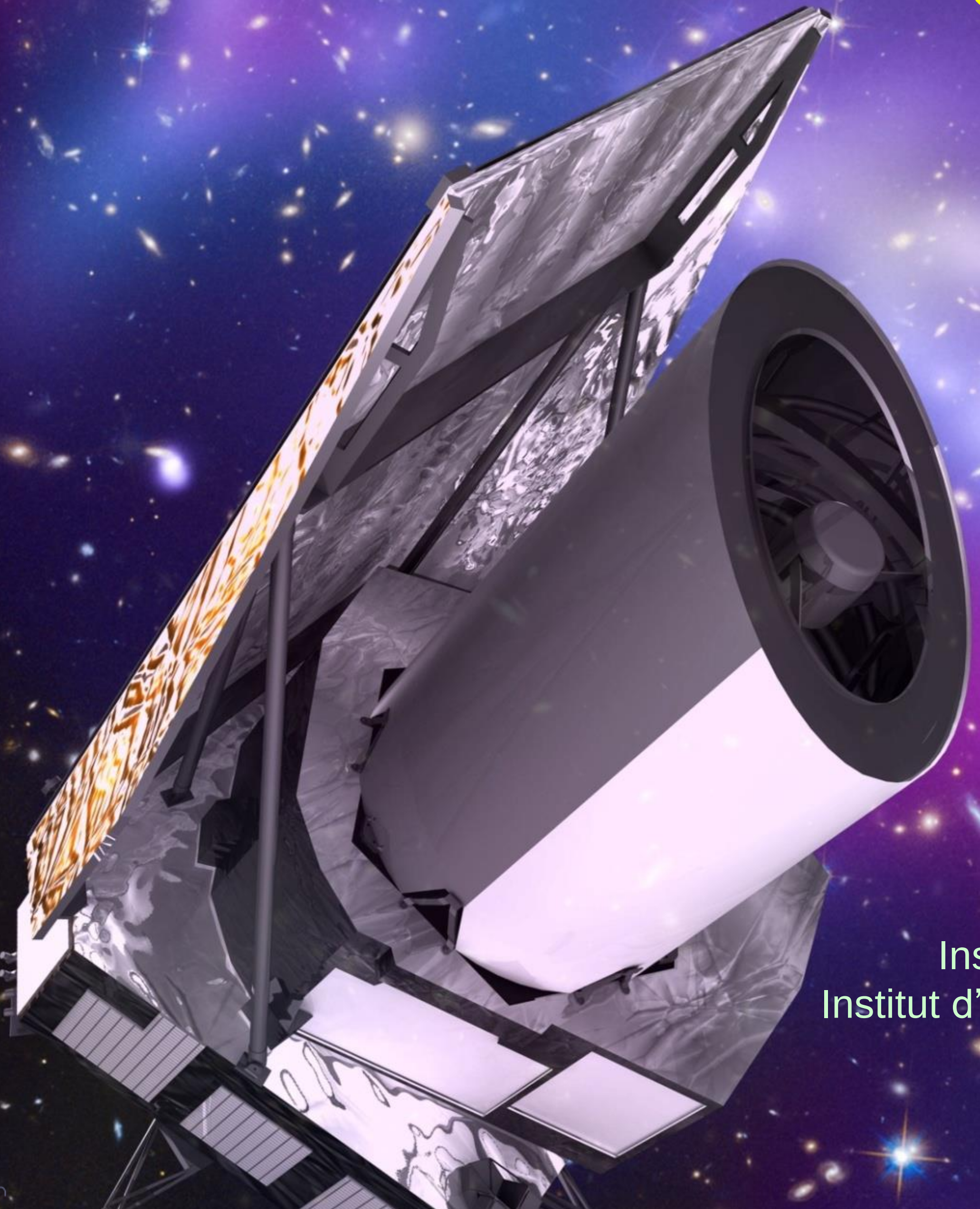
Euclid: ESA Cosmology Mission

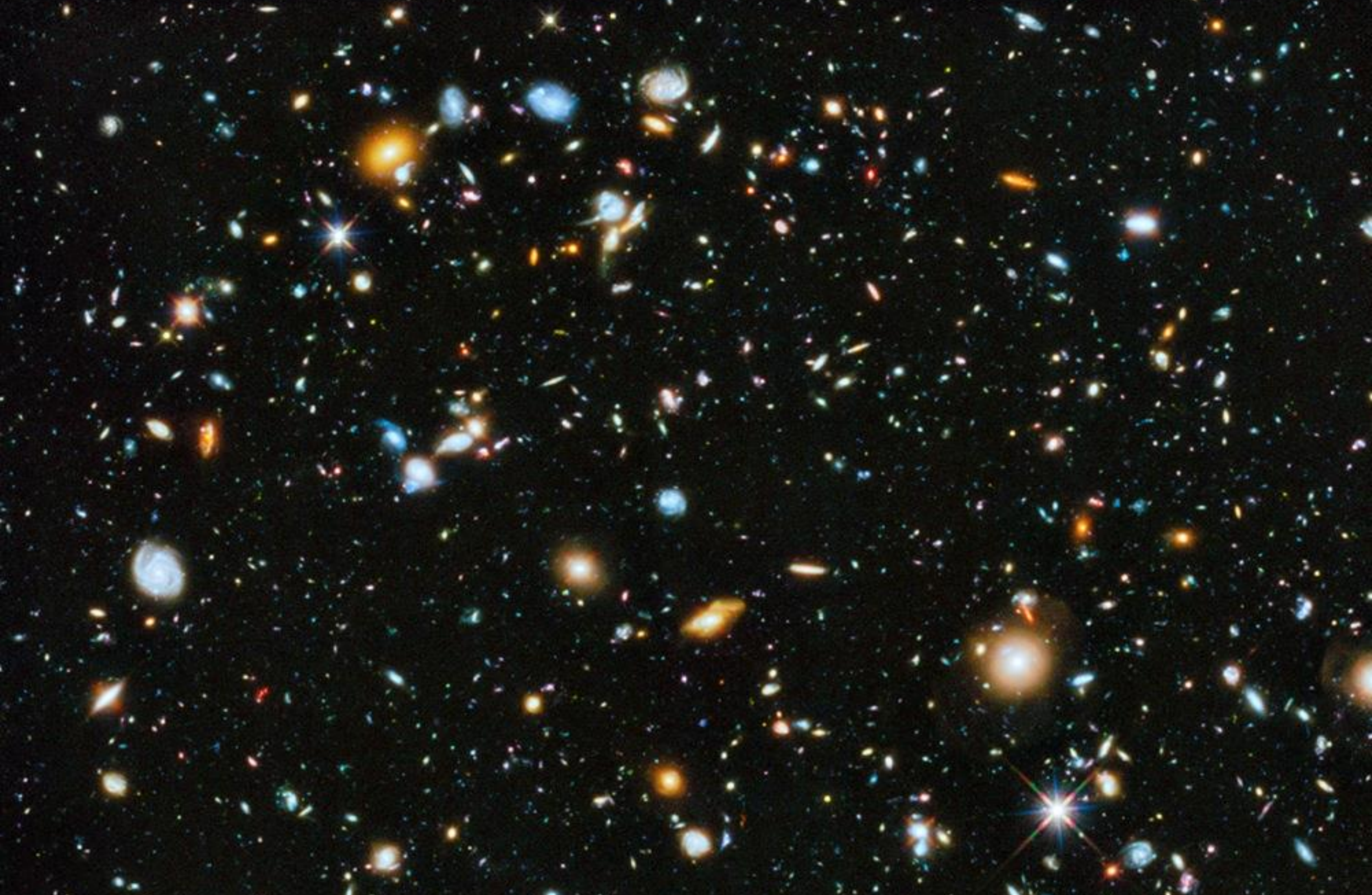


F.J. Castander
on behalf of the Euclid Consortium
www.euclid-ec.org

Institut de Ciències de l'Espai (ICE-CSIC)
Institut d'Estudis Espacials de Catalunya (IEEC)

Outline

- Introduction to modern cosmology
- Euclid
  - Overview and current status
  - Simulations
  - Performance & forecasts
  - Legacy Science
  - Schedule
  - Summary



Cosmology

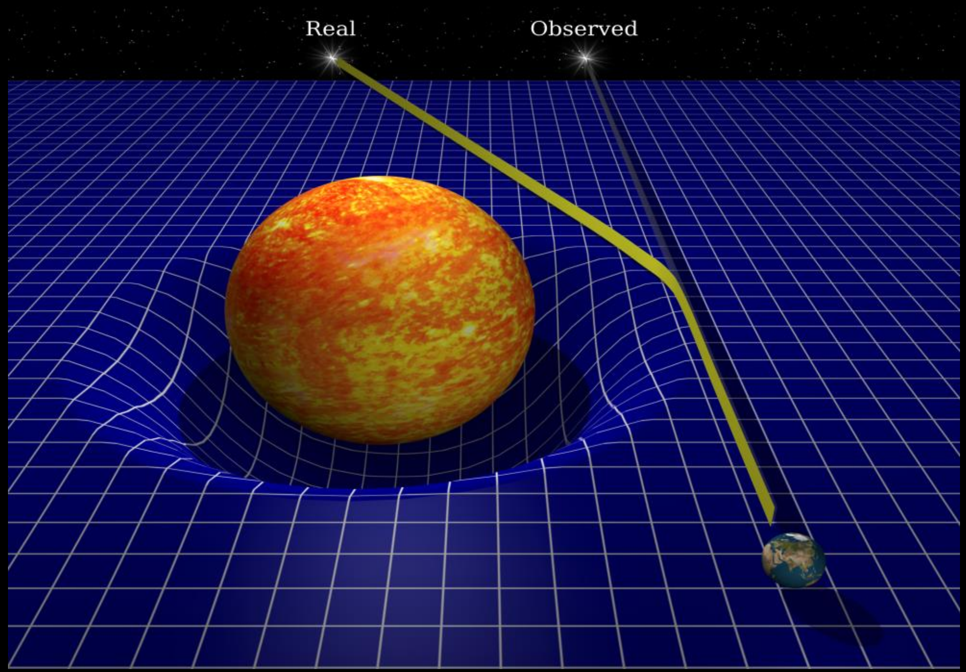
- Description of the Universe as a whole, studying its origin, evolution and eventual fate
  - How is the Universe?
  - What is it made of?
  - How does it evolve?
- Modern Cosmology based on two pillars
  - Theory of General Relativity
  - Cosmological Principle

Theory of General Relativity

A key concept of the theory of General Relativity is that gravity is not described by a gravitational “field” but it is a distortion of space-time. “Spacetime tells matter how to move; matter tells spacetime how to curve” (John Wheeler)

$$R_{\mu\nu} = -8\pi G T_{\mu\nu}$$

Geometry ⟺ Matter



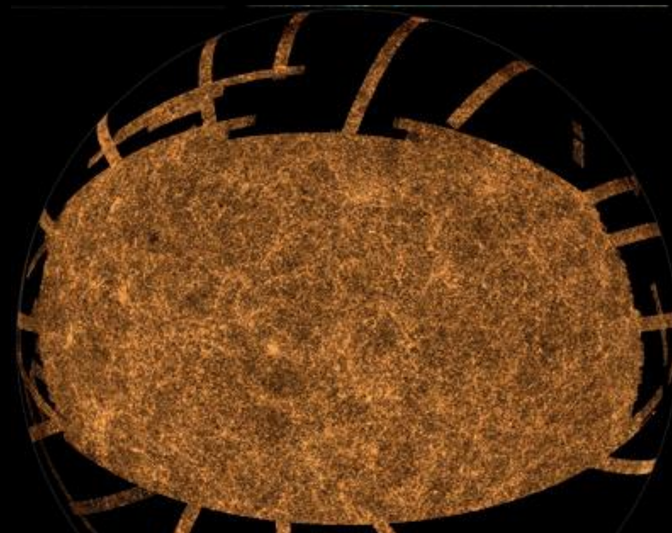
Originally, the theory explained the pecularities of the orbit of Mercury and the curvature of light near the Sun, both unexplained by Newton’s theory. Since then, GR has passed several rigorous tests and validations

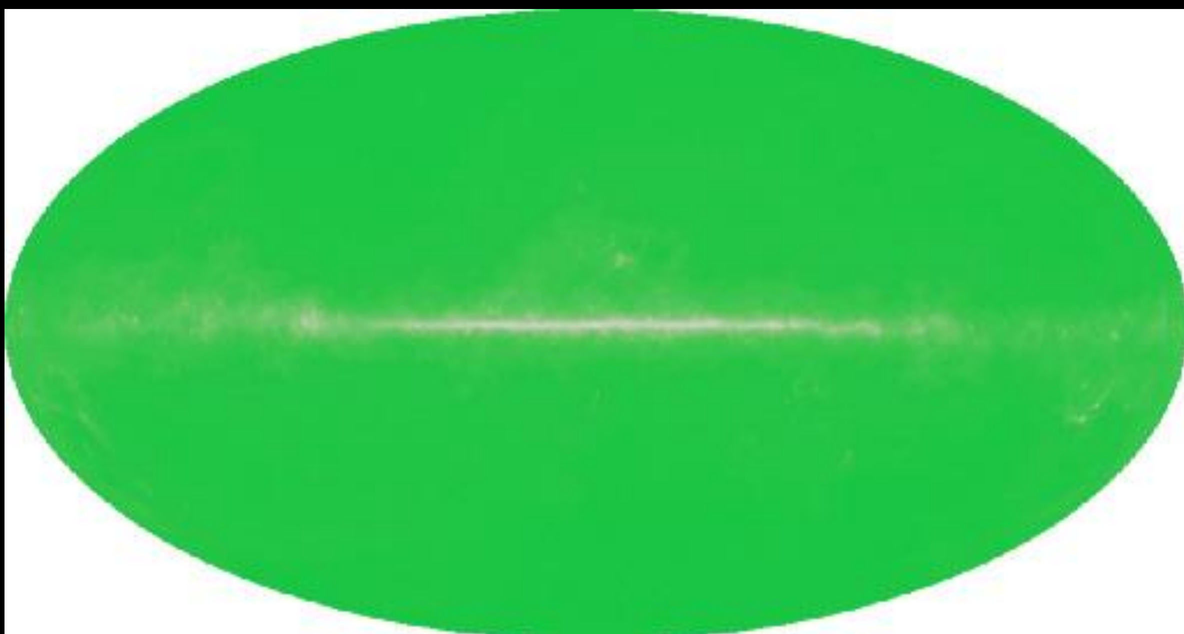
Cosmological Principle

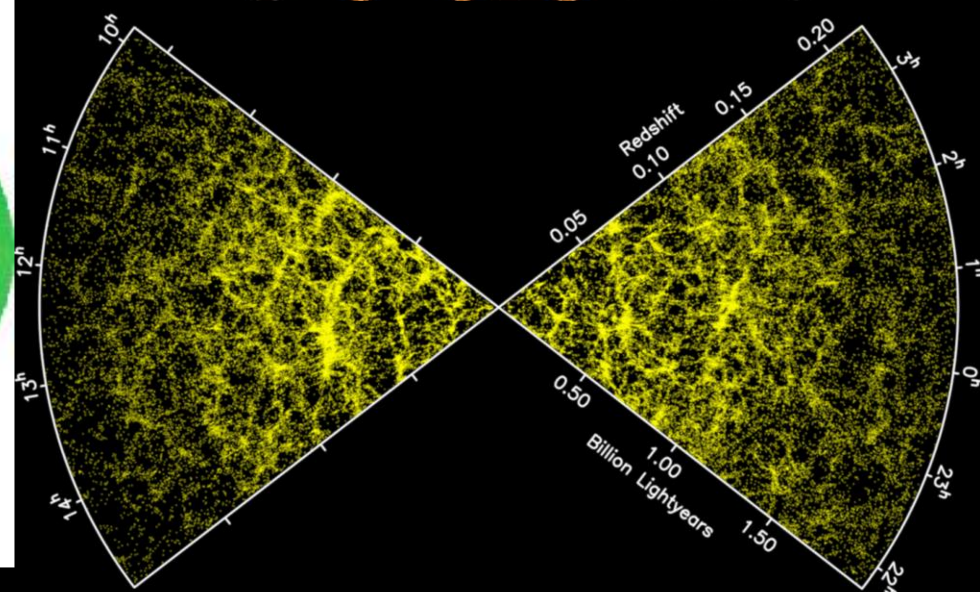
Viewed on a sufficiently large scale, the properties of the universe are the same for all observers

The universe is homogeneous and isotropic

The laws of physics are the same everywhere





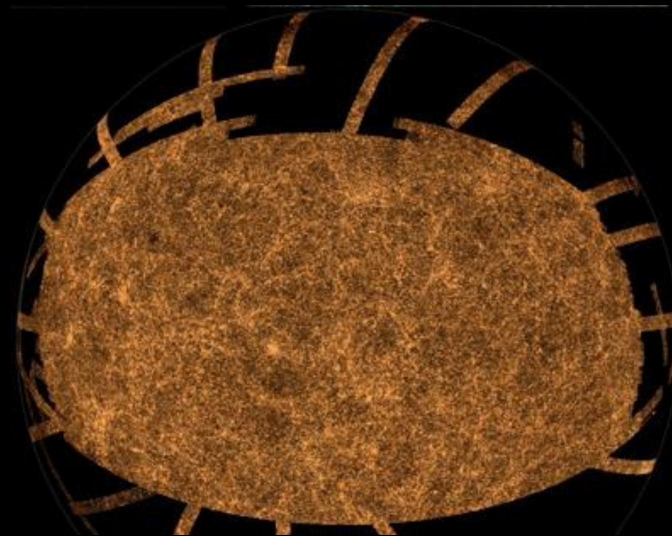


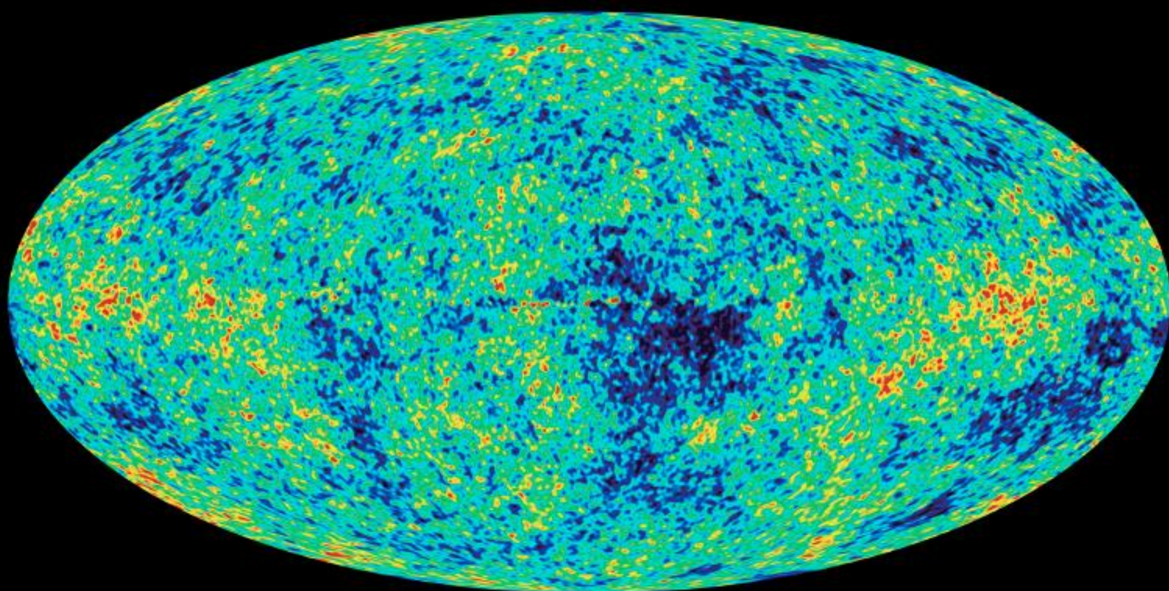
Cosmological Principle

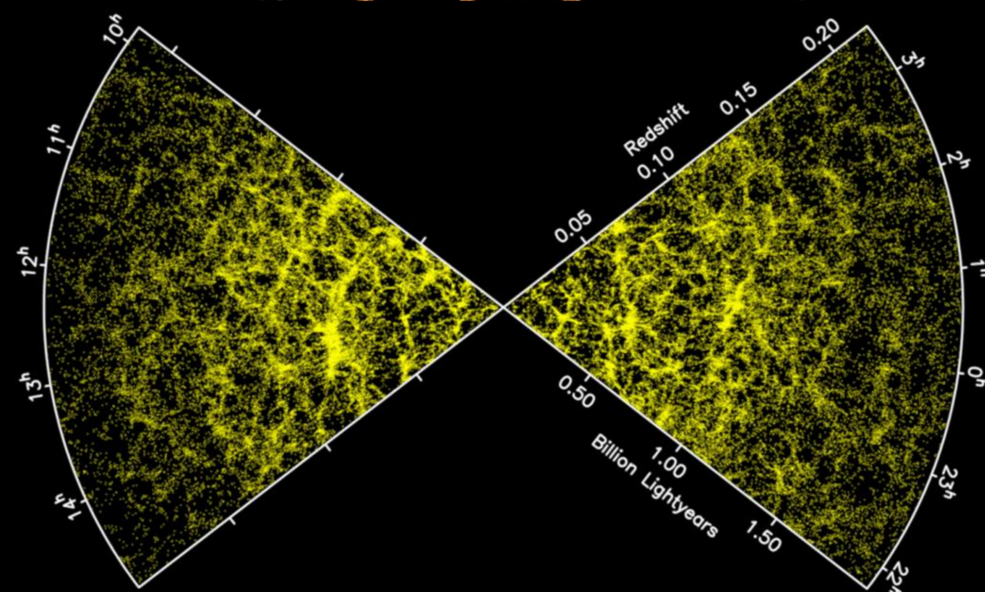
Viewed on a sufficiently large scale, the properties of the universe are the same for all observers

The universe is homogeneous and isotropic

The laws of physics are the same everywhere





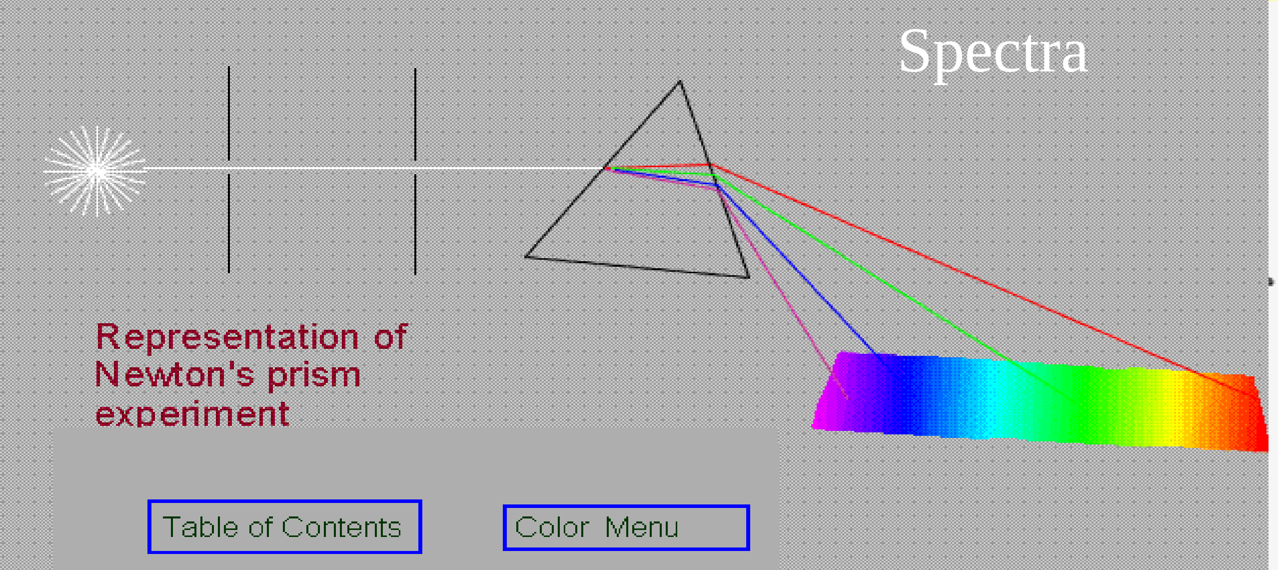


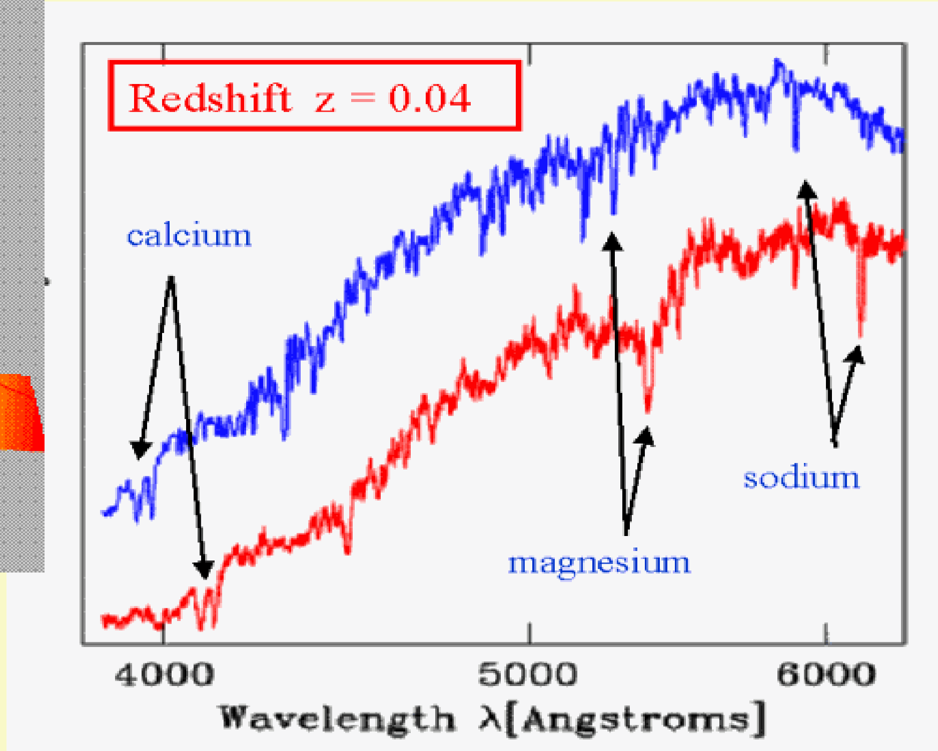
Theoretical Cosmology

General Relativity and Cosmological Principle

The combination of the theory of General Relativity and the Cosmological Principle allows us to study the universe as a whole. A surprising consequence is that the universe should expand or contract: the matter-energy content of the universe responds to gravity and precludes it from being static

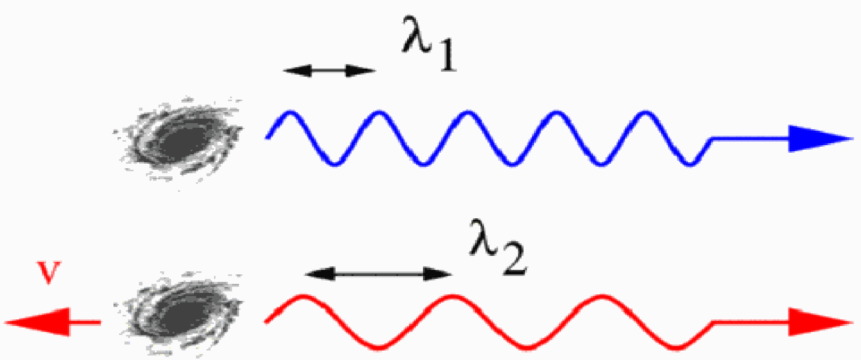
At the time of the formulation of GR (1915) the universe was thought to be static and therefore this implication was against the established belief. Einstein changed his theory to include a cosmological constant (which could be Dark Energy)





The expanding universe

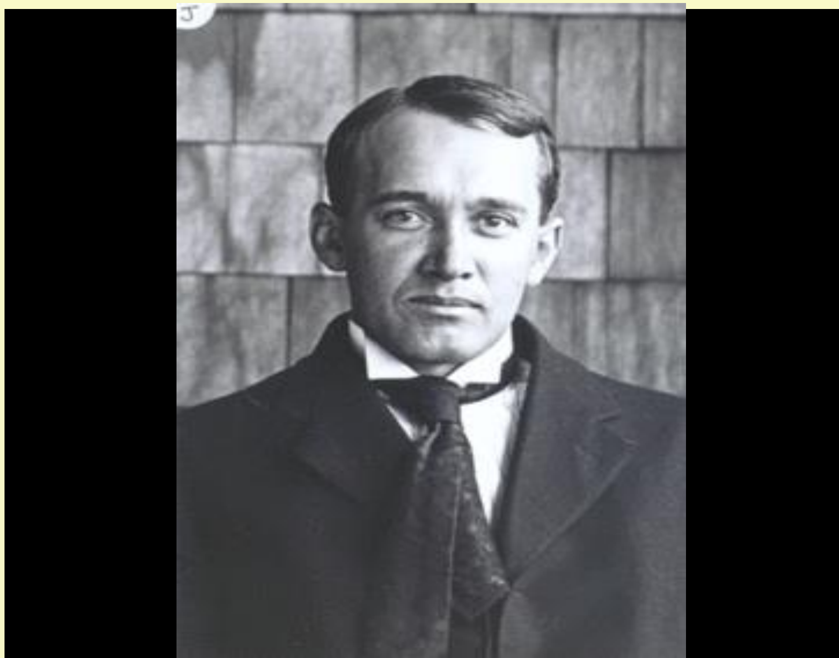
1912 - 1920s: Slipher finds most galaxies are redshifted

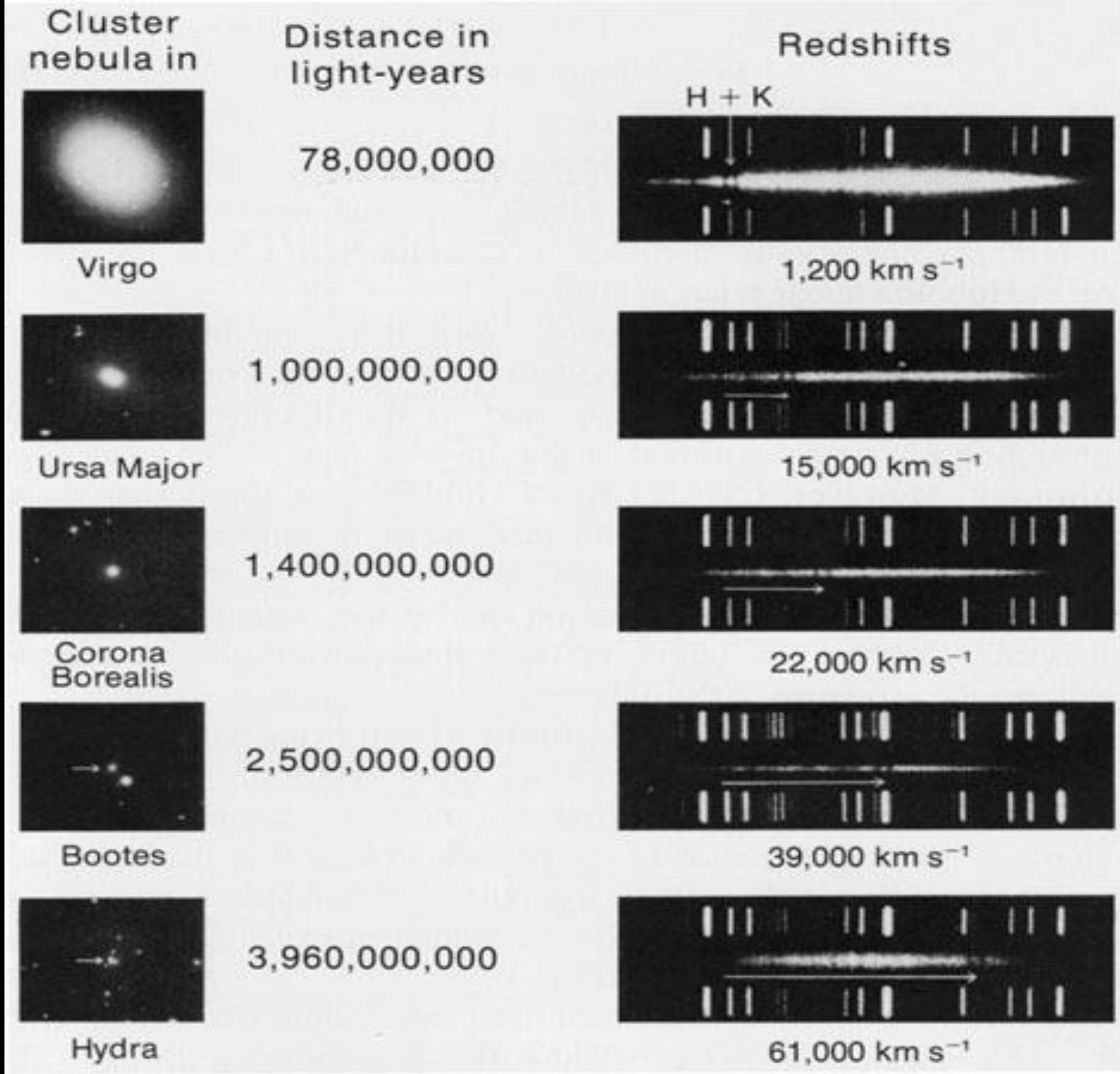


Vesto Slipher (1875 - 1969)

$$1 + z = \frac{\lambda_2}{\lambda_1} \simeq 1 + \frac{v}{c}$$

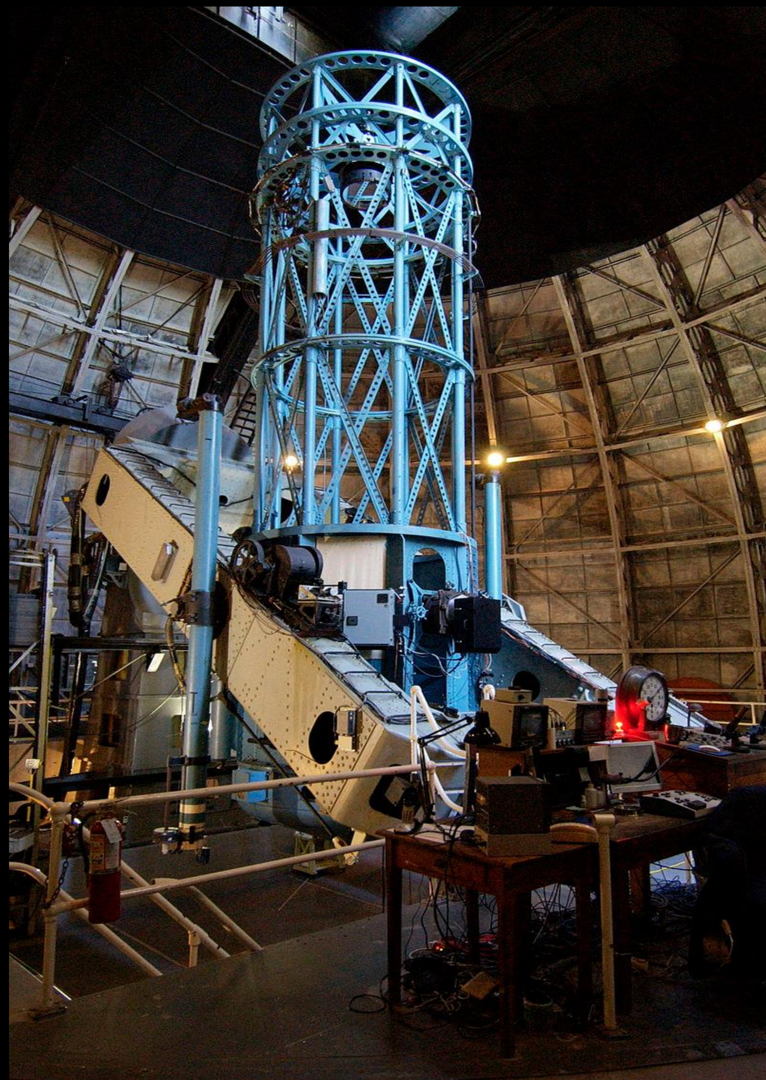
The Doppler (red)shift




Cluster nebula in
Distance in light-years
Redshifts
H + K
Virgo
78,000,000
1,200 km s⁻¹
Ursa Major
1,000,000,000
15,000 km s⁻¹
Corona Borealis
1,400,000,000
22,000 km s⁻¹
Bootes
2,500,000,000
39,000 km s⁻¹
Hydra
3,960,000,000
61,000 km s⁻¹

Observational Cosmology

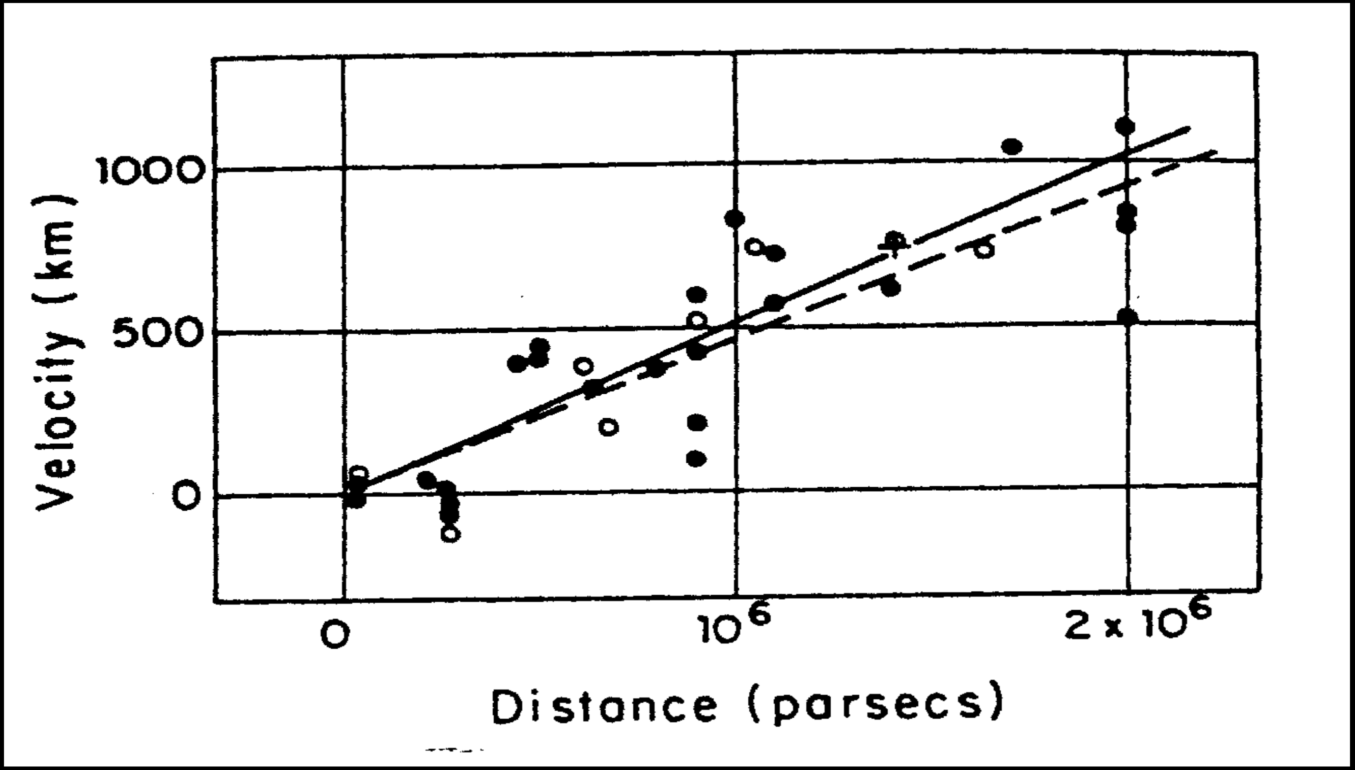
The expanding universe



In 1929, Edwin Hubble announced that their observations of galaxies outside the Milky Way were systematically moving away from us at a speed proportional to their distance. The furthest a galaxy was, the fastest it was separating from us. Hubble observed that the light from the galaxies he observed was shifted more to the red the furthest it was from us

Observacional Cosmology

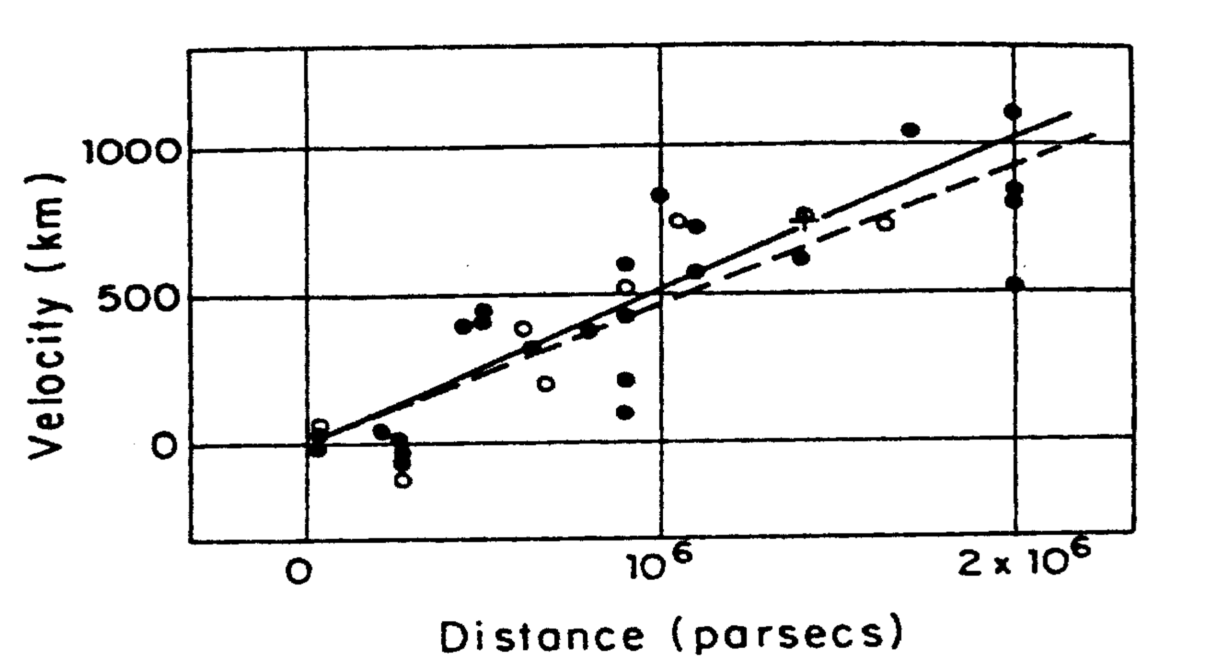
The expanding universe

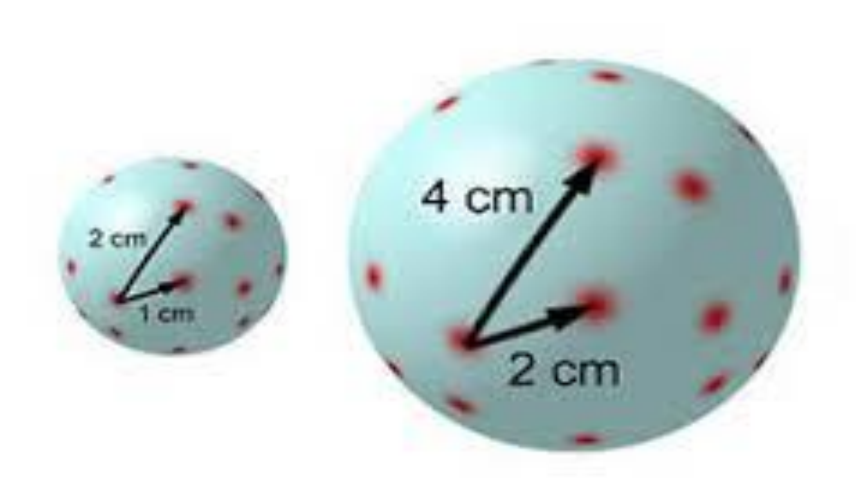


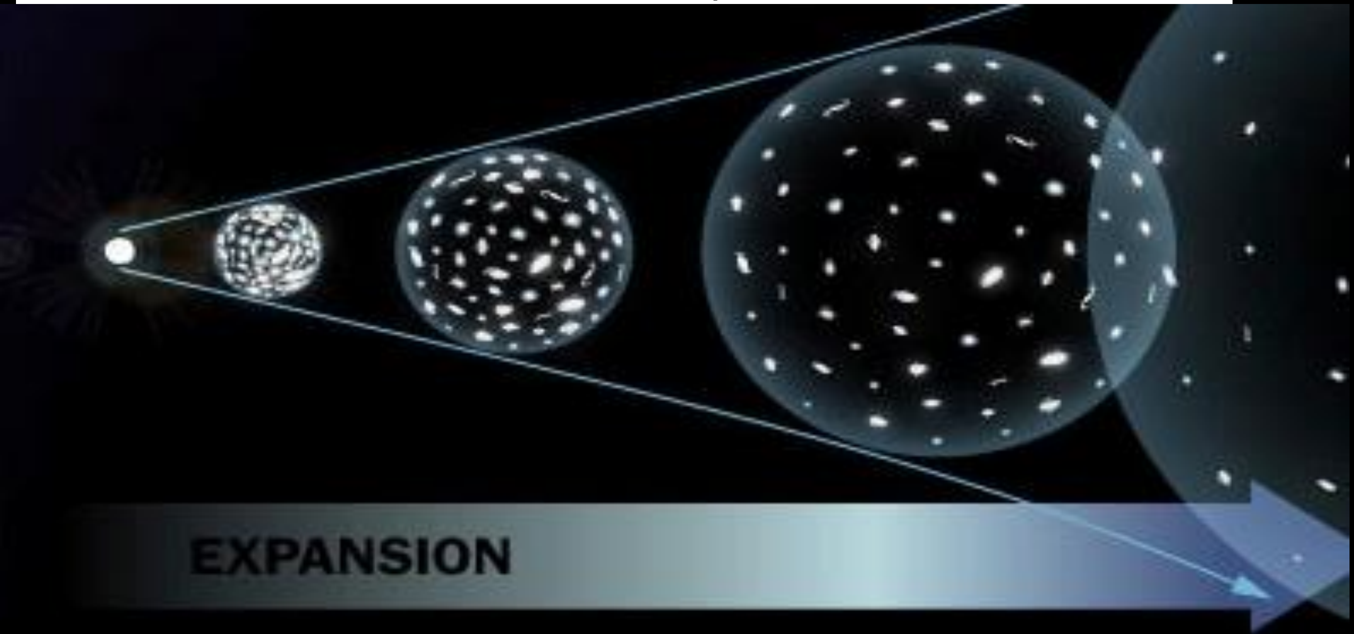
In 1929, Edwin Hubble announced that their observations of galaxies outside the Milky Way were systematically moving away from us at a speed proportional to their distance. The furthest a galaxy was, the fastest it was separating from us. Hubble observed that the light from the galaxies he observed was shifted more to the red the furthest it was from us

Observational Cosmology

The expanding universe







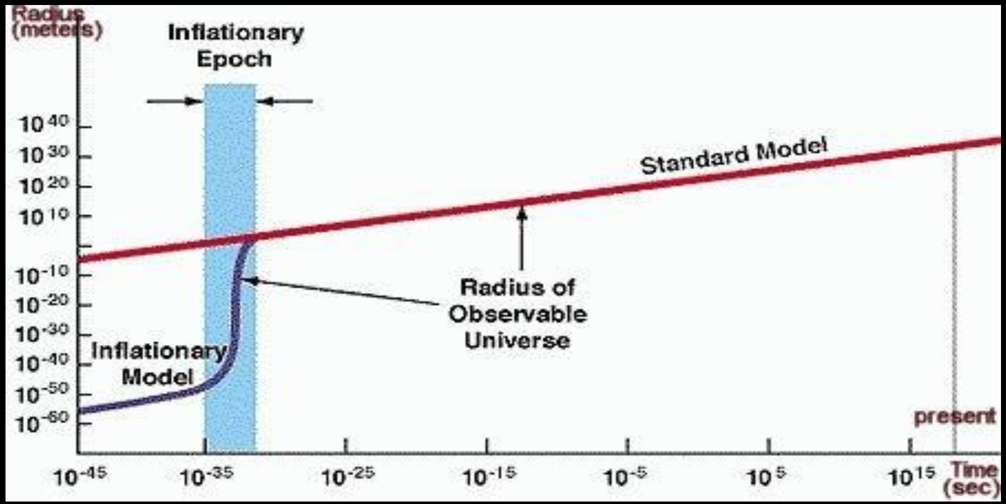
The universe was expanding, as the theory of General Relativity had originally predicted! Einstein then considered the introduction of the cosmological constant his biggest blunder

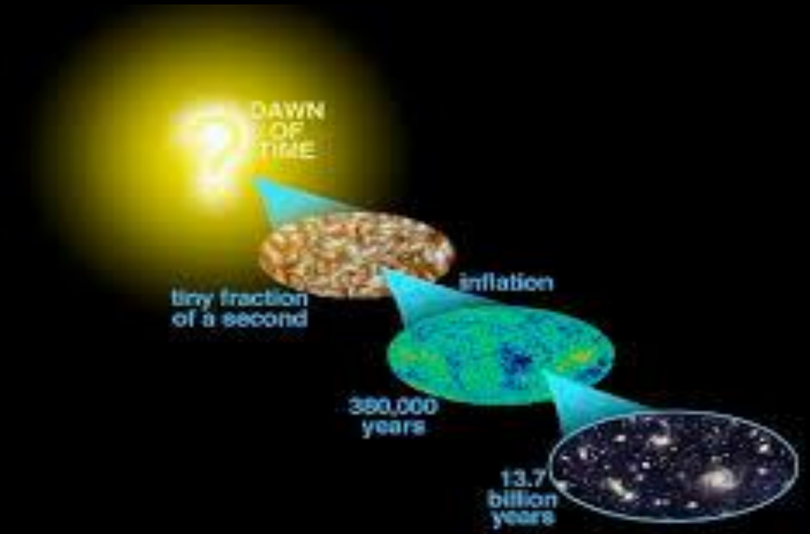
The evolution of the universe: inflation

Moments after the Big Bang (10^{-34} s), the universe experienced a brief period of accelerated expansion known as inflation

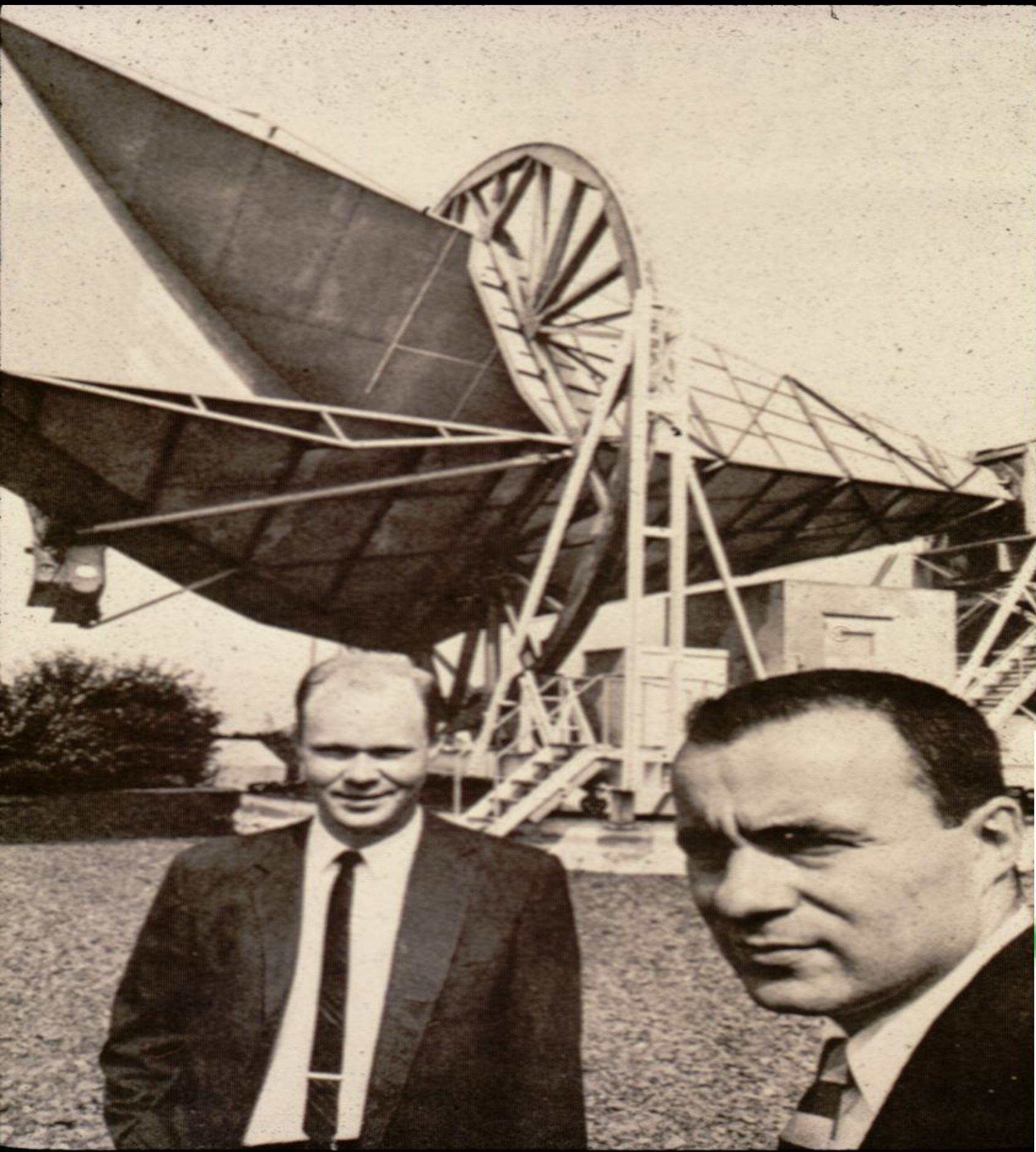
Quantum fluctuations generated during this inflationary epoch are the seeds of primordial fluctuations in the density of the universe (10^{-5} at the epoch of decoupling)

Alan Guth

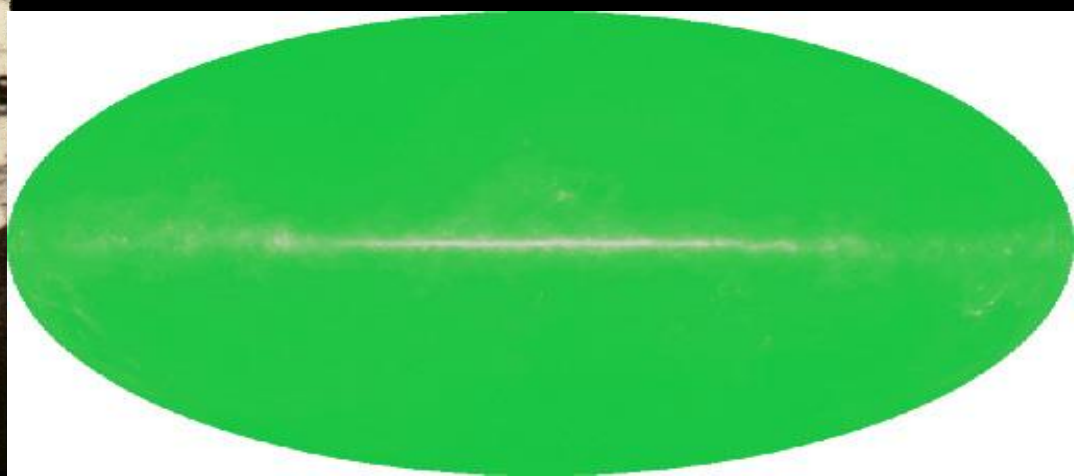




The evolution of the universe: the cosmic background radiation



Penzias and Wilson discovered the Cosmic Microwave Background (CMB) Radiation in 1965
Detected as a noise that they could not understand

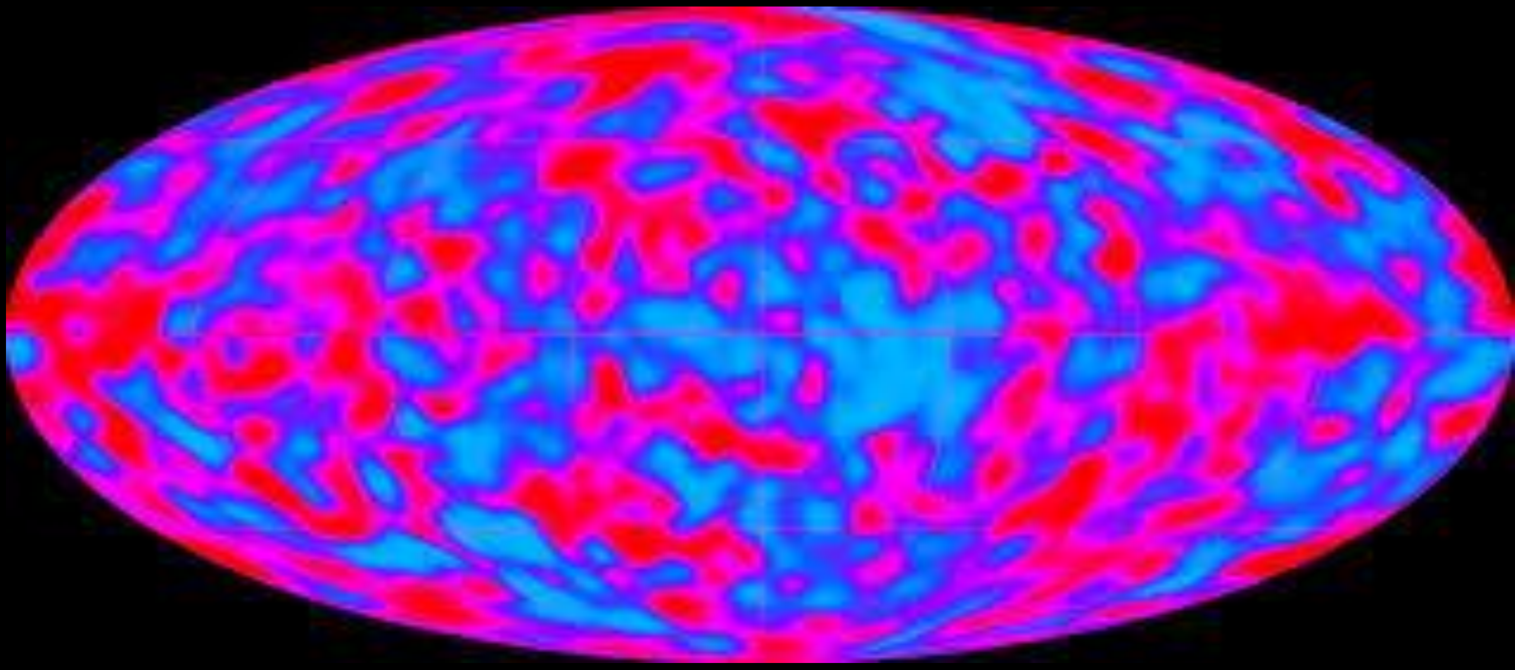


The evolution of the universe: structure formation

In 1992 the NASA satellite COBE detected these fluctuations in the Cosmic Microwave Background Radiation

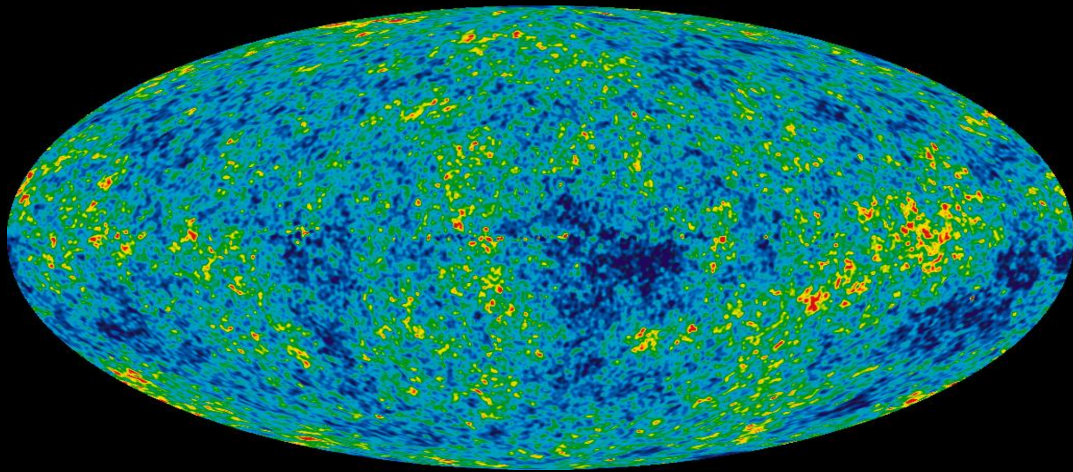
George Smoot

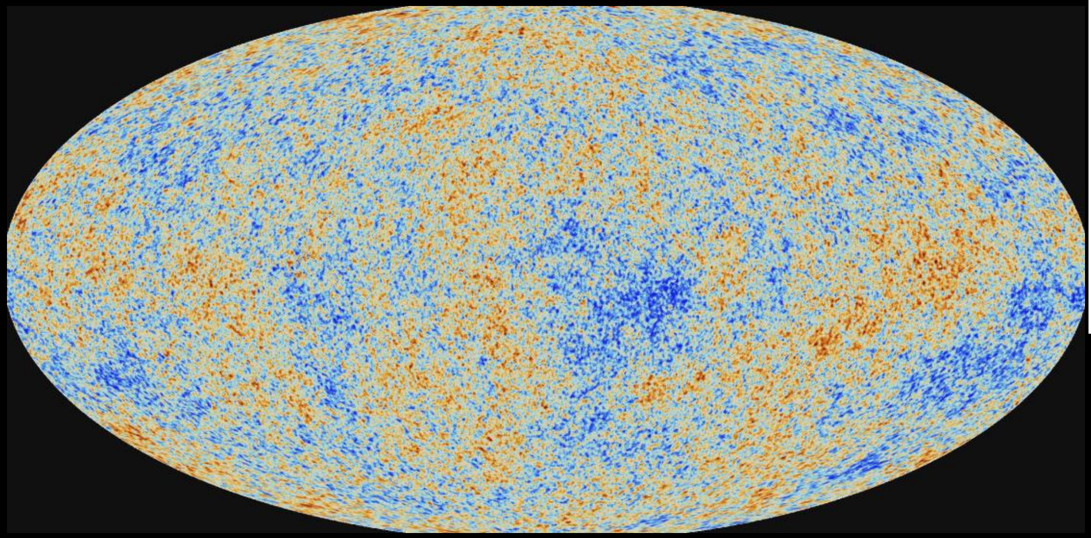
John Mather

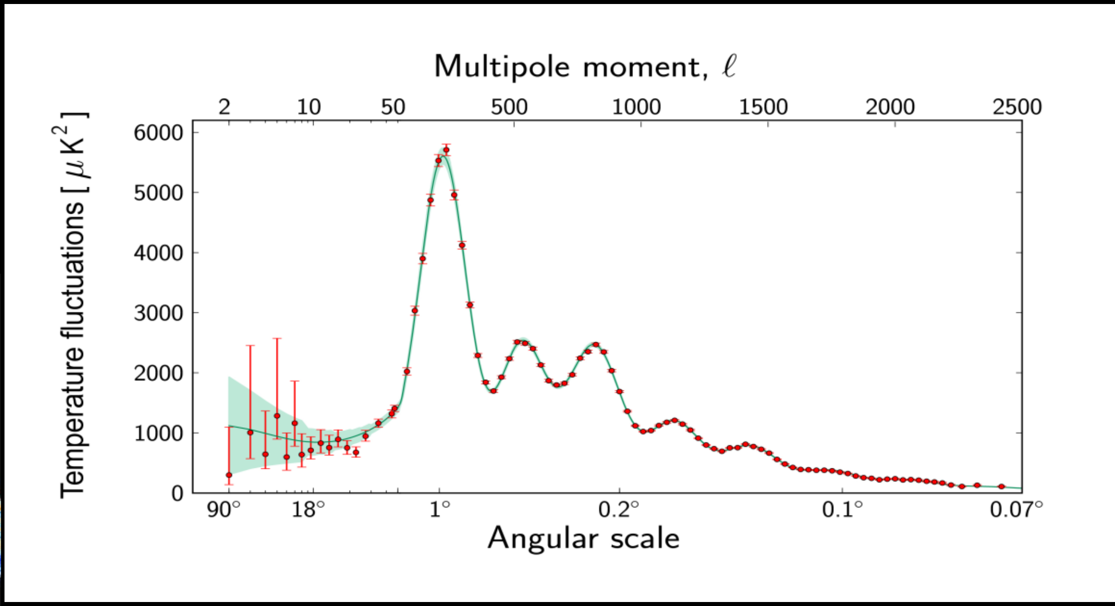


The evolution of the universe: structure formation

In 2003 the NASA satellite WMAP and recently the ESA satellite Planck have measured this fluctuations with high accuracy







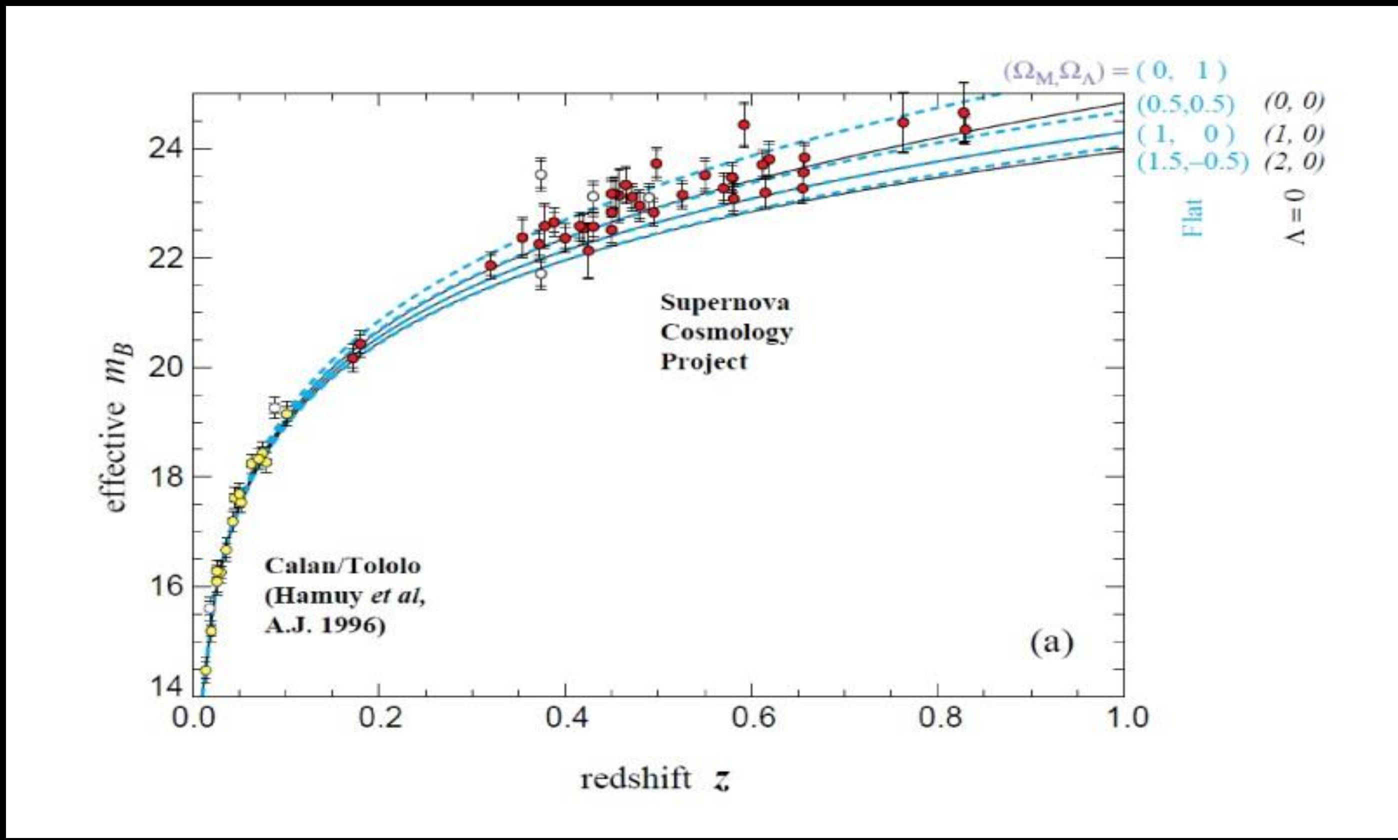
The evolution of the universe: structure formation

The primordial fluctuations grow due to gravity and form the structures we see today (galaxies and stars)

The evolution of the universe: accelerated expansion

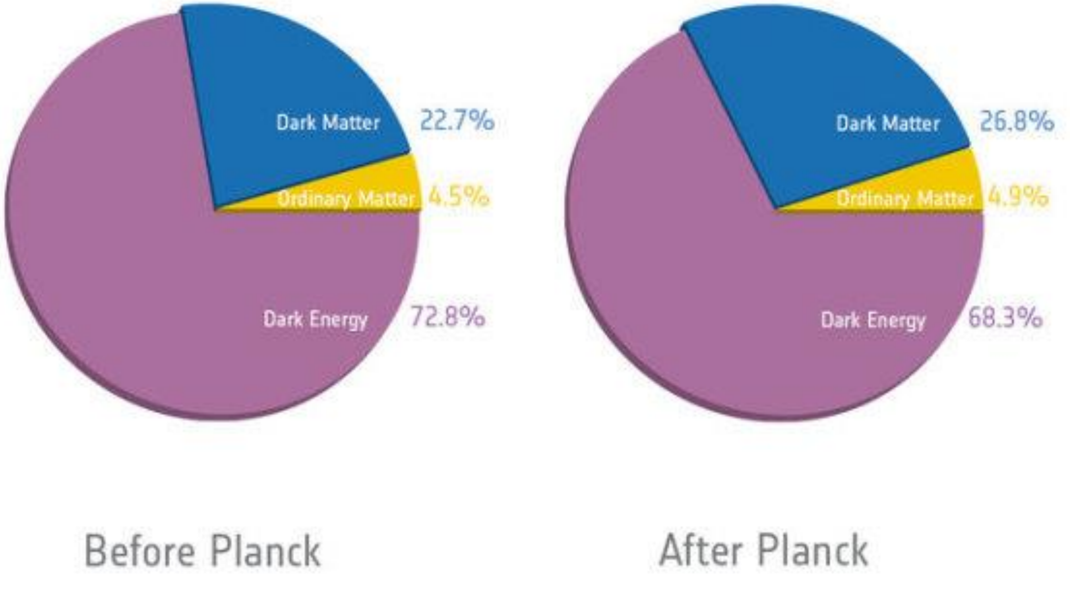
The measurement of supernovae explosions in 1998 confirmed that the universe was expanding faster and faster

We ignore the cause of this accelerated expansion and call it dark energy



Questions in Cosmology

- What is the physical cause of cosmic acceleration?
  - Dark Energy or modification of General Relativity?
    - If Dark Energy, is it Λ (the vacuum) or something else?
      - What is the DE equation of state parameter *w*?



Probing Cosmology

- Cosmology is probed mainly measuring the expansion rate of the universe H(z), the rate growth of structure g(z)

$$H^2(z) = H^2_0 \; [\; \Omega_M (1+z)^3 + \Omega_R (1+z)^4 + \Omega_K (1+z)^2 + \Omega_{DE} (1+z)^{3(1+w)} \;]$$

matter radiation curvature dark energy

g(z) in general a complicated function of cosmological parameters

Probing Cosmology

- Geometric test: integrals over H(z):

Comoving distance		$r(z) = \int dz/H(z)$
Standard Candles	Supernovae	$D_L(z) = (1+z)\, r(z)$
Standard Rulers	Baryon Oscillations	$D_A(z) = (1+z)^{-1}\, r(z)$
Standard Population	Clusters	$dV/dzd\Omega = r^2(z)/H(z)$

- Growth of Structure test: g(z)

Clusters, Weak lensing, clustering, redshift space distortions

- Matter distribution: P(k,z)

Galaxy clustering, weak lensing

Dark Energy Task Force

Best observational probes

- Weak lensing (geometrical & growth)
- Baryon acoustic oscillations (geometrical)
- Supernovae (geometrical)
- Clusters of galaxies (growth & geometrical)

Requirements for cosmology survey

- sample large volumes
- sample enough (many) objects
- measure distances
- measure shapes
- time sampling

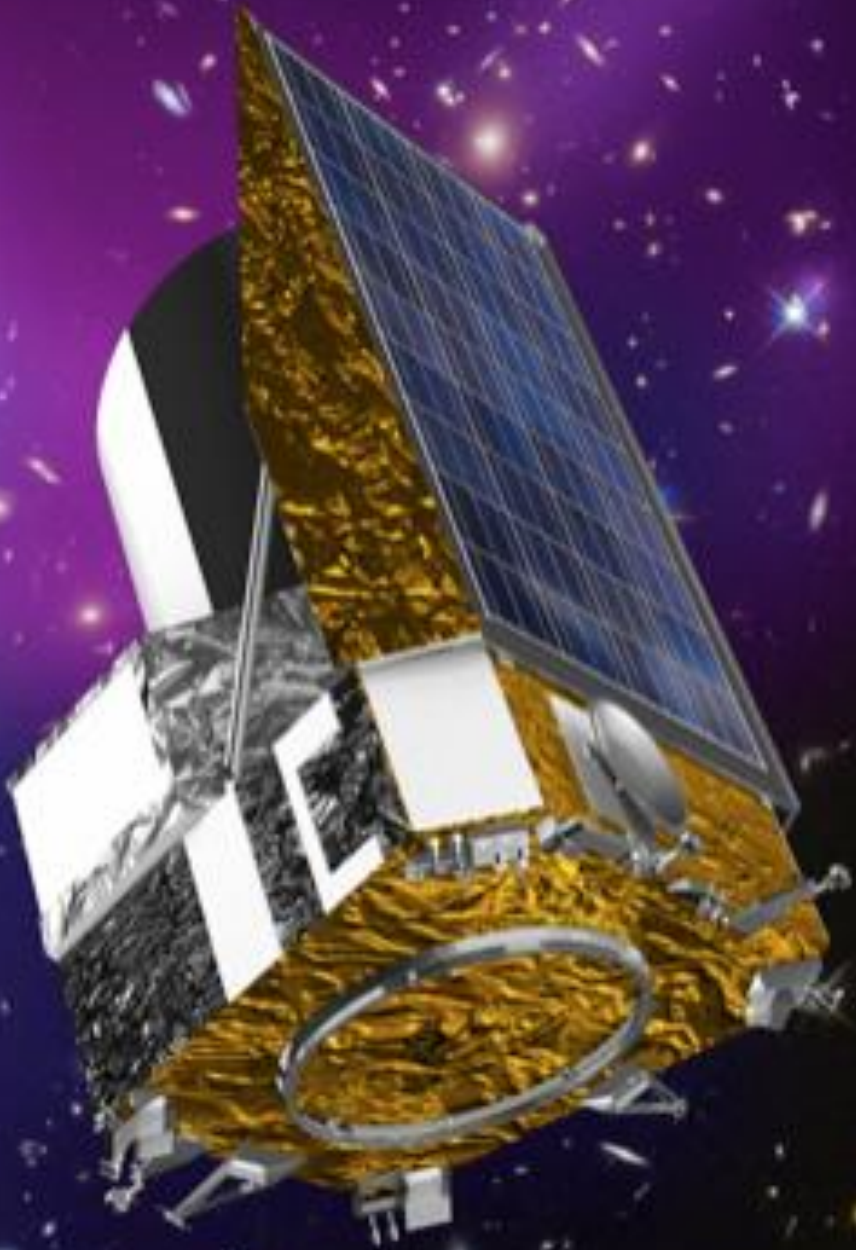
Dark Energy Task Force

Survey design optimization: Figure of Merit

- Inverse of the marginalized errors
- Higher FoM => smaller errors
- Fisher matrices approach

Euclid

- Cosmology mission to study the accelerated expansion of the universe aka dark energy
- Selected by ESA on October 4th 2011
- Adopted June 19th 2012
- M class mission
- M2 launch slot
- launch Q4 2022



Euclid:
Overview and current status

Euclid Science Objectives

Issue	Euclid's Targets
What is Dark Energy	**Measure the Dark Energy equation of state parameters** w_p and w_a to a precision of 2% and 10%, respectively, using both expansion history and structure growth.
Test Gravity	**Distinguish General Relativity from modified-gravity theories**, by measuring the galaxy clustering growth factor exponent γ with a precision of 2%.
The nature of dark matter	**Test the Cold Dark Matter paradigm** for structure formation, and measure the sum of the neutrino masses to a precision better than 0.04eV when combined with Planck.
The seeds of cosmic structure	**Improve by a factor of 20 the determination of the initial condition parameters** compared to Planck alone. n (spectral index), σ_8 (power spectrum amplitude), f_{NL} (non-gaussianity)

Euclid Top Level Science Requirements

Sector	Euclid Targets
Dark Energy	• Measure the cosmic expansion history to better than 10% in redshift bins $0.9 < z < 1.8$ • 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
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: $f \sim \Omega^{\gamma}$;
- $FoM = 1/(\Delta w_a \times \Delta w_p) > 400 \rightarrow$ ~1% precision on w's.

Euclid Consortium Institutions

RWTH Aachen University
Aalto University School of Science
Aarhus University
Suomen Akatemia Finlands Akademi Academy of Finland
Argelander-Institut für Astronomie
AIM
agenzia spaziale italiana
Aix Marseille université
Astronomický ústav AV ČR
belspo
Berkeley Center for Cosmological Physics
Caltech
CSA ASC
Carnegie Mellon University
Centro de Astrofísica da Universidade do Porto
CCIN2P3
CDTI
cea
IPhT Saclay
CEFCA
CENTRA
CAB
CFH
Faculty of Mathematics and Physics Charles University
Ciemat
cnes
CPPM
CPT
CRAL
CSIC
CSL
DAL
University of Cambridge Department of Applied Mathematics and Theoretical Physics
Dark Cosmology Centre
DLR
DTU Technical University of Denmark
Durham University
ENS
PSL
EPFL
esa
ESO
ETH zürich Institute for Theoretical Physics
FINCA
Fyzikální ústav Akademie věd ČR, v. v. i.
NASA Goddard
GRAPPA
ICRAR
ia instituto de astrofísica e ciências do espaço
IAP
IAS
IEEC
Imperial College London
IASF
Osservatorio Astronomico di Brera
INAF Osservatorio Astronomico di Bologna Istituto Nazionale di Astrofisica
INAF Istituto Nazionale di Astrofisica Osservatorio Astronomico di Capodimonte
INAF- Osservatorio Astrofisico di Catania
OAR INAF Osservatorio Astronomico di Roma
INAF - Istituto di Radioastronomia
INFN
INFN Padova
INFN Sezione di Roma
ICE
ICG Portsmouth
Institute for Astronomy
Institute for Astronomy University of Hawaii
institut für astronomie
IFAE
IFCA Instituto de Física de Cantabria
cnrs IN2P3
NRC CNRC
cnrs INSU
ioa
ipac
ICCUB
IPAG
IPNL
irap
Irfu cea
ISS
ISDC
LMU
USM
TÉCNICO LISBOA
Johns Hopkins University
LJMU
JPL Jet Propulsion Laboratory California Institute of Technology
The Kavli Foundation
King's College London
LAB
LAL Laboratoire de l'Accélérateur Linéaire
LAM
Lancaster University
Berkeley Lab
LPNHE Paris
LPSC Grenoble
AIP Leibniz-Institut für Astrophysik Potsdam
Universiteit Leiden
L2S
l'Observatoire de Paris
LUTH
Maynooth University 1997-2017
Max-Planck-Gesellschaft
Max-Planck-Institut für Astrophysik
MPE
McGill
McMaster University
UCL Mullard Space Science Laboratory
NASA
NOAO
NAOJ
NORDITA

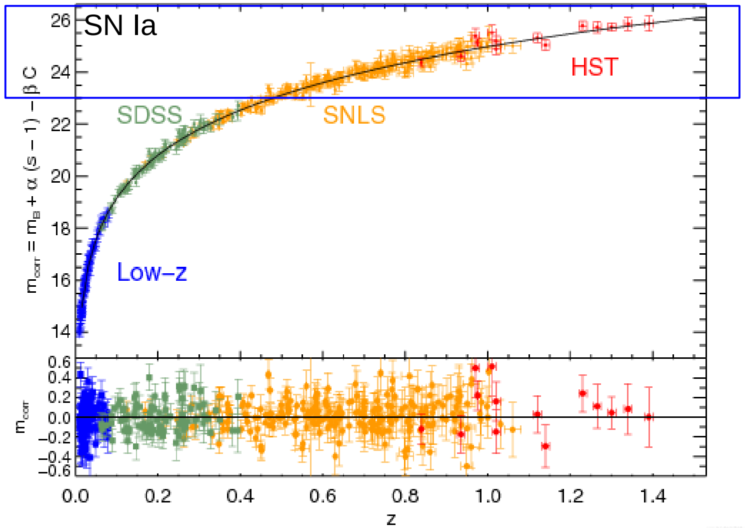
Euclid

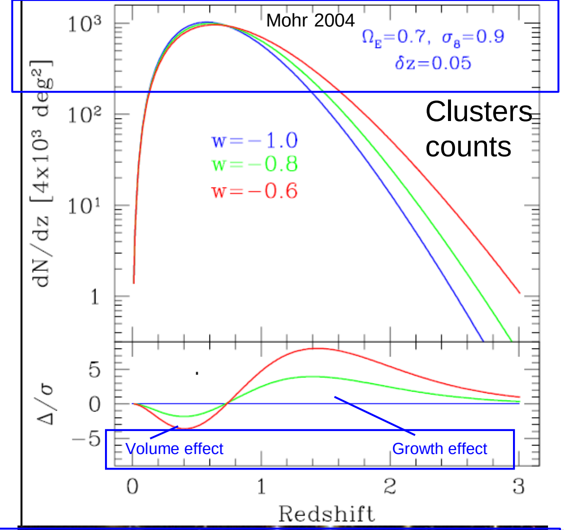
Euclid Consortium Institutions

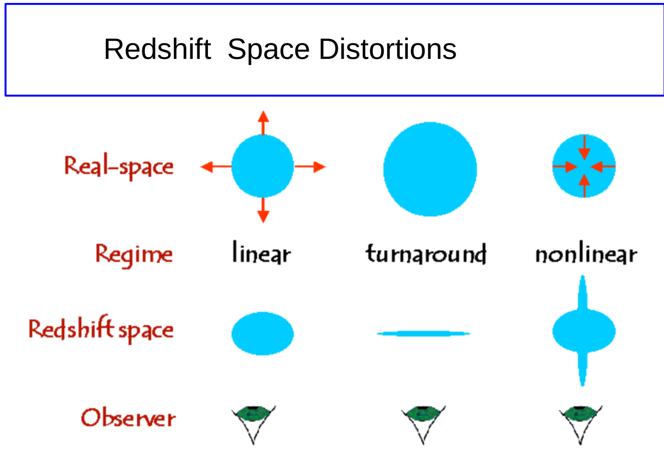
EUCLID CONSORTIUM

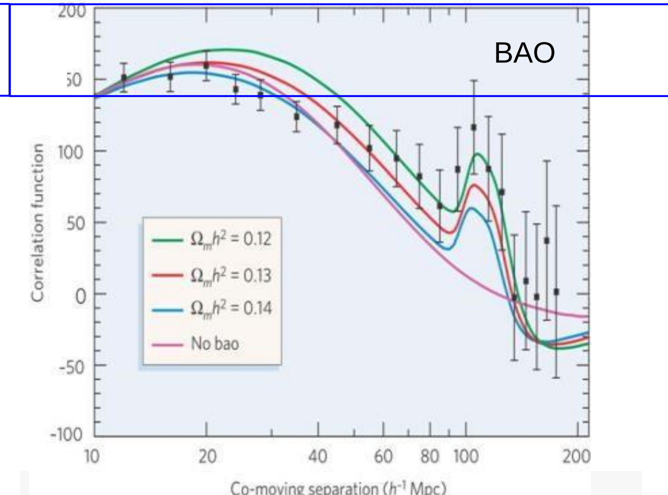
Norsk Romsenter, Norwegian Space Centre
NWO
Observatoire de la Côte d'Azur
Observatoire de Paris
Observatoire astronomique de Strasbourg
The Ohio State University
Perimeter Institute
PIC
Princeton University
Queen's University Belfast
Radboud Universiteit
RMC CMR
Saint Mary's University
SISSA
Scuola Normale Superiore
SLAC National Accelerator Laboratory
Sorbonne Universités
Space Science Center
SRON Netherlands Institute for Space Research
Stanford University
UK Astronomy Technology Centre
Stockholm University
sc | nat
TarGet
TUM Technische Universität München
Tsinghua University Department of Physics
UK Space Agency
University of Applied Sciences and Arts Northwestern Switzerland
DSFC
UAM
Universidade de Aveiro
University of Bath
University of Birmingham
Universität Bonn
UBC
Berkeley
UC Irvine
Universidad Politécnica de Cartagena
The University of Chicago
dfi
fcfm
UCL
UC Davis, University of California
UC Riverside
University of Cambridge
Università degli Studi di Catania
Universidad Complutense Madrid
University of Cyprus Department of Physics
Università degli Studi di Ferrara
Università degli Studi Firenze
UF University of Florida
Université de Genève
Ghent University
University of Groningen
University of Helsinki
ZAH Zentrum für Astronomie
Universität Hamburg
University of Hawai'i Manoa
Universität Heidelberg
UiO Institute of Theoretical Astrophysics, University of Oslo
University of Bristol
Jyväskylän Yliopisto, University of Jyväskylä
AGO
University of Louisville
UCL Université catholique de Louvain
L-Università ta' Malta
Manchester 1824, The University of Manchester
UMass Amherst
The University of Melbourne
Università degli Studi di Milano
University of Minnesota
UMKC
Universidad Nacional Autónoma de México
Université de Namur
The University of Nottingham
University of Oxford
Universidad del País Vasco, Euskal Herriko Unibertsitatea
Università degli Studi di Padova
Penn, University of Pennsylvania
University of Portsmouth
UPMC Sorbonne Universités
Dipartimento di Matematica, Università degli Studi di Roma "Tor Vergata"
Roma Tre
Sapienza Università di Roma
Universidad de Salamanca, Departamento de Física Fundamental
Università del Salento
Università degli Studi di Salerno
The University of Sheffield
Université Nice Sophia Antipolis
University of Southampton
University of St Andrews
University of Surrey
University of Sussex
Texas at Austin
University of Toronto
Università degli Studi di Trento
Università degli Studi di Trieste
Turun yliopisto, University of Turku
Universitat de València
University of Victoria
University of Waterloo
Universität Zürich
Utrecht University
VUB
Yale University
York University

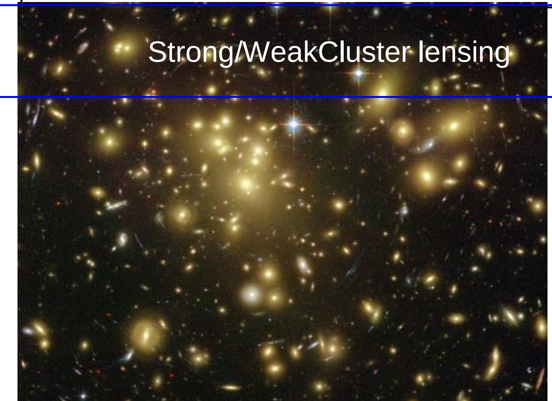
Probes of Dark Energy

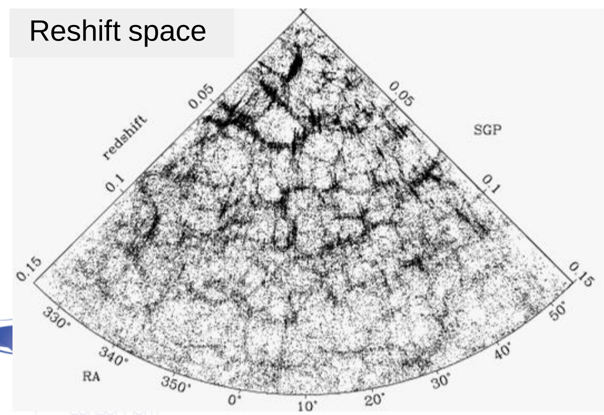


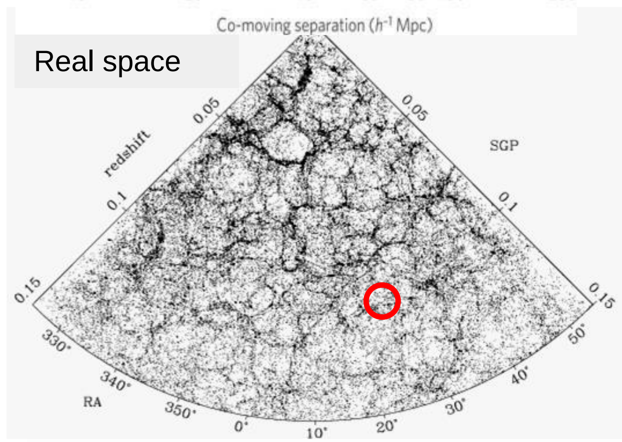


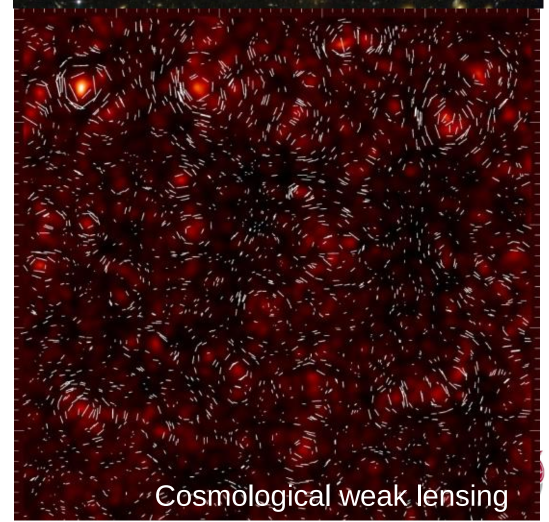




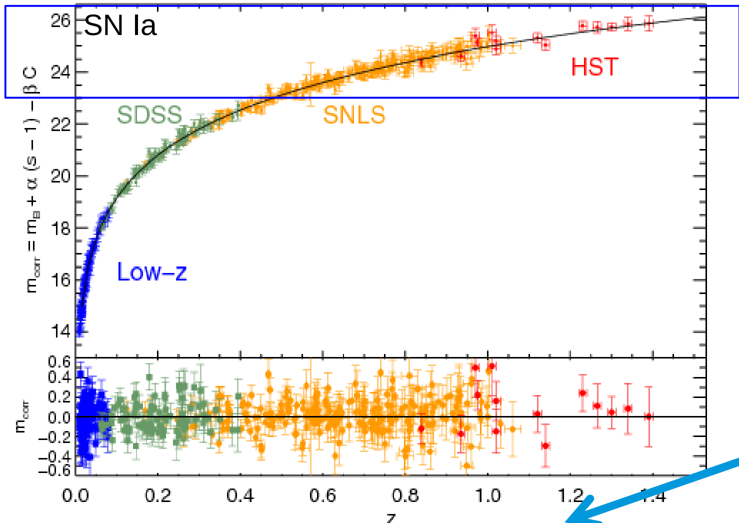


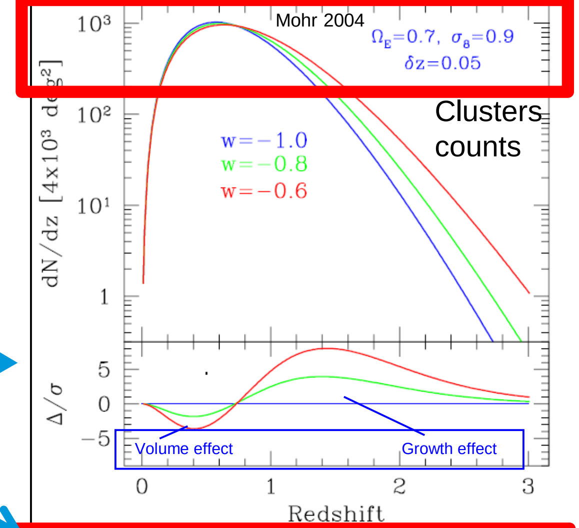


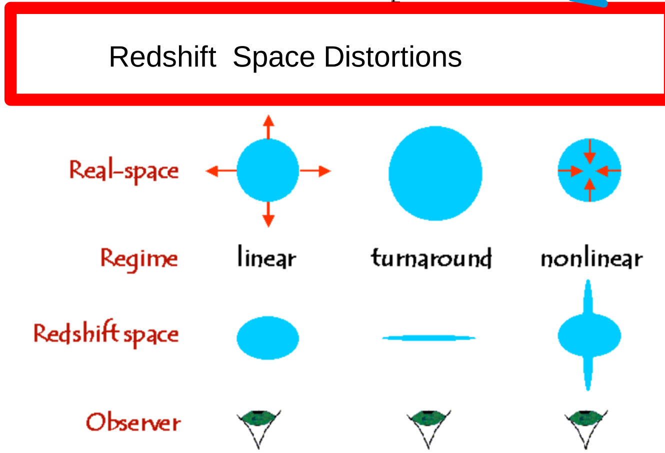


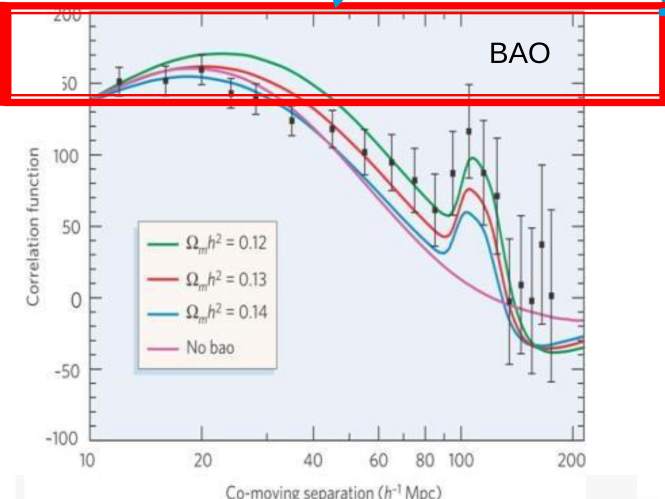


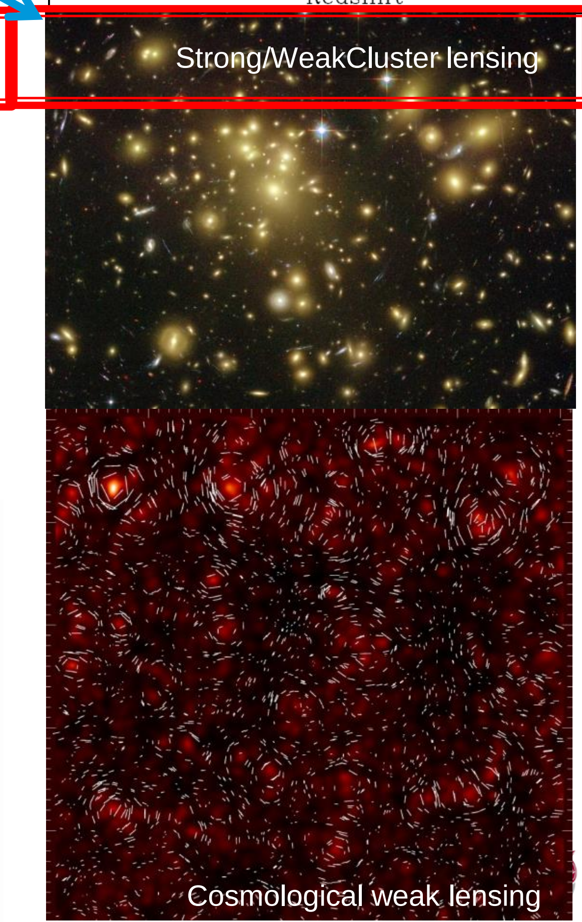
Euclid probes of Dark Energy

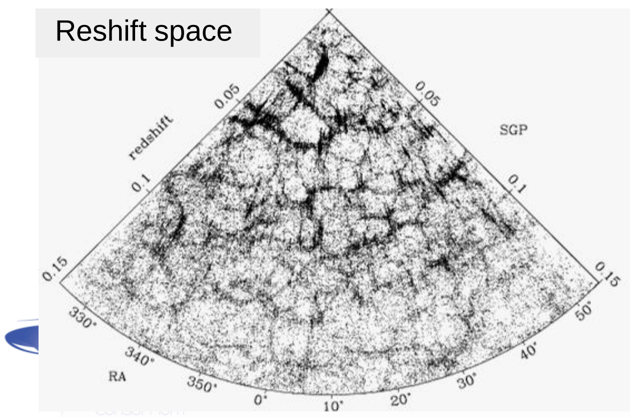


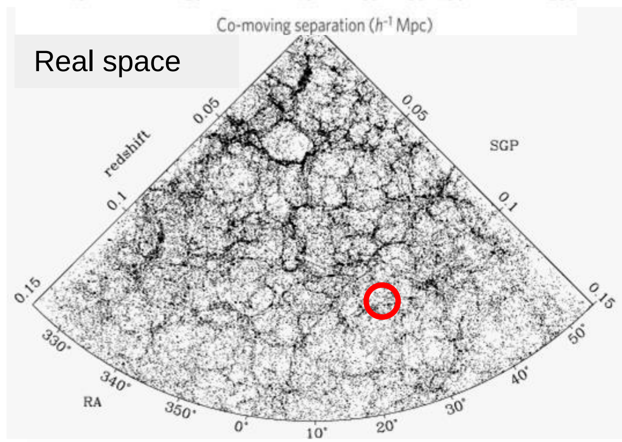




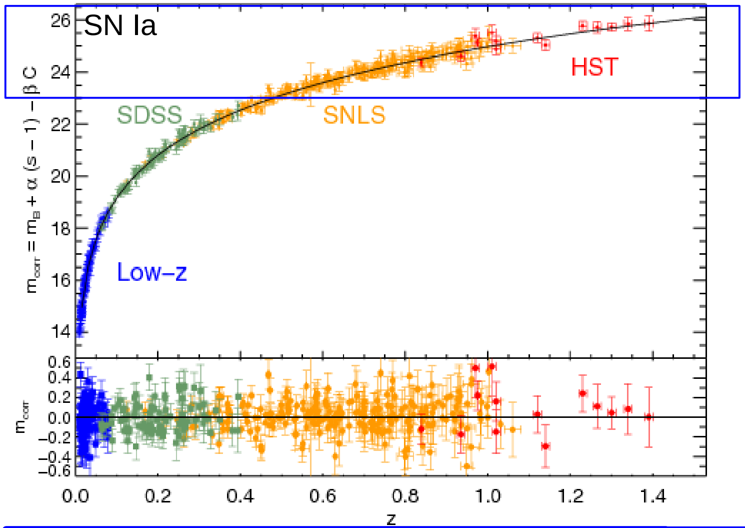


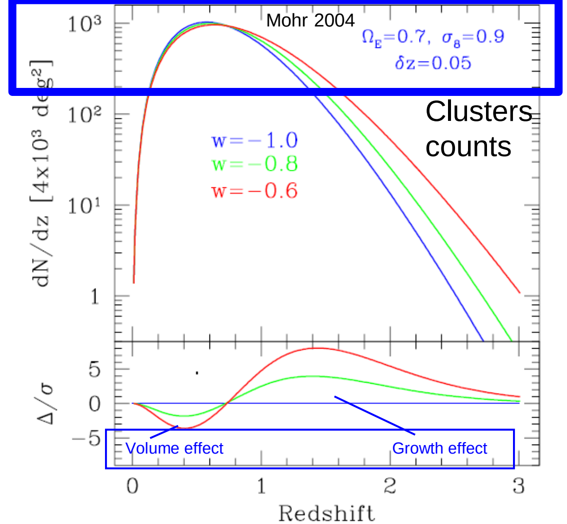


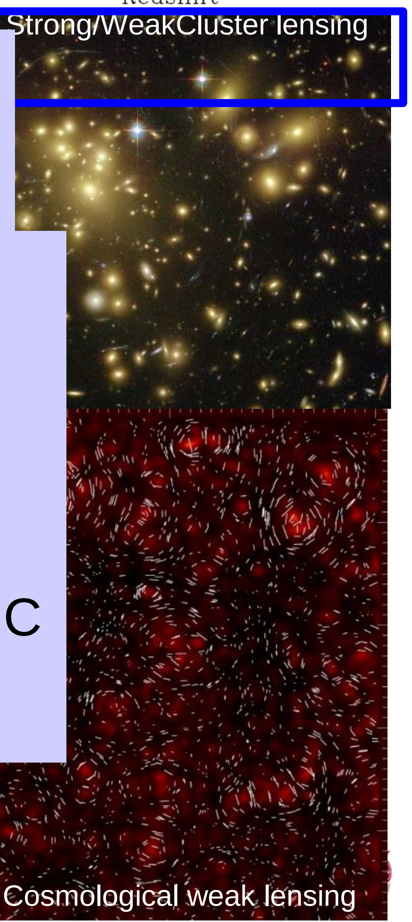




Euclid probes of Dark Energy







A single survey: use the same data sets for 3 probes → optimal use of a space mission:

- Imaging/spectroscopy: wide fields
- 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 Mission concept

- Optimize the mission for galaxy clustering and weak lensing, two dark energy complementary probes
- Two instruments: optical imager (VIS) and near-infrared spectrophotometer (NISP)
- Minimum survey area of 15000 deg2 → 6 years nominal mission

Weak Lensing: → VIS imager + NIR photometer

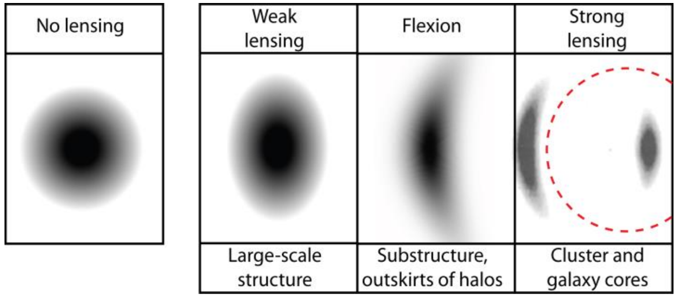
- Shapes and shear of galaxies with a density of >30 galaxies/arcmin^2.
- Very high image quality, high stability
- Minimum Systematics $\sigma_{sys} < 10^{-7}$
- Redshift accuracy dz/z ~ 0.04, down to z~2

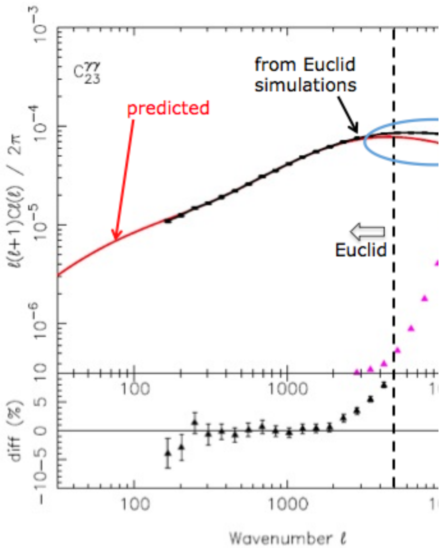
Galaxy clustering → NIR slitless spectrometer

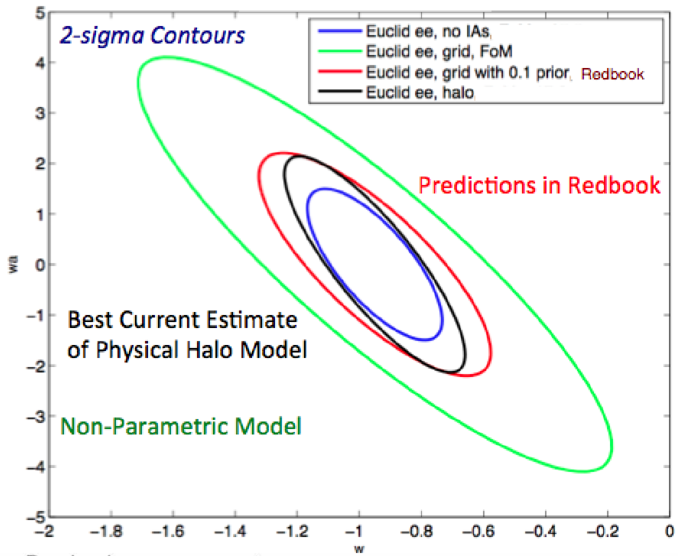
- Redshifts for >3500 galaxies/deg^2
- Redshift range $0.7 < z < 2.05$
- Redshift accuracy dz/z < 0.001 in same volume as WL
- Line Flux limit < 3 10^{-16} erg cm^{-2}s^{-1}

Euclid Weak Lensing

EUCLID CONSORTIUM



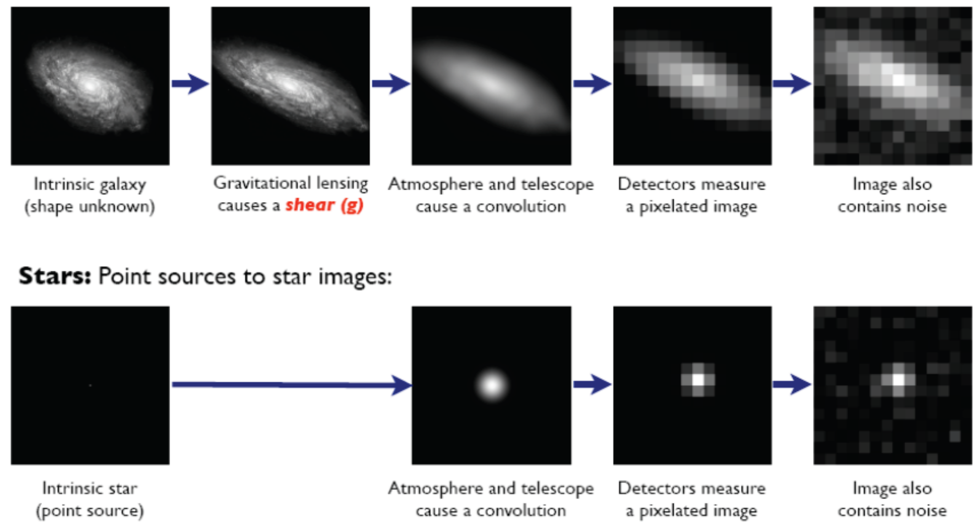




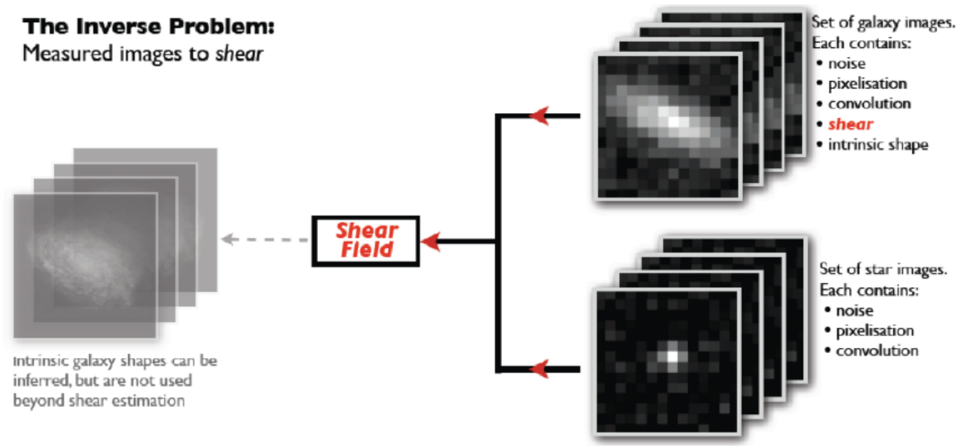
The Forward Process.

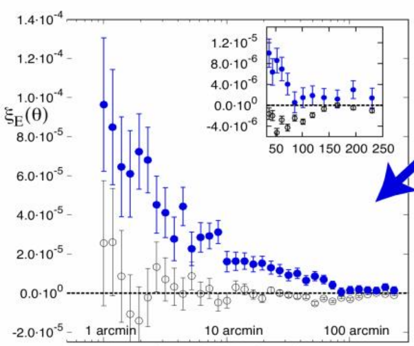
Galaxies: Intrinsic galaxy shapes to measured image:

Stars: Point sources to star images:



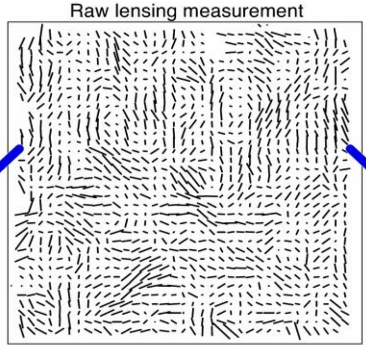
The Inverse Problem:
Measured images to *shear*

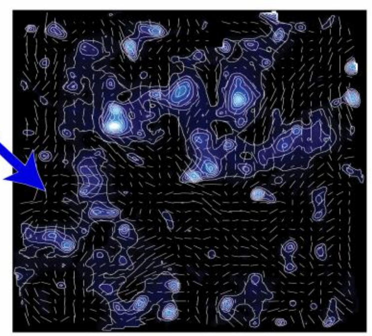




Correlation function

Raw lensing measurement

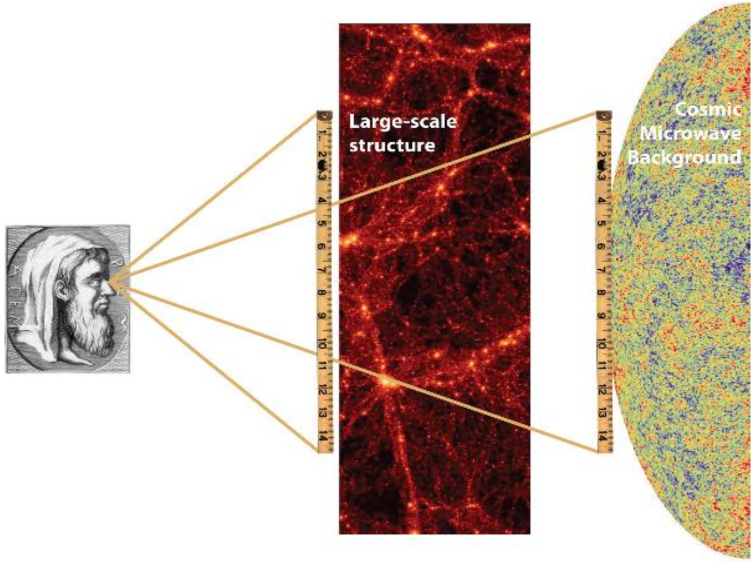


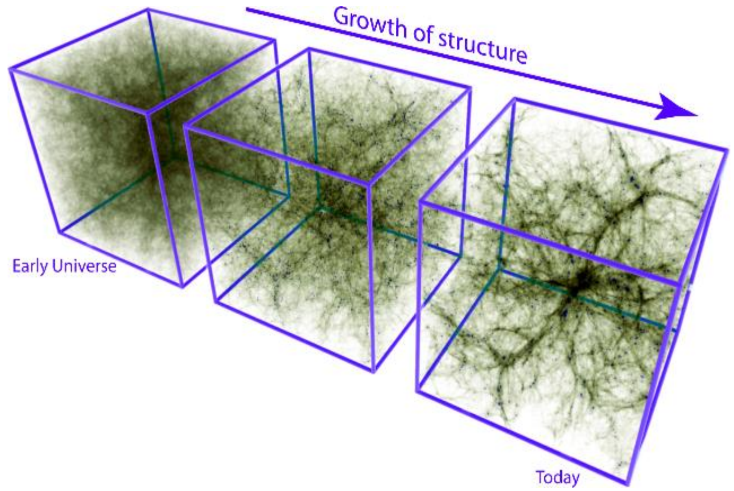


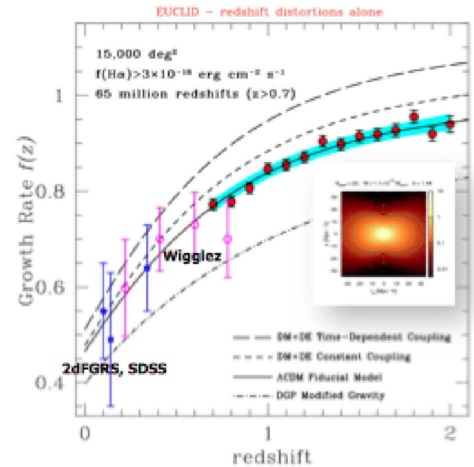
Dark matter distribution

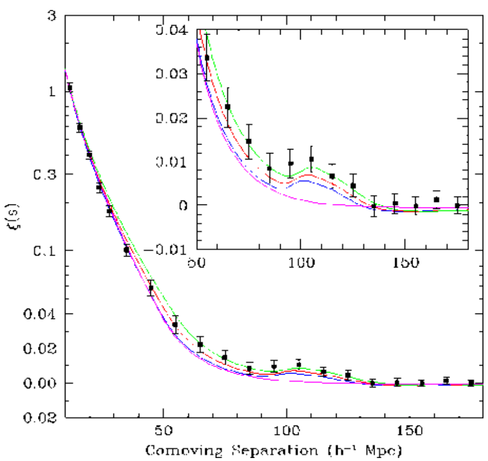
Euclid Galaxy clustering

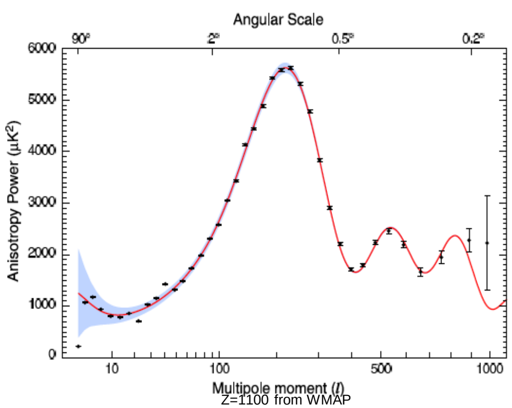
EUCLID CONSORTIUM

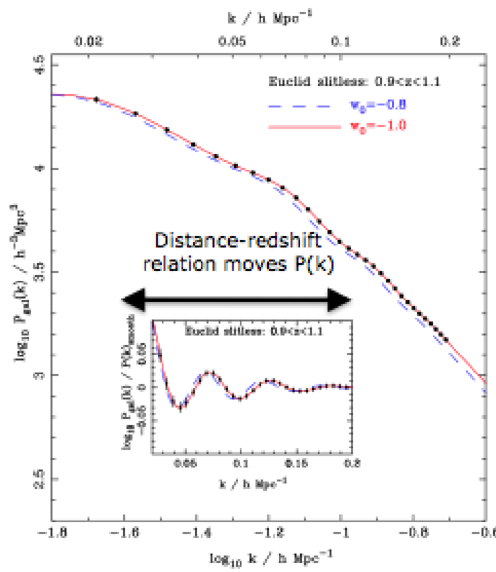


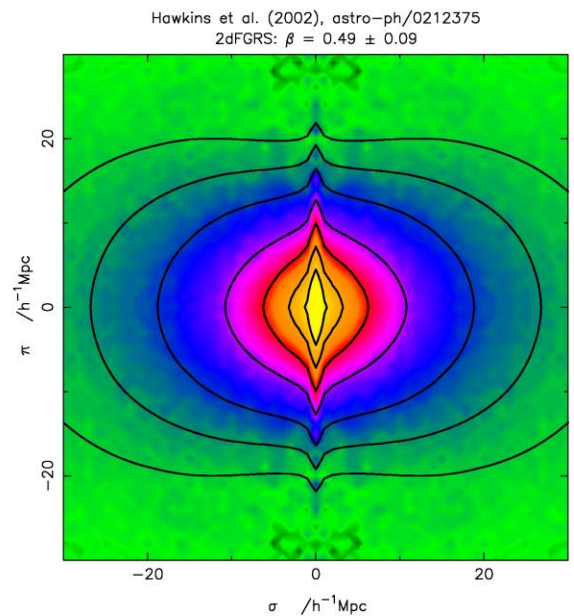






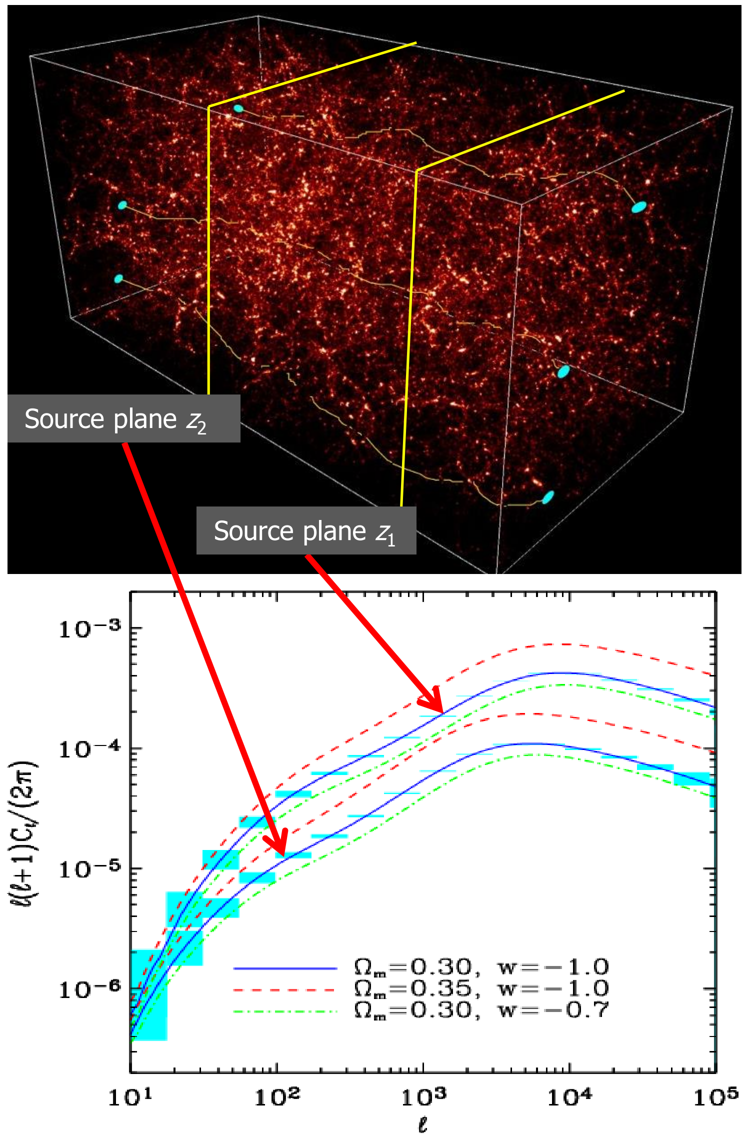






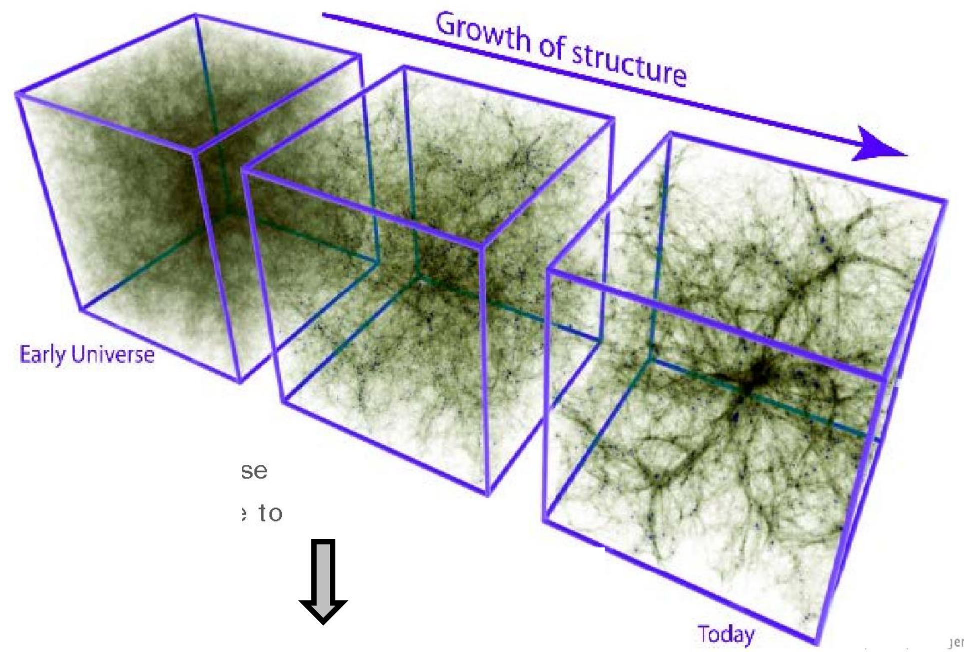
WL probe: Cosmic shear over 0<z<2 :

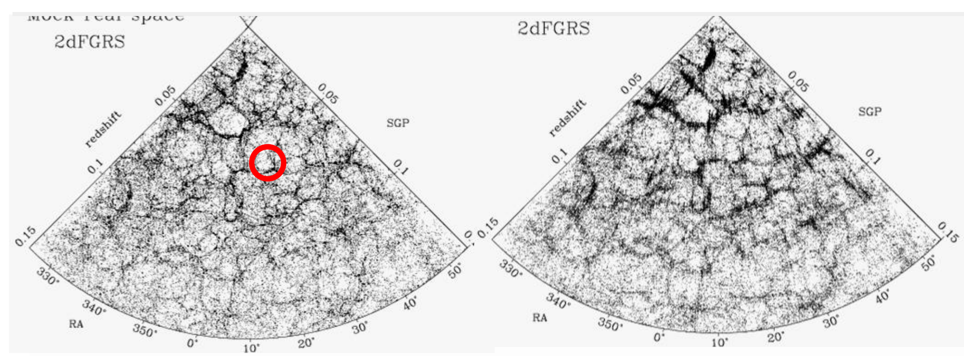
1.5 billion galaxies shapes, shear and phot-z (u,g,r,i,z, Y,J,H) with 0.05 (1+z) accuracy over 15,000 deg^2



GC: BAO, RSD probes: 3-D positions of galaxies over 0.9<z<1.8 :

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





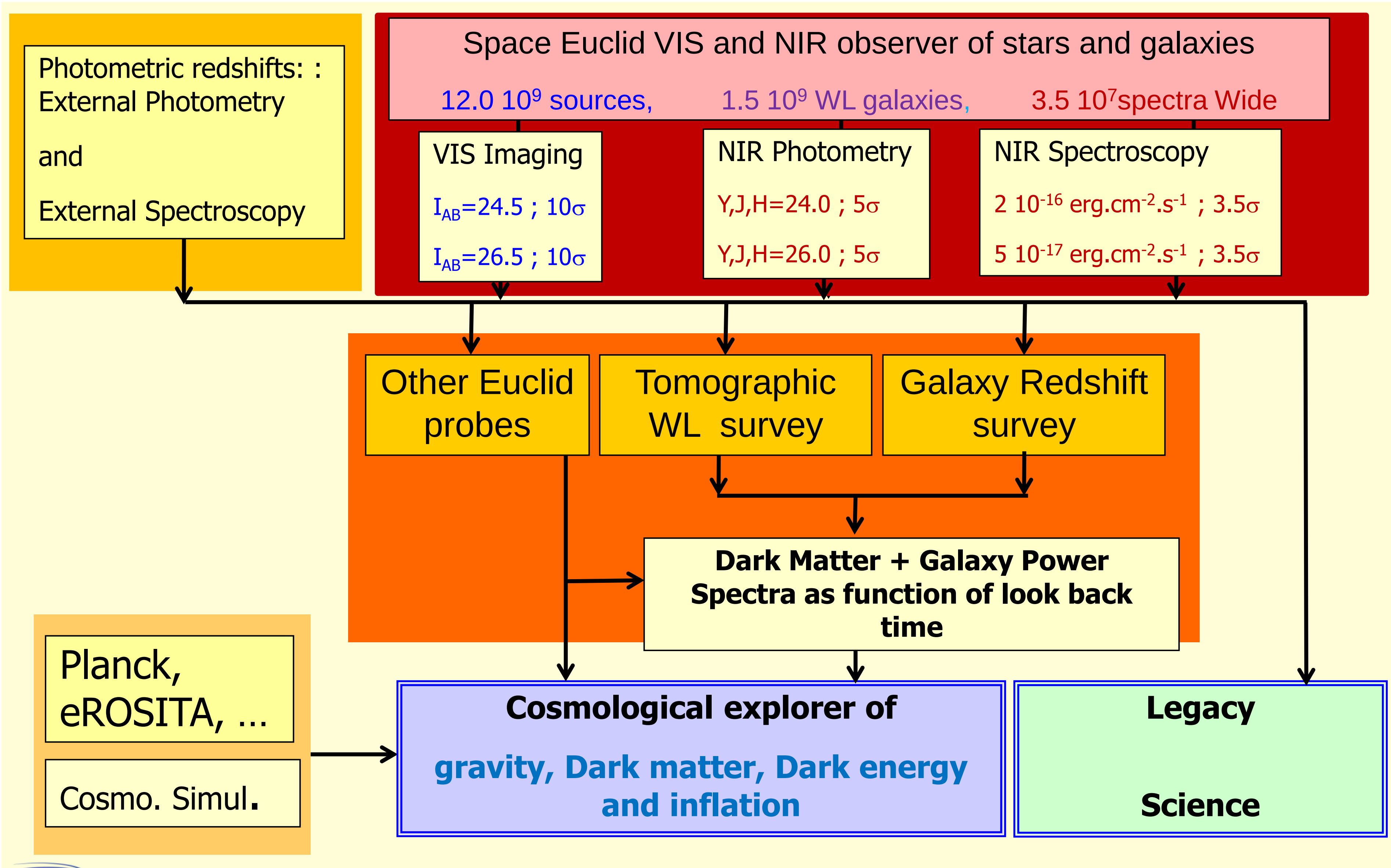
Euclid Two survey strategy: Wide+Deep

- **Euclid Wide:**
  - 15000 deg^2 : avoid 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
    - Hα galaxies within 0.9 < z < 1.85
    - Flux line: 2 . 10^{-16} $erg.cm^{-2}.s^{-1}$; 3.5σ

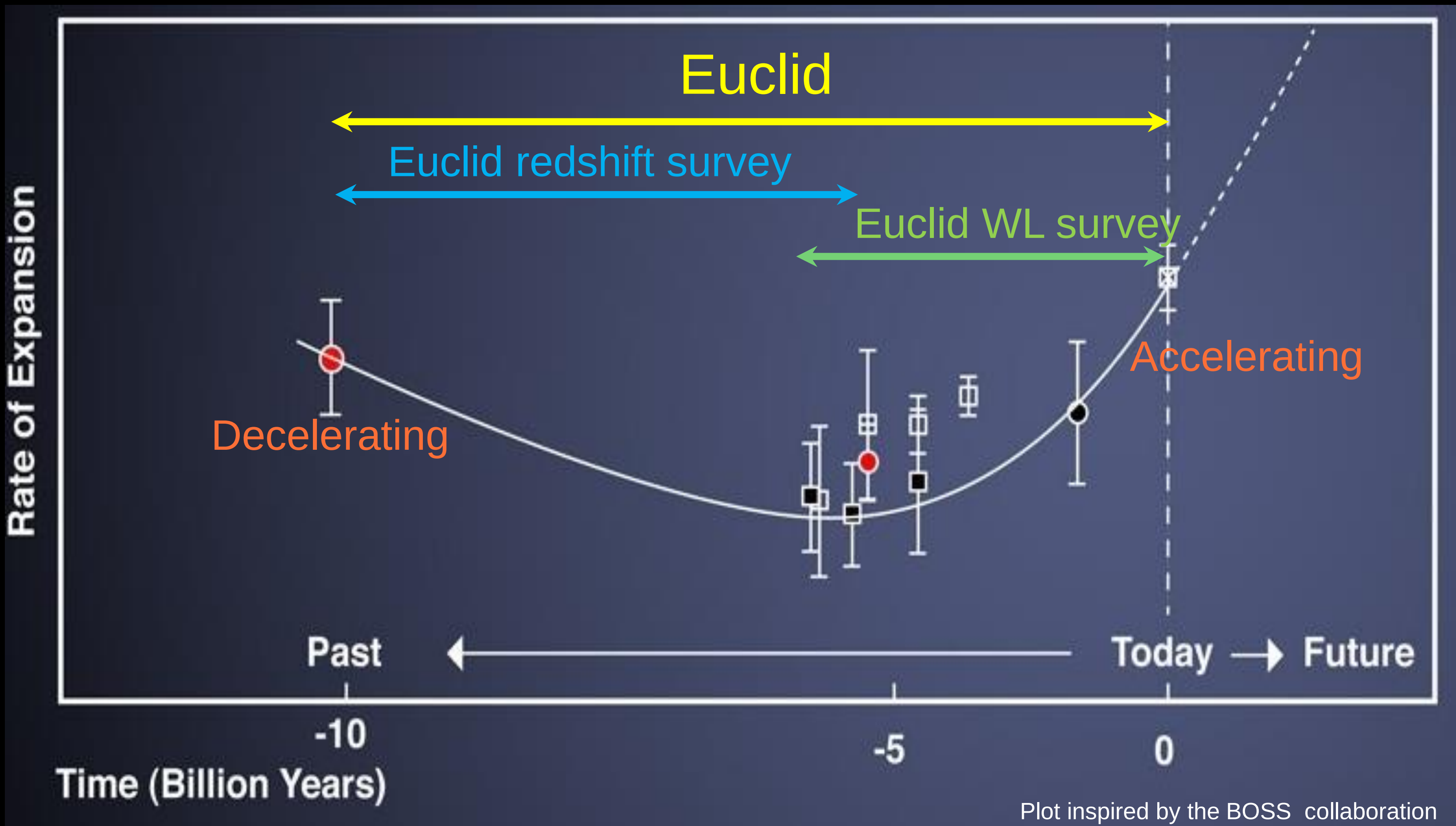
- **Euclid Deep:**
  - 1x10 deg^2 North Ecliptic pole (EDF-N) + 1x20 deg^2 South Ecliptic pole (EDF-S1 + 1x10 deg^2 at CDFS (EDF-S2)
  - 10 million sources (3-σ)
  - 1.5 million galaxies with
    - Very accurate morphometric information (WL)
    - Visible photometry: (u), g, r, i, z , (R+I+Z) AB=26.5, 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
    - Hα galaxies within 0.7 < z < 1.85
    - Flux line: 5 . 10^{-17} $erg.cm^{-2}.s^{-1}$; 3.5σ

Euclid consortium

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

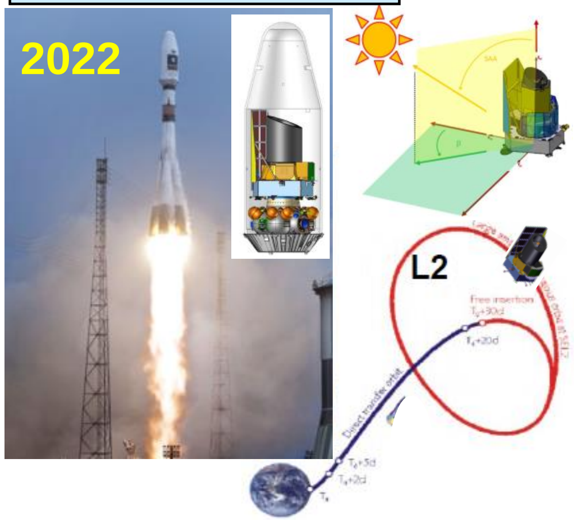


Euclid: exploring the DM-dominated / DE-dominated transition period

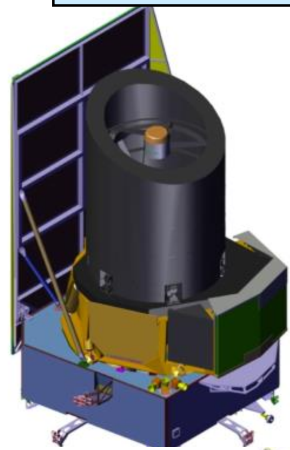


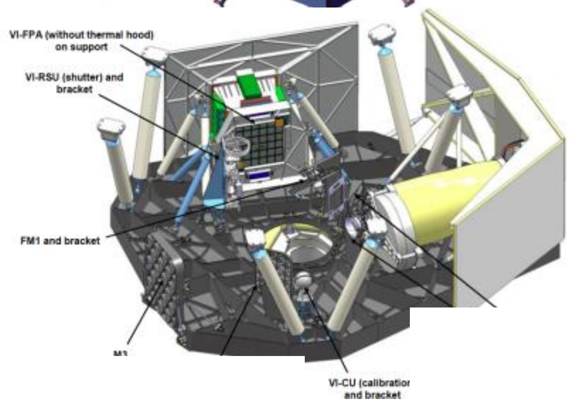
The Euclid mission

Launch and transfer to L2

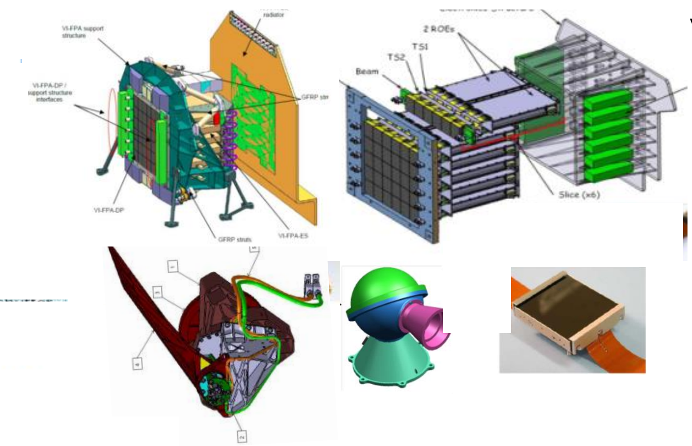


Satellite, Telescope …. and… Instruments

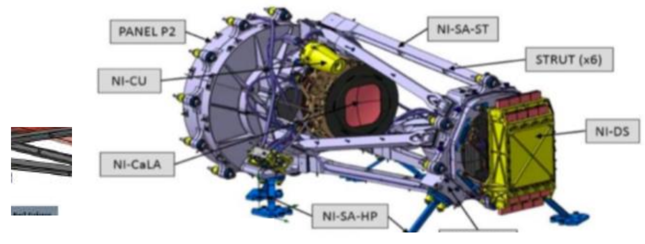




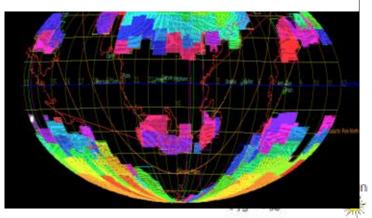
VIS

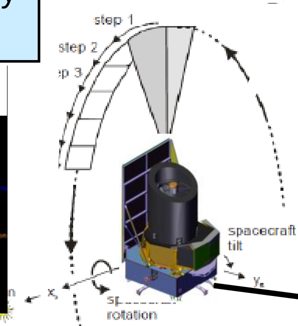


NISP

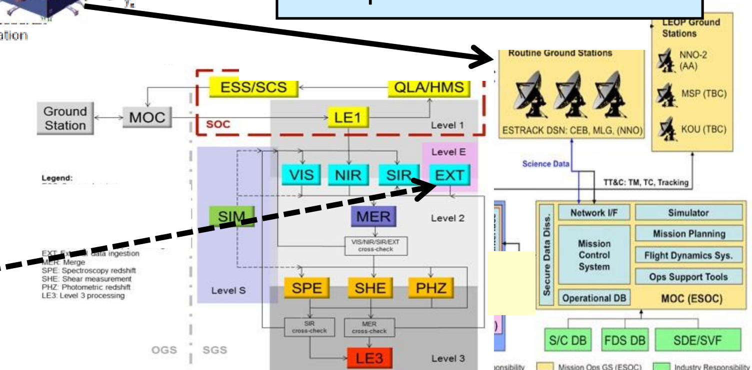


Euclid & complementary observations

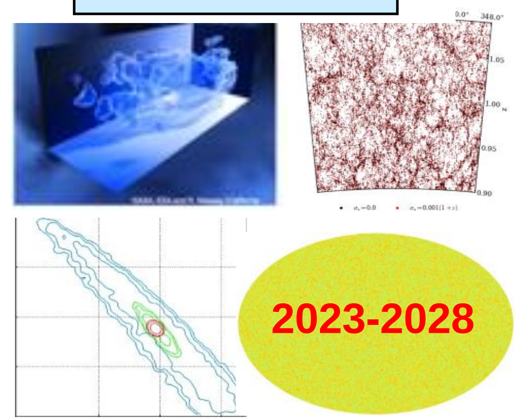


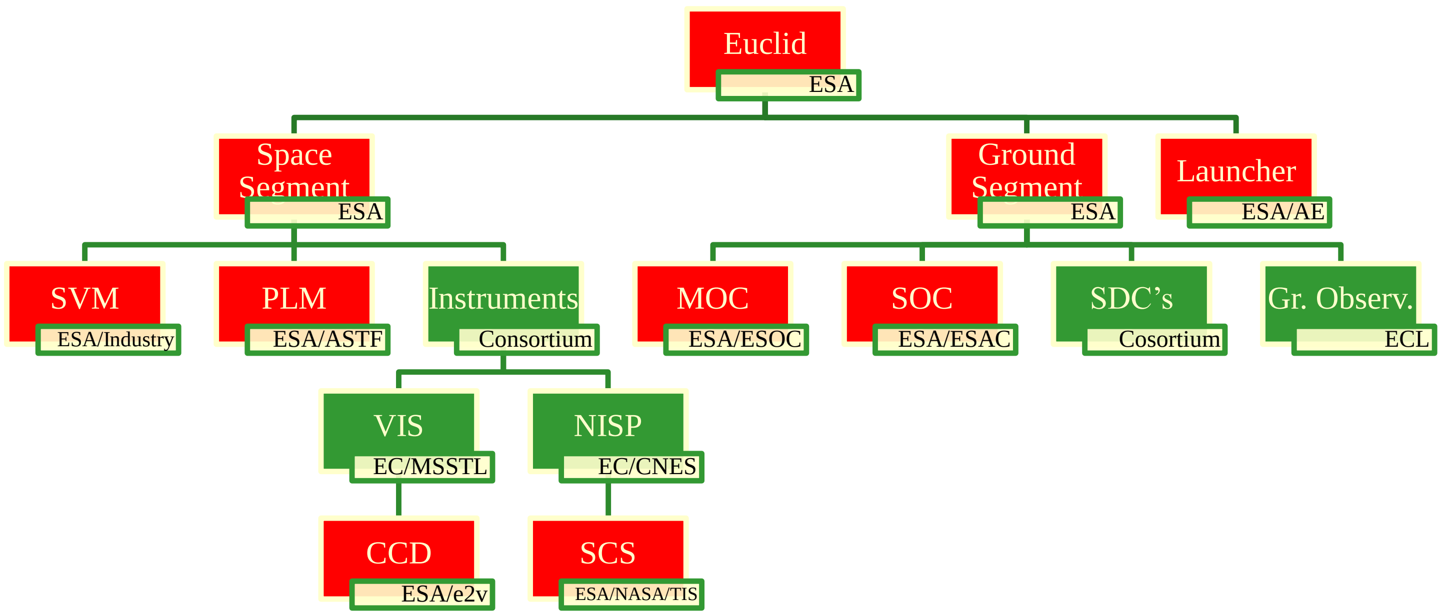


Data production and archive

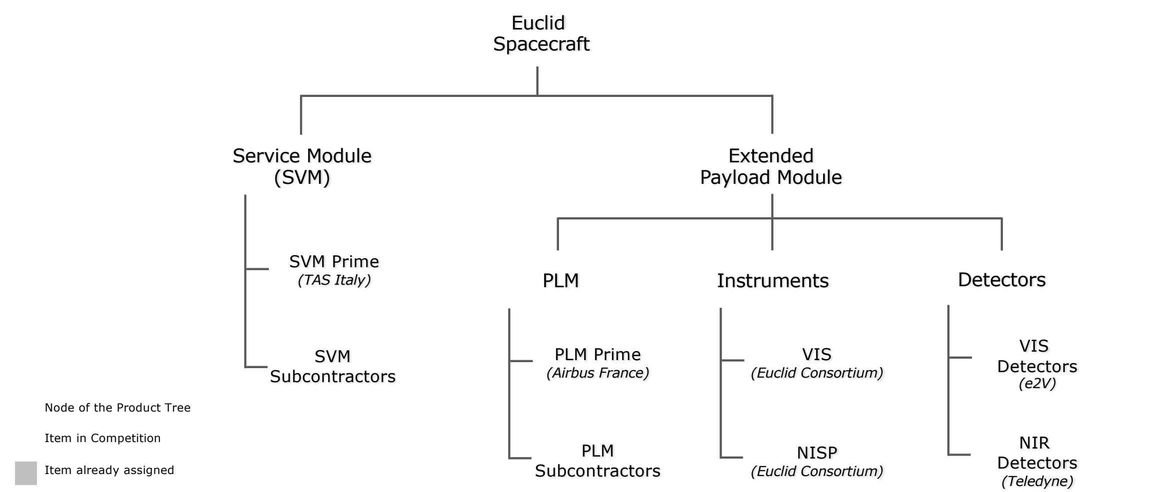


Scientific exploitation





Space Segment Product Tree

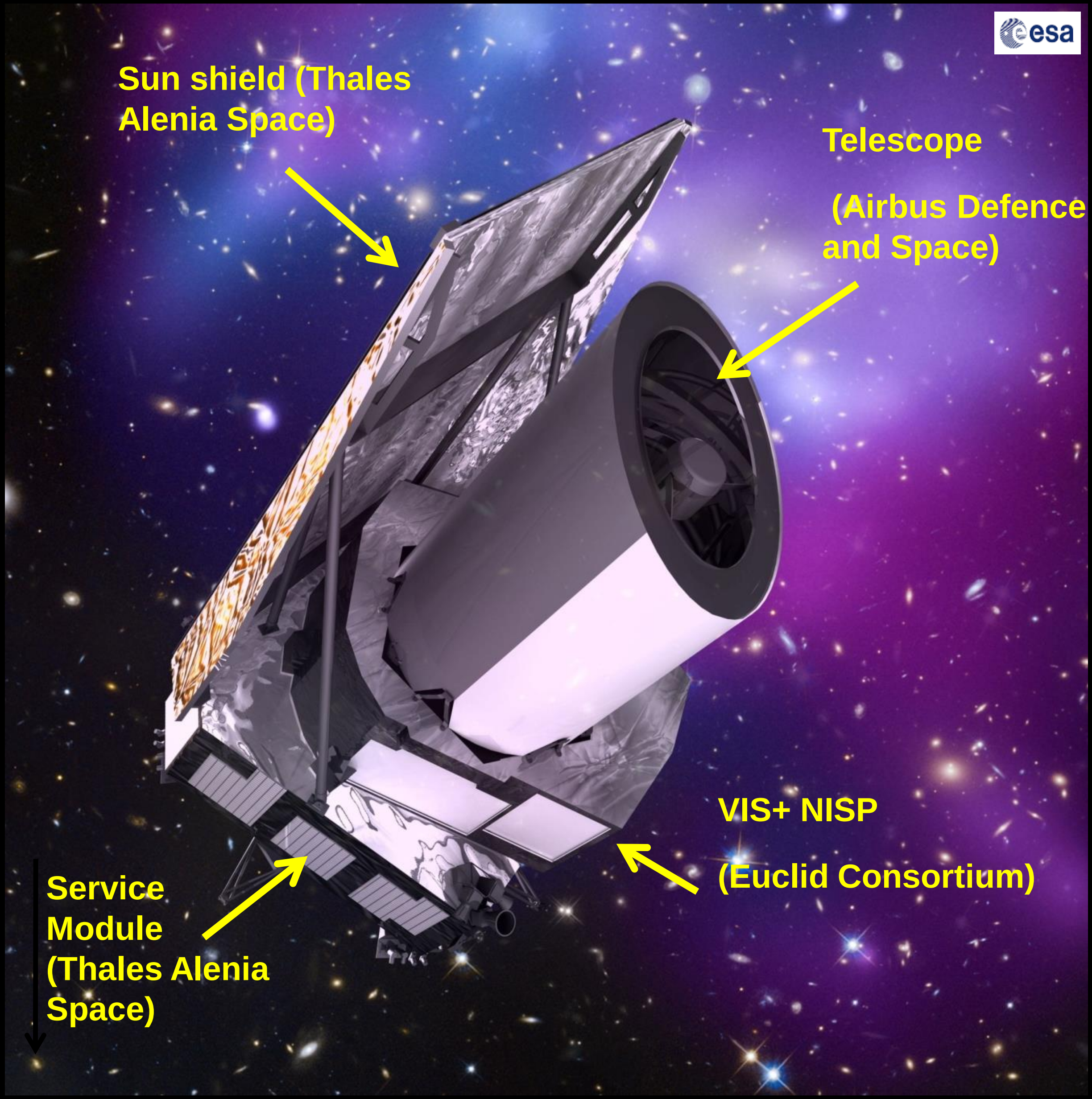


ESA Euclid mission:

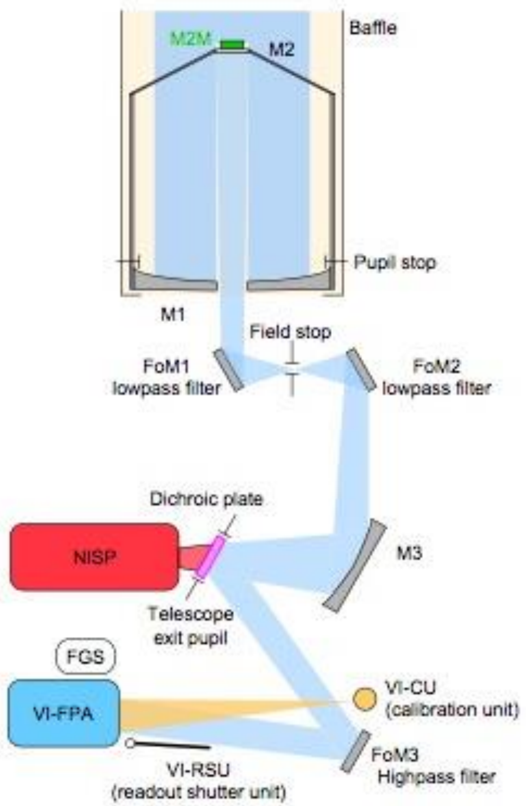
- - Total mass satellite :
- 2 200 kg
- - Dimensions:
- 4,5 m x 3 m

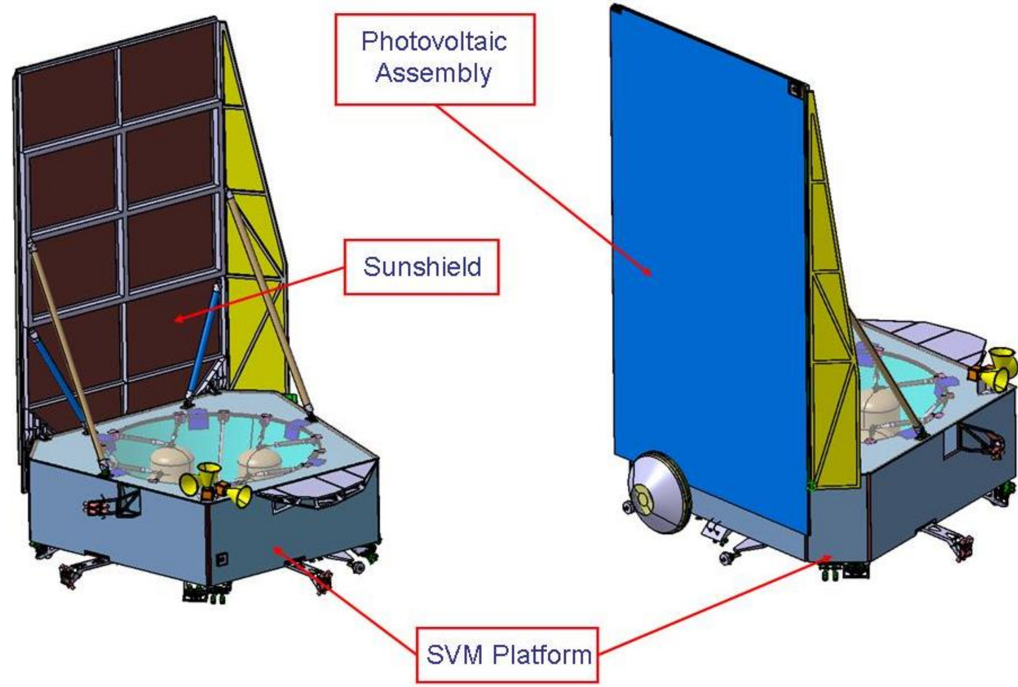
- - Launch: end 2022 by a Soyuz rocket from Kourou
- Euclid placed in L2

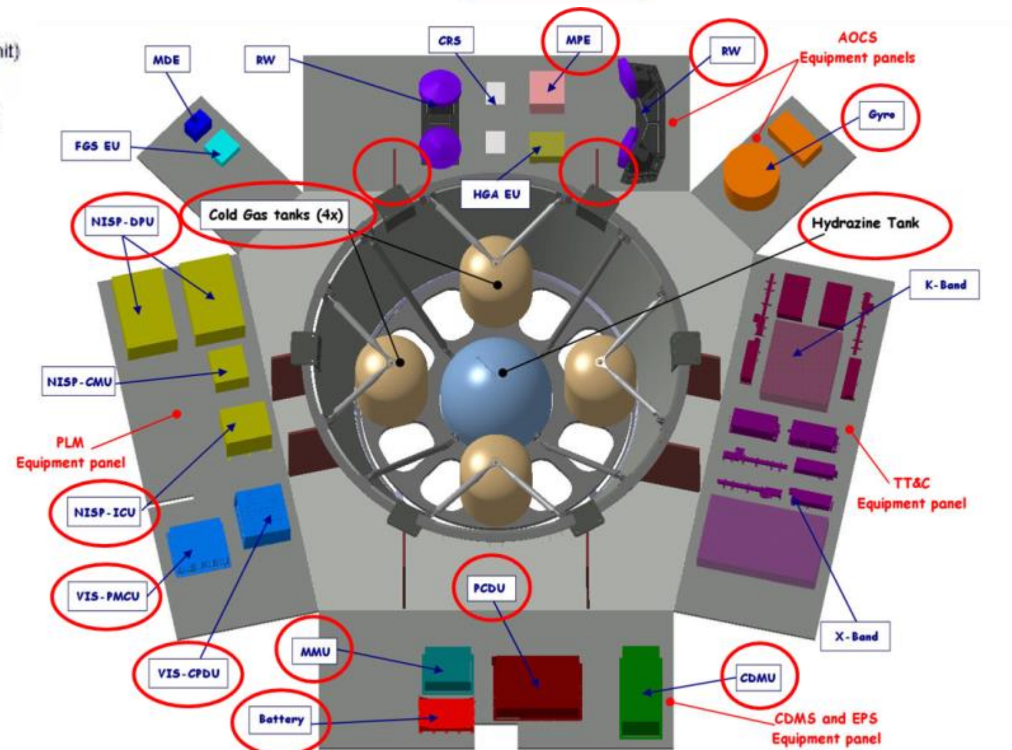
- - Survey: 6 years



Euclid satellite elements







S/C Sys
CDR done

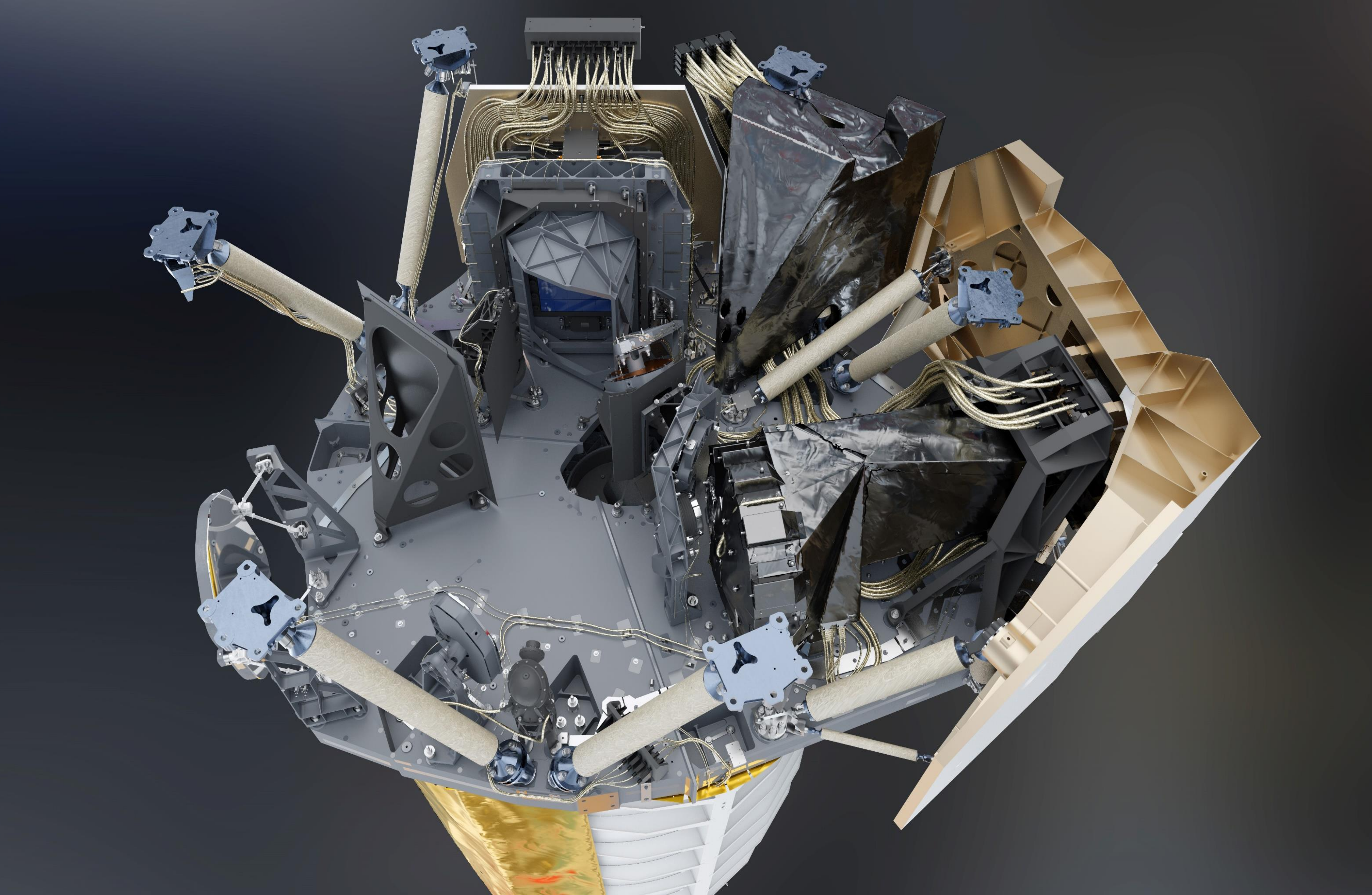
S/C QR
soon

Euclid Spacecraft Flight Hardware

QM dichroic plate

M1

M1




ERAL FRAME
BASSY COG
euclid

PLM, scientific instruments

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

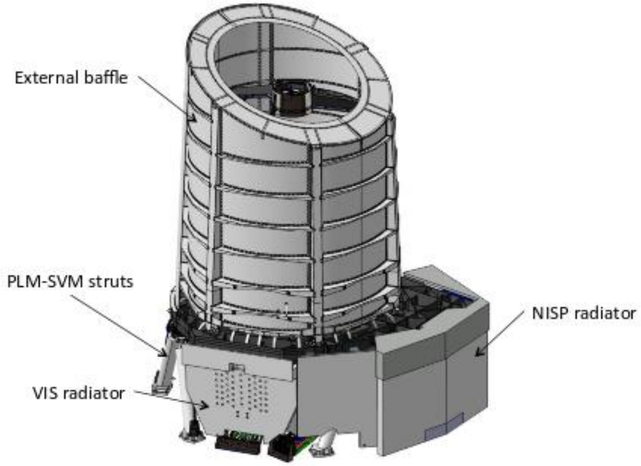
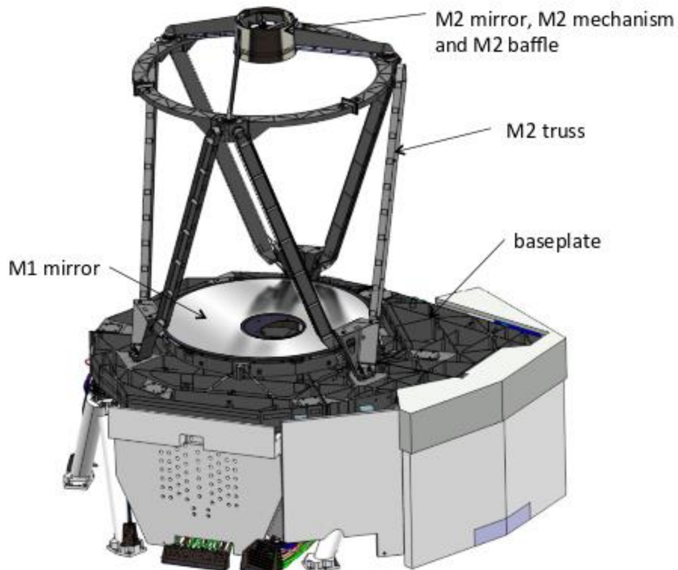
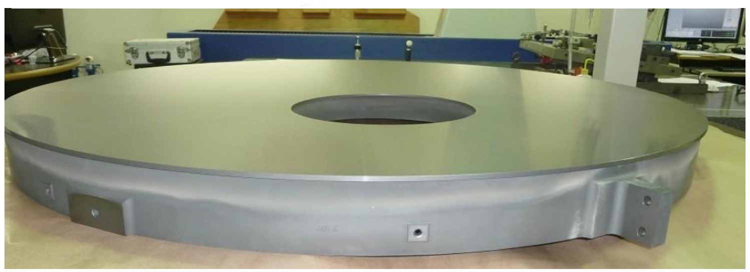
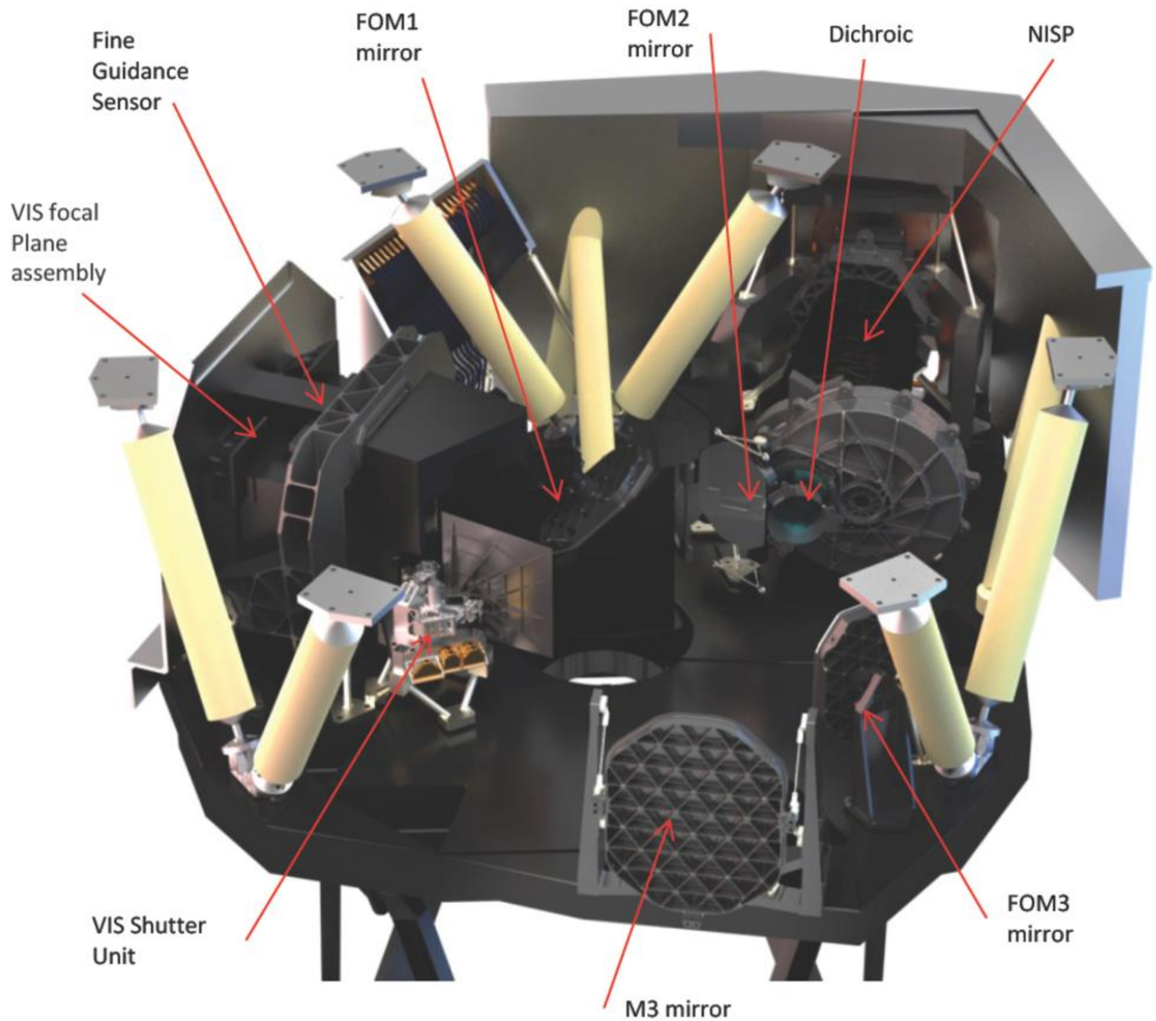


Figure 3-7 External front view of the PLM





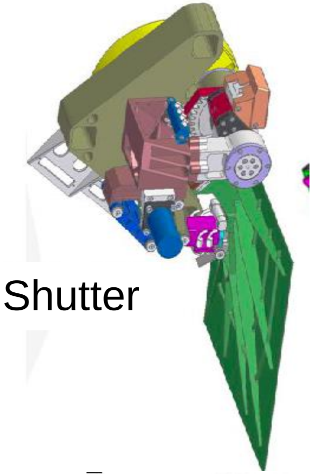


PLM FM e2e tests : May-June 2021

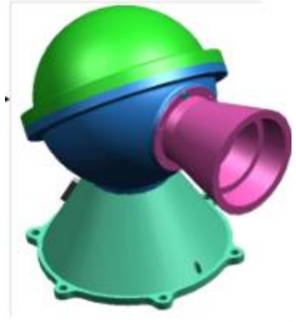
Courtesy: S. Pottinger, M. Cropper and the VIS team

VIS

VIS delivered Mar 2021



Shutter

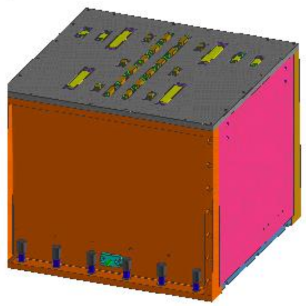


Calibration Unit

Cropper et al 2016:SPIE

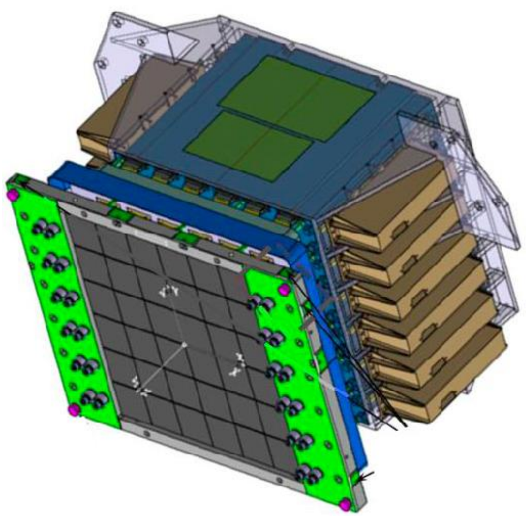
Spectral Band	550 – 900 nm
System Point Spread Function size	≤0.18 arcsec full width half maximum at 800 nm
System PSF ellipticity	≤15% using a quadrupole definition
Field of View	>0.5 deg^2
CCD pixel sampling	0.1 arcsec
Detector cosmetics including cosmic rays	≤3% of bad pixels per exposure
Linearity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

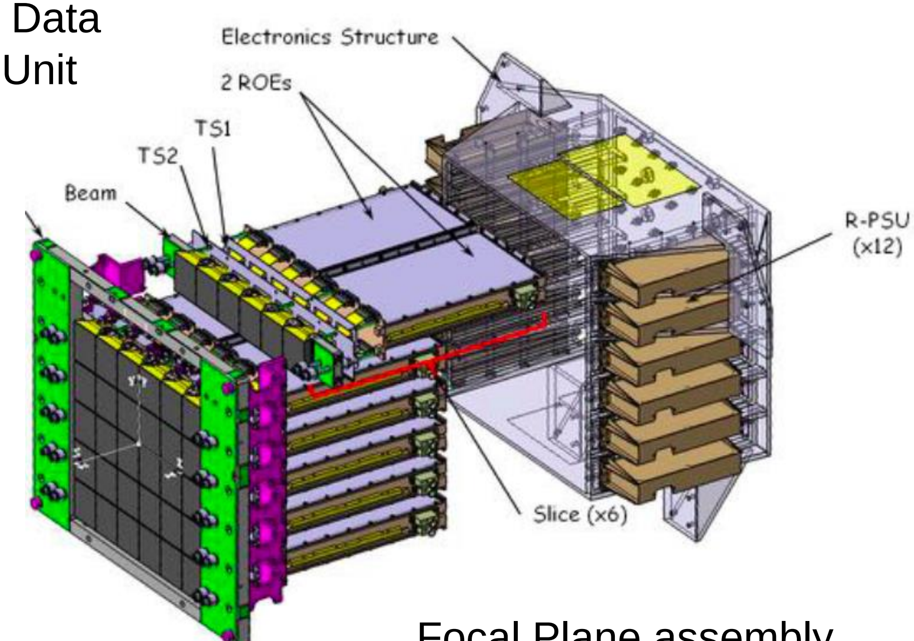
Power and Mechanism Control Unit



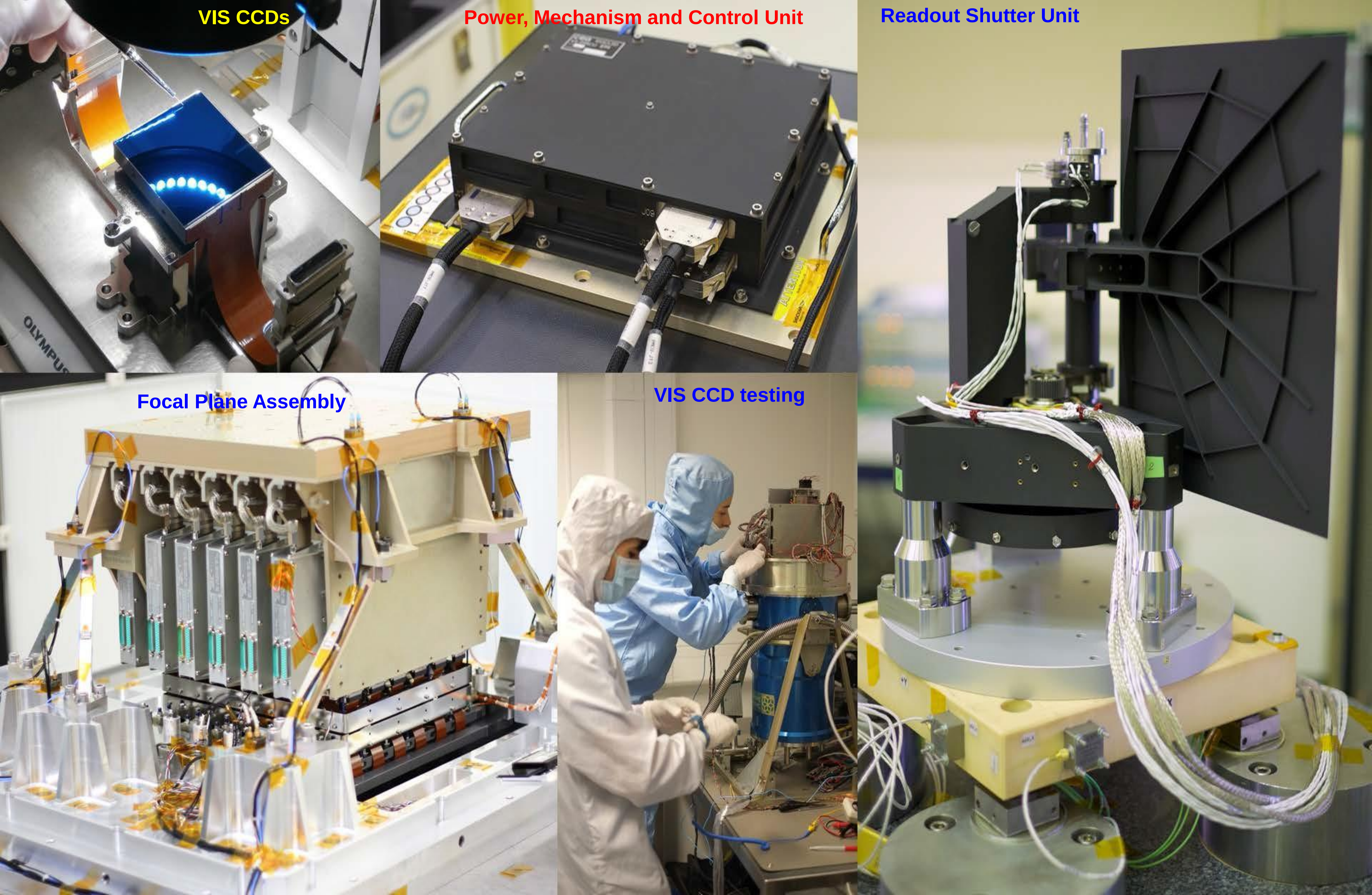
Control and Data Processing Unit

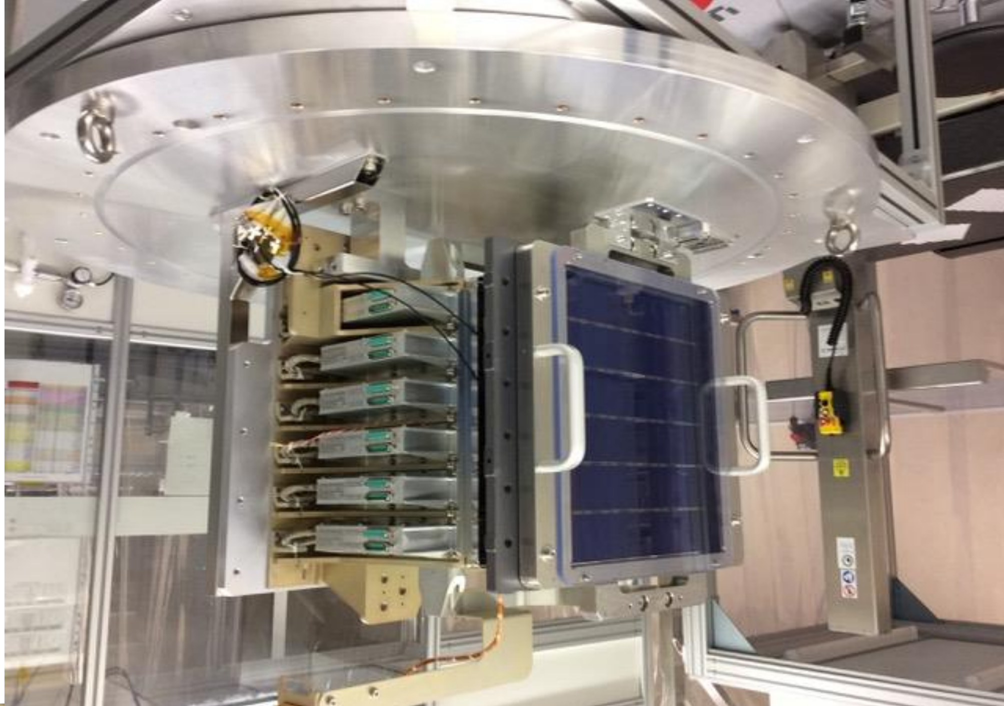
CCD

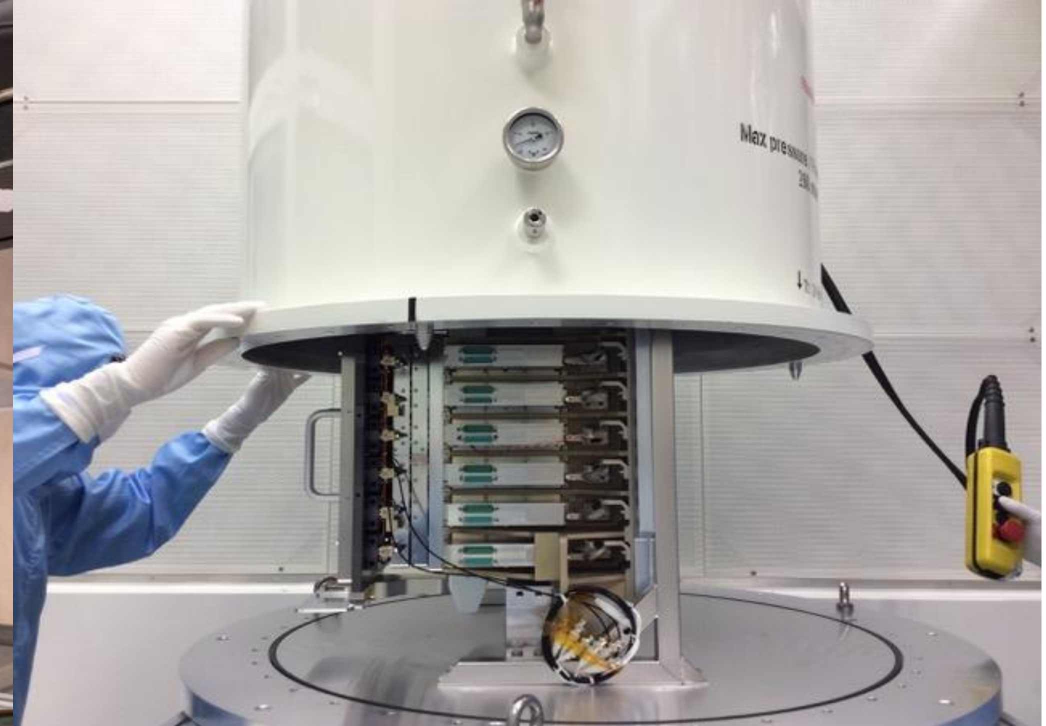




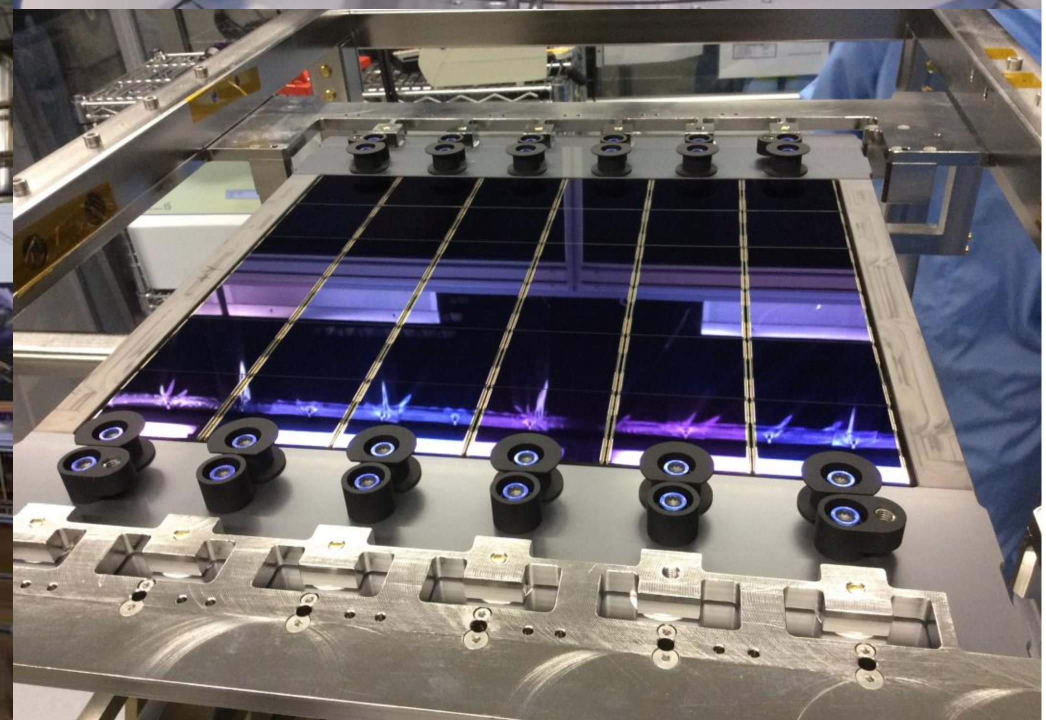
Focal Plane assembly


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





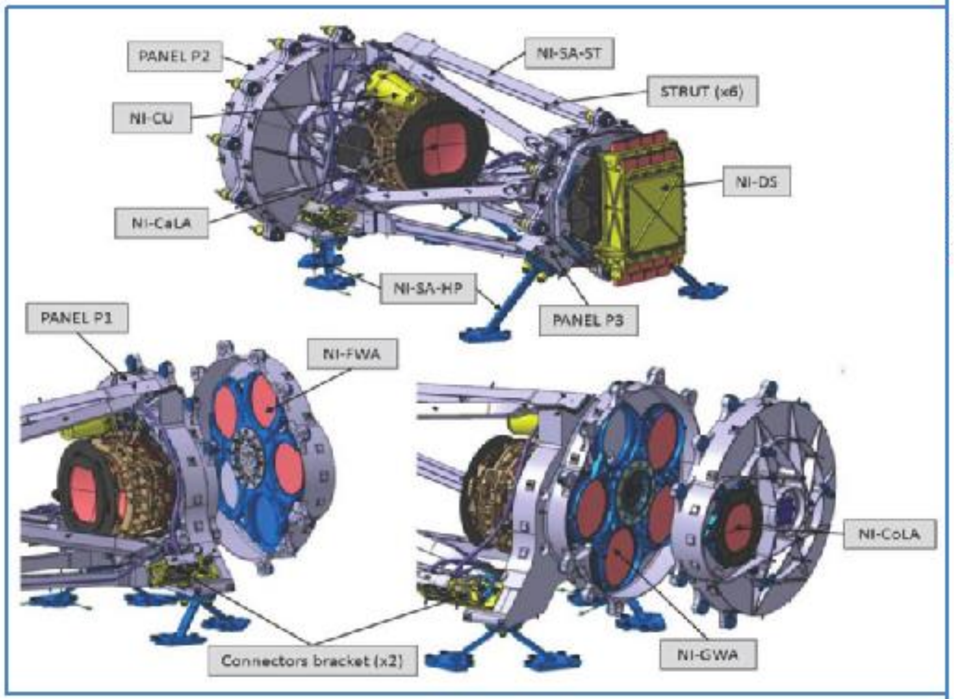

Conteneur de transport FPA
Container of transport FPA
Irfu
cea
saclay
cnes

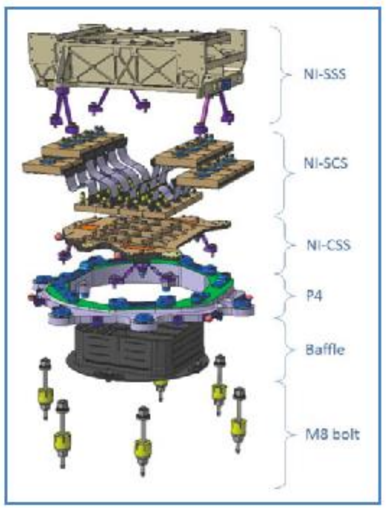


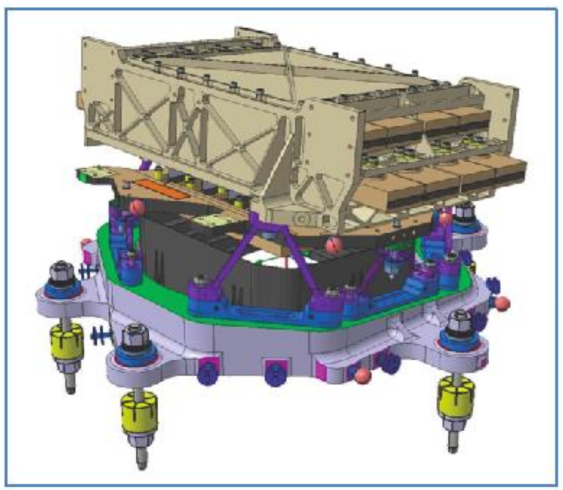
NISP

NISP delivered April 2021

Courtesy: T. Maciaszek and the NISP team



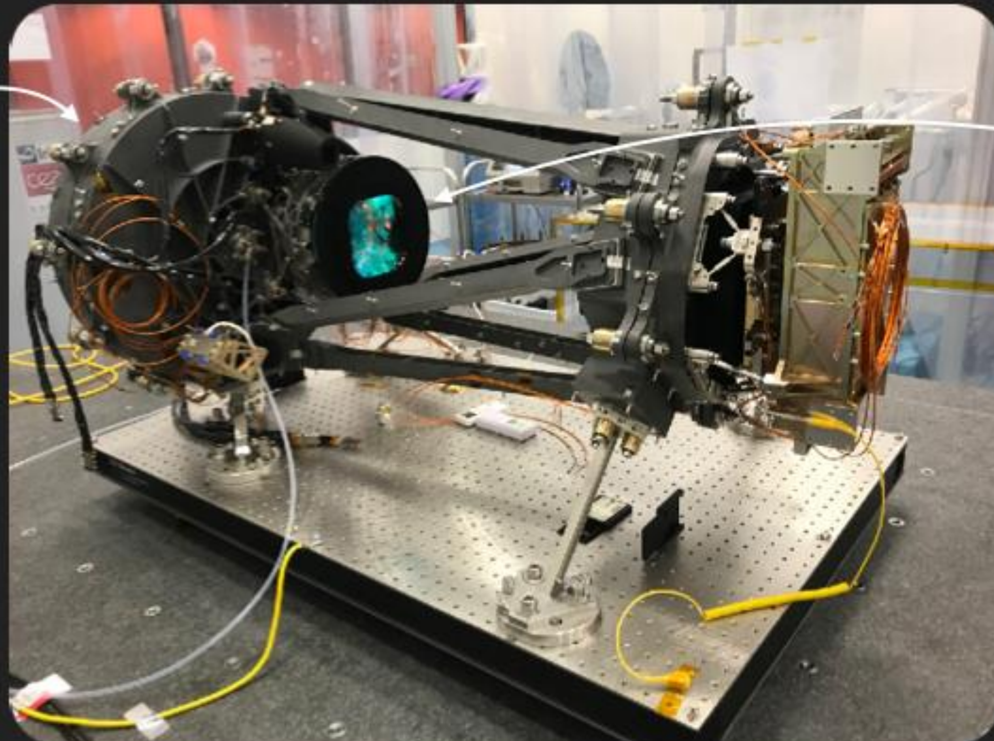




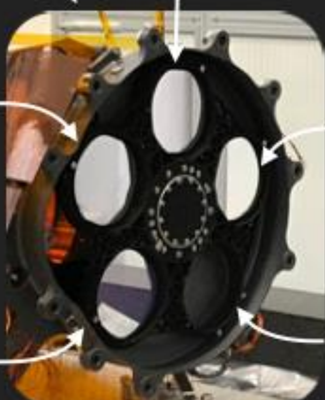
- FoV: 0.55 deg^2
- Mass : 159 kg
- Telemetry: < 290 Gbt/day
- Size: 1m x 0.5 m x 0.5 m
- 16 2kx2K H2GR detectors
- 0.3 arcsec pixel on sky
- Limiting mag, wide survey AB : 24 (5 σ)
- **3 Filters**:
- Y (950-1192nm)
- J (1192, 1544nm)
- H (1544, 2000nm)
- **4 grisms**:
- 1B (920 – 1300) , 1 orientation 0°
- 3R (1250 – 1850), 3 orientations 0° , 270° , 180°

OVERVIEW OF THE NISP INSTRUMENT

CoLA (Corrector lens Assembly)



CaLA (Camera lens Assembly)



GWA (Grism Wheel Assembly)

Slitless Spectrometer:

RGS 0°, 180°, 270°	1250-1850 nm
BGS 0°	920-1250 nm

Photometer:

FW-Y	950 - 1192 nm
FW-J	1192 - 1544 nm
FW-H	1544 - 2000 nm

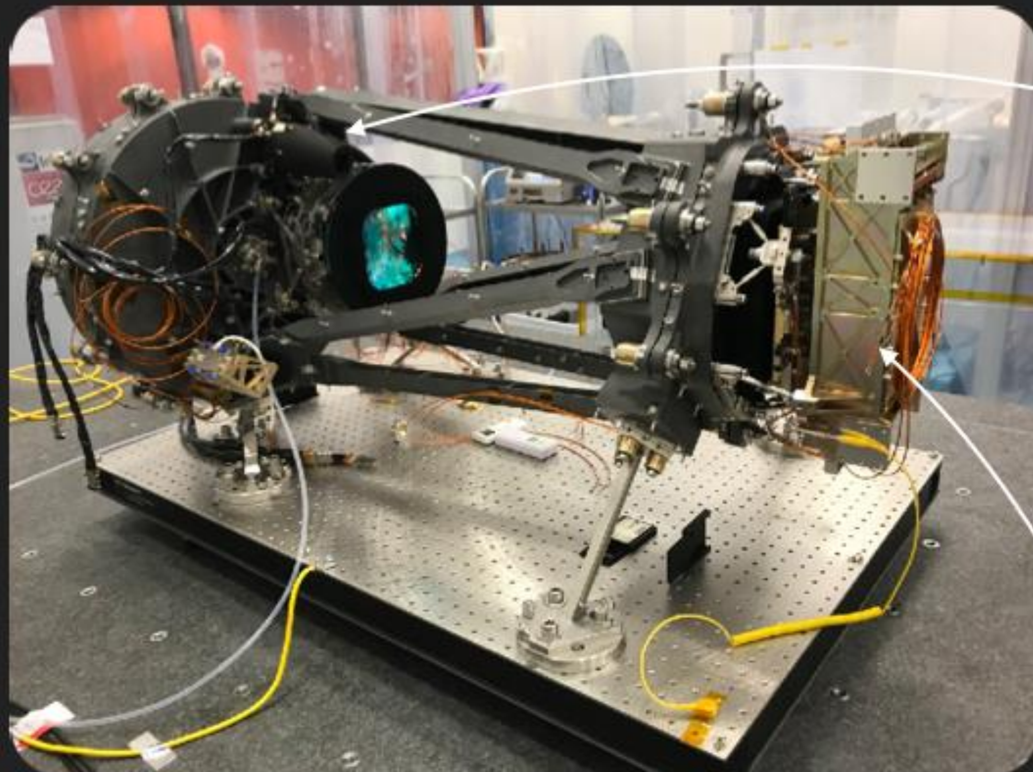
FWA (Filter Wheel Assembly)

Overview of the NISP instrument

Warm electronic

ICU : Instrument Control Unit

DPU : in-flight Data Processing Unit



NI-CU (NISP Calibration Unit)

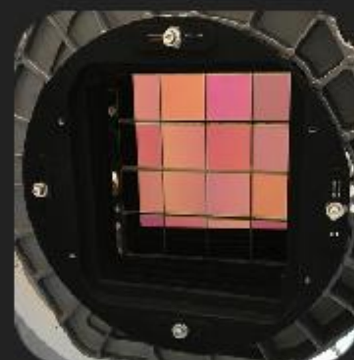
Calibration unit:

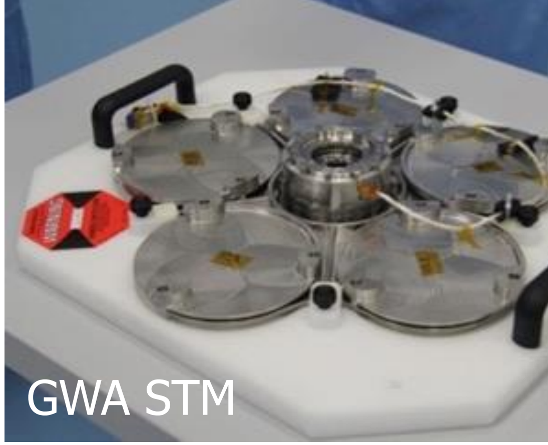
2×5 infrared LEDs (nominal+redundant) for detector flat field and detector calibration

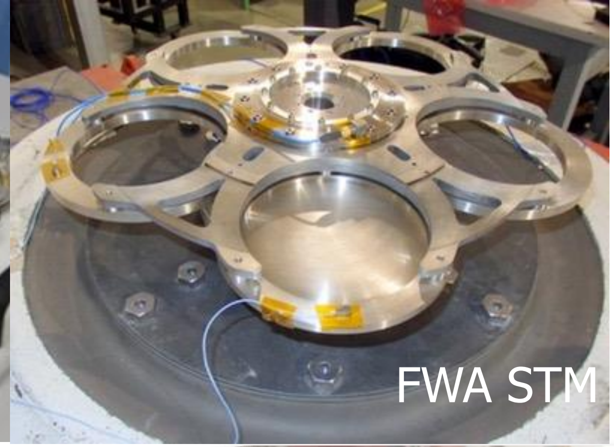
Focal Plane Array:

16 HgCDTe infrared sensor of 2048×2048 pixels

FoV	0.55 deg^2
Pixel scale	0.3″

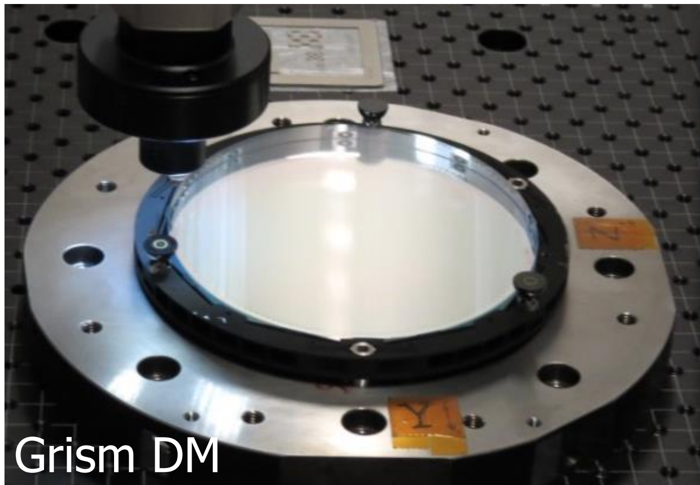


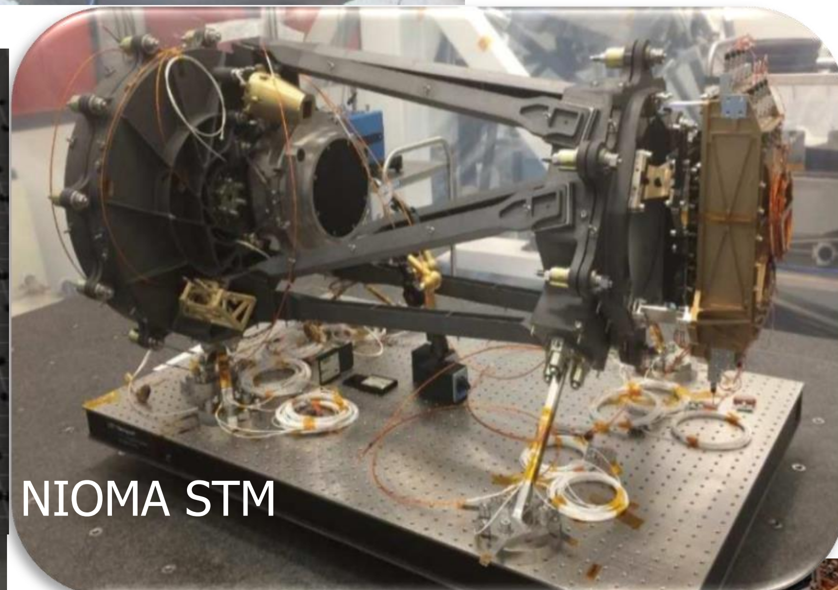


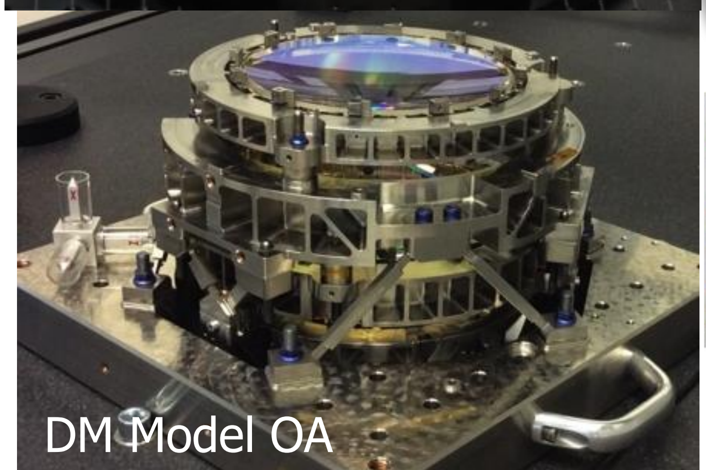


NISP

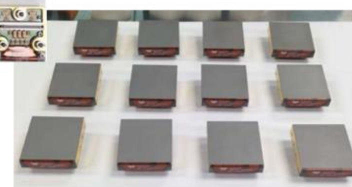
Courtesy::
Euclid
Consortium
NISP team

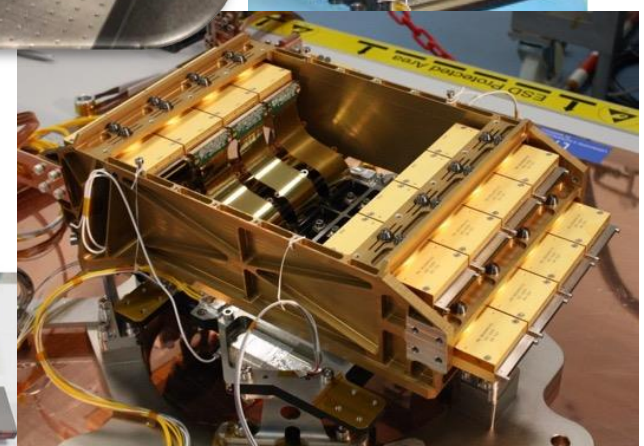






12 flight grade SCA packages were received





Euclid Focal planes

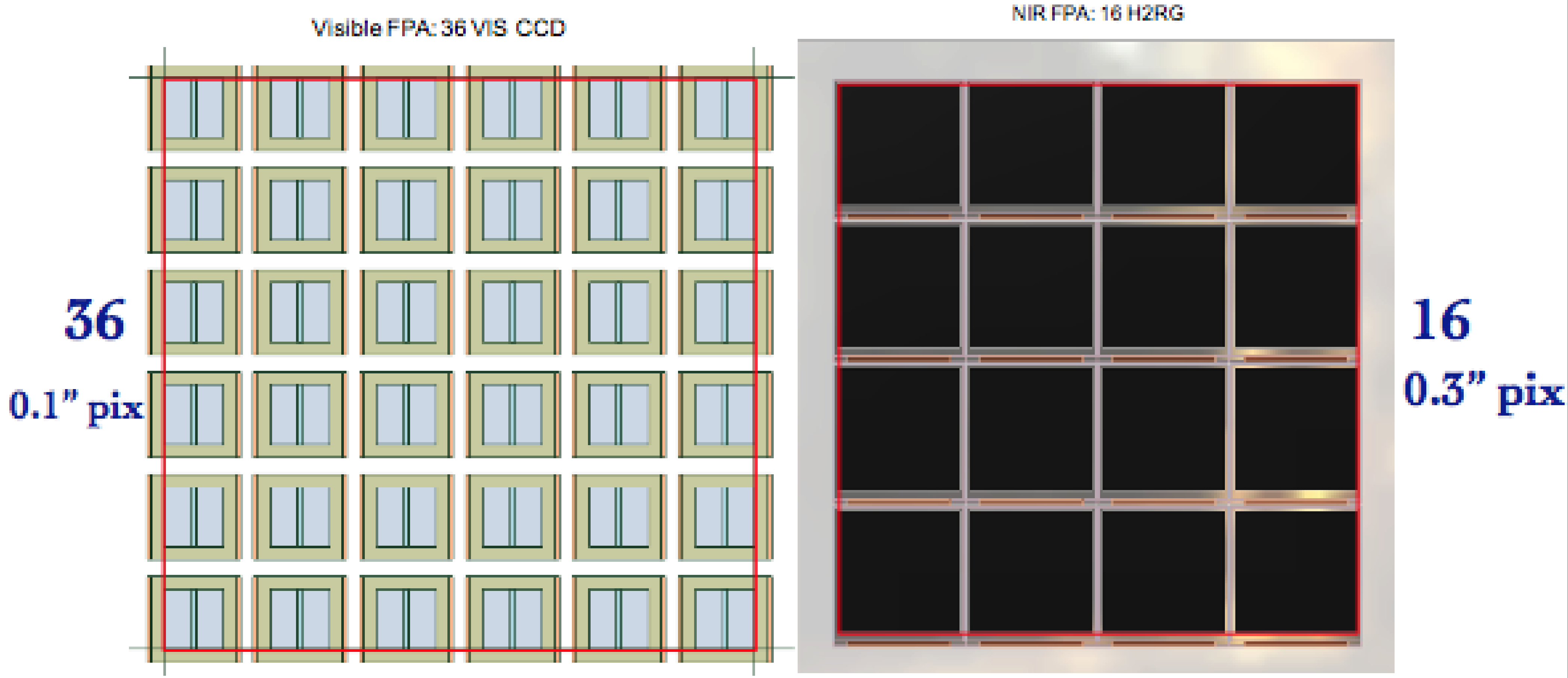
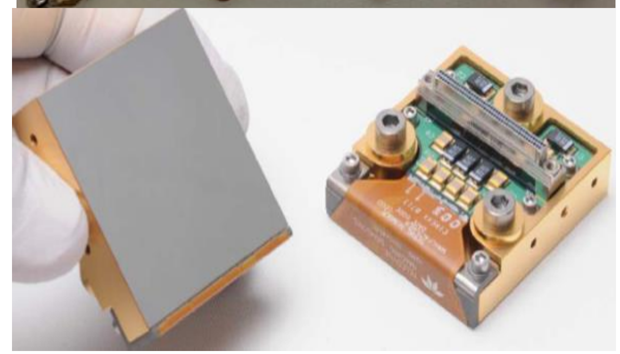


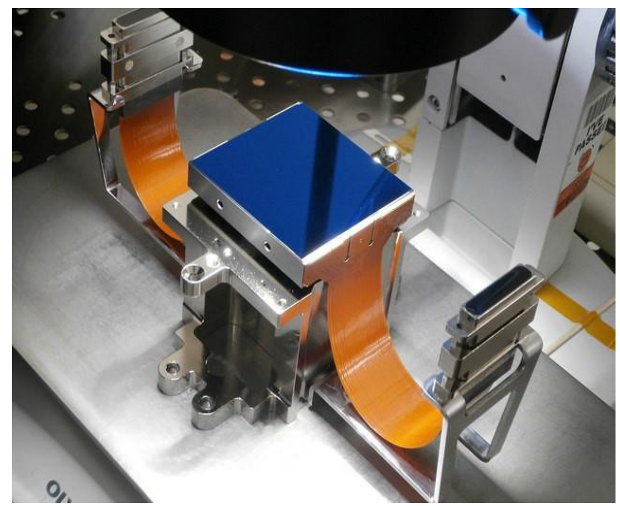
Figure 6-1: VIS (left red ensquared area) and NISP (right red ensquared area) Geometrical FoV.

NIR detectors and VIS 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-

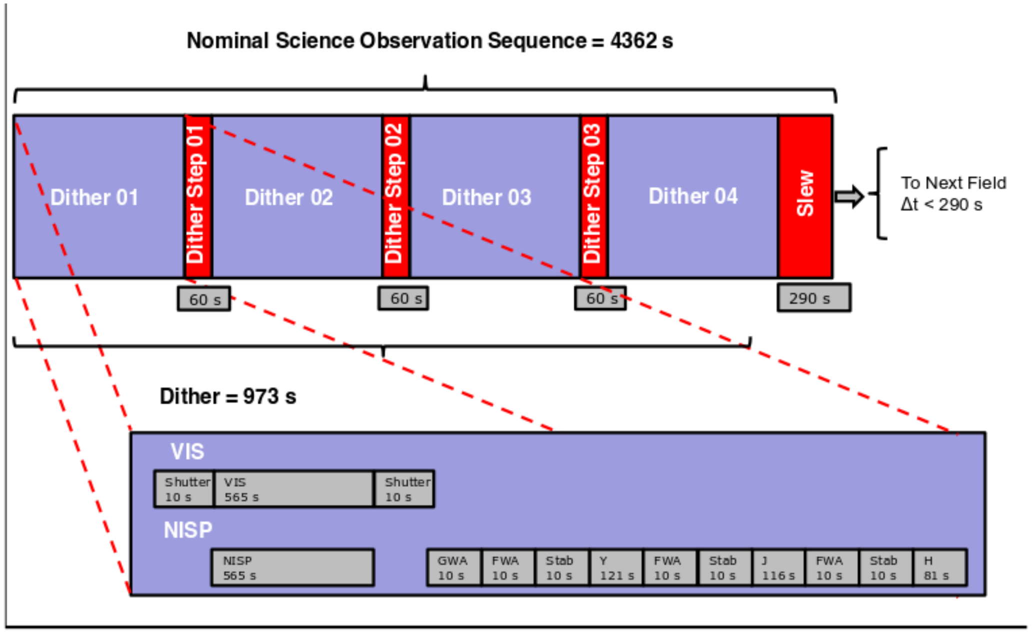


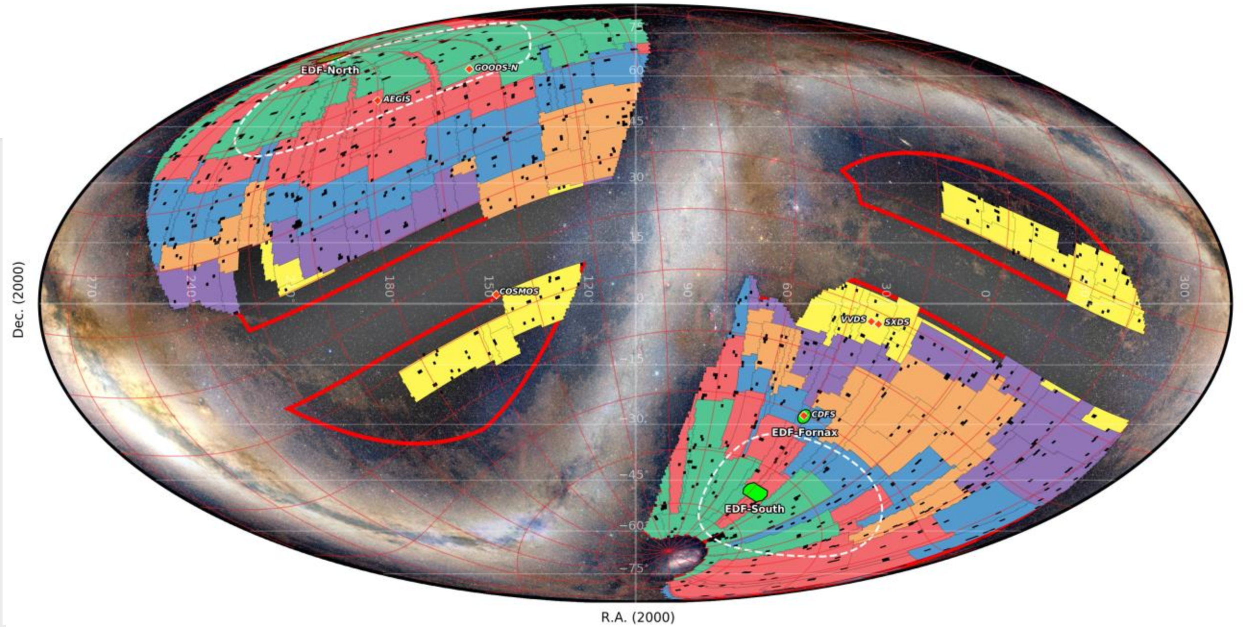
- CCD (e2v), 4096 x 4132 pixels, 12x12 µm FWC=175,000e-
- 4 read-out nodes (in corners)
- SiC package extremely tight flatness
- QE ≥ 70% 500nm to 850nm (95% at 650nm)
- PRNU much better than 2% at all spatial scales
- Noise better than required 3.6 e- at 70 kpix/s

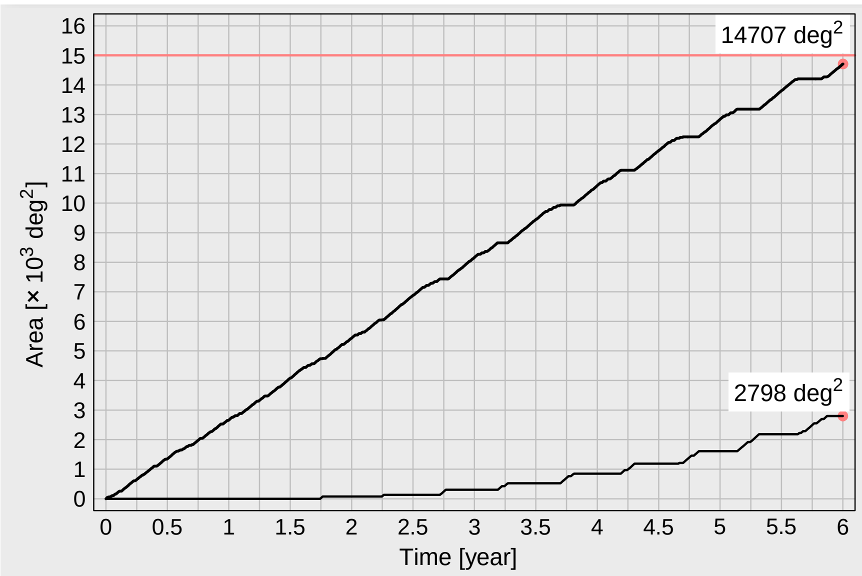


Euclid Survey

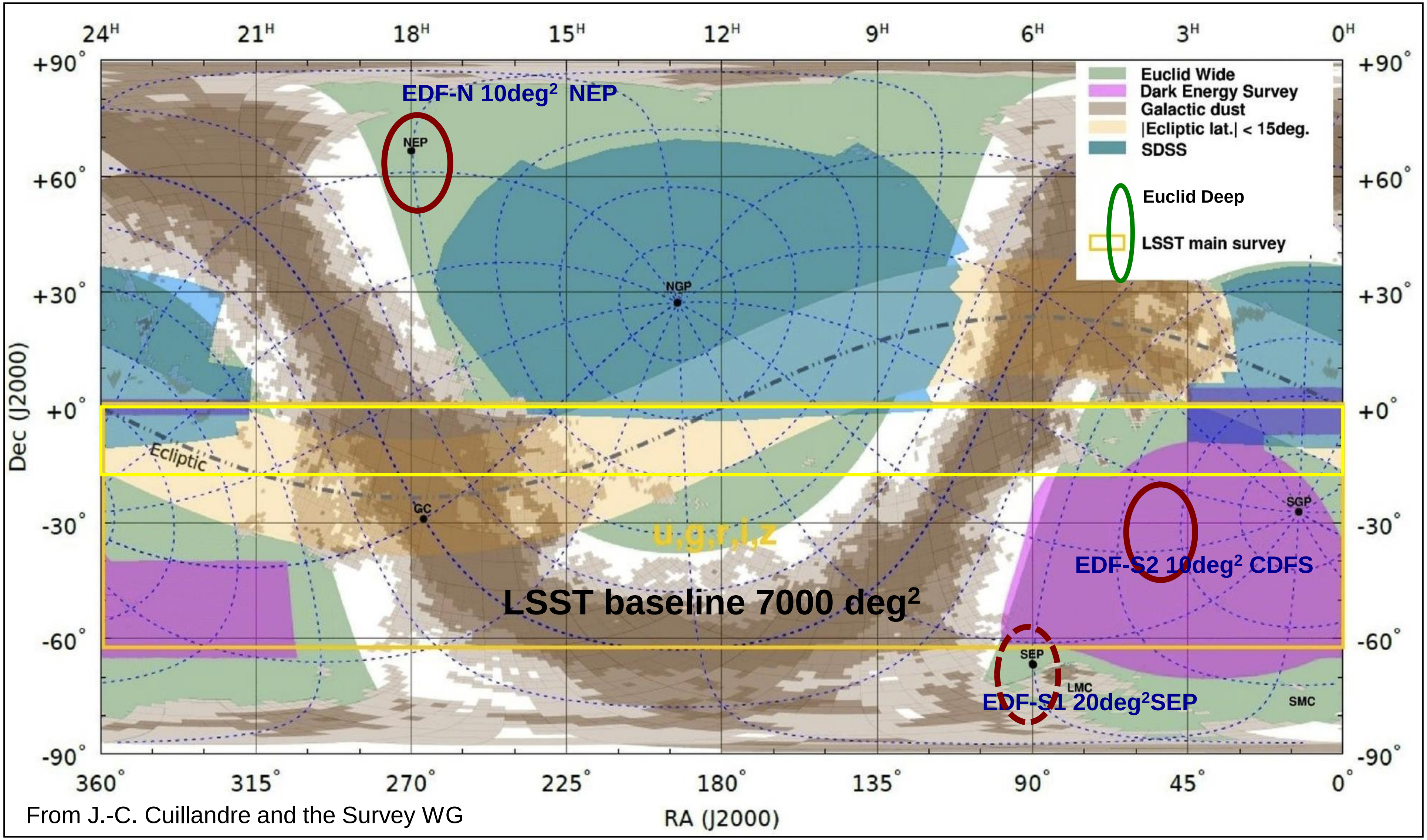
- |b|>30º
- Minimise SAA variations;
- Minimise zodiacal light
  → high ecliptic latitude;
- Low galactic extinction;
- Specific pointed calibration;
- Wide survey: one visit / field
- Deep survey: many visits







Euclid Wide and Deep Surveys



From J.-C. Cuillandre and the Survey WG

Euclid complementary data

- Spectroscopy:
  - 45 nights at Keck telescope: spectroscopy on Euclid Wide fields north
  - 25 nights at VLT VMOS/KMOS: spectroscopy on Euclid Wide fields south
  - pilot programme at GTC: preparation of a spectroscopic large program
- Complementary space data on Euclid Deep Fields:
  - 5300 hrs of Spitzer satellite, period 13, priority 1 on 2 Euclid Deep field (20 deg2)
- Complementary visible photometry on Euclid Wide:
  - 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
  - *i*-band and *z*-band on Euclid Wide Norht with Pan-STARRS PS1/2

Ground Segment

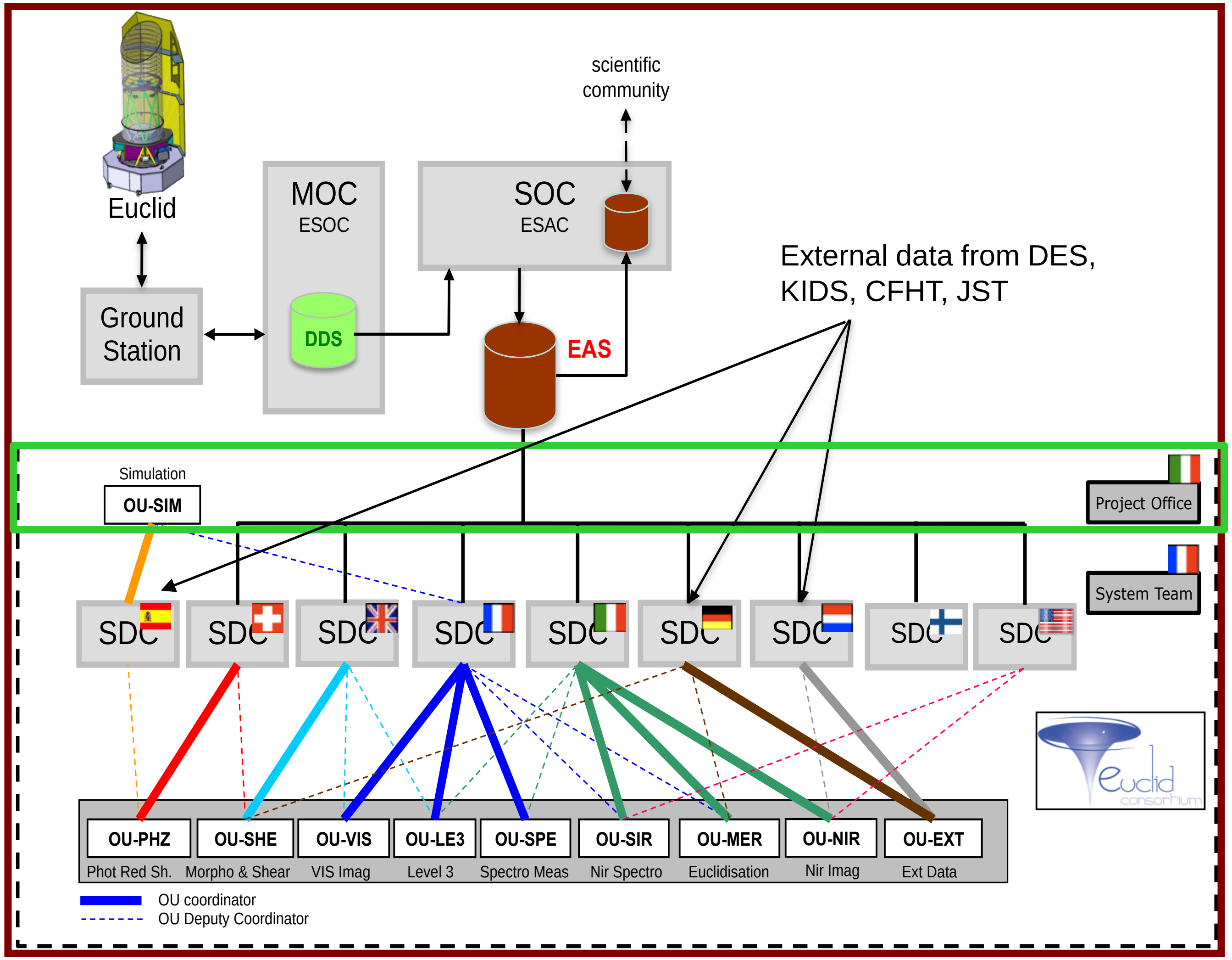
Complex organisation:

- 10 Organisation Units
- 9 Science Data Centers

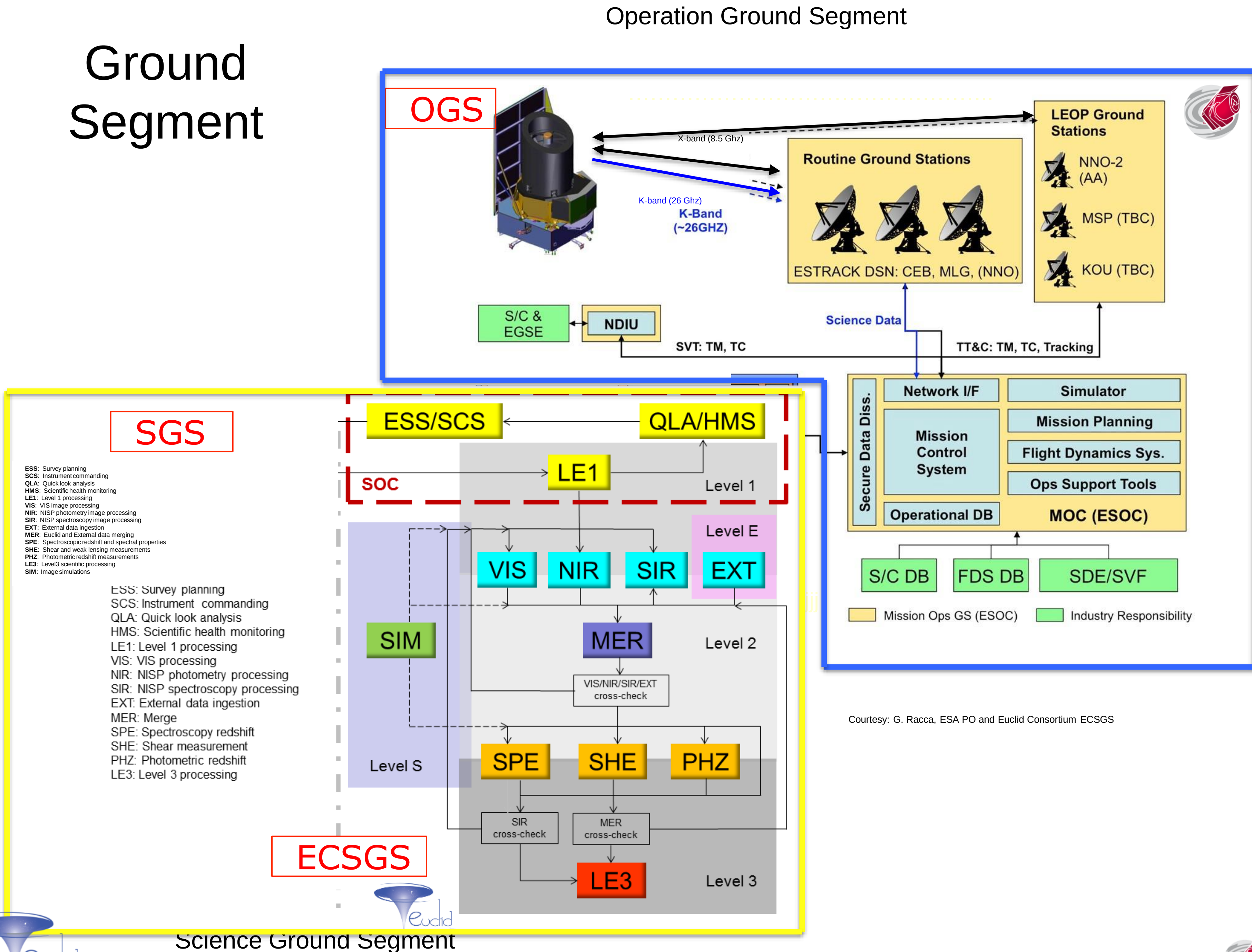
Data: huge volumes, heterogeneous data sets

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

SGS Implementation Review passed Mar 2021



Ground Segment

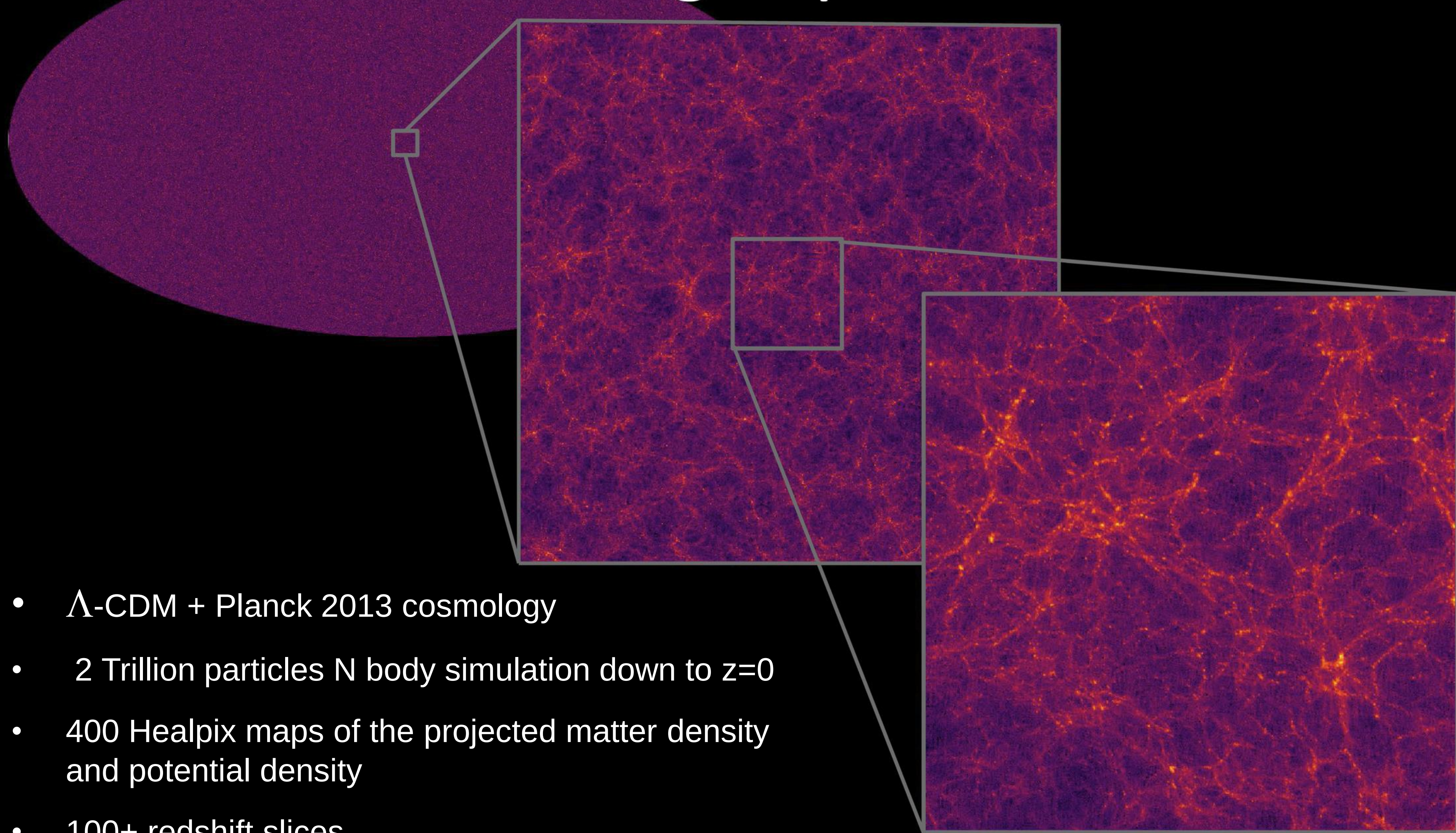


Courtesy: G. Racca, ESA PO and Euclid Consortium ECSGS

Euclid Flagship Simulation:

a tool for Euclid E2E performances

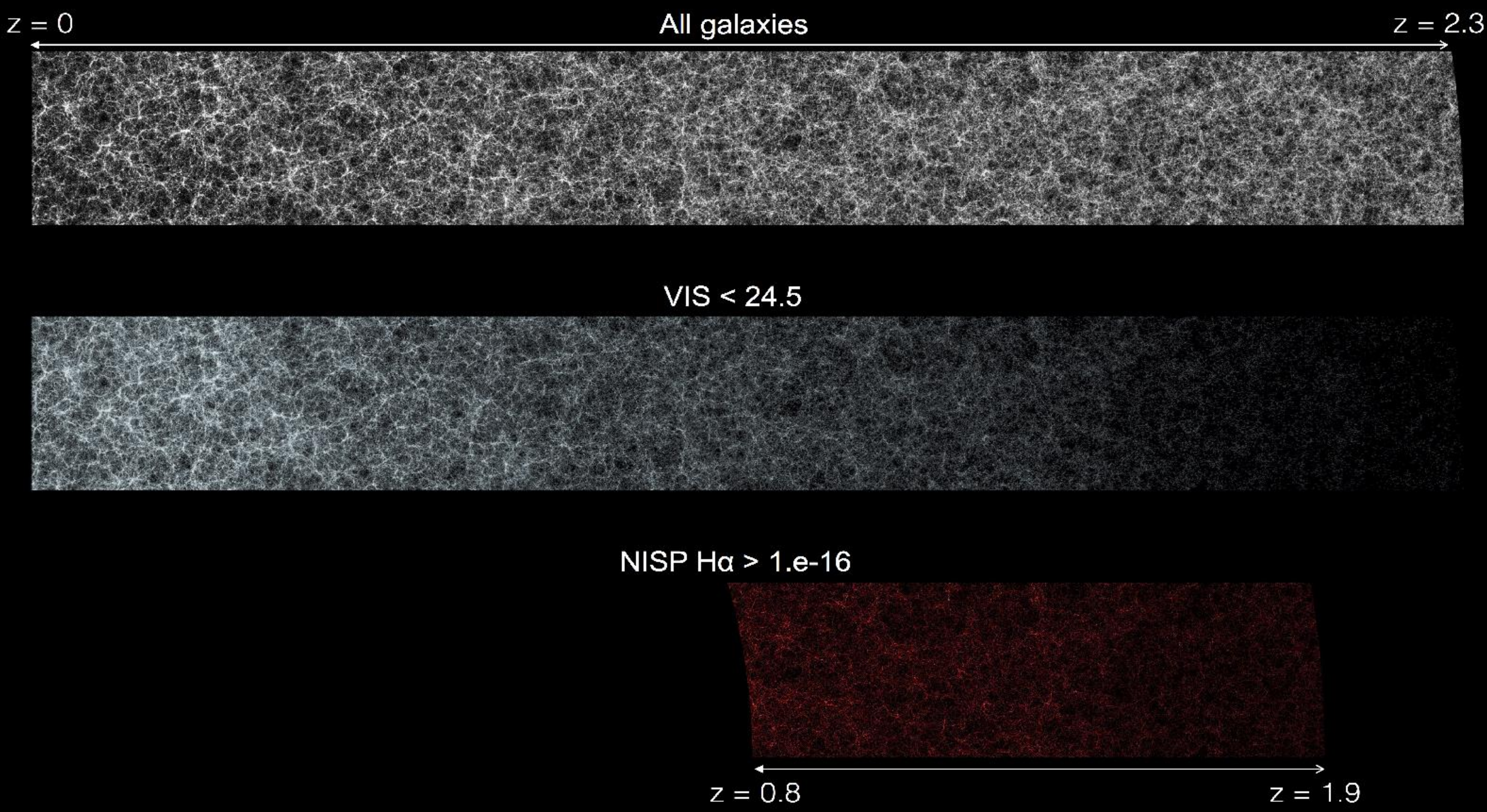
The Euclid Flagship Simulation



- Λ-CDM + Planck 2013 cosmology
- 2 Trillion particles N body simulation down to z=0
- 400 Healpix maps of the projected matter density and potential density
- 100+ redshift slices
- Consistent mocks for WL and GC

From D. Potter, J. Stadel, R. Teyssier

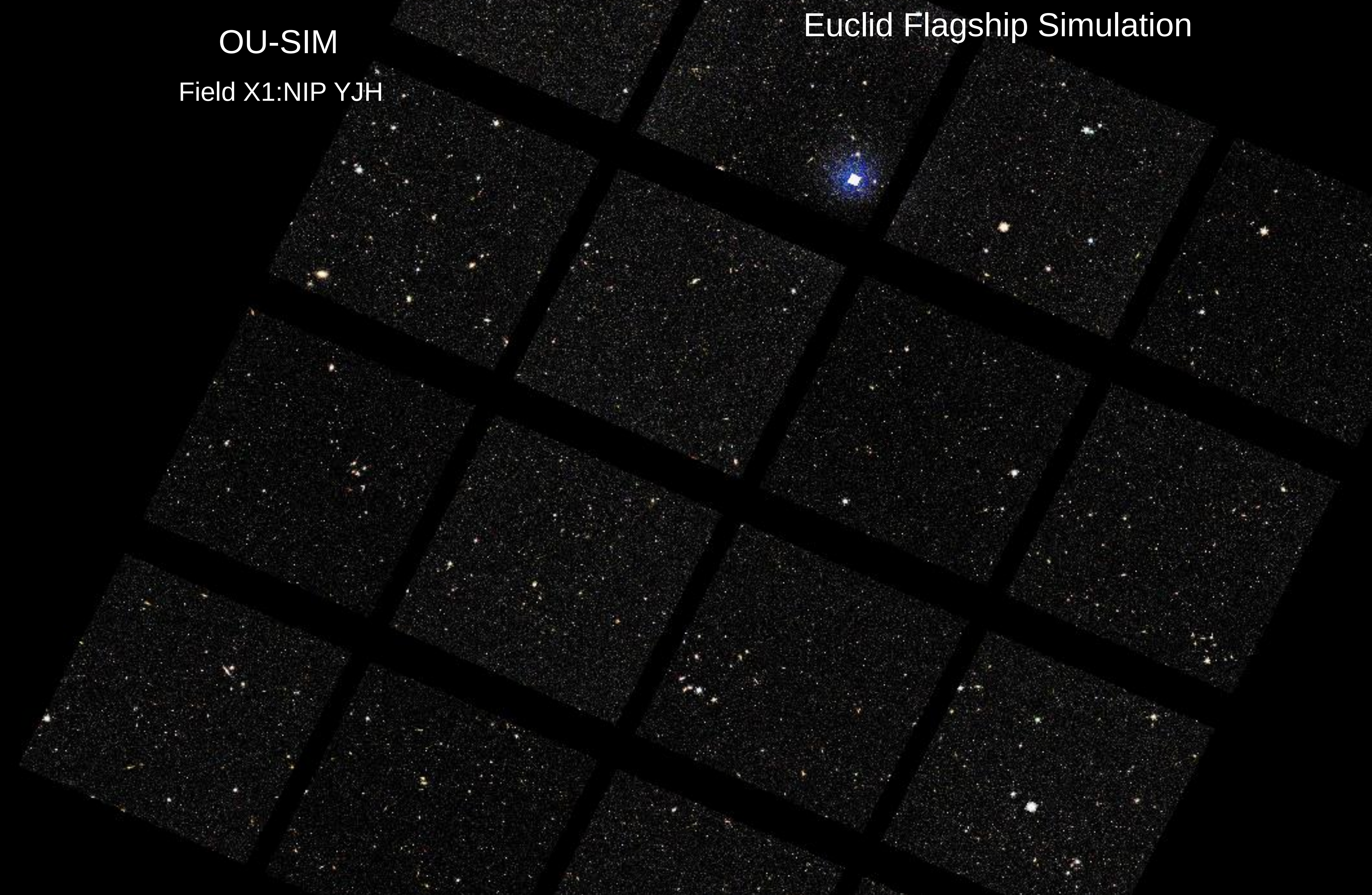
Euclid Flagship Simulation: mock galaxy catalog



OU-SIM

Field X1:NIP YJH

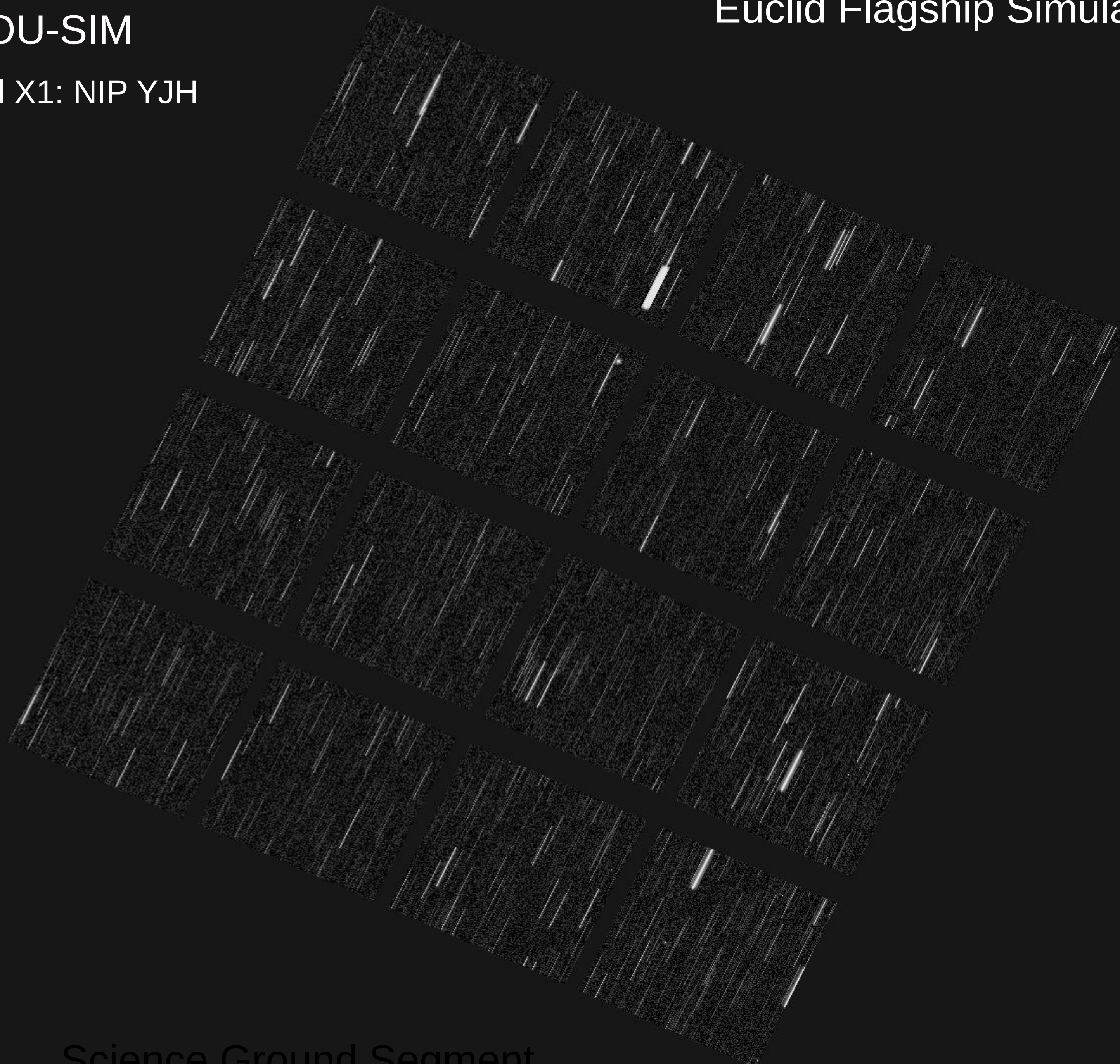
Euclid Flagship Simulation


OU-SIM
Field X1:NIP YJH
Euclid Flagship Simulation

OU-SIM

Field X1: NIP YJH

Euclid Flagship Simulation

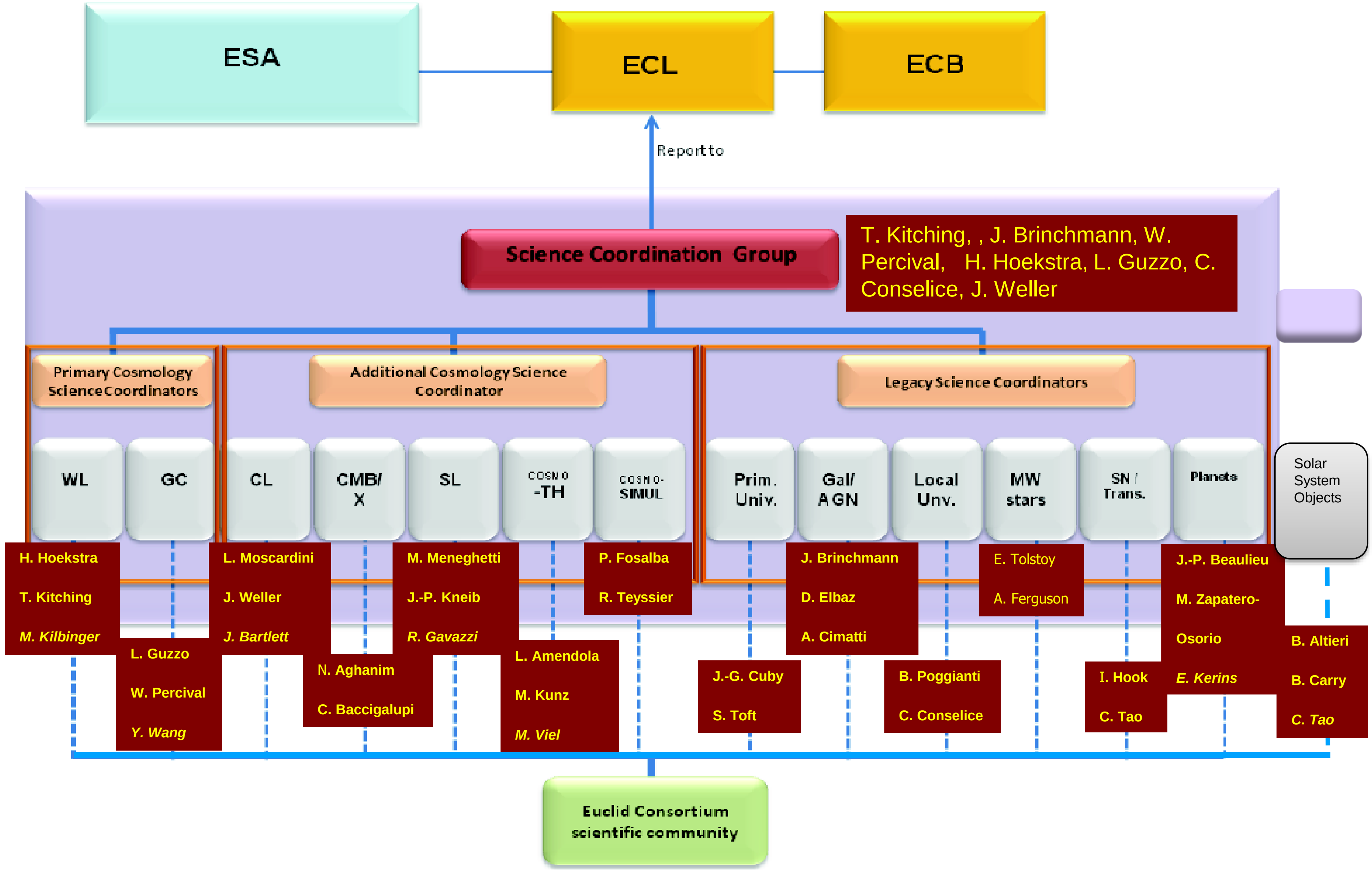


Science Ground Segment


OU-SIM
Field X1: NIP YJH
Euclid Flagship Simulation

Performances and forecasts

EC Science Working Groups



Performance Status on Oct 2018

Technical Performance Measure		Requirement	CBE Current
Image Quality			
VIS Channel	FWHM (@ 800nm)	180 mas	160 mas
	ellipticity	15.0%	9.4%
	R2 (@ 800 nm)	0.0576	0.0551
	ellipticity stability σ(εi)	2.00E-04	1.90E-04
	R2 stability σ(R2)/<R2>	1.00E-03	1.00E-04
	Plate scale	0.10 "	0.100 "
NISP Channel	rEE50 (@1486nm)	400 mas	225 mas
	rEE80 (@1486nm)	700 mas	584 mas
	Plate scale	0.30 "	0.299 "
Sensitivity			
VIS SNR (for mAB = 24.5 sources)		10	16.99
NISP-S SNR (@ 1.6um for 2xe-16 erg cm-2		3.5	4.81
NISP- P SNR (for mAB = 24 sources)	Y-band	5	5.89
	J-band	5	6.69
	H-band	5	5.34
NISP-S Performance			
Purity		80%	72%
Completeness		45%	52%
Survey			
Wide Survey Coverage		15,000 deg2	15,000
Survey length [years]		5.5	5.4

From ESA PO

Mission CDR passed in Oct 2018

Euclid performances meet the scientific and survey requirements

- Image quality of the system fully in line with needs.
- Ellipticity, R^2 stability and Non-convolutive errors performance dictated mainly by ground processing
- *Purity* not compliant with current data processing methods but expected to be recovered with Euclid specific algorithms (not yet installed at this stage).

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

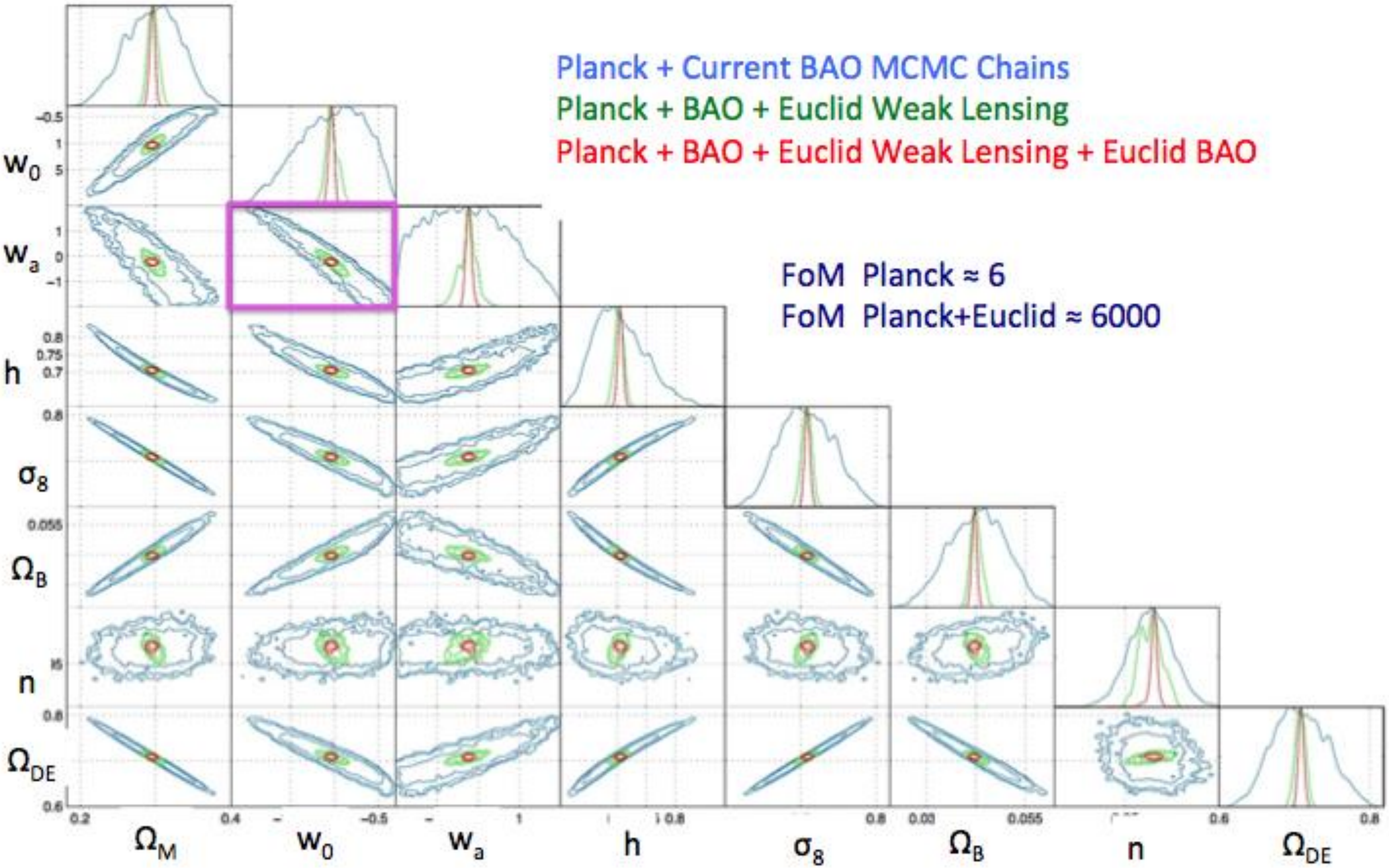
DE equation of state: $P/\rho = w$, and $w(a) = w_p + w_a(a_p - a)$

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

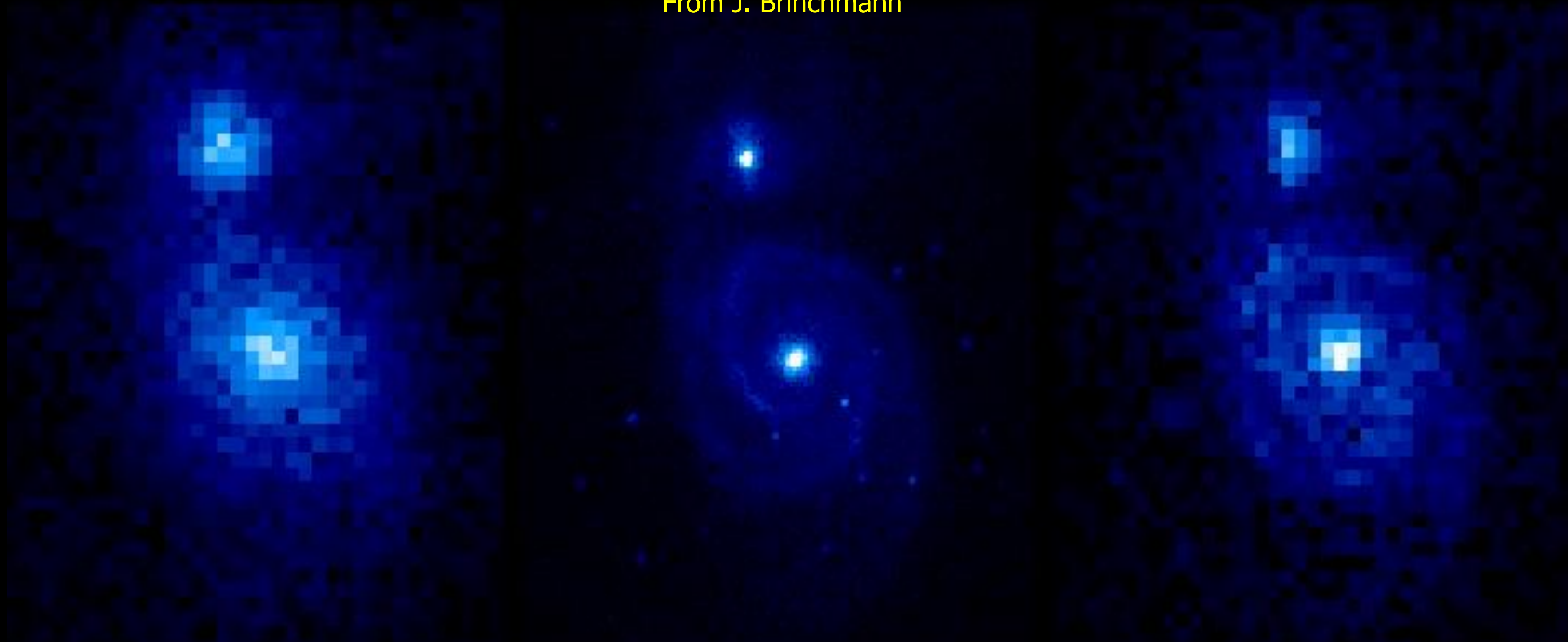
Euclid Science prediction



Euclid Legacy Science

VIS: Simulation of M51

From J. Brinchmann

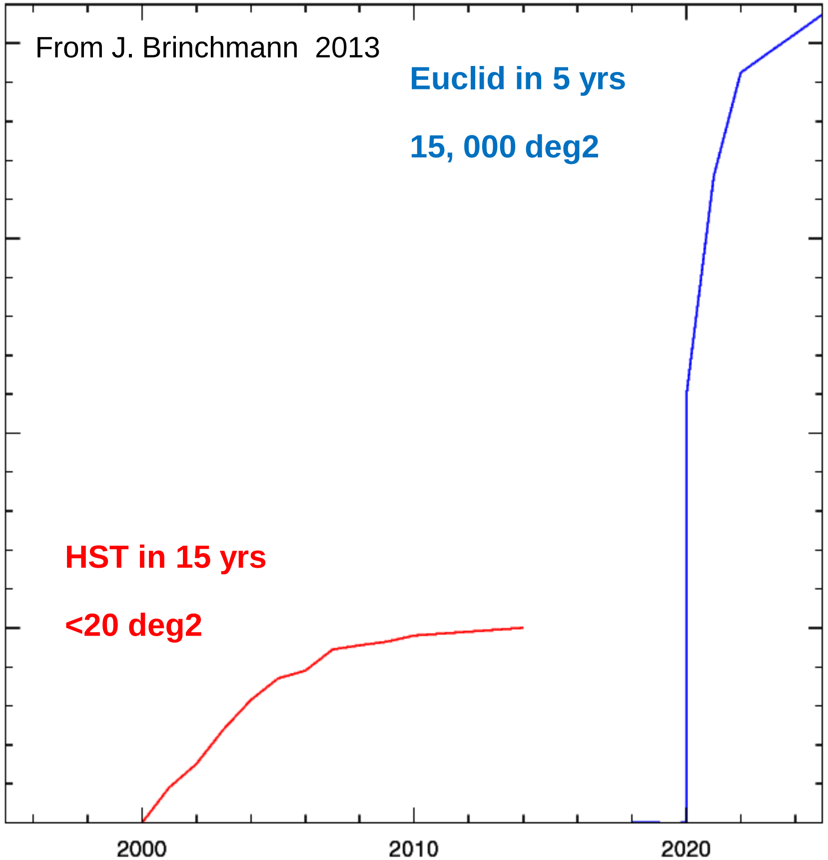


2.4m SDSS-like @ z=0.1 | Euclid @ z=0.1 | Euclid @ z=0.7

- 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

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

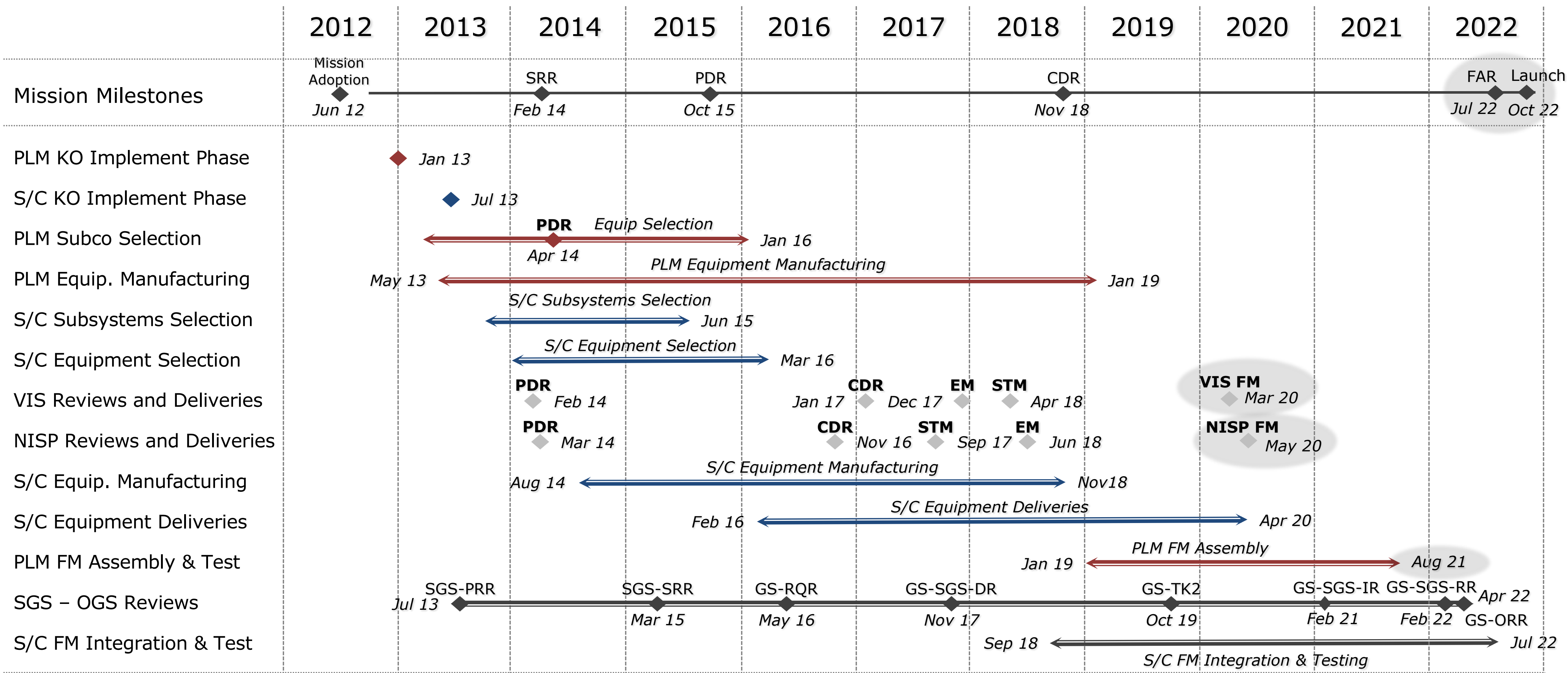


- Spectroscopic targets for JWST, E-ELT, TMT, Subaru, VLT, 4MOST, MSE,
- Synergy with Rubin-LSST, eROSITA, Subaru/HSC, Roman, Planck, SKA

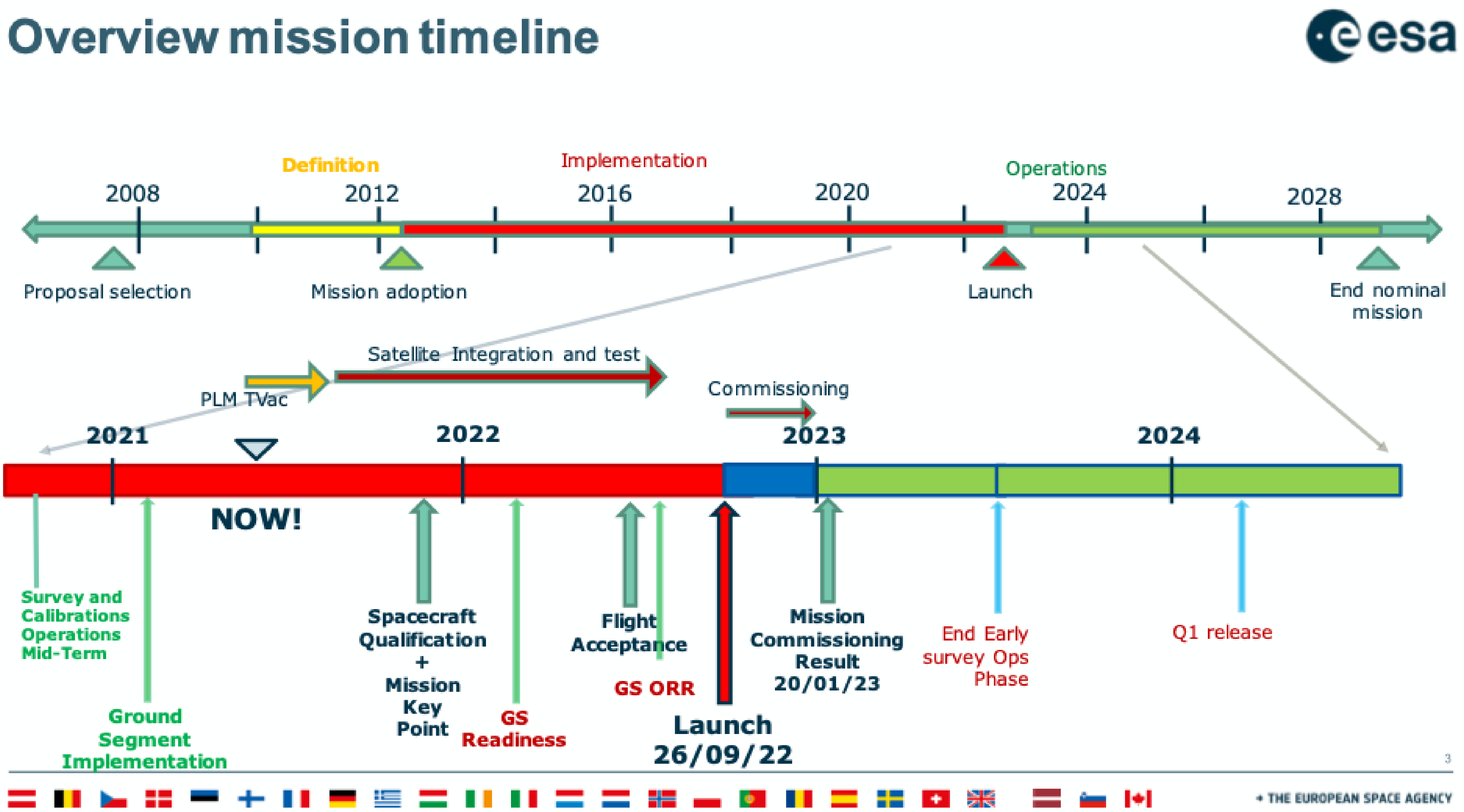
Schedule

Euclid Schedule

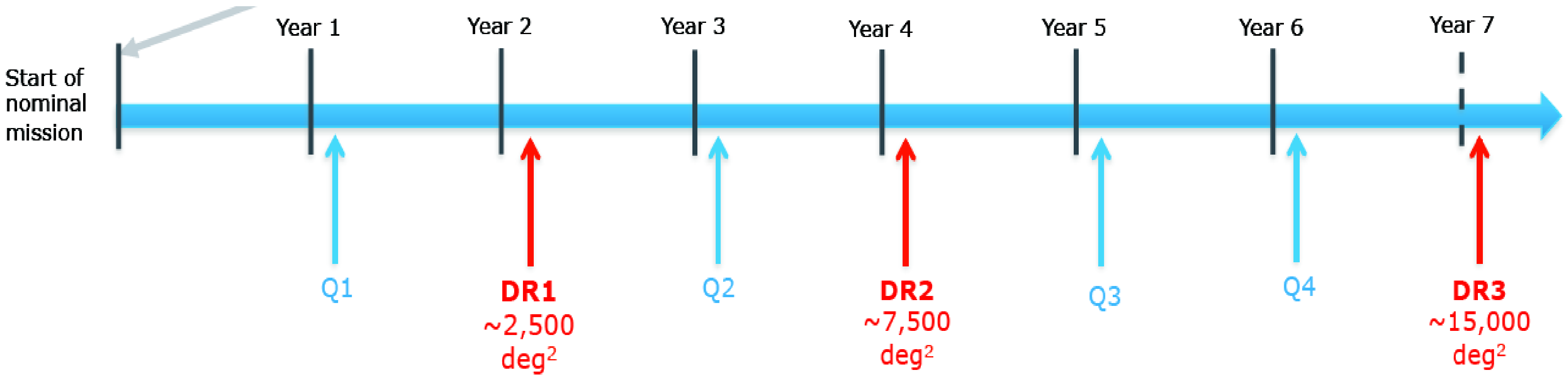
Euclid Schedule: Lausanne 2021



Mission Timeline



Data Releases



Science with Euclid will start in 2024 with Q1 and in 2025 with DR1

Summary

- Euclid cosmology mission to study the structure of the Universe and the nature of dark energy:
  - Uses 3 cosmological probes, and their cross-correlations
  - Optimised for Weak Lensing and Galaxy Clustering
  - Perfect complementarity with Planck: probes and data, cosmic time
  - 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: Rubin-LSST, Roman, e-ROSITA, SKA
- Euclid =12 billion sources, 35 million redshifts, 1.5 billion shapes/photo-z of galaxies;
  - A huge dataset of images and spectra for the community to study for years;
  - A reservoir of spectroscopic targets for JWST, E-ELT, TMT, ALMA, VLT, MSE, 4MOST, MOONS,
  - A set of astronomical catalogues useful until 2040+
- Big challenges: data processing (100-300 Petabytes), cosmological simulations
- Launch 2022, start 2023: **2500 deg^2 public in 2025**, 7500 deg^2 in 2027, final 2029

Euclid Consortium Meeting in Helsinki 2019

Thanks