Astrometry and Direct Detection

ExoPAG-2

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Questions To Answer

1. Do astrometric precursors help increase the science yield of direct detection missions?
2. Are astrometric precursors required for direct detection mission success?
3. Will orbit fits from astrometry/RV be useful for timing planet observations?
4. Will orbit fits from astrometry/RV be useful for direct detection confirmation?
5. What is the probability that a direct detection of an object which *could* be in the HZ actually represents an HZ planet?
6. How can we determine if a followup detection in a system with a previous detection is of the same planet as before?

Helpful Precursor Data

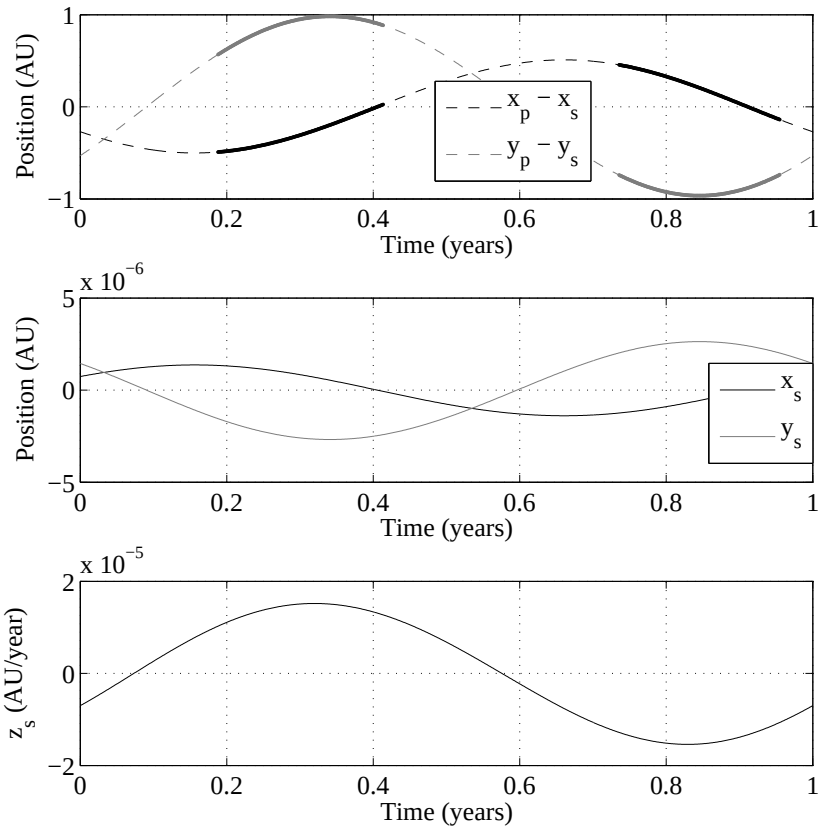


Figure: Observed data from planetary system. (a) Direct detection. (b) Astrometry. (c) Radial velocity.

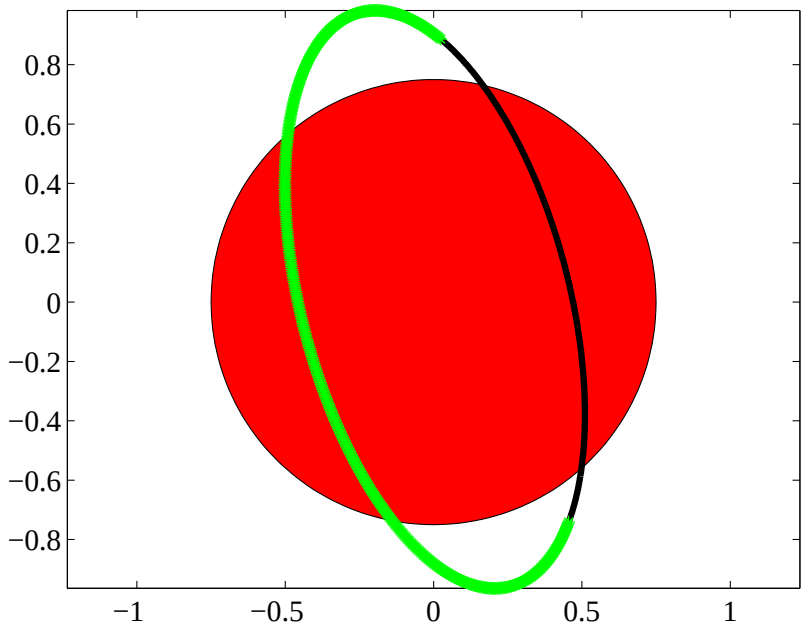


Figure: Schematic of a planetary system. Red circle represents projected IWA. Planet is sufficiently illuminated on green portion of the orbit.

Unhelpful Precursor Data

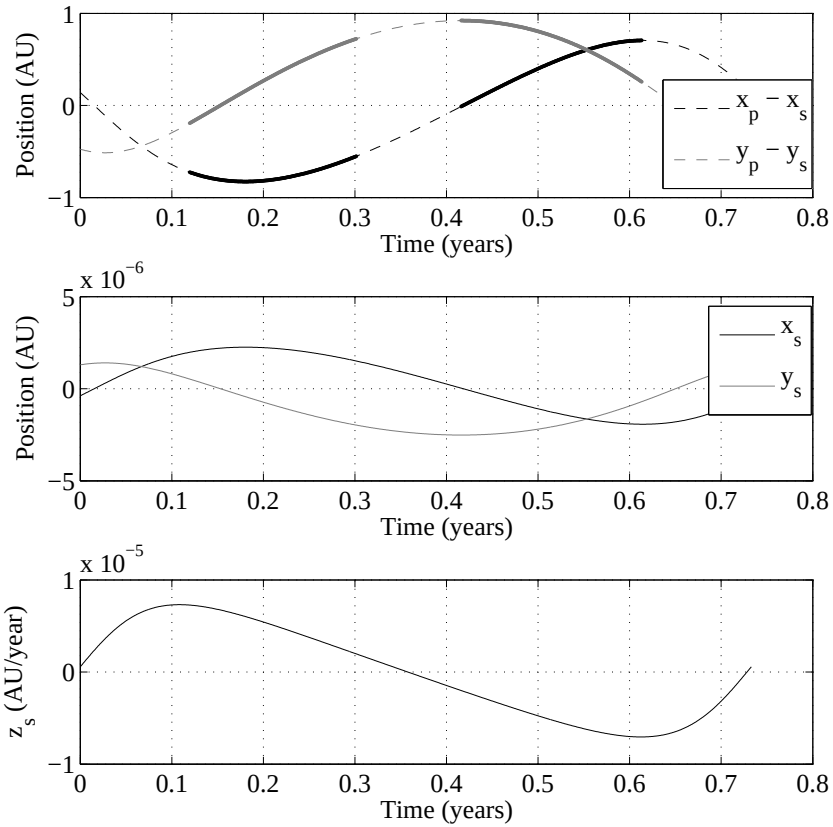


Figure: Earth-twin on a 0.8 AU semi-major axis, 0.3 eccentricity orbit: (a) Components of apparent separation. (b) Components of star's position with respect to system barycenter, in the plane of the sky. (c) Radial velocity of the star.

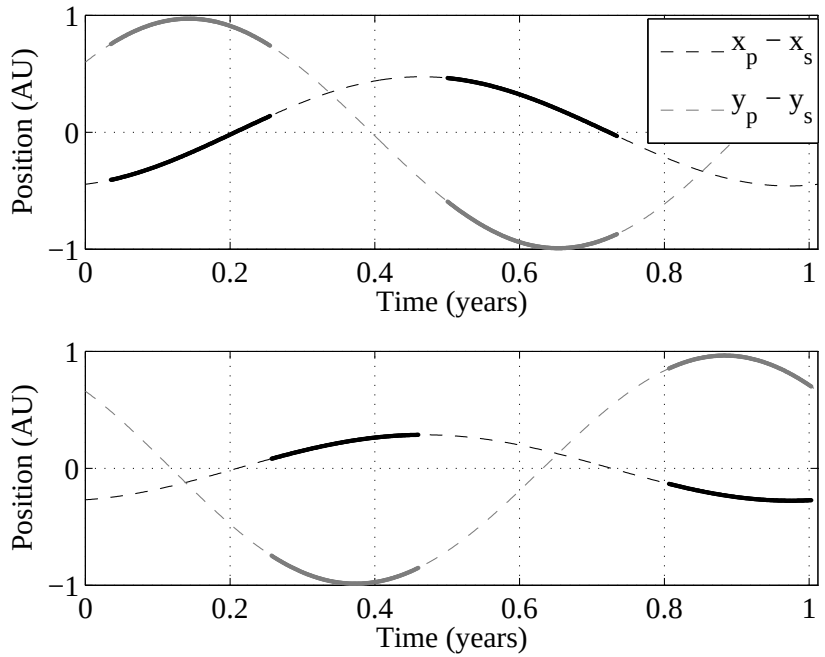


Figure: Earth-twin on a 1 AU semi-major axis and 0.0167 eccentricity orbit, the components of apparent separation for: (a) The original planet position propagated forward by five years. (b) The planet position derived from average orbital elements with an initial 0.1% error in the semi-major axis.

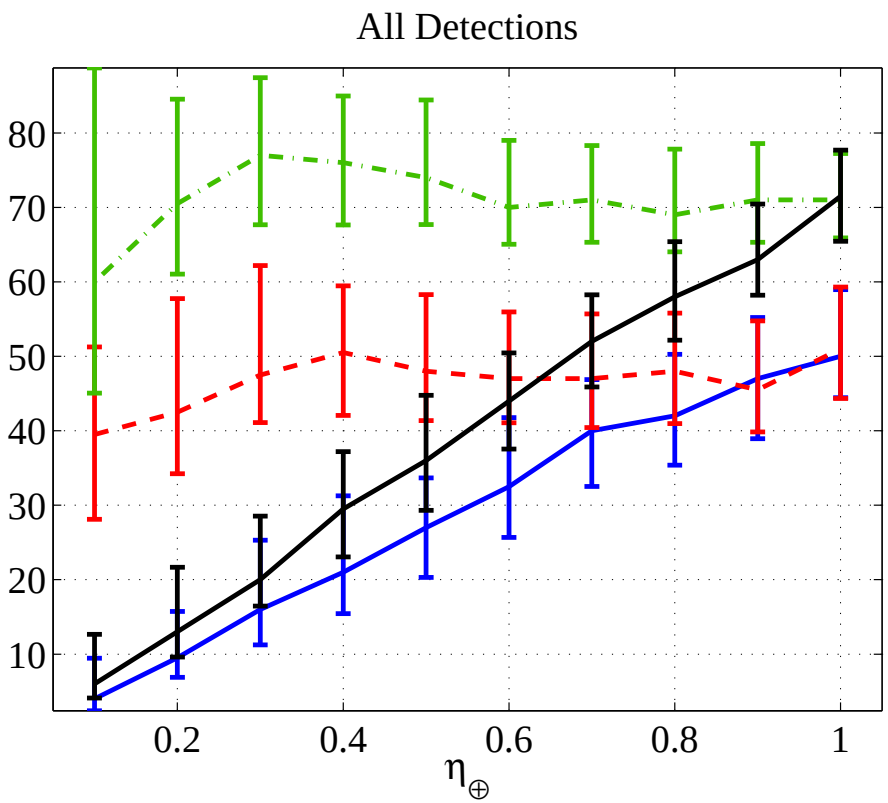
Mission Simulation

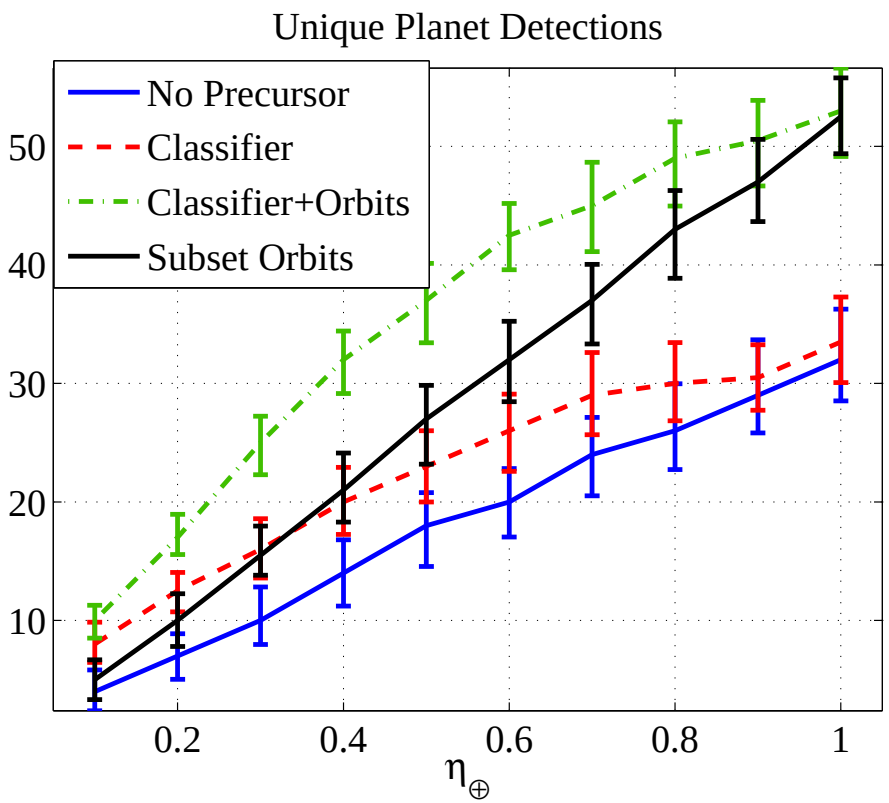
- Simulate complete missions with randomly generated populations of planets.
- Generate ensembles of mission timelines and derive science yield metric statistics.
- Metric definitions:
  - All Detections - total number of observations yielding detections with sufficiently low false positive probability
  - Unique Detections - number of detections of bodies assumed to be of individual planets

Precursor data incorporated into scheduling algorithm as

- Classifiers - Know which stars have planets.
- Orbit Fitters - Precursor produces orbital elements for discovered planets' orbits.

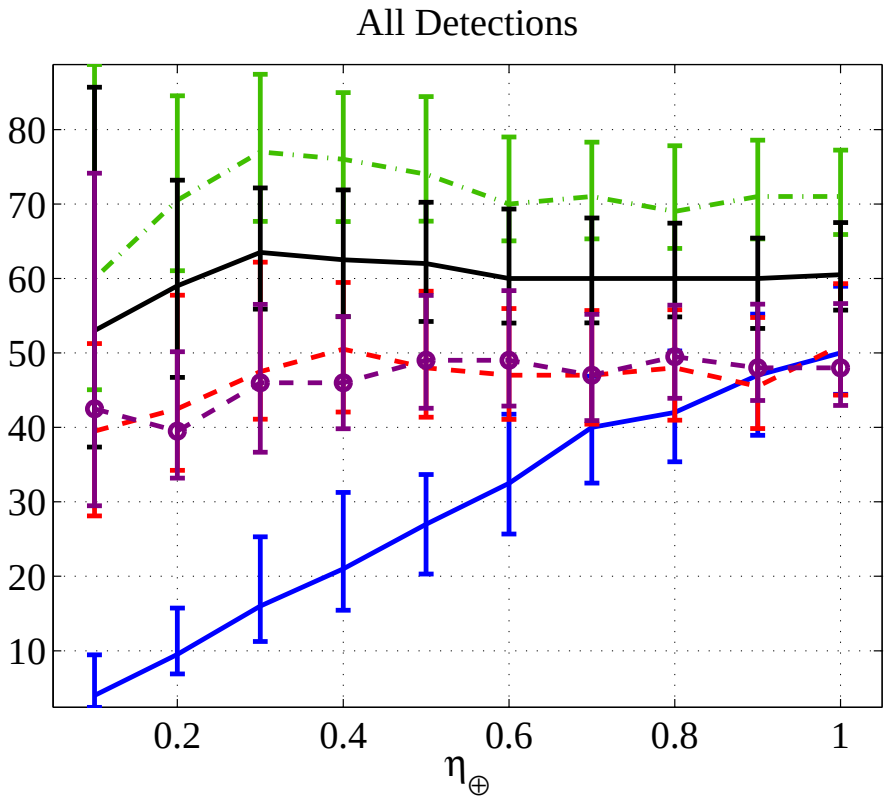
Ideal Cases - THEIA (4m)

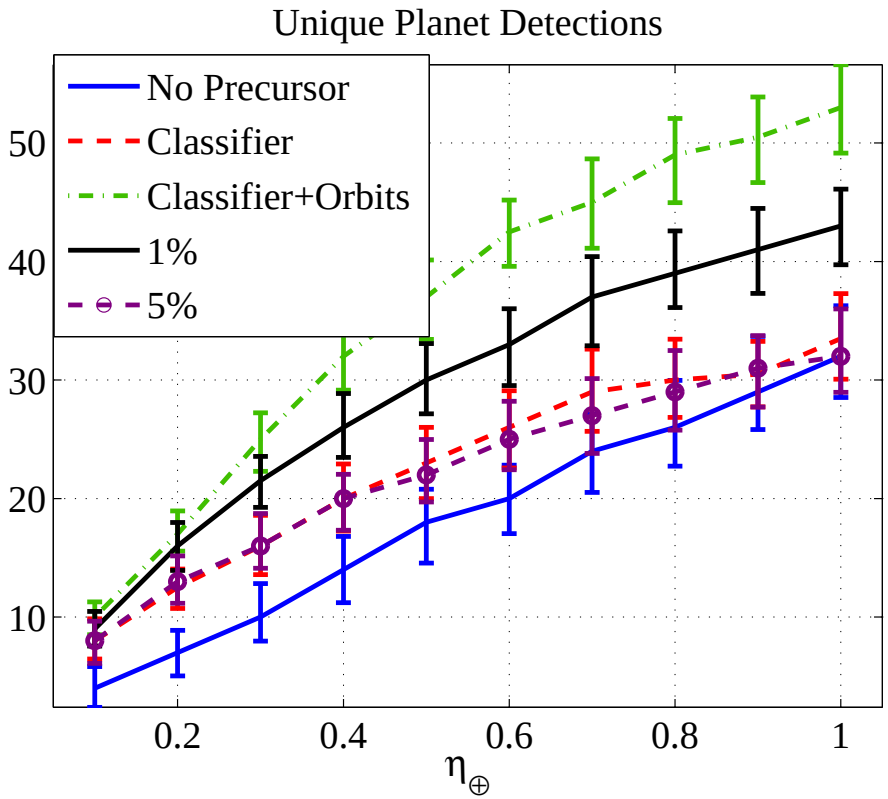




- Perfect orbital knowledge increases number of planets found from 30% to 50% of all existing planets in simulation.
- Classifier knowledge by itself is helpful for other science in low $\eta_\oplus$ cases, but only helps find a small number of additional planets.

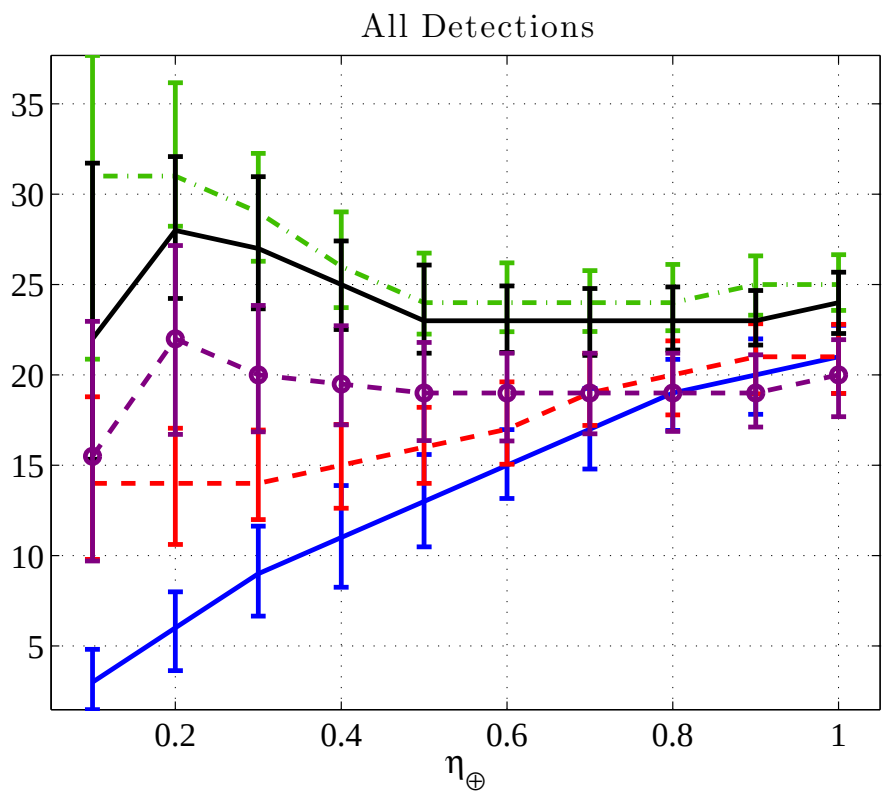
Non-Ideal Cases - THEIA (4m)

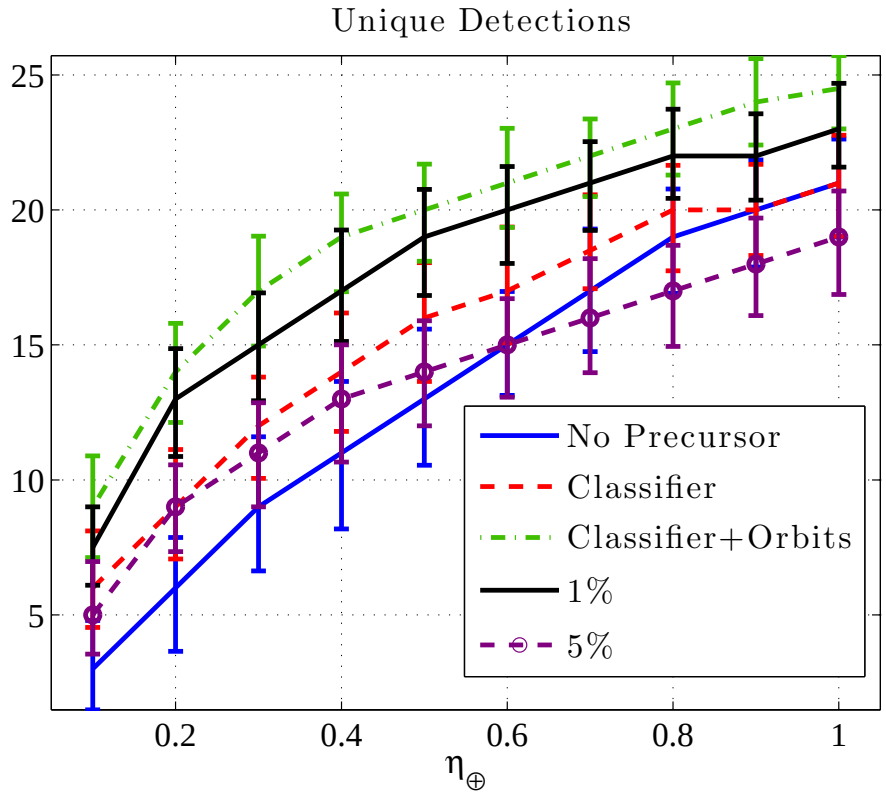




- 1% and 5% cases are precursors modeled as ideal classifiers which produce orbital fits with 0.1% errors in the semi-major axis estimate, and errors in the eccentricity and orbit inclination of 1% and 5% each.
- At 1% error, 15% fewer unique detections than with perfect orbit knowledge.
- At 5% error, the precursor produces results identical to the ideal classifier only (no benefit from orbital data).

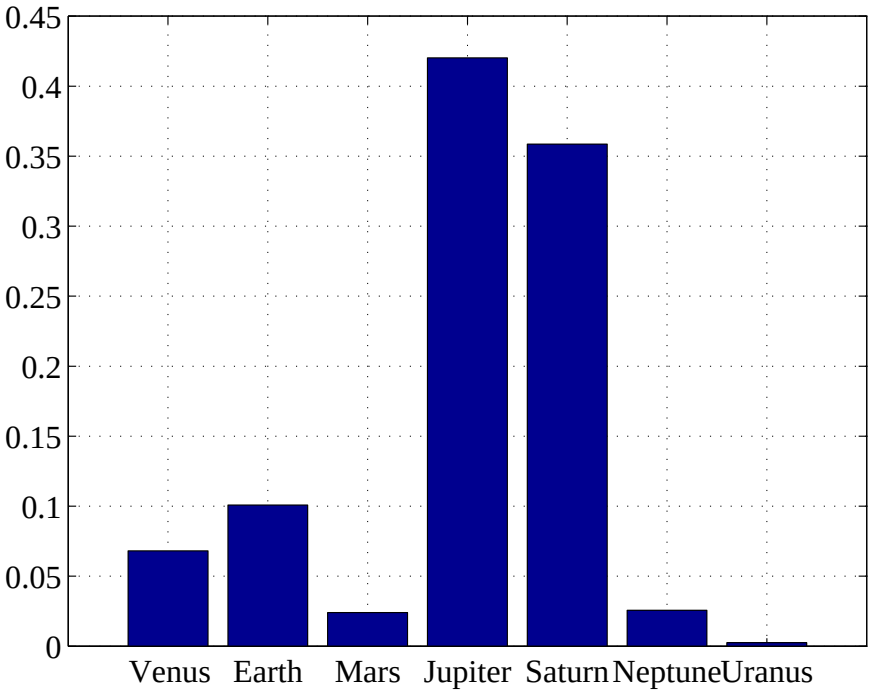
Non-Ideal Cases - O_3 (2m)





- Perfect orbit fits yield almost twice as many unique planets for $\eta_\oplus < 0.5$
- At 1% error, 10% fewer unique detections than with perfect orbit knowledge.
- At 5% error, for $\eta_\oplus > 0.6$ the mission with precursor data actually finds fewer unique planets (detriment from imprecise orbital data).
- At 5% error, for $\eta_\oplus < 0.6$ slightly fewer planets found than with ideal classifier data alone.

Solar System Analogues



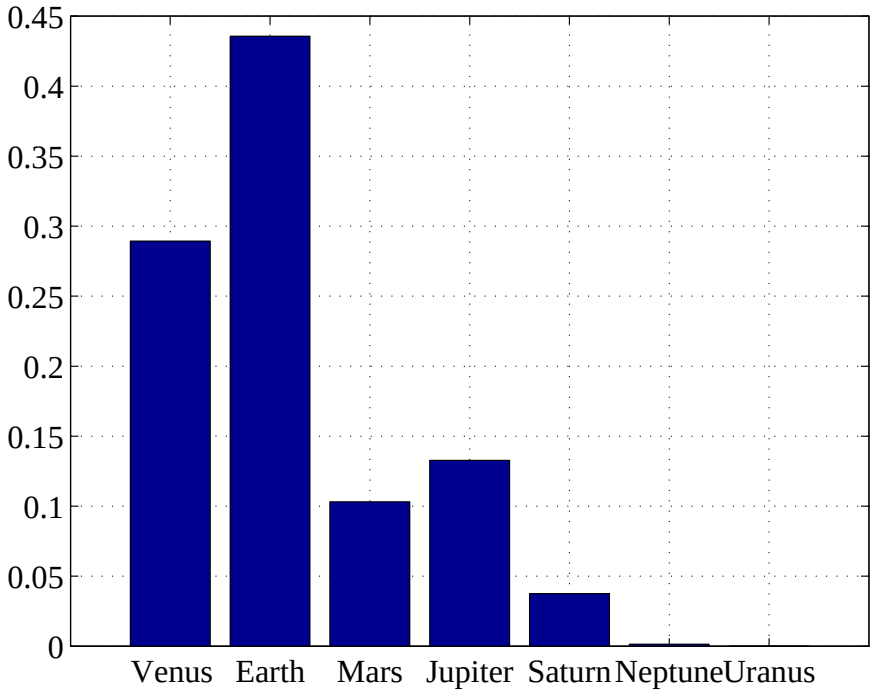


Figure: If every target system with planets observed by O_3 was a solar system copy: (a) Number of detections of each planet analogue scaled by total number of detections. (b) Number of detections of each planet analogue that could be in HZ, scaled by total number of detections.

Solar System Analogues

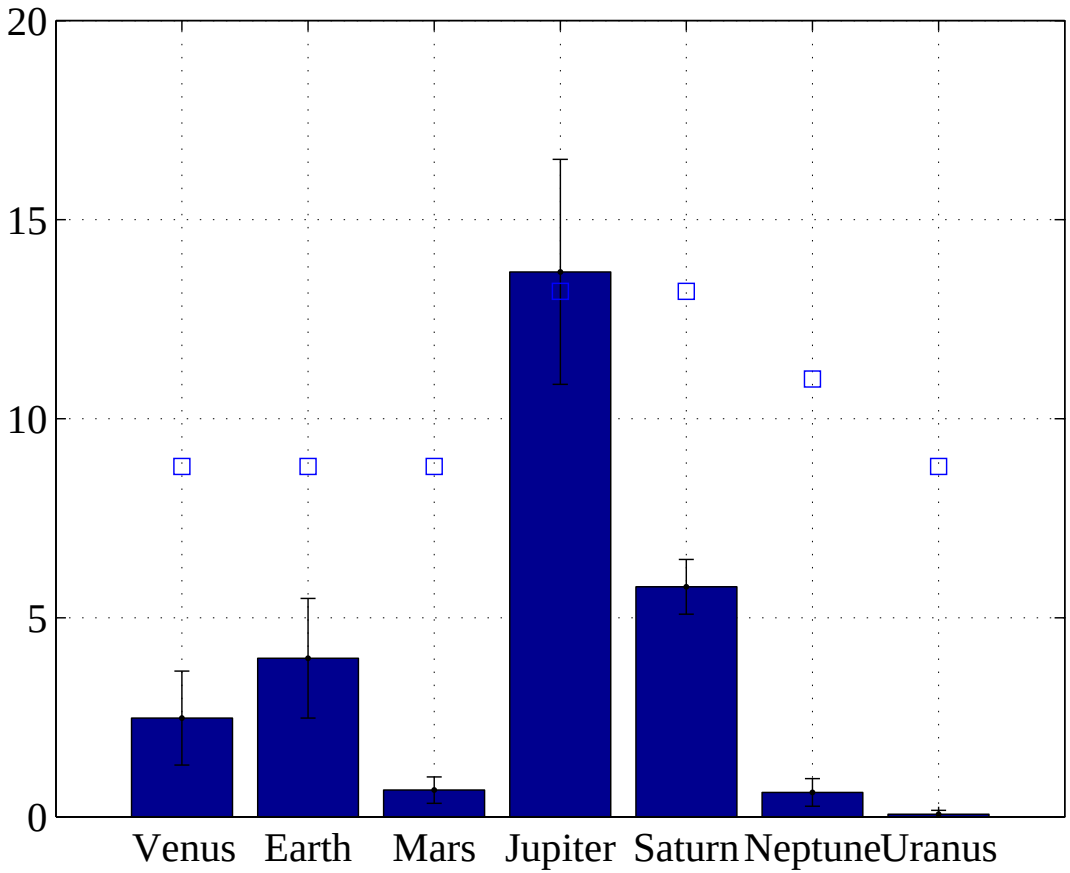


Figure: Average number of analogues classified by probabilistic algorithm as unique (40% error rate). The squares indicate the average number of each analogue type that was included in the simulations.

Conclusions

- Classification alone does not significantly improve the science yield of a direct detection mission, although it provides more observing time for other instruments in low η cases.
- Perfect orbital knowledge significantly improves science yield, if planetary radii and albedo are also known (or can be constrained).
- Small errors (as low as 1% in period and 5% in eccentricity and inclination) can make orbital data useless for planning detections.
- Ideal classifiers are actually unrealistic and the assumed errors in orbital knowledge are quite low.
- If every exosystem we observe is a solar system clone, any detection representing a planet in the HZ has a 43% chance of being an Earth, and an 83% chance of being a rocky planet. HZ candidates would represent 22% of all detections.
- It is quite difficult to determine whether repeat detections are of the same planet as previous ones, but possible to calculate probabilities.