TPF
Phase 1 Preliminary Architecture Review (PAR)

Lockheed Martin Team

12-14 December, 2000

San Diego, CA

Introduction &
Evaluation Process

Domenick Tenerelli
Lockheed Martin Space systems Company (LMSSC)

Terrestrial Planet Finder (TPF)
Phase 1 Architecture Study Report
Dec 12, 2000

Agenda

Tuesday, December 12, 2000

0800 - 0815	Welcome/Logistics	JPL
0815 - 0845	Introduction/Evaluation Process	Domenick Tenerelli
0845 - 0925	Science Requirements/Rationale	Nick Woolf
0925- 0945	Planetary Science	Jonathan Lunine
0945 - 1015	Optical Systems	Roger Angel
1015 - 1030	Break	
1030 - 1130	Architectures/Technology	Nick Woolf
1130 - 1200	System Trades & Analyses	David Miller
1200 - 1230	Summary, Conclusions & Plans	Domenick Tenerelli

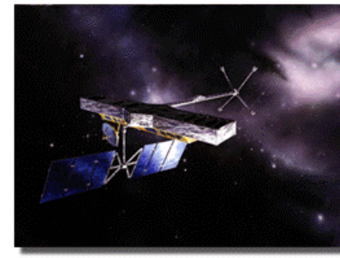
Thank You...

- To the folks at JPL who decided to send us to sunny San Diego.

Effective Partnering- Key to Total System Success

Lockheed Martin

- Program Management
- Systems Engineering
- System Concepts
- Spacecraft Technologies
- Spacecraft Design
- Integrated Modeling/Perf. Analysis



MIT

- Autonomous Formation Flying
- Systems Engineering Spt
- Integrated Performance Analysis
- Cost Cycle Analysis

U of A

- Optical System/ Mirror Design/Fab
- Observatory Configuration
- Science Instruments / Detectors

SCIENCE TEAM

- Oversight and direction
- Evaluations

BUSEK

- Micro-Thrust Propulsion

Kodak

- Mirror Design / Fab

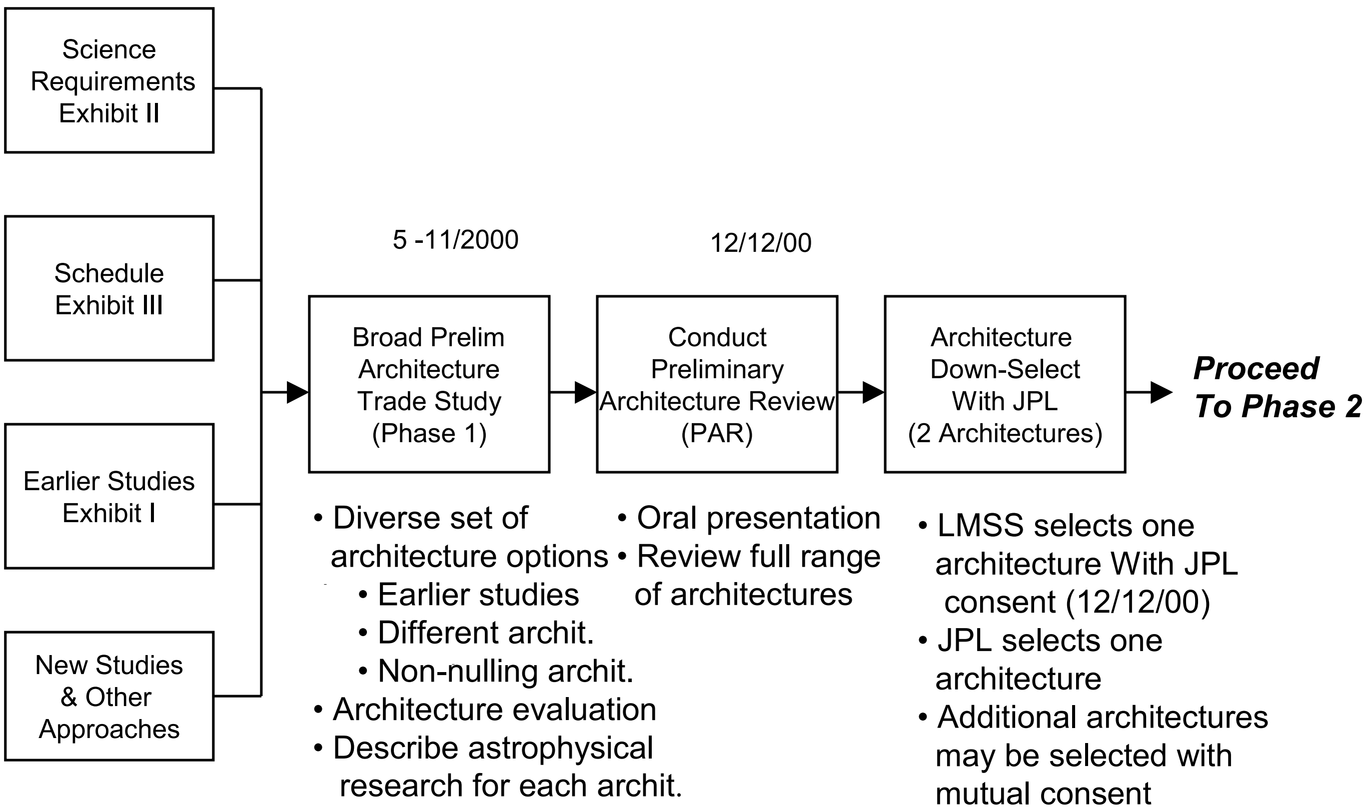
Lockheed Martin Team Organization

- Remote Sensing & Space Sciences
  Ron Paulson, VP
  - TPF Program
    Domenick Tenerelli
    Program Manager
    Lockheed Martin
    - Program Technologist
      Y. C. Yiu
    - Business Operations
      G. Painter
    - Spacecraft/ATLO
      Ken Hooper
    - Science Team
      Neville Woolf
      Univ. of Arizona
    - System Engineering & Mission Design
      Amy Mainzer
      LMMS
      - Busek - Micro-thrusters
      - Tom Sherrill - Orbit & sky coverage
      - Kin Chan - SE & I&T
      - Bob Jones - SE
    - Optical System/ Obs Configuration
      Roger Angel
      Univ. of Arizona
      - Gary Matthews, Optics
      - Jim Burge, Optics
      - Phil Hinz, Architect
    - Integrated Performance Analyses
      David Miller
      MIT
    - Autonomous Formation Flying
      Larry Capots, LMMS
      Jonathon How, MIT

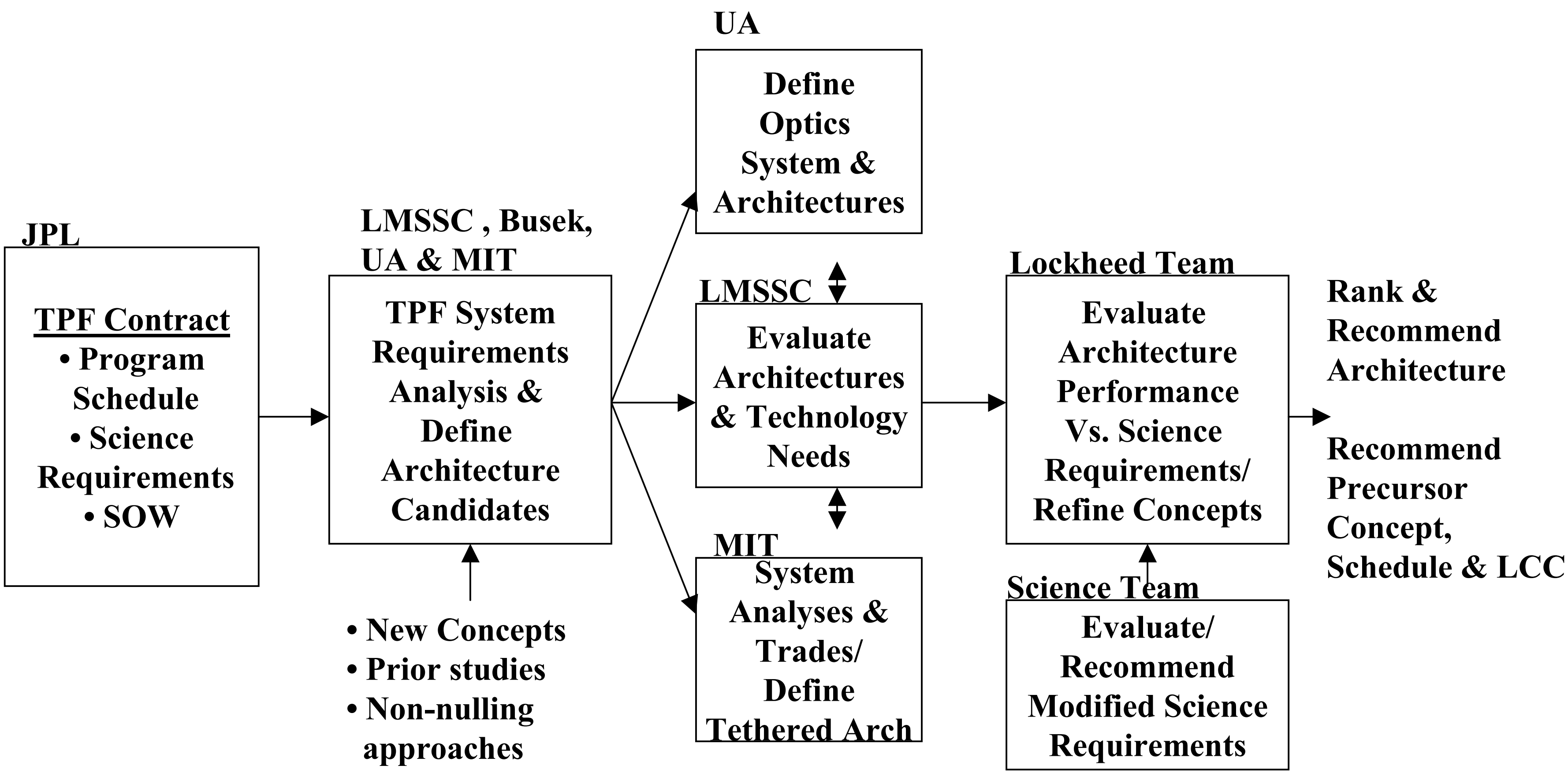
Team Meetings & Telecons

• Offsite Team Meeting - Boulder Creek - 3 1/2 days	May
• Weekly Team Telecons (1/2 to 2 hours) - 29	May-Dec
• JPL Telecons (1/2 - 1 hour)- 14	May - Dec
• Science Team Telecons - 4	May - Dec
• Team Meeting - LMSSC (2 days)	June
• Team Meeting - UA (1 day)	July
• Team Meeting -MIT (1 day)	August
• Team Meeting - UA (2 days)	September
• Team Meeting - LMSSC (2 days)	October
• Team Meeting - LMSSC (4 days)	November

Phase 1 Study Logic



Phase 1 Study Flow



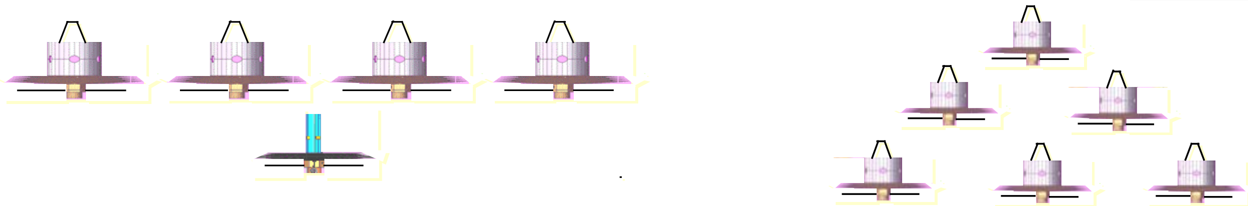
Summary of Phase 1 Results

- Have developed 5 “Islands of Sanity”
  - Island 1: Free flying spacecraft
  - Island 2: Mirror segments
  - Island 3: Connected structure
  - Island 4: Tethered spacecraft
  - Island 5: Coronagraph

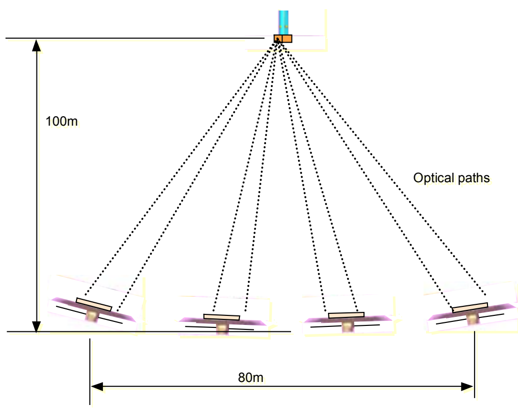
- Going to longer wavelengths greatly simplifies many aspects of mission

Architectural Configurations

Island 1

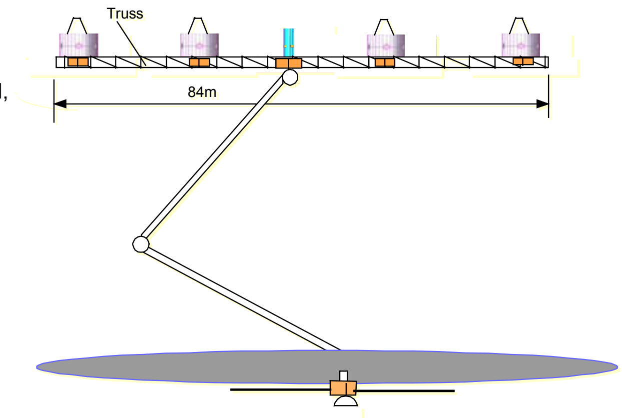


Island 2

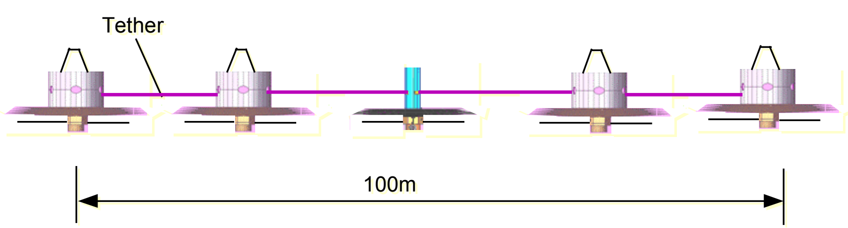


Island 3

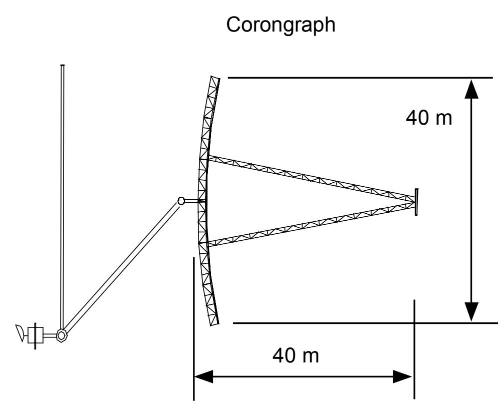
8 mirrors total,
6x1.1m ea



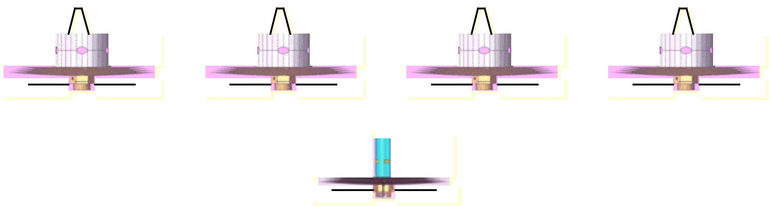
Island 4



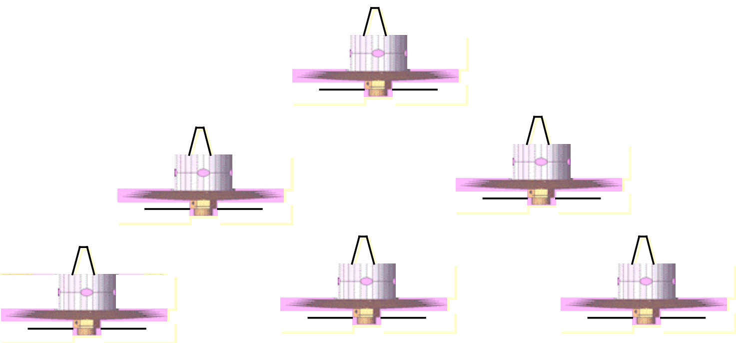
Island 5



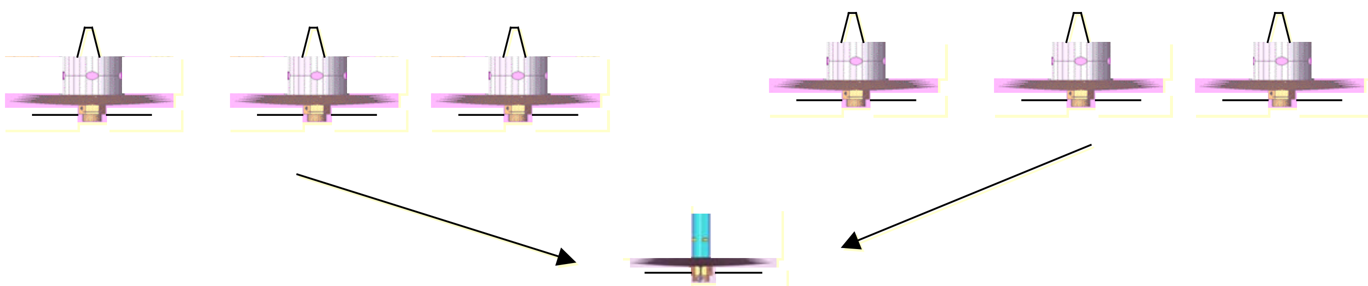
Island 1 Configurations



Configuration 1 : JPL Monograph Baseline



Configuration 2: Marriotti



Configuration 3: Dual 3-element

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Exhibit II Science Requirements*
January 7, 1999

	Requirement	Goal	Comments
General Mission Assumptions			
1. Sky coverage	60%	90%	
2. Mission duration (years)	5	10	
3. Nominal planet is defined as a solid body with Earth radius at 1 AU, T=270 K.			
4. The planet detection and characterization program will be allocated ~50% of the design mission lifetime with the remainder of the lifetime allocated for general imaging and spectroscopy.			
5. Spacecraft use non-nuclear power sources.			
Planet Detection/Characterization			
1. Number of stars (F5-K5) surveyed for planets (R=3, SNR=5)	150	500	
2. Number of scans for CO_2/H_20 (R=20, SNR=10)	30	100	
3. Number of scans for Ozone/strong CH_4 (R=20, SNR=25)	5	25	
4. Spectral Band (μ m)	7(TBR) to 17(TBR)	3 to 23	Zodiacal light limited
5. Spectral Resolution	20	100	Add'l goal R=100 at 7.6 μm
6. Maximum distance of ozone detection (pc)	10	20	
7. Minimum distance of planet detection (pc)	3	2	
8. Exo-zodiacal dust will be the same as in our own solar system for requirement, up to 10 times the solar system level.			
9. Follow-up (high spectral resolution) surveys are uniformly distributed throughout the volume of the initial survey.			
10. Point source sensitivity: 5 σ, 2 hr at 12 μm, R=3. (μ Jy)	0.3	0.1	
High Resolution Imaging (TBR)			
1. Imaged objects for 5 year mission	800	1600	(1 object/day)
2. Resolution at 3 μm (milliarcsecond)	0.75	0.75	
3. Band (μm)	3 to 17	2 to 40	(zodi limited at λ<=20μm)
4. Spectral resolution	3 to 300	3 to 300	
5. Special purpose spectral resolution (FTS mode) in specified lines		10^5 at 3-20 μm	
6. Capable of using a guide source within radius (arcsecond)	On-axis	120	(guide source equivalent to K band at 2 μm, 14^{th} mag)
7. Effective minimum baseline for synthetic imaging (m)	100	<50	Applies only to interferometric architectures
8. Dynamic range in Reconstructed Image	50:1	100:1	

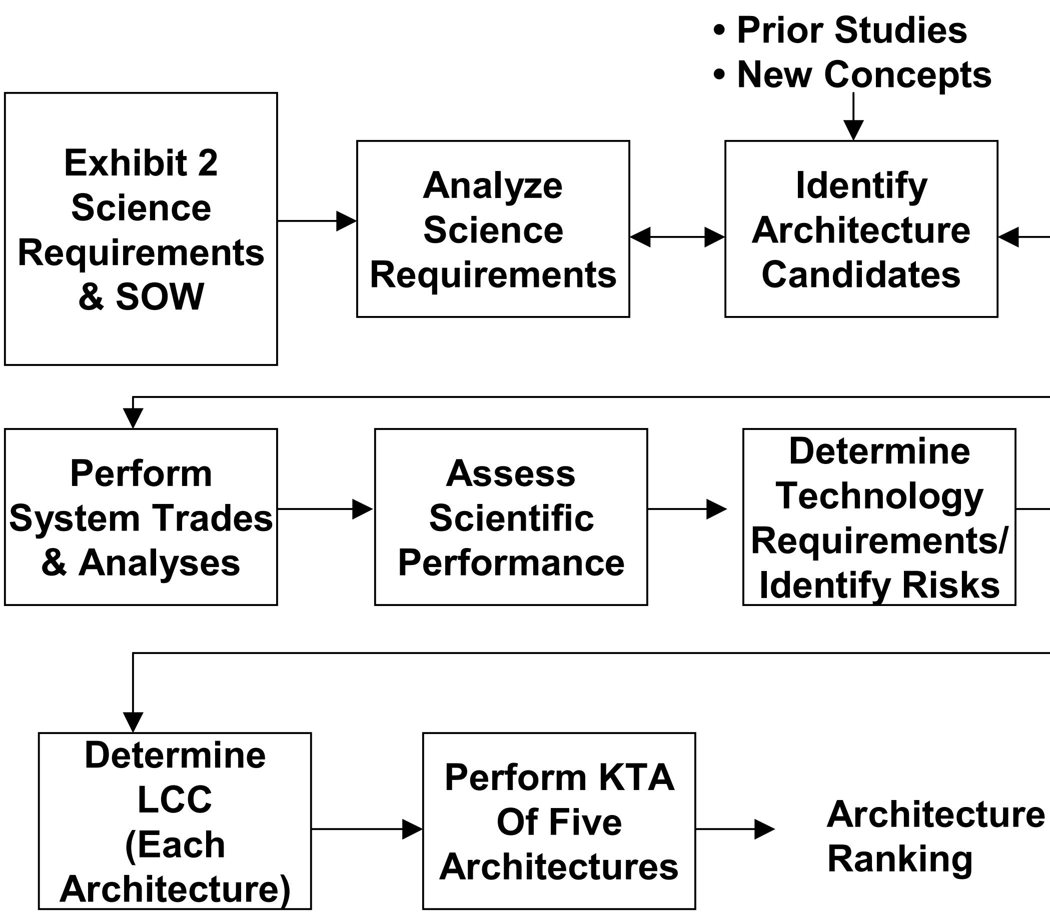
TBR=To Be Resolved

Exhibit II Science Requirements January 7, 1999 (Cont)

Note to proposers:

The use of the science requirements Exhibit represented above as a baseline in no way represents a commitment that the final mission will be built to the same scientific program. The contractor may propose corrections and additions to the baseline mission. See Exhibit I for more detailed descriptions of the scientific goals of TPF.

Evaluation Process Flow



Evaluation Items

- RISK is the danger that the concept will encounter a major technological hurdle that prevents it being implemented in cost and time.
- RELIABILITY/ROBUSTNESS is the mean time to failure/the amount of redundancy placed in the system without change in performance with a failure.
- HERITAGE is the ability to make technological and experiential progress towards Life Finder and TPI.
- ASTROPHYSICAL IMAGING presented problems for every concept considered. Free flying systems required an additional mission to fill in short baseline information. Fixed baseline systems were unable to supply the long baseline information. In all cases, optimization for planet studies de-optimized astrophysical abilities and vice versa.

Planet-Star Contrast

0.5-4 μm	5×10^9
7 μm	10^8
10 μm	1.2×10^7
20 μm	1.7×10^6
10 μm	2×10^5

- Note the rapid change of star-to-planet ratio from 7-20 μm.
- Fluctuation of residual star signal must be reduced to allow high signal-to-noise for planet.
- The 10 μm number does not allow for the greenhouse increase of 8-13 μm fluxes.

TPF Architecture Evaluation

Configuration Number	Number of Telescopes	Architecture	Planetary Detection	Astrophysics Opportunities	Technology Requirements	Risk	LCC Phase B,C,D	Reliability/ Robustness	Heritage (Legacy)	TOTAL
Weighting			10	5	9	8	10	7	4	
Island 1	3 Collectors 2 Combiner/ Collectors	Separate S/C Interferometer (SSI)	10 (100)	5 (25)	9 (81)	9 (72)	10 (100)	10 (70)	10 (40)	488
Island 2	1	Segmented Mirror Interferometer (SMI)	10 (100)	5 (25)	7 (63)	7 (56)	4 (40)	5 (35)	5 (20)	339
Island 3	4 Collectors 1 Combiner	Structurally Connected Interferometer (SCI)	10 (100)	5 (25)	10 (90)	10 (80)	8 (80)	7 (49)	8 (32)	456
Island 4	3 Collectors 2 Combiner/ Collectors	Tethered S/C Interferometer (TSI)	10 (100)	5 (25)	6 (54)	6 (48)	5 (50)	3 (21)	6 (24)	322
Island 5	1	Coronagraph	10 (100)	5 (25)	3 (27)	2 (16)	3 (30)	2 (14)	4 (16)	228

Life Cycle Cost

- Costs include development, phase A/B/C/D, and launch vehicle.
- Cost categories:
  - Very high = Over 2.5 billion
  - High = 1.75-2.5 billion
  - Moderate = 1.0-1.75 billion
  - Low = 0.5-1.0 billion
- Island 1 - Separate Spacecraft Interferometer High
- Island 2 - Segmented Mirror Interferometer Very High
- Island 3 - Structurally Connected Interferometer Very High
- Island 4 - Tethered Spacecraft Interferometer Very High
- Island 5 - Coronograph Very High
- Island 1 Precursor Moderate
- Island 3 Precursor Low

Summary of Architecture Evaluation

- The leading architecture to meet Exhibit II requirements is Formation Flying, (SSI, Island 1) (essentially the system of the TPF monograph)
- Structurally Connected Interferometer (SCI, Island 3) has least development however costs increase vs interferometer baseline increases
- Coronagraph, Island 5, has difficulty because of the low photon rate for the objects we are observing
- Island 2 and 4 have potential

Science Requirements for Minimal TPF

- Detect giant planets (Jupiters and Saturns) in Solar System-like orbits in ~50-60 star systems out to ~13 pc
- Detect Earth-like planets up to at least 3-8 pc in 10 star systems
- Detect CO2, H2O, and planet's temperature if Earths are found
- Paring down requirements to a minimum → mission buildable within reasonable time/cost