Cosmology and Astrophysics at NCKU

I-Non Chiu (National Cheng Kung University, Tainan City, Taiwan)

Outlines

- Observational cosmology and astrophysics (PI: I-Non Chiu)
- High-energy astrophysics (PI: Kwan-Lok Li)
- Numerical astrophysics (PI: Hwei-Jang Yo)
- Particle physics lab (PI: Chuan-Hung Chen)
- Theoretical cosmology lab (PI: Shun-Pei Miao)
- Gravitation and quantum theory of fields (PI: Chopin Soo)

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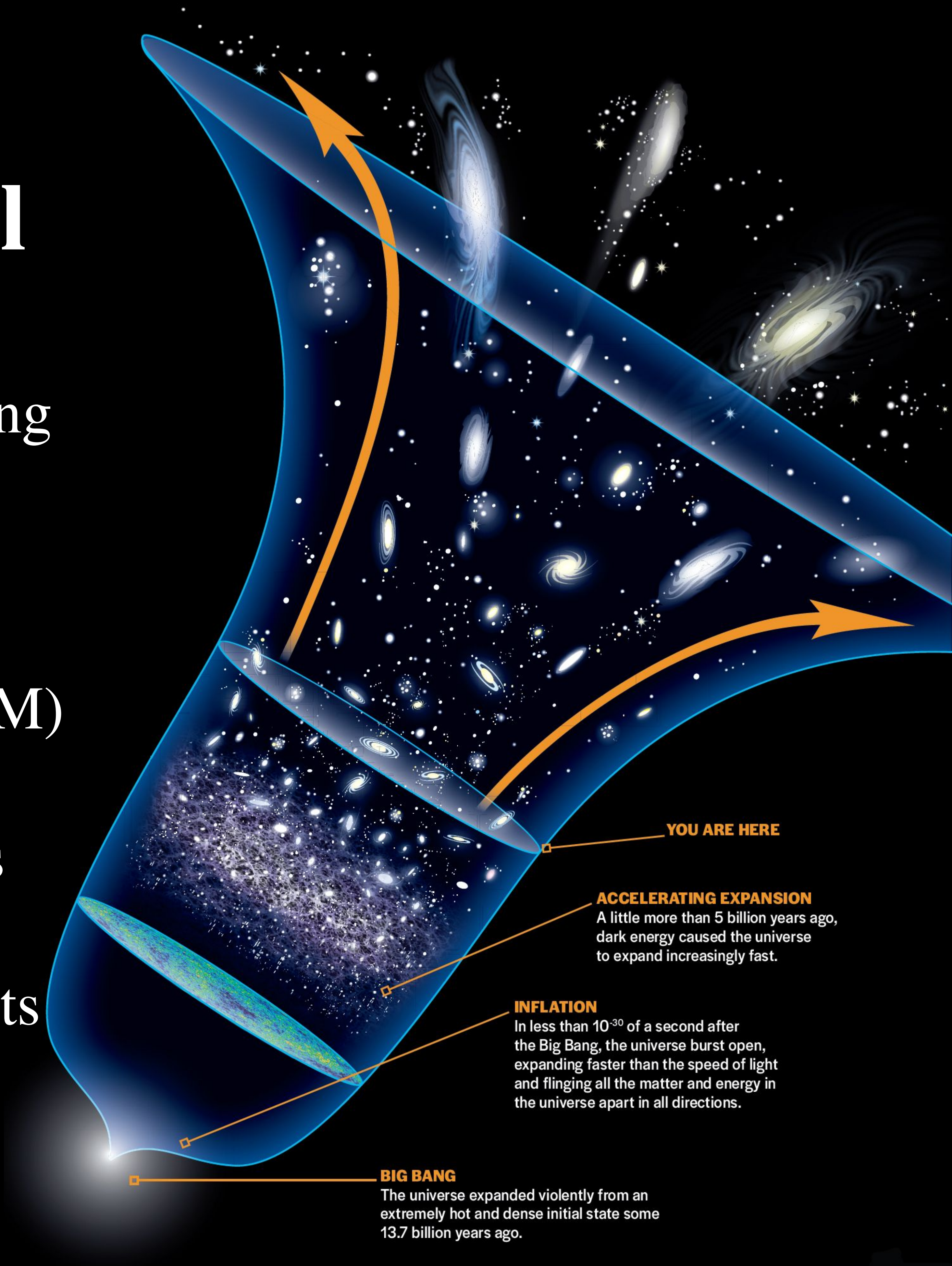
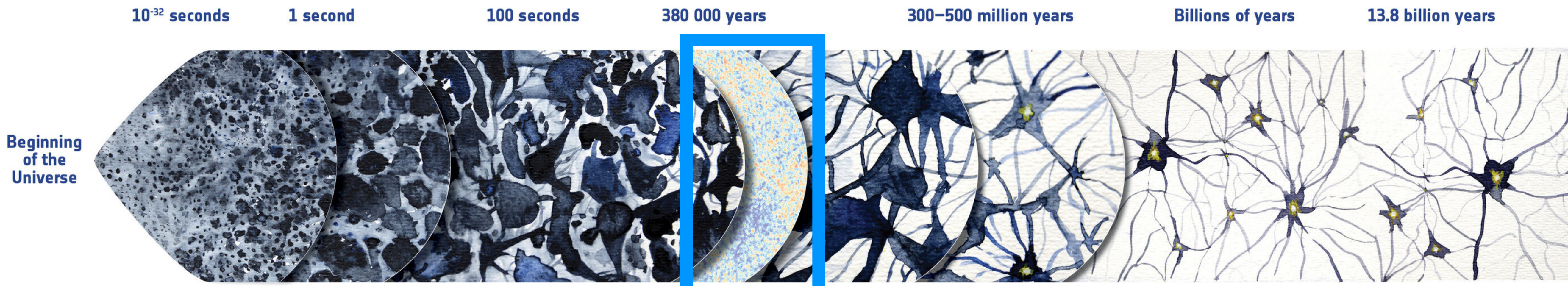
The Standard Cosmological Model

- The universe has been expanding since a "big bang"
- The flat **ΛCDM** model:
  - ≈5% baryonic matter
  - ≈25% cold dark matter (CDM)
  - ≈70% dark energy (Λ)
- The recent cosmic expansion is accelerating
- Supported by observational facts

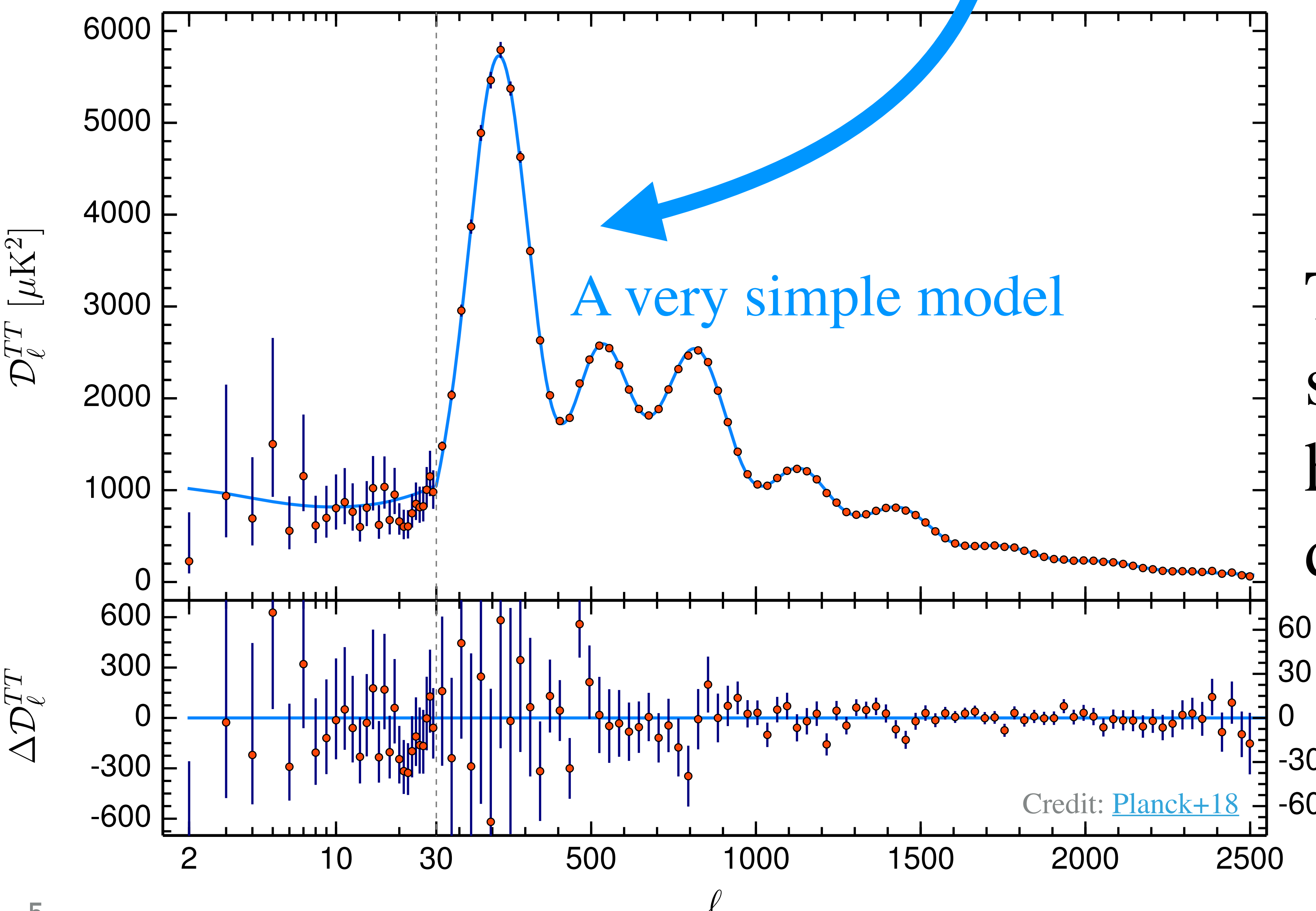


Credit: Discover Magazine

Cosmic Microwave Background (CMB)



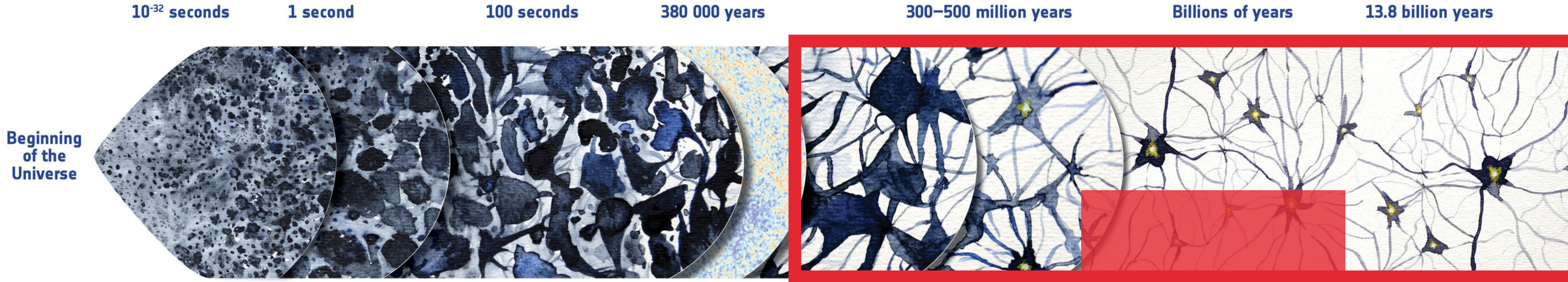
Credit: ESA



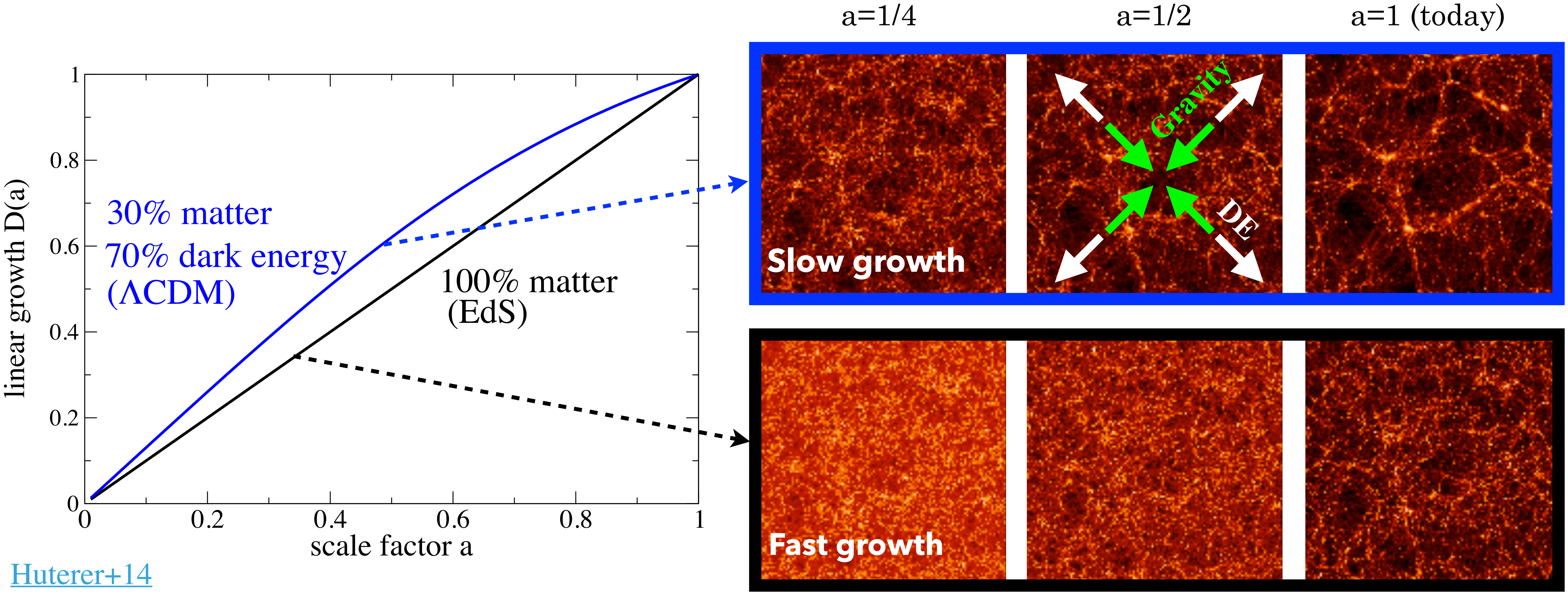
Credit: Planck+18

The CMB at a single snapshot ($z \approx 1100$) has a great success in describing the Universe.

Cosmological Structure Formation



Credit: ESA



Huterer+14

The probes based on the growth of structures have put a stringent test on the ΛCDM model.

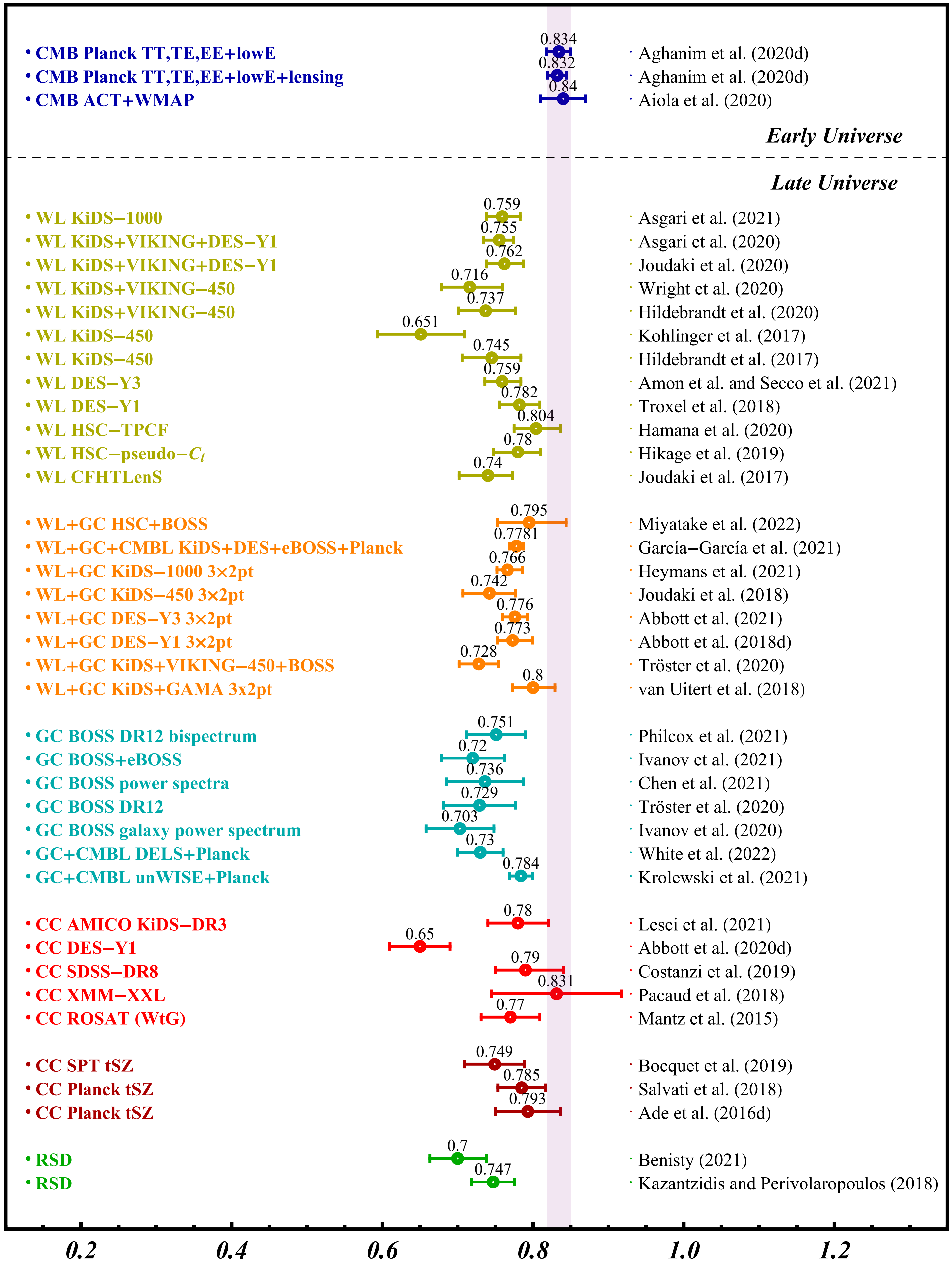
The S_8 (or σ_8) Tension

- The cosmic inhomogeniety is described by the variance of overdensity fluctuations at a scale of 8 h^{-1}Mpc

$$\sigma_8 \equiv \left[\left\langle \left(\frac{\delta\rho_{\mathrm{matter}}}{\rho_{\mathrm{matter}}} \right)^2 \right\rangle_{8\ h^{-1}\mathrm{Mpc}} \right]^{\frac{1}{2}}$$

$$S_8 \equiv \sigma_8 \left(\frac{\Omega_{\mathrm{m}}}{0.3} \right)^{\frac{1}{2}}$$

- The extrapolation from the CMB at $z \approx 1100$ disagrees with the late-time observations at $z \lesssim 2$ at a statistically significant level



Adhikari+21

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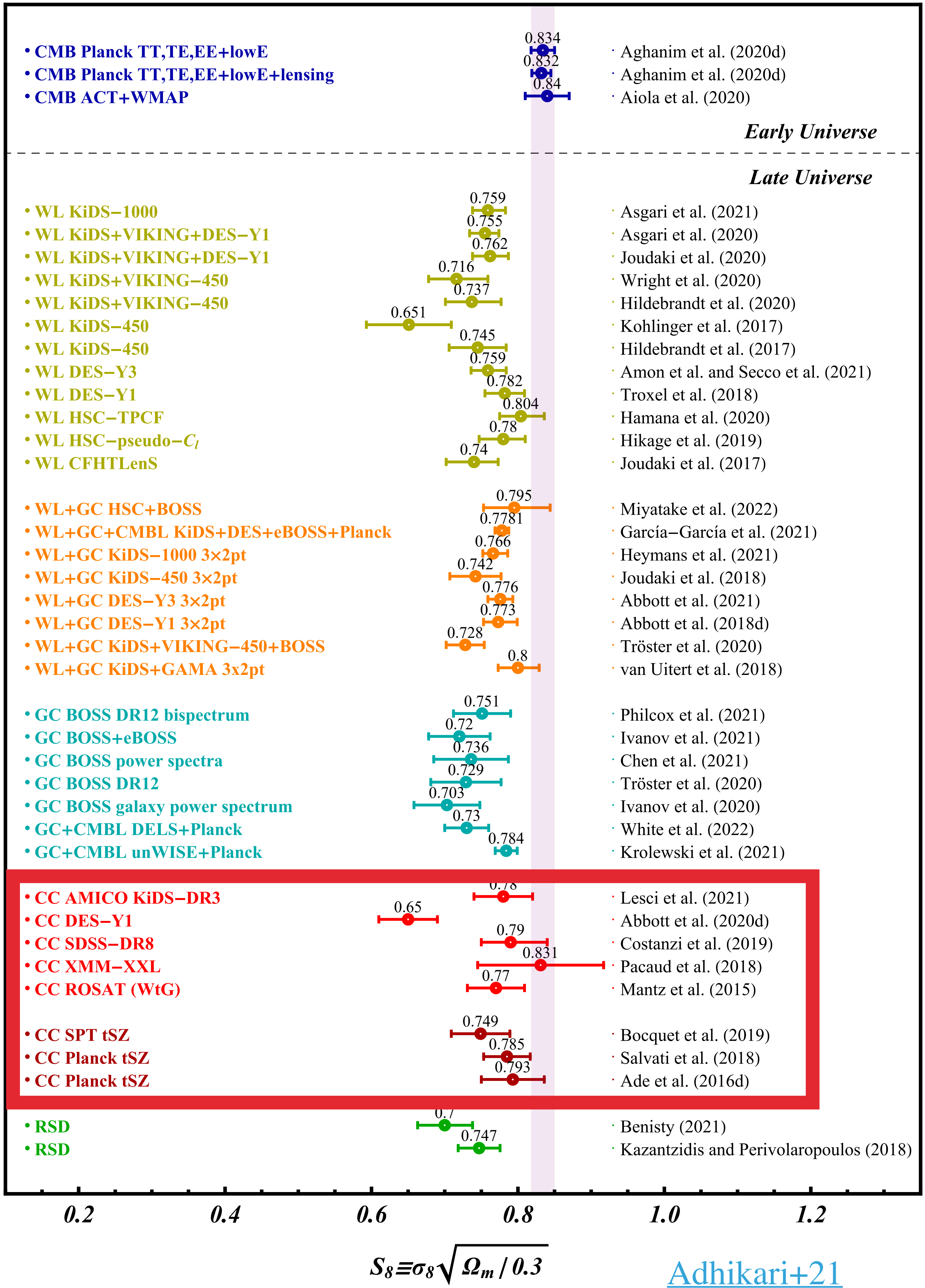
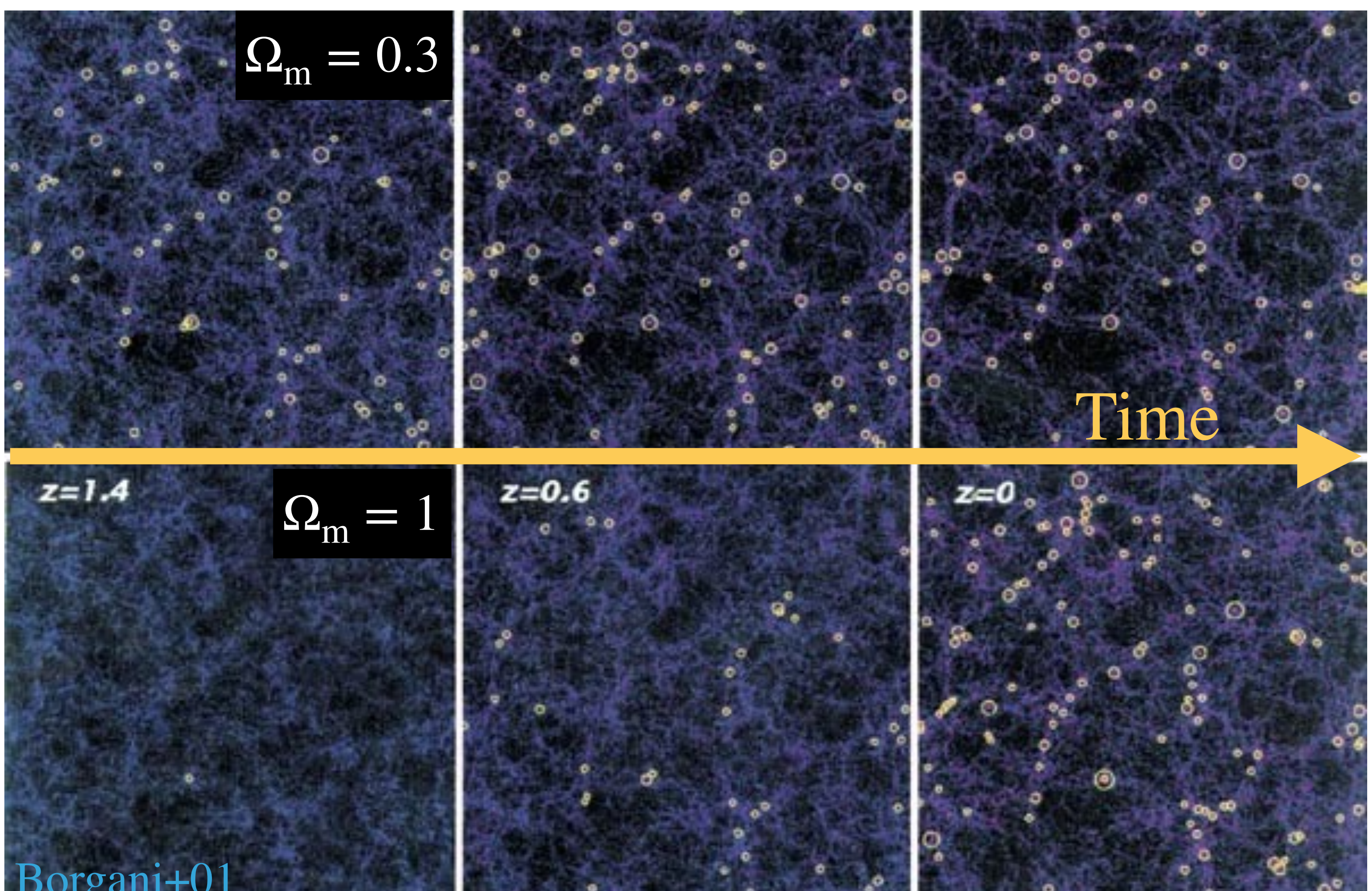
Galaxy clusters

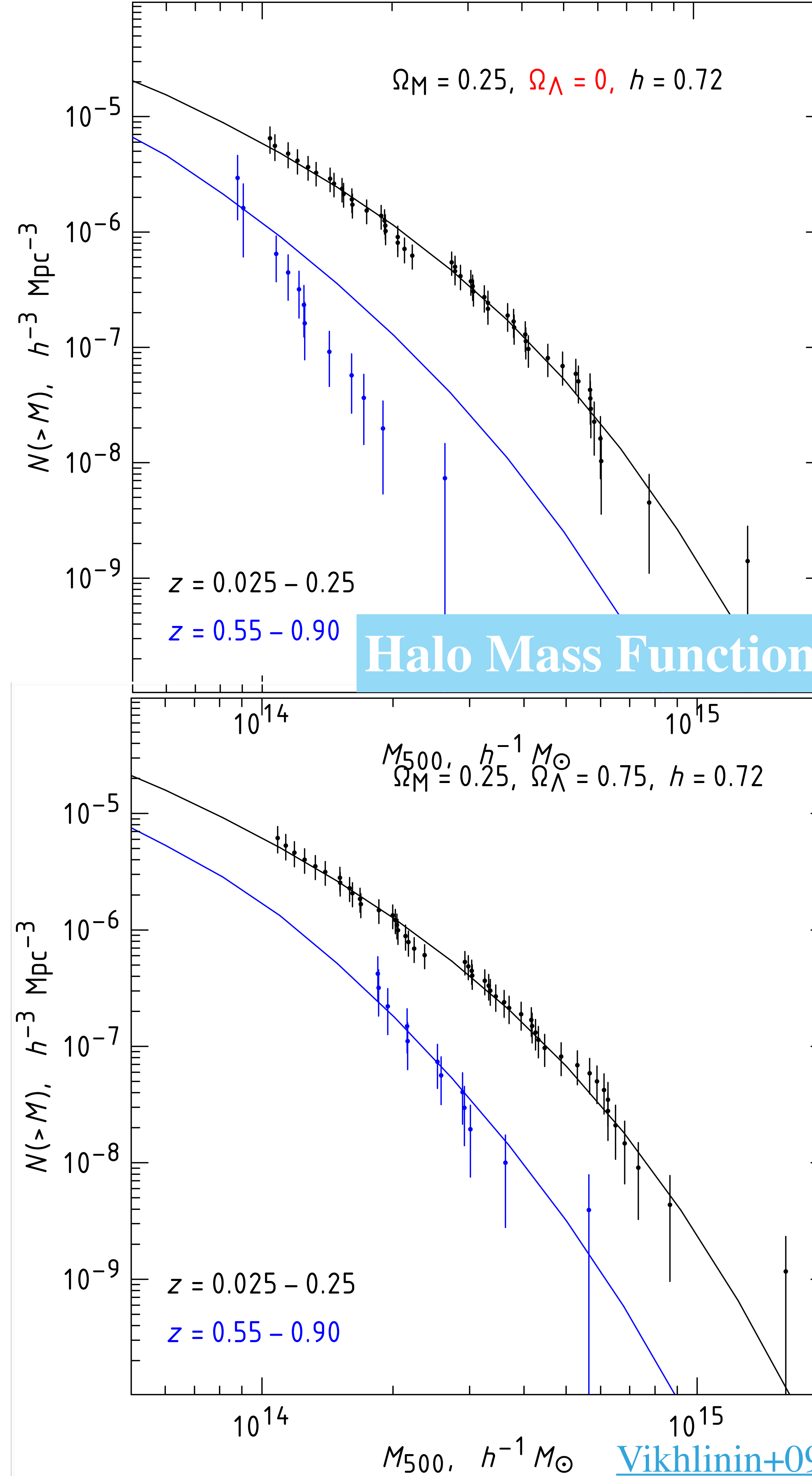


Adhikari+21

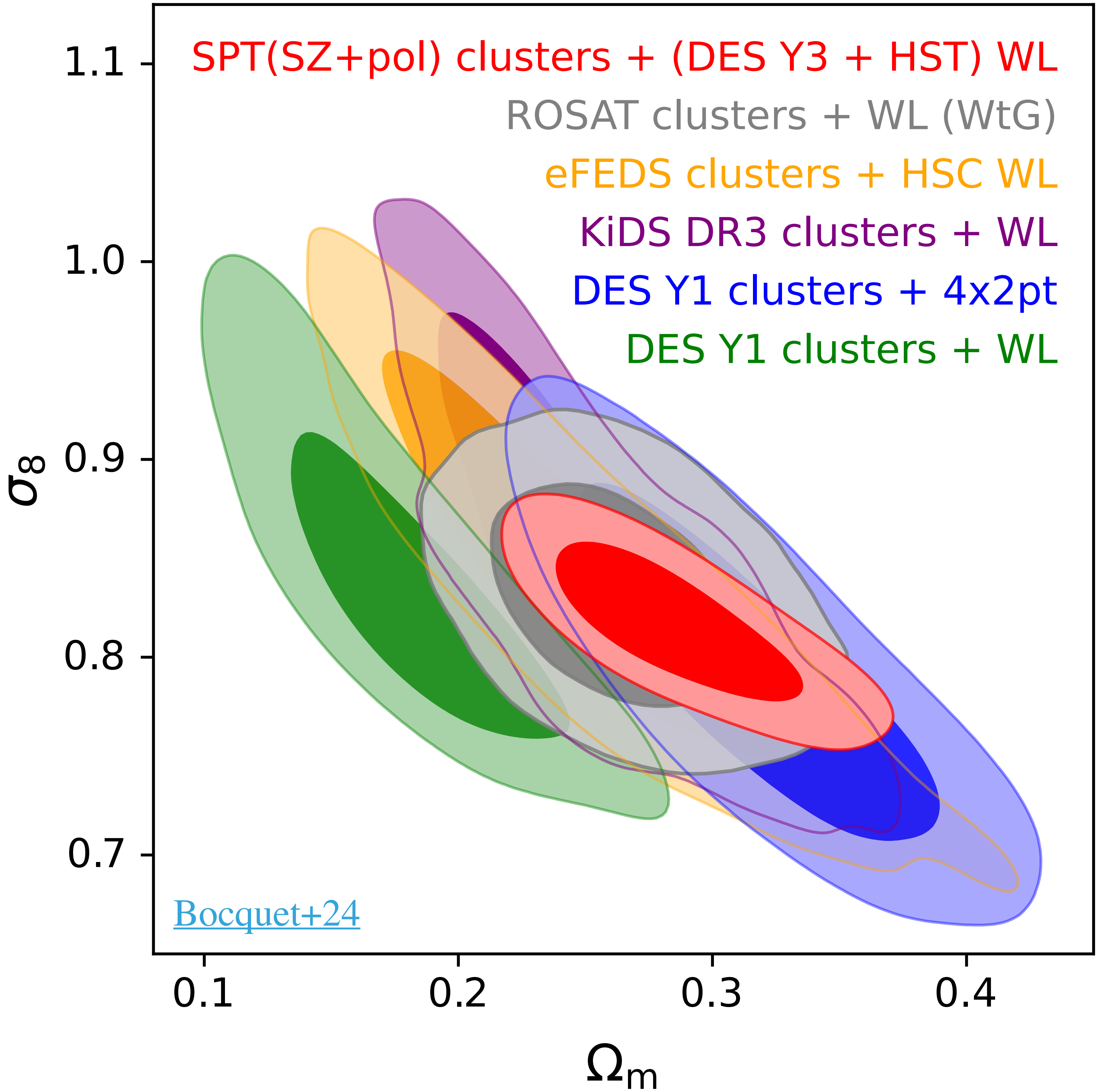
Cluster Cosmology

- Galaxy clusters locate at the density peaks of large-scale structures
- The number density of clusters over time puts strong constraints on cosmology
- Cluster cosmology is rooted in the measurement of the **halo mass function**



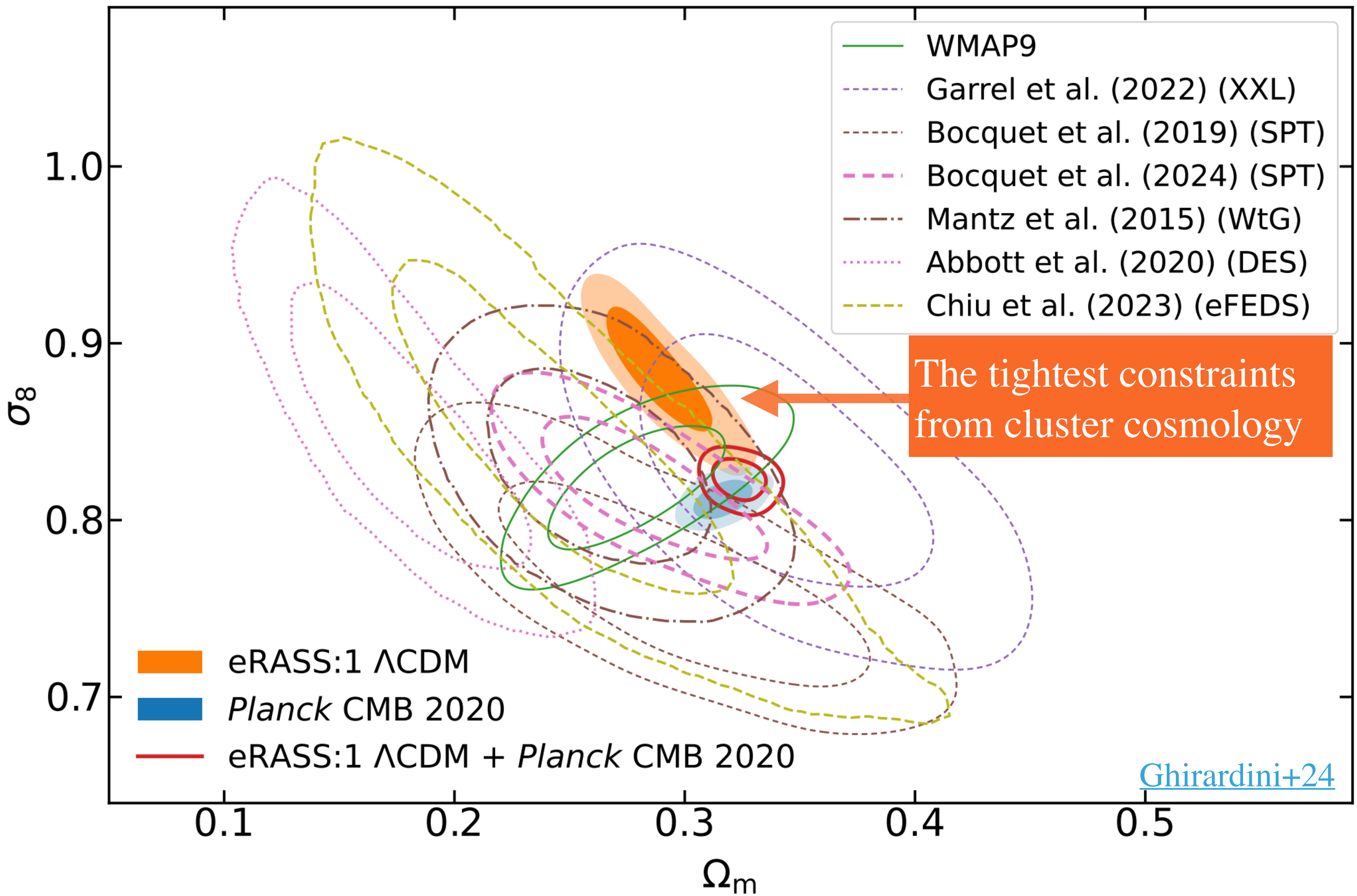


State of the Art



- Cluster cosmology has received great success in multiple wavelengths
- Current sample sizes $\approx 10^3$ clusters (or only few percents of the whole sky).

The Latest Cosmology From eROSITA All-Sky Survey (eRASS)



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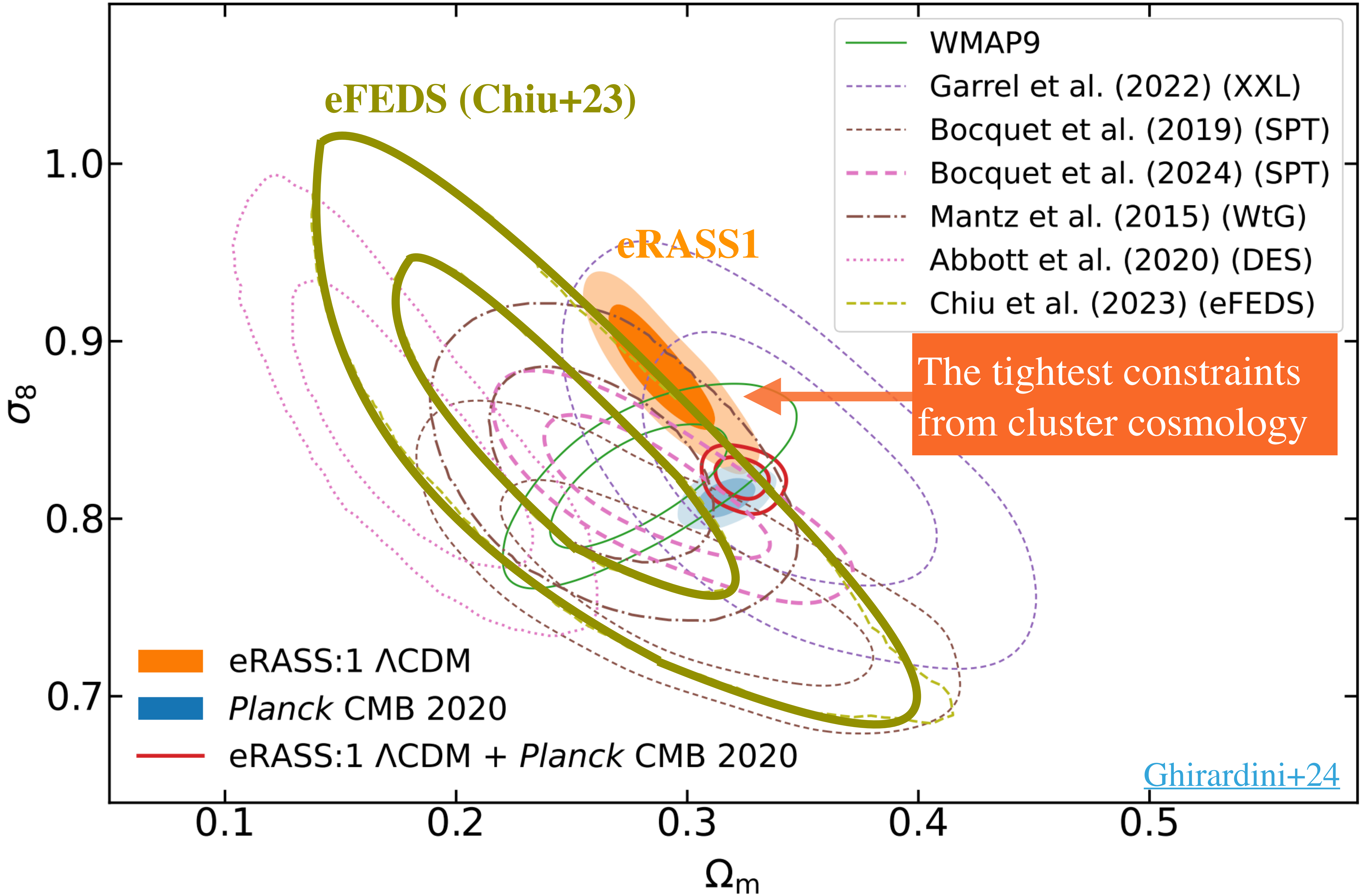

eROSITA Cluster Cosmology

- eROSITA is an X-ray space mission (2019–2024) aiming to search for galaxy clusters from all sky.
- The eROSITA all-sky survey has stopped due to the Ukraine War. Data from Science Verification (eFEDS) and Year-One survey (eRASS1) have been released.
- The first eROSITA-based cluster cosmology (eFEDS) was out in 2023 (Chiu+23), followed by the eRASS1 results in 2024 (Ghardini+24).

arXiv > astro-ph > arXiv:2107.05652

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[Submitted on 12 Jul 2021 (v1), last revised 21 Sep 2021 (this version, v3)]

The eROSITA Final Equatorial-Depth Survey (eFEDS): X-ray Observable-to-Mass-and-Redshift Relations of Galaxy Clusters and Groups with Weak-Lensing Mass Calibration from the Hyper Suprime-Cam Subaru Strategic Program Survey

I-Non Chiu, Vittorio Ghirardini, Ang Liu, Sebastian Grandis, Esra Bulbul, Y. Emre Bahar, Johan Comparat, Sebastian Bocquet, Nicolas Clerc, Matthias Klein, Teng Liu, Xiangchong Li, Hironao Miyatake, Joseph Mohr, Masamune Oguri, Nobuhiro Okabe, Florian Pacaud, Miriam E. Ramos-Ceja, Thomas H. Reiprich, Tim Schrabback, Keiichi Umetsu

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[Submitted on 25 Jul 2022 (v1), last revised 28 Mar 2023 (this version, v2)]

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3 May 2023

An initial study of dark energy with eROSITA X-Ray telescope indicates that it is uniformly distributed in space and time.

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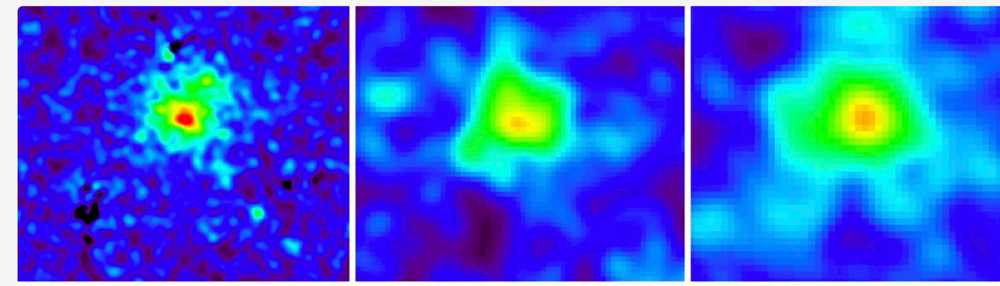
Unravelling the Enigma of Dark Energy with eROSITA X-Ray Telescope

SCIENCE - An initial study of dark energy with eROSITA X-Ray telescope indicates that it is uniformly distributed in space and time.

NEWS 4 MAY 2023



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Peer-Reviewed Publication

LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

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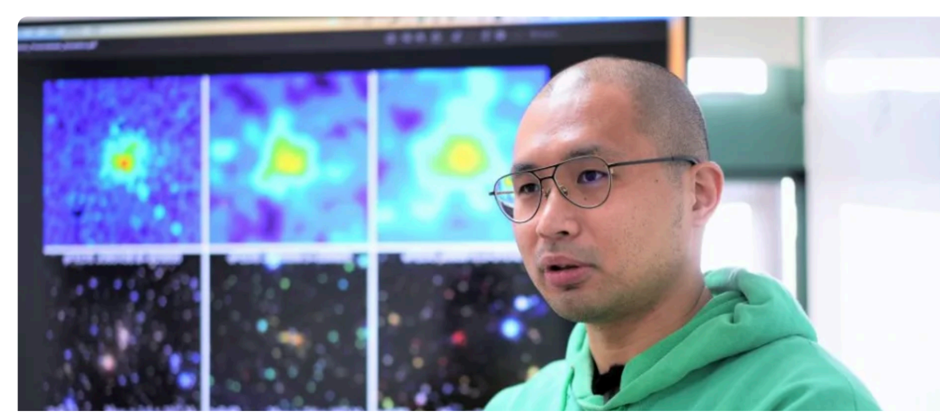
成大邱奕儂跨國研究 解鎖宇宙暗能量

CDNS E
2023年4月10日

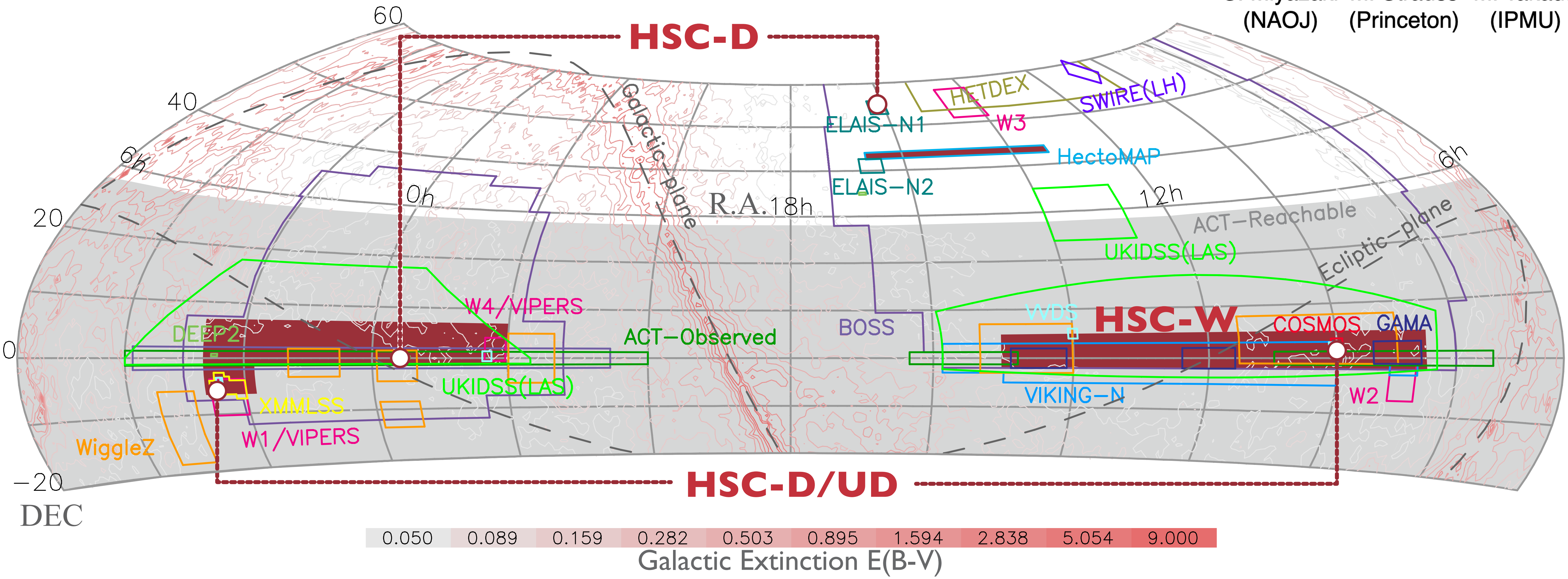


The Hyper Suprime-Cam Subaru Strategic Program


S. Miyazaki (NAOJ)


M. Strauss (Princeton)


M. Takada (IPMU)



- 8m telescope located at Maunakea, carrying out an optical and wide-field survey (2016–2022)
- The deepest optical survey at achieved area (≈ 1100 deg^2 and $i \approx 26$ mag) with $n_{\rm source} \approx 20$ gals/arcmin^2
- Uniqueness
  - Depth + Area + Quality (seeing $\lesssim 0.6$ arcsec)
  - The only WL survey capable of executing shear-selected cluster cosmology

Weak-Lensing Shear-Selected Galaxy Clusters

arXiv > astro-ph > arXiv:2406.11966

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[Submitted on 17 Jun 2024]

Weak-Lensing Shear-Selected Galaxy Clusters from the Hyper Suprime-Cam Subaru Strategic Program: I. Cluster Catalog, Selection Function and Mass--Observable Relation

Kai-Feng Chen, I-Non Chiu, Masamune Oguri, Yen-Ting Lin, Hironao Miyatake, Satoshi Miyazaki, Surhud More, Takashi Hamana, Markus M. Rau, Tomomi Sunayama, Sunao Sugiyama, Masahiro Takada

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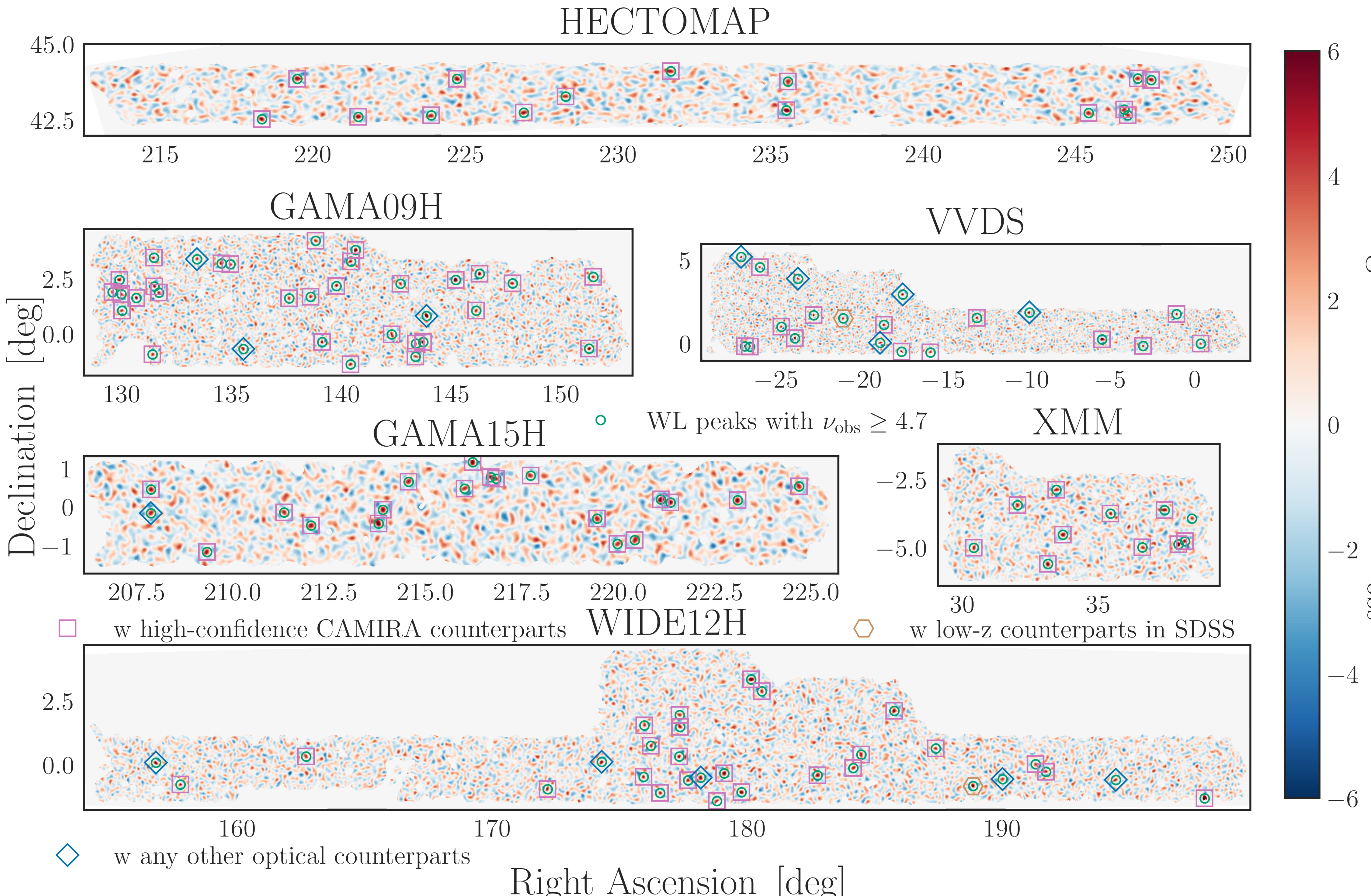
[Submitted on 17 Jun 2024]

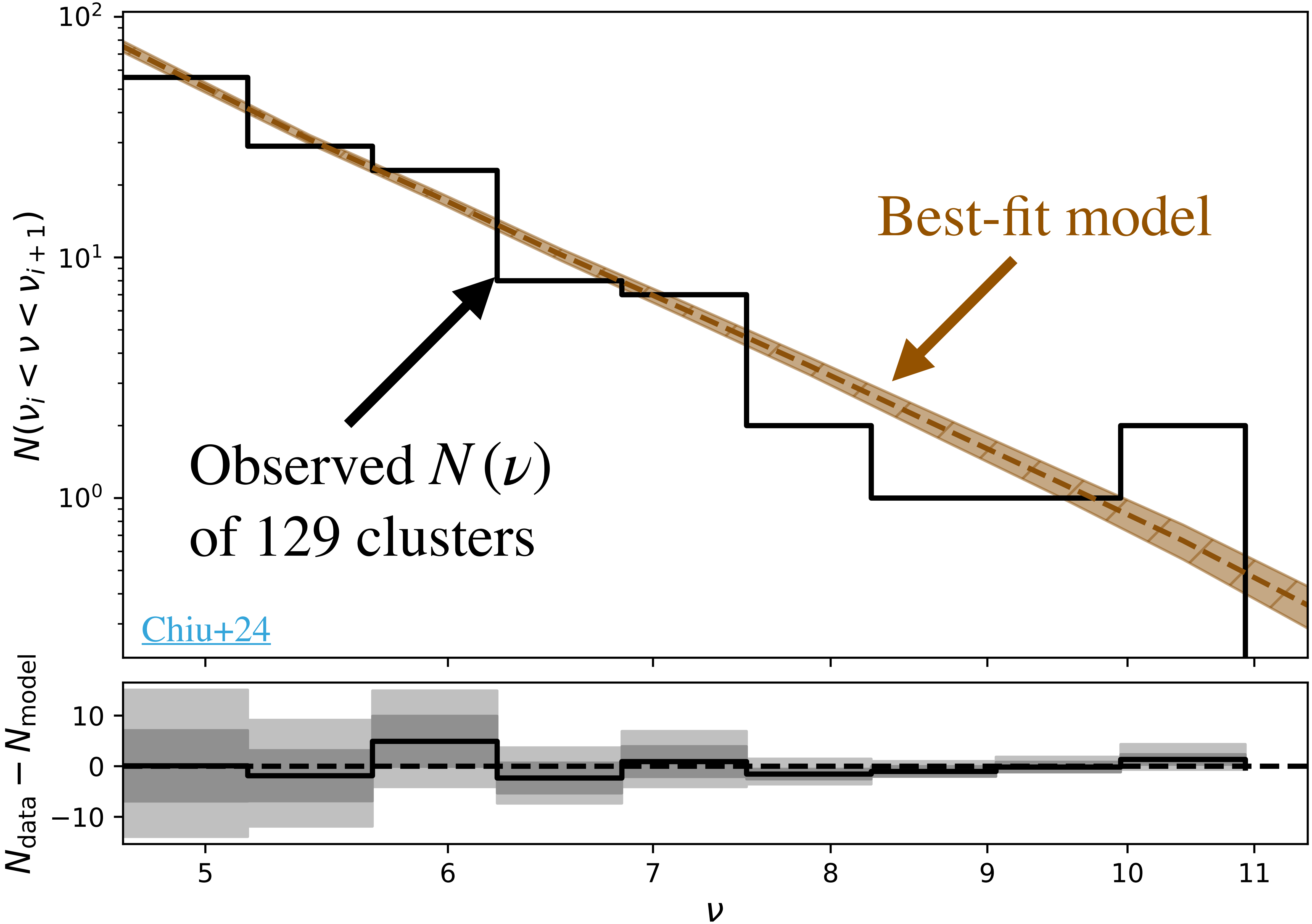
Weak-lensing Shear-selected Galaxy Clusters from the Hyper Suprime-Cam Subaru Strategic Program: II. Cosmological Constraints from the Cluster Abundance

I-Non Chiu, Kai-Feng Chen, Masamune Oguri, Markus M. Rau, Hironao Miyatake, Satoshi Miyazaki, Surhud More, Takashi Hamana, Tomomi Sunayama, Sunao Sugiyama, Masahiro Takada

HSC WL Mass Maps

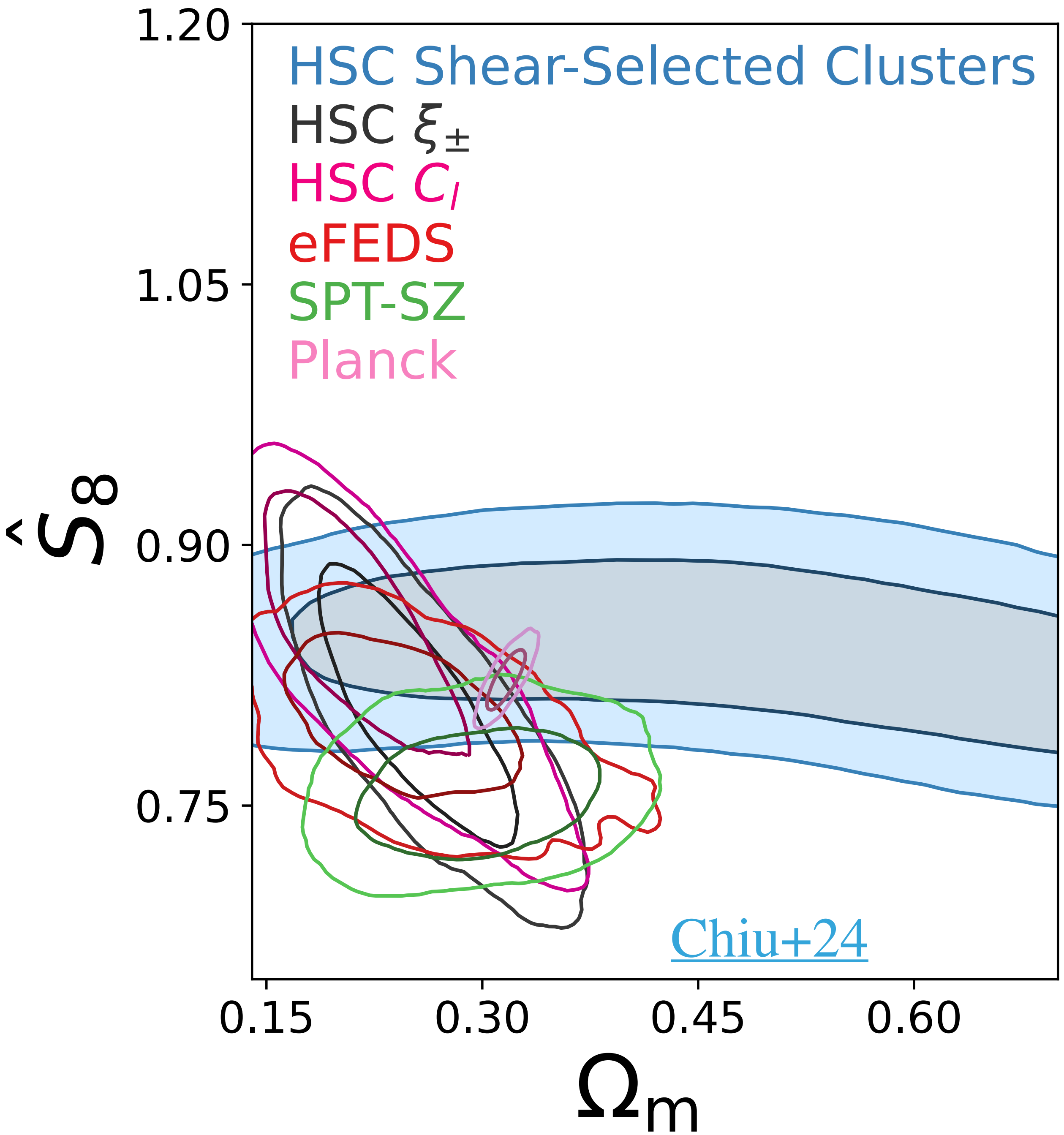


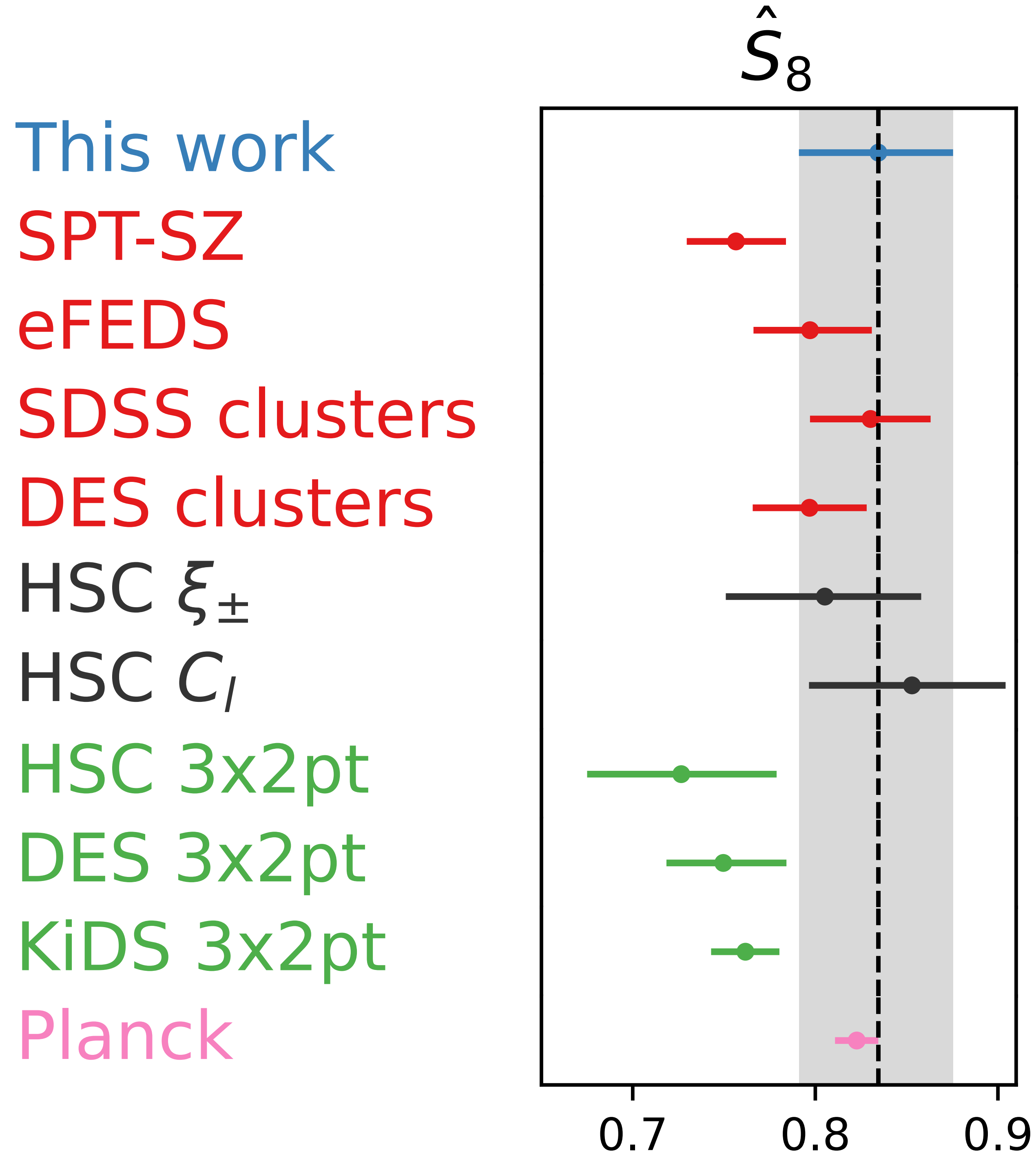
Chen+submitted



Excellent description of the data!

$$\hat{S}_8 \equiv \sigma_8 \left(\Omega_\mathrm{m}/0.3\right)^{0.25} = 0.835^{+0.041}_{-0.044}\ (4.7\ \%\ \text{constraint})$$





Excellent agreement with others except for 3×2pt at $\approx 2\sigma$

➡ systematics?

Sloshing Cold Fronts (CFs) in Intracluster Medium of Galaxy Clusters

I-Hsuan Li (email: l26134314@gs.ncku.edu.tw)

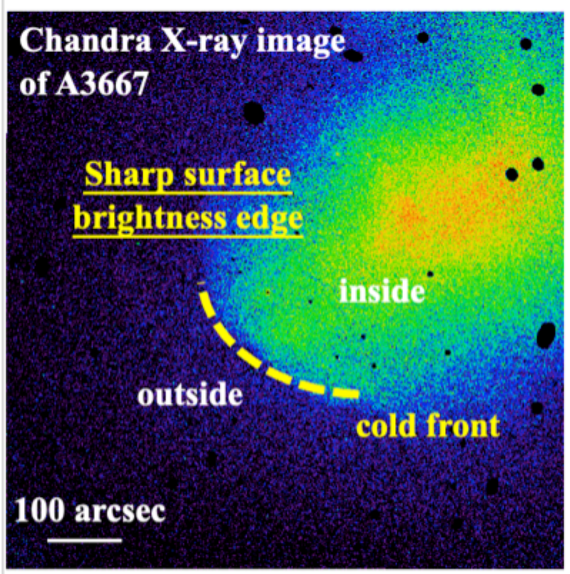
Cold front properties:

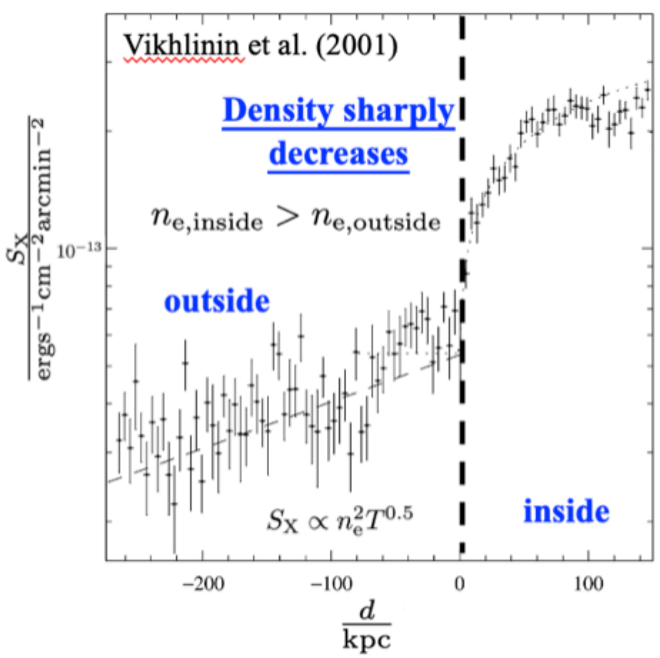
1. **Sharp surface brightness (Sx) edge**
2. **Density sharply decreases**
3. **Temperature increases abruptly**

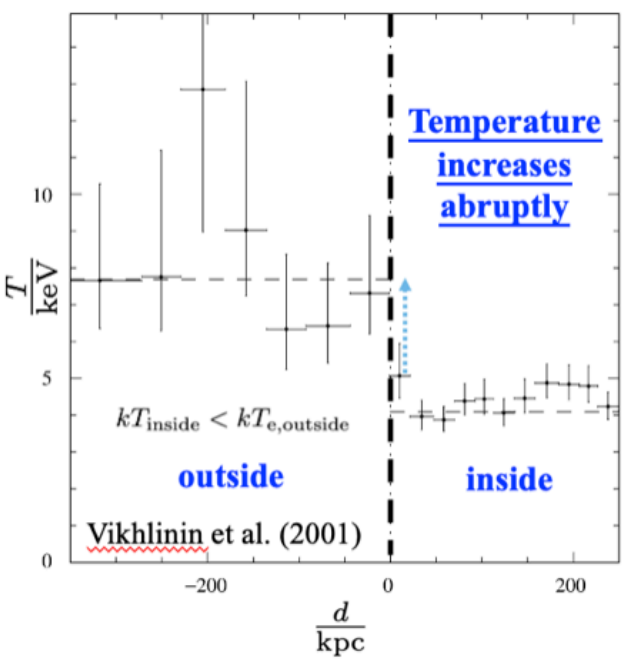
- **Sloshing CFs** are observed as **multiple concentric CFs** with subtle density and temperature contrasts at various radii **near the cluster center** and are thought to be generated by **gas sloshing**.

→ **Contact discontinuities are generated between gases of different entropy originally at different places in the cluster.**

→ **The underlying physics of sloshing CFs and stripping CFs may differ and require further study.**

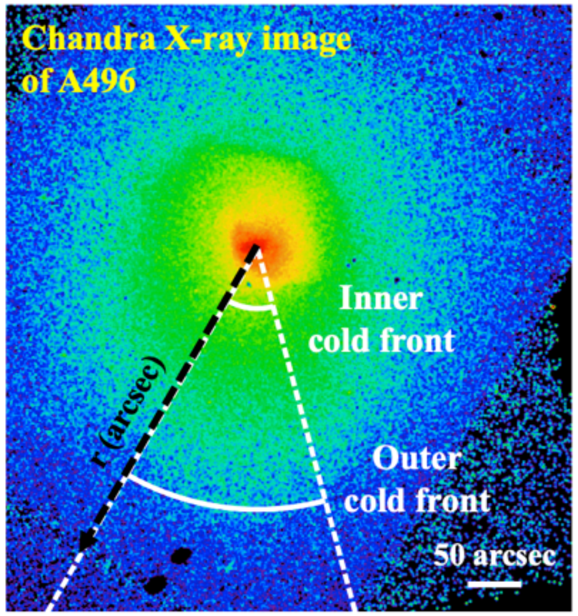






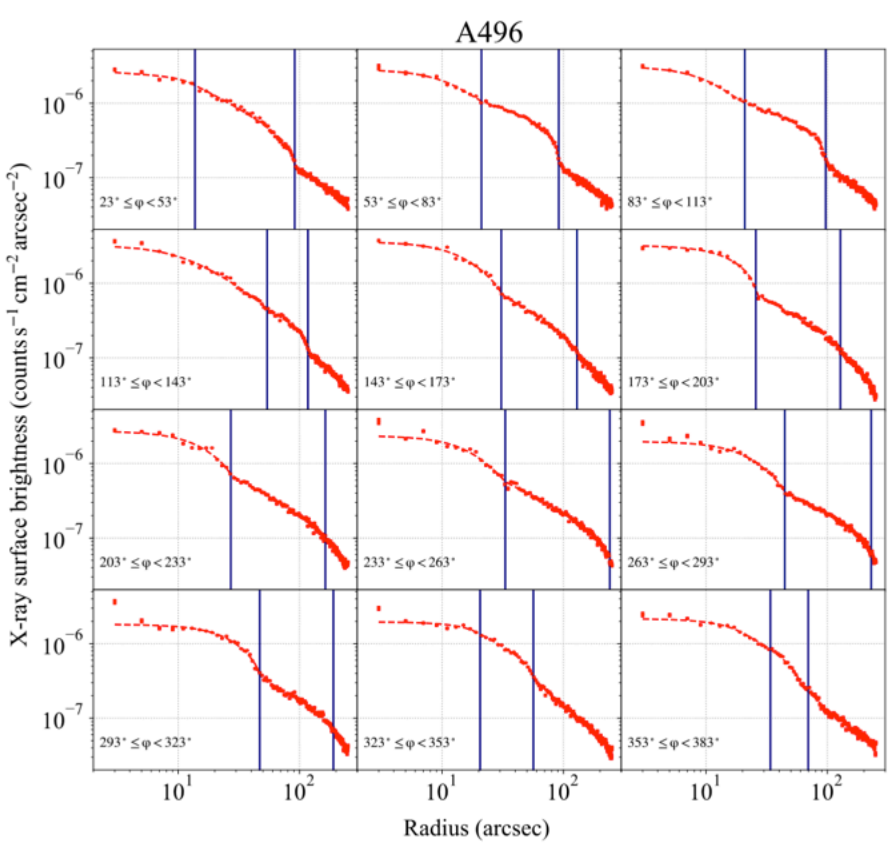
Stripping CF

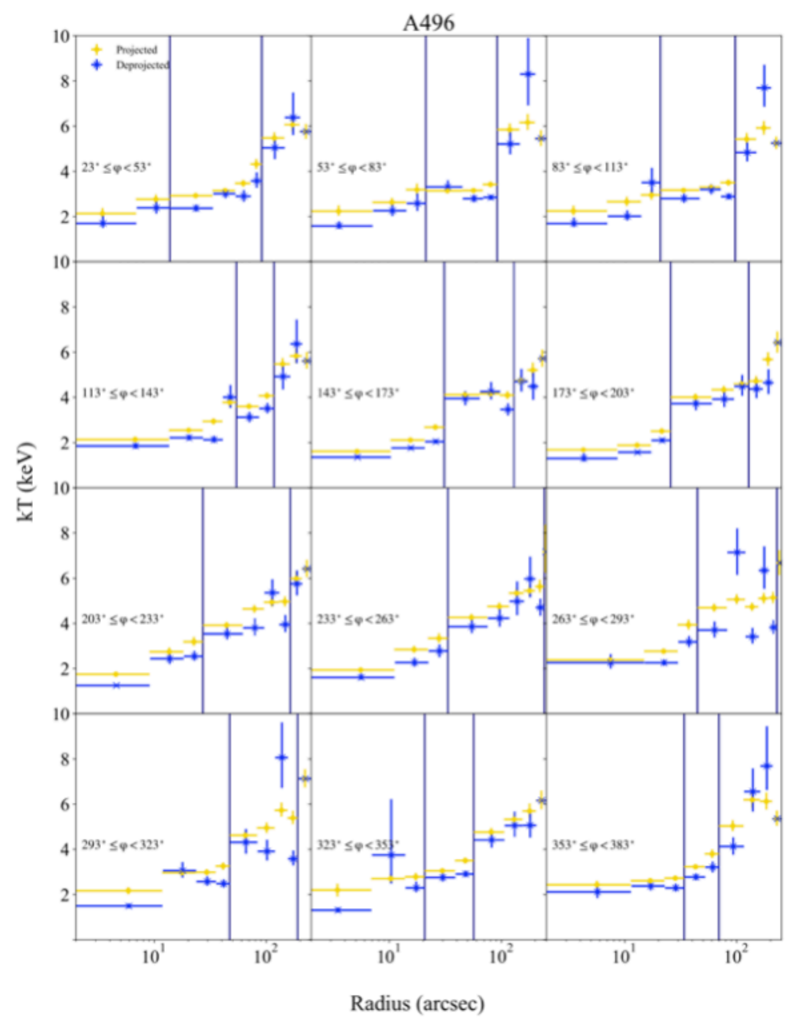
Sloshing CF

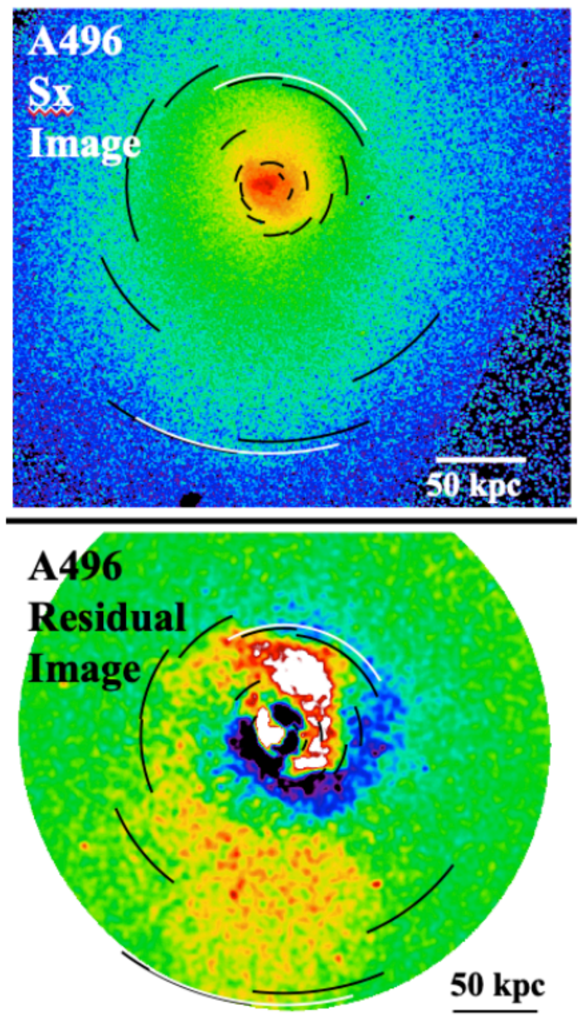


We divide the circular region around the cluster into 12 sectors and perform X-ray surface brightness fitting and spectral analysis to identify the Sx edges and measure the density and temperature contrasts across these edges.

Radial Surface Brightness Profiles	Radial Temperature Profiles	Detected Sx Edges (Black arcs)







White arcs: Ghizzardi et al. (2014)

Future Work: We will identify which edges can be classified as cold fronts.

Using Cross-Correlation Functions to Constrain the Host Environment of Fast Radio Bursts

Zi Jia Lai, I-Non Chiu

Motivation

The host environment of FRBs is unclear → Set FRB rate $\begin{cases} \propto M_* \rightarrow \text{old} \\ \propto SFR \rightarrow \text{young} \end{cases}$, and to compare these two scenarios.

Methods

halo catalogs from Takahashi et al. → Mock galaxy catalogs → Two kinds of mock FRB catalogs

Galaxy properties

- Stellar mass → Stellar-to-Halo Mass Relation & Halo Occupation Distribution
- Angular position → pNFW
- SFR → star-forming fraction & star formation main sequence

FRB properties

- Observed energy (from Shin et al.)
- FRB rate (two scenerios)
- DM → $\begin{cases} \text{skewed (in Macquart et al.)} \\ \text{Gaussian (in Hashimoto et al.)} \end{cases}$

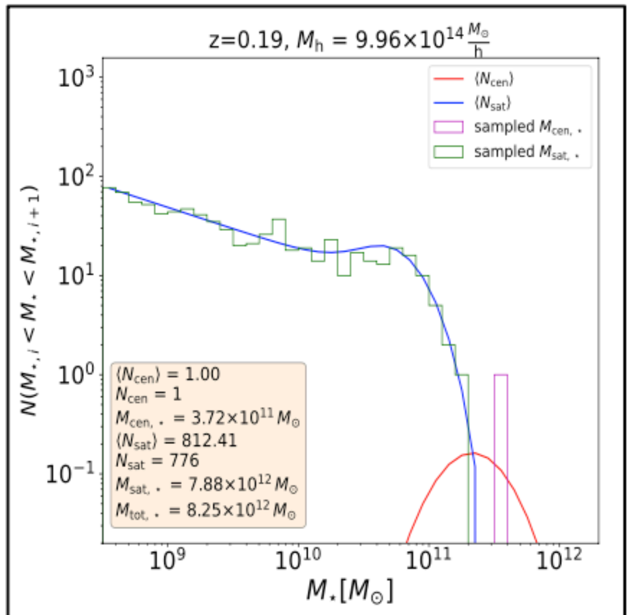


Fig 1. The stellar mass distribution of galaxies

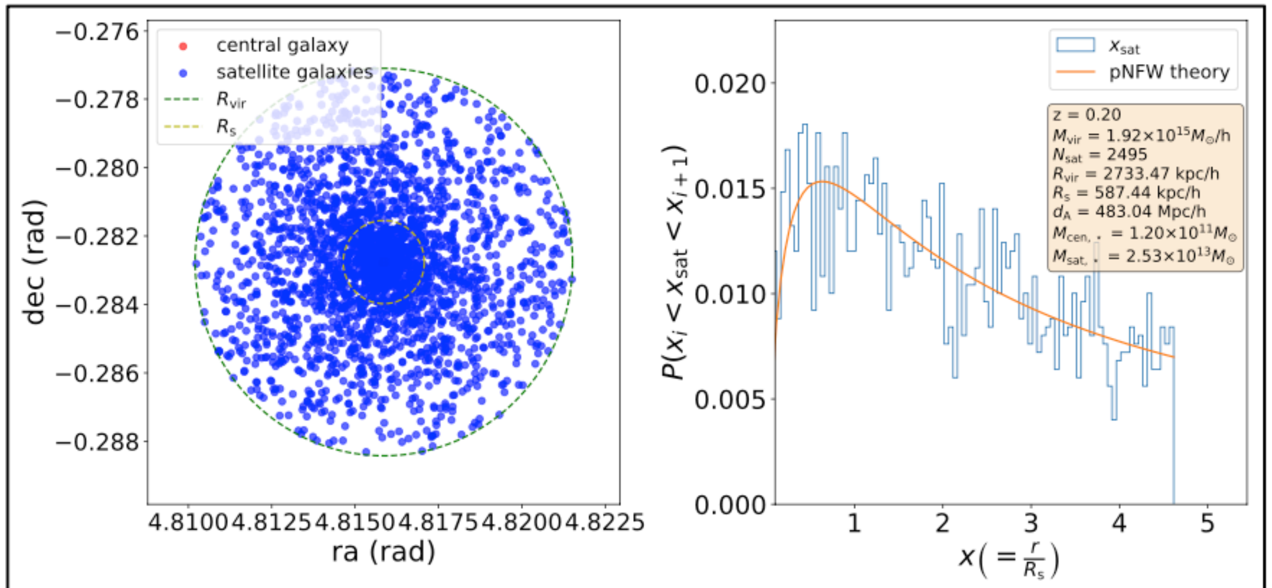


Fig 2. The distribution of angular positions of the galaxies

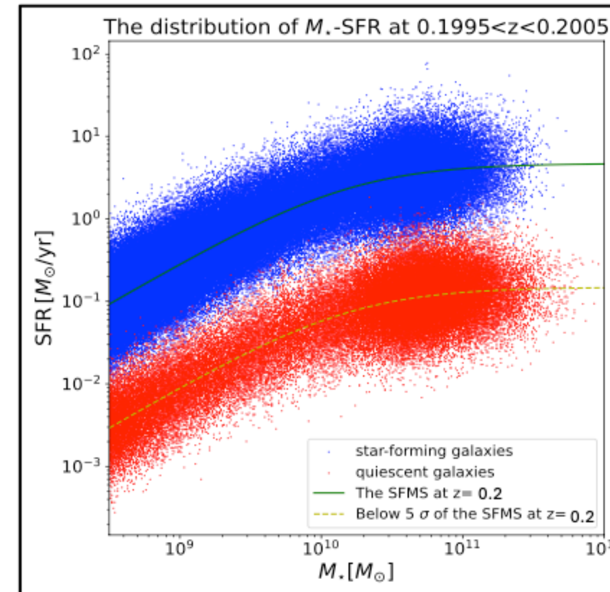


Fig 3. Our SFR sampling

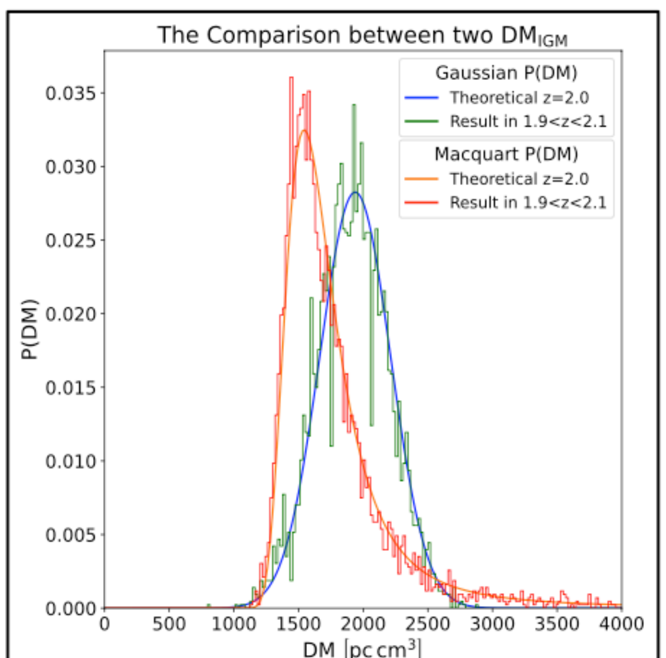


Fig 4. Two kinds of DM_{IGM}

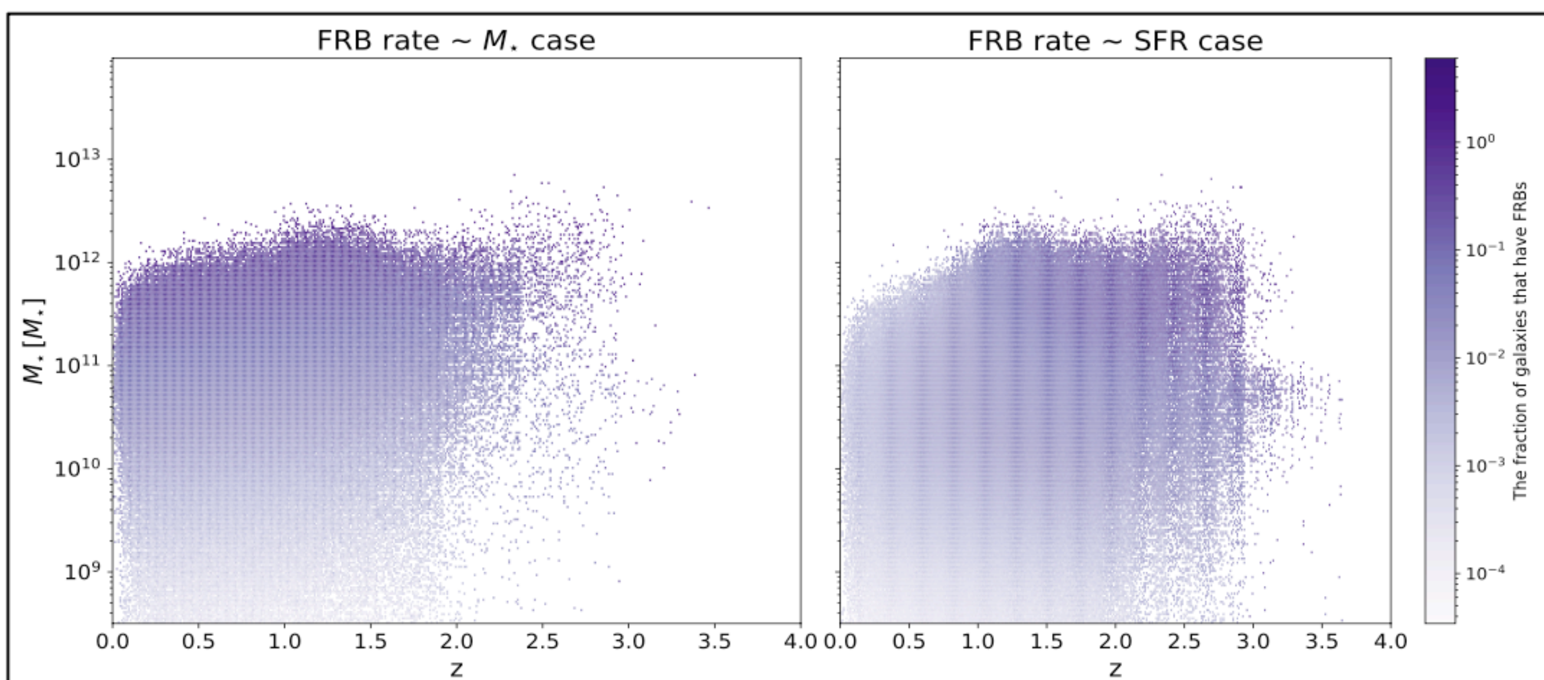
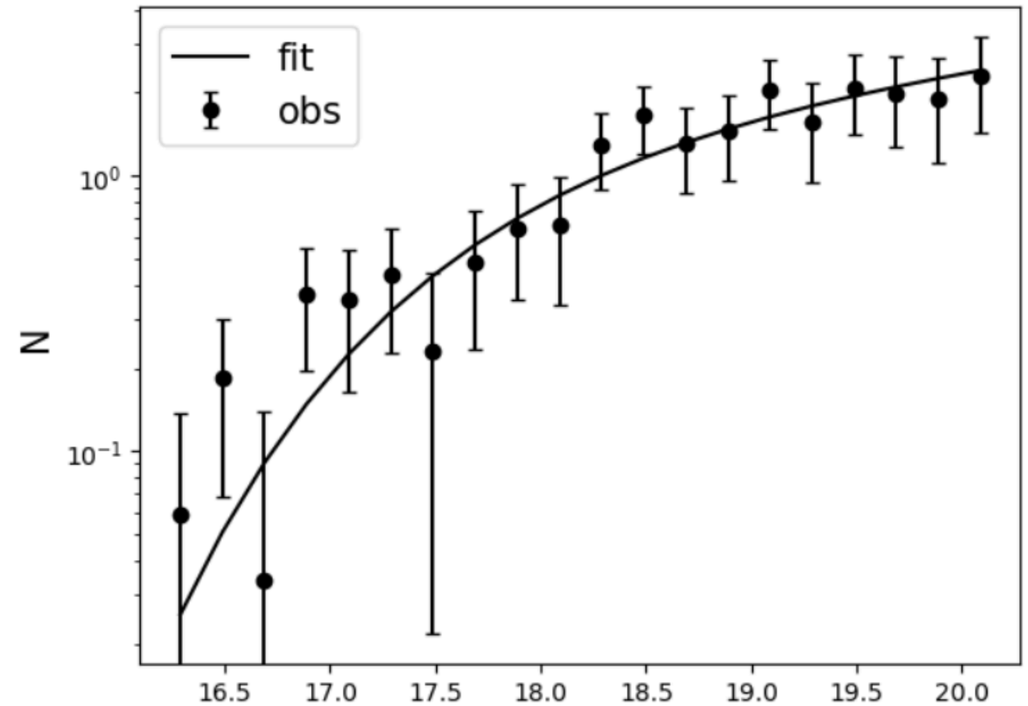
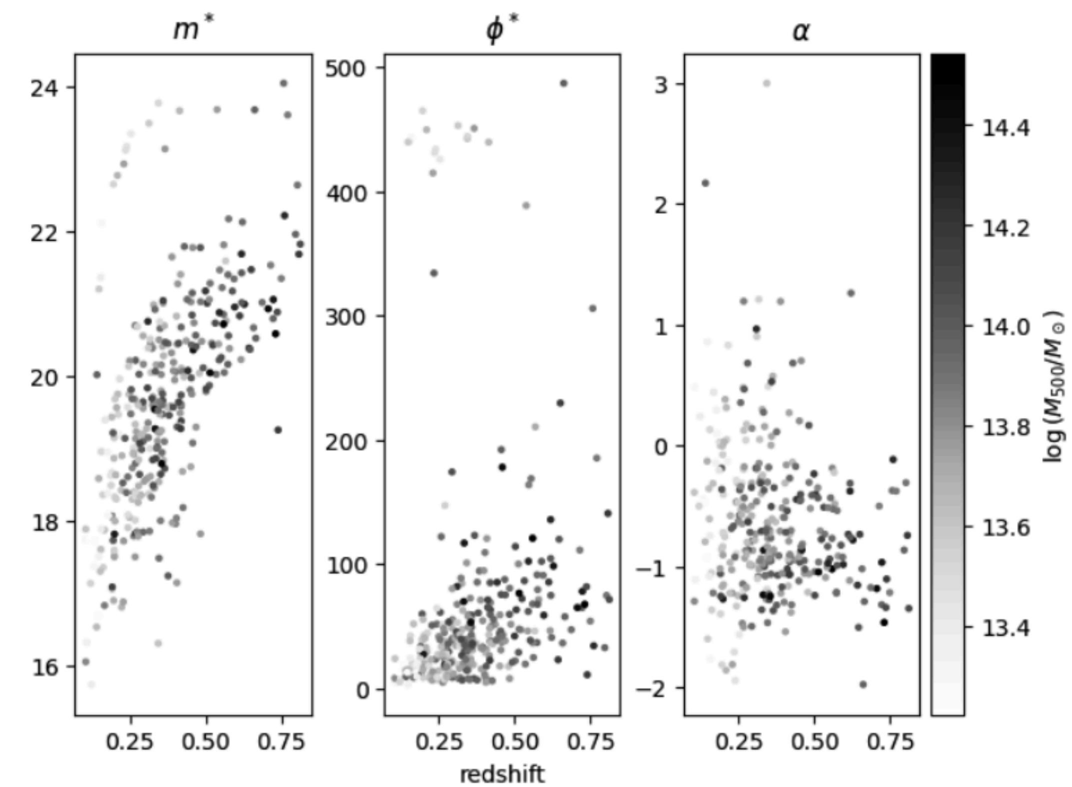


Fig 5. The probabilities for a galaxy that have FRBs in two cases

Luminosity Function

Hung-Yu, Lin





- Luminosity/Magnitude distribution of galaxies in a cluster
- Cluster data:
  The eROSITA Final Equatorial-Depth Survey (eFEDS)
- Galaxy data:
  The Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP)
- Try to find the relation between mass/redshift and the luminosity function

Particle Physics Lab (PI: Chuan-Hung Chen)

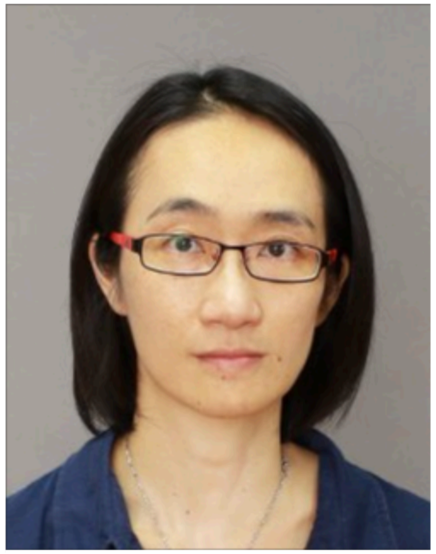
- **Research interest**: The standard model (SM) has been established as a very good effective theory at and below the electroweak scale. However, certain empirical observations still await resolutions, such as the origin of neutrino mass and the nature of dark matter (DM), which constitutes around 27% of the universe's total energy. Based on these unsolved issues and the anomalous processes indicated by experiments, we focus on the following research topics:

- **Scotogenic model**: Proposed by E. Ma in 2006, this model explains the origin of neutrino mass through a one-loop mechanism. The particles mediating the loop carry a dark charge, making them potential candidates for dark matter. Building on the concept of scotogenesis, **we explore not only the generation of neutrino mass but also its implications for lepton-flavor-violating (LFV) processes and its potential to address the muon g-2 anomaly**.

- **Leptoqaurk model**: Unexpectedly large branching ratios (BRs) of $B \to D^{(*)} \tau \bar{\nu}$ have been reported by BaBar, Belle, and LHCb. Additionally, Belle II recently reported a 2.7σ deviation from the SM prediction in the BR for $B \to K \nu\bar{\nu}$. It is of interest to simultaneously explain both excesses in a unified model. It is even more challenging if the model can also be used to fit the neutrino data. Since leptoquarks, which mediate interactions between quarks and leptons, provide peculiar couplings to quarks and leptons, we explore the above issues in the framework of leptoquark models.

Theoretical Cosmology Lab (PI: Shun-Pei Miao)

Large Quantum Loop Effects during Primordial Inflation



- MMC scalars & gravitons are massless & no classical conformal invariance ➔ bigger chance to interact with classical particles➔ large loop effects
  - Massless: virtual particles live longer than massive ones
  - no classical conformal invariance: emergence rates are not suppressed
  - Space-time expansion: live longer than those in flat space-time
- Particular part of quantum loop effects: leading logarithms (leading logs)
  - From loops of massless particles ➔ non-analytical (not affected by finite parts of local counter-terms) ➔ not affected by non-renormalizability of current Q.G. ➔ low energy effect field theory
  - Time(or space)–growing effects: overwhelm the smallness of loop counting parameters $GH^2 \sim 10^{-11}$ ➔ effects become physically significant or even non-perturbatively strong
    - $GH^2 \sim 10^{-11}$: bounded by measured scalar primordial power spectrum & upper bound of the tensor-scalar ratio
- Potential consequences:
  - Survive at surface of last scattering & might twist cosmic microwave background radiations
  - penetrate to very late time to provide a seed for non-local modification of gravity

Two issues for capturing leading logs -- Q.F.T. ➔ non-trivial even at 1-loop on de Sitter or FRW

- First issue: obtain leading logs from (1) the tail part of the graviton propagator (2) renormalizations
  - (1) Generalize Starobinsky's technique from scalar models to those involving Q.G ➔
    1. Obtaining leading logs from the tail part of the graviton propagator without Q.F.T. computations
    2. Allow us to re-sum leading logarithms from all loop orders when perturbations break down
  - Reduce the Q.G. models (with derivative couplings) to the original scalar model without derivative interactions ➔ induced effective potentials ➔ then apply Starobinsky's technique
  - (2) part of leading logs from incomplete cancellations between primitive UV divergence and counter-terms
  - Succeed in Yukawa, SQED, non-linear sigma models, Q.G. induced by MMC scalars etc. by combing a variant of Starobinsky's technique with a variant of Callan-Symanzik equation
  - Need to check for pure Q.G. (Q.G. induced by gravitons)
- 2nd issue: gauge issue
  - No well-defined S-matrix on de Sitter or FRW (unlike the gauge-independent S matrix in flat space-time)
  - Purge gauge dependence at the level of linearized effective field equations (1PI 2-point function)
  - By including correlations from sources and observer & not taking the states to asymptotically early & late times
  - Succeed in MMC scalars induced by GR & EM induced by GR in flat space-time ➔ Generalize to de Sitter