Searching for Planets Around Cool Stars

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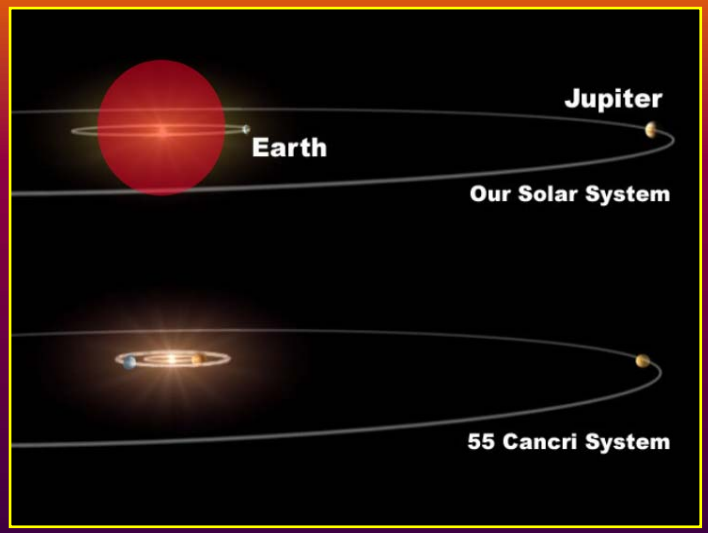
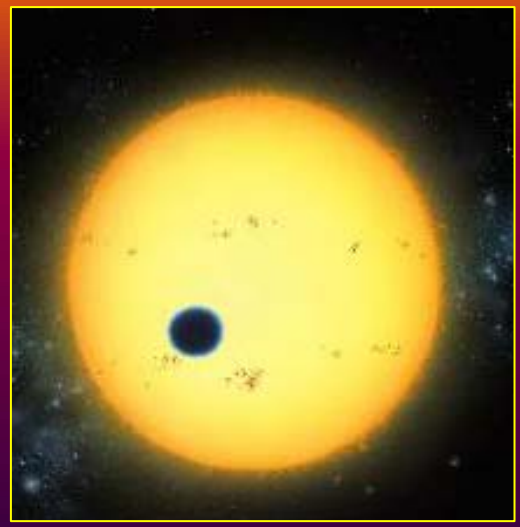
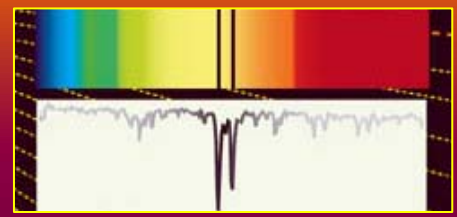
We are Using 21st Century Tools to Address 2,500 Year Old Questions

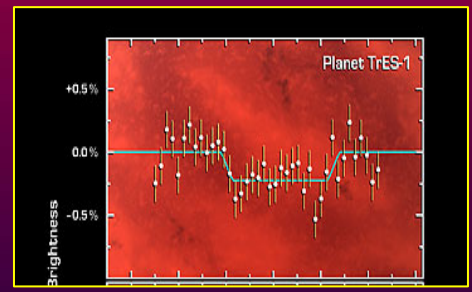


198 RV Planets

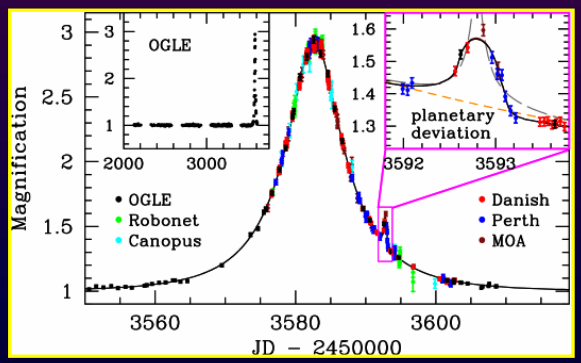


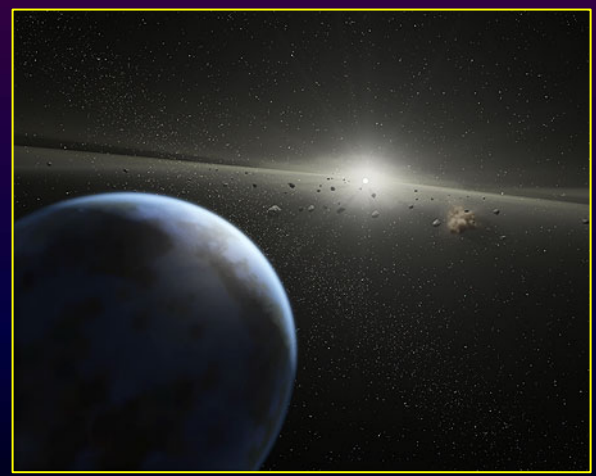
14 Transit Planets





Transits Heat/Spectra





4 Microlensing Planets (5.5 M⊕)

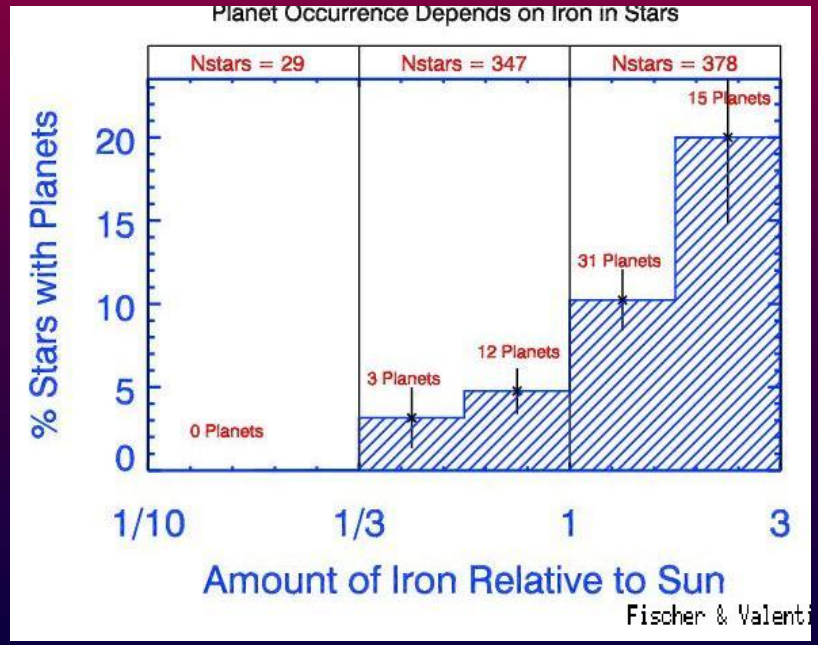
Hot Young Jupiters

Comet & Asteroid Belts

Astrophysics, Planets and Life

What are the astrophysical properties of stars that might lead to the formation and evolution of habitable planets and ultimately to the genesis of life itself?

- Rich/poor in heavy elements
  - Formation of planets →life
- More or less massive than Sun
  - Habitable planets around M stars, giant stars, white dwarfs
- Dynamical effects
  - Single or multiple stars
  - Tidal effects
  - Orbital stability in multiple systems
- Younger or older than the sun
  - Effects of stellar activity (U/X-rays) on planetary atmospheres, evolution of life
- With or without massive Kuiper or asteroid belts
  - Periods of late bombardment
  - Transport of volatiles

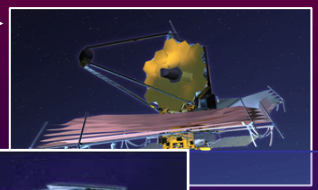


A Vision for Planet Finding

TPF-C/I

- Characterize temperature, size, composition of other Earths
- Look for signatures of Life

Distant Planets



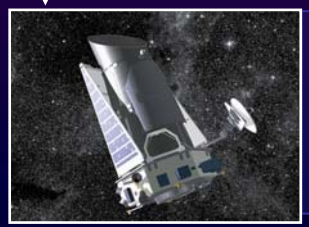
JWST

- Image 1-2 Jupiter's within 5 pc
- Image disks and distant hot young Jupiter's
- Follow–up Kepler "Jupiter's" with spectroscopy

SIM

- Search 200 *neighboring* stars for Earths (<30 pc)
- Determine architecture of systems
- Measure masses and orbits

Find Nearby Earths & Life



Kepler (2008)

- Transits to identify Jupiter's → Earths around 100,000 *distant stars* (<1 kpc) to determine incidence of Earths

Keck-I (2006)

- Dust disks at 10-100 zodi for nearby stars.
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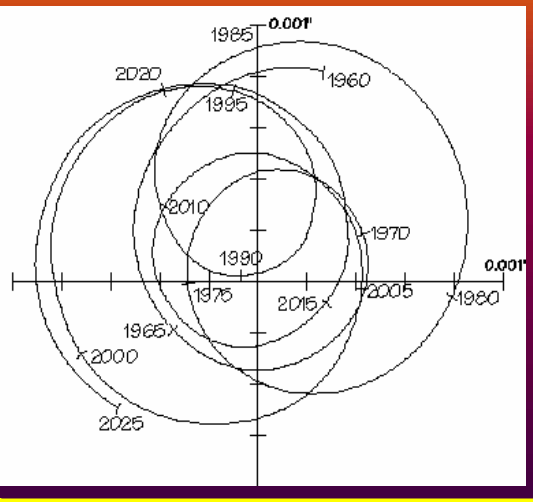
Looking For Habitable Planets Around *Nearby* Stars



SIM PlanetQuest will measure positional wobbles due to planets

What We Don't Know

1. Are there low-mass planets in 'habitable zone' ?
2. Are planetary systems like our own common?
3. How Do planets Evolve?

1. A Deep Search for Earths

- Study nearest ~150 Sun-like stars
- Detection limit of ~3 M_e at 30 ly
- Determine mass, orbits
- Make reconnaissance for TPF

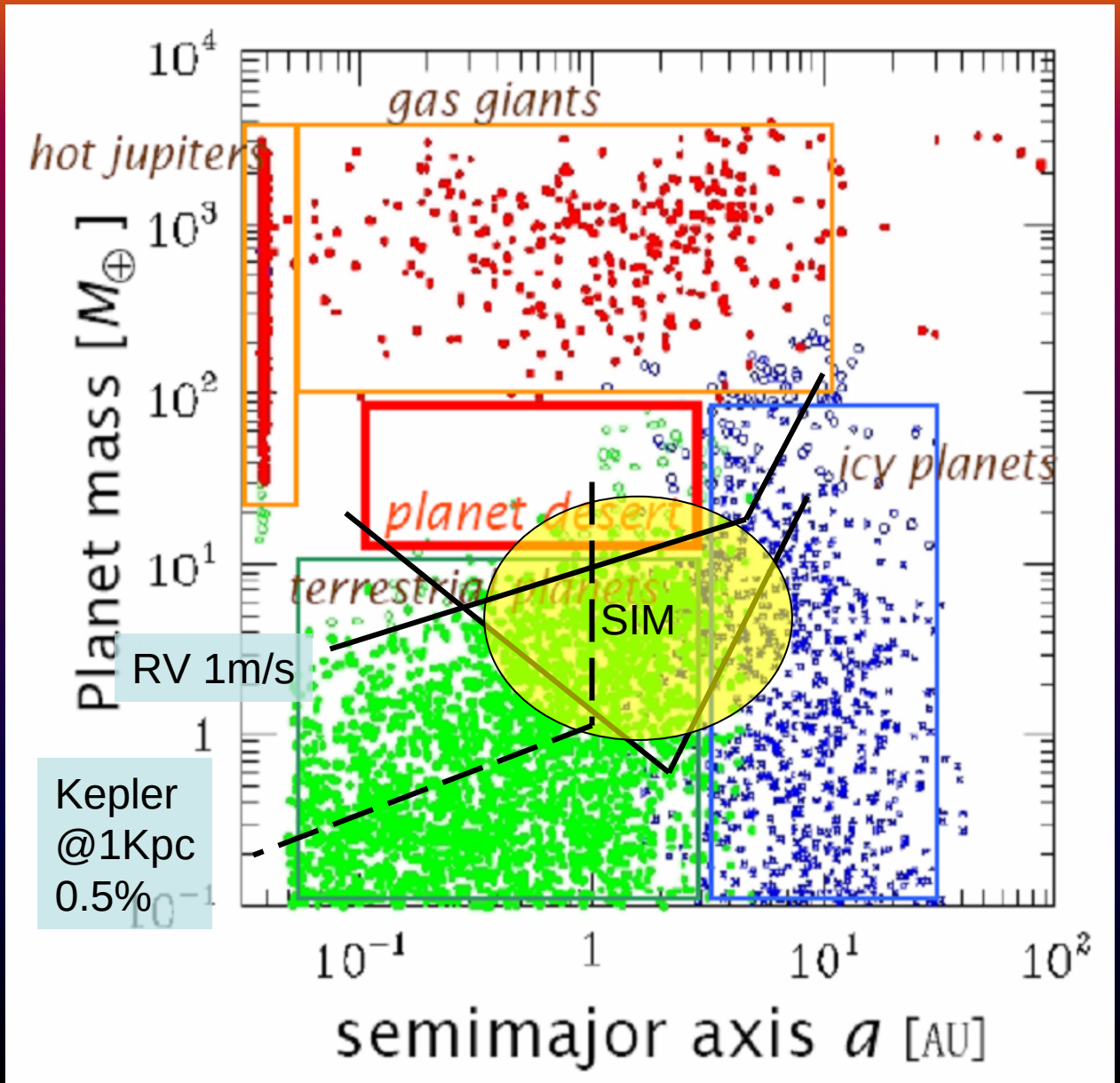
2. System Architecture

- Is our solar system unusual?
- Survey ~2,000 stars within ~100 pc
- Study wide variety of stars
- Detect and characterize multiple planet systems

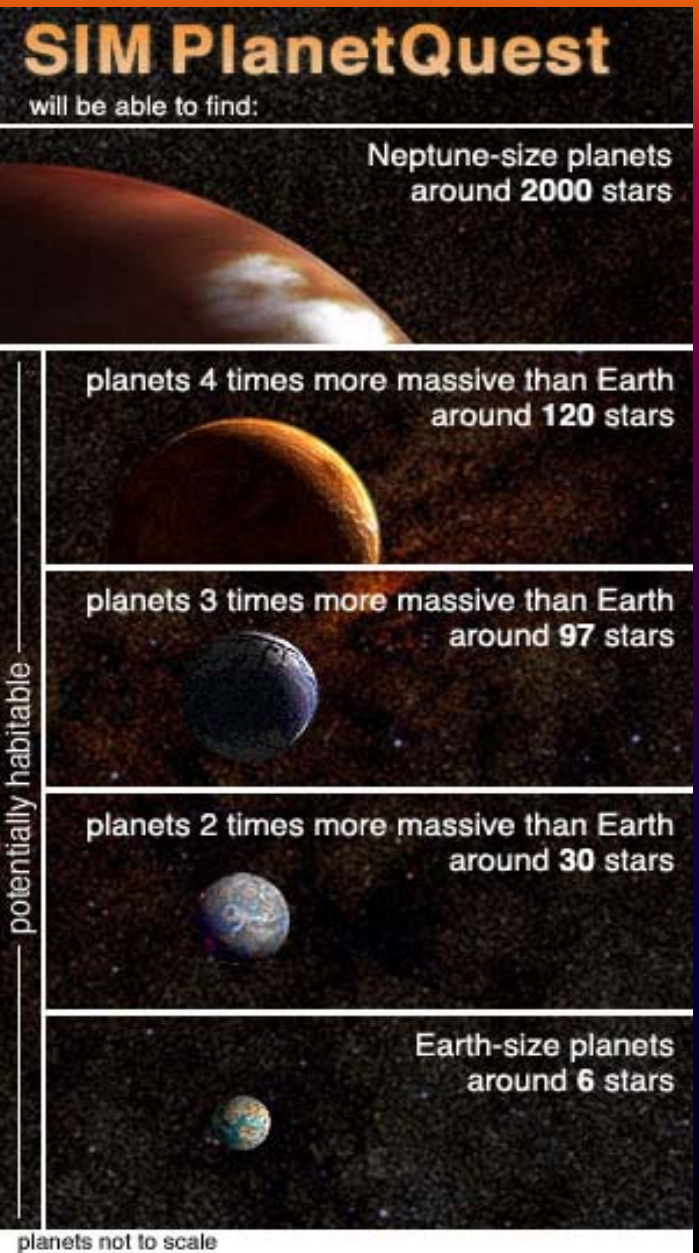
3. Evolution of Planets

- Survey ~200 1~50 Myr stars
- How do systems evolve?
- Is the evolution conducive to the formation of Earth-like planets in stable orbits?

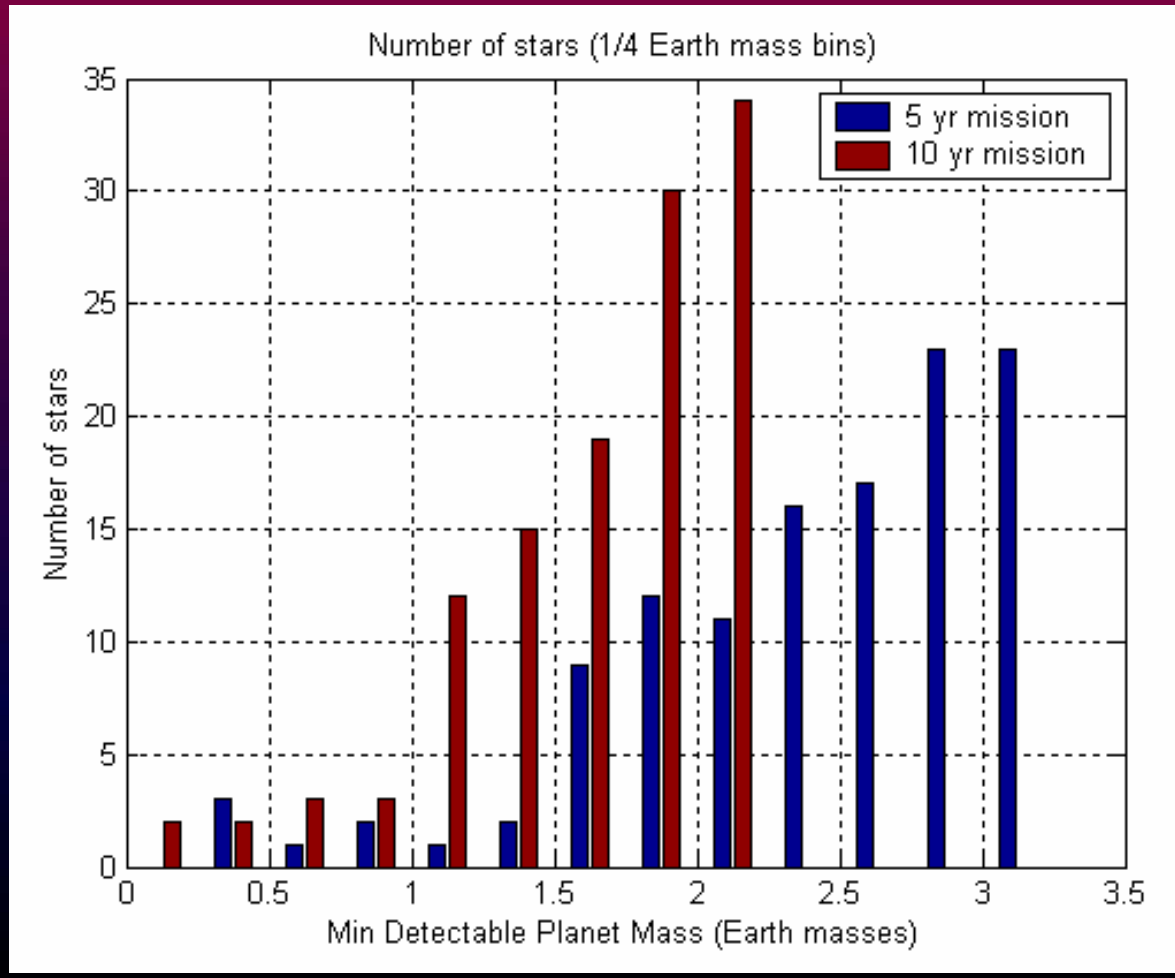
What Do We Expect to Find?



Deep Search of 100 Nearby Stars

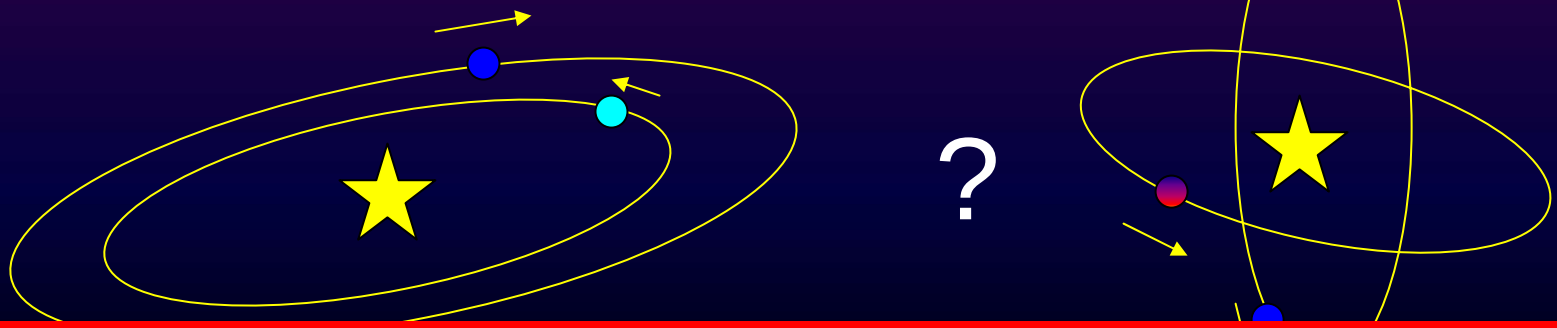


For the nearest 100 solar-type stars SIM has the capacity to detect earth mass planets in the Habitable Zone



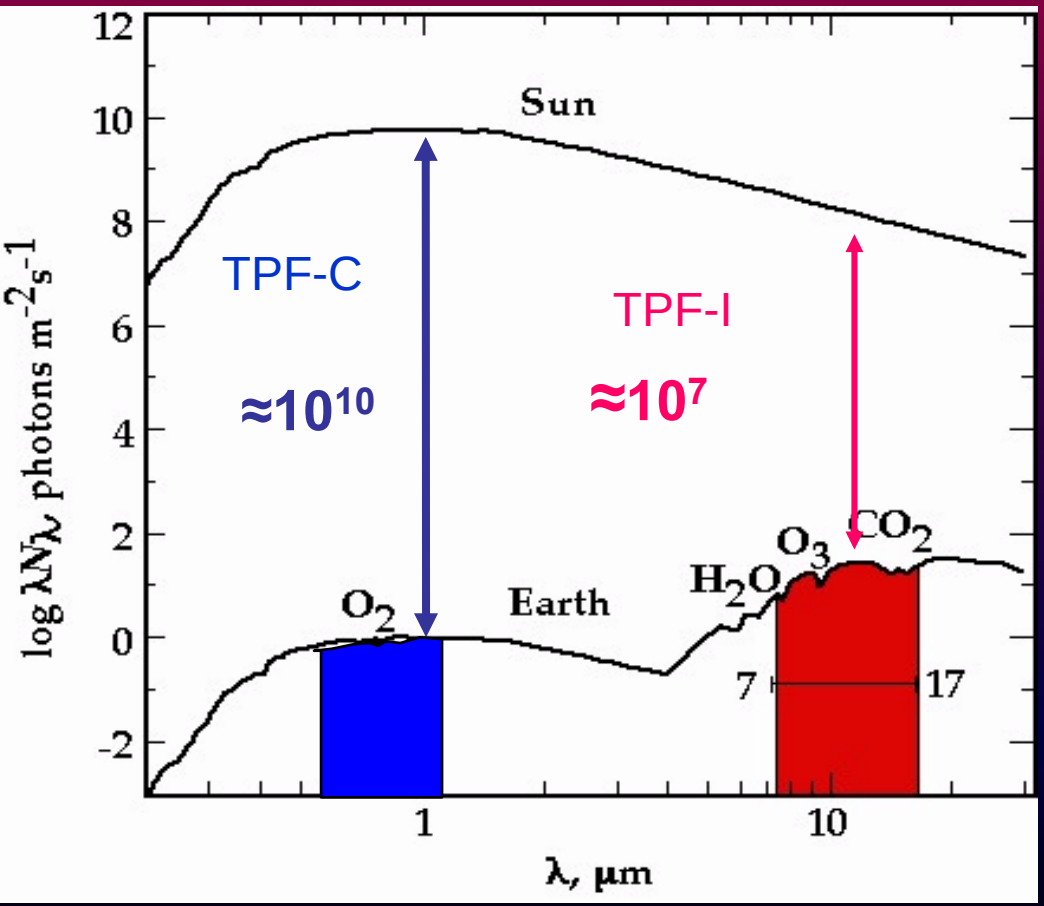
Planetary System Architectures & Diversity

- Comprehensive survey of 2,000 stars to probe Jovian/Neptunian planets (metallicity, debris disks, binary systems)
- Search for planets around stars not probed by any other technique (O, B, A, early F, white dwarfs).
- Uniquely probe for planets around young stars and thus provide insight into evolution of planetary systems
- *Only SIM can directly provide the masses, eccentricities, orbital directions, and mutual orbital inclinations of the planets it detects!*



SIM: Mature, Robust, Affordable, READY

Long Term Goal to Detect Photons from Planets Directly with the Terrestrial Planet Finder (TPF)/Darwin



- Collecting area of 6 m telescope
- Angular resolution for habitable zone at 10 pc:
  -- 4~8 m telescope in visible
  -- ~80 m IR interferometer
- Extreme contrast ratio

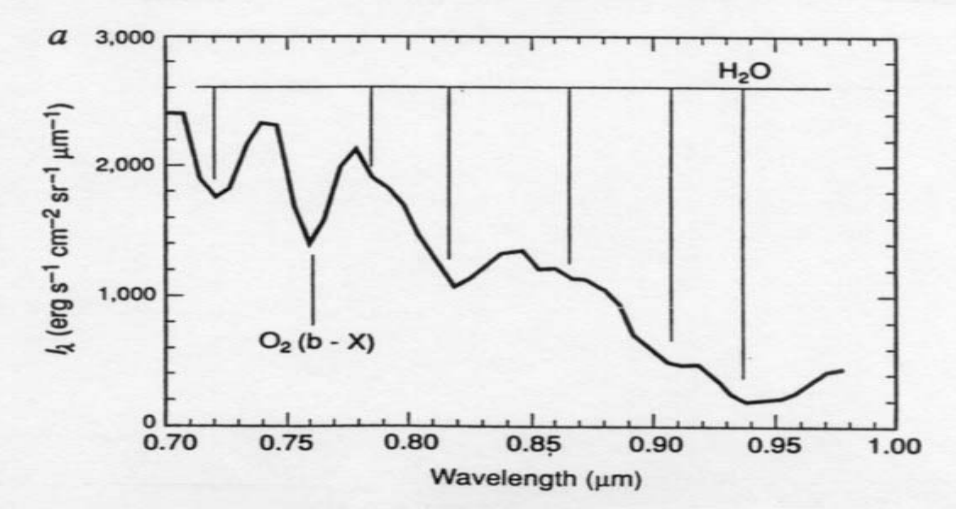
Potential Designs of Terrestrial Planet Finder

TPF-Interferometer
Darwin

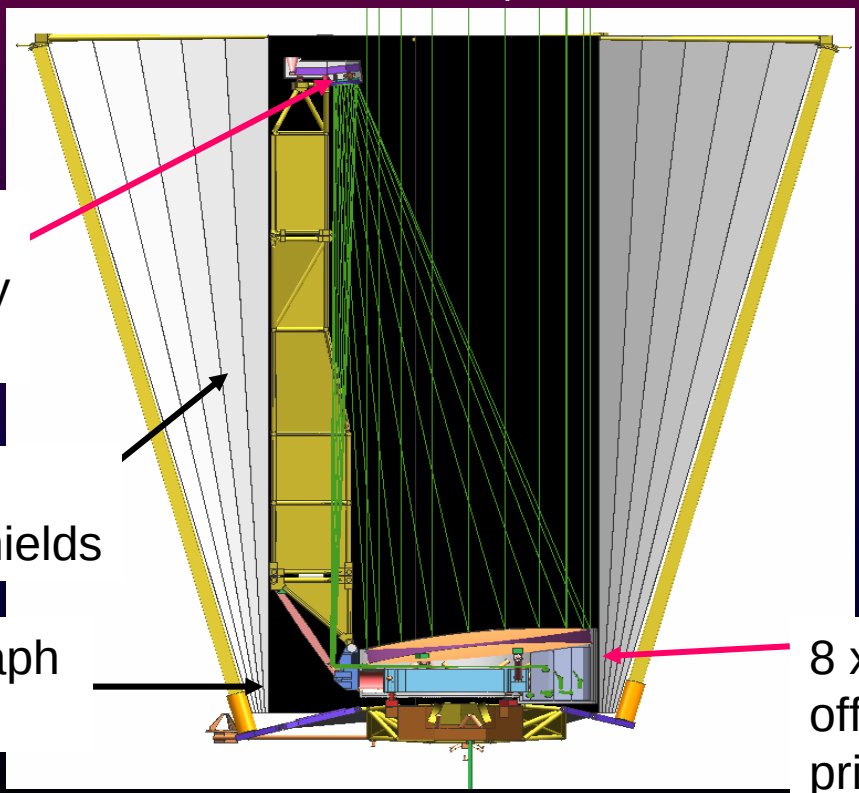
TPF-Coronagraph

TPF-Coronagraph

- Visible light telescope, nominally 3.5x8.5m with coronagraph operating at 4λ/D to study Habitable Zones with 60 mas resolution
- Study many 10s of FGK stars
- Biomarkers include O2, H2O

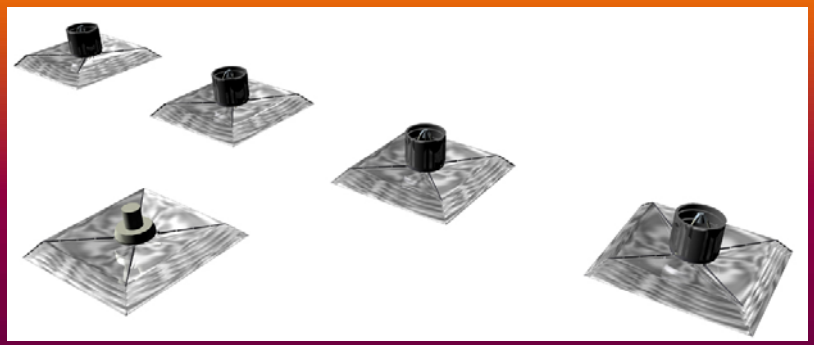


Sagan et al. (1993), Toby Owen (1980)

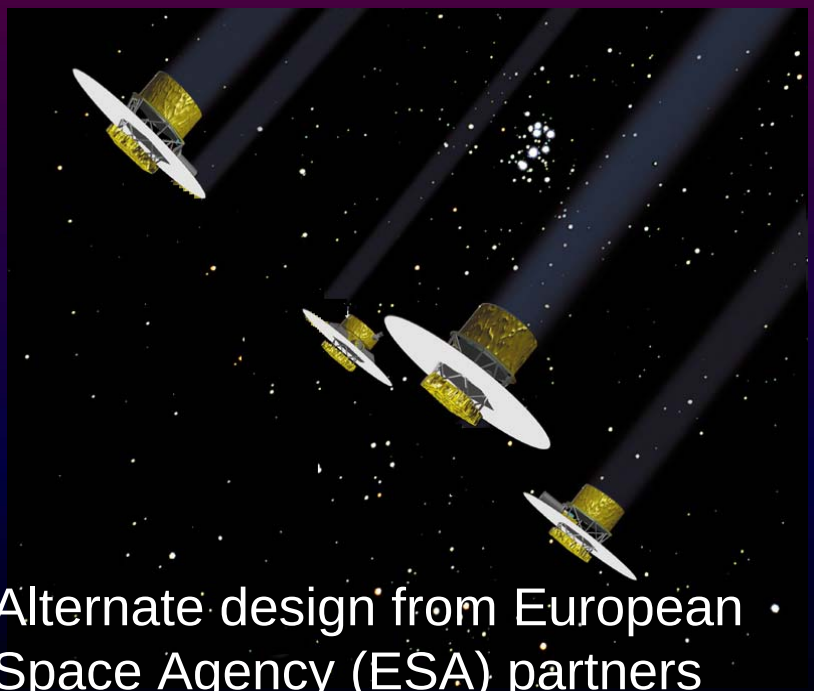


- Promising coronagraph designs could work at 2λ/D allowing more stars or smaller (cheaper) telescope

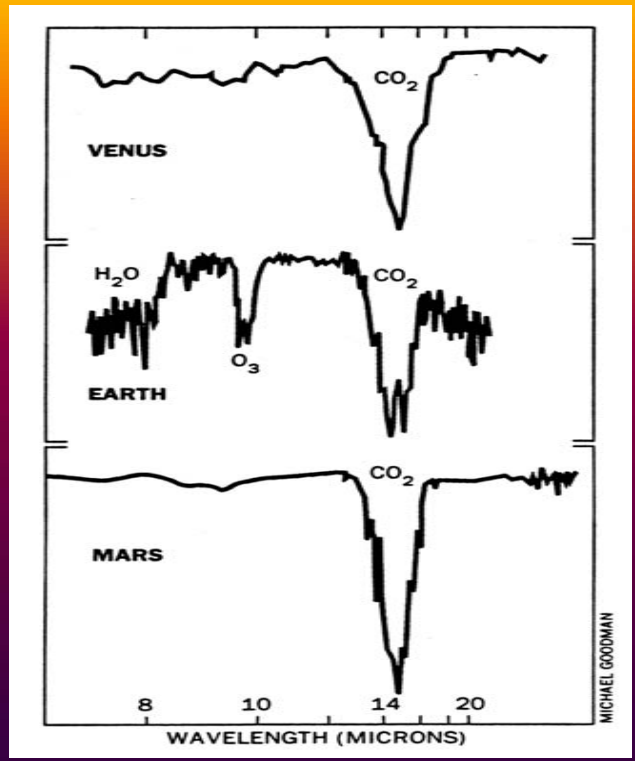
TPF-I/Darwin



NASA linear array: 5 free-flyers (4 collectors, 1 combiner)



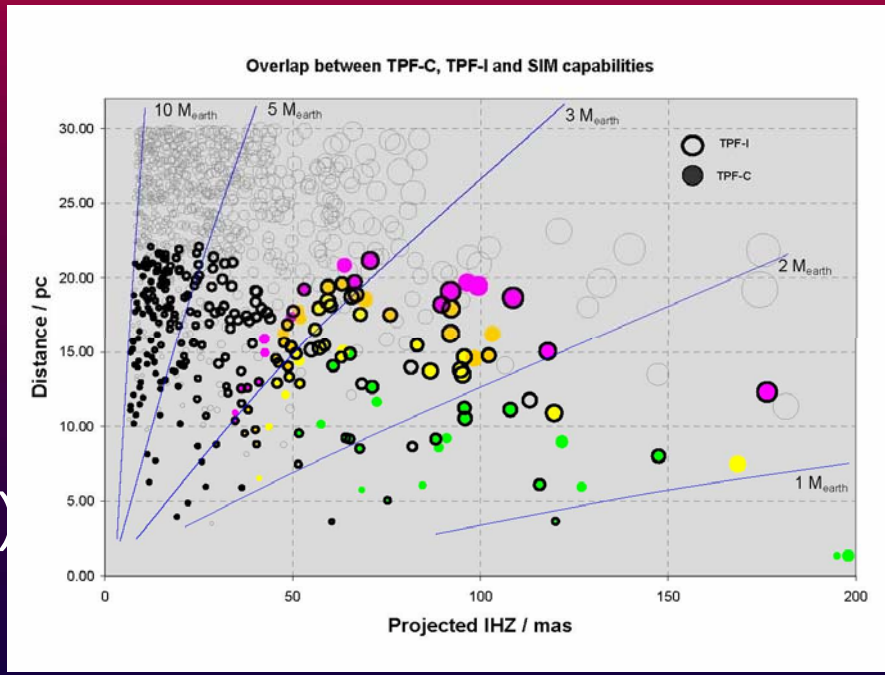
Alternate design from European Space Agency (ESA) partners



- Free-flying interferometer with 25 mas resolution to study ~150 FGK and M stars
- Atmospheric signatures, Biomarkers include O_3, CO_2, H_2O

Dynamics, Orbits, Visible & IR Required for Planet Characterization

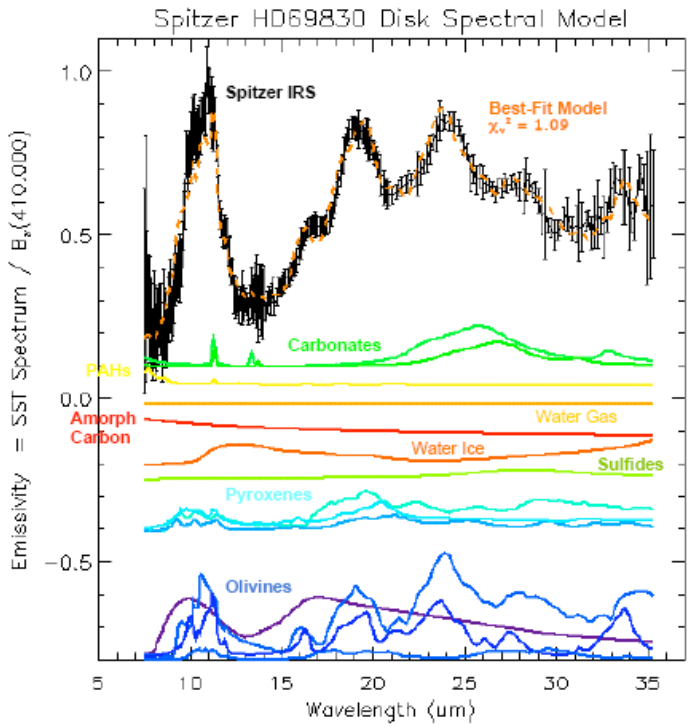
- Stable orbits in HZ (SIM)
  - –Orbital Temperature Variability
- Habitability
  - –Mass --- (SIM)
  - –Radius (SIM & TPF-I)
  - –Albedo (SIM & TPF-C)
  - –Surface gravity (SIM & TPF-I/C)
  - –Temperature (TPF)
  - –Composition (TPF)
- Solar System
  - –Influence of other planets (SIM)
  - –Comets or asteroid belts (TPF)
- Indicators of Life (TPF)

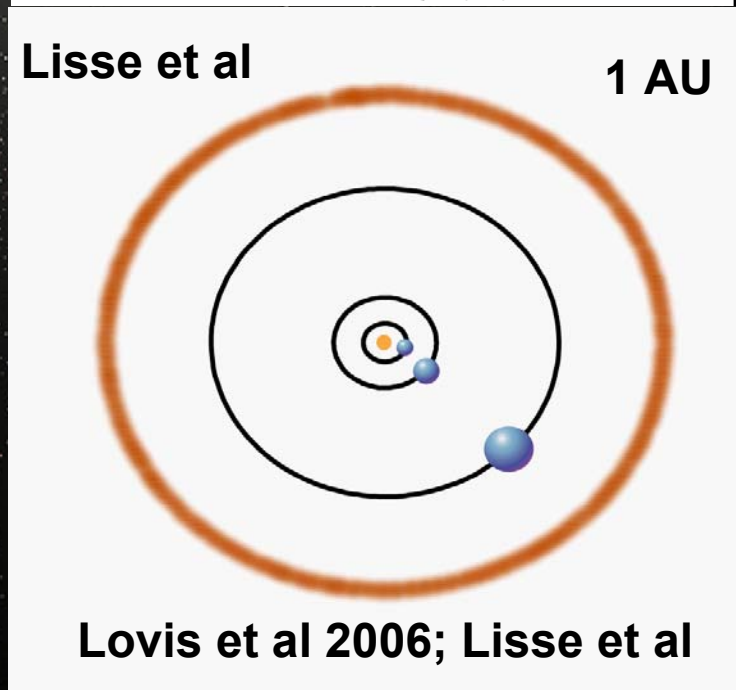


At least 35 nearby F,G,K stars are available for joint observations by SIM, TPF-C, TPF-I/Darwin

Debris Disks-1

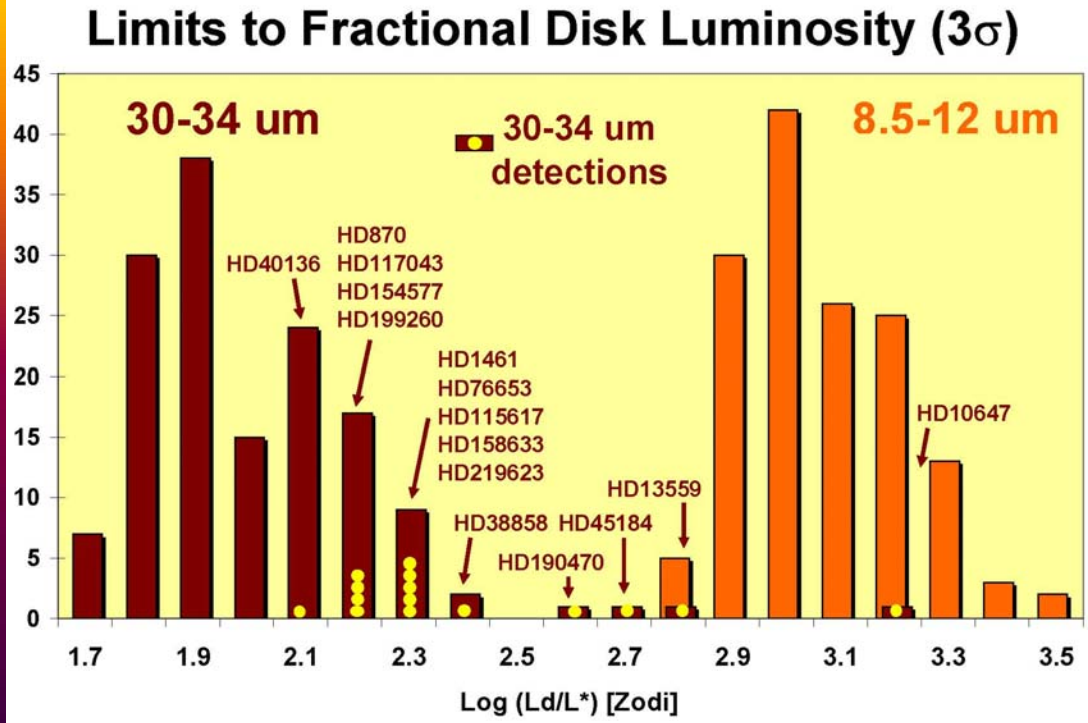
- Planetesimals are common around all young (<100 Myr) FGK stars (Siegler et al 2006)
- Kuiper Belts are common around mature stars (15%@5x)
- Intense emission in the habitable zone is rare (<1%) among mature stars, but could be a signpost of a period of Heavy Bombardment
- HD69830 rare but interesting laboratory for EZ studies
  - Remnants of P or D asteroid with crystalline pyroxenes, olivines, water ice, carbonates
  - Giant asteroid(s) broken up after perturbation by planet, trapped in resonance



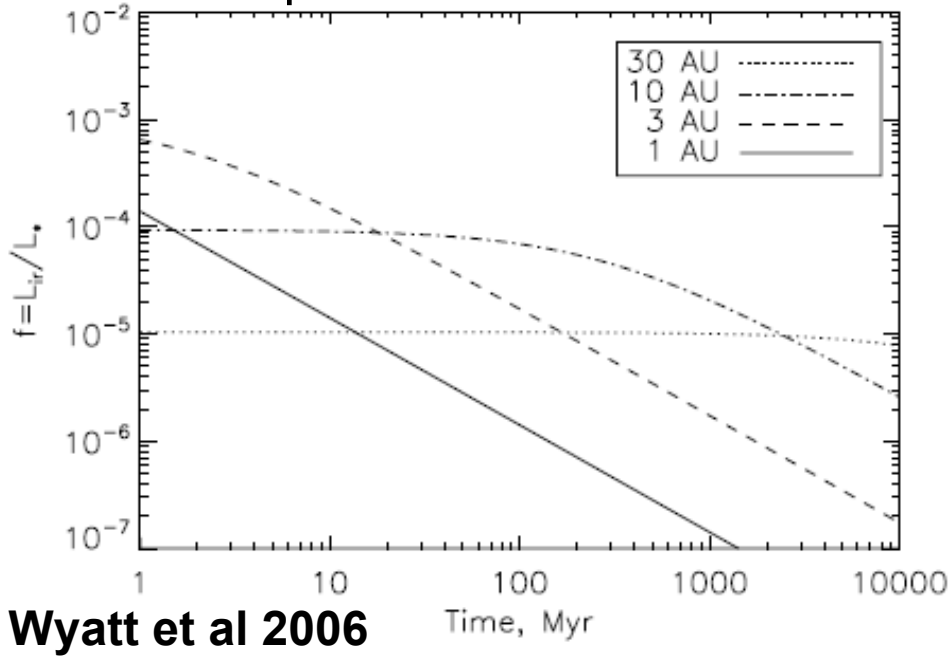


Debris Disks-2

- IRS spectra reveal dust outside of snowline (>5 AU), but relatively little inside 2-3 AU at levels >10^3×Solar System
- Next steps include Keck-I and LBTI for hot dust, Herschel for cold dust, and JWST for composition
- EZ is noise source for planet finding but critical for understanding planet formation and evolution, as well as transport of volatiles

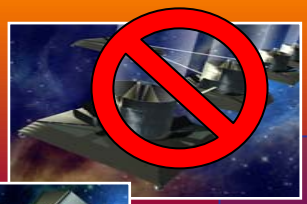


Lawler et al poster



Wyatt et al 2006

A *VERY Long Term* Vision for Planet Finding



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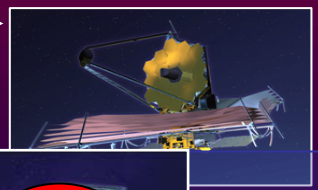

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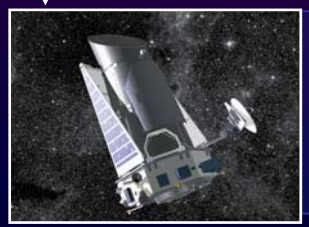

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"Space Science In Love" --- A Parable For Our Times

NASA Executive (Exec) **---** The space science program has been closed by the plague!

Scientist ---Oh, that.

Exec **---** But it is by order of the NASA Administrator!

Scientist **---** Let me explain about the space business… The natural condition is one of unsurmountable obstacles on the road to imminent disaster. Believe me, to be closed by the plague is a bagatelle in the ups and downs of running a space mission.

Exec **---** So what do we do?

Scientist **---** Nothing. Strangely enough, it all turns out well.

Exec **---** How?

Scientist **---** I don't know. It's a mystery.

Suddenly, the Town Crier is heard…

NASA Watch *---* The space program is reopened. By order of the NASA Administrator, the missions are restarted.

It's a mystery, but it all turns out well

How To Make Sure Everything Turns Out Well

- Community must pursue ***science, science, science*** with available facilities:
  - Ground-based: RV, coronagraphs, transits, microlensing
  - Space based: Transits, HST, Herschel, JWST
- Prepare technology and mission plans for large scale missions: SIM, TPF, other alternatives as input to ExoPlanets Task Force (NSF+NASA), NRC decadal review
- These questions are and will remain compelling to the science community and the general public. They will be addressed!