an edge-on disc by computing the flux in a rectangular aperture centred on the star of width $1.5 \times \text{beam}$ (since we assume an edge-on disc co-planar with TRAPPIST-1 b–h) and variable length and position angle; no $>3\sigma$ detection was found.

We use the clean image to derive an upper limit on the 0.88 mm flux from any hidden dust in the system below our detection threshold. For an unresolved disc with a radius smaller than 4 au, we

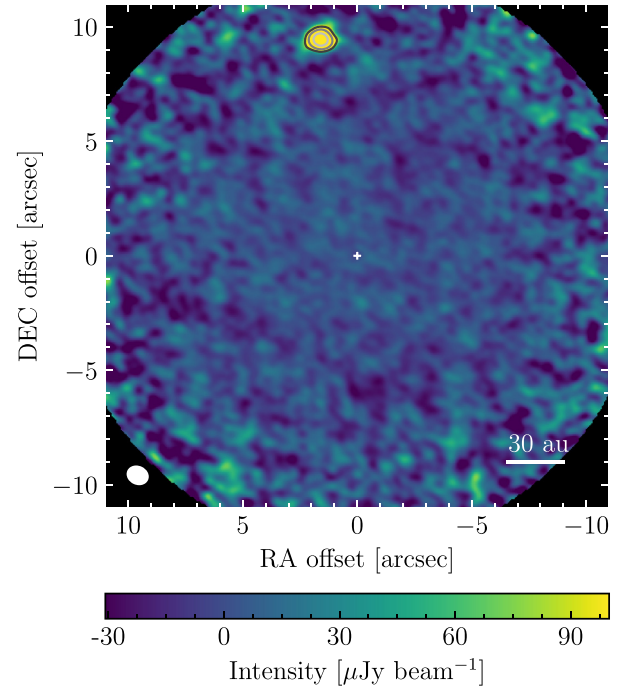


Figure 1. ALMA band 7 (0.88 mm) continuum image obtained with clean using natural weights. The beam size is 0.71 arcsec \times 0.54 arcsec and has a PA of 65 deg. The image rms is 7.7 $\mu\text{Jy beam}^{-1}$. The beam size is represented by a white ellipse on the bottom left corner. The black regions at the edges of the image represent where the sensitivity drops below 20 per cent of that at the image centre. The grey contours show emission above 5, 10, and 20 times the rms level.

obtain a 3σ limit of 23 μJy . A planetesimal belt in the system could be larger and resolved. For this case we derive a flux upper limit by estimating the integrated flux uncertainty over a rectangular aperture centred on the star as described above, also taking into account the number of beams in this area and how the noise level increases away from the phase centre. This leads to a flux upper limit that increases as a function of the disc diameter or aperture size, e.g. we find an upper limit of 150 μJy if it has an outer radius of 100 au. These flux upper limits can be converted to an upper limit on the disc fractional luminosity as a function of radius as shown in Fig. 2. For this, we assume the dust has blackbody equilibrium temperatures $T_{\text{BB}}(r) = 42(r/1 \text{ au})^{-1/2}$ ($L_{\star} = 5.2 \times 10^{-4} L_{\odot}$, Filippazzo et al. 2015) and an opacity that declines with wavelength as $1/\lambda$ beyond 200 μm (Wyatt 2008). In the same figure we also overlay in blue the upper limit derived from WISE 22 μm (3 mJy, Wright et al. 2010) and MIPS 24 μm observations (0.2 mJy, which are limited by calibration uncertainties of ~ 5 per cent, Gautier et al. 2007). We find that the ALMA limit is significantly more constraining than the WISE and MIPS limit beyond 0.4 au. This is due to its high sensitivity and the longer wavelength, being more sensitive to cold dust. Based on our new observations we can rule out a debris disc with fractional luminosity higher than $\sim 2 \times 10^{-5}$ at a radius between 10 and 100 au.

Note that assuming blackbody equilibrium temperatures only based on the stellar radiation might not be a good assumption since the interstellar radiation field (ISRF) could contribute significantly to the radiation field at tens of au. In order to take this into account, we calculate the dust temperature as $(T_{\text{BB}}^4(r) + T_{\text{ISRF}}^4)^{1/4}$, where T_{ISRF} is a fixed equilibrium temperature due to the ISRF.

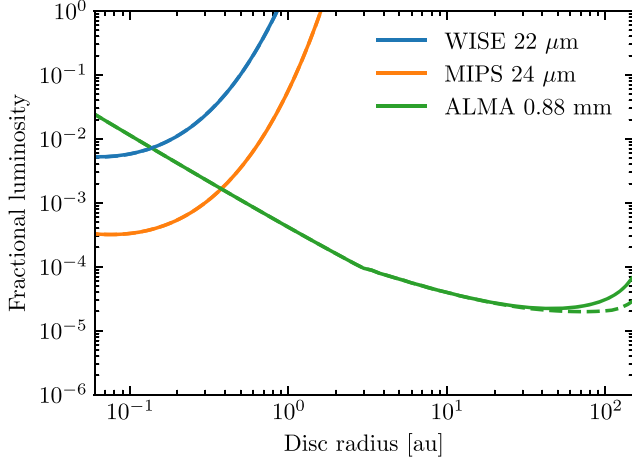


Figure 2. Upper limits on the fractional luminosity of a debris disc around TRAPPIST-1 based on WISE 22 μm (blue), MIPS 24 μm (orange), and ALMA 0.88 mm (green) data, assuming blackbody equilibrium temperatures (continuous lines). The dashed line represents the corrected limit by considering also the ISRF when calculating the equilibrium dust temperatures. Both green lines assume an edge-on disc orientation.

The equilibrium temperature of grains in the diffuse interstellar medium has been studied extensively (e.g. Li & Draine 2001), finding temperatures in the range 10–20 K for dust grains smaller than 1 μm , significantly higher than the blackbody equilibrium temperature of 3.6 K (obtained by integrating the analytic expressions presented by Mezger, Mathis & Panagia 1982; Mathis, Mezger & Panagia 1983). Larger grains, however, have lower temperatures close to blackbody since they have almost constant opacities at short wavelengths that dominate the ISRF. We thus assume $T_{\text{ISRF}} = 3.6$ K and incorporate this lower bound for dust temperatures to all calculations in Section 3. The green dashed line in Fig. 2 is the corrected upper limit when taking into account the ISRF.

We also look for any CO 3–2 line emission, which also led to a non-detection. The achieved rms per 0.42 km s^{-1} channel is 0.5 mJy beam^{-1} . Therefore we can set a 3σ upper limit of 6 mJy km s^{-1} for any unresolved CO 3–2 emission interior to 4 au and with a maximum Doppler shift of 10 km s^{-1} (i.e. beyond 1 au if in Keplerian rotation). Using the non-LTE tool by Matrà et al. (2018a) we translate this upper limit to a CO gas mass of $\sim 2 \times 10^{-8} M_{\oplus}$.

Because low-mass stars can have strong and highly variable emission at mm to cm wavelengths due to flaring activity, we also search for unresolved variable emission at the stellar position by imaging the data in time intervals of 12 s. In Fig. 3 we show the measured flux at the stellar position. We do not find any significant variable emission above the noise level (rms of 0.23 mJy over 12 s window) that could arise from flares (as in Proxima Cen, MacGregor et al. 2018). We only find three single 3σ peaks over 1400 data points which is roughly consistent with the expected number of false positives for a normal distribution. The non-detection of variable emission from TRAPPIST-1 is consistent with results reported by Hughes et al. (2019) which did not detect any emission at 3 mm with ALMA nor at 7 mm with the Very Large Array for TRAPPIST-1. Note that the limits presented here at 0.88 mm are still consistent with flaring levels similar to Proxima Cen when taking into account the integration length and larger distance to TRAPPIST-1.

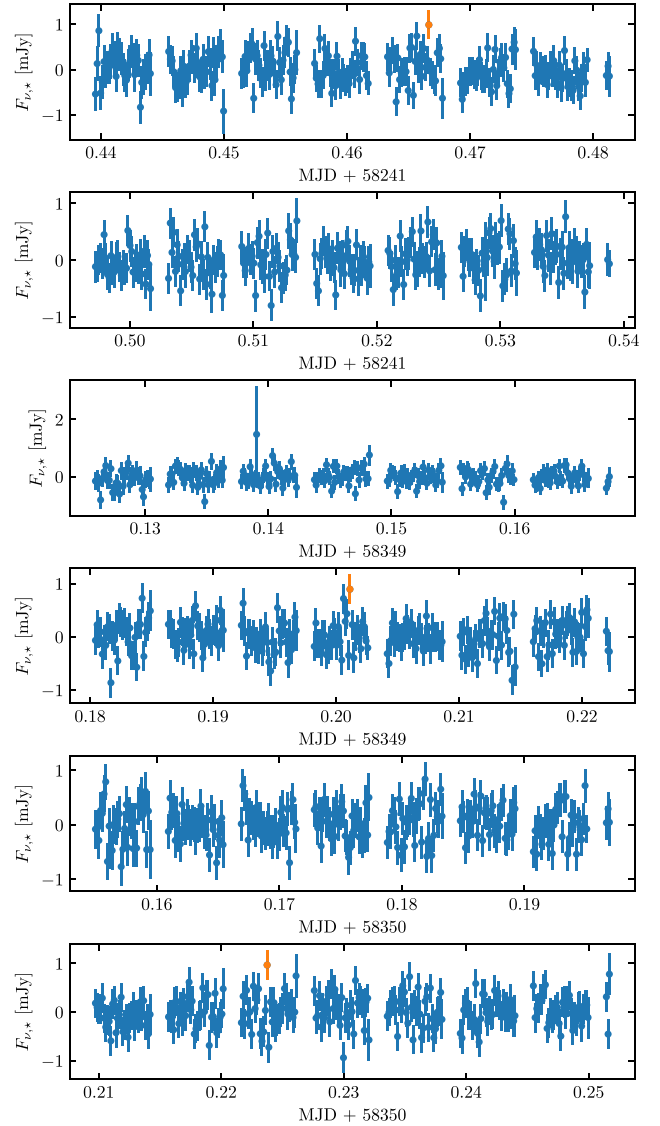


Figure 3. Measured flux at TRAPPIST-1 location versus time, integrated over 12 s windows. Data points above 3σ are displayed in orange.

3 DISCUSSION

In this section we aim to constrain what initial planetesimal belt properties are still consistent with the observational limits and what we can rule out. We do this by comparing a collisional evolution model to our non-detection of a debris disc around TRAPPIST-1 (Section 3.1) and to archival ALMA observations of Proxima Cen (Section 3.2).

We use the same collisional evolution model that has been used to fit observations of resolved debris discs (Wyatt, Clarke & Booth 2011; Marino et al. 2017). This model solves the evolution of the size distribution of solids in a collisional cascade, and here we assume the following:

- (i) a maximum planetesimal size of 100 km,
- (ii) size dependent strengths (Benz & Asphaug 1999; Stewart & Leinhardt 2009),
- (iii) internal densities of 2.7 g cm^{-3} ,
- (iv) mean orbital eccentricities of 0.05 and inclinations of 1.4 deg ($i \sim e/2$) that set the relative velocities,

(v) an initial surface density of solids equivalent to a Minimum Mass Solar Nebula (MMSN) extrapolated out to 100 au [$\Sigma(r) = (r/1 \text{ au})^{-1.5} M_{\oplus} \text{ au}^{-2}$, Weidenschilling 1977; Hayashi 1981).

For more detail on assumptions of this model we direct the reader to Wyatt et al. (2011) and Marino et al. (2017). The output from these simulations are size distributions at different radii that we translate to surface densities or disc masses in mm-sized grains, here defined as all grains smaller than 1 cm. These mm-sized grains are what our ALMA observations are most sensitive to, since grains in the range 0.1–10 mm dominate the emission at these wavelengths and the mass of grains smaller than 1 cm. This choice is consistent with the dust opacity that is assumed to translate fluxes to dust masses (see below).

3.1 TRAPPIST-1 collisional evolution

Given the estimated age of 7.6 ± 2.2 Gyr (Burgasser & Mamajek 2017), it is likely that any debris disc present around TRAPPIST-1 has suffered significant collisional evolution. This means that even if this system was born with a massive disc of planetesimals and detectable dust levels, after 8 Gyr of evolution it could have lost most of its mass through collisions and the removal of small dust subject to stellar winds and radiation pressure (although the latter is not high enough to remove grains larger than $\sim 0.01 \mu\text{m}$).

To quantify which initial planetesimal belt parameters are allowed by our non-detection, we derive an upper limit on the surface density and total mass of a collisionally produced dust disc by assuming:

- (i) the belt is edge-on, i.e. co-planar to TRAPPIST-1 b–h,
- (ii) a dust opacity of $3 \text{ cm}^2 \text{ g}^{-1}$ at 0.88 mm,
- (iii) equilibrium blackbody temperatures in the optically thin regime (considering both the stellar radiation and ISRF),
- (iv) a belt width that is half of the belt central radius (typical of debris discs, Matrà et al. 2018b).

The adopted dust opacity is consistent with the one expected for grains smaller than 1 cm in a size distribution according to our collisional evolution model, i.e. $N(a) \sim a^{-3.4}$ in the range $10 \mu\text{m}$ to 100 m (Woitke et al. 2016).

Fig. 4 compares the predicted surface density (top) and disc mass (bottom) in mm-sized grains at different epochs (continuous lines) with the 3σ upper limit derived by our observations (dashed lines). Note that our upper limits for the surface density do not correspond to expected disc profiles, but rather the maximum surface density if the planetesimal belt was centred at that radius and had a fractional width (width over central radius) of 0.5. Beyond 40 au, our model predicts dust levels that would be detectable. Therefore we conclude that our observations rule-out that TRAPPIST-1 was born with a planetesimal belt of mass similar to or larger than an MMSN ($\gtrsim 20 M_{\oplus}$) at a radius between 40 and 100 au. If we take the mass and orbits of TRAPPIST-1 planets derived by Grimm et al. (2018) we find a *minimum mass TRAPPIST-1 nebula* that is $\Sigma = 670 \pm 40 (r/0.02 \text{ au})^{-1.8 \pm 0.1} M_{\oplus} \text{ au}^{-2}$. This expression extrapolated to large radii translates into surface densities lower than assumed in our model and thus consistent with our non-detection. Note that this approach to derive an initial mass in solids assumes planets' orbits do not evolve significantly, which might not be the case for TRAPPIST-1 planets (Ormel et al. 2017; Schoonenberg et al. 2019). Moreover, extrapolating the relationship of stellar luminosity and belt radius found by Matrà et al. (2018a) to TRAPPIST-1's luminosity, we do not expect a belt radius larger than 25 au. Interior to 40 au, our upper limit is significantly higher than the

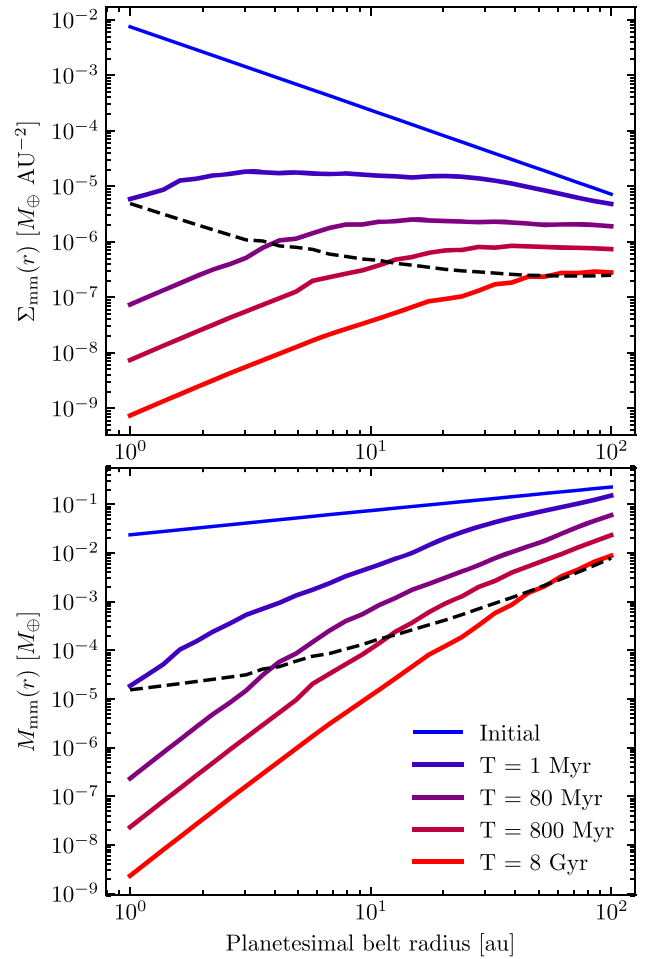


Figure 4. Collisional evolution of the surface density (top) and belt mass (bottom) in mm-sized grains around TRAPPIST-1, as a function of radius and time (continuous colour lines). As a comparison, the dashed line shows the ALMA upper limit derived in this work. The upper limit for the surface density is derived assuming a belt fractional width of 0.5 and an edge-on orientation (i.e. the dashed line shows the limit on the surface density of a belt at that radius, rather than the limit on the surface density of an extended disc at that radius).

predicted dust levels after 8 Gyr of evolution, hence collisional evolution alone can explain our disc non-detection, and thus a planetesimal disc more massive than an MMSN could have formed there when this system formed. Note that interior to 40 au this system could still host an MMSN-like planetesimal disc but that is faint today due to how the size distribution has evolved, with the mass in small bodies orders of magnitude more depleted than the mass in the largest bodies (Schüppler et al. 2016; Marino et al. 2017).

These conclusions hold when varying model parameters such as the maximum planetesimal size and level of stirring since the surface density of mm-sized grains in collisional equilibrium is not very sensitive to these (see equation 3 in Marino et al. 2019). Other assumptions to translate flux upper limits to surface densities could have a small effect. For example, assuming the belt is wider would distribute roughly the same dust mass upper limit (or flux upper limit) over a larger area, and thus it would lower our upper limit on the surface density derived from observations. Only by

decreasing the initial surface density of solids in our collisional model or narrowing the assumed belt, the predicted surface density of mm-sized dust would be lower than our upper limit at all radii. A caveat in the use of our collisional evolution model is that it assumes the system has been stable for 8 Gyr. The non-detection of a disc could also be explained by an instability in the system that scattered and depleted a massive planetesimal belt.

3.2 Proxima Cen collisional evolution

We applied the same model to Proxima Cen (age of ~ 5 Gyr, Bazot et al. 2016) which hosts a low mass temperate planet (Anglada-Escudé et al. 2016) and has also been observed by ALMA at 1.3 mm. To derive upper limits we re-imaged the data after applying the calibration script provided by ALMA. In the original analysis of the data by Anglada et al. (2017), they proposed the existence of warm dust component at 0.4 au, a cold belt at 1–4 au and an outer belt at 30 au. An independent analysis by MacGregor et al. (2018) of the same observations showed that in the same ALMA data there is strong and time variable flaring activity from Proxima Cen. This time-variable and unresolved emission could have misled Anglada et al. (2017) to conclude that there is circumstellar dust within a few au. Moreover, the signal from the putative outer belt after azimuthally averaging (as in Marino et al. 2016) is only marginally significant at 3.5σ . A future detailed analysis of more sensitive observations in the visibility space, taking into account the time variable emission of Proxima Cen, should be able to confirm or rule out the presence of dust emission in this system at the levels claimed by Anglada et al. (2017).

Despite this ongoing debate on the presence of debris-like dust around Proxima Cen, in Fig. 5 we compare the results from collisional evolution with the upper limits from the ACA map (dotted line) and 12m and ACA combined (dashed line) assuming a disc inclined by 45 deg and azimuthally averaging. We find that the ACA observations could have marginally detected a disc if it had a mean radius between 10 and 40 au and was as massive as an MMSN ($10\text{--}20 M_{\oplus}$) under the assumptions stated above. This mass however is not well constrained since interior to 40 au the whole size distribution is in collisional equilibrium (proved by the constant slope of $r^{7/3}$ in the model surface density, Wyatt 2008; Kennedy & Wyatt 2010). This means that even if the belt had started with a larger mass it would have depleted faster reaching the same mass after 5 Gyr. By varying the initial disc mass we find that discs with a mass lower than a tenth of an MMSN would have a surface density below the detection limit (at ~ 30 au). Therefore, we conclude that the amount of mm-sized dust in the putative outer belt around Proxima Cen is not unrealistic, and roughly consistent with the collisional evolution of a planetesimal belt that was born with a tenth of an MMSN ($1\text{--}2 M_{\oplus}$).

3.3 Searching for debris-like dust around low mass stars

In this paper we have shown how important collisional evolution is when interpreting upper limits on the presence of dust around low mass stars. At tens of au, the dust mass is expected to decrease with age roughly as $t^{-0.4}$ while the lifetime of the largest planetesimals is longer than the age of the system, and t^{-1} at later times (e.g. Löhne, Krivov & Rodmann 2008). Thus, the age of surveyed systems is a key factor to consider when selecting targets to observe. In addition to this, the distance to the source is very important too since the flux

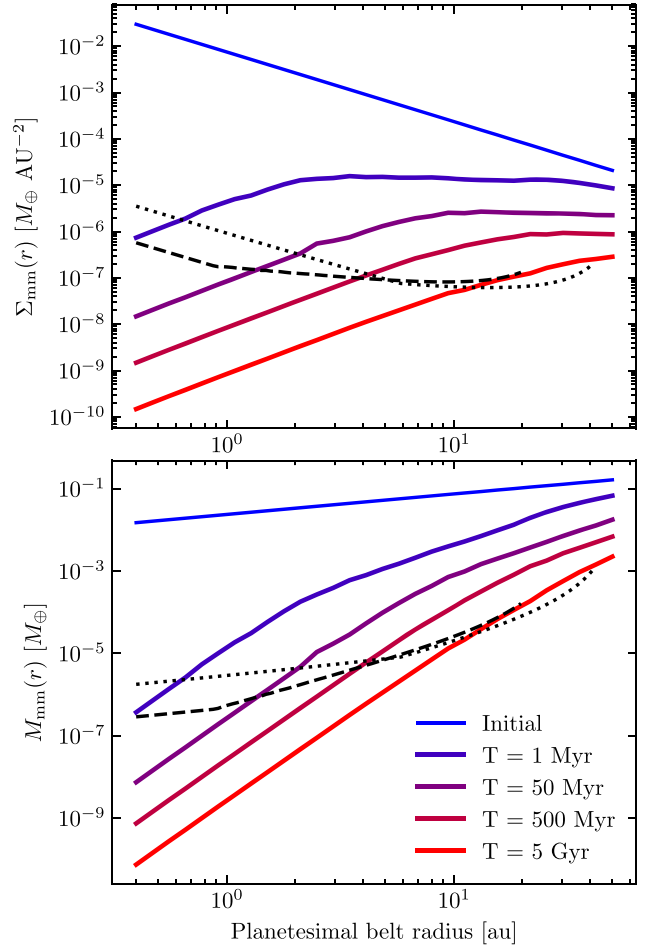


Figure 5. Collisional evolution of the surface density (top) and belt mass (bottom) in mm-sized grains around Proxima Cen, as a function of radius and time (continuous colour lines). As a comparison, the dashed and dotted lines show the ALMA upper limit derived using the 12m+ACA and ACA alone images, respectively. The upper limit for the surface density is derived assuming a belt fractional width of 0.5 and a belt inclination of 45 deg as suggested by Anglada et al. (2017).

is inversely proportional to the distance squared. Proof of this is that the sensitivities or upper limits on the dust mass around Proxima Cen are ~ 5 times better than for TRAPPIST-1, even though the noise in the reconstructed images was poorer. Future searches should take into account both age and distance to be the most sensitive to debris-like dust. Therefore, we recommend then that surveyed samples should be composed of young and nearby systems that are expected to have the largest flux, i.e. that minimize the quantity $t^{0.4} d^2$ if the largest planetesimals are not yet in collisional equilibrium ($r > r_c$ in equation 8 from Marino et al. 2017), or td^2 if they are ($r < r_c$).

4 SUMMARY AND CONCLUSIONS

In this paper we have reported new ALMA observations around TRAPPIST-1 at 0.88 mm, the deepest to search for dust emission from a debris disc around this system. These observations did not detect circumstellar dust or CO 3–2 emission. We compared our dust upper limits with collisional evolution models, which given

TRAPPIST-1's age of ~ 8 Gyr predict detectable dust levels beyond 40 au if the initial disc was as massive as an MMSN. Therefore our model rules-out that TRAPPIST-1 was born with a planetesimal belt larger than 40 au and with a mass similar or higher than an MMSN ($\gtrsim 20 M_{\oplus}$). Within 40 au, on the other hand, the surface density or total mass of mm-sized dust could be simply depleted due to collisional evolution and avoid detection. The solid mass upper limit derived here is comparable to the mass in TRAPPIST-1 planets ($\sim 5.7 M_{\oplus}$, Grimm et al. 2018), thus it possible that most of the available solid mass in these systems was transported inwards and used to form the known planets.

We searched in time bins of 12 s for any flaring activity of TRAPPIST-1 that could be present in this data. We did not find any significant emission, and we derive a 5σ upper limit of 1.2 mJy for variable emission over 12 s windows.

Given the available archival ALMA data on Proxima Cen, also a system around a low-mass star hosting a low mass temperate planet, we performed a similar analysis. We compared our model with ALMA observations and showed that the current upper limits are slightly below the mass of mm-sized dust that we expect given our collisional evolution model. The archival observations could have marginally detected a belt with a mean radius between 10 and 40 au and with an initial mass $\gtrsim 1 M_{\oplus}$. This means that the marginal detection of an outer belt at 30 au by Anglada et al. (2017) is consistent with our collisional evolution model and a belt that was born with a tenth of an MMSN. An even more massive disc would have collisionally evolved to the same mass and thus these observations cannot constrain well the initial mass of a putative planetesimal belt. Interior to 10 au, the limits cannot rule out that the system was born with a planetesimal belt more massive than an MMSN.

We conclude that in order to set tighter constraints on planetesimal discs around low mass stars with planets, we should focus most efforts on nearby and, if possible, young ($\lesssim 1$ Gyr old) systems. Nearby systems ensure a higher flux with a strong dependence on the distance, while younger systems are also more likely to host not yet collisionally depleted belts beyond a few au. In Section 3.3 we showed how the flux depends more strongly on the distance, and how both distance and age can be taken into account when prioritising which targets to observe. Such systems could provide important constraints to the formation of planetary systems around low-mass stars.

ACKNOWLEDGEMENTS

GMK is supported by the Royal Society as a Royal Society University Research Fellow. LM acknowledges support from the Smithsonian Institution as a Submillimeter Array (SMA) Fellow. MK gratefully acknowledges funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Fellowship grant agreement no. 753799. TH acknowledges support from the European Research Council under the Horizon 2020 Framework Program via the ERC Advanced Grant Origins 83 24 28. This paper makes use of the following ALMA data: ADS/JAO.ALMA#2017.1.00215.S and ADS/JAO.ALMA#2016.A.00013.S. ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada), MOST and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ.

REFERENCES

- Anglada G. et al., 2017, *ApJ*, 850, L6
 Anglada-Escudé G. et al., 2016, *Nature*, 536, 437
 Aravena M. et al., 2016, *ApJ*, 833, 68
 Bazot M., Christensen-Dalsgaard J., Gizon L., Benomar O., 2016, *MNRAS*, 460, 1254
 Benz W., Asphaug E., 1999, *Icarus*, 142, 5
 Binks A. S., Jeffries R. D., 2017, *MNRAS*, 469, 579
 Burdanov A. Y. et al., 2019, *MNRAS*, 487, 1634
 Burgasser A. J., Mamajek E. E., 2017, *ApJ*, 845, 110
 Carniani S. et al., 2015, *A&A*, 584, A78
 Cresswell P., Nelson R. P., 2006, *A&A*, 450, 833
 de Wit J. et al., 2016, *Nature*, 537, 69
 de Wit J. et al., 2018, *Nat. Astron.*, 2, 214
 Dencs Z., Regály Z., 2019, *MNRAS*, 487, 2191
 Dorn C., Mosegaard K., Grimm S. L., Alibert Y., 2018, *ApJ*, 865, 20
 Eiroa C. et al., 2013, *A&A*, 555, A11
 Filippazzo J. C., Rice E. L., Faherty J., Cruz K. L., Van Gordon M. M.,Looper D. L., 2015, *ApJ*, 810, 158
 Gautier T. N., III et al., 2007, *ApJ*, 667, 527
 Gillon M. et al., 2016, *Nature*, 533, 221
 Gillon M. et al., 2017, *Nature*, 542, 456
 Grimm S. L. et al., 2018, *A&A*, 613, A68
 Hansen B. M. S., Murray N., 2012, *ApJ*, 751, 158
 Hardegree-Ullman K. K., Cushing M. C., Muirhead P. S., Christiansen J. L., 2019, *AJ*, 158, 75
 Hayashi C., 1981, *Prog. Theor. Phys. Suppl.*, 70, 35
 Hughes A. G., Boley A. C., Osten R. A., White J. A., 2019, *ApJ*, 881, 33
 Hughes A. M., Duchêne G., Matthews B. C., 2018, *ARA&A*, 56, 541
 Kennedy G. M., Wyatt M. C., 2010, *MNRAS*, 405, 1253
 Kennedy G. M. et al., 2018, *MNRAS*, 476, 4584
 Kral Q., Wyatt M. C., Triaud A. H. M. J., Marino S., Thébaud P., Shorttle O., 2018, *MNRAS*, 479, 2649
 Krivov A. V., 2010, *Res. Astron. Astrophys.*, 10, 383
 Lestrade J. F., Wyatt M. C., Bertoldi F., Menten K. M., Labaigt G., 2009, *A&A*, 506, 1455
 Li A., Draine B. T., 2001, *ApJ*, 554, 778
 Löhne T., Krivov A. V., Rodmann J., 2008, *ApJ*, 673, 1123
 Luger R. et al., 2017, *Nat. Astron.*, 1, 0129
 MacGregor M. A., Weinberger A. J., Wilner D. J., Kowalski A. F., Cranmer S. R., 2018, *ApJ*, 855, L2
 Marino S. et al., 2016, *MNRAS*, 460, 2933
 Marino S., Wyatt M. C., Kennedy G. M., Holland W., Matrà L., Shannon A., Ivison R. J., 2017, *MNRAS*, 469, 3518
 Marino S., Bonsor A., Wyatt M. C., Kral Q., 2018, *MNRAS*, 479, 1651
 Marino S., Yelverton B., Booth M., Faramaz V., Kennedy G. M., Matrà L., Wyatt M. C., 2019, *MNRAS*, 484, 1257
 Mathis J. S., Mezger P. G., Panagia N., 1983, *A&A*, 500, 259
 Matrà L., Wilner D. J., Öberg K. I., Andrews S. M., Loomis R. A., Wyatt M. C., Dent W. R. F., 2018a, *ApJ*, 853, 147
 Matrà L., Marino S., Kennedy G. M., Wyatt M. C., Öberg K. I., Wilner D. J., 2018b, *ApJ*, 859, 72
 Matthews B. C., Krivov A. V., Wyatt M. C., Bryden G., Eiroa C., 2014, *Protostars and Planets VI*. Univ. Arizona Press, Tucson, p. 521
 Mezger P. G., Mathis J. S., Panagia N., 1982, *A&A*, 105, 372
 Montesinos B. et al., 2016, *A&A*, 593, A51
 Moran S. E., Hörst S. M., Batalha N. E., Lewis N. K., Wakeford H. R., 2018, *AJ*, 156, 252
 Mulders G. D., Pascucci I., Apai D., 2015, *ApJ*, 814, 130
 O'Malley-James J. T., Kaltenegger L., 2017, *MNRAS*, 469, L26
 Ormel C. W., Liu B., Schoonenberg D., 2017, *A&A*, 604, A1
 Plavchan P., Jura M., Lipsky S. J., 2005, *ApJ*, 631, 1161
 Schoonenberg D., Liu B., Ormel C. W., Dorn C., 2019, *A&A*, 627, A149

- Schüppler C., Krivov A. V., Löhne T., Booth M., Kirchsclager F., Wolf S., 2016, *MNRAS*, 461, 2146
- Schwarz R. et al., 2018, *MNRAS*, 480, 3595
- Sibthorpe B., Kennedy G. M., Wyatt M. C., Lestrade J. F., Greaves J. S., Matthews B. C., Duchêne G., 2018, *MNRAS*, 475, 3046
- Simpson J. M. et al., 2015, *ApJ*, 807, 128
- Stewart S. T., Leinhardt Z. M., 2009, *ApJ*, 691, L133
- Terquem C., Papaloizou J. C. B., 2007, *ApJ*, 654, 1110
- Wakeford H. R. et al., 2019, *AJ*, 157, 11
- Weidenschilling S. J., 1977, *Ap&SS*, 51, 153
- Woitke P. et al., 2016, *A&A*, 586, A103
- Wright E. L. et al., 2010, *AJ*, 140, 1868
- Wyatt M. C., 2008, *ARA&A*, 46, 339
- Wyatt M. C., Clarke C. J., Booth M., 2011, *Celest. Mech. Dyn. Astron.*, 111, 1

This paper has been typeset from a $\text{\TeX}/\text{\LaTeX}$ file prepared by the author.