What Do We Need to Know Before TPF Flies?

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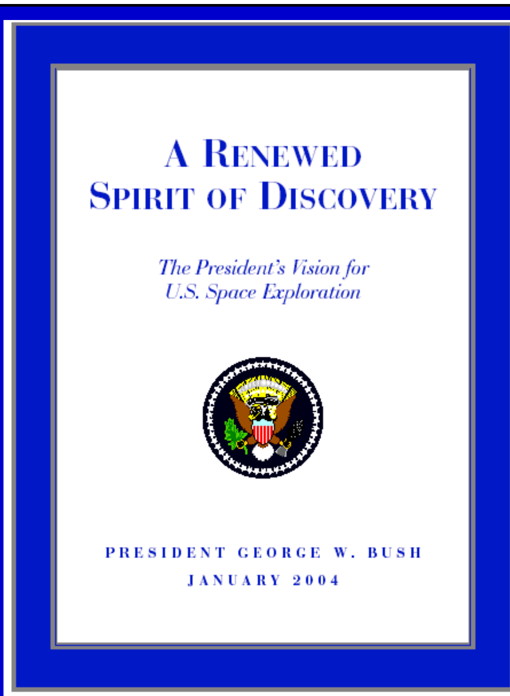
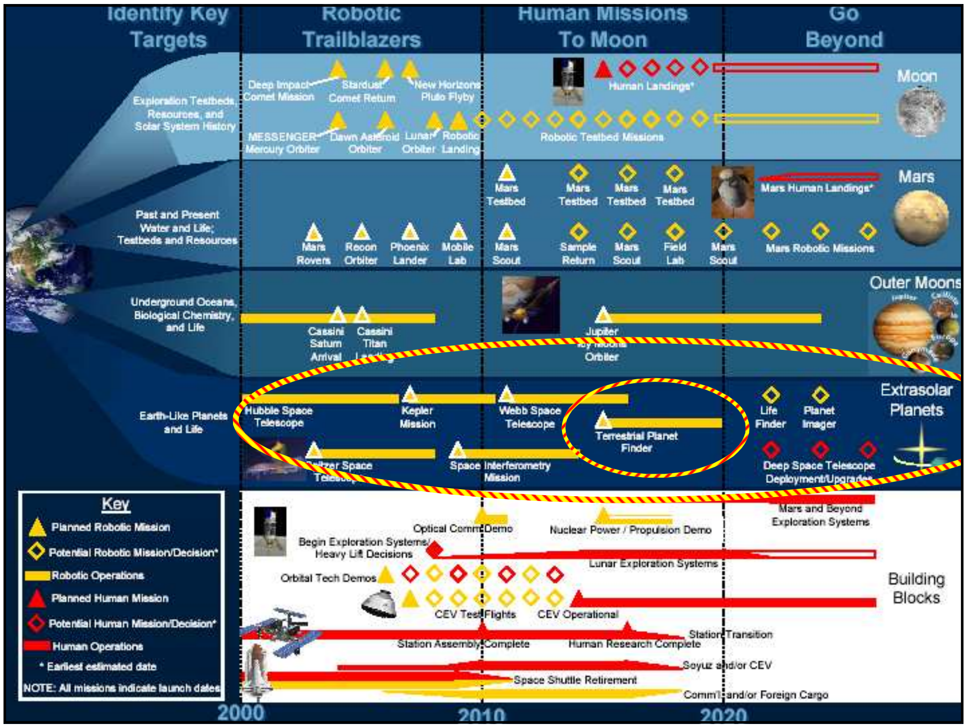
2 March 2004

Post-Columbia Vision for NASA Explicitly Incorporates TPF

- Focus on manned mission to Moon and Mars, robotic exploration of solar system, and search for life around other stars
- Among ~20 specific goals the President set for NASA is the following:
  - ***"Conduct advanced telescope searches for Earth-like planets and habitable environments around other stars"***





Shift of Emphasis for TPF

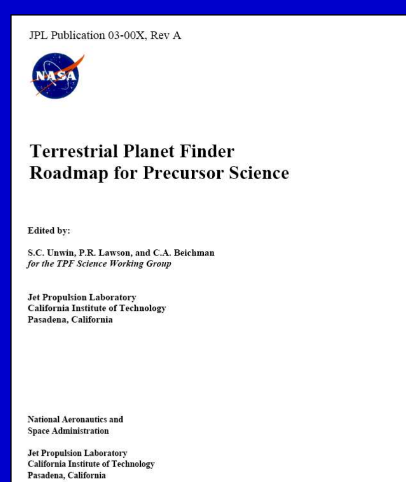
- Define a *capabilities-driven* mission that *enables* but which *does not guarantee* detection of planets
  - De-emphasize requirements based on $\eta_\oplus$ and associated Poisson statistics
  - Do not wait for Kepler results (>2010) to select architecture
- Select mission of appropriate scale with an *interesting* search capability
  - Base decision on information available in next 1-2 years
  - Search $\geq$30-50 stars out to f(spectral type)=5,10,15 parsec
- Enable study of all constituents of planetary systems (comparative planetology)
- Provide dramatic new capabilities for additional astrophysics
- Get National Academy approval for mission at entry into phase B,C/D (2010) based on best available data, e.g $\eta_\oplus$, exozodi etc.

Representative TPF Science Requirements

Key Parameter	*Minimum TPF*	*Full TPF*
Star types	**F G K**	**F G K & others**
Habitable Zone	**0.7--1.5 AU scaled as $L^{1/2}$**	**0.7--1.5 AU scaled as $L^{1/2}$**
Orbit Phase Space	**axis & incl = const; e < 0.35**	**axis & incl = const; e < 0.35**
Assumed $\eta_{\oplus}$	**0.1**	**0.1**
Expected # planets	**3**	**15**
# stars to search	**35 core stars**	**35 core + 130 add'l + extended**
Completeness: each core star	**90%**	**90%**
Completeness: add'l star set	**N/A**	**90% over ensemble**
Minimum # visits per target	**5**	**5**
Minimum planet	**1/2 Earth area**	**1/2 Earth area**
Geom. albedo	**Earth**	**Earth**
Color	**at least 3 bands; TBD**	**at least 3 bands; TBD**
Spectral range	**0.5-0.8 [0.5-1.05]μm 6.5-13 [6.5-17] μm**	**0.5-0.8 [0.5-1.05]μm 6.5-13 [6.5-17] μm**
Characterization completeness	**50%**	**50%**
Giant planets	**Jupiter flux, 5 AU, 50% of stars**	**Jupiter flux, 5 AU, 50% of stars**
Maximum tolerable exozodi	**10 zodi**	**10 zodi**

Focus of Precursor Science Roadmap

- Estimating the frequency of earth-like planets
- Determining the level of exozodiacal dust
- Refining the characteristics of stars that might harbor earth-like planets
- Predicting the characteristics of planets that might support life
- Ensuring the development of TPF science community and infrastructure


JPL Publication 03-00X, Rev A

Terrestrial Planet Finder
Roadmap for Precursor Science

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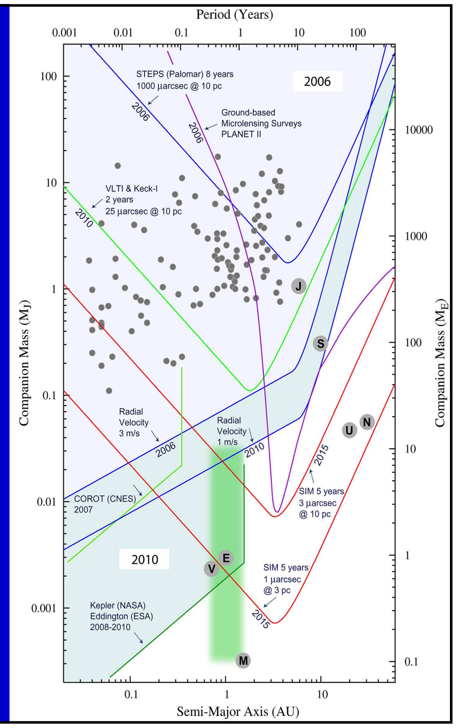
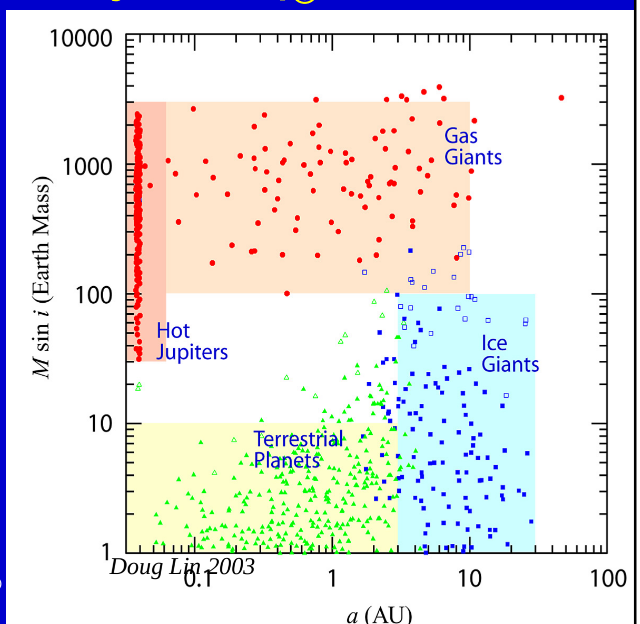
Observations and $\eta_\oplus$

- Confidence going into Phase A
  - Improving sensitivity and temporal baseline for RV may detect 10 Earth Mass at <1 AU
  - Ground-based mircolensing might find few earth mass planets around distant stars
- Robust results to move into Phase B,C/D
  - Transit experiments (MOST, COROT, Kepler/Eddington) will determine incidence of 1~few Earth masses at orbits 0.1~1 AU
- Knowledge for targeting during operations
  - Astrometry from SIM to identify best/worst targets



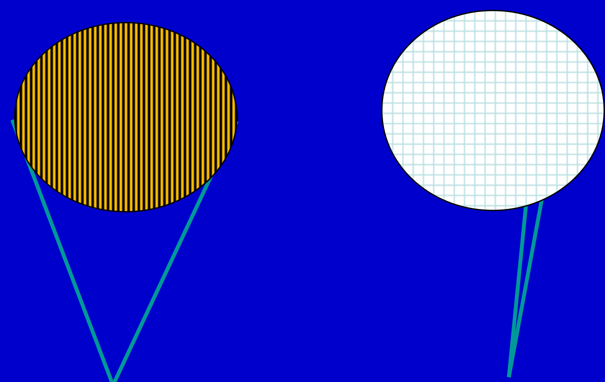
Theory and $\eta_\oplus$

- Theory combines disparate data to permit extrapolation to desired range of (mass, orbit) for TPF
  - Formation scenarios for gas giant, icy (oceanic) and rocky planets
  - Orbital migration
  - Long term dynamical stability
- Models, simulation, theory (Lin, Lunine, Tremaine) suggest $\eta_\oplus$ >0.1



Exo-Zodi Is Significant Noise Source

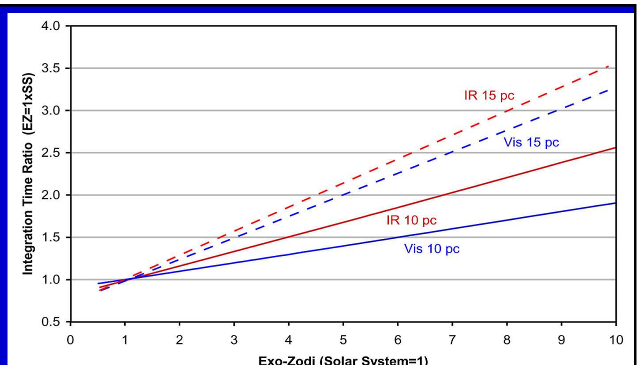
- Fundamental architectural difference between Interferometer and Coronagraph is how they see exo-zodiacal (EZ) emission



Interferometer takes in entire EZ
Resolution: 50 mas = 0.5 AU but
FOV: 0.5 λ/D=1.5”=+/-7.5 AU
For 4 m telescope at 10 μm at 10 pc

Coronagraph resolves EZ
Image size: 50 mas = 0.5 AU
For 5 m telescope at 0.5 μm
at 10 pc

Exo-Zodi Affects IR and Visible Systems



- Interferometer takes in entire EZ signal in primary beam (λ/D) producing noise independent of resolution (λ/B)
  - Modulated by null pattern so that peaked EZ signal is reduced by x 3-5
  - Local zodi and stellar leakage, *dominate* noise for EZ≤10× solar system
- Coronagraph resolves EZ signal into (λ/D) pixels, so that noise within planet pixel is reduced relative to entire EZ
  - Amount of EZ/pixel increases with distance
- Zodi structures may mark planets but also confuse observations

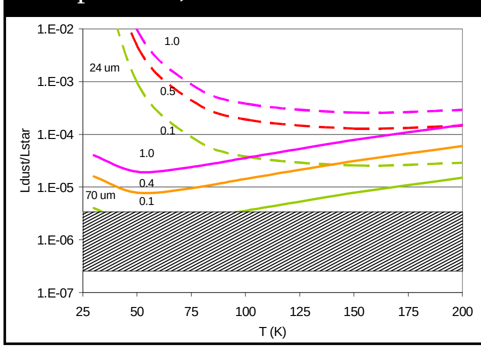
- Both interferometer and coronagraph need targets with EZ≤10 × SS
- May affect architecture decision

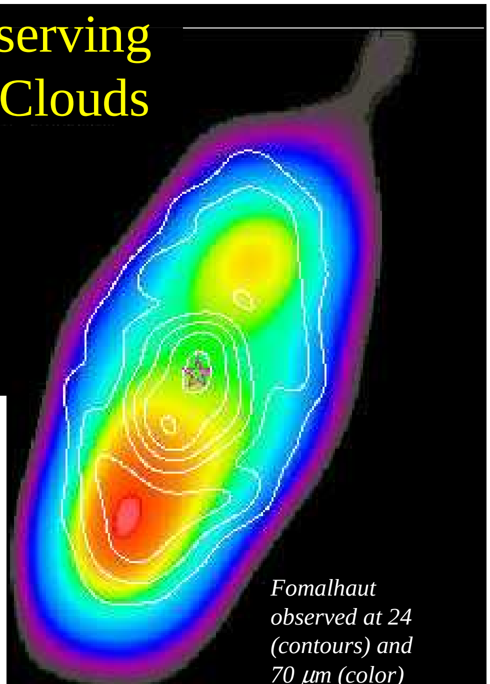
Interferometric Limits to Exo-zodiacal Emission

- Space Observatories like IRAS, ISO, SIRTF are "resolution-challenged"
  - Measure Kuiper Belts (3-100 AU), not asteroid belts!
  - Cannot measure small amounts of emission close to parent star, i.e. in the habitable zone
  - Limited by photometric calibration, but can measure 10x level of dust in our solar system at 10-40 AU.
  - SIRTF/MIPS is taking data. Stay tuned!
- Interferometers such as Keck-Keck, Large Binocular Telescope Interferometer (LBTI) and VLT-I/GENIE will probe zodiacal emission in habitable zones (0.1-3 AU)
  - Solar system analog, EZ ($\tau=10^{-7}$) at 10 μm is 0.10 mJy. Star is 280 mJy.
  - Nulling architecture to reject starlight to 10^{-2}~10^{-3} to measure faint halos
  - Keck-I and VLT-I are taking visibility data. Stay tuned.

Spitzer Starts Observing Exozodical Dust Clouds

- Spitzer will observe ~150 stars at 24 and 70 μm in GTO/Legacy programs with another 150 proposed for GO observations
- Sensitivity approaches few times Kuiper Belt, 100x zodiacal cloud

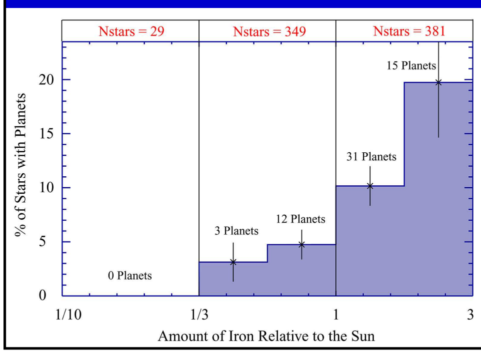


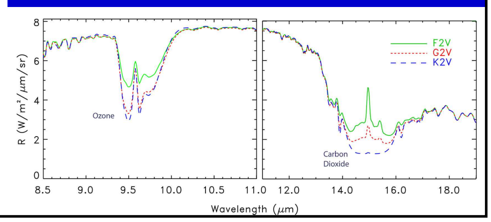


Fomalhaut observed at 24 (contours) and 70 μm (color)

Properties of Stars and Planets That Might Harbor Life

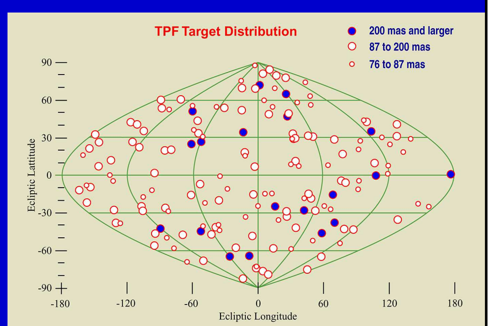
- Theoretical modeling to develop star list(s) including subset optimized for life
  - Stellar Age and lifetime
  - UV and X-ray fluxes, stellar activity
  - Metallicity
- Develop improved understanding of how to interpret TPF data in terms of physical properties of planet, habitability, presence/absence of life
  - Very low (R=4) to modest resolution
- Refine understanding of biomarkers





Necessary Data On TPF Target Stars

- Primary information
  - Distance, luminosity, spectral type, multiplicity
  - Presence and properties of planets (from radial velocity, transits, etc.)
- Secondary information
  - Uniform set of magnitudes with <~3% accuracy
    - Need for accurate determination of exo-zodiacal dust excess
  - Stellar Rotation and orientation
  - Photospheric Variability
  - Atmospheric/chromspheric activity
  - UV brightness/variability (astrobiological implications)
  - Exozodiacal dust
- Derived properties
  - Ages---to the extent that above information can be used to infer this
  - Metallicity (correlate with planet, exozodi properties)
    - Need uniform set of spectra and models



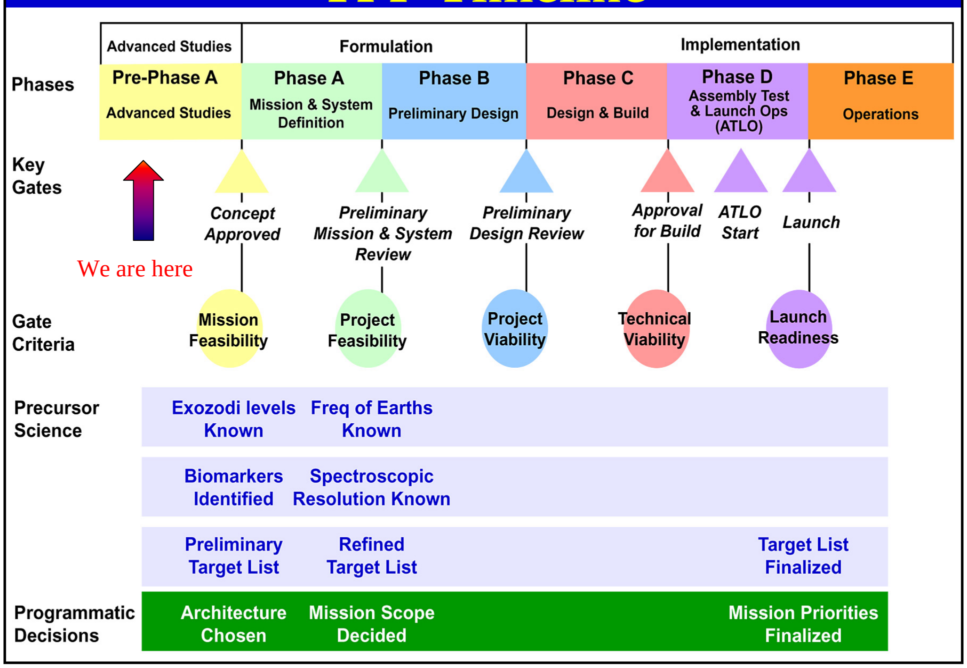
NASA has selected IPAC team led by John Stauffer to develop STARS database for TPF and SM

"Precursor Science Roadmap" Address Important TPF Questions

- Coordinated observing/theoretical program: What is $\eta_{\oplus}$?
  - Transits (MOST,COROT, Kepler/Eddington)
  - Theory extrapolating from gas giant statistics → terrestrial planets
- What is level of exo-zodiacal emission?
  - SIRTF (Kuiper belts @ 3-300 of AU)
  - Keck-I/LBT-I/VLT-I (Zodiacal clouds at ~0.3-3 AU)
  - Theory extrapolating from dust distribution → terrestrial planets
- What wavelength region should we observe?
  - Atmospheric and bio-markers from visible to mid-IR
- What are physical properties of giant planets?
  - Advance understanding and demonstrate techniques
- What controls orbital stability in region of habitable zone?
  - Are solar systems "dynamically full" with planets in all stable orbits?
- What are properties of target stars (including summary database)
  - Activity, presence of giant planets, zodi disks, gal/x-gal backgrounds

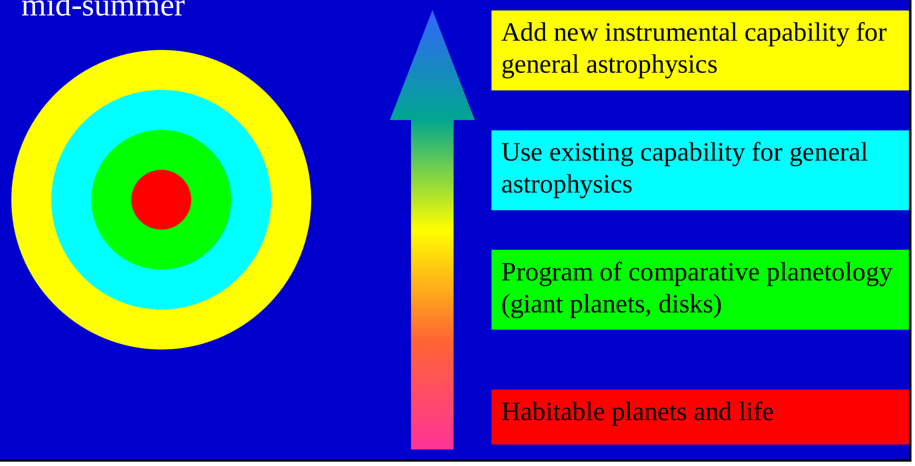
5-10% of TPF budget will support scientific activities

TPF Timeline



Ancillary Astrophysics for TPF

- Marc Kuchner is leading TPF-SWG effort on ancillary astrophysics with meeting at Princeton on April 13-14 to prepare briefing package for CAA meeting in May with White Paper by mid-summer



Ancillary Science

- What are contributions TPF can make to “comparative planetology?”
  - Study of all constituents of external solar systems, including gas giant planets, comets, zodiacal dust, etc.
  - Formation and evolution of planetary systems
- What additional observational capabilities would improve TPF capabilities in these areas?