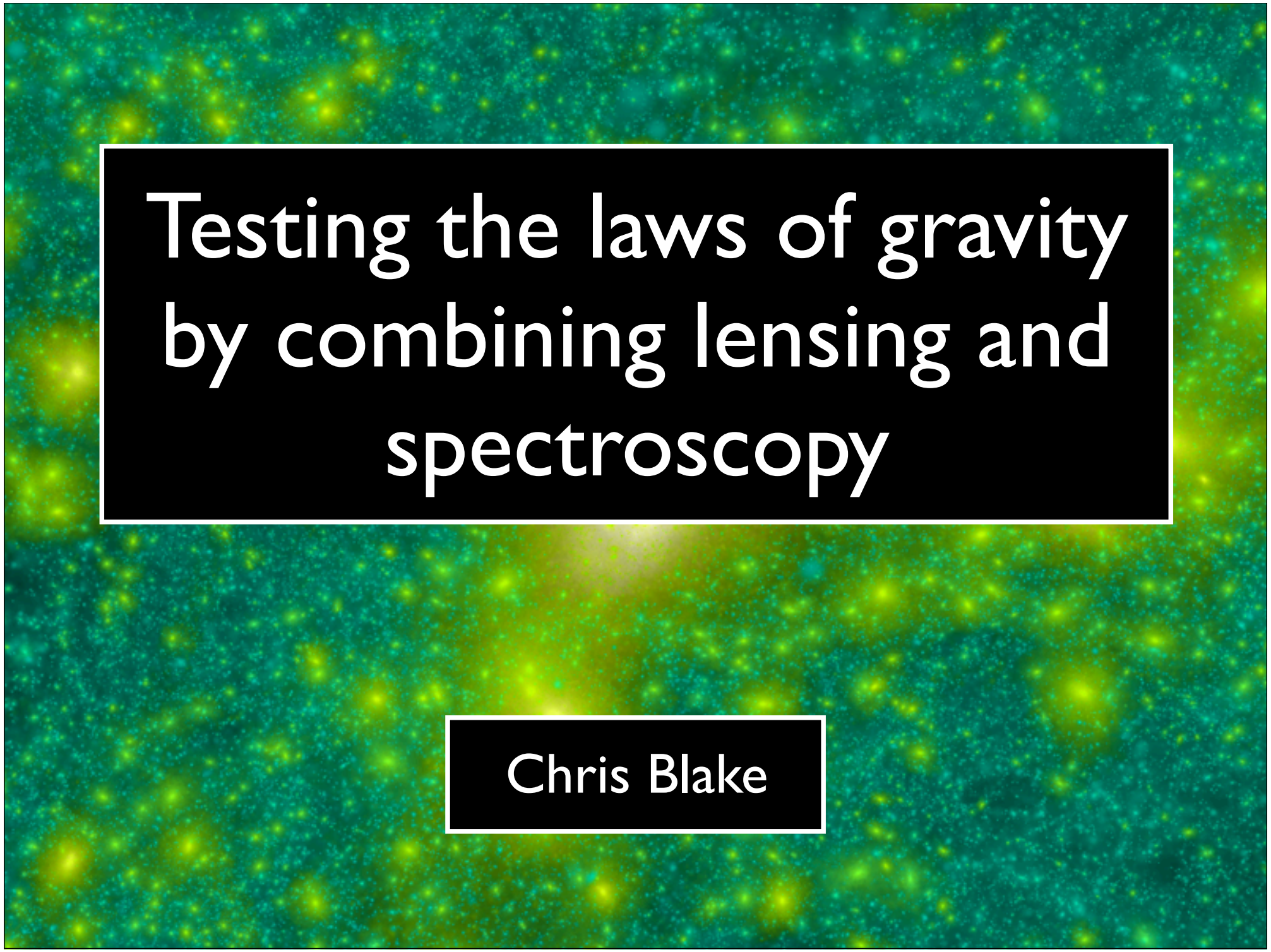
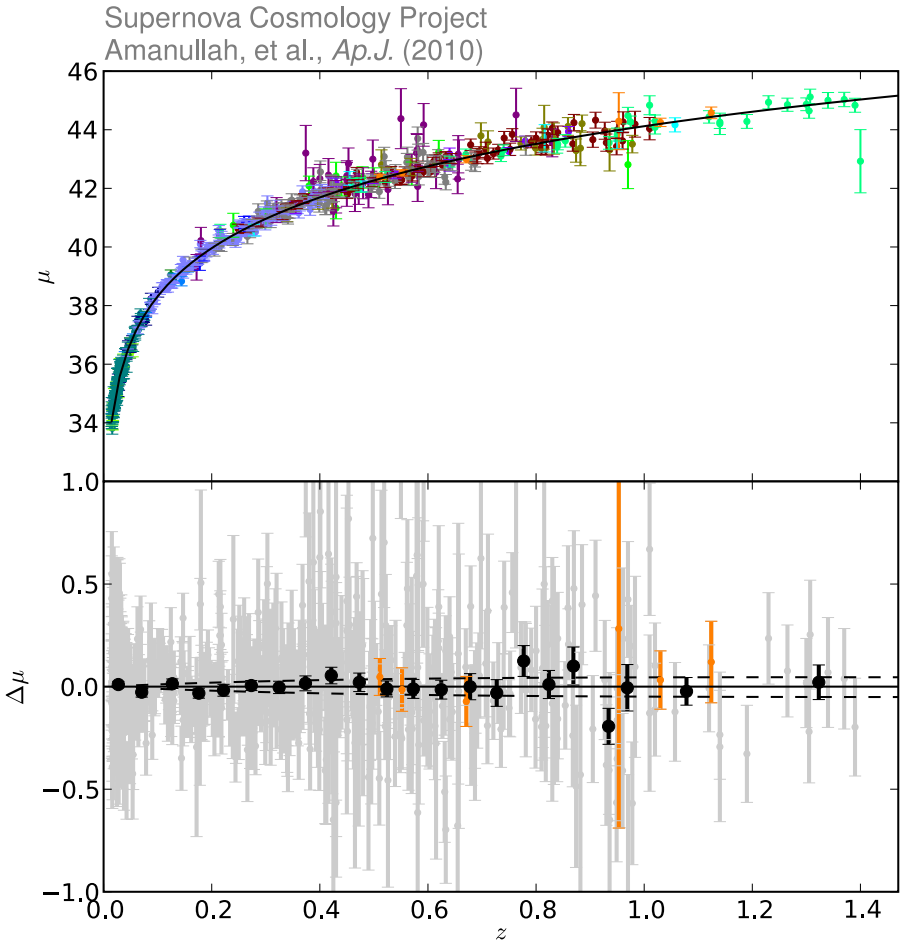
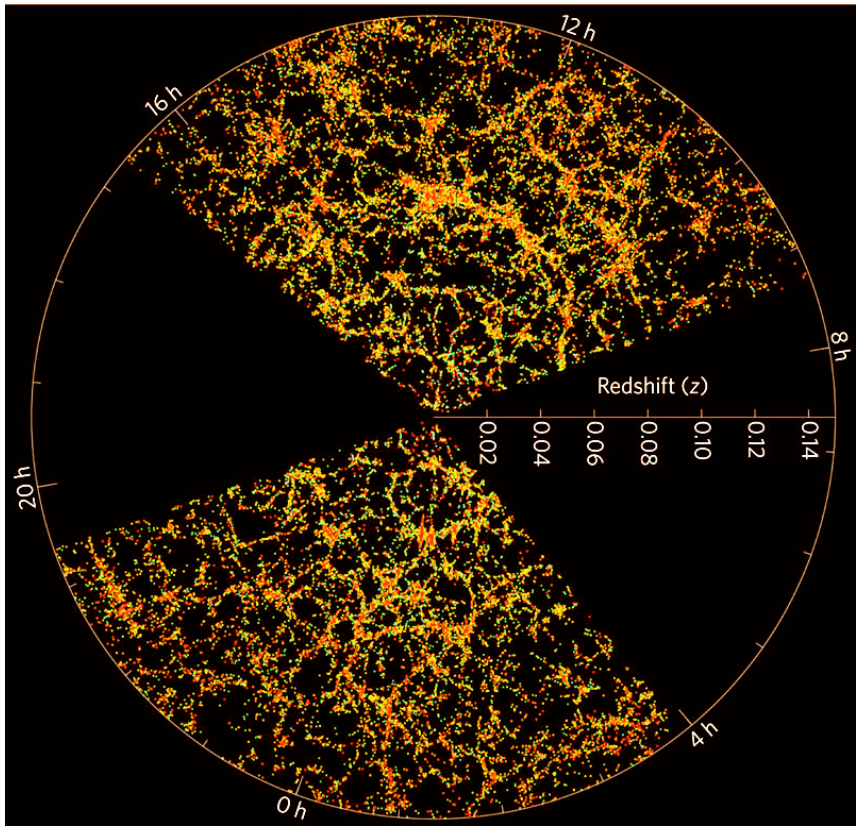

Testing the laws of gravity by combining lensing and spectroscopy
Chris Blake

Probes of the cosmological model

How fast is the Universe expanding with time?

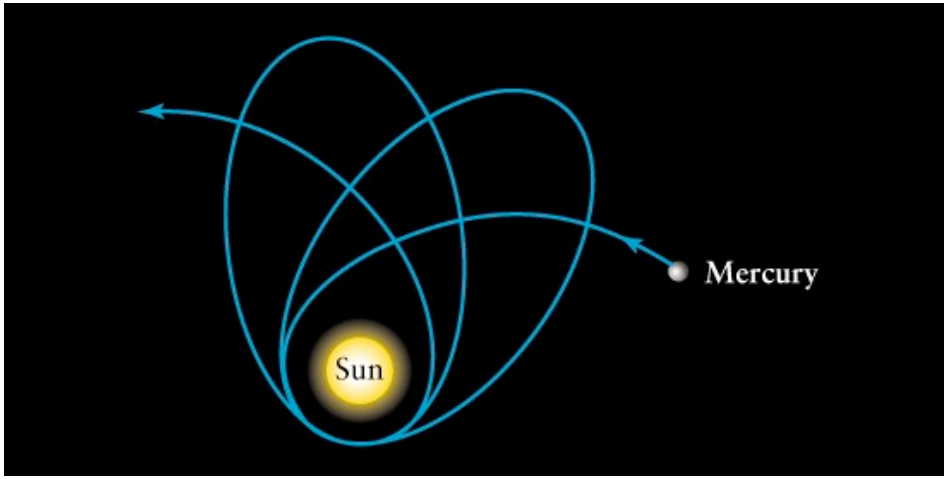
How fast are structures growing within it?

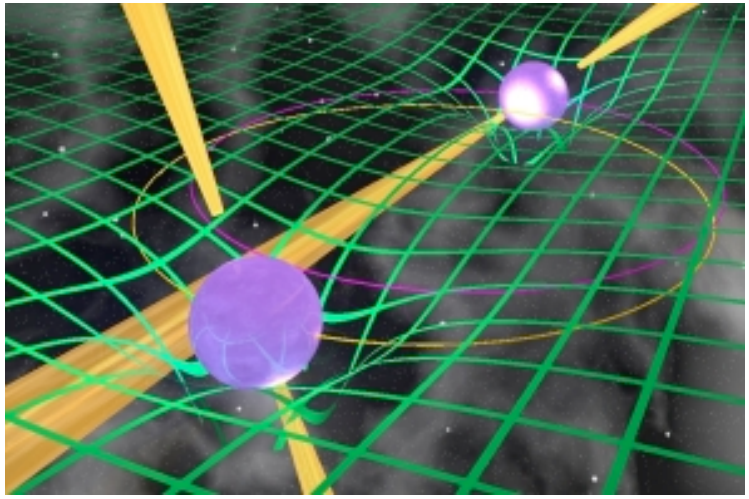


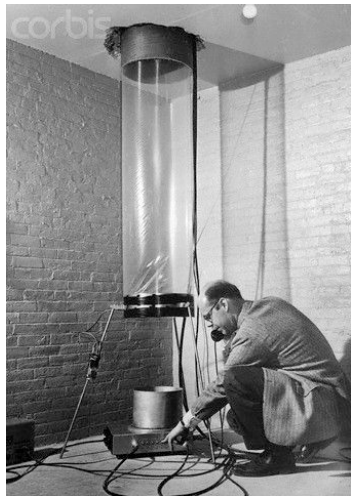


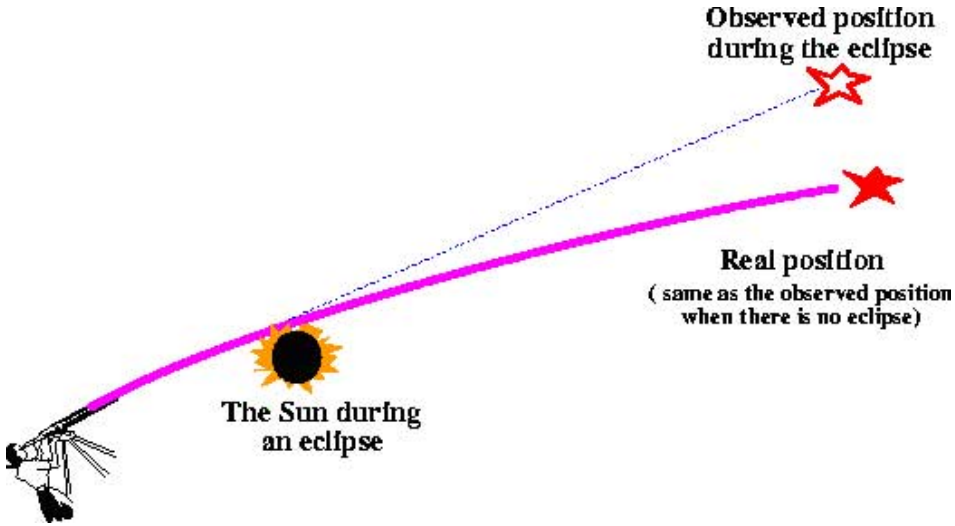
Tests of large-scale gravity

- Can tests of G.R. be extended to cosmic scales?
  And can that yield insight into dark energy?





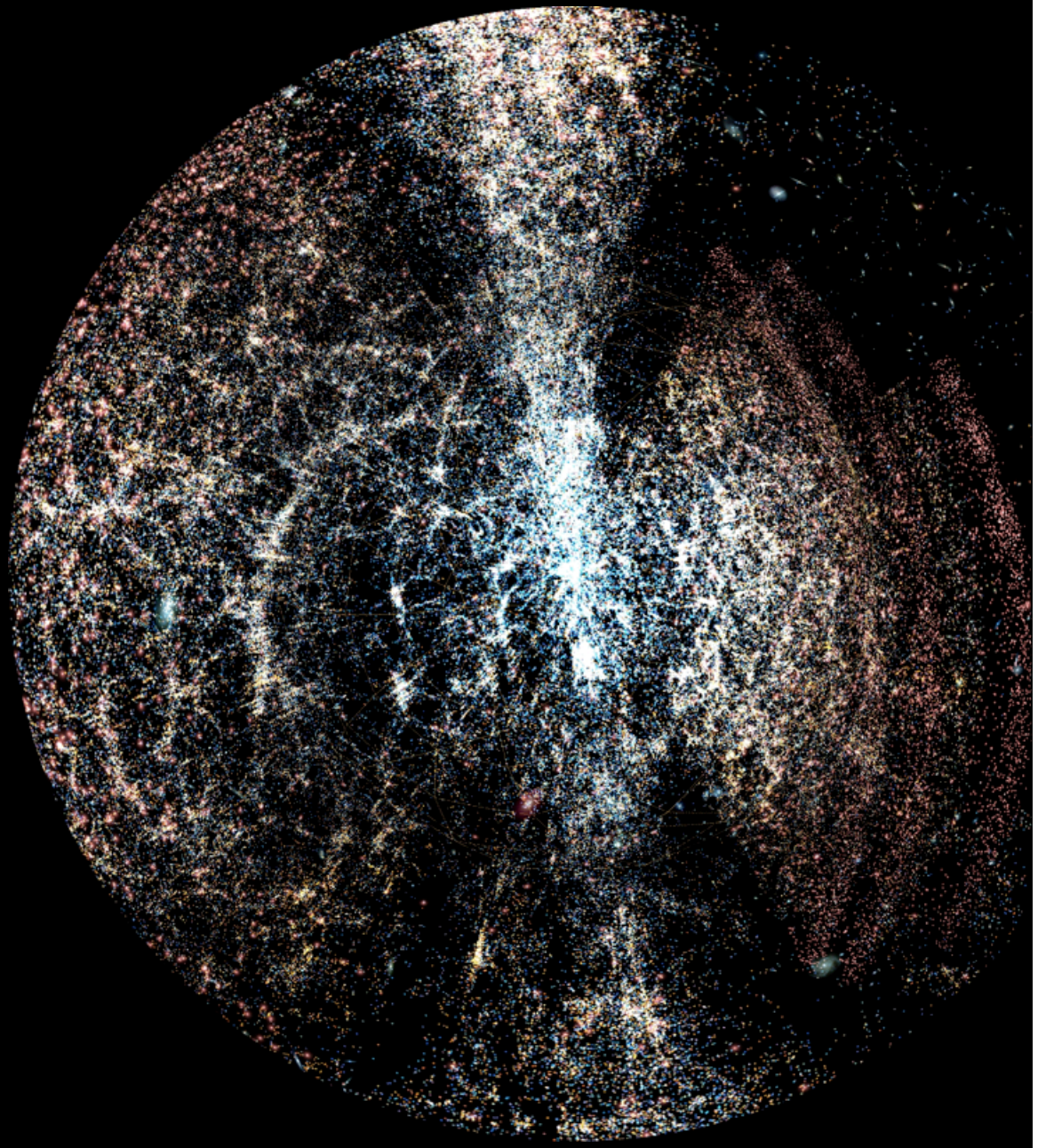




Tests of large-scale gravity

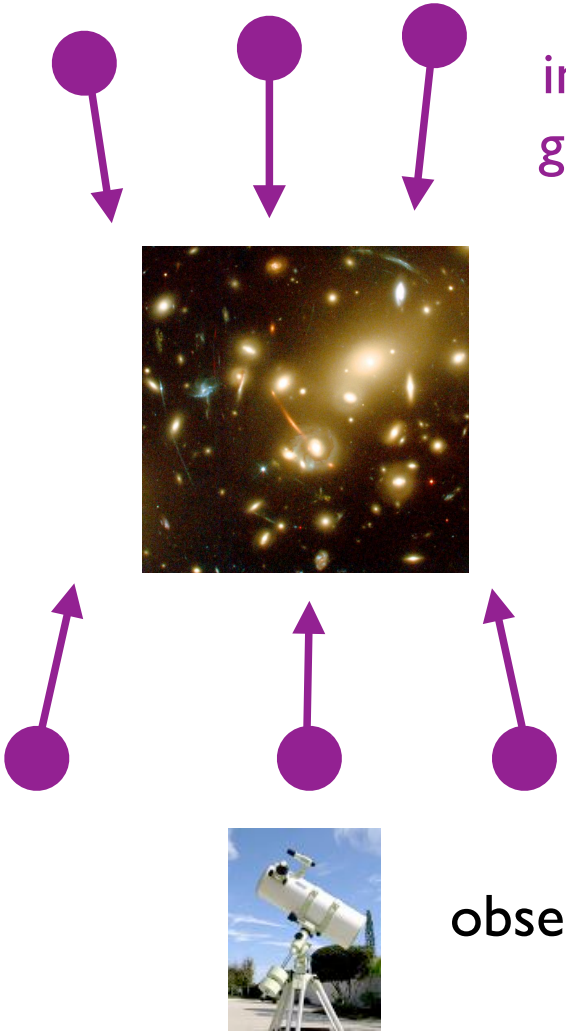
- The large-scale structure of the Universe creates a rich variety of observable signatures we can explore in the gravitational sector!

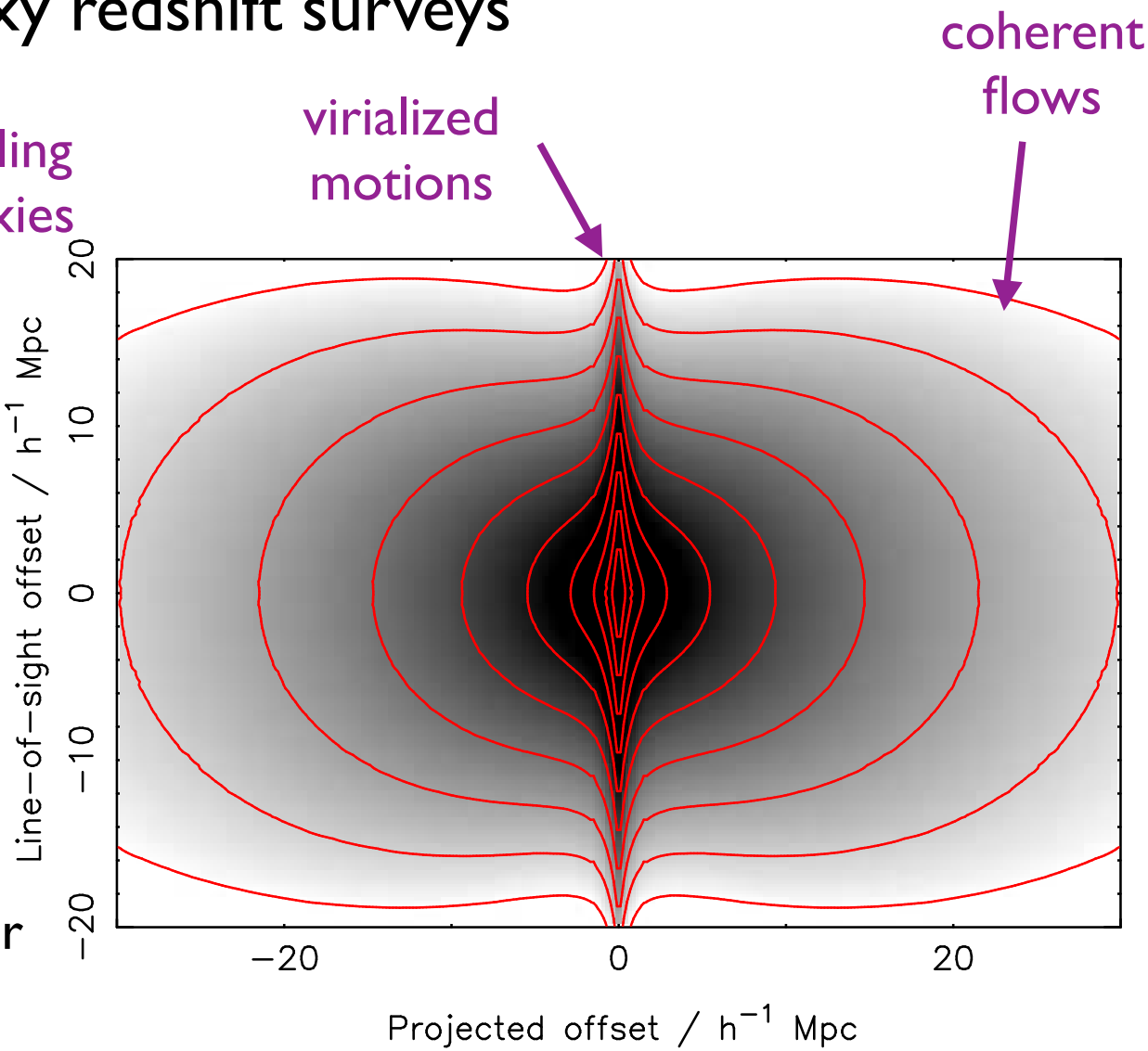
- Two of the most important are galaxy velocities and gravitational lensing



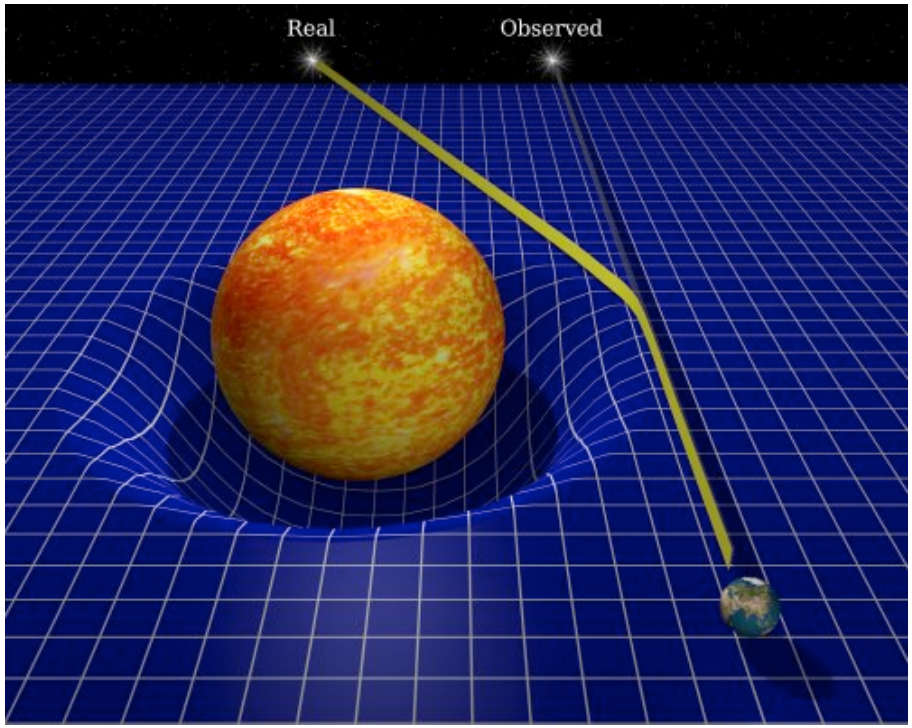
Measuring galaxy velocities

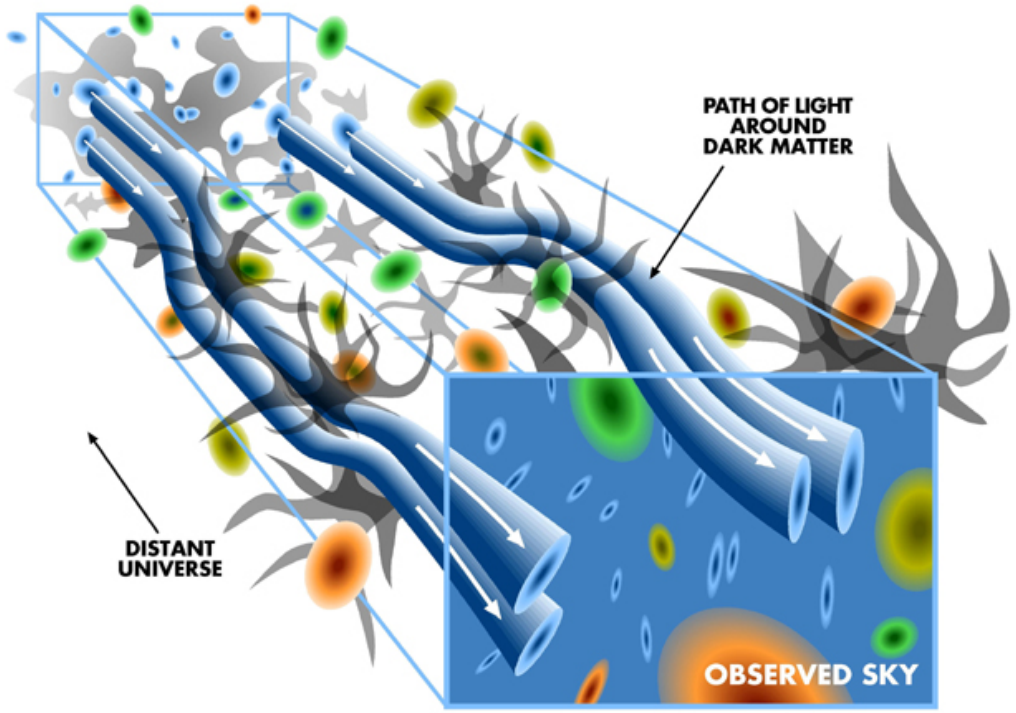
- Galaxies move coherently, creating redshift-space distortion in galaxy redshift surveys

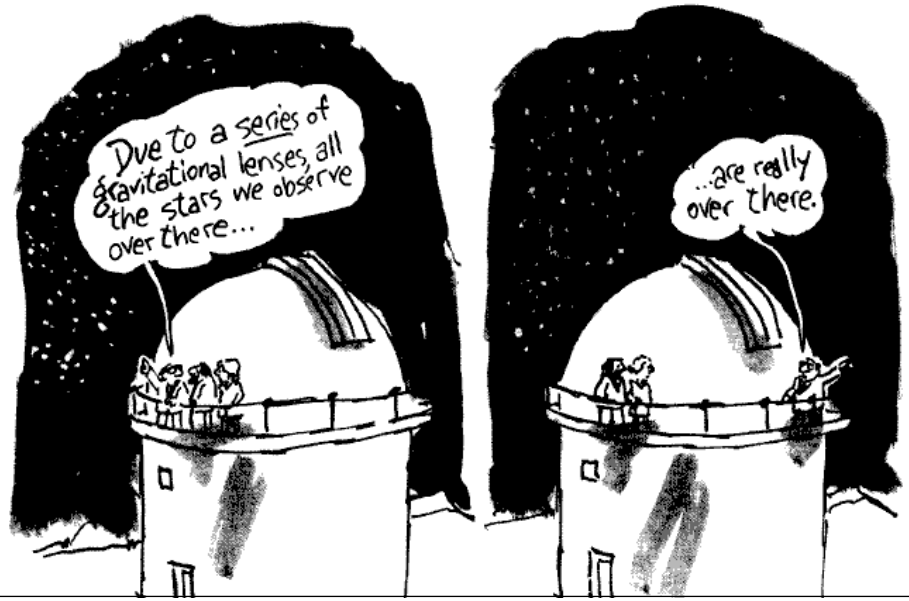


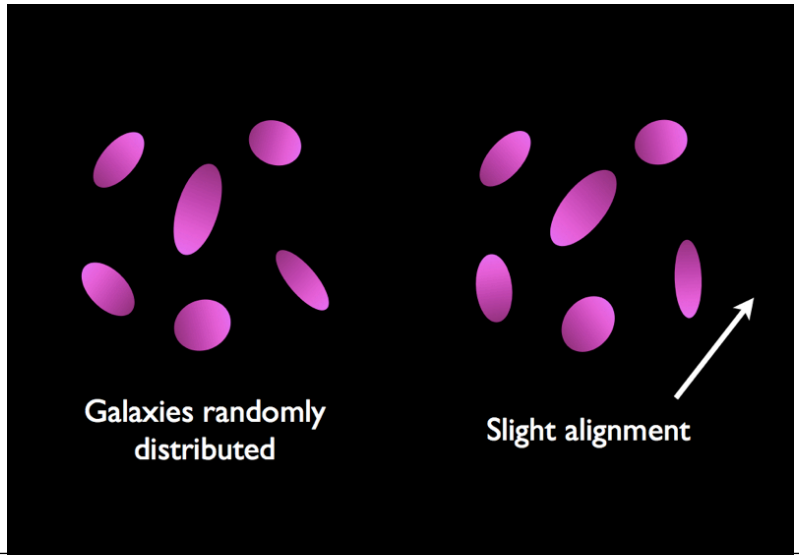


Gravitational lensing



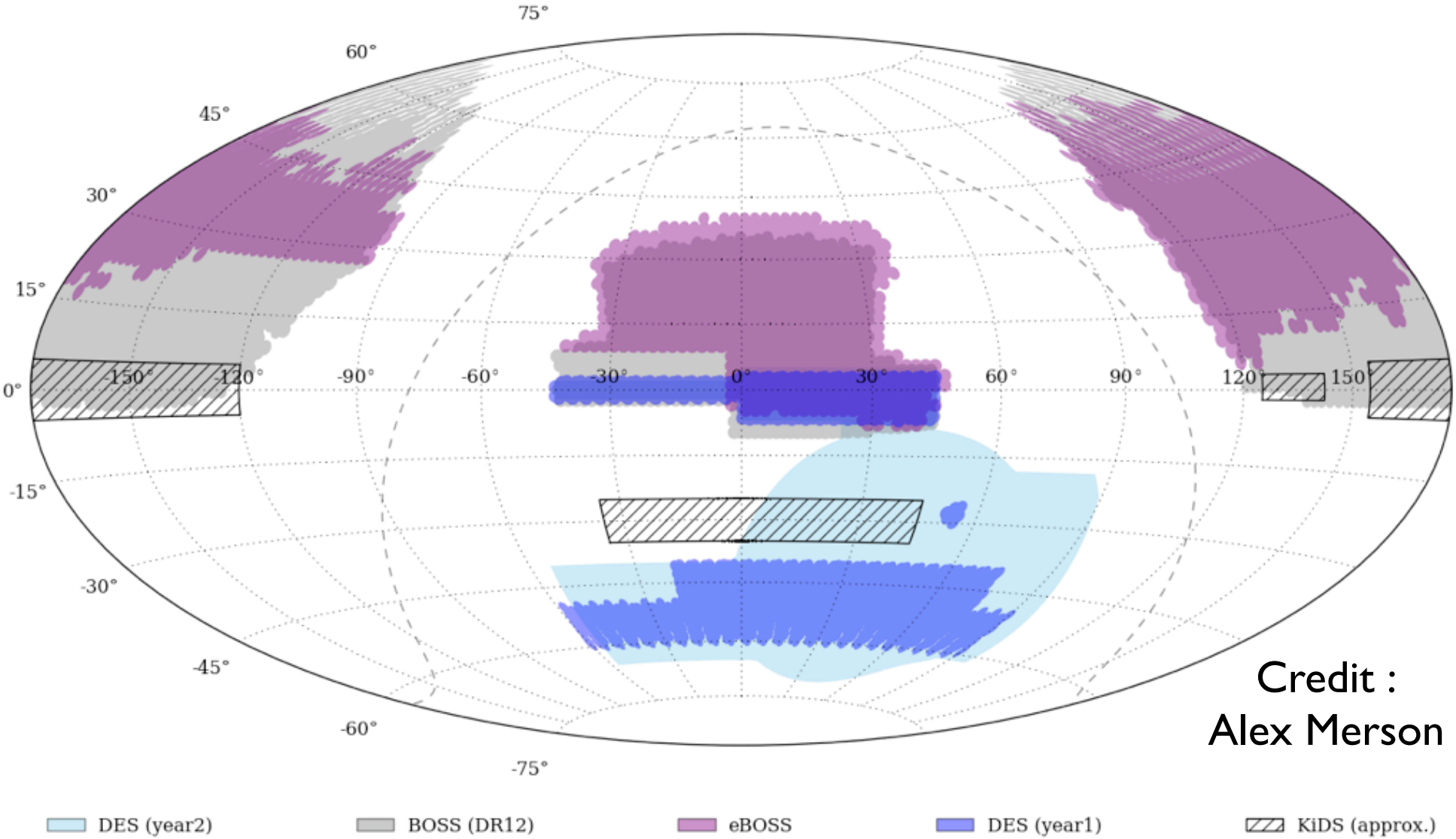






Combining galaxy velocities and lensing

- Mis-match between imaging and spectroscopy



Credit :
Alex Merson

Combining galaxy velocities and lensing

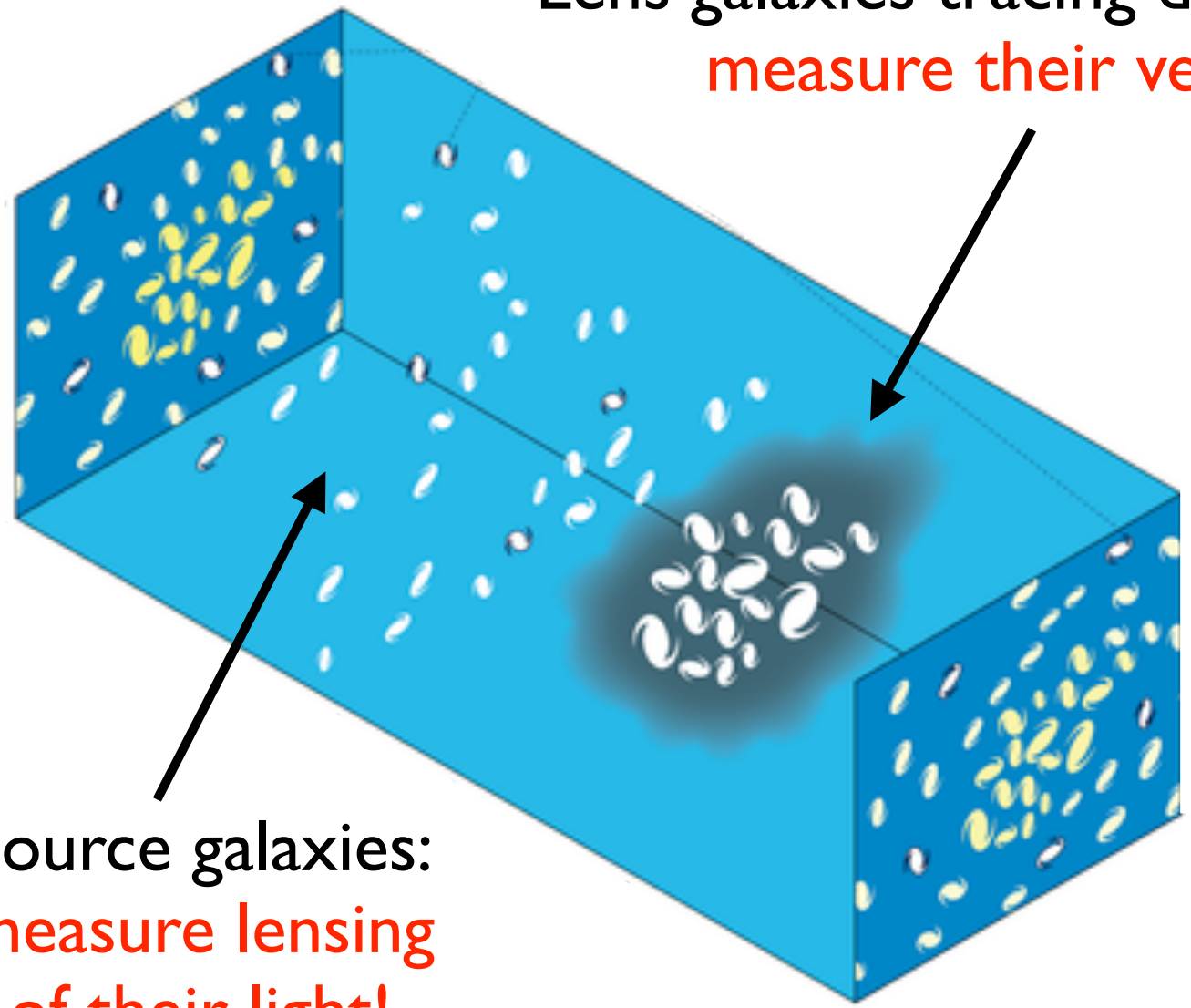
- Sensitive to theories of gravity in complementary ways
- General perturbations to FRW metric:

$$ds^2 = [1+2\psi(x,t)]\,dt^2 - a^2(t)\,[1-2\phi(x,t)]\,dx^2$$

- (ψ, ϕ) are metric gravitational potentials, identical in General Relativity but can differ in general theories
- Relativistic particles (e.g. light rays for lensing) collect equal contributions and are sensitive to $(\psi + \phi)$
- Non-relativistic particles (e.g. galaxies infalling into clusters) experience the Newtonian potential ψ

Combining galaxy velocities and lensing

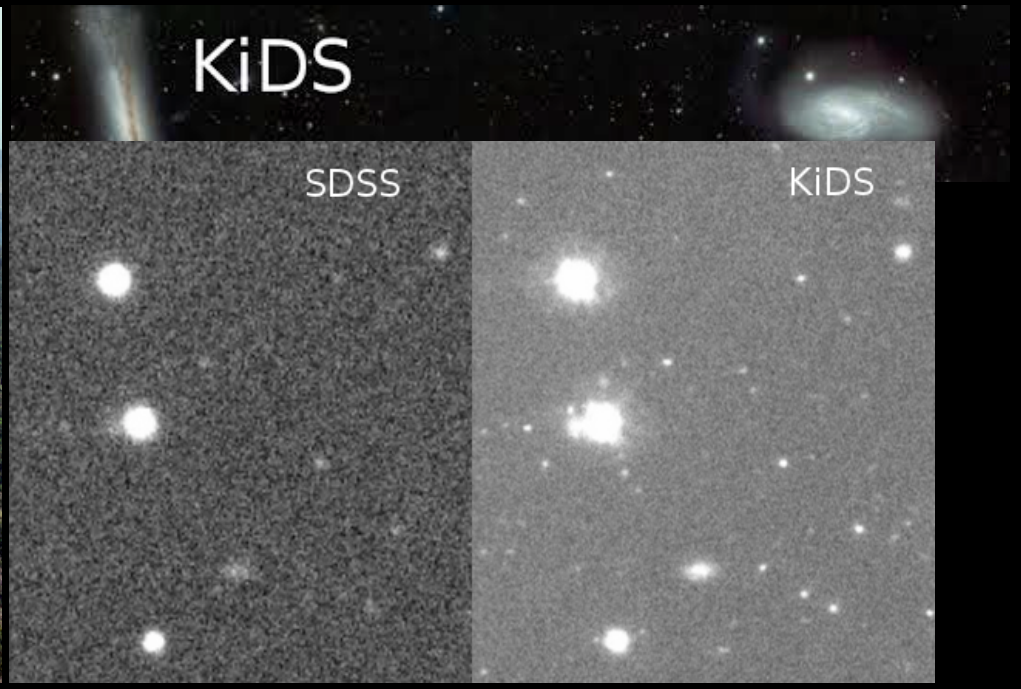
Lens galaxies tracing density ripples:
measure their velocities!



Observations
on the sky

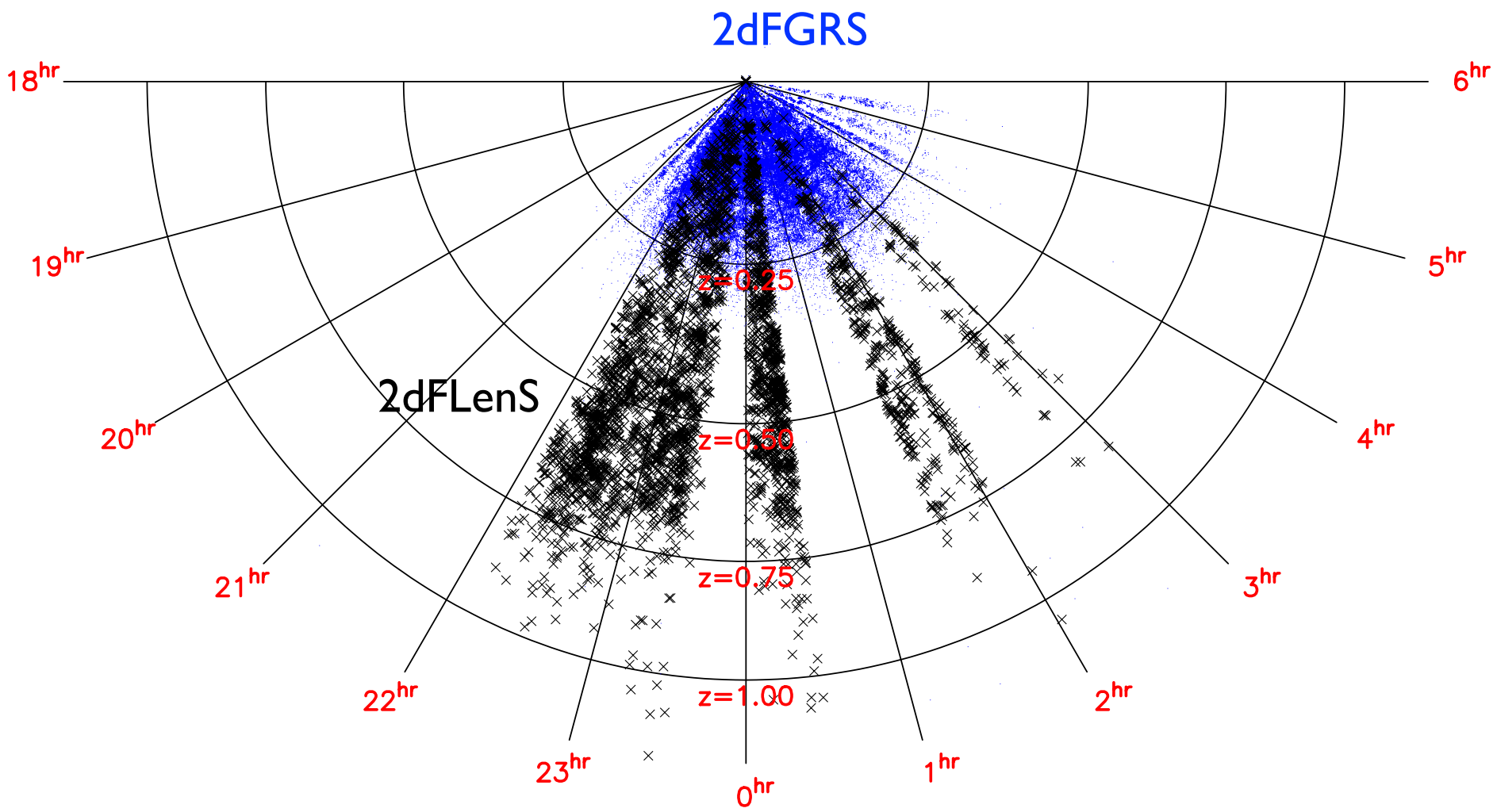
Source galaxies:
measure lensing
of their light!

2dF Lensing Survey (2dFLenS)



- 50 AAT nights granted for spectroscopic follow-up of southern lensing surveys such as KiDS and DES
- Galaxy lens sample to test gravity by cross-correlating weak lensing distortions and galaxy velocities
- Perform photometric redshift calibration

Cone plot (initial data)



Photometric redshift calibration

- Photometric redshift errors are one of the leading systematics for weak lensing tomography
- Mean and width of redshift distributions in each photo-z bin must be known to accuracy ~ 10^{-3}
- Method (1) : spectroscopic training set [issues : sample variance, incompleteness of training set, outliers]
- Method (2) : photo-z/spec-z cross-correlations [issues : degeneracies with galaxy bias, cosmic magnification]
- Currently unsolved problem for current and future lensing surveys (DES, LSST, Euclid)

LSST and 4MOST

- 4MOST is a wide-field spectroscopic survey facility for ESO on the 4m-class VISTA telescope, starting in 2020
- The AAO is involved via the construction of a tilting-spine positioner with ~2400 fibres
- Opportunities to fund Australian involvement through an ARC-LIEF grant [outcome not yet known]
- 4MOST "cosmology" survey could provide ~20 million redshifts over the southern hemisphere
- 4MOST+LSST powerfully extends the KiDS/DES science that OzDES & 2dFLenS are pursuing at the AAT

Summary

- Apparent existence of dark energy motivates new tests of large-scale gravitational physics
- Two observable signatures are non-relativistic galaxy velocities and relativistic lensing of light
- Overlap of imaging/spectroscopy enhances tests of gravity by improving both statistics (galaxy-galaxy lensing) and systematics (photo-z calibration)
- Existing efforts by OzDES and 2dFLenS will lead to future science with LSST and 4MOST