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Observing Exoplanets with SOFIA

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SOFIA

Fig. 1: SOFIA is a NASA partnership with the German Space Agency (DLR) to develop a Boeing 747SP airliner fitted with a 2.7-meter reflecting telescope. SOFIA is the largest airborne observatory in the world, and has had its first light observation in May 2010. On this poster we present the prospects of SOFIA in the field of extrasolar planets.

On this poster we present the prospects of the Stratospheric Observatory for Infrared Astronomy (SOFIA, fig. 1) in the field of extrasolar planets.
A careful analysis showed that the huge group of **photometric and spectrophotometricfollow-up observations during planetary transits and eclipses (see fig. 2) will be feasible with SOFIA's instrumentation, especially with HIPO-FLITECAM.** SOFIA's unique advantages using this technique and two example science cases are presented in this poster.

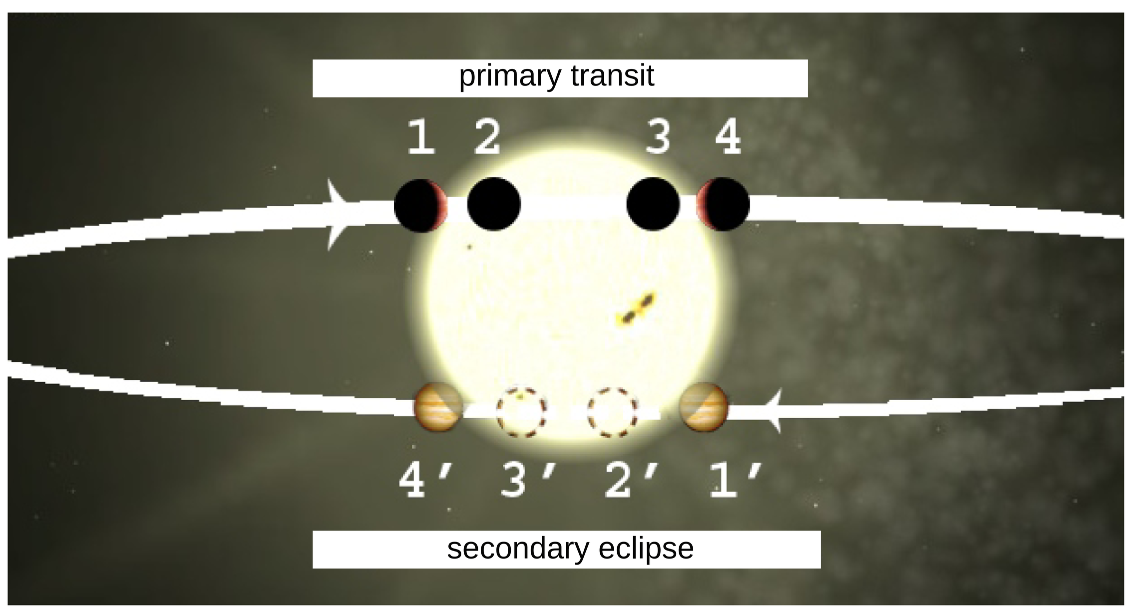

Fig. 2: Planetary systems with mutual eclipses of the star and the planet offer two opportunities for transit observations. In primary transit the planet occults the star, while in secondary eclipse the planet disappears behind its host star. During the two important orbital phases, the primary transit and secondary eclipse, distinct parts of the atmosphere may be studied.

Advantages

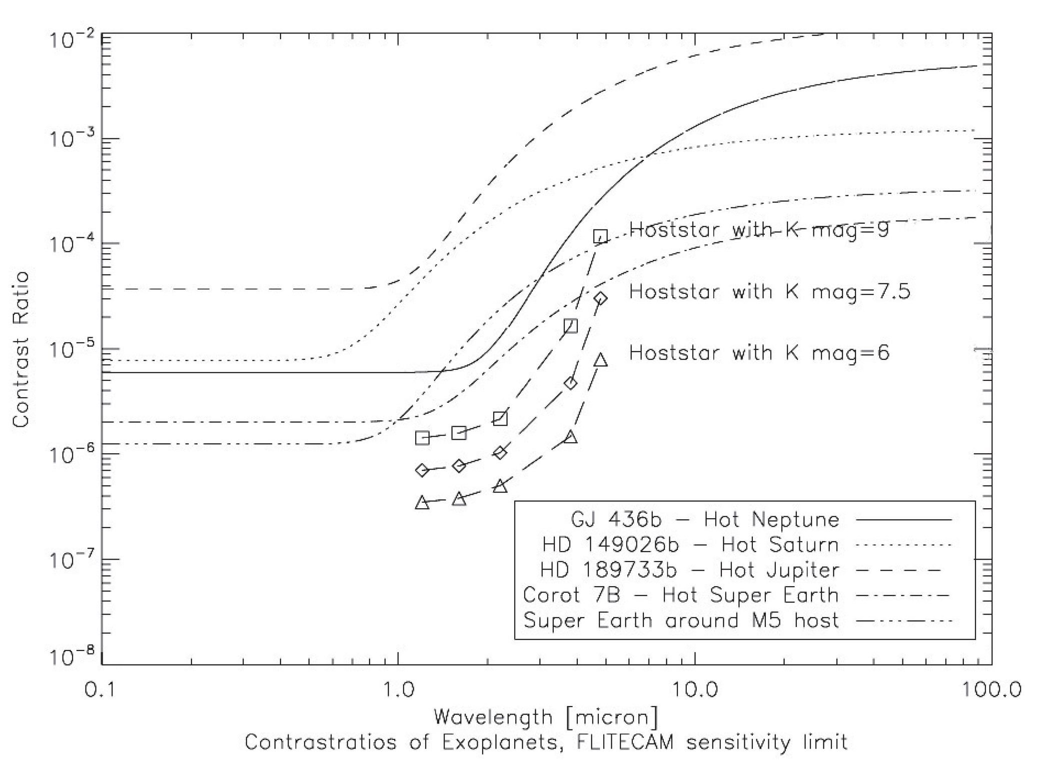

Fig. 3: Expected contrast ratios for different 'prototypes' of extrasolar planets. (See legend for details). From this perspective SOFIA operates in the optimal wavelength regime for exoplanet observations. The symbols in the center show the photon/background-noise limit for a 60 minute observation in the 5 imaging bandpasses of the FLITECAM instrument assuming host stars with apparent K magnitudes of 6, 7.5, and 9 (triangles, diamonds, squares). The figure shows that the noise limits are well below the contrast ratios for most of the targets. Thus reasonable S/N ratios even in low resolution spectroscopy mode can be expected.

SOFIA, the "Stratospheric Observatory for Infrared Astronomy" is a joint project of the Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR; German Aerospace Centre) and the National Aeronautics and Space Administration (NASA). It is funded on behalf of DLR by the Federal Ministry of Economics and Technology grant 50 OK 0901 based on legislation by the German Parliament the state of Baden-Württemberg and the Universitaet Stuttgart. Scientific operation for Germany is coordinated by the German SOFIA-Institute (DSI) of the Universität Stuttgart, in the USA by the Universities Space Research Association (USRA).The development of the German Instruments is financed by the Max Planck Society (MPG) and the German Research Foundation (DFG)

Advantages

Even the very close-in extrasolar planets, with distances to their host star of only a few stellar radii, are not much hotter than T ~ 2000 K. Therefore the equivalent black-body emission always peaks in the infrared. From this perspective **SOFIA operates in the optimal wavelength regime for exoplanet observations** (see fig. 3 for various targets).

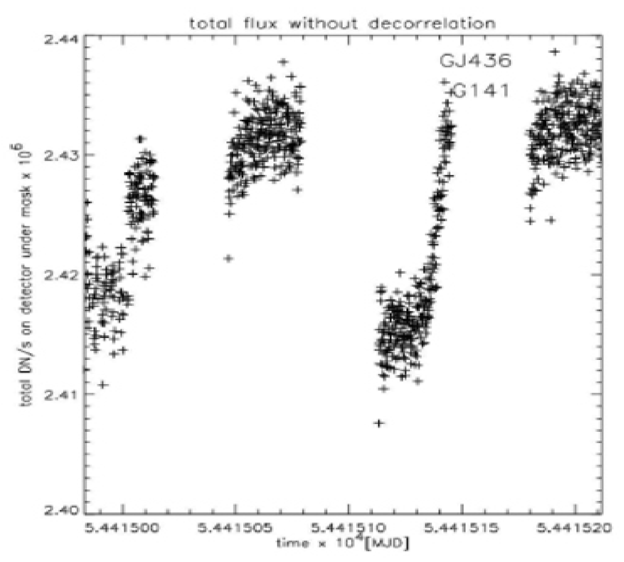

Fig. 4: Example for a photometric time-series observation of a transit of the Hot Neptune GJ 436b with HST-NICMOS. The Hubble space telescope is limited to series of 96 minute on/off-target batches due to its near-earth orbit.

For short-period close-in transiting planets with transits occurring every 2-4 days, the optimal observing schedules for ground-based transit observations are reduced to only few nights per year for a given observing site as the event is best observed close to target culmination and local midnight. For the Hubble Space Telescope (HST) the situation is reversed: It is able to observe transits at many more opportunities but is limited to series of 96 minute on/off-target batches due to its near-earth orbit (see fig.4). Especially for transiting planets with a very long orbit (such as HD80606, see science case) and therefore long transit durations this presets a substantial hurdle. The analysis of potential flight schedules (see fig. 6 as an example) shows that the mobile platform **SOFIA will be able to take off close to the optimal geographic location for each of those events and will be able to observe the complete event continuously** and with a very stable setup (telescope elevation, airmass etc.).

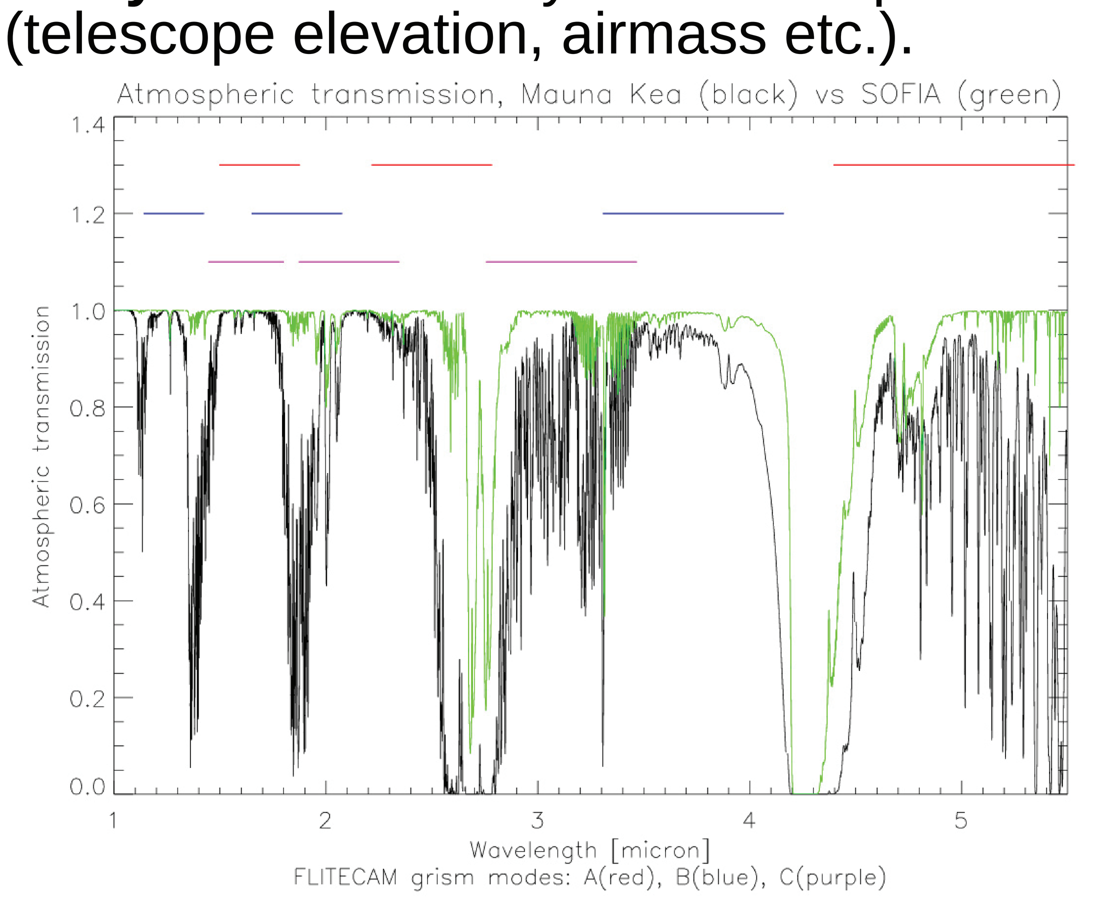

Fig. 5.: Comparison of the atmospheric transmission on Mauna Kea (black) and at SOFIA's service ceiling (green). The flight level will place the nstrument above most of the earth's atmospheric absorption of telluric trace gases that are also present in the observed exoplanet's atmospheres. The red, blue and purple lines show the possible orders/filters for the 3 FLITECAM grisms.

The variability of earth's atmospheric transmission as well as the temporal variability of its constituents is the most crucial challenge in ground-based transit observations, in particular when it comes to the spectroscopic analysis of molecular features in the exoplanet's atmosphere that are also present as telluric trace gases. Again, SOFIA will also deal very favorably with these effects since it will be **able to fly high enough to be independent of near surface processes affecting in particular the water and methane lines** (see fig. 5) .

Science Cases

With HIPO and FLITECAM, SOFIA is well equipped with two (especially in combination) perfectly suited instruments for (spectro-)photometric transit observations. One of the **advantages of HIPO-FLITECAM is the ability to observe simultaneously in the optical and the IR** with a dichroic beam splitter. It is for example possible, to get an independent broad-band lightcurve from HIPO at optical wavelengths (e.g to exclude or trace stellar activity such as starspots) as a calibrator for the spectroscopic data analysis with FLITECAM in the infrared.
Here two example observations using HIPO-FLITECAM on board of SOFIA are described in detail to provide the reader with a better impression about the feasibility of such projects.

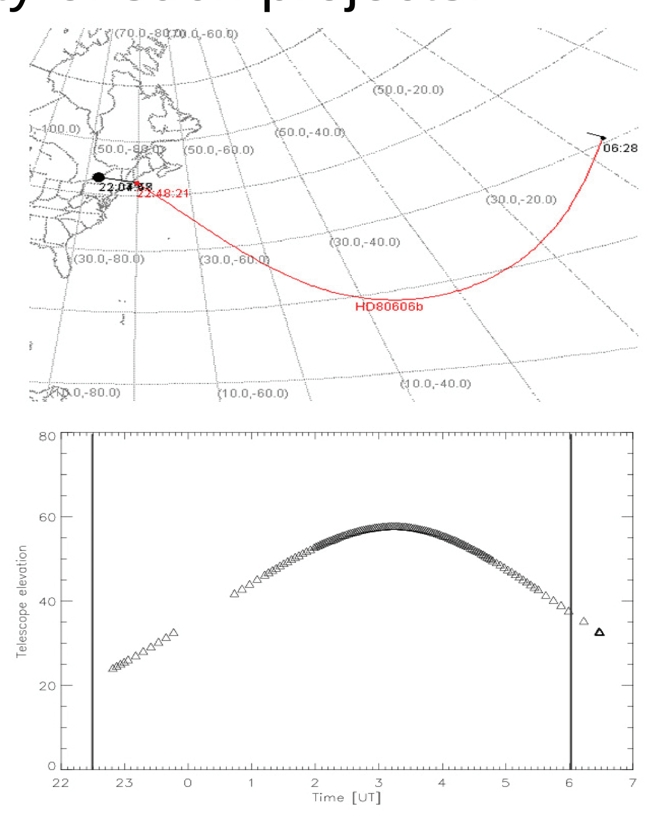

Fig. 6: Example flight plan for a SOFIA observation of a HD 80606b transit in January 2010. During a flight from Northern America to the Canary Islands (top) SOFIA is able to keep the star within the observable elevation range for the telescope, i.e. above 20 deg and below 60 degree, for more than 8 hours (bottom).

The HD 80606b project is meant to be an example for observing long-period transiting planets with transit durations of more than 6 hours. The extremely long 12 hour transit of HD80606b is hard to cover completely, since it exceeds SOFIA's maximum flight duration. But for candidates with 6-8 hour transits, long periods and therefore rare observing opportunities the **SOFIA timing and mobility advantage** is obvious (see fig. 4 and 6).

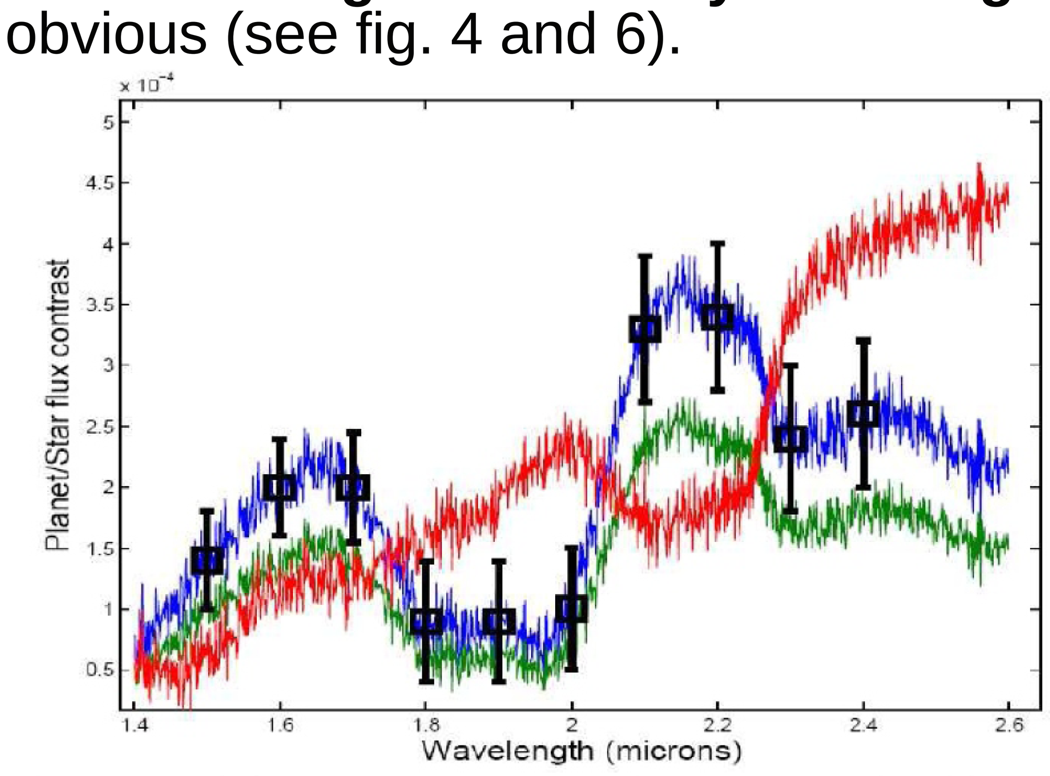

Fig. 7: Model contrast-spectra of HD 149026b with two classical (chemical equilibrium, no inversion) emission spectra that assume no (blue) and reasonably efficient (green) transport of the energy deposited by stellar insolation. The red model assumes a volatile high altitude absorber causing a deep temperature inversion, whereby the spectral bands of water and CO appear in emission. FLITECAM on board of SOFIA is operating in the crucial wavelength region (between H- and K-band), that is not observable from the ground due to water absorption. Observations at a spectral resolution of R~20 with a S/N ration of 10^-4 per spectral channel to distinguish between the models are feasible (compare to fig. 3).

HD 149026b can serve as an example for NIR spectrophotometry of the Hot Jupiter and Hot Saturn class (see fig.7). **FLITECAM on SOFIA can become an important tool for characterization observations** of such kind in the sample of known and still to be discovered CoRoT and KEPLER transiting exoplanet types.