DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

DESI Cosmological Results : 1st year

Dr. Axel de la Macorra Pettersson

Instituto de Física UNAM

Member of the “DESI Institutional Board”

Instituto de Física UNAM

Mexican participating Institutions

- Instituto de Física - UNAM
- Instituto de Astronomía - UNAM
- Instituto de Ciencias Físicas –UNAM
- Cinvestav
- ININ
- Universidad de Guanajuato (León)

and more than 72 International Institutions

Department of Energy United States of America · NSF · NERSC · cea From research to industry · Gobierno de España · Ministerio de Economía y Competitividad · Heising-Simons Foundation · CONAHCYT · Gordon and Betty Moore Foundation · Science & Technology Facilities Council

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.

Universe History

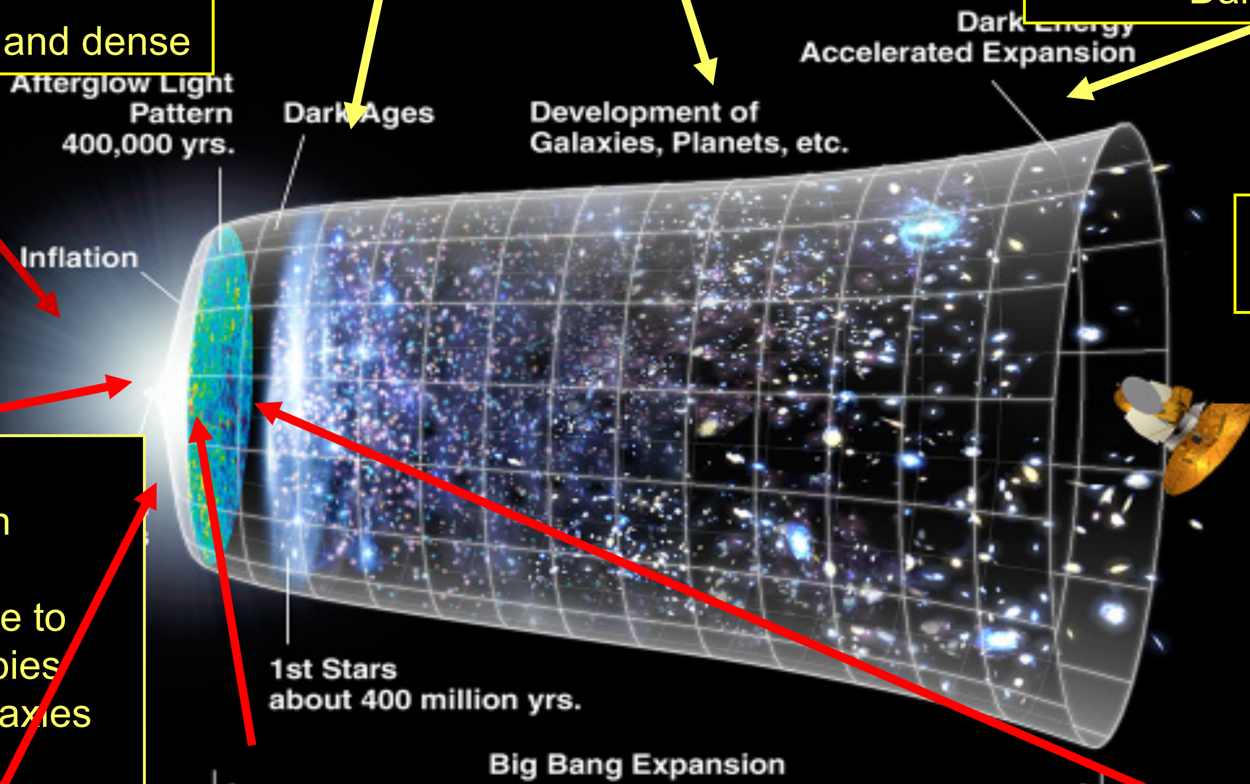
“Big Bang ”

Universe starts hot and dense

Universe grows with decelerating speed

Universe grows at an accelerating speed

Dark Energy



Today 13.8 billion years

- Inflation ~ 1 sec,
- Universe grows at an accelerating rate
- First seeds giving rise to small energy anisotoipies (forming stars and galaxies at a later stage)

Formation of light nuclei

~ 1st minute

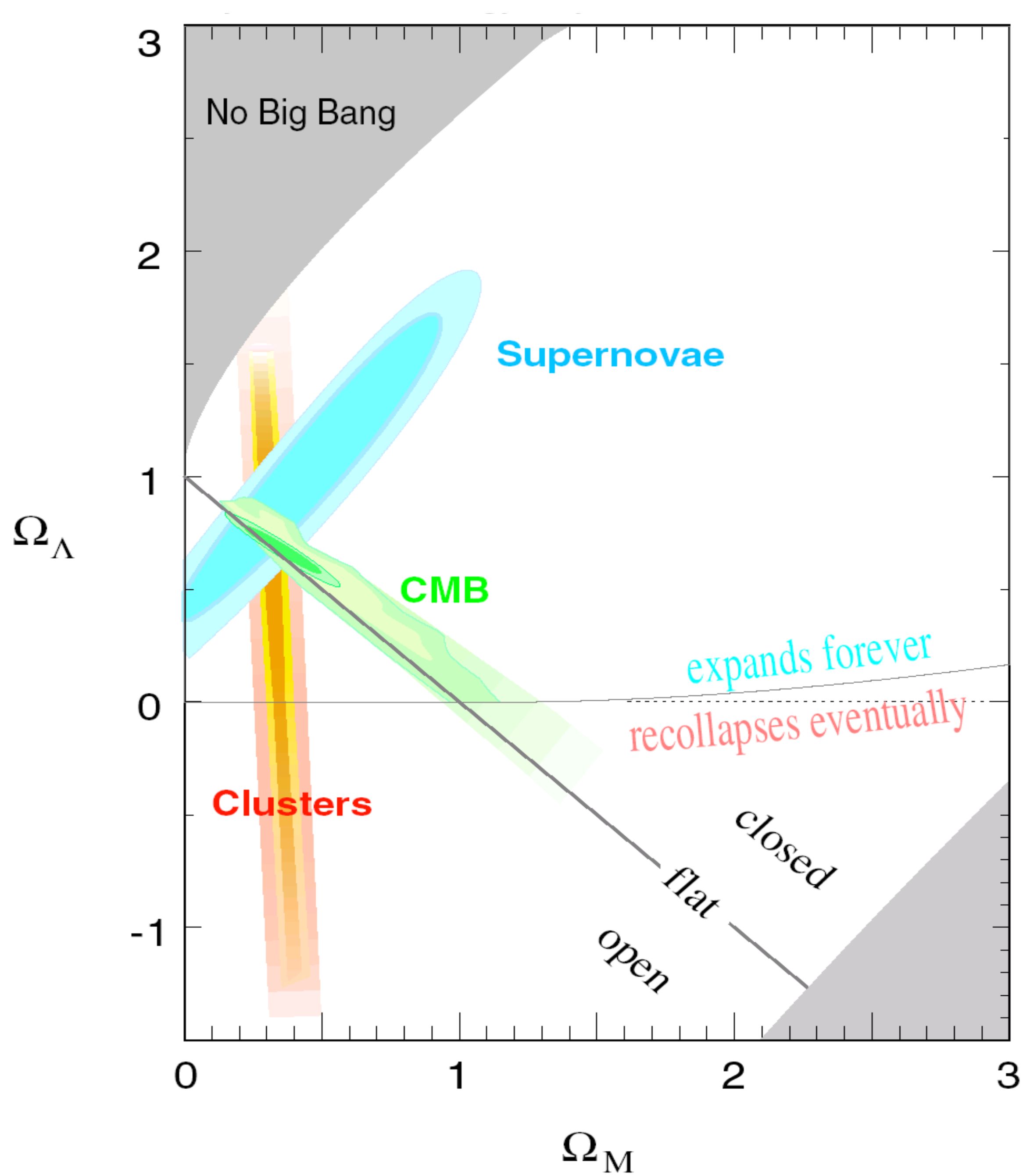
-CMB Cosmic Microwave Background oldest radiation we receive (380,000 years old)

- Atoms form: Oldest light we receive

- Inflation seeds imprinted in CMB

Fisrt stars

200 million years



$$\Omega_\Lambda = \frac{\rho_\Lambda}{\rho_{critical}}$$

$$\Omega_M = \frac{\rho_M}{\rho_{critical}}$$

Flat Universe if $\Omega_{Tot} = 1$

Today

$\Omega_B = 0.04$

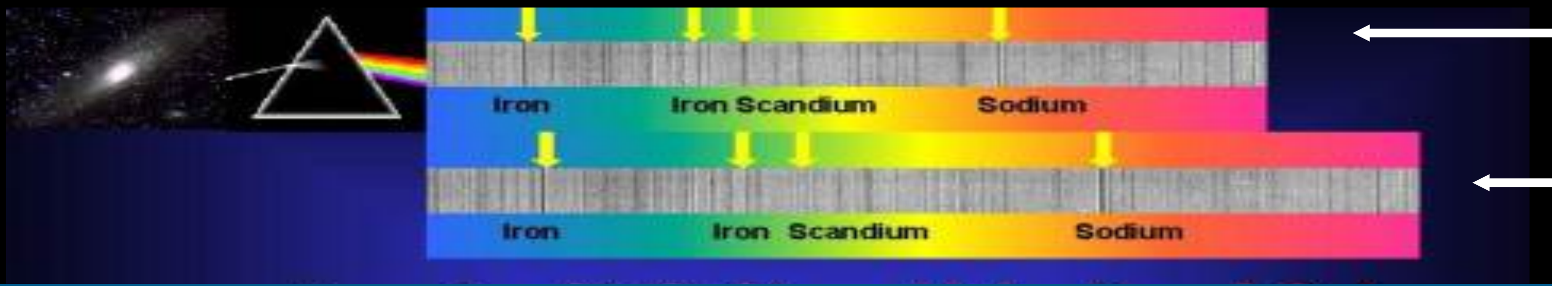
$\Omega_{DM} = 0.28$

$\Omega_{DE} = 0.68$

$\Omega_{rad} = 0.00001$

How do we know the compostion of stars, galaxies or gas ?

Every Atoms has a specific spectra



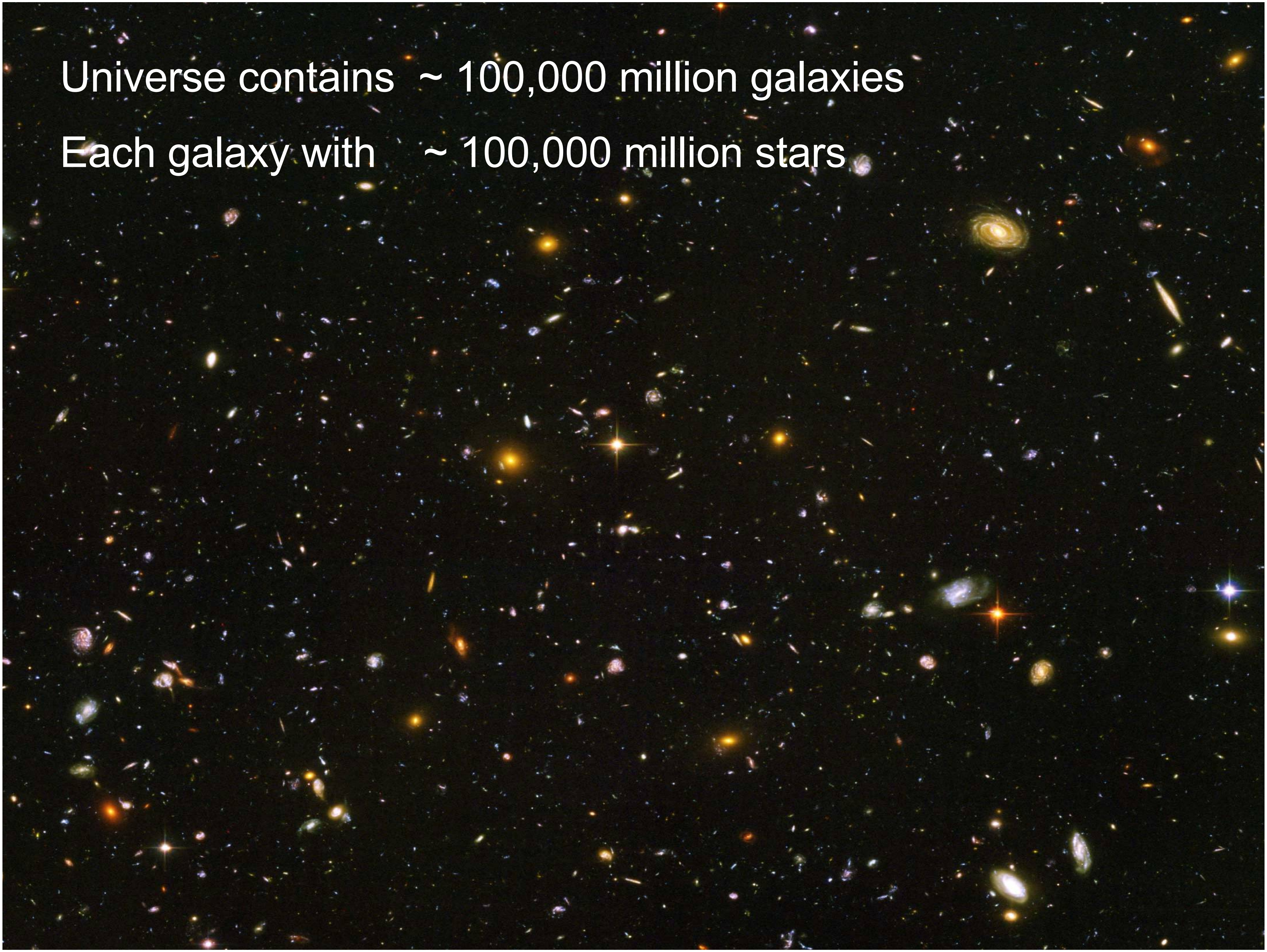
Still

In motion relative to us

- Spectra of athoms are displaced due to the relative velocity between the emitting object and us
- Measuring the wave lenght displacement we obtain the relative velocity given by the redshift z

$$\lambda o / \lambda i = 1 + z$$

- If z is positive the objects (eg galaxies) are moving away from us (this is what we see)
- The expansion rate decreases with time due to gravity
- Surprisingly in recent times the universe is expanding in an accelerating way implying the existence of Dark Energy


Universe contains ~ 100,000 million galaxies
Each galaxy with ~ 100,000 million stars


Two galaxies merging

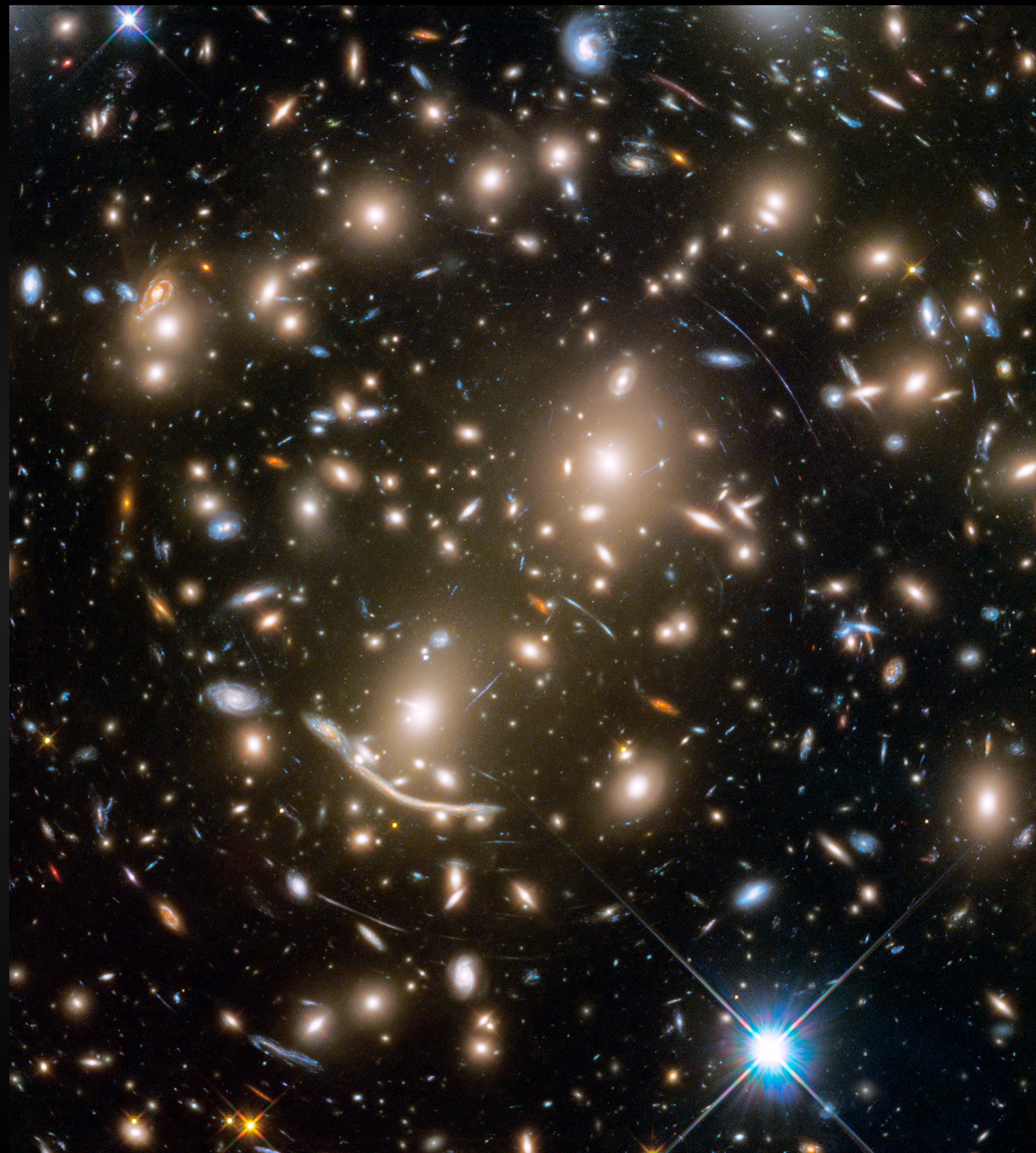
Dark Matter

Image Abell 370 Cluster from Hubble Telesocpe

We notice strange elongated bows.

Light from far away Abell 370 Cluster is deformed in its path to us by non-visible matter:

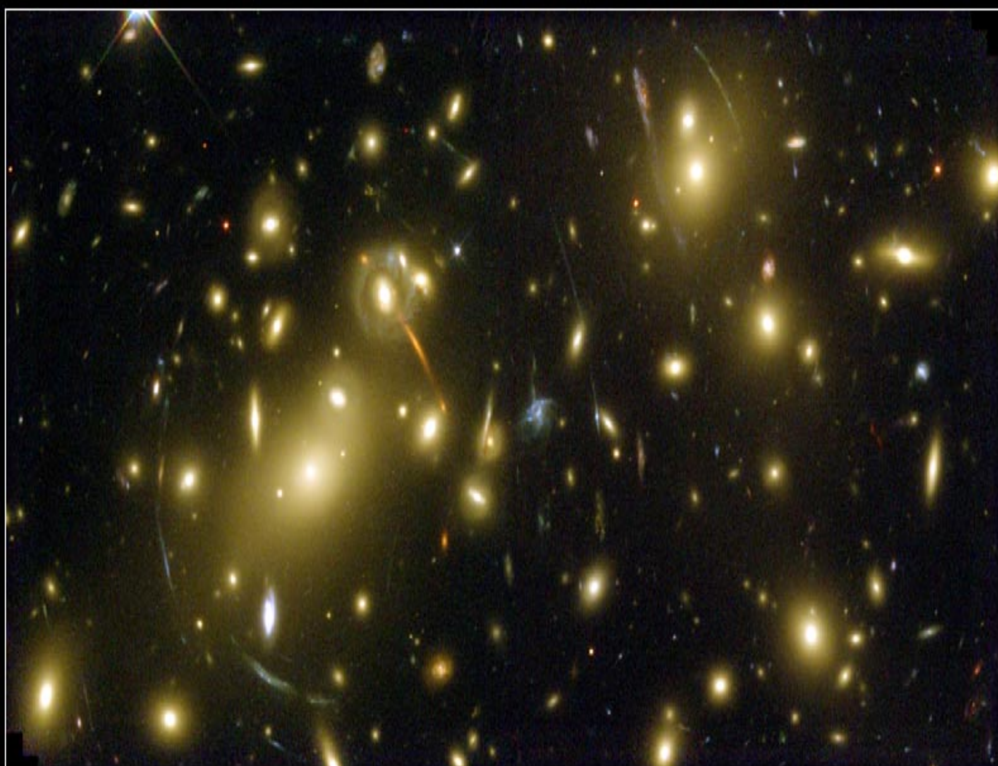
Dark Matter



Gravitacional lensing

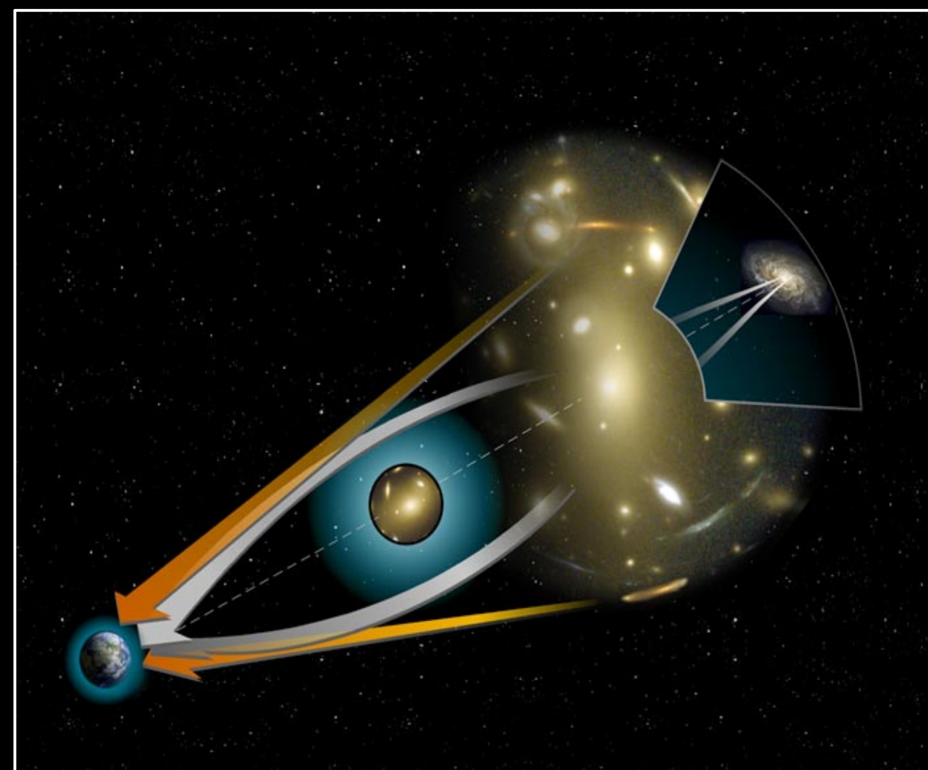
General Relativity predicts the light to bend due to gravity

- Far away galaxies appear deformed
- The light emited by these far away galaxies is bend in its path to us due the exitence of matter in its path to us



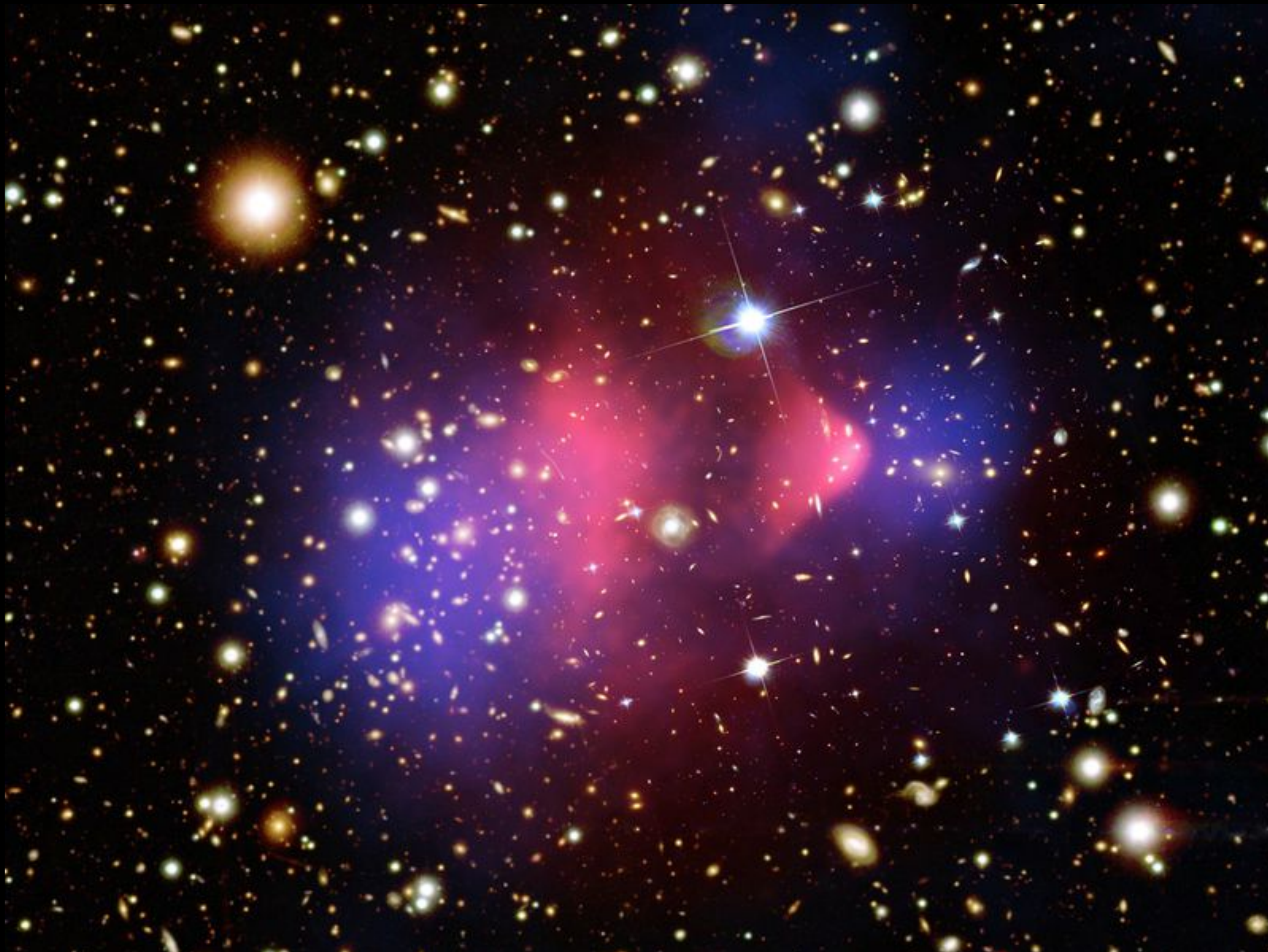
Galaxy Cluster Abell 2218 **HST** • WFPC2

NASA, A. Fruchter and the ERO Team (STScI, ST-ECF) • STScI-PRC00-08



We show an example on how light is bend due to the presence of massive object know as gravitational lensing (in this example by a glass of water) and in the universe by the existence of dark matter.

“Einstein Ring”

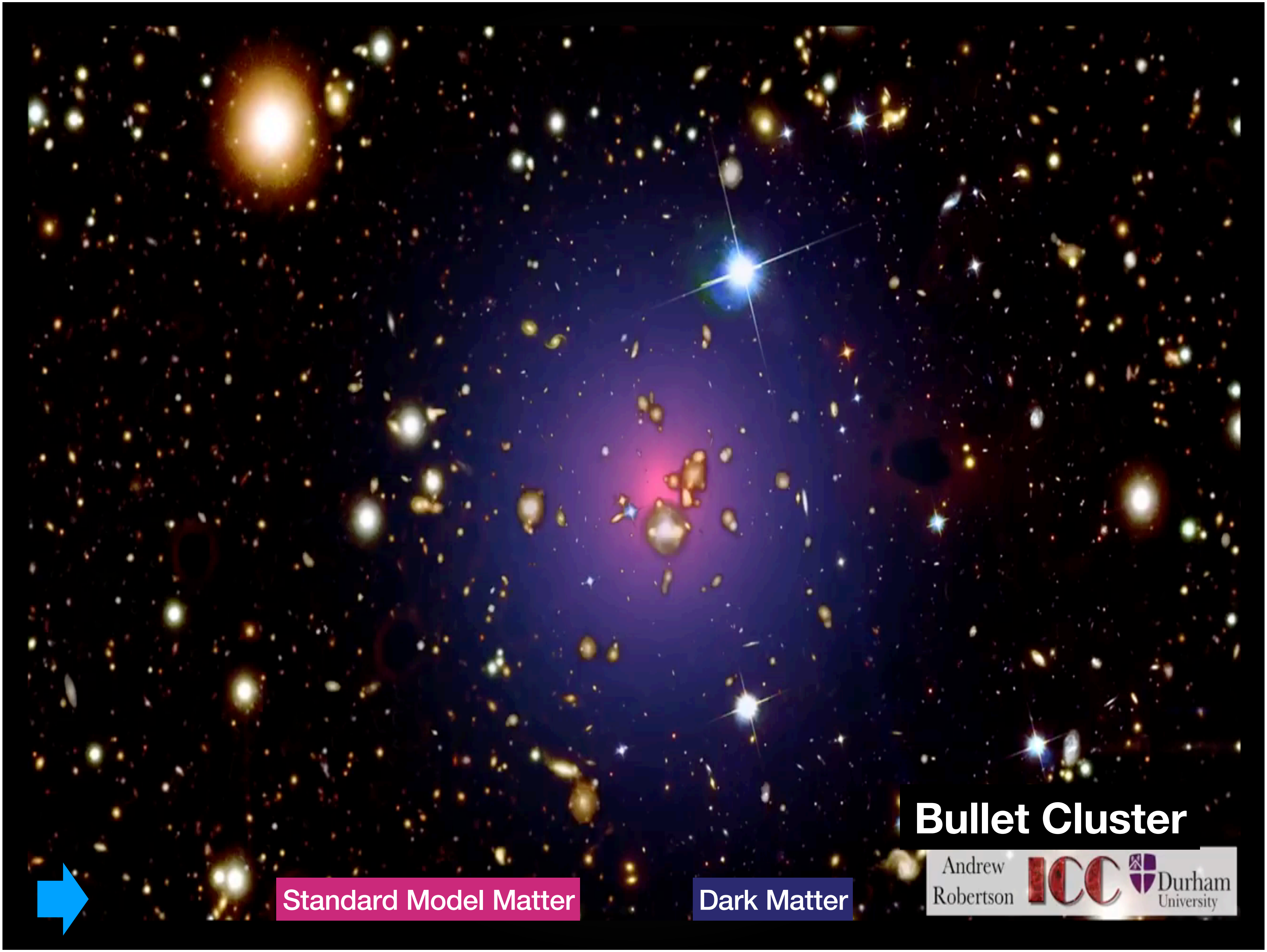


Ordinary Matter (galaxies, stars, gas)

Dark Matter

Colision of two clusters of galaxies.

- In “pink” we see light emitted by the galaxies in the clusters
- In “blue” we have distorted light from farther away galaxies passing trhough a region with large quantity of Dark Matter
- We can therefore determine the position of Dark Matter


Bullet Cluster
Andrew Robertson
ICC
Durham University
Standard Model Matter
Dark Matter

Solving the Friedmann Equation

$$H \equiv \frac{\dot{a}}{a}$$

Expansion rate

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{Kc^2}{a^2} + \frac{\Lambda}{3}$$

Density measures

In order to solve it, we also need to define the behavior of the mass/energy density $\rho(a)$ of any given mass/energy component. Recall the basic GR paradigm:

Density determines the expansion

Expansion changes the density

K= 1,0,1

Each component will lead to a different evolution in redshift

With:

matter

$$\rho_{\rm m}(t) = \rho_{\rm m,0}\, a^{-3}(t)$$

radiation

$$\rho_{\rm r}(t) = \rho_{\rm r,0}\, a^{-4}(t)$$

cosmological constant

$$\rho_{\rm v}(t) = \rho_{\rm v} = \text{const.}$$

What is Dominant When?

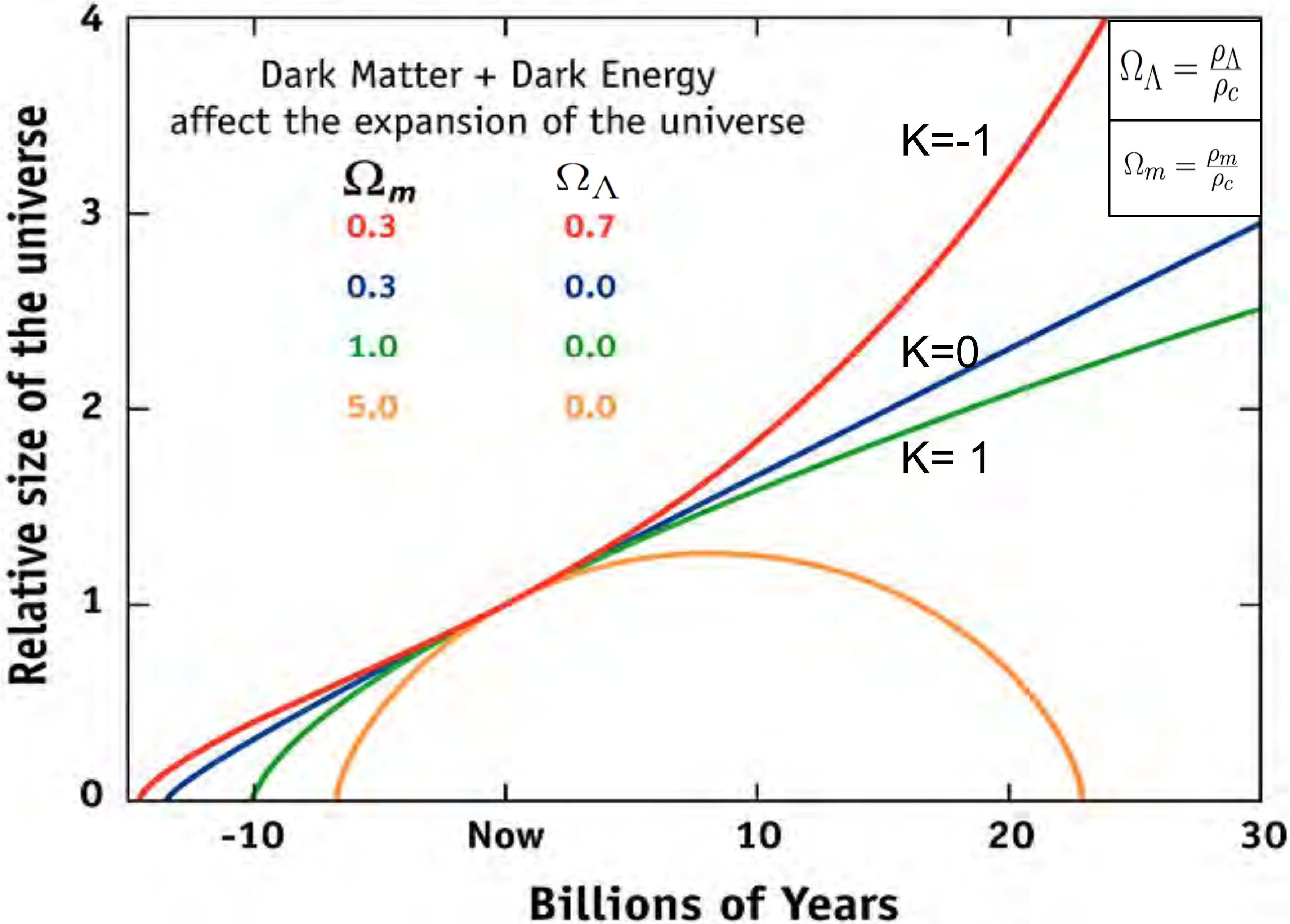
Matter dominated ($w = 0$): $\rho \sim a^{-3}$
Radiation dominated ($w = 1/3$): $\rho \sim a^{-4}$
Dark energy ($w \sim -1$): $\rho \sim constant$

- Radiation density decreases the fastest with time
  - Must increase fastest on going back in time
  - Radiation must dominate early in the Universe
- Dark energy with $w \sim -1$ dominates last; it is the dominant component now, and in the (infinite?) future

Radiation domination → Matter domination → Dark energy domination

Note that w can be a function of time e.g. dynamical Dark Energy

Examples of Models



How can we measure cosmological distances?

Baryon Accoustic Oscillations "BAO"

Supernovae

BAO

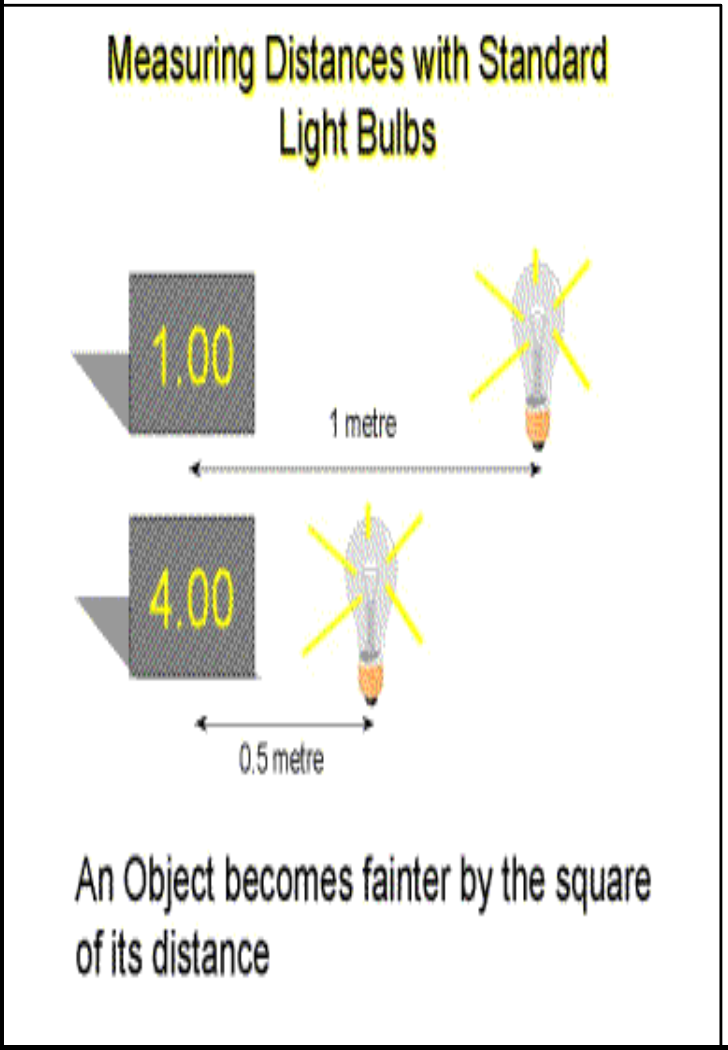
Standard candles

Same luminosity

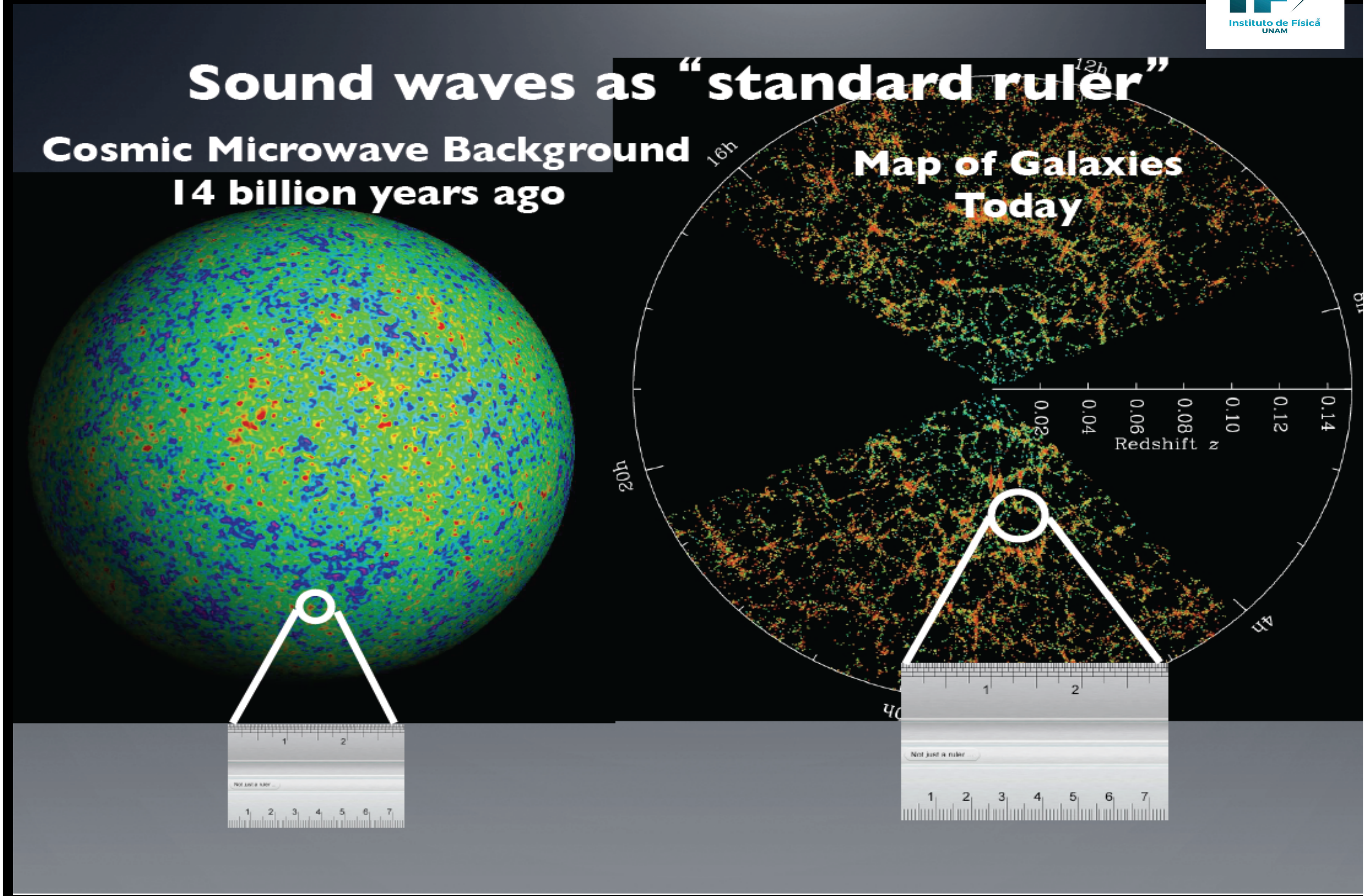
Standard rulers

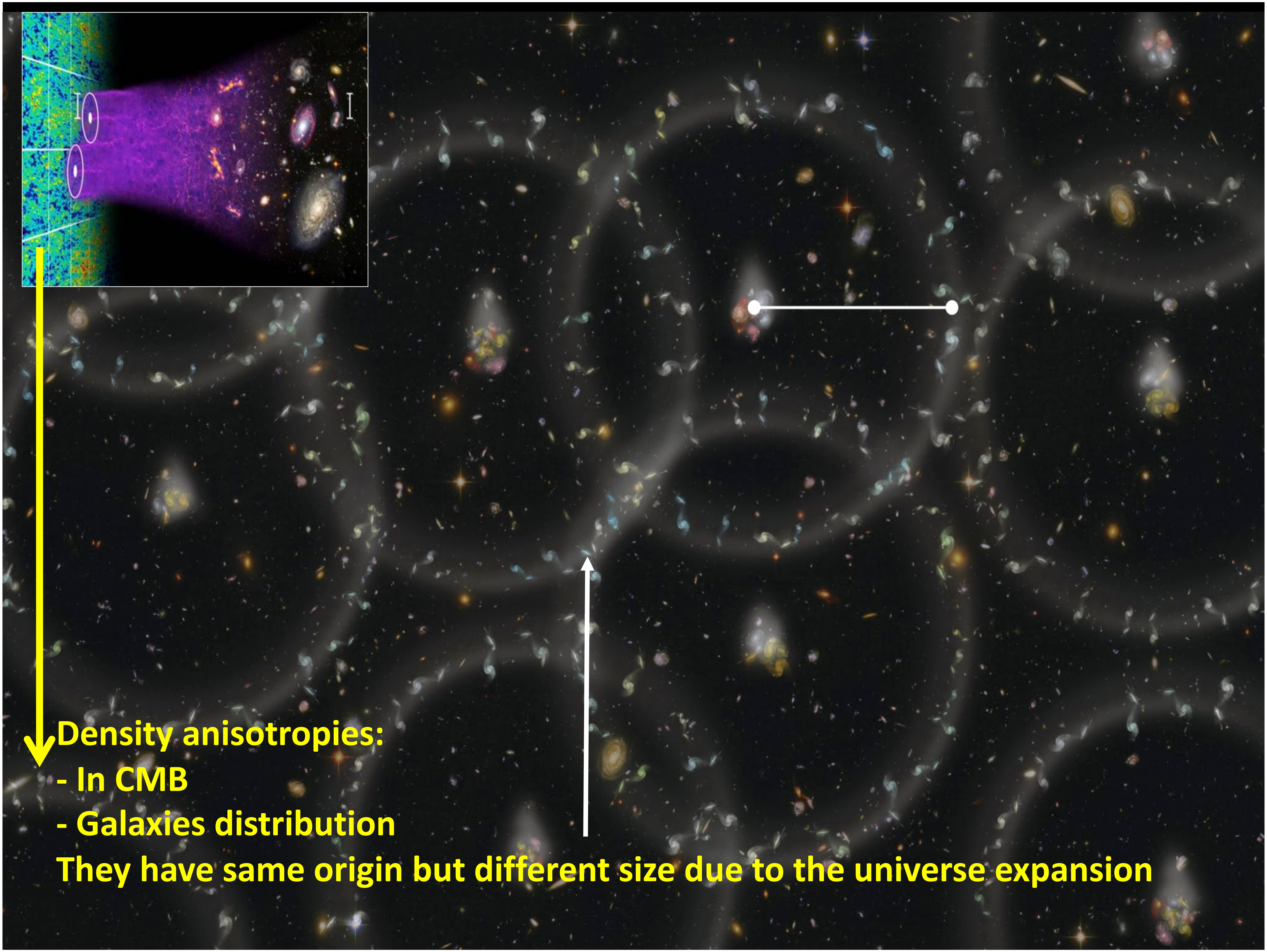
Supernovas

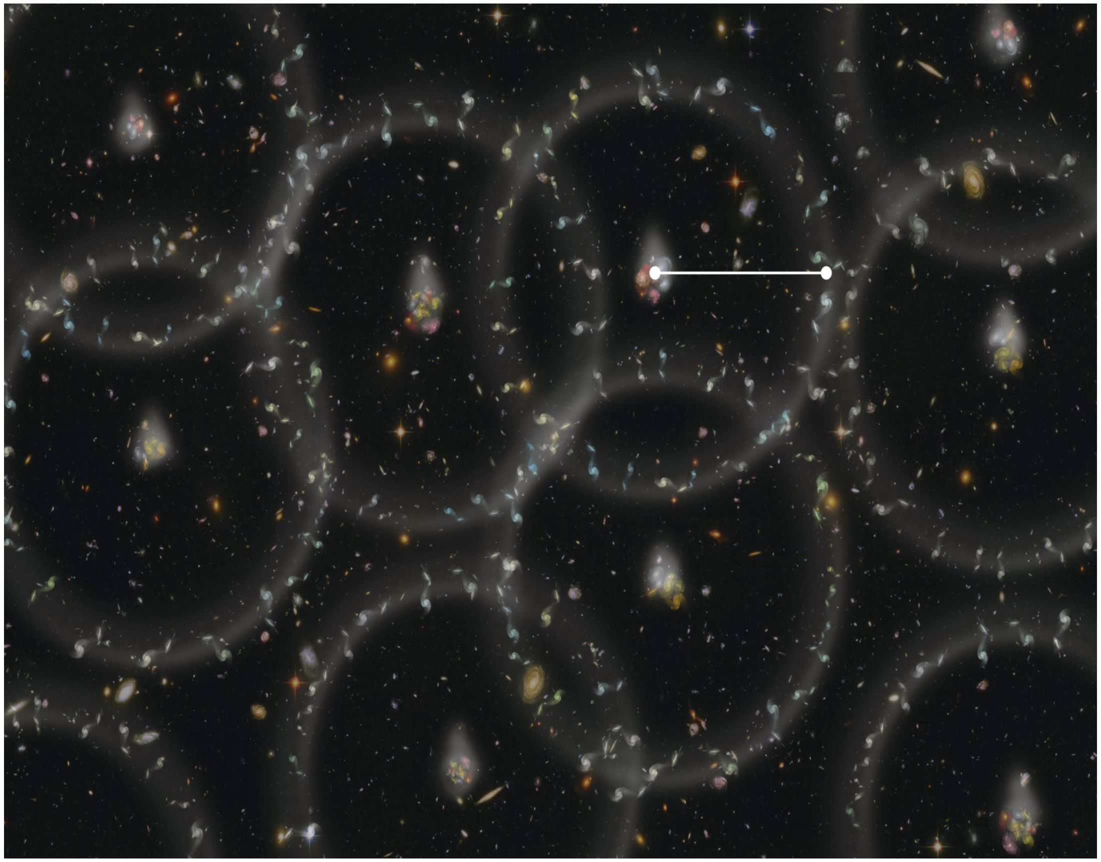
SNIa as Standard Candle



Baryon Acoustic Oscillations

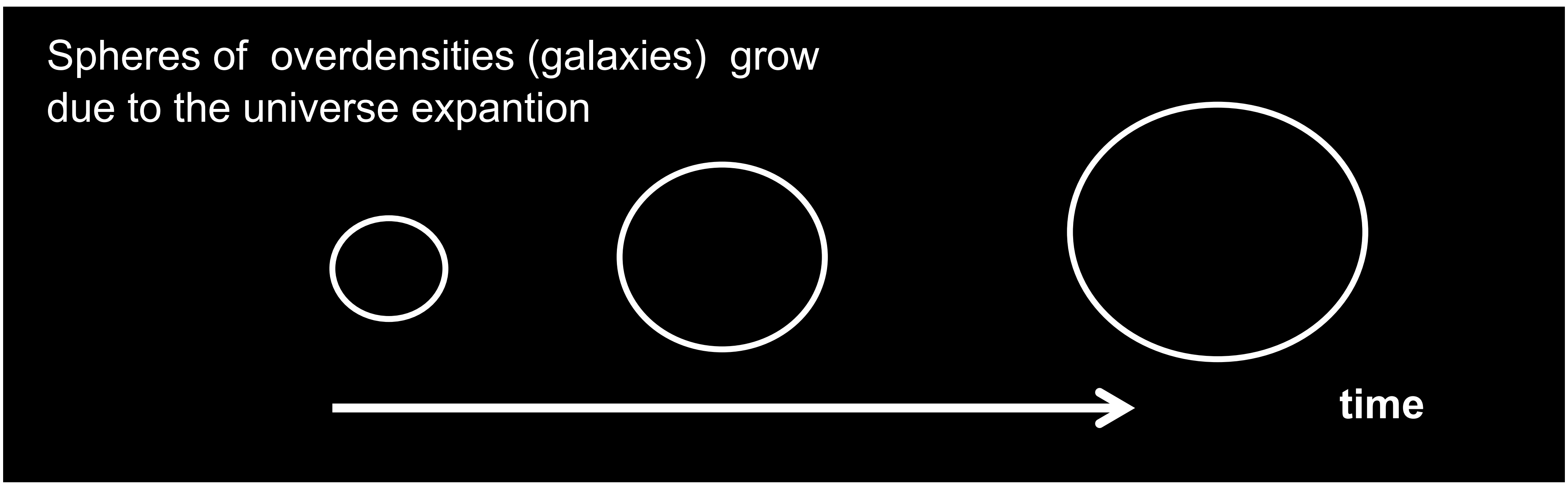



Density anisotropies:
- In CMB
- Galaxies distribution
They have same origin but different size due to the universe expansion



Galaxies Spheres

- We have matter overdensities (galaxies) at the central region and at the radius of these spheres
- These spheres grow due to the expansion of the universe
- We measure these spheres at different distances
- Obtain precise information on the universe expansion rate
- And the dynamics of Dark Energy



DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

DESI

Instituto de Física UNAM

DESI measures ~ 40 millions of galaxies and quasars

Mayall Telescope, Kit Peak, Arizona (4 mts diameter)

DESI Timeline

- Proposal: We suscribed "The BigBoss Experiment" 9 Jun 2011 (arXiv:1106.170) and later changed name from "BigBoss" to "DESI" (Dark Energy Spectrosopic Instrument)

- DESI was accepted and funded in 2014
- DESI First Light, 19 October 2019
- DESI 1st year observations May 2021- May 2022
  Obtained 12.8 millions galaxies in 242 observation nights
  (Lost nights: 72 for maintenance and 51 due to weather)

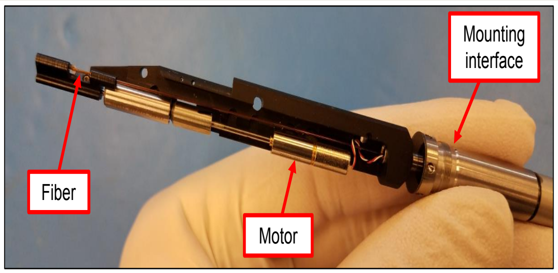
- DESI Early Data Release,June 13, 2023: 1.2 million galaxies/quasars
- DESI First Cosmological Results, April 4, 2024
- DESI 1st Year Data Release 2025

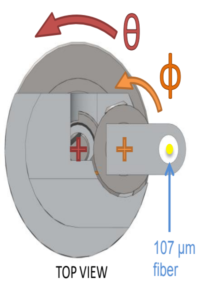
Note:

- 12 February 2024 was a spectacular night. DESI broke its own record and acquired nearly 200,000 redshifts of galaxies and quasars
  (at this rate we would have 1.4 millon observations per week !)

- **DESI has 5000 optical fibers directed by 5000 minirobots**
- **They measure the light (spectra) of 5000 galaxies at the same time**
- **Our 3-dimensional Map consists of two angles and the relative velocity**

Technical progress:
Fiber positioner mass production is proceeding well

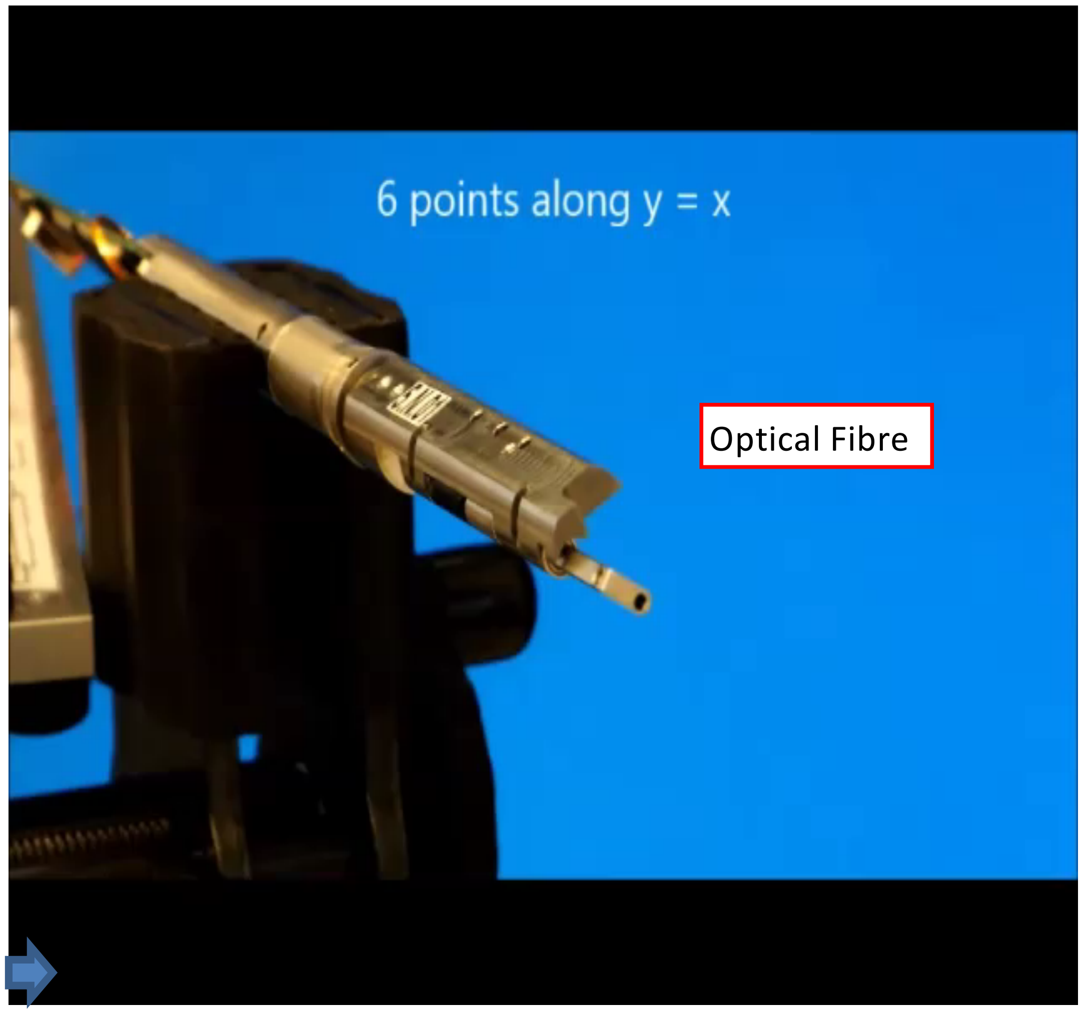




- Over 2500 built
- 98% pass precision accuracy test and infant mortality
- 98% pass inspection of physical envelope, angular alignment, and all other QC
- Our production total is within one week of baseline
- The main challenge at this point is just keeping the part kits flowing from our suppliers to UM

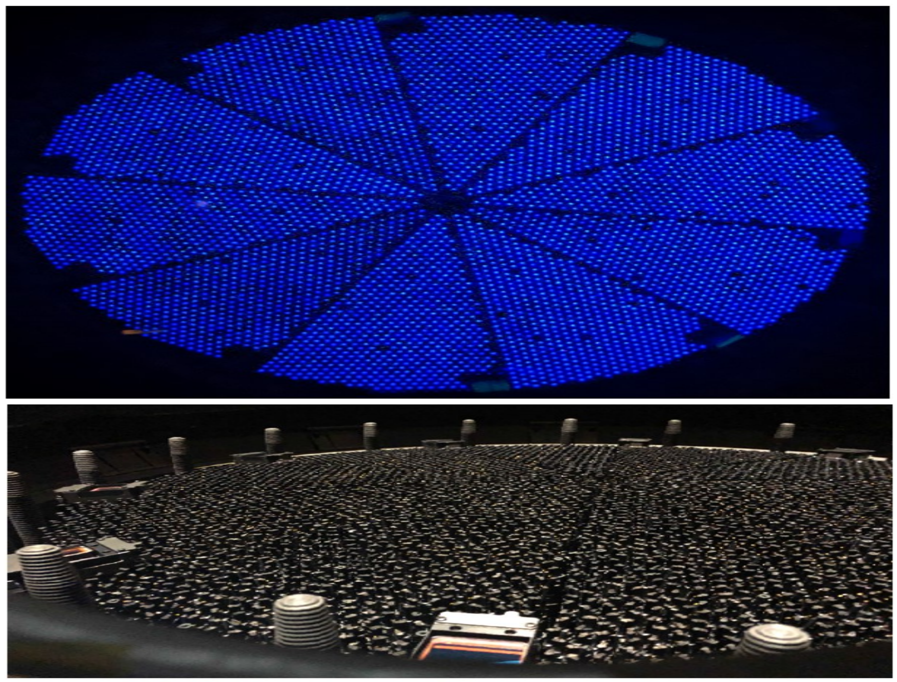
Dark Energy Spectroscopic Instrument
U.S. Department of Energy Office of Science
Lawrence Berkeley National Laboratory

J. Silber - P4
DOE Annual Status Review
Slide 15

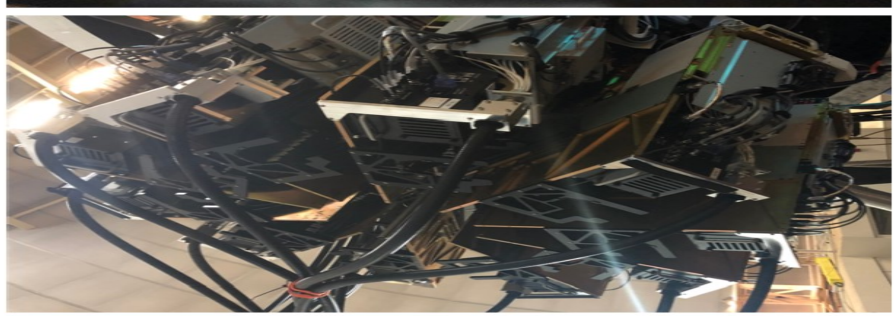


DESI Focal Plane

- 5000 robotic positioners each holding a fiber-optic cable.
- Each one is automatically positioned to fix on individual galaxies or quasars, so that the fibers can collect their light.
-The movements of these positioners must be carefully choreographed to avoid collisions.



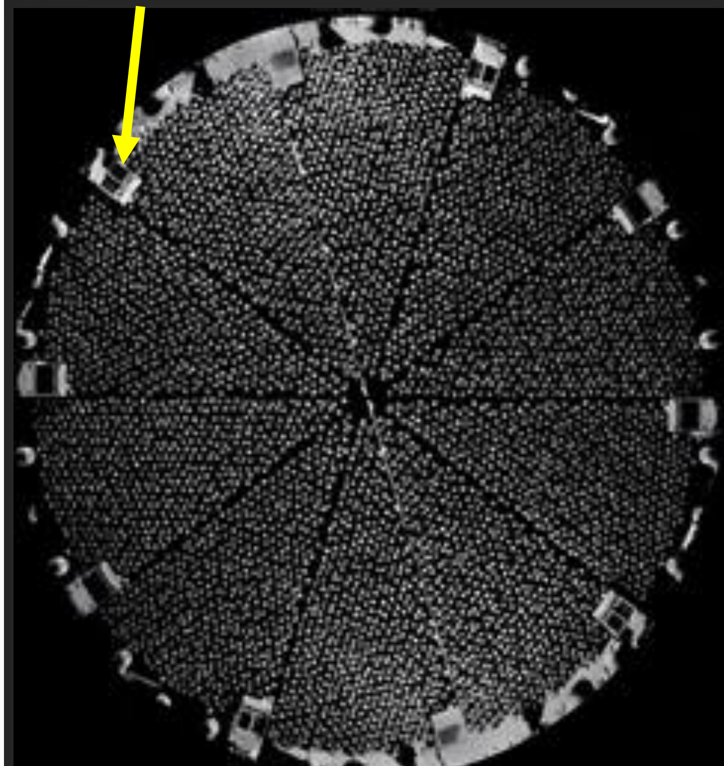
Focal Plane

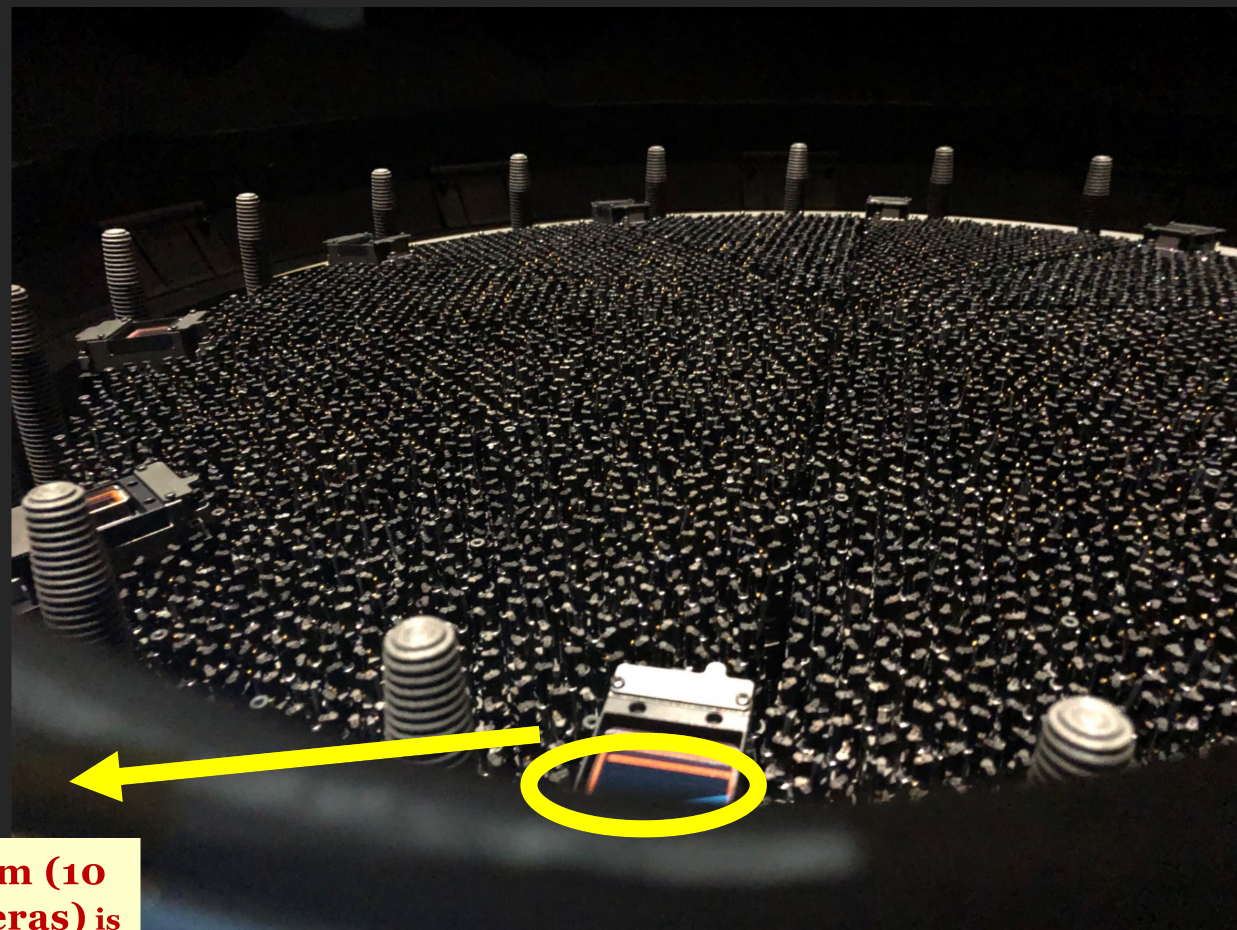


10 Spectrographs

DESI: Fibers and GFA Systems

6 Guide Cameras
r filter



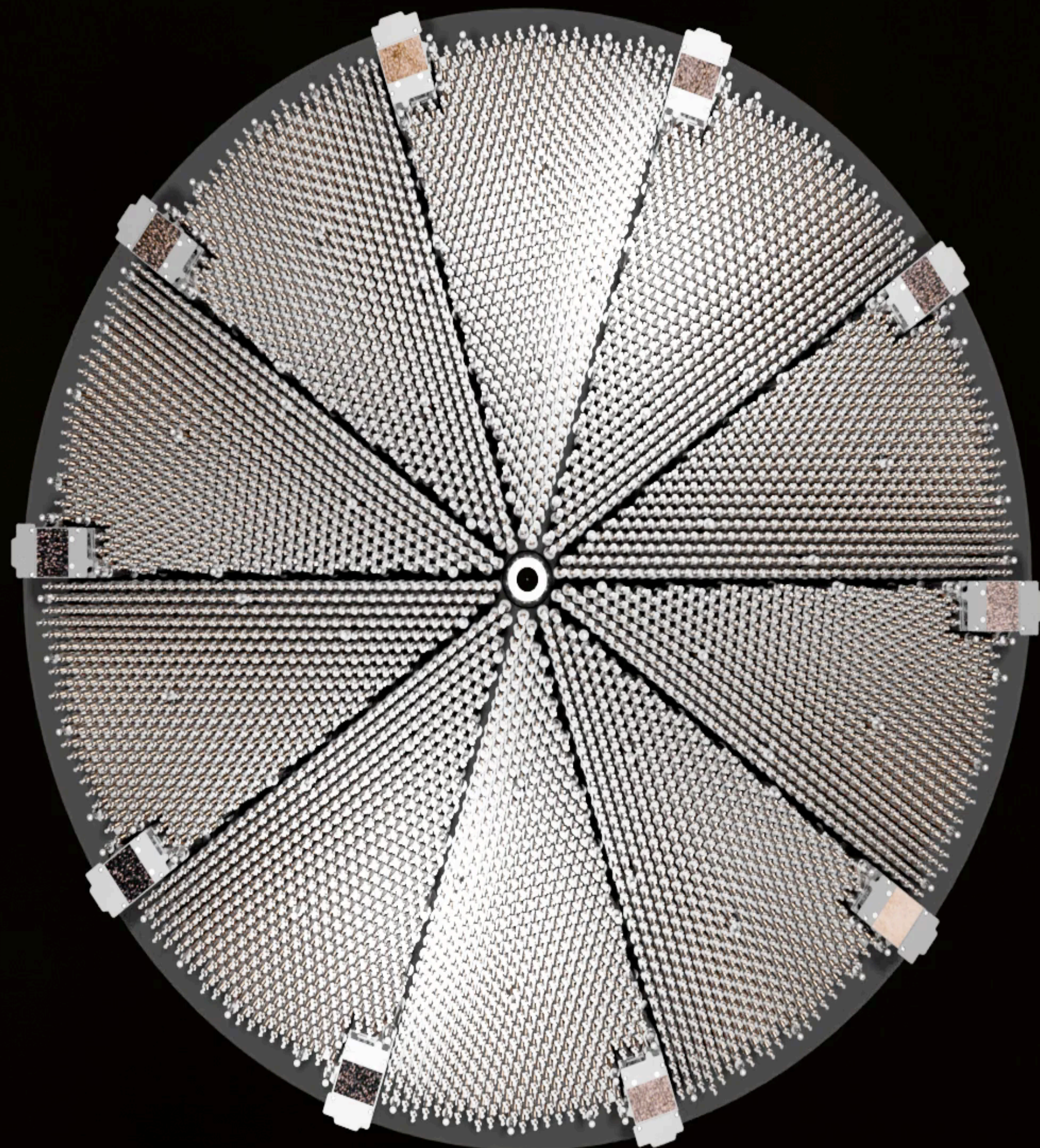


4 **Wavefront Cameras**
r filter, split thickness

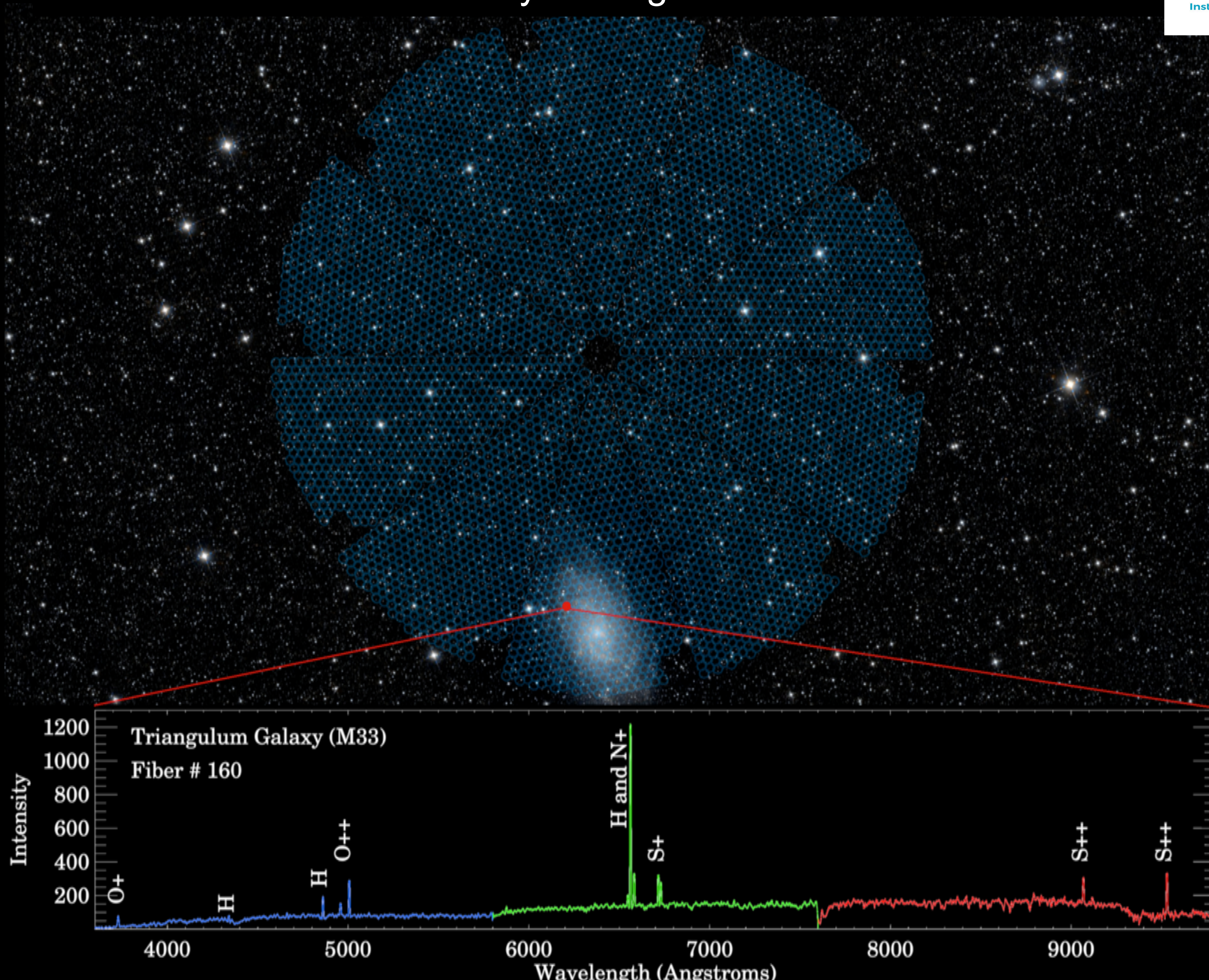
GFA System (10 mini-cameras) is the spanish (Barcelona-Madrid) contribution to the instrument

GFA=Guiding, Focus and Alignment

DESI 5000 EYES

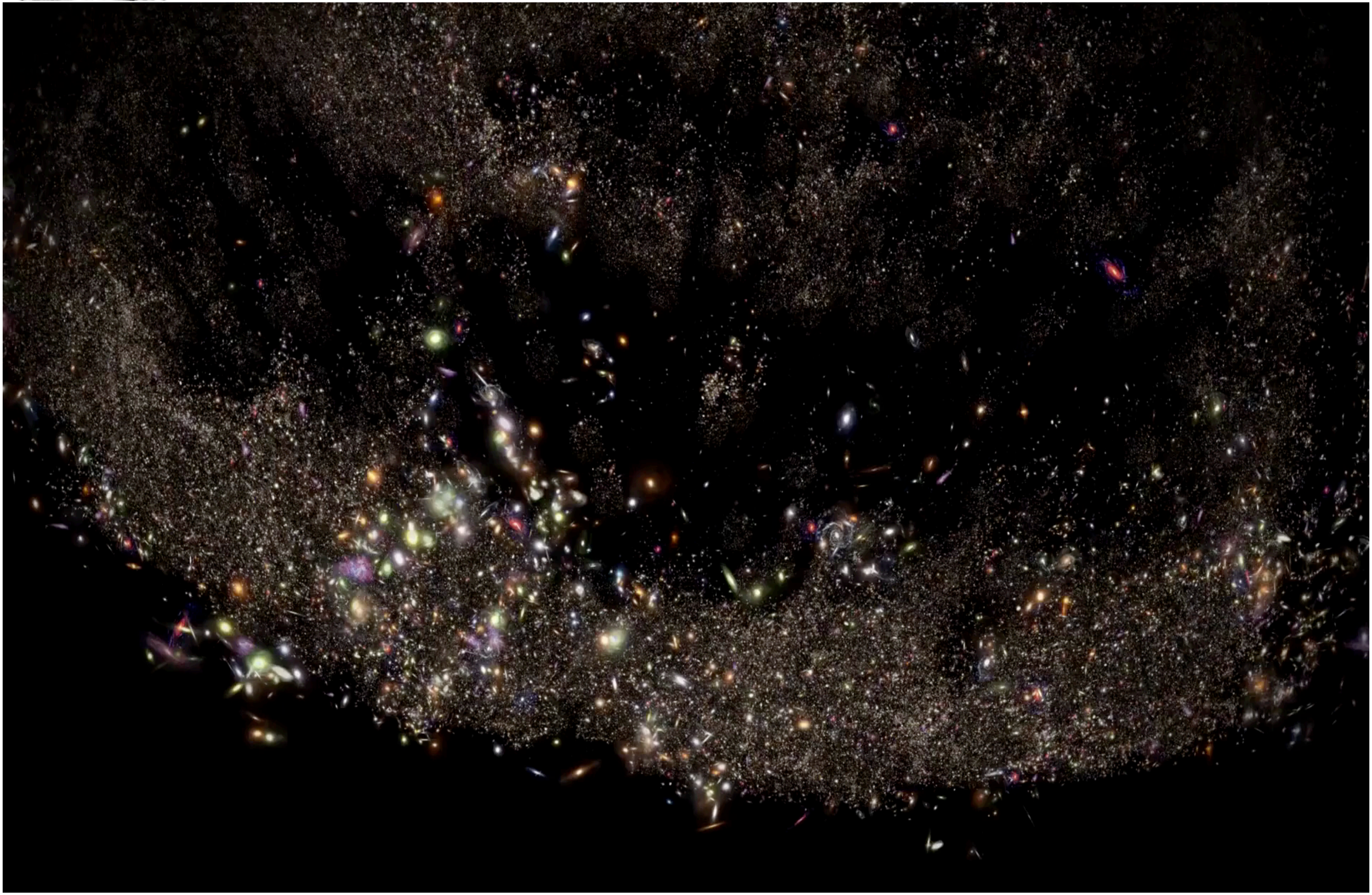


DESI First Light (22 October 2019)
Galaxy Triangulum M33

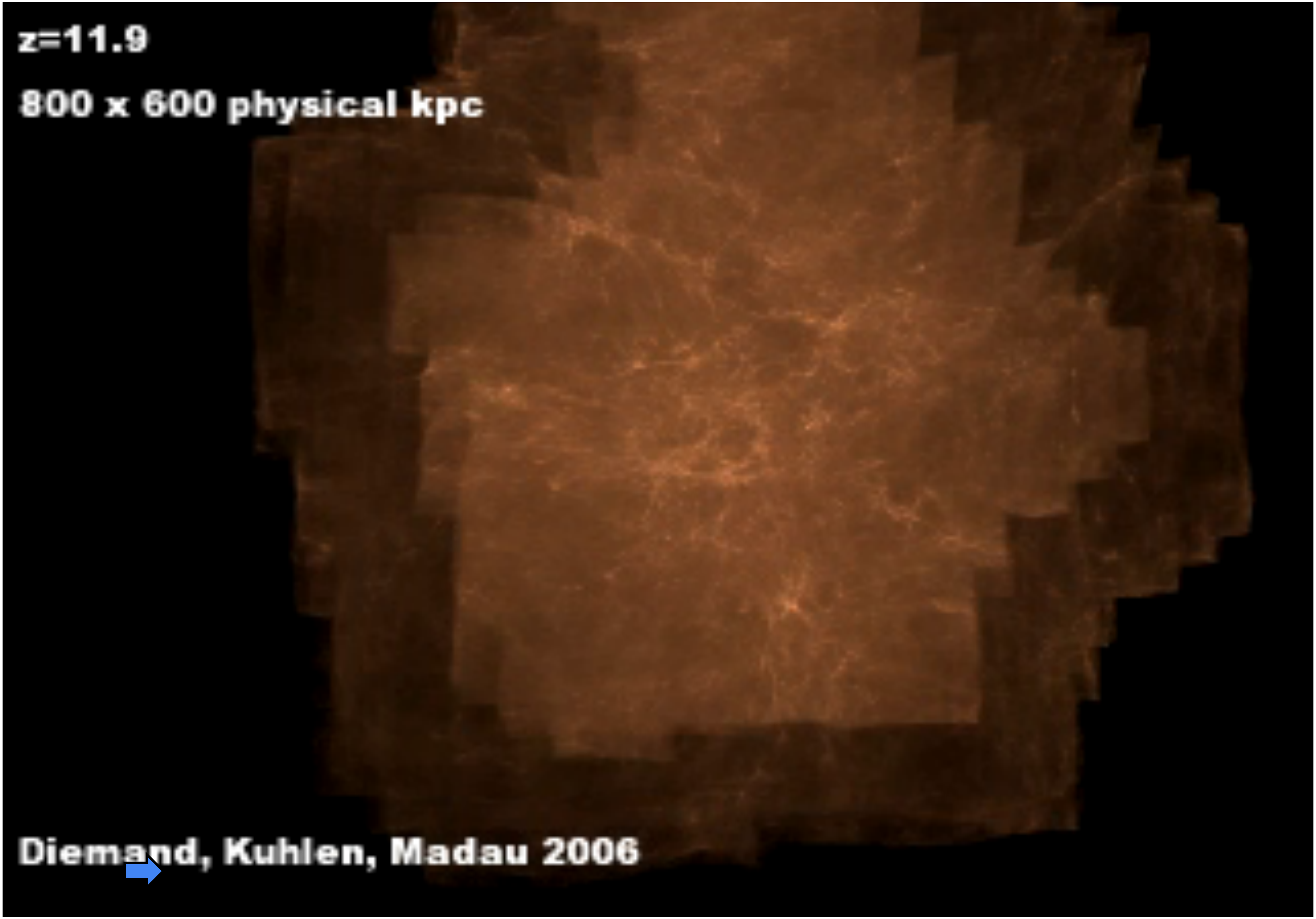


DARK ENERGY SPECTROSCOPIC INSTRUMENT

DESI Fly Through



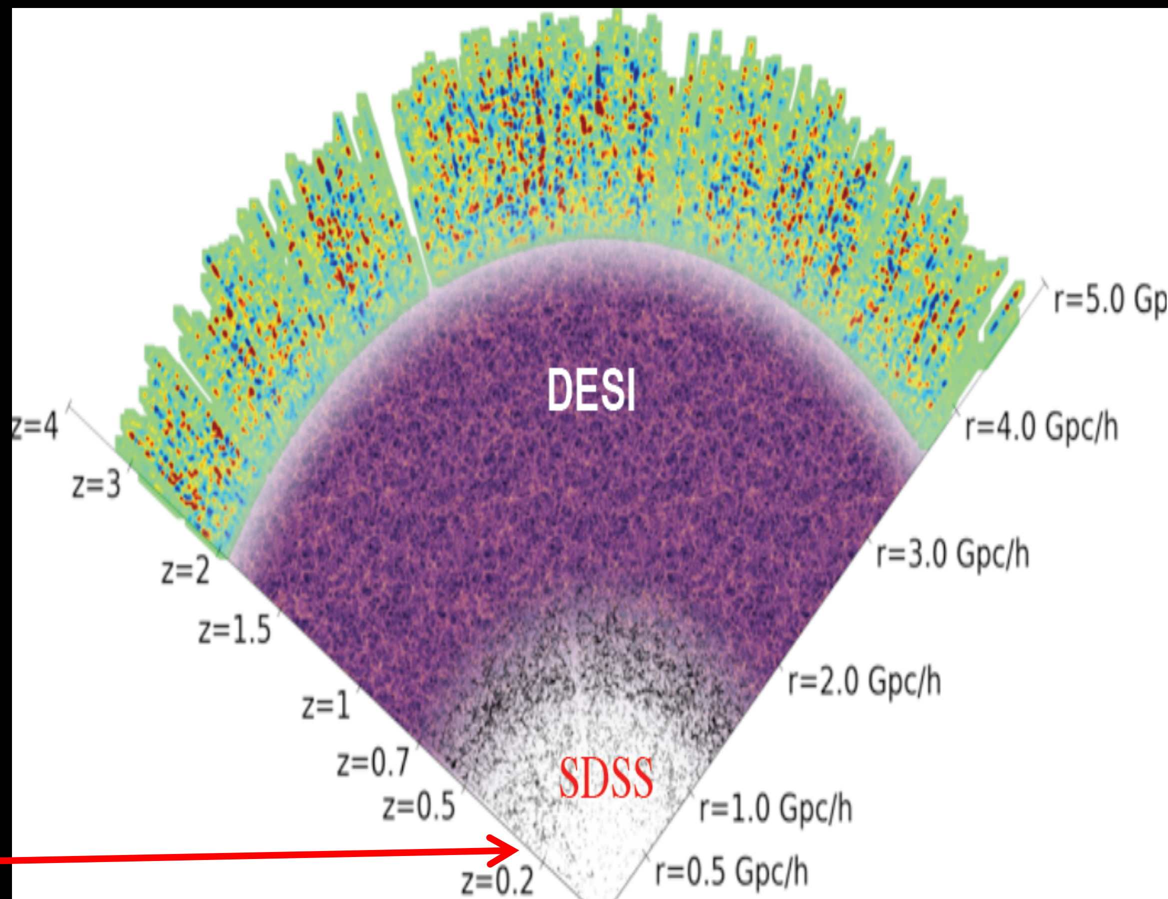
Galaxies and Clusters of Galaxies formation

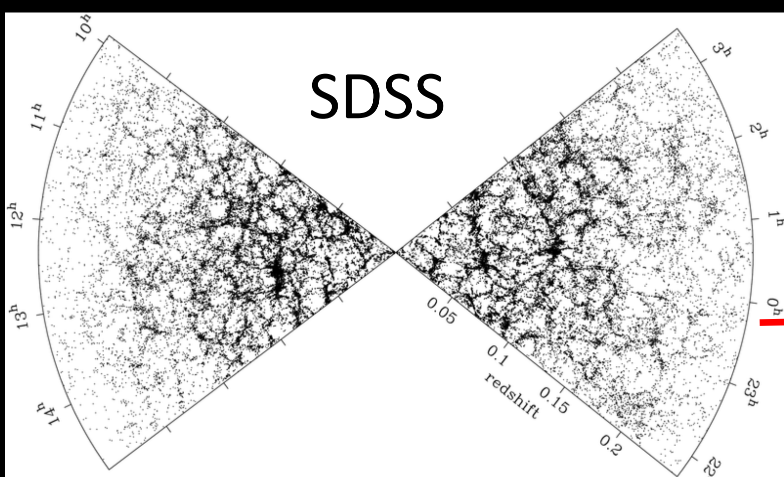


DARK ENERGY
SPECTROSCOPIC
INSTRUMENT
U.S. Department of Energy Office of Science

DESI (Dark Energy Spectroscopic Instrument)

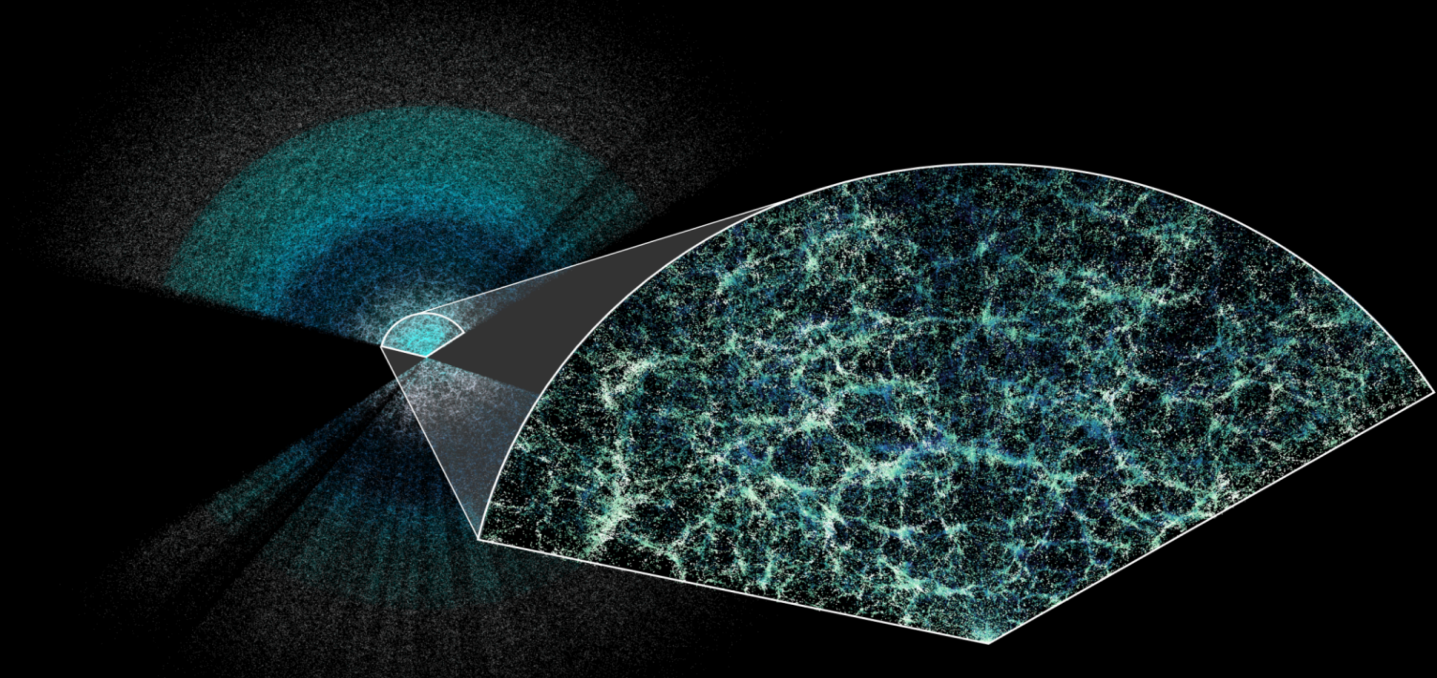
- *Largest and deepest map of the Universe*
- *Will measure over 40 millions galaxies and quasars*
- *Will span over 10 thousand million years*





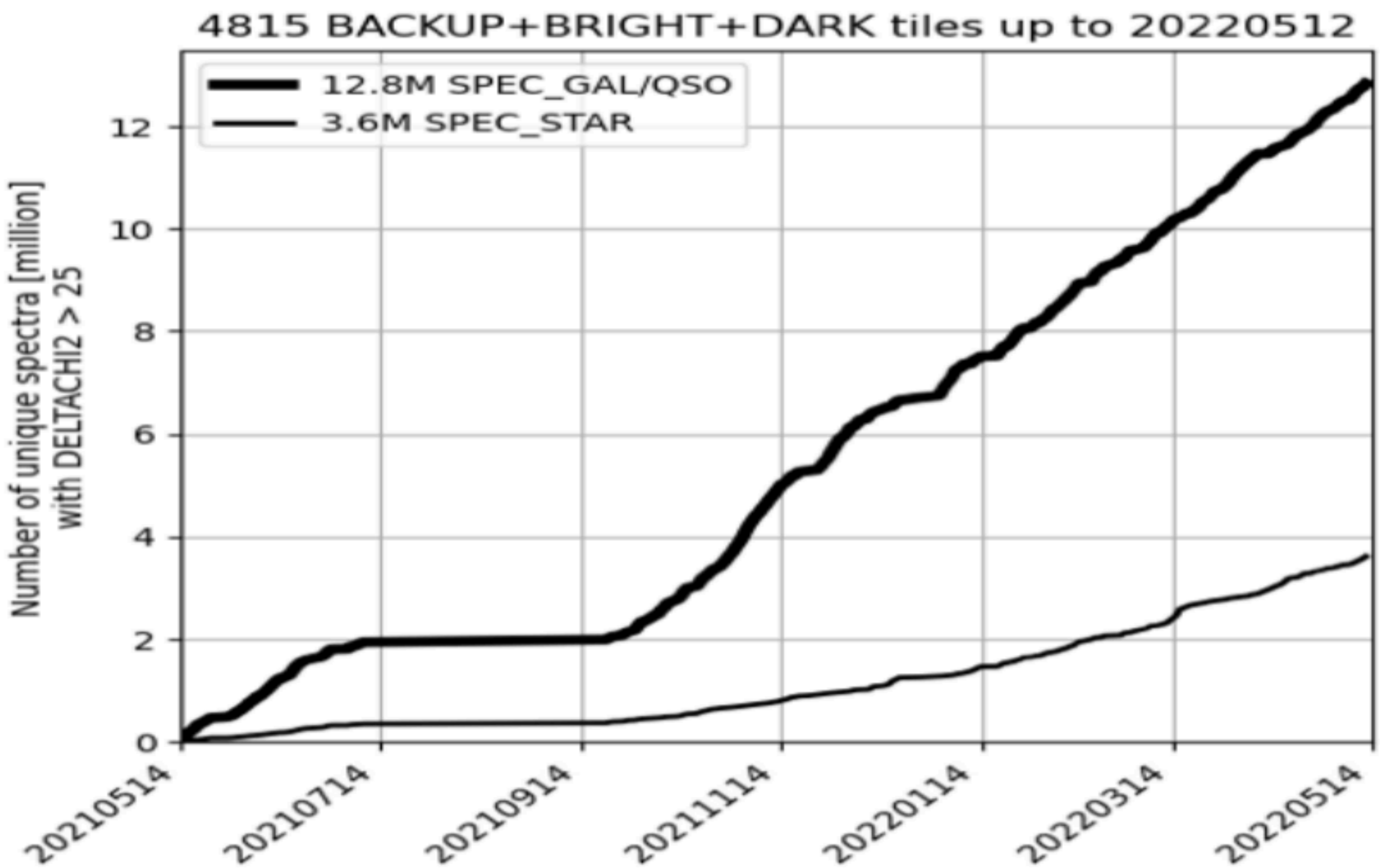
DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

- Largest 3D map
- We have know more than 6 million galaxies and quasars
- We expect to measure over 40 millions galaxies and quasars



Galaxy type	Redshift range	Bands used	Targets per deg^2	Exposures per deg^2	Good z's per deg^2	Baseline sample
LRG	0.4–1.0	r,z,$W1$	350	580	285	4.0 M
ELG	0.6–1.6	g,r,z	2400	1870	1220	17.1 M
QSO (tracers)	< 2.1	g,r,z,$W1$,$W2$	170	170	120	1.7 M
QSO (Ly-α)	> 2.1	g,r,z,$W1$,$W2$	90	250	50	0.7 M
Total in dark time			**3010**	**2870**	**1675**	**23.6 M**
BGS	0.05–0.4	r	700	700	700	9.8 M
Total in bright time			**700**	**700**	**700**	**9.8 M**

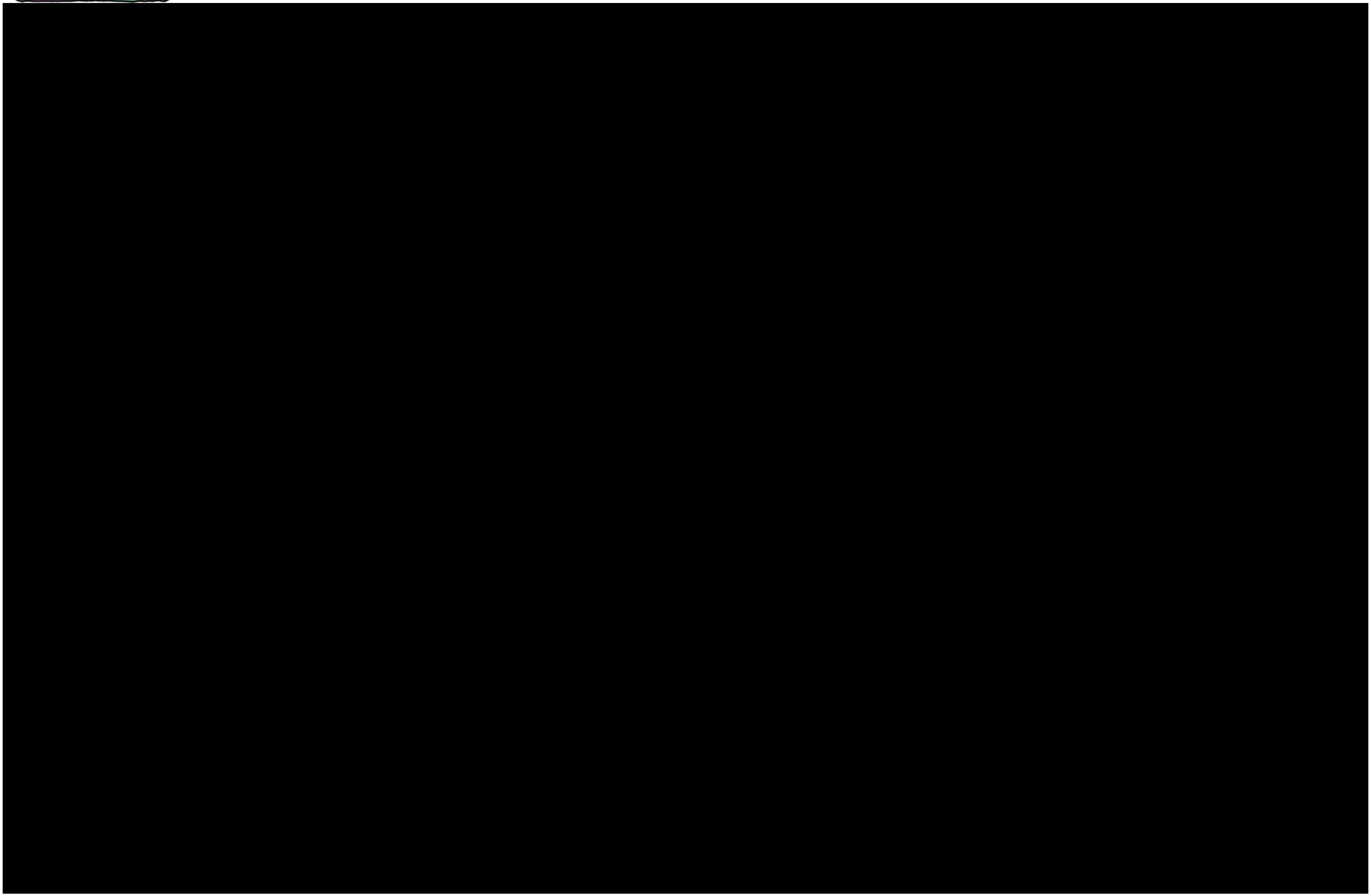
- DESI in its first year of survey operations, has dwarfed all prior redshifts surveys by mapping **12.8 million** unique galaxies and quasars.
- **Dates: May 2021 to May 2022**



The number of unique galaxies and quasars (top curve) and unique stars (bottom curve) with confidently-determined redshifts as a function of time. The first year of survey operations from May 14, 2021, through May 13, 2022, has delivered 12.8 million and 3.6 million such redshifts, respectively. (Anand Raichoor)

DARK ENERGY SPECTROSCOPIC INSTRUMENT

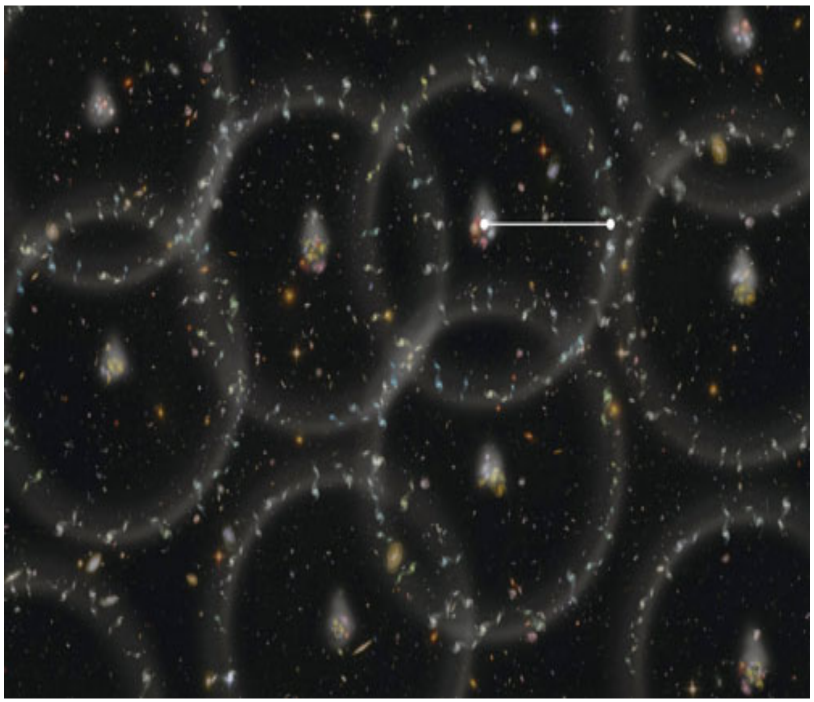
Flythrough SDSS and DESI data

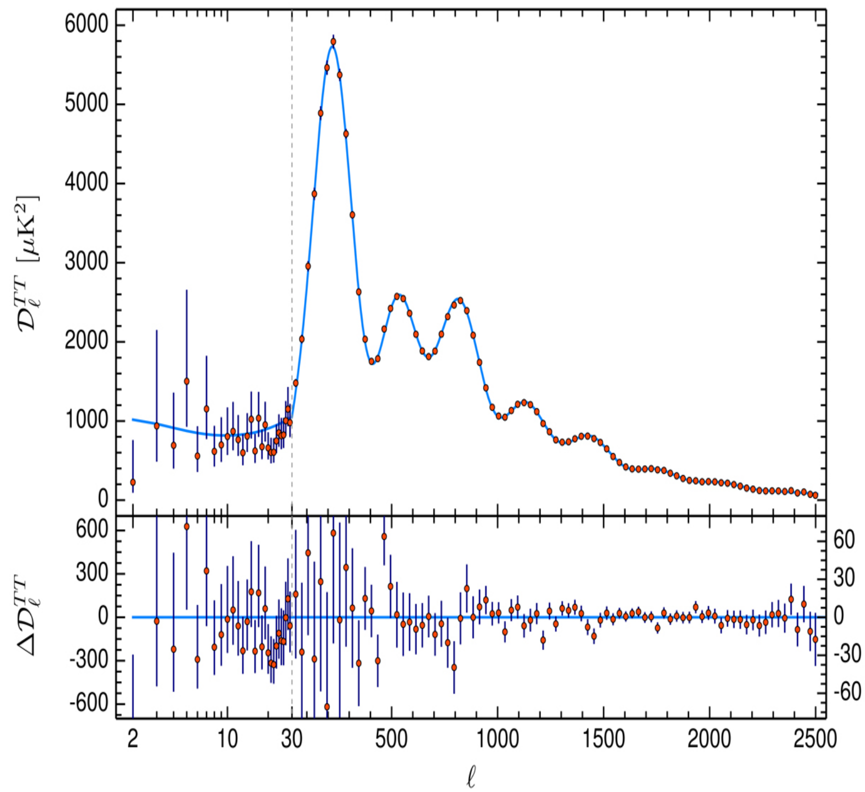


DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

The BAO standard ruler

Instituto de Física UNAM

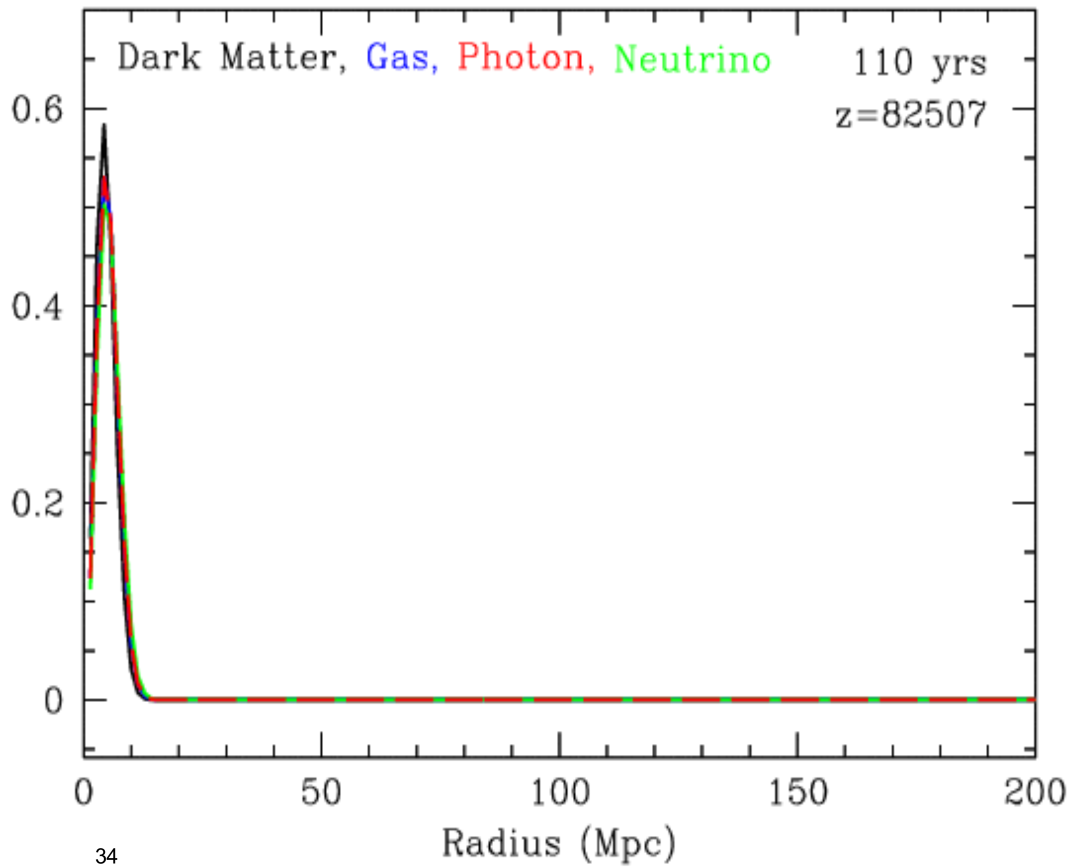


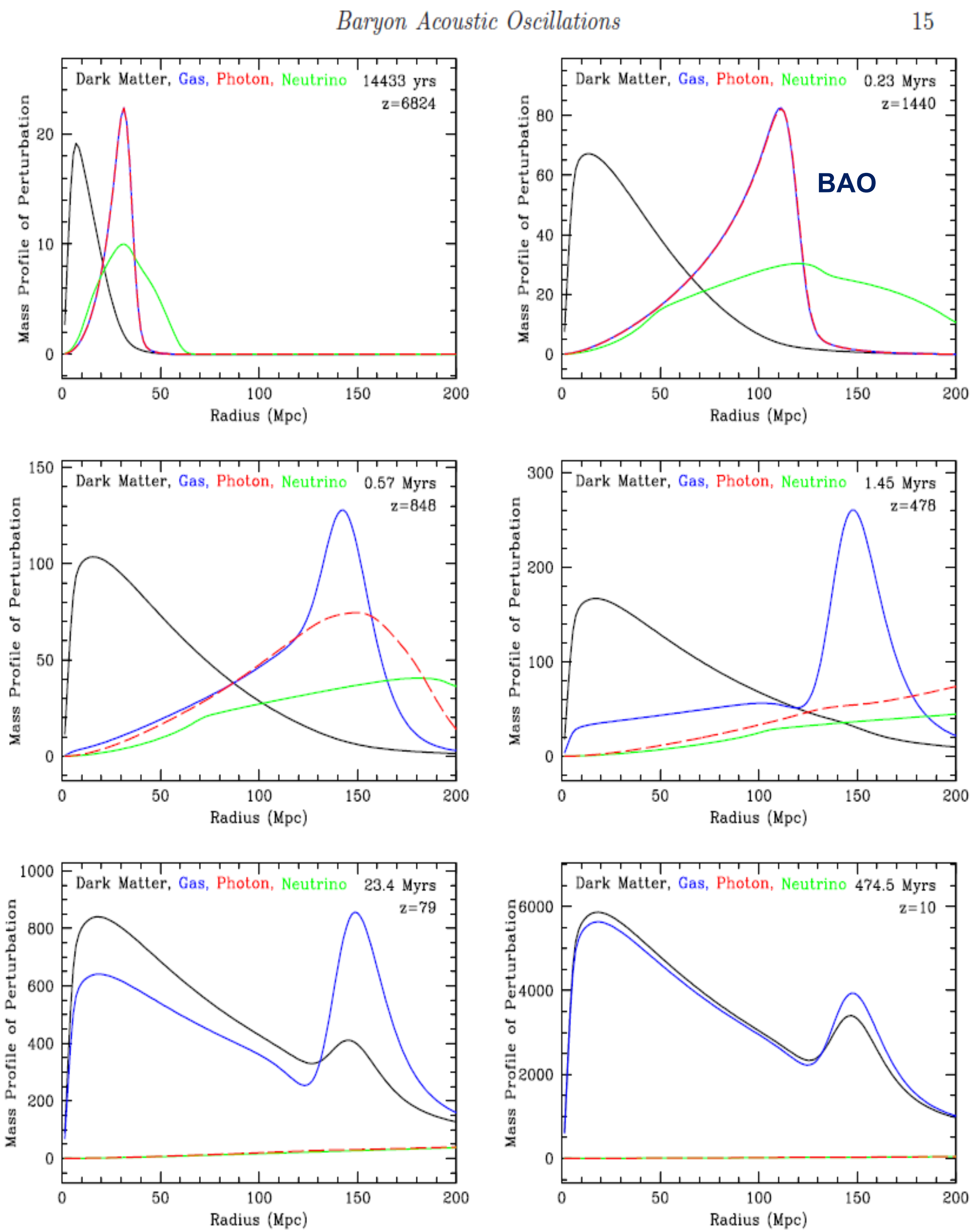


The same BAO features are also measured in the CMB!

Physics behind the Baryon Accustic Oscilations “BAO”

- Initial Fluctuations
- The universe expands and cools down, eventually forming atoms (mainly hydrogen)
- Once the energy of the photons do not longer ionize hydrogen atoms, photons decouple and stream away
- At this stage gravity prevails and forms spheres of matte with a radious given by the comovil accustic scale
- Matter is mainly distributed at the center of the spheres and at the accustic scale radius
- The radius is 150Mpc/h

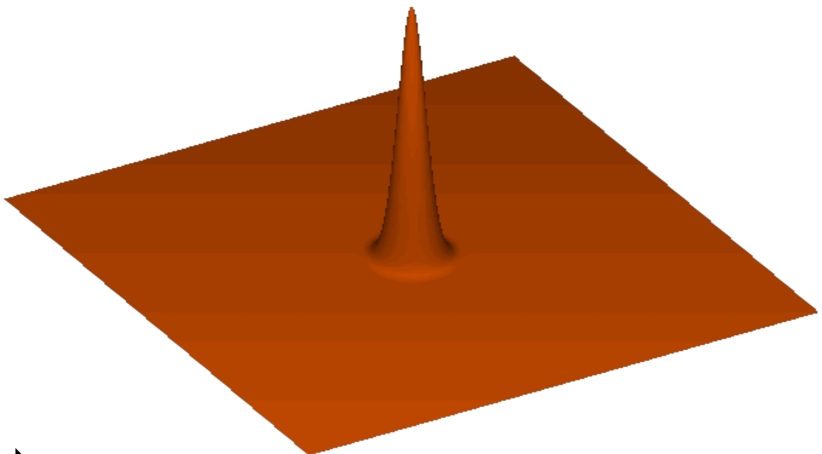




- Galaxies form at the center of the spheres and at the accustic scale radius

- Size ~ 150Mpc/h

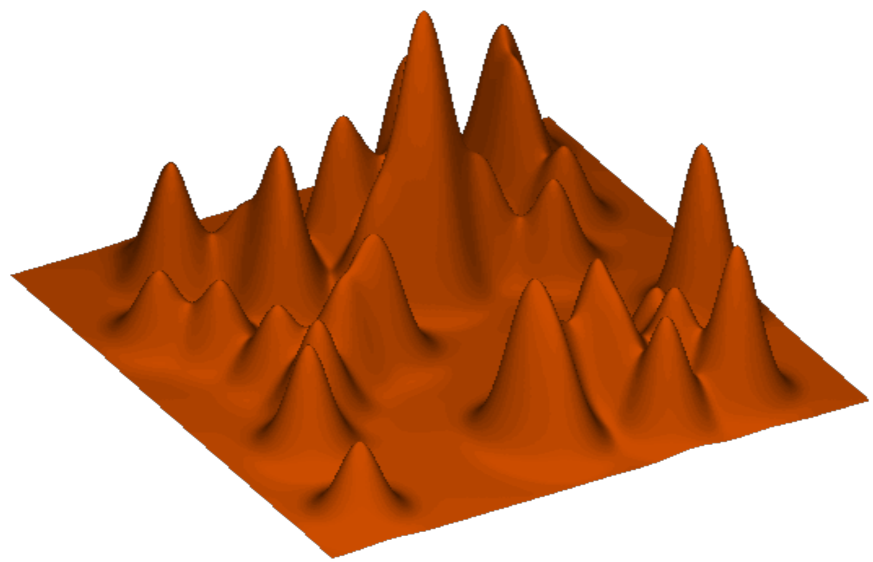
Observing BAO



- Small overdensities regions grow due to gravity
- Photon pressure inhibits this compression
- Obtain an overdensity in central region at a characteristic scale named:

  Baryon Accoustic Oscillations

- Multiple overdensities
- Statistical signal seen in
- matter distribution (excess of 1%)



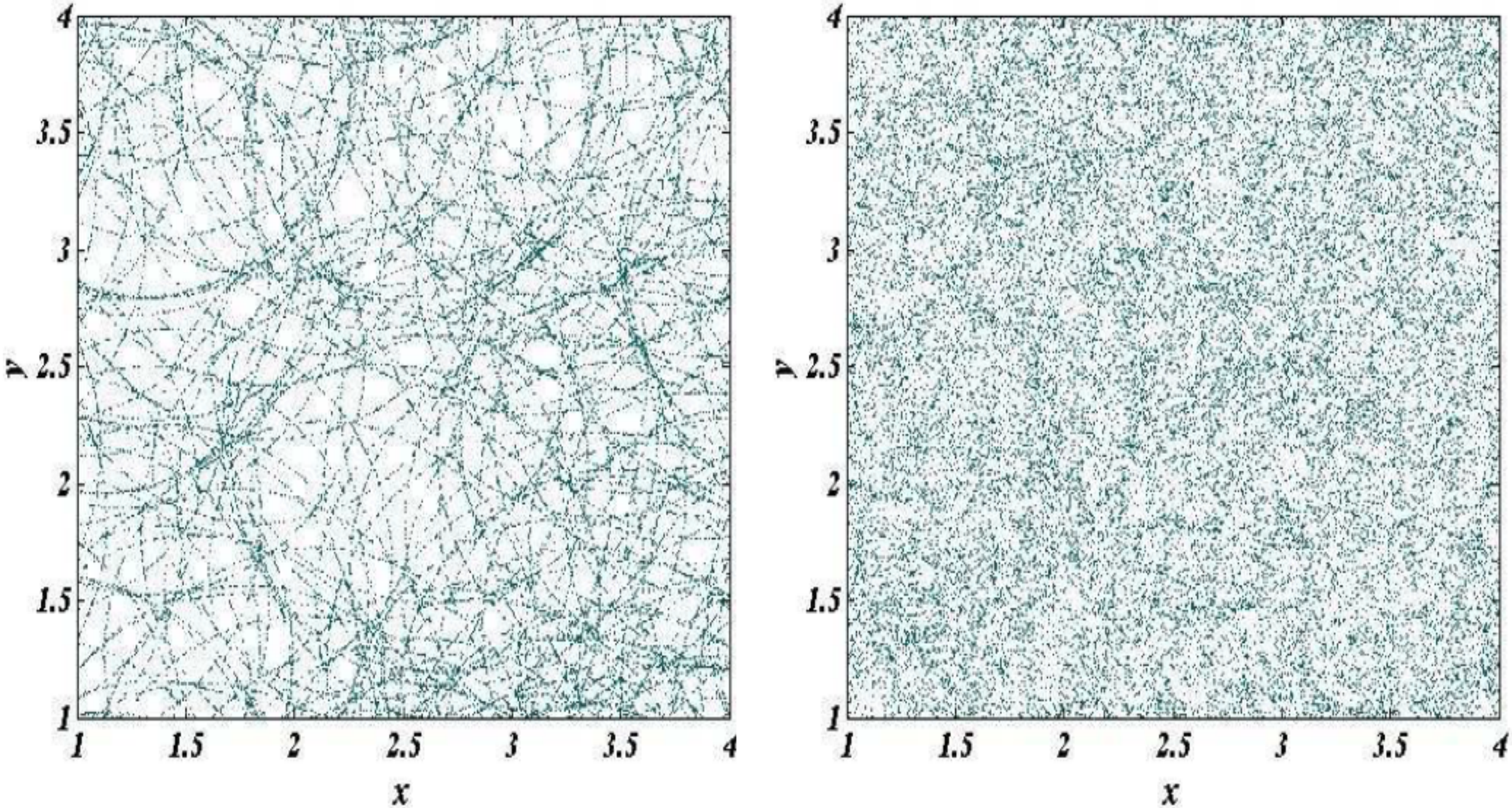


Fig. 1.5. Rings of power superposed. Schematic galaxy distribution formed by placing the galaxies on rings of the same characteristic radius L. The preferred radial scale is clearly visible in the left hand panel with many galaxies per ring. The right hand panel shows a more realistic scenario - with many rings and relatively few galaxies per ring, implying that the preferred scale can only be recovered statistically.

DARK ENERGY SPECTROSCOPIC INSTRUMENT

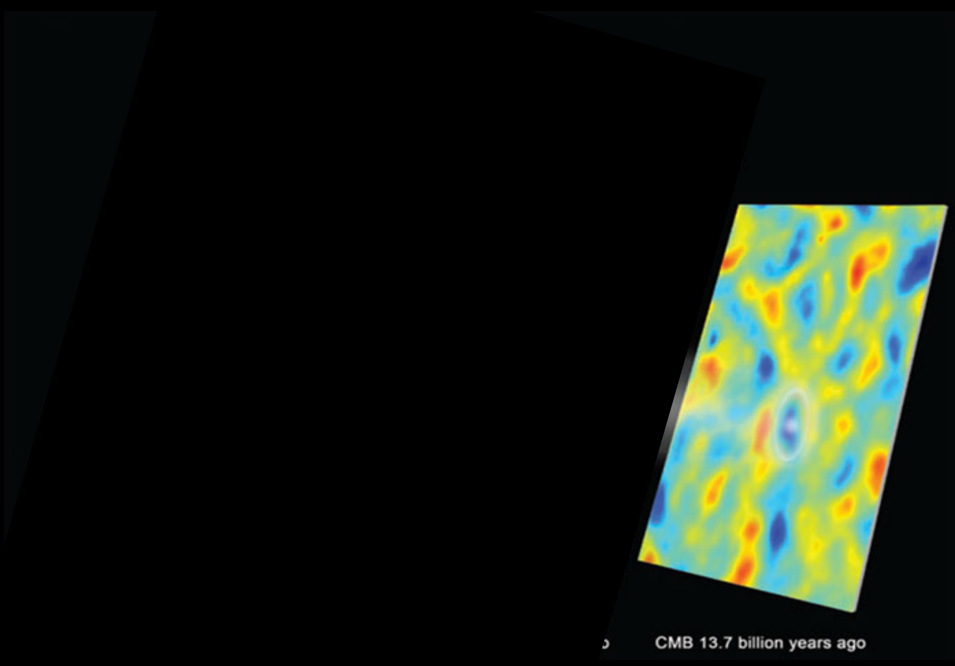
U.S. Department of Energy Office of Science

Baryon Accoustic Oscillations “BAO"

Instituto de Física UNAM

Early Universe (z >> 1000): hot plasma with tightly coupled baryons and photons

Overdensities make overpressures and a sound wave in the gas, wich propagates with velocity $c_s = c/\sqrt{3}$



- **at z ~ 1100 (*age* ~ 350 000 yr), temperature is low enough (3000 K) for the formation of hydrogen.**
- **Photons decouple and propagate freely (CMB, 13.7 billions years ago)**
- **Acoustic waves freeze at a distance given by the acoustic horizon:**

$$r_d \approx \mathbf{110\ Mpc}\ h^{-1} \mathbf{or\ 150\ Mpc}$$

DARK ENERGY SPECTROSCOPIC INSTRUMENT

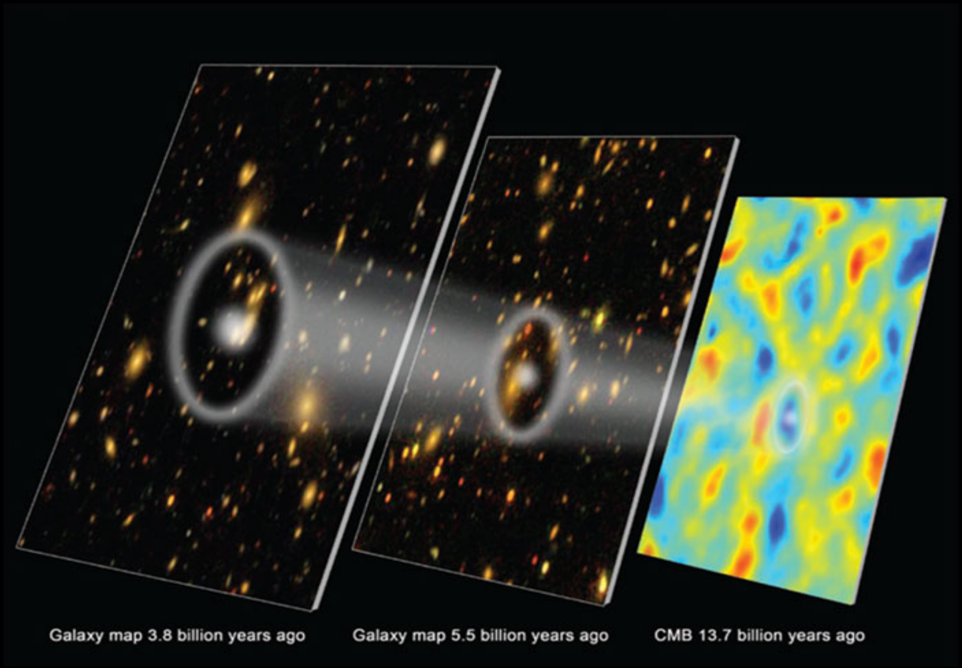
U.S. Department of Energy Office of Science

Baryon Accoustic Oscillations "BAO"

Instituto de Física UNAM

Early Universe (z >> 1000): hot plasma with tightly coupled baryons and photons

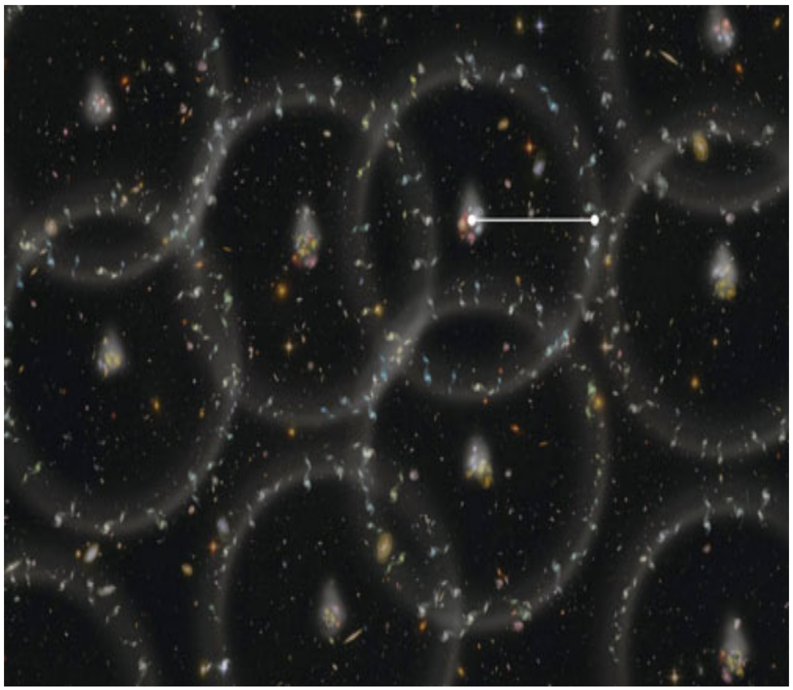
Overdensities make overpressures and a sound wave in the gas, wich propagates with velocity $c_s = c/\sqrt{3}$

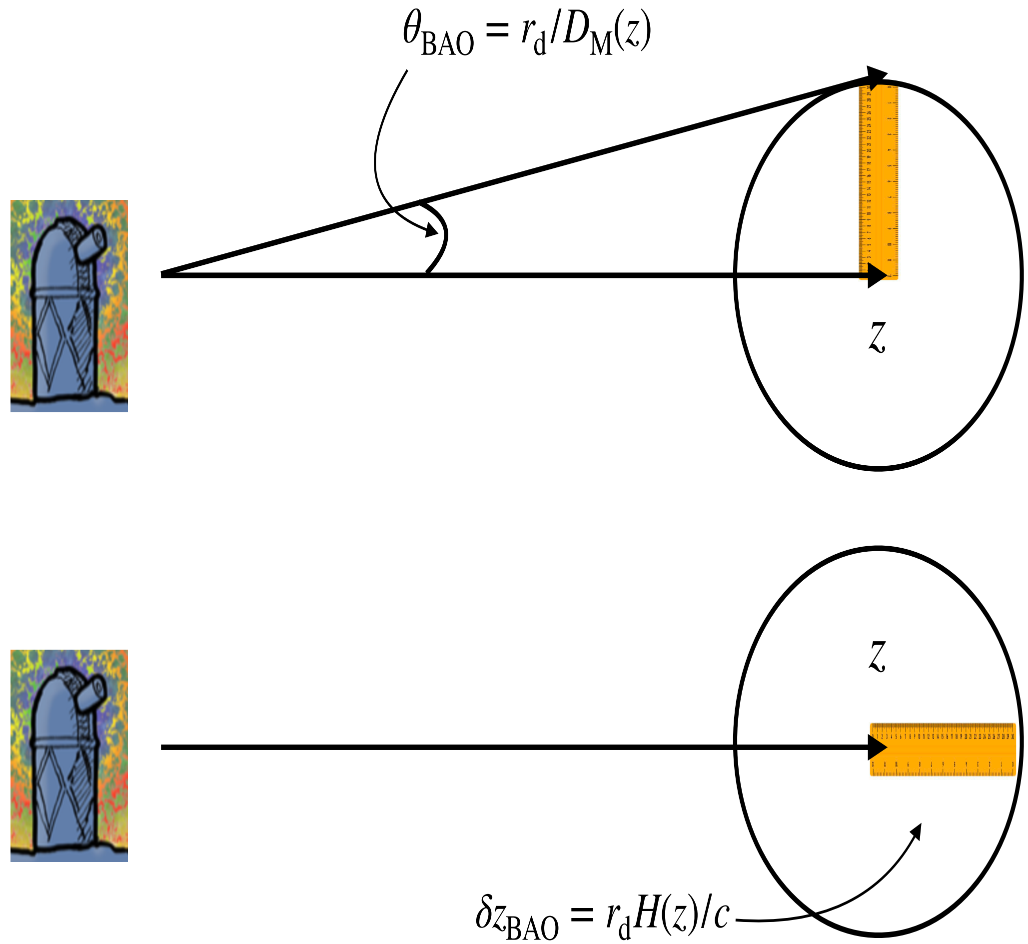


- Galaxies form in the overdense central regions. Mostly, where the initial overdensities were.
- There is a 1% enhancement in spheres at 150 Mpc away from the initial overdensities.
- There should be a small excess of galaxies 150 Mpc away from other galaxies
- DESI measures this spheres ~ 150 Mpc
- This corresponds to a single *acoustic peak* in the correlation function of galaxies.

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

The BAO standard ruler





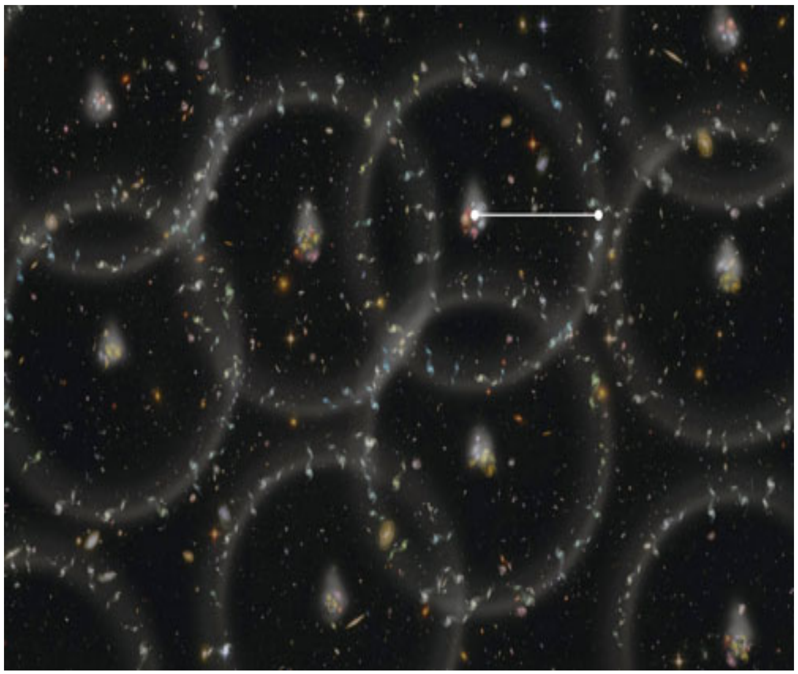
$$D_{\rm M}(z) = \frac{c}{H_0}\int_0^z \frac{dz'}{H(z')/H_0}\Big]$$

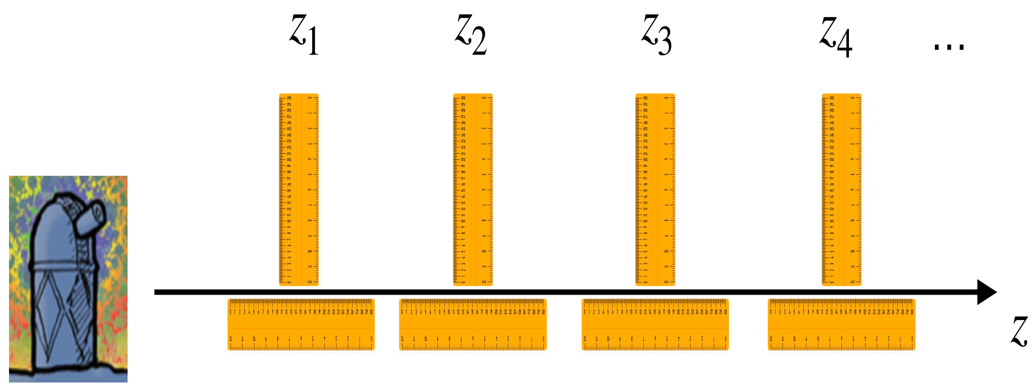
$D_{\rm M}(z)$ and $H(z)$ encode **expansion history** of the Universe

Slide courtesy of DESI collaboration

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

The BAO standard ruler





DESI measures BAO rulers at many times/redshifts

$$D_{\rm M}(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{H(z')/H_0} \Big]$$

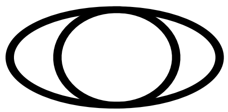
$D_{\rm M}(z)$ and $H(z)$ encode **expansion history** of the Universe

Slide courtesy of DESI collaboration

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

Scaling parameters

Instituto de Física UNAM

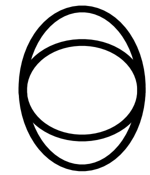


perpendicular ruler size

$$\alpha_\perp = \frac{D_\mathrm{M}}{r_\mathrm{d}} \frac{r_\mathrm{d}^\mathrm{fid}}{D_\mathrm{M}^\mathrm{fid}}$$

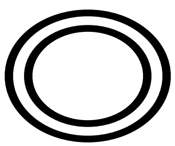
and

$$\alpha_{||} = \frac{D_\mathrm{H}}{r_\mathrm{d}} \frac{r_\mathrm{d}^\mathrm{fid}}{D_\mathrm{H}^\mathrm{fid}}$$



line-of-sight ruler size

OR

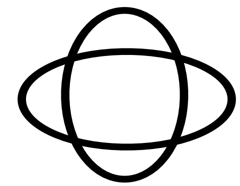


overall scale of BAO

$$\alpha_\mathrm{iso} = \left(\alpha_\perp^2 \alpha_{||}\right)^{1/3}$$

and

$$\alpha_\mathrm{AP} = \frac{D_\mathrm{H}}{D_\mathrm{M}} \frac{D_\mathrm{M}^\mathrm{fid}}{D_\mathrm{H}^\mathrm{fid}}$$



anisotropy of BAO

$$D_\mathrm{M}(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{H(z')/H_0} \Big]$$

$$D_\mathrm{H} = c/H(z)$$

$$r_\mathrm{d} = \int_{z_\mathrm{d}}^\infty \frac{c_\mathrm{s}(z)}{H(z)} dz$$

$$r_\mathrm{d} = \frac{147.05}{\mathrm{Mpc}} \left(\frac{\omega_\mathrm{m}}{0.1432}\right)^{-0.23} \left(\frac{N_\mathrm{eff}}{3.04}\right)^{-0.1} \left(\frac{\omega_\mathrm{b}}{0.02236}\right)^{-0.13}$$

ΛCDM is

$$H(z) = H_0 \sqrt{\Omega_\mathrm{m}(1+z)^3 + \Omega_\mathrm{R}(1+z)^4 + \Omega_\mathrm{K}(1+z)^2 + \Omega_\Lambda}.$$

Correlation function: Baryon Acoustic Oscillations (BAO) for different tracers and redshits “z”
BGS= Bright Galaxy Survery, ELG = Emission Line Galaxy, LRG = Luminous Red Glaxies, QSO = Quasars,
- Redshifts “z”: BGS=0.1-0.4; ELG=0.8-1.1; LRG= 0.4-0.6, 0.6-0.8, 0.8-1.1, LRG+ELG=0.8-1.1, ELG = 1. -1.6
- BAO bump at ~ 100/h Mpc

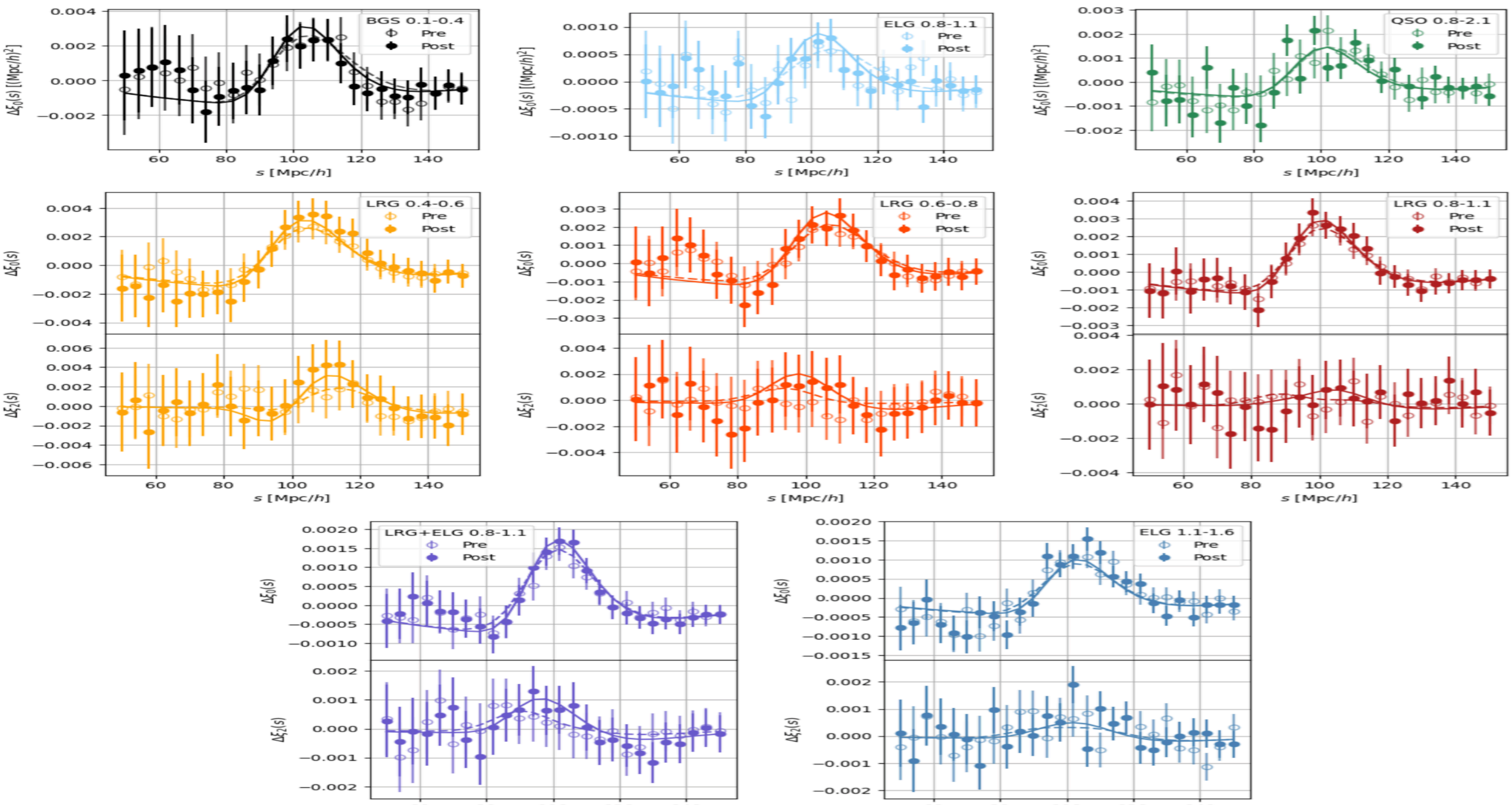


Figure 7. The isolated BAO feature in the correlation function of DESI-2024 data before (open circles) and after reconstruction (solid circles). A 1-D BAO fitting is performed for BGS, ELG1, and QSO, while the rest is fitted for 2-D BAO scales. The solid lines show the best fit to the data.

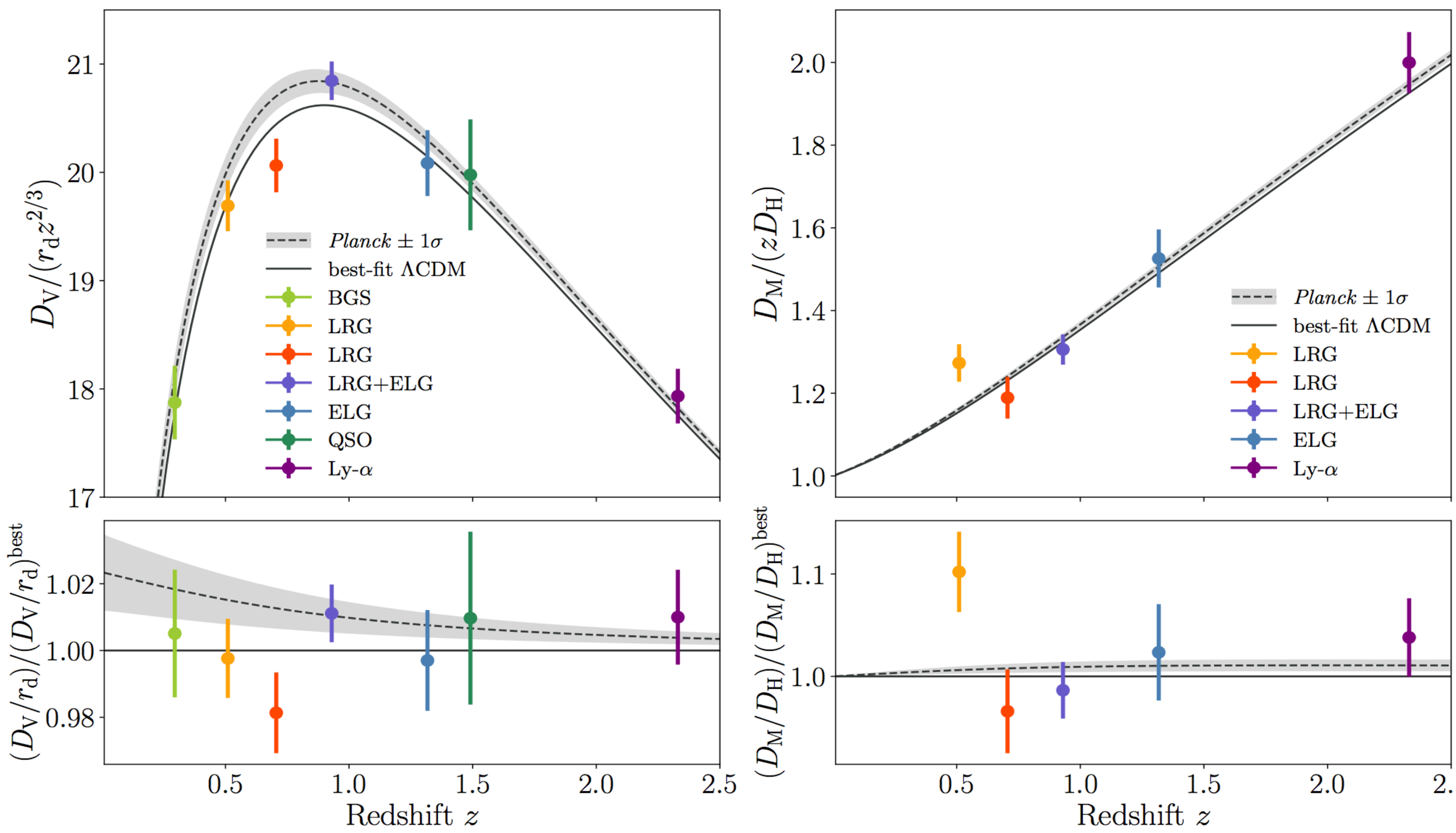
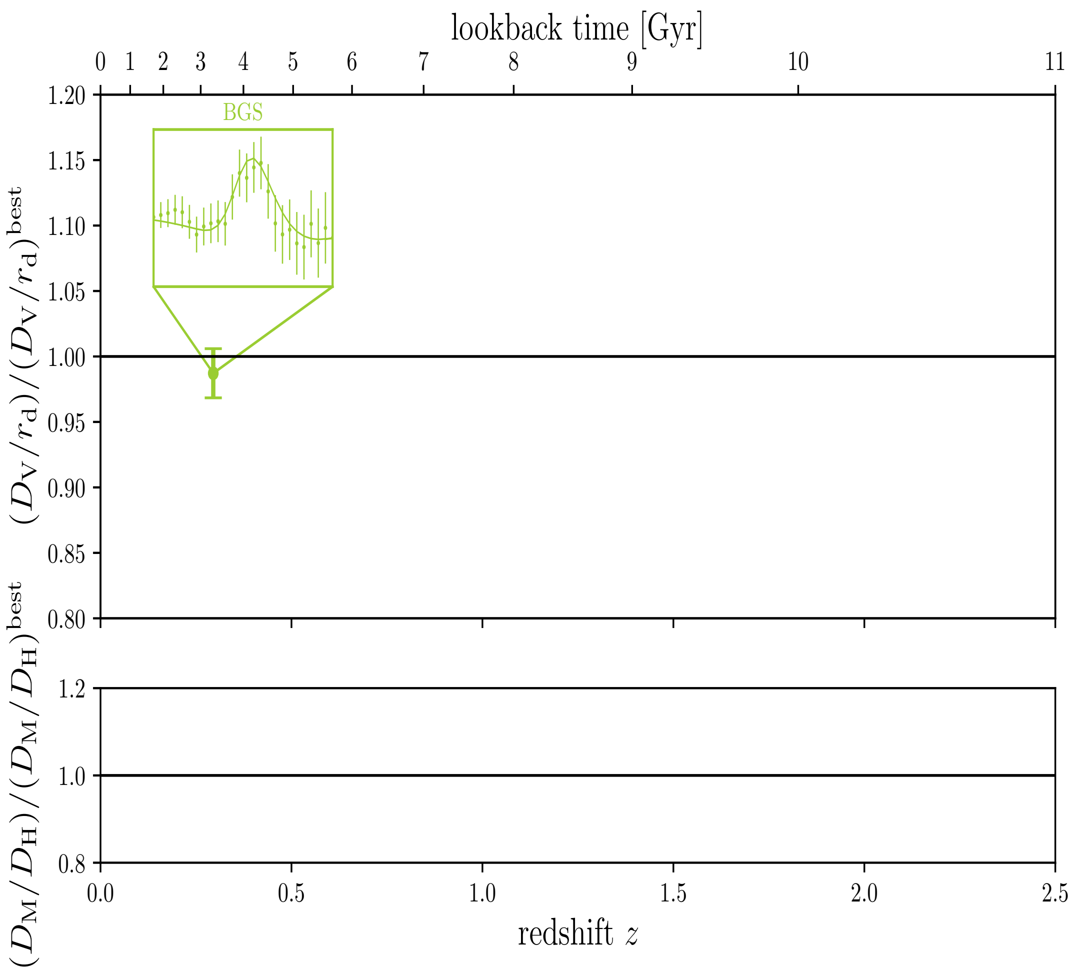


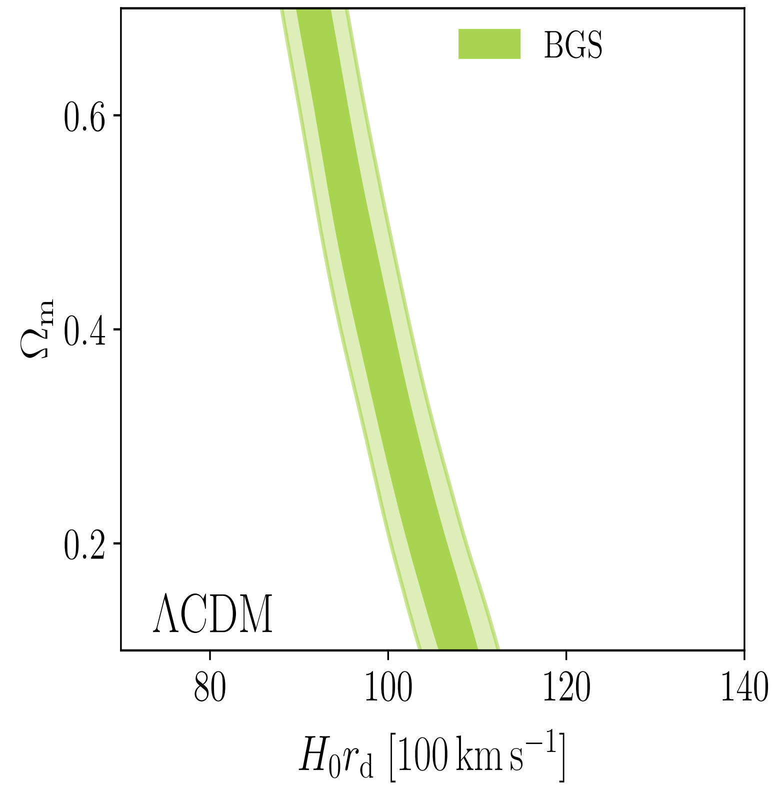
Figure 1. Top row: DESI measurements of the BAO distance scales at different redshifts, parametrized as (*left*) the ratio of the angle-averaged distance $D_V \equiv (zD_M^2 D_H)^{1/3}$ to the sound horizon at the baryon drag epoch, r_d, and (*right*) the ratio of transverse and line-of-sight comoving distances $F_{AP} \equiv D_M/D_H$, from all tracers and redshift bins as labeled. For visual clarity and to compress the dynamic range of the plot, an arbitrary scaling of $z^{-2/3}$ has been applied on the left, and z^{-1} on the right. The solid and dashed grey lines show model predictions from, respectively, the flat ΛCDM model that best fits this data, and from a ΛCDM model with parameters matching the *Planck* best-fit cosmology. The BGS and QSO data points appear only in the left panel and not the right one because the signal-to-noise ratio of the data is not yet sufficient to measure both parameters for these tracers. Bottom row: The same data points and models as in the top row, but now shown as the ratio relative to the predictions for the best-fit flat ΛCDM model.

DESI Y1 BAO

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

Instituto de Física UNAM





$$D_M(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{H(z')/H_0}]$$

$$D_H = c/H(z)$$

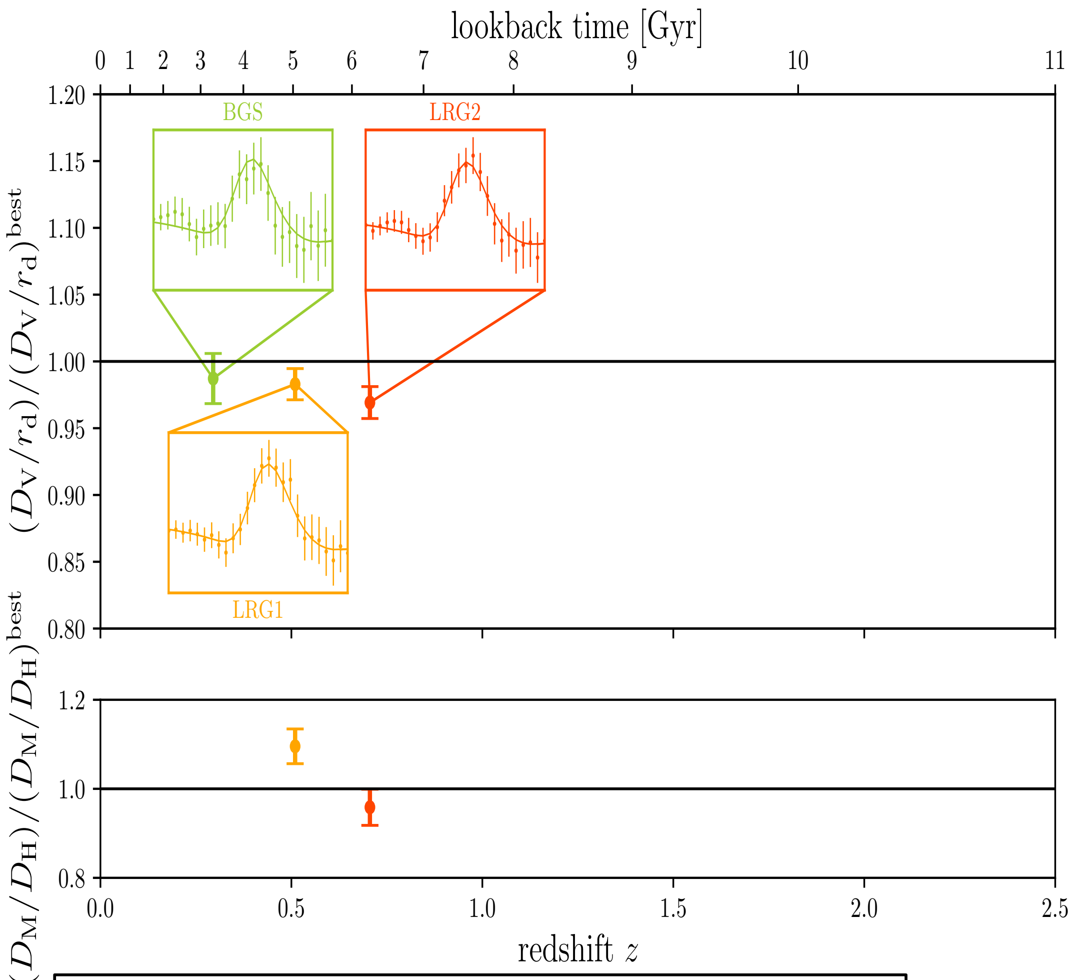
Slide courtesy of DESI collaboration

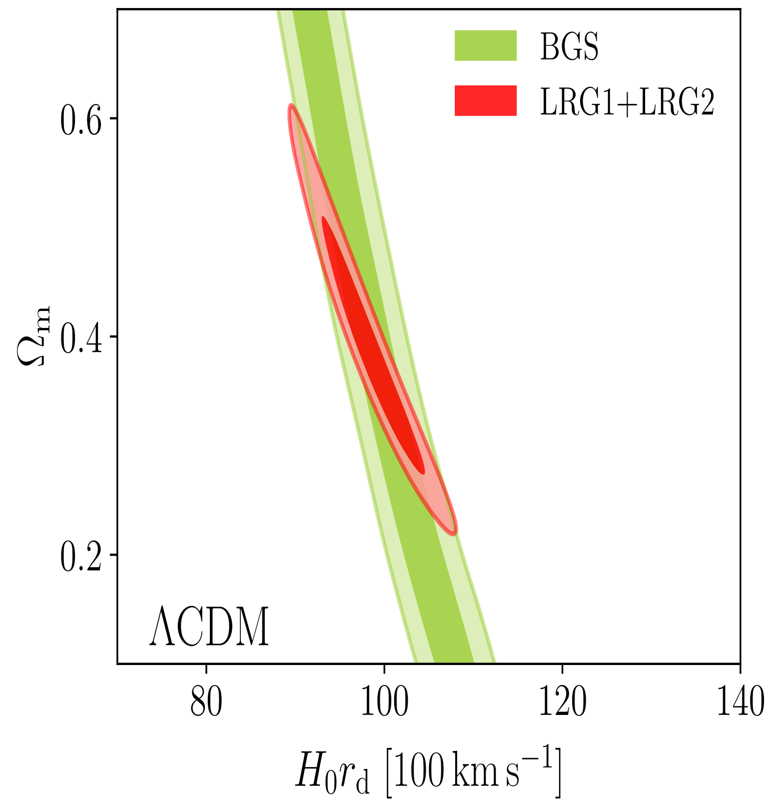
DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

DESI Y1 BAO

Instituto de Física UNAM





$$D_M(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{H(z')/H_0}$$

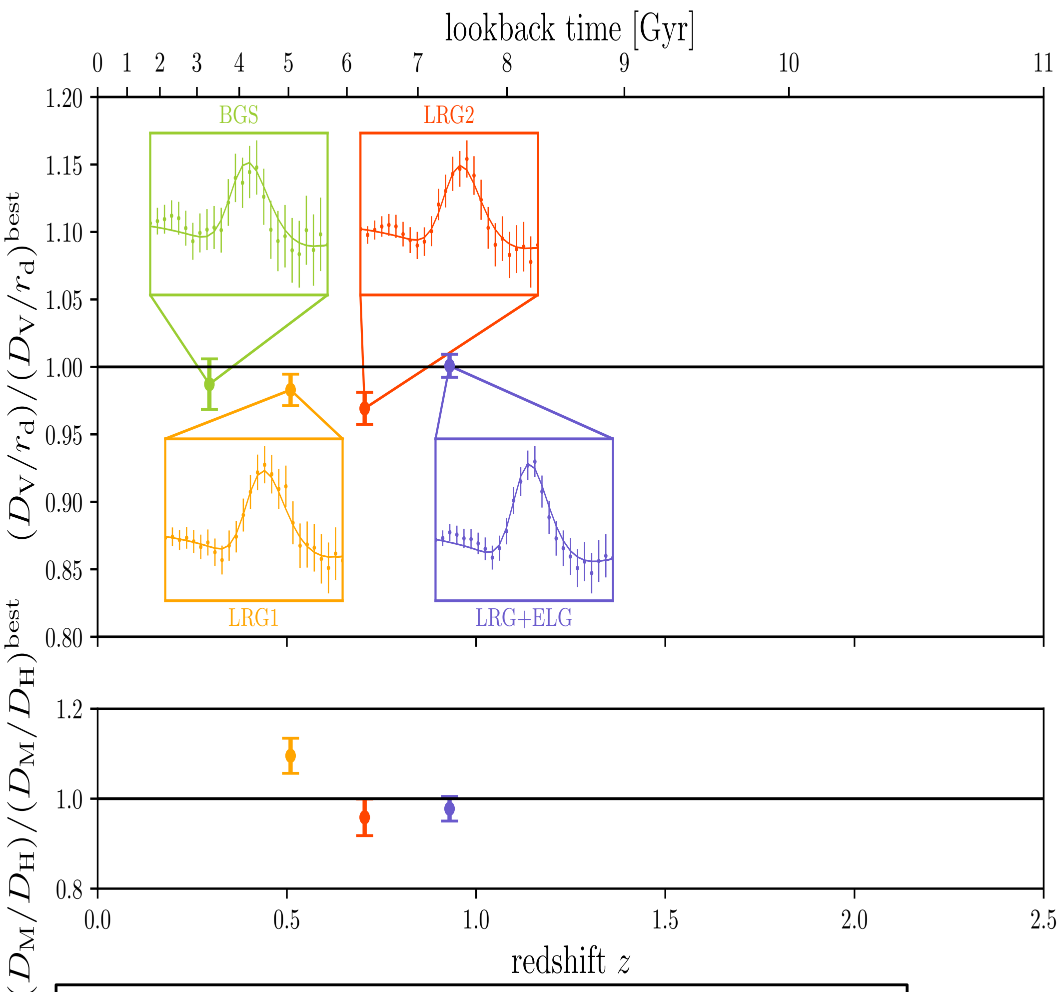
$$D_H = c/H(z)$$

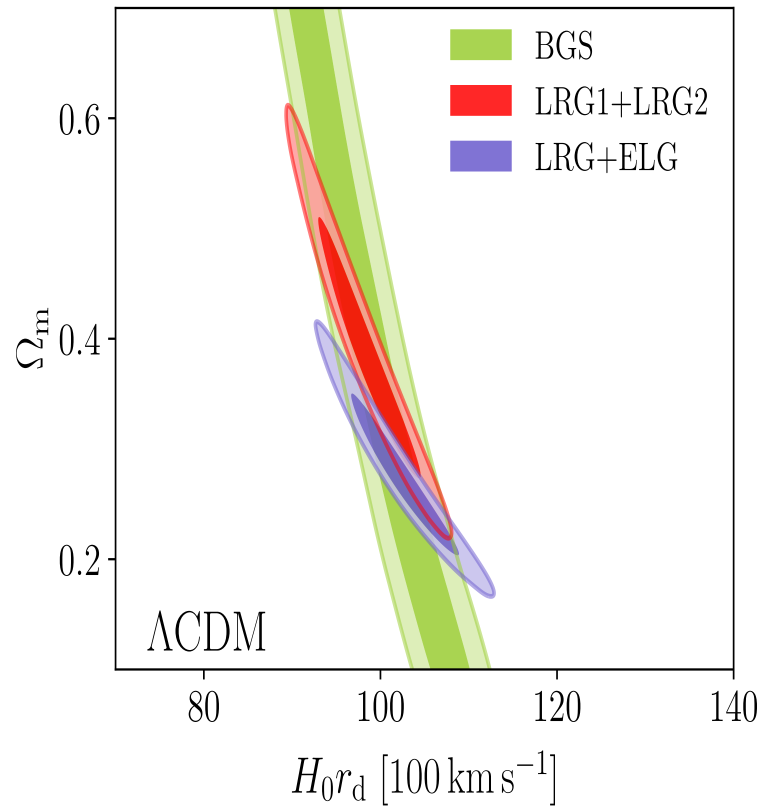
Slide courtesy of DESI collaboration

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

DESI Y1 BAO





$$D_M(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{H(z')/H_0}]$$

$$D_H = c/H(z)$$

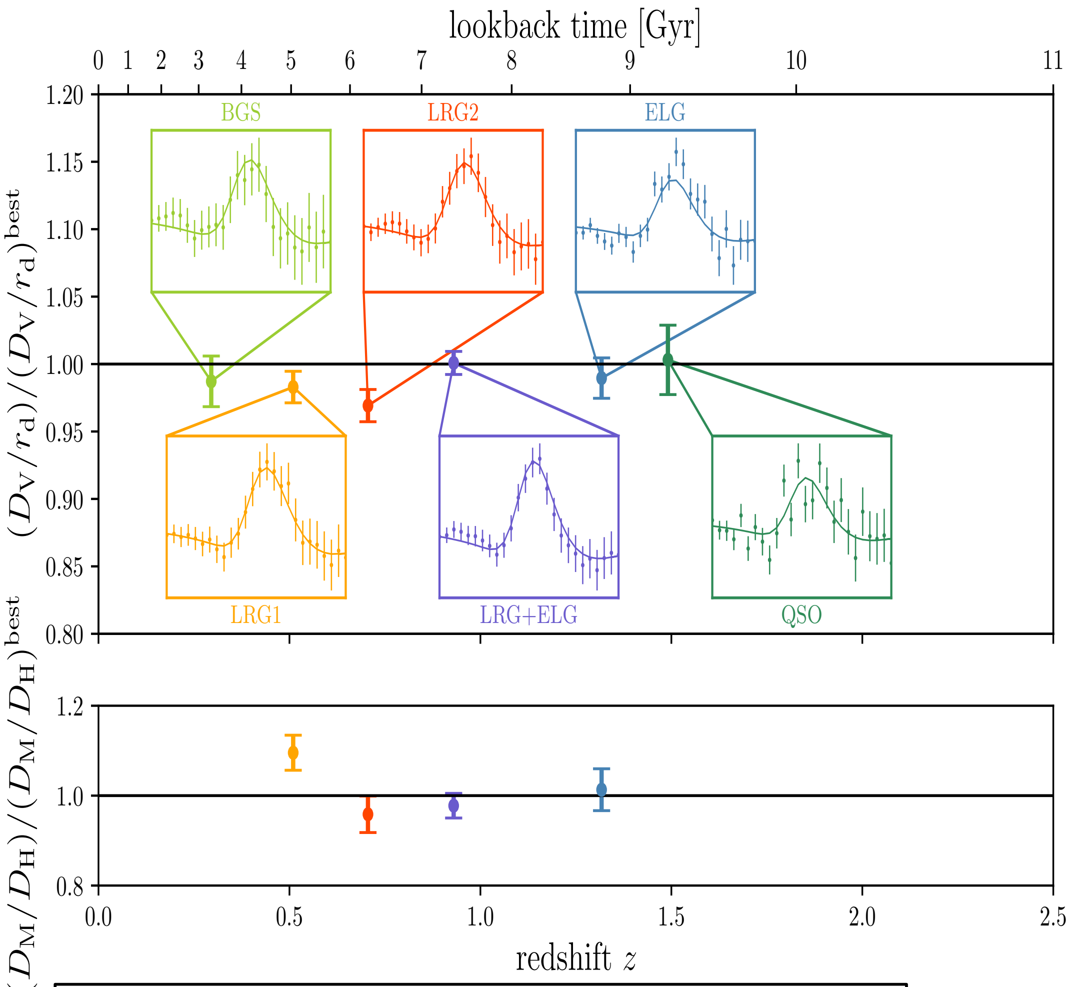
Slide courtesy of DESI collaboration

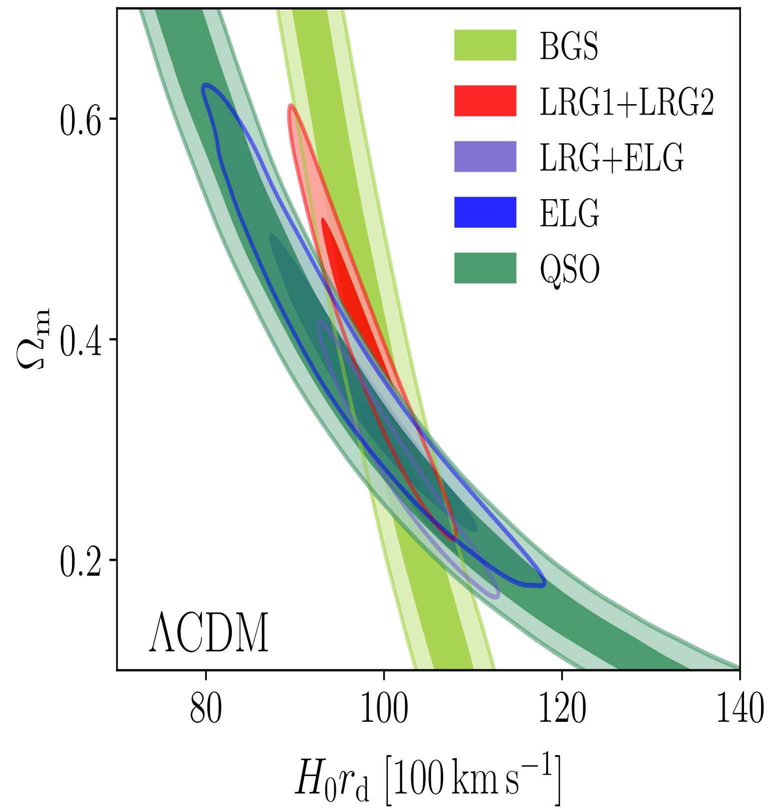
DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

DESI Y1 BAO

Instituto de Física UNAM





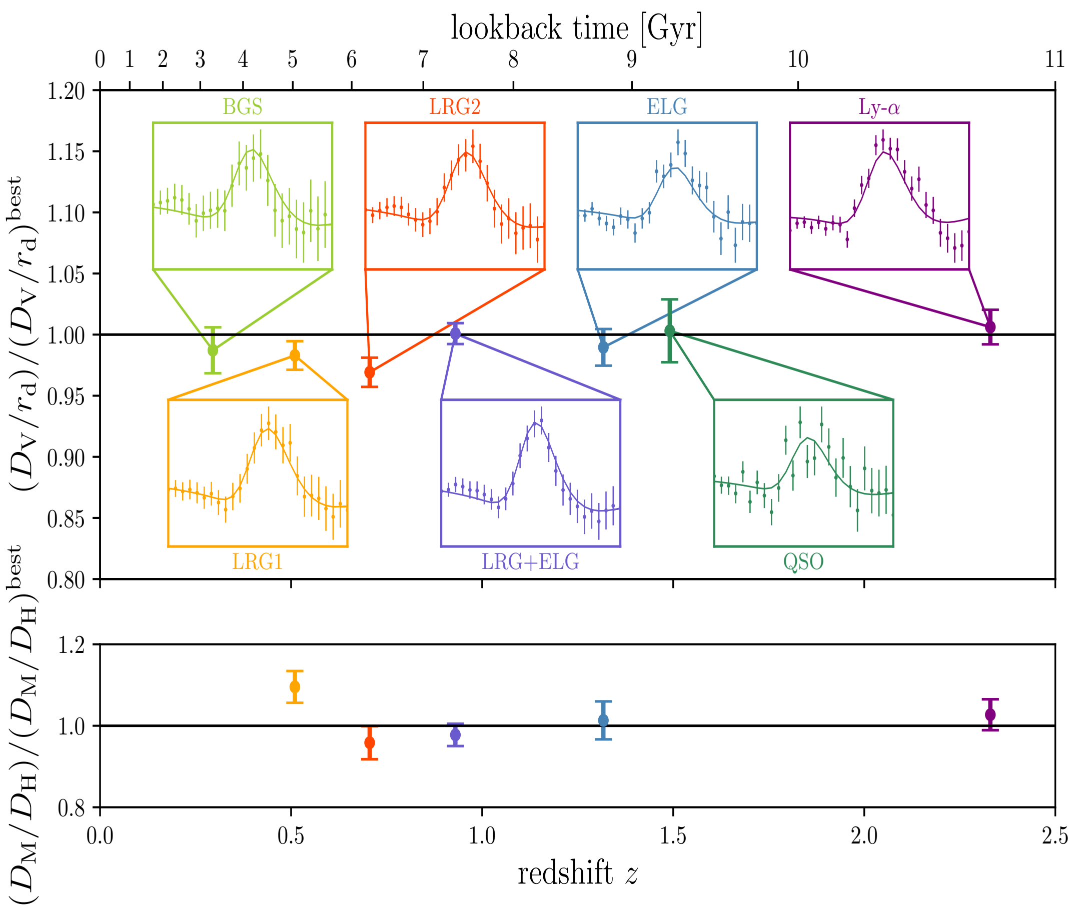
$$D_M(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{H(z')/H_0}]$$

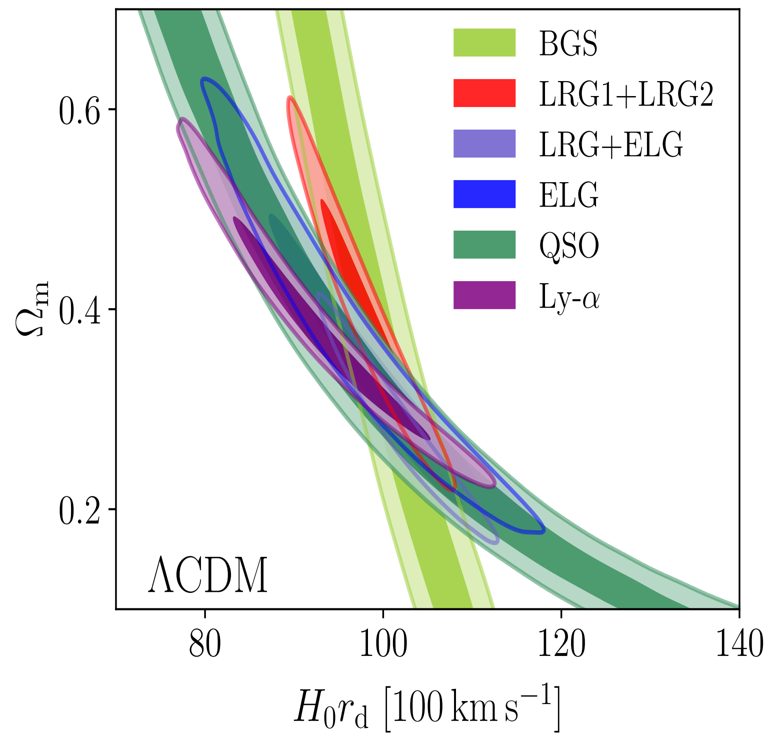
$$D_H = c/H(z)$$

Slide courtesy of DESI collaboration

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

DESI Y1 BAO





$$D_M(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{H(z')/H_0}]$$

$$D_H = c/H(z)$$

Slide courtesy of DESI collaboration

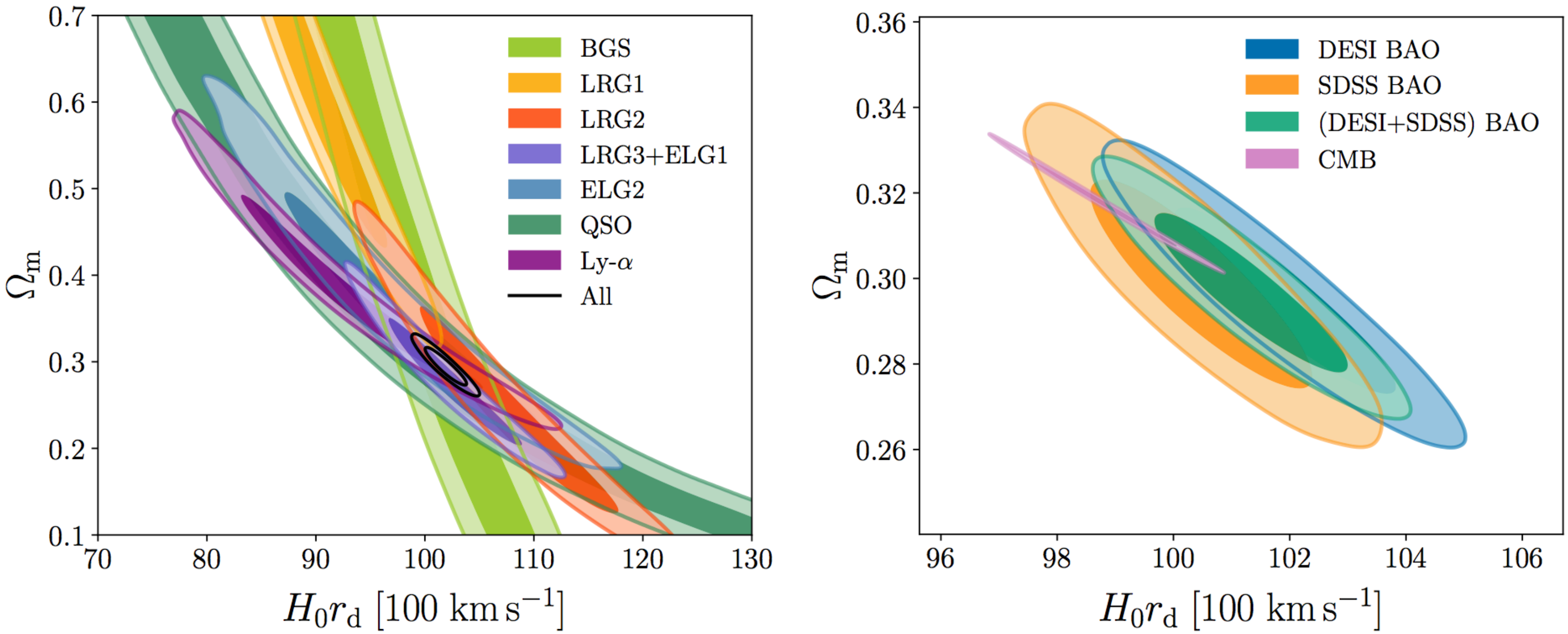
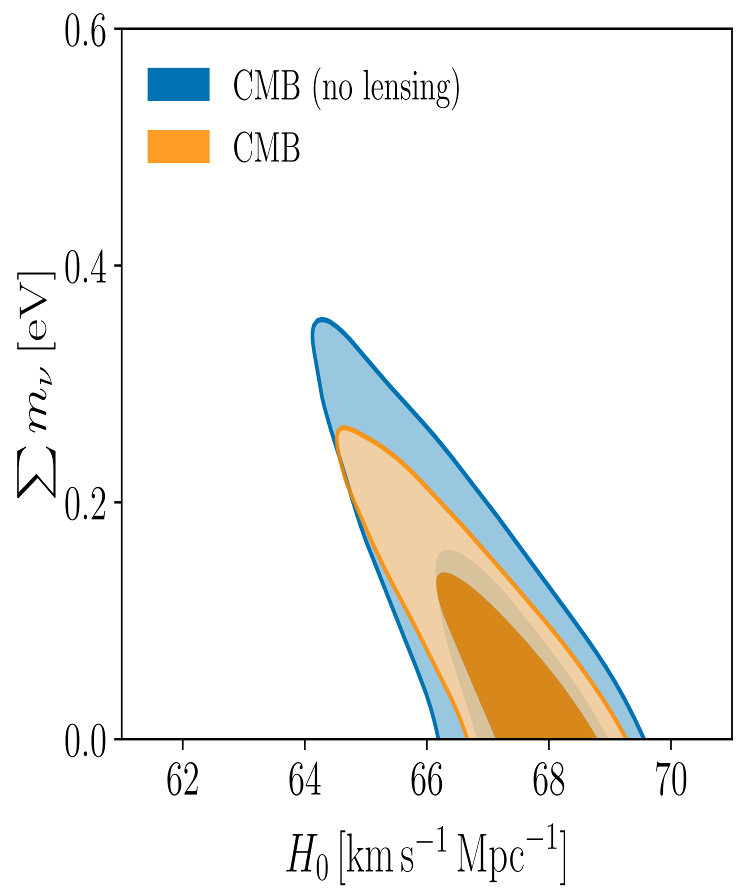


Figure 2. *Left panel:* 68% and 95% credible-interval contours for parameters Ω_m and $r_d h$ obtained for a flat ΛCDM model from fits to BAO measurements from each DESI tracer type individually, as labeled. Results from all tracers are consistent with each other and the change in the degeneracy directions arises from the different effective redshifts of the samples. *Right panel:* the corresponding results in flat ΛCDM for fits to BAO results from all DESI redshift bins (blue), the final SDSS results from [139] (orange), and the combination of these two as described in the text (green). The corresponding result from the CMB (including CMB lensing) is shown in pink.

Sum of neutrino Mass

Internal CMB degeneracies limiting precision on the sum of neutrino masses



DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Sum of neutrino Mass

Instituto de Física UNAM

Internal CMB degeneracies limiting precision on the sum of neutrino masses

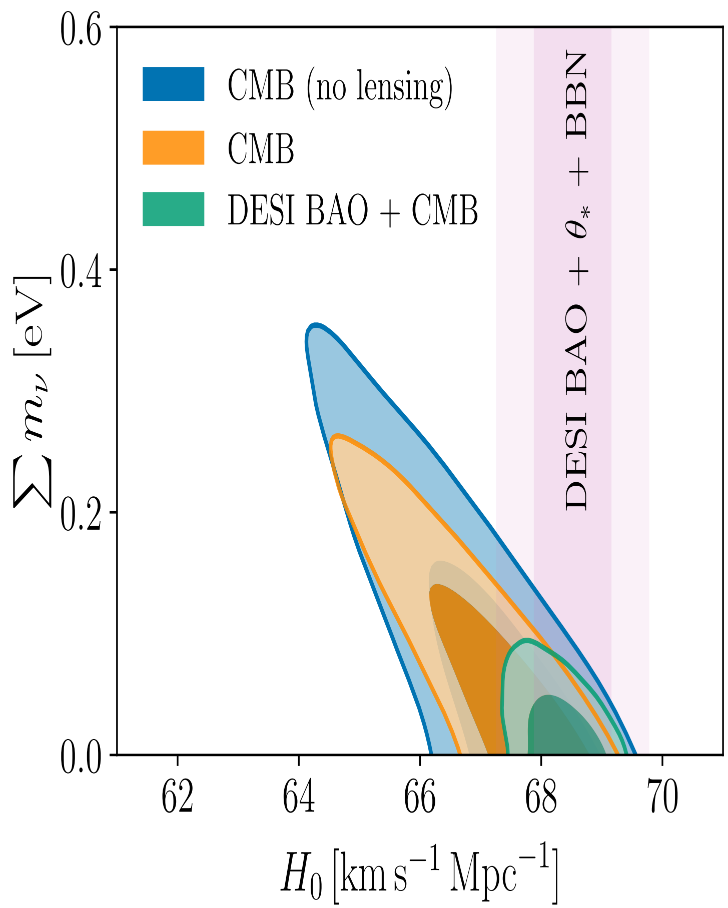
Broken by BAO, especially through H_0 constraint

Low preferred value of H_0 yields

$\sum m_\nu < 0.072\text{eV}$ (95%, DESI+CMB)

Limit relaxed for extensions to ΛCDM

$\sum m_\nu < 0.195\text{eV}$ for $w_0 w_a$CDM

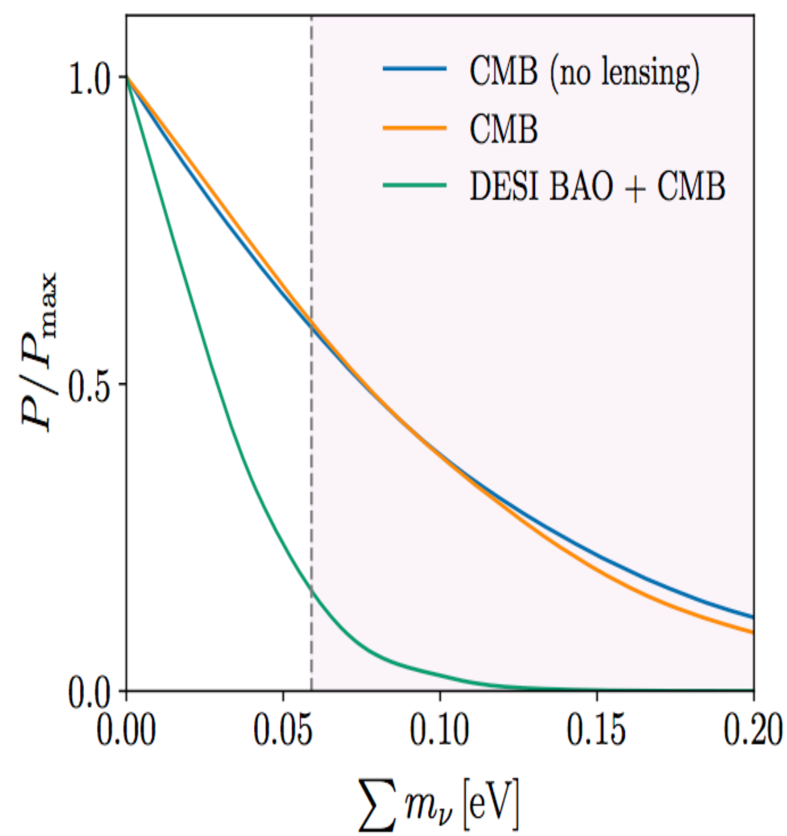


Slide courtesy of DESI collaboration

Neutrino mass hierarchies

With $> 0.059\mathrm{eV}$ prior (NH)

$$\sum m_\nu < 0.113\mathrm{eV}$$ (95%, DESI+CMB)



NH = normal hierachy

Slide courtesy of DESI collaboration

Neutrino mass hierarchies

DARK ENERGY SPECTROSCOPIC INSTRUMENT

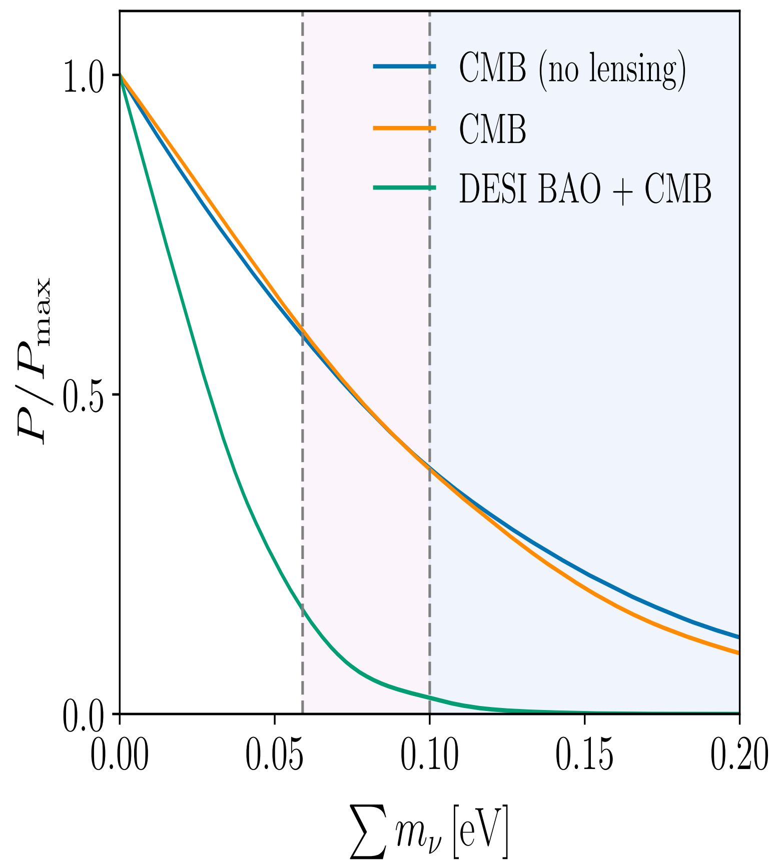
U.S. Department of Energy Office of Science

With $> 0.059\mathrm{eV}$ prior (NH)

$\sum m_\nu < 0.113\mathrm{eV}$ (95%, DESI+CMB)

With $> 0.1\mathrm{eV}$ prior (IH)

$\sum m_\nu < 0.145\mathrm{eV}$ (95%, DESI+CMB)



NH = normal hierarchy

IH = inverse hierarchy

Slide courtesy of DESI collaboration

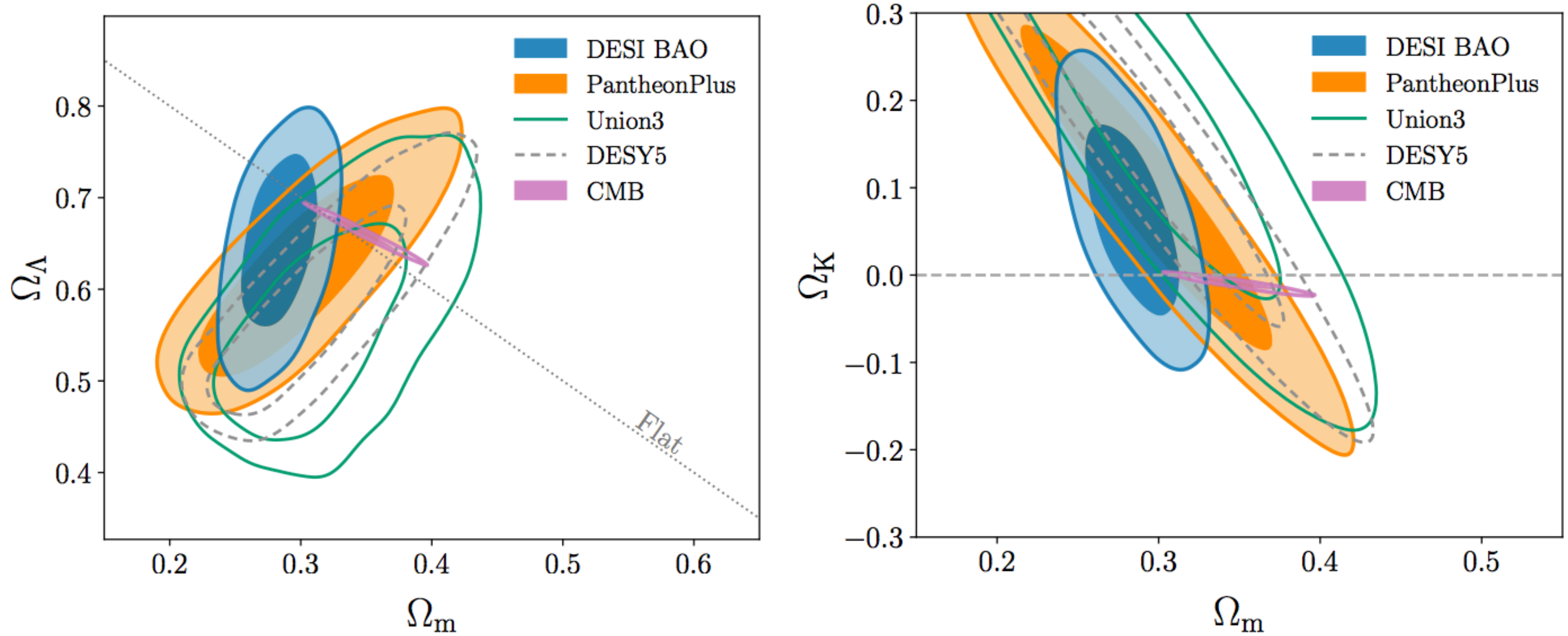


Figure 4. 68% and 95% marginalized posterior constraints on Ω_m–Ω_Λ plane (left) and Ω_m–Ω_K (right) in the one-parameter extension of the ΛCDM model with free curvature, ΛCDM+Ω_K. In the left panel the supernova contours are truncated at the lower-left by the $\mathcal{U}[-0.3, 0.3]$ prior on Ω_K.

$$\left.\begin{aligned} \Omega_m &= 0.3069 \pm 0.0050, \\ H_0 &= (67.97 \pm 0.38)\,\mathrm{km\,s^{-1}\,Mpc^{-1}} \end{aligned}\right\} \text{DESI BAO+ CMB.}$$

Slide courtesy of DESI collaboration

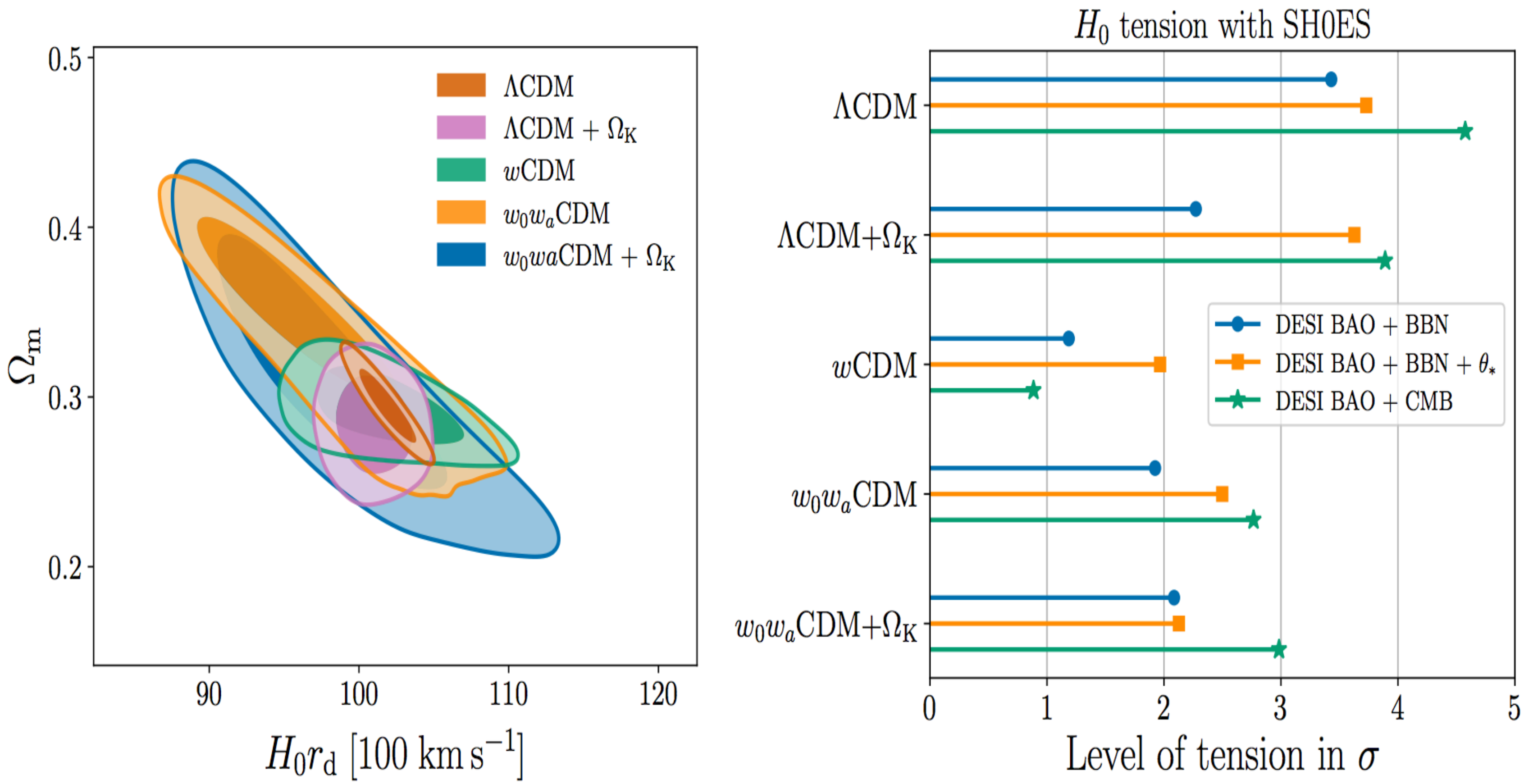


Figure 10. *Left panel*: The 68% and 95% credible-interval contours for Ω_m and $H_0 r_d$ obtained from fitting DESI DR1 BAO data in the base flat ΛCDM model and in four extension models which modify the background geometry or late-time expansion history. *Right panel*: A summary of the tension in the H_0 measurements obtained from the DESI BAO results combined with other data, and the SH0ES result of [225], assuming different cosmological models.

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

Dark Energy Equation of State

Instituto de Física UNAM

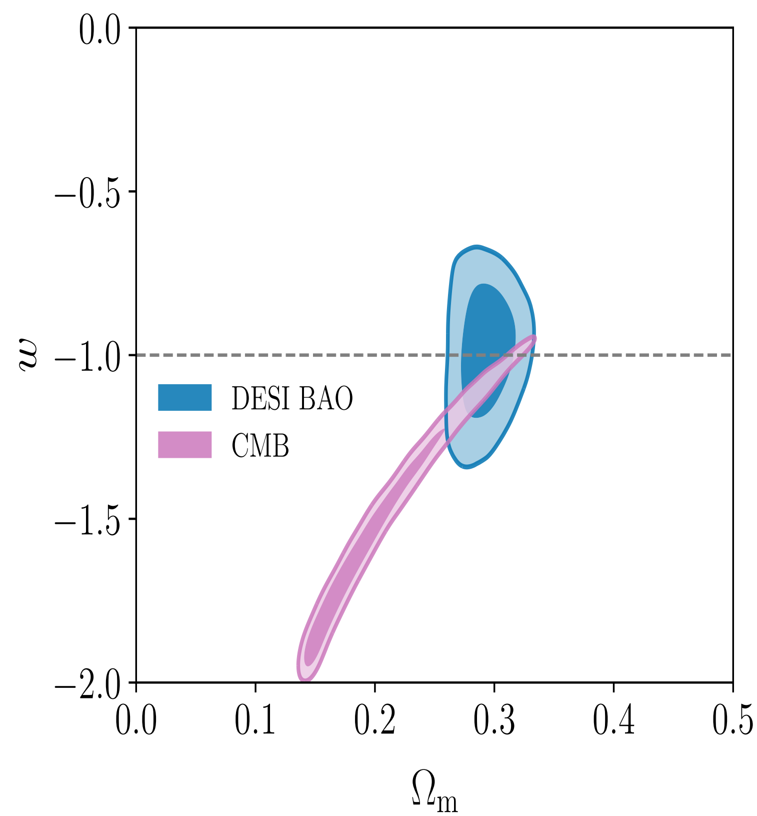
DESI

Constant EoS parameter w

$$\Omega_m = 0.293 \pm 0.015$$

$$w = -0.99^{+0.15}_{-0.13}$$

with constant w



Consistent with w = -1

Slide courtesy of DESI collaboration

Slide courtesy of DESI collaboration

Dark Energy Equation of State

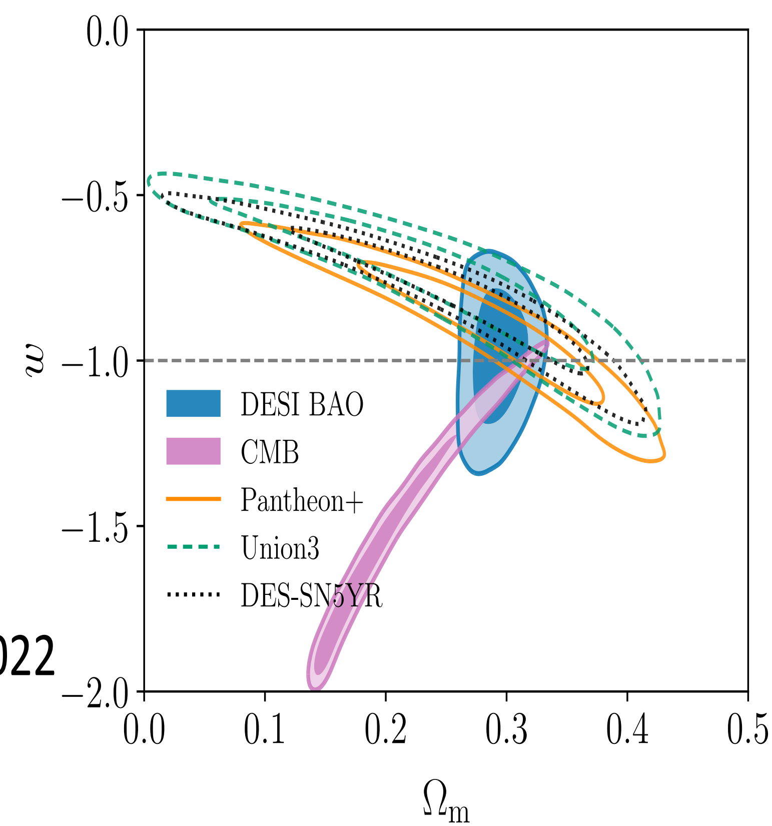
DESI

Constant EoS parameter w

$$\Omega_m = 0.293 \pm 0.015$$

$$w = -0.99^{+0.15}_{-0.13}$$

with constant w



With different supernovae data sets SNe:

- Pantheon+ Brout, Scolnic, Popovic et al., 2022
- Union3 Rubin, Aldering, Betoule et al. 2023
- DES-SN5YR DES Collaboration et al. 2024

Slide courtesy of DESI collaboration

Dark Energy Equation of State

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

DESI

Constant EoS parameter w

$$\Omega_m = 0.293 \pm 0.015$$

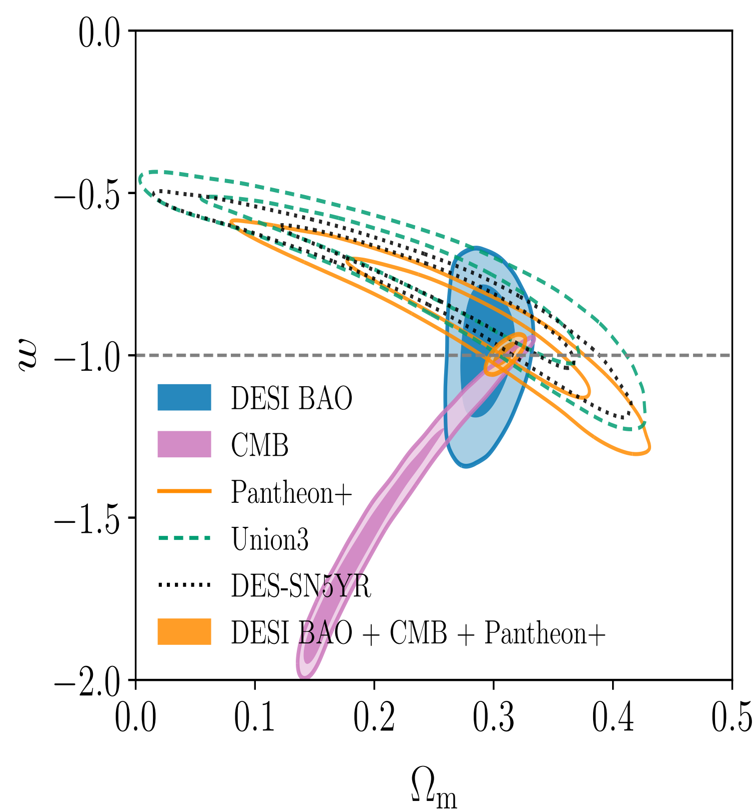
$$w = -0.99^{+0.15}_{-0.13}$$

DESI + CMB + Pantheon+

$$\Omega_m = 0.2095 \pm 0.0065$$

$$w = -0.997 \pm 0.025$$

with constant w



Assuming a constant EoS, DESI BAO fully compatible with a cosmological constant...

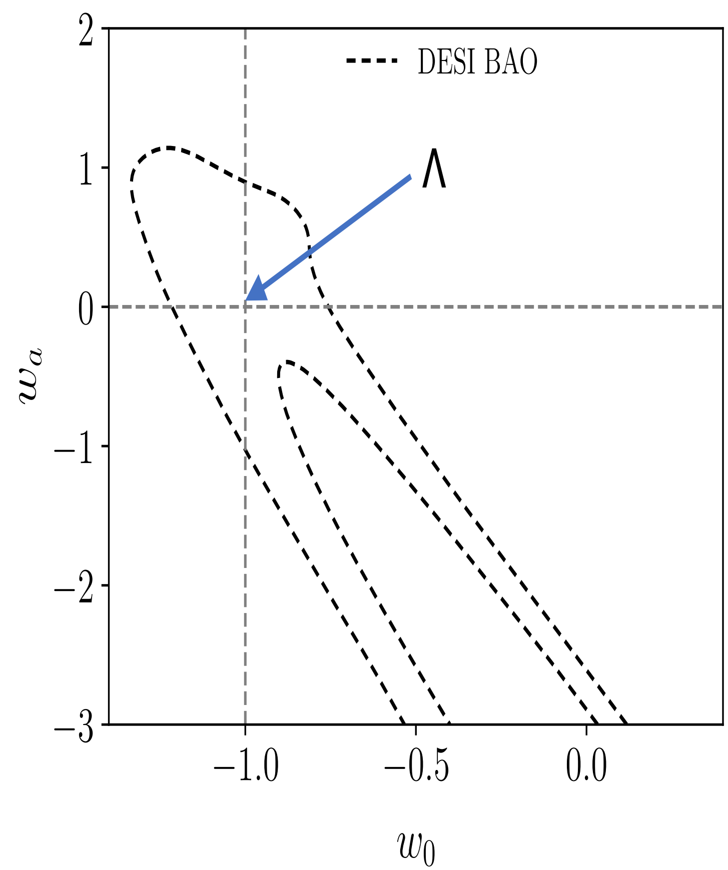
Slide courtesy of DESI collaboration

Dark Energy Equation of State

Varying EoS (CPL EoS)

$$w(a) = w_0 + (1 - a)w_a$$

$$w_0 = -0.55^{+0.39}_{-0.21} \qquad w_a < -1.32$$



Slide courtesy of DESI collaboration

Dark Energy Equation of State

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

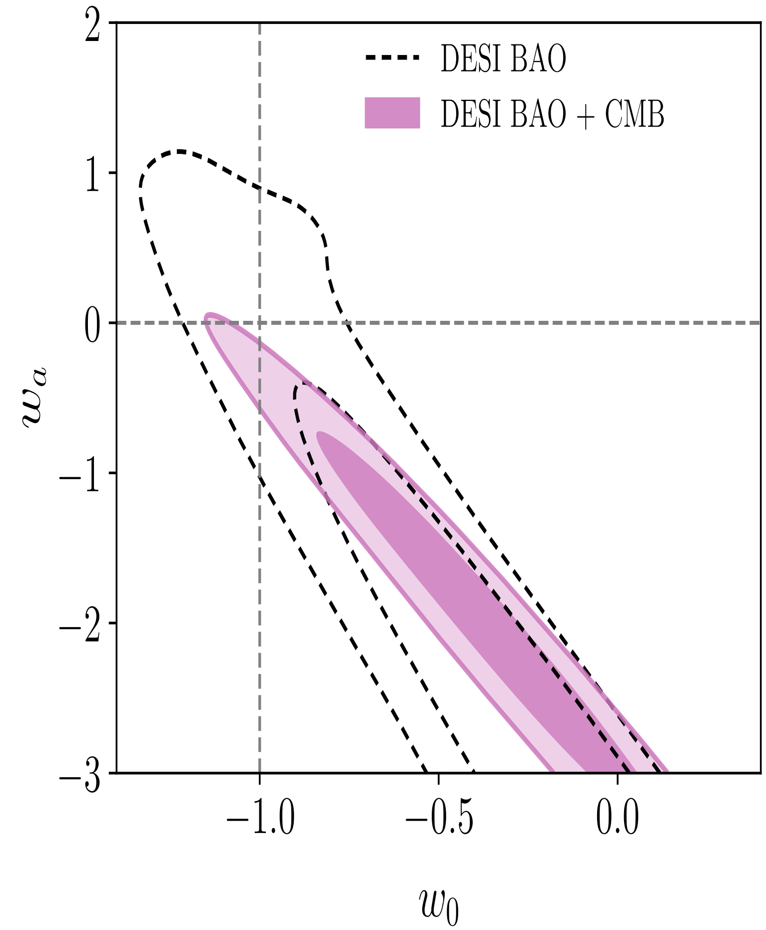
Instituto de Física UNAM

Varying EoS (CPL EoS)

$$w(a) = w_0 + (1 - a)w_a$$

DESI + CMB ⟹ 2.6σ

$$w_0 = -0.45^{+0.34}_{-0.21} \qquad w_a = -1.79^{+0.48}_{-1.0}$$



Slide courtesy of DESI collaboration

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

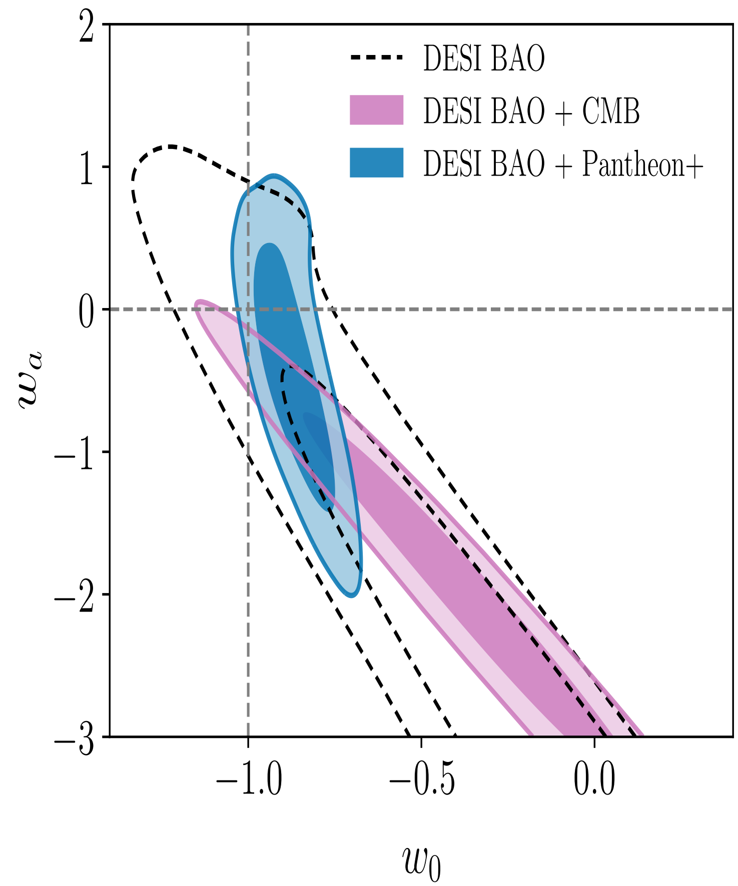
Dark Energy Equation of State

Varying EoS (CPL EoS)

$$w(a) = w_0 + (1-a)w_a$$

DESI + CMB ⟹ 2.6σ

$$w_0 = -0.45^{+0.34}_{-0.21} \qquad w_a = -1.79^{+0.48}_{-1.0}$$



Slide courtesy of DESI collaboration

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

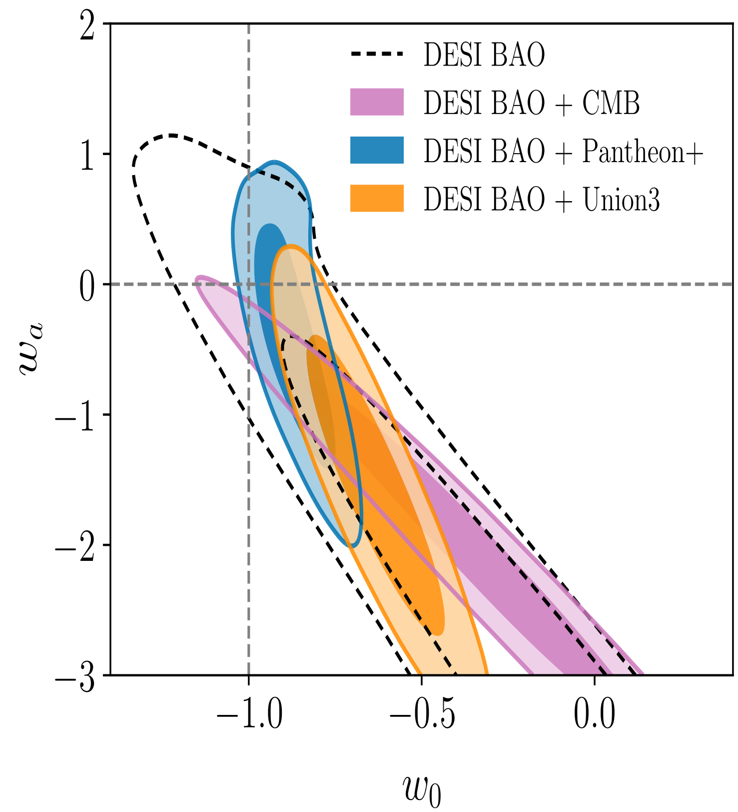
Dark Energy Equation of State

Varying EoS (CPL EoS)

$$w(a) = w_0 + (1-a)w_a$$

DESI + CMB ⟹ 2.6σ

$w_0 = -0.45^{+0.34}_{-0.21}$ $w_a = -1.79^{+0.48}_{-1.0}$



Slide courtesy of DESI collaboration

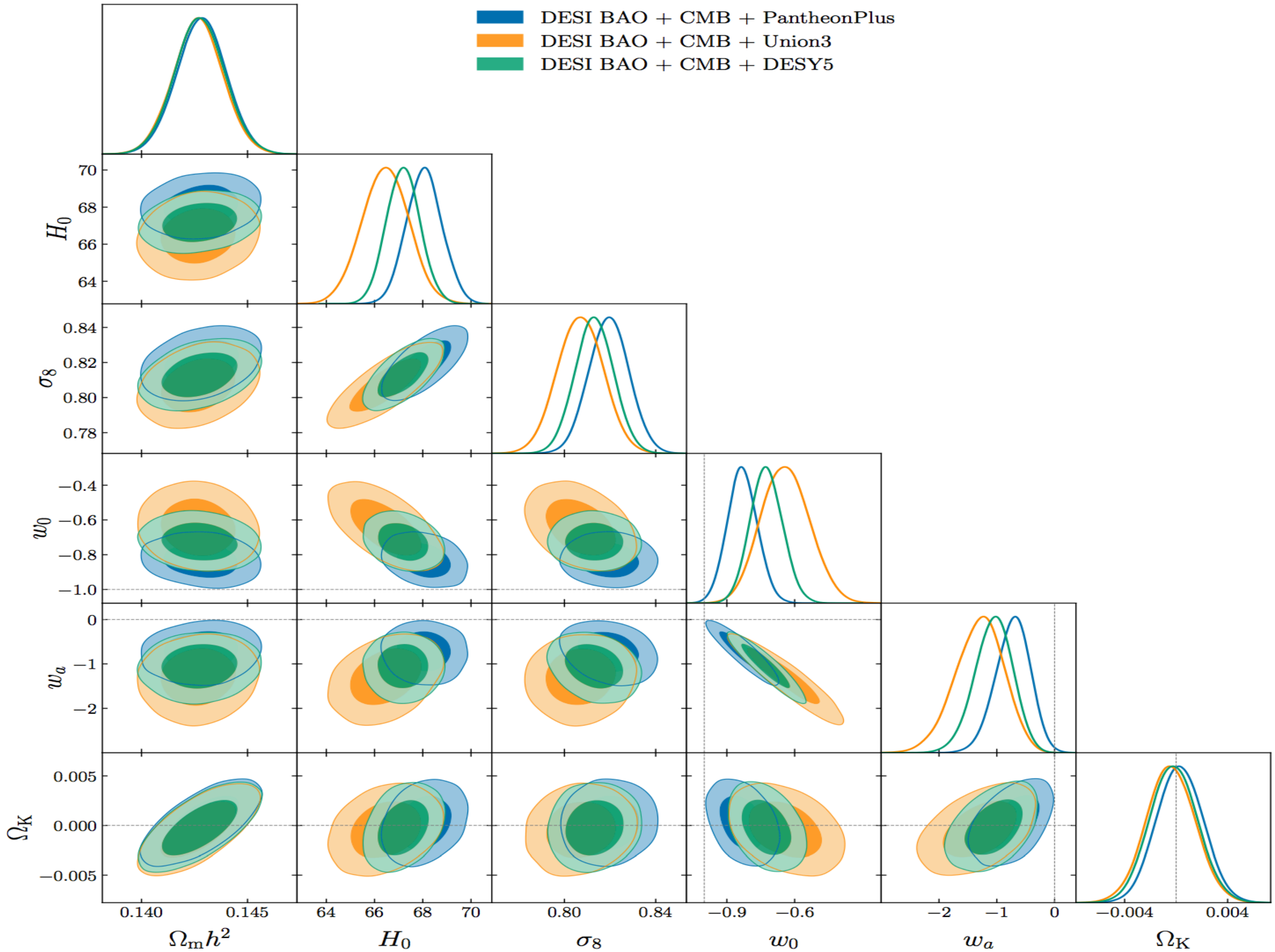


Figure 8. Marginalized posteriors on w_0, w_a and Ω_K in a model with a time-varying dark energy equation of state and free spatial curvature, from DESI and CMB data combined with SN Ia from PantheonPlus, Union3 and DESY5 in blue, orange and green respectively. All combinations provide tight limits on Ω_K. Constraints on w_0 and w_a in each case broaden a little compared to those shown in the flat case (Figure 6) but the overall trend remains the same.

Slide courtesy of DESI collaboration

model/dataset	Ω_m	H_0 [$\mathrm{km\,s^{-1}\,Mpc^{-1}}$]	$10^3\Omega_K$	w or w_0	w_a
Flat ΛCDM					
DESI	0.295 ± 0.015	—	—	—	—
DESI+BBN	0.295 ± 0.015	68.53 ± 0.80	—	—	—
DESI+BBN+θ_*	0.2948 ± 0.0074	68.52 ± 0.62	—	—	—
DESI+CMB	0.3069 ± 0.0050	67.97 ± 0.38	—	—	–
ΛCDM+Ω_K					
DESI	0.284 ± 0.020	—	65^{+68}_{-78}	—	—
DESI+BBN+θ_*	0.296 ± 0.014	68.52 ± 0.69	$0.3^{+4.8}_{-5.4}$	—	—
DESI+CMB	0.3049 ± 0.0051	68.51 ± 0.52	2.4 ± 1.6	—	—
***w*CDM**					
DESI	0.293 ± 0.015	—	—	$-0.99^{+0.15}_{-0.13}$	—
DESI+BBN+θ_*	0.295 ± 0.014	$68.6^{+1.8}_{-2.1}$	—	$-1.002^{+0.091}_{-0.080}$	—
DESI+CMB	0.281 ± 0.013	$71.3^{+1.5}_{-1.8}$	—	$-1.122^{+0.062}_{-0.054}$	—
DESI+CMB+Panth.	0.3095 ± 0.0069	67.74 ± 0.71	—	-0.997 ± 0.025	—
DESI+CMB+Union3	0.3095 ± 0.0083	67.76 ± 0.90	—	-0.997 ± 0.032	—
DESI+CMB+DESY5	0.3169 ± 0.0065	66.92 ± 0.64	—	-0.967 ± 0.024	—
w_0w_aCDM					
DESI	$0.344^{+0.047}_{-0.026}$	—	—	$-0.55^{+0.39}_{-0.21}$	< -1.32
DESI+BBN+θ_*	$0.338^{+0.039}_{-0.029}$	$65.0^{+2.3}_{-3.6}$	—	$-0.53^{+0.42}_{-0.22}$	< -1.08
DESI+CMB	$0.344^{+0.032}_{-0.027}$	$64.7^{+2.2}_{-3.3}$	—	$-0.45^{+0.34}_{-0.21}$	$-1.79^{+0.48}_{-1.0}$
DESI+CMB+Panth.	0.3085 ± 0.0068	68.03 ± 0.72	—	-0.827 ± 0.063	$-0.75^{+0.29}_{-0.25}$
DESI+CMB+Union3	0.3230 ± 0.0095	66.53 ± 0.94	—	-0.65 ± 0.10	$-1.27^{+0.40}_{-0.34}$
DESI+CMB+DESY5	0.3160 ± 0.0065	67.24 ± 0.66	—	-0.727 ± 0.067	$-1.05^{+0.31}_{-0.27}$
w_0w_aCDM+Ω_K					
DESI	0.313 ± 0.049	—	87^{+100}_{-85}	$-0.70^{+0.49}_{-0.25}$	< -1.21
DESI+BBN+θ_*	$0.346^{+0.042}_{-0.024}$	$65.8^{+2.6}_{-3.5}$	$5.9^{+9.1}_{-6.9}$	$-0.52^{+0.38}_{-0.19}$	< -1.44
DESI+CMB	$0.347^{+0.031}_{-0.025}$	$64.3^{+2.0}_{-3.2}$	-0.9 ± 2	$-0.41^{+0.33}_{-0.18}$	< -1.61
DESI+CMB+Panth.	0.3084 ± 0.0067	68.06 ± 0.74	0.3 ± 1.8	-0.831 ± 0.066	$-0.73^{+0.32}_{-0.28}$
DESI+CMB+Union3	$0.3233^{+0.0089}_{-0.010}$	66.45 ± 0.98	-0.4 ± 1.9	-0.64 ± 0.11	$-1.30^{+0.45}_{-0.39}$
DESI+CMB+DESY5	0.3163 ± 0.0065	67.19 ± 0.69	-0.2 ± 1.9	-0.725 ± 0.071	$-1.06^{+0.35}_{-0.31}$

Table 3. Cosmological parameter results from DESI DR1 BAO data in combination with external datasets and priors, in the baseline flat ΛCDM model and extensions including spatial curvature and two parametrizations of the dark energy equation of state, as listed. Results are quoted for the marginalized means and 68% credible intervals in each case, including for upper limits. Note that

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Instituto de Física UNAM

DESI
“First Cosmological Results” 2024

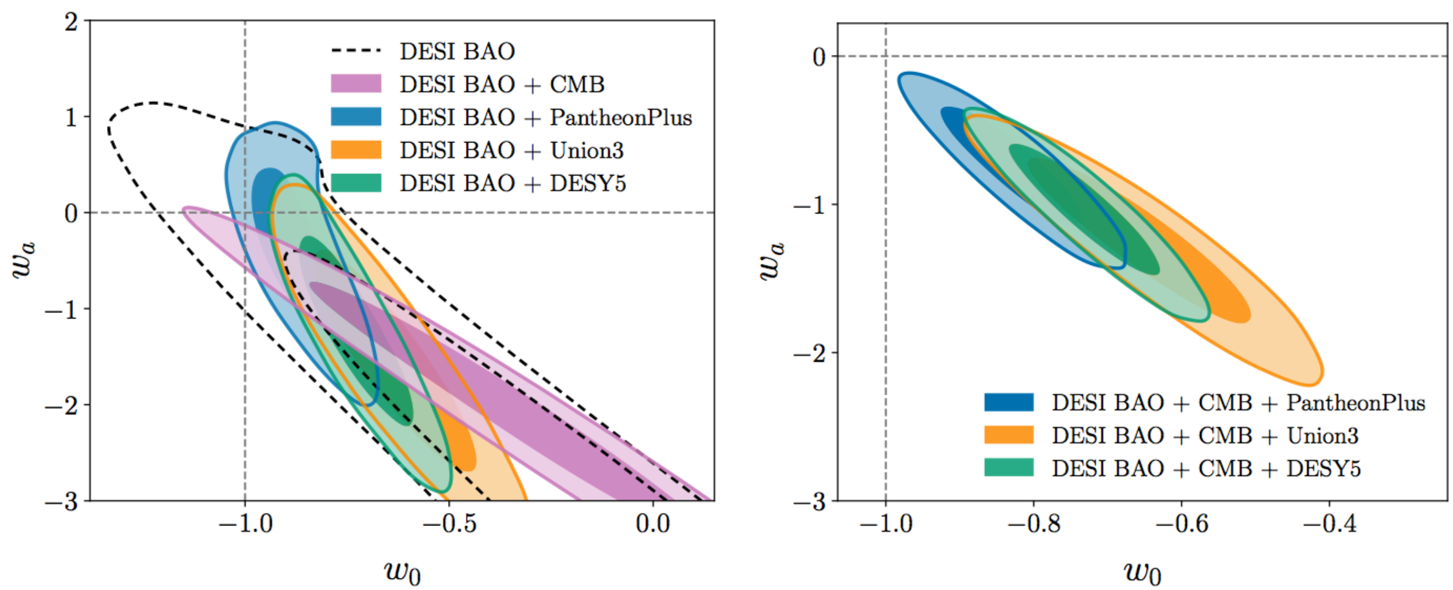


Figure 6. *Left panel*: 68% and 95% marginalized posterior constraints in the w_0–w_a plane for the flat w_0w_aCDM model, from DESI BAO alone (black dashed), DESI + CMB (pink), and DESI + SN Ia, for the PantheonPlus [24], Union3 [25] and DESY5 [26] SNIa datasets in blue, orange and green respectively. Each of these combinations favours $w_0 > -1$, $w_a < 0$, with several of them exhibiting mild discrepancies with ΛCDM at the $\gtrsim 2\sigma$ level. However, the full constraining power is not realised without combining all three probes. *Right panel*: the 68% and 95% marginalized posterior constraints from DESI BAO combined with CMB and each of the PantheonPlus, Union3 and DESY5 SN Ia datasets. The significance of the tension with ΛCDM ($w_0 = -1$, $w_a = 0$) estimated from the $\Delta\chi^2_{\rm MAP}$ values is 2.5σ, 3.5σ and 3.9σ for these three cases respectively.

Slide courtesy of DESI collaboration

DARK ENERGY SPECTROSCOPIC INSTRUMENT

Summary and Conclusions

Instituto de Física UNAM

- DESI has gathered the largest and deepest map of galaxies and quasars as well as Lyman-Alpha Forest in our Universe, spanning 11 billion years

- DESI is measuring a record high of millions galaxies/quasars of 1.2 million in week (weather dependent)

- Lymann-Alpha data allow as to determine the clustering of matter even before galaxies have been formed

- DESI year-one results suggest that Dark Energy is NOT a Cosmological Constant (at 95% confidence level) implying a dynamical Dark Energy

- In the next years DESI, together with other cosmological data, will be able to rule out a cosmological constant as Dark Energy

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Evolution of our Universe

Instituto de Física UNAM

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

$$t_{Planck} = 10^{-44} seg$$

$$t_{Inf} = 10^{-32} seg$$

$$t_{NS} = 1 \min$$

$$\rho_{Planck} = (10^{19} GeV)^4$$

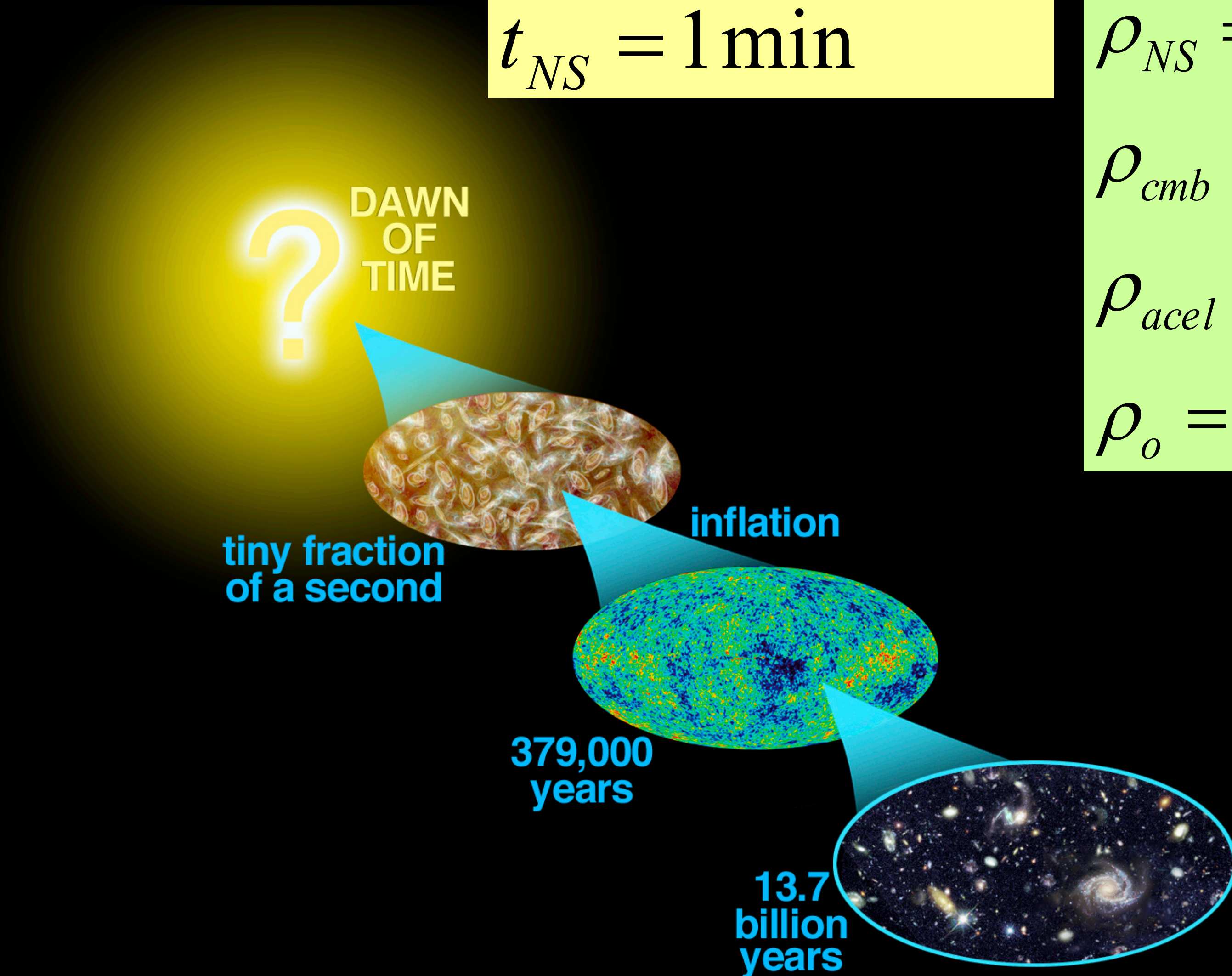
$$\rho_{Inf} = (10^{16} GeV)^4$$

$$\rho_{NS} = (10^{-3} GeV)^4$$

$$\rho_{cmb} = (0.5 * 10^{-9} GeV)^4$$

$$\rho_{acel} = (1.5 * 10^{-13} GeV)^4$$

$$\rho_o = (10^{-13} GeV)^4$$



$$\frac{\rho_{Planck}}{\rho_o} = 10^{138}$$