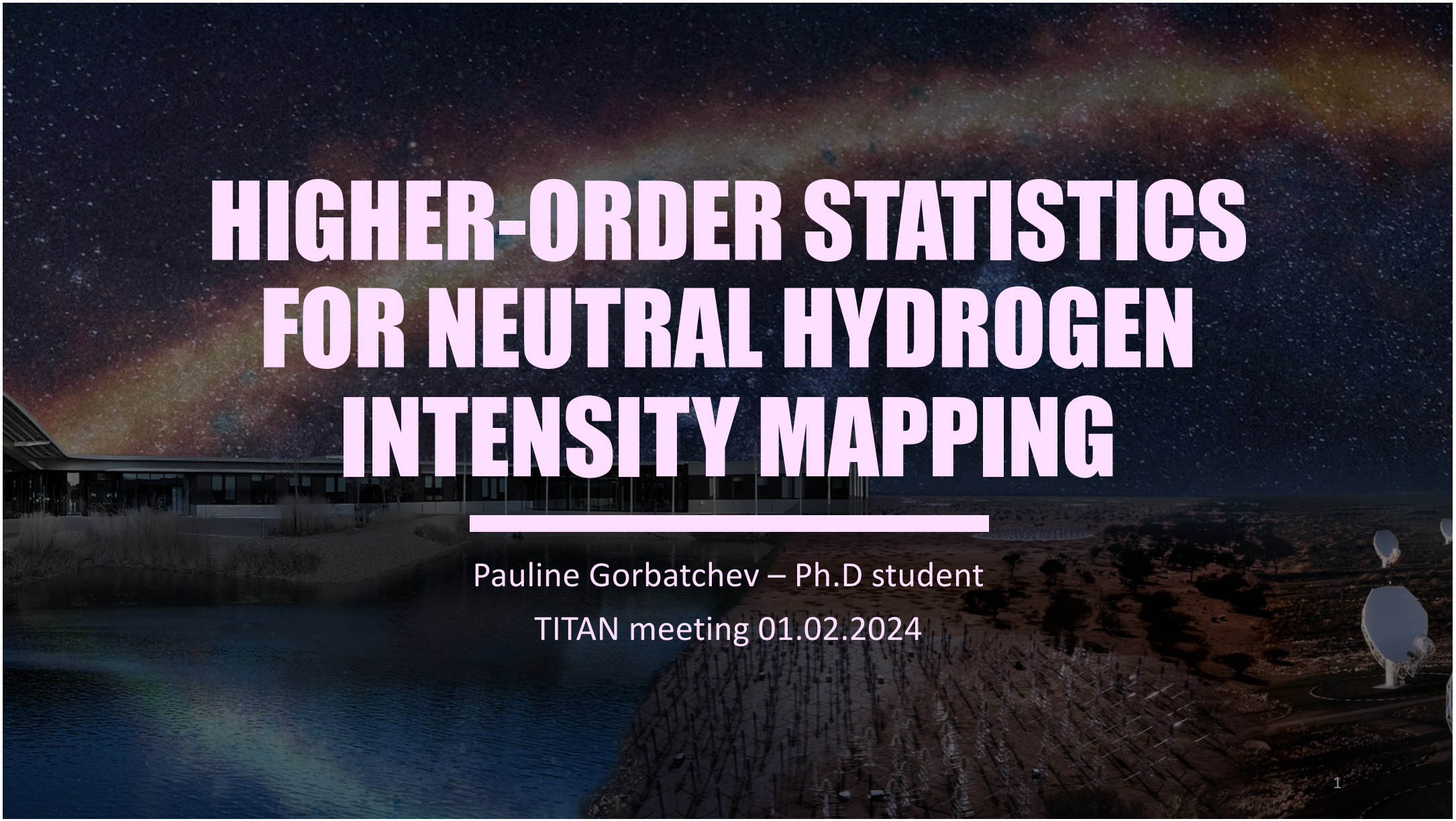
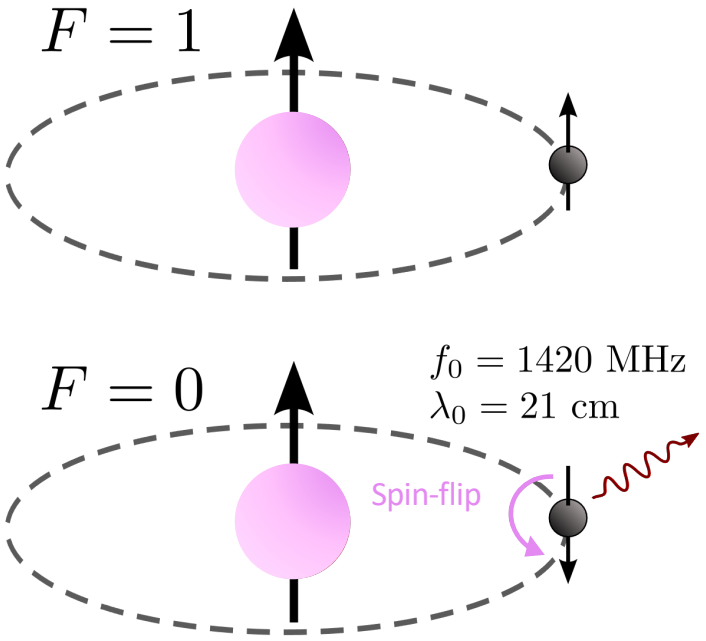


HIGHER-ORDER STATISTICS FOR NEUTRAL HYDROGEN INTENSITY MAPPING

Pauline Gorbatchev – Ph.D student

TITAN meeting 01.02.2024

Physics behind



HI hyperfine transition

- Hydrogen: most abundant element in the Universe
- After reionization, HI is located inside galaxies

$\Longrightarrow$ **biased tracer** of the underlying **matter distribution** of the Universe.

Why using 21 cm line ?

Benefits:

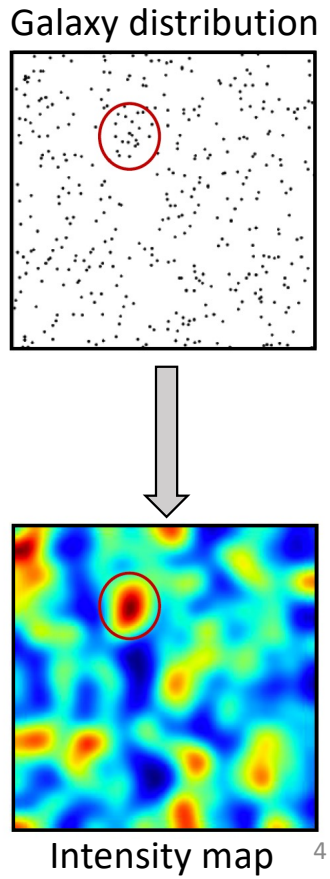
- The only astrophysical spectral feature in the L-band (GHz)
- Can be **measured from earth** (penetrate the atmosphere)
- thermal noise in HI surveys is less important than shot noise in galaxy surveys $\Longrightarrow$ HI analysis is **more constraining than galaxies**

Uses:

- Probe the **Dark Ages**
- Reconstruct **DM density fields**
- **Map 3D Large Scale Structures** of the Universe
- Complementary measurement to optical surveys to **constrain cosmological parameters**

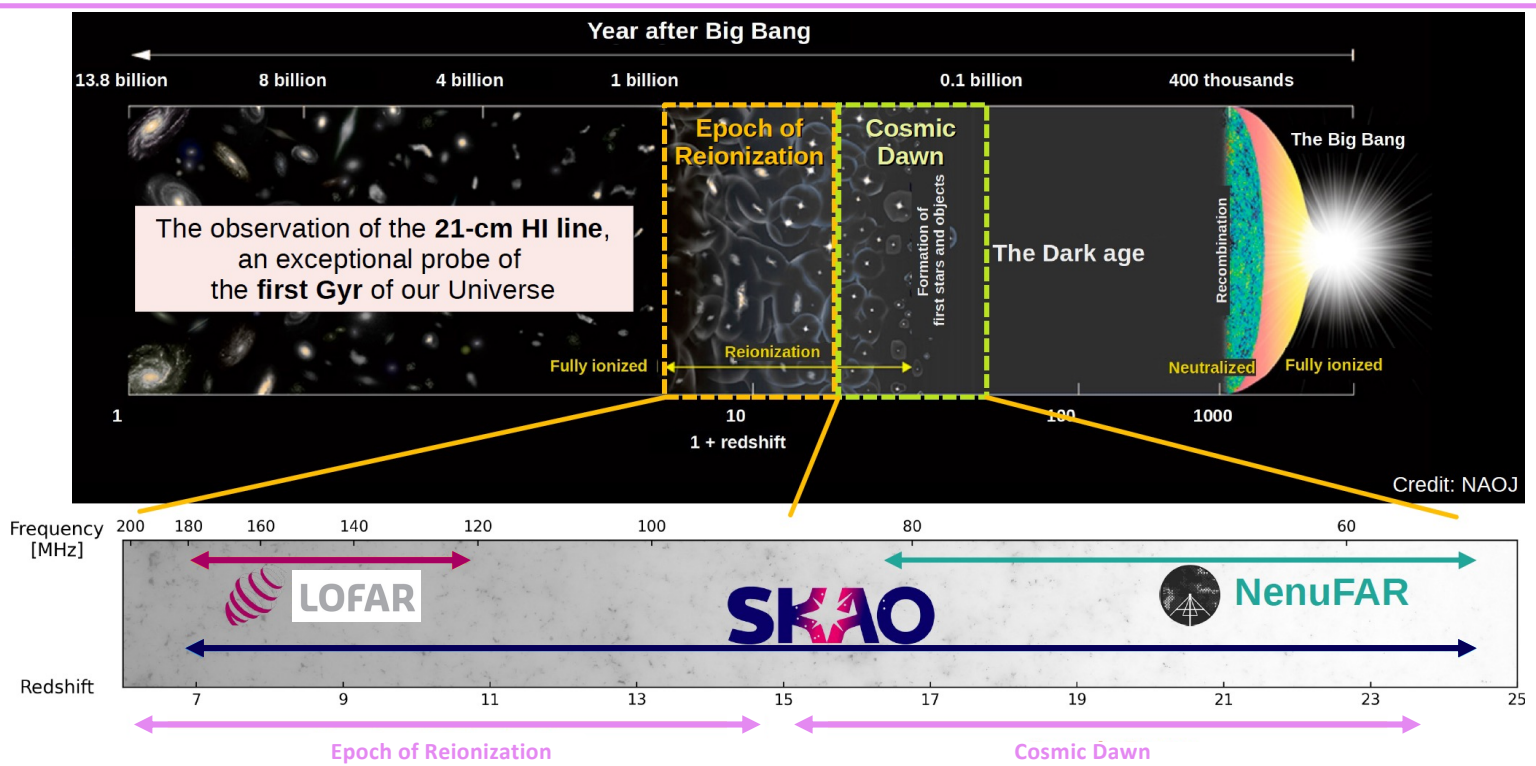
What is Intensity Mapping ?

- Measurement of redshift and intensity of HI over the **whole sky**
- Treats HI signal as a **diffuse background**
- Large cosmological volume
- Less costly, less time consuming
- High spectral resolution $\Longrightarrow$ **high redshift resolution**
- Individual galaxy detection not needed for LSS study.

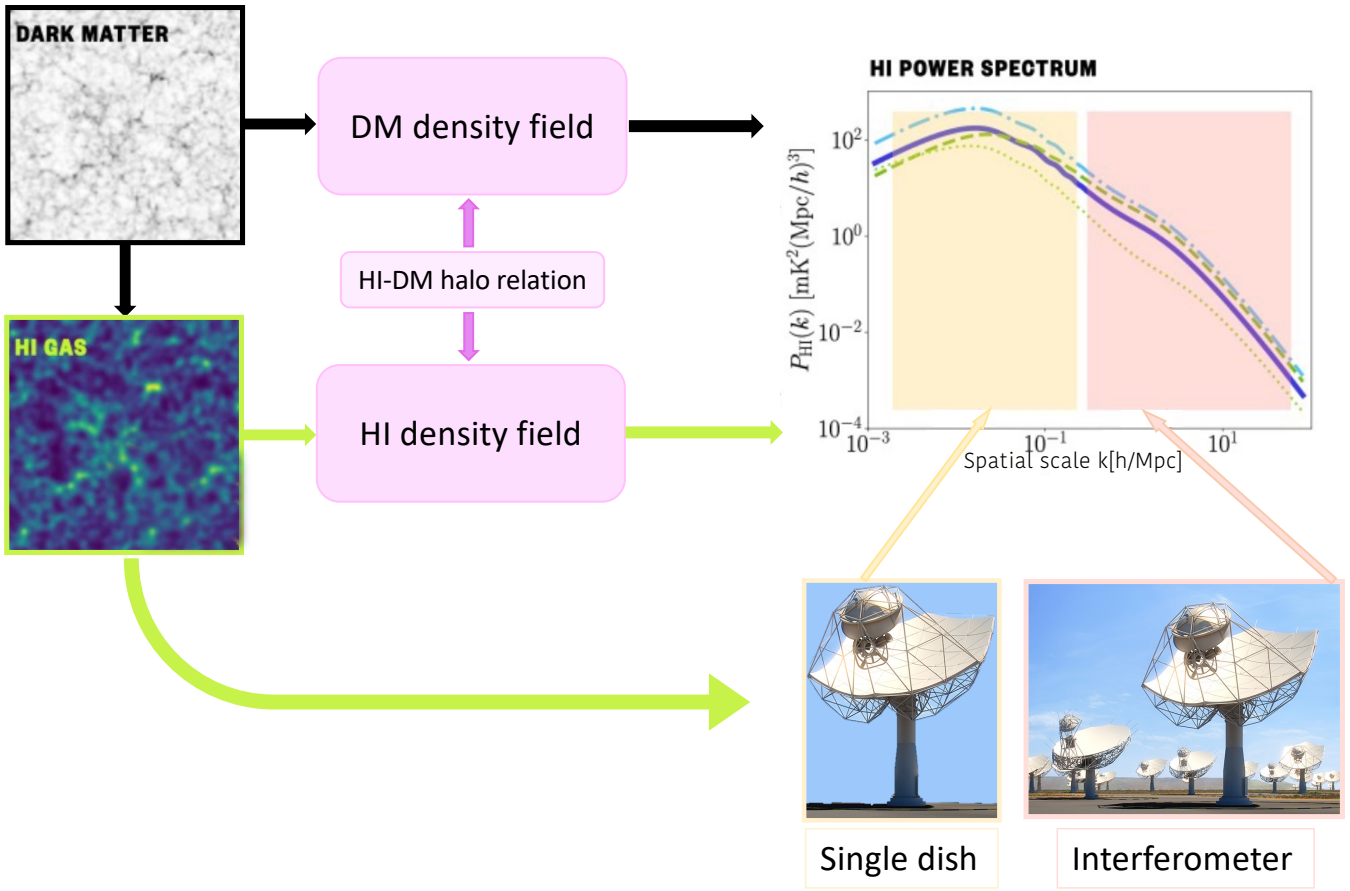


Latest advancements

- For now detection by **cross-correlation between galaxy and 21cm**
- **Not yet possible** to obtain a measurement of the **21cm auto-Power Spectrum**



Inferring the Power Spectrum



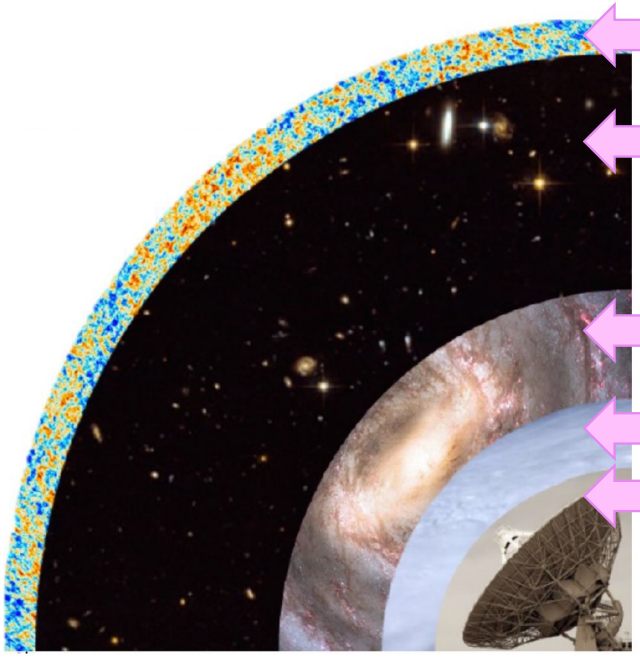
Challenges of HI IM

Foregrounds:

- Synchrotron emission (high energy electrons accelerated by magnetic fields).
- Extra-galactic point sources (Active Galactic Nuclei).
- Galactic/extra galactic free emissions (electrons scattered by ions).
- **4 orders of magnitude higher than the signal !**

$\Longrightarrow$ Foreground removal needed

End to end measurements



- 21 cm signal
- Extra galactic emission (AGNs)
- Galactic emission (Milky Way synchrotron)
- Ionosphere
- Instrumental effects

→ Signal

↓

Analysis pipeline

- Foreground cleaning
- Noise cleaning

↓

Power spectrum

↓

Cosmological parameters constraints

↓

Ω_b, Ω_m, Ω_Λ, σ_8, f_{NL}, Σm_ν, H_0...

Foreground removal

Foregrounds have a smooth variation of the brightness with frequency

$\Longrightarrow$ make use of the spectral smoothness

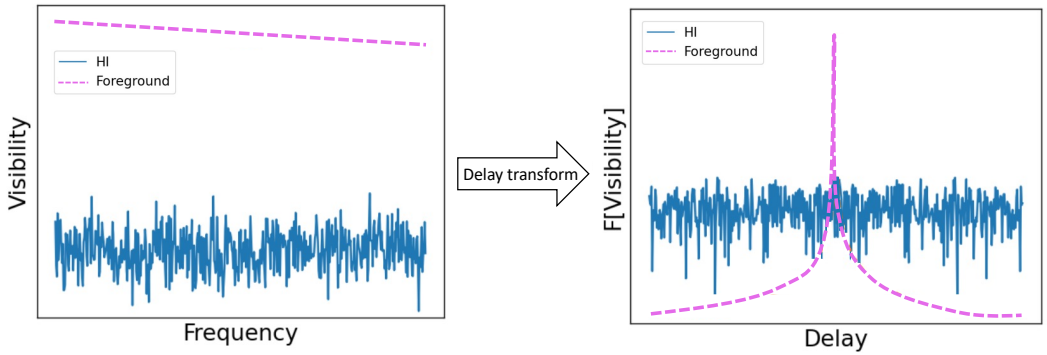
Single dish

Component separation:

- Principal Component Analysis
- Wavelet decomposition
- Gaussian Process Regression
- Bayesian approaches
- Blind source separation…

Interferometer

Delay transform: V(u,v,ν) -> V(u,v,τ)



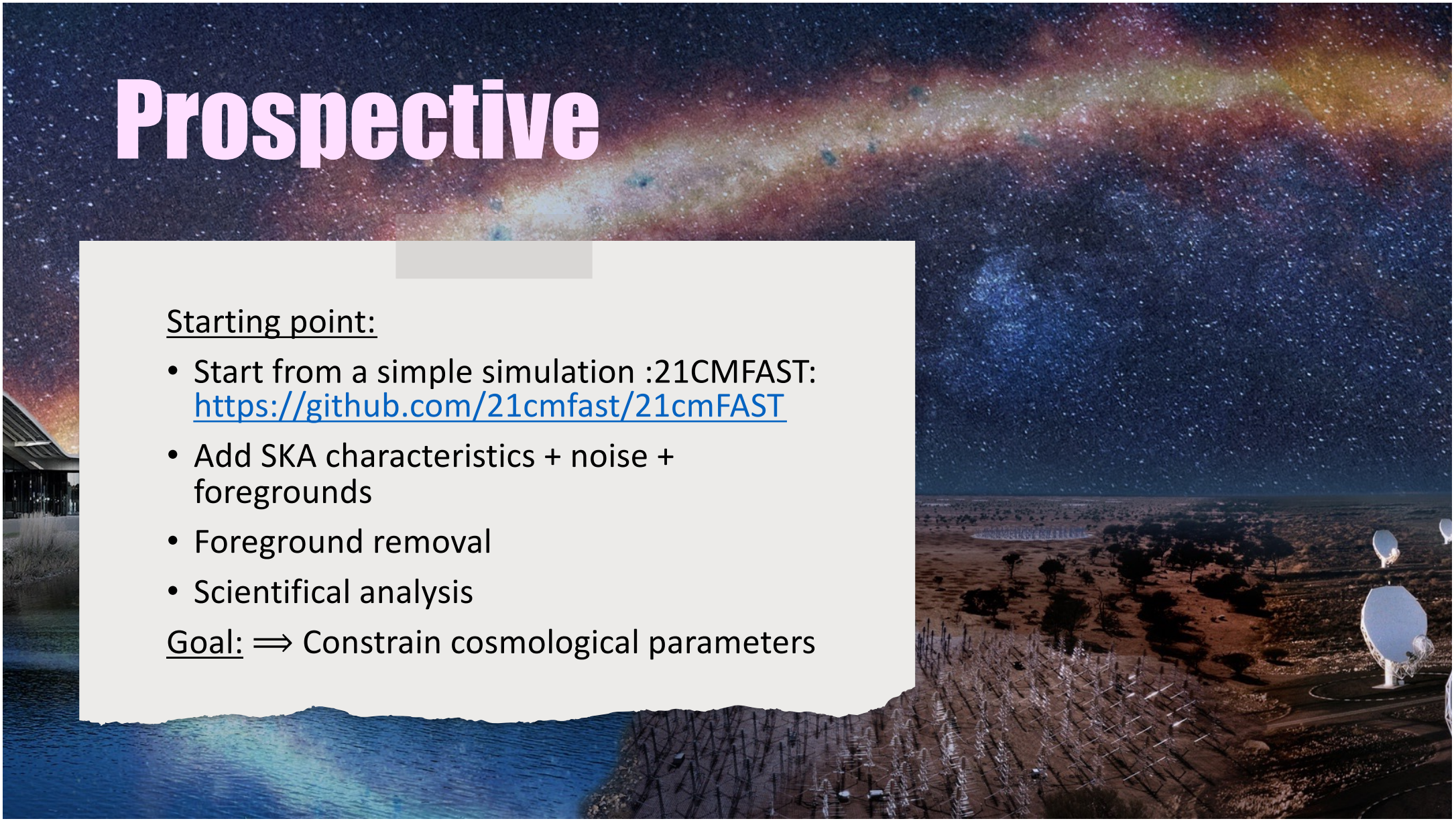
In reality instrumental effects and calibration errors mix the foregrounds and the signal together.

Higher order statistics

Second order statistics (Power spectrum, two-point correlation function…) **cannot capture the Non-Gaussianities** that appear after Early times of the Universe.

⇒ **Need third order statistics**: Bispectrum, three-point correlation function, l1-norm... in order to study the evolution of the Universe.

Prospective



Starting point:

- Start from a simple simulation :21CMFAST: https://github.com/21cmfast/21cmFAST
- Add SKA characteristics + noise + foregrounds
- Foreground removal
- Scientifical analysis

Goal: $\Longrightarrow$ Constrain cosmological parameters

References

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- Foreground Leakage from Calibration Errors in Interferometric MeerKAT 21cm Observations, Zhaoting Chen, University of Edinburgh, 2024.

All pictures were modified following my needs for the presentation