Late-time cosmology with the SKA Observatory

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SKA Cosmology *Science Working Group*

https://www.skao.int/en/science-users/science-working-groups/104/cosmology

Co-chairs: Stefano **Camera** & **MS**

HI galaxies

Intensity Mapping

Continuum

Weak lensing

italian contribution (*e.g.*):
S. Camera, A. Raccanelli,
M. Migliaccio, G. Picirilli

Continuum

FG leads: C. Hale & D. Parkinson

Angular clustering of radio sources - look at projected large-scale structures
lots of systematics in radio data: source finder measurement/detection errors, sensitivity variations, etc.

Large area	**Small area**
dipole, ISW, fNL, cross-corr, auto-corr	Bias evolution models for different source types

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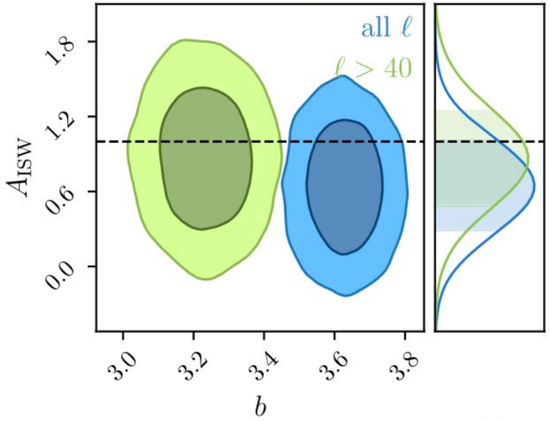
Rapid ASKAP Continuum Survey

data from Hale et al. (2021)

ISW measurement
Bahr-Kalus, et al (2022)



NVSS and TGSS

- Angular clustering Dolfi et al. (2019)
- NVSS x CMB lensing Planck Collaboration XVII 2014
- TGSS x CMB lensing Piccirilli et al. (2023)

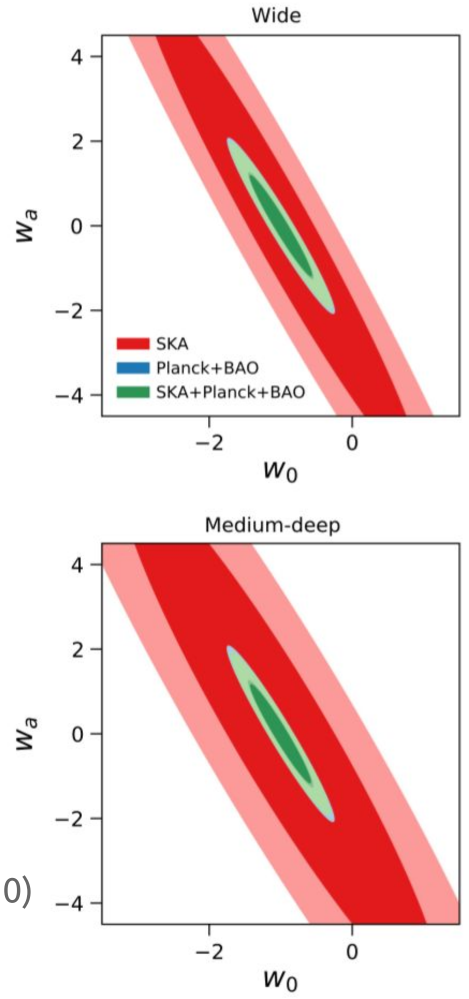
LoTSS DR2

- Angular clustering of radio sources Hale et al. (2023)
- cross-corr with CMB lensing (27σ detection and σ8) Nakoneczny et al (2023)
- cross-with eBOSS Zheng et al. (in prep)

Continuum

FG leads: C. Hale & D. Parkinson

SKA-Mid in Band1 (350 MHz -1.05 GHz) - 20.000 deg2: *Wide*
SKA-Mid in Band2 (950 MHz - 1.75 GHz) - 5.000 deg2: *Medium-deep*



access to dark sector equation of state **w0-wa**

source population bias marginalised over: constraint will improve with better knowledge on the bias parameters

access to fNL

comparable with Planck
e.g. Raccanelli et al. (2014), Camera et al. (2015)
can do better with multi-tracer
e.g. Ferramacho et al. (2014)

dipole: test of cosmological principle

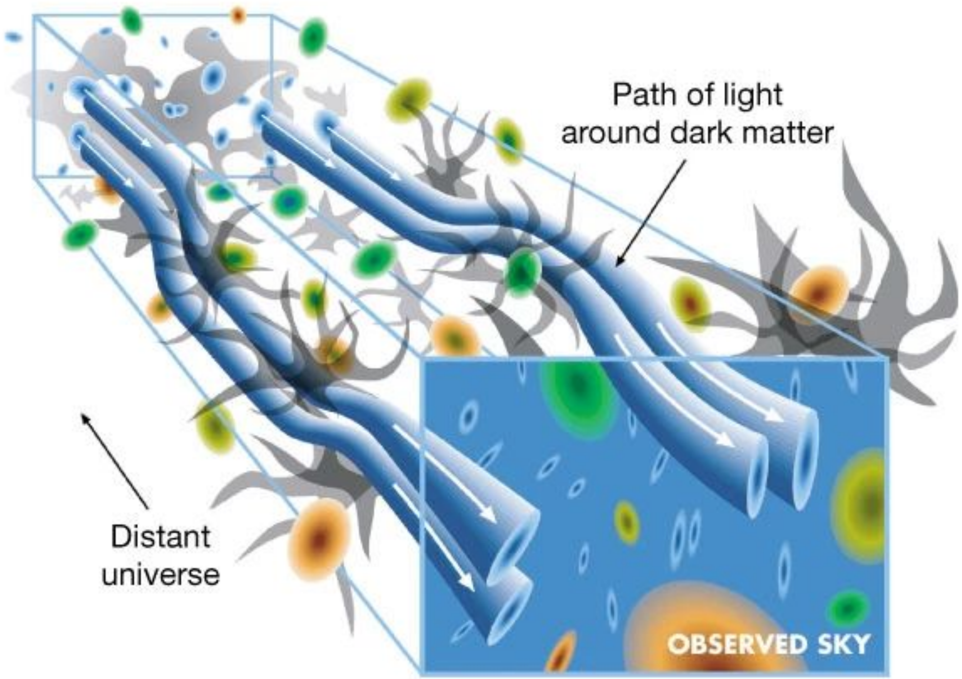
e.g. Rubart & Schwarz (2013)
Bengali et al. (2018)

SKA Red Book (2020)

Radio weak lensing

FG lead: I. Harrison

Wittman et al. (2020)



probe of growth of cosmic structures
Dark matter & Dark energy

key observable in many current and future large optical/near-IR surveys

Requires shape measurement of ~billions of high redshift (z~1) galaxies

3.6σ detection in archival VLA FIRST
Chang, Refregier & Helfand (2004)

Unsuccessful measurements in too-noisy data (VLA + MERLIN)
Patel et al. (2010), Harrison et al. (2020)

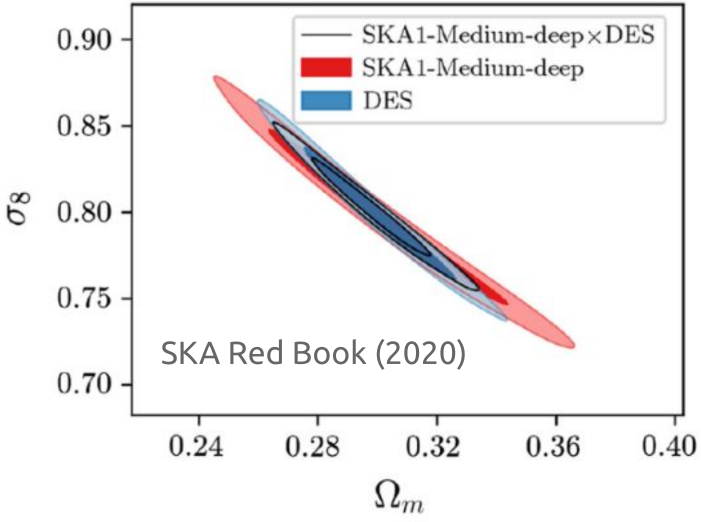
Successful detections of radio-optical correlations (VLA + HST) e.g. Hiller et al. (2019)

italian contribution (*e.g.*): S. Camera

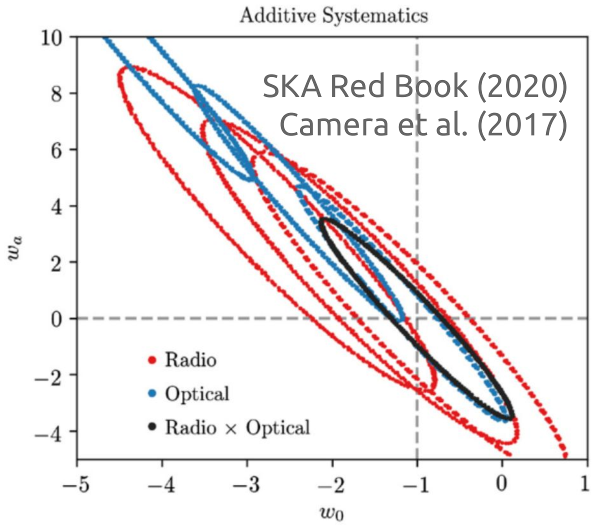
Radio weak lensing

FG lead: I. Harrison

SKAO SWG forecast assuming:
5,000 deg2 survey with **SKA-Mid**
Band 2 (950 MHz - 1.75 GHz) at 1 arcsec PSF



SKAO alone competitive
with completed Dark Energy Survey (DES)



cross-correlation retains almost all of the statistical power of individual experiments

systematic errors on the measured weak lensing signal **uncorrelated** between the radio and the optical

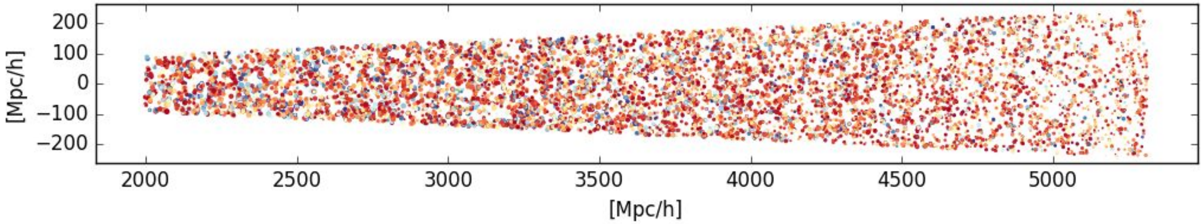
caveat: radio shear measurement methods need improvements

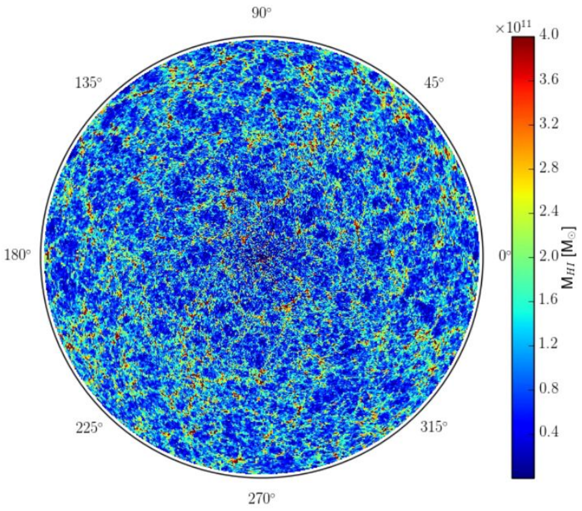
italian contribution (*e.g.*): G. De Lucia, F. Lelli, L. Xie, MS, A. Zoldan

HI galaxies

FG leads: **G. De Lucia** & A. Ponomareva

Simulations: e.g. **GAEA Semi-analytic model**
De Lucia et al. (2014), Xie et al. (2018), Zoldan et al. (2018)





light-cone construction: essential also for cross-correlation studies with **galaxy surveys (e.g. Euclid)**

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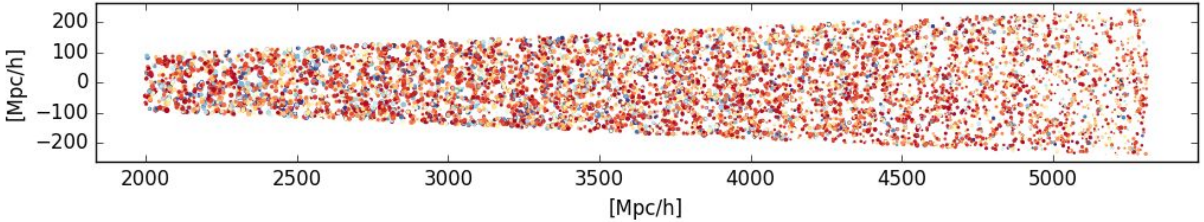

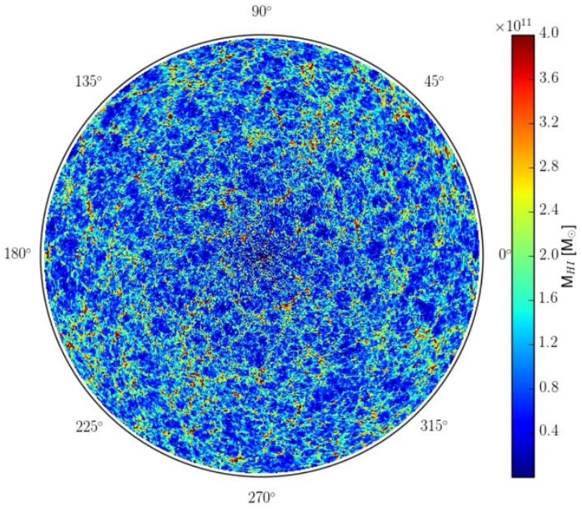

light-cone construction: essential also for cross-correlation studies with **galaxy surveys (e.g. Euclid)**

direct peculiar velocity measurements

growth rate of structures
e.g. Koda et al. (2014)
probes of modified gravity

baryonic Tully-Fisher

TF task force in collaboration with (part of) the HI SWG

distance ladder

measurement of H0
e.g. Lelli et. al (2019), Schombert et al. (2020)

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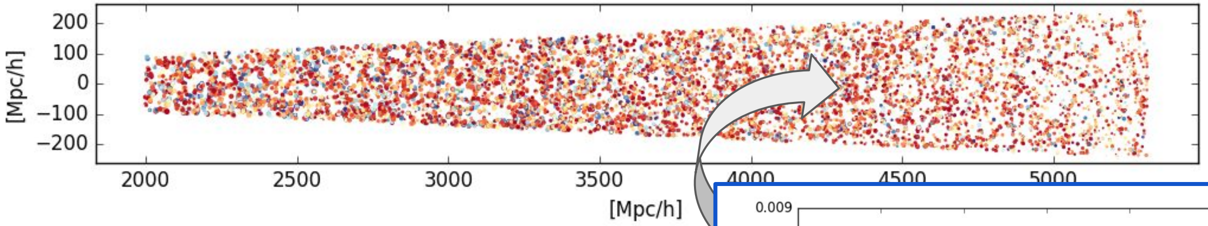

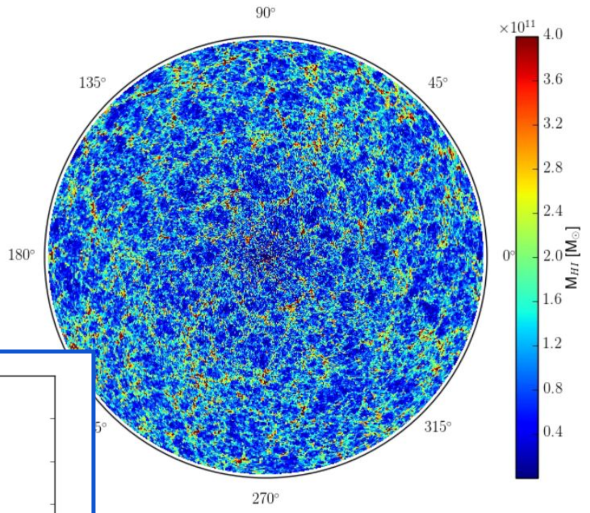

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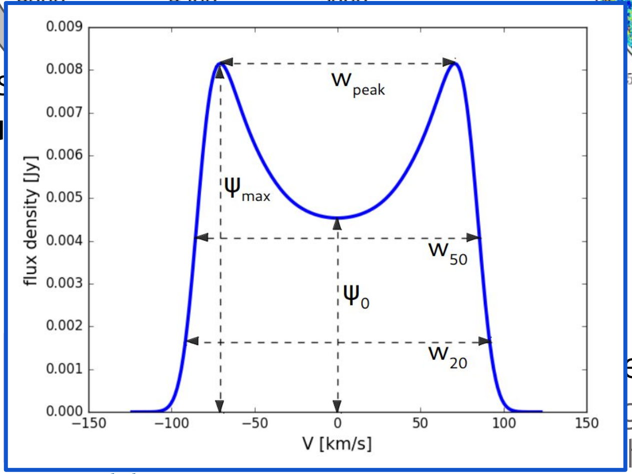
studies with **galaxy surveys (e.g. Eu**



Zoldan, Major, De Lucia, MS, Xie

direct peculiar velocity measurements

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HI galaxies

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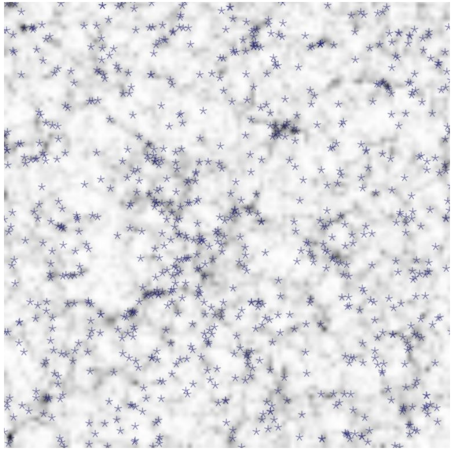
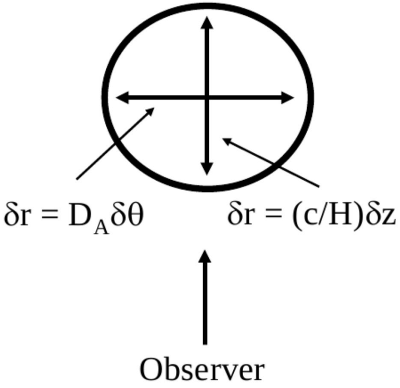
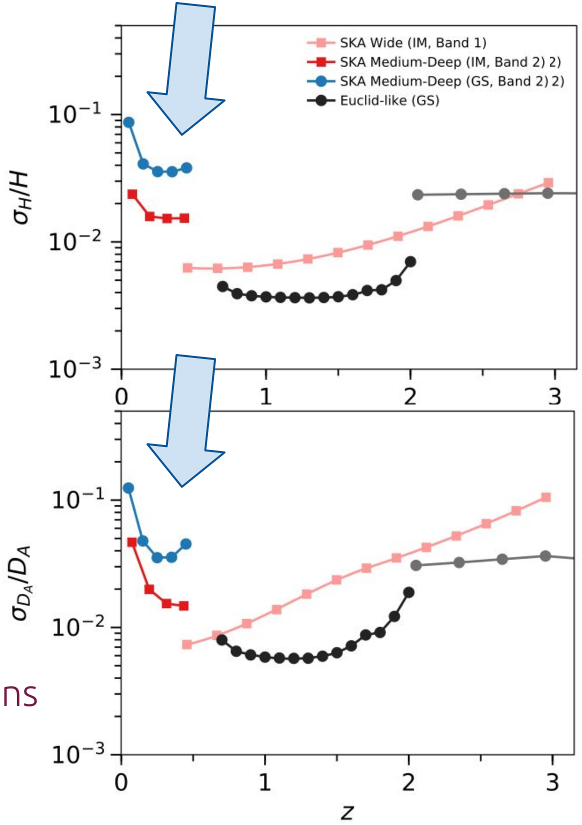
the distribution of **HI galaxies** is a biased tracer of the **matter clustering**







SKA Red Book (2020)

We can measure the Baryon Acoustic Oscillations
e.g. Bull et al. (2015)

Intensity Mapping

FG leads: J. Wang & L. Wolz

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M. Barberi-Squarotti,
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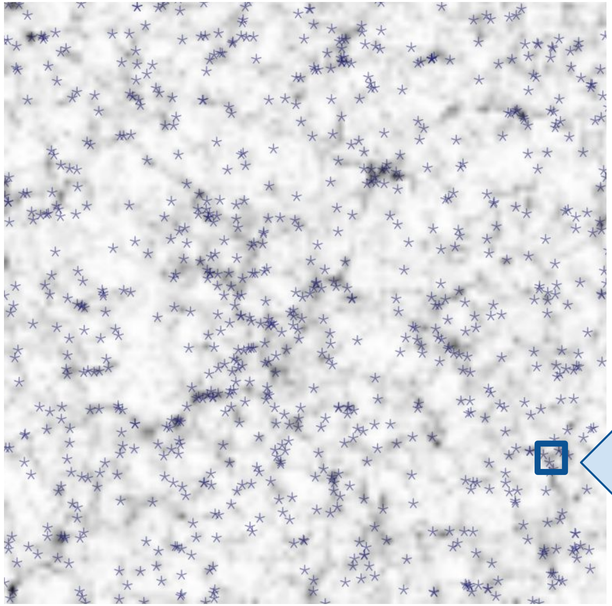
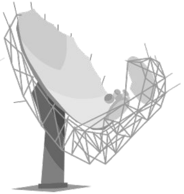


costly to resolve each HI galaxy
and limited to local Universe

How can we efficiently observe cosmological volumes?

Intensity Mapping:
total intensity of the 21cm emission line
in a **large pixel** (low spatial resolution)



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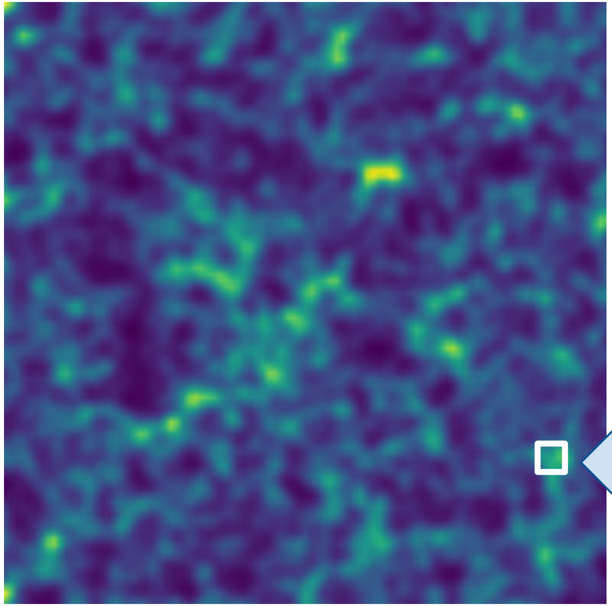

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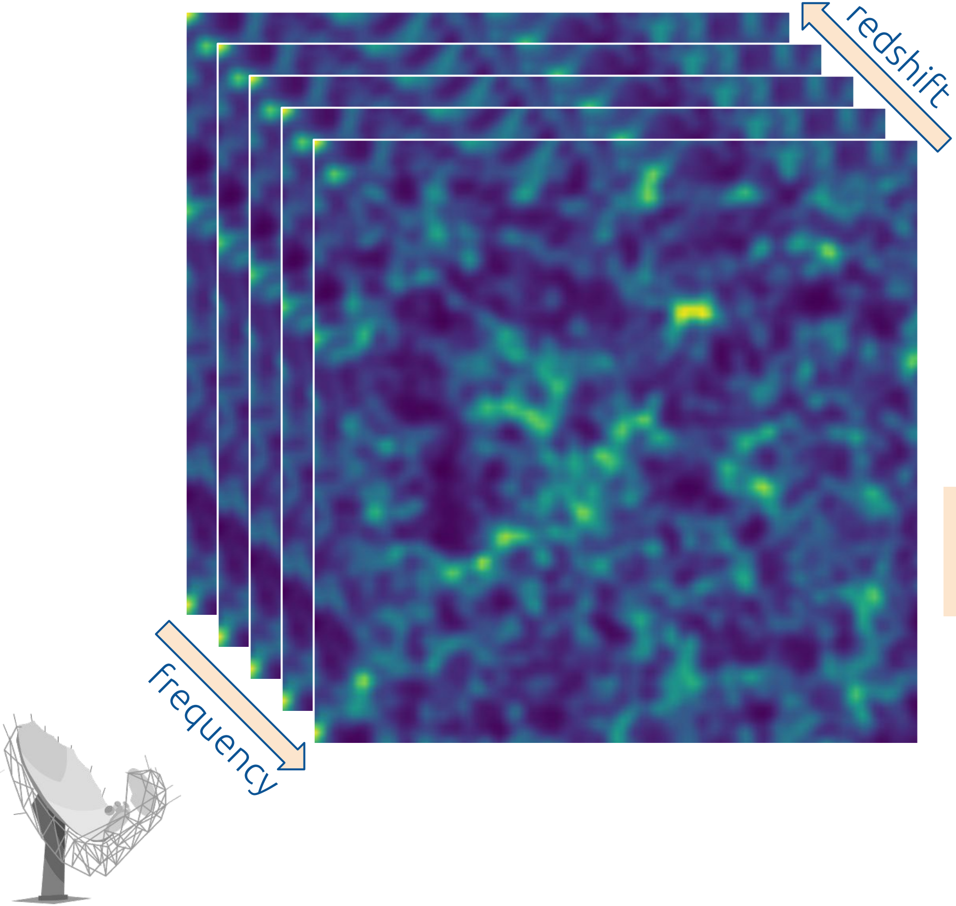


costly to resolve each HI galaxy
and limited to local Universe

How can we efficiently observe cosmological volumes?

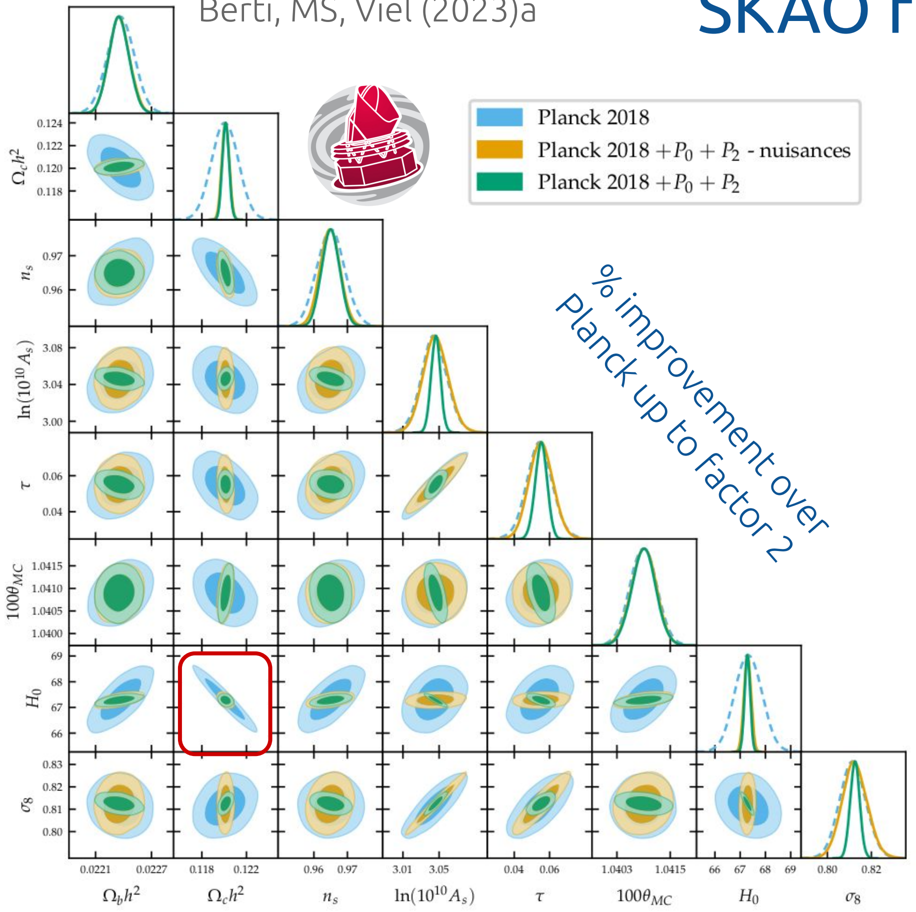
one-to-one correspondence frequency-redshift
high spectral resolution (tomography)

Key cosmological probe

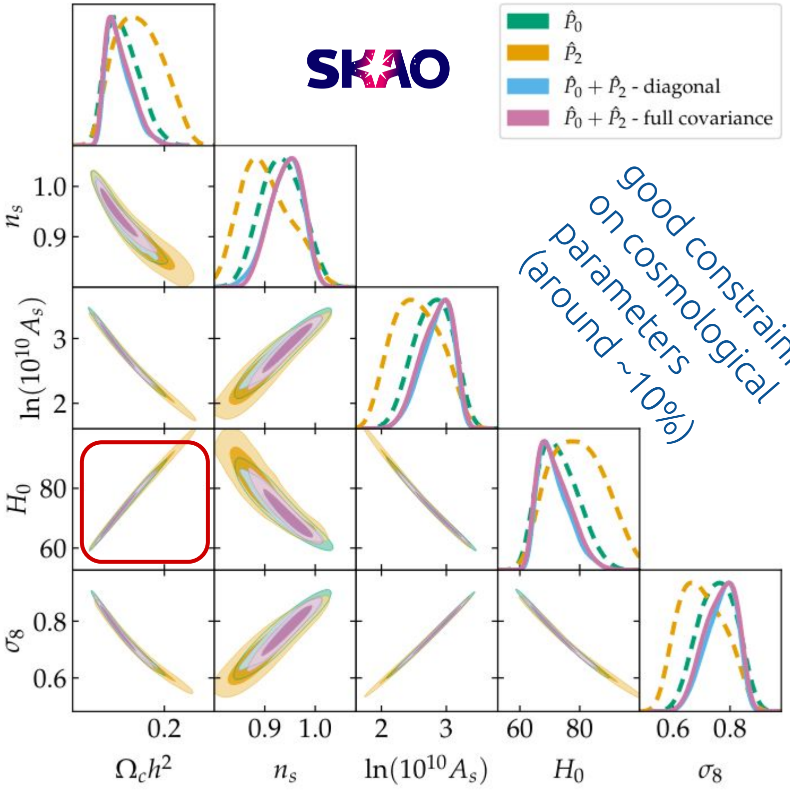
SKAO forecasts

Berti, MS, Viel (2023)a

see also (e.g.): Fonseca et al. (2015), Carucci et al. (2015), Obuljen et al. (2017), Ballardini et al. (2018), Camera et al. (2020), Scelfo et al. (2022), Berti et al. (2022)



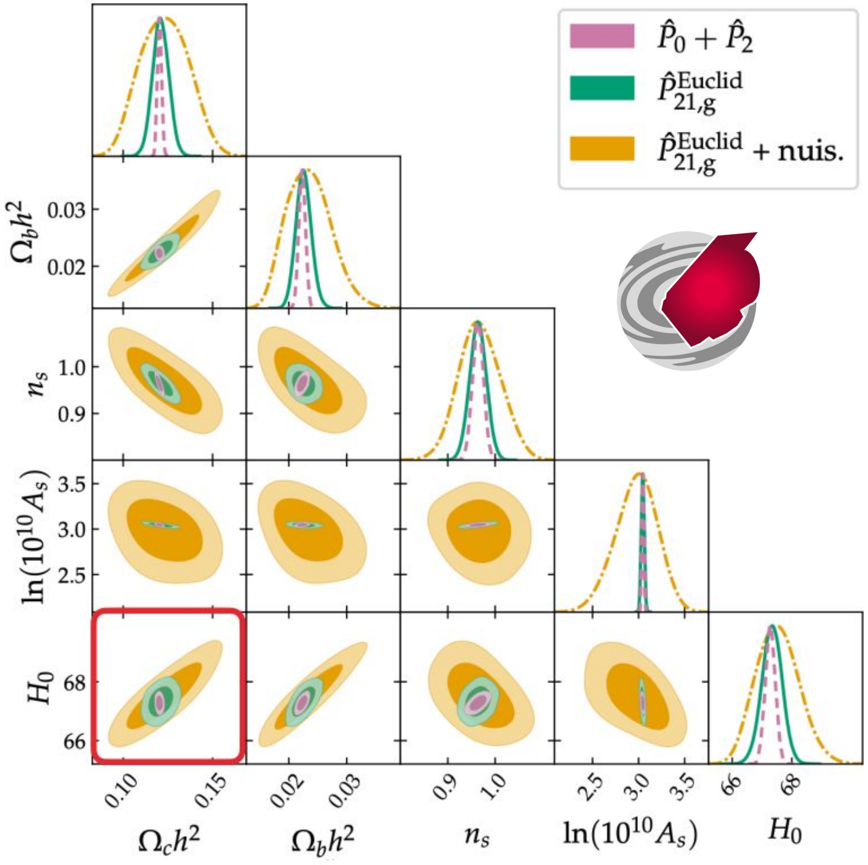
% improvement over Planck up to factor 2



good constraining power on cosmological parameters (around ~10%)

Berti, MS, Viel (2023)b

SKAO forecasts: cross-correlation



SKAOxEuclid and **SKAOxDESI** comparable constraining power

Broader constraints assuming no knowledge on e.g. HI bias (nuisances)

Synergies with other surveys to measure non-Gaussianity and modified gravity
e.g. Pourtsidou et al. (2016), Ballardini et al. (2018, 2019), Casas et al. (2023), Scelfo et al. (2023)

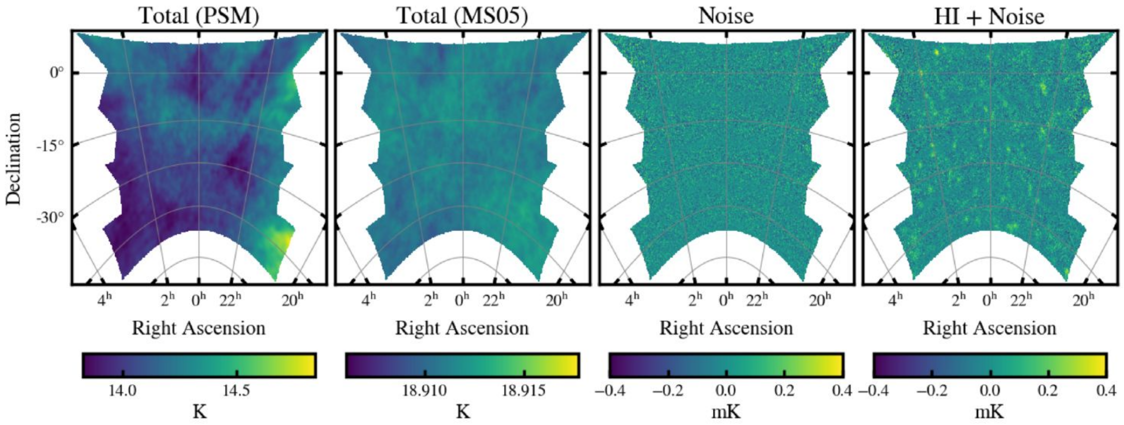
Foreground subtraction challenge

(subset) of the SKA Cosmo IM Focus Group

***Isabella Paola Carucci**, Steve Cunnington, Ze Fonseca, Stuart Harper, Mel Irfan, Alkistis Pourtsidou, **Marta Spinelli**, Laura Wolz*

Project setup:

- various foreground models and realistic HI maps
- instrumental modeling MeerKAT-like and SKAO-like
- 9 different foreground removal methods (PCA, FastICA, …)



Blind challenge to discover weaknesses and strengths of the various methods

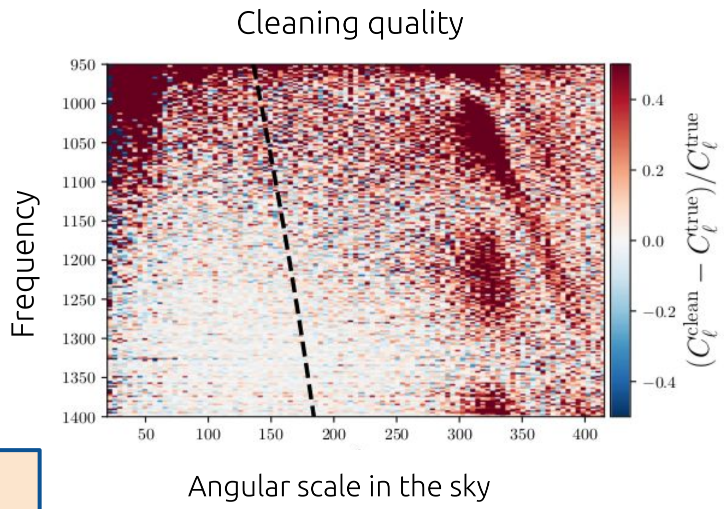
given IM "data",
would your favorite method extract the cosmological signal?

Foreground subtraction challenge

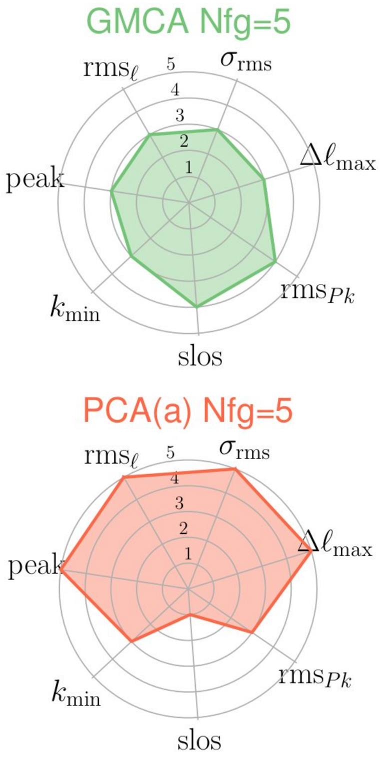
- How much can **instrument/foregrounds coupling** impact the signal reconstruction?

- definition of statistics and metrics to evaluate the relative performances

Realistic instrumental effects inevitably **complicate** the foreground cleaning



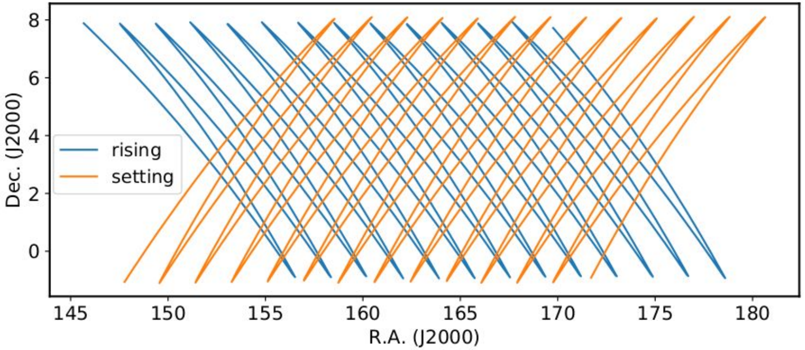
MS et al. (2022)

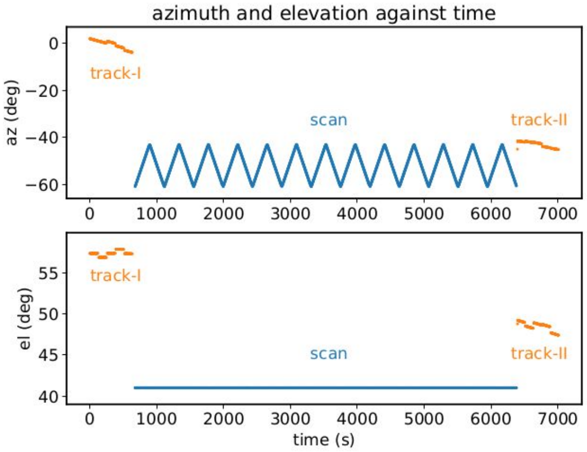


Intensity Mapping with MeerKAT

Santos et al. 2017, Wang et al. 2021

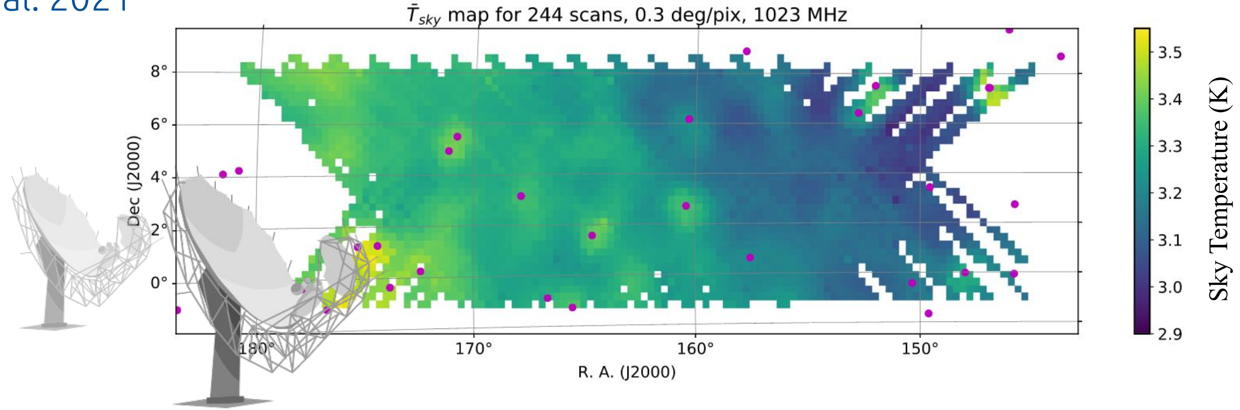
Antennas	All 64 MeerKAT dishes
Observation mode	Single-dish
Frequency range	0.856-1.712 GHz
Frequency resolution	0.2 MHz
Time resolution	2s
Exposure time	1.5hr x 7 scans
Target field	WiggleZ 11hr field ($10^\circ \times 30^\circ$)





MeerKAT observations

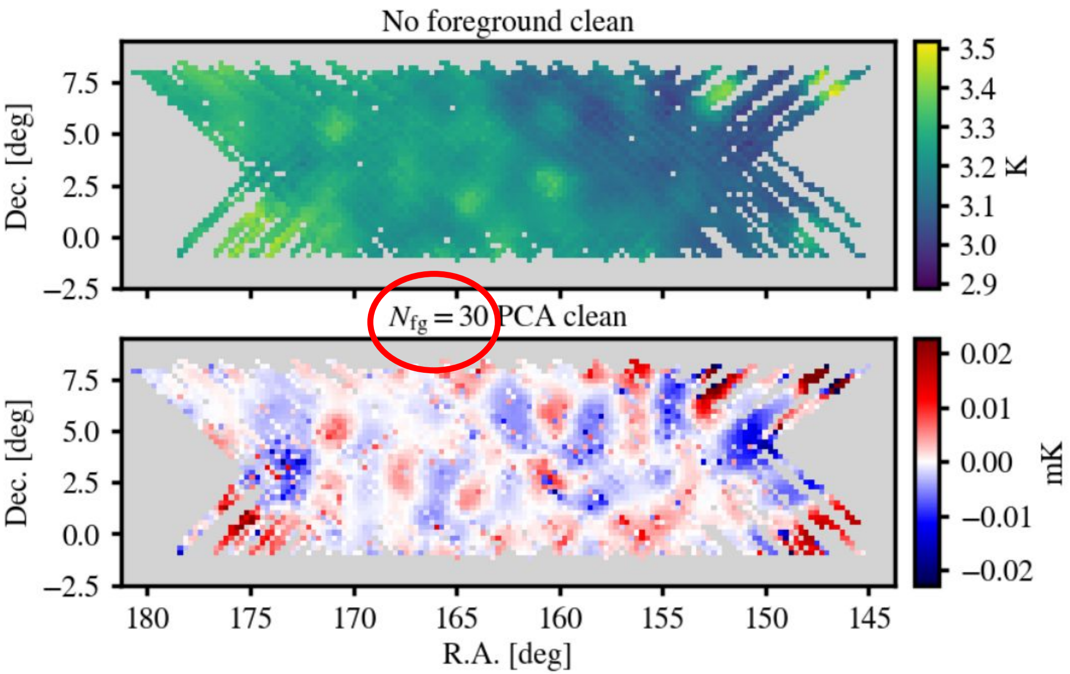
Wang et al. 2021



MeerKLASS: 64 MeerKAT antennas used in single-dish mode
PI: M. G. Santos (Santos et al. 2017)

- first successful calibration of intensity mapping data from MeerKAT
- L-band: 850-1700 MHz (4096 channels)

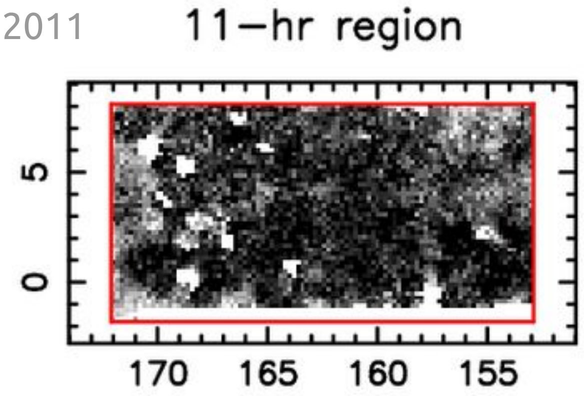
MeerKLASS observations

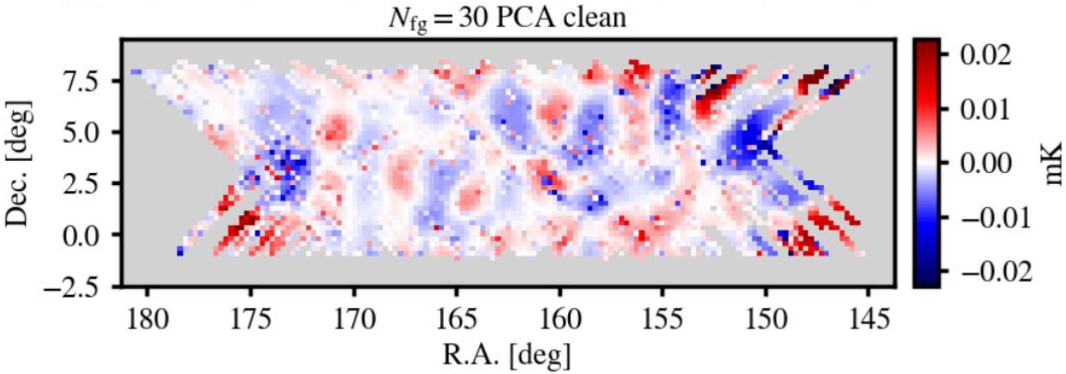


Cunnington et al. 2022

MeerKLASS results

Blake et al. 2011





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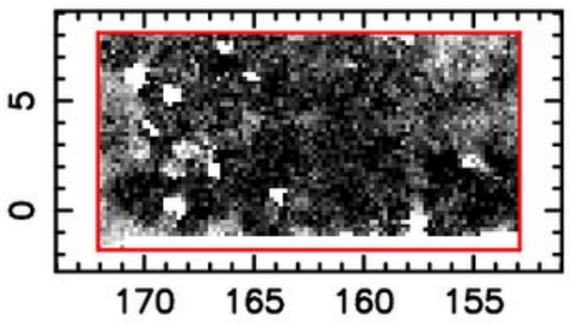

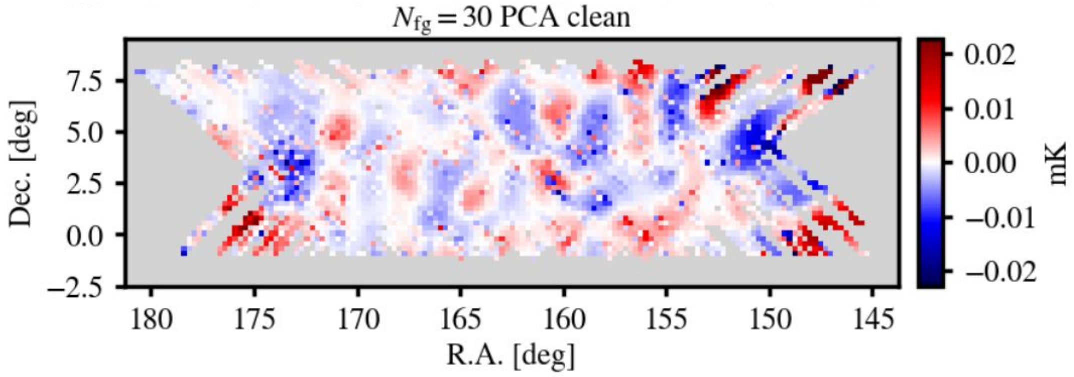

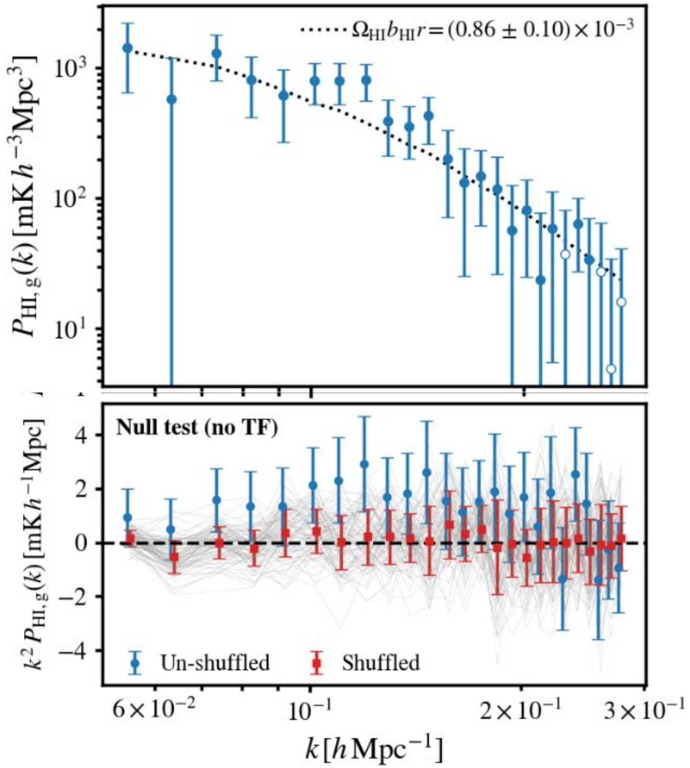

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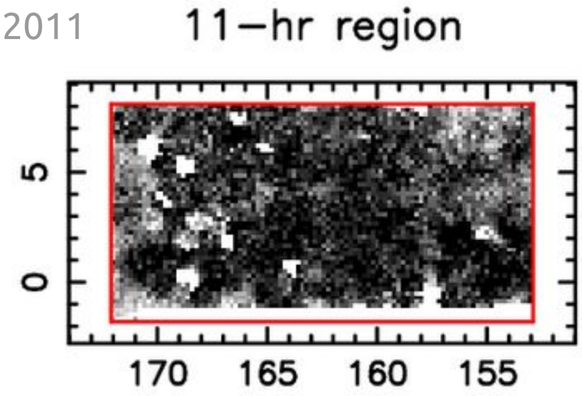
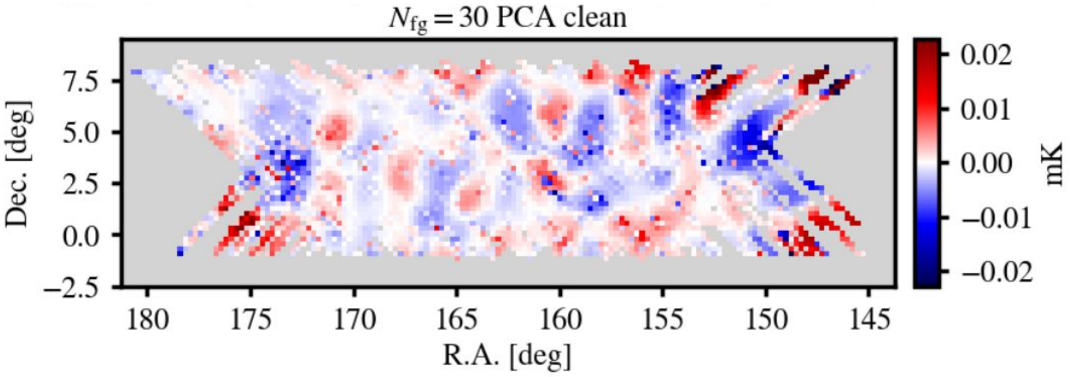
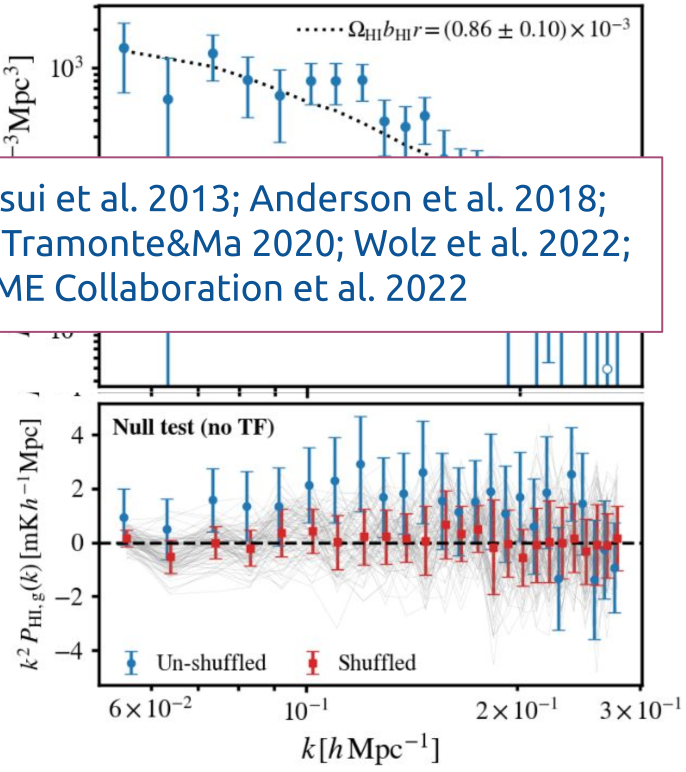






see also: Masui et al. 2013; Anderson et al. 2018;
Li et al. 2021; Tramonte&Ma 2020; Wolz et al. 2022;
CHIME Collaboration et al. 2022

Cunnington et al. 2022

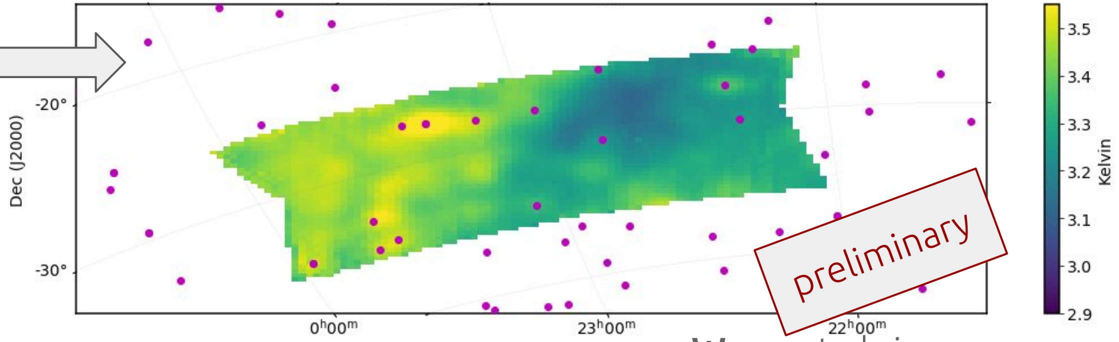
MeerKLASS ongoing

Improved cleaning/comparison on 2019 L-band data (**Carucci** et al. *in prep*)

L-band: 41x1.5h scans

UHF-band: 50x1.5h scans

L-band: split data to reduce systematics cross-correlating different blocks (**Barberi-Squarotti**)



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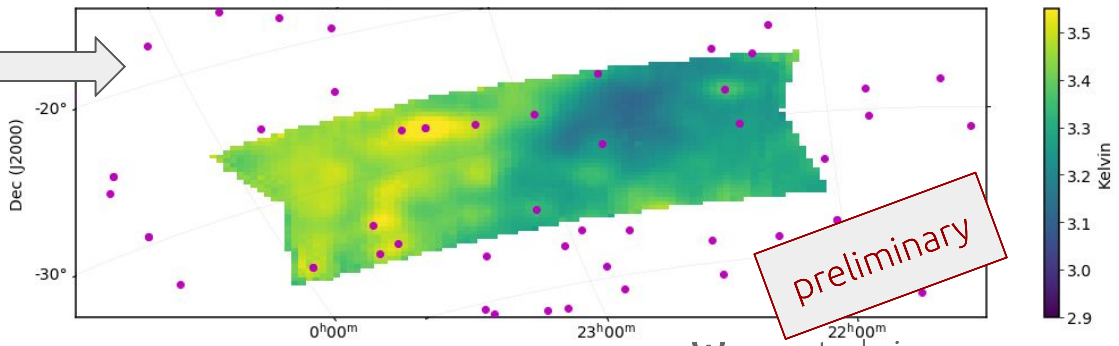


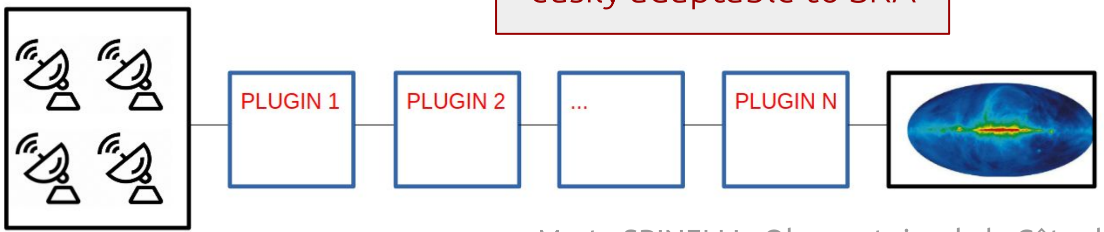
Wang et al. *in prep*

New calibration pipeline(s):

KATcali: improved RFI flagging, improved sky model with self-calibration (**Wang** et al. *in prep*)

Ivory/MuSEEK: new improved modular plugin-based architecture (**Wild** et al. *in prep*)

easily adaptable to SKA



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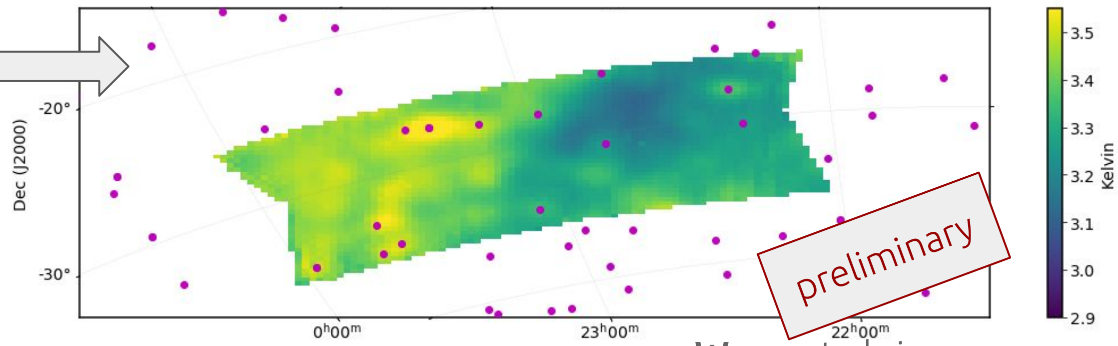

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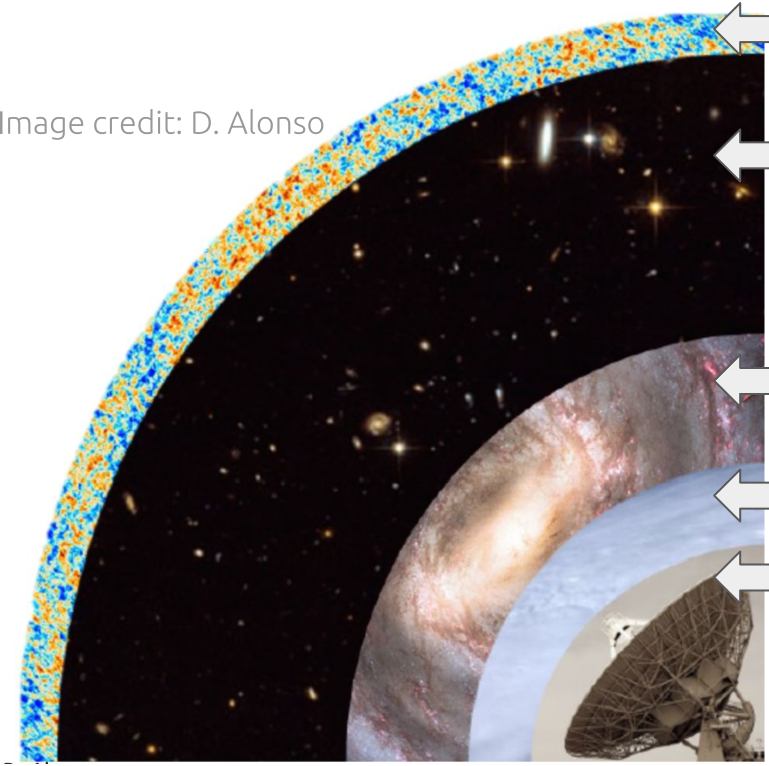
On-the-fly (OTF) interferometry

commensal IM and interferometric imaging (no dedicated OTF obs mode on MeerKAT but engineering & commissioning team involved)

Rozgonyi et al. *in prep*

End-to-end Simulations

Image credit: D. Alonso



- 21cm signal maps
- extra-galactic emission
- Galactic emission
- instrumental and systematic effects

realistic mocks

↓

analysis pipeline:
TOD, beam convolution,
calibration errors, …

↓

power spectrum

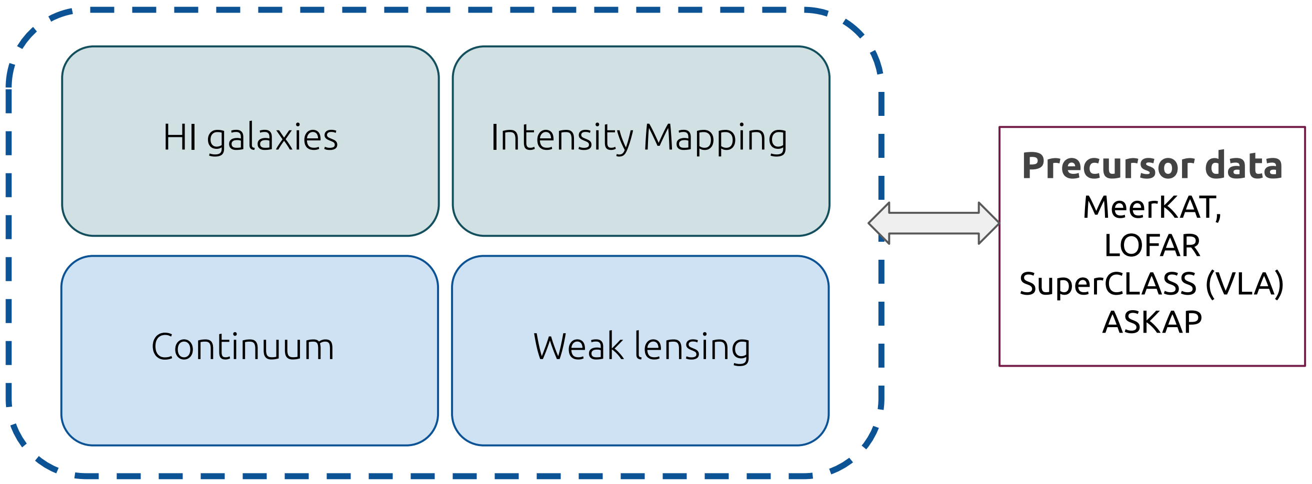
↓

cosmological parameter constraints

late-time cosmology & SKAO

HI galaxies	Intensity Mapping
Continuum	Weak lensing

late-time cosmology & SKAO



late-time cosmology & SKAO

Simulations Coordination

Synergies

HI galaxies

Intensity Mapping

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Weak lensing

Precursor data
MeerKAT,
LOFAR
SuperCLASS (VLA)
ASKAP

late-time cosmology & SKAO

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ASKAP

Cosmology SWG annual meeting
Porto,
15-17 Jan 2024

If you are interested in joining the SWG please email
Stefano Camera (stefano.camera@unito.it)
and me (spinemart@gmail.com)