Occulting Ozone Observatory Science Overview
SPIE Astronomical Telescopes and Instrumentation

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Why O₃?

- There is great interest in directly imaging exoplanets down to Earth size.
- Previous mission concepts (TPF-C/I, THEIA, NWO, etc.) are mostly flagship class.
- These are very expensive, require completely new hardware, and in some cases, new launch systems.

Can a smaller/cheaper mission produce useful science data?

See:

- 7731-87 - Shaklan et al., *Error budgeting and tolerancing of starshades for exoplanet detection*
- 7331-187 - Pravdo et al., *Orbiting starshade’s performance in observations of potential Earth-like planets*
- 7731-190 - Sirbu et al., *Performance verification for stationkeeping control of O₃*
- 7731-191 - Thomson et al., *Occulting Ozone Observatory starshade design and development*
Outline

1. Observatory Design

2. $O_3$ Science

3. Mission Simulations
**O₃ Telescope**

- 1 to 2 m aperture telescope, based on ITT 1.1 and 1.5 m NextView Telescopes
- 2 reflections in telescope + 4 reflections in instrument
- Al plus MgF₂ coating
- Most of repositioning done with telescope spacecraft
  - Use pair of arcjet thrusters (600 s $I_{sp}$, 500 mN thrust)
  - Average of 16 days to next target, 8 days to change occulter/telescope separation

**Table: O₃ filters.**

<table>
<thead>
<tr>
<th>Filter #</th>
<th>Blue</th>
<th>Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.25 - 0.31</td>
<td>0.5 - 0.7</td>
</tr>
<tr>
<td>2</td>
<td>0.31 - 0.4</td>
<td>0.7 - 0.9</td>
</tr>
<tr>
<td>3</td>
<td>0.4 - 0.48</td>
<td>0.9 - 1.1</td>
</tr>
<tr>
<td>4</td>
<td>0.48 - 0.55</td>
<td>Narrowband</td>
</tr>
</tbody>
</table>
O₃ Occulter

- 34 m diameter occulter with 6.5 m petals
- Geometric IWA of 90 mas - 38960 km separation for Blue band, 19480 km separation for Red band
- Petals are wrapped about bus for launch - unfurl and rigidize when deployed [Thomson and Lisman, 2010]
- Telescope and Occulter fit into existing 5 m fairings
- Provides $1 \times 10^{-12}$ suppression at telescope image plane at IWA [Shaklan et al., 2010]
Outline

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Time Resolved Photometry

- For nearest targets, can infer rotational period from photometric variation [Palle et al., 2008]
- Can produce binned light curves showing changes in photometry over one day [Fujii et al., 2010]
Light curves yield trajectories on color-color diagrams, indicating different ground cover types [Kawahara and Fujii, 2010]
Photometric variations between bands allow for inferences about atmospheric composition and ground cover.

Even small amounts of ozone are detectable by contrasting first two blue bands [Anderson et al., 1969, Schachter, 1991]
Other Science

- **Orbit Determination**
  - Will be able to determine whether planet is in HZ with 4 or more detections, and constrain orbital elements
  - See [Pravdo et al., 2010]

- **General Astrophysics**
  - At least 50% of mission time will be available for non-exoplanet observations
  - Perfect for wide field observations in the optical and near-UV
Outline

1. Observatory Design
2. O₃ Science
3. Mission Simulations
$O_3$ Configurations

All Detections

Unique Detections

Blue Band Photometry

Blue and Red Band Photometry

Savransky et al. (Princeton, JPL, & Univ. of Tokyo)
Higher burn portion decreases mission duration with a relatively small loss in number of detections
Multi-planet Systems
Multi-planet Systems
Multi-planet Systems
Solar System Analogues

**Figure:** If every target system with planets observed by O3 was a solar system copy:
(a) Number of detections of each planet analogue scaled by total number of detections.
(b) Number of detections of each planet analogue that could be in HZ, scaled by total number of detections.
Solar System Analogues (cont).

Figure: Average number of analogues classified by probabilistic algorithm as unique (40% error rate). The squares indicate the average number of each analogue type that was included in the simulations.
Conclusions

- It is possible to design a direct-detection exoplanet observatory significantly smaller than a flagship mission scale.
- O_3 will be able to detect Earth-size planets and photometrically characterize them.
- We can expect to find on the order of 5 Earth-twins if η⊕ = 0.3.
- Over 50% of the mission time will still be available for general astrophysics.
- We have demonstrated a method for assigning probabilities to whether repeat detections represent the same planet as was previously observed.
References

Spectra of Venus and Jupiter from 1800 to 3200 Å.
*Journal of Atmospheric Sciences*, 26:874–888.


Global mapping of earth-like exoplanets from scattered light curves.

Identifying the rotation rate and the presence of dynamic weather on extrasolar earth-like planets from photometric observations.

Orbiting starshade’s performance in observations of potential earth-like planets.
In *Proceedings of SPIE*, volume 7731.

Ozone absorption bands in the 3100 Å - 3400 Å region.

Error budgeting and tolerancing of starshades for exoplanet detection.
In *Proceedings of SPIE*, volume 7731.

Occulting ozone observatory starshade design and development.
In *Proceedings of SPIE*, volume 7731.
Target Lists

All Detections

Unique Detections

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