US-ELTP: Cosmological applications of gravitational lensing

Francis-Yan Cyr-Racine
(University of New Mexico)

Tommaso Treu, UCLA
Anowar Shajib, UCLA
Simon Birrer, Stanford

NSF's National Optical-Infrared Astronomy Research Laboratory

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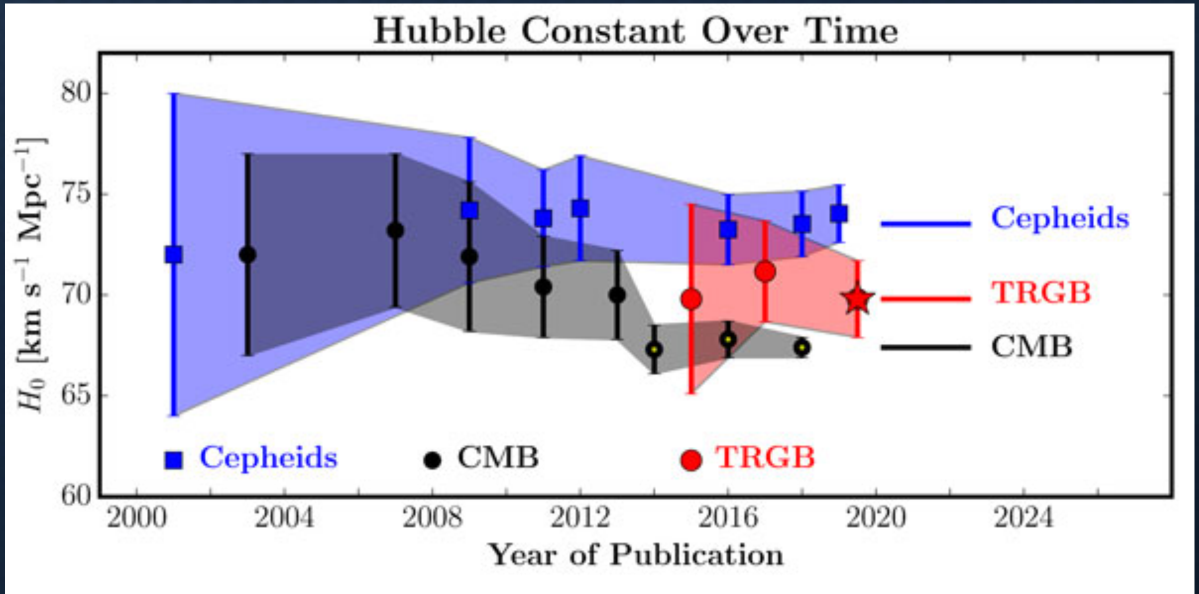
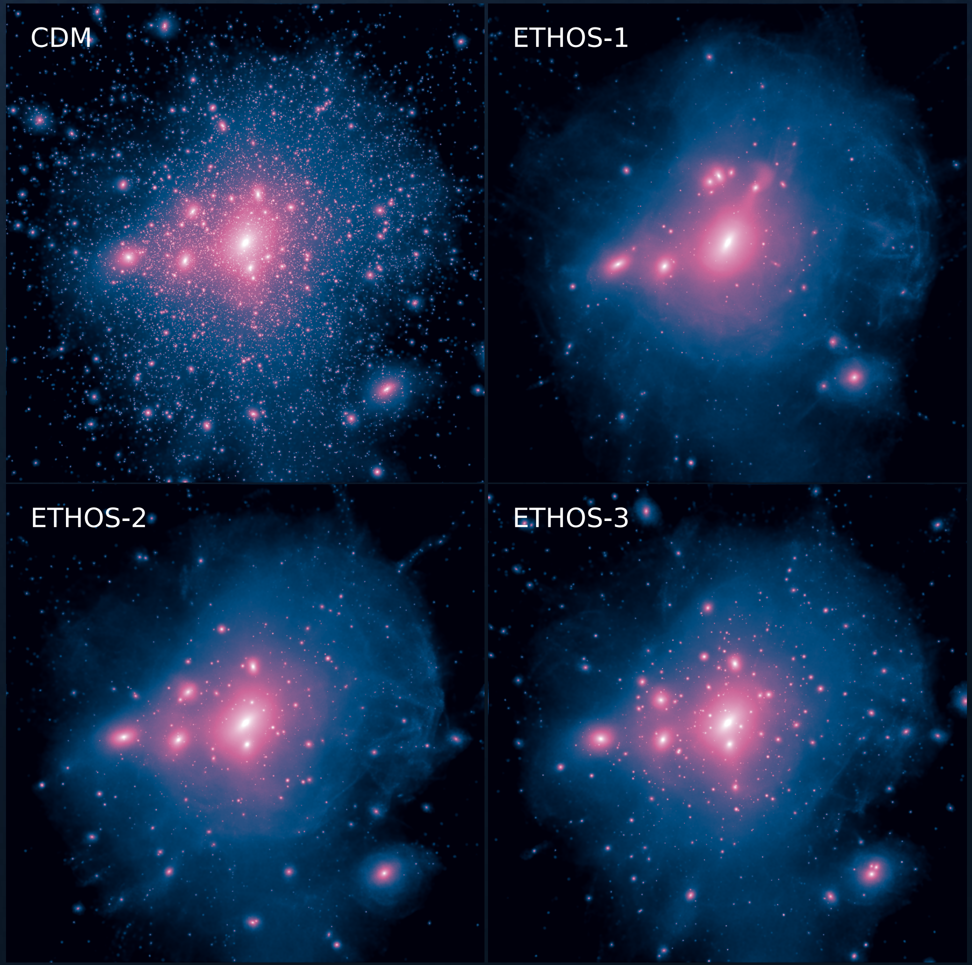
Key cosmological science cases enabled by the US-ELTP

1) The Hubble constant



Freedman et al. (2019)

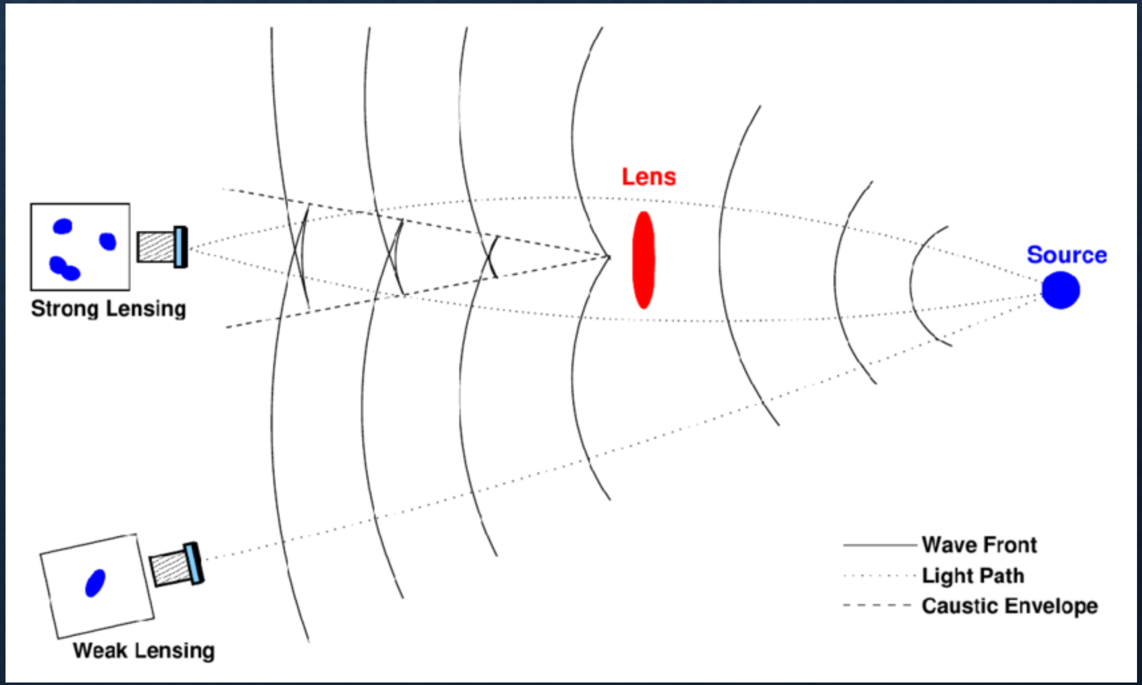
2) The nature of Dark Matter



Vogelsberger, Zavala, Cyr-Racine +, arXiv:1512.05349

Hubble constant with time-delay cosmography

- Use relative arrival time delay as a geometric probe of distance

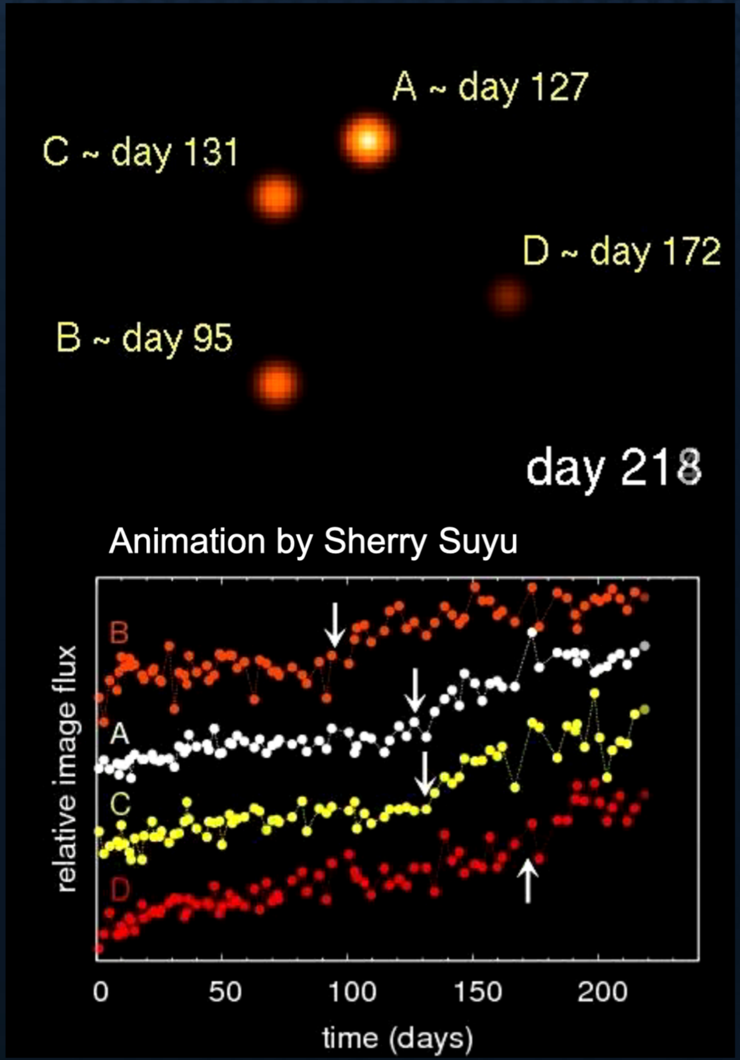


Anguita (2009)

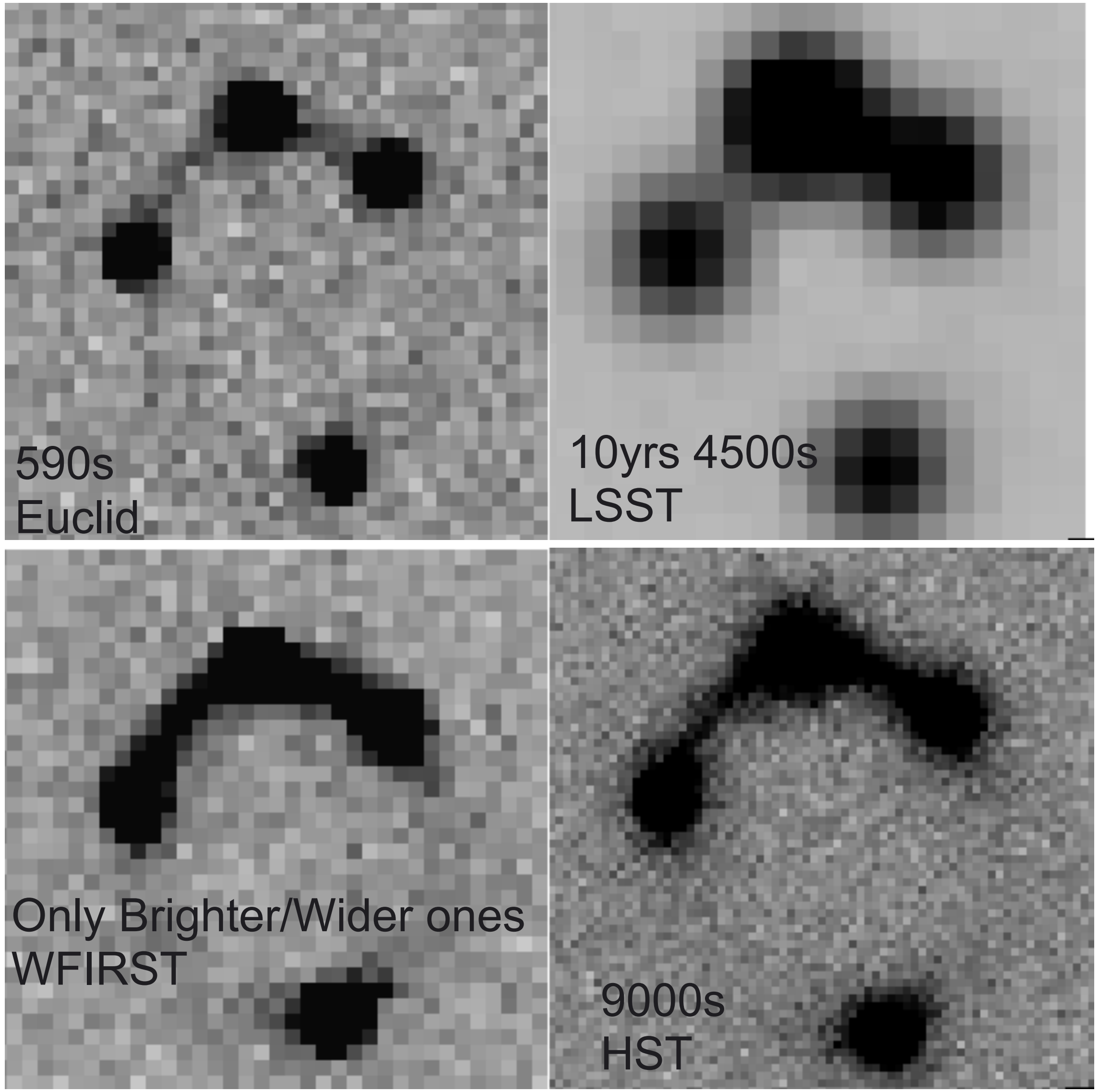
$$D_{\Delta t} \propto \frac{1}{H_0}$$

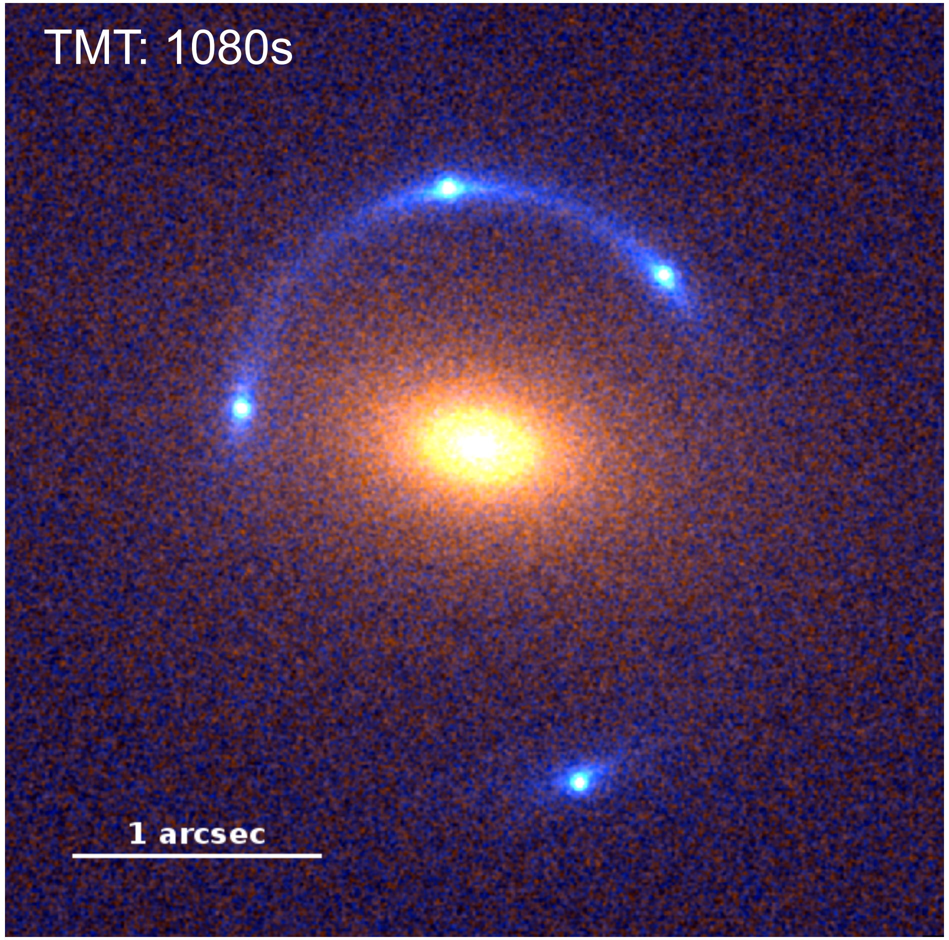
$$\Delta t \propto D_{\Delta t} \times \phi_{\text{lens}}$$

This is where the ELTs can make a huge difference!



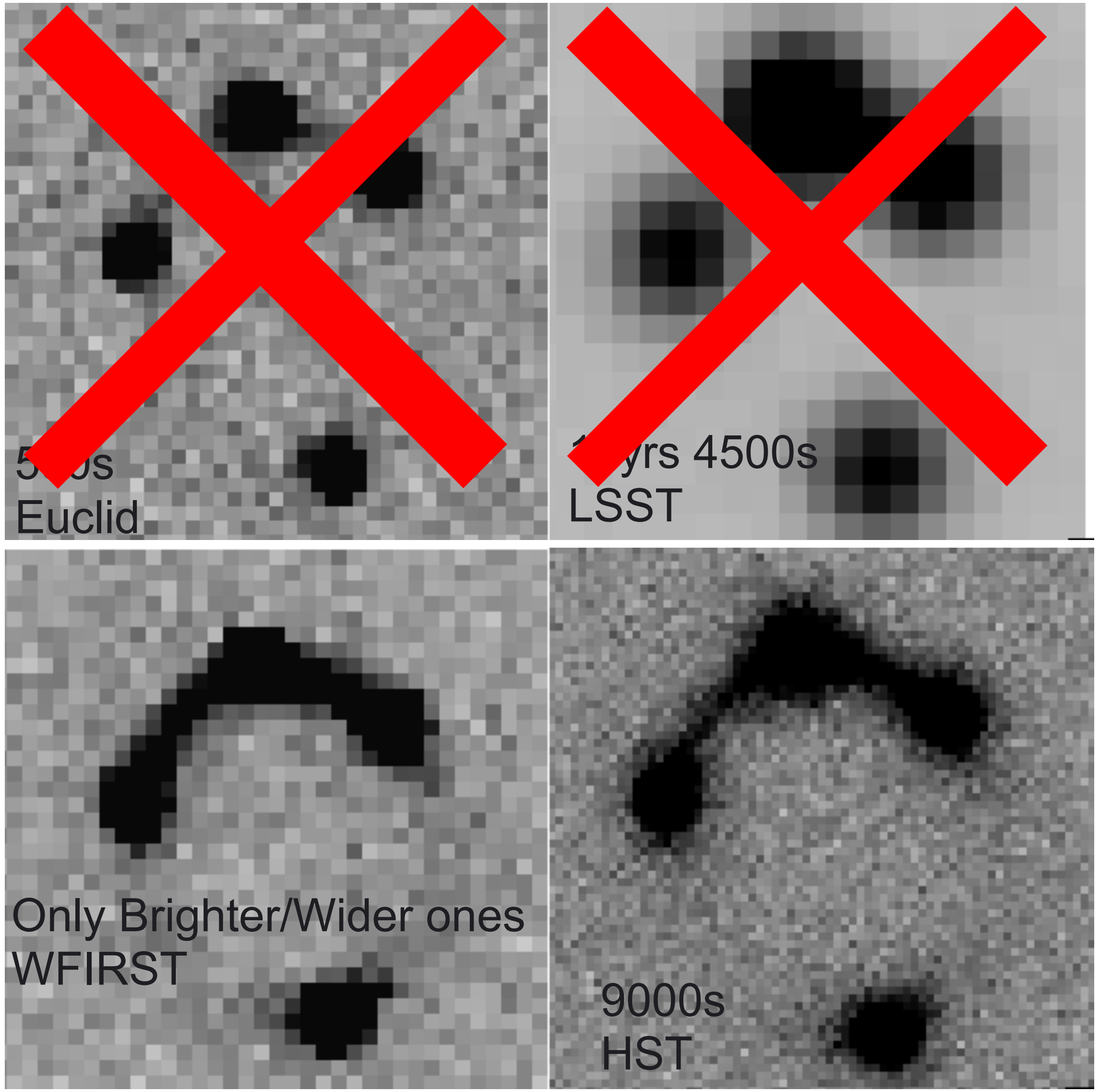
H_0: High resolution imaging of strong lenses

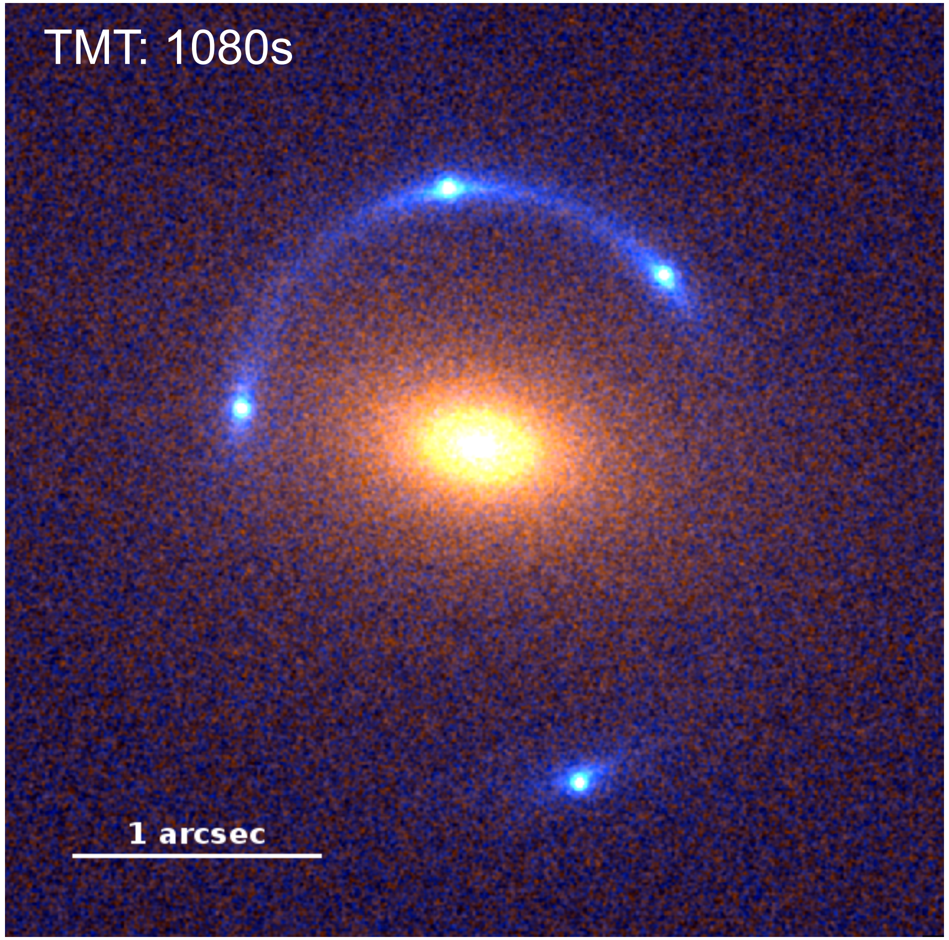




Meng, Treu et al. 2015

H_0: High resolution imaging of strong lenses

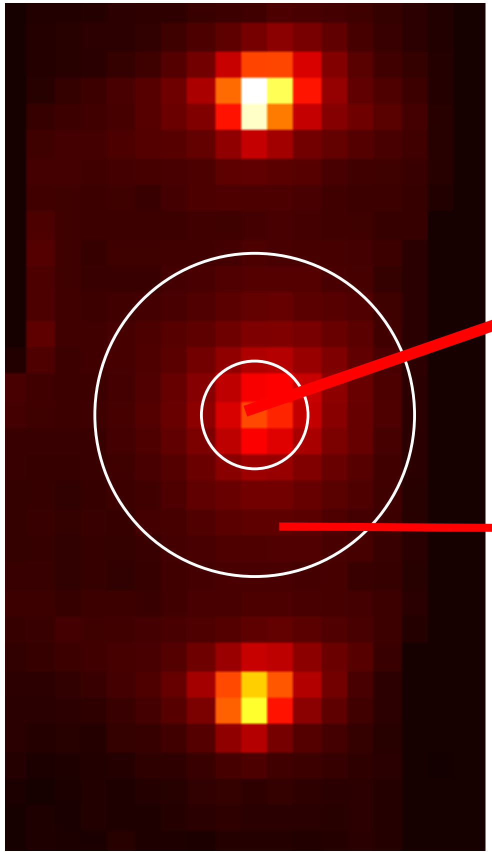


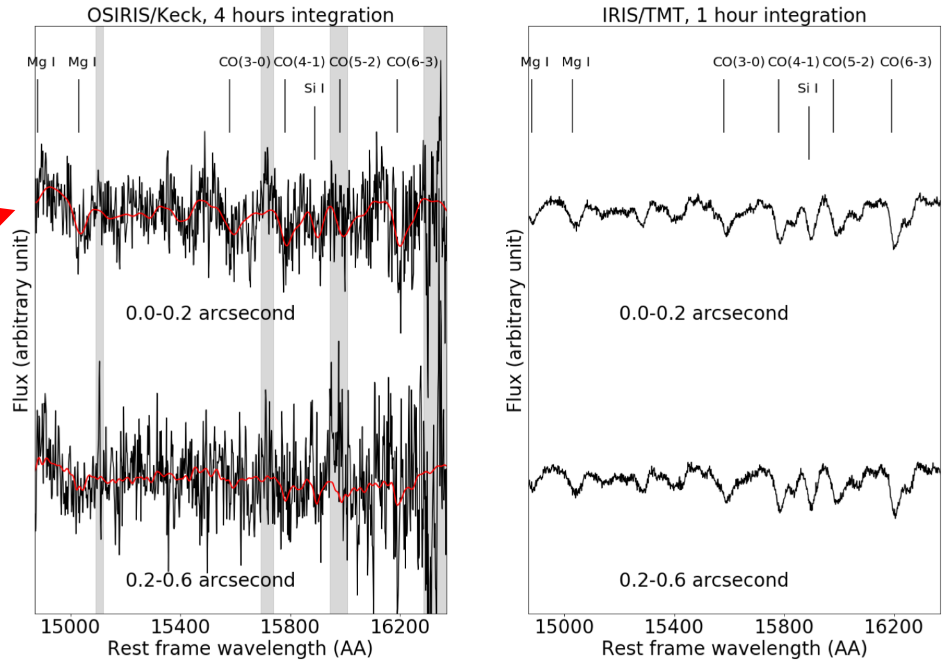


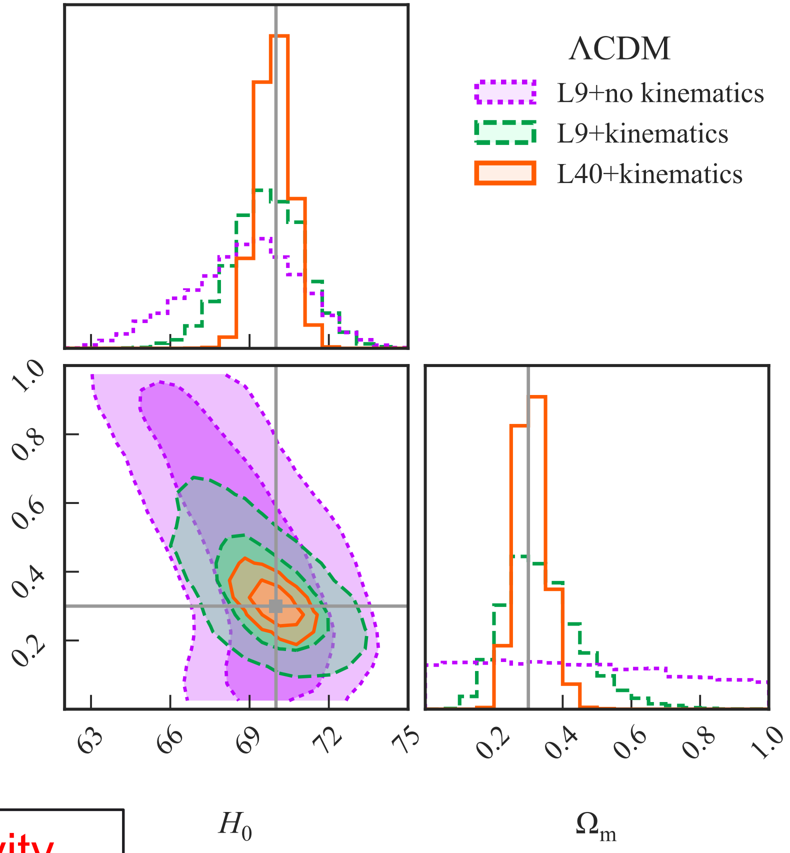
Meng, Treu et al. 2015

H_0: Spatially resolved kinematics of lens galaxies

- Internal kinematic of main lens galaxies helps break the mass anisotropy degeneracy







Key ELT capabilities: (1) Resolution, (2) Sensitivity

Shajib et al. 2018, 2019

The US ELT Program and the Hubble tension

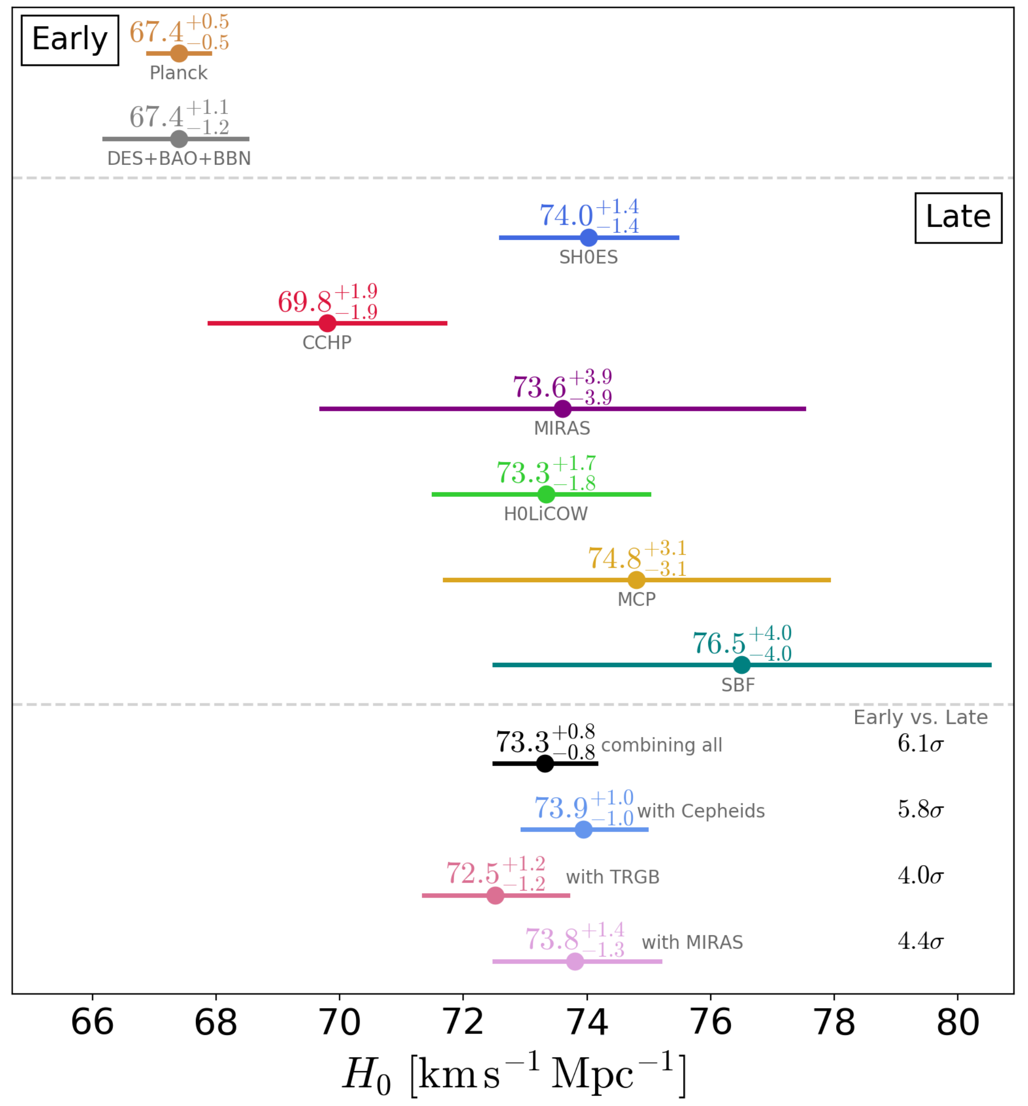
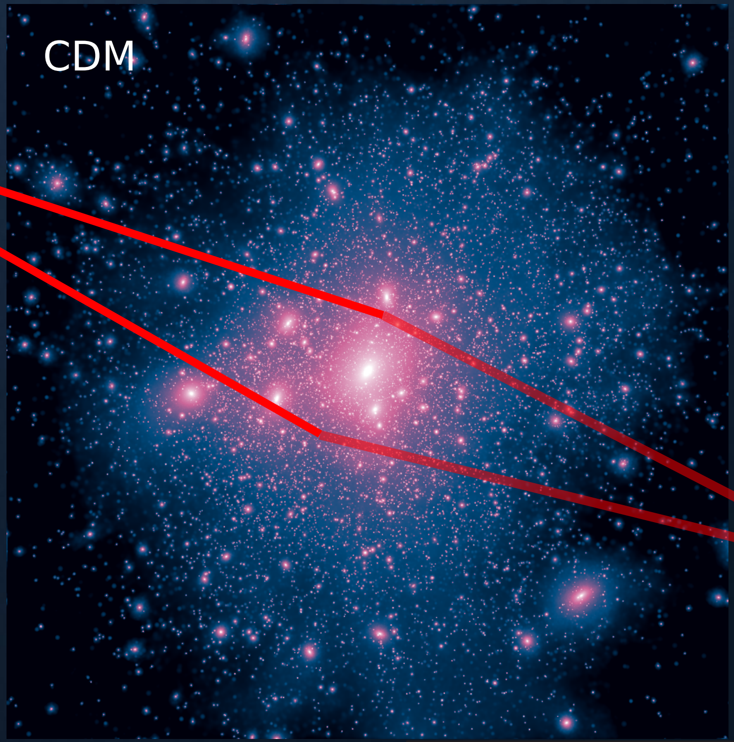


Figure: A. Shajib and V. Bonvin (Verde, Treu & Riess, 1907.10625)

By combining exquisite angular resolution with high sensitivity, the ELTs will enable time-delay cosmography to measure *H_0* to a precision close to that of the CMB, while being *completely* independent.

Dark matter physics from substructure Lensing

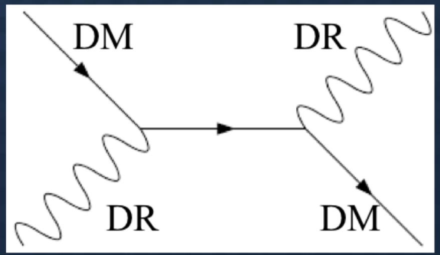
- Use universality of gravity to probe smallest dark matter structures.

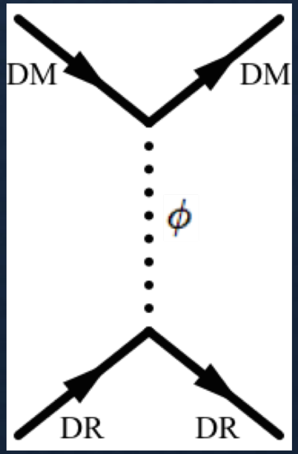


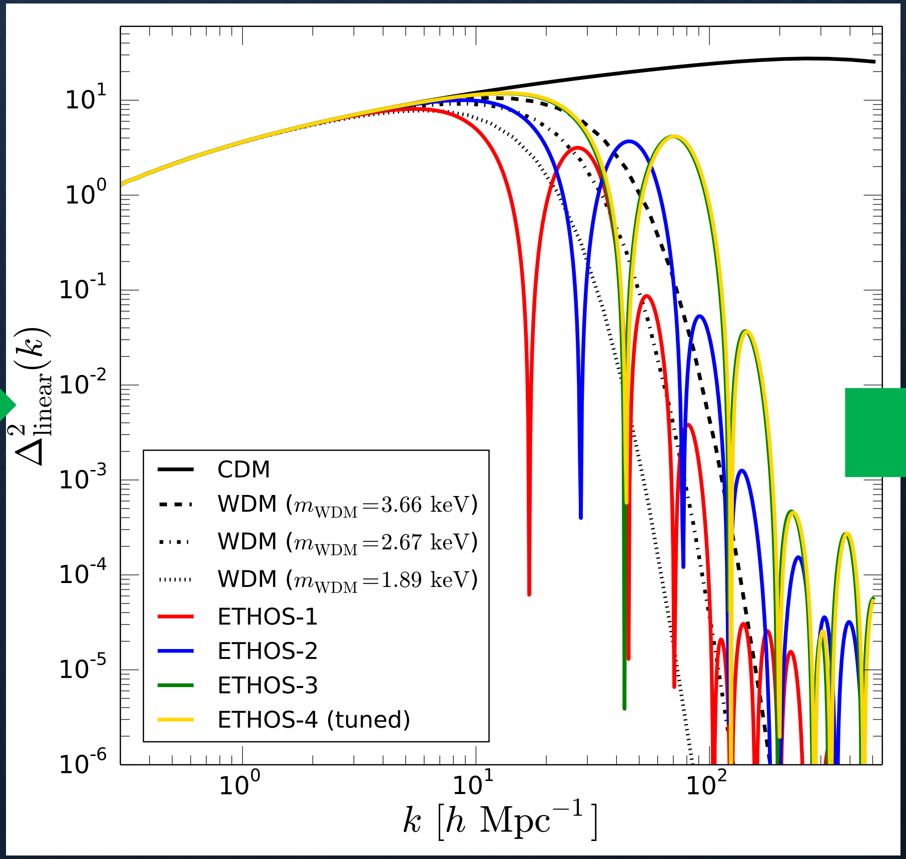
Not to scale!

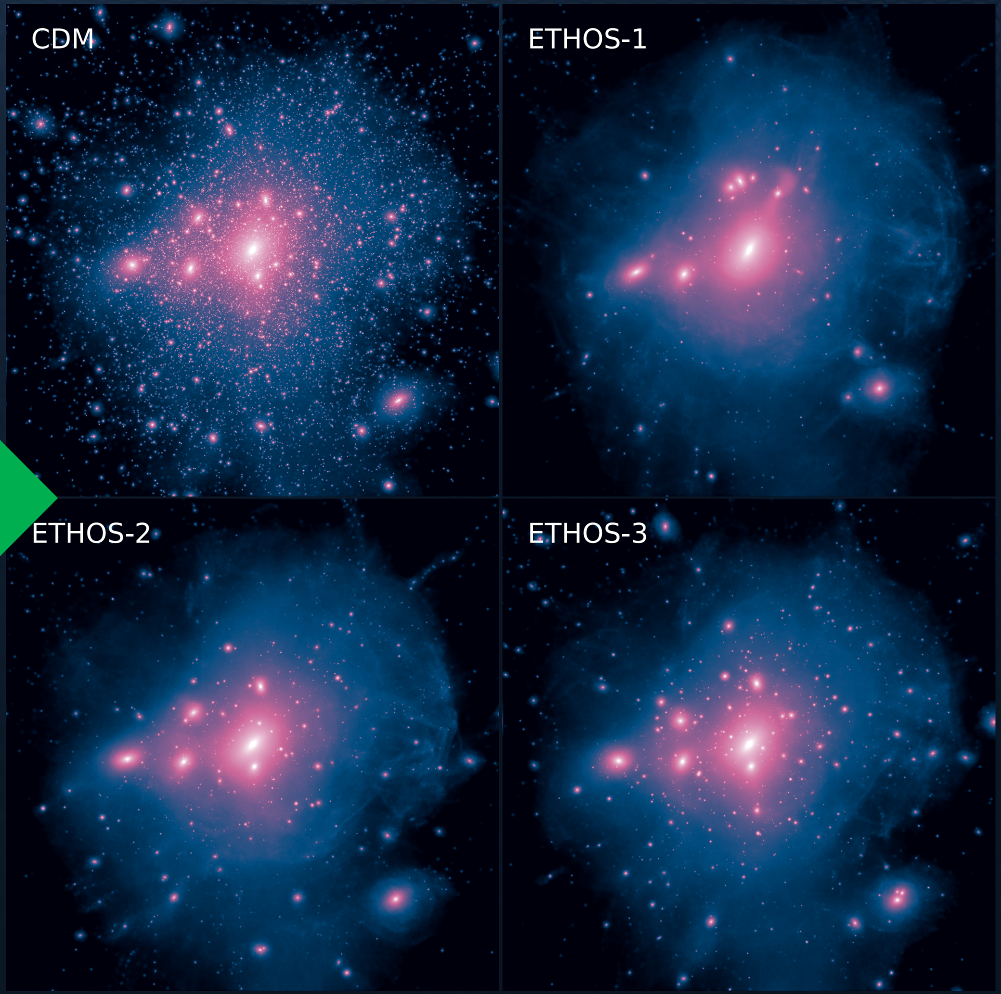
See e.g. Dalal & Kochanek (2002); Vegetti et al. *Nature*, (2012); Hezaveh et al., (2016), Gilman et al. (2019)

Particle dark matter and small-scale structure



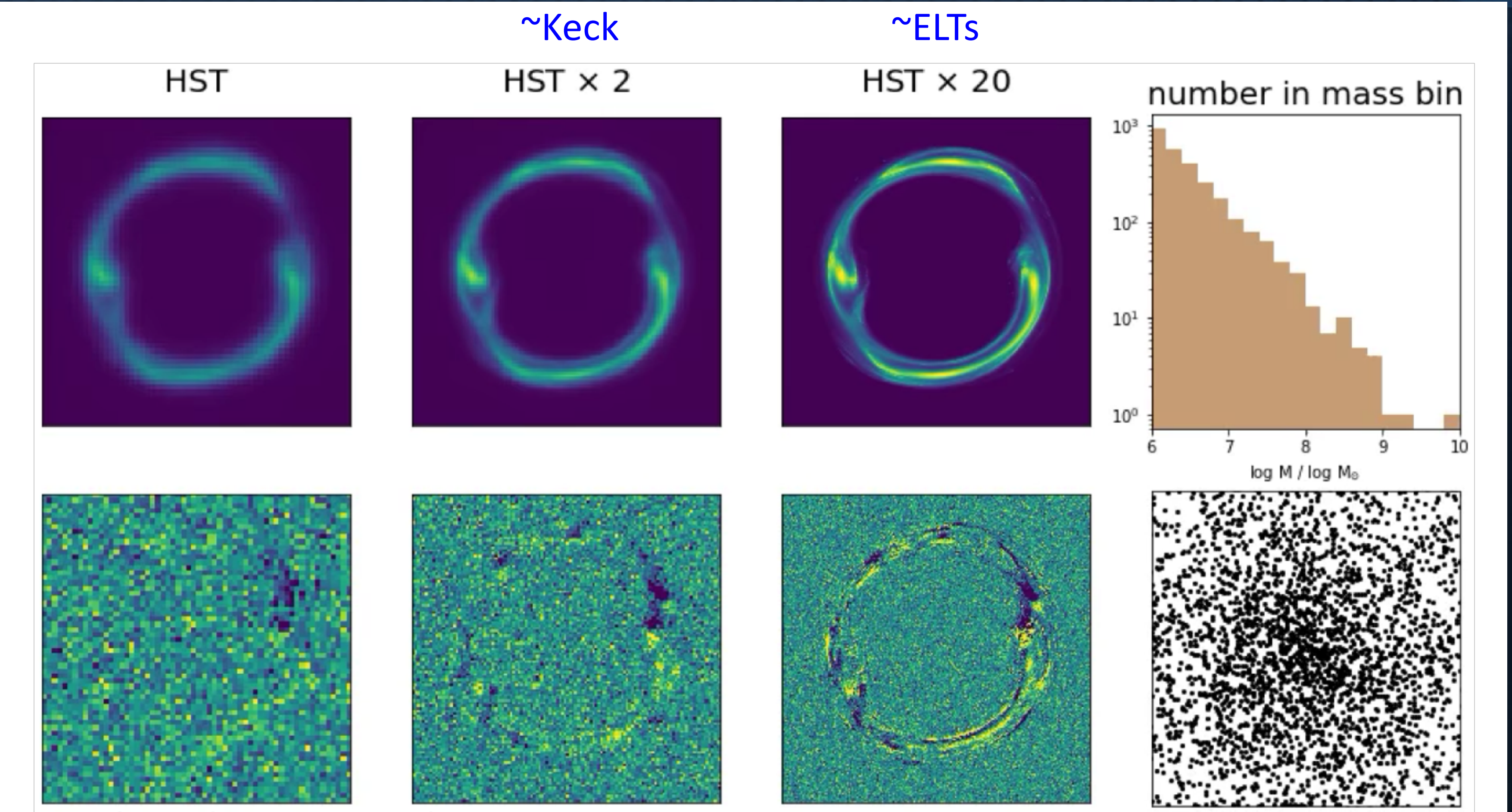






Vogelsberger, Zavala, Cyr-Racine +, arXiv:1512.05349

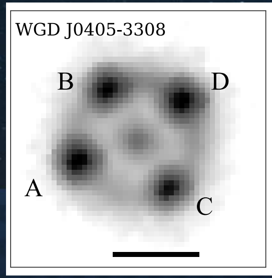
Substructure lensing I: High-resolution imaging



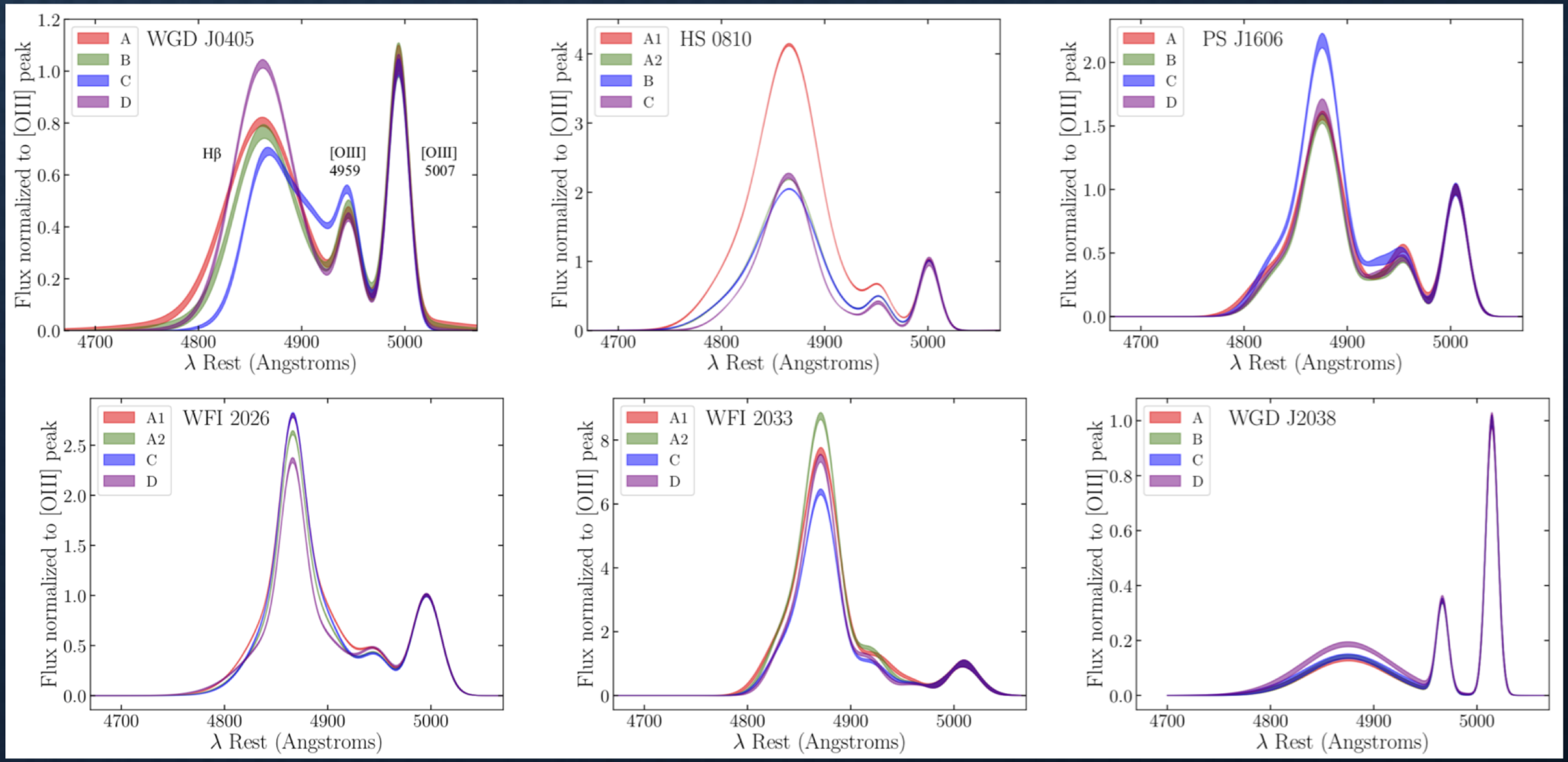
Simulation by S. Birrer with `lenstronomy`

Key ELT capabilities: (1) Resolution, (2) Sensitivity

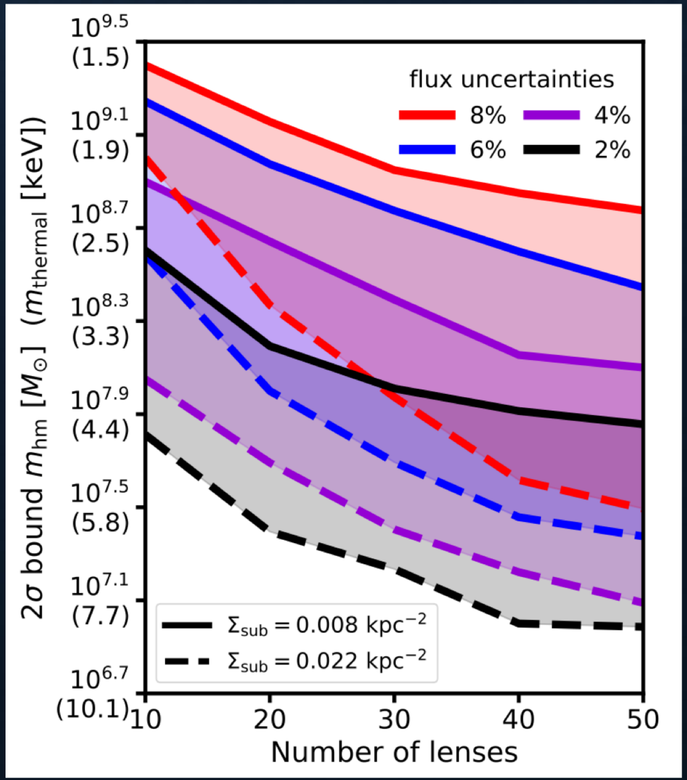
Substructure lensing II: Flux ratio anomalies



- To avoid microlensing effects, focus on quasar narrow-line emission



Nierenberg et al. (2019)



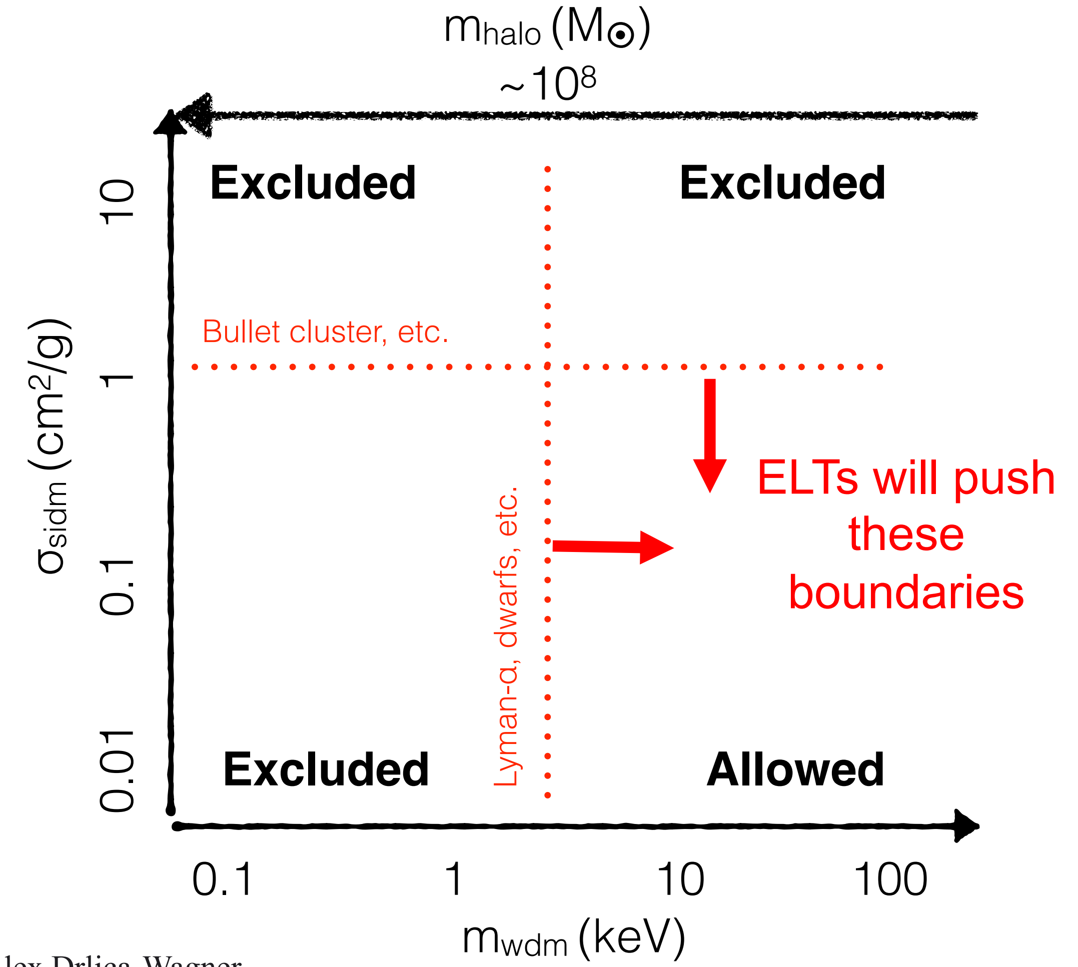
Gilman et al. (2019)

Need both north and south sky coverage to achieve required number of targets!

Mao & Schneider 1998, Dalal & Kochanek 2002, Moustakas & Metcalf 2003, Nierenberg+2014, 2017 Hsueh+2016, 2017, 2019.

Dark matter physics from substructure Lensing

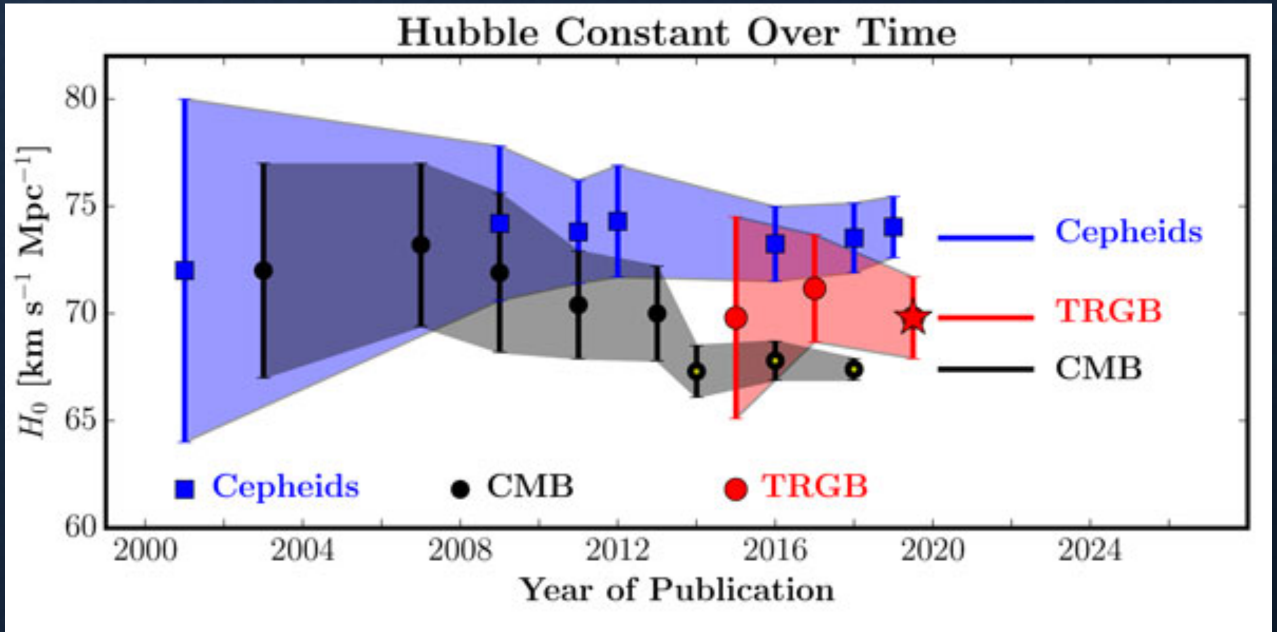
- By being sensitive to both the abundance and density profiles of subhalos and line-of-sight halos, strong lensing with the ELTs will provide key information on a possible halo mass function cutoff or the presence of dark matter self-interaction in the higher redshift Universe.



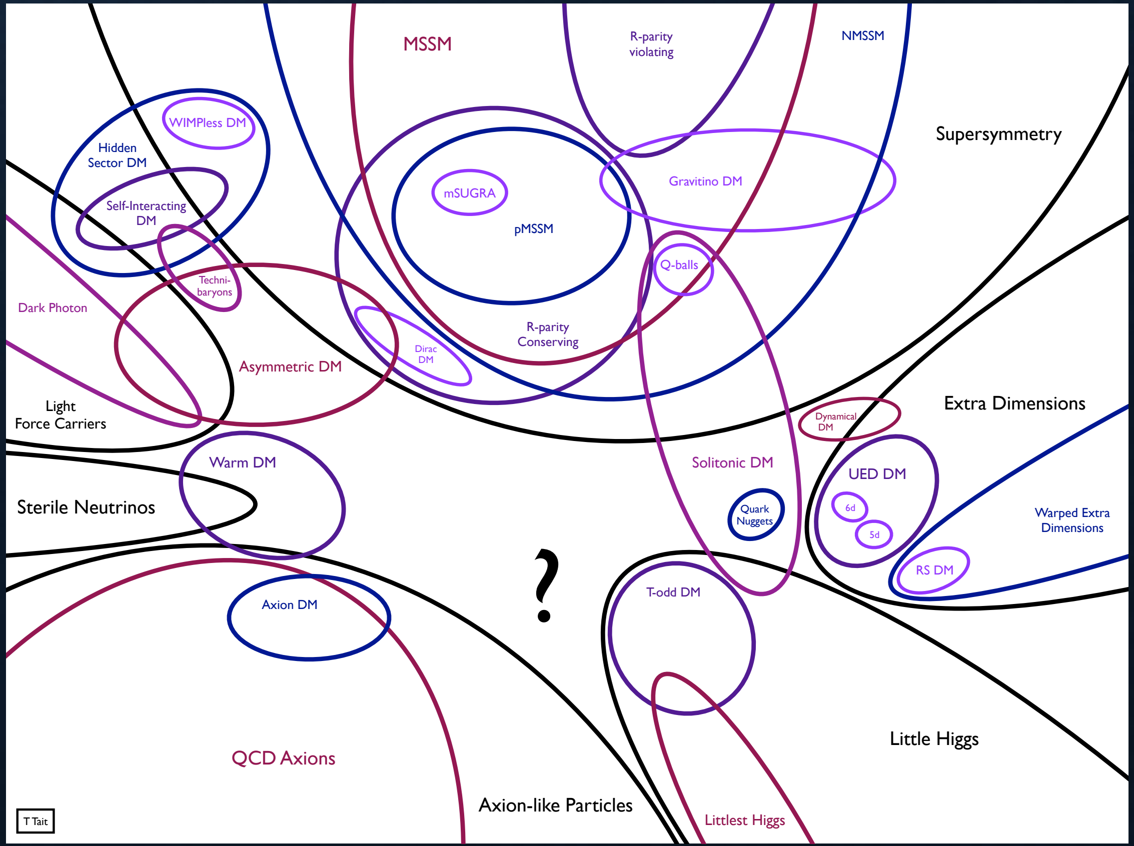
Credits: Alex Drlica-Wagner

Summary

- The resolution and sensitivity of the ELTs will address 2 of the most pressing questions in cosmology right now: What is the nature of dark matter and Is there physics beyond ΛCDM?

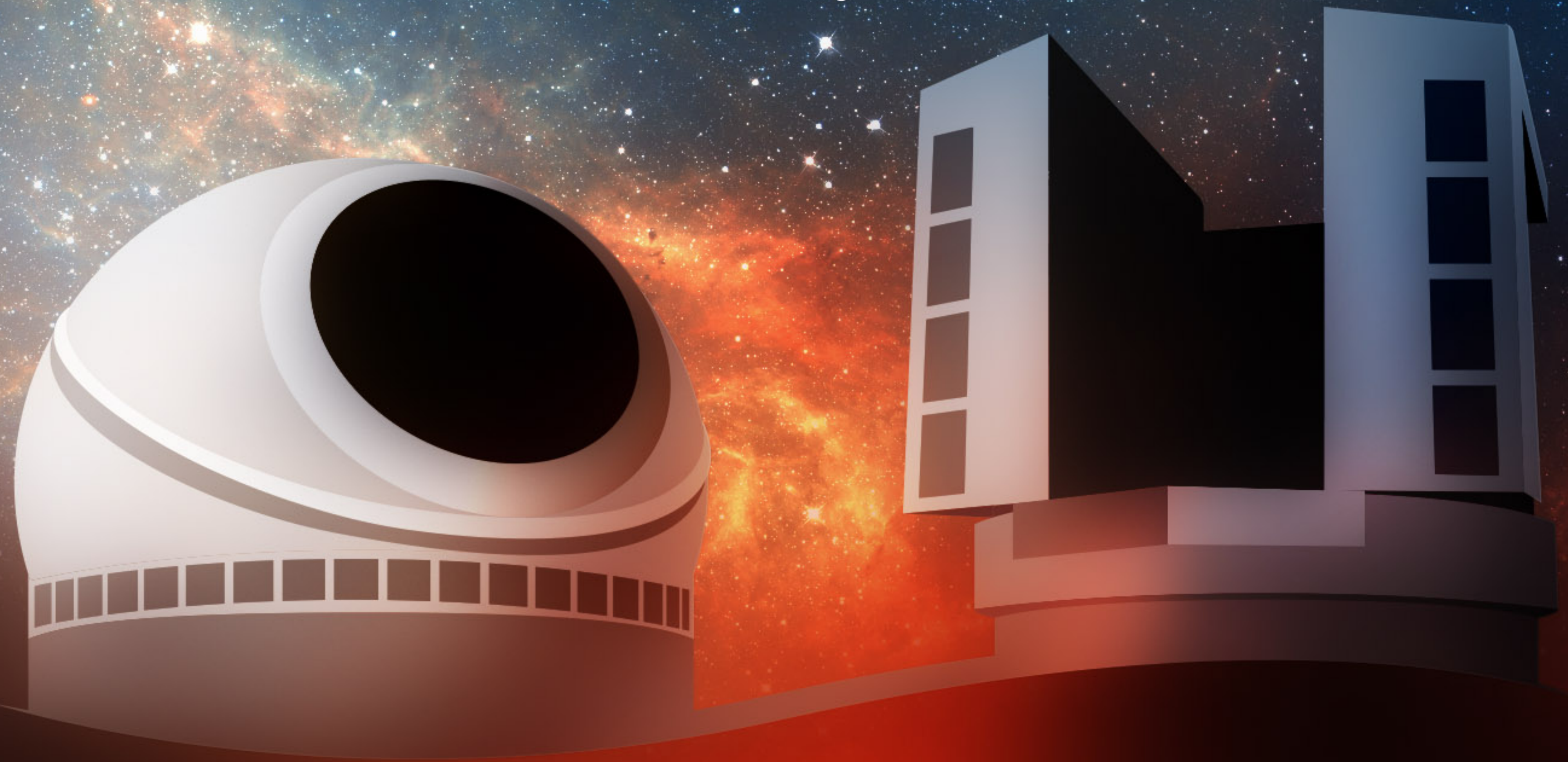


Freedman et al. (2019)



Credits: Tim Tait

Thank you!



https://nationalastro.org/USELTP

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Spectroscopy of lenses with US-ELT

Table 4. Uncertainties of $D_{\rm d}$ and $D_{\Delta t}$ for a single lens with different observational setups

Model	Kinematics data	$\sigma_{D_{\rm d}}$ (per cent)	$\sigma_{D_{\Delta t}}$ (per cent)
Baseline	No	-	6.5
	Integrated	19.8	6.5
	Resolved	9.6	5.8
Conservative	Integrated	27.0	7.8
	Resolved	16.7	7.5
Futuristic	Resolved	7.7	5.3

Shajib, Treu & Agnello 2018

Imaging lenses with US-ELT

Table 6. Exposure time requirements

Instrument	double		quad	
	faint	bright	faint	bright
HST	6×10^3s	360 s	3×10^3s	150 s
JWST	690s	180 s	210s	<60 s
Keck (LGSAO)	105×10^3s	3600 s	75×10^3s	2400 s
Keck (NGAO)	18×10^3s	180 s	12×10^3s	150 s
TMT	1200s	—	1080s	—

TMT will image any known lens to the required precision within 10-20 minutes! Meng, Treu et al. 2015