CCAT EoR-Spec: Observation planning from commissioning to the full deep spectroscopic survey

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Canadian Consortium

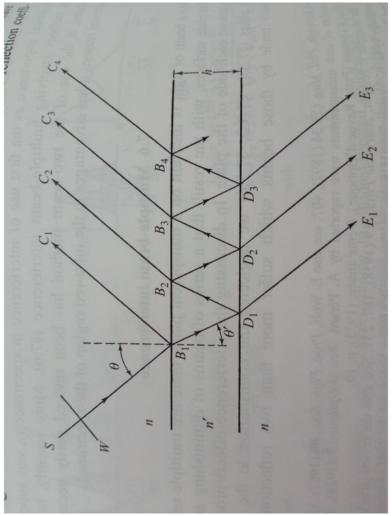
EoR-Spec (Epoch of Reionization Spectrometer)

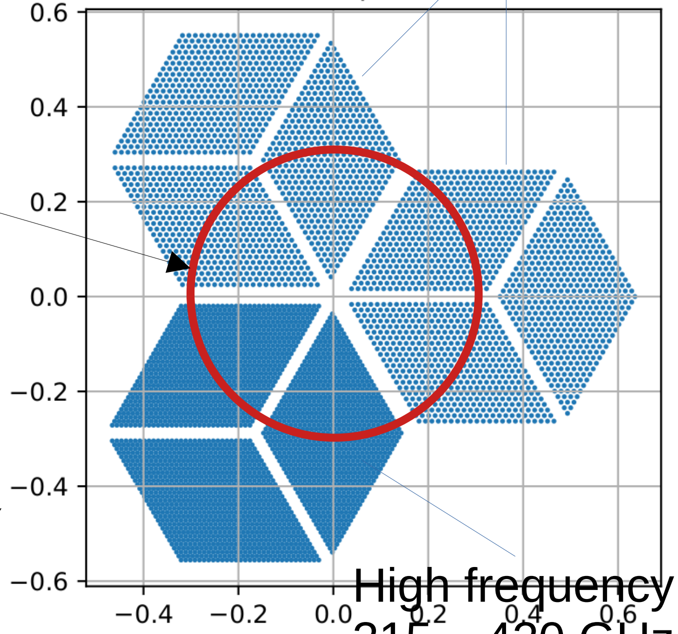
one of the Prime-Cam modules of Fred Young Submillimeter Telescope (FYST) operated by the CCAT Observatory

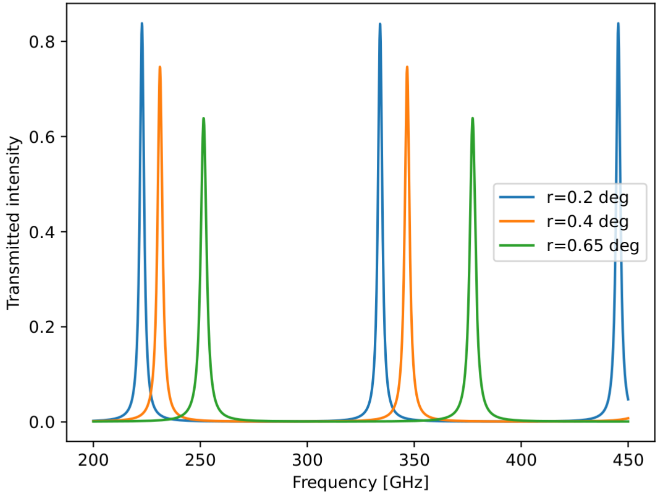
FYST
CCAT

Low frequency array
210 – 315 GHz (2nd order)

Example f_0 = 220GHz







High frequency array
315 – 420 GHz (mostly 3rd order)

Footprint on sky [deg]

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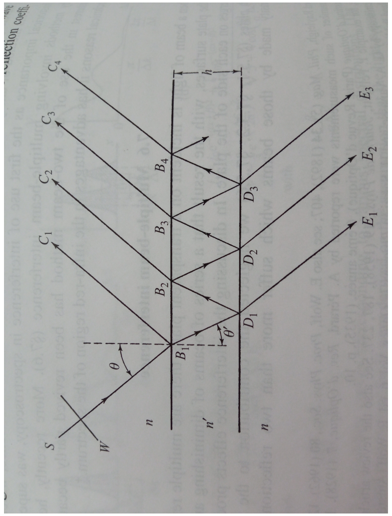

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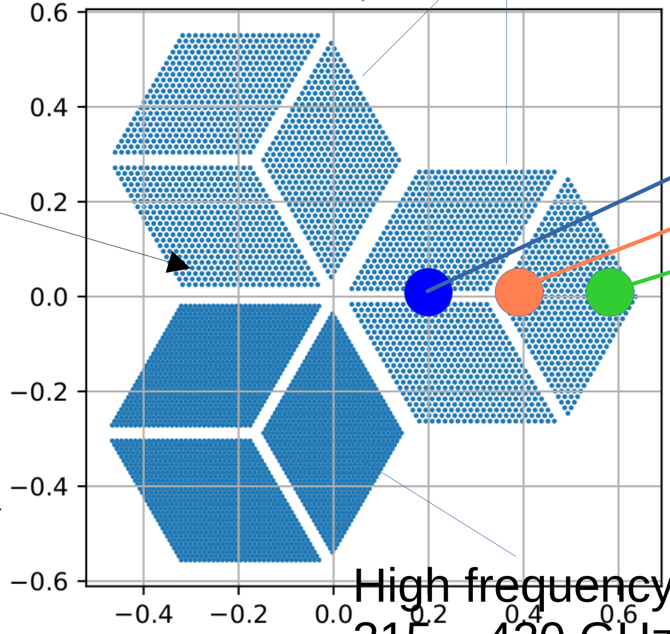

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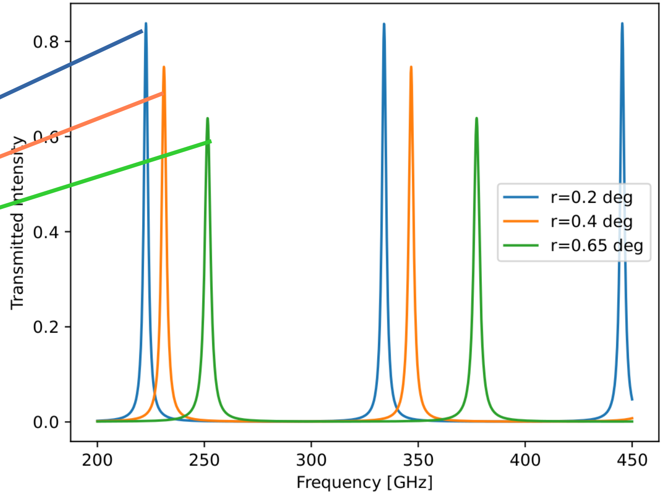

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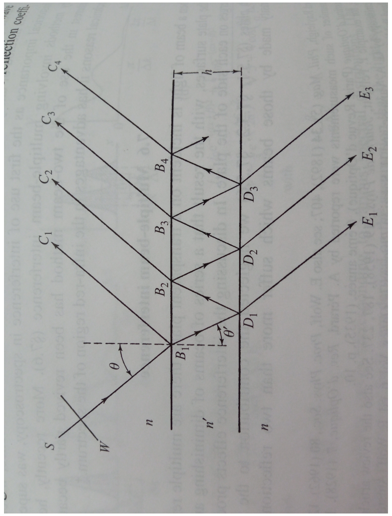

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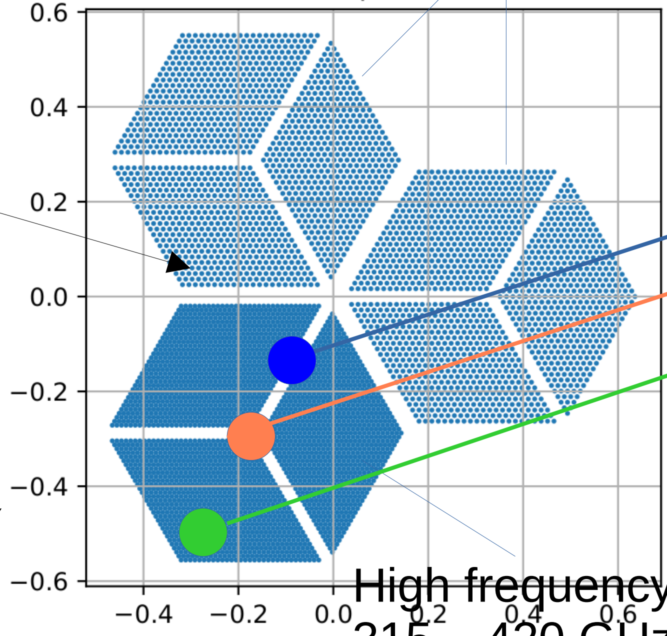

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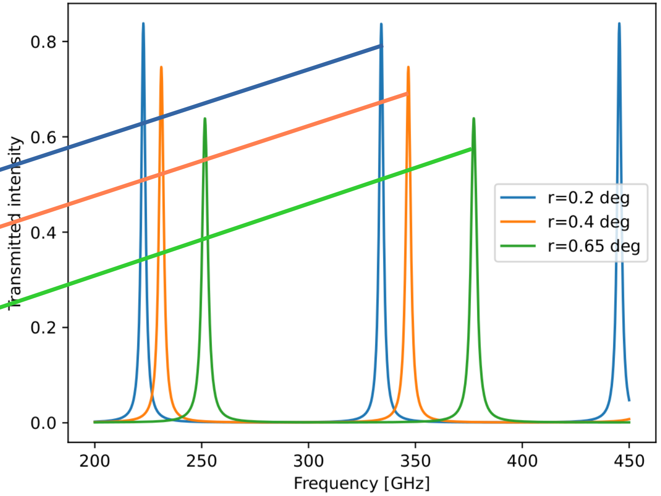
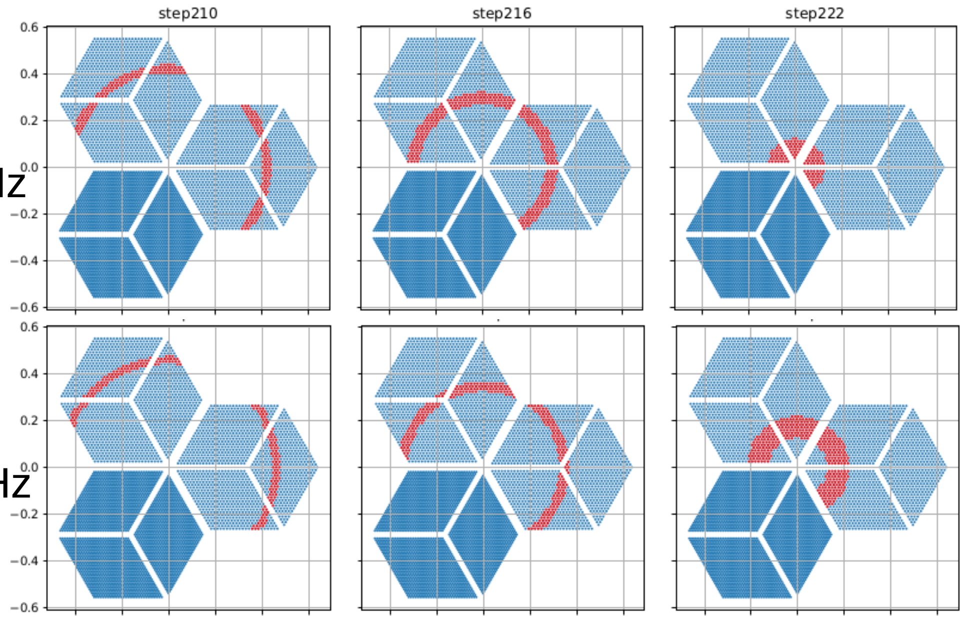


Operation: map at a fixed Fabry-Perot mirror spacing and step through to cover the full frequency range

Fabry-Perot Interferometer (FPI) steps



220.838 – 223.047 GHz

223.047 – 225.277 GHz

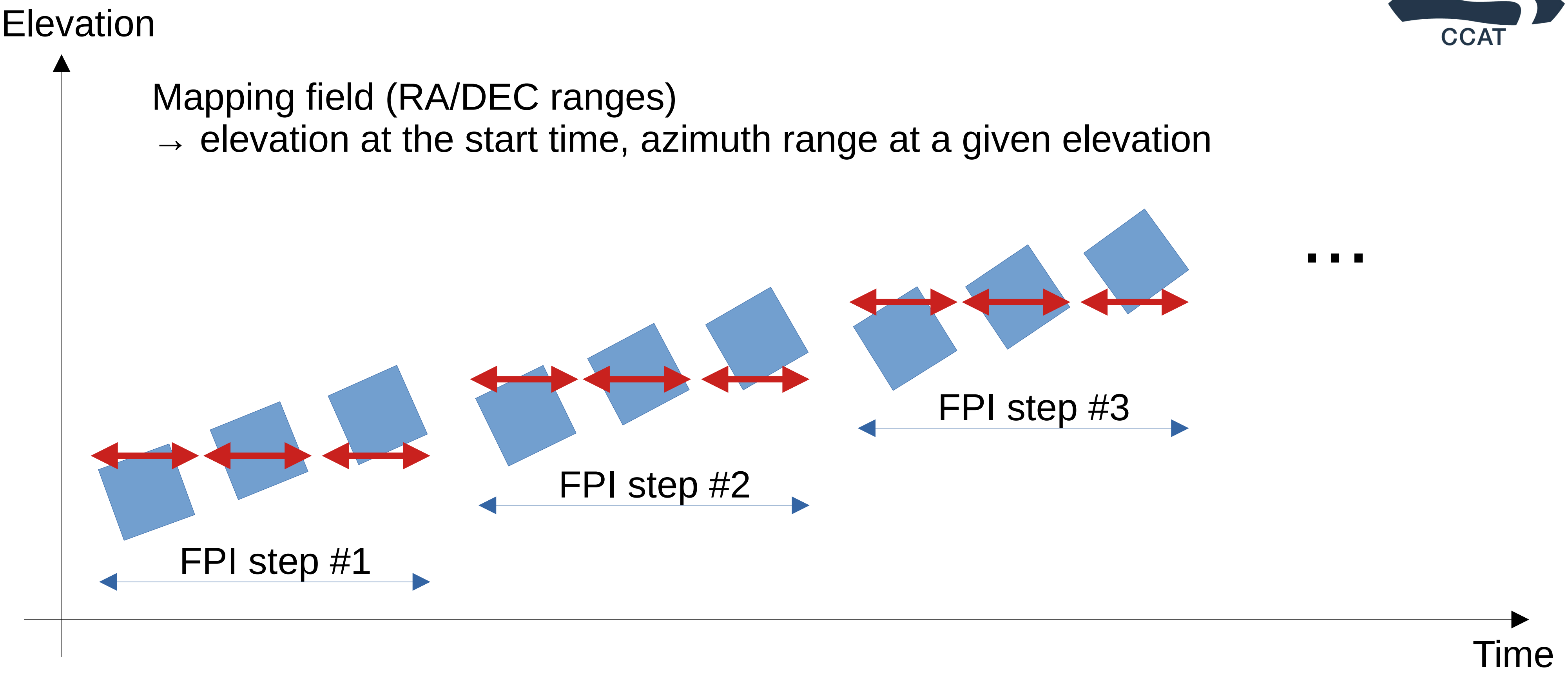
Frequency bins

Coverage of this frequency bin

- Comparison of three different scan patterns
- Commissioning tasks and towards the calibration pipeline

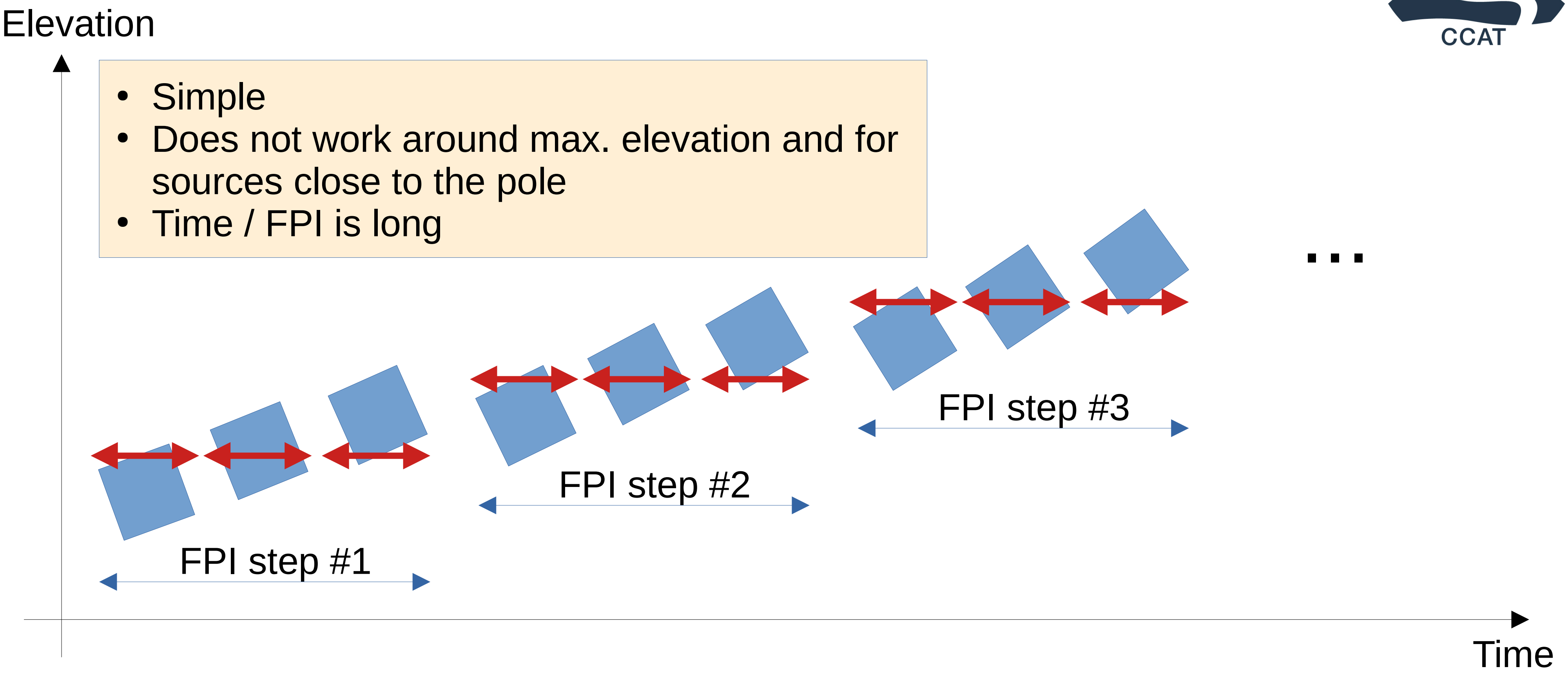
Constant elevation scans

Mapping field (RA/DEC ranges)
→ elevation at the start time, azimuth range at a given elevation



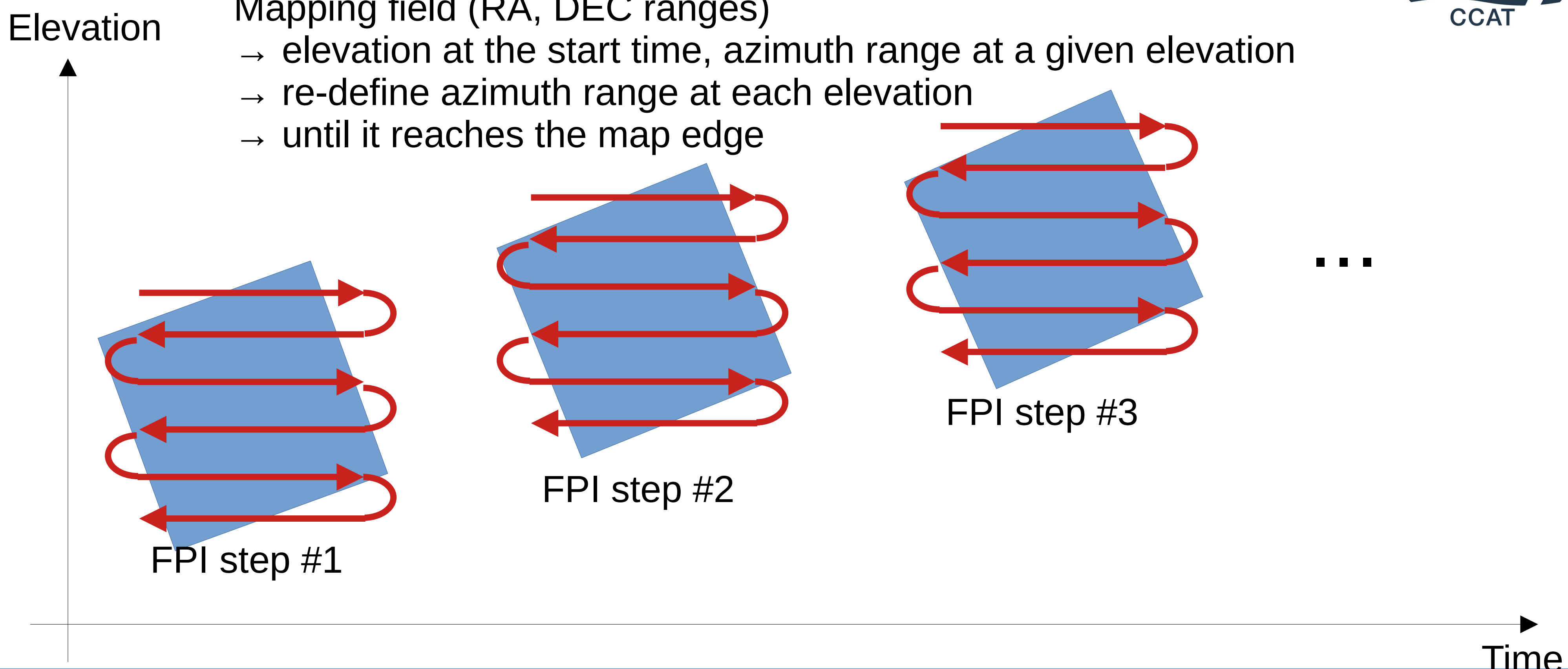
Constant elevation scans

- Simple
- Does not work around max. elevation and for sources close to the pole
- Time / FPI is long



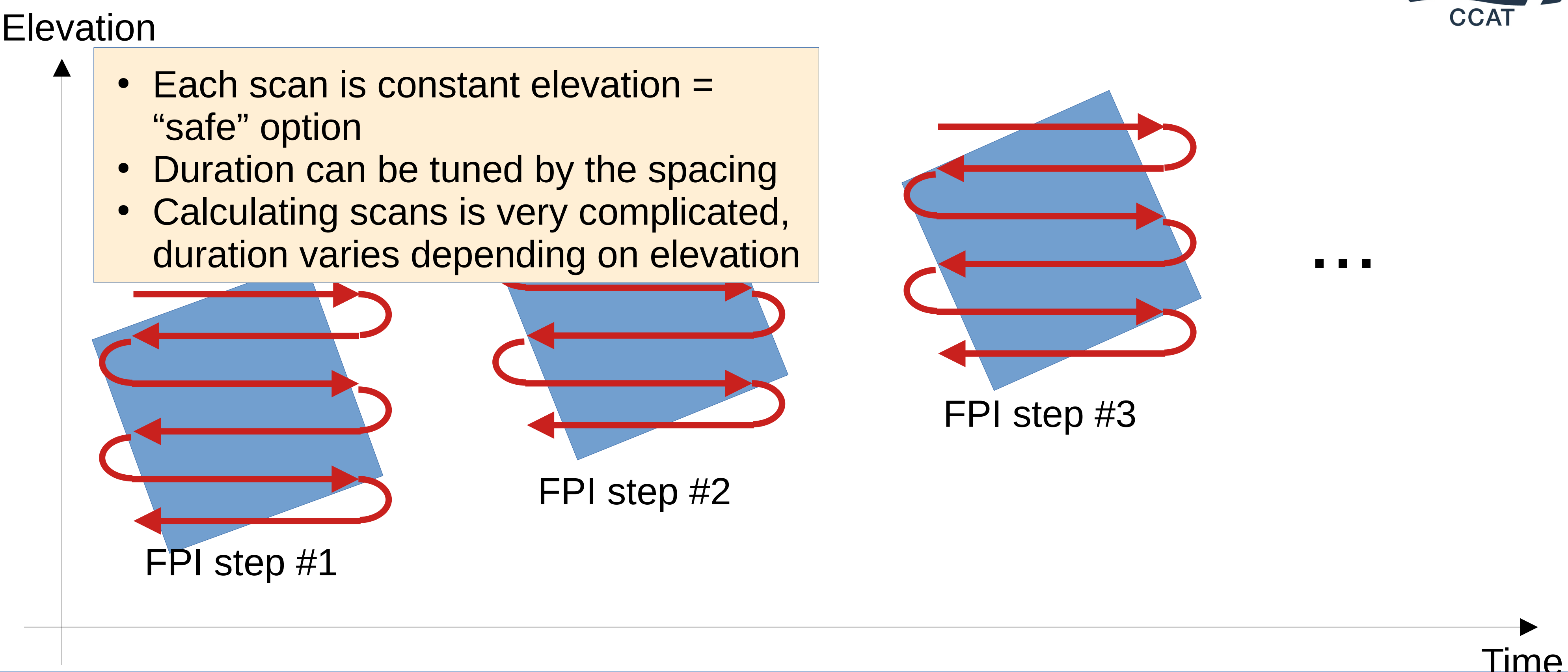
Constant elevation map

Mapping field (RA, DEC ranges)
→ elevation at the start time, azimuth range at a given elevation
→ re-define azimuth range at each elevation
→ until it reaches the map edge



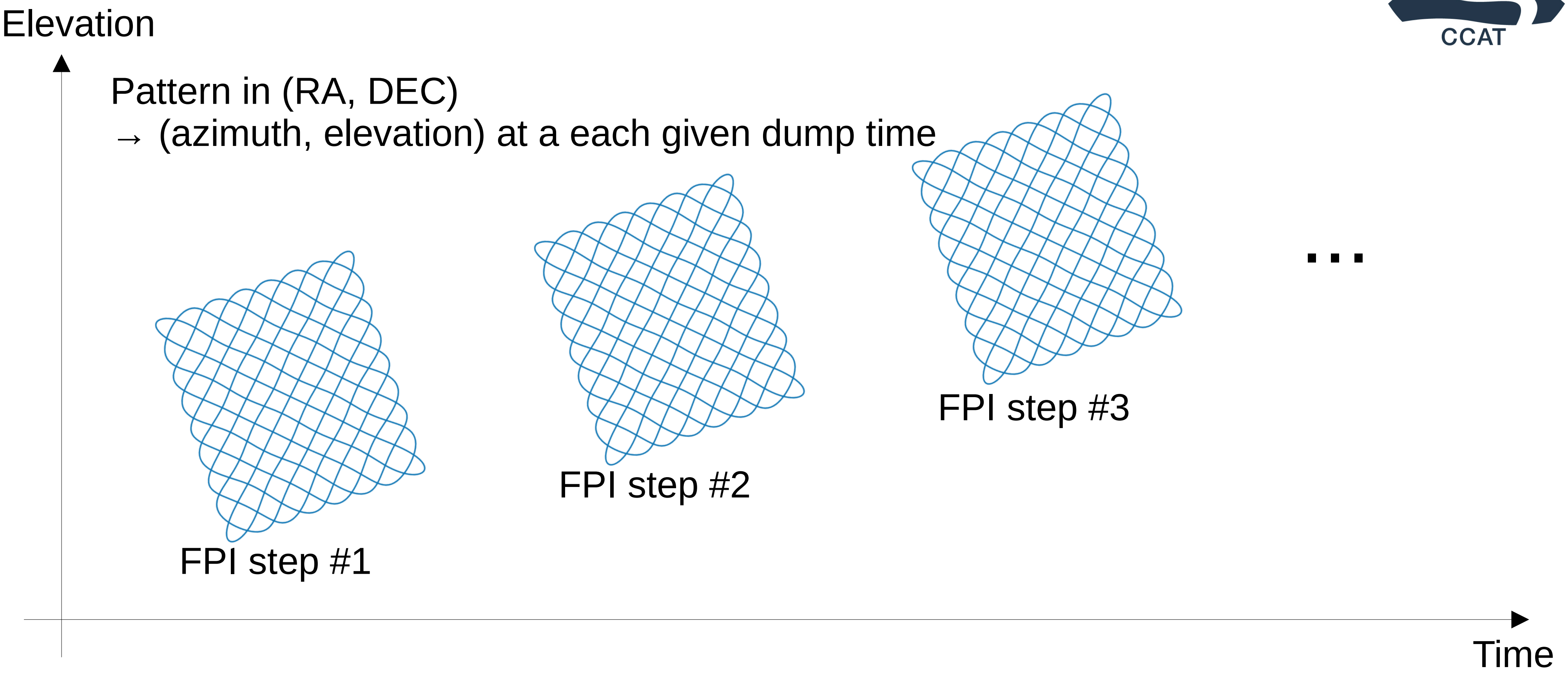
Constant elevation map

- Each scan is constant elevation = “safe” option
- Duration can be tuned by the spacing
- Calculating scans is very complicated, duration varies depending on elevation



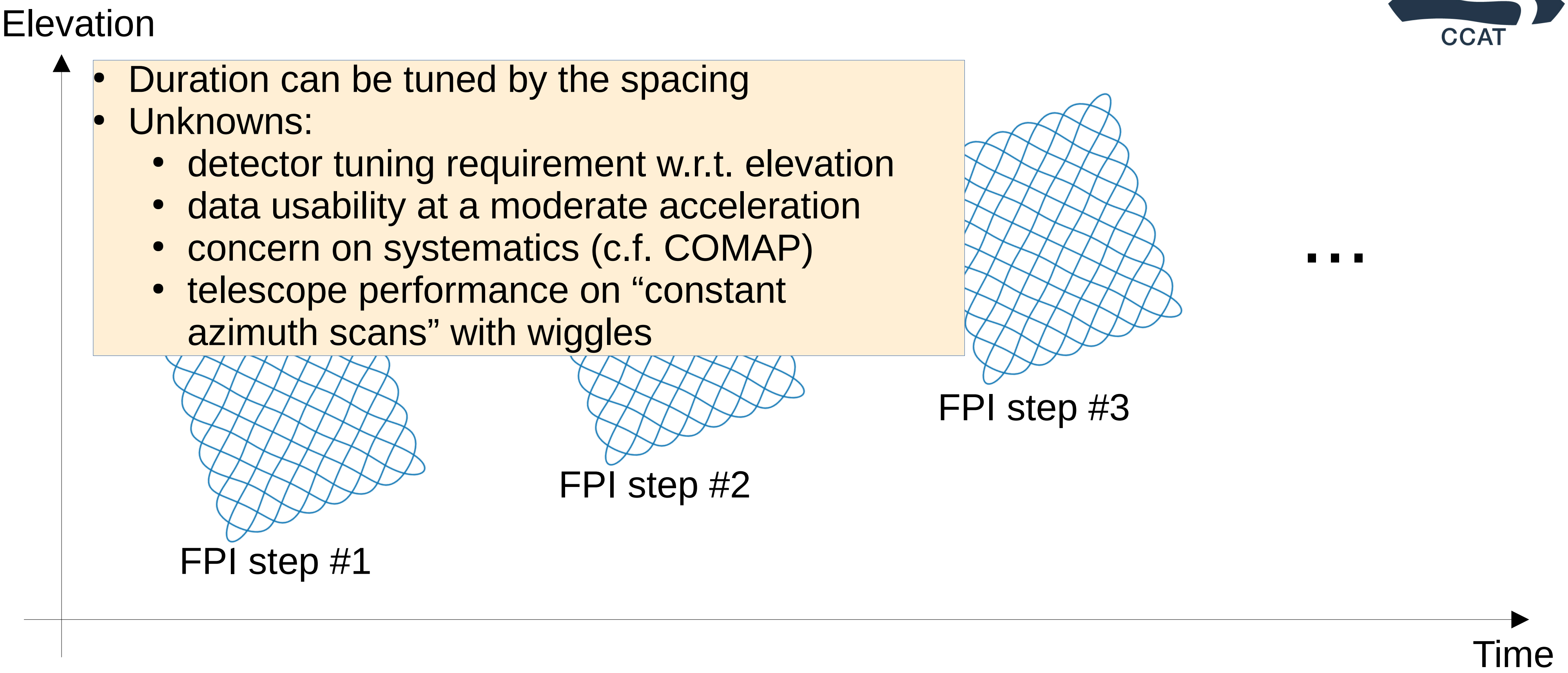
Curvy Pong pattern

Pattern in (RA, DEC)
→ (azimuth, elevation) at a each given dump time



Curvy Pong pattern

- Duration can be tuned by the spacing
- Unknowns:
  - detector tuning requirement w.r.t. elevation
  - data usability at a moderate acceleration
  - concern on systematics (c.f. COMAP)
  - telescope performance on “constant azimuth scans” with wiggles

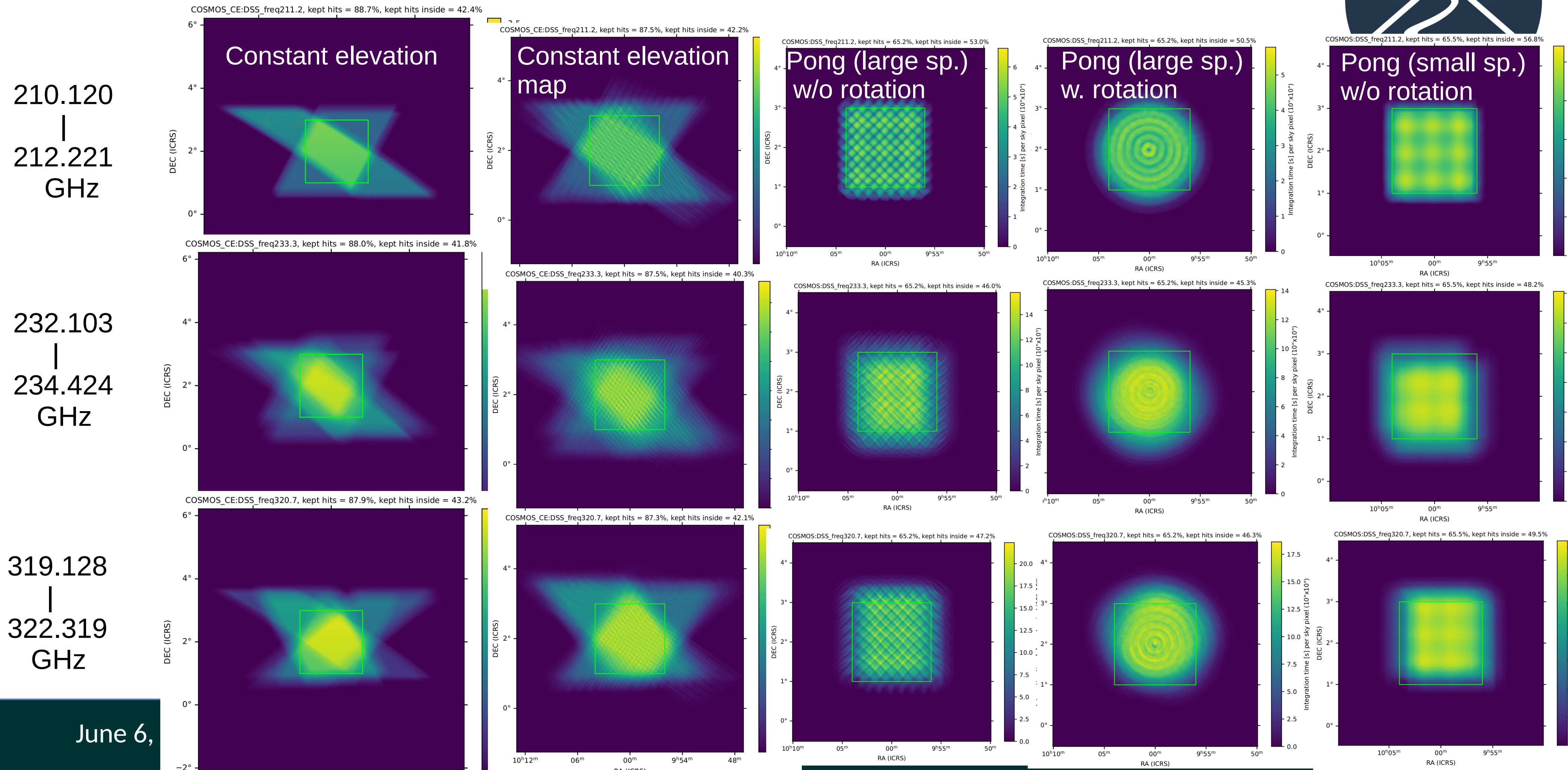


	Duration per FPI step		Scheduled hours	
	COSMOS [min]	ECDF-S [min]	COSMOS [h]	ECDF-S [h]
Constant elevation	10.0	11.2	110 - 170	146 - 218
Constant elevation map (spacing 0.08 deg)	2.8	2.8	96 - 141	146 - 216
Curvy Pong (spacing 0.05 deg)	9.0	9.0	151 - 221	122 - 176
Curvy Pong (spacing 0.2 deg)	2.5	2.5	157 – 225	159 - 228

(on-sky velocity 0.5 deg/s)

(optimistic two months with a weather variation)

“Hitmaps” by 1 month scheduling (COSMOS)



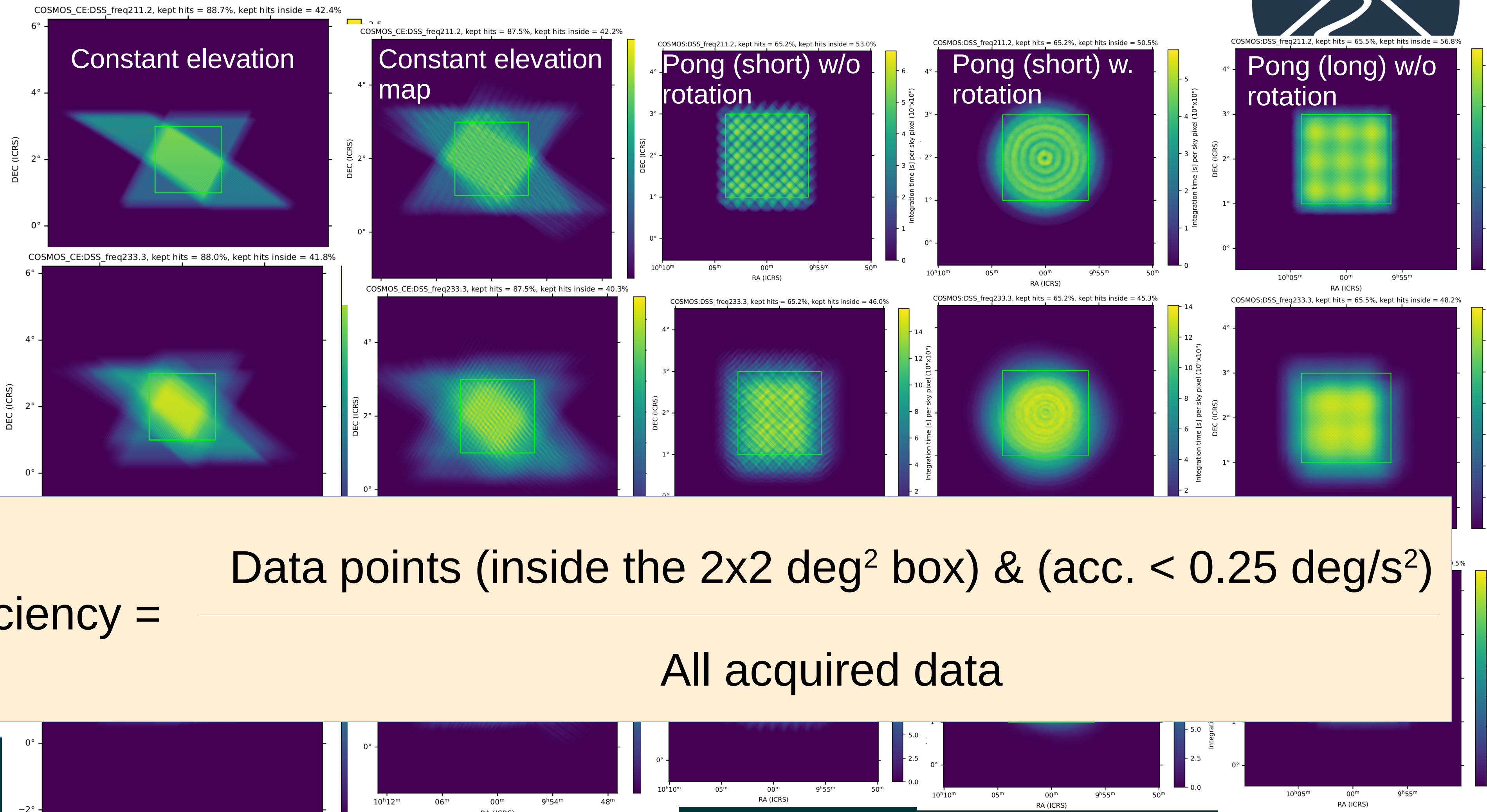
“Hitmaps” by 1 month scheduling (COSMOS)

210.120
|
212.221
GHz

232.103
|
234.424
GHz

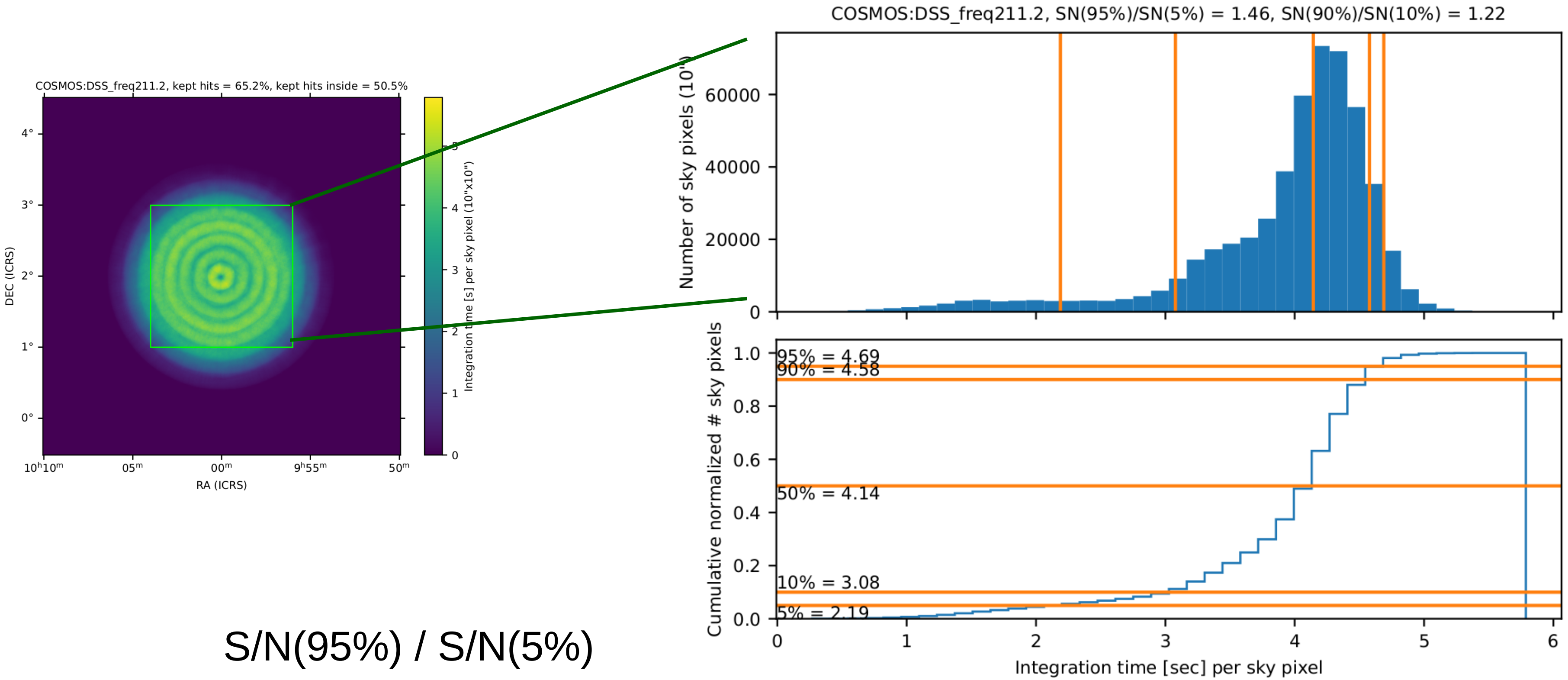
31

32



$$\text{Efficiency} = \frac{\text{Data points (inside the 2x2 deg}^2\text{ box) \& (acc. < 0.25 deg/s}^2\text{)}}{\text{All acquired data}}$$

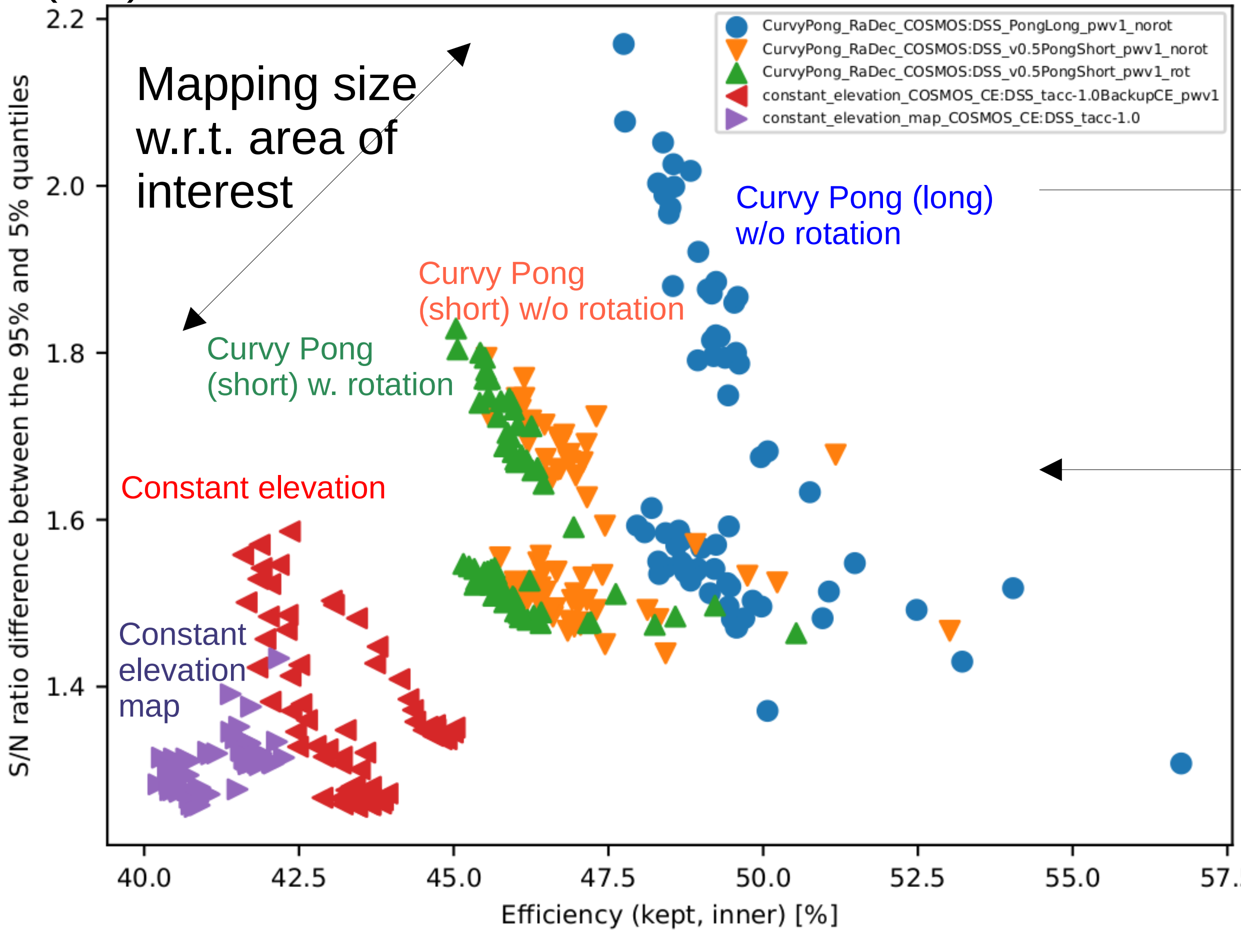
Homogeneity



S/N(95%) / S/N(5%)

Comparison of different scan patterns

S/N(95%) / S/N(5%)



If more edge data are usable (Pong)

Faster scan (constant elevation)

More homogeneous

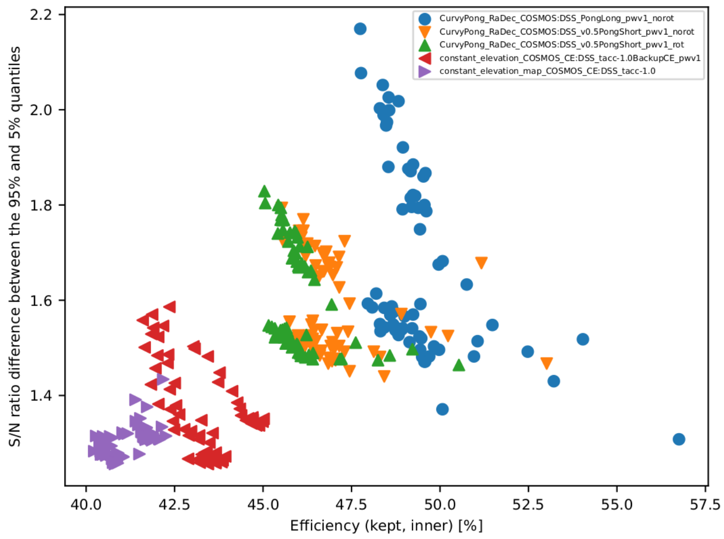
Scan pattern decisions

- Inhomogeneity → impact on the power spectrum?

  Any calibration residual may introduce artifacts → investigating with the data on-sky needed

- Some unknowns (detector stability, data usability at turn-around etc.)

  → should be clarified during the CCAT first year observations with Mod-Cam



Commissioning tasks

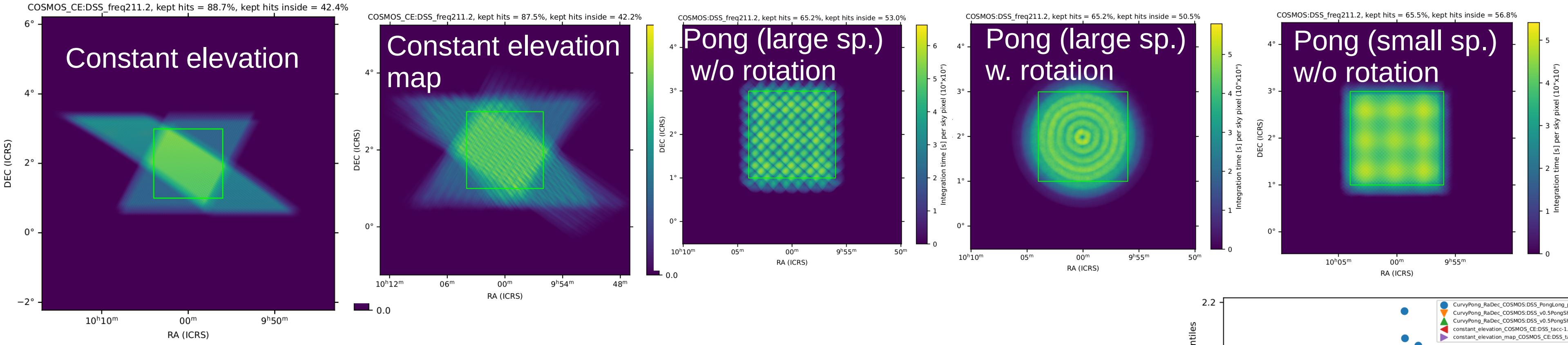
- Frequency verification across the array on sky
- Investigation of common modes and residual systematics with
  - different scan patterns
  - variation of pwv / atmospheric conditions
  - different elevations / azimuths
- How important it is to cycle FPI steps fast
- Finalize the scan speed (1/f noise vs. efficiency)
- Lead-trail analysis with a fixed FPI step

Towards the calibration pipeline

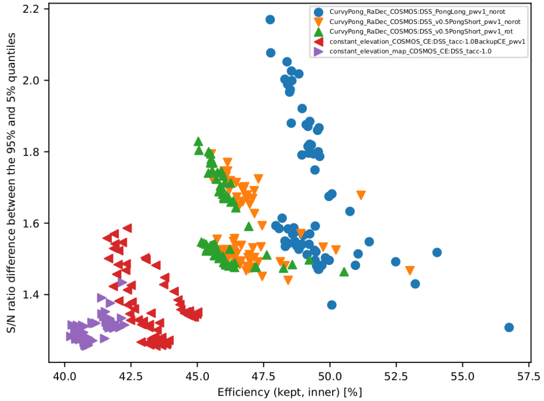
- Basic flow: following COMAP and TIME
- Different ways of common-mode subtraction need to be designed and tested – with complication of coupled spatial and spectral distribution
- Effect of spectral gridding need to be investigated: irregularly oversampled data point (with the Lorenzian width being a function of the radius of the array)
- Effect of a chosen map-making method

Summary

- Scan patterns for the CCAT EoR-Spec survey
- “Hitmap” simulations with actual scheduling



- Baseline for designing tests on sky and consideration in building the data reduction pipeline



DYNAVERSE

Our Dynamic Universe
Cluster of Excellence
+ CCAT/FYST

FYST
CCAT

We are hiring!

1) D. Riechers (U Cologne, EoR-Spec DSS Science Lead):
   - Postdoc position: DSS Predictions and Analysis & Cross-Correlations

2) D. Riechers, J. Baselmans (TU Delft, Global Faculty U Cologne)
   [AMKID, DESHIMA 1+2, TIFUUN, PRIMA]
   - Postdoc & PhD position: CCAT/FYST 2nd generation instrumentation; focus broad-band multiplexing (sub)mm spectroscopy

Ads to be put out; positions starting 2026, securely funded until end of 2032

Interested? Provide your information to Jonathan or Yoko to be looped-in

More info: https://dynaverse.astro.uni-koeln.de/

Backup slides

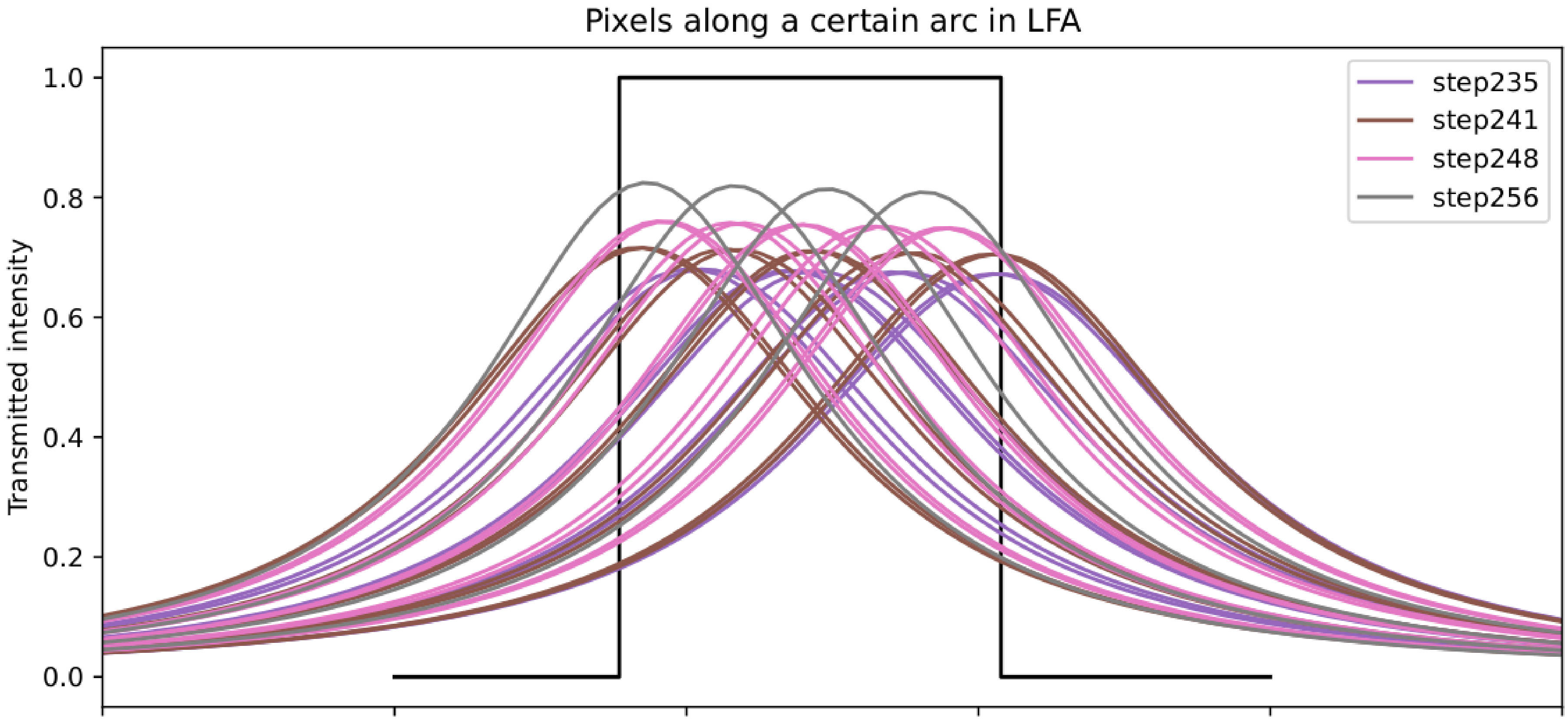
In the event that abrubt changes in velocity at the turnaround points are not preferable, one could simple change the velocity in some way near the turnarounds. An alternative is that the corners can be 'rounded-off' by approximating the Pong scan with a Fourier expanded Lissajous scan instead (Fig. 5). In this case, *x(t)* and *y(t)* are approximations of triangle waves with 5 terms each. Pseudo-code for this 'straight' Pong scanning pattern can be found in Appendix E. The specific formulae are :

$$x(t) = \frac{8\alpha_x}{\pi^2} \sum_{n=1,3,5,7,9} \frac{(-1)^{\frac{n-1}{2}}}{n^2} \sin\left(\frac{2\pi nt}{\beta_x}\right); \tag{1}$$

$$y(t) = \frac{8\alpha_y}{\pi^2} \sum_{n=1,3,5,7,9} \frac{(-1)^{\frac{n-1}{2}}}{n^2} \sin\left(\frac{2\pi nt}{\beta_y}\right). \tag{2}$$

Where α_x and α_y are the amplitudes of the x and y motion, respectively, and β_x and β_y are the periods of the x and y motion, respectively.

JCMT SCUBA2 document


Pixels along a certain arc in LFA
Transmitted intensity
1.0
0.8
0.6
0.4
0.2
0.0
step235
step241
step248
step256