Could the stellar magnetic field explain the structures in the AU Mic debris disk?

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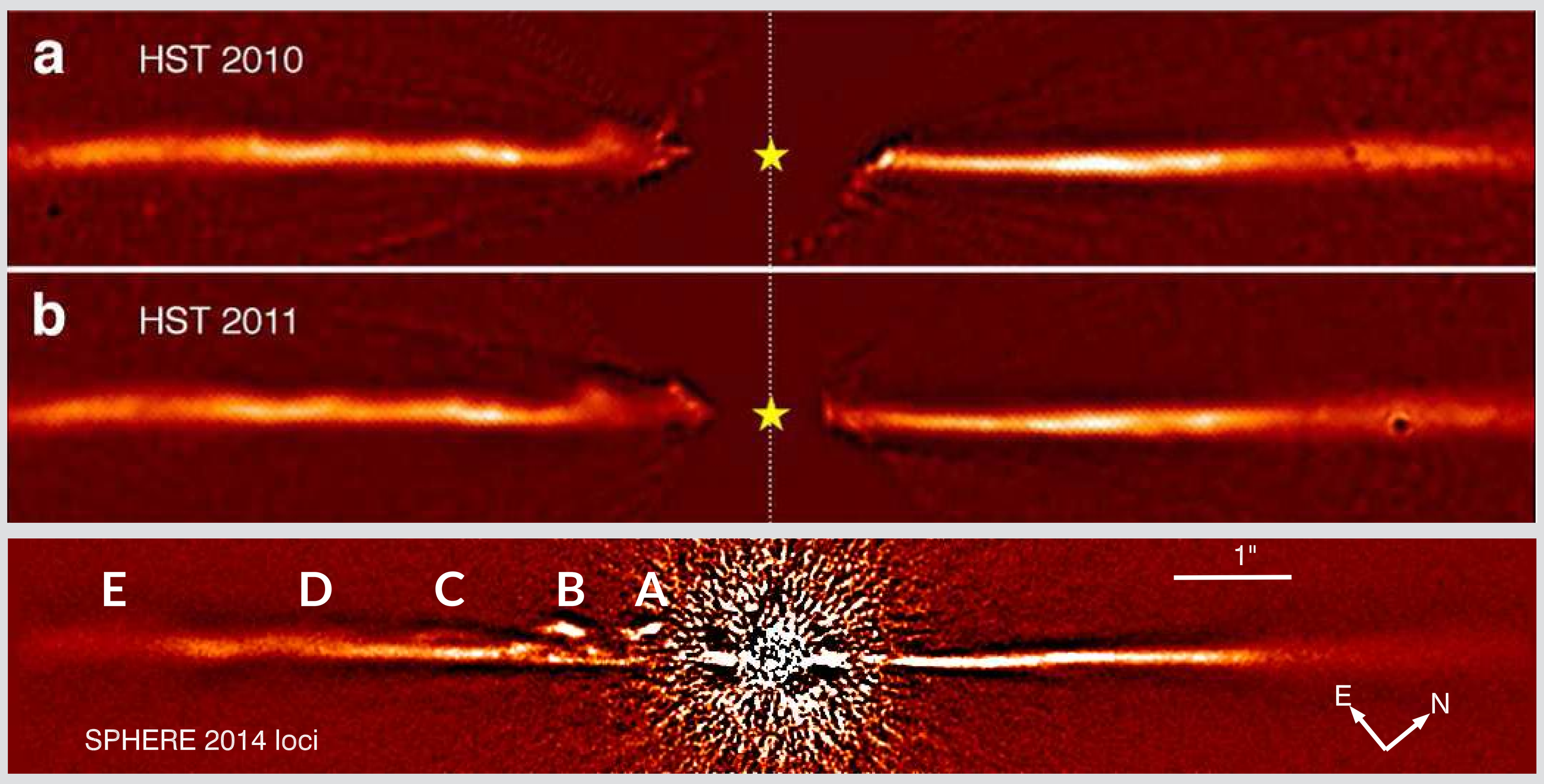
Fast-moving features

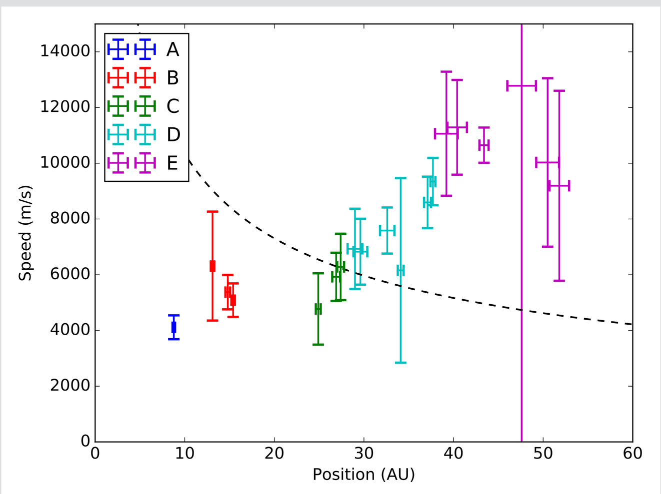


AU Mic is an active M-type star in the β Pictoris moving group (23 Myr). Recent high contrast imaging with SPHERE has revelead 5 arch-like structures close to the star (annotated A to E, see fig. 1) in the southeastern side of the disk.
These features have been shown to move away from the star at high speeds, possibly exceeding the local escape velocities. No model can readily explain how to form such moving arch-like structures.
In this study, we elaborate on models aiming to explain:

- how to reach such high speeds?
- how to form arch-like structures?

Figure 1: Top to bottom: 2010, 2011 HST and 2014 SPHERE images of the debris disk of AU Mic. Images from Boccaletti et al. (2015).

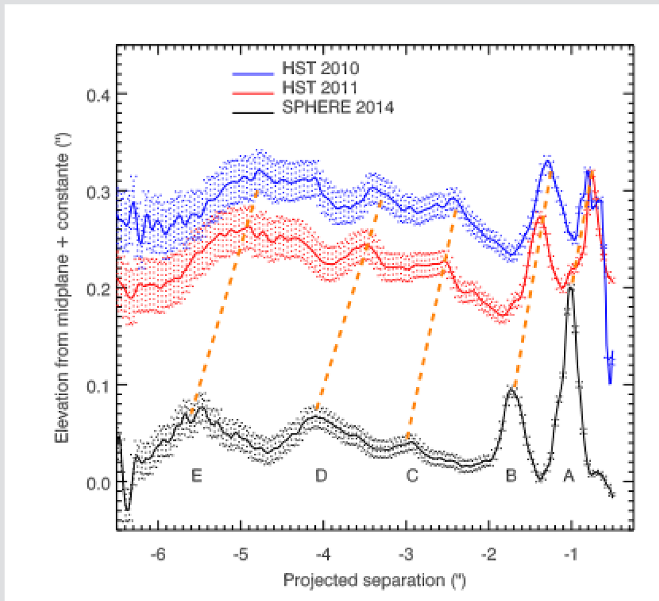
Stellar wind pressure



Dust particules are expected to be exposed to a strong stellar wind, which exerts a pressure force that can overcome the stellar gravity.
The β parameter, the ratio of the pressure to the gravitation forces, quantifies this effect (e.g. Krivov et al. 2006).

Figure 2: Projected speeds of the 5 structures vs apparent position. The dashed line corresponds to the escape velocity for a 0.6$M_\odot$ star. The outermost features show the highest velocities.

Magnetic field topology



A 4.2 kG magnetic field has been measured at the stellar surface (Saar 1994). It is supposed to extent at tens of AUs. If the magnetic field and the rotation axis of the star are misaligned, the Lorentz force on a charged dust particule could change sign along its orbit. This magnetic field topology is known as a *ballerina skirt structure* (e.g. Alfvén 1977).

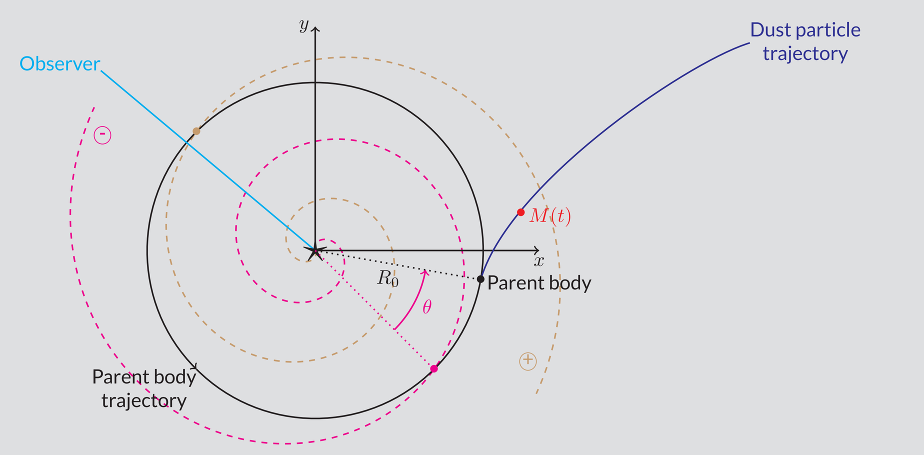
Figure 3: Mean elevation vs distance from the star, displayed for the 3 epochs (Boccaletti et al. 2015).

Model

The dust particles are emitted by a parent body on a circular orbit in the disk midplane. They are released with the keplerian speed plus a vertical component. Their charge is fixed over the time. They feel the gravity of the star, the stellar wind pressure, the radiation pressure and the Lorentz force.

The 5 key parameters defining the trajectory:

- β pressure/gravitation forces ratio
- q/m charge/mass ratio
- R_0 radius of the parent body orbit
- V_{z0} initial vertical speed of the particle
- θ angle between released point and $\mathbf{B}$ inversion point



Ejected dust grains

Considering only β and R_0, we adjust the speeds by projecting the trajectories. The best fits are obtained for particles emitted at typically 25 AU, with $\beta > 1$ (β ~6). The A, B structures may require lower R_0 values than the C, D, E structures.

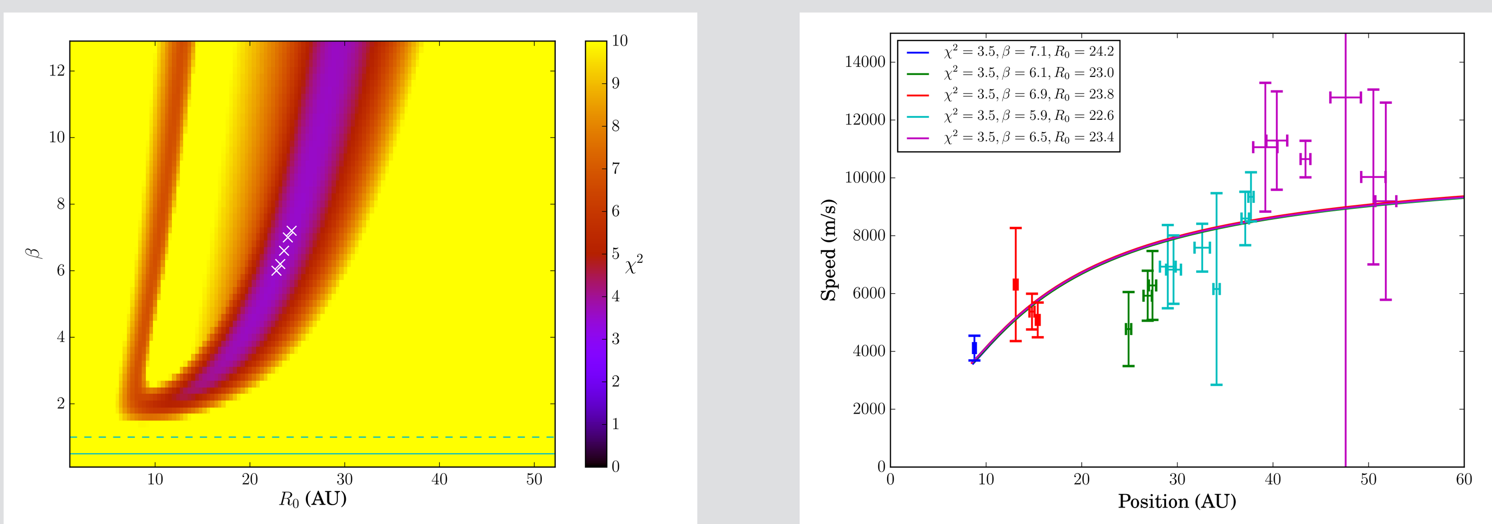


Figure 4: Left: χ^2 map for the fit of the observed speeds of the 5 structures all together. Right: best fits for the speeds, corresponding to the white crosses on left panel.

Arch formation

We examine the vertical position of the dust particles as a function of time to search for extrema as proxies for arch formation. The number of extrema corresponds to twice the number of arches formed. Arches are easier to form with bound particles (β <0.5). We could not form more than 3 arches with unbound particles.

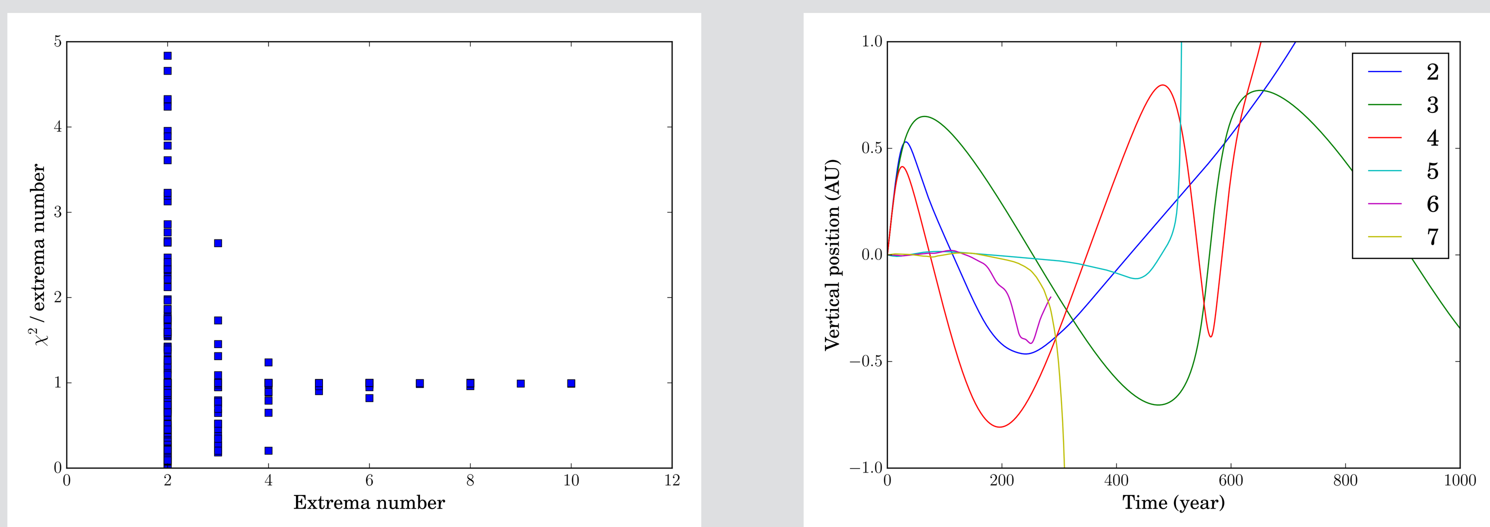


Figure 5: Left: χ^2 normalized by the number of extrema. Right: best fits for the first numbers of extrema.

Conclusions

- We need unbound dust particles to explain the projected speeds: the structures are evolving fast.
- A ballerina skirt magnetic field topology can produce oscillating trajectories, but not 5 arches.
- Several arches formation by a single grain and high velocities seem to require inconsistent β values.

A more advanced model is under development. For example, we can reject the hypothesis of all the structures being created by one emitter at a fixed point in space (giant collision).

Bibliography

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