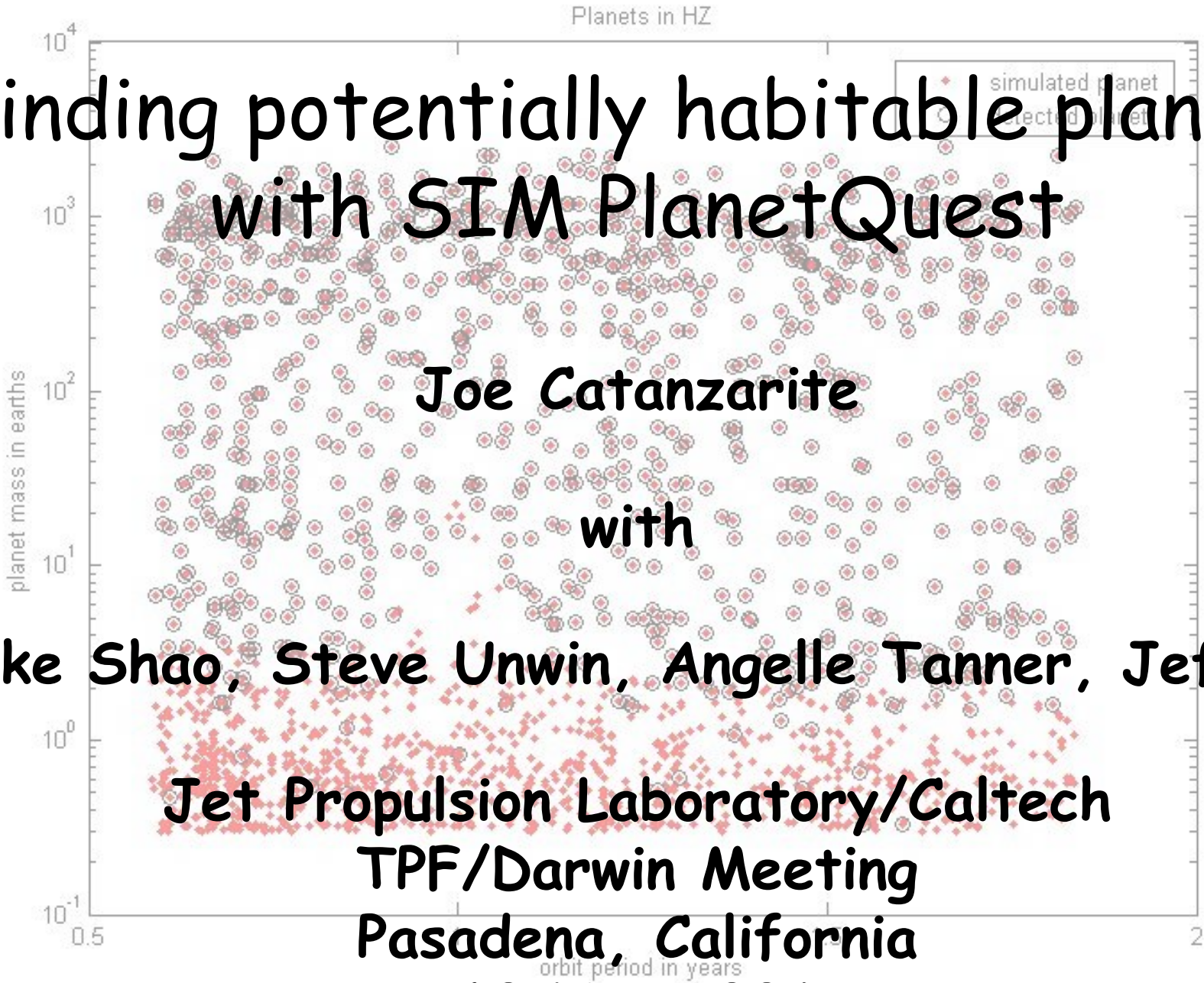

Finding potentially habitable planets with SIM PlanetQuest

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with

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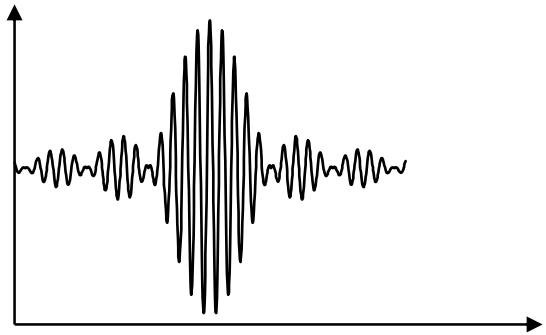
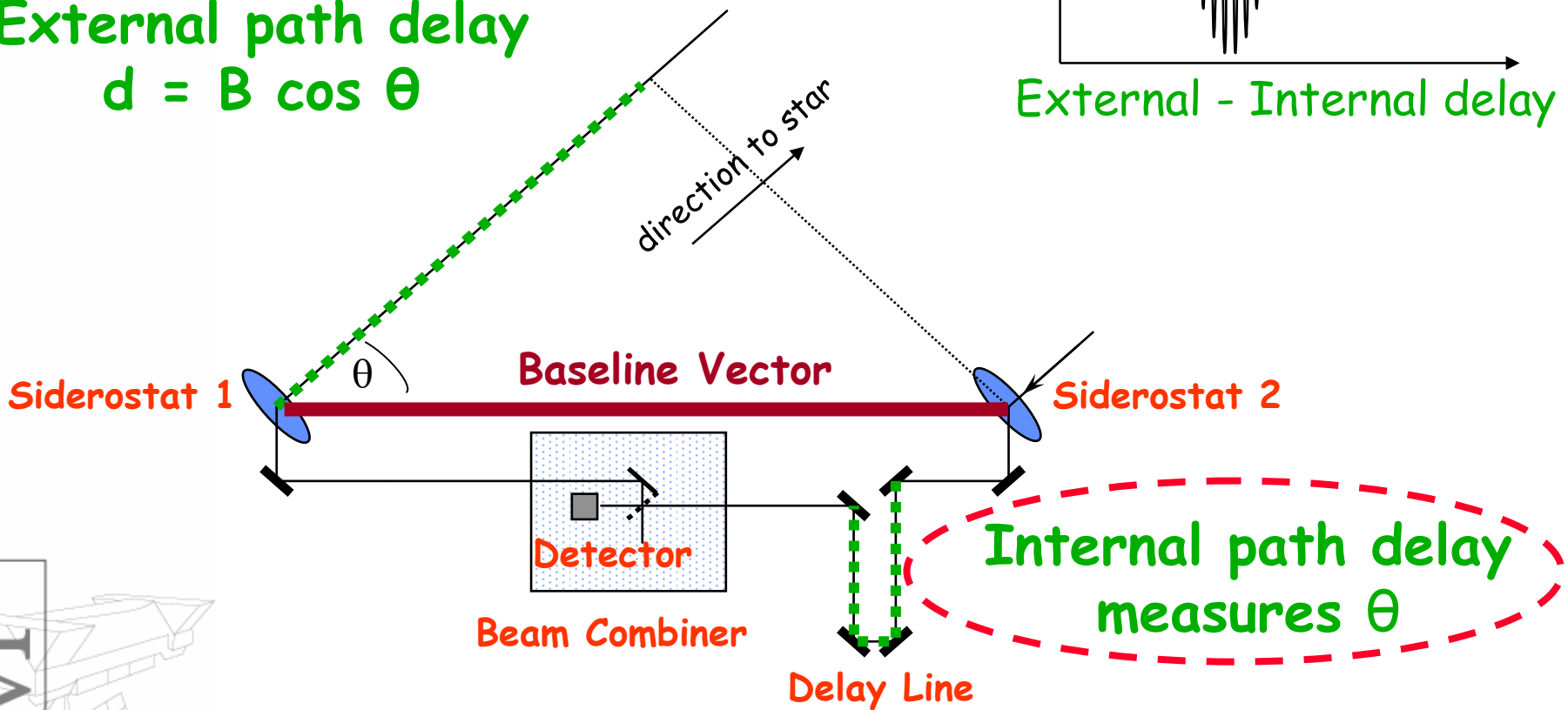
Overview

- SIM PlanetQuest is a Michelson interferometer
- Observing scenario
- Planet survey – hypothetical target list and strategies
- Astrometric planet detection
- Monte Carlo simulation
- Planet-finding performance

SIM PlanetQuest is a Michelson interferometer

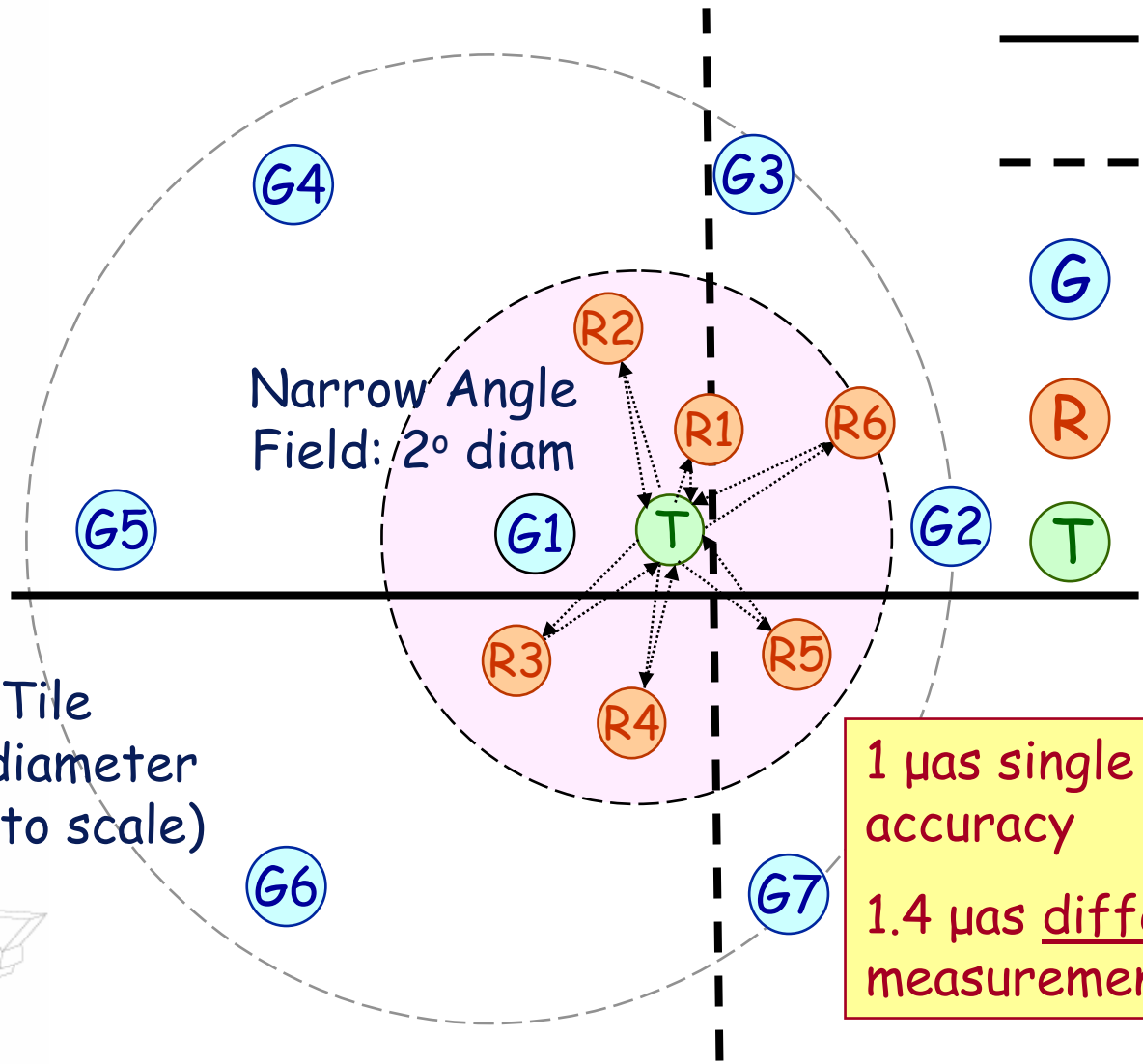


External path delay
d = B cos θ



The peak of the interference pattern occurs when the internal path delay equals the external path delay.

Observing scenario for a 'visit' to a target star



1 μas single measurement accuracy

1.4 μas differential measurement in ~ 20 min.

'Chopping' mitigates linear temporal drift and field dependence

Hypothetical SIM planet survey target list

- Start w/Turnbull's database of 2350 stars within 30 pc
- Eliminate giant stars with L > 25
- Include wide binary companions (outside 1.5")
- Include close binary companion (within 1.5") IF
  - Not too close: $0.4'' \leq \theta \leq 1.5''$ AND
  - Not too bright: $\Delta V > 1$

Hypothetical SIM planet survey strategies

Survey mode	Targets	Visits for 5/10 year SIM mission	Single-measurement accuracy
Medium-deep	240	104/208	1 uas
Deep	120	208/416	1 uas
Ultra-deep	60	416/832	1 uas

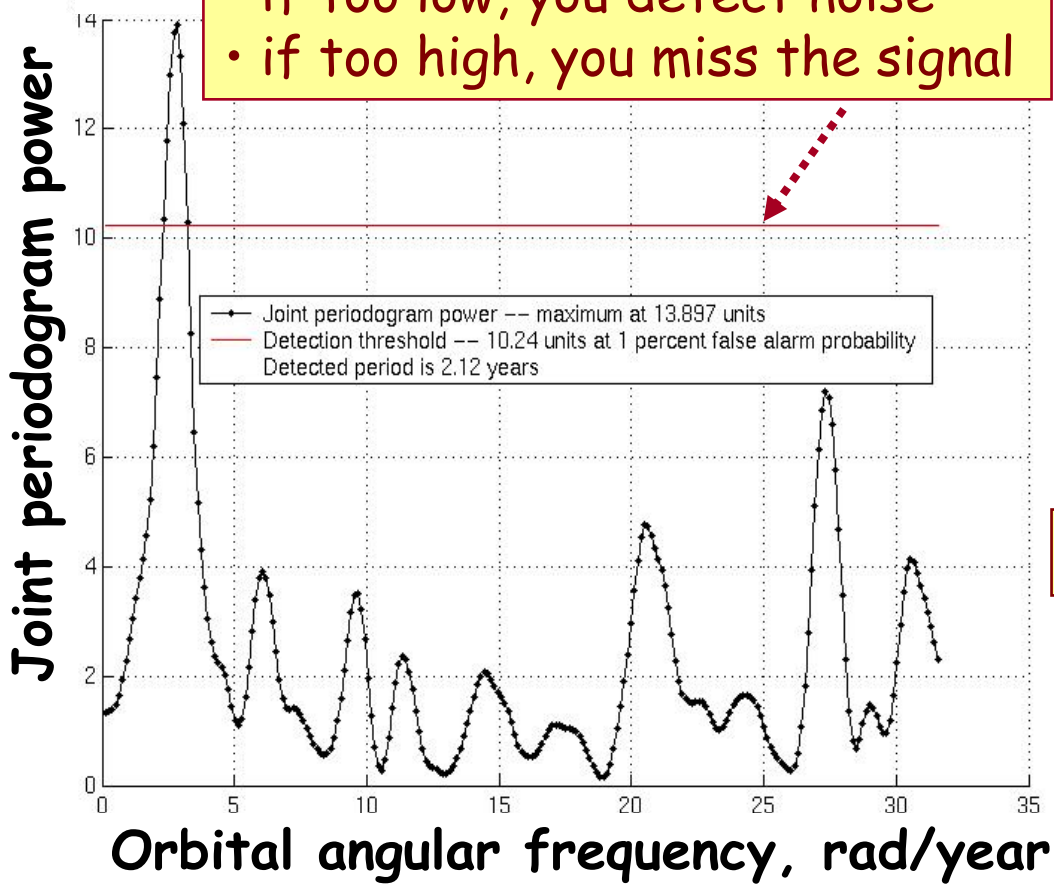
Spend more time on fewer targets if terrestrial planets are common.

The joint periodogram

- The Lomb-Scargle periodogram is commonly used to identify frequencies in unevenly-sampled one-dimensional time series -- such as RV measurements
- BUT astrometric orbits are two-dimensional
- We define the joint periodogram as the SUM of the Lomb-Scargle periodograms of the two orthogonal components of the stellar reflex motion trajectory
- The joint periodogram
  - Incorporates orbital phase information
  - Is optimal for circular orbits
  - Works well for eccentric orbits, especially for $e < 0.3$

Planet detection with the joint periodogram

Detection threshold
- if too low, you detect noise
- if too high, you miss the signal



3.3 M_{earth} planet

P = 2.3 yrs
e = 0.69
i = 38°

Detected P = 2.1 yrs

Solar-mass star at 10 pc
5 year mission, 50 two-dimensional SIM measurements
1 μas single-measurement accuracy

How to set the detection threshold

Detection threshold is the level above which a signal is counted as a detection.

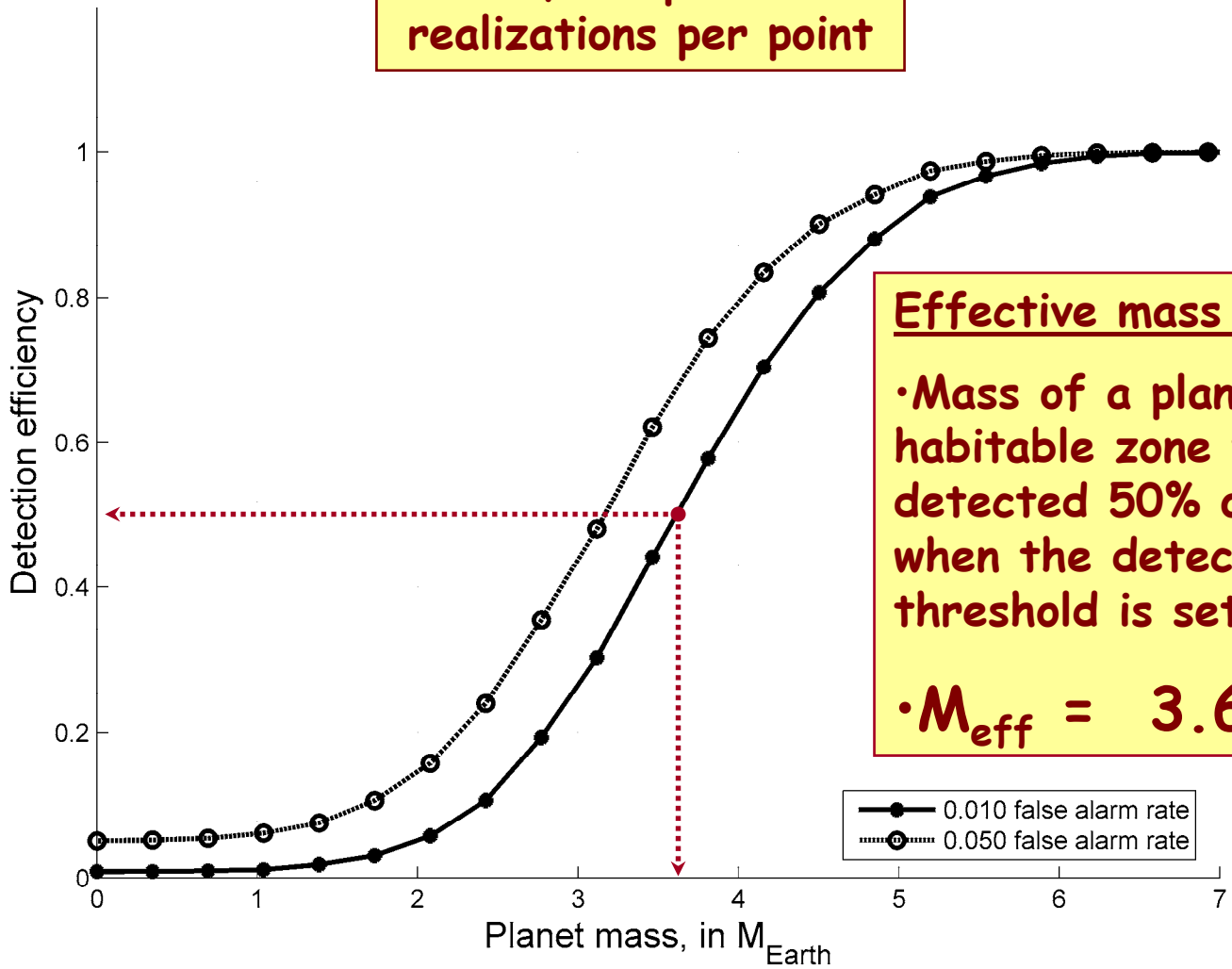
False-alarm probability (FAP) is the chance that a noise peak could exceed the detection threshold.

The detection threshold is meaningful only when it is associated with a FAP. For our study we chose the FAP to be 1%.

The detection threshold corresponding to a given FAP must be determined by Monte Carlo simulations of pure noise.

Monte Carlo simulation of planet detection

10,000 planet realizations per point



Effective mass sensitivity

- Mass of a planet at mid-habitable zone that is detected 50% of the time, when the detection threshold is set to 1% FAP
- $M_{eff} = 3.6 M_{earth}$

- Solar-mass star at 10 pc, planet at 1 AU
- 5 year SIM mission, 50 2-D observations @1 μas noise

Space Interferometry Mission
SIM

Effective mass sensitivity

- For each target, SIM's effective mass sensitivity is
  - the mass of a planet in the mid-HZ that can be detected half the time at a threshold that gives a 1% false detection rate.
  - a one-parameter characterization of the detection efficiency curve

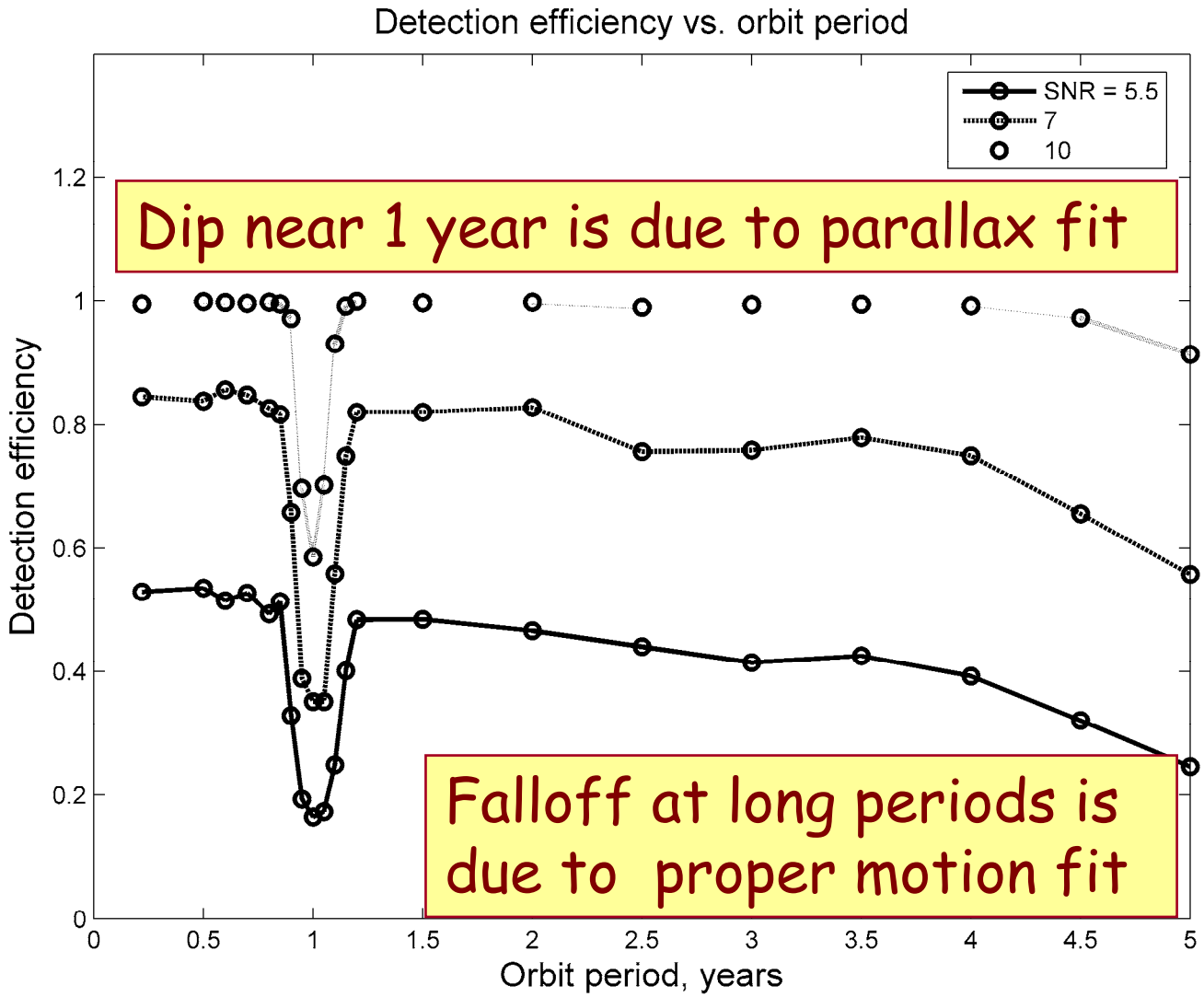
- This is the best SIM performance metric, because it
  - depends only on known quantities: characteristics of the SIM instrument and the target star
  - is independent of the 'unknowns' of planetary astrophysics, i.e. the mass distribution and occurrence frequency of terrestrial planets

- Effective mass sensitivity for astrometric detection of a planet at the mid-habitable zone of a main sequence star:

$$M_{eff} = (2.6 M_{earth}/L^{0.24})(50/N)^{0.5}(\sigma/1\ \text{uas})(D/10\ \text{pc})$$

  - **L is stellar luminosity in solar units**
  - **D is stellar distance in pc**
  - **σ is differential measurement error in micro-arcseconds**
  - **N is number of two-dimensional measurements**

Correction for orbit period dependence, 5 year mission



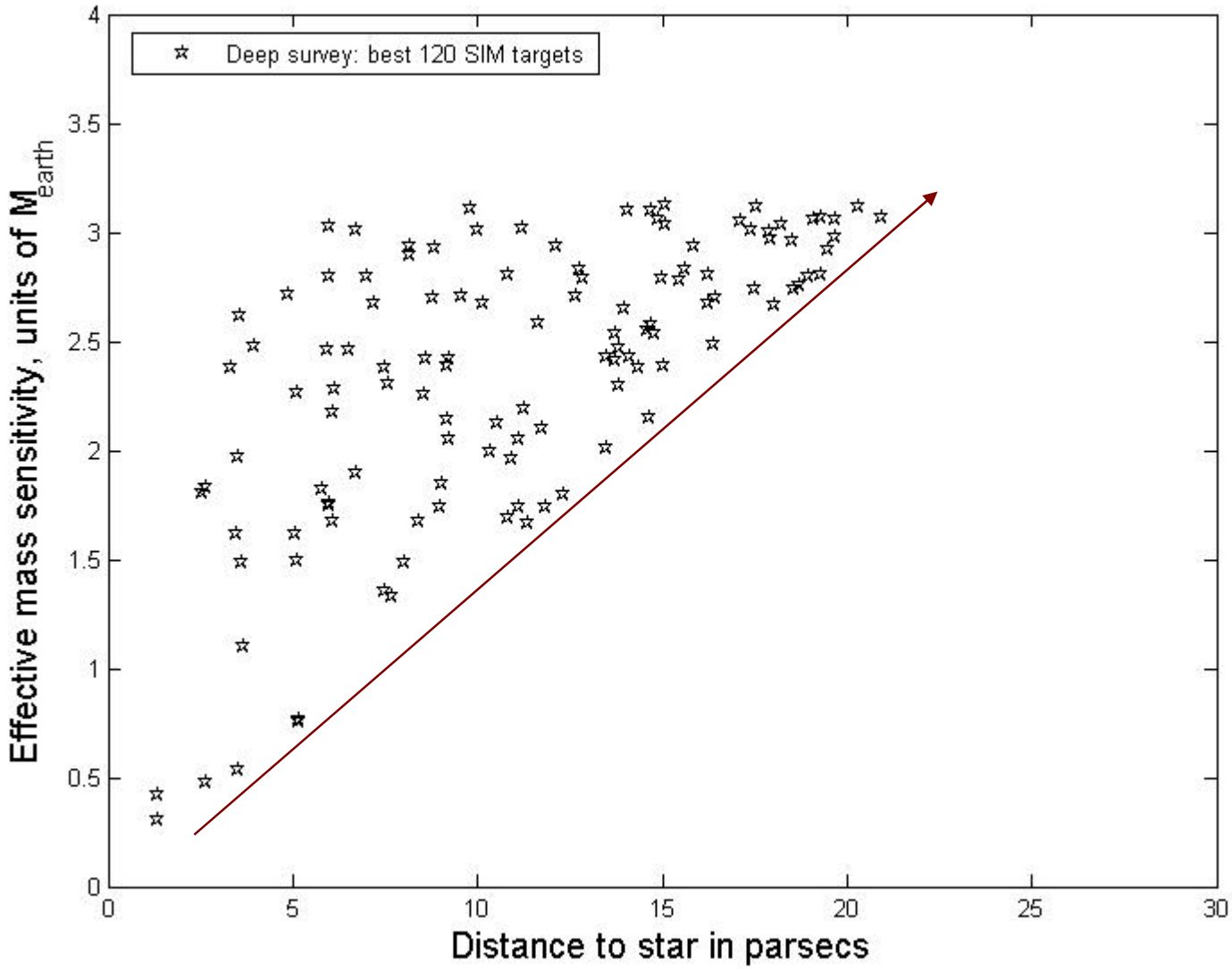
Dip near 1 year is due to parallax fit

Falloff at long periods is due to proper motion fit

Apply correction via lookup table
Get mass sensitivity for each target star

Results, deep survey (5 year mission, 120 targets)

Effective mass sensitivity vs. target star distance

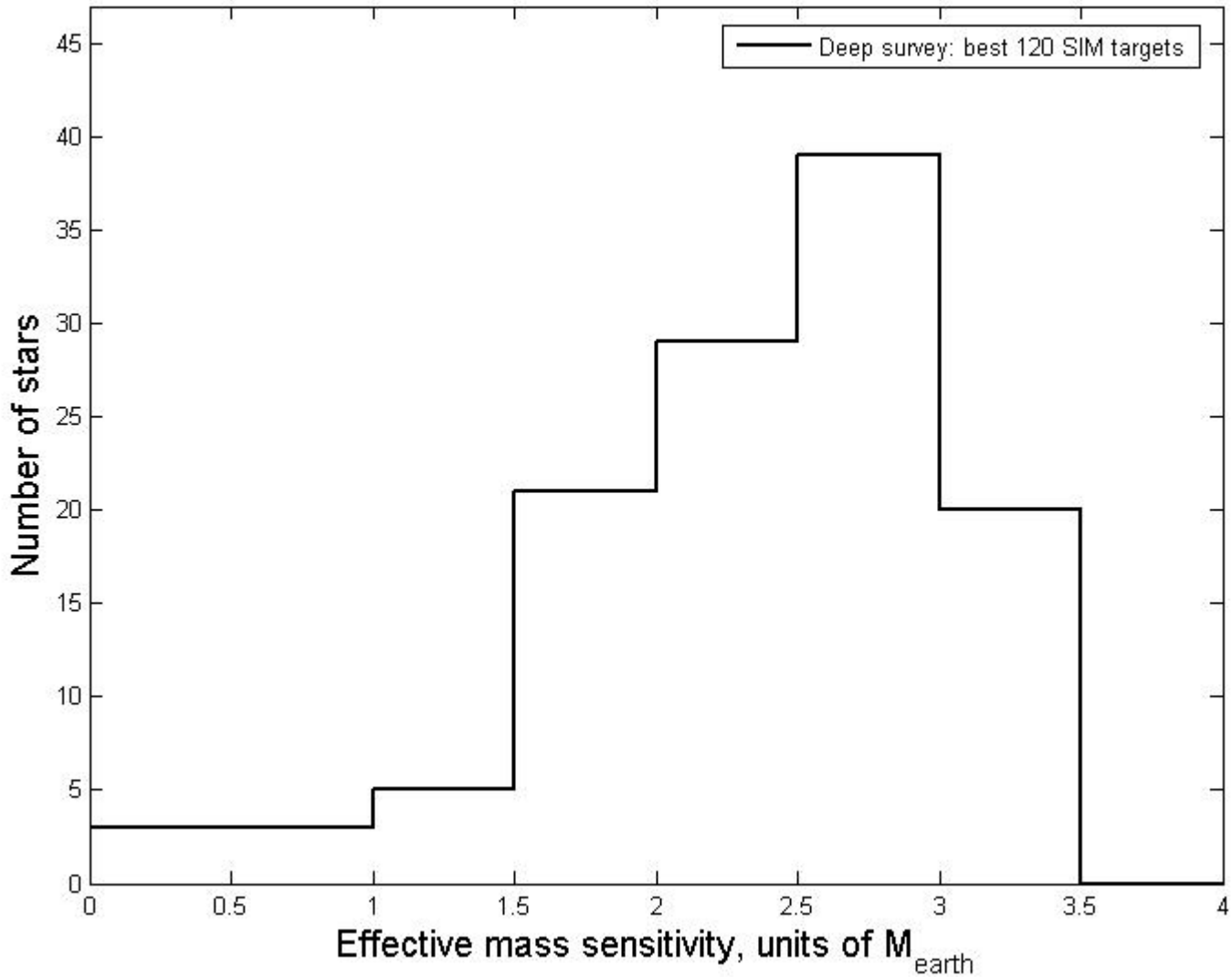


Space Interferometry Mission

SIM

Results, deep survey (5 year mission, 120 targets)

Sensitivity ranges from 0.3 to 3.2 M_{earth}, with median of 2.5 M_{earth}

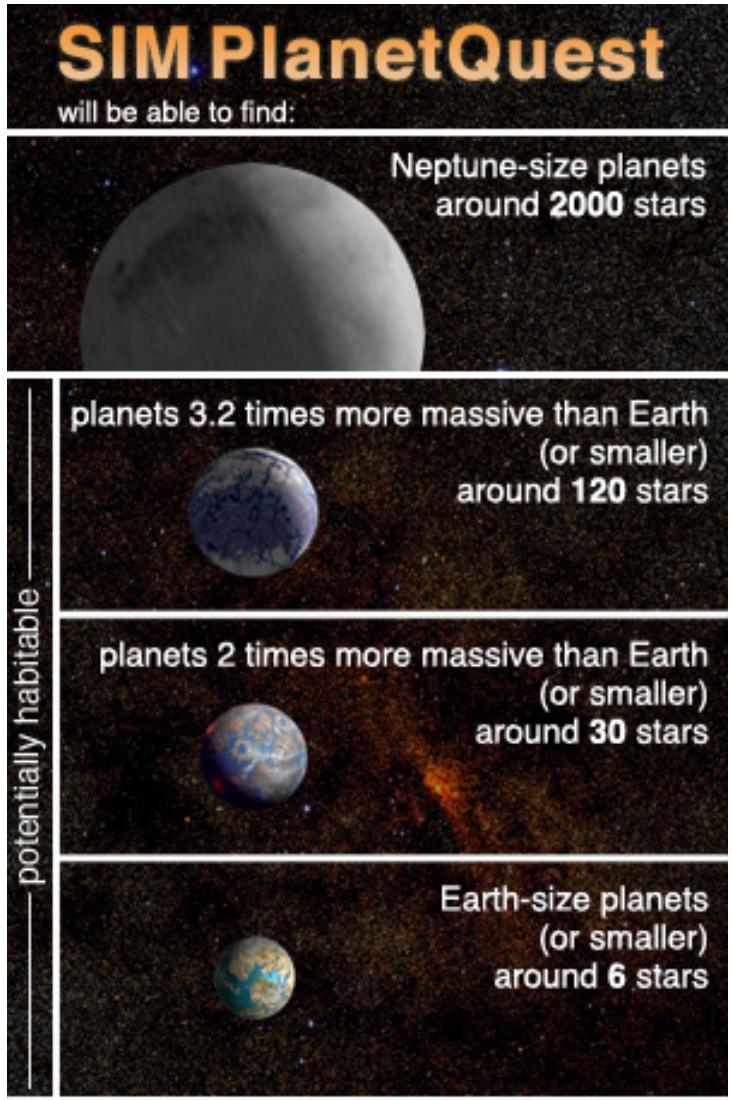


Summary

- 5 year mission, deep survey
- 120 stars
- 104 2D measurements/star
- 1.4 uas differential measurement accuracy

SIM probes

- 120 stars for planets below 3.2 M_{earth}
- 97 stars for planets below 3 M_{earth}
- 30 stars for planets below 2 M_{earth}
- 6 stars for planets from 0.3 to 1 M_{earth}



SIM performance, 5 year mission

	Planet mass sensitivity, units of M_{earth}		
Survey mode	Minimum	Median	Maximum
Medium-deep 240 stars, 104 2D obs	0.4	4.5	5.8
Deep 120 stars, 208 2D obs	0.3	2.5	3.2
Ultra-deep 60 stars, 416 2D obs	0.2	1.4	1.8

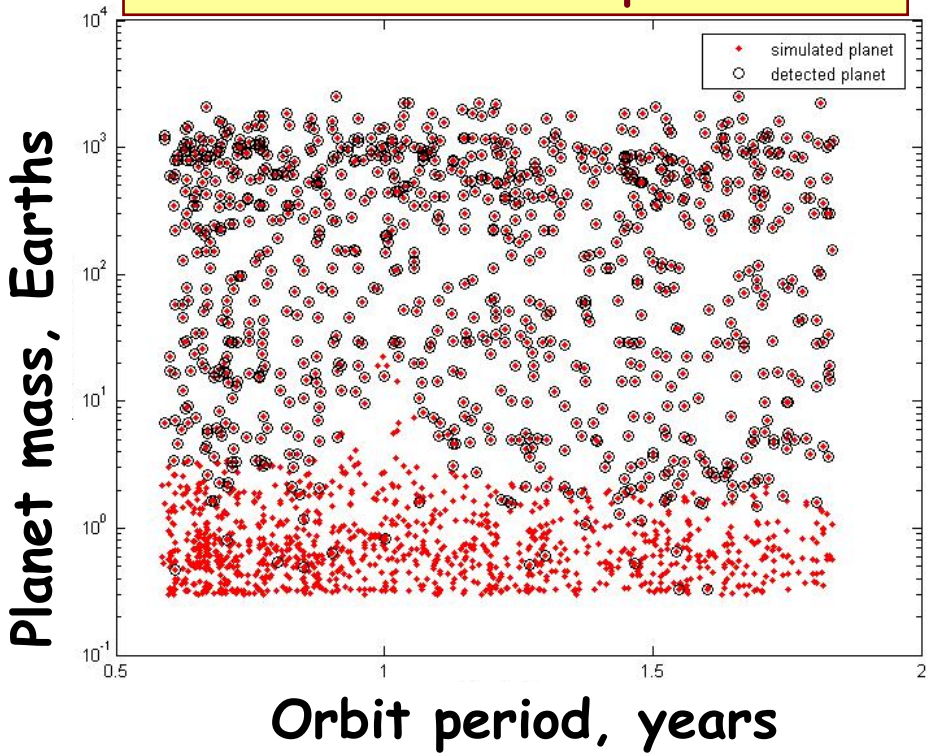
SIM performance, 10 year mission

	Planet mass sensitivity, units of M_{earth}		
Survey mode	Minimum	Median	Maximum
Medium-deep 240 stars, 104 2D obs	0.3	3.1	4.0
Deep 120 stars, 208 2D obs	0.2	1.8	2.2
Ultra-deep 60 stars, 416 2D obs	0.2	1.0	1.3

SIM will put planet formation theories to the test

- Micro-arcsecond angular resolution makes SIM uniquely sensitive for astrometric detection and characterization of rocky planets in the habitable zones of solar-type stars.
- SIM launches in 2015/2016, and during a five-year mission, can survey 5-10% of the solar-type stars within 30 pc for the presence of rocky planets.

SIM discovery space: habitable zone of a solar mass star at 10 pc



Mass & period distribution, from simulations (Ida and Lin 2006 – in situ cores)

Reference

"Astrometric Detection of Terrestrial Planets in the Habitable Zones of Nearby Stars with SIM PlanetQuest", by Joseph Catanzarite, Michael Shao, Angelle Tanner, Stephen Unwin, and Jeffrey Yu, 2006 PASP 118, 1319-1339