

# Astrometric view of companions in the inner dust cavities of protoplanetary discs

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Received 2 September 2025 / Accepted 26 November 2025

## ABSTRACT

**Context.** Protoplanetary discs with inner dust cavities (often referred to as ‘transition discs’) are potential signposts of planet formation. However, few companions have been identified within these cavities, and the role of companions in shaping them remains unclear.

**Aims.** We used *Gaia* astrometry to search for planetary and stellar companions in a sample of 98 transition discs, assessing the occurrence rate of such companions and their potential influence on cavity formation.

**Methods.** For the 98 young stellar objects (YSOs) with inner dust cavities, we computed *Gaia* proper motion anomalies, which together with the renormalised unit weight error (RUWE), identify companions with mass ratios  $q \gtrsim 0.01$  at  $\sim 0.1$ –30 au. We assessed the impact of disc gravity, accretion, disc-scattered light, dippers, starspots, jets, and outflows on the measured proper motion anomalies, concluding that these effects are unlikely to affect our analyses and that astrometric techniques such as the one of this work can be robustly applied to YSOs.

**Results.** Significant proper motion anomalies are found in 31 transition discs (32% of the sample), indicative of companions. We recovered 85% of the known companions within our sensitivity range. Assuming that the astrometry of each system is dominated by a single companion, we modelled the semi-major axis and mass required to reproduce the observed astrometric signals. Most inferred companions have  $M > 30 M_J$ , placing many within or near the stellar mass regime. Seven sources host companions compatible with a planetary mass ( $M < 13 M_J$ , HD 100453, J04343128+1722201, J16102955-3922144, MHO6, MP Mus, PDS 70, and Sz 76). For the non-detections, we provide the companion masses and semi-major axes that can be excluded in future searches. About half (53%) of detected companions cannot be reconciled with having carved the observed dust cavities.

**Conclusions.** We have gathered evidence of the presence of companions in a large sample of transition discs. However, we find that the population of transition discs cannot be fully described as a circumbinary population. Transition discs host as many companions within our sensitivity range as do randomly sampled groups of YSOs and main-sequence stars. If dust cavities are shaped by companions, such companions must reside at larger orbital separations than those of the companions detected here, and we predict them to be of planetary mass.

**Key words.** planets and satellites: formation – protoplanetary disks – planet-disk interactions – stars: formation – stars: pre-main sequence – stars: variables: T Tauri, Herbig Ae/Be

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## 1. Introduction

Detecting planetary or stellar companions around forming stars, or young stellar objects (YSOs), is crucial for understanding how multiple systems interact with their natal environments and how companions and protoplanetary discs co-evolve as well as for placing observational constraints on the formation of planets and stellar multiples. In addition, the origin and evolution of companions in YSOs are key to understanding the exoplanet population.

However, the fraction of YSOs with companions, and their typical separation and mass, are largely uncharacterised (Raghavan et al. 2010; Reipurth et al. 2014; Cuello et al. 2025). Despite the abundance of dust substructures that has been found in protoplanetary discs (Andrews 2020; Bae et al. 2023), the role of multiplicity in planet formation and disc architectures is poorly understood. One reason for these unknowns is the difficulty involved in identifying companions in the  $\sim 0.1\text{--}30$  au separation range from the central star (Benisty et al. 2023). These companions are often too distant for spectroscopic identification, but they are also too close for direct imaging or millimetre-interferometry due to the protoplanetary disc presence and the contrast luminosity of the central star (e.g. Ren et al. 2023; Rawcliffe et al. 2025). In this work, we use *Gaia* astrometry to look for companions in this  $\sim 0.1\text{--}30$  au separation range, bridging the gap where neither direct imaging nor spectroscopy can efficiently detect them.

We focus on the population of YSOs hosting protoplanetary discs with inner dust cavities (often called ‘transition’ or ‘pre-transition’ discs). These inner dust cavities have often been explained by companions carving the dust-disc, and thus these discs have the highest chances of hosting massive companions (e.g. Ragusa et al. 2017; Pinilla et al. 2018b; van der Marel et al. 2018; Francis & van der Marel 2020; Guzmán-Díaz et al. 2023). However, to date, only a few companions have been identified within the cavities of transition discs (Currie et al. 2023a; Benisty et al. 2023; van der Marel 2023), and these are often too close ( $<1$  au) to explain the cavity size. The small number of known circumbinary discs at the YSO stage contrasts with the high multiplicity fraction observed among main-sequence stars (approximately 20–40% for stars with masses between 0.3 and 1  $M_{\odot}$ , and up to 100% for O-type stars, Offner et al. 2023). It is unknown if this is caused by an observational limitation. Ragusa et al. (2025) conclude that in 40% of the systems they analysed, the hypothesis that a still undetected stellar binary companion is responsible for carving the cavity cannot be ruled out. In contrast, the possibility that still undetected planetary companions are responsible for the cavities cannot be excluded in any system. Similarly, the analyses of van der Marel et al. (2021) and Wölfer et al. (2023) show that, with current observational constraints, still undetected massive substellar companions are possible at close radii (typically of a few tens of astronomical units). We note other processes such as grain growth, dead zones, and photoevaporation have also been proposed for producing inner dust cavities (e.g. Pinilla et al. 2016; Ercolano & Pascucci 2017; Huang et al. 2024).

Different techniques leveraging the *Gaia* data have proven to be successful at tracing companions (e.g. Stassun & Torres 2021; Gaia Collaboration 2023; Holl et al. 2023; Castro-Ginard et al. 2024). Among these, the one called ‘proper motion anomaly’ is particularly suited to infer the presence of companions in YSOs. This technique traces astrometric accelerations of the system photocentre due to the presence of unresolved companions by comparing proper motions measured across different

epochs (Perryman et al. 2014; Brandt 2018; Kervella et al. 2019). It is mostly sensitive to asymmetric perturbations, and hence it is less affected by the different types of azimuthally symmetric variability typical of YSOs. Proper motion anomalies have already been used to identify exoplanets and brown dwarfs around main-sequence stars (later confirmed with direct imaging, e.g. Bonavita et al. 2022; Currie et al. 2023b; De Rosa et al. 2023; Franson et al. 2023; Mesa et al. 2023; Kiefer et al. 2025b). In particular, the combination of the HIPPARCOS astrometric survey with *Gaia* has provided the community with large catalogues of proper motion anomalies (e.g. Brandt 2021; Kervella et al. 2022; Kiefer et al. 2025b). However, because YSOs are typically faint, most of them do not appear in the HIPPARCOS catalogue, and thus in this work we focus on *Gaia*-only proper motion anomalies (e.g. Penoyre et al. 2022a,b; Dodd et al. 2024). This *Gaia*-only approach was already successfully used to infer the presence of a gas giant in the protoplanetary disc around MP Mus (Ribas et al. 2025).

In this work, we use *Gaia* proper motion anomalies to survey the population of companions in the  $\sim 0.1\text{--}30$  au separation range of protoplanetary discs with inner dust cavities (‘transition discs’). We describe the methodology in Sect. 2. Our results for individual transition discs are presented in Sect. 3. We present a population analysis in Sect. 4, describe possible sources of astrometric noise in Sect. 5, and conclude in Sect. 6.

## 2. Methodology

We selected a sample of ‘transition discs’ from the literature. We define ‘transition disc’ as any source with an identification of an inner-dust cavity at millimetre wavelengths. From this compilation, there is enough *Gaia* DR3 and DR2 astrometry to derive proper motion anomalies for 98 sources (Figs. 1, A.1, Table A.1). Only three of the compiled transition discs do not have enough *Gaia* DR3 and DR2 data for deriving proper motion anomalies: XZ Tau B, J16070384-3911113, and J17110392-2722551 ([BHB2007] 1).

We used the proper motion anomaly defined in Penoyre et al. (2022a) as the change in velocity between *Gaia* DR2 and *Gaia* DR3 (Gaia Collaboration 2016, 2018, 2021):

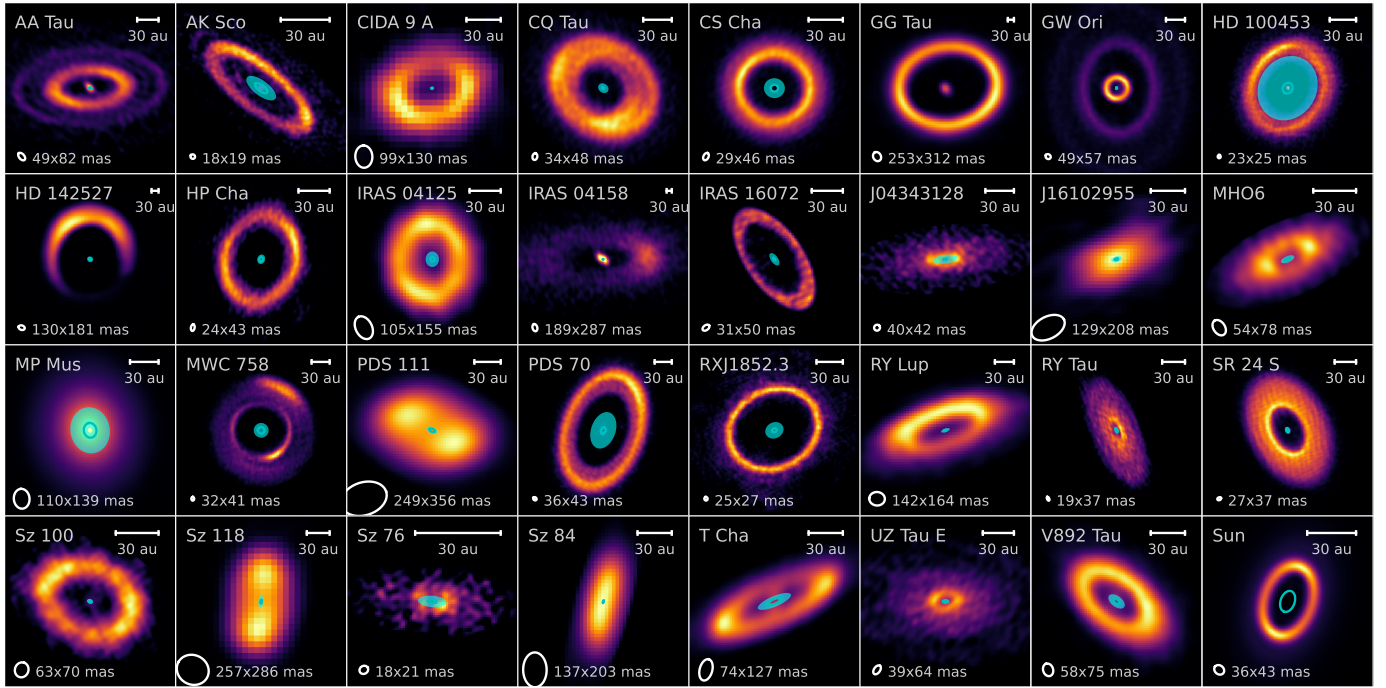
$$|\Delta\mu| = \sqrt{(\mu_{\alpha,DR3} - \mu_{\alpha,DR2})^2 + (\mu_{\delta,DR3} - \mu_{\delta,DR2})^2}, \quad (1)$$

where  $\mu_{\alpha}$  and  $\mu_{\delta}$  are the proper motion in right ascension and declination, respectively.<sup>1</sup> We note  $|\Delta\mu|$  does not depend on the proper motion of the centre of mass of the system. The uncertainty of this proper motion anomaly is defined in Penoyre et al. (2022b) as

$$\sigma_{|\Delta\mu|} = \frac{\sqrt{\Delta\mu_{\alpha}^2(\sigma_{\mu_{\alpha,DR3}}^2 + \sigma_{\mu_{\alpha,DR2}}^2) + \Delta\mu_{\delta}^2(\sigma_{\mu_{\delta,DR3}}^2 + \sigma_{\mu_{\delta,DR2}}^2)}}{|\Delta\mu|}, \quad (2)$$

where  $\sigma$  indicates the uncertainty associated with each quantity. The significance of the proper motion anomaly is defined as  $|\Delta\mu|/\sigma_{|\Delta\mu|}$ . This technique is most sensitive to tracing companions at intermediate orbital periods that are not very different from the *Gaia* DR2 and DR3 time baseline. When combined with the RUWE (renormalised unit weight error, a goodness-of-fit measure contained in *Gaia* DR3, Lindgren et al. 2021)

<sup>1</sup> We explore applying the *Gaia* DR3 corrections of Cantat-Gaudin & Brandt (2021) and find our results are mostly unchanged. We decide not to apply these corrections for consistency with *Gaia* DR2.



**Fig. 1.** ALMA continuum images of the sample of 31 discs with inner dust cavities (‘transition discs’) for which we find a significant proper motion anomaly ( $|\Delta\mu|/\sigma_{|\Delta\mu|} \geq 3$ ) indicative of the presence of companions. Assuming one companion dominates the proper motion anomaly (Sect. 2), the solid cyan line indicates the 50th percentile of the companion location (the cyan coloured areas are the 10th and 90th percentiles) as derived in Sect. 3.1 (see Figs. 2 and A.2, exception is GG Tau, whose companion could not be modelled). Bottom-right corner: Image of the Sun, for reference, as it is predicted to look at 1 Myr (Berges-Casalou et al. 2022) with Jupiter’s orbit in cyan. The ALMA synthesised beams are included at the bottom left of each panel. Non-detections can be seen in Fig. A.1.

simulations suggest most detections occur for orbital separations between  $\sim 0.1$  to 30 au, approximately (or periods between 0.03 and 160 years for a  $1 M_{\odot}$  star, Sect. 3.1 and Penoyre et al. 2022a,b). The measured  $|\Delta\mu|$  and  $\sigma_{|\Delta\mu|}$  for all 98 transition disc sources considered in this work are presented in Table A.1.

The sensitivity to detect astrometric accelerations via proper motion anomalies decays linearly with distance from Earth, as the observed proper motion anomaly equals the real tangential velocity of the moving photocentre ( $v_t$ ) times the parallax ( $\varpi$ ,  $|\Delta\mu| = \varpi \cdot v_t$ ). In addition, the uncertainties of *Gaia* astrometry are heavily dependent on source brightness (Lindgren et al. 2021). Hence  $|\Delta\mu|/\sigma_{|\Delta\mu|}$  varies for otherwise identical systems if located at different distances. Orientation also plays a role, as the signal is smaller for edge-on orbits. In Sect. 5, we evaluate the potential impact of other sources of astrometric signals on the proper motion anomaly in YSOs and conclude that this methodology can be robustly applied to companion searches in YSOs.

We compiled effective temperatures ( $T_{\text{eff}}$ ), stellar luminosities ( $L_{\star}$ , updated to *Gaia* DR3 distances when needed), disc geometries (inclinations and position angles), and disc cavity sizes from the literature for all 98 sources. Using  $T_{\text{eff}}$  and  $L_{\star}$ , we derive stellar masses homogeneously for all sources, using Baraffe et al. (2015) evolutionary tracks for stars less than  $1.35 M_{\odot}$  and Nguyen et al. (2022) PARSEC V2.0 for masses above  $1.35 M_{\odot}$ . This approach has proven to give accurate stellar masses in YSOs (Zallio et al. in prep.). All stellar and disc properties for the considered transition discs can be found in Table A.1, with references.

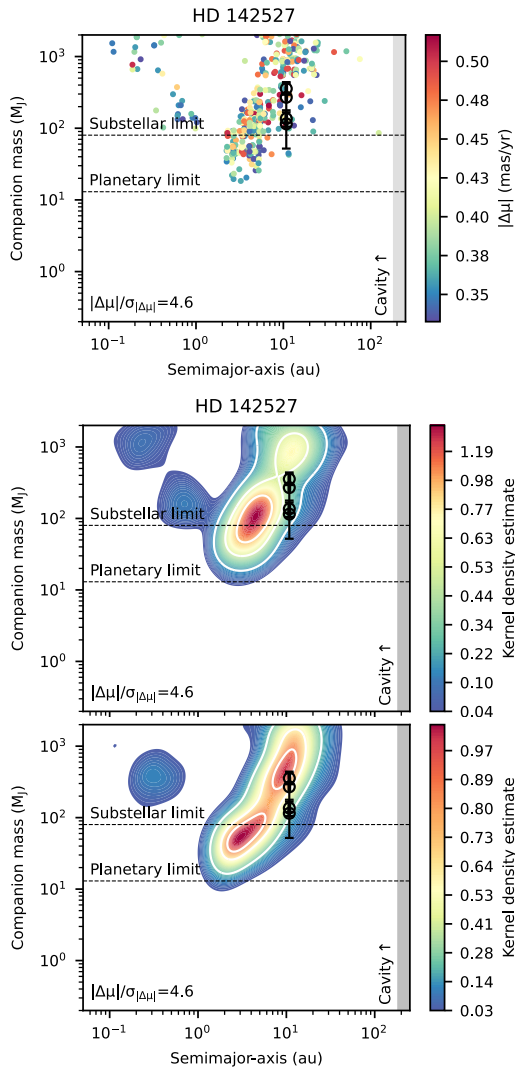
For each transition disc in the sample, we performed 40 000 simulations modelling a two-body interaction to study the

parameter space of semi-major axis and companion mass that produces the observed  $|\Delta\mu|$ ,  $\sigma_{|\Delta\mu|}$ , and RUWE. The procedure is as follows: we first adopt the scanning law of *Gaia* DR2 (Boubert et al. 2021) and *Gaia* DR3<sup>2</sup> to retrieve the epochs and scan angles at which *Gaia* observed each source. Using these epochs and scan angles, along with realistic *Gaia* uncertainties (Lindgren et al. 2018, 2021), we simulate the *Gaia* DR2 and DR3 astrometric observations of each source under the assumption of a two-body system with varying mass ratios and orbital periods<sup>3</sup>. *Gaia* synthetic observables, including the RUWE, are calculated via a close emulation of the original astrometric pipeline of the *Gaia* mission (Lindgren et al. 2012; Penoyre et al. 2022a). Underlying correlations between *Gaia* DR2 and DR3 which could have a small effect on  $\sigma_{|\Delta\mu|}$  are not modelled.

For each of the 40 000 simulations per system, we randomly sampled the log-uniform space of mass ratios (from 0.0001 to 1) and periods (from 0.01 to 2512 yr). The mass of the primary source is sampled at random every time following the measured values and uncertainties of stellar mass (see Table A.1). Eccentricity is sampled at random in each simulation uniformly between 0 and 1 (Duchêne & Kraus 2013; Moe & Di Stefano 2017). Viewing angles and orbital phases are also taken at random. Alternatively, viewing angles and orbital phases can be sampled within the measured values and uncertainties of the disc inclinations and position angles. This adds the assumption that

<sup>2</sup> [Gaia Archive scan law](#)

<sup>3</sup> These simulations are performed using the *astromet* package developed by Penoyre et al. (2022a): <https://github.com/zpenoyre/astromet.py>



**Fig. 2.** Orbital separation and mass of the companion that would produce the observed *Gaia* astrometry of HD 142527 ( $0.33 < |\Delta\mu| < 0.52 \text{ mas yr}^{-1}$ ,  $|\Delta\mu|/\sigma_{|\Delta\mu|} > 4$ , and  $\text{RUWE}_{\text{DR3}} < 1.25$ , from Sect. 3 Eqs. (3)–(5)). The top panel shows the individual *Gaia* simulations for this system. The middle panel presents the same simulations but smoothed with a kernel density estimate (contours indicate the 20, 50, and 80% levels of the normalised area). Black circles mark the location and the proposed masses for the known companion in this system (see Sect. 3.3). The bottom panel is the same as the middle panel but assuming the companion responsible for the astrometric signal is in the plane of the disc. Similar plots for all other 30 systems with significant astrometric accelerations are shown in Fig. A.2.

possible companions are contained in the plane of the disc. However, we find that this assumption does not reduce the space of companion solutions significantly (e.g. Fig. 2), and hence we do not consider it in this work to account for companions outside the disc plane (see Barber et al. 2024; Biddle et al. 2025).

We model each system as a two-body interaction because the interpretation of the astrometric accelerations becomes more complex for higher-order multiple systems. Therefore, for these simulations we assume that, even if multiple companions are present, the astrometric signal is dominated by a single companion. Additionally, we adopt a relation between the mass ratio ( $q = M_{\text{comp}}/M_{\text{primary}}$ ) and light ratio ( $l = L_{\text{comp}}/L_{\text{primary}}$ ) of the components, given by  $l = q^{3.5}$ . We extend this commonly

used heuristic for main-sequence stars to Class-II YSOs, which are optically bright and have almost reached their final mass (Hartmann et al. 2016).

From each of the 40 000 simulations we retrieve the  $|\Delta\mu|$ ,  $\sigma_{|\Delta\mu|}$ , and RUWE each simulated companion would produce in each considered transition disc system.

### 3. Analysis of individual transition discs

#### 3.1. Sources with significant astrometric accelerations

We consider  $|\Delta\mu|/\sigma_{|\Delta\mu|} \geq 3$  a significant detection of astrometric acceleration, or proper motion anomaly ( $|\Delta\mu|$ ), in a system. In our sample of transition discs, 31 sources show significant astrometric acceleration (Fig. 1), 15 of them having  $|\Delta\mu|/\sigma_{|\Delta\mu|} \geq 5$ . These sources are indicated in Table A.1 and Fig. A.2. Only 3 sources have significant ( $>3\sigma$ )  $|\Delta\mu|$  in the independent HIPPARCOS-*Gaia* proper motion analysis of Kervella et al. (2022, RY Tau, GW Ori, and HD 142527), which we also retrieve with our methodology.

For the 31 detections, we considered the simulated companions that produce both a proper motion anomaly and a RUWE consistent with the observations. This defines the range of companion separations and masses capable of reproducing the observed astrometry (under the assumptions of Sect. 2). In particular, we considered the simulations with  $|\Delta\mu|_{\text{sim}}$ ,  $\sigma_{|\Delta\mu|_{\text{sim}}}$ , and  $\text{RUWE}_{\text{sim}}$  satisfying all the following conditions:

$$|\Delta\mu|_{\text{sim}} - \sigma_{|\Delta\mu|_{\text{sim}}} < |\Delta\mu| < |\Delta\mu|_{\text{sim}} + \sigma_{|\Delta\mu|_{\text{sim}}}, \quad (3)$$

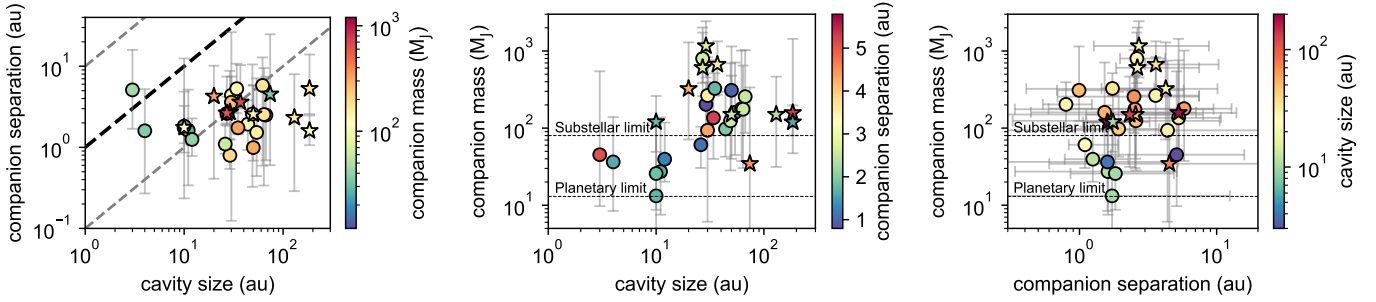
$$\text{int}[|\Delta\mu|/\sigma_{|\Delta\mu|}] < |\Delta\mu|_{\text{sim}}/\sigma_{|\Delta\mu|_{\text{sim}}}, \quad (4)$$

$$\begin{cases} 0.5 \text{ RUWE} < \text{RUWE}_{\text{sim}} < 1.5 \text{ RUWE} & \text{if } \text{RUWE} \geq 1.25, \\ \text{RUWE}_{\text{sim}} < 1.25 & \text{if } \text{RUWE} < 1.25. \end{cases} \quad (5)$$

We use the index ‘sim’ to differentiate simulated from observed quantities. The 1.25 threshold for the RUWE was proposed as the upper limit for a single star solution by Penoyre et al. (2022b) and Castro-Ginard et al. (2024). We consider a broad range around the observed RUWE as it has been suggested protoplanetary discs can impact the RUWE (e.g. Fitton et al. 2022).

Fig. 2 exemplifies this methodology for the system HD 142527. It shows the orbital semi-major axes and masses a companion should have to induce the  $|\Delta\mu|$ ,  $\sigma_{|\Delta\mu|}$ , and RUWE observed in this system. Equivalent plots for the other 30 transition discs with significant astrometric accelerations are shown in Fig. A.2. In general, our simulations show that beyond  $\sim 1 \text{ au}$  the companion mass needed to produce the observed astrometry increases with increasing semi-major axis. Under  $\sim 1 \text{ au}$ , the required companion mass increases with decreasing semi-major axis (similar behaviour was reported in Kiefer et al. 2025a).

From this space of possible companions (e.g. Fig. 2), we derive the 10th, 50th, and 90th percentiles of the distribution of possible companion masses and semi-major axes (which we call ‘separations’) for every source with a significant astrometric acceleration. These are presented in Fig. 3 (and tabulated in Table A.1). Despite its significant proper motion anomaly, no two-body simulation could reproduce the astrometry of GG Tau (in this work we consider GG Tau A, which is a known hierarchical triple stellar system, Di Folco et al. 2014; Keppler et al. 2020; Toci et al. 2024), and thus we report no companion mass and separation for GG Tau.



**Fig. 3.** Predicted space of possible companions. Central values and uncertainties indicate the 10th, 50th, and 90th percentiles of the distribution of companion masses and separations (semi-major axes) for the transition discs with significant astrometric acceleration (30 sources, as no two-body solution was found for GG Tau). Sources with known companions are shown with a star symbol. Left panel: cavity size at millimetre wavelengths vs companion semi-major axis. One-to-one line is shown in black and  $\pm 1$  dex lines are shown in grey. All companions are consistent with being inside the dust cavity (MP Mus is the source appearing above the one-to-one line). Centre panel: cavity size vs companion mass. Right panel: companion semi-major axis vs companion mass.

All the companions identified in this work are consistent with being within the dust cavity as seen at millimetre wavelengths (Fig. 3). Fig. 3 also shows we mostly recover  $M > 30 M_J$  companions, many of which are largely compatible with the stellar mass regime. Only eight companions have median masses in the brown-dwarf regime. Seven sources host companions compatible with a planetary mass within uncertainties ( $< 13 M_J$ , HD 100453, J04343128+1722201, J16102955-3922144, MHO6, MP Mus, PDS 70, and Sz 76), although J04343128+1722201 is the only one with a companion median mass close to the planetary limit.

### 3.2. Constraints from non-detections

The remaining 67 transition disc sources considered in this work do not have a significant astrometric acceleration (i.e.  $|\Delta\mu|/\sigma_{|\Delta\mu|} < 3$ ). For these, we consider the simulated companions that should have produced a significant proper motion anomaly or a RUWE higher than the one observed. This allows us to define the ranges of companion masses and separations that can be discarded in these systems (assuming each system’s astrometry is dominated by a single companion, Sect. 2). In particular, we considered the simulations with  $|\Delta\mu|_{\text{sim}}$ ,  $\sigma_{|\Delta\mu|_{\text{sim}}}$ , and  $\text{RUWE}_{\text{sim}}$  that satisfied either of the following conditions:

$$|\Delta\mu|_{\text{sim}}/\sigma_{|\Delta\mu|_{\text{sim}}} \geq 3, \quad (6)$$

$$\begin{cases} \text{RUWE} < \text{RUWE}_{\text{sim}}, & \text{if } \text{RUWE} \geq 1.25, \\ \text{RUWE}_{\text{sim}} \geq 1.25, & \text{if } \text{RUWE} < 1.25. \end{cases} \quad (7)$$

Fig. 4 shows this methodology for the systems LkCa 15 and WISPIT 2. Equivalent plots for the other 65 transition discs with non-detections are shown in Fig. A.3.

A non-detection does not imply the absence of companions in a system. In fact, as exemplified in Fig. 4, even when considering the ideal two-body scenario only a narrow range of companion masses and separations can be discarded. These are typically masses  $> 40 M_J$  at separations of 0.3–10 au, but it varies from source to source and we encourage the reader to check the plots in Fig. A.3 for any particular object. In addition, different sources of astrometric noise (e.g. variable extinction, jets, starspots, crowding, scattered light, see Sect. 5) might have diluted potential companion astrometric signals, expanding the parameter space of possible companions in the non-detection scenario beyond what is described by our simulations.

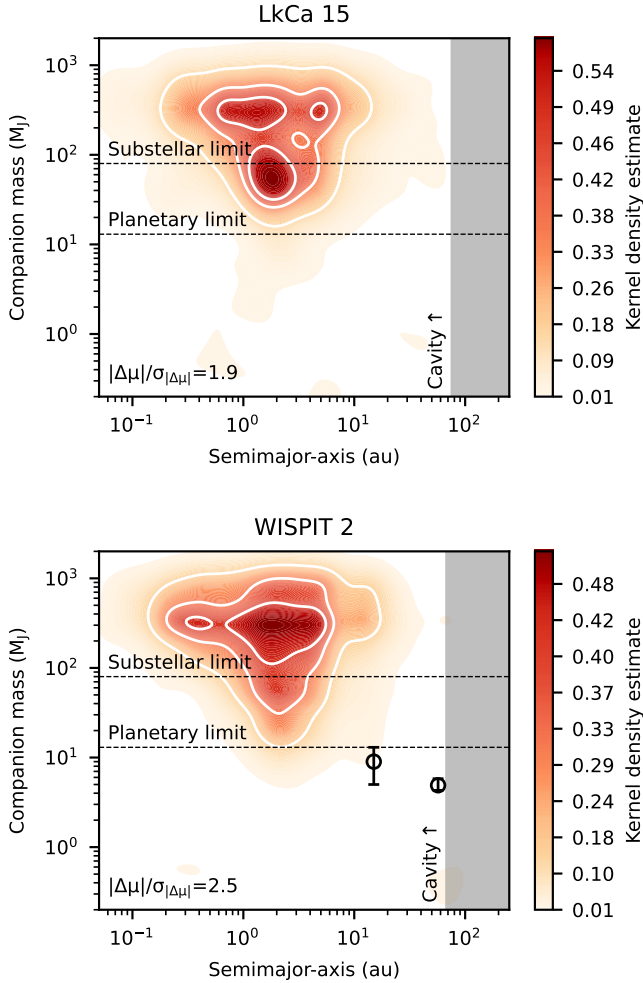
### 3.3. Comment on individual sources

In this section, we touch on how our companion detections and non-detections compare with the results of other works (see Figs. A.2 and A.3 and Table A.1).

There are 14 known circumbinaries in the complete considered sample of 98 transition discs (see van der Marel 2023; Cuello et al. 2025, and references therein): AK Sco, AS 205 S, CS Cha, GG Tau (circumtriple), GW Ori, HD 142527, HD 34700, HP Cha, IRAS 04158+2805, MHO2, RXJ1633.9-2442, UZ Tau E, V4046 Sgr, and V892 Tau. To this we add PDS 70, IRAS 04125+2902, and WISPIT 2 with confirmed substellar companions (Keppler et al. 2018; Haffert et al. 2019; Barber et al. 2024; van Capelleveen et al. 2025; Close et al. 2025). We detect significant astrometric accelerations in 11 of these sources, with the exceptions being AS 205 S, HD 34700, MHO2, RXJ1633.9-2442, V4046 Sgr, and WISPIT 2. However, AS 205 S, HD 34700, and V4046 Sgr are spectroscopic binaries with short (a few days) orbital periods (Kurtovic et al. 2018; Torres 2004; Stempels & Gahm 2004), and hence they are outside the separation-detection range of Sect. 2 technique. On the other end is WISPIT 2 b, which at  $\sim 57$  au (van Capelleveen et al. 2025) is too separated for our detection range (Fig. 4). MHO2 and RXJ1633.9-2442 have stellar companions reported at 7.3 and 3.3 au, respectively (Kraus et al. 2011; Ruiz-Rodríguez et al. 2016), and thus they could have been detected with our methodology. This comparison with known companions sets a recovery fraction for Sect. 2 methodology of 85% (11/13, excluding the three spectroscopic binaries and WISPIT 2).

Close et al. (2025) propose another nearby planetary mass companion to WISPIT 2 at 15 au with  $9 \pm 4 M_J$ . As shown in our non-detection plot (Fig. 4), a companion with that mass and separation lies at the upper mass limit consistent with our non-detection and could therefore have escaped detection with the methodology of this work. Our results align best with the lower end of the mass range proposed by Close et al. (2025) and disfavour substantially higher masses.

We also highlight the case of PDS 70, an intensively studied system because of the broad consensus regarding the planetary nature of the companions identified in its disc (e.g. Müller et al. 2018; Wang et al. 2021; Christiaens et al. 2024; Hammond et al. 2025). Notably, among the 98 discs with inner dust cavities analysed homogeneously in this study, PDS 70 stands out. We detect a significant proper motion anomaly in this system that is consistent with the presence of a planetary-mass companion. However, along with the hierarchical triple system GG Tau (Sect. 3.1), PDS



**Fig. 4.** Parameter space of orbital separations and companion masses that would produce either a significant *Gaia* proper motion anomaly or a higher-than-observed RUWE value in LkCa 15 and WISPIT 2, smoothed with a kernel density estimate (contours indicate the 20, 50, and 80% levels of the normalised area). These regions can be discarded as hosting a companion dominating the astrometry (Sect. 3.2, Eqs. (6), (7)). For WISPIT 2, the confirmed (at  $\sim 57$  au, van Capelleveen et al. 2025) and proposed (at  $\sim 15$  au, Close et al. 2025) planetary mass companions are indicated. Similar plots for all other 65 systems with non-detections are shown in Fig. A.3.

70 is one of only two systems exhibiting astrometric behaviour that is difficult to model using a simple two-body interaction. Very few of our two-body simulations reproduce the observed astrometric signature of PDS 70 (Fig. A.2). We attribute this to the system’s multiple-planet configuration, where both PDS 70 b and c are of high mass and contribute significantly to the overall astrometric signal. Our results therefore support the idea that PDS 70 is a rare planetary system. From the perspective of this study, the planets in PDS 70 are unusually massive ( $4.9 M_J$  for b and  $13.6 M_J$  for c, Trevascus et al. 2025), which may have facilitated their detection, whereas planets in other systems may still lie below current detection thresholds. In addition, because PDS 70 c is at  $\sim 33$  au, at the limit of our technique separation sensitivity range, it is possible we are seeing the effect of other massive bodies in the system which are closer to the star (e.g. PDS 70 b and d, Christiaens et al. 2024).

The separations and masses we obtain for the companion of HD 142527 (Fig. 2) are in agreement with the independently

characterised separation and mass of the known companion in this system. The semi-major axis has been measured to  $10.80 \pm 0.22$  au (Nowak et al. 2024). Reported companion mass estimates range from  $\sim 100$  to  $400 M_J$  ( $136 \pm 31 M_J$  from SED, Lacour et al. 2016,  $356 \pm 63 M_J$  and  $115 \pm 63 M_J$  from spectral fitting, Christiaens et al. 2018 and Claudi et al. 2019, and  $270^{+170}_{-150} M_J$  from dynamical considerations, Claudi et al. 2019). Our results indicate that companion masses above  $300 M_J$  are more likely. However, we note that we obtain a higher stellar mass for HD 142527 than the one reported in Mendigutía et al. (2014, 2.2 instead of  $2.0 M_\odot$ , both consistent within uncertainties), which has been used as a benchmark in the aforementioned studies. A lower stellar mass for HD 142527 would result in lower companion masses in our astrometric analysis.

Some other sources with companion detections in this work deserve special mention:

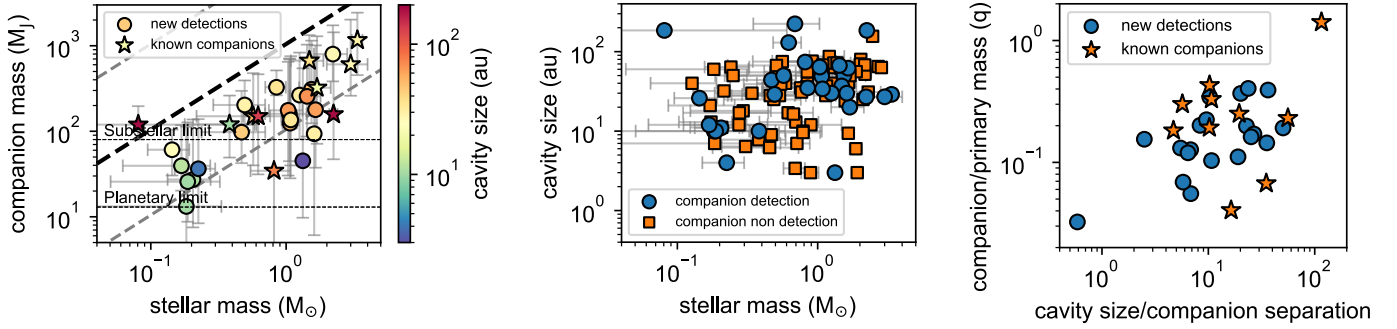
- MWC 758 and CQ Tau. We detect a significant proper motion anomaly in these systems, consistent with a brown dwarf or stellar companion (Fig. A.2). For MWC 758, Reggiani et al. (2018) reported a companion at 20 au, which could be the one we are tracing (although it was questioned by Wagner et al. 2019). In CQ Tau a nearby massive embedded companion has been proposed (Wölfer et al. 2021), which is confirmed here. Both systems can be reconciled with no previous detections with direct imaging (Ragusa et al. 2025).
- MP Mus. A gas giant was detected using the methodology of this work. This detection is presented in Ribas et al. (2025).
- RY Tau stands out among the detections of this work because the predicted companion has a very high median mass (although it is also compatible with lower masses, Fig. A.2), yet RY Tau has no known stellar companion. It also shows a significant proper motion anomaly in the independent work of Kervella et al. (2022). Garufi et al. (2019) and Petrov et al. (2021) found indirect evidence of an unseen planetary or substellar companion at sub-au to few-au scales, which might be the one detected here.

We also report new companion detections with a high mass ratio in the systems Sz 100, CIDA 9 A, and SR 24 S. The remaining 13 YSOs with inner dust cavities for which we find companions are: AA Tau, HD 100453, IRAS 16072-2057, J04343128+1722201, J16102955-3922144, MHO6, PDS 111, RXJ1852.3-3700, RY Lup, Sz 118, Sz 76, Sz 84, and T Cha. All detections are presented in Table A.1 and Fig. A.2.

In contrast, there are sources with proposed companions for which we obtained non-detections. These are AB Aur (Currie et al. 2022), HD 100546 (Quanz et al. 2013; Blakely et al. 2025), HD 135344 B (Maio et al. 2025), HD 163296 (Pinte et al. 2018), HD 169142 (Hammond et al. 2023), HD 97048 (Pinte et al. 2019), LkCa 15 (Kraus & Ireland 2012; Sallum et al. 2015, Fig. 4), and 2MASS J16120668-3010270 (Sierra et al. 2024a; Ginski et al. 2025; Li et al. 2025). However, some of these companions are debated and have unclear status, and we are only sensitive to a particular range of companion separations and masses. We refer the reader to Fig. A.3 where the companion separations and masses that can be discarded for these systems with our methodology are presented.

#### 4. Transition disc population analysis

Of the 98 transition discs considered, 31 have significant proper motion anomalies (32%, Sect. 3.1) and 67 do not (68%,



**Fig. 5.** Left panel: stellar mass of the primary star vs companion mass. One-to-one line is shown in black and  $\pm 1$  dex lines are shown in grey. Centre panel: stellar mass of the primary star vs cavity size at millimetre wavelengths. Right panel: mass ratio ( $q$ ) vs cavity size to semi-major axis ratio. We note only median values (50th percentiles) are shown.

Sect. 3.2). In this section we analyse this sample of transition discs from a population perspective.

#### 4.1. Companions in the transition disc population

A two-sided Kolmogorov–Smirnov (KS) test shows no significant difference in stellar mass between the population of transition discs with companion detections and that with non-detections (considering both  $|\Delta\mu|/\sigma_{|\Delta\mu|} \geq 3\sigma$  and  $\geq 5\sigma$  thresholds for companion detection). Indeed, we do not recover the expected trend that more massive stars have a higher probability of hosting a companion (Offner et al. 2023). However, the methodology described in Sect. 2 loses sensitivity to low mass companions as the mass of the primary star increases (because we trace the companion’s gravitational influence on the system’s photocentre), which biases the inferred companion probability as low mass companions fall below our detection threshold and are removed from the statistics. This effect can be seen in the left panel of Fig. 5, which shows we detect the lowest mass companions around the lower mass stars, and mostly find stellar mass companions for stars  $\geq 0.4 M_{\odot}$  (the exceptions being MP Mus and PDS 70, with sub-stellar mass companions). Hence, with the aid of the right panel of Fig. 5, we place a lower limit on the mass ratio to which our method is sensitive,  $q \gtrsim 0.01$ . By construction, we do not detect companions more massive than the primary star (as we would have considered them the primary star, note we are working under the assumption of bright companions,  $l = q^{3.5}$ ). IRAS 04158+2805 is an exception to this, but it is indeed an equal mass binary (Ragusa et al. 2021).

The centre panel of Fig. 5 shows the distribution of sources with detected companions with the methodology of this work as a function of stellar mass and dust cavity size. From this plot we note that we detect companions only in a specific region of the cavity-size versus stellar-mass plane. In particular, we do not detect companions in high mass stars ( $>0.4 M_{\odot}$ ) with small cavities ( $\leq 20$  au, the exception to this being MP Mus), and in low mass stars ( $<0.4 M_{\odot}$ ) with large cavities ( $\geq 20$  au, the exception to this being IRAS 04158+2805). We speculate that this is a consequence of selection effects arising from the method’s detection limits in mass ratio and separation (Sect. 2). In particular, we theorise that small cavities may host low mass bodies for which our sensitivity decreases as the primary mass increases, explaining the lack of detected companions in small cavities around high mass stars. Similarly, the lack of companion detections in large cavities around low mass stars can be explained if these systems host companions at separations larger than our detection range (0.1–30 au, sensitivity peaks at 1–10 au).

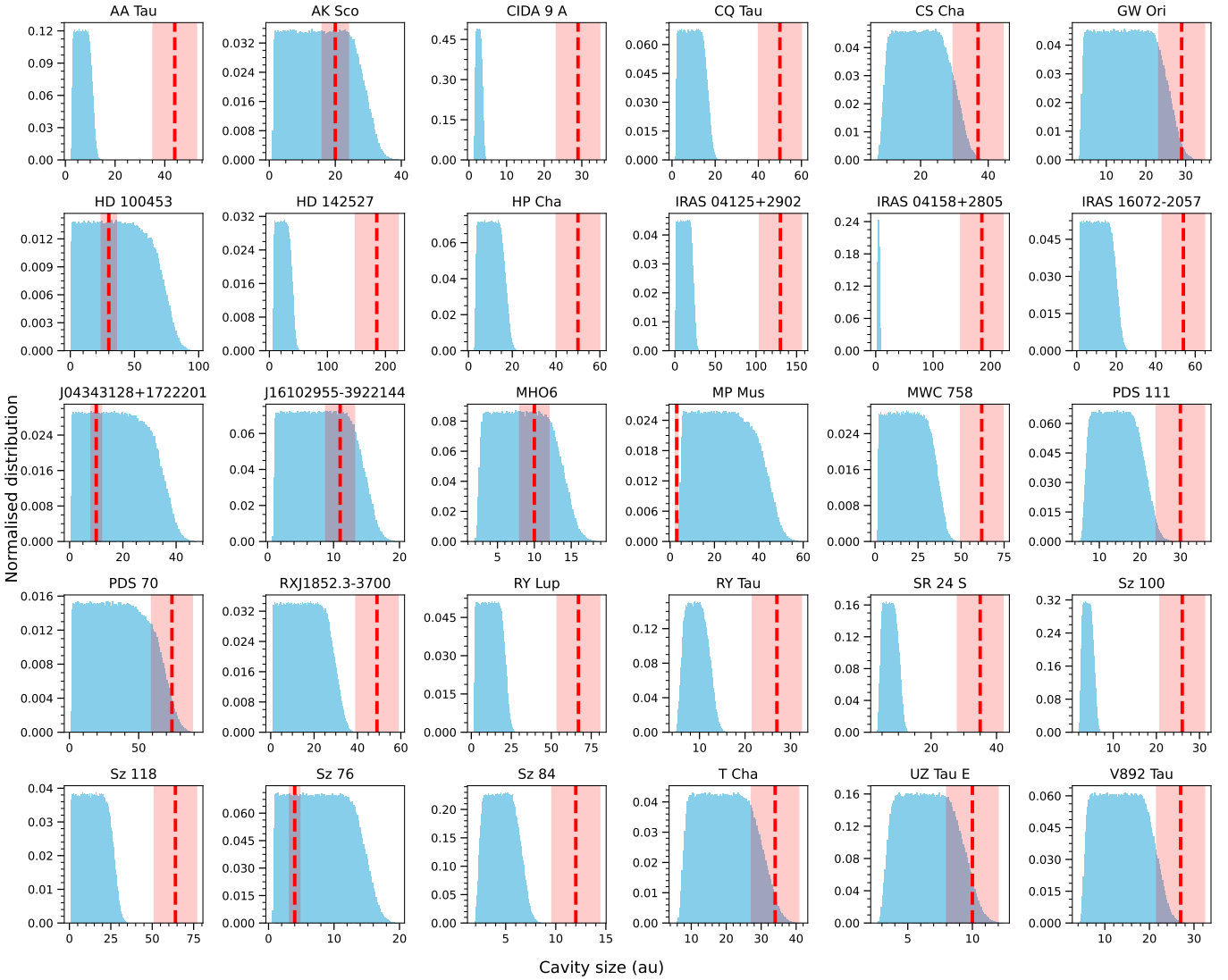
We find that the fraction of companions in transition discs identified with *Gaia* DR2–DR3 proper motion anomalies (32%) is similar to the fraction found in random populations of main-sequence and YSO stars. In particular, we compare to all *Gaia* stars within 100–200 pc (where 92% of the considered transition discs are), to the Sco-Cen YSO catalogues of Luhman (2022) and Ratzenböck et al. (2023), and to the Taurus catalogue of YSOs from Esplin & Luhman (2019) and Luhman (2023). In all those catalogues we find a fraction of companions compatible within uncertainties with the fraction found for transition discs (accounting for the dependence of proper motion anomalies with distance and brightness). These fractions are smaller than, and inconsistent with, the companion fractions found in populations of known binary stars. For example, we recover a  $\sim 75\%$  companion fraction in the *nss\_two\_body\_orbit Gaia* DR3 table of sources compatible with an orbital two-body solution (Gaia Collaboration 2023; Halbwachs et al. 2023; Holl et al. 2023), a  $\sim 53\%$  companion fraction in the Washington Visual Double Star Catalog (Mason et al. 2001, 24-Feb-2025 version) and a  $\sim 73\%$  companion fraction in the circumbinary catalogue of Cuello et al. (2025).

Hence, the population of transition discs cannot be fully described as a circumbinary population, and transition discs host as many binaries as do randomly sampled groups of YSOs and main-sequence stars within the separations and mass ratios probed by the methodology of this work (Sect. 2). This is remarkable given that our sample of transition discs has 14 sources in common with the circumbinary sample of Cuello et al. (2025, Sect. 3.3). In addition, many of the considered transition discs are on the high end of the stellar mass distribution (Herbig stars, Vioque et al. 2018, 2022). Hence, if normalised by stellar mass the fraction of companion detections in transition discs could be even smaller.

#### 4.2. About the detected companions carving the dust cavities

The formation of transition disc dust cavities has often been attributed to unseen companions (e.g. Ragusa et al. 2017; van der Marel et al. 2018; Pinilla et al. 2018b; Francis & van der Marel 2020; Guzmán-Díaz et al. 2023; Vioque et al. 2025). In this section, we evaluate whether the companions detected with our method are consistent with carving the observed cavities (Fig. 1).

Companions able to carve a dust cavity are expected to have a semi-major axis 2–3 times smaller than the size of the cavity (e.g. Miranda et al. 2017; Hirsh et al. 2020; Ragusa et al. 2020; Dittmann & Ryan 2024; Penzlin et al. 2024). In



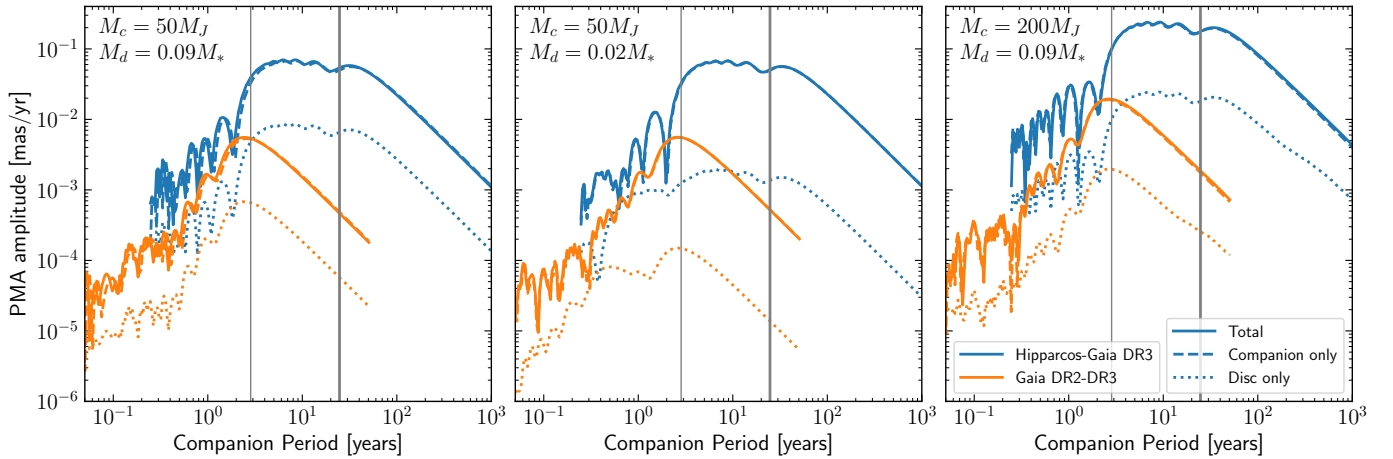
**Fig. 6.** Dust-disc cavity sizes that could be produced by the detected companions. For each source with a significant proper motion anomaly, blue distributions show the cavity sizes each Sect. 3.1 (Fig. A.2) companion could produce in their discs (from bootstrapping uncertainties). These distributions consider the mass ratio of each source and the theoretical prescription presented in Ragusa et al. (2025). Uncertainties in stellar mass, companion mass, and semi-major axis have been propagated consistently. We consider all possible companion inclinations and eccentricities. Vertical red lines show the observed dust cavity sizes at millimetre wavelengths (Fig. 1, with a generic 20% uncertainty).

particular, Ragusa et al. (2025) report from theoretical considerations an average ratio between cavity size and semi-major axis of  $\sim 3.5$  for stellar companions and  $\sim 1.7$  for planetary companions. Typical cavities do not exceed 7 times the companion’s semi-major axis (Sudarshan et al. 2022; Penzlin et al. 2025).

We find a preferred locus for the companions detected in this work in the mass ratio vs cavity radius-to-semimajor axis ratio plot (Fig. 5, right panel). Most companions have  $q = 0.1\text{--}0.5$  and their cavities have sizes 4 to 60 times larger than their semi-major axes. We find that the four sources with the more massive companions ( $>400 M_J$ ) are all located at  $\sim 1/10$  of their cavity size. This trend breaks for lower mass companions, although only two sources (MP Mus and Sz 76) have companions closer than one-fourth of their cavity size. However, we note these numbers only consider the median values of the distribution for companion mass and separation. To evaluate if the detected companions can be responsible for carving the observed cavities, we need to propagate uncertainties consistently in stellar mass, companion mass, and companion location. To do this, we apply the

theoretical prescription described in Ragusa et al. (2025) to derive the cavity size that each companion could carve. To propagate uncertainties, we bootstrap the stellar mass of the primary star and the companion’s mass and separation from the results of Sect. 3.1. We consider all possible companion inclinations and eccentricities over the full range of companion mass and separation. This provides an assessment of which companions are entirely inconsistent with having carved the inner dust cavity in their respective protoplanetary discs under current theoretical considerations (Ragusa et al. 2025).

Our results are shown in Fig. 6. We find that in the following 14 sources the companion detected with our method could be responsible for carving the cavity (considering a 20% cavity size uncertainty): AK Sco, CS Cha, GW Ori, HD 100453, J04343128+1722201, J16102955-3922144, MHO6, MP Mus, PDS 111, PDS 70, Sz 76, T Cha, UZ Tau E, and V892 Tau. We remark that, although the cavities in these systems are consistent with tidal truncation from the detected companions, this consistency alone is not sufficient to claim such companions



**Fig. 7.** Measured proper motion anomalies ( $|\Delta\mu|$ ) from hydrodynamical simulations describing the effect of protoplanetary disc gravity on *Gaia* DR2–DR3 and HIPPARCOS–*Gaia* DR3  $|\Delta\mu|$  (see Brandt 2021; Kervella et al. 2022 for the latter). We consider a  $1 M_{\odot}$  central star at 150 pc. Mass of the simulated companion and disc are shown in the legend of each plot. Vertical grey lines are HIPPARCOS–*Gaia* and *Gaia* DR2–*Gaia* DR3 time baselines. The effect of the disc on the measured proper motion anomaly is at most  $\sim 10\%$  for very massive discs ( $M_d \sim 0.1 M_{\star}$ ) across different mass ratios ( $q$ ).

are responsible for carving the cavity. In contrast, even considering large companion eccentricities (expected to produce larger cavities), we find that the companions in the following 16 sources are unable to carve the dust cavity of their protoplanetary discs: AA Tau, CIDA 9 A, CQ Tau, HD 142527 (in agreement with Nowak et al. 2024), HP Cha, IRAS 04125+2902, IRAS 04158+2805, IRAS 16072-2057, MWC 758, RXJ1852.3-3700, RY Lup, RY Tau, SR 24 S, Sz 100, Sz 118, and Sz 84. Our results agree with the dust modelling predictions of Sierra et al. (2024b, for the sources in common for which we detect companions, CQ Tau and SR 24 S).

In conclusion, our analysis suggests that tidal truncation from the detected companions cannot explain the dust cavities in 53% of the protoplanetary discs with companion detections, as their orbital semi-major axes are too small. However, as discussed in Sect. 4.1, a non-detection does not preclude unseen companions at larger separations that could be responsible for carving these cavities. If present, such putative, unseen companions must be sufficiently low-mass to remain undetected by direct imaging campaigns (they should be below  $\sim 10$ – $15 M_J$ , e.g. van der Marel et al. 2021; Ren et al. 2023; Stolker et al. 2024; Ruzza et al. 2025; Ragusa et al. 2025). This is consistent with the limited sensitivity of our method to companions with mass ratios  $q \lesssim 0.01$ , as discussed in Sect. 4.1.

## 5. Other possible sources of astrometric signal

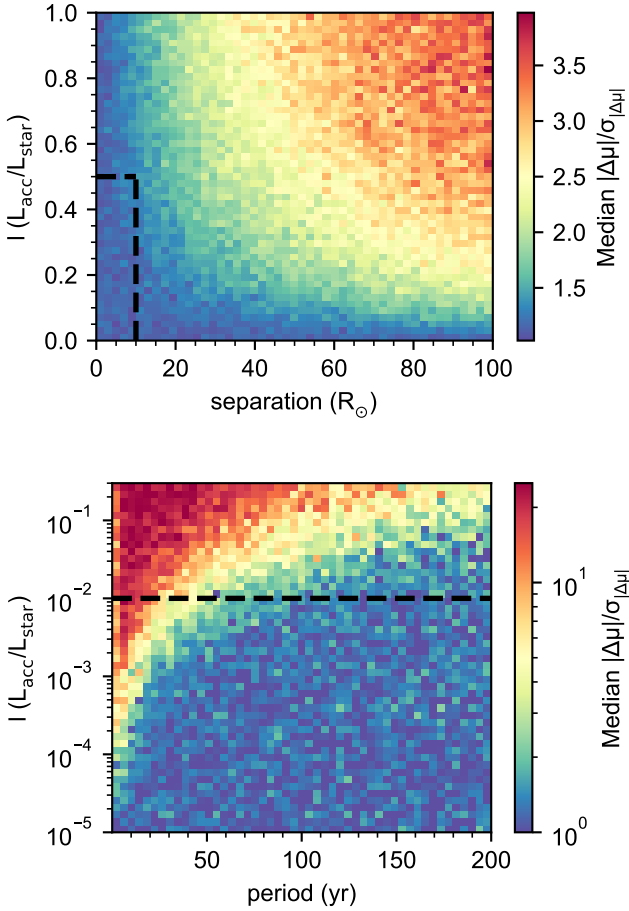
Young stellar objects have additional sources of astrometric noise than main-sequence stars. In this section we evaluate the impact of disc gravity, accretion, disc-scattered light, dippers (mostly caused by variable inner extinction or misaligned inner discs), starspots, jets, and outflows, in the measured proper motion anomaly ( $|\Delta\mu|$ ), and whether any of these effects can significantly cause false positive companion detections in YSOs.

The disc mass can contribute a proper motion anomaly signature via its gravitational influence on the system if the disc is not axisymmetric. This could be important for transition discs, as many are Herbig stars known to host massive discs (Stapper et al. 2024, 2025). While many processes can break the disc’s symmetry, we focus here on cases where a companion is present

and breaks the symmetry by making the disc eccentric. Since the disc eccentricities produced by a massive companion can reach 0.5 (e.g. Penzlin et al. 2024), this represents one of the largest expected sources of astrometric noise. The process likely to produce the largest signature in the absence of a companion would be the large-scale spiral arms generated by gravitational instability. However, transition discs do not typically exhibit large-scale spirals in the continuum at millimetre wavelengths and are therefore unlikely to be significantly affected by gravitational instability.

To test the effect of disc mass on  $|\Delta\mu|$ , we model companions on protoplanetary discs of different masses using hydrodynamical simulations. This effect mainly depends on the companion to stellar mass ratio ( $q$ ) and the disc to stellar mass ratio (see Appendix B for details). Disc masses are notoriously challenging to measure (Miotello et al. 2023; Teague et al. 2025; Zhang et al. 2025), but from the work of Martire et al. (2024) and Longarini et al. (2025) we constrain them to be at most 10% of the stellar mass for the vast majority of YSOs. Hence, we explore a range of mass ratios from  $q = 0.005$  to 0.2, and a range of disc masses from 1% to 10% the stellar mass. Higher  $q$  mass ratios result in a  $|\Delta\mu|$  entirely dominated by the binary system. Fig. 7 shows the impact of the disc’s gravity on  $|\Delta\mu|$  for some representative cases. We also evaluate the impact of disc gravity on the HIPPARCOS–*Gaia* DR3  $|\Delta\mu|$  (see Brandt 2021; Kervella et al. 2022). The main conclusions are that while the effect of the disc increases with companion mass from  $5 M_J$  to  $200 M_J$ , it remains a small fraction of the signal due to the companion. While increasing the disc mass increases the importance of the disc’s contribution to  $|\Delta\mu|$  (to at most  $\sim 10\%$ ), the disc mass would have to be implausibly high (and also gravitationally unstable) before its contribution to  $|\Delta\mu|$  is significant. While other disc parameters such as the viscosity, the locally-isothermal assumption, or the 2D nature of the simulations will affect the precise amplitude of the disc’s contribution (see, e.g. Sudarshan et al. 2022), the companion should always dominate the measured  $|\Delta\mu|$ . Empirically, in our sample we find no correlation between  $|\Delta\mu|$  and the reported disc masses, nor a higher fraction of detected companions in the more massive discs.

Independently, the accretion luminosity in YSOs can account for a significant amount of the total system luminosity



**Fig. 8.** Simulations of a point-like accretion element (top) and scattered light element (bottom) and the significance of the *Gaia* DR2-DR3 proper motion anomaly they induce ( $|\Delta\mu|/\sigma_{|\Delta\mu|}$ ). Black dashed lines indicate the conservative range where YSO accretion ( $l < 0.5$ , separation  $< 10 R_{\odot}$ ) and scattered light (any period,  $l < 0.01$ ) are observed.

(Delfini et al. 2025). In the case of the transition discs considered in this work, 26 have direct measurements of their accretion luminosity (Wichittanakom et al. 2020; Guzmán-Díaz et al. 2021; Manara et al. 2023, and references therein). We find that the median accretion luminosity for this sample is around 7.4% of the stellar luminosity, with some sources having values as high as 28% (SZ Cha). To evaluate whether the accretion luminosity can have an effect on  $|\Delta\mu|$  or  $|\Delta\mu|/\sigma_{|\Delta\mu|}$ , we simulate the effect of a point-like accretion element in rotation at a range of separations, periods, and luminosities. As accretion is often more axisymmetrical and stochastic than a single rotating accretion element, any real stellar accretion phase would produce a net effect in  $|\Delta\mu|$  and  $|\Delta\mu|/\sigma_{|\Delta\mu|}$  smaller than these simulations.

To recreate the point-like accretion element, we simulate a single star with a companion of no mass but a range of light-ratios  $l = 0.0$  to  $l = 1.0$  (i.e. from no accretion luminosity to half the luminosity coming from the accretion phase). Because accretion luminosity originates on scales near the stellar radius (Hartmann et al. 2016), we simulate separations between 0.1 to 100  $R_{\odot}$ . Stellar masses between 0.1 and 1.5  $M_{\odot}$  are considered. We run 1 000 000 simulations uniformly covering these ranges of  $l$ , separation, and stellar mass. The rest of the parameters, including magnitude (within  $G=6.5$  to 19 mag), parallax (within 5–10 mas, or 100–200 pc), inclination, position angle, eccentricity, and coordinates (which determine the *Gaia* observational

coverage) are taken at random in each simulation. The accretion periodicity is randomly sampled between periods of 0.1 and 100 days at each simulation (Keplerian rotation is not assumed), a range that encompasses the rotation period of most stars.

The result of these simulations is shown in Fig. 8. We find no dependence of the accretion element producing the detection of companions (i.e.  $|\Delta\mu|/\sigma_{|\Delta\mu|} > 3$ ) with any parameter except for separation and light-ratio. Only 1% of simulations in a conservative range where accretion luminosity is expected to originate (red box,  $l < 0.5$  and separation  $< 10 R_{\odot}$ ) produce false positive companions. Hence, we conclude that fewer than 1% of false positives can be attributed to accretion. Fig. 8 shows that only accretion elements at separations larger than 20  $R_{\odot}$  with  $l > 0.1$  have the potential to cause a significant proper motion anomaly.

Similarly, we simulate the effect of a single point of disc-scattered light on the proper motion anomaly. Again, scattered light is often extended and axisymmetrical, so any real scattered light would produce a net effect in  $|\Delta\mu|$  and  $|\Delta\mu|/\sigma_{|\Delta\mu|}$  smaller than these simulations. For the scattered light element, we also assume no Keplerian rotation, and sample at random periods from 0.1 days to 1370 years and separations from 0.1 to 1000 au. We find no dependence of the scattered-light element producing the detection of companions (i.e.  $|\Delta\mu|/\sigma_{|\Delta\mu|} > 3$ ) with any parameter except for period and light-ratio. The sources with the brightest scattered light in the sample have on the order of 1–2% of their stellar luminosity at optical wavelengths, although this light-ratio is much below 1% for most sources (Garufi et al. 2022, in prep., Ren et al. 2023). Considering this, Fig. 8 shows that scattered light can lead to false positives if localised in periods under  $\sim 50$  years. However, we find that the scattered light elements of Fig. 8 with  $|\Delta\mu|/\sigma_{|\Delta\mu|} > 3$  have periods at least 100 times shorter than Keplerian. Hence, only very non-axisymmetric, bright, and fast-moving scattered light elements can contribute significantly to  $|\Delta\mu|$  and produce false positive companion detections.

We note that the analyses of Fig. 8 can be extrapolated to evaluate the effect of dippers or photospheric cold spots. Dippers are irregularly variable YSOs whose variability is believed to be caused by misaligned inner discs and irregular extinction events (Empey et al. 2025). For example, the accretion element interpretation can be replaced by one in which the visible photosphere appears to move due to occultation by a misaligned inner disc or starspots. This argument also leads to the conclusion that dippers or starspots cannot contribute significantly to  $|\Delta\mu|$ . Indeed, we find a similar companion fraction ( $\sim 30\%$ ) in the dipper catalogue of Capistrant et al. (2022) to that in randomly sampled groups of YSOs and main-sequence stars (see Sect. 4.1). Likewise, the analyses of Fig. 8 can be extrapolated to jet and outflow emission. Some sources can have very bright jets (e.g. Flores-Rivera et al. 2023), which could potentially shift their photocentre. As shown in Fig. 8, if the outflow emission is far from the central star, or if it rotates rapidly, it could indeed lead to false positive companion detections.

To provide additional support for the conclusions of this section, we note that in our sample there are discs with very high accretion rates (e.g. SZ Cha), bright scattered light (e.g. AT Pyx and J160421.7-213028: Ginski et al. 2022; Pinilla et al. 2018a), and misaligned inner discs (e.g. DoAr 44, HD 139614), all of which show no significant  $|\Delta\mu|$ .

The analyses in this section illustrate that astrometric techniques, such as the one employed in this work, can be applied to YSOs to infer the presence of companions, and the different caveats involved. We conclude that only disc-scattered light or jet emission could have a substantial impact in the

astrometry and the proper motion anomaly, and only if they are highly non-axisymmetric, bright, and fast-moving.

## 6. Conclusions

In this work, our focus has been on the search for planetary and stellar companions in a sample of 98 YSOs with inner dust cavities in their protoplanetary discs (or ‘transition discs’). We re-derived stellar masses in a homogeneous manner for all sources and compile disc geometries and cavity sizes from the literature (Table A.1). We then computed *Gaia* proper motion anomalies for the entire sample, which together with the RUWE can reveal the presence of companions with mass ratios  $q = M_{\text{comp}}/M_{\text{primary}} \gtrsim 0.01$  at separations between 0.1 and 30 au. Our main conclusions are the following:

- Of the 98 transition discs considered, 31 have significant proper motion anomalies (32%) indicative of companions in the system, and 67 do not (68%). These are presented in Table A.1, and Figs. 1 and A.1. Twenty of these systems have either no previously reported companions or only indirect detections that are confirmed here (Sect. 3.3). We recover 85% of the known companions within the sample at separations between 0.1 and 30 au;
- For the 31 detections, assuming that the astrometry of each system is dominated by a single companion, we simulate the companion mass and semi-major axis required to reproduce the observed astrometric signals (Fig. A.2). We present the 10th, 50th, and 90th percentiles of the distribution of possible companion masses and semi-major axes in Table A.1. Most recovered companions have  $M > 30 M_{\text{J}}$ , placing many of them within or near the stellar mass regime. Eight sources have median companion mass estimations in the brown-dwarf regime. Seven sources are compatible with hosting a planetary mass companion (HD 100453, J04343128+1722201, J16102955-3922144, MHO6, MP Mus, PDS 70, and Sz 76);
- For the 67 non-detections, we estimate the semi-major axis and mass that a companion would need to produce a significant proper motion anomaly or a high RUWE, thereby defining the region of the separation-mass parameter space that can be excluded in future searches (Fig. A.3);
- Several sources with previously proposed companions yielded non-detections in our analysis. These include AB Aur, HD 100546, HD 135344 B, HD 163296, HD 169142, HD 97048, LkCa 15, 2MASS J16120668-3010270, and WISPIT 2. We emphasise that these non-detections do not imply the absence of companions in these systems. Rather, we exclude only a narrow range of companion masses and separations (typically masses  $> 40 M_{\text{J}}$  at separations of 0.3 to 10 au, though the exact limits vary from source to source). We encourage the reader to consult Fig. A.3 for the detailed constraints for each source;
- We find that 53% of detected companions cannot be reconciled with having carved the inner dust cavities (Sect. 4.2). If such cavities are indeed shaped by companions, they must reside at larger orbital separations than those of the companions detected here. Provided they have not been identified in other surveys sensitive to these wider separations, we predict that, if these companions exist, they are likely to be of planetary mass. This hypothesis that dust cavities are caused by planetary-mass companions located relatively close to the cavity edge is also consistent with the large fraction of non-detections observed in sources with both small and large inner dust cavities (Sect. 4.1);

- The population of transition discs cannot be fully described as a circumbinary population, and transition discs host as many binaries within the sensitivity range of this work as do randomly sampled groups of YSOs and main-sequence stars. We test this using the Sco-Cen and Taurus regions, together with known binary samples (Sect. 4.1). This further supports the idea that inner dust cavities are not a consequence of stellar binary companions;
- We assess the impact of disc gravity, accretion, disc-scattered light, dippers (typically caused by variable inner extinction or misaligned inner discs), starspots, jets, and outflows on the measured proper motion anomaly, evaluating whether any of these effects could significantly contribute to the astrometric signal. We conclude that only disc-scattered light or jet emission could have a substantial impact, and only if such emission is highly non-axisymmetric, bright, and fast-moving (with periods shorter than 100 times the Keplerian period). This demonstrates that astrometric analyses such as the one presented here can be reliably applied to forming stars.

In this work, we have gathered indirect evidence of the presence of companions in a large sample of transition discs. Our results lay the groundwork for applying this and similar astrometric techniques to other populations of forming stars for planetary and stellar companion searches.

## Data availability

Table A.1 is available at the CDS via <https://cdsarc.cds.unistra.fr/viz-bin/cat/J/A+A/705/A238>

*Acknowledgements.* We thank the Star and Planet Formation group at ESO and Nienke van der Marel for insightful discussions which improved this work. This work has made use of data from the European Space Agency (ESA) mission *Gaia* (<https://www.cosmos.esa.int/gaia>), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, <https://www.cosmos.esa.int/web/gaia/dpac/consortium>). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement. This paper makes use of the following ALMA data: ADS/JAO.ALMA#2012.1.00631.S, ADS/JAO.ALMA#2012.1.00698.S, ADS/JAO.ALMA#2013.1.00437.S, ADS/JAO.ALMA#2015.1.01301.S, ADS/JAO.ALMA#2016.1.00344.S, ADS/JAO.ALMA#2016.1.00715.S, ADS/JAO.ALMA#2016.1.01286.S, ADS/JAO.ALMA#2016.1.01511.S, ADS/JAO.ALMA#2017.1.00449.S, ADS/JAO.ALMA#2017.1.00969.S, ADS/JAO.ALMA#2017.1.01404.S, ADS/JAO.ALMA#2017.1.01578.S, ADS/JAO.ALMA#2017.1.01678.S, ADS/JAO.ALMA#2018.1.00310.S, ADS/JAO.ALMA#2018.1.00532.S, ADS/JAO.ALMA#2018.1.00689.S, ADS/JAO.ALMA#2018.1.01054.S, ADS/JAO.ALMA#2018.1.01066.S, ADS/JAO.ALMA#2018.1.01302.S, ADS/JAO.ALMA#2018.1.01458.S, ADS/JAO.ALMA#2018.1.01829.S, ADS/JAO.ALMA#2019.1.00566.S, ADS/JAO.ALMA#2019.1.00847.S, ADS/JAO.ALMA#2019.1.01091.S, ADS/JAO.ALMA#2019.1.01270.S, ADS/JAO.ALMA#2021.1.00378.S, ADS/JAO.ALMA#2021.1.00994.S, ADS/JAO.ALMA#2021.1.01137.S, ADS/JAO.ALMA#2021.1.01705.S, ADS/JAO.ALMA#2022.1.00313.S, ADS/JAO.ALMA#2022.1.00646.S, ADS/JAO.ALMA#2013.1.00291.S, ADS/JAO.ALMA#2015.1.00979.S, ADS/JAO.ALMA#2015.A.00005.S, ADS/JAO.ALMA#2016.1.00484.L, ADS/JAO.ALMA#2016.1.01164.S, ADS/JAO.ALMA#2016.1.01344.S, ADS/JAO.ALMA#2017.1.00388.S, ADS/JAO.ALMA#2017.1.00492.S, ADS/JAO.ALMA#2017.1.01151.S, ADS/JAO.ALMA#2017.1.01460.S, ADS/JAO.ALMA#2017.1.01631.S, ADS/JAO.ALMA#2018.1.00028.S, ADS/JAO.ALMA#2018.1.00350.S, ADS/JAO.ALMA#2018.1.00536.S, ADS/JAO.ALMA#2018.1.01020.S, ADS/JAO.ALMA#2018.1.01055.L, ADS/JAO.ALMA#2018.1.01255.S, ADS/JAO.ALMA#2018.1.01309.S, ADS/JAO.ALMA#2018.1.01755.S, ADS/JAO.ALMA#2018.A.00030.S, ADS/JAO.ALMA#2019.1.00607.S, ADS/JAO.ALMA#2019.1.01059.S, ADS/JAO.ALMA#2019.1.01210.S, ADS/JAO.ALMA#2021.1.00128.L, ADS/JAO.ALMA#2021.1.00709.S, ADS/JAO.ALMA#2021.1.01123.L, ADS/JAO.ALMA#2021.1.01661.S, ADS/JAO.ALMA#2022.1.00154.S, ADS/JAO.ALMA#2022.1.00340.S, ADS/JAO.ALMA#2022.1.00742.S,

ADS/JAO.ALMA#2022.1.00760.S, ADS/JAO.ALMA#2022.1.00908.S, ADS/JAO.ALMA#2022.1.01302.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. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory. RAB thanks the Royal Society for their support through a University Research Fellowship. ER acknowledges financial support from the European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 101102964 (ORBIT-D). A.R. has been supported by the UK Science and Technology Facilities Council (STFC) via the consolidated grant ST/W000997/1 and by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No. 823823 (RISE DUSTBUSTERS project). GR and ER acknowledge support from the European Union (ERC Starting Grant DiscEvol, project number 101039651) and from Fondazione Cariplo, grant No. 2022-1217. Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Council. Neither the European Union nor the granting authority can be held responsible for them. SF acknowledges financial contribution from the European Union (ERC, UNVEIL, 101076613) and from PRIN-MUR 2022Y5ACE. MB has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (PROTOPLANETS, grant agreement No. 101002188). NH is funded by the Spanish grant MCIN/AEI/10.13039/501100011033 PID2023-150468NB-I00. This project has received funding from the European Research Council (ERC) under the European Union Horizon Europe programme (grant agreement No. 101042275, project Stellar-MADE). This work was partly funded by ANID – Millennium Science Initiative Program – Center Code NCN2024\_001. S.P. acknowledges support from FONDECYT 1231663. Funded by the European Union (ERC, WANDA, 101039452). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Council Executive Agency. Neither the European Union nor the granting authority can be held responsible for them. IM's research is funded by grants PID2022-138366NA-I00, by the Spanish Ministry of Science and Innovation/State Agency of Research MCIN/AEI/10.13039/501100011033 and by the European Union, and by a Ramón y Cajal fellowship RyC2019-026992-I.

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## Appendix A: Detections and non-detections

Table A.1 lists the stellar (effective temperature, luminosity, and mass) and disc properties (cavity size, inclination, and position angle) of the 98 sources with inner dust cavities (‘transition discs’) considered in this work, and whether we detect companions in them via proper motion anomalies ( $|\Delta\mu|/\sigma_{|\Delta\mu|} \geq 3$ ). For the detected companions, we report the predicted companion mass and semi-major axis (Sect. 3.1). Figs. A.2 and A.3 show the parameter space of semi-major axis versus companion mass for companion detections and non-detections (for the latter, Fig. A.3 shows the space of separations and masses where a companion dominating the astrometric signal can be excluded), as illustrated by Figs. 2 and 4, respectively.

The references for the ALMA continuum images of Figs. 1 and A.1 are: AA Tau (Yamaguchi et al. 2024), AB Aur (Speedie et al. 2024), AK Sco (2019.1.01210.S, PI: Czekala), AS 205 S (Kurtovic et al. 2018), AT Pyx (2021.1.01705.S, PI: Ginski), BP Tau and Sz 98 (Gasman et al. 2025), CIDA 1 (Pinilla et al. 2021), CIDA 9 A (Harsono et al. 2024), CQ Tau (Wölfer et al. 2021), CS Cha (Kurtovic et al. 2022), DM Tau (Hashimoto et al. 2021b), AS 209, HD 142666, HD 163296, SR 4, and Sz 129 (Huang et al. 2018b), EX Lup, J16090141-3925119, J16092697-3836269, Sz 131, Sz 72, Sz 90, Sz 96, Sz 100, Sz 108 B, Sz 111, Sz 123 A, and Sz 76 (Guerra-Alvarado et al. 2025), GG Tau (Rota et al. 2024), GM Aur (Huang et al. 2020), GW Ori (2021.1.01661.S, PI: Kraus), MHO2 and HD 139614 (2022.1.01302.S, PI: Mulders), HD 142527 (Yamaguchi et al. 2019), HD 290764 (Wölfer et al. 2023), HD 34282 and PDS 99 (Francis & van der Marel 2020), HD 34700 (2022.1.00760.S, PI: Stadler), HD 100453 (Gonzalez et al. 2020), HD 100546 (Casassus et al. 2022), HD 135344 B (Casassus et al. 2021), HD 143006 (Pérez et al. 2018), HD 169142 (Pérez et al. 2019), HP Cha and RY Lup (Norfolk et al. 2021), IP Tau (Long et al. 2018), IRAS 04125+2902 (Shoshi et al. 2025), IRAS 04158+2805 (Ragusa et al. 2021), IRAS 16072-2057, J16140792-1938292 (2022.1.00646.S, PI: Long), IRAS16201-2410 (Dasgupta et al. 2025), IRS 48 (Yang et al. 2023), J04124068+2438157 (Long et al. 2023), J04343128+1722201, J04360131+1726120, and J05080709+2427123 (Shi et al. 2024), J16120668-3010270 (Sierra et al. 2024a), J16163345-2521505, J16202863-2442087, and J16221532-2511349 (Vioque et al. 2025), J160421.7-213028 (Stadler et al. 2023), J16083070-3828268 and RXJ1852.3-3700 (2018.1.00689.S, PI: Muto), J16102955-3922144 (2016.1.00715.S, PI: Facchini), LkCa 15 (Long et al. 2022), LkHa 330 (Pinilla et al. 2022), MHO6 (Kurtovic et al. 2021), MP Mus, RXJ1842.9-3532, and V4046 Sgr (Curone et al. 2025), MWC 758 (Dong et al. 2018), PDS 111 (Derkink et al. 2024), PDS 70 (Benisty et al. 2021), RW Aur B (Kurtovic et al. 2024), RXJ1615.3-3255 (2016.1.01286.S, Benisty), DoAr 44, ISO-Oph 2, RXJ1633.9-2442, WSB 60, and WSB 82 rho-Oph 38 (Cieza et al. 2021), RY Tau, J16070854-3914075, and HD 97048 (Ribas et al. 2024), SR 21 A (Stapper et al. 2025), SR 24 S (2022.1.00908.S, PI: Rodriguez Jimenez), SY Cha (Orihara et al. 2023), SZ Cha (Pascucci et al. 2016), Sz 118 (2022.1.00340.S, PI: Andrews), Sz 84 (Hashimoto et al. 2021a), Sz 91 (Maucó et al. 2021), T Cha (Hendler et al. 2018), TW Hya (Huang et al. 2018a), UX Tau A (2021.1.00994.S, PI: Perez), UZ Tau (2017.1.00388.S, PI: Liu), V892 Tau (Long et al. 2021), ZZ Tau IRS (Hashimoto et al. 2022).

## Appendix B: Details of the hydrodynamic simulations

This Appendix details the hydrodynamical simulations presented in Sect. 5 and Fig. 7.

We investigate the impact of a massive, eccentric disc produced by a companion by conducting 2D locally-isothermal hydrodynamic simulations with FARGO3D (Benítez-Llambay & Masset 2016). The disc aspect ratio is set to  $h = 0.05(R/R_{p,0})^{0.25}$ , where  $R_{p,0}$  is the planet’s initial location and  $R$  is the distance from the star. The surface density is set to  $\Sigma(R) = \Sigma_0(R/R_{p,0})^{-1} \exp(-R/R_c)$ , where  $R_c = 30 R_{p,0}$  is used by default. The normalisation,  $\Sigma_0$ , is set by specifying the Toomre  $Q$  parameter at  $R_{p,0}$ . For a fiducial value of  $Q = 20$ , our choices correspond to a disc-to-star mass ratio within the simulation domain of 0.09. We have explored  $Q$  in the range [10, 500],  $R_c$  in the range [10, 30]  $R_{p,0}$  and companion-to star masses in the range [0.005, 0.2], which corresponds to approximately 5 to 200  $M_J$  for a 1  $M_\odot$  star.

The simulations are computed on a grid of size  $N_R \times N_\phi = 1500 \times 2048$ . The radial cells are logarithmically-spaced from 0.2  $R_{p,0}$  to 30  $R_{p,0}$ . We use an  $\alpha$  viscosity with  $\alpha = 10^{-4}$ . We apply damping boundary conditions with a damping zone 1.15 times larger/smaller than the inner/outer radius. The disc self-gravity is included using the scheme of Baruteau & Masset (2008). To ensure that Newton’s 3rd law is properly accounted for, we include the indirect term (e.g. Crida et al. 2025). The potentials due to the planet and disc are both softened over a length scale 0.04  $R$ , as the self-gravity module requires a softening law  $\propto R$ . The simulations are run for 1000 orbits at  $R_{p,0}$ .

Since the simulations are conducted in a frame centred on the star, the motion of the star is tracked by computing the centre of mass of the system in that frame. The proper motion anomaly is then estimated by sampling the centre of mass at 50 uniformly chosen points over the observational time baseline and computing the average motion during that baseline. To convert the signal to physical units,  $R_{p,0}$  is scaled to the appropriate distance and the star is assumed to be at a distance of 150 pc.

Table A.1: YSO sources with protoplanetary discs with inner dust cavities ('transition discs') considered in this work.

Name	Companion mass ( $M_J$ )	Companion separation (au)	$T_{\text{eff}}$ (K)	$L_*$ ( $L_{\odot}$ )	Ref. stellar param.	$M_*$ ( $M_{\odot}$ )	inc (deg)	PA (deg)	Cavity size (au)	Ref. disc geom.	$ \Delta\mu /\sigma_{ \Delta\mu }$	RUWE
AA Tau	Yes	$98^{+200}_{-55}$	$3762^{+190}_{-190}$	$0.75^{+0.34}_{-0.34}$	1	$0.47 \pm 0.23$	$58.540 \pm 0.020$	$93.770 \pm 0.030$	44.0	a	5.11	3.33
AB Aur	No	$1.93^{+1.9}_{-1.00}$	$9000^{+120}_{-120}$	$45.7^{+4.6}_{-4.6}$	2	$2.464 \pm 0.094$	$23.0 \pm 1.0$	$36.0 \pm 1.0$	156.0	b	1.37	1.37
AK Sco	Yes	$323^{+970}_{-250}$	$6000^{+250}_{-250}$	$5.6^{+1.5}_{-1.5}$	2	$1.69 \pm 0.45$	$65.0 \pm 1.0$	$53.0 \pm 5.0$	20.0	this work	5.35	1.60
AS 205 S	No	$4.3^{+5.9}_{-3.8}$	$3970^{+50}_{-30}$	$0.44^{+0.20}_{-0.20}$	3	$0.69 \pm 0.12$	$66.3 \pm 1.7$	$109.60 \pm 0.80$	3.4	c	1.00	1.75
AS 209	No		$4266^{+310}_{-280}$	$1.42^{+0.83}_{-0.52}$	4	$0.90 \pm 0.58$	$34.97 \pm 0.13$	$85.76 \pm 0.16$	12.0	d	1.02	1.48
AT Pyx	No		$4760^{+160}_{-210}$	$1.63^{+0.73}_{-0.73}$	5	$1.31 \pm 0.37$			63.0		2.12	3.53
BP Tau	No		$3777^{+190}_{-190}$	$0.98^{+0.10}_{-0.10}$	5	$0.466 \pm 0.058$	$38.20 \pm 0.50$	$151.1 \pm 1.0$	9.0	e	2.23	2.20
CIDA 1	No		$3125^{+160}_{-160}$	$0.210^{+0.094}_{-0.094}$	1	$0.171 \pm 0.085$	$38.20 \pm 0.15$	$11.20 \pm 0.18$	21.0	f	2.14	1.07
CIDA 9 A	Yes	$0.80^{+0.44}_{-0.26}$	$3589^{+180}_{-180}$	$0.049^{+0.022}_{-0.022}$	1	$0.49 \pm 0.20$	$46.0 \pm 1.0$	$103.0 \pm 1.0$	29.0	b	5.08	3.59
CQ Tau	Yes	$309^{+840}_{-190}$	$6750^{+120}_{-120}$	$6.61^{+0.66}_{-0.66}$	2	$1.541 \pm 0.062$	$35.240 \pm 0.020$	$53.870 \pm 0.020$	50.0	a	4.04	3.70
CS Cha	Yes	$668^{+670}_{-400}$	$4900^{+240}_{-240}$	$2.04^{+0.92}_{-0.92}$	1	$1.48 \pm 0.40$	$17.9 \pm 1.0$	$82.6 \pm 1.0$	37.0	g	18.48	6.41
DM Tau	No		$3415^{+170}_{-170}$	$0.24^{+0.11}_{-0.11}$	1	$0.29 \pm 0.17$	$35.970 \pm 0.050$	$155.600 \pm 0.080$	18.0	a	1.10	1.49
DoAr 44	No		$4780^{+240}_{-240}$	$1.91^{+0.19}_{-0.19}$	6	$1.30 \pm 0.49$	$20.0 \pm 1.0$	$30.0 \pm 1.0$	40.0	b	2.18	1.29
EX Lup	No		$3850^{+180}_{-180}$	$0.74^{+0.33}_{-0.33}$	7	$0.53 \pm 0.29$	$32.40 \pm 0.90$	$64.6 \pm 3.3$	28.0	h	0.80	1.12
GG Tau	Yes	No solution	$4060^{+200}_{-200}$	$1.11^{+0.19}_{-0.16}$	8	$0.69 \pm 0.34$	$36.0 \pm 1.0$	$98.0 \pm 1.0$	224.0	b	12.68	6.44
GM Aur	No		$4202^{+210}_{-210}$	$0.90^{+0.41}_{-0.41}$	1	$0.84 \pm 0.41$	$53.0 \pm 1.0$	$56.0 \pm 1.0$	40.0	b	1.71	2.53
GW Ori	Yes	$1162^{+1300}_{-710}$	$5700^{+150}_{-150}$	$35.5^{+4.2}_{-3.5}$	9	$3.36 \pm 0.30$	$40.0 \pm 1.0$	$1.0 \pm 1.0$	29.0	this work	8.65	4.23
HD 100453	Yes	$94^{+660}_{-87}$	$7250^{+120}_{-120}$	$6.17^{+0.62}_{-0.62}$	2	$1.61 \pm 0.11$	$30.0 \pm 1.0$	$149.0 \pm 1.0$	30.0	b	3.76	1.08
HD 100546	No		$9250^{+120}_{-120}$	$21.9^{+2.2}_{-2.2}$	2	$2.10 \pm 0.10$	$42.0 \pm 1.0$	$139.0 \pm 1.0$	25.0	b	2.16	1.30
HD 135344 B	No		$6250^{+120}_{-120}$	$5.13^{+0.51}_{-0.51}$	2	$1.504 \pm 0.073$	$20.730 \pm 0.020$	$28.920 \pm 0.090$	52.0	a	1.68	0.91
HD 139614	No		$7500^{+120}_{-120}$	$6.76^{+0.68}_{-0.68}$	2	$1.65 \pm 0.14$			9.4		0.83	1.05
HD 142527	Yes	$158^{+1300}_{-110}$	$6750^{+120}_{-120}$	$22.4^{+2.2}_{-2.2}$	2	$2.24 \pm 0.16$	$27.0 \pm 1.0$	$25.0 \pm 1.0$	185.0	b	4.60	1.18
HD 142666	No		$7250^{+120}_{-120}$	$13.5^{+1.3}_{-1.3}$	2	$1.87 \pm 0.18$	$62.22 \pm 0.14$	$162.11 \pm 0.15$	6.0	d	1.12	1.04
HD 143006	No		$5500^{+120}_{-120}$	$3.47^{+0.35}_{-0.35}$	2	$1.66 \pm 0.21$	$18.690 \pm 0.090$	$7.53 \pm 0.35$	41.0	a	1.32	1.13
HD 163296	No		$8750^{+120}_{-120}$	$15.5^{+1.7}_{-1.7}$	2	$1.91 \pm 0.11$	$46.70 \pm 0.10$	$133.33 \pm 0.15$	3.0	d	0.33	0.92
HD 169142	No		$7250^{+120}_{-120}$	$5.75^{+0.58}_{-0.58}$	2	$1.571 \pm 0.093$	$12.0 \pm 1.0$	$5.0 \pm 1.0$	24.0	b	0.88	0.78
HD 290764	No		$7750^{+120}_{-120}$	$21.9^{+2.2}_{-2.2}$	2	$2.17 \pm 0.10$	$30.0 \pm 1.0$	$115.4 \pm 1.0$	52.0	this work	2.03	1.25
HD 34282	No		$9500^{+250}_{-250}$	$14.5^{+1.4}_{-1.4}$	10	$2.03 \pm 0.15$	$59.090 \pm 0.010$	$117.150 \pm 0.010$	80.0	a	0.72	1.41
HD 34700	No		$6000^{+120}_{-120}$	$22.9^{+2.3}_{-2.3}$	2	$2.70 \pm 0.40$	$37.9 \pm 2.0$	$87.1 \pm 1.2$	65.0	i	1.43	1.05
HD 97048	No		$11000^{+120}_{-120}$	$64.6^{+6.5}_{-6.5}$	2	$2.846 \pm 0.096$	$41.0 \pm 1.0$	$4.0 \pm 1.0$	63.0	b	1.32	1.43
HP Cha	Yes	$150^{+330}_{-110}$	$4060^{+200}_{-200}$	$3.29^{+0.33}_{-0.33}$	11	$0.57 \pm 0.35$	$37.0 \pm 1.0$	$162.0 \pm 1.0$	50.0	b	3.66	3.25
...	...	...	...	...	...	...	...	...	...	...	...	...

Notes. 98 YSO sources with inner dust cavities ('transition discs') considered in this work. Stellar masses were derived in this work (Sect. 2). The full version of the table is available in electronic form at the CDS (Sect. 6). The online version of the table also includes *Gaia* DR3 and DR2 source IDs, *Gaia* DR3 coordinates,  $|\Delta\mu|$ ,  $\sigma_{|\Delta\mu|}$ , and the remaining *Gaia* DR3 astrometric parameters. References for effective temperatures and luminosities: 1–Manara et al. (2021), 2–Guzmán-Díaz et al. (2019), 3–Eisner et al. (2005), 4–Andrews et al. (2018), 5–Herczeg & Hillenbrand (2014), 6–Manara et al. (2014), 7–Alcalá et al. (2017), 8–White et al. (1999), 9–Valegård et al. (2021), 10–Wichitanakom et al. (2020), 11–Manara et al. (2017). References for disc geometries: a–Curone et al. (2025), b–Francis & van der Marel (2020), c–Kurtovic et al. (2018), d–Huang et al. (2018), e–Gasman et al. (2025), f–Kurtovic et al. (2021), g–Kurtovic et al. (2022), h–Hales et al. (2018), i–Columba et al. (2024).

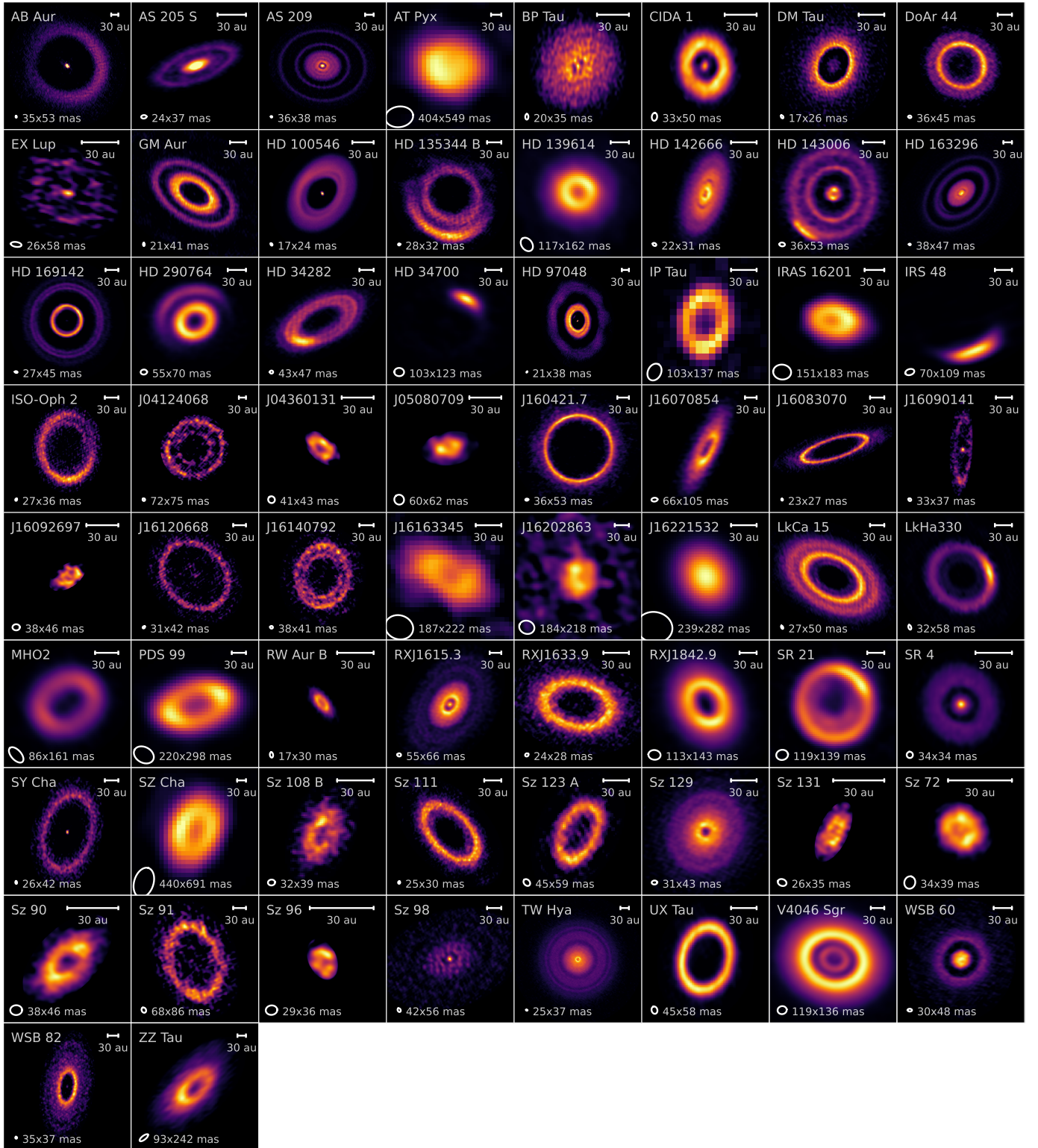


Fig. A.1: ALMA continuum images of the sample of 67 discs with inner dust cavities (“transition discs”) for which we do not find a significant proper motion anomaly ( $|\Delta\mu|/\sigma_{|\Delta\mu|} < 3$ ) indicative of companions. WISPIT 2 is missing from this mosaic because its ALMA image showing an inner dust cavity (priv. comm.) was not publicly available at the time of publication. The companion separation–mass parameter space in which a companion dominating the astrometric signal can be excluded based on this non-detection is described in Sect. 3.2 (see Figs. 4 and A.3).

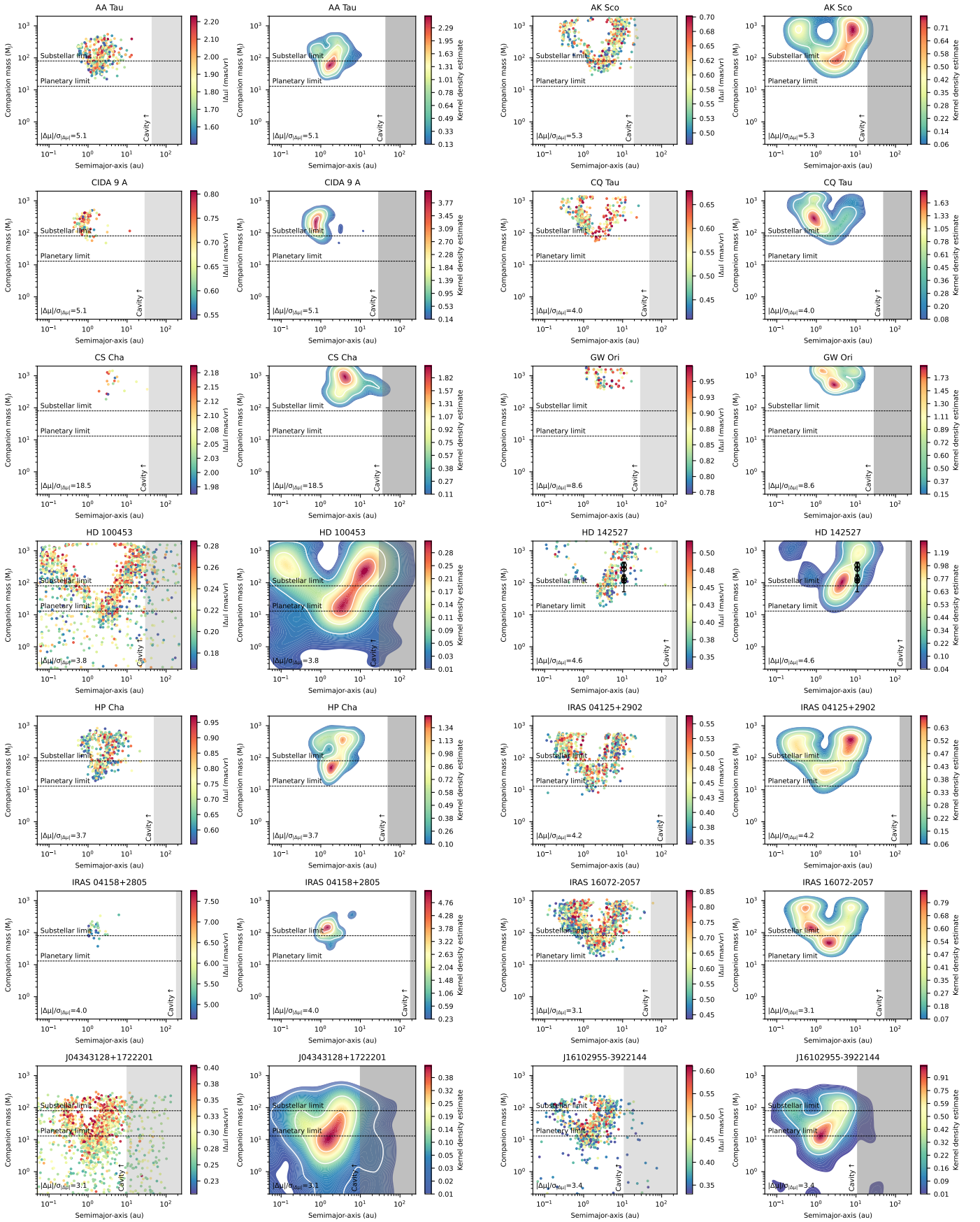


Fig. A.2: Orbital separation and companion mass that would produce the observed *Gaia* astrometry for the 31 sources with a significant proper motion anomaly ( $|\Delta\mu|/\sigma_{|\Delta\mu|} \geq 3$ ). GG Tau is not shown here because its companion could not be modelled.

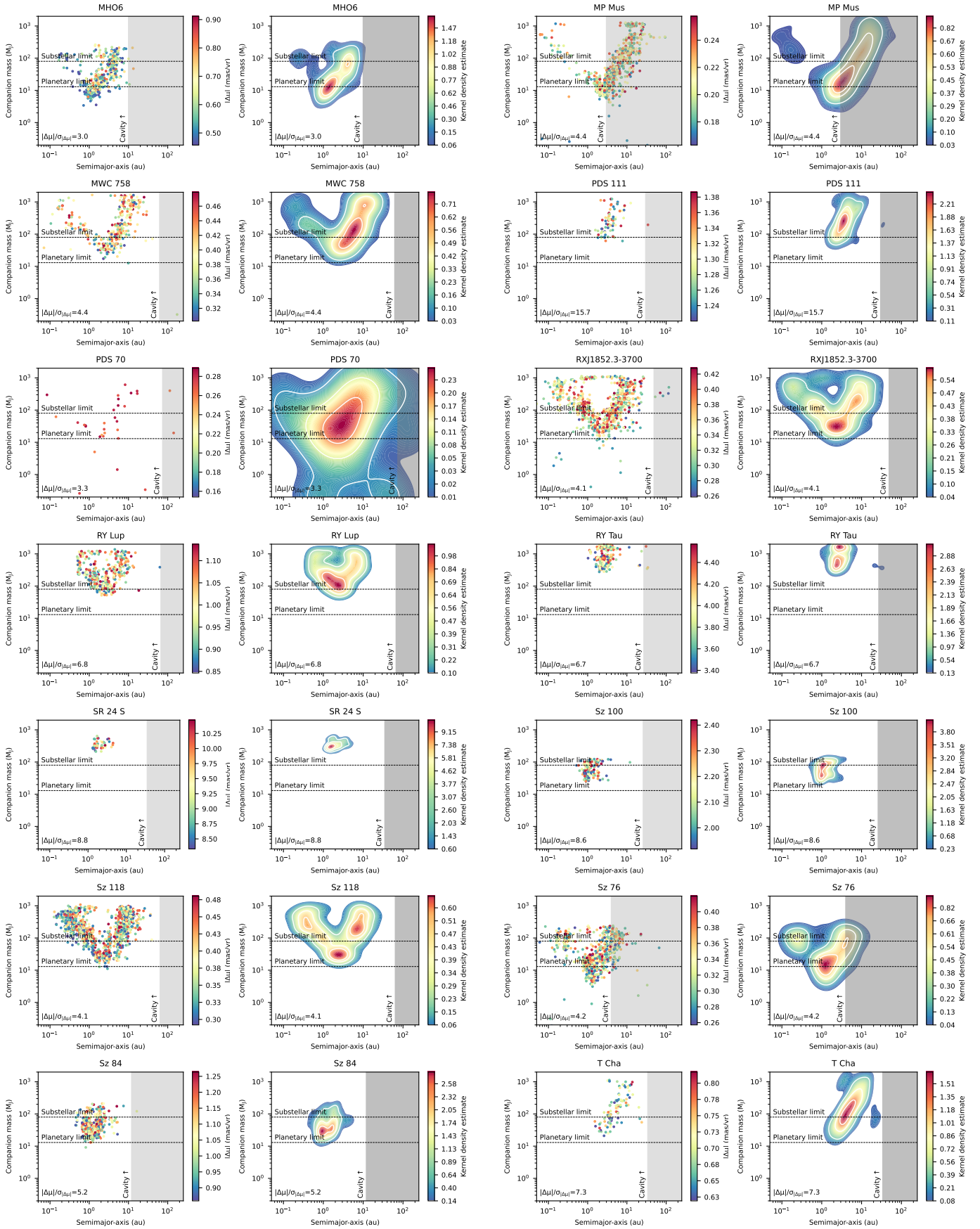


Fig. A.2: continued.

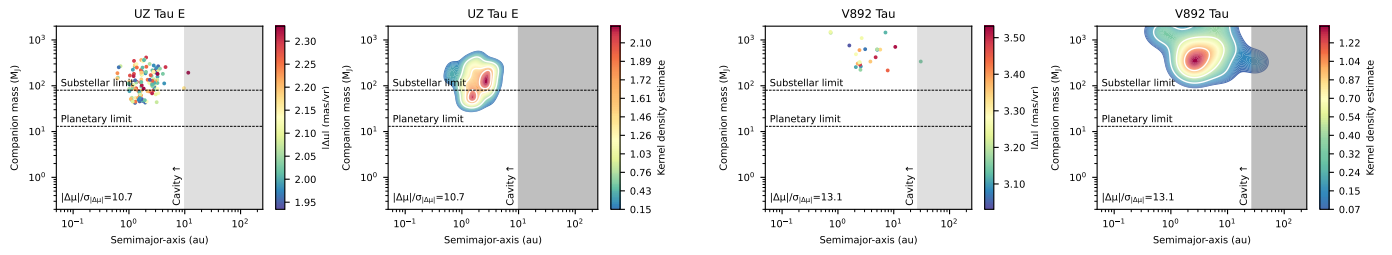


Fig. A.2: continued.

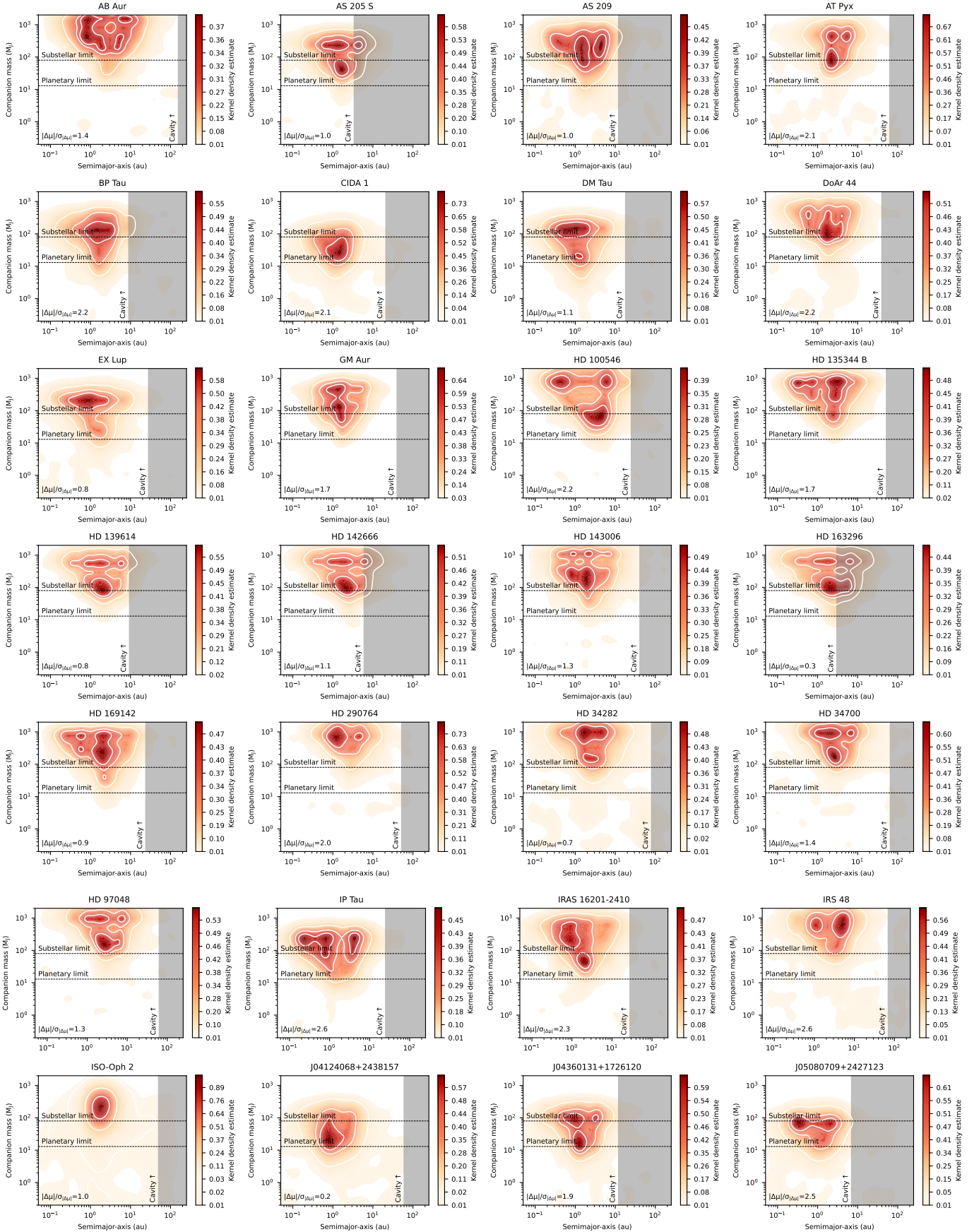


Fig. A.3: Parameter space of orbital separations and companion masses that would produce either a significant *Gaia* proper motion anomaly or a high RUWE value, for sources without a significant proper motion anomaly ( $|\Delta\mu|/\sigma_{|\Delta\mu|} < 3$ ). These figures indicate the companion separation–mass parameter space in which a companion dominating the astrometric signal can be excluded.

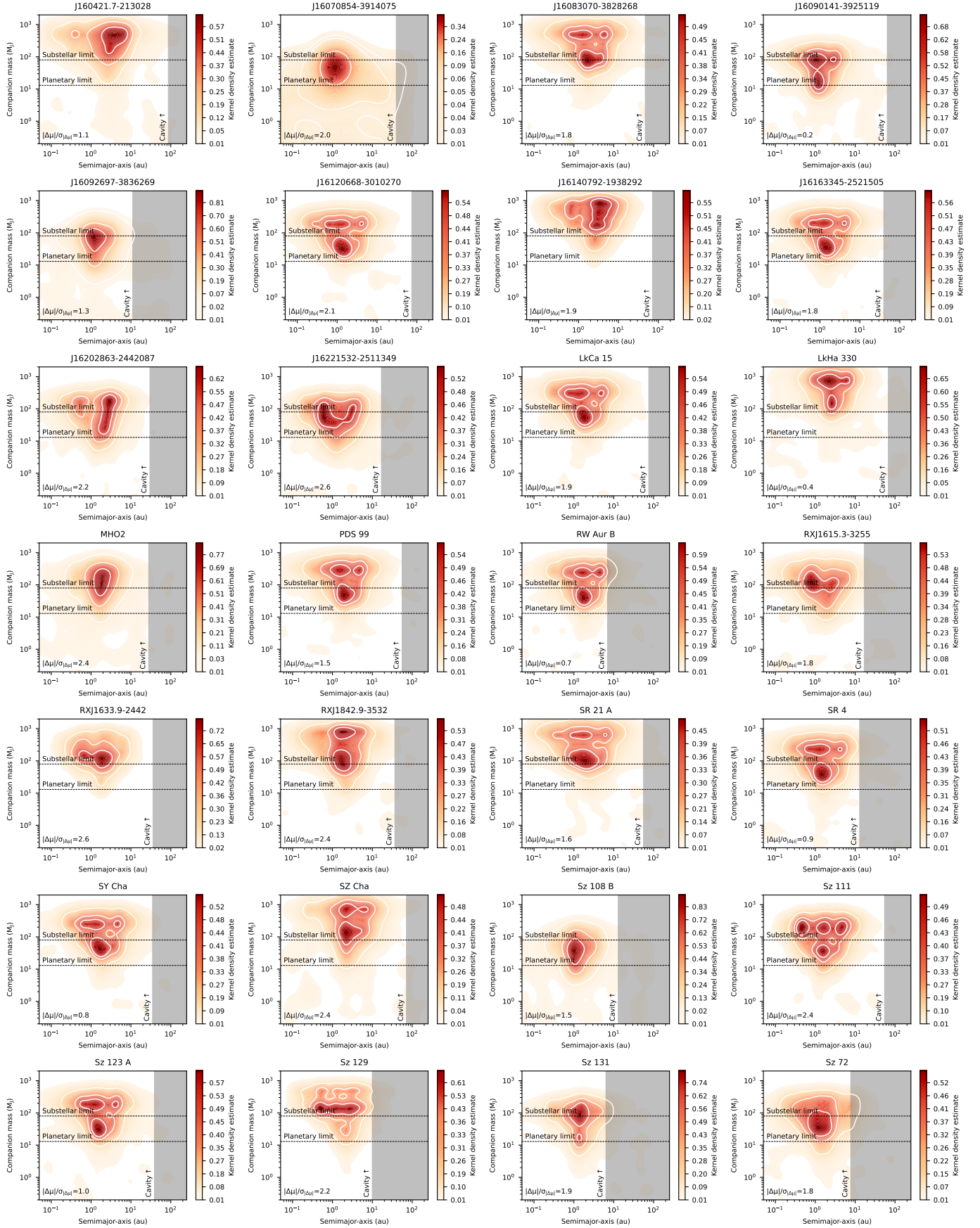


Fig. A.3: continued.

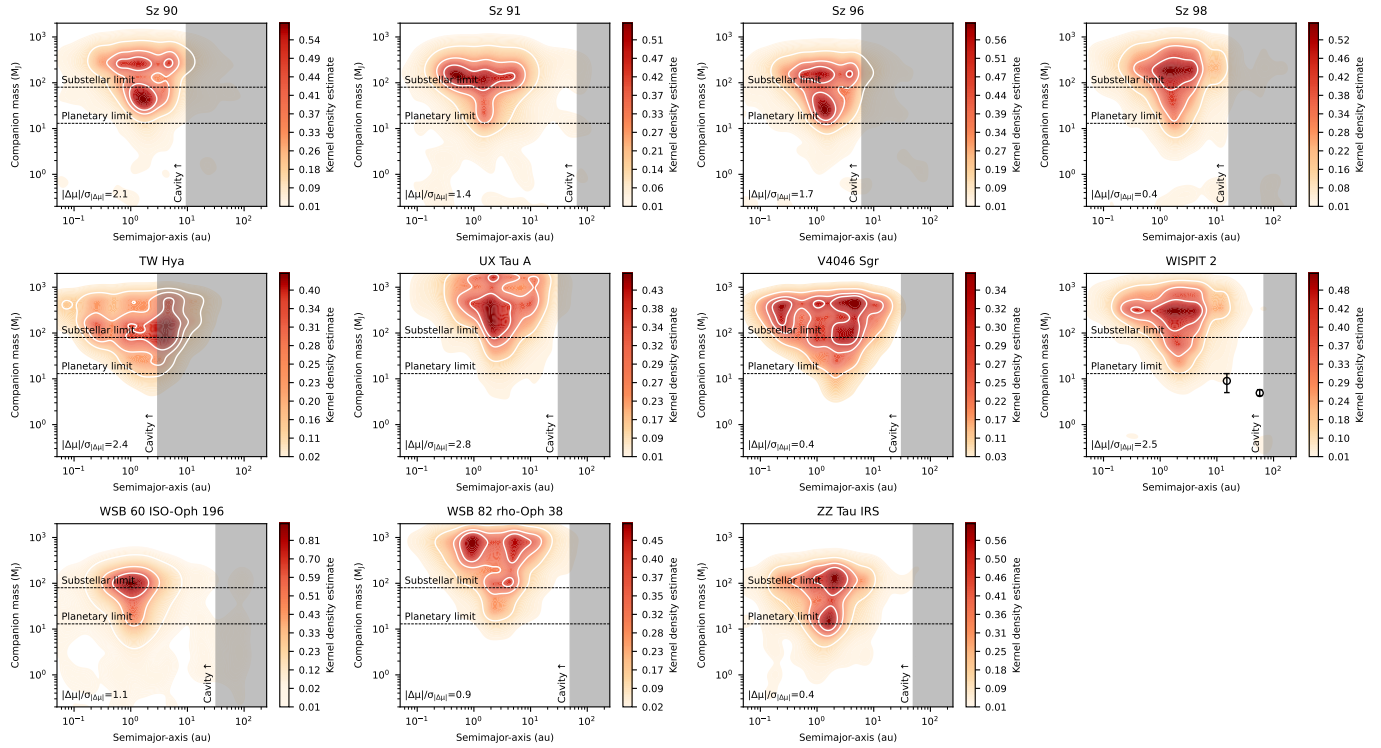


Fig. A.3: continued.