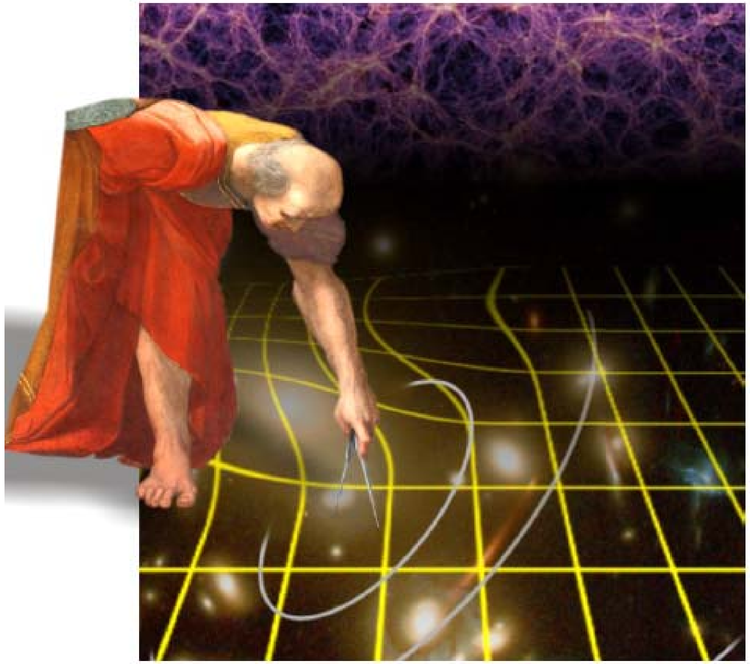


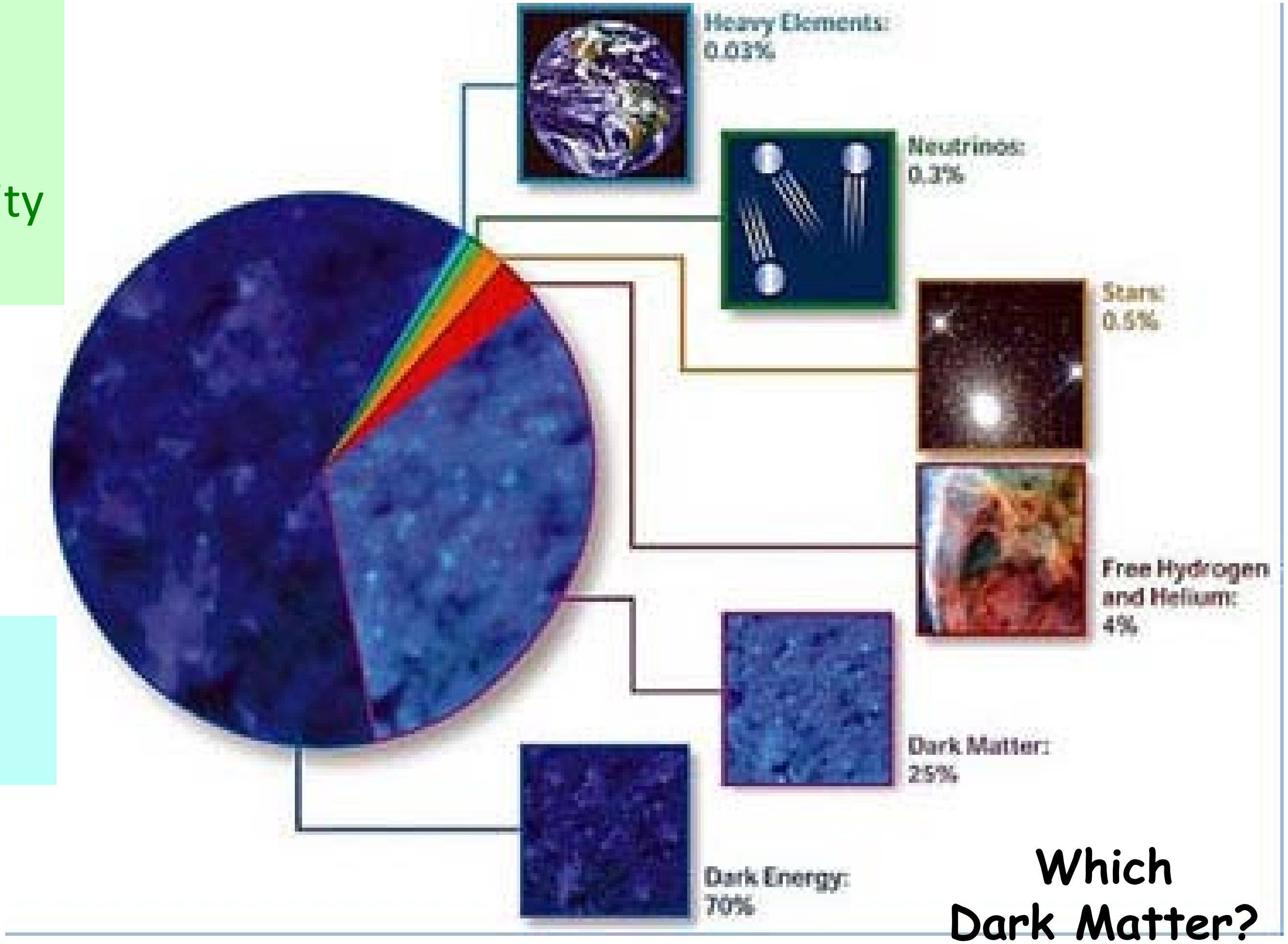
Cosmology with the ESA Euclid mission

Charling Tao
CPPM/IN2P3/CNRS and THCA, Tsinghua University

on behalf of the Euclid Consortium
In APRIM 3-7 Jul, 2017

A mysterious Universe

What we know is only 4-5% of the energy density of the Universe

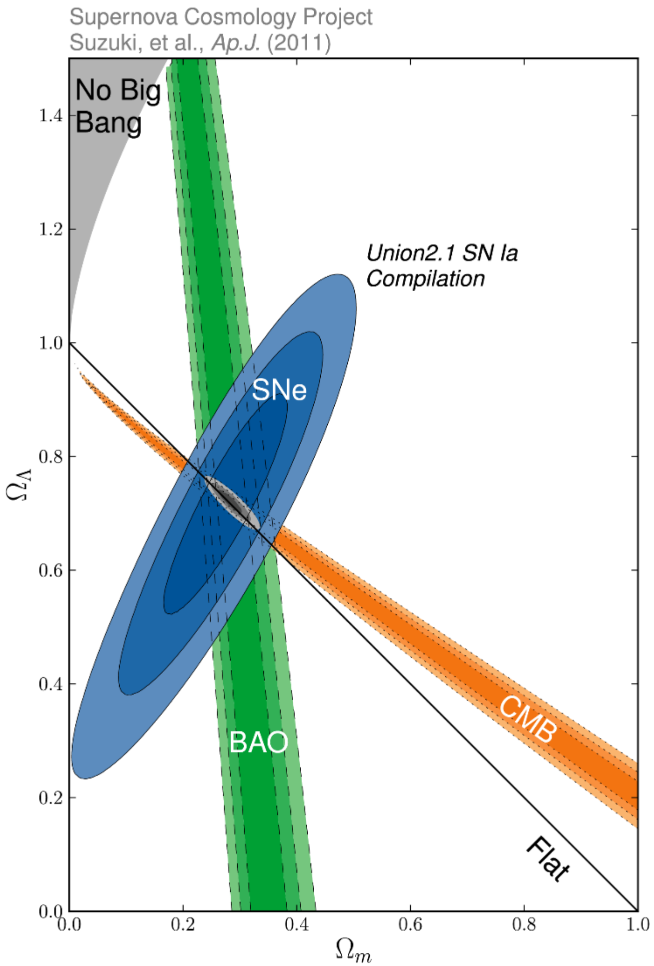


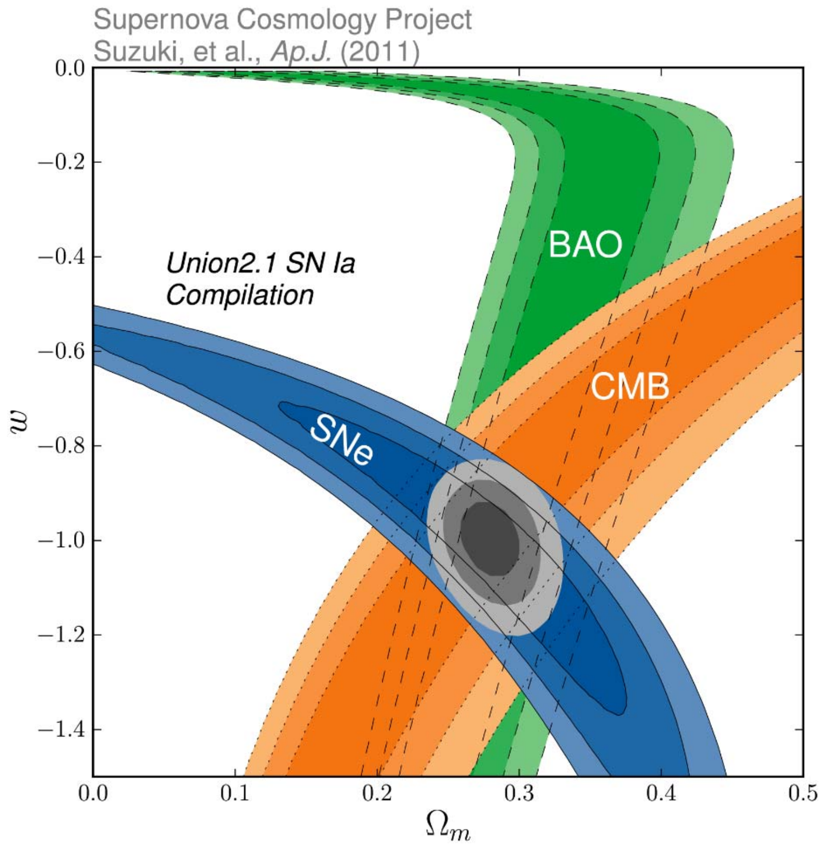
What is Dark Energy?

Which Dark Matter?

Graph source: Wikipedia

Concordance Λ–CDM model





But is it a cosmological constant or some Dark Energy?

Definition: $\Omega = \rho/\rho_c$ ($\rho_c = 10^{-29}$ g/cm^3)

What is Dark Energy?

New form of
« field/matter? »
Quintessence?

Unified Dark Matter?

Cosmological Constant???

w =-1

Modified
Gravity/GR ?

- Non minimal
Couplings?

- Extra-Dimensions?

- Anisotropy/
inhomogeneity
effects?

- Negative energy?

- Torsion?

-...

How to distinguish between models?

- equation of state $w(z) = p/\rho$

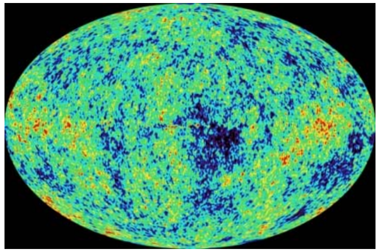
Many cosmological probes

CMB

Snapshot at ~400,000 yr, viewed from z=0

Angular diameter distance to z~1000

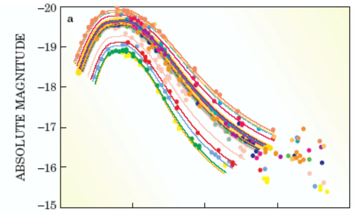
Growth rate of structure (from ISW)



Supernovae

Standard candle

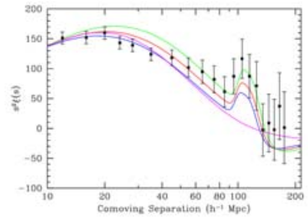
Luminosity distance



Baryon Wiggles

Standard ruler

Angular diameter distance

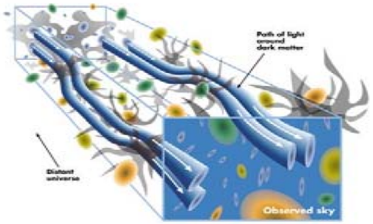


Cosmic Shear

Evolution of dark matter perturbations

Angular diameter distance

Growth rate of structure

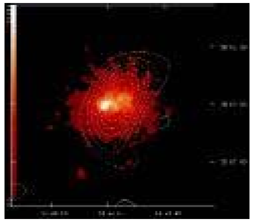


Cluster counts

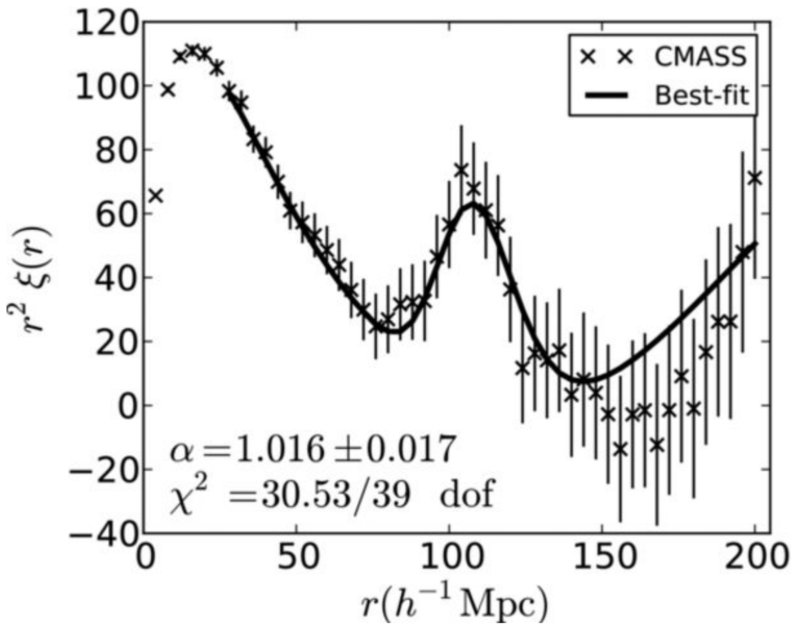
Evolution of dark matter perturbations

Angular diameter distance

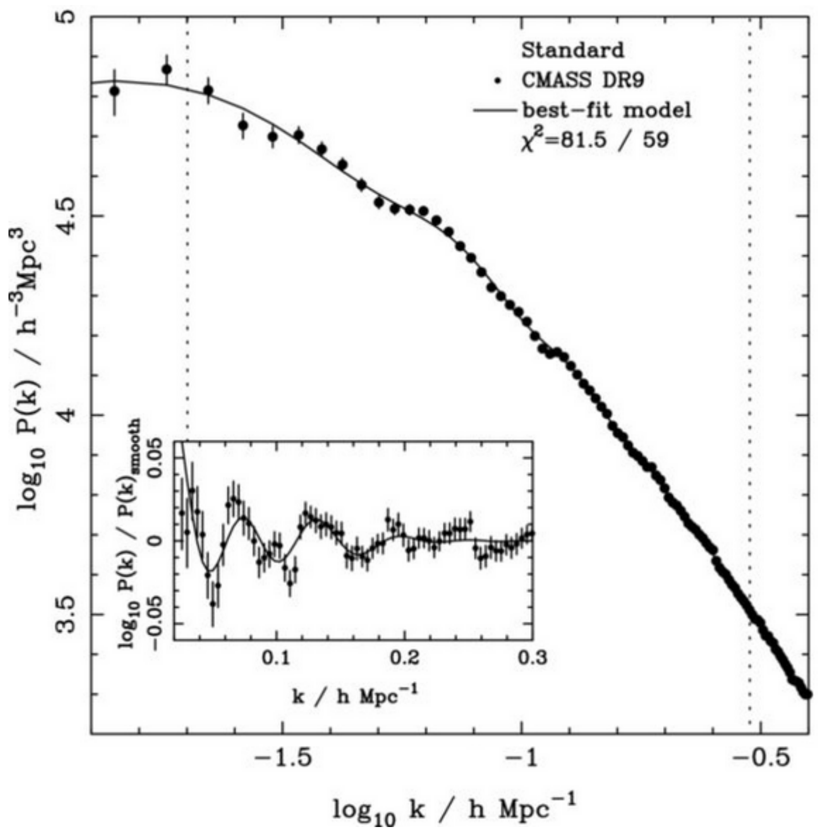
Growth rate of structure



Large Scale Structures Correlations

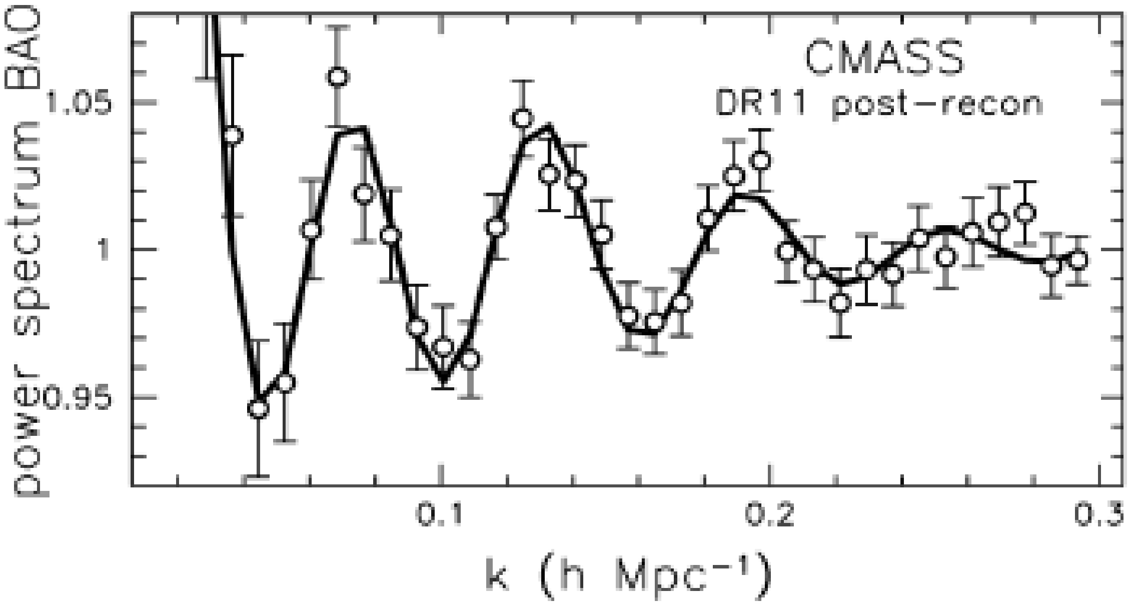


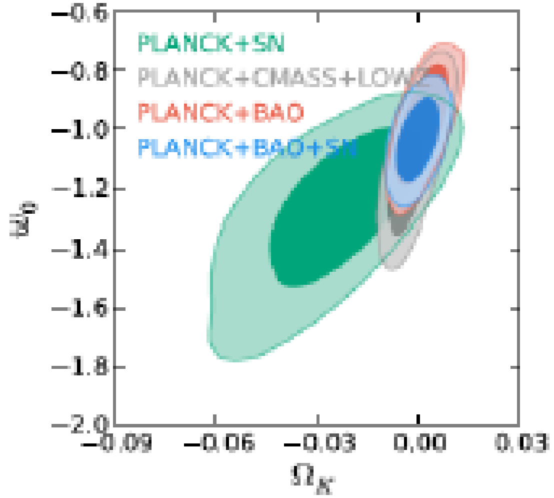
Galaxy-galaxy correlations



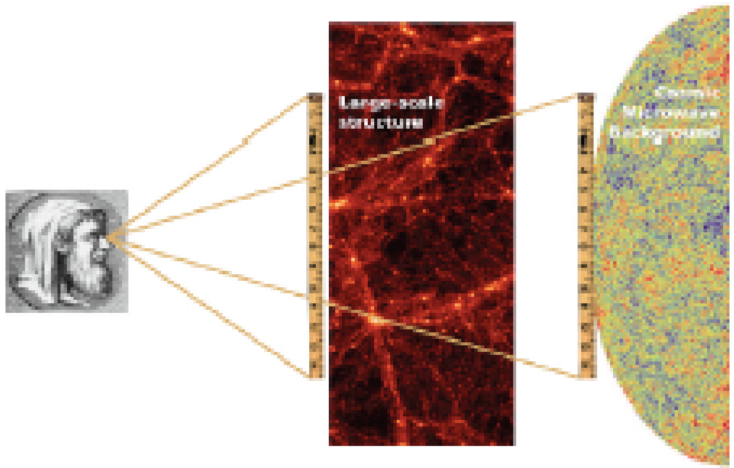
Anderson et al, 2012

1% distances with Baryonic Acoustic Oscillations





BOSS - Anderson et al (2013)

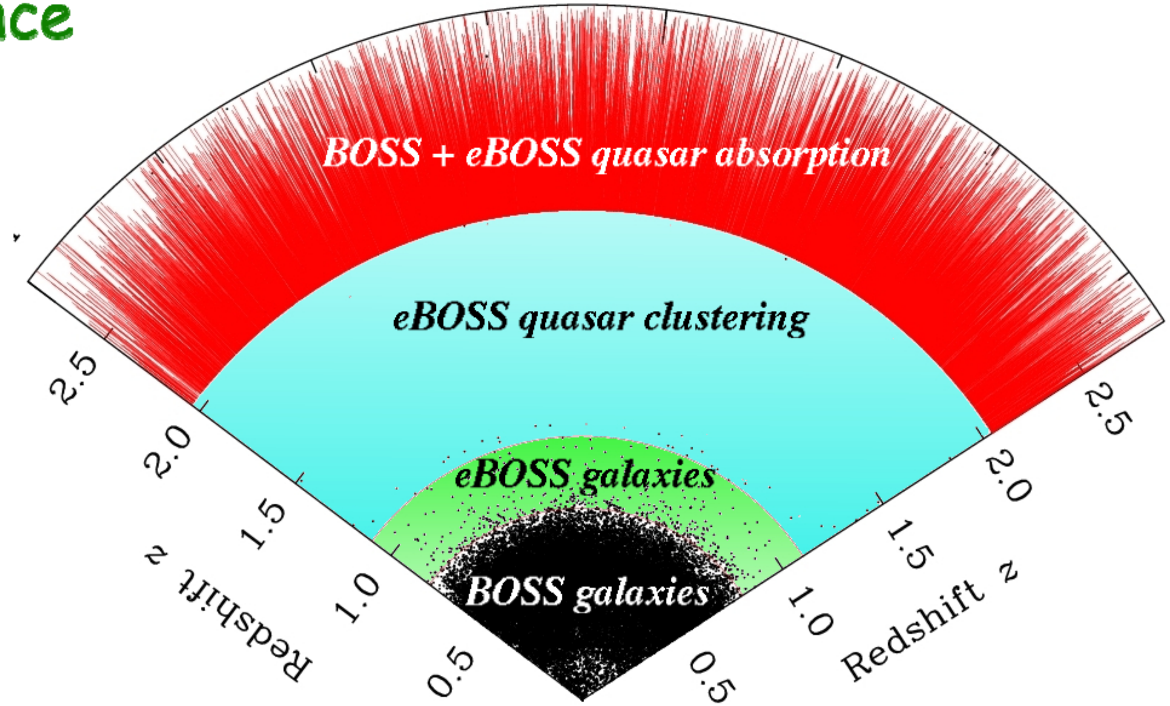


SNIa: Best single probe till 2013
Now BAO (Baryonic Acoustic Oscillations) with SDSS/BOSS results

eBOSS(SDSS4) started in August 2014

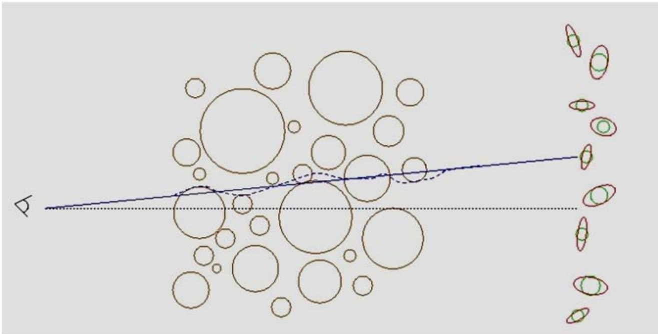
- Transition from deceleration to acceleration ($H(z)$)
- Structure growth (test of GR-ΛCDM)
- Neutrinos
- QSO/galaxy science
- …

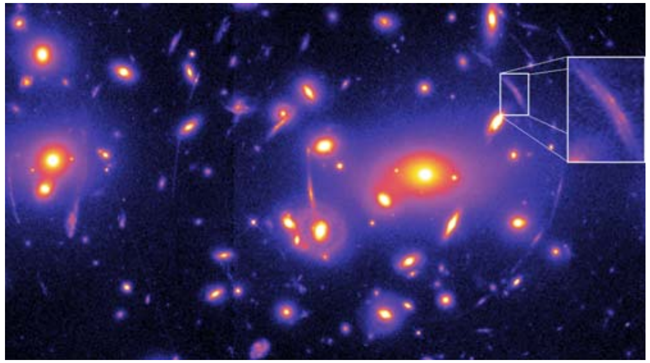
C. Tao + Zhao Cheng + Liang Yu



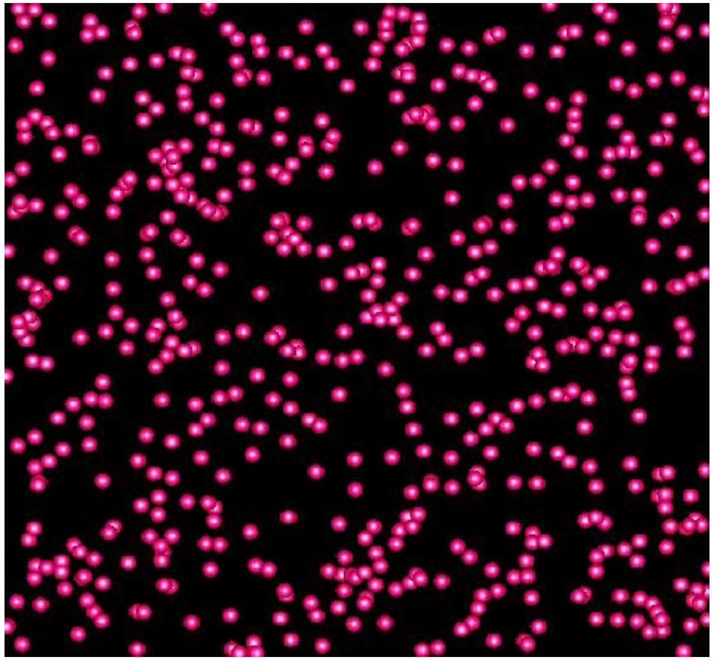
http://www.sdss3.org/future/eboss.php

Future best probe: Weak Lensing ?

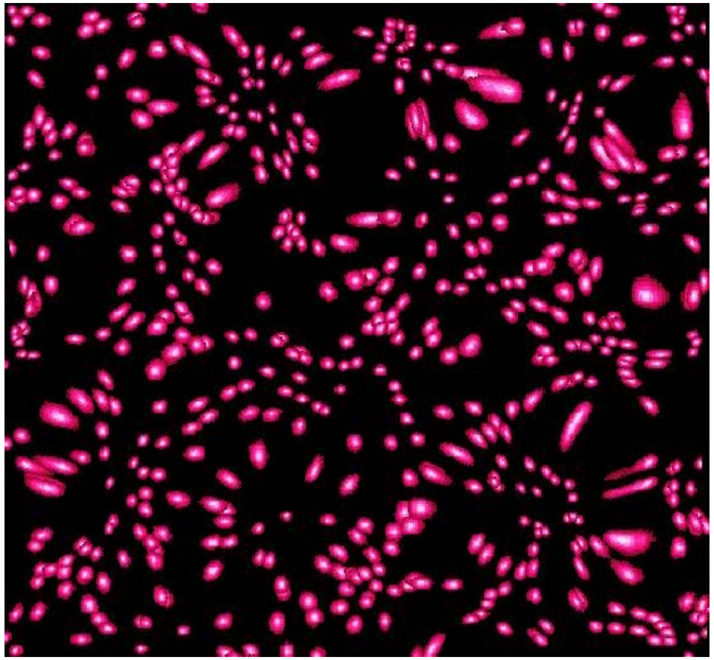




Distorsion of galaxy shapes by foreground matter

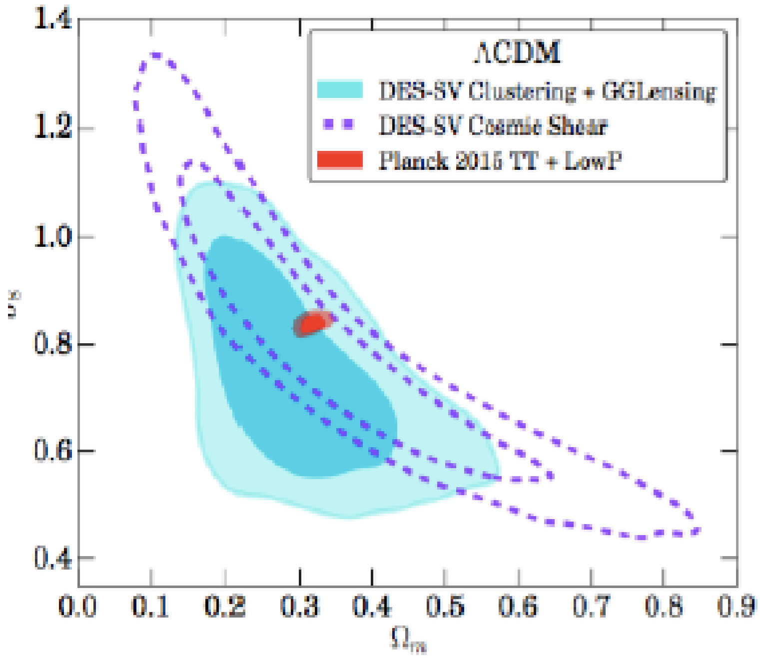


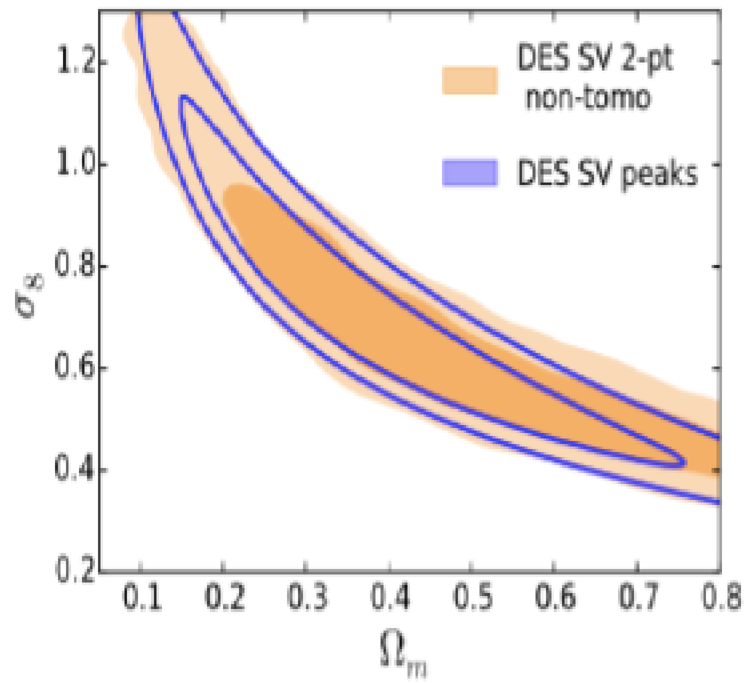
without lensing



Lensing effect

Testing LCDM with DES Weak Lensing and clustering





Kwan et al. 1604.07871
(dashed line: DES Collaboration 1507.05552)

Kacprzak et al. 1603.05040

Also KIDS 450 sqdeg

Weak Lensing : Best from space!

M51

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

- Euclid images of z~1 galaxies: same resolution as SDSS images at z~0.05 and at least 3 magnitudes deeper.
- Space imaging of Euclid will outperform any other surveys of weak lensing.

Many DE projects

Ground

Photometric : KIDS, DES, HSC → LSST, …

Spectroscopic: SDSS, PFS, HETDEX → DESI,….

Space

Euclid (2020?), China Space Station (2022?), WFIRST (2025?)

Euclid: Scientific Objectives

- Understanding the origins of the Universe accelerating expansion
- Derive properties and nature of Dark Energy(DE), test gravity (MG)
- Distinguish DE,MG, DM (Dark Matter) effects

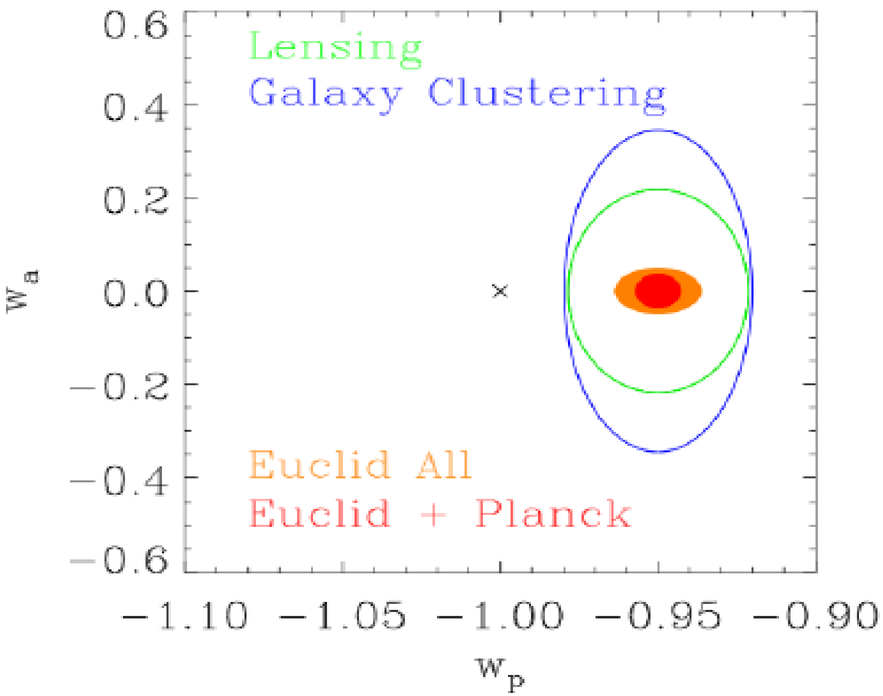
- *Decisively* by:
  - Using at least 2 independent but complementary probes
  - Tracking their observational features on the
    - Geometry of the Universe with 2 main probes:

      Weak Lensing (WL),   Galactic Clustering (GC)
    - Cosmic history of structure formation: WL, redshift space distortion, Clusters of galaxies
  - Precise Control of systematics

Parametrising our ignorance

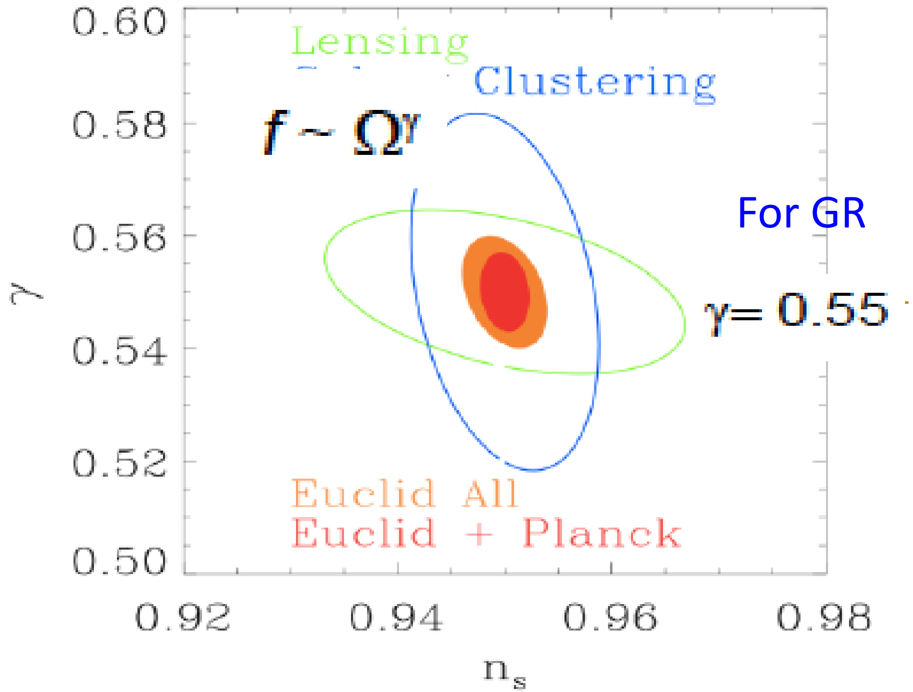
- DE equation of state:

$P/\rho = w$ and $w(a) = w_p + w_a(a_p - a)$



DE constraints from Euclid: 68% confidence contours in the (w_p, w_a).

- Growth rate of structure formation controlled by gravity:



Constraints on the γ and n_s. Errors marginalised over all other parameters.

Ref: Euclid RB arXiv:1110.3193

The Euclid Mission: baseline and options

Euclid Consortium

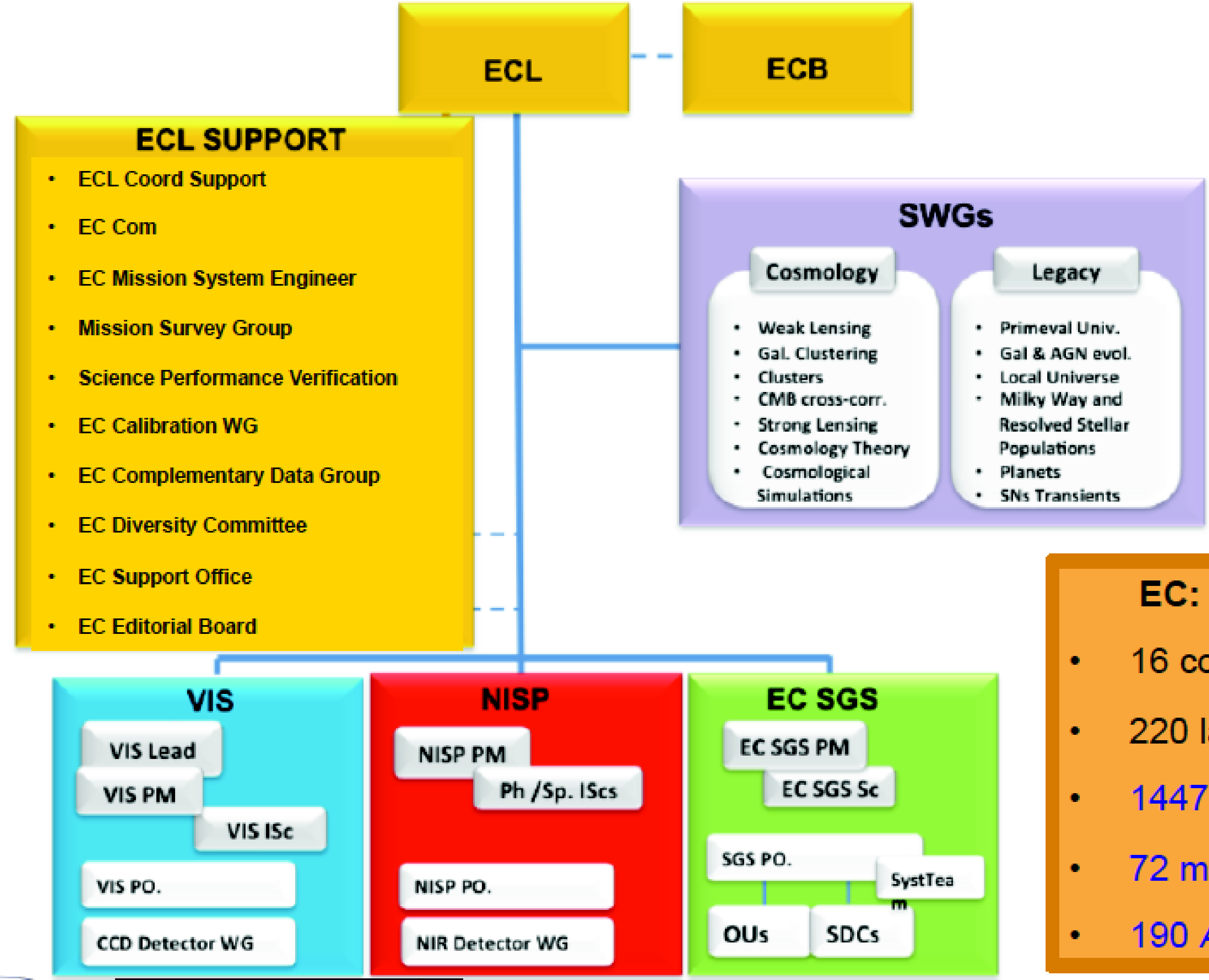
SURVEYS In ~5.5 years		
	Area (deg2)	Description
Wide Survey	**15,000 deg^2**	Step and stare with 4 dither pointings per step.
Deep Survey	**40 deg^2**	In at least 2 patches of > 10 deg^2 2 magnitudes deeper than wide survey

PAYLOAD					
Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	VIS	NISP			
Field-of-View	0.787×0.709 deg^2	0.763×0.722 deg^2			
Capability	Visual Imaging	NIR Imaging Photometry			NIR Spectroscopy
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	$3\ 10^{-16}$ erg cm-2 s-1 3.5σ unresolved line flux
	Shapes + Photo-z of $n = 1.5\times10^9$ galaxies ?			**z of $n=5\times10^7$ galaxies**	
Detector Technology	36 arrays 4k×4k CCD	16 arrays 2k×2k NIR sensitive HgCdTe detectors			
Pixel Size Spectral resolution	0.1 arcsec	0.3 arcsec			0.3 arcsec R=250

Possibility to propose other surveys: SN and/or μ-lens surveys, Milky Way ?

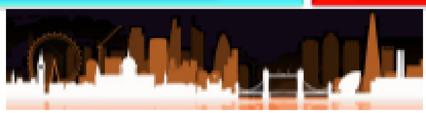
Ref: Euclid RB arXiv:1110.3193

Euclid Consortium organisation



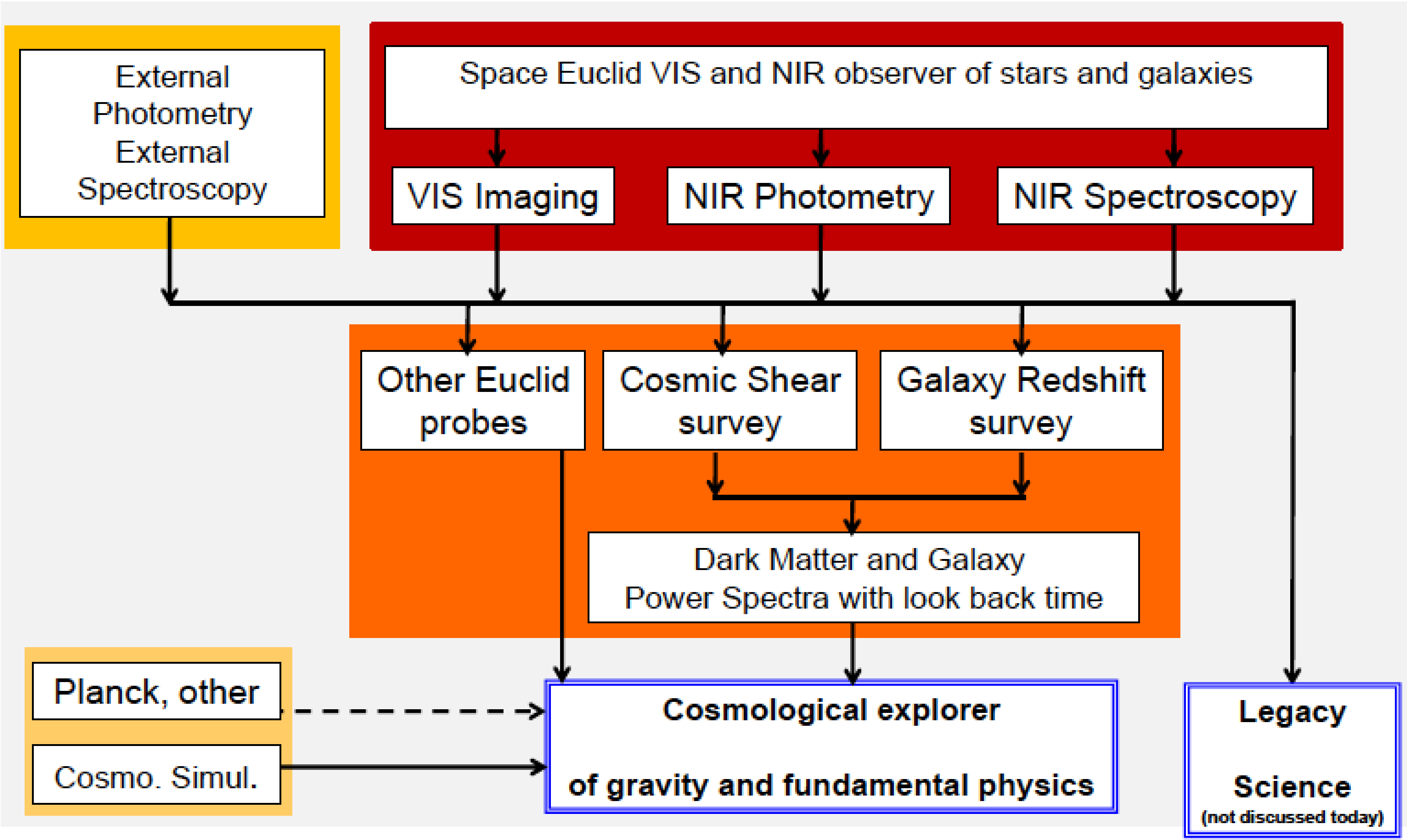
EC: JUN 05 2017:

- 16 countries
- 220 labs
- 1447 *Full* members
- 72 members *at Large*
- 190 *Alumni*



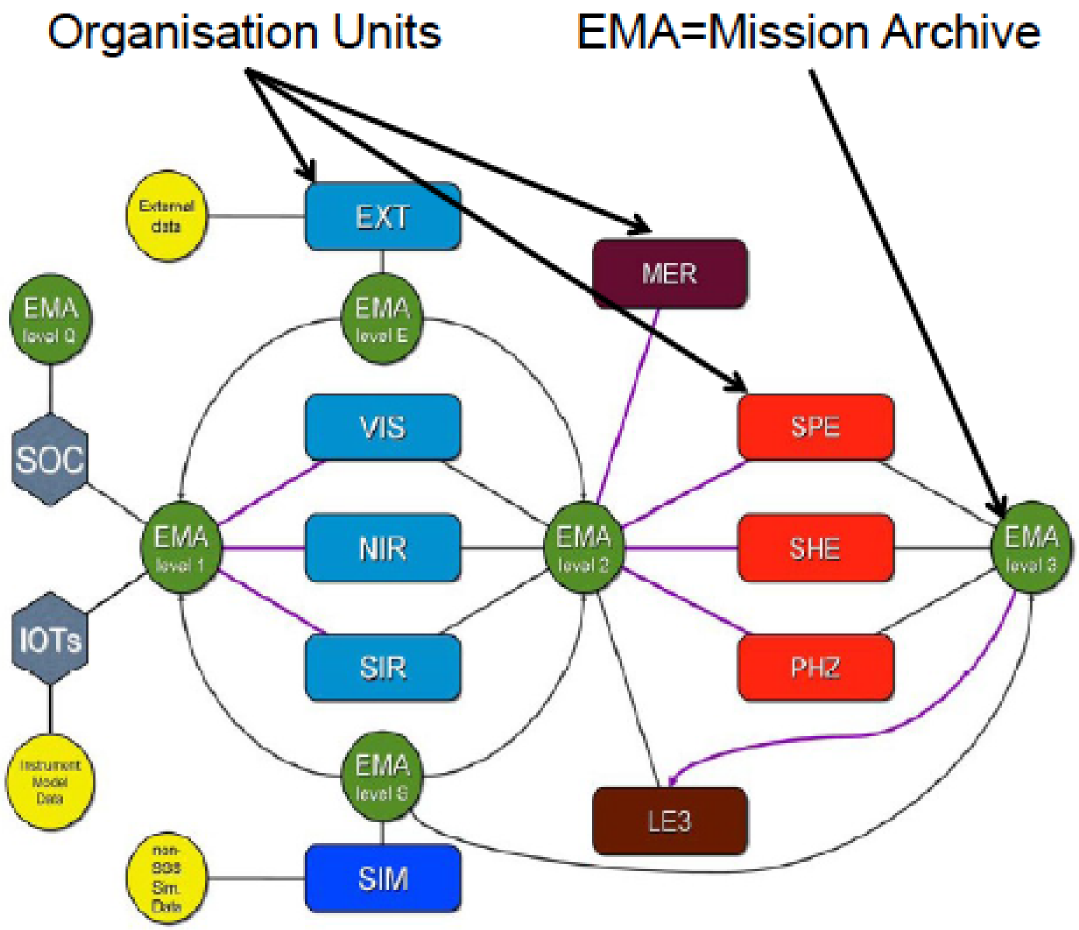
The Euclid Machine

Euclid Consortium



Euclid/SGS flow and Organisation Units

Euclid Consortium



- Total: ~ < 2PB of Euclid data (~ 10^6 images)
  + >10 PB of external data.
- Data volume for simulations may be much larger

- ESA Mission Operation Center
- ESA Science Operation Center

- Science Working Groups: 13 SWGs
  - Science objectives
  - Requirements: pipeline products
  - Requirements: pipeline performances
  - Verify that the requirements are met
  - Final science analyses

- Organisation Units: 10 OUs
  - Algorithmic definition of the processing
  - Validating the implementation

  →OU scientists are from the SWGs

- Science Data Centers: 8 SDCs
  - Implementing pipelines
  - Procuring local H/W and S/W resources
  - SDC-DEV: algorithms → robust codes
  - SDC-PROD:integration on local infrastructure, production runs of pipelines

Main requirements to design the mission

Euclid Consortium

	Wide survey	Deep survey
Survey		
size	15000 deg ^{2}	40 deg^2 N/S
VIS imaging		
Depth	n_{gal} > 30/arcmin^2 → M_{AB} =24.5 → <z> ~0.9	M_{AB} = 26.5
PSF size knowledge	$\sigma[R^2]/R^2<10^{-3}$	
Multiplicative bias in shape	$\sigma[m]<2\times10^{-3}$	
Additive bias in shape	$\sigma[c]<5\times10^{-4}$	
Ellipticity RMS	$\sigma[e]<2\times10^{-4}$	
NIP photometry		
Depth	24 M_{AB}	26 M_{AB}
NIS spectroscopy		
Flux limit (erg/cm^2/s)	3 10^{-16}	5 10^{-17}
Completness	> 45 %	>99%
Purity	>80%	>99%
Confusion	2 rotations	>12 rotations

- WL and WL systematics

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

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

→ $m < 2\times10^{-3}$: multiplicative bias
$\sigma^2_{sys} \approx \langle c^2\rangle < 10^{-7}$: additive bias

→ Small PSF
→ Knowledge of the PSF size
→ Knowledge of distortion
→ Stability in time
→ External visible photometry for photo-z accurary: 0.05x(1+z)

- GC and GC systematics

→ Catastrophic **z** < 10%
→ <z>/(1+z)<0.002

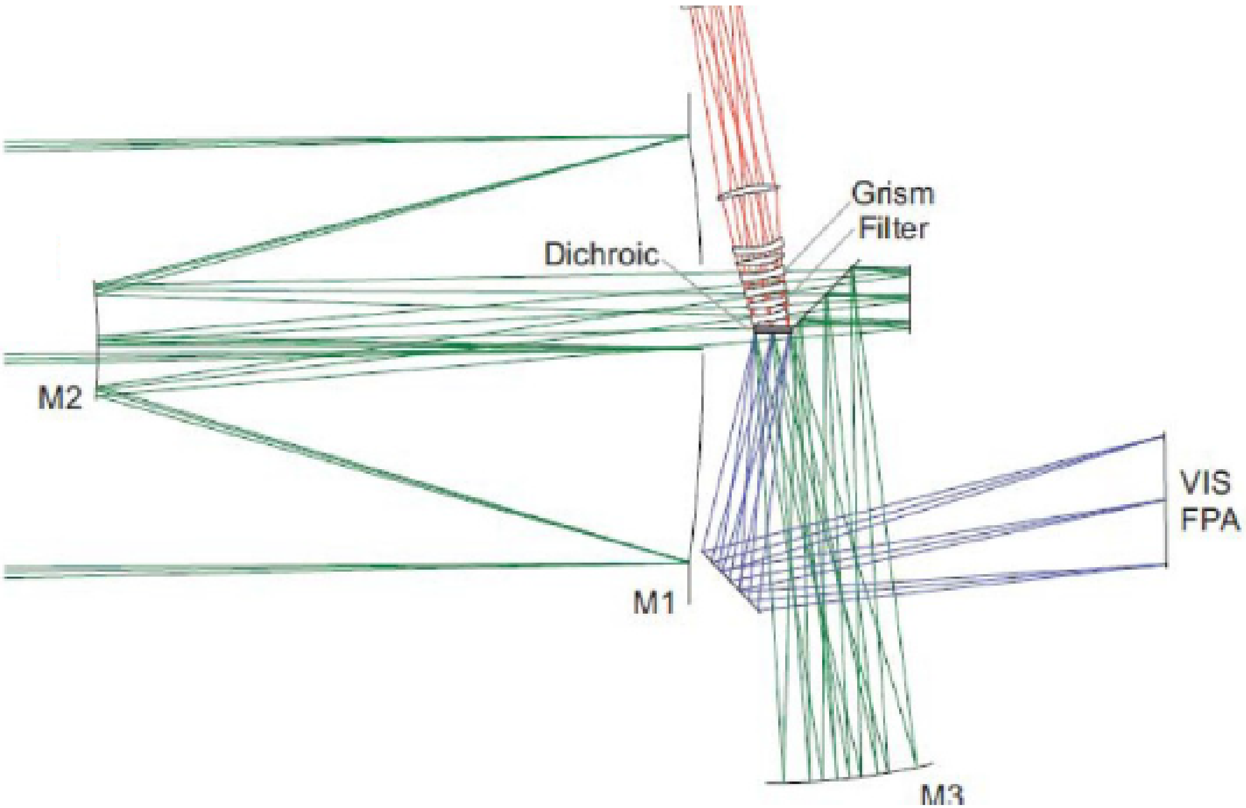
→ Understand selection→Deep field
  - Completeness
  - Purity

Current optical design

Telescope:

1.2 m Korsch , 3 mirror anastigmat, with a 0.45 deg. off-axis field , f=24.5m

Optically corrected and unvignetted FoV : 0.79 x1.16 deg^2



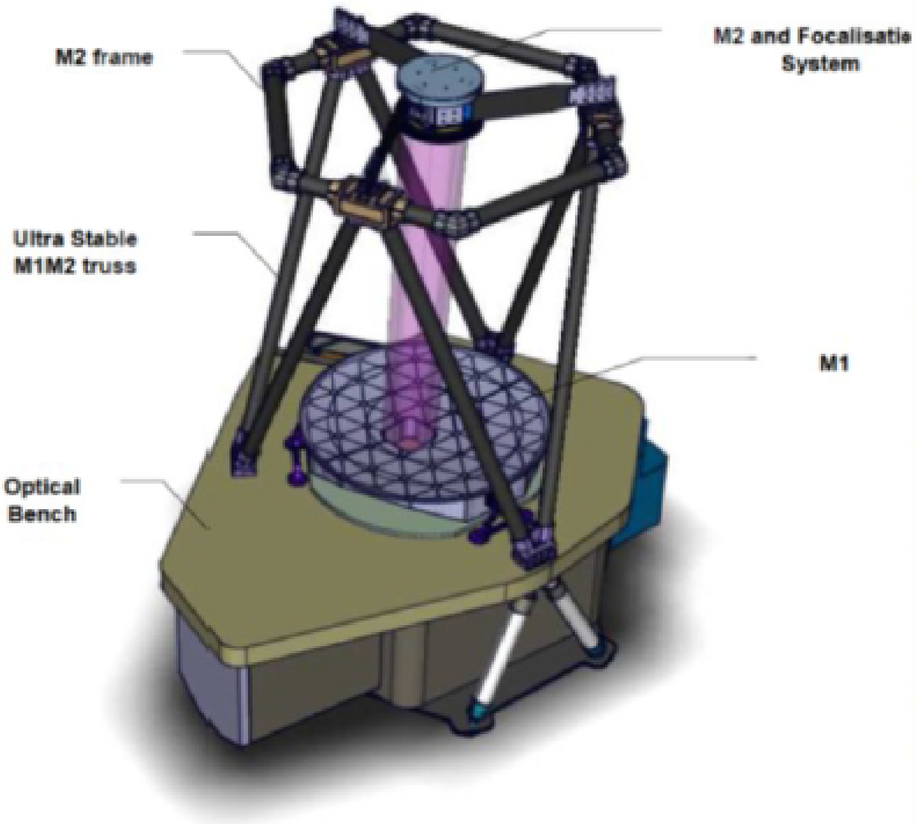
VIS and NISP: share the same FoV (0.54 deg^2)

Dichroic beam splitter at exit pupil : Visible and Near Infrared observations in parallel

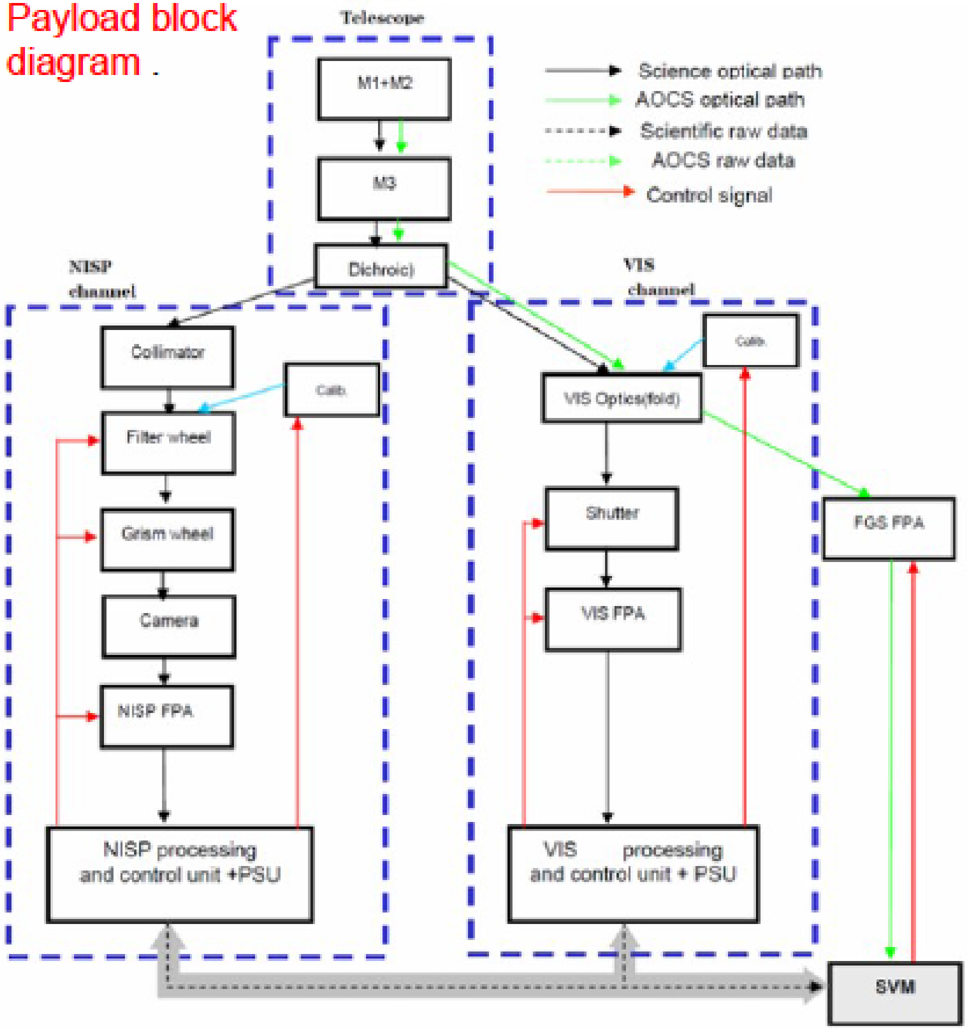
Telescope and payload module

Euclid Consortium

Typical telescope mechanical architecture



Payload block diagram .



Note: pointing error in spacecraft x,y direction = 25mas over 600 s.

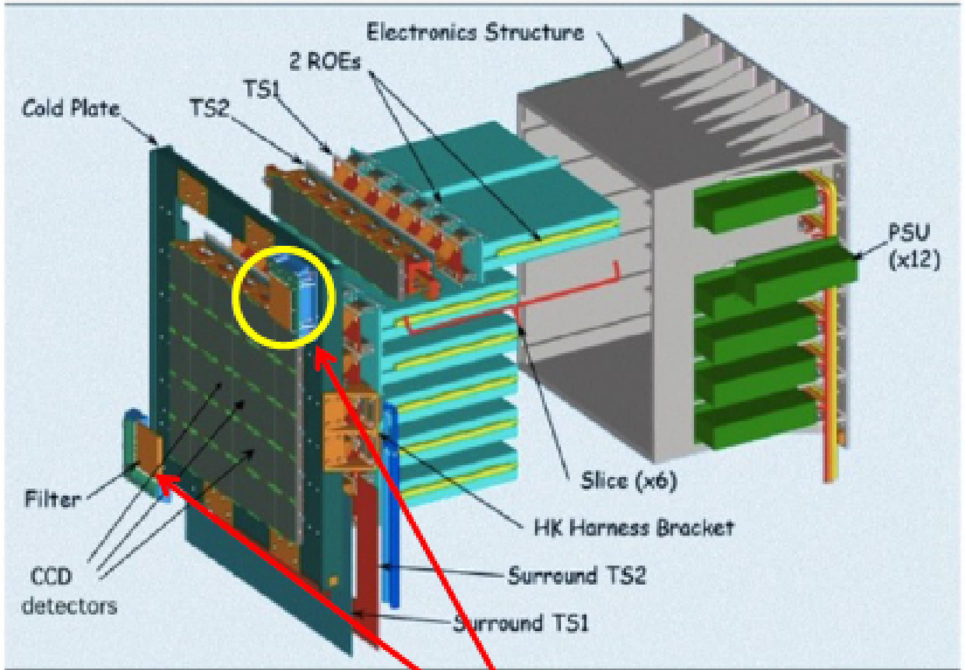
Reference: Laureijs et al 2012. SPIE.

FGS FPA = Fine Guidance Focal Plane Array: mounted on the VIS FPA and part of the Attitude and Control Orbit System (AOCS)

VIS Instrument

Euclid Consortium

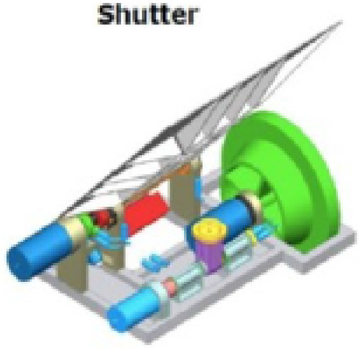
- large area imager – a 'shape measurement machine'
- 36 4kx4k CCDs with 12 micron pixels
- 0.1 arcsec pixels on sky
- bandpass 550-900 nm –
- limiting magnitude for wide survey of magAB = 24.5 for 10σ (extended)
- data volume – 520Gbit/day



Focal Plane Assembly

Narrow band filters
(color gradient)
→ Suppressed .

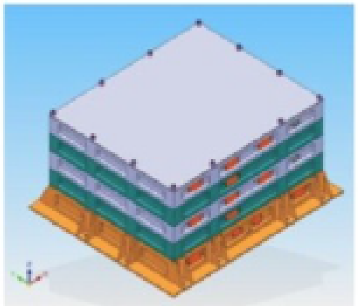
Shutter



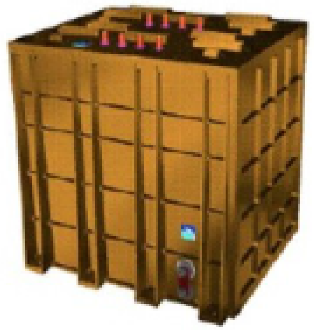
Cal Unit

WARM

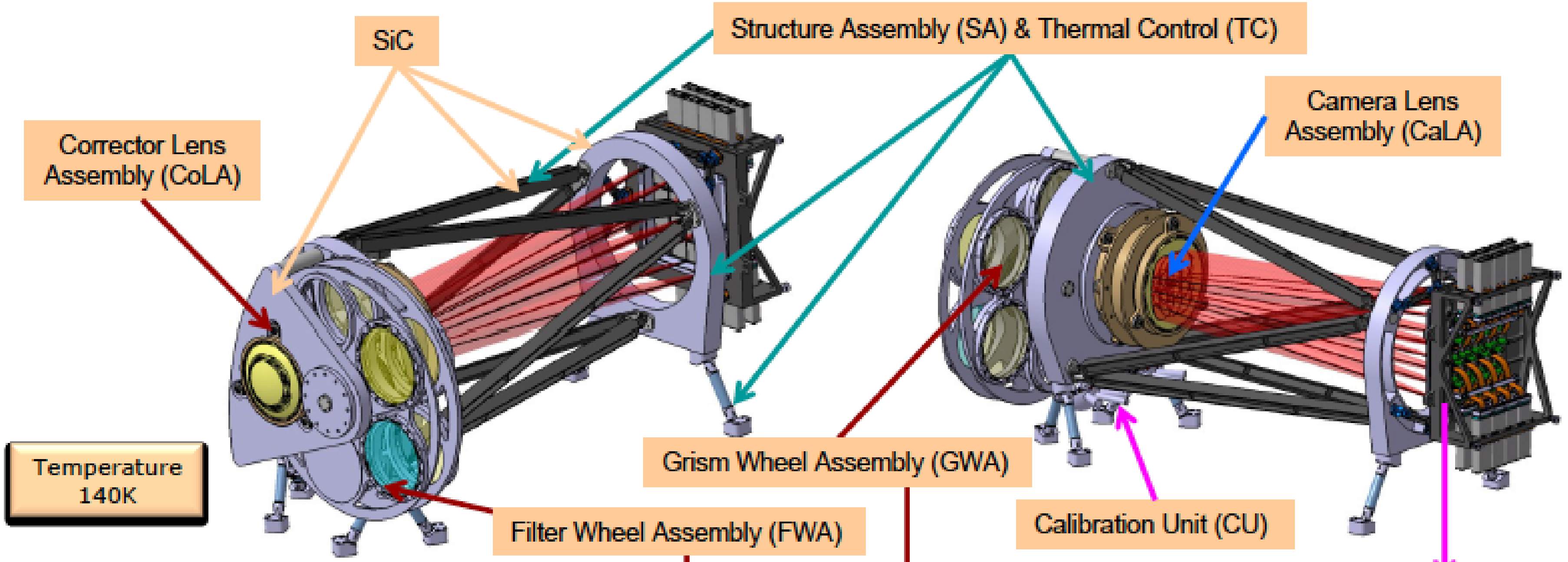
Power and Mechanisms Control Unit



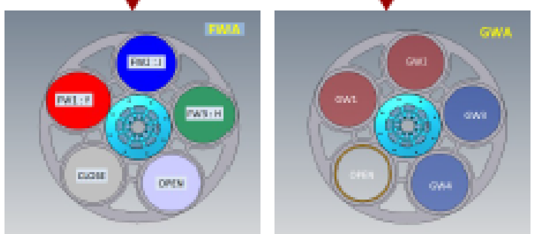
Command and Data Processing Unit

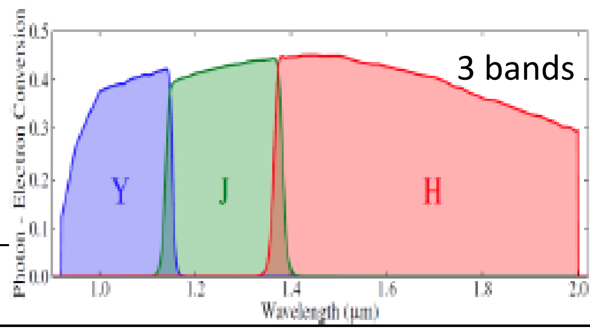


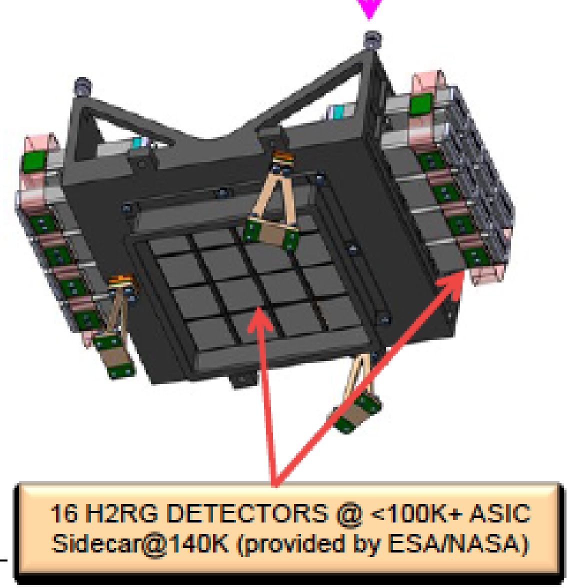
NISP instrument



- 16 NIR 2kx2k H2RG detectors
- 0.3 arc/pixel
- 1 "Blue" grism (920-1250nm) , 3 "Red" grisms (12501850 nm) 3 different orientations)
- Telemetry= 1 855 Gbit/day, transfer: 4hrs daily slot in K band (25.5-27.0 Ghz)





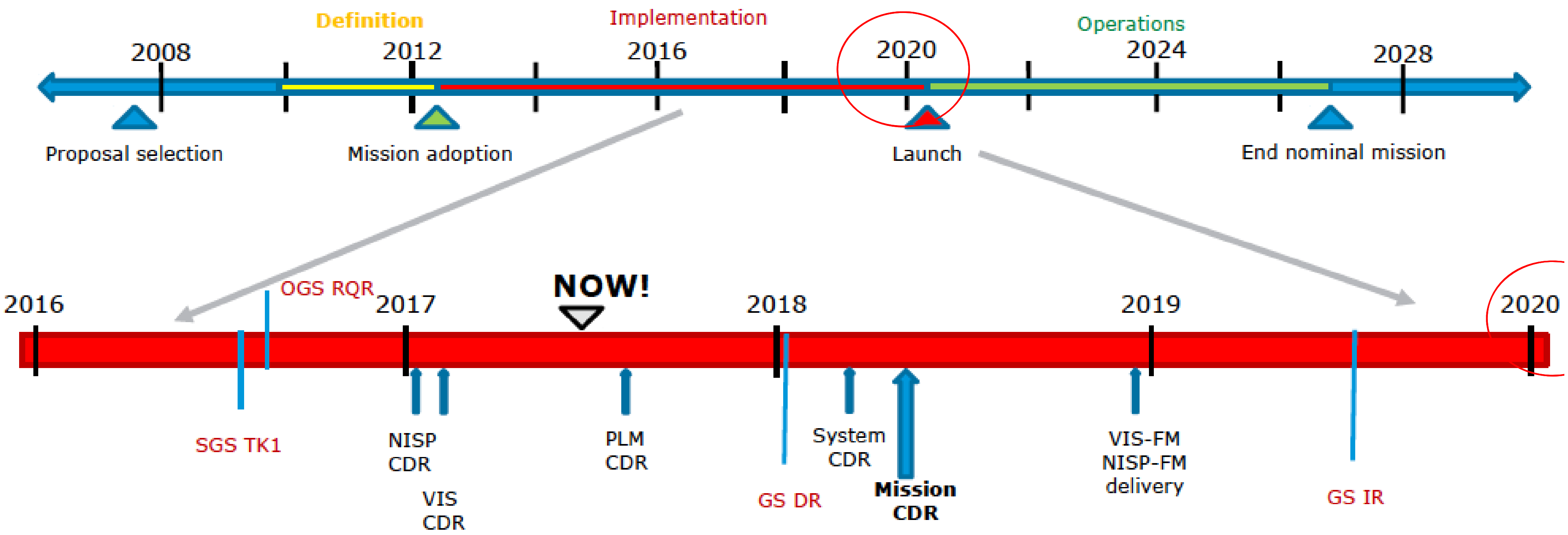


Schedule

Euclid Consortium

• October 4, 2011	:	Euclid selected as ESA M2 Cosmic Vision
• Spring 2012	:	Completion of the Definition phase (A/B1)
• June 20, 2012	:	Adoption for the Implem. Phase (B2/C/D/E1)
• July 2012	:	ITT release for PLM
• November 2012	:	KO PLM contract
• December 2012	:	ITT release for SVM
• June 2013	:	KO SVM contract
• Q1 2014	:	Instrument PDR
• Q3/Q4 2017	:	Flight Model delivery
• Q2 2020	:	Launch (L)
• <(L+6 months)	:	Start Routine Phase
• L+7 yrs	:	End of Nominal Mission
• L+9 yrs	:	End of Active Archive Phase

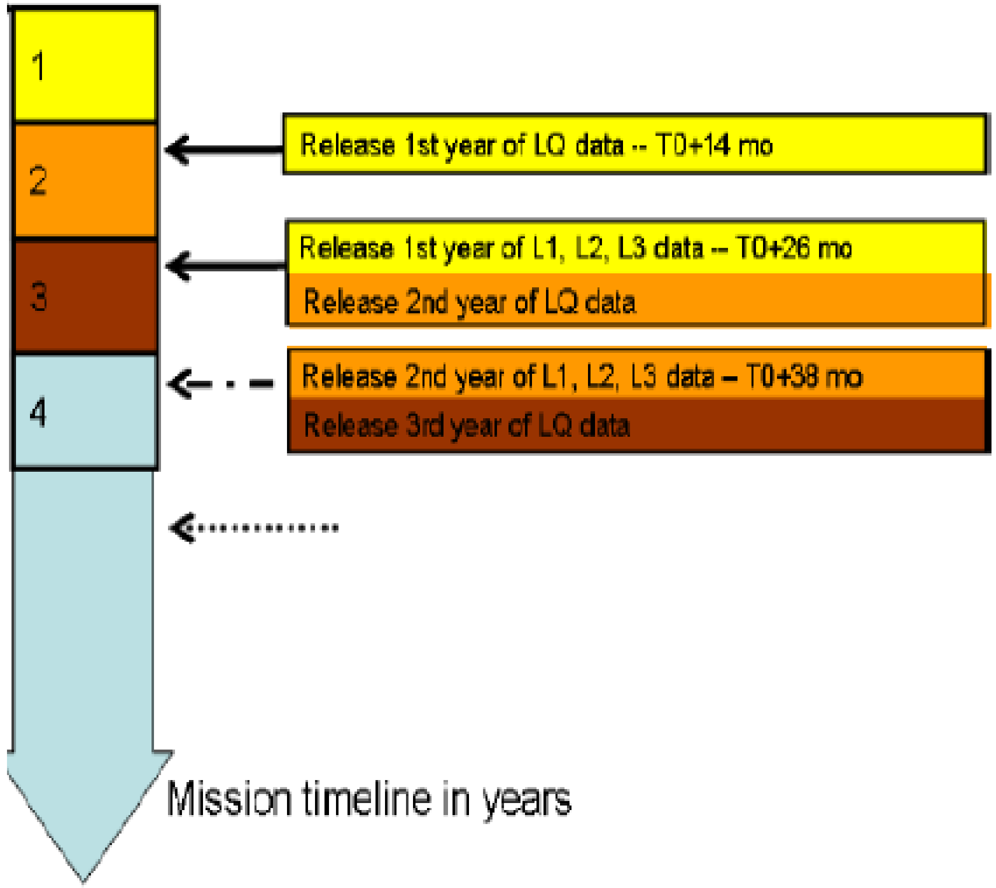
Overview mission timeline



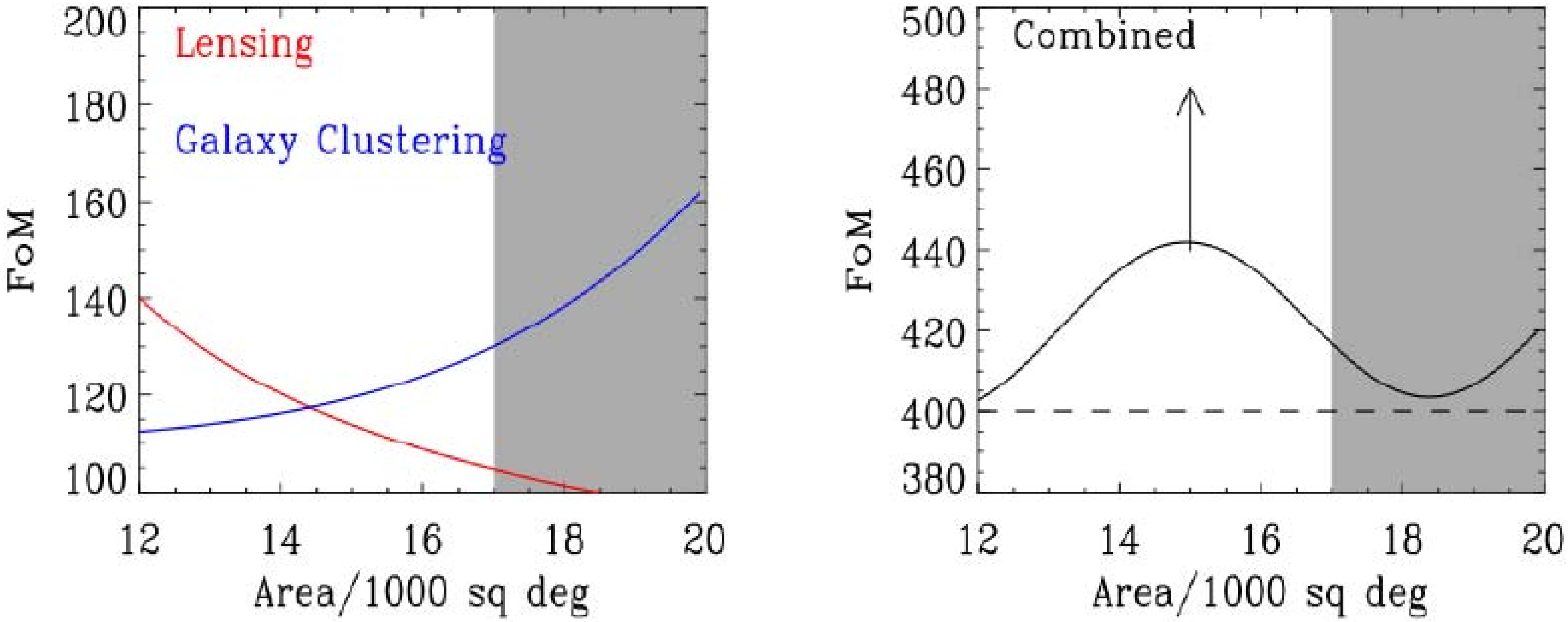
Data products and releases

Euclid Consortium

- First release Level Q (Quick) data release: 14 months after the start of the survey (TBC)
-
- First complete data release: 26 months after the start of the survey
- Then yearly releases

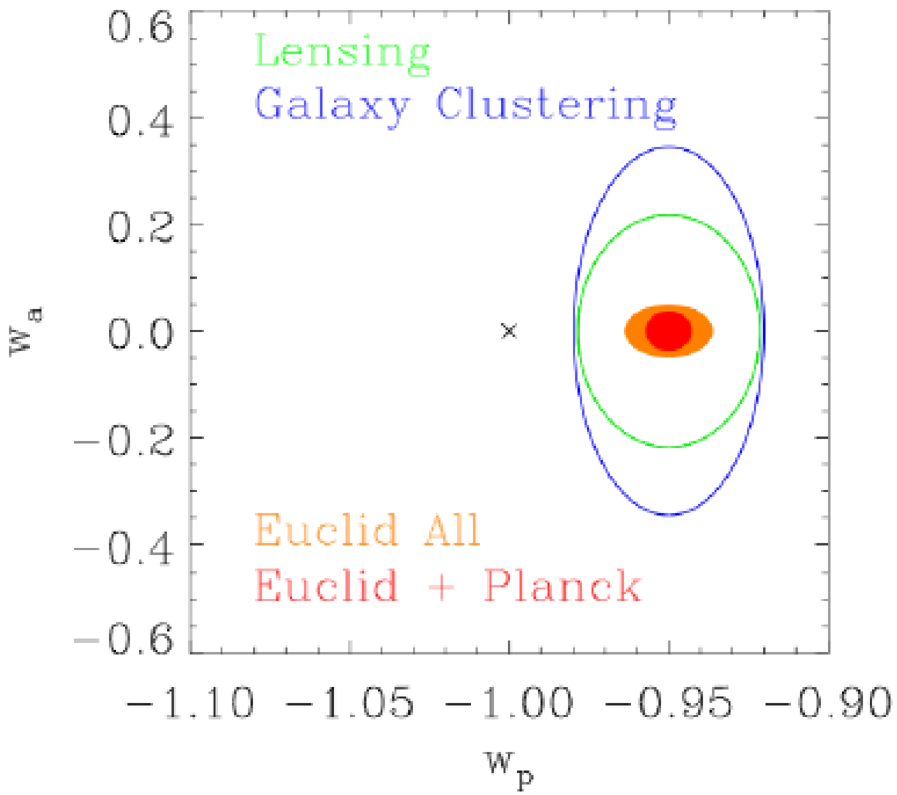


Optimisation of sky coverage for fixed-length survey

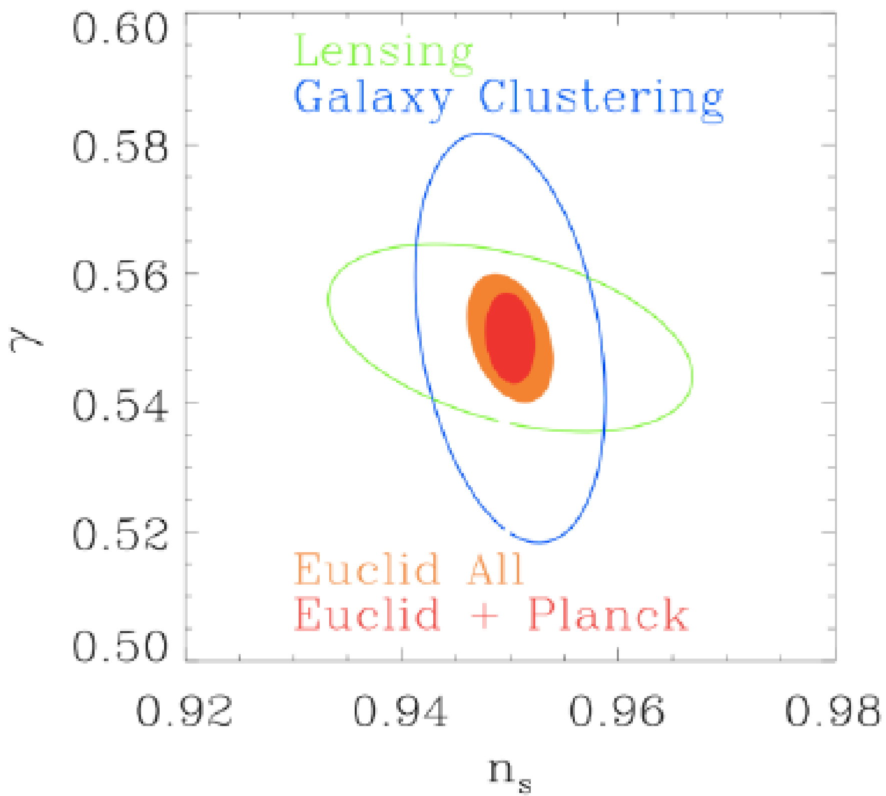


- With 15,000 deg^2 for for GC and WL: optimisation for a fixed time survey.
- Allows Euclid to do WL and GC simultaneously on the same area.

Euclid WL+GC combined: predicted performances



DE constraints from Euclid: 68% confidence contours in the (w_p, w_a).



Constraints on the γ and n_s. Errors marginalised over all other parameters.

Ref: Euclid RB, arXiv:1110.3193

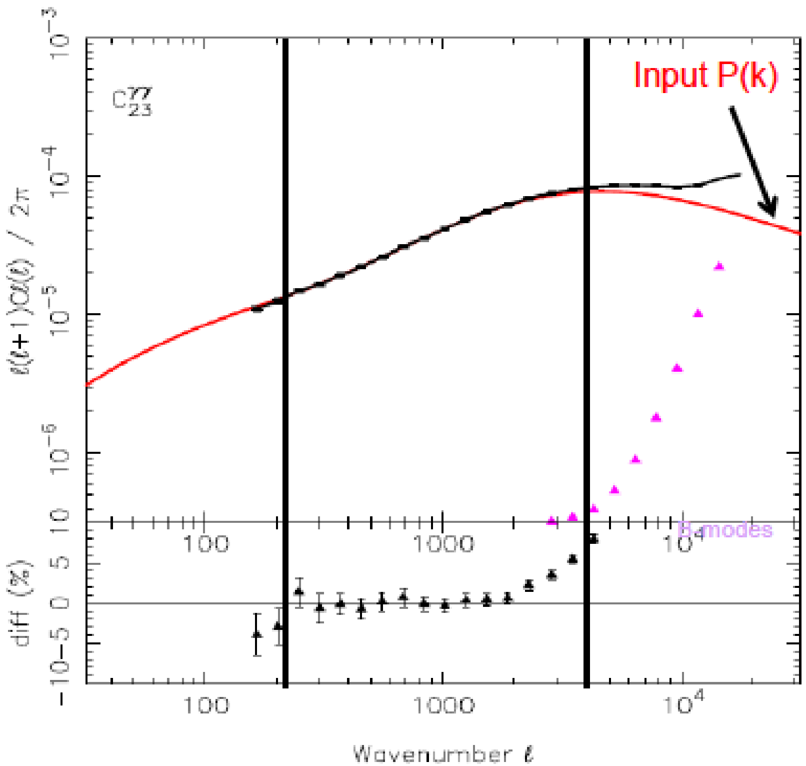
Predicted performances of the Euclid mission

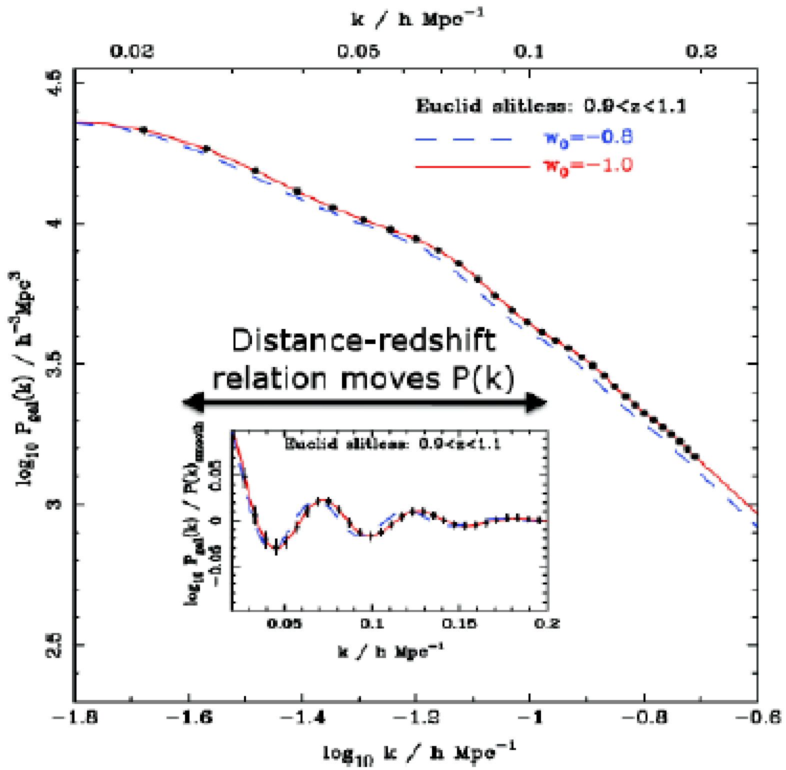
	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_{ν} /eV	f_{NL}	w_p	w_a	FoM
Euclid primary (WL+GC)	0.010	0.027	5.5	0.015	0.150	430
Euclid All	0.009	0.020	2.0	0.013	0.048	1540
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	4020
Current (2009)	0.200	0.580	100	0.100	1.500	~10
Improvement Factor	**30**	**30**	**50**	**>10**	**>40**	**>400**

Also Warm vs Cold DM (if baryon simulations well understood)

Ref: Euclid RB arXiv:1110.3193
More detailled forecasts given in Amendola et al arXiv:1206.1225

Euclid WL and GC: DM and Galaxy reconstructed P(k)





• Tomographic WL shear cross-power spectrum for 0.5 < z < 1.0 and 1.0 < z < 1.5 bins.

• Percentage difference [*expected* – *measured*]

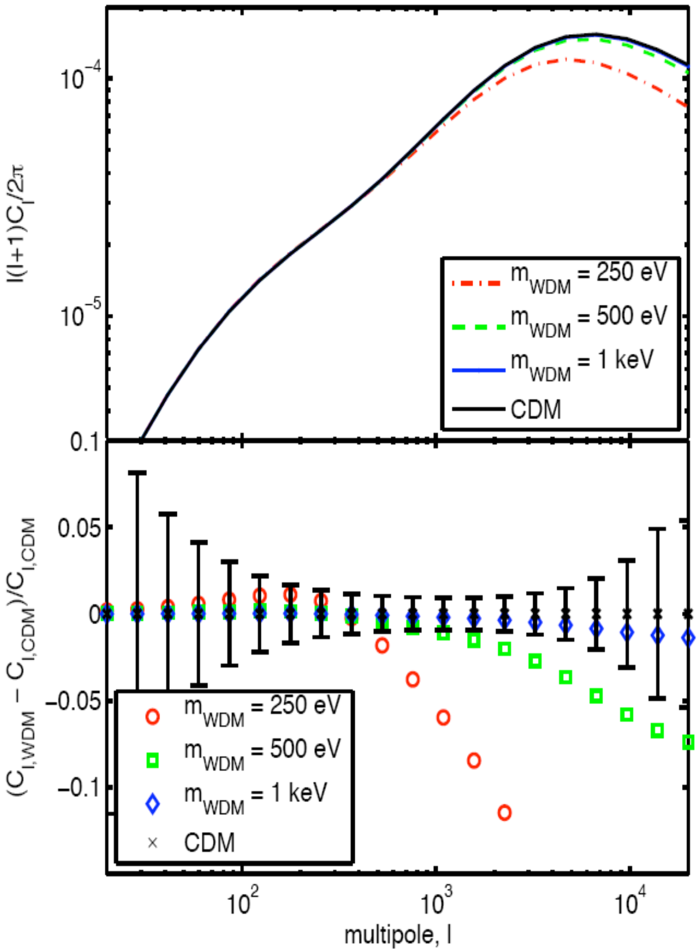
• $V_{eff} \approx 19\ h^{-3}\ Gpc^3 \approx$ 75x larger than SDSS
• Redshifts 0<z<2

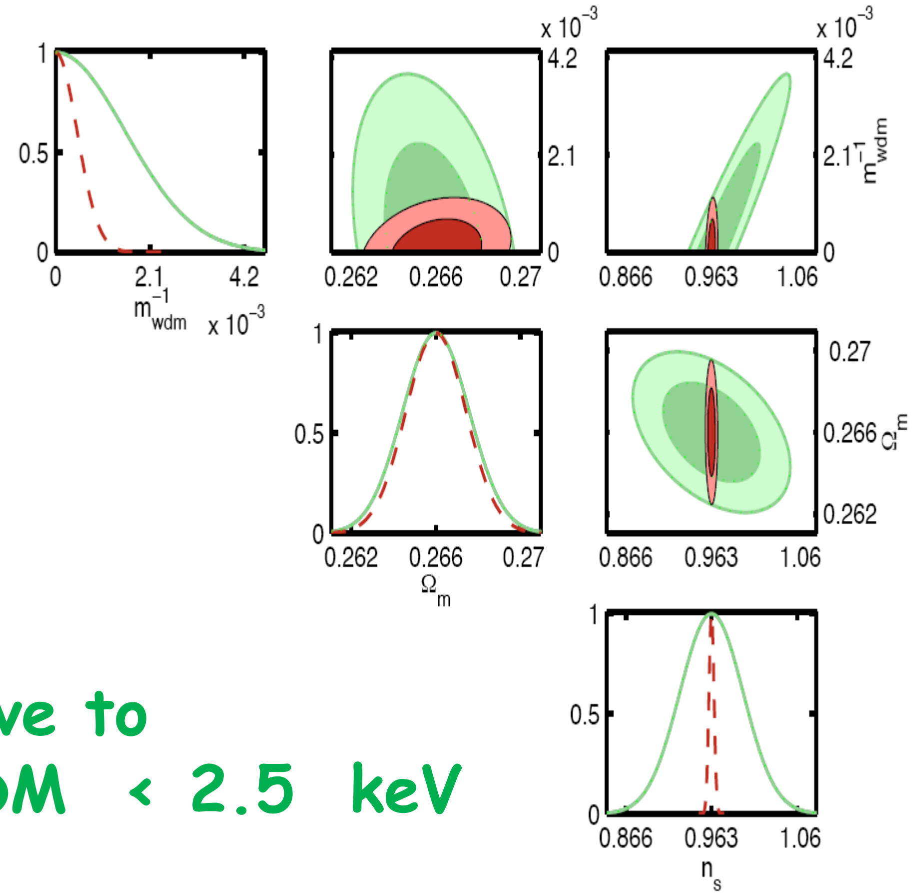
• Percentage difference [*expected* – *measured*]

Cosmic shear power spectra

Markovic et al. 2010 Euclid-like DE space survey +Planck:

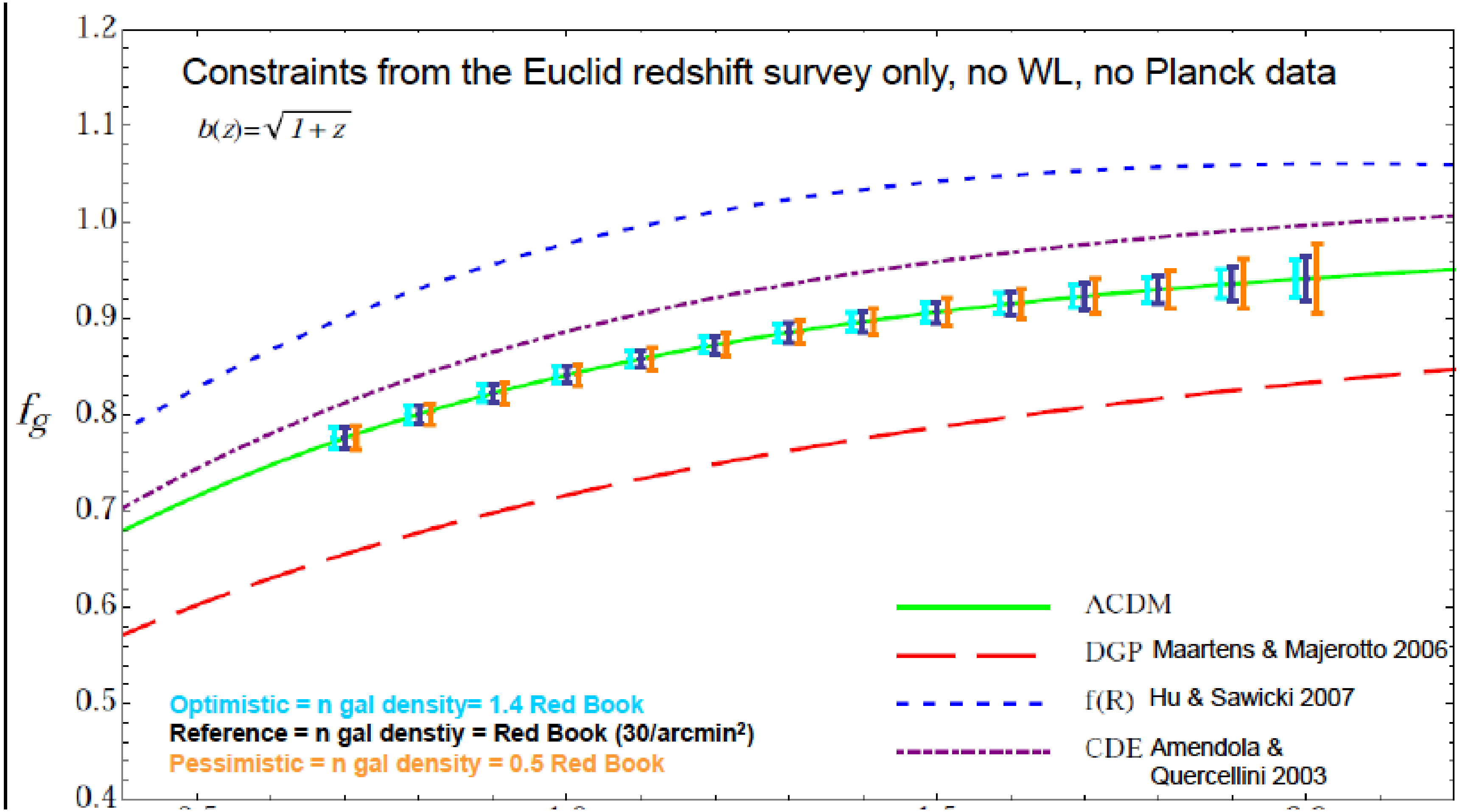
Integral effects → better than matter power spectrum





Sensitive to m_WDM < 2.5 keV

Biasing and Growth rate from GC rate



Third Euclid probe: Clusters of galaxies

- Clusters of galaxies: probe of peaks in density distribution
  - number density of high mass, high redshift clusters very sensitive to
    - any primordial non-Gaussianity and
    - deviations from standard DE models

- Euclid data =
  - 60,000 clusters with a S/N>3 between $0.2<z<2$ (obtained for free).
  - more than 10^4 of these will be at $z>1$.
  - ~ 5000 giant gravitational arcs

→ very accurate masses for the whole sample of clusters (WL)
→ dark matter density profiles on scales >100 kpc
  → direct constraints on numerical simulations.
→ 300000 strong galaxy lensing + 5000 giant arcs
  → test of CDM : probe substructure and small scale density profile.

Euclid SN survey priorities

- Basic goal: a significant gain over existing SN surveys
  - In particular SNLS and DES
- Euclid has the potential to provide the first NIR survey for SNe from space
- Provides an independent Euclid probe of cosmology
- With 6 months of observing time, the most interesting option is the “DESIRE “survey
  - Reaches high redshift : up to z ~ 1.5
  - Cannot be done from the ground

arxiv 1409.8562

DESIRE project!

Published by A&A december 2014

Extending the supernova Hubble diagram to $z \sim 1.5$ with the Euclid space mission

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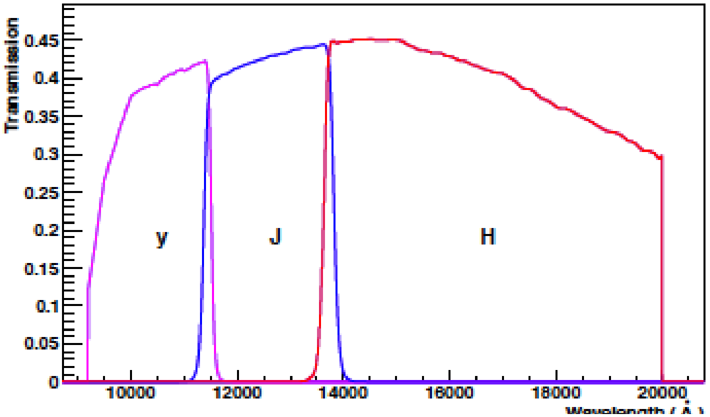
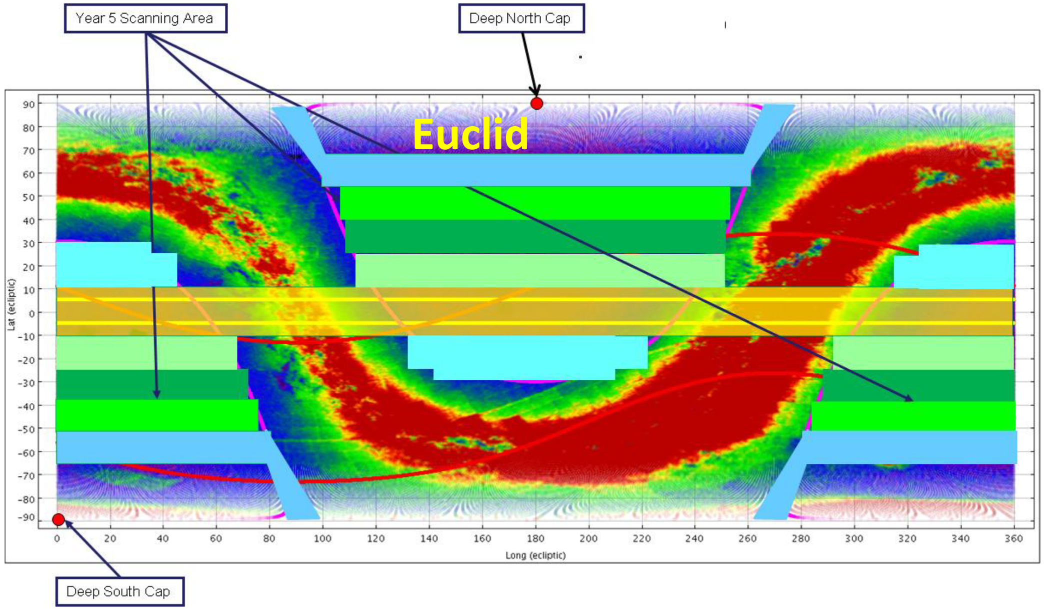
ABSTRACT

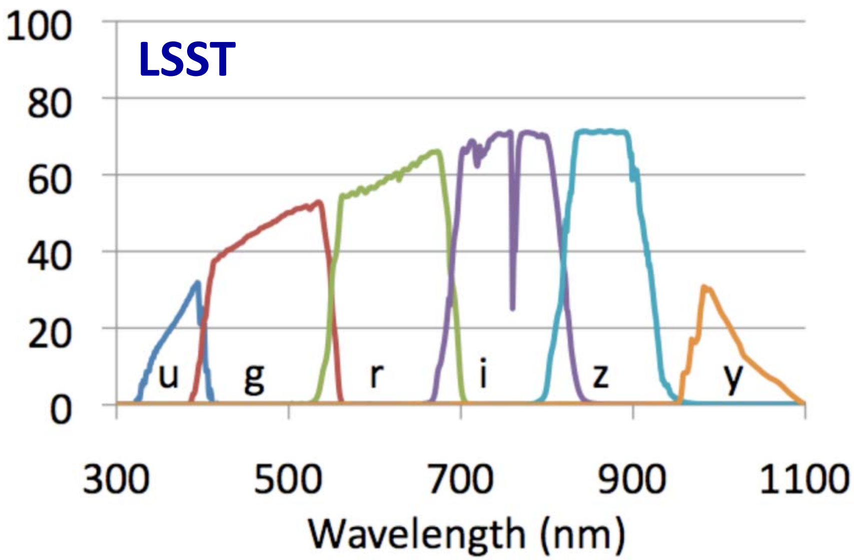
We forecast dark energy constraints that could be obtained from a new large sample of Type Ia supernovae where those at high redshift are acquired with the Euclid space mission. We simulate a three-prong SN survey: a $z < 0.35$ nearby sample (8000 SNe), a $0.2 < z < 0.95$ intermediate sample (8800 SNe), and a $0.75 < z < 1.55$ high-z sample (1700 SNe). The nearby and intermediate surveys are assumed to be conducted from the ground, while the high-z is a joint ground- and space-based survey. This latter survey, the "Dark Energy Supernova Infra-Red Experiment" (DESIRE), is designed to fit within 6 months of Euclid observing time, with a dedicated observing programme. We simulate the SN events as they would be observed in rolling-search mode by the various instruments, and derive the quality of expected cosmological constraints. We account for known systematic uncertainties, in particular calibration uncertainties including their contribution through the training of the supernova model used to fit the supernovae light curves. Using conservative assumptions and a 1-D geometric *Planck* prior, we find that the ensemble of surveys would yield competitive constraints: a constant equation of state parameter can be constrained to $\sigma(w) = 0.022$, and a Dark Energy Task Force figure of merit of 203 is found for a two-parameter equation of state. Our simulations thus indicate that Euclid can bring a significant contribution to a purely geometrical cosmology constraint by extending a high-quality SN Ia Hubble diagram to $z \sim 1.5$. We also present other science topics enabled by the DESIRE Euclid observations.

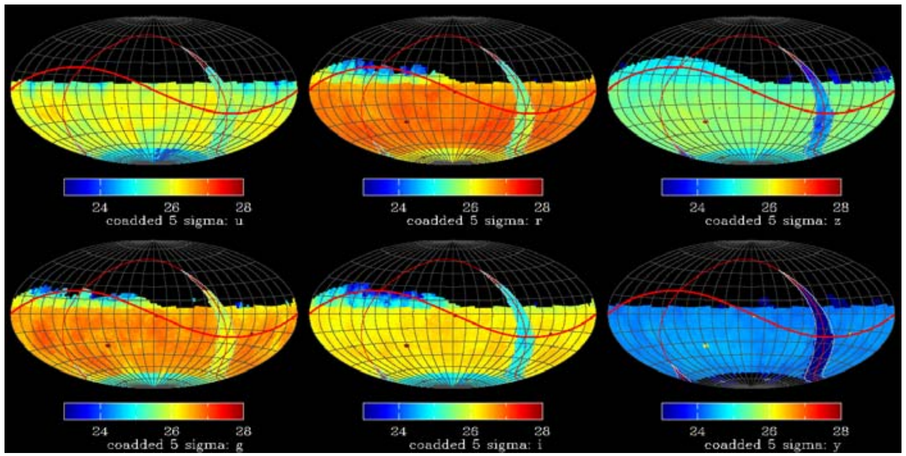
Complementary Observations with LSST





EUCLID NIR + Broad visible bands





DESIRE with EUCLID + LSST

Table 4. Main parameters of the simulated surveys.

	z_{min}	z_{max}	area (deg^2)	duration (months)	events
DESIRE	0.75	1.55	10	2x6	1740
LSST-DDF	0.15	0.95	50	4x6	8800
Low z	0.05	0.35	3000	6	8000

NB: 2* 6 months (use half time → total 6 months up-time)

Table 2. Depth of the visits simulated for the DESIRE survey.

	i	z	y	J	H
Depth (5σ)	26.05	25.64	25.51	25.83	26.08
Exp. time (s)	700	1000	1200	2100	2100

Notes. Depth (5σ for a point source) and exposure times at each visit for a 4-day cadence of the proposed DESIRE joint SN survey. The exposure times for LSST i and z bands assume nominal observing conditions. For Euclid NIR bands, the exposures times are the ones that would deliver the required depth in a single exposure, if such long exposures are technically possible. The S/N calculations are described in appendix A.

DESIRE:

An ultra deep survey!

final stacked depth

28 to 28.5 mag

(AB, 5 σ point source limit)

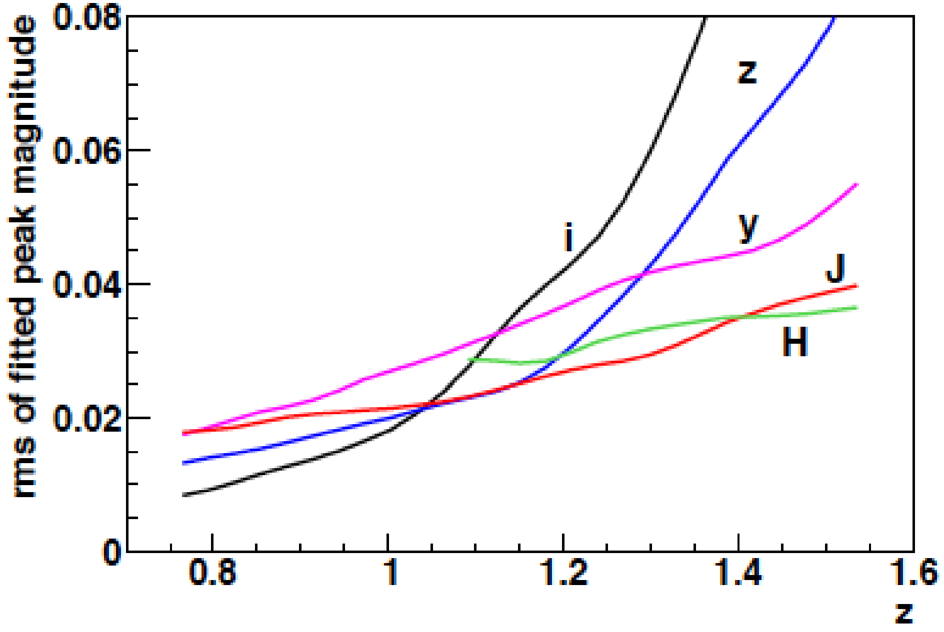


Fig. 5. Precision of light curve amplitudes as a function of redshift for the 5 bands of the DESIRE survey, assuming a 4-day cadence with the exposure times of Table 2. To fulfill the requirements in §2.3, i-band is used up to z = 1, z-band up to z = 1.2, and distances at z = 1.5 rely mostly on J- and H-band. For y, J and H bands, these calculations assume a reference image gathering 60 epochs in Euclid.

FOM > 200

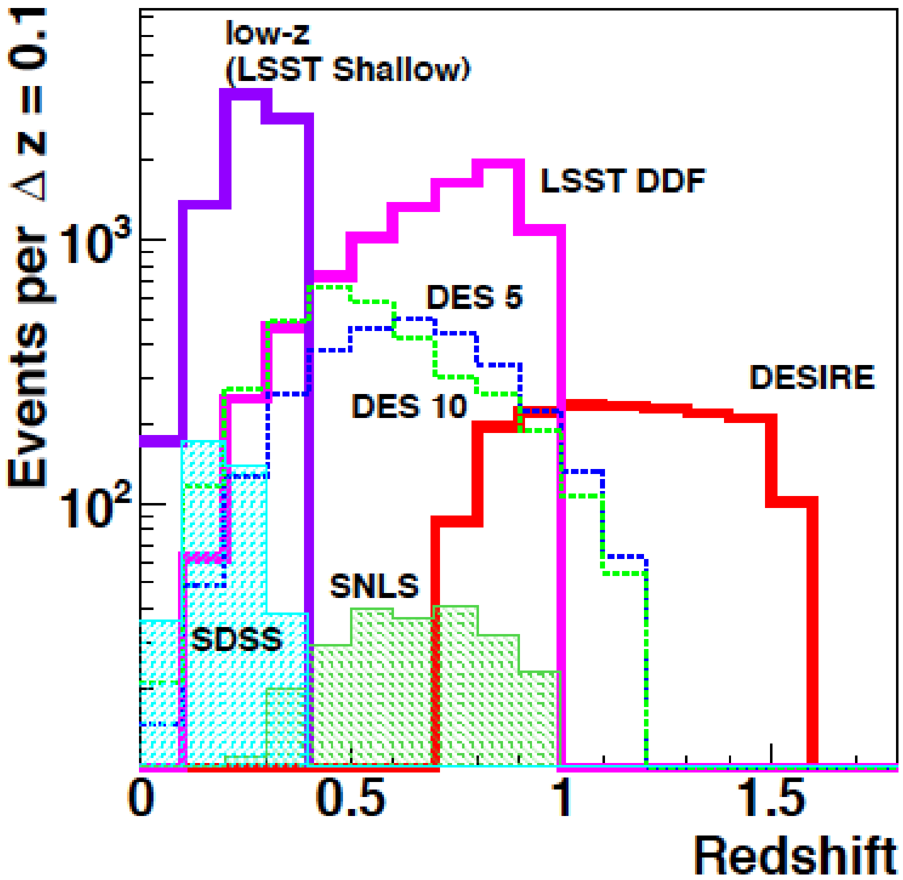


Fig. 12. Redshift distribution of events for various surveys. For the SDSS and SNLS, the distributions sketch the total sample of spectroscopically identified events eventually entering the Hubble diagram. "DES 5" and "DES 10" refer respectively to the "hybrid-5" and "hybrid-10" strategies studied in Bernstein et al. (2012), where the baseline is hybrid-10. "LSST-SHALLOW", "LSST-DDF" and "DESIRE" refer to the three prongs studied in this proposal.

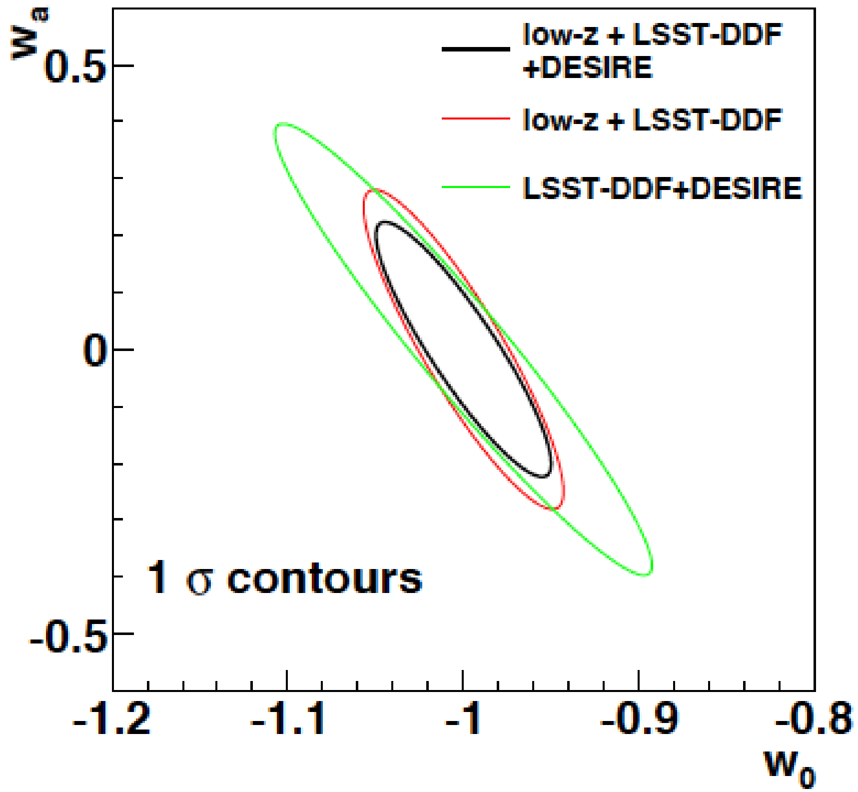


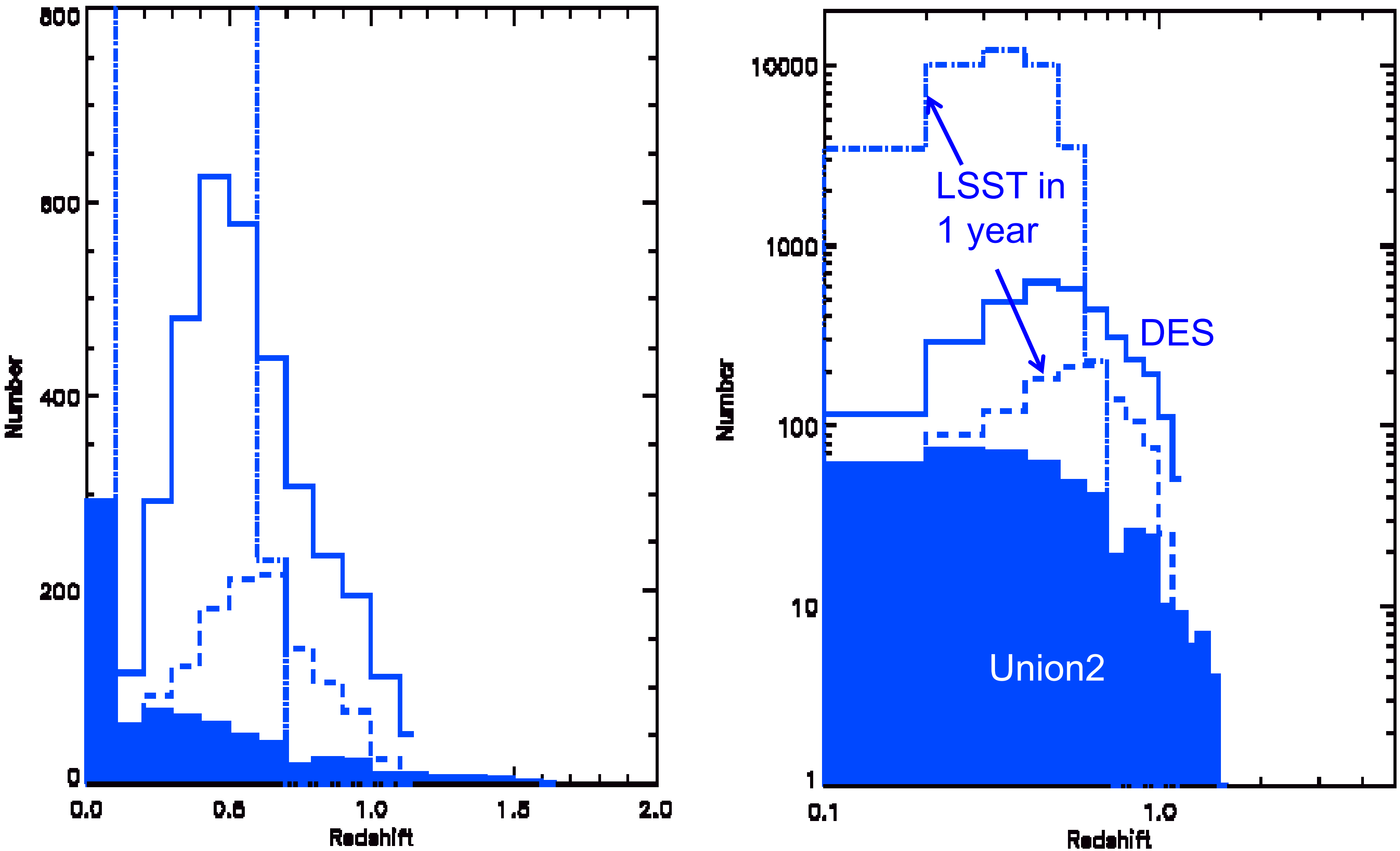
Fig. 9. Confidence contours (at the 1σ level) of the survey combinations listed in Table 5. The assumptions for systematics correspond to the last row o

Table 5. Cosmological performance of the simulated surveys.

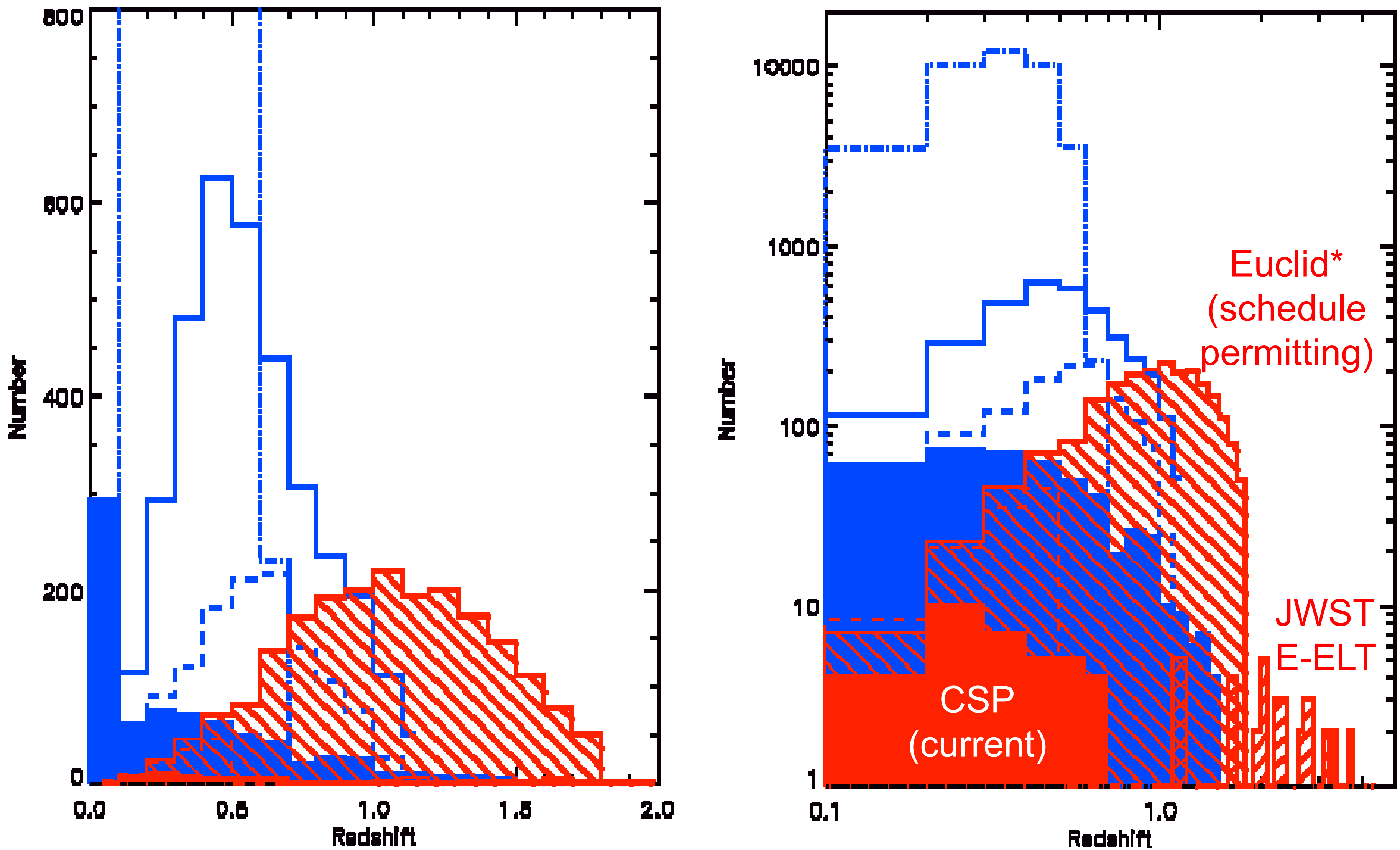
	$\sigma(w_a)$	z_p	$\sigma(w_p)$	FoM
low-z + LSST-DDF + DESIRE	0.22	0.25	0.022	203.2
low-z + LSST-DDF	0.28	0.22	0.026	137.1
LSST-DDF + DESIRE	0.40	0.35	0.031	81.4

Notes. The FoMs assume a 1-D geometrical *Planck* prior and flatness. z_p is the redshift at which the equation of state uncertainty reaches its minimum $\sigma(w_p)$. The FoM is defined as $[Det(Cov(w_0, w_a))]^{-1/2} = [\sigma(w_a)\sigma(w_p)]^{-1}$ and accounts for systematic uncertainties. The contributions of the main systematics are detailed in Table 6.

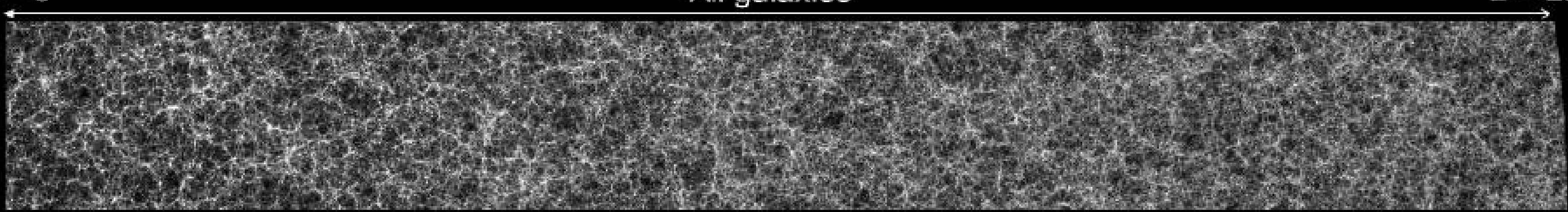
OPTICAL SN samples

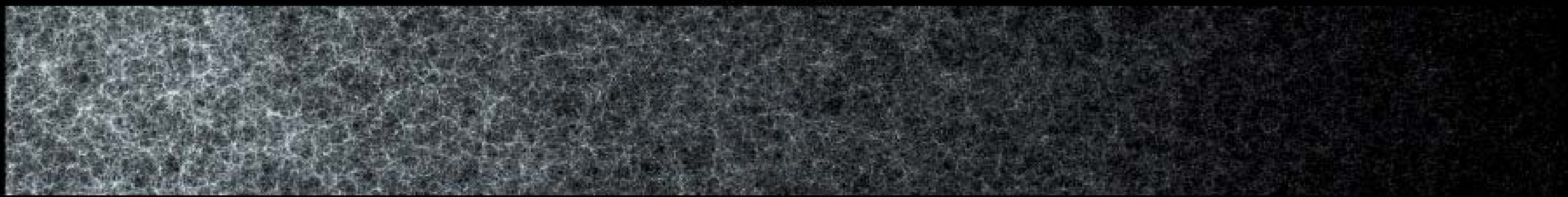


OPTICAL and NIR SN samples



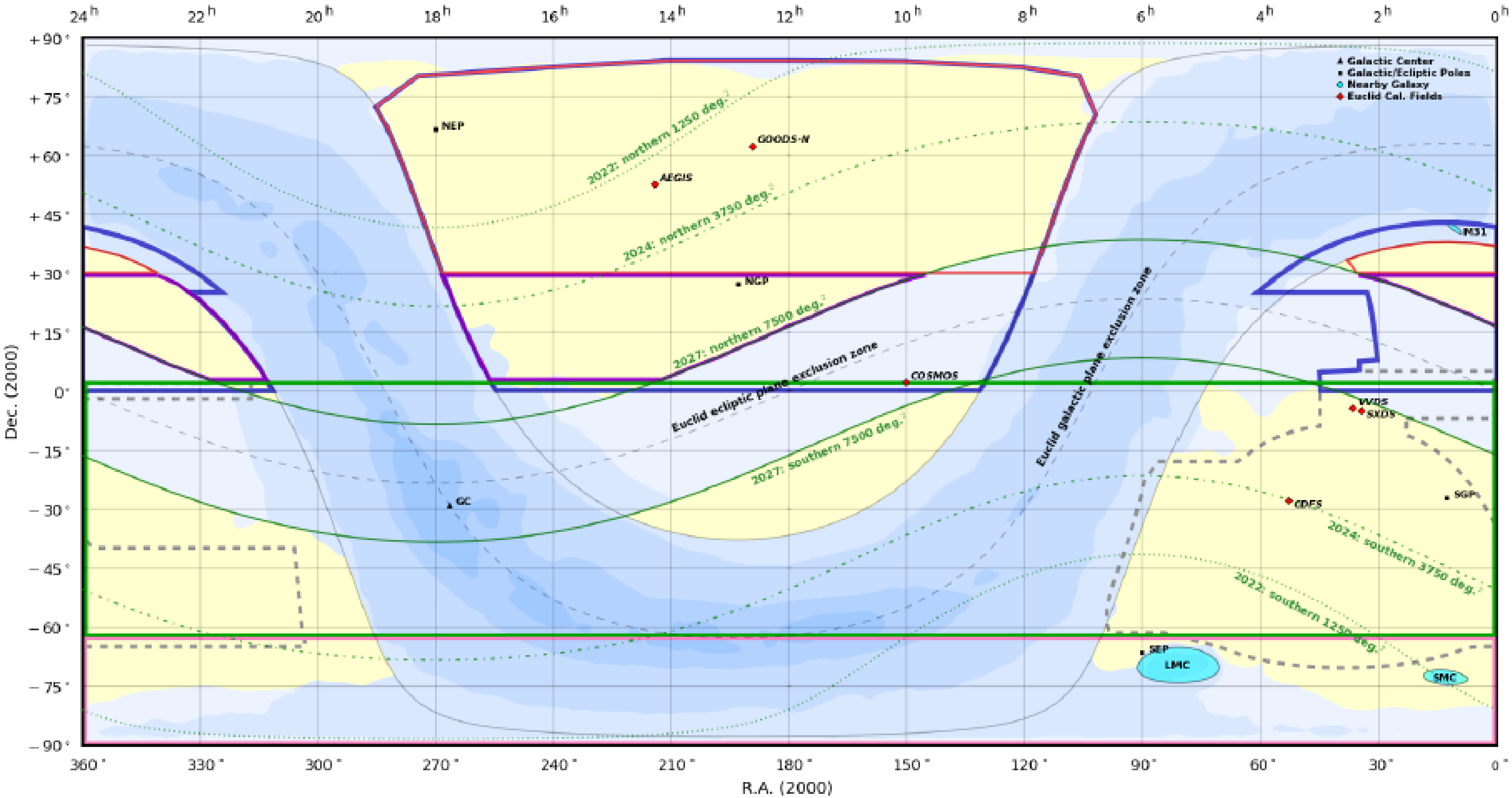
Euclid Flagship Simulation: mock galaxy catalog





- L-CDM + Planck 2013 cosmology
- 2 Trillion particles N body simulation down to z=0
- First catalogues and images: OU-SIM delivered for validations: SPV, SGS→ OUs/SDC
- 5000 deg^2 expected for SVP by June
- See P. Fosalba's presentation on Wednesday Jun 07

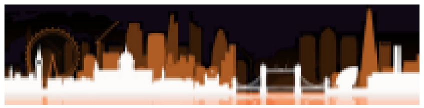
Updates: ground based observations for Euclid



Expected ground-based coverage of the Euclid Wide Survey available by 2024/7 for DR2/3 = 7,500/15,000 deg.² (origin/bands/overlap)

- Euclid exclusion zone : 26,000 deg.² [galactic+ecliptic planes]
- Euclid Wide Survey : 15,000 deg.² [with E(B-V)<0.08]
- DES-griz : 4,500 deg.²
- CFIS-u : 7,300 deg.²
- CFIS-r + JEDIS-g + PS-iz : 4,800 deg.²
- LSST main survey, ugrizy : 7,000 deg.²
- LSST south extension, ugrizy : 1,000 deg.²
- LSST Euclid extension, griz : 3,000 deg.²

From J.-C. Cuillandre

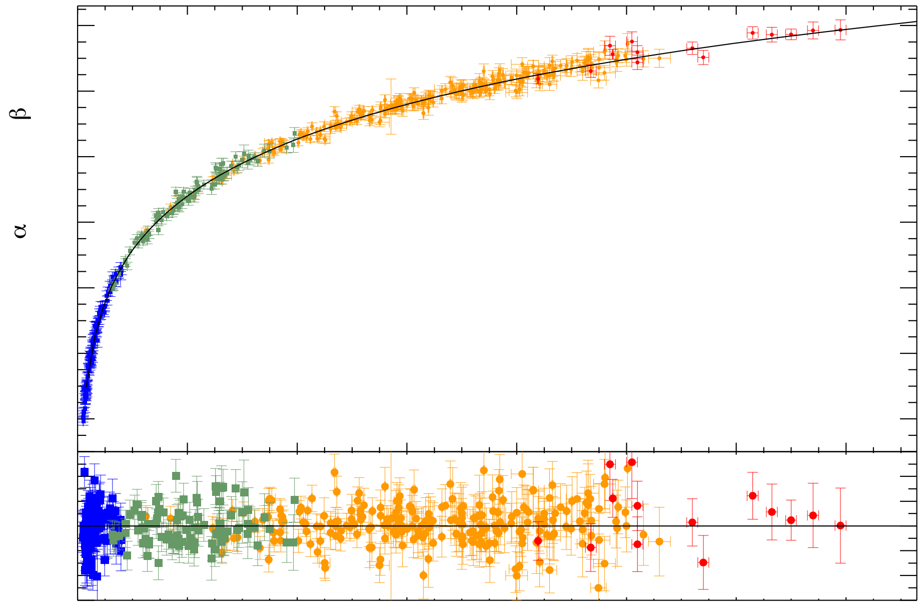


Thank you for your attention!

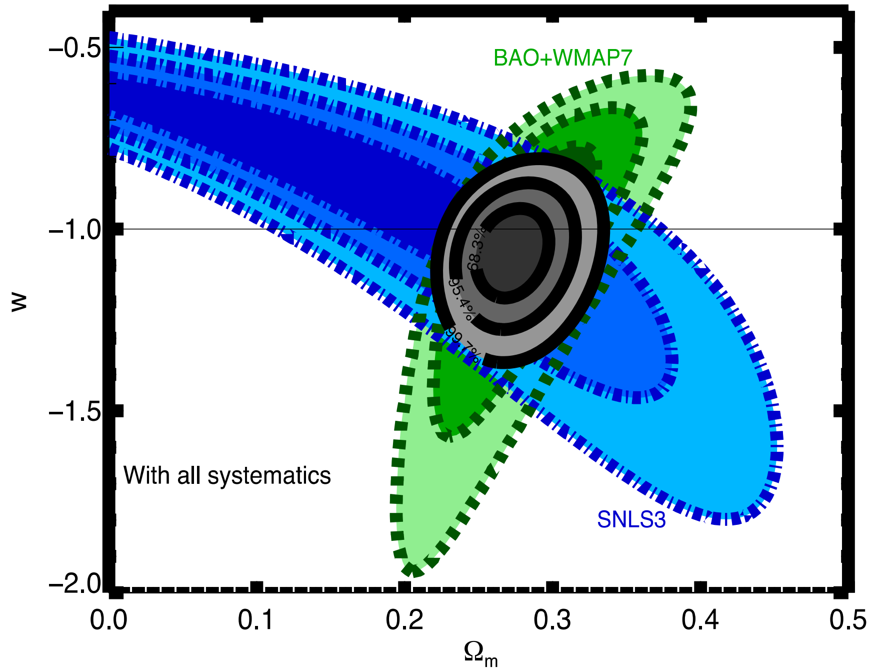
谢谢！

Current SNIa cosmological constraints

Compilation of 472 SNeIa
123 low-z, 93 SDSS, 242 SNLS, 14 HST



w (=P/ρ) = -1.06 +/- 0.07
(including systematics, assuming flat universe with WMAP7, BAO and H_0 constraints)



SNLS 3-year results (Conley et al 2010, Sullivan et al 2011, Guy et al 2010),