Cosmology

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TAE 2023 - International Workshop on High Energy Physics

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IPARCOS
UNIVERSIDAD COMPLUTENSE MADRID
GOBIERNO DE ESPAÑA MINISTERIO DE UNIVERSIDADES
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CENTRO DE CIENCIAS DE BENASQUE PEDRO PASCUAL

Contents

Galaxy Surveys

Spectroscopic:

good or very good radial resolution (0.1-1Mpc/h), but less deep (small Volume)

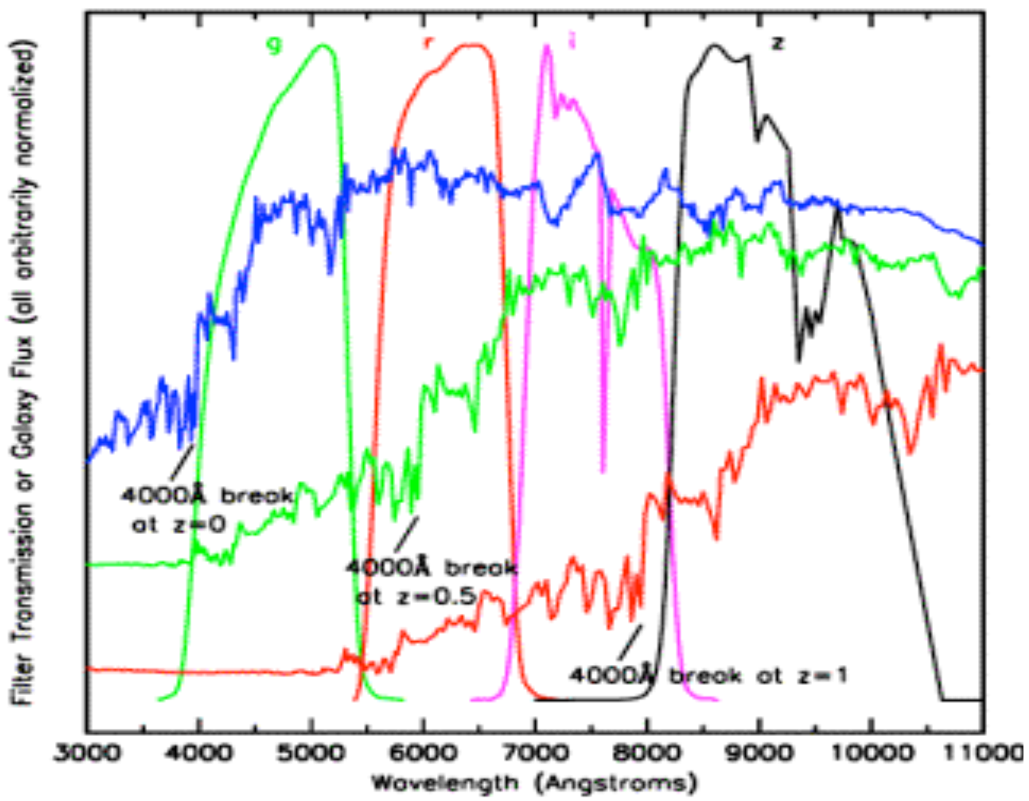
WiggleZ, BOSS, e-BOSS, Subaru/Sumire, OzDES, DESI, HETDEX, SKA, VISTA/Spec, Euclid, WFIRST

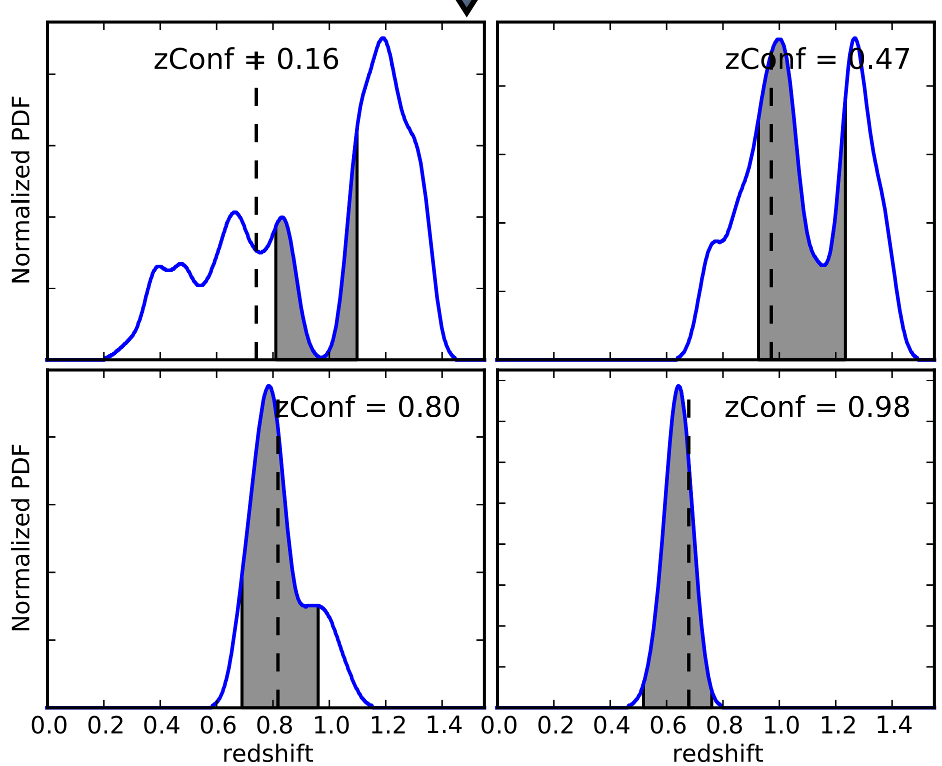
***Photometric*:**

poor radial (redshift) resolution (~300 Mpc/h) but deeper (more Volume, more evolution)

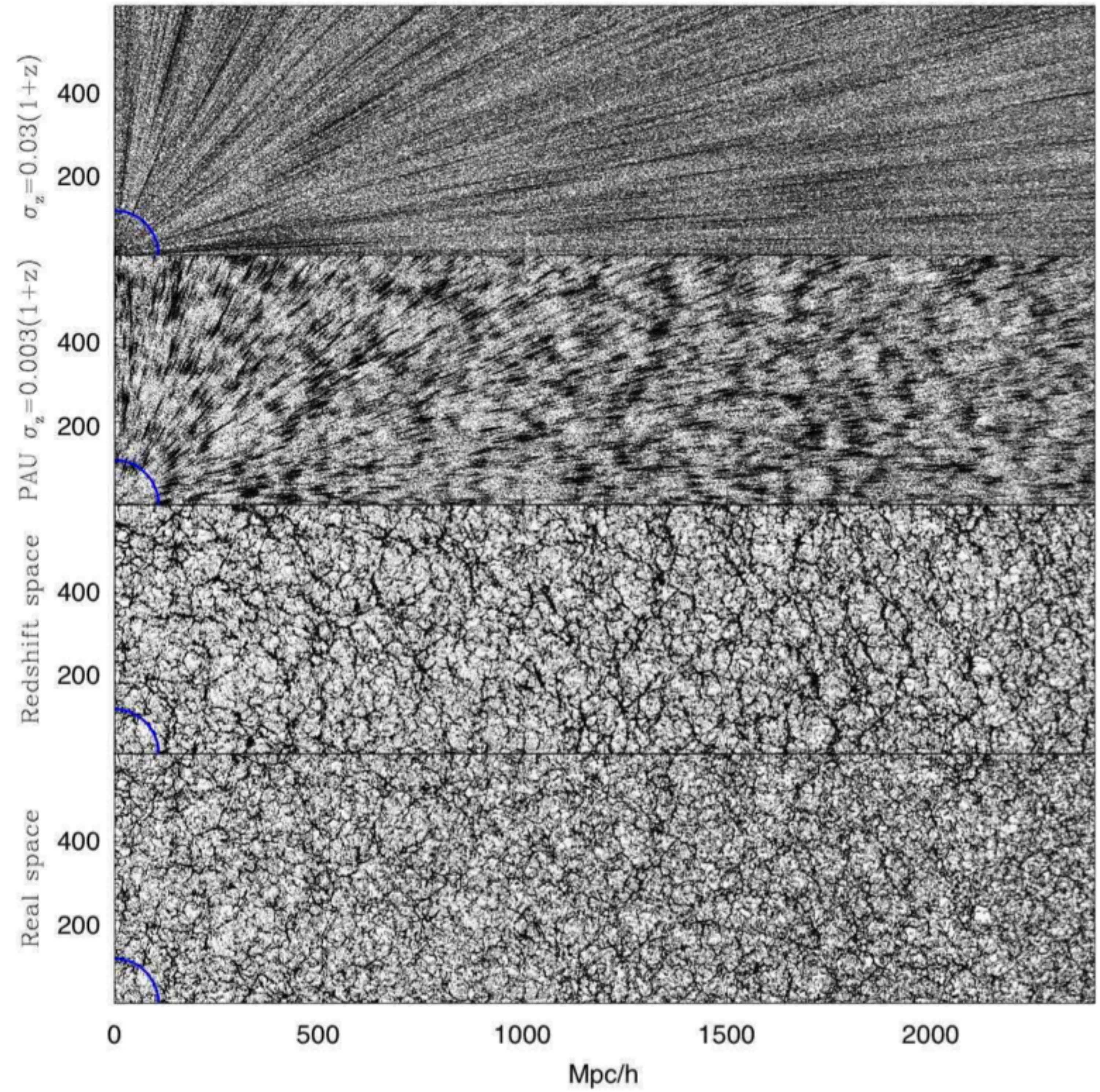
DES, VISTA, Pan-STARRS, Subaru/HSC, KIDS, Skymapper, LSST, Euclid, WFIRST

Photometric surveys





Carrasco Kind & Brunner 2013a (MNRAS, 432, 1483)

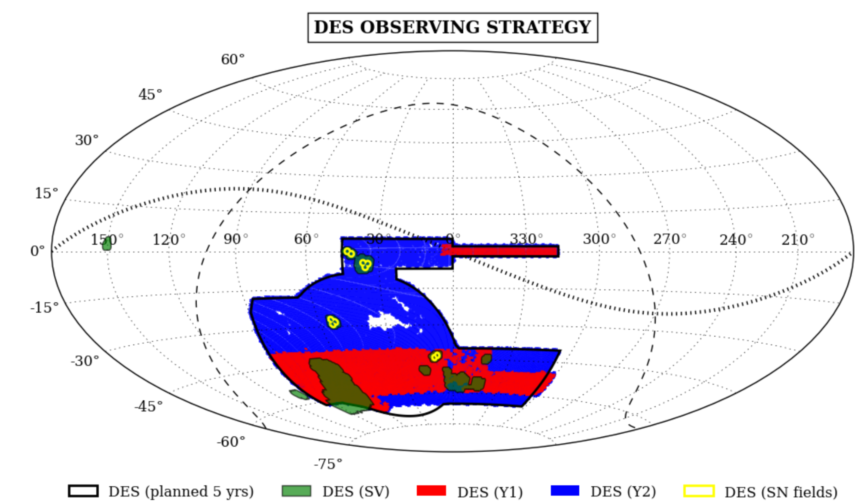


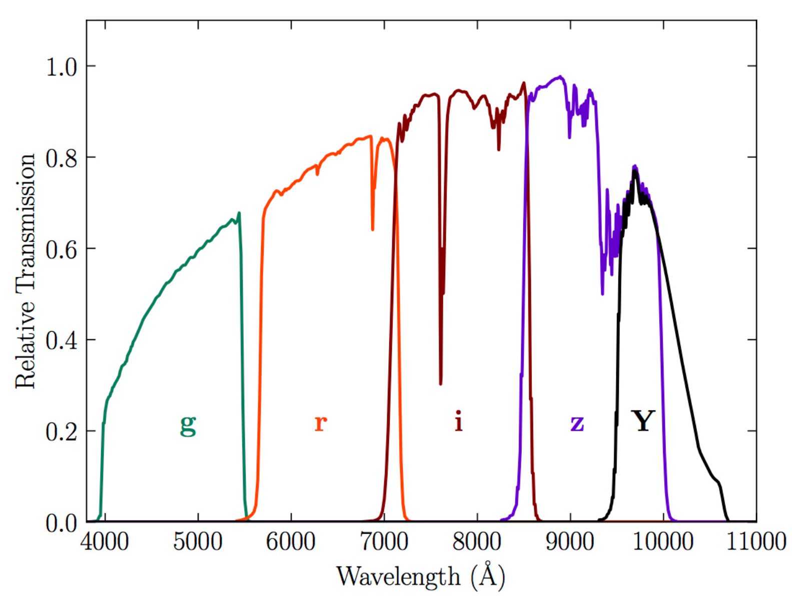
Benitez et al., 2009

Dark Energy survey

- 570 Mpixel DECam situated at 4-m Blanco Telescope, at Cerro Tololo (Chile)
- 2.2 degrees FoV.
- 5 broad-band filters grizY
- Expects to record over 300 million galaxies to depth i_{AB}~ 24
- Two surveys:
  - Wide: 5000 deg^2 during 5 years
  - Deep: 30 deg^2 repeated visits for transients (e.g. SN Type 1a)

DARK ENERGY SURVEY



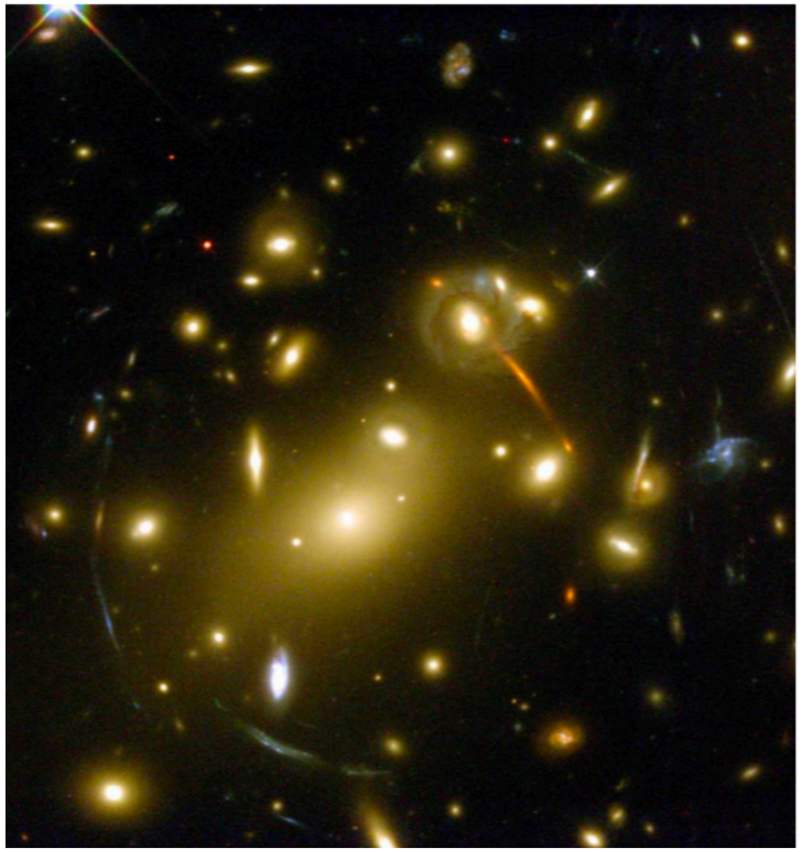


Gravitational lensing

As light its affected by gravity, the bright and shape of lensed objects change. -> Potential cosmological observable.

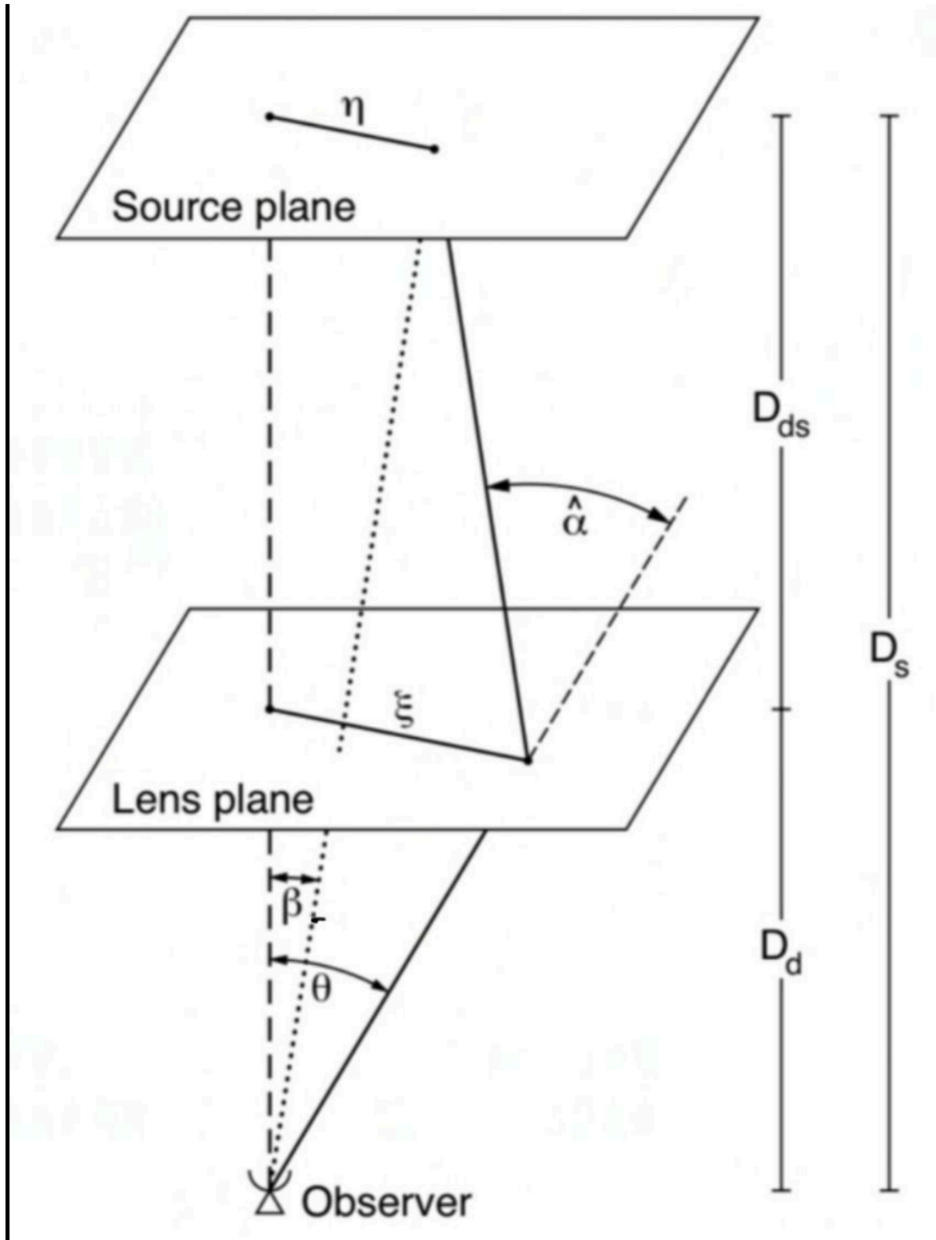
Depending on the distance to the lens and source and the properties between them, we can define 2 lensing effects

Strong lensing



Weak lensing

Gravitational lensing



Bartelmann & Schneider 2001

For a point source:

$$\hat{\alpha} = \alpha \frac{Ds}{Dds} = \frac{4GM}{\xi c^2}$$

$$\theta - \alpha = \beta$$

For an extended potential:

$$\hat{\alpha}(\xi) = \frac{4GM(\xi)}{\xi c^2}$$

$$M(\xi) = 2\pi \int_0^{\xi} \Sigma(\xi')\xi' d\xi'$$

Gravitational lensing

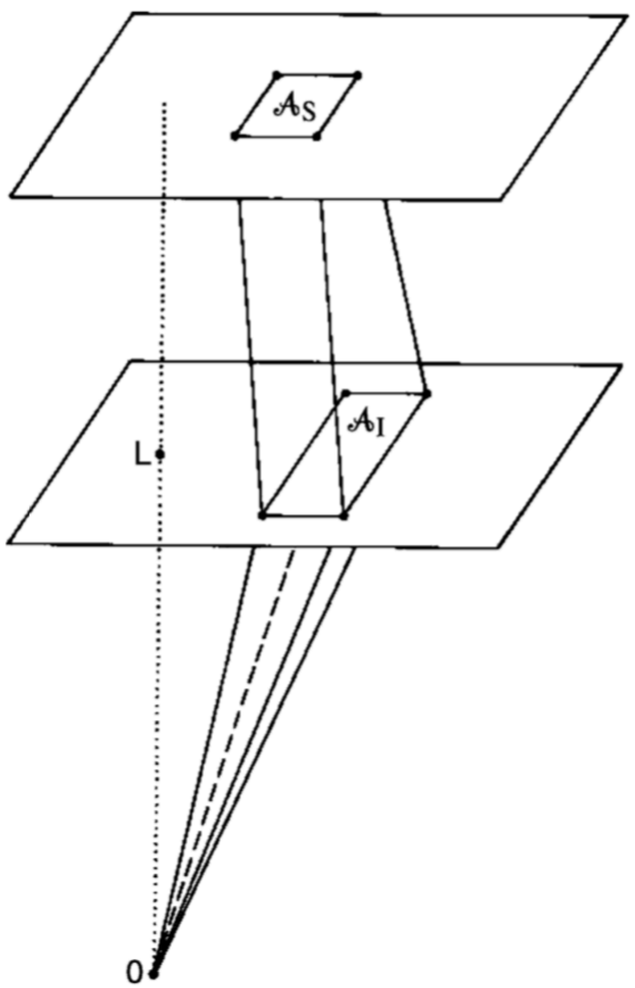


Fig. 2.23. Light beams are deflected differentially, leading to changes of the shape and the cross-sectional area of the beam. As a consequence, the observed solid angle subtended by the source, as seen by the observer, is modified by gravitational light deflection. In the example shown, the observed solid angle $\mathcal{A}_I/D_d^2$ is larger than the one subtended by the undeflected source, $\mathcal{A}_S/D_s^2$ – the image of the source is thus magnified

An extended object change shape and brightness by the lensing of multiple light trajectories. Described by the Jacobian between the unlensed and lensed coordinates.

$$A_{ij} = \frac{\partial \beta_i}{\partial \theta_j} = \delta_{ij} - \frac{\partial \alpha_i}{\partial \theta_j} = \delta_{ij} - \frac{\partial^2 \psi}{\partial \theta_i \partial \theta_j} = \begin{bmatrix} 1-\kappa-\gamma_1 & \gamma_2 \\ \gamma_2 & 1-\kappa+\gamma_1 \end{bmatrix}$$

$$\vec{\theta} - \vec{\beta} = \vec{\alpha}(\vec{\theta}) = \vec{\nabla}\psi(\vec{\theta})$$

$$\kappa(\vec{\theta}) = \frac{1}{2}\nabla^2\psi(\vec{\theta})$$

κ is the convergence (change of brightness) -> magnification

γ define the shape change -> (shear)

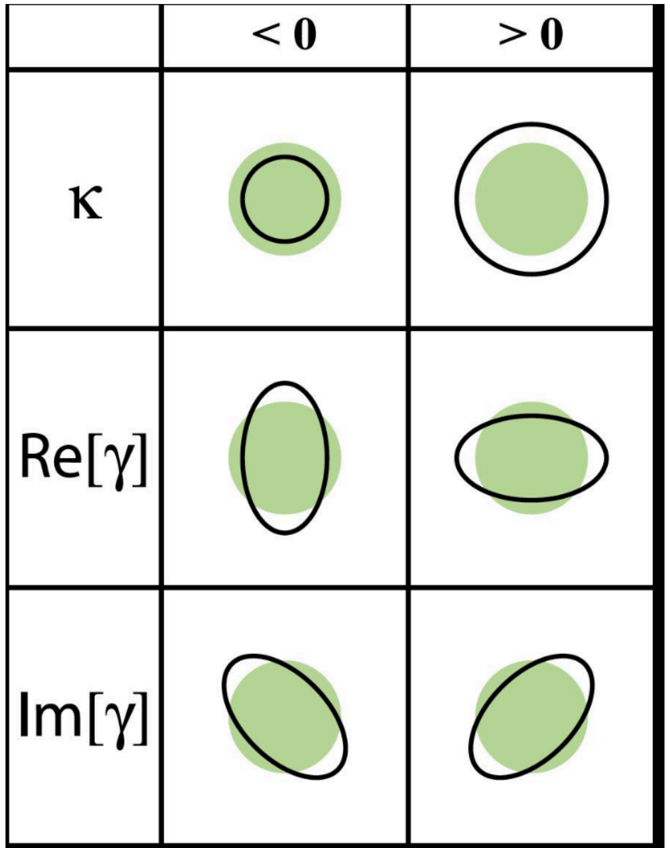
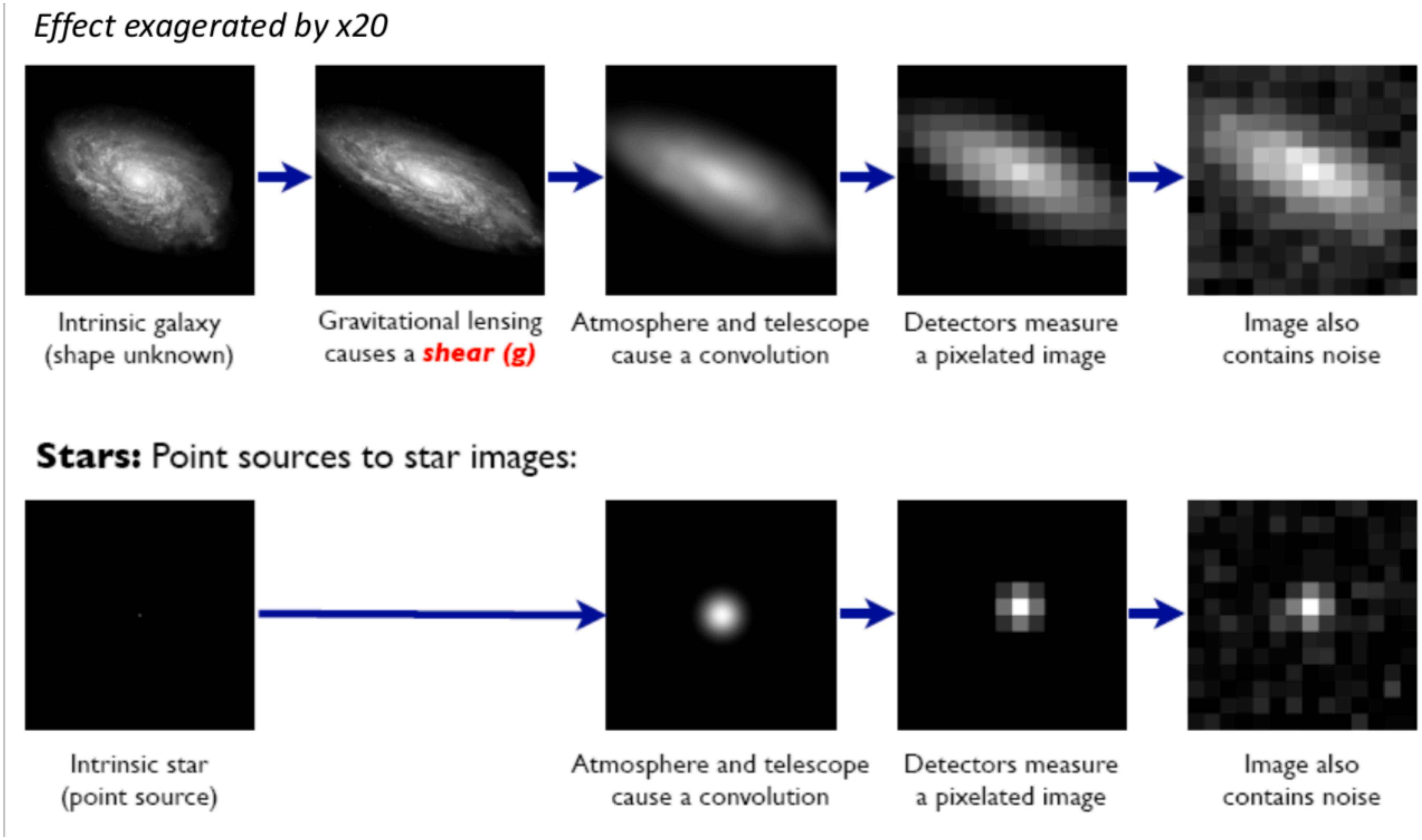


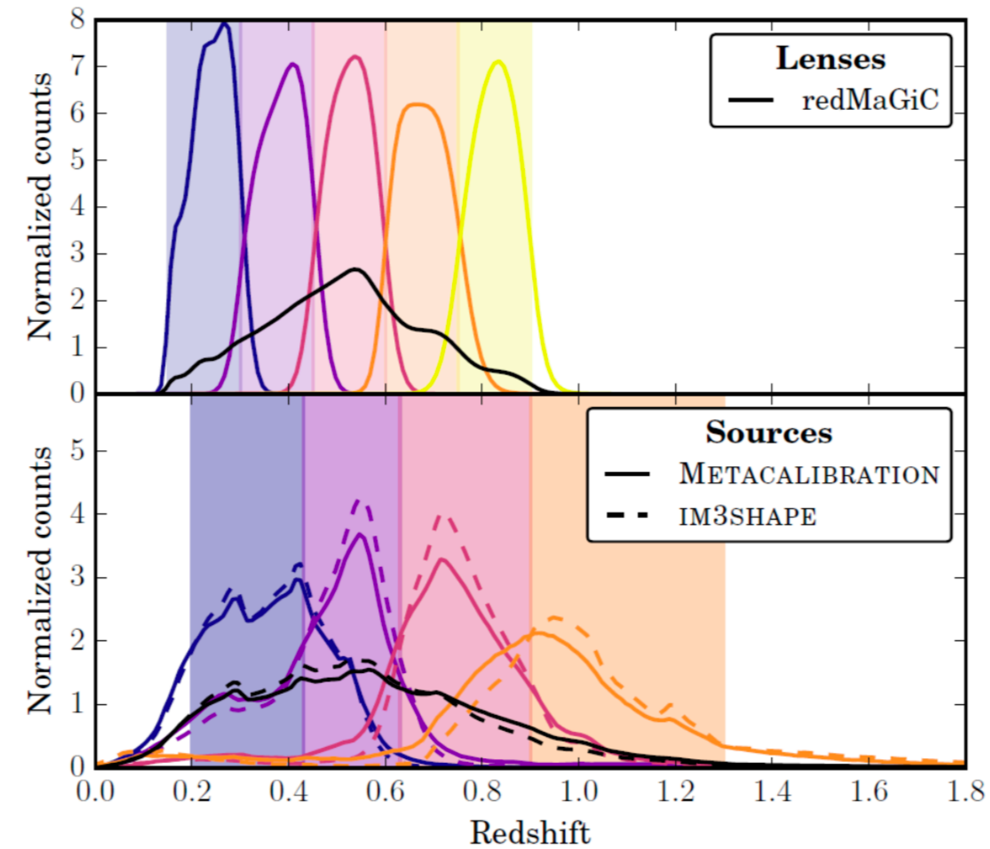
Figure by Jim Bosch

Shear



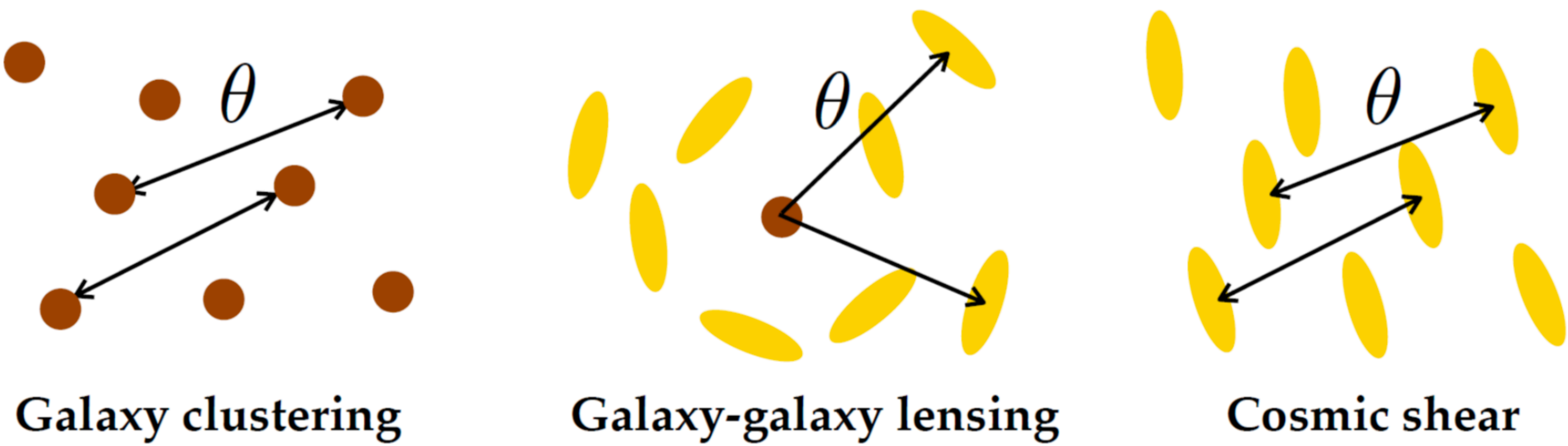
The measurement of shear from images requires the calibration with stars images.

Cosmology 3x2pt (with DES)



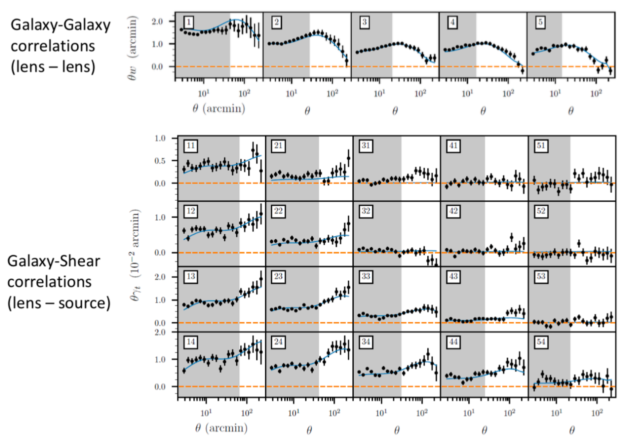
Combination of clustering with gravitational shear.

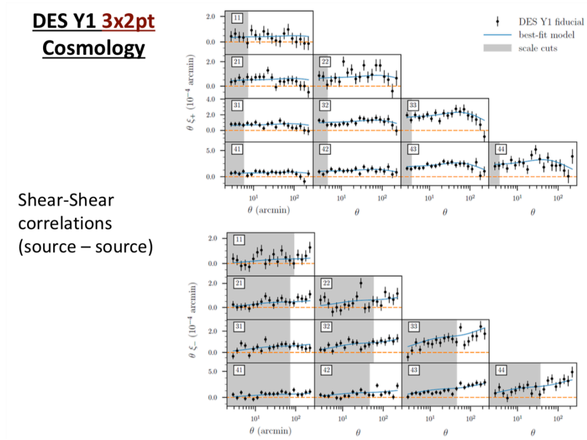
Main observational problems, the photometric uncertainty and the shear measurements.
Main theory problem. Intrinsic alignments



Cosmology 3x2pt (with DES)

Dataset composed by three different types with multiple redshift bin combinations and angular scales





$$w^i(\theta) = (b^i)^2 \int \frac{dl\, l}{2\pi} J_0(l\theta) \int d\chi \times \frac{\left[n_l^i(z(\chi))\right]^2}{\chi^2 H(z)} P_{\rm NL}\left(\frac{l+1/2}{\chi}, z(\chi)\right)$$

Galaxy Clustering Correlation position-position

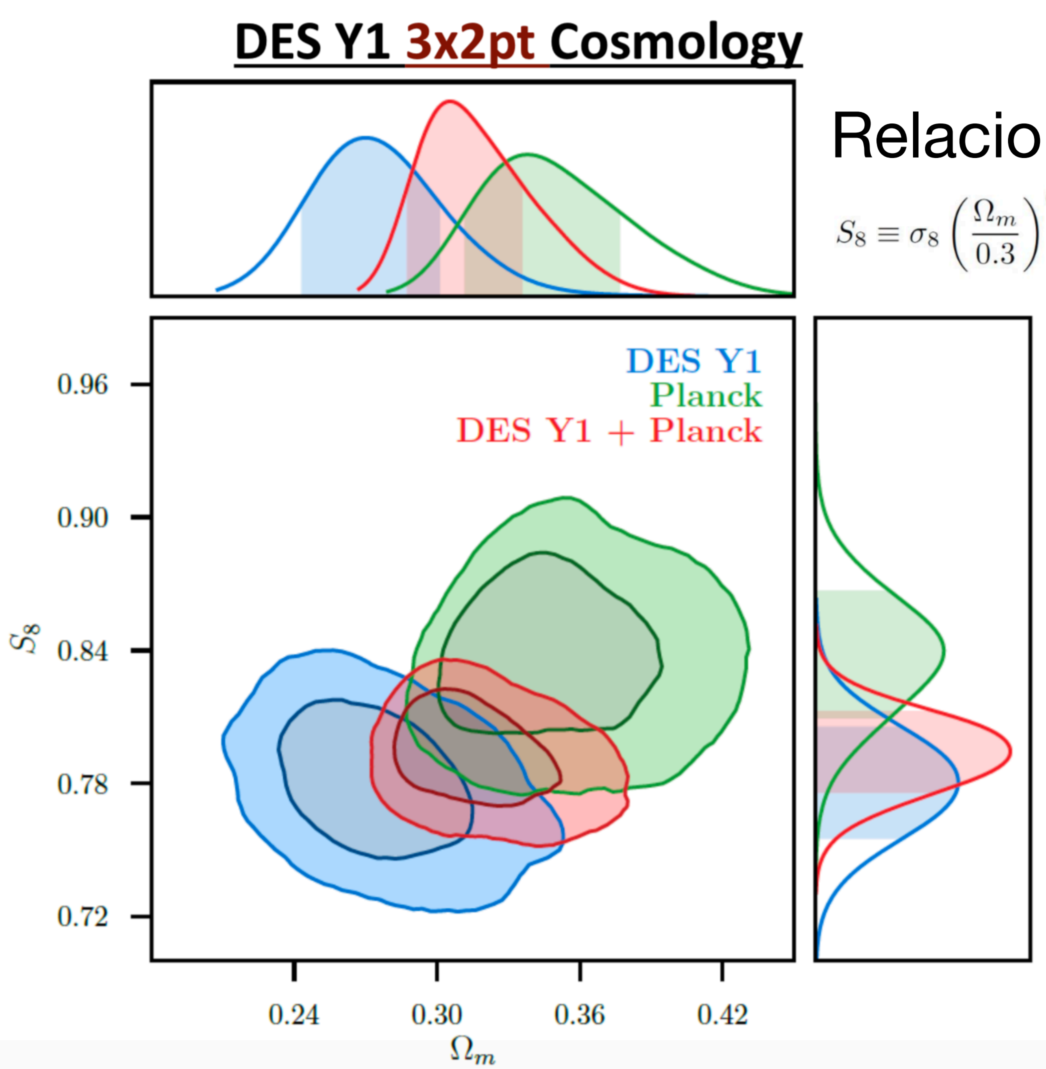
$$\gamma_t^{ij}(\theta) = b^i(1+m^j) \int \frac{dl\, l}{2\pi} J_2(l\theta) \int d\chi n_l^i(z(\chi)) \times \frac{q_s^j(\chi)}{H(z)\chi^2} P_{\rm NL}\left(\frac{l+1/2}{\chi}, z(\chi)\right)$$

Galaxy-Glaxy Lensing Correlation position-shape

$$q_s^i(\chi) = \frac{3\Omega_m H_0^2}{2} \frac{\chi}{a(\chi)} \int_\chi^{\chi(z=\infty)} d\chi' n_s^i(z(\chi')) \frac{dz}{d\chi'} \frac{\chi' - \chi}{\chi'} \quad \text{(IV.3)}$$

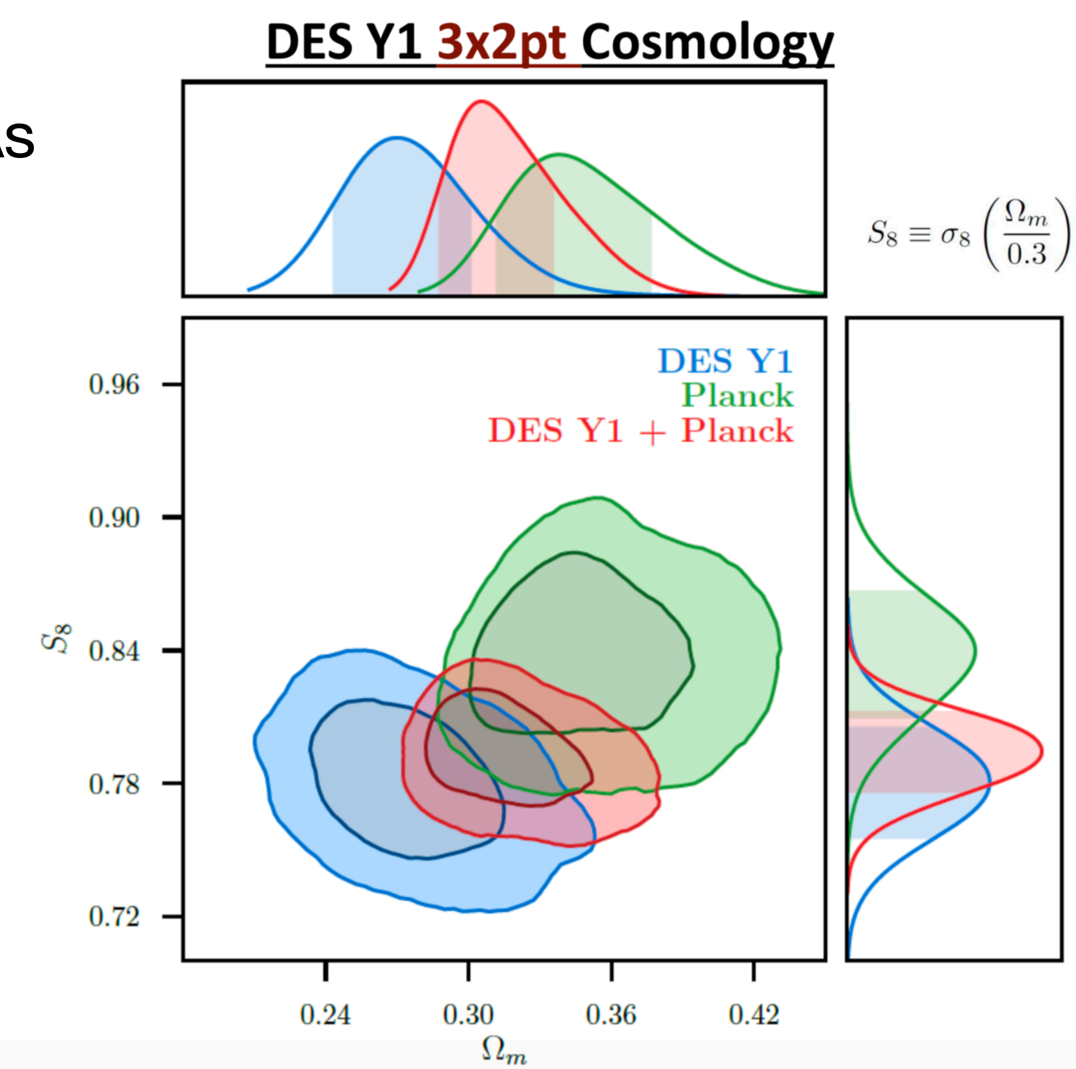
$$\xi_{+/-}^{ij}(\theta) = (1+m^i)(1+m^j) \int \frac{dl\, l}{2\pi} J_{0/4}(l\theta) \int d\chi \times \frac{q_s^i(\chi) q_s^j(\chi)}{\chi^2} P_{\rm NL}\left(\frac{l+1/2}{\chi}, z(\chi)\right)$$

Cosmic Shear Correlation shape-shape



Relacionado con As

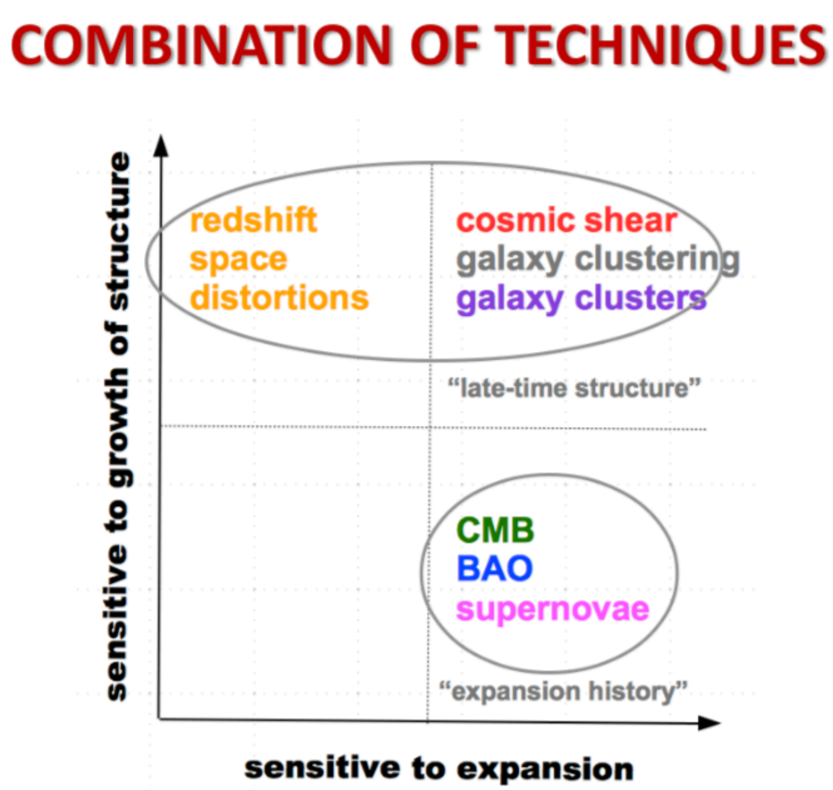
$$S_8 \equiv \sigma_8 \left(\frac{\Omega_m}{0.3}\right)^{0.5}$$

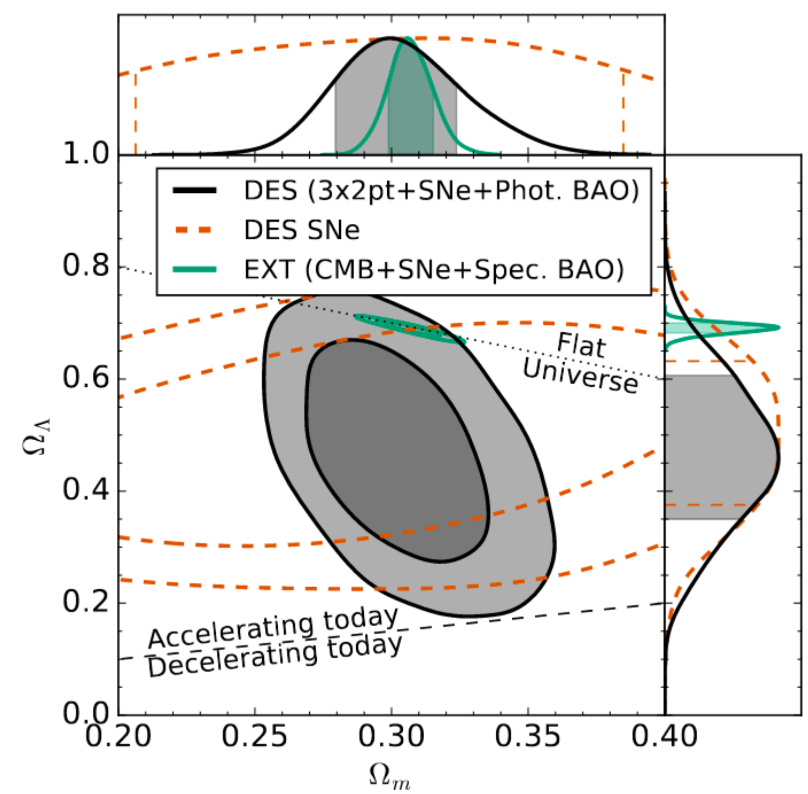


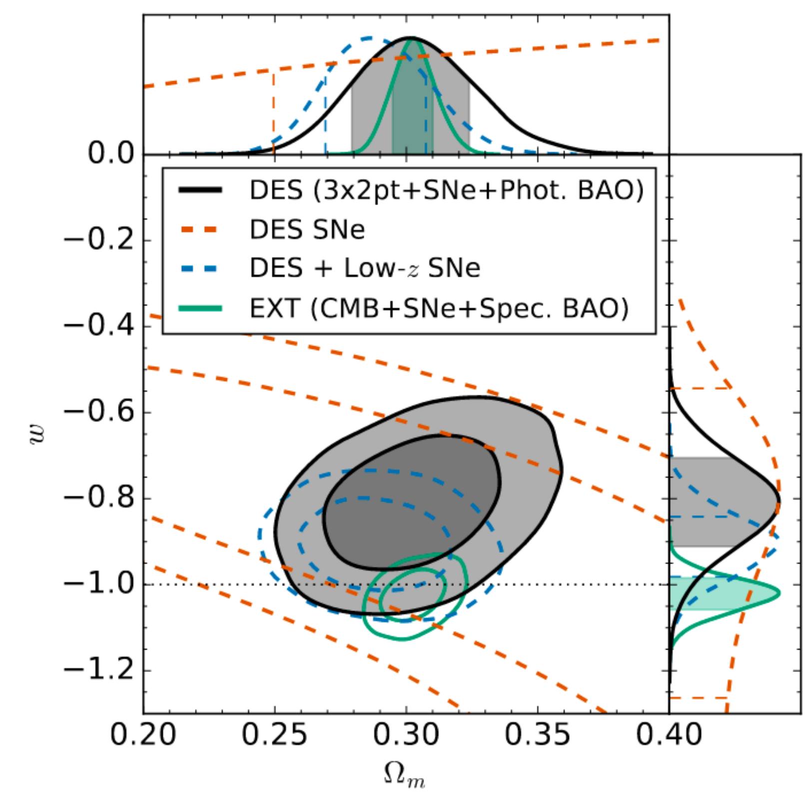
$$S_8 \equiv \sigma_8 \left(\frac{\Omega_m}{0.3}\right)^{0.5}$$

Combining multiple probes

DES was able to combine multiple probes with just one single telescope.







Significancia de 2sigma para la detección de la aceleración del Universo.

Extended models

- Dark Energy equation of state:

$$\frac{H(a)}{H_0} = \left[\Omega_m a^{-3} + (1-\Omega_m) a^{-3(1+w_0+w_a)} e^{-3w_a(1-a)}\right]^{1/2} .$$

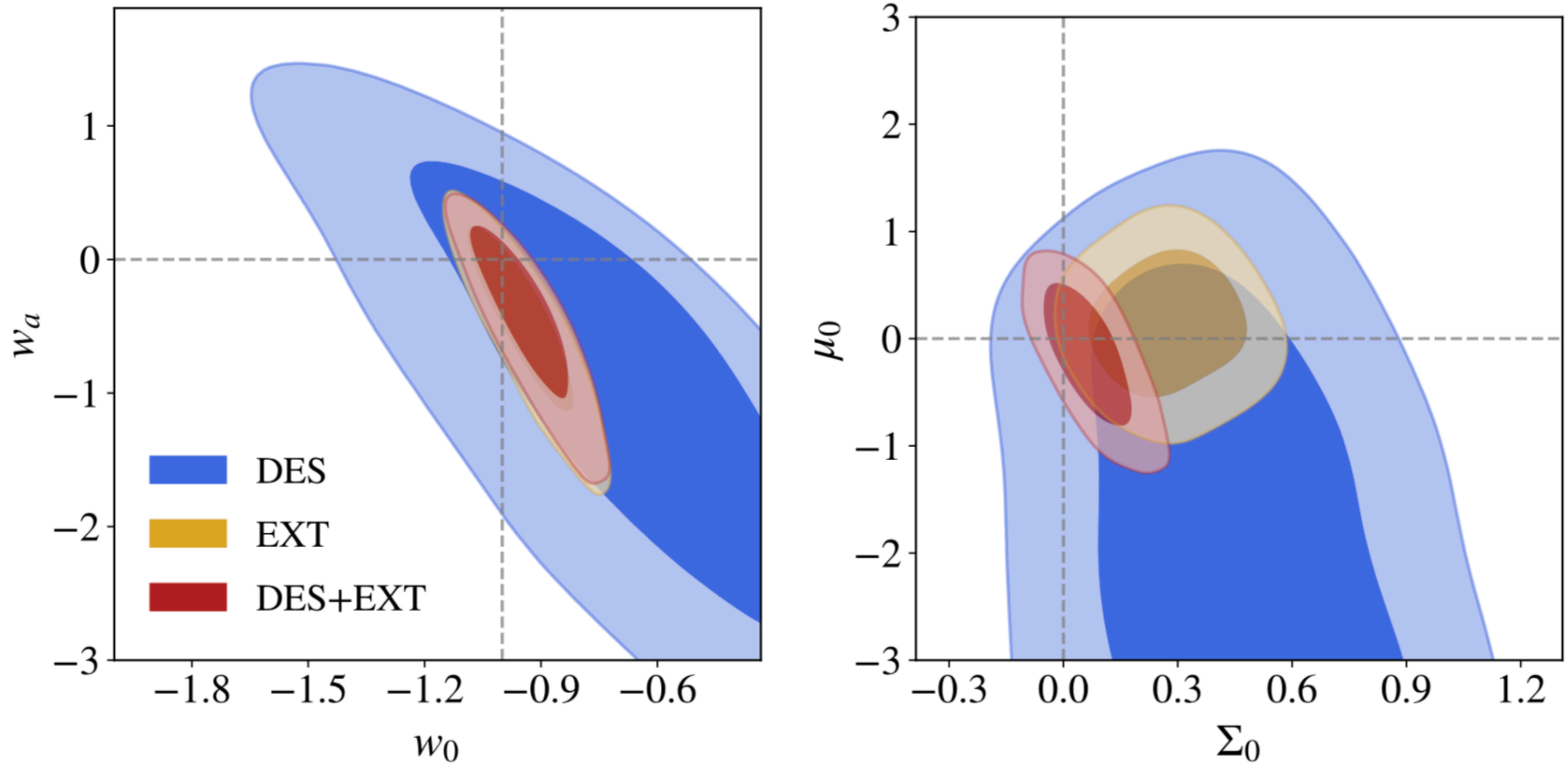
- Metric perturbations and GR test:

$$ds^2 = a^2(\tau)\left[(1+2\Psi)d\tau^2 - (1-2\Phi)\delta_{ij}dx_i dx_j\right]$$

$$k^2\Psi = -4\pi G a^2(1+\mu(a))\rho\delta ,$$
$$k^2(\Psi+\Phi) = -8\pi G a^2(1+\Sigma(a))\rho\delta ,$$

$$\mu(z) = \mu_0 \frac{\Omega_\Lambda(z)}{\Omega_\Lambda} , \quad \Sigma(z) = \Sigma_0 \frac{\Omega_\Lambda(z)}{\Omega_\Lambda}$$

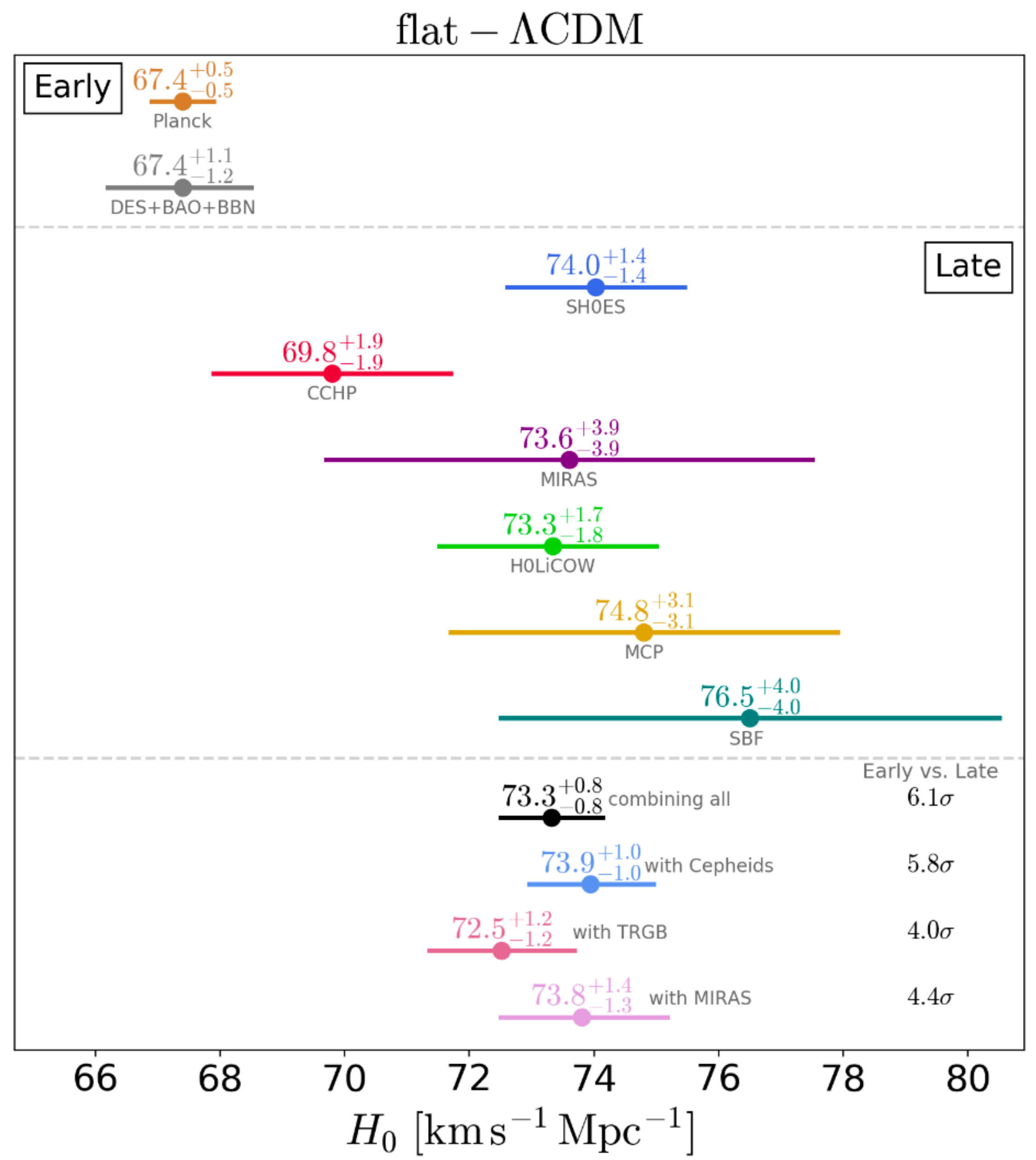
Extended models



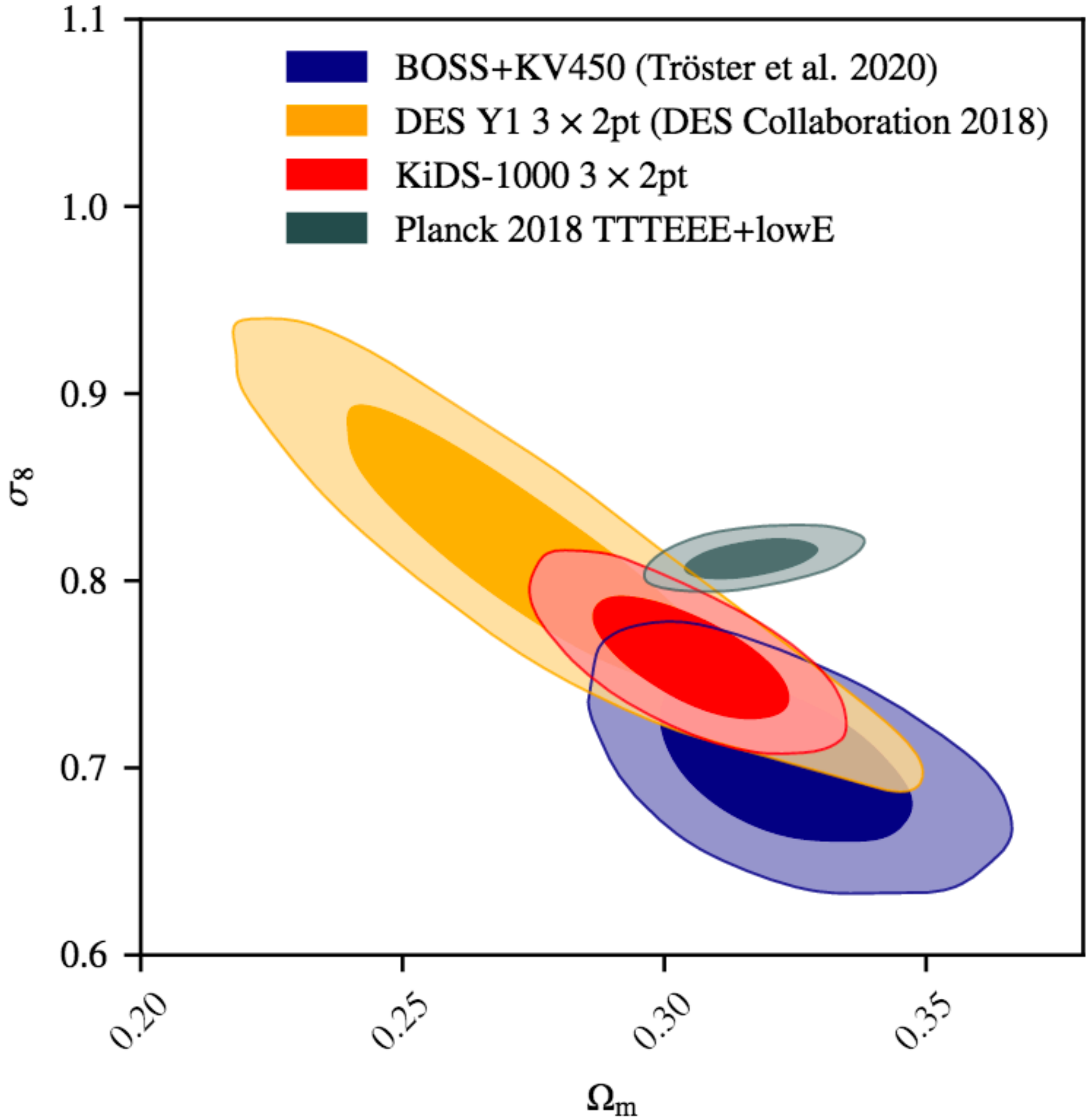
Dark Energy Survey Collaboration,2019a

Tensions

Some hints of tensions between early Universe measurements of the local expansion rate and local measurements

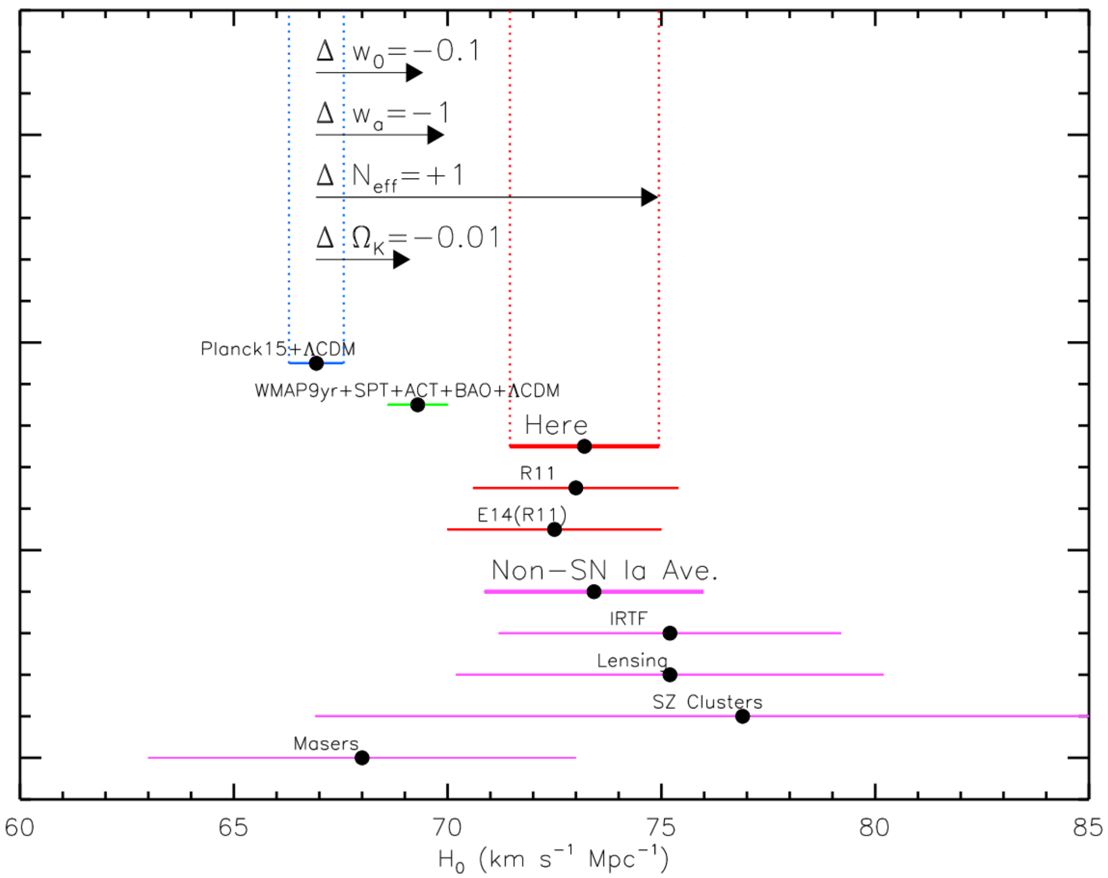


Verde, Riess, Treu (2019)

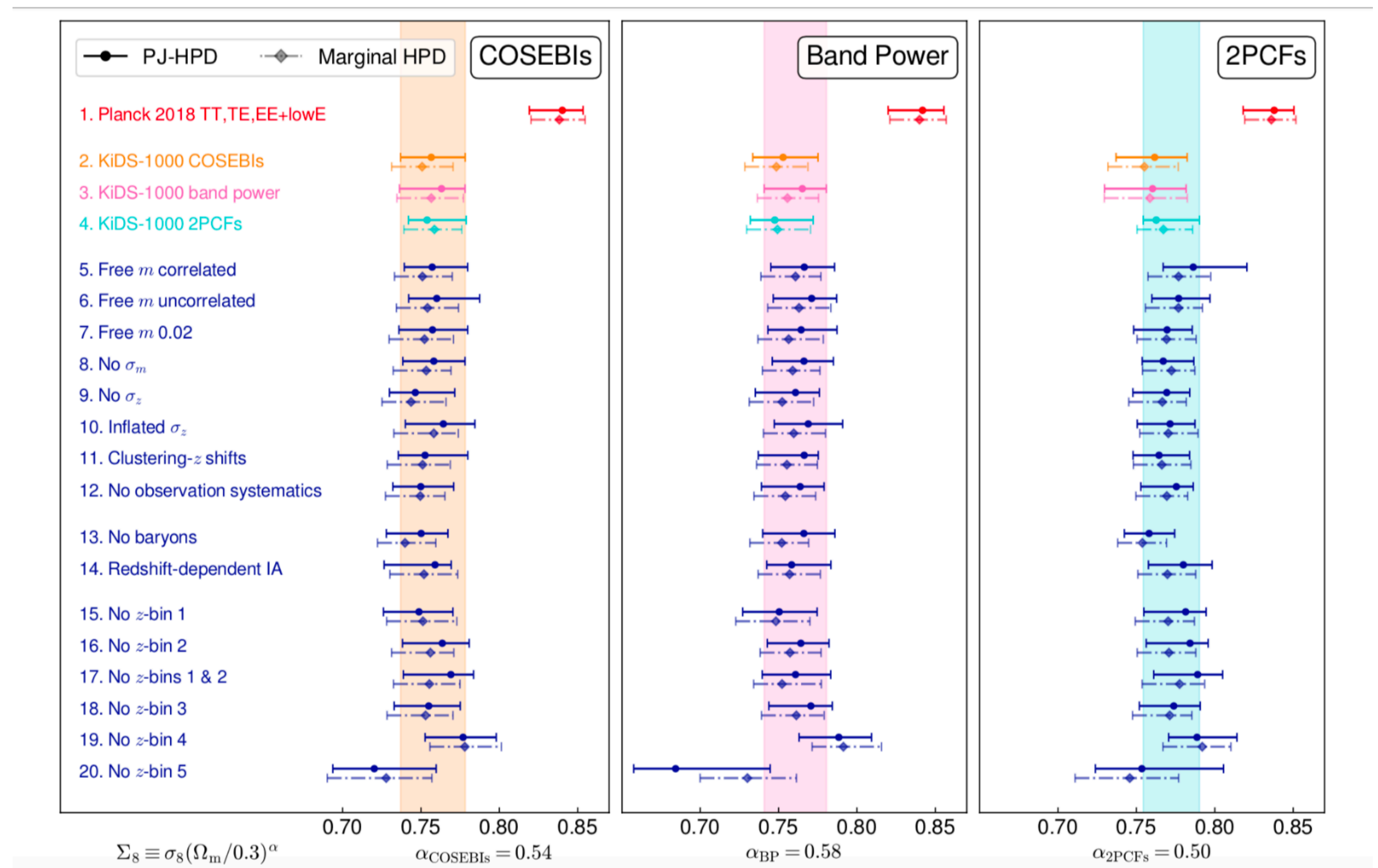


Heynmans et al. (2020)

New physics or systematics?



Riess et al. (2016)

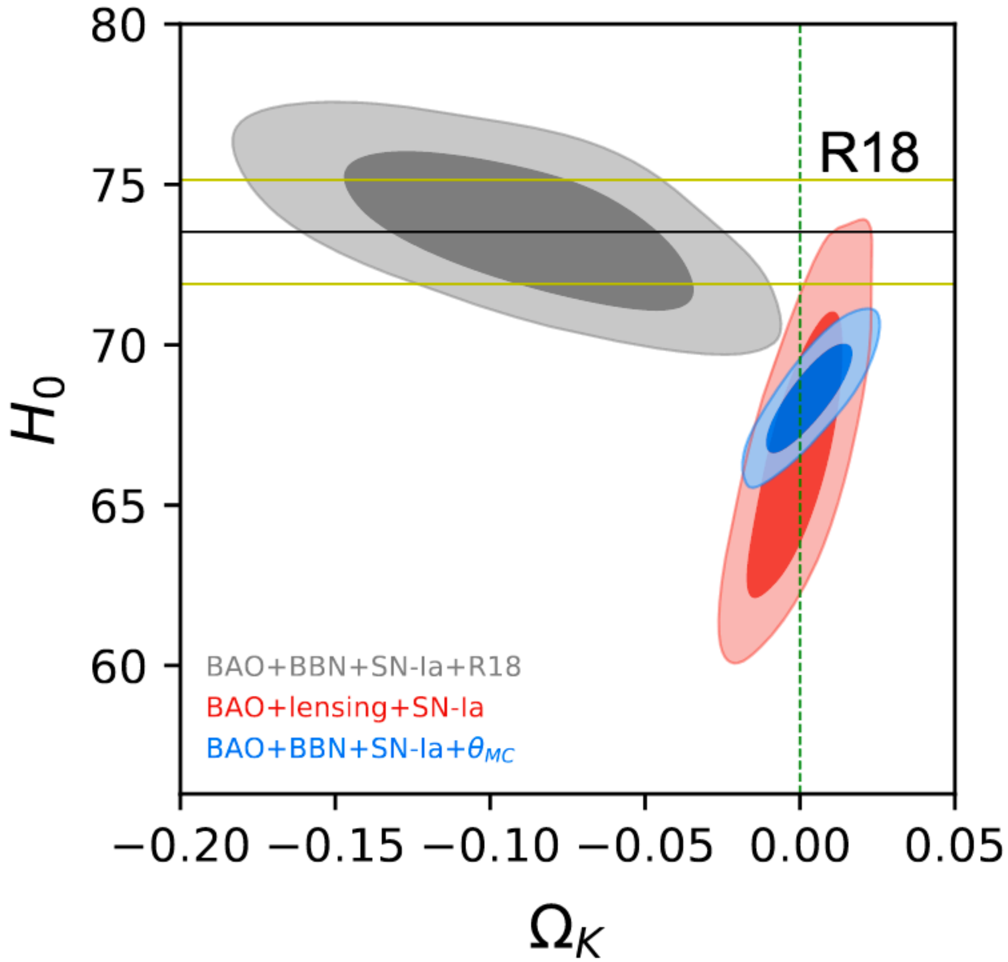


Asgari et al. (2020)

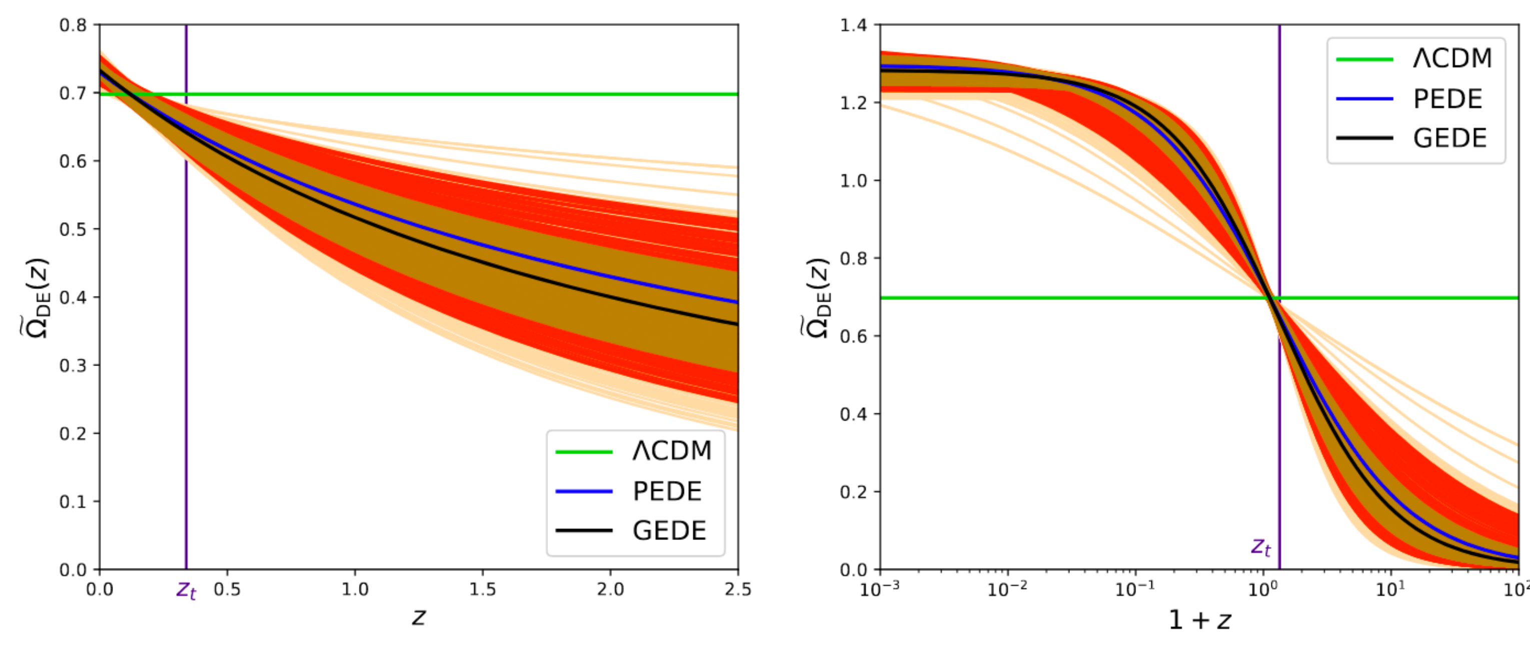
Should we change the model?
Is this explained by systematics?

Importance of tensions

- Tensions can be a hint of new physics (if not explained by systematics)



Di Valentino et al., 2020 (2019)



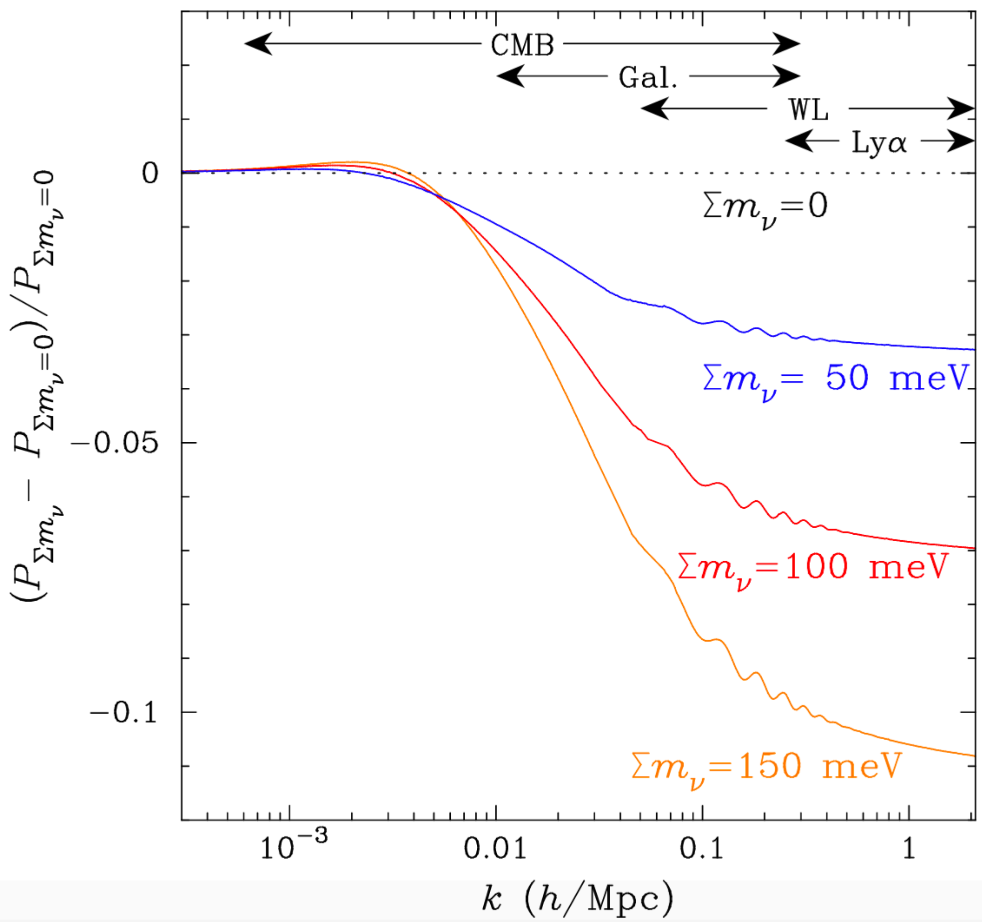
Li et al. 2020 (2019)

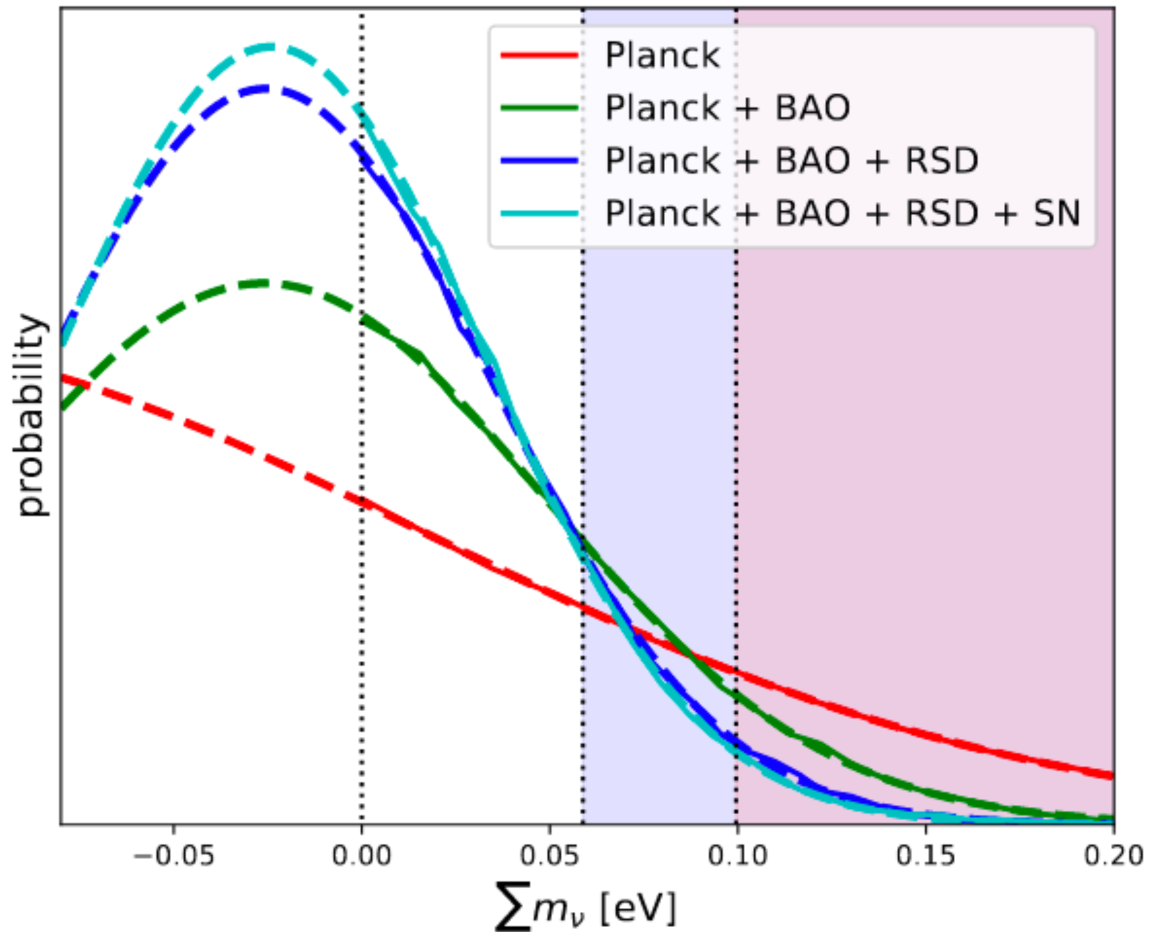
Neutrino cosmology

- Neutrinos participate as relativistic particles first and then as part of the matter component where their contribution is related with the sum of masses of neutrino families.

$$\Omega_\nu = \frac{\rho_\nu}{\rho_c^0} = \frac{\sum_i m_i}{93.14\, h^2 \text{ eV}} \, .$$

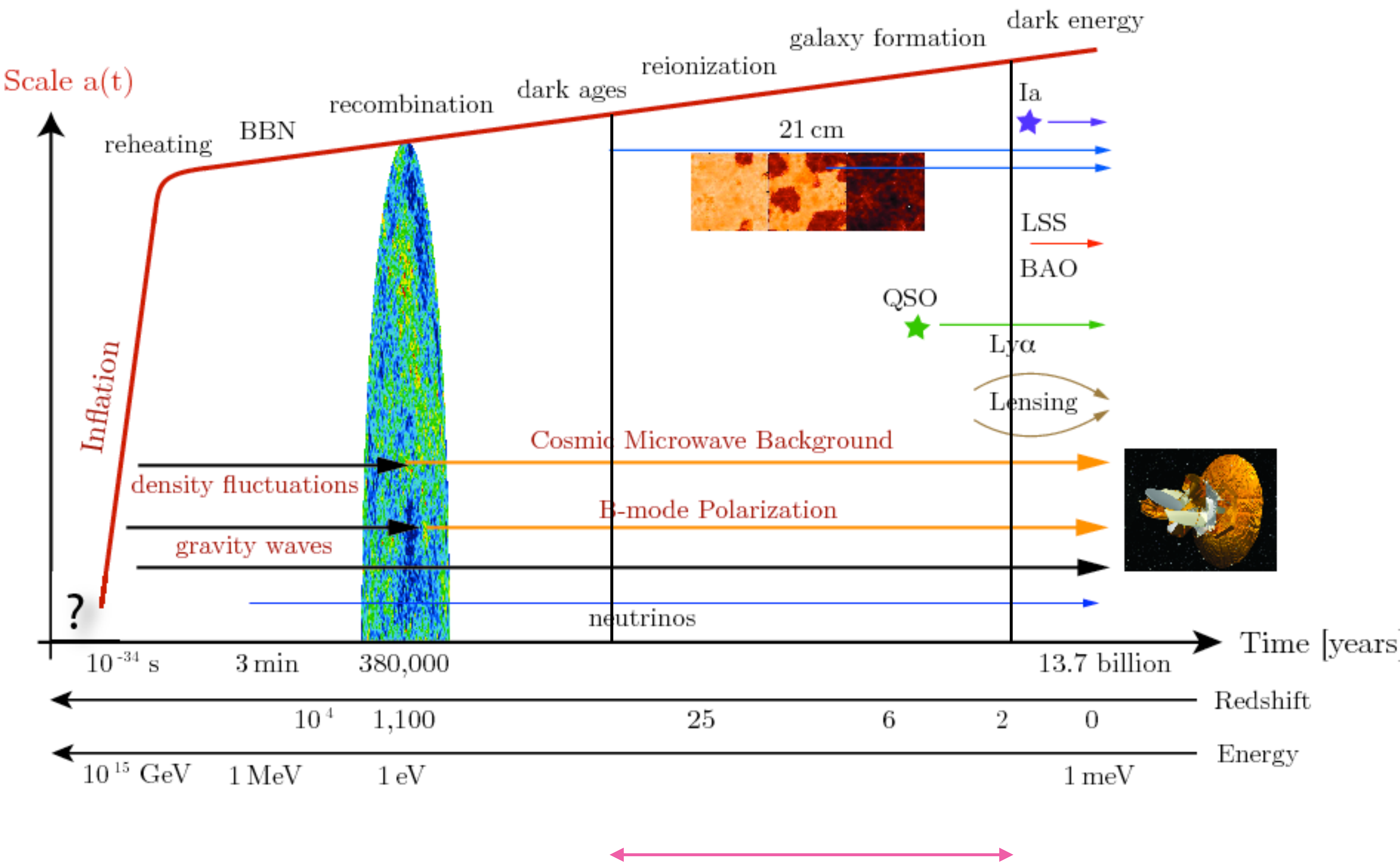
- Main effect in the power spectrum is the suppression of the growth of structures for scales beyond the free streaming scale (similar to radiation domination effect on the growth of structures). The suppression of growth depends on the masses of the neutrinos.





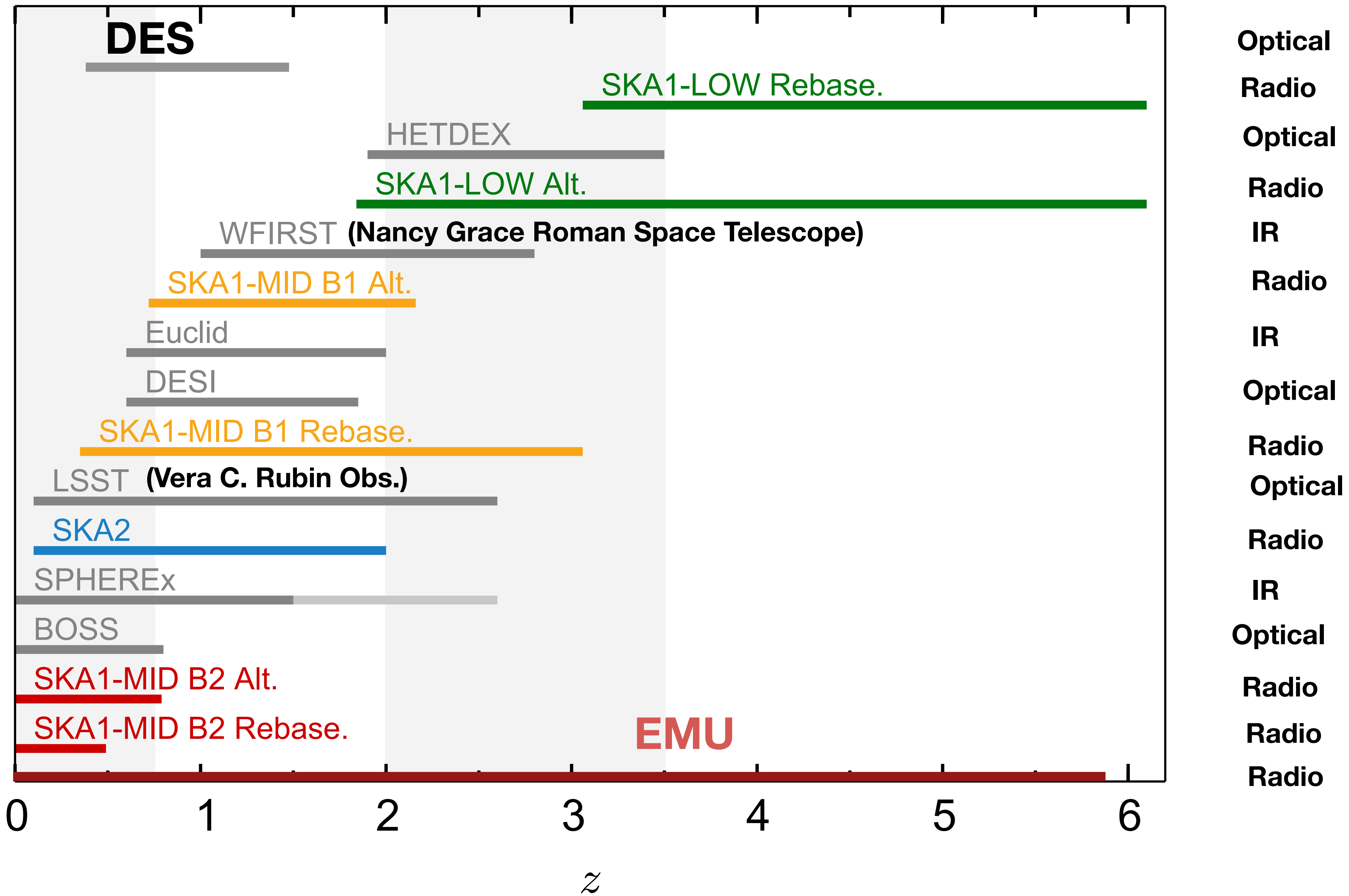
eBOSS Collaboration 2020

"The redshift desert"



Redshift desert

Present and future

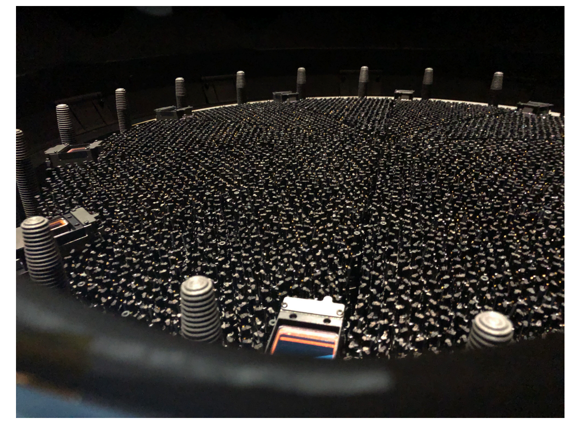


P. Bull (2016)

Dark Energy Spectroscopic Instrument (DESI)

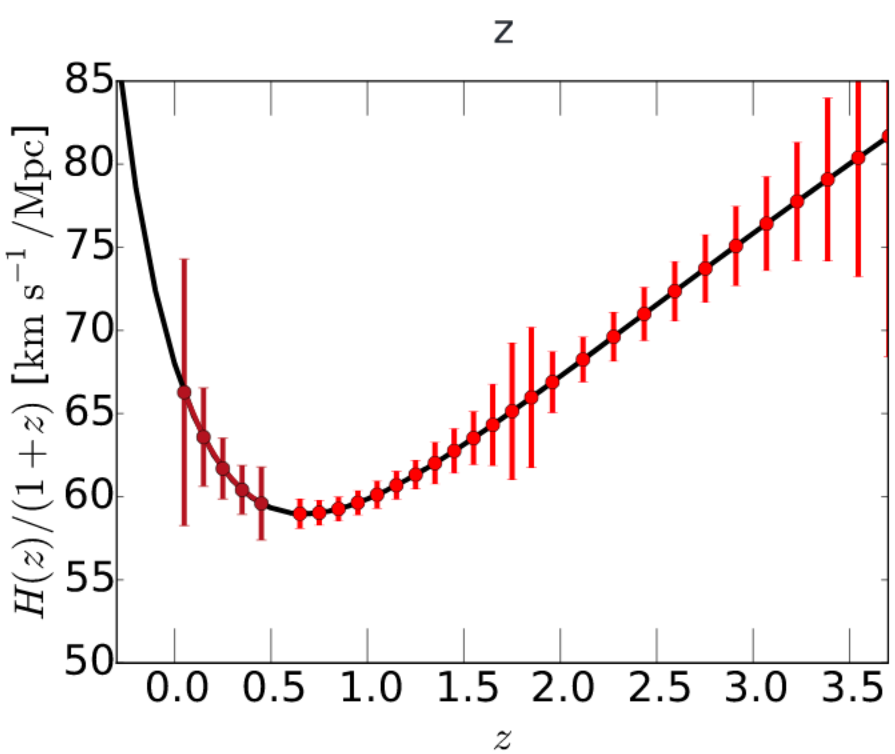
DESI survey (2019 -) (@ 4m Mayall telescope, Kitt Peak Observatory, Arizona, USA):

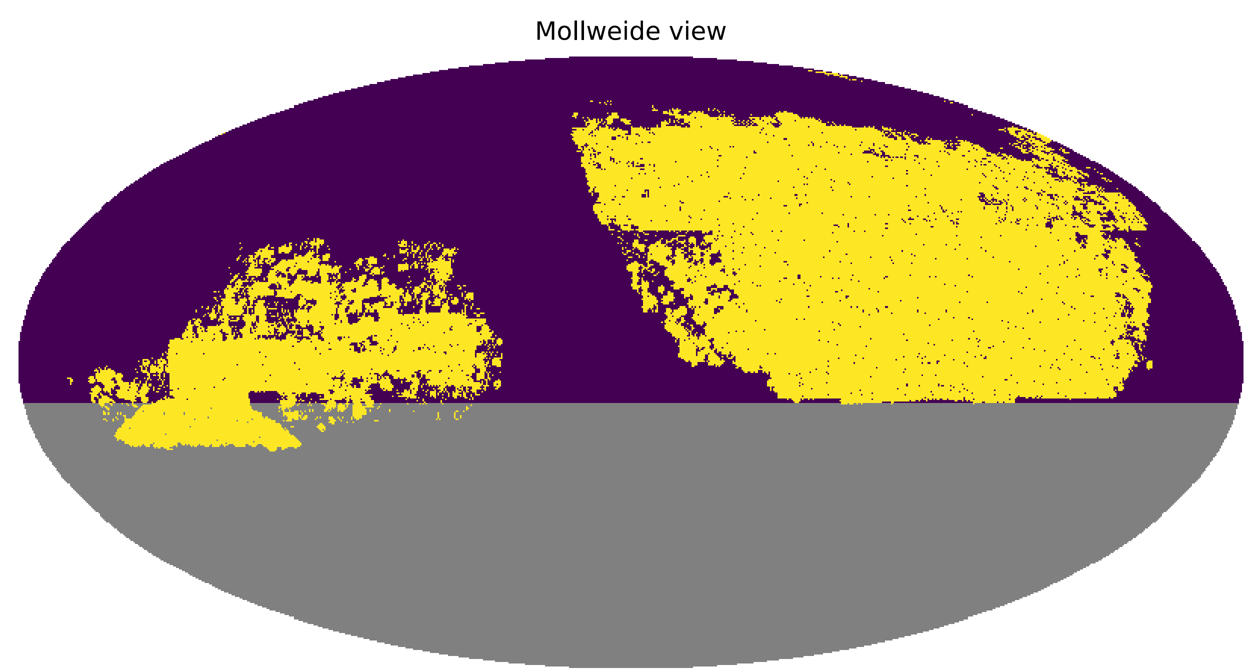
- 5000 fibre multi-object
- Footprint of 14000 sq. degs:
  - 35 million ELGs
  - 4 million LRGs
  - 2.4 million QSOs



Credit: R. Lafever

Will produce the most precise BAO and RSD measurements up to date



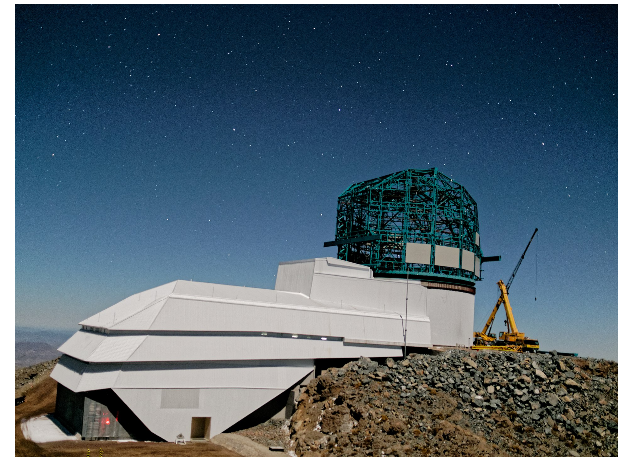


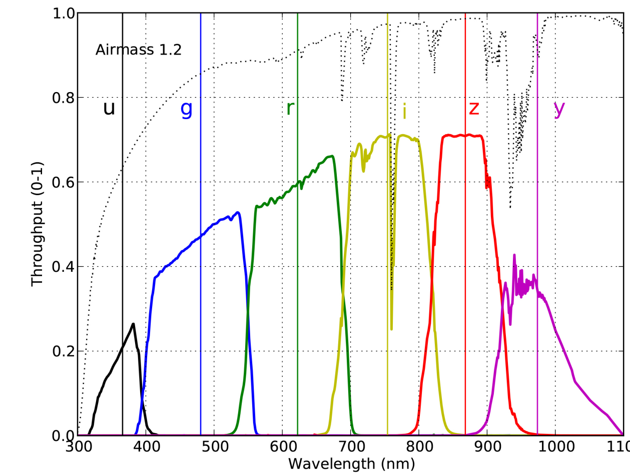
Vera C. Rubin Observatory

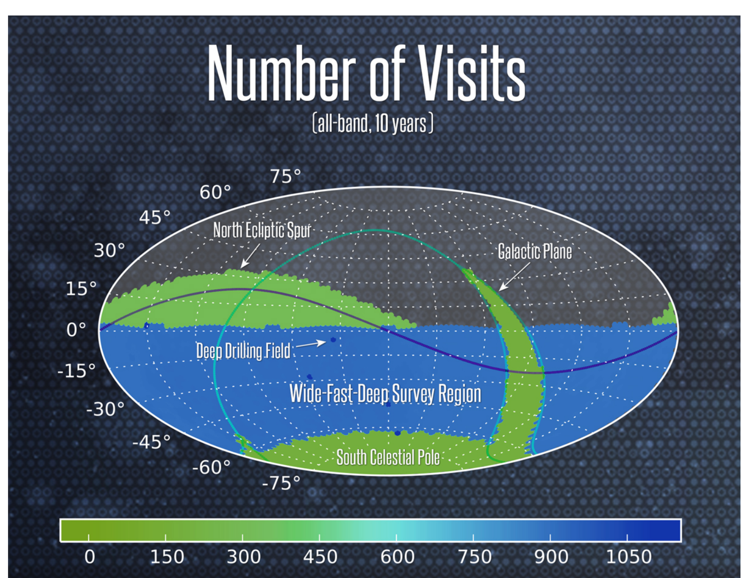
- 3.2 Gpixel camera at 8.4m Simonyi telescope situated Vera C. Rubin Observatory, at Cerro Pachón (Chile)

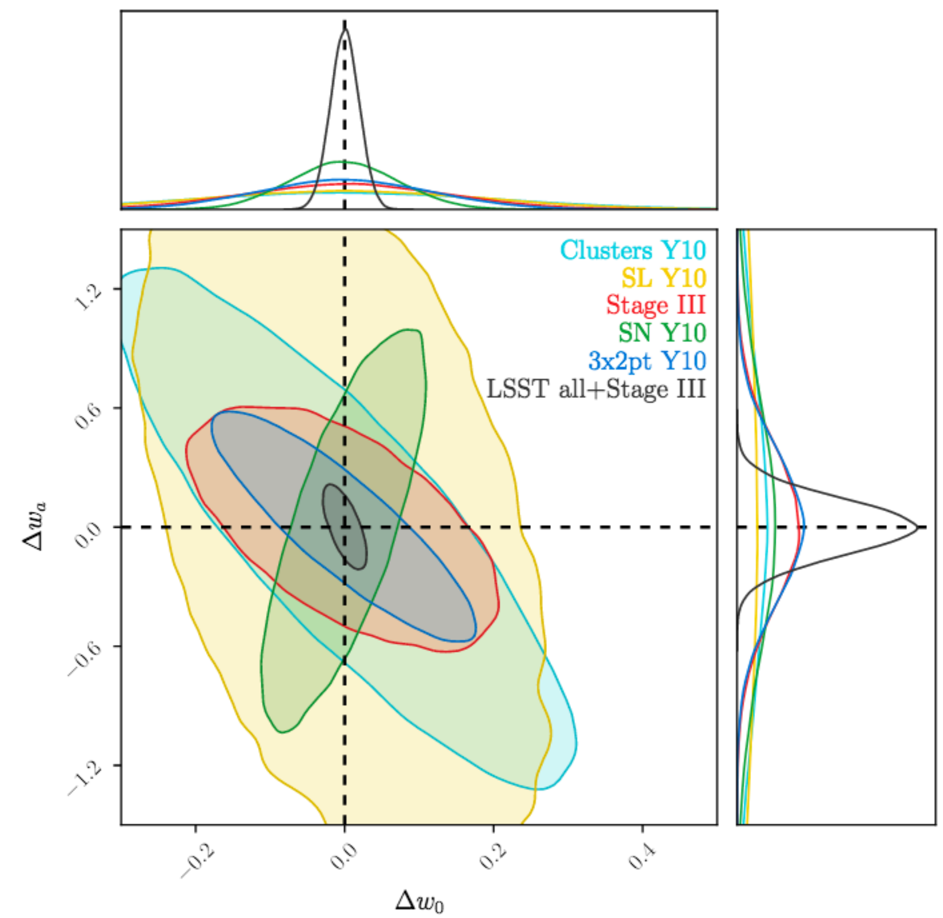
- 3.5 degrees FoV.

- 6 broad-band filters ugrizY
- Expects to record over 20000 million galaxies to depth i_{AB}~ 26.8
- Legacy Survey of Space and Time (LSST): Wide fast survey of 18000 sq. deg.









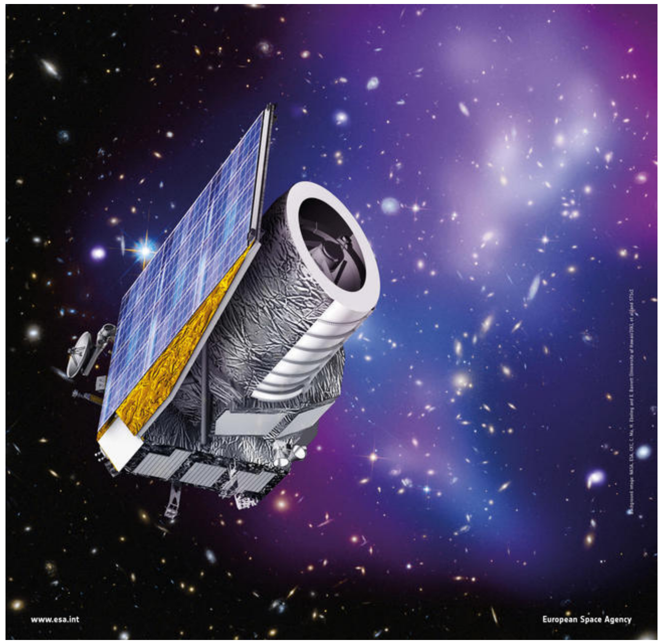
LSST Collab (2018)

LSST DESC
Dark Energy Science Collaboration

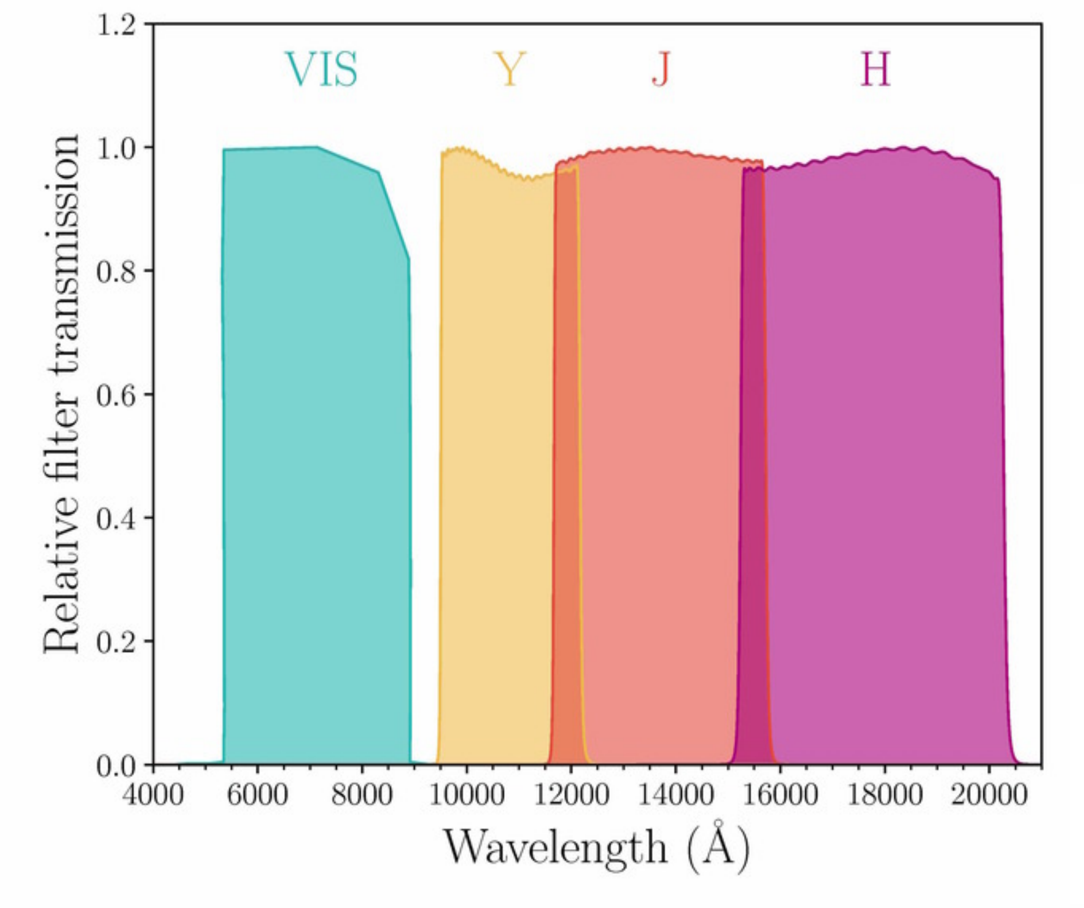
Euclid Constortium

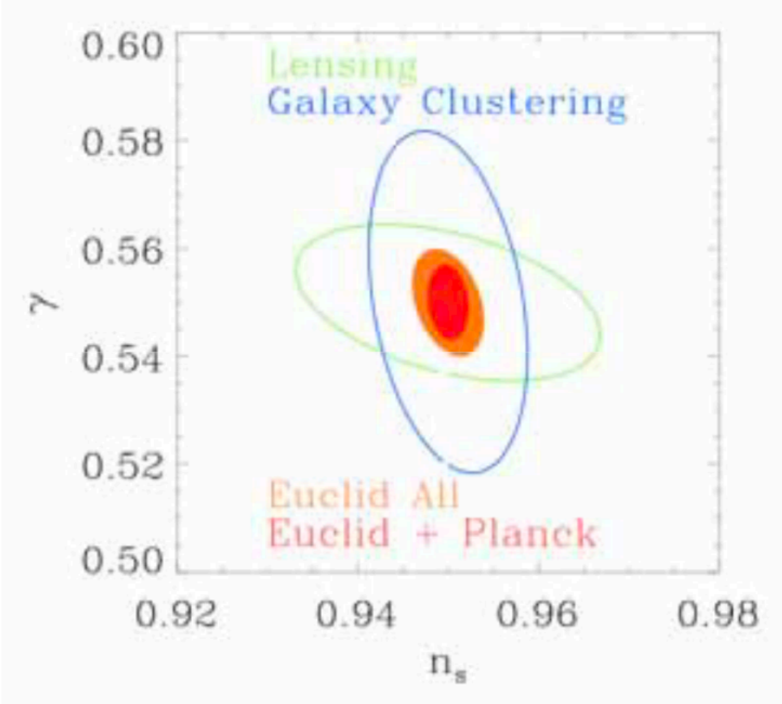
ESA mission of class M. Expected launch at 2023
1.2m spatial telescope with 2 instruments:

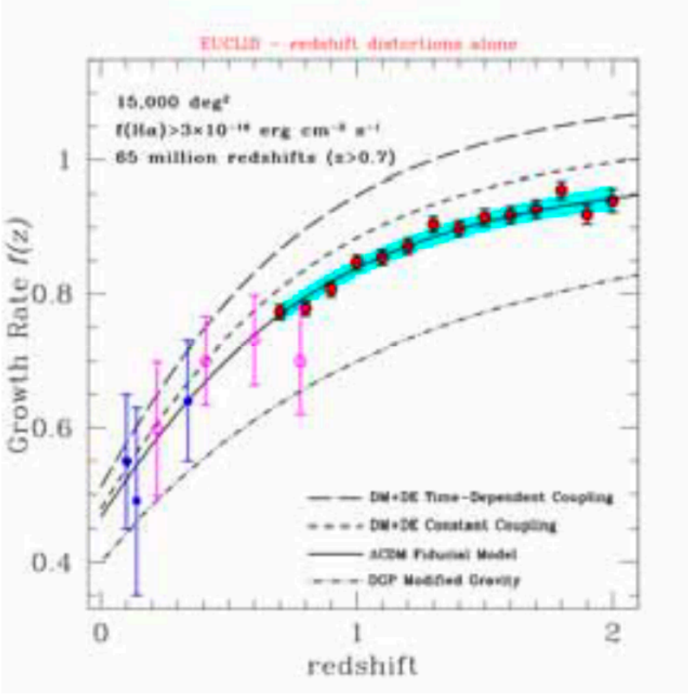
- VISP: Imager
- NISP: Near Infrared Spectrometer and Photometer



Wide field survey: 15000 sq. deg. $AB_{VIS} < 24.5$
Deep field survey: 40 sq. deg $AB_{VIS} < 26.5$







Radiocosmology

Radio Cosmology

HI galaxy

(like spectroscopic surveys)

[e.g., HIPASS, ALFALFA]

Continuum galaxy

(like photometric) surveys)

[e.g., EMU]

HI intensity mapping

(like 3D CMB)

[e.g., CHIME, TIANLAI]

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[e.g., CHIME, TIANLAI]

ASKAP overview

- 36 12-metre antennas spread over a region 6 km in diameter
- frequency band of 700–1800 MHz, with an instantaneous bandwidth of 300 MHz.
- 75% of the time: Survey projects

EMU: Continuum

WALLABY: Spectroscopy 21cm

DINGO: HI evolution

POSSUM: MW magnetic fields

FLASH: HI absorption

CRAFT: Fast transients

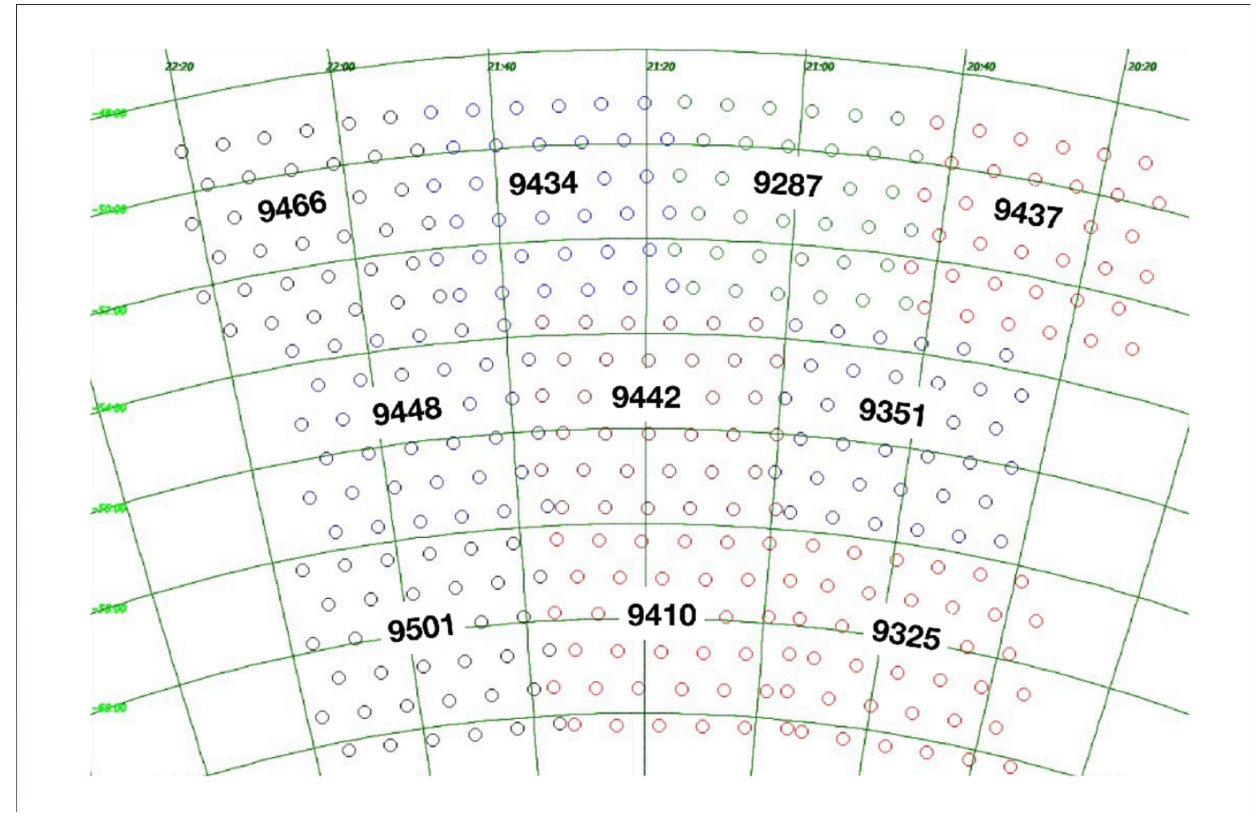
COAST: PTA

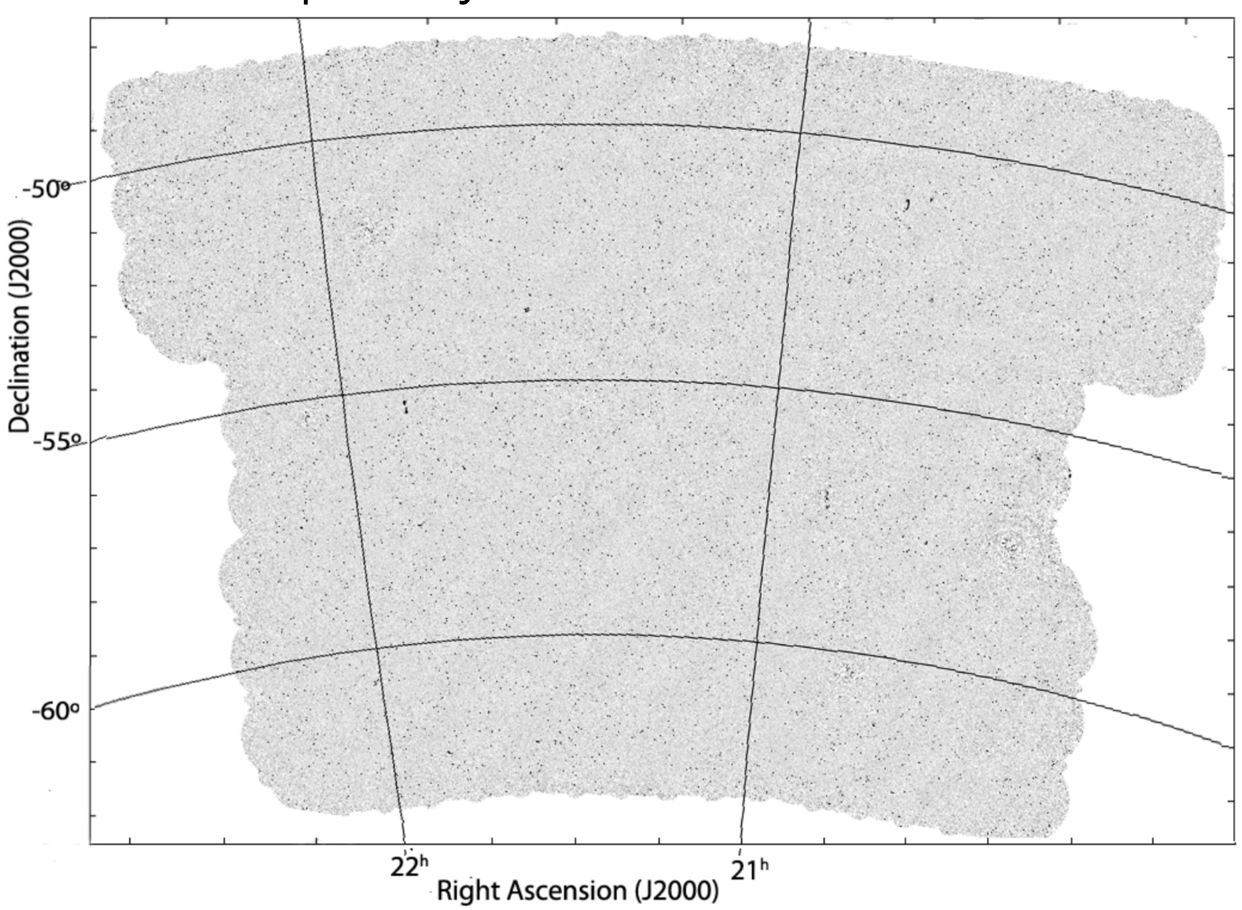
VAST: Slow transients

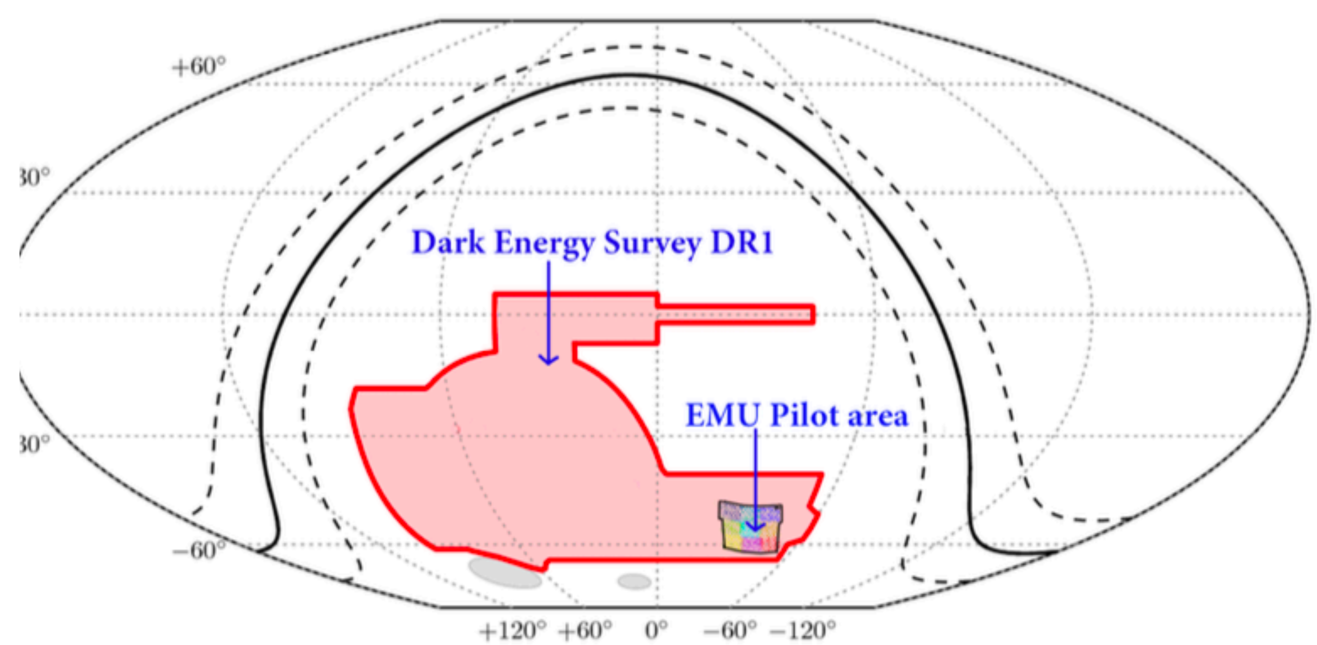
VLBI: long baseline

ASKAP-EMU

- Already analysing pilot data
- Almost 300 sq. deg
- 10 pointings (field). 1 field per scheduling block (SB)
- 10 hours per SB. Total integration time: 100 hours
- July-November 2019
- Synthesized bandwidth: 13'' x 11'' FWHM
- Frequency: 800 - 1088 MHz





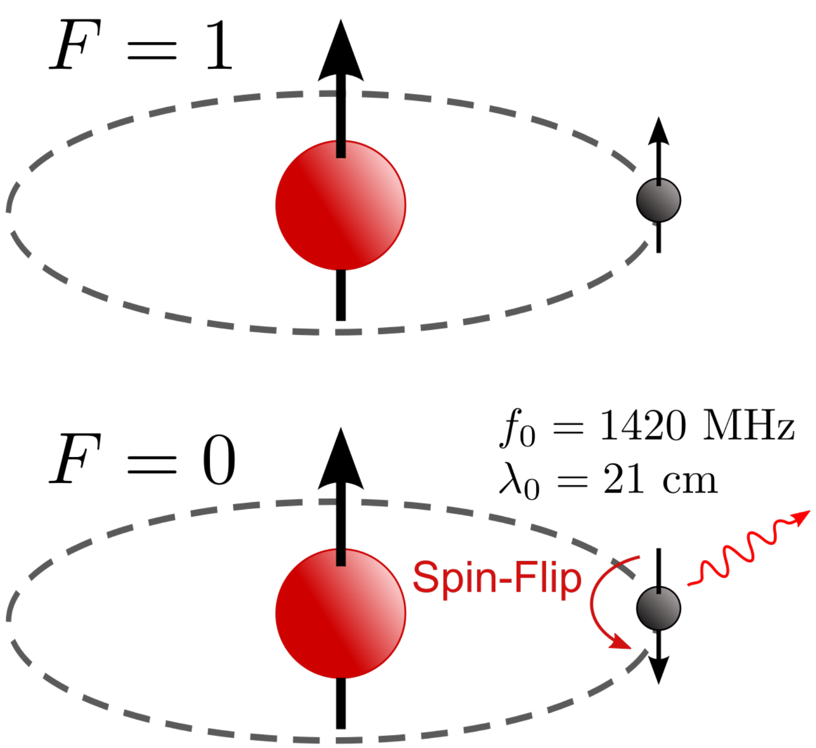


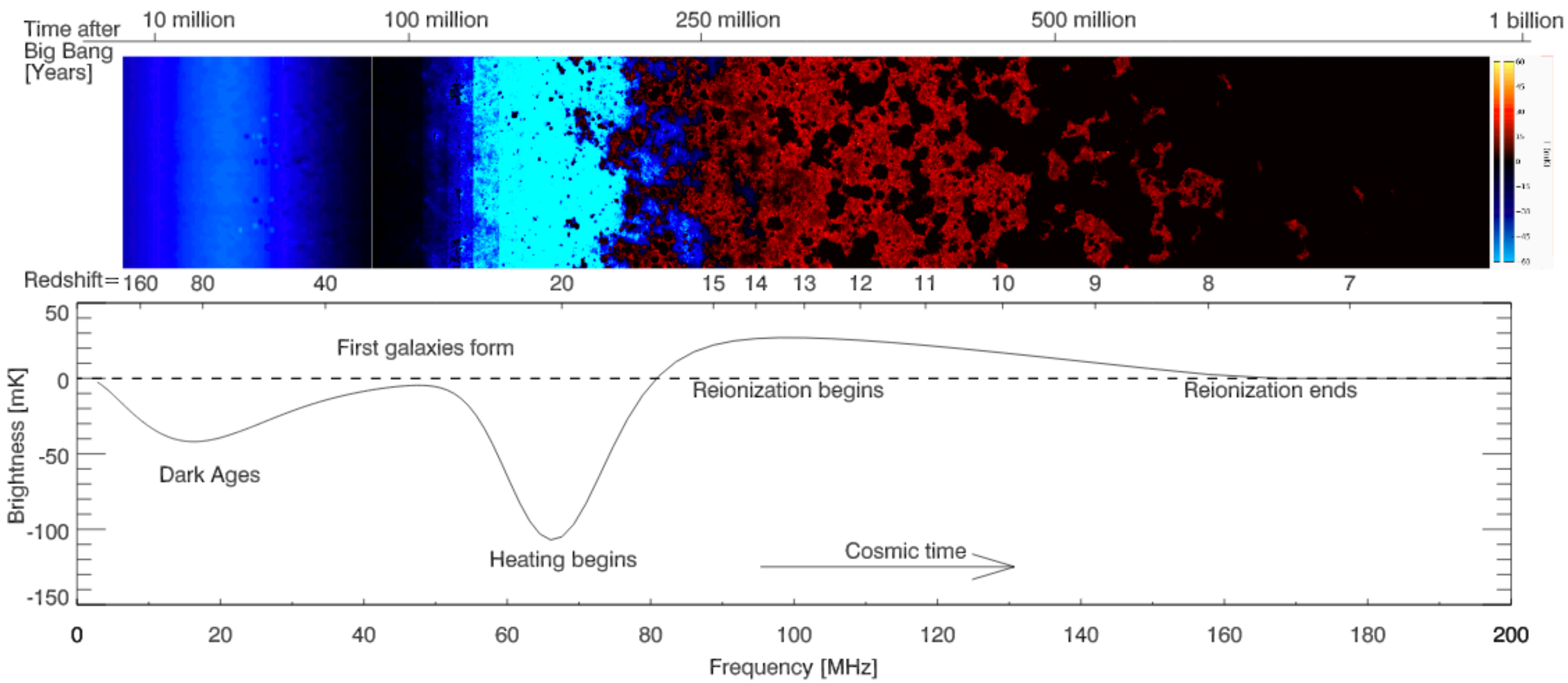
R. Norris et al, 2021, PASA

HI intensity mapping

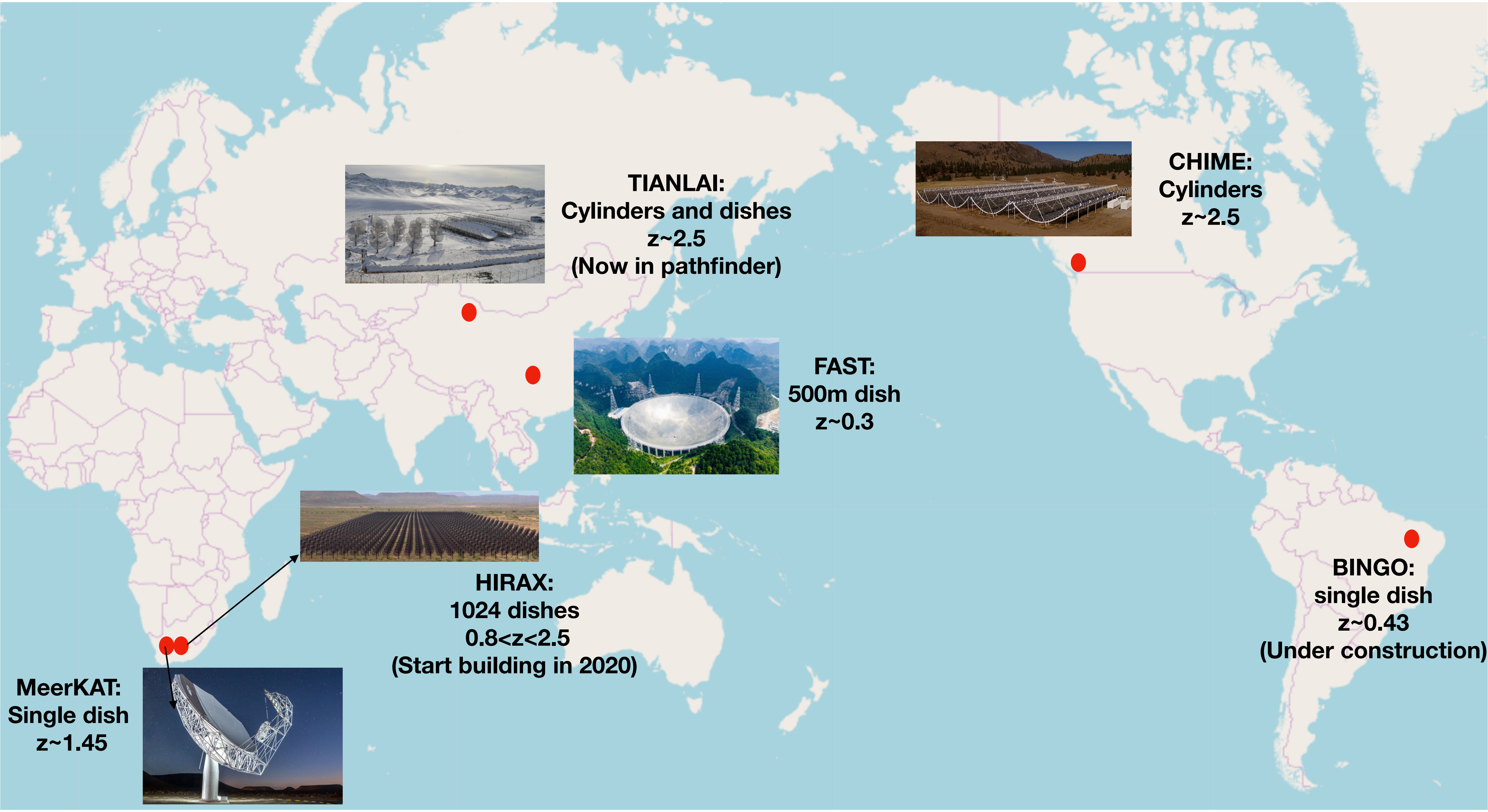
Radio Cosmology allows us to reach higher redshifts opening gates to new probes of large-scale structure.

The newest technique is the use of 21cm line intensity mapping

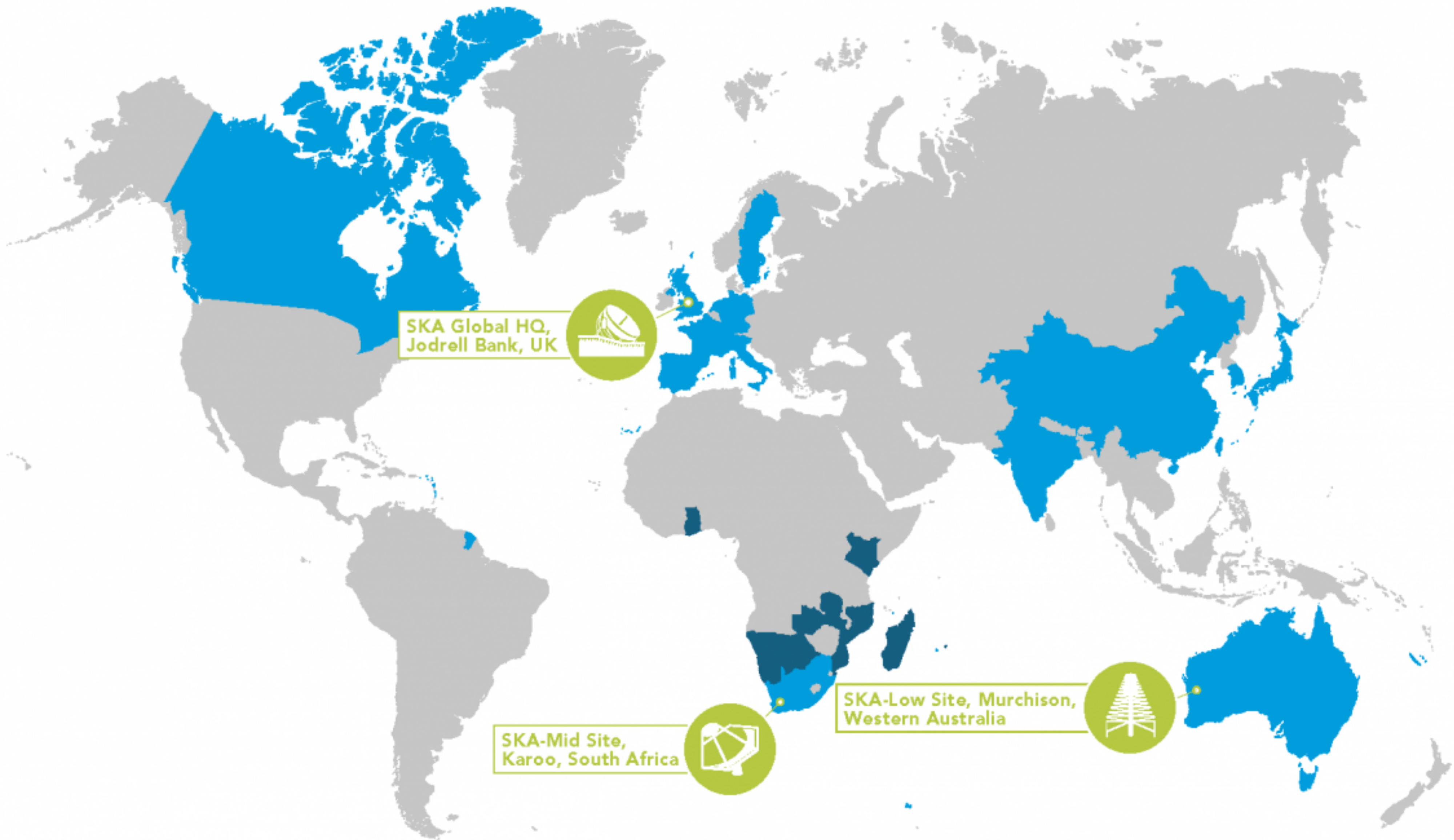




21cm line emission surveys



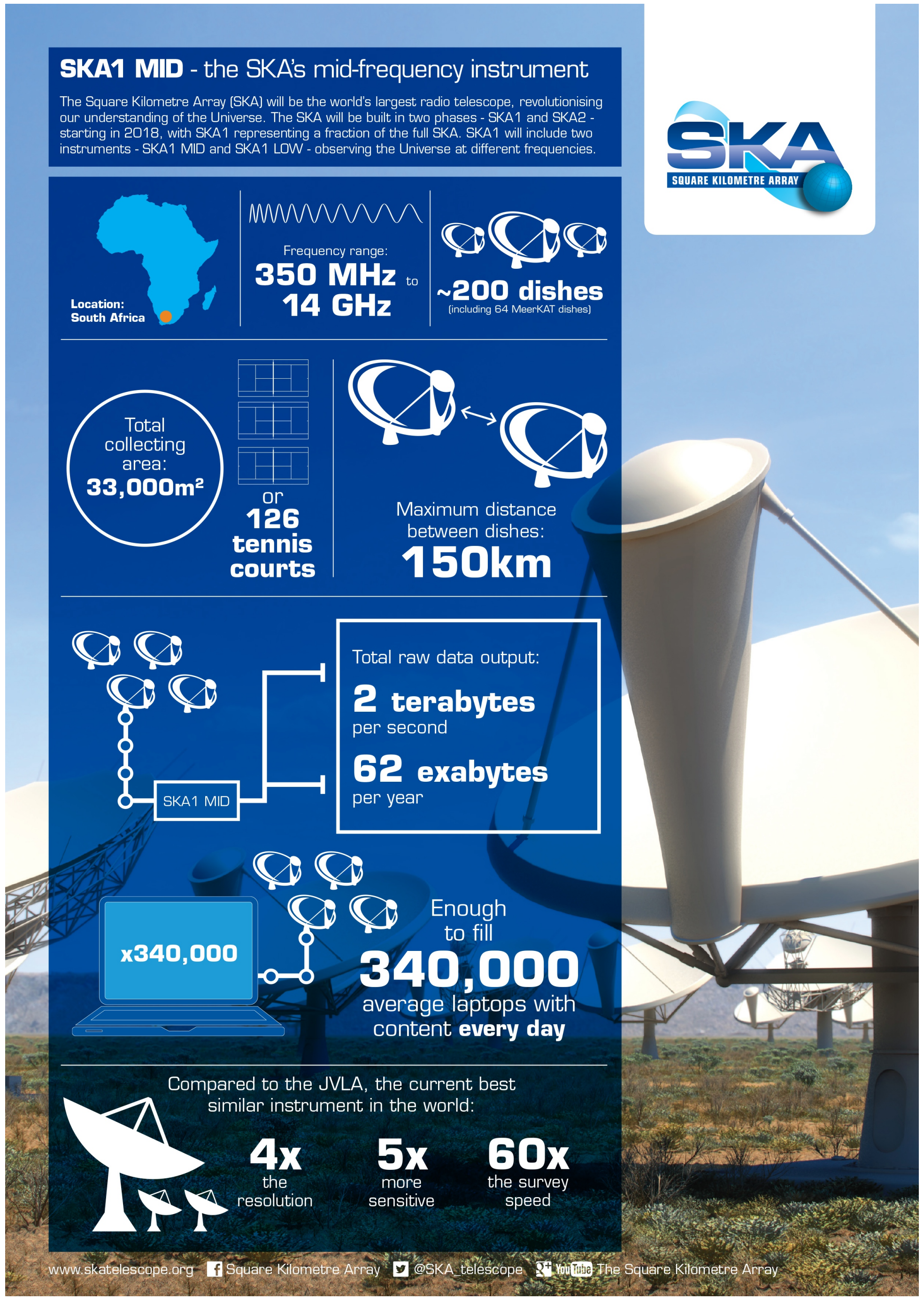
SKA Observatory (SKAO)

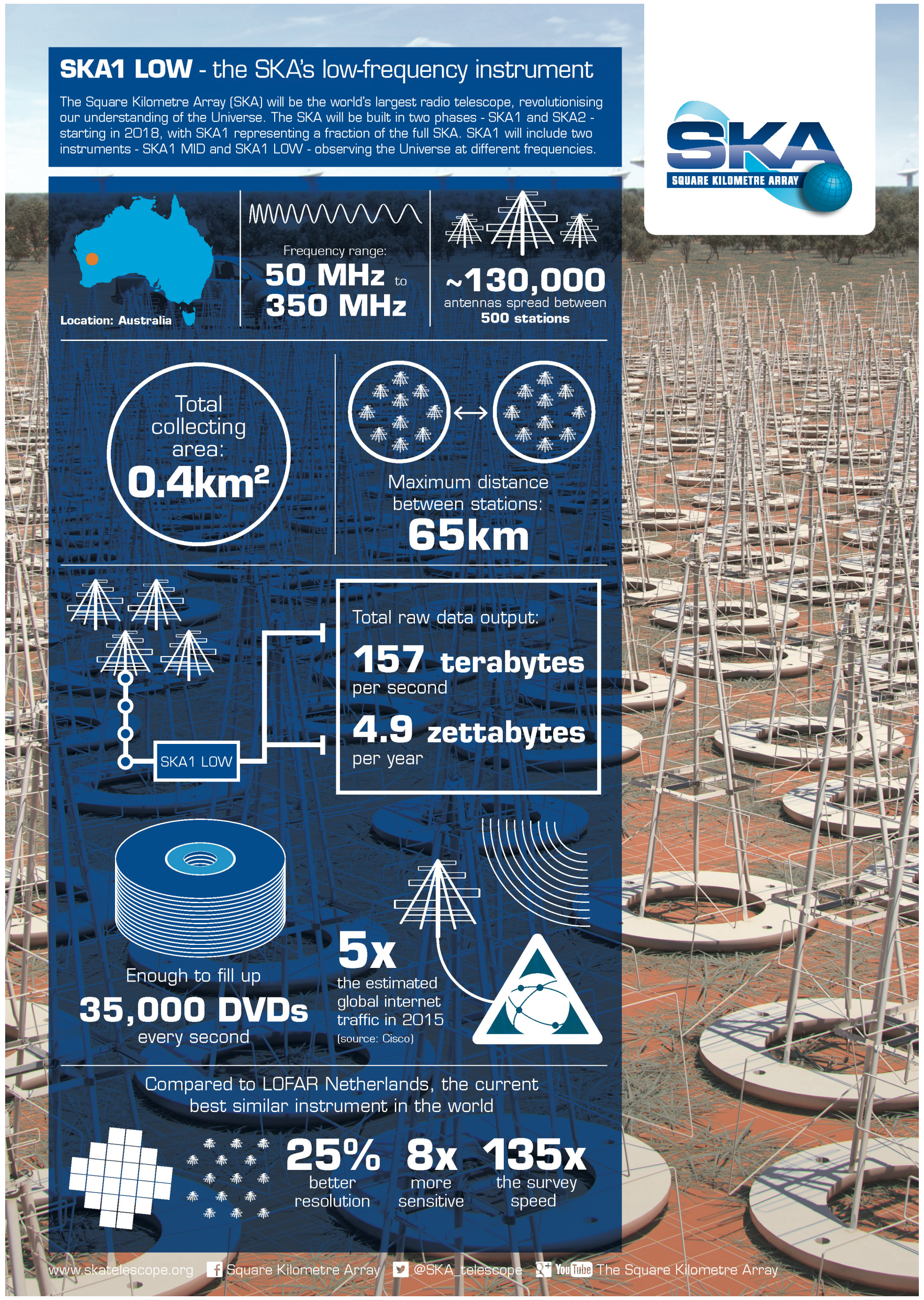


SKA Partners – includes Members of the SKA Organisation – precursor to the SKAO –, current SKAO Member States*, and SKAO Observers (as of June 2021)

African Partner Countries

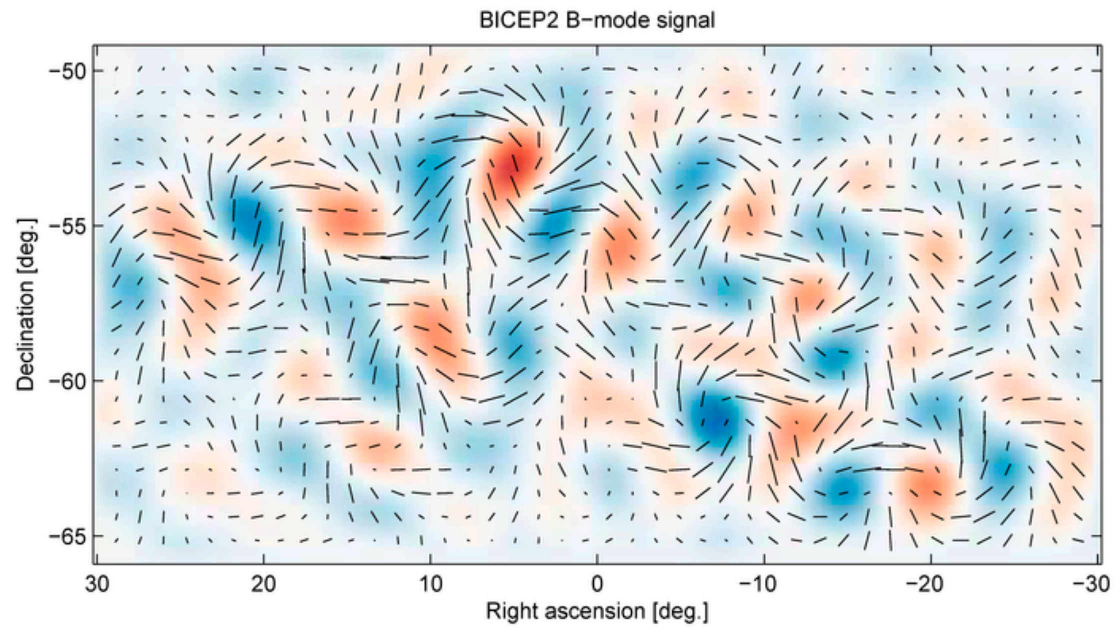
SKA Observatory

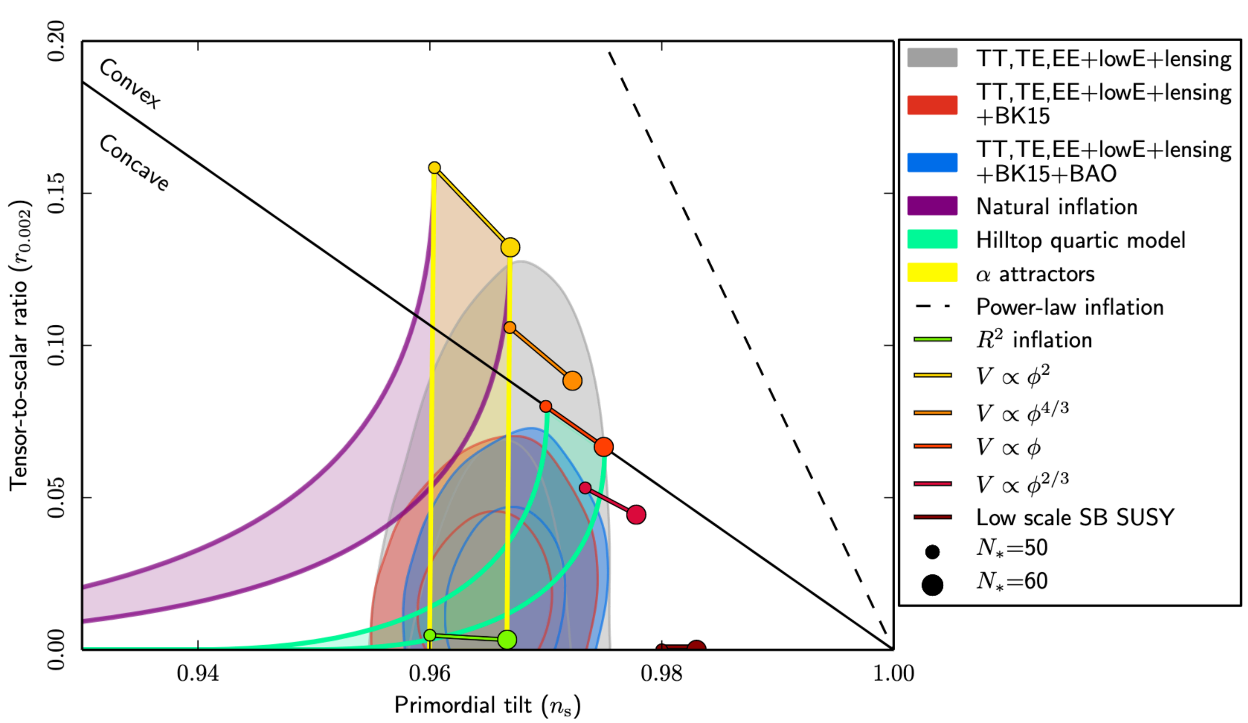


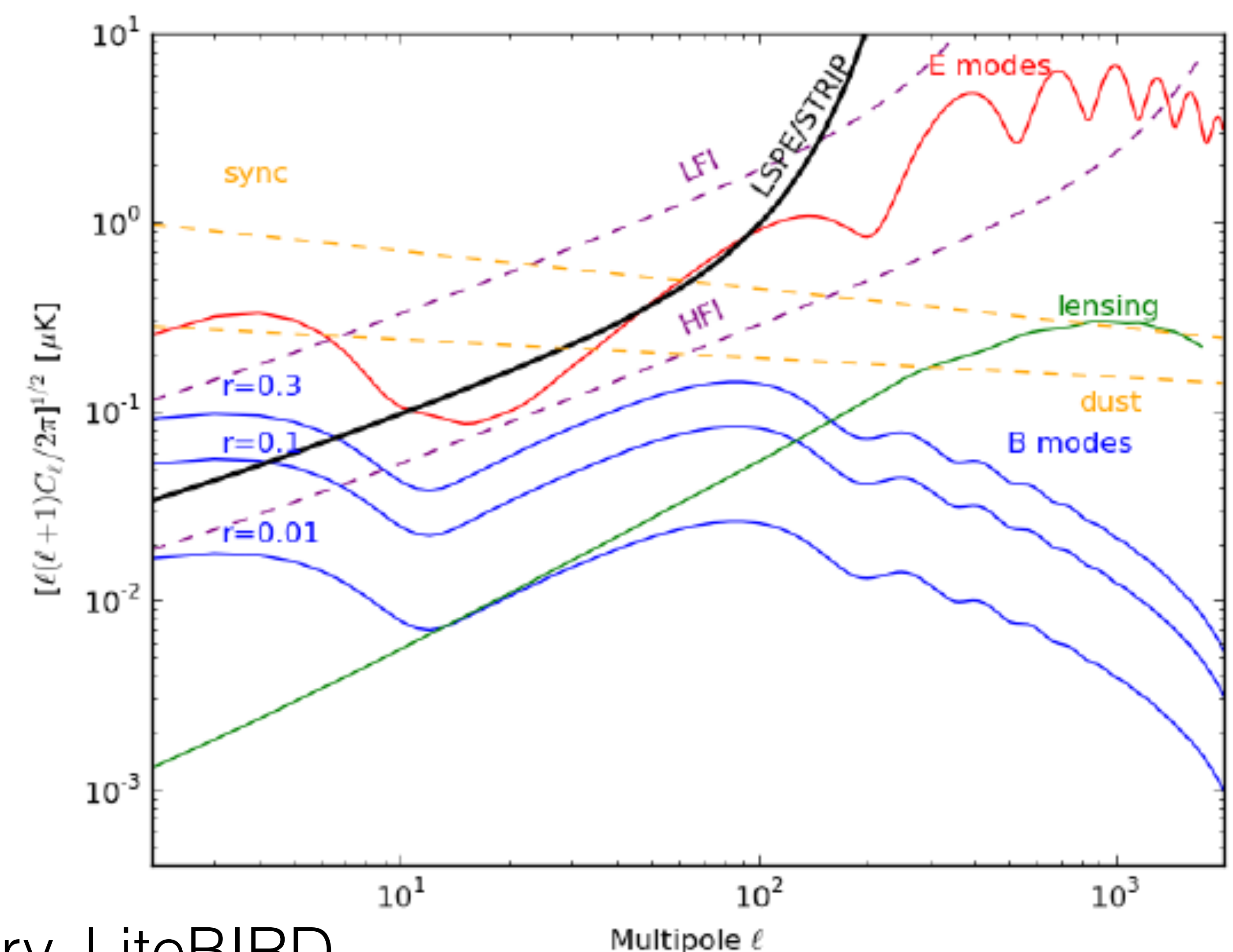


CMB future

If we can measure the primordial B-modes, that is a direct check in the tensor perturbations of the metric and directly linked with gravitational waves produced during inflation







BICEP3/KECK array, Simons Observatory, LiteBIRD, …

¡Thank you!