



Jet Propulsion Laboratory
California Institute of Technology

Future Exoplanet Missions

Wes Traub

KISS Workshop on Planetary Magnetic Fields

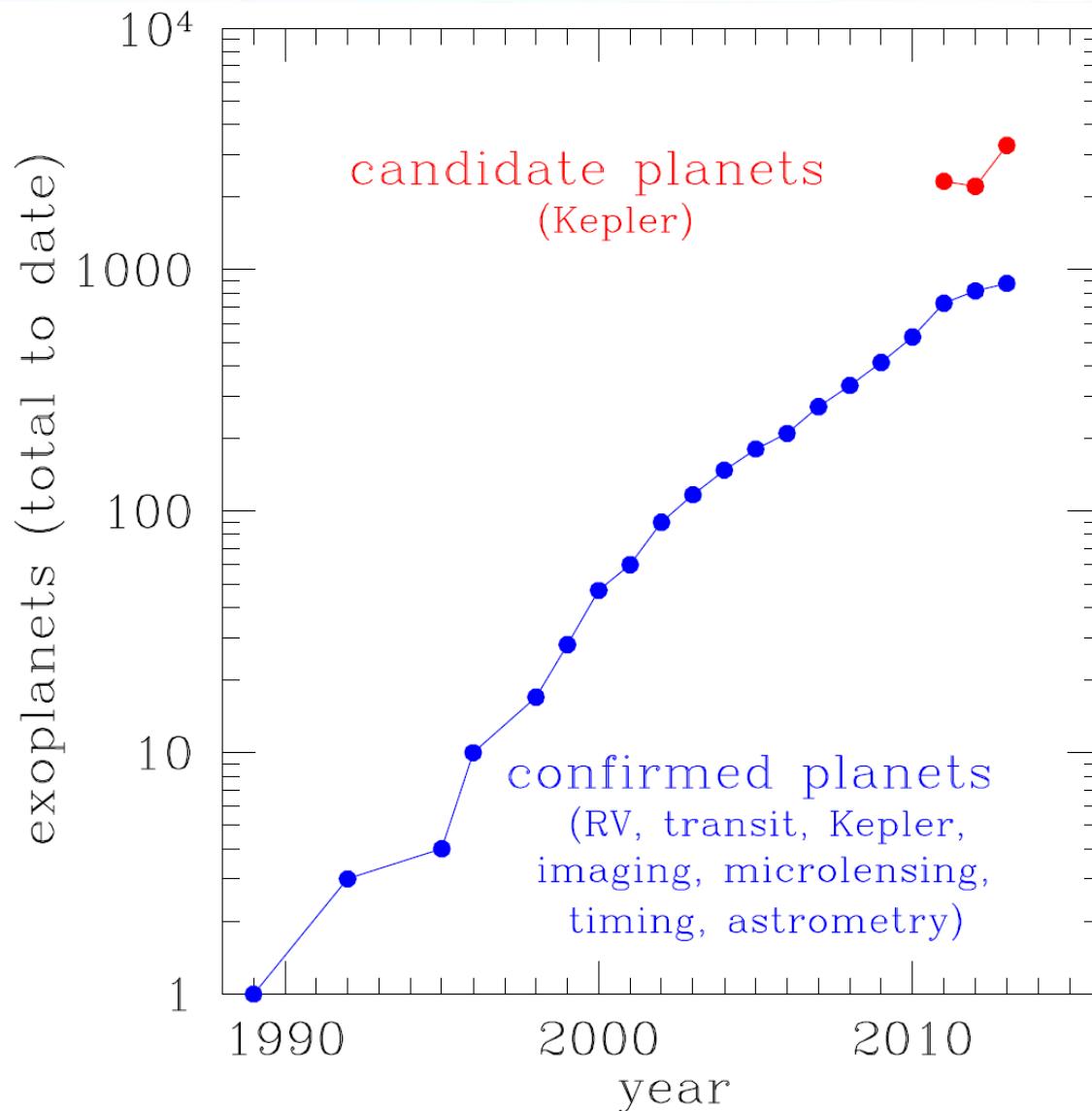
12-16 August 2013, Caltech

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ExoPlanet Exploration Program

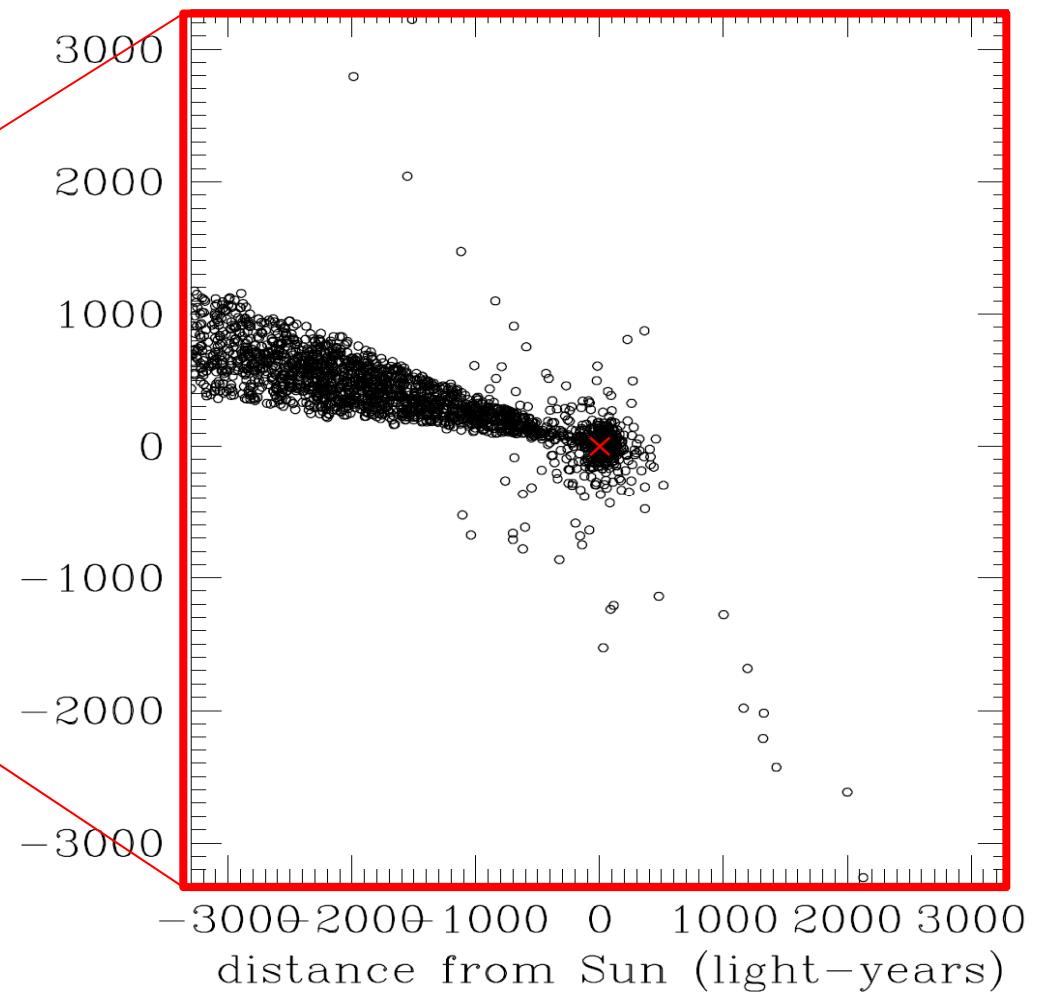
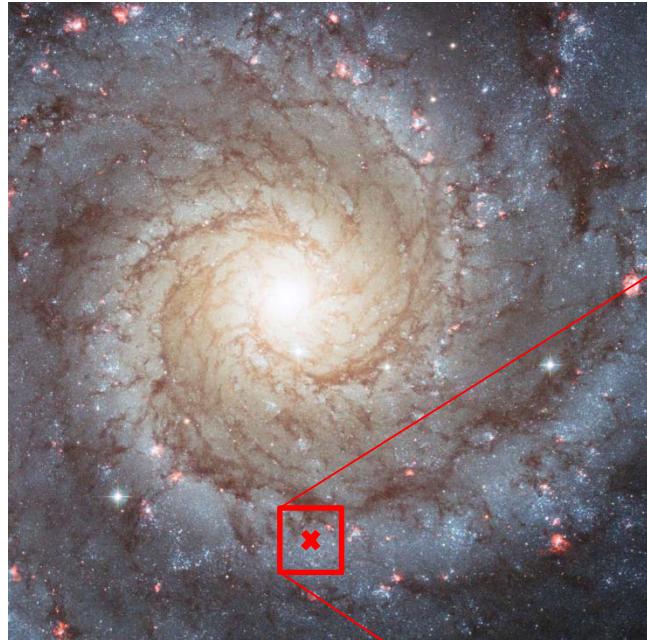
Total # exoplanets, confirmed & candidates



Ref.: data from http://exoplanetarchive.ipac.caltech.edu/docs/counts_detail.html and <http://exoplanet.eu/>

Most known exoplanets are from Kepler

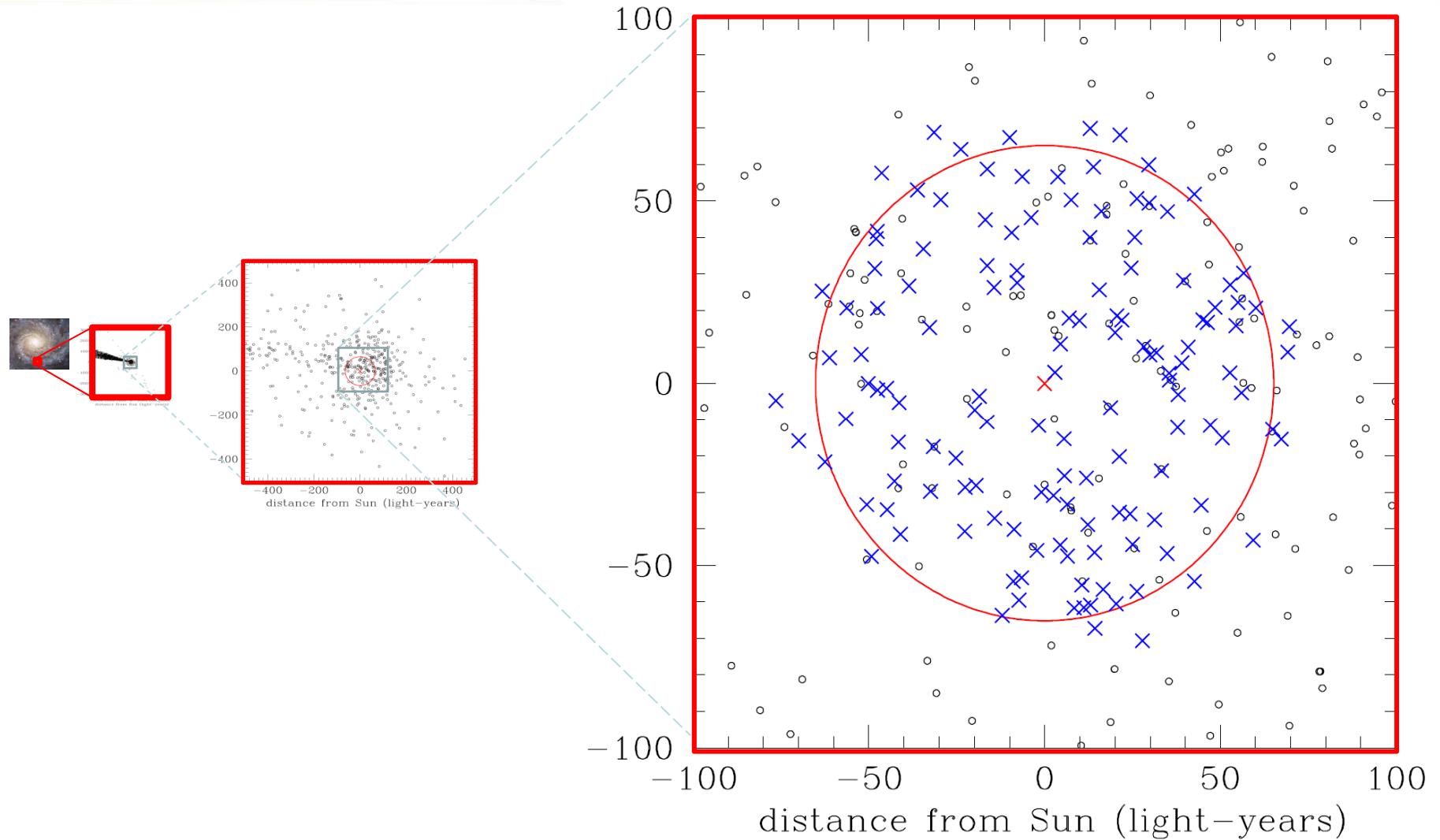
ExoPlanet Exploration Program



Other "spokes" are from ESA's Corot.
Local "cloud" of points from ground-based telescopes.

And now add the AFTA target stars ...

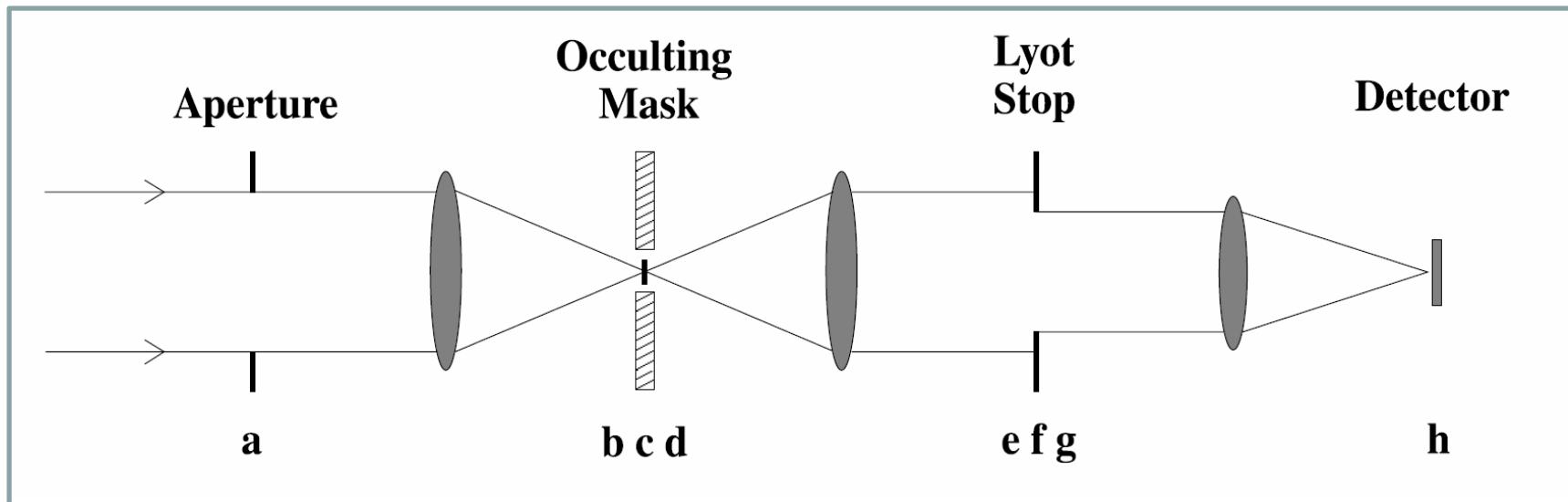
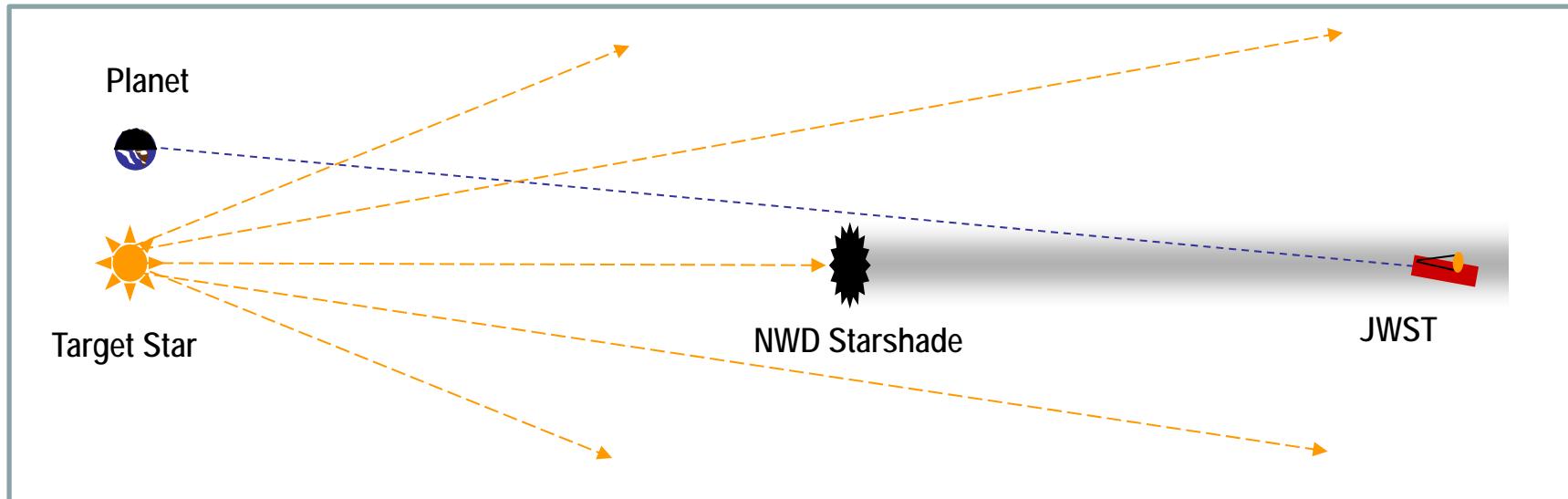
ExoPlanet Exploration Program



Each **X** is a prime target star for searching for "Earth-like" planets, out to 65 light years.
So there are many nearby stars where we can search for "Earth-like" exoplanets!

External and Internal Coronagraphs

ExoPlanet Exploration Program





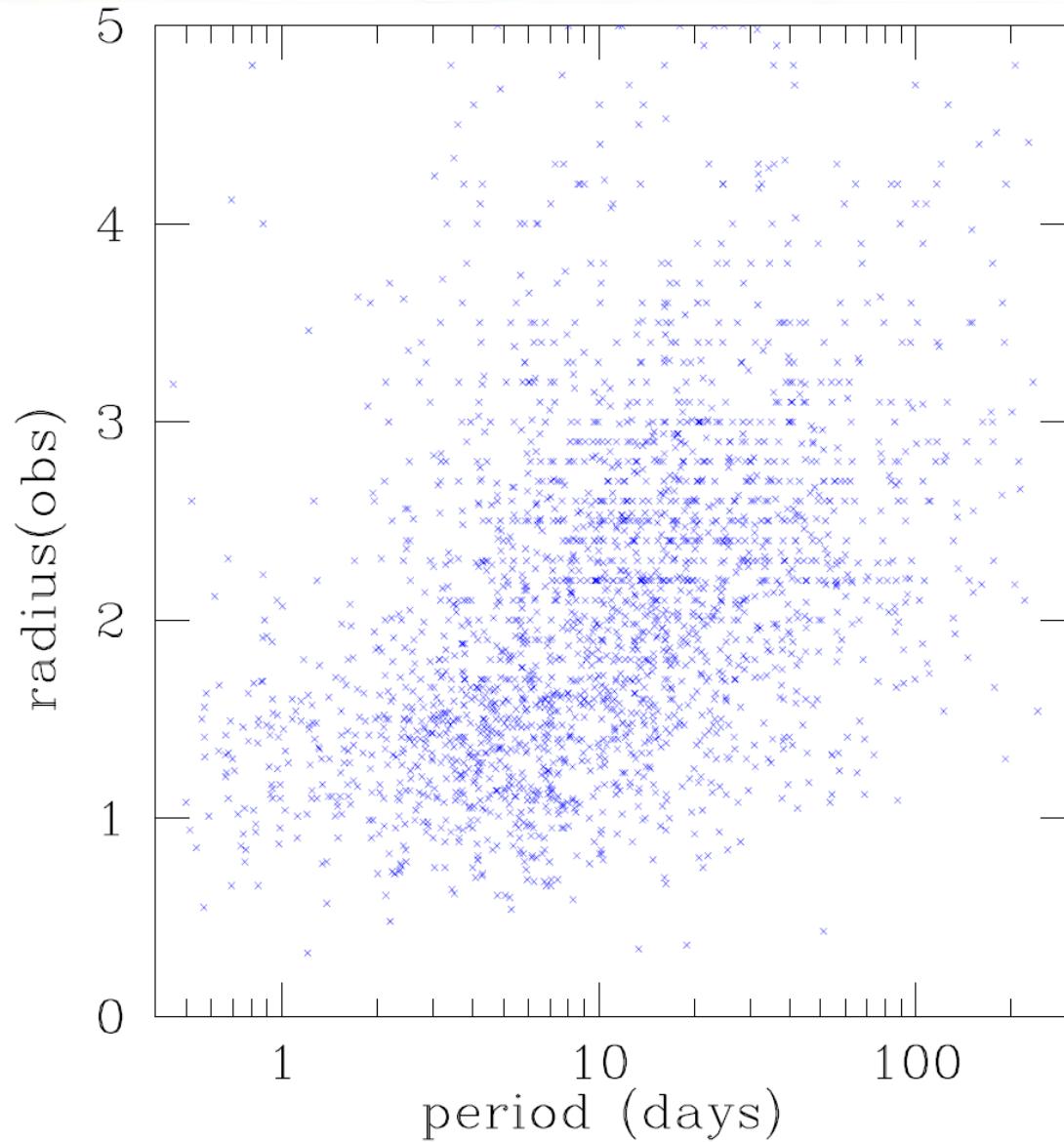
ExoPlanet Exploration Program

Current plans for exoplanets

- **Kepler** completed its mission, found 138 planets, & 3548 candidates, new mission science being solicited
- **JWST** will have a simple band-limited coronagraph that will be able to see companion stars but not exoplanets, launch Oct 2018
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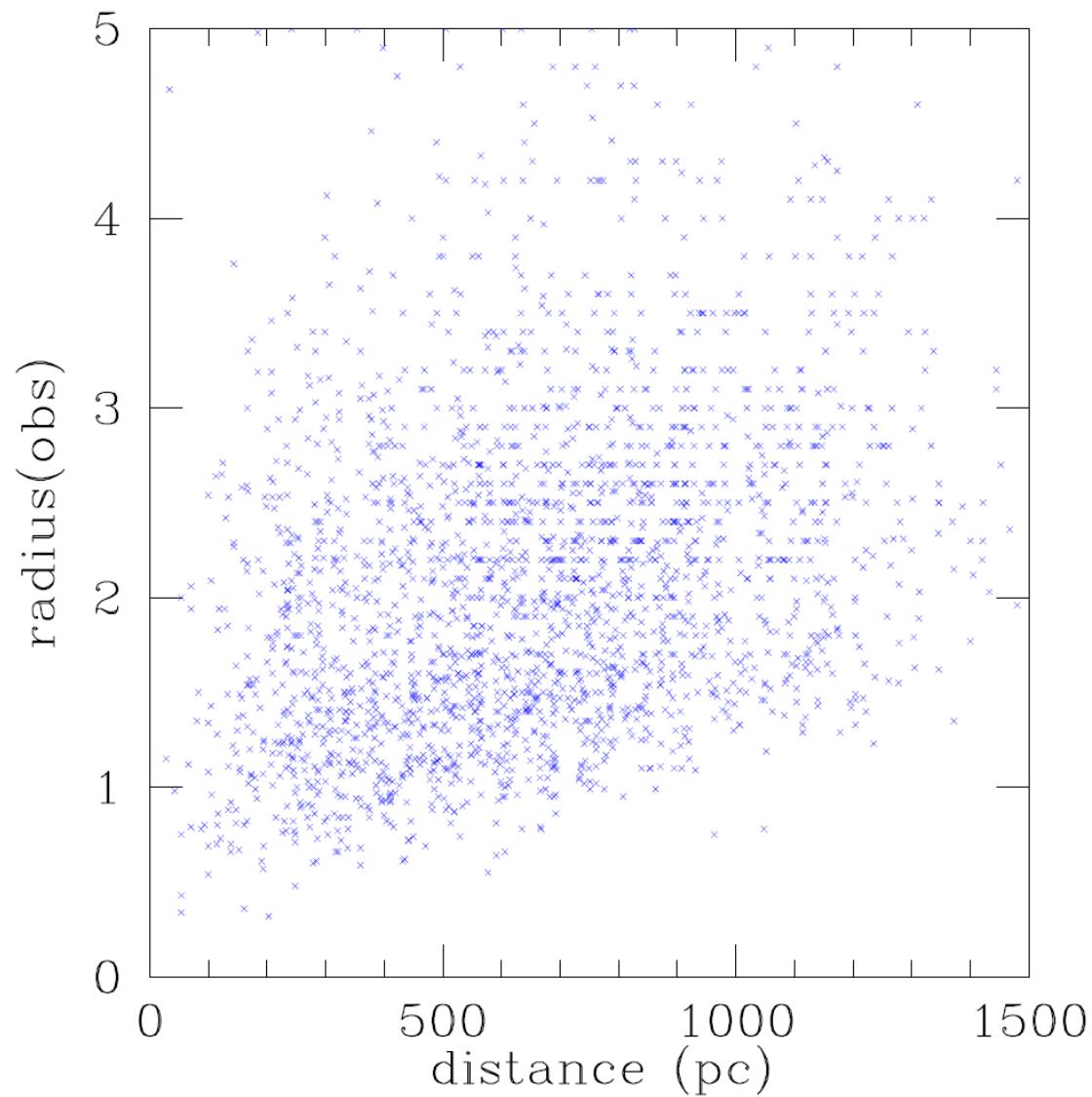
Radius vs Period (Kepler)



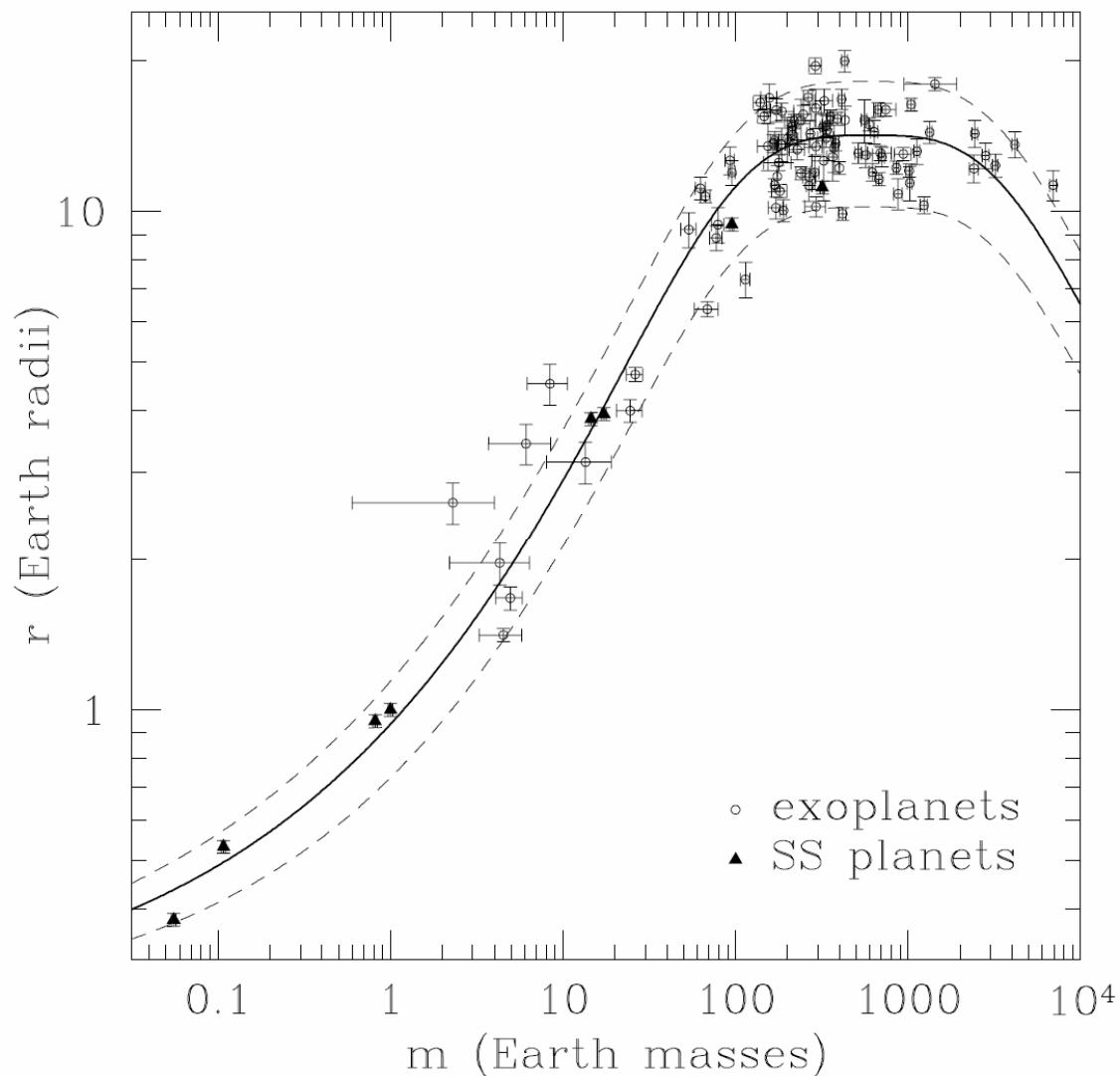


Radius vs Distance (Kepler)

ExoPlanet Exploration Program



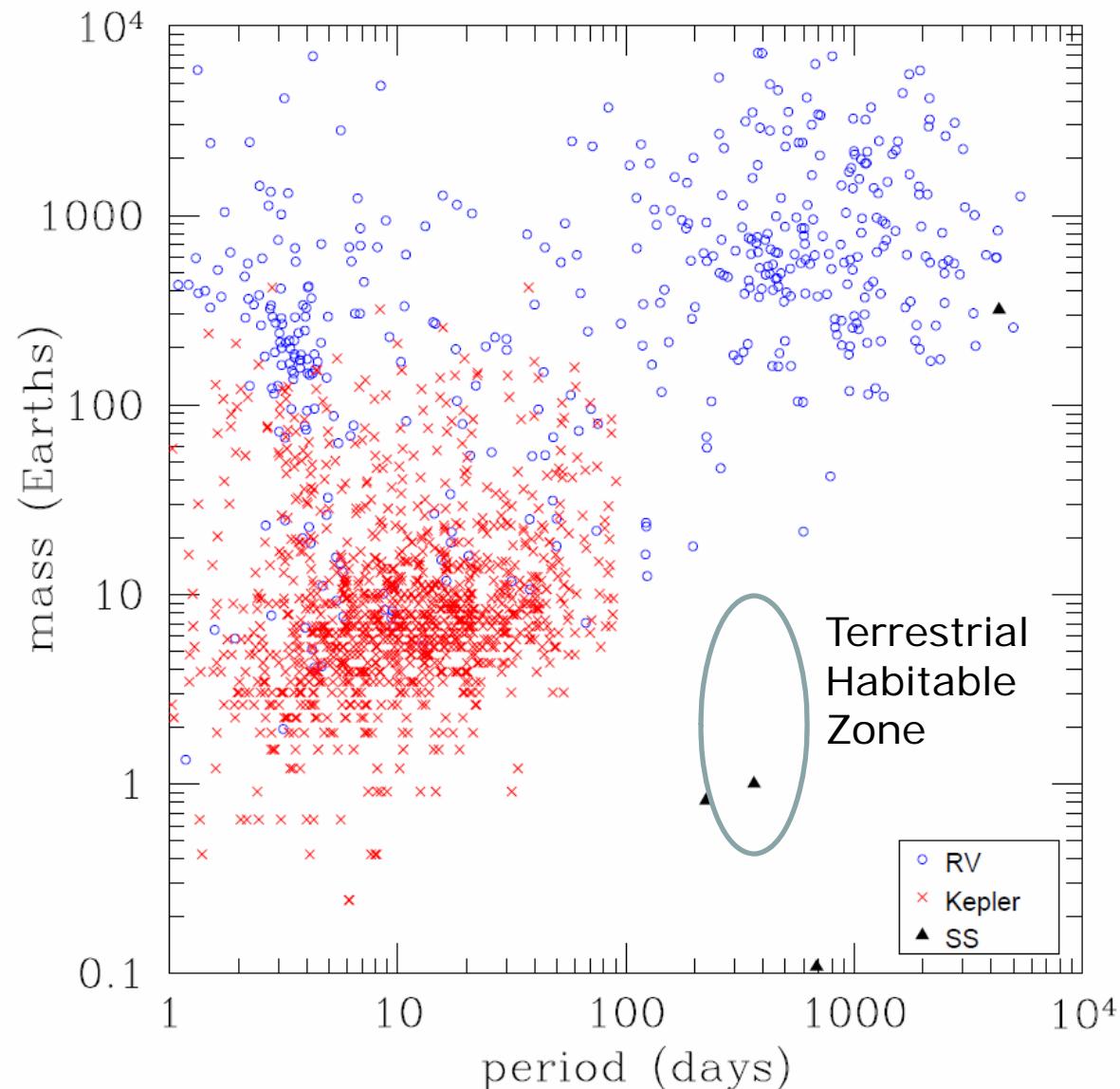
All measured planet masses & radii



Smooth curve is a best fit to all data.

Curve can be used to convert Kepler's radii to Kepler masses.

All exoplanet $M_{\text{sin}(i)}$ and $M(\text{Kepler, est.})$ masses vs orbital period



AFTA modified to show Earths & strong zodi/EKB

ExoPlanet Exploration Program

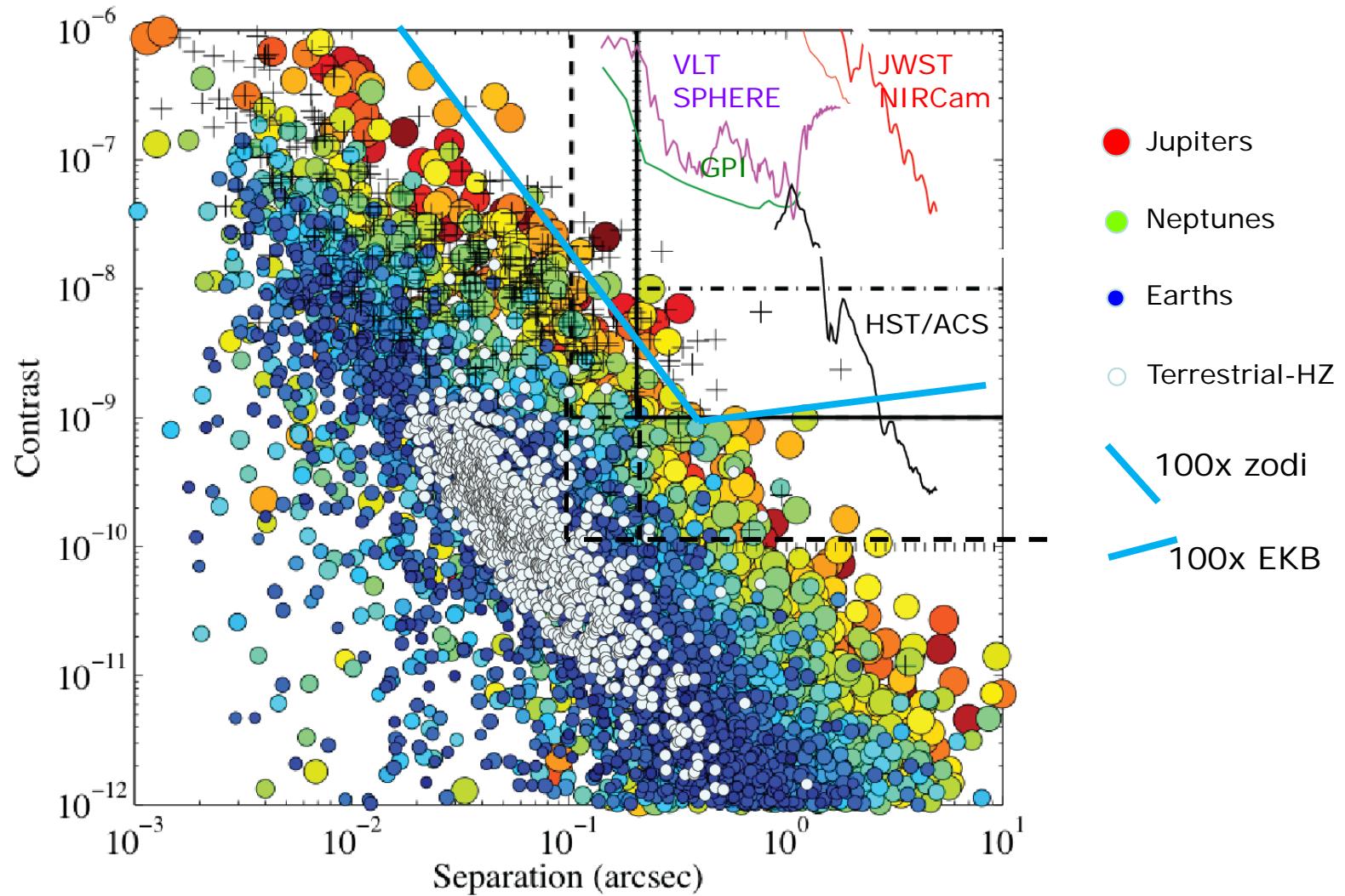
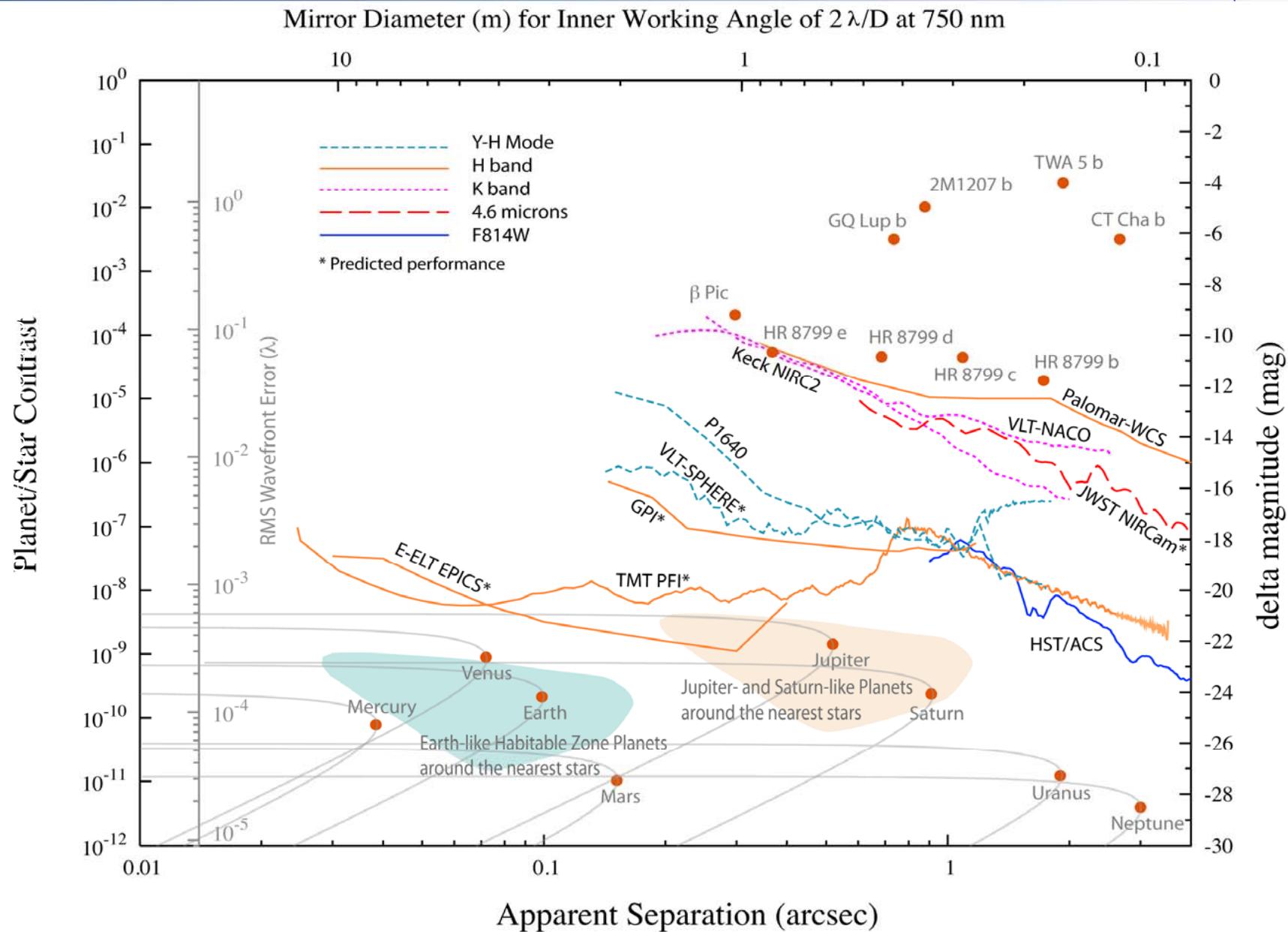


Fig. from AFTA Final Report 2013, for 2.4-m, modified by Traub & Lawson



State of the Art in Exoplanet Imaging

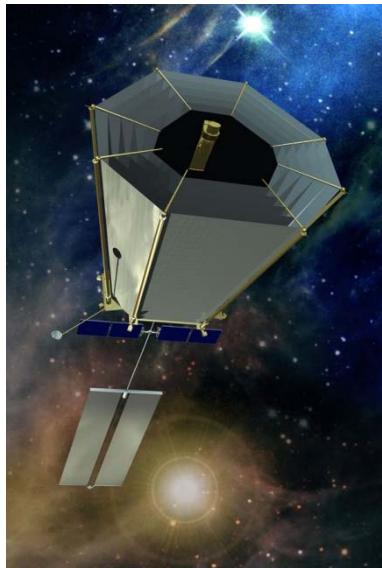
ExoPlanet Exploration Program



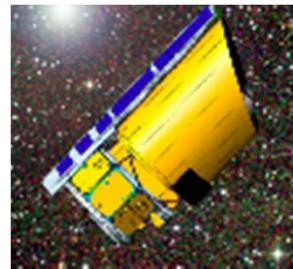
Illustrative Exoplanet Mission Concepts



ExoPlanet Exploration Program



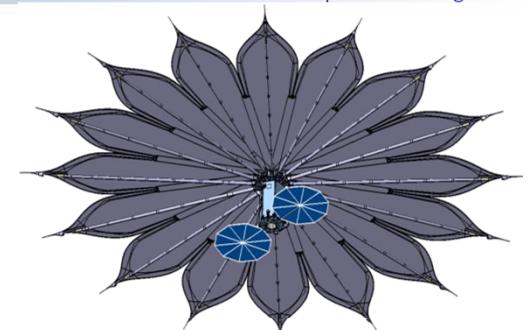
Terrestrial Planet
Finder Coronagraph



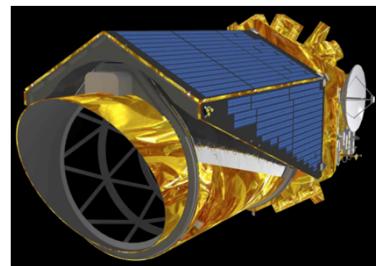
Pupil-Mapping Exoplanet
Coronagraphic Observer



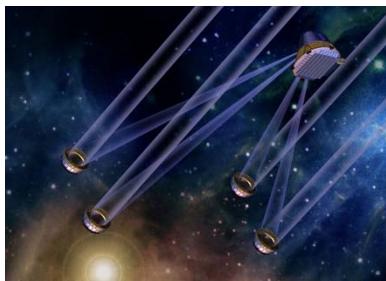
Actively-Corrected
Coronagraph for
Exoplanet System
Studies



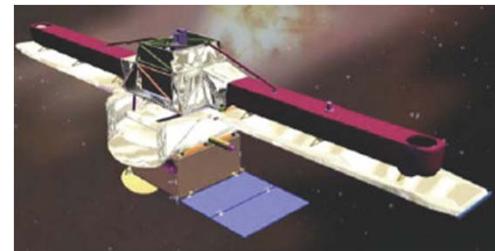
NWO
New Worlds Observer



Extrasolar Planetary Imaging
Coronagraph



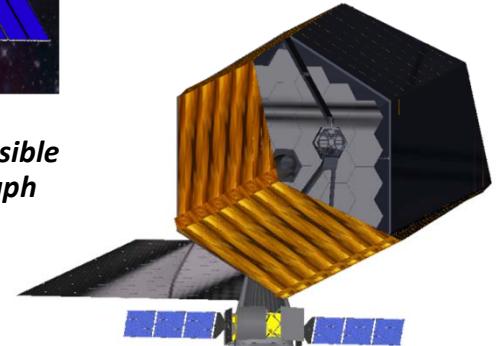
Terrestrial Planet
Finder Interferometer



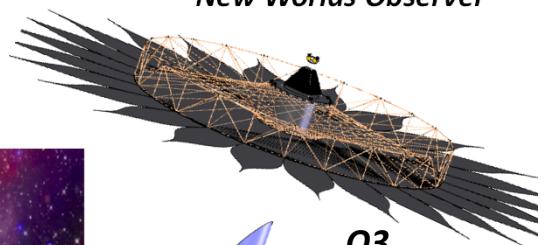
Fourier-Kelvin Stellar
Interferometer



Dilute Aperture Visible
Nulling Coronagraph
Imager



ATLAST Advanced Technology
Large-Aperture Space Telescope



O3
Occulting
Ozone
Observatory



Selected Coronagraph Concepts

ExoPlanet Exploration Program

Image Plane Amplitude & Phase Mask (Trauger, JPL)

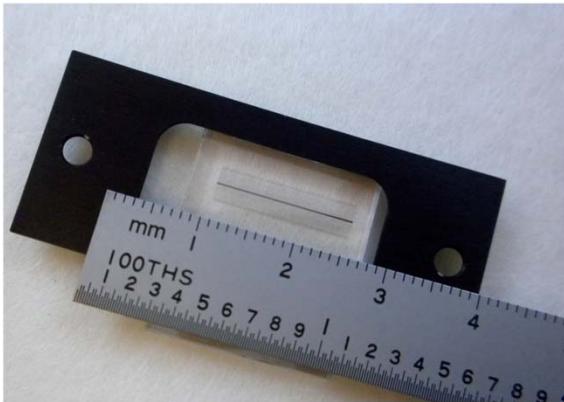
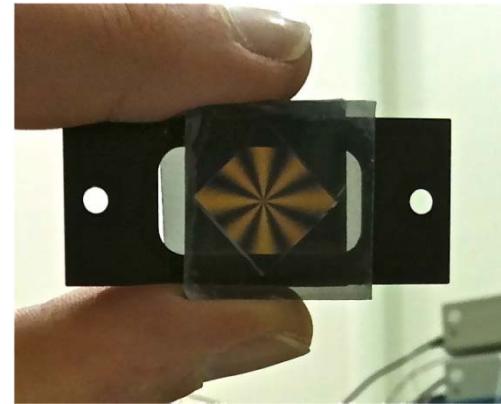
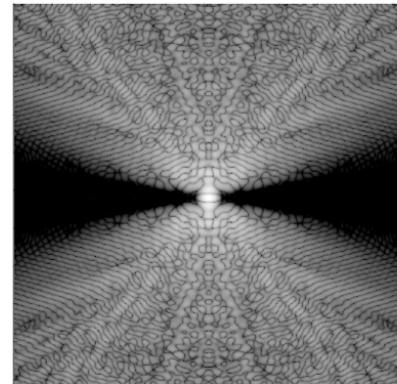
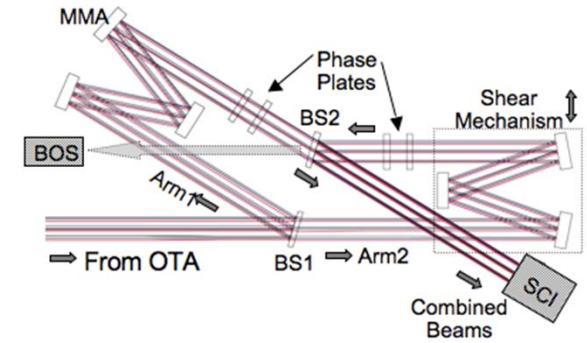


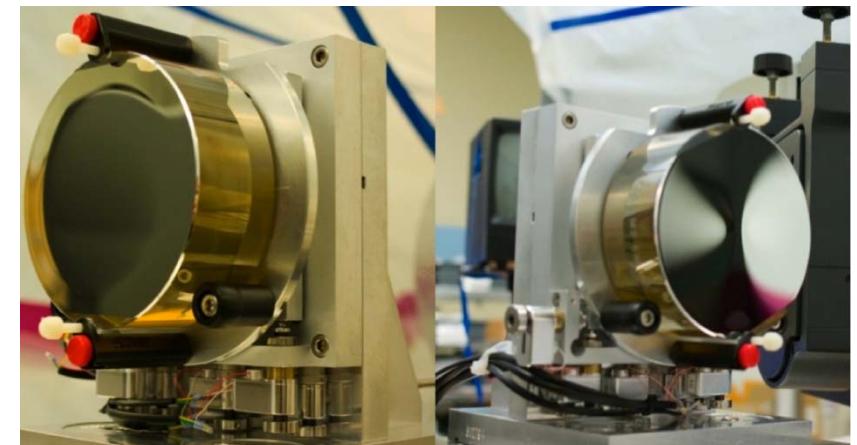
Image Plane Phase Mask (Serabyn, JPL)



Pupil Shearing (Clampin, NASA GSFC)



Pupil Masking (Vanderbei, Univ. Princeton)

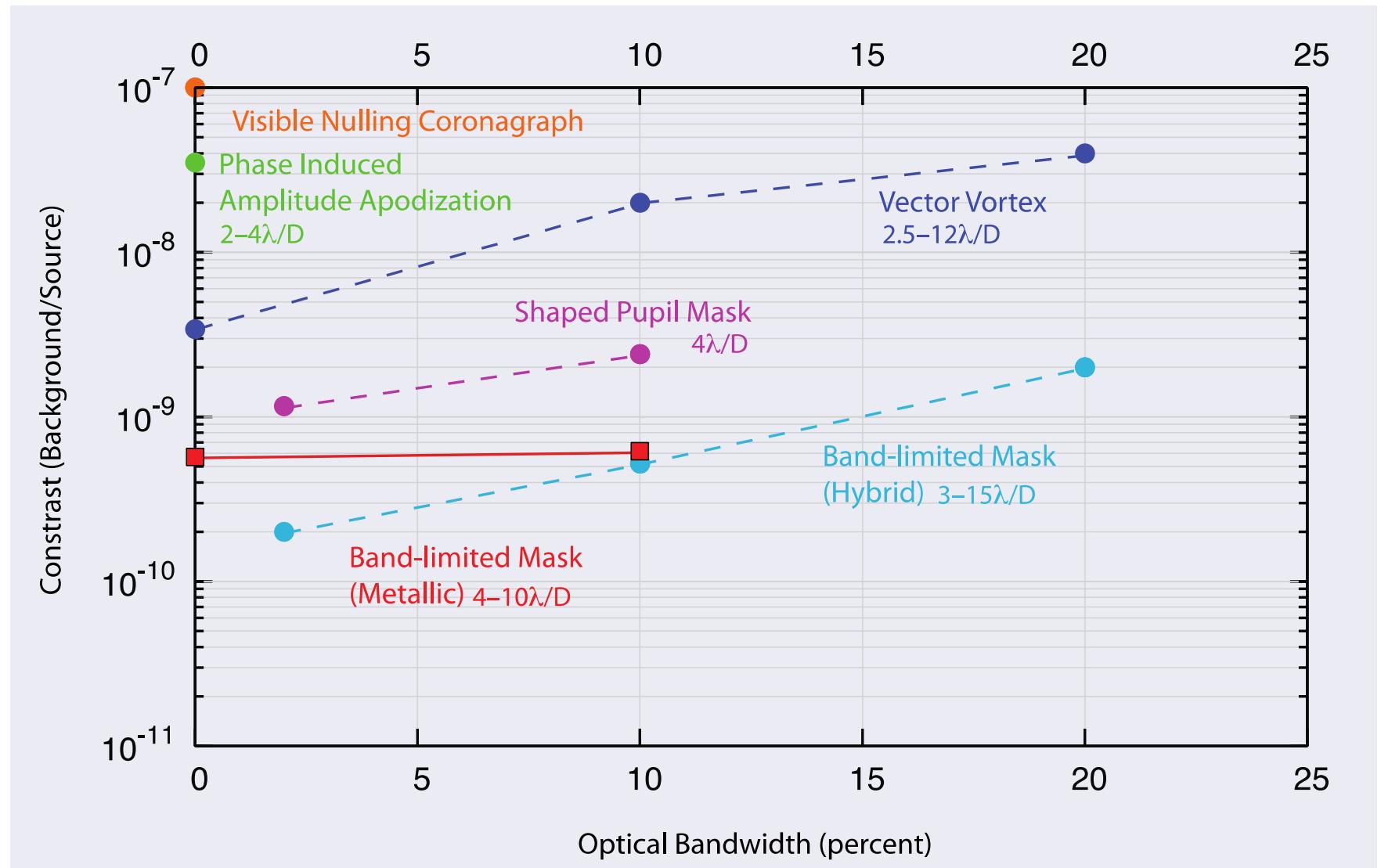


Pupil Mapping (Guyon, Univ. Arizona)



ExoPlanet Exploration Program

State-of-the-Art in Coronagraph Lab Experiments



Eta-Earth: number of Earth-like planets per star



ExoPlanet Exploration Program

- 2011: Catanzarite & Shao estimated 1-3% from early Kepler data
- 2012: Traub estimated $34 \pm 14\%$, same data
- 2013: Gaidos estimates $46 (\pm 16) \%$, from newer Kepler data
- 2013: Dressing & Charboneau est. 15% for M dwarfs from Kepler
- 2013: Kopparapu revised that up to 48 % with new HZ definition
- 2013: Bonfils etal estimate 41% for M dwarfs from RV
- Average value is roughly 25%, about 1 star in 4
- Milky Way has about 200 billion stars (red dwarfs plus Sun-like)
- So there could be about 50 billion Earth-like planets in our Galaxy

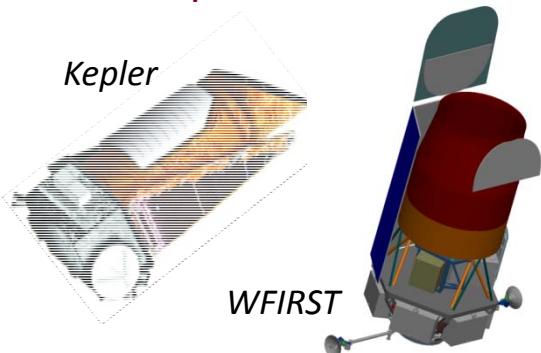
The Exoplanet Exploration Program



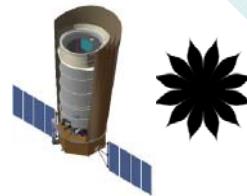
ExoPlanet Exploration Program

*Exploring How the Universe Works
Discovering and Characterizing Earth-like Planets
Searching for Life on other Worlds*

Space Missions and Mission Studies



Probe-class
mission studies



Public Engagement

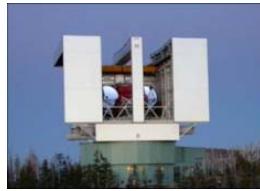


Supporting Research & Technology

Key Sustaining Research



Keck Single Aperture
Imaging and RV



Large Binocular
Telescope Interferometer

Technology Development

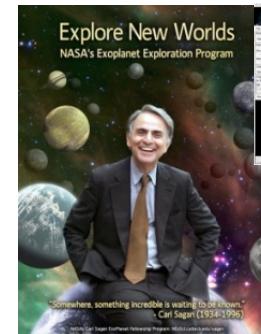


High Contrast
Imaging



Deployable
Star Shades

Archives, Tools & Professional Education



NASA Exoplanet Science Institute



AFTA-2.4 Exoplanet Science



ExoPlanet Exploration Program

The combination of microlensing and direct imaging will dramatically expand our knowledge of other solar systems and will provide a first glimpse at the planetary families of our nearest neighbor stars.

Microlensing Survey

Monitor 200 million Galactic bulge stars every 15 minutes for 1.2 years

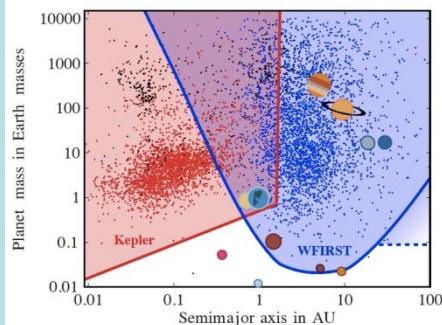
2800 cold exoplanets
300 Earth-mass planets
40 Mars-mass or smaller planets
40 free-floating Earth-mass planets

High Contrast Imaging

Survey up to 200 nearby stars for planets and debris disks at contrast levels of 10^{-9} on angular scales $> 0.2''$
 $R=70$ spectra and polarization between 400-900 nm

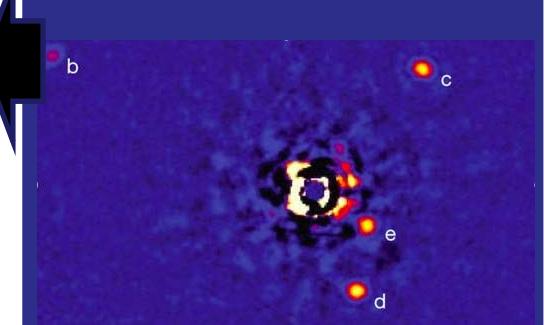
Detailed characterization of up to a dozen giant planets.
Discovery and characterization of several Neptunes
Detection of massive debris disks.

Complete the Exoplanet Census



- **Identification and characterization of nearby habitable exoplanets**
- **How diverse are planetary systems?**
- **How do circumstellar disks evolve and form planetary systems?**
- **Do habitable worlds exist around other stars, and can we identify the tentative signs of life on an exoplanet?**

Discover and Characterize Nearby Worlds



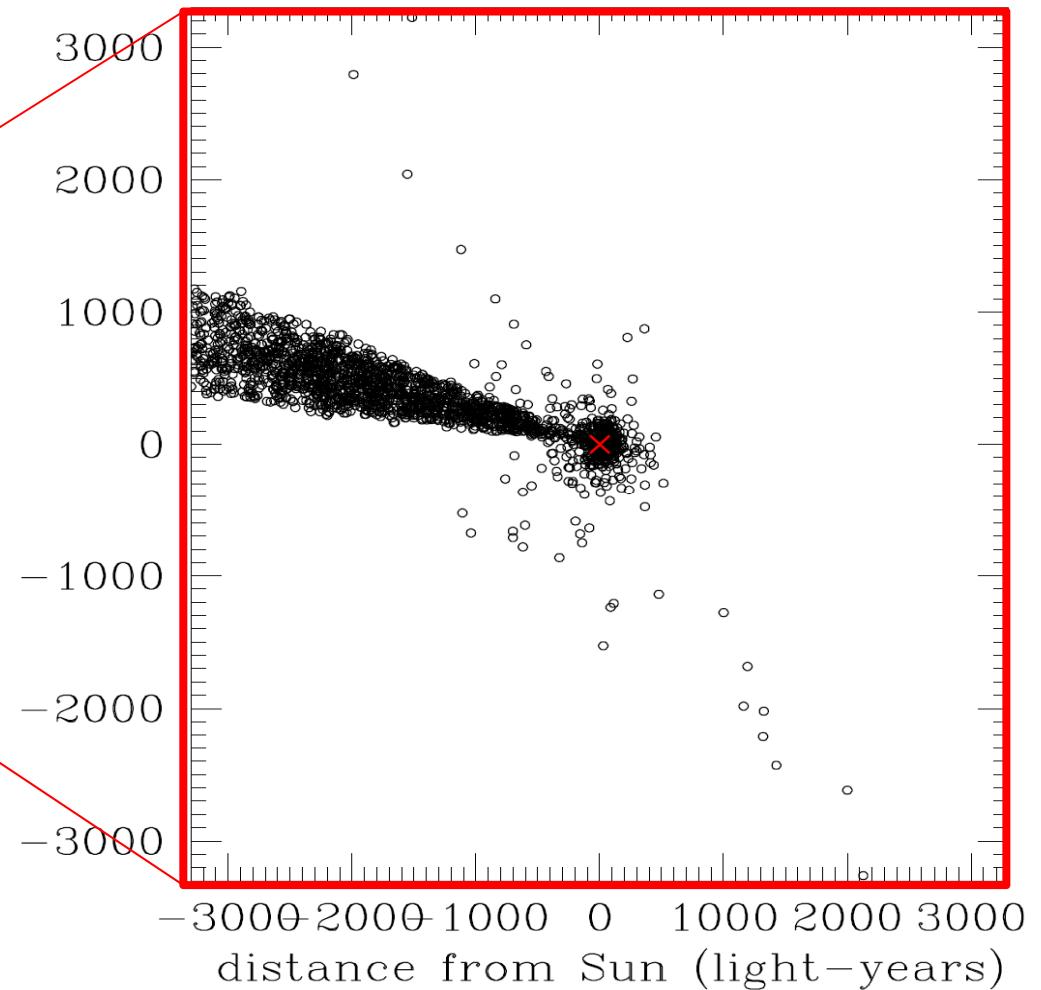
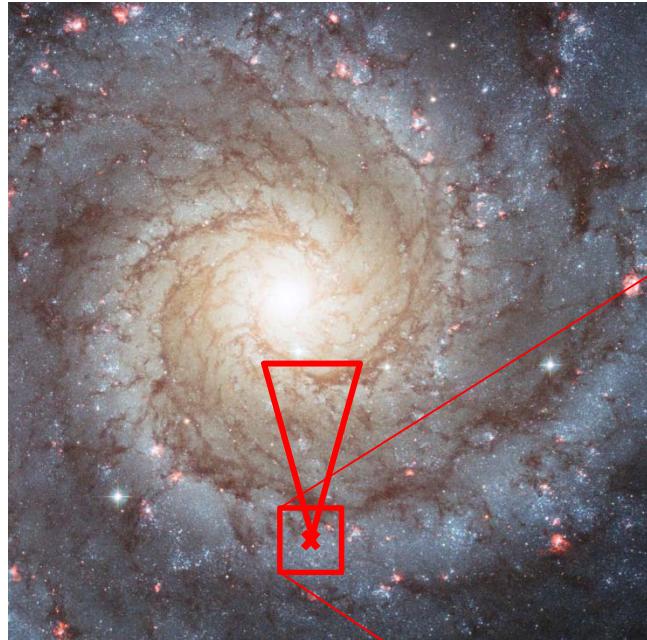


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AFTA: microlensing & direct imaging



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AFTA modified to show Earths & strong zodi/EKB

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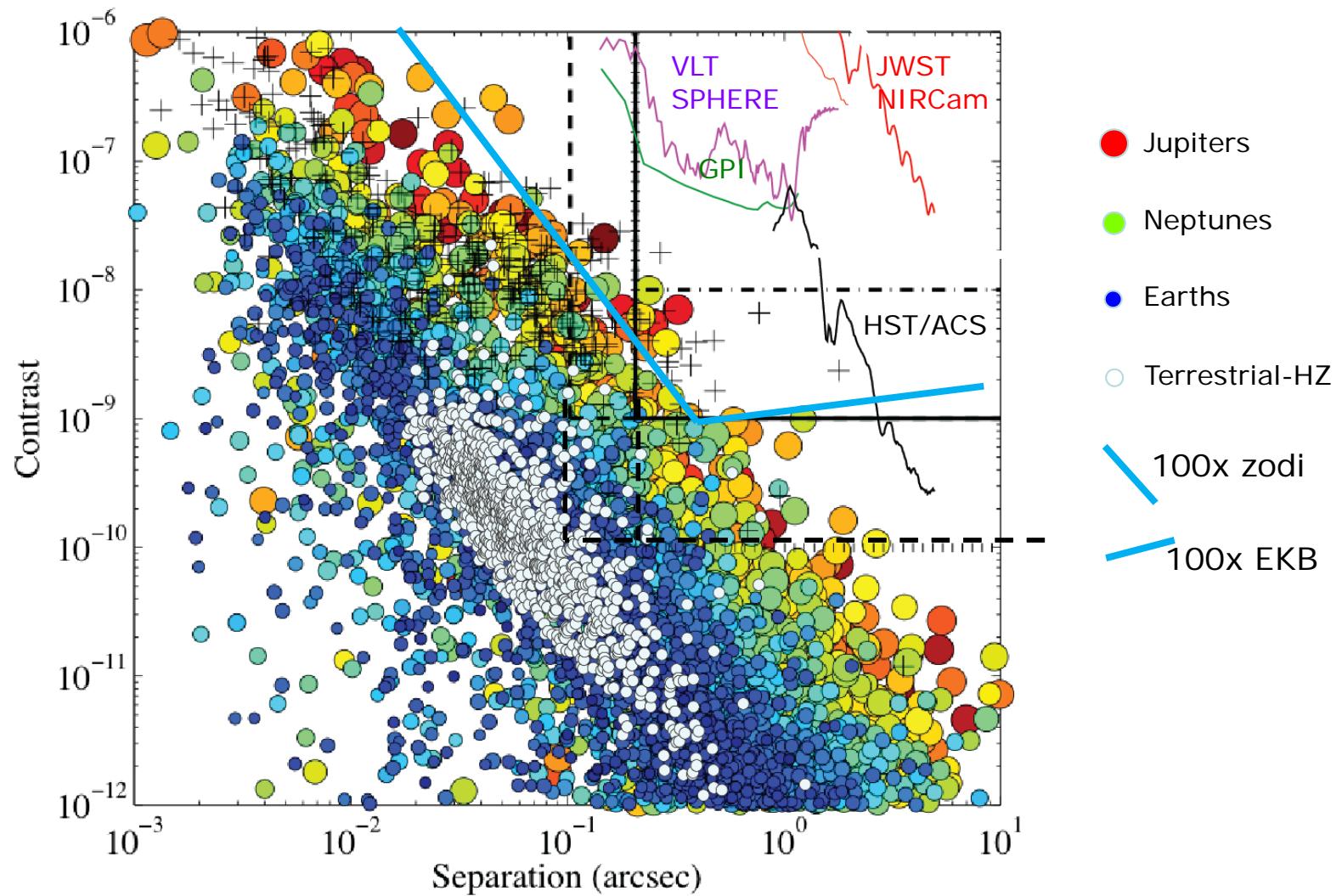


Fig. from AFTA Final Report 2013, for 2.4-m, modified by Traub & Lawson



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Thank you!