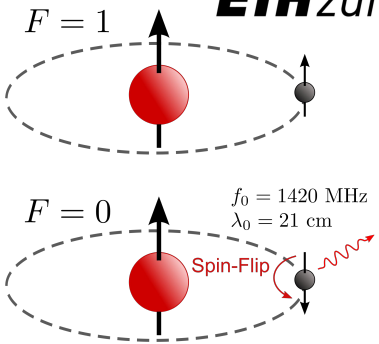
Post-reionisation 21cm Cosmology Sky and Instrument Simulations

Devin Crichton and ETHZ Radio Cosmology Group†
SKACH Consortium Meeting @ ETHZ
24.05.22

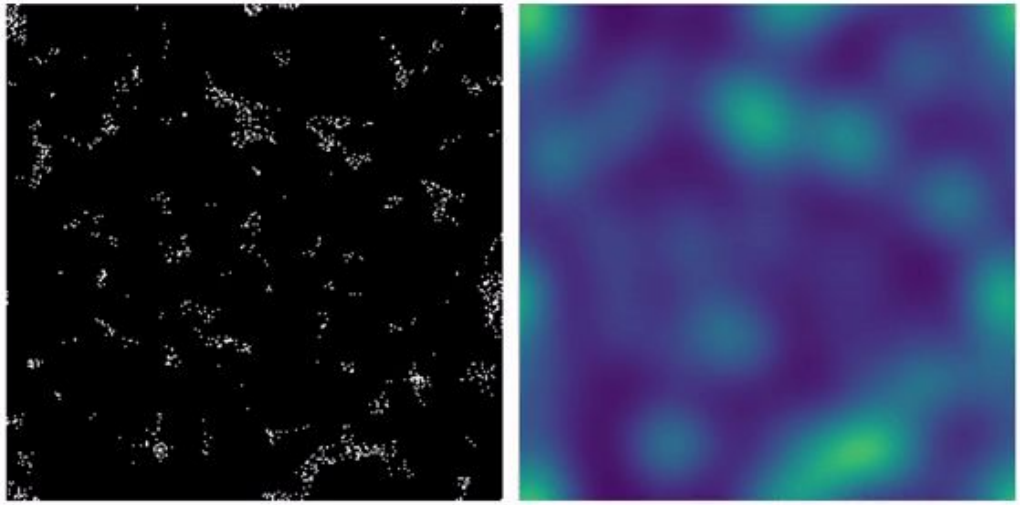
†Alexandre Refregier, Marta Spinelli, Sara A. Safari, Pascal Hitz, Pascale Berner

HI Intensity Mapping



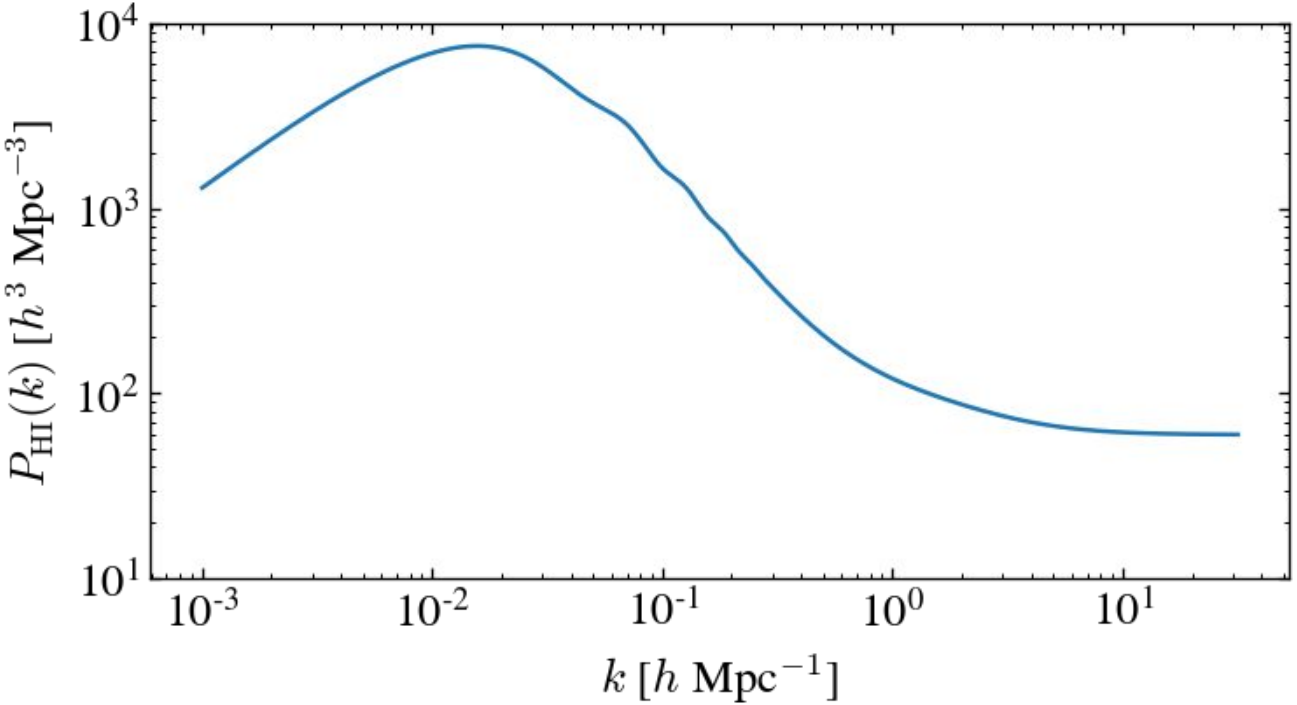
Credit: Wikimedia Commons

- Hyperfine Hydrogen transition line at 1420.4 MHz
- Efficiently and tomographically map cosmological volumes
  - Generally low angular resolution but redshift information cheap
  - Probe epoch of reionisation at low frequencies and large scale structure at high frequencies.
- Post-reionisation IM
  - ν > 200-300MHz
  - Biased tracer of large scale structure
  - Cosmological constraints from HI power spectrum
  - Large volumes achievable



HI Power Spectrum

ETH zürich

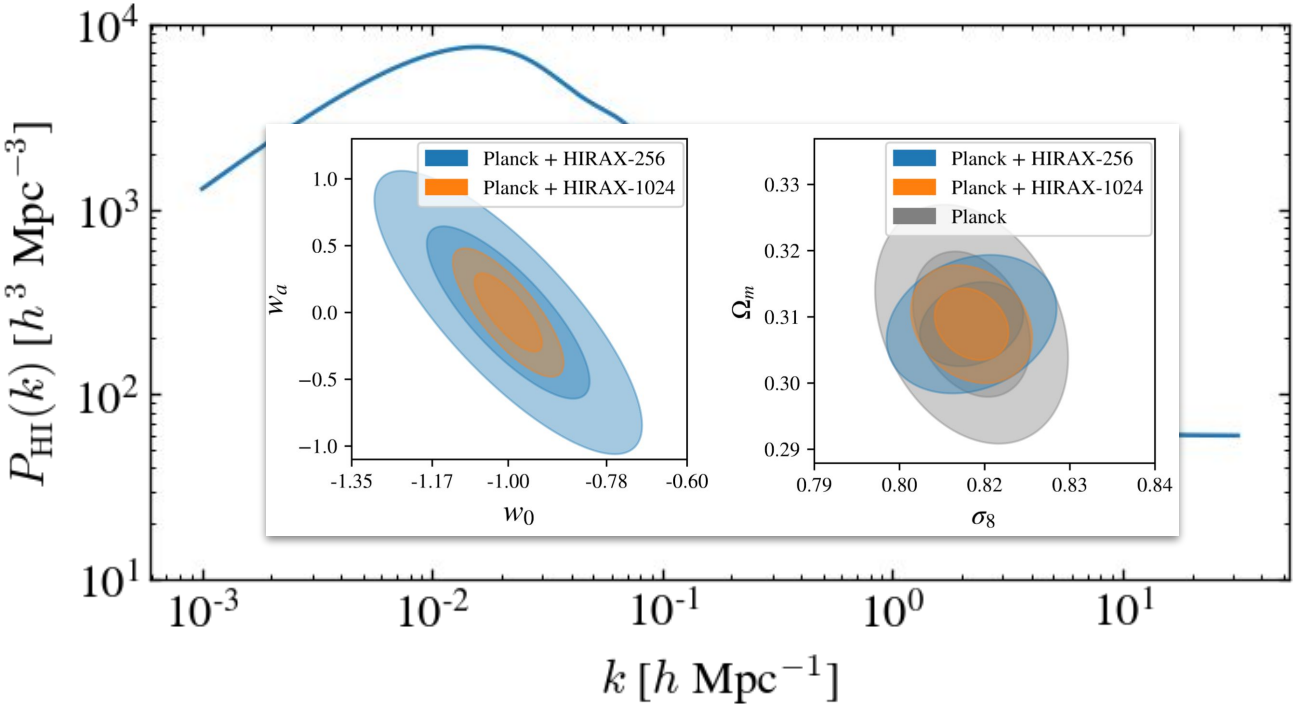


- Primordial non-gaussianity
- Modified gravity theories

- Growth of structure
- Geometric Constraints
- Expansion rate
- Dark energy

- Non-linear dynamics
- HI content of galaxies

HI Power Spectrum



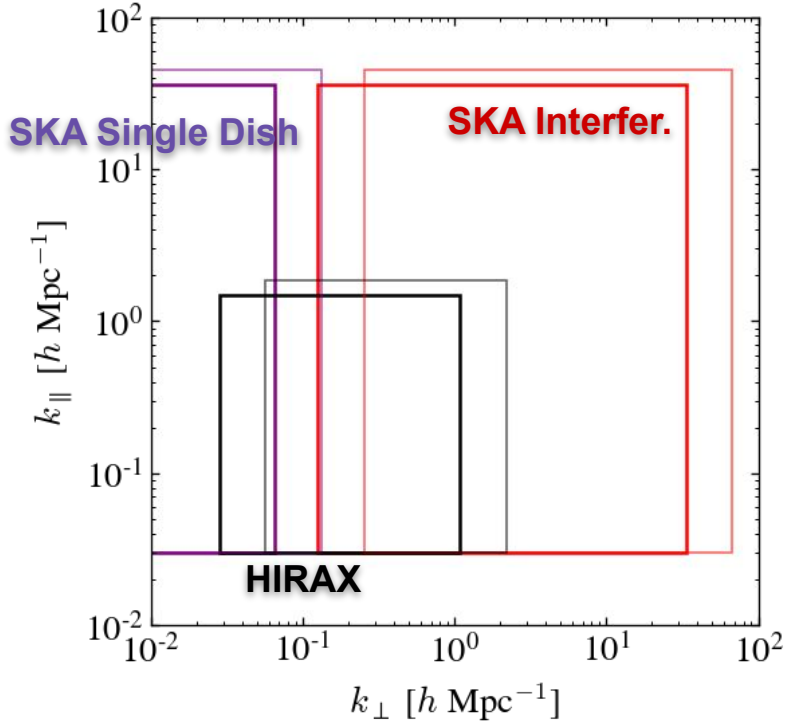
- Primordial non-gaussianity
- Modified gravity theories

- Growth of structure
- Geometric Constraints
- Expansion rate
- Dark energy

- Non-linear dynamics
- HI content of galaxies

Instrument Diversity

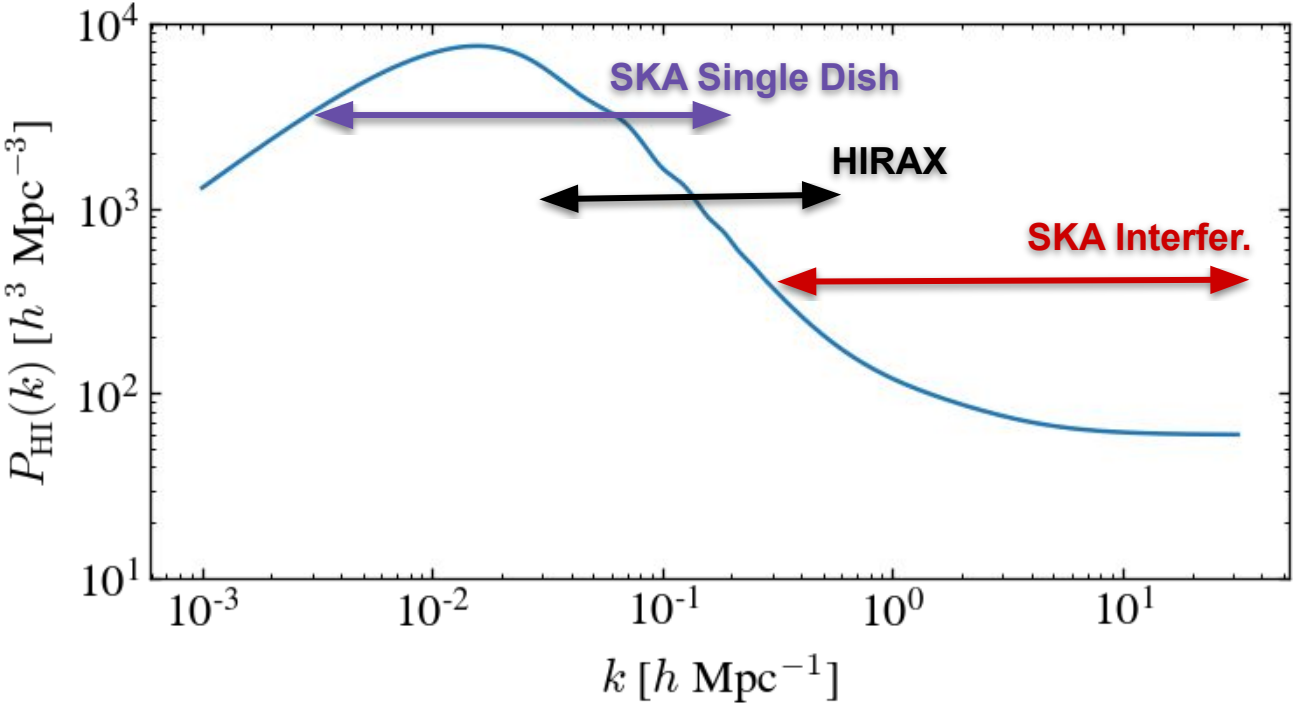
ETH zürich



- Power spectrum sensitivity:
  - $k_\perp$: Angular scales (baselines/beam)
  - $k_\parallel$: $k_{FG} \rightarrow$ Channel width / k_{NL}

HI Power Spectrum

ETH zürich



- Primordial non-gaussianity
- Modified gravity theories

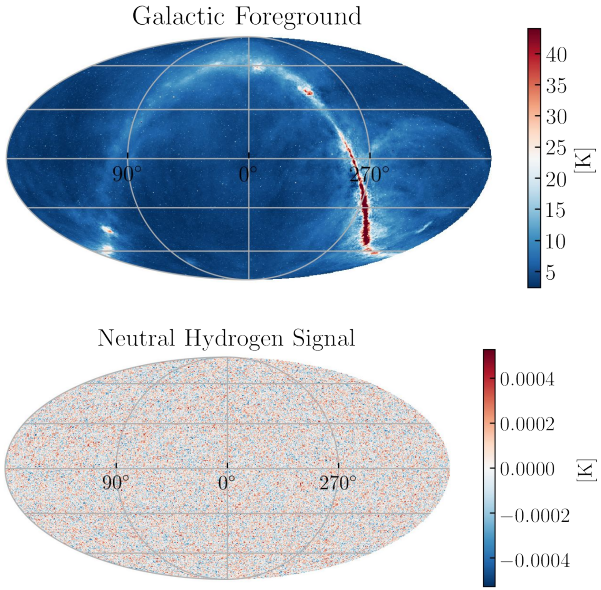
- Growth of structure
- Geometric Constraints
- Expansion rate
- Dark energy

- Non-linear dynamics
- HI content of galaxies

Systematics / Chromaticity and Foregrounds

ETH zürich

- Foregrounds are the primary challenge for 21cm cosmology
  - Galactic signal brighter by many orders of magnitude
- Signal and Foregrounds have different, *on-sky* properties
  - Galactic emission is:
    - Polarised
    - Strongly correlated over wide frequency bands
    - Structured on the sky in ~known way
  - In principle, there are not many mixed *on-sky* degrees of freedom
- Mode-mixing inherent in measurement is a major issue
  - Instrument has chromatic response fundamentally as well as arising from systematics
  - With perfect knowledge of the instrument, this can be accounted for, however the large contrast in signal strengths can make small reconstruction residuals a big problem



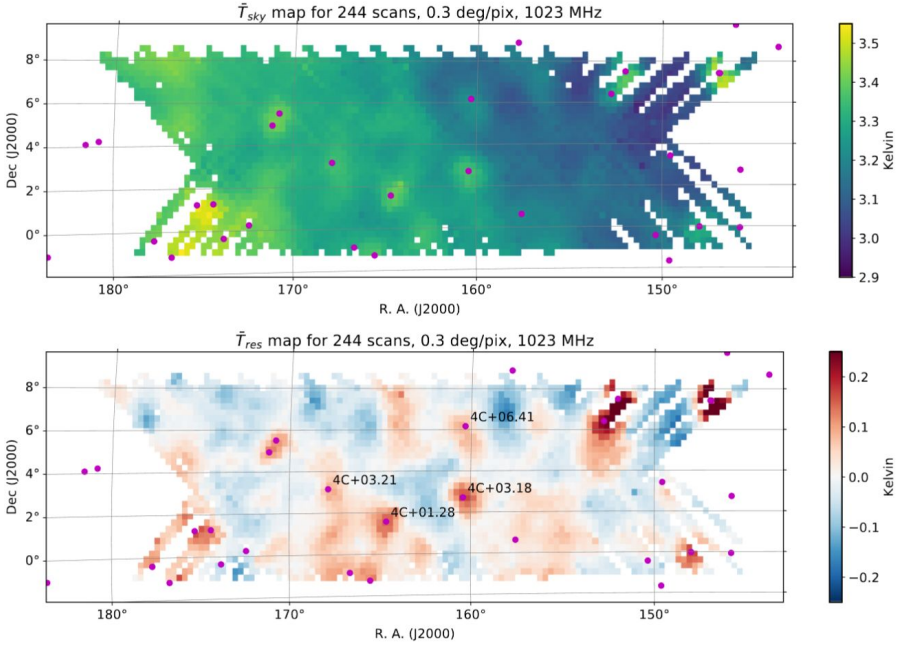
Single Dish Observations with MeerKAT

ETH zürich

Cosmology with MeerKAT is underway

MeerKLASS pilot survey:

- 11 hours, ~200 deg^2
- Demonstrated analysis and foreground mitigation techniques work on real data
- Synchrotron model constraints
- **Cosmological signal detected in cross-correlation with WiggleZ**

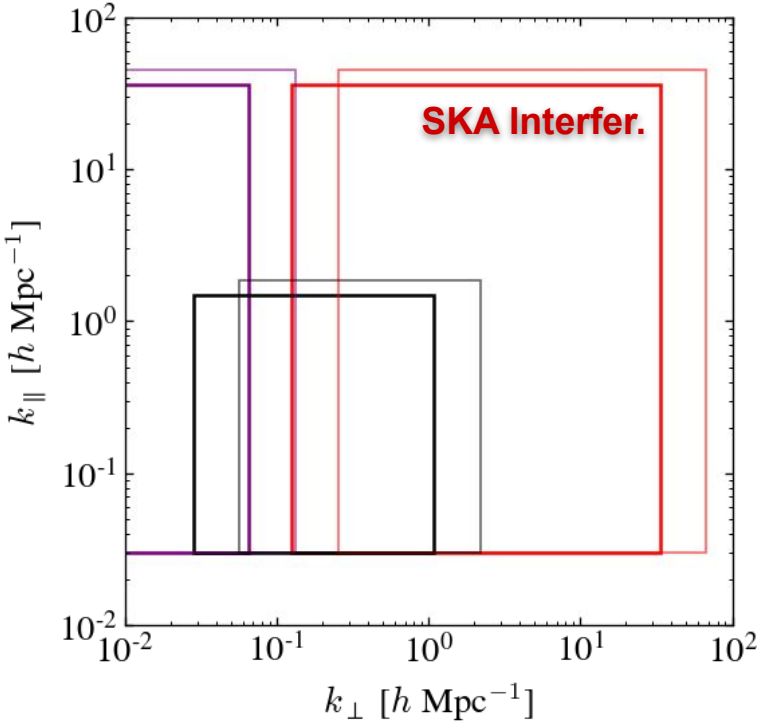


Credit: Jingying Wang et al. 2021 | arXiv: 2011.13789

SKA Interferometric Intensity Mapping

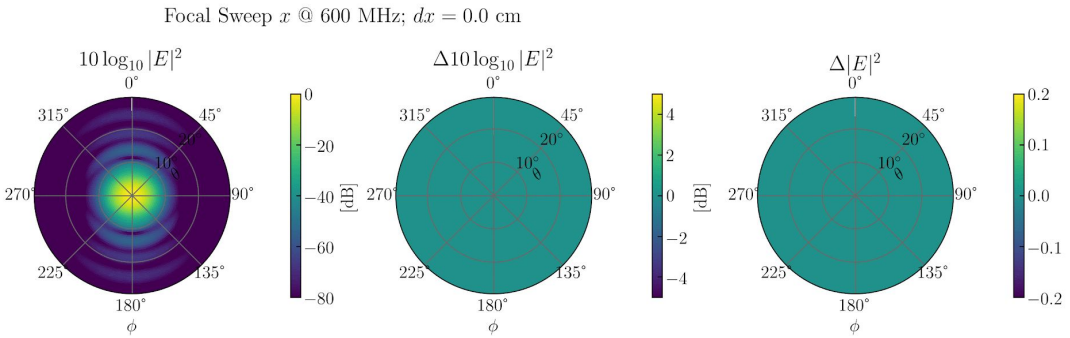
ETH zürich

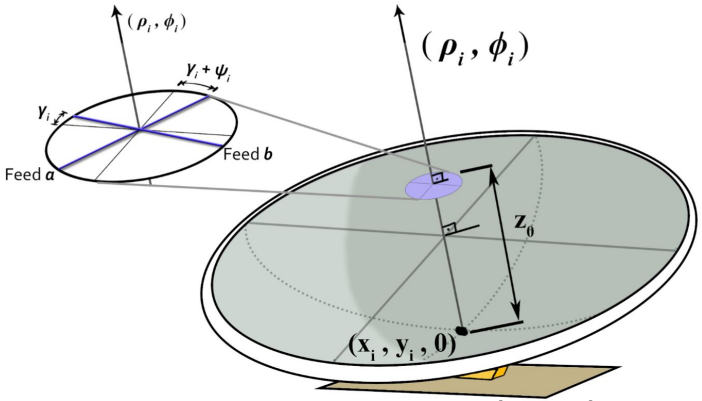
- Work package at ETHZ for Digital Twin project (Sara A. Safari @ ETHZ)
  - Develop flexible, scalable power spectrum extraction pipeline
  - Robust to spectral gaps
  - Include primary beam models and foreground mitigation



- Mosaicing / survey strategy optimisation
  - Commensural opportunities

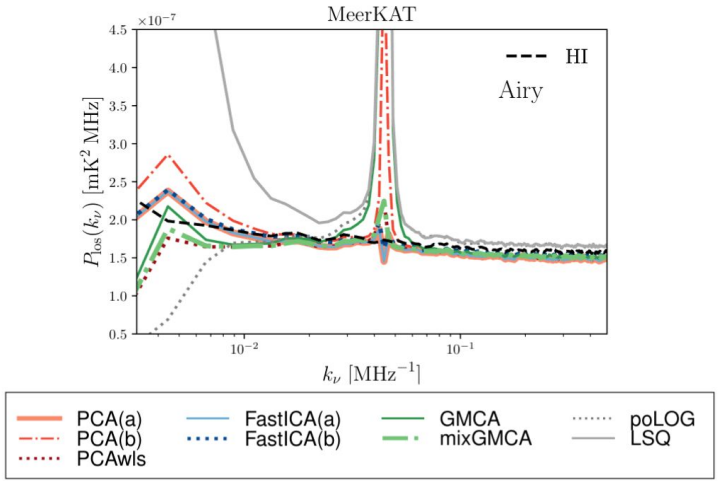
Instrumental Systematics





Credit: Dalian Sunder

- Instrument modeling is critical
  - Chromatic response needs to be characterised
  - Signal loss needs to be minimal and understood
  - Incorporate instrument simulation techniques
- Beam measurement informative
  - External constraints on chromaticity
  - Holography, drone etc.

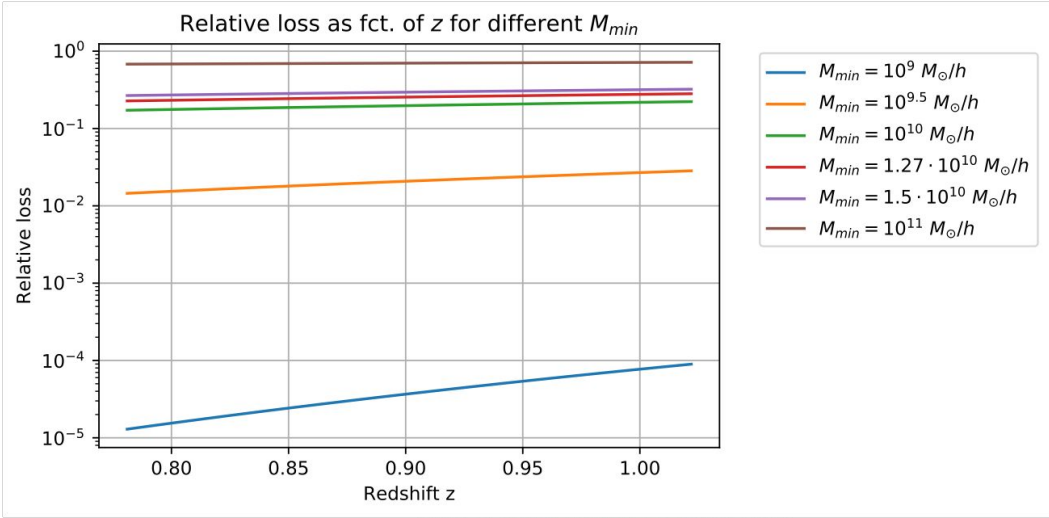


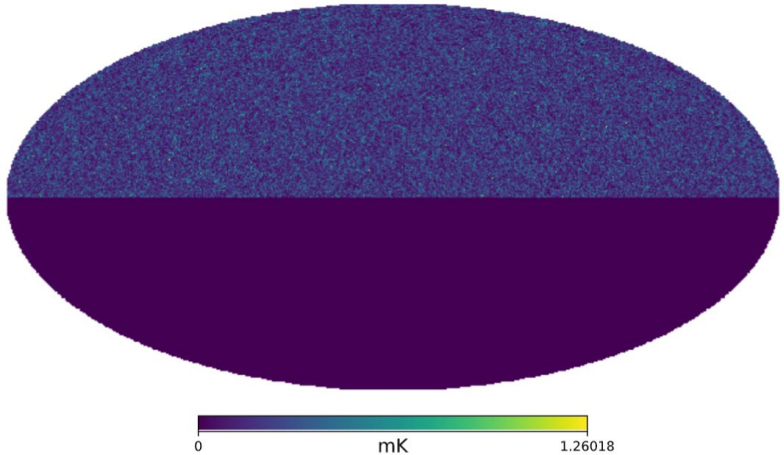
Credit: Marta Spinelli et al. 2021 | arXiv: 2107.10814

Pinocchio Sky Simulations

ETH zürich

- Developing 21cm sky
- PINOCCHIO LPT haloes + HI mass function → Simulated sky maps
  - Use empirical halo model from Padmanabhan et al. 2017
- Fast and robust alternative to n-body simulations suitable for forward modeling and x-corr.
- Aim significant scale up simulations and provide interface in digital twin
  - Lower mass resolution
  - Range of cosmologies and mass function parameters

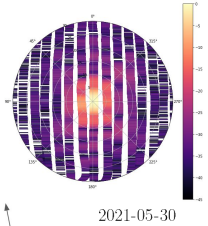


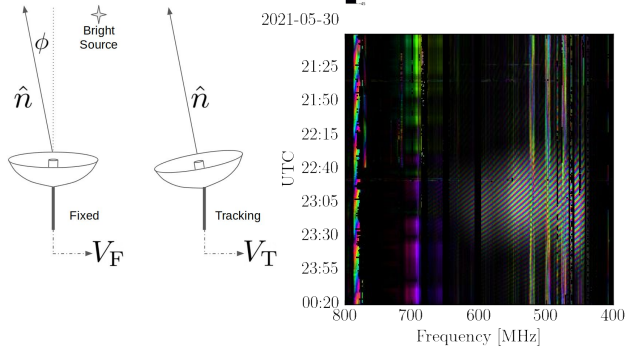


Credit: Pascal Hitz and Pascal Berner (ETHZ PhD Students) + Digital Twin group

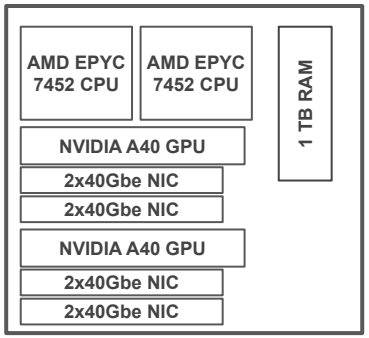
Other ETH work

- HIRAX Correlator and Science Data Processor
- Drone beam mapping
- Holographic Beam mapping





Christian Monstein, Thierry Viant, Tony Walters



Thierry Viant, Andre Renard, Keith Vanderlinde and others

ETH zürich

Thanks!