Coronagraph Imaging of Planets and Debris Disks from a High-Altitude Balloon Platform

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Debris disks: signposts of planets, asteroids, and comets

- *Debris disks* are rings of micron-size dust orbiting in the outer regions of planetary systems
- Asteroid and comet collisions, closer to the parent star, are the probable source of the dust
- Radiation pressure pushes this dust outward
- Planets shepherd and sculpt the dust into a ring
- The dust ring is bright enough to be imaged, brighter than the planets themselves
- *So debris disk images are our connection to as-yet unseen planets, comets, and asteroids*
Edgeworth-Kuiper Belt: our own debris disk

• (left) EKOs and dust occupy ~circular orbits just beyond Neptune
• (center) ~1000 EKOs are known, incl. Pluto, but $10^9$ are suspected
• (right) Simulations show that dust must accumulate along with the EKOs, shepherded by Neptune, in 30-50 AU ring
• Pioneer 10 & 11 found dust impacts from 3-50 AU
• Luminosity of EKB is $\sim 10^{-7}$, roughly same as zodiacal light
• Mass of EKB is $\sim 0.1$ Earth

Fomalhaut’s debris disk: ALMA detection

- ALMA detection at 850 µm finds sharp-edged ring at ~140 AU
- Ring width is 13-19 AU
- 2 shepherd planets suffice, with, e.g., each < 3 Earths

Boley et al., *apastroph* (2012)
Fomalhaut’s debris disk: Herschel detection

• (left) Herschel 70-µm image
• (right) Schematic of belt & 2 shepherd planets

**Science from visible & thermal images**

- Thermal flux → # grains * area/grain * $\sigma T^4$
- Thermal spectrum → T → size (star-belt separation, AU)
- Visible image size → location of comet/asteroid source of grains
- Visible image shape → width/warp → shepherd planet locations
- Visible image shift → massive planet
- Visible image brightness → # grains * area/grain * albedo
- Visible image color → type of material, size of grain, weathering
- Visible image numbers → relative history of planetary systems
Imaging telescopes for debris disks

- Ground-based: impossible for all but Fomalhaut (speckles)
- Hubble: limited to handful of bright disks with contrast $> 10^{-7}$
- Spitzer: combined-light thermal photometry only
- JWST: difficult (see next chart)
- Balloon-borne coronagraph: promising (see charts after next)
JWST imaging of debris disks

- (left) NIRCAM occulter 1.25 arcsec radial sombrero, with F480M
- (right) 3-σ envelope to the azimuthally averaged contrast, for no coronagraph (black), and for occulter (colors)
- Result: The contrast & radius of known and expected debris disks is outside the range of sensitivity of JWST

Ref.: adapted from Green et al, SPIE (2005)
Zodiac II: Example of a feasible coronagraph on a balloon platform

We show here the 1.1-m diameter version of Zodiac II.

A mini-Zodiac should have nearly comparable performance.
Instrument

- 1.1-m diameter telescope, for angular resolution and collecting power
- Imaging coronagraph, to keep bright star from flooding disk image: final contrast $10^{-8}$
- Visible wavelength operation, to see reflected light from disk: 500-990 nm
- Four spectral bands, to measure disk color
- Stratospheric balloon platform, to get above Earth’s turbulence: 35 km
- Multi-hour integration times, to capture faint disk images: 4 flights, 25 targets
- No current or planned facility can match Zodiac II on debris disks, by factor of 100
Coronagraph schematic showing optical path and control loops

- The low-order modes are measured by a LOWFS using light reflected off the occulter. These modes are corrected by the LODM.
- The high order deformable mirror is adjusted based on science camera images of the residual speckles.
- Dichroics (D1, D2, D3) split the beam into 4 wavelength bands that pass through individual Lyot stops (LS) before reaching the single science camera.
Focal plane simulation

- Four Zodiac II bands are recorded onto a single CCD camera
- Images are scaled to give 2.5 pixel per FWHM in each image
  - R- and I-band images smaller than the V-band images
- Simulated disk structure (assumed two belts) surrounding a V=6 star
  - 1 hour of -1-minute-long integrations
  - Disk can be seen within each of the circular dark holes
Predicted debris disc sizes and contrasts

- 89 target debris disks for Zodiac II shown in the U-shaped area
  - Complete list derived from Spitzer data
  - Inner angular limit of the U is for V1-band; outer limit is for I-band
- Zodiac II contrast and angular resolution open up a large discovery space
Sensitivity

- SNR per resolution element
- 1 hour integration
- V1 (520 nm) band

Signal-to-noise ratio (SNR) for our target debris disks vs. stellar magnitude and disk contrast
Thank you!

Further references:

