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
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 resonances > clumps
  – map pointing to planet location

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 $M_{\text{Earth}}$ … 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

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 $\text{H}_2\text{O}$, $\text{CO}$ etc.
    • limits only so far: e.g., marginally less $\text{CO}$ 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
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!