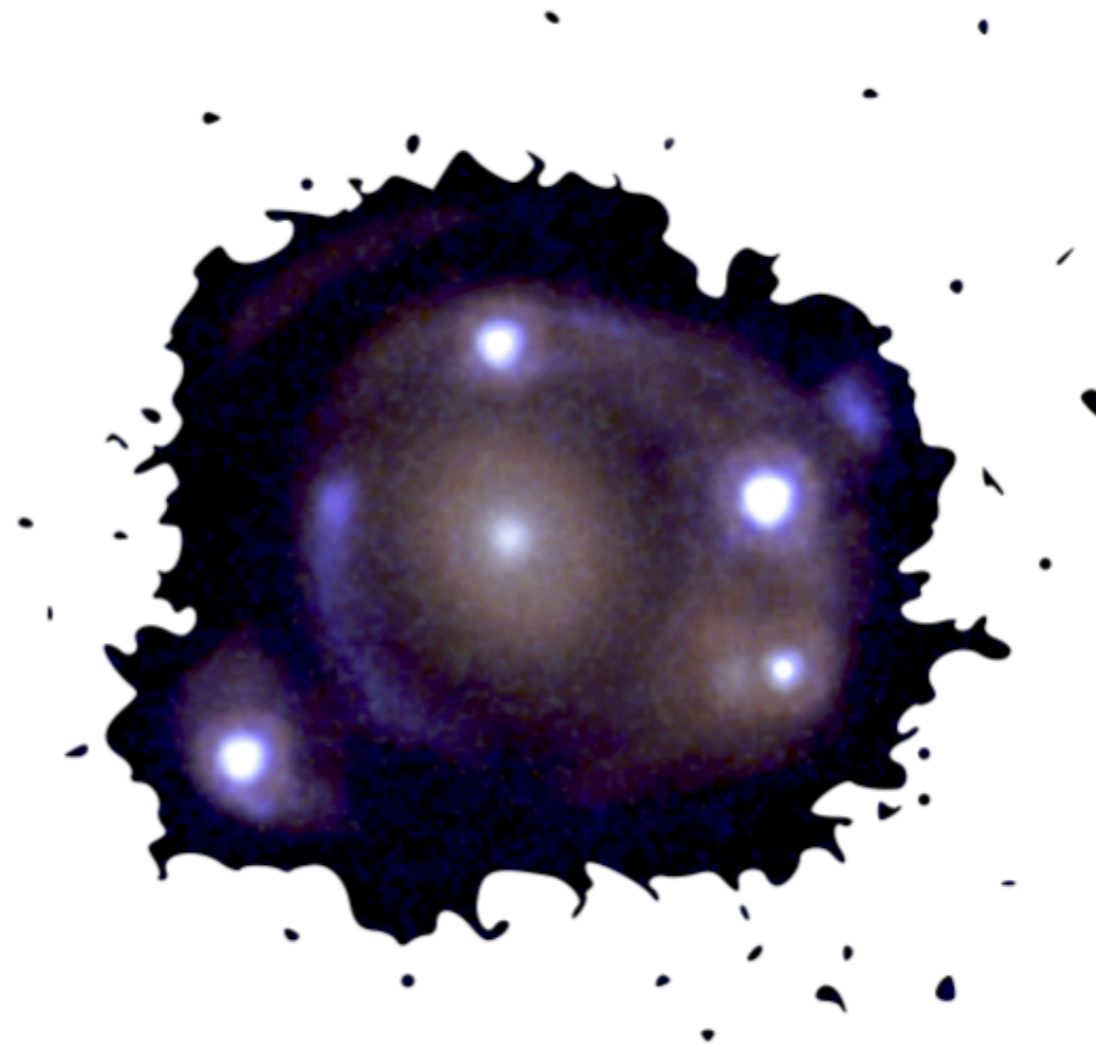


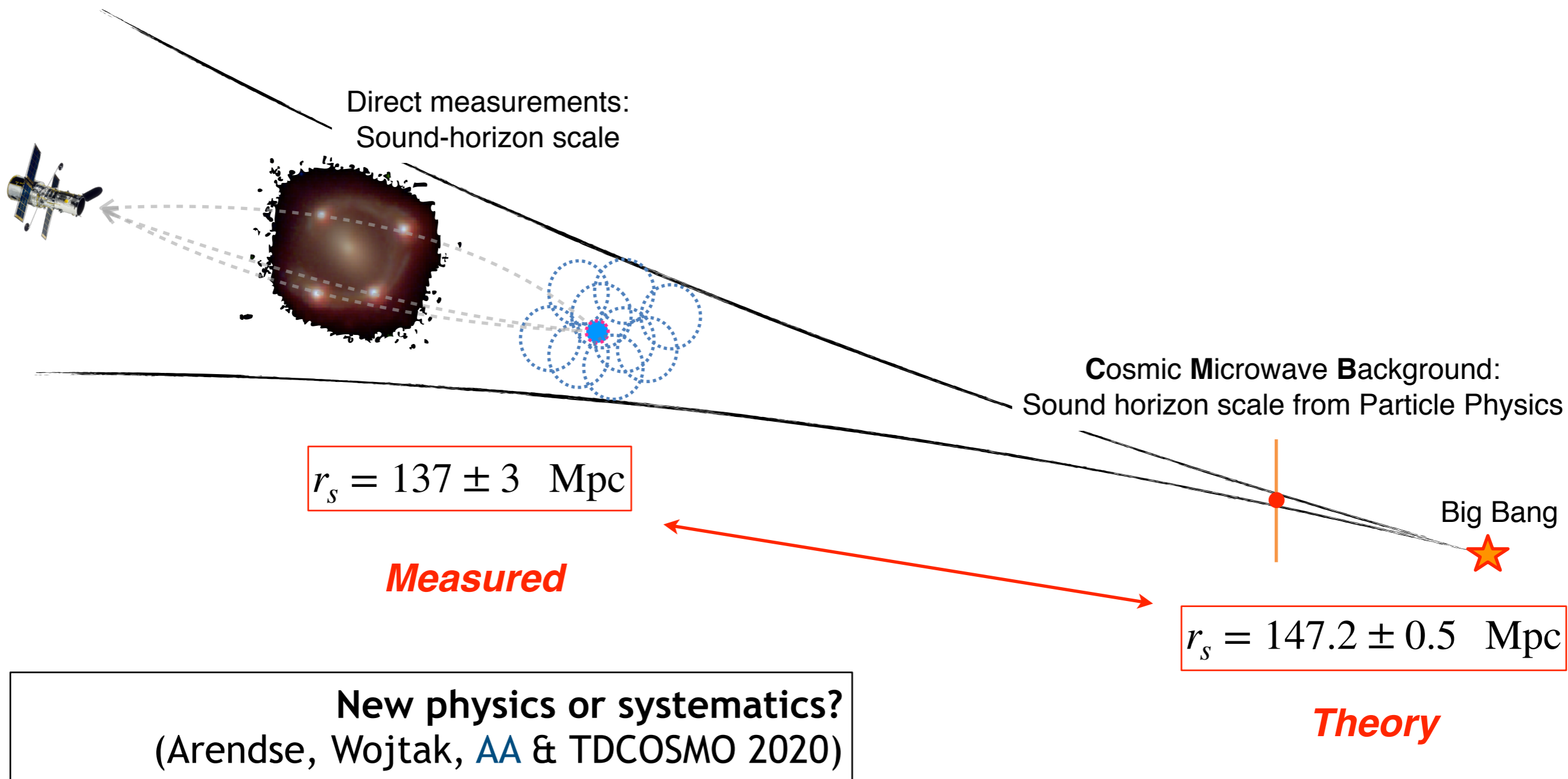
Cosmology and fundamental physics with strongly lensed quasars



Adriano Agnello
(MAAT workshop, 05/05/2020)

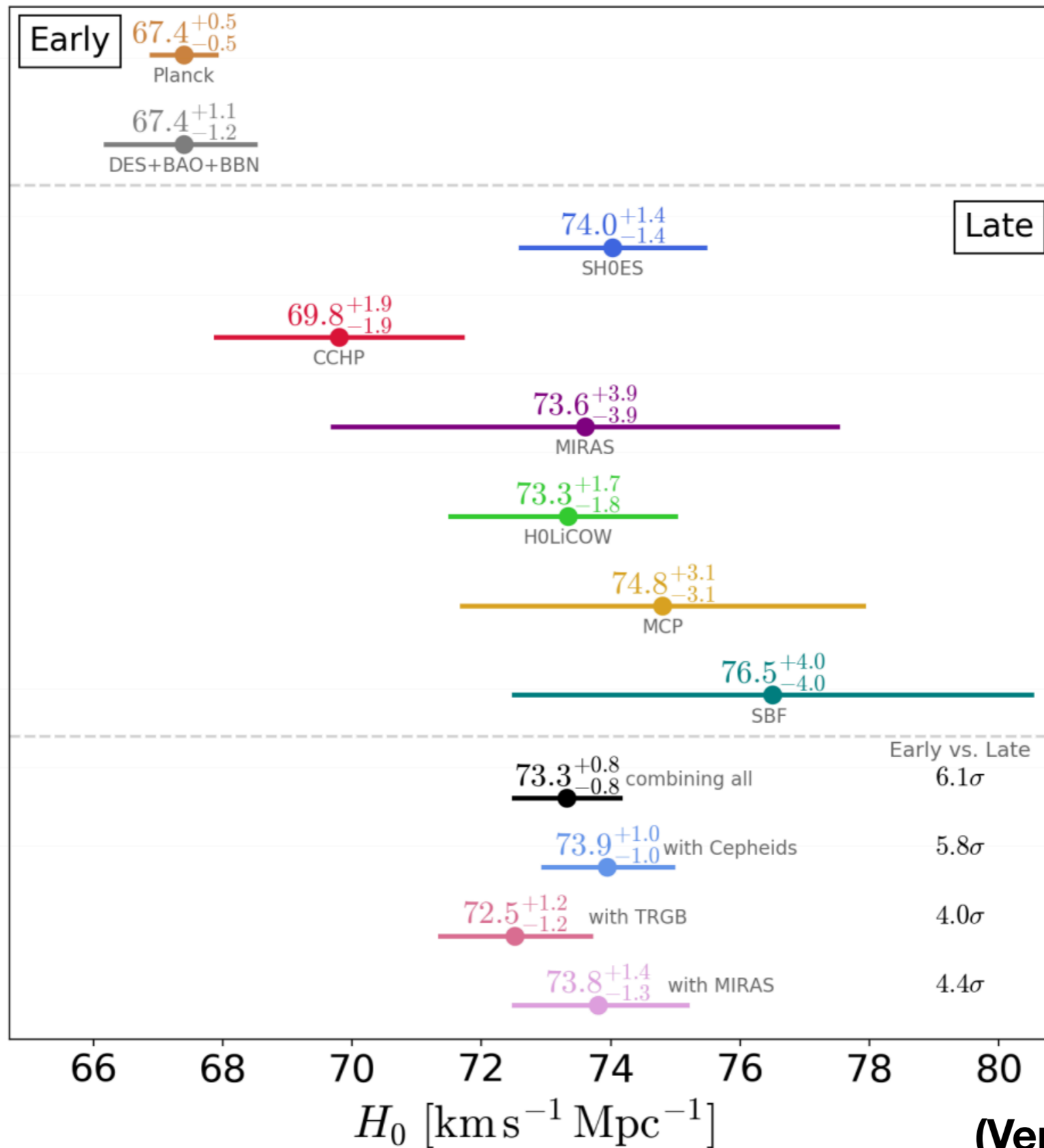
WHY

$$\frac{\dot{a}}{a} = H_0 \sqrt{\Omega_r(1+z)^4 + \Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_\Lambda}$$



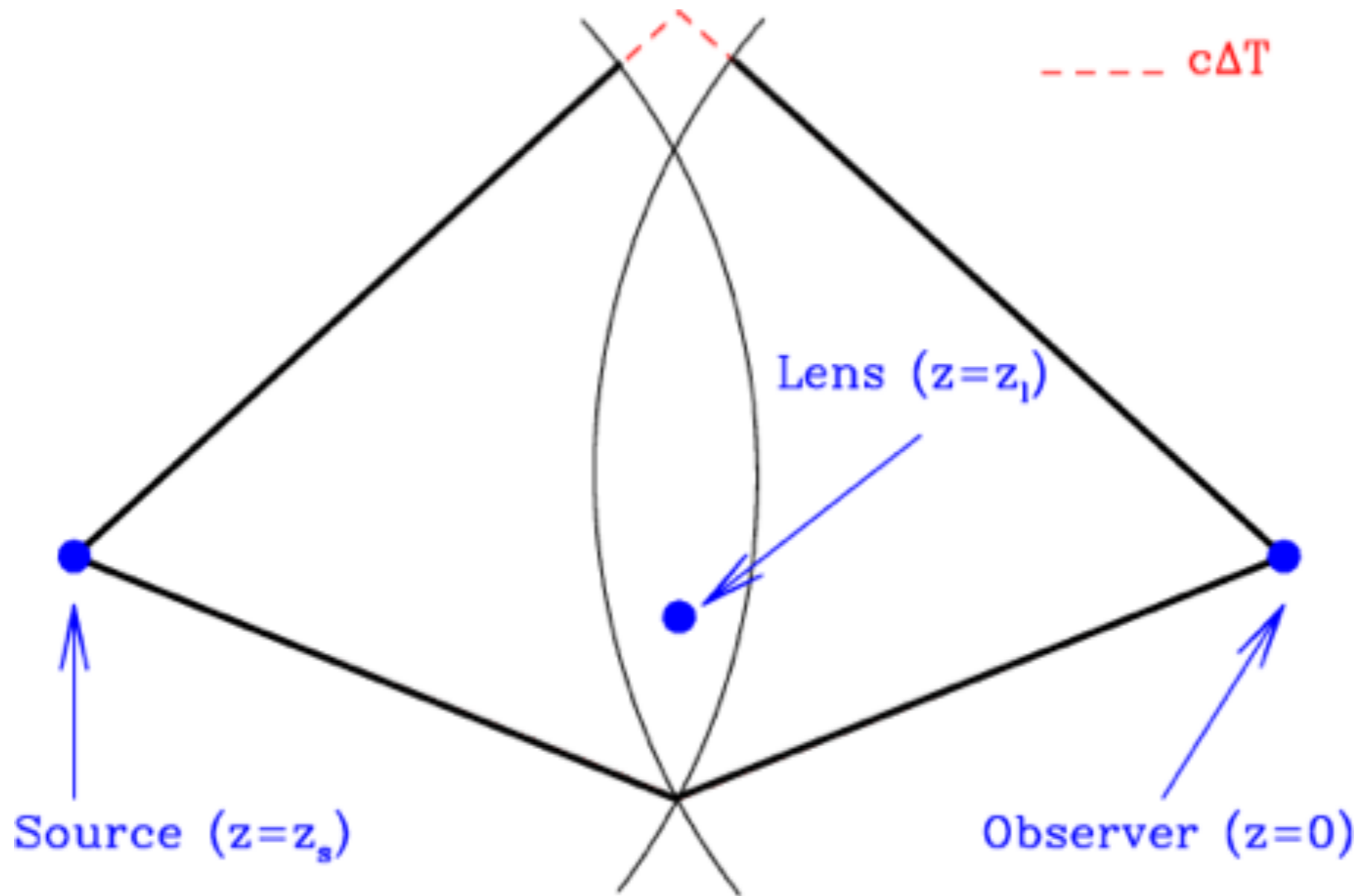
The *Hubble tension*

flat – Λ CDM



(Verde et al. 2019)

Time-delay Cosmography

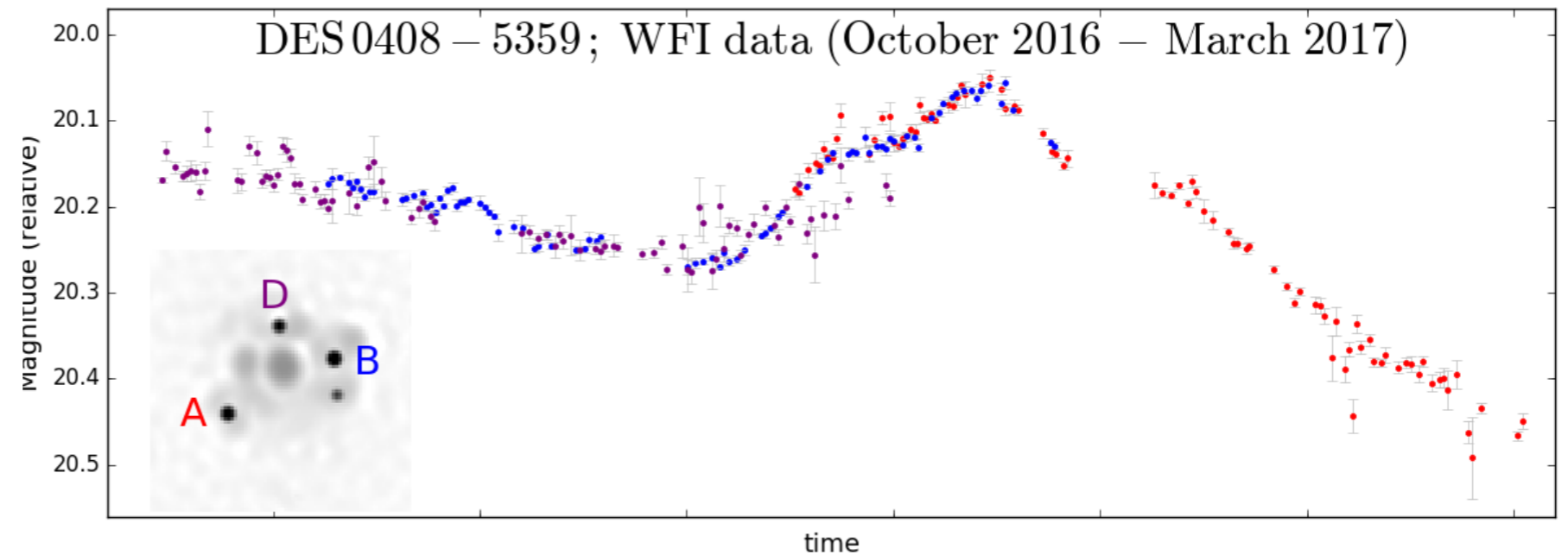


$$t(\vec{\theta}) = \frac{(1+z_d)D_d D_s}{c D_{ds}} \left[\frac{1}{2} \left| \vec{\theta} - \vec{\theta}_s \right|^2 - \psi(\vec{\theta}) \right]$$

What do we need?

- Accurate time-delays

(high-cadence monitoring)



- Accurate lens models (from high-resolution imaging)
(Meng, Treu, [AA](#) et al. 2015)

- Accurate masses!

$$\Delta t \propto \frac{1 - \kappa_e}{H_0} \tilde{\phi}$$

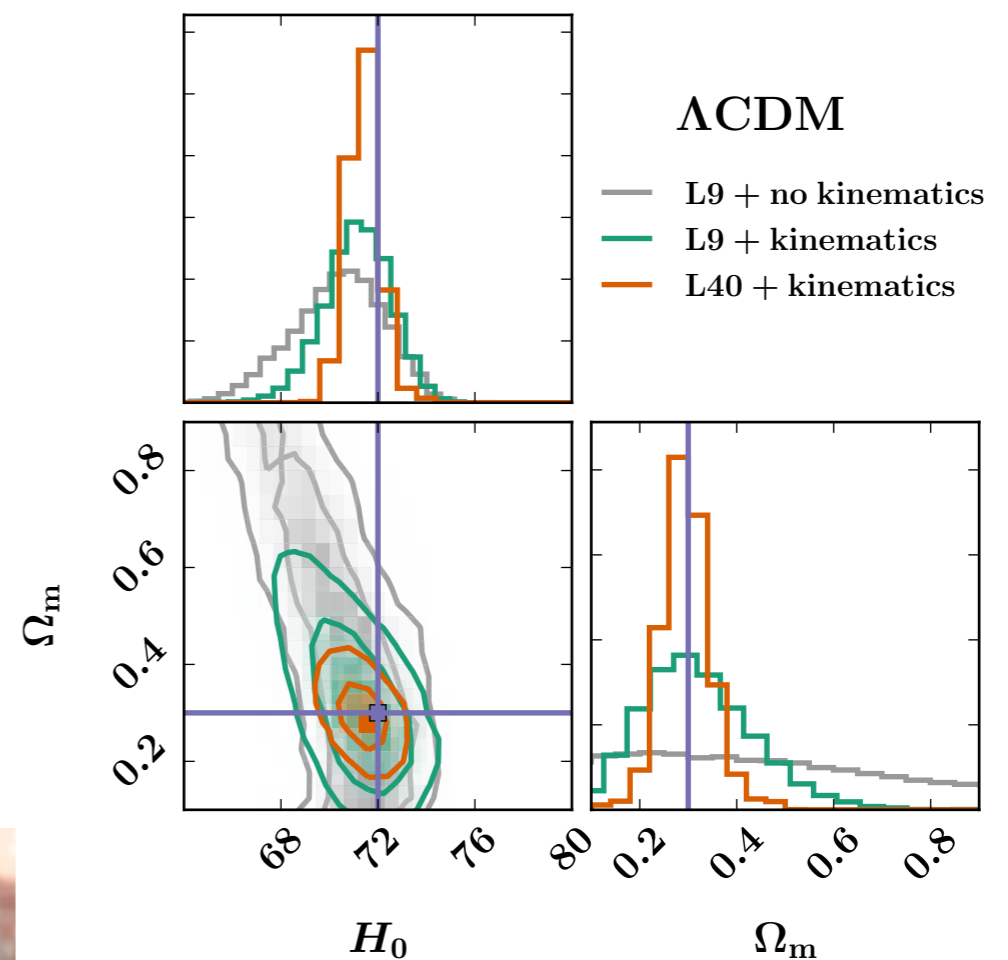
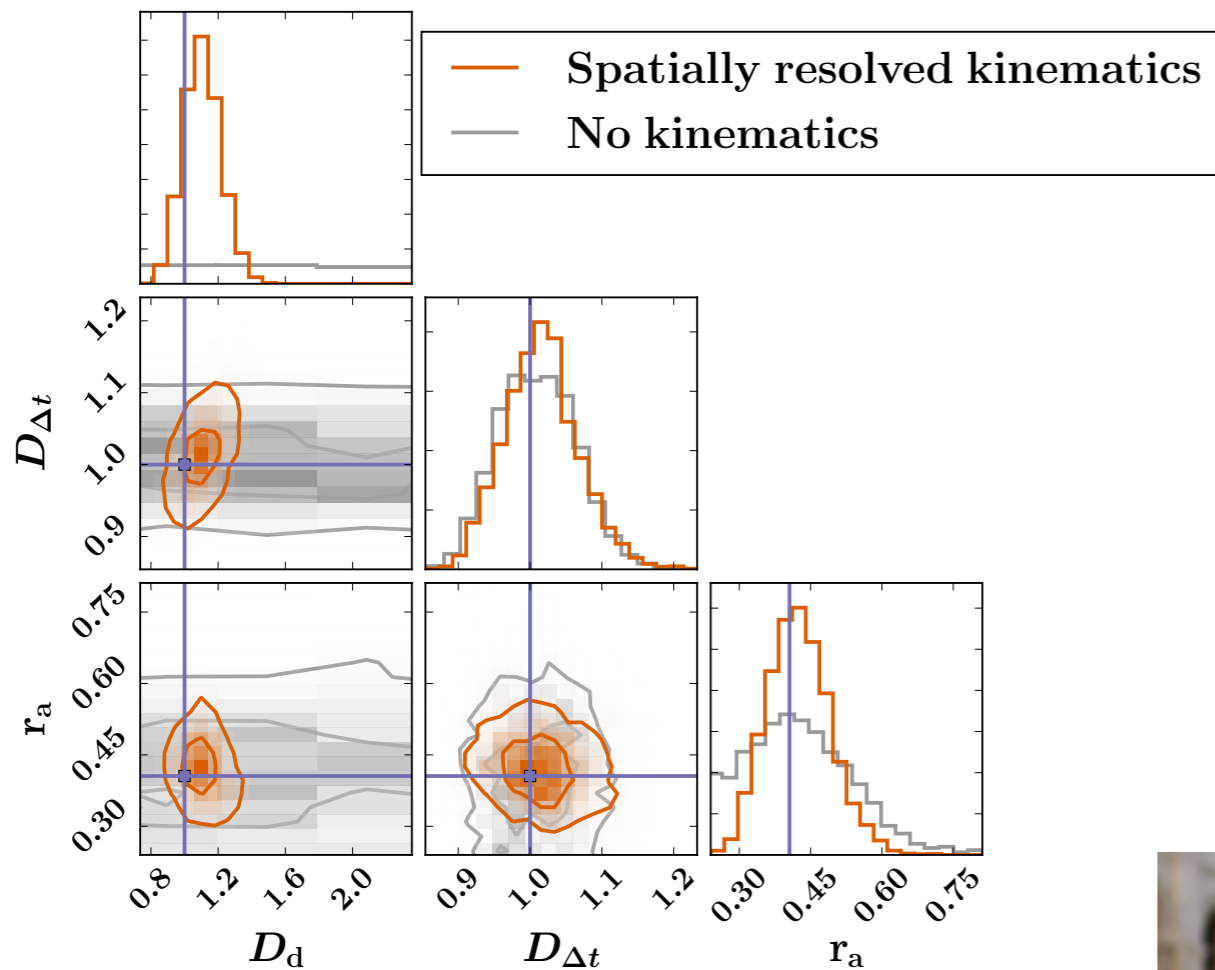


So why kinematics?

$$\Delta t \propto \frac{1 - \kappa_e}{H_0} \tilde{\phi}$$

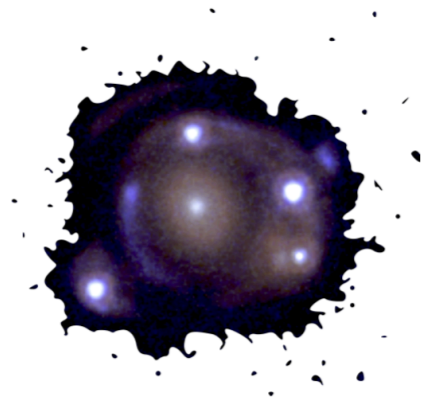
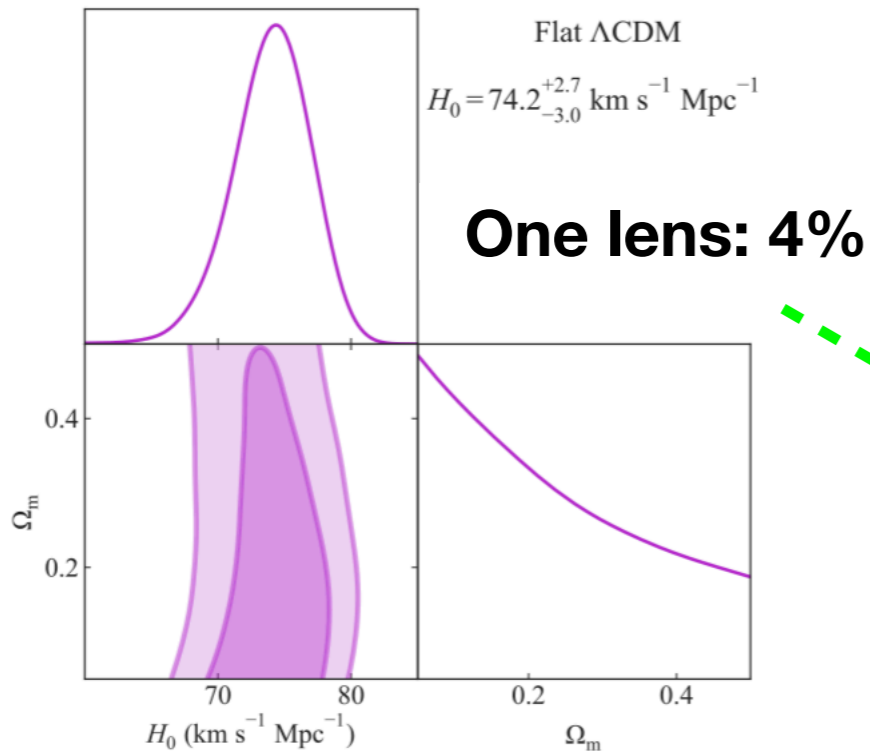
$$\sigma^2 \propto (1 - \kappa_e) \Rightarrow \frac{c^3 \Delta t}{\sigma^2} \propto D_d$$

With stellar kinematics,
time-delay lenses become standard rulers!



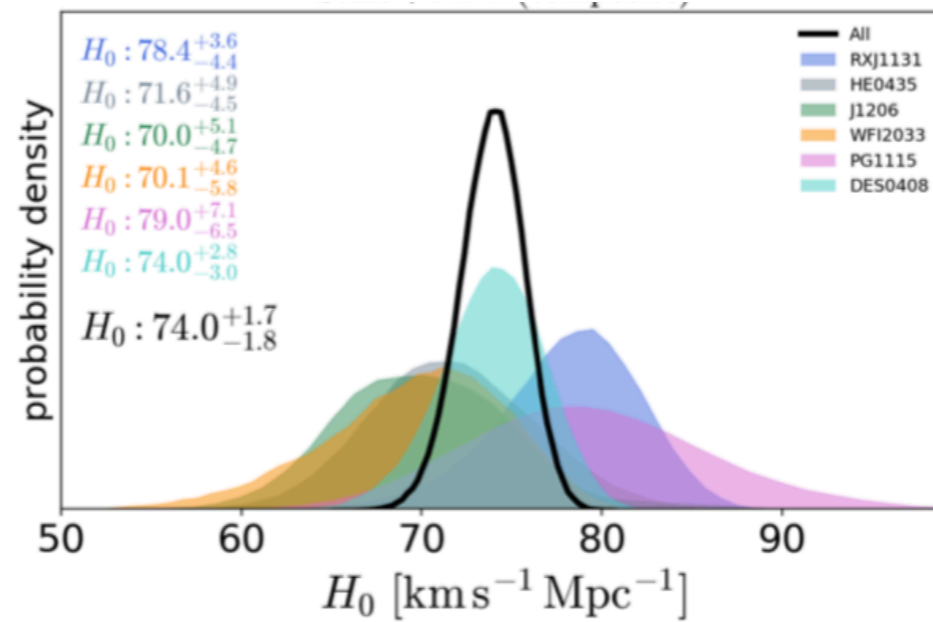
(Shajib, Treu, & **AA**, 2018)

The Roadmap



(Shajib et al. 2019)

Six lenses: 2.4%

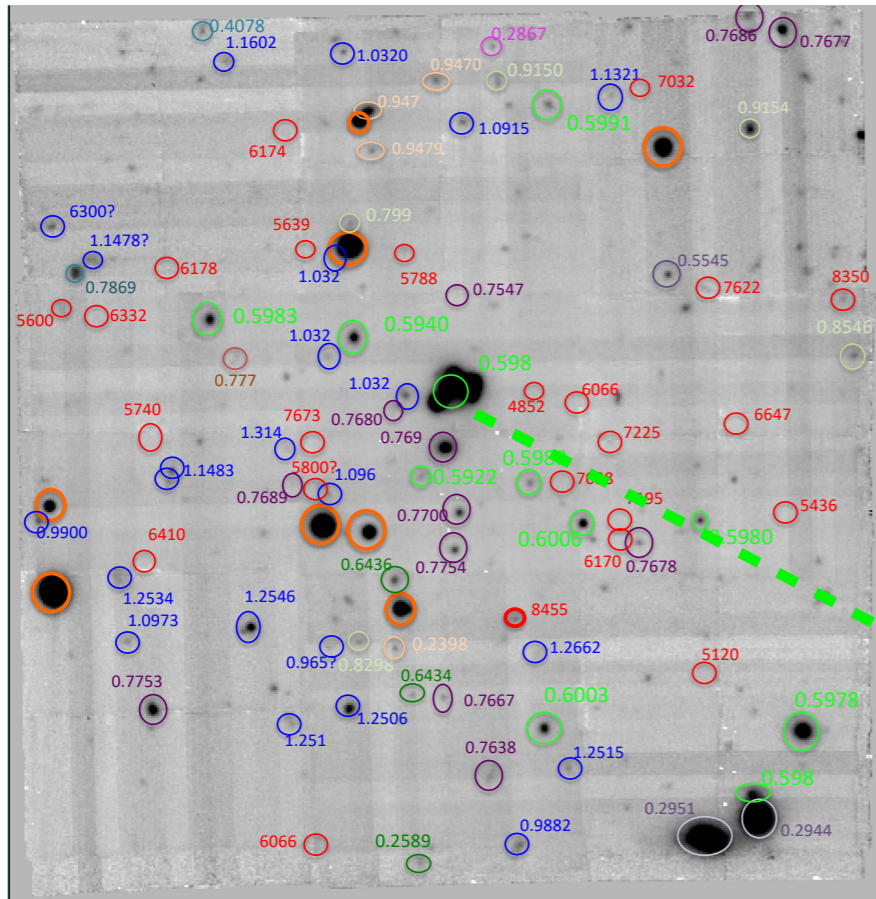


(Millon et al. 2019)

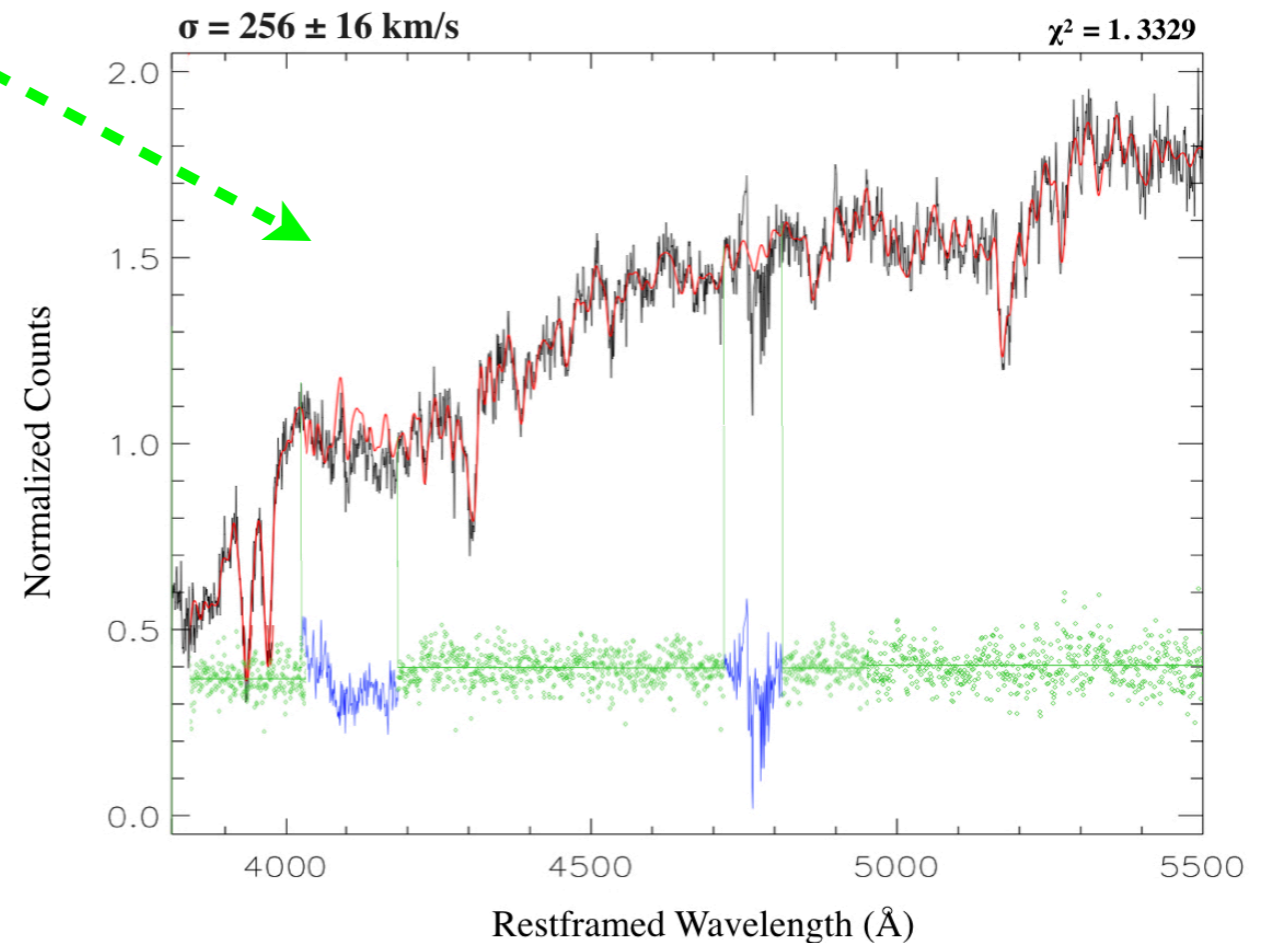
12 lenses: 2%

40 lenses: 1%

Lensed quasars seen through an IFU

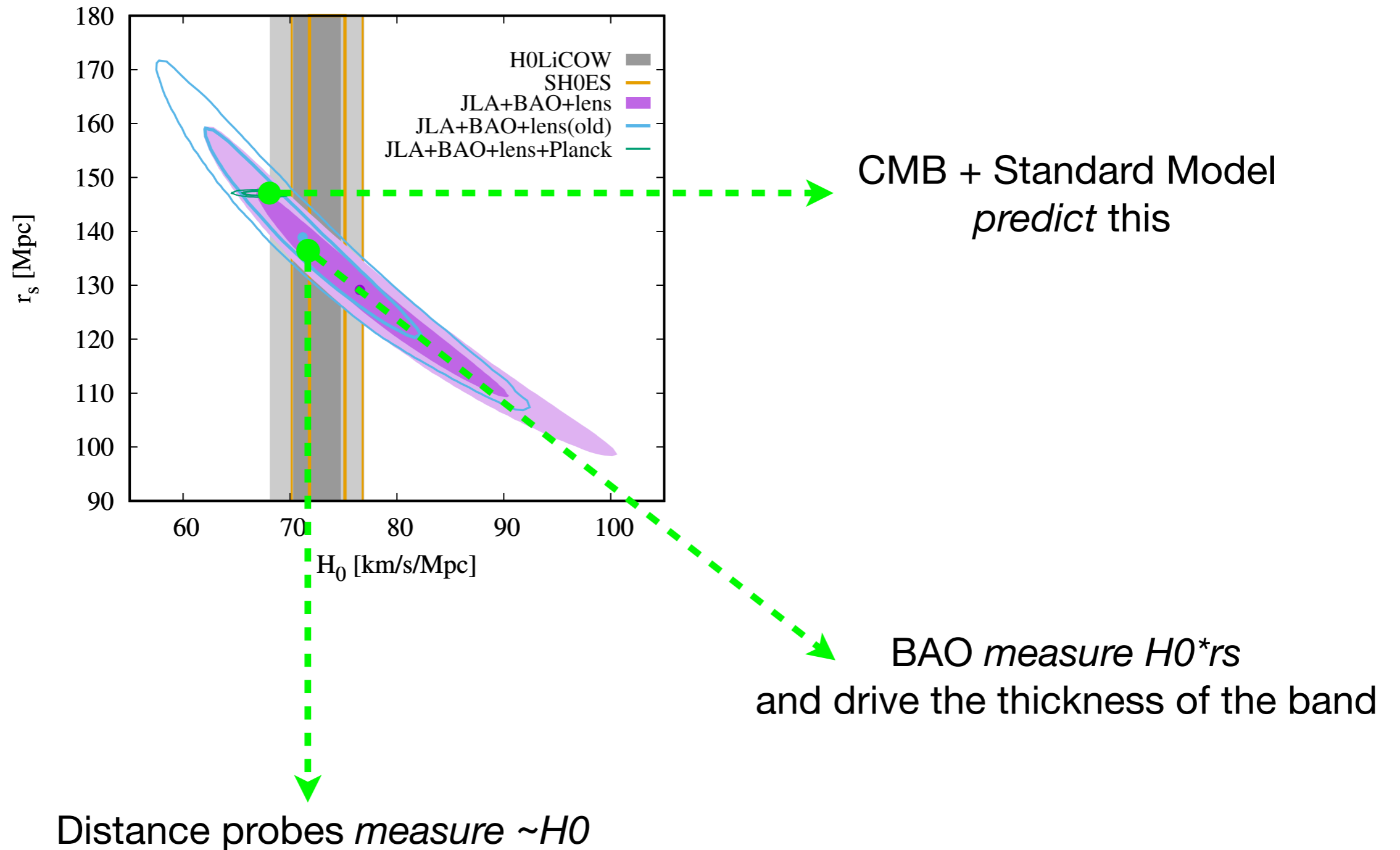


5h with VLT-MUSE
(Shajib et al. 2019,
Buckley-Geer et al. 2019)

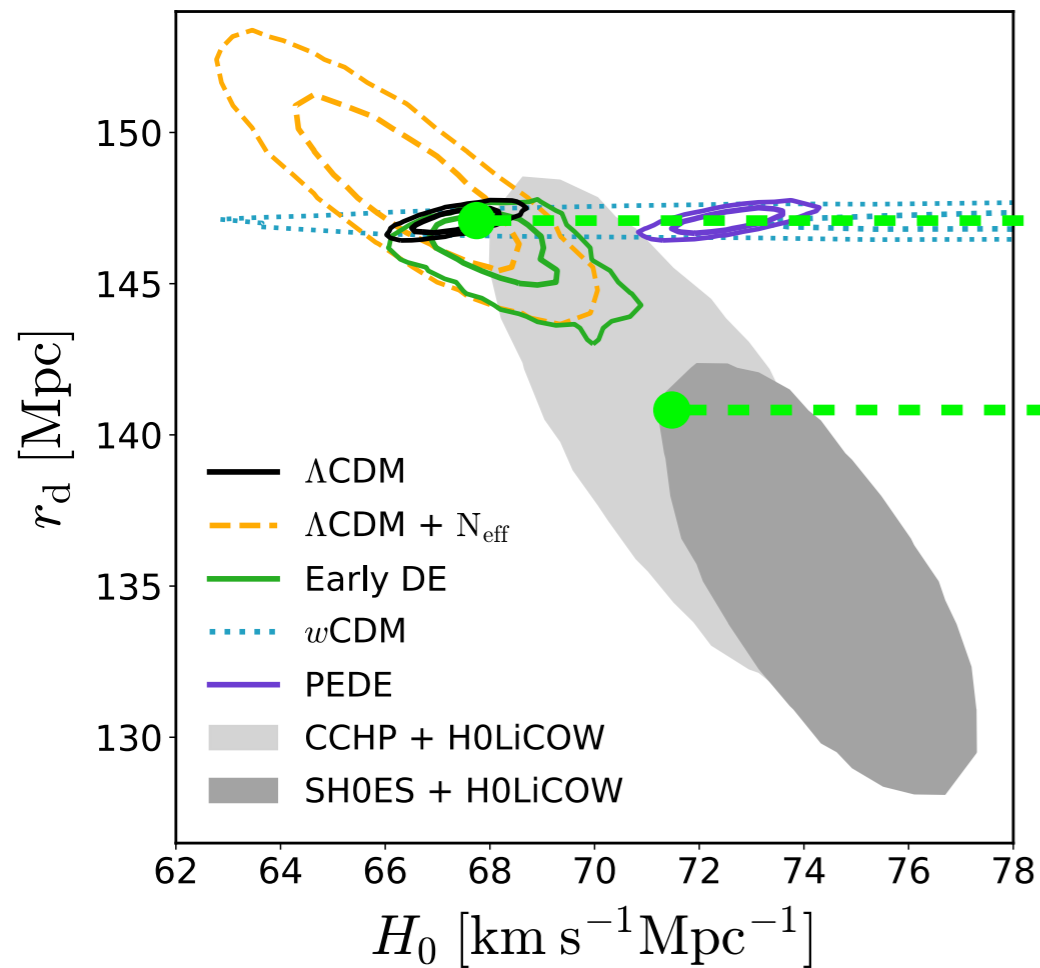


NB: what about lenses in the North?!

Why it matters: the Sound Horizon

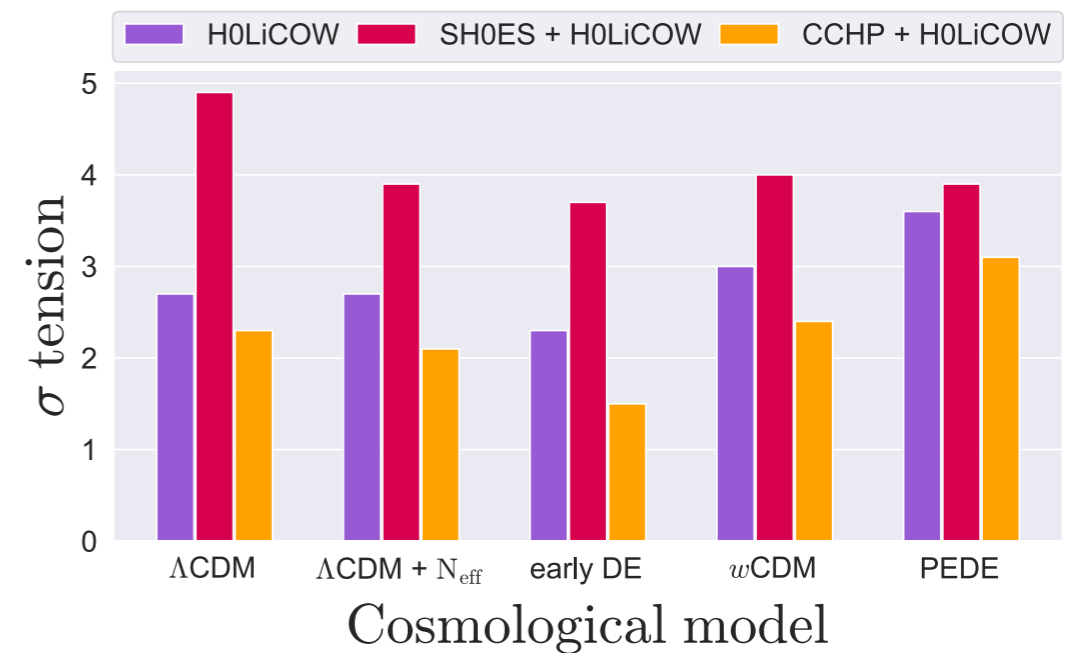


Why it matters: the Sound Horizon



CMB + Standard Model

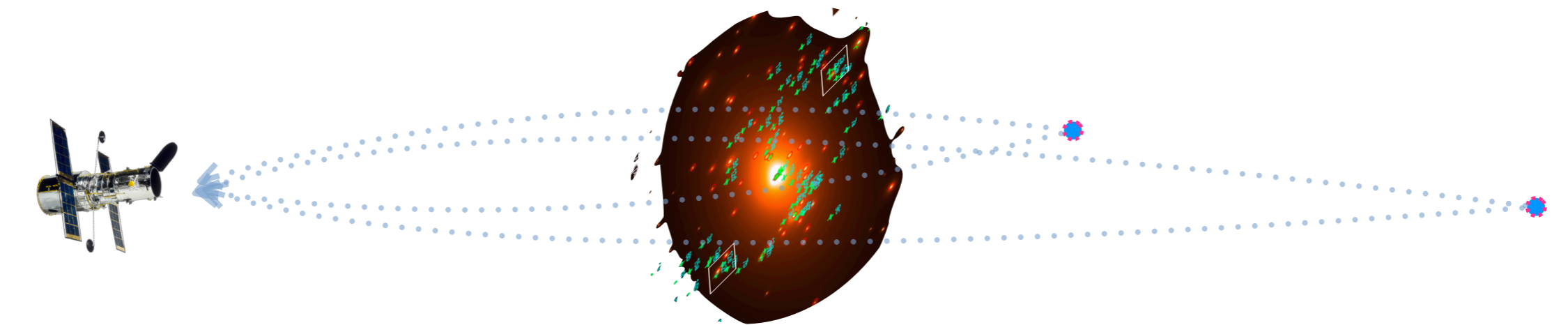
Low- z measurements
(3sigma contours)



Not all models resolve the *tension* between low- z and high- z probes, and not all probes are compatible with SM extensions.

(Arendse, Wojtak, [AA](#) & TDCOSMO 2020)

Bonus Track: Galaxy Clusters



(observer)

lensing cluster ($z \sim 0.4$)

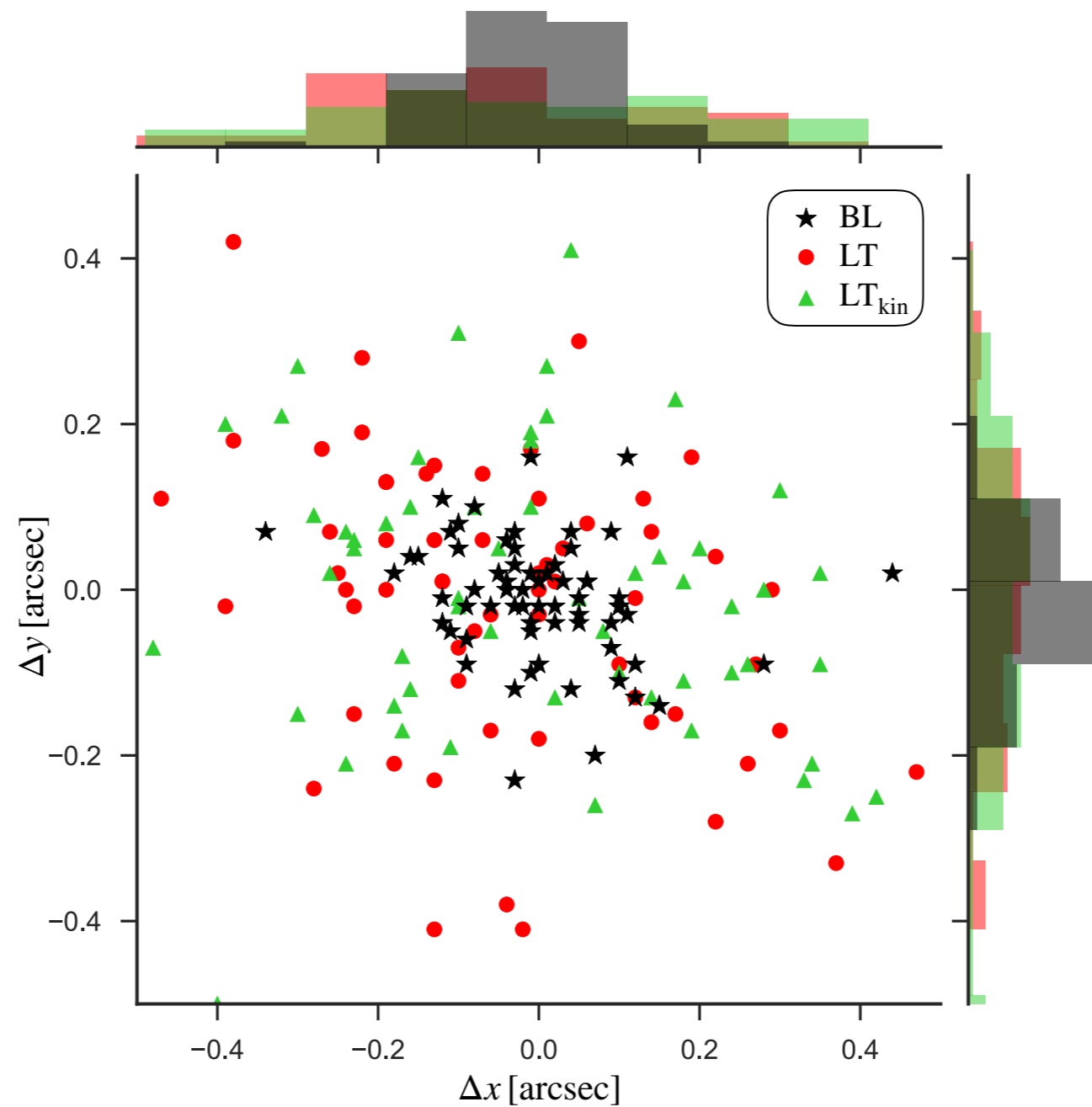
sources ($z \sim 0.6-4.0$)

mass \leftrightarrow deflections

cosmology \leftrightarrow rel.distances

BUT CAN WE?

Cluster Lensing Models



Stellar Kinematics: more model freedom, better accuracy.
(Bergamini et al. 2019, 2020)

To Sum Up...

- There are *fundamental physics* quantities that cosmologists don't agree upon; BSM physics?
- We need accurate measurements, independent of Local Universe *distance ladder* measurements
- Lensing is one of them
- Stellar kinematics to break residual degeneracies
—> towards ***percent-level H_0***
- “wide-field” IFUs on large telescopes are needed (MUSE in the South, MAAT in the North?)
- we may even extend this into more complicated systems (i.e. galaxy clusters), still tricky though