



JPL

Terrestrial Planet Finder Mission

TPF

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Mission

Interferometer System Overview

Gary Blackwood

Interferometer Systems Manager

October 14, 2003

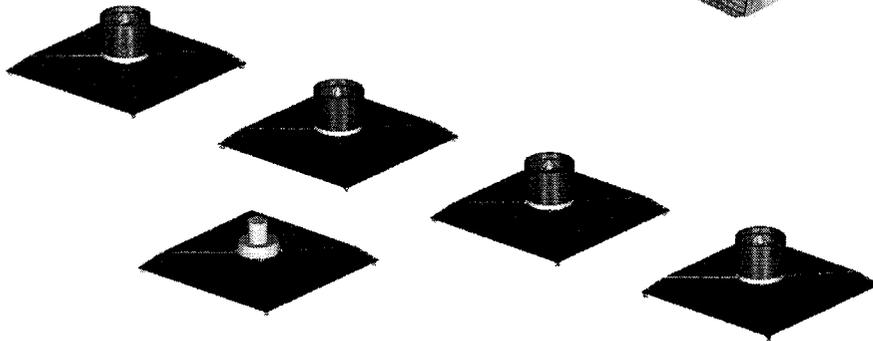


Interferometer Systems

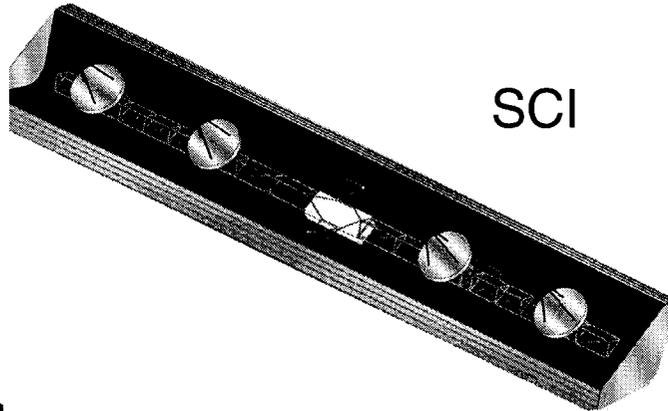


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FFI



SCI



TPF

How:

- Architecture Team
- Design Team
- Technology Teams

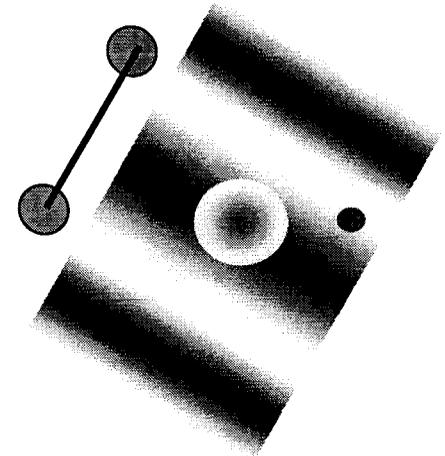
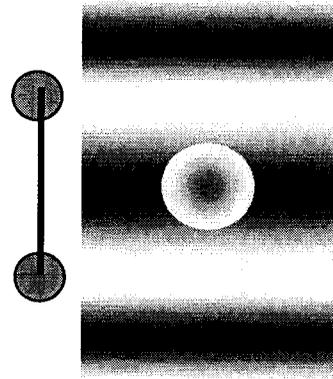
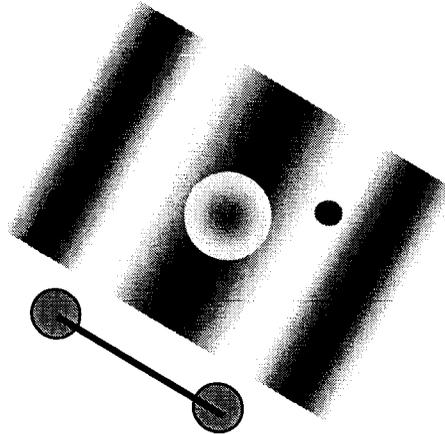
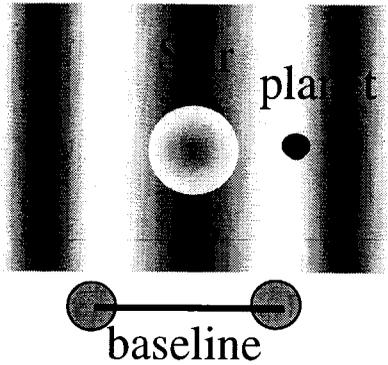
Will Deliver

- Structurally-Connected Interferometer concept for the *minimum* TPF science
- Formation-Flying Interferometer concept for the *full* TPF science
- Technology results, end-to-end simulation, and model validation to demonstrate viability of concepts

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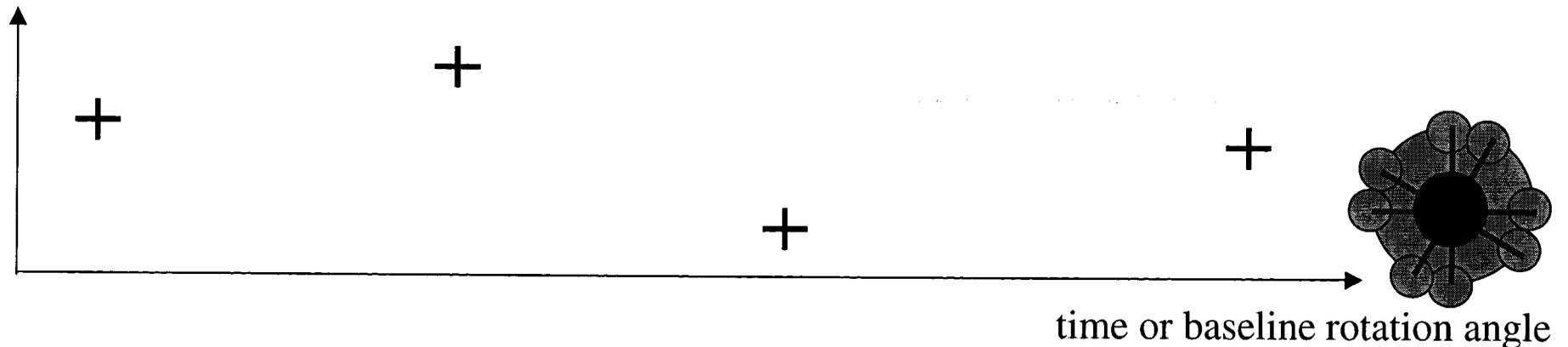
Interferometric Exo-Planet Detection

antenna pattern on the sky

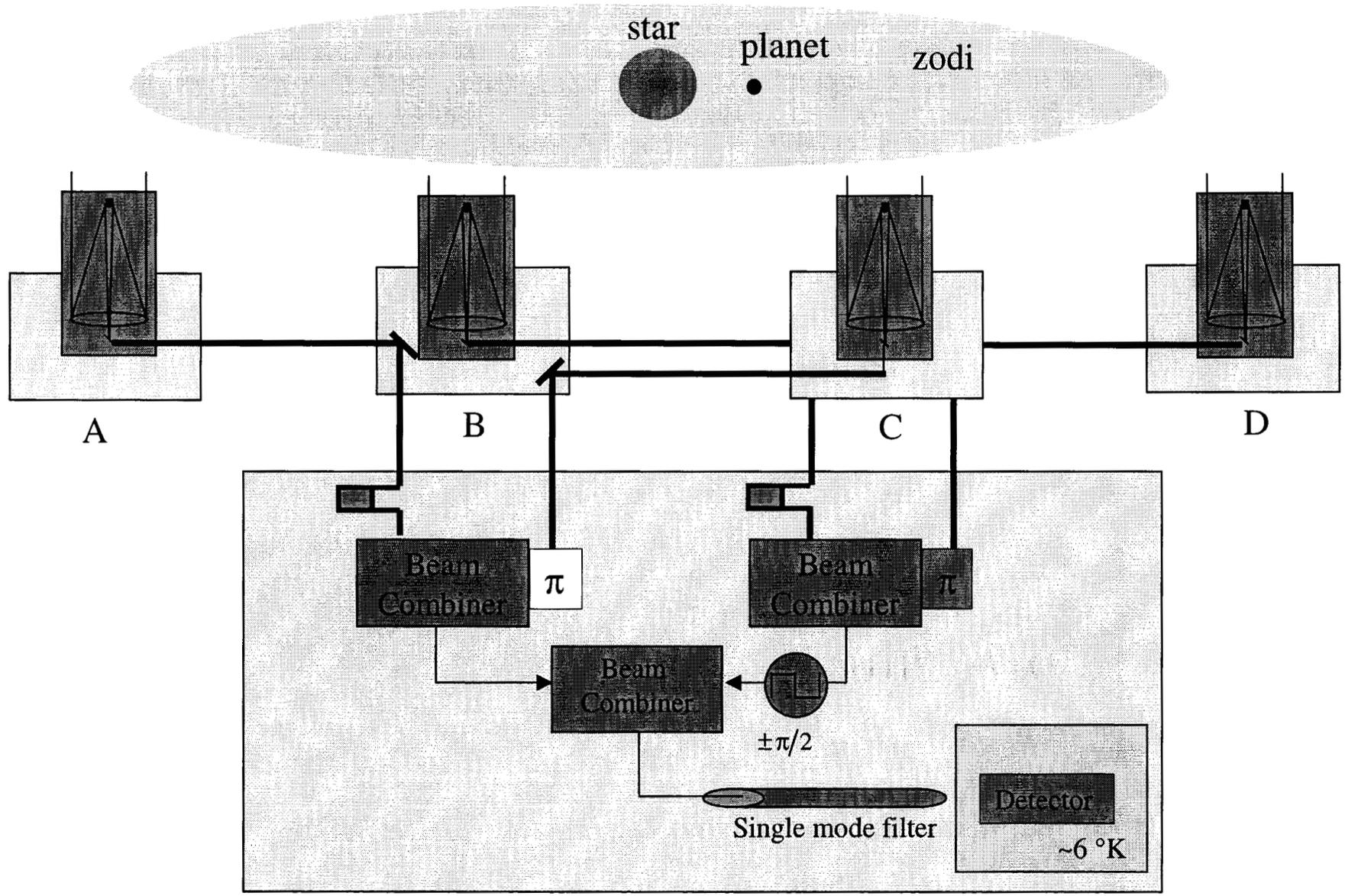


- Star is always on the dark fringe (null)
- Planet crosses the fringes as the baseline rotates:
signal modulation due to planet

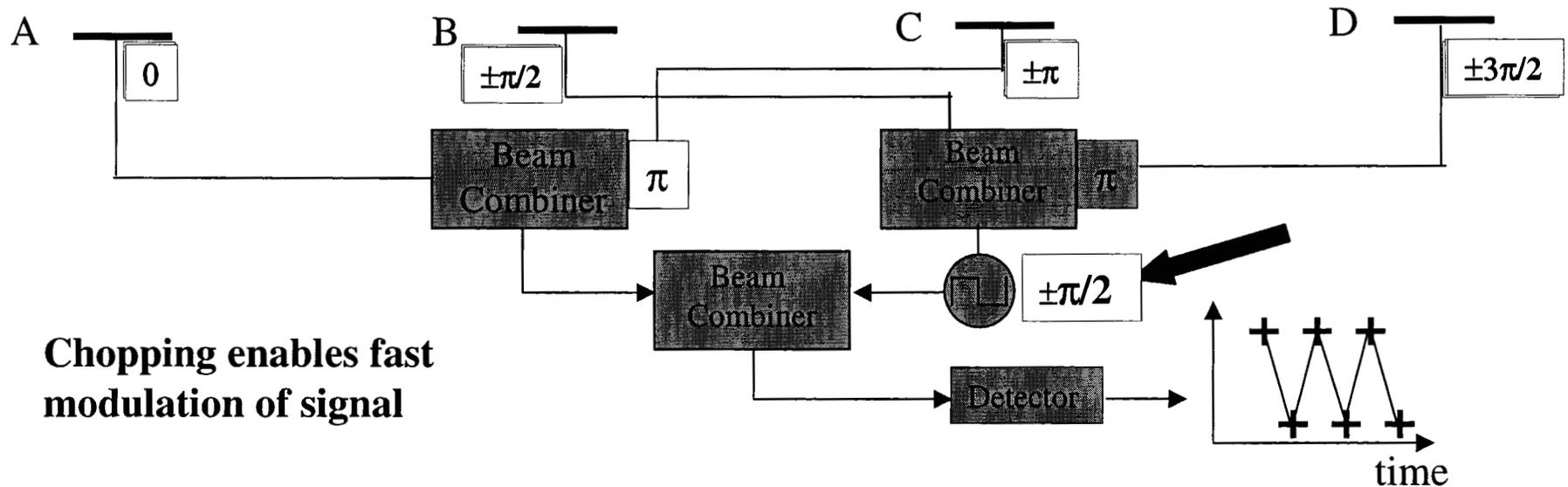
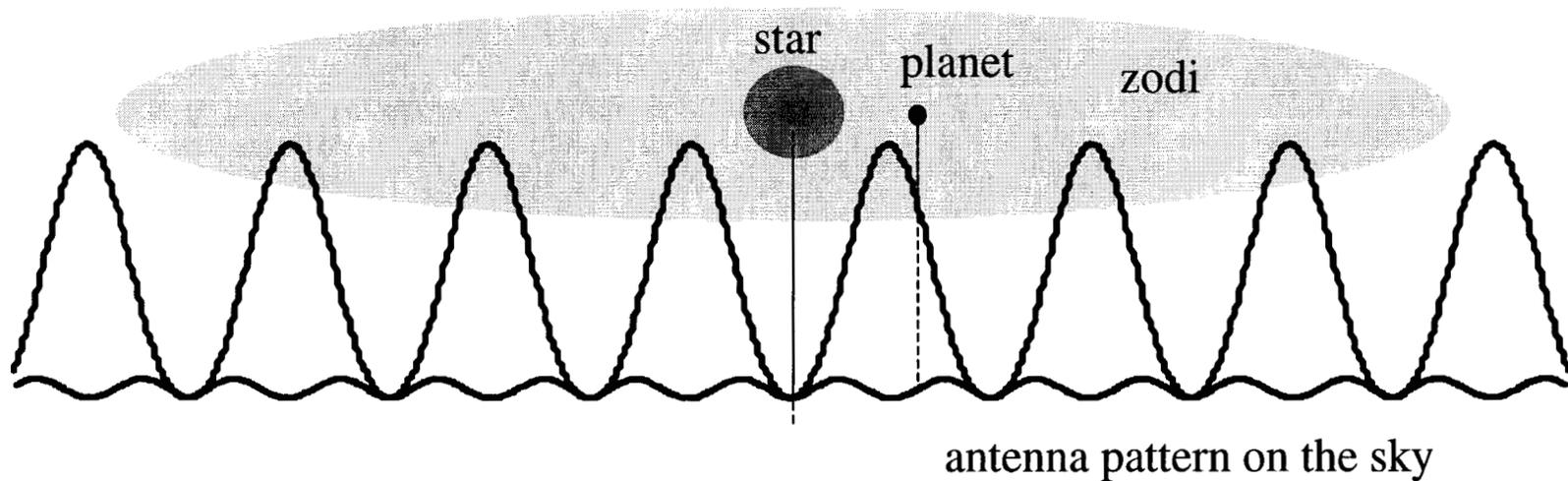
Detected
optical energy



Dual Chopping Bracewell Nulling Architecture



Chopping: a method for background suppression





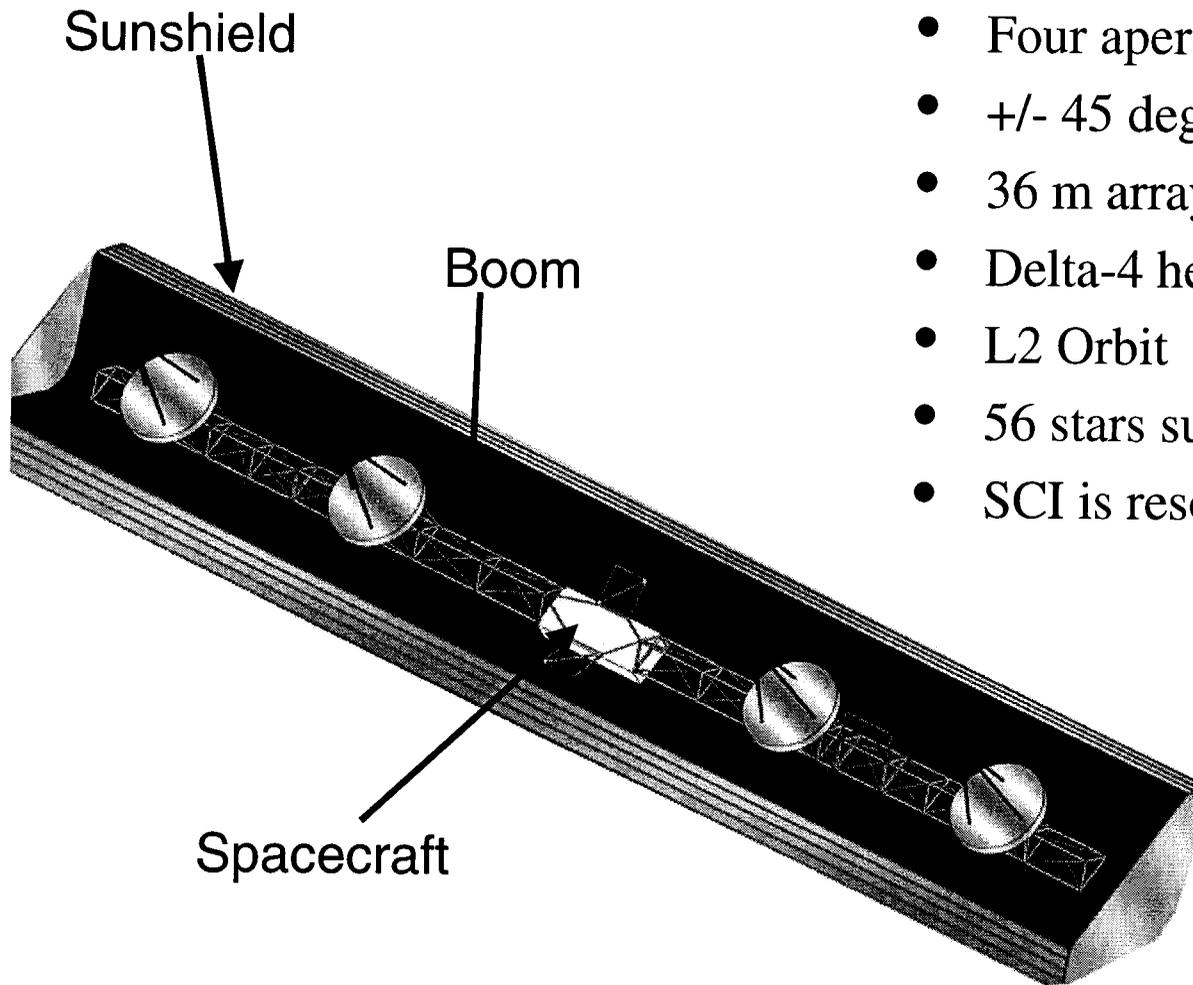
Strawman for Structurally-Connected Interferometer



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- Dual-chopped Bracewell
- Four apertures, 3.2 m diameter
- +/- 45 degrees sky coverage
- 36 m array
- Delta-4 heavy, 22.4 m fairing
- L2 Orbit
- 56 stars surveyed in 2 years
- SCI is resolution-limited

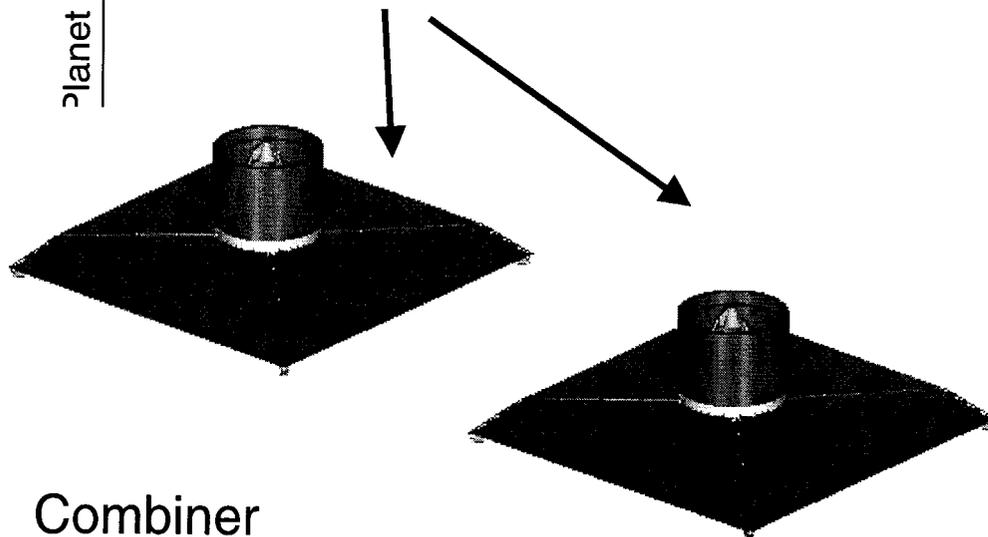


Formation Flying Interferometer Strawman



Planet Finder Mission

Four
Collectors



Combiner

- Dual-chopped Bracewell
- Four apertures, 4.0 m diameter
- +/- 45 degrees sky coverage
- Array size: 70 to 150 m
- Delta-4 heavy, 22.4 m fairing
- L2 Orbit
- 150 stars surveyed in 2 years
- FFI is sensitivity-limited

Strawman Comparison

	Structurally Connected Interferometer	Formation Flying Interferometer
Science Capability		
Number of Stars	56	150
Science Assumptions		
Local zodi (MJy per sr, at 12 μ m)	14	14
Star List:	modified Ebbets	modified Ebbets
Engineering Assumptions		
SNR for Detection	5	5
Min Wingtip-to-Wingtip spacing (m)	NA	10
Number of visits	3	3
Inclination Factor = (IHZ / IWA)	1.29	1.29
HZ (au) for 95% completeness, half-earth area	0.7-1.5	0.7-1.5
Engineering Parameters (Derived)		
Nulling Architecture	uneven DCB	even DCB
Array size (m)	36	70 to 150
Number of apertures	4	4
Mirror diameter (m)	3.2	4.0
Sky coverage (+/- degrees, from anti-sun)	45	45
Throughput	5%	7%
Integration Time / (2 yrs Calendar time)	50%	75%
Number of detectors	1	2



Collaboration with ESA

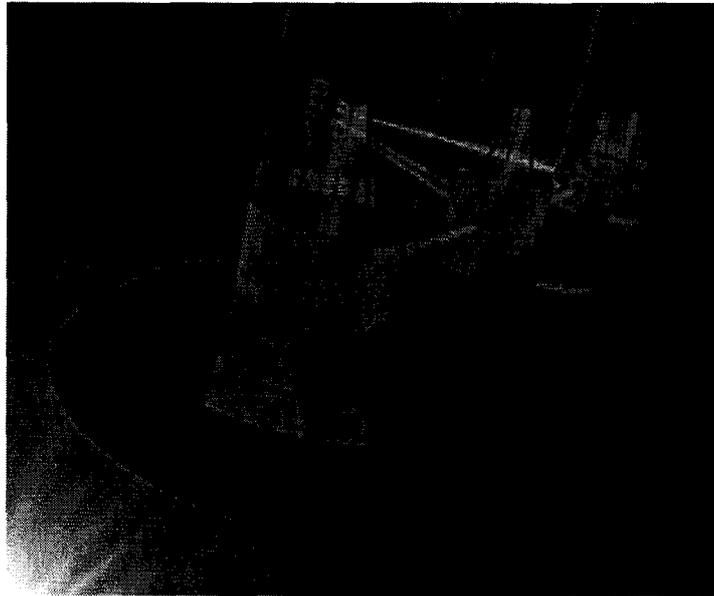


Terrestrial Planet Finder Mission

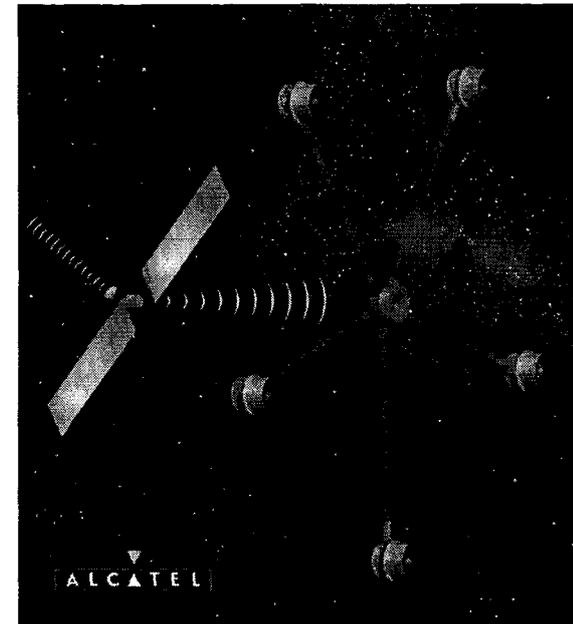
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TPF Book Design



ESA - Darwin



- Objective – make common nulling architecture recommendation
- Figures of Merit:
 - Detection Sensitivity
 - Fuel Usage
 - Leakage suppression
 - Launch packaging
 - Beam combiner complexity
 - Array size

**SWG +
Interferometer
Scientist**

Interferometer System

**FF
Technology
Team**

**Inter-
ferometer
Technology
Team**

**Architecture
Team**

**Core
Team**

**Design
Team**

**TPF
Project**

Science Reqts

Testbed Results

Technology Reqts

Testbed Results

Technology Reqts

Performance Reqts

Point
Designs
& Sims

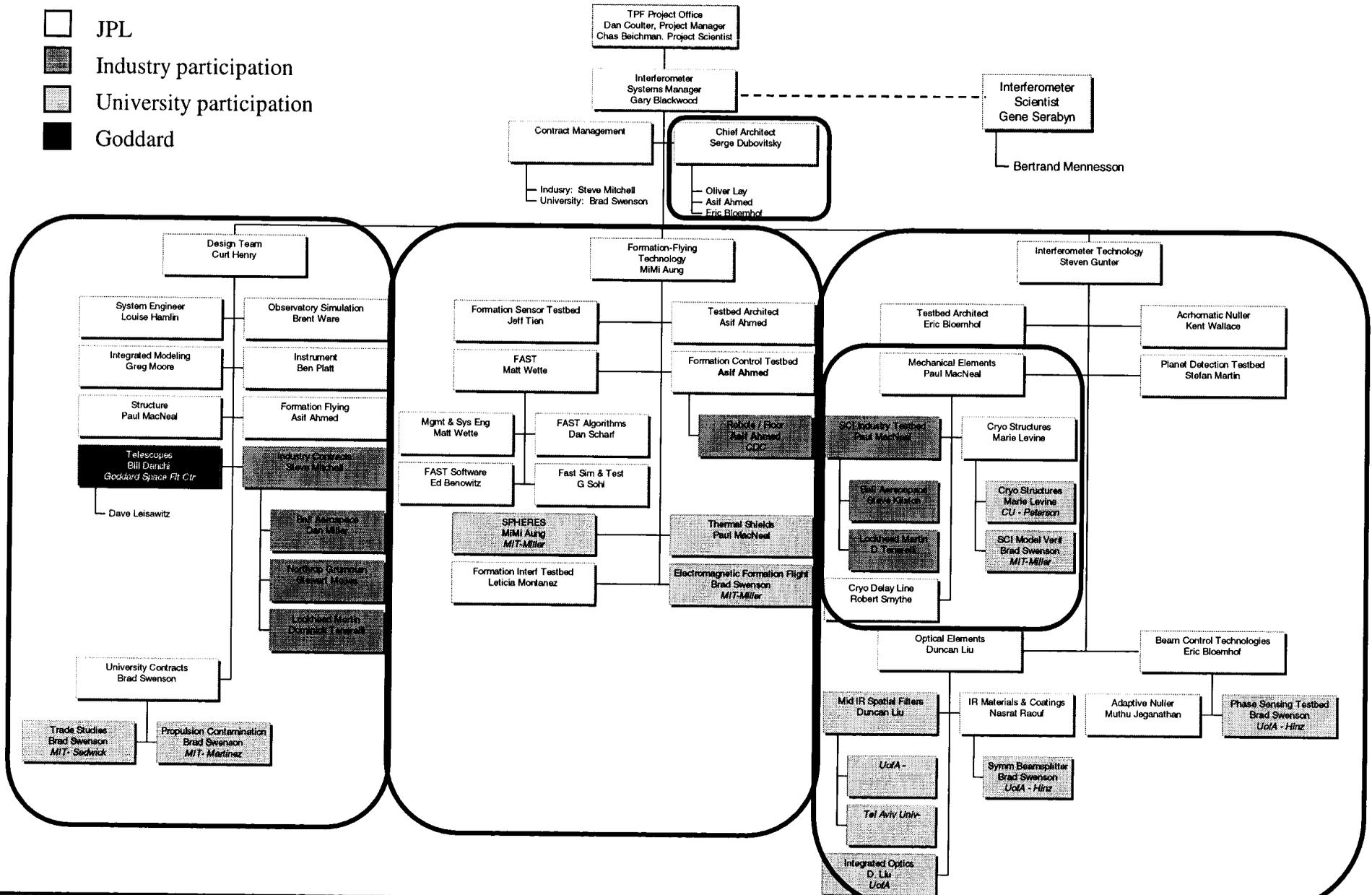
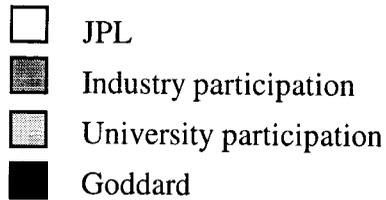
Mission Reqts

2 Viable Point Designs

2 Viable
Point Designs

**Project
Engineer**

TPF Interferometer Systems





Top Technical Concerns: Kepner-Trego Method



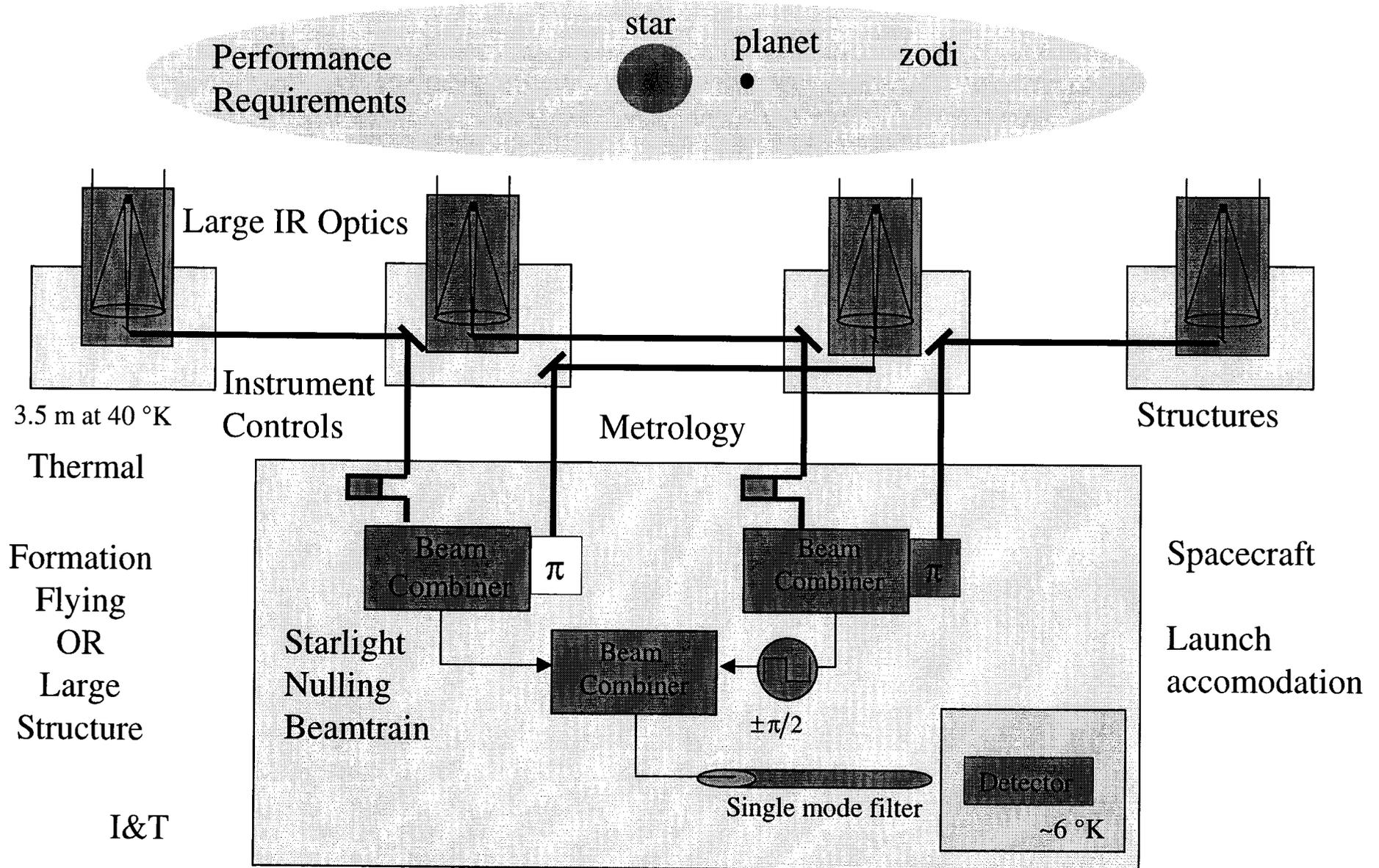
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- Concerns Prioritized by:
 - Gap (Seriousness) → compare Reqt to SOA
 - Urgency → will it be a showstopper in 2006?
 - Trend → is anyone else working on it?
- Top Concerns Mitigated by:
 - System Engineering → Design Team
 - Technology Development → Technology Teams
 - Inheritance → Current, by 2006, by Phase C/D

Interferometer Building Blocks: Categories for Concerns





Technical Concerns (1 of 2)



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CORE

StarLight Nulling BeamTrain

- Nulling Architecture
- Beam Combination
- Internal Thermal Emissions
- Spatial Filters
- Intensity Matching
- Phase Control

Instrument Controls

- Pointing control of compressed beam
- Cryo Delay Line path stability

Detectors

- Cryocoolers

COMMON

Flight and Mission System

- Launch packaging of SCI and FFI
- Interspacecraft communications
- Sky coverage / thermal shield packaging

Integration and Performance Verification

- End-to-end flight system test
- Overall system complexity

Retired Primarily by Technology
Retired Primarily by System Engineering

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Technical Concerns (2 of 2)



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CRYO STRUCTURE

Precision Cryogenic Deployed Structure

- Stability of long cold deployed structure
- Cryo hinge and latch stability
- Ability to predict on orbit performance
– availability of modeling tools

FORMATION FLYING

Formation Flying System

- Long Term System Robustness
- Performance of Fine Formation Control
- Algorithm Functionality in Deep Space
- Coarse Acquisition Sensor

Formation Flying Accommodation

- RF Interference from thermal shield
- Inter spacecraft stray light

Retired Primarily by Technology
Retired Primarily by System Engineering



NOT on the Top Concerns List because of Inheritance

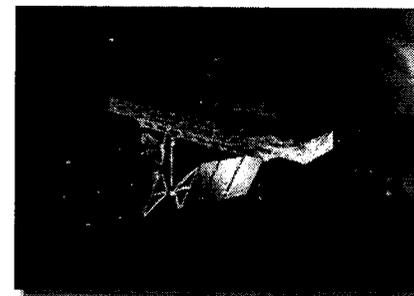
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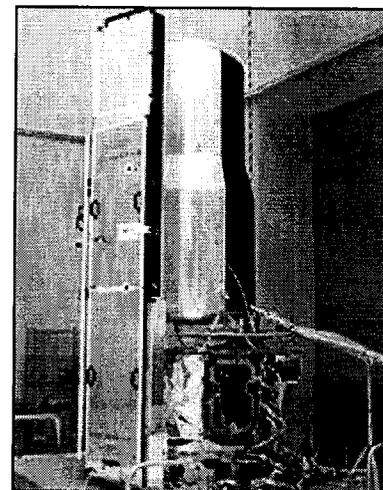
- Large IR optics
NGST
- Relative linear metrology
StarLight, SIM
- Absolute metrology
Code R: Distributed Spacecraft
Technology program
- Detectors
SIRTF, NGST
- Passive cooling
NGST
- Knowledge of on orbit disturbances and environment
SIM, NGST, SIRTF, IPEX
- Microdynamic Disturbances
IPEX



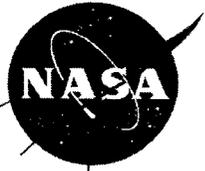
SIM



NGST



SIRTF



Achromatic Nulling Testbed

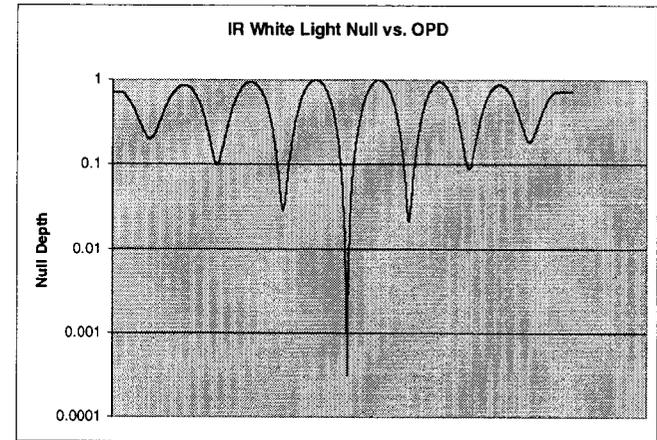


Terrestrial Planet Finder Mission

- Key Intended Result:
 - Stable 10^{-6} white light null with 50% bandwidth
- 7-12 μm

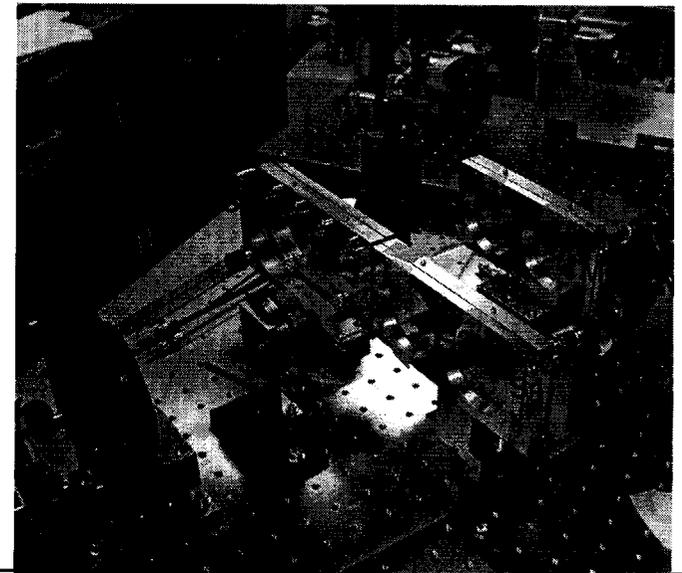
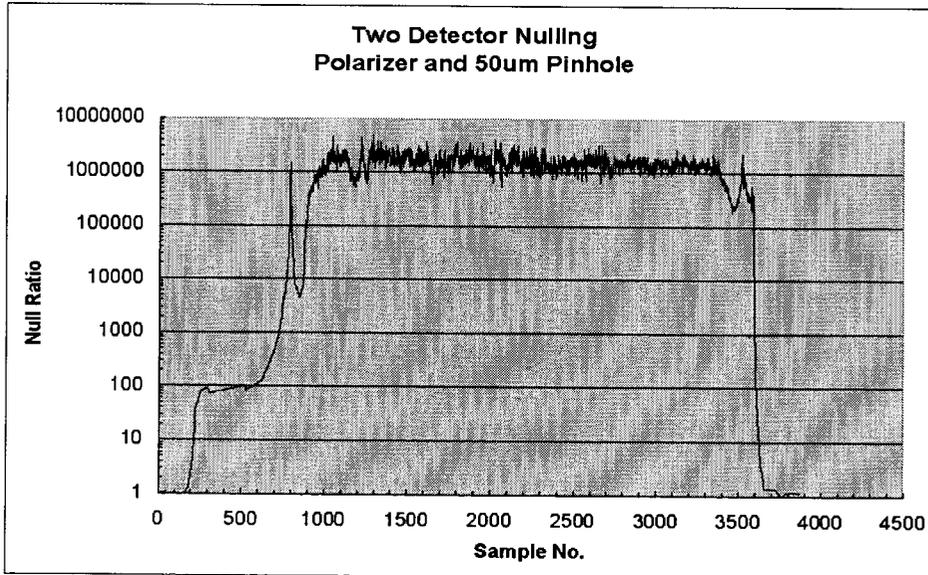
10^{-6} Laser Null, 10 μm

4×10^{-4} WL Null, 20% bw



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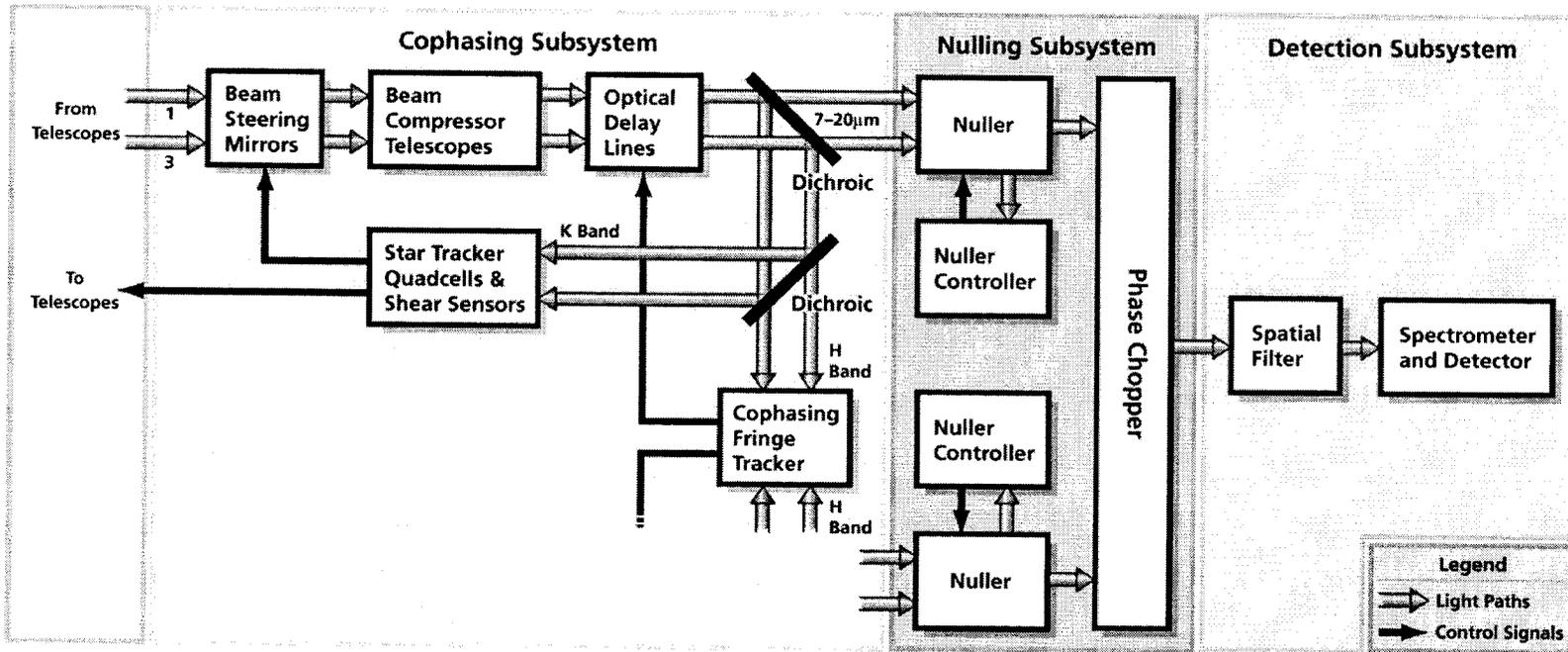
Planet Detection Testbed



Terrestrial Planet Finder Mission

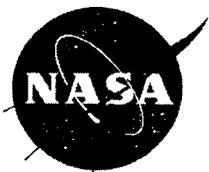
- 4-beam demonstration of dual-chopped Bracewell
- Key intended result:
 - Planet extraction (10^{-6} planet/star contrast), at 10 μm
 - 10^{-6} null depth
 - 10^{-7} null stability
 - Amplitude and phase control (0.4%, 4 nm)

Functional diagram of TPF nuller



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Nulling and Planet Detection



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NULLING

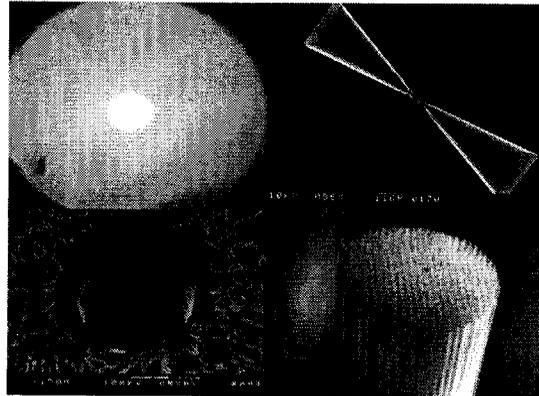


Core Interferometer Technology



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Mid-Infrared Spatial Filters



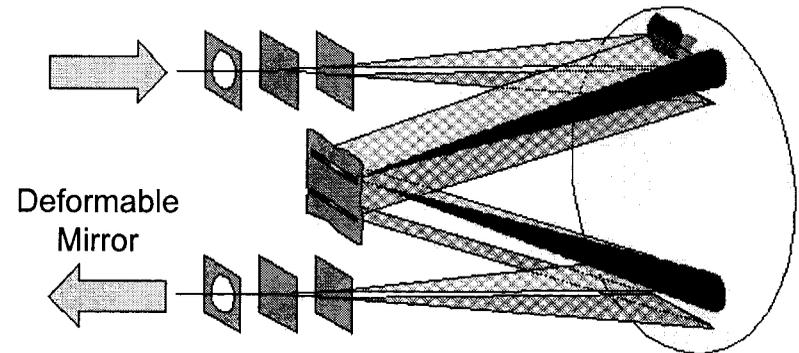
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Cryogenic Delay Line



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Adaptive Nuller





Cryogenic Structures Technology

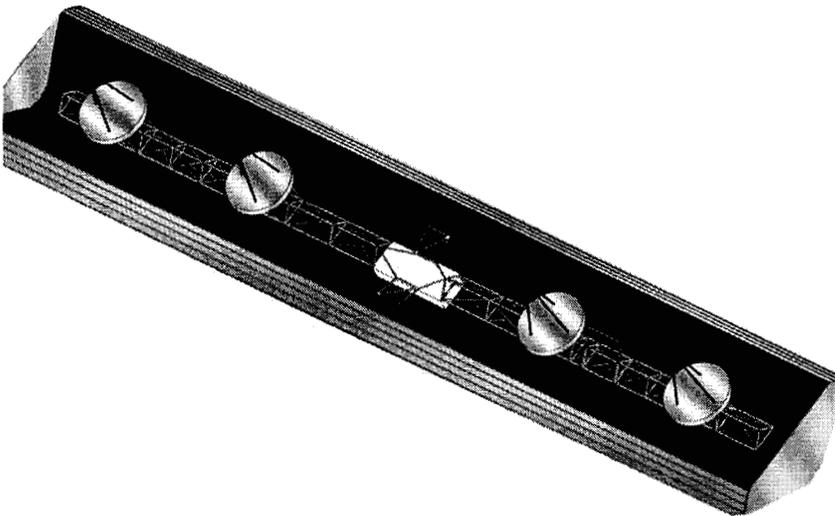


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Structurally-Connected Interferometer Testbed

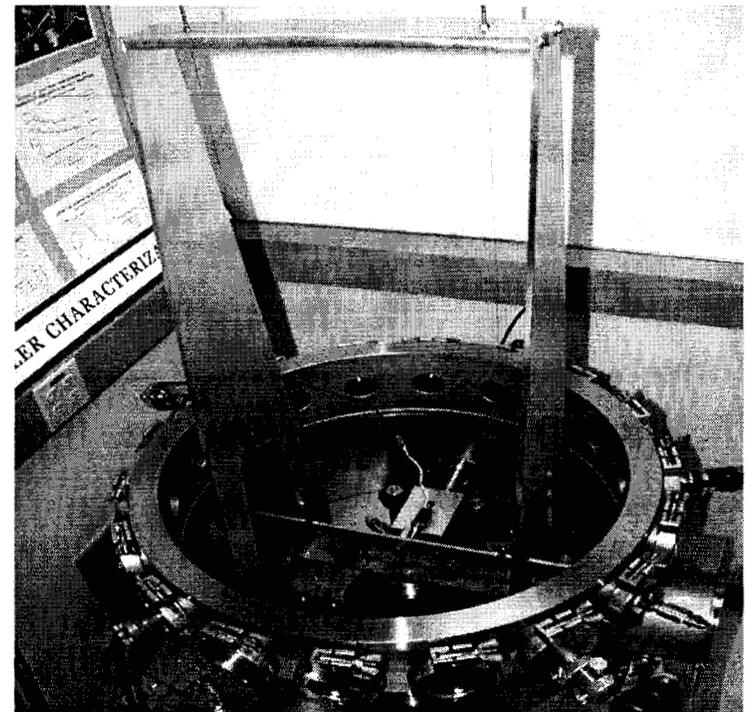


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Cryogenic Structures Technology



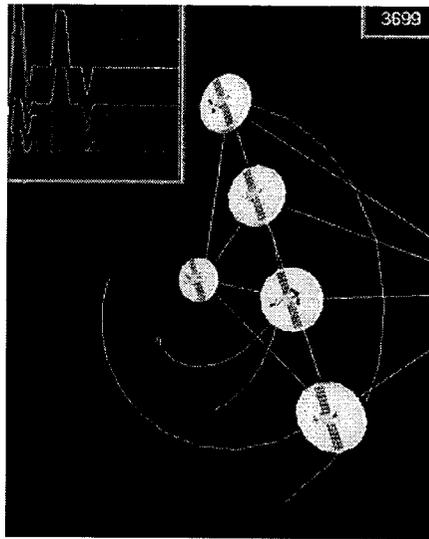


Formation Flying Technology

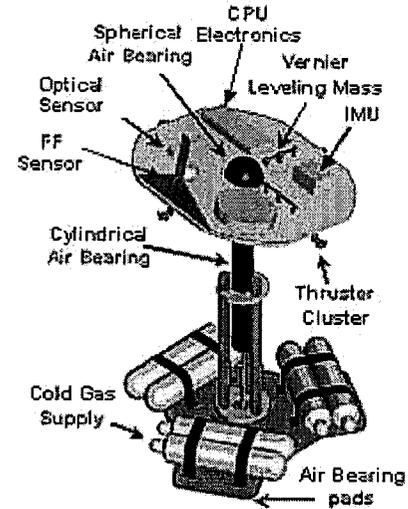


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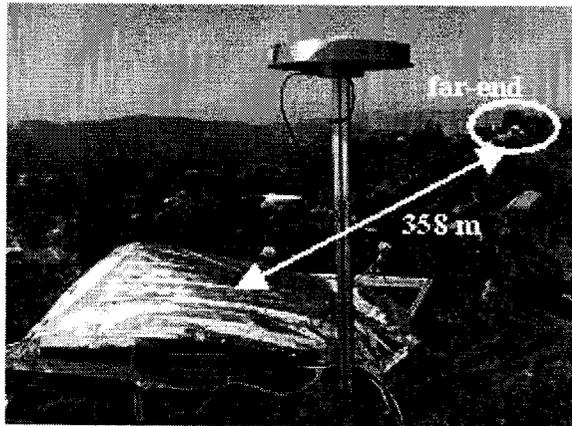
FAST



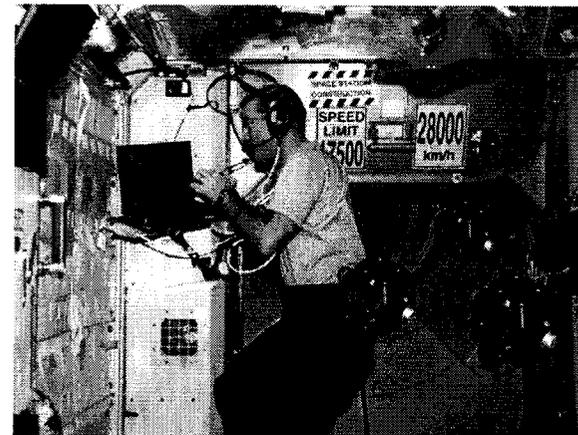
Formation Control Testbed



Formation Sensor Testbed



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Next Steps



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- Architecture
 - Update concerns
 - Ensure testbed plan effectiveness
 - Nulling architecture recommendation with ESA
 - Science capability assessment (
- Design Team
 - Next level of design
 - Engineering Capability assessment
- Technology
 - Deliver results per plan
 - Meet interim milestones



Summary



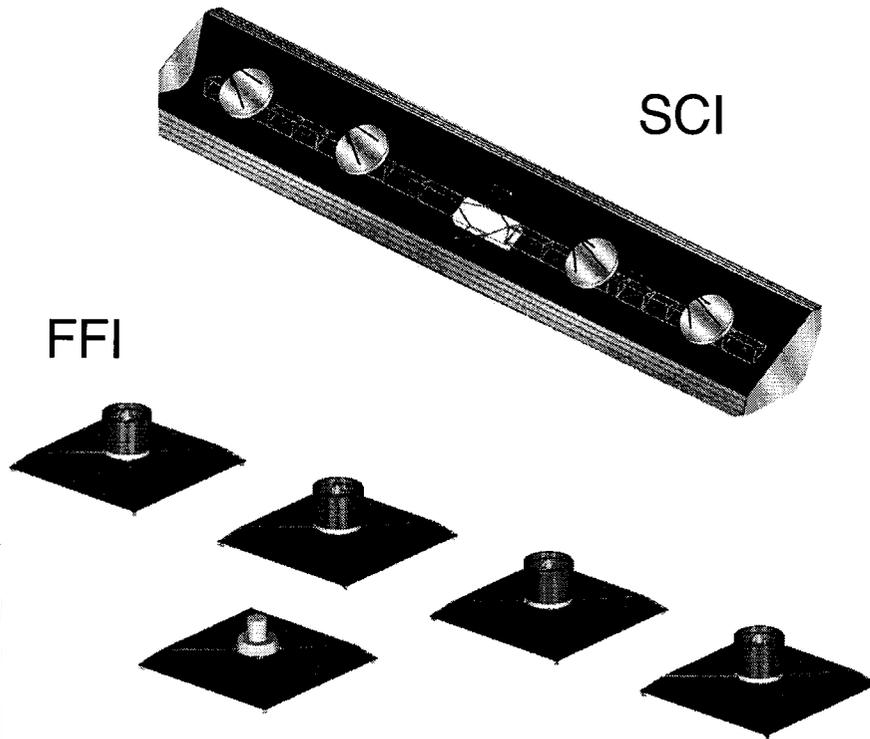
Interferometer Systems Will Deliver

- Structurally-Connected Interferometer concept for the *minimum* TPF science
- Formation-Flying Interferometer concept for the *full* TPF science
- Architecture Trades
- Concerns Identification / Mgmt
- Design Team
- Technology Development

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BACKUP



Top Concerns: Core Interferometry

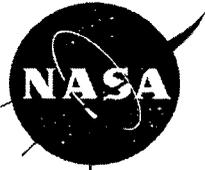


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Category	Primary Concern	TPF Requirement
Starlight Nulling Beamtrain	Nulling architecture	Survey 30-150 stars for terrestrial planets
	Beam combination	4 or 6 beams, 10^{-5} null 6.5- 17 μ m
	Internal thermal emissions	$\ll 100$ photons/sec
	Spatial Filters	70% throughput in single mode, 6.5-17 μ m
	Intensity matching	0.2%
	Phase control	1nm (all frequencies)
Instrument Controls	Pointing control accuracy of compressed beam	50 mas
	Cryogenic delay line closed loop stability	0.1 nm at 40K
Detectors	Cryocoolers	30mW at 6K



Common Concerns



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Category	Primary Concern	TPF Requirement
Flight & Mission System	Launch packaging of structure, formation flight systems	Self imposed
	Interspacecraft communications	Continuous reliable high data rate 4 Mbits/sec
	Sky coverage	At least +/- 45 deg
Integration and Performance Verification	End to end flight system test	Ability to verify multi-collector distributed flight system
	Overall system complexity	Acceptable risk



Top Concerns: Formation-Flying



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Category	Primary Concerns	TPF Requirements
Formation-Flying System	Long-term system robustness	5-10 years
	Performance of fine formation control	1 cm range, 20 arcsec bearing accuracy
	Algorithm functionality in deep space	5 s/c autonomous sensing collision avoidance performance
	Course acquisition sensor	50 cm, 1 deg, 4π steradian FOV with no calibration maneuvers
Formation Flying Accommodation	RF interference from thermal shield	Low multipath effects on RF range measurements
	Inter spacecraft stray light	$\ll 100$ photons/sec





Top Concerns: Connected Structure



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Category	Primary Concern	TPF Requirement
Precision Cryogenic Deployed Structure	Stability of long Cryogenic structure	1nm, 36m, 40K
	Cryo hinge and latch stability	< 100m
	Structural modeling tools	Confident prediction of performance

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