# Summary of Science Driven Telescope Specifications

Dave McGinnis

Fermilab

# Survey Area

The survey area for a drift telescope

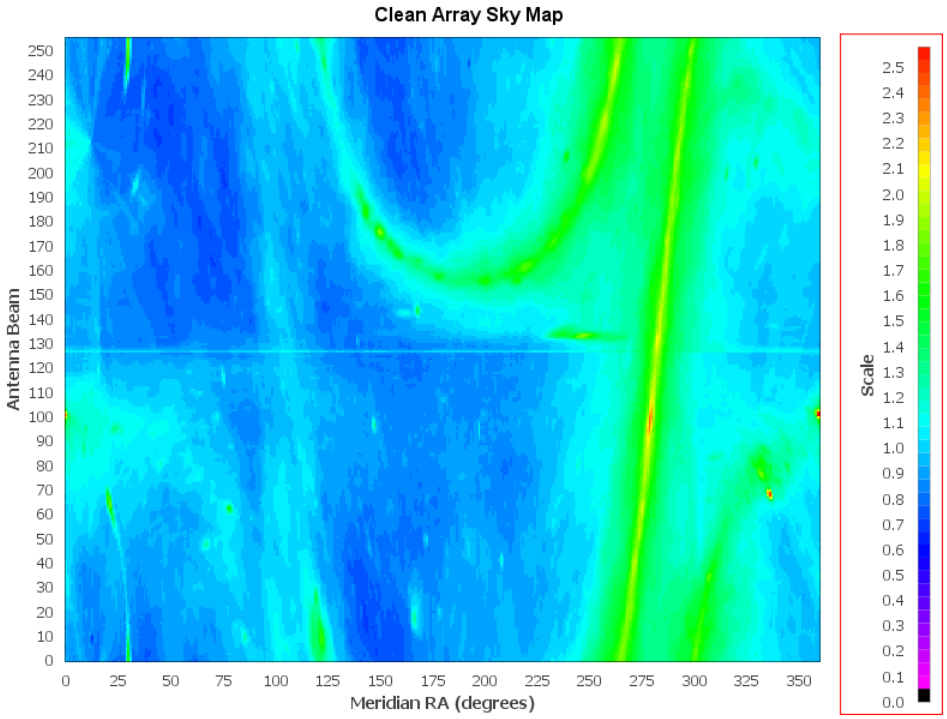
$$\mathrm{A} = \int_0^{2\pi} d\phi \int_{-\Delta\theta/2}^{\Delta\theta/2} \cos(\theta)\, d\theta = 4\pi sin\left(\frac{\Delta\theta}{2}\right)$$

where $\Delta\theta$ is the angular span of the telescope beam along the meridian.

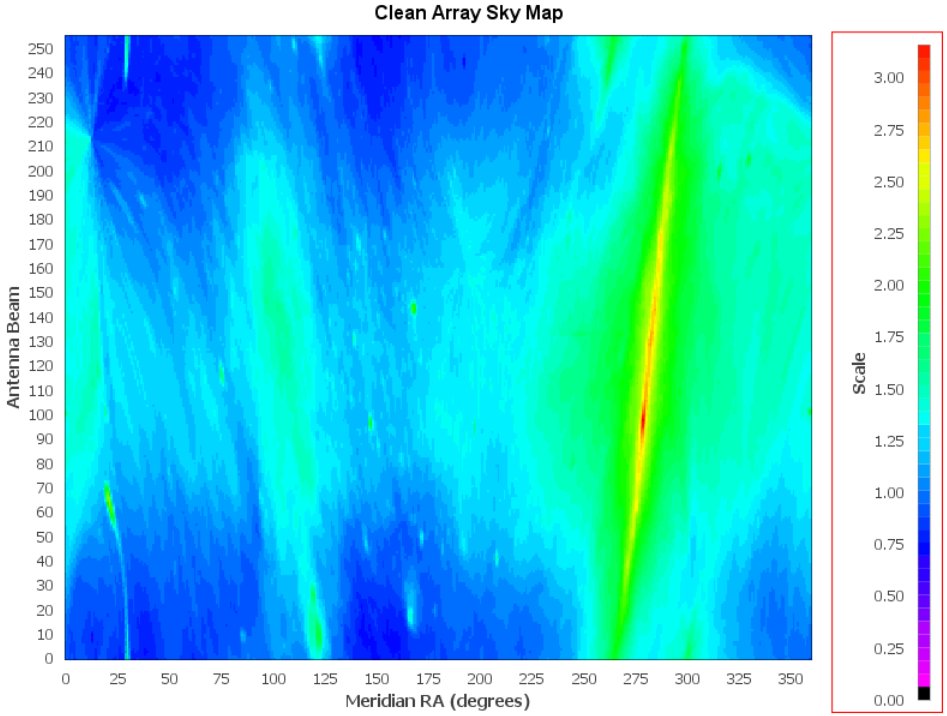
If the antennae are summed in such away as to minimize the impact of the grating lobes folding over into the main field of view, then:

$$A = 2\pi\frac{\lambda}{d}$$

# Sky Map for Feed Spacing=λ




Antenna spacing at λ
Feed spacing at λ
equal weight




Antenna spacing at λ/2
Feed spacing at λ
Weight = 0.7, 1.0, 0.7

# Resolution

Meridian Resolution

$$\delta\theta = \frac{\lambda}{L_{cyl}} = \frac{\lambda}{N_{feed}\,d}$$

Azimuthal Resolution

$$\delta\phi = \frac{\lambda}{\left(\Delta N_{max\ cyl} + 1\right) W_{cyl}}$$

For a “uniform cubic” pixel

$$\delta z \approx 0.436 \times \delta\theta(\text{radians}) \times z(z+2)$$

$$\delta F = \frac{1.4GHz}{(1+z)^2}\,\delta z$$

$$\delta F \approx 610MHz \times \delta\theta(\text{radians}) \times \frac{z(z+2)}{(1+z)^2}$$

# Survey Speed

The azimuthal angular resolution of a single cylinder is

$$\delta\phi_{cyl} = \frac{\lambda}{W_{cyl}} \tag{16}$$

where $W_{cyl}$ is the width of the cylinder. In one day, the amount of time that an object will sit in the cylinder beam as it drifts across the cylinder beam width is given as:

$$\Delta\tau_{day} = 24 \times 3600\text{sec} \times \frac{\lambda/W_{cyl}}{2\pi} \tag{17}$$

The amount of time that can be integrated in one year for an object is:

$$\Delta\tau_{year} = 365 \times D_f \Delta\tau_{day} \tag{18}$$

where $D_f$ is the duty factor of observations. If observing is done only at night, then $D_f$~50%. The total amount of time integrated is:

$$\Delta\tau_{total} = N_{year}\Delta\tau_{year} \tag{19}$$

where $N_{year}$ is the number of years the survey runs.

A single measurement length is inversely proportional to the resolution bandwidth. The total amount of measurements made is given be the total integration time divided by the measurement length. The total number of measurements, M, is:

$$M = \Delta\tau_{total}\delta F \tag{20}$$

# Pixel Sensitivity for a Configuration with "missing" Cylinders

$$\delta T = \frac{1}{\sqrt{M}}\left( T_{sky} + \frac{1}{g_a}\frac{d}{h_f}\sqrt{\frac{N_f}{(N_f - 1)}}\sqrt{\frac{N_{cyl}}{(N_{cyl} - 1)}}\left(\frac{\Delta N_{max\,cyl} + 1}{N_{cyl}}\right) T_a \right)$$

$$A_{feed} = h_f W_{cyl}$$

For an infinitely short dipole, $h_f \sim \lambda$.

# Array Cost

- Electronics = $3000/polarization channel
- Reflector Cost = $7000 / meter
  - Assuming reflector ~10meters wide
  - ~3x Pittsburgh cost
- Keep cost below 20M$
- Break design into two bands to keep fraction bandwidth 1/3 of center frequency
- Assume no extra cost for the second band

# Band 1 Two Band Expensive Design Band 2

| Number | Requirement | Limit | Average | Limit | Unit |
|---|---|---|---|---|---|
| 1.01 | Redshift Range | 1.80 | 1.33 | 1.00 | |
| 1.02 | Survey Area | 3.60 | 3.00 | 2.57 | steradians |
| 1.03 | Angular Resolution | 12.1 | 10.1 | 8.6 | arc-Min |
| 1.04 | Survey Time | | 1.60 | | Years |
| 1.05 | Sensitivity per Pixel | 125 | 182 | 255 | uK |
| 1.06 | Polarization Imbalance | | -20 | | dB |
| | | | | | |
| 2.01 | Minumum Antenna efficiency | | 80 | | % |
| 2.02 | Antenna Width Fill factor | | 80 | | % |
| 2.03 | Effective Feed Length | | 1 | | Wavelenth |
| 2.04 | Maximum Sky Temperature | | 10 | | K |
| 2.05 | Maximum Amplifier Noise Temp | | 50 | | K |
| 2.06 | Observing duty Factor | | 50 | | % |
| 2.07 | Latitude | | 0 | | degrees |
| 2.08 | Reflector Cost Rate | | 7000 | | $/meter |
| 2.09 | Electronics cost per Channel | | 3000 | | $/Channel |
| | | | | | |
| 3.01 | Center Frequency | | 600.0 | | MHz |
| 3.02 | Frequency Span | | 200.0 | | MHz |
| 3.03 | Frequency | 500 | 600.0 | 700 | MHz |
| 3.04 | Wavelength | 60.0 | 50.0 | 42.9 | cm |
| 3.05 | Resolution Bandwidth | 1.9 | 1.5 | 1.1 | MHz |
| 3.06 | Integration Time per pixel | 2.86 | 2.38 | 2.04 | day |
| 3.07 | Feed Spacing | | 33.3 | | cm |
| 3.08 | Declination Span | 128.3 | 97.2 | 80.0 | degrees |
| 3.09 | Number of Digital Channels per Cylinder per Polarization | | 512 | | |
| 3.10 | Minimum Digital Memory | | 348 | | |
| 3.11 | Length of Cylinder | | 170.6 | | meters |
| 3.12 | Width of Cylinder | | 9.8 | | meters |
| 3.13 | Cylinder Nominal Spacing | | 12.2 | | meters |
| 3.14 | Number of Cylinders Locations | | 14.0 | | |
| 3.15 | Number of Actual Cylinders | | 6.0 | | |
| 3.16 | Number of Channels per Polarization | | 3072 | | |
| 3.17 | Number of Polarizations | | 2 | | |
| 3.18 | Reflector Cost | | 7.2 | | M$ |
| 3.19 | Electronics Cost | | 18.4 | | M$ |
| 3.20 | Total Cost | | 25.6 | | M$ |

2x hit in sensitivity
4x hit in survey speed

| Number | Requirement | Limit | Average | Limit | Unit |
|---|---|---|---|---|---|
| 1.01 | Redshift Range | 1.00 | 0.67 | 0.43 | |
| 1.02 | Survey Area | 3.60 | 3.00 | 2.57 | 8 steradians |
| 1.03 | Angular Resolution | 12.1 | 10.1 | 8.6 | arc-Min |
| 1.04 | Survey Time | | 1.70 | | Years |
| 1.05 | Sensitivity per Pixel | 133 | 203 | 305 | uK |
| 1.06 | Polarization Imbalance | | -20 | | dB |
| | | | | | |
| 2.01 | Minumum Antenna efficiency | | 80 | | % |
| 2.02 | Antenna Width Fill factor | | 80 | | % |
| 2.03 | Effective Feed Length | | 1 | | Wavelenth |
| 2.04 | Maximum Sky Temperature | | 10 | | K |
| 2.05 | Maximum Amplifier Noise Temp | | 50 | | K |
| 2.06 | Observing duty Factor | | 50 | | % |
| 2.07 | Latitude | | 0 | | degrees |
| 2.08 | Reflector Cost Rate | | 7000 | | $/meter |
| 2.09 | Electronics cost per Channel | | 3000 | | $/Channel |
| | | | | | |
| 3.01 | Center Frequency | | 840.0 | | MHz |
| 3.02 | Frequency Span | | 280.0 | | MHz |
| 3.03 | Frequency | 700 | 840.0 | 980 | MHz |
| 3.04 | Wavelength | 42.9 | 35.7 | 30.6 | cm |
| 3.05 | Resolution Bandwidth | 1.6 | 1.1 | 0.8 | MHz |
| 3.06 | Integration Time per pixel | 2.17 | 1.81 | 1.55 | day |
| 3.07 | Feed Spacing | | 23.8 | | cm |
| 3.08 | Declination Span | 128.4 | 97.2 | 80.0 | degrees |
| 3.09 | Number of Digital Channels per Cylinder per Polarization | | 512 | | |
| 3.10 | Minimum Digital Memory | | 717 | | |
| 3.11 | Length of Cylinder | | 121.9 | | meters |
| 3.12 | Width of Cylinder | | 9.7 | | meters |
| 3.13 | Cylinder Nominal Spacing | | 12.2 | | meters |
| 3.14 | Number of Cylinders Locations | | 10.0 | | |
| 3.15 | Number of Actual Cylinders | | 5.0 | | |
| 3.16 | Number of Channels per Polarization | | 2560 | | |
| 3.17 | Number of Polarizations | | 2 | | |
| 3.18 | Reflector Cost | | 4.3 | | M$ |
| 3.19 | Electronics Cost | | 15.4 | | M$ |
| 3.20 | Total Cost | | 19.6 | | M$ |

# Two Band Expensive Design

Band 1

| Number | Requirement | Limit | Average | Limit | Unit |
|---|---|---|---|---|---|
| 1.01 | Redshift Range | 1.80 | 1.33 | 1.00 | |
| 1.02 | Survey Area | 3.60 | 3.00 | 2.57 | steradians |
| 1.03 | Angular Resolution | 12.09 | 10.07 | 8.63 | arc-Min |
| 3.05 | Resolution Bandwidth | 1.9 | 1.5 | 1.1 | MHz |
| 1.05 | Sensitivity per Pixel | 125 | 182 | 255 | uK |

Band 2

| Number | Requirement | Limit | Average | Limit | Unit |
|---|---|---|---|---|---|
| 1.01 | Redshift Range | 1.00 | 0.67 | 0.43 | |
| 1.02 | Survey Area | 3.60 | 3.00 | 2.57 | steradians |
| 1.03 | Angular Resolution | 12.09 | 10.08 | 8.64 | arc-Min |
| 3.05 | Resolution Bandwidth | 1.6 | 1.1 | 0.8 | MHz |
| 1.05 | Sensitivity per Pixel | 133 | 203 | 305 | uK |

Hee-Jong BAO “wiggle” calculation
FoM = 88 (Plank priors)
Fom = 248 (Plank + Stage II DE priors)

# Two Band Cheap Design

## Band 1

| Number | Requirement | Limit | Average | Limit | Unit |
|---|---|---|---|---|---|
| 1.01 | Redshift Range | 1.80 | 1.33 | 1.00 | |
| 1.02 | Survey Area | 2.40 | 2.00 | 1.71 | steradians |
| 1.03 | Angular Resolution | 16.1 | 13.4 | 11.5 | arc-Min |
| 1.04 | Survey Time | | 1.70 | | Years |
| 1.05 | Sensitivity per Pixel | 133 | 195 | 273 | uK |
| 1.06 | Polarization Imbalance | | -20 | | dB |
| | | | | | |
| 2.01 | Minumum Antenna efficiency | | 80 | | % |
| 2.02 | Antenna Width Fill factor | | 80 | | % |
| 2.03 | Effective Feed Length | | 1 | | Wavelenth |
| 2.04 | Maximum Sky Temperature | | 10 | | K |
| 2.05 | Maximum Amplifier Noise Temp | | 50 | | K |
| 2.06 | Observing duty Factor | | 50 | | % |
| 2.07 | Latitude | | 0 | | degrees |
| 2.08 | Reflector Cost Rate | | 7000 | | $/meter |
| 2.09 | Electronics cost per Channel | | 3000 | | $/Channel |
| | | | | | |
| 3.01 | Center Frequency | | 600.0 | | MHz |
| 3.02 | Frequency Span | | 200.0 | | MHz |
| 3.03 | Frequency | 500 | 600.0 | 700 | MHz |
| 3.04 | Wavelength | 60.0 | 50.0 | 42.9 | cm |
| 3.05 | Resolution Bandwidth | 2.5 | 1.9 | 1.5 | MHz |
| 3.06 | Integration Time per pixel | 2.89 | 2.41 | 2.07 | day |
| 3.07 | Feed Spacing | | 50.0 | | cm |
| 3.08 | Declination Span | 73.7 | 60.0 | 50.8 | degrees |
| 3.09 | Number of Digital Channels per Cylinder per Polarization | | 256 | | |
| 3.10 | Minimum Digital Memory | | 261 | | |
| 3.11 | Length of Cylinder | | 128.0 | | meters |
| 3.12 | Width of Cylinder | | 10.2 | | meters |
| 3.13 | Cylinder Nominal Spacing | | 12.8 | | meters |
| 3.14 | Number of Cylinders Locations | | 10.0 | | |
| 3.15 | Number of Actual Cylinders | | 5.0 | | |
| 3.16 | Number of Channels per Polarization | | 1280 | | |
| 3.17 | Number of Polarizations | | 2 | | |
| 3.18 | Reflector Cost | | 4.5 | | M$ |
| 3.19 | Electronics Cost | | 7.7 | | M$ |
| 3.20 | Total Cost | | 12.2 | | M$ |

1.8x hit in sensitivity
3.2x hit in survey speed

## Band 2

| Number | Requirement | Limit | Average | Limit | Unit |
|---|---|---|---|---|---|
| 1.01 | Redshift Range | 1.00 | 0.67 | 0.43 | |
| 1.02 | Survey Area | 2.40 | 2.00 | 1.71 | steradians |
| 1.03 | Angular Resolution | 16.1 | 13.4 | 11.5 | arc-Min |
| 1.04 | Survey Time | | 1.80 | | Years |
| 1.05 | Sensitivity per Pixel | 145 | 222 | 333 | uK |
| 1.06 | Polarization Imbalance | | -20 | | dB |
| | | | | | |
| 2.01 | Minumum Antenna efficiency | | 80 | | % |
| 2.02 | Antenna Width Fill factor | | 80 | | % |
| 2.03 | Effective Feed Length | | 1 | | Wavelenth |
| 2.04 | Maximum Sky Temperature | | 10 | | K |
| 2.05 | Maximum Amplifier Noise Temp | | 50 | | K |
| 2.06 | Observing duty Factor | | 50 | | % |
| 2.07 | Latitude | | 0 | | degrees |
| 2.08 | Reflector Cost Rate | | 7000 | | $/meter |
| 2.09 | Electronics cost per Channel | | 3000 | | $/Channel |
| | | | | | |
| 3.01 | Center Frequency | | 840.0 | | MHz |
| 3.02 | Frequency Span | | 280.0 | | MHz |
| 3.03 | Frequency | 700 | 840.0 | 980 | MHz |
| 3.04 | Wavelength | 42.9 | 35.7 | 30.6 | cm |
| 3.05 | Resolution Bandwidth | 2.1 | 1.5 | 1.0 | MHz |
| 3.06 | Integration Time per pixel | 2.15 | 1.79 | 1.53 | day |
| 3.07 | Feed Spacing | | 35.7 | | cm |
| 3.08 | Declination Span | 73.8 | 60.0 | 50.8 | degrees |
| 3.09 | Number of Digital Channels per Cylinder per Polarization | | 256 | | |
| 3.10 | Minimum Digital Memory | | 537 | | |
| 3.11 | Length of Cylinder | | 91.4 | | meters |
| 3.12 | Width of Cylinder | | 10.4 | | meters |
| 3.13 | Cylinder Nominal Spacing | | 13.1 | | meters |
| 3.14 | Number of Cylinders Locations | | 7.0 | | |
| 3.15 | Number of Actual Cylinders | | 4.0 | | |
| 3.16 | Number of Channels per Polarization | | 1024 | | |
| 3.17 | Number of Polarizations | | 2 | | |
| 3.18 | Reflector Cost | | 2.6 | | M$ |
| 3.19 | Electronics Cost | | 6.1 | | M$ |
| 3.20 | Total Cost | | 8.7 | | M$ |

# Two Band Cheap Design

Band 1

| Number | Requirement | Limit | Average | Limit | Unit |
|---|---|---|---|---|---|
| 1.01 | Redshift Range | 1.80 | 1.33 | 1.00 | |
| 1.02 | Survey Area | 2.40 | 2.00 | 1.71 | steradians |
| 1.03 | Angular Resolution | 16.11 | 13.43 | 11.51 | arc-Min |
| 3.05 | Resolution Bandwidth | 2.5 | 1.9 | 1.5 | MHz |
| 1.05 | Sensitivity per Pixel | 133 | 195 | 273 | uK |

Band 2

| Number | Requirement | Limit | Average | Limit | Unit |
|---|---|---|---|---|---|
| 1.01 | Redshift Range | 1.00 | 0.67 | 0.43 | |
| 1.02 | Survey Area | 2.40 | 2.00 | 1.71 | steradians |
| 1.03 | Angular Resolution | 16.12 | 13.43 | 11.51 | arc-Min |
| 3.05 | Resolution Bandwidth | 2.1 | 1.5 | 1.0 | MHz |
| 1.05 | Sensitivity per Pixel | 145 | 222 | 333 | uK |

Hee-Jong BAO “wiggle” calculation
FoM = 23 (Plank priors)
Fom = 138 (Plank + Stage II DE priors)

# Prototype?

| Number | Requirement | Limit | Average | Limit | Unit |
|---|---|---|---|---|---|
| 1.01 | Redshift Range | 0.24 | 0.12 | 0.02 | |
| 1.02 | Survey Area | 2.22 | 2.00 | 1.82 | ¬steradians |
| 1.03 | Angular Resolution | 29.8 | 26.9 | 24.4 | arc-Min |
| 1.04 | Survey Time | | 1.70 | | Years |
| 1.05 | Sensitivity per Pixel | 115 | 184 | 525 | uK |
| 1.06 | Polarization Imbalance | | -20 | | dB |
| | | | | | |
| 2.01 | Minumum Antenna efficiency | | 80 | | % |
| 2.02 | Antenna Width Fill factor | | 80 | | % |
| 2.03 | Effective Feed Length | | 1 | | Wavelenth |
| 2.04 | Maximum Sky Temperature | | 10 | | K |
| 2.05 | Maximum Amplifier Noise Temp | | 50 | | K |
| 2.06 | Observing duty Factor | | 50 | | % |
| 2.07 | Latitude | | 0 | | degrees |
| 2.08 | Reflector Cost Rate | | 7000 | | $/meter |
| 2.09 | Electronics cost per Channel | | 3000 | | $/Channel |
| | | | | | |
| 3.01 | Center Frequency | | 1250.0 | | MHz |
| 3.02 | Frequency Span | | 250.0 | | MHz |
| 3.03 | Frequency | 1125 | 1250.0 | 1375 | MHz |
| 3.04 | Wavelength | 26.7 | 24.0 | 21.8 | cm |
| 3.05 | Resolution Bandwidth | 1.9 | 1.0 | 0.2 | MHz |
| 3.06 | Integration Time per pixel | 1.61 | 1.45 | 1.32 | day |
| 3.07 | Feed Spacing | | 24.0 | | cm |
| 3.08 | Declination Span | 67.5 | 60.0 | 54.1 | degrees |
| 3.09 | Number of Digital Channels per Cylinder per Polarization | | 128 | | |
| 3.10 | Minimum Digital Memory | | 3261 | | |
| 3.11 | Length of Cylinder | | 30.7 | | meters |
| 3.12 | Width of Cylinder | | 8.2 | | meters |
| 3.13 | Cylinder Nominal Spacing | | 10.2 | | meters |
| 3.14 | Number of Cylinders Locations | | 3.0 | | |
| 3.15 | Number of Actual Cylinders | | 3.0 | | |
| 3.16 | Number of Channels per Polarization | | 384 | | |
| 3.17 | Number of Polarizations | | 2 | | |
| 3.18 | Reflector Cost | | 0.6 | | M$ |
| 3.19 | Electronics Cost | | 2.3 | | M$ |
| 3.20 | Total Cost | | 2.9 | | M$ |

# Prototype Sky Map