Double Blind Study of Astrometric Detection of Earth Clones in Multiple Planet Systems

What are the Major Problems and Solutions

M. Shao JPL May 2013 Grenobole

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Overview

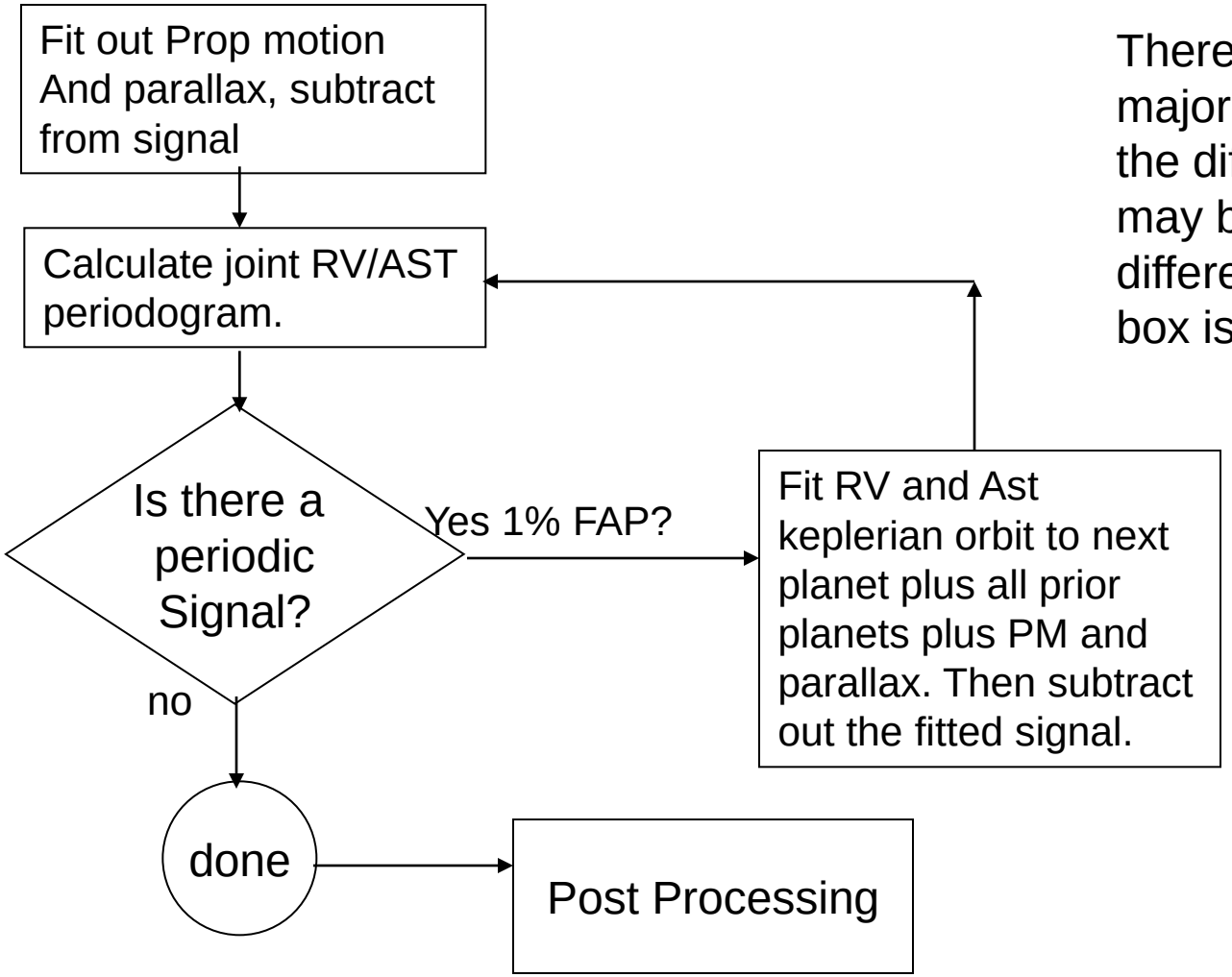
Basic hierarchical approach using Astrometry and RV data

a) fit out Proper motion, parallax
b) Use periodogram to find largest peak
c) fit Keplerian orbit to largest peak
d) Remove orbit from astrometric signal
e) repeat a,b,c until chi^2 ~=1
    fit of planet N+1 includes a refit of planets 1~N, PM, Prlx
f) post processing

This talk, introduce:

a) what are the hard problems
   False positives, why they arise (in multiplanet systems)
b) identifying false positives, when is the lowest χ^2 not the right answer

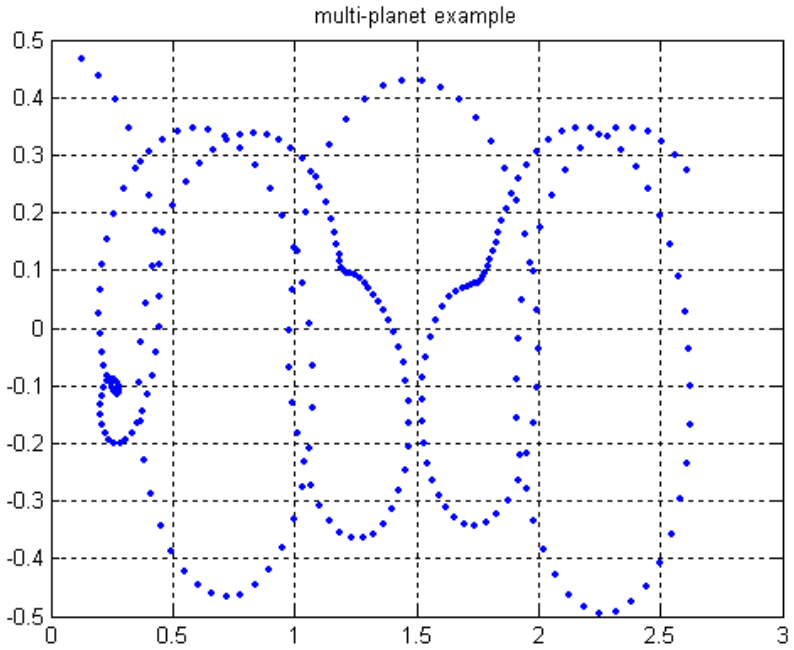
Generic Hierarchical Planet Search



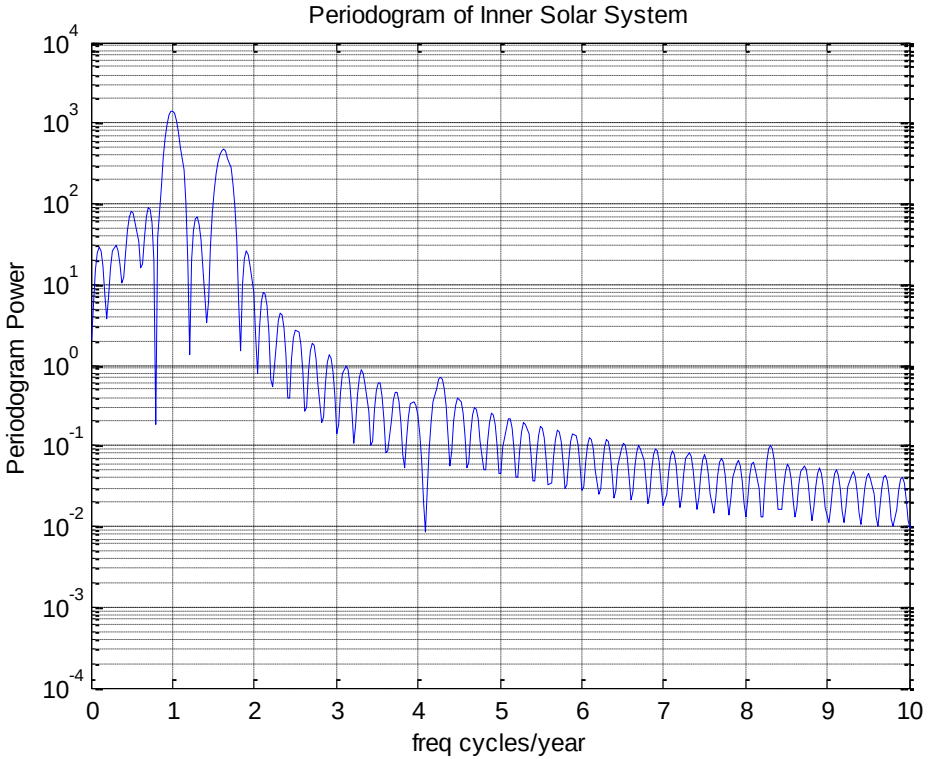
There will be minor and major variations between the different teams. There may be significant differences in how each box is implemented.

What are the Hard Problems?

- On first glace, if a star has 4 planets, with different periods, a periodogram of the astrometry & RV data should show 4 peaks at different orbital frequencies. So why is there a problem?

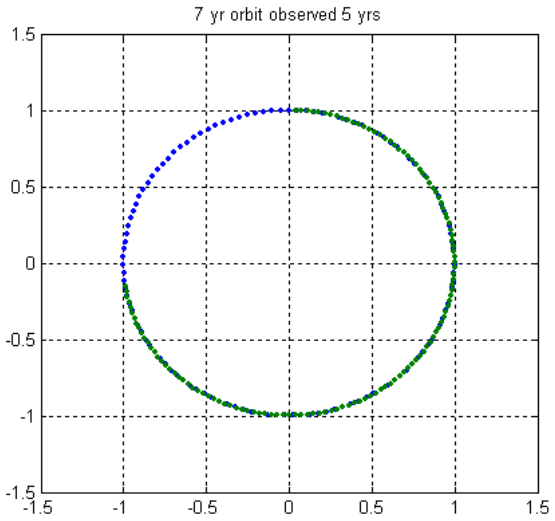


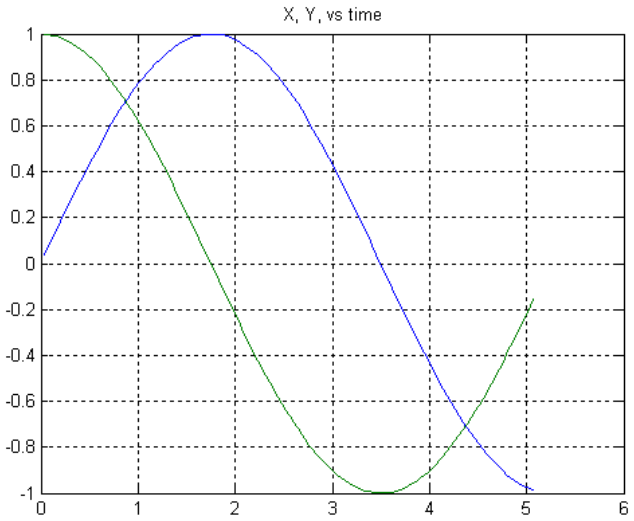
Zero noise example

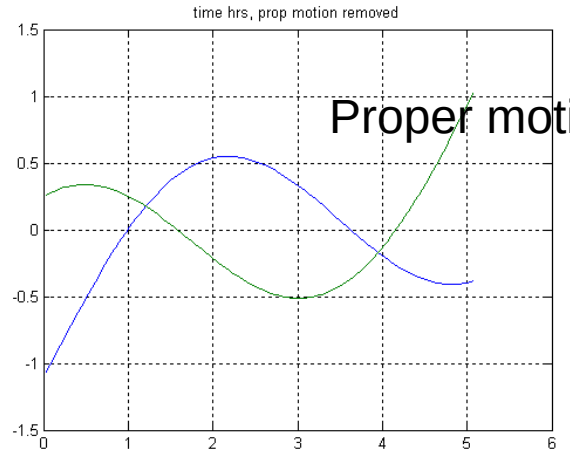


Periodogram shows 3 obvious peaks, for Earth, Venus and Mercury, Mars is lost in the sidelobes of Earth

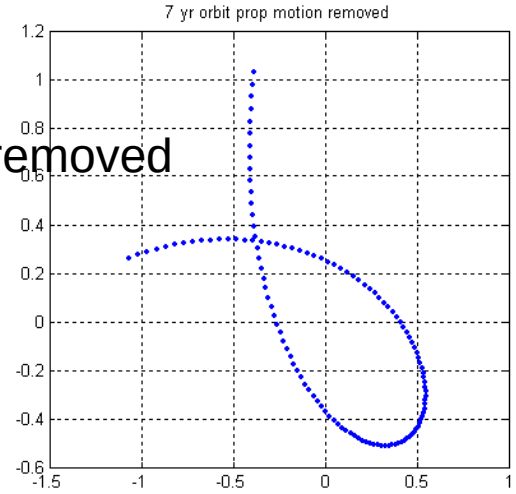
Interaction of proper motion, and partial orbits







Proper motion removed



Long period planets after PM subtraction will show a periodogram peak in the 4~5year period, Even when its period is >> 5yrs.

- After removing proper motion, the periodogram will show a peak at ~4.5 yrs
- Removal of PM removed a lot of the signature of a long period planet. Fitting a planet to the residual (after PM) will give a grossly wrong answer.
- Fitting a keplerian orbit AND proper motion simultaneously will result in removing both effects.

Periodogram Confusion

- Confusion arises when there are two planets whose orbit freq are unresolved by the periodogram.
  - For a 5 yr data set, the fourier transform width of a periodogram peak is **0.2 cycles/yr.**
- For short period planets, “dynamically stable orbitts” usually precludes fourier confusion.
- But all the planets with periods longer than 5yrs, will all fall into 1 fourier bin in the periodogram.
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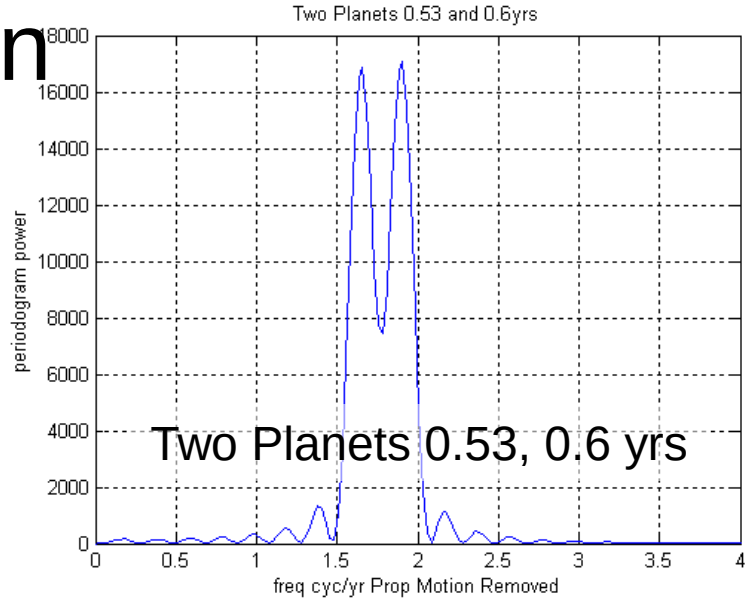
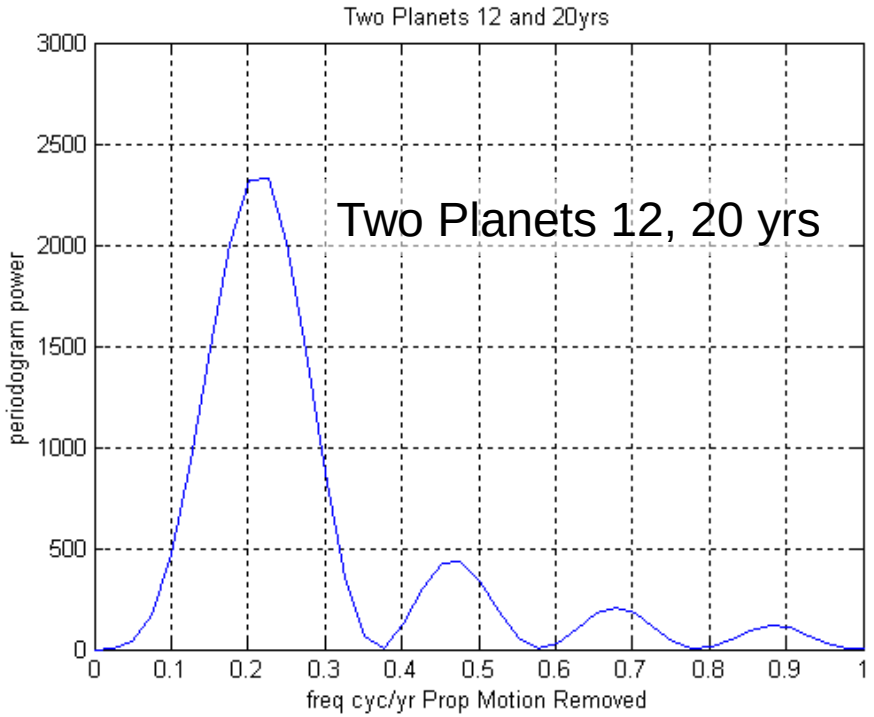
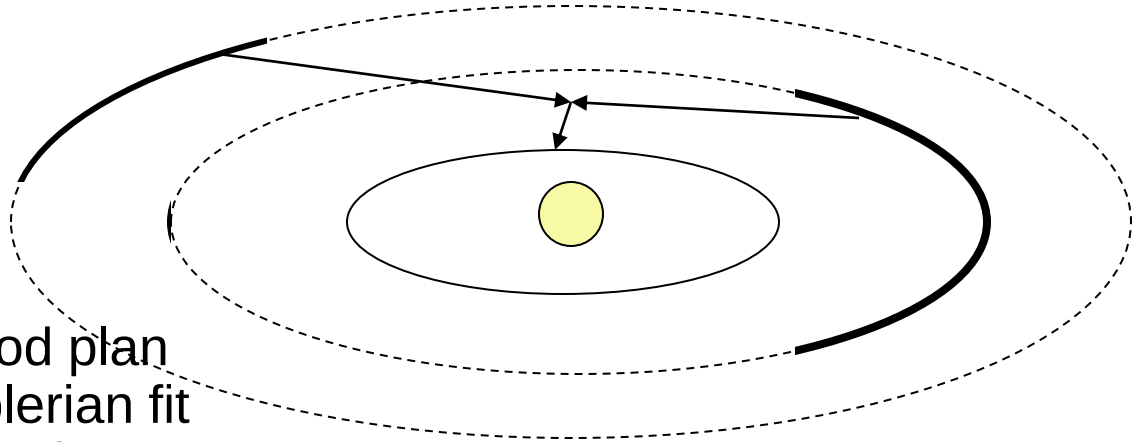


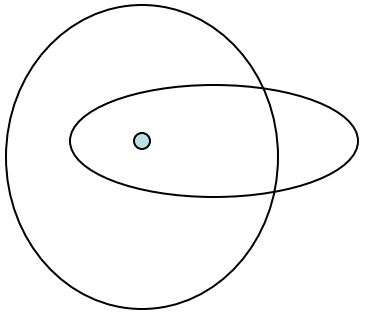


False Positives from Multiple Outer Planets



- If there is just 1 long period plan almost all the time, a keplerian fit of that long period planet will not introducing false positives.
- When there are multiple outer planets, often there will be multiple multi-planet solutions that are **statistically indistinguishable**. The reduction in chi^2 of these multiple solutions are the same.
  - Solution 1 has a jupiter in a 12 yr and saturn 30 yr orbit
  - Solution 2 has a jupiter in a 18 yr and a neptune in 5 yr orbit
- Often, but not always, the “wrong” solution will produce residuals that look like smaller short period planets.

Identifying False Planets
(when they occur)



- Things to look for
  - High eccentricity orbits
  - Crossing orbits (dynamically unstable orbits)
  - Inconsistancy between RV and Ast
    - In one case, joint solution predicted an RV SNR=3. That is if you believed the joint RV/Ast solution, the RV periodogram should have had a SNR=3 peak. The RV periodogram had a peak less than SNR=0.5

- How well were we able to detect false positives?

Confidence of Detection = # det/(#det + # false_positives)
Completeness = #det/(# detectable planet (solor))

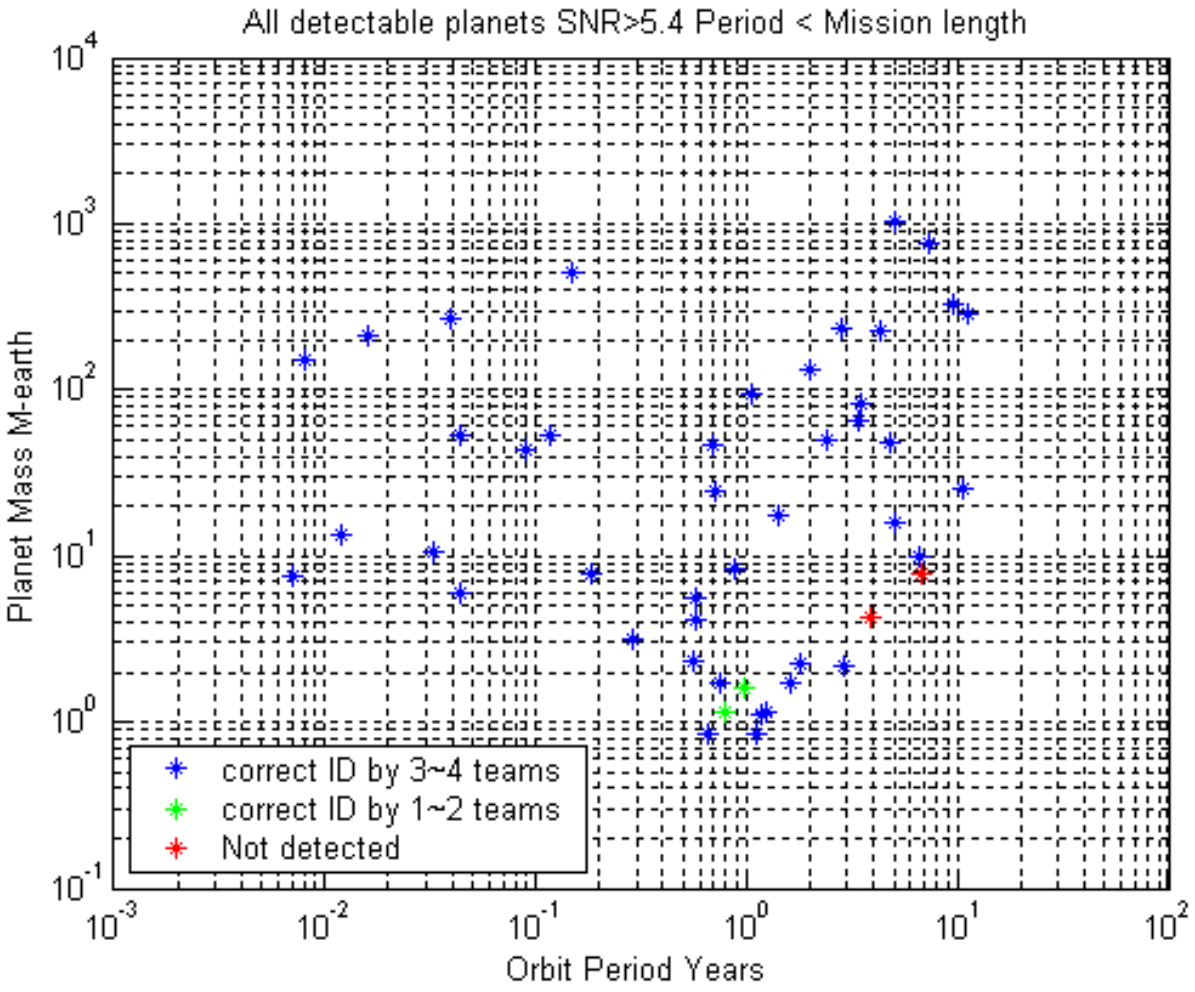
	All planets	Hab Zone	0.3~10Me	Earths
Confidence	98%	100%	96%	100%
Completeness	96%	100%	91%	100%

Other Tests

- In the simulation, we were given 15 yrs of RV (1 m/s) data and 5 years of astrometry (1uas). While long period planets are more easily detected by astrometry, the long time baseline of the RV data would makes identification of long period Jovian planets easier.
- Another test is to conduct an N-body simulation to see if the multiplanet solution is stable for >1e6~1e7 years.
- Joint RV, astrometry periodogram. For most planets, either the RV data has much higher SNR (neptunes in 3 day orbits), or the Astrometry data has much higher SNR (neptunes in 3yr orbits). But once in a while there's a planet at an intermediate period where the combined RV+Astrometry results in pushing the periodogram power above the 1% FAP threshold. One should be careful in properly weighting the SNR of RV+Astrometry data. (how do you add a signal in m/s and another one in uas?)

Completeness,

What fraction of reasonably detectable planets were detected?



Define SNR>5.8 as Threshold for detectability

All planets, period < 5,10yr
There are 48 reasonably detectable planets (out of 95 total planets)

These were results After 1st problem set

Summary

- Earthlike planets in multiple planet system can be detected with ultra-precise astrometry.
- Multiple outer planets can often have multiple solutions with indistinguishable chi^{2}s. Sometime, but not always, picking the wrong one can trigger a false planet to appear with a shorter period. A relative large “false” planet can trigger a cascade of false planets with successively shorter periods.
  - The outer planets are not important as long as they don’t trigger a false positives. When there are multiple solutions to multiple outer planets, it may be that only a small fraction of the “wrong” solutions trigger false short period planets. (very often the wrong outer planet solution is just soaking up the signatures of 60~200 yr orbits.)
  - While it is possible to engineer multiple planet systems that are “unsolvable” using current techniques, such systems are relatively rare in the 48 system in the first phase of the double blind study.

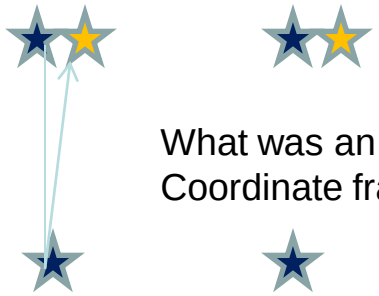
Not Covered

Motion of reference stars

- The SIM double blind test was aimed at detecting Earths in a multiplanet system. While not fundamentally difficult, the problem of motion of the ref stars was not addressed.
- All reference stars move (proper motion) at ~ 1mas/yr. All references stars(11~14mag) will have a measurable parallax (~1~2 Kpc)
- 5~10% of reference stars will have Jovian planets whose signature may be in the ~1 uas range.
- The conceptual solution is outline in the next 2 slides, but while some work on SIM was done on ref stars, it was not integrated into the planet detection simulation.

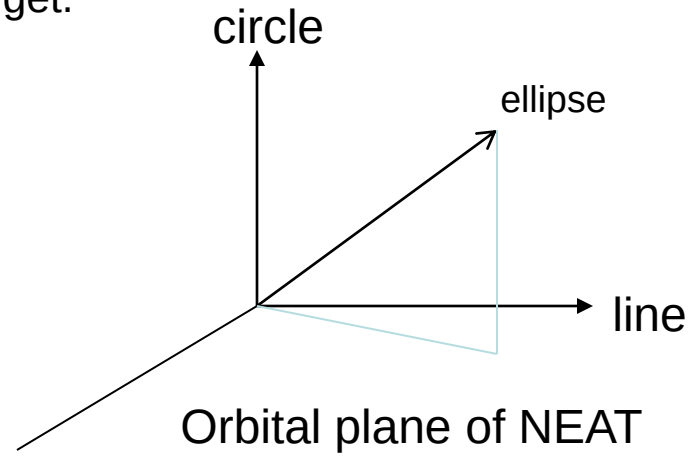
Proper Motion/Parallax of Ref Stars

- Motion of the ref stars will cause a distortion in the sky
  - However this distortion is small enough not to matter.
- Ref stars at 1~2 Kpc will have a parallax of 500~1000 uas.
- The parallactic motion is nearly but not exactly the same for all stars. (the parallactic ellipse depends on ecliptic longitude/lat of the star)
- One has to fit a different 1 year ellipse for each star in the sky.
  - It's possible to measure absolute parallax ~100x less accurately than relative parallax
  - This abs parallax maybe slightly better than GAIA.



What was an orthogonal Coordinate frame is no longer

Ref stars ~15 arcmin from target
Induces an apparent linear motion in the target.



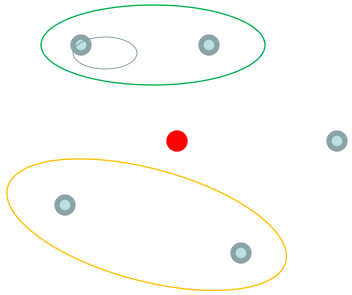
Orbital plane of NEAT around the Sun

Exoplanets around Ref Stars

- 5~10% of ref stars will have Jovian planets. (Ref stars are 100X more distant than target stars, ~100 Mearth ~ 1 Saturn)
- As in parallax, we can not treat the ensemble of reference stars as 1 object. Each reference star must be treated individually.
  - If we look at ref_1, using the target and other ref stars to define the ref frame, we can detect a Jupiter around ref-1.
  - What makes the problem tractable is that it is highly unlikely that planets around ref star(s) have the same period as the planets around the target star.
- If we look at the relative position of (ref-1 and ref-2), (ref-1 and ref-3) etc. to (ref-n vs ref-(n-1)), then if ref-1 has a jupiter with a 2yr period, we will see a 2yr peak in the periodogram of every pair that has ref-1. But not see that peak in any other pair of stars.

Ref Star Planets (illustration)

- If analyzed in pairs, all the pairs that have the ref star with a planet will show a periodicity. But the pairs that do not have the planet won't.



- The prob of a ref star having a jovian planet is small, and the prob that that planet's period is the same as another planet in this system (of N stars) is small.

- Other issues like star spots are very small for ref stars because of their distance from Earth.