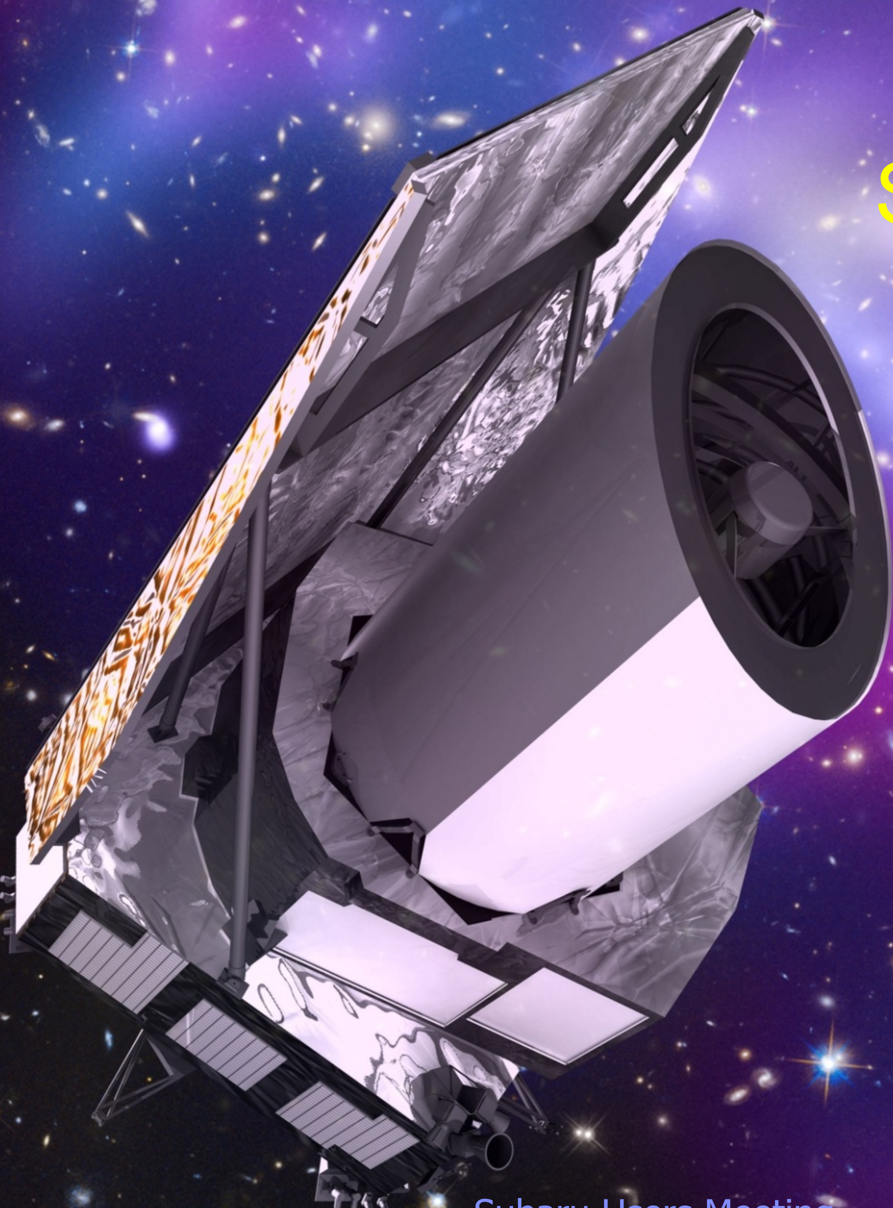


Subaru & Euclid
(updated)

Y. Mellier
&
J.-C. Cuillandre

On behalf of the Euclid Consortium

www.euclid-ec.org

Euclid Primary Objectives: the Dark Universe

- Understand the origin of the Universe's accelerating expansion
- Probe the properties and nature of Dark Energy and Gravity,

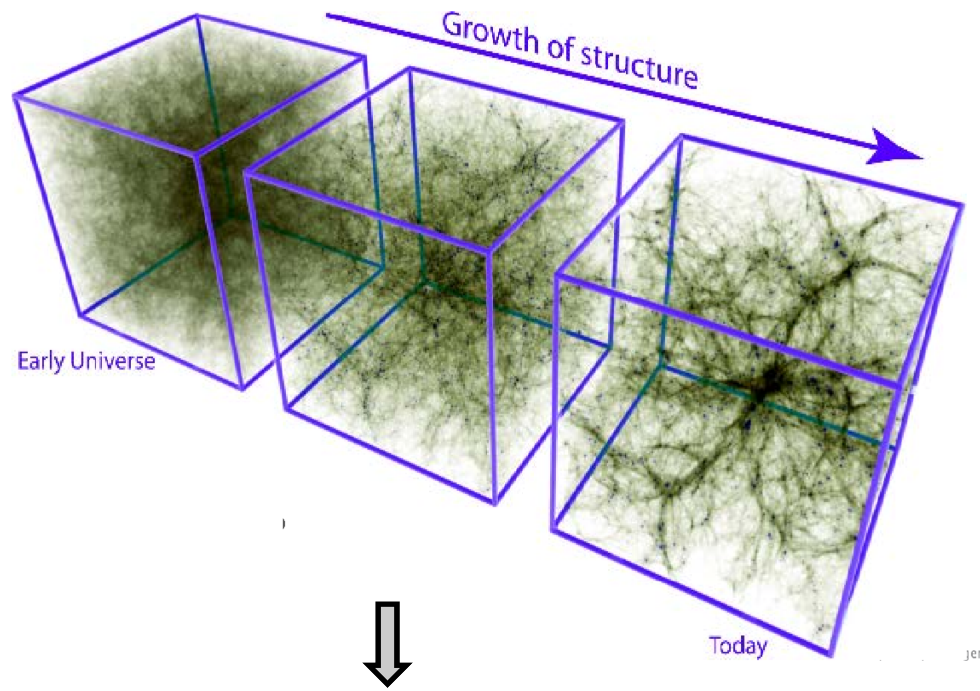
- Probe the effects of Dark Energy, Dark Matter and Gravity by:
  - Using at least 2 independent but complementary probes (5 probes)
  - Tracking their observational signatures on the
    - Geometry of the universe: Weak Lensing (WL), Galaxy Clustering (GC)
    - Cosmic history of structure formation: WL, Redshift-Space Distortion (RSD), Clusters of Galaxies (CL)
  - Controling systematic residuals to an unprecedented level of accuracy.

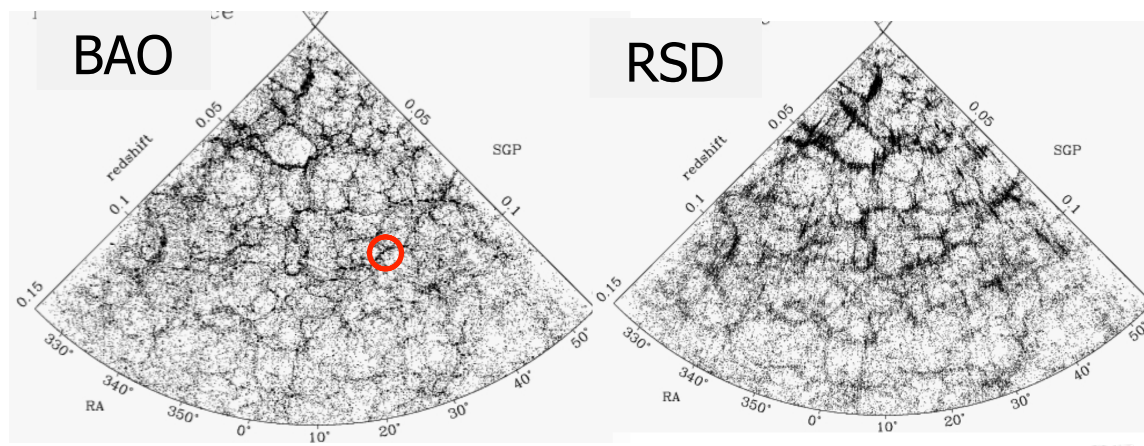
Primary Probe 1 : Galaxy Clustering: BAO + RSD

3-D position measurements of galaxies over 0.7<z<1.8

- Probes expansion rate of the Universe (BAO) and clustering history of galaxies induced by gravity (RSD); ψ, *H*(*z*).

- Need high precision 3-D distribution of galaxies with spectroscopic redshifts.





Euclid:

35 million spectroscopic redshifts with 0.001 (1+z) accuracy
over 15,000 deg^2

Primary probe 2: Dark matter in the Universe

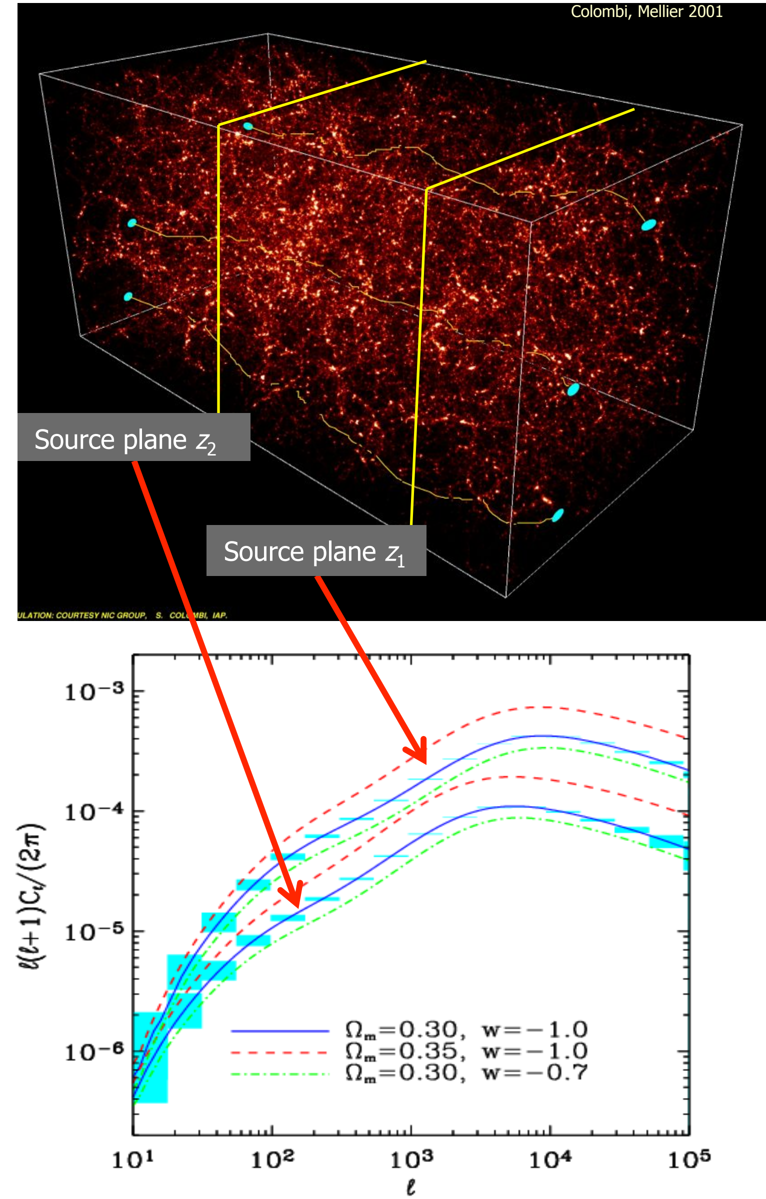
Cosmic shear over 0<z<2

$$\kappa_{eff} = \frac{3H_0^2\Omega_0}{2c^2}\int_0^{\omega}\frac{f_K(\omega-\omega')\,f_K(\omega')}{f_K(\omega)}\frac{\delta\left[f_K(\omega')\,\boldsymbol{\theta};\omega'\right]}{a(\omega')}\mathrm{d}\omega'$$

• Probes distribution of (Dark+Luminous) matter with Weak Lensing (WL): expansion history, lensing potential φ+ψ.

→ Shapes+distance of galaxies: shear amplitude, and bin the Universe into slices.

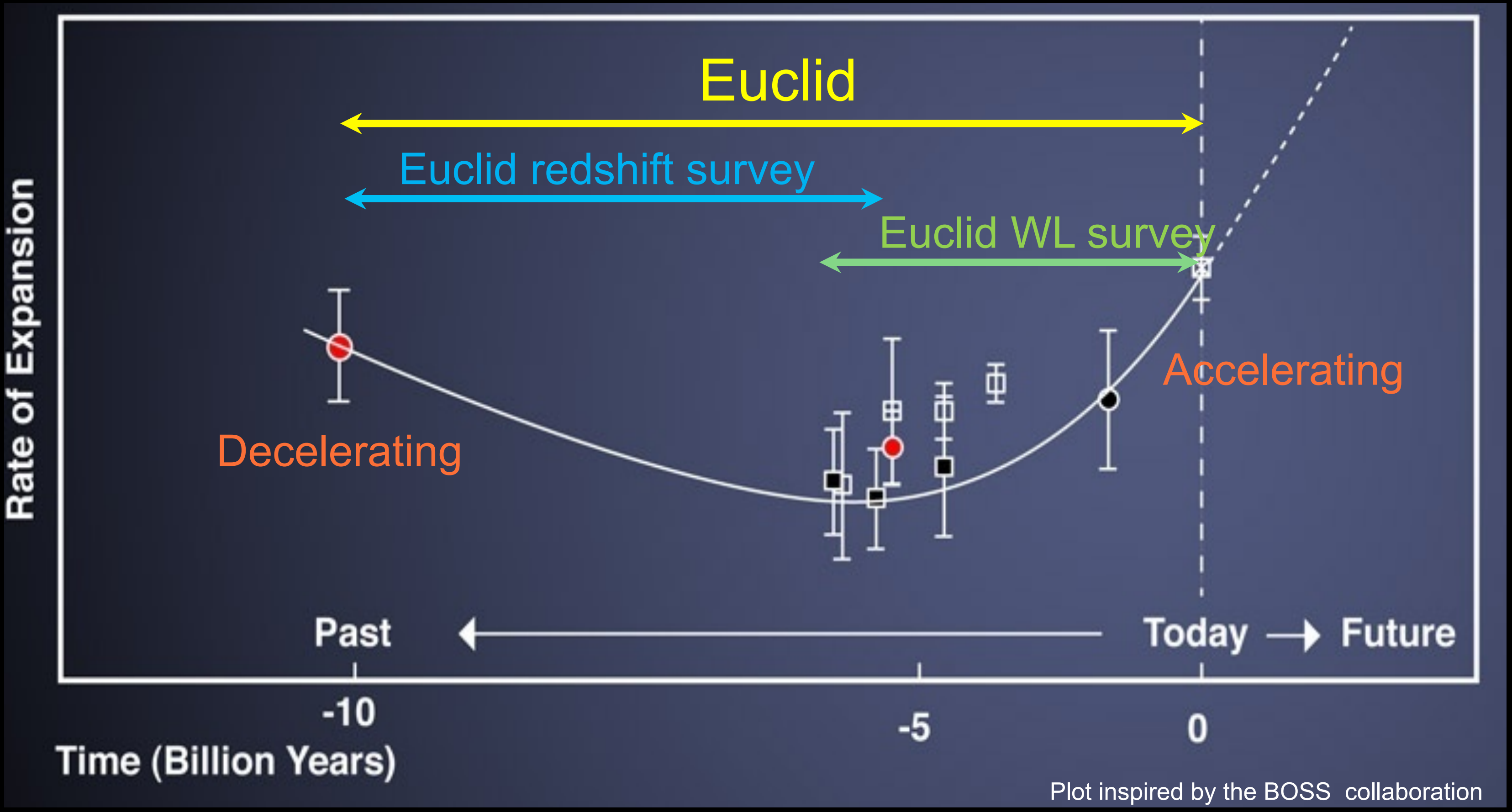
→ "Photometric redshifts" sufficient for distances: optical+NIR data.



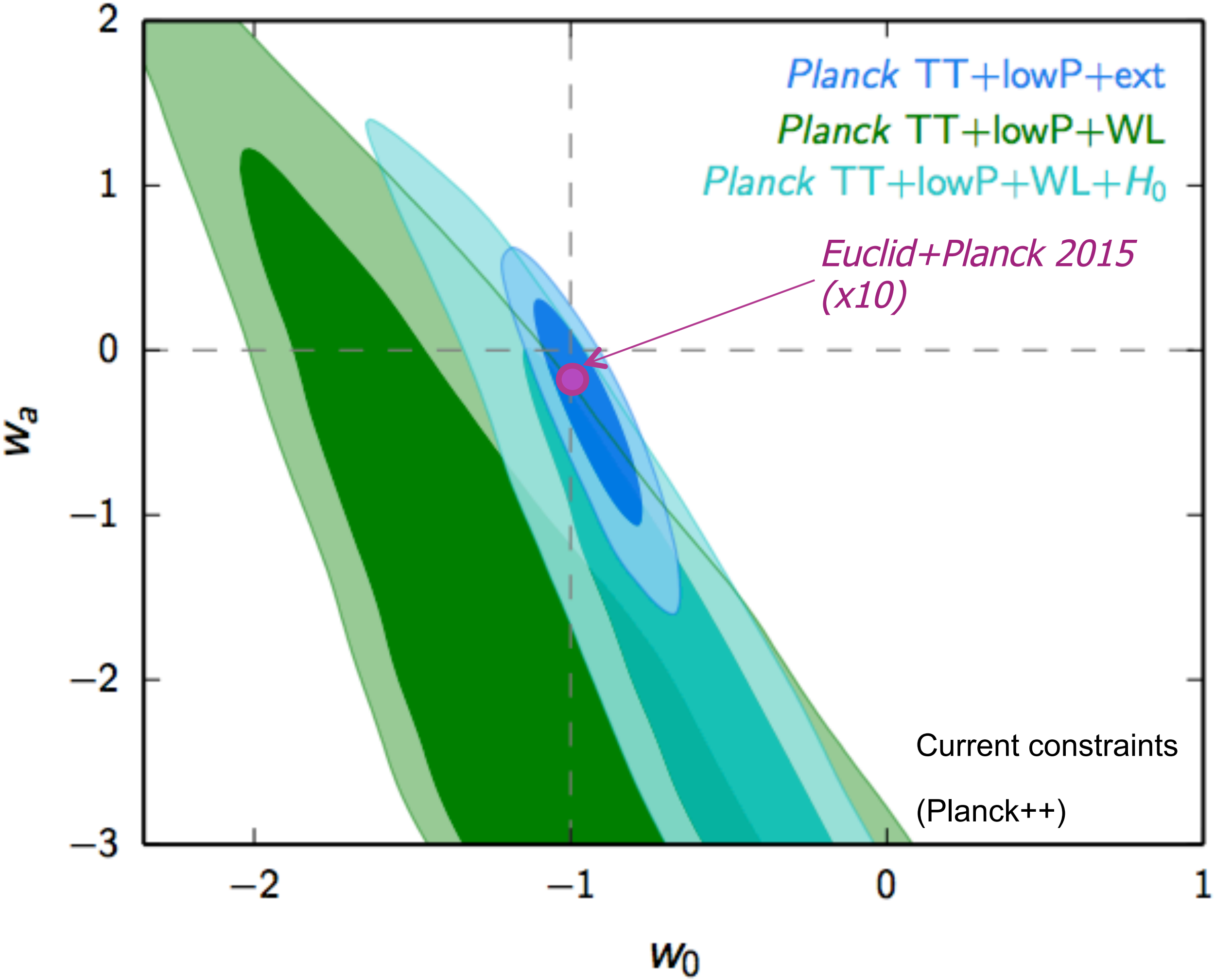
Euclid:

WL with 1.5 billion galaxies over 15,000 deg^2

Euclid will explore the dark universe and the DM-dominated / DE-dominated transition period



Euclid Post-Planck Forecast for the Primary Program



Dark Energy		
w_p	w_a	FoM $= 1/(\Delta w_0 \times \Delta w_a)$
0.015	0.150	430
0.013	**0.048**	**1540**
0.007	0.035	**6000**
0.100	**1.500**	**~10**
>10	**>40**	**>400**

DE equation of state: $P/\rho = w$, and $w(a) = w_p + w_a(a_p - a)$

From Euclid data alone, get FoM=$1/(\Delta w_a \times \Delta w_p)$ > 400→ ~1% precision on w's.

Euclid Post-Planck Forecast for the Primary Program

Ref: Euclid RB arXiv: 1110.3193	**Modified Gravity**	**Dark Matter**	**Initial Conditions**
Parameter	γ	m_ν /eV	f_{NL}
Euclid primary (WL+GC)	0.010	0.027	5.5
EuclidAll (clusters,ISW)	**0.009**	**0.020**	**2.0**
Euclid+Planck	0.007	0.019	2.0
Current (2009)	**0.200**	**0.580**	**100**
Improvement Factor	**30**	**30**	**50**

Assume systematic errors are under control

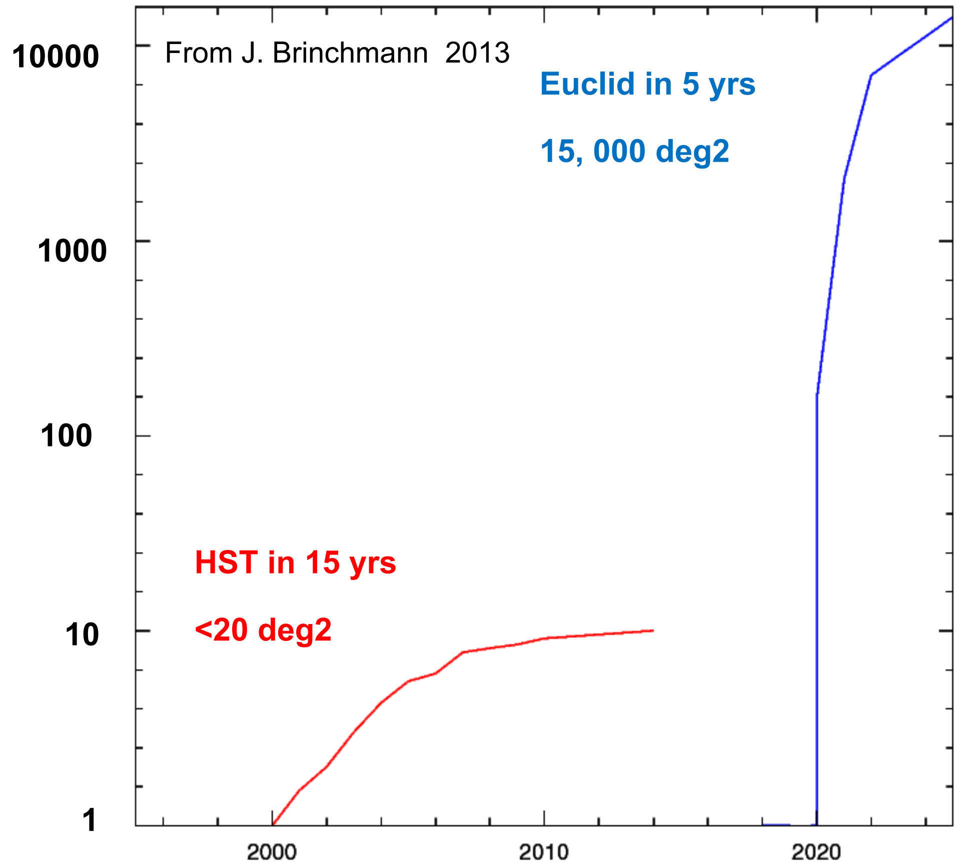
Growth rate of structure formation: $f \sim \Omega^{\gamma}$; .

Notice neutrino constraints -> minimal mass possible ~ 0.05 eV!

Euclid:

contributing to the revolution in wide field VIS/NIR surveys for the whole scientific community

- Very large samples
  - → Diversity of populations
  - → Distribution functions
  - → ~50,000 clusters of galaxies
- Huge volumes and numbers
  - → Rare sources, probing the extremes
- Exquisite imaging of galaxies
  - → Morphologies, mergers, galaxy-scale lenses
  - → Observations of 10^6 dwarf galaxies
- Strong and Weak Lensing
  - → Galaxy evolution as function of halo properties
  - → Galaxy alignement
  - → 5000 clusters with giant arcs
- NIR Spectroscopy
  - → Metals, star formation@ z>1
  - → Cool stars
  - → Very high-z QSOs



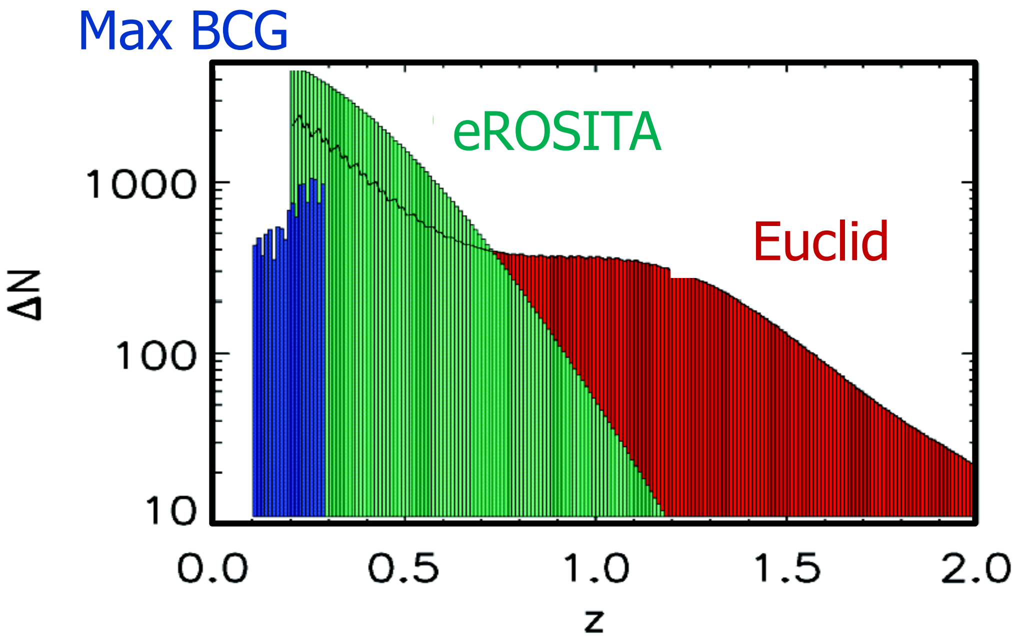
Clusters of galaxies with Euclid

- Probe of peaks in density distribution
- Nb density of high mass, high redshift clusters very sensitive to
  - primordial non-Gaussianity and
  - deviations from standard DE models
- Euclid data will get for free:
  - 60,000 clusters between $0.2<z<2$, 10^4 at $z>1$.
  - ~ 5000 giant gravitational arcs (→ SL +WL mass)

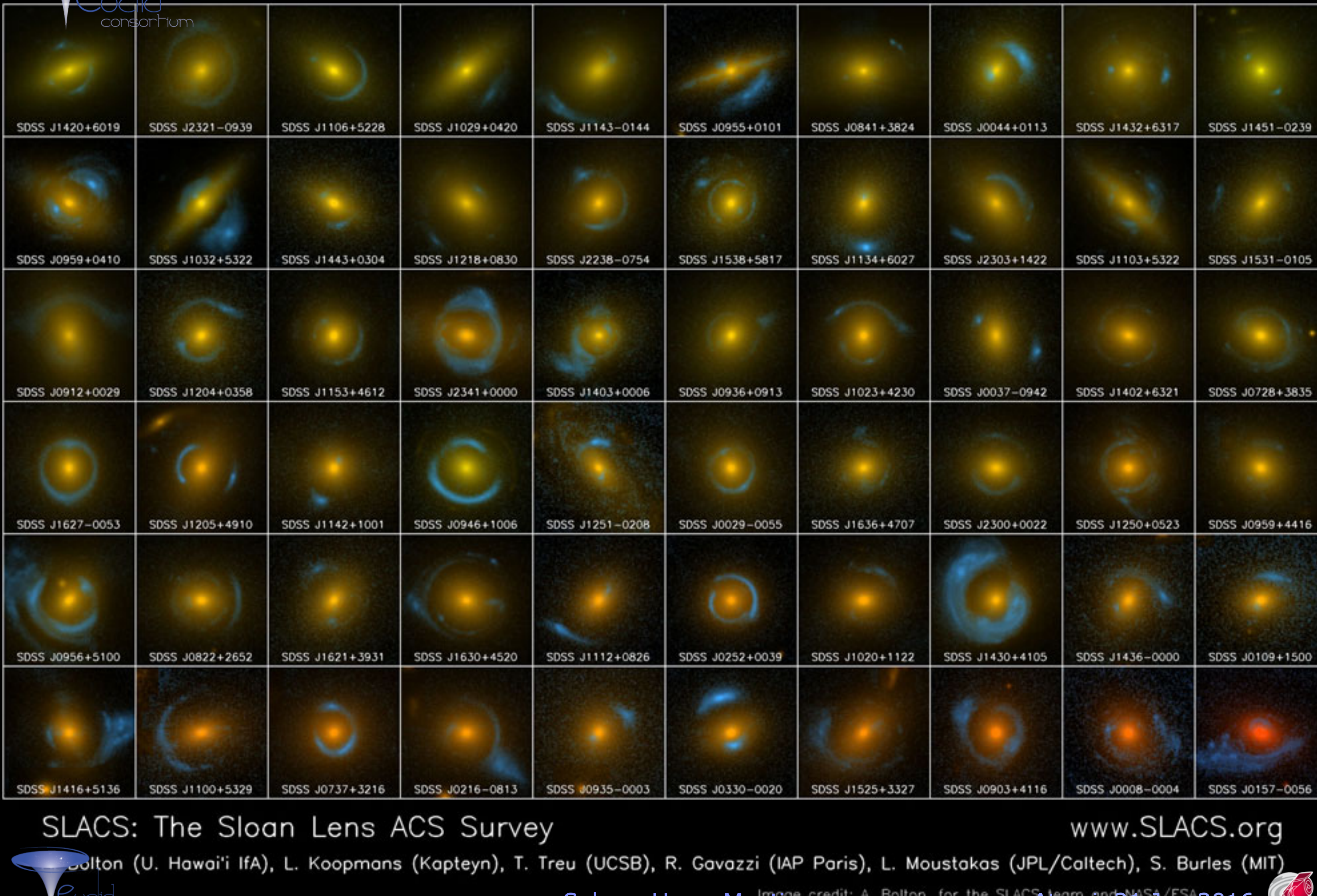
  → very accurate masses for the whole sample of clusters (WL)

  → dark matter density profiles on scales >100 kpc

Synergy with Planck and eROSITA



SLACS (~2010 - HST)



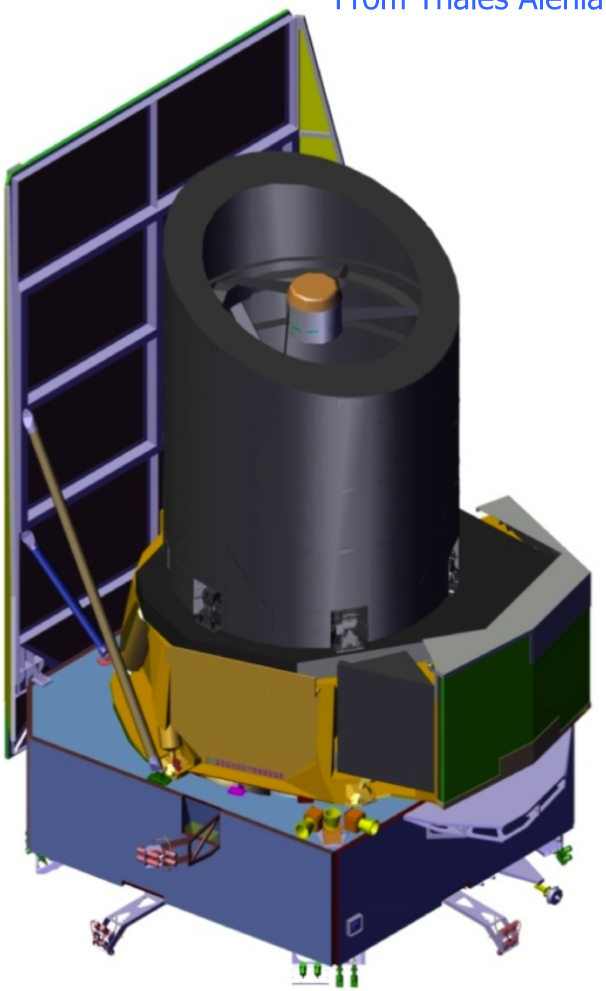

SLACS
Euclid VIS Legacy : after 2 months
(66 months planned)

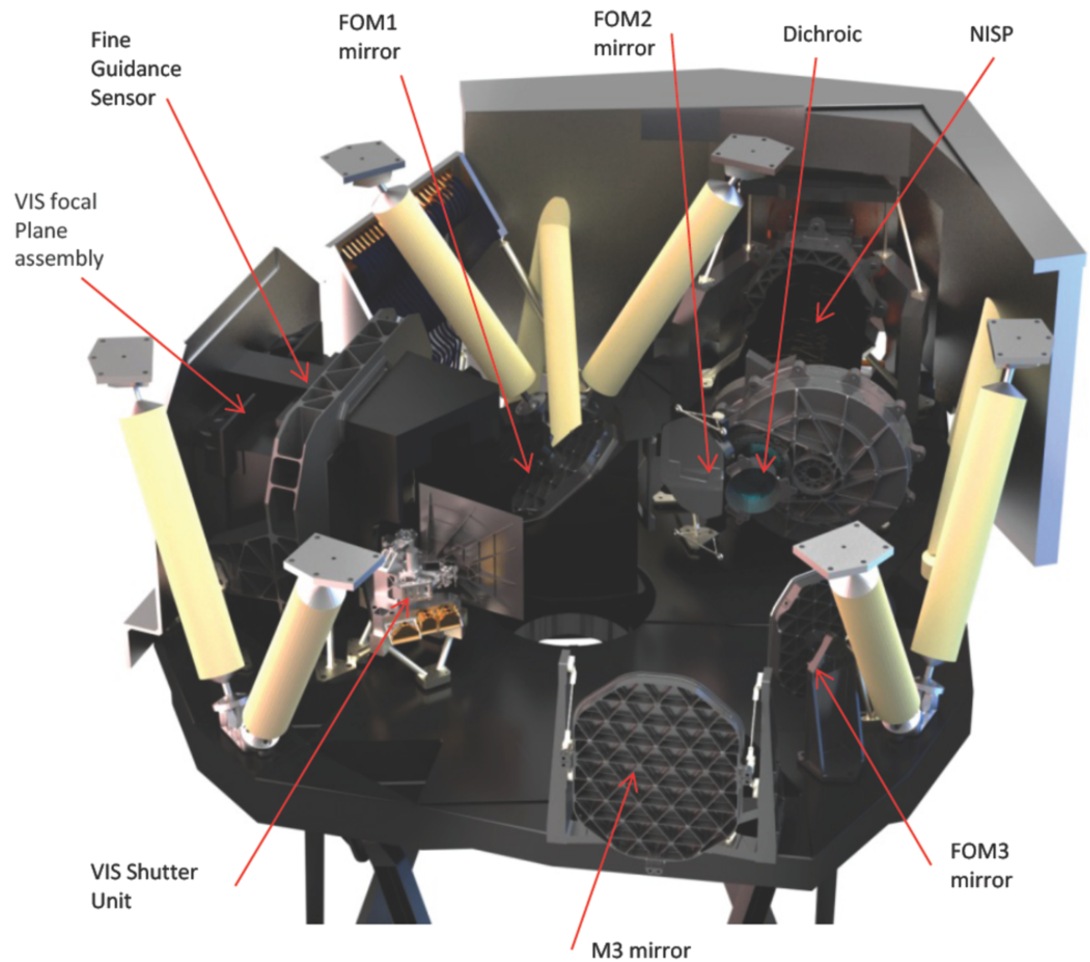
ESA Euclid mission

- Total mass satellite :
- 2 200 kg
- Dimensions:
- 4,5 m x 3 m
- Launch: end 2020 by a Soyuz rocket from the Kourou space port
- Euclid placed in L2
- Survey: 6 years,
- Wide: 15,000 deg^2 , 12 10^9 sources, 1.5 10^9 WL galaxies, 3.5 10^7spectra
- Deep: 2x20 deg^2

Telescope and scientific instruments

From Thales Alenia Italy, Airbus DS, ESA Project office and Euclid Consortium





- Télescope 1,2 m: FoV: 0.54 deg^2
- Miror in Silicon Carbide= ultra-stable:

Temp.: -150 deg. Stability +:- 0.05 deg.

Common visible and infrared field of view

= 0.54 deg^2

Simulation of M51 with VIS

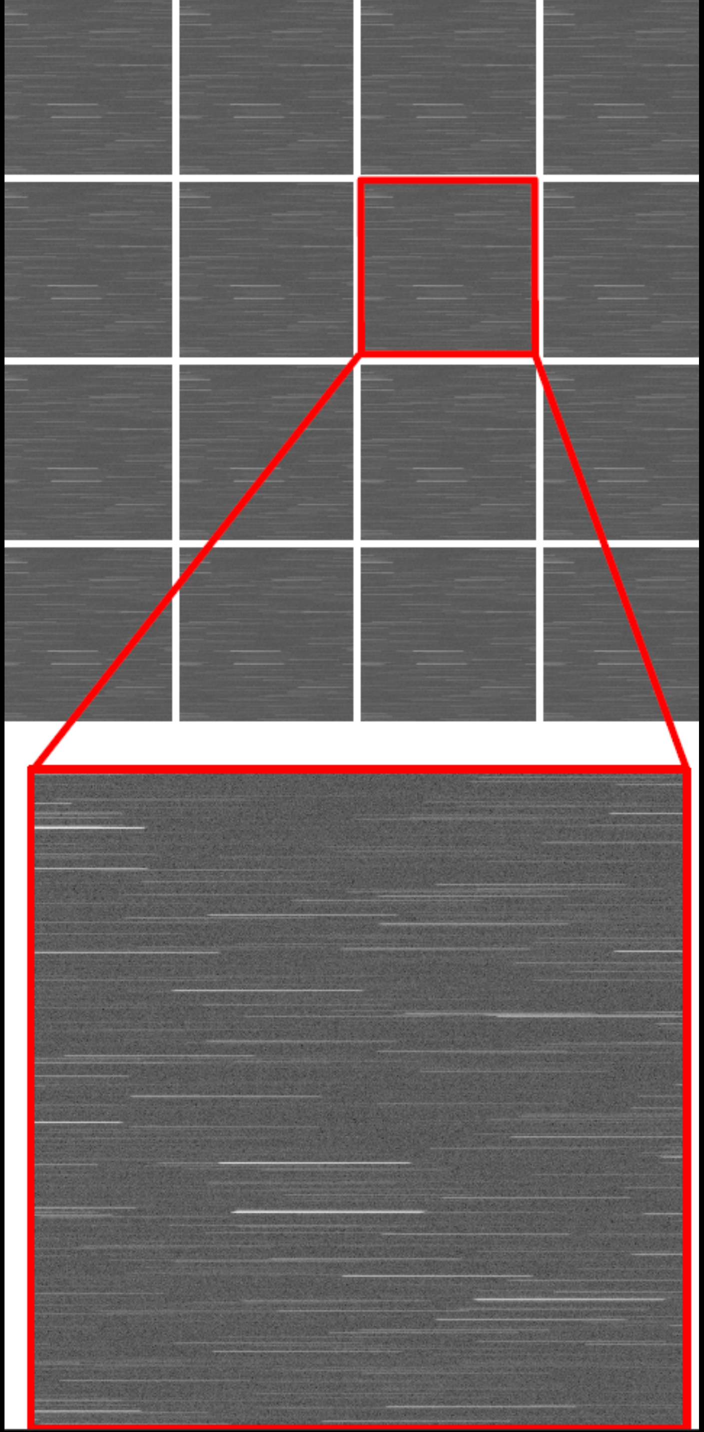
2.4m SDSS-like @ z=0.1 Euclid @ z=0.1 Euclid @ z=0.7

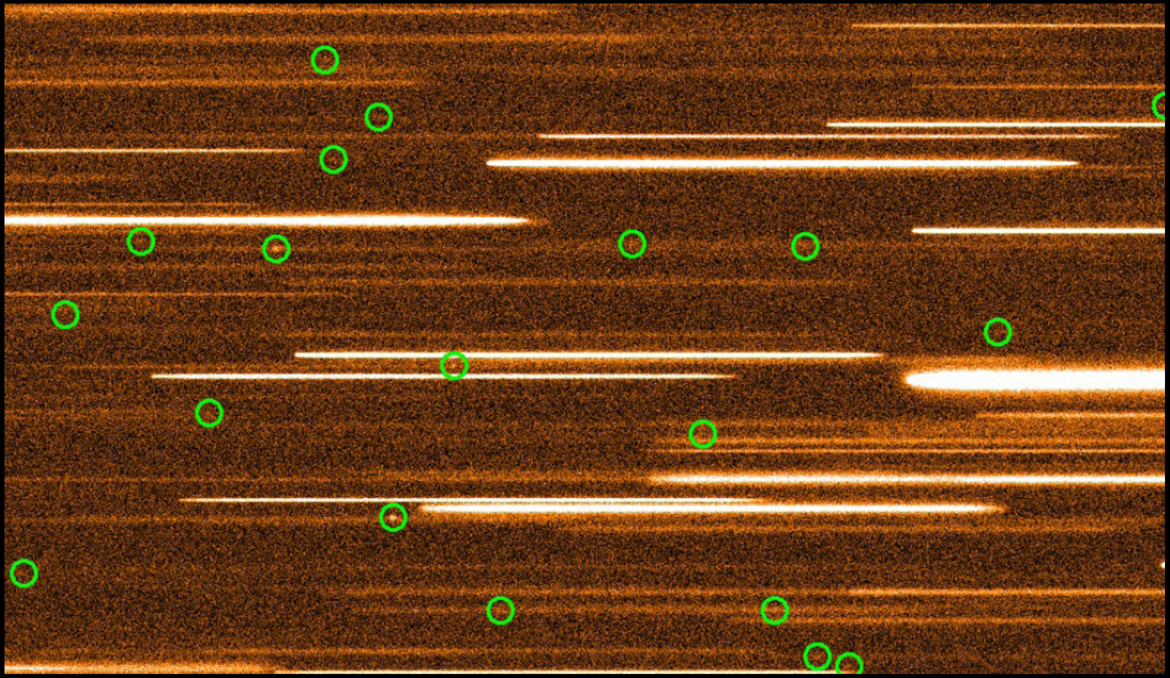
Euclid will get the resolution of SDSS but at z=1 instead of z=0.05.

Euclid will be 3 magnitudes deeper → Euclid Legacy = Super-Sloan Survey

NISP-spectroscopy for Euclid (2015)

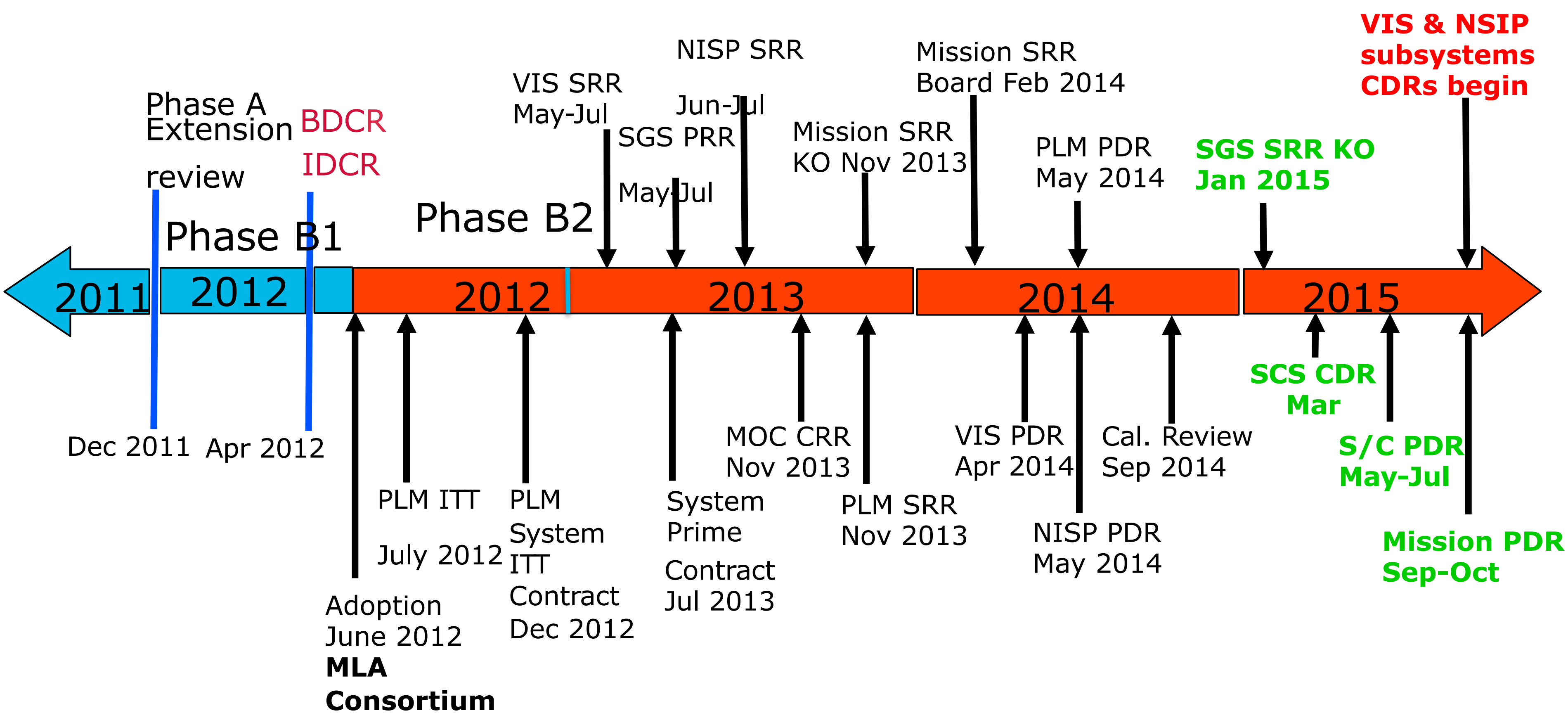
From P. Franzetti, B. Garilli, A. Ealet, N. Fourmanoit & J. zoubian



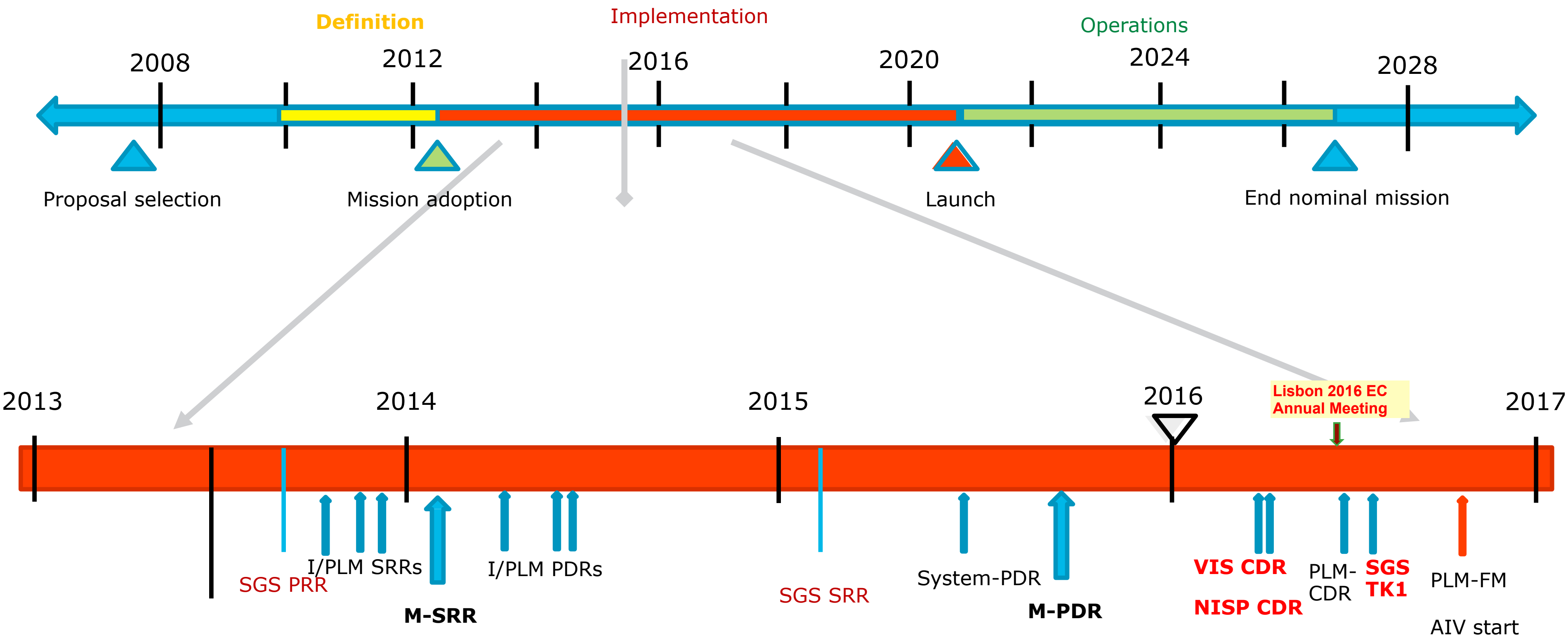


35 million spectra → deviation of recession velocity of galaxies produced by gravitational attraction

Euclid planning history 2011 - 2015



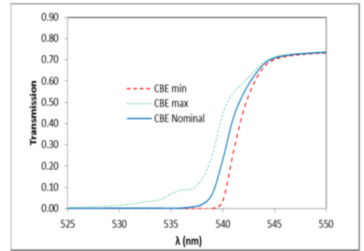
Overview mission timeline

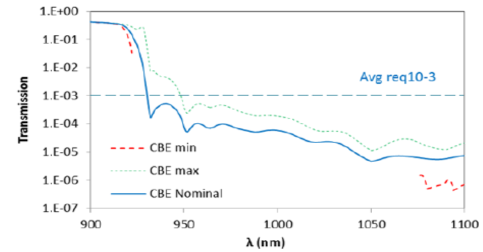


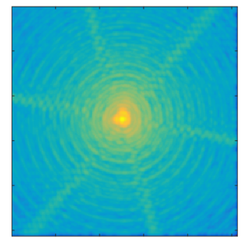
ESA Mission PDR 2015 successful:

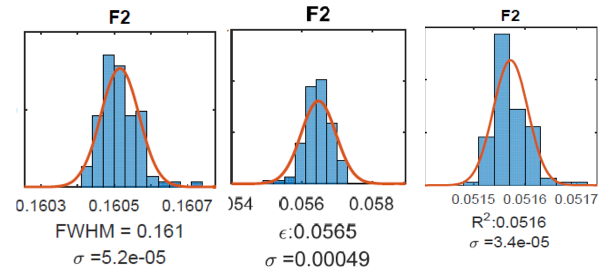
Euclid performances meet the scientific and survey requirements

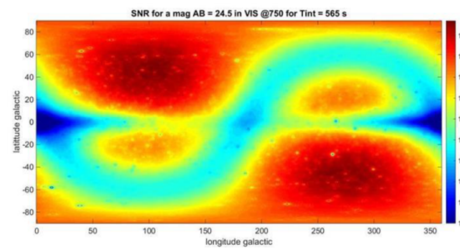
Technical Performance Measure		Requirement	CBE
Image Quality			
VIS Channel	FWHM (@ 800nm)	180 mas	163 mas
	ellipticity	15.0%	5.9%
	R2 (@ 800 nm)	0.0576	0.0530
	ellipticity stability σ(εi)	2.00E-04	2.00E-04
	R2 stability σ(R2)/<R2>	1.00E-03	1.00E-03
	Plate scale	0.10 "	0.10 "
	Out-of-band avg red side	1.00E-03	1.13E-05
	Out-of-band avg blue side	1.00E-03	2.12E-04
	Slope red side	35 nm	15 nm
	Slope blue side	25 nm	8 nm
NISP Channel	rEE50 (@1486nm)	400 mas	217 mas
	rEE80 (@1486nm)	700 mas	583 mas
	Plate scale	0.30 "	0.30 "
Sensitivity			
VIS SNR (for mAB = 24.5 sources)		10	17.1
NISP-S SNR (@ 1.6um for 2xe-16 erg cm-2 s-1 source)		3.5	4.87
NISP- P SNR (for mAB = 24 sources)	Y-band	5	5.78
	J-band	5	6.69
	H-band	5	5.35
NISP-S Performance			
Purity		80%	72%
Completeness		45%	0.52
Survey			
Wide Survey Coverage		15,000 deg2	15,000
Survey length [years]		5.5	5.4

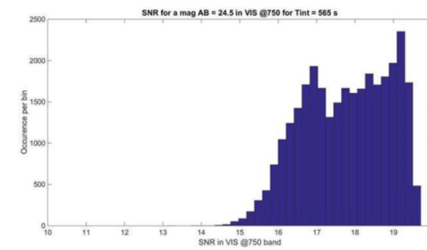






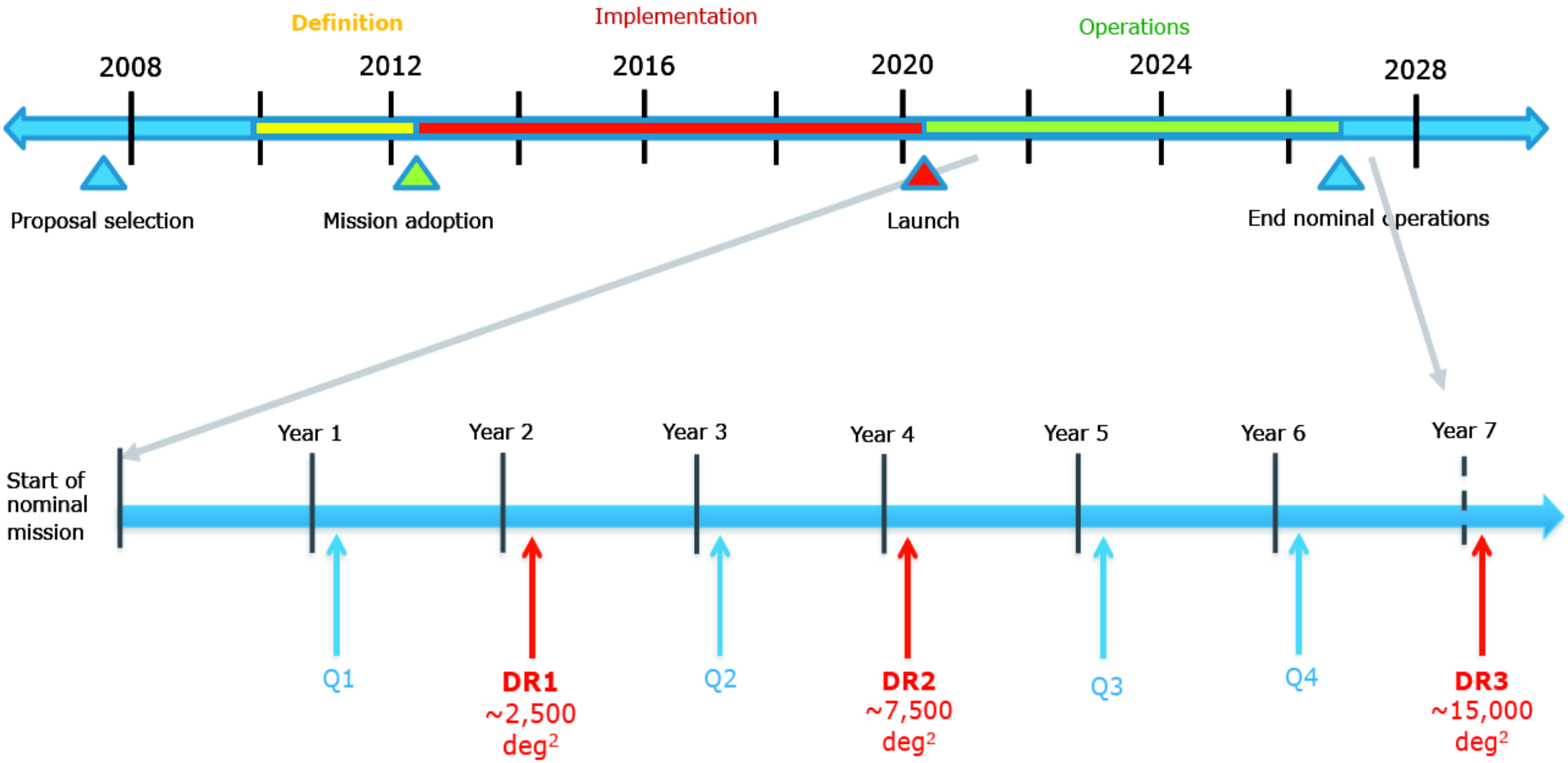




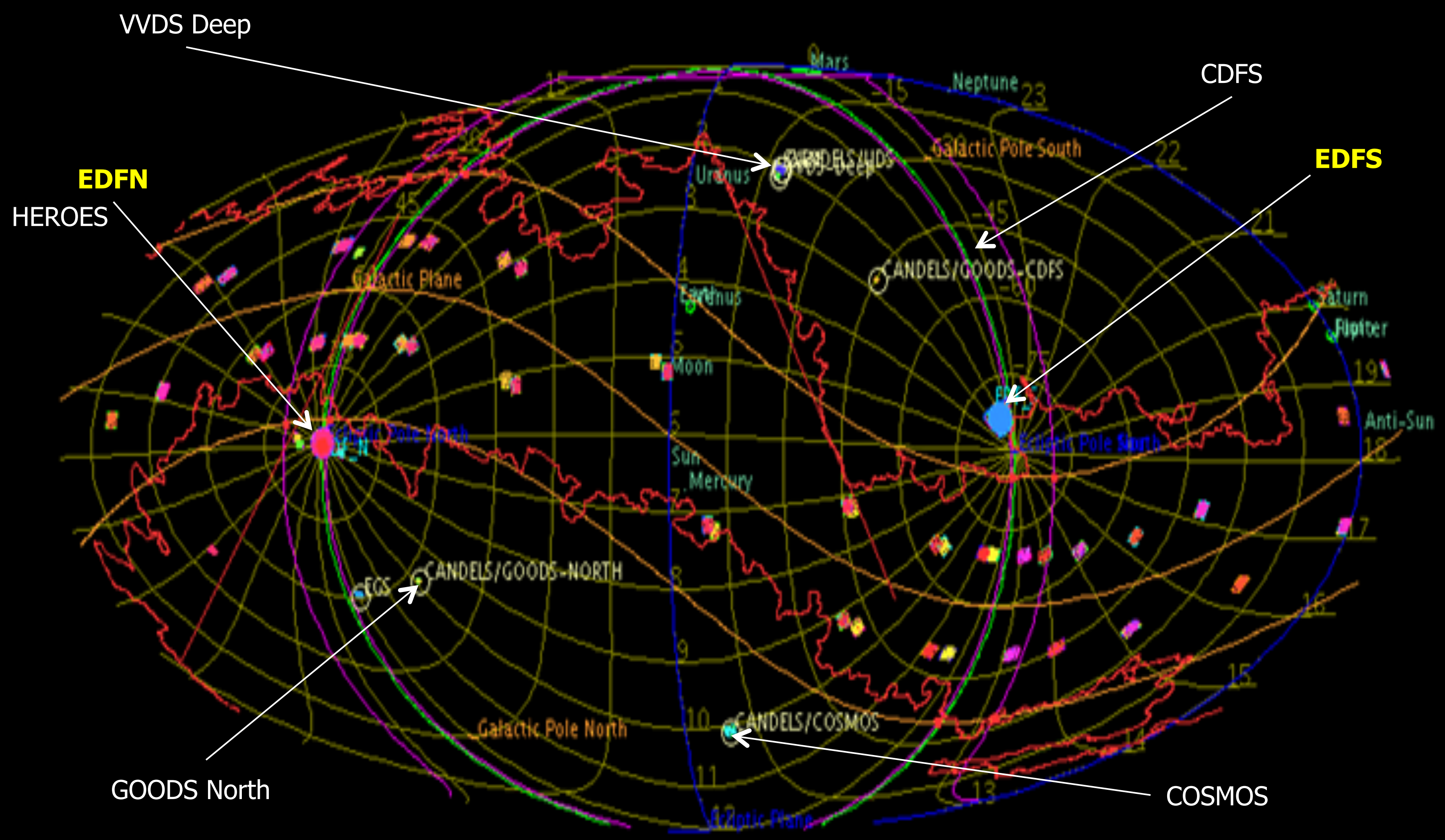


- **Performance at mission level in general in very good state.**
- Image quality of the system fully in line with needs.
- Ellipticity, R^2 stability and Non-convolutive errors performance dictated mainly by ground processing and will be evaluated at SGS DR
- *Purity* not compliant with current data processing methods but expected to be recovered.

Data release



Calibration observations



- Calibration sequence over 6 years (ecliptic coordinates, Mollweide projection)→All calibration fields are shown, including HST targets and the EDFS and EDFN near the ecliptic poles. The ecliptic is shown as a vertical line, jagged lines show background level contour E(B-V)=0.08

A challenge for Euclid : photometric redshifts

Weak Lensing : redshifts of 1.5 x10^9 sources to

- Slice the universe
- Control contamination by intrinsic alignments of galaxies

$$\langle \epsilon_i \epsilon_j \rangle = \underbrace{\langle \gamma_i \gamma_j \rangle}_{\text{GG}} + \underbrace{\langle \epsilon_i^s \epsilon_j^s \rangle}_{\text{II}} + \underbrace{\langle \gamma_i \epsilon_j^s \rangle + \langle \epsilon_i^s \gamma_j \rangle}_{\text{GI}}$$

Redshifts of Euclid clusters: 60,000 clusters, 5,000 giant arcs

→ synergy with Planck and eROSITA

→ Redshifts of sources and lenses: needed at least in the range 0.2<z<2

→ Photo-z are needed with VIS+NIR data

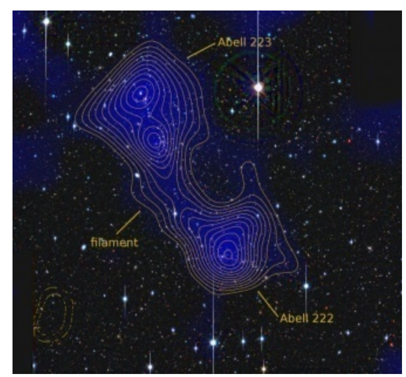
HST/ACS credit NASA/ESA

HST/ACS; credit NASA/ESA

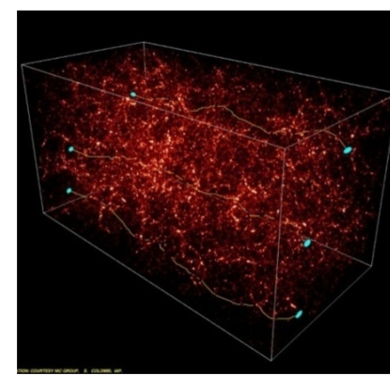
Galaxy halos

Clusters of galaxies

Dietrich et al 2012



Colombi/Mellier



Filaments between clusters

Cosmic shear

Euclid+ground: photo-z of 1.5 billion galaxies

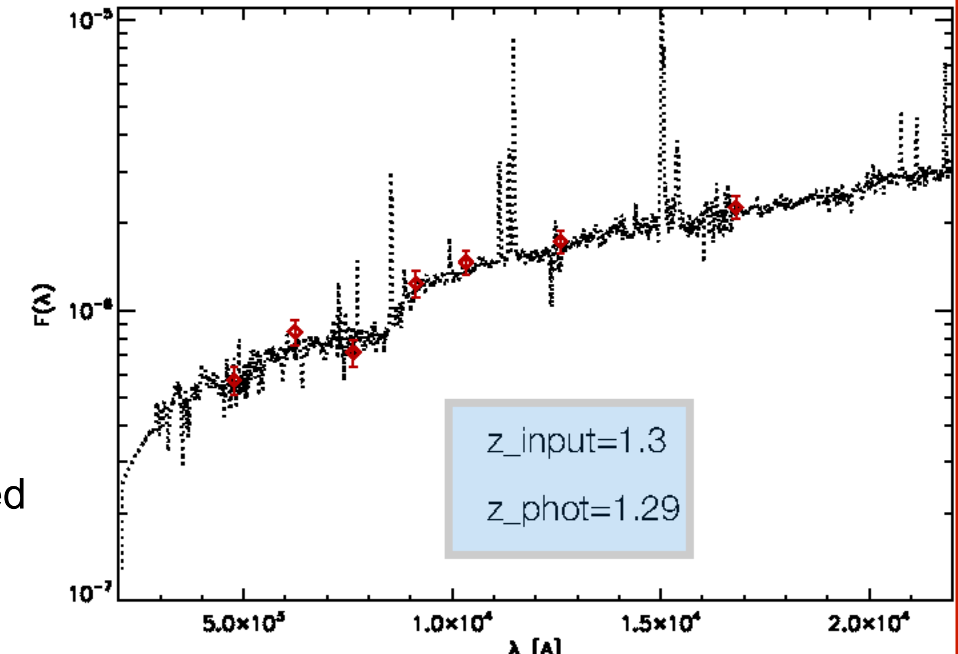
Critical: need ground based imaging over 15,0000 deg^2 in 4 bands

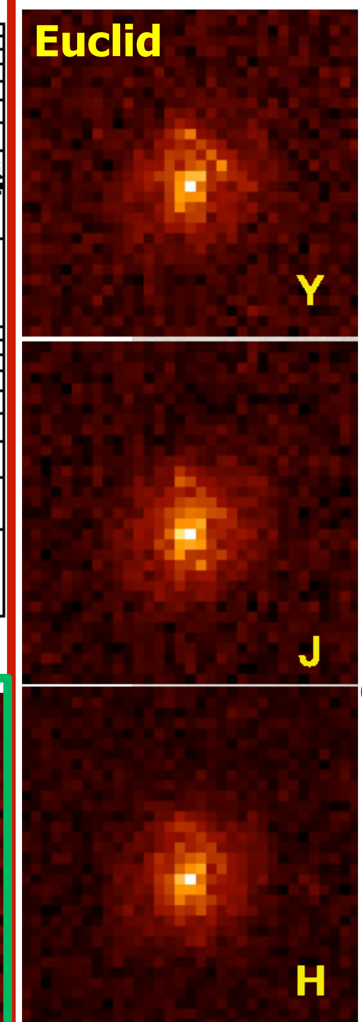
Courtesy Euclid SWG Photo-z and OU-PHZ

Requirements:

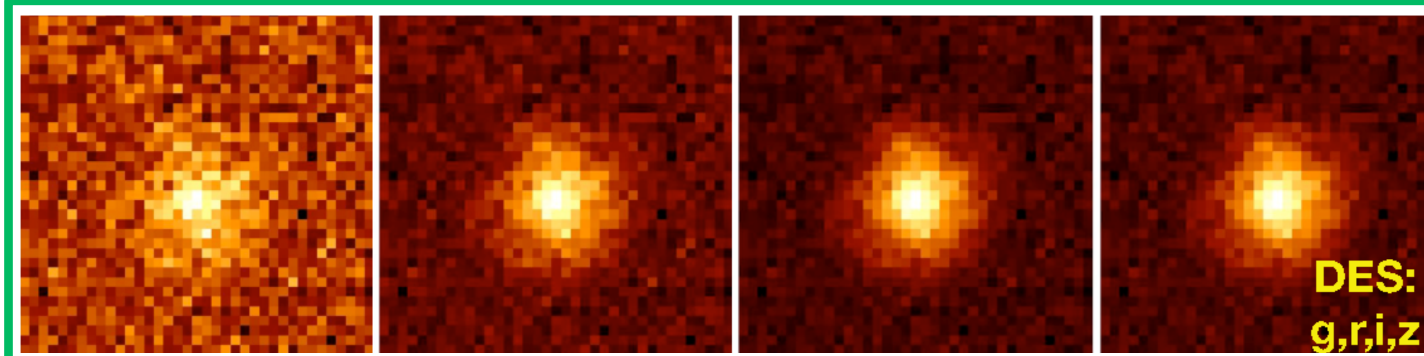
- get photo-z for ~all WL galaxies
- cover the whole Euclid sky (15000 deg^2)
- accuracy = 0.05x(1+z)

→ 4 optical bands needed

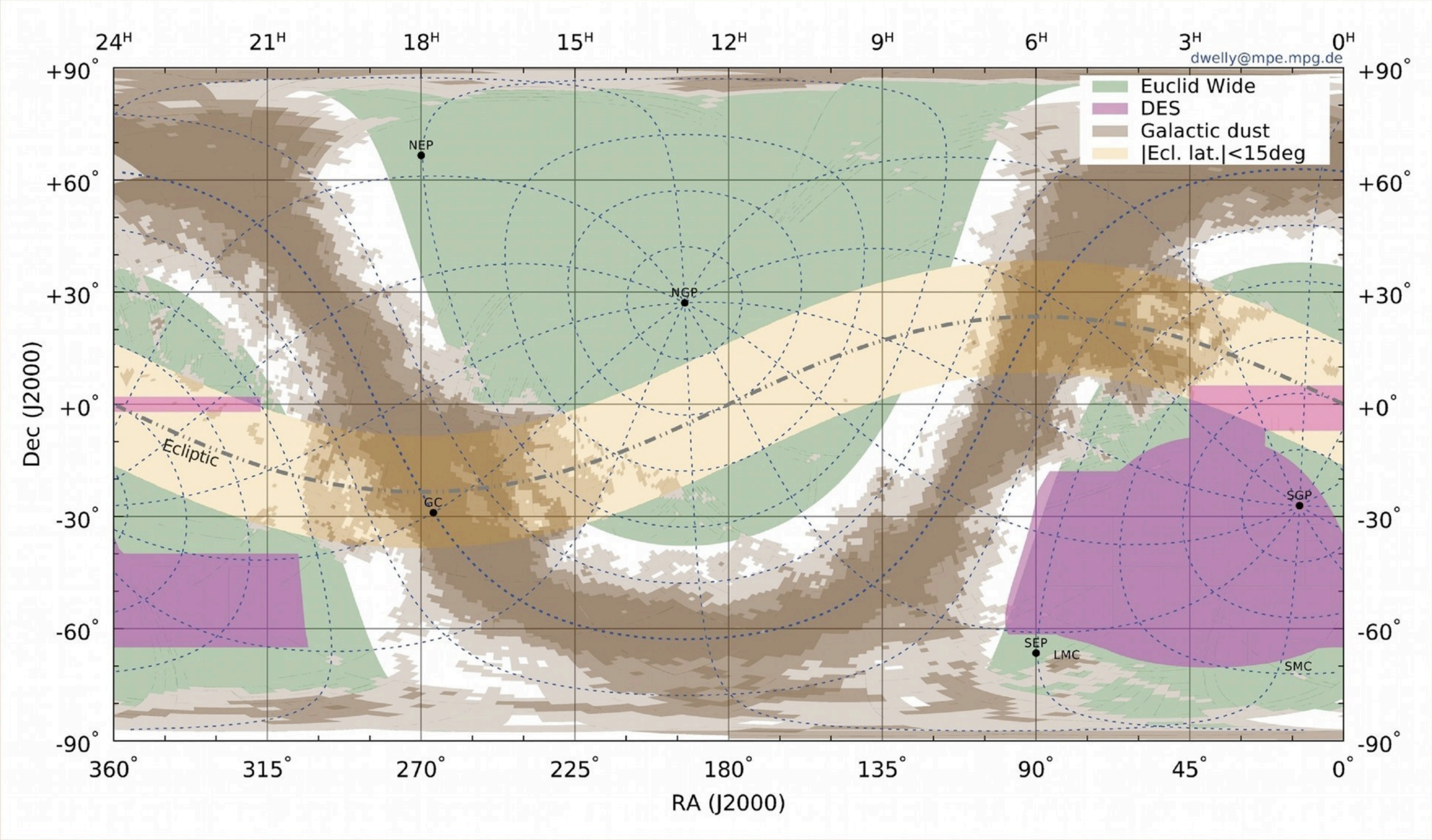




NIR data from Euclid NIR images.



A wide optical ground–based survey: Euclid "4th" instrument



Euclid Wide covers ~15,000 square degrees, avoiding the galactic and ecliptic planes

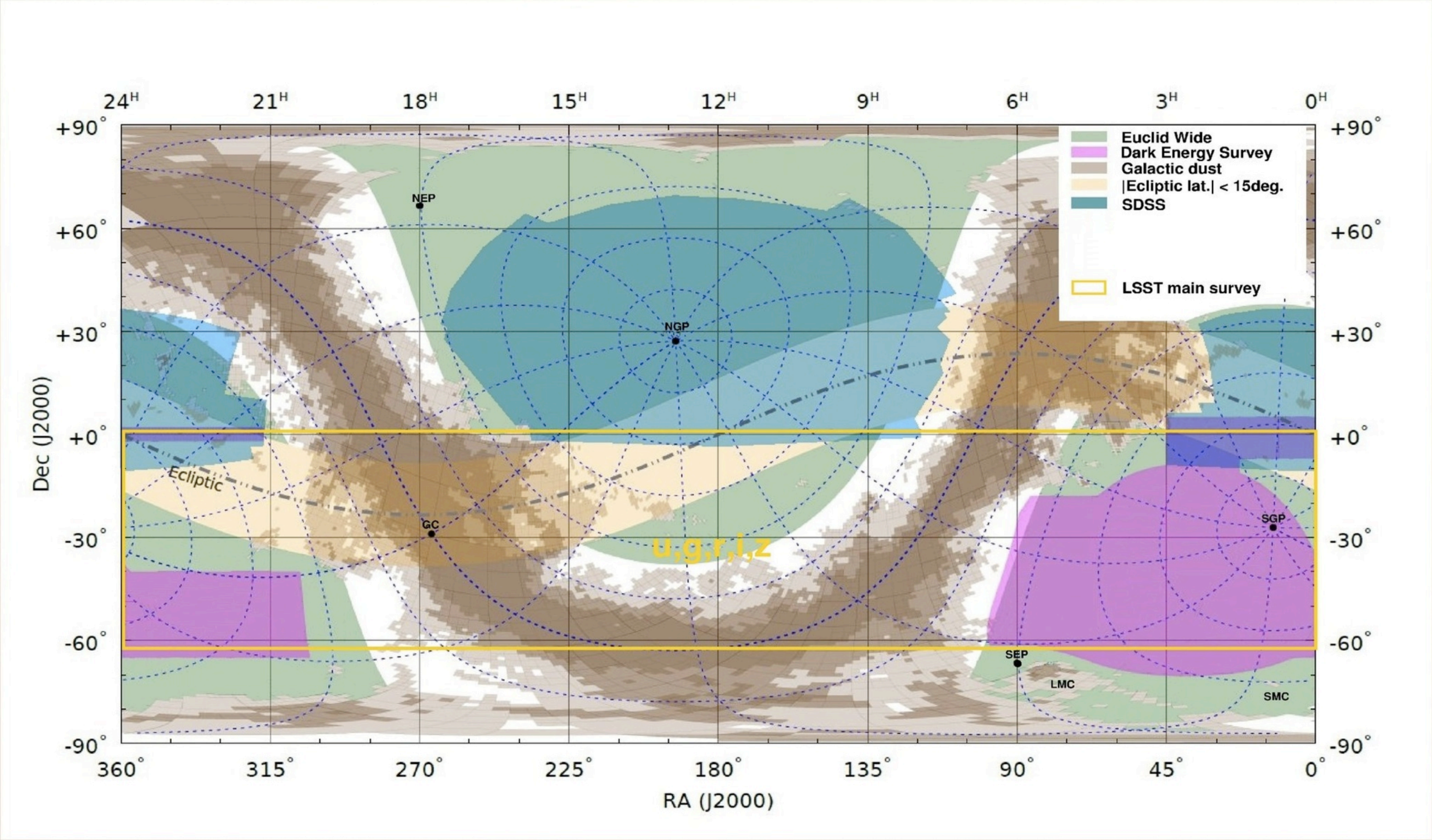
As of today (2016), only the DES ~4,500 square degrees in griz match Euclid's requirements

Present and upcoming wide–field imagers relevant to Euclid

Etendue ↑

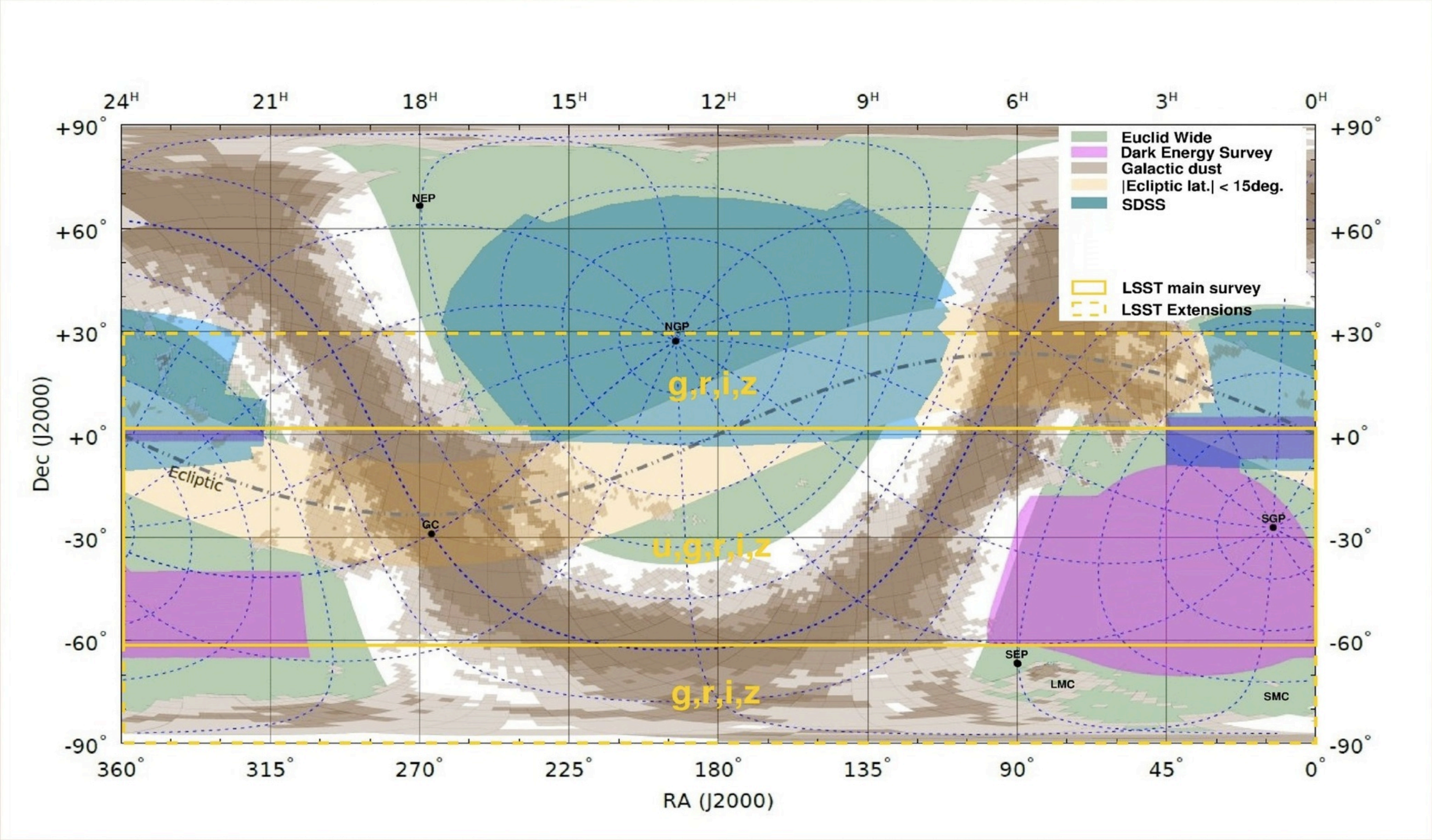
Facility	Year	Aper.	FOV	IQ	CCD class	Type	Hemisphere
LSST	2021	6.6m	9.6 sq.deg.	0.8''	Deep depletion	Surveyor	South
Subaru	2013	8.2m	1.8 sq.deg.	0.6''	Fully depleted	Observatory	North
Blanco	2013	4.0m	3 sq.deg.	0.9''	Fully depleted	Observatory	South
J–PAS	2017	2.5m	7 sq.deg.	0.9''	Deep depletion	Surveyor	North
CFHT	2003	3.6m	1 sq.deg.	0.6''	EPI	Observatory	North
PS1	2008	1.5m	7 sq.deg.	1.0''	Fully depleted	Surveyor	North

Euclid Wide + LSST Main Survey



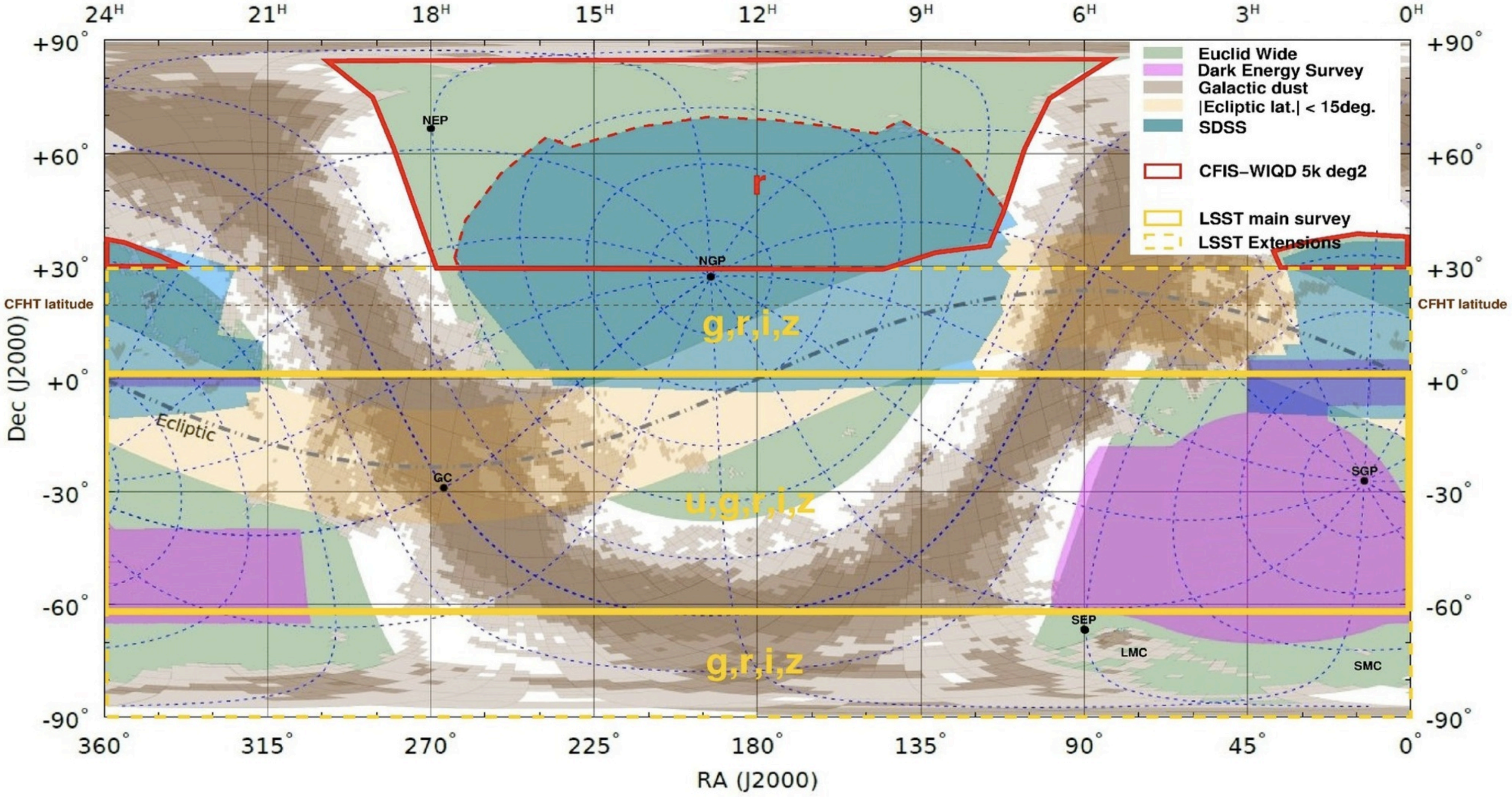
LSST will cover to great depths in ugriz nearly 7,000 square degrees of Euclid Wide

Euclid Wide + LSST Main Survey + LSST Extensions



LSST extensions to DEC−90&+30 could bring an extra ~3,000 square degrees to Euclid Wide
The southern extension (DEC −60−>−90) already planned to depths greater than Euclid Wide
The northern extension (DEC 0−>+30) is discussed for the nominal Euclid Wide depths

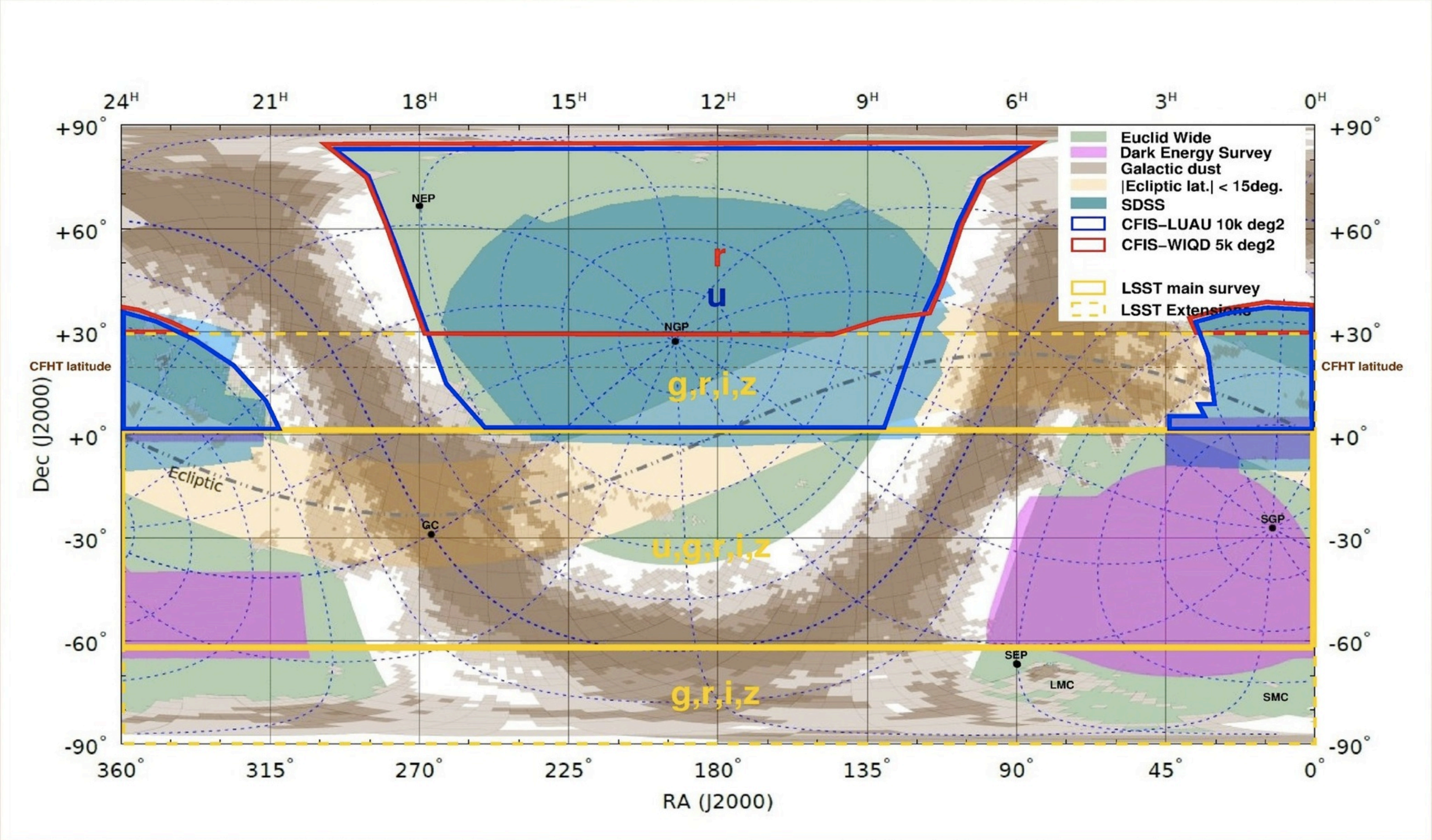
Euclid Wide + CFHT−r [CFIS−WIQD 2016 proposal for 2017−9]



The Canada−France Imaging Survey (CFIS) Wide/ImageQuality/Deep (WIQD)

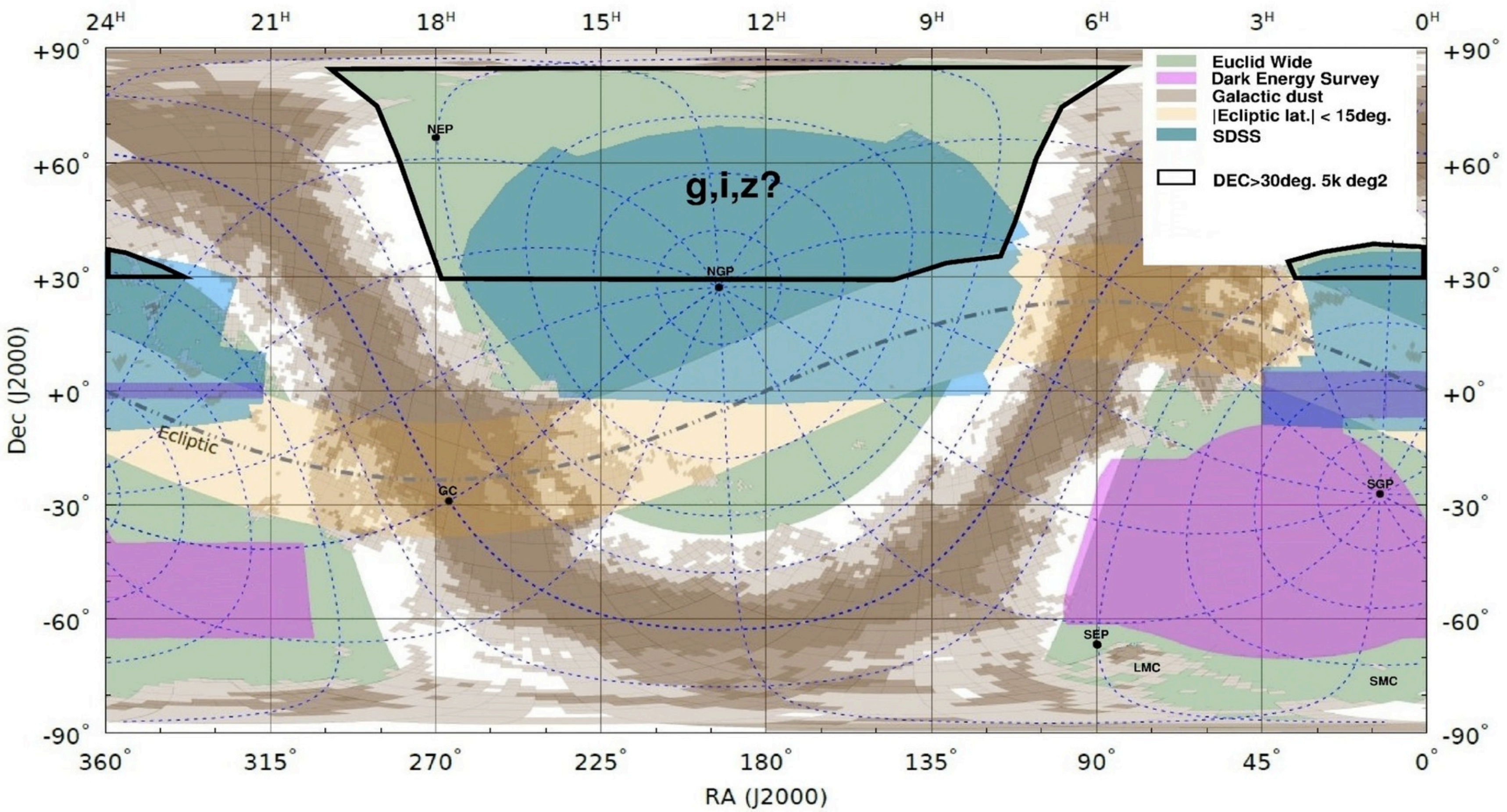
The 5,000 most northern Euclid Wide square degrees in r−band at the nominal Euclid depth

Euclid Wide + CFHT−u [CFIS−LUAU 2016 proposal for 2017−9]



The Canada−France Imaging Survey (CFIS) Legacy for the U−band All−sky Universe (LUAU)
10,000 northern square degrees in u−band above the galactic plane, shallow (240s total)

Euclid Wide's missing part: 5,000 square degrees in g,i,z



On the condition the CFHT CFIS proposal (r−band) is selected (May 2016)

Euclid Wide depths and northern sky areas

- Depths derived from a COSMOS Euclid photo–z study (not the 2011 Euclid Red Book):

g	r	i	z
24.5	23.9	23.6	23.4

- Metric: color–optimized aperture photometry (photo–z) for faint extended sources
- 10–sigma depth (SNR=10) extended source in SNR optimal aperture (1.8xFWHM)
- Reliable proxy metric: 10–sigma point source in a 2'' diameter aperture (ETCs)
- Add 1.2 mag. to get the PSF photometry performance on point sources at 5–sigma
- Distribution of the Euclid Wide per declination bin (+20 deg. galactic latitude clip):

Equatorial Dec.	Area
+80 to +90	102
+70 to +80	466
+60 to +70	791
+50 to +60	1068
+40 to +50	1258
+30 to +40	1592
+20 to +30	1363
+10 to +20	970
0 to +10	568

~ 5000 square degrees

HyperSuprimeCam time budget estimate

- Total integration per band using the NAOJ HSC Exposure Time Calculator:

g	i	z
87s	142s	312s

- ETC mode of operation: point source photometry in a 2'' diameter aperture, SNR=10
- ETC sky condition: Dark for g, Gray for i & z + 0.9 sky transparency for all (default)
- ETC seeing condition: median (although no impact on this 2'' aperture metric)
- ETC depth: +0.2 mag. buffer for misc. data effects (processing, conditions, metrics, etc.)

- Total integration split in 4 ultra–large dithered exposures, 30s overhead per exposure
- HSC's circular footprint brings the total field of view to 1.8 square degree
- Time loss to weather and misc. overheads is 75% over an average night length of 9hr (6.75)

g	i	z
24n	30n	49n

g+i+z	i+z	g+z
103n	79n	73n

- Rule: nights (n) = (((total_integration + n_readoutx30) x (5000/1.8)) / 3600) / (9x0.75)
- ! The Euclid Wide northern sky is heavily skewed towards the winter/spring sky

Spectroscopy North: Keck proposals for 2016-2017

- NASA proposal : 10 nights allocated, all DEIMOS, split evenly between 2016B and 2017B
- Caltech proposal 5 nights in 2016A, to be resubmited in future semesters. All time allocated on DEIMOS), MOSFIRE and LRIS.

Summary: 15 nights guaranteed, 15 more probable, 10-15 more possible

Spectroscopy South: ESO proposal for 2016

- Targetting ~2500 galaxies with plan to resubmit in 2017
  - FORS/blue: 500 galaxies; 20 hours , FORS/red: 1200 galaxies; 90 hours
  - KMOS/YJ: 300 galaxies; 35 hours, KMOS/H: 400 galaxies; 50 hours
- Fields: SXDS, VVDS-Deep, ECDFS, COSMOS

Summary: 0 nights guaranteed, TAC does not considers ground-space synergy

Summary ground based observations for Euclid

Wide survey

Wide North Imaging LSST+CFHT+?	Wide North Spectroscopy	Wide South Imaging DES+LSST	Wide South Spectroscopy
YJH ugriz dec<30° ugriz dec>30°	Keck 15+15	YJH ugriz dec<0°	ESO 0

Deep survey

Deep North Imaging LSST+?	Deep North Spectroscopy	Deep South Imaging LSST?	Deep South Spectroscopy
YJH ugriz dec<30° ugriz dec>30°	?	YJH ugriz dec<0°	?

Summary ground based observations for Euclid

Wide survey

Wide North Imaging LSST+CFHT+?	Wide North Spectroscopy	Wide South Imaging DES+LSST	Wide South Spectroscopy
YJH ugriz dec<30° ugriz dec>30°	Keck 15+15	YJH ugriz dec<0°	ESO 0

Euclid top priority

5000 deg^2 missing

Deep survey

Deep North Imaging LSST+ ?	Deep North Spectroscopy	Deep South Imaging LSST?	Deep South Spectroscopy
YJH ugriz dec<30° ugriz dec>30°		YJH ugriz dec<0°	?

Euclid and northernmost northern sky

- In the north, LSST and Subaru/HSC outperform all other telescopes options Euclid can explore
- For the northernmost Subaru/HSC outperforms all other options
- We do not have any consolidated options today that can provide the remaining 5000 deg^2 north with one single telecope: we must combine
- Euclid is looking for collaboration to get the northernmost bands by combining with at least CFHT-CFIS (u shallow+r)
- The Euclid Consortium need these data for photo-z only and EC will not be proprietary of and will not use these data for any other purpose
- Euclid need these data during the period 2020-2025: data can be obtained over the period 2017-2023 (+2yr before space data)

Subaru-Euclid synergy and collaboration

Several options could be discussed:

- **z-band**: being the hardest to get, Subaru/HSC could provide only the z: the best way to use the red performance of HSC, the easiest to implement as bright time can be used: 49 n over 7 yrs (e.g. 5 yrs + 2 yrs margin)

- **i-band**: As the z is also the most expensive, Subaru could provide instead the i only: still optimal use of HSC red performance and bright time: 30 n over 7 yrs (5yrs + 2 yrs margin)

- **g-band**: As the g-band is much less expensive, even the HSC-g band is an interesting option for Euclid (but overheads dominated): 24 n in 7yrs (5+2)

- **The several-bands** options are obviously better for Euclid: → overall we see options ranging between 24 to 103 nights over 7 yrs → our preferences: (g+i+z) or (i+z) or (g+z: but overheads)

Subaru-Euclid synergy and collaboration

What could be the return for the Japanese community (ideas):

- Outside Euclid:
  - As the Euclid Consortium will only use the data for photo-z, the HSC data can be used by the Japanese community for any science program without being in Euclid: Euclid just need full access to create its Euclid photo-z catalogue
  - Stand alone programs with HSC data, outside Euclid can then be set up in other collaborations, like with CFIS for example: possible stand alone programs TBD (gal-gal lensing, arcs,cosmic magnification, high-z QSOs and AGNs)

Subaru-Euclid synergy and collaboration

What could be the return for the Japanese community (ideas):

- Within Euclid:
  - Depending on the number of HSC nights and contributions, between 20 to 40 Japanese will be invited as Euclid full members: access to all space and ground Euclid products (including spectro and photo-z)
  - Japan will have 1 seat in the Euclid Consortium Board + 1 seat in the Euclid Consortium Editorial Board (leads: P. Schneider & J. Peacock)
  - Japanese EC members will be invited in EC organisation Units, EC Science Working Groups and work package and can lead some of them (*see next slides on EC organisation*)
  - Japan will lead the OU-EXT data processing for the Subaru data
  - The Japanese EC members could lead the spectroscopic follow up of the Euclid Deep Field North with Subaru as well as contribute to other calibration fields targetted by Euclid (COSMOS for example)

Euclid: the post-Planck cosmology mission

Euclid cosmology core program will

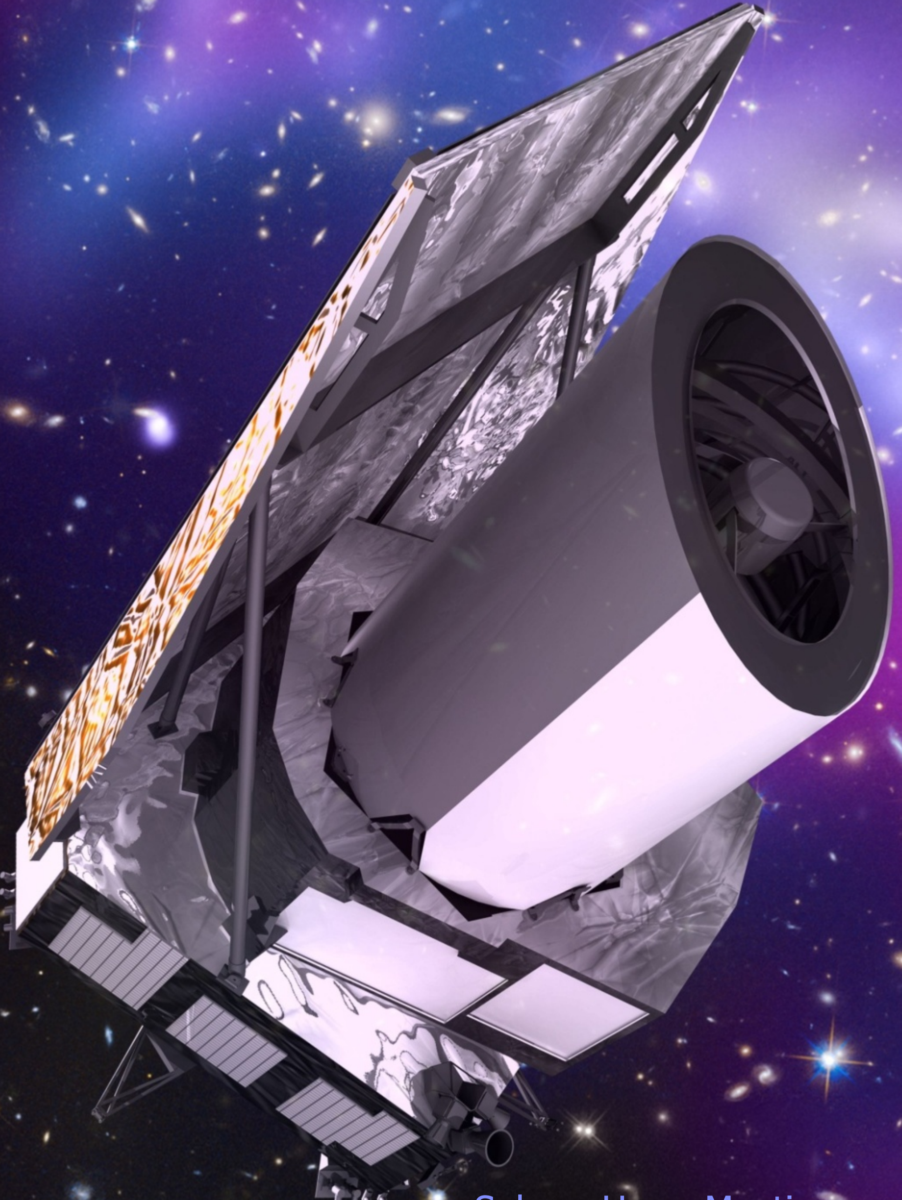
- Explore the dark universe: DE, DM (neutrinos), MG, inflation
- Explore the transition DM-to-DE-dominated universe periods
- Use 5 cosmological probes, with at least 2 independent
- Get the percent precision on w and the growth factor γ
- Prepare the New Gen. wide field surveys: GAIA, LSST, WFIRST, e-ROSITA, SKA

Euclid Legacy = 12 billion sources, 35 million redshifts, 1.5 shapes/photo-z;

- A mine of images and spectra for the community for years;
- A reservoir of targets for JWST, E-ELT, TMT, ALMA, VLT
- A set of astronomical catalogues useful until 2040+

But Euclid need photo-z for the whole sky: the relevant ground based data

- **Subaru/HSC can be a major partner and complete the visible deep full sky survey with LSST and Euclid**



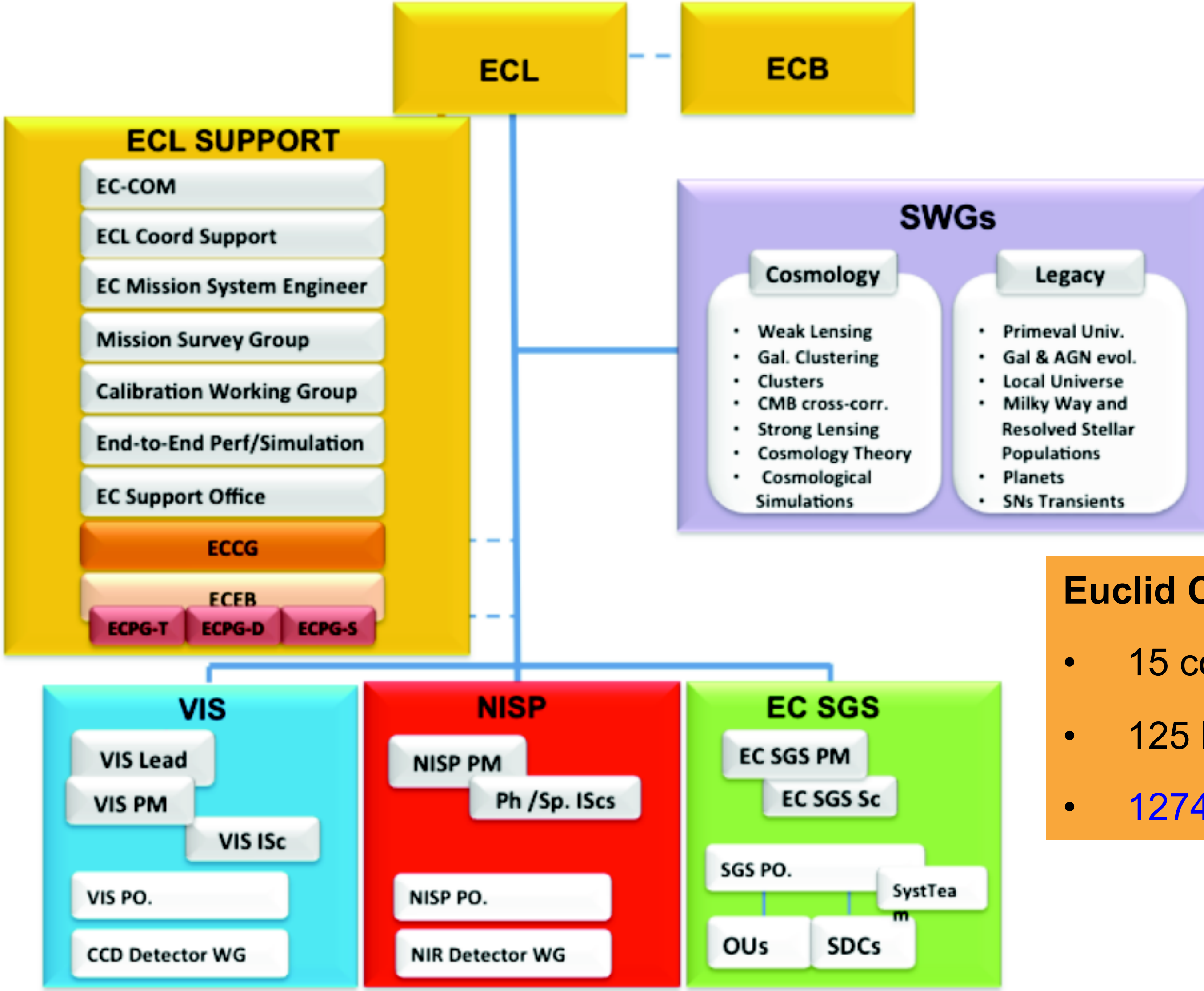
Thank you

www.euclid-ec.org

Backup slides:

Organisation of the Euclid Consortium

Euclid Consortium (Jan 2016 - update)



Euclid Consortium Jan 04 2015:

- 15 countries
- 125 labs
- 1274 Full members

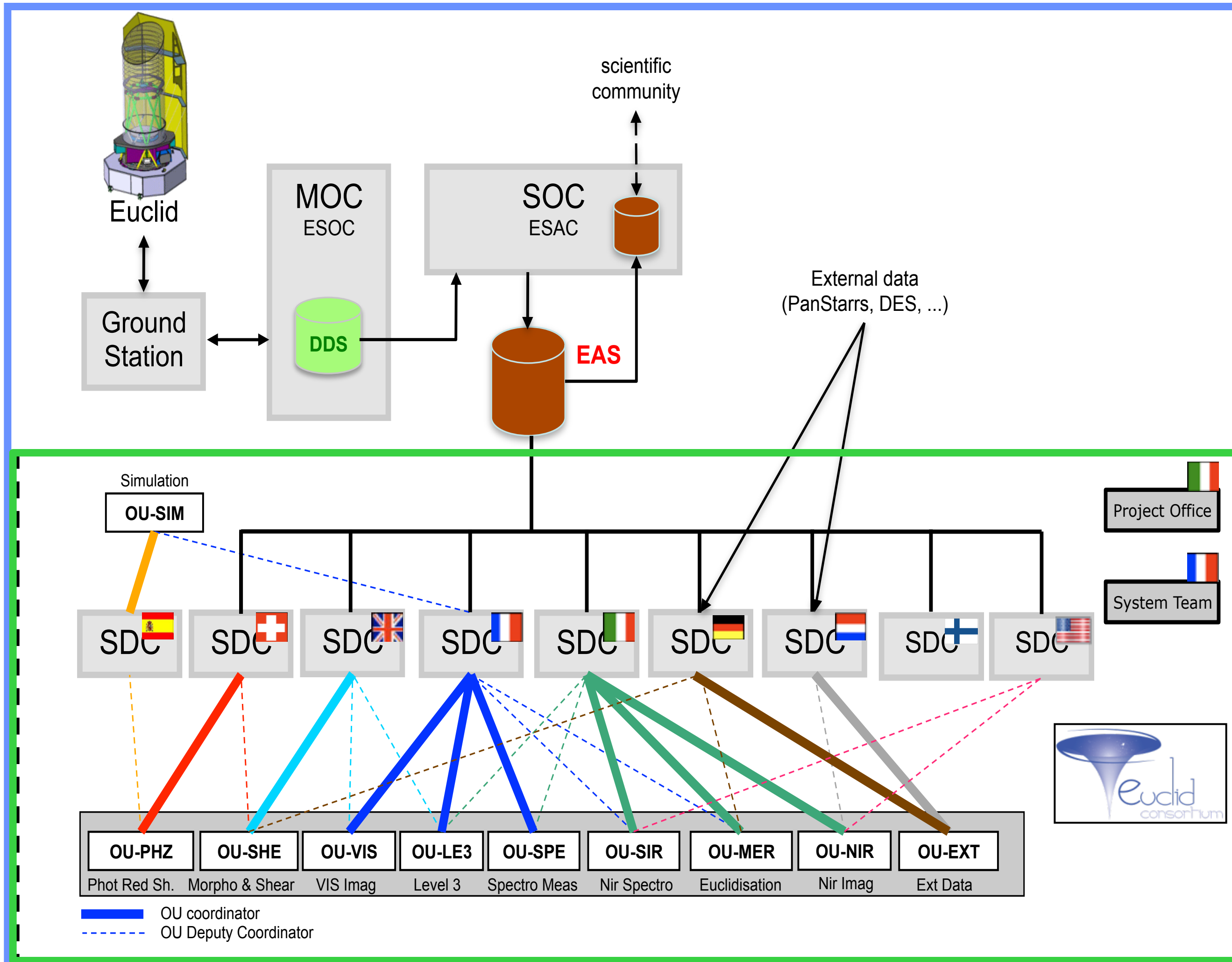
Ground Segment

Complex organisation:

- 10 Organisation Units
- 9 Science Data Centers

Data: huge volumes, heterogeneous data sets

- VIS+NIR imagery and morphometry, photometry , spectroscopy, astrometry, transients
- data from ground and space
- ~100 Pbytes
- 1+ million images
- > 10^{10} sources (>3-σ)



Science Working Groups (Jan 2016)