Inferring the presence of planets by application of the Γ–L★ relationship to unresolved debris discs

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Abstract

Circumstellar debris discs are remnant rings of icy and rocky material left over from planet(esimal) formation processes around their host stars. A relationship between stellar luminosity and the dust grain properties has previously been determined, based on a sample of 34 debris discs resolved by *Herschel*. This can be expressed as a trend between stellar luminosity ($L_{\star}$) and the ratio of the resolved and blackbody extent of the disc ($\Gamma = R_{disc}/R_{bb}$). We have examined a larger sample of debris discs, both resolved and unresolved, observed at far-infrared wavelengths by *Herschel* and *Spitzer*, in order to determine the fidelity of that relationship. We further examine whether the inferred extents of these discs are consistent with self-stirring models or may be indicative of dynamical perturbation by a companion. Disc radii were determined from 2D Gaussian fits to the source brightness profiles for resolved targets, or estimated from the blackbody radius and stellar luminosity for unresolved targets. Using simple stirring models for comparison, we identify several systems with radii larger than expected given the stellar age. The resolved extent and our predictions reveals good agreement between the two in almost all cases, both stirred and unstirred, suggesting that Γ–$L_{\star}$ relationship is a fair predictor of disc extent.

Sample selection:

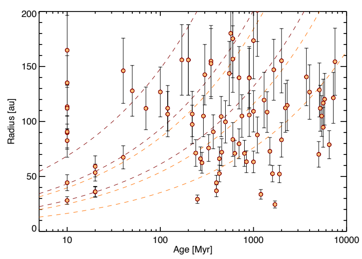
The resolved sample comprises the 34 debris discs modelled in Pawellek et al. (2014) and Pawellek & Krivov (2015) with an additional 27 debris discs with extended emission taken from from the literature; 19 resolved discs from Morales et al. (2016), 7 resolved discs from Vican et al. (2016), and HD 105211 (Hengst et al. 2017).

The unresolved sample comprises 120 unresolved discs taken from the papers listed above combined with those discs not already included that were observed by *Spitzer* from Ballering et al. (2013), and the unresolved discs observed by *Herschel* from Eiroa et al. (2013), and Montesinos et al. (2016).

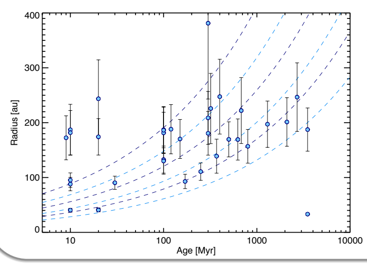
Identifying potentially stirred discs:

To identify systems with potentially non-steady state evolution, we compare the disc extent calculated from the Γ–$L_{\star}$ relationship to the disc stirring model of Mustill &Wyatt (2009). In their model, the extent of a disc will increase monotonically over time. Planetesimals in the disc grow to sufficient size, with those at smallest semi-major axes the quickest grow, and begin to dynamically excite the disc producing detectable dust through collisions. As the age of the system advances, bodies at larger semi-major axes become large enough to stir the disc there and the material at smaller semi-major axes becomes depleted. Thus the disc appears to become cooler over time as the collisional front (i.e. peak of the dust density distribution) proceeds outward through the disc. The initial mass of the system plays a role in the evolution, with more massive discs, or discs around more massive stars, evolving more quickly than their fellows.

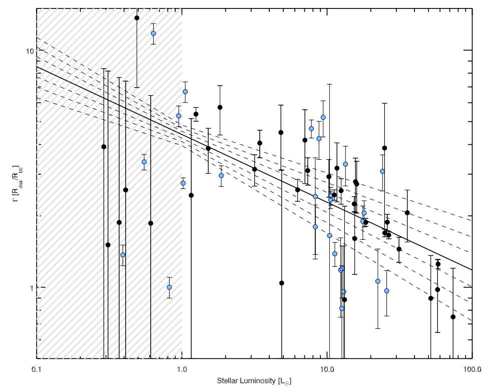
We identify 21 discs in the sample that have calculated radii greater than expected from the model of Mustill & Wyatt (2009). Due to the relatively large uncertainties in disc radius, up to 50 per cent, we define a metric $\chi_R = (R_{disc}/R_{model}) = \sigma_{disc}$. For those discs with $\chi_R > 3$, we presume they are significantly larger than the predicted models and might therefore be reliably considered candidates for planetary stirring. Amongst the 14 selected systems, only one of them has $\chi_R > 3$.



Disc radii vs. age for FGK stars in the unresolved sample. The orange and red dashed lines show the maximum extent for a disc evolving in steady state around stars of 0.5 and 1.5 $M_{\odot}$, assuming initial masses of 1, 3 and 10x MMSN, based on models Mustill & Wyatt (2009).

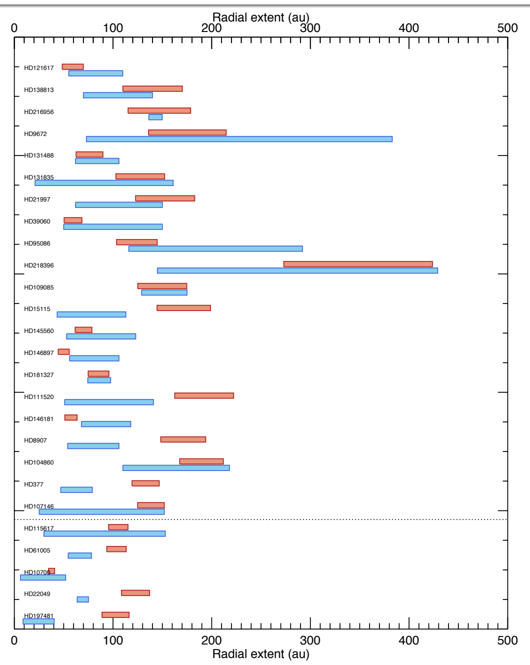


Disc radii vs. age for A stars in the unresolved sample. The light and dark blue dashed lines show the maximum extent for a disc evolving in steady state around stars of 1.5 and 2.5 $M_{\odot}$, assuming initial masses of 1, 3 and 10x MMSN, based on models Mustill & Wyatt (2009).



Γ–$L_{\star}$ relationship:

Plot showing Γ, the ratio of a disc's resolved extent to its blackbody radius, to the stellar luminosity for the sample of resolved discs. The original sample from Pawellek et al. (2014) are black dots, additional systems are blue dots. With the larger sample, we find a best-fit to the relation $\Gamma = \alpha L^{\beta}$ inconsistent with Pawellek & Krivov (2015) for a dust composition of astronomical silicate and water ice, with $\alpha = 4.41 \pm 0.16$, $\beta = -0.286 \pm 0.028$.



Comparison to (sub-)mm resolved discs:

Plot of resolved radii for debris discs (in blue) compared to Γ–$L_{\star}$ predictions (in red). The resolved radii are taken from Matra et al. (2018). Systems below the dashed line have $L_{\star} < 1$, where the Γ–$L_{\star}$ relationship has no predictive capacity. Generally, the results are only in good agreement for stars > 2 $L_{\odot}$.

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