Debris Disks with ALMA

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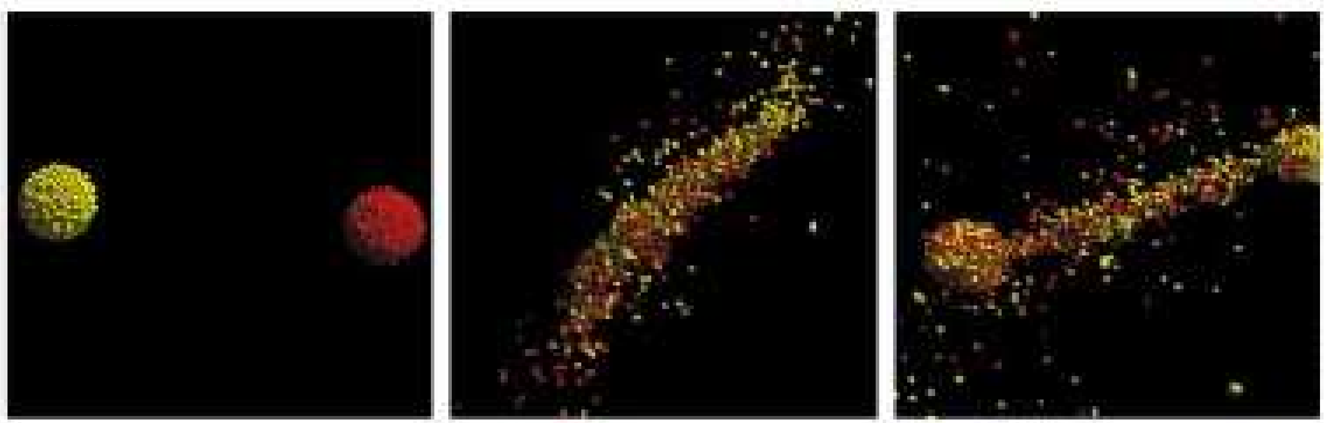
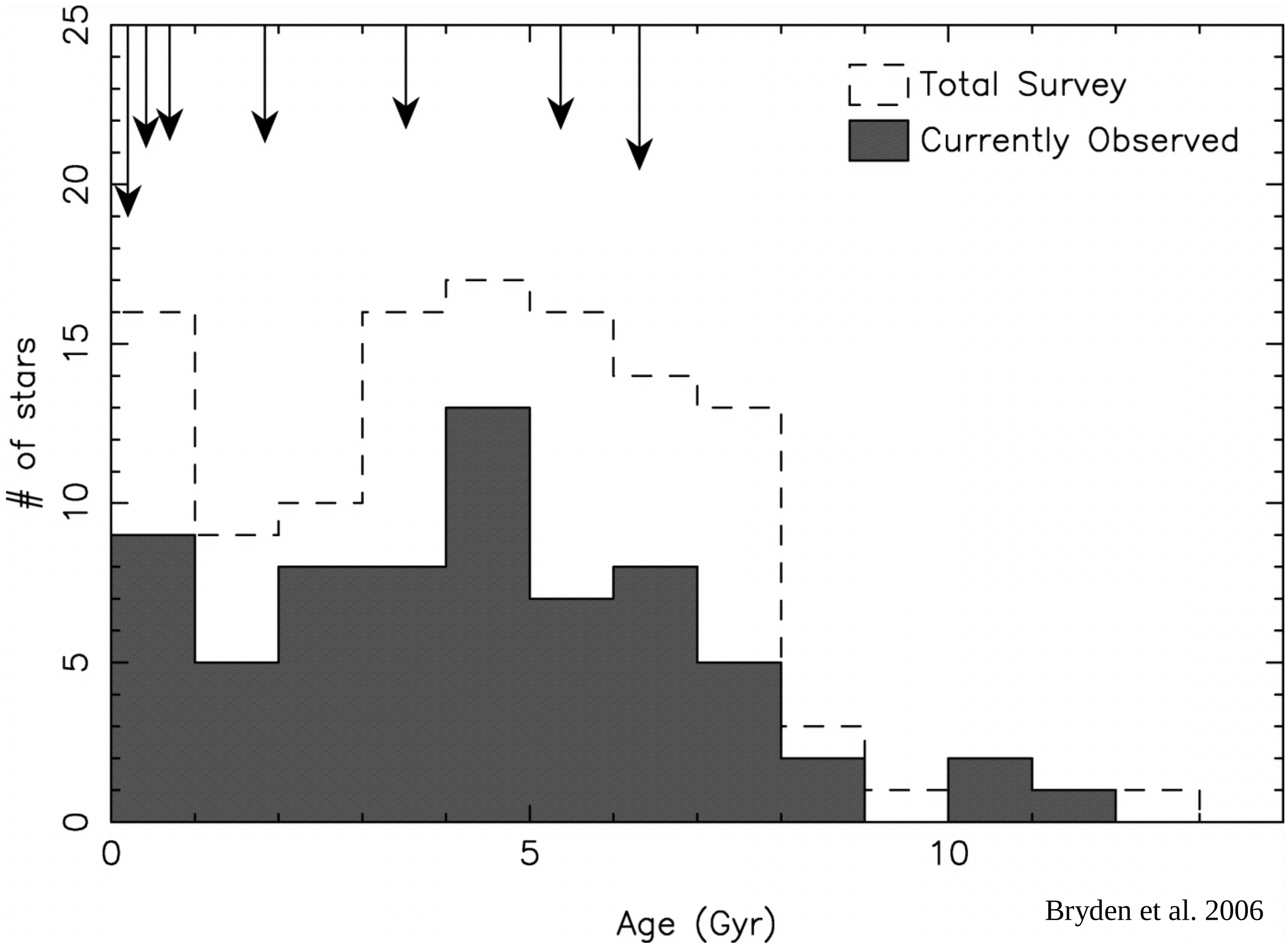
origins of debris

- debris is generated by collisions of comets or asteroids…
  - traces planetesimal belts > signpost to systems where planet formation got started
  - perturbations of dust disks indicate where distant giant planets are located
  - seen around main-sequence stars of *any* age



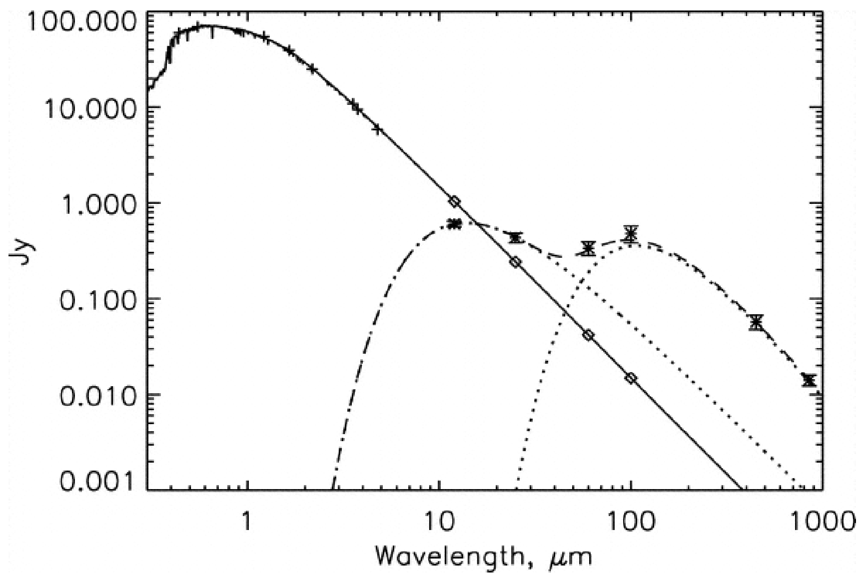
Leinhardt & Richardson



Bryden et al. 2006

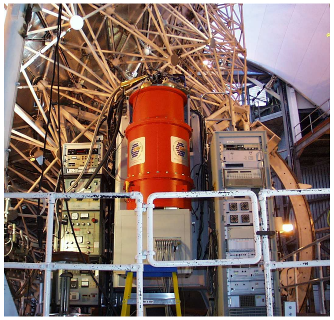
submm imaging

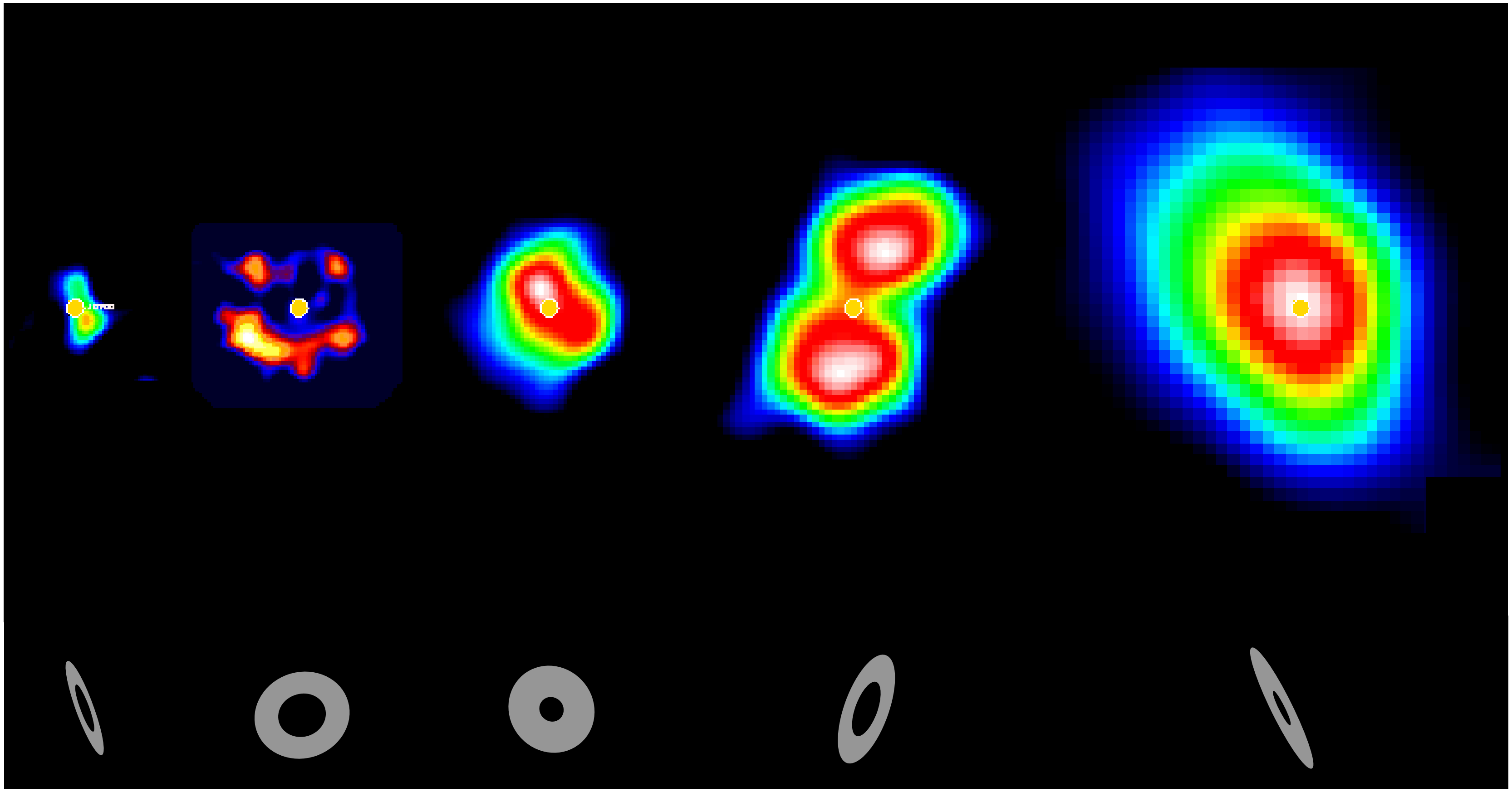
- optically thin dust in thermal equilibrium with the star
  - so for dust rings at tens of AU, far-infrared to submillimetre greybody emission
    - traces mass of debris: infer mass of comets
    - spectral slope > properties of grains
  - imaging shows scale of planetary system



eta Corvi: Wyatt et al. 2005

submm 'rogues gallery'



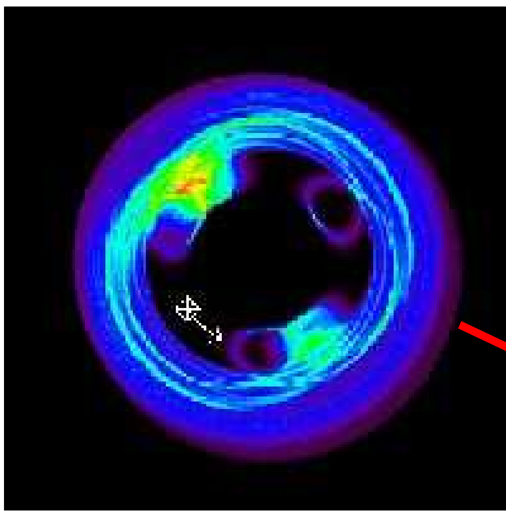


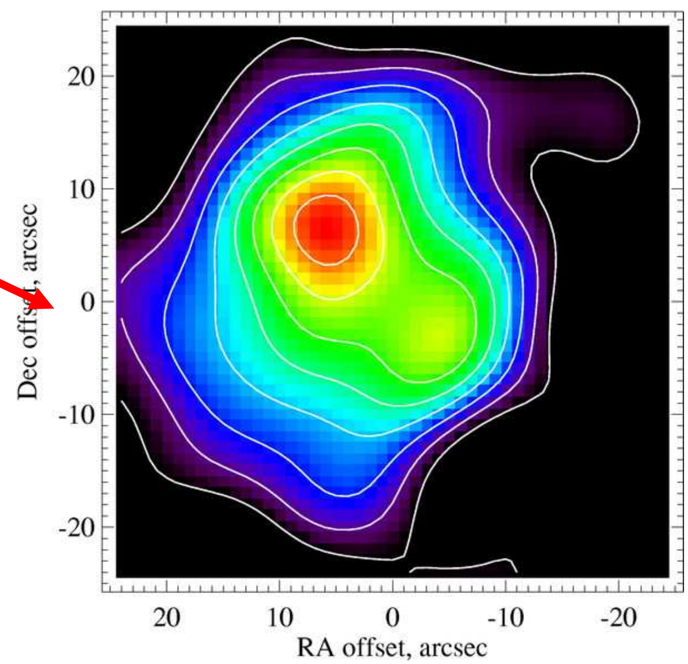
diversity

- unexpectedly, great variety among disks
  - wide range of disk sizes: radii ~50 to 300 AU
    - Solar System's Kuiper Belt is at the small end
  - majority perturbed
    - requiring planets out to ~100 AU
    - explained by outwards migration via angular momentum exchange with planetesimal belt
- no 'predictor' of whether a particular star will have debris
  - unclear whether seeing debris 'events' … or stars with steady state debris from very large numbers of comets > great diversity of planetary systems

planetary interpretations

- dust trapped in resonanances > clumps
  - map pointing to planet location

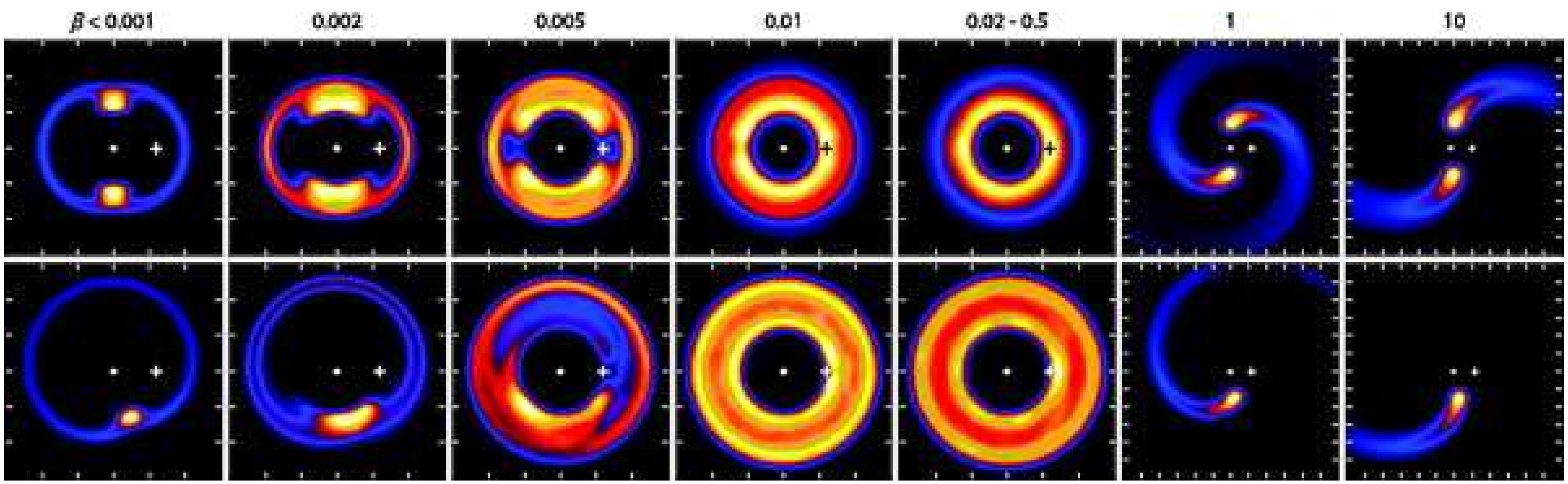




Vega: Wyatt et al. 2003;
Holland et al. 1998, 2003

wavelength dependence

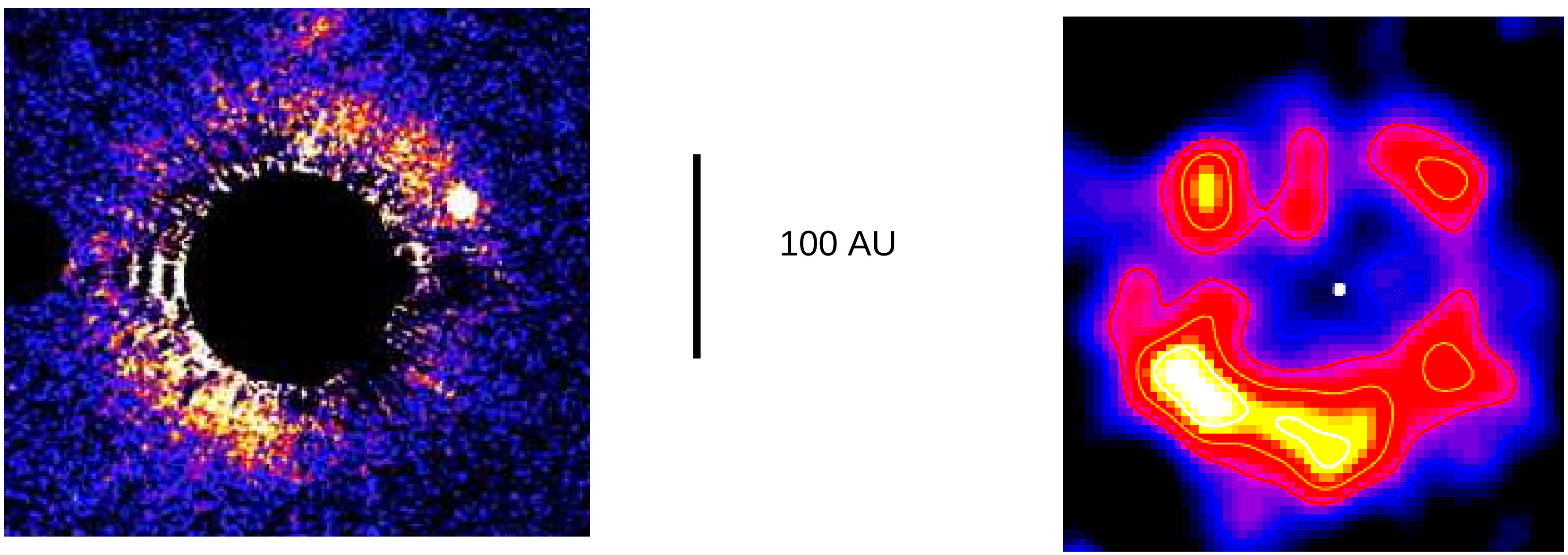
- balance of radiation pressure and gravity means dust of different sizes trapped differently
  - small particles feel more radiation force: so short-wavelength data show more blow-out
    - submm is ideal for imaging perturbations… brighter than millimetre, sensitive to large-ish well-trapped dust



Wyatt 2005

- *much* better than optical scattering, which is sensitive to very small grains
    - e.g. compare HST image of HD 53143 and SCUBA image of epsilon Eridani

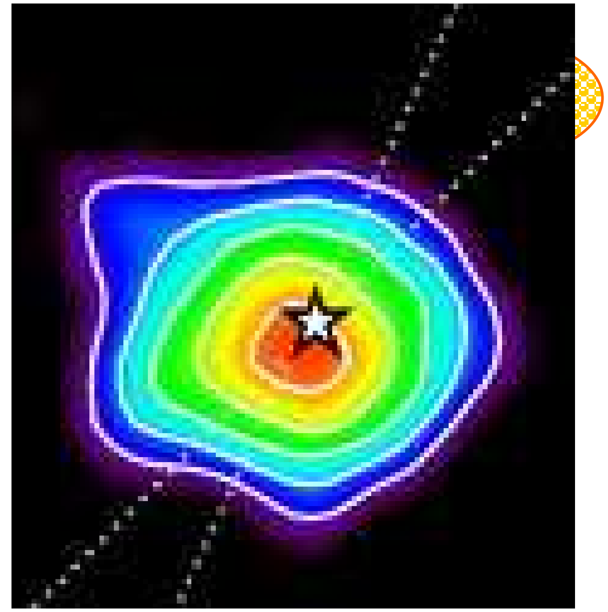
      (…both early K-stars ~ 1 Gyr old)



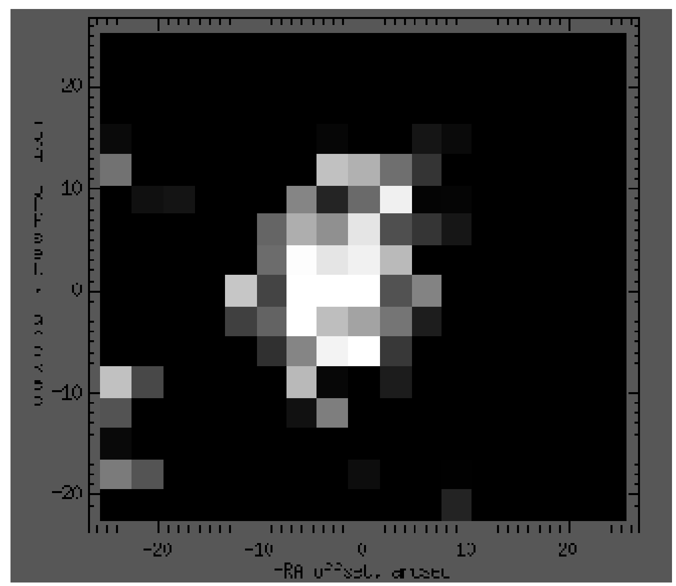
Kalas et al. 2006; Greaves et al. 2005

problems

- submm imaging with single dishes has severe limitations
  - Kuiper Belt at 10 pc subtends only 10"… but this is around the diffraction limit of ~10-30m telescopes
  - very low masses of dust: < 0.01 M_{Earth} … so fluxes in few-mJy regime



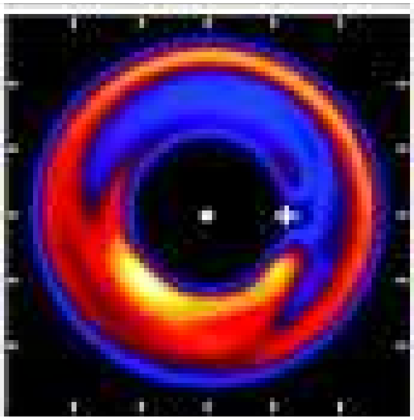
HD 107146 at 28 pc: Williams et al. 2005

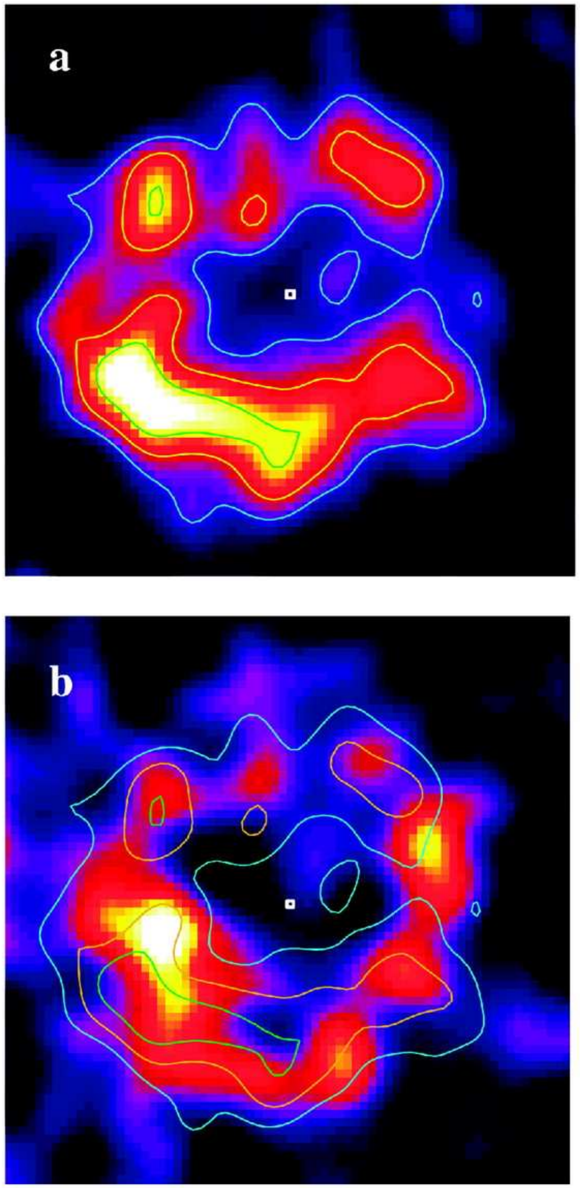


HD 30495 at 13 pc: Greaves et al. 2007

ALMA advantages (1)

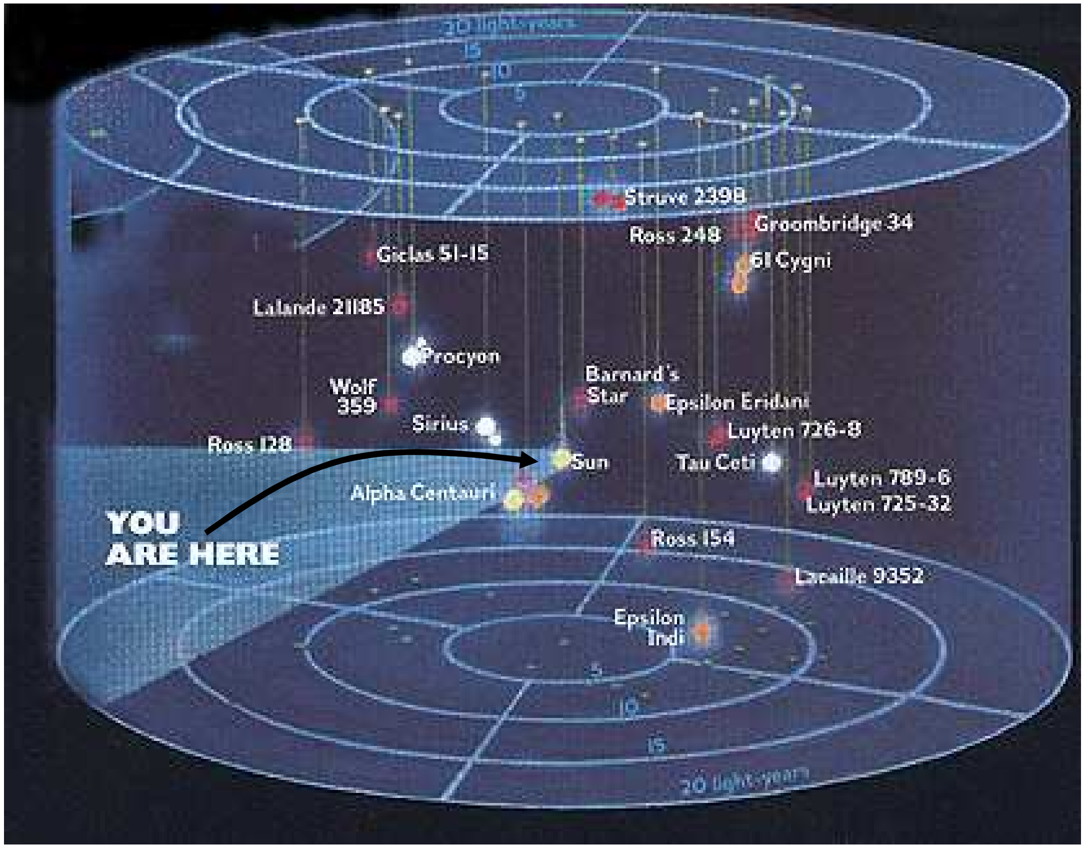
- high resolution
  - unambiguous identification of resonances
    - many clumps possible, e.g. 5:4 resonance would produce 4…
    - distinguish characteristic arcs etc. from background objects





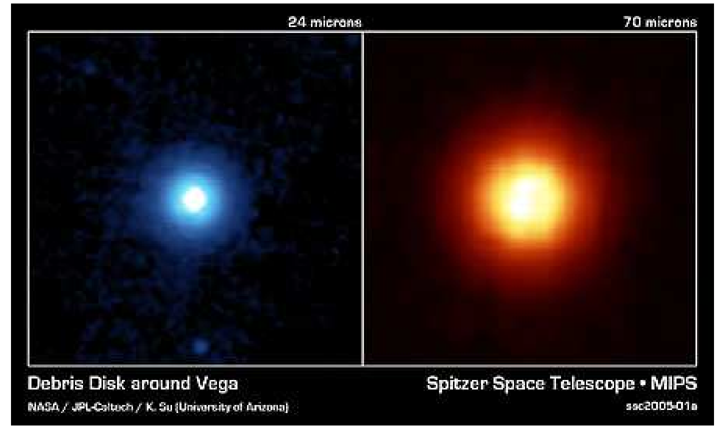
epsilon Eridani at 850 and 450 microns:
Greaves et al. 2005

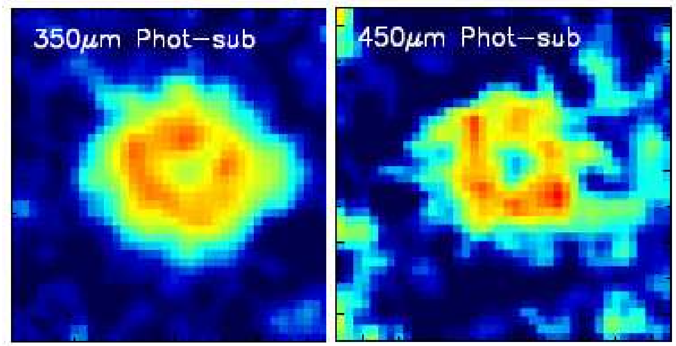
- high resolution also gives good structural data for more distant stars
  - e.g. at the moment, only ~5 debris disks known within 10 pc … highly biased picture!

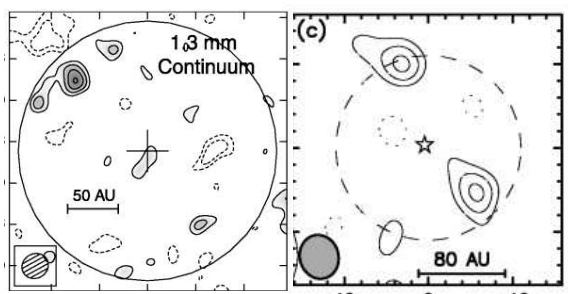


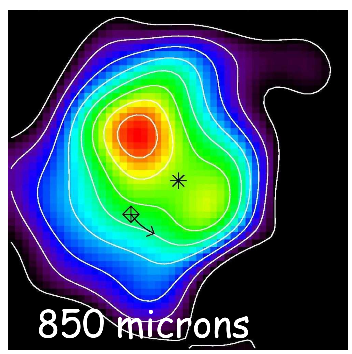
ALMA advantages (2)

- multi-wavelength capability
  - understand dust trapping; full picture of what debris is present





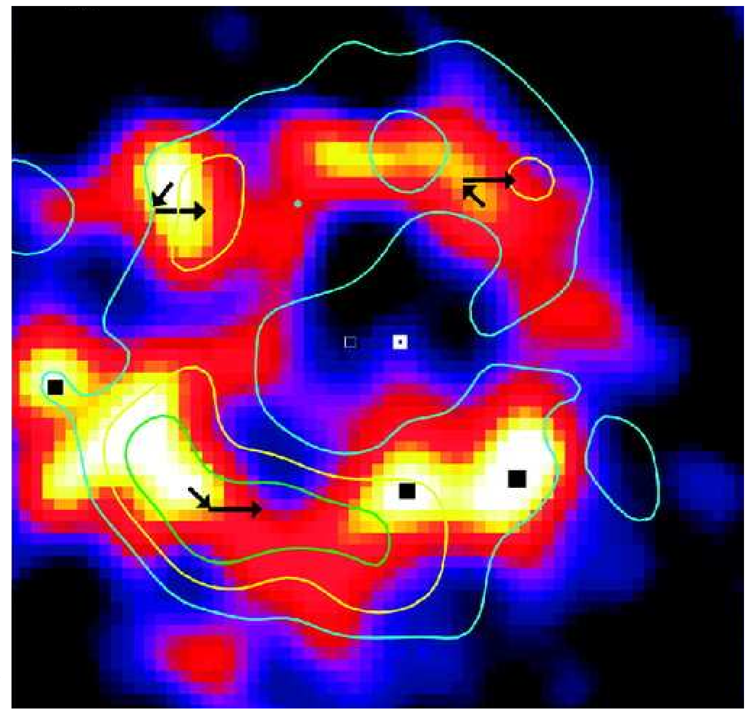




Su et al 2005; Marsh et al. 2006; Wilner et al. 2002; Koerner et al. 2001; Holland et al. 2003, 1998

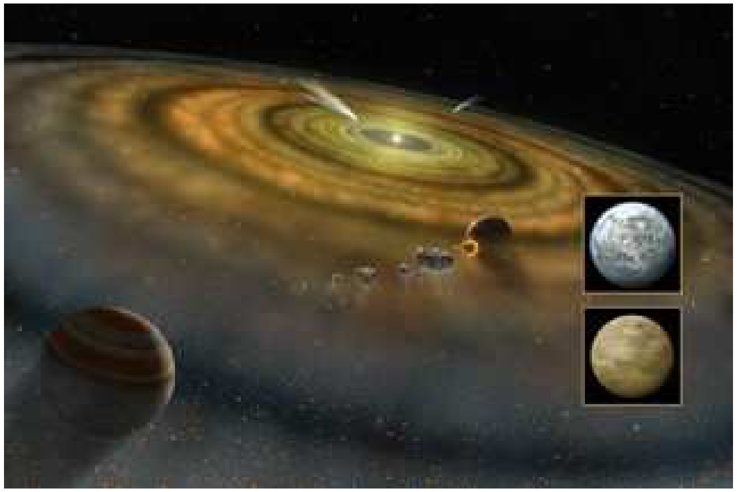
ALMA advantages (3)

- collecting power
  - nearby disks quick to image… repeat observations easy
  - e.g., perturbations co-rotate with planet
    - 2-sigma detection of this effect for epsilon Eridani, over 5 years of observation
    - detectable after ~1 month with ALMA !
  - *opens up new method of planet detection… unique for distant giants*



ALMA advantages (4)

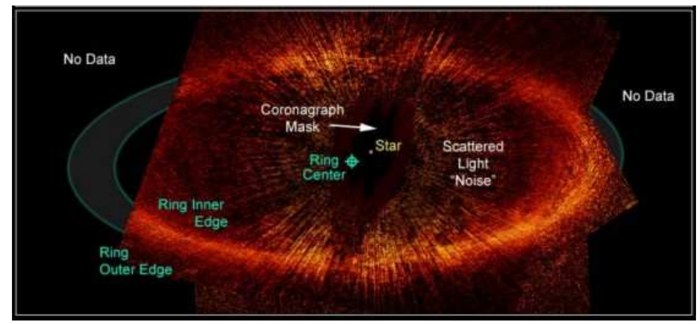
- deep spectroscopy
  – comet collisions should evaporate H_2O, CO etc.
    - limits only so far: e.g., marginally less CO than expected for epsilon Eri, if KBO-like comets
  – method to study exo-comet composition
    - e.g., test models of comets/asteroids delivering ocean water to the early Earth

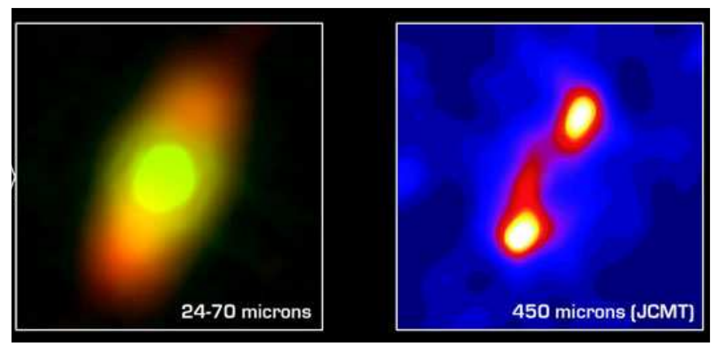


Lynette Cook

ALMA requirements

- long baselines
  - e.g. 0.03" resolution: 1 AU at 30 pc
- mosaicing + sensitivity to all spatial scales
  - closest disks ~1 arcmin in size
    - resolved out unless smaller telescopes and/or total power mode included
- multi-wavelength capability
  - grain trapping seen at ~350 microns longwards, but this varies with stellar luminosity





Fomalhaut: Kalas et al. 2005;
Stapelfeldt et al. 2004; Holland et al. 2003,

ALMA targets

- pathfinder surveys very soon
  - e.g. SCUBA-2 Legacy Survey in 2008-9
    - first unbiased submm survey of nearby stars: what are the origins of debris?
    - 5 stellar types x 100 targets (A,F,G,K,M)
    - approved for 390 hours
  - expect to find ~50 disks for future ALMA imaging!

SCUBA-2 undergoing testing in the laboratory at UK ATC