Future instruments for CCAT

• Impact of future instruments on telescope design
  – Space at Naysmith focus
  – Strategy for switching between & changing instruments
  – Driven mainly by FoV
FoV

- For finding “rare” objects, wider is always better, but might not be worth it if time to confusion is short.
- Survey size
  - 20’ FoV is fine for projects we are thinking about now. CCAT can see \( \sim 10^4 \) z=2-3 galaxies per deg\(^2\). A 10deg\(^2\) survey to confusion takes a couple of weeks. 10deg\(^2\) matches existing surveys at other wavelengths.
  - For rare objects, CCAT is pretty slow. The density of bright, strongly lensed, high-z galaxies is \(<1\) deg\(^2\), so we might want to survey \( \sim 100\) deg\(^2\). Same for SZE. This takes months with 20’ FoV.
Source counts

![Graph showing source counts for different wavelengths](image)

**Figure 3.** Predicted counts of high-$z$ protospheroidal galaxies (solid line), late-type (starburst plus normal spiral) galaxies (dot--dashed line), and radio sources (dotted line). The dashed line shows the predicted counts of strongly lensed protospheroidal galaxies. The 850-μm data are from Coppin et al. (2006, circles) and Scott et al. (2006, squares). The heavy solid line on the lower right-hand corner of each panel shows the count estimates by Serjeant & Harrison (2005).

Negrello et al., MNRAS 377 (2007)
## CCAT continuum mapping speed

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>NEFD</th>
<th>Confusion</th>
<th>Time to CL</th>
<th>Time to map 10deg$^2$</th>
<th>Time to map 200deg$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$m</td>
<td>mJy</td>
<td>mJy</td>
<td>s</td>
<td>hr</td>
<td>months</td>
</tr>
<tr>
<td>350</td>
<td>14</td>
<td>1.3</td>
<td>3100</td>
<td>155</td>
<td>4.3</td>
</tr>
<tr>
<td>620</td>
<td>16</td>
<td>1.3</td>
<td>4100</td>
<td>205</td>
<td>5.7</td>
</tr>
<tr>
<td>740</td>
<td>9</td>
<td>1.1</td>
<td>1500</td>
<td>75</td>
<td>2.1</td>
</tr>
<tr>
<td>1180</td>
<td>2</td>
<td>0.6</td>
<td>200</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td>2000</td>
<td>2</td>
<td>0.2</td>
<td>3500</td>
<td>175</td>
<td>4.9</td>
</tr>
<tr>
<td>3300</td>
<td>3</td>
<td>0.1</td>
<td>31000</td>
<td>775</td>
<td>21.5</td>
</tr>
<tr>
<td>SNR=1 in 1s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20’ FoV, 5$\sigma$, 50% efficiency</td>
</tr>
</tbody>
</table>

From CCAT feasibility study
How wide a FoV do we need/want?

- We don’t know what will be interesting in 15 yrs, but rare objects have always been interesting.
- A good plan is to avoid limiting the FoV available from the telescope optics. This prevents a competitor scooping CCAT in future just by building the same telescope with a wider FoV.

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>FoV basic telescope</th>
<th>FoV with corrector</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>350,\mu m</td>
<td>20'</td>
<td>0.9°</td>
<td></td>
</tr>
<tr>
<td>1,mm</td>
<td>1°</td>
<td>1.2°</td>
<td>Limited by field curvature</td>
</tr>
</tbody>
</table>

- 1° FoV at $\lambda=350$ \,\mu m requires a 5M-pixel camera. Should be possible by 2025.
Submillimeter detector arrays

Number of Detectors

Year


10^0 10^1 10^2 10^3 10^4 10^5

CCAT

Scuba II

Scuba II (initial)

ACT

MKID

SPT

SPT (initial)

Sharc II

Laboca & Apex SZ

Mambo II

Bolocam

Scuba

Mambo

Sharc I

CSO

UKT14
f/6 CCAT with corrector plate
Corrector plate details

• Plate scale is 2.6m/deg (at f/6) so corrector will be ~3m diameter.
• A large corrector plate must be at room temperature, so it must be made of Si or Ge.
• Loss of high-resistivity Si is a few % cm$^{-1}$ at submm wavelengths, so we can tolerate ~1cm thick plate.
• High-resistivity Si is available up to 200mm diameter, so plate has to be made from many smaller pieces.
• Corrector can be thin because it has no power.
• If loss <1% at mm wavelengths, can leave corrector in place for higher Strehl ratio.
Reflective relay for 1° FoV
Sub-field camera at 0.4° field offset

“Real” design
- Flat focal plane at f/3
- Small, sharp pupil
- Distortion not awful

Marginal rays ±0.03°
Sub-field camera image quality at 0.4° field offset, \( \lambda = 350 \mu \text{m} \)
Sub-field camera image distortion at 0.4° field offset
Need 50-100 sub fields for 1° FoV in, e.g., 7 or 19 close-packed cryostats.

Plate scale 2.6m/degree.

4-5’ sub fields are consistent with existing lens, filter & window designs, e.g., 4’ field is 175mm diameter at Naysmith, cf. can buy high-resistivity Si up to 200mm diameter.
Load instruments into a non-rotating tube running along the EL axis. Semi-automatic instrument changer loads instruments that are sitting cold, cabled & ready on the Naysmith platforms. Can support 2 wide-field instruments (1 on each side), or several narrow-field instruments in a single tube.
Cost of wider FoV

- 3m diameter EL bearings & wider yoke arms, bigger mount
- 1m deeper truss

Sebring & Parshley +$6-8M, cost driven by truss support at 0.6R, not by FoV.
Summary

• Can achieve 1° FoV at $\lambda=350\mu$m at Naysmith focus.
  – Use a thin, Si, corrector plate at room temperature, $\sim2$m before focus.
• Reflective relay optics are huge for wide FoV instruments.
• Can use refractive optics to break the FoV into many sub fields.
  – 4’ sub fields at 350$\mu$m with a corrector, 9’ sub fields at 1mm without a corrector.
  – Cameras with refractive relay optics are compact, so the truss/mount simply has to clear the beam.
  – Allows staged deployment of cameras.
  – Can support multiple, narrow-field instruments, mounted side-by-side.

f/6 RC with clearance for 3m diameter beam to Naysmith will allow us to take full advantage of the available FoV in future.