TRW Response to Questions

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TPF Final Review

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TRW Team Discussion Topics

TRW

What is the speckle from your mirror (DL @ 3μm) and how will it affect planet finding?

What is the effect of edges and segments?

What are the mid-spatial frequency errors in your mirror panels?

Can you really work at lambda/D to find planets?

What are the effects of variations in transmission and reflectivity in the optical system and how are they controlled?

What is the largest, most precise system TRW has deployed - (Diameter/rms error)?

Discuss science program with respect to Design Reference Program.

What was the wavefront error assumed in the integration time calculations?

What is the effect of color leakage?

How well do the masks work over a broad optical bandwidth?

What is the state of the art in vibration control?

What is the speckle from your mirror (DL @ 3µm) and how will it affect planet finding?

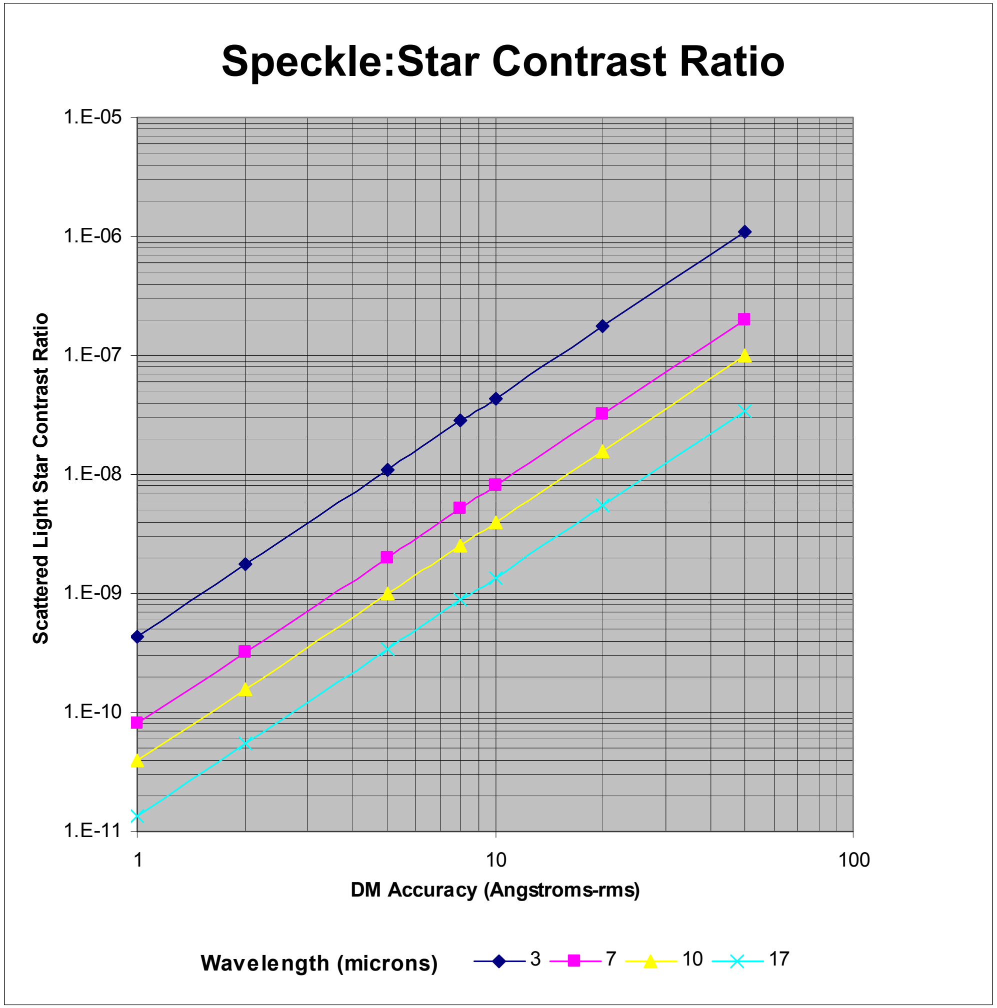
TRW

Since the scattered light intensity goes as $1/\lambda^2$ it's much fainter in the IR (>100x) . . . And the star:planet ratio is also smaller

With the DM controlling the WFE to 16 Å rms, the scattered light:starlight (contrast) ratio is ~10^{-8} at 10 microns and ~ 2×10^{-8} at 7μm

This level is ~100x fainter than the star and should not effect planet detection.

[Note: the DM can correct the WFE to <1 Å rms, producing a contrast ratio >4×10^{-11} at 10 μm]



OTA Wavefront Error Budget (28m Aperture Telescope)

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- **System Wavefront Error 980 nm rms (0.14λ rms at 7 μm)**
  - Contingency 300 nm rms
  - Active Dynamic Control Residual Error 540 nm rms (>10 Hz)
  - OTA Static Wavefront Error 686 nm rms
    - Design Residual 9 0nm rms
    - Forward Optics Assembly (FOA) 592 nm rms
      - Primary Mirror Assembly (PMA) 500 nm rms
      - Secondary Mirror Assembly (SMA) 300 nm rms
      - SMA to PMA integration 100 nm rms
    - Rear Optics Assembly (ROA) 200 nm rms
    - SIM 250 nm rms
    - Integration and Alignment 100 nm rms
  - Launch Induced Error 80 nm rms
  - On-orbit Thermal/Structural Error 319 nm rms
    - PM Segment Drift 230 nm rms
    - SM Drift 90 nm rms
    - Other Uncorrected Drift 200 nm rms

What is the state of the art in vibration control?

TRW

The SIM testbed represents the state of the art in vibration control, keeping the OPD <6 nm for fringe tracking

- 7.5Hz spacecraft:optical bench isolators and 7-12Hz reaction wheel isolators provide 14 to 40 dB attenuation over the reaction wheel speed range (~15-80 Hz)
- Active path length control compensates for low frequency vibrations
- Better attenuation could be attained at low end of wheel speed range by softening strut to 1-2 Hz, at expense of adding offload for 1G testing

Current SIM vibration control is close to TPF requirements

- 6 nm OPD would be OK, but we can do better

Further advances in the SOA may come from SBL and NGST

Current SOA: SIM Dual-Stage Passive Vibration Isolation

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First Stage at Wheel

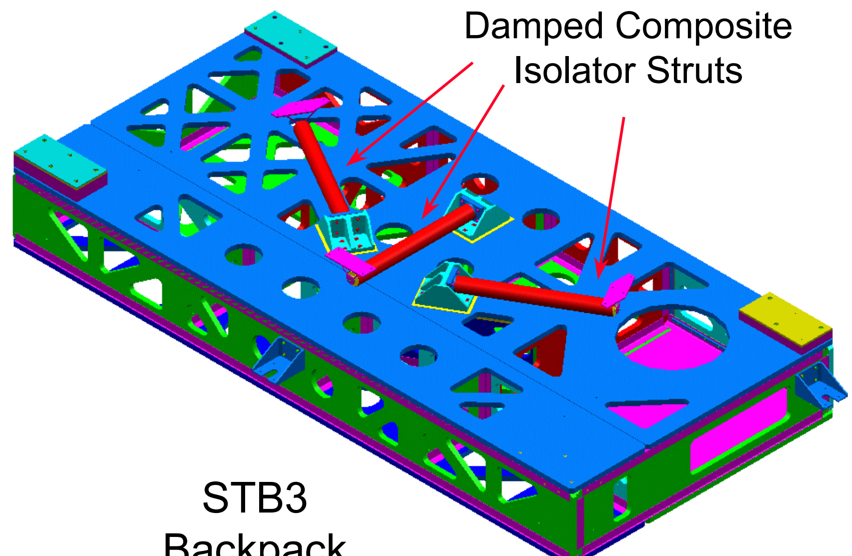
Spacecraft backpack houses six Teldix reaction wheels on Chandra-heritage vibration isolators at 7 Hz in rocking and 12 Hz in translation

- SIM does not at present require damping in the optical payload
- Low frequency vibrations are further rejected by active pathlength control at 100 Hz

Second Stage at Backpack

The spacecraft is isolated from residual backpack vibrations by a flexible kinematic mount composed of three damped beams with transverse “V”-flexures, transmitting only bending loads

- No offload is required in 1G testing for 5 Hz struts



SIM Dynamic Stability Performance

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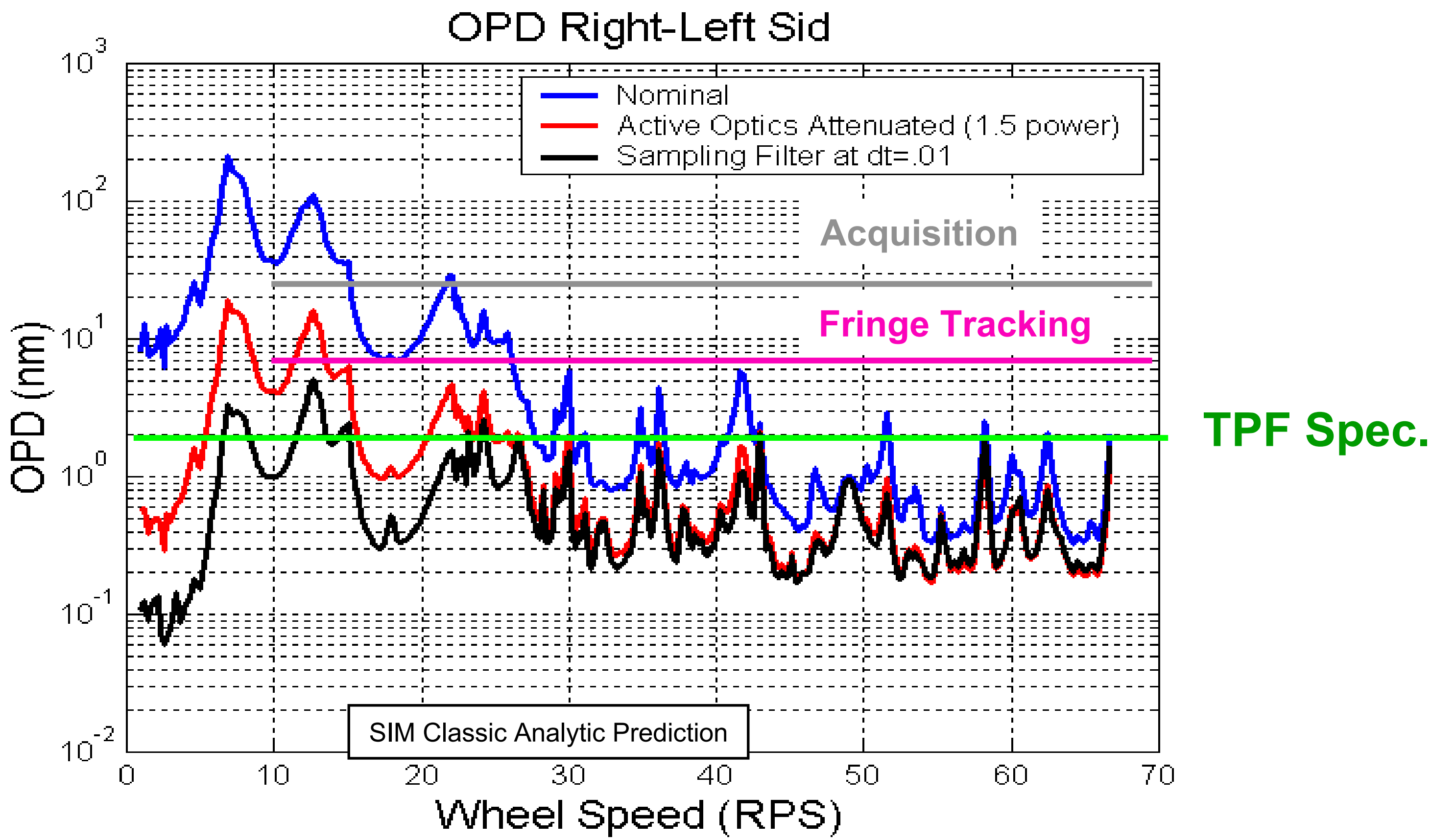
- Nominal is raw optical path difference due to Teldix reaction wheel disturbance with 7.5 Hz backpack isolator and 7-12 Hz Chandra wheel isolators.
- In fringe tracking mode a 100 Hz path length control loop attenuates low frequency response. The 6 nm allocation is met if wheels spin above 15 rev/second
- In acquisition mode the fringes must lock on within a 10 msec window. Motion must be less than 25 nm



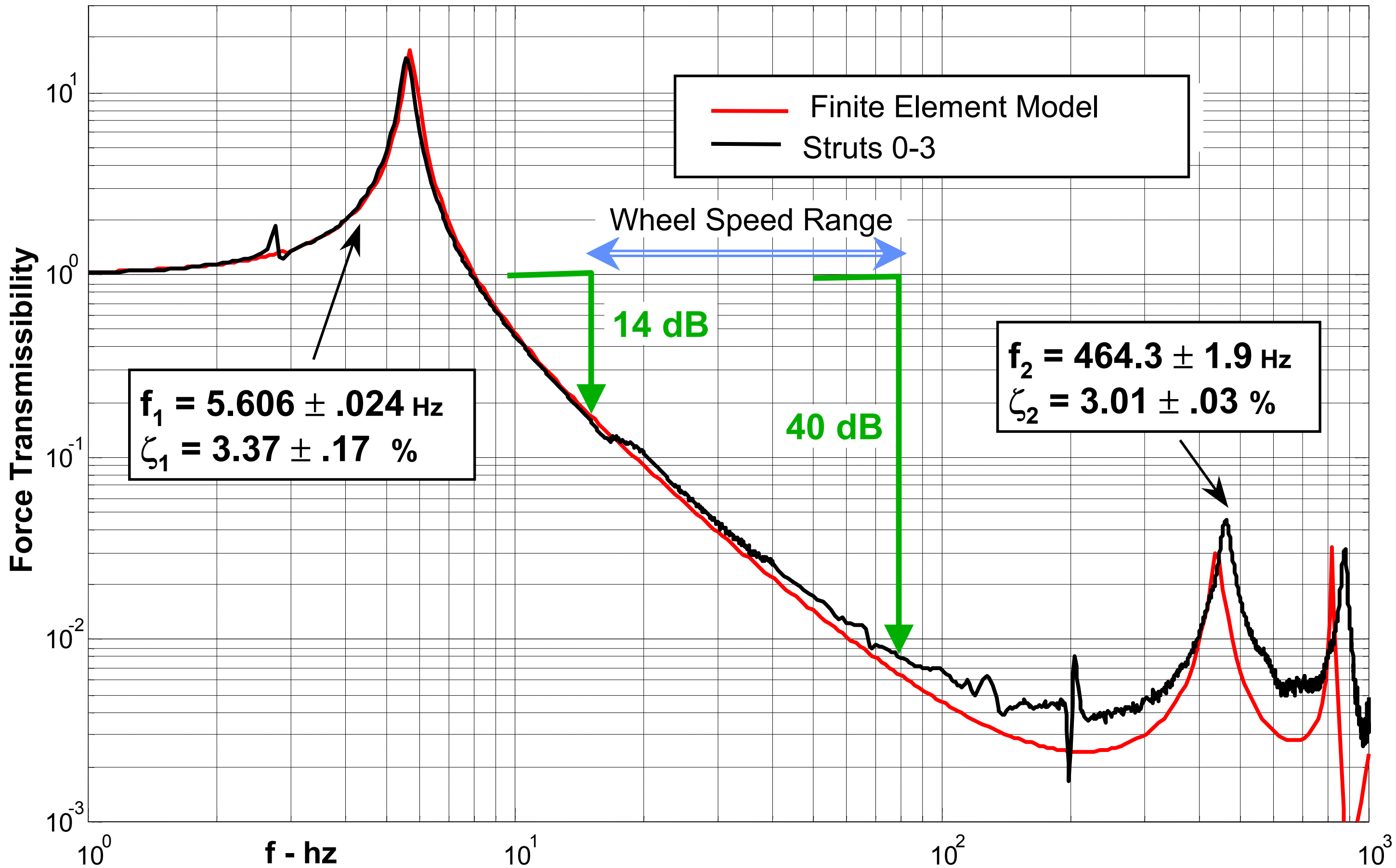
STB3 Beam Isolator Performance

TRW

Excellent match to FEM prediction and excellent repeatability

Very little high frequency dynamics due to wave absorption feature

Better attenuation could be attained at low end of wheel speed range by softening strut to 1-2 Hz, at expense of adding offload for 1G testing



What are the mid-spatial frequency errors in your mirror panels?

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Our mirror specifications are:

- Surface roughness < 100 Angstroms (30 Angstroms goal)
- Mid-spatial frequency errors < 4 nm RMS (< 3 nm goal)

CMA has demonstrated (at room temperature):

- Surface roughness <10 Angstroms.
- Mid-spatial frequency errors <3 nm RMS.

We recommend a technology development to achieve this performance at cryogenic temperatures

What is the largest, most precise system TRW has deployed -(Diameter/rms error)?

TRW

That data is proprietary and/or restricted.

- Using our engineering rules of thumb we can deploy a 28-m structure to <1mm rms
- The (8 mil rms) measured surface accuracy of HARD says 1.22 mm rms for 28-m
- The (1 mil rms) repeatability of HARD says we could achieve ~0.15 mm rms for a 28-m with the the HARD mechanisms,if we work at it
  - The repeatability of the mechanisms themselves it ~5 microns

Actuators with a stroke of 4 mm should be more than adequate to phase the primary mirrors in our telescope

- <5 nm actuator resolution is desirable
- 50 nm resolution would be acceptable

What is the effect of edges and segments?

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Gaps are <1 mm between segments

Issues for this are:

- Scattered light
- Diffraction

Scattered Light

- Edges of segments must be formed to minimize scatter of MIR photons
- Can “black” the edges to absorb rather than reflect
  - Increases emissivity but fractional area is very small

Diffraction

- Lyot mask in Coronagraph blocks diffraction from these areas
- For general astrophysics, Lyot mask may also be implemented though to a lesser degree

Can you really work at lambda/D to find planets?

TRW

Simple performance model says YES!

Dynamical and Thermal modeling has been done but the connected optical model has not been run

- This is in process and will be completed by 2/02

Stable errors in PSF can be removed by rotating about the line of sight by +/- 5 degrees and subtracting

- System designed to allow this rotation for imaging

What are the effects of variations in transmission and reflectivity in the optical system and how are they controlled?

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Effects not modeled

Reflectivity variations minimized by using gold coatings

- Stable
- Highly uniform
- Will place stringent requirements on coating of mirrors

Transmission uniformity is technical tall pole

- Identified transmissive elements in Technology Roadmap as issue
- Needs to be investigated more fully in a later stage of the program

Discuss science program with respect to Design Reference Program

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Science program surveys the habitable zone of ≥150 F/G/K stars

Uses Earth location in HZ as nominal separation with cutoff at 75 milliarcseconds for HZ

- Gives list of >200 candidates
- Eliminate known "pathological" cases of variables and doubles and get 162 "Golden Oldies"

Probes closer for shorter wavelength observations to sample more of the orbit

Initially used 50 mas as inner working distance but 28 m does not allow work at that distance at 10 microns

- Use 7-8 microns for 65-80 mas to keep integration times reasonable
  - Still ~75% chance to detect planet with maximum separation of 75 mas in two observations
- May need different plate scale
- Will use optimized occulting spots tailored to the wavelength used for detection mission and planetary system parameters

Probability of Detection Given Orbital Parameters

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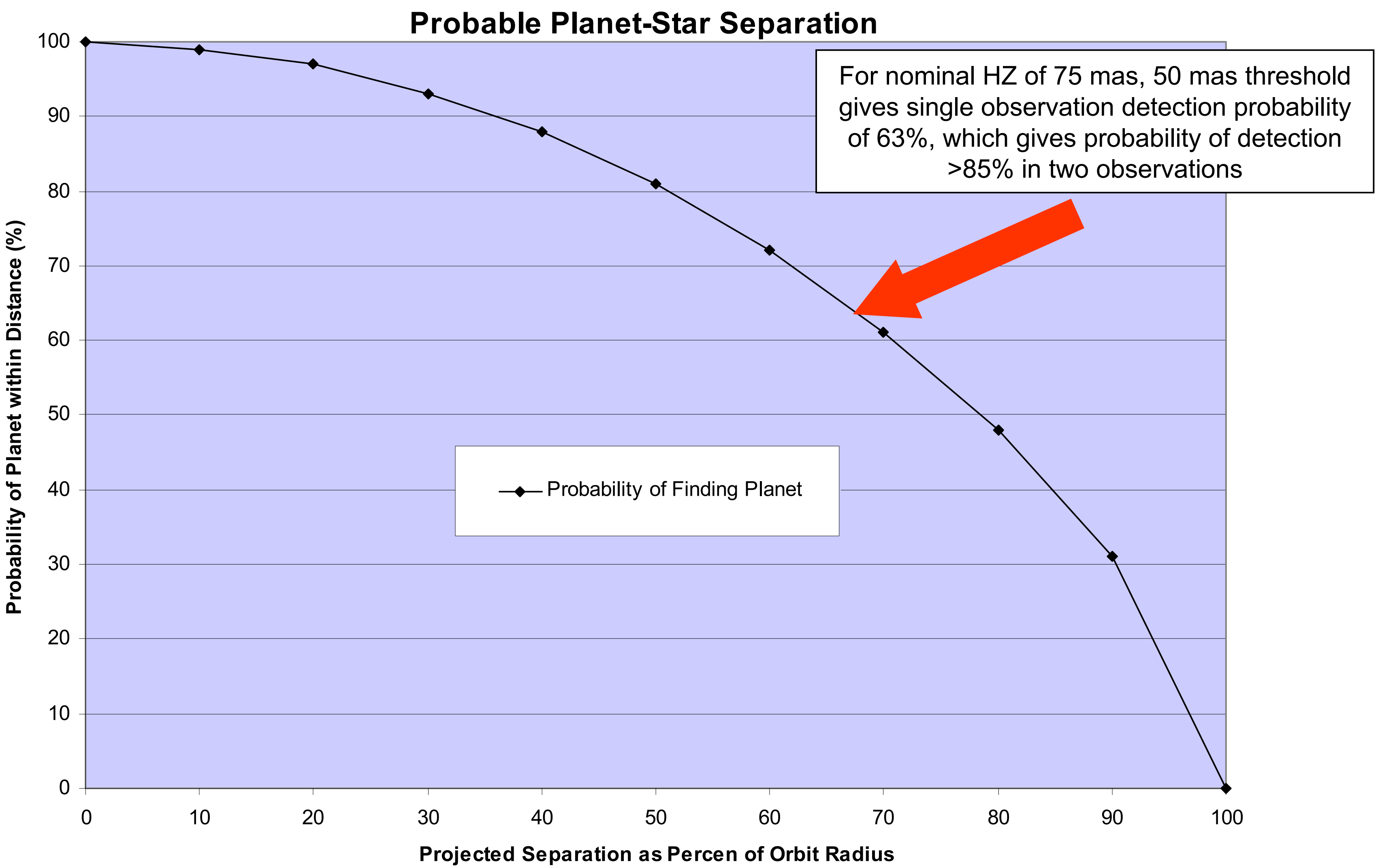

How do you take a spectrum?

TRW

Spectrometer built into back end of coronagraph

- Build on MOS spectrometer for NGST
- Must be built in to coronagraph to reduce stellar light
- Use dispersive system to disperse light onto the detector
  - Issues with dispersive element at these wavelengths
  - Ratio of planet light to star light independent of occulting spot size so limit is the full well capacity of detector
  - Initial studies show ~2×10^5 e^- collected in 1000s integration from all sources

Performance issues

- Temperature is a factor but assume cold shield on detector to minimize impact and telescope is estimated to reach 35K or less
- QE/transmission/effects of change in stellar profile over the spectra will be presented in the final report

Optical Bandpass issues: two related questions

TRW

What is the effect of color leakage?

Have assumed a filter wheel in coronagraph after the Lyot stop in imaging mode

- Limits passband to R=5
- Allows wavelength optimization for detection mission

How well do the masks work over a broad optical bandwidth?

Issue with masks are only present if assume they are deposited on a tranmissive substrate due to filters as above

- Baseline assumption with associated technical development and risk in substrate identification and analysis
- Could use reflective spot where starlight is allowed through but technology for this not investigated