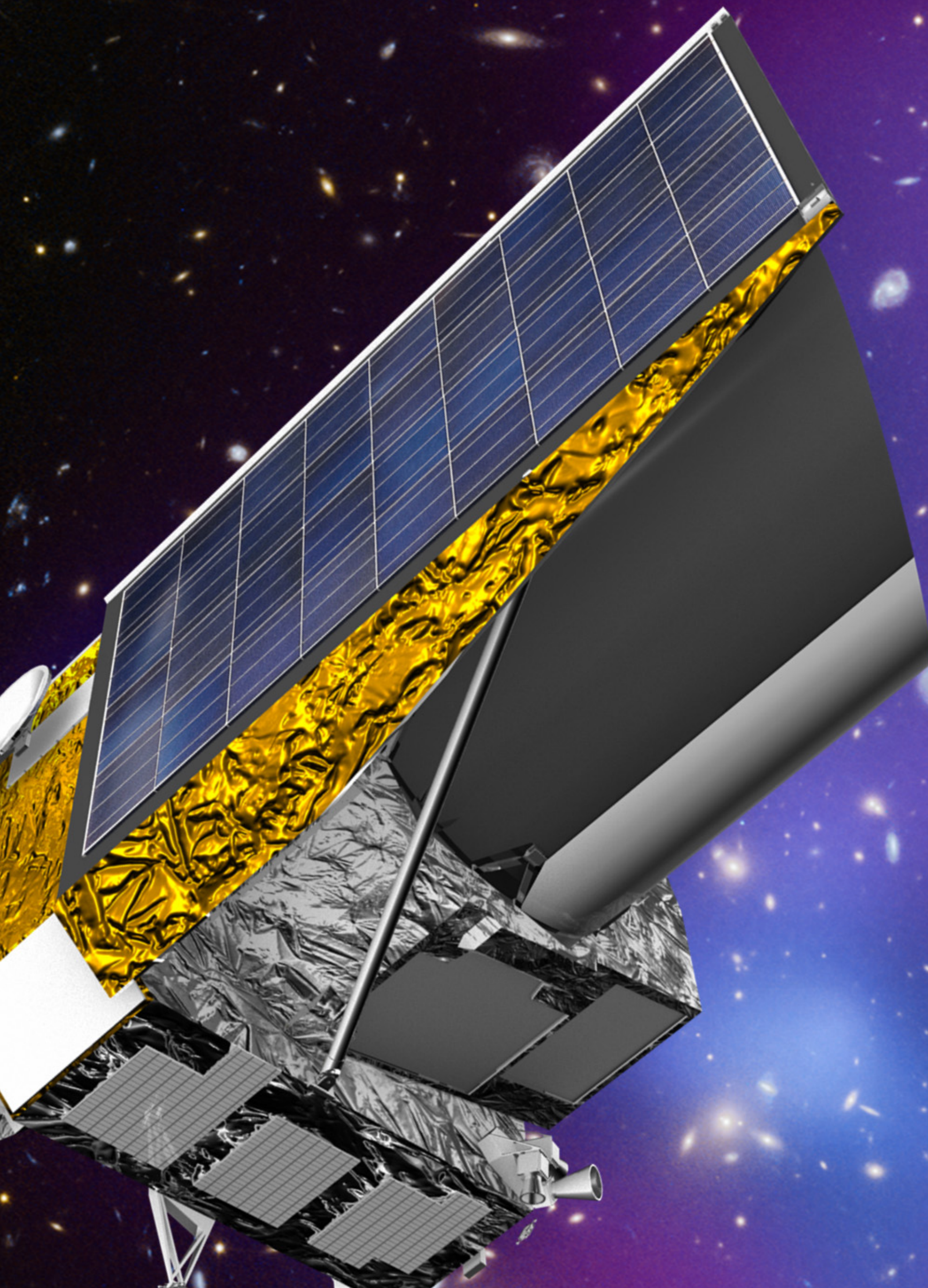
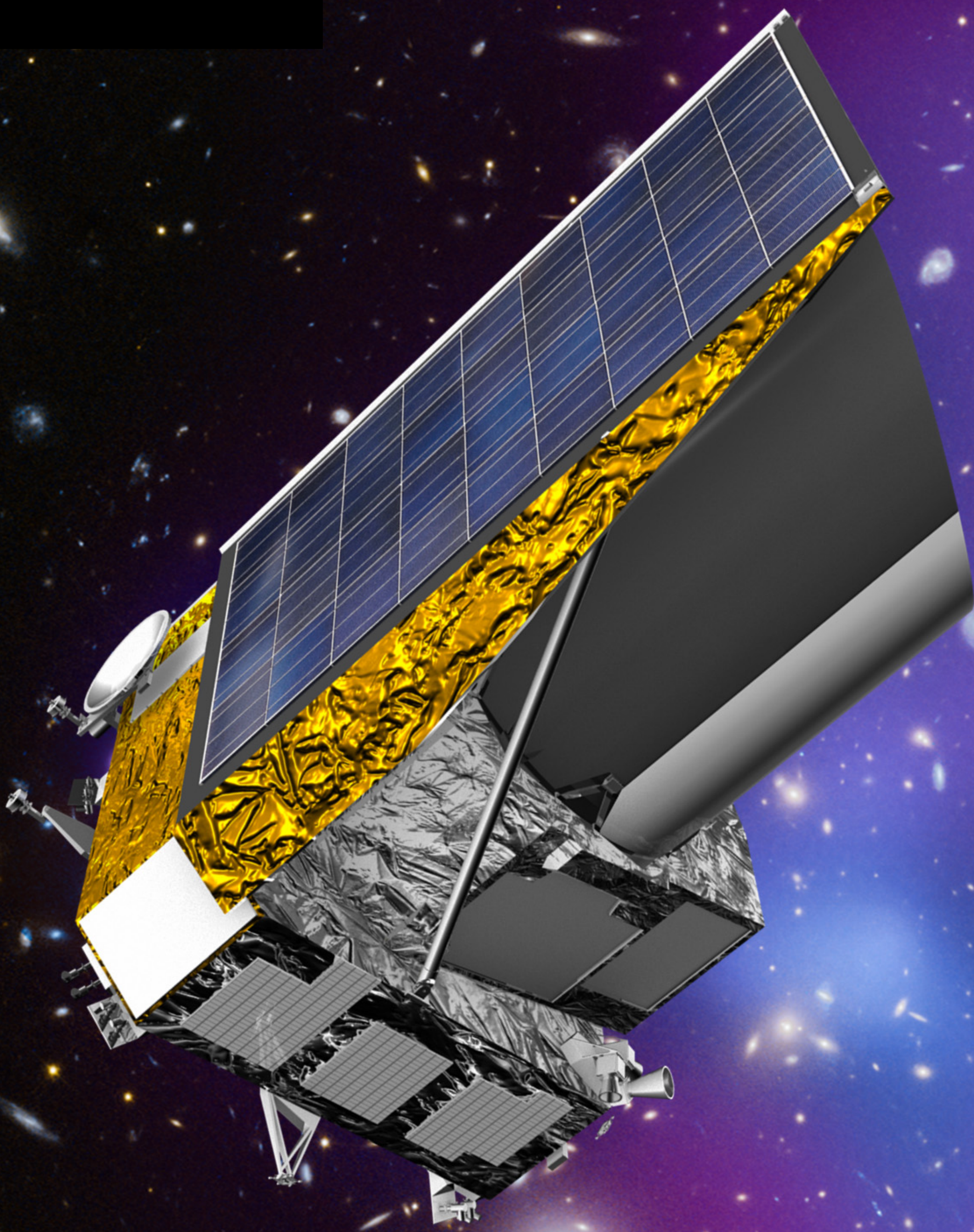
Mapping the Universe with Euclid

Luigi (Gigi) Guzzo
on behalf of the Euclid Consortium



Euclid



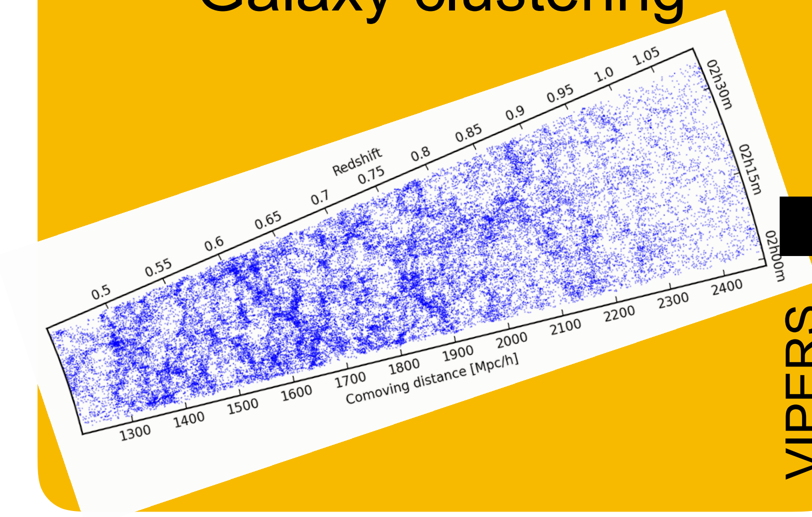
- **Cosmic Vision 2007 program: merge of two original proposals: SPACE & DUNE**
- **Euclid Consortium (EC): more than 1000 members**
- **EC Lead: Yannick Mellier (F) (Interim: Francis Bernardeau)**

Unveiling gravity and dark energy

Φ

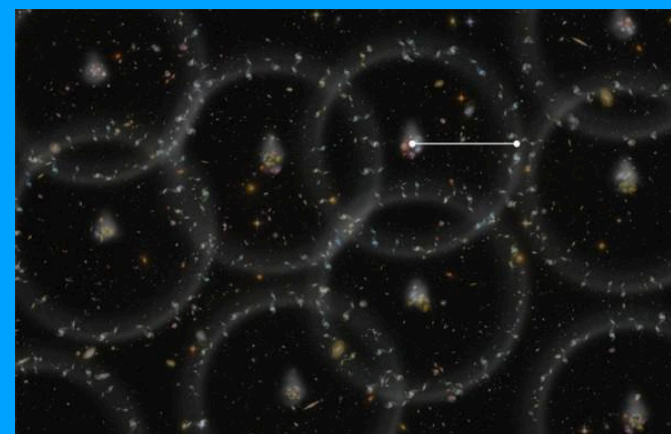
Ψ

Galaxy clustering



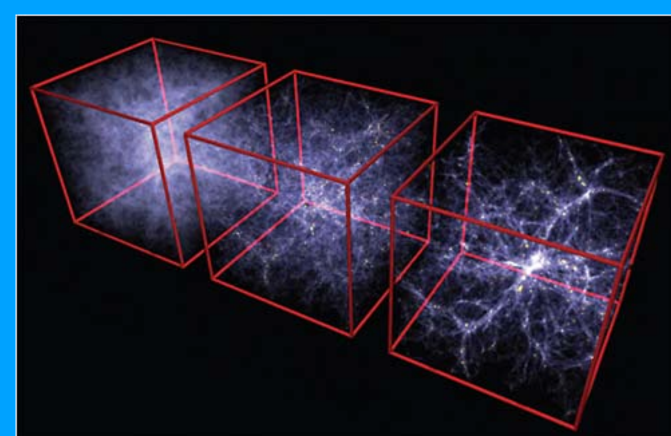
VIPERS

Expansion history



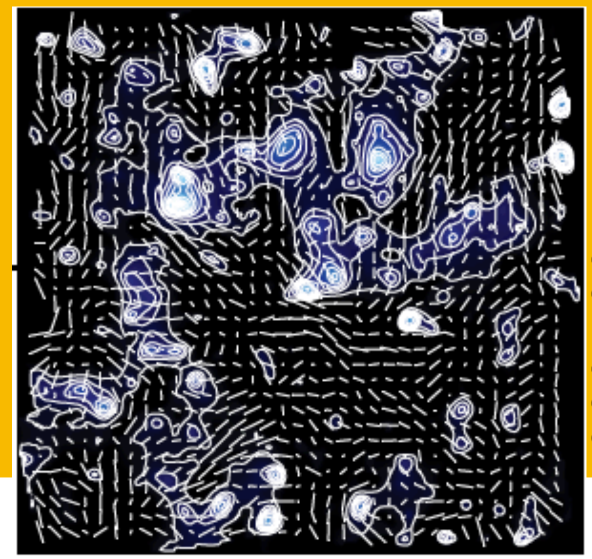
SDSSIII BOSS

Growth of structure



MPA/Millennium

Weak lensing

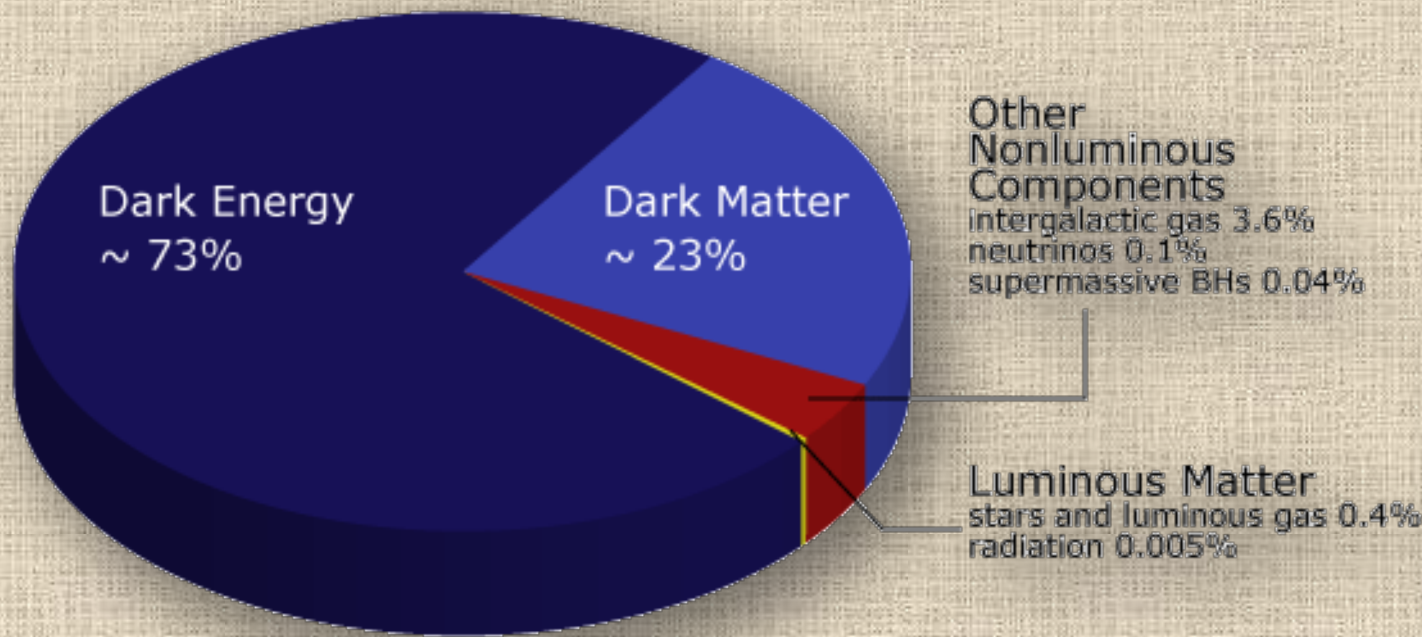


COSMOS

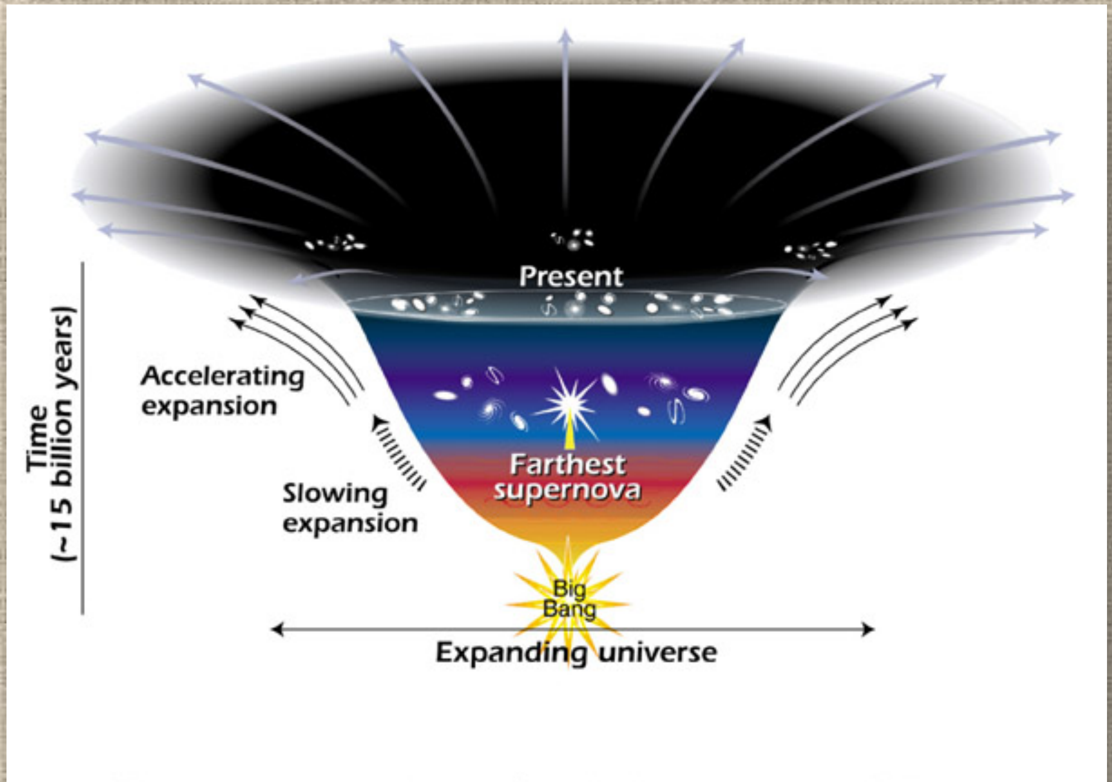
…plus

- Clusters
- CMB cross-correlations
- Strong lensing
- … and more

The "cosmic pizza" of the 21st century: but who ordered it?

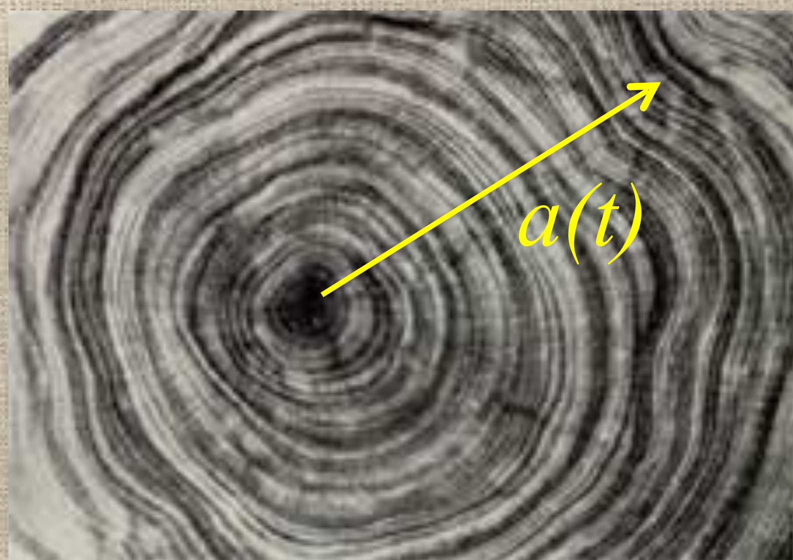


2011 Nobel Prize



This diagram reveals changes in the rate of expansion since the universe's birth 15 billion years ago. The more shallow the curve, the faster the rate of expansion. The curve changes noticeably about 7.5 billion years ago, when objects in the universe began flying apart at a faster rate. Astronomers theorize that the faster expansion rate is due to a mysterious, dark force that is pushing galaxies apart.

All starts (again) with a “Hubble diagram”, which, using Type Ia supernovae (1998), gives a surprising indication…



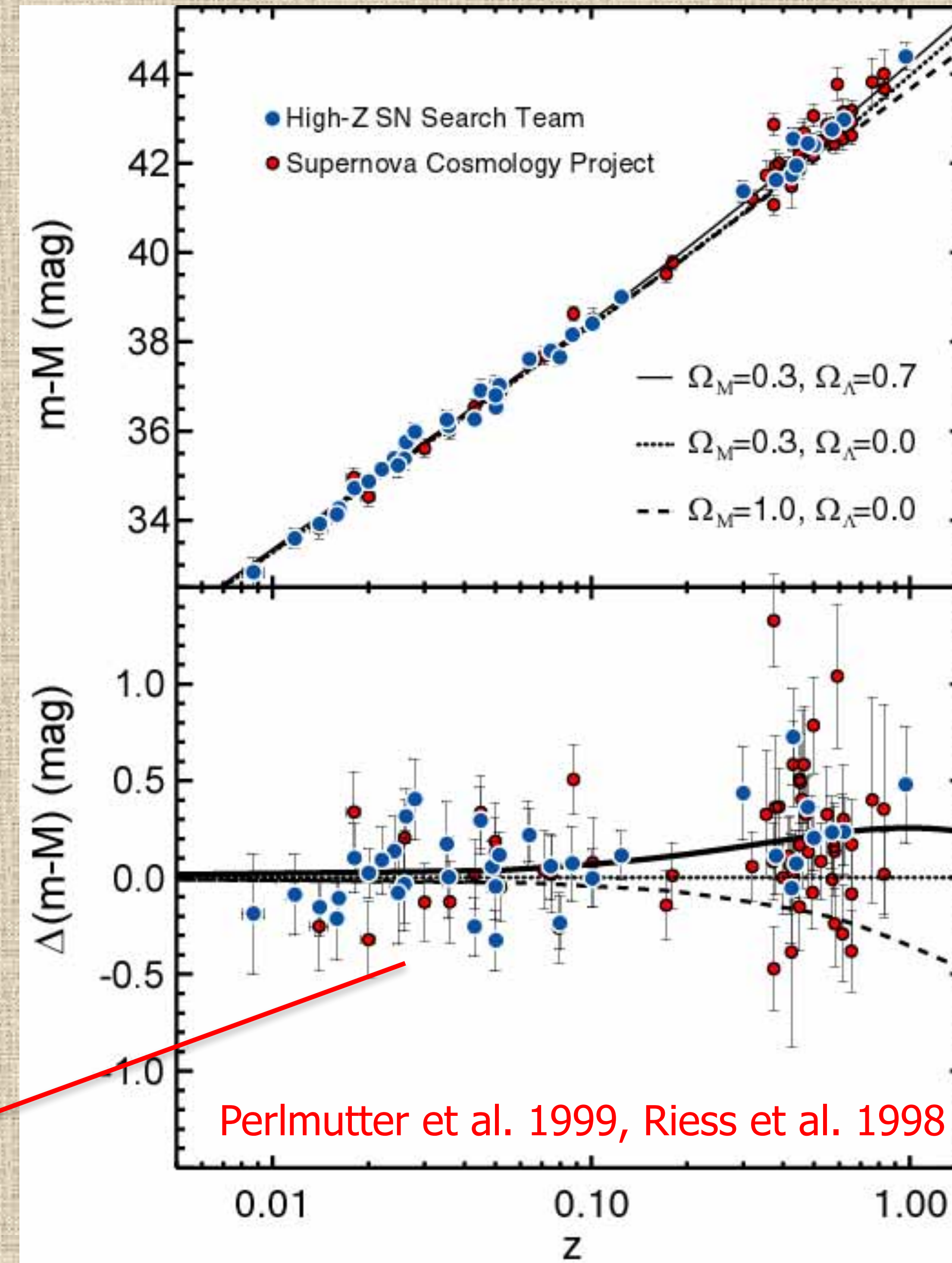
$$H \equiv \frac{\dot{a}}{a}$$

$$d_L = (1+z)\int_0^z \frac{dz'}{H(z',\Omega_m,\Omega_\Lambda)}$$

$$H^2(z) = H_0^2\{\Omega_m(1+z)^3 + \Omega_\Lambda\}$$

~0.3 ~0.7

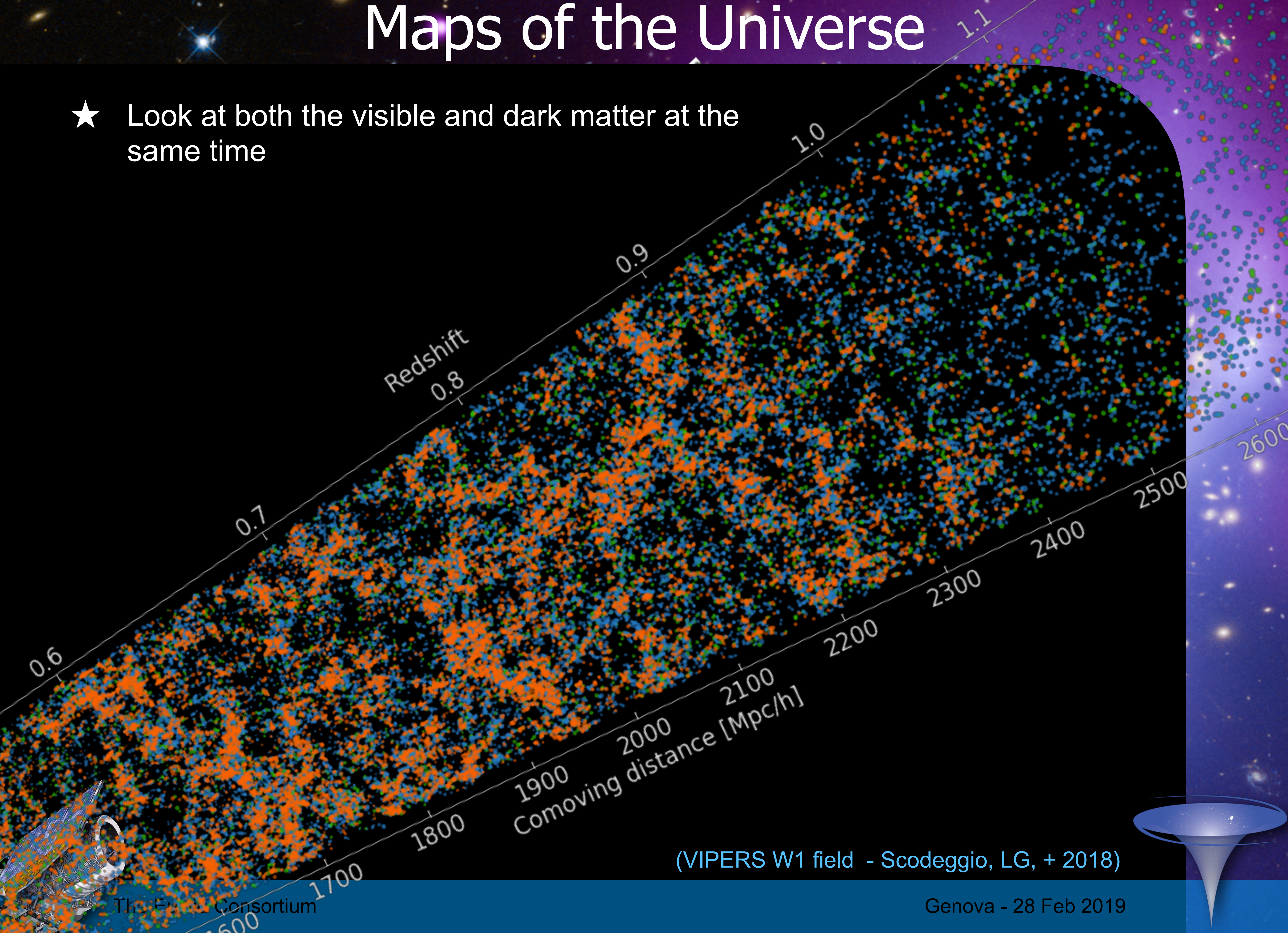
log(Distance d_L)



Redshift of spectral lines

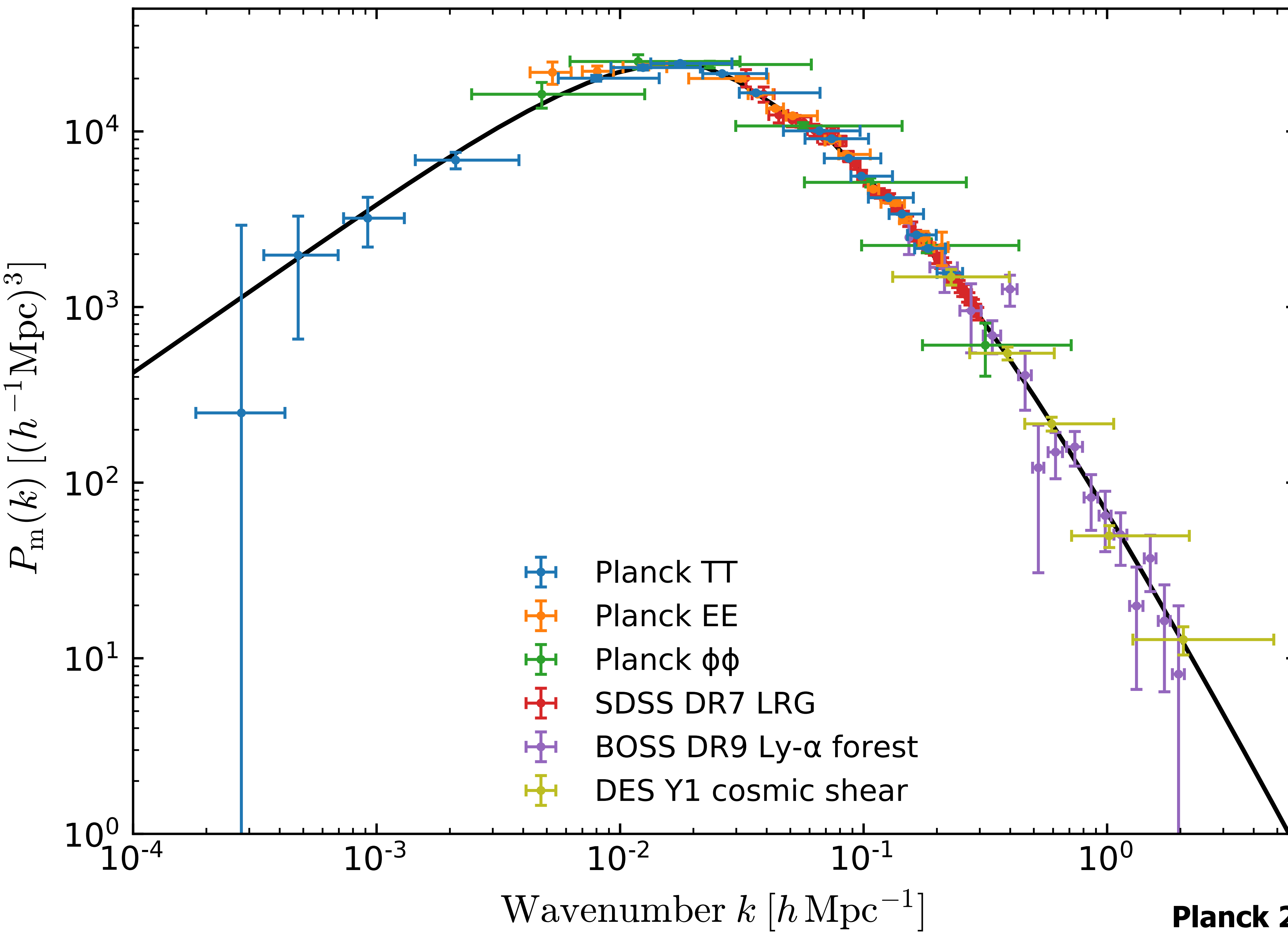
Maps of the Universe

- ★ Look at both the visible and dark matter at the same time



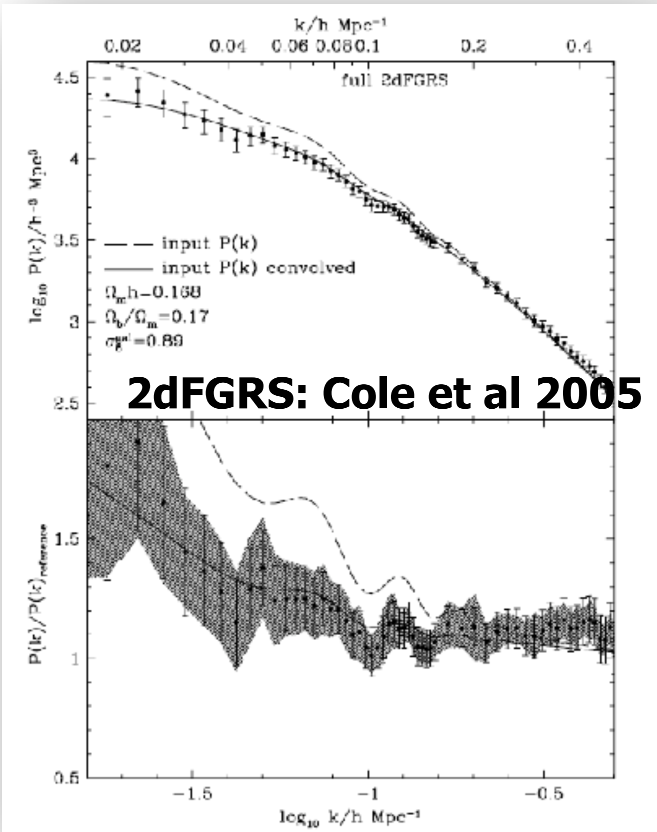
(VIPERS W1 field - Scodeggio, LG, + 2018)

The galaxy power spectrum



Planck 2018 - I

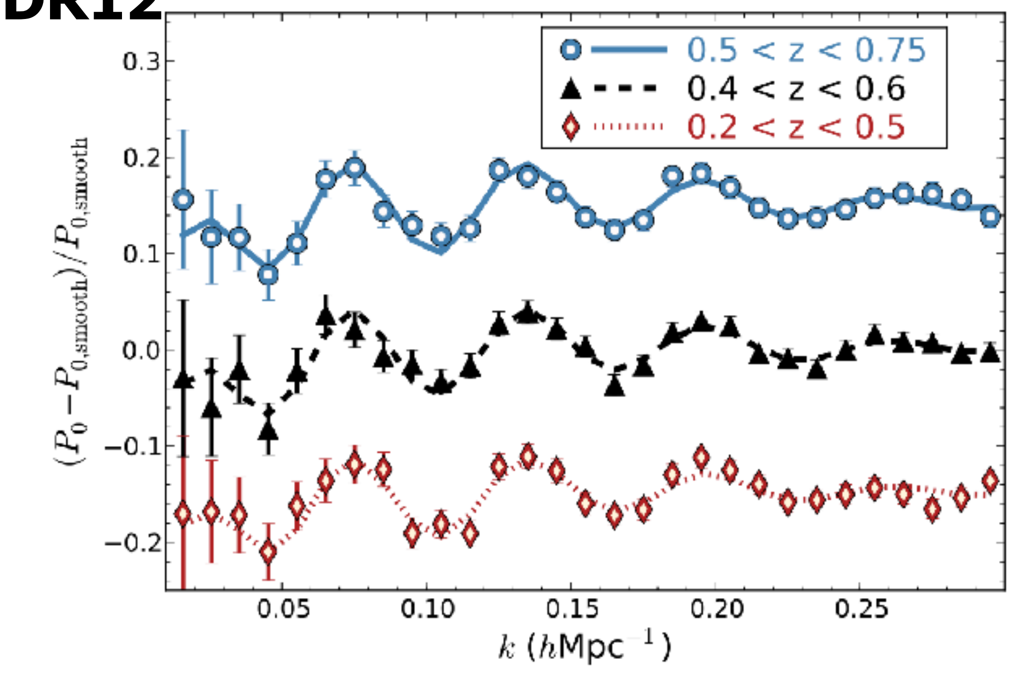
Baryonic Acoustic Oscillations (BAO) in the galaxy P(k)



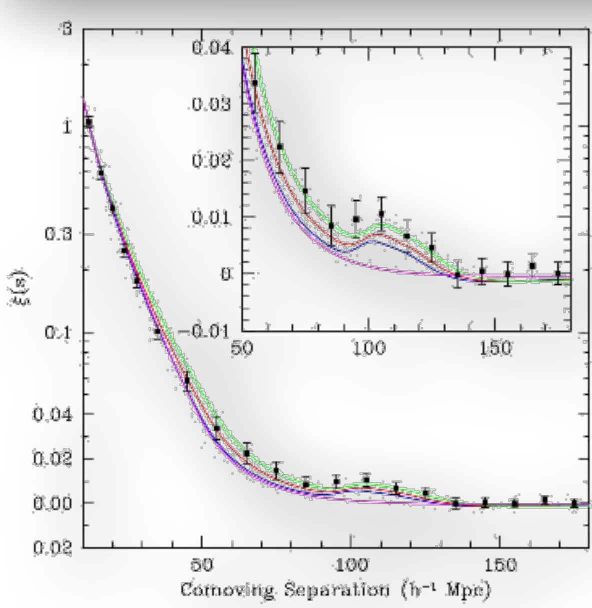
2dFGRS: Cole et al 2005

Fourier Space (wiggles):

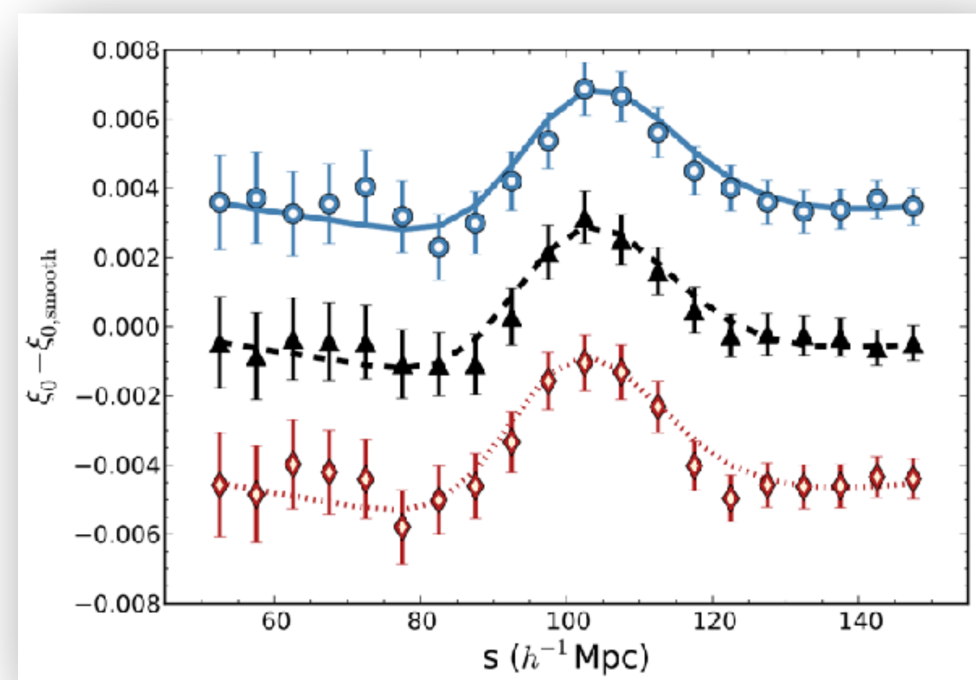
2016: Final measurement from BOSS-DR12



Configuration Space (BAO peak):

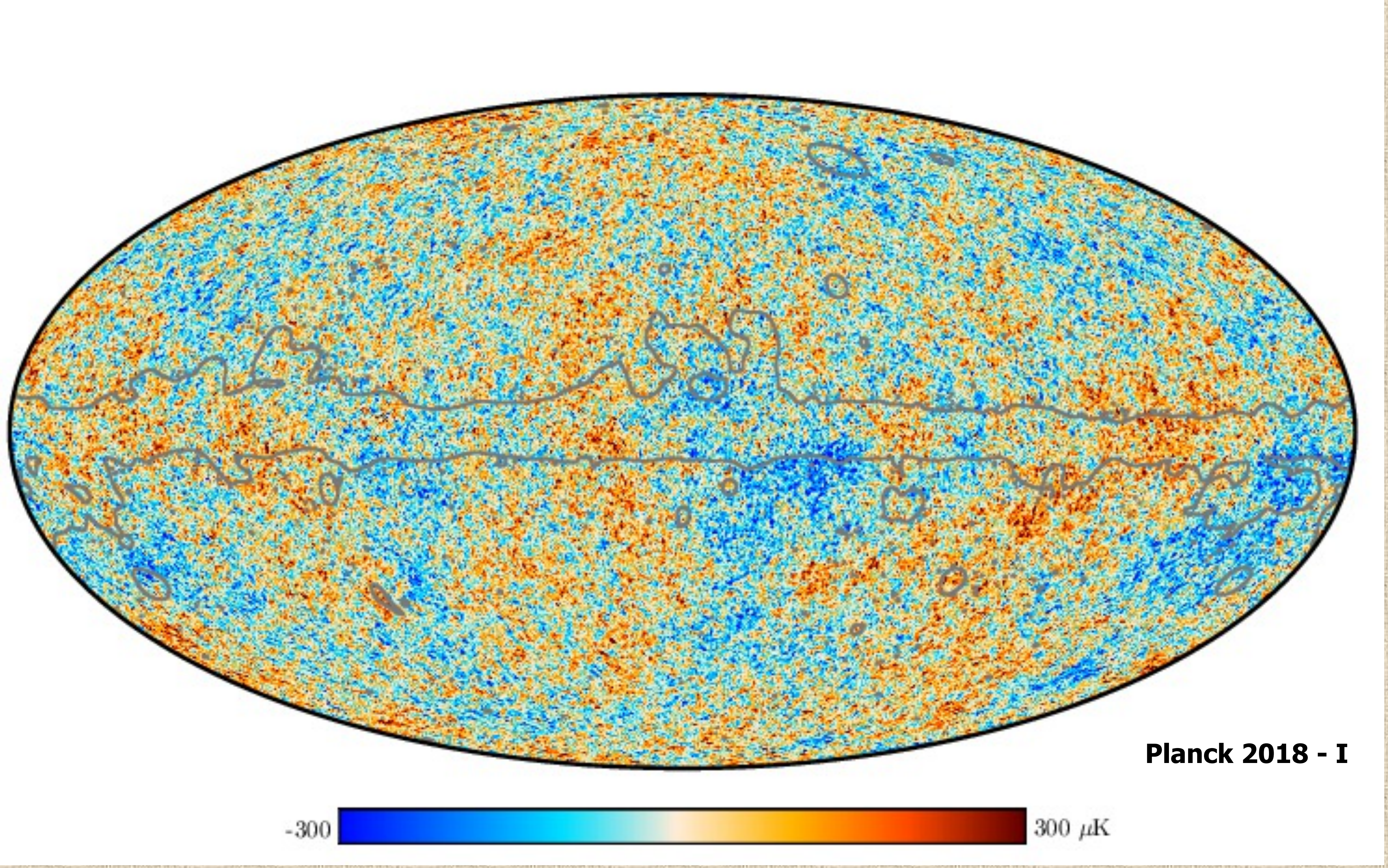


SDSS: Eisenstein et al 2005



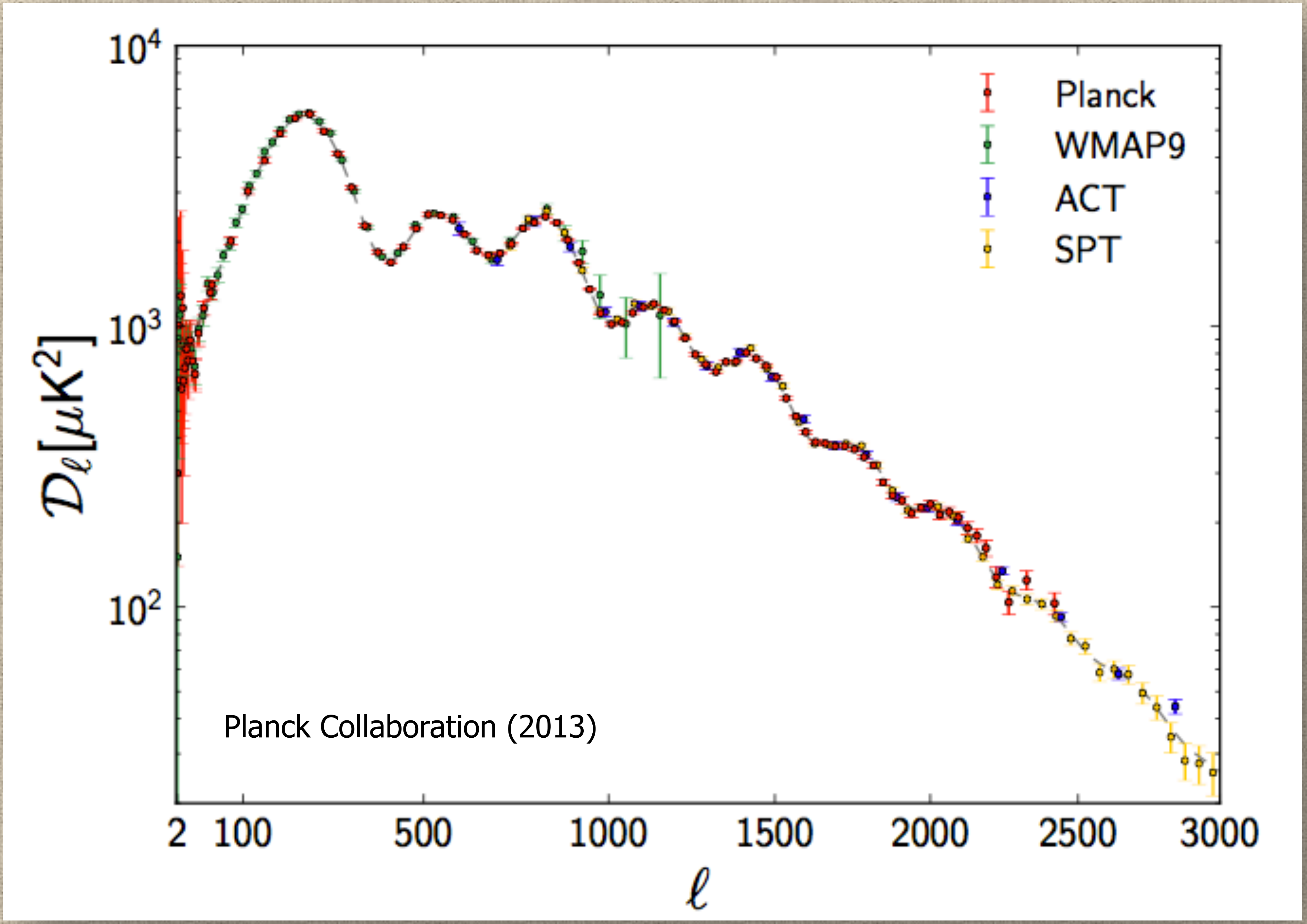
(BOSS Collaboration 2016, arXiv:1607.03155)

Anisotropies in the Cosmic Microwave Background



Fluctuations on all scales: however, one characteristic angular scale emerges

Baryonic Acoustic Oscillations in the CMB



Λ is too small and fine-tuned: an evolving equation of state $w(a)$?

Friedmann equation for Universe with matter plus component with generic equation of state $p = w_x \rho c^2$

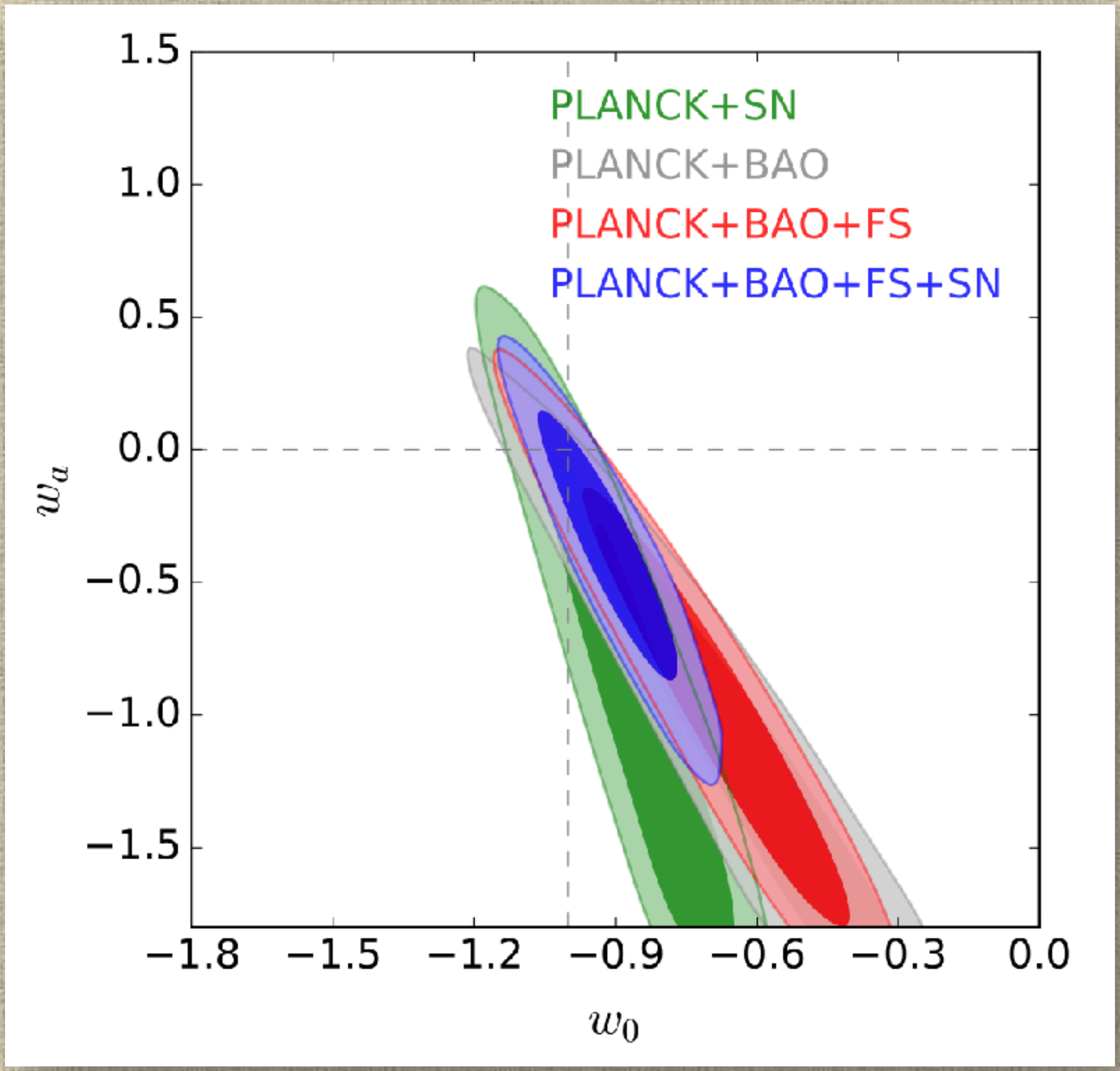
$$H^2(a) = H_o^2 \left[\Omega_m a^{-3} + \Omega_x a^{3(1+w_x)} \right]$$

And if w depends on a?

…parameterize our ignorance:

$$w(a) = w_0 + (1-a) w_a$$

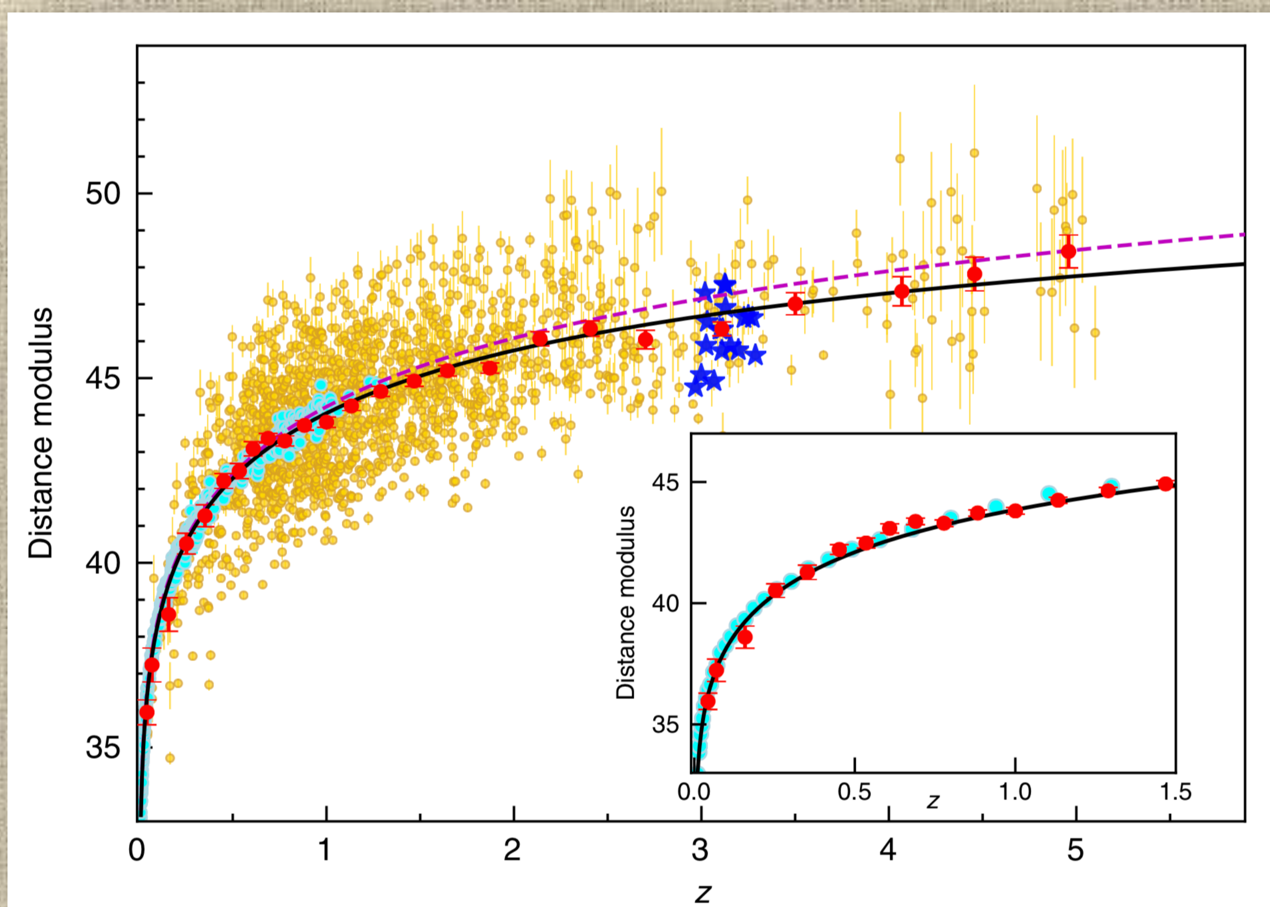
[a = scale factor of the Universe = $(1+z)^{-1}$]

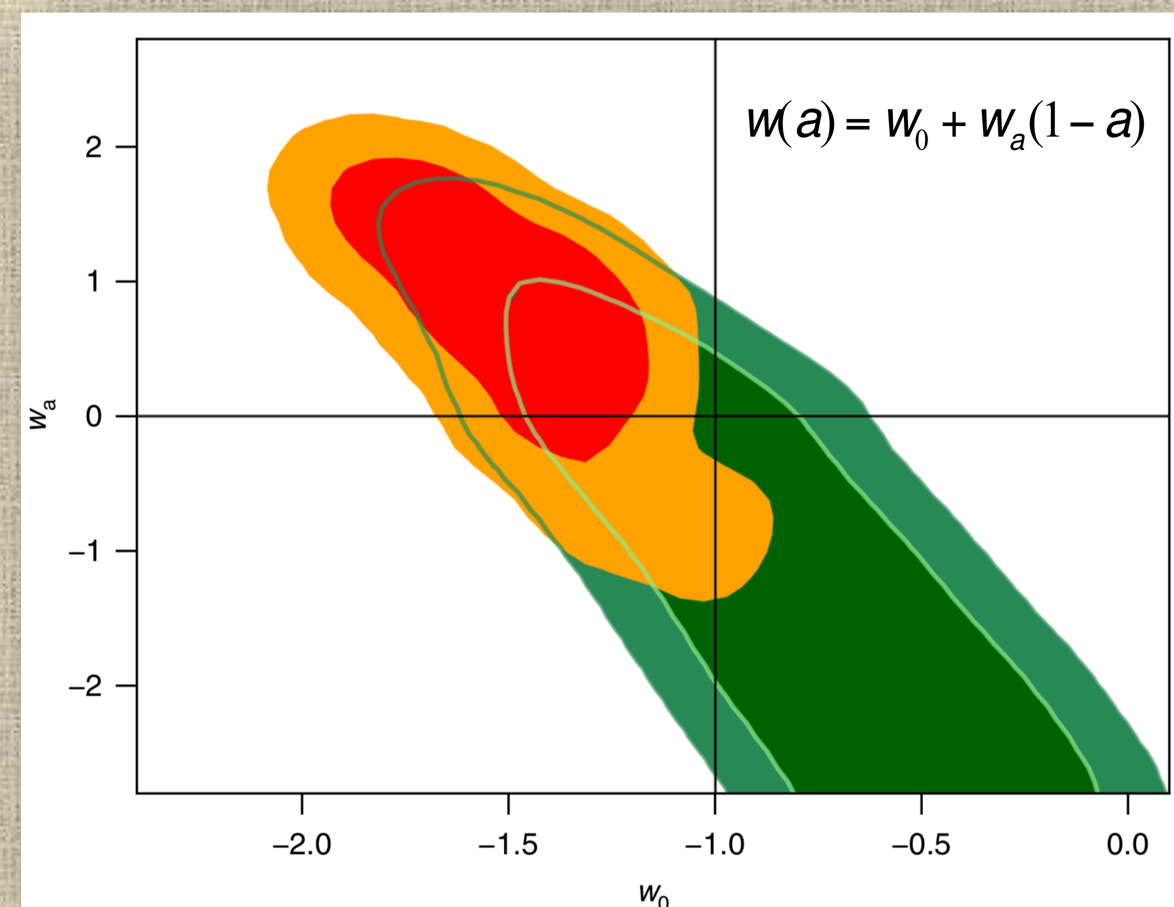


(BOSS Collaboration 2016, arXiv:1607.03155)

Hints for a varying *w(a)* from high-z quasars?

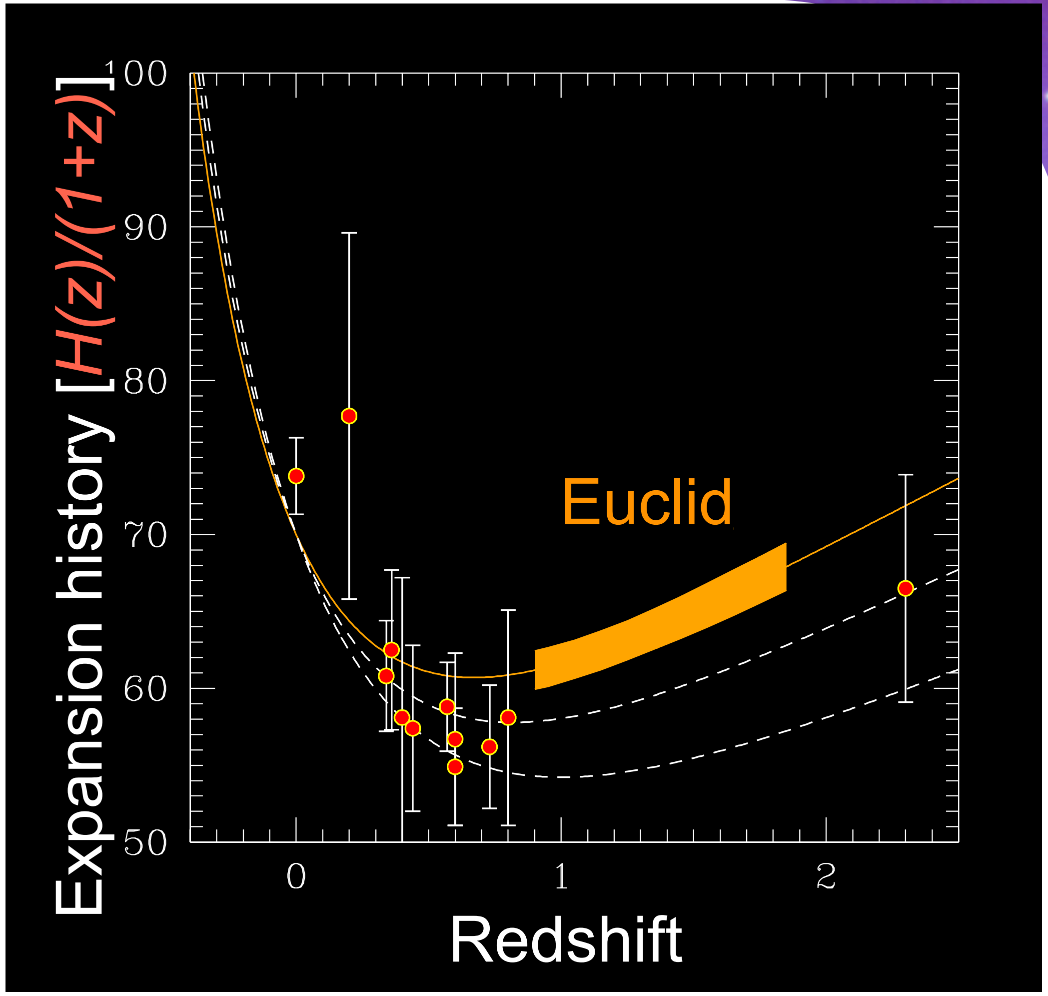
Risaliti & Lusso, 2019, Nature Astronomy

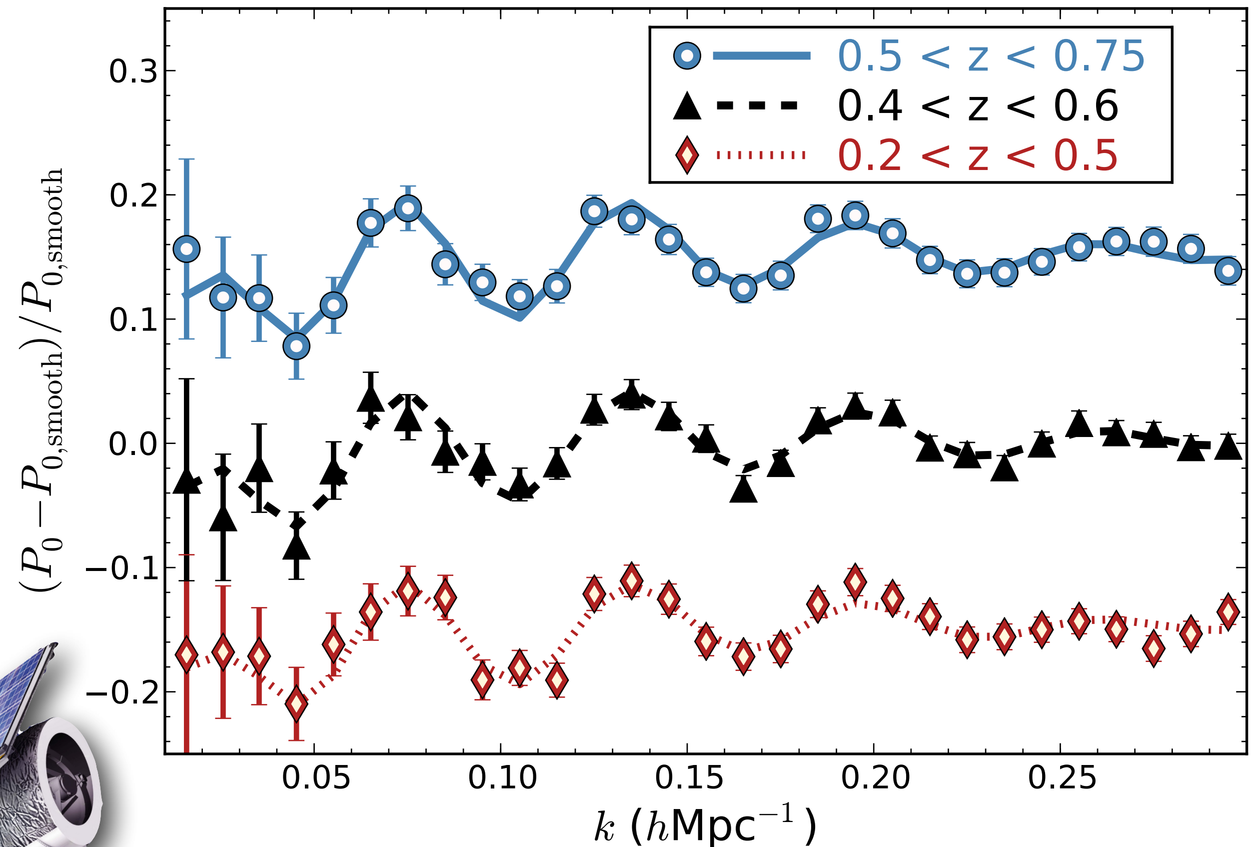




Euclid galaxy clustering probe

- ★ Baryon acoustic oscillations (BAO) as a standard ruler
- ★ Sensitive to the expansion history H(z) and angular diameter distance relation $d_A(z)$
- ★ **Test "beyond Λ" scenario, i.e. an evolving equation of state**





Alam+16
SDSSIII BOSS

Euclid w(a) forecasts: SPV2

H. Aussel and SPV2 team, October 2018 report (see C. Carbone)

$$\mathrm{FoM} = (\det C)^{-1/2}$$

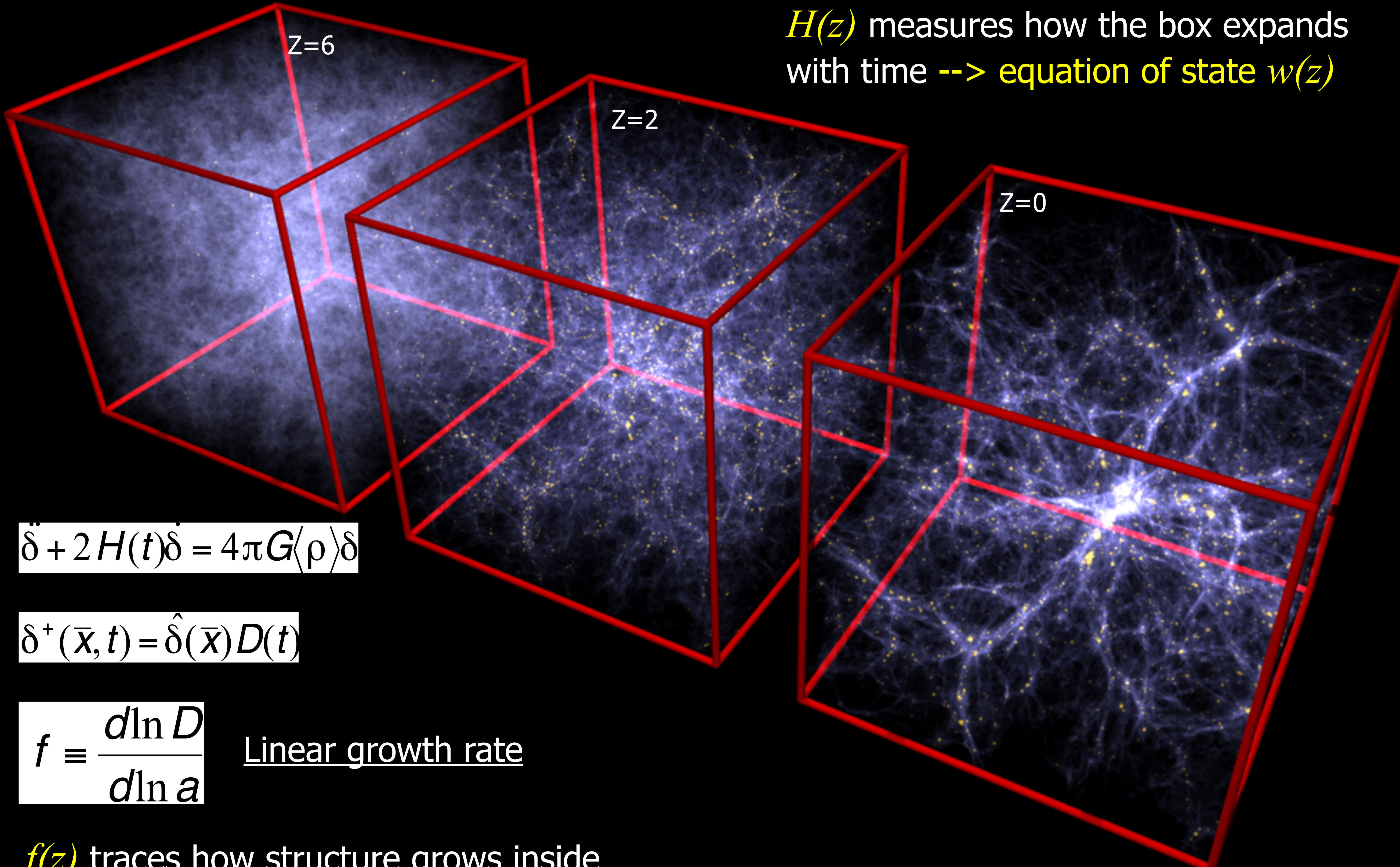
	FoM Model3 θ=3000	FoM Model3 θ=5000	FoM Model1 θ=3000	FoM Model1 θ=5000
v 2.0 DR3 best	227	347	n/a	n/a
v 2.1 DR1	31	54	34	57
v 2.1 DR3 secure	202	360	241	408
v 2.1 DR3 best	223	400	263	449

$$w(a) = w_0 + (1-a)w_a$$

$$C = \begin{pmatrix} \sigma^2_{w_0 w_0} & \sigma^2_{w_0 w_a} \\ \sigma^2_{w_0 w_a} & \sigma^2_{w_a w_a} \end{pmatrix}$$

Not only H(z)…

H(z) measures how the box expands with time --> equation of state *w(z)*



$$\ddot{\delta} + 2H(t)\dot{\delta} = 4\pi G\langle\rho\rangle\delta$$

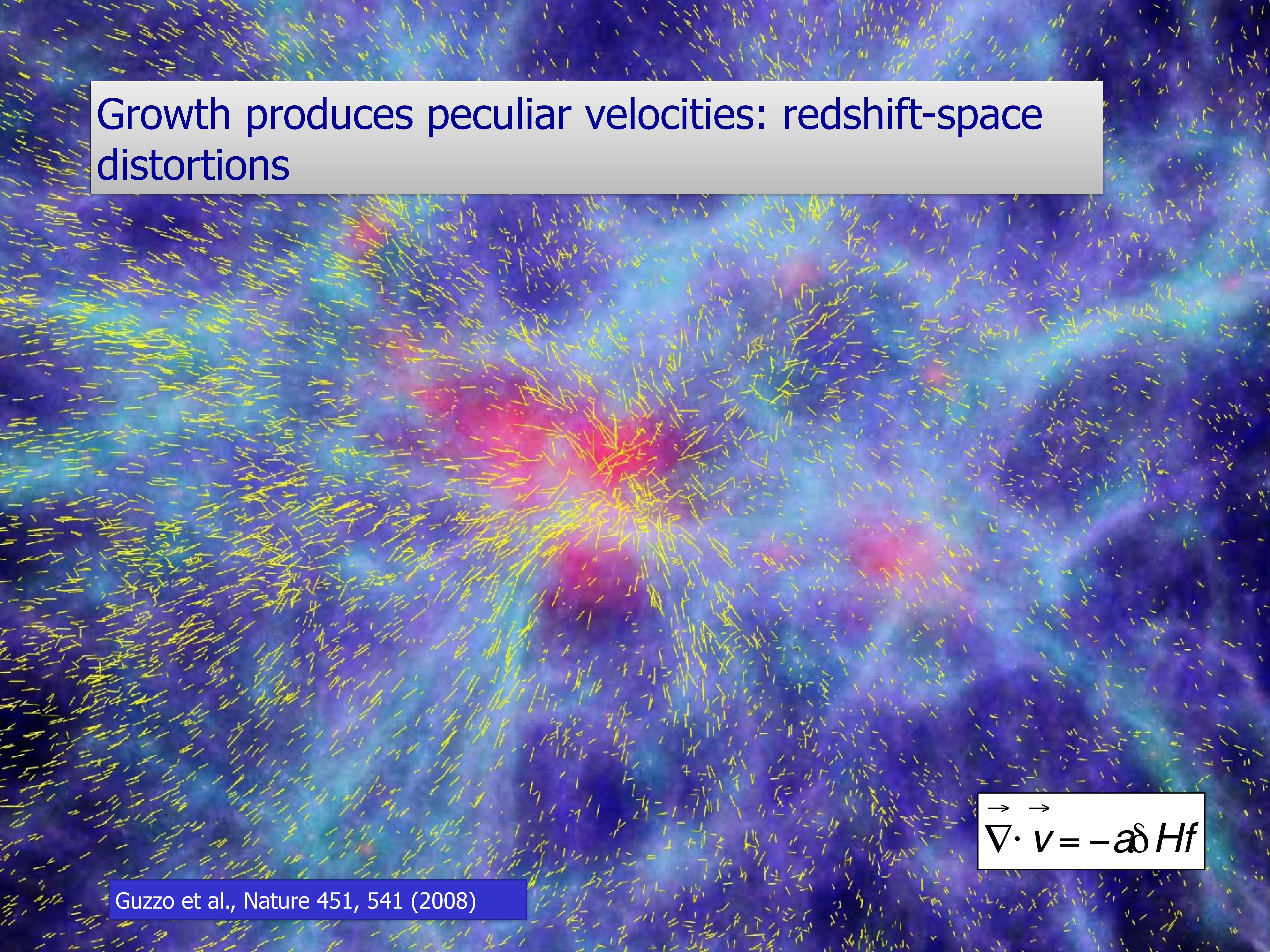
$$\delta^{+}(\bar{x},t) = \hat{\delta}(\bar{x})D(t)$$

$$f \equiv \frac{d\ln D}{d\ln a}$$ Linear growth rate

f(z) traces how structure grows inside the box --> gravitation theory

Springel et al.

Growth produces peculiar velocities: redshift-space distortions



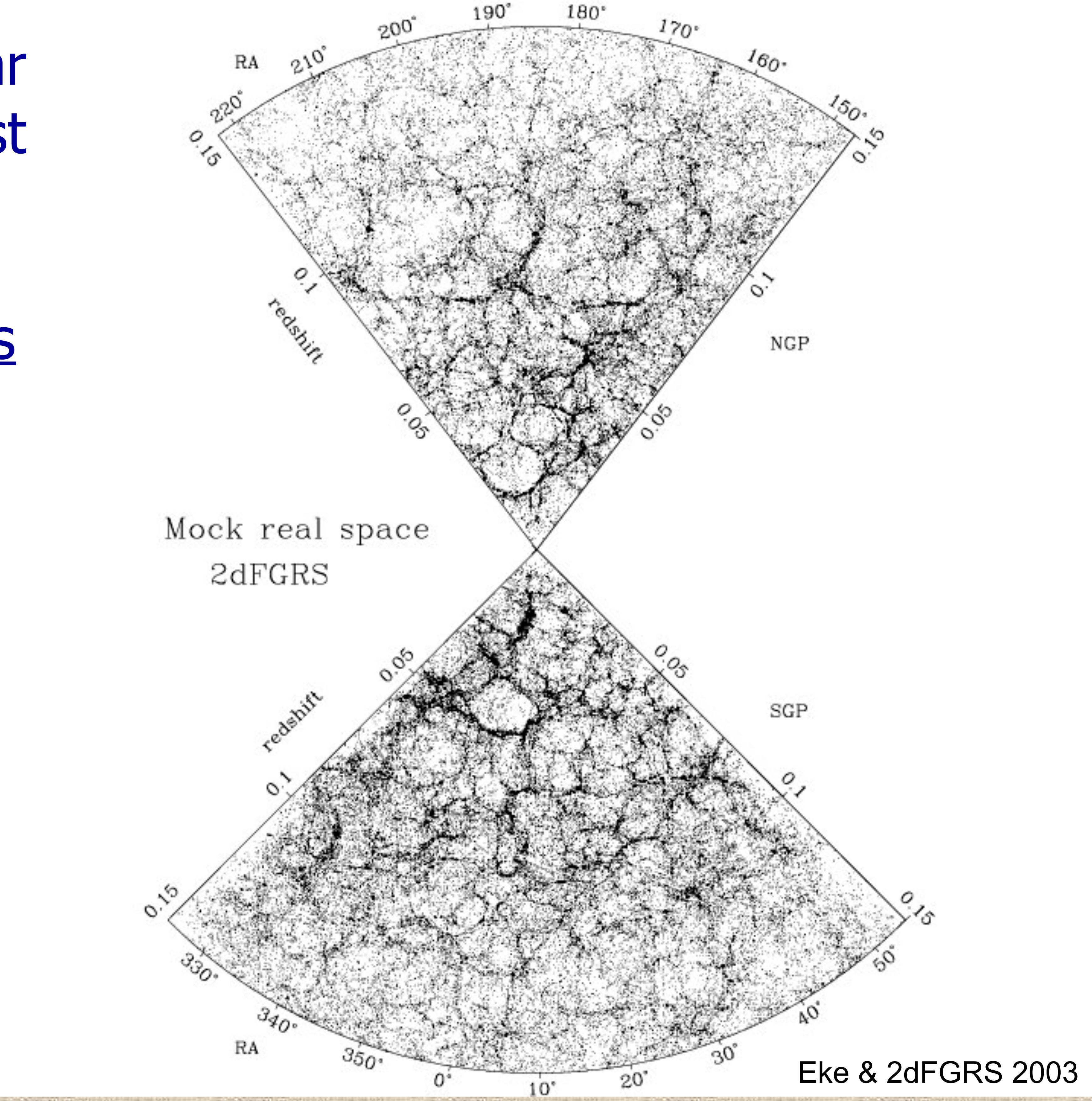
$$\vec{\nabla}\cdot\vec{v} = -a\delta H f$$

Guzzo et al., Nature 451, 541 (2008)

Growth produces peculiar velocities, which manifest themselves in galaxy redshift surveys as redshift-space distortions

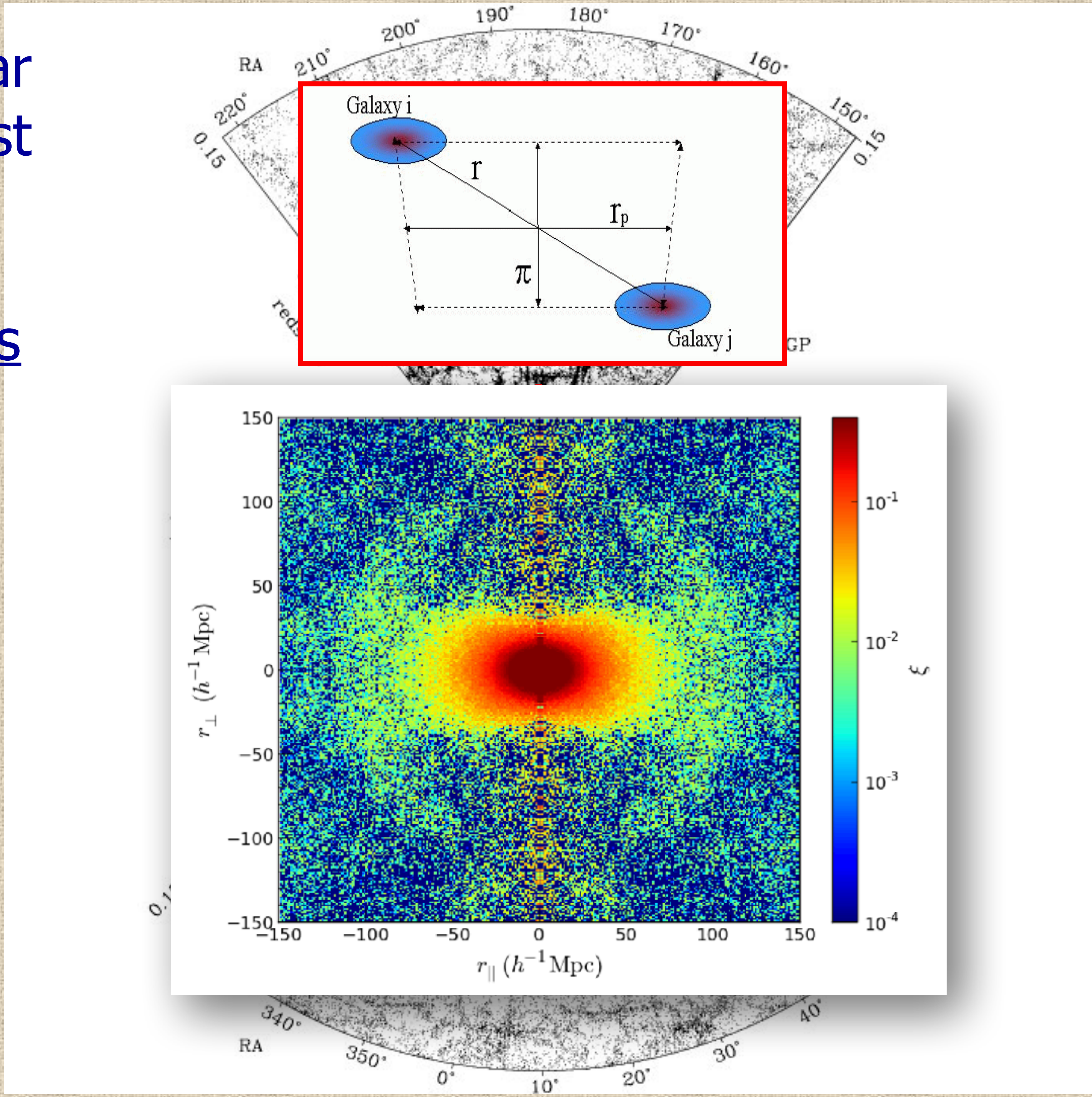
real space

(Kaiser 1987)



Eke & 2dFGRS 2003

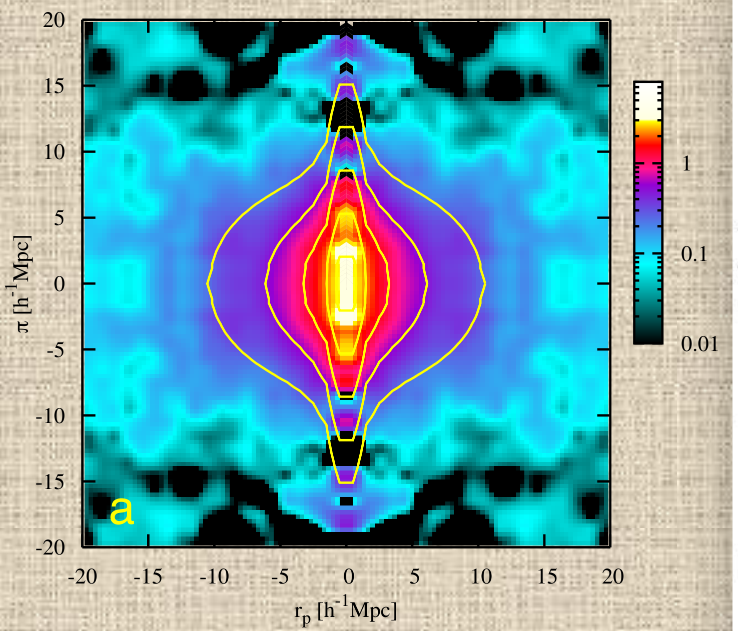
Growth produces peculiar velocities, which manifest themselves in galaxy redshift surveys as redshift-space distortions



redshift space

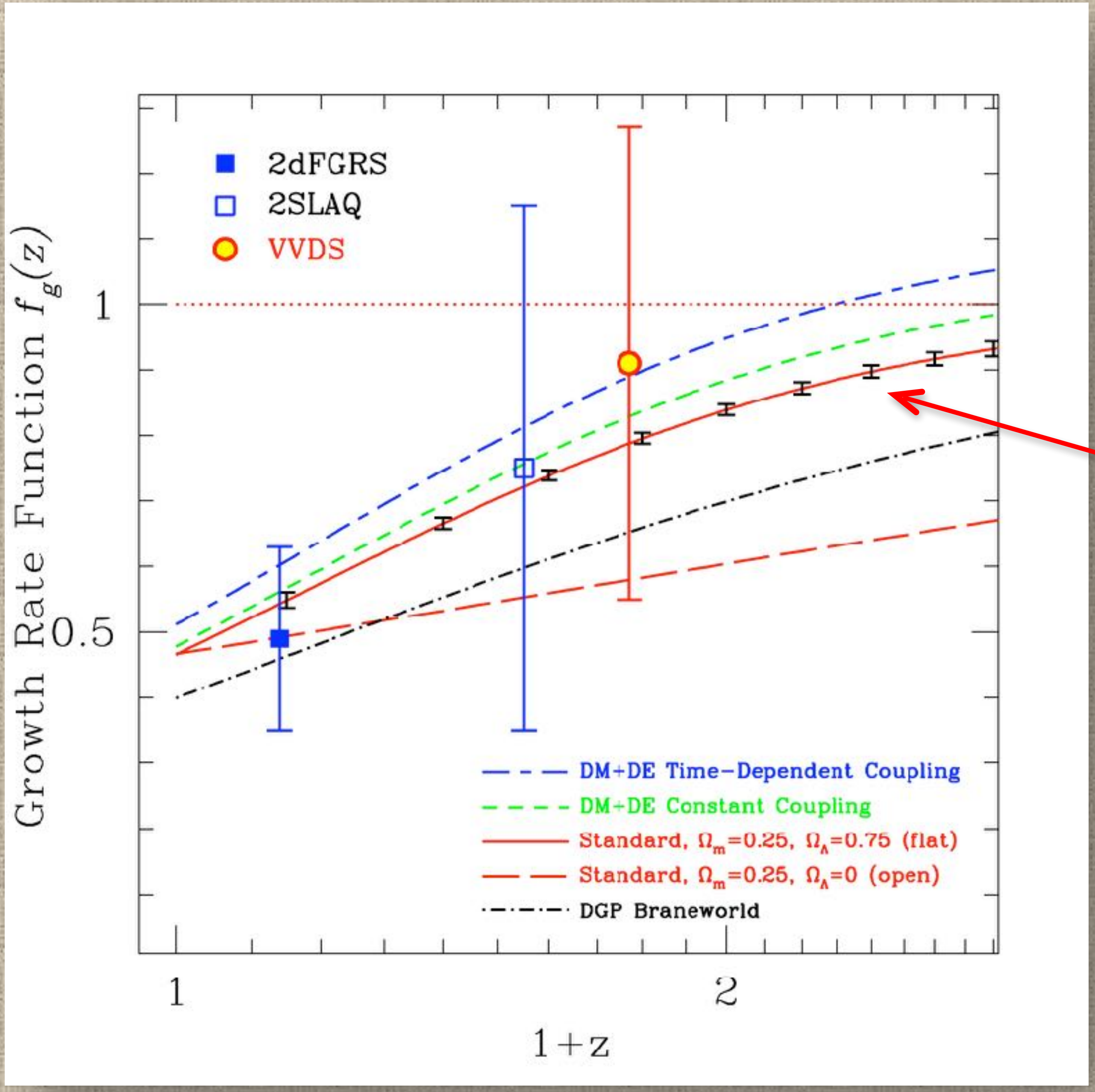
(Kaiser 1987)

Peculiar velocities distort our redshift-space maps: a dark energy test (2008)



VIMOS-VLT Deep Survey proof of concept at z=0.77:

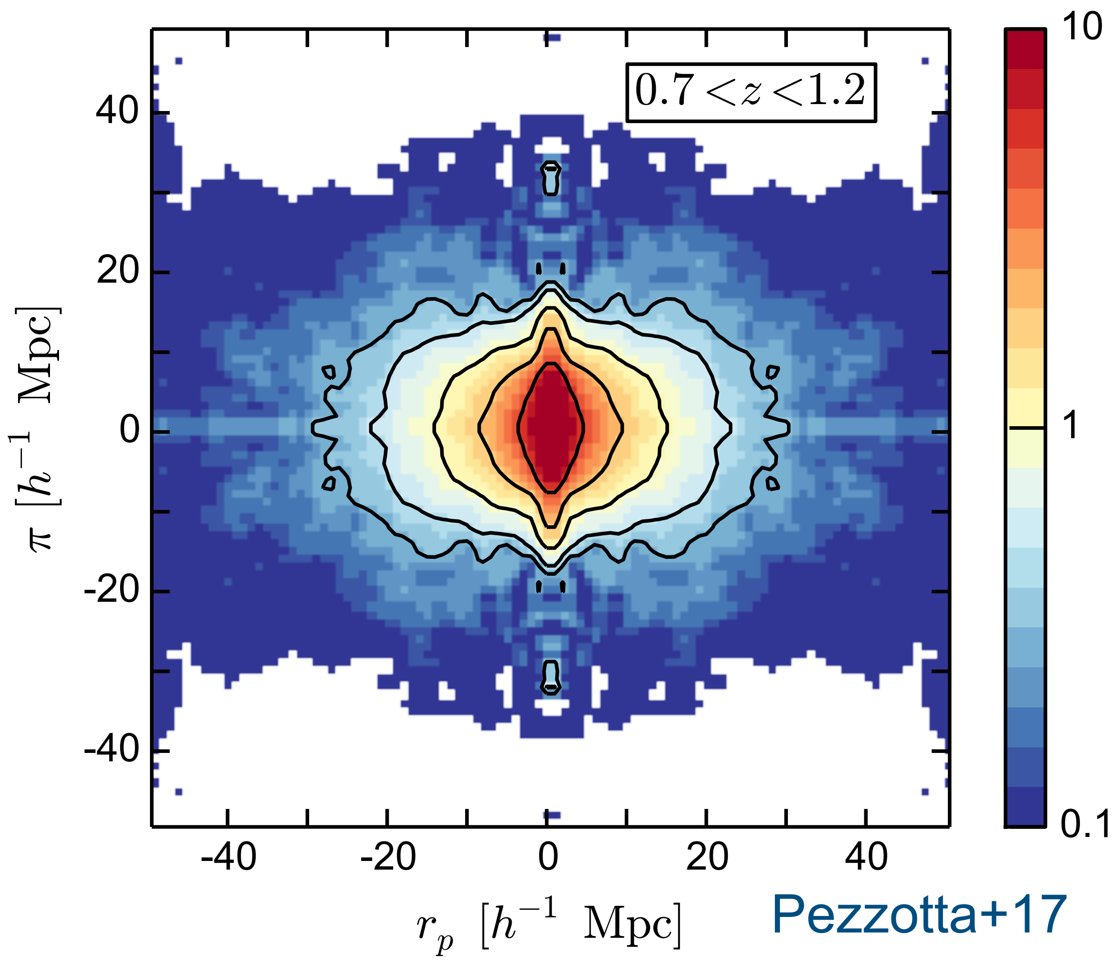
***f*=0.91±0.36**

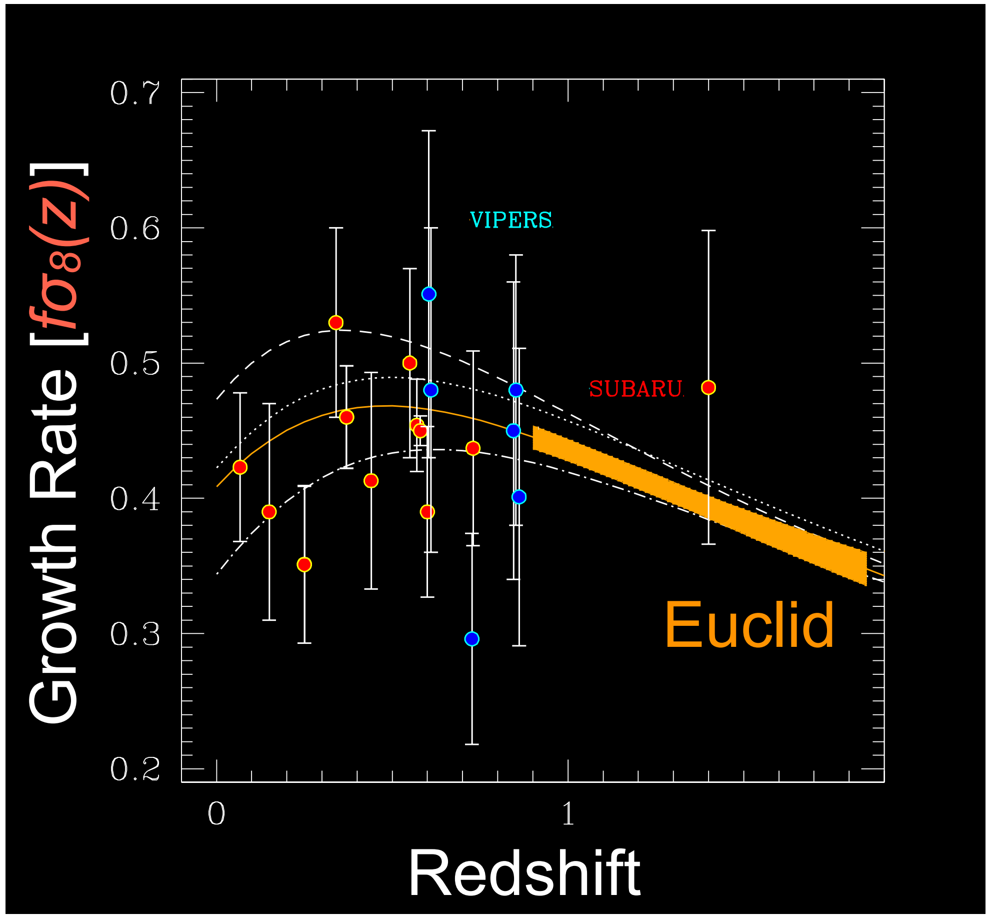


First forecasts for a Euclid -like mission → ESA 2007 Cosmic Vision proposal

Guzzo et al., Nature 451, 541 (2008)

Galaxy clustering probe





★ Redshift-space distortions (RSD) probe the growth rate of structure

★ **Test "beyond Einstein" scenario, as alternative to Λ**

★ Note: RSD not really considered as a primary "dark energy probe" before 2008 (see DETF 2006 report): key feature in original SPACE (Euclid-spectro) proposal

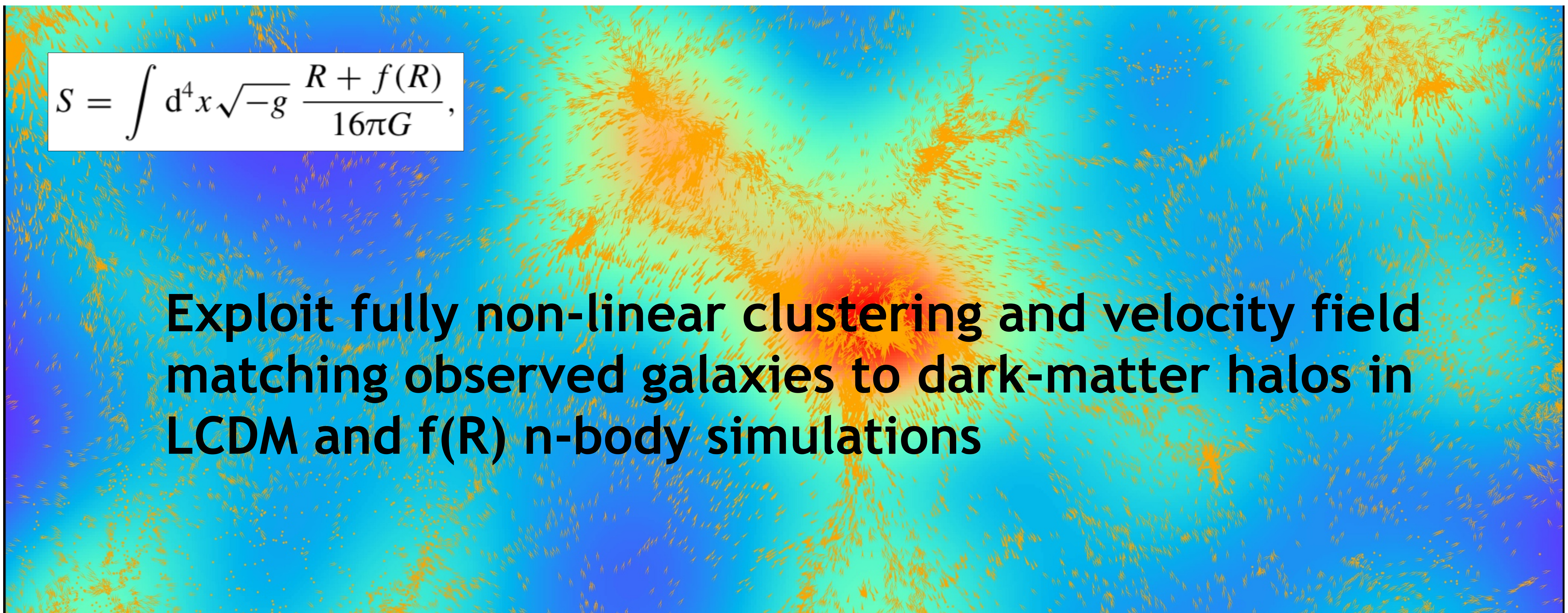
nature astronomy

LETTERS

https://doi.org/10.1038/s41550-018-0573-2

No evidence for modifications of gravity from galaxy motions on cosmological scales

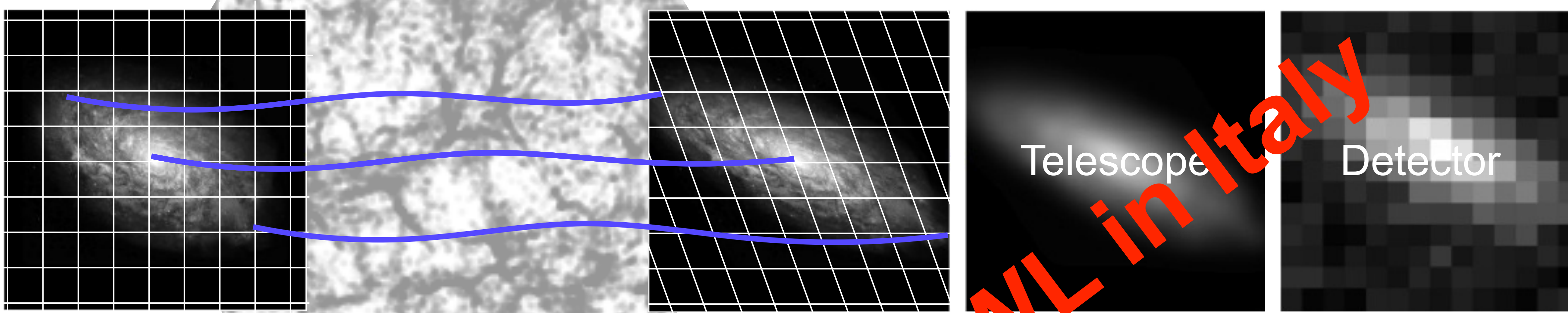
Jian-hua He[1*], Luigi Guzzo[2,3,4], Baojiu Li[1] and Carlton M. Baugh[1]

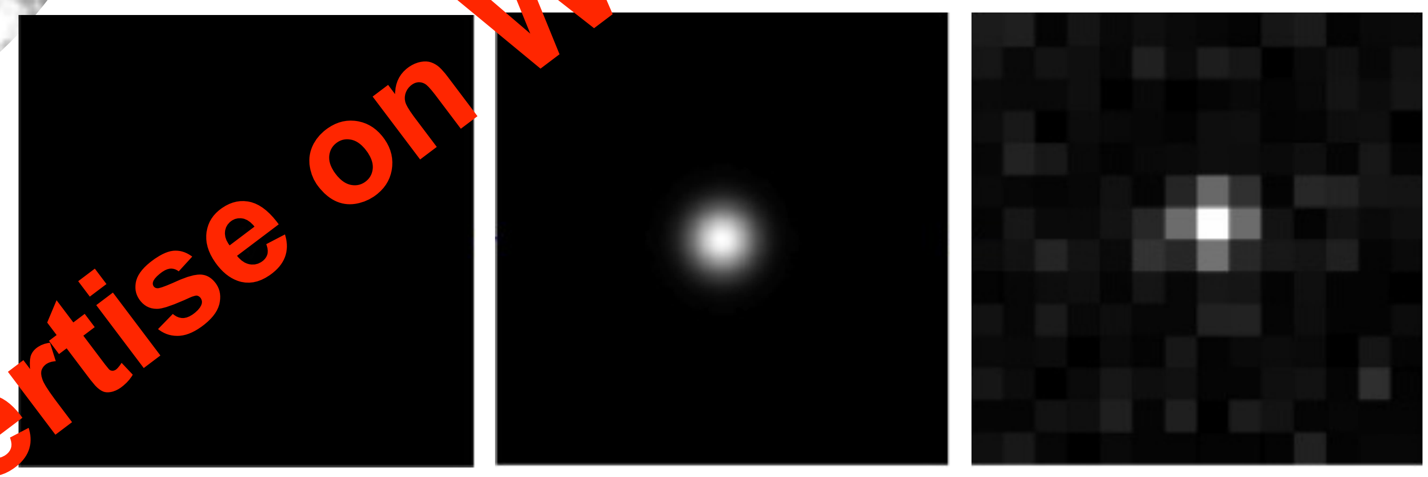


$$S = \int d^4x \sqrt{-g}\, \frac{R + f(R)}{16\pi G},$$

Exploit fully non-linear clustering and velocity field matching observed galaxies to dark-matter halos in LCDM and f(R) n-body simulations

Euclid weak lensing probe

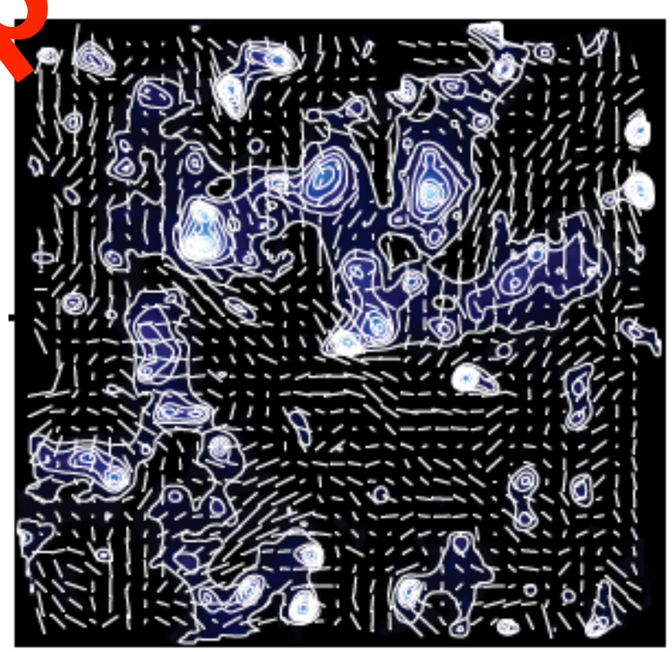




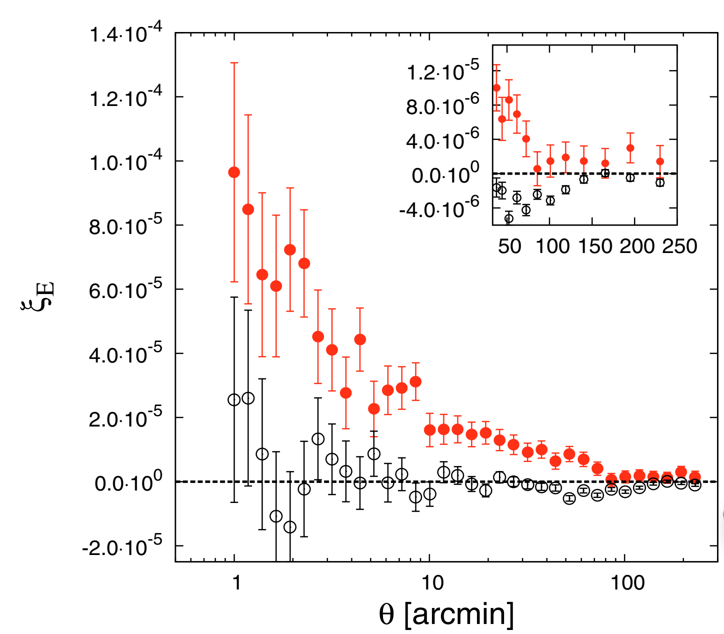
Light propagation through large-scale structure results in a lensed image

- ★ Correlate shapes of millions of galaxies to measure the cosmological signal at 10^{-3} in ellipticity
- ★ **Test combined growth and expansion history**

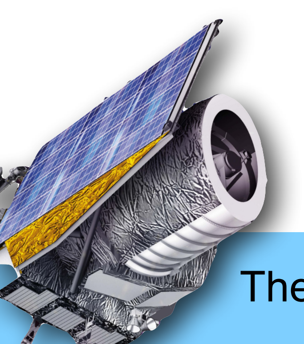
Grow expertise on WL in Italy

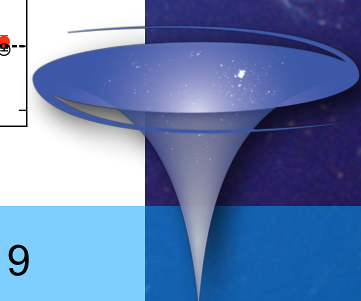


Massey+



Fu+2008

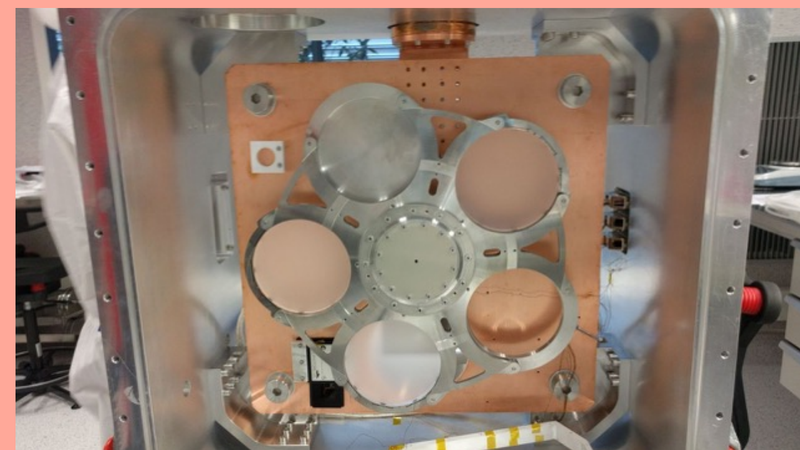




Euclid telescope and instrumentation

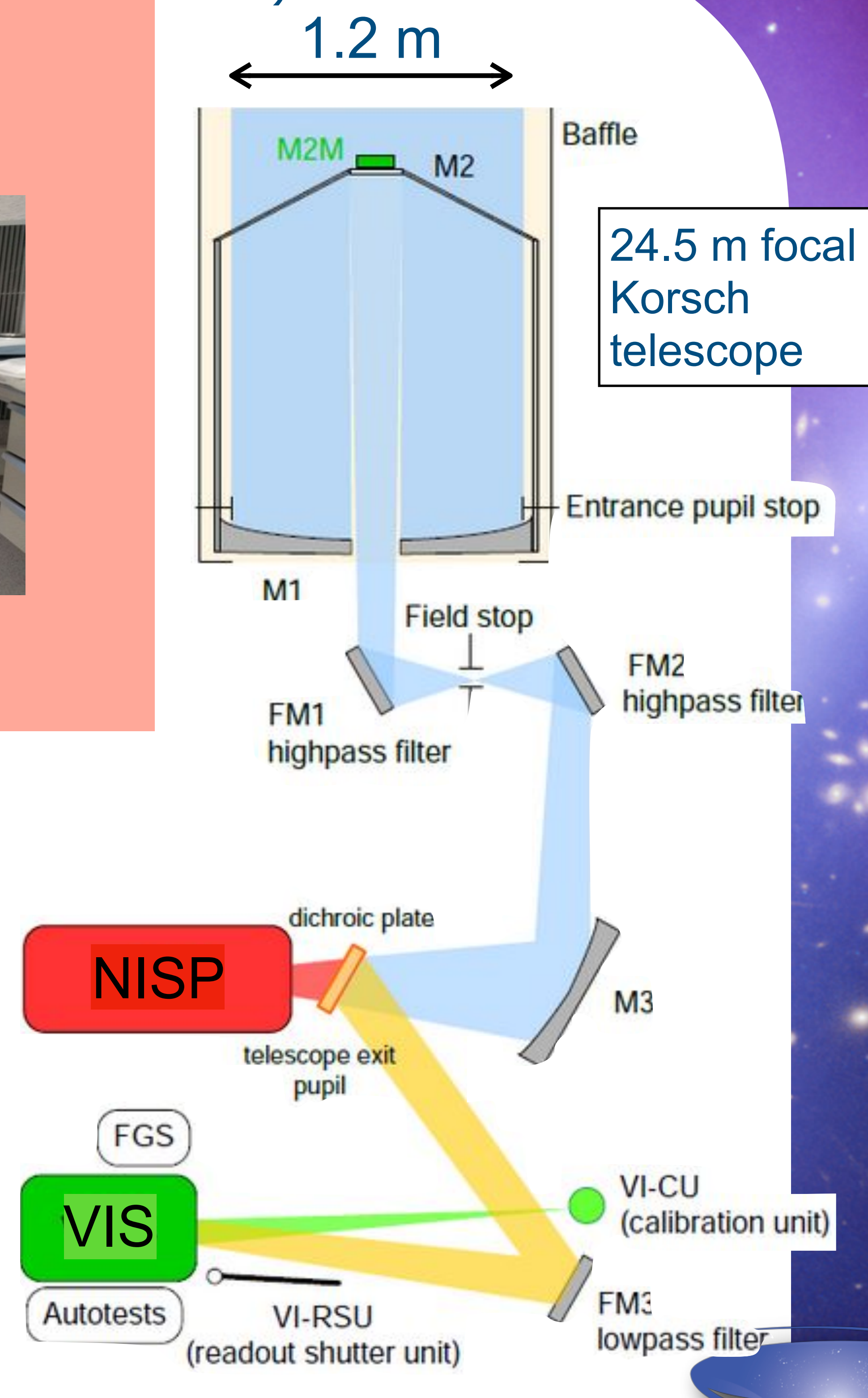
Near Infrared channel (NISP)

(T. Maciaszek, A. Ealet & NISP Team)



Visible channel (VIS)

VIS thermal/structural model

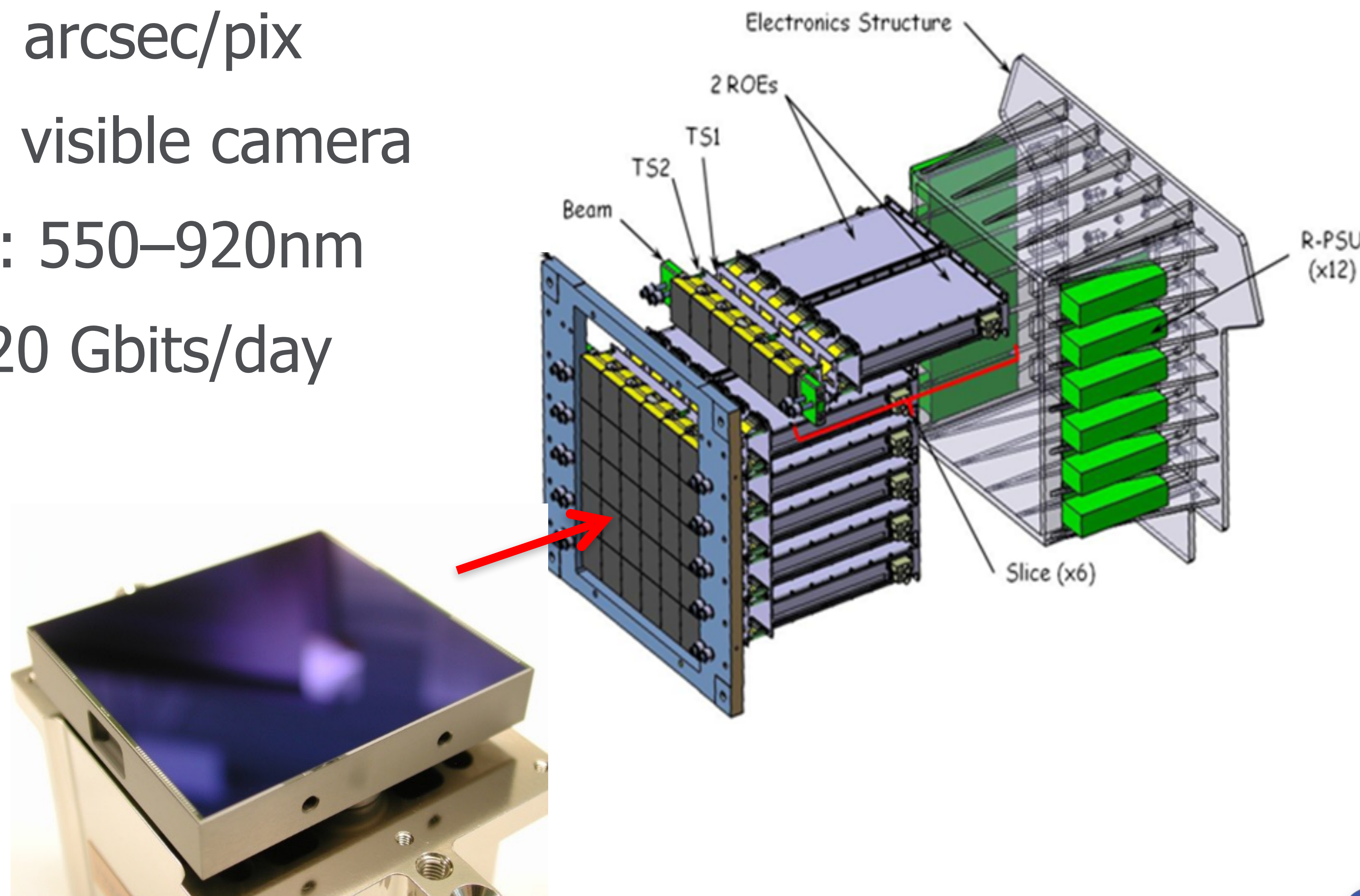


Overview of the PLM sub-systems – Courtesy Airbus Defence and Space

VIS

(M. Cropper & VIS Team)

- **FoV**: 0.787 x 0.709 = 0.557 deg^2
- **Active area**: 877 cm^2
- **Detectors**: 6 x 6 e2v CCDs
- **Plate scale**: 0.1 arcsec/pix
- **609 megapixel** visible camera
- **Spectral range**: 550–920nm
- **Data-rate**: ≤ 520 Gbits/day



NISP

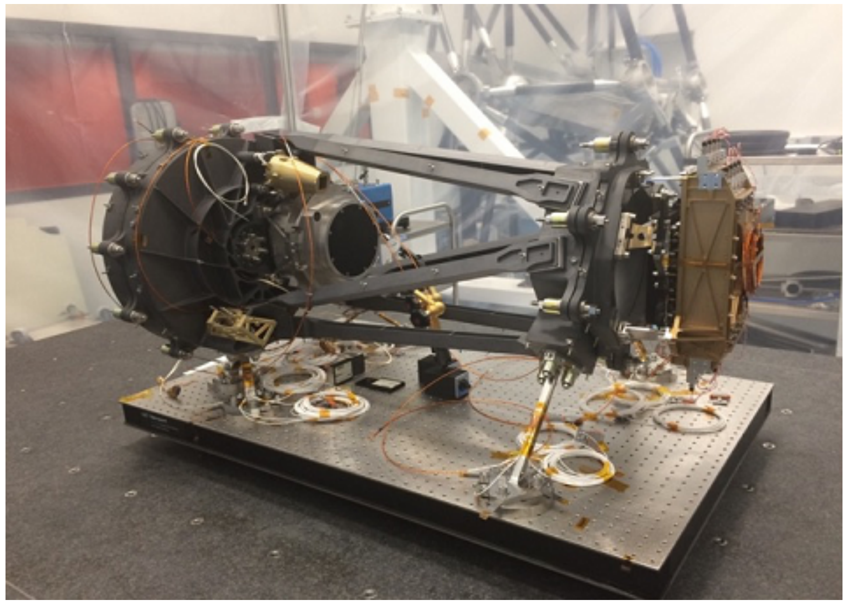
(T. Maciaszek, A. Ealet & NISP Team)

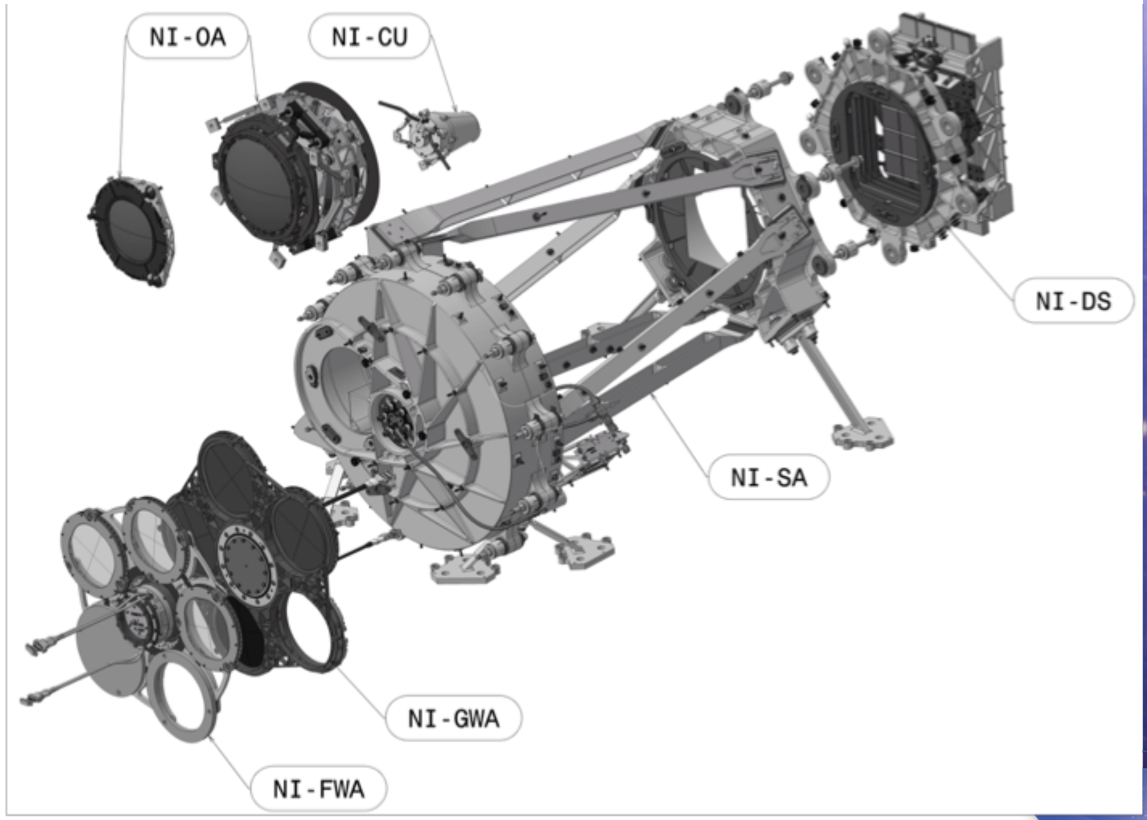
- **FoV**: 0.55 deg^2
- **Mass**: 158 Kg
- **Telemetry**: < 290Gb/day
- **Size**: 1m x 0.5m x 0.5m
- **IR detectors**: 16x 2Kx2K H2RG (Teledyne)
- **Plate scale**: 0.3 arcsec/pix
- **3 Filters:**

Y (950-1192nm)
J (1192-1544nm)
H (1544-2000nm)

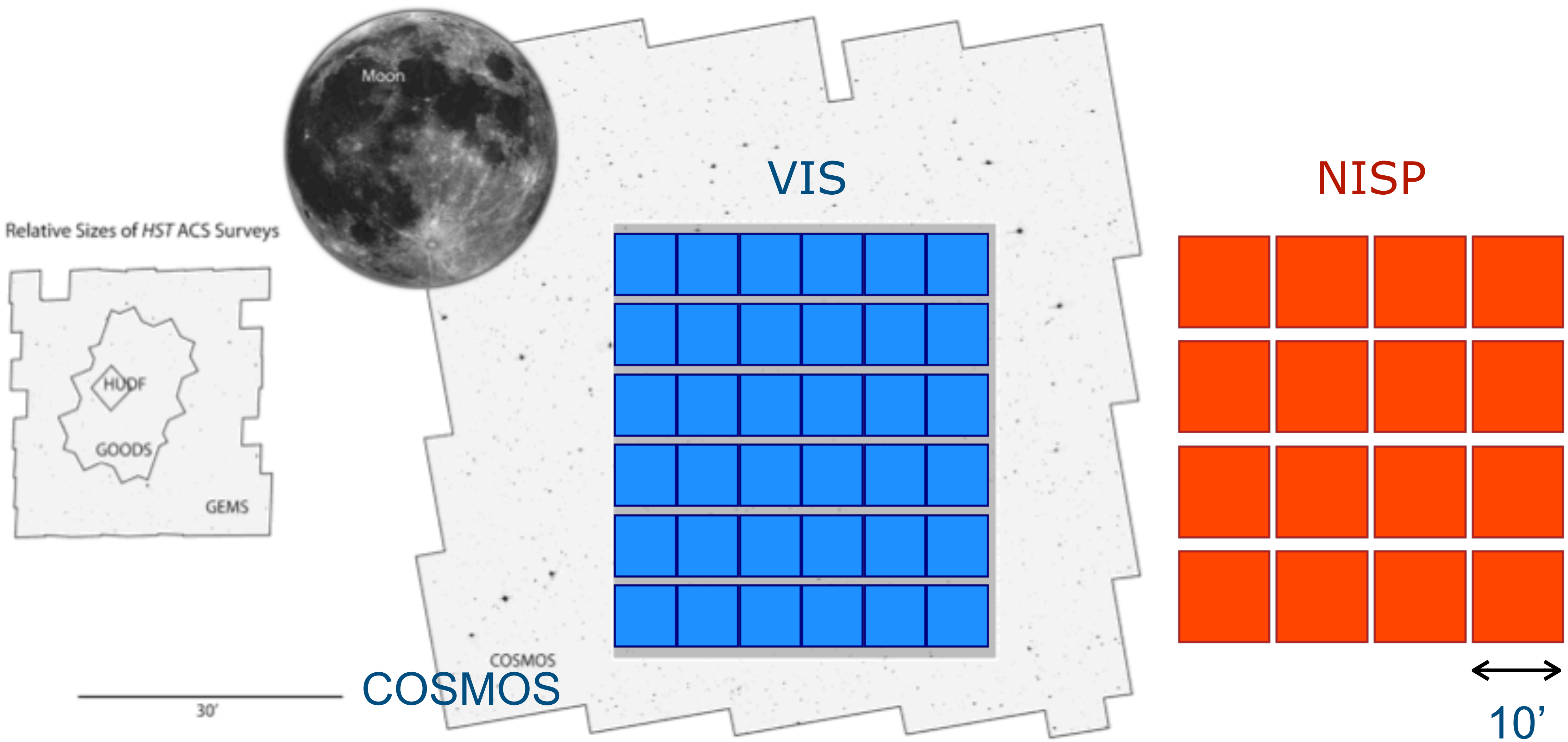
- **4 Grisms**:

1B (920-1300), 1 orient. 0^0
3R (1250-1850), 3 orient. 0^0,90^0,180^0





Dual wide-field imagers



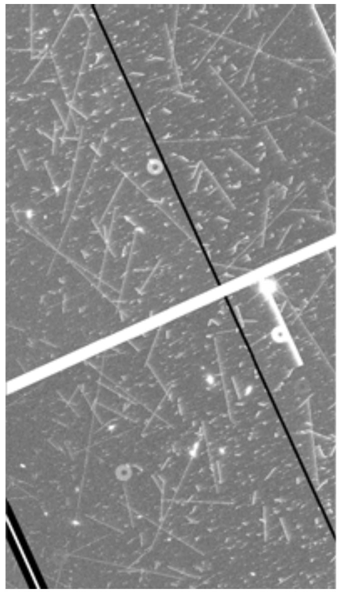
Credit: Space Telescope Science Institute/Nick Scoville (Caltech)

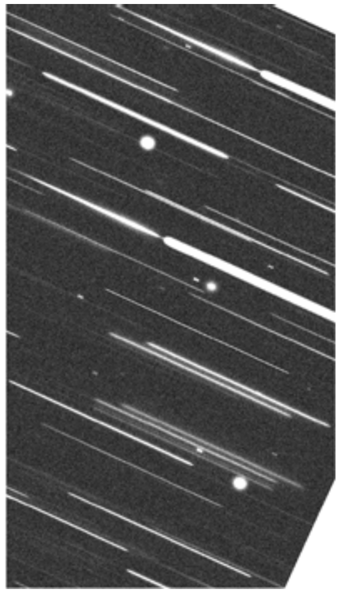
	VIS	NISP
Pixel size	0.1″	0.3″
Dispersion	-	R~380, 13.4 A/pixel

A panchromatic view

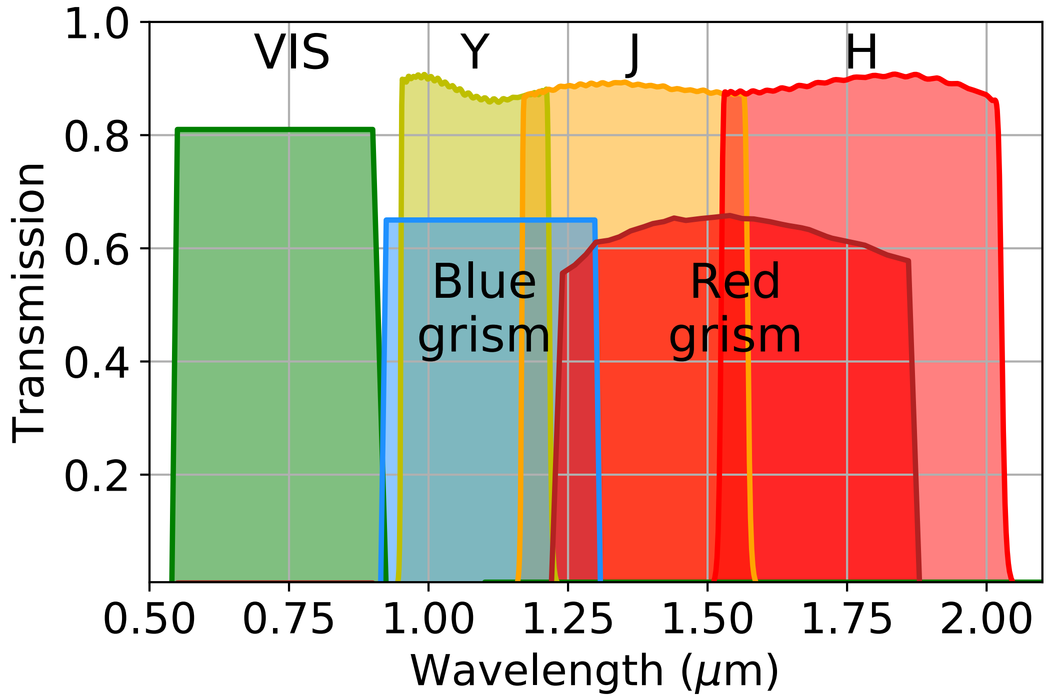
4 x

VIS (565 s)	NISP (120 x 3 s)	NISP grism (565 s)





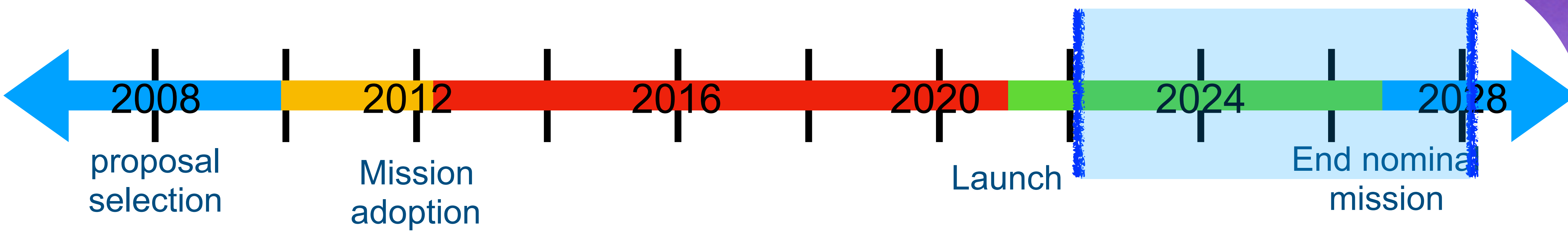
*NISP sim does not include cosmic rays



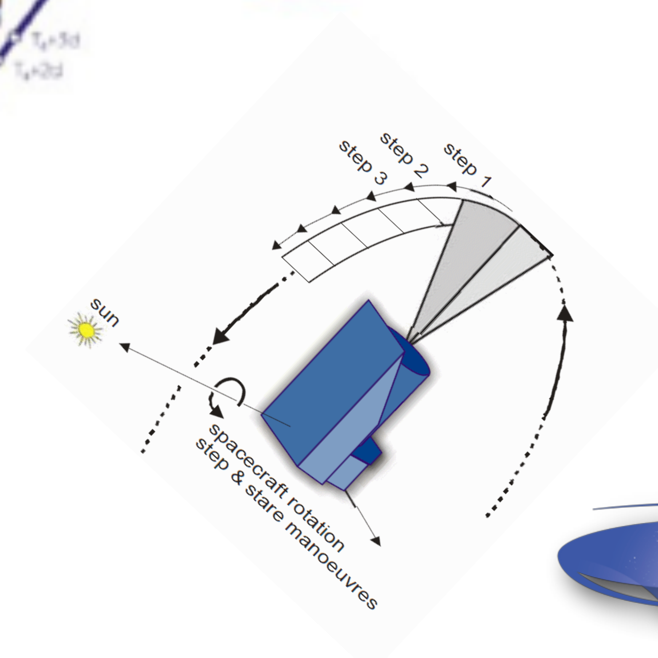
*Blue grism is exposed on Deep fields only

	VIS	Y	J	H	Grism
Wide	24.5	24	24	24	2 10^{-16} erg/s/cm^2
Deep	26.5	26	26	26	2 10^{-17} erg/s/cm^2

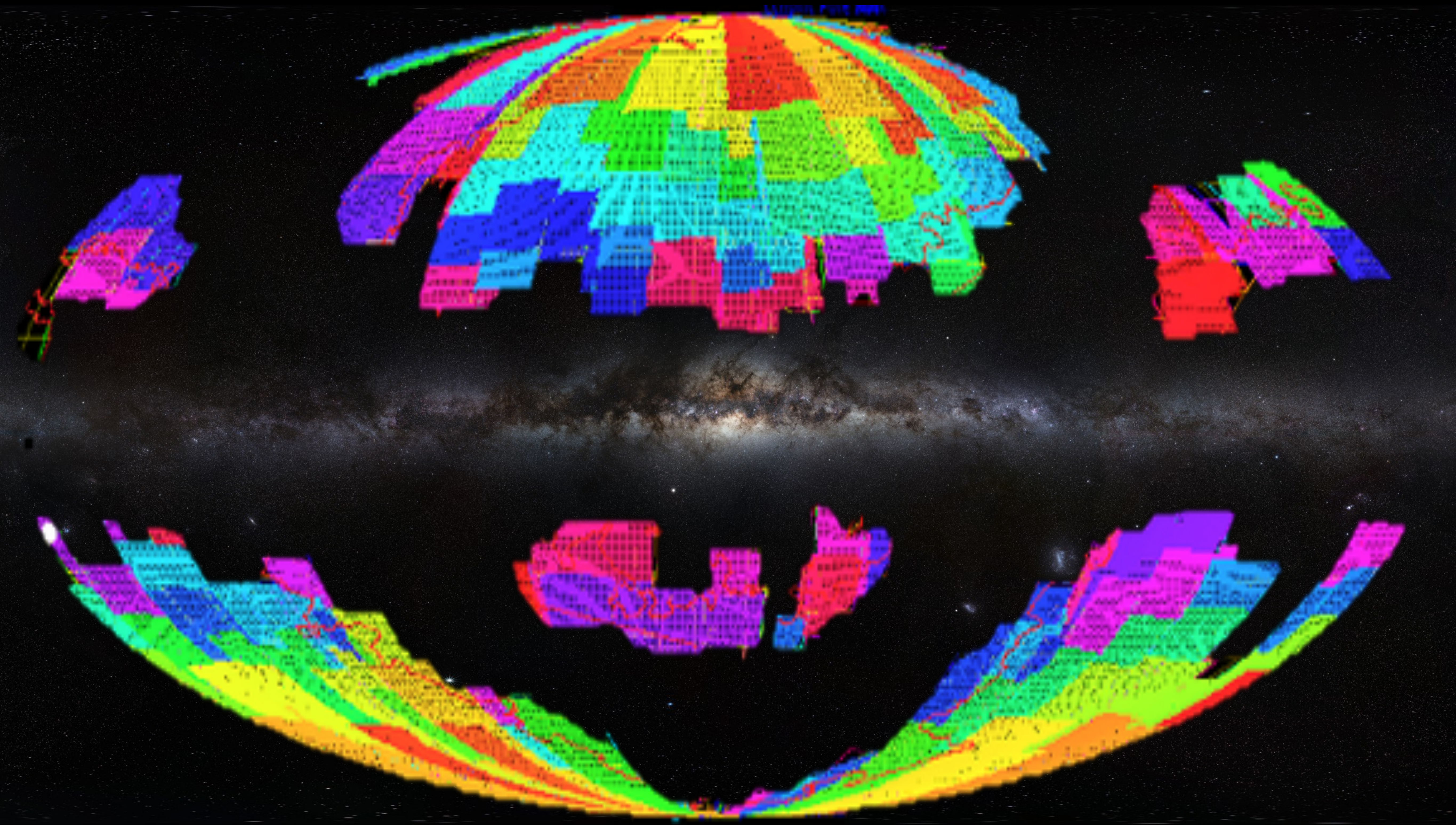
The Euclid mission



- Soyuz 2.1B + Fregat from Kourou and direct SEL2 transfer orbit
- Step-and-stare scanning of the sky
- Sun-spacecraft-Earth angle of 35º
- Telescope LOS normal to the Sun: 87º < SAA< 110º, -5º<α<+5º

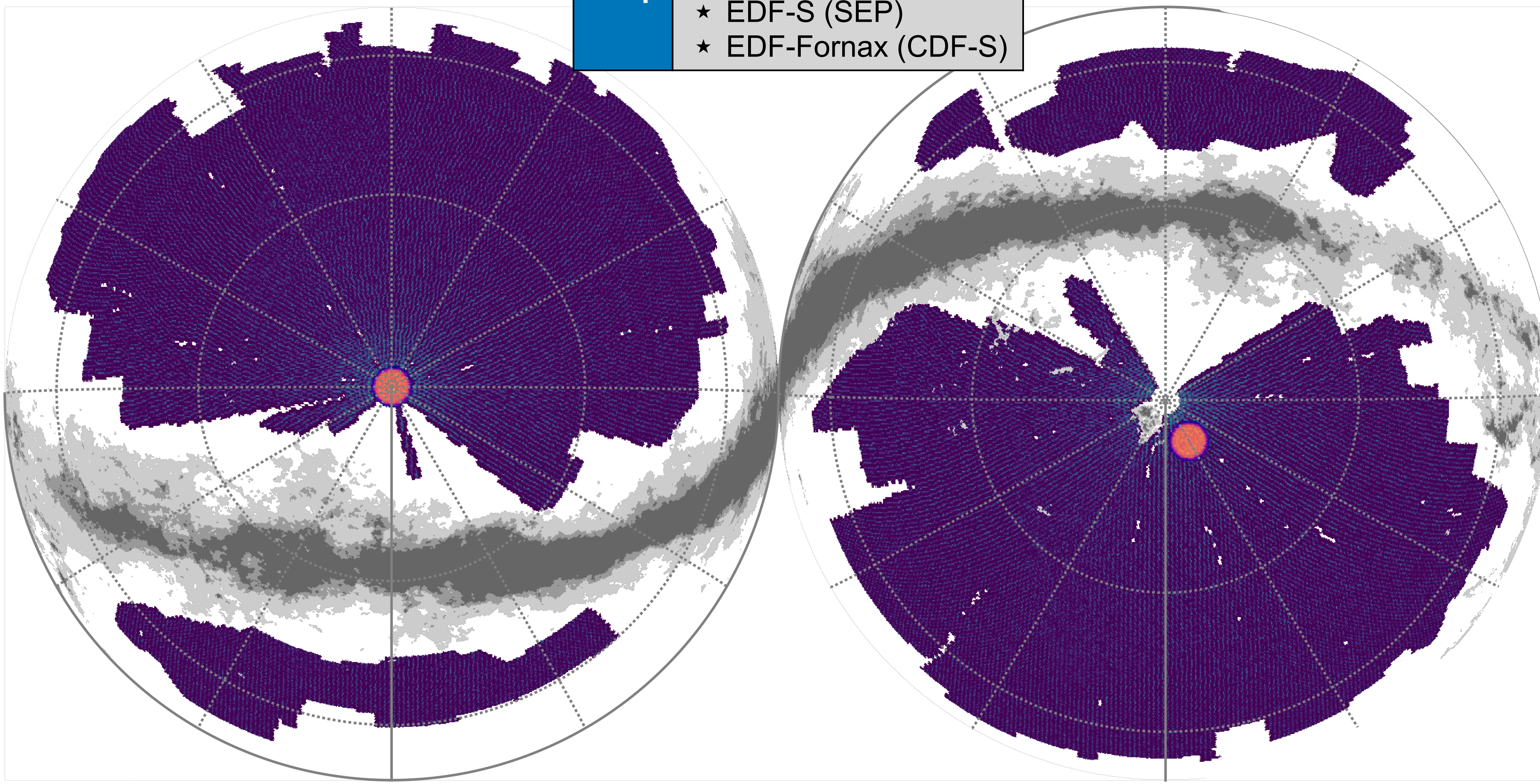


Euclid Wide Survey



Euclid reference surveys

Wide	15000 sqr deg
Deep	40 sqr deg
	⋆ EDF-N (NEP) ⋆ EDF-S (SEP) ⋆ EDF-Fornax (CDF-S)



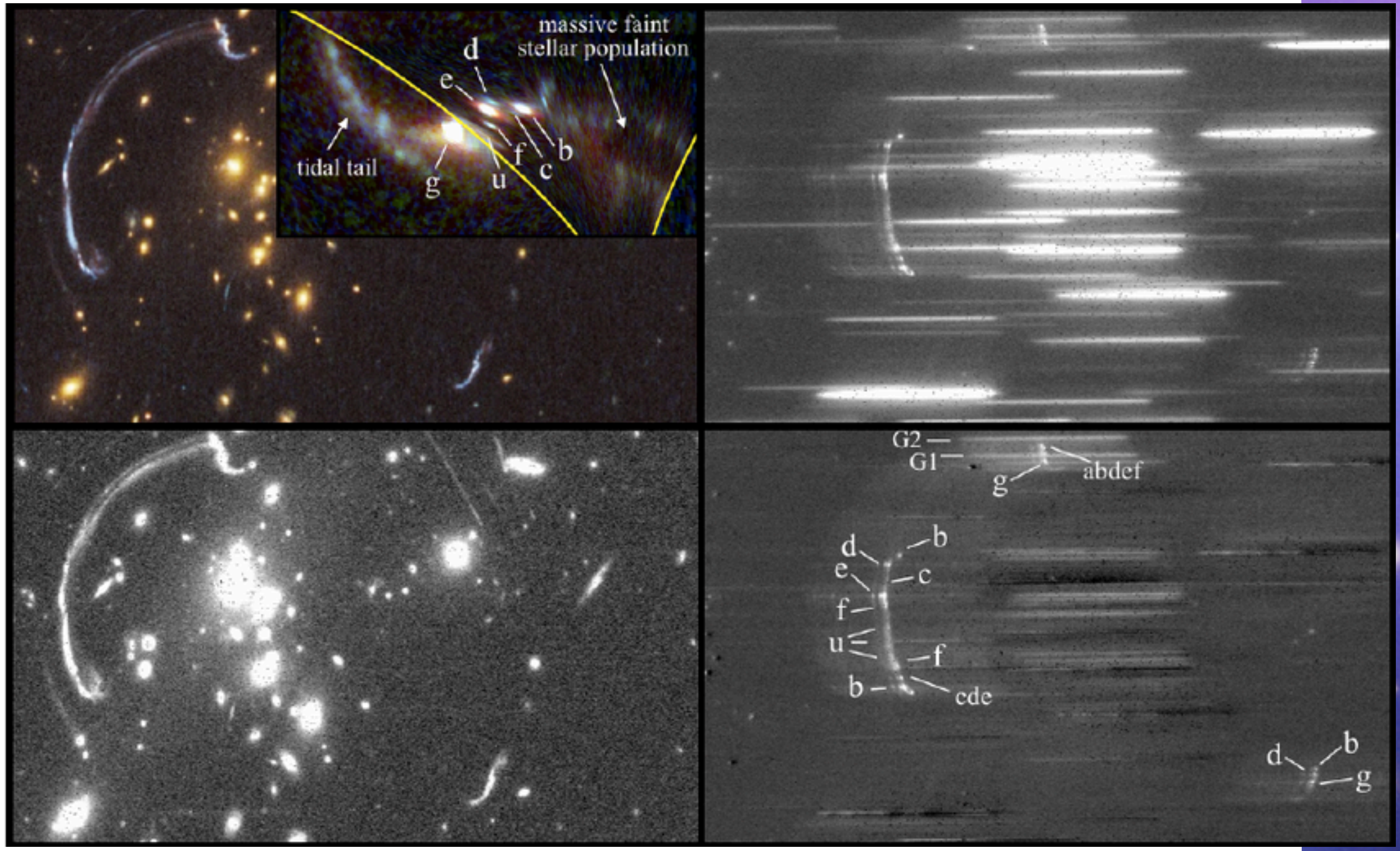
North ecliptic pole

South ecliptic pole

Mission Survey Scientist: R. Scaramella

Slitless Spectroscopy

- ★ Euclid original spectroscopic concept (SPACE) used DMD's (yes, what ATLAS is now re-proposing)
- ★ ESA argued technology not mature yet and forced slitless approach (but complicating data analysis…)
- ★ all photons pass the grism (no slits or fibers)
  - No targeting required
  - Efficiency loss due to higher background
  - Emission line galaxies are main targets
- ★ Euclid will be first large-scale application of this technique

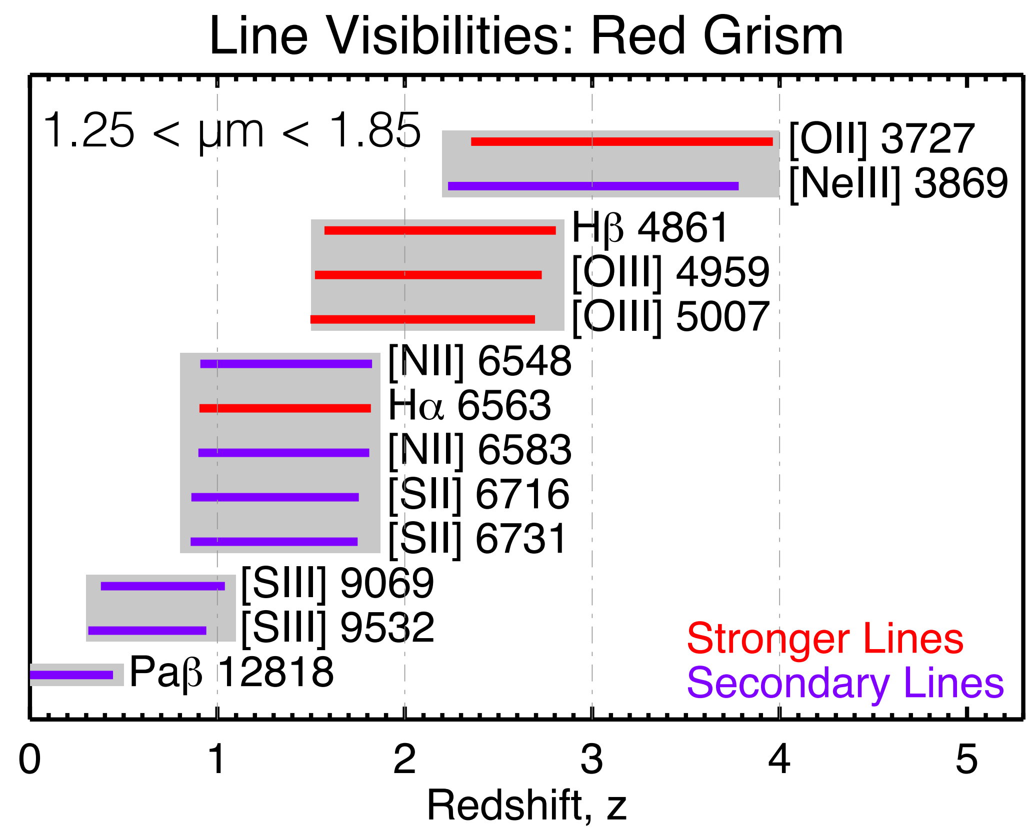


HST WFC3 grism exposure (Whitaker+14)

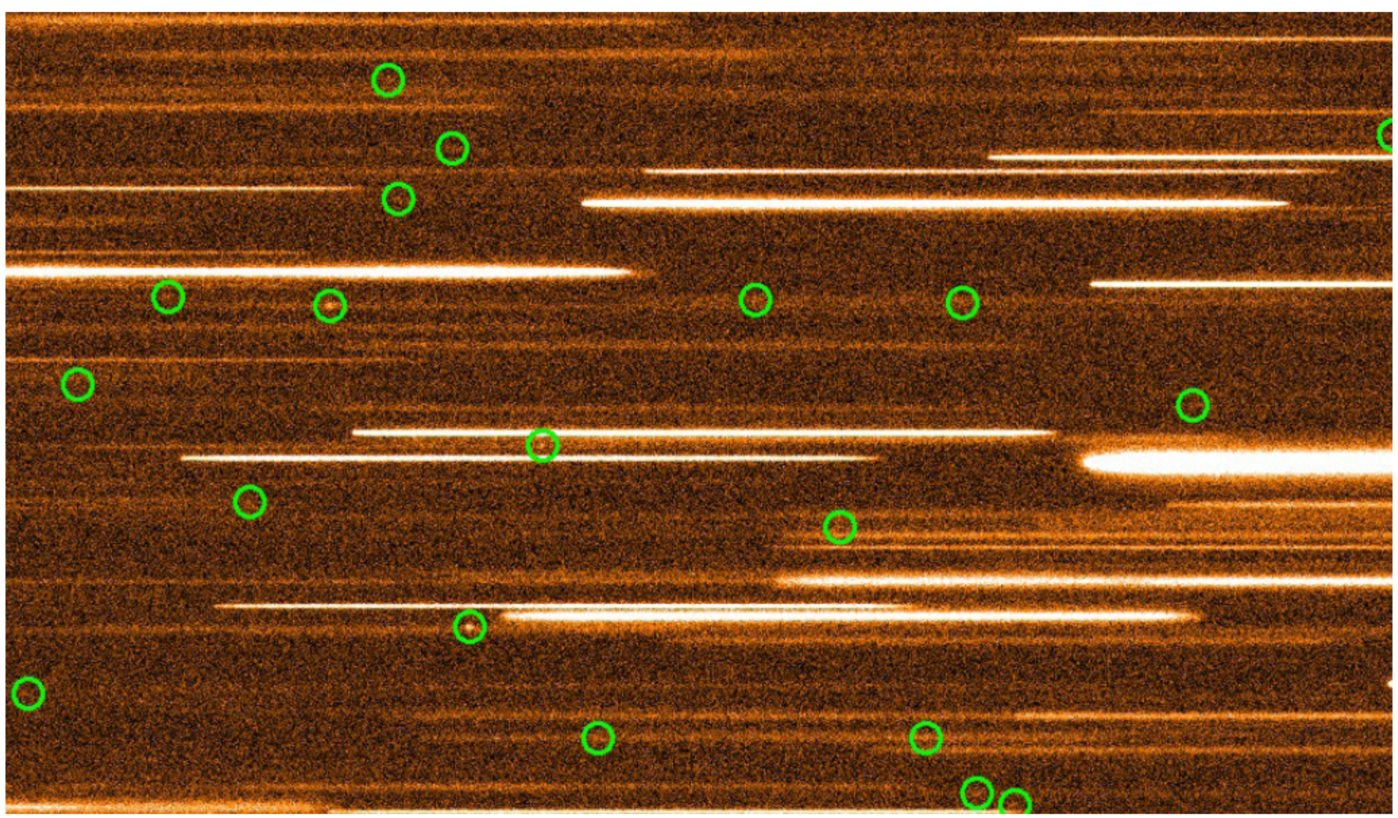
The redshift challenge

★ Pushing the detection limit:

- Line misidentification
- Spectra confusion
- Detector persistance
- Foregrounds



G. Addison



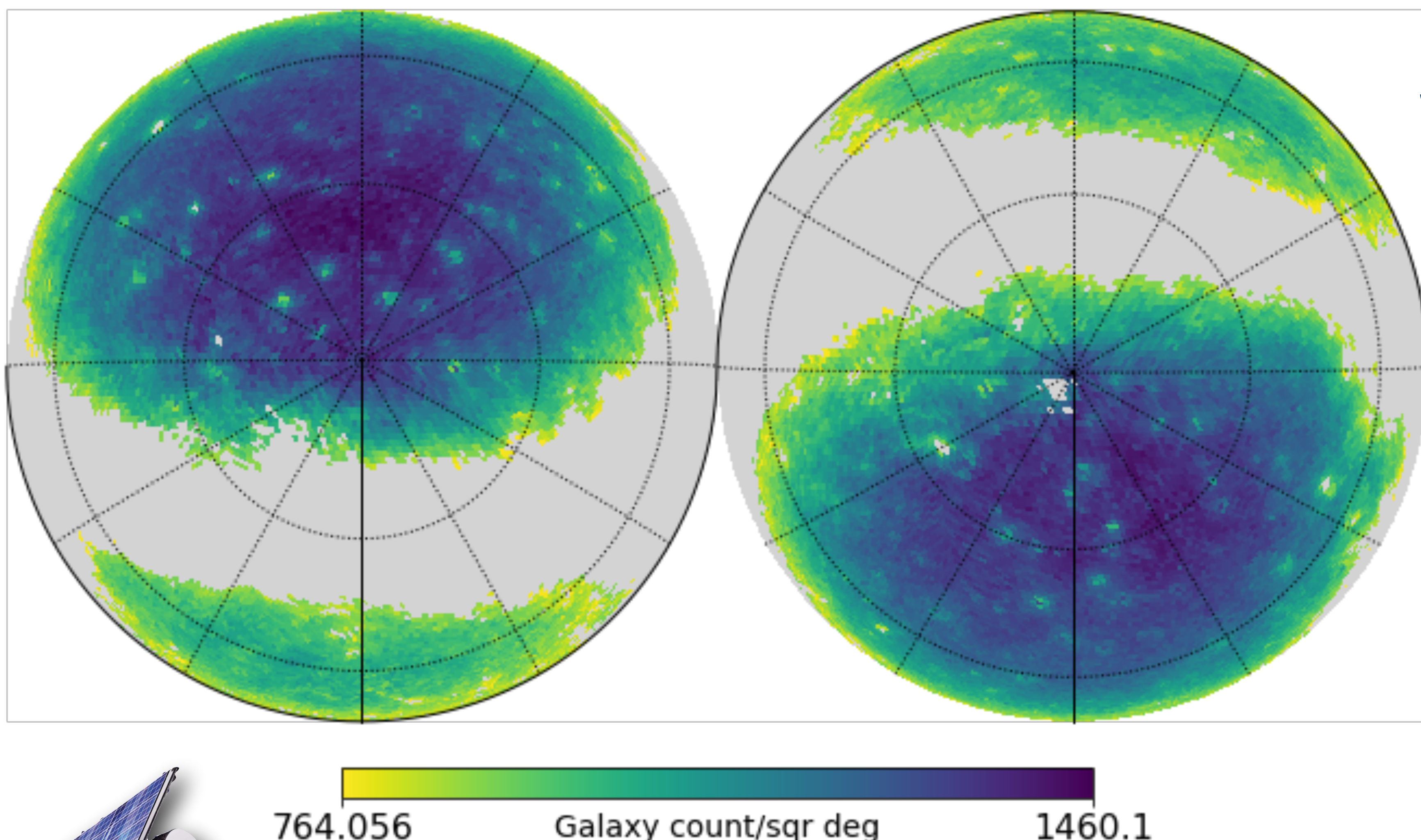
Bianca Garilli et al.

Foregrounds

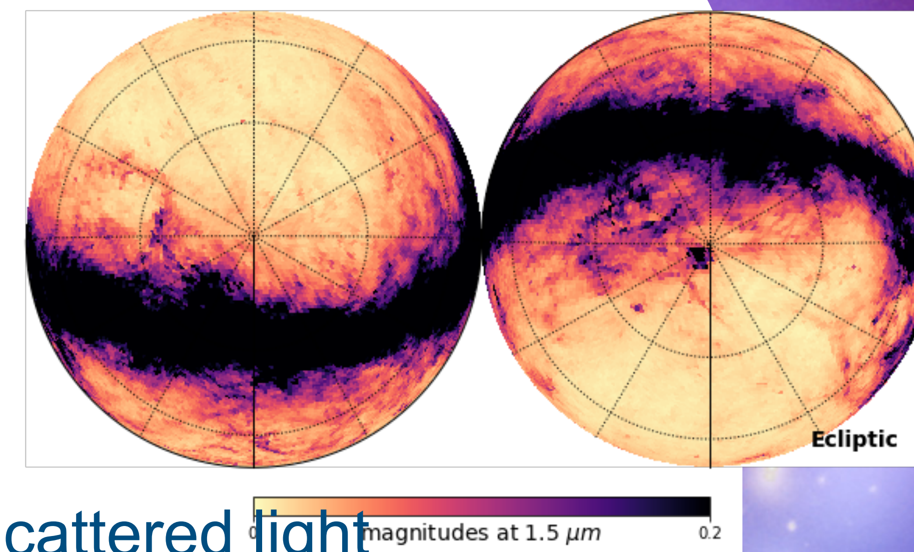
(Ben Granett and e2e group)

★ The dominant foreground contamination will be zodiacal light and scattered light of Milky Way stars

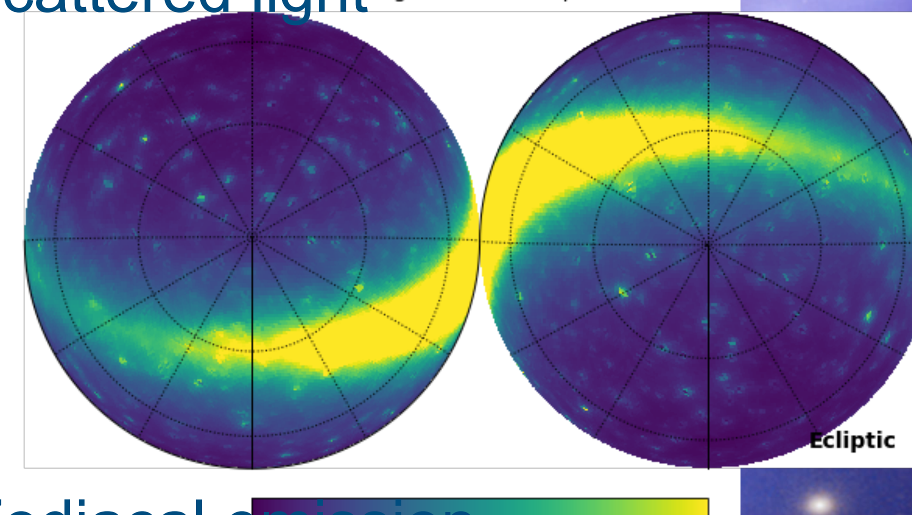
★ These will modulate the observed number density.



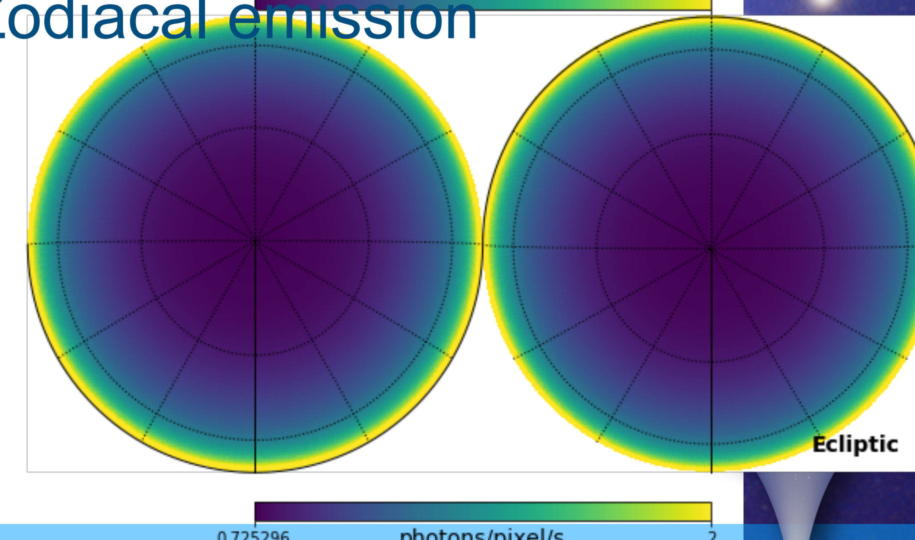
Extinction



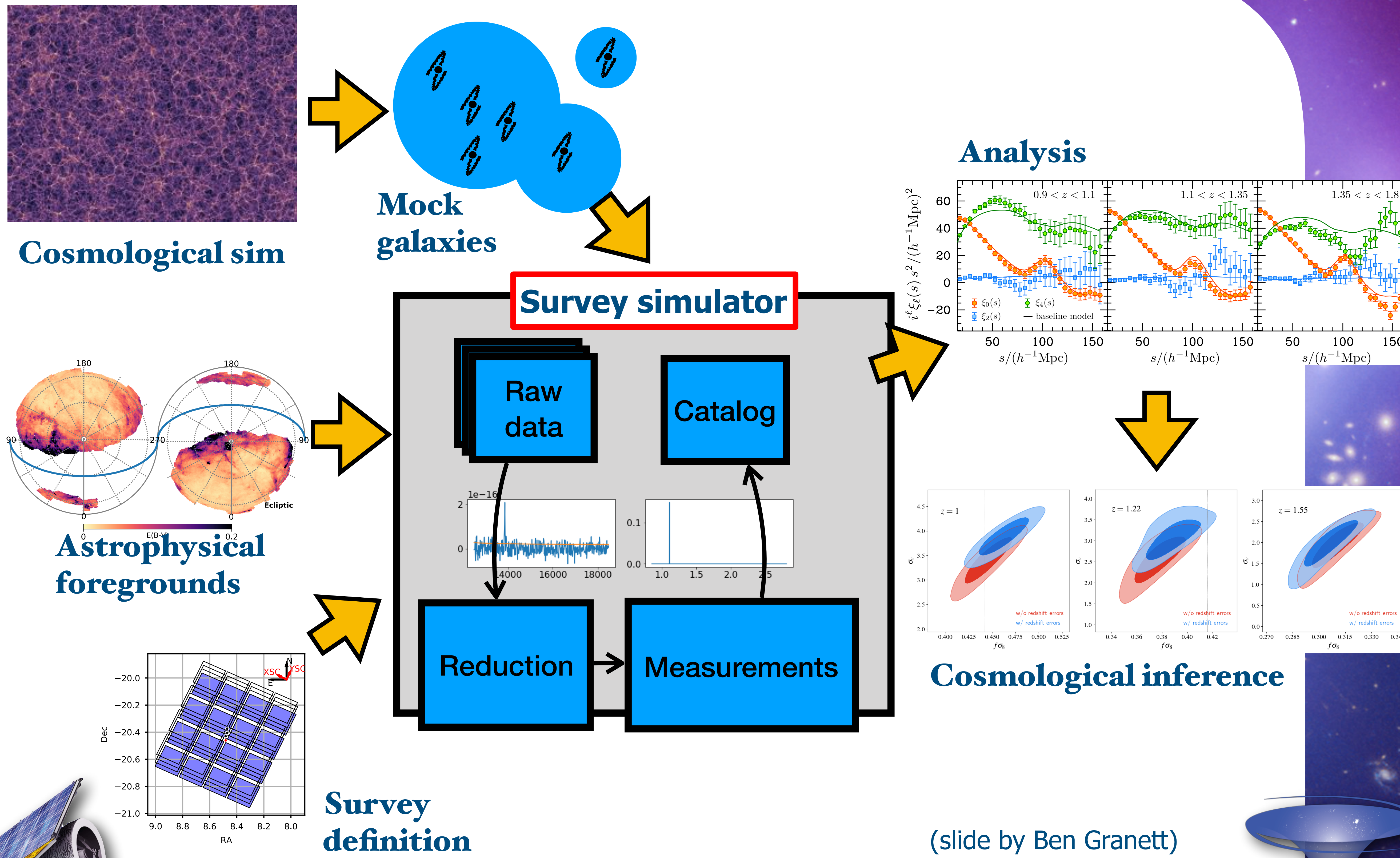
Scattered light



Zodiacal emission

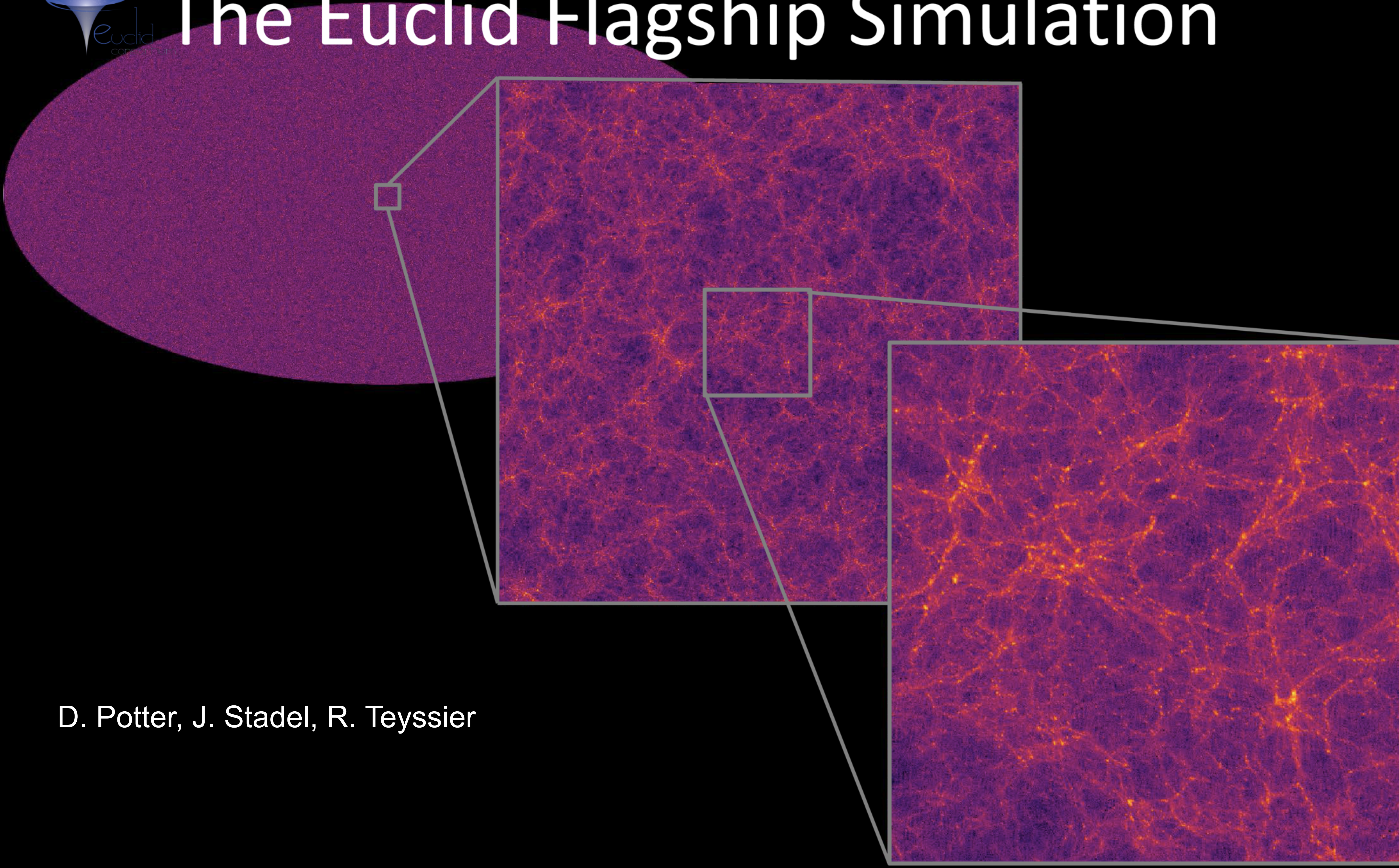


Role of simulations



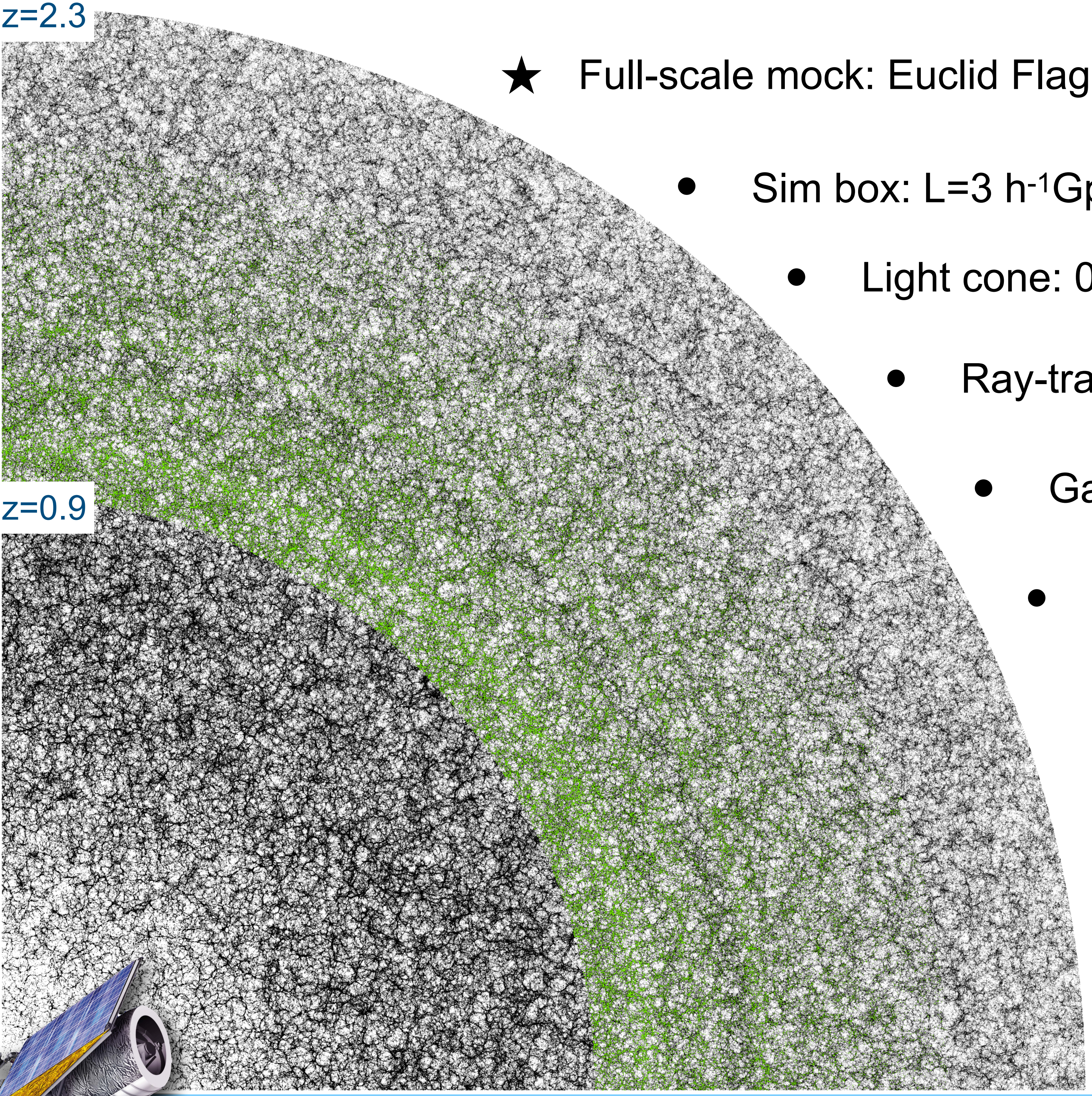
(slide by Ben Granett)

The Euclid Flagship Simulation



D. Potter, J. Stadel, R. Teyssier

Mock universes

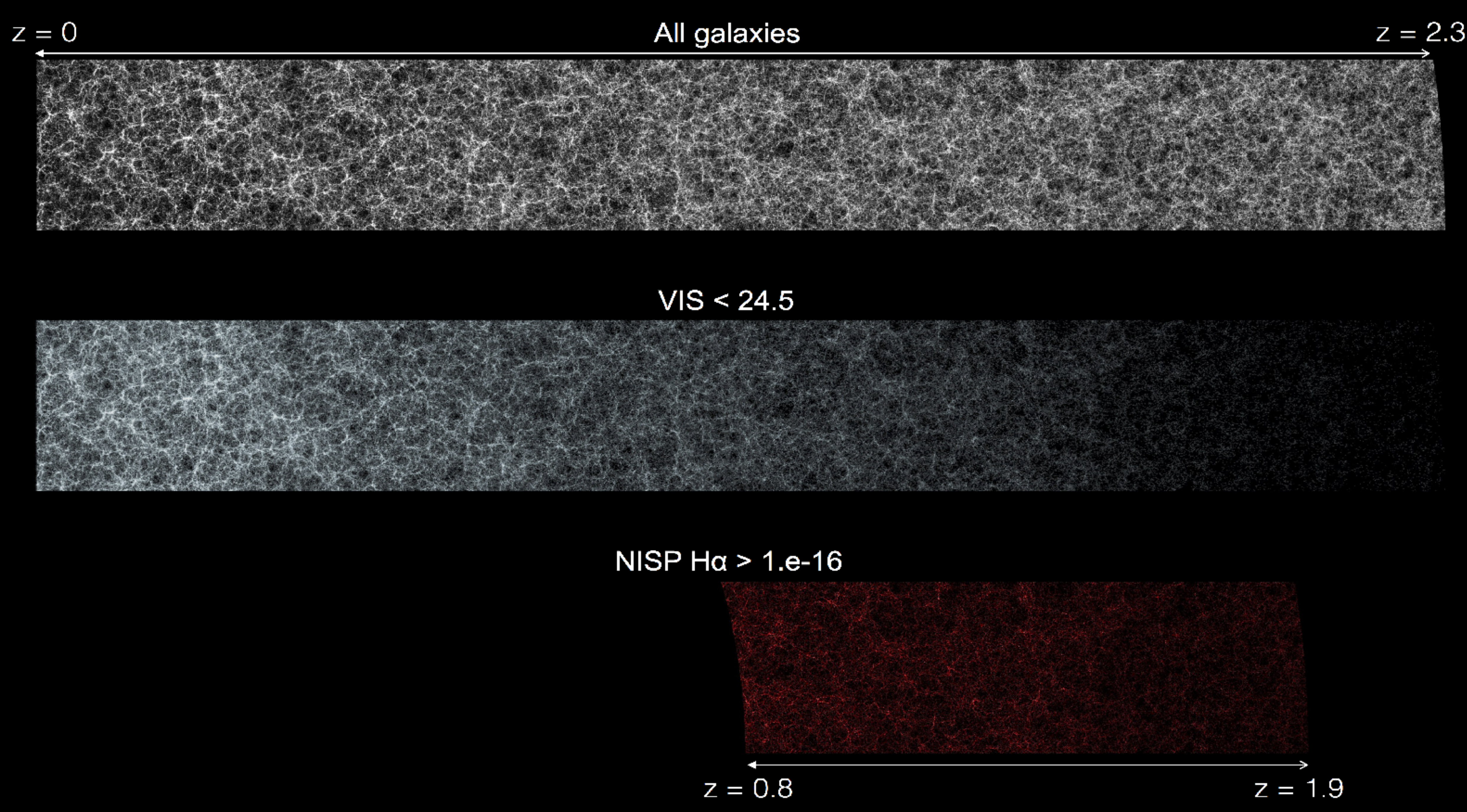


★ Full-scale mock: Euclid Flagship simulation

- Sim box: L=3 h^{-1}Gpc, 2 trillion DM particles
- Light cone: 0 < z < 2.3
- Ray-traced lensing maps
- Galaxy properties by HOD
- Consistent mocks for WL and GC

★ Cosmological Simulation Science Working Group
P. Fosalba (Barcelona)
R. Teyssier (U. Zurich)

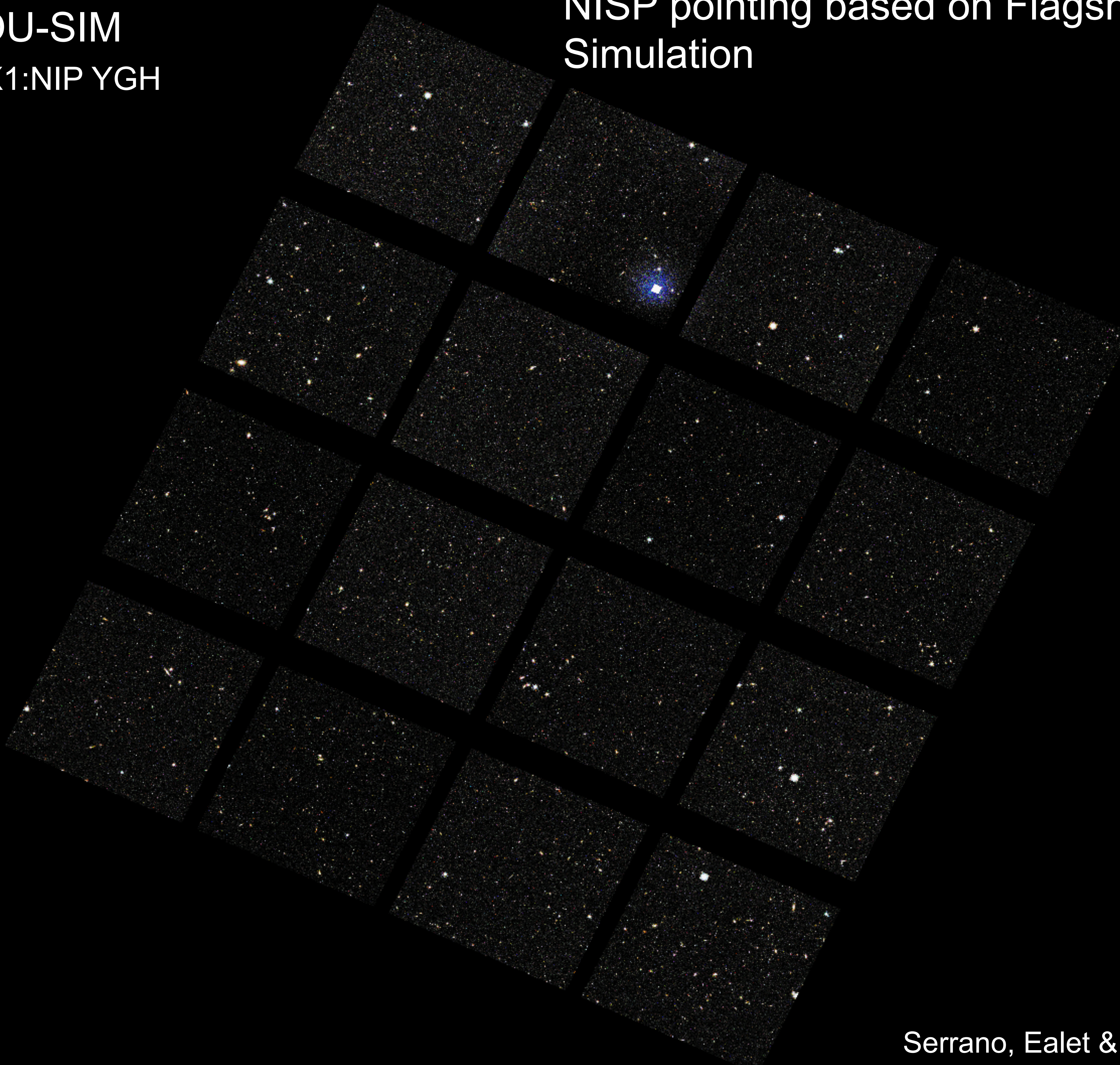
Euclid Flagship Simulation: mock galaxy catalog



OU-SIM

Field X1:NIP YGH

NISP pointing based on Flagship Simulation

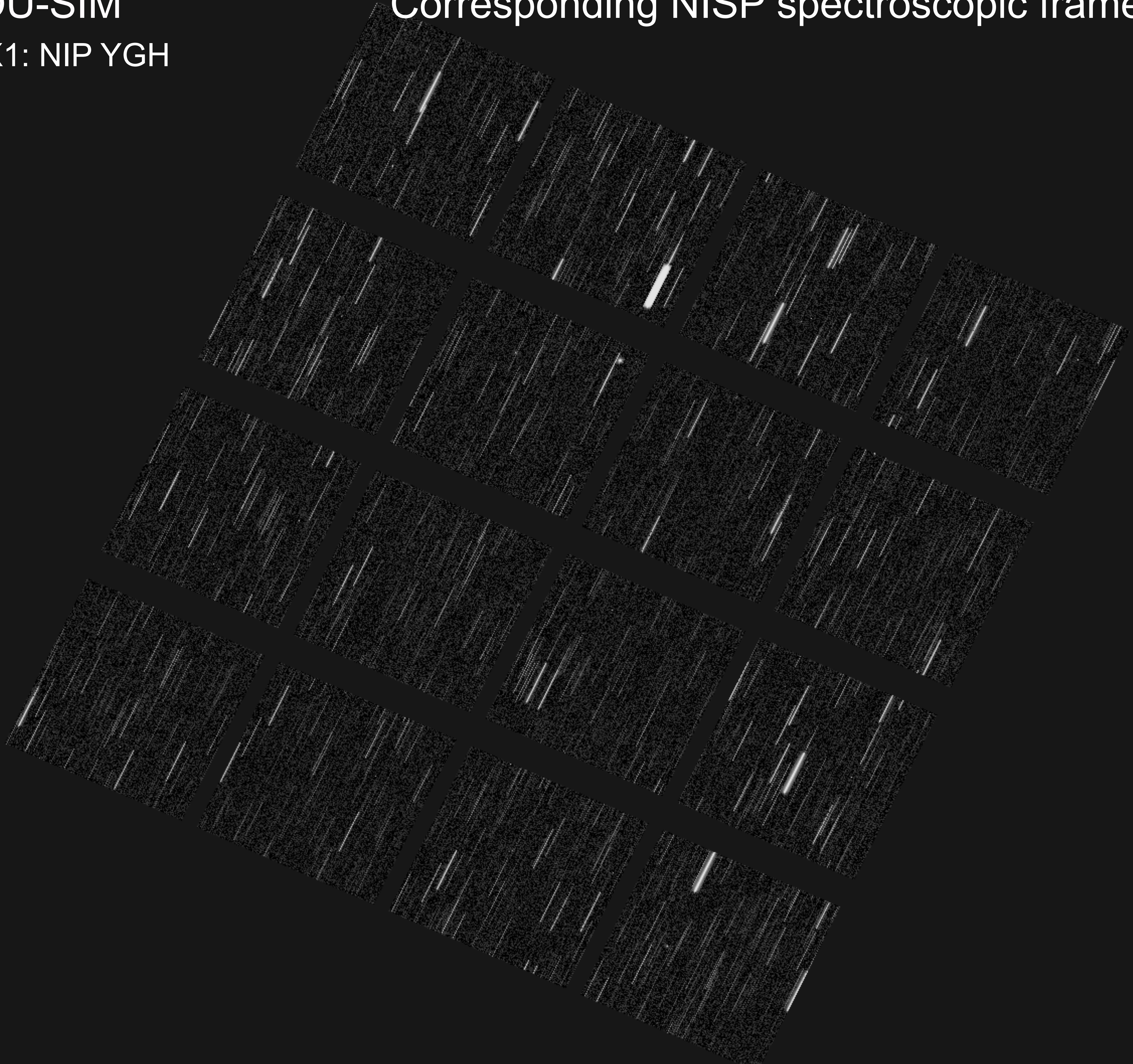


Serrano, Ealet & OU-SIM

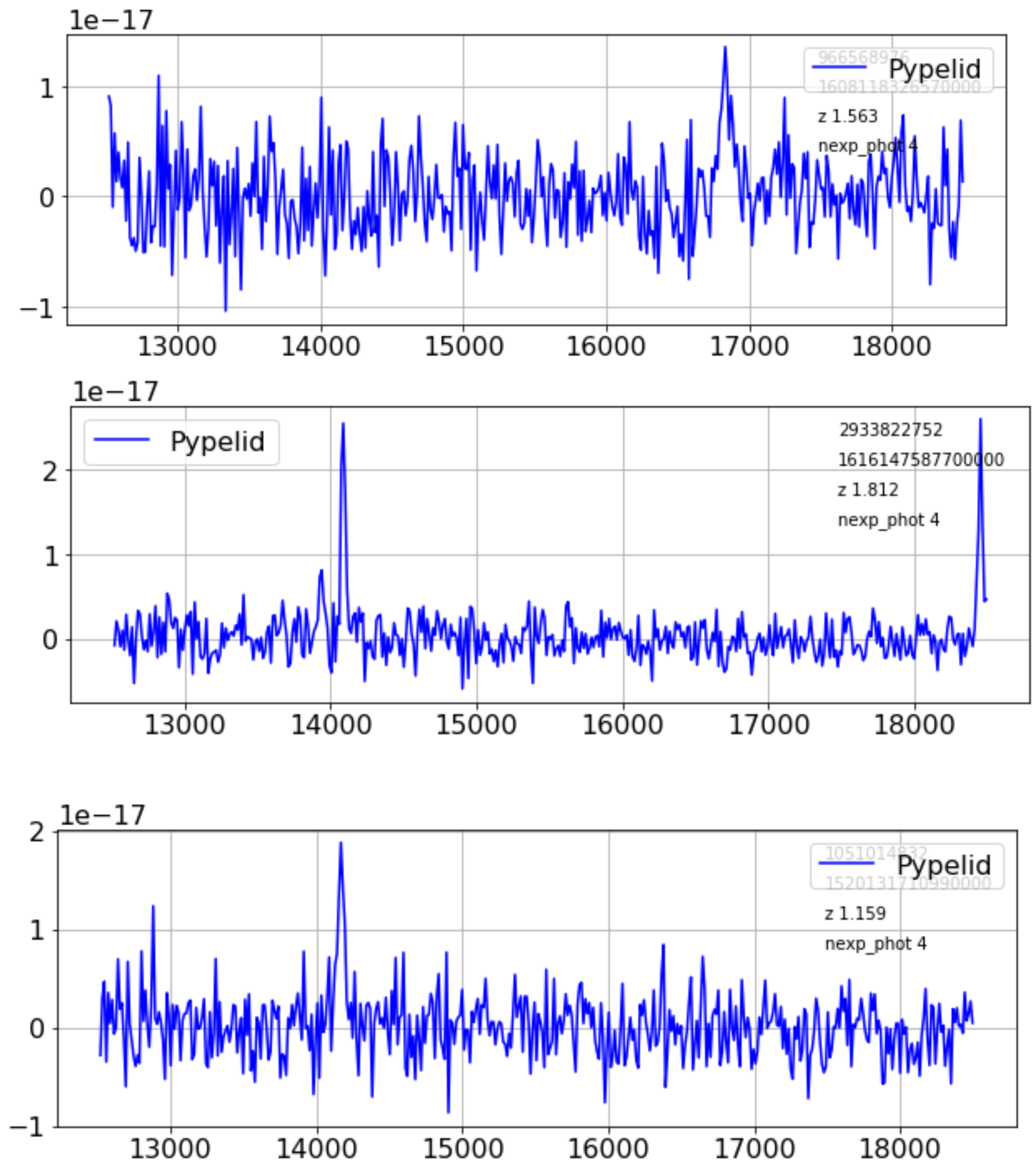
OU-SIM

Field X1: NIP YGH

Corresponding NISP spectroscopic frame

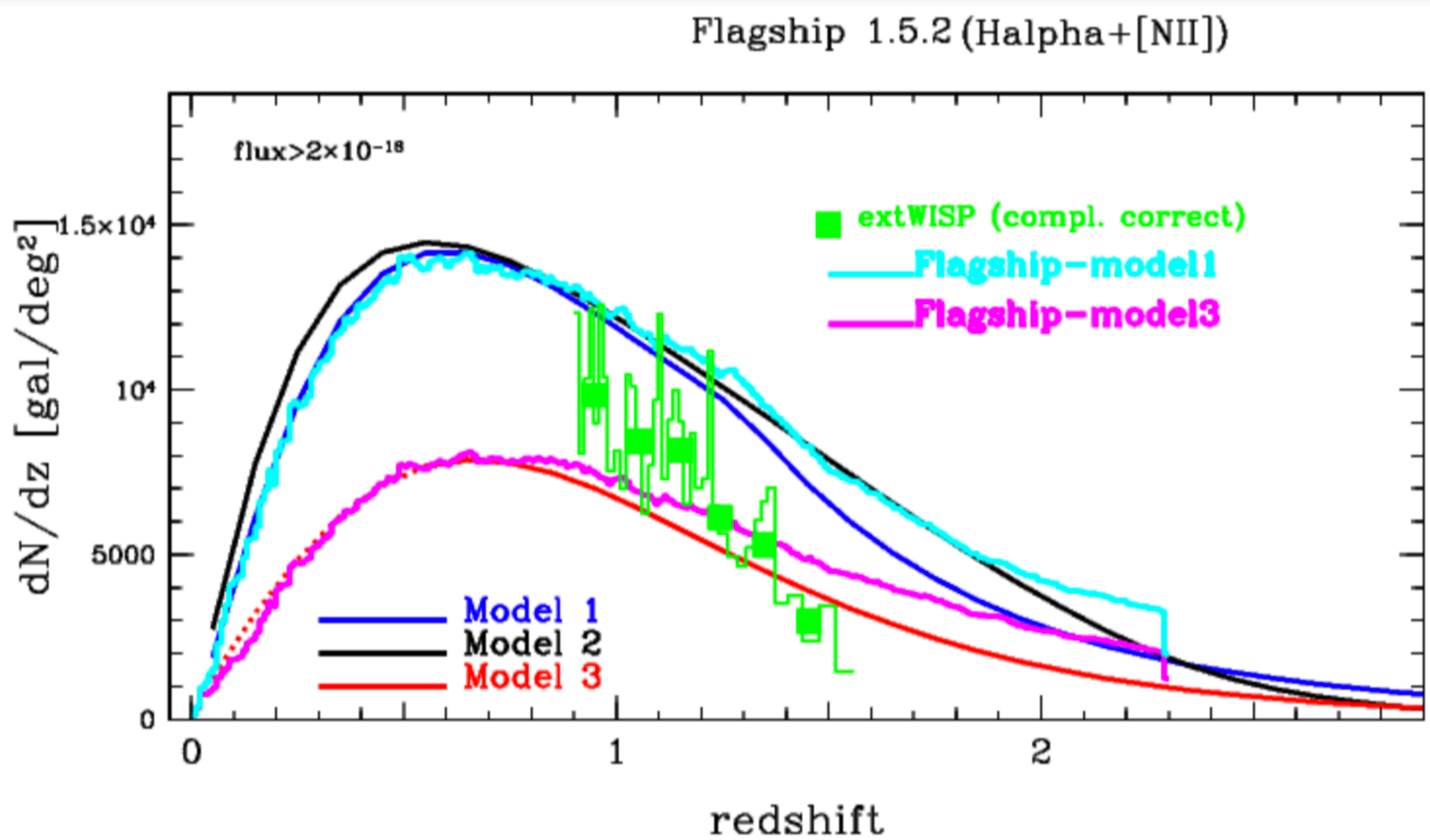


Example simulated spectra



Pypelid: Granett, Markovic, De la Torre et al.

Simulating Hα emitters at z >0.9

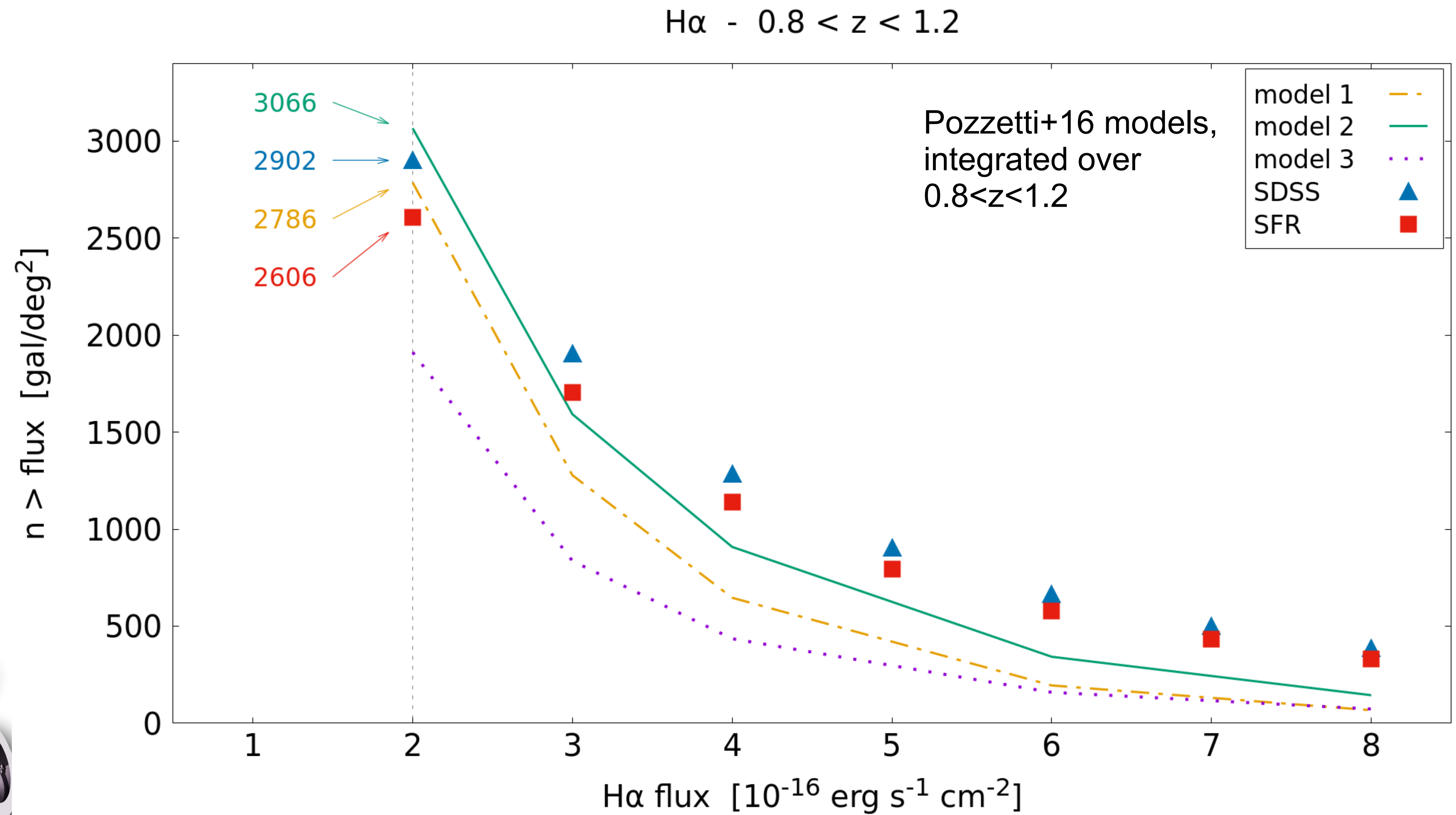


- Conservative H number counts: Pozzetti+16 model3 used
- WISP counts from Bagley+18
- Additional simulations have been run with Pozzetti+16 model1

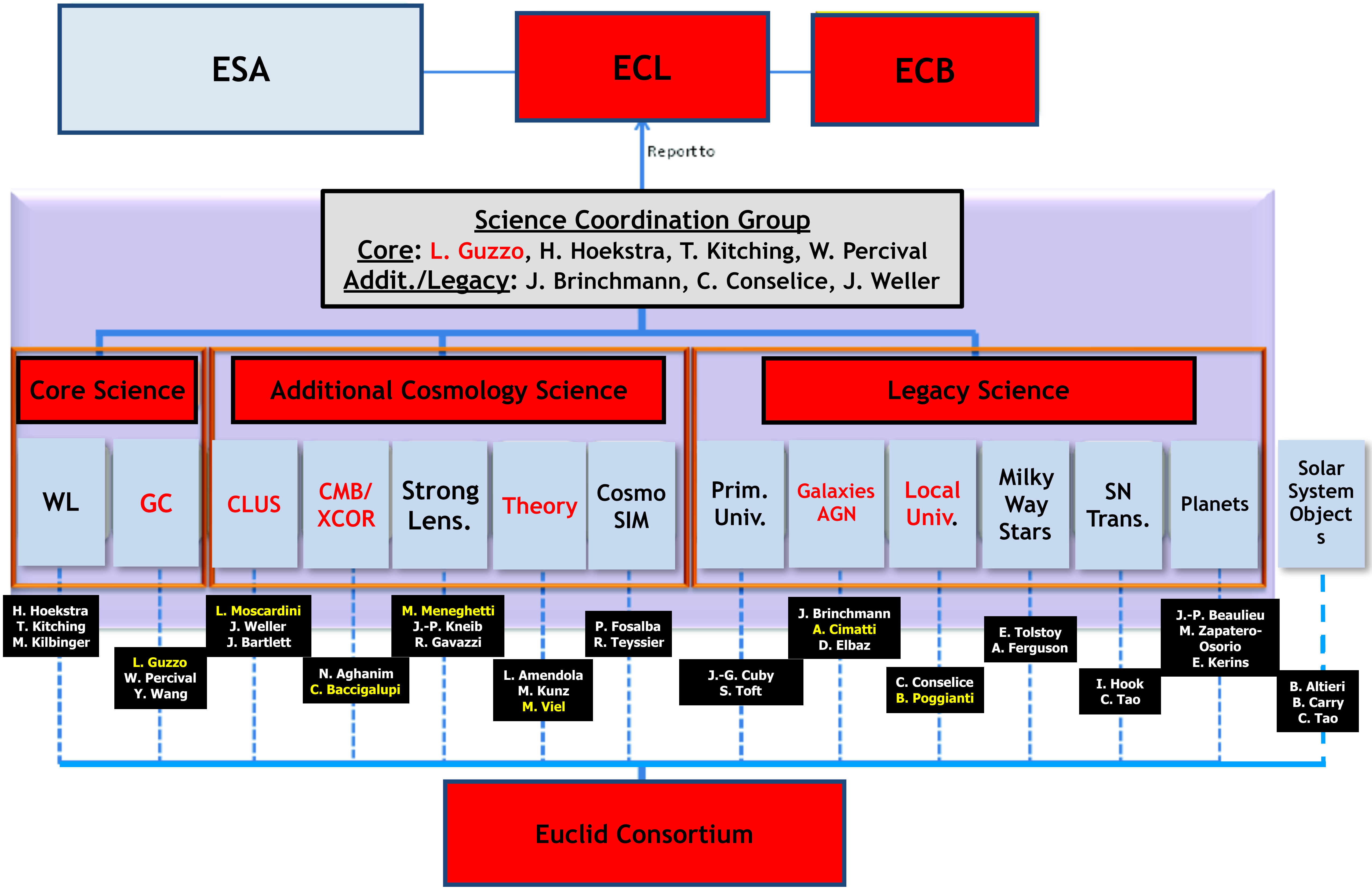
Validate expected Hα emitters density using VIPERS

Visconti, Scodeggio, LG, Granett, et al. in prep.

- ★ Derive Ha fluxes from measured [OII]3727 fluxes of 53,000 galaxies in VIPERS, using SDSS relation and accounting for stellar mass and metallicity dependence
- ★ Actual data support higher density model
- ★ Note: $\text{Area}_{\text{VIPERS}}$ ~ 50 area(WISP+HST3D)



EC Science Organisation



e.g. Galaxy Clustering SWG

Leads: L. Guzzo (I), W. Percival (CA), Y. Wang (US)

WP	
Observational Systematics	M. Scodeggio (I)
Likelihood Fitting (link to IST:Likelihood)	C. Carbone (I)
Non-linear Effects (link to IST:Nonlinear)	M. Crocce (E)
Higher-Order Statistics	E. Sefusatti (I)
Additional GC Probes	A. Hawken (F)
Photo-z Clustering	S. Camera (I) (Jan 2019-)

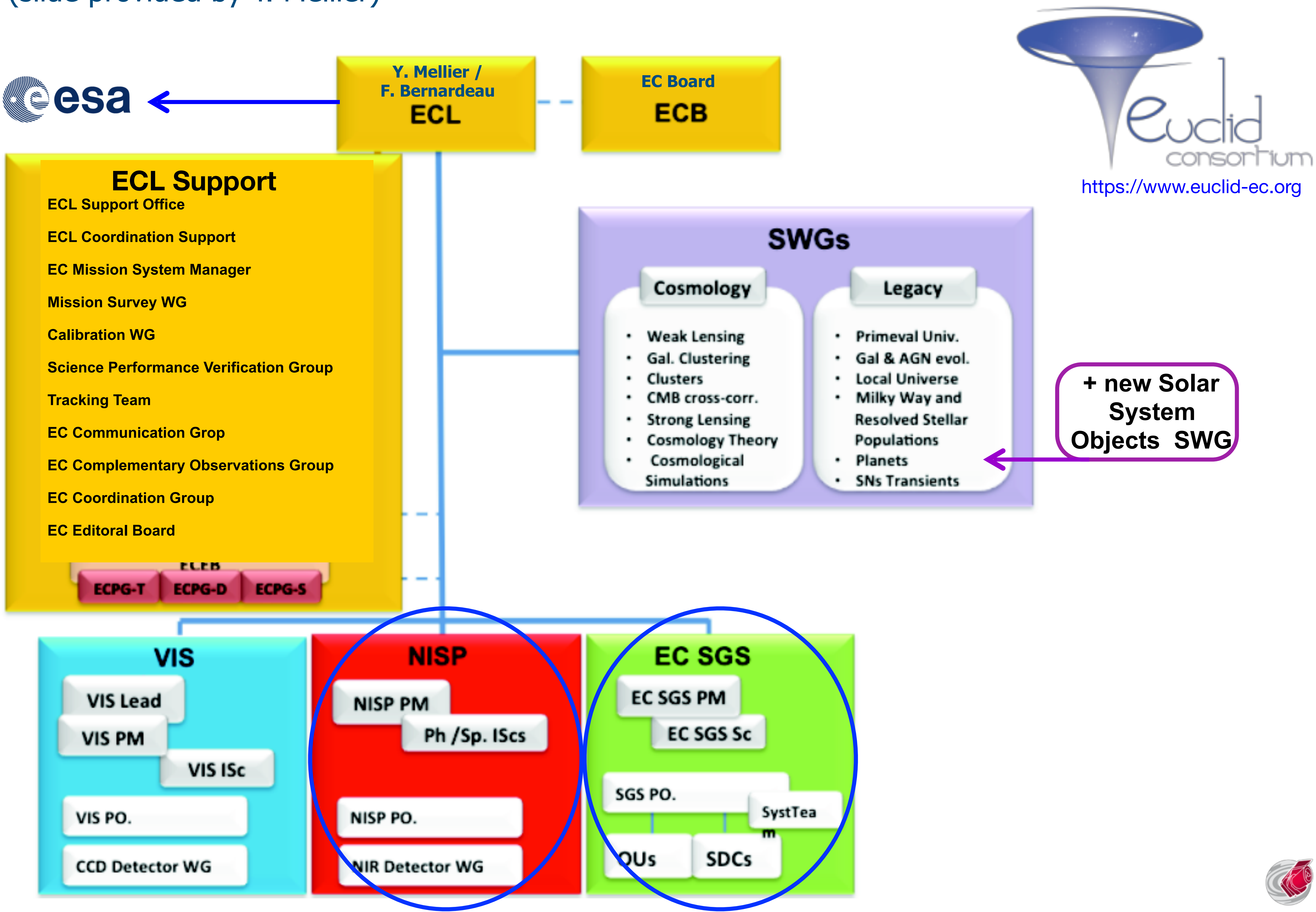
—> Additionally, specific task forces and focused groups are formed when needed…

Inter-swg Science Taskforces (ISTs)

- Joint ventures involving more than one SWG
- Guarantees link and combination between single-probe measurements
- IST-Forecasts (closing, C. Carbone, V. Cardone)
  - End-module of Science Performance Verification 2 chain (SPV-2)
  - IST:F Paper ready and being submitted to ECEB
  - IST:F being disbanded after this
- IST-Likelihood (V. Cardone, V. Pettorino, A. Sanchez)
  - Combine likelihood of GC-WL and more
  - Natural evolution of IST-Forecasts
  - Links to corresponding WPs in GC and WL
- IST-Nonlinear (M. Crocce, C. Giocoli, A. Pourtsidou)

Euclid Consortium organisation

(slide provided by Y. Mellier)



The end