

Lecture 1

Brief history of the

Universe (B)

Gong-Bo Zhao
NAOC

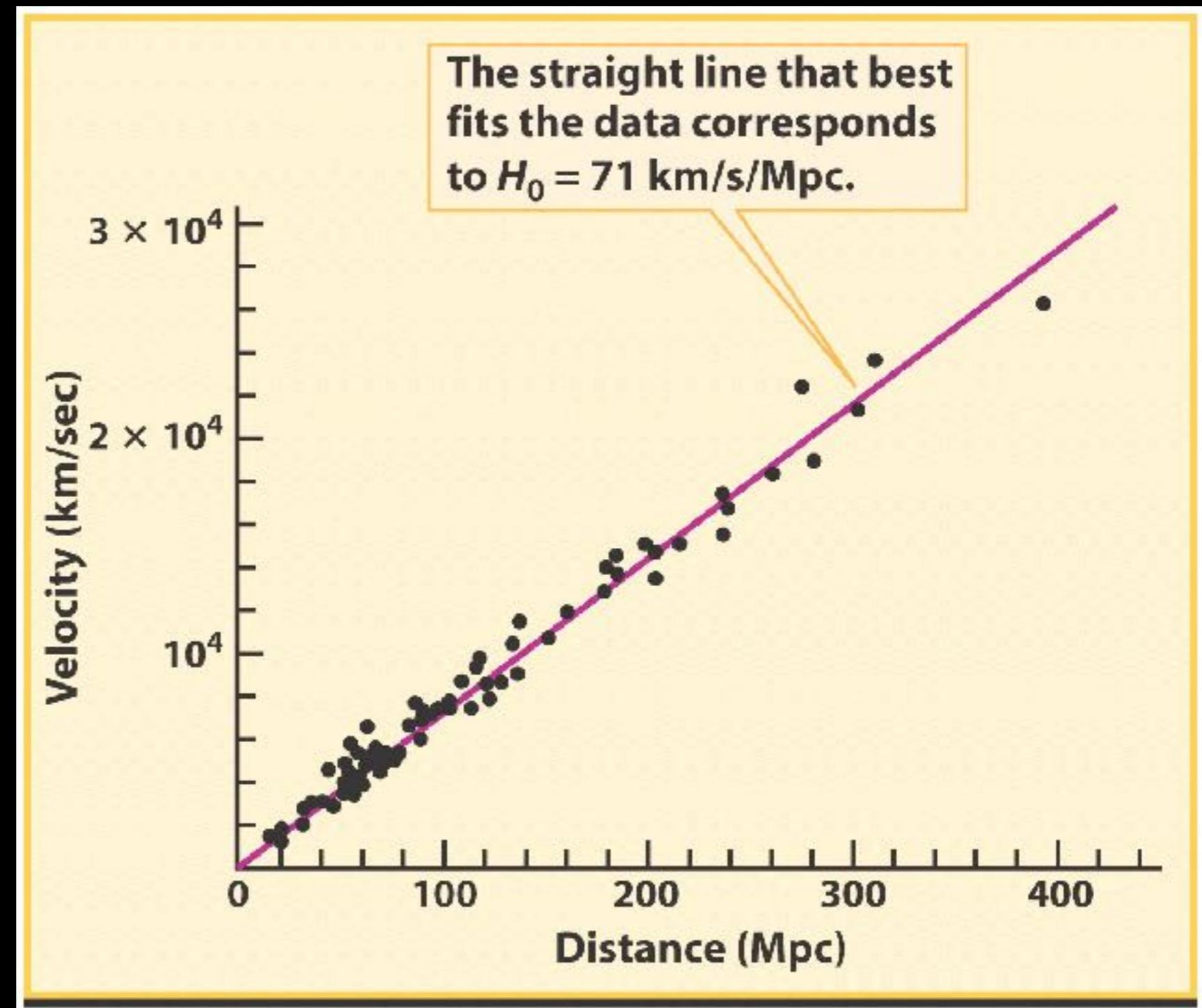
The Hubble law is $v = H_0 d$



Velocity v from redshift z :

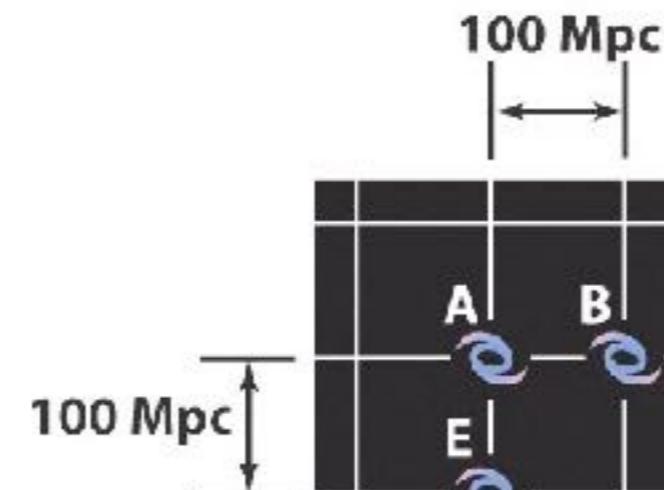
$$v = cz$$

provided that
 $z < 1$



The value of the Hubble constant, H_0 , is not known with certainty but is close to 71 km/s/Mpc

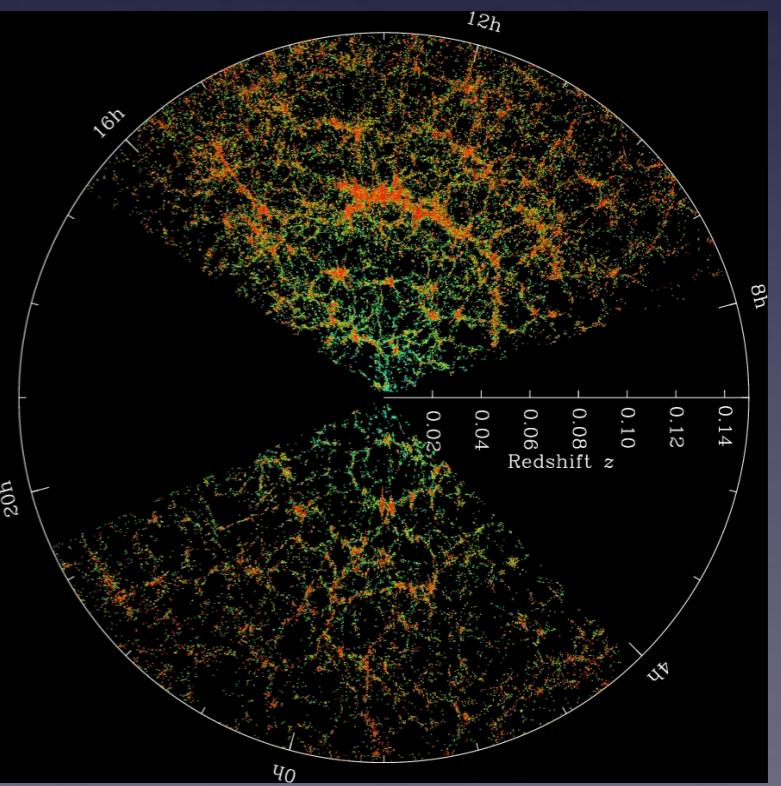
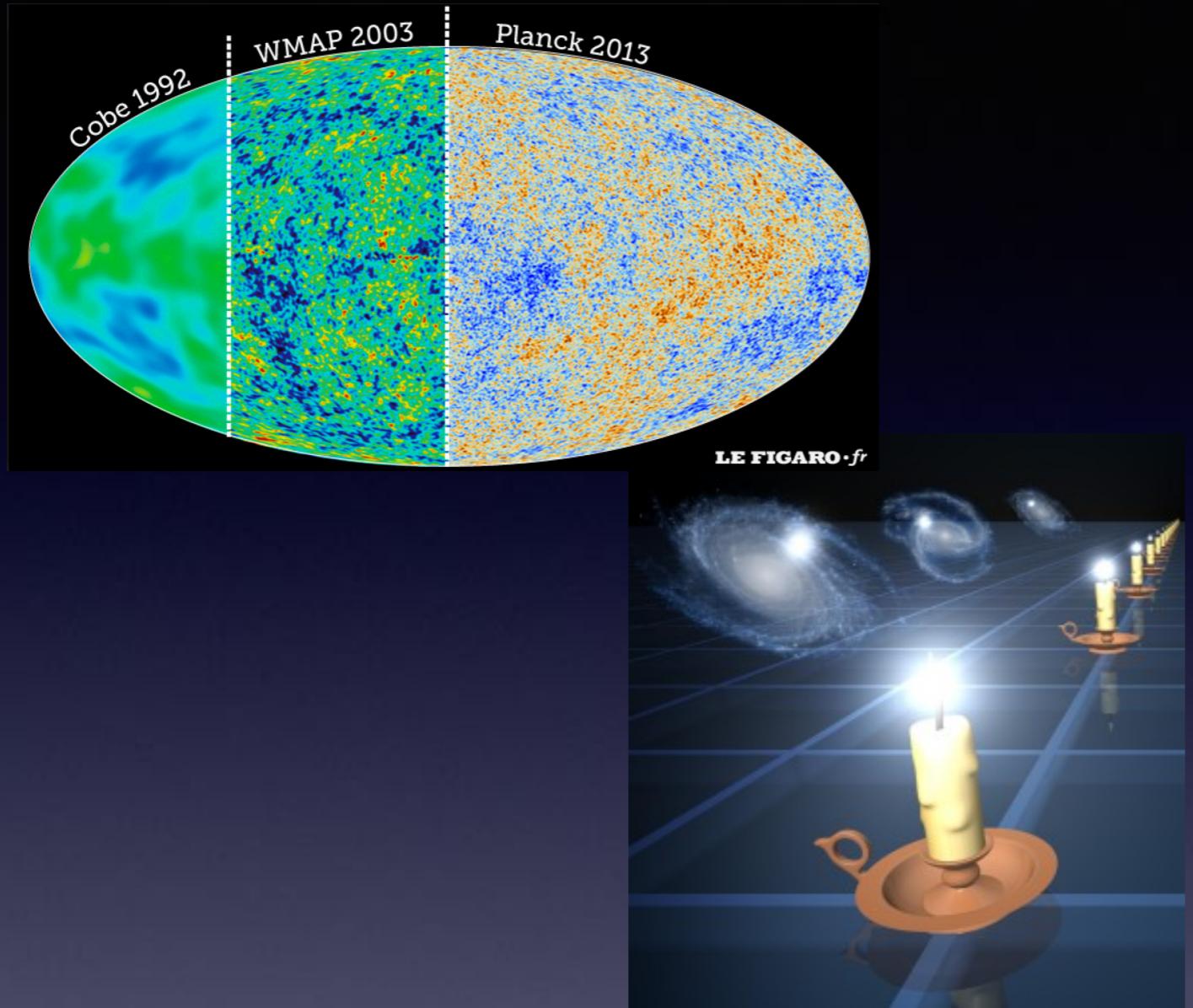
The universe is expanding



(a) Five galaxies spaced 100 Mpc apart



(b) The expansion of the universe spreads the galaxies apart



The Nobel Prize in Physics 2011



Photo: Ariel Zambelich, Copyright © Nobel Media AB

Saul Perlmutter



Photo: Belinda Pratten, Australian National University

Brian P. Schmidt

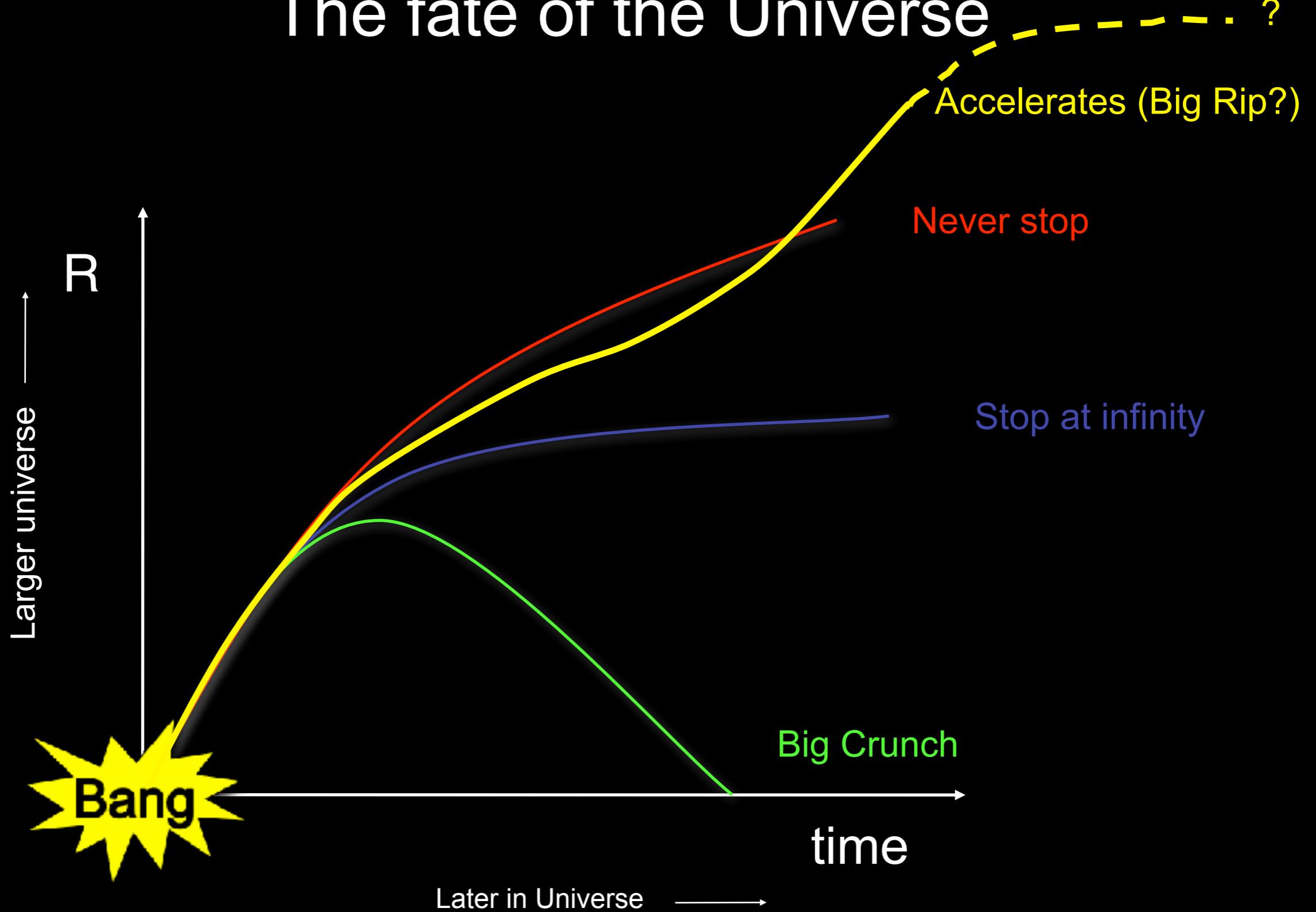


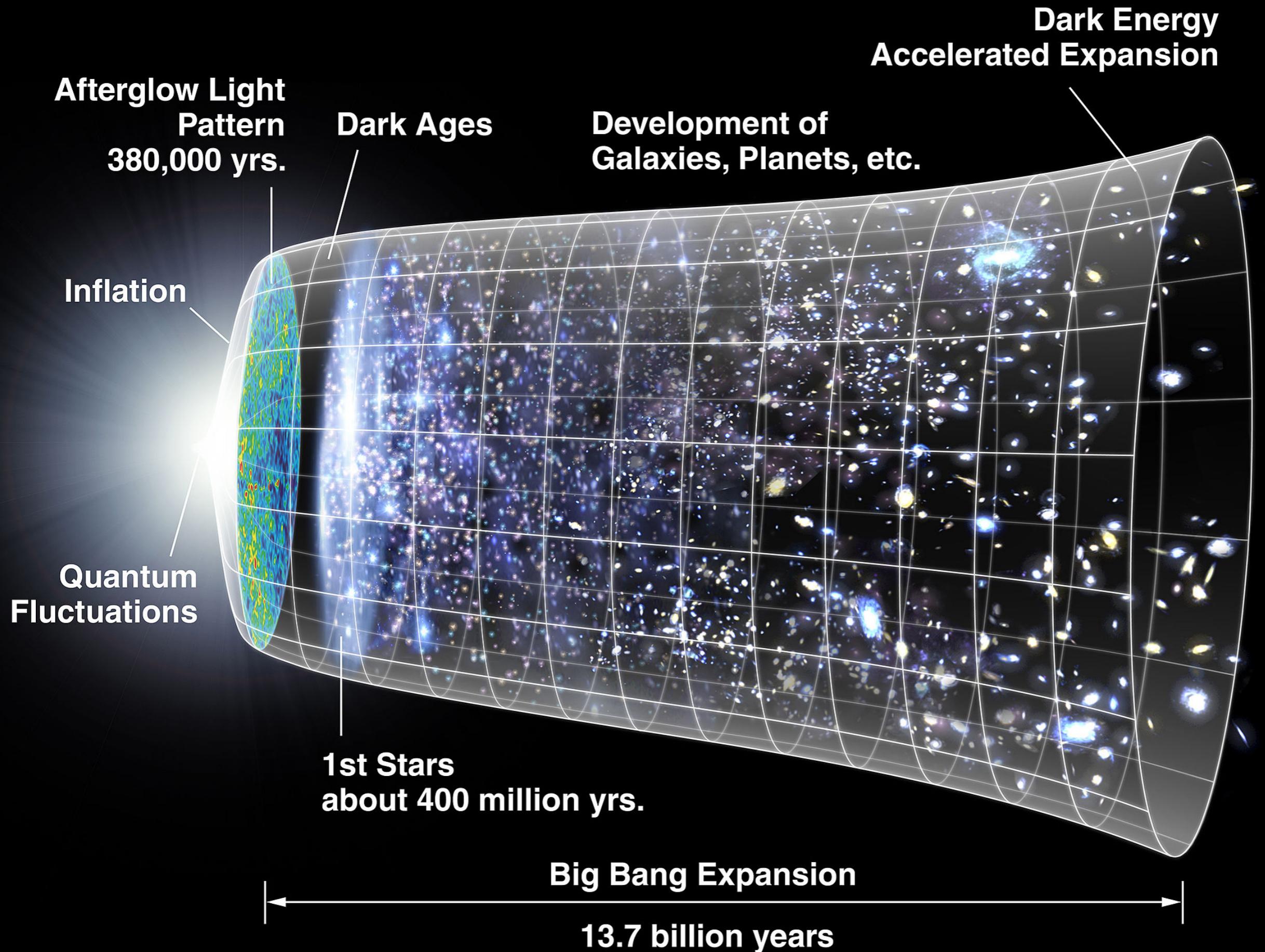
Photo: Homewood Photography

Adam G. Riess

The Nobel Prize in Physics 2011 was divided, one half awarded to Saul Perlmutter, the other half jointly to Brian P. Schmidt and Adam G. Riess "*for the discovery of the accelerating expansion of the Universe through observations of distant supernovae*".

The fate of the Universe



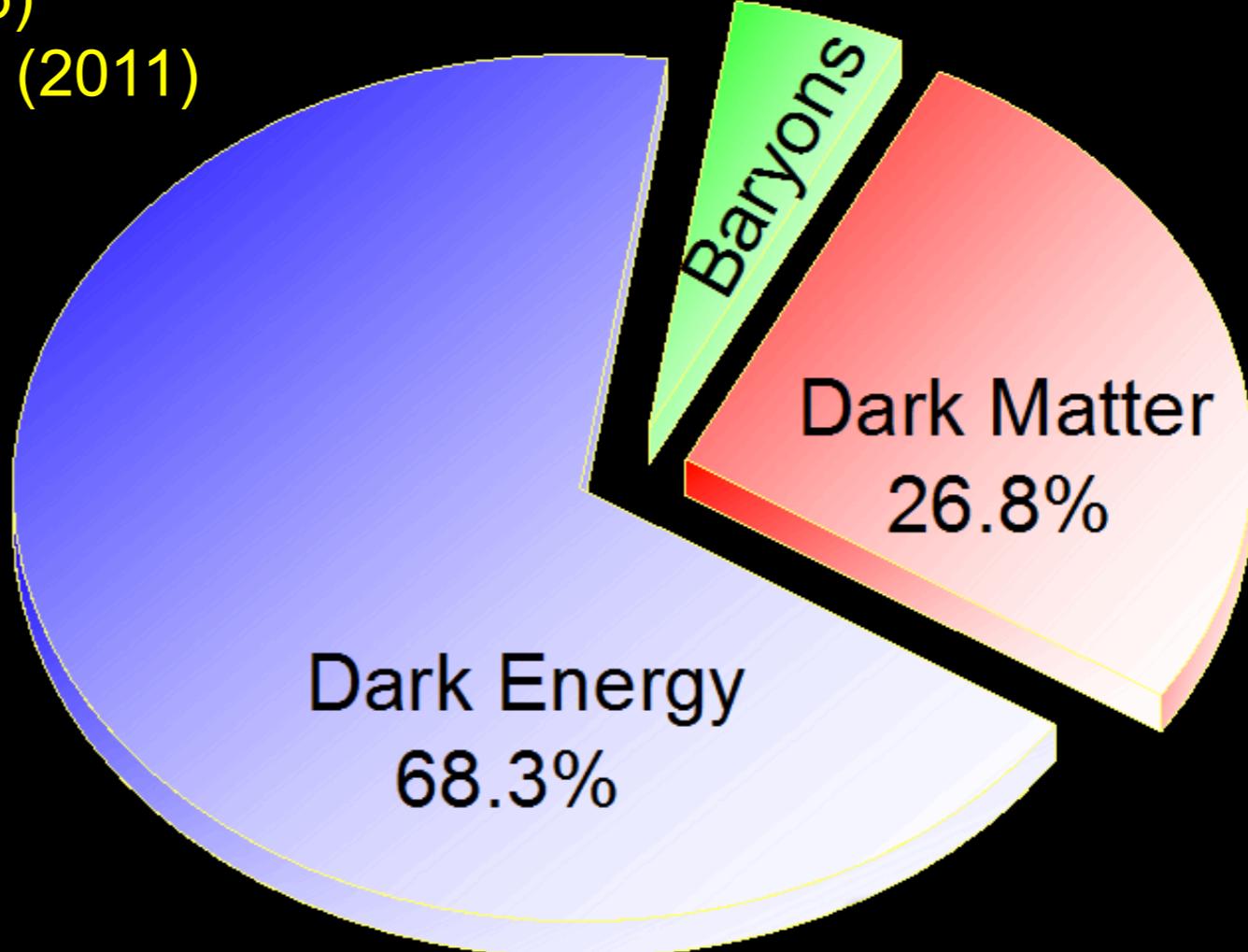


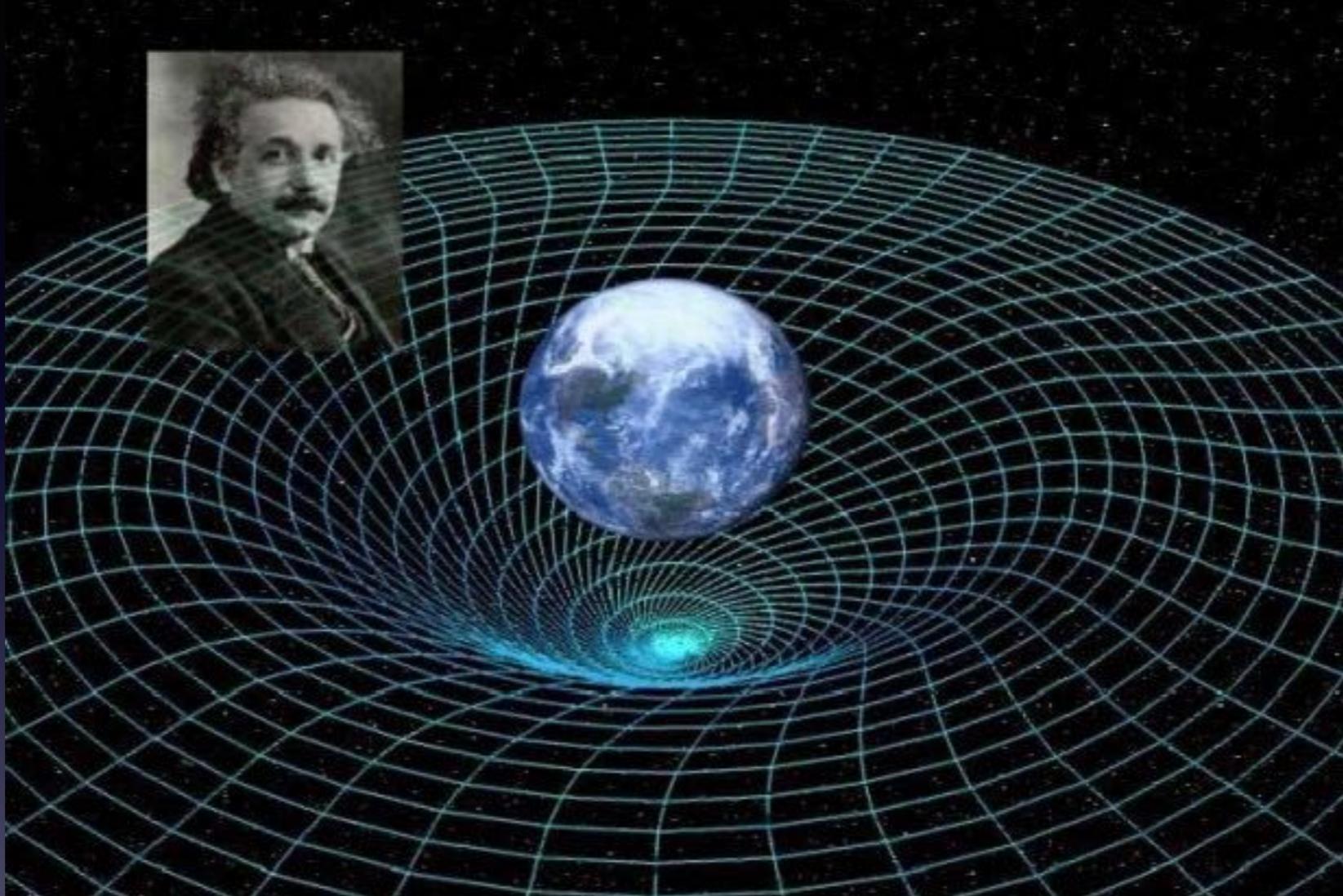
100+ Nobel Prizes since 1901!



Huge discovery space in the dark sector!

CMB (1978; 2006)
Cosmic Acceleration (2011)





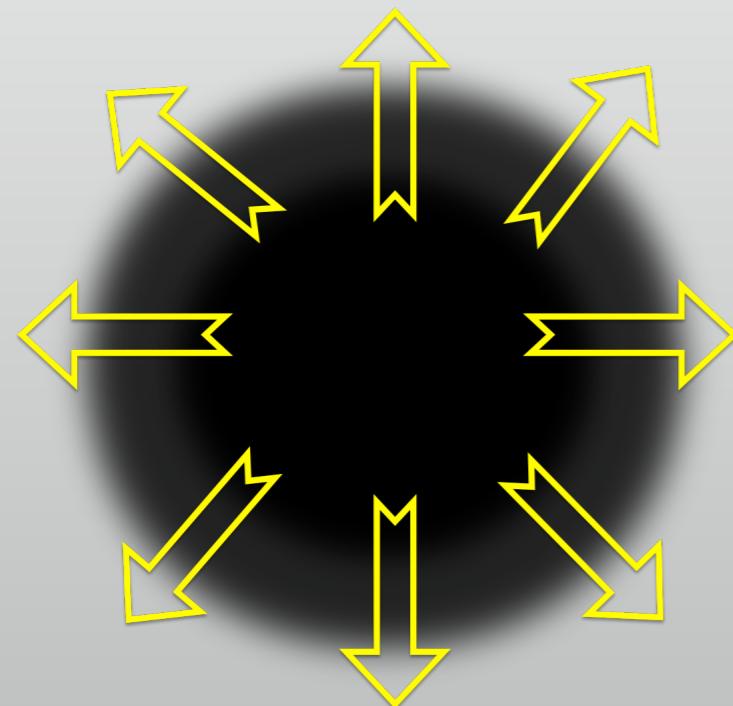
$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

The expansion of the Universe can **accelerate** if

In GR, to add new ‘repulsive matter’,
which contributes 70% total energy



To modify General Relativity



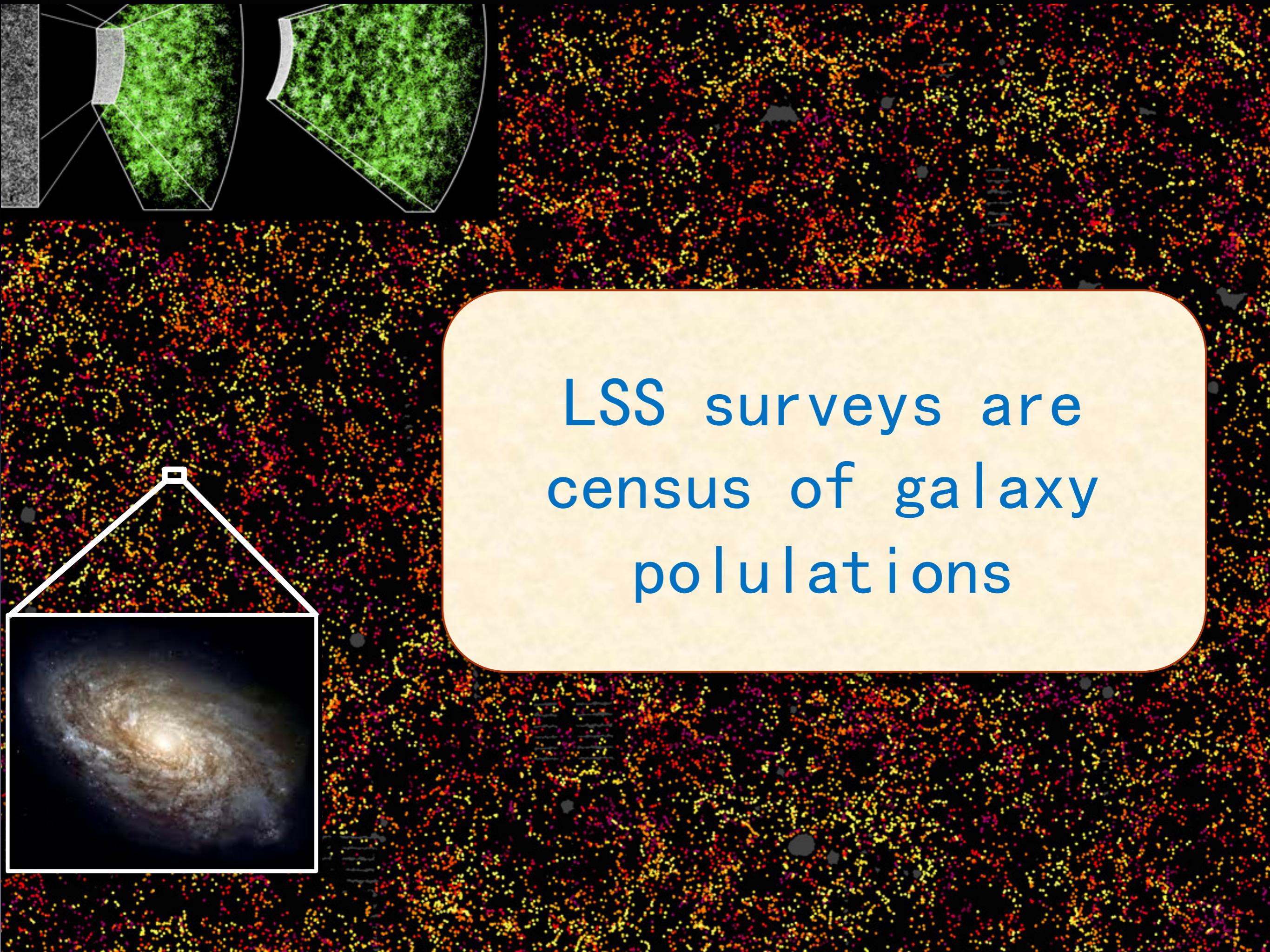
Dark Energy

$$G_{\mu\nu} = 8\pi G \tilde{T}_{\mu\nu}$$



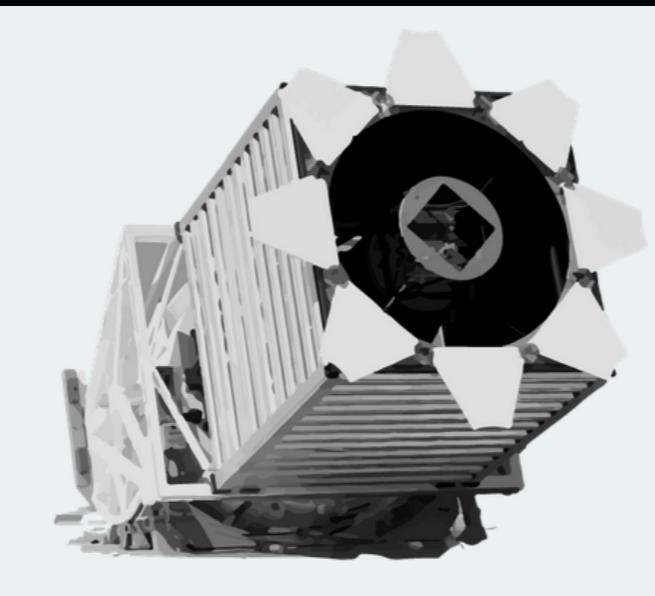
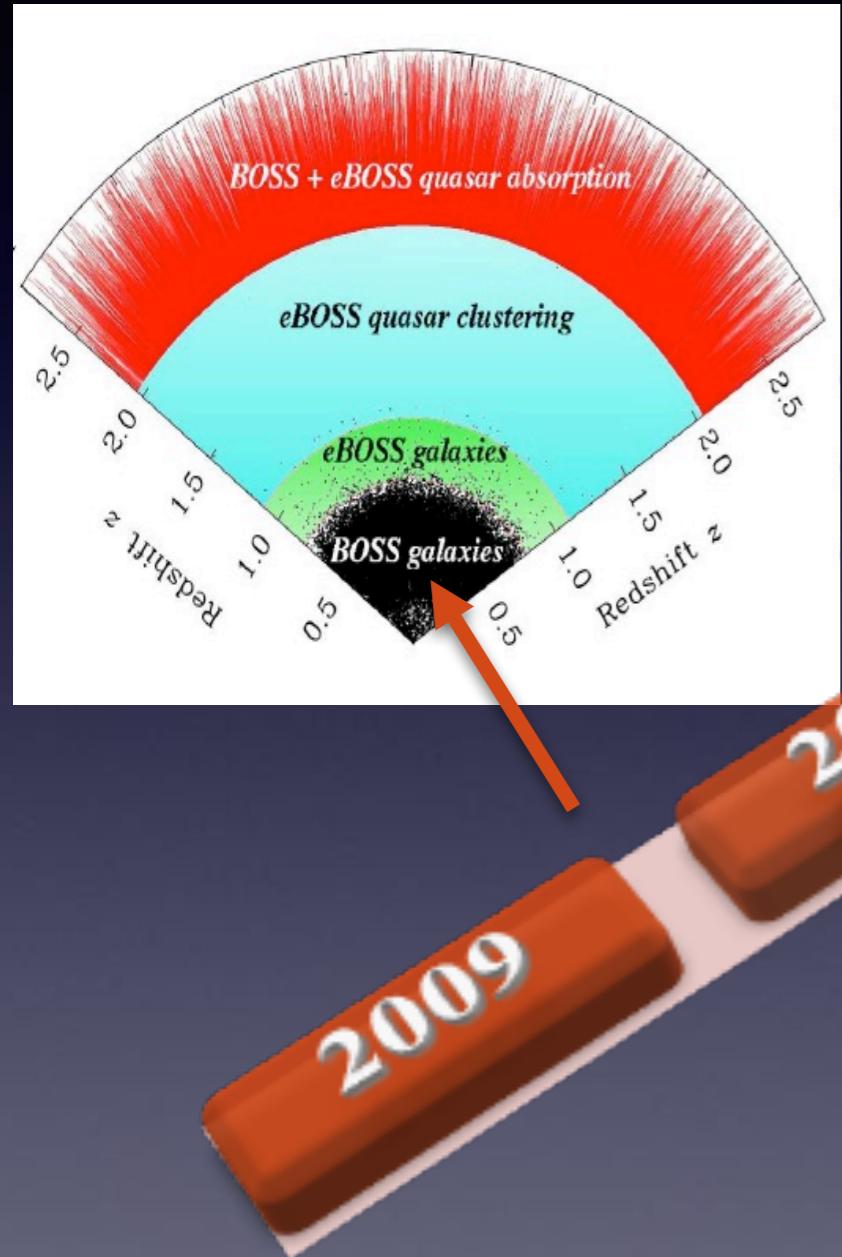
Modified Gravity

$$\tilde{G}_{\mu\nu} = 8\pi G T_{\mu\nu}$$



LSS surveys are
census of galaxy
populations





2.5 meter

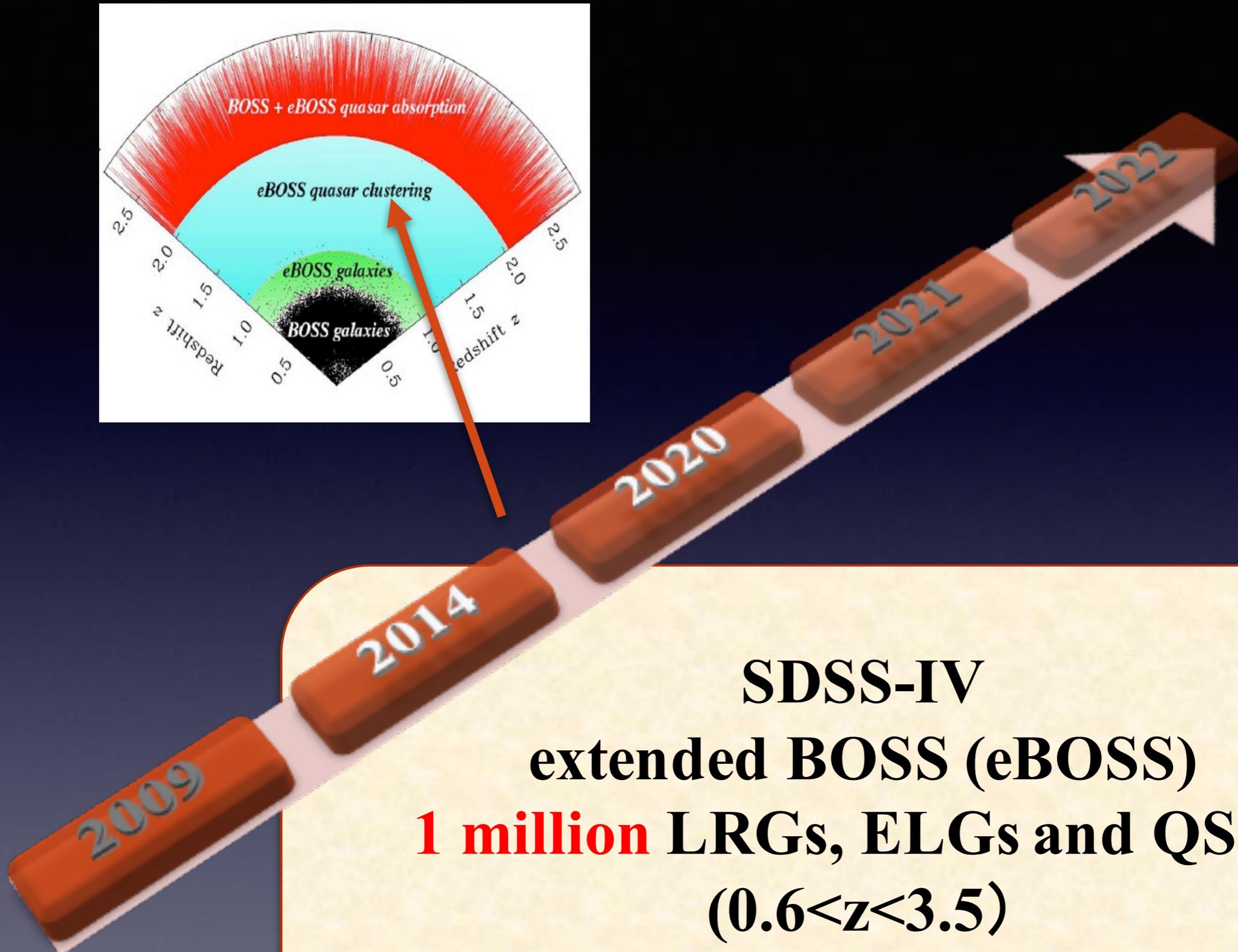
2014

2020

2021

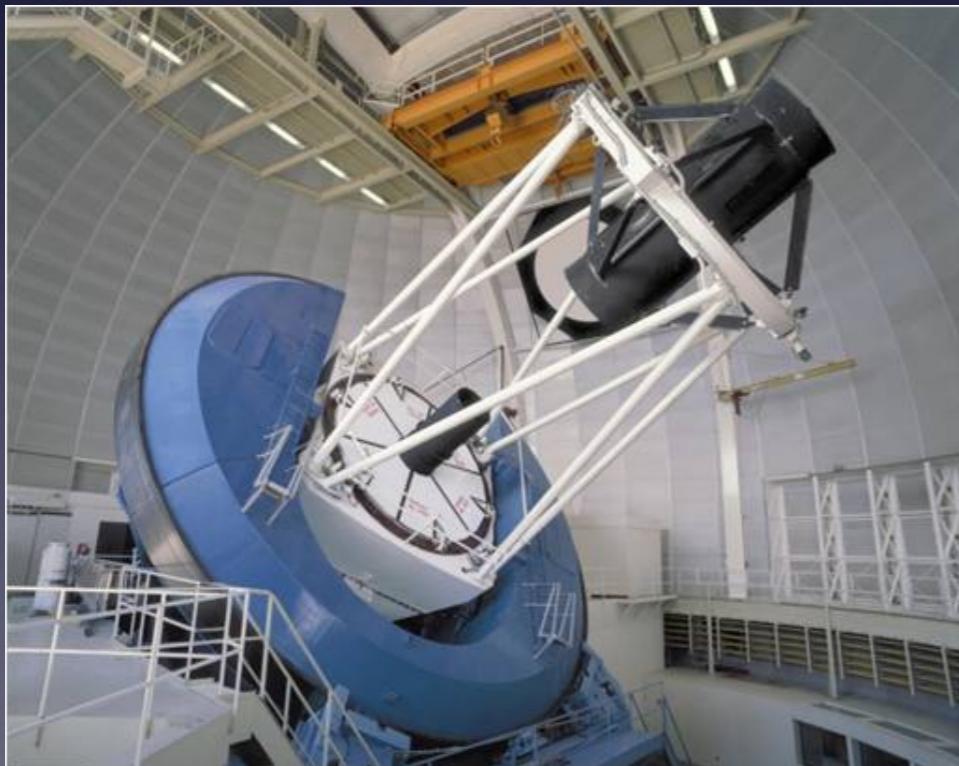
2022

**SDSS-III
Baryon Oscillation
Spectroscopic Survey
(BOSS)**
1.6 million LRGs
($z < 0.6$)
**Largest in the world in
the past 5 years**

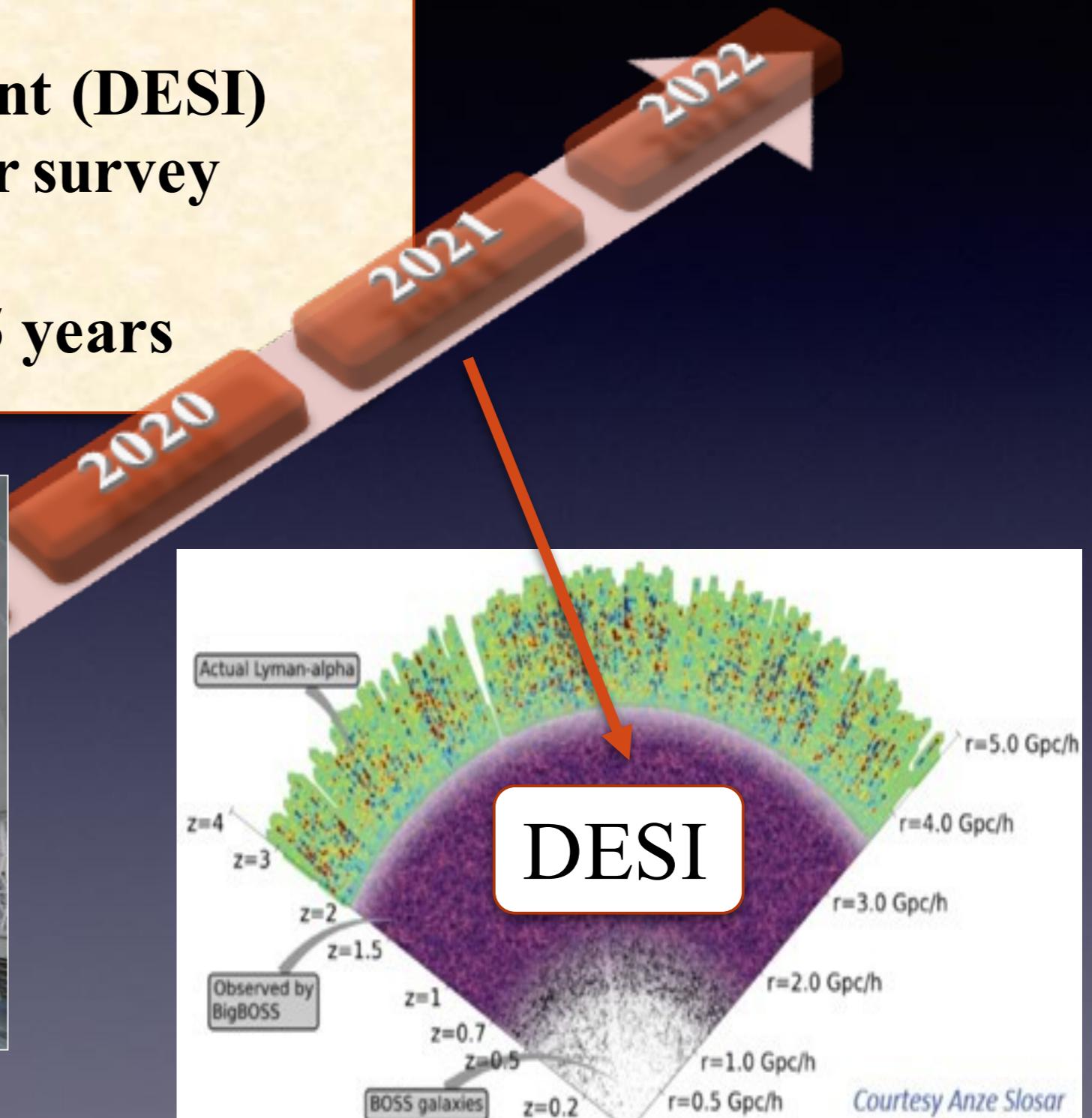


SDSS-IV
extended BOSS (eBOSS)
1 million LRGs, ELGs and QSOs
($0.6 < z < 3.5$)
Largest ongoing survey

Stage-IV survey
Dark Energy
Spectroscopic Instrument (DESI)
20 million multi-tracer survey
($0 < z < 3.5$)
Largest in the next 5 years

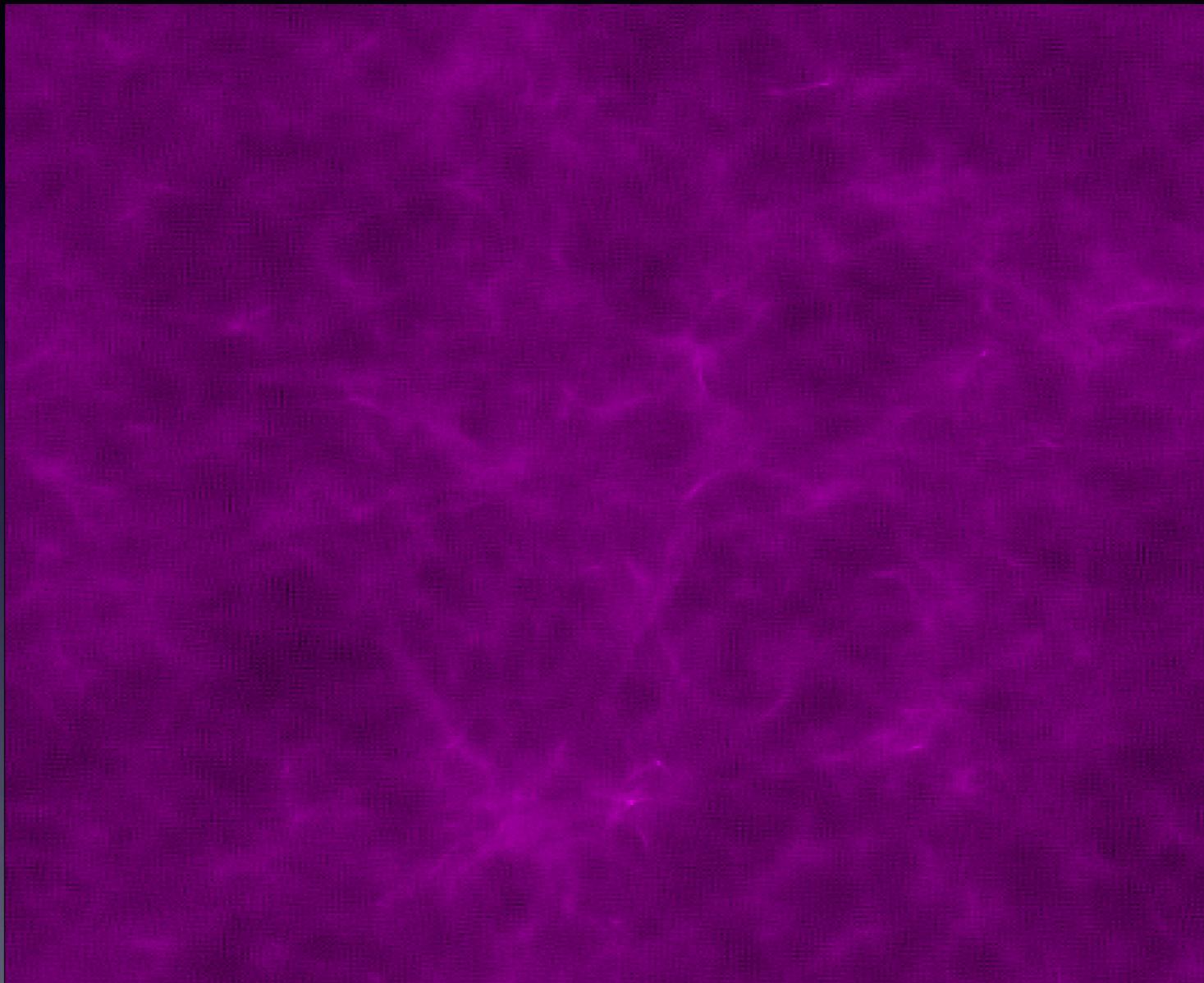


4 meter

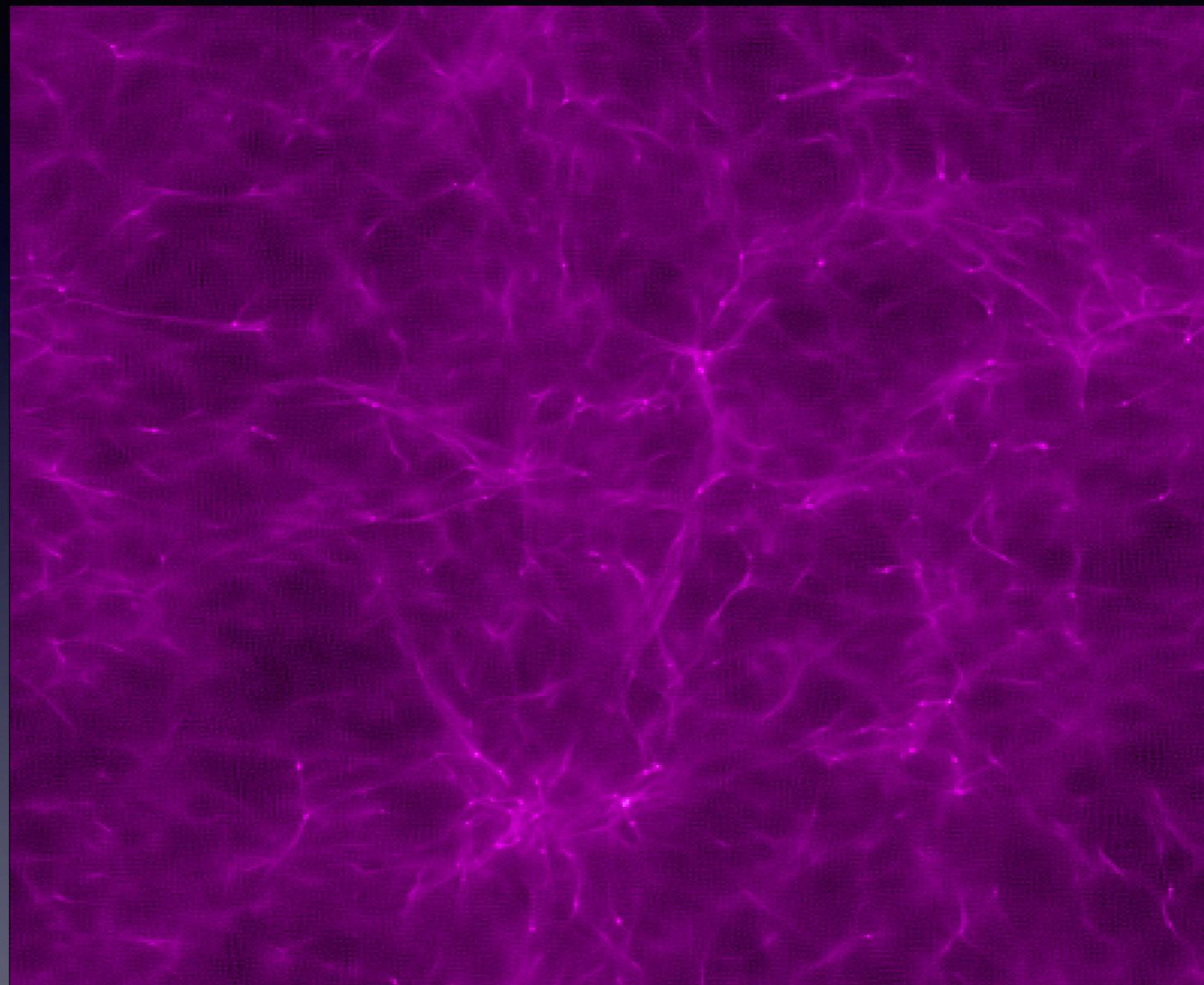


Courtesy Anze Slosar

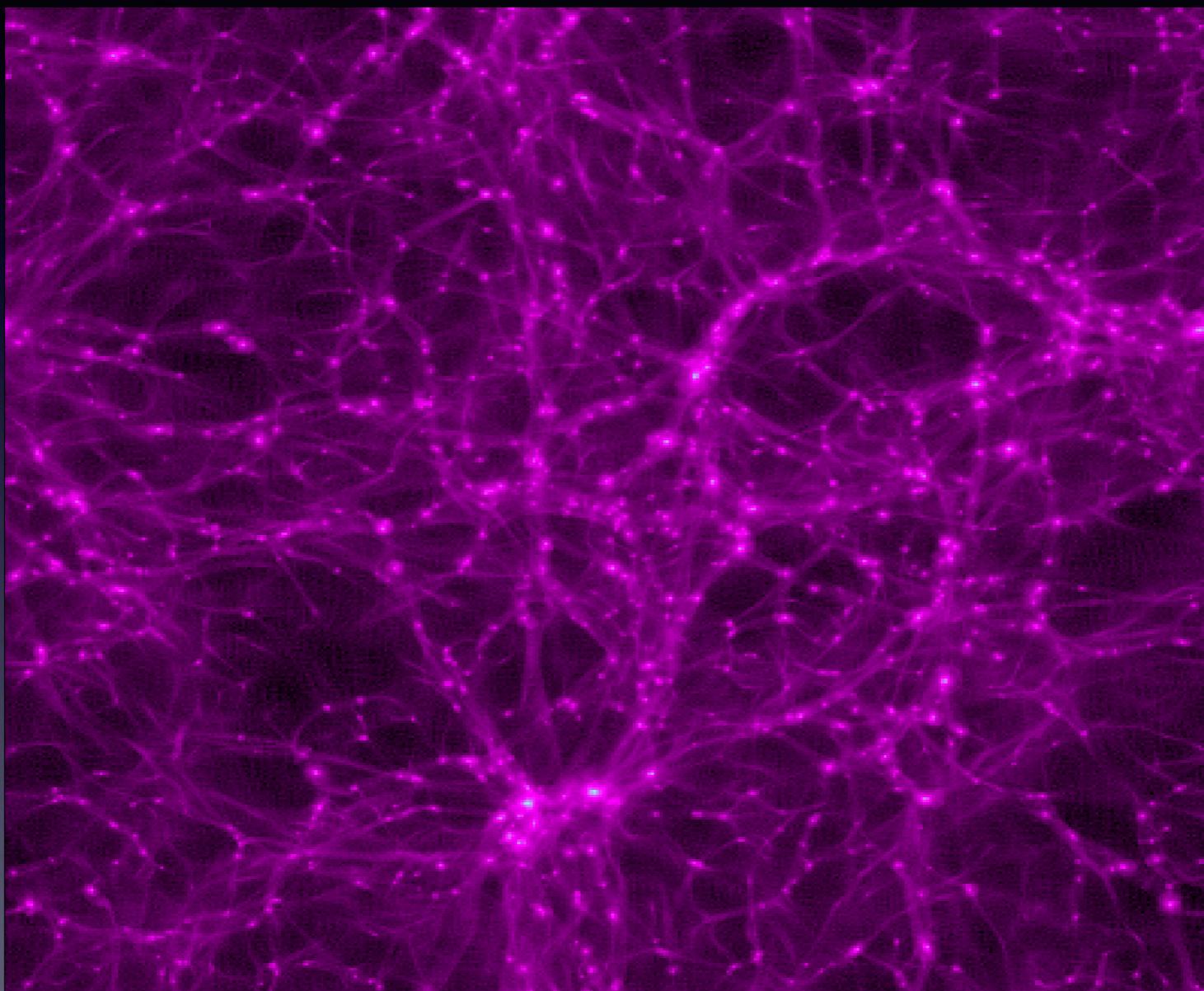
12 billion years ago



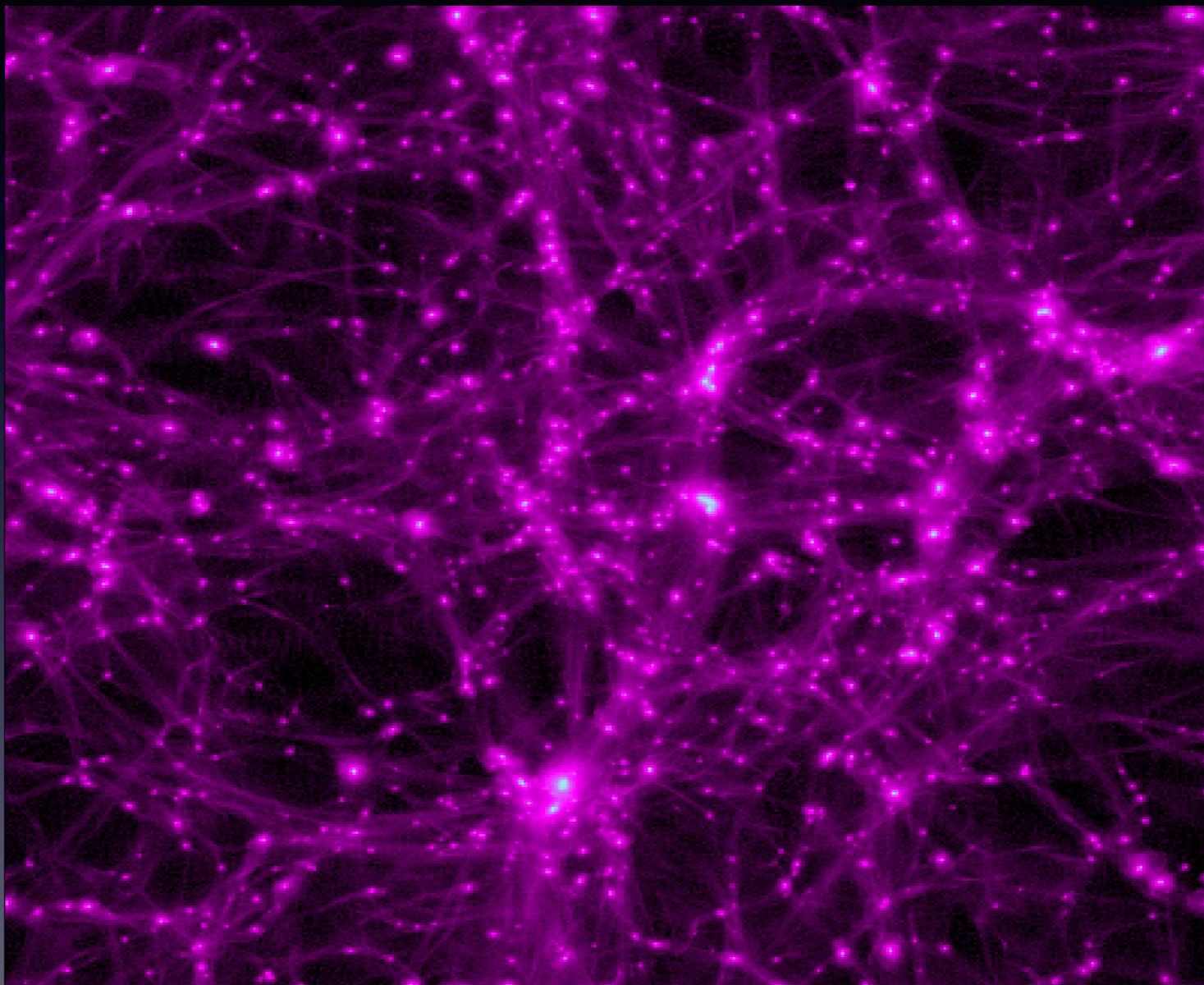
10 billion years ago



8 billion years ago



Today



Dark Energy

- Negative pressure:

$$\ddot{a} / a = -\frac{4\pi G}{3}(\rho + 3p) > 0$$

$$\Rightarrow w \equiv p / \rho < -1/3$$

- Candidates: Vacuum energy : $w = -1$

Dynamical fields:

Quintessence (Ratra & Peebles, 1988):

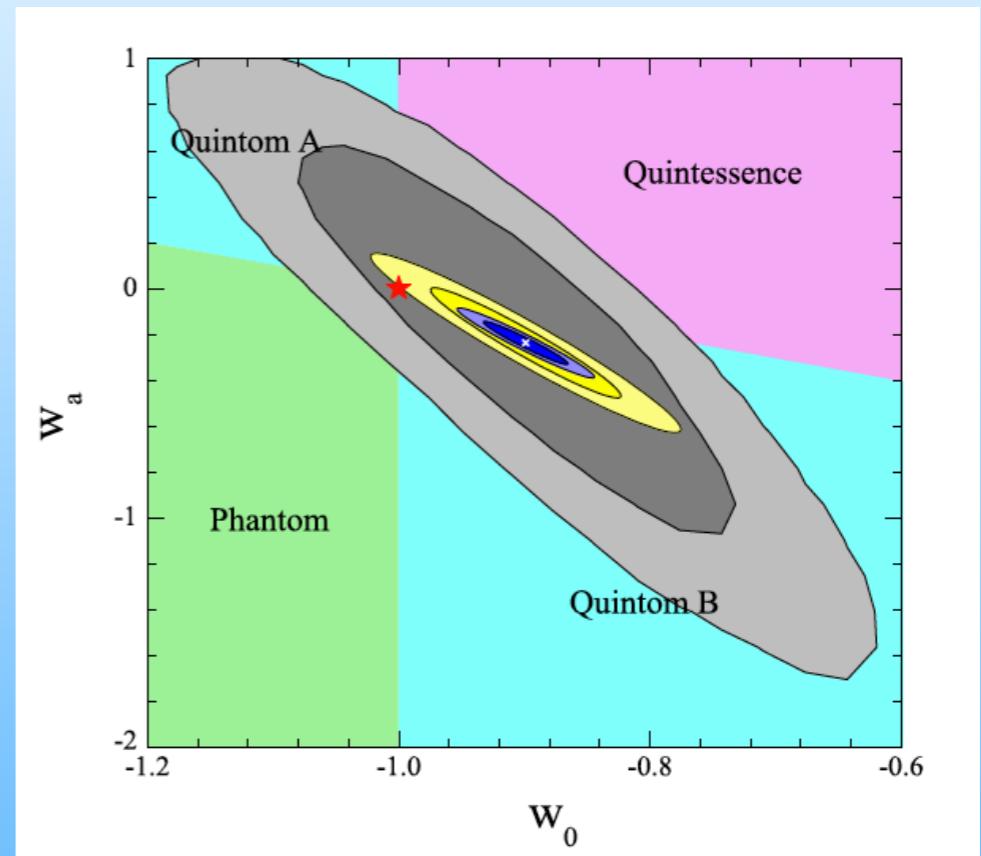
$w(a) > -1$

Phantom (Caldwell, 2002):

$w(a) < -1$

Quintom (Feng, Wang and Zhang 2004):

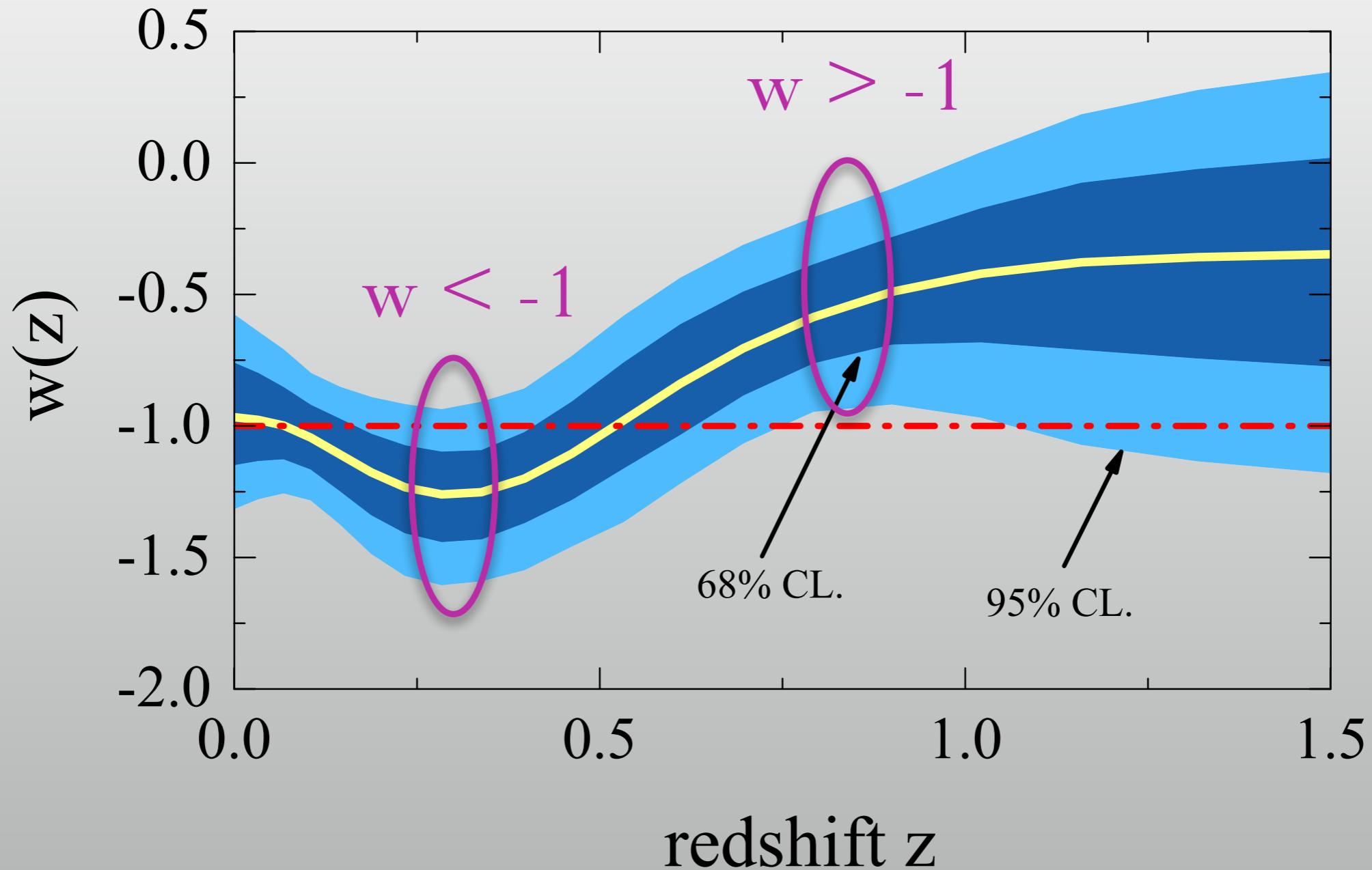
$w(a)$ across -1



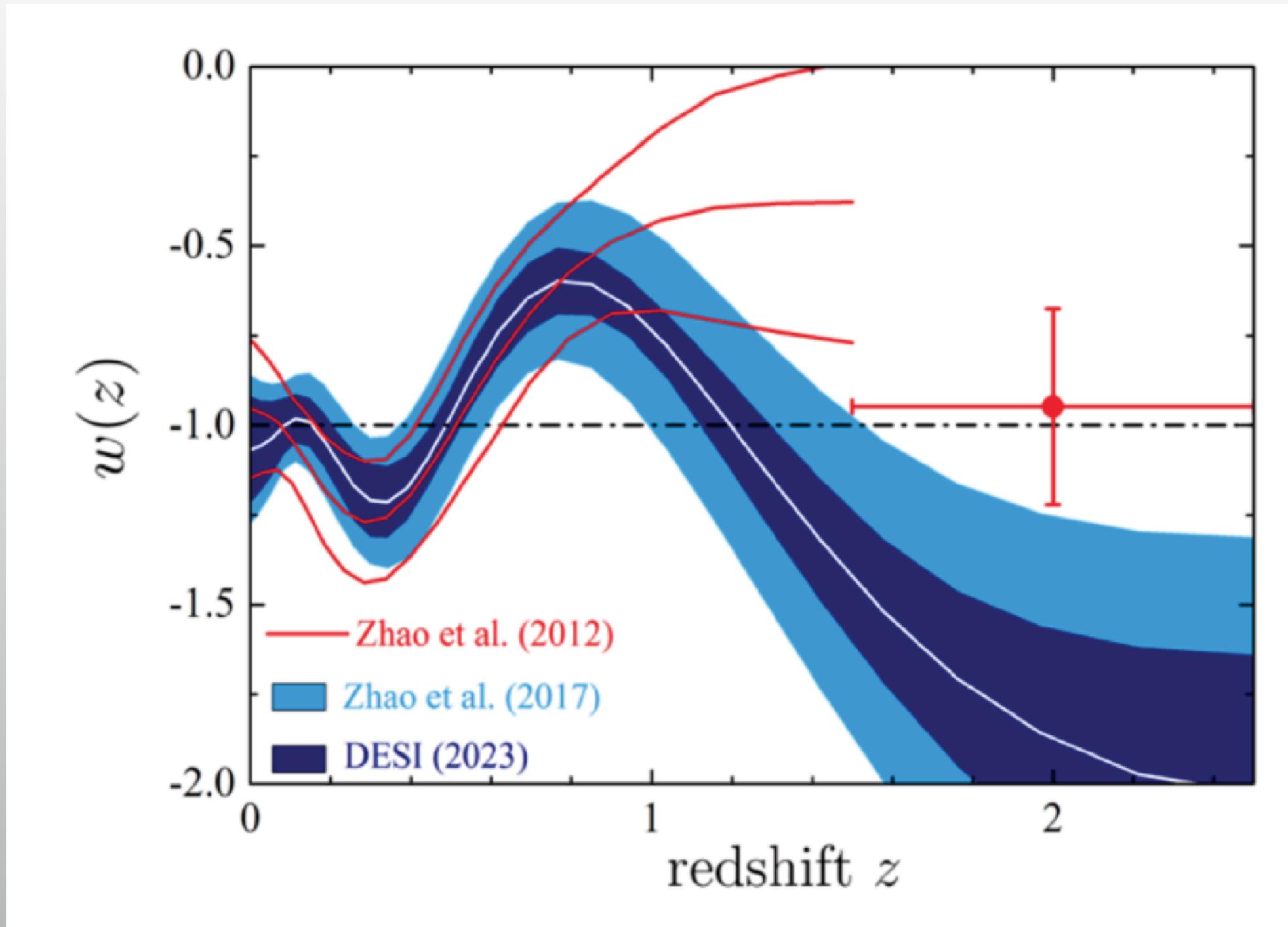
GBZ & Zhang, 2010

Reconstruct $w(a)$ non-parametrically

Real data circa 2012

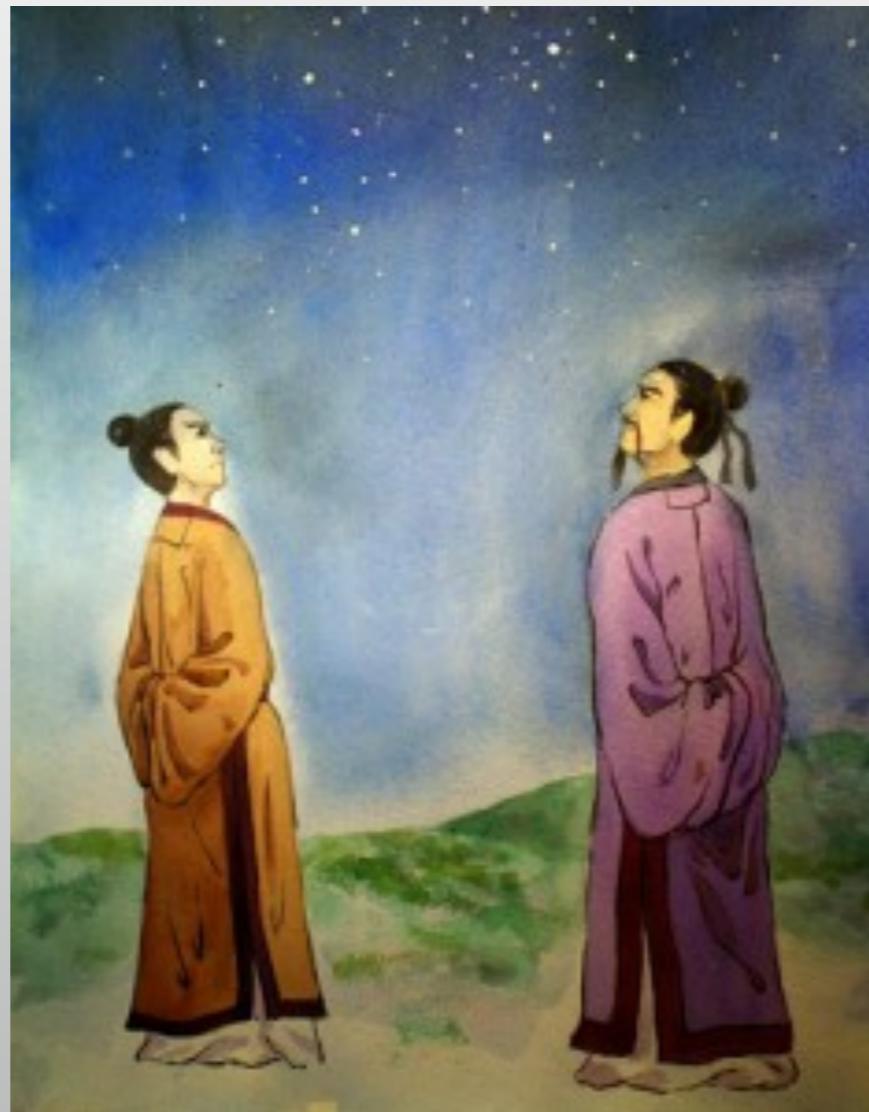


Reconstruct w(a) non-parametrically



Zhao et al., (BOSS collaboration), 2017
Nature Astronomy

China was GREAT in astronomy!!



The first star catalogues in the world
(Shi Shen & Gan DE; 4th century, BC)

China was GREAT in astronomy!!



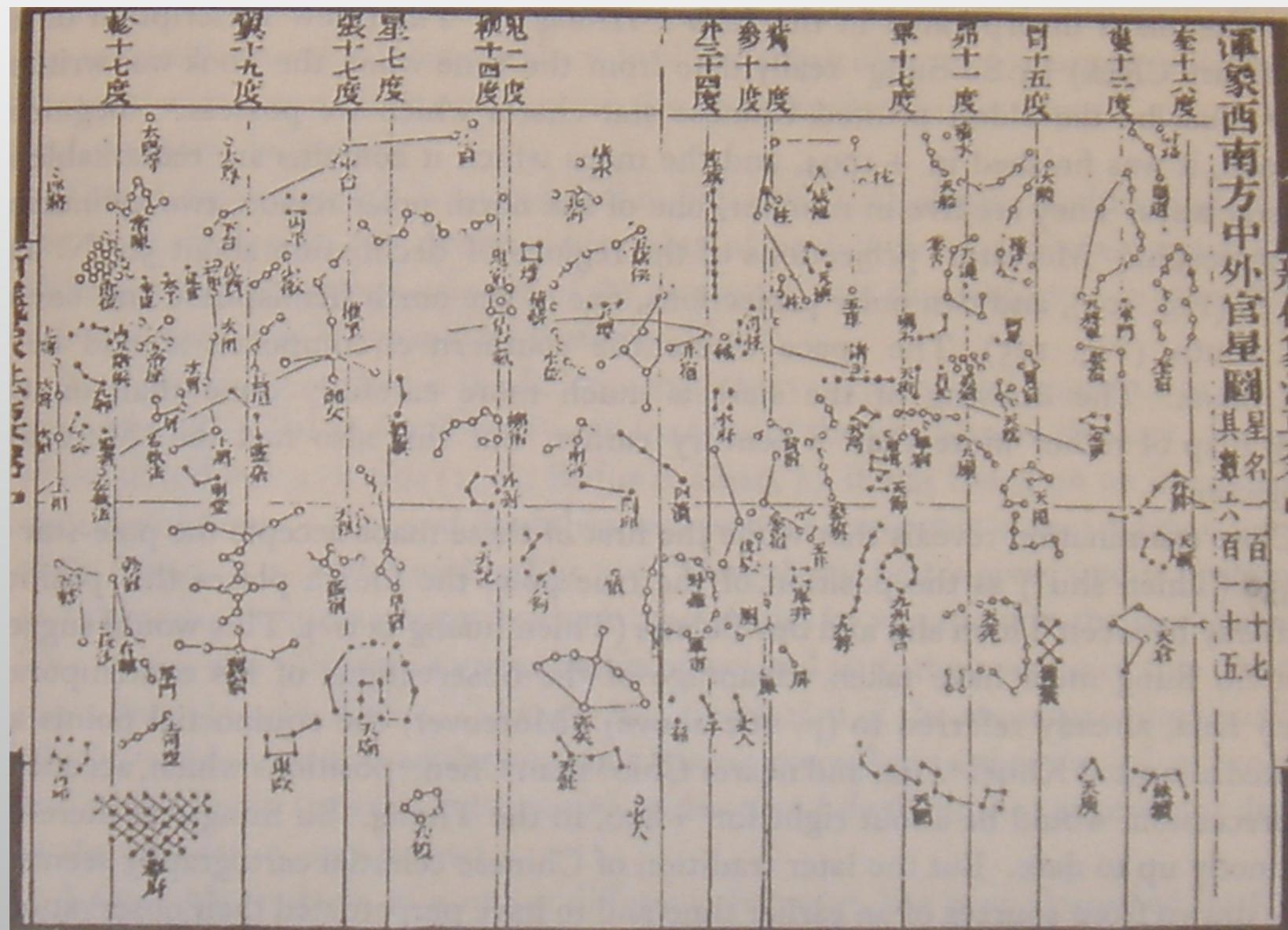
The first observation and record of
solar eclipse in the world
(2th century, BC)

China was GREAT in astronomy!!



The Earliest Record on Comet Halley
(613 BC)

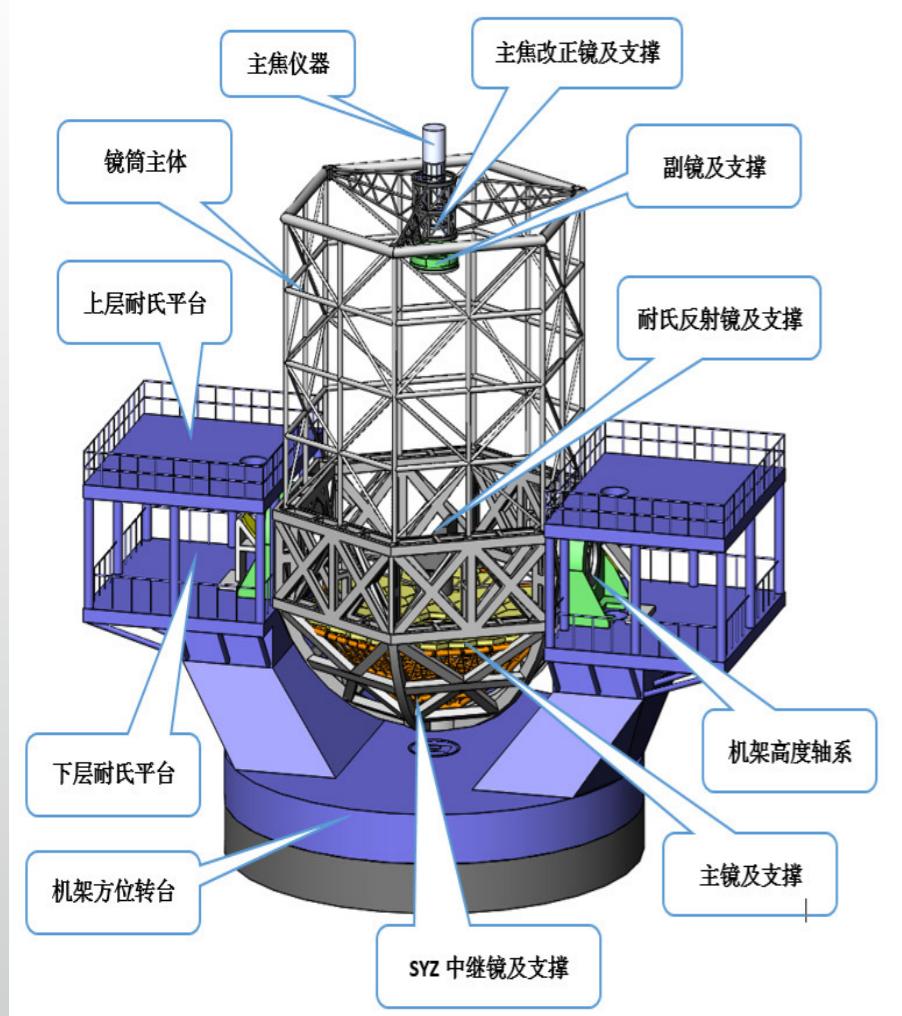
China was GREAT in astronomy!!



The Oldest Star Maps (Su Song; 1020 AD)

China was GREAT in astronomy!!





Make China GREAT
again in astronomy!!