Terrestrial Planet Finder Mission

TPF

TPF Interferometer Architecture Studies

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October 15, 2003

1. Architecture Options
2. Figures of Merit
3. Strawman Configurations

A NASA
Origins
Mission

Architecture Studies Objective

Terrestrial Planet Finder Mission

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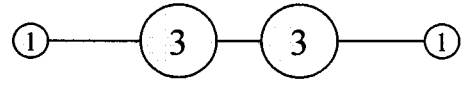
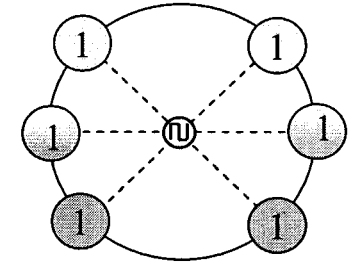
Science Performance	**Minimum Science Mission (~30 stars)**	**Full Science Mission (~150 stars)**
Implementation Platform	**Structurally Connected Interferometer (SCI)**	**Formation Flying Interferometer (FFI)**

Architecture

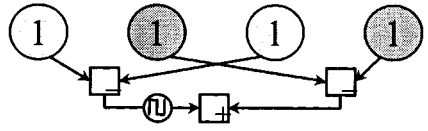
Bracewell



OASES 1331

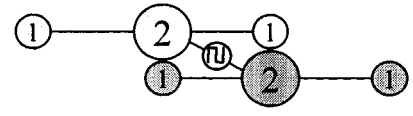


Darwin: bow-tie



Dual Chopped Bracewell (DCB)

Chopped Degenerate Angel Cross (DAC)



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- **Choose an Architecture to support the two missions**

Nulling Architectures Options

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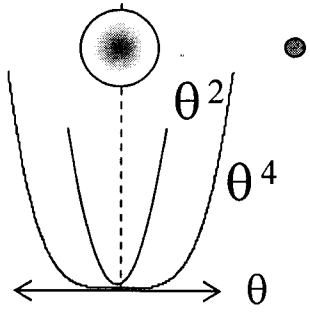
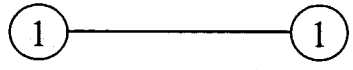
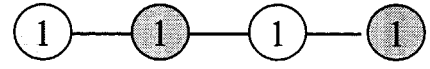


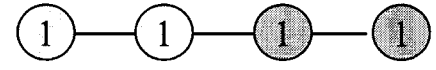
θ^2



Bracewell

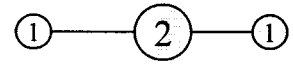


Chopped Dual Bracewell (hi-res)



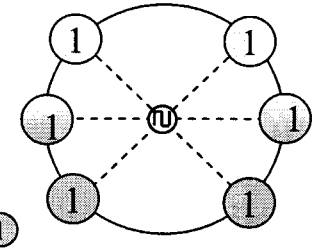
Chopped Dual Bracewell (lo-res)

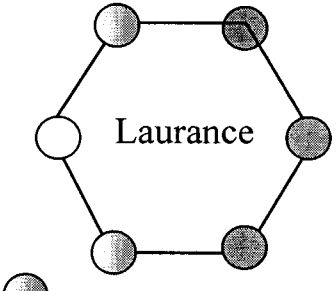
θ^4



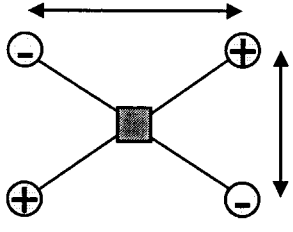
Degenerate Angel Cross (DAC)

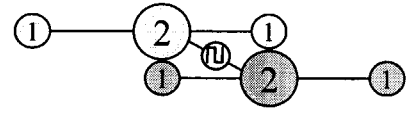
Darwin: bow-tie



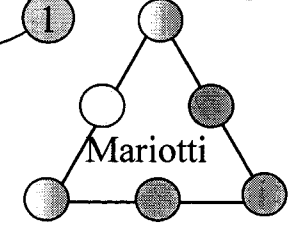


Angel Cross

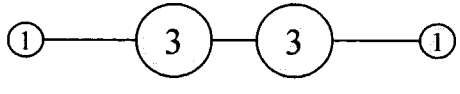




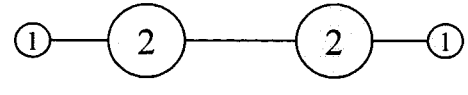
Chopped Degenerate Angel Cross (DAC)



θ^6



OASES 1331



OASES 1221

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Figures of Merit

- Ability to isolate planet signal
  - Exo-zodi suppression
  - Instrumental background suppression

  } Phase Chopping
- Practical Configuration
  - Beam combiner complexity
- Ability to examine an adequate number of stellar systems
  - Resolution
  - Sensitivity

Resolution and Signal-to-Noise Ratio

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Nulling Architectures Options that Support Phase Chopping

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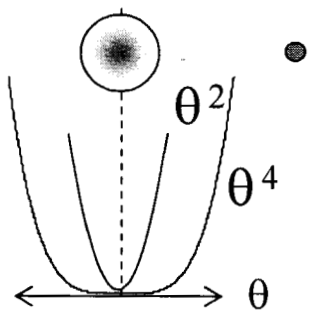
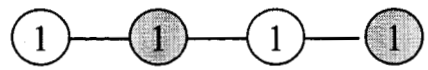


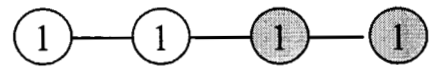
θ^2

θ^4

θ^6

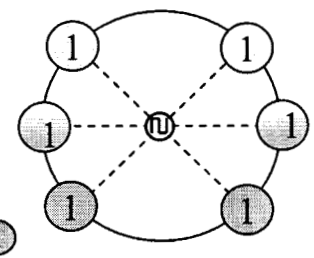


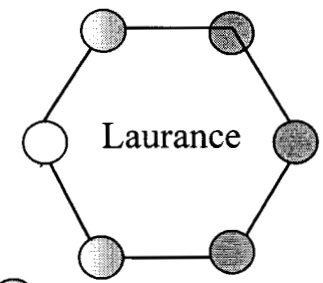
Chopped Dual Bracewell (hi-res)

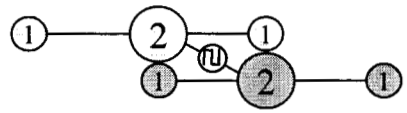


Chopped Dual Bracewell (lo-res)

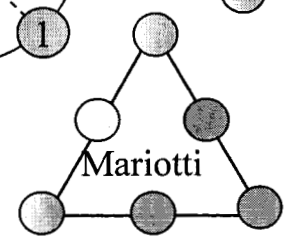
Darwin: bow-tie







Chopped Degenerate Angel Cross (DAC)



Nulling Architectures Options Remaining

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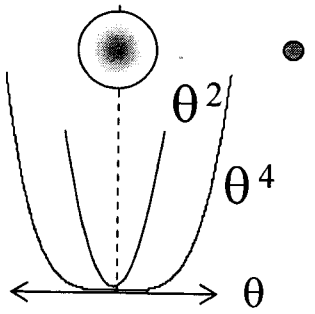
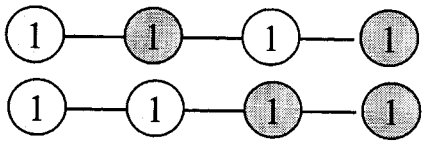


θ^2

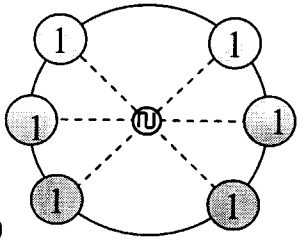
θ^4

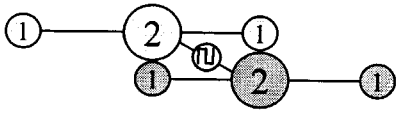
θ^6



Hi-Lo-Res Chopped Dual Bracewell

Darwin:
bow-tie





Chopped Degenerate
Angel Cross (DAC)

Figures of Merit

- Performance
  - Adequate number of stars
  - Exo-zodi suppression
  - Instrumental background suppression

  } Chopping
- Complexity/Difficulty
  - **Beam combiner complexity**
- Risk and robustness
- Cost and Utility

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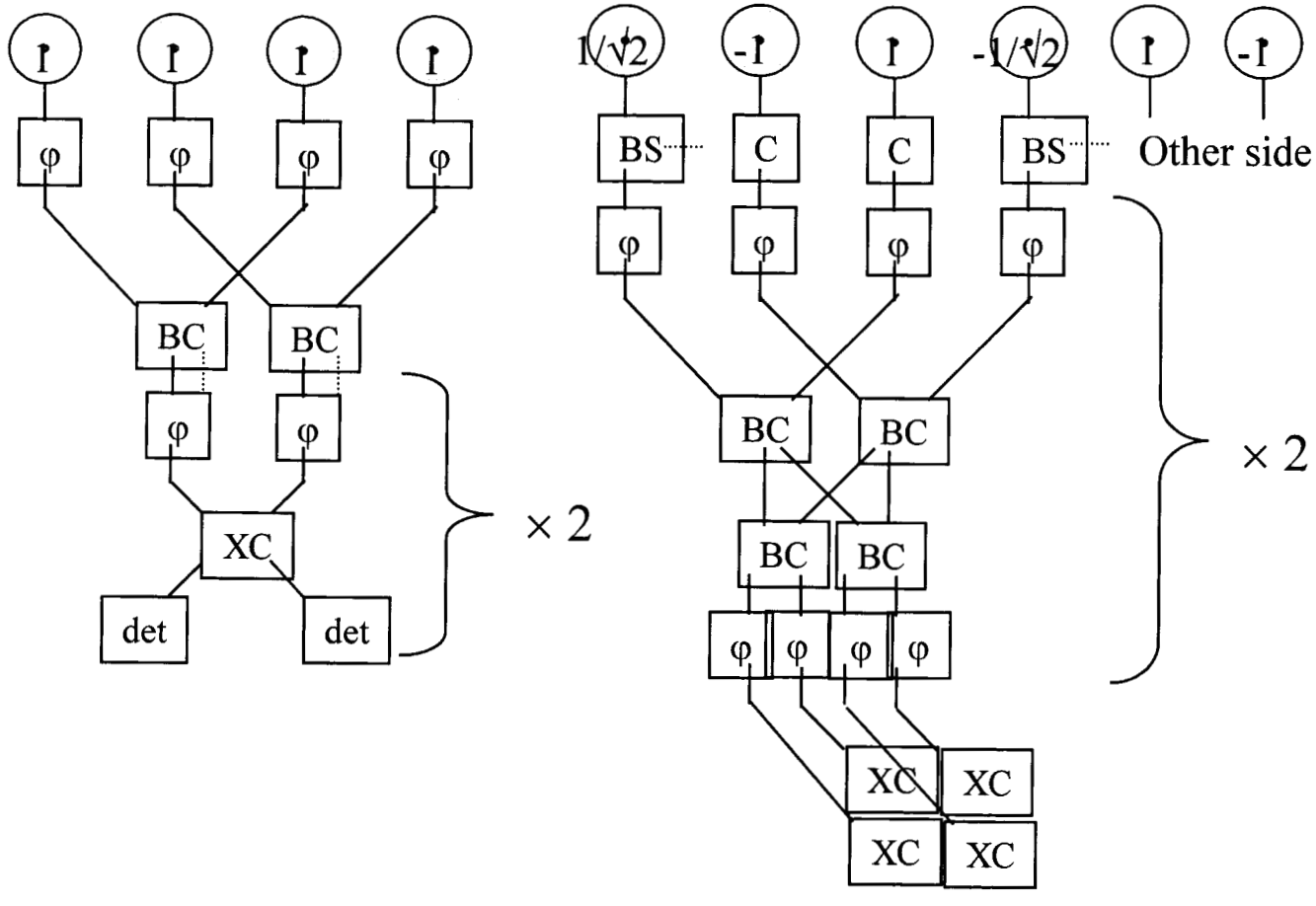
Dual Chopped Bracewell Beamcombiner



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Figures of Merit

- Performance
  - Number of stellar systems
  - Exo-zodi suppression
  - Instrumental background suppression

  } Chopping
- Complexity/Difficulty
  - **Beam combiner complexity:**
    - **Dual Chopped Bracewell has the simplest beamcombiner**
- Risk and robustness
- Cost and Utility

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Performance Models

- Interferometer Performance Model (IPM)
  - Rigorous model of a single observation
  - Connects instrument Level 3 engineering requirements to a signal-to-noise performance on a single canonical planetary system, e.g. sun at 10 parsecs
- Star Selectors Analysis
  - Uses simplified and parametrized model of the instrument sensitivity (based on the IPM)
  - Accounts for non-SNR limitations of the instrument
  - Works on the entire star list to determine the number of measurable stars

Interferometer Peformance Model (IPM) flowdown to level 3 milestone complete

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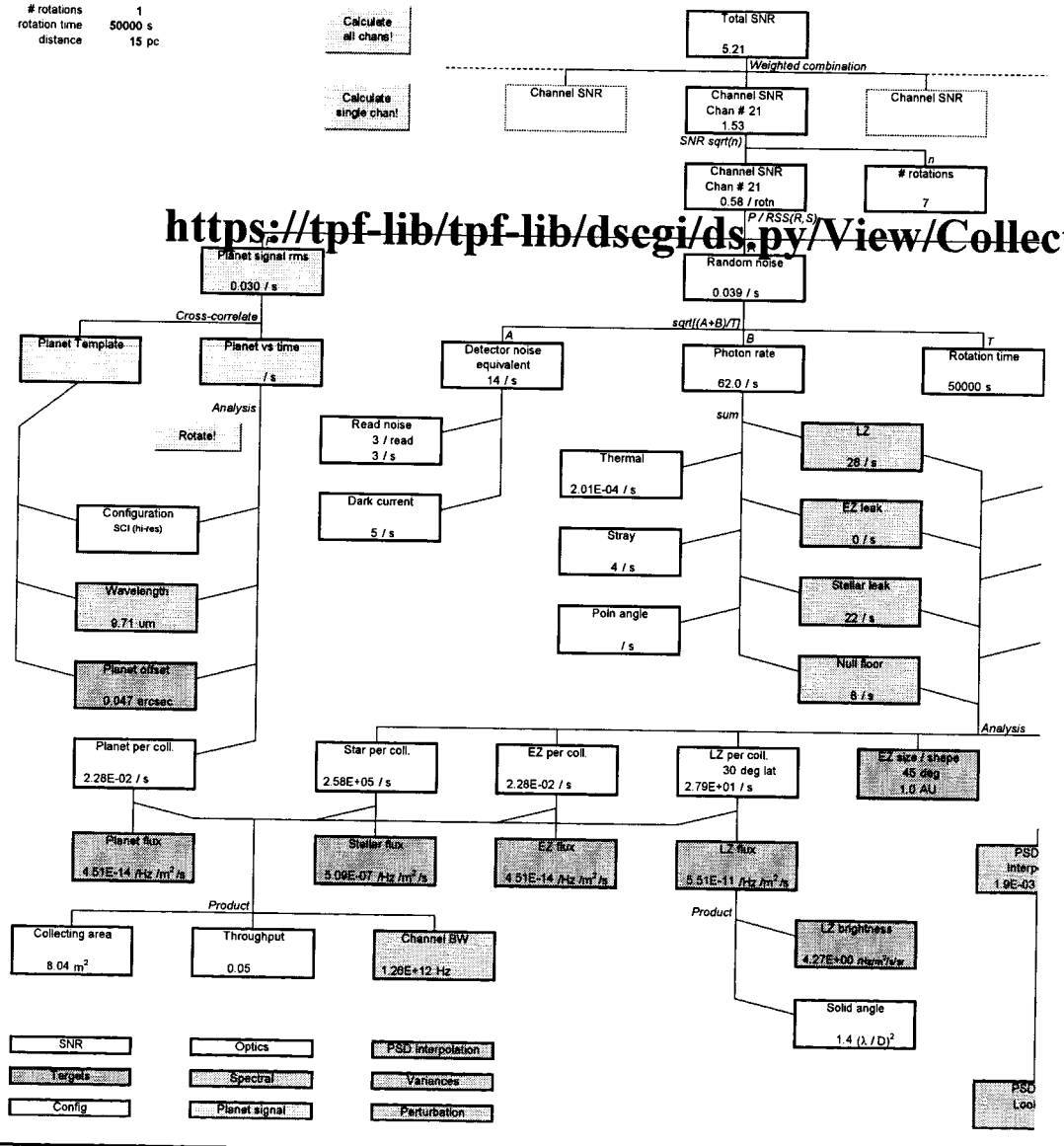

A self consistent set of assumptions, constrains and requirements that can be use as a starting reference point by the design teams

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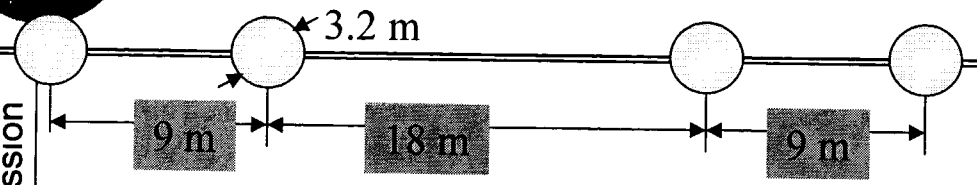
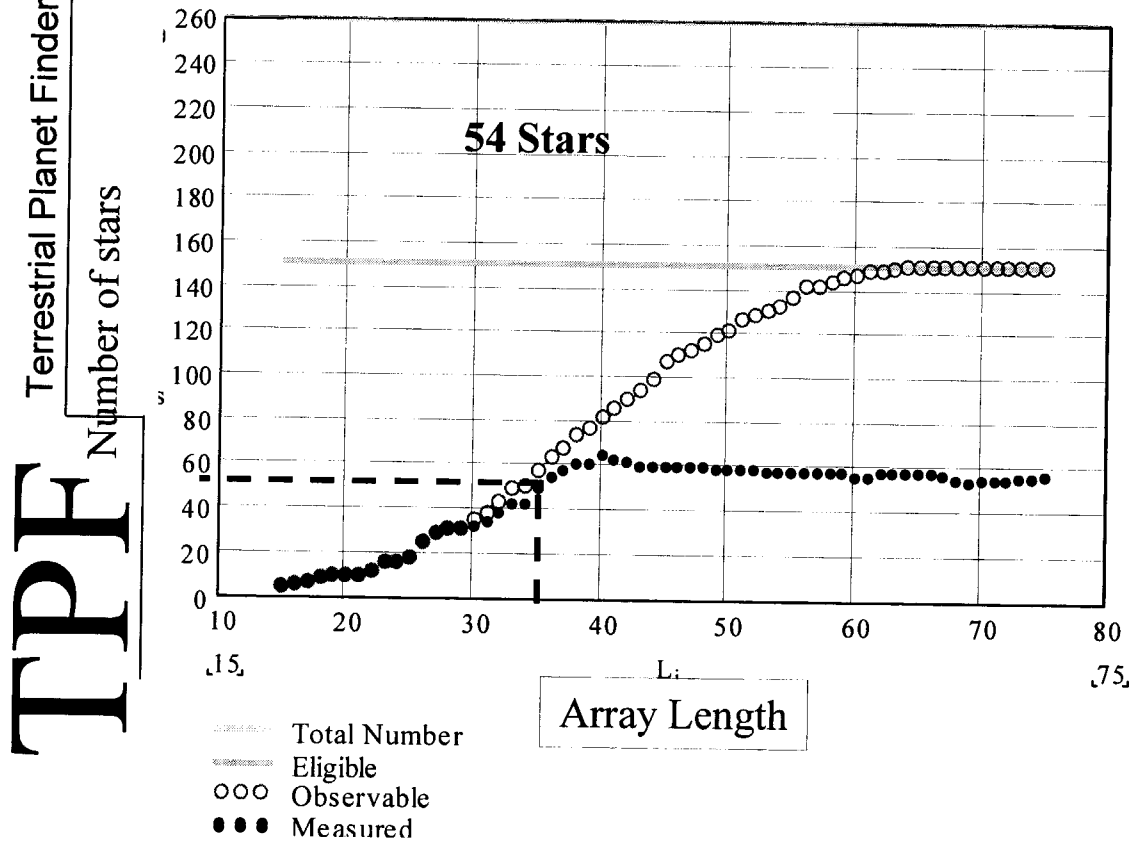
SCI Baseline: Minimum Mission



hi-lo-res Chopped Dual Bracewell, x=0.25



	Baselined Option
CONFIGURATION SPECIFICATIO	
Array length	**36**
Enrance pupil/nulling architecture	**DCB hi/lo res**
Chop response (right-left)	0.87/0.77
Chop de-modulation efficiency (~Ndet)	0.5
BeamCombiner efficiency (on top of ideal)	1
Apertures Locations Factor (x=bs/s)	**0.25**
Collecting area (m^2)	**32.2**
Number of apertures	4
Apertures diameter (m)	3.2
IMPLEMENTATION ASSUMPTIONS	
Inner Working Distance (fraction of 1st peak at 10um)	1
Sky coverage (+/- degrees)	**45**
Internal throughput	**0.05**
Optics transmission	0.2
Det Response	0.5
Number of detectors (Ndet)	1
Null floor	**1.E-06**
OBSERVATION PARAMETERS (Constrains)	
planet surface area	0.5 Earth
planet distance from star	0.7 MidHZ
Required SNR (shot noise only)	**7**
Bandwidth (um)	**7-17**
Completeness	**95%**
Number of visits	3
Orbit Inclanation factor	1.29
Time avaliable for integration	**1 year**
Max single observation time	**7 days**
LZ flux density	**13.7 Mjy/sr @ 12um**
PERFORMANCE METRICS	
Number of stars (req=30)	**54**
F	7
G	20
K	27

- Under current implementation assumptions SCI Baseline achieves the Minimum Mission Requirement (30 stars)

Statistics of the Minimum Mission

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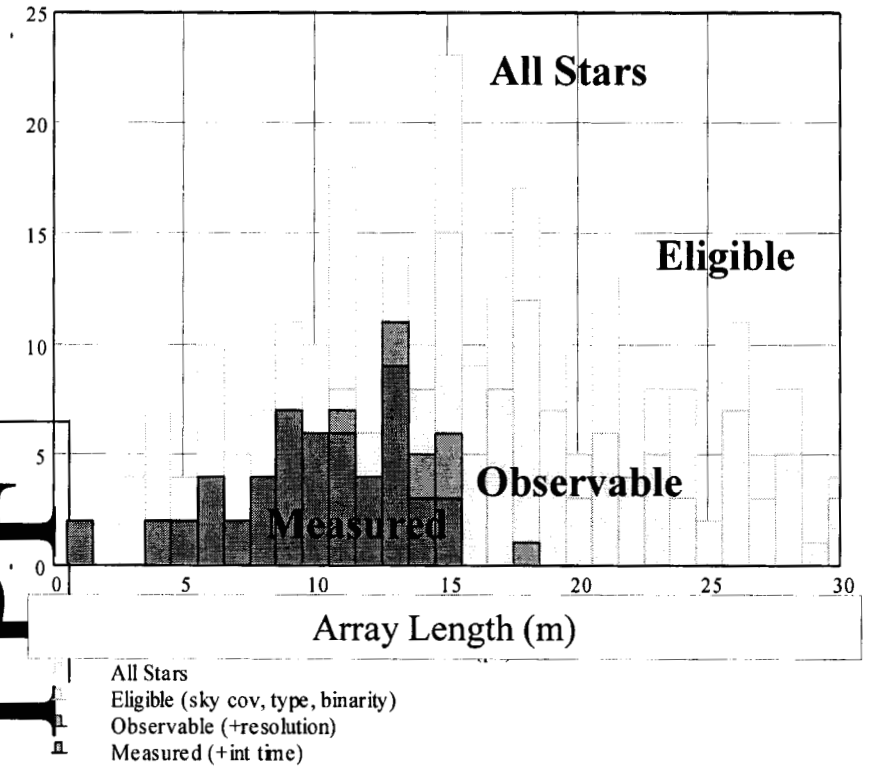
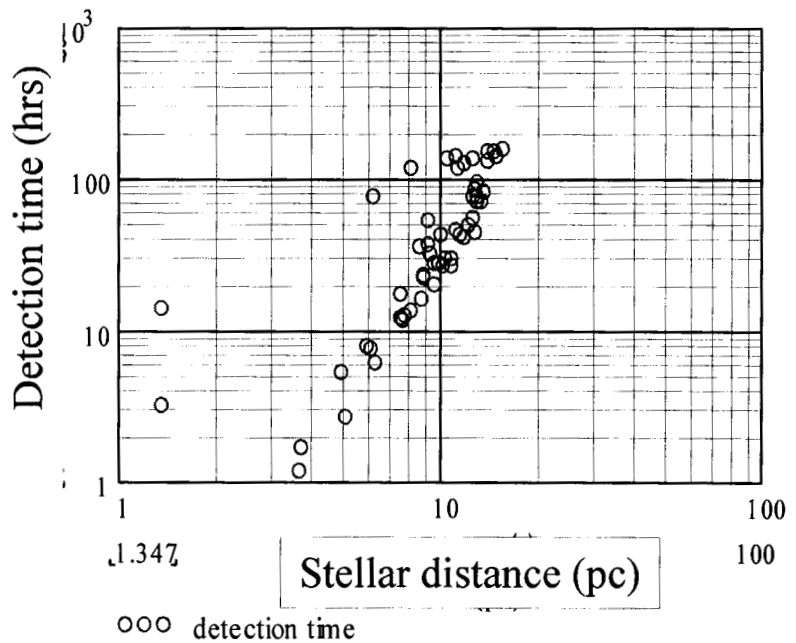
Histograms of star sets



Detection times



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Full Mission FFI Performance Considerations

- Sensitivity for further out stars (strongest signal)
  - Favors Dual Chopped Bracewell (q2)
- Stellar leakage Nearby stars (low noise)
  - Favors θ^4 architectures, e.g. Darwin bow-tie

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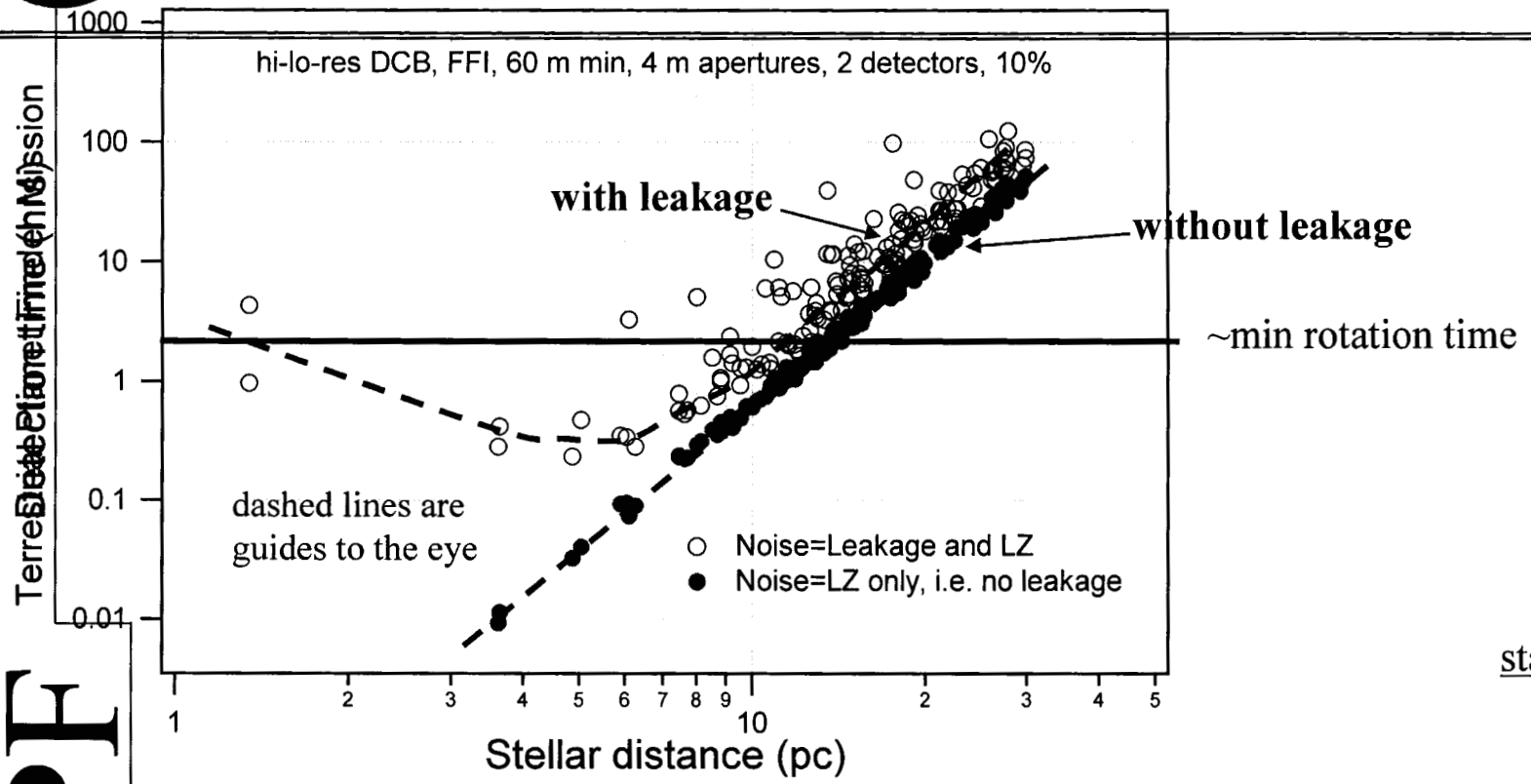
Criteria

Options -->	1-D		2-D						Supporting Documents
	Chopping Dual Bracewell hi-lo-res, 3.5 m		DARWIN (1.5 m) Alcatel		DARWIN (1.5 m) Bow-tie		Dual Chopped DAC (3.5 m)		
MUSTS									
Exo-zodi suppression	v		v		v		v		
Feasible beamcombiner	v		v		v		v		D.2
Equal pathlengths	v		v		v		v		
Instrument background suppression?	v		v		v		v		
In one plane	v		v		v		v		
Top Discriminators									
Performance									
Number of stars	2	x2.8	0	<65	0	x1	2	x2.9	D.1, D.4
Speed=beam combiner efficiency+ sky response+collecting area	0	4.9	-2	1	-2	1	-1	2.1	
Stellar Leakage	0		2		2		2		
Local Zodi	0		-1		-1		0		
Nearest stars	0		1		1		1		D.1, D.6
Unambiguous planet position-?	0		0		0		0		
Complexity/Difficulty									
Beamcombiner Complexity	0		-3		-3		-2		D.2
Beam transport complexity	0		1		1		0		
Concept Maturity	0		1		-1		-2		
Fuel usage	0		1 (?)		-1		0		"D.3" and see comment
Robustness and Risk									
Redundancy	0		1		0		0		D.5
Number of s/c	0		-1		-1		0		
Cost and Utility									
Equal size collectors	0		0		0		-1 (maybe)		
Legacy (scalable to future missions)	0		1		1		0		

What about Stellar Leakage?



star table

- Although stellar leakage is the dominant noise source for nearby stars, it is NOT a problem for observation of nearby stars.
- More distant stars, which we need to pick up for a full mission, are NOT leakage dominated

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What would it take to see 150 stars? Details of the example

Star Selector Calculations Main Panel

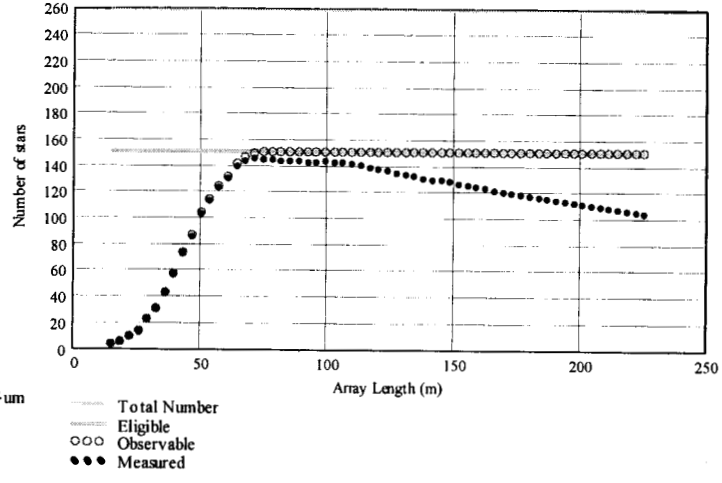
INSTRUMENT Configuration: $m \equiv 1$ $config_m$ = "DCB_lo_res" TwoConfigs ≡ 1 N_elig_stars = 151

Collecting area: Atot = 50.3
N apertures Napm = 4
Aperture diameter: Dap ≡ 4.0 *
Rotation modulation Mrotm = 0.5
Chopping modulation Mchm = 0.89
Beam Combiner eff Tbcm = 1

SIMULATION PARAMETERS Lmin ≡ 15 Lmax ≡ 75.3 N_L ≡ 30.2 Req_stars ≡ 30

IMPLEMENTATION ASSUMPTIONS
IWD as fraction of first peak: IWD ≡ 1
Sky coverage(deg) SkyHalfAngle ≡ 45
Internal Throughput Tintm = 0.07 *
Optics Topt ≡ 0.07
Detector Tdet ≡ 1
# of detectors Ndet ≡ 2 *
Null floor Null ≡ 10^{-6}

OBSERVATION PARAMETERS
Required SNR SNR_det ≡ 7
Wavelength band: λd_min ≡ 7·um λd_max ≡ 17·um
λres ≡ 10·um
Planet temperature: T_pl ≡ 300
Planet radius (Rearth): $R_pl \equiv \frac{1}{\sqrt{2}}$
Inner HZ definition InnerHzFactor ≡ 0.7
Completeness visits ≡ 3
η_incl ≡ 1.29
Time available for AvailableTime ≡ 1.5year *
MaxSingleObsTime ≡ 7·day
LOCAL ZODI R_AU ≡ 1 LZOptDepth ≡ 4.010^{-8}
SPECTROSCOPY
λs_min ≡ 9.5um λs_max ≡ 10·um SNR_spectr ≡ 14
SpectrTime ≡ 2·year η_earth ≡ 0.5



Req number met at: $L_{j_reqL} = 32.5$ j_reqL = 5

Maximum number at: N_meas_stars_max = 146
$L_{L_maxN_index} = 71$
L_maxN_index = 16

Run statistics for Variable baseline? FF := 1 or j_SCI := 21
minimum FF array size FFminL := 60
$L_{j_SCI} = 88.5$

TIME LIMITS
$TotalTime \equiv \frac{AvailableTime}{visits}$
TotalTime = 0.5year
TotalTime = 4.38×10^3 hr
MaxSingleObsTime = 168hr

Test case (259 is sun at 10 pcs)
n_test ≡ 259 L_test ≡ 35 $d_pc_{n_test} = 10$
S_pl_test = 5 $L_{j_test} = 36$
S_leak_test = 1×10^3
S_LZ_test = 2023 Time_test = 1.697hr

	Full	Min
Configuration	FFI	36 m SCI
Architecture	hi-lo DCB	hi-lo DCB
Aperture diameter	4.0	3.2
Sky Coverage	45	45
Throughput	7%	5%
Number of detectors	2	1
Total available time	1.5 years	1 year
Min FF Length	60	NA
Number of Stars	149	52

- A self-consitent, but not necessarily practical example

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What would it take to see 150 stars? Star Statistics

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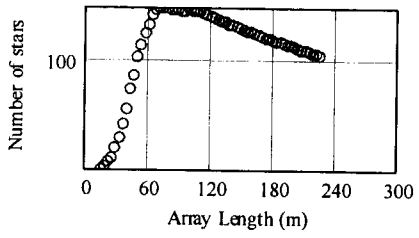
$config_m$ = "DCB_lo_res" TwoConfigs = 1 FF = 1

Resolution selector: IWD = 1

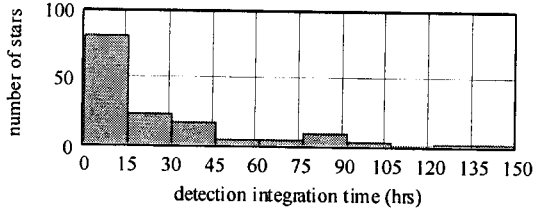
Sky coverage(deg) SkyHalfAngle = 45 Dapm = 4



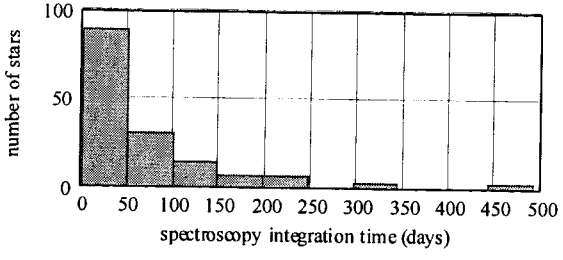
With an SCI array set at $L_{j_SCI} = 89$ or FFI operating with Lmin = $L_{j_FFminL} = 61$

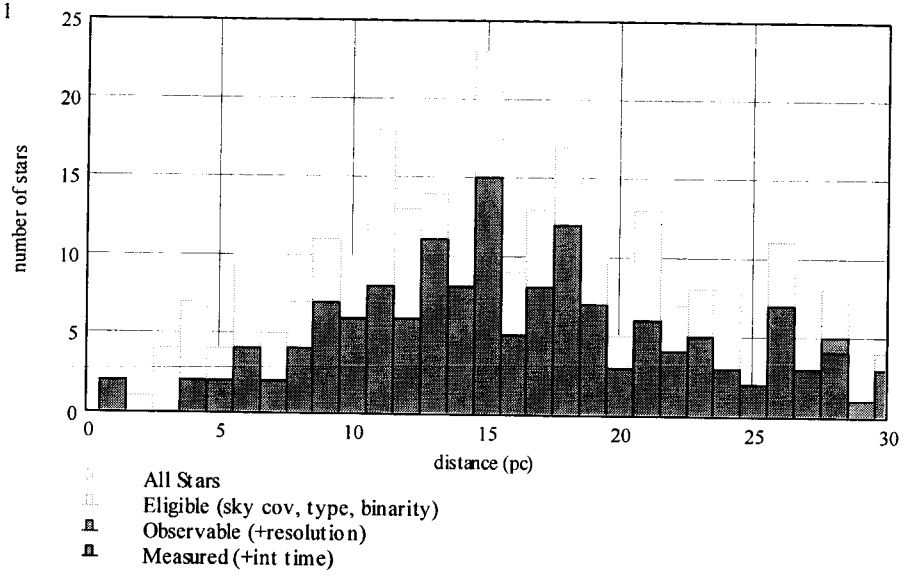
Measured stars: number N_meas_stars_All = 149

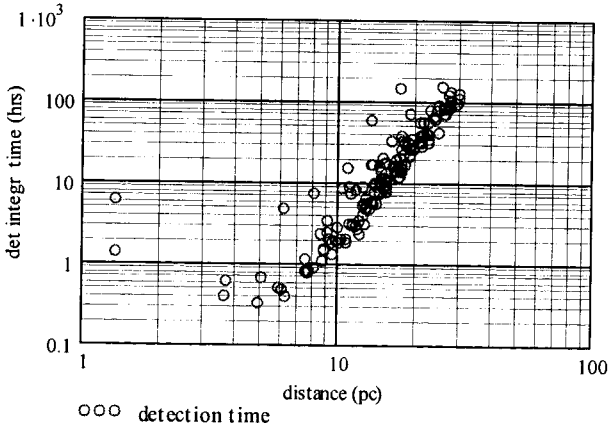
types N_F = 72 N_G = 44 N_K = 33



Spectroscopy η_earth = 0.1 N_stars_spectr = 14







Parameters used as input to Strawman Design

Feature	Interferometer	Coronagraph
SNR/visit	5	5
Inner HZ	0.7 "AU"	0.7 "AU"
IWA/IHZ	1/1.29	1
IWA Defined	$\frac{3}{4}\frac{\lambda}{L_o}$ (for hi-res Bracewell)	$3\frac{\lambda}{L_o}$
IWA	43 mas for 36m structure	82 mas for 6m aperture
λo	10 μm	0.8 μm
Outer HZ	1.5 "AU" (not yet a filter)	1.5 "AU" (not yet a filter)
Visits (for completeness)	3	11
Total time for survey	Elapsed observing time is 1 yr out of 2 calendar yrs	Elapsed observing time is 1 yr out of 2 calendar yrs
Planet surface area	Half earth	Half earth
Field Of Regard (from anti sun)	+/- 45 deg	+/- 85 deg

What's Next

- For the Architecture Team
- Next presentation: Curt

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission