Summary of Science Driven Telescope Specifications

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Requirement Process

- Define the science
  - Dark energy
- Define parameter that measures success
  - Dark Energy Task force Figure of Merit
- Define science technique
  - Baryon Acoustic Oscillations with intensity mapping
- Pick an Instrument
  - Develop a rough engineering model
  - Estimate the cost versus science of the instrument
  - Pick a parameter set or “punt”

CRT Constraints

- Divide survey into two by dividing frequency span into two bands
  - Performance maximized by noise performance
  - Noise match easier over smaller bandwidth
  - Larger digitizer dynamic range for smaller bandwidth
- Bands are adjacent
- Fractional bandwidth of each band < 33%
- Limit the maximum span to half the digitizer bandwidth
- Digital electronics are re-used for each band
- Number of electronic channels are the same for both bands
- Reflector width and spacing the same for both bands

Parameter Set

- Static Engineering Parameters (STE)
- Dynamic Engineering Parameters (DYE)
- Derived Engineering Parameters (DRE)
- Scientific Parameters (SCI)

Parameter Set

- Static Engineering Parameters (STE)
  - The static engineering parameters are independent parameters that are
    - important in describing the telescope
    - not easily changed for design optimization
  - such as the latitude of the telescope site, amplifier temperature, etc.

Static Engineering Parameters (STE)

Number	Description	Symbol
STE.01	Survey Time	τ_s
STE.02	Observing Duty Factor	D_f
STE.03	Latitude of telescope site	α_L
STE.04	Average Sky Temperature	T_s
STE.05	Maximum Frequency Span per band	$\Delta F_{b_{max}}$
STE.06	Maximum Fractional Bandwidth per band	δ_{f_b}
STE.07	Number of Polarizations	N_p
STE.08	Antenna Feed Power Efficiency	g_a
STE.09	Cylinder Width / Cylinder Spacing	x_{cyl}
STE.10	Equivalent Amplifier Temperature	T_A
STE.11	Electronics Cost per Channel	R_e
STE.12	Feed Structure Cost per meter	R_f
STE.13	Reflector Cost per Cylinder volume	R_r

Dynamic Engineering Parameters (DYE)

- Dynamic engineering parameters are independent parameters that can be easily varied during the design stage
  - such as feed spacing and the number of channels per cylinder

Number	Description	Symbol
DYE.01	Center Frequency of both bands combined	F_c
DYE.02	Average Feed Spacing	D_f
DYE.03	Number of digital channels per cylinder per polarization	N_f
DYE.04	Average Number of possible cylinder locations	N_L
DYE.05	Average Cylinder packing factor	p_f
DYE.06	Target Cost	C_T

Derived Engineering Parameters (DRE)

- Derived engineering parameters are design specific parameters
  - such as cylinder length and width
  - but are derived from the static and dynamic engineering parameters.

Derived Engineering Parameters (DRE)

Number	Description	Symbol
DRE.01	Number of Cylinders	N_c
DRE.02	Cylinder Length	L_c
DRE.03	Cylinder Width	W_c
DRE.04	Cylinder Spacing	S_c
DRE.05	Declination Span	$\Delta\theta_d$
DRE.06	Feed Length	h_f
DRE.07	Feed Spacing	d_f
DRE.08	Band Center Frequency	F_{cb}
DRE.09	Wavelength	λ
DRE.10	Band Frequency Span	ΔF_{b}
DRE.11	Resolution Bandwidth	δf
DRE.12	Minimum Digital Memory	M_d
DRE.14	Integration Time per Pixel	τ_p
DRE.15	Number of Channels per polarization	N_{fT}
DRE.16	Electronics Cost	C_e
DRE.17	Feed Structure Cost	C_f
DRE.18	Reflector Cost	C_R
DRE.19	Total Cost	C_T

Derived Engineering Parameters (DRE)

$$\delta_f < \frac{F_c}{\Delta F_{b_{max}}} \frac{2}{1 + \sqrt{\frac{4F_c - \Delta F_{b_{max}}}{2F_c}}}$$

$$F_{c_\pm} = F_c \frac{4 \pm 2\delta_f}{4 + \delta_f{}^2}$$

$$\Delta F_\pm = \delta_f F_{c_\pm}$$

$$N_{L_\pm} = round\left(N_L \frac{F_c}{F_{c_\pm}}\right)$$

$$d_{f_\pm} = D_f N_{L_\pm}$$

$$p_{f_+} = p_{f_-} \frac{N_{L_-}}{N_{L_+}}$$

$$N_{f_+} = N_{f_-} = N_f$$

$$N_{C_+} = N_{C_+} = N_C = p_{f\_} N_{L_-}$$

$$R_\pm = \frac{1}{2} \frac{N_C(N_C - 1)}{N_{L_\pm} - 1}$$

$$N_C > \frac{1}{2}\left(1 + \sqrt{1 + 8(N_{L_-} - 1)}\right)$$

$$p_{f_-} > \frac{1}{2N_{L_-}}\left(1 + \sqrt{1 + 8(N_{L_-} - 1)}\right)$$

$$L_{C_\pm} = N_f d_f$$

$$W_C = x_{cyl} S_C = x_{cyl} \frac{N_f d_{f_\pm}}{N_{L_\pm}}$$

$$\sin\left(\frac{\Delta\theta_{d_\pm}}{2}\right) = \frac{\lambda}{2d_{f_\pm}}$$

$$A_f = h_f W_C$$

$$\sin\left(\frac{\Delta\theta_f}{2}\right) = \frac{\lambda}{2h_f}$$

$$h_{f_\pm} = d_{f_\pm}$$

Telescope Cost

- It is not intended that these costs include everything that would arise in designing and building a large radio telescope
  - such as site preparation, non-recoverable engineering costs, overhead, contingency etc.,
- These costs should only be used in trying to compare sets of design parameters.
- The cost of the digital electronics is assumed to scale only with the number of feeds:

$$C_e = N_f N_c N_p R_e$$

Telescope Cost

- The cost of the telescope structure is broken into two parts.
- The feed line is the most complicated part of the reflector system and this cost will scale as the total length of the array.

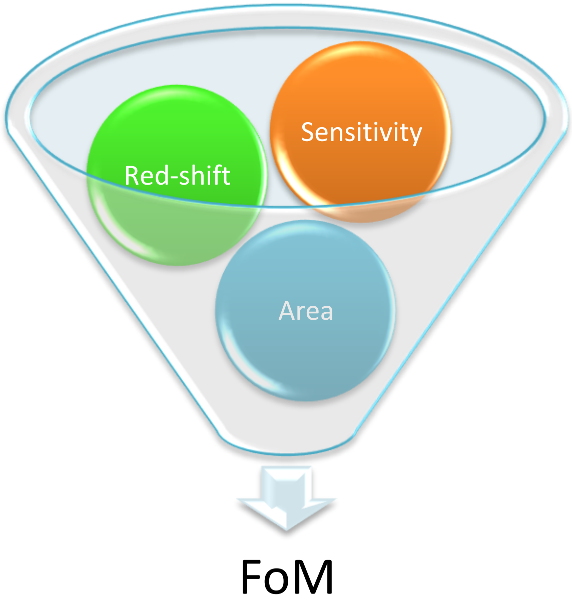
$$C_f = L_c N_c R_f = N_f N_c d_f R_f$$

- The cost of the main reflector surface will not only be proportional to area
  - but height as well since tall structures will be more difficult to build.
  - For a fixed f-ratio, the height will scale with cylinder width.

$$C_r = L_c N_c W_C^2 R_f = N_f N_c d_f W_C^2 R_f$$

Scientific Parameters (SCI)
(a.k.a. the 5 magic numbers)

- We want to have a set of numbers that
  - Describe the science
  - Can be derived from **ANY** telescope configuration
- The magic numbers for determining dark energy parameters using BAO
  - Minimum red-shift
  - Maximum red-shift
  - Survey area
  - Pixel Resolution
  - Pixel Sensitivity



Scientific Parameters (SCI)

Number	Description	Symbol
SCI.01	Maximum Red-shift	z_{max}
SCI.02	Minimum Red-shift	z_{min}
SCI.03	Angular Resolution	$\delta\psi$
SCI.04	Survey Area	A_s
SCI.05	Sensitivity per Pixel	δT_p
SCI.06	Figure of Merit with Plank Priors	FoM_p
SCI.07	Figure of Merit with Stage II Dark Energy Priors	FoM_{II}

Scientific Parameters (SCI)

$$z_{min\,\pm} = \frac{1.42GHz}{F_{c\pm} - \frac{1}{2}\Delta F_{\pm}} - 1$$

$$\mathrm{M}_{\mathrm{d}\pm} = \frac{2\Delta F_{\pm}}{\delta \mathrm{f}_{\pm}}$$

$$z_{\pm} = \frac{1.42GHz}{F_{c\pm}} - 1$$

$$\mathrm{A} = \int_0^{2\pi} d\phi \int_{\theta_{d\,min}}^{\theta_{d\,max}} \cos(\theta)\, d\theta = 2\pi\left[sin(\theta_{d\,max}) - sin(\theta_{d\,min})\right]$$

$$z_{max\,\pm} = \frac{1.42GHz}{F_{c\pm} + \frac{1}{2}\Delta F_{\pm}} - 1$$

$$\theta_{d\,max} = \alpha_L + \frac{\Delta\theta_d}{2} \quad if \quad \alpha_L + \frac{\Delta\theta_d}{2} < \frac{\pi}{2}$$

$$\theta_{d\,max} = \frac{\pi}{2} \quad if \quad \alpha_L + \frac{\Delta\theta_d}{2} > \frac{\pi}{2}$$

$$sin(\delta\psi_{\pm}) = \frac{\lambda}{N_f d_{f\pm}}$$

$$\delta z_{\pm} \approx 0.436 \times \delta\psi_{\pm}(\mathrm{radians}) \times \mathrm{z}_{\pm}(\mathrm{z}_{\pm} + 2)$$

$$\theta_{d\,min} = \alpha_L - \frac{\Delta\theta_d}{2} \quad if \quad \alpha_L - \frac{\Delta\theta_d}{2} < -\frac{\pi}{2}$$

$$\theta_{d\,min} = -\frac{\pi}{2} \quad if \quad \alpha_L - \frac{\Delta\theta_d}{2} < -\frac{\pi}{2}$$

$$\delta \mathrm{f}_{\pm} = \frac{1.4GHz}{(1 + \mathrm{z}_{\pm})^2}\delta \mathrm{z}_{\pm}$$

Scientific Parameters (SCI)

$$\sin(\psi_n) = \left(-\frac{1}{2} + \frac{n}{N_f}\right)\frac{\lambda}{d_f}$$

$$\theta_n = \psi_n + \alpha_L$$

$$\Delta\phi_C = \frac{\lambda}{W_c}$$

$$\sin\left(\frac{\Delta\varphi_{RA_n}}{2}\right) = \frac{1}{cos(\theta_n)}\sin\left(\frac{\Delta\phi_C}{2}\right)$$

$$\tau_p = \frac{\tau_s D_f}{N_f + 1}\sum_{n=0}^{N_f}\frac{\Delta\varphi_{RA_n}}{2\pi}$$

$$\delta T_{p_\pm} = \frac{1}{\sqrt{\tau_{p_\pm}\delta f_\pm}}\left(T_s + \frac{1}{g_a}\frac{1}{p_{f_\pm}}\frac{d_{f_\pm}}{h_{f_\pm}}\sqrt{\frac{N_f}{(N_f - 1)}}\sqrt{\frac{N_c}{(N_c - 1)}}T_A\right)$$

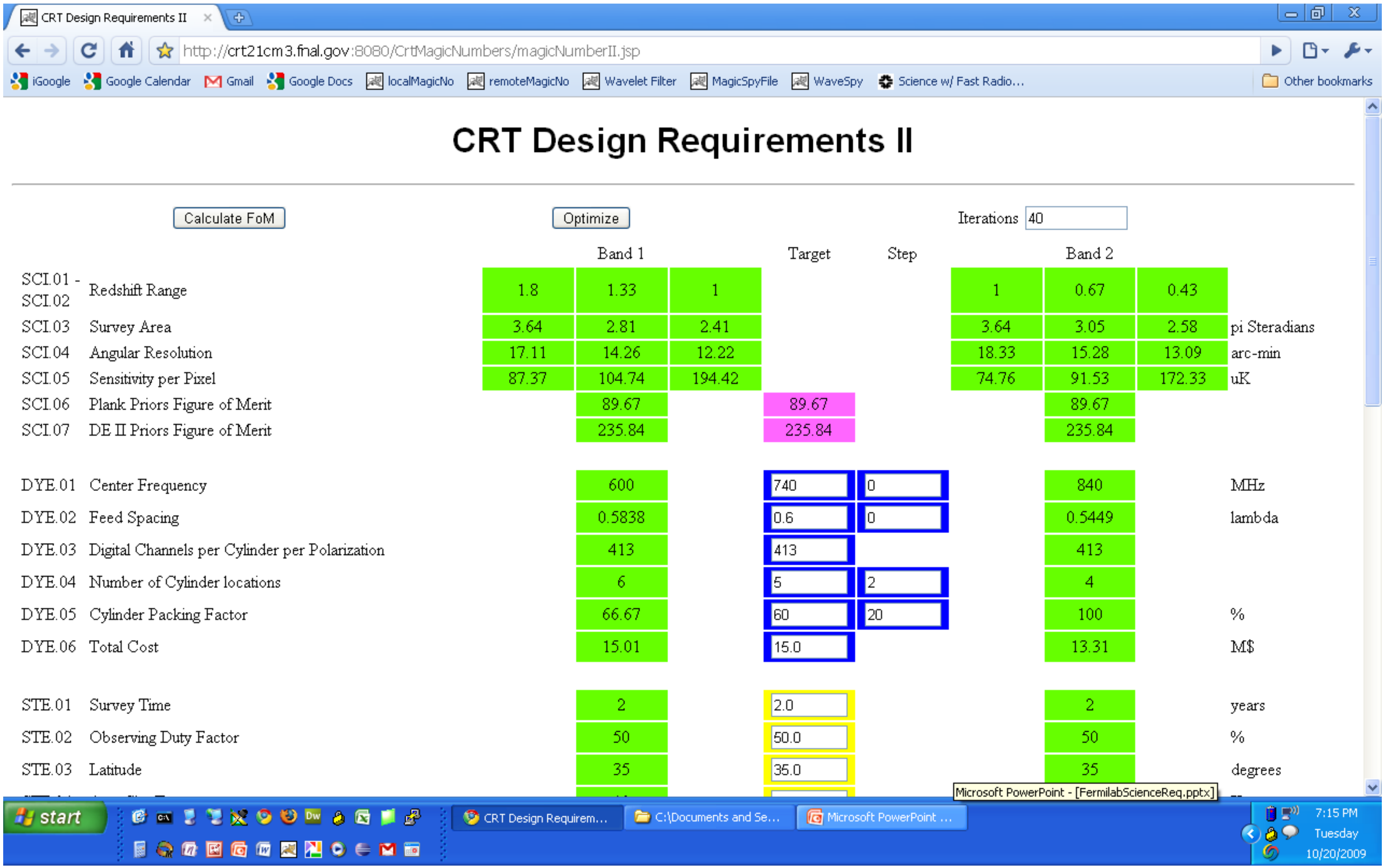
Requirement Optimization

- Developed a web application to evaluate parameter sets
  - Helps with focus loosely organized world-wide collaboration
- Uses Hee-Jong's BAO analysis technique for determining Figure of Merit
- Web application has two features
  - Evaluator
  - Optimizer

Requirement Optimizer

- Vary
  - Center Frequency
  - Feed spacing
  - Number of cylinder <u>locations</u>
  - Cylinder packing factor
- Constrain
  - Number of feeds per cylinder to reach target cost

Requirement Web Application



		Band 1			Target	Step	Band 2			
SCI.01 - SCI.02	Redshift Range	1.8	1.33	1			1	0.67	0.43	
SCI.03	Survey Area	3.64	2.81	2.41			3.64	3.05	2.58	pi Steradians
SCI.04	Angular Resolution	17.11	14.26	12.22			18.33	15.28	13.09	arc-min
SCI.05	Sensitivity per Pixel	87.37	104.74	194.42			74.76	91.53	172.33	uK
SCI.06	Plank Priors Figure of Merit		89.67		89.67			89.67		
SCI.07	DE II Priors Figure of Merit		235.84		235.84			235.84		
DYE.01	Center Frequency		600		740	0		840		MHz
DYE.02	Feed Spacing		0.5838		0.6	0		0.5449		lambda
DYE.03	Digital Channels per Cylinder per Polarization		413		413			413		
DYE.04	Number of Cylinder locations		6		5	2		4		
DYE.05	Cylinder Packing Factor		66.67		60	20		100		%
DYE.06	Total Cost		15.01		15.0			13.31		M$
STE.01	Survey Time		2		2.0			2		years
STE.02	Observing Duty Factor		50		50.0			50		%
STE.03	Latitude		35		35.0			35		degrees

Requirement Web Application

CRT Design Requirements II

http://crt21cm3.fnal.gov:8080/CrtMagicNumbers/magicNumberII.jsp

STE.08	Antenna Efficiency		80		80.0		80		%
STE.09	Antenna Width Fill Factor		80		80.0		80		%
STE.10	Amplifier Temperature		50		50.0		50		K
STE.11	Electronics Cost per Channel		3000		3000.0		3000		$
STE.12	Feed Structure Cost Rate		2300		2300.0		2300		$/meter
STE.13	Reflector Volume Cost Rate		32		32.0		32		$/meter^3
DRE.01	Number of Cylinders		4				4		
DRE.02	Cylinder Length		120.55				80.37		meters
DRE.03	Cylinder Width		16.07				16.07		meters
DRE.04	Cylinder Spacing		20.09				20.09		meters
DRE.05	Declination Span	180	117.85	94.47		180	133.17	103.73	degrees
DRE.06	Feed Length		29.19				19.46		cm
DRE.07	Feed Spacing		29.19				19.46		cm
DRE.08	Frequency	500	600	700		700	840	980	MHz
DRE.09	Wavelength	60	50	42.86		42.86	35.71	30.61	cm
DRE.10	Frequency Span		200				280		MHz
DRE.11	Res. Bandwidth	2.65	2.07	1.63		2.44	1.73	1.18	MHz
DRE.12	Minimum Digital Memory		245				472		
DRE.13	Integration Time per Pixel	8.02	7.16	2.64		5.74	5.39	2.23	days
DRE.14	Number of Channels per polarization		1652				1652		
DRE.15	Electronics Cost		9.91				9.91		M$
DRE.16	Feed Structure Cost		1.11				0.74		M$
DRE.17	Reflector Volume Cost		3.99				2.66		M$

Static Engineering Parameters

	Cost	64C66	64C133	64C200	64C266	128C66	128C133	128C200	128C266	256C66	256C133	256C200	256C266	512C66	512C133	512C200	512C266	M$
STE.01	Survey Time	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	years
STE.02	Observing Duty Factor	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	%
STE.03	Latitude	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	degrees
STE.04	Avg. Sky Temperature	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	K
STE.05	Maximum Span	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	MHz
STE.06	Center Freq / Freq Span	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
STE.07	Number of Polarizations	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
STE.08	Antenna Efficiency	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	%
STE.09	Antenna Width Fill Factor	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	%
STE.10	Amplifier Temperature	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	K
STE.11	Electronics Cost per Channel	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	$
STE.12	Feed Structure Cost Rate	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	$/meter
STE.13	Reflector Volume Cost Rate	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	$/meter^3

Dynamic Engineering Parameters

	Cost	64C66	64C133	64C200	64C266	128C66	128C133	128C200	128C266	256C66	256C133	256C200	256C266	512C66	512C133	512C200	512C266	M$
DYE.01	Center Frequency	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	MHz
DYE.02	Feed Spacing	0.5838	0.5838	0.5838	0.5838	0.5838	0.5838	0.5838	0.5838	0.5838	0.5838	0.5838	0.5838	0.5838	0.5838	0.5838	0.5838	lambda
DYE.03	Digital Channels per Cylinder	64	64	64	64	128	128	128	128	256	256	256	256	512	512	512	512	
DYE.04	Number of Cylinder locations	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	
DYE.05	Cylinder Packing Factor	66.67	133.33	200	266.67	66.67	133.33	200	266.67	66.67	133.33	200	266.67	66.67	133.33	200	266.67	%
DYE.06	Total Cost	1.72	3.45	5.17	6.89	3.53	7.07	10.6	14.14	7.78	15.56	23.34	31.12	21.26	42.52	63.78	85.03	M$

Band 1

	Cost	64C66	64C133	64C200	64C266	128C66	128C133	128C200	128C266	256C66	256C133	256C200	256C266	512C66	512C133	512C200	512C266	M$
DYE.01	Center Frequency	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	MHz
DYE.02	Feed Spacing	0.5449	0.5449	0.5449	0.5449	0.5449	0.5449	0.5449	0.5449	0.5449	0.5449	0.5449	0.5449	0.5449	0.5449	0.5449	0.5449	lambda
DYE.03	Digital Channels per Cylinder	64	64	64	64	128	128	128	128	256	256	256	256	512	512	512	512	
DYE.04	Number of Cylinder locations	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
DYE.05	Cylinder Packing Factor	100	200	300	400	100	200	300	400	100	200	300	400	100	200	300	400	%
DYE.06	Total Cost	1.66	3.32	4.98	6.64	3.38	6.76	10.14	13.52	7.24	14.47	21.71	28.94	18.27	36.54	54.81	73.07	M$

Band 2

Derived Engineering Parameters

Band 1

	Cost	64C66	64C133	64C200	64C266	128C66	128C133	128C200	128C266	256C66	256C133	256C200	256C266	512C66	512C133	512C200	512C266	M$
DRE.01	Number of Cylinders	4	8	12	16	4	8	12	16	4	8	12	16	4	8	12	16	
DRE.02	Cylinder Length	18.68	18.68	18.68	18.68	37.36	37.36	37.36	37.36	74.72	74.72	74.72	74.72	149.45	149.45	149.45	149.45	meters
DRE.03	Cylinder Width	2.49	2.49	2.49	2.49	4.98	4.98	4.98	4.98	9.96	9.96	9.96	9.96	19.93	19.93	19.93	19.93	meters
DRE.04	Cylinder Spacing	3.11	3.11	3.11	3.11	6.23	6.23	6.23	6.23	12.45	12.45	12.45	12.45	24.91	24.91	24.91	24.91	meters
DRE.05	Declination Span	117.85	117.85	117.85	117.85	117.85	117.85	117.85	117.85	117.85	117.85	117.85	117.85	117.85	117.85	117.85	117.85	degrees
DRE.06	Feed Length	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	cm
DRE.07	Feed Spacing	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	29.19	cm
DRE.08	Frequency	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	MHz
DRE.09	Wavelength	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	cm
DRE.10	Frequency Span	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	MHz
DRE.11	Res. Bandwidth	13.33	13.33	13.33	13.33	6.66	6.66	6.66	6.66	3.33	3.33	3.33	3.33	1.67	1.67	1.67	1.67	MHz
DRE.12	Minimum Digital Memory	38	38	38	38	76	76	76	76	152	152	152	152	304	304	304	304	
DRE.13	Integration Time per Pixel	31.67	31.67	31.67	31.67	18.71	18.71	18.71	18.71	10.48	10.48	10.48	10.48	5.95	5.95	5.95	5.95	days
DRE.14	Number of Channels	256	512	768	1024	512	1024	1536	2048	1024	2048	3072	4096	2048	4096	6144	8192	
DRE.15	Electronics Cost	1.54	3.07	4.61	6.14	3.07	6.14	9.22	12.29	6.14	12.29	18.43	24.58	12.29	24.58	36.86	49.15	M$
DRE.16	Feed Structure Cost	0.17	0.34	0.52	0.69	0.34	0.69	1.03	1.37	0.69	1.37	2.06	2.75	1.37	2.75	4.12	5.5	M$
DRE.17	Reflector Volume Cost	0.01	0.03	0.04	0.06	0.12	0.24	0.36	0.47	0.95	1.9	2.85	3.8	7.6	15.19	22.79	30.38	M$

Band 2

	Cost	64C66	64C133	64C200	64C266	128C66	128C133	128C200	128C266	256C66	256C133	256C200	256C266	512C66	512C133	512C200	512C266	M$
DRE.01	Number of Cylinders	4	8	12	16	4	8	12	16	4	8	12	16	4	8	12	16	
DRE.02	Cylinder Length	12.45	12.45	12.45	12.45	24.91	24.91	24.91	24.91	49.82	49.82	49.82	49.82	99.63	99.63	99.63	99.63	meters
DRE.03	Cylinder Width	2.49	2.49	2.49	2.49	4.98	4.98	4.98	4.98	9.96	9.96	9.96	9.96	19.93	19.93	19.93	19.93	meters
DRE.04	Cylinder Spacing	3.11	3.11	3.11	3.11	6.23	6.23	6.23	6.23	12.45	12.45	12.45	12.45	24.91	24.91	24.91	24.91	meters
DRE.05	Declination Span	133.17	133.17	133.17	133.17	133.17	133.17	133.17	133.17	133.17	133.17	133.17	133.17	133.17	133.17	133.17	133.17	degrees
DRE.06	Feed Length	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	cm
DRE.07	Feed Spacing	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	cm
DRE.08	Frequency	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	MHz
DRE.09	Wavelength	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	cm
DRE.10	Frequency Span	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	MHz
DRE.11	Res. Bandwidth	11.2	11.2	11.2	11.2	5.6	5.6	5.6	5.6	2.8	2.8	2.8	2.8	1.4	1.4	1.4	1.4	MHz
DRE.12	Minimum Digital Memory	73	73	73	73	146	146	146	146	292	292	292	292	585	585	585	585	
DRE.13	Integration Time per Pixel	25.42	25.42	25.42	25.42	14.38	14.38	14.38	14.38	8.09	8.09	8.09	8.09	4.49	4.49	4.49	4.49	days
DRE.14	Number of Channels	256	512	768	1024	512	1024	1536	2048	1024	2048	3072	4096	2048	4096	6144	8192	
DRE.15	Electronics Cost	1.54	3.07	4.61	6.14	3.07	6.14	9.22	12.29	6.14	12.29	18.43	24.58	12.29	24.58	36.86	49.15	M$
DRE.16	Feed Structure Cost	0.11	0.23	0.34	0.46	0.23	0.46	0.69	0.92	0.46	0.92	1.37	1.83	0.92	1.83	2.75	3.67	M$
DRE.17	Reflector Volume Cost	0.01	0.02	0.03	0.04	0.08	0.16	0.24	0.32	0.63	1.27	1.9	2.53	5.06	10.13	15.19	20.25	M$

Scientific Parameters

	Cost	64C66	64C133	64C200	64C266	128C66	128C133	128C200	128C266	256C66	256C133	256C200	256C266	512C66	512C133	512C200	512C266	M$
SCI.01 - SCI	Redshift Range	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	
SCI.03	Survey Area	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	pi-Ster.
SCI.04	Angular Resolution	92.01	92.01	92.01	92.01	46.01	46.01	46.01	46.01	23	23	23	23	11.5	11.5	11.5	11.5	arc-min
SCI.05	Sensitivity per Pixel	19.72	10.02	7.1	5.7	36.16	18.37	13.03	10.45	68.2	34.66	24.58	19.72	127.91	65.01	46.11	36.99	uK
SCI.06	Plank Priors Figure of Merit	3.98	11.18	16.28	20.77	17.05	53.68	71.23	87.2	62.05	128.04	152.87	184.45	114.99	184.35	236.41	241.13	
SCI.07	DE II Priors Figure of Merit	70.58	93.44	104.56	112.2	113.22	174.25	201.21	233.86	196.07	293.45	337.03	388.93	272.45	387.34	465.85	472.79	

Band 1

	Cost	64C66	64C133	64C200	64C266	128C66	128C133	128C200	128C266	256C66	256C133	256C200	256C266	512C66	512C133	512C200	512C266	M$
SCI.01 - SCI	Redshift Range	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	
SCI.03	Survey Area	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	pi-Ster.
SCI.04	Angular Resolution	98.58	98.58	98.58	98.58	49.29	49.29	49.29	49.29	24.65	24.65	24.65	24.65	12.32	12.32	12.32	12.32	arc-min
SCI.05	Sensitivity per Pixel	16.69	8.81	6.44	5.3	31.27	16.51	12.08	9.94	58.84	31.08	22.73	18.71	111.62	58.96	43.13	35.5	uK
SCI.06	Plank Priors Figure of Merit	3.98	11.18	16.28	20.77	17.05	53.68	71.23	87.2	62.05	128.04	152.87	184.45	114.99	184.35	236.41	241.13	
SCI.07	DE II Priors Figure of Merit	70.58	93.44	104.56	112.2	113.22	174.25	201.21	233.86	196.07	293.45	337.03	388.93	272.45	387.34	465.85	472.79	

Band 2

Figure of Merit vs Cost

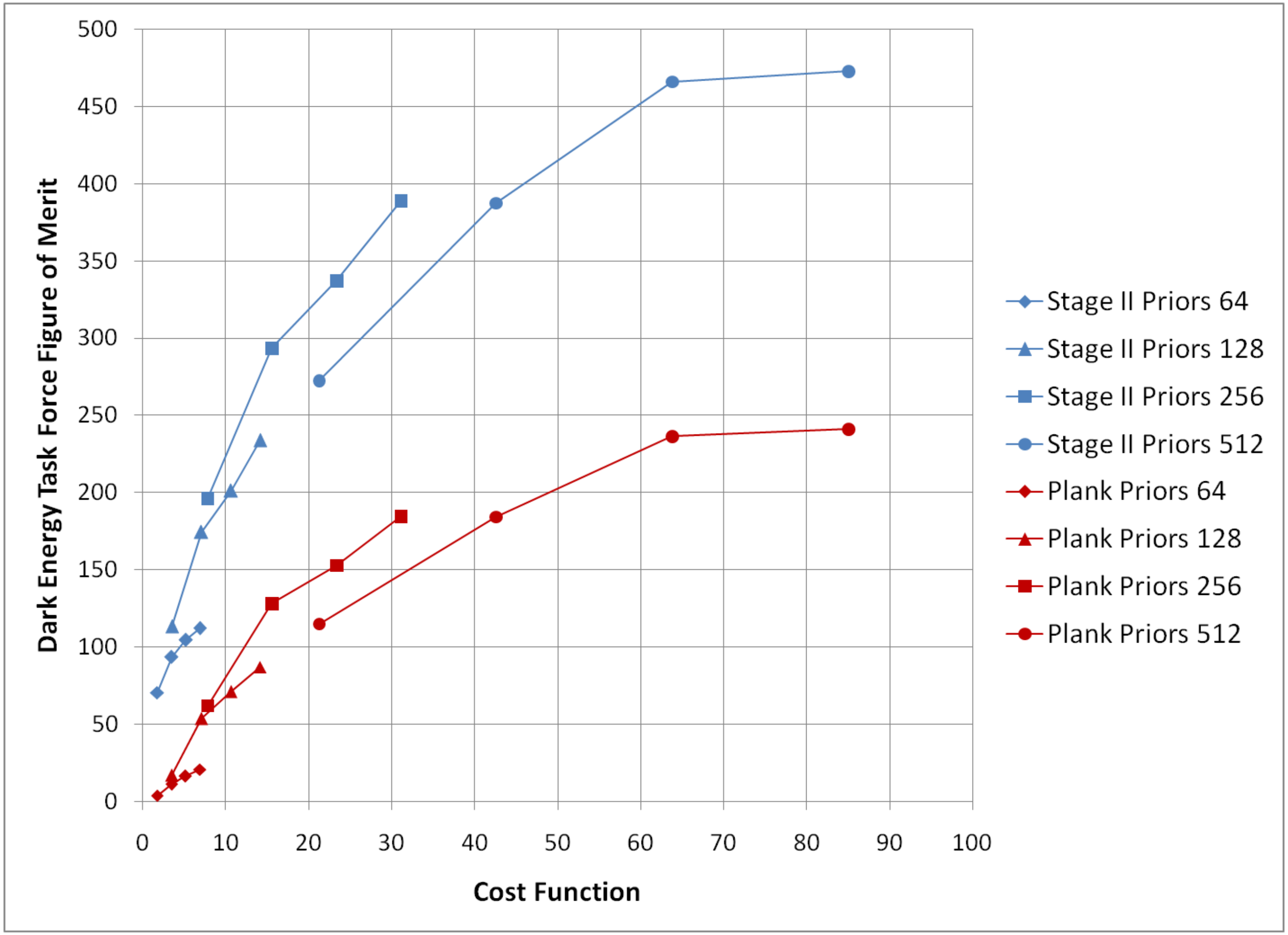
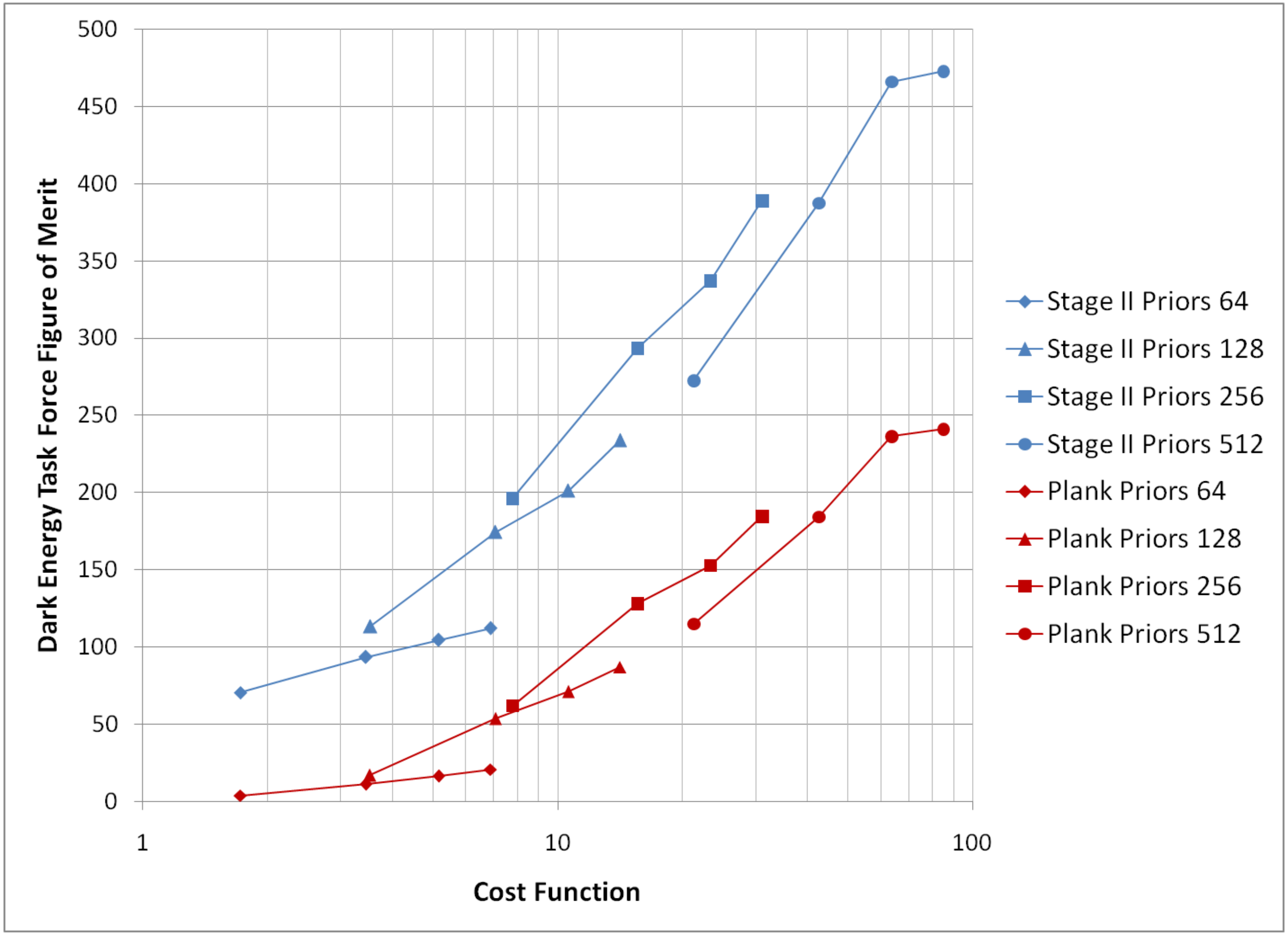
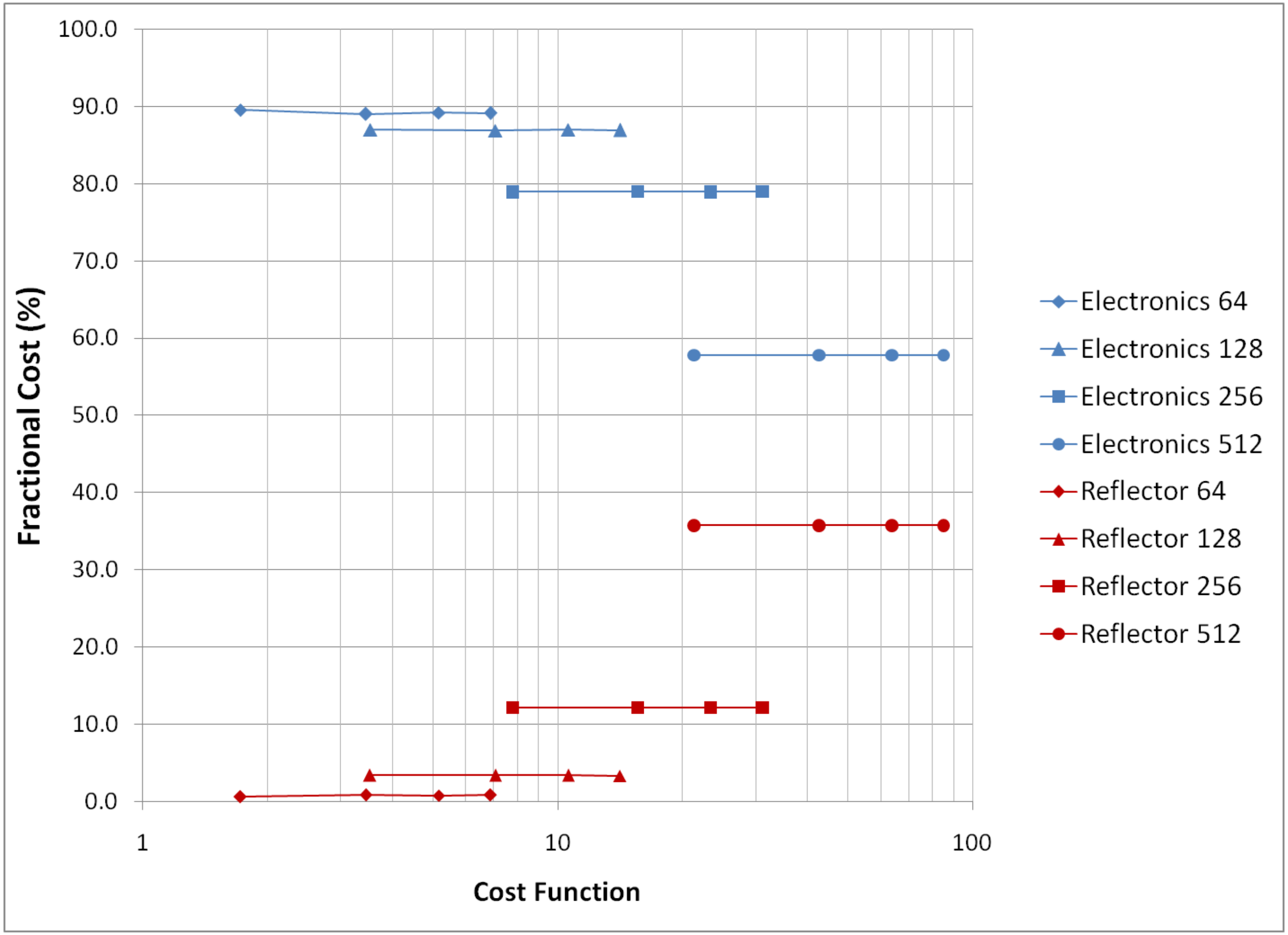


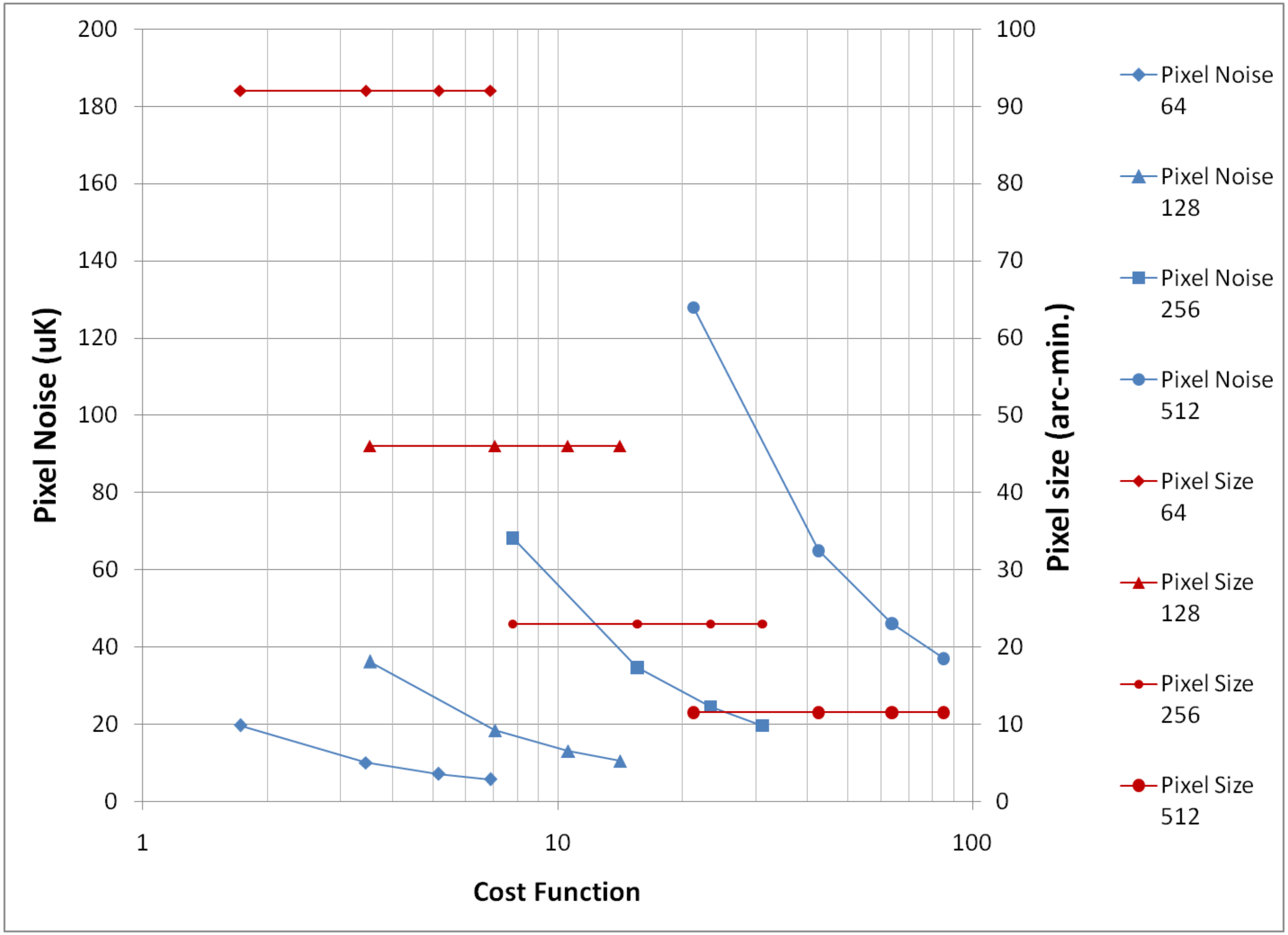
Figure of Merit vs Cost



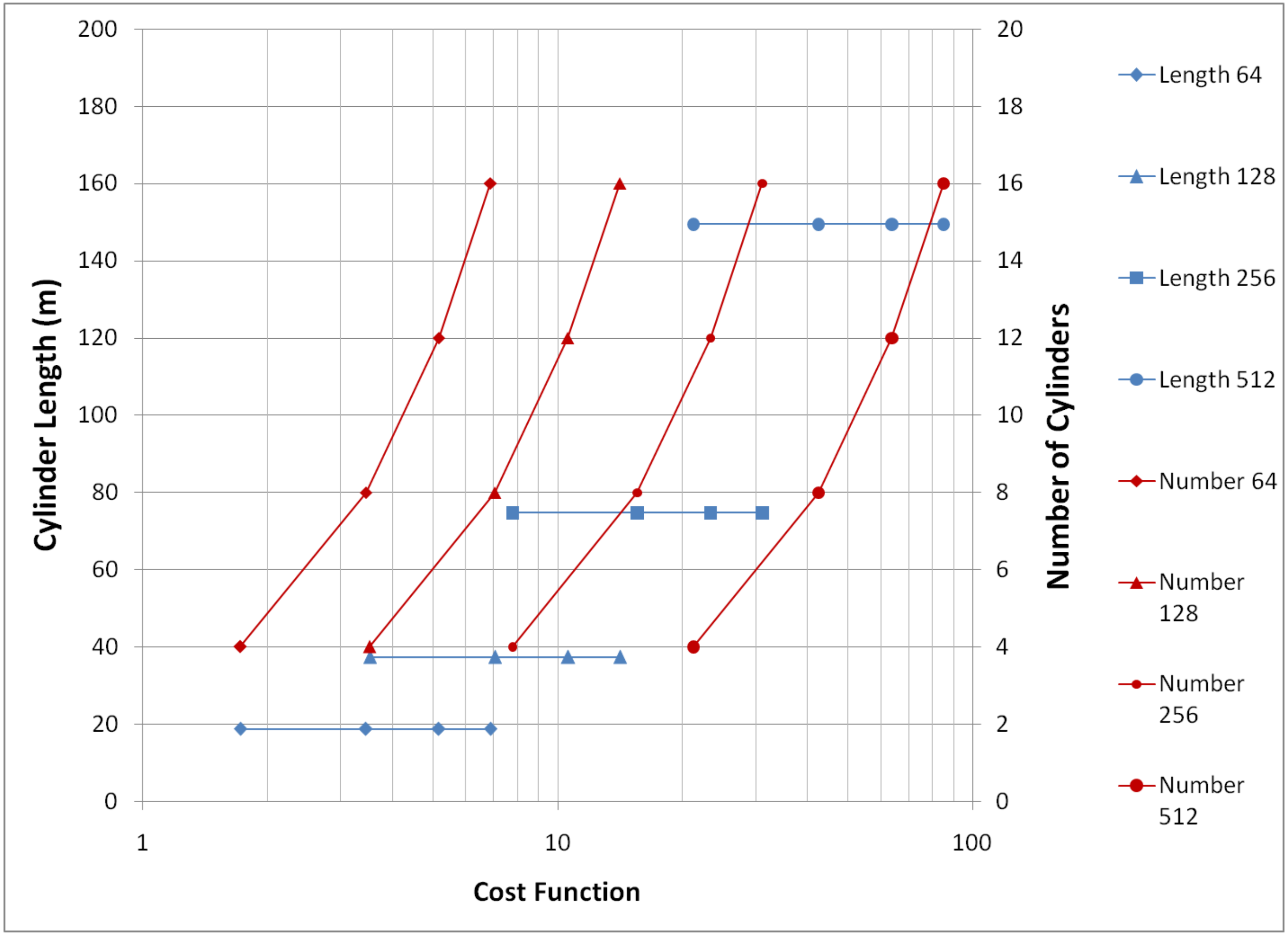
Fractional Cost



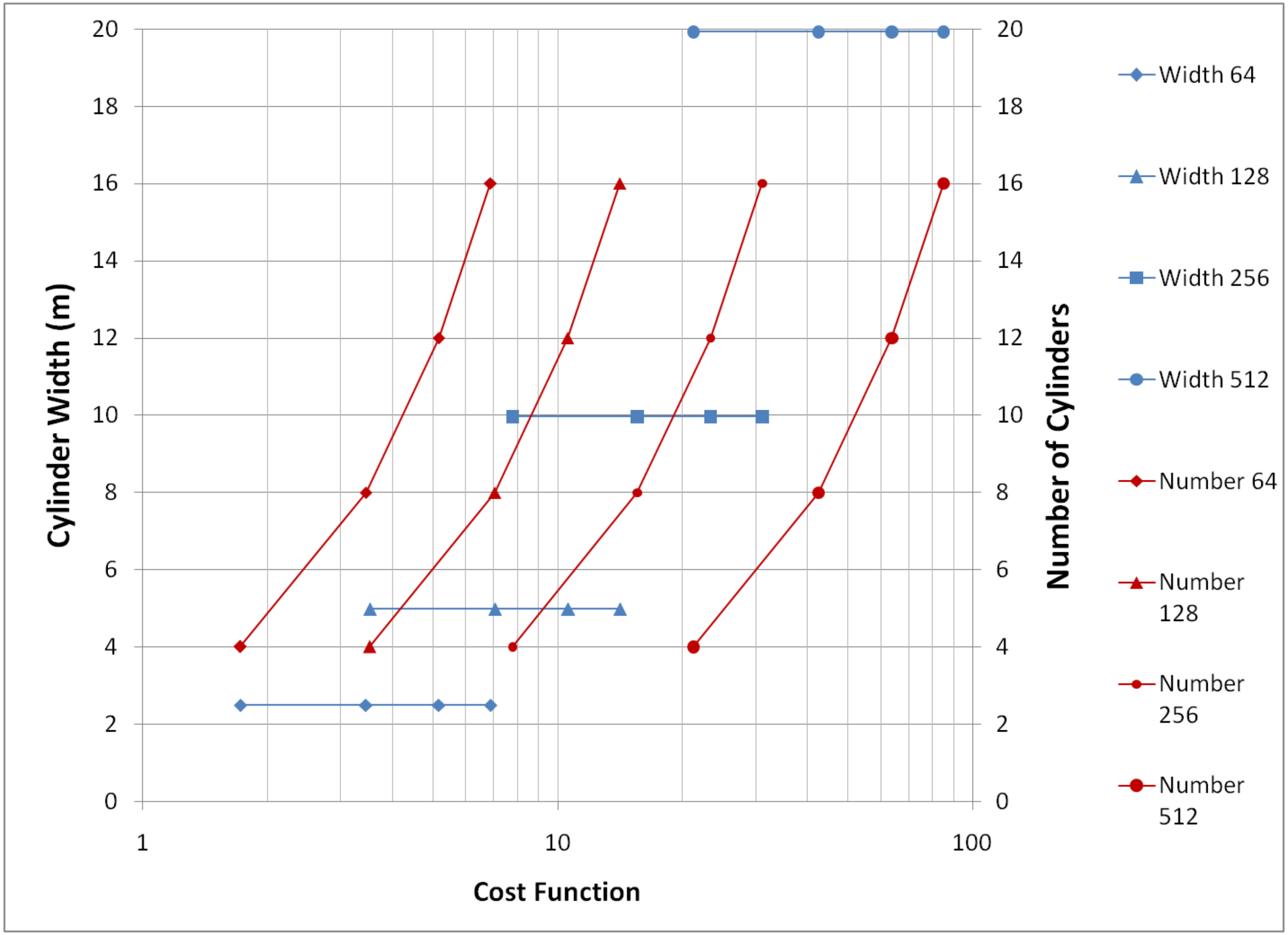
Pixel Noise and Resolution



Cylinder Length



Cylinder Width



Conclusions

- A Dark Energy Task Force Figure of Merit of 270 can be obtained with a CRT that “costs” ~20MS
- Resolution is the most important factor in increasing the FOM for a fixed cost