Nasa Logo

Terrestrial Planet Finder Science Overview

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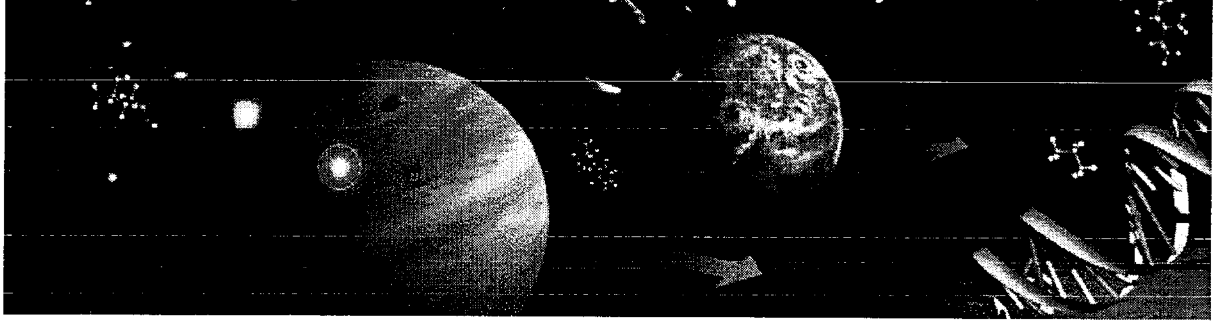
TPF Science, Technology and Design Expo

What will TPF do?

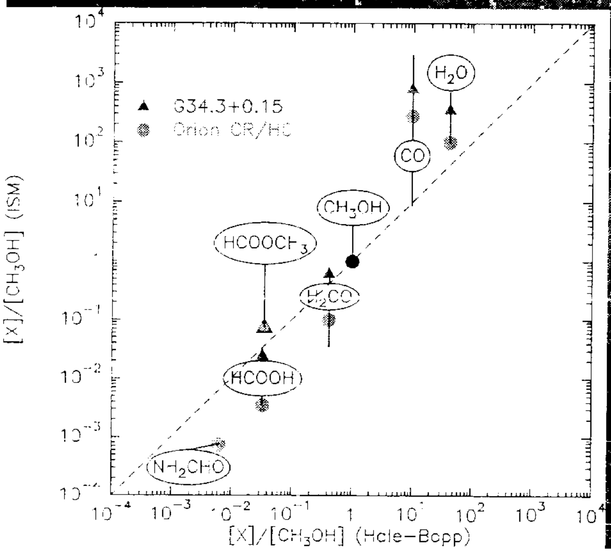
- Survey the local stellar neighborhood for terrestrial planets
  - Sample size: ~150-250 stars
  - *Direct* detection in optical or mid-IR
- Characterize the planets it detects
  - Orbital solutions
  - Low-resolution (R~50) spectroscopy
  - Search for possible biomarkers
- Learn about the formation and evolution of planetary systems
  - TFP study multiple-planet systems with giant and terrestrial planets, dust clouds
- General astrophysics
  - Use TPF's unique capabilities for astrophysical imaging
  - Design is driven by planet-searching requirements
  - Little incremental cost to the mission

Fundamental Facts To Remember About the Search for Planets and Life

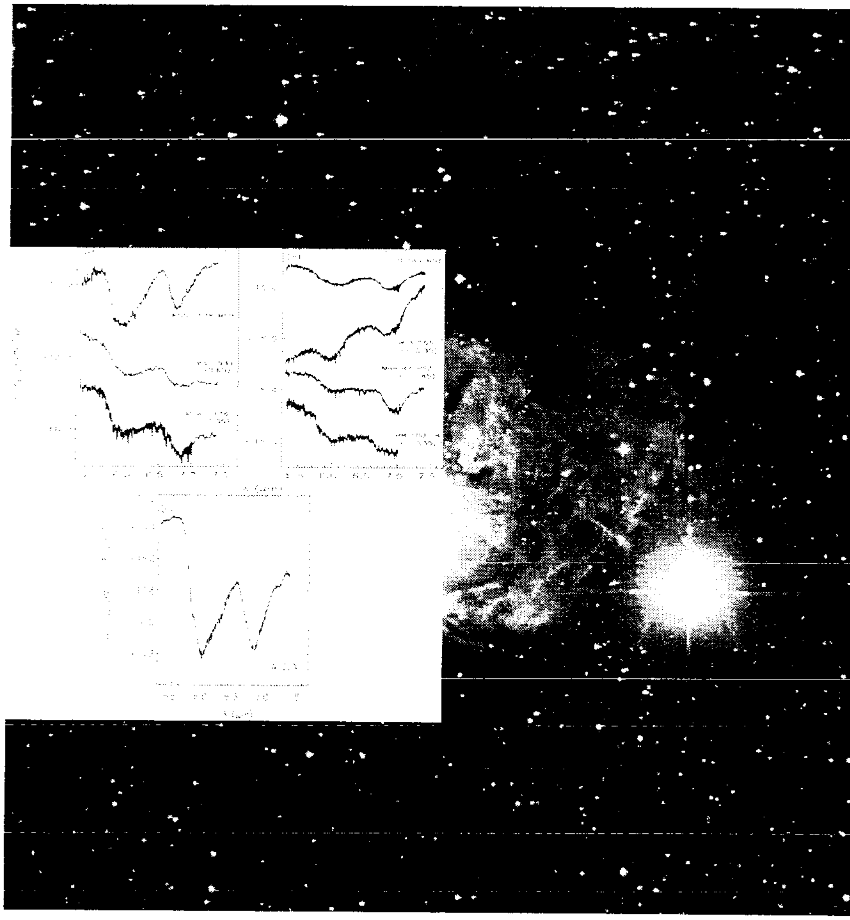
- The necessary ingredients of life are widespread
  - Observation reveals uniformity of physical and chemical laws
  - Origin of the elements and their dispersal is well understood
  - Carbon bond is unique and ubiquitous! Forget Silicon life
- Life on Earth can inhabit harsh environments
  - Micro- and environmental biology reveal life in extremes of temperature, chemistry, humidity
- Life affects planetary environment in a detectable way
  - Our own atmosphere reflects the presence of primitive through advanced life
- Planets are a common outcome of star formation
  - Modern theory of *star* formation makes *planet* formation likely



Organic Chemistry Ubiquitous: in Comets…



H2O	100	IR	
CO	23	radio, IR, UV	
CO2	6	IR	a)
*CH4	0.6	IR	
*C2H2	0.1	IR	
*C2H6	0.3	IR	
CH3OH	2.4	radio, IR	
H2CO	1.1	radio	
*HCOOH	0.09	radio	
*CH3CHO	0.02	radio	
*HCOOCH3	0.08	radio	
*NH3	0.7	radio	
HCN	0.25	radio, IR	
*HNC	0.04	radio	
*CH3CN	0.02	radio	
*HC3N	0.02	radio	
*HNCO	0.1	radio	
*NH2CHO	0.015	radio	
H2S	1.5	radio	
*SO	0.3	radio	
*SO2	0.2	radio	
*OCS	0.4	radio, IR	
CS2	0.2	UV, radio	b)
*H2CS	0.02	radio	
S2	0.005	UV	c)



...Star & Planet Forming Regions

IR, submm, mm spectra reveal gas phase, ices, mineralogical signatures of many species, incl: H_2O, CO_2, CH_3OH, CO, CH_4, formic acid ($HCOOH$) and formaldehyde (H_2CO), etc.

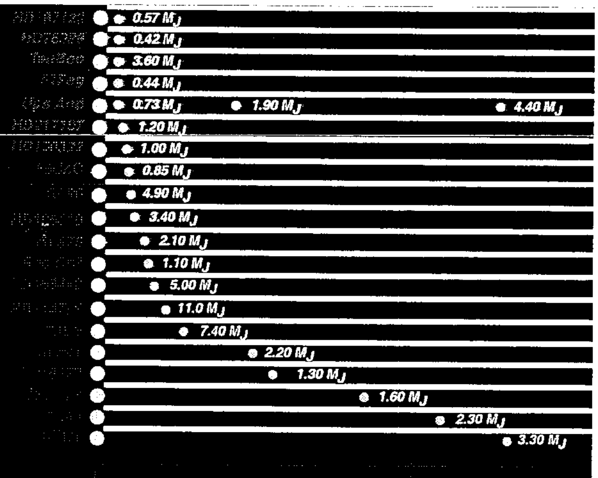
Signatures of Life

- *Oxygen* or its proxy *ozone* is most reliable biomarker
  - *Ozone* easier to detect at low *Oxygen* concentrations but is a poor indicator of quantity of *Oxygen*
- *Water* is considered essential to life.
- *Carbon dioxide* indicates an atmosphere and oxidation state typical of terrestrial planet.
  - Long wavelength lines in both near (1 μm) and mid-IR (16 μm) drives angular resolution and system temperature (mid-IR)
- Abundant *Methane* can have a biological source
  - Non-biological sources might be confusing
  - High spectral resolution and short wavelength rejection
- Find an atmosphere out of equilibrium
- Expect the unexpected

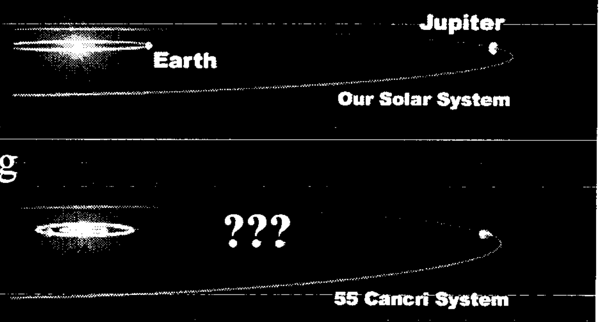
Visible and mid-IR provide significant atmospheric signatures and potential biomarkers

Gas Giant Planets

- Over 100 planets found using radial velocity wobble
  - ~10% of stars have planets
  - Most orbits < 2-3 AU
  - Half may be multiple systems



- Planets on longer periods starting to be identified
  - 55 Cancri is solar system analog
- Astrometry (SIM) and radial velocity will determine solar system architecture to few $M_\oplus$



Marcy et al.

Space Interferometer Mission (SIM) Will Make Definitive Planet Census

What We *Don't* Know

- Are planetary systems like our own common?
- What is the distribution of planetary masses?
  - Only astrometry measures planet masses unambiguously
- Are there low-mass planets in 'habitable zone' ?

A Deep Search for Earths

- Are there Earth-like (rocky) planets orbiting the nearest stars?
- Focus on ~250 stars like the Sun (F, G, K) within 10 pc
- Sensitivity limit of ~3 M_e at 10 pc requires 1 μas accuracy

A Broad Survey for Planets

- Is our solar system unusual?
- What is the range of planetary system architectures?
- Sample 2000 stars within ~25 pc at 4 μas accuracy

Evolution of Planets

- How do systems evolve?
- Is the evolution conducive to the formation of Earth-like planets in stable orbits?
- Do multiple Jupiters form and only a few (or none) survive?

TPF Science Requirements-I

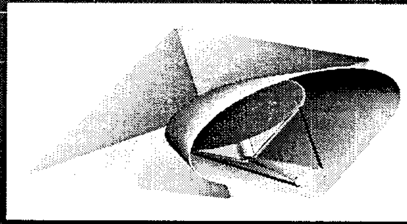
- Detect and characterize terrestrial-sized planets around nearby stars.
- Satisfy requirements for "core sample" of 30 (late-F, G and K dwarf) stars
- Partially satisfy requirements for "extended" sample of 120 additional stars (late-F, G, and K dwarf) as well as M-dwarf, early-F, and A- star targets of opportunity.
  – Survey of core and extended stars, including at least 3 visits, should be completed in ~2 years.
  – Additional visits of detected planets to determine orbits beyond the 2 year detection phase.
- A "TPF stretch mission" should meet the above requirements for the full sample of ~150 stars.
- Within the CHZ (0.9-1.1 AU for a G-type star $\propto L^{1/2}$), TPF shall be able to detect with 95% completeness, terrestrial planets at least half the surface area of the Earth with Earth's albedo.
  – Within a more generously defined HZ (0.7-1.5 AU for a G-dwarf), TPF shall be able to detect an Earth-sized planet with Earth albedo with 95% completeness.

TPF Science Requirements-II

- TPF must be able to obtain spectra in an effort determine the existence of an atmosphere, detect water, detect carbon dioxide (in the infrared), and detect oxygen/ozone or methane if these are present in astrobiologically interesting quantities.
  – The wavelength range 0.5-0.8 μm (1.05 μm desirable) in the optical and 6.5-13 μm (17 μm desirable) in the infrared, with spectral resolutions of 75 and 25, respectively.
  – Spectrometer capable of R>100 for the brightest sources.
  – Detection of Rayleigh scattering and the absorption edges desirable
- Strong desire for large field of view, 0.5-1.0 arcsec, to search the nearest stars for terrestrial planets and to characterize giant planets in Jupiter-like orbits

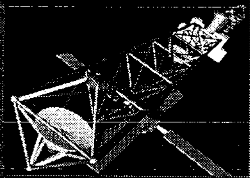
TPF Candidate Architectures

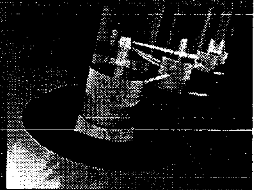
- Visible Coronagraph
  - System concept is relatively simple, 4–10 m mirror on a single spacecraft
  - Components are complex
    - Build adequately large mirror of appropriate quality (λ/100)
    - Hold (λ/3,000) with (λ/10,000) stability during observation with deformable mirror



Visible Coronagraphs

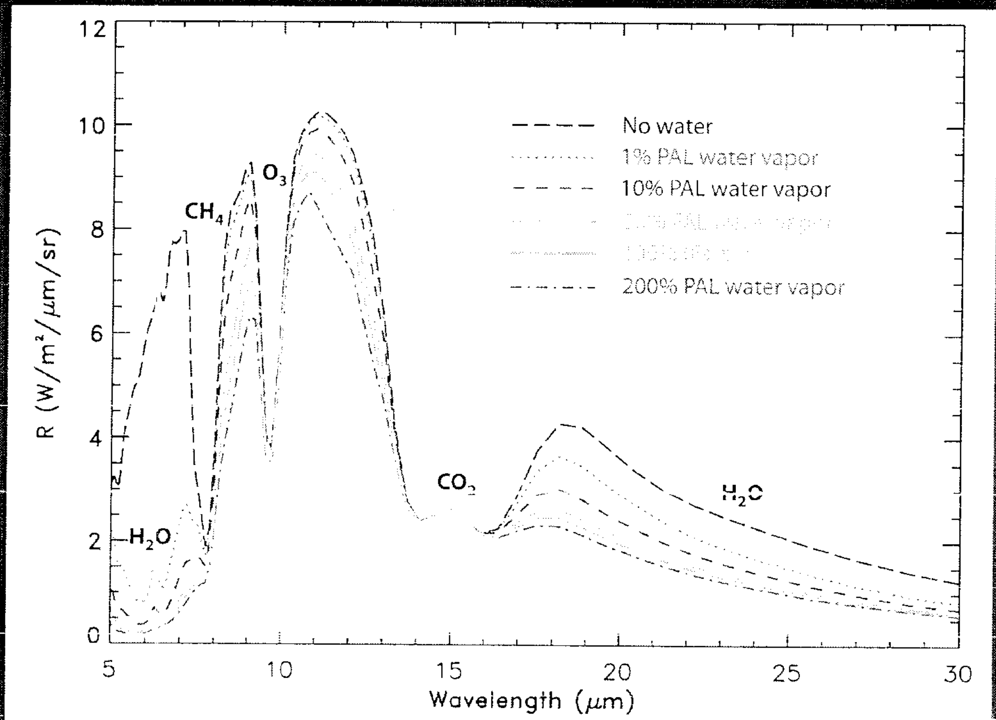
- IR Interferometer
  - _ Components are simple: 3-4 m mirrors of average quality
  - _System is complex: 30 m boom or separated spacecraft with ~ nm stability





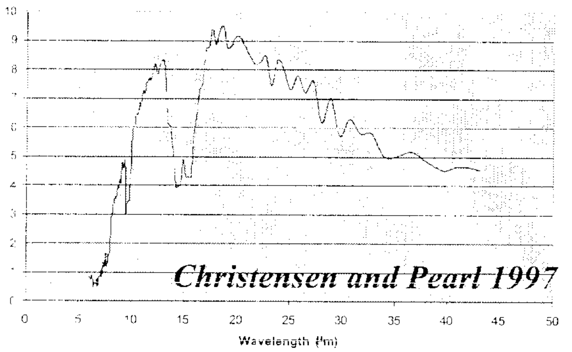
IR Interferometers

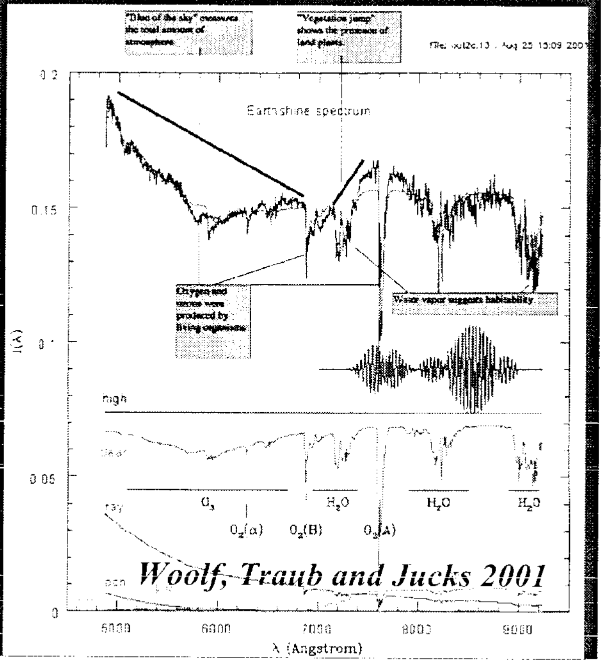
Spectral Range and Resolution



Atmospheric Spectrum Reveals Physical Characteristics and Signs of Life

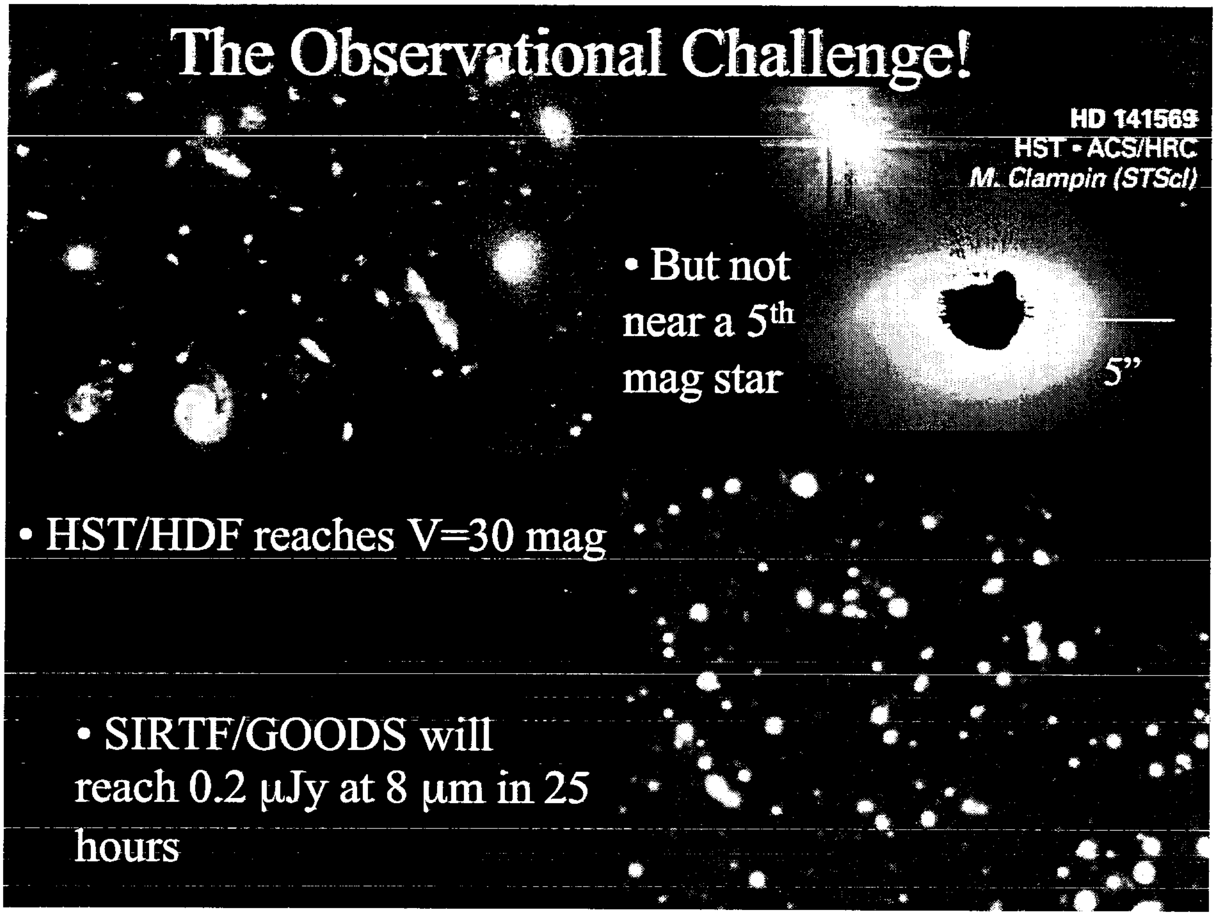
- Good physical indicators and atmospheric tracers in both visible and mid-IR
- TPF spectroscopy at resolution R ~ 50

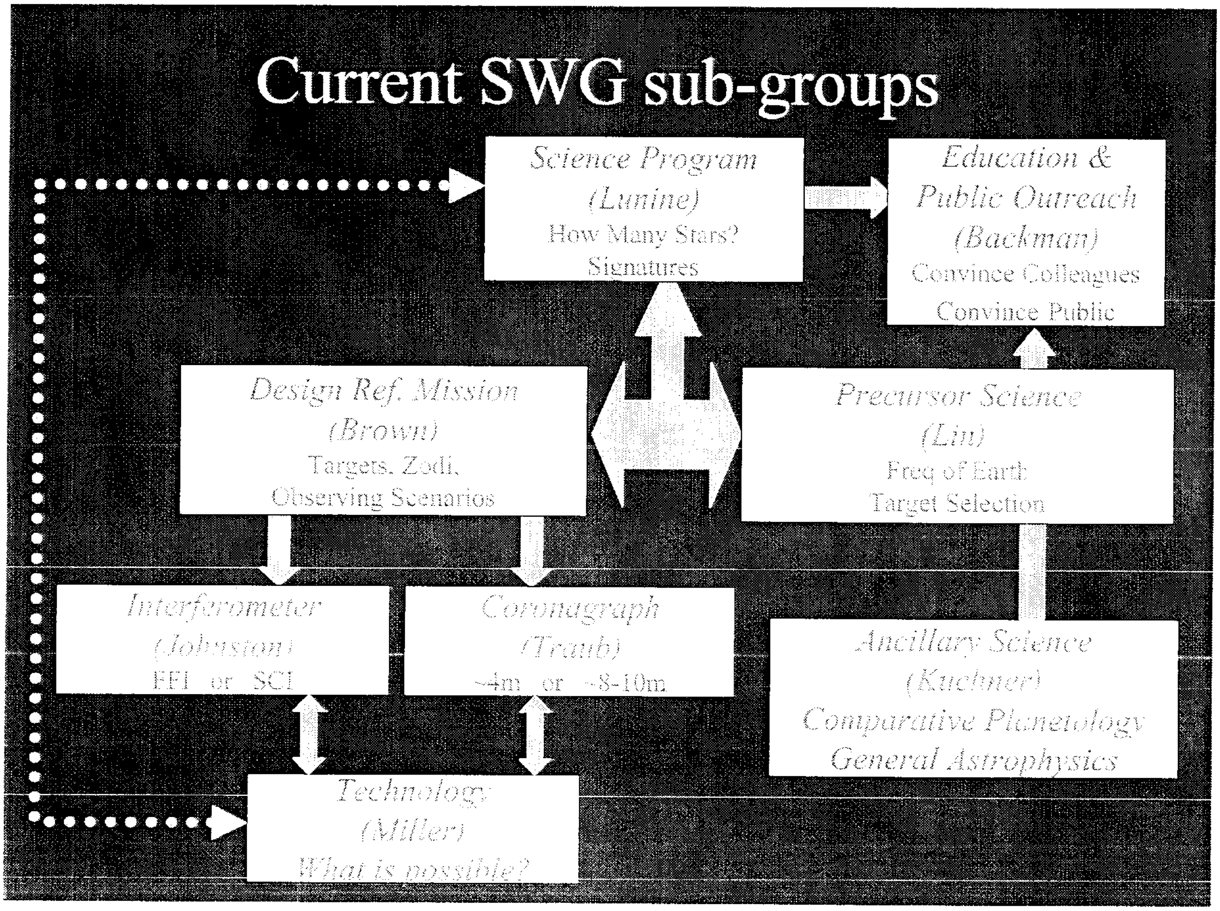




Four Hard Things About TPF

- Sensitivity (relatively easy)
  - Detection in hours → spectroscopy in days in Visible or mid-IR
  - Need 12 m^2 of collecting area ($\geq$ 4 m) for star at ~10 pc
  - Integration time $\propto$ (distance/diameter)^4
- Angular resolution (hard)
  - 100 milliarcsec is enough to see ~25 stars
    - But this requires $\geq$ 4-m coronagraph or $\geq$ 20-m interferometer
  - Baseline/aperture $\propto$ distance
- Starlight suppression (hard to very hard)
  - 10^{-4} to 10^{-6} in the mid-IR
  - 10^{-8} to 10^{-10} in the visible/near-IR
- Solar neighborhood is sparsely populated
  - Fraction of stars with Earths (in habitable zone) unknown
  - Unknown how far we need to look to ensure success
  - Surveying substantial number of stars means looking to ~15 pc


The Observational Challenge!
HD 141569
HST - ACS/HRC
M. Clampin (STScI)
• But not near a 5th mag star
5"
• HST/HDF reaches V=30 mag
• SIRTF/GOODS will reach 0.2 μJy at 8 μm in 25 hours


Current SWG sub-groups
Science Program
(Lunine)
How Many Stars?
Signatures
Education & Public Outreach
(Backman)
Convince Colleagues
Convince Public
Design Ref. Mission
(Brown)
Targets, Zodi,
Observing Scenarios
Precursor Science
(Lin)
Freq of Earth
Target Selection
Interferometer
(Johnston)
FFI or SCI
Coronagraph
(Traub)
~4m or ~8-10m
Ancillary Science
(Kuchner)
Comparative Planetology
General Astrophysics
Technology
(Miller)
What is possible?

TPF Precursor Science Roadmap

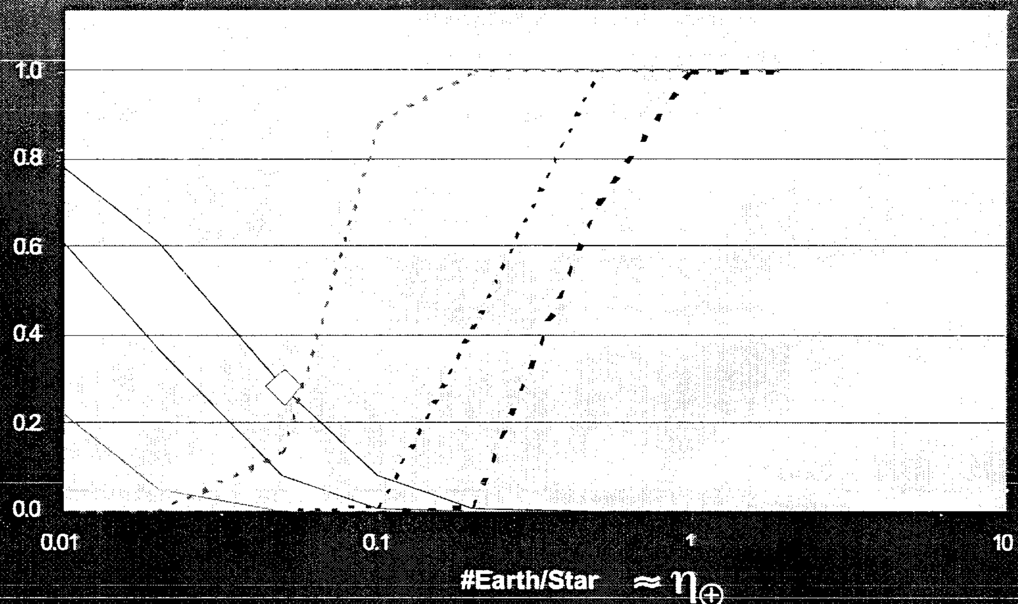
- What observational and theoretical / modeling programs shouldd be done to help the choice of TPF architecture?
- What observational and theoretical / modeling programs shouldd be done to help define the scientific 'scope' of TPF?
- What should be done to endure that the scientific infrastructure is built to support TPF?
- What areas of extrasolar planet research should be supported to develop the field and make a firm foundation for correctly interpreting TPF science results?

Questions for TPF Precursor Science

- 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?
  - Activity, presence of giant planets, zodi disks, gal/x-gal backgrounds

5-10% of TPF budget will support scientific activities

How Many Planets Are Enough?



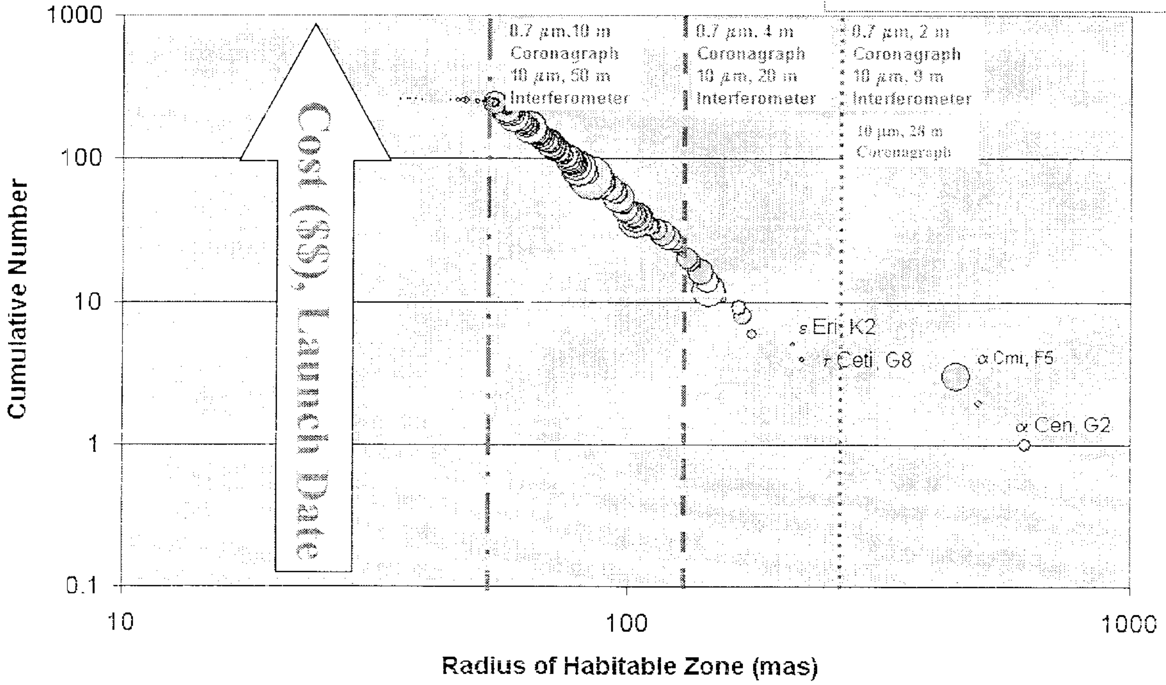
- How many stars to avoid mission failure (N_p=0)
- How many stars to ensure enough planets (N_p=5,10?)

•$\eta_\oplus$ → # Stars →Dist→(Aperture, Baseline)→Cost→Schedule

Angular Resolution → Sample Size

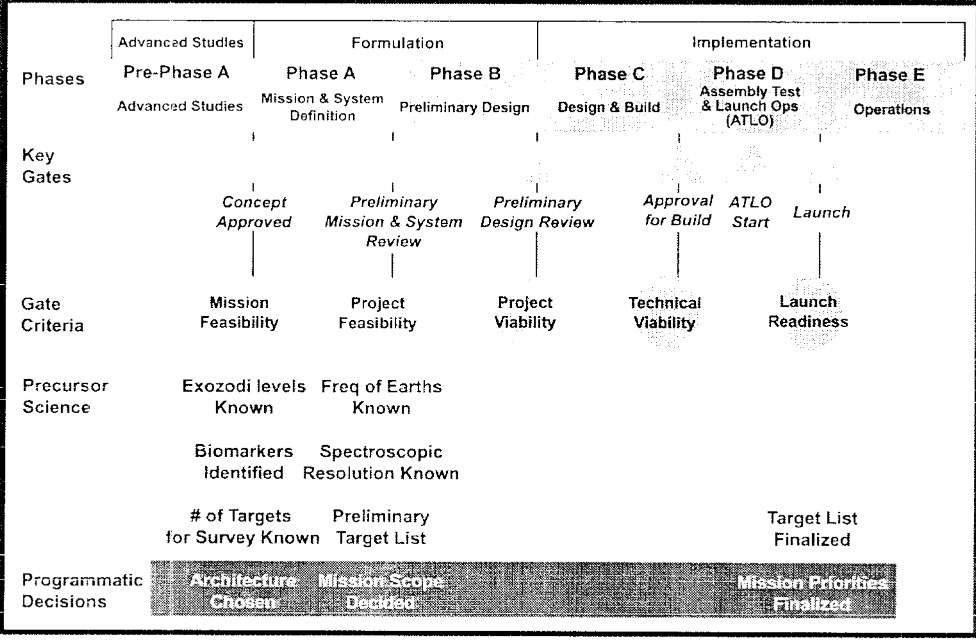
Potential TPF Targets (FGKM)

- Coronagraphs at >3λ/D
- Interferometers at > 1 λ/B



Precursor Science Timeline

- Precursor science goals are linked to major project milestones

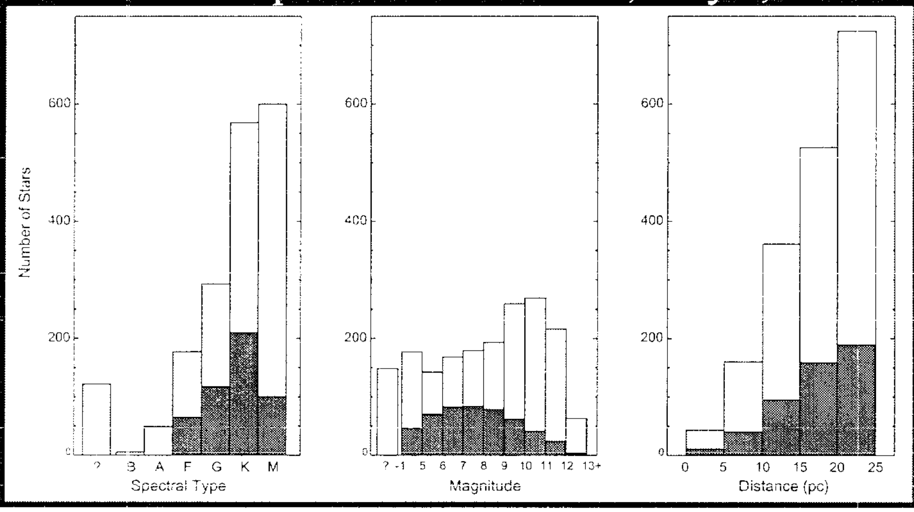


How Will We Learn About $\eta_{\oplus}$?

- Radial velocity, transit data from ground-based, early space-based missions (MOST and COROT)
  - Search for Jupiters → Saturns on day/month/year orbits
- Theoretical interpretation of available data
  - Extrapolation from properties of giant planets
  - Interpretation of properties of exo-zodiacal disks from SIRTF, Keck-I/LBTI

Target list selection

- Selection based on:
  - Stars closer than 25 pc
  - Spectral type F, G, K dwarfs
  - Eliminate close binaries etc.
  - Extended sample: include M dwarfs, early F, A

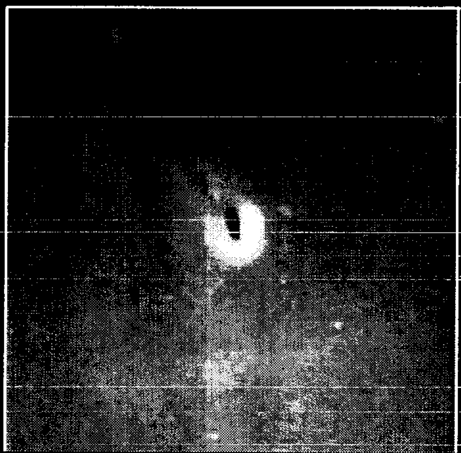


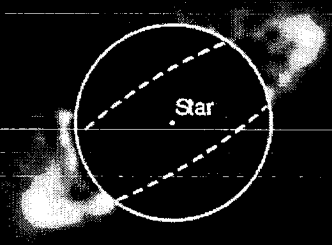
How Will We learn About Exozodiacal Dust ?

- Exozodiacal dust may degrade the ability of TPF to detect planets
  - Hence an understanding of the likely levels of dust arount TPF targets is important to the TPF design
  - At high levels, could be design discriminator between interferometers and coronagraphs
- Learing how dust disks form around other stars can help us to understand better the formation and evolution of planets
- Dust disks can act as signposts for the presence of planets
- Robust determination of the amount of exozodiacal emission around potential TPF targets using a combination of space-based and ground based telescopes.

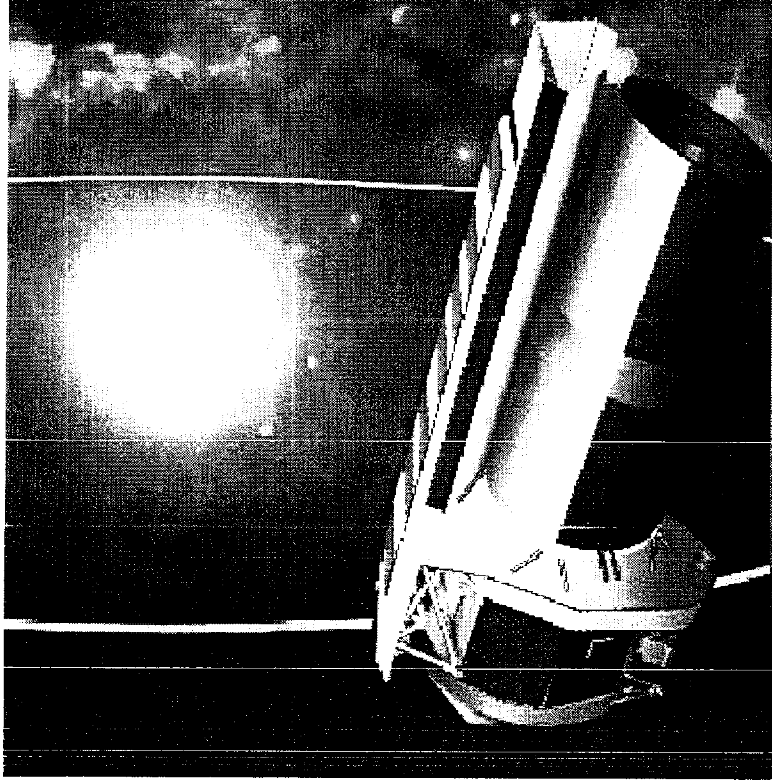
Star Formation & Protoplanetary Disks

- The formation of planets is an integral part of our theory of how stars form
  - Hundreds of planetary masses of gaseous and solid material in the protostellar disk
- Solar System-scale dust disks found around nearby stars





SIRTF Observations of Disks



–Lo/high metals

–1 Myr to 5 Gyr

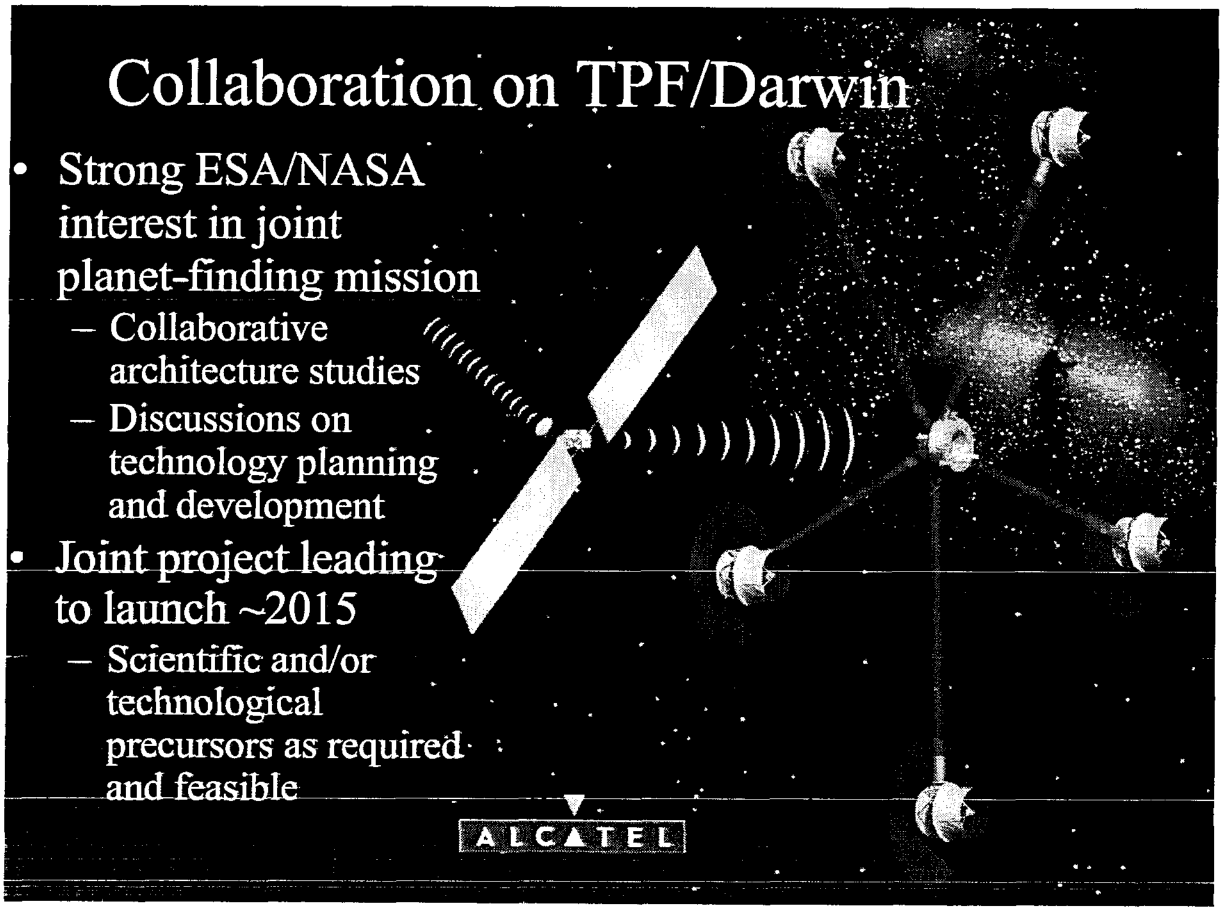
–Grain composition

–Reach 1-10x Kuiper belt at 70 μm

- SIRTF launches April 28 (oops), August TBD after 25 years!

Table 1. Key Missions and Scientific Contributions to TPF Precursor Science

Instrument / Mission	Science Contribution
•	• **Architecture Decision (Entry into Phase A)**
• SIRTF	• IRS/MIPS survey of ~250 stars for exozodiacal dust at >5 AU
• Radial velocity monitoring	• Detect planets of Saturn mass or less at 2–5 AU to help refine the incidence of low mass planets
• COROT/MOST	• Transits of planets of 8–10 Earth mass at <0.5 AU to help refine incidence of low mass planets
• Keck-I, LBTI, VLTI	• Warm dust (10 μm) for ~ 150 stars for exozodiacal dust at 0.5-2 AU
• Theory/modeling	• Estimate of frequency of Earth-like planets based on giant planets detected by radial velocity or other techniques
• Theory/modeling	• Refine spectral signatures to be searched
•	•
•	• **Scientific scope (Entry into Phases B, C, D)**
• Kepler	• Statistics of Earth-like planets (transiting) to determine incidence of low-mass planets
• Eddington	• Statistics of Earth-like planets (transiting) to determine incidence of low-mass planets.
•	•
•	• **Target List Refinement (now until launch, Phase E)**
• SIM	• Detect potential TPF target systems by finding planets. Few Earth-mass planets around nearby stars.
• JWST/HST	• Images of TPF target fields R>30 mag; $F_\nu(8\ \mu m) < 1\ \mu Jy$
• SIRTF/Interferometers/Herschel/ SOFIA	• Characterize exozodiacal emission of potential targets



Second TPF/Darwin Conference

- *Dust Disks and the Formation, Evolution and Detection of Planetary Systems*
  - Featuring new SIRTF images/spectra of zodi disks, etc.
- San Diego, July 26-29, 2004 *(confirmed dates)*
- http://planetquest.jpl.nasa.gov/TPF_darwin/

2nd Darwin/TPF Conference

Overall goal to develop the field of extra-solar planet research

- *Involve the community in establishing high level goals for TPF/Darwin*
- *Address research relevant to design and architecture of TPF/Darwin.*

1. Assess results on exo-zodiacal disks from SIRTF, Keck-I etc.
   - What is frequency of EZ clouds of different levels?
   - How to combine outer zodiacal cloud (SIRTF) to the inner zodiacal cloud (Keck-I, LBT-I, VLT-I) that will be measured by TPF?
   - What does EZ tell us about the presence or absence of planets?
2. Investigate link between physical conditions in early solar nebula and astrobiology.
   - How might astronomical conditions in the Hadean/Archaen period affect the formation and evolution of life?
   - What does EZ imply in terms of bombardment and infall?
   - What other astronomical properties of a star and planetary system might be relevant to the formation of stable, habitable planets, e.g. dynamics of giant planets, UV/X-ray output of stars, chemistry of nebular material
3. Discussion of TPF/Darwin designs, science requirements and technology advances