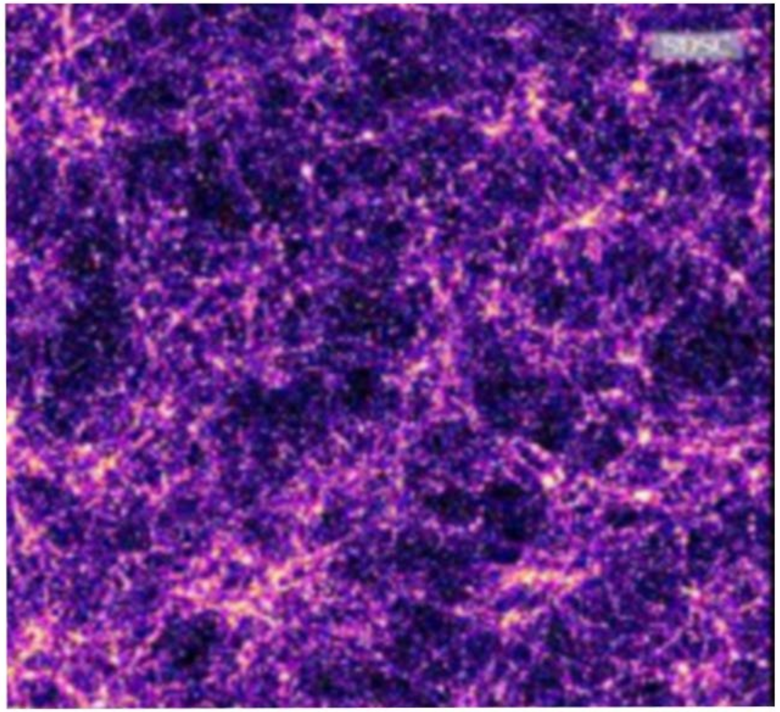
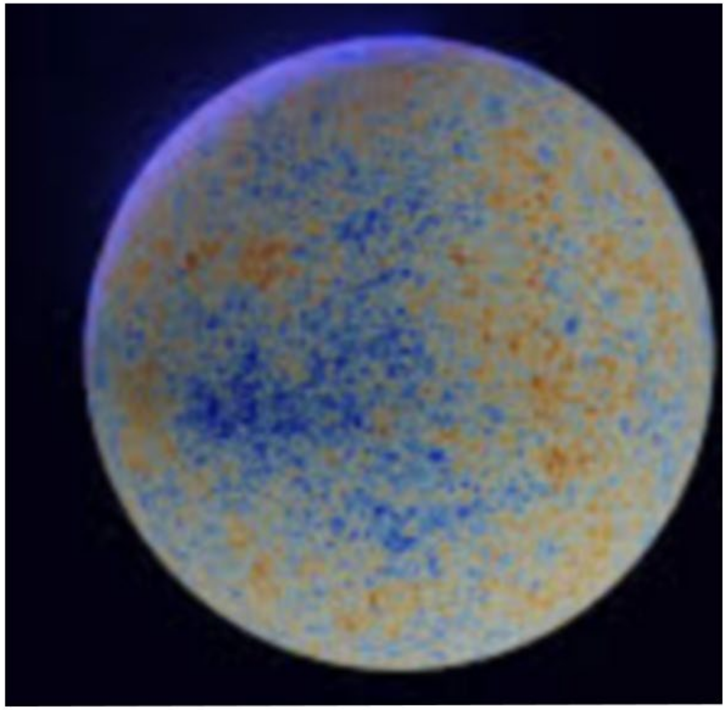




SSM
Scuola Superiore Meridionale

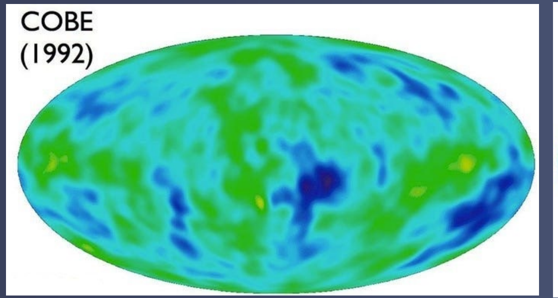
Quasar Cosmology and tensions with cosmological probes

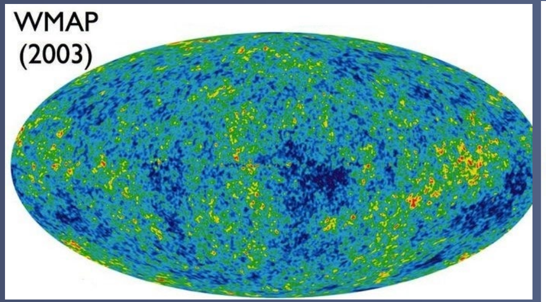
Micol Benetti

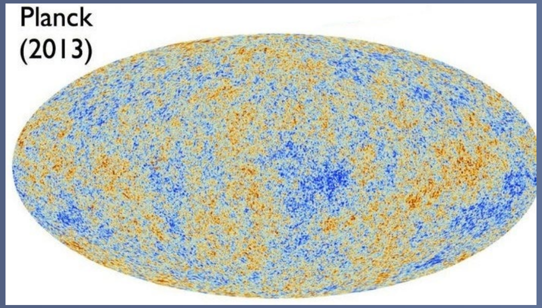
PONT 2023

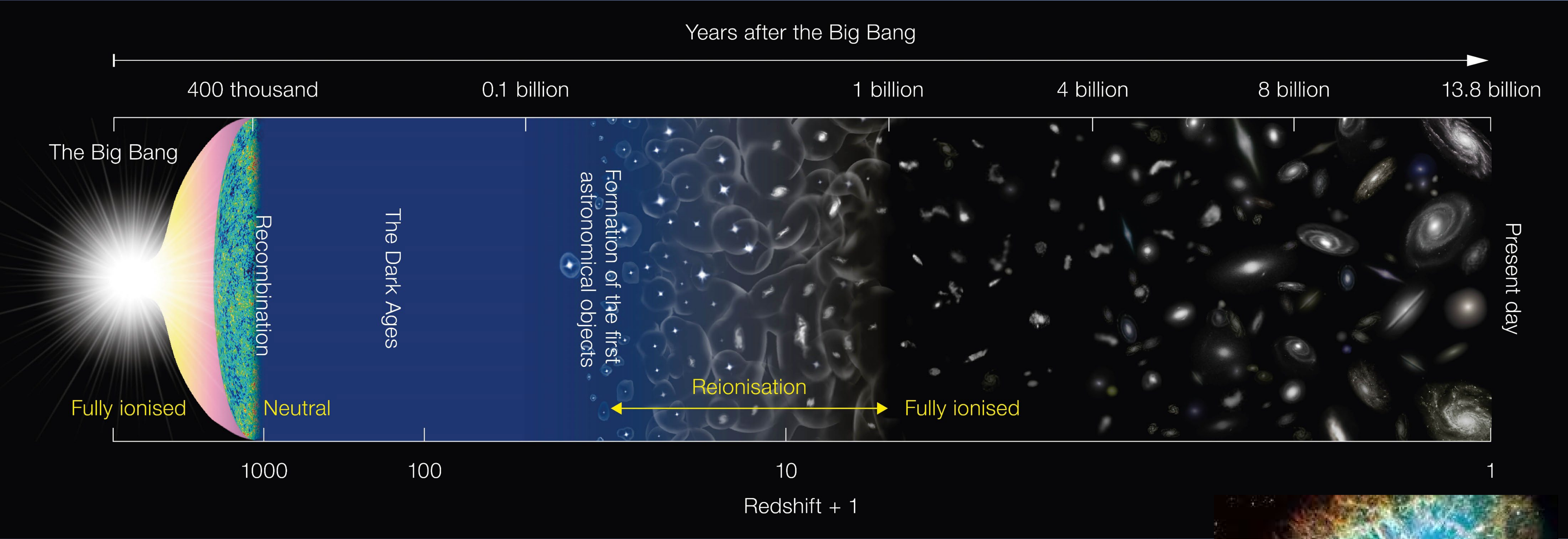
Outline

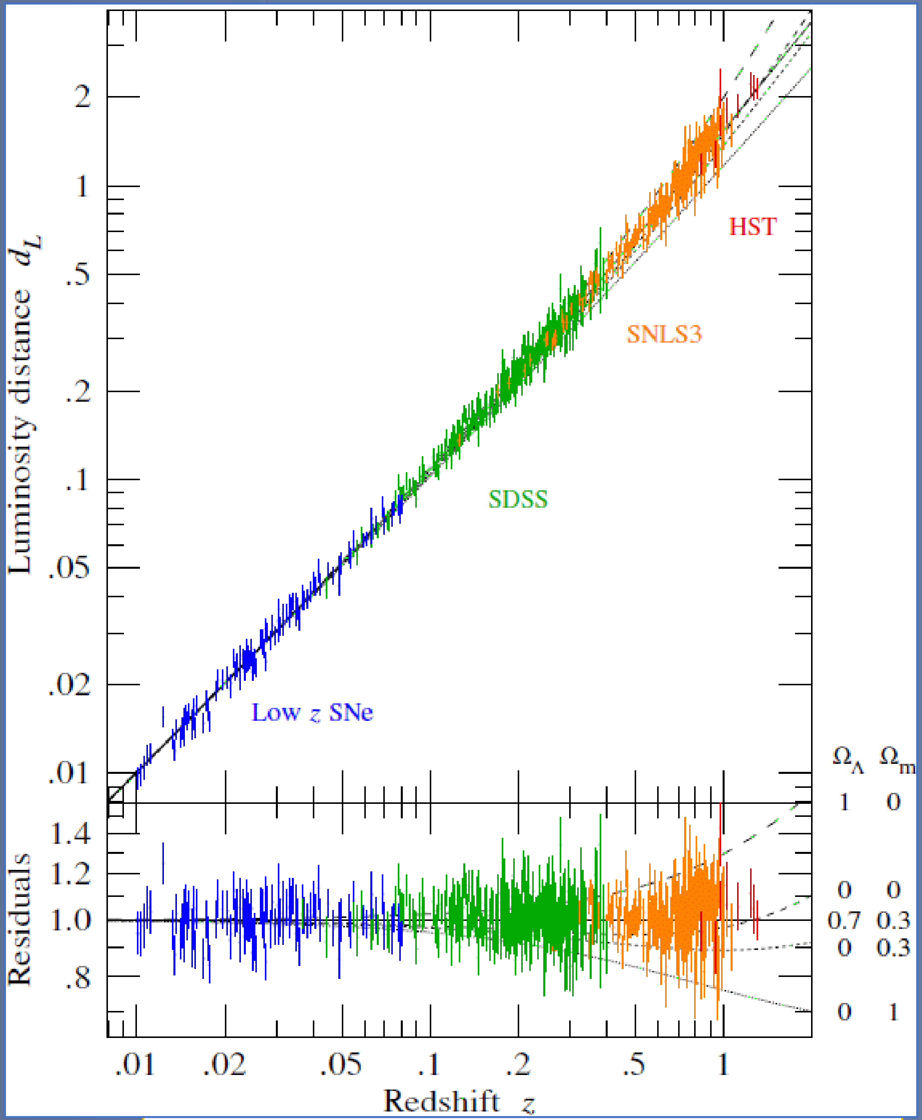
- Quasars as standard candles: limitations and assumptions
- QSOs vs BAO
- Conclusions and next goals


COBE
(1992)

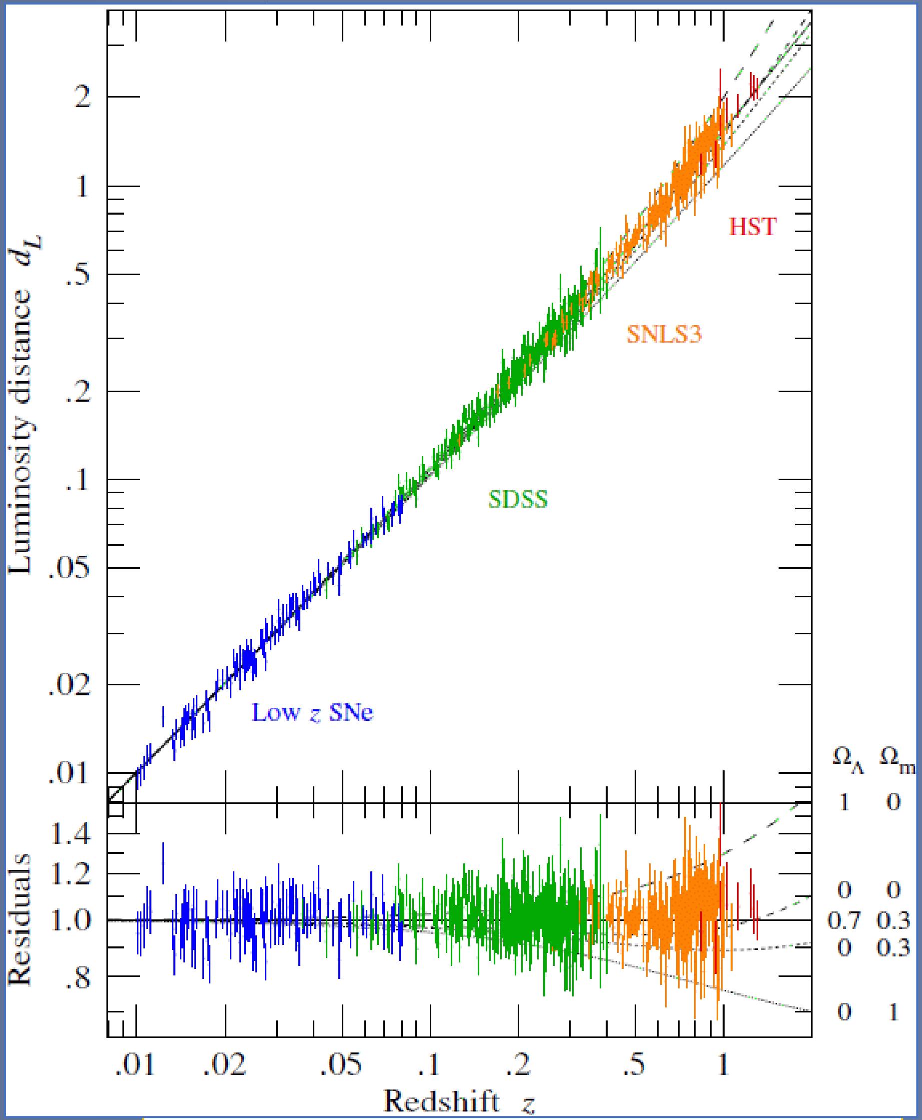

WMAP
(2003)


Planck
(2013)

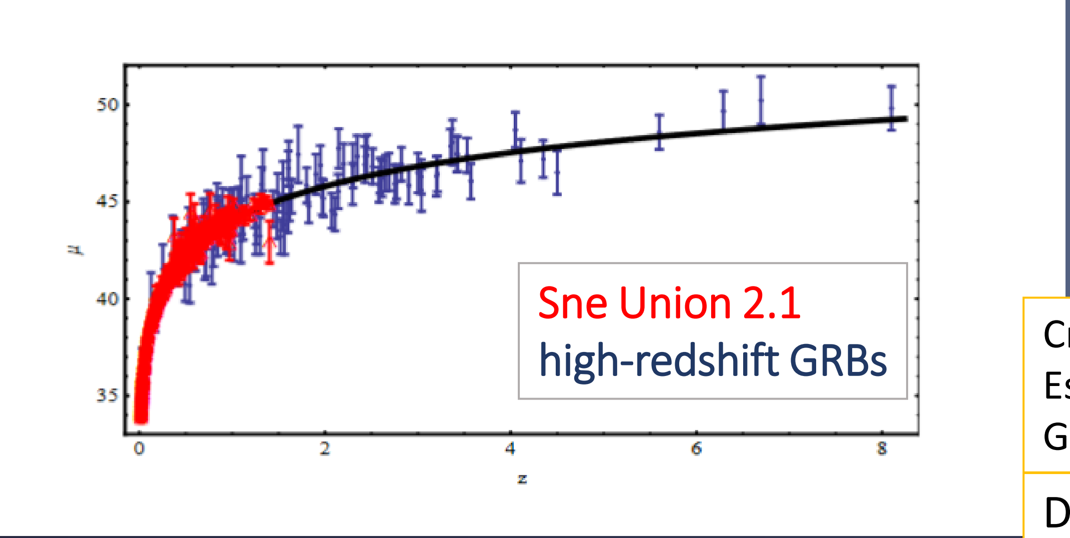

Years after the Big Bang
400 thousand
0.1 billion
1 billion
4 billion
8 billion
13.8 billion
The Big Bang
Recombination
The Dark Ages
Formation of the first astronomical objects
Present day
Fully ionised
Neutral
Reionisation
Fully ionised
1000
100
10
1
Redshift + 1



Credit: Betoule et al. A&A 568 (2014)

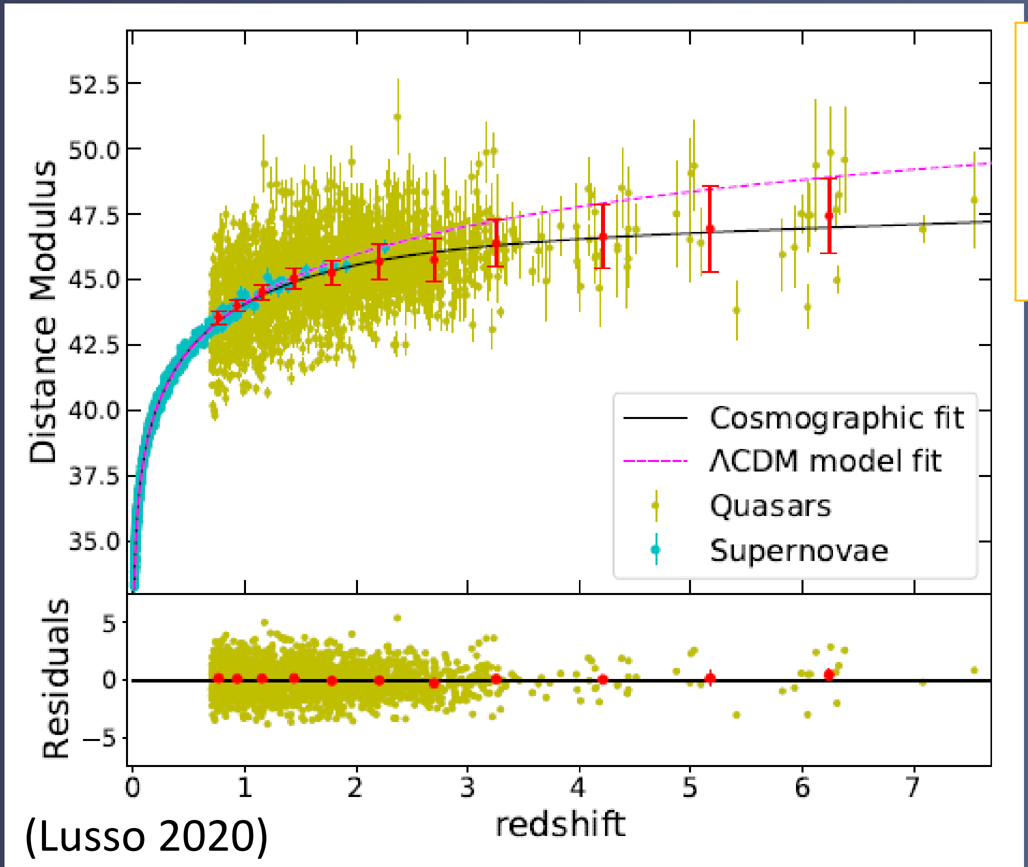


Credit: Betoule et al. A&A 568 (2014)

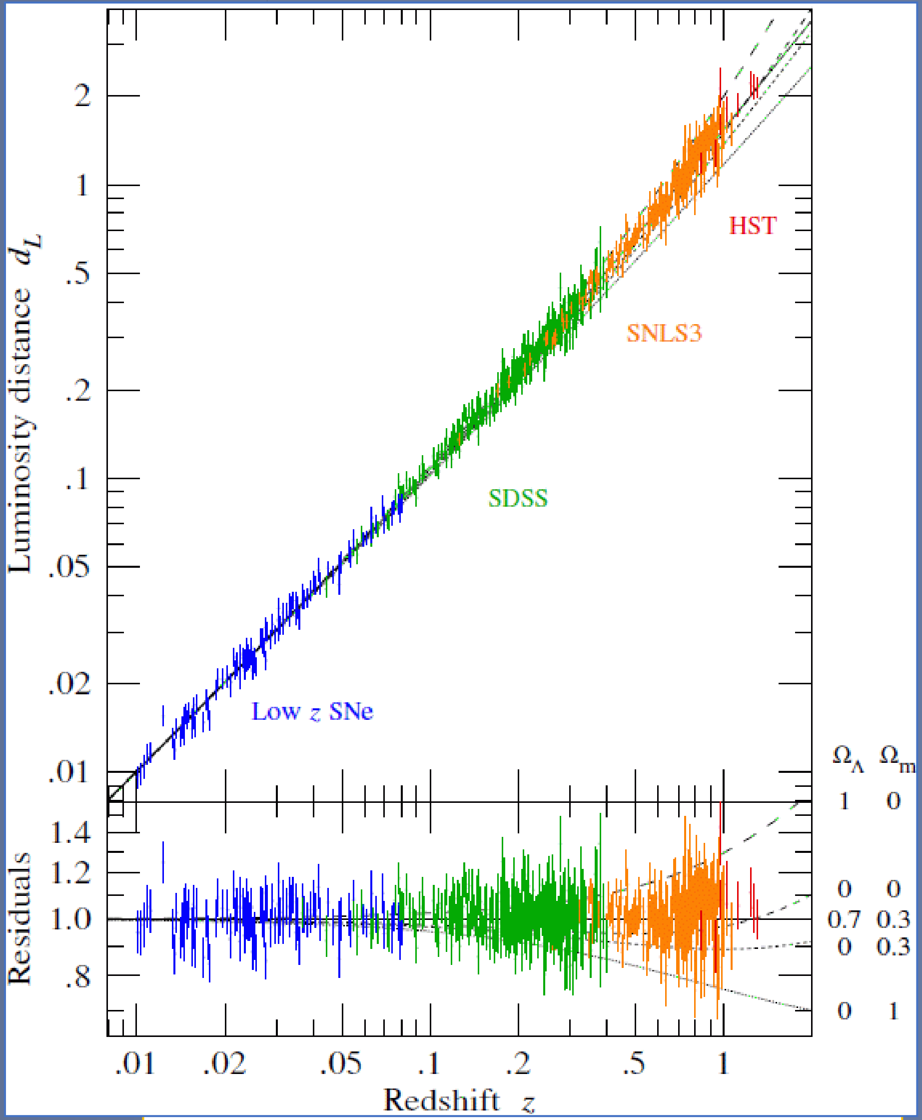


Credit: Piedipalumbo, Scudellaro, Esposito, Rubano, Gen. Rel. and Gravit. 44, 10 (2012)

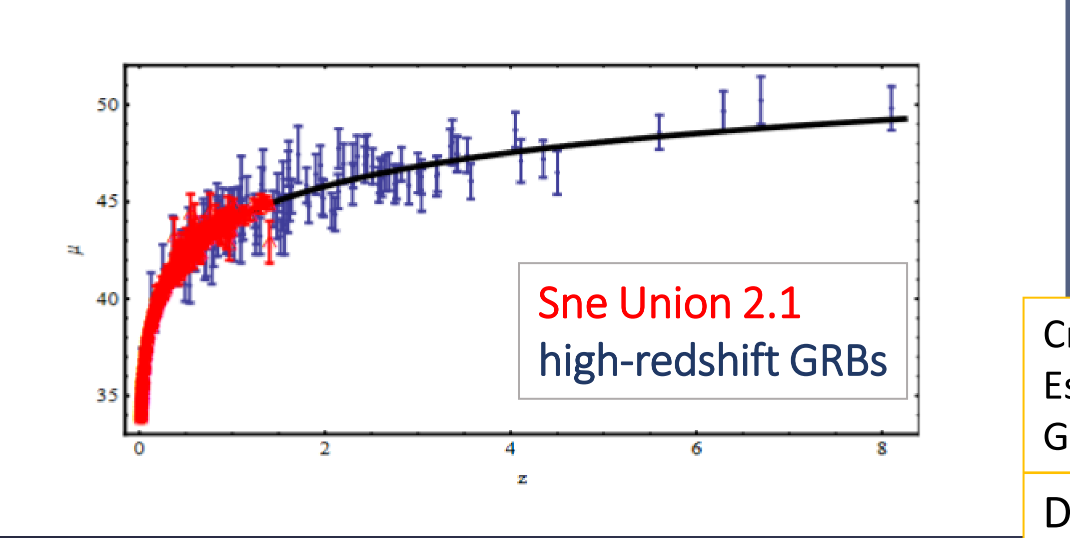
Dainotti+ 2008, 2011, 2013, 2015, 2017, 2020



Credit: Bargiacchi, Risaliti, **MB**, Capozziello, E. Lusso, Saccardi, Signorini A&A, 649, A65 (2021)

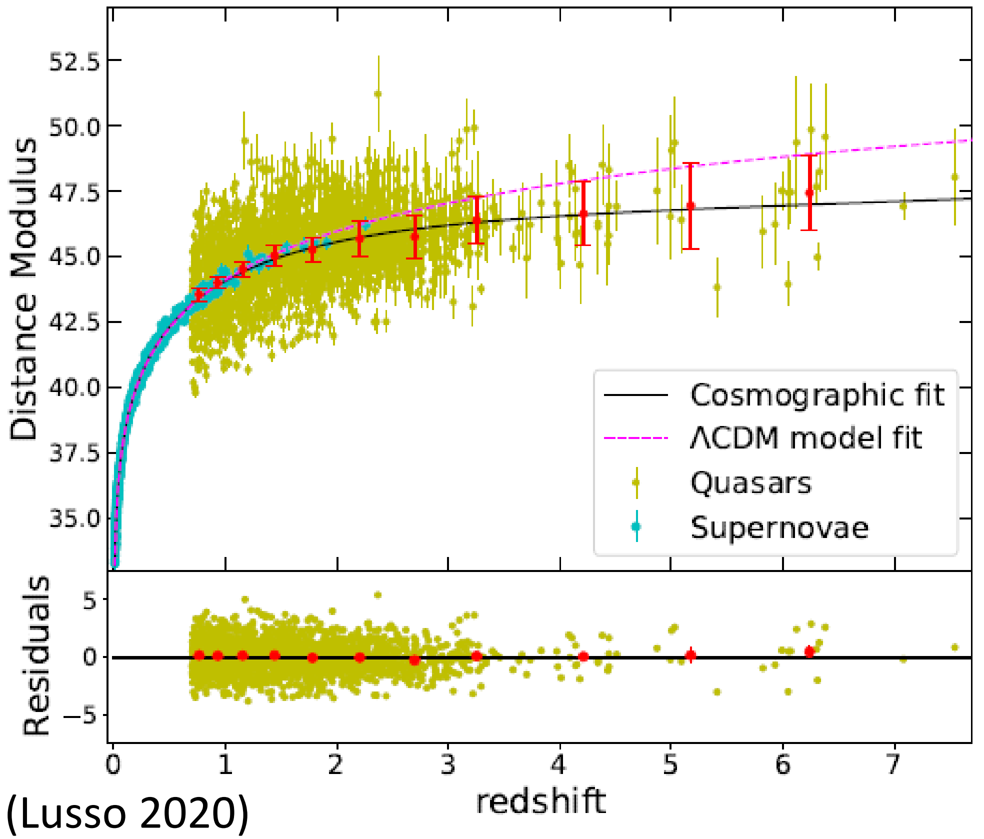


Credit: Betoule et al. A&A 568 (2014)



Credit: Piedipalumbo, Scudellaro, Esposito, Rubano, Gen. Rel. and Gravit. 44, 10 (2012)

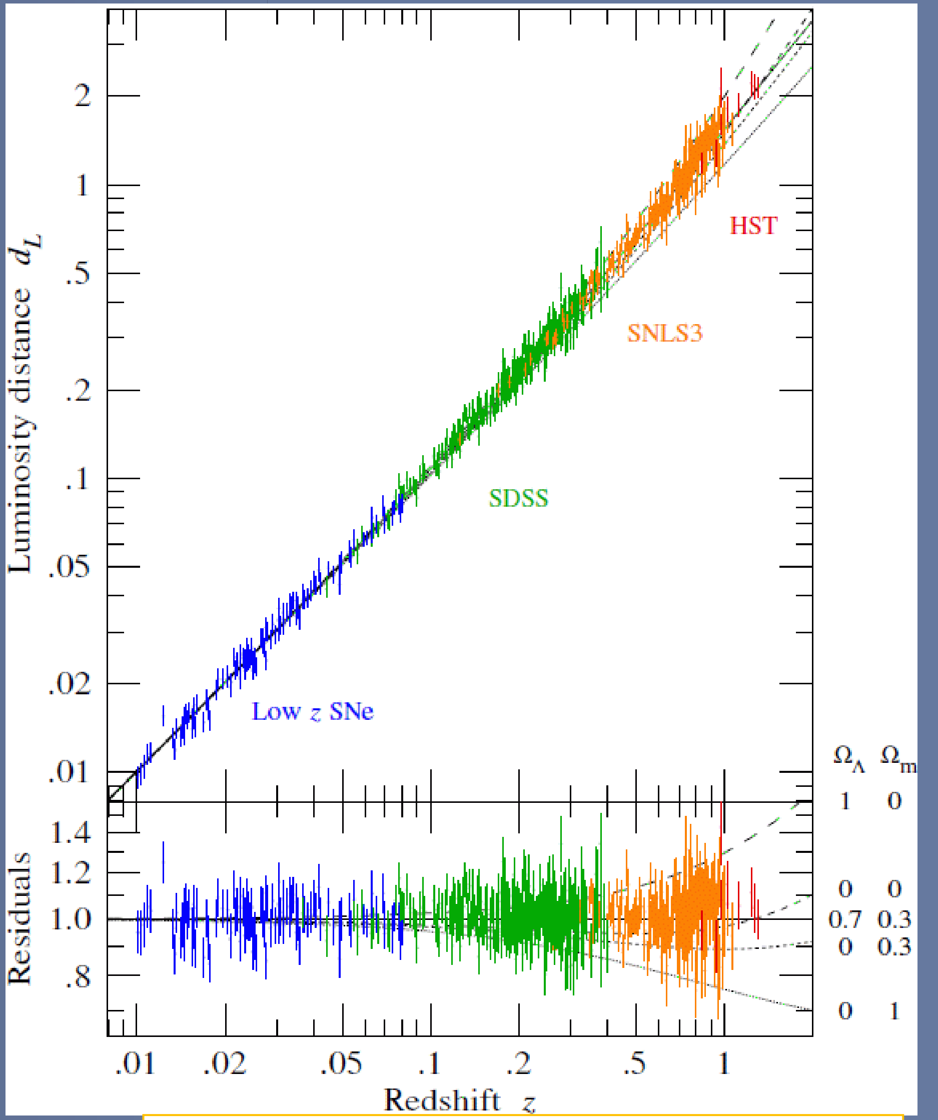
Dainotti+ 2008, 2011, 2013, 2015, 2017, 2020



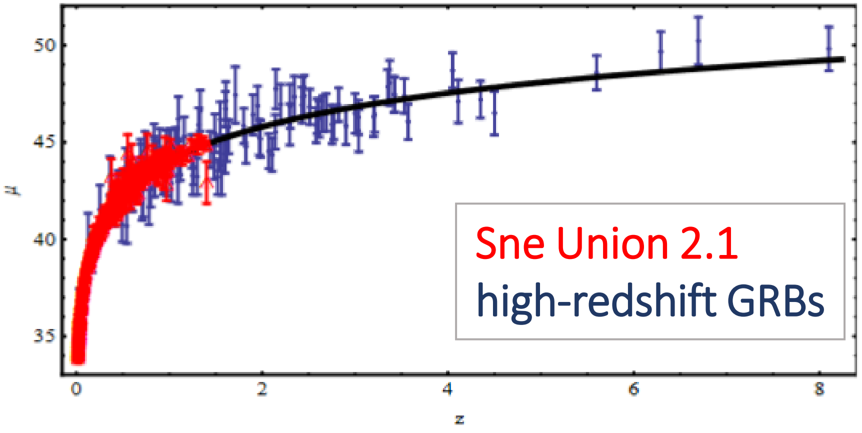
(Lusso 2020)

Credit: Bargiacchi, Risaliti, **MB**, Capozziello, E. Lusso, Saccardi, Signorini A&A, 649, A65 (2021)

The red points are binned information shown for visualization purposes only, without any statistical application



Credit: Betoule et al. A&A 568 (2014)



Credit: Piedipalumbo, Scudellaro, Esposito, Rubano, Gen. Rel. and Gravit. 44, 10 (2012)

Dainotti+ 2008, 2011, 2013, 2015, 2017, 2020

QSOs as standard candles

- QuasiStellar radio sources, are Active Galactic Nuclei with integrated luminosities of 10^{44-48} erg/s over the ultra-violet (UV) to the X-ray energy range.

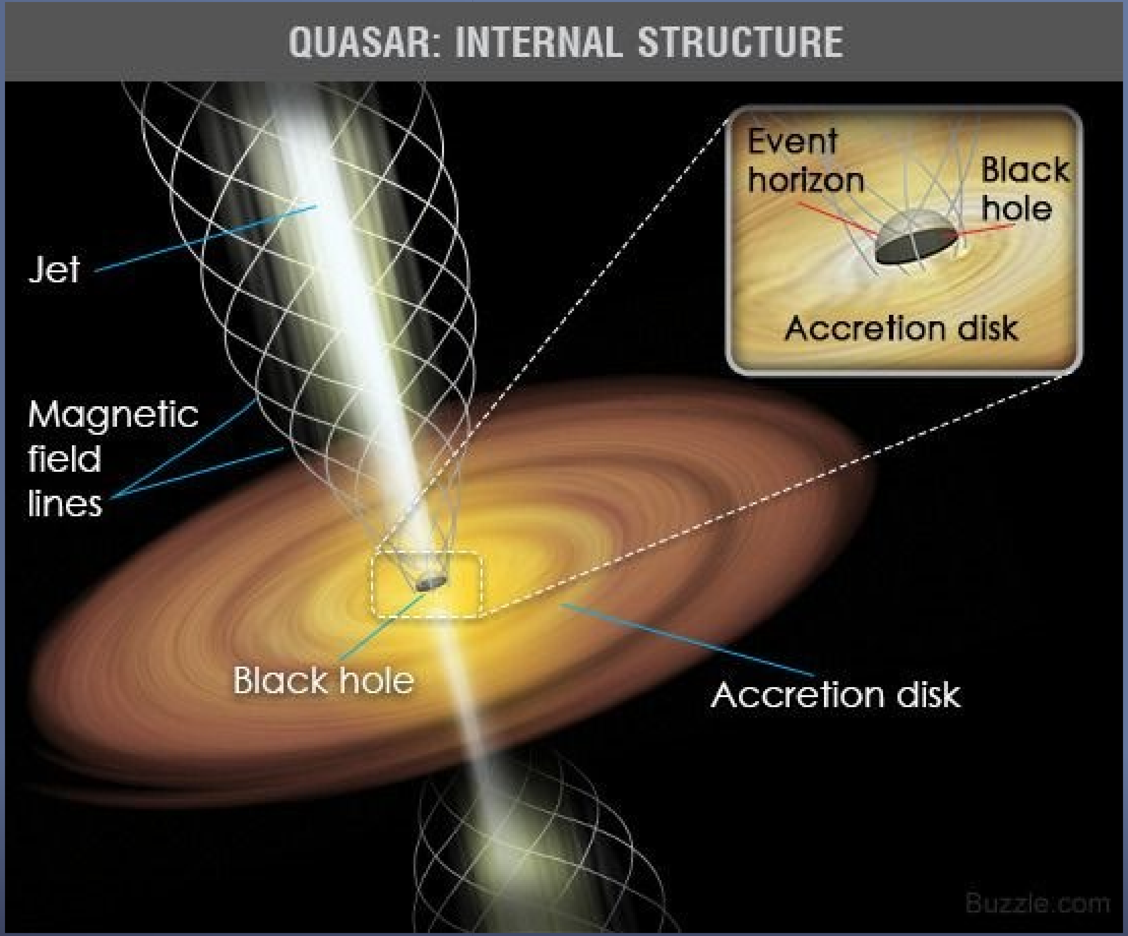
The UV emission are roughly 90% of the quasar bolometric budget.

The X-rays are originate in a hot plasma of relativistic electrons, that Compton up-scatter photons coming from the disk.

The UV and X-ray fluxes obey to non-linear

$$L_X \propto L_{UV}^{\gamma}$$

Luv at the rest frame 2500 Å
Lx at the rest frame 2 keV
$\gamma \sim 0.6$



QSO as standard candles is based on two key points:

1- the LX−LUV relation is due to an observational issue: exist an unknown physical mechanism that links the emission from the accretion disc with that from the X-ray emitting corona

2- the slope of the LX−LUV relation does not evolve with redshift

Steffen+2006, Just+2007; Lusso+2010; Risaliti+2015, Lusso+2016, Risaliti+2019, Lusso+2019, Lusso+2020; Bargiacchi+2021, Bisogni+2021; Dainotti+2022

A key consequence is that the L_X−L_{UV} relation must be the manifestation of a universal mechanism at work in the quasar engines

QSO as standard candles

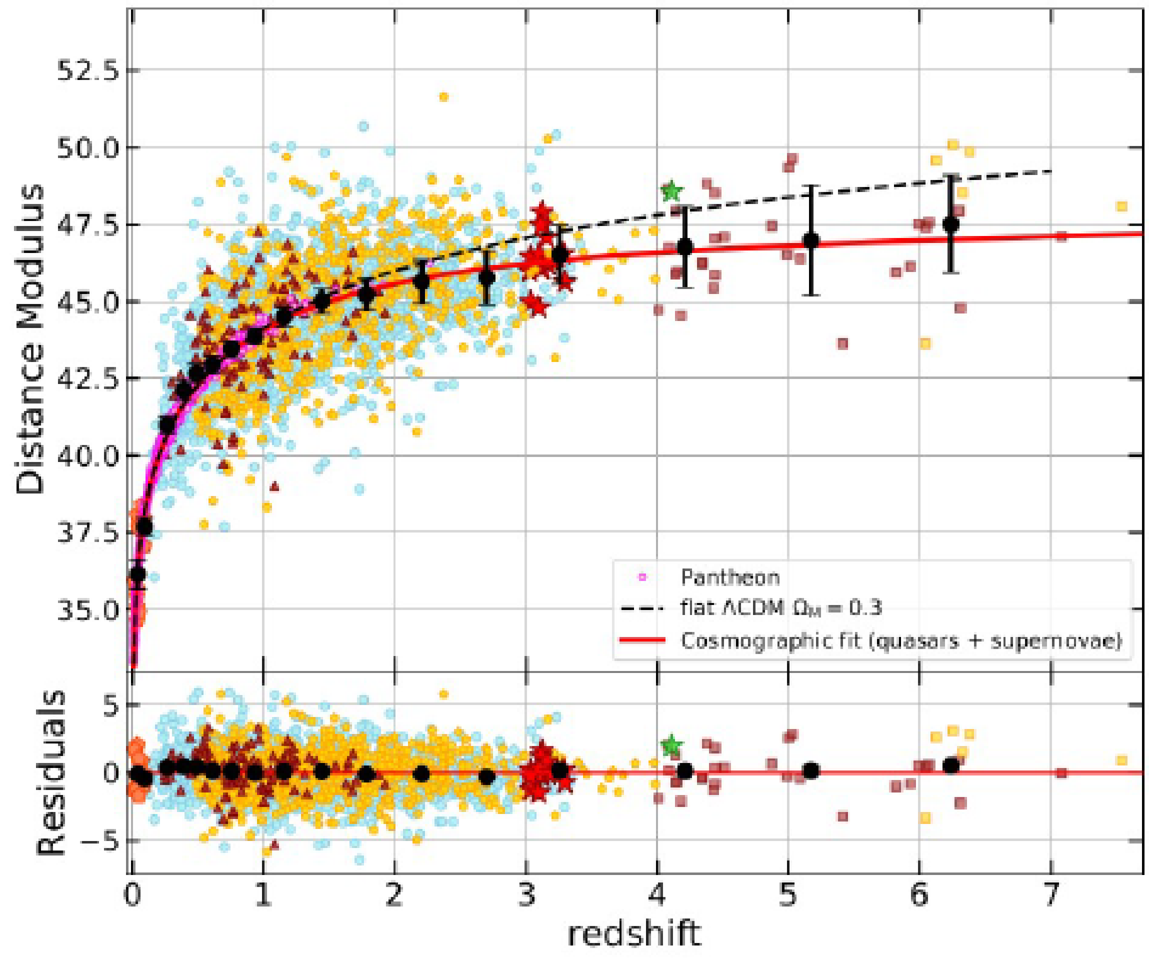
Can QSO then be a new probe
to constrain H0?

A key consequence is that the L_X−L_{UV} relation must be the manifestation of a universal mechanism at work in the quasar engines

For any analysis that involves a detailed test of cosmological models, the quasar distances should be calibrated by making use of the distance ladder through supernovae Ia.

In fact, the DM values of quasars are not absolute

!!! Quasar do not constrain H0 !!!



Lusso et al. 2020

Need for joint fit with SNe Ia to fix the "zero-point" of the diagram

Overlap with SNe Ia in the common redshift range

Information on the cosmic evolution at z>1.5 where different cosmological models can be tested and distinguished

Lusso2020 selection: 2036 sources covering up to z = 7.54

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

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Advance Access publication 2022 July 22

Quasar cosmology: dark energy evolution and spatial curvature

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Data set

Pantheon SNIA

Collection of 1048 sources from the Pantheon sample
(Scolnic et al. 2018)

We use the values of the distance moduli to calibrate QSO distances

BAO

Survey	z	Quantity	Measurement	$r_{s,fid}$
6dFGS	0.106	$\frac{r_s(z_d)}{D_V(z)}$	0.336 ± 0.015	
SDSS DR7(MGS)	0.15	$D_V(z)\frac{r_{s,fid}}{r_s(z_d)}$	664 ± 25	148.69
BOSS DR12	0.38	$D_M(z)\frac{r_{s,fid}}{r_s(z_d)}$	1512.39	147.78
		$H(z)\frac{r_s(z_d)}{r_{s,fid}}$	81.2087	147.78
BOSS DR12	0.51	$D_M(z)\frac{r_{s,fid}}{r_s(z_d)}$	1975.22	147.78
		$H(z)\frac{r_s(z_d)}{r_{s,fid}}$	90.9029	147.78
BOSS DR12	0.61	$D_M(z)\frac{r_{s,fid}}{r_s(z_d)}$	2306.68	147.78
		$H(z)\frac{r_s(z_d)}{r_{s,fid}}$	98.9647	147.78
eBOSS	1.52	$D_V(z)\frac{r_{s,fid}}{r_s(z_d)}$	3843 ± 147	147.78

Data set

QSOs

Lusso2020 selection: 2036 sources covering up to $z = 7.54$

For detailed description of selection, choices, validation of the procedure used and explanation of the fitting technique used to include them in the cosmological analysis:

Lusso E., et al., 2020, A&A, 642, A150
Risaliti G., Lusso E., 2015, ApJ, 815, 33
Lusso E., Risaliti G., 2016, ApJ, 819, 154
Risaliti G., Lusso E., 2019, Nature Astronomy, p. 195
Salvestrini et al. ,2019, A&A,631,A120

Data set

non-linear relation between their UV and X-ray luminosity:

$$\log(\mathrm{L}_X) = \gamma\, log(L_{UV}) + \beta$$ X: 2 KeV, UV: 2500 Å

The fitted distance moduli are obtained from

DM(z) = 5log[DL(z) (Mpc)] + 25 + k

where

$$\log D_{\mathrm{L}}(z) = \frac{[\log F_X - \beta - \gamma\,(\log F_{UV} + 27.5)]}{2(\gamma - 1)} - \frac{1}{2}\log(4\pi) + 28.5.$$

The slope γ and the intercept β of the logarithmic X-UV luminosity relation are free parameters of the fit

Data set

non-linear relation between their UV and X-ray luminosity:

$$\log(\mathrm{L}_X) = \gamma\, log(L_{UV}) + \beta \qquad \text{X: 2 KeV, UV: 2500 Å}$$

The fitted distance moduli are obtained from

$$\mathbf{DM}(z) = \mathbf{5log}[D\mathbf{L}(z)\ \mathbf{(Mpc)}] + \mathbf{25} + k$$

k is shared by both SNe and QSOs and is a rigid shift of the QSO Hubble diagram to match the one of SNe in the common redshift range.

MODELS

ΛCDM

$$E(z) = \frac{H(z)}{H_0} = \left[\Omega_{M,0}(1+z)^3 + \Omega_{r,0}(1+z)^4 + \Omega_{\Lambda,0}\right]^{\frac{1}{2}}$$

$1 = \Omega M,0 + \Omega r\ ,0 + \Omega\Lambda,0$

MODELS

ΛCDM

$$E(z) = \frac{H(z)}{H_0} = \left[\Omega_{M,0}\,(1+z)^3 + \Omega_{r,0}\,(1+z)^4 + \Omega_{\Lambda,0}\right]^{\frac{1}{2}}$$

$1 = \Omega M,0 + \Omega r\ ,0 + \Omega\Lambda,0$

DE extensions

$$+\,\Omega_{\Lambda,0}\exp\left(3\int_0^z dz'\,\frac{1+w(z')}{1+z'}\right)$$

$w(z) = P_\Lambda/\rho_\Lambda$

Flat LCDM model

QSOs+SNe:

$$\Omega_{M,0} = 0.295^{+0.013}_{-0.012}$$

BAO:

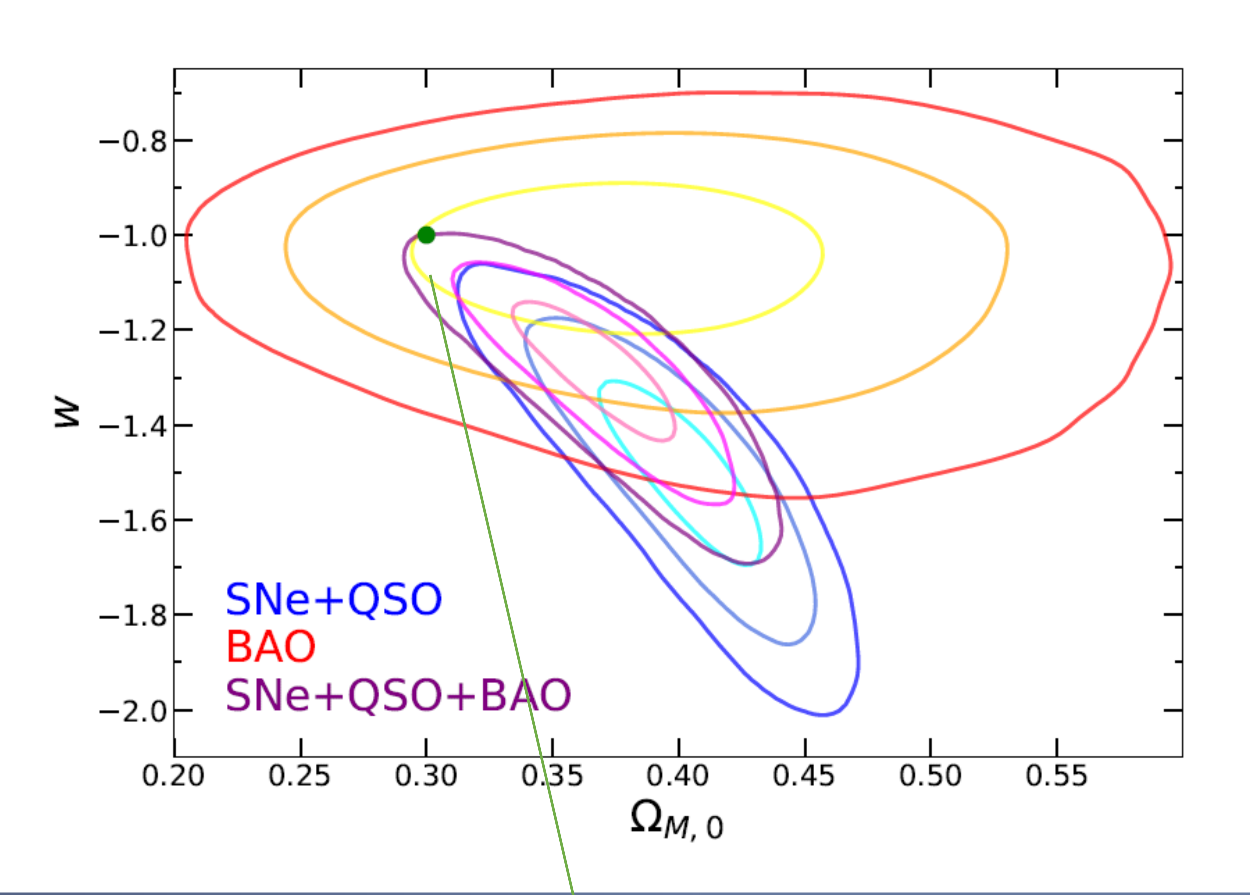
$$\Omega_{M,0} = 0.373^{+0.056}_{-0.048}$$

QSOs+SNe+BAO:

$$\Omega_{M,0} = 0.300 \pm 0.012$$

→ Completely agreement with the latest cosmological evidence

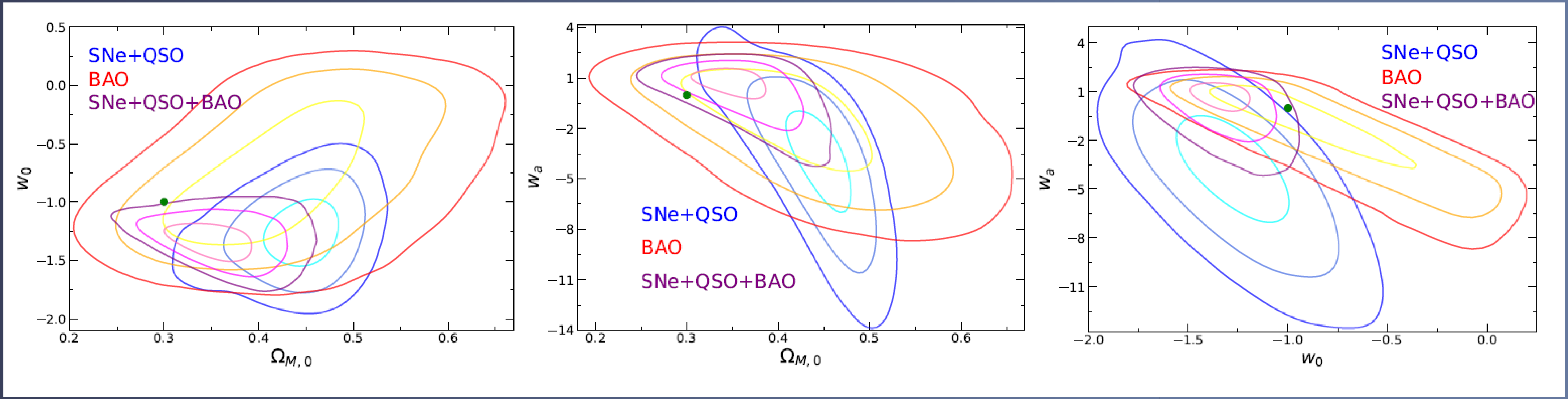
Flat wCDM model



Green point : Best fit LCDM model

Flat CPL model

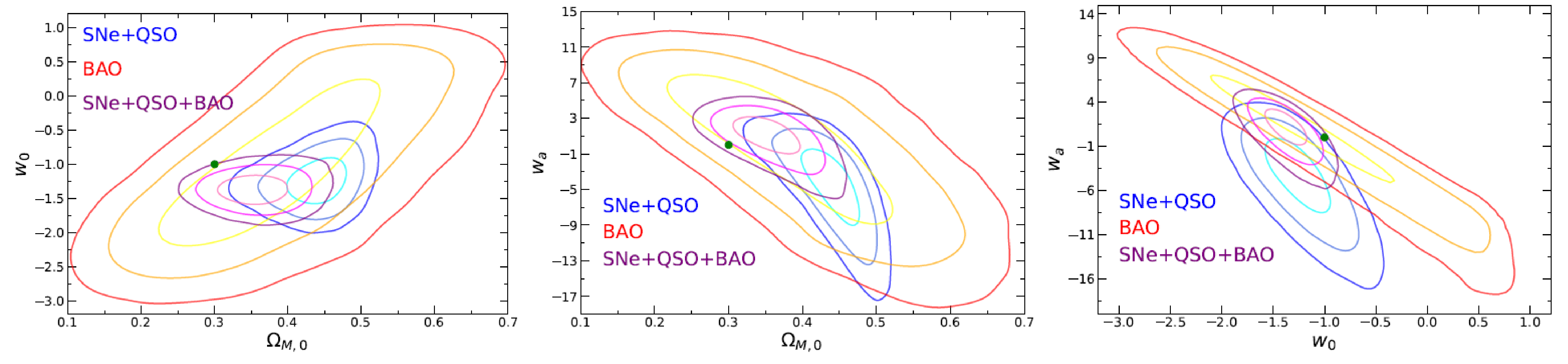
$$w(z) = w_0 + w_a\,(1-a) = w_0 + w_a\,\frac{z}{1+z}$$



	QSOs + SNe	BAO	QSOs + SNe + BAO
$\Omega_{M,0}$	$0.447^{+0.023}_{-0.027}$	$0.420^{+0.073}_{-0.070}$	$0.354^{+0.032}_{0.030}$
w_0	$-1.267^{+0.196}_{-0.191}$	$-0.821^{+0.469}_{-0.349}$	$-1.323^{+0.103}_{-0.112}$
w_a	$-3.771^{+2.113}_{-2.496}$	$-1.269^{+1.835}_{-2.608}$	$0.745^{+0.483}_{-0.974}$

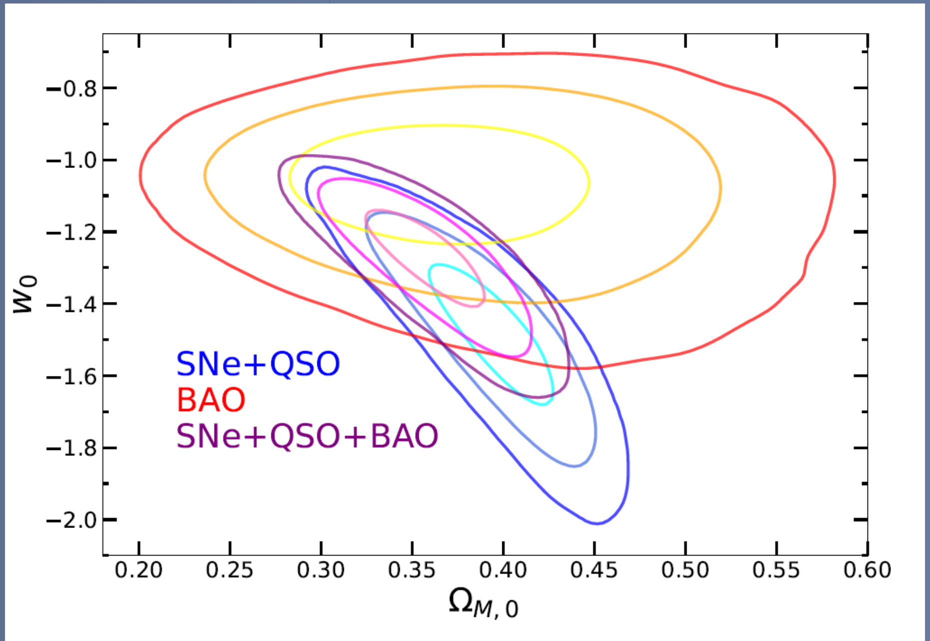
Flat Jassal-Bagla-Padmanabhan model

$$w(z) = w_0 + w_a \frac{z}{(1+z)^2}$$



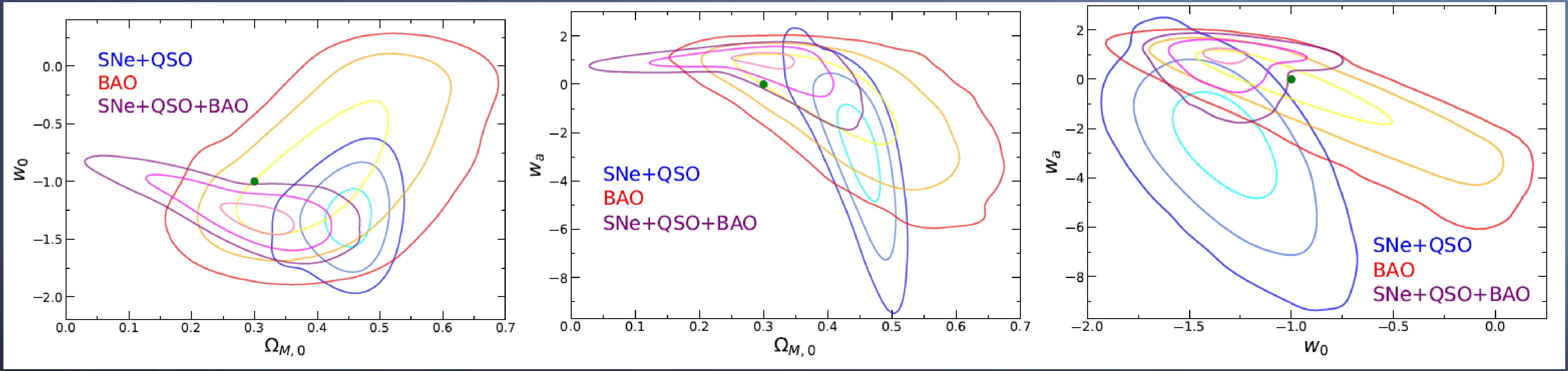
Flat exponential model

$$w(z) = w_0\,(1+z)^{-1}\,e^{\frac{z}{1+z}}$$



Flat Barboza-Alcaniz model

$$w(z) = w_0 + w_a\,z\,(1+z)\,(1+z^2)^{-1}$$



Take-home message

Quasars are standardizable candles crucial to extend the Hubble diagram

Assuming flatness:

ΛCDM model: $\Omega_{M,0}$ completely consistent with 0.3 in all data sets

DE extensions:

QSOs+SNe and BAO are consistent in all models

QSOs+SNe+BAO recover LCDM bestfit

Next goals

- Shed light on the physical origin of X-UV relation to strengthen the use of quasars in cosmology
- Implementation of the quasar sample with new catalogues and high quality observations from surveys
- Cosmological analyses including other probes such as CMB, DES, GRBs
- Tests of other (more interesting) model

Work in progress, coming soon!

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