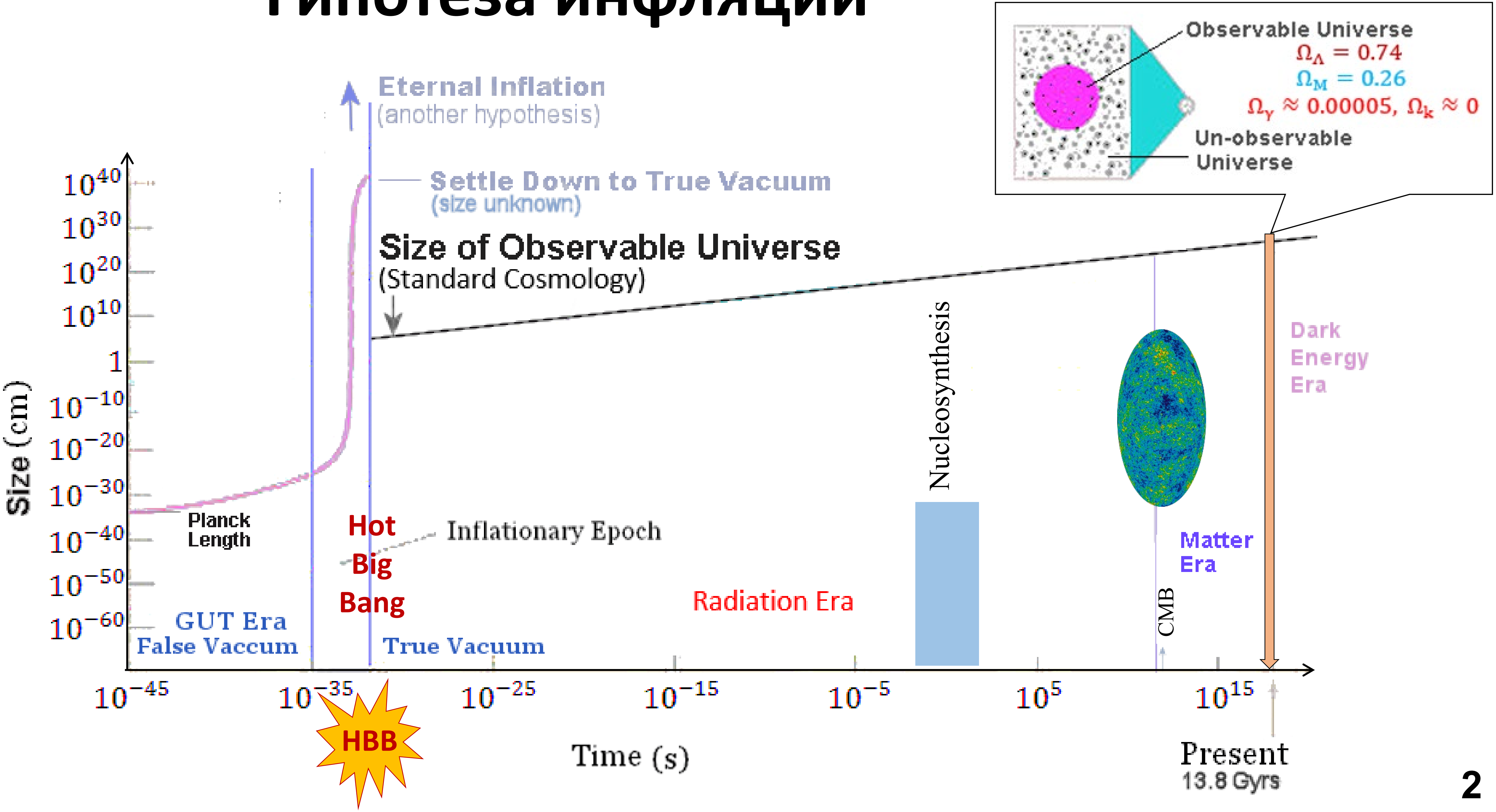
Новости наблюдательной АСТРОфизики и космоЛОГИИ

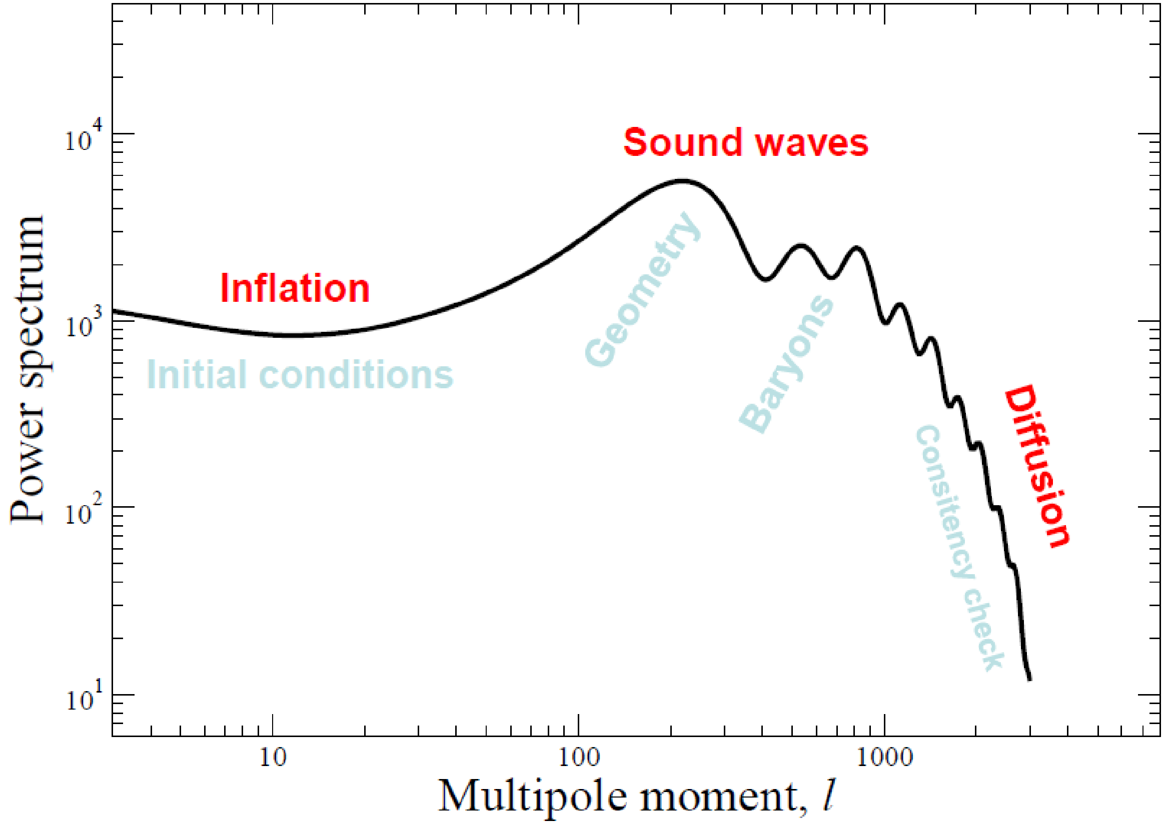
Гипотеза инфляции



Гипотеза инфляции

Гипотеза инфляции Вселенной была впервые предложена Алексеем Старобинским и позднее независимо (в различных вариациях) Alan Guth и Андреем Линде. Впоследствии было предложено множество модификаций и развитий этих идей.

Практически независимо от варианта модели, инфляция ПРЕДСКАЗЫВАЕТ наличие первичных гравитационных волн, проявление которых возможно обнаружить из анализа характеристик реликтового излучения (сейчас активно ищутся).



Кроме того, модель инфляции ПРЕДСКАЗЫВАЕТ отличие показателя спектра первичных возмущений от единицы (подтверждено в наблюдениях!):

$$n_s = 1 - \frac{2}{N}, \qquad 50 < N < 60$$

– показатель экспоненты инфляции!

Красное смещение

Для фотонов $ds = 0$, тогда можно показать, что:

$$z \equiv \frac{\lambda_{\text{рег}} - \lambda_{\text{исп}}}{\lambda_{\text{исп}}} = \frac{a(t_0)\lambda - a(t)\lambda}{a(t)\lambda} = \frac{a(t_0)}{a(t)} - 1$$

То есть космологическое покраснение фотонов отражает изменение масштабного фактора со временем.

$$\frac{a_0}{a} = 1 + z$$

Таким образом, в отличие от эффекта Доплера, фотон «чувствует» расширение Вселенной **в процессе распространения**, что сказывается на его физической длине волны.

$$T(z) = T_0(1 + z)$$

Эпохе рекомбинации (отделение CMB от вещества) соответствует $z \simeq 1090$.

Самые ранние галактики, которые «видит» JWST имеют $z \simeq 16$.

Vanilla ΛCDM

arXiv:1807.06209

Parameter	Planck Combined
$\Omega_b h^2$	0.02233 ± 0.00015
$\Omega_c h^2$	0.1198 ± 0.0012
$100\theta_{MC}$	1.04089 ± 0.00031
τ	0.0540 ± 0.0074
$\ln(10^{10} A_s)$	3.043 ± 0.014
n_s	0.9652 ± 0.0042
$\Omega_m h^2$	0.1428 ± 0.0011
H_0 [km s^{-1}Mpc^{-1}]	67.37 ± 0.54
Ω_m	0.3147 ± 0.0074
Age [Gyr]	13.801 ± 0.024
σ_8	0.8101 ± 0.0061
$S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5}$	0.830 ± 0.013
z_{re}	7.64 ± 0.74
$100\theta_*$	1.04108 ± 0.00031
r_{drag} [Mpc]	147.18 ± 0.29

ΛCDM с высокой точностью описывает ВСЕ результаты CMB (ранняя Вселенная $z \simeq 1090$). Используя эти параметры как «начальные», можно рассчитать всю дальнейшую эволюцию Вселенной и сравнить с НЕЗАВИСИМЫМИ измерениями для «поздней» Вселенной (малые значения $z \lesssim 2$).

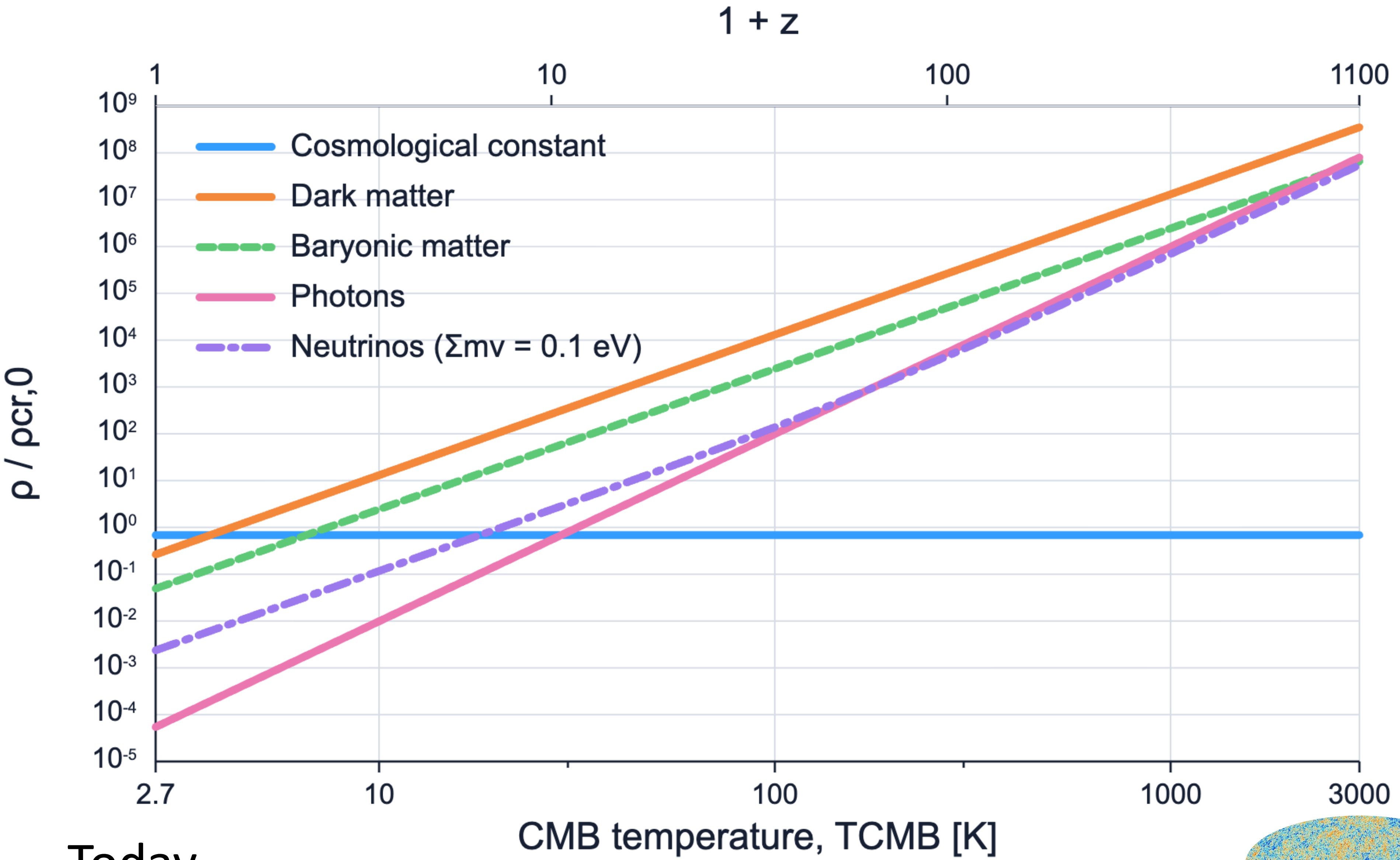
Параметр Хаббла сегодня, по SN Ia

Возраст Вселенной

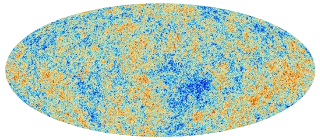
Кластеризация скоплений галактик

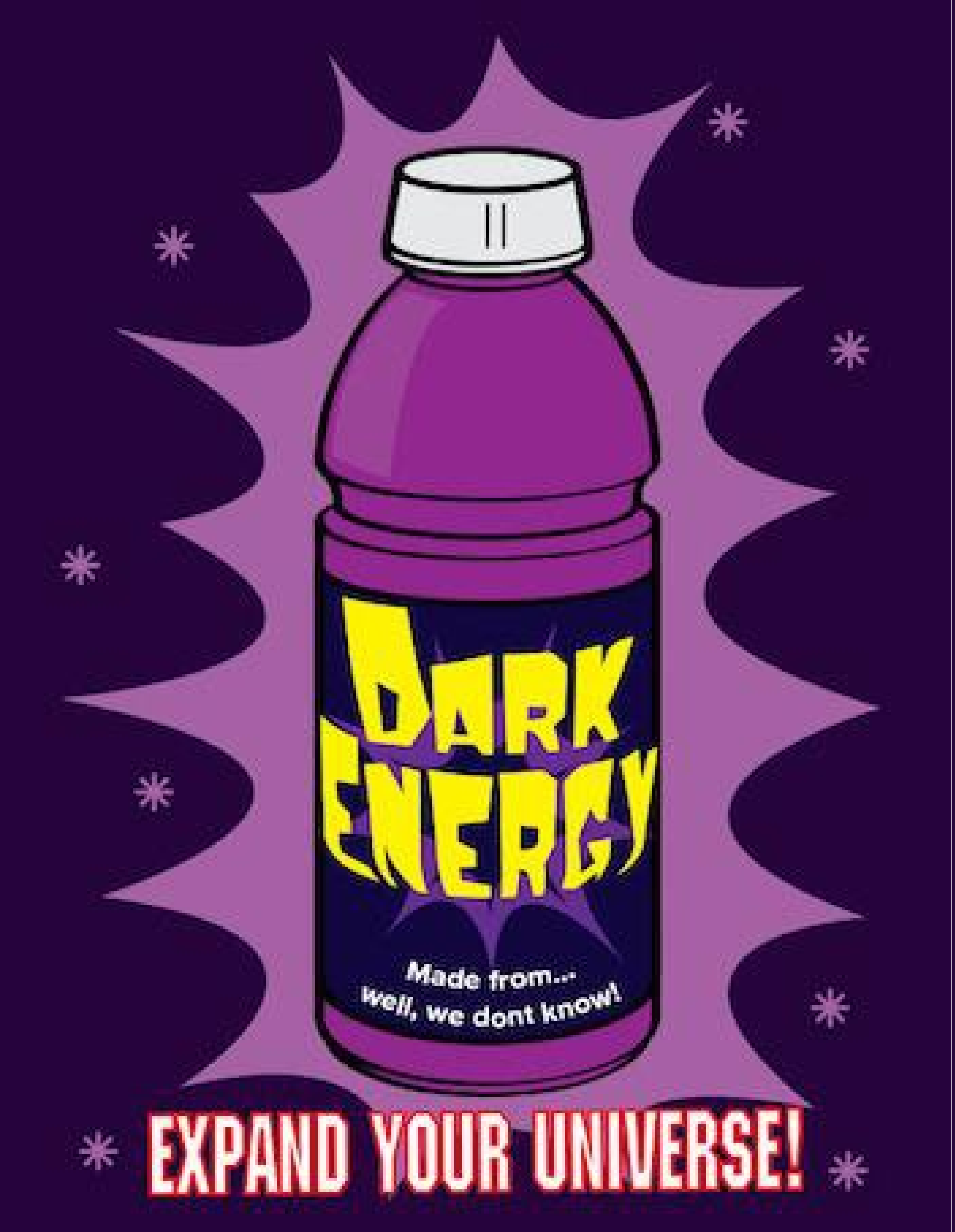
Главный пик в CMB

Fiducial Cosmological Model: ΛCDM



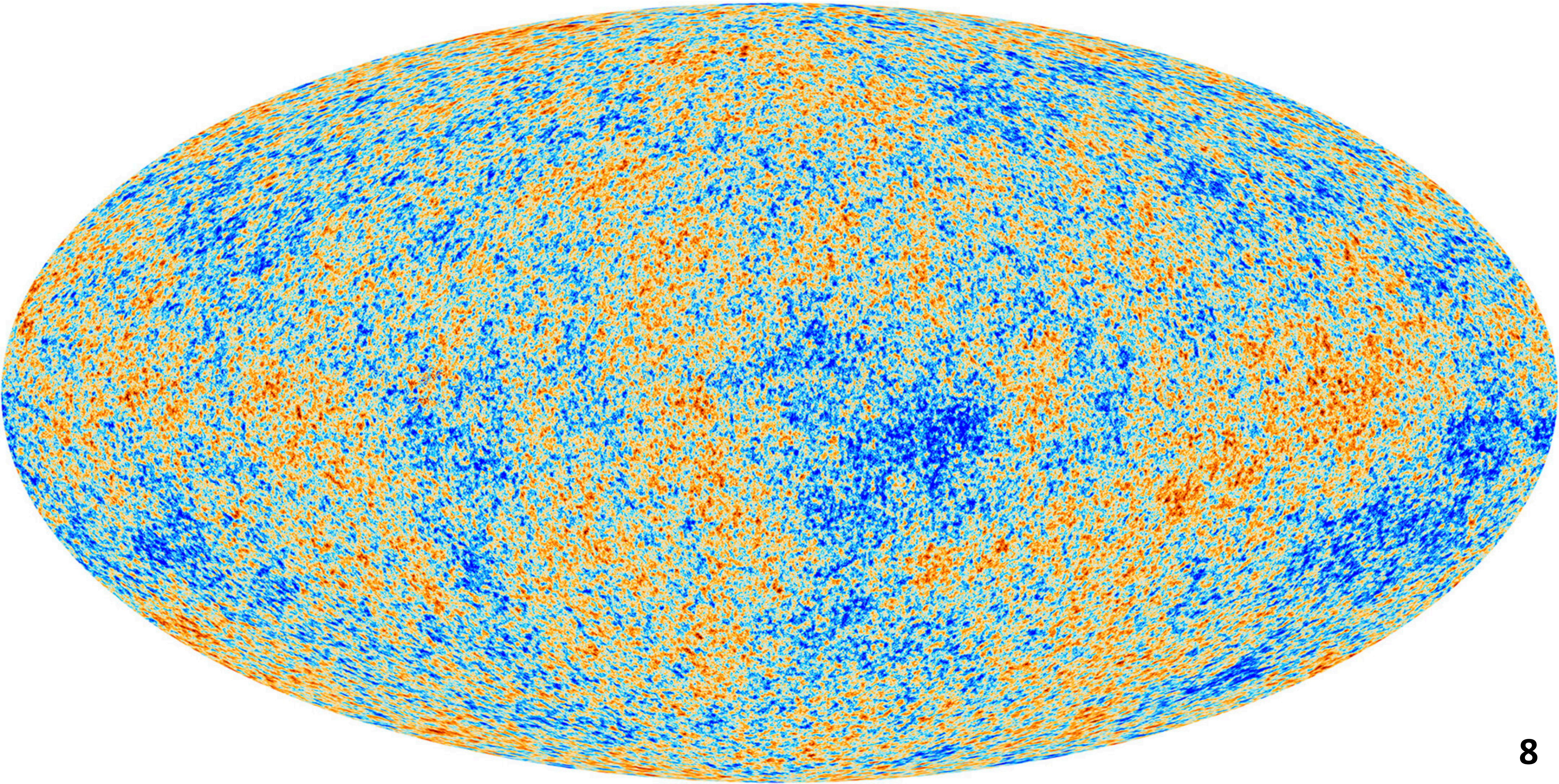
Today



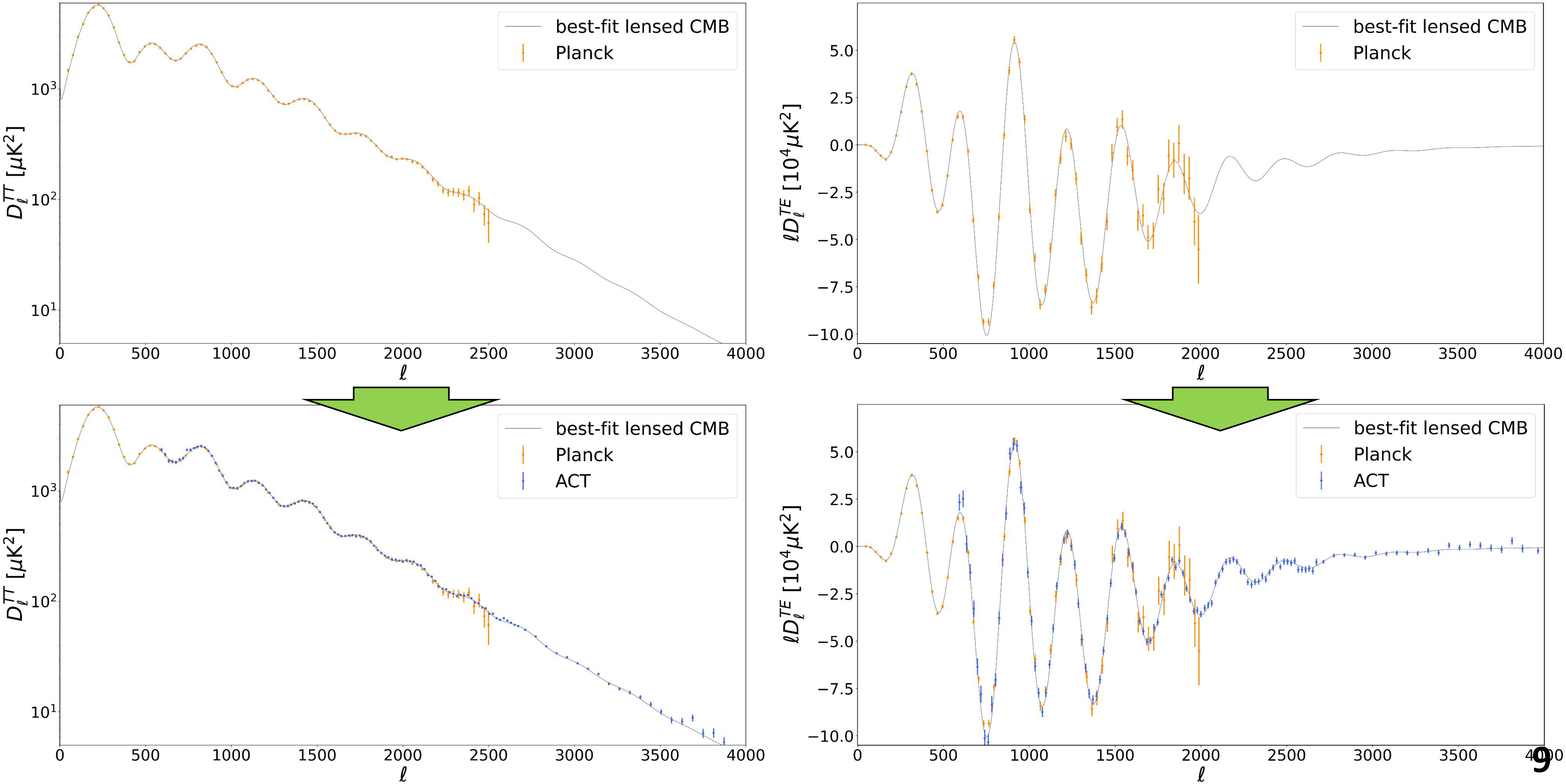

DARK ENERGY
Made from...
well, we dont know!
EXPAND YOUR UNIVERSE!


NEW!
GENERAL RELATIVITY
DARK MATTER
NEW IMPROVED!
MYSTERY FLAVOR!
NET WT ???
NUTRITION FACTS
INGREDIENTS:
No one really knows!
If you figure it out, let us know.

Planck CMB Map

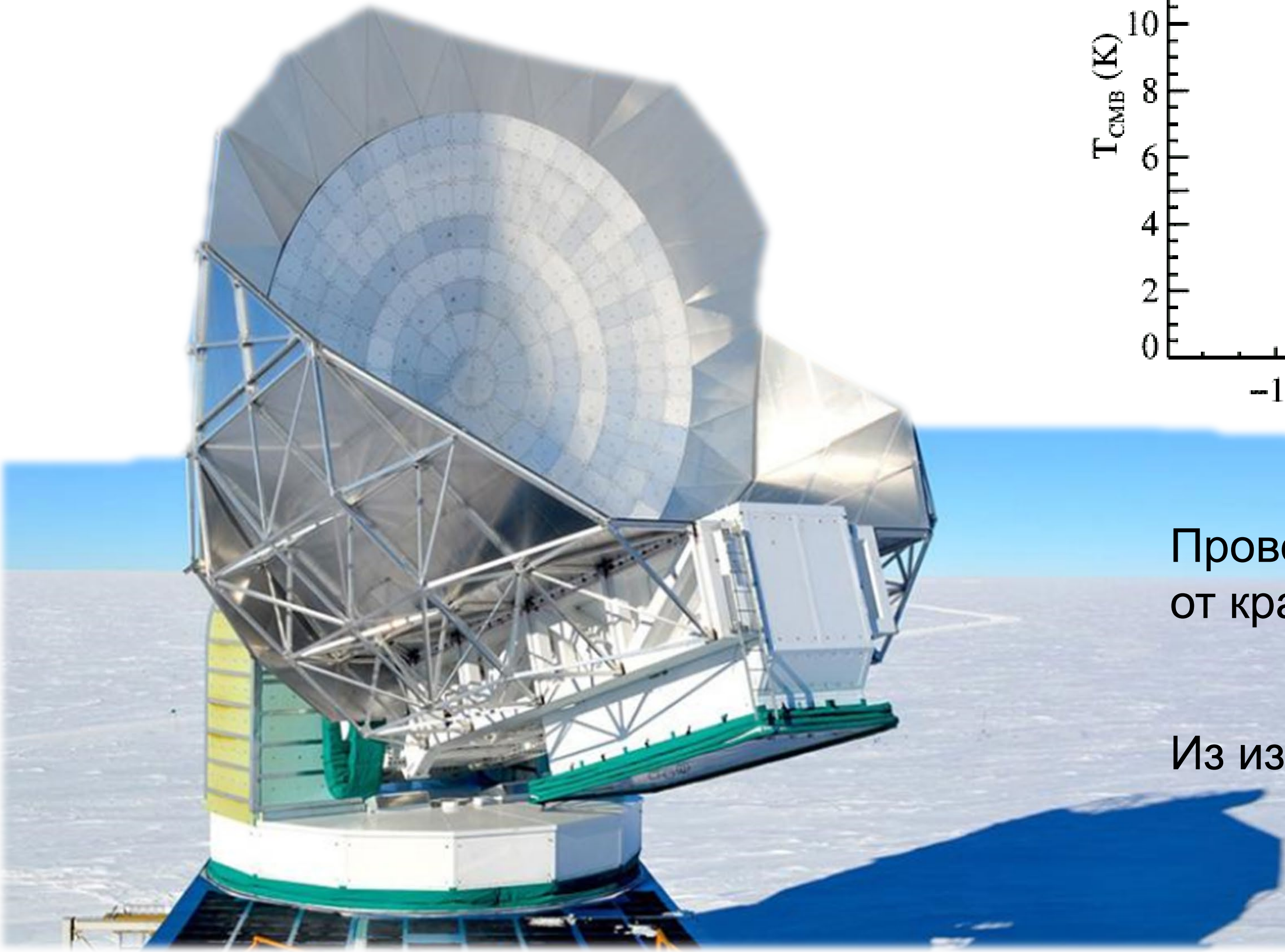


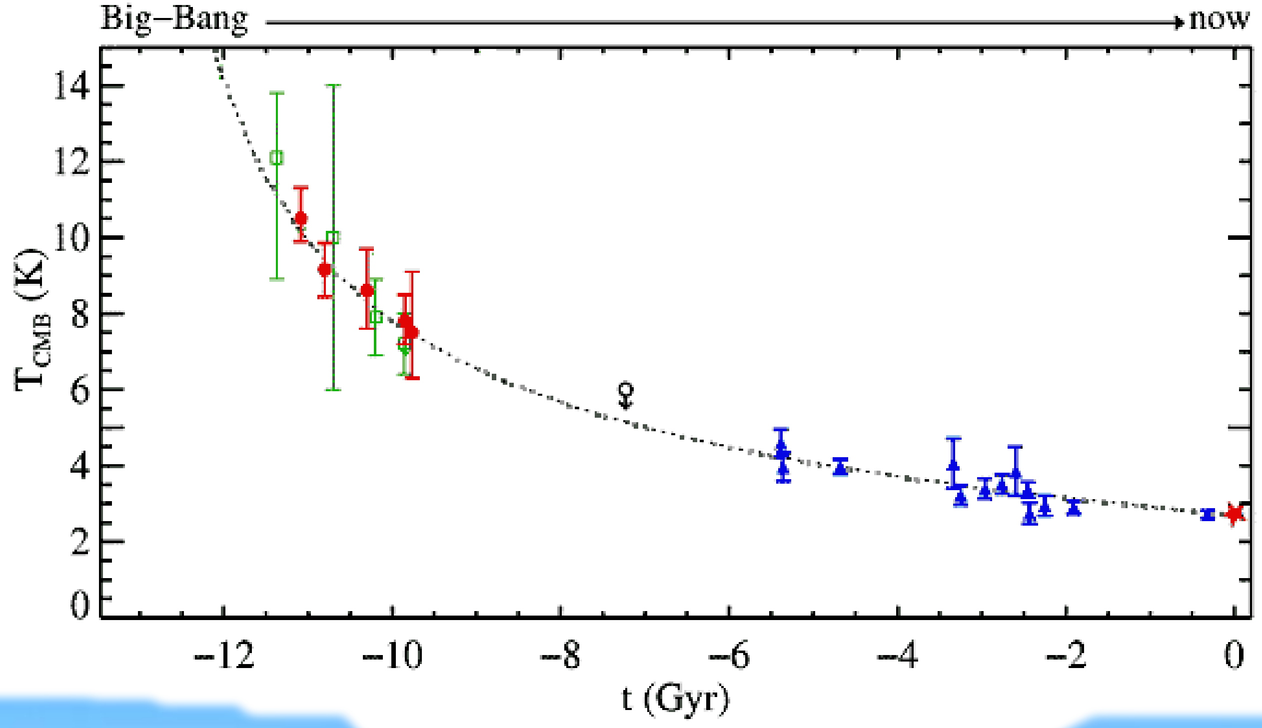
Ранняя космология: CMB



Эффект Сюняева-Зельдовича

На South Pole Telescope авторы исследовали 158 скоплений галактик при z = 0.05…1.35





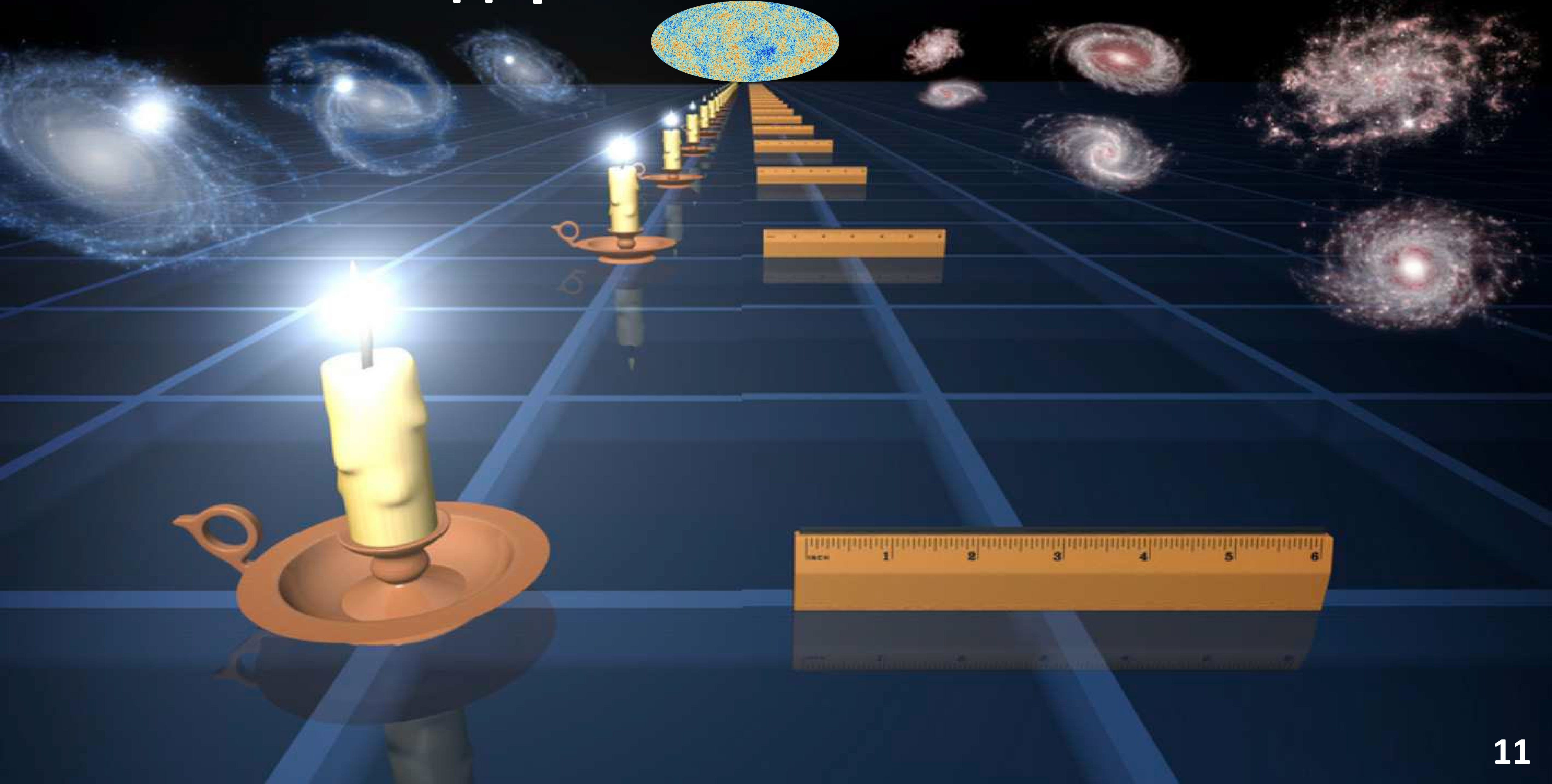
Проверялась зависимость температуры CMB от красного смещения:

$$T(z) = T_0(1+z)^{\alpha}$$

Из измерений получено, что:

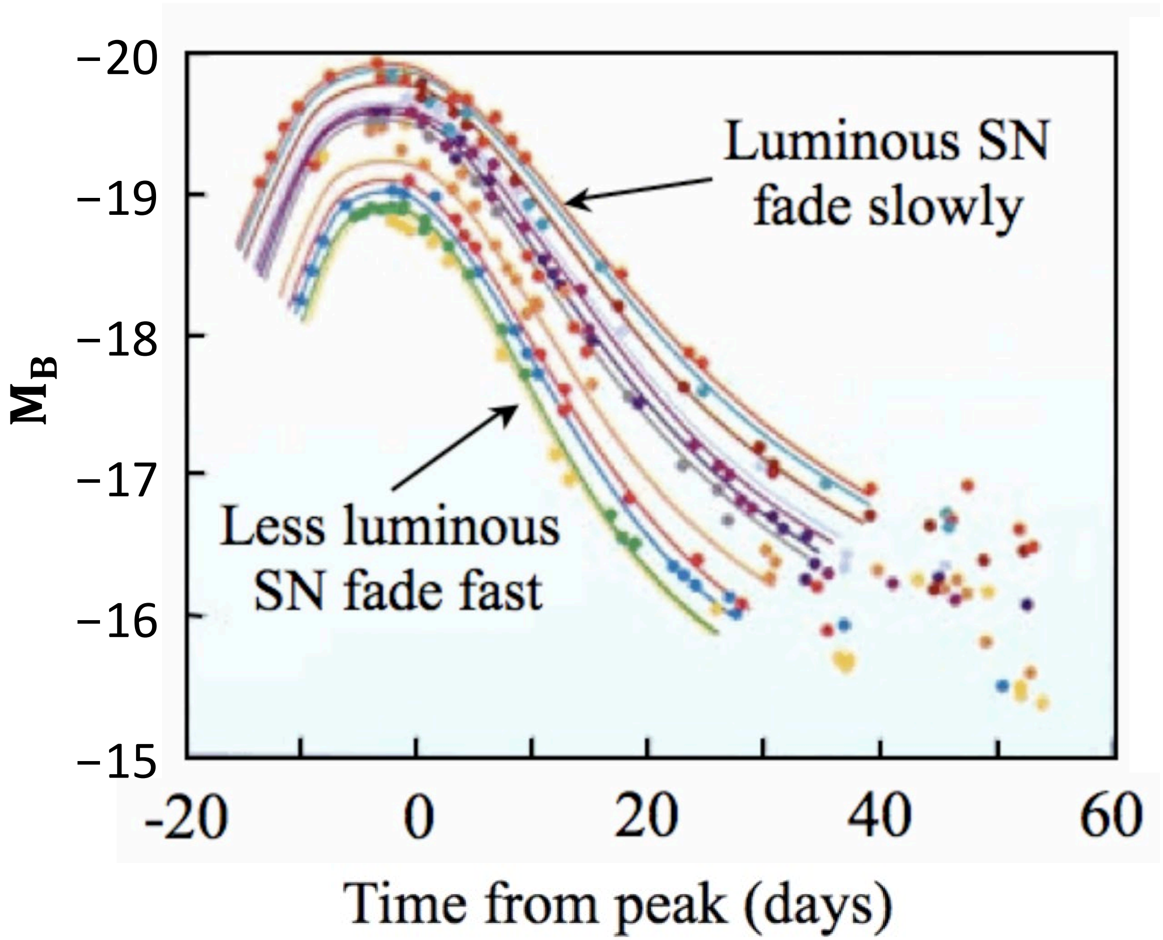
$$\alpha = 0.983 \pm 0.029$$

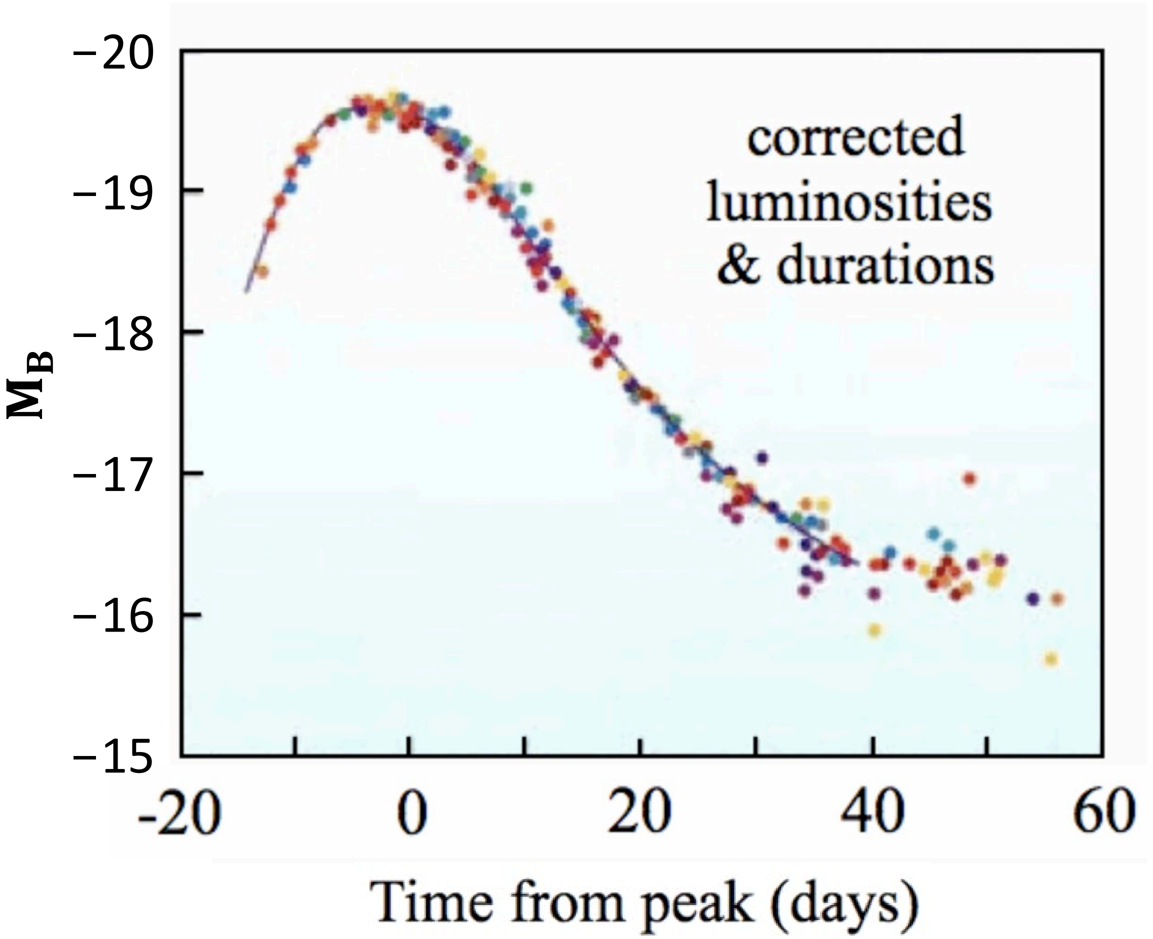
Стандартные свеча и линейка



Сверхновые типа Ia: Стандартные свечи

После введения поправки Филипса:

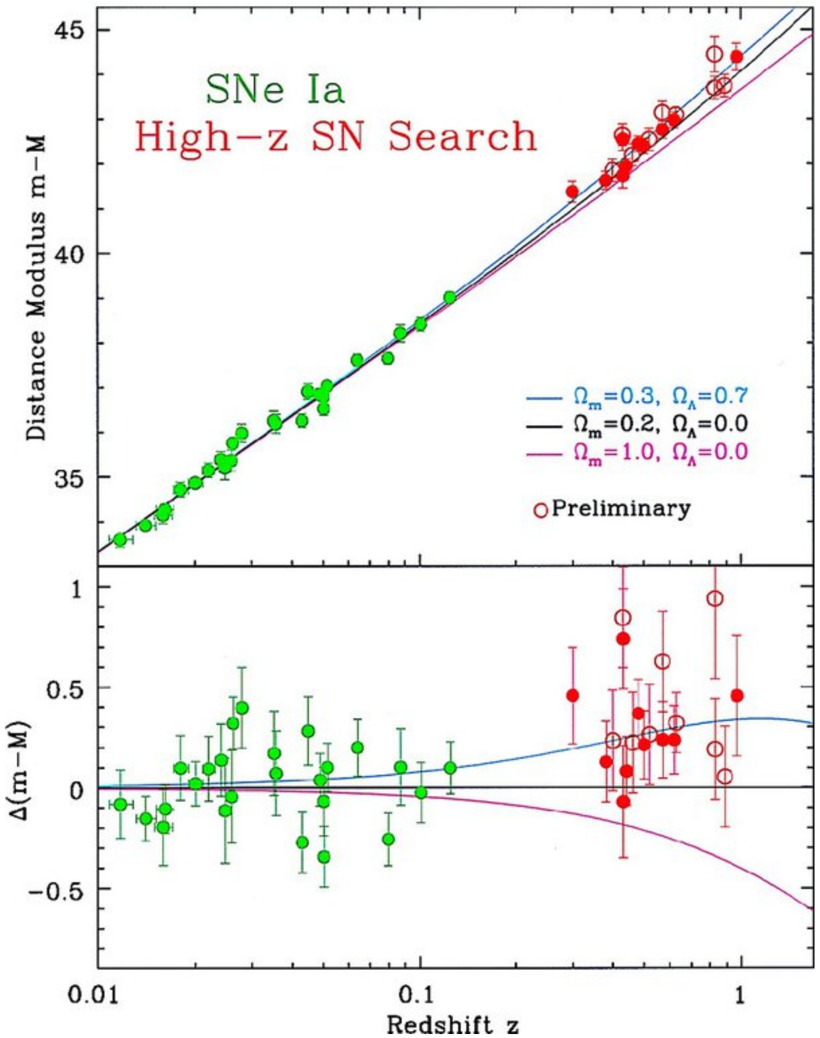


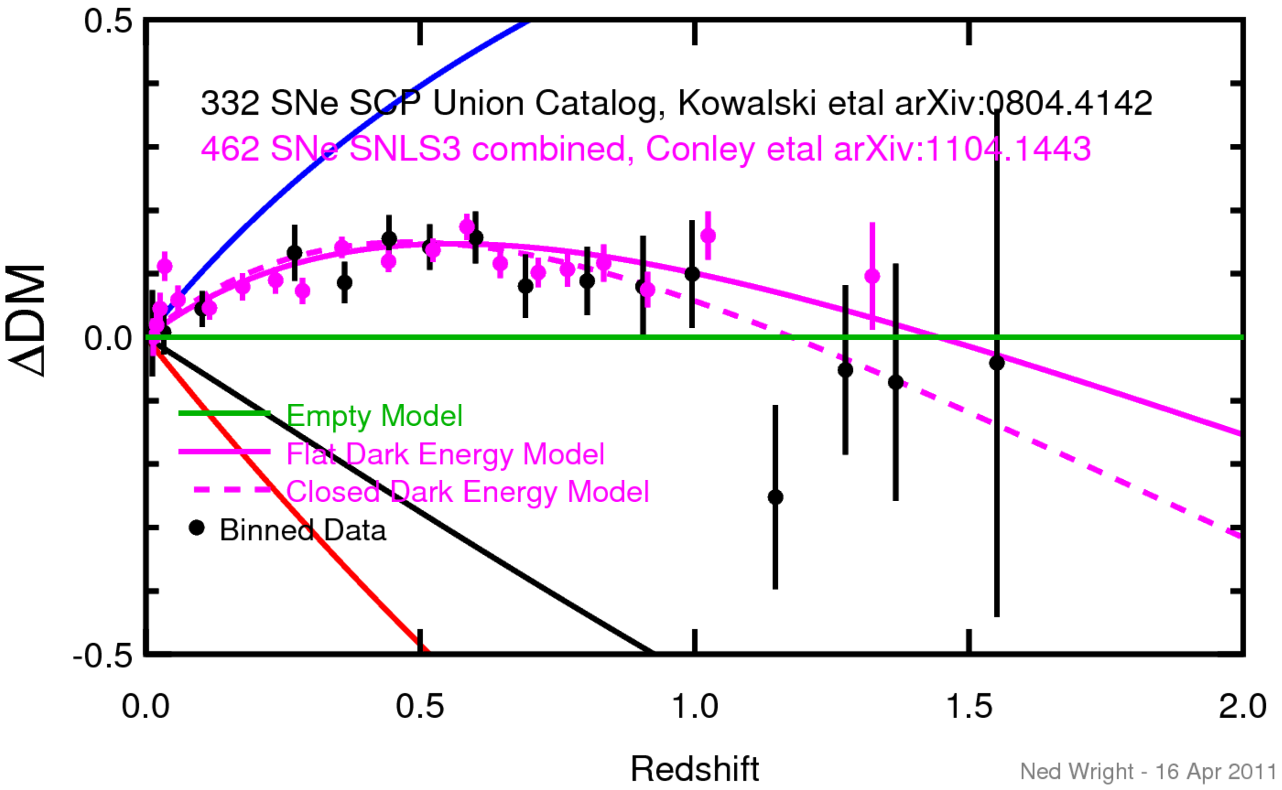


Это позволяет использовать вспышки SN Ia как «стандартные свечи».

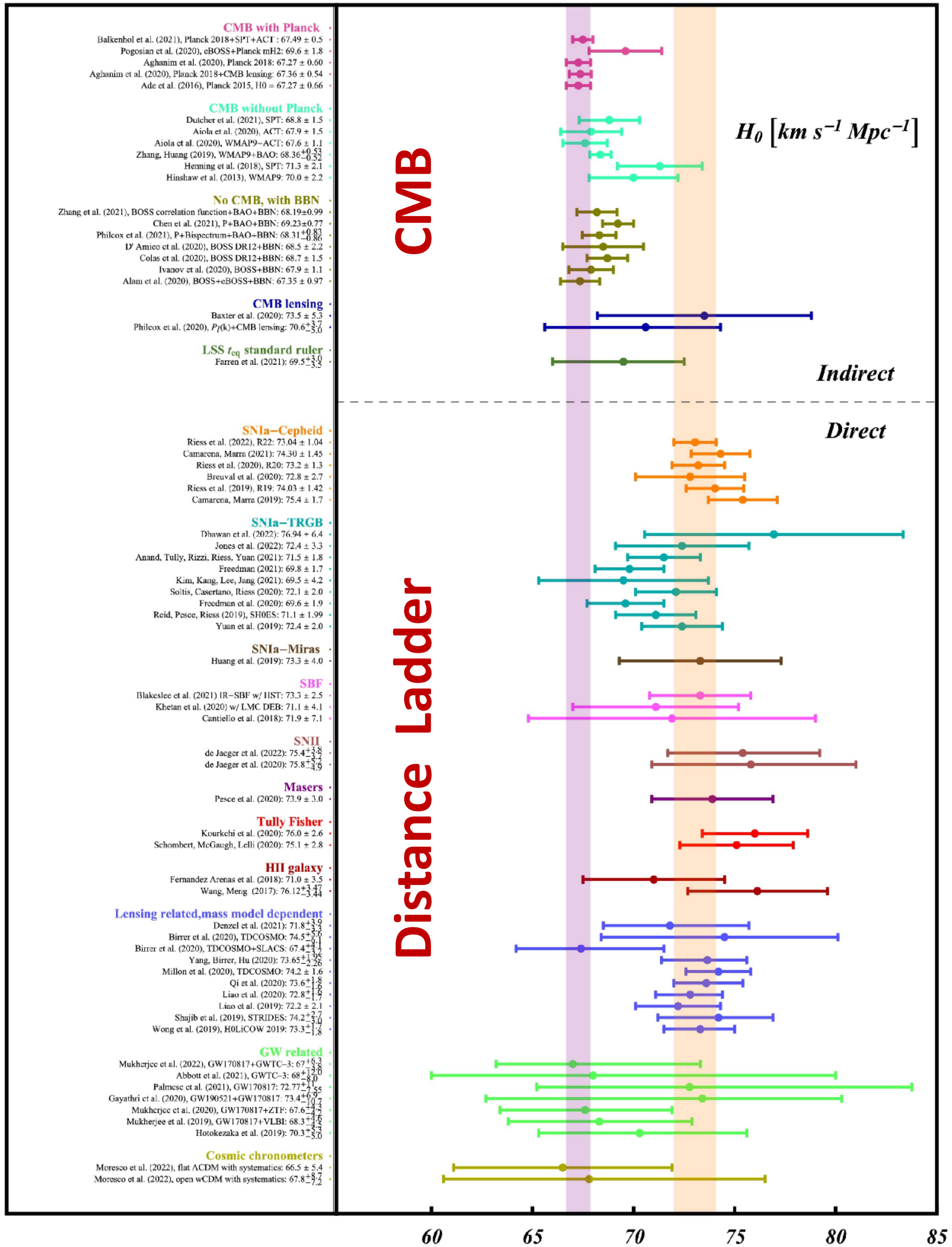
Поздняя космология

В 1990-ые две группы астрофизиков – The Supernova Cosmology Project (Соул Перлмутер) и High-Z Supernova Search Team (Брайан Шмидт) независимо изучали эволюцию расширения Вселенной с использованием вспышек сверхновых типа Ia на больших красных смещениях ($z \sim 1$).



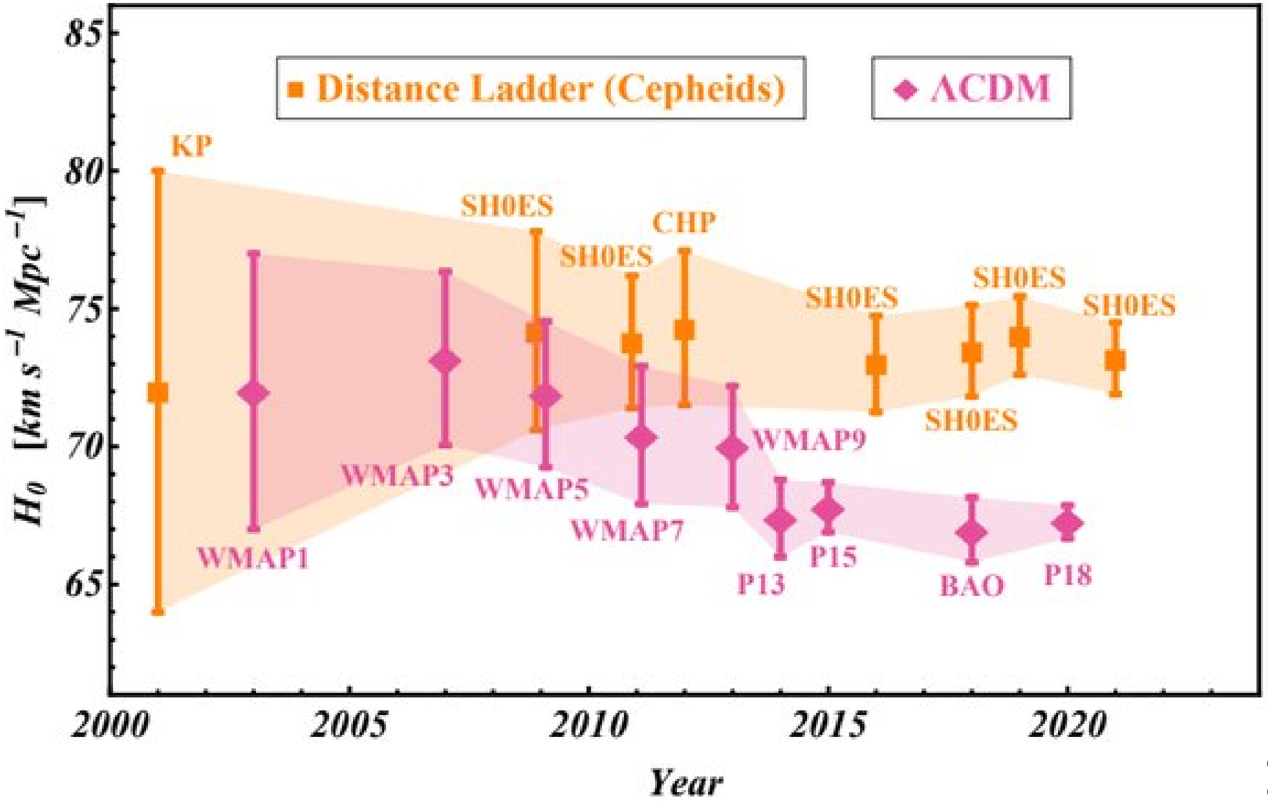


Новые данные, полученные для $z > 1$ подтверждают первоначальные выводы!

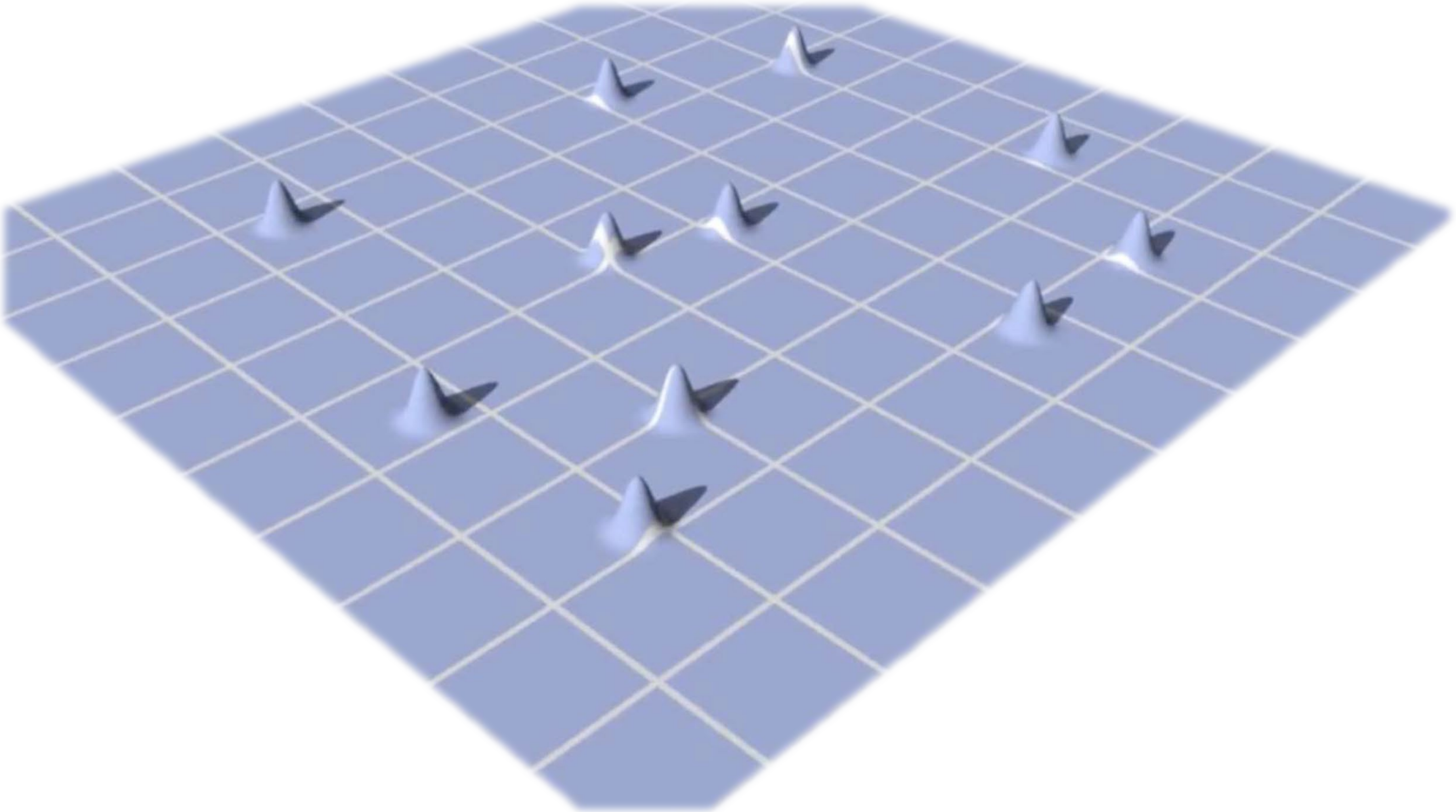


Hubble Tension

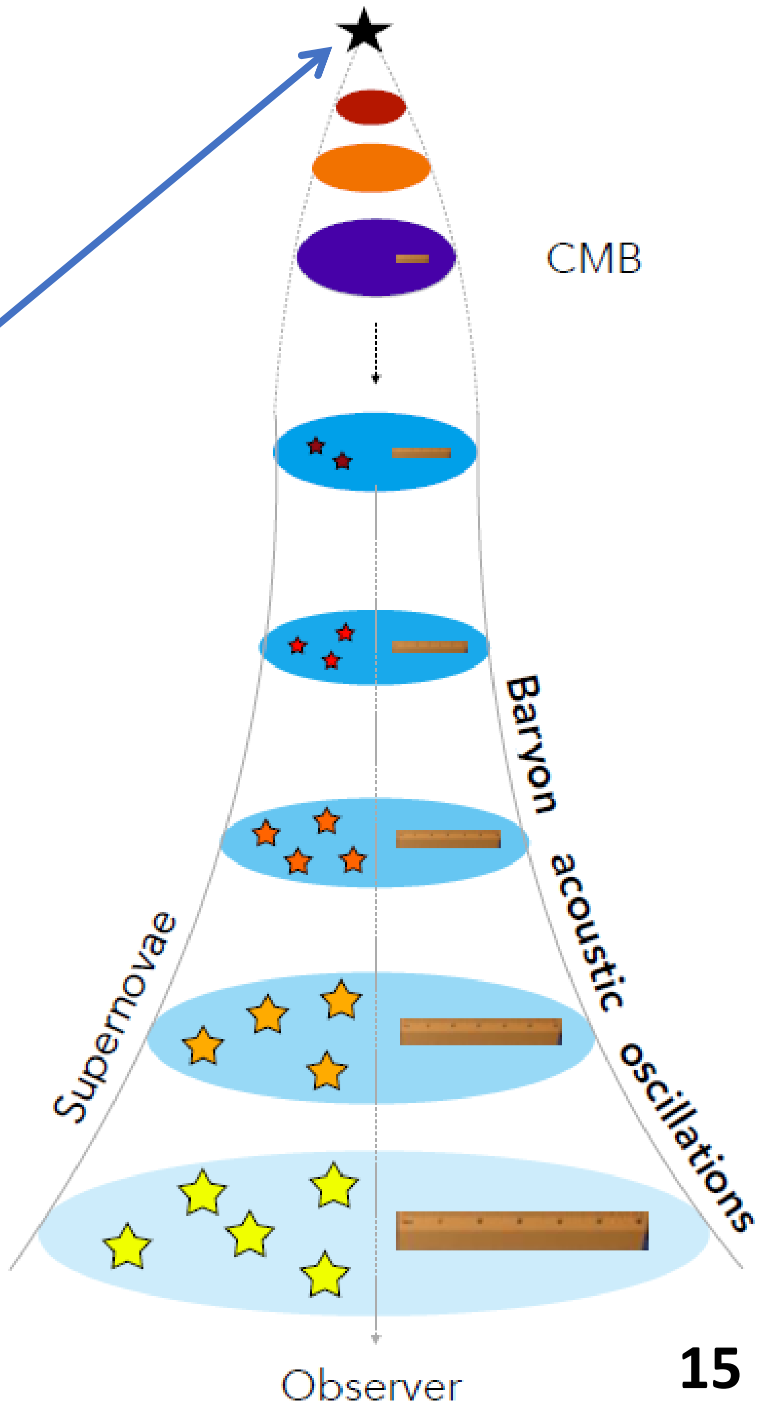
С повышением точности измерений нарастает напряженность в значении (при z=0) параметра Хаббла H_0, полученным по CMB, и по «локальным» измерениям (классическая «лестница расстояний»: цефеиды + SN Ia).



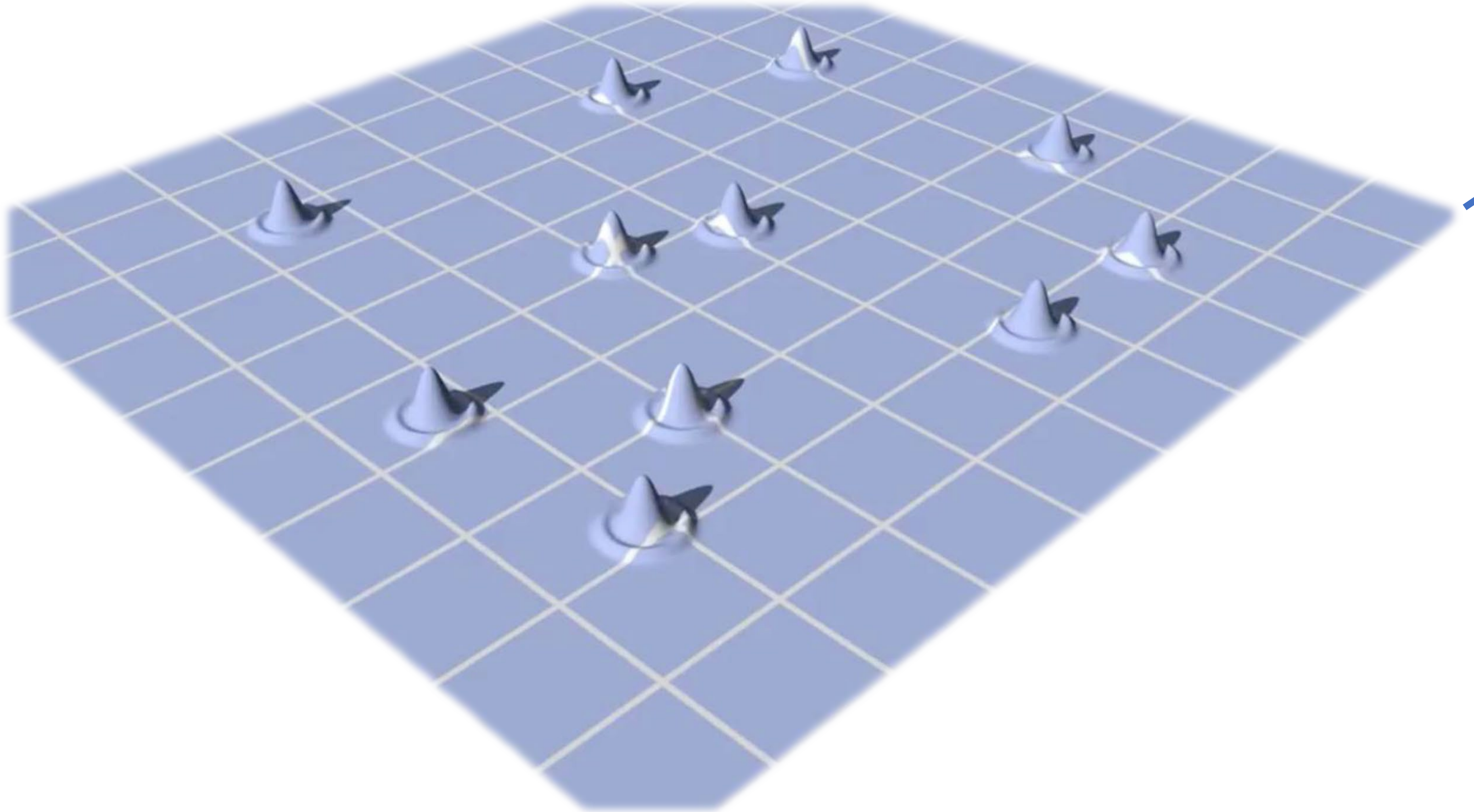
Baryon Acoustic Oscillations



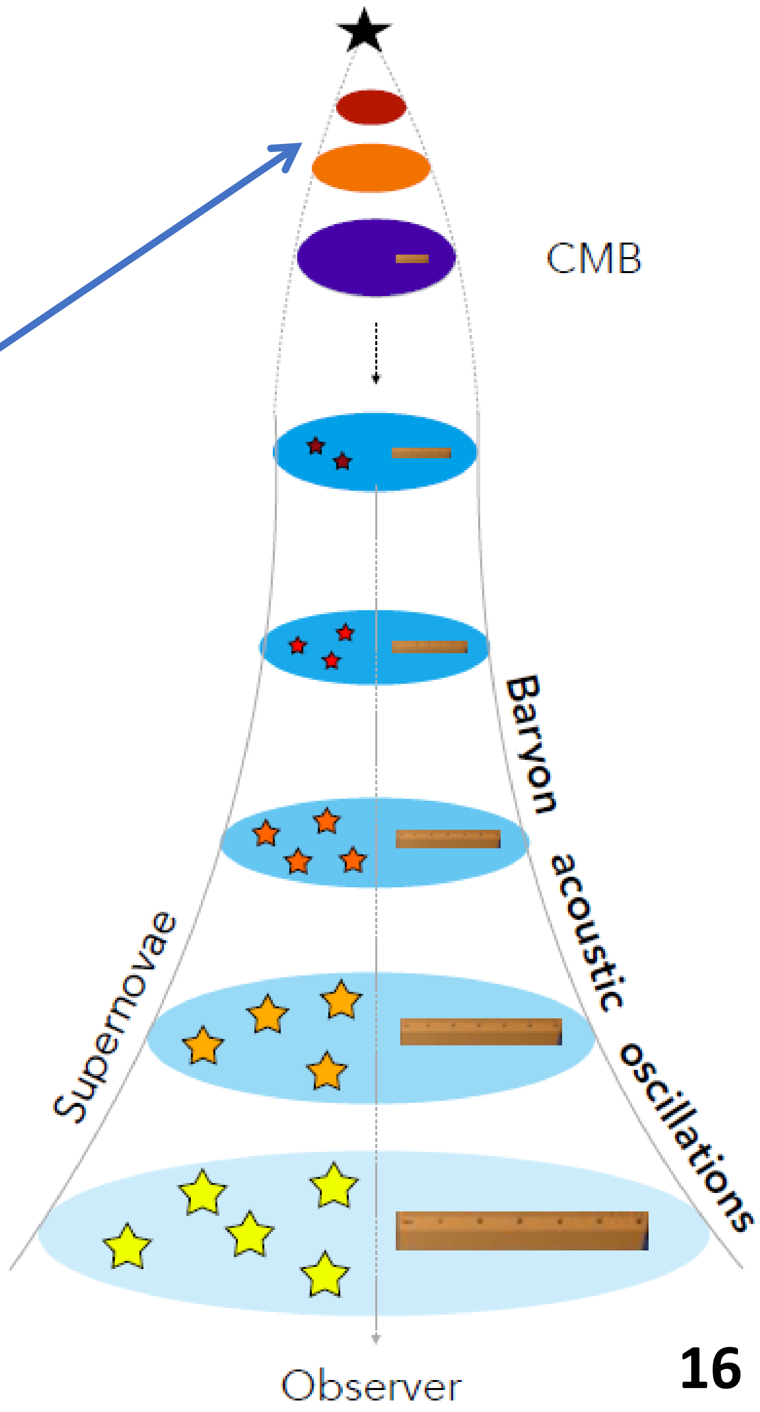
Initial perturbations during Inflation



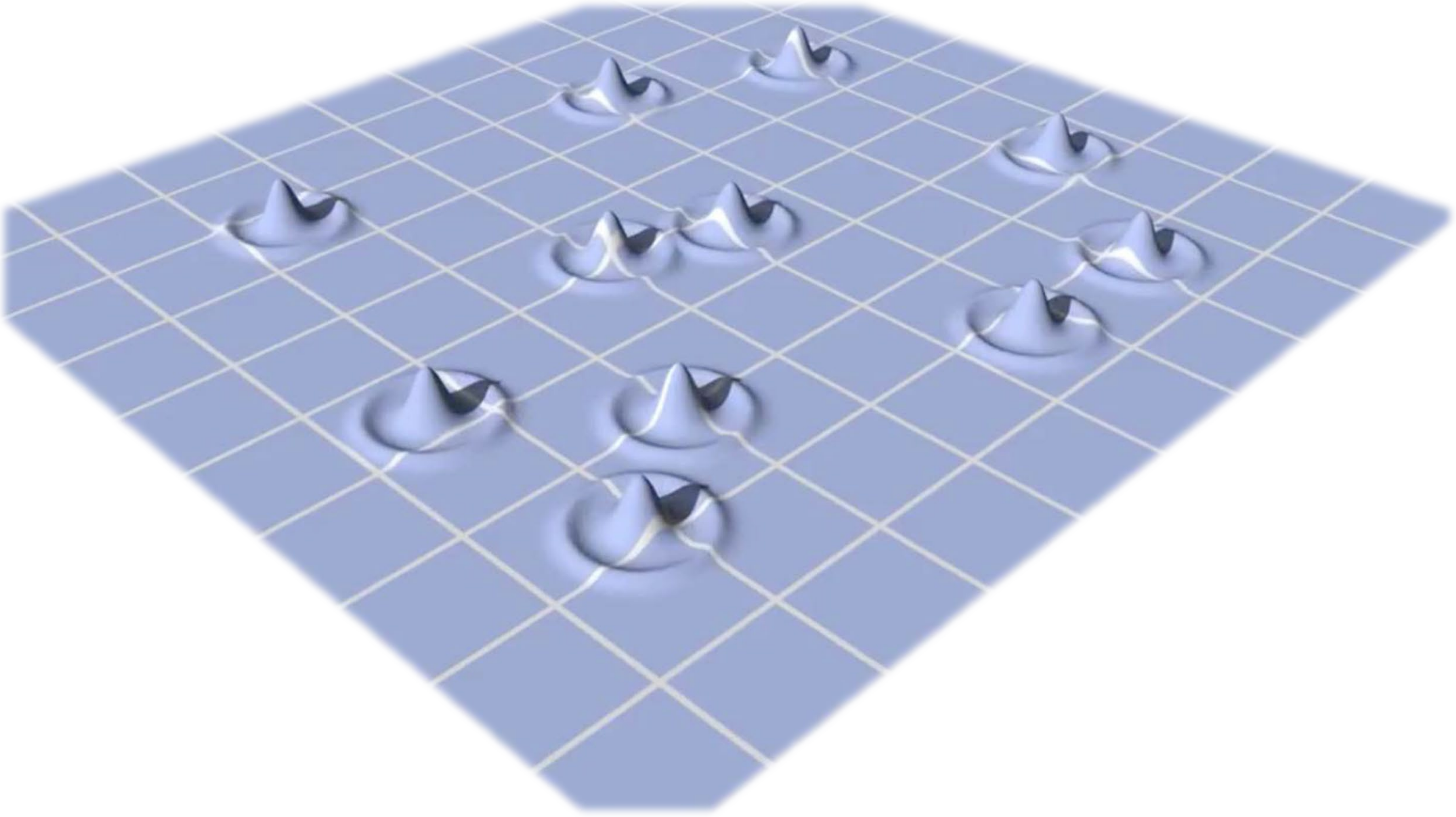
Baryon Acoustic Oscillations



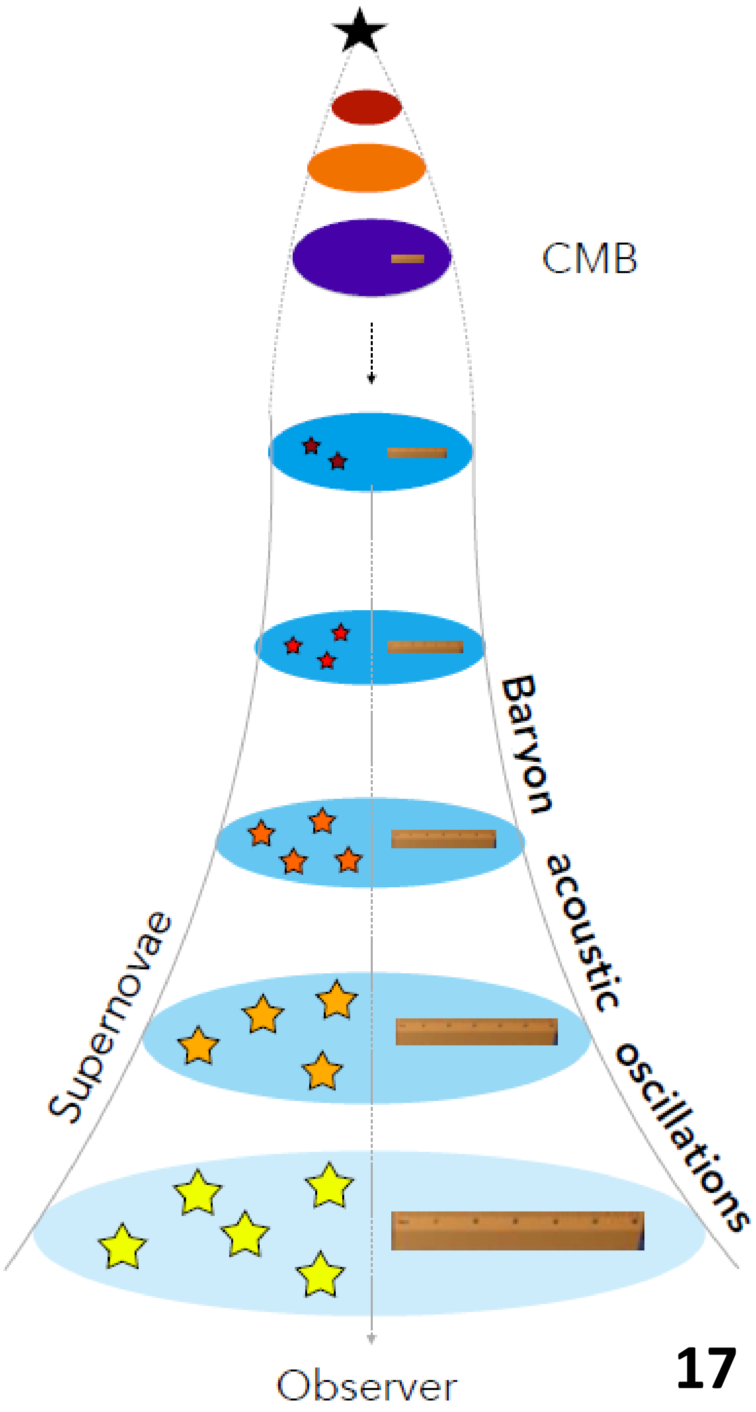
Initial perturbations in hot universe



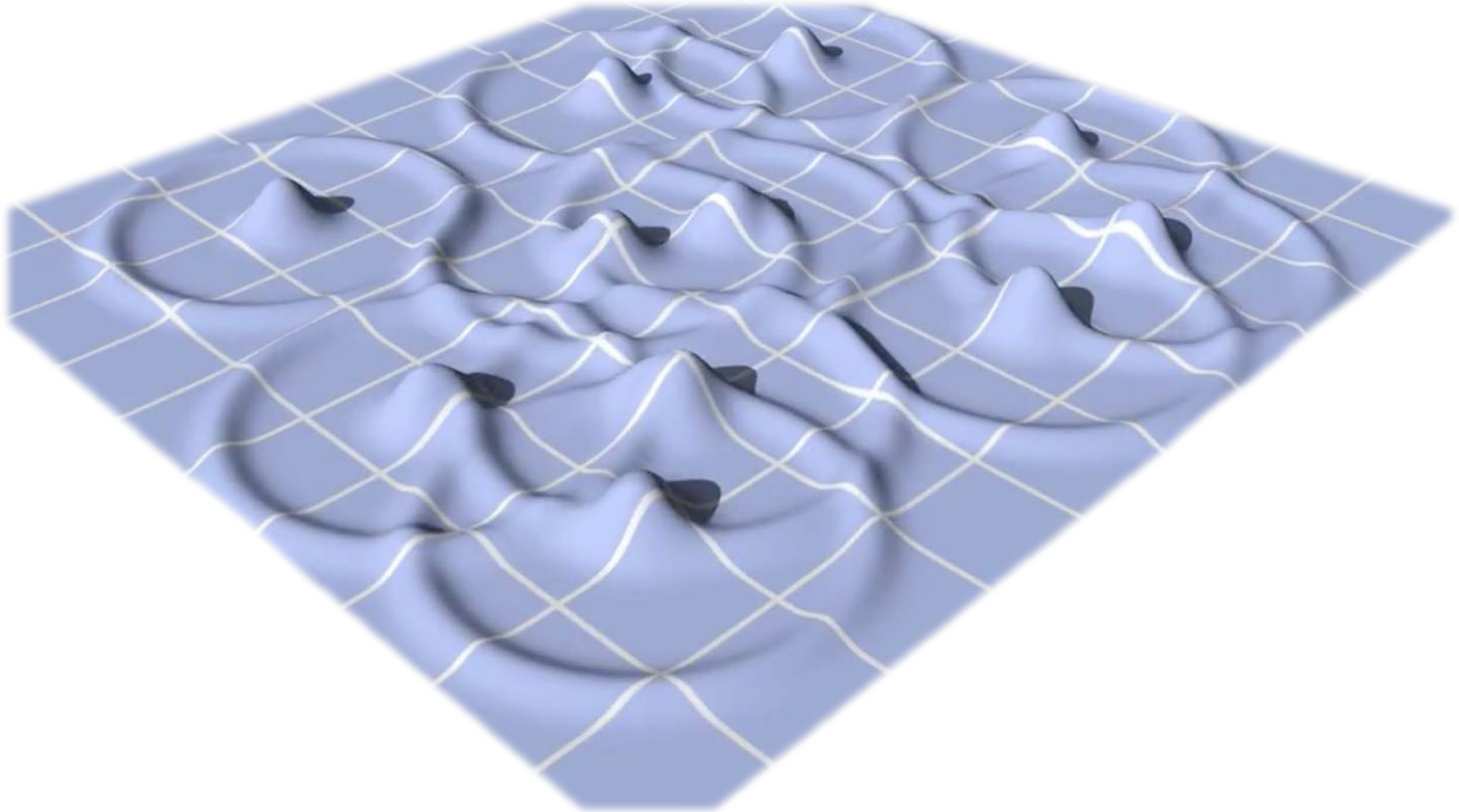
Baryon Acoustic Oscillations

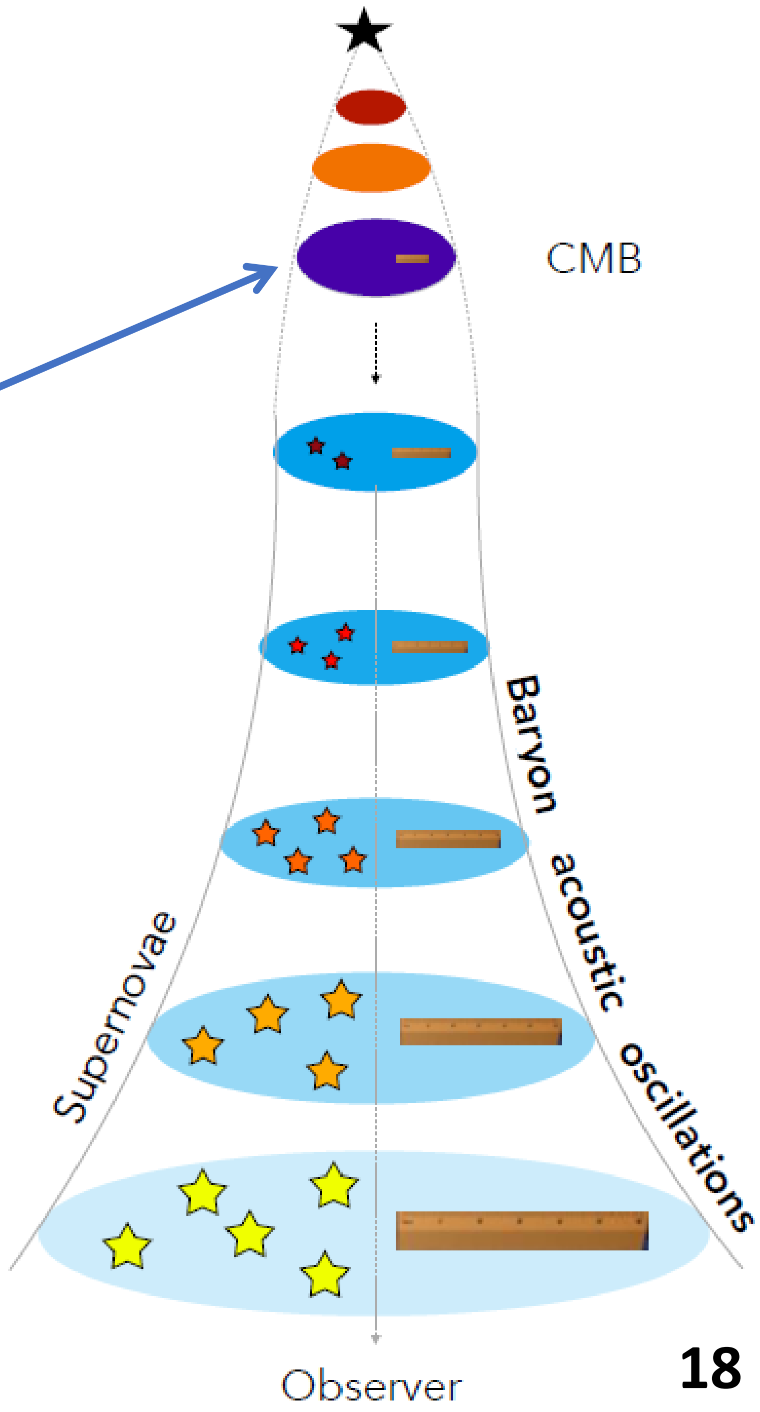


Initial perturbations in hot universe



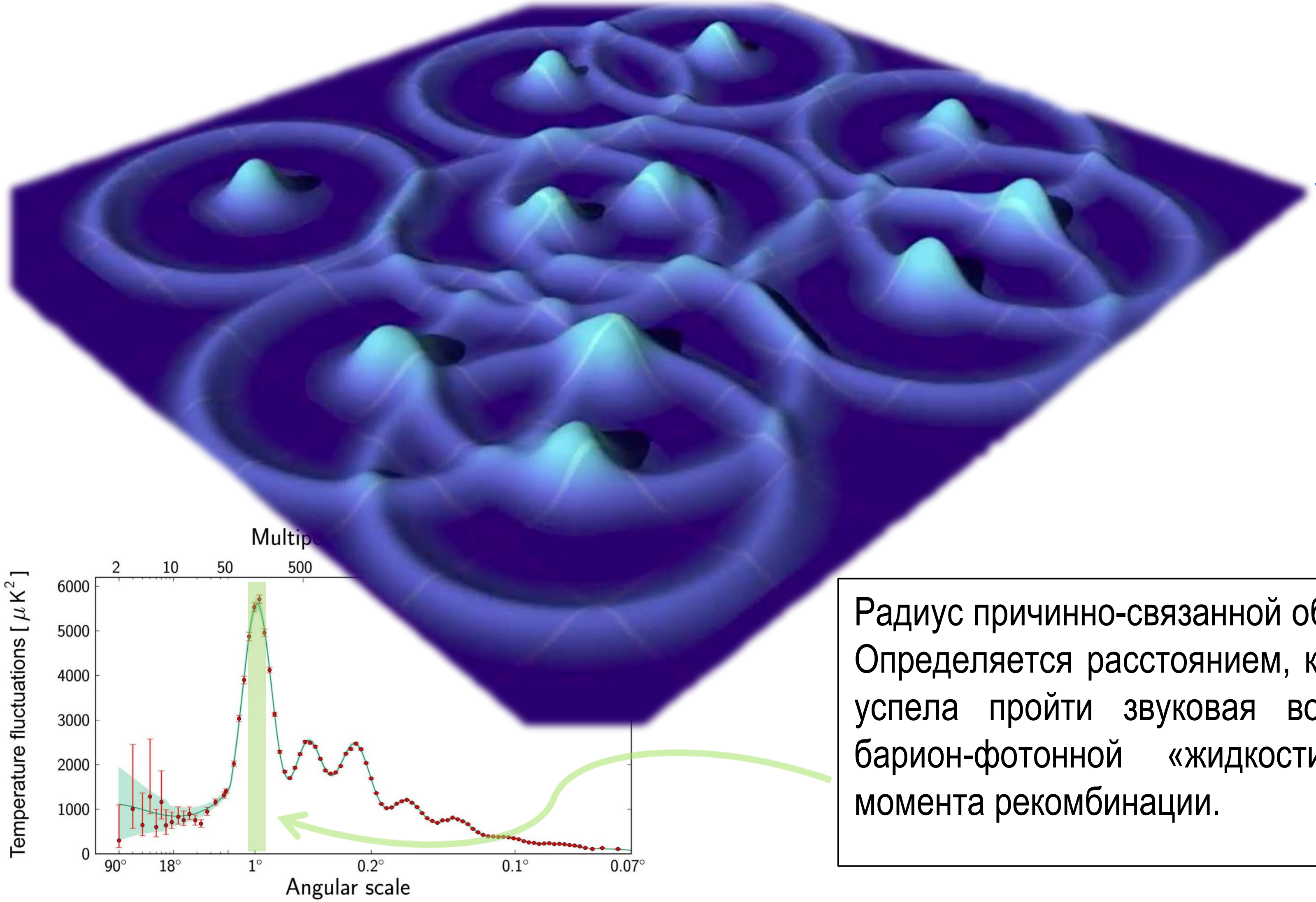
Baryon Acoustic Oscillations



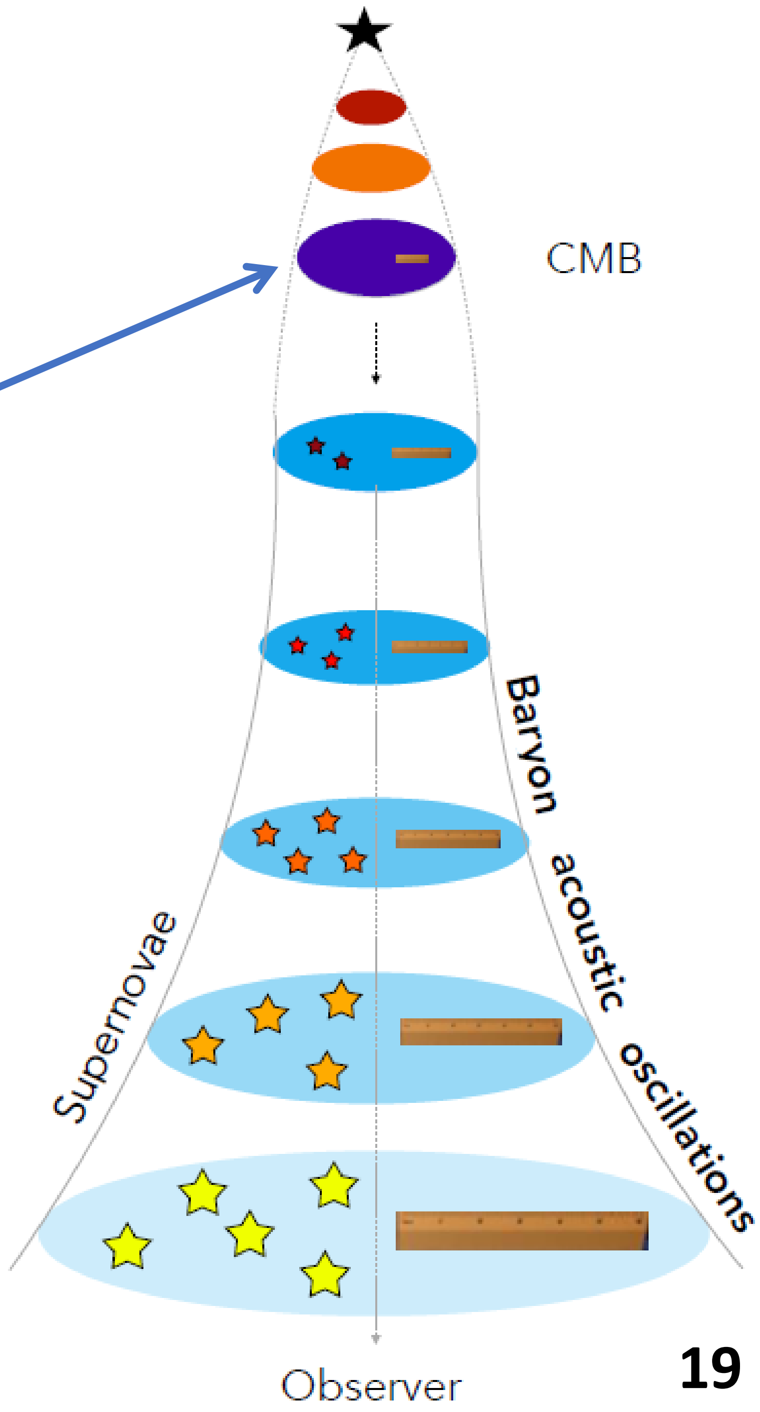


Sound wave propagation freezes at $r_d \sim 150$ kpc

Baryon Acoustic Oscillations

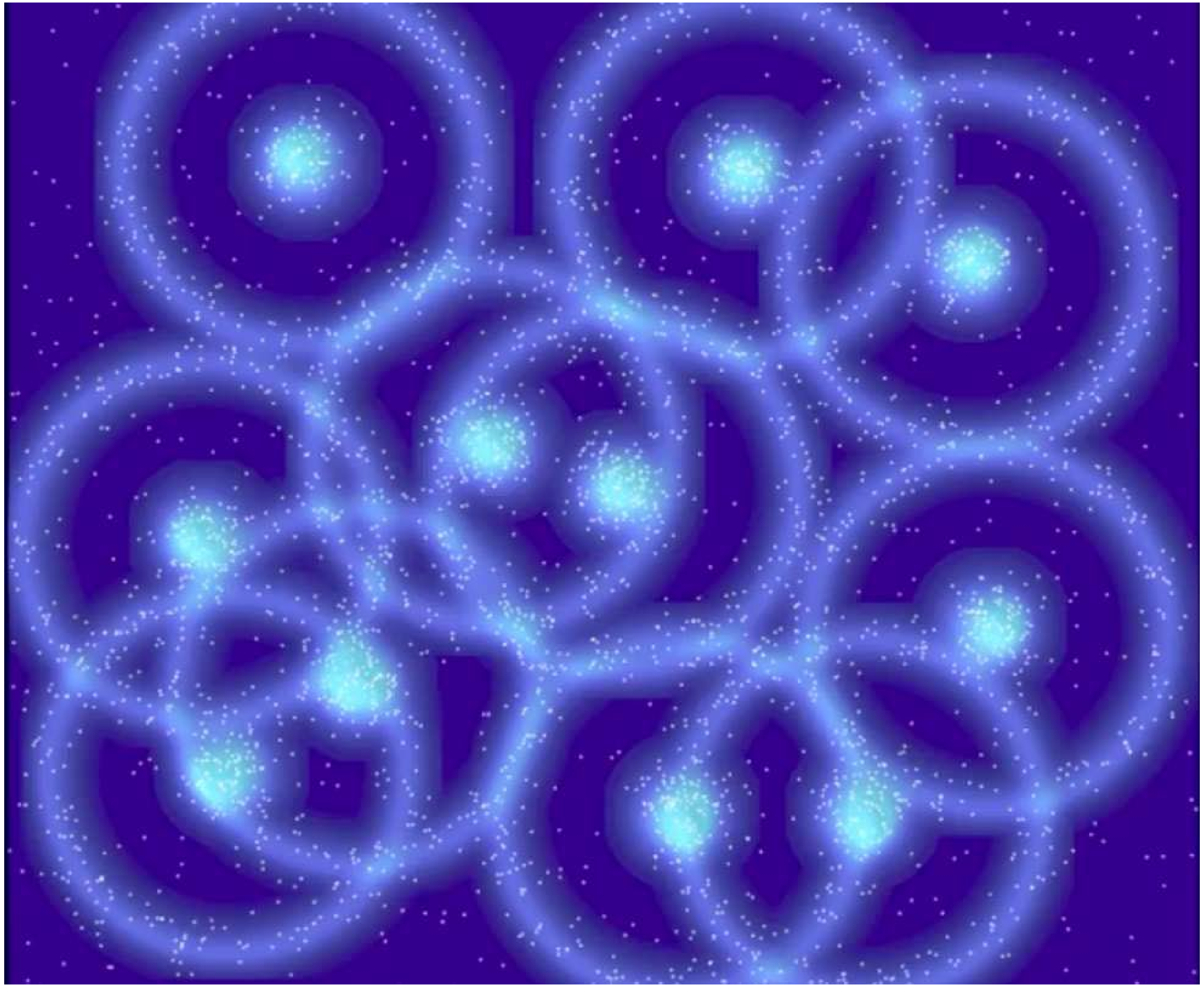


Радиус причинно-связанной области. Определяется расстоянием, которое успела пройти звуковая волна в барион-фотонной «жидкости» до момента рекомбинации.

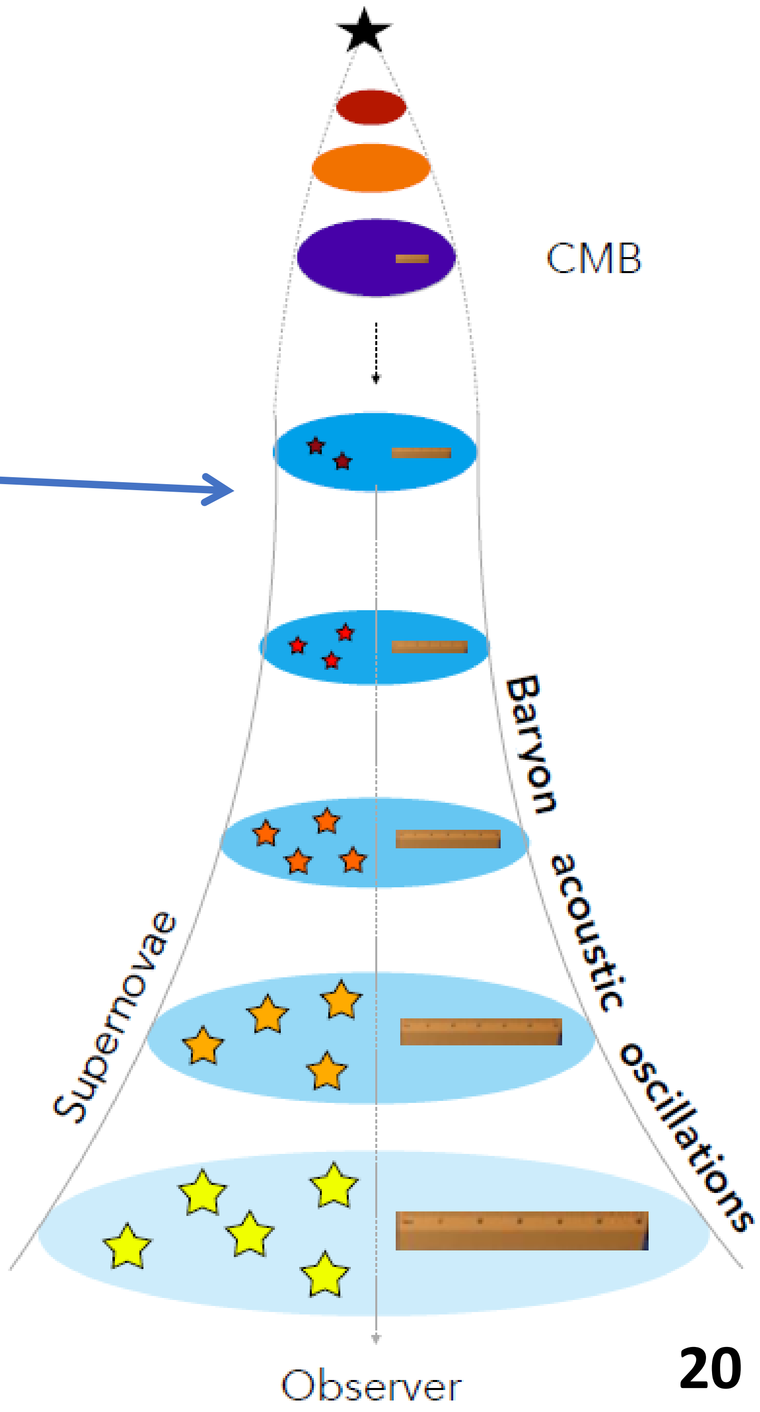


BAO imprint in the matter distribution at the CMB epoch

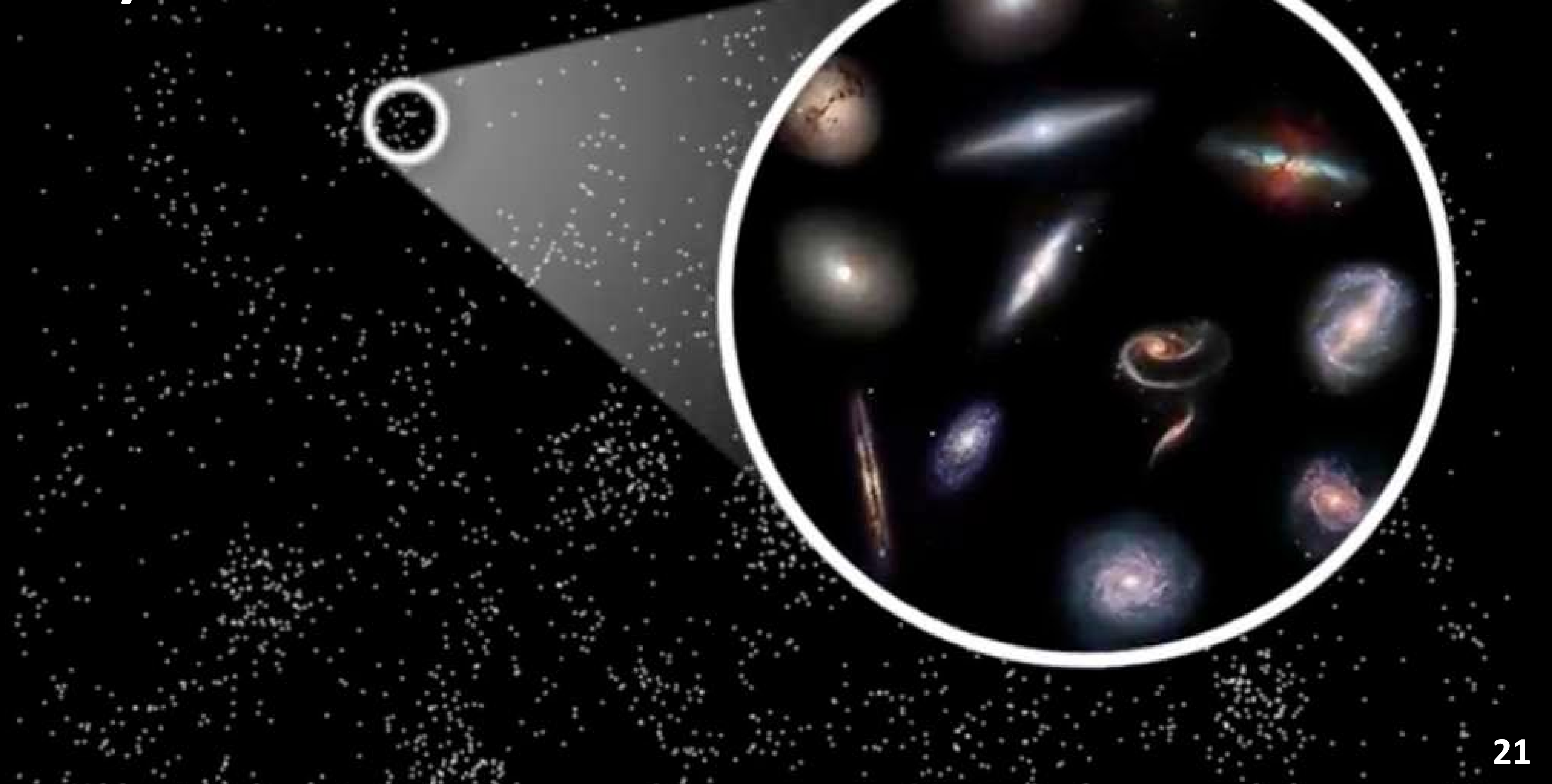
Baryon Acoustic Oscillations



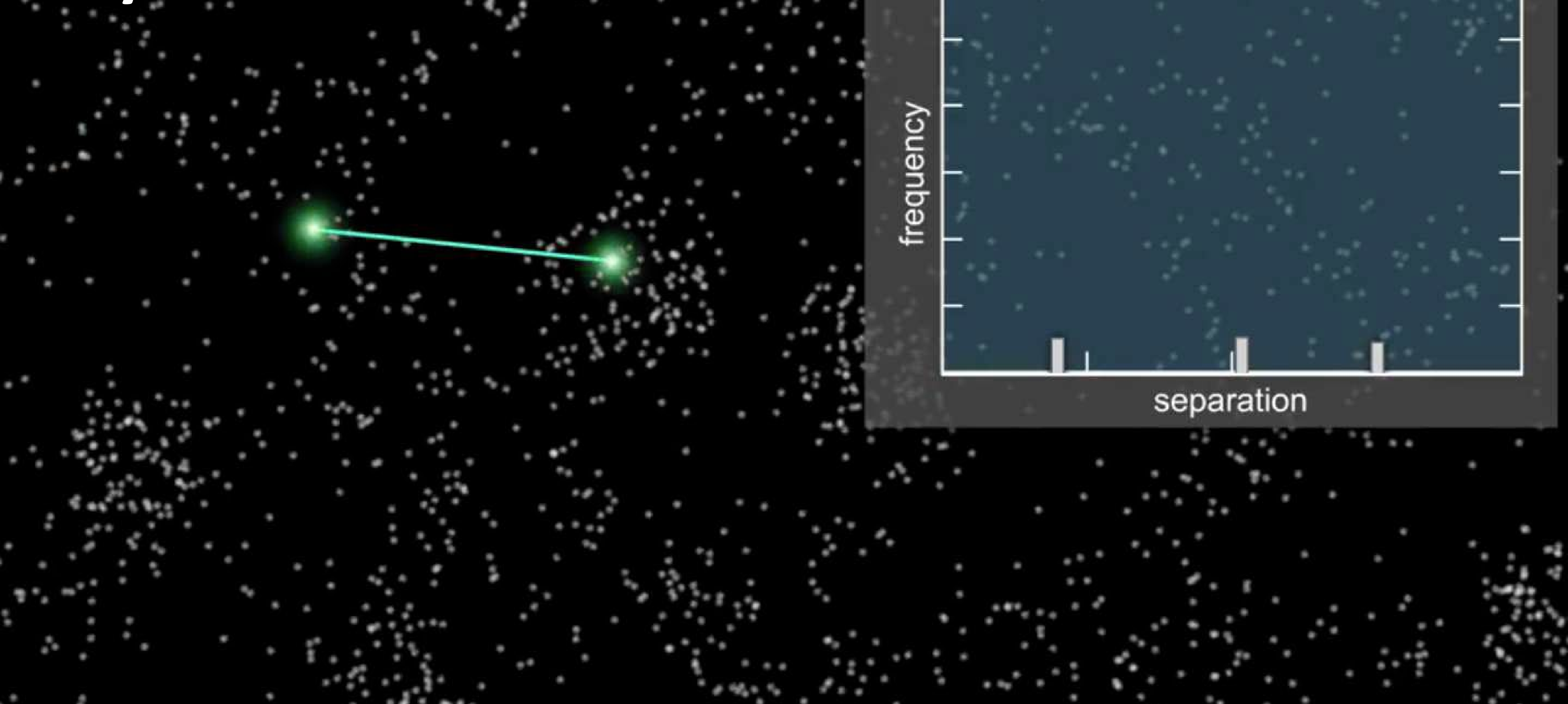
Galaxies (dots) formation around matter clusters



Baryon Acoustic Oscillations

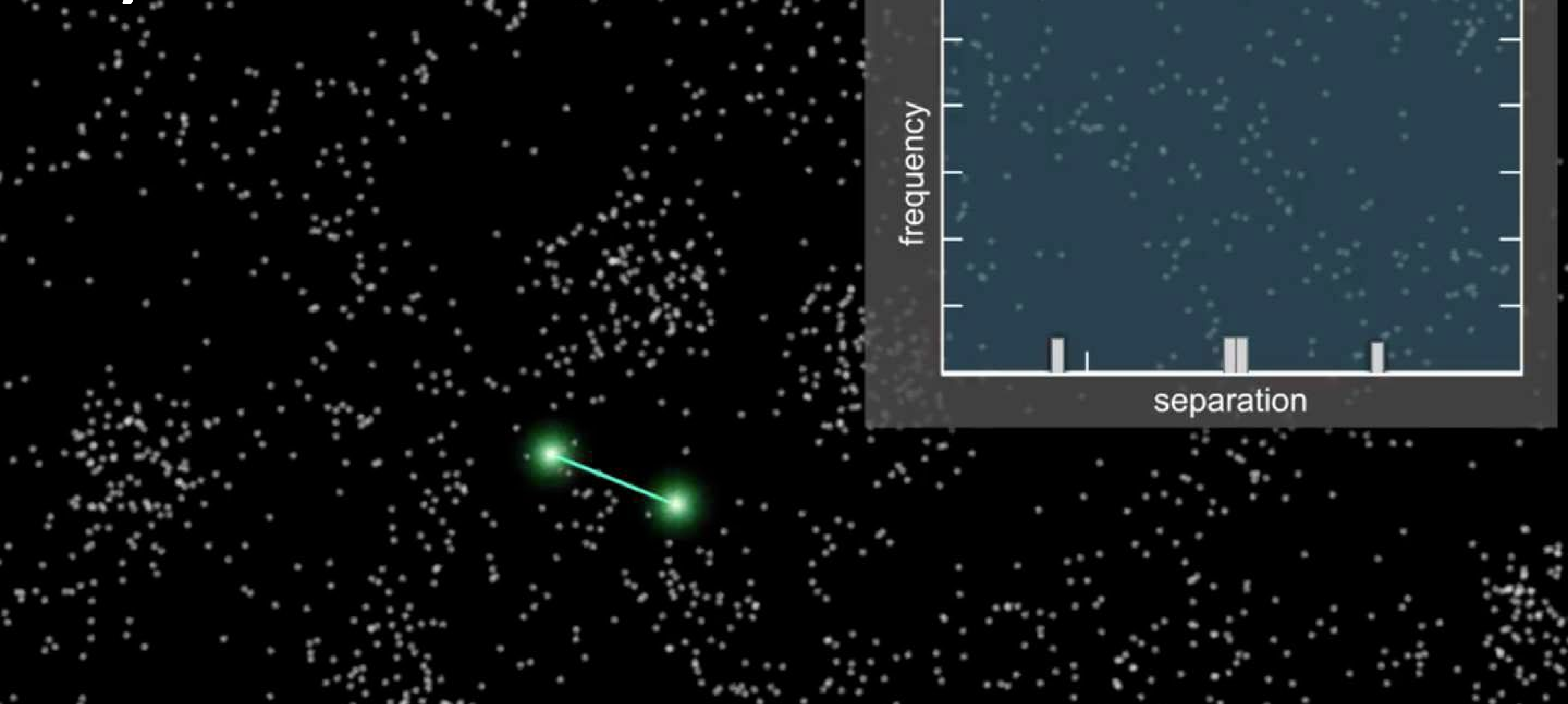


Baryon Acoustic Oscillations



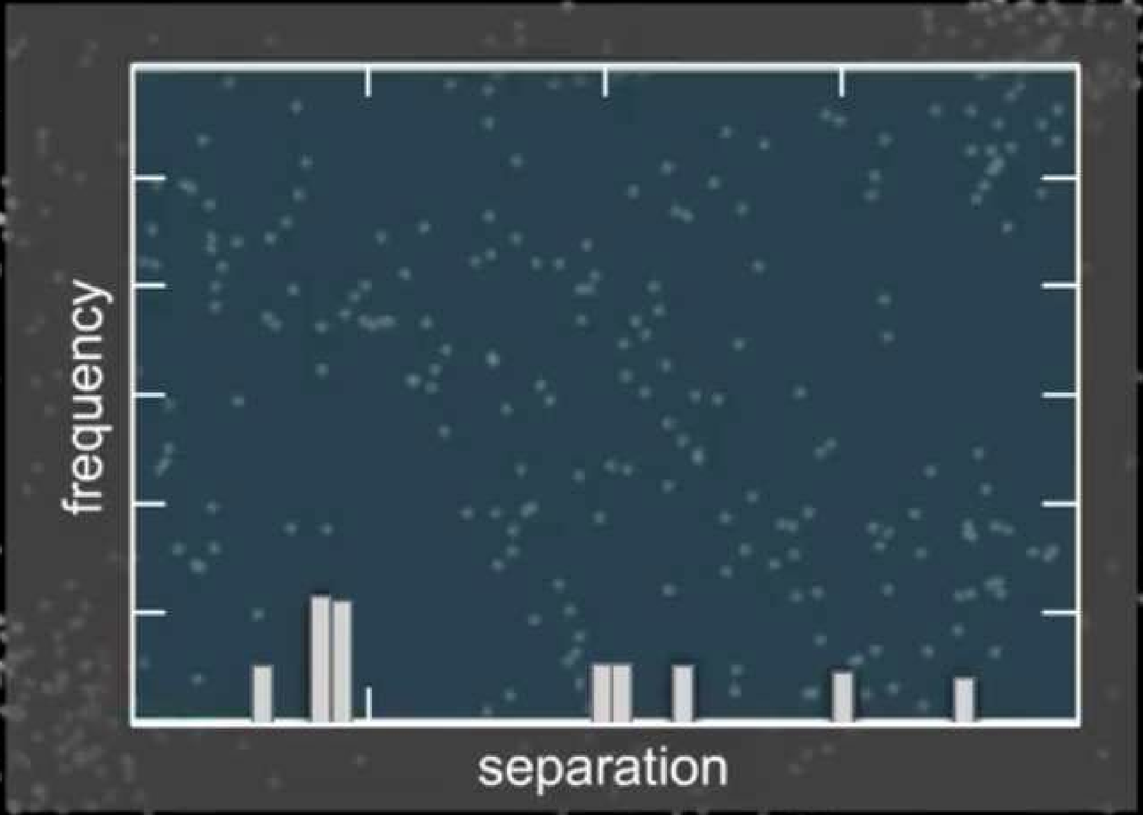
Distances between pairs of galaxies

Baryon Acoustic Oscillations



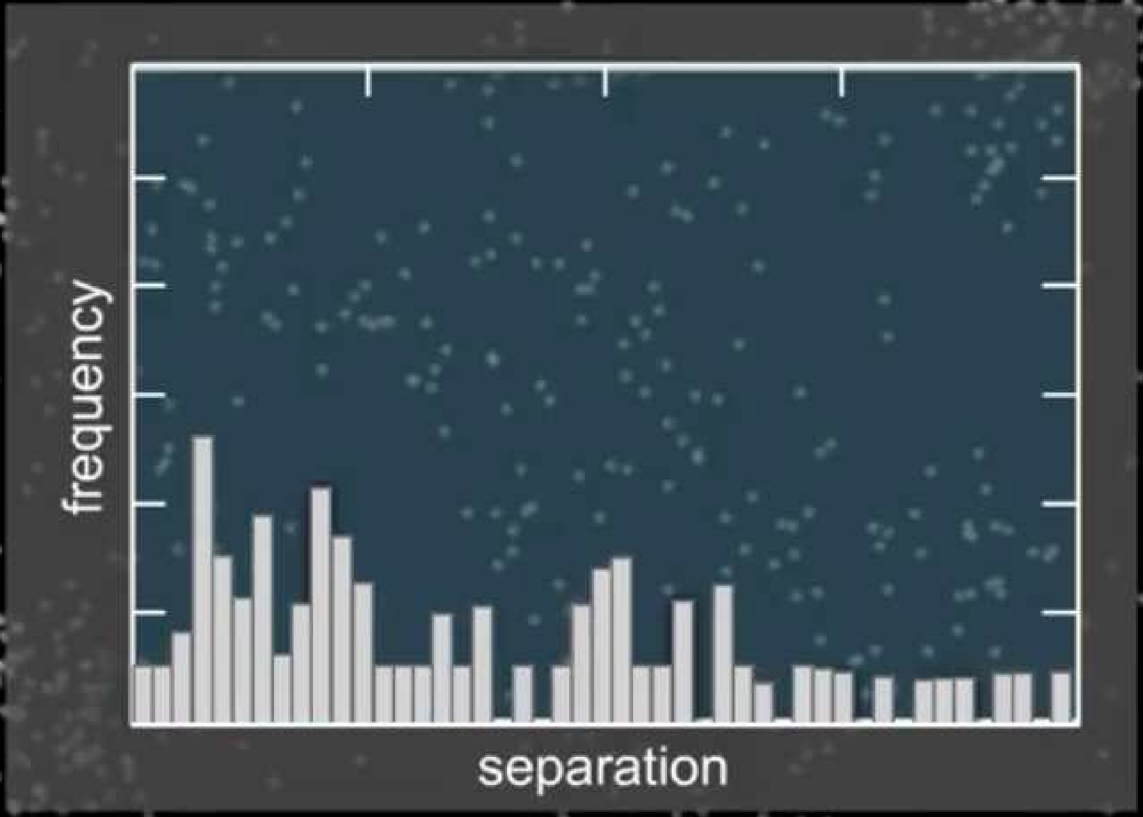
Distances between pairs of galaxies

Baryon Acoustic Oscillations



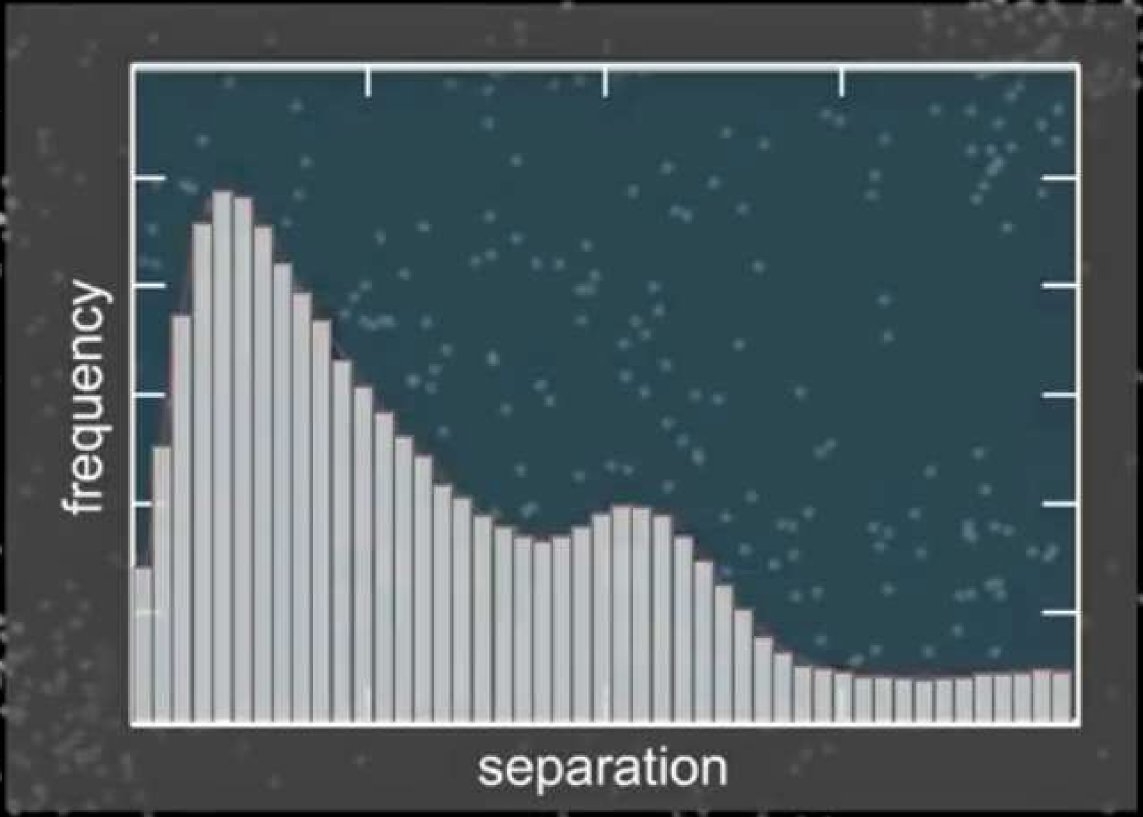
Distances between pairs of galaxies

Baryon Acoustic Oscillations



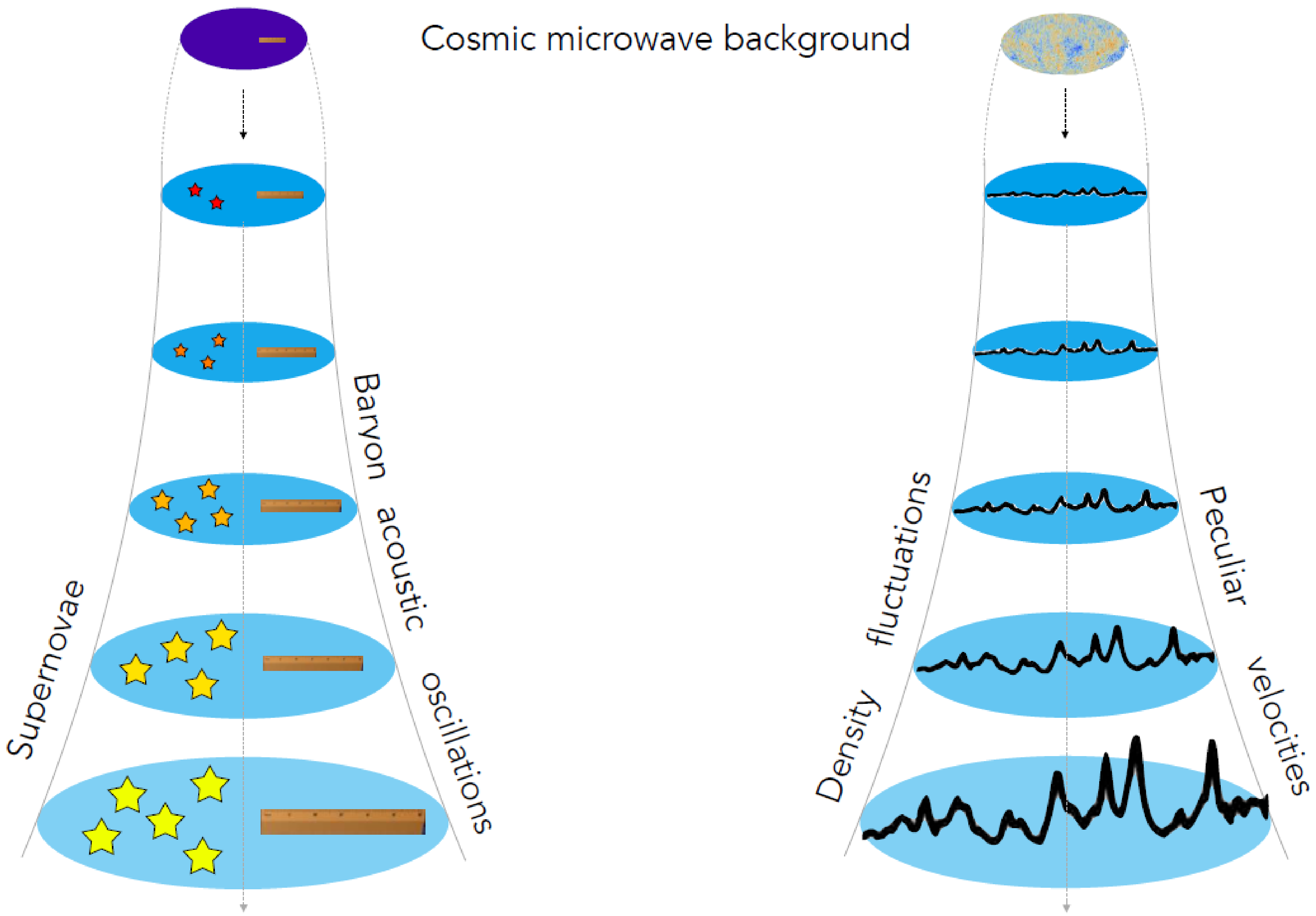
Distances between pairs of galaxies

Baryon Acoustic Oscillations



Distances between pairs of galaxies

Динамика расширения: от CMB до наших дней

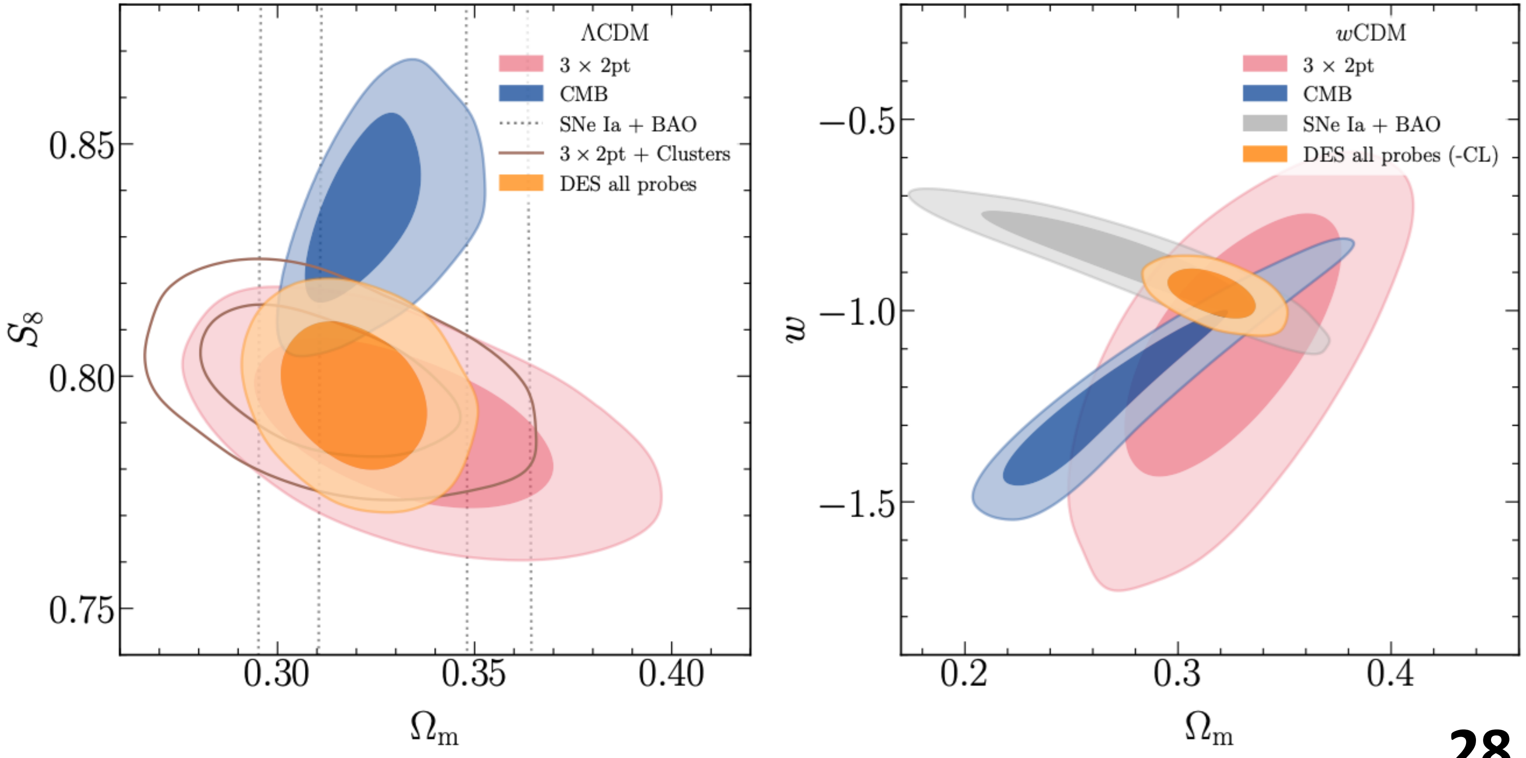


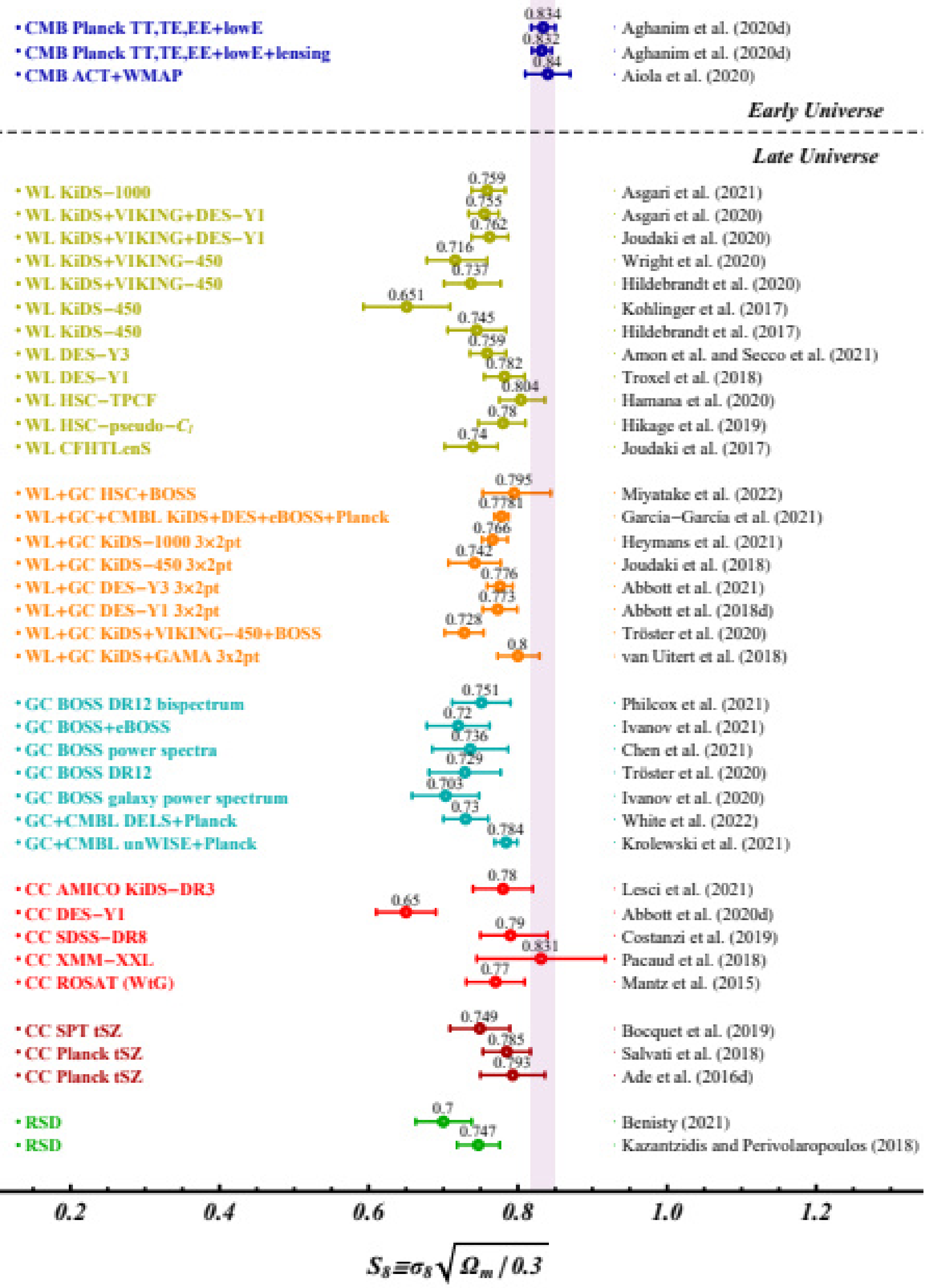
Baryon Acoustic Oscillations results

Full DES data set. The most stringent constraints (after combination with external probes) on ΛCDM.

DES Collaboration, **PRD** in review, arXiv:2601.14559
Sanchez-Cid et al., **PRD** in review, arXiv:2601.14859

- The most recent paper features the full DES dataset and a comprehensive combination of probes, and achieving the tightest constraint to, the ΛCDM model.
- Joint with DESI DR2 BAO, DES SNe Ia, SPT clusters, and the Planck CMB, we obtained the most precise measurement of the ΛCDM model parameters to date!





S_8 Tension

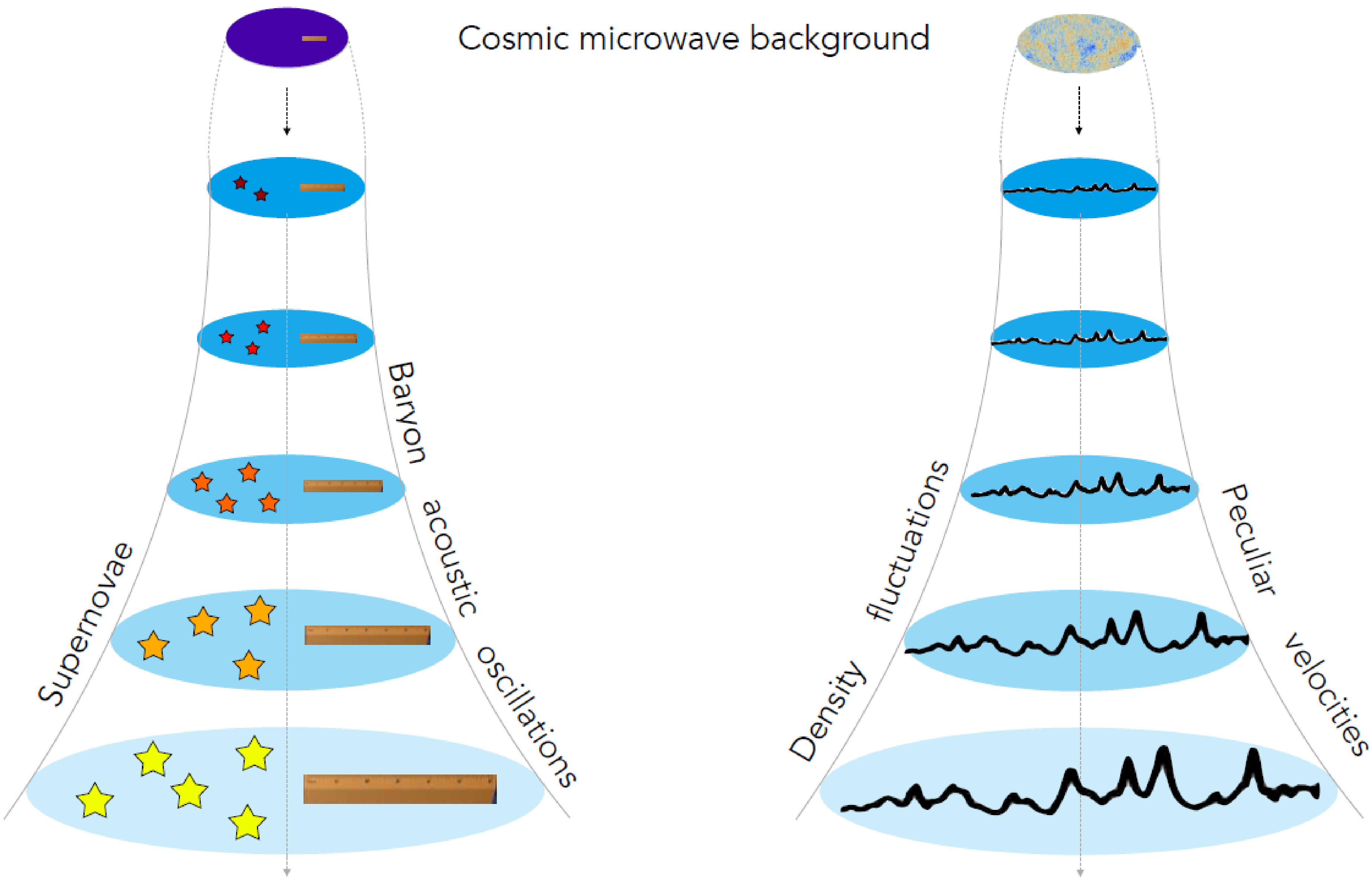
Параметр S_8 характеризует дисперсию флюктуаций плотности материи (барионной+темной) на характерном масштабе 8 Мпк.

Значение S_8, определенное из спектра CMB (ранняя Вселенная) и пересчитанное согласно ΛCDM на сегодня, систематически отличается от значения, полученного по измерениям распределения вещества в поздней Вселенной (малые значения z).

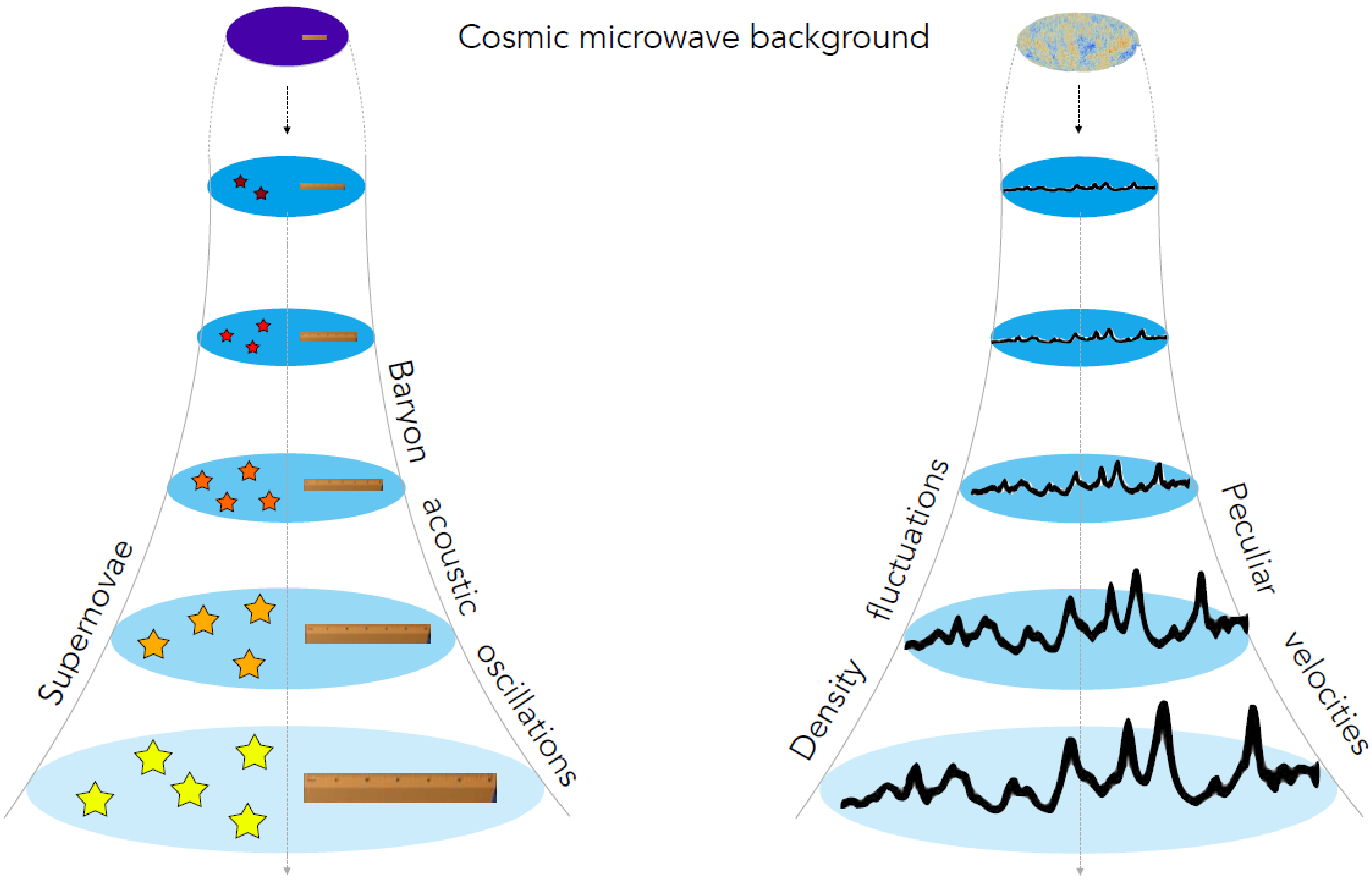
В комбинации с напряженностью Хаббла, эти нестыковки рассматриваются как результат возможной неполноты стандартной (минимальной) ΛCDM.

Расширения ΛCDM: эволюция темной материи, модификация ОТО и т.д. Новые эксперименты…

Расширения ΛCDM



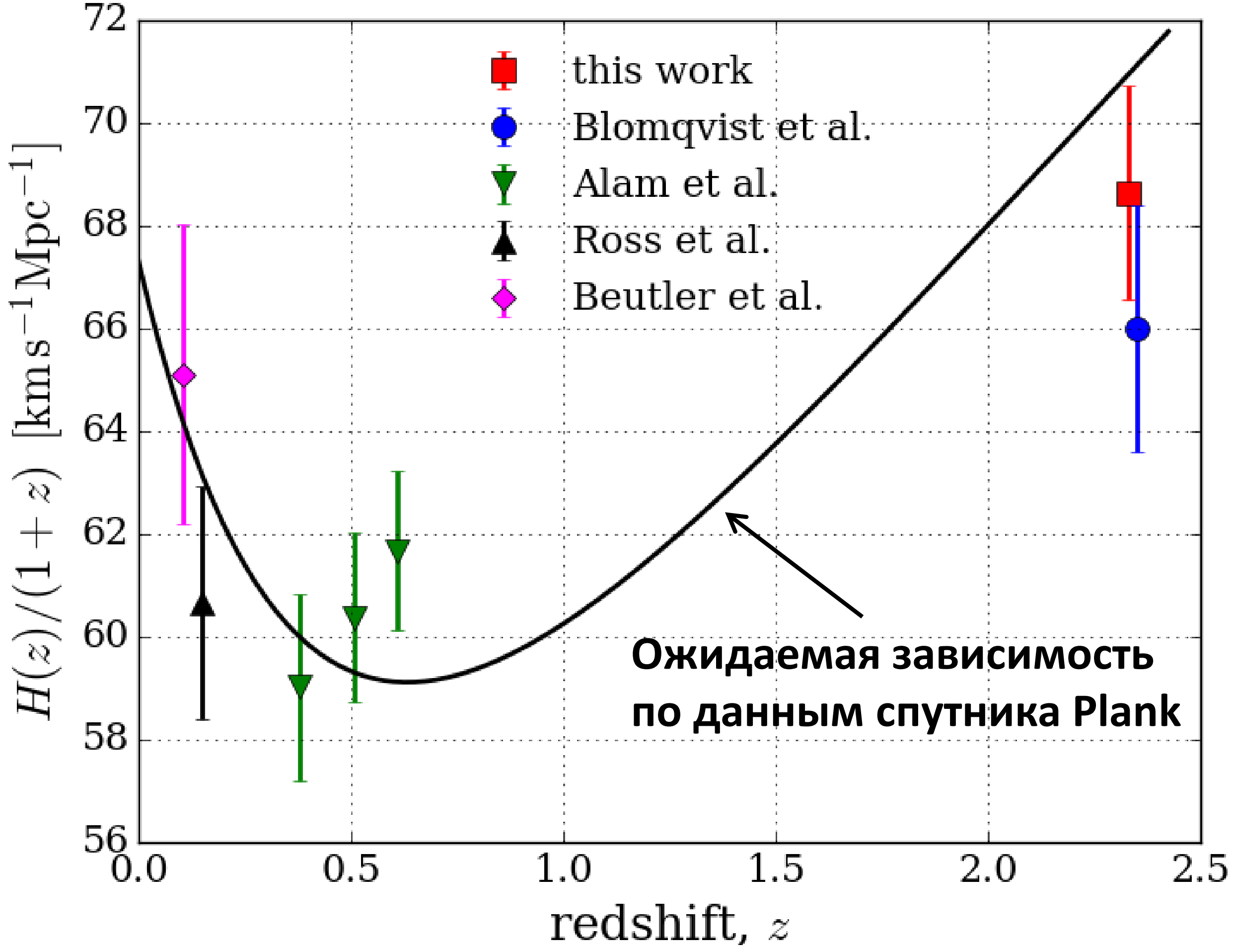
Расширения ΛCDM

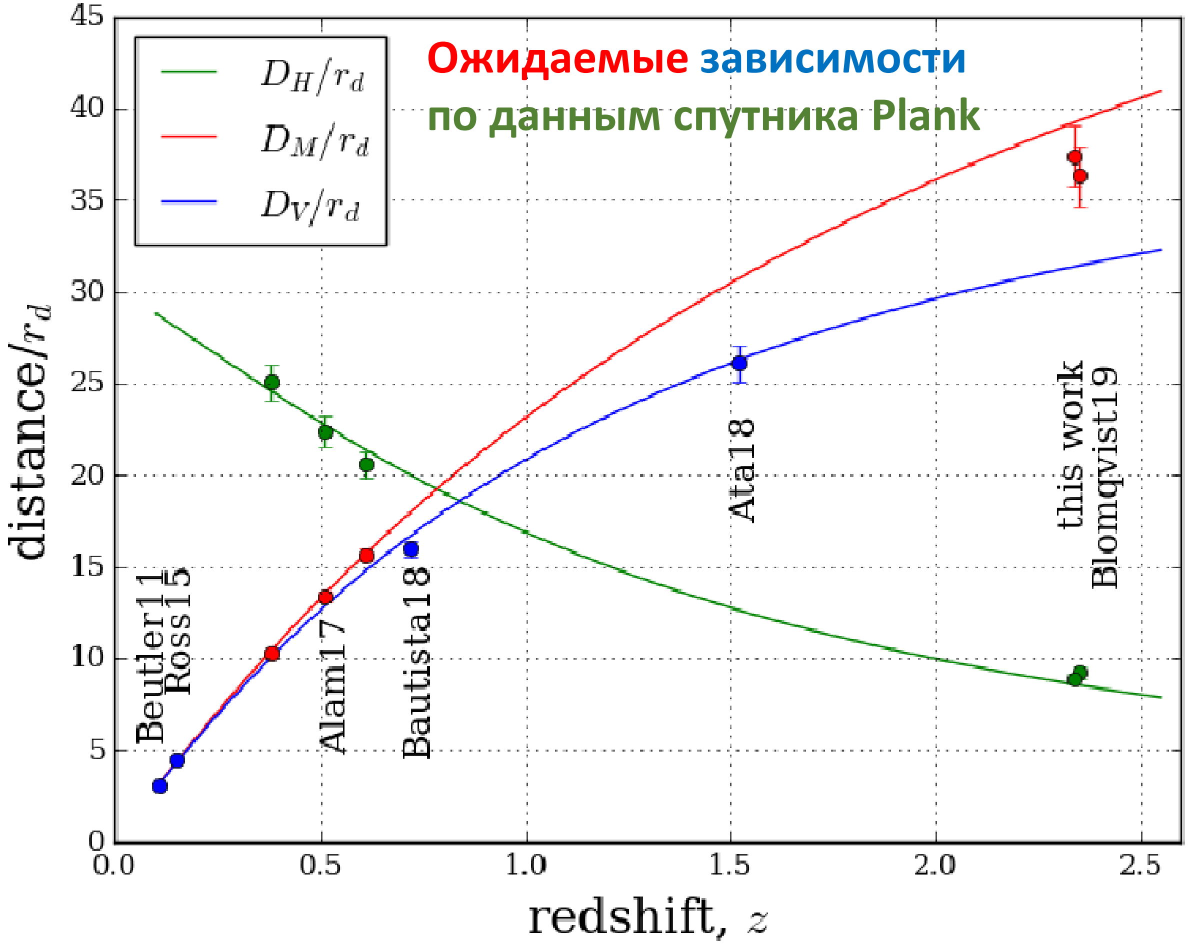


Стандартная линейка

arXiv:1904.03400

Baryon acoustic oscillations at z = 2.34 from the correlations of Lyα absorption in eBOSS DR14

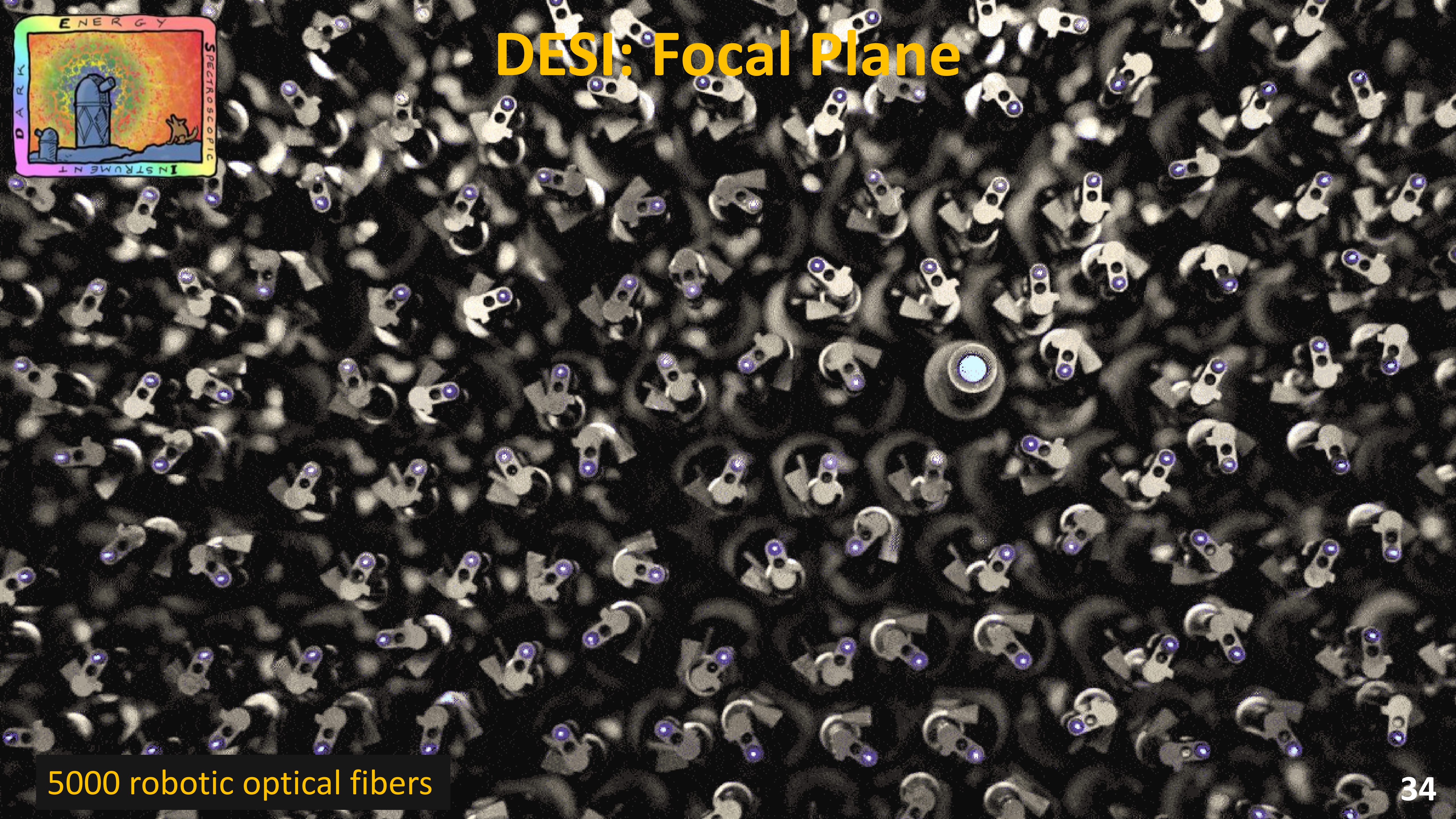




DESI: Telescope

Mayall Telescope @ Kitt Peak, Arizona USA
4m hyperboloidal mirror

DESI: Focal Plane

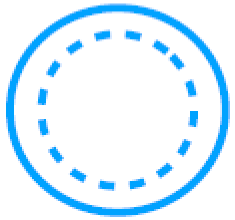


5000 robotic optical fibers

Стандартная линейка

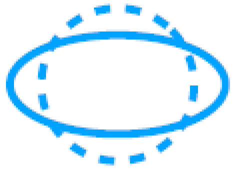
Isotropic BAO

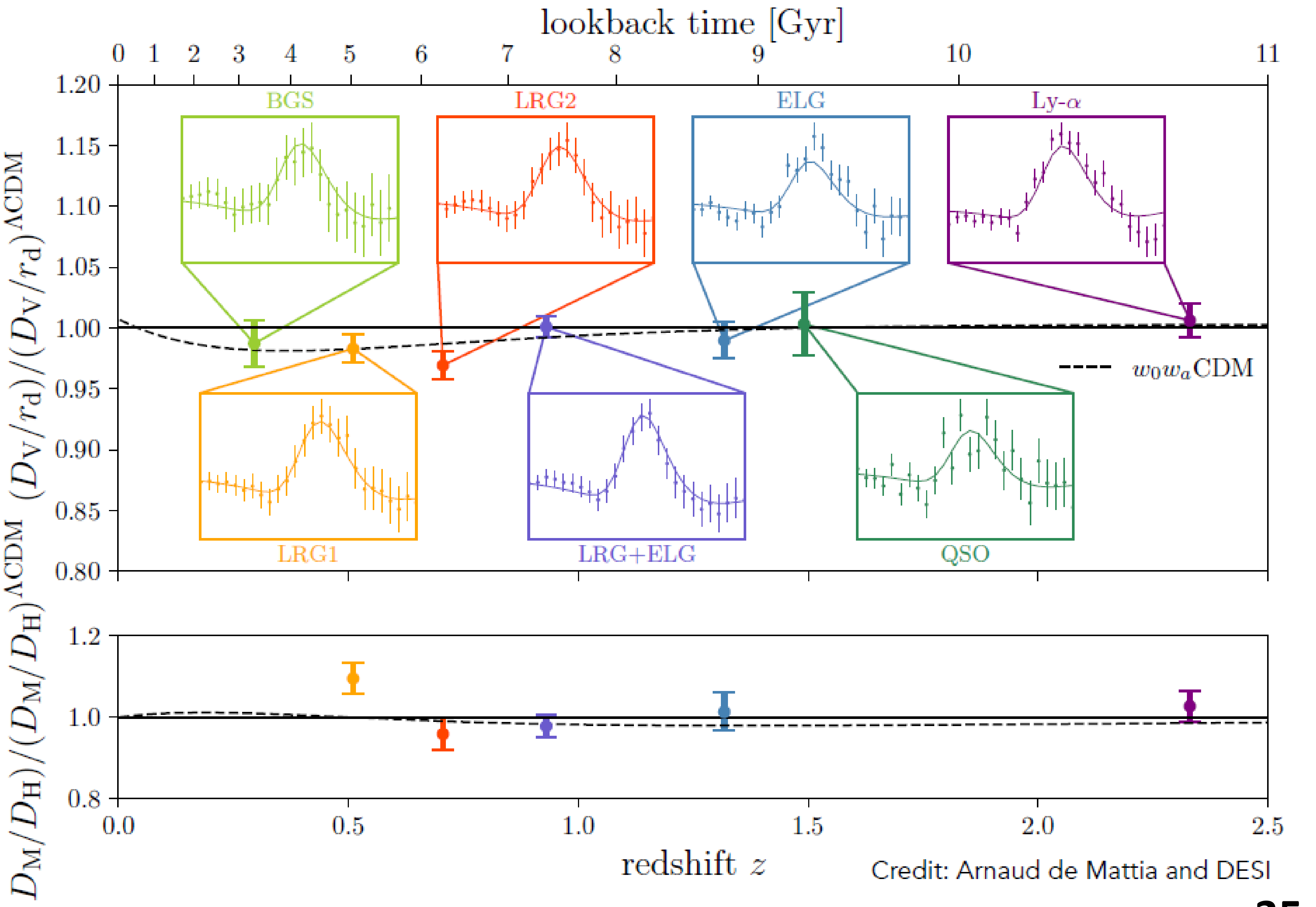
$$\frac{D_V(z)}{r_{\mathrm{drag}}}$$



Anisotropic BAO

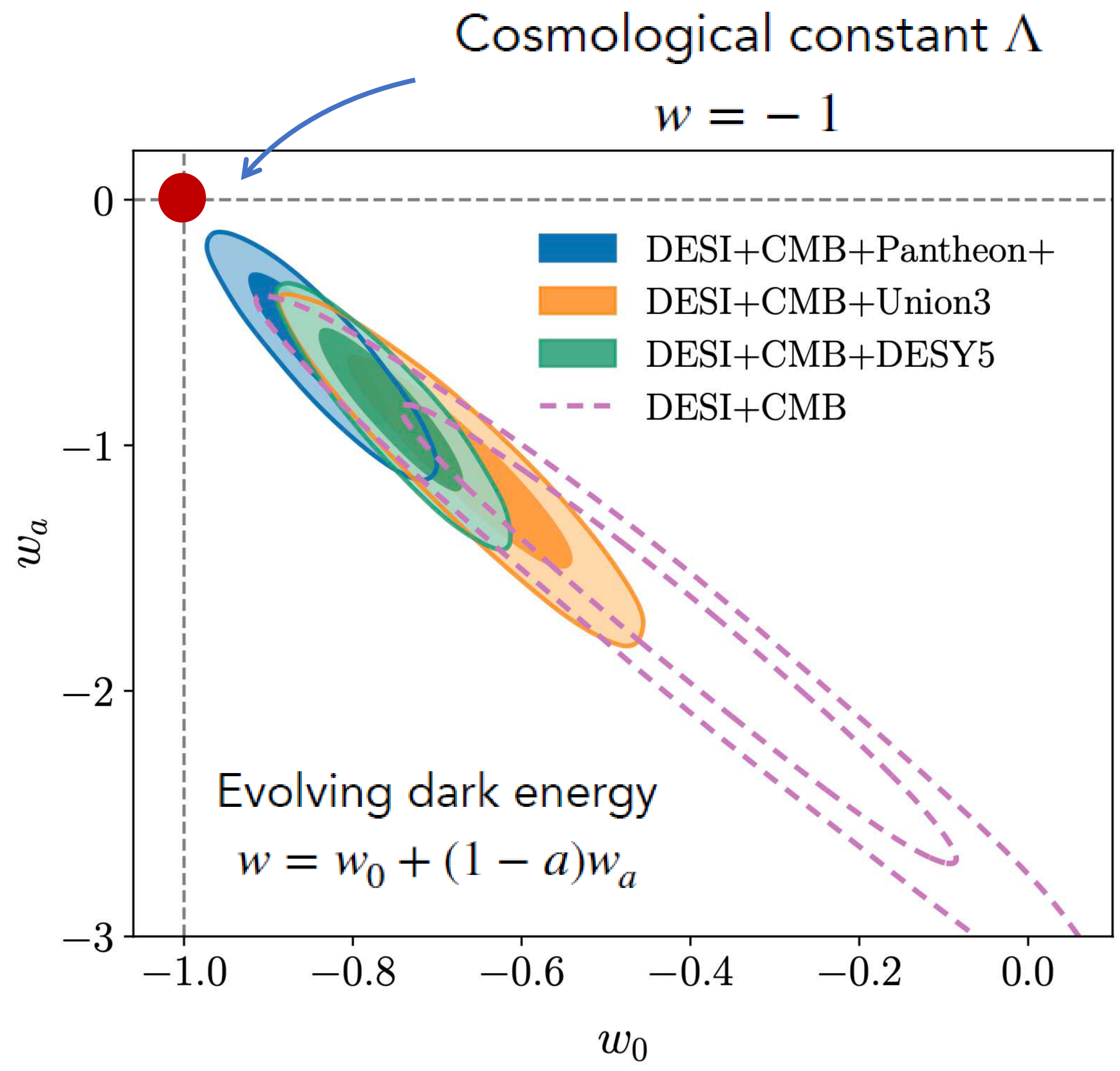
$$\frac{D_M(z)}{D_H(z)}$$



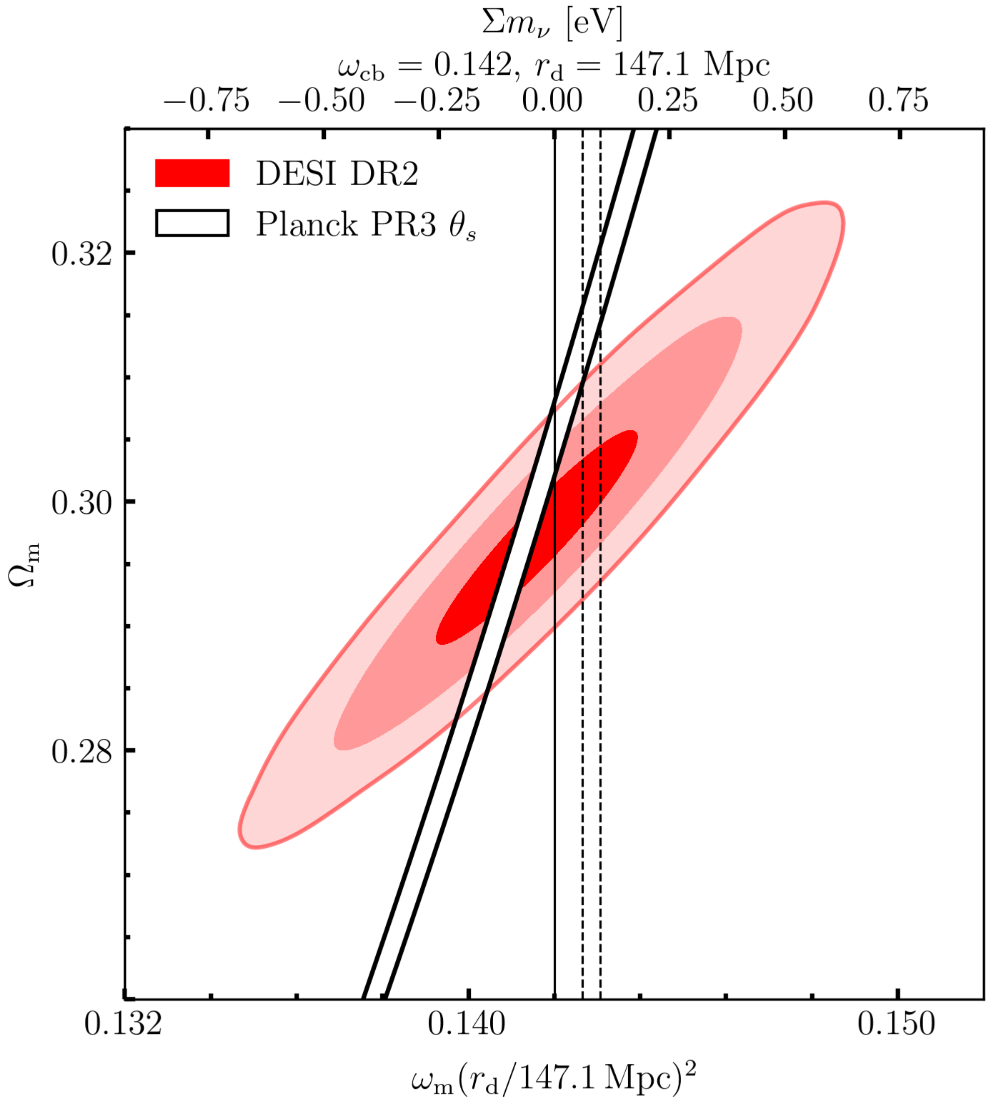


Credit: Arnaud de Mattia and DESI

BAO Tension!

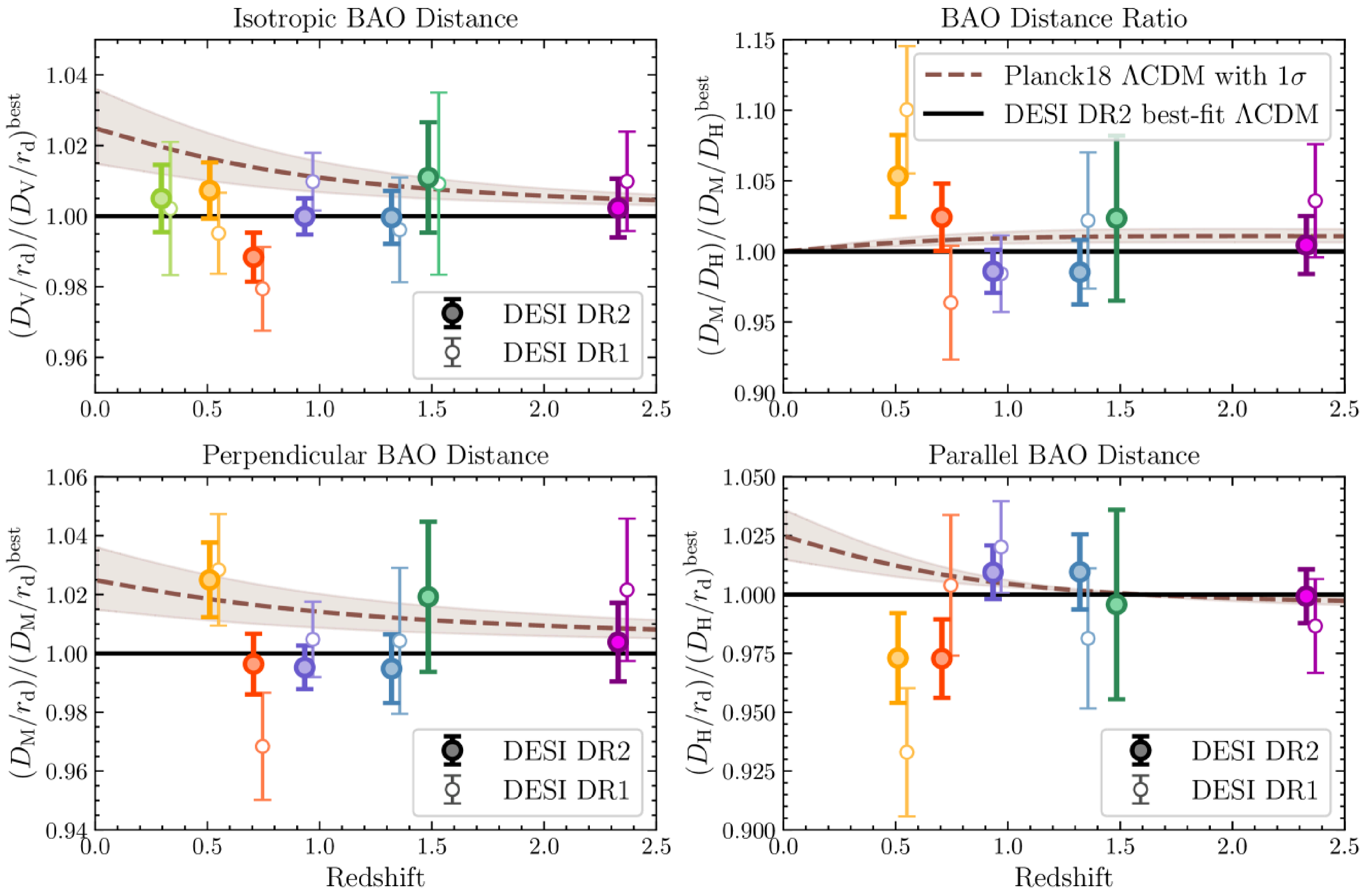


Cosmological constant Λ
$w = -1$
DESI+CMB+Pantheon+
DESI+CMB+Union3
DESI+CMB+DESY5
DESI+CMB
Evolving dark energy
$w = w_0 + (1 - a)w_a$
w_a
w_0
0
−1
−2
−3
−1.0
−0.8
−0.6
−0.4
−0.2
0.0



Σm_ν [eV]
$\omega_{cb} = 0.142,\ r_d = 147.1$ Mpc
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
DESI DR2
Planck PR3 θ_s
Ω_m
0.32
0.30
0.28
0.132
0.140
0.150
$\omega_m (r_d/147.1\ \mathrm{Mpc})^2$

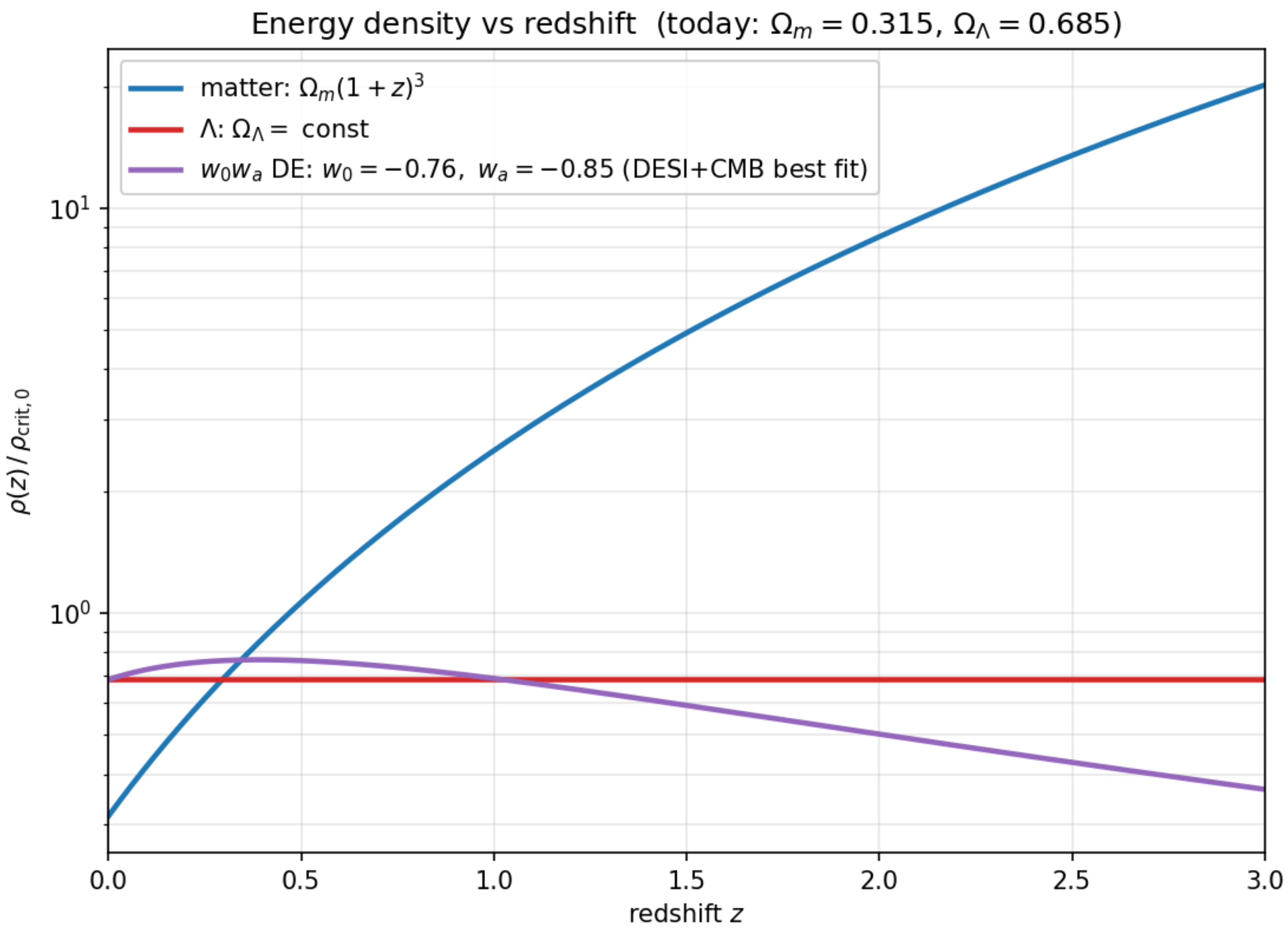
BAO Tension?



Isotropic BAO Distance
$(D_V/r_d)/(D_V/r_d)^{best}$
DESI DR2
DESI DR1
BAO Distance Ratio
$(D_M/D_H)/(D_M/D_H)^{best}$
Planck18 ΛCDM with 1σ
DESI DR2 best-fit ΛCDM
Perpendicular BAO Distance
$(D_M/r_d)/(D_M/r_d)^{best}$
DESI DR2
DESI DR1
Parallel BAO Distance
$(D_H/r_d)/(D_H/r_d)^{best}$
DESI DR2
DESI DR1
Redshift
Redshift

BAO Tension?

- Evolving Dark Energy with w<-1 contributes less energy than ΛCDM at high z
- Lower energy density at z>2 → Distances are larger, resolving the tension
- But the ensuing model requires dark energy density to *increase* with time, which does not seem physical

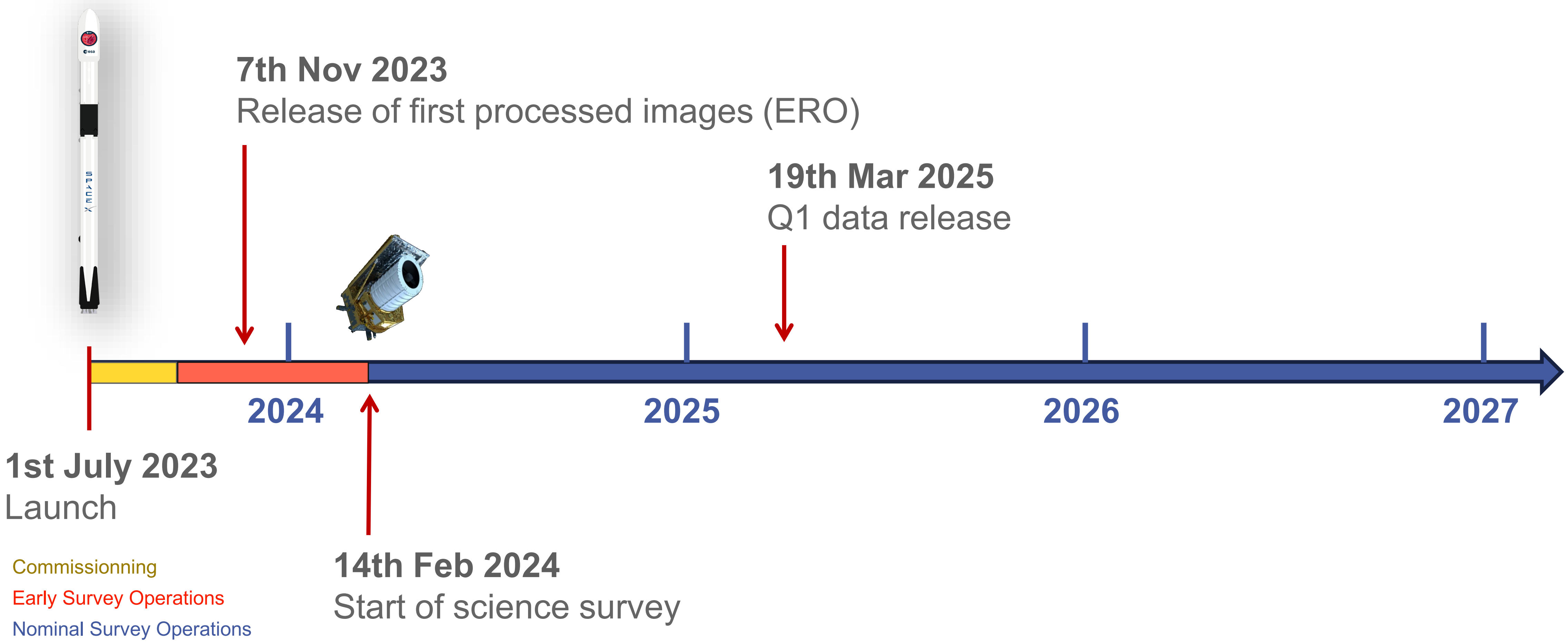


Conclusion

- ΛCDM fits individual data sets remarkably well
- Stage 3 experiments have left us with hints of tensions that need to, and will be, resolved – one way or another – with upcoming surveys
    - CMB and Galaxy surveys (most notably DES) seem to be measuring slightly different values of S_8
    - CMB and Galaxy surveys (most notably DESI) seem to disagree on distances
        - This is often ascribed to evolving dark energy
        - But the model used to expose the tension is unphysical (increasing dark energy or negative neutrino mass)
            - Essence of the disagreement: distance in the Matter Dominated Era is off: might imply our understanding of dark matter needs to be modified
            - Essence of the disagreement: late measurements imply *less* non-relativistic matter than the CMB: might imply our understanding of dark matter needs to be modified

Euclid timeline

Euclid is great for anything that requires large areas, high sensitivity and high resolution



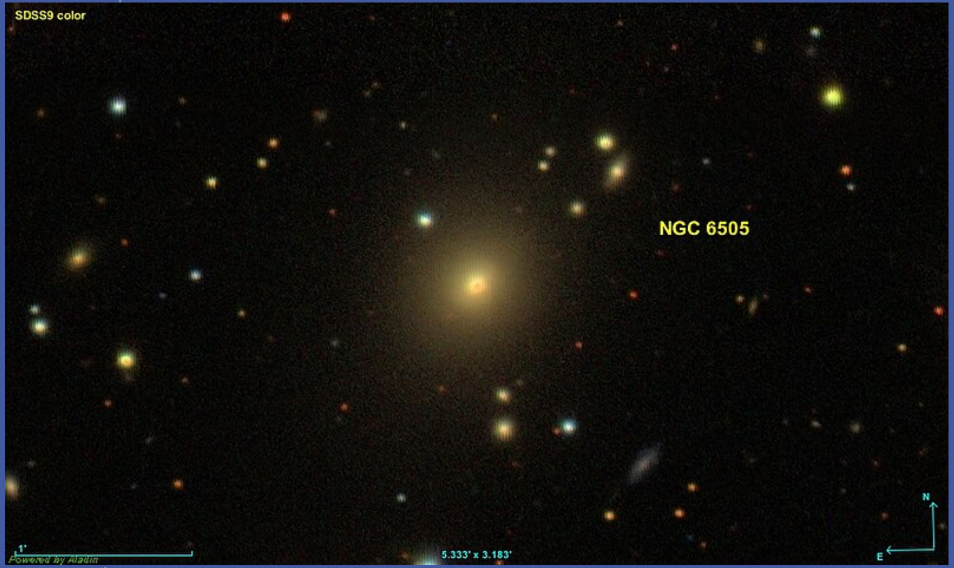
The Euclid Legacy revolution

Revolution in wide field high resolution imaging and spectroscopy

	Before Euclid	After Euclid
Total sky coverage with high-resolution images	<25 deg^2 Hubble Space Telescope	15, 000 deg^2 Euclid Wide Survey
Galaxies at redshift $1 < z < 3$ with precise mass measurement	5 million	200 million
Galaxies in clusters of galaxies at $1 < z < 3$	Several hundreds	Several thousands
Dwarf galaxies	< 10	> 2 000 000
Active galaxy nuclei ($0.7 < z < 2$)	1000	10 000
Very Distant Quasars at redshift $z > 8$	< 5	> 30
Lensing galaxies with gravitational arcs and rings	100 - 1000	300 0000
Giant gravitational arcs in clusters of galaxies	< 200	> 50 000
Solar System Object	200 000	400 000

STRONG LENSING

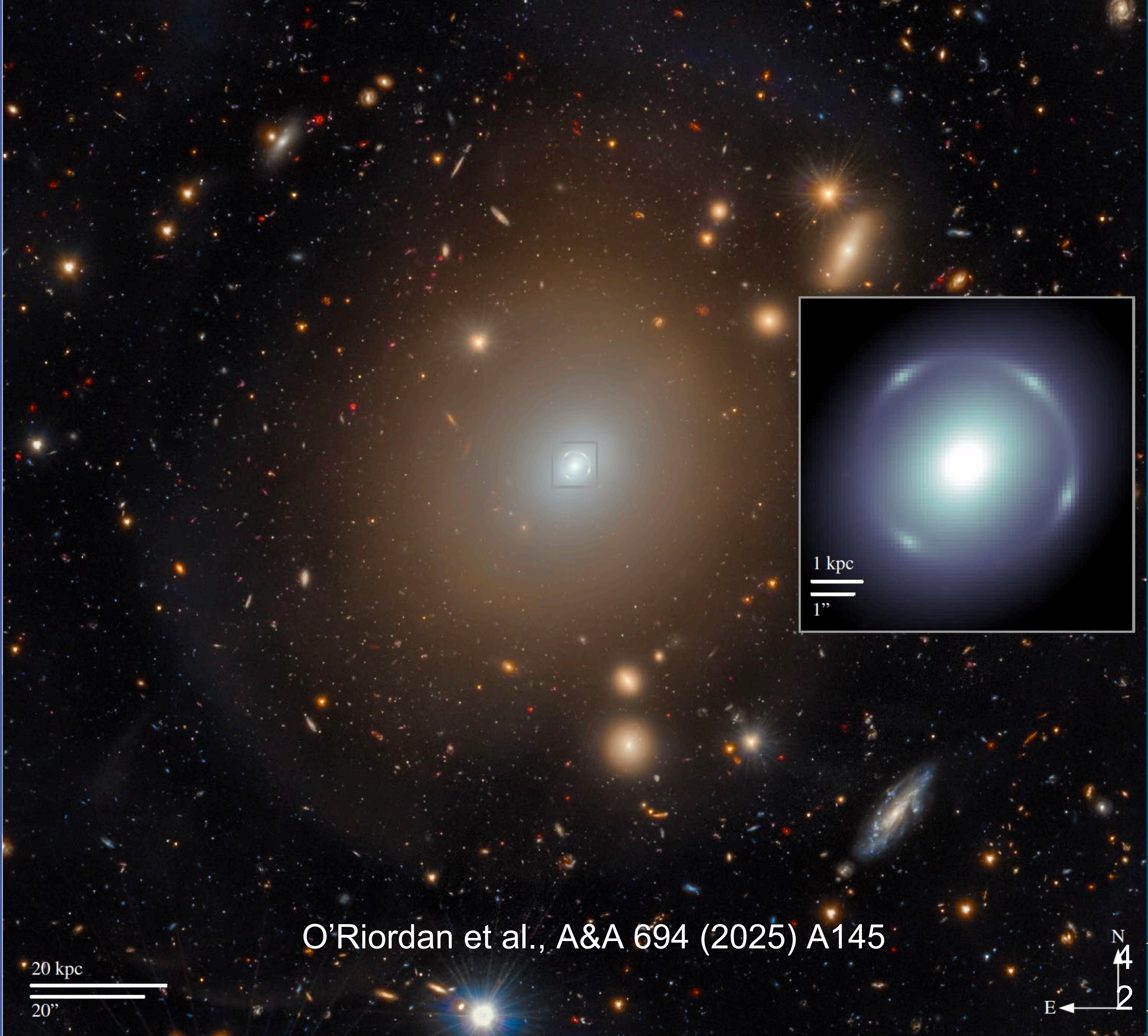
Euclid's Einstein Ring around galaxy NGC 6505



- Galaxy NGC 6506 has been known since the 1886, but this ring has never been observed !

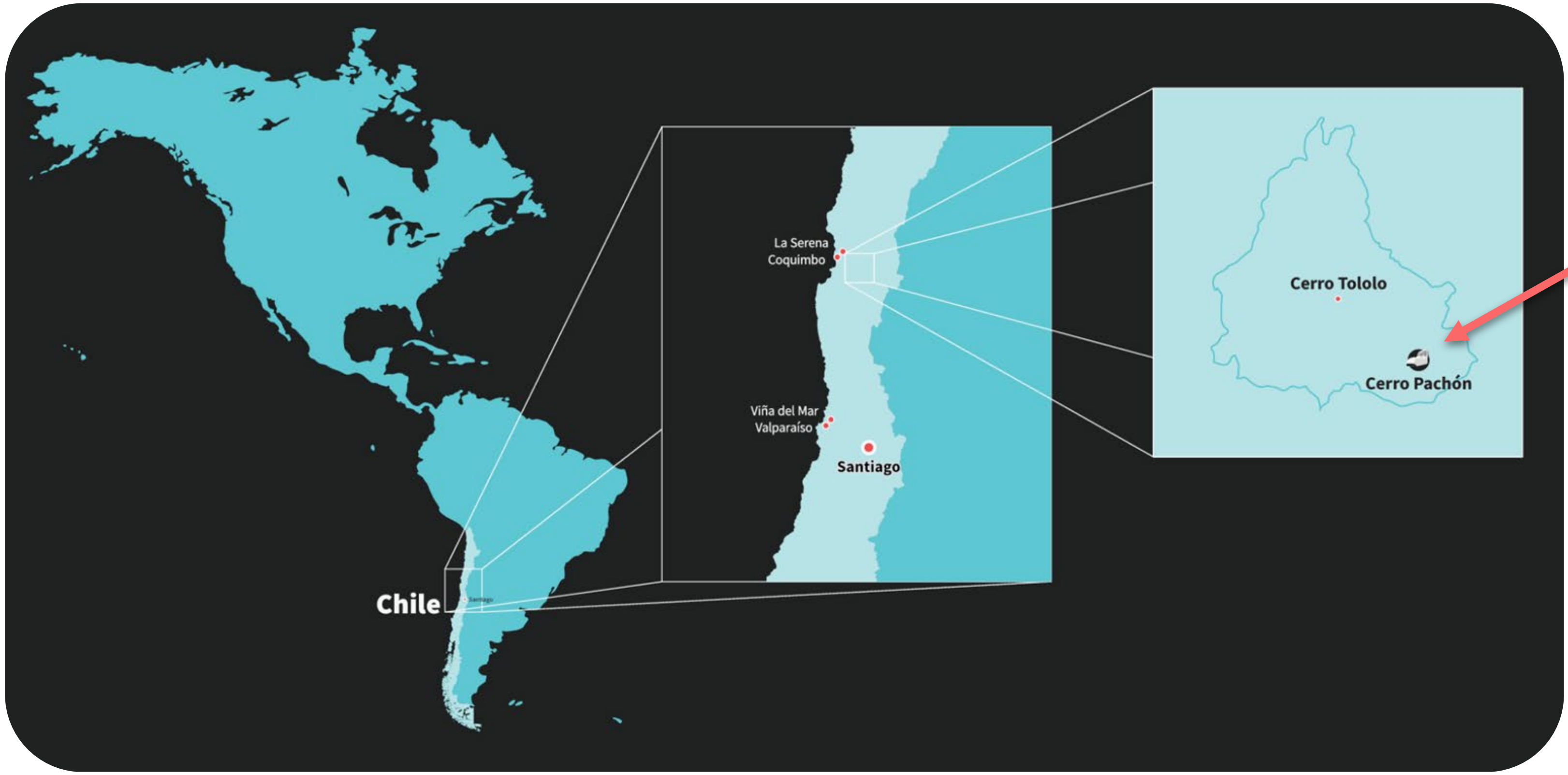
- Lens at z = 0.042
- Source at z = 0.406

Near-perfect Einstein ring observed with Euclid



O'Riordan et al., A&A 694 (2025) A145

Meet Rubin Observatory



RubinObs/NOIRLab/SLAC/NSF/DOE/AURA/A. Pizarro D.

Located on **Cerro Pachón**, in the Coquimbo region of Chile

Jointly funded by the **U.S. National Science Foundation** and the **U.S. Department of Energy, Office of Science**

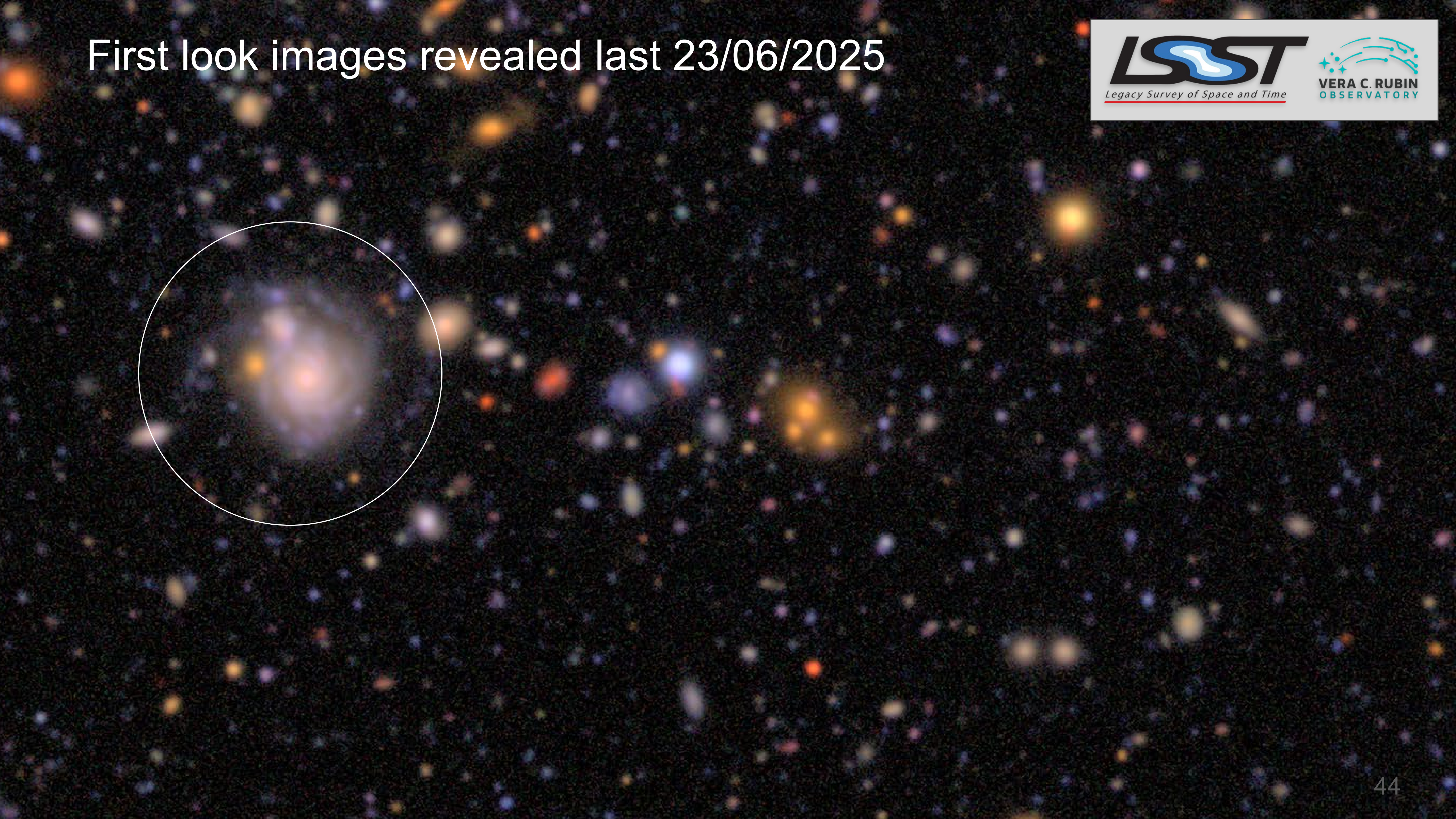
VERA C. RUBIN OBSERVATORY | U.S. National Science Foundation | U.S. DEPARTMENT of ENERGY | Office of Science

NOIRLab | AURA | SLAC NATIONAL ACCELERATOR LABORATORY

First look images revealed last 23/06/2025

LSST Legacy Survey of Space and Time

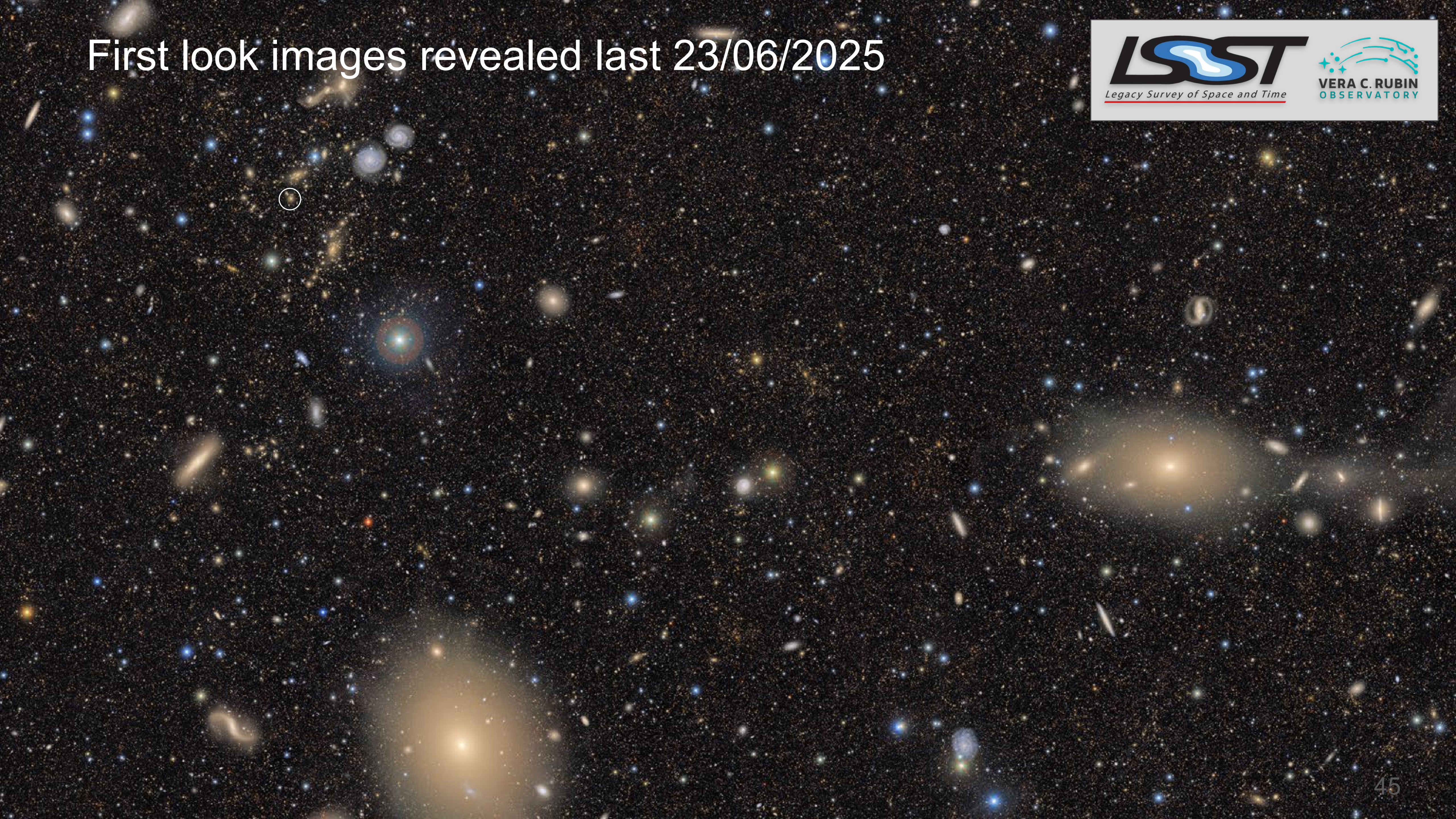
VERA C. RUBIN OBSERVATORY



First look images revealed last 23/06/2025

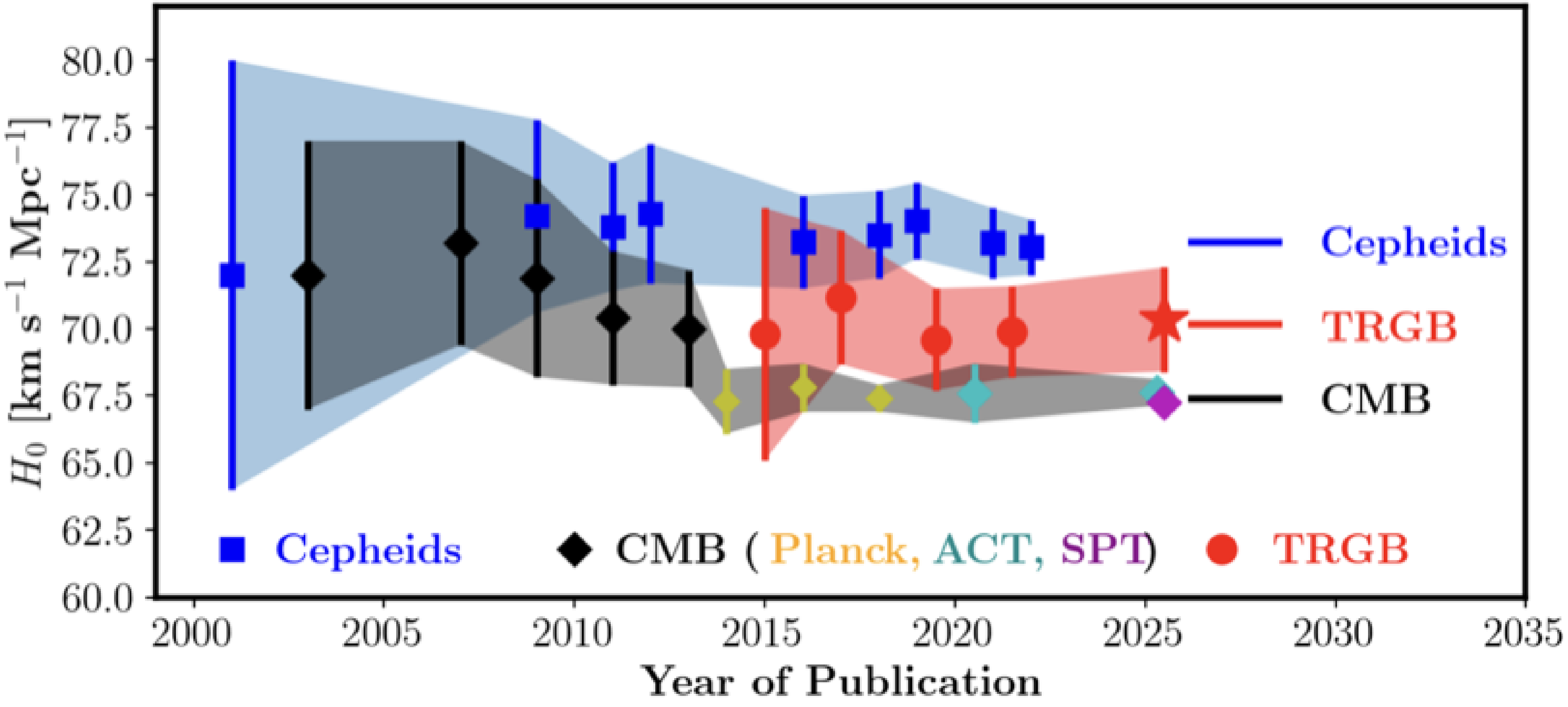
LSST Legacy Survey of Space and Time

VERA C. RUBIN OBSERVATORY



Hubble Tension

Возможной причиной расхождения результатов измерения H_0 по CMB и по сверхновым Ia может являться еще не понятая систематика в калибровке «лестницы расстояний». Это можно проверить используя методы измерения расстояния не основанные на стандартной лестнице параллакс-цефеиды-SNIa.

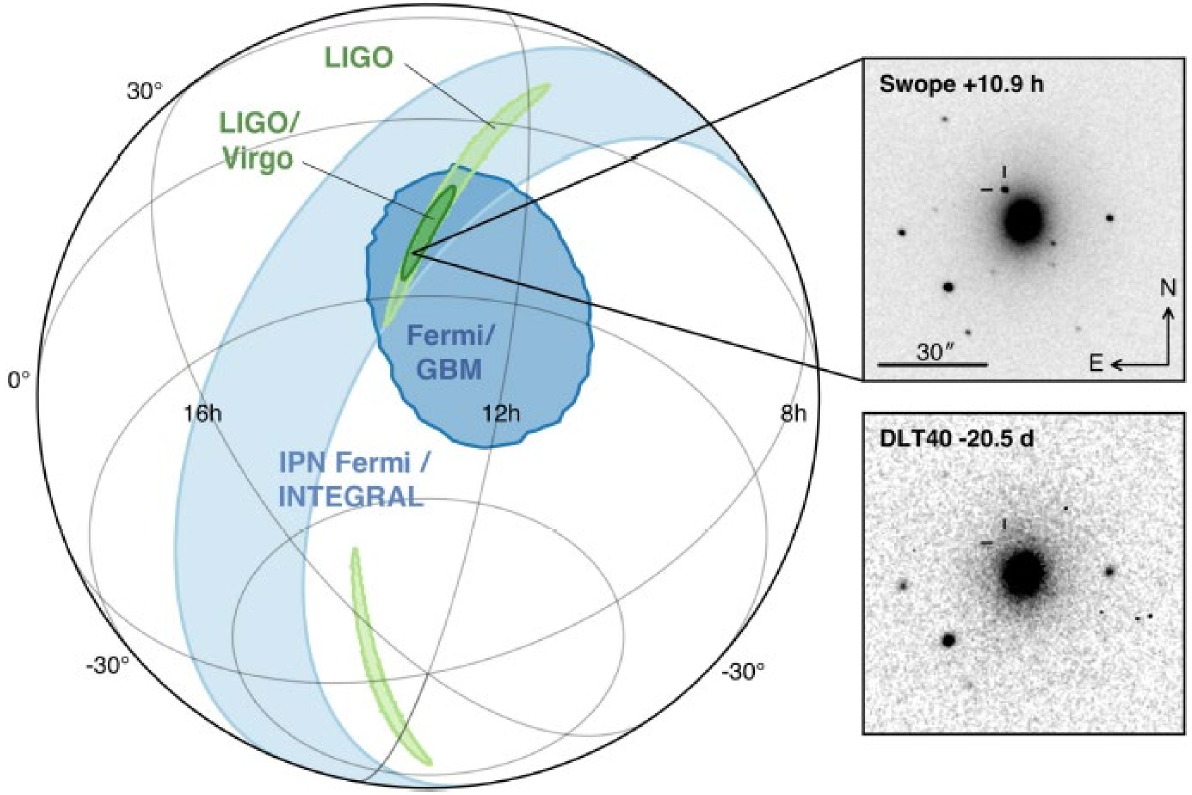


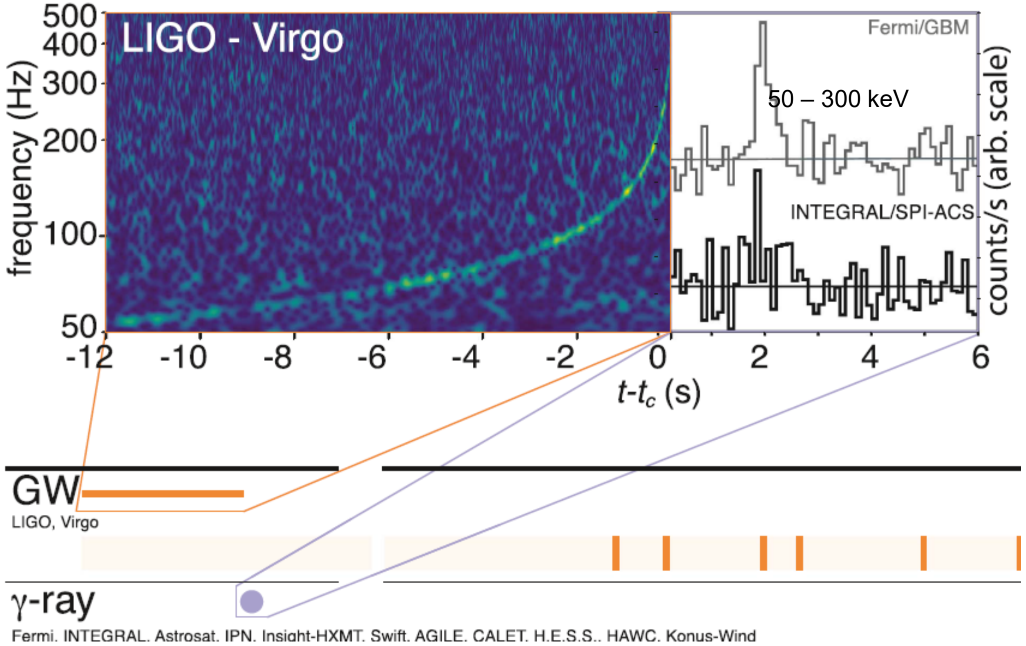
Событие: GW170817

arXiv:2012.04810

First Multimessenger Observations of a Neutron Star Merger

17 августа 2017 года в 12:41:04.4 UTC обсерватории LIGO и VIRGO зарегистрировали гравитационную волну GW170817, предположительно от слияния двух нейтронных звезд.





Всего через 1.74±0.05 секунды сигнал был зарегистрирован орбитальными гамма обсерваториями Fermi и INTEGRAL.

В оптическом диапазоне первая регистрация сигнала телескопом Swope через 10.9 часов – точная идентификация источника – галактика NGC 4993 (расстояние 40.7 Мпк).

Стандартные сирены

An exciting possibility to expand our portfolio of cosmological probes.

Nature 323 310, 1986

Determining the Hubble constant from gravitational wave observations

Bernard F. Schutz

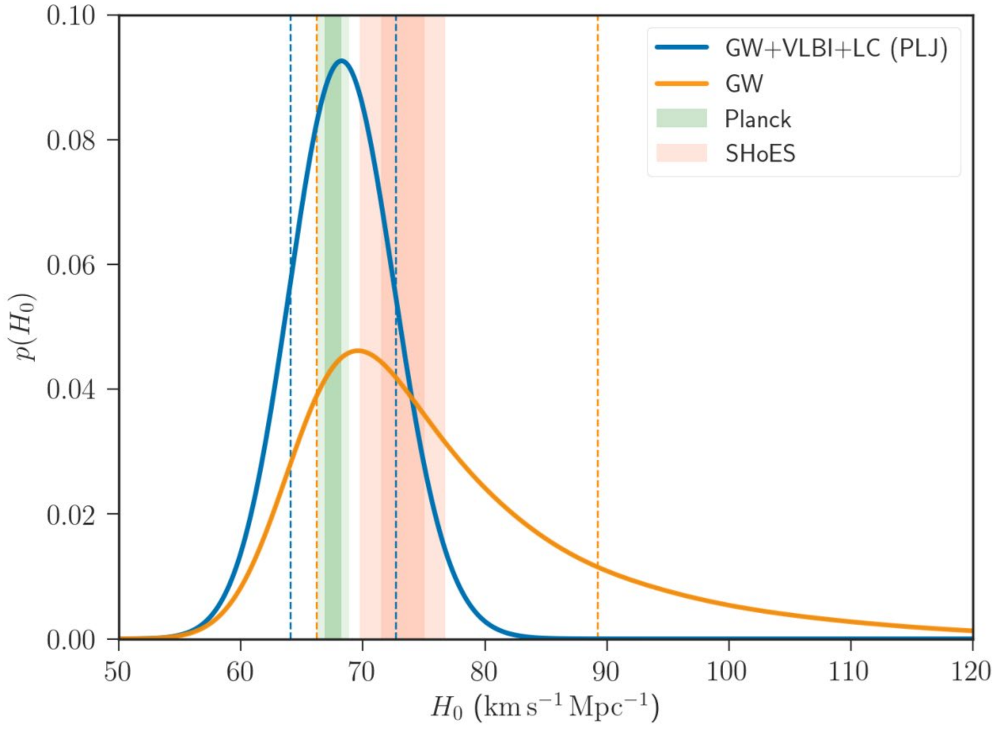
Department of Applied Mathematics and Astronomy, University College Cardiff, PO Box 78, Cardiff CF1 1XL, UK

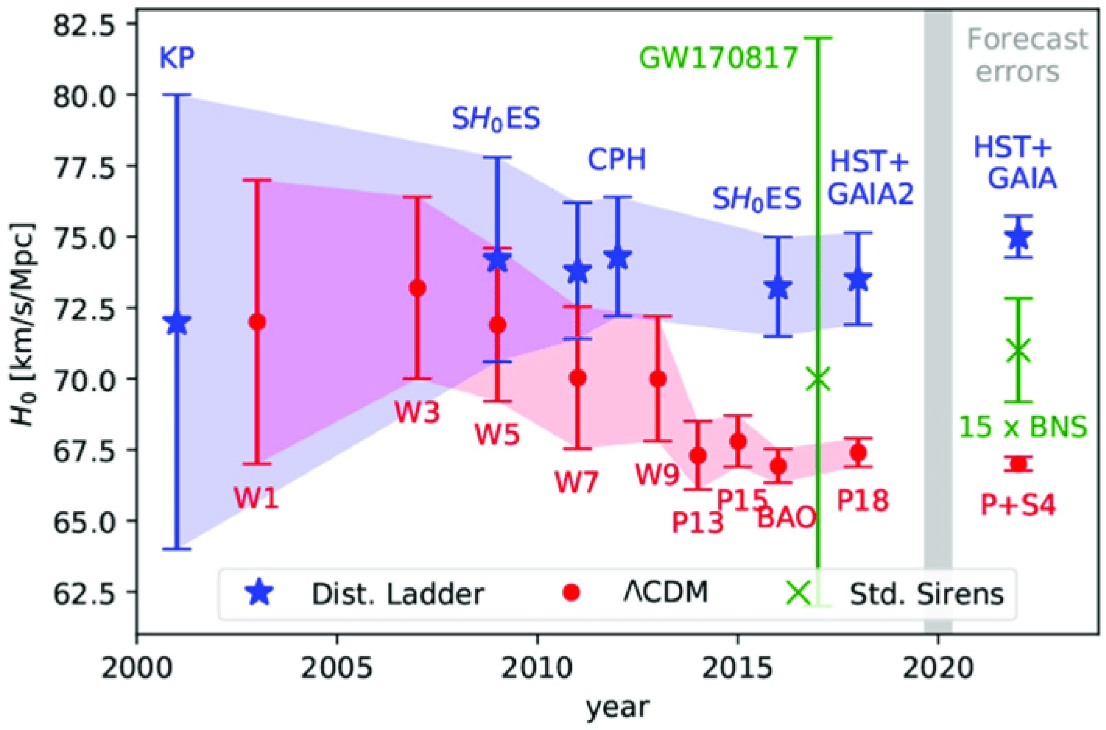
I report here how gravitational wave observations can be used to determine the Hubble constant, H_0. The nearly monochromatic gravitational waves emitted by the decaying orbit of an ultra-compact, two-neutron-star binary system just before the stars coalesce are very likely to be detected by the kilometre-sized interferometric gravitational wave antennas now being designed[1–4]. The signal is easily identified and contains enough information to determine the absolute distance to the binary, independently of any assumptions about the masses of the stars. Ten events out to 100 Mpc may suffice to measure the Hubble constant to 3% accuracy.

- In a merging NS binary, the change in GW signal frequency, gives the size of the system.
- Once we know the size, we can predict the intrinsic amplitude to compare with the observed amplitude in our detectors!
- Need to observe optical counterpart to determine the redshift

GW170817 Cosmology

arXiv:1806.10596 [astro-ph.CO]





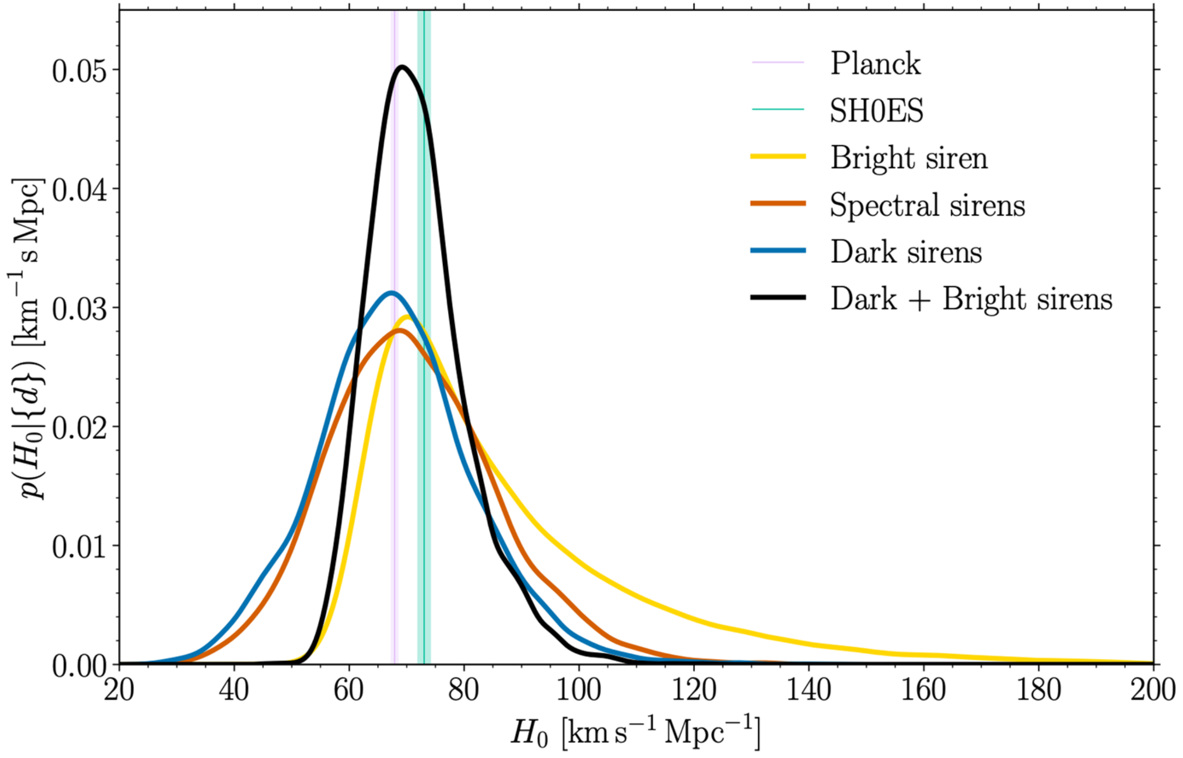
С 2017 года не наблюдалось ни одного нового события слияния нейтронных звезд!

Adding GW to the portfolio of cosmological probes

We have promising results. How can we reach the "precision cosmology" level in the near future?

- Get **larger samples** of standard sirens, with better localization areas (IR1, O5).
- Discover new **EM counterparts** (LSST)
- Develop new analyses methods (**cross-correlation**)
- Improve **galaxy catalogs** (LSST).
- Improve multi-messenger modeling of bright sirens (**viewing angle constraints**, **peculiar velocity field reconstruction**)
- **Combine with other probes!**

LVK Collaboration, **ApJL** submitted, arXiv:2605.27227

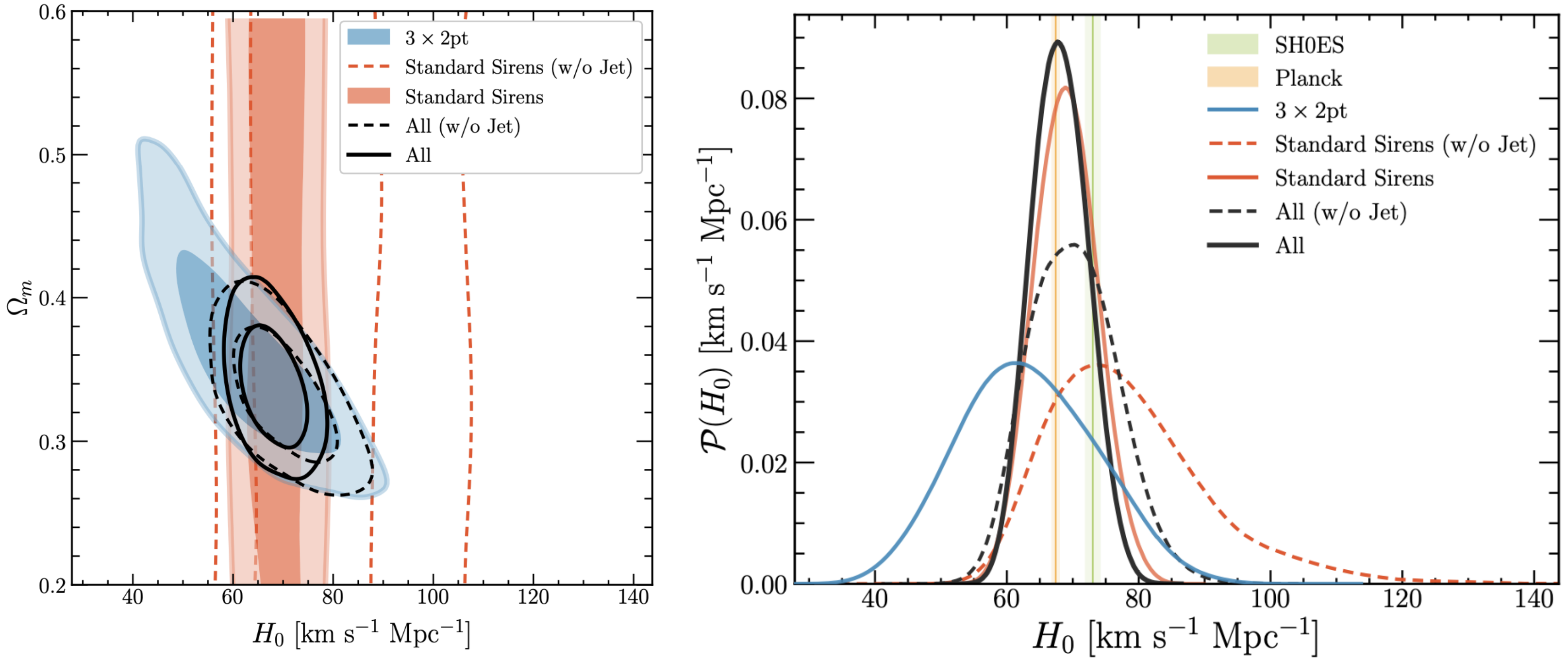


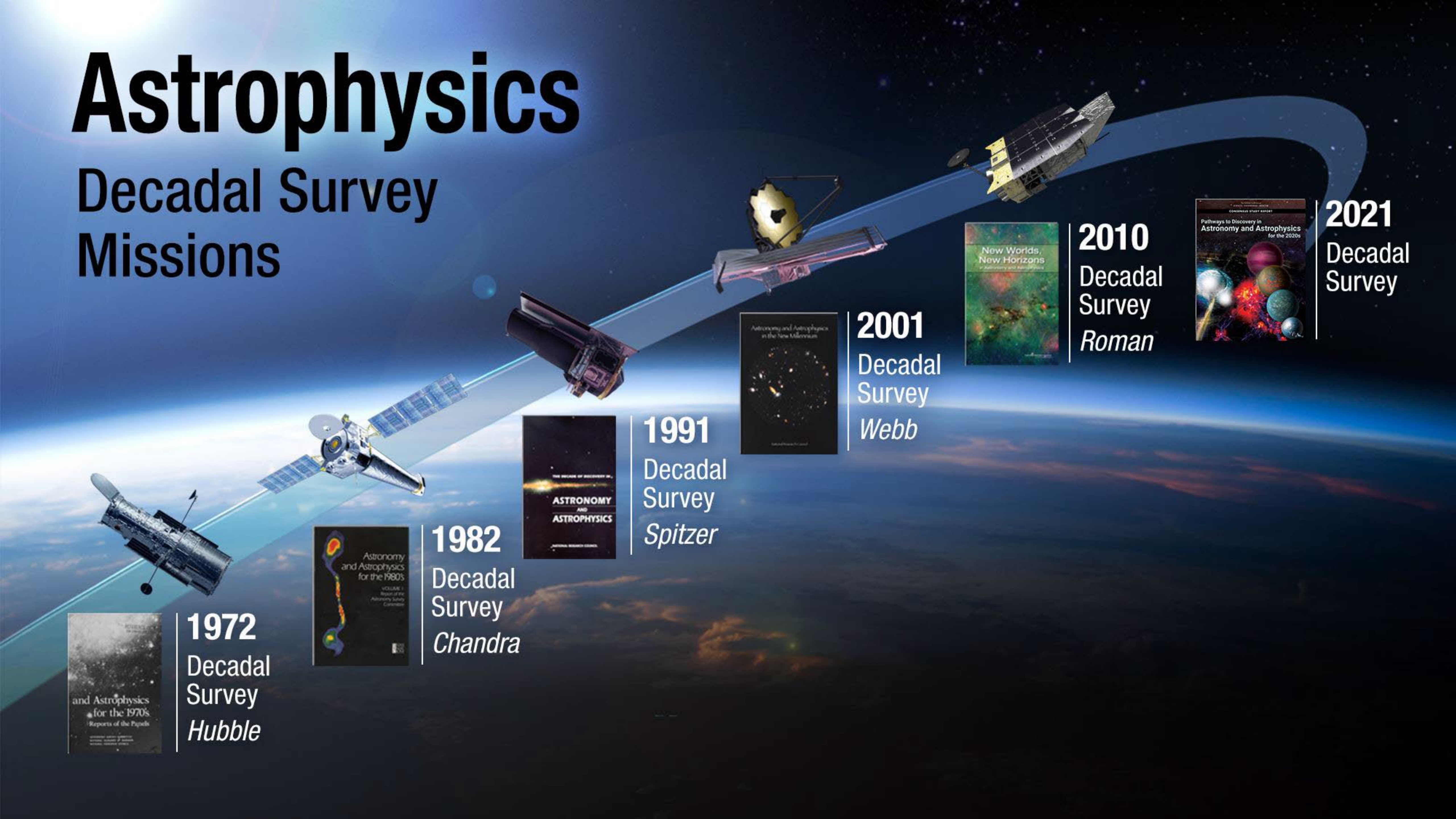
DES Y3 3x2pt + LVK GWTC-4.0 Standard Sirens

First multi-messenger combination of 3x2pt and gravitational-wave observables

- Our combination reached 6.4% precision on the Hubble constant.
- And, surprisingly, it also improved the overall constraining power by 22% relative to the 3x2pt analysis alone.
- We are looking forward to presenting results based on Y6 and GWTC-5.0 soon. — Stay tuned!

Andrade-Oliveira, F. et al., **A&A** 709 14 2026, arXiv:2601.04774

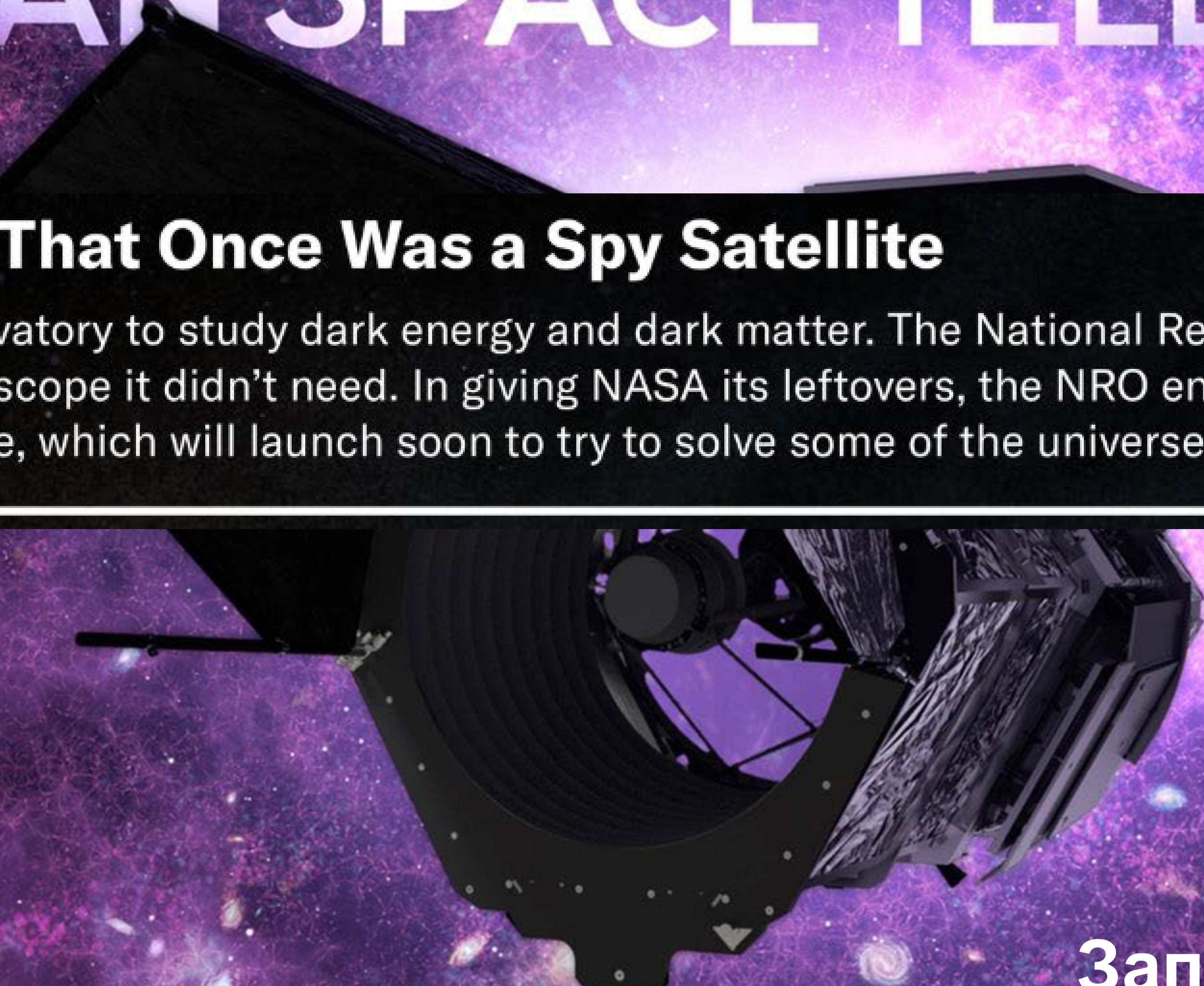



Astrophysics
Decadal Survey
Missions
and Astrophysics
for the 1970's
Reports of the Panels
1972
Decadal
Survey
Hubble
Astronomy
and Astrophysics
for the 1980's
1982
Decadal
Survey
Chandra
ASTRONOMY
AND
ASTROPHYSICS
1991
Decadal
Survey
Spitzer
Astronomy and Astrophysics
in the New Millennium
2001
Decadal
Survey
Webb
New Worlds,
New Horizons
2010
Decadal
Survey
Roman
Pathways to Discovery in
Astronomy and Astrophysics
for the 2020s
2021
Decadal
Survey

THE NANCY GRACE ROMAN SPACE TELESCOPE

The Telescope That Once Was a Spy Satellite

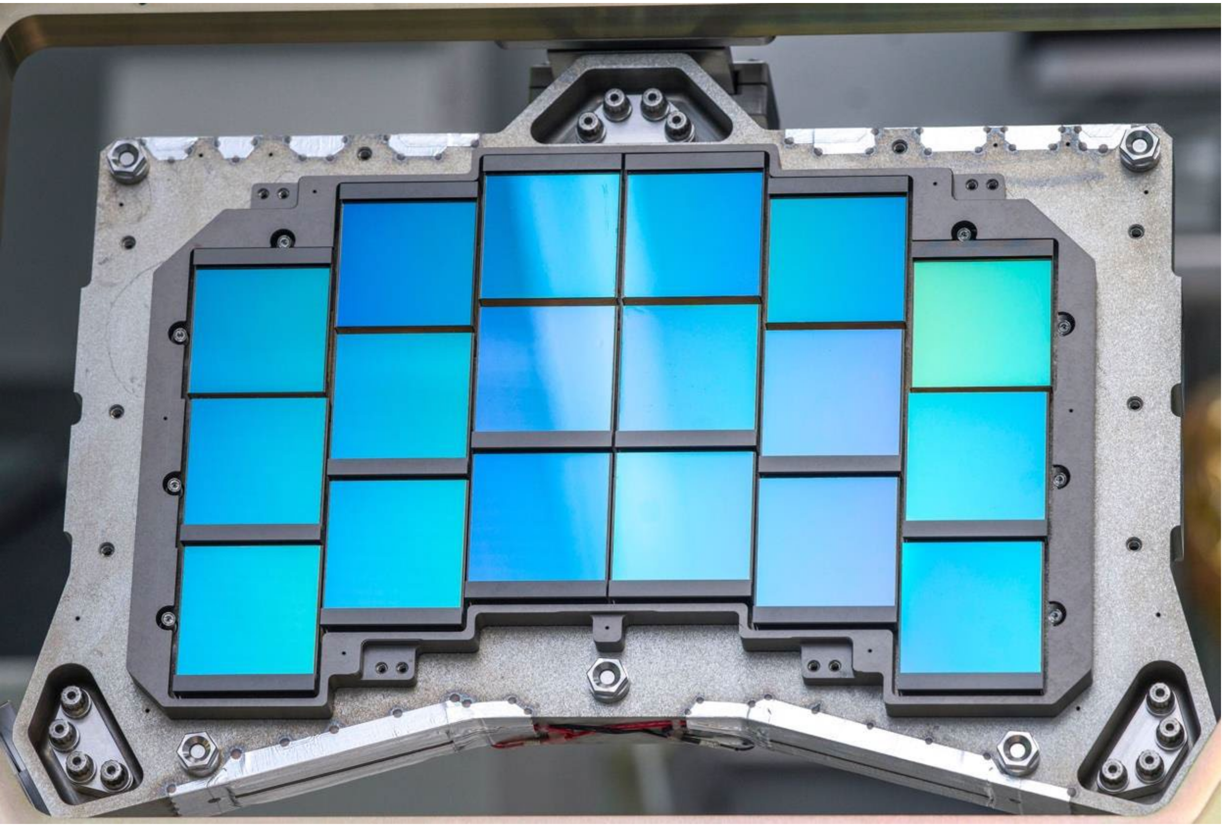
NASA wanted an observatory to study dark energy and dark matter. The National Reconnaissance Office (NRO) had an extra Hubble-class telescope it didn't need. In giving NASA its leftovers, the NRO enabled the birth of the Nancy Grace Roman Space Telescope, which will launch soon to try to solve some of the universe's biggest mysteries.

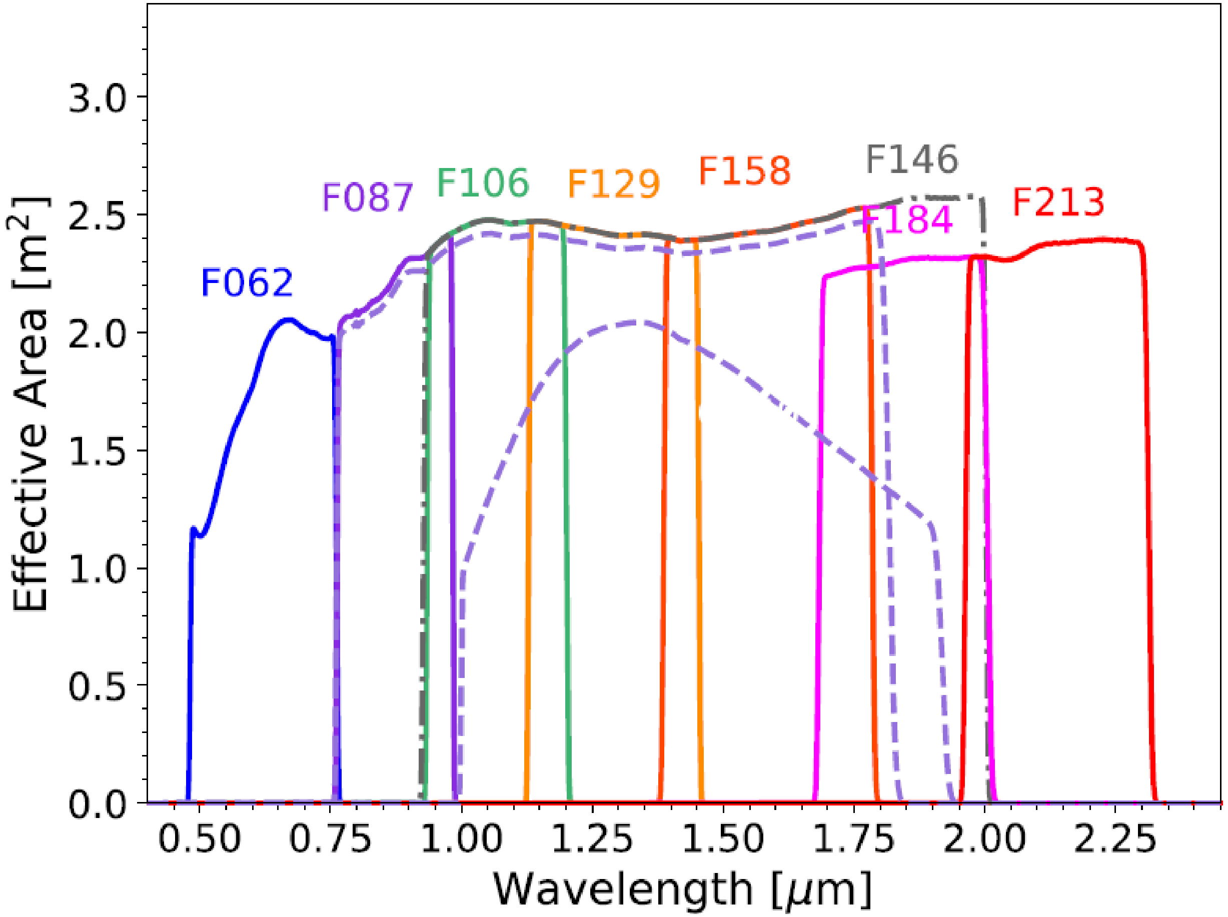


NANCY GRACE ROMAN SPACE TELESCOPE

Запуск: 30 августа 2026

RST Wide Field Camera





Primary science instrument for surveys

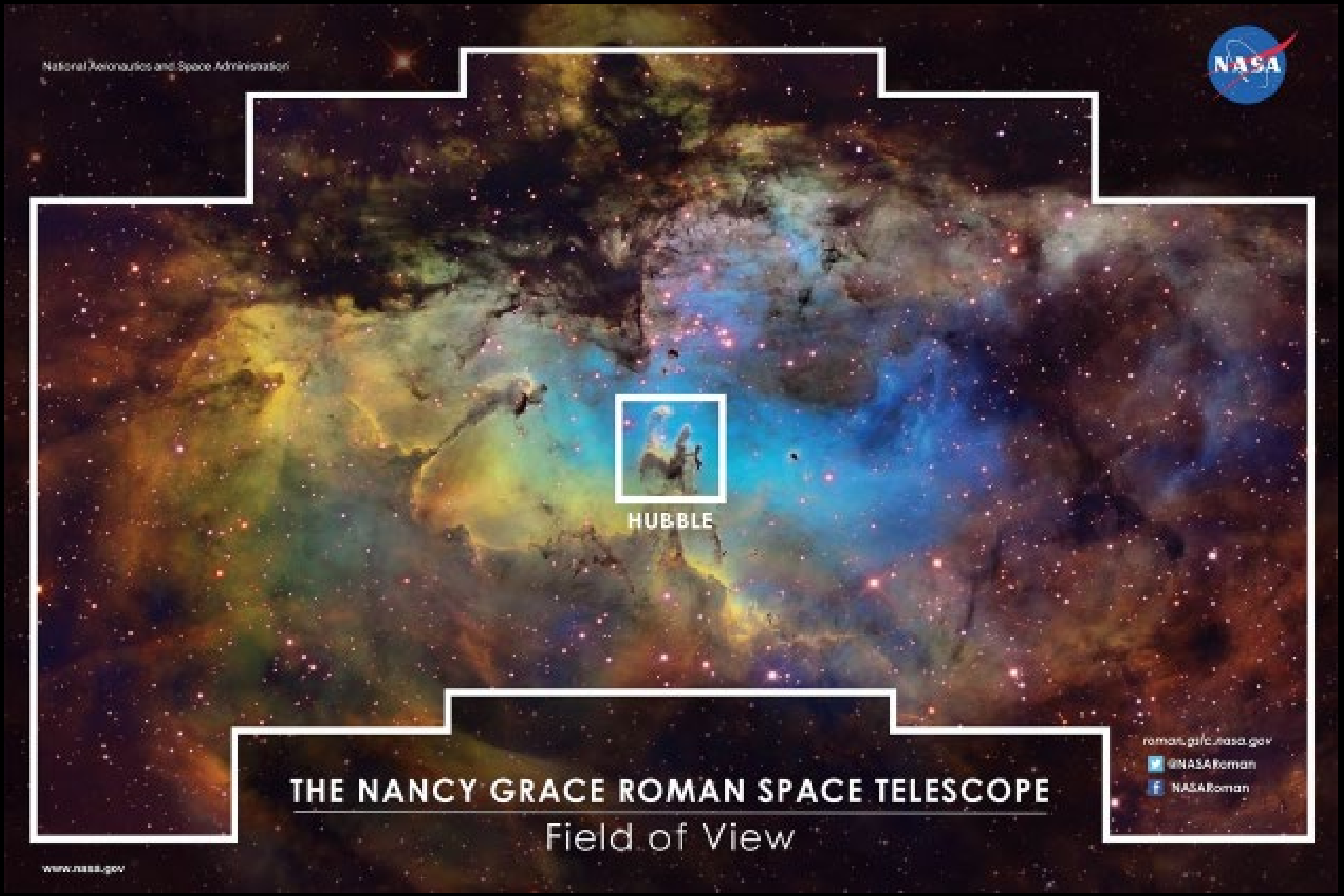
Focal plane array of 18 4k ×4k detectors, Large FOV – 0.8 x 0.4 deg (0.281 deg^2)

300,000,000 pixels with 0.11”/pix

Image stability: 1.0 nm RMS wave front error (WFE) variation in 180 sec

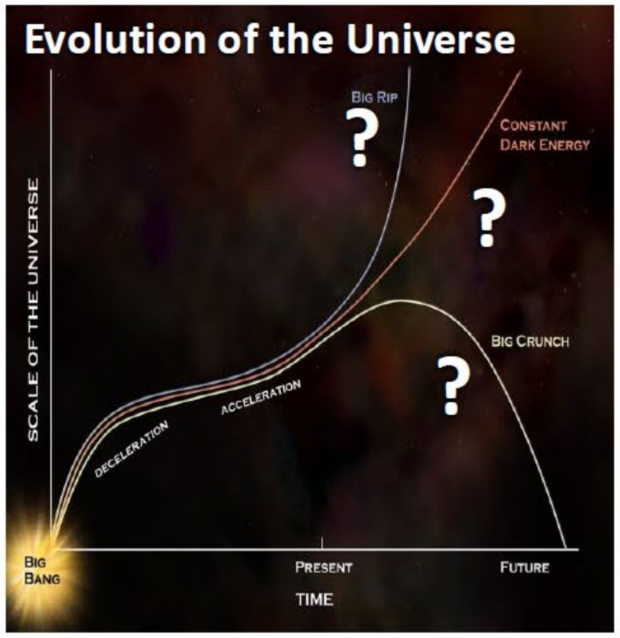
Guide star sensing interleaved with science data collection

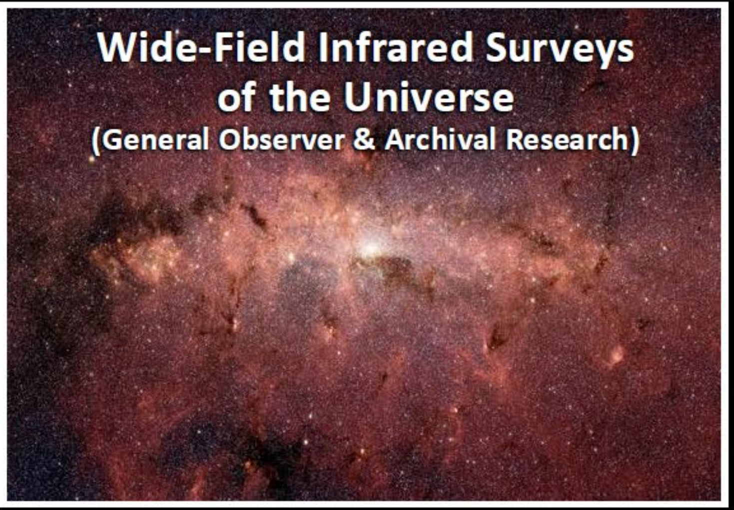
RST Wide Field Camera

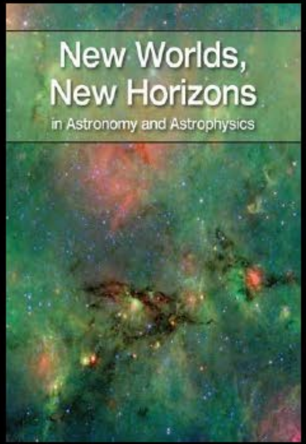


The Eagle Nebula, M16, in the constellation Serpens, containing the "Pillars of Creation," in the Milky Way Galaxy, 5,700 light-years from earth

ROMAN SCIENTIFIC OBJECTIVES







National Academy of Sciences
Astronomy & Astrophysics
Decadal Survey (2010)