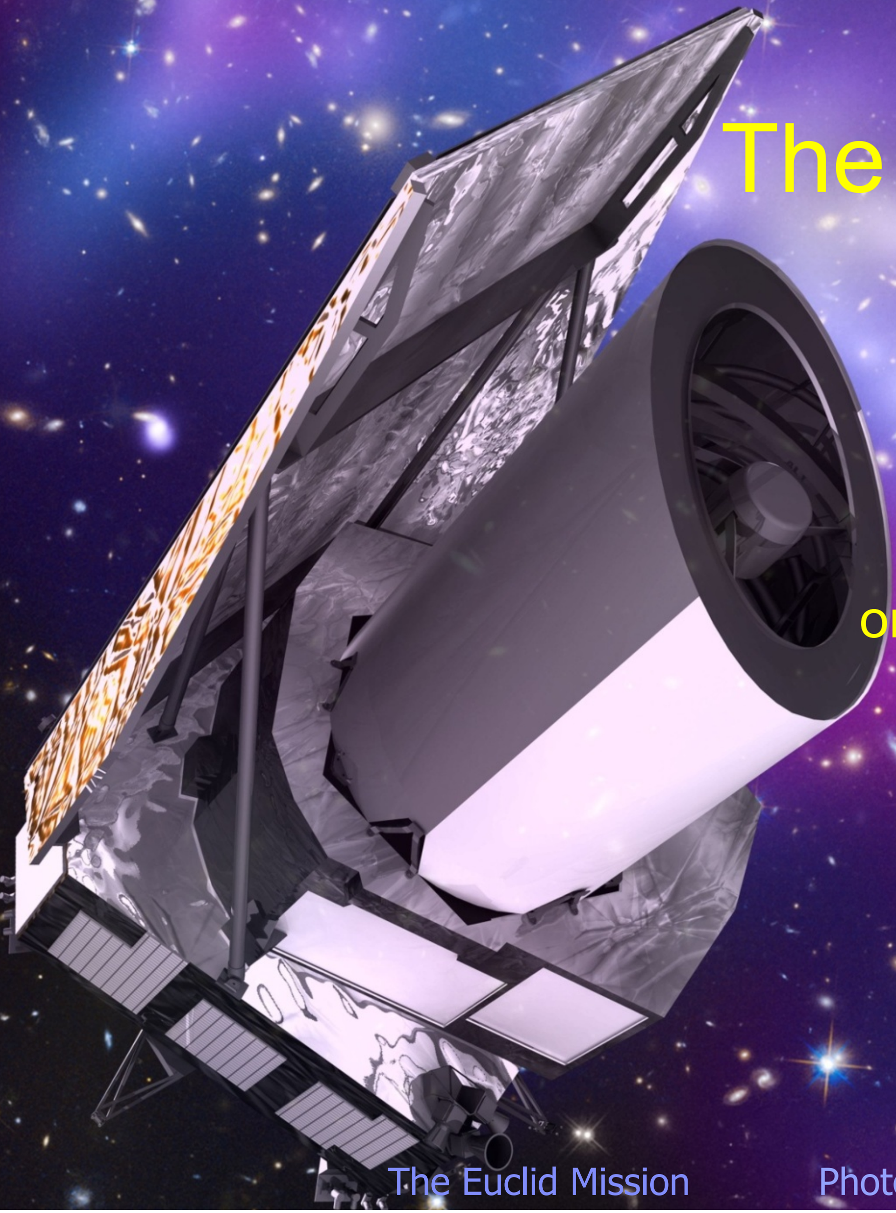
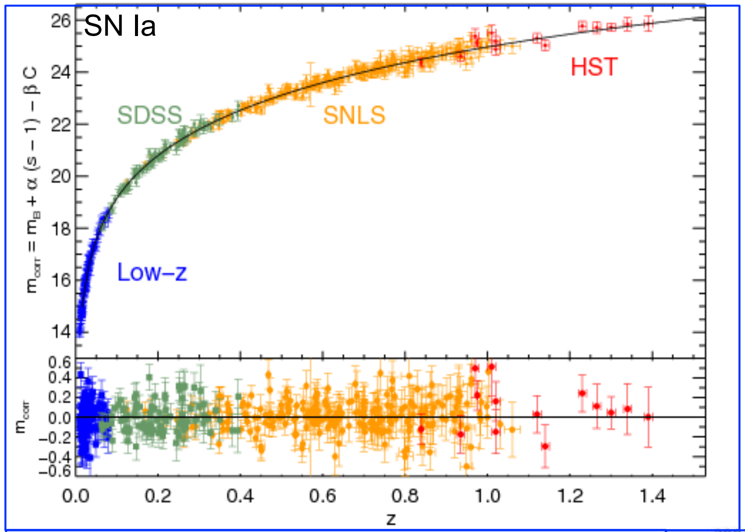
The Euclid Mission

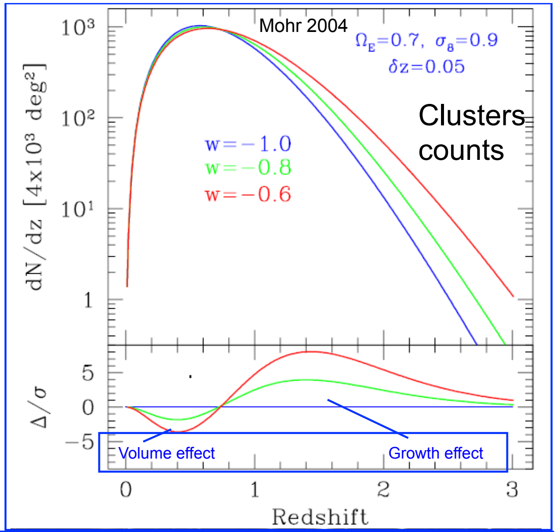


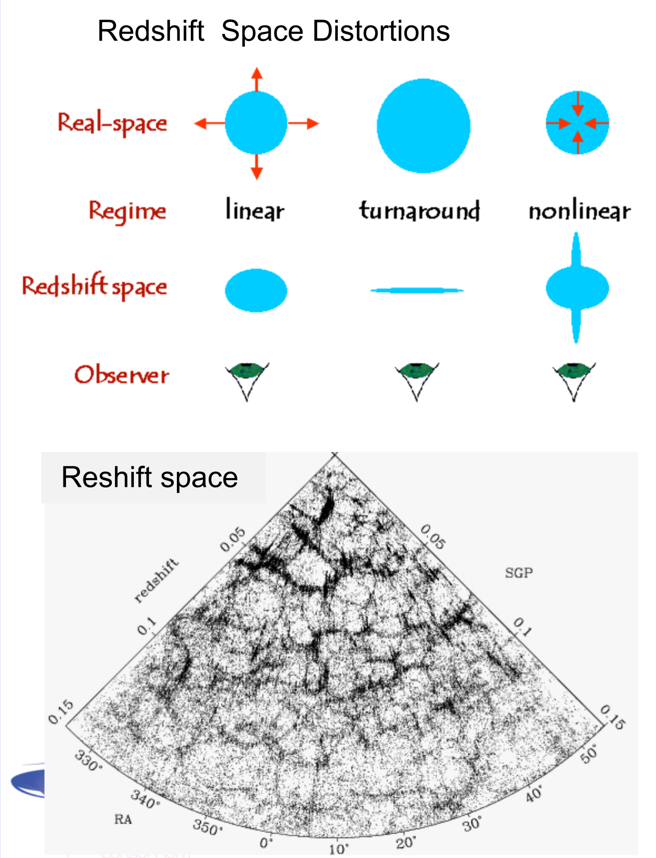
Konrad Kuijken
on behalf of the Euclid Consortium

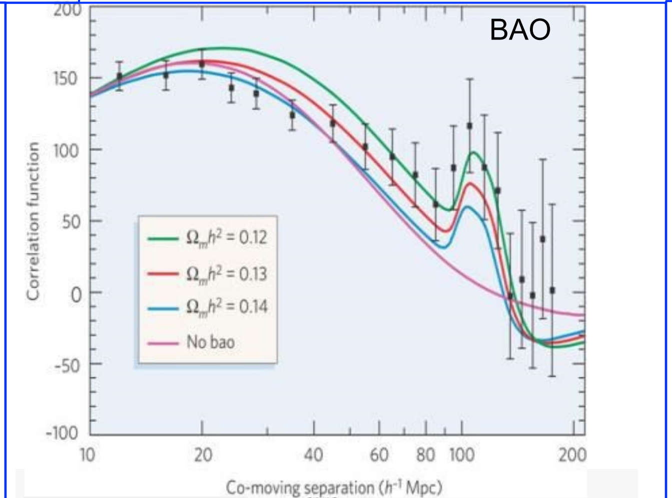
www.euclid-ec.org

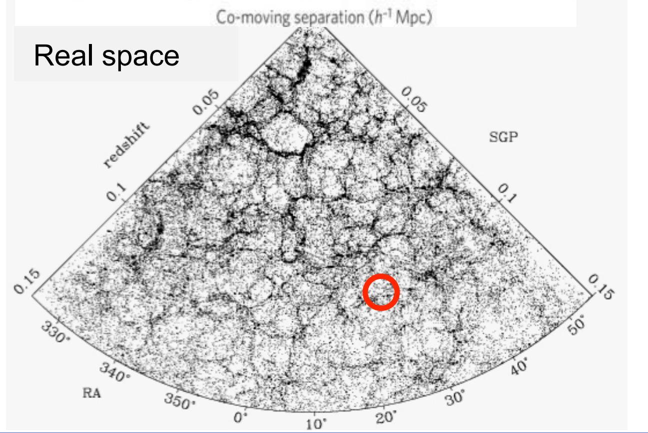
Observational probes of Dark Energy

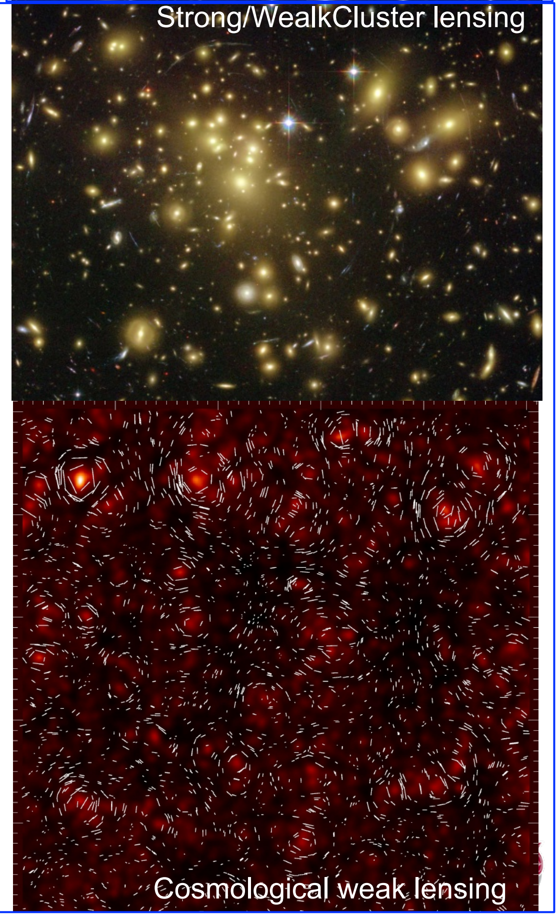




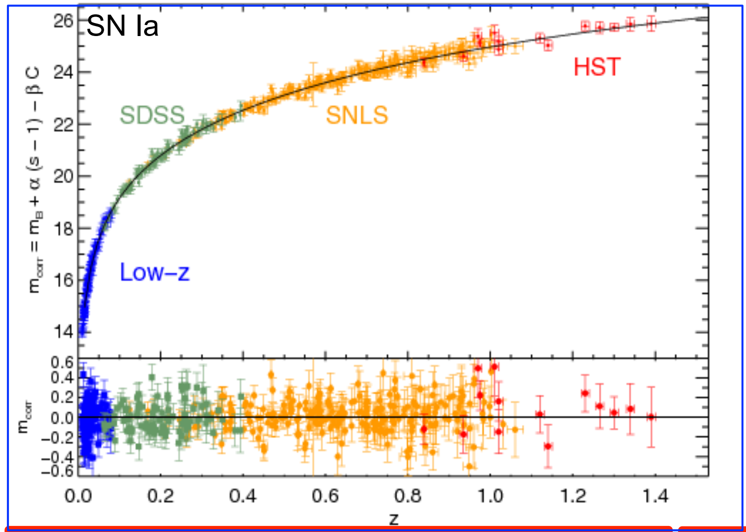


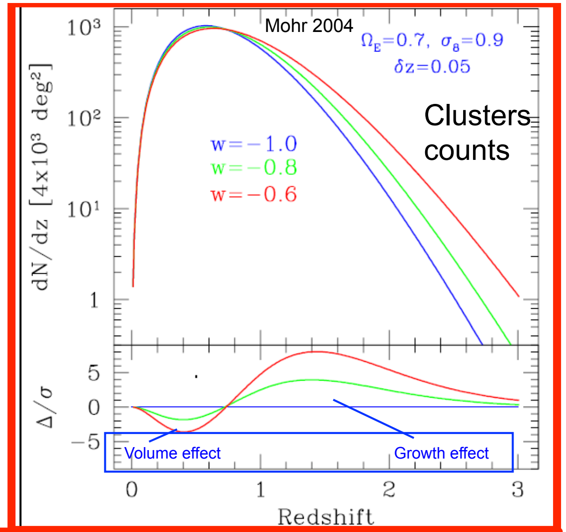


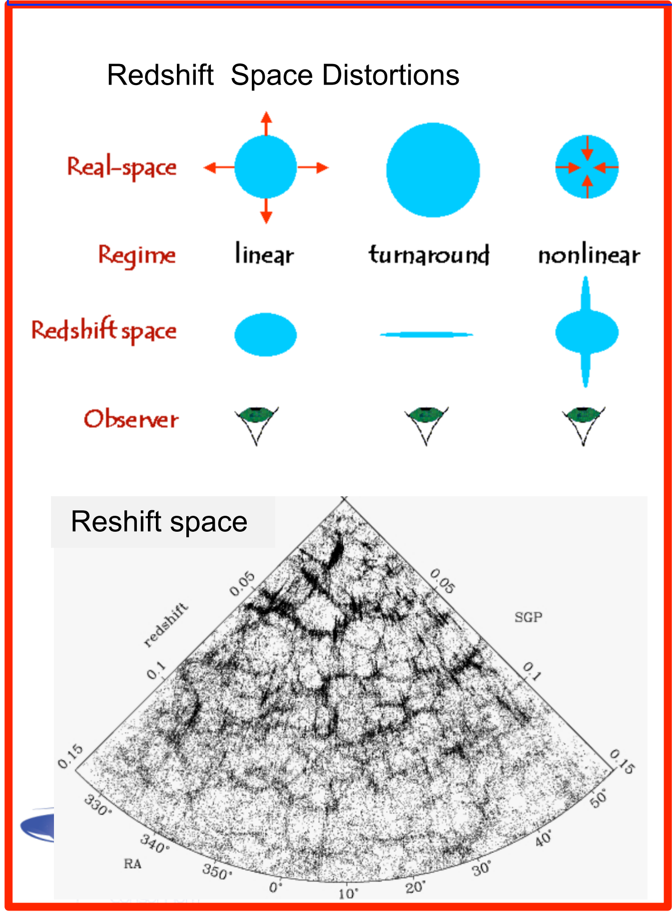


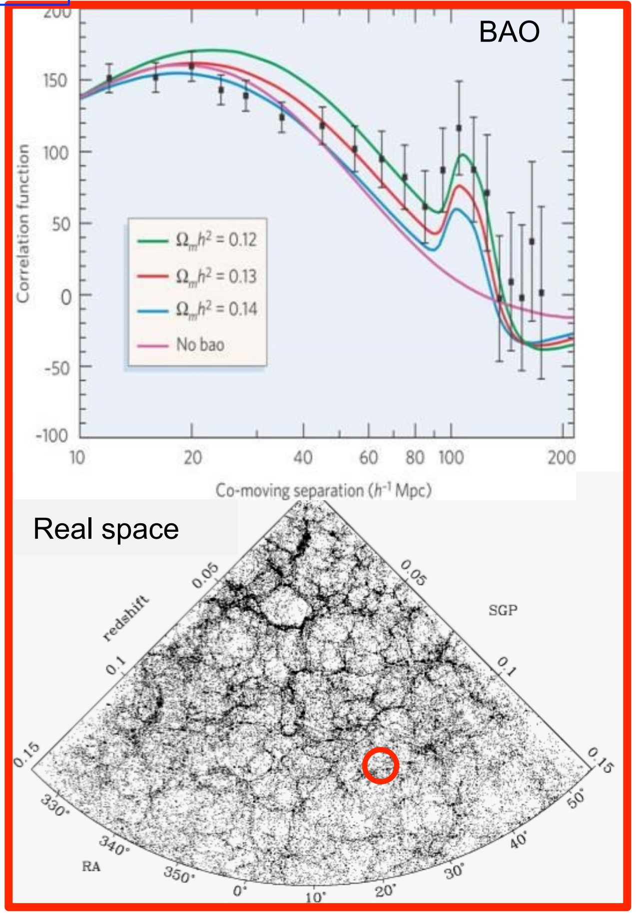


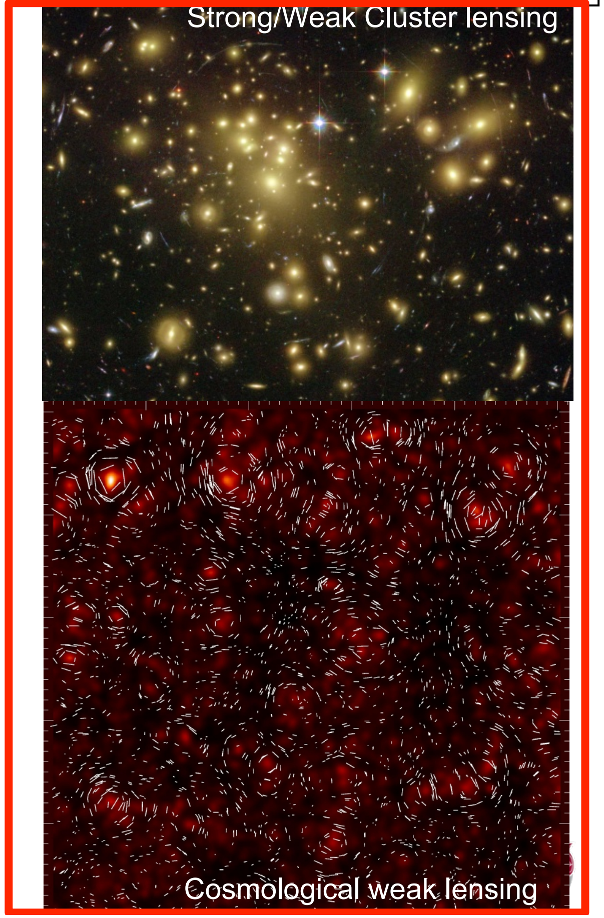
Euclid probes of Dark Energy

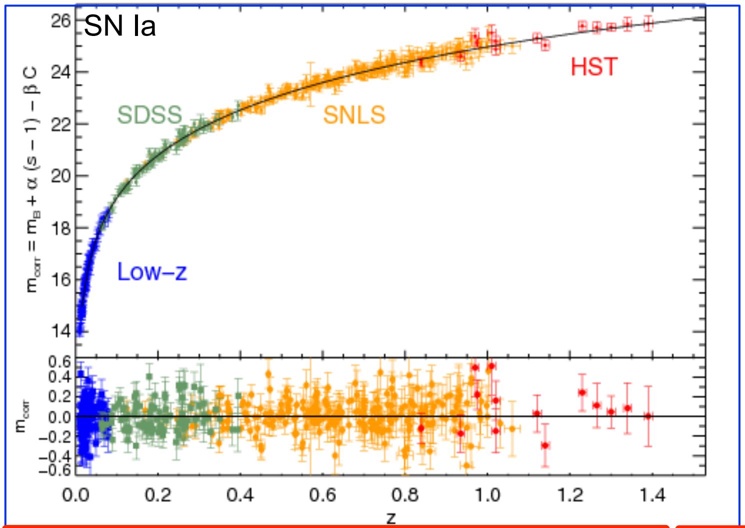




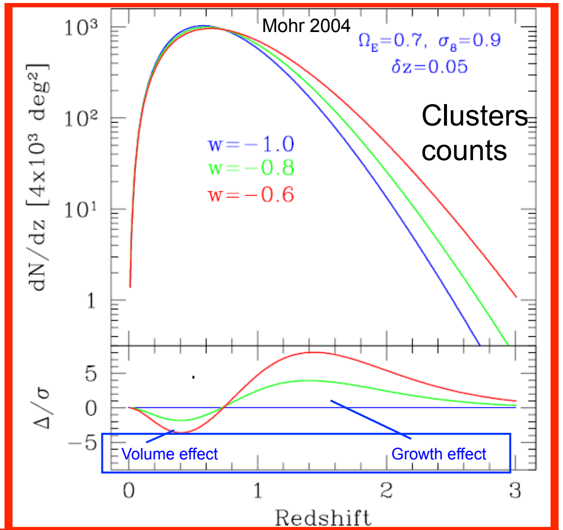


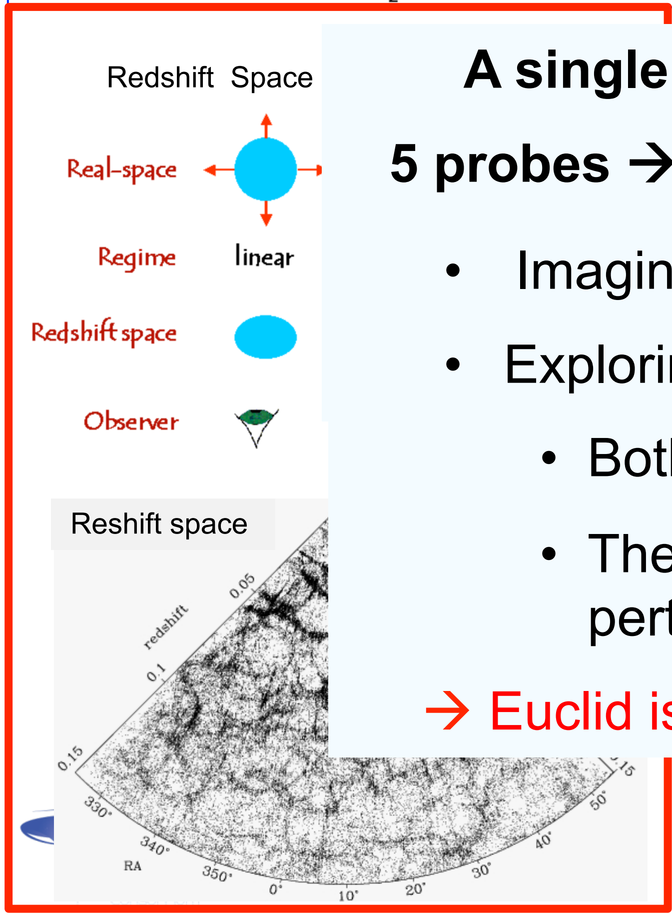


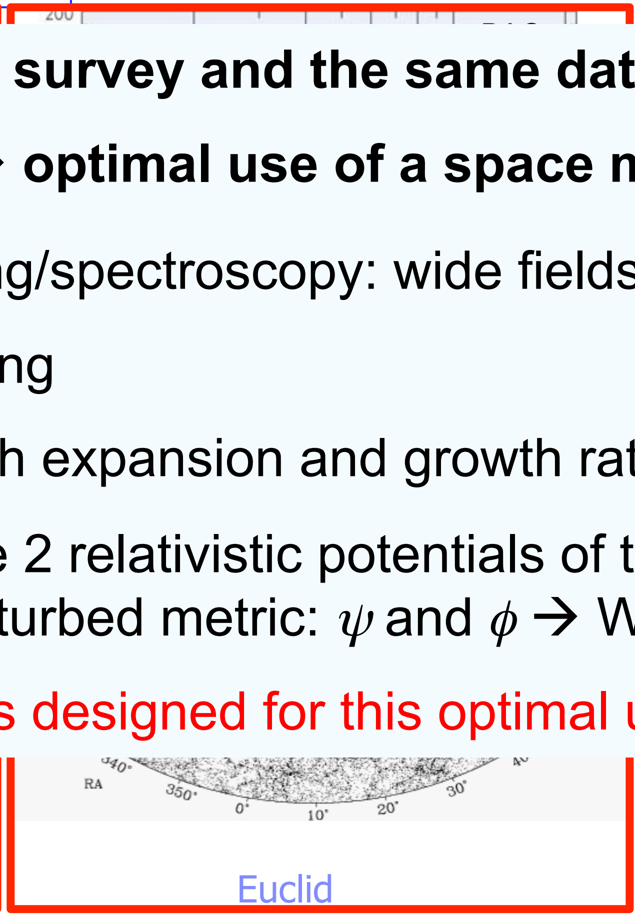


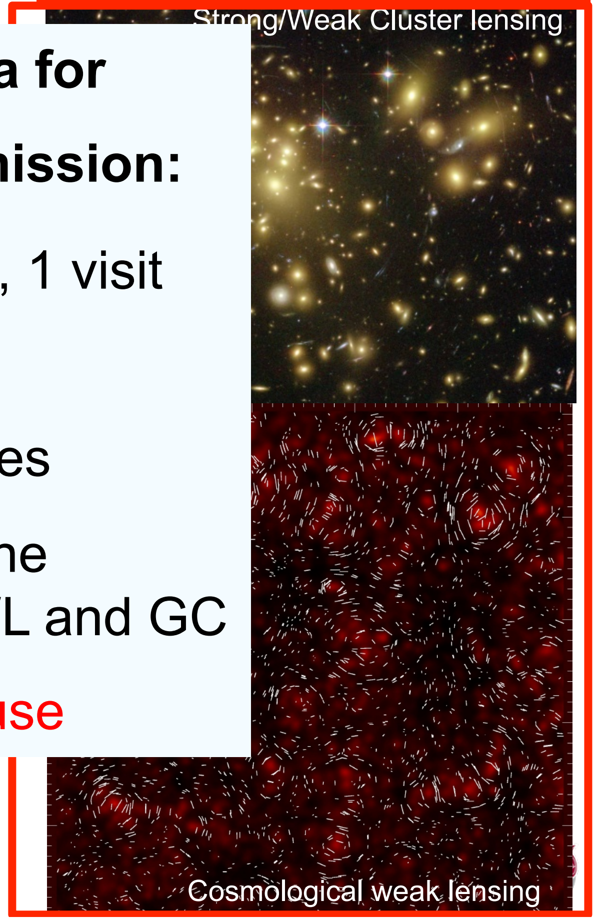


Euclid probes of Dark Energy









A single survey and the same data for

5 probes → optimal use of a space mission:

- Imaging/spectroscopy: wide fields, 1 visit
- Exploring
  - Both expansion and growth rates
  - The 2 relativistic potentials of the perturbed metric: ψ and ϕ → WL and GC

→ Euclid is designed for this optimal use

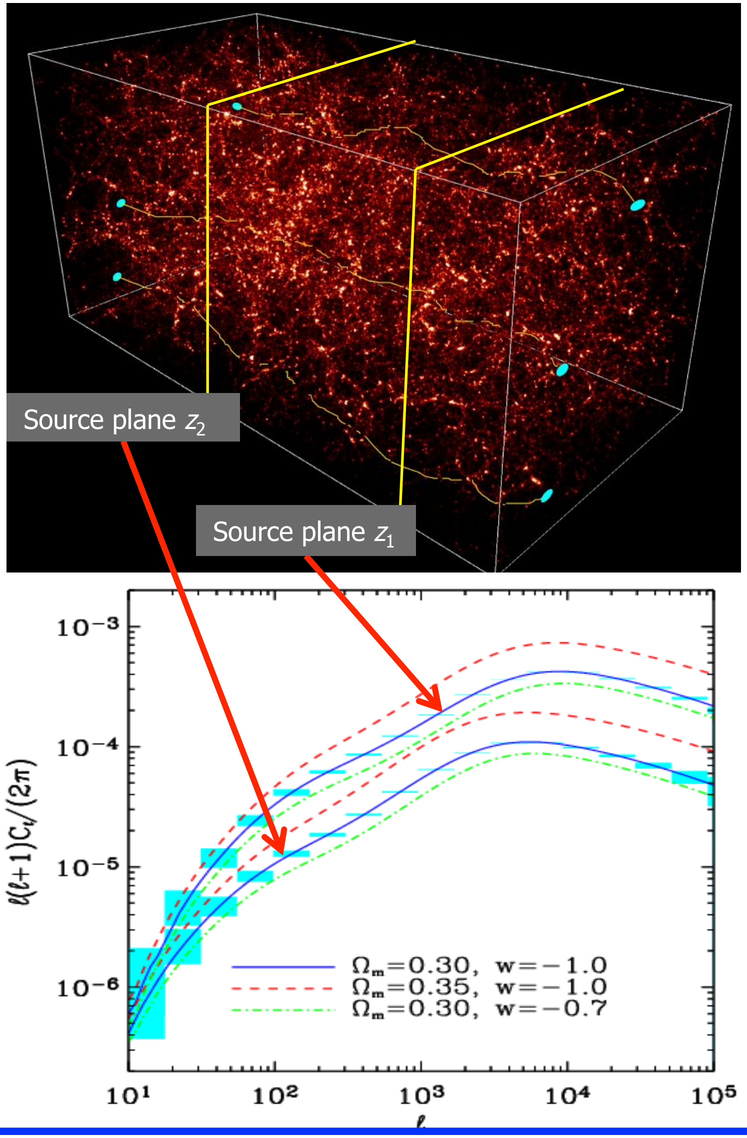
Euclid Top Level Science Requirements

Sector	Euclid Targets
Dark Energy	• Measure the cosmic expansion history to better than 10% in redshift bins $0.7 < z < 2$. • Look for deviations from $w = -1$, indicating a dynamical dark energy. • Euclid *alone* to give $FoM_{DE} \geq 400$ (1-sigma errors on w_p, & w_a of 0.02 and 0.1 respectively)
Test Gravity	• Measure the growth index, γ, with a precision better than 0.02 • Measure the growth rate to better than 0.05 in redshift bins between $0.5 < z < 2$. • Separately constrain the two relativistic potentials ψ and ϕ • Test the cosmological principle (consistency between H(z) and D(z)).
Dark Matter	• Detect dark matter halos on a mass scale between 10^8 and $>10^{15}$ M_{Sun} • Measure the dark matter mass profiles on cluster and galactic scales • Measure the sum of neutrino masses, the number of neutrino species and the neutrino hierarchy with an accuracy of a few hundredths of an eV
Initial Conditions	• Measure the matter power spectrum on a large range of scales in order to extract values for the parameters σ_8 and n to a 1-sigma accuracy of 0.01. • For extended models, improve constraints on n and α wrt to Planck alone by a factor 2. • Measure a non-Gaussianity parameter : f_{NL} for local-type models with an error < +/-2.

- DE equation of state: $P/\rho = w$, and $w(a) = w_p + w_a(a_p - a)$
- Growth rate of structure formation: $f \sim \Omega^\gamma$;
- FoM=1/(Δw_a x Δw_p) > 400→ ~1% precision on w's.

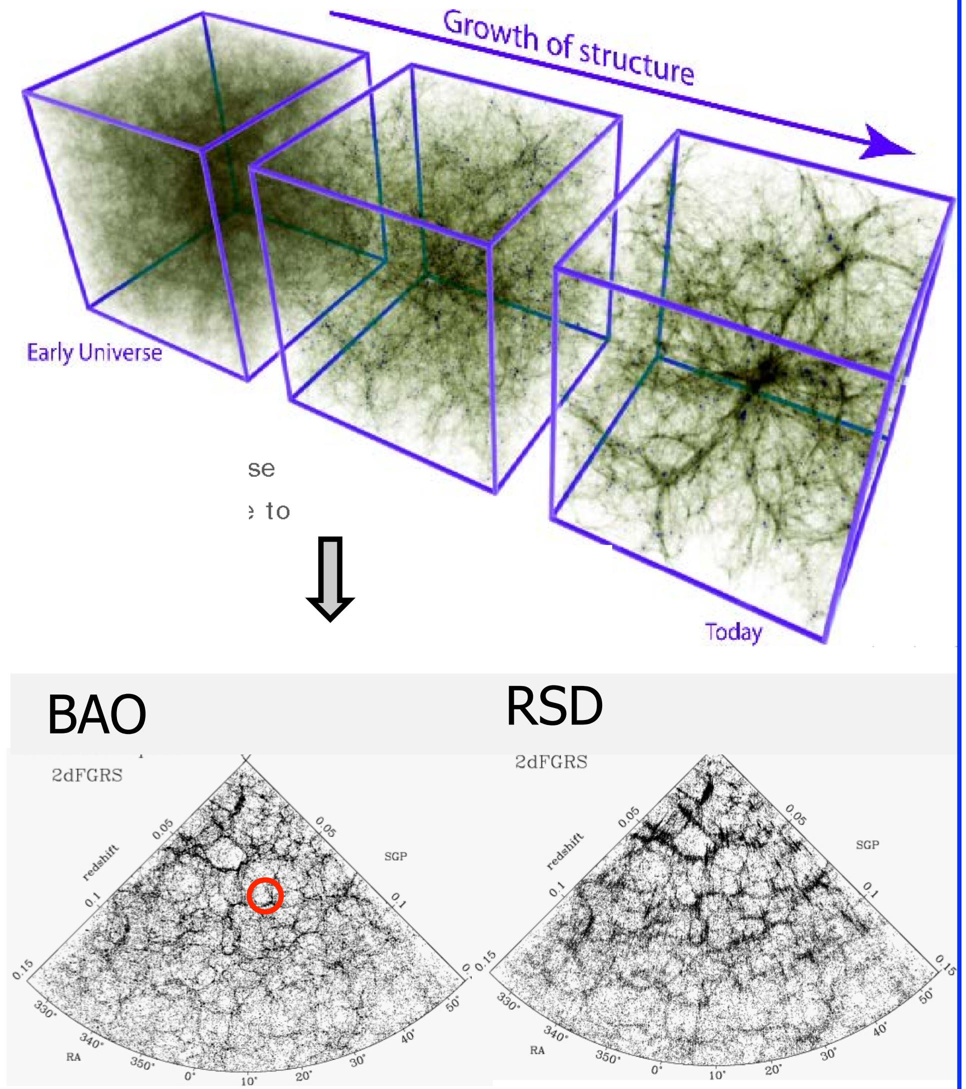
WL probe: Cosmic shear over 0<z<2 :

1.5 billion galaxies shapes, shear and phot-z (u,g,r,i,z, Y,J,H) with 0.05 (1+z) accuracy over 15,000 deg^2

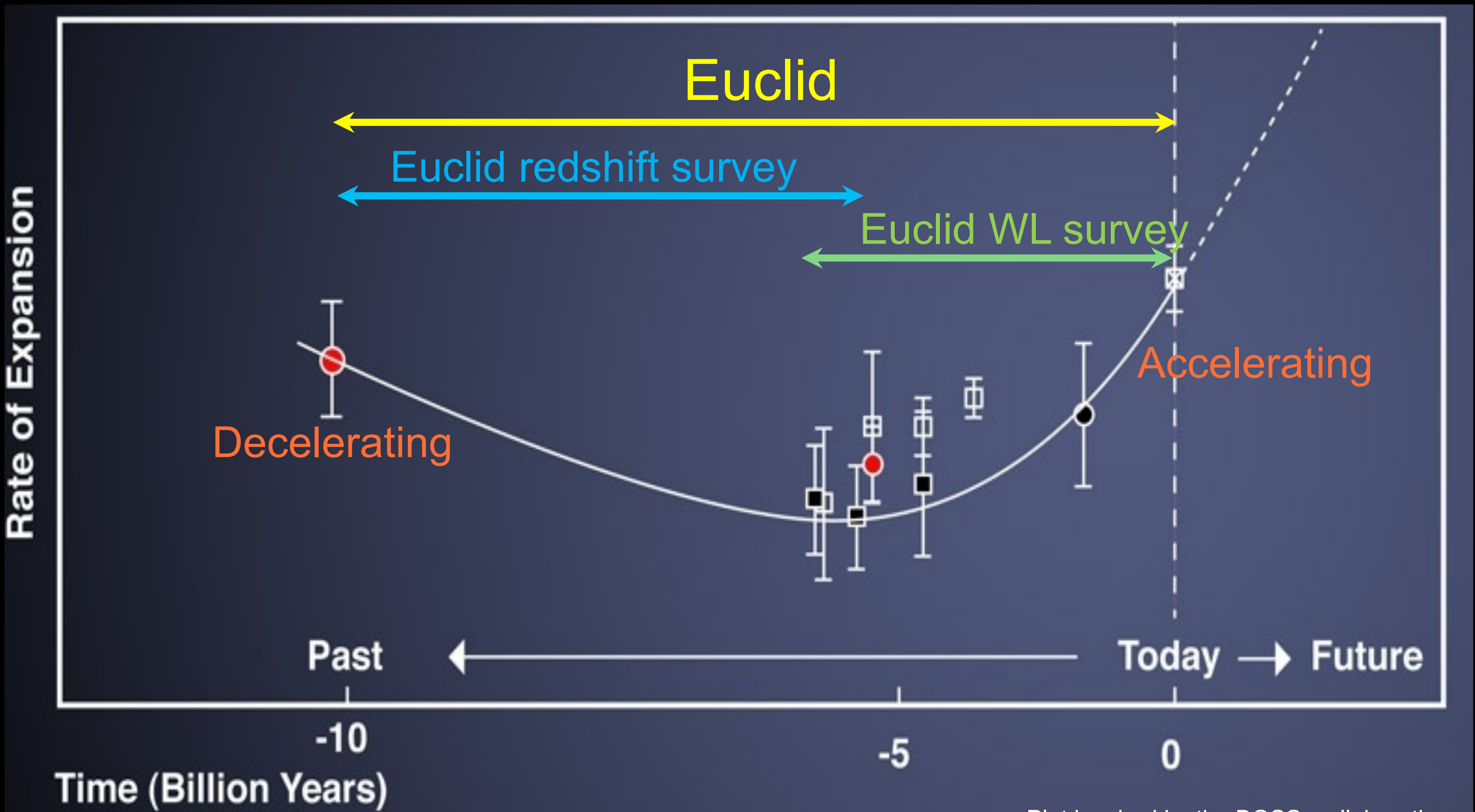


GC; BAO, RSD probes: 3-D positions of galaxies over 0.7<z<1.8 :

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

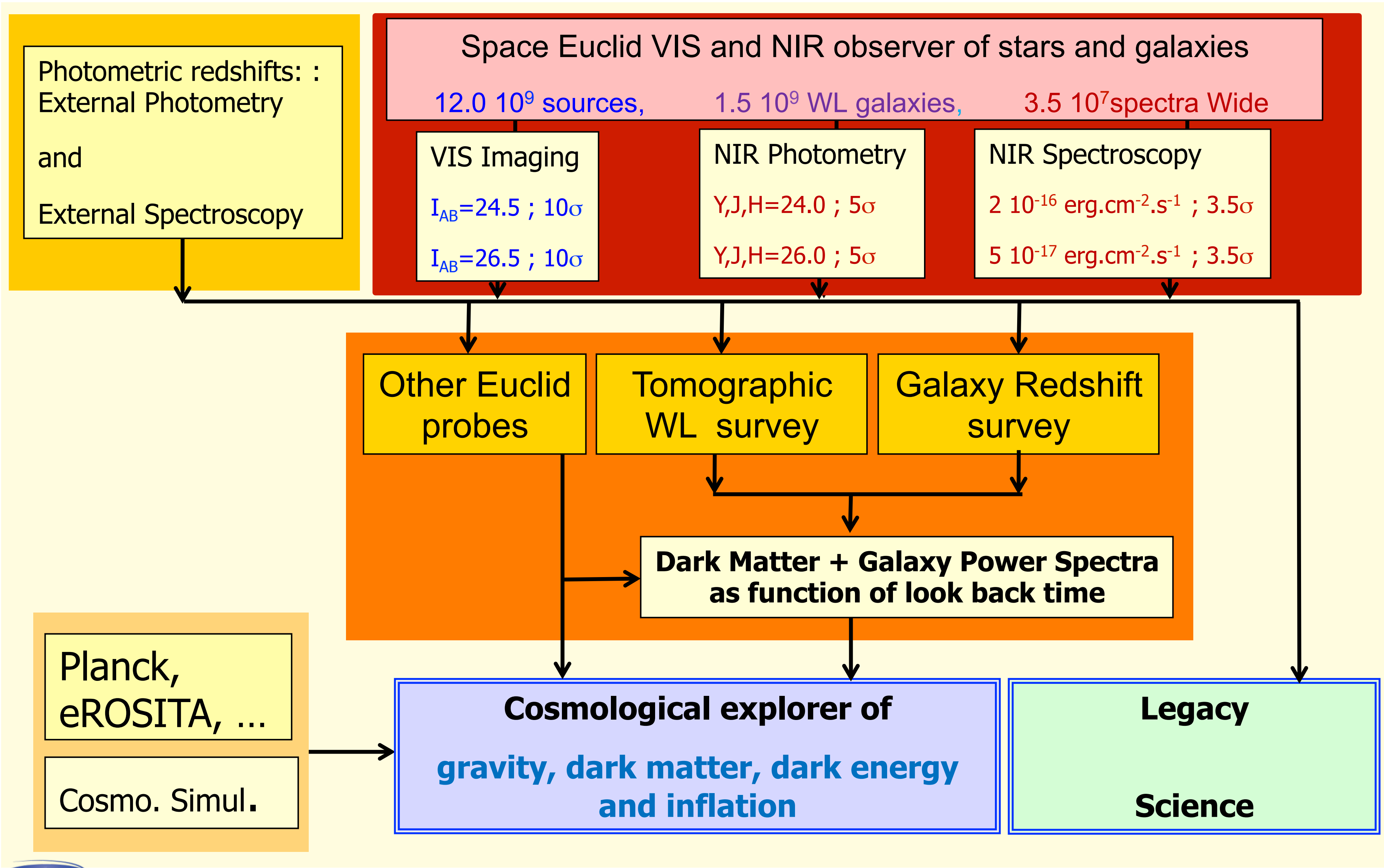


Euclid: exploring the DM-dominated / DE-dominated transition period



Plot inspired by the BOSS collaboration

Euclid Survey Machine:15,000 deg^2 + 40 deg^2



Euclid Wide+Deep Surveys

- **Euclid Wide:**
  - 15000 deg^2 outside the galactic and ecliptic planes
  - 12 billion sources (3-σ)
  - 1.5 billion galaxies (30 gal/$arcmin^2$) with
    - Very accurate morphometric information (WL)
    - Visible photometry: (u), g, r, i, z , (R+I+Z) AB=24.5, 10.0 σ +
    - NIR photom: Y, J, H AB = 24.0, 5.0σ
    - Photo-z with 0.05(1+z) accuracy
  - 35 million spectroscopic redshifts of emission line galaxies with
    - R: 260
    - 0.001 z accuracy
    - 21 mag
    - Hα galaxies within 0.7 < z < 1.85
    - Flux line: 2 . 10^{-16} $erg.cm^{-2}.s^{-1}$; 3.5σ

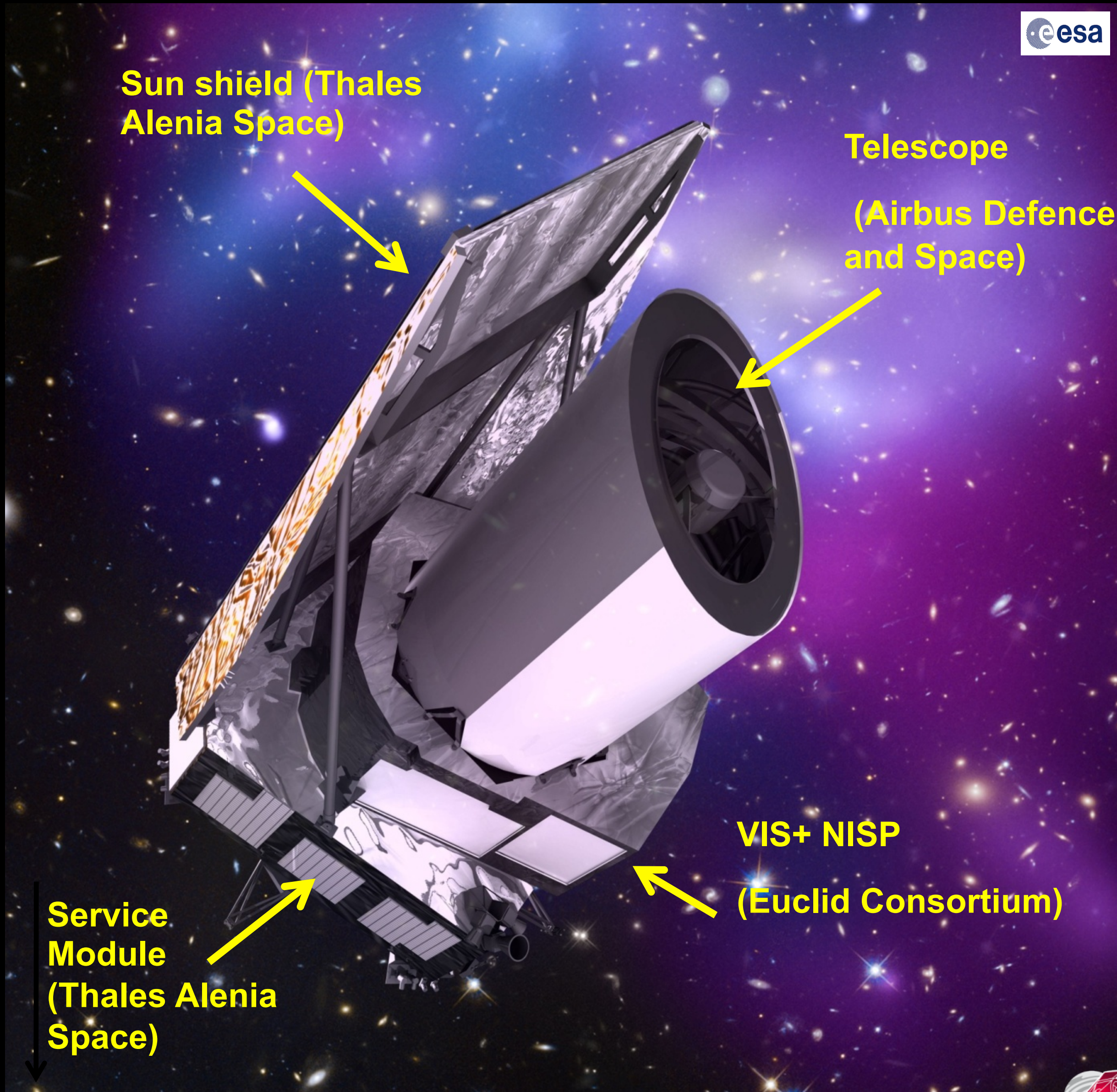
- **Euclid Deep:**
  - 1x10 deg^2 North Ecliptic pole (EDF-N) + 1x20 deg^2 South Ecliptic pole (EDF-S1 + 1x10 deg^2 at CDFS (EDF-S2)
  - 10 million sources (3-σ)
  - 1.5 million galaxies with
    - Very accurate morphometric information (WL)
    - Visible photometry: (u), g, r, i, z , (R+I+Z) AB=26.5, 10.0 σ +
    - NIR photom: Y, J, H AB = 26.0, 5.0σ
    - Photo-z with 0.05(1+z) accuracy
  - 150 000 spectroscopic redshifts of emission line galaxies with
    - R: 260
    - 0.001 z accuracy
    - 23 mag
    - Hα galaxies within 0.7 < z < 1.85
    - Flux line: 5 . 10^{-17} $erg.cm^{-2}.s^{-1}$; 3.5σ

ESA Euclid mission

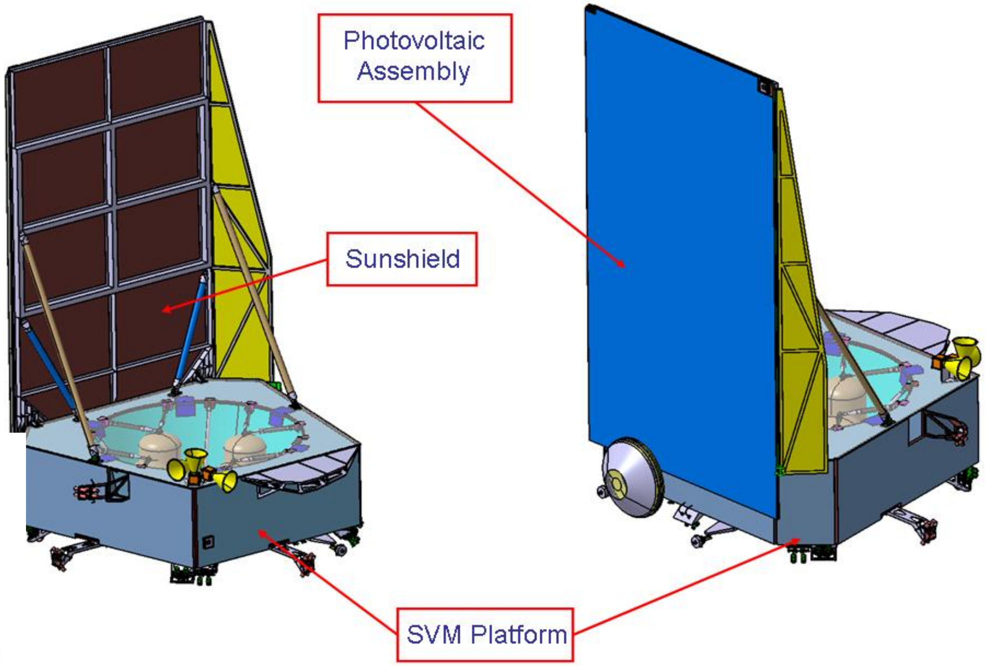
- - Total mass satellite :
- 2 200 kg
- - Dimensions:
- 4,5 m x 3 m

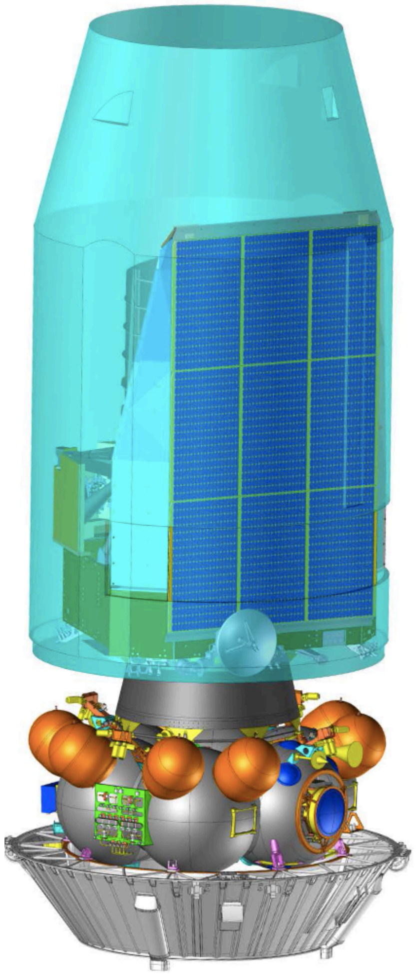
- - Launch: end 2020 by a Soyuz rocket from the Kourou space port
- Euclid placed in L2

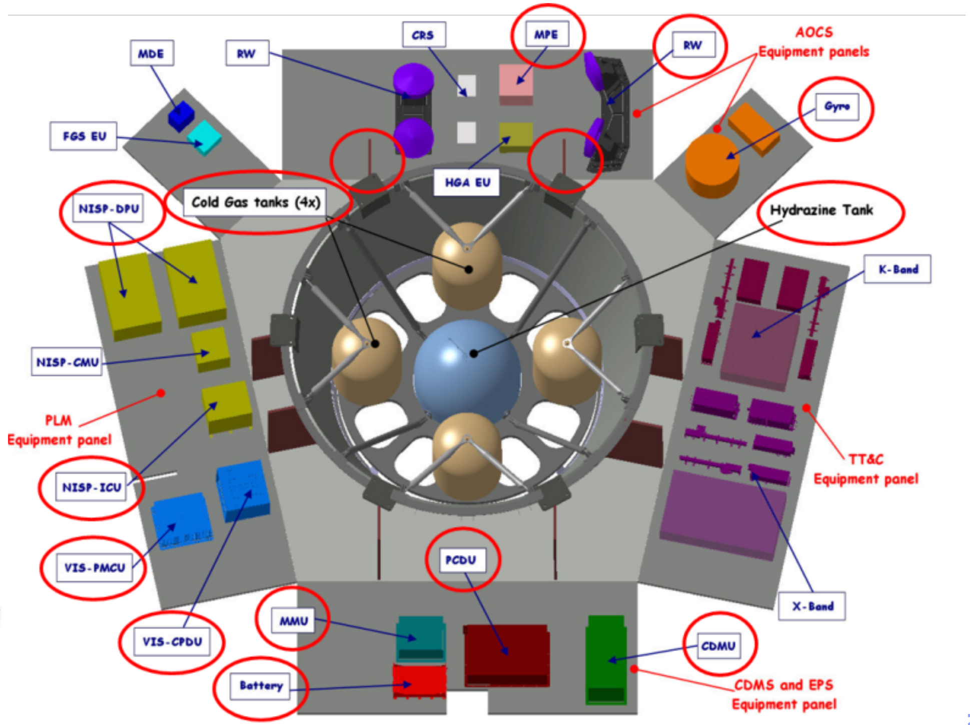
- - Survey: 6 years,

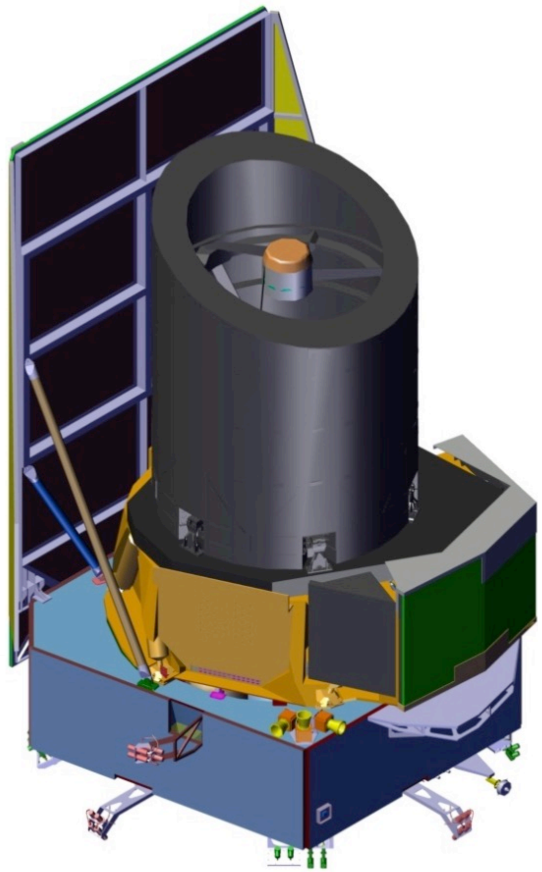


Euclid satellite elements



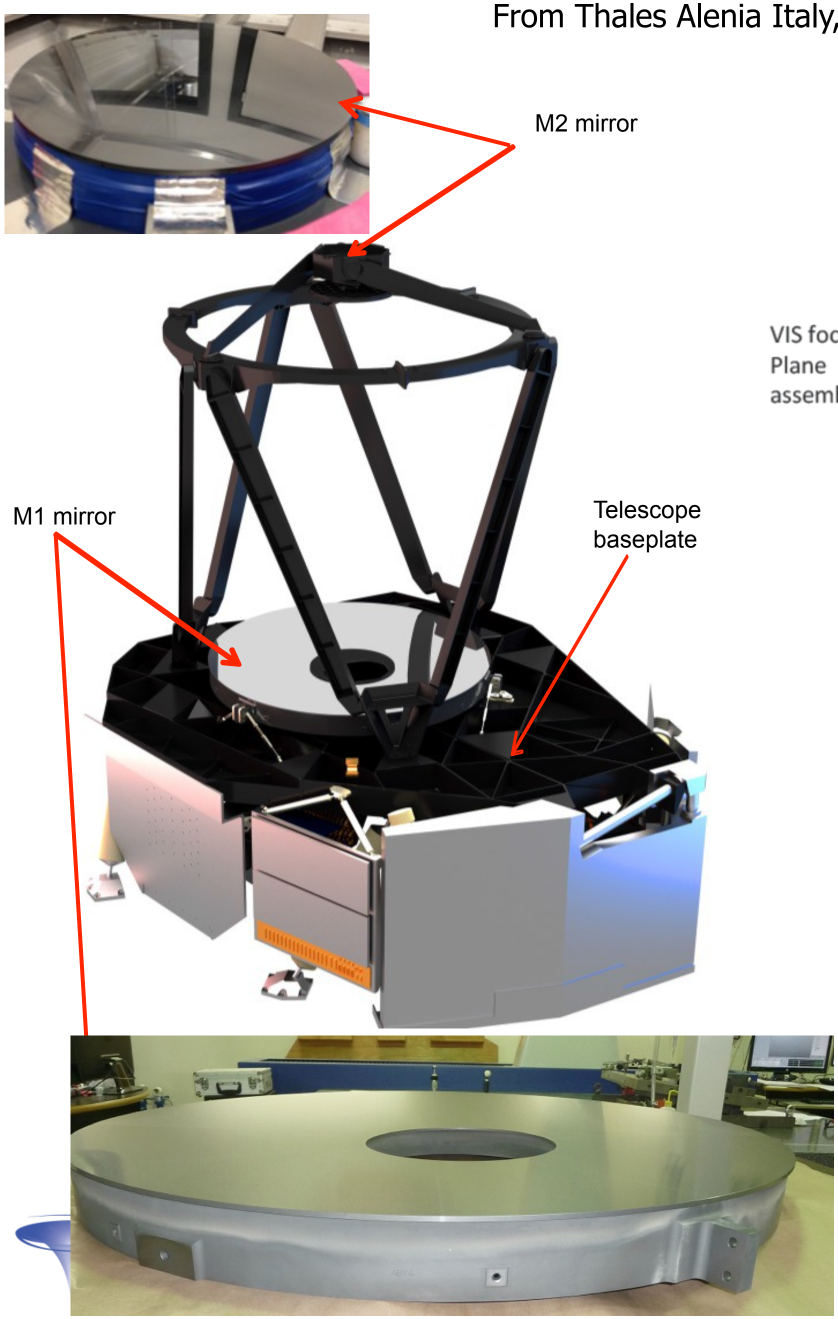


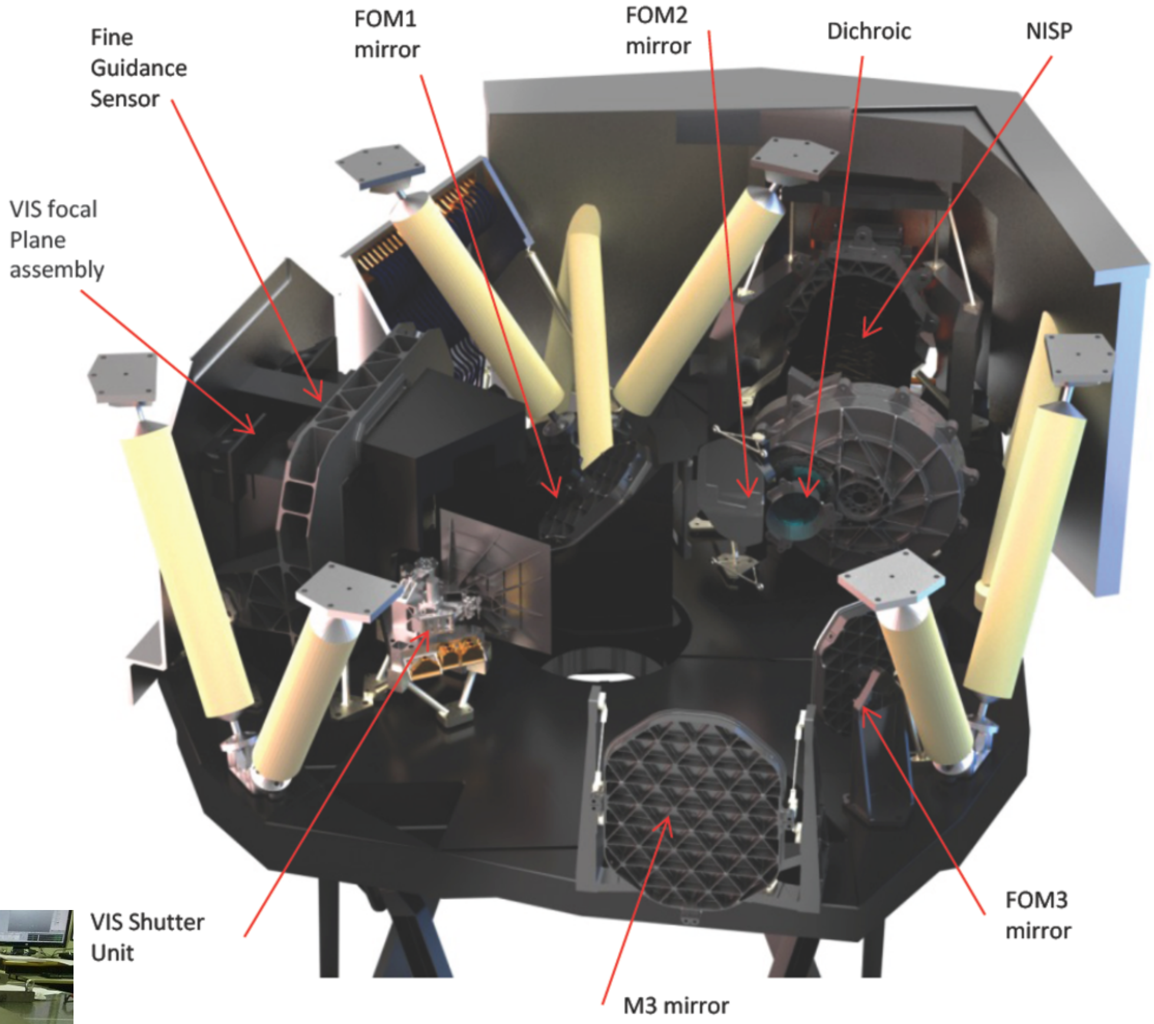




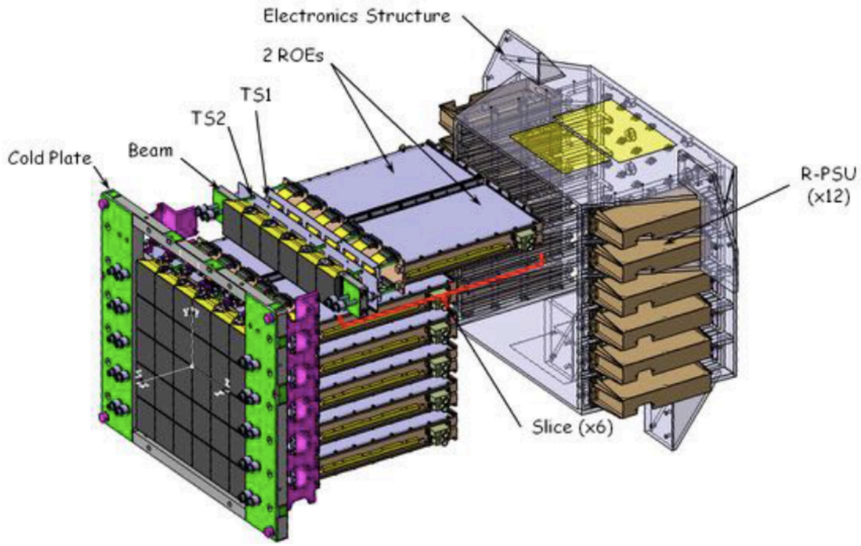
PLM, scientific instruments

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





PLM CDR in July 2017



VIS

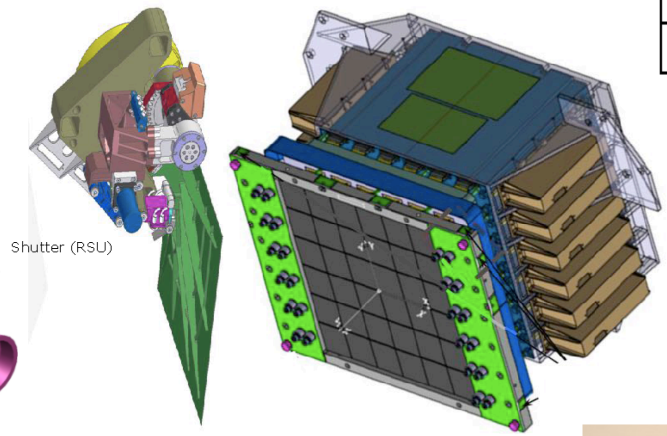
VIS CDR on going

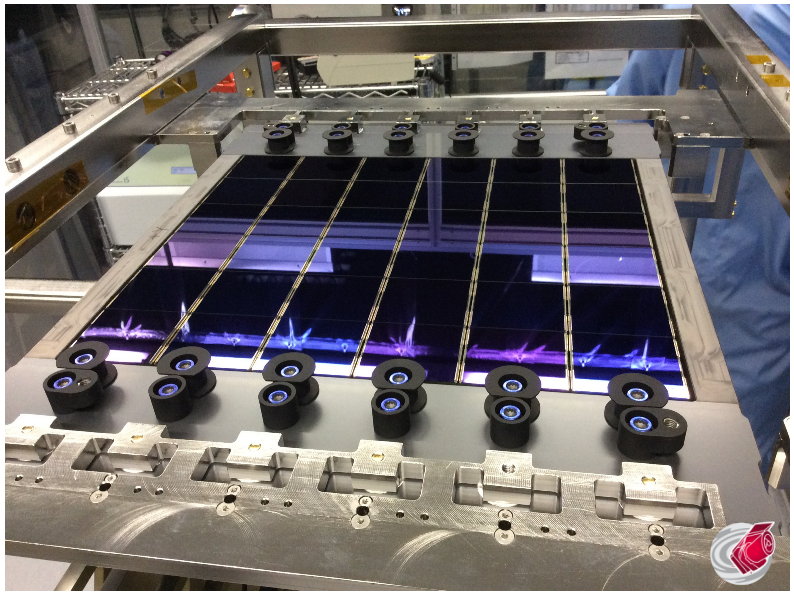
Table 1: VIS and weak lensing channel characteristics

Spectral Band	550 – 900 nm
System Point Spread Function size	≤0.18 arcsec full width half maximum at 800 nm
System PSF ellipticity	≤15% using a quadrupole definition
Field of View	>0.5 deg^2
CCD pixel sampling	0.1 arcsec
Detector cosmetics including cosmic rays	≤3% of bad pixels per exposure
Linearity post calibration	≤0.01%
Distortion post calibration	≤0.005% on a scale of 4 arcmin
Sensitivity	$m_{AB} \geq 24.5$ at 10σ in 3 exposures for galaxy size 0.3 arcsec
Straylight	≤20% of the Zodiacal light background at Ecliptic Poles
Survey area	15000 deg^2 over a nominal mission with 85% efficiency
Mission duration	6 years including commissioning
Shear systematic bias allocation	additive $\sigma_{sys} \leq 2 \times 10^{-4}$; multiplicative $\leq 2 \times 10^{-3}$

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

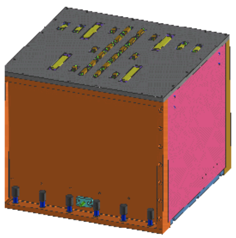
Cropper et al 2016.SPIE

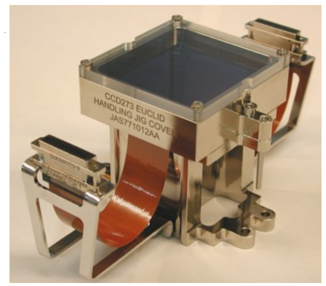




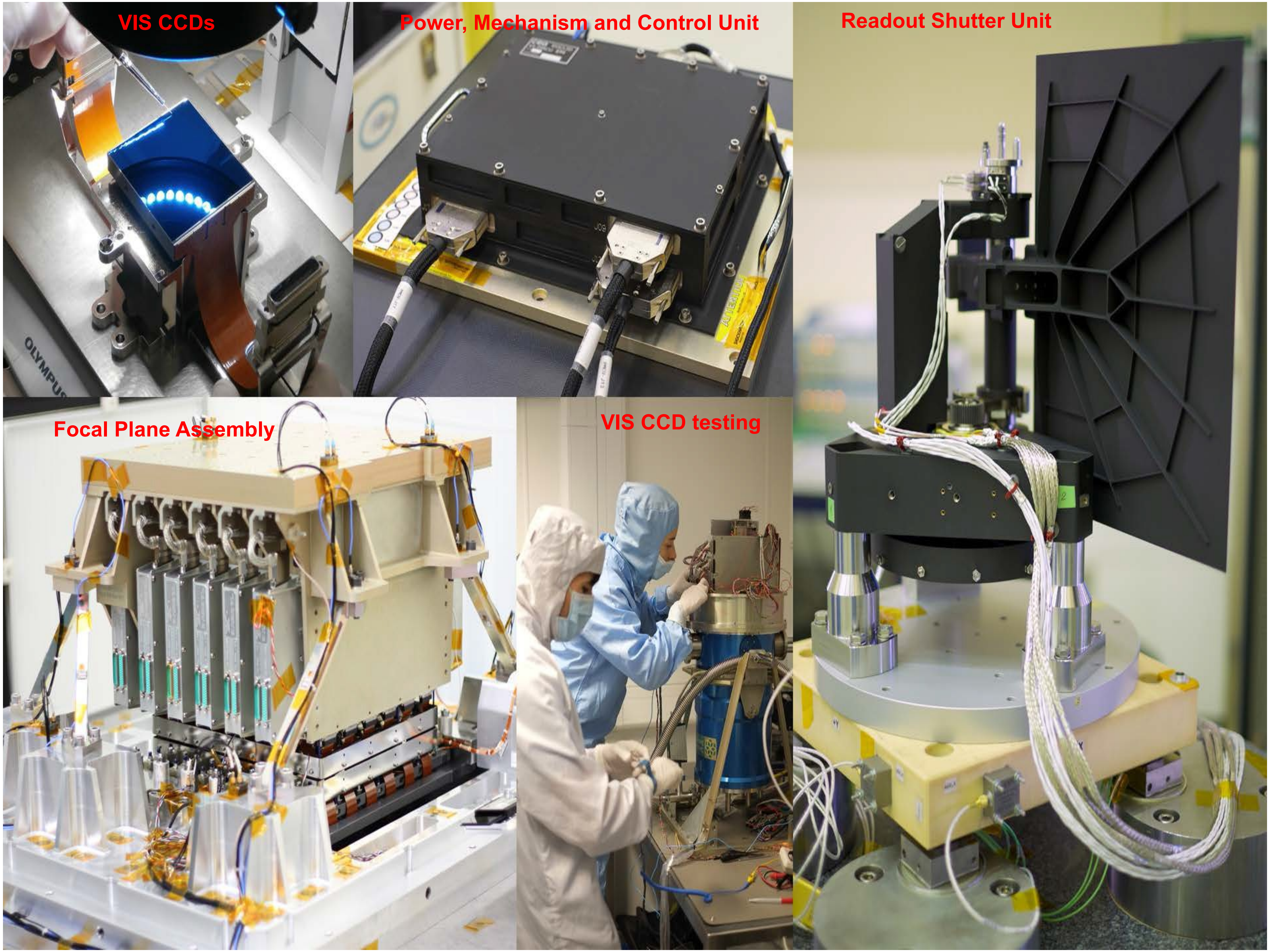
Warm Units
in Service Module

Payload and Mechanism
Control Unit (PMCU)



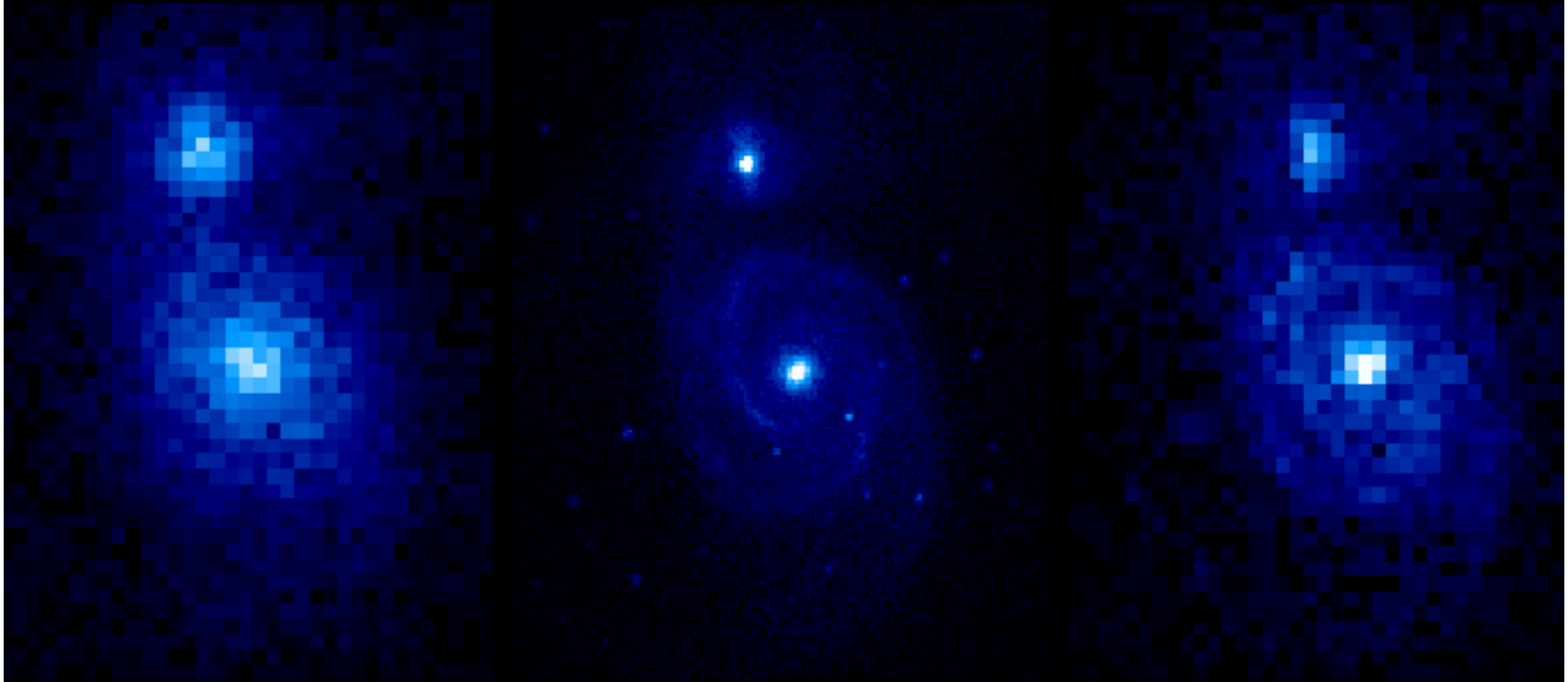


Euclid consortium


VIS CCDs
Power, Mechanism and Control Unit
Readout Shutter Unit
Focal Plane Assembly
VIS CCD testing

VIS: Simulation of M51

From J. Brinchmann



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

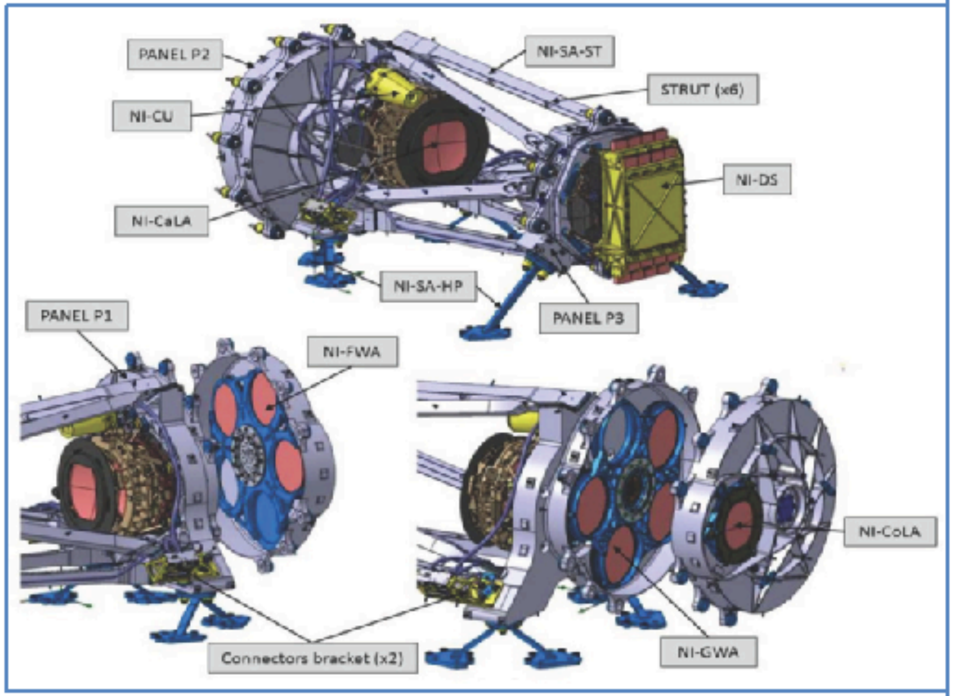
Euclid will get the resolution of SDSS but at z=1 instead of z=0.05.

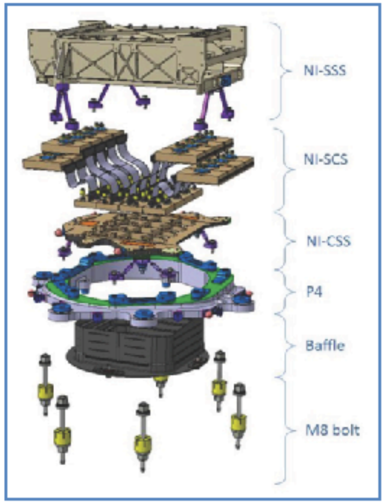
Euclid will be 3 magnitudes deeper → Euclid Legacy = Super-Sloan Survey

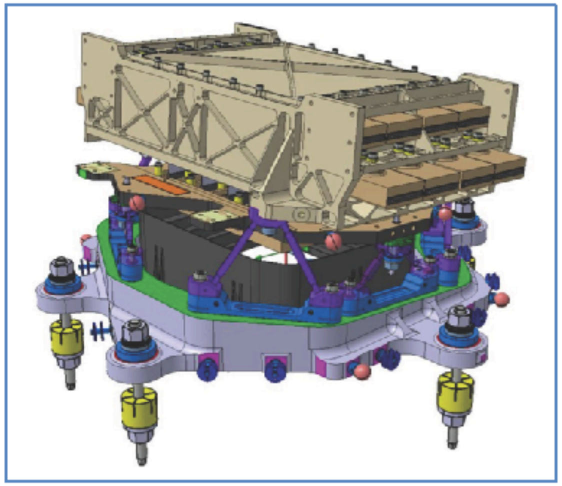
NISP

NISP CDR successful in Nov 2016

Courtesy: T. Maciaszek and the NISP team







- FoV: 0.55 deg^2
- Mass : 159 kg
- Telemetry: < 290 Gbt/day
- Size: 1m x 0.5 m x 0.5 m
- 16 2kx2K H2GR detectors
- 0.3 arcsec pixel on sky
- Limiting mag, wide survey AB : 24 (5 σ)
- **3 Filters**:

•Y (950-1192nm)

•, J (1192, 1544nm)

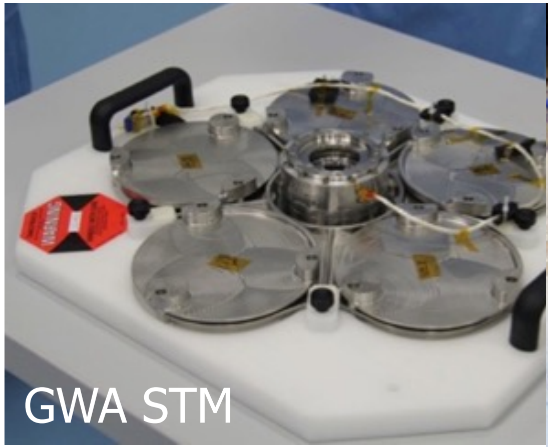
•, H (1544, 2000nm)

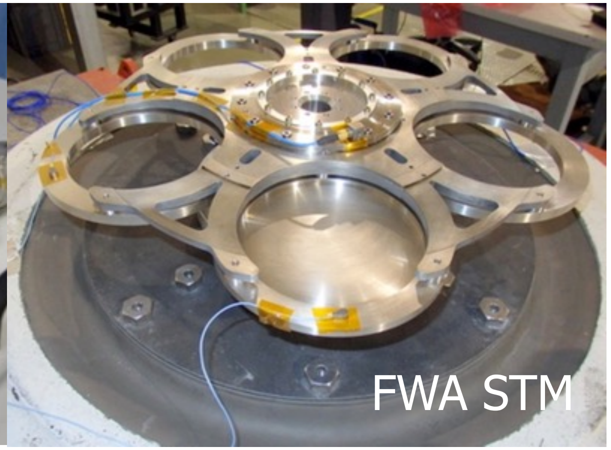
- **4 grisms**:

•1B (920 – 1300) , 1 orientation 0°

•3R (1250 – 1850), 3 orientations 0°, 90°, 180°

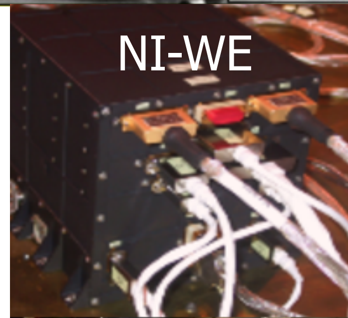
Maciaszek et al 2016:SPIE

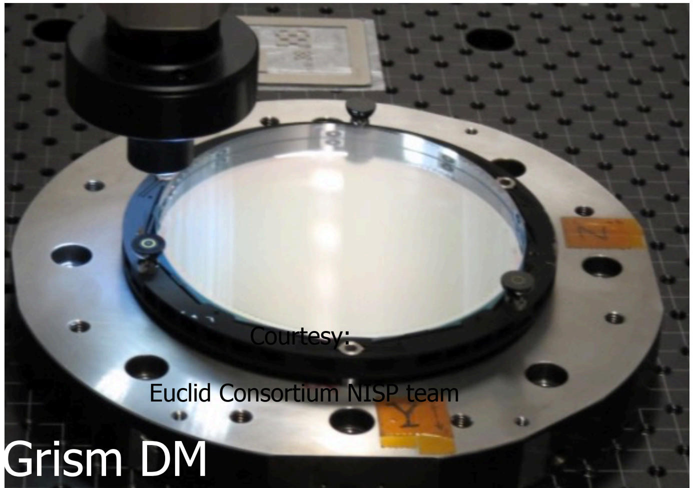


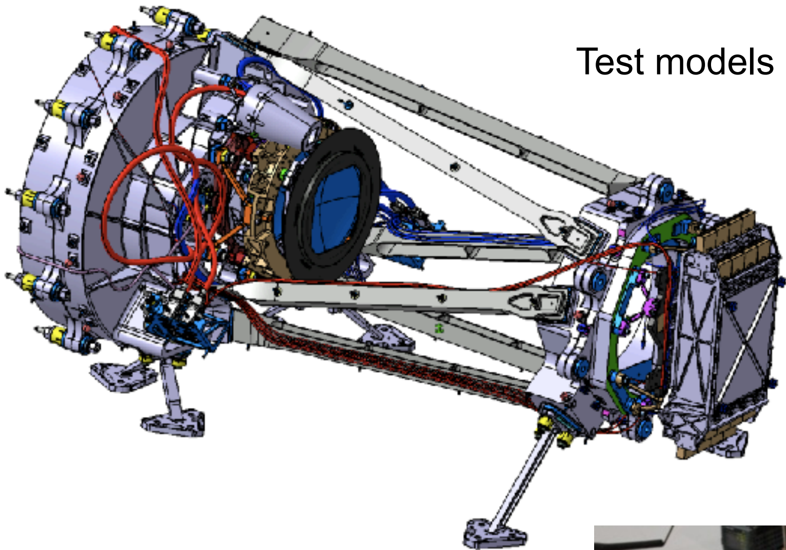


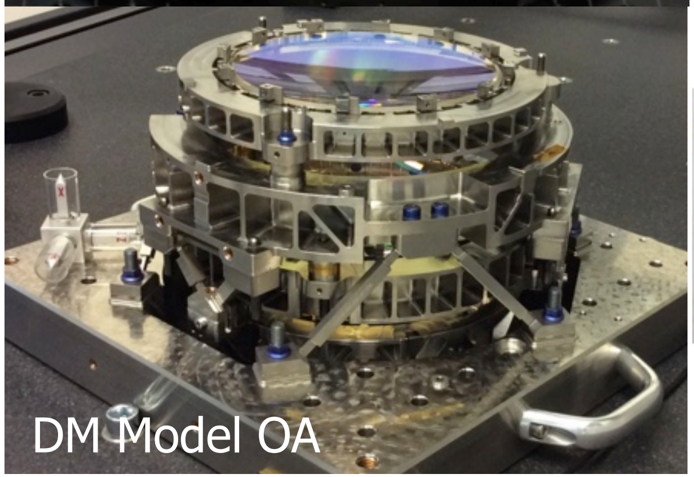
NISP

Test models

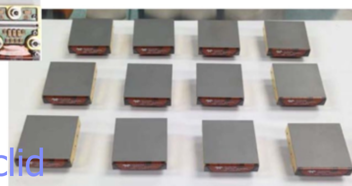


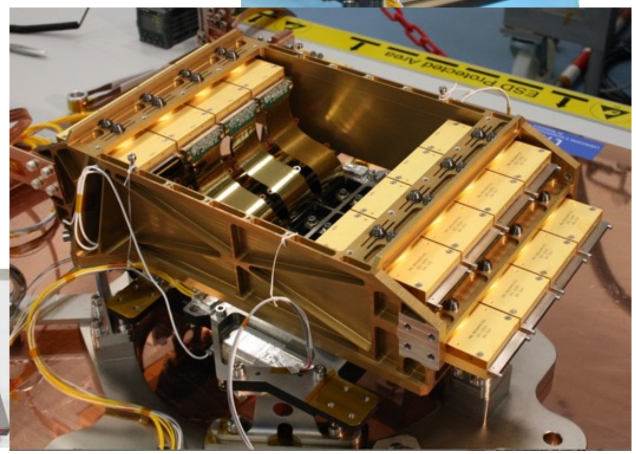






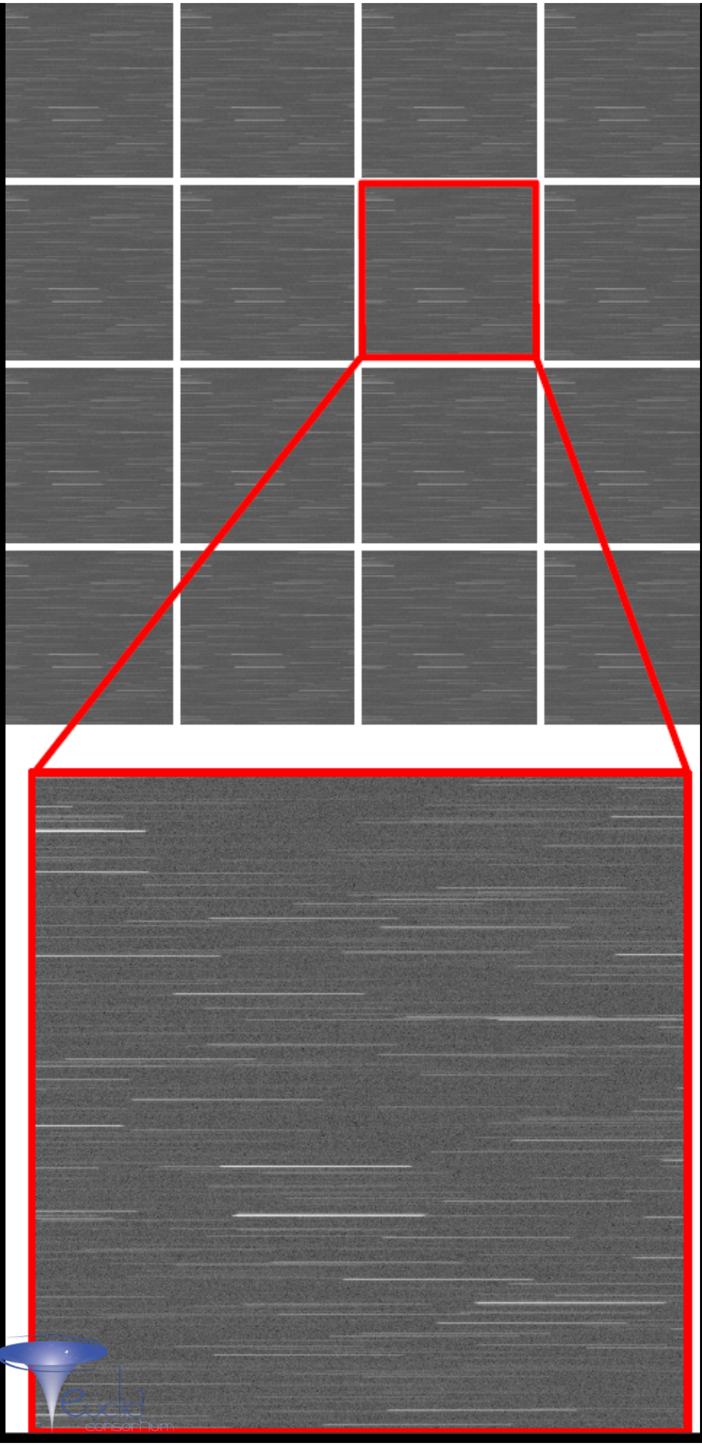
12 flight grade SCA packages were received

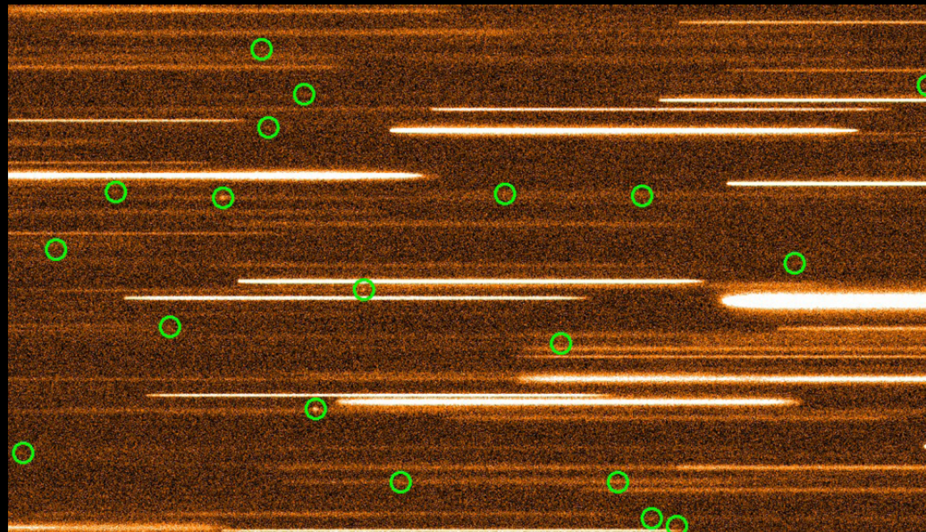


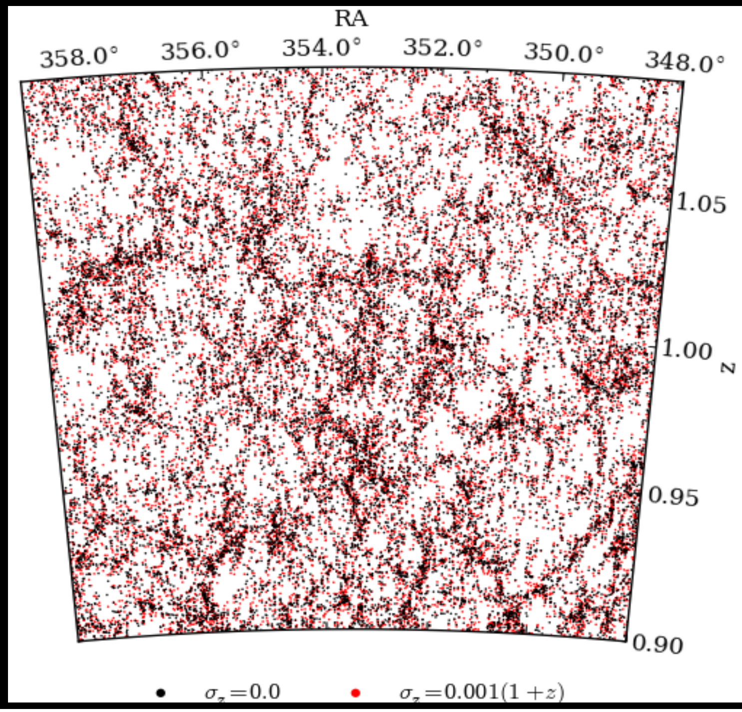


NISP-spectroscopy for Euclid

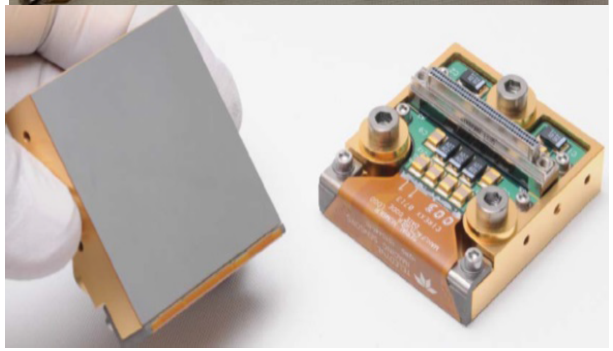
From P. Franzetti, B. Garilli, A. Ealet, N. Fourmanoit & J. zoubian



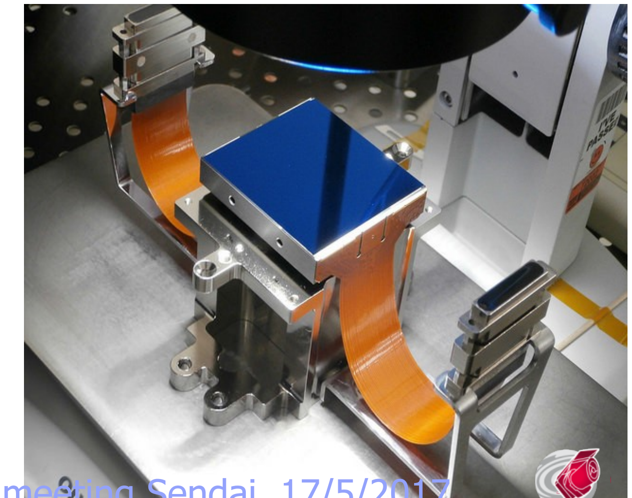




NIR detectors and CCD's



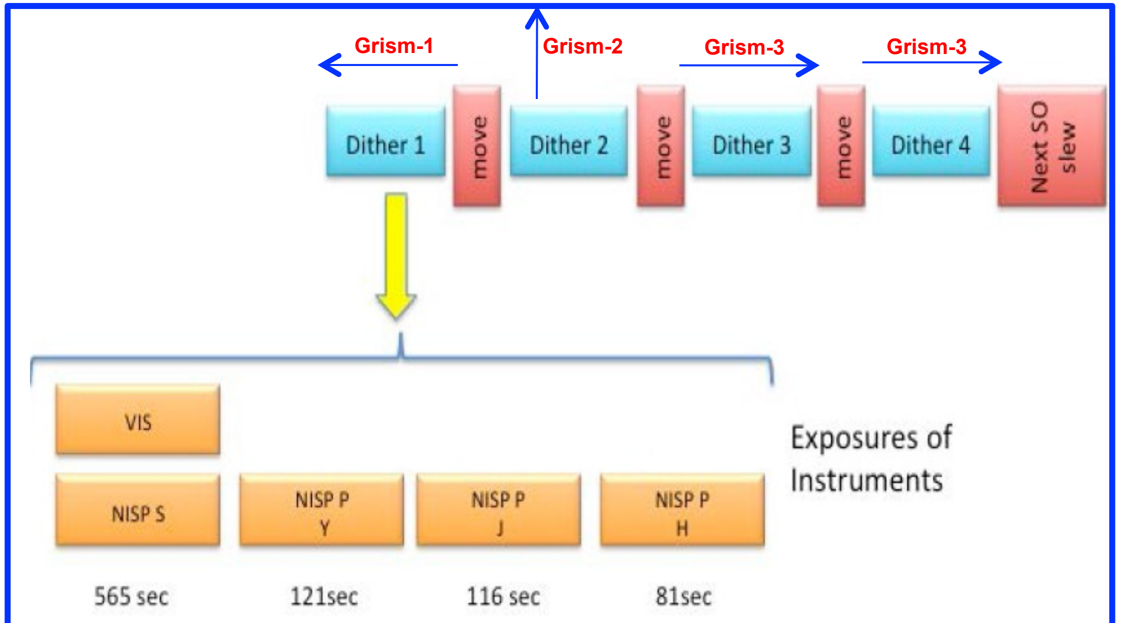
- **NIR HgCdTe detectors** (Teledyne), 2040X2040 pixels, 18x18 µm, 2.3 µm cut-off, FW=130,000 e-:
- QE ≥ 90% 1 µm to 2.2 µm
- Spectroscopic noise ≤ 7 e- over 560 s
- Photometric noise ≤ 5 e- over 60 s
- Dark current ≤ 0.005 e-/s/px
- Linearity ≤ 0.7% between 6 ke- and 60 ke-



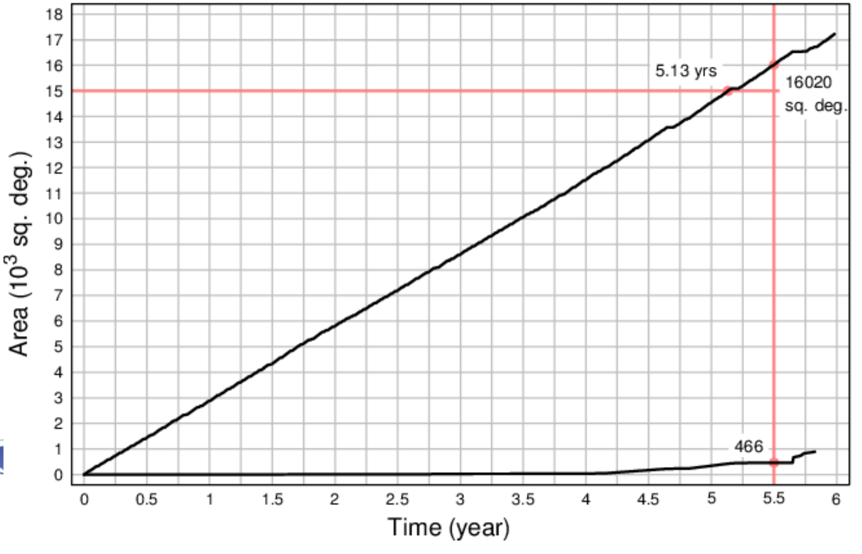
- **CCD** (e2v), 4096 x 4132 pixels, 12x12 µm FWC=175,000e-
- 4 read-out nodes (in corners)
- SiC package extremely tight flatness
- QE ≥ 70% 500nm to 850nm (95% at 650nm)
- PRNU much better than 2% at all spatial scales
- Noise better than required 3.6 e- at 70 kpix/s

Euclid Survey

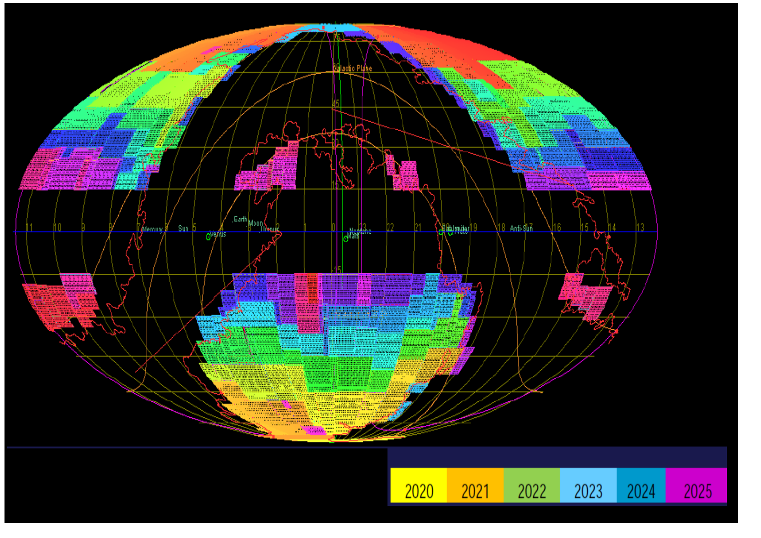
- |b|>30º
- Minimise SAA variations;
- Minimise zodiacal light
  → high ecliptic latitude;
- Low galactic extinction;
- Specific pointed calibration;
- Wide survey: one visit/ field
- Deep survey: many visits



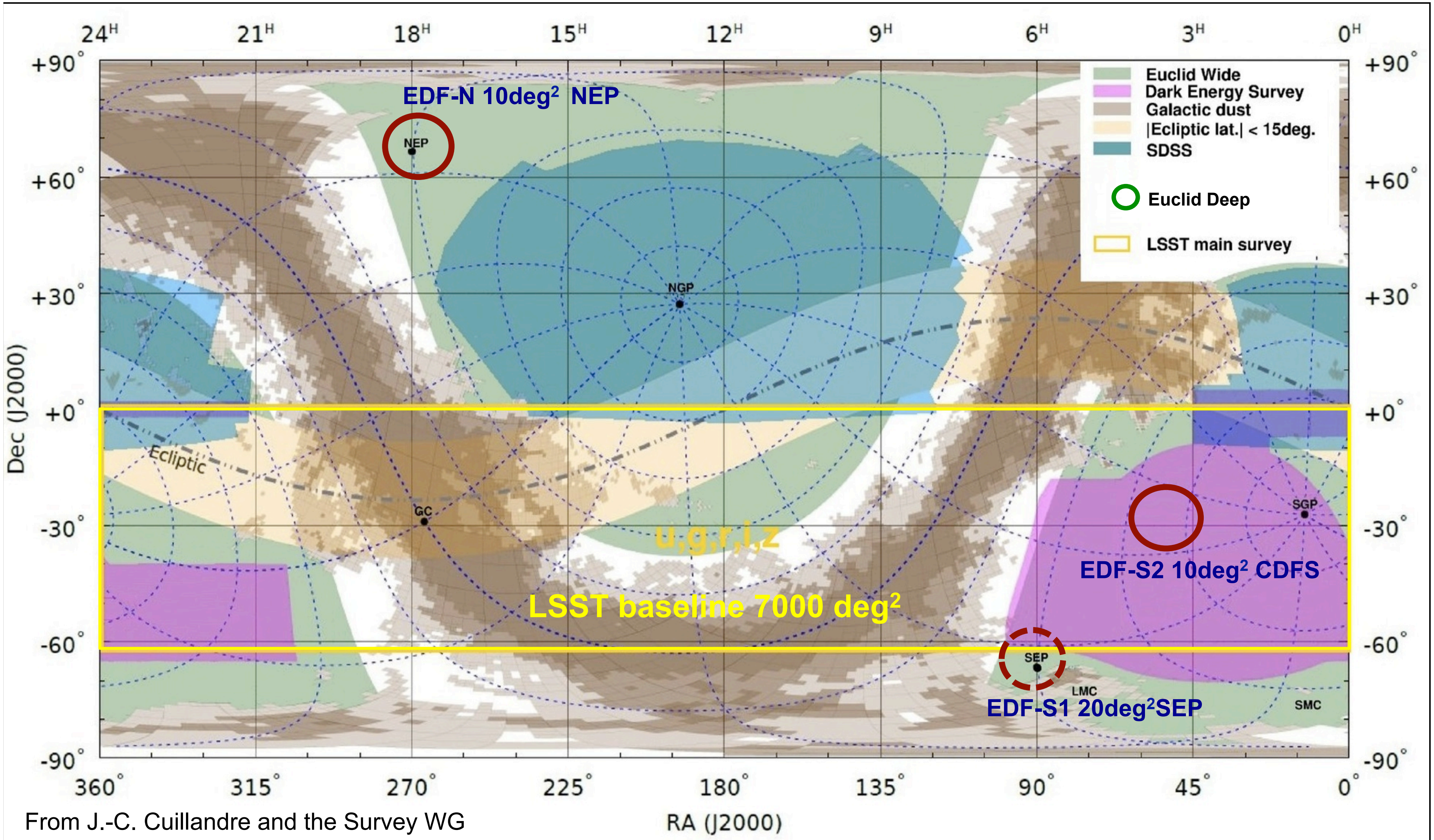
Instruments observation sequence of one field



Wide survey area (colour = epoch of observation).
Empty regions: ecliptic equator and galaxy plane.



Euclid Wide and Deep Surveys



From J.-C. Cuillandre and the Survey WG

Euclid complementary data

- 45 nights at Keck telescope: spectroscopy on Euclid Wide fields north
- 25 nights at VLT VMOS/KMOS: spectroscopy on Euclid Wide fields south
- 2 nights pilot program at GTC: preparation of a spectroscopic large program

- 5300 hrs of Spitzer satellite, period 13, priority 1 on 2 Euclid Deep field (20 deg2)
- DES+KiDS survey data
- 271 nights at CFHT *u-, r-* band data on Euclid Wide North
- 110 nights at JST/T250 *g-* band data on Euclid Wide North
- Discussions on going with other telescopes

Ground Based Observations for Euclid

	North		South	
	Imaging	Spectroscopy	Imaging	Spectroscopy
Wide survey	**Wide North Imaging** **LSST+CFHT+Subaru+T250?**	**Wide North Spectroscopy**	**Wide South Imaging** **DES+LSST**	**Wide South Spectroscopy**
	YJH **ugriz dec<30°** **ugriz dec>30°**	Keck 15+30	**YJH** **ugriz dec<0°**	ESO+GTC?
Deep survey	**Deep North Imaging** **LSST+Subaru**	**Deep North Spectroscopy**	**Deep South Imaging** **LSST**	**Deep South Spectroscopy**
	YJH **ugriz**	Subaru+ GTC?	**YJH** **ugriz**	ESO+ **GTC**?

GTC: ground based spectroscopic survey beyond the pilot program

Ground Segment:

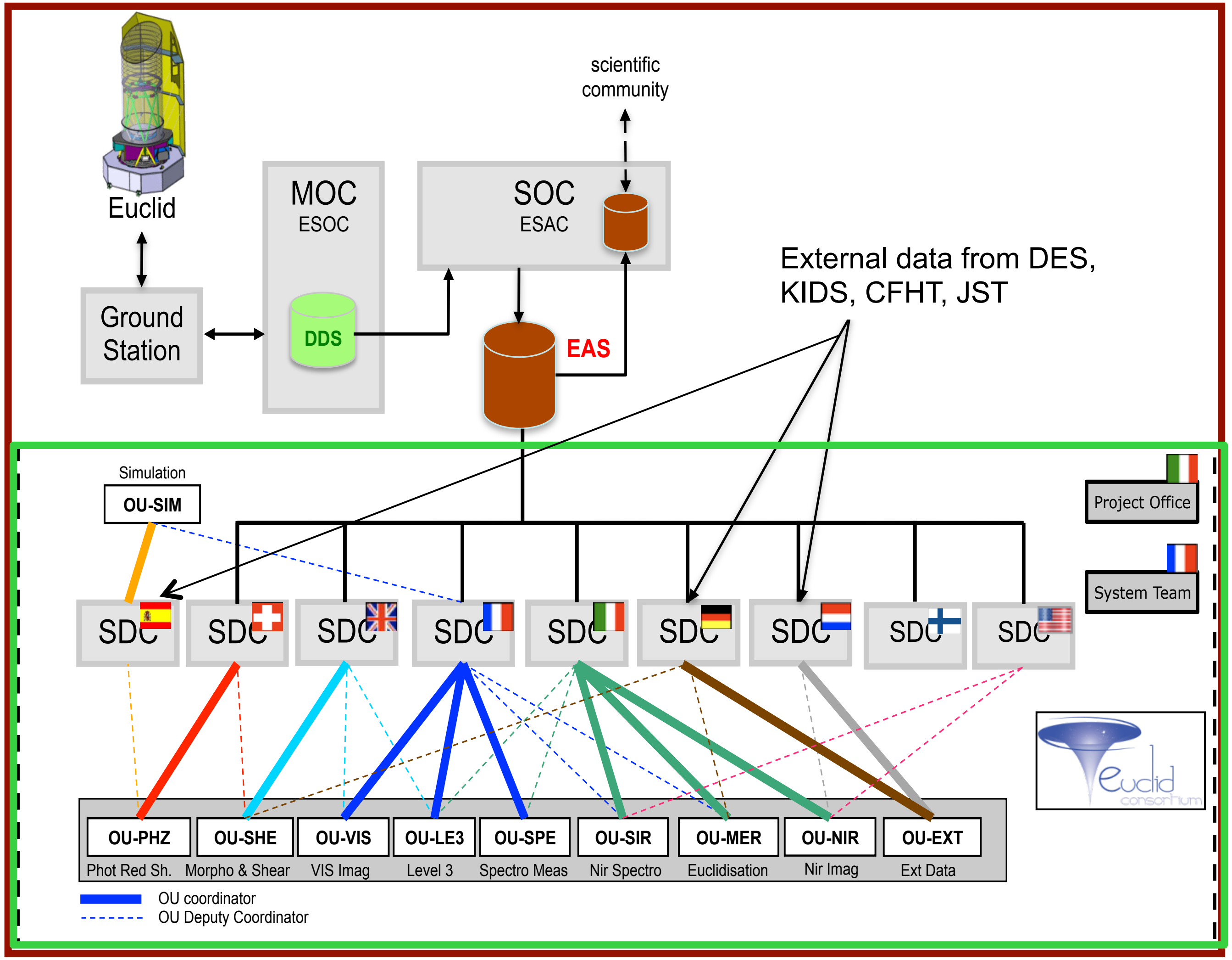
Design Review in Nov 2017

Complex organisation:

- 10 Organisation Units
- 9 Science Data Centers

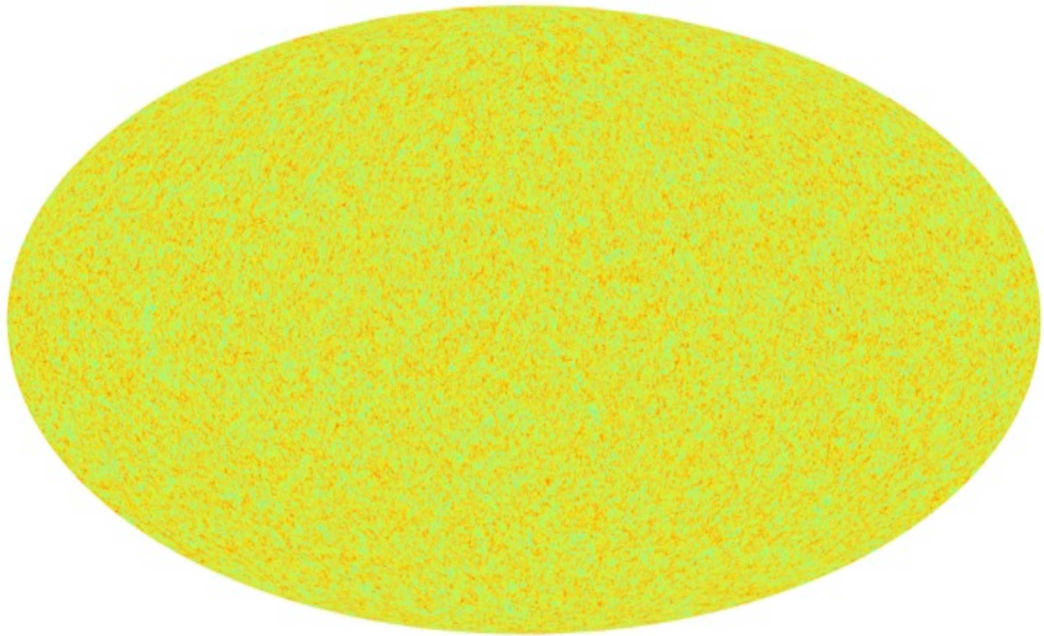
Data: huge volumes, heterogeneous data sets

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



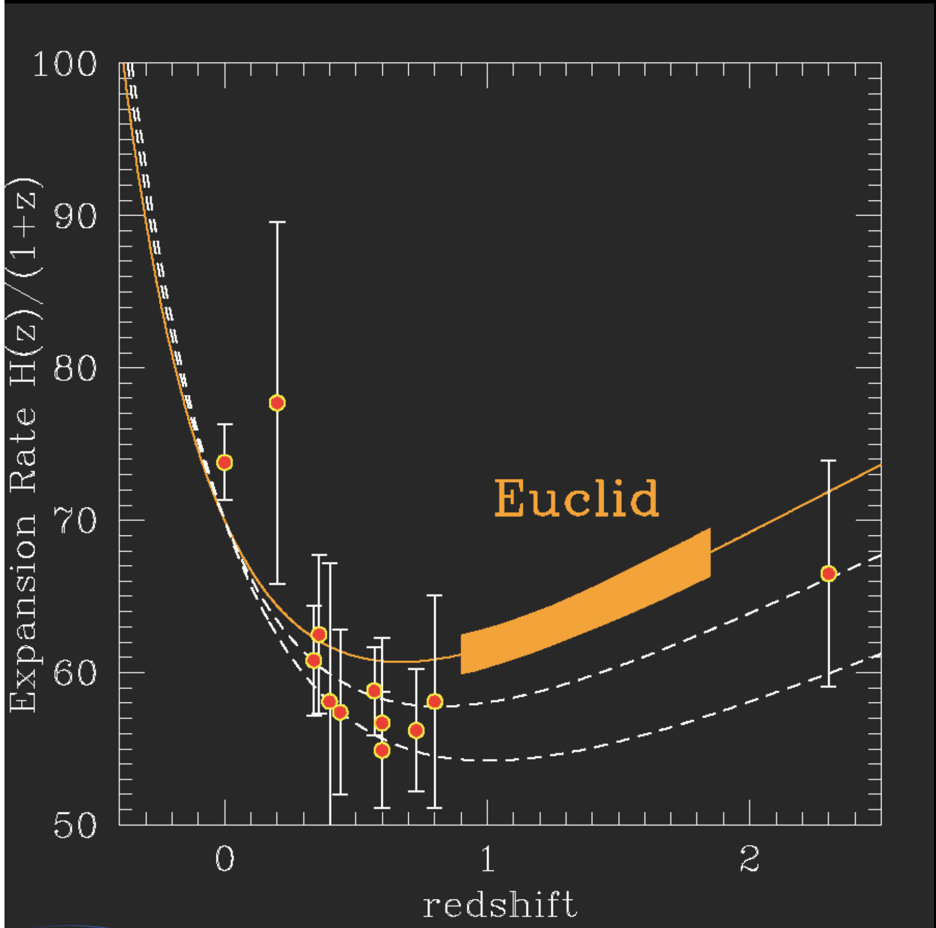
Euclid is also: Flagship Euclid Simulation

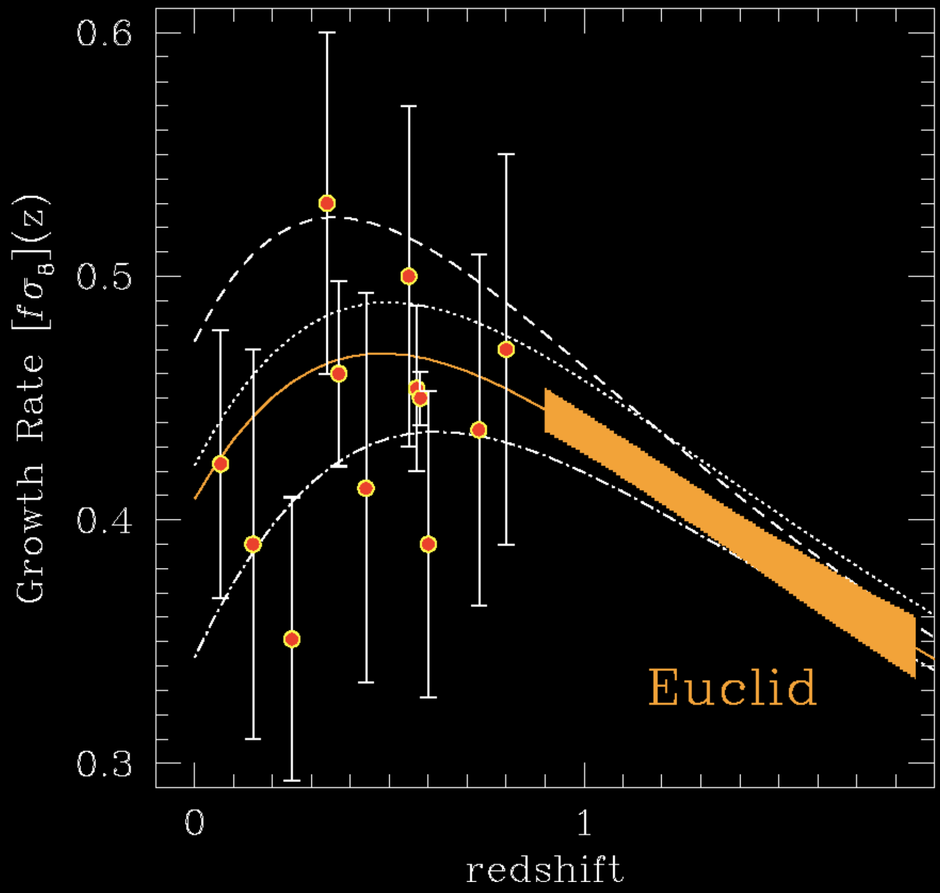
- 2 Trillion particles N body simulation down to z=0
- 100 redshift slices
- 10 different HOD and halo catalogues up to z=2.3
- Consistent mocks for WL and GC data
- SED: 23 bands from u to IRAC
- 213 Bruzual&Charlot models with different ages and star formation history
- Includes dust absorption
- Normalised to fit H-band photometry
- Galaxy sizes and morphologies
- **Partly released, release June 2017**



- Key innovation: analysis is done entirely on the fly (light cone and halo catalogue)

Exploration of DE models with Euclid (redshifts only)





Euclid forecast: Primary Program

Ref: Euclid RB arXiv: 1110.3193	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	**6000 →**
Current (2009)	**0.200**	**0.580**	**100**	**0.100**	**1.500**	**~10**
Improvement Factor	**30**	**30**	**50**	**>10**	**>40**	**>400**

Laureijs et al 2011

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

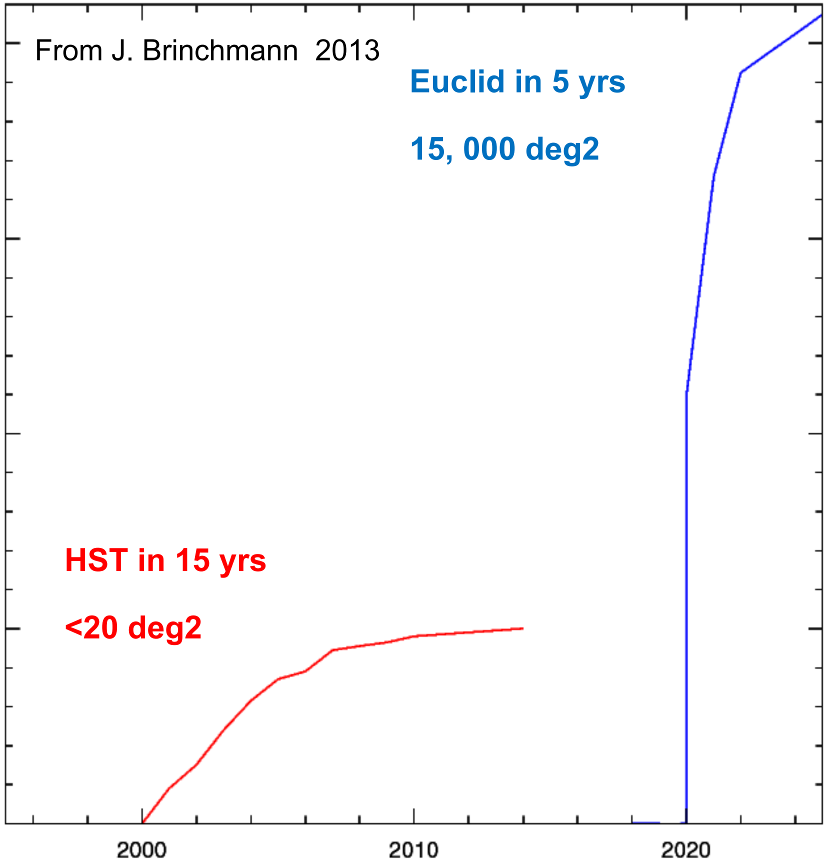
From Euclid data alone, get FoM=1/(Δw_a x Δw_p) > 400→ ~1% precision on w's.

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

Notice neutrino constraints -> minimal mass possible ~ 0.05 eV

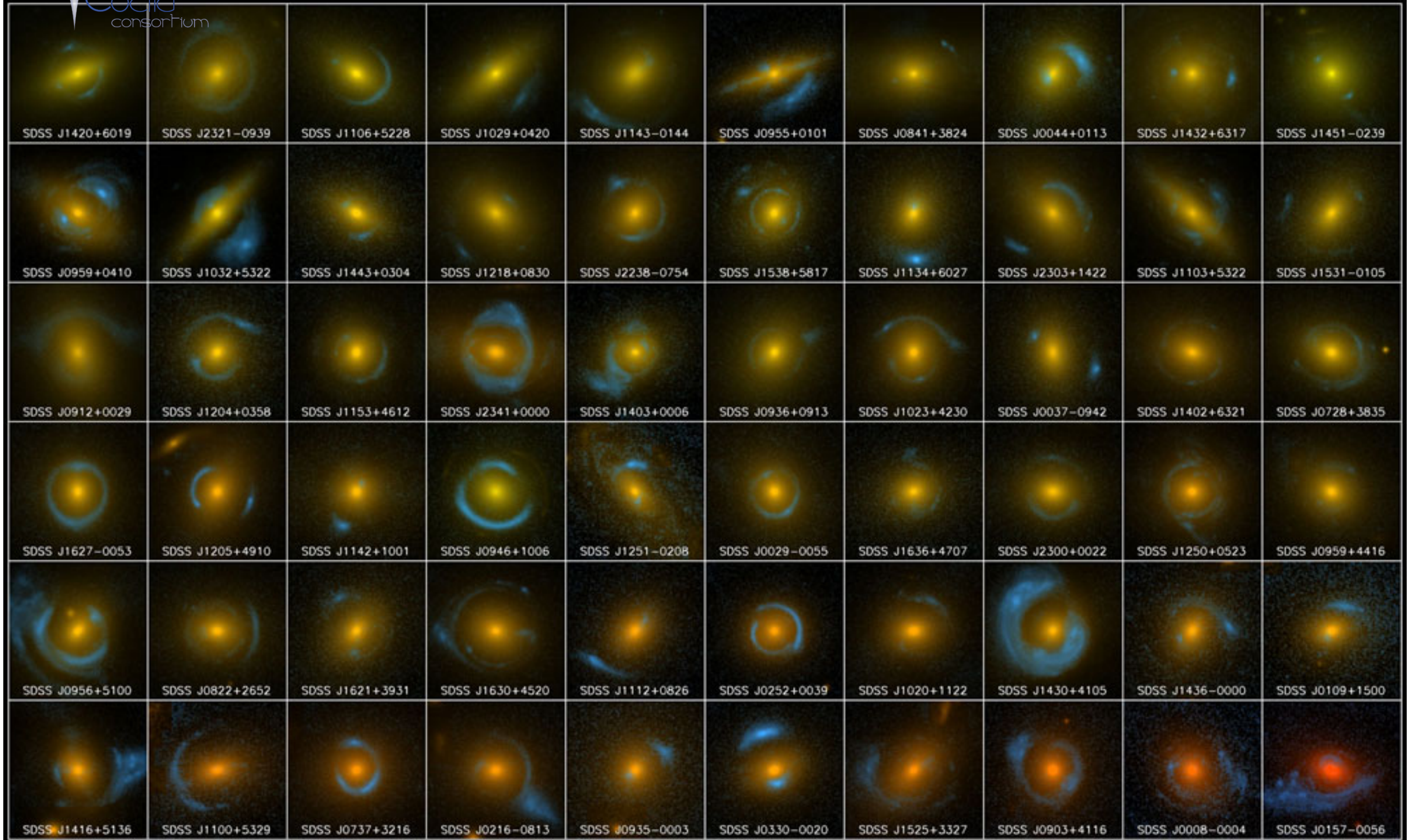
Euclid and the next generation wide field VIS/NIR surveys

Objects	Euclid	Before Euclid
Galaxies at 1 < z < 3 with precise mass measurement	~2x10^8	~5x10^6
Massive galaxies (1< z< 3)	Few hundreds	Few tens
Hα Emitters with metal abundance measurements at z~2-3	~ 4 10^7 ?	~10^4 ?
Galaxies in clusters of galaxies at z > 1	~1.8x10^4	~10^3 ?
Active Galactic Nuclei galaxies (0.7 < z< 2)	~10^4	<10^3
Dwarf galaxies	~10^5	
T_{eff} ~400K Y dwarfs	~few 10^2	<10
Lensing galaxies with arcs and rings	~150,000	~10-1000
Quasars at z > 8	~30	None



- Targets for JWST, E-ELT, TMT, Subaru, VLT, MSE, etc…
- Synergy with LSST, eROSITA, Subaru/HSC, WFIRST, Planck, SKA

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)

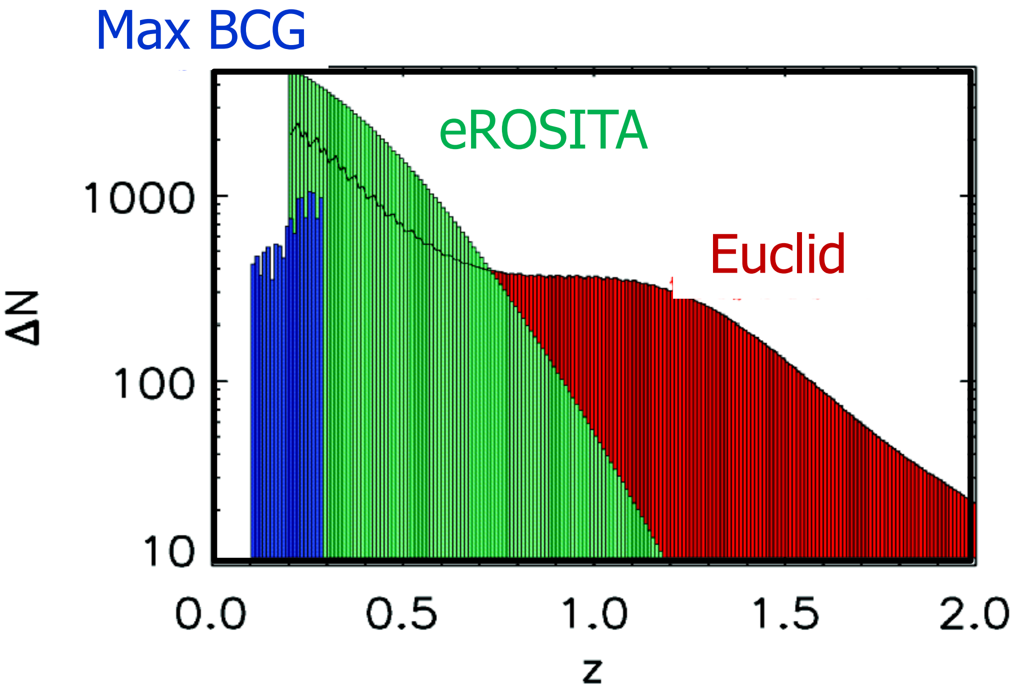
Image credit: A. Bolton, for the SLACS team and NASA/ESA


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

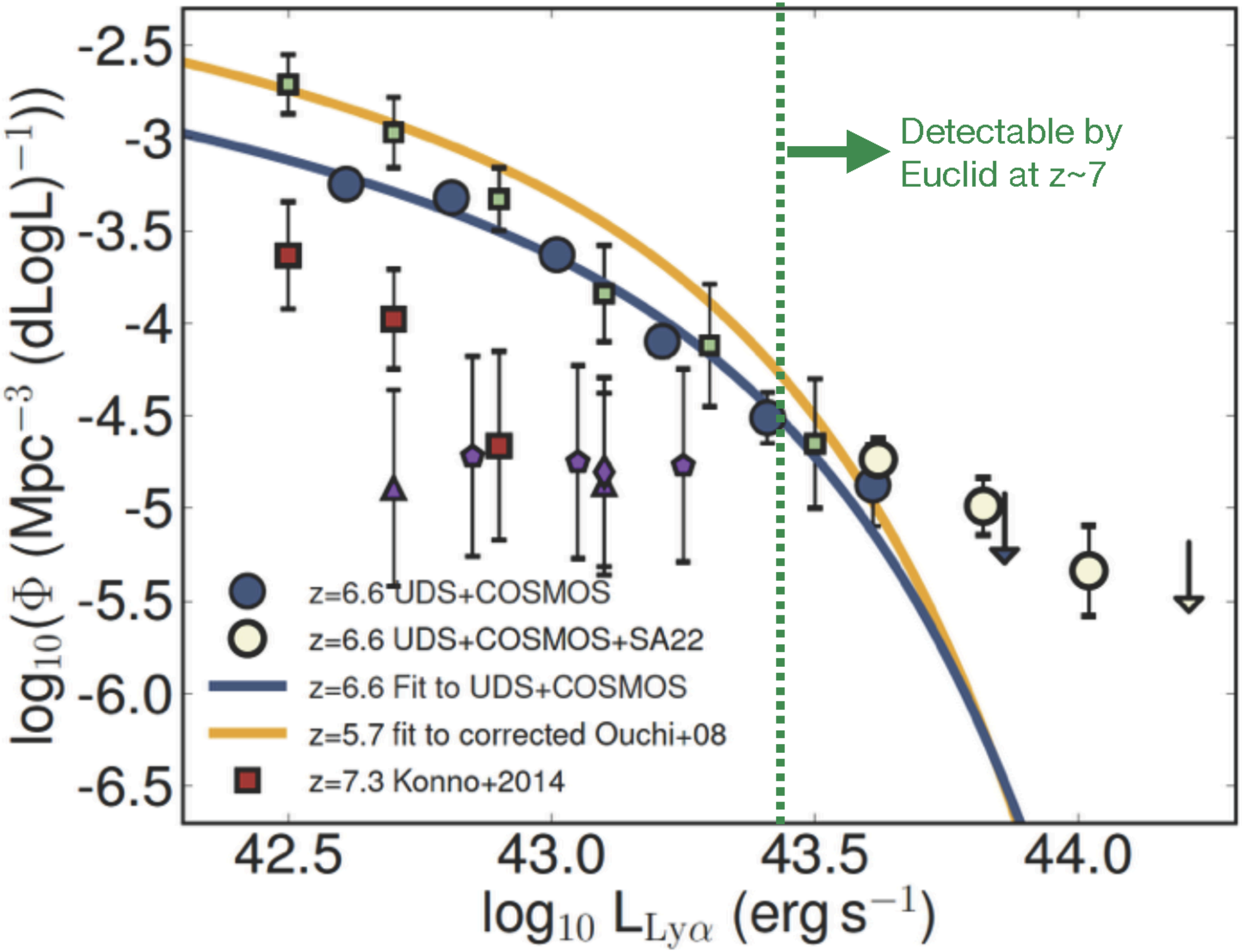
Clusters of galaxies with Euclid

- 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:
  - Λ-CDM: all clusters with M>2 .10^{14} Msol detected at 3-σ up to z=2
    - → 60,000 clusters with 0.2<z<2 ,
    - → 1.8 10^4 clusters at z > 1.
  - ~ 5000 giant gravitational arcs
    - → accurate masses for the whole sample of clusters
    - → dark matter density profiles on scales >100 kpc

→ Synergy with Planck and eROSITA

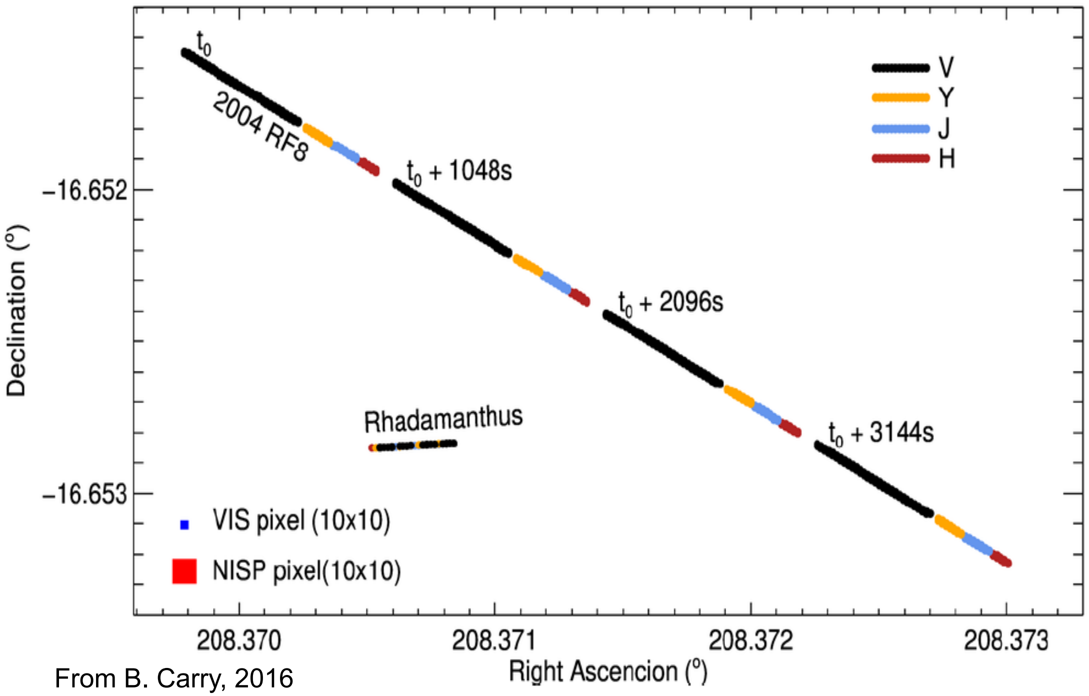


Prospect for detecting high-z Ly-a emitters



From Matthee et al (2015)

SSO: opportunities with Euclid

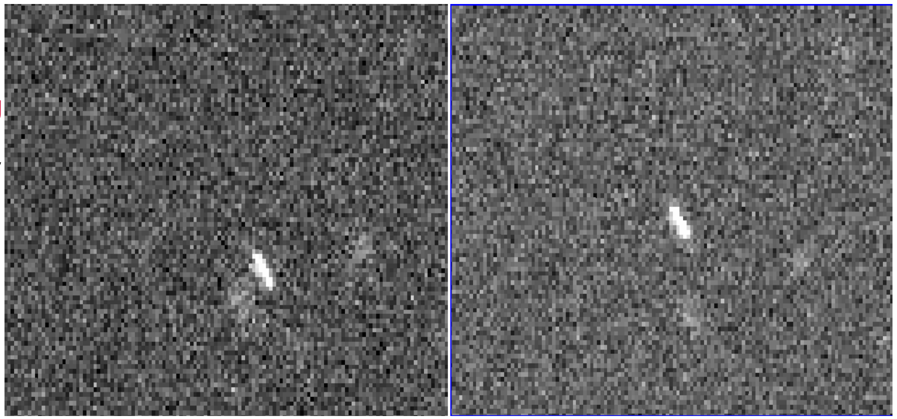


From B. Carry, 2016

VIS 23.5 mag

Simulation by

L. Conversi



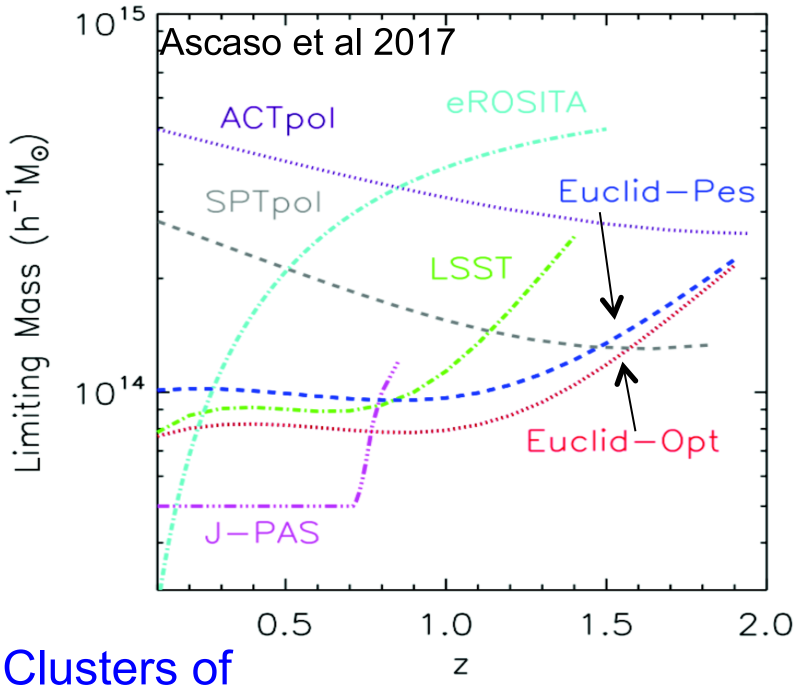
- **Detection of 1.9-3.5 ×10^5 of known SSOs in Euclid Wide**
- **Similar number of new SSOs expected**

- Stability and high resolution enables detection of:
  - multiple systems (~15% of total)
  - object activity
  - light curves

  → data to be combined with Gaia + LSST
- Unambiguous classification for most Euclid detections

- Propose and develop dedicated analysis procedures and algorithms→ coordination with EC SGS, possible integration in SDCs;
- Setting up ground based follow up (and define requirements) and collaborations;
- Technical + operational support from ESA;
- Involvement of other ESA missions (Gaia).

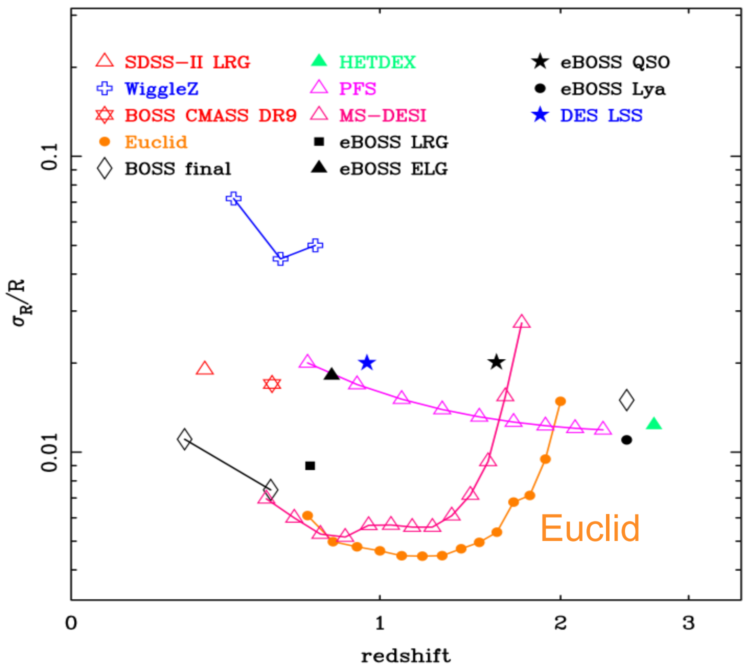
Euclid and competition

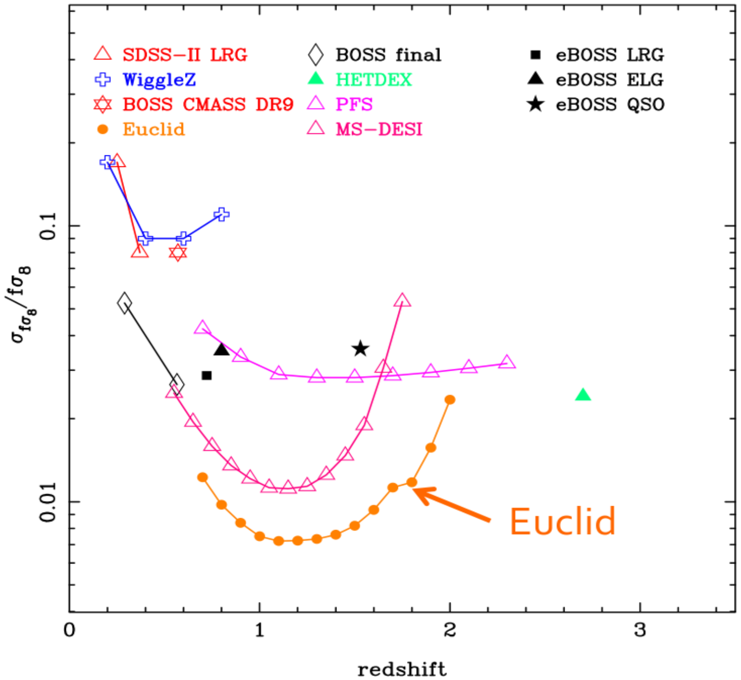


Clusters of galaxies:

WL masses

BAO: Euclid spectra

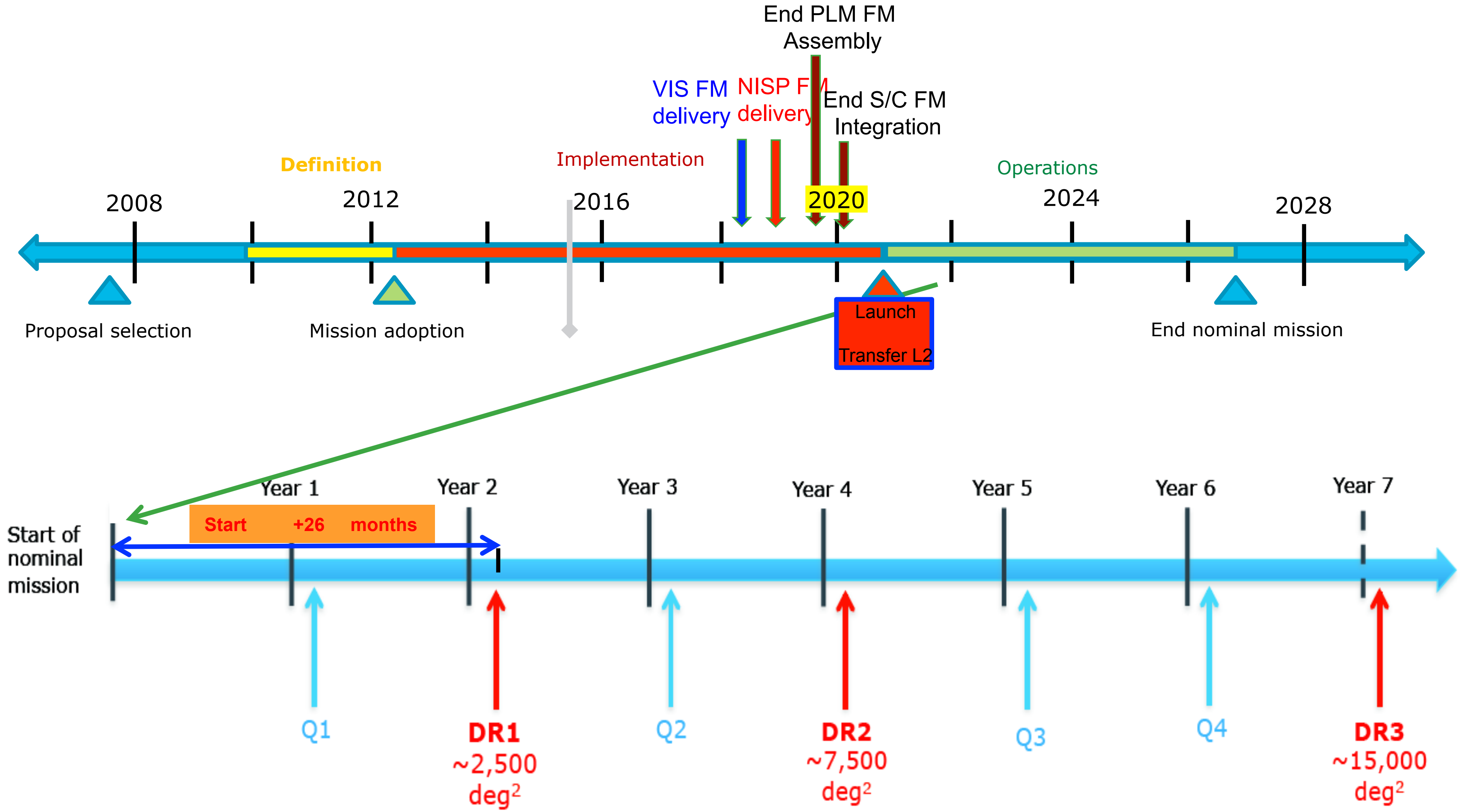




From Euclid SWG-GC group 2015

RSD: Euclid spectra

Mission Timeline and Data Releases



Science with Euclid will start in 2022 with Q1 and in 2023 with DR1

Summary

- Euclid cosmology core program:
  - Use 5 cosmological probes, with at least 2 independent, and 3 power spectra
  - Perfect complementarity with Planck: probes and data, cosmic periods
  - Explore the dark universe: DE, DM (neutrinos), MG, inflation, biasing, baryons
  - Explore the transition DM-to-DE-dominated universe period
  - Get the percent precision on w and the growth factor γ
  - Synergy with New Gen wide field surveys: LSST, WFIRST, e-ROSITA, SKA
  - 140,000 strong lenses → DM haloes of galaxies, galaxies, groups, clusters
- Euclid =12 billion sources, 35 million redshifts, 1.5 billion shapes/photo-z of galaxies;
  - 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+
- Big challenges: data processing (100-300 Petabytes), cosmological simulations
- Launch 2020, start 2021: **2500 deg^2 public in 2023**, 7500 deg^2 in 2025, final 2027