A deeper look into the morphology of the HD 110058 debris disk using SPHERE multiband data

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Abstract

Debris disks are composed of small dust grains with short lifetimes, generated by the continuous collisions of larger bodies. Scattered light images can uncover disk structures- such as gaps, warps, and asymmetries- that act as signposts for planetary companions that may be yet undetected.

We investigate the near edge-on debris disk of HD 110058, first detected by Kasper et al. 2015. The target was observed using VLT/SPHERE integral field and infrared dual-band imaging spectroscopy at two epochs . We utilise the multiple observations and star subtraction algorithms in producing higher contrast images to better aid the morphological analysis of the faint outer regions of the disk.

Reduced images show a NW-SE offset in the inner disk, evocative of the warped features seen in the disk of Beta Pictoris, which had been attributed to the presence of a massive body orbiting in the plane of an inclined planetesimal belt, later identified as Beta Pictoris b. The similarities to the warp present in the Beta Pictoris disk suggest that the features observed in HD 110058 are due to a misaligned inner disk caused by the presence of an unseen planet on an inclined orbit.

HD 110058: Background

HD 110058 is an **A0V** type star located in the Lower Centaurus Crux of the **Scorpius-Centaurus** association at a distance of **130pc**, with an age of ~**17 Myr**.

Protoplanetary disks have short lifetimes and are expected to dissipate within 10 Myr (Guarcello+ 2016). With the star placed at an age of ~**17 Myr**, the continued presence of a disk suggests larger bodies in the system are regenerating dust through collisions. While some debris disks can be self-sustaining, the presence of asymmetrical warps in the disk indicates a possible planetary companion in the system.

Spine Fitting

To fit the spine, ~1 FWHM horizontally binned vertical slices were taken along both sides of the disk rotated by an estimated initial PA of 156.5°. A Gaussian was fit to the vertical profiles to find the centroid position of the disk. To account for the lower disk SNR beyond 0.35", larger horizontal bins were used in those areas.

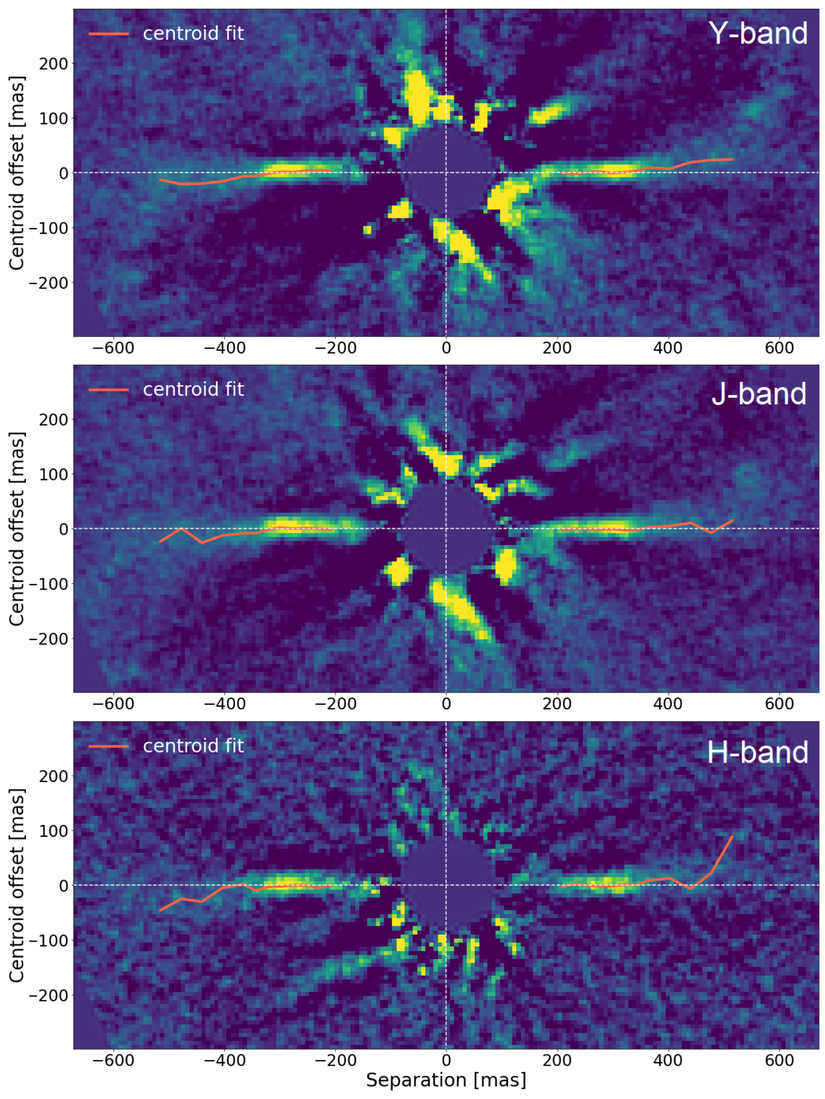

Fig 2: Reduced images of HD 110058 in the Y-, J-, and H- band. Overlaid are the centroid spine fits (orange). Y- and J- band images use 2015-04-03 and 2015-04-12 combined IFS reductions, while H- uses only the IFS data from 2015-04-03.

Observations

The star was observed with VLT/SPHERE **IRDIS** and **IFS** in parallel on **3 April 2015** and **12 April 2015**.

2015-04-03: IRDIS images were taken in the **K12** bands and IFS images over the **YJH** wavelengths, over a parallactic angle range of **14.62°**. **(Data presented in Kasper+ 2015)**

2015-04-12: IRDIS images were taken in the **H23** bands and IFS images over the **YJ** wavelengths, over a parallactic angle range of **34.25°**. **(Data not previously presented)**

Both observations placed the star behind a 185 mas focal mask.

Data Reduction

The data were pre-processed using the SPHERE-DC reduction pipelines (Delorme+ 2017) and PCA ADI was performed on the temporally normalised centred cubes. The correlations between frames of the pre-ADI combined residuals cube were used to identify badly correlated frames and remove them from the cube before reprocessing with PCA due to low-wind effects on the 2015-04-12 data.

The wavelength channels were combined for each reduced cube using an SNR weighted mean to produce broad band images. Both epochs were also combined for the IFS Y and J bands, scaling the reduced cubes by the mean stellar PSF before taking the SNR weighted mean as before.

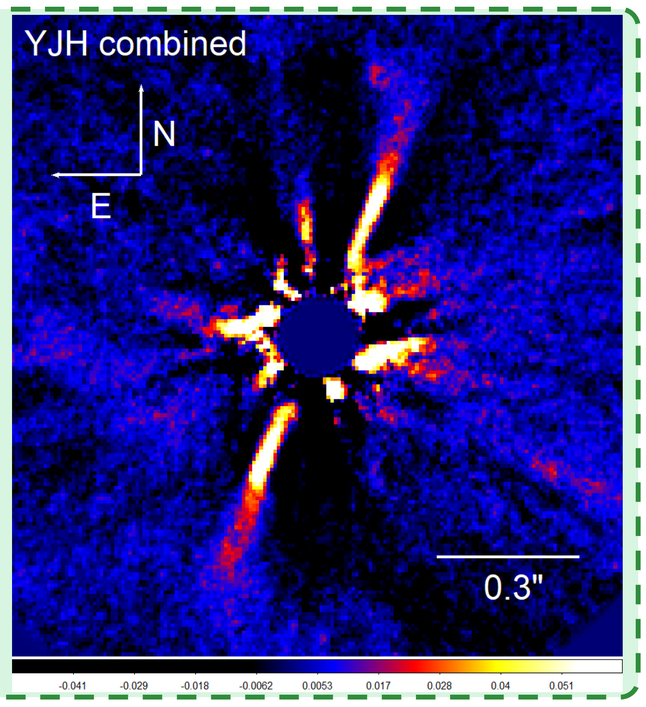

Fig 1: Reduced image of HD 110058 using **temp-mean PCA ADI with 3 PCs**. Image shows SNR weighted mean of IFS YJH channels from both 2015-04-03 and 2015-04-12 data sets.

All analysis henceforth will be performed on reductions carried out with these parameters unless otherwise stated.

Position Angle

A subsection of the spine between 0.20-0.37"—where the disk is brightest—was used to fit a straight line across the entire disk, and for both sides separately. The angular offset from the horizontal was then used to calculate the PA of the disk.

The PA measured across the whole disk was **156.41° ± 0.10** for the YJH combined image, which is consistent with PA measurements in the other images within 1σ.

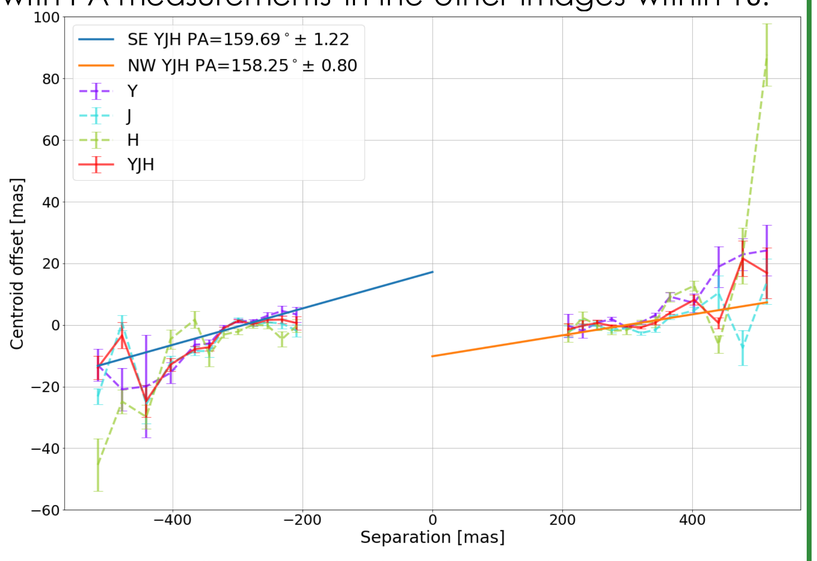

Fig 3: Centroid fits shown in **Fig 2** (Y- purple; J- cyan; H- lime) with additional fit of YJH combined image (red) shown in **Fig 1**. PA fits for the SE (blue) and NW (orange) sides are overlaid.

Reflectance Spectrum

The flux was measured in each channel for the 2015-04-12 YJ IFS data within the region shown in **Fig 4**, chosen to enclose the brightest part of the disk while being far enough away from the central mask to avoid contamination via residual speckles.

We assume achromatic self-subtraction for the ADI reduced image, and normalise the spectrum by the stellar flux before dividing by the flux at 1μm.

The disk spectrum appears grey with no distinguishing features.

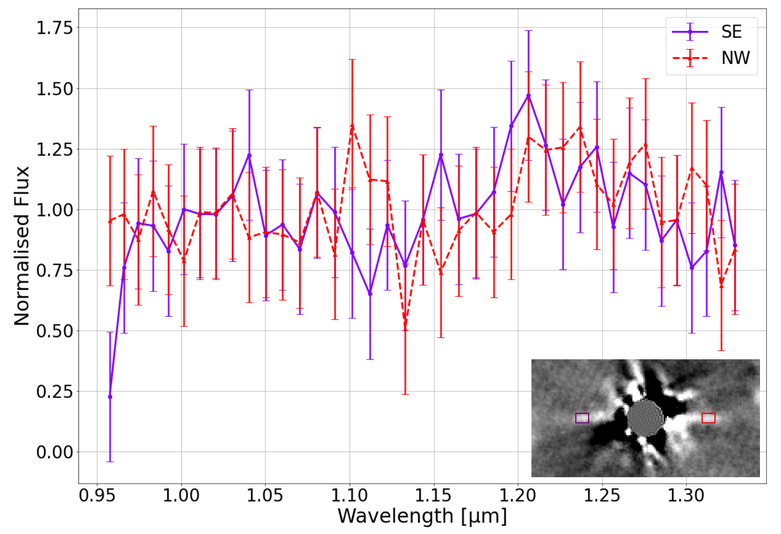

Fig 4: Normalised reflectance spectrum of 2015-04-12 IFS spat-mean PC 5 reduction for the SE (purple) and NW (red) disk sides, measured within the regions shown on the bottom right.

Inner Offset: A Beta Pictoris Analogous System?

The disk spine fitting and position angle calculations of the HD 110058 disk show an offset between the SE and NW sides, with PA fits for the separate sides not crossing the centre of the star, reminiscent of the Beta Pic disk.

Fig 5 shows the spine of the Beta Pic disk from STIS observations, in addition to two using a composite (two disk) models of the system.

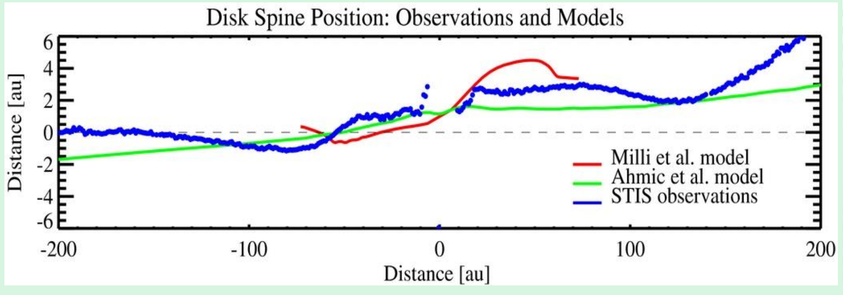

Fig 5: Comparison of the observed (STIS, blue) and modelled (Milli+ 2014, red; Ahmic+ 2009, green) positions of the Beta Pic disk spine. (Apai+ 2015)

We can calculate the minimum MD^2 ratio of a perturbing planet in the HD 110058 system using equation:

$$\log\left(\frac{R_W}{10AU}\right) = 0.29\log\left(\frac{M}{M_*}\left(\frac{D}{10AU}\right)^2\frac{t}{t_{unit}}\right) - 0.2$$

Where M_*, M, R_W, D, t, and t_{unit} are the mass of the star, mass of the planet, radius of warp in the parent body disk, planetary orbital radius, age of system, and time unit $\sqrt{\{(10AU)^3/(GM_*)\}}$ ~ 5.2 y. (Augereau+ 2001).

For a minimum R_W of 60AU, M_* = 2.1 M_{Sun} (Chen+ 2014) and t=17 Myr, $MD^2 \geq 64.68\ M_{Jup}AU^2$, which for a **$1M_{Jup}$ planet would give a separation of 8.04 AU** (61.86 mas) For a planet causing the warp seen in the disk **to be detectable in our images, the warp radius must be ≳ 170 AU** (1300 mas) (**Fig 6**), which is outside the IFS FOV and in the background noise dominated regime of our IRDIS images.

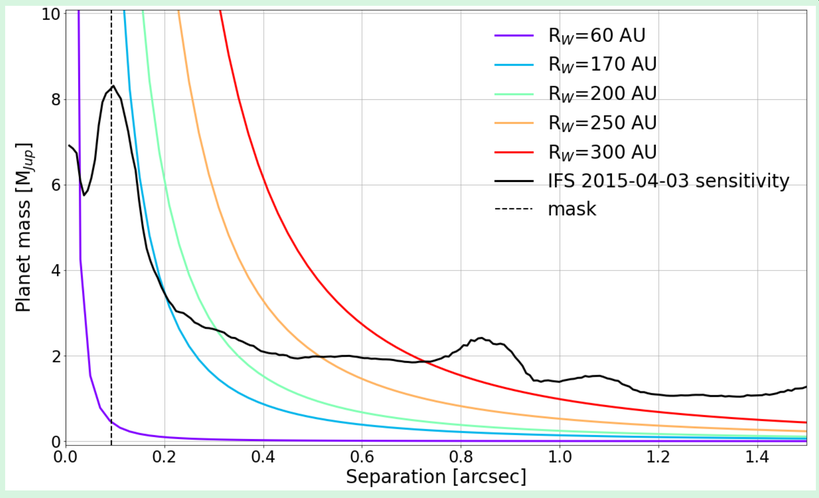

Fig 6: Mass-separation relation for a planet causing a warp of radius 60 (purple), 170 (blue), 200 (green), 250 (orange), and 300 (red) AU in HD 110058. The mass-sensitivity for the PCA ASDI reduction of the 2015-04-03 epoch (black) and mask radius (black, dashed) are overlaid.