TPF Final Architecture Review

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San Diego, CA

Boeing-SVS, Inc.

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NASA BOEING National Optical Astronomy Observatory GOODRICH SDCL

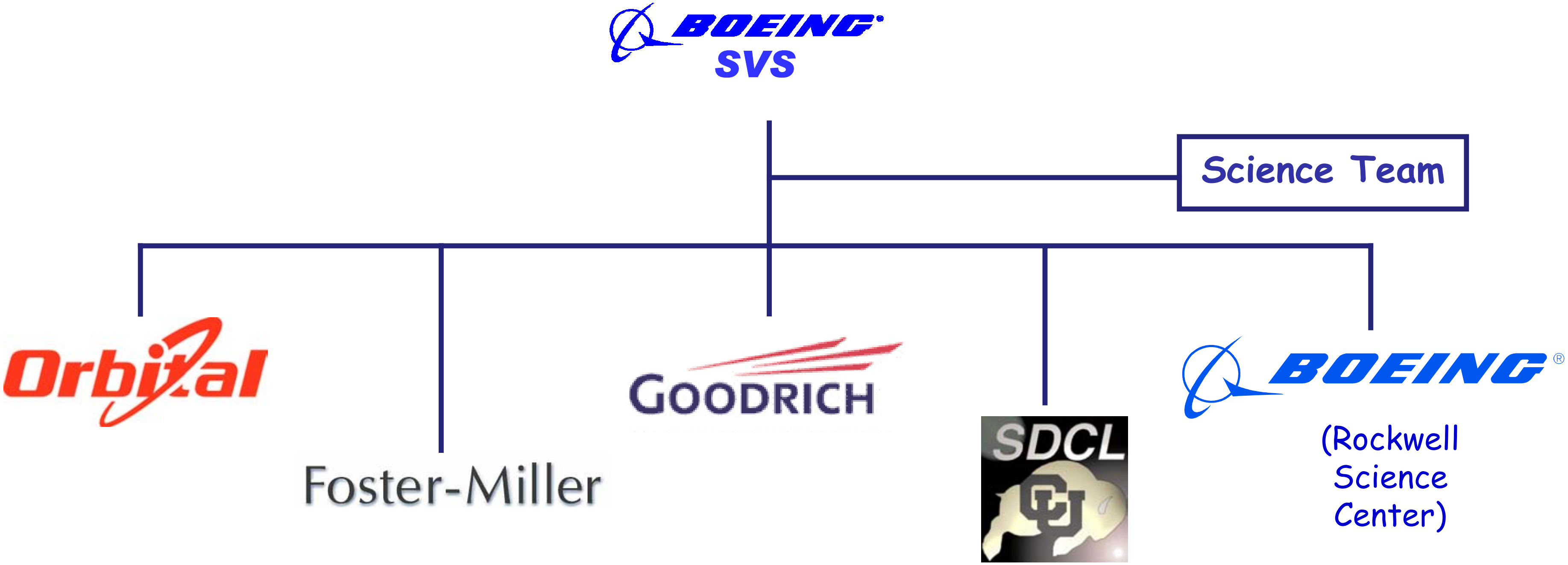
JPL Foster-Miller Orbital Smithsonian Astrophysical Observatory

Outline of Presentation

- Background & Executive Summary
- Introduction
- Non-Redundant Linear Array (NRLA)
- Apodized Square Aperture (ASA)
- Summary

Background
&
Executive Summary

Our TPF Architecture Team



BOEING
SVS

Science Team

- Orbital
- Foster-Miller
- GOODRICH
- SDCL
- BOEING (Rockwell Science Center)

Boeing - SVS TPF Team

Mike Kaplan, Program Director
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Dr. Ed Friedman, Program Manager
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Senior Scientist

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Picture
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Dr. Steve Griffin, Structures & Controls
Senior Scientist & Boeing Tech. Fellow

Dr. Ralph Pringle, Adaptive Optics
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First Science Team Meeting, in Annapolis, MD

TPF Team at Pre-PAR Review @ OHP, France

Boeing - SVS Science Team (1 of 2)

Steve Ridgway, NOAO - Principal Scientist

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Staguhn, Johannes	**Maryland**
Townes, Charles	**Berkeley**
Vakili, Farokh	**O.C.A.**

Team Responsibilities

- **Boeing - SVS**
  - Program management, modeling and simulation lead, systems engineering lead, and study integration
- **Goodrich**
  - Optics concept development, space systems concept definition, systems engineering, modeling & simulation
- **Orbital Sciences**
  - Space mission concept development, space systems life-cycle costing, spacecraft engineering, orbit selection and launch vehicle analysis
- **Boeing - Anaheim**
  - Instrument concept development
- **Foster-Miller**
  - Technology road-mapping and assessment
- **University of Colorado**
  - Large space structures analysis and simulation
- **Science Team**
  - Concept formulation, architecture analysis, modeling and simulation, instrument design, science assessment & instrument concept development

Executive Summary of Final Architecture Review

Concept Overview

Parameters	NRLA	ASA
System Wavelength	IR	Visible
Size	~100 m	~ 8 m
Launch	2 Shuttle & 1 Delta IV	1 Delta IV or Shuttle
Mission life	5 years	5 years

Conclusions - Hypertelescopes

- Non Redundant Linear Array (NRLA) -- A simple version of a hypertelescope -- accomplishes all of the TPF planet detection and characterization science in the infrared
- Hypertelescopes represents an architecture scalable up to Planet Imager capabilities
- NRLA is a “hybrid interferometer/coronagraph”
  - Interferometer-like architecture to gather the light
  - Densified pupil coronagraph as its instrument
- A sub-scale version could be a precursor that demonstrates technologies key for both interferometers & coronagraphs

Conclusions: Apodized Square Apertures (ASA)

- ASA architectures are robust, with a large trade space to be exploited
- NGST-class ASA telescope can accomplish all of the TPF planet detection and characterization in the visible
  - Significant technological transfer from NGST
- The principal technology challenge for ASA is the production of precise flight qualified optics
  - A single launch on an existing launch vehicle appears feasible
- A modest size ASA system can serve as a scientific and technological precursor

Introduction

Our Terrestrial Planet Finder Strategy

- Need an imaging system with full UV coverage
- Both visible and infrared are important for exo-planet science
  - Need albedo, temperature, broad-band coverage for radiometric budget; cloud indicators; surface reflectivity; multiple molecular bands for confirmation/temperature.
- Both visible and infrared TPF imagers similarly powerful for astrophysics
- Visible and infrared offer different technical challenges
  - Size and mass, surface quality, thermal, detectors, …
- Our knowledge of exo-planet systems is growing at an accelerating rate
- We see advantages in meeting TPF objectives with more than a single mission
  - TPF is already a component of Navigator
  - A visible TPF may logically precede an IR TPF

Knowledge of Exo-Planet Systems - We Know More Every Day

- Ground-based
  - Radial velocity surveys - productivity increasing
  - Cold Jupiter detections following hot Jupiter detections
  - Transit searches produce detections now, statistics soon
  - Keck outrigger interferometer will detect outer planets
- Precursor Missions
  - Kepler for terrestrial planet statistics
  - SIM for detection of intermediate and earth mass planets
- If all systems are dynamically full, as hypothesized, we will begin to pinpoint stars with likely habitable-zone rocky planets within a few years
- TPF planning will become focused on fewer, specific targets

There are advantages if TPF is a multi-mission project within Navigator

- Each stage is based on previous results, investment in each stage is limited, with technical and scientific inheritance at each stage
- Science precursor missions/studies
  - Statistical information - e.g. Kepler, HST
  - Giant planets orbiting nearby stars - SIM
  - Rocky planets orbiting nearby stars - SIM
- Characterization in multiple TPF missions optimized for specific astrobiological objectives
  - Visible photometry/spectroscopy
  - Infrared photometry/spectroscopy

TPF Specimen Contract Exhibit II

- Survey 150 (F-K) stars R=3, SNR ≥ 5
- Characterize 30 planets R = 20, SNR ≥ 10
- Characterize 5 planets R = 20, SNR ≥ 25
- Mission life > 5 years
- Astrophysical objectives have not driven mission design

Boeing-SVS Planet Finder Mission Concepts

- We see two main opportunities for TPF
- A dilute interferometric array, operated as a **hypertelescope**, with coronagraphic nulling for star suppression, obtaining images in the thermal infrared by Fourier image synthesis
- An ultra-low diffraction telescope, the **ASA**, forming real, visible IR images

The Apodized Square Aperture (ASA)

- Shorter wavelengths enable high angular resolution with modest aperture size
- ASA uses conventional optical techniques
- We invented the ASA combination of square aperture shape and tailored transmission
- We developed the concept through analysis, numerical modeling and lab demos

The Apodized Square Aperture (cont'd)

- The square aperture profile concentrates diffracted light in two directions, leaving the PSF dark in most of 4 quadrants
- Apodization further suppresses the diffraction
- In lab demos, high dynamic range demonstrated with simple techniques
- PSF speckle structure is stable and symmetric, extending dynamic range for planet characterization.
- A planet finder mission is already possible with today's optical surface quality (search of TPF candidate stars for Jupiter analogs)
- An ASA takes advantage of the best available surface quality, enabling reductions in aperture and integration time
- **It's just a telescope**

The Hypertelescope Concept Family

- A hypertelescope consists of an array of telescopes which employs pupil densification to form a direct image
  - A densified pupil is simply a rearrangement of the sub-aperture beams which yields a compact PSF
- Our hypertelescope concept family includes an array of free-flyers (eg, Boccaletti et al, Icarus 145, 628), and a 2-d connected array (Roddier et al., PASP 111, 132))
- We have studied the Non-Redundant Linear Array (NRLA) in depth
  - Fully develops 1-d and 2-d hypertelescope technology
  - Accomplishes full TPF baseline mission in the infrared

The Non-Redundant Linear Array (NRLA)

- The NRLA employs **pupil densification** to form a compact, real image of the star
- Coronagraphic nulling removes most of the stellar photons
- Pupil expansion and re-imaging provides the image Fourier components with full 1-d UV coverage along a single position angle from a single snapshot image
- Additional snapshot images during rotation by 180 degrees provides full 2-d UV coverage
- De-rotation of the snapshot images provides the high signal-to-noise stellar light residual map
- Inversion of the Fourier components yields the image

TPF and Astrophysics

- Our philosophy is simple:
  - A true imaging TPF will immediately have outstanding capability for general astrophysics, including many specific programs which we have described at the PAR
  - No enhancement of the mission is required beyond the basic TPF requirements in order to make it astrophysics-capable
  - This is true for our visible and infrared concepts, and for precursors as well as full TPF implementations
    - Considering wavelength range, angular resolution, dynamic range, field of view, spectral resolution, and typical integration times

Problems to be Addressed in Astrophysics

- Extragalactic Astronomy
  - What is the nature of quasar host galaxies?
  - How are quasars and starburst galaxies related?
  - Are quasars born in mergers or through other processes?
  - Do orientation effects account for the diversity of AGNs?
  - What determines whether a quasar is radio-loud or -quiet?
  - What is the dark-matter distribution in lensing galaxies?
  - Are damped Lyman-alpha systems protospiral galaxies?
- Galactic Astronomy
  - Differentiate between brown dwarfs and giant planets
  - Determine the mass & luminosities of binary white dwarfs
  - Map the mass loss from Mira variables and AGB stars
  - Observe the changes in outflow symmetries as AGBs age
  - Image the environs of T tauri and other young stars
  - Study the mass exchange in symbiotic variables
  - Follow the outflow in cataclysmic variables