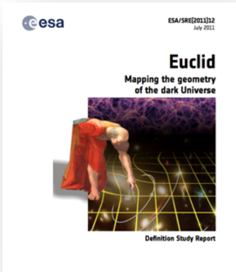
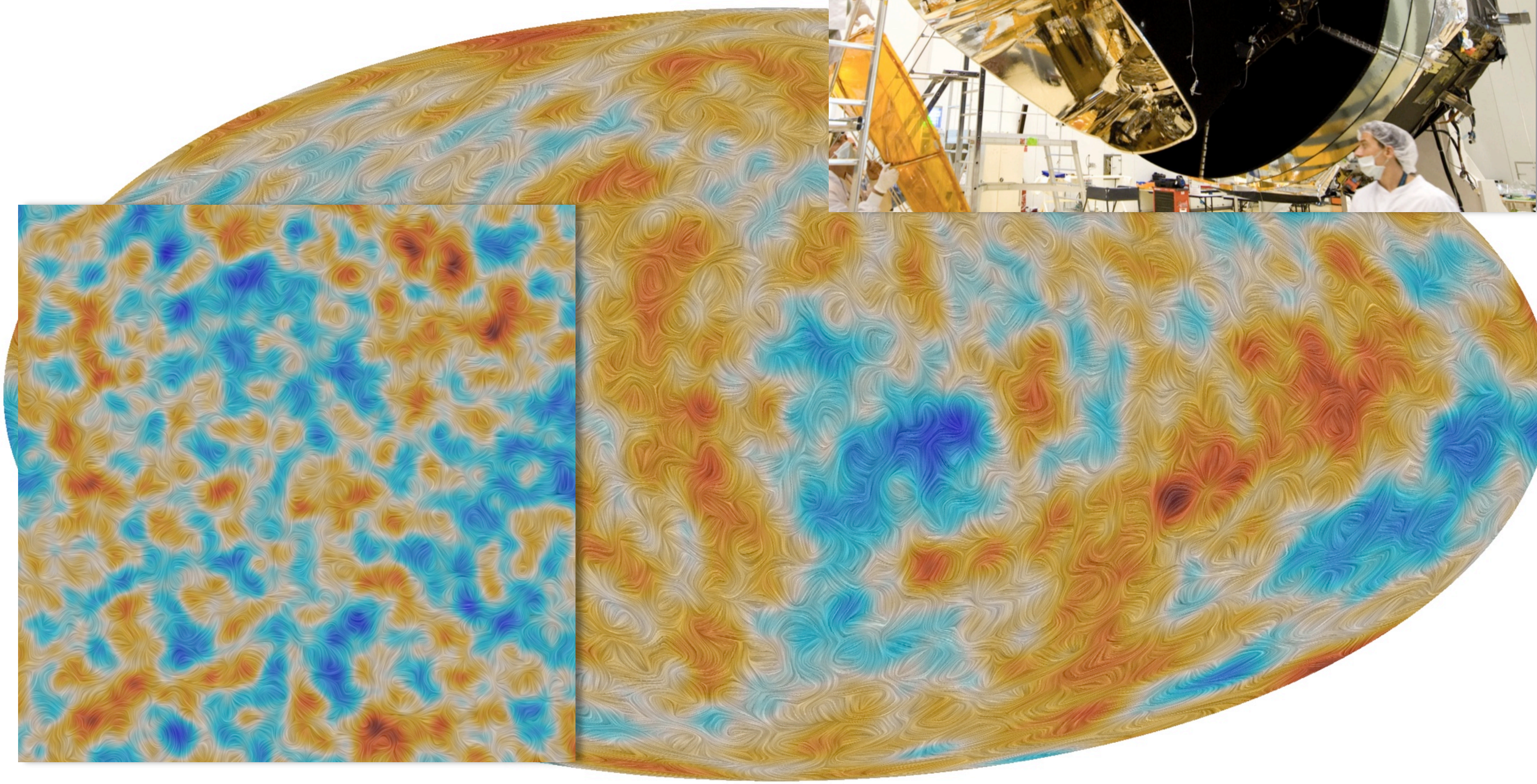


Investigating the *Dark* Universe with the Euclid satellite

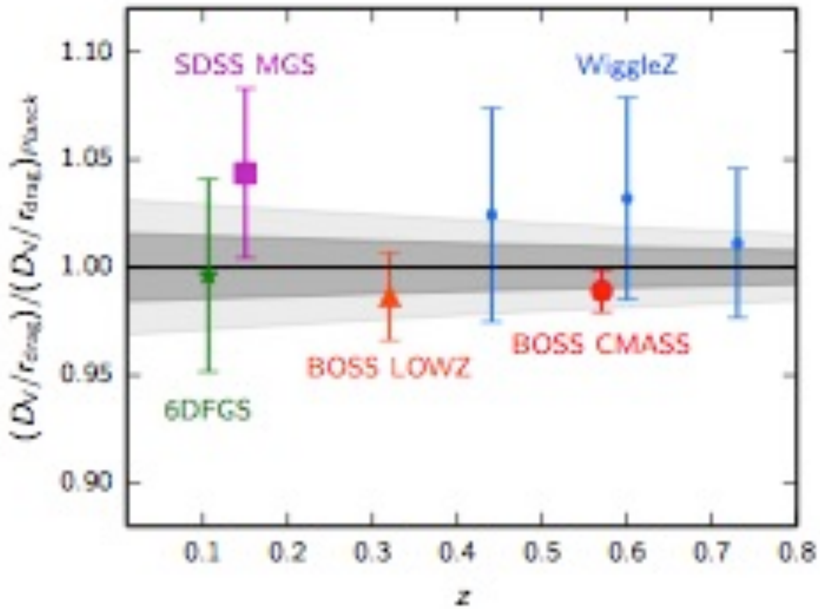
Luca Valenziano
INAF/IASF-Bologna
& INFN – Bologna

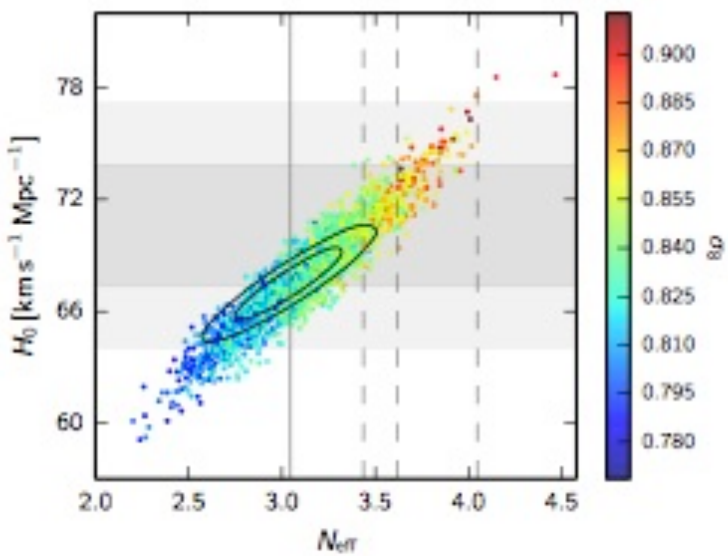
On behalf of the EC and Euclid Italia
INFN Bologna - 2015

Planck & CMB



Beyond Planck





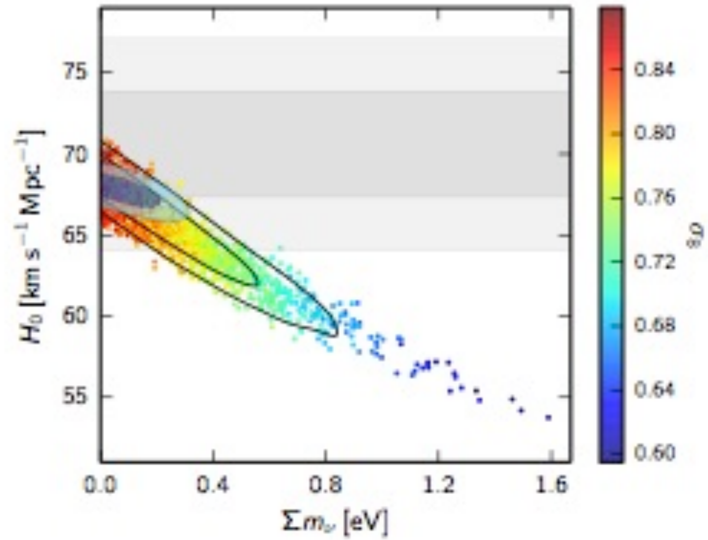
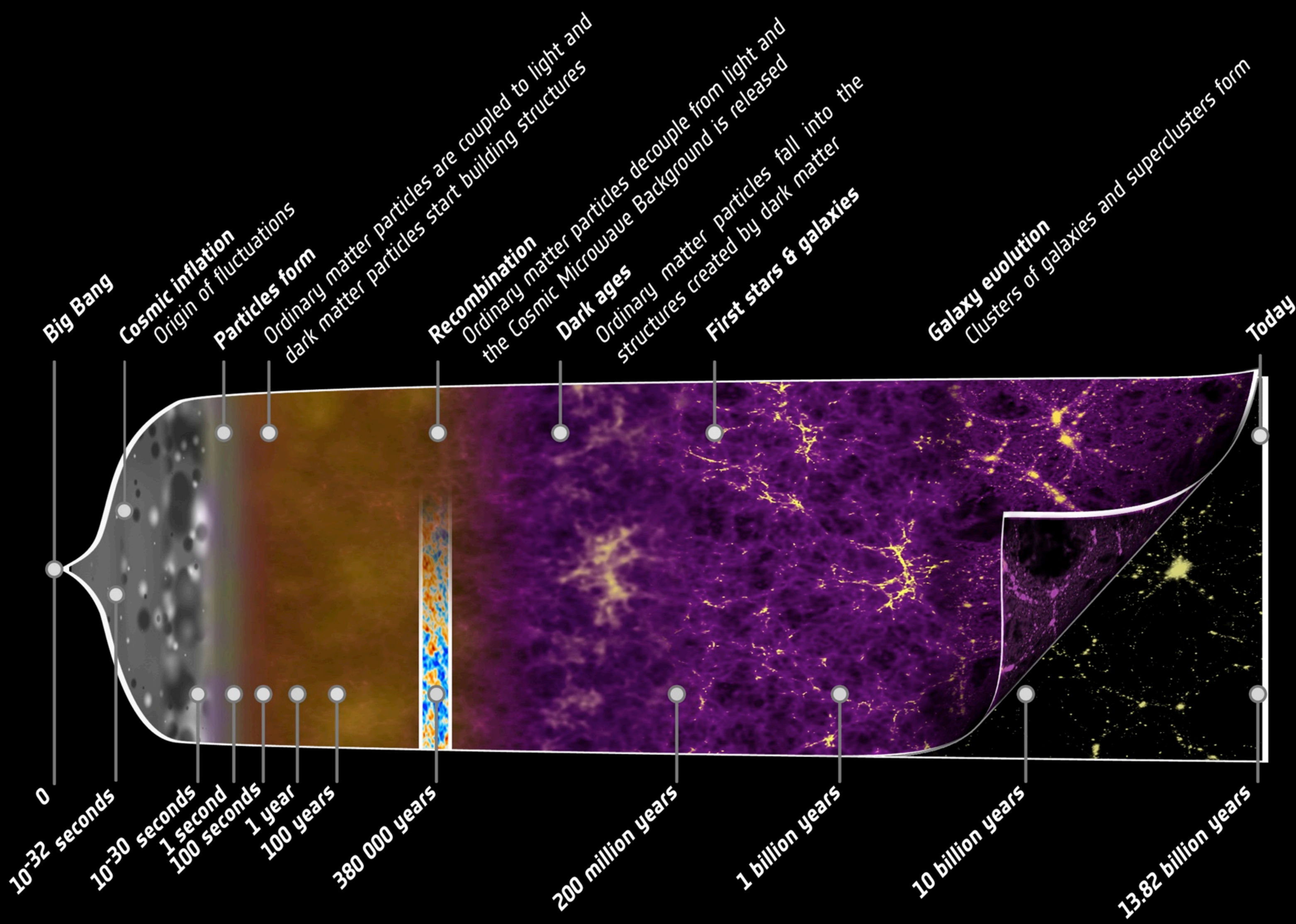


Fig. 29. Samples from the *Planck* TT+lowP posterior in the $\sum m_\nu$–H_0 plane, colour-coded by σ_8. Higher $\sum m_\nu$ damps the matter fluctuation amplitude σ_8, but also decreases H_0 (grey bands show the direct measurement $H_0 = (70.6 \pm 3.3)$ km s^{-1}Mpc^{-1}, Eq. 30). Solid black contours show the constraint from *Planck* TT+lowP+lensing (which mildly prefers larger masses), and filled contours show the constraints from *Planck* TT+lowP+lensing+BAO.

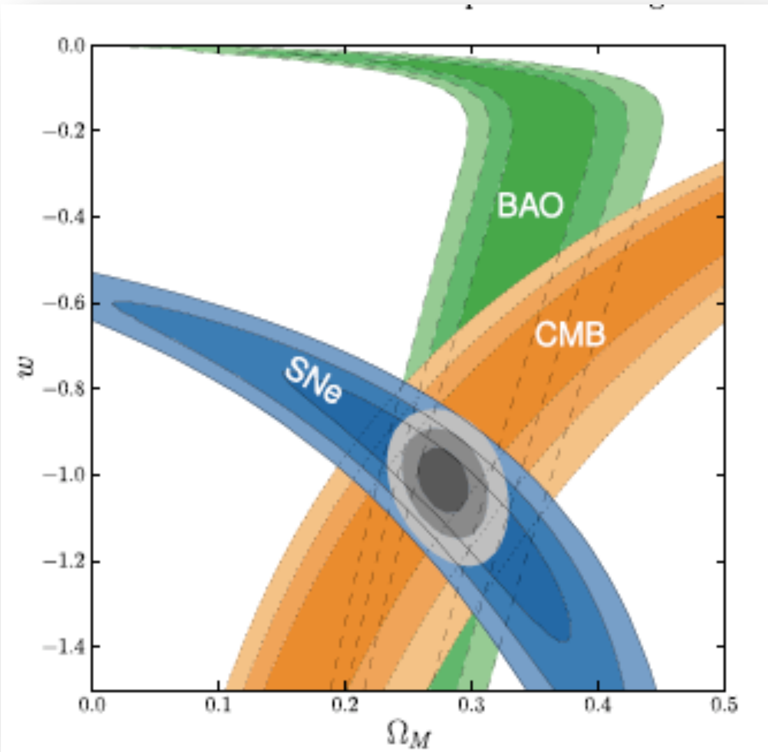
Planck Collaboration, XIII Cosmological Parameters, 2015



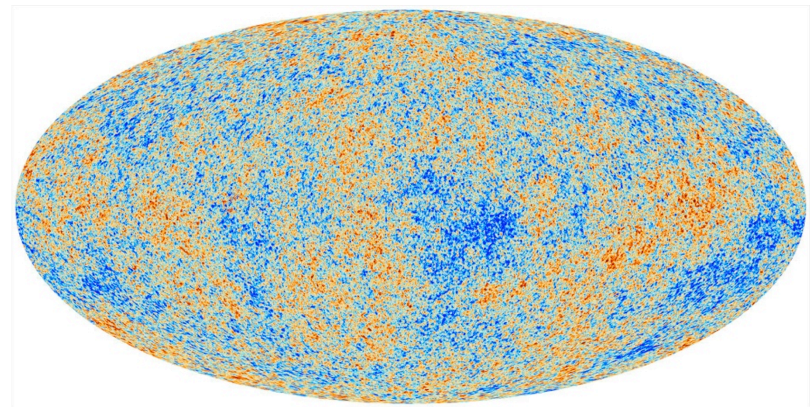
Big Bang
Cosmic inflation
Origin of fluctuations
Particles form
Ordinary matter particles are coupled to light and
dark matter particles start building structures
Recombination
Ordinary matter particles decouple from light and
the Cosmic Microwave Background is released
Dark ages
Ordinary matter particles fall into the
structures created by dark matter
First stars & galaxies
Galaxy evolution
Clusters of galaxies and superclusters form
Today
0
10-32 seconds
10-30 seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years

Euclid cosmological motivation

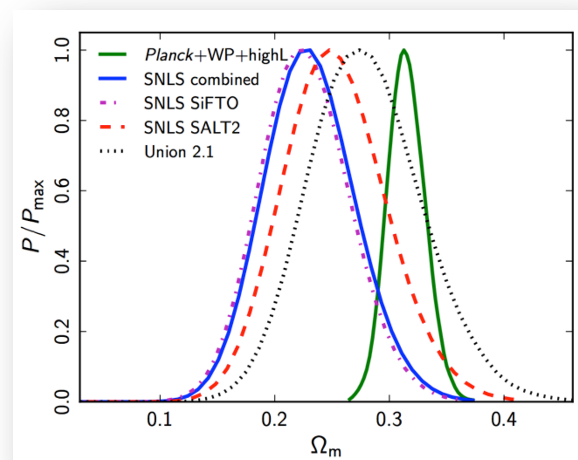
An accelerating L-dominated Universe: "concordance", but with a few key open questions…



Amanullah et al. 2010 (Union supernovae)



Planck Collaboration 2013, paper XVI



Q1: Is cosmic acceleration produced by a cosmological constant or by an evolving scalar field?

Evolving equation of state of DE:

e.g. $$w(a) = w_0 + w_a(1-a)$$

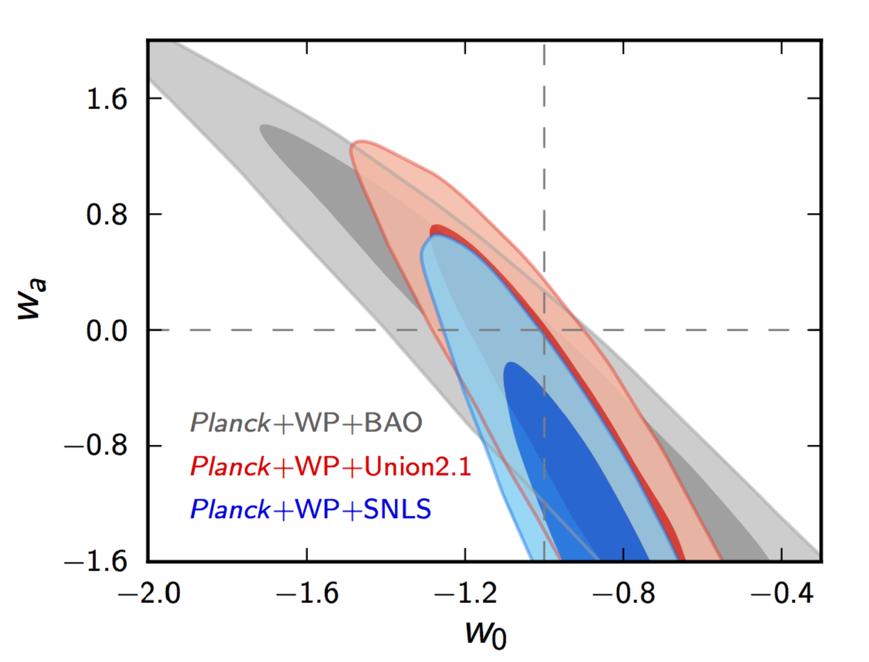
Parameterizing our ignorance

DETF (Albrecht et al. 2006): characterize experiments through a Figure of Merit in (w_0,w_a) plane (or similar):

$$\mathrm{FoM} = 1/(\Delta w_0 \times \Delta w_a)$$

But this reflects chosen parameterization

→ <u>FoMs should be taken with a big grain of salt</u> (e.g. NASA/DOE/ESA FoMSWG report, Albrecht et al. 2009): there is much more science in a galaxy survey



Planck Collaboration 2013, XVI

Q2: Does General Relativity still work on cosmological scales? "Dark Gravity" instead of Dark Energy…?

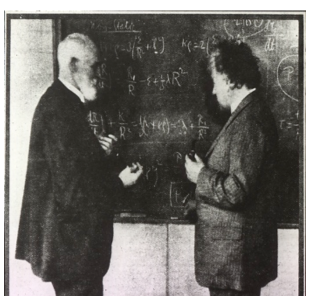
A story with two sides…

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\frac{8\pi G}{c^2} T_{\mu\nu} + \Lambda g_{\mu\nu}$$

?

Modify gravity theory [e.g. ***R → f(R)***]

Add dark energy



→ Distinguish by measuring both background expansion H(z) and growth rate of structure f(z)

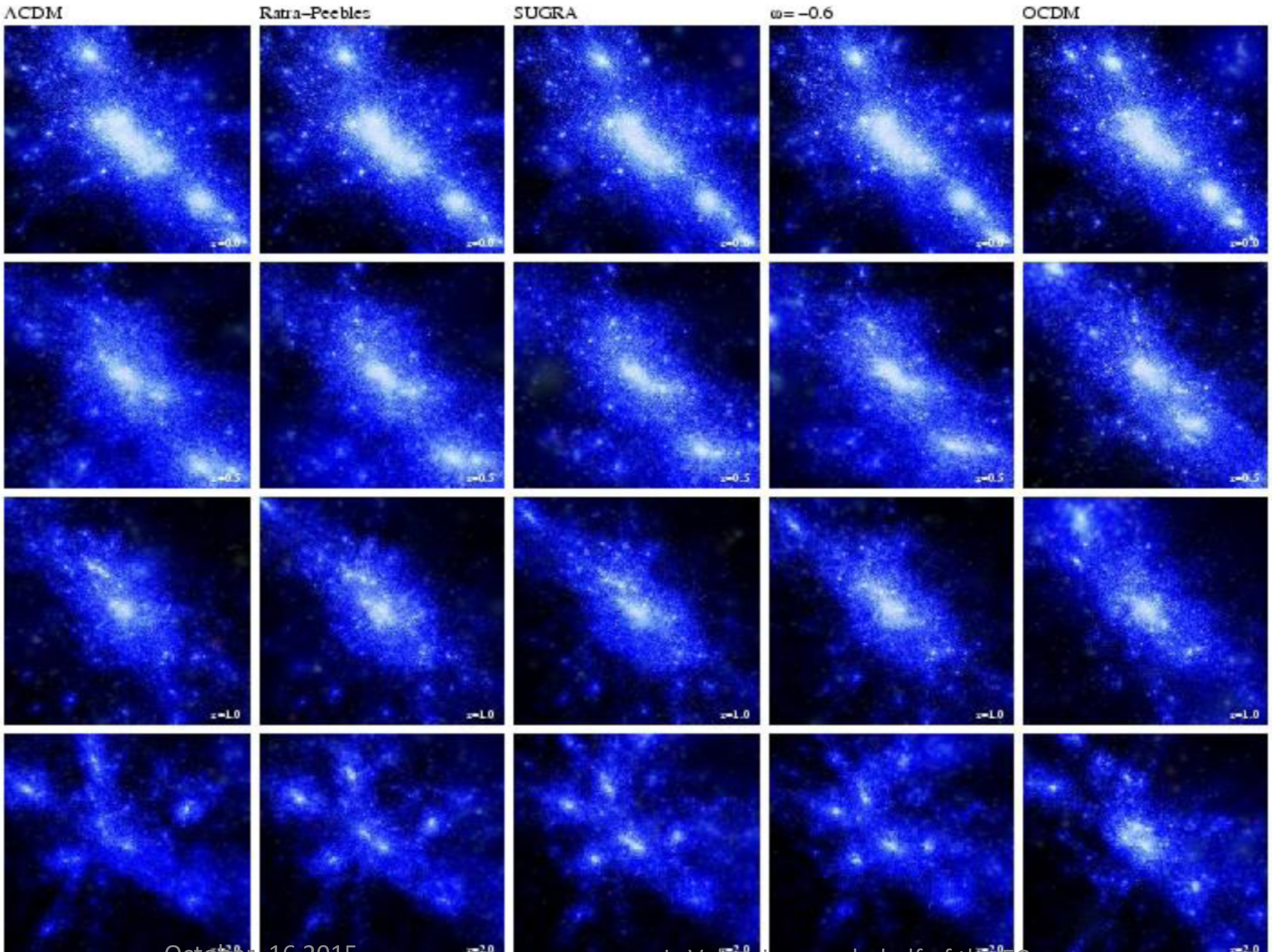
Tiny differences between DE/MG models

z=0.0

z=0.5

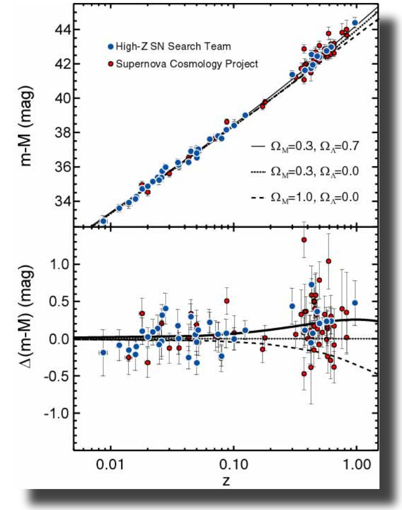
z=1.0

z=2.0



Euclid: answer both questions

1. Measure ***the expansion history H(z)*** to high accuracy, as to detect percent variations of DE *equation of state* w(z) with robust control of systematics:



Achieve this through **two probes**:

A. Using the scale of Baryonic Acoustic Oscillations (BAO) in the clustering pattern of galaxies as a standard rod

B. Using shape distortions induced by Weak Gravitational Lensing

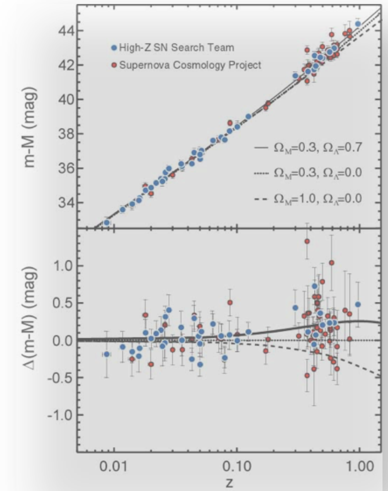
Euclid: answer both questions

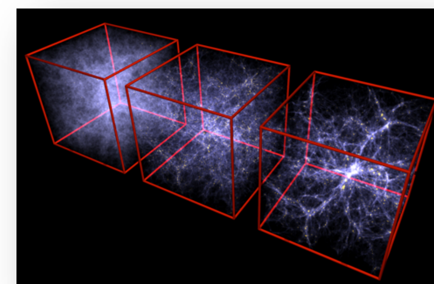
2. Measure at the same time ***the growth rate of structure*** from the same probes, to detect modifications of gravity:

   A. Clustering redshift-space distortions (RSD)

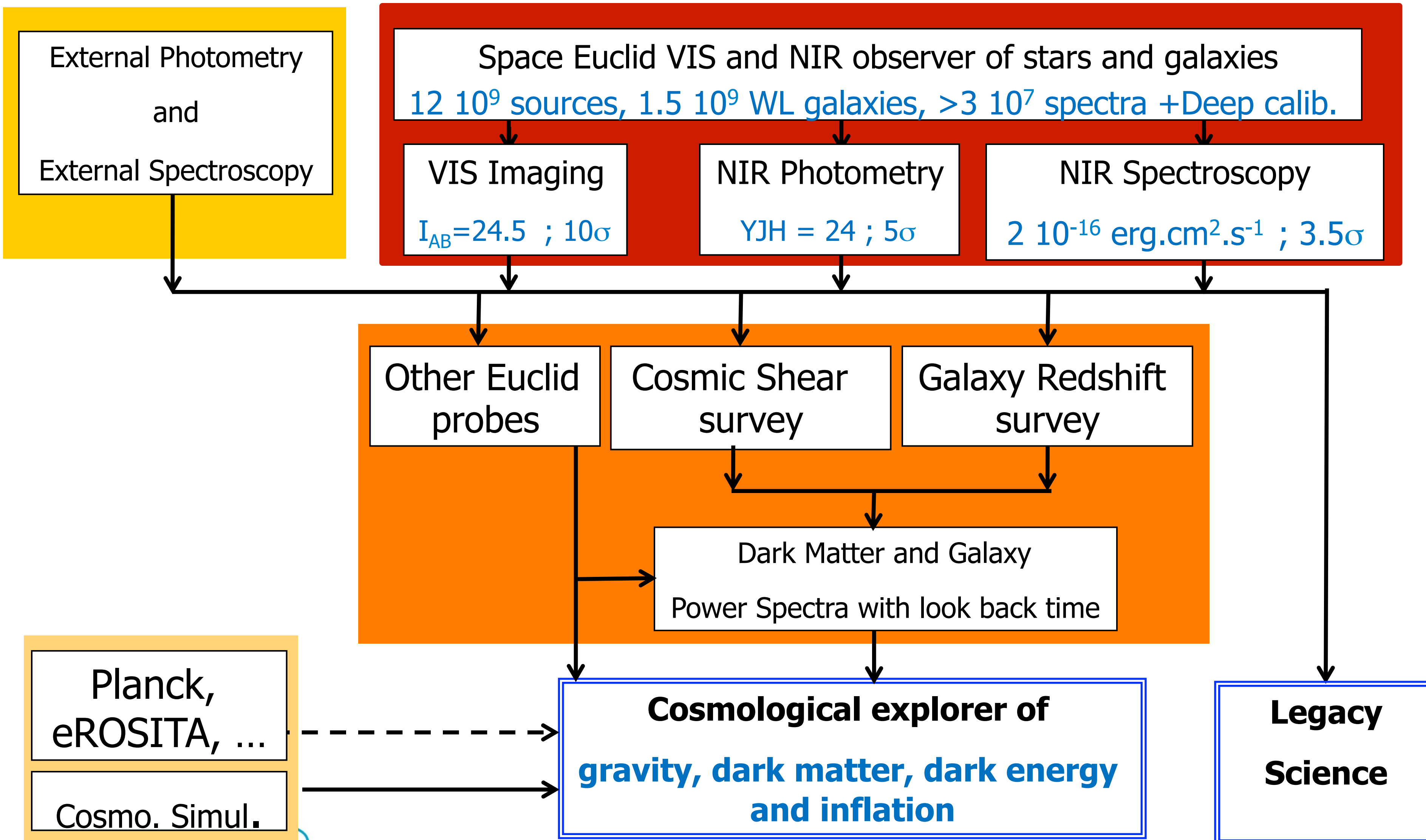
   B. Weak Lensing (WL) Tomography

   •→ These two probes are differently sensitive to the Ψ and Φ potentials of the perturbed metric, i.e. to deformations of time and space





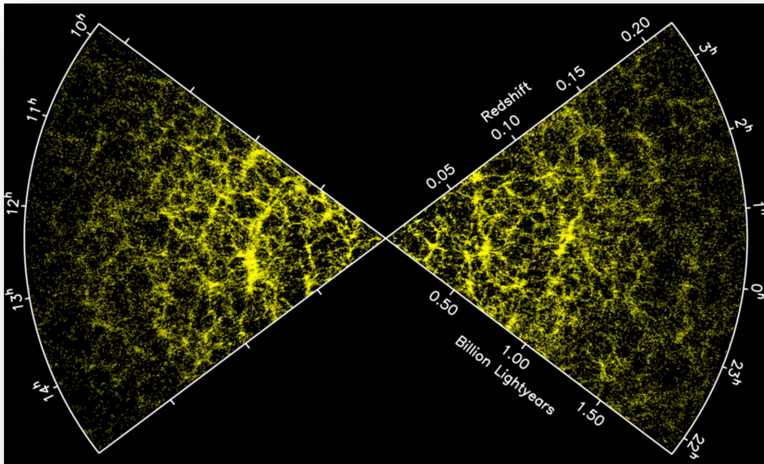
The Euclid Wide Survey Machine



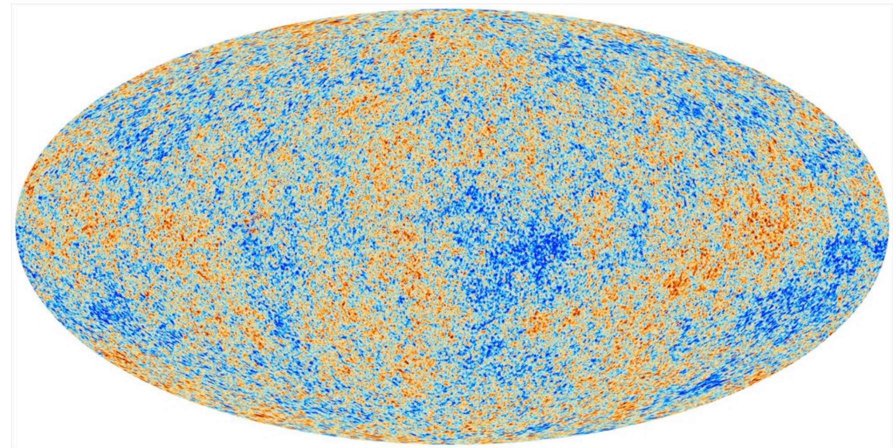
Baryonic Acoustic Oscillations

Galaxies

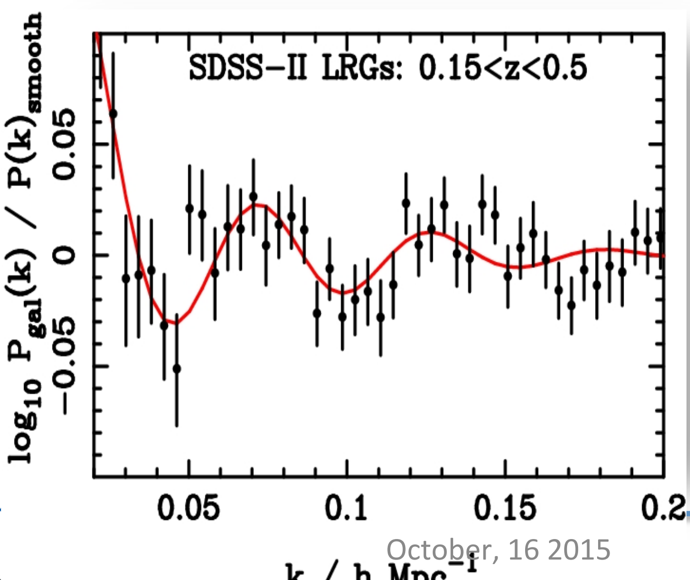
Microwave background

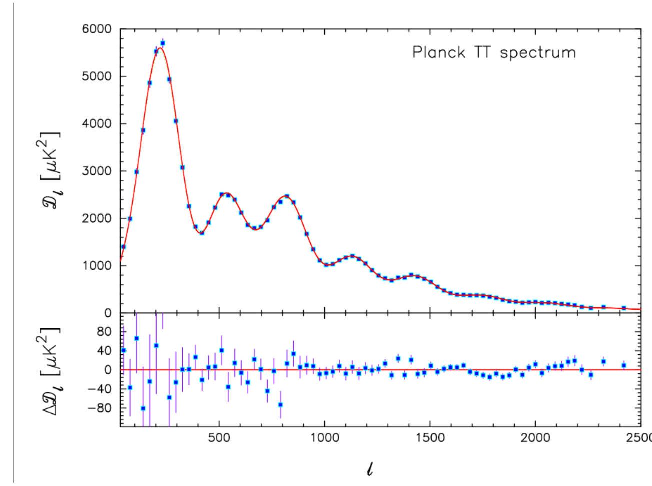


Percival et al. (2007, 2009, 2010); Anderson et al 2012

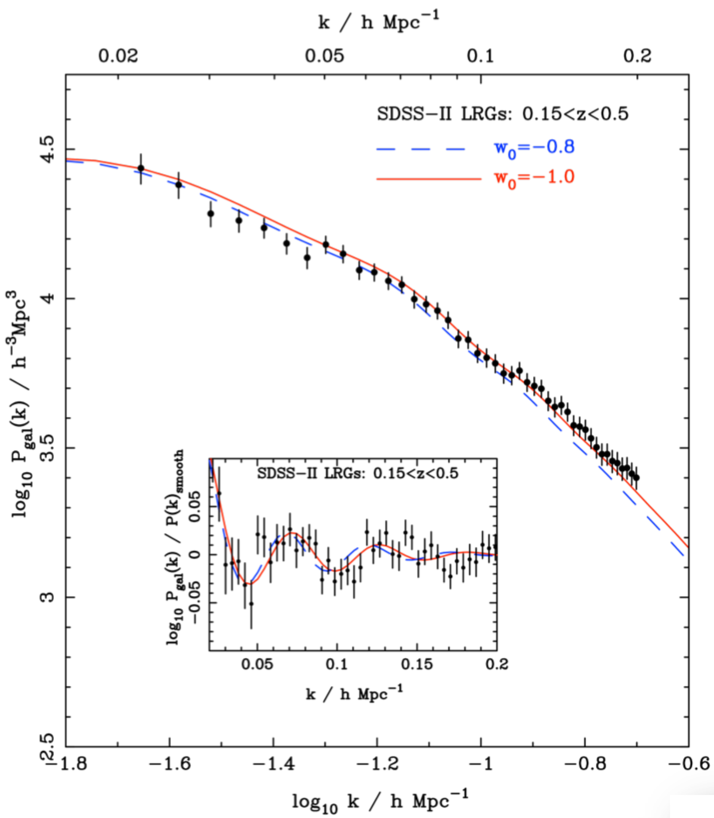


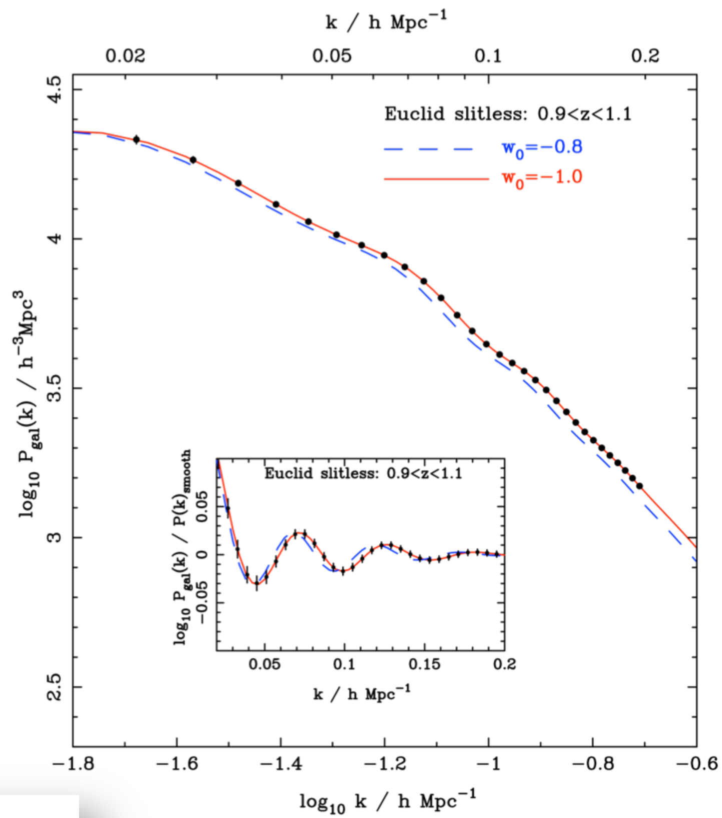
Planck 2013, XVI: Cosmological results





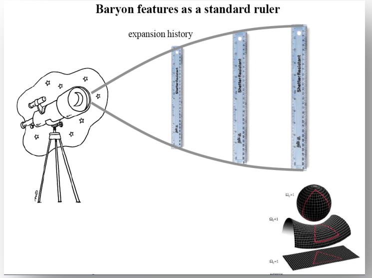
w(z) from Baryonic Acoustic Oscillations





SDSS LRGs at z~0.35

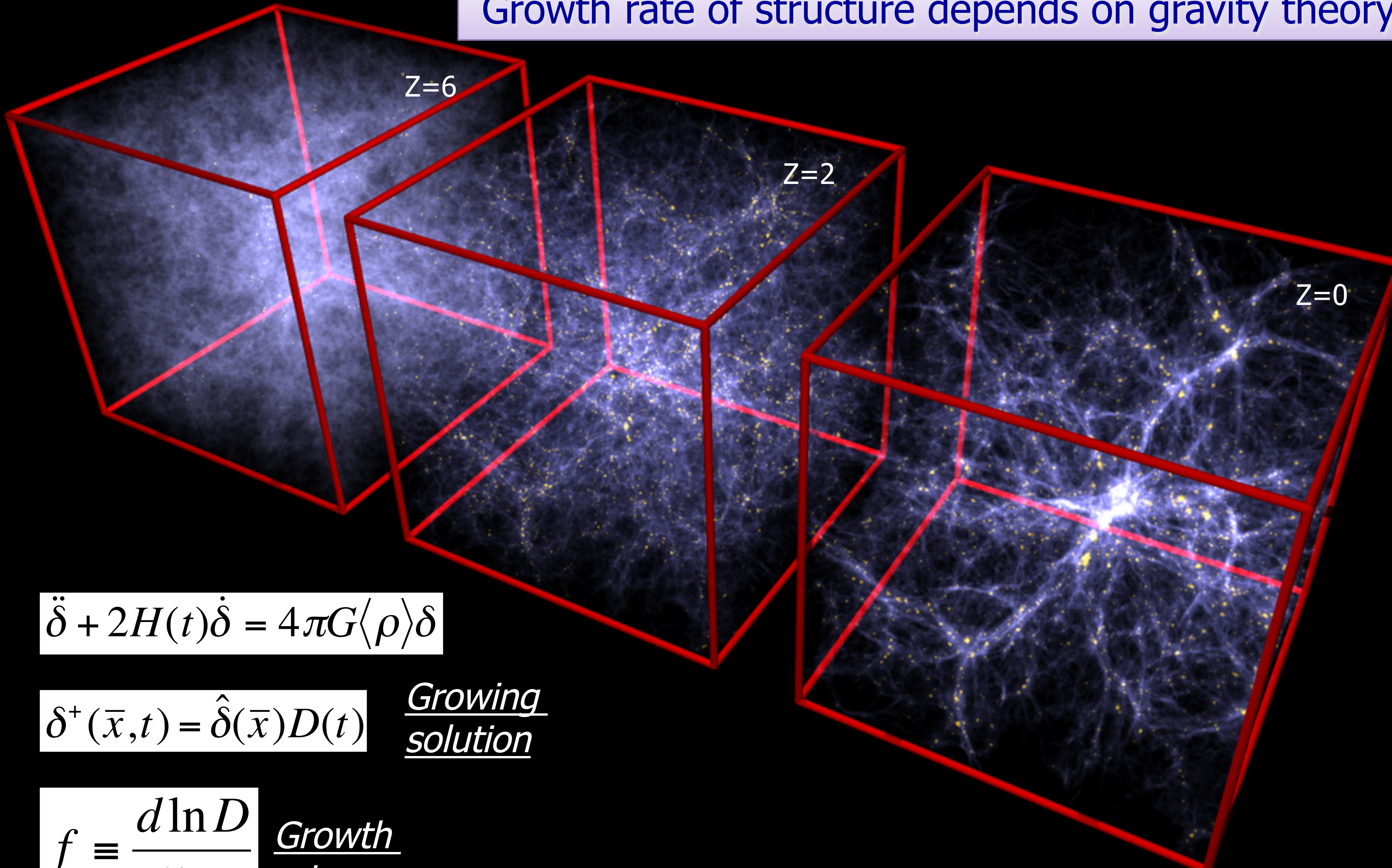
Total effective volume
V_{eff} = 0.26 Gpc^3h^{-3}



20% of the Euclid slitless data at z~1

Total effective volume (of Euclid)
V_{eff} = 19.7 Gpc^3h^{-3}

Growth rate of structure depends on gravity theory



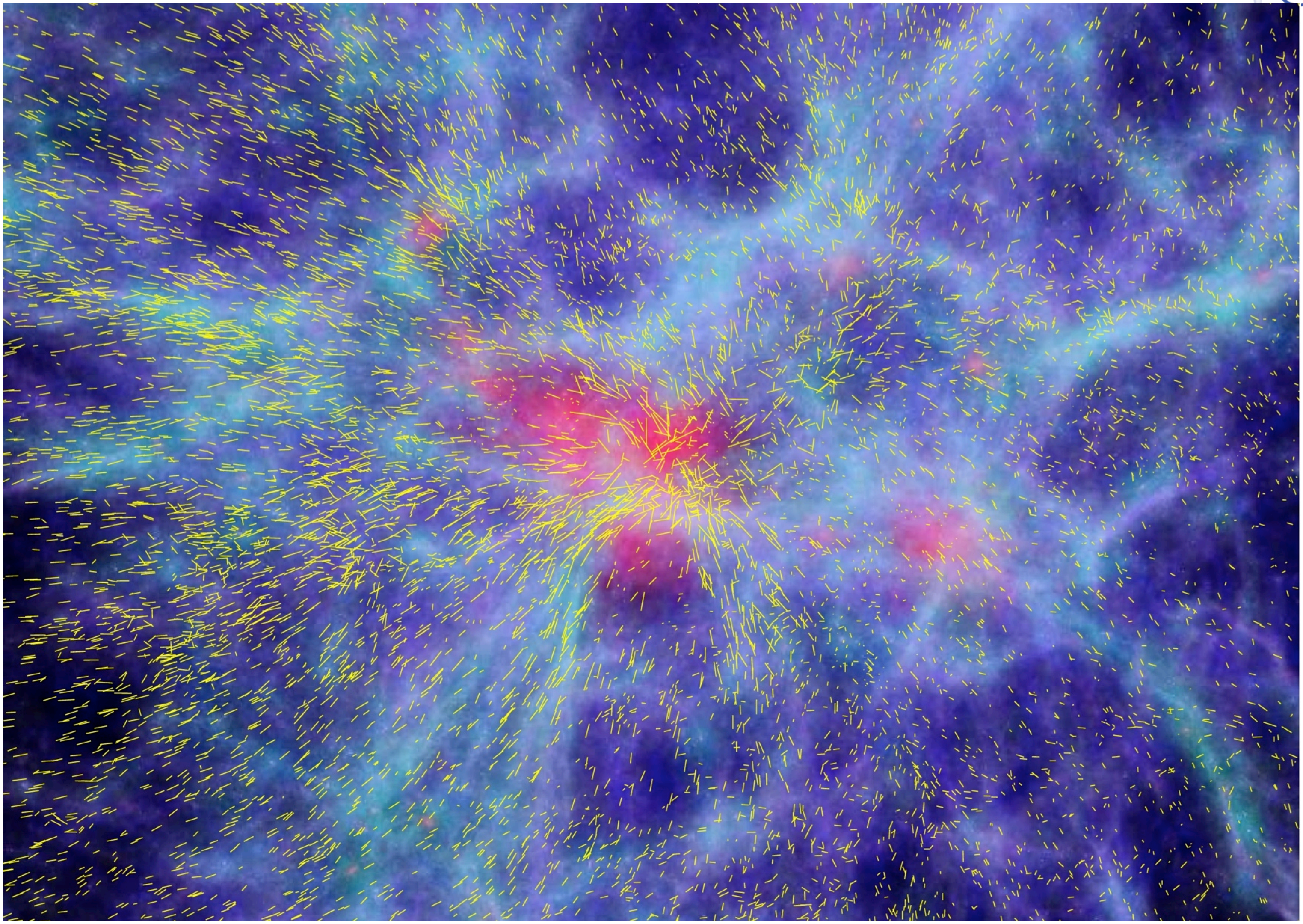
$$\ddot{\delta} + 2H(t)\dot{\delta} = 4\pi G\langle\rho\rangle\delta$$

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

$$f \equiv \frac{d\ln D}{d\ln a}$$ *Growth rate*

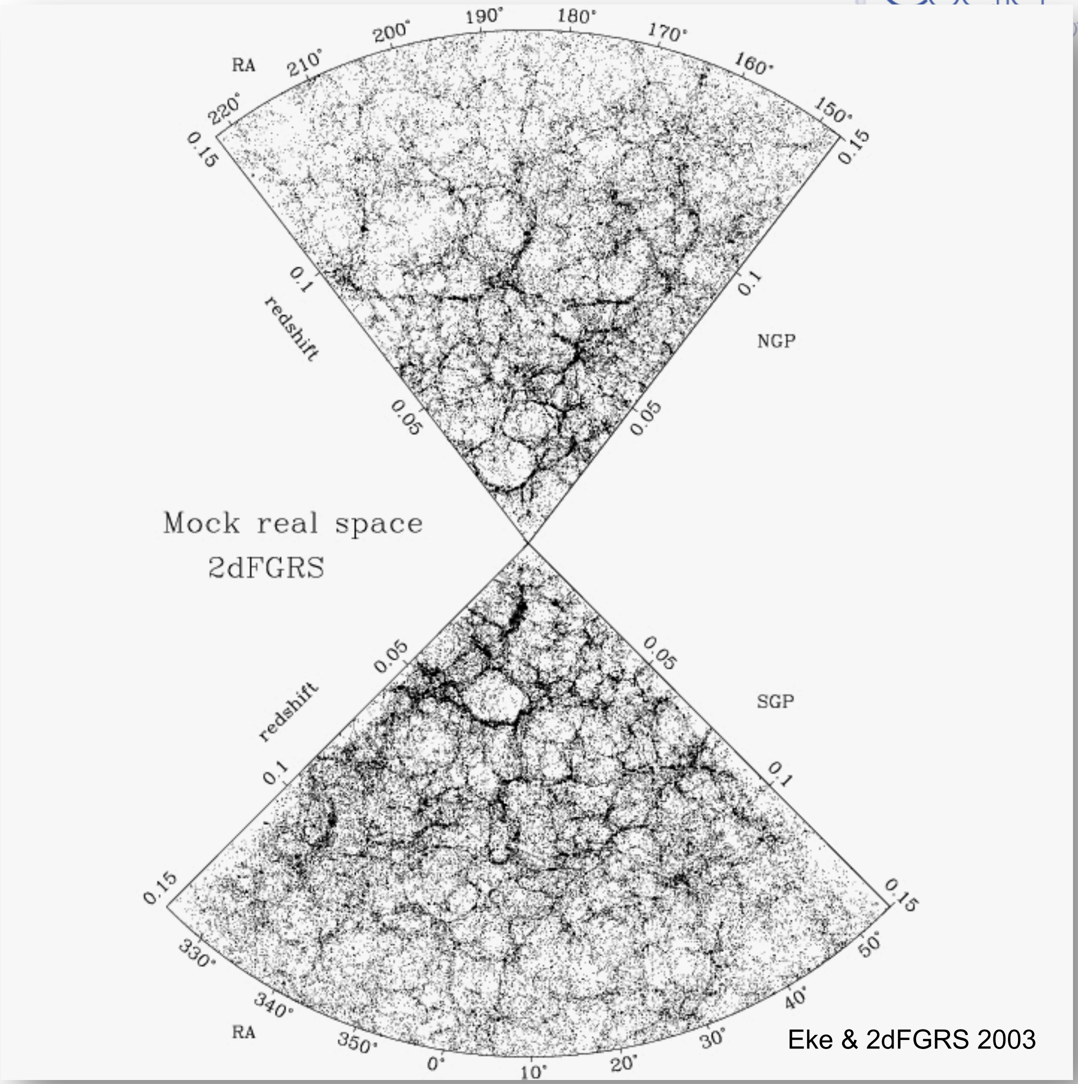
(Image credit: V. Springel)

Growth produces motions: galaxy peculiar velocities



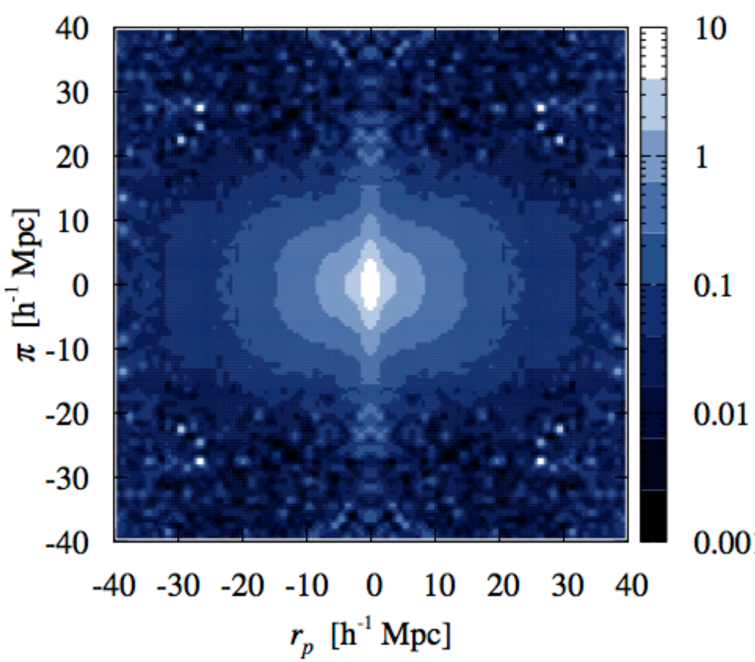
In galaxy redshift surveys peculiar velocities manifest themselves as *redshift-space distortions* (Kaiser 1987)

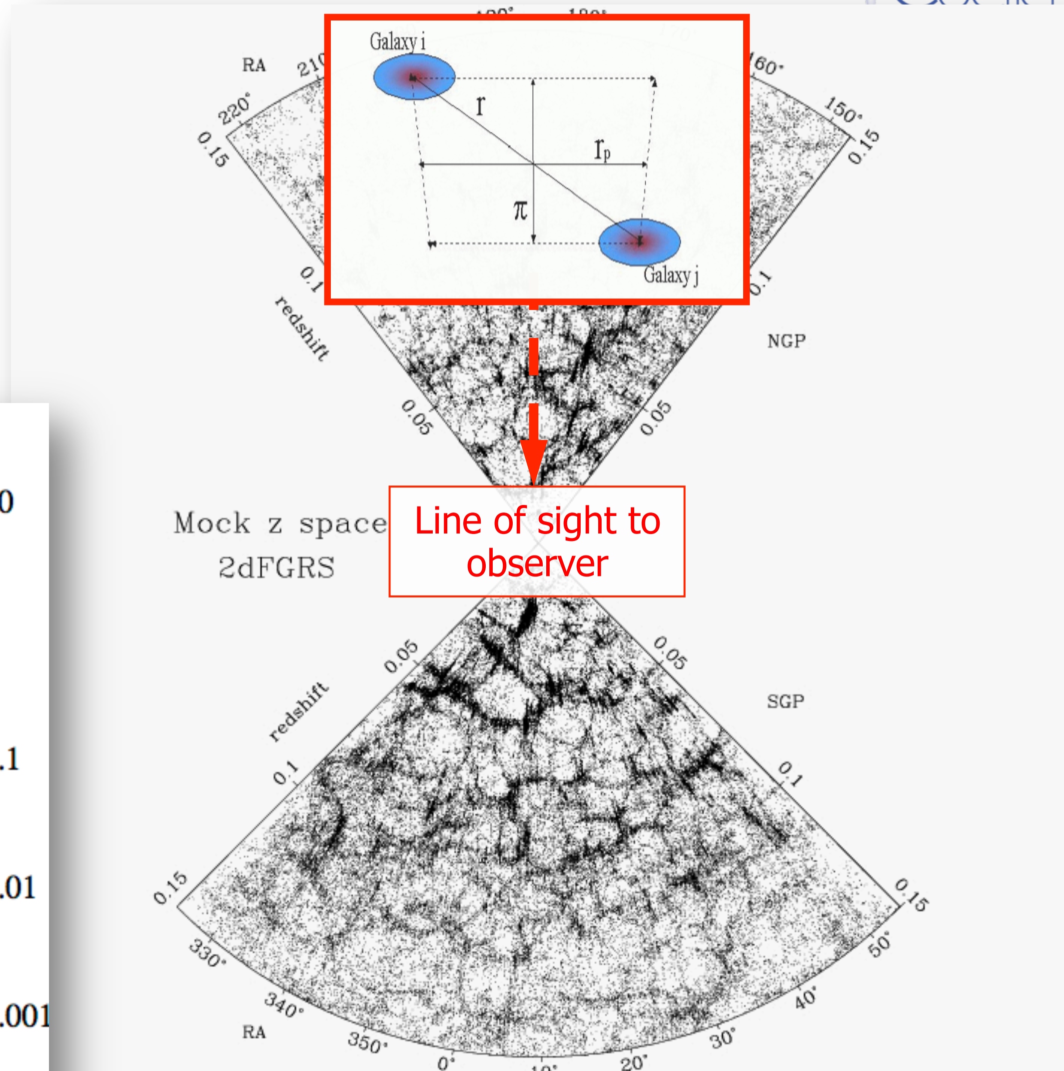
real space



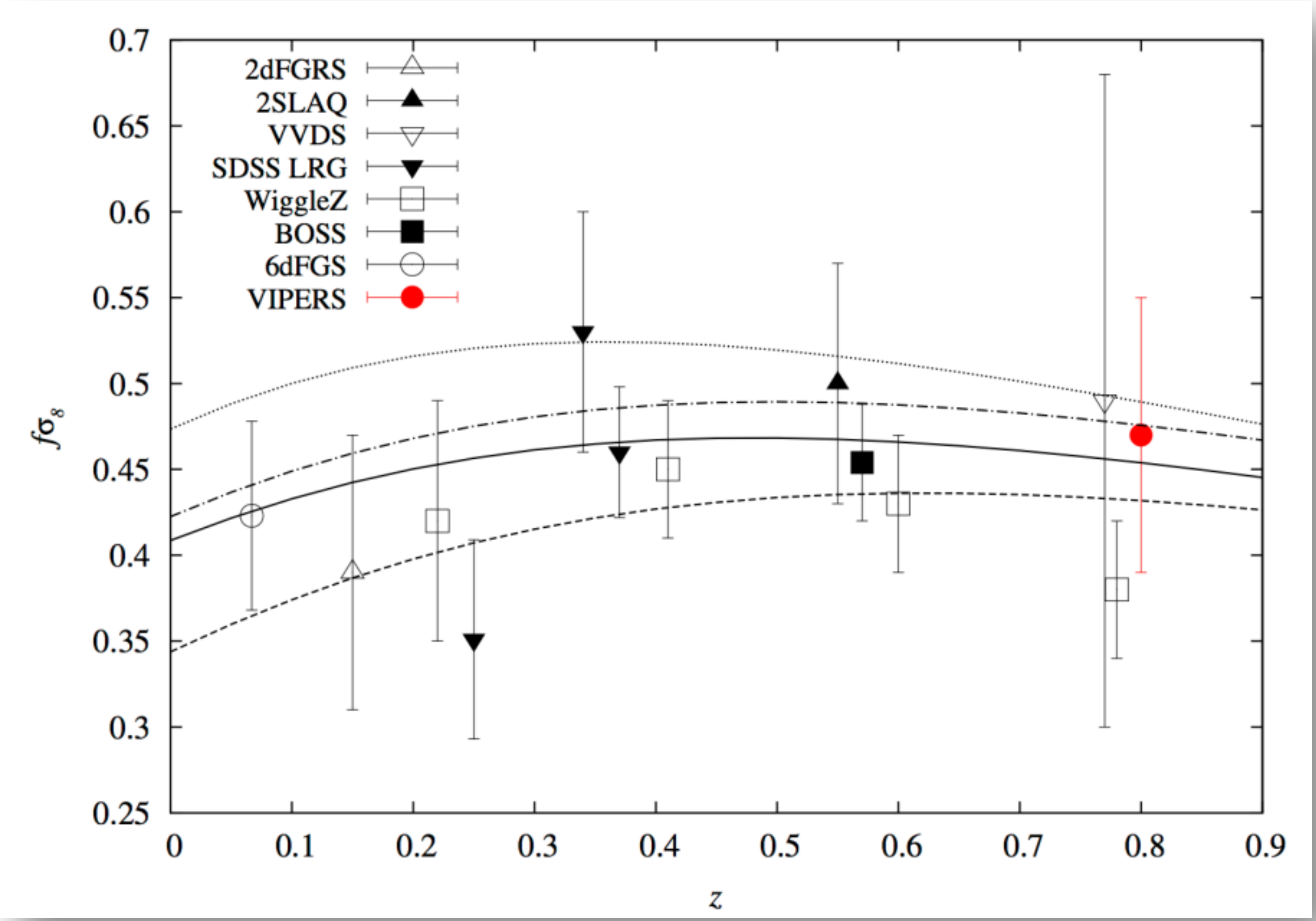
In galaxy redshift surveys peculiar velocities manifest themselves as *redshift-space distortions* (Kaiser 1987)

De la Torre & VIPERS team, 2013



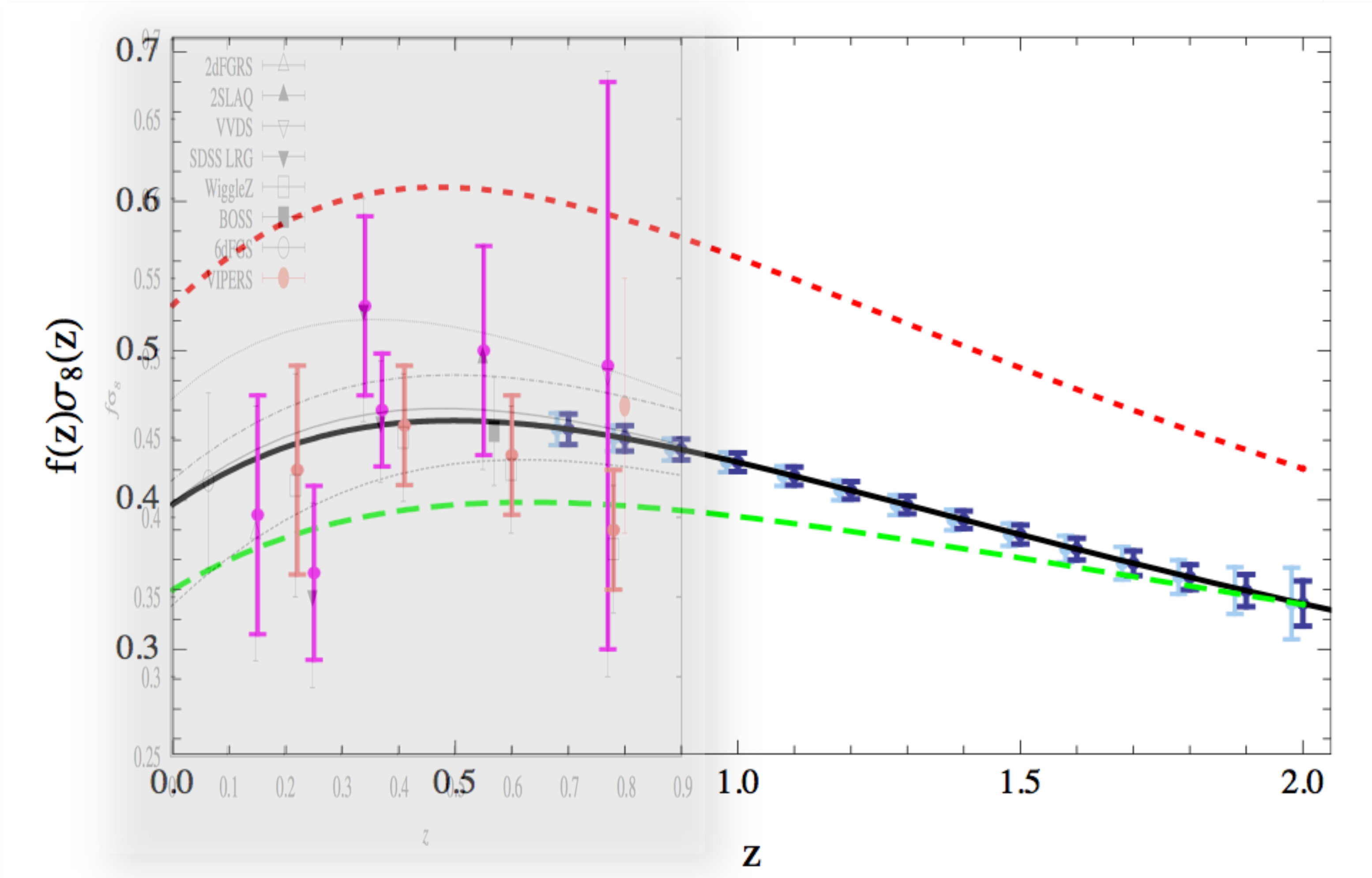


State-of-the art



De la Torre, Guzzo & VIPERS team, 2013

Euclid potential

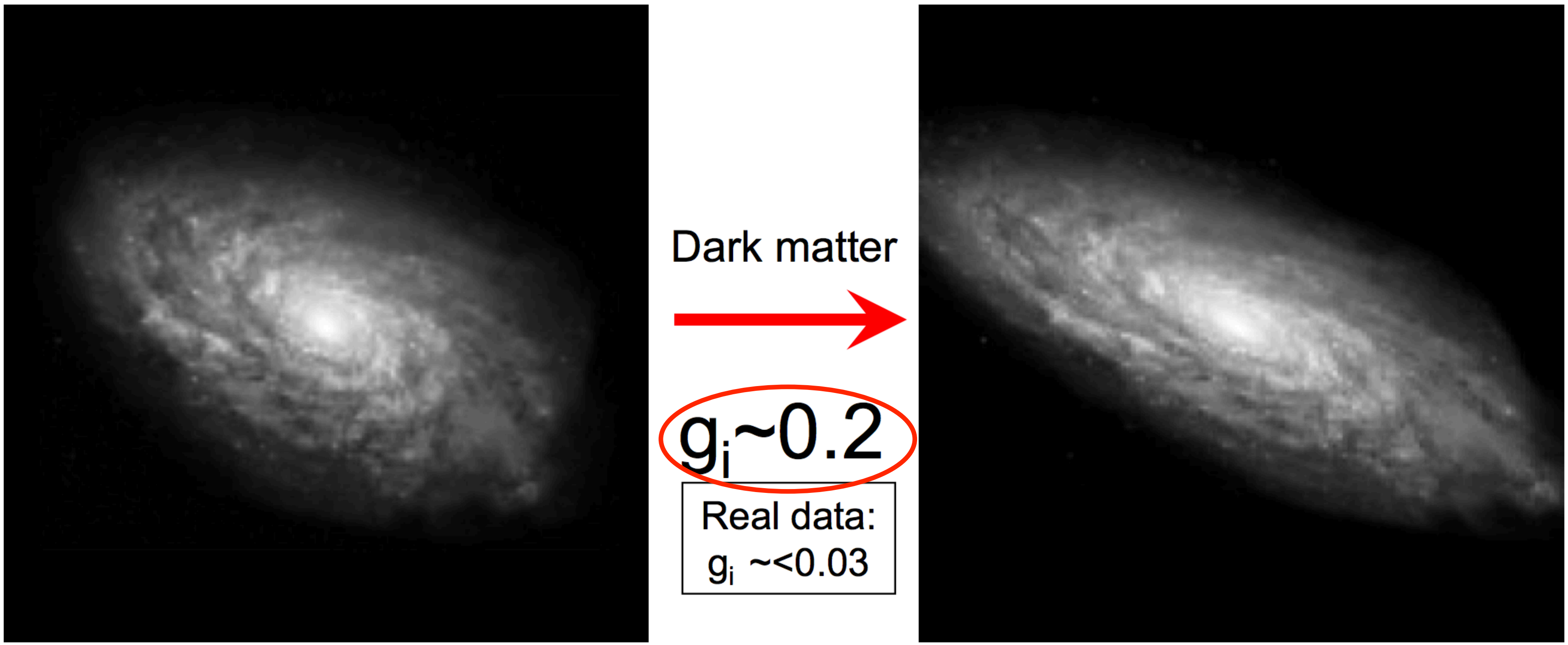


Majerotto, Guzzo, Samushia, Percival, Wang, et al. 2012

Weak Lensing increases galaxy ellipticity

$$\langle \epsilon \rangle = \langle \epsilon^S \rangle + \langle g \rangle$$
$$\langle \epsilon \rangle \approx \langle g \rangle .$$

Assuming galaxy orientations are randomly distributed

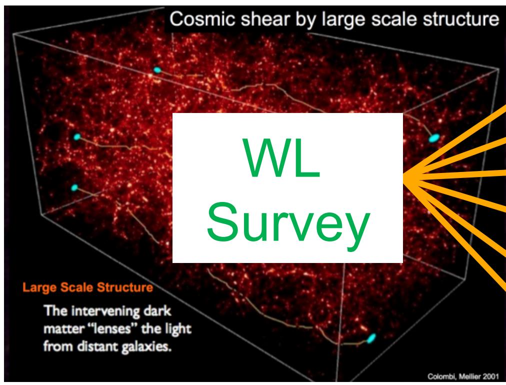


Kitching 2010

$$\begin{pmatrix} x_u \\ y_u \end{pmatrix} = \begin{pmatrix} 1-g_1 & -g_2 \\ -g_2 & 1+g_1 \end{pmatrix} \begin{pmatrix} x_l \\ y_l \end{pmatrix}$$

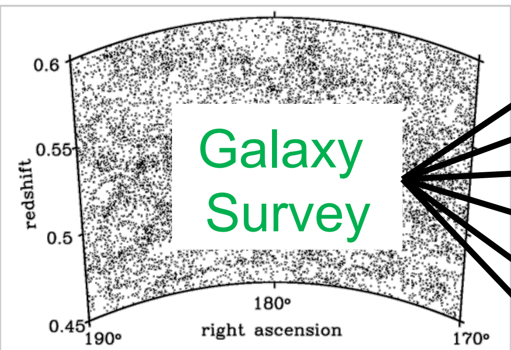
Cosmology with the Euclid

Weak Lensing survey



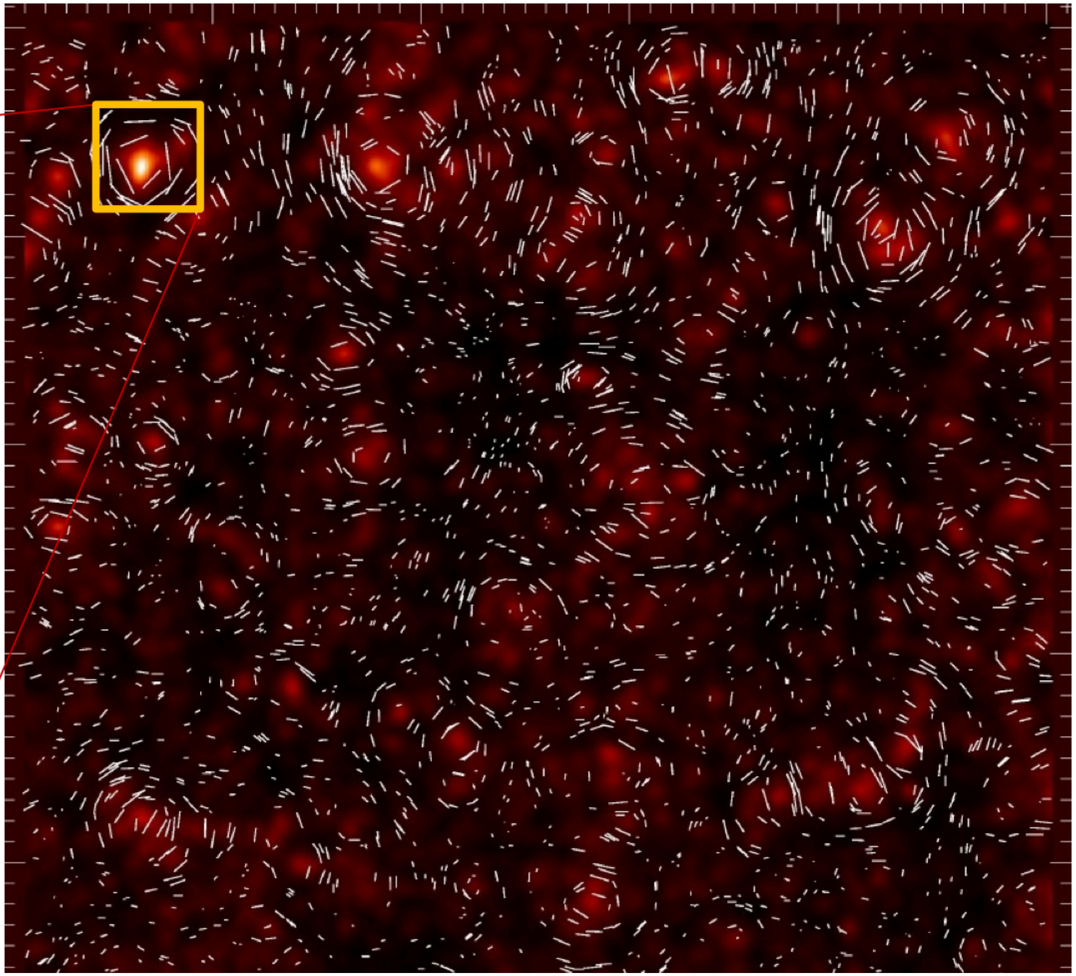
- DM power spectrum, tomography → What is the expansion rate of the Universe?
- Peak stat, Clusters Mass Func → What is the expansion rate of the Universe?
  - → Understanding Dark Energy
- DM power spectrum, tomogr → How does structure form within this background? → Understanding energy-density, gravity
- DM power spectrum → What are the neutrino masses, matter density? → Understanding energy-density
- 3-pt statistics, Halos → What is f_{nl}, which quantifies non-Gaussianity? GR-horizon effects → Understanding Inflation, GR
- ISW effect → Does the potential change along line-of-sight to CMB → Understanding DE, GR

Cosmology with the Euclid Redshift Survey



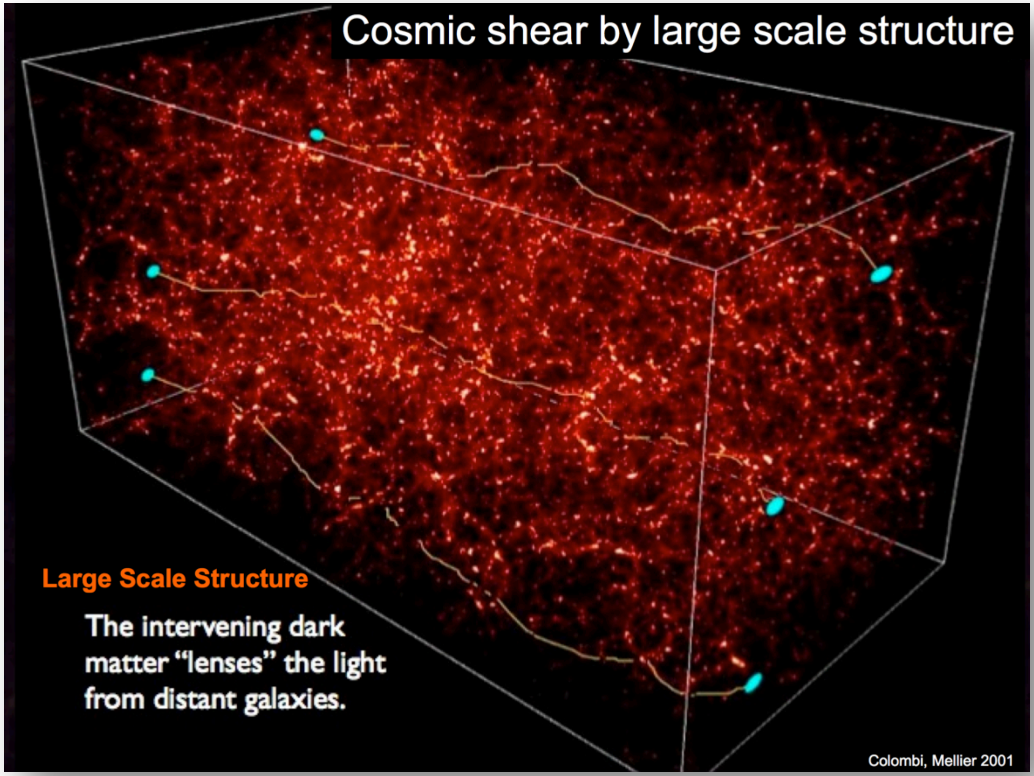
- Baryon Acoustic Oscillations → What is the expansion rate of the Universe?
- Alcock-Paczynski effect → What is the expansion rate of the Universe?
  - → Understanding Dark Energy
- Redshift-Space Distortions → How does structure form within this background? → Understanding energy-density, gravity
- Comoving clustering → What are the neutrino masses, matter density? → Understanding energy-density
- Large-scale shape → What is f_{nl}, which quantifies non-Gaussianity? GR-horizon effects → Understanding Inflation, GR
- ISW effect → Does the potential change along line-of-sight to CMB → Understanding DE, GR

Cosmological distortion field projected on the sky



Weak Lensing tomography: get matter P(k,z)

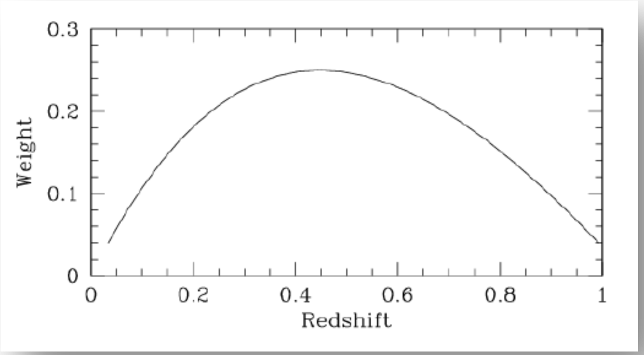
- The lensing kernel is most sensitive to structure halfway between the observer and the source. But the kernel is broad: we do not need precise redshifts for the sources: photometric redshifts are fine
- Also, since the kernel is broad the tomographic bins are very correlated. The gain saturates quickly with the number of bins: not many z bins



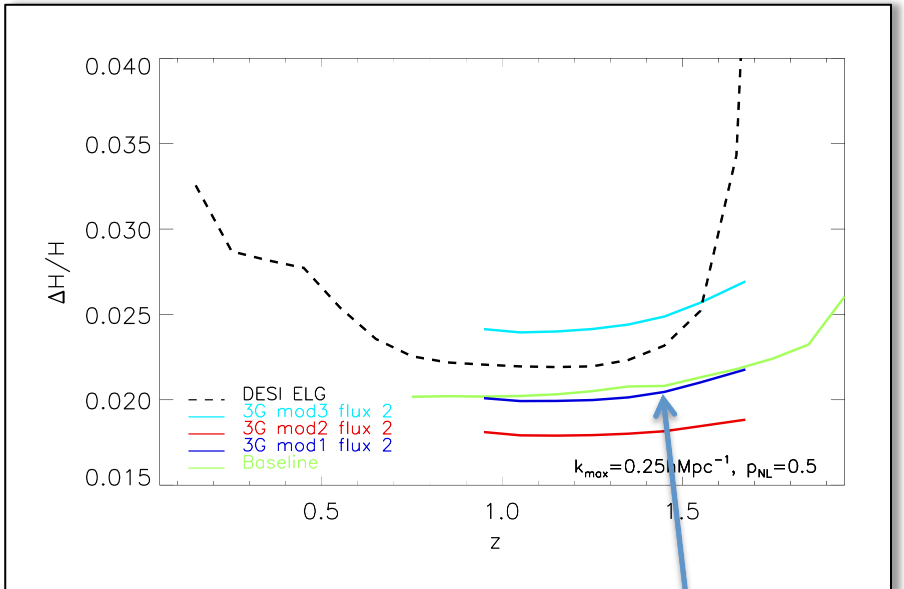
Geometry — Large Scale Structure

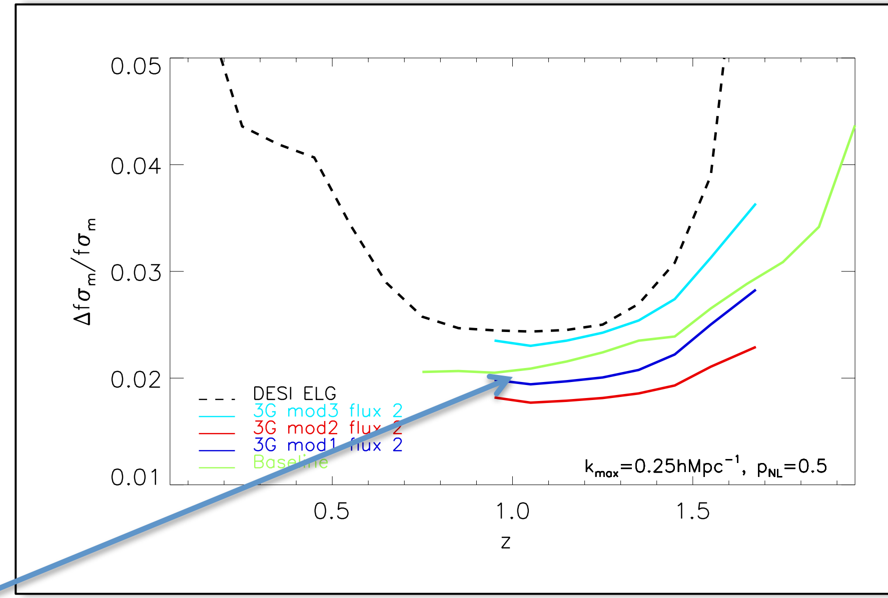
$$C_{ij}(\ell) = \int_0^{r_H} \mathrm{d}r\, W_{ij}^{GG}(r) P_{\delta\delta}\left(\frac{\ell}{S_k(r)}; r\right)$$

Lensing Power Spectrum



Forecast on H(z) and growth errors





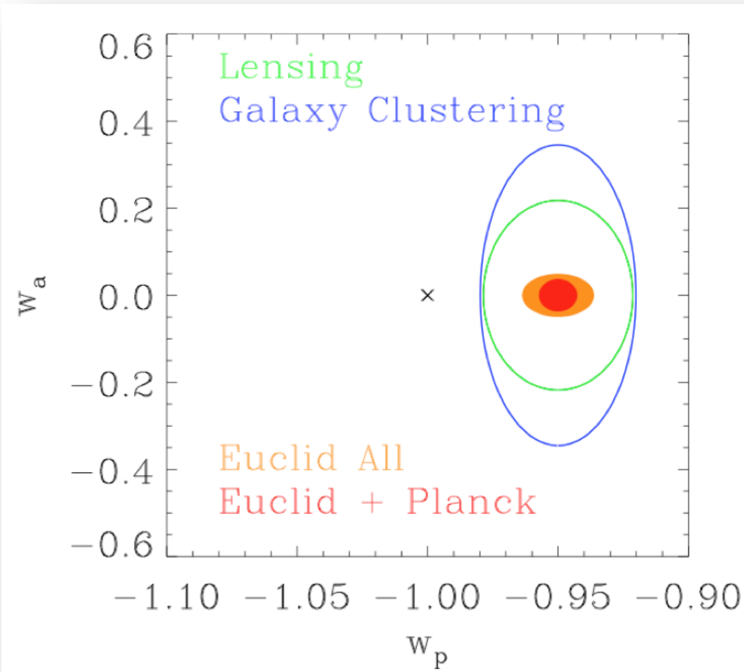
Flux>2 x 10^{-16} erg cm^{-2} s^{-1}

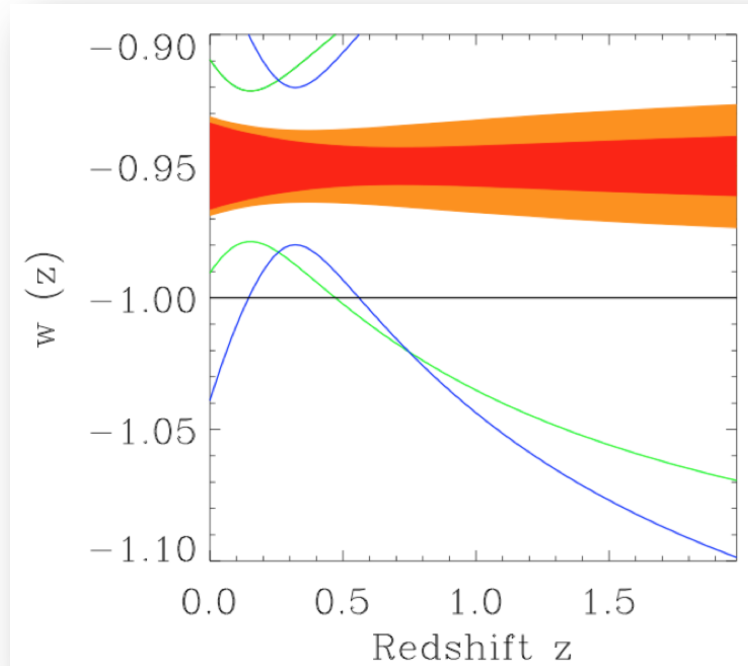
z=0.9 start, Mod. 1, No. of galaxies= 26.2M   FoM= 433 (γ fixed)

- Deep flux limit: 2 x 10^{-16} erg cm^{-2} s^{-1}
- 3 up-to-date models for dN/dz by Pozzetti, Geach & Hirata
- Forecast code by R. Bean

The full power of EUCLID (RedBook reference)

1. Dark Energy equation of state from combined Weak Lensing and Galaxy Clustering (BAO)



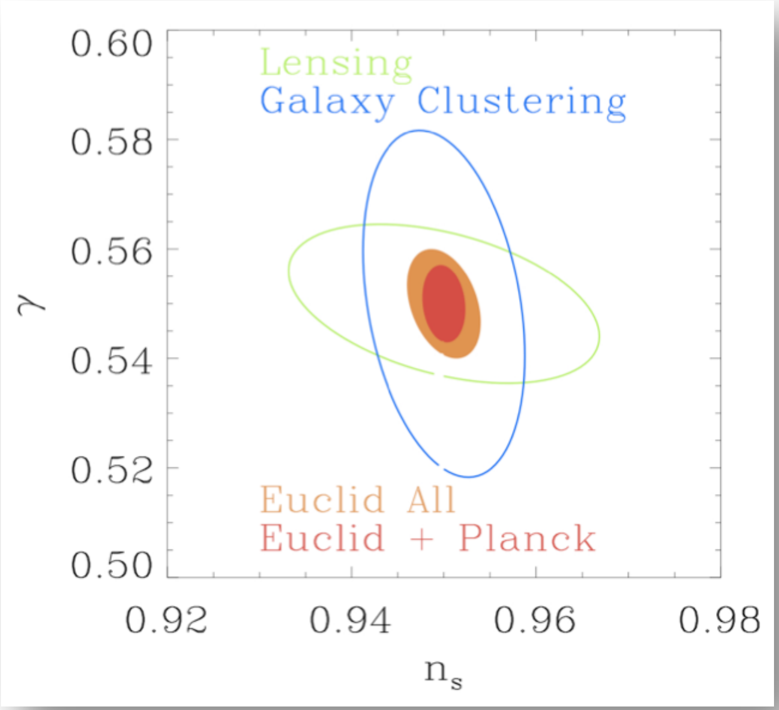


Answering Euclid key science question 1: Is dark energy simply a cosmological constant, or is it a field that evolves dynamically with the expansion of the Universe?

The full power of EUCLID

2. Growth rate of structure from combined Weak Lensing (tomography) and Galaxy Clustering (redshift-space distortions)

$f(z)=[\Omega_m(z)]^\gamma$



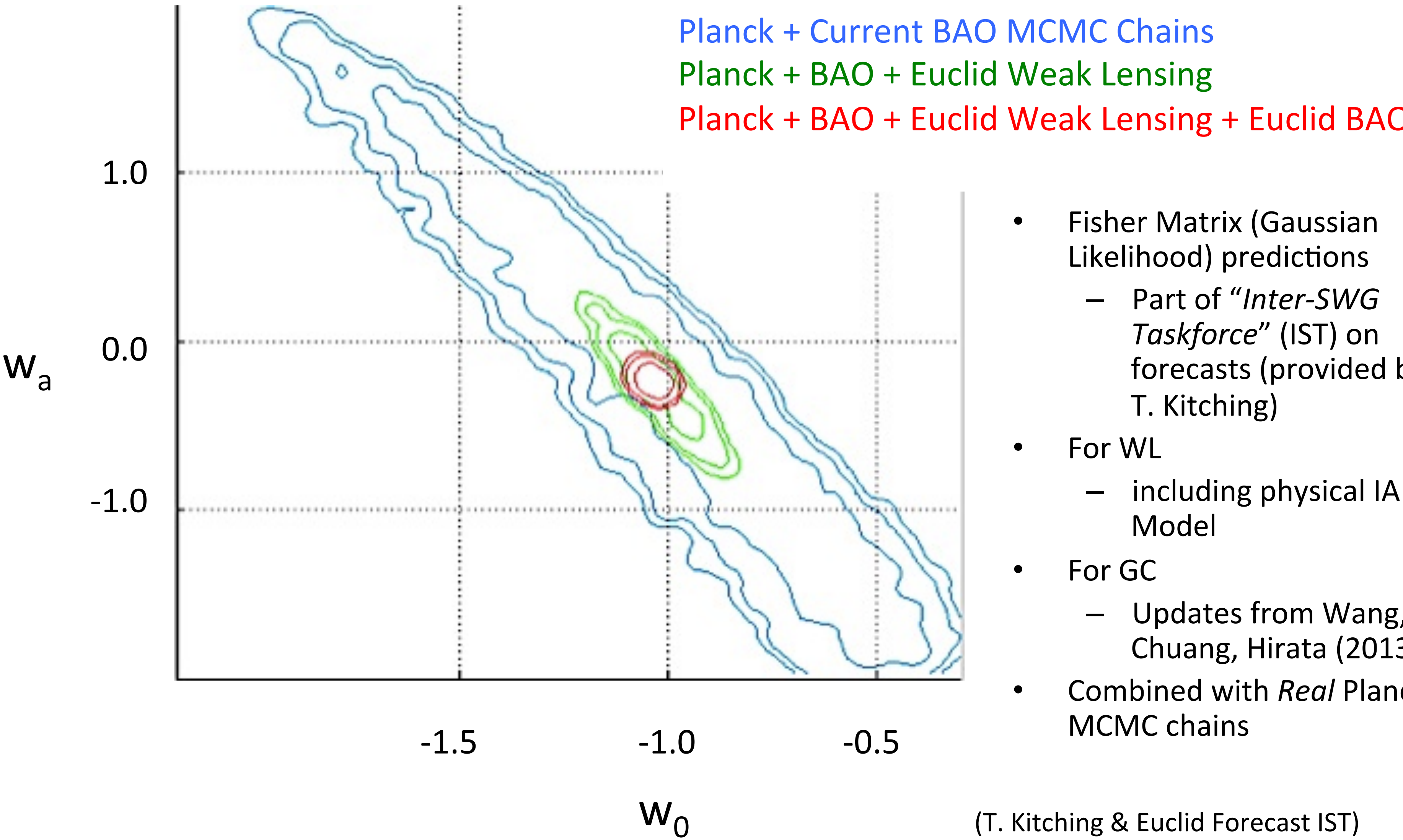
$P_o(k)=Ak^n$

Answering Euclid key science question 2: Is is the apparent acceleration instead a manifestation of a breakdown of General Relativity on the largest scales?

Euclid performance

	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_ν/eV	f_{NL}	w_p	w_a	FoM
Euclid Primary	0.010	0.027	5.5	0.015	0.150	430
Euclid All	0.009	0.020	2.0	0.013	0.048	1540
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	4020
Current (09/2011)	0.200	0.580	100	0.100	1.500	~10
Improvement Factor	**30**	**30**	**50**	**>10**	**>50**	**>300**

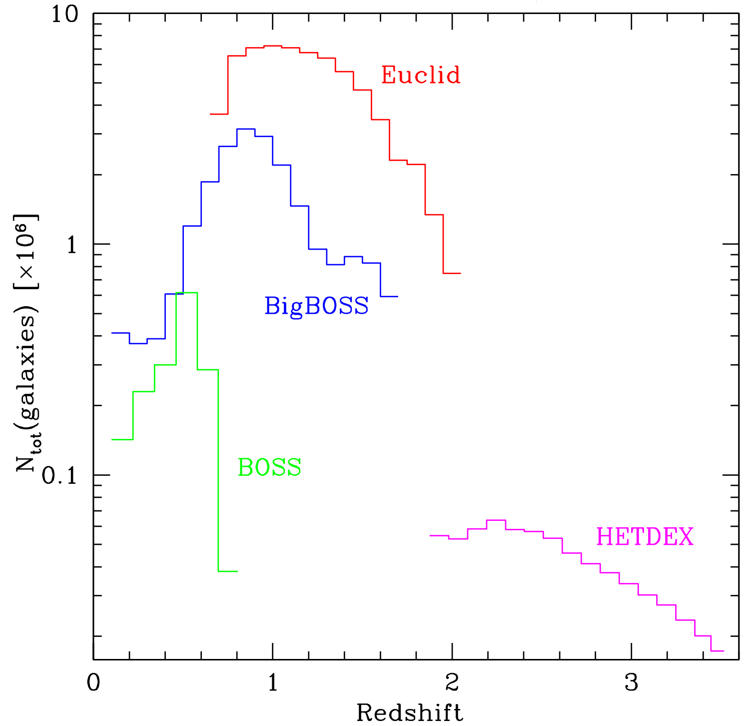
Euclid addresses most aspects of the current cosmological paradigm



- Fisher Matrix (Gaussian Likelihood) predictions
  - Part of "*Inter-SWG Taskforce*" (IST) on forecasts (provided by T. Kitching)
- For WL
  - including physical IA Model
- For GC
  - Updates from Wang, Chuang, Hirata (2013)
- Combined with *Real* Planck MCMC chains

(T. Kitching & Euclid Forecast IST)

- Wide survey
  - 15,000deg^2
  - 4 dithers
  - NIR Photometry
    - Y, J, H
    - 24mag, 5σ point source
  - NIR slitless spectroscopy
    - 1100-2000nm
    - 3×10^{-16}ergcm^{-2}s^{-1} 3.5σ line flux
    - 2 dispersion directions, 2 wavebands
    - 52M galaxies



- Deep survey
  - 40deg2
  - 48 dithers
  - 12 passes, as for wide survey
  - dispersion directions for 12 passes >10deg apart

Euclid Mission Requirements

	Wide survey	Deep survey
Survey: 6 years		
size	15, 000 deg ^{2}	40 deg^2 N/S
VIS imaging		
Depth	n_{gal} > 30/arcmin^2 M_{AB} =24.5, 10σ for gal size 0.3 » → <z> ~0.9	M_{AB} = 26.5
PSF size knowledge	$\sigma[R^2]/R^2<10^{-3}$	
Multiplicative bias in shape	$\sigma[m]<2\ .10^{-3}$	
Additive bias in shape	$\sigma[c]<2\ .10^{-4}$	
Ellipticity RMS	$\sigma[e]<2\ .\ 10^{-4}$	
NIP photometry: YJH		
Depth	24 M_{AB}	26 M_{AB}
NIS spectroscopy: 4 R exp., 3 R orientations		
Flux limit (erg/cm^2/s)	2 10^{-16}	5 10^{-17}
Completness	> 45 %	>99%
Purity	>80%	>99%
Confusion	3 rotations	>12 rotations

WL and systematics

$$\gamma^{obs} = (1+m)\times\gamma^{true} + c$$

$$C_l^{true} \approx \left[1+2\langle m\rangle\right]\times C_l^{obs} + \langle c^2\rangle$$

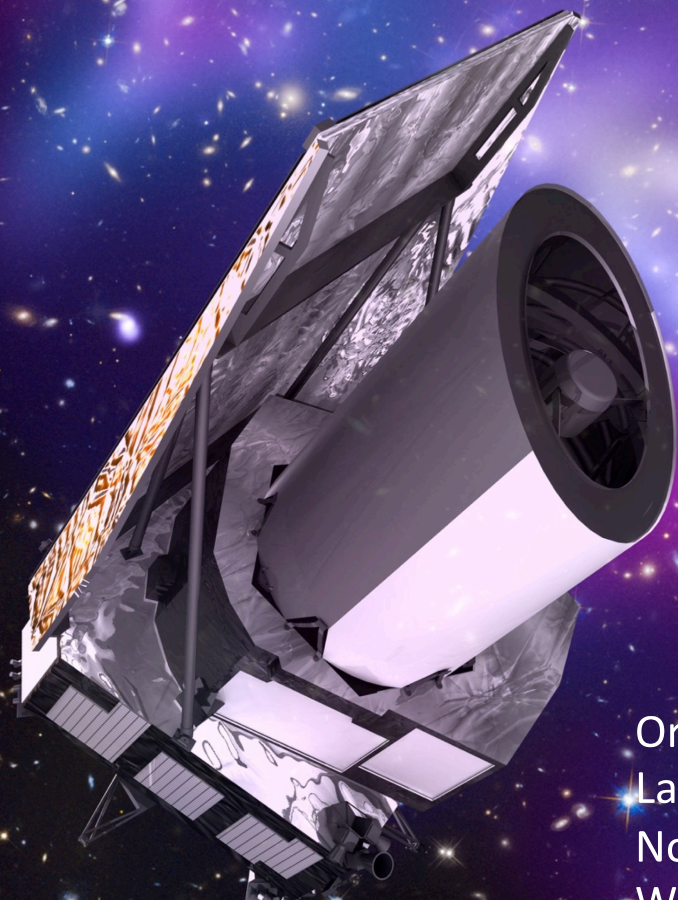
- Small PSF, Knowledge of the PSF size
- Knowledge of distortion
- Method to correct distortion
- Method to correct Non-convolutive PSF
- Stability in time → space telescope
- Visible photom photo-z accurary: 0.05x(1+z)
- Catastrophic z < 10%

GC and systematics

- Understand selection→Deep field (photo+spectro)
  - Completeness
  - Purity

Euclid

- Payload: Airbus Defence & Space
- Spacecraft: Thales AleniaSpace Torino
- Instruments: Euclid Consortium
  - 13 EU countries + NASA+ US labs
  - >120 institutes/ labs
  - >1100 members

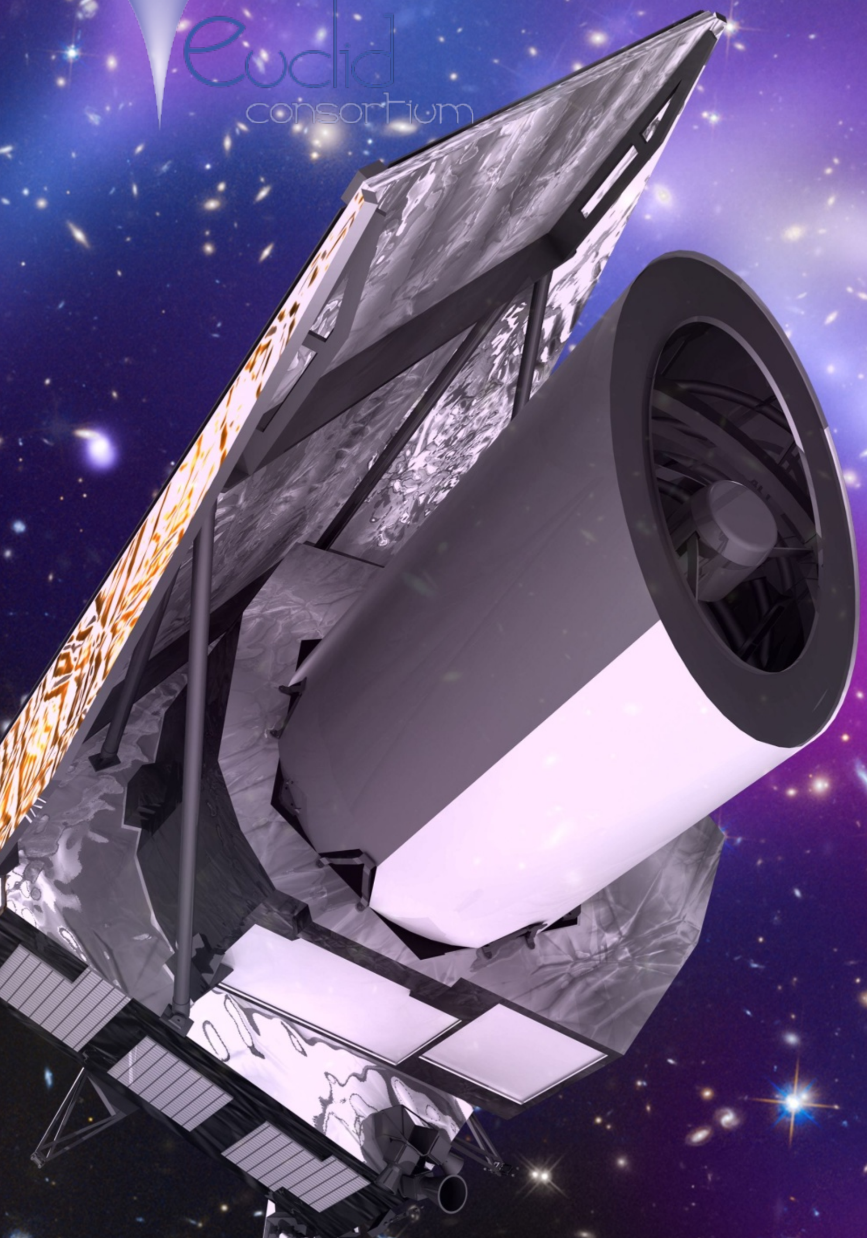


An artist view of the Euclid satellite – courtesy ESA

Orbit: L2
Launch: Q4 2020
Nominal Mission: 6.5 y
Wide survey: 15000 sq deg

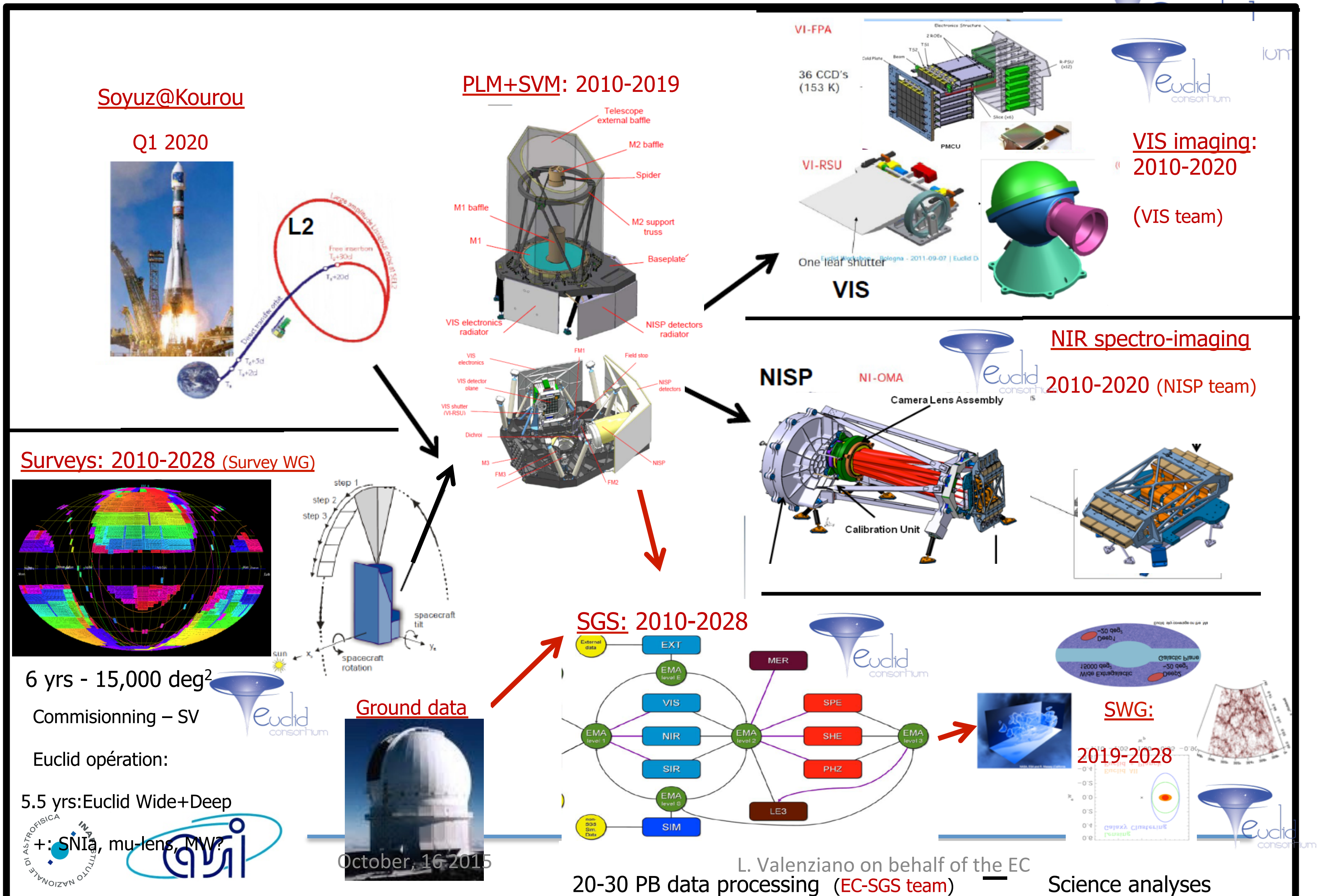
Euclid consortium

Euclid

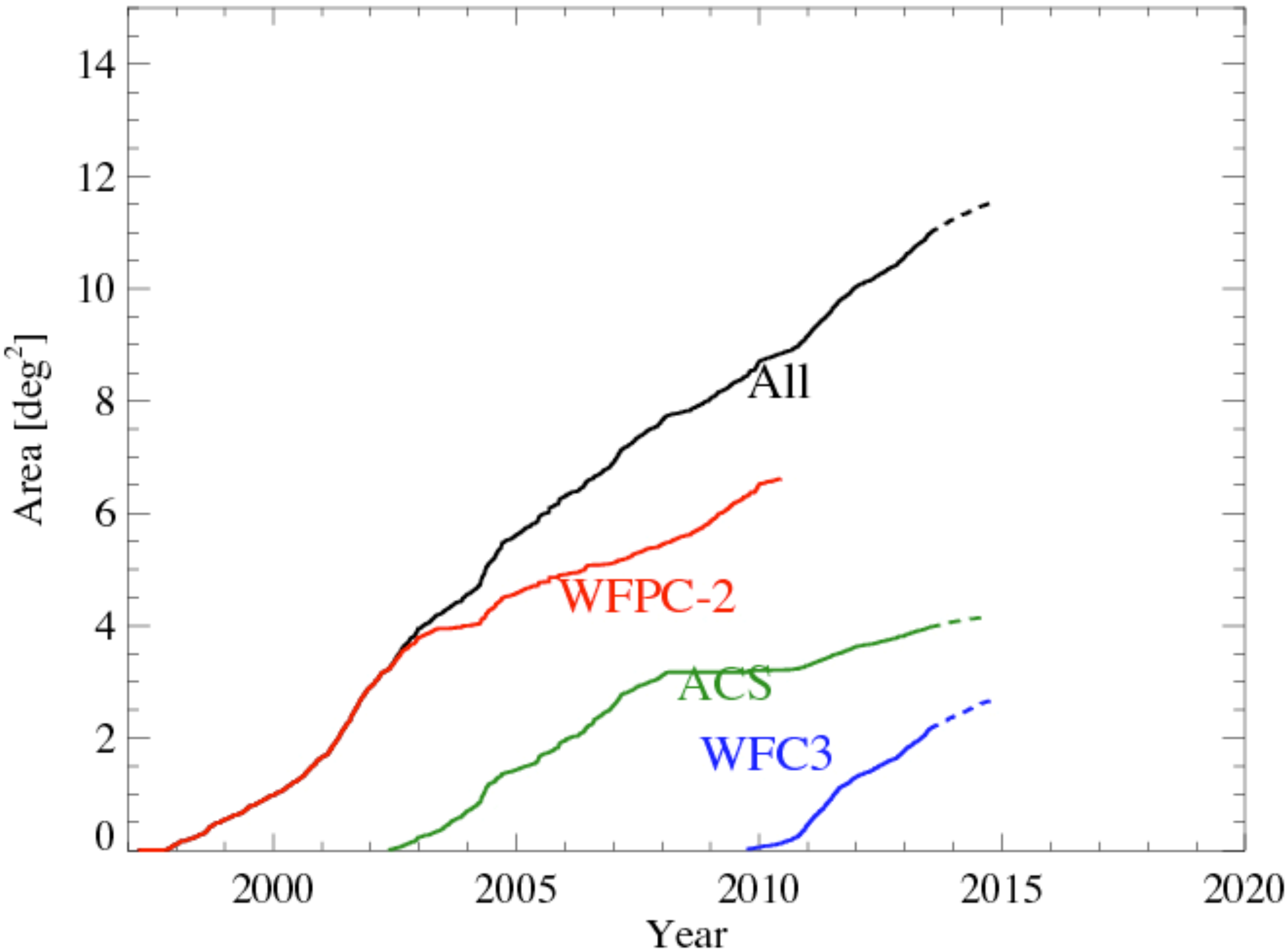


- **ESA-led mission**
- Selected in Oct. 2011 - Fully funded
- Partners: ESA, TAS, Airbus DS, Euclid Consortium (EC)
- Cost: ~ 850 Meuros (~ 2/3 ESA; ~1/3 EC)
- Overall Mass: ~2020 kg
- Power : 1710 W
- Telescope :
  - 1.2m aperture primary ,3 mirror anastigmat
- 2 Instruments (VIS, NISP); 2 channels
  - Wide field instrument, VIS: 36 e2v 4kx4k CCDs
  - 576 M pixels, 0.11 arcsec/pix, 0.53 deg^2 FoV
  - Photom.+spectrom.: 16 H2GR HgCdTe detectors;
  - 64 Mpixels, 0.30 arcsec/pix, 0.53 deg^2 FoV (=VIS)
  - Grism slitless spectro (1B + 3R grisms)
- Downlink Rate: X/X + K-band to Ground Station 55 Mbits/s. 850 Gbit/day to transfer 4hr/day.
- Ground Segment: ESA (50%,) EC (50%, EC leads science and external data): 1.5 billion galaxies for WL, 30 million redshifts, 12 billion sources (3sigma)
- L2 orbit
- Launch Vehicle – Soyuz-Fregat
- Launch date 2020, from Kourou space port
- 6.5 years mission+additional surveys (exopl, SN)
- Main surveys: 15,000 deg^2+40 deg^2 2 mag. deeper
- Science drivers: DE
- Science leads: Euclid Consortium

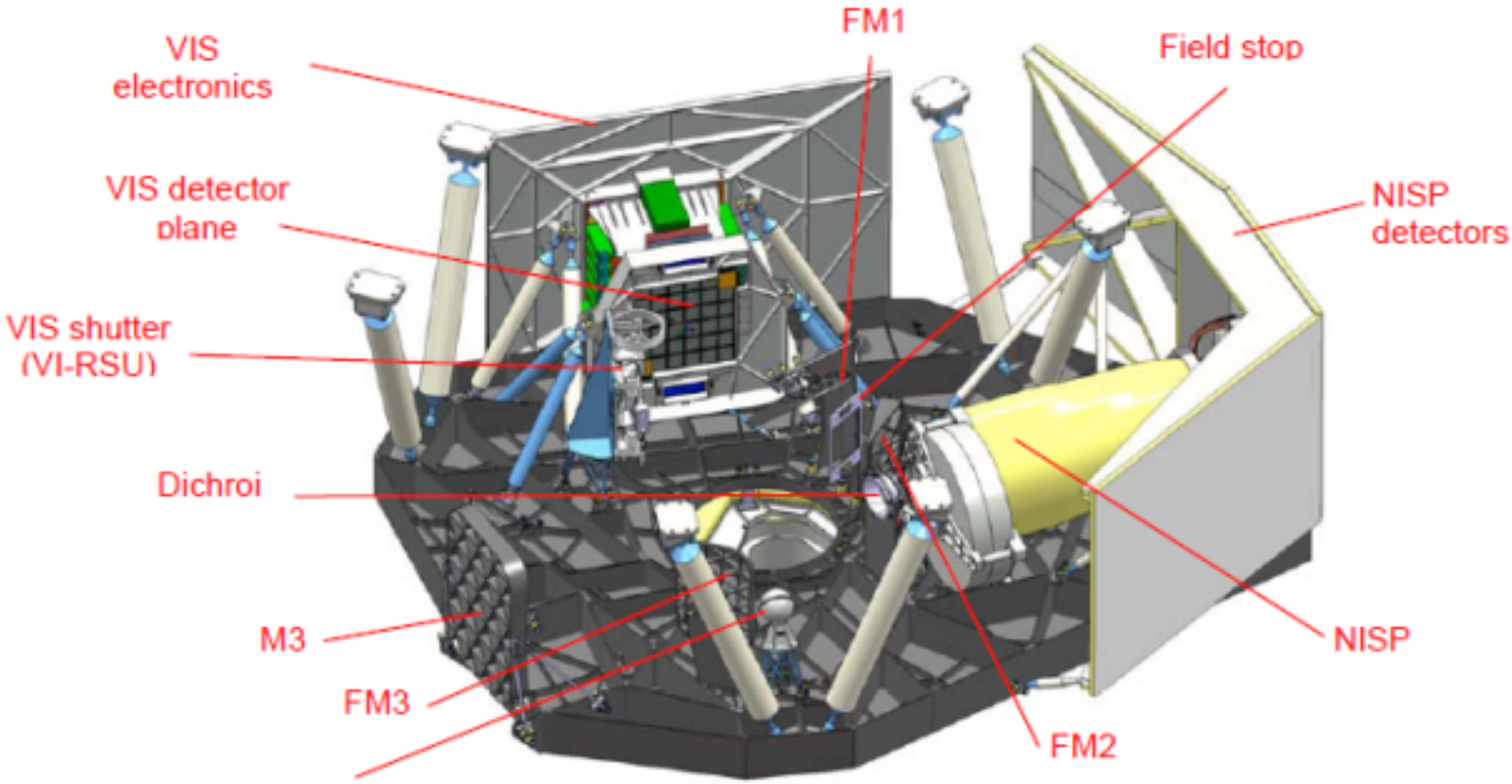
The Euclid Mission in one slide



HST survey amplitude

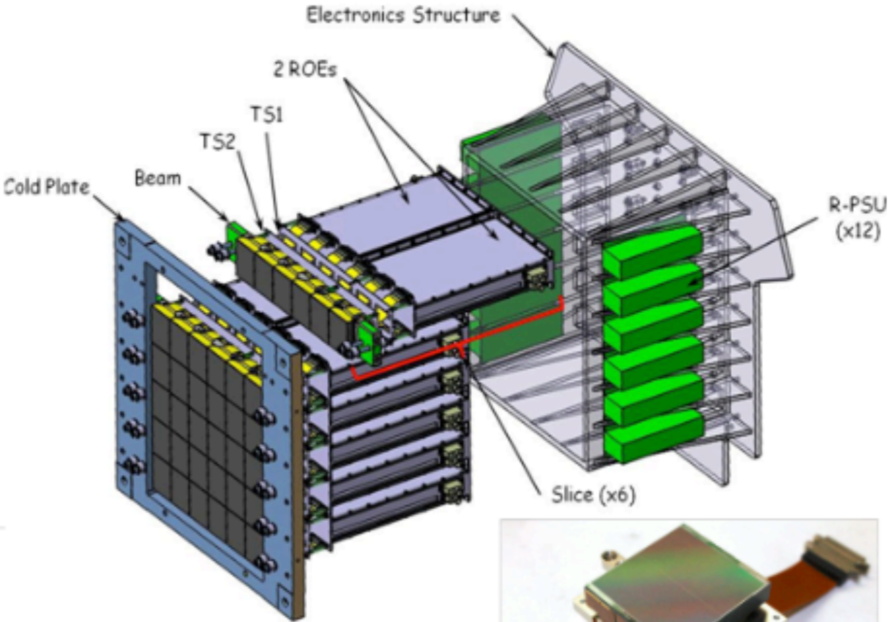


Euclid Instruments

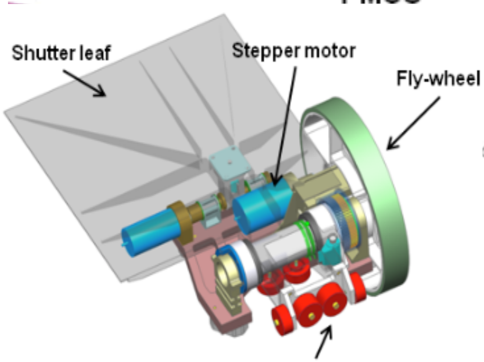


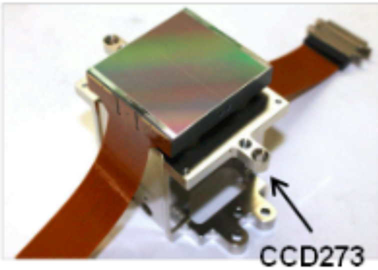
VIS and NISP Scientific Instrument

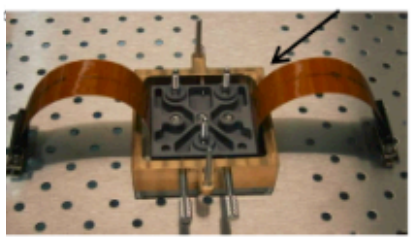
Courtesy: S. Pottinger, M. Cropper and the VIS team



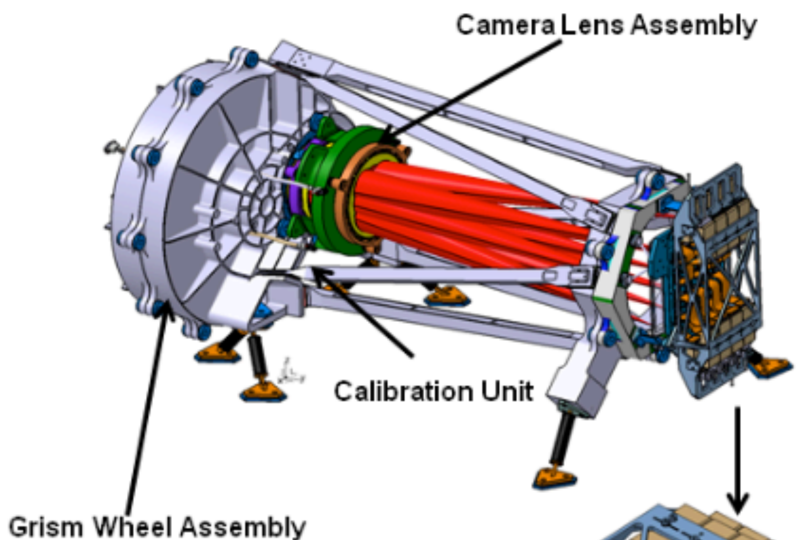
PMCU

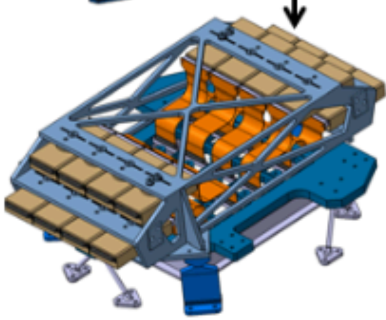




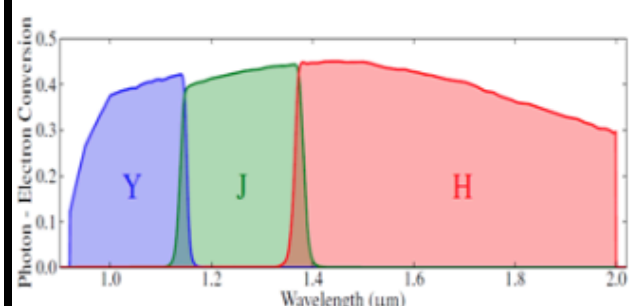


Courtesy: T. Maciaszek and the NISP team



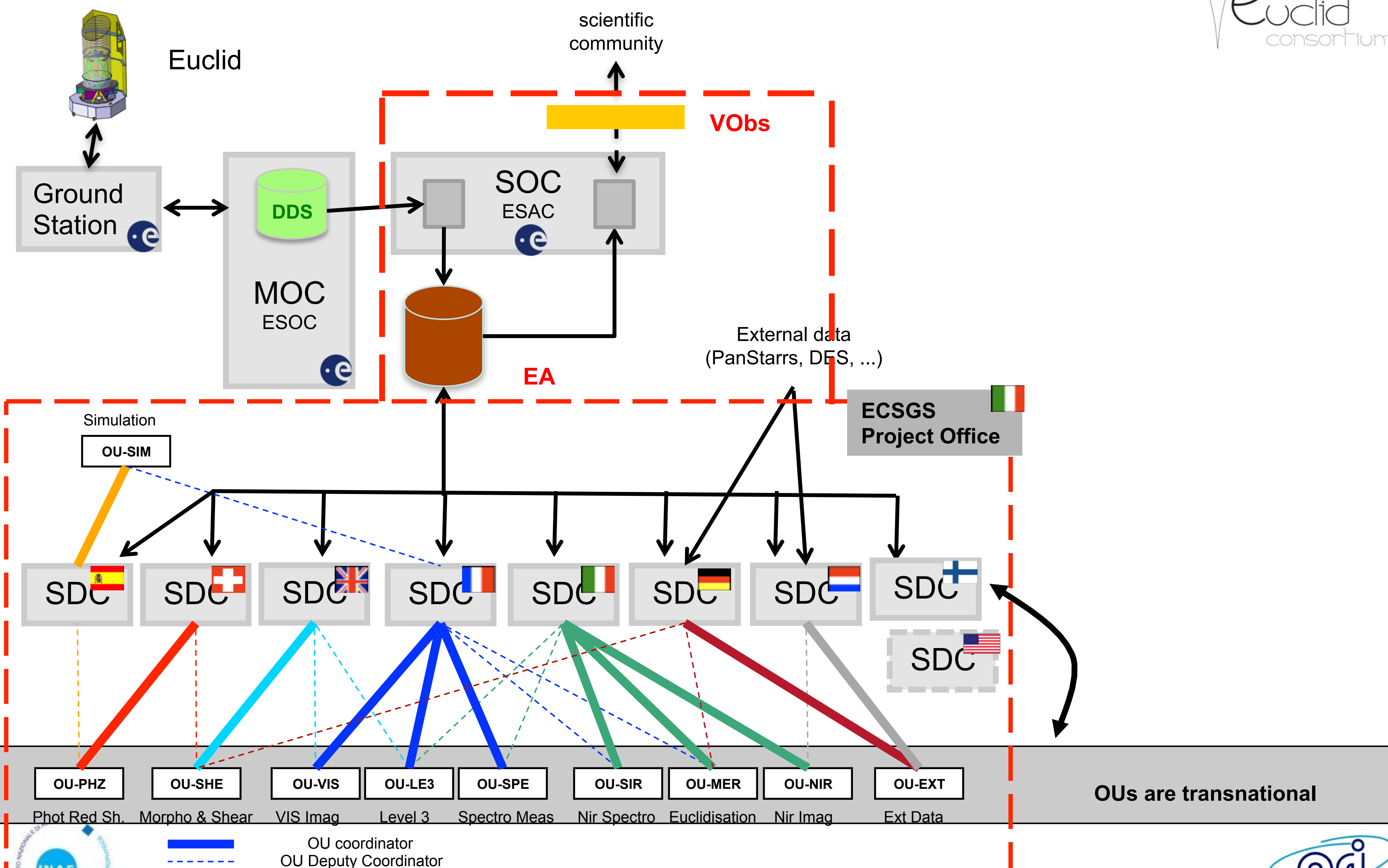


16 H2GR detectors

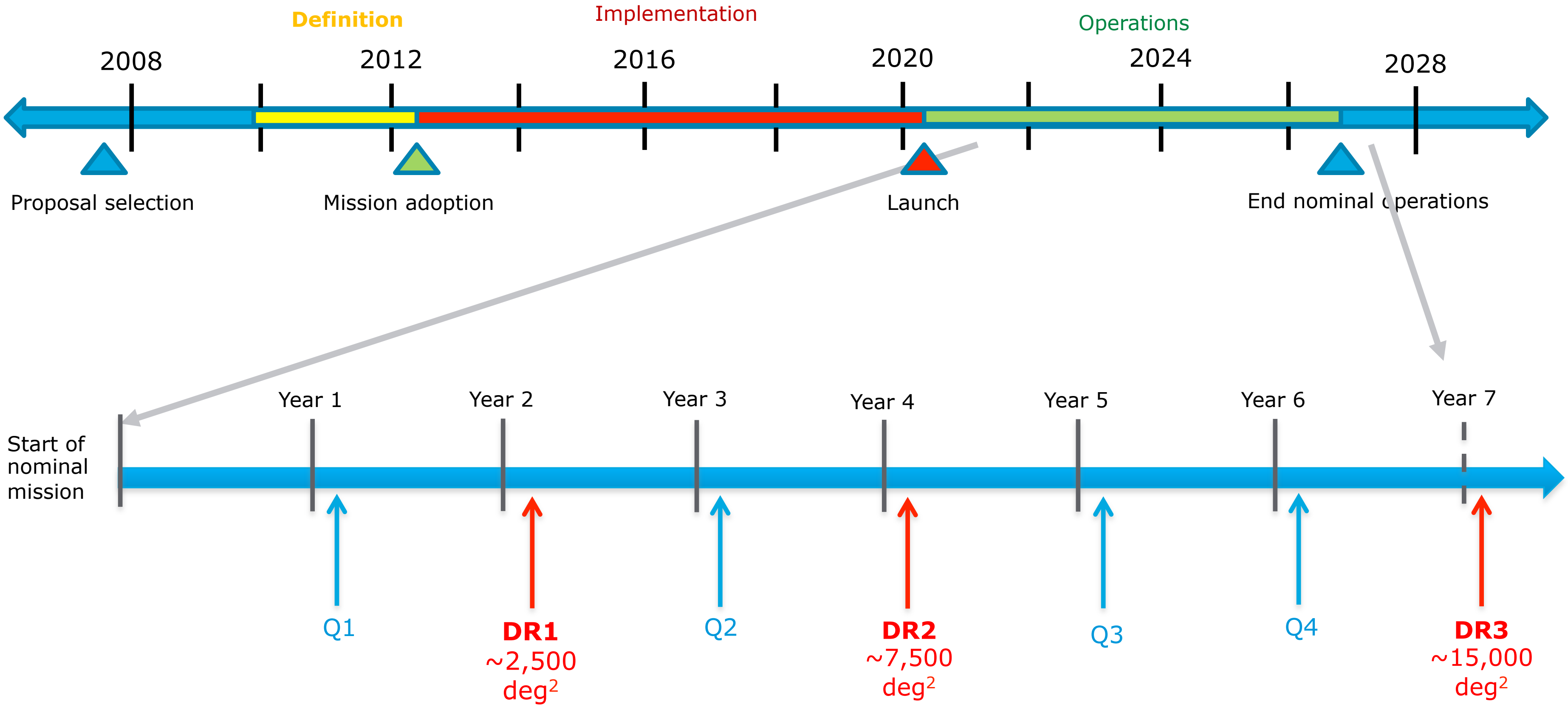


NISP throughputs through the Y, J and H filters

The Ground Segment at a glance



Euclid Schedule



Euclid Imaging

M51

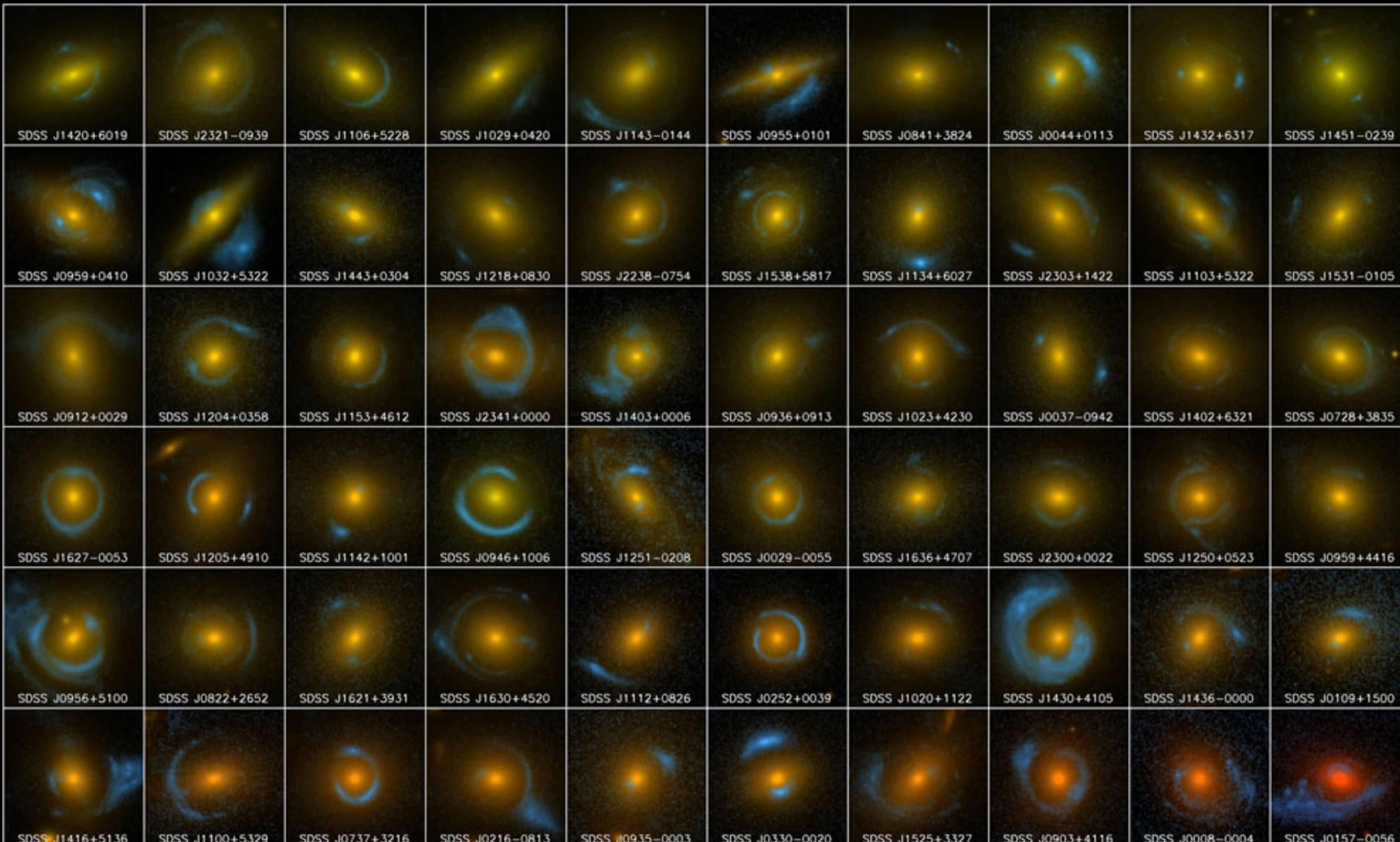
Courtesy J. Brinchmann, Steve Warren

SDSS @ z=0.1 | Euclid @ z=0.1 | Euclid @ z=0.7


Télescope Canada France Hawaii


Euclid

SLACS (~2010 - HST)



SLACS: The Sloan Lens ACS Survey

www.SLACS.org

A. Bolton (U. Hawai'i IfA), L. Koopmans (Kapteyn), T. Treu (UCSB), R. Gavazzi (IAP Paris), L. Moustakas (JPL/Caltech), S. Burles (MIT)

Image credit: A. Bolton, for the SLACS team and NASA/ESA


SLACS
Euclid VIS Legacy : after 2 months
(66 months planned)

Neutrinos and Relativistic Species

Amendola et al 2013

	General cosmology					
fiducial →	$\Sigma = 0.3\,\text{eV}^a$	$\Sigma = 0.2\,\text{eV}^a$	$\Sigma = 0.125\,\text{eV}^b$	$\Sigma = 0.125\,\text{eV}^c$	$\Sigma = 0.05\,\text{eV}^b$	$N_{\text{eff}} = 3.04^d$
EUCLID+Planck	0.0361	0.0458	0.0322	0.0466	0.0563	0.0862
	ΛCDM cosmology					
EUCLID+Planck	0.0176	0.0198	0.0173	0.0218	0.0217	0.0224

[a] for degenerate spectrum: $m_1 \approx m_2 \approx m_3$; [b] for normal hierarchy: $m_3 \neq 0$, $m_1 \approx m_2 \approx 0$
[c] for inverted hierarchy: $m_1 \approx m_2$, $m_3 \approx 0$; [d] fiducial cosmology with massless neutrinos

Changes in neutrino mass and species make tiny changes in P(k) and in the Alcock-Paczynski test.

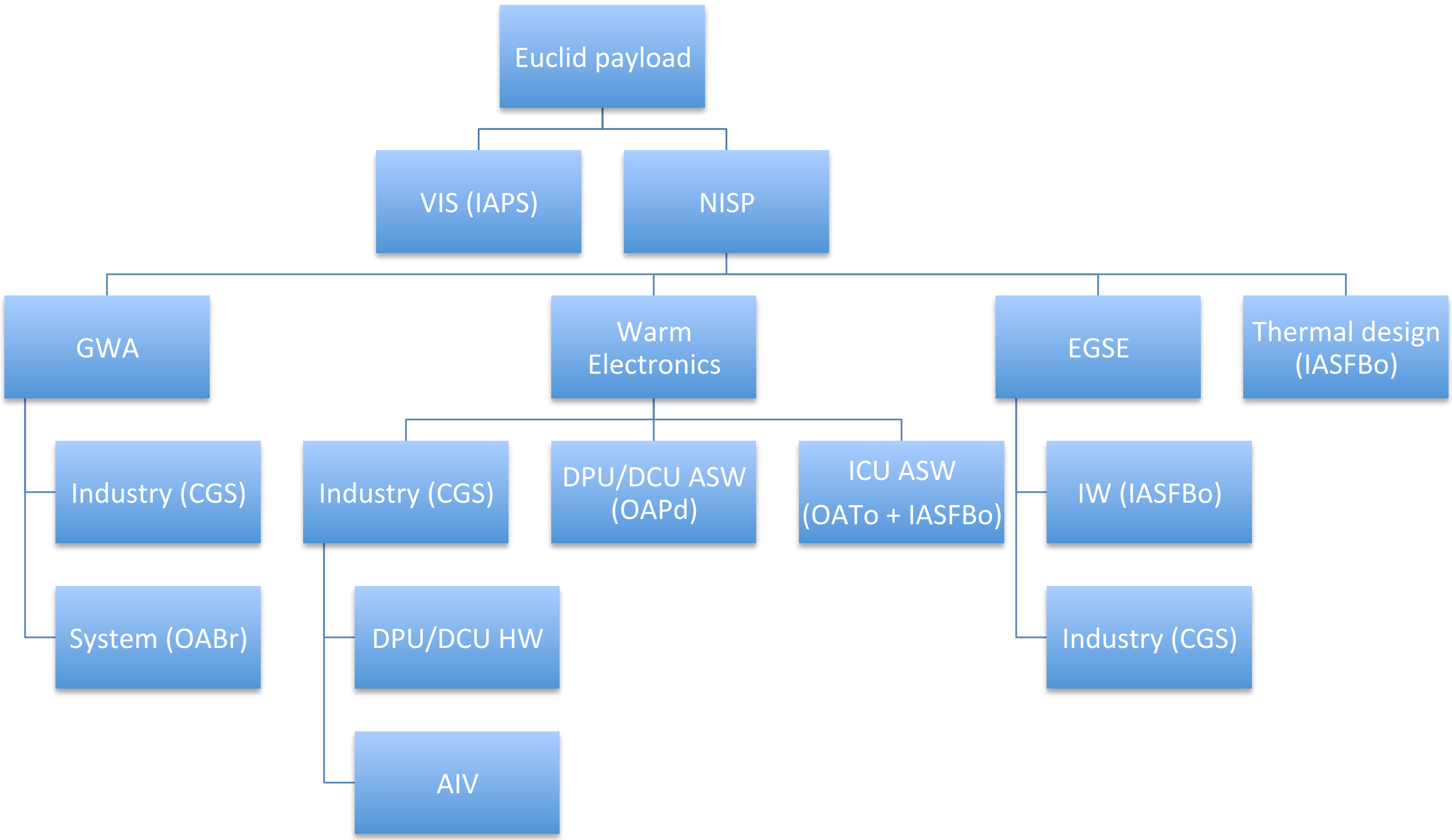
- If Σ >0.1 eV then Euclid spectroscopic survey will be able to determine the neutrino mass scale independently of the model cosmology assumed.
- If Σ <0.1 eV, the sum of neutrino masses, and in particular the minimum neutrino mass required by neutrino oscillations, can be measured in the context of the Λ-CDM

Forecast for the Primary Program

	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_{ν} /eV	f_{NL}	w_p	w_a	FoM $= 1/(\Delta w_0 \times \Delta w_a)$
Euclid primary (WL+GC)	0.010	0.027	5.5	0.015	0.150	430
EuclidAll (clusters,ISW)	**0.009**	**0.020**	**2.0**	**0.013**	**0.048**	**1540**
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	4020 → **6000**
Reference value (2009)	0.200	0.580	100	0.100	1.500	~10
Improvement Factor	**30**	**30**	**50**	**>10**	**>40**	**>400**

Assume systematic errors are under control

Italian Contribution to Euclid instruments



INFN@Euclid in 2016

BOLOGNA 5.4 FTE, 13 persone	**PADOVA 5.9** FTE, 16 persone
L. Patrizii (INFN) **Resp. Nazionale**	S.Dusini (INFN) Resp. Locale Coord. AIV WP Coord. attività DPU
G. Sirri (INFN) Resp.Locale Coord. attività ICU	F. Dal Corso (INFN)
T. Chiarusi (INFN)	M. Roda (Dottorando)
F. Giacomini (CNAF)	C.Sirignano (UniPd)
F. Fornari (dottorando)	L.Stanco (INFN)
A. Margiotta (PA UniBO)	S.Ventura (INFN)
N. Mauri (AR INFN)	N.Bartolo (UniPd teorico)
L. Pasqualini (Dottoranda)	M.Liguori (UniPd teorico)
M. Spurio (UniBo)	S.Matarrese (UniPd teorico)
M. Tenti AR CNAF	D.Karagiannis (UniPd teorico)
F. Tronconi (INFN, grIV)	G. Naletto (CISAS)
F. Finelli (INAF)	C. Bonoli (INAF)
L. Valenziano (INAF)	F.Bortoletto (INAF)
	A. Balestra (INAF)
	Dottorando da Ottobre
	RTD su fondi ASI

Bologna – Attività su ICU

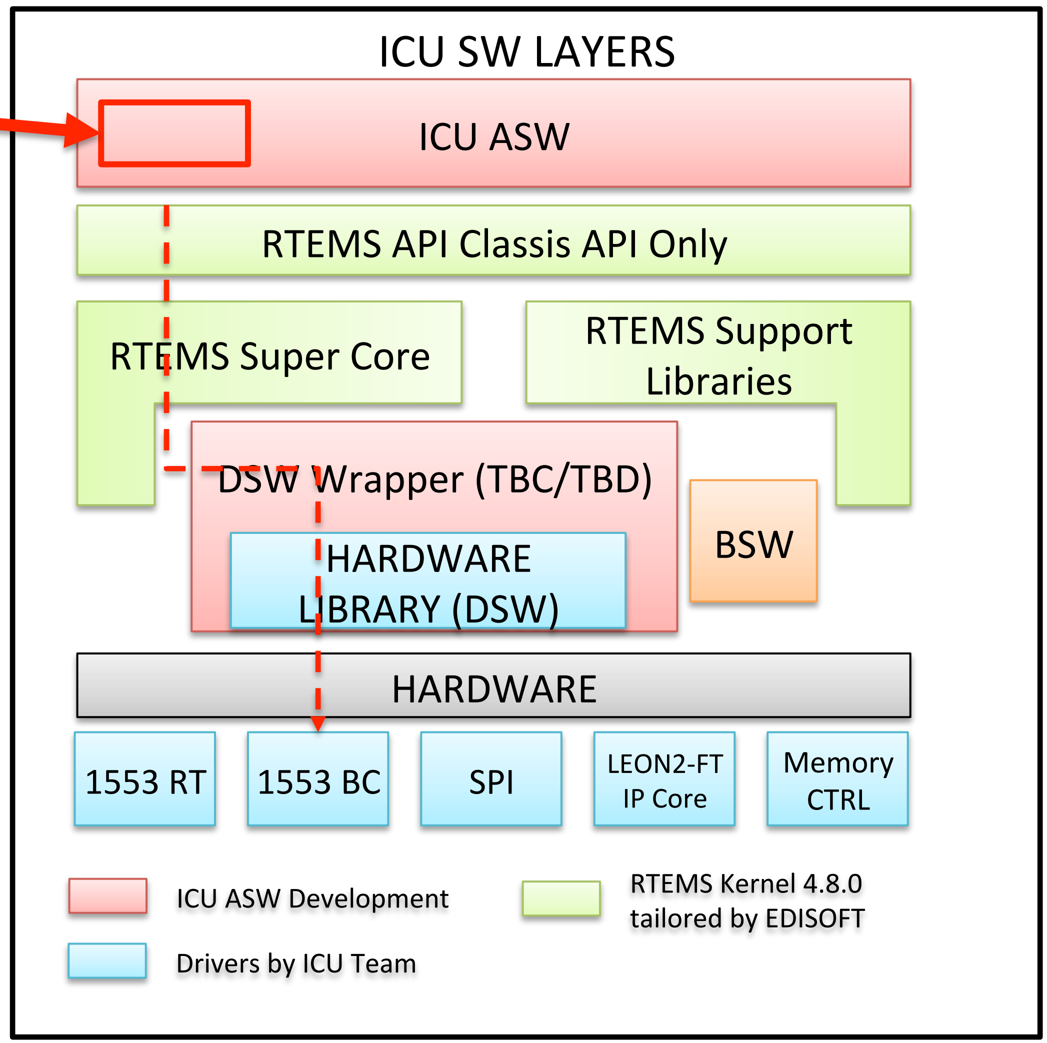
Contributo all'application software della ICU:
sviluppo del modulo SW di comunicazione con le DPU attraverso il bus di comunicazione MIL1553

- inoltro di telecomandi
- richiesta telemetrie
- gestione bus 1553 (BC = bus controller)

Processore: LEON2
OS : RTEMS (versione spazio)
Linguaggio : C

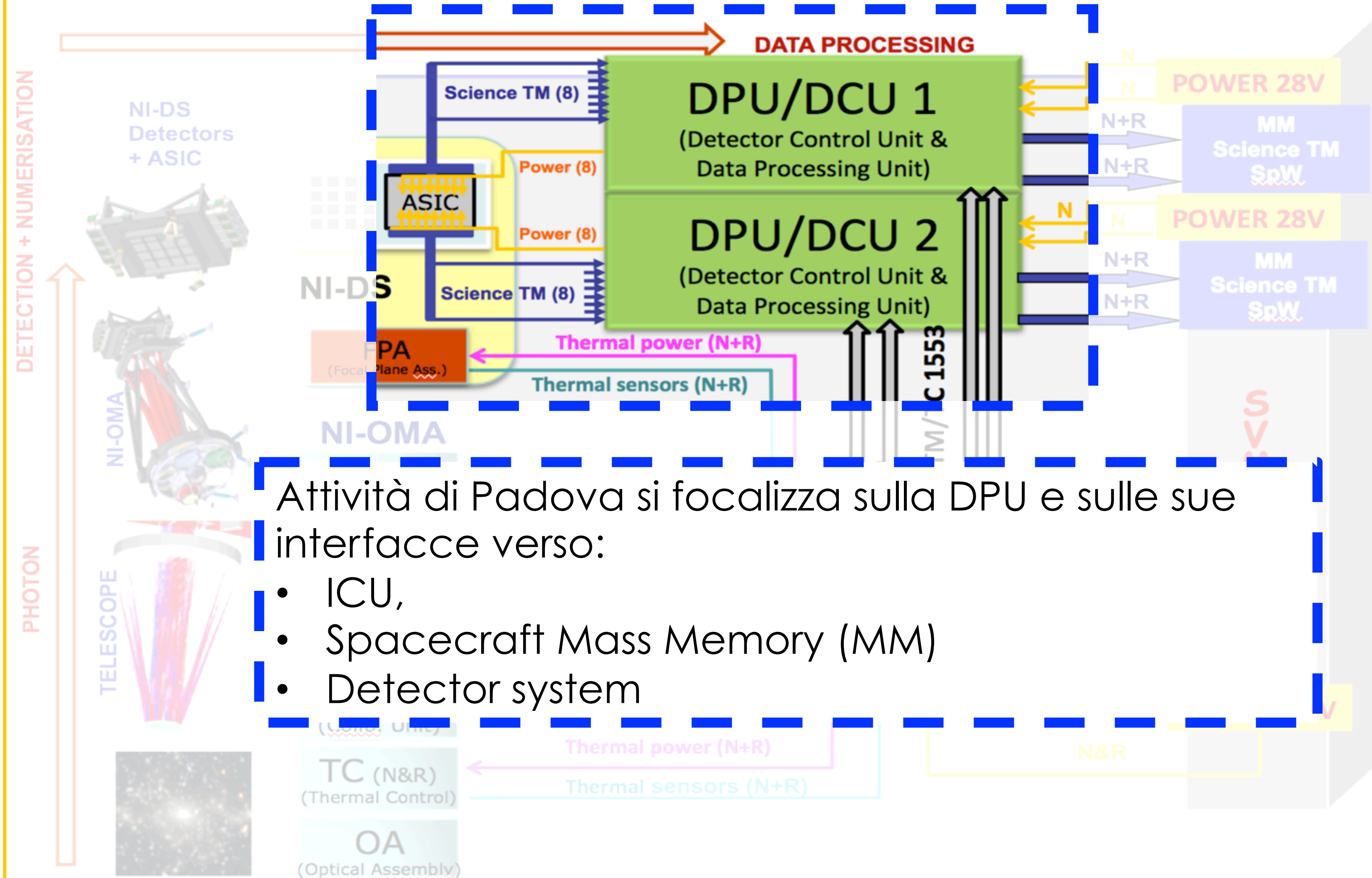
Supporto allo sviluppo:
- repository
- Unit test automatico
- Sviluppo procedure di test

[con l'aiuto del CNAF]



NISP

Attività gruppo Padova (coord. S. Dusini – Pd)



Attività di Padova si focalizza sulla DPU e sulle sue interfacce verso:

- ICU,
- Spacecraft Mass Memory (MM)
- Detector system

Summary

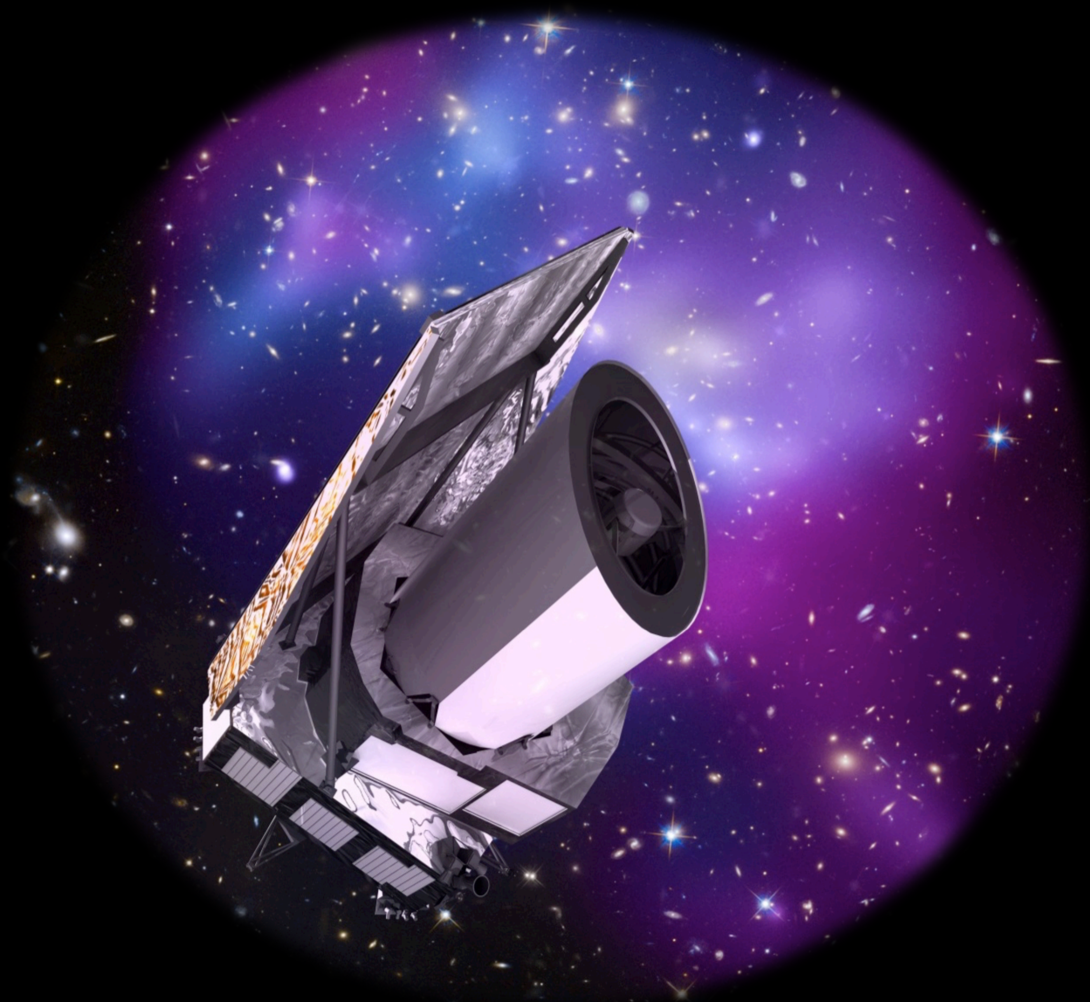
1. Euclid is an experiment combining GC and WL: an unprecedented match of an imaging and redshift survey from space, building a sample of $>10^9$ galaxy shapes and $\sim 5\ 10^7$ galaxy distances (and much more).

2. Euclid results may well revolutionize our understanding of physics: for sure it will provide a huge database for unexpected discoveries (legacy).

3. Ideal complementarity to CMB observations.

4. Euclid is one of the most sophisticated scientific instruments ever launched: large cryo optics, large focal planes, the most powerful on-board data processing.

5. Italy: one of the major contributors, leading the SGS and providing critical elements to the payload.
   The Italian participation is funded by ASI.



Acknowledgements

The Euclid Consortium acknowledges the European Space Agency and the support of a number of agencies and institutes that are funding the development of Euclid. A detailed complete list is available on the Euclid web site (http://www.euclid-ec.org). In particular the Agenzia Spaziale Italiana, the Centre National d'Etudes Spatiales, the Deutches Zentrum fur Luft- and Raumfahrt, the Danish Space Research Institute, the Fundação para a Ciênca e a Tecnologia, the Ministerio de Economia y Competitividad, the National Aeronautics and Space Administration, the Netherlandse Onderzoekschool Voor Astronomie, the Norvegian Space Center, the Romanian Space Agency, the United Kingdom Space Agency and the University of Helsinki.

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