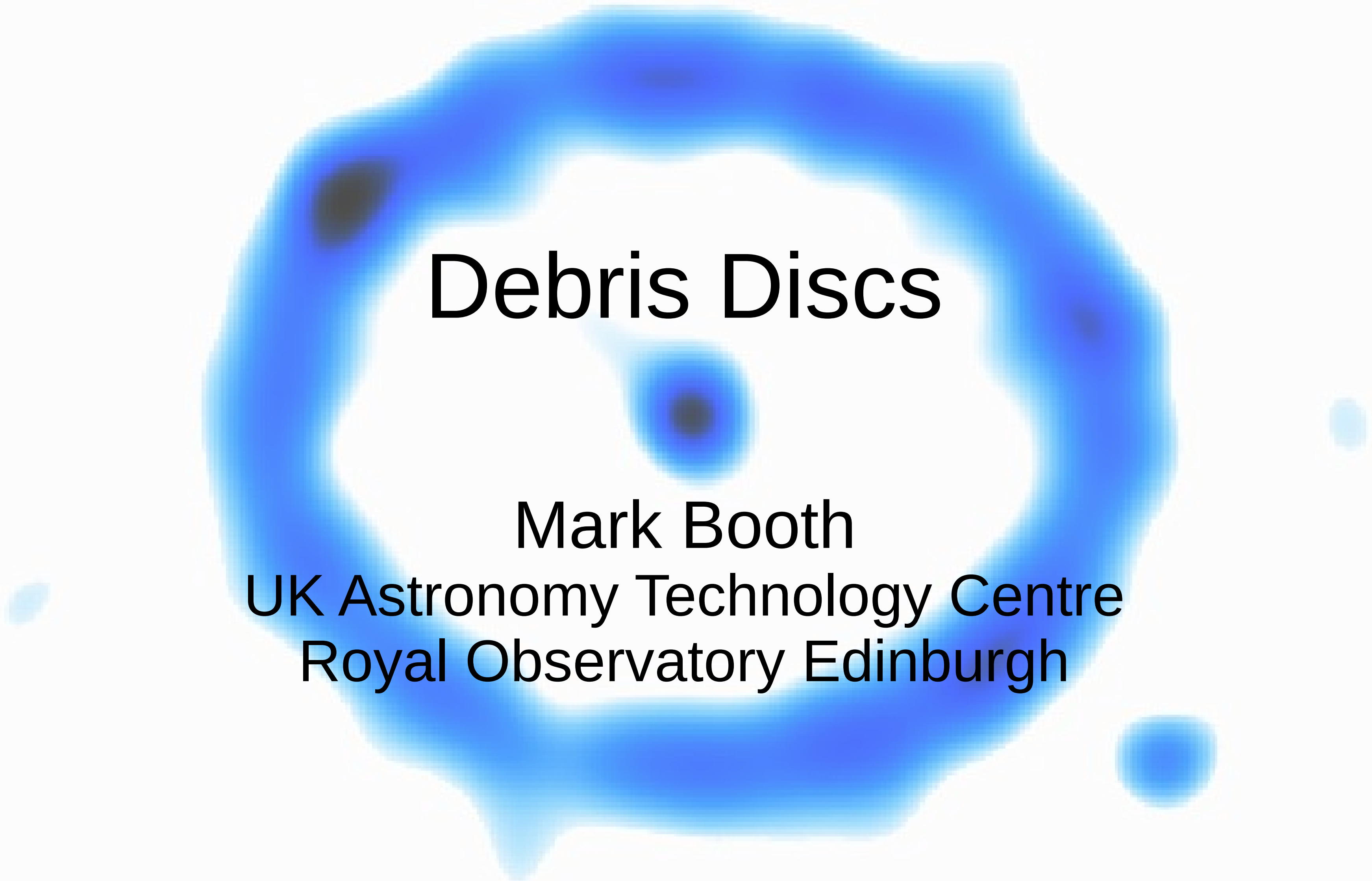


Debris Discs

Mark Booth
UK Astronomy Technology Centre
Royal Observatory Edinburgh

1984: The Vega Phenomenon

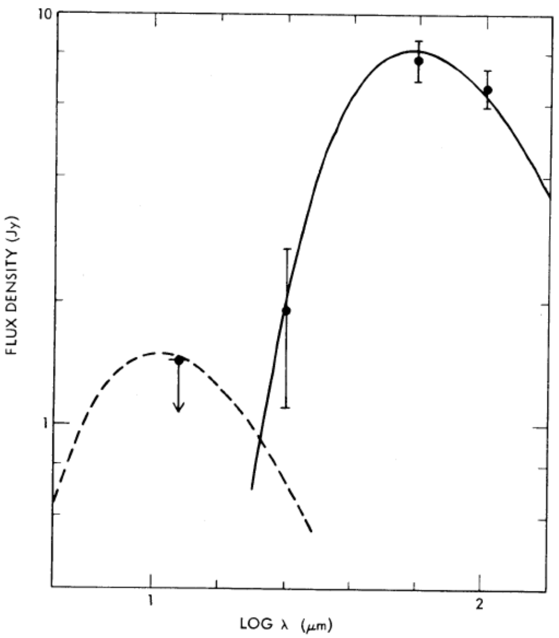


FIG. 1.—Energy distribution of the infrared excess from α Lyr. The error bars represent the 10% calibration uncertainty. The 12 μm upper limit indicates the effect of the 5% uncertainty in the absolute calibration at 12 μm. The solid line represents a 85 K blackbody spectrum with a solid angle of 7×10^{-13} sr fitted to the excess. The dashed line represents a 500 K blackbody spectrum with a solid angle of 6.3×10^{-16} sr arbitrarily fitted to the 12 μm upper limit.

Aumann et al. 1984

- IRAS discovers an infrared access around Vega.
- A blackbody can be fit to this to estimate its temperature and infer the distance of the dust from the star.

1984: The Vega Phenomenon

Grain temperature gives radius from star where most of the dust resides, but distinguishing a shell versus disc architecture requires resolved imaging.

DISCOVERY OF A SHELL AROUND ALPHA LYRAE[1]

H. H. AUMANN, F. C. GILLETT, C. A. BEICHMAN, T. DE JONG, J. R. HOUCK, F. J. LOW, G. NEUGEBAUER, R. G. WALKER, AND P. R. WESSELIUS

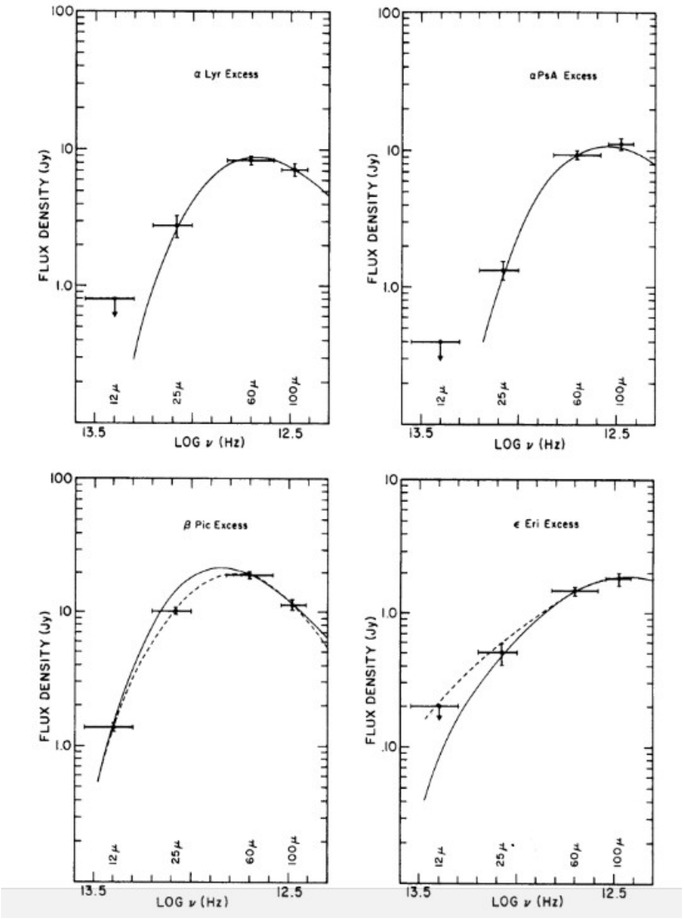
Received 1983 September 22; accepted 1983 November 18

ABSTRACT

IRAS observations of α Lyrae reveal a large infrared excess beyond 12 μm. The excess over an extrapolation of a 10,000 K blackbody is a factor of 1.3 at 25 μm, 7 at 60 μm, and 16 at 100 μm. The source of 60 μm emission has a diameter of about 20″. This is the first detection of a large infrared excess from a main-sequence star without significant mass loss. The most likely origin of the excess is thermal radiation from solid particles more than a millimeter in radius, located approximately 85 AU from α Lyr and heated by the star to an equilibrium temperature of 85 K. These results provide the first direct evidence outside of the solar system for the growth of large particles from the residual of the prenatal cloud of gas and dust.

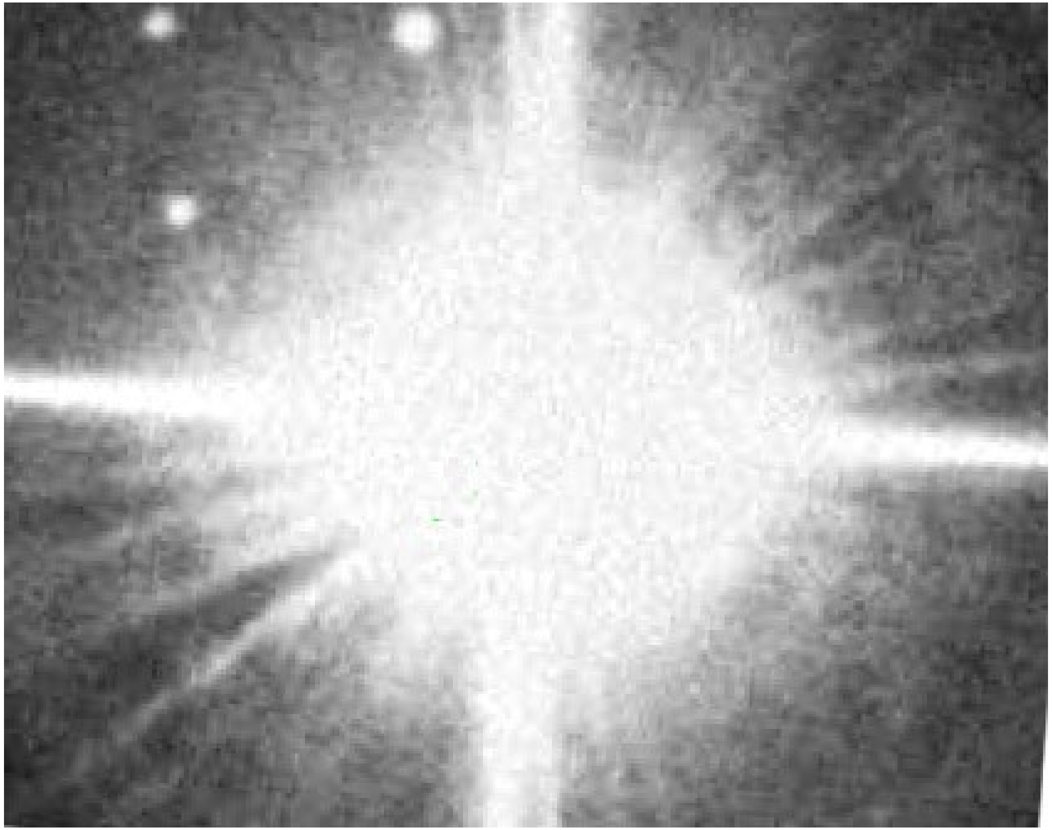
Not a 150K exozodi that was discovered, but a cold exo Kuiper Belt/Shell, before the Kuiper Belt was detected in 1992.

The Fab Four



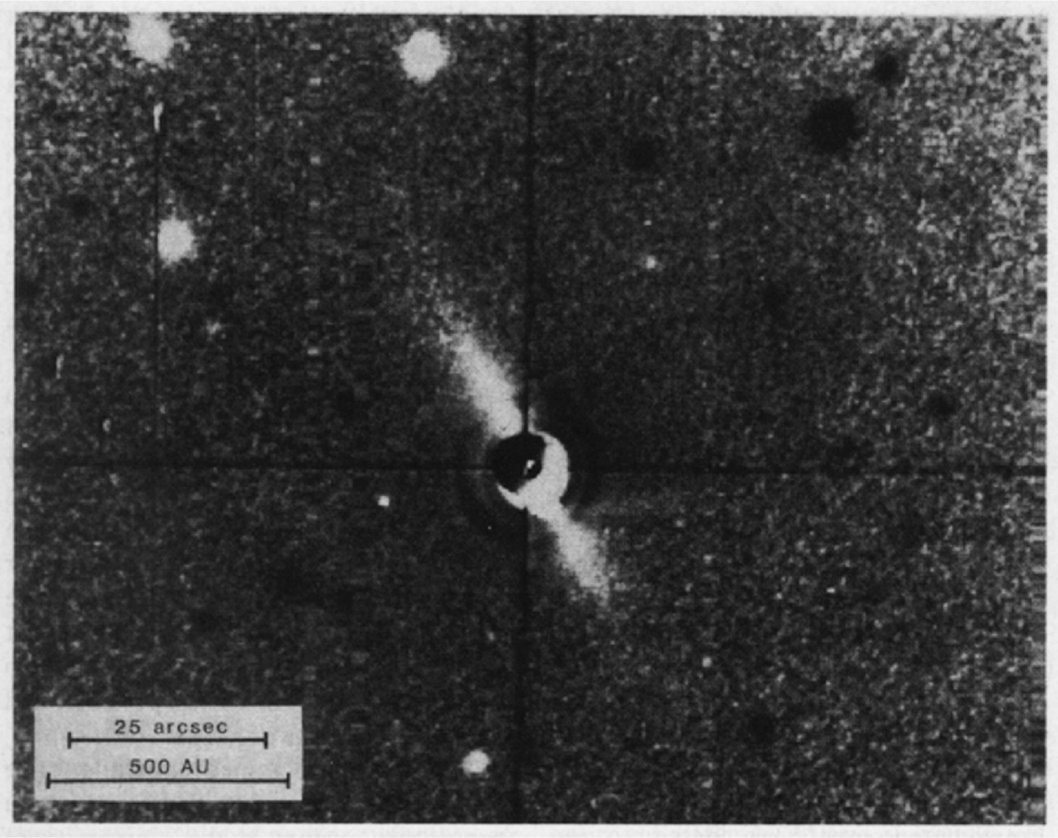
- Gillett 1986 (although announced at a conference in 1984)
- Detection of IR excess around Vega was soon followed by detection of IR excesses around Fomalhaut, beta Pictoris and epsilon Eridani – to become known as The Fab Four.
- eps Eri is the closest of the four – at just 3.2pc away – and stands out as the only one of the four that is not an A star.

Resolving the beta Pic Disc



Smith & Terrile 1984

Resolving the beta Pic Disc

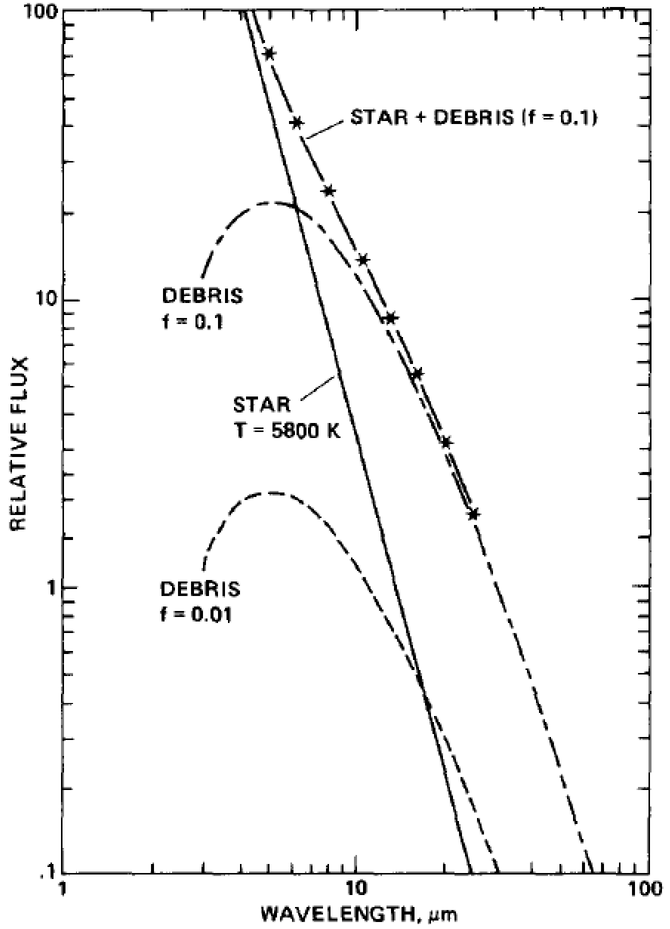


Smith & Terrile 1984

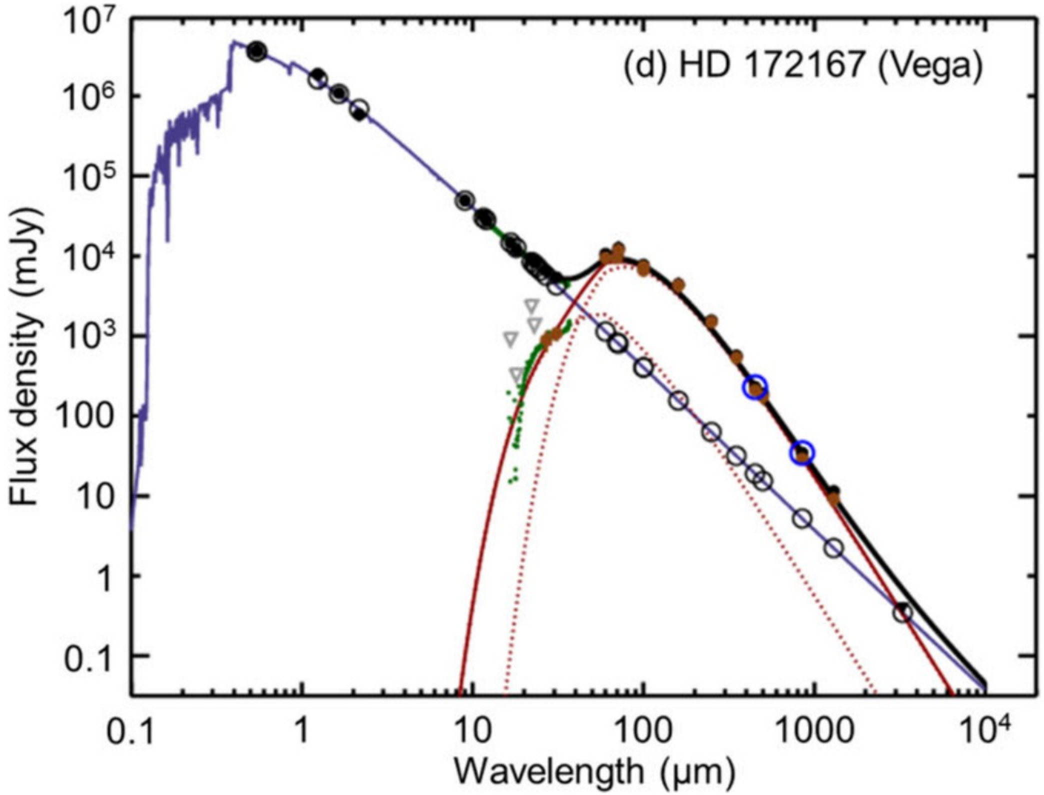
This made it clear that the dust was distributed as a disc not a shell.

Debris Disc Predictions

- Inspired by the nebular hypothesis of planetary system formation and the cratering history of the Moon, Witteborn et al. (1982) predicted infrared excesses due to 'debris clouds'.
- They assumed the planetesimals would follow the orbits of the planets, but otherwise the model was very similar to current debris disc models for instance in predicting the optical properties of the dust and its size distribution.



Key Concept: Spectral Energy Distribution



Holland et al. (2017)

- With photometry covering a range of wavelengths, we build up an SED.
- Fitting models to this, we can estimate properties of the disc.

  SED → T → ~R

- Disc flux can usually be approximated by one or more greybodies.
- Detailed optical property calculations can be made, although this introduces many degeneracies including composition, porosity and size distribution.

1984: The Vega Phenomenon

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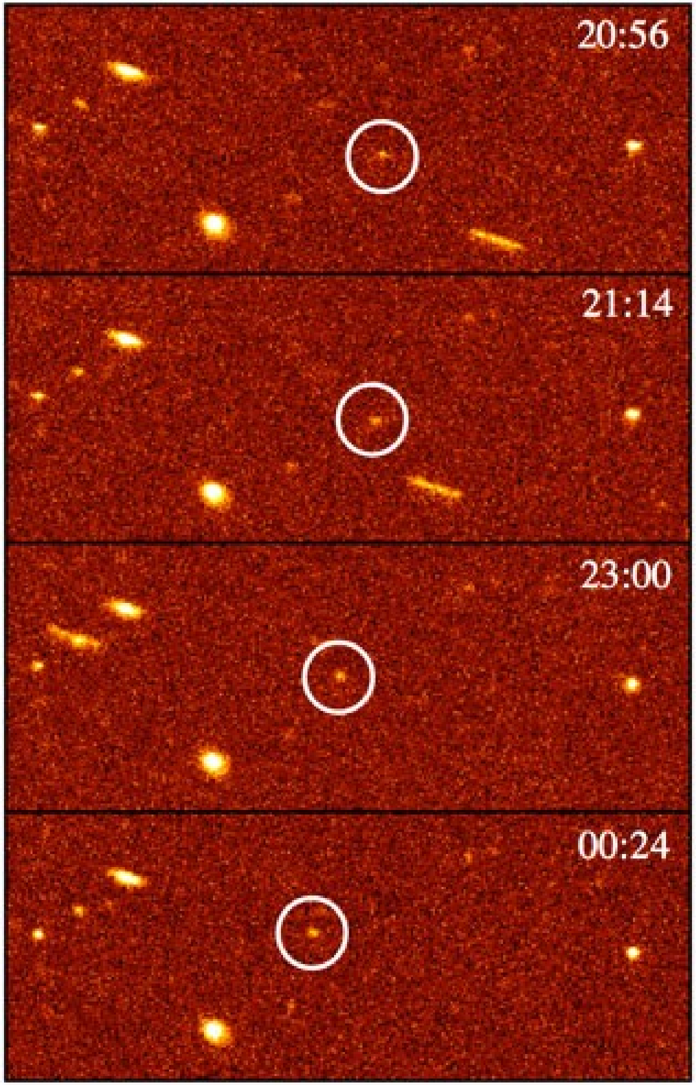
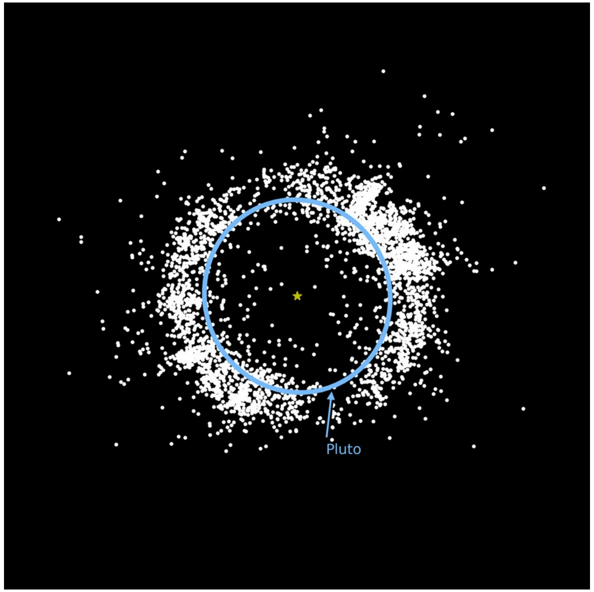


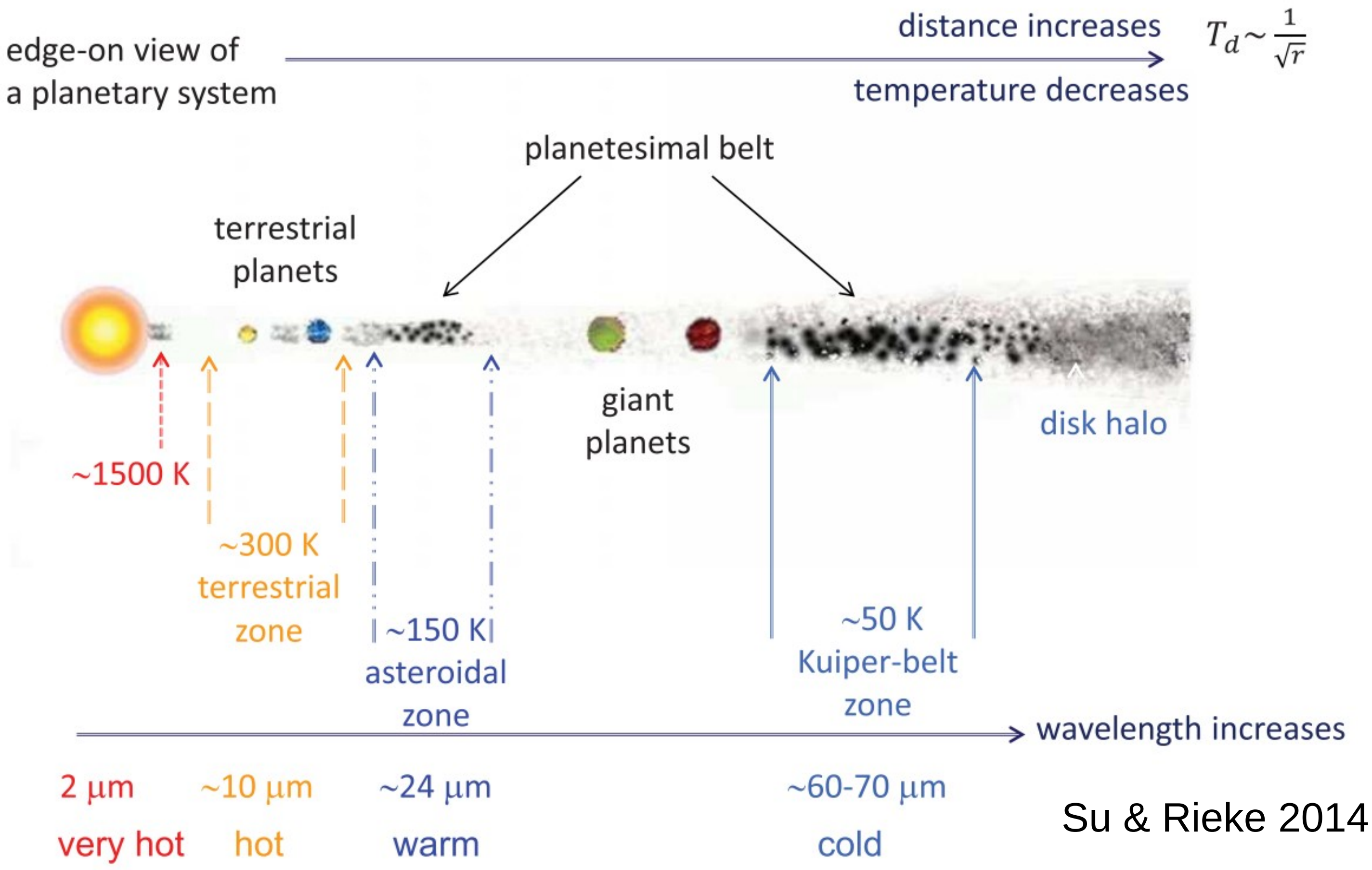
Credit: David Jewitt

Kuiper belt



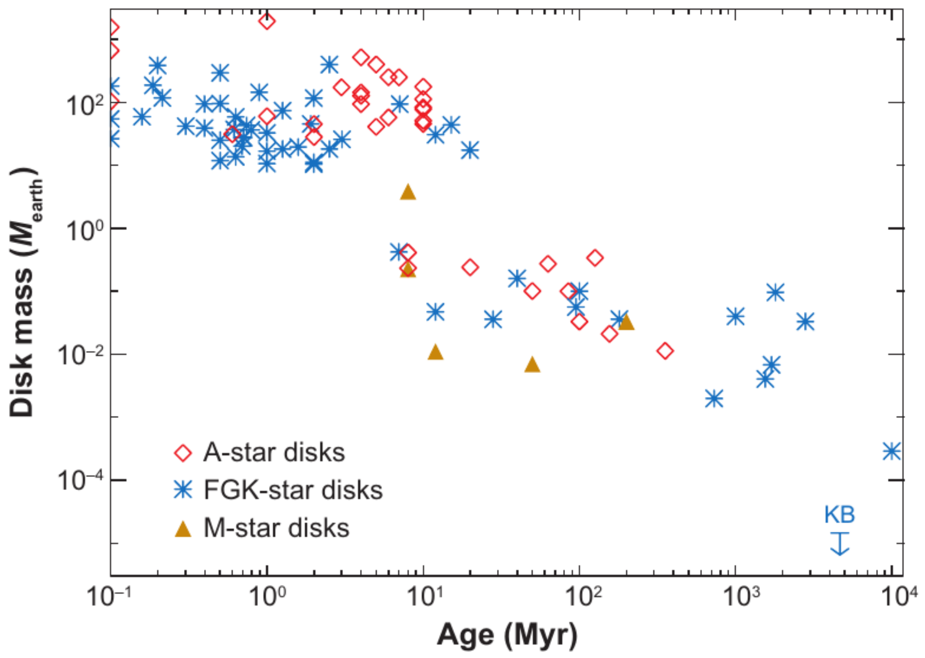
- Predicted to exist by Fernandez (1980)
- First Kuiper belt object (after Pluto and Charon) discovered by Jewitt, Luu & Marsden (1992).
- By now 1000s are known.

Key concept: Radial distribution



Su & Rieke 2014

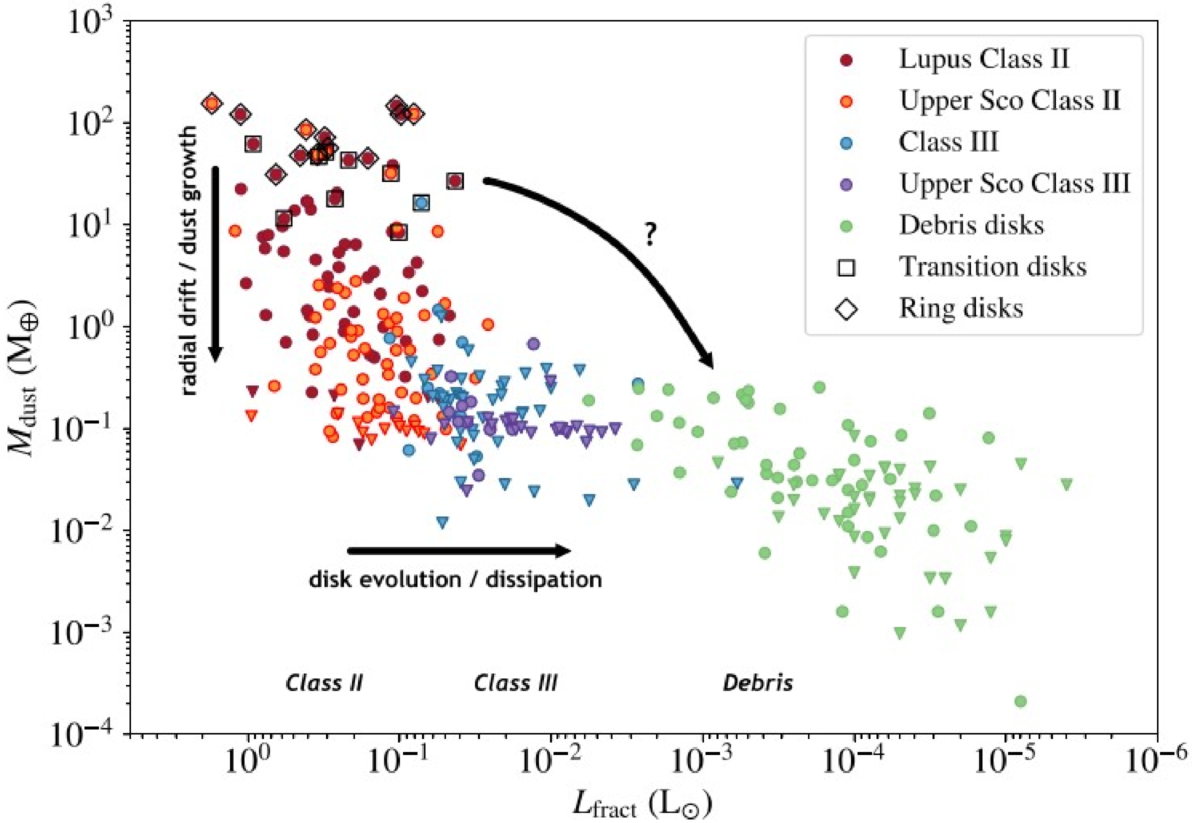
Debris disc evolution



Sub-mm dust masses, Wyatt 2008

- In the 00s and 10s, surveys with ISO, Spitzer, Herschel, JCMT and others built up our picture of the population of debris discs.
- This has furthered our understanding of how disc properties related to other properties of the star such as age and spectral type.

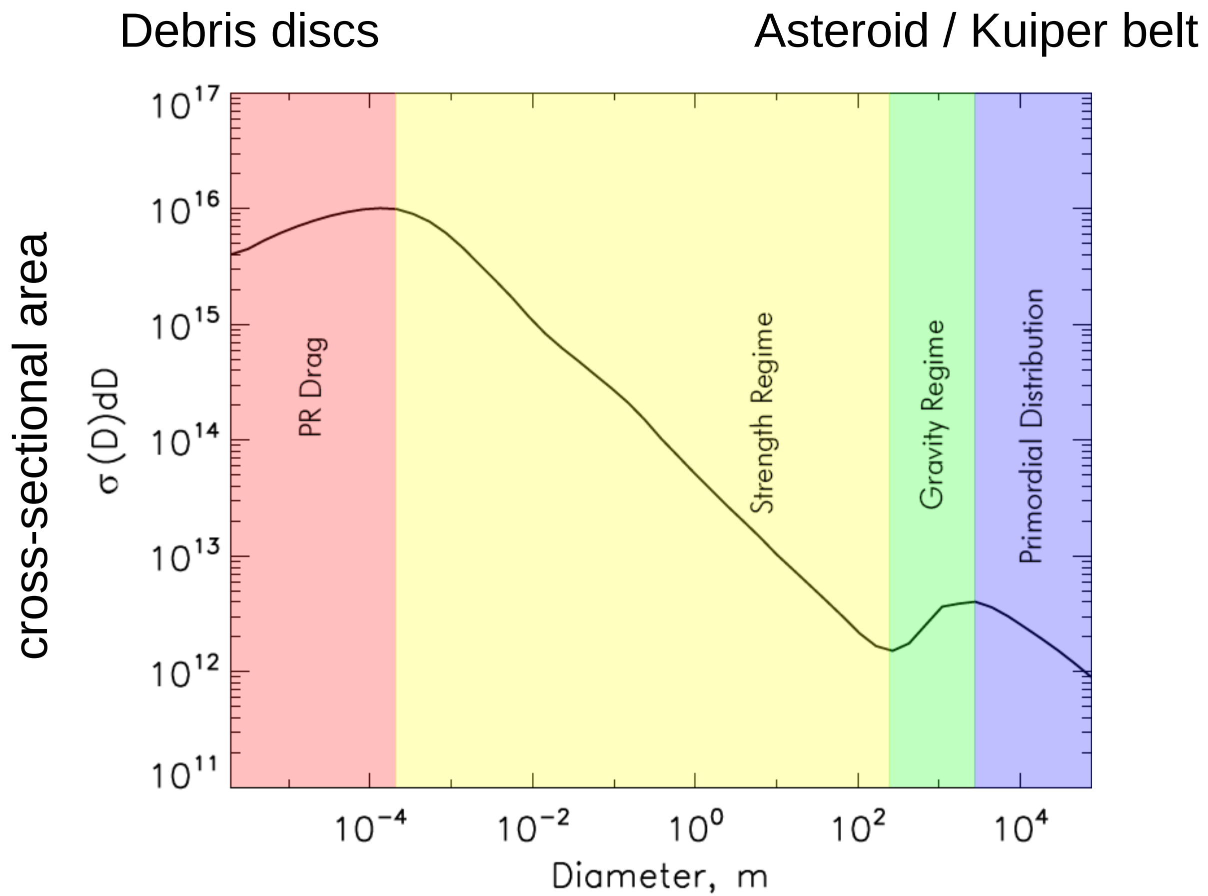
From Protoplanetary to Debris



Michel et al. 2021

- Evolution from class II → III → debris is still not fully understood.
- Could it be that the structured discs (boxes) are the ones that become debris discs and all others lose too much of their dust mass to remain detectable?

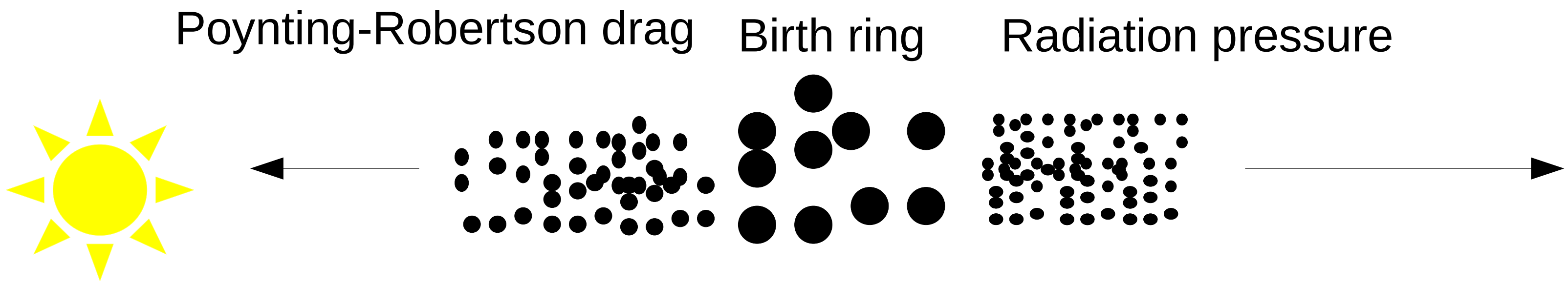
Key Concept: Size Distribution



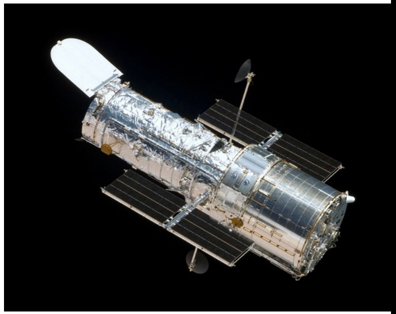
- Small grains have a short lifetime and must be replenished through collisions, necessitating a size distribution.
- Studies of the asteroid belt suggested this can be approximated by a power law $n(D)\mathrm{d}D \propto D^{-3.5}\mathrm{d}D$ (Dohnanyi 1969).
- More detailed models of size distributions take into account effects like the dependence of strength on size (e.g. O'Brien & Greenberg 2003) and the impact of transport forces (e.g. Wyatt, Clarke & Booth 2011).

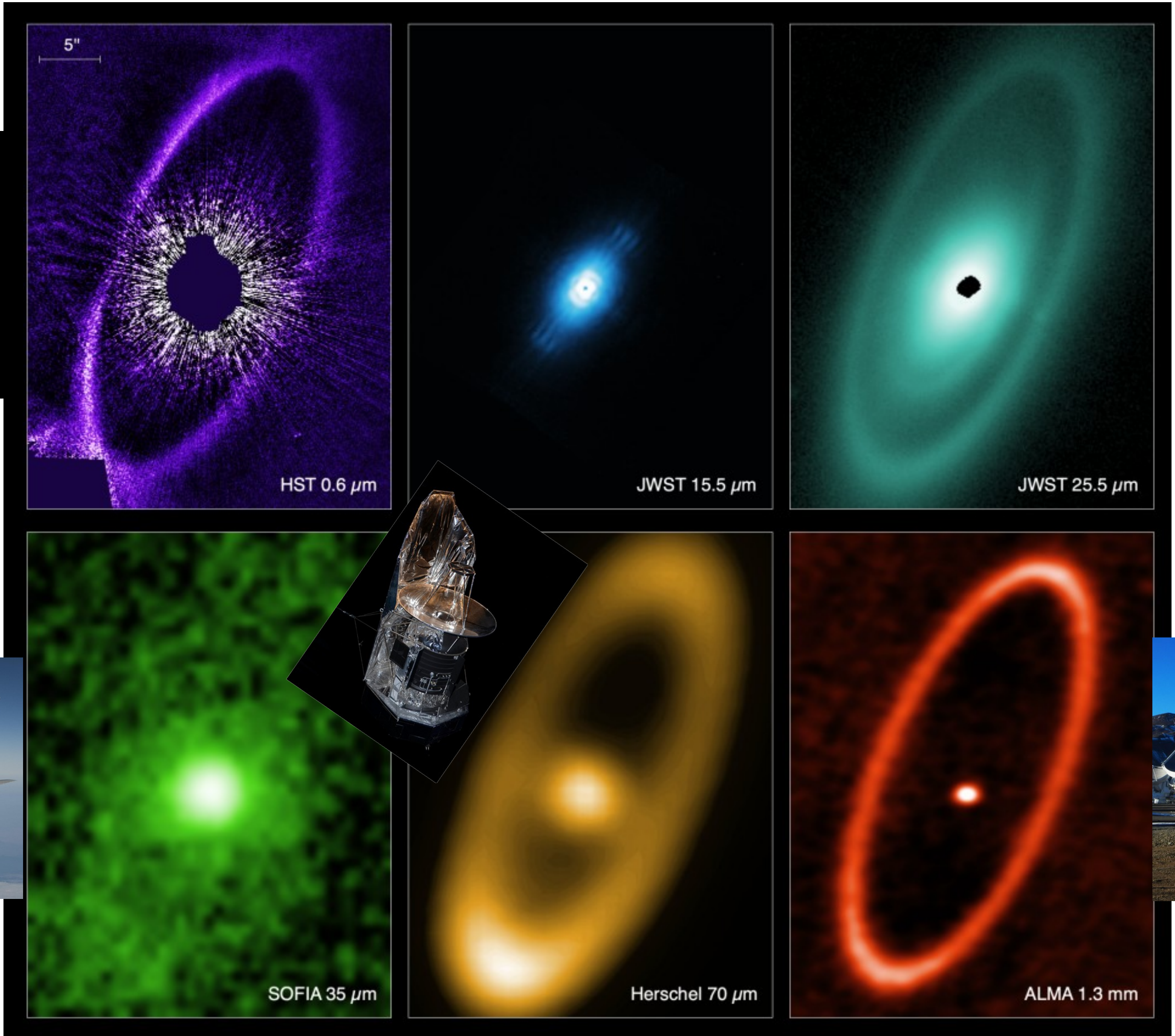
Key Concept: Transport forces

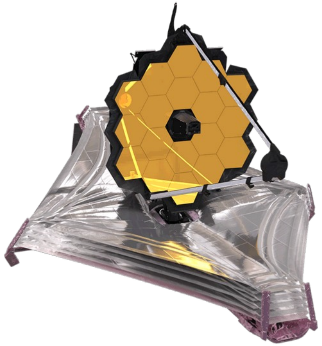
- Emission seen at a given wavelength is dominated by grains of roughly the same size as the wavelength.



- Stellar radiation causes grains of certain sizes to be pushed out or dragged in. Such small grains are typically not seen at sub-mm and longer wavelengths.





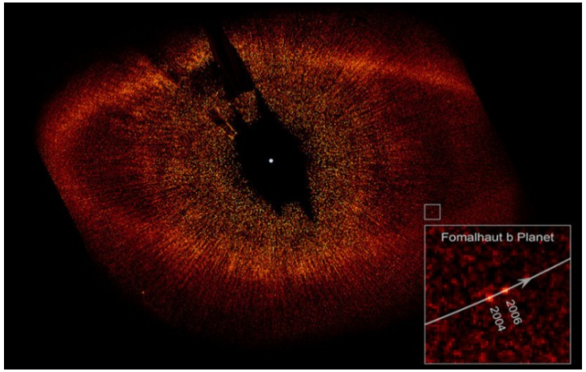


Gáspár et al. 2023

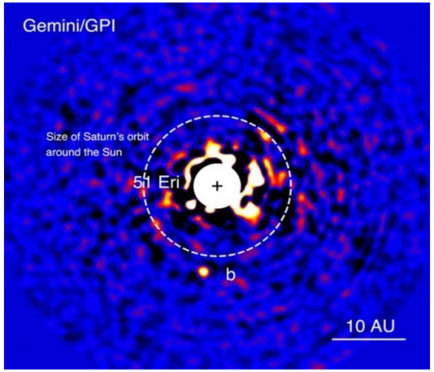

ONE DOES NOT SIMPLY
GIVE A DEBRIS DISC TALK
WITHOUT MENTIONING PLANETS
imgflip.com

Directly Detected Planets

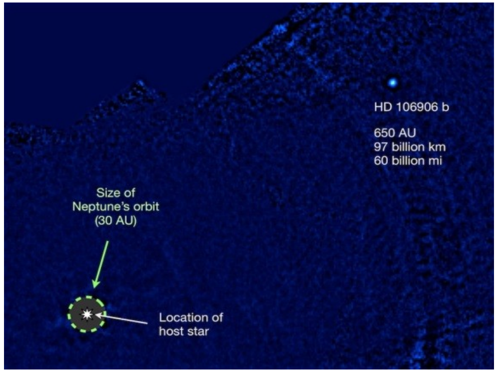
Fomalhaut



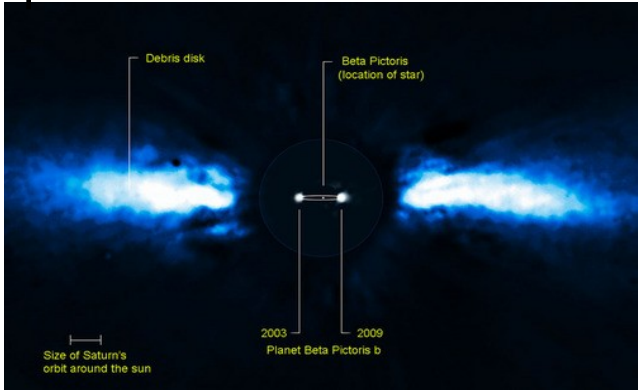
51 Eri



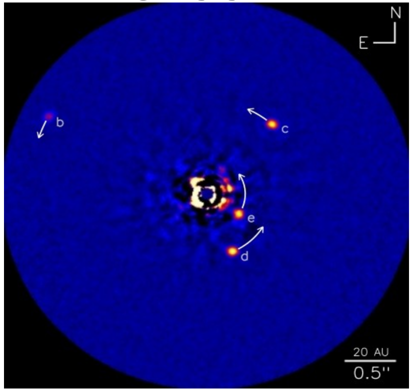
HD 106906



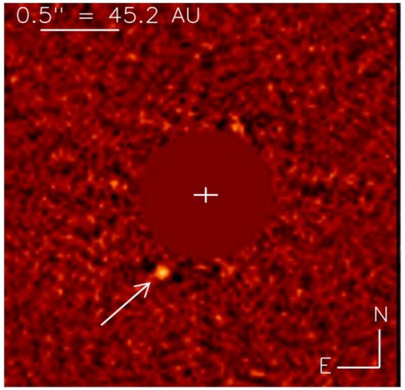
β Pic



HR 8799

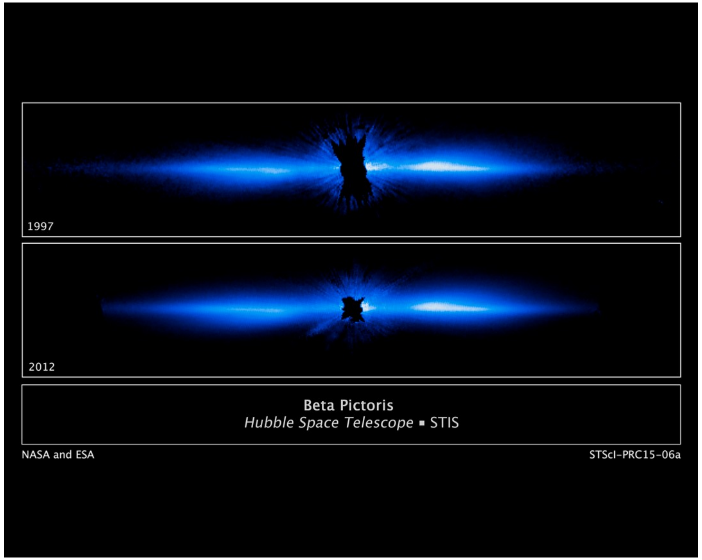


HD 95086



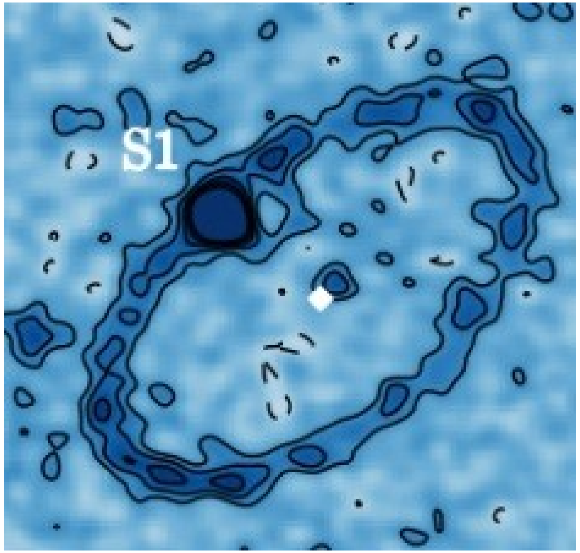
Planet Signatures

Warps



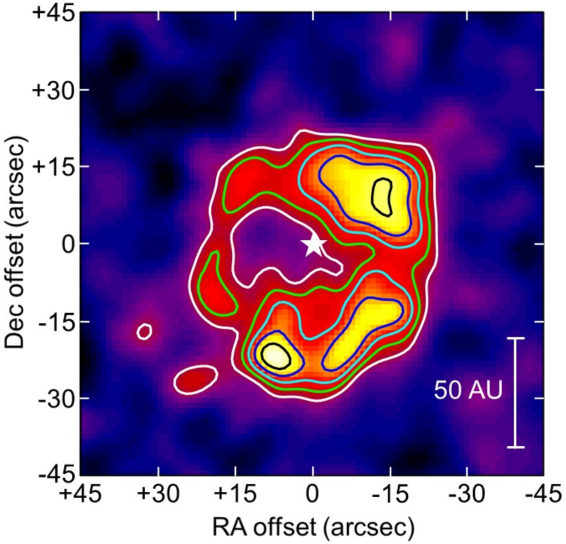
Apai et al. 2015

Eccentricity



Faramaz et al. 2019

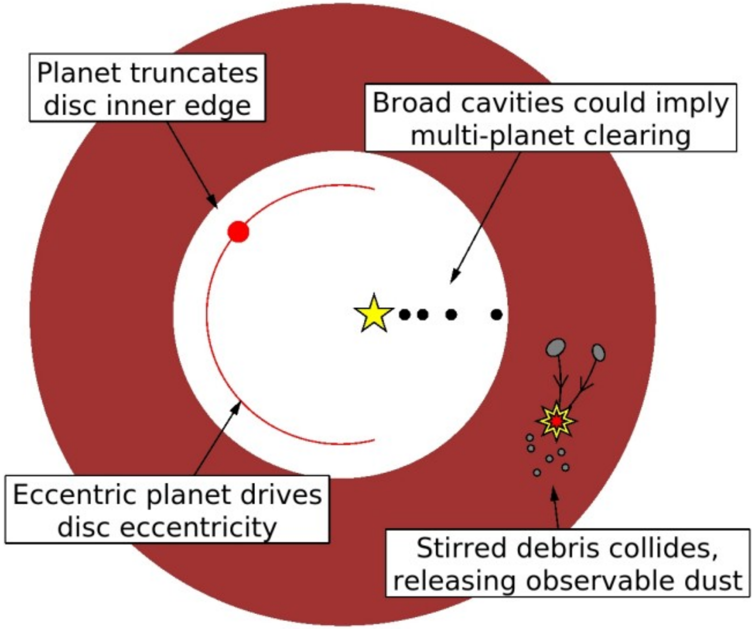
Resonant clumps?

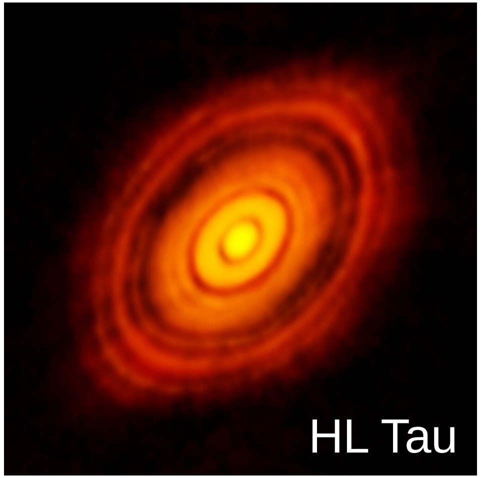


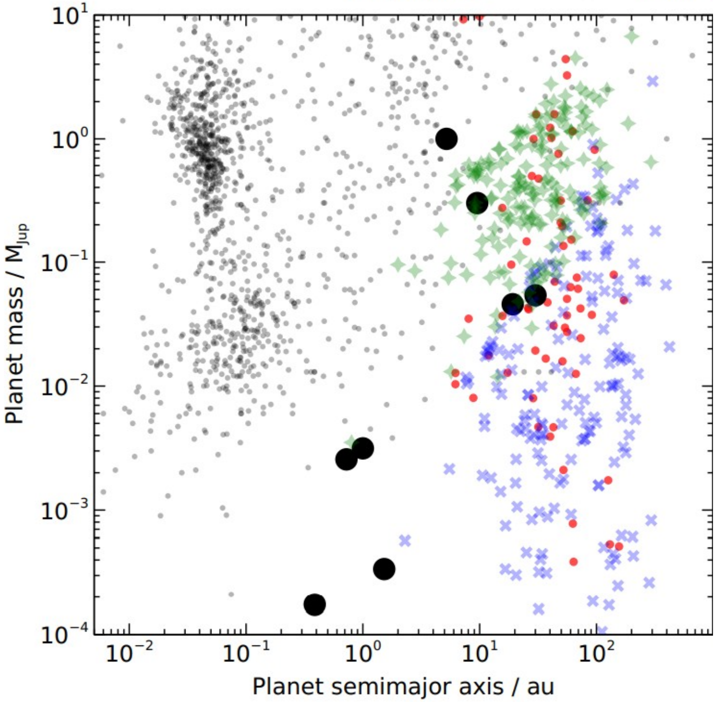
Holland et al. 2017

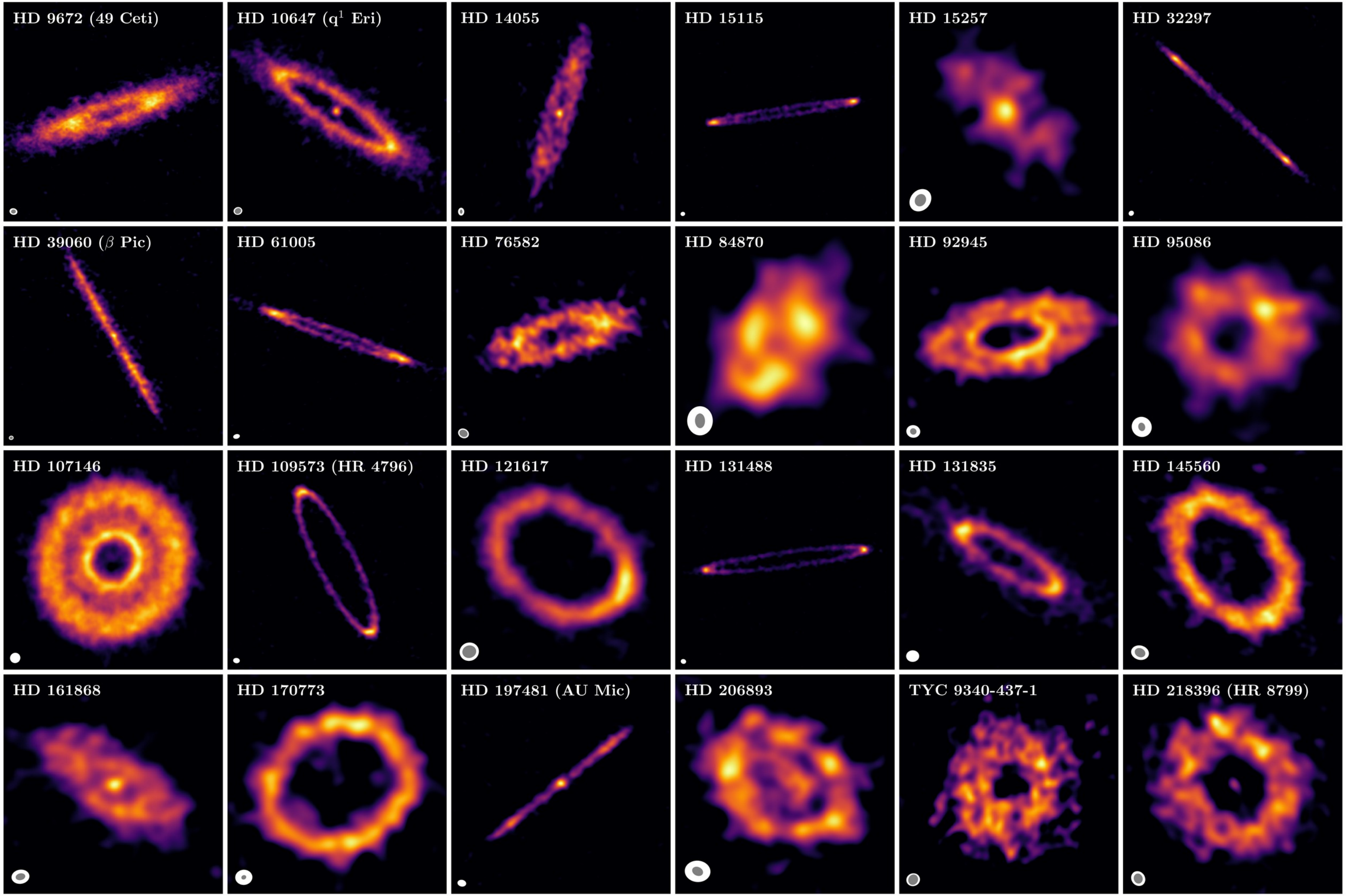
Planet Signatures: Inner Edge

Locations of planets predicted to be shaping debris disc inner edges (Pearce et al. 2022) are in roughly the same region of parameter space as those predicted to be carving gaps in protoplanetary discs (Lodato et al. 2019).





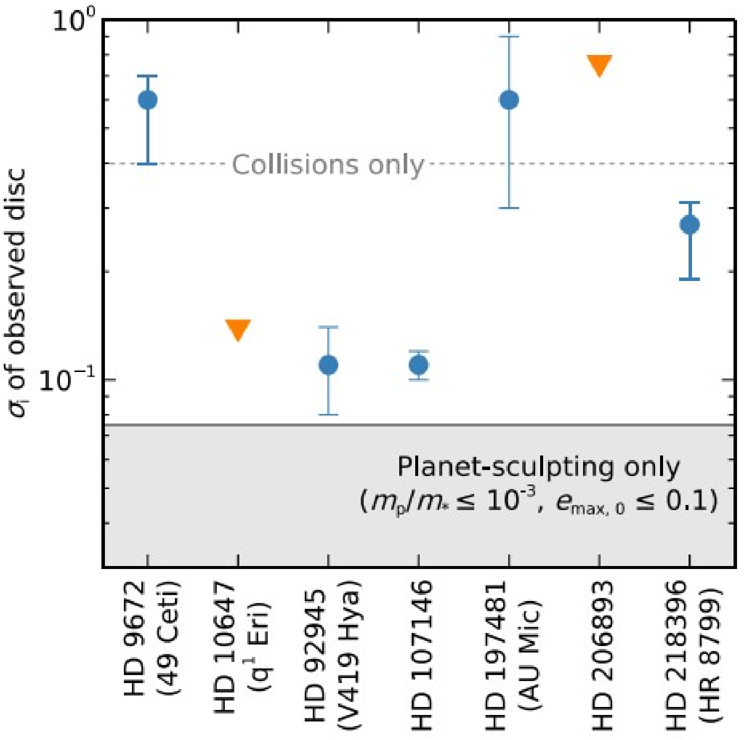




ARKS – ALMA large survey – PI: S. Marino

Shape of the Inner Edge

- With high resolution observations we are not simply measuring the location of the inner edge, but also its shape, which helps us distinguish between an inner edge carved by collisions and one carved by planets.

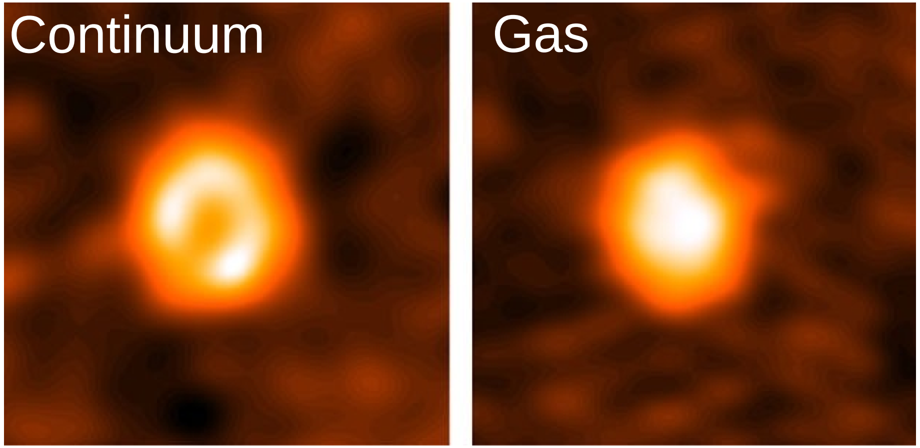


Pearce et al. 2024

Gas in debris discs

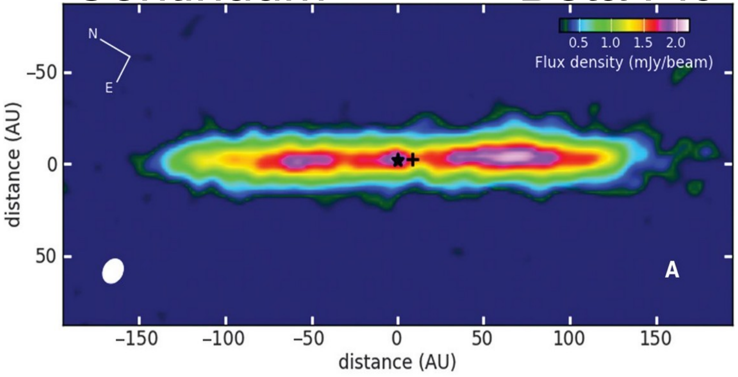
Presence of gas has often been used as a way to define the difference between protoplanetary and debris discs, but a growing number of debris discs have been found to have gas emission.

HD 21997

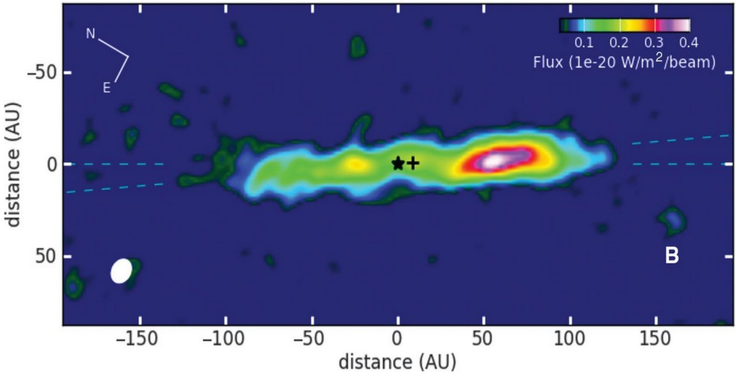


Moór et al. 2013, Kóspál et al. 2013

Continuum Beta Pic



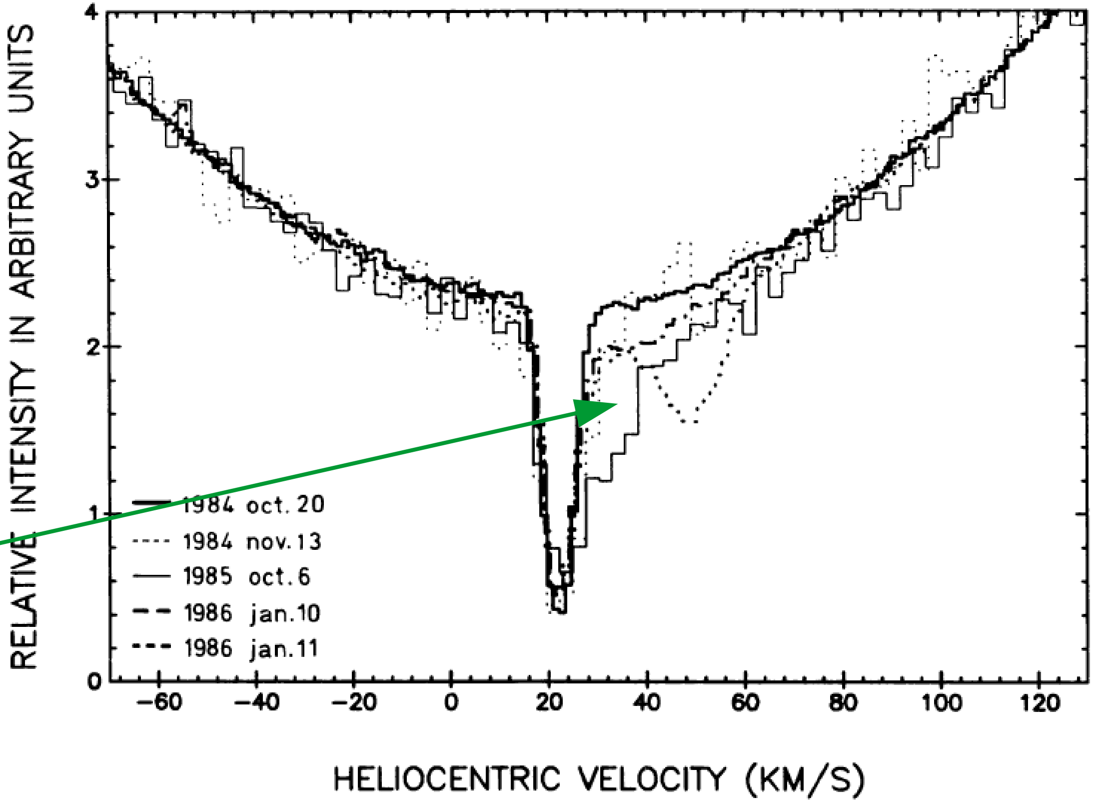
Gas



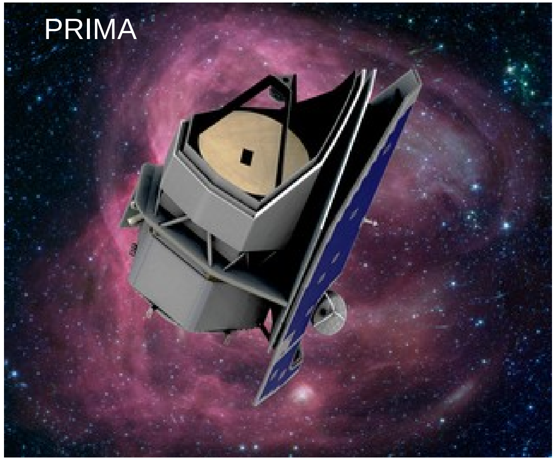
Dent et al. 2014

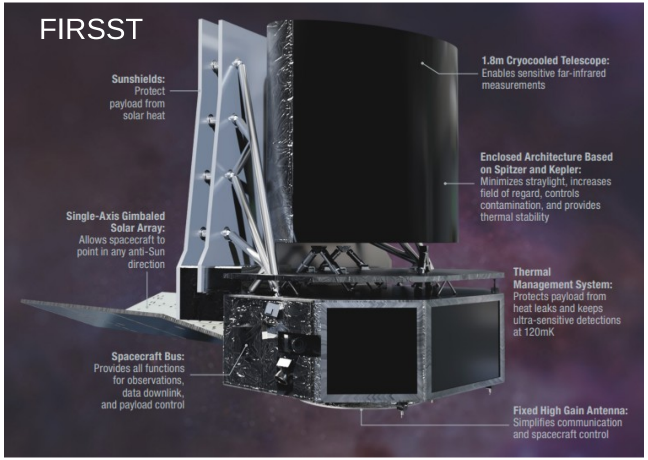
Gas absorption

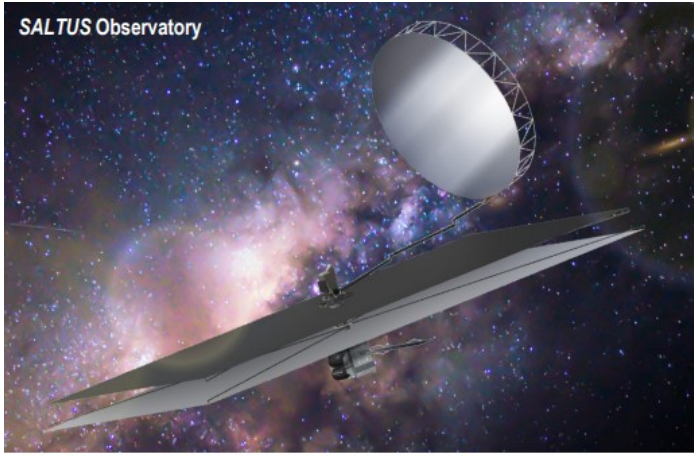
- Slettebak 1975, Kondo & Bruhweiler 1985, Hobbs + 1985, Vidal-Madjar 1986 all noted absorption lines showing that there must be gas in the beta Pic disc.
- In Ca II-K, Ferlet + 1987 also noted that the absorption spectrum was variable and suggested this was due to comets.



Future telescopes: Far-IR







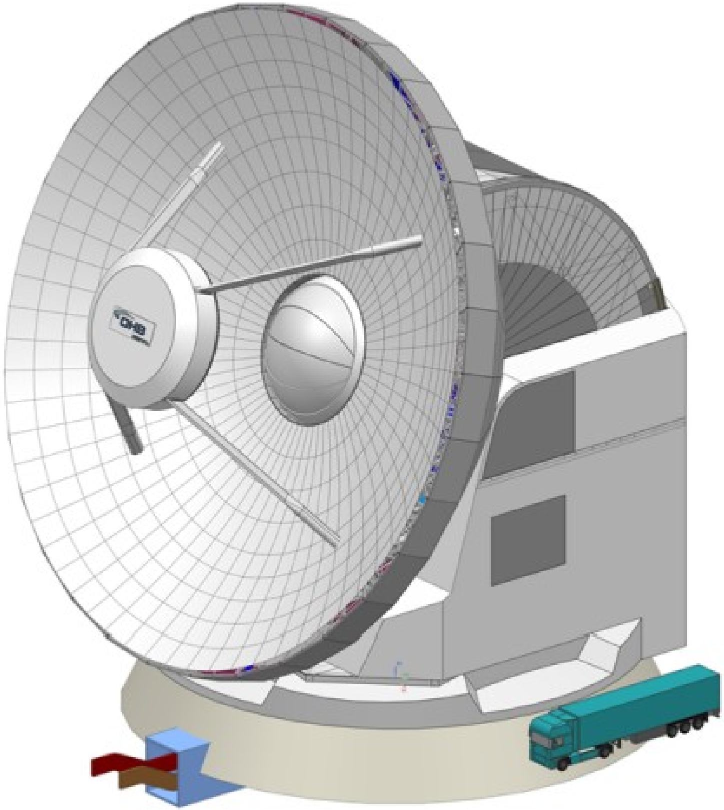
- Astro2020 Decadal Survey report called for either a far-infrared or an X-ray observatory to be implemented this decade.
- All three far-IR concepts will be excellent for the discovery and characterisation of debris discs.

Future telescopes: Sub-mm

- Atacama Large Aperture Submillimeter Telescope (AtLAST): 50m single-dish telescope (order of magnitude increase in collecting area over JCMT!) with 2° field of view covering 0.3-1mm.
- Capable of detecting large-scale emission around nearby stars and reaching discs as faint as the Kuiper belt.
- Capable of rapidly mapping star forming regions and clusters to follow the evolution of debris discs.
- See Booth et al. (2024) and Klaassen et al. (2024) for more details.

www.atlast-telescope.org

Mroczkowski et al. 2024



Further Reading

- Wyatt 2008, ARA&A 46: 339–383
- Krivov 2010, Research in Astronomy and Astrophysics 10 (5):383–414
- Matthews et al. 2014, Protostars and Planets VI, 521–544
- Hughes, Duchêne & Matthews 2018, ARA&A 56: 541–591
- Marino 2022, Planetary Systems Now
- Pearce 2024, Encyclopedia of Astrophysics