DIREx: Direct Imaging Reconnaissance of Exoplanets

Astrophysics (astrobiology); Planetary Science

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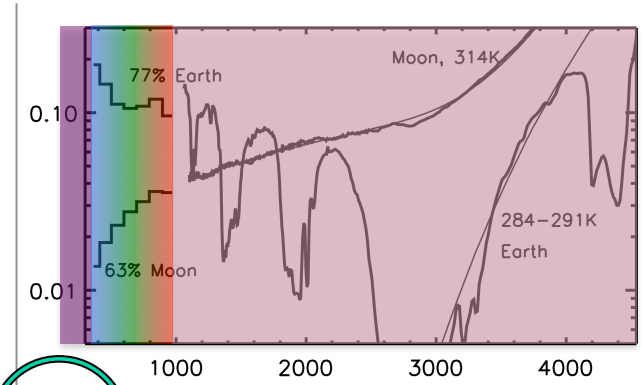
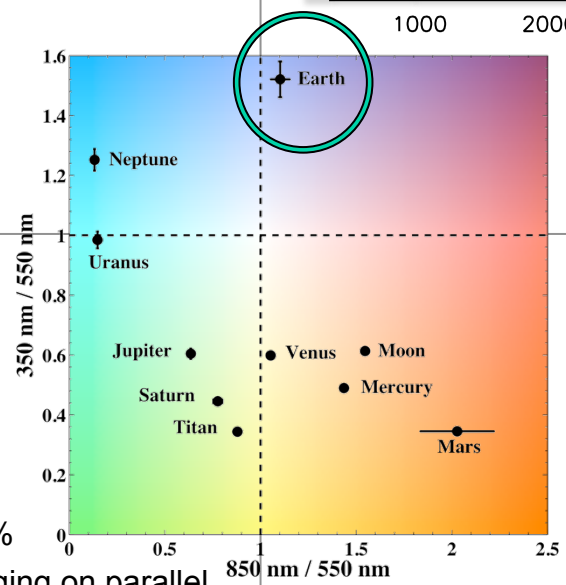
Visible-light direct imaging of nearby stars to identify and categorize substellar/exoplanet companions.

Follow-up detection with visible-NIR spectroscopy to characterize atmosphere, surface, temperature.

Solar system science: KBO detection, multiwavelength occultation photometry, remote spectroscopy of atmospheres (e.g., giant planet H_3^+ auroral emission) and surfaces (e.g., hydration features, mineral identification).



EPOXI measured visible photometry and NIR spectrum of Earth.
3-color photometry efficiently sorts solar system bodies. IR spectroscopy characterizes composition, color temperature.



Livengood *et al.* 2011; Crow *et al.* 2010

Description:

- Visible-light direct imaging
  - psf ~0.05" @ 500 nm
  - 1AU projects to ~14psf at α Cen
  - psf projects to ~1AU at ~20 pc
  - 20 pc volume encloses >3000 stars
- Broadband reconnaissance, Δλ/λ=10–25%
- Cascading dichroics for multispectral imaging on parallel detector arrays – simultaneous, efficient, automatically registered, cross-check for cosmic-ray identification
- High dynamic range enabled by pixel-addressable imaging array – rapid readout on bright targets, long integration on faint targets.
- Spectroscopy resolving power <1000.
- Reconnaissance of human exploration targets.

Value to NASA:

Optical criteria to categorize exoplanets for deeper investigation – short wavelength for better diffraction limit.

Near-IR criteria for follow-up investigation – establish presence of atmosphere, broad compositional information to distinguish exo-Mars from exo-Jupiter from possible exo-Earth.

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The POC and collaborator are planetary scientists with 20+ years' experience in spectroscopy of planetary atmospheres from ground- and space-based platforms. The collaborators were named co-investigators on the EPOXI mission. The POC led the effort to observe Earth and Mars as model exoplanets.

Category: Astrophysics (Astrobiology) and Planetary Science

Direct imaging reconnaissance of exoplanets is a capability that has just begun to be achieved from the ground. Even with adaptive optics, however, it is very difficult to accommodate observations through the Earth's atmosphere with sufficient image stability and signal-to-noise to detect planets through imaging, and information to definitely characterize planets as gas giants, solid bodies, etc., is limited. Recent observations by the EPOXI mission have shown that low spectral-resolution visible photometry of solar system bodies is sufficient to sort them into quadrants of a color-color diagram in which Earth is uniquely isolated into its own quadrant. Near-IR spectroscopy, which has not previously been considered highly diagnostic for exoplanet atmospheres, draws a clear distinction between Earth, Mars, and the Moon. We propose that these capabilities should be integrated into a mission using the large space optics telescopes for an investigation of stars within ~20 pc, at which range the diffraction limit is equal to ~1 AU.

The rapid pace of discoveries from the Kepler mission have made it clear that planets are not rare, and thus the approximately 3000 stars within 20 pc will host several thousand planets. Direct imaging is indifferent to the inclination of the orbital plane. A reconnaissance survey of the nearest several thousand stars can establish critical criteria for the next generation of exoplanet investigations, without requiring a prior investment in risky technologies.

The 20 pc limit is approximate, based on the projected angular separation of a planet at 1 AU orbital radius, which is 0.05 arcsec at 20 pc, corresponding to the diffraction limit (Rayleigh criterion) of a 2.4 m telescope at 500 nm. A minimum of three wavelengths is required to sort out planets according to the criteria determined from EPOXI, 350, 650, and 850 nm, having somewhat different diffraction limits. Follow-up observations in the 1-5 µm range can further distinguish between target objects. The presence of strong water bands in Earth's atmosphere, for example, distinguishes it from Mars and Venus; CO2 features distinguish Mars and Venus from the giant planets. A survey of the nearest several thousand stars will establish a measure of the diversity for which the next generation of exoplanet observatories must prepare.

The capabilities that we propose to apply to exoplanets are derived from successful observations within our own solar system. These capabilities will continue to be useful in planetary science. Space-based spectroscopy of the Moon from EPOXI detected hydration features that were unobservable from the ground and discovered a hydration cycle that isolates hydration at the

lunar terminator. The proposed spectroscopic capability will be able to detect similar features in asteroidal bodies. Simultaneous multicolor imaging will be useful for time-resolved events such as stellar occultations by planetary atmospheres, requiring short integration times. The proposed instrumentation is similar in wavelength capabilities to the instrument payload of Deep Impact, designed from comet investigations. The wide field of view and high magnification available with the large space optics telescopes will enable similar observations of many comets from a remote vantage.

Approach:

For the visible-light component, we propose a system to observe three wavelengths simultaneously, using a system of cascading dichroic filters to deliver the telescope image to separate co-registered detectors operating in parallel. Each arm of the system can be equipped with narrowband filters to further refine the range for other astrophysical or planetary observations. Imaging planets near to a star poses a problem in dynamic range. We propose using Charge-Injection Device technology rather than CCD's. CIDs are pixel-addressable so that pixels can be read nondestructively. Pixels in bright portions of the field can be reset rapidly (e.g., milliseconds), while dim portions of the field can be reset on longer time scales (e.g., 1000's of seconds) for high dynamic range and no bleeding of signal between pixels. Cascading dichroic systems already are commercially available in consumer-level camera systems.

The near-IR system needs to operate to at least 4 micron, and preferably to 5 micron. This range captures the 3.4 micron band of methane, important to distinguishing the presence of methane in, e.g., giant planet atmospheres or in a possible equivalent to early Earth. Only modest spectral resolving power is required, of order $\lambda/\Delta\lambda \sim 200$. The region from 1 to 2.5 micron is highly diagnostic of the presence of substantial water vapor in Earth's atmosphere, which is unique within the solar system but may not be unique everywhere.