Overview of the FG Challenge projects

Fridays 4pm CEST (online)

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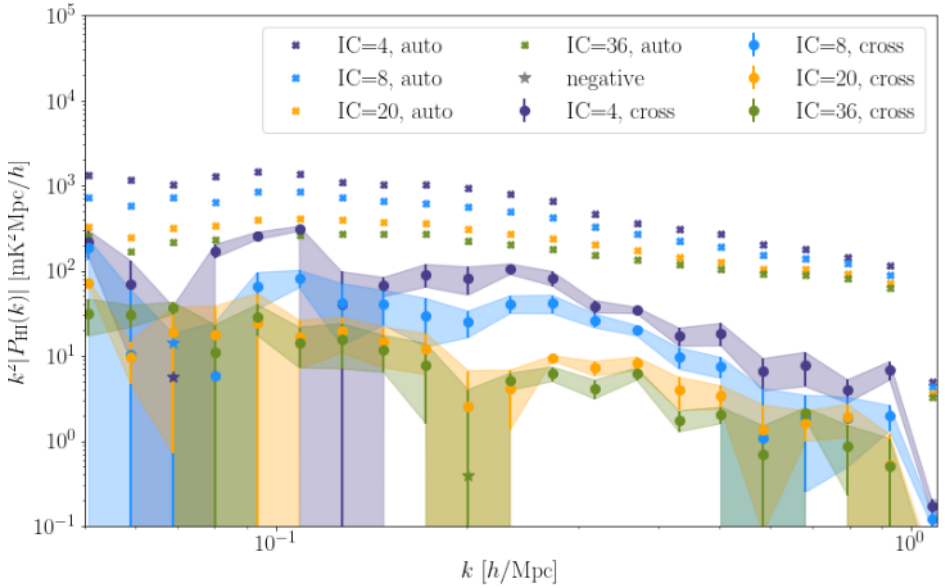
Detections up to now

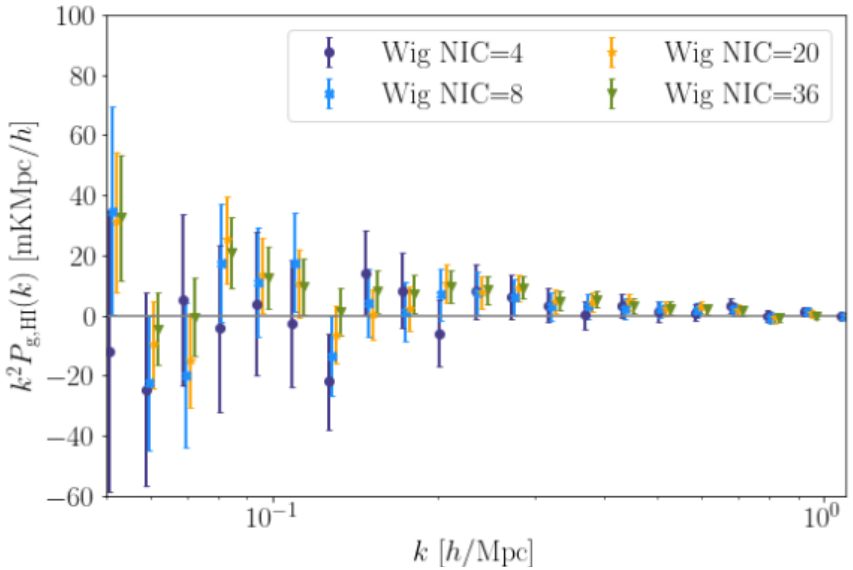
only in cross-correlation

- DEEP2 x GBT
  Chang et al. (2010)
- WiggleZ x GBT
  Masui et al. (2013)
- 2dF x Parkes
  Anderson et al. (2018)
- eBOSS x GBT
  WiggleZ x GBT
  Wolz et al. (2021)
  see plots

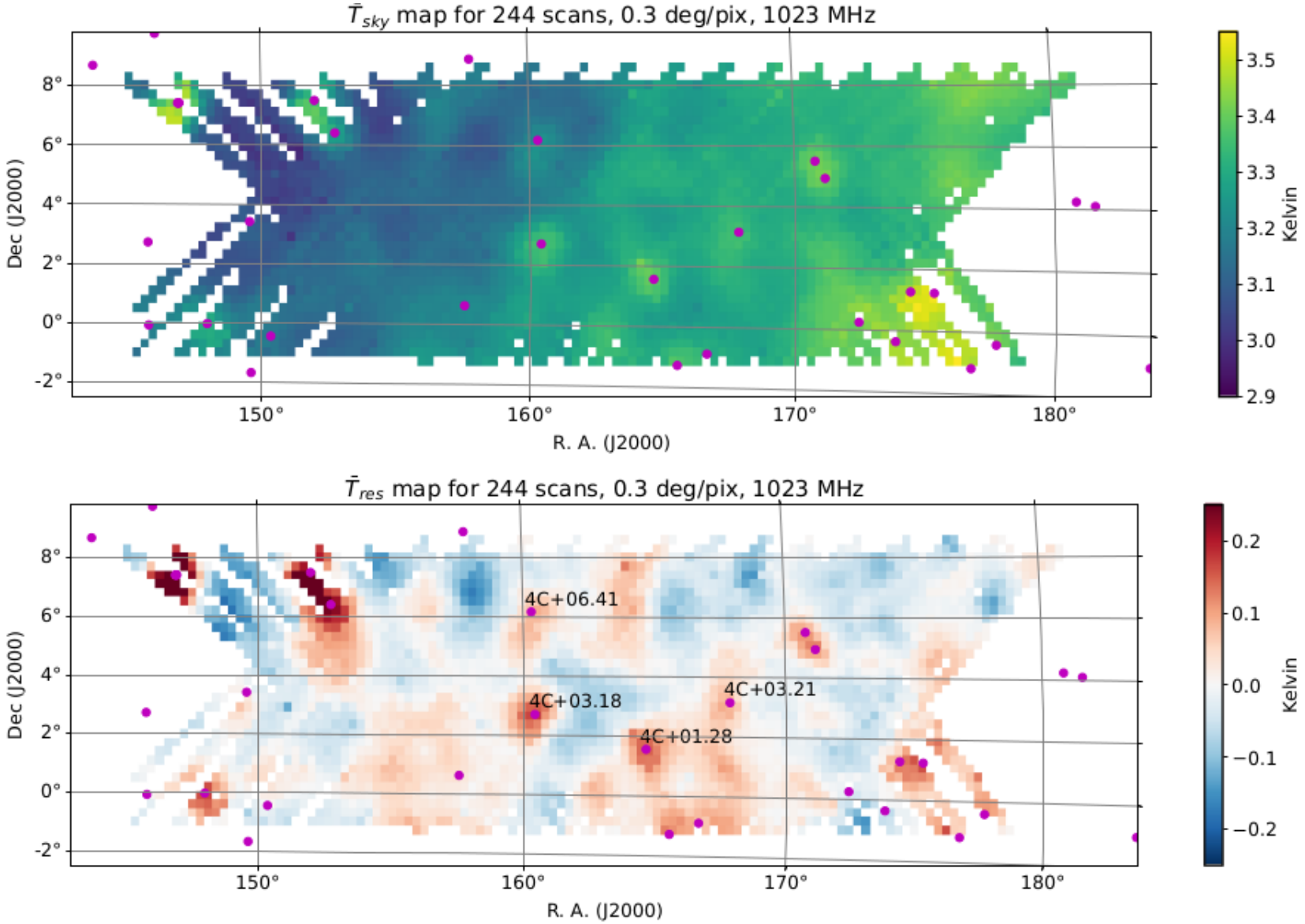
MeerKLASSxWiggleZ detection!

Cunnington et al., submitted

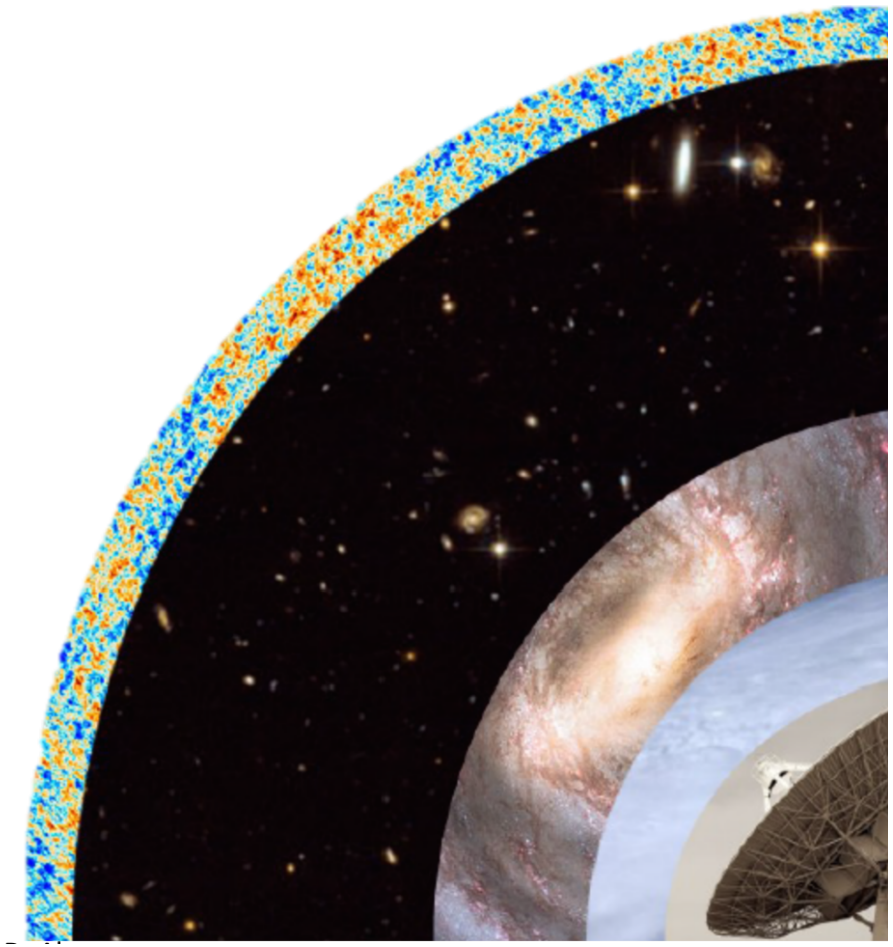




MeerKLASS


$\bar{T}_{sky}$ map for 244 scans, 0.3 deg/pix, 1023 MHz
Dec (J2000)
R. A. (J2000)
8°
6°
4°
2°
0°
-2°
150°
160°
170°
180°
3.5
3.4
3.3
3.2
3.1
3.0
2.9
Kelvin
$\bar{T}_{res}$ map for 244 scans, 0.3 deg/pix, 1023 MHz
4C+06.41
4C+03.18
4C+03.21
4C+01.28
0.2
0.1
0.0
−0.1
−0.2

Challenges with HI observations



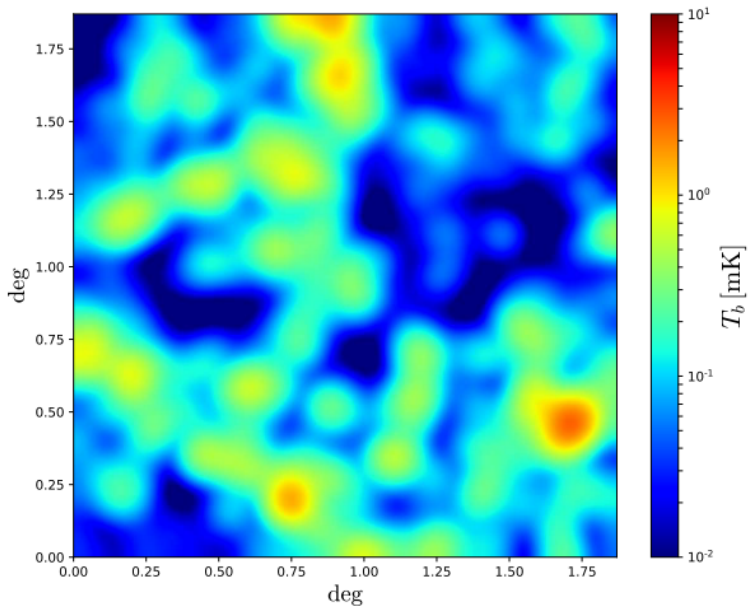
credit: D. Alonso

- HI IM signal
- Extragalactic Foregrounds
  - Point Sources (I,Q,U)
  - Free Free
- Galactic Foregrounds
  - Synchrotron (I,Q,U)
  - Free Free
- Earth
  - Atmosphere, RFI
- Instrument
  - Beam fluctuations
  - Polarization leakage

Mock 21cm maps

(non exhaustive) list of methods:

- hydro-dynamical simulations + HI in post processing e.g. Villaescusa-Navarro et al. 2014,2018

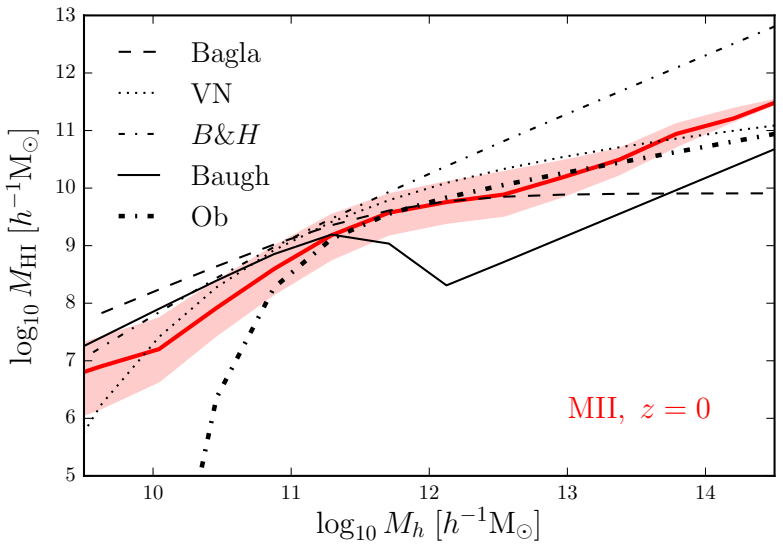


- log-normal simulations + prescriptions e.g. Alonso et al. 2014
- N-body (LCDM, WDM) + prescriptions e.g. Carucci et al. (2015,2017)
- Semi-analytic models
- HOD techniques on mock halo catalogues informed by SAMs/hydro/data

The $M_{\rm HI} - M_{\rm halo}$ relation

- Total HI content $M_{\rm HI}$ of a halo of mass M_h
- $z = 0$: fit a functional form with: low mass cut-off + power law with an inflection point
  (due to AGN feedback: Baugh et al. 2019)
- a fundamental ingredients for the halo model
  (e.g.Chen,Wolz,MS et al. (2021))

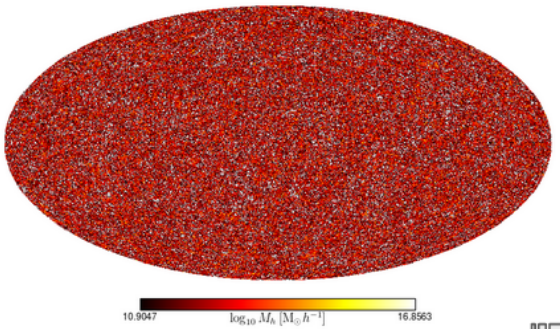
From the GAEA SAM model
Xie, De Lucia et al. (2018)

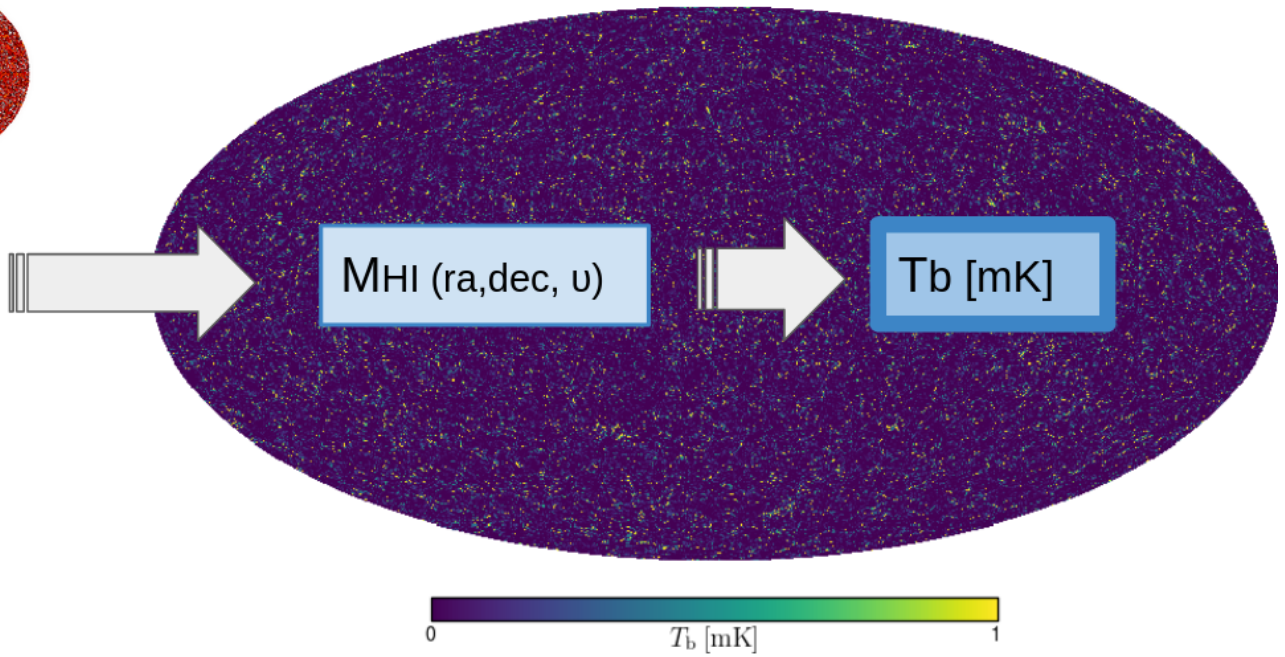


MS et al. (2020)

HI-Probe Populator (HIP-POP)

How to get big volumes for large-scale studies?
Combining SAMs and fast halo catalogues
(LPT: e.g. Pinocchio, Monaco et al. (2002))



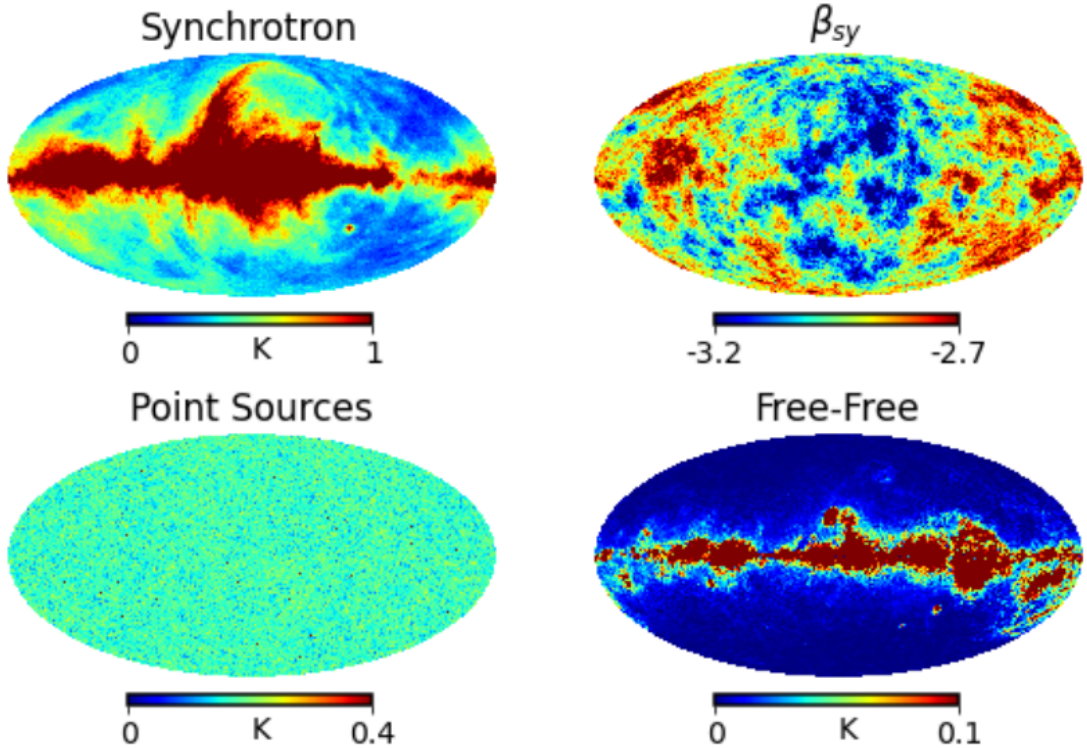


Can explore different cosmologies!
(Work in progress with Moretti and Pourtsidou, Castro)

Foregrounds

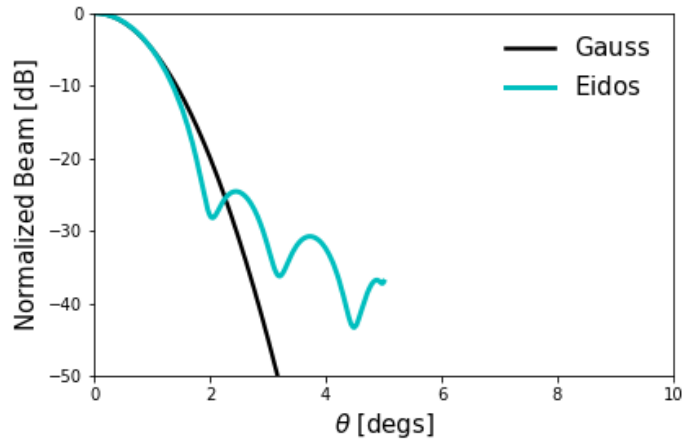
Typical modeling:

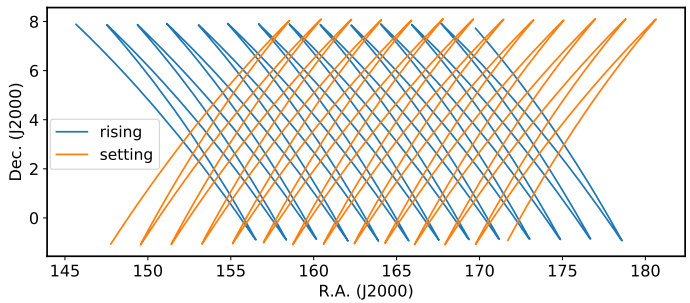
- Haslam 408 MHz Ramazeilles et al (2015)
- Spatially varying synch spectral index Miville-Deschenes et al (2008)
- Free-Free from Planck Sky Model Delabruille et al (2013)
- Extragalactic PS Olivari (2018) (flux cut at 0.1 Jy)

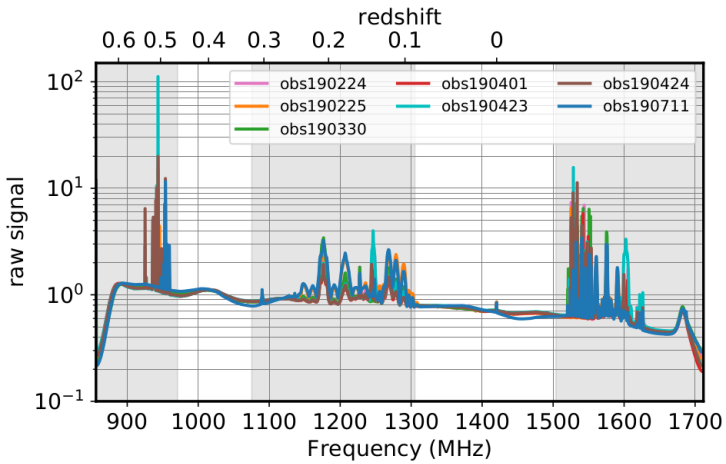


Instrumental effects

- Need a realistic beam modeling
  (side-lobes, frequency evolution, more accurate deconvolution)
- Scanning strategies
  (non homogeneous noise, need for real space convolution, polarization leakage)
- RFI
  (impact on cleaning, impact on signal interpretation)

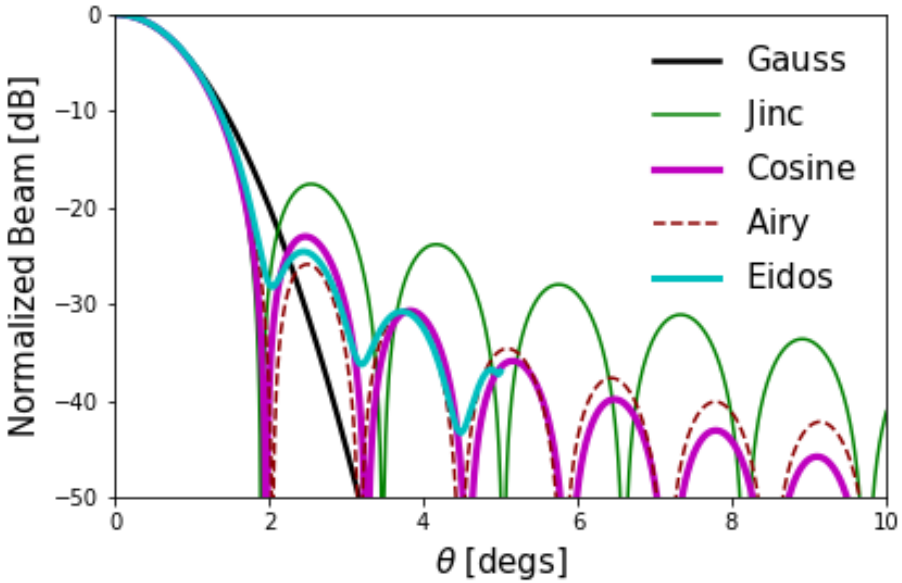


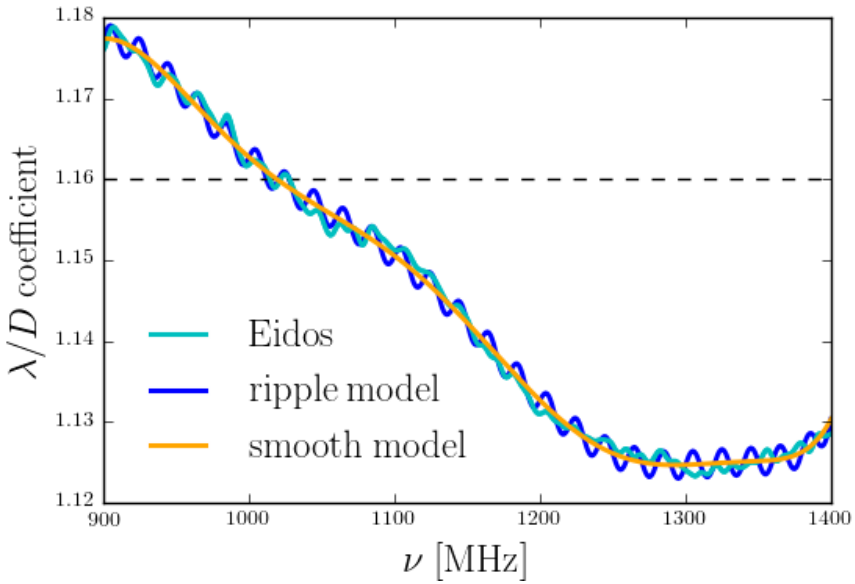




Realistic beam modeling

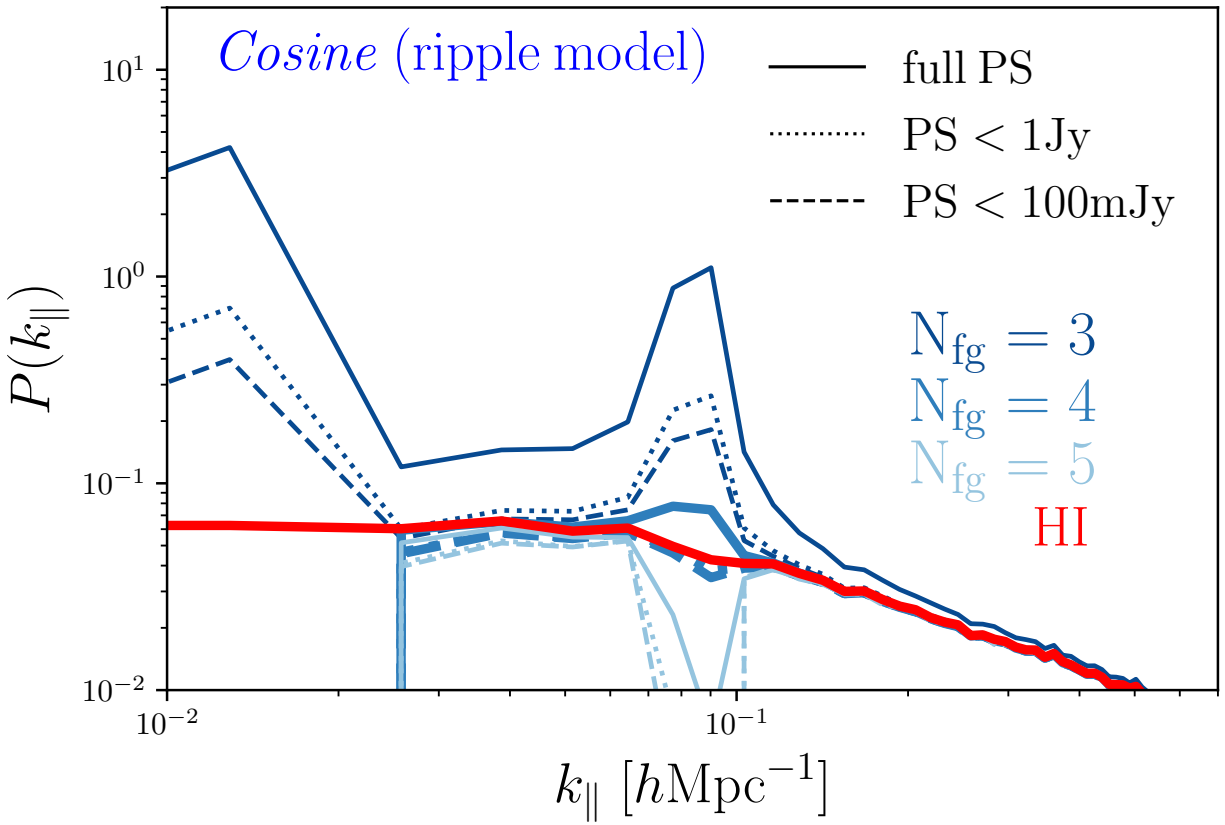
Holography on MeerKAT beam: side-lobes and non-trivial FWHM
Asad et al. (2021)





What is the effect on foreground cleaning?
Matshawule,MS et al (2021)

Systematics can be dangerous



Matshawule,MS et al (2021)

Foreground cleaning

$$T = As + n + c$$

A mixing matrix of the foreground sources

Noise

21cm signal

Parametric Fitting:

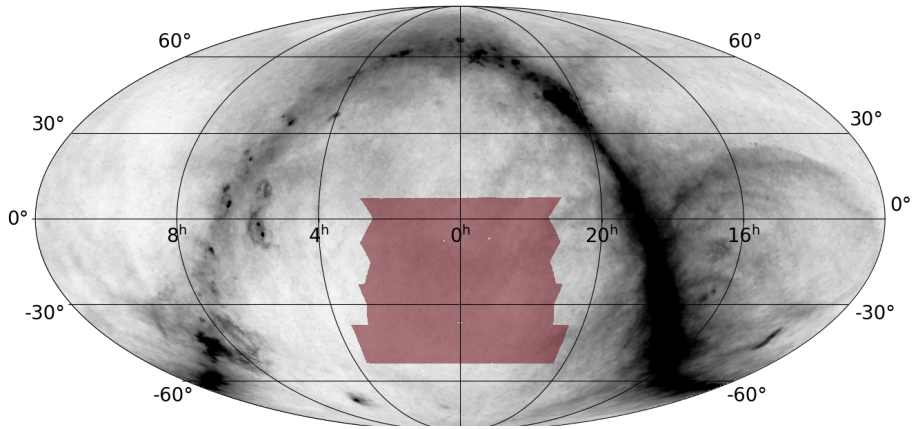
- Use known properties of foregrounds: synchrotron and free free (prior knowledge for the A)
- Ad-hoc smooth basis functions to model the foregrounds e.g. Alonso et al 2015

Blind foreground subtraction:

- Principal Component Analysis (PCA)
- Fast Independent Component Analysis (FastICA) e.g. Wolz et al. (2017), Cunnington et al. (2019)
- Generalized Morphological Component Analysis (GMCA) e.g. Carucci et al. (2020)

SKAO HI Intensity Mapping Foreground Subtraction Challenge

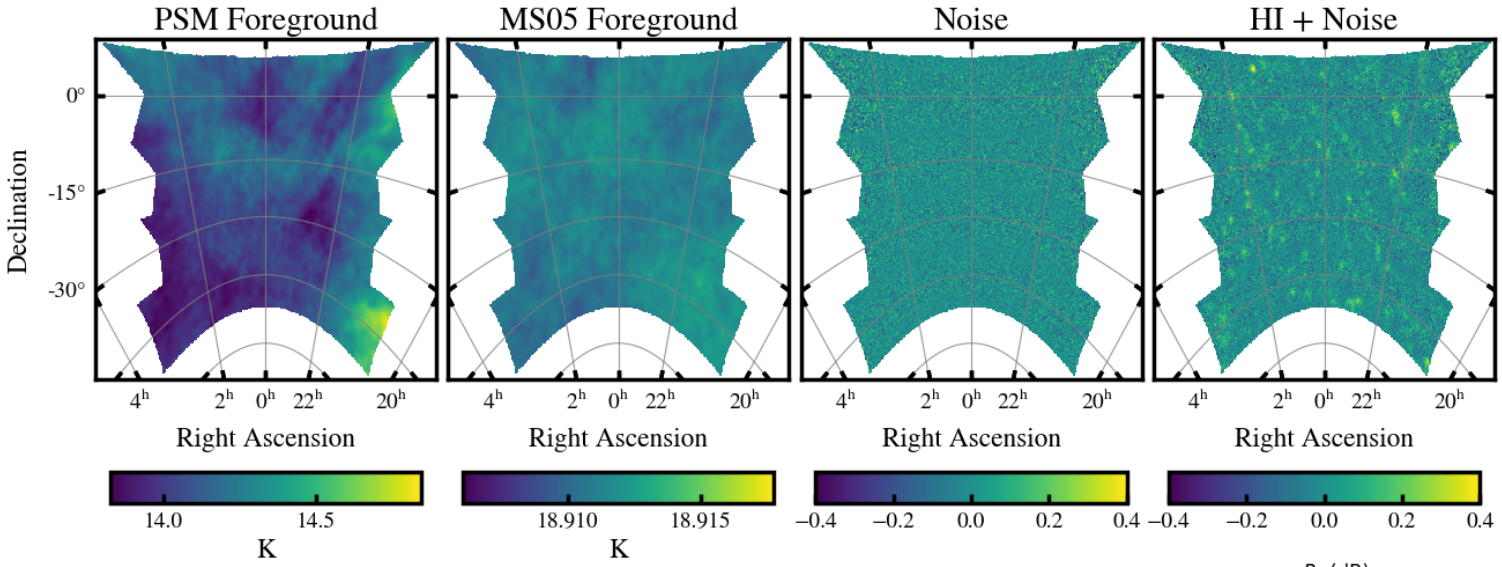
- Realistic foregrounds and HI
- Instrumental modeling MeerKAT-like and SKAO-like
  - L-band: 950-1400 MHz
  - single-dish mode
  - Realistic scanning strategy and beam
- Different foreground removal methods



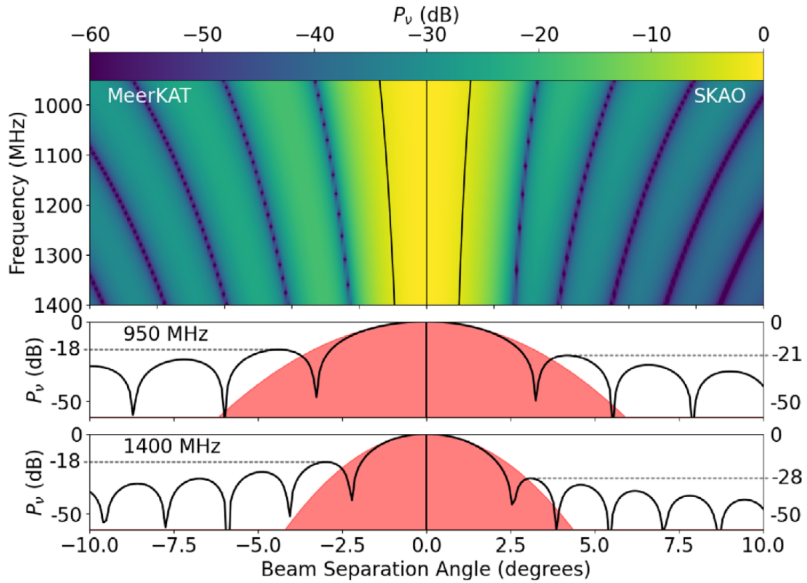
Group effort of the SKA IM FG
arxiv:2107.10814

Blind challenge for weaknesses and strengths of the various methods.

Challenge key points



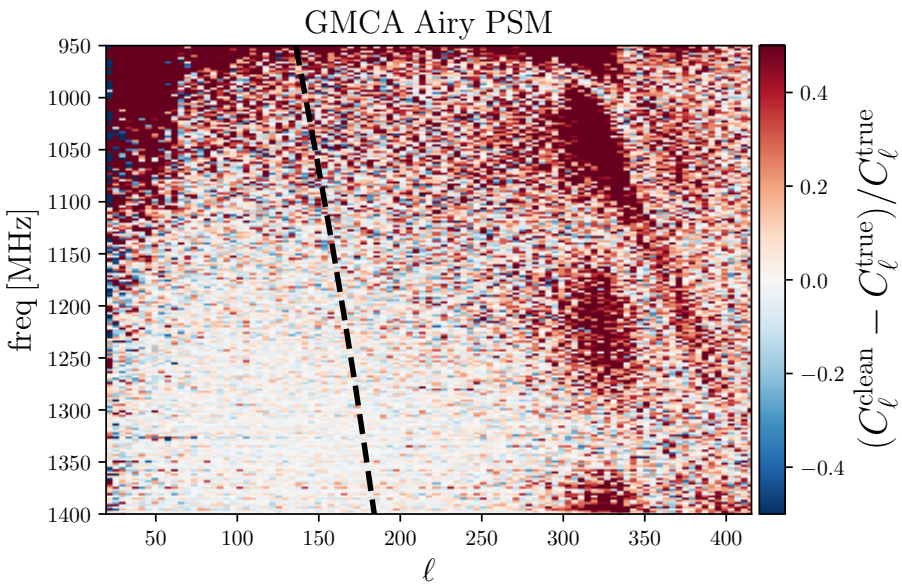
- Which accuracy do we get?
- How does it relate with N_{fg}?
- Methods *perform differently* facing different *systematics*?
- What are the weak points?

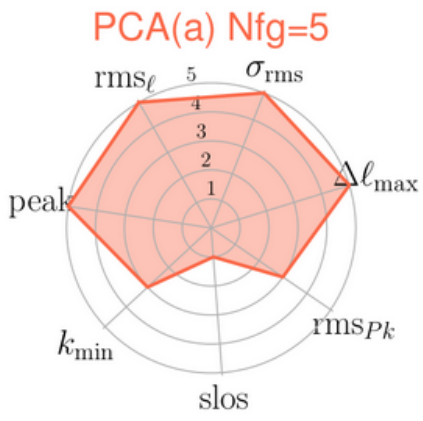


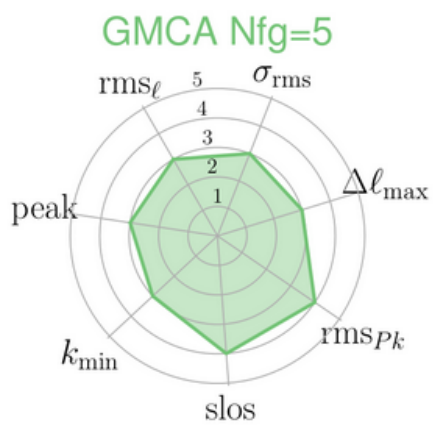
Some results

- Blind testing is useful
- Standard cleaning methods start struggling in presence of realistic instrumental effects
- Hybrid methods works better
- Better to always compare different strategies

Ultimately, can we trust the recovery of the cosmological signal?







Ongoing/future projects

1. Parameter inference in presence foreground and systematic residuals

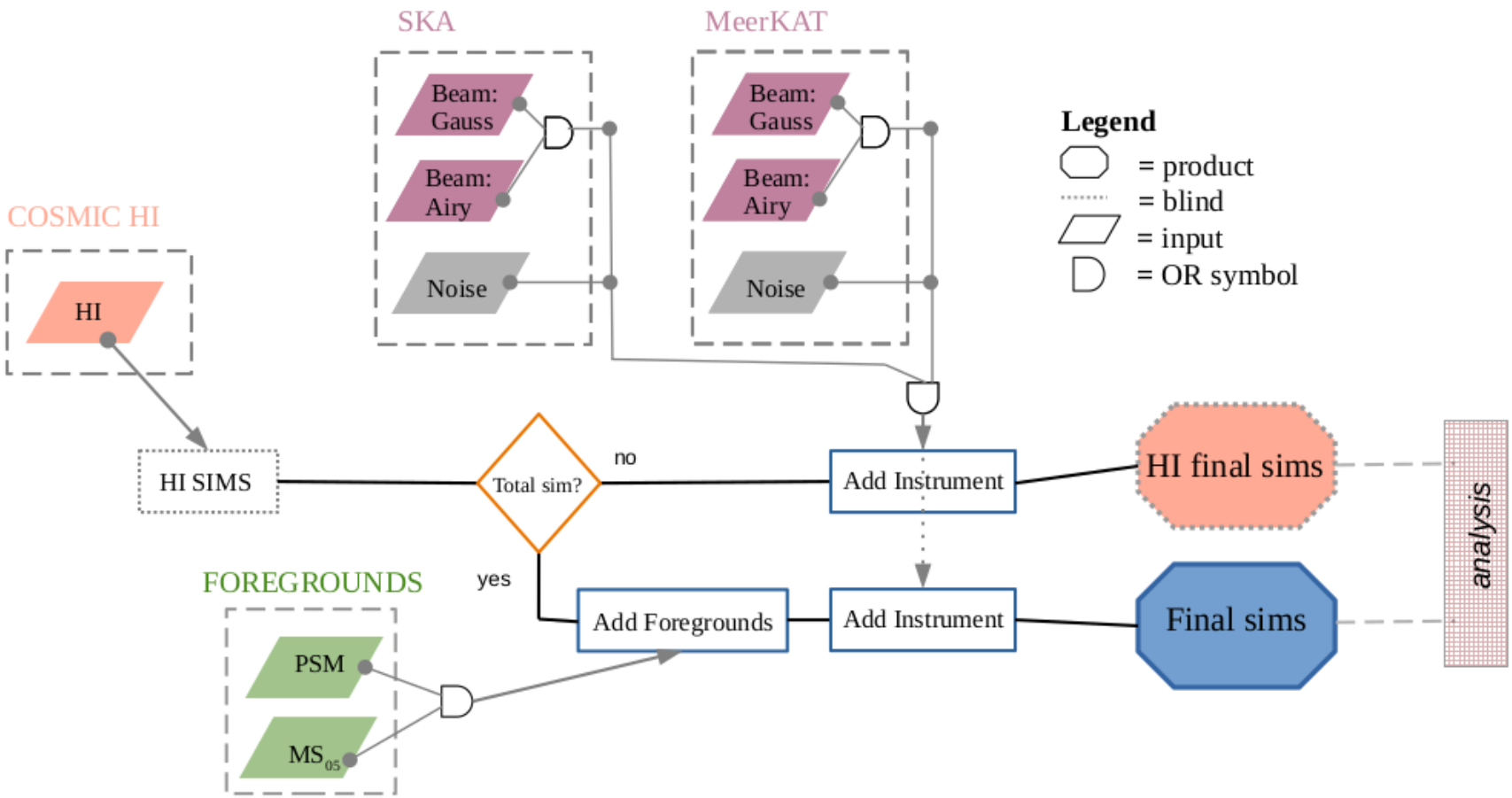
2. Add more realism to the simulations both for the sky and the instrument

3. Cross-correlations with galaxy surveys and synergies with other lines

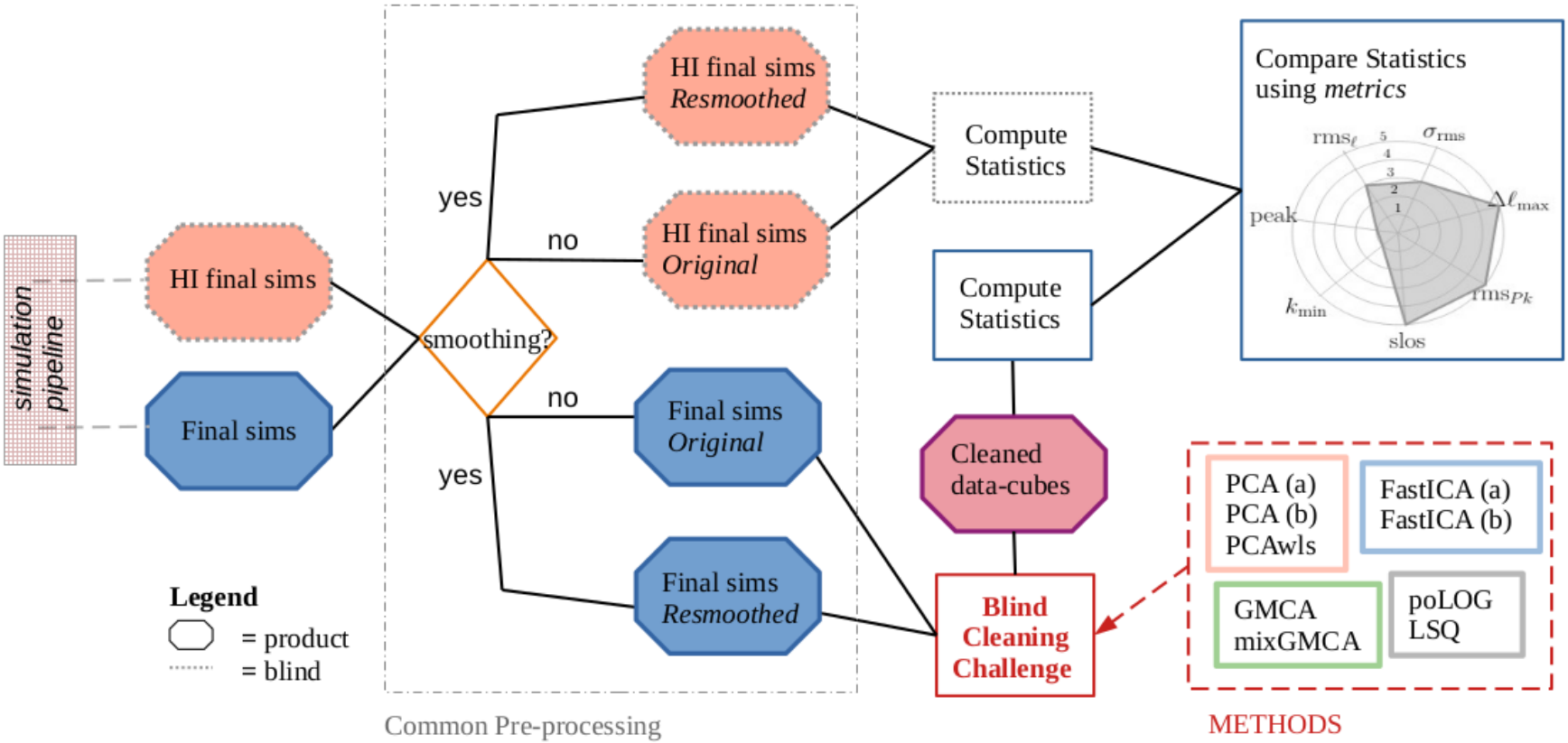
1. How to match theoretical Pk and C_ℓ and simulations? How much are they contaminated by residual foregrounds? Which cosmological parameters are biased by this? Later today and tomorrow
2. Working with (MeerKLASS) data gives input to simulate new systematics (Strong PS, Satellite contamination, RFI, ...) Wednesday
3. Interact with researchers in e.g. Euclid both to prepare data combinations and re-use simulations Thursday

Backup

Flowchart (I)

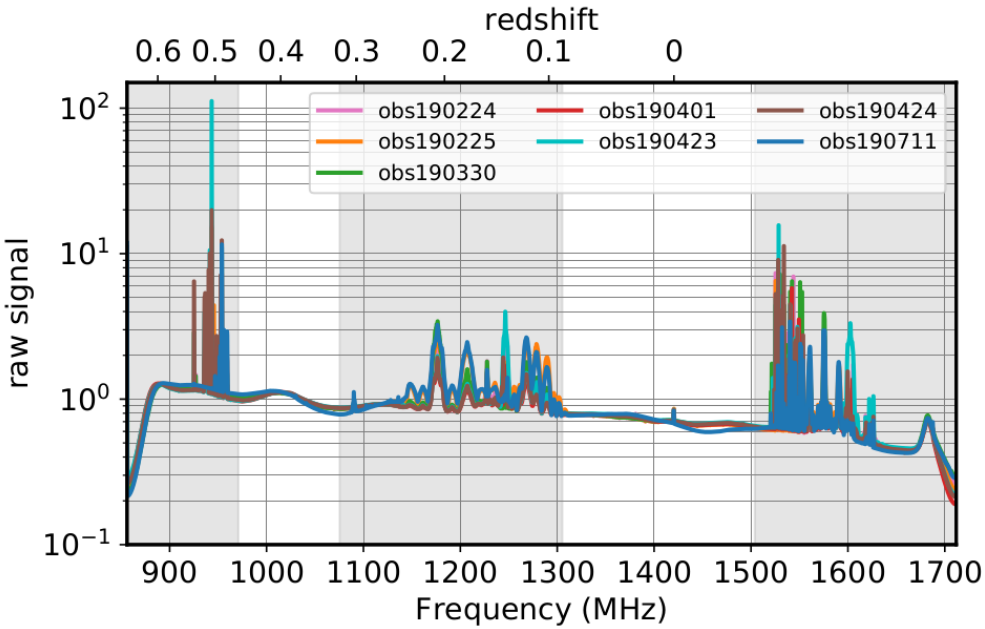

SKA
MeerKAT
Beam: Gauss
Beam: Airy
Noise
Beam: Gauss
Beam: Airy
Noise
Legend
= product
= blind
= input
= OR symbol
COSMIC HI
HI
HI SIMS
Total sim?
no
yes
Add Instrument
HI final sims
FOREGROUNDS
PSM
MS05
Add Foregrounds
Add Instrument
Final sims
analysis

Flowchart (II)



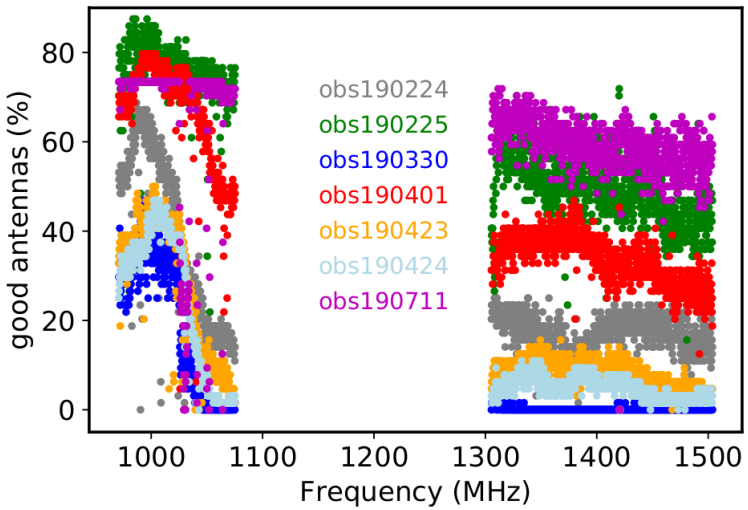
Radio Frequency Interference (RFI)

RFI is everywhere, even in the Karoo desert



- contamination from satellites
- much worse in the future?

- RFI flagging steps
- discard data



Wang et al. [including MS] (2021)

MeerKLASS scanning strategy