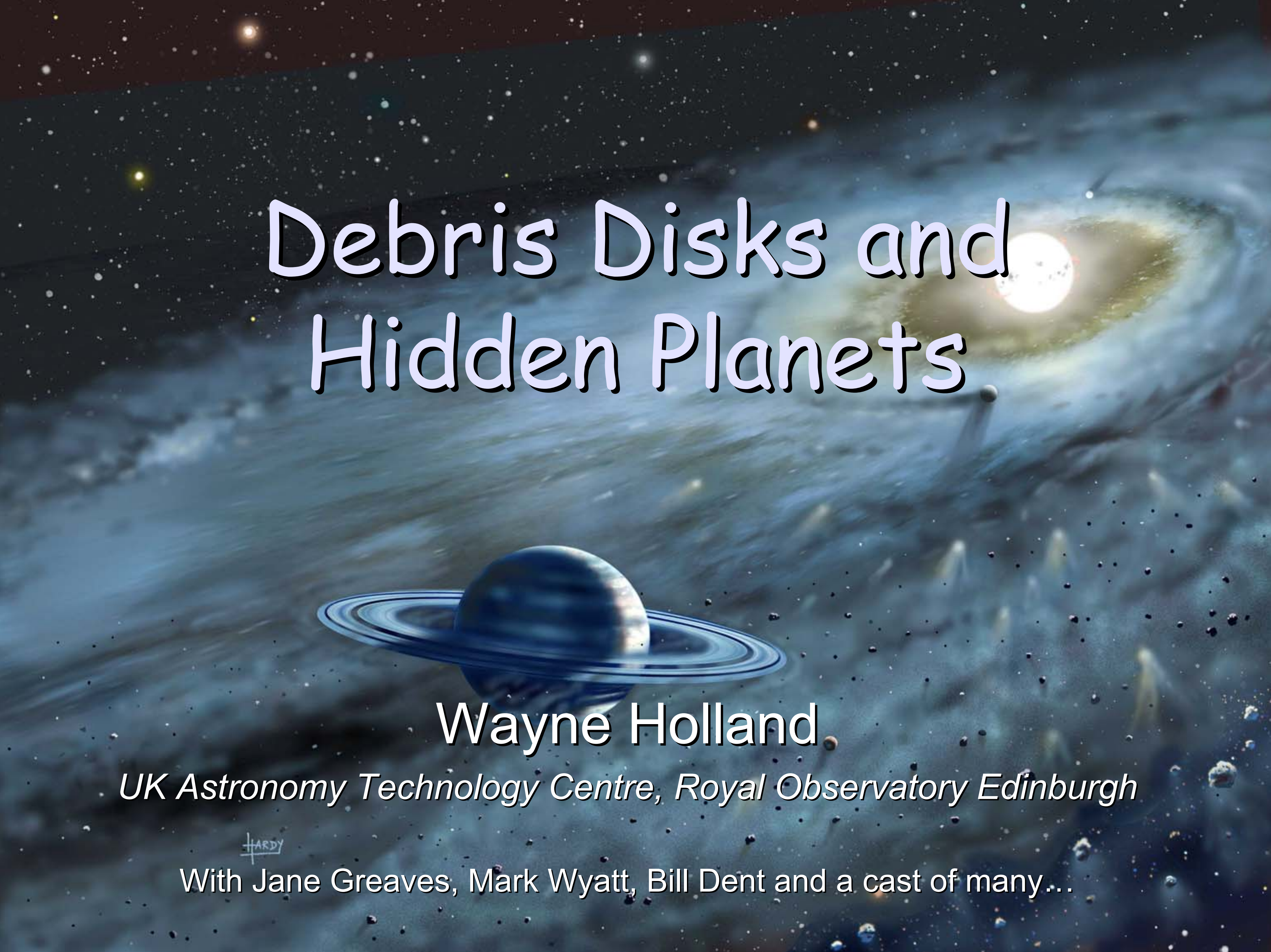


Debris Disks and Hidden Planets

Wayne Holland

UK Astronomy Technology Centre, Royal Observatory Edinburgh

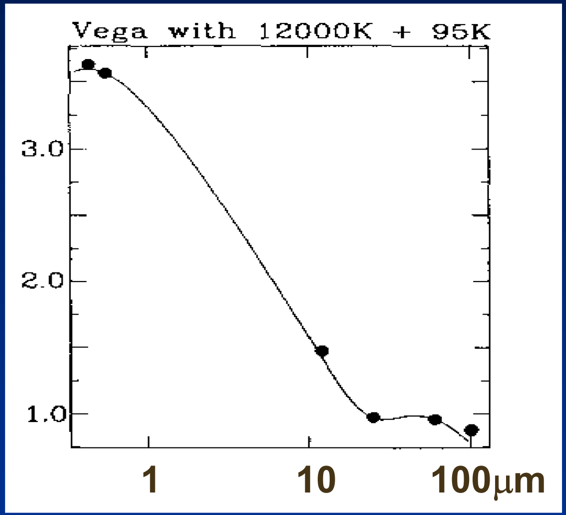
With Jane Greaves, Mark Wyatt, Bill Dent and a cast of many…

Talk Outline

- What are debris disks?
- Observations of debris disks
- Interpreting the data
- Current work and limitations
- Prospects for the future

Debris disks

Walker & Wolstencroft, 1988



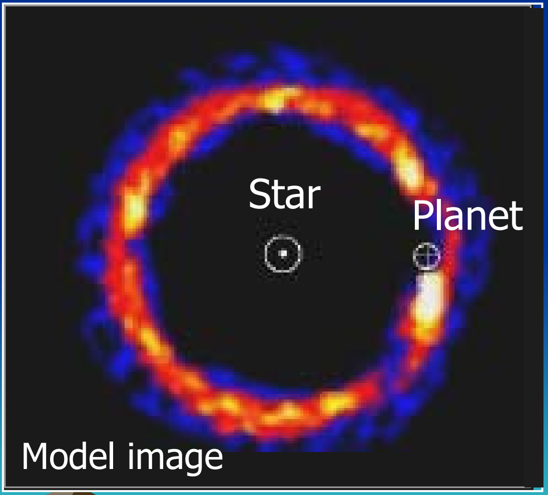
- Debris disks are found around 15% of nearby main sequence stars

- Disks contain dust that is continually replenished by collisions

Debris disks

- Provides strong evidence for the existence of both asteroids/comets and giant planets

- Can reveal the locations of large unseen bodies (such as planets) through warps and perturbations



Observing debris disks

Debris disks must be cold (e.g. Pluto temperature)
$\rightarrow$ so observe at long wavelengths

Large submillimetre telescope (JCMT)
and sensitive camera (SCUBA)

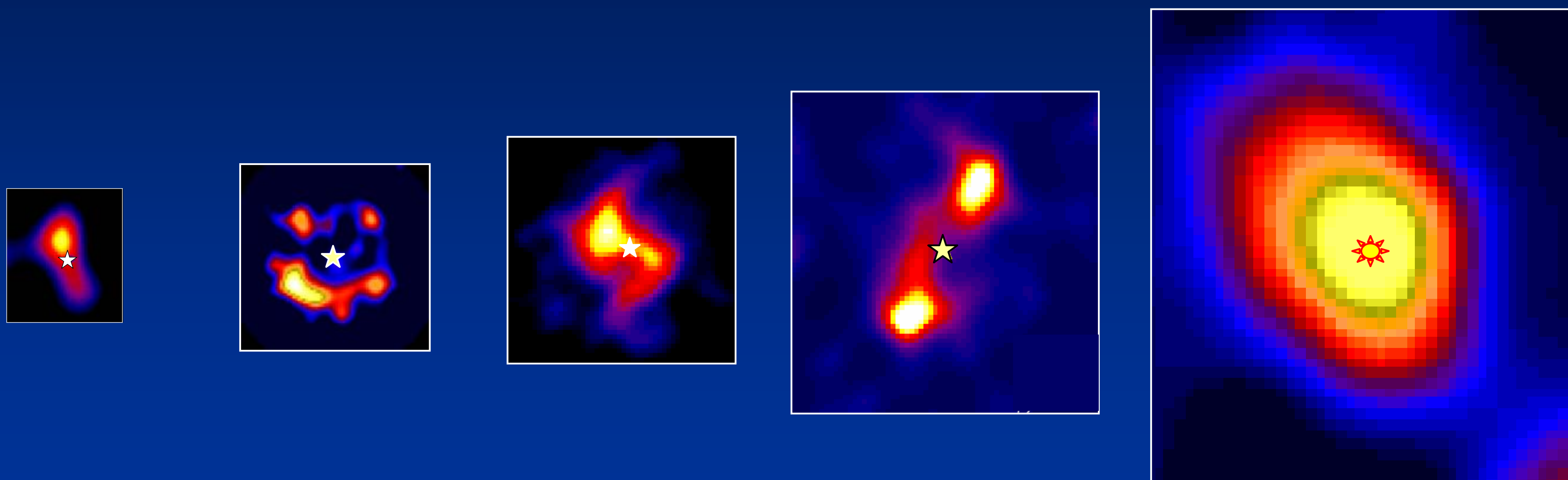
$\Rightarrow$ can attain sub-mJy noise levels but it takes a long time…

Thus can detect < 1 Lunar-mass of dust around stars within ~10pc

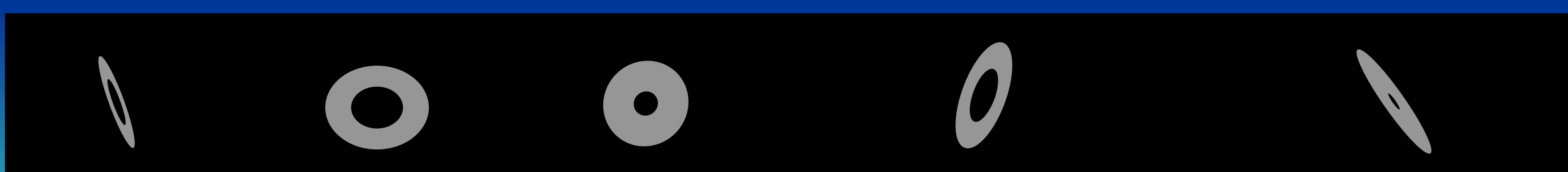
Submillimetre observations

- Submm observations pick up the thermal emission from cold dust grains
  - Sensitive to large scales (10’s to 100’s AU) so can probe Solar System-sized regions
  - Signal is optically thin (so traces mass) and is >> the photosphere (minimal calibration errors)
  - Modelling the SED shows the grains are a few microns up to centimetres (or more) in size

Famous examples
(to same physical scale)



τ Ceti ε Eridani Vega Fomalhaut β Pictoris

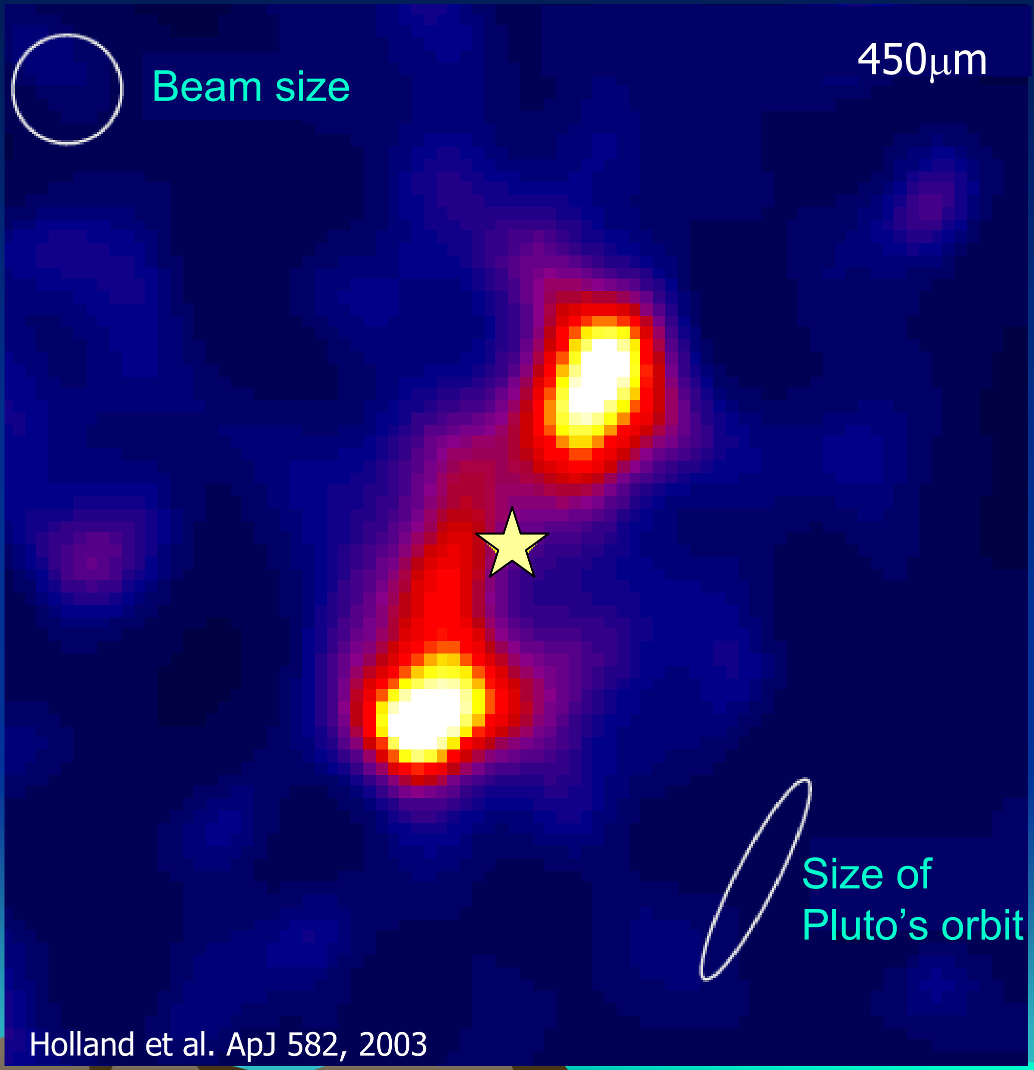


Evidence for planets?

- Two kinds of evidence
  - Inner holes in most of the disks
    - dust is ejected by the planets
  - Structure within the dust belts
    - if due to planets, ‘clumps’ should be associated with particular resonances
    - could pinpoint the planet position, in advance of imaging missions!

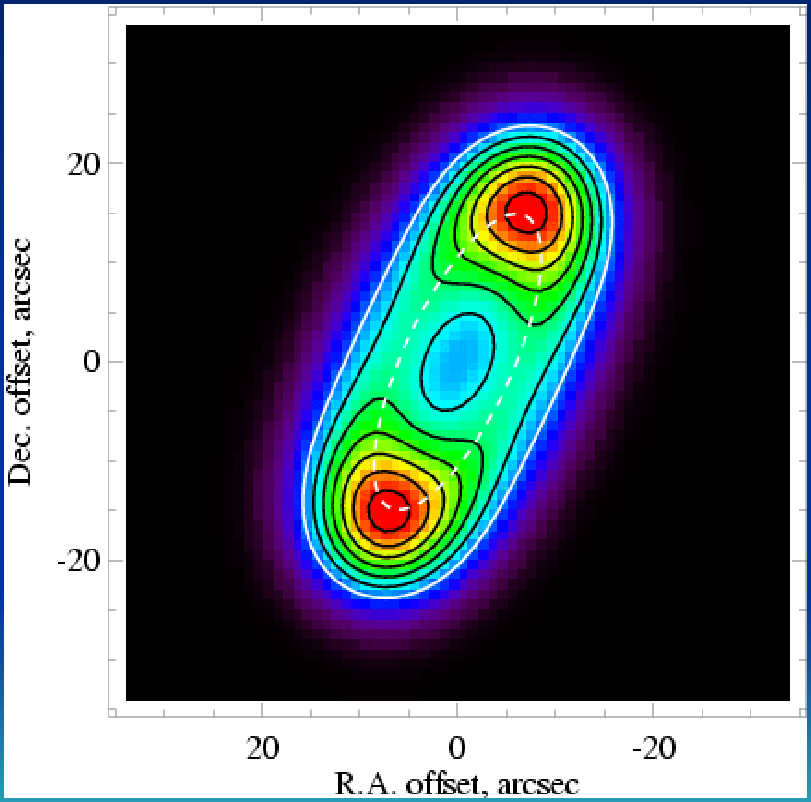
Fomalhaut

- Disk is almost edge-on with little emission between the 2 peaks
- The torus appears to be *distorted* with emission seen mainly towards one side of the star
- The torus cannot be a completely smooth ring - the left side is brighter than the right!



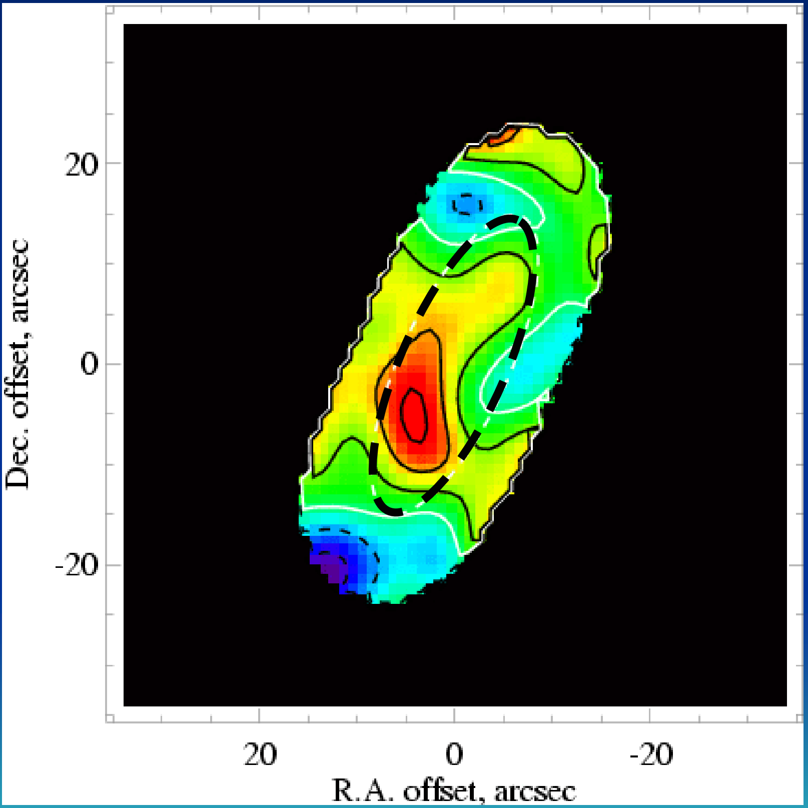
Modelling the Fomalhaut disk

An axisymmetric smooth ring model, scaled to fit the faint west side, was fitted to the image



Modelling the Fomalhaut disk

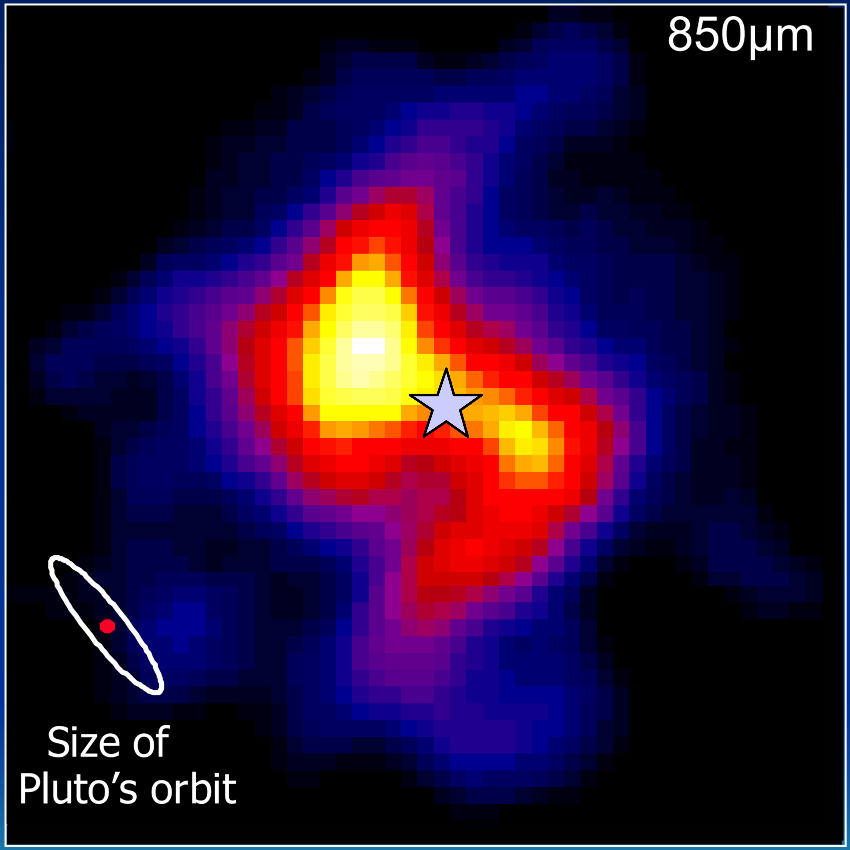
The model was subtracted from the observed image



- Suggests that the asymmetry is caused by a *clump* embedded in a smooth ring
- Clump extends over more than one beam width (and may even be *inside* the ring...)
- What is the origin of this clump? Could it be due to dust trapped in resonance with a planet?

Vega: latest observations

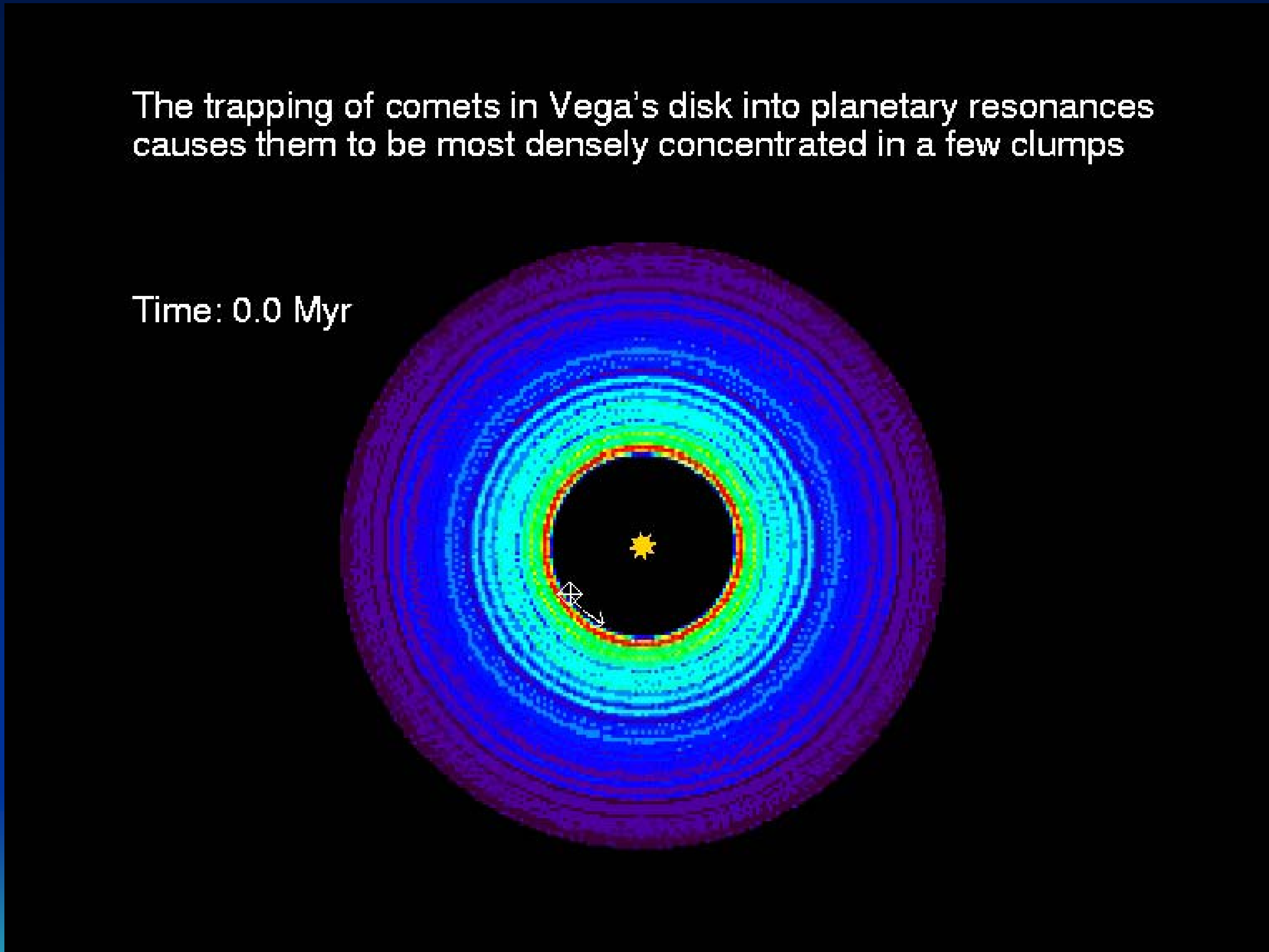
- Total integration time is now ~25 hours; peak flux is 16mJy at 850μm
- Two peaks seen in an otherwise face-on disk structure



Holland et al. in prep

Planet migration in the Vega system

- Vega's two asymmetric clumps can be explained by the migration of a $17M_{Earth}$ planet from 40–65 AU in 56 Myr



Wyatt, ApJ 598, 2003

Planet migration in the Vega system

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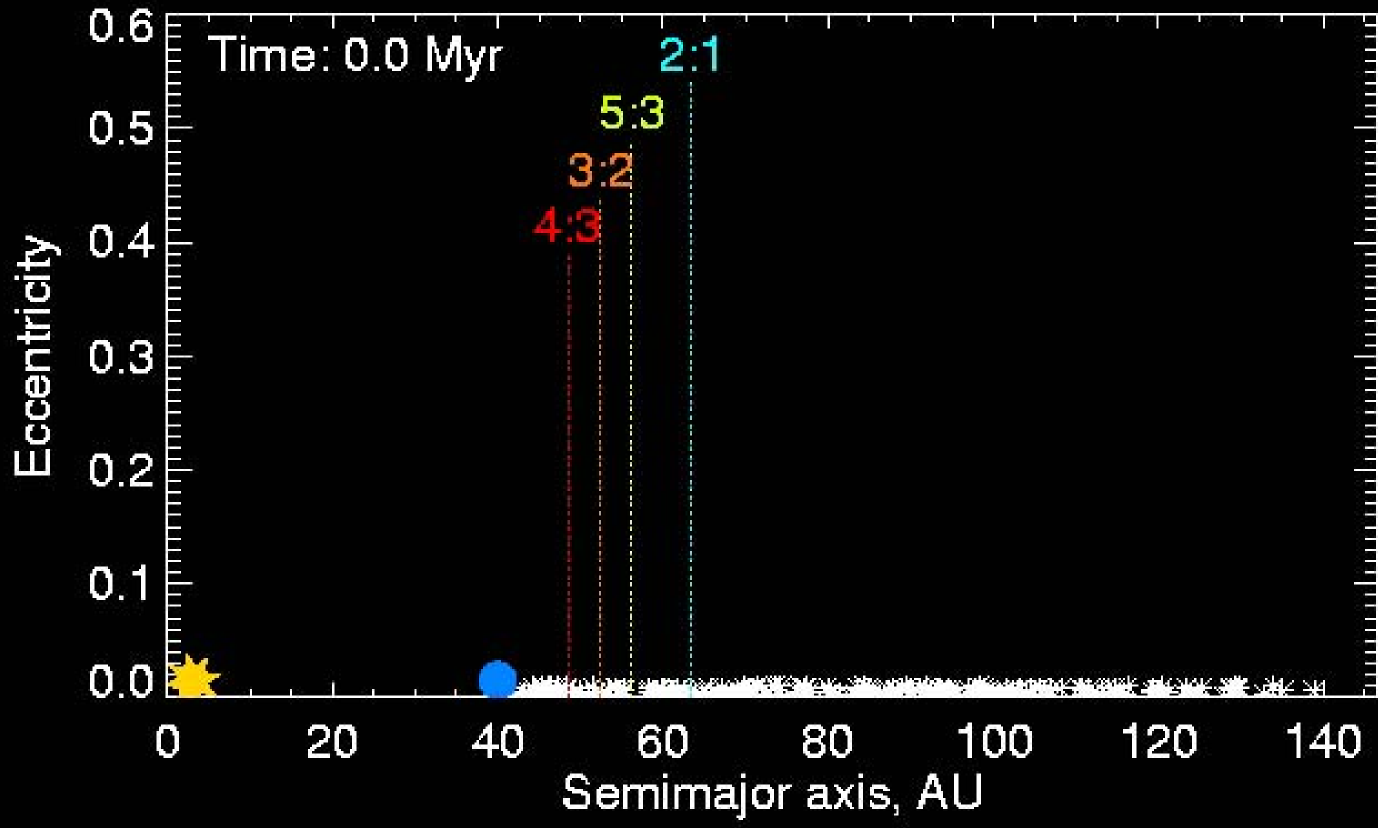
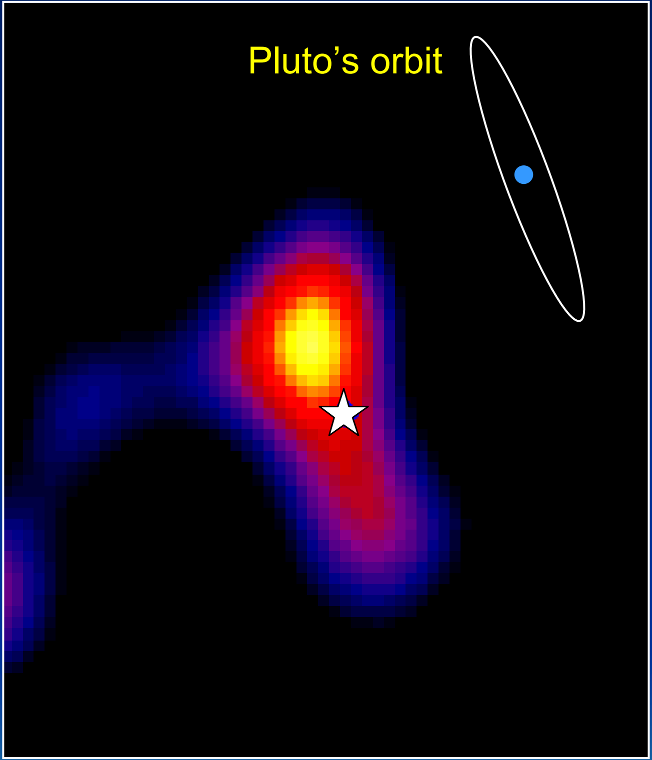
- Most planetesimals end up in the planet's 2:1(u) and 3:2 resonances

The outward migration of a Neptune mass planet (●) around Vega sweeps many comets (*) into the planet's resonances



τ Ceti – Solar analogue?

τ Ceti is a G8V star, 3.7 pc away, with an estimated age of 10 Gyr
- More than 20x dustier than the Solar System Kuiper belt
- Implies lots more comets, but why haven't they all been ground to dust?



If there are planets around τ Ceti, might they have undergone heavy bombardment for the whole 10 Gyr?
- *We don't know which star is 'normal' – the Sun or τ Ceti…*

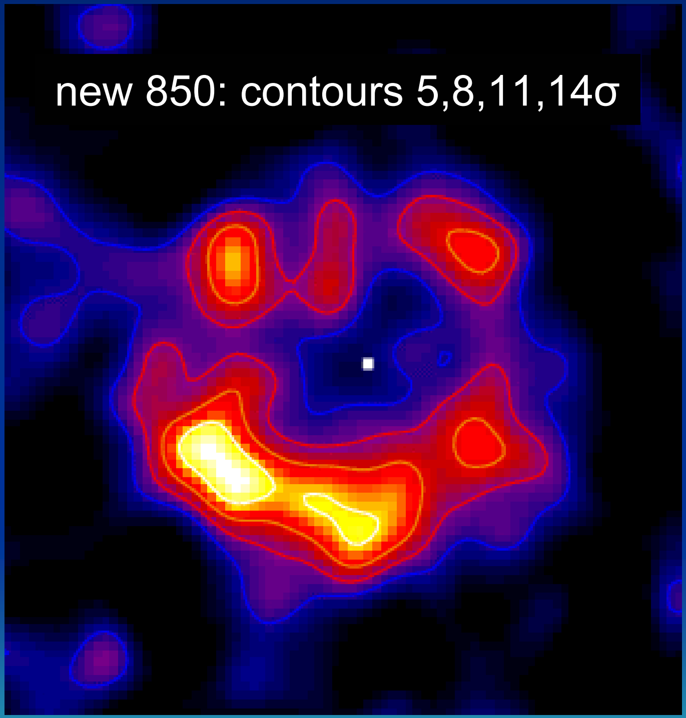
ε Eridani

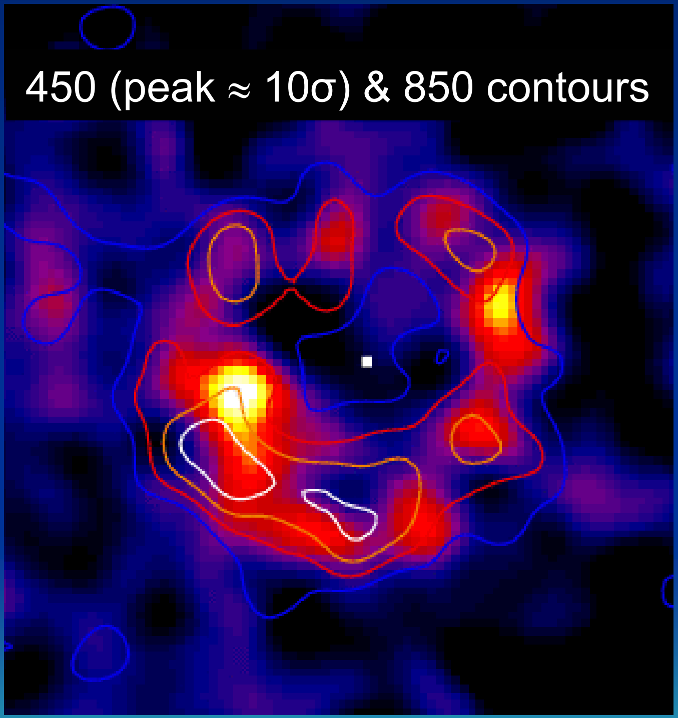
ε Eridani is a K2V star, 3.22 pc away

- Of all the disks so far studied we have the most detailed view of the structure around ε Eri
- SCUBA data from 1997/8 (published) up to 2002 (submitted)
  - new data confirms the structure seen at 850 μm
  - imaged also now at 450 μm → same structure
  - also 350 and 1200 μm images from Wilner et al. (SHARC II on CSO), Schütz et al. (SIMBA on SEST)

- Compare the 450 and 850μm images
  - same ring structure and similar peak locations

    (differ by 2-7'', consistent with expectation from noise)





Current work

- The submm is sensitive to *cold* disks
  - missed even by Spitzer? disk excess is small compared to the photosphere for $T_{dust} \leq 40$ K
    - very accurate calibration needed to be sure an excess is real; also the true photosphere is uncertain for K and M dwarfs
- Sun-like stars are more likely to have cold 'missed' disks
  - IRAS excesses for 60% of nearby A stars!

G-star survey

- Ongoing with SCUBA... unbiased survey of G dwarfs 10–15 pc from the Sun
  - one IRAS detection confirmed
  - one to three new detections, out of 13 stars
- If all 4 SCUBA results are real, detection rate rises to ~30%!
  - versus 7% for G stars observed with IRAS/ISO

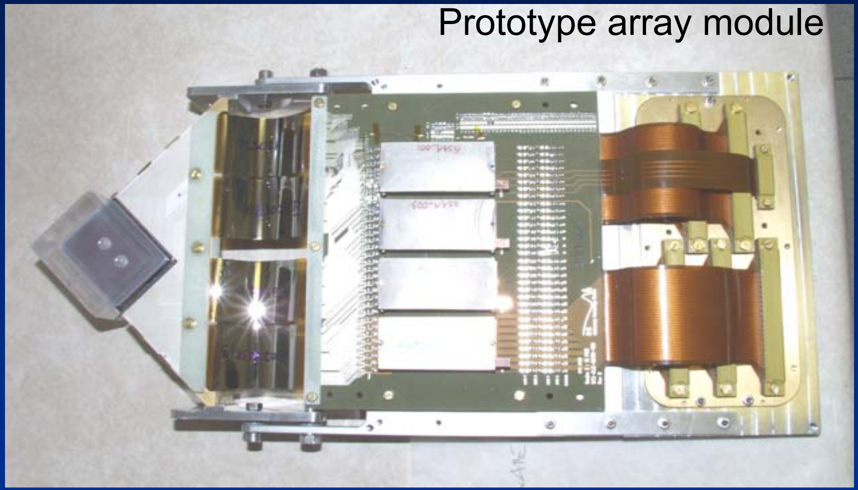
Limitations

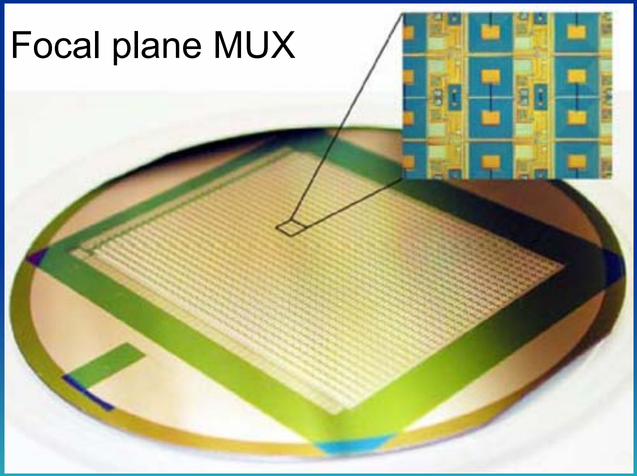
- Observations are sensitive to mJy fluxes... but still need to observe for tens of hours to get deep images
  - especially at 450μm
- Observing with 8–15'' beams limits us to nearby stars... but it's the only way to detect outer bounds of planetary systems
  - finding mostly large examples!
  - only one is as small as the Sun's Kuiper Belt, with r ~ 50AU

New generation arrays

SCUBA-2 is a new generation imaging array for the JCMT

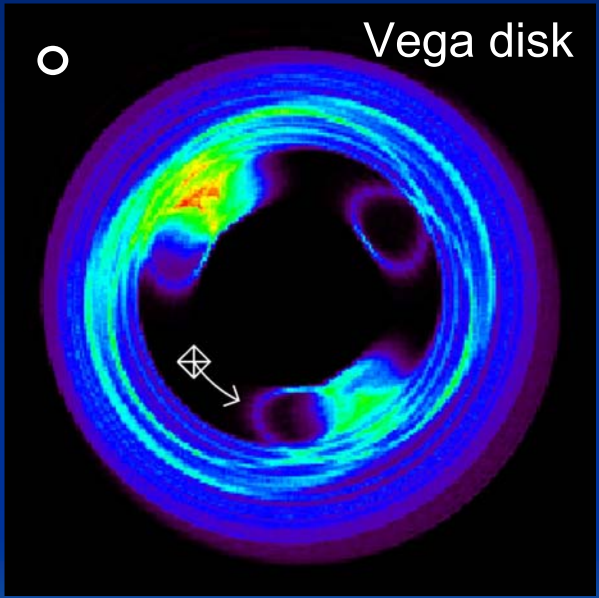
- Image large areas of sky 1000× faster than SCUBA to the same S/N
- Disk observations will take minutes instead of many hours…
- SCUBA-2 will be capable of detecting many more disks
- Due on the telescope in less than 2 yrs…





Large Submillimetre Telescope

The Future: a 30m-class telescope operating to 200μm, with <2'' beam...

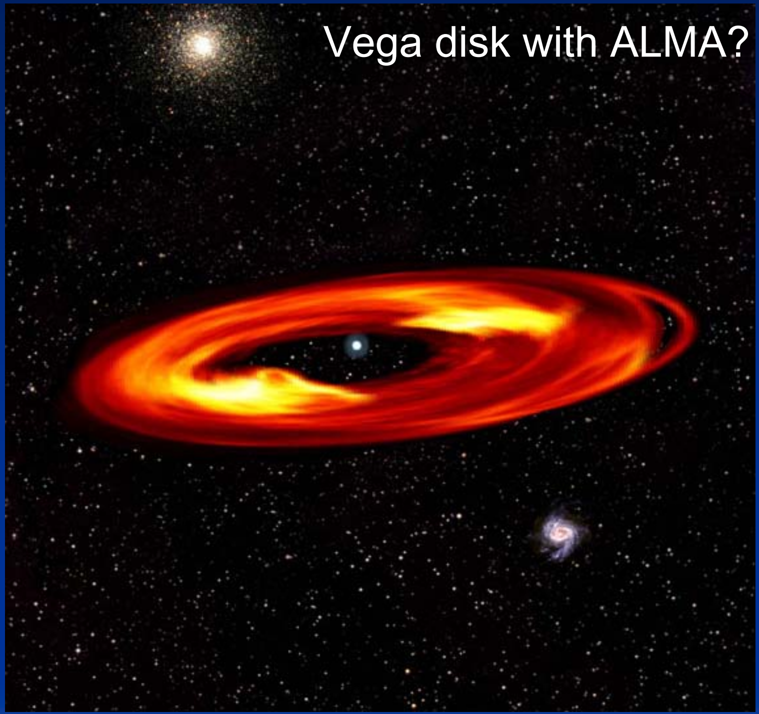


With arcsecond resolution we can resolve clumpy structure and test the uniqueness of formation models

ROE Workshop
Towards Large Submm Dishes
(22-24th October, Edinburgh)
www.roe.ac.uk/roe/workshop

The Future: Interferometry

- With ALMA more than an order of magnitude better spatial resolution
- Sensitivity will allow more distant sources to be studied
- Also measure CO emission within the disks – a narrow ring of evaporating comets?



David Wilner & David Aguilar

Summary

- Debris disks are a powerful way of determining the existence of planetary systems
- Most of the debris disk population around Sun-like stars may have been missed…
- New imaging arrays, telescopes and interferometers are about to revolutionise this field of astronomy