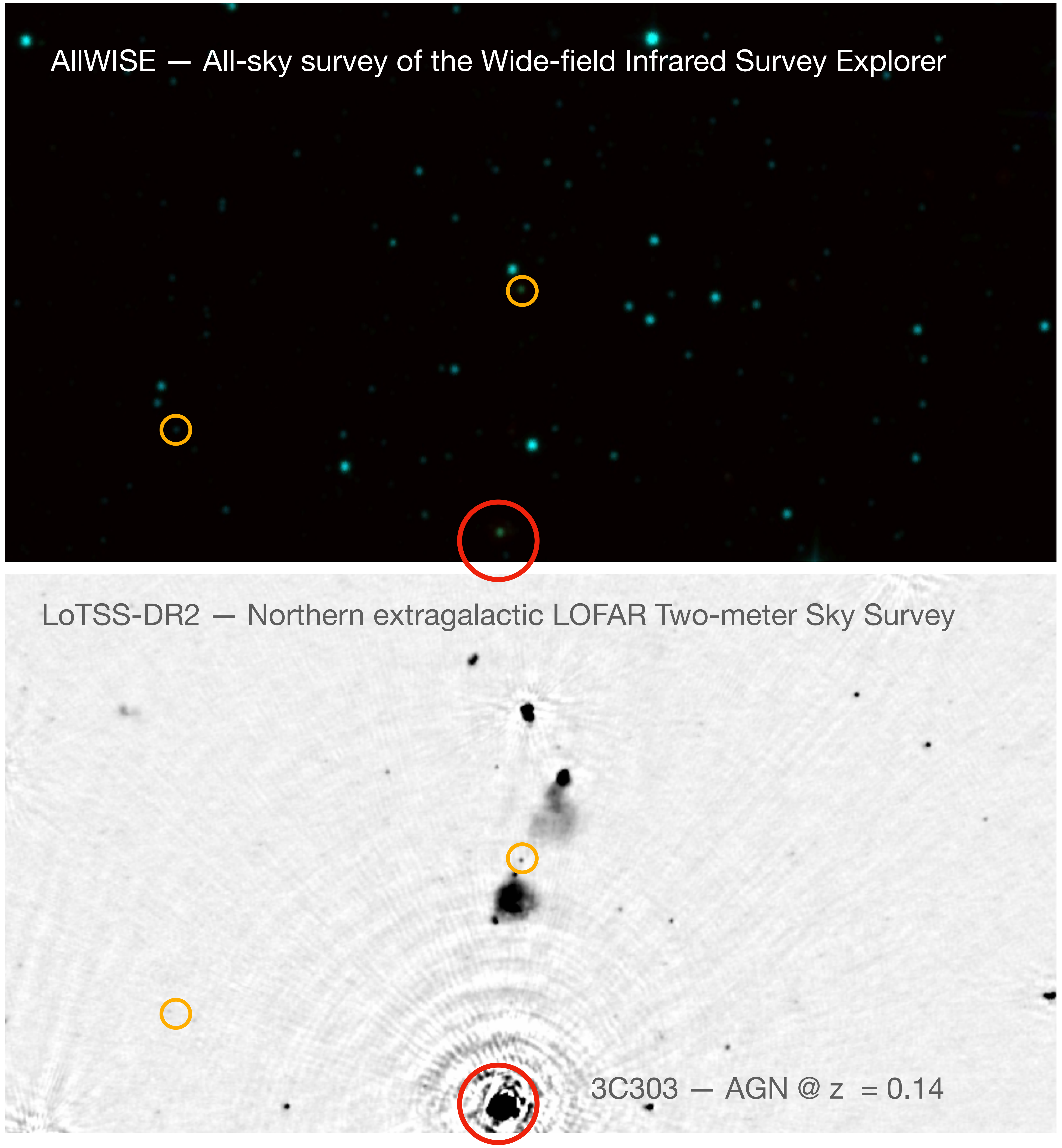
UNIVERSITÄT BIELEFELD

Faculty of Physics

Multi-Messenger Cosmology

Dominik Schwarz

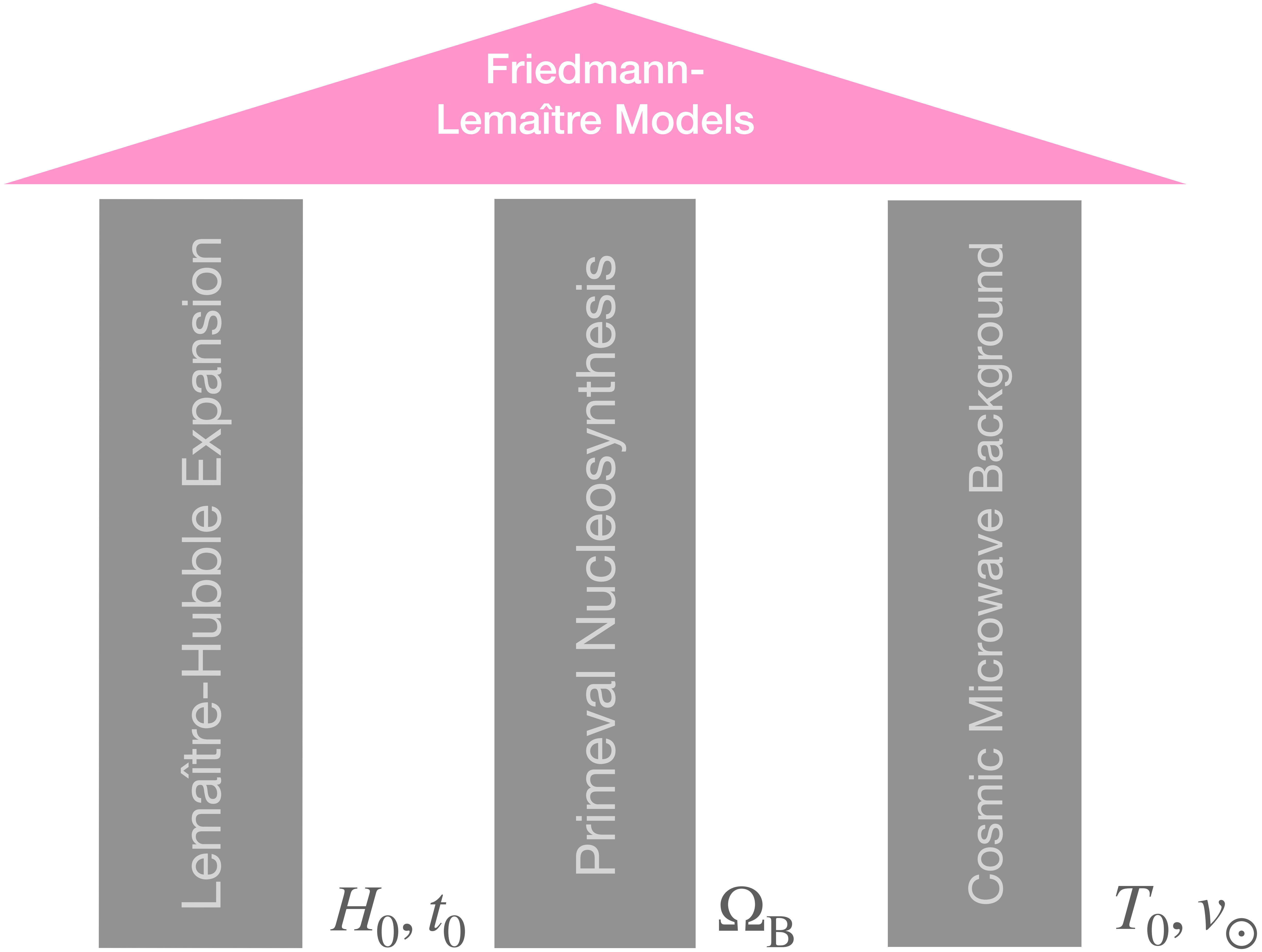
Multi-Messenger Astrophysics 2024, Görlitz



Images prepared with ESA-Sky tool

Cosmology — a traditional multi-messenger science

The three classical pillars (already in last century)



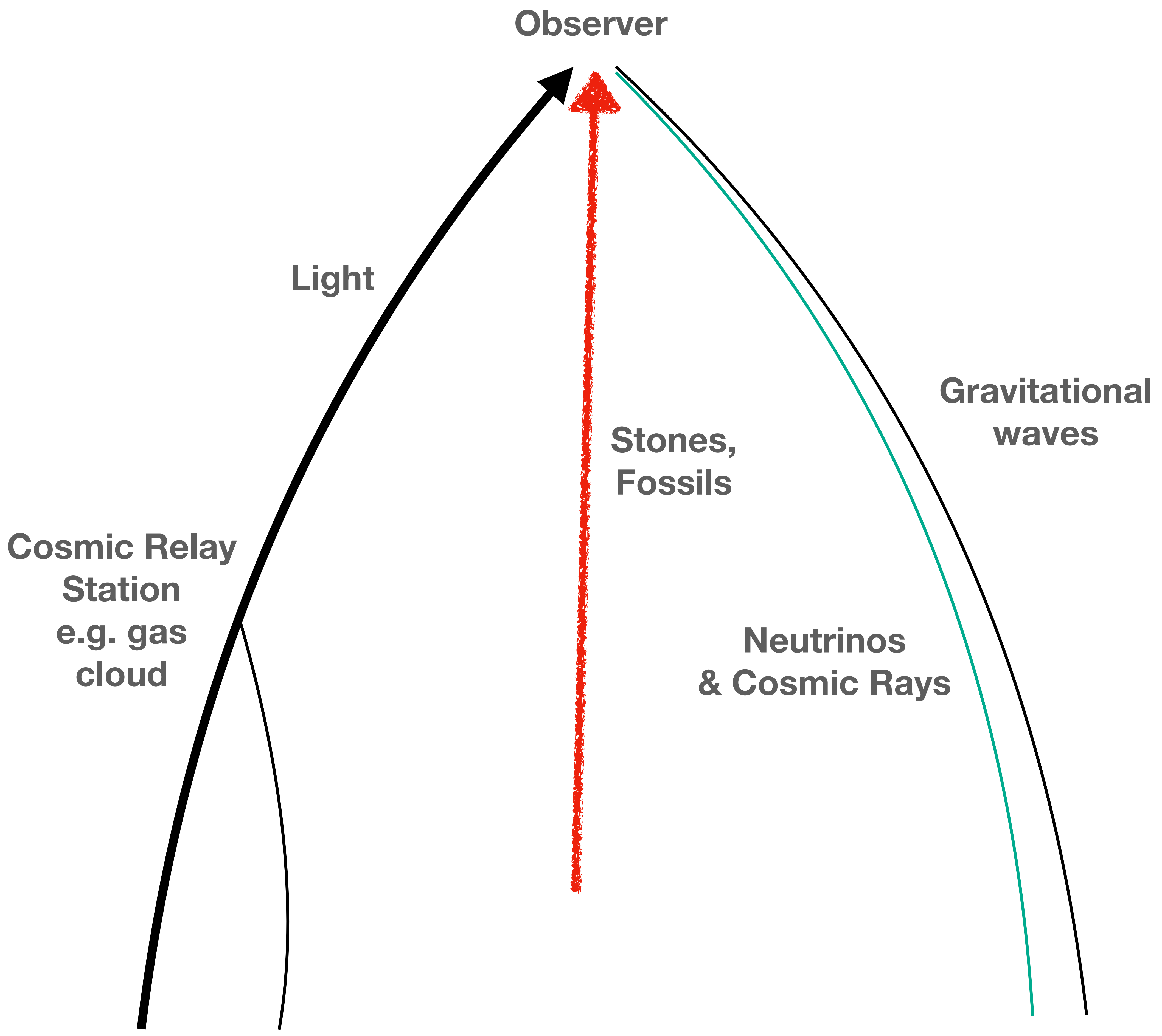
Lemaître-Hubble expansion
cepheids, SN1a, …

Primeval Nucleosyntheis
element abundance

Cosmic Microwave Background
spectrum, monopole & dipole

Why Multi-Messenger Cosmology

What could we learn?



Understand the evolution of the Universe

Solve equations of motion
for initial conditions
and compare to data.
Improve model and start over.

Multiple messengers
to maximise space-time coverage.

Multi-Messenger Cosmology

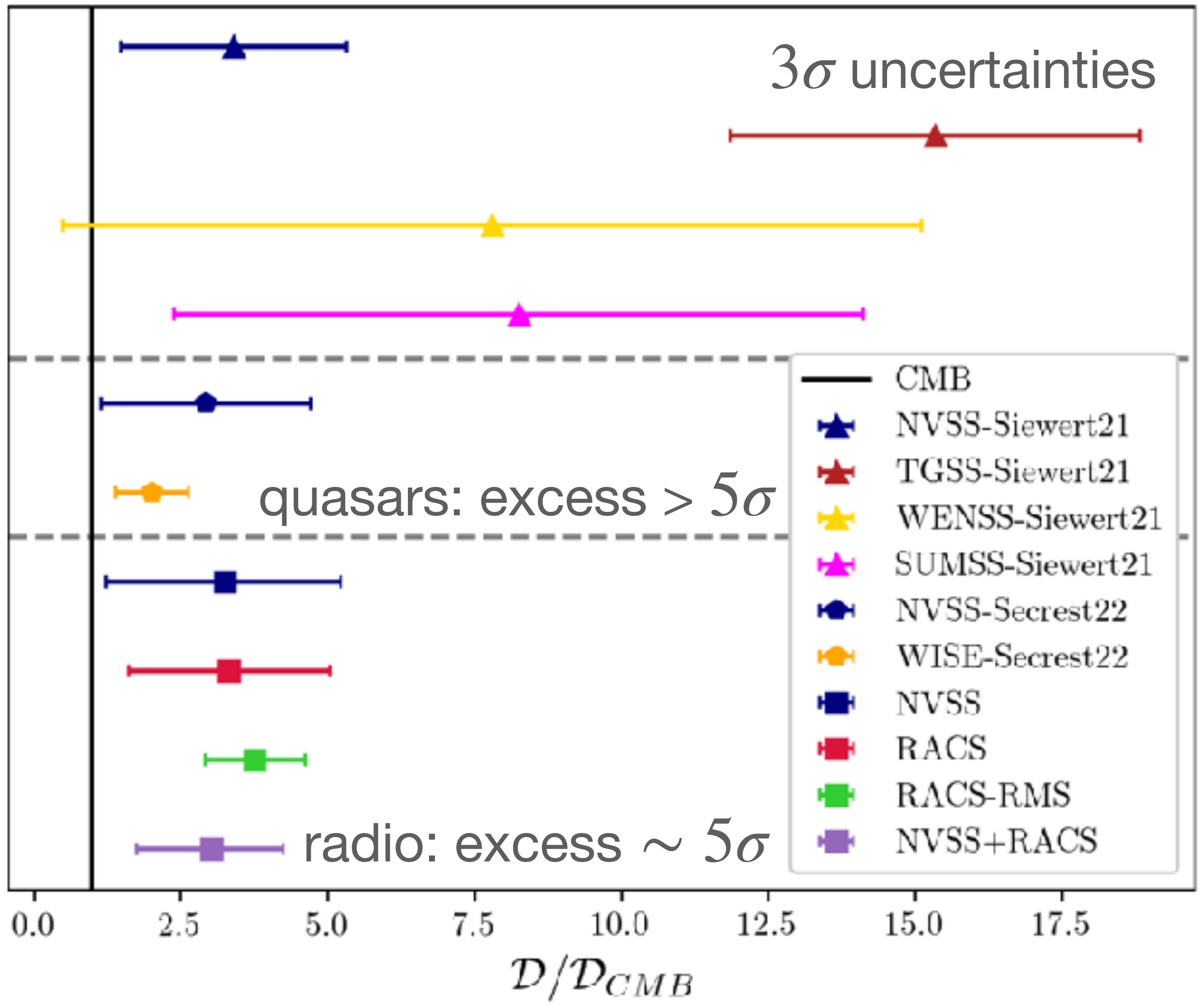
The current state

- **Cosmological Principle** — allows predictions without initial conditions
- **Lambda Cold Dark Matter** model allows us to describe all observations, but leaves us with 95% of unknowns in its energy budget
- **Cosmological parameters** from individual missions (Planck, Euclid, …)
- Combination of **multi-wavelength** and **multi-messenger probes** naturally leads to tensions, $H_0, S_8,$ curvature, matter dipole, …
- In the following 3 examples for synergies

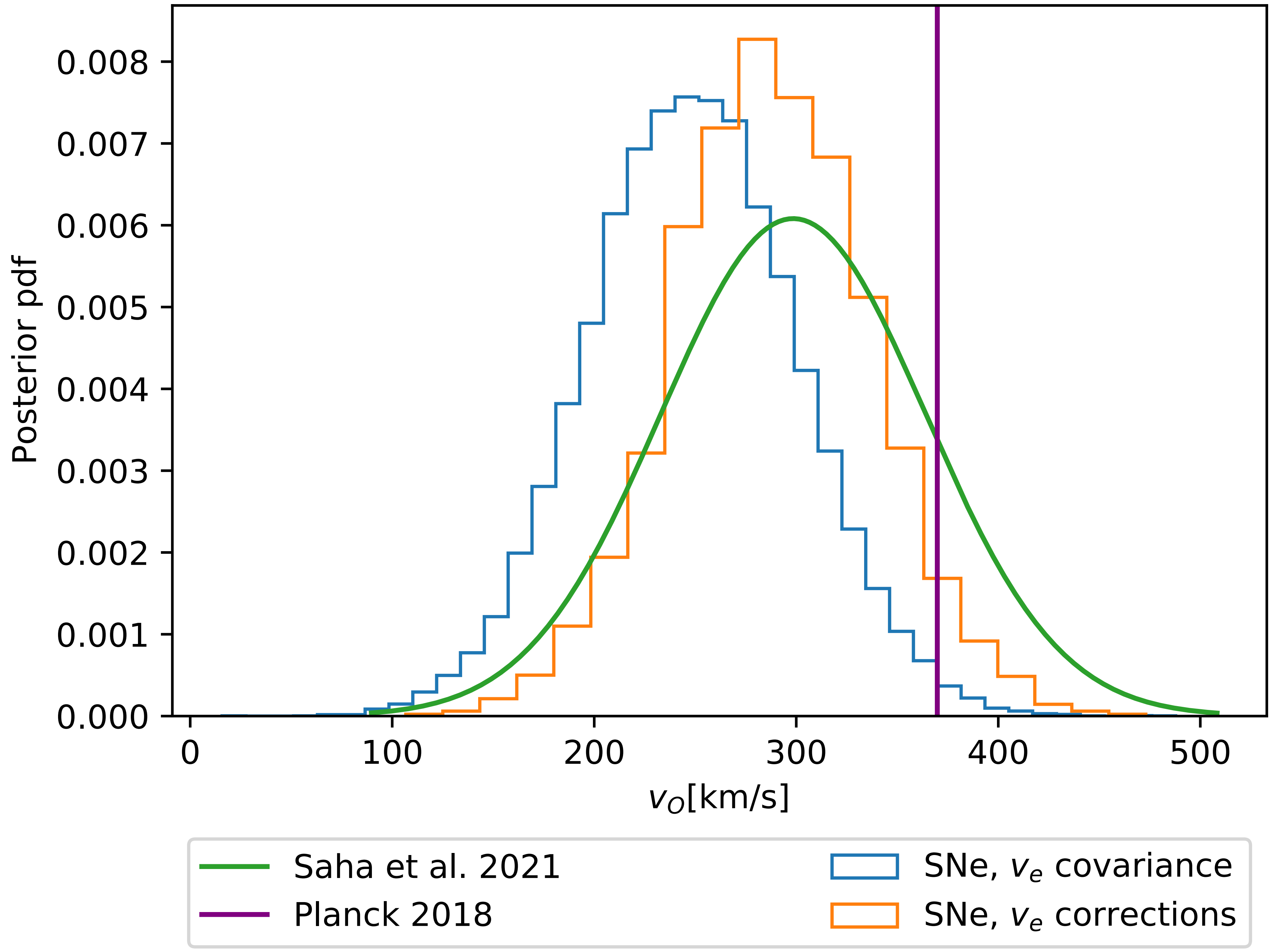
Cosmological Principle

Proper motion of Solar system

- Kinematic CMB dipole Steward & Sciama 1967
- Radio sources and quasars Ellis & Baldwin 1984
- SN1a Sasaki 1987
- …
- LOFAR & SKA



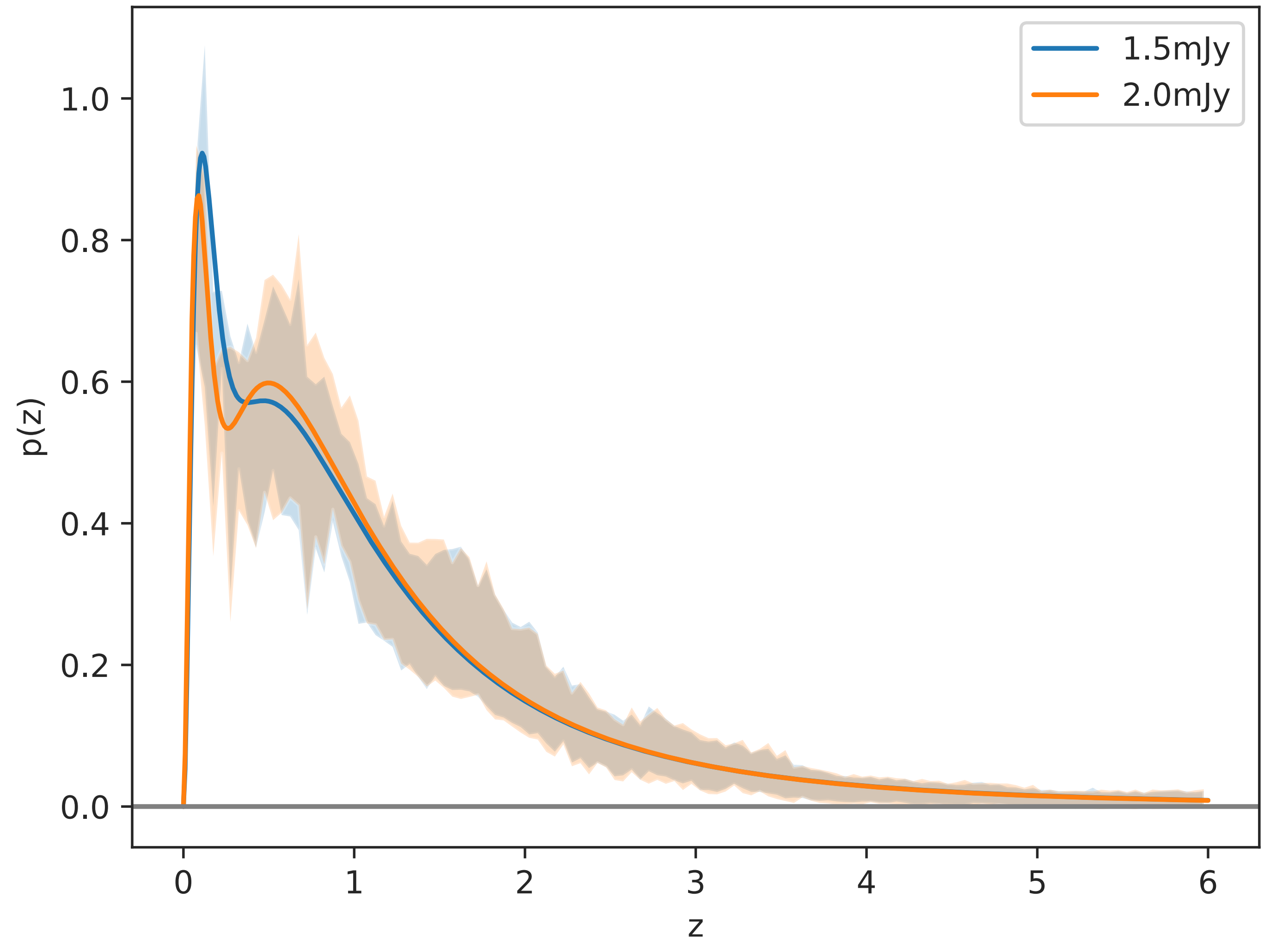
radio and quasar **source count dipole direction agrees, amplitude disagrees with CMB**
Wagenveld, Klöckner, Schwarz 2023



Pantheon compilation of SN1a **consistent with CMB**
Horstmann, Pietschke, Schwarz 2022

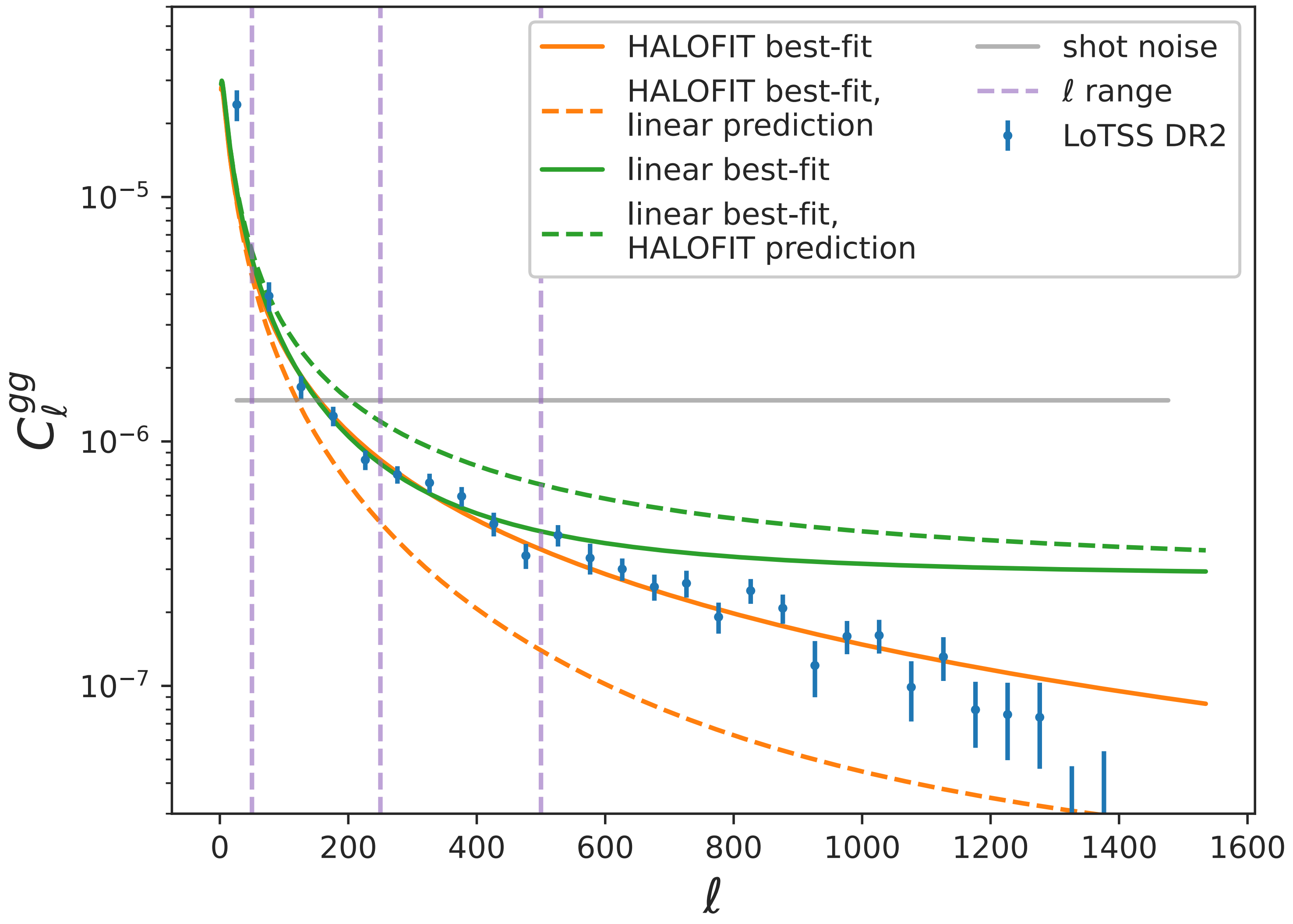
Large Scale Structure

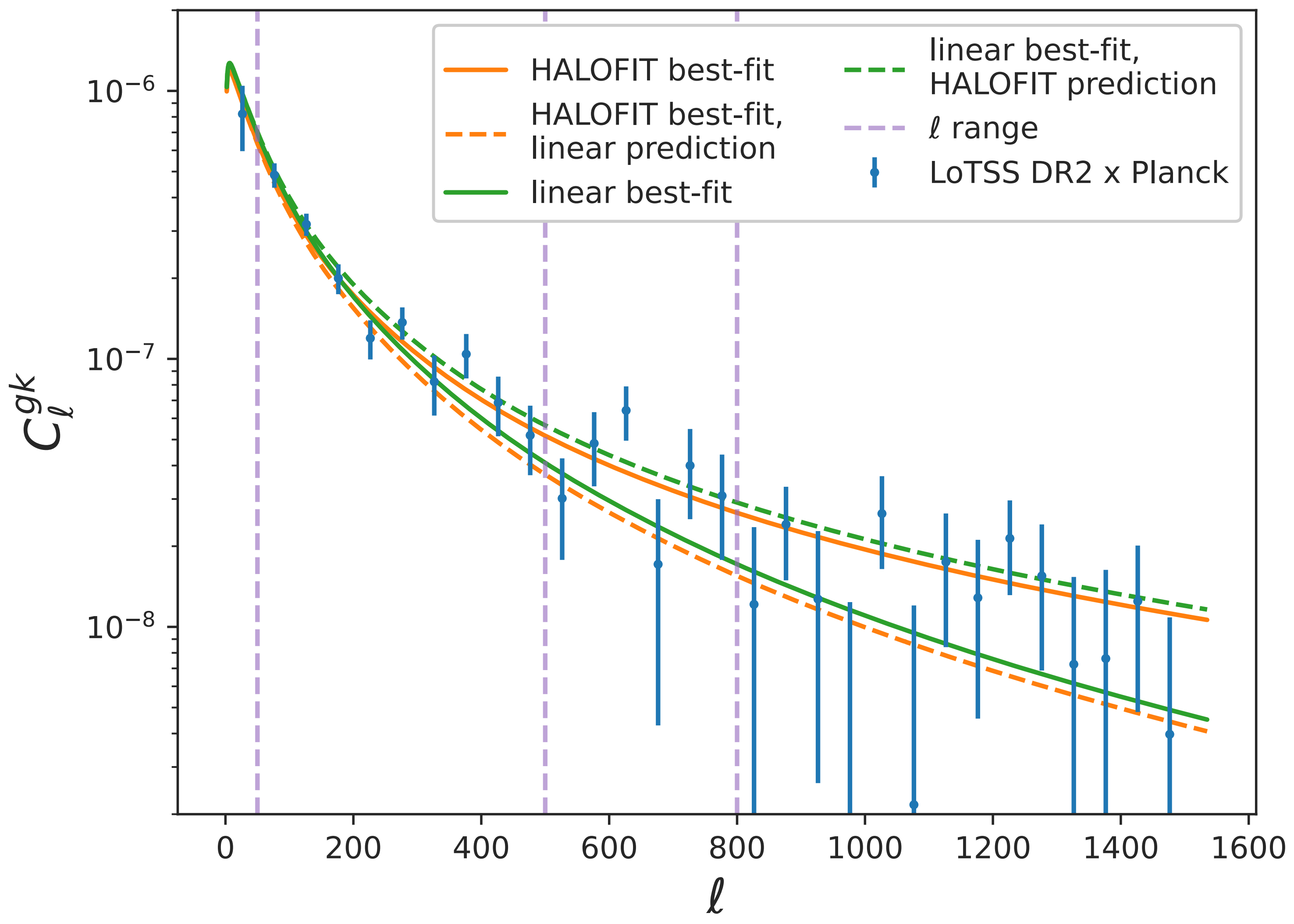
Synergies Now: LOFAR, Planck and photo-z — Soon: LOFAR2.0 & Euclid

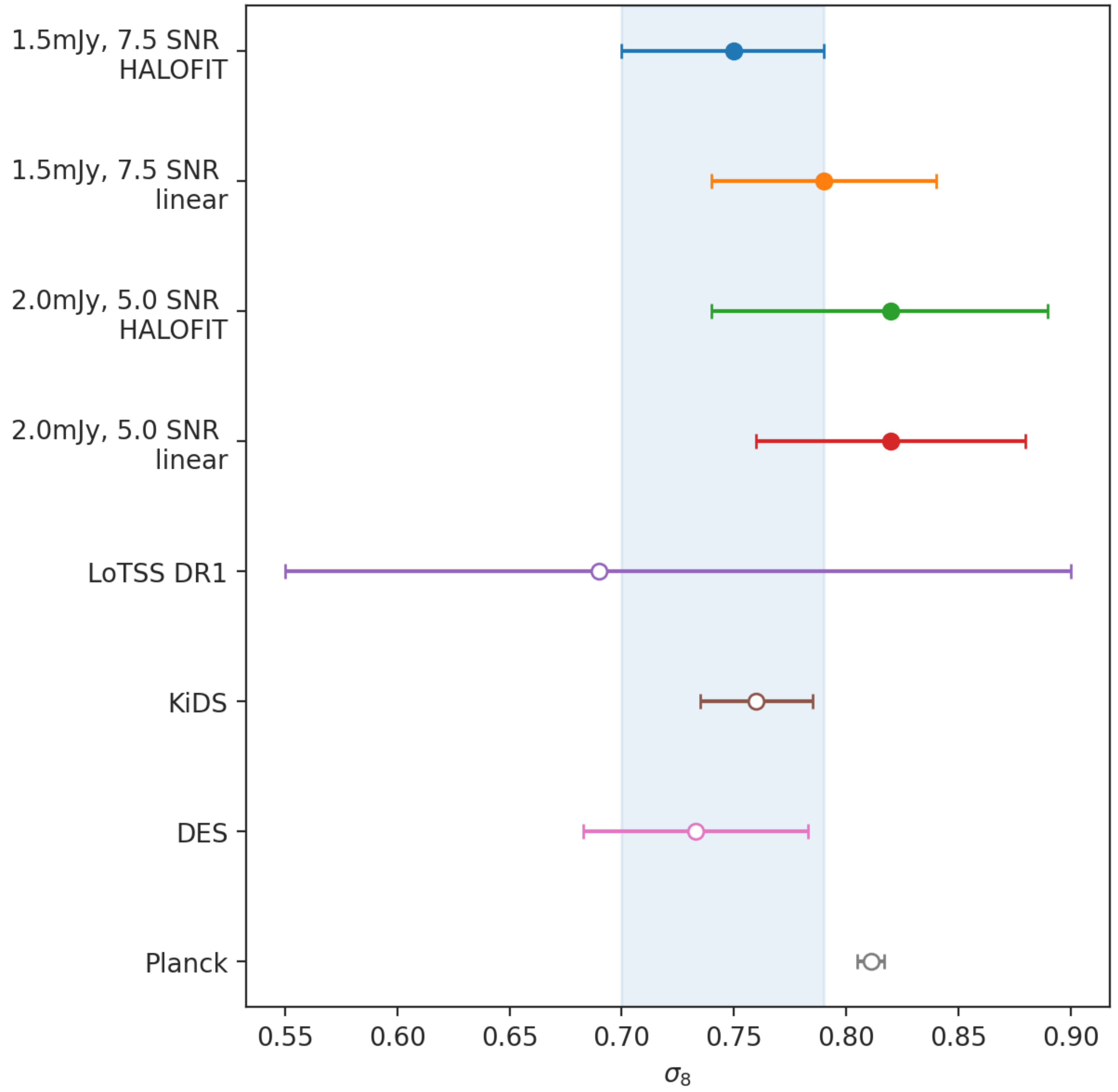


p(z) from LoTSS deep fields
stacked photo-z posteriors

LoTSS DR2 galaxy-galaxy and **galaxy-Planck lensing convergence** angular power spectra







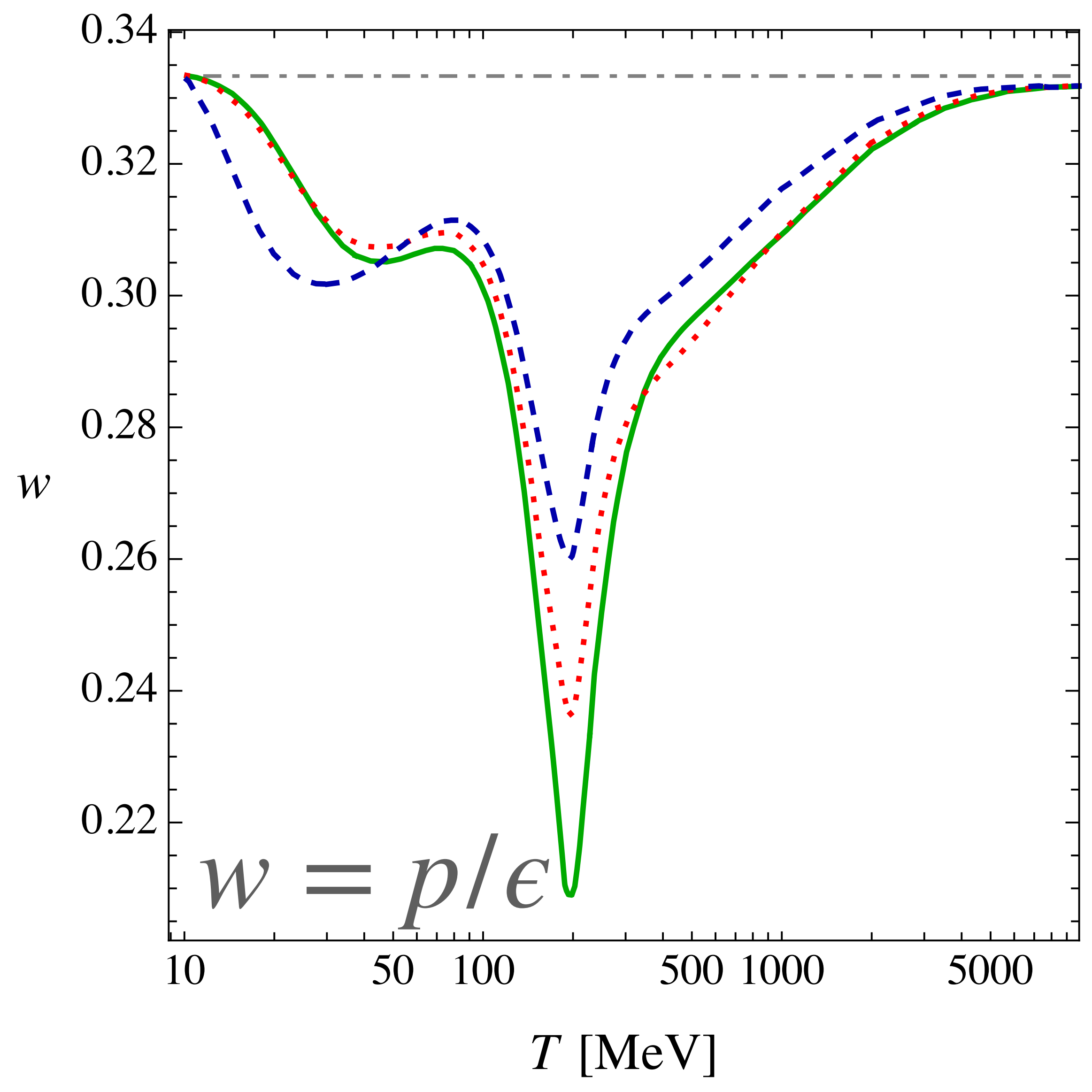
LoTSS DR2 assessment of σ_8 tension
LoTSS DR3 will reduce errors by factor of 1.7
Nakoneczny et al. 2024

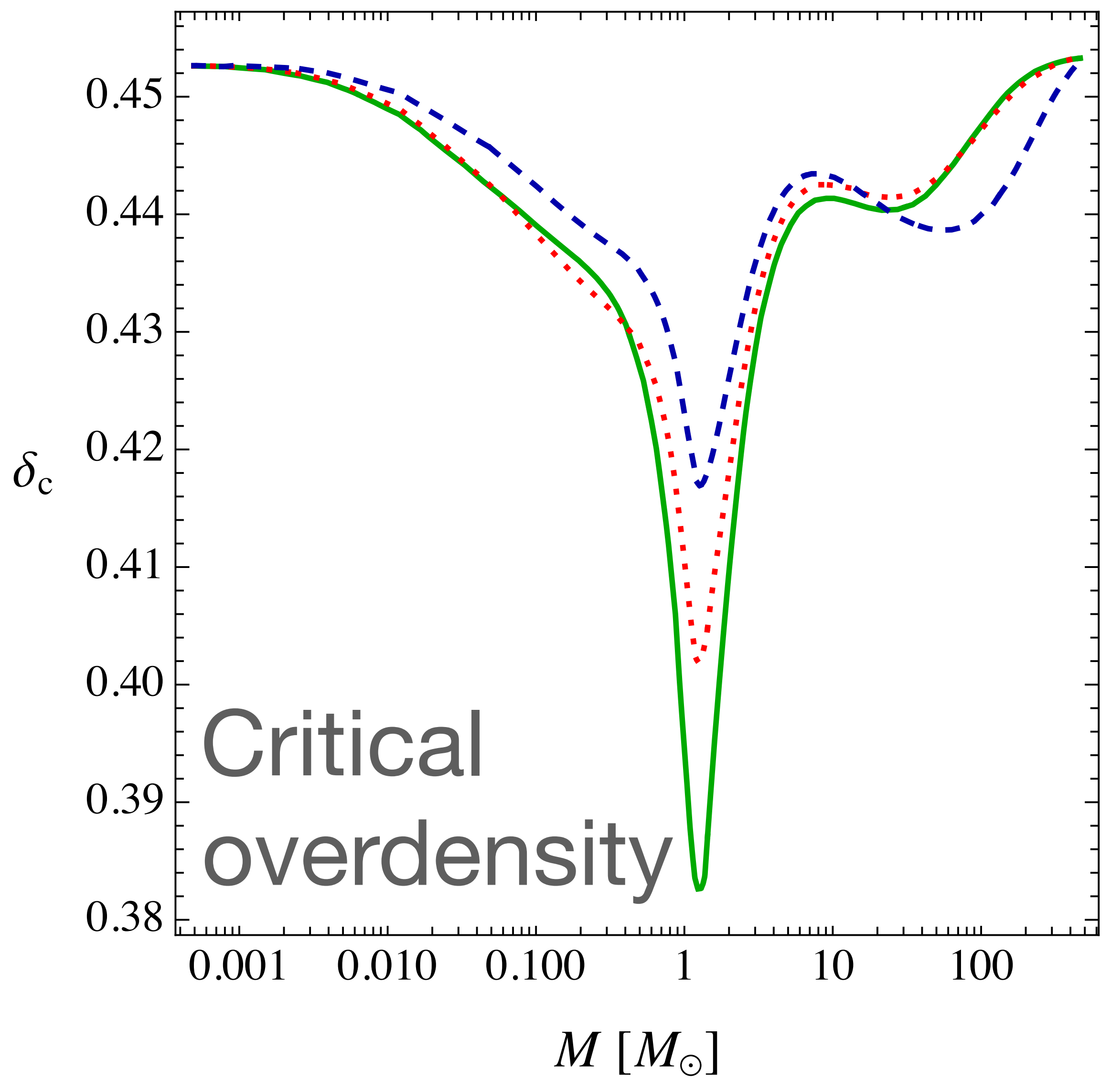
A window to the very early Universe

Lepton asymmetry, primordial black holes, and LIGO/VIRGO data

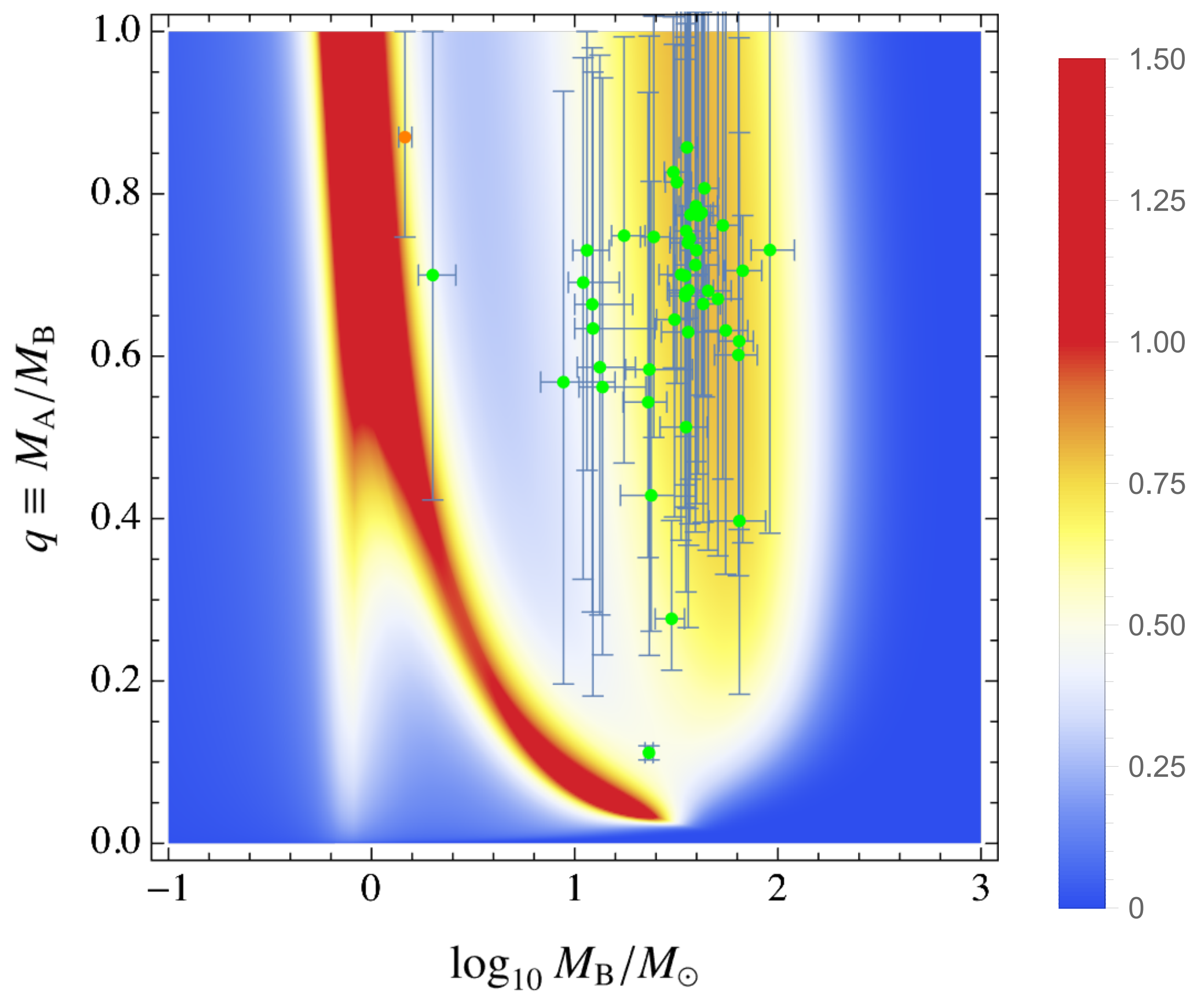
Unknown lepton (flavour) asymmetry of Universe
Influences cosmic QCD epoch @ $T \sim 150$ MeV

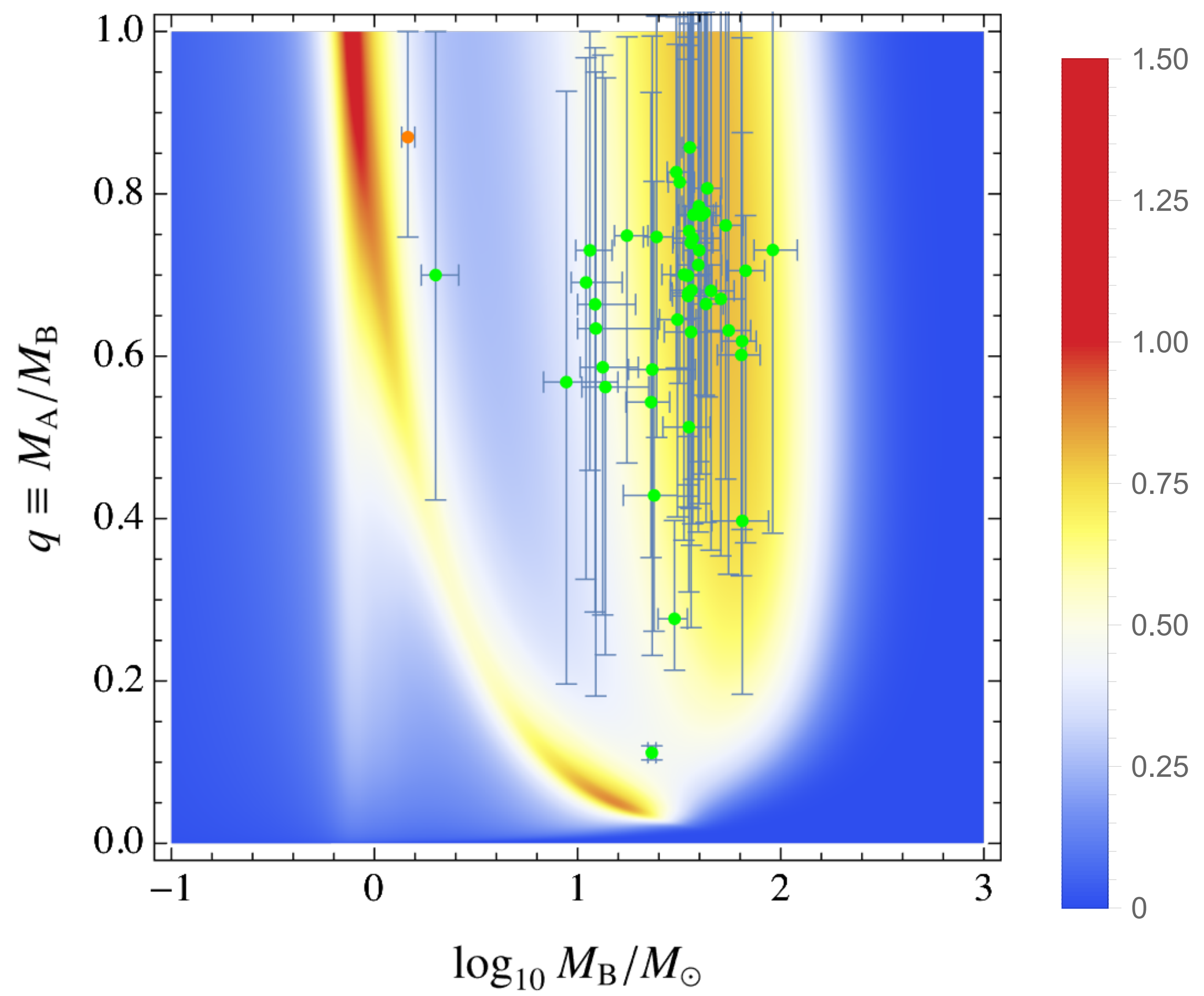
equation of state softens at **QCD transition** and **pion/muon annihilation** epoch ⇒ **PBHs**





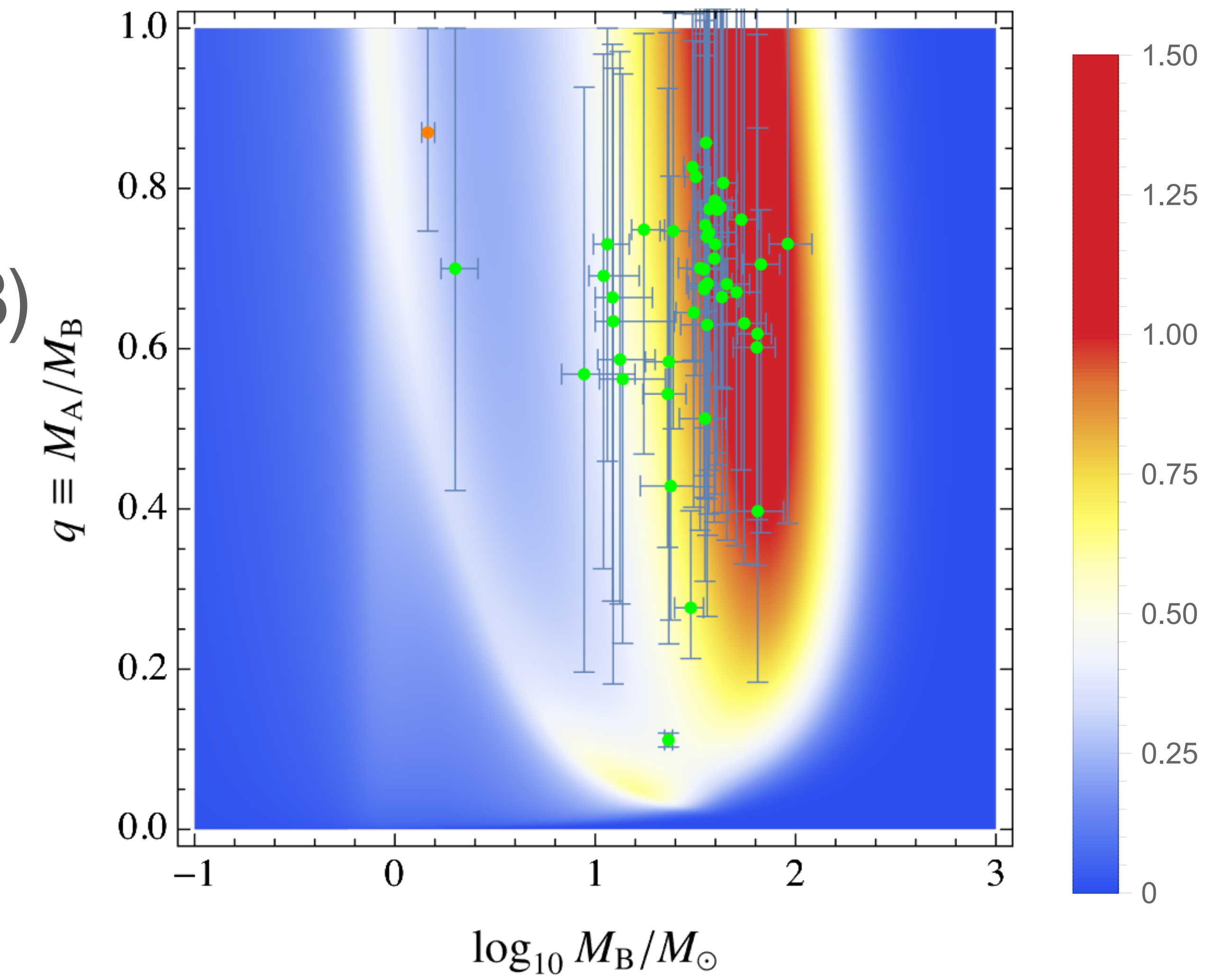
Green: lepton asymmetry follows baryon asymmetry l = 51/28 b
Red: l = 0, but large lepton flavour asymmetry in μ and τ
Blue: l = 0, but large lepton flavour asymmetry in e, μ, and τ





Prediction of PBHBM as function of lepton asymmetry
Compare to LIGO/VIRGO (O1-3) black hole population

Bödeker, Kühnel, Oldengott, Schwarz 2021



Conclusions

Opportunities for the DZA

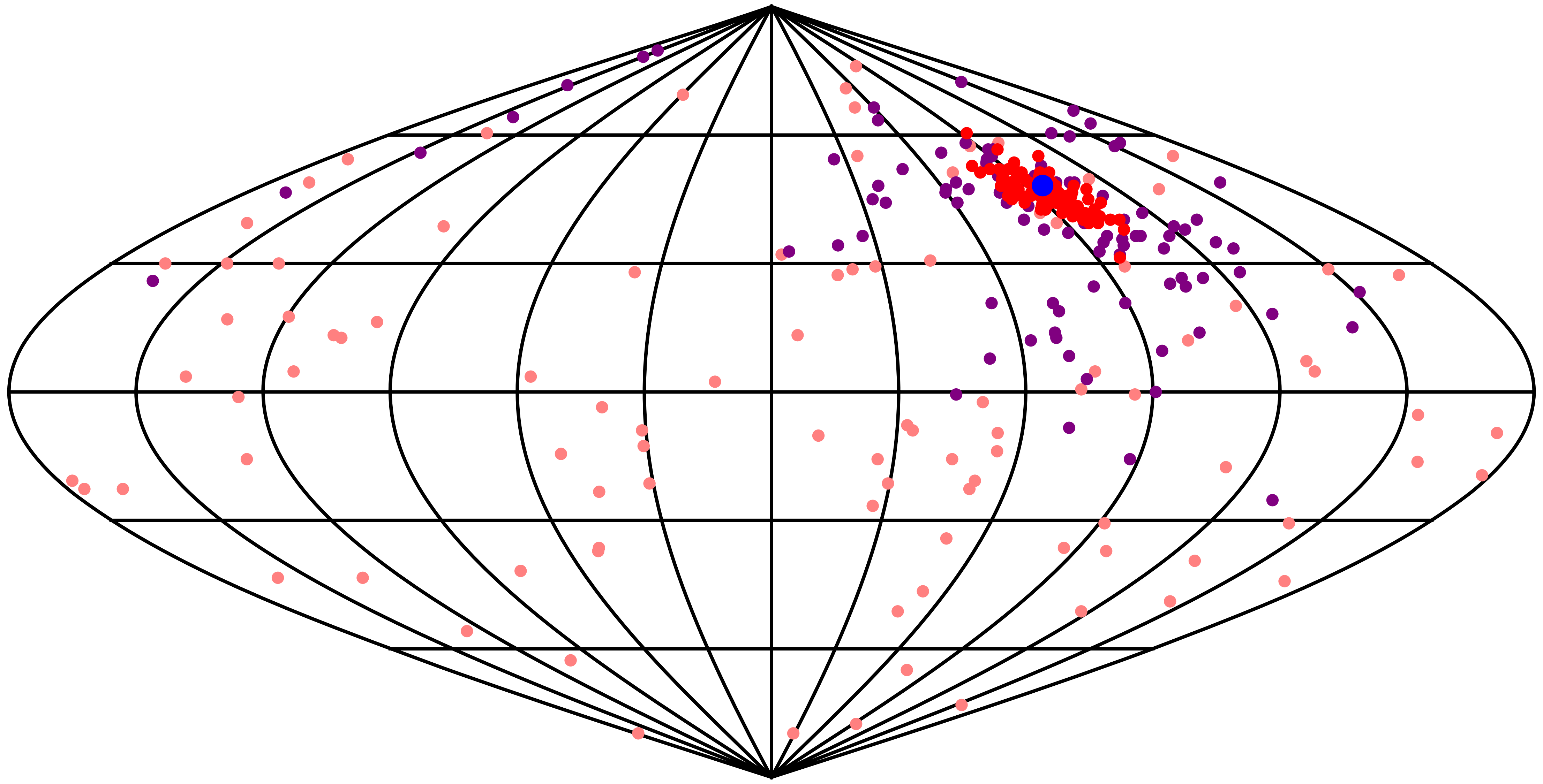
- **Excess source count dipole** needs to be understood, same for $H_0, \sigma_8, \ldots$
- Check „established“ cosmology by independent methods
- Look into data that do not address your science question
  — you might find an answer

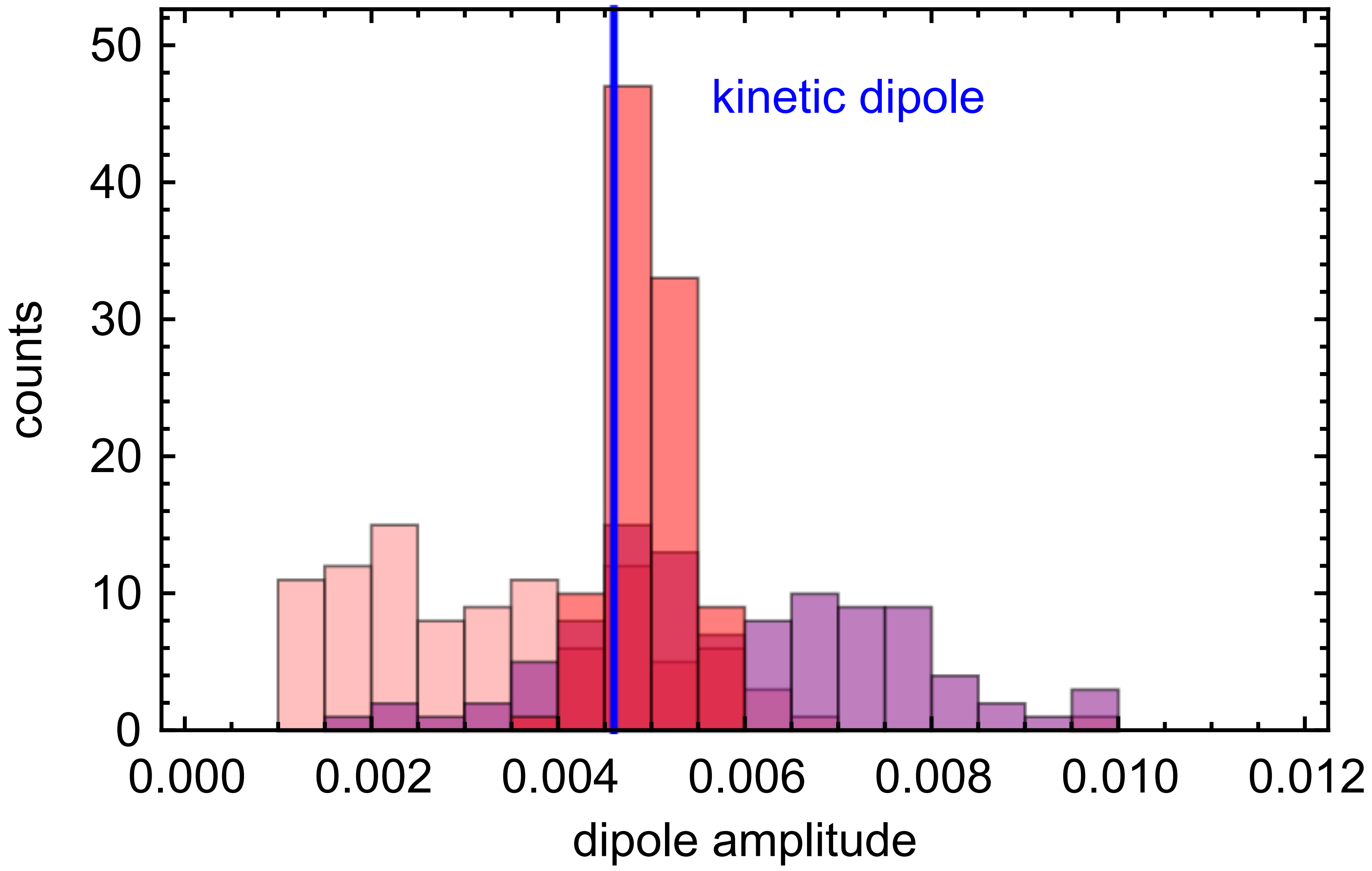
- Combining **SKA** and **ET** @ DZA offers fantastic potential for many **synergies**
- **Instrumentation**, **pipelines**, and **data analysis** need **theory** to maximise RoI

Backup

Cosmic source count dipole forecasts for SKA

- CMB dipole
- structure dipole
- kinematic & structure dipole
- kinematic & structure dipole, w/o local structure

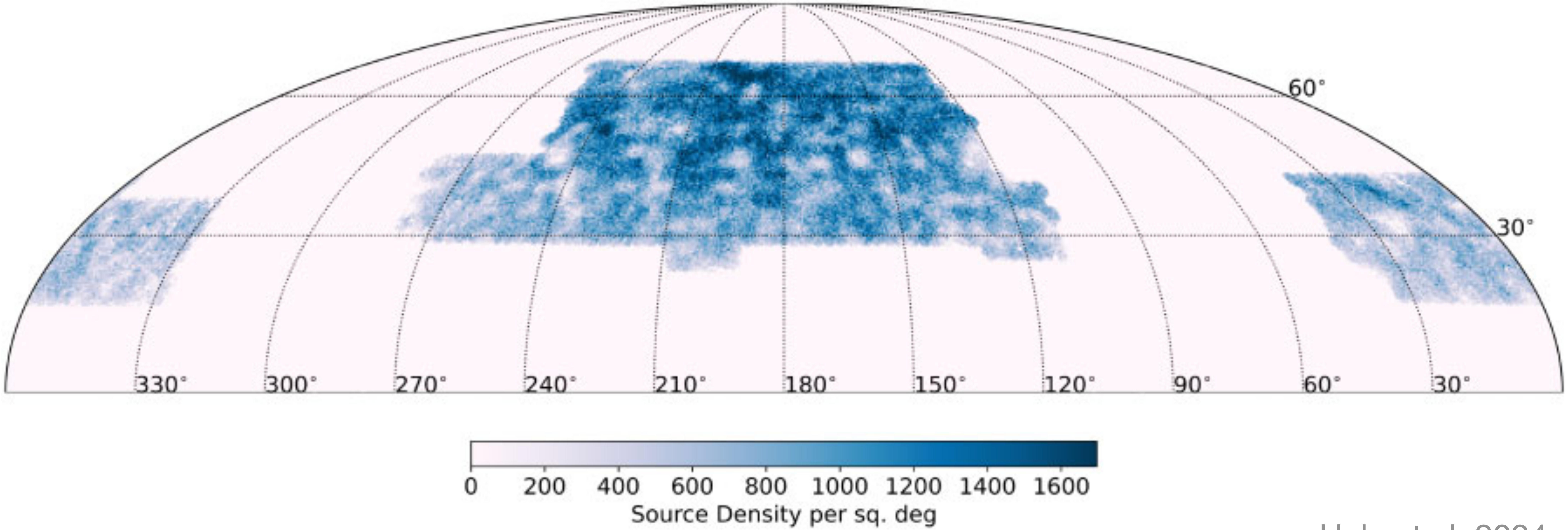




SKA Cosmology SWG: Bacon et al. 2020

Backup

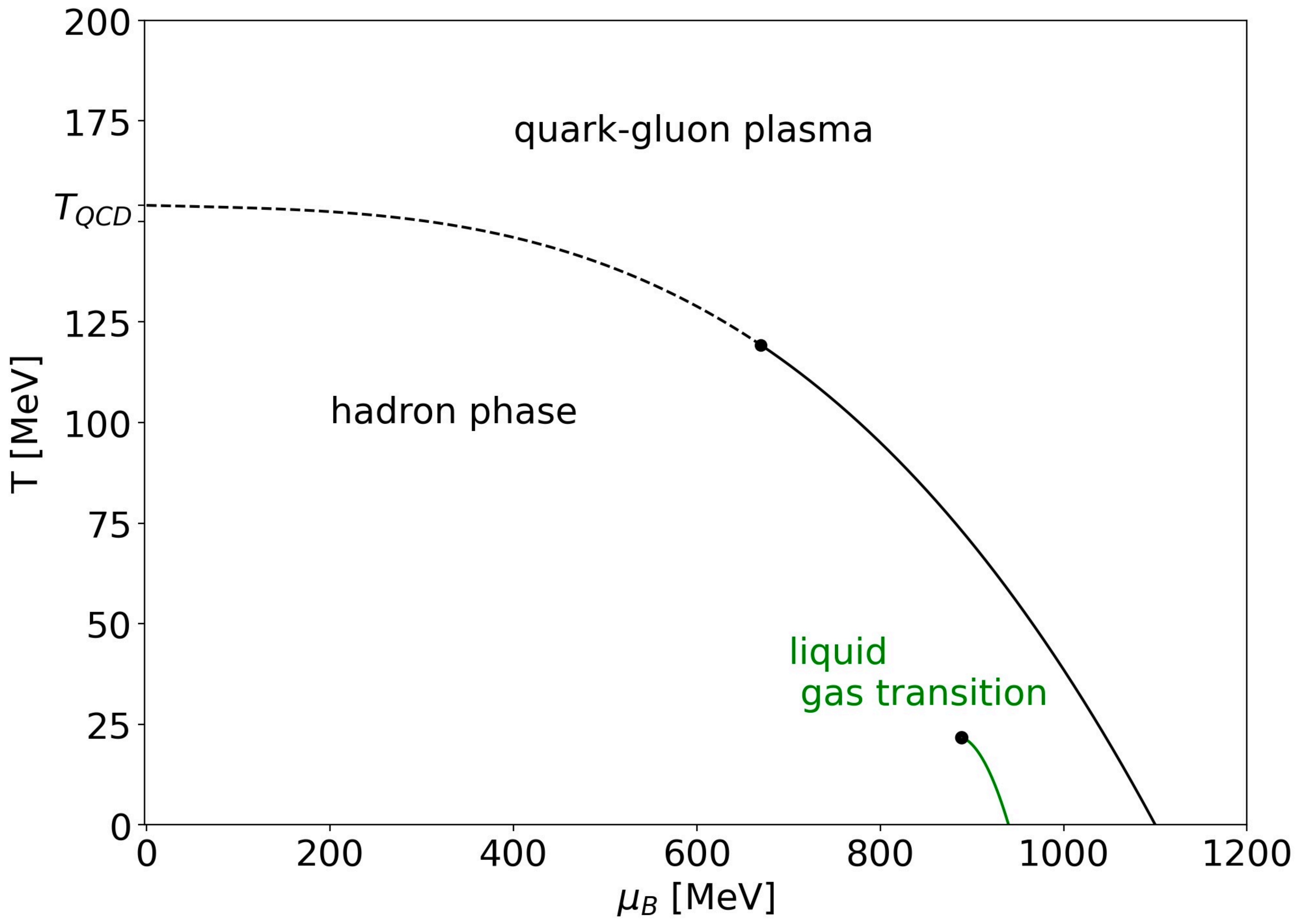
LOFAR Two-metre Sky Survey DR2

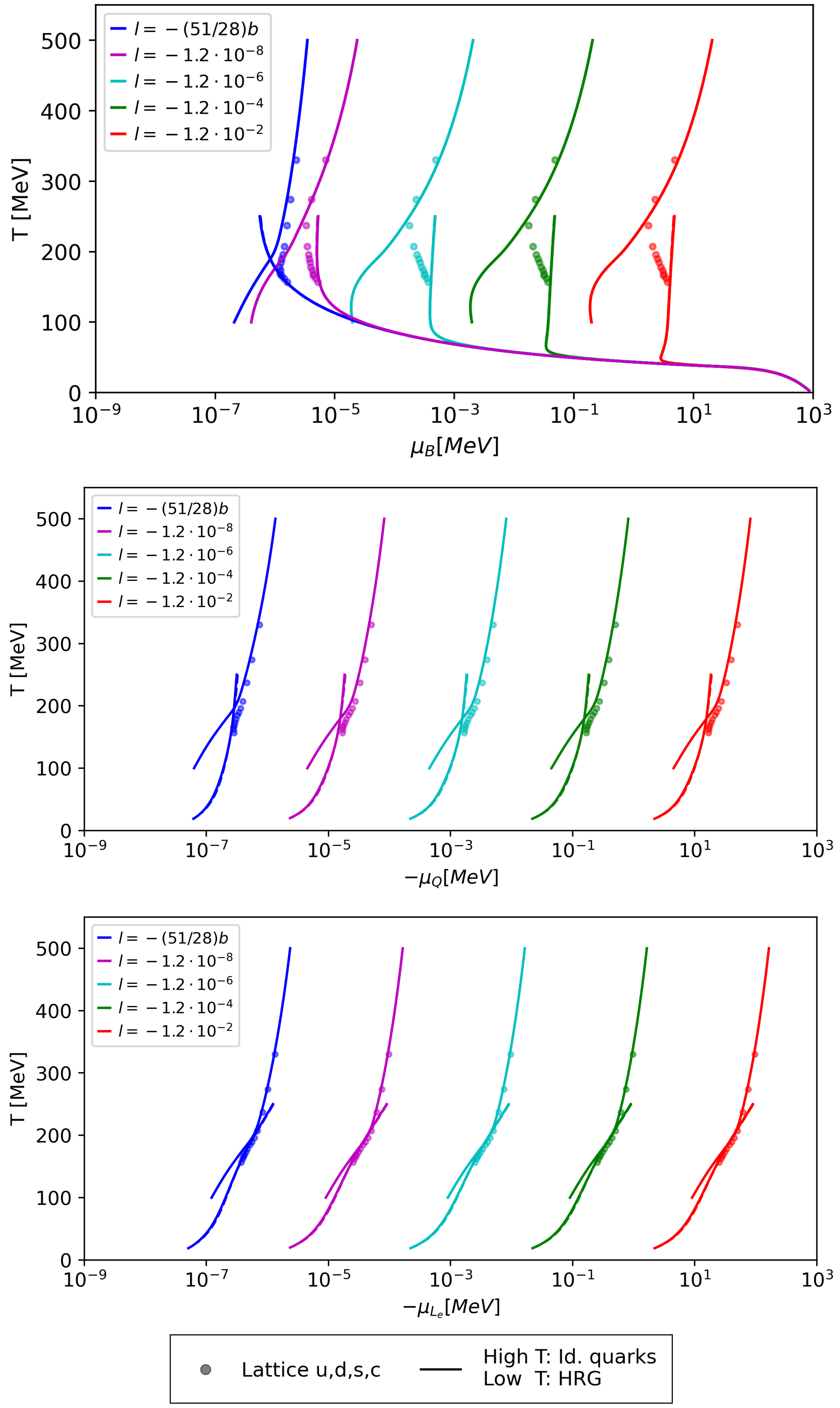


Hale et al. 2024

Backup

Cosmic trajectory in QCD epoch





V. Gashi, master thesis 2024