

# Mentoring and Research Plans at the Department of Astronomy, Universidad de Chile

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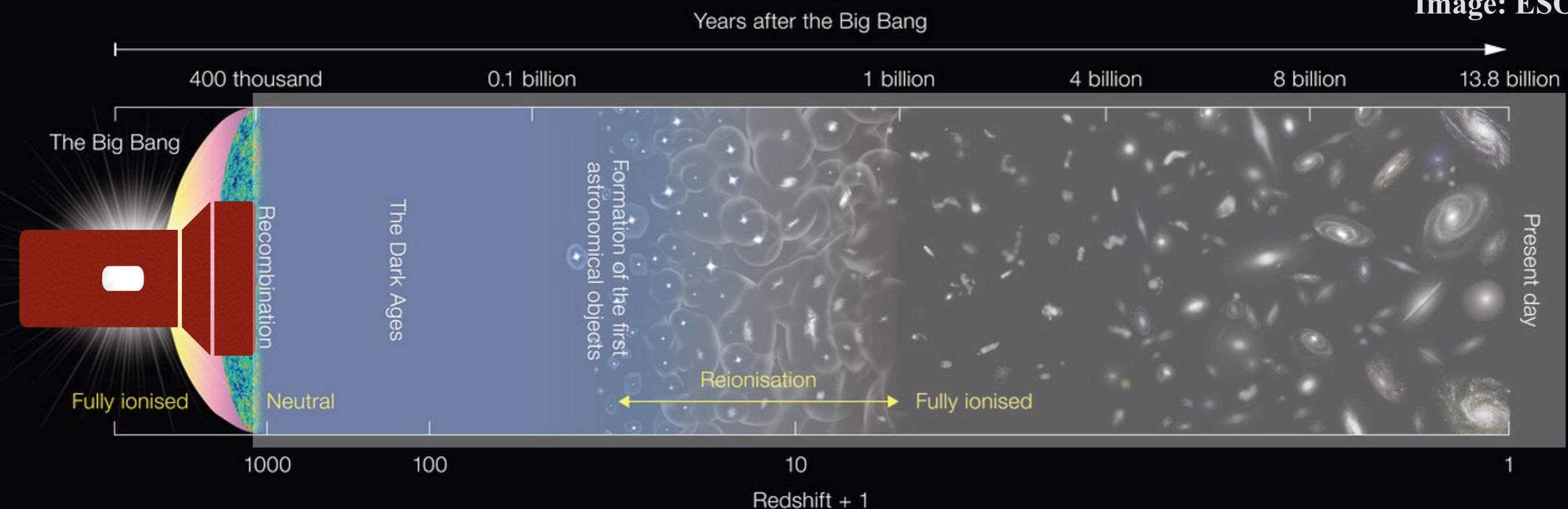
National Centre for Supercomputing Applications

University of Illinois, Urbana Champaign

Interview  
Faculty Position in Astronomy  
Universidad de Chile  
12 December, 2024

# Cosmic Microwave Background (CMB)

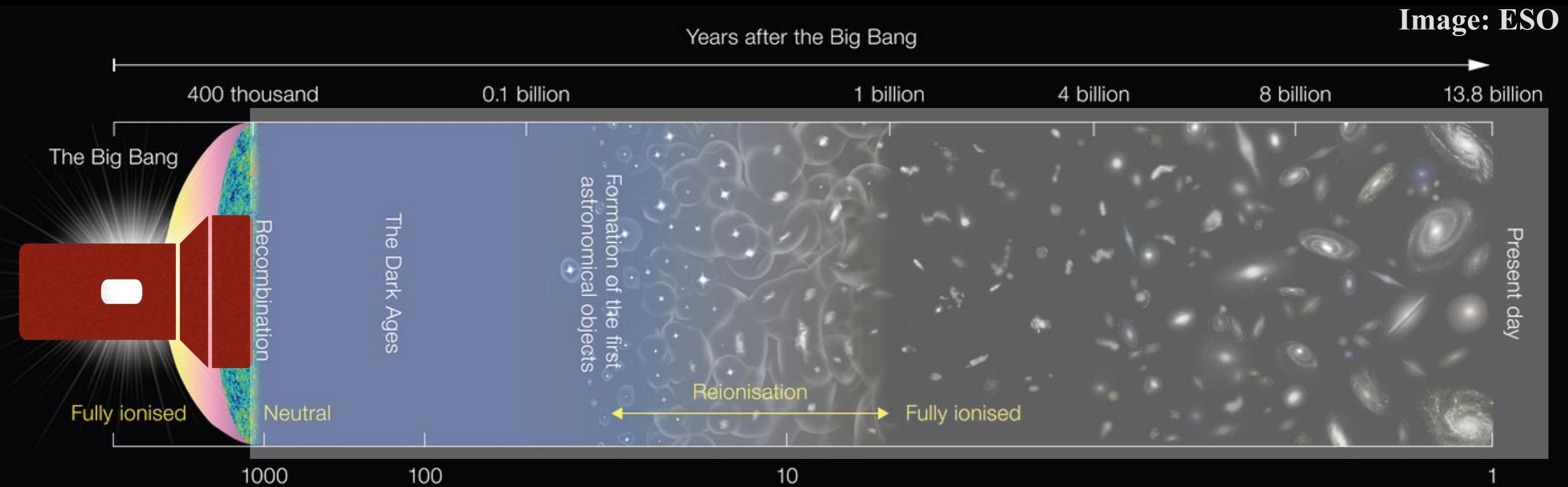
Image: ESO



*CMB is the relic radiation from the Big-Bang that is free streaming towards us from the epoch of recombination  $z \sim 1100$ .*

*Besides learning about the origin, CMB serves as a backlight to study about the contents and evolution of the Universe, and structure formation.*

# Cross-correlation science



Reionisation science:

kSZ x LIM, CMB EE/TE/BB, ++

Structure formation:

kSZ/tSZ/lensing x LIM / galaxy surveys

Impact of baryons / astrophysical feedback:

kSZ/tSZ/lensing x FRB/galaxy surveys

Surveys for cross correlation:

Cherenkov array, DES, LSST, VISTA, ++ (From Chile).

- Roman, Euclid, eROSITA, ++.
- DESI, Pan-STARRS, ++.
- COMAP, TIM, ++ LIM surveys.
- ++

*Excellent synergy with  
DAS / DFI, FCFM*

Legend:

SZ: Sunyaev–Zeldovich effect

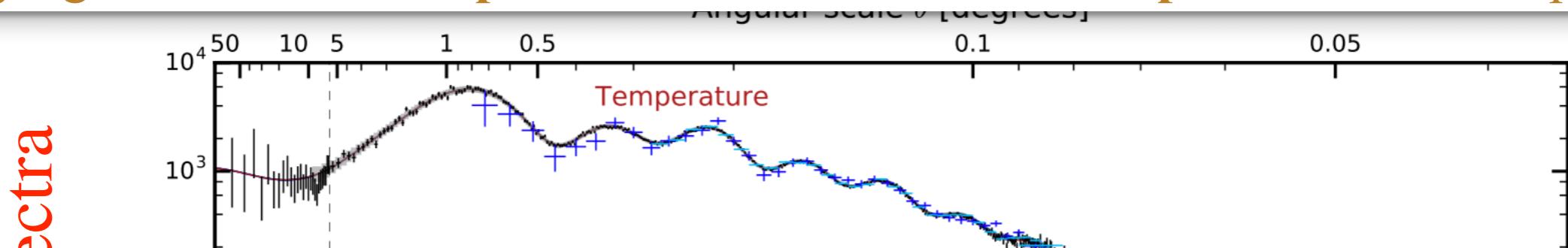
kSZ / tSZ: Kinematic / thermal SZ

LIM: Line Intensity Mapping

FRB: Fast Radio Bursts

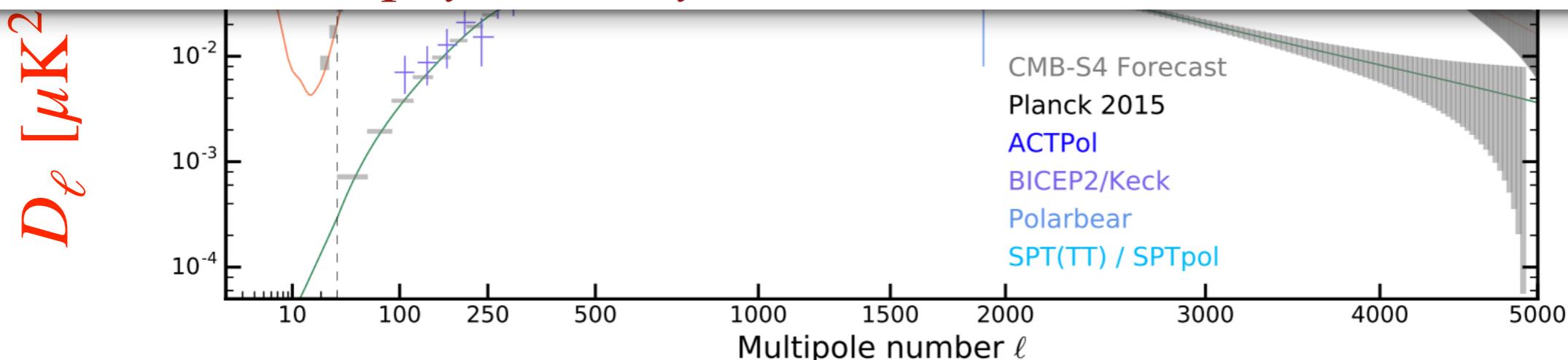
# Cosmic Microwave Background (CMB)

Underlying curve is LCDM prediction — not a best-fit to points from all experiments —.



*If all is so well determined why build new surveys?*

1. **Mysteries remain:** Inflation, dark matter, dark energy, neutrinos, ++.
2. **Tensions between probes remain:** Hubble tension, structure growth tension, ++. New physics or systematics?

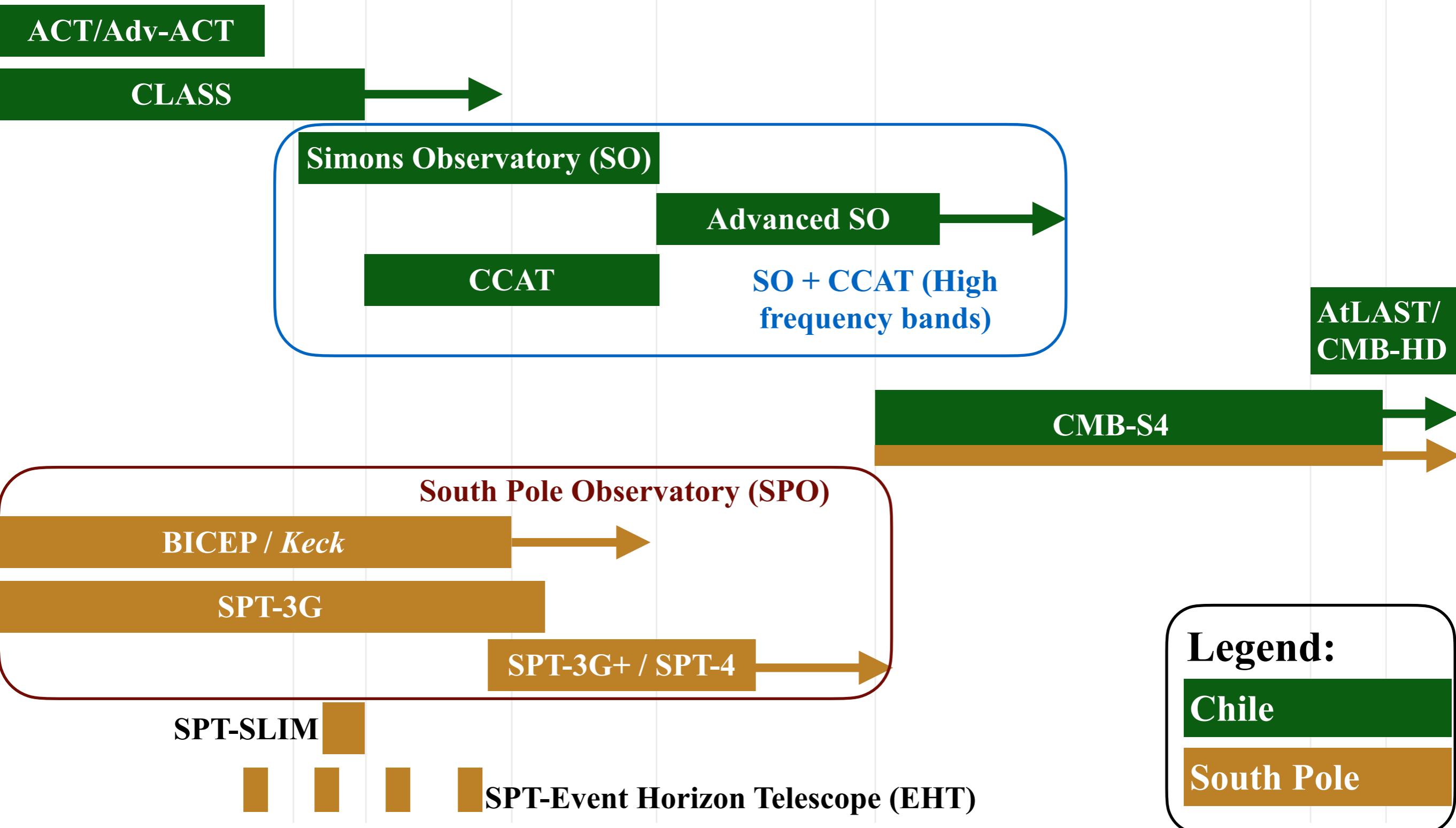


CMB-S4 collaboration 2016, arXiv: 1610.02743.

# Timeline of CMB experiments



2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
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# Timeline of CMB experiments

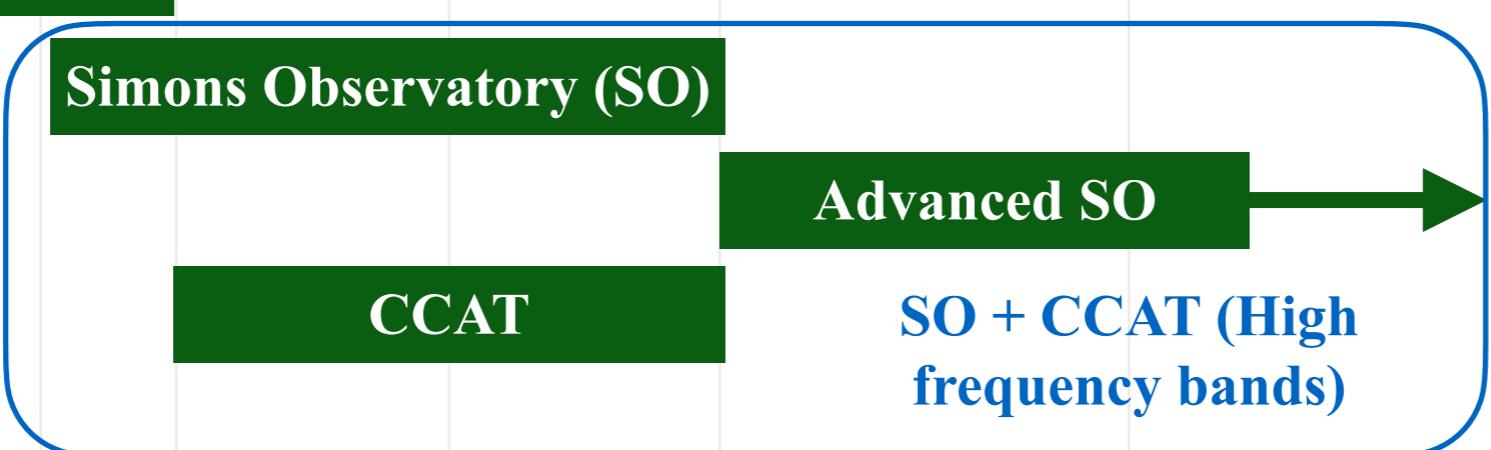


2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
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ACT/Adv-ACT

CLASS

*Strong Chilean presence + large surveys  
like CTA, DES, LSST, ++*



AtLAST/  
CMB-HD

CMB-S4

BICEP / Keck

SPT-3G

SPT-3G+ / SPT-4

SPT-SLIM

Legend:

Chile

South Pole

South Pole Observatory (SPO)

SPT-Event Horizon Telescope (EHT)

# What can I bring in to DAS?

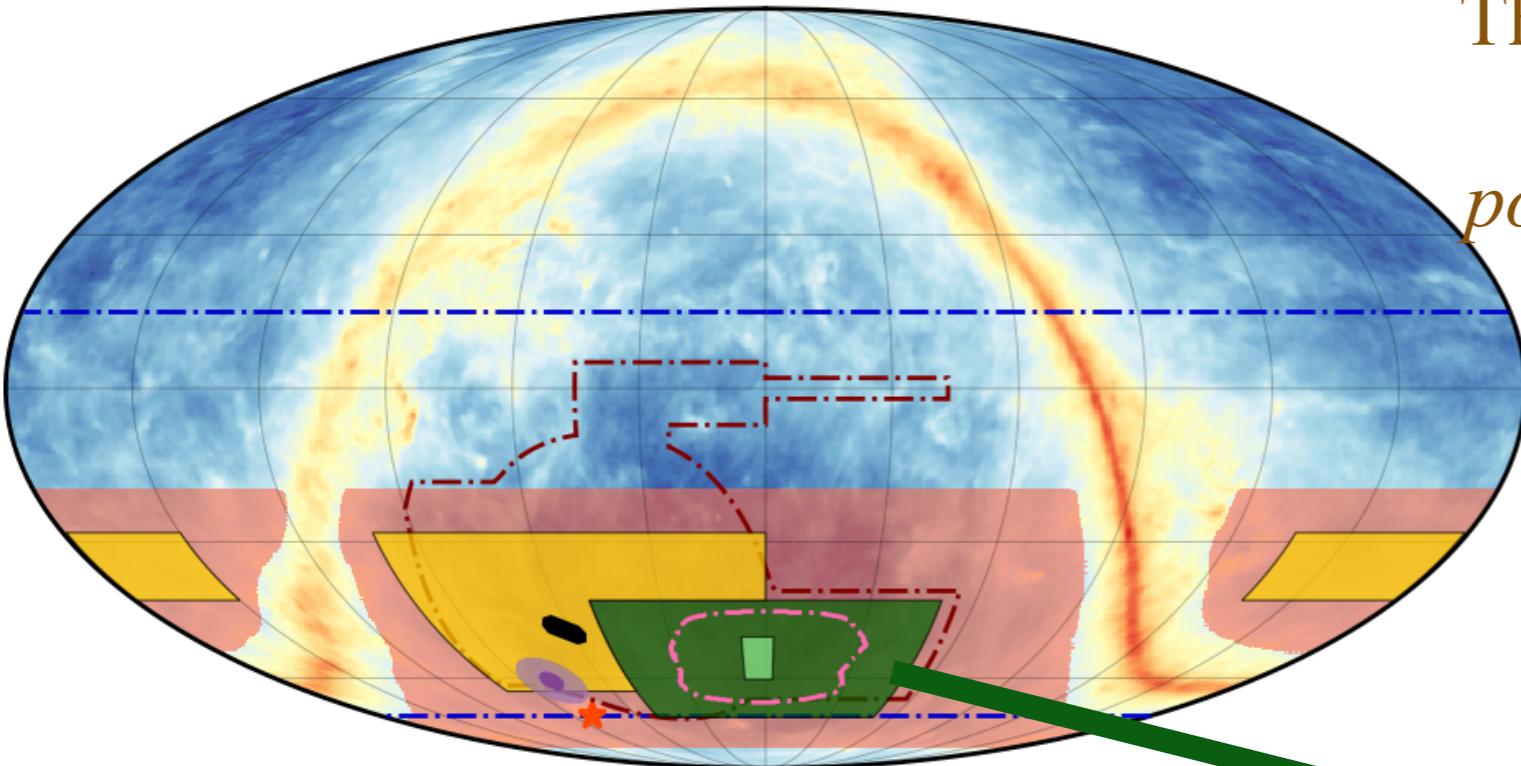


## South Pole Telescope



- ❖ Major state-of-the art cosmological collaborations: South Pole Telescope (SPT) and the next generation CMB-S4.
  - ❖ *Co-ordinator of CMB secondaries and cross-correlations working group for SPT.*
  - ❖ *Co-ordinator of galaxy cluster working group for CMB-S4.*
- ❖ Being part of SPT also provides access to other surveys like DES, eROSITA, Euclid, SPHEREx, ++
- ❖ Also part of LSST, South Pole Observatory, Terahertz Intensity Mapper (TIM), and possibly Simons Observatory in the future.
- ❖ Guaranteed access to data products and high-resolution sim → *Plenty of student/postdoc projects.*
- ❖ *I hope my presence and CMB expertise will be a timely addition to DAS.*

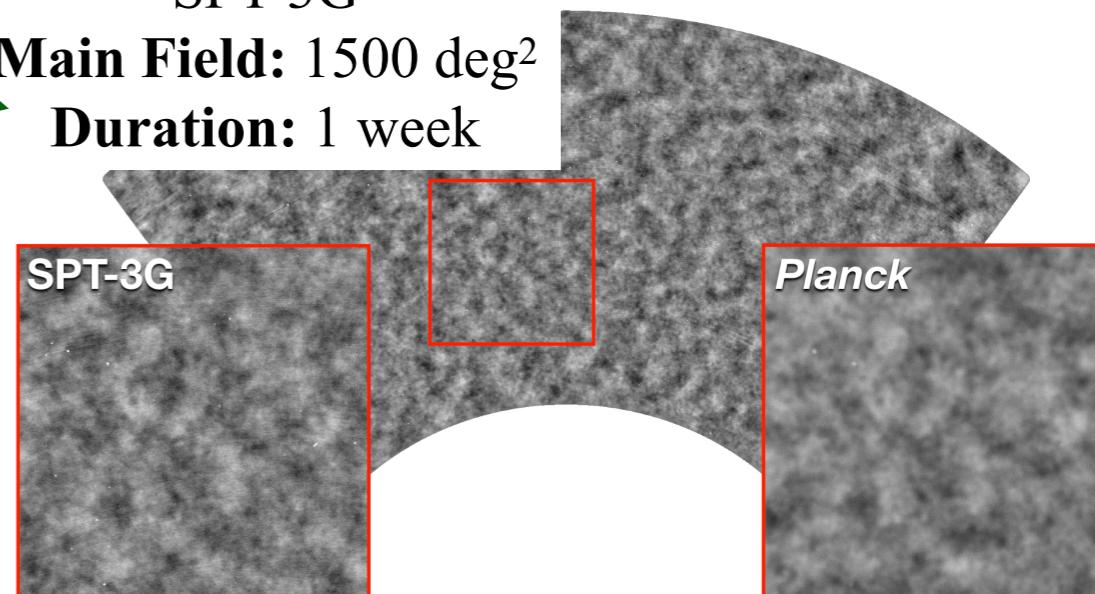
# South Pole Telescope: SPT-3G



The most sensitive measurement of the mm-wave sky (*temperature and polarisation*) over  $\sim 10000$  sq. degrees.

Excellent overlap with current / future galaxy surveys from Chile and other places.

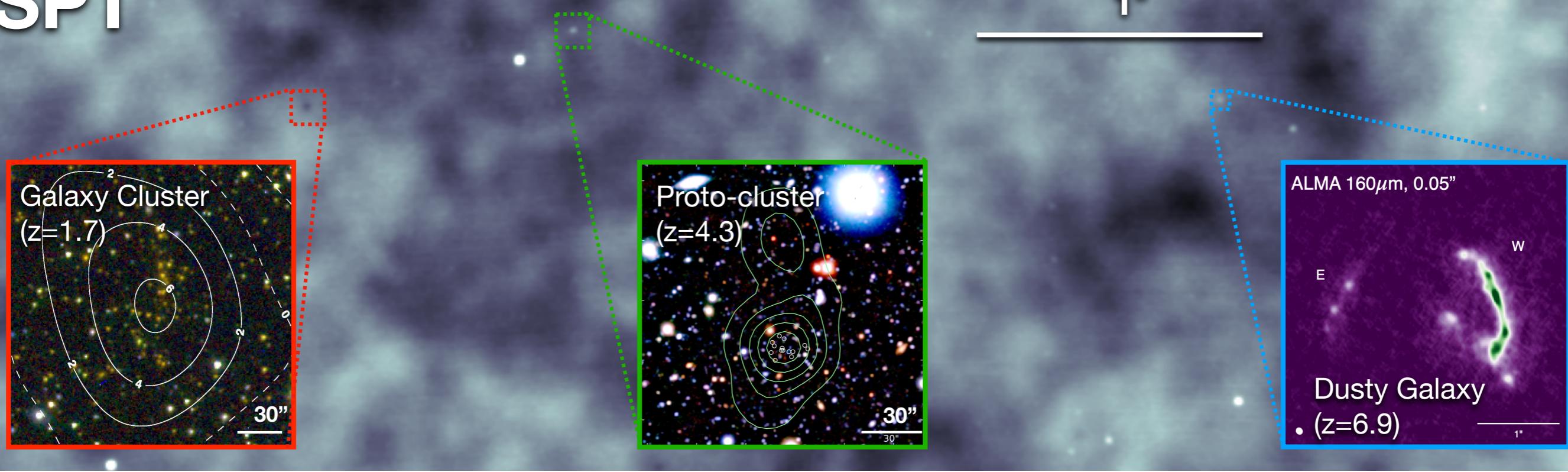
SPT-3G  
**Main Field:**  $1500 \text{ deg}^2$   
**Duration:** 1 week



*SPT-3G can achieve Planck's depth in roughly 1 week and we have 5 years (Austral winter) of data at the moment.*

# South Pole Telescope: SPT-3G

SPT



*Science drivers for the Main-1500d field:*

1. *Inflation* in combination with BICEP using CMB delensing.
2. *Cosmology* using primary and secondary CMB anisotropies.
3. *Physics of reionization* using kSZ.
4. *Cross-correlation with galaxy surveys and LIM (21cm, CO, CII, ++).*
5. *Blind cluster and high redshift galaxy catalogues.*
6. *mm-wave transients, AGN monitoring, Asteroids, Stellar Flares, Planets.*
7. *And many more.*

*Plenty of student/  
postdoc projects.*

# South Pole Telescope: Collaboration

*~100 scientists (1/3 senior, 1/3 postdocs, 1/3 students)  
across more than 20 institutions*

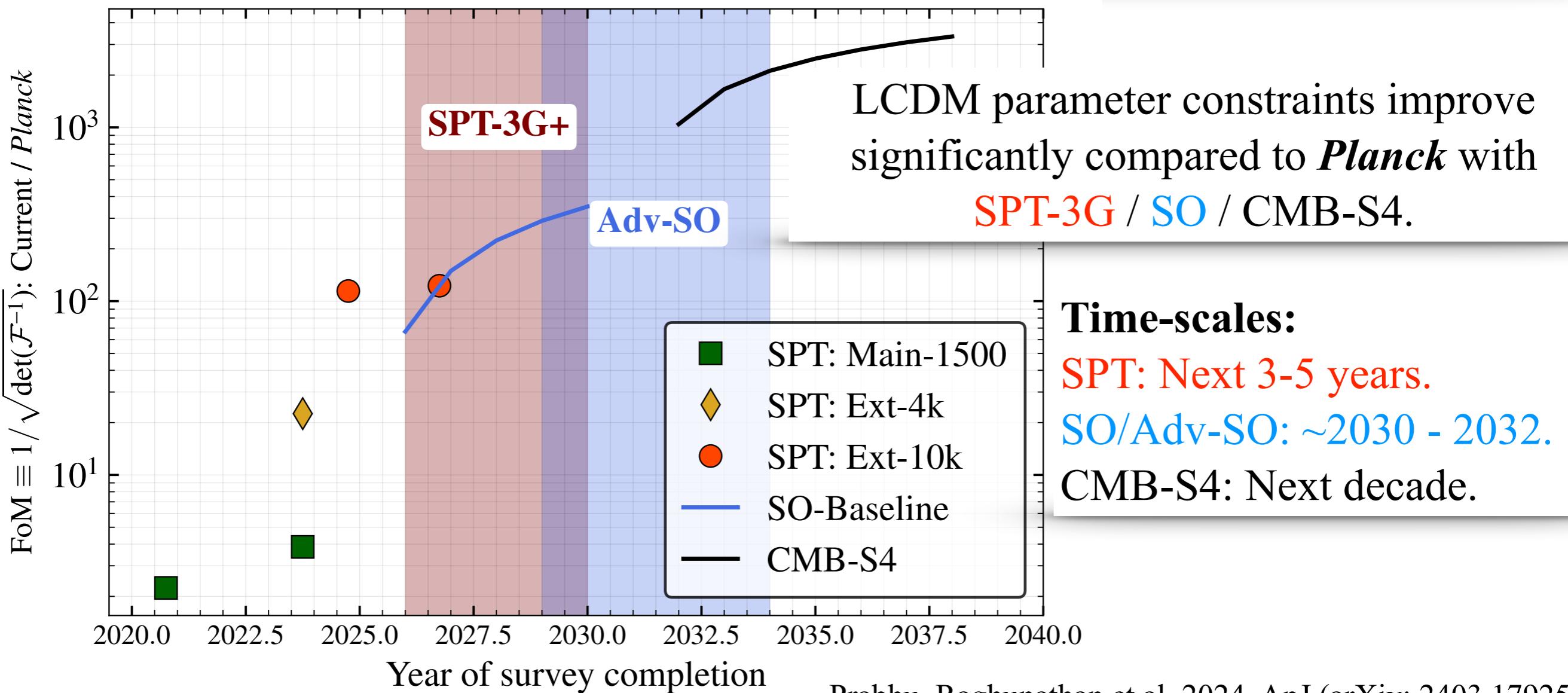


Harvard-Smithsonian Center for Astrophysics



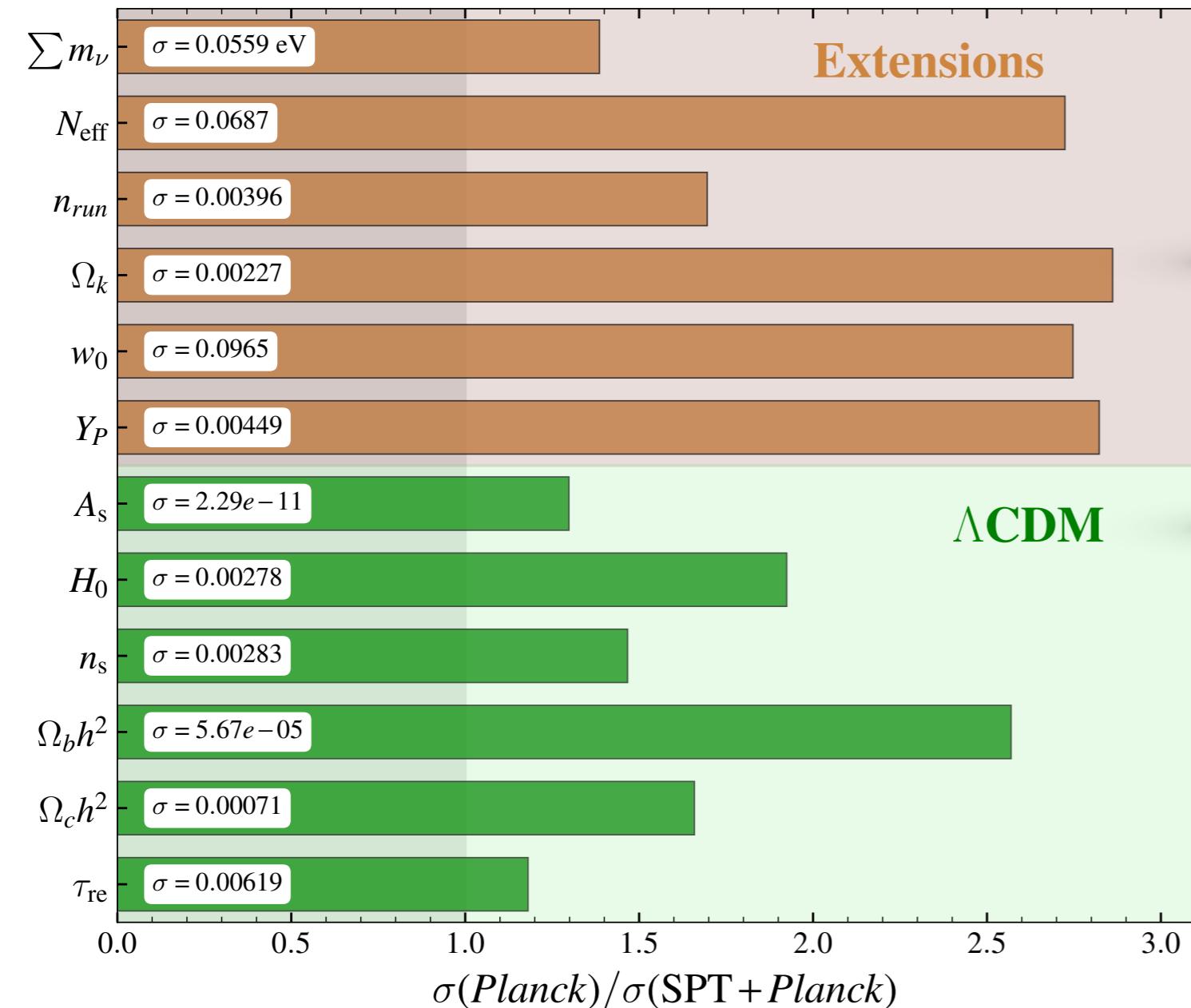
# Plans for the near-future (2025 - 30)

- ❖ SPT-3G is currently funded until 2029 and there is a good chance that we will get extended.
- ❖ We have plans to upgrade the current camera at the end of 2026.
- ❖ Extremely deep maps enables a lot of unique science cases. In particular using the polarised CMB.
- ❖ Excellent dataset to prepare for the next generation cosmological surveys like CMB-S4 and Adv-SO.



Prabhu, Raghunathan et al. 2024, ApJ (arXiv: 2403.17925).

# Plans for the near-future (2025 - 30)



**SPT** can significantly improve constraints on LCDM and extensions compared to *Planck*.

**SO** and **CMB-S4** will further strengthen the constraints.

Prabhu, Raghunathan et al. 2024, ApJ (arXiv: 2403.17925).

Mentored UC Davis **grad student Karthik Prahu** for the SPT forecasting paper.

Also currently working on MI-based extragalactic simulations.



# Plans for the near-future (2025 - 30)

Some of my current “high-level science” projects:

- ❖ Probing the **epoch of reionisation** using **kinematic SZ effect** (**SPT-3G** and **Herschel**).
- ❖ Understanding the **impact of baryonic feedback on structure formation** using **thermal SZ effect** and its correlation with **galaxy weak-lensing** (**SPT-3G**, **DES**, and **Euclid**).
- ❖ Constraining **structure formation** using the **gravitational lensing** of the CMB (**SPT-3G**).
- ❖ Probing the **epoch of cosmic noon** ( $z \sim 2$ ) by cross-correlating **quasar absorption lines** with CMB and galaxy surveys (**Planck** and **SDSS**).
- ❖ Constrain **structure formation** using **kinematic SZ x galaxy surveys** (**SPT-3G** and **Euclid**).
- ❖ Mapping the **high redshift universe** using **intensity fluctuations** of hydrogen / carbon / metal lines (**SPT-SLIM** and **TIM**).
- ❖ Detecting **stellar flares** and **mm-wave transients** (**SPT-3G**).
- ❖ ++



Kevin Levy, 3rd year grad  
student at Melbourne:  
**CMB-lensing.**



Achintya Krishnan, 1st year  
grad student at UIUC:  
**SPT kSZ x Euclid.**



Mathilde Van Cuyck, 2nd  
year postdoc at UIUC:  
**Intensity mapping.**



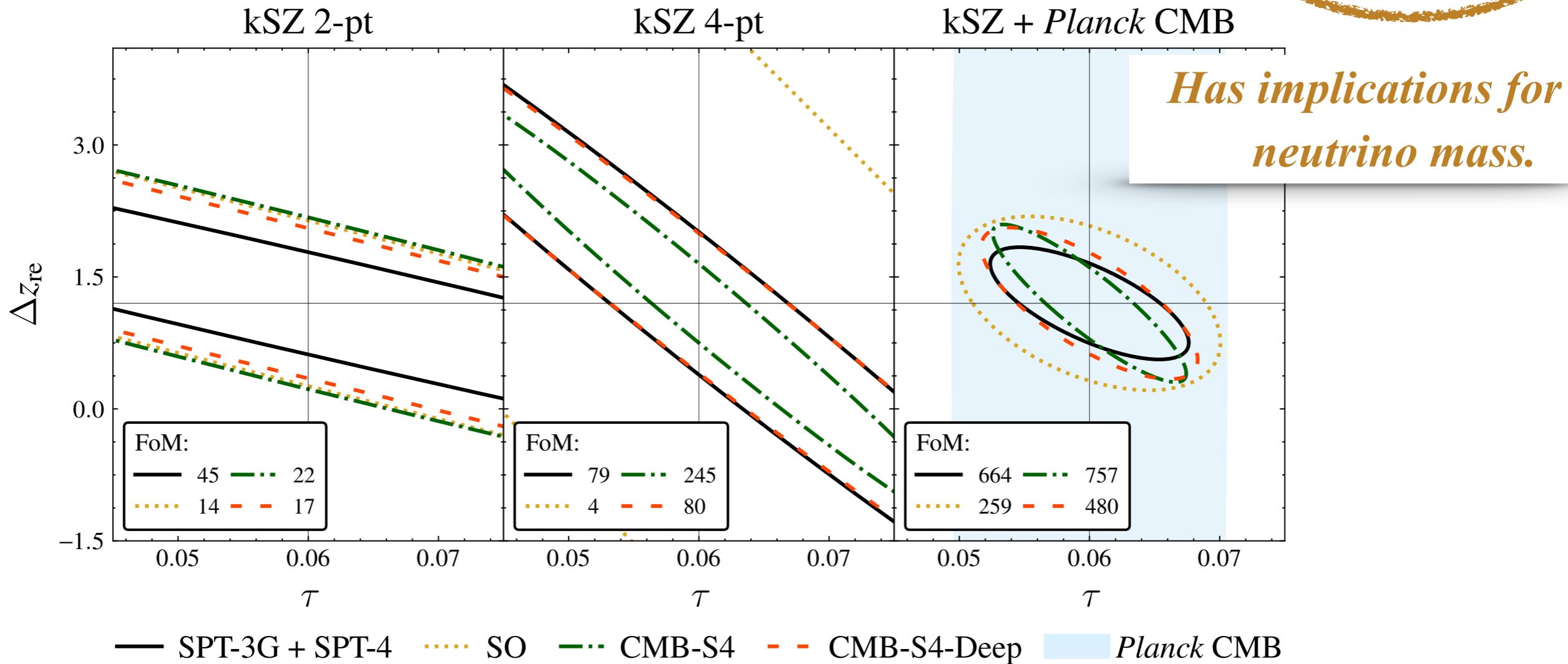
Chris Tandoi, 5th year grad  
student at UIUC:  
**Stellar flares & transients.**



Eduardo Schiappucci, recently graduated  
from Melbourne:  
**Mentored for CMB-S4 kSZ forecasts.**

# Reionisation science using kSZ

SPT-3G+SPT-4 / CMB-S4:  $\sigma(\Delta z) \sim 0.5$  (unconstrained by *Planck*) and  $\sigma(\tau) \sim 0.005$ .



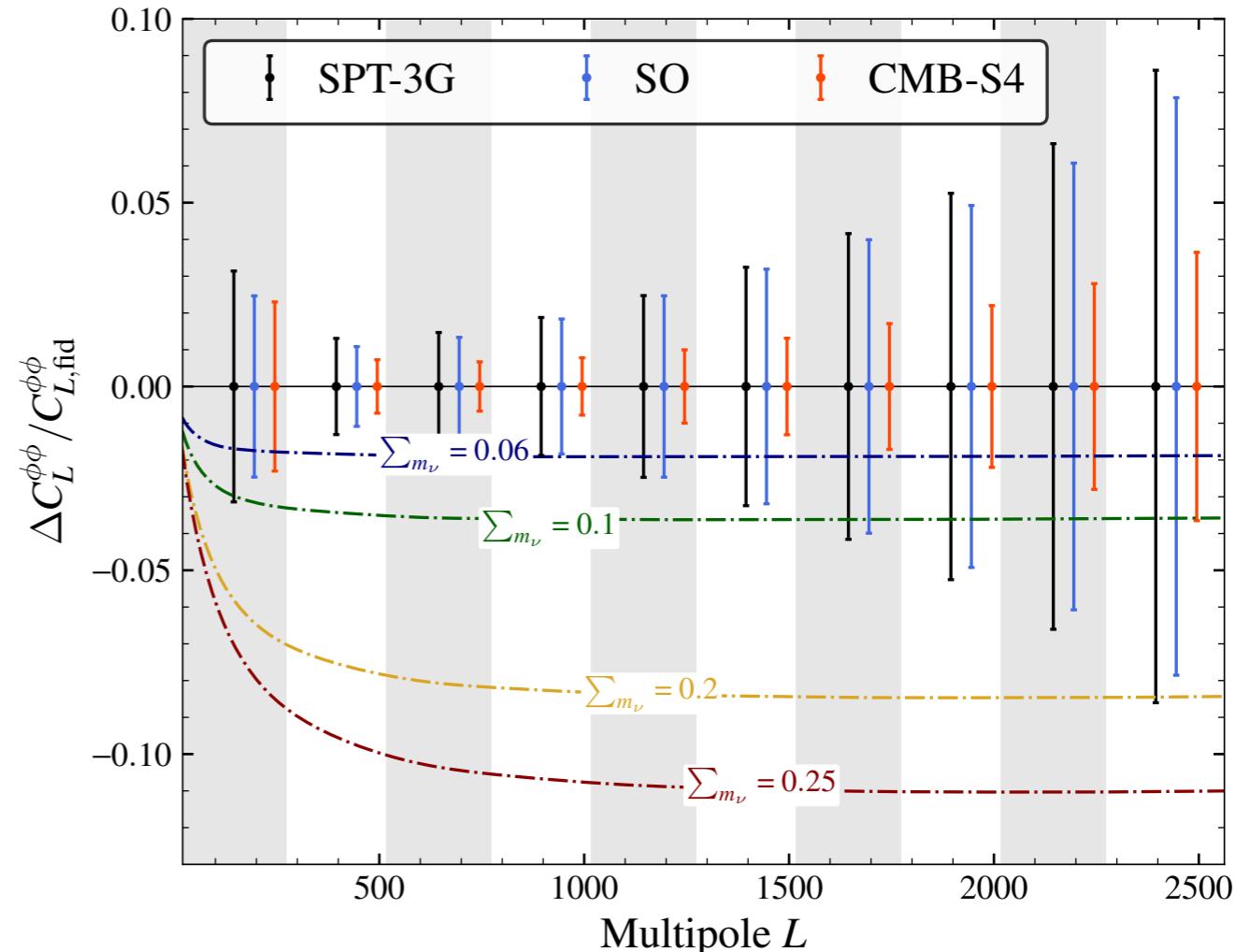
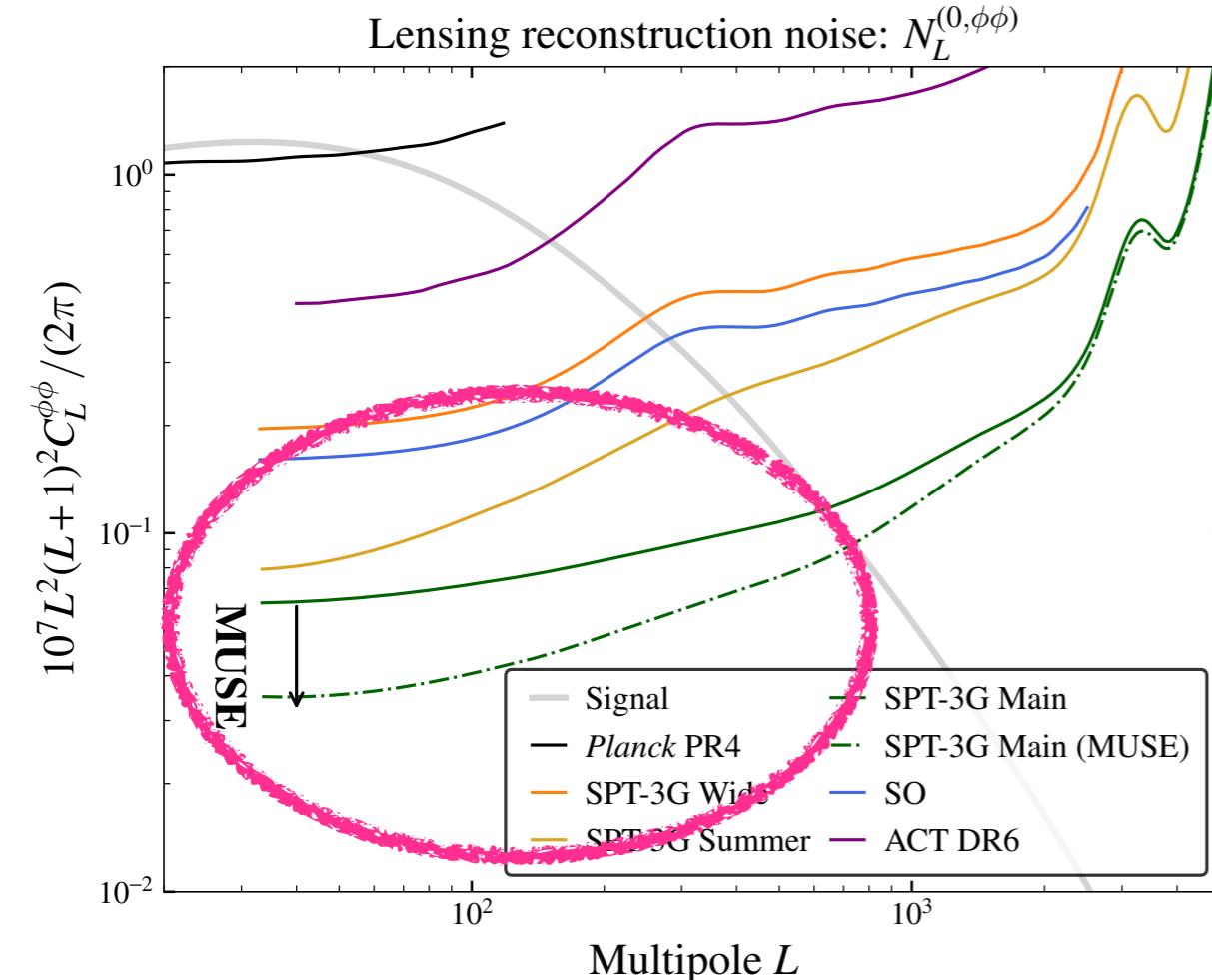
*kSZ: Unique window into the EoR — complementary view of the high- $z$  galaxy observations from JWST —.*

*Lots of potential cross-correlations with intensity mapping experiments in the future.*

kSZ 2-pt (power spectrum): Raghunathan & Omori 2023, ApJ, arXiv: 2304.09166.

kSZ 4-pt (trispectrum): Raghunathan et al. 2024, PRL, arXiv: 2403.02337.

# Structure formation and inflation using CMB-lensing



*>100  $\sigma$  measurement of the gravitational lensing with SPT-3G: Polarisation noise levels are so low and have reached a regime where standard lensing estimators are sub-optimal.*

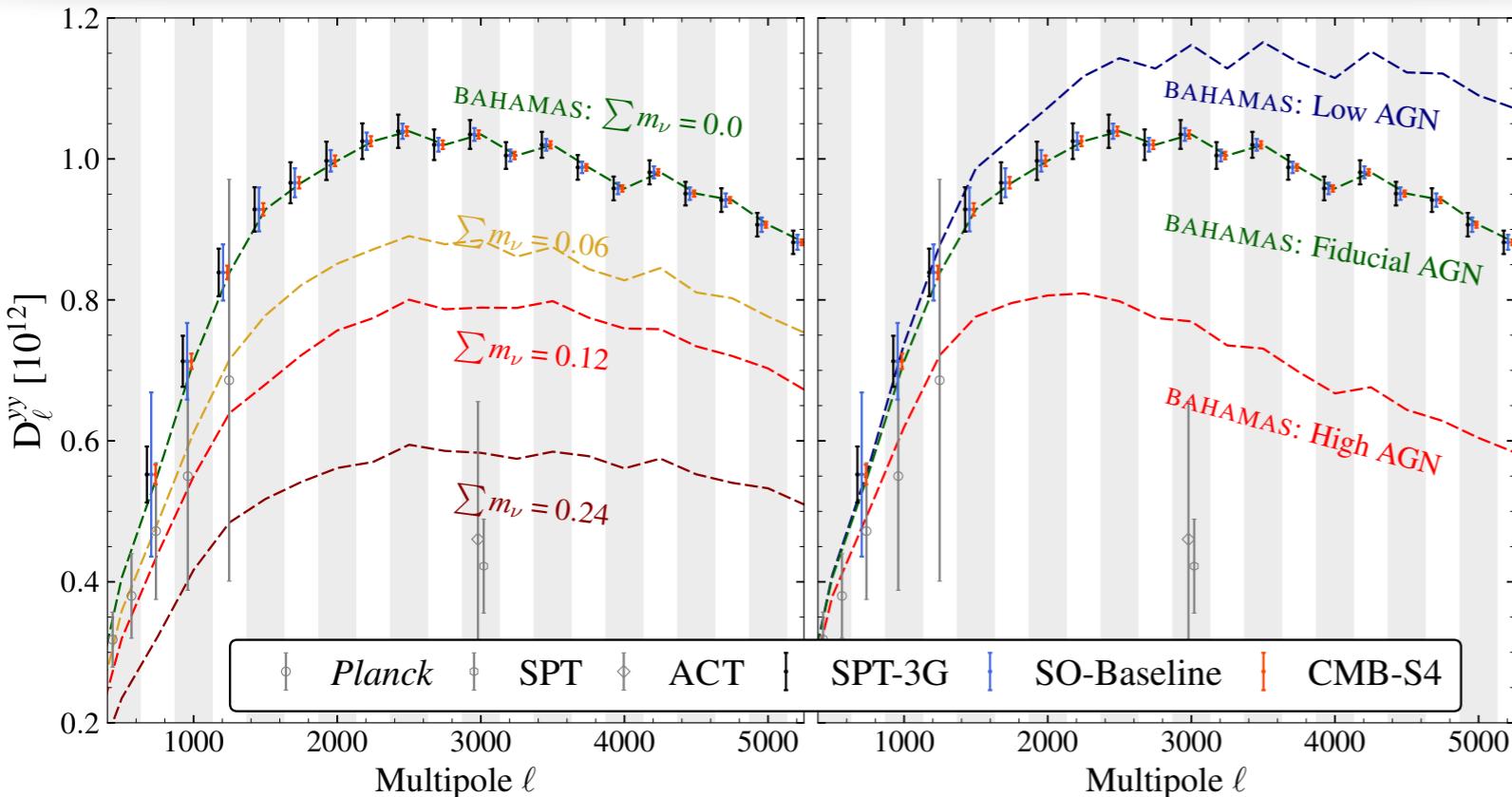
*Extremely crucial for delensing and inflationary B-mode science.*

x3 improvement on  $\sigma(\sum m_\nu)$  with SPT/SO and  $\sim 2.5\sigma$  detection with CMB-S4.

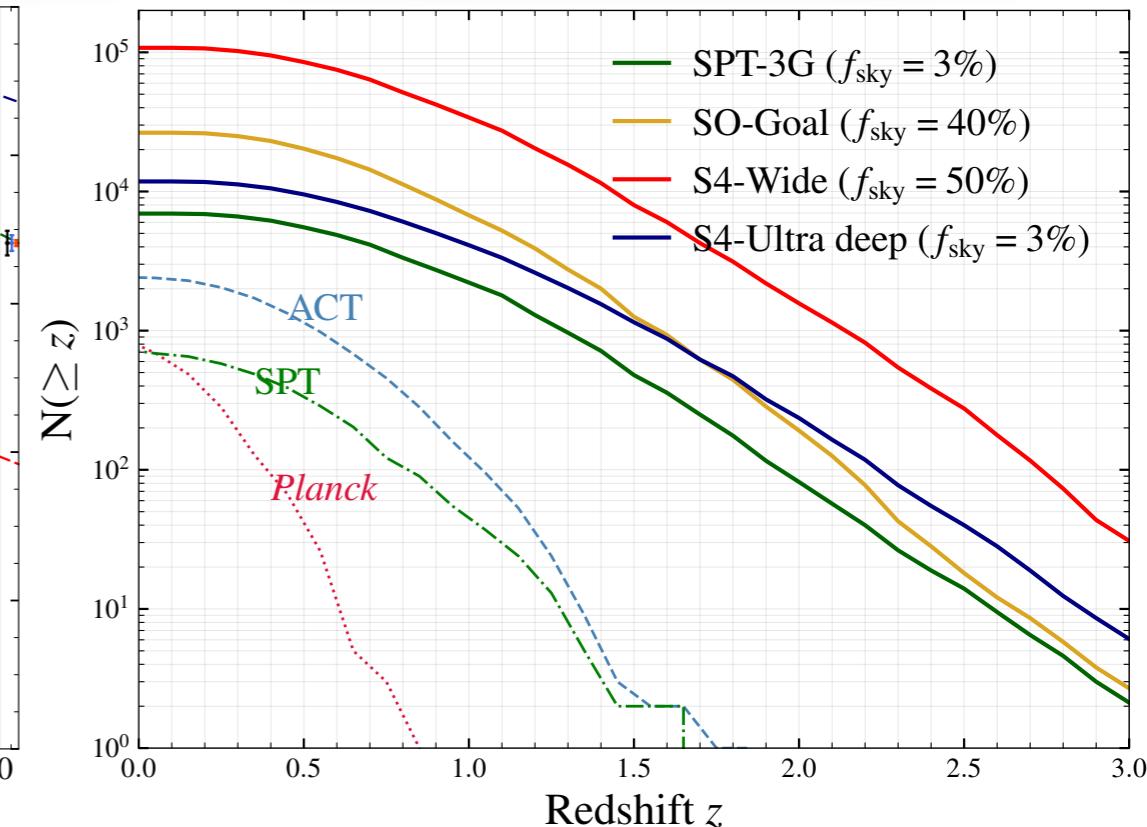
Prabhu, Raghunathan et al. 2024, ApJ (arXiv: 2403.17925).  
 Levy, Raghunathan et al. SPT collaboration, (in prep).  
 Raghunathan et al. SPT collaboration, (in prep).

# Structure formation and baryon physics with tSZ

## Neutrino physics and AGN feedback with tSZ power spectrum



## Galaxy cluster counts



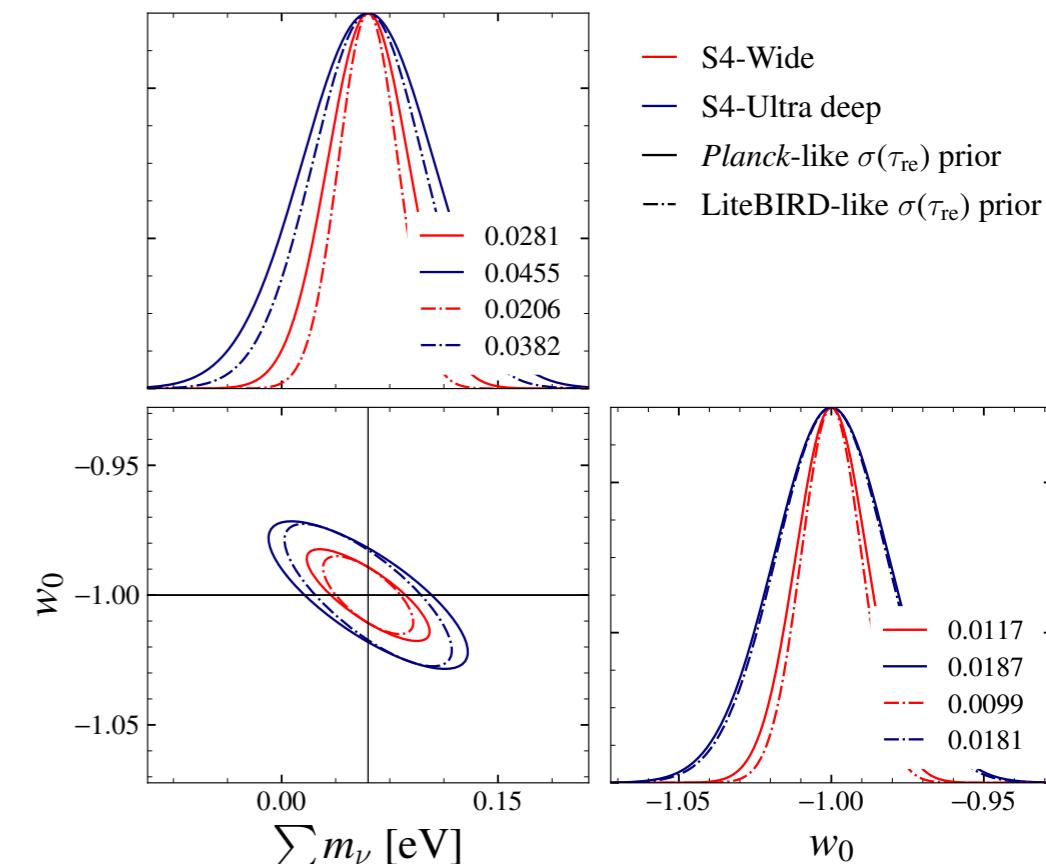
- Rule out many of the existing **baryonic feedback models** using **tSZ power spectrum**.
- Has **implications for resolving the S8 tension**.
- **Sub-per cent** constraint on dark energy equation of state  $\sigma(w_0)$  and  $\sim 3\sigma$  measurement of sum of neutrino mass.

Raghunathan et al. SPT collaboration, (in prep).

Raghunathan, Patil, Baxter et al. 2019, PRL (arXiv: 1907.08605).

Raghunathan, Alvarez, Battaglia et al. 2022, ApJ, arXiv: 2107.10250.

Raghunathan 2022, ApJ, arXiv: 2112.07656.



# Mentoring / Outreach / Teaching

- **Mentoring experience along with papers co-authored:**
  - Behzad Ansarinejad: **Postdoc** / Melbourne, Australia / 1 paper (**Galaxy clusters and gravitational lensing**).
  - Dwaipayan Chanda: **MSc** / USC, USA: Ongoing (**Velocity reconstruction**).
  - Tracey Friday: **PhD** / UCLAN, UK / 2 papers: Complete (**Large-scale structures**).
  - Milo Korman: **PhD** / Case Western Reverse, USA: Complete (Galaxy clusters and **SZ**).
  - Achintya Krishnan: **Summer Undergrad** / UIUC, USA: Complete (**Cosmological emulators**).
  - Achintya Krishnan: **PhD** / UIUC, USA: Ongoing (Galaxy clusters, **SZ**, and velocity reconstruction).
  - Kevin Levy: **MSc** / Bonn, Germany / 1 paper: Complete (Galaxy clusters and gravitational lensing).
  - Kevin Levy: **PhD** / Melbourne, Australia: Ongoing (**CMB-lensing**).
  - Alexia Lopez: **MSc** / UCLAN, UK / 1 paper: Complete (**Quasars** and large-scale structures).
  - Sanjay Patil: **PhD** / Melbourne, Australia / 4 papers: Complete (Galaxy clusters, and gravitational lensing).
  - Karthik Prabhu: **PhD** / UC Davis, USA / 1 paper: Ongoing (CMB power spectra and gravitational lensing).
  - Eduardo Schiappucci: **PhD** / Melbourne, Australia / 1 paper: Complete (**Structure formation** and velocity recon).
  - Chris Tandoi: **PhD** / UIUC, USA: Ongoing (**mm-wave transients**).
- **Outreach:** Have been involved in outreach activities in **Chile, Australia**, and recently in **India**.
  - Currently guiding research of 2 MSc students in India whom I met as part of the outreach activity.
- **Teaching:** As a TA during my PhD in the University of Chile: Undergrad / Masters level.
  - Introduction to Astronomy/cosmology; Advanced Cosmology; Observational Astrophysics; and Galaxies.
  - **Received 82% rating by Chile undergrads (Average score for TA is 70%).**
  - I will be willing to teach the following courses: Observational and data-driven astronomy; electromagnetism; introduction to astronomy / cosmology; and also design a course on cosmology.

# Long-term plans / Summary

- My long-term goal is to build the Chilean CMB data analysis and cosmological inference centre with Universidad de Chile as the lead institution.
- Involves participation from DAS/DFI, FCFM; and also from other institutions (PUC, ESO, ++) across Chile and the globe.
- Having CMB expertise will be timely for DAS, given that Chile is the home of many current / upcoming CMB experiments.
- Aligns with the goals of DAS/UChile and Chilean astronomy community (DECYTI) in general.
- Look into suitable funding schemes (CONICYT —> FONDECYT ++ ).
- SPT/SO/CMB-S4 are excellent cosmological datasets and key experiments to advance the cosmic frontier.
- SPT is already achieving the depths of CMB-S4/SO —> Excellent dataset to identify the important systematics for the future cosmological analyses.
- I already have leadership role in both SPT and CMB-S4.
- This proposal offers a number of students / postdoc projects.
- Excellent synergies with DAS/DFI, FCM and across Chile: inflation; cosmology using SNe; structure formation; galaxy formation/evolution and astrophysical feedbacks; first galaxies / reionisation science; high-energy phenomena; synoptic survey / big-data science; mm-wave transients; high-resolution follow-ups and multi-wavelength/multi-messenger astronomy; ++.