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SOFIA - Science Potential for Extrasolar Planet Research

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Abstract. The joint U.S. and German Stratospheric Observatory For Infrared Astronomy (SOFIA) project to develop and operate a 2.5-meter infrared airborne telescope in a Boeing 747-SP is now well into development. The telescope was delivered to the U.S. in September 2002 and will be integrated into the aircraft in early 2003. First science flights will begin in late 2004. Once fully operational the observatory will do 960 observing hours/year, with an expected lifetime of over 20 years. We give an overview of the characteristics of the observatory and its first suite of nine instruments, three of which are facility instruments, five are principal investigator instruments and one is a specialty instrument.

1. Introduction

SOFIA will fly at and above 12.5 km, where the typical water vapor column density is $\leq 10\ \mu$m and where $\sim 80\%$ of the atmosphere is transparent. The telescope will be diffraction limited at wavelengths longer than 15 μm; for example at 100 μm this corresponds to a beam size of $10''$, and we estimate that the background limited NEFD in a 30% band should be ~ 400 mJy/$\sqrt{\mathrm{Hz}}$.

We anticipate that at least four of the SOFIA science instruments will be used for studies of extrasolar planets, but note that instrument upgrades and the addition of new instruments are likely to further advance the studies of extrasolar planets. HIPO, our specialty instrument - a fast CCD camera, which can be co-mounted with FLITECAM, our near IR imager, will do high precision photometry of transits of extrasolar planets. The combination of HIPO and FLITECAM is also ideally suited for transit measurements of extrasolar giant planets. FORCAST, our mid-IR facility camera and HAWC, our FIR facility camera, will be used to image debris disks and protoplanetary disks, which may provide indirect evidence for the existence of extrasolar planets.

2. HIPO Photometry of Transits by Extrasolar Planets

In 1995 the discovery of a giant planet orbiting the star 51 Pegasi in an extremely tight orbit was announced Mayor & Queloz (1995). Subsequent realization that this was the first of a class of similar planets led to the expectation that a planet of this type would soon be found with an orbital inclination suitable to show transits. This expectation was fulfilled with the discovery of transits in HD209458 (Charbonneau, et al. 2000; Henry et al. 2000). The recently approved Kepler mission (Koch et al. 1998; Borucki et al. 2003) will result in discovery of many transiting planets with sizes as small as the Earth, or even smaller in favorable cases. Long-term follow-up transit photometry of Kepler objects as well as additional Doppler objects that show occultations will be very valuable. Secular accelerations and changes in certain orbital elements caused by perturbations from other planets in a particular system will cause observable drifts in transit times.

Photometry with a precision of 5 mmag is sufficient to provide an estimated density for a giant inner planet given a mass from radial velocity data. High precision photometry obviously allows planetary diameters to be measured for smaller planets, and also for rings and satellites of giant inner planets (Brown et al. 2001). Precise photometry will also show evidence of perturbations on the planetary orbit sooner than would be possible with lower precision data. Photometry with SOFIA has several advantages over ground-based photometry:

- Scintillation noise will be very low. Extrapolating a commonly used ground-based model (Dravins et al. 1998) to stratospheric altitude indicates a scintillation noise floor of 4×10^{-5} in 15 minute integrations. The fact that SOFIA operates above the tropopause suggests that this model will break down, suggesting that there will in fact be less scintillation noise.

- Reliably low and very stable extinction coefficients, including almost complete freedom from clouds and fog.

- The ability to use deployments to provide optimized, uninterrupted observing windows up to 12 hours long.

These advantages will help provide very stable and precise photometry over the duration of most transits. It is important to understand that a transit observation is fundamentally differential in nature. One must only detect the time variation of the target star relative to other stars in the field - calibration to a standard photometric system is not required. Many of the lessons learned during the Kepler mission's laboratory test demonstration (Koch et al. 2000; Jenkins et al. 2000) can be applied to SOFIA photometry. Taking all these factors into account, we expect to obtain photometric stability close to the fundamental scintillation and shot noise limits. This will allow routine follow-up observations of many of the Kepler planetary system discoveries.

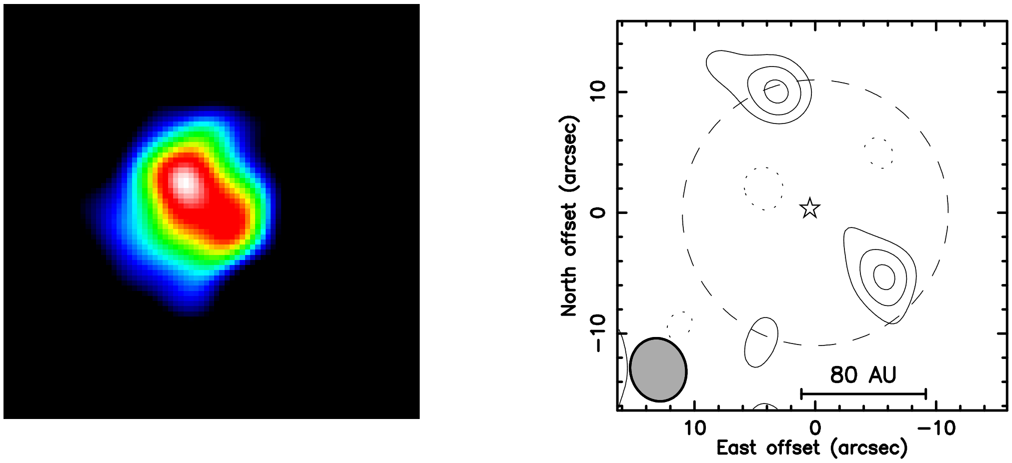

Figure 1. Above we show a SCUBA image of Vega (Holland et al. 1998) and the high resolution PdB image at 1.3 mm from Wilner et al. (2002) focussing in on the central area of the SCUBA image. The high resolution 1.3 mm image resolves the dust emission into two blobs, but with rather low S/N. SOFIA can do much better and the well-known debris disk stars will be prime targets for first light observations.

3. Occultations with HIPO and FLITECAM

FLITECAM (1 - 5 μm), when co-mounted with HIPO, will allow occultation observations over the whole wavelength range from 0.3 to 5 μm. In the 2 to 5 μm region FLITECAM will provide very high signal to noise for the same reasons as discussed for HIPO. Observations in this wavelength regime include potential strong atmospheric bands due to CH_4 and water in the planetary atmosphere (Seager & Sasselov 2000).

4. FORCAST and HAWC - Debris Disk Imaging

FORCAST, our mid-IR camera, and HAWC, our FIR camera, will not have the sensitivity to directly detect extrasolar planets, but they can image debris disks and protoplanetary disks to look for indirect evidence for planets, like asymmetries and gaps in the disk, which signal the presence of a planet (see e.g., Wyatt et al. 1999). The dust which surrounds main sequence stars is cold and peaks at wavelengths > 30 μm, which means that it is very difficult to observe from the ground. Observations in the 30 – 200 μm regime are essential for determining the dust temperature and dust properties like emissivity and particle size.

Spatial resolution is essential! Both FORCAST and HAWC can image the well-known debris disks (Vega, Fomalhaut, β Pic, and ϵ Eri) with higher spatial resolution and fidelity than what has previously been possible in the mid- and far-infrared. With FORCAST a 1 hr integration will yield a $S/N > 5$ per pixel at 38 μm for all of them except the cold ϵ Eri disk. SCUBA images of debris disks at 850 μm show clear asymmetries in the dust distribution for both ϵ Eri (Greaves et al. 1998)) and Vega (Holland et al. 1998), which could be caused by jupiter sized planets.

5. Circumstellar Dust in Extrasolar Planet Systems?

For circumstellar dust in extrasolar planet systems one really needs high spatial resolution to ensure that any excess emission is related to the planetary system and not due to nearby background sources; see e.g., Jayawardhana et al. (2002) for 55 Cancri, where the ISO 60 μm excess has now been shown to be due to background sources. Even though SIRTF will have better sensitivity than SOFIA, it will be important to follow-up SIRTF detections with the higher spatial resolution that only SOFIA can provide.

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