National Aeronautics and Space Administration

Zodiac II

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Debris Disk Science from a Balloon

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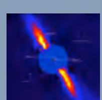
Zodiac II is a proposed telescope-coronagraph system, operating at visible wavelengths, mounted on a balloon-borne gondola in the stratosphere. The science objective is to image debris disks around nearby stars. Debris disks, usually found in the outer reaches of a planetary system, are significant for exoplanet science because (a) they tell us that planet formation did actually get started around a star, (b) they are a contributing source of potentially obscuring dust to the inner part of the disk where we will someday start searching for terrestrial planets, and (c) for a disk with an inner edge, this feature is a signpost for a shepherding planet and thus a sign that planet formation did indeed proceed to completion around that star.

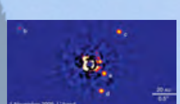
The proposed telescope has a 1.1-m diameter, clear-aperture primary mirror, designed to operate in the cold stratospheric environment. The coronagraph is designed to suppress starlight, including its diffracted and scattered components, and allow a faint surrounding debris disk to be imaged. We will control the speckle background to be about 7 orders of magnitude fainter than the star, with detection sensitivity about one more order of magnitude fainter, in order to comfortably image the expected brightness of typical debris disks. Zodiac II will be designed to make scientifically useful measurements on a conventional overnight balloon flight, but would also be fully compatible with future Long Duration Balloon flights. Zodiac II has a technical objective of advancing the technology levels of future mission components from the lab to near-space flight status. These components include deformable mirrors, wavefront sensors, coronagraph masks, lightweight mirrors, precision pointing, and speckle rejection by wavefront control.

Science Goal

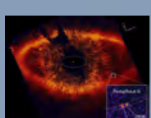
To image planetary debris disks and resolve any structure induced by co-orbiting exoplanets



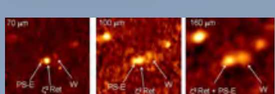
The ~10 AU planet in beta Pic's disk may be driving some of the observed structure, in particular the inner warp. (Lagrange 2009)



The HR 8799 system (4 imaged planets) has an interior asteroid belt and outer Kuiper belt analog. (Marois 2010)



Fomalhaut's dust disk is shepherded by an eccentric (imaged!) planet that creates a well-defined offset ring. (Kalas 2008)

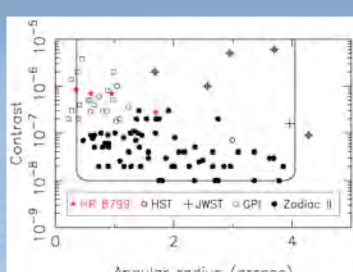


Herschel far-IR images of zeta2 Ret showing strong asymmetry consistent with an eccentric planet at ~80 AU. (Eiroa 2010)

- Images of debris disk structure – gaps, rings, offsets, warps, and clumps – provide evidence for the locations of faint planets embedded within brighter disks.
- Zodiac II will directly image debris disks around nearby stars, revealing the dust present at angular separations of 0.4 - 4 arcsec.
- These images will probe closer to the parent star and at a better contrast ratio than is currently possible from ground or space (raw contrast of 10^{-7}; an order of magnitude better after speckle subtraction).

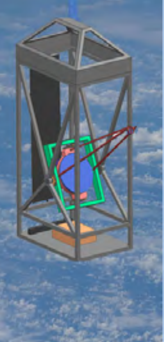
Debris disks and planets are intimately related:

- All three of the stars with imaged planetary systems also host prominent debris disks.
- The planets in those systems directly sculpt the disk structure through gap clearing and ring shepherding.
- The planet orbiting Fomalhaut was successfully predicted based on its Spitzer IR image. The expected disk eccentricity was confirmed by HST.
- Herschel is marginally resolving many debris disks at far-IR wavelengths, many with similarly asymmetric profiles.
- Visible-light observations have ~100x better resolution, but currently lack sufficient contrast to image most disks discovered by Spitzer and Herschel.



Detection Limits

The post-processing contrast floor for Zodiac II is shown as a function of angular separation (solid line). The 89 potential targets for Zodiac II, derived from Spitzer data, are shown as solid circles. Some other targets for past and future ground and space instruments are also shown. The detected giant planets orbiting HR 8799 are shown as red stars.



Technical Goal

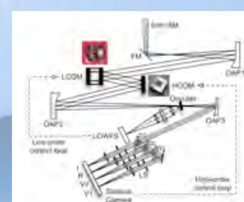
To advance imaging technology in preparation for direct imaging of Earth-like extrasolar planets

Zodiac II will have a 1.1-m clear-aperture, off-axis primary mirror made of light-weight, thermally-stable SiC, controlled to room temperature. Its high-performance coronagraph will contain fine guidance controls which, combined with new gondola pointing systems, will provide the PSF stability required to reach a speckle contrast level of 10^{-7}.

The Coronagraph

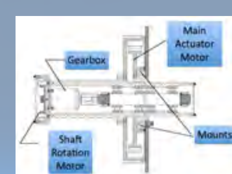
A coronagraph design has been developed based on results from JPL's High-Contrast Imaging Testbed (HCIT) and from the ACCESS mission concept study.

- Band-limited Lyot coronagraph
- Imaging in 4 wavelength bands using dichroics
- Low-order wavefront sensing (LOWFS) with 5 mas rms
- Xinetics 48x48 deformable mirror (DM)



Optical path through the instrument, showing the low-order and high-order DMs, LOWFS and dichroics splitting the 4 color band images on the CCD

Coronagraph schematic



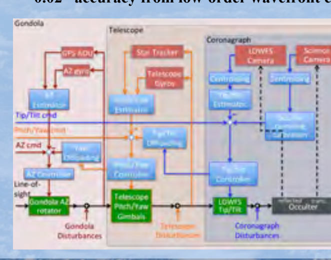
WASP continuous rotation bearing

The left motor provides constant slow rotation. The main motor (center) drives the main load.

Attitude Control System

The ACCESS mission concept study included detailed calculations on the effect of beamwalk on the coronagraph. 10^{-7} contrast requires 20 mas pointing.

- 0.25″ accuracy from telescope pitch/yaw pointing using constantly rotating bearing shafts to avoid static friction (WASP - Wallops Arc-Second Pointing)
- 0.02″ accuracy from low-order wavefront correction within a fine guidance loop.



Fine Guidance Loop

The LOWFS picks off the star image from the telescope and records it on a dedicated camera. The image centroid is sensed and sent to the tip-tilt stage of the LODM for centering. Low-order wavefront error is sensed by a Shack-Hartmann and fed back to the LODM. The wavefront error that generates speckles in the science camera is sensed in the science focal plane and fed back to the 48x48 HODM for correction.

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