

New Directions for TPF

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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”*

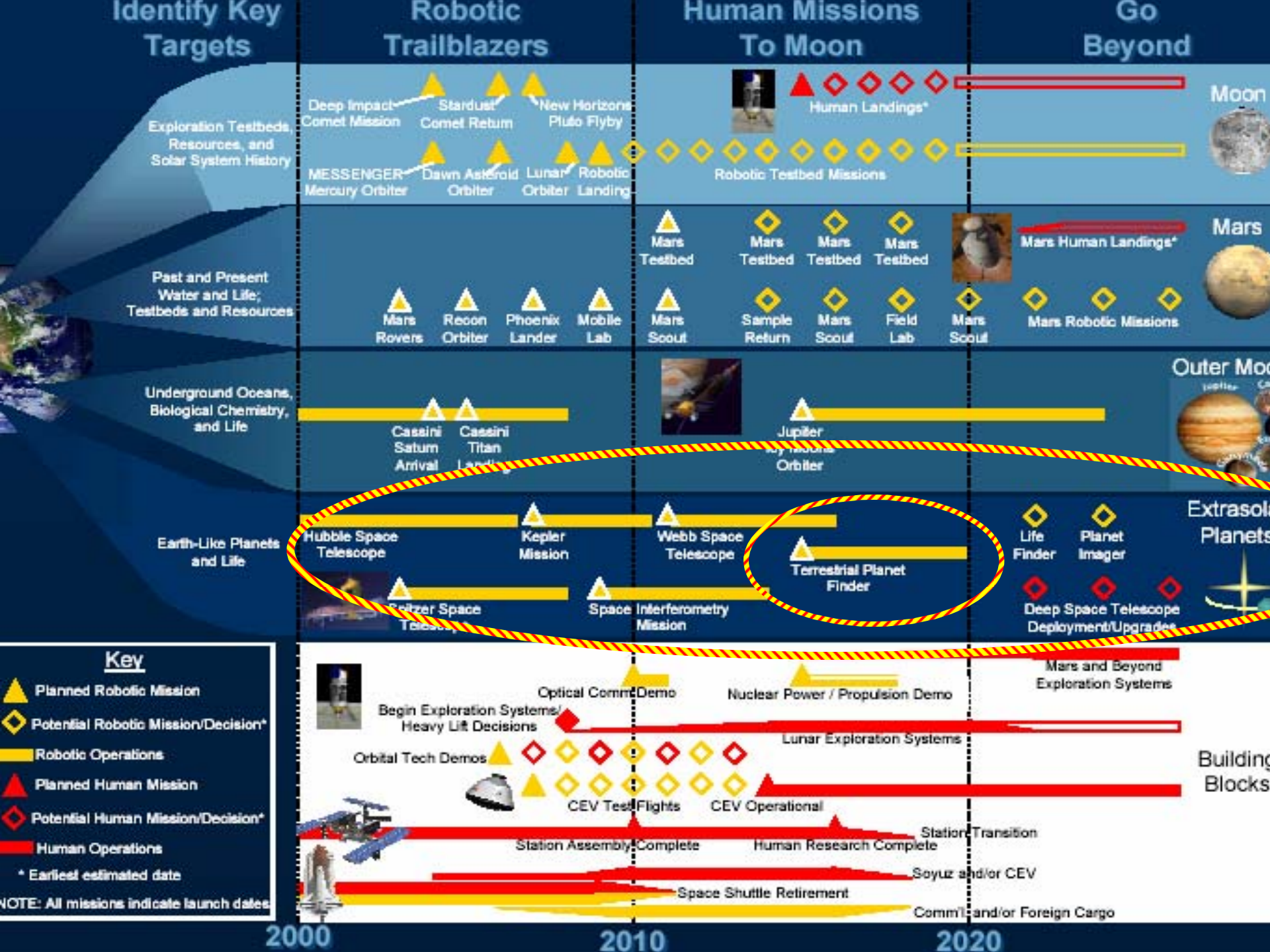
A RENEWED SPIRIT OF DISCOVERY

*The President's Vision for
U.S. Space Exploration*



PRESIDENT GEORGE W. BUSH

JANUARY 2004



Why Fly a Coronagraph and an Interferometer?

President's new Vision directs NASA to “*conduct advanced telescope searches for Earth-like planets and habitable environments around other stars*”

The technology is maturing for both the coronagraph and interferometer

We want to obtain discovery data on habitable planets as soon as possible

- Fly a moderate sized coronagraph (4x6 m) in ≈ 2014 to study 30-50 stars out to 10-15 pc.

We want to obtain confirming data and extend the search with a more capable mission

- Fly a formation flying interferometer jointly with ESA at the end of the next decade to study hundreds of stars out to 25 pc

The combination of two 1st generation missions delivers most compelling science

- Data from both wavelength regions provides robust assessment of habitability and biomarkers
- Enables selection of optimized 2nd generation vision mission(s), possibly needing human assembly at L2 or at lunar base

International collaboration enables NASA's funding to accomplish two missions

- More science, earlier results, lower risk
- Support President's vision for international participation

NASA can carry out both missions during 2010-2020 within the existing Origins line with no near term augmentation

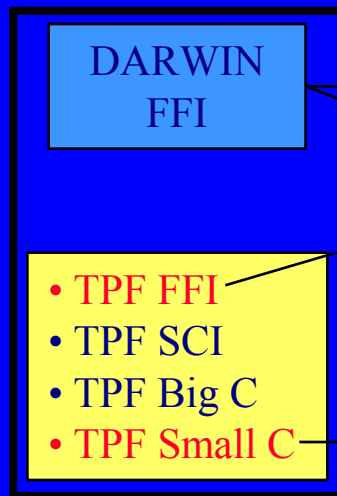
History Of Planet Finding Architectures

- 1985-1995 (AIT, TOPS)
 - Coronagraph based on super-polished mirror
 - Abandoned due to unreasonable requirements on primary mirror quality
- 1995-2000 (ExNPS)
 - Free-flying interferometer based on Bracewell/Angel/Shao nulling concepts
 - Designs included 1-2 m telescopes @ 5 AU (lower background) and 3-4 m telescopes @ 1 AU (easier space system)
 - Parallel architecture development with Darwin project
- 2000-2004 (TPF)
 - Investigate over 40 innovative designs using multiple contractors, university groups
 - Focus on coronagraph and interferometer
 - Coronagraph returns to consideration due to development of precision deformable mirror technology
 - Both technologies progress sufficiently to support missions in 2010-2020 timeframe
- 2004
 - Select coronagraph for flight in 2014
 - Formation flying interferometer for 2019 as joint program with ESA

Recommended TPF Mission Scenario

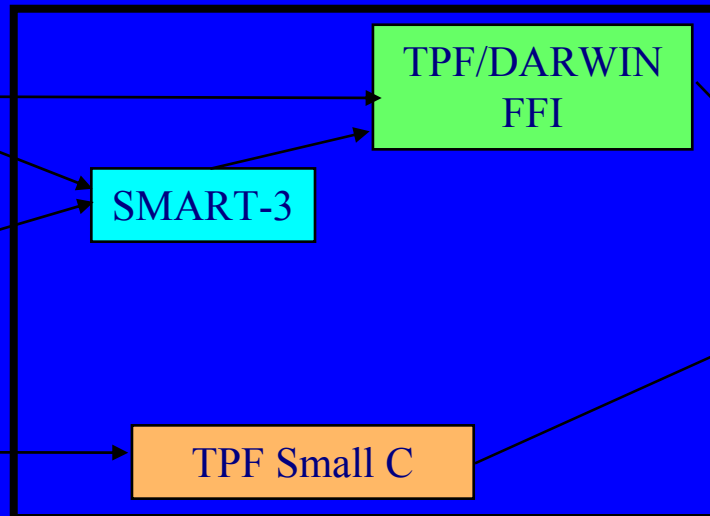
Today

Mission Studies
& Technology



Recommended Option

1st Generation
Missions (2010-2020)



Far Future

Vision Missions
Based on 1st
Generation
Results
(2020-2030)



Large apertures/baselines
needed for vision mission
will require astronauts for
servicing at L2 and/or
construction on moon

- NASA Missions
- NASA Minor Partner
- ESA Mission
- ESA Minor Partner
- Joint Missions

- Do a less costly coronagraph mission first, providing an early opportunity for detection & characterization of Earth-like planets
- Continue the technology leading to a more capable (and more costly) formation flying interferometer later with ESA.

The Science Case

Science Goals	TPF-C	TPF-I (FFI)	TPF-C + TPF-I
<i>Detect Earth-like planets¹</i>	◆	◆◆	◆◆
<i>Characterize Earth-like planets - biomarkers²</i>	◆	◆	◆◆◆◆
<i>Characterize Host Planetary Systems³</i>	◆◆	◆	◆◆◆
<i>General Astrophysics⁴</i>	◆◆	◆	◆◆◆◆

- 1) TPF-C is limited in resolution. TPF-I reaches further away, but is ultimately limited by sensitivity
- 2) Both TPF-C and TPF-I can detect biomarkers, but the combination of two offers better determination of physical properties and much more robust detection of life
- 3) TPF-C performs better on giant outer planets and has less problems separating multiple planets, combination of TPF-C and TPF-I is much better in characterizing the entire planetary system
- 4) TFP-C appeals to broader community and science topics, but TPF-I opens new and unique parameter space because of greatly improved angular resolution.

TPF-C and TPF-I Science Objectives

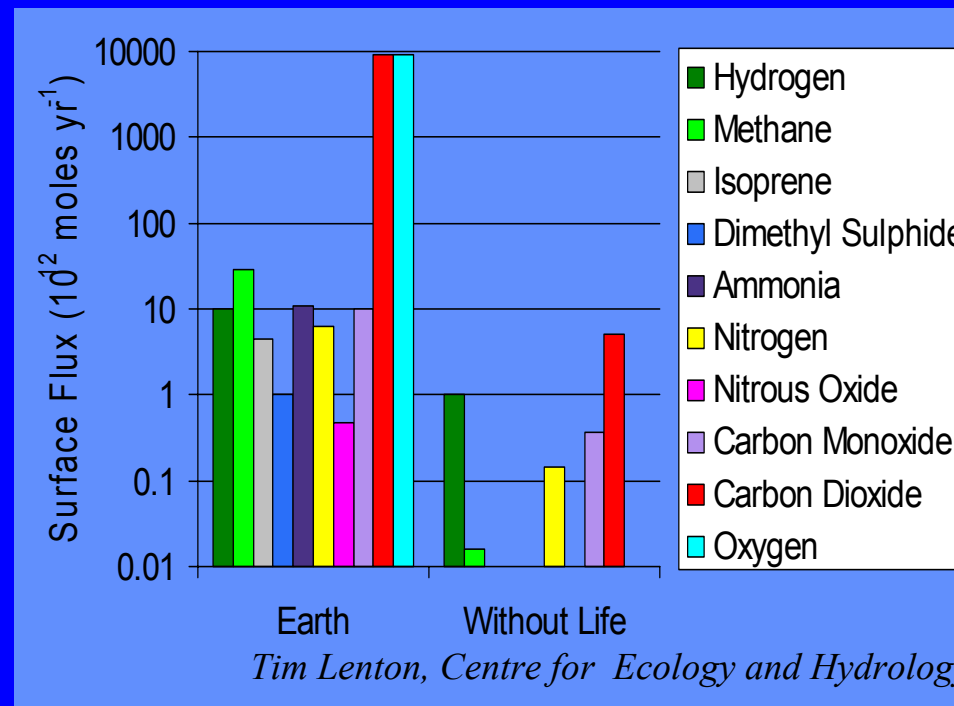
<i>Key Parameter</i>	<i>TPF-C</i>	<i>TPF-I</i>
# stars to search	35 core stars	>150 stars
Spectral range	0.5-0.8 [0.5-1.05] μm for water, oxygen	6.5-13 [6.5-17] μm for water, carbon dioxide, ozone
Star types	F G K	F G K & <i>others</i>
Habitable Zone	0.7--1.5 AU scaled as $L^{1/2}$	0.7--1.5 AU scaled as $L^{1/2}$
Orbit Phase Space	axis & incl = const; $e < 0.35$	axis & incl = const; $e < 0.35$
Assumed η_{\oplus}	0.1	0.1
Expected # planets	3	15
Minimum planet	1/2 Earth area	1/2 Earth area
Geom. albedo	Earth	Earth
Spectral Resolution	75-150	25-150
Giant planets	Jupiter @ 5 AU	< Jupiter flux @ 5 AU
Maximum tolerable exozodi	10 zodi	10 zodi

The Case for 2 TPF's: IR & Visible

- The TPF-SWG and relevant astrobiology researchers strongly endorse a TPF program that ultimately observes planets in BOTH mid-IR and near-IR/visible spectral ranges
 - *“Both the mid-infrared and the visible to near infrared spectral ranges offer valuable information regarding biomarkers and planetary properties, therefore both ranges merit serious scientific consideration for TPF. The best overall strategy for the Origins program includes a diversity of approaches, therefore both wavelength ranges ultimately should be examined prior to launching the ‘Life-Finder’ mission.” (Des Marais et al 2002).*
- Observations at two wavelength regions yields greatly improved knowledge and understanding → Great Observatories program for multi-wavelength observations of planets and planetary systems
 - Imagine cosmology without visible (stars and galaxies) or IR (ultra-luminous galaxies, high-redshift universe, or CMB) coverage

Multi-Wavelengths Make Characterization & Life Detection Robust

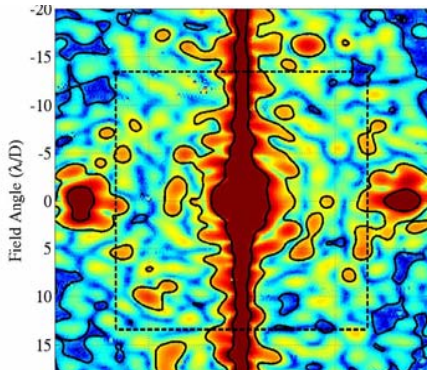
- Photometry at visible and mid-IR provides unique determination of albedo, radius, temperature
 - Visible + Spitzer limit constrains Sedna's properties and ultimate nature
- Improved characterization of sources too faint for spectroscopy
- Multiple lines in different wavebands confirm initial detections and extend possibilities for physical interpretation
- Simultaneous solution for mid- and near-IR lines of CO₂ or H₂O would yield information on concentration, temperature, vertical temperature gradient, and atmospheric pressure that would be hard to obtain from a single line.
- For planets with atmospheres (and modest cloud cover), we get complementary information since IR primarily characterizes atmosphere while visible sees down to planet's surface



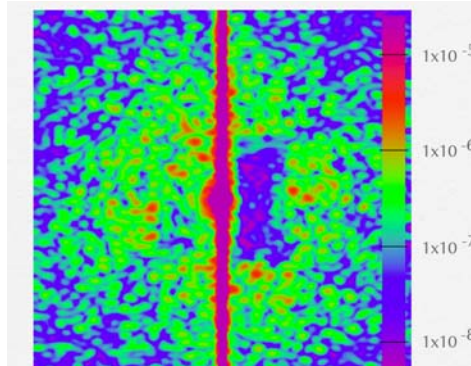
- Simultaneous multi-wavelength coverage is not required to measure planet-wide, bulk properties

Starlight Suppression Progressing Well at Both Wavelengths

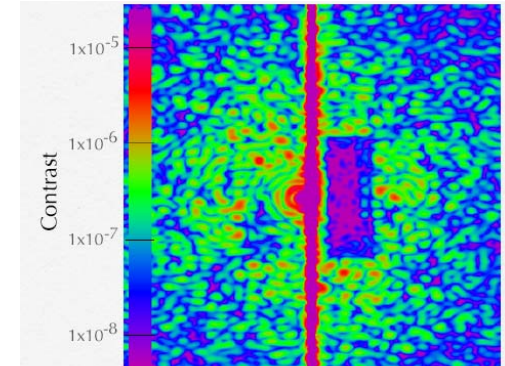
Recent Progress in On the High Contrast Imaging Testbed: TPF Requirement 10^{-9} - 10^{-10}



October '03
(Contrast = 2×10^{-6} @ $0.8 \mu\text{m}$)

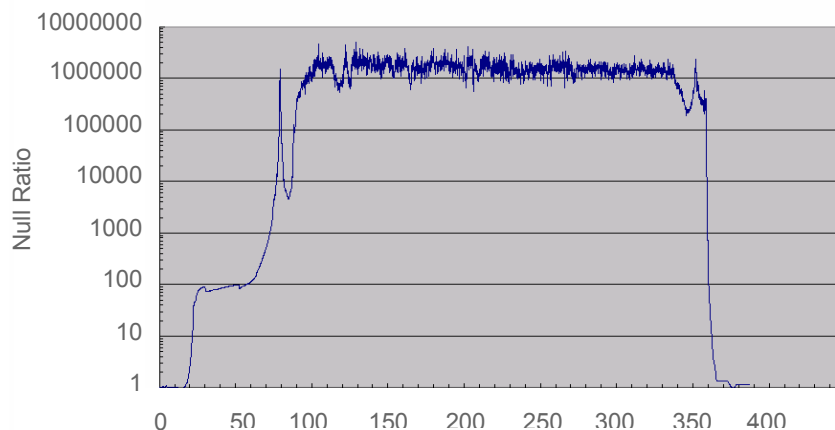


December '03
(Contrast = 3×10^{-8} @ $0.8 \mu\text{m}$)

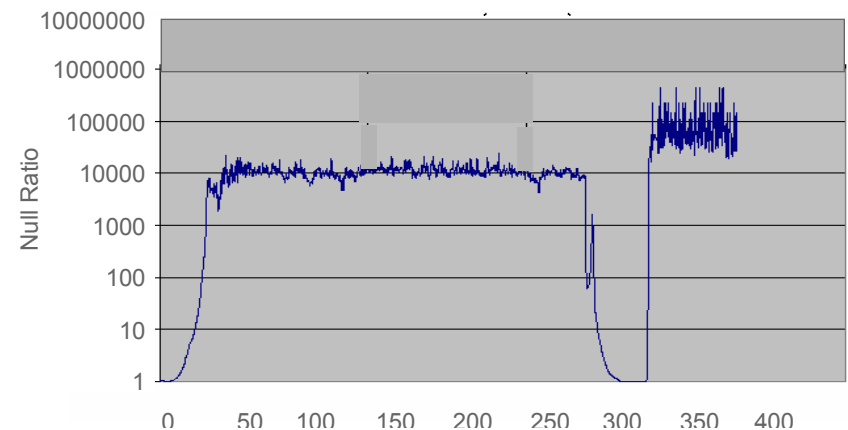


February '04
(Contrast = 8×10^{-9} @ $0.8 \mu\text{m}$)

Recent Progress on Nulling: TPF Requirement 10^{-5} - 10^{-6}

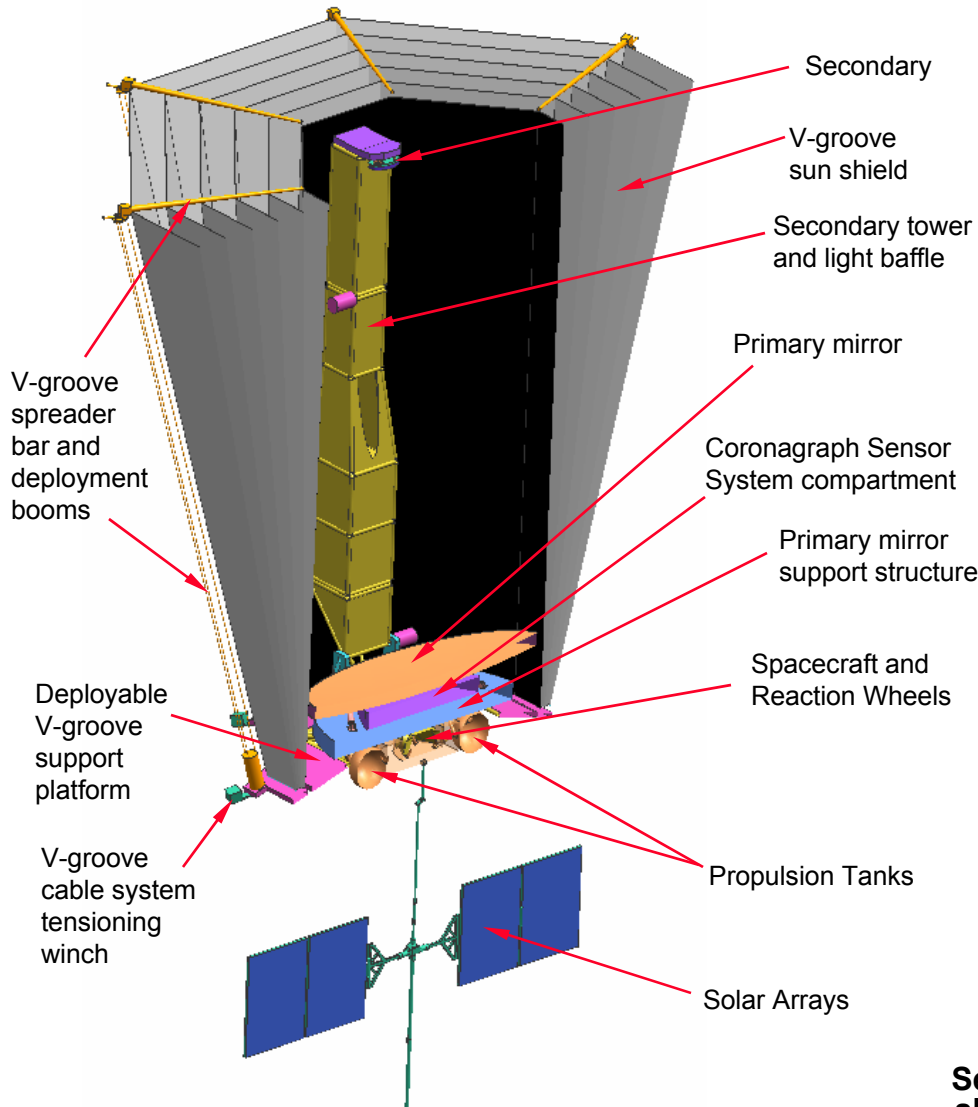


October '03 (9×10^{-7} @ $10 \mu\text{m}$ -laser)



November '03 (1×10^{-4} @ $10 \mu\text{m}$ -30% BW)

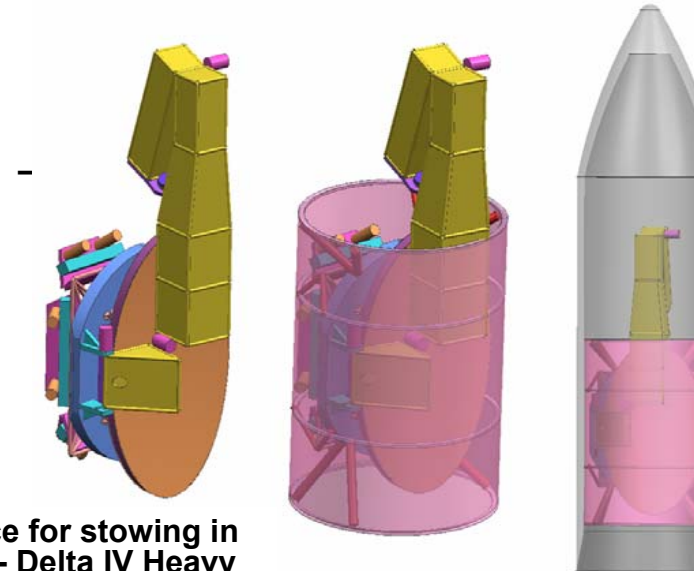
Coronagraph Baseline Concept Includes Detailed Design and Error Budget



- **TPF Coronagraph, Minimum Mission Design**

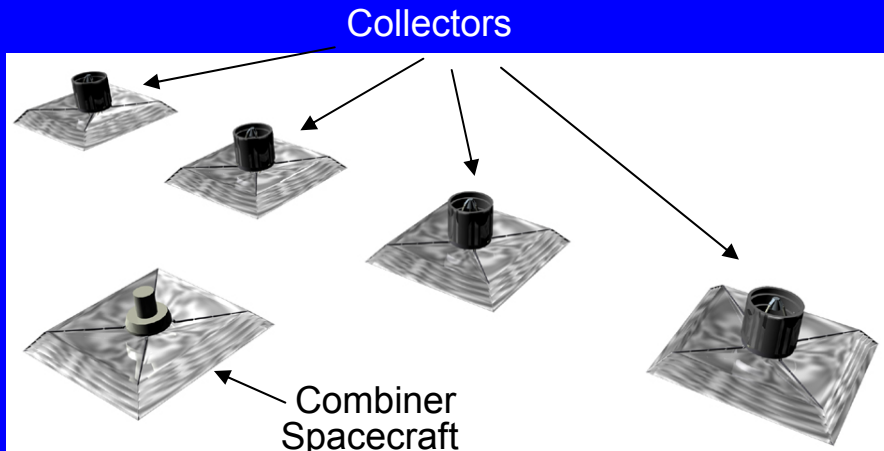
- Primary Mirror: 6 x 3.5 meters, ULE
- Can survey >35 stars
 - 95% completeness in two years
 - Observing sequence defined
- Delta IV-H w/ currently available fairing
 - Realistic packaging

Double click for animation

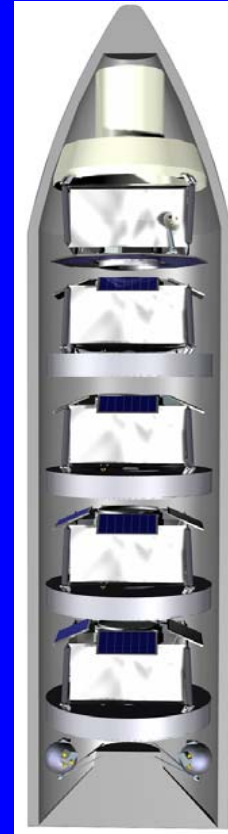


Sequence for stowing in shroud – Delta IV Heavy

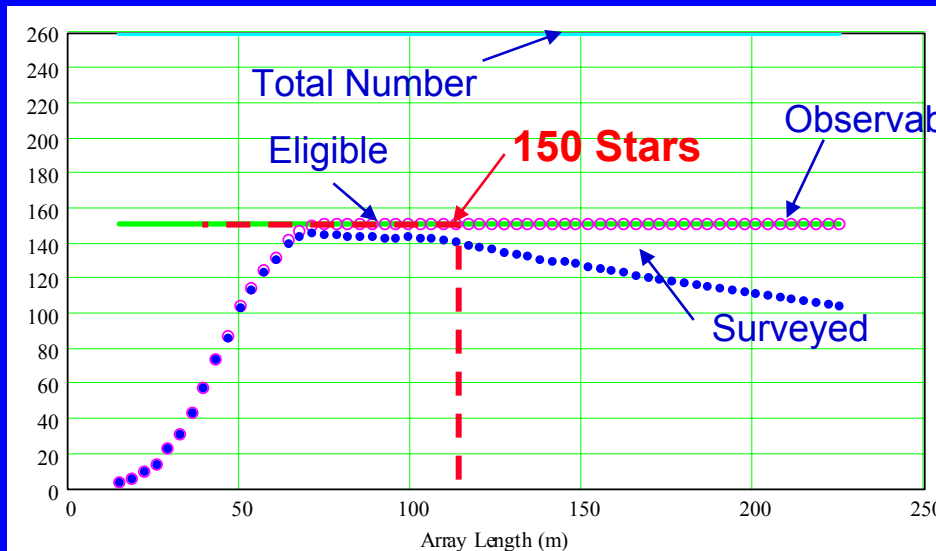
Formation-Flying Interferometer Baseline Design Concept



- Dual-chopped Bracewell
- Array size: 70 to 150 m
- Four apertures, 4.0 m diameter
- +/- 45 degrees sky coverage
- Delta-4 heavy, 22.4 m fairing
- L2 Orbit
- 150 stars surveyed, sensitivity-limited



Star Selector Analysis



Deployment



Comparative Planetology And General Astrophysics Programs

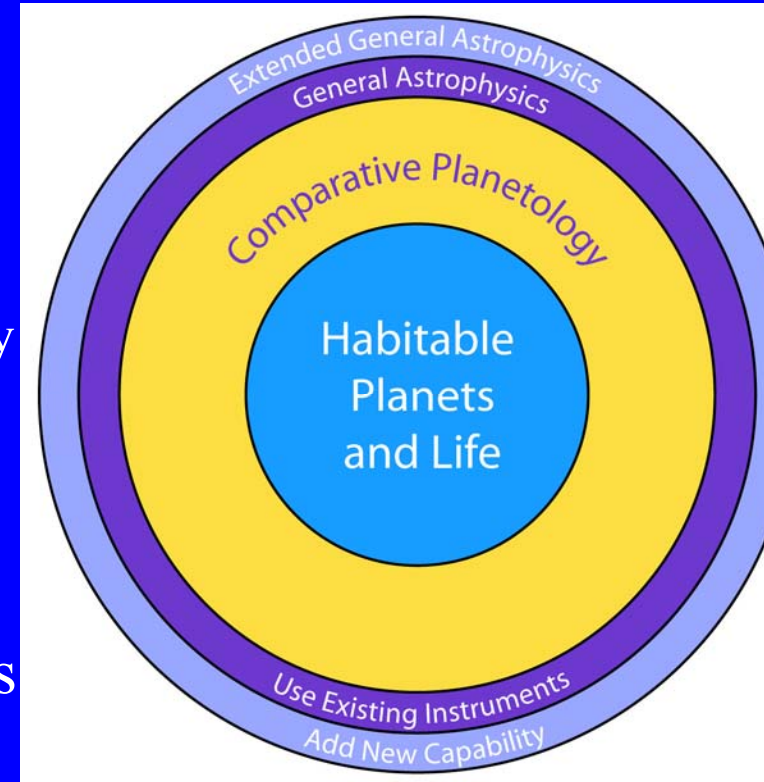
Goals of TPF extend beyond simply detecting and characterizing Earth-like planets

- Understand the environment within which life might originate and evolve
- Understand formation and evolution of planetary systems
- Detect and characterize all constituents of other planetary systems, including outer planets, dust disks, comet and asteroid belts

TPF should be capable of carrying out a meaningful program of general astrophysics relevant to Origins, SEU & SSE goals

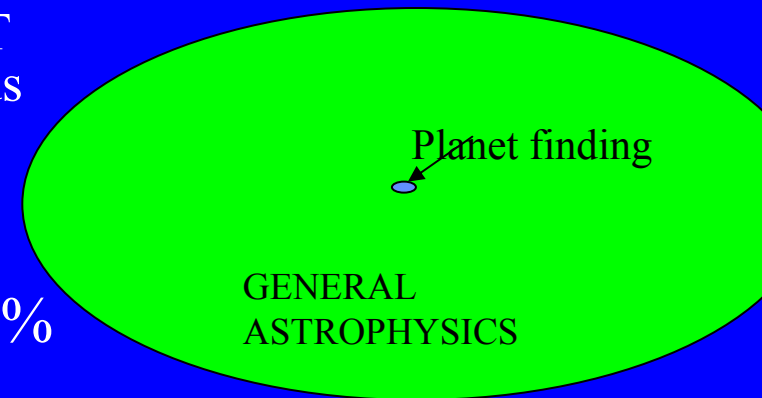
Ground rules for general astrophysics program

- *Thou shalt not compromise planet-finding (at all!)*
- *Thou shalt not affect the facility (much)*
- *Thou shalt not increase the mission cost (minimal)*
- *Thou shalt not take up too much observing time (<25%)*



Additional Capabilities for TPF-C Will Greatly Enhance Science Return

- Near unanimous agreement on a visible/near-IR camera for TPF-Coronagraph to add additional astrophysics capability
 - 2' ~5' field of view with 10 mas pixels available at all times for parallel and targeted observations for broad range of scientific investigations (solar system to most distant supernovae and forming galaxies)
 - Visible light channel (0.4-1.0 μm) provides for dramatic new imaging capability to replace HST and SNAP/JDEM
 - IR channel (short wavelength HgCdTe <1.6 μm) provides guiding for entire facility as well as high redshift imaging to complement JWST
- 50 target stars (50% of 5 yr mission)
 - 18 days of integration per field with 6 x HST collecting area > UDF sensitivity on 50 fields
 - Multiple visits: variability studies
 - Very complementary to LSST program
 - Complement with repeat return visits?
- 200 comparative planetology targets (25% of mission time)
 - 3 days of integration ~ HDF sensitivity
- *NASA HQ has not yet agreed to providing any additional capability!*



Project's Conclusion

- TPF-C ready to go at low risk for 2014 launch
- TPF-I ready to proceed with technology development for 2018 launch
 - Requires formation flying space demonstration currently planned as joint program with ESA, SMART-3 in 2010
 - Continuing technology development of nulling and other key technologies
- Near term plans
 - Support CAA review as required
 - Develop plan on TPF-C in preparation for Phase-A by 2005/6
 - Develop plans with ESA for TPF-I and SMART-3
 - Hold additional workshops on general astrophysics as designs mature
 - Continue support for key science and technology