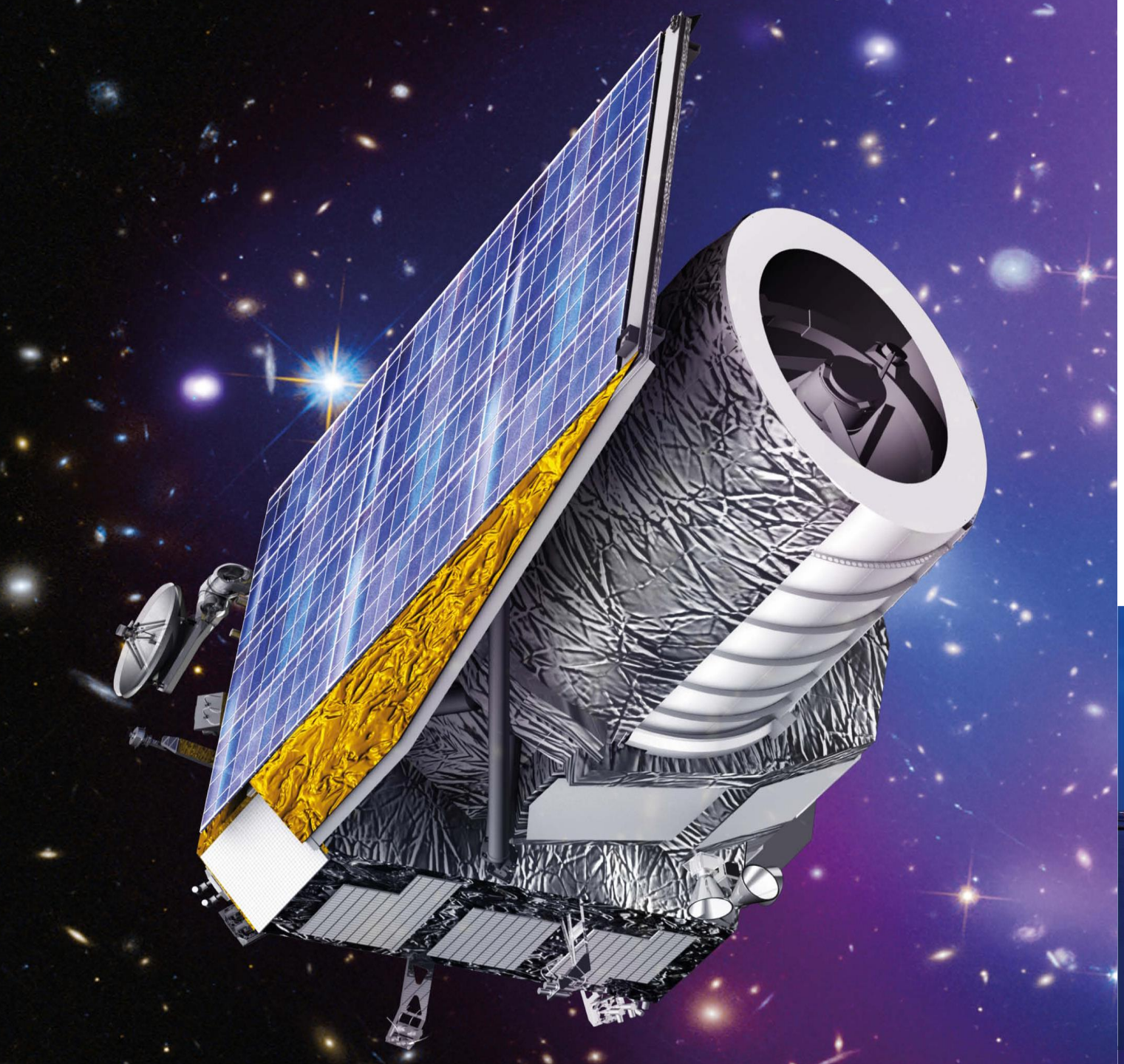
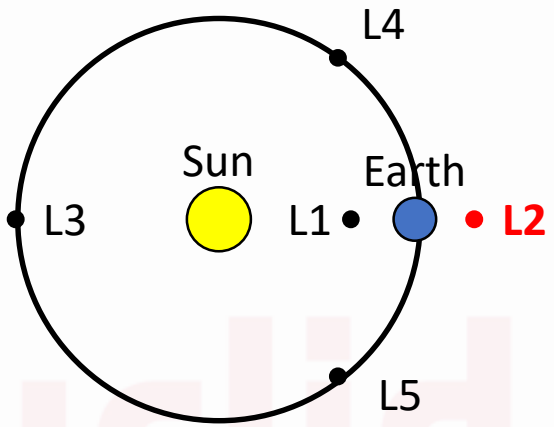


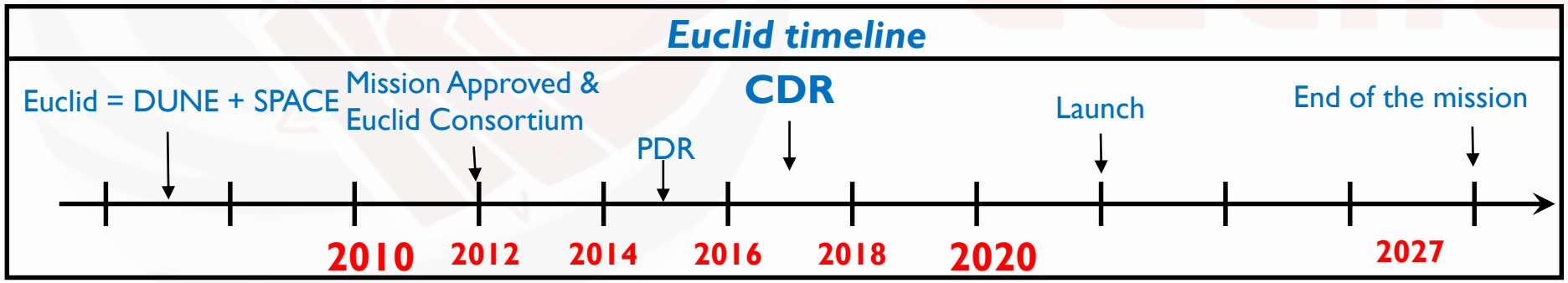
The Euclid Mission

M. Tenti on behalf of the INFN Euclid Team

The Euclid Mission

- Euclid is a **medium class** mission of the ESA **Cosmic Vision** program (2015-2025)
- **Launch: 2022** from ESA spaceport in Kourou (France Guyana) with Soyuz ST-2.1 B rocket
- Orbit around the Lagrangian point **L2** of Sun-Earth system (1.5 Mkm from Earth)
- Nominal mission: **6.5 years**





Euclid Consortium

euclid

Euclid Consortium

- The Euclid Consortium has been selected by ESA in June 2012 as the **single** official scientific consortium having the **responsibility** of:
  - the scientific instruments,
  - the production of the data and
  - leading the scientific exploitation of the mission

until completion.

- 13 European countries + USA & Canada
- ~ 2000 members
- Lead: Chair (Y. Mellier – IAP France) + EC Board
- France, Italy & UK are the major contributors

Physics Motivation

- *Why*: understand the physical origin of the **accelerated expansion** of the Universe
- *How*: mapping **matter distribution** at different redshifts (i.e. looking ~ 10 Gyr back in time)
- Two fundamental questions:
  - Q1: What are the nature/properties of Dark Energy?
  - Q2: Is the General Relativity still valid at cosmological scales? Modified Gravity?
- Other primary goals: information on Dark Matter, Neutrino masses and numbers

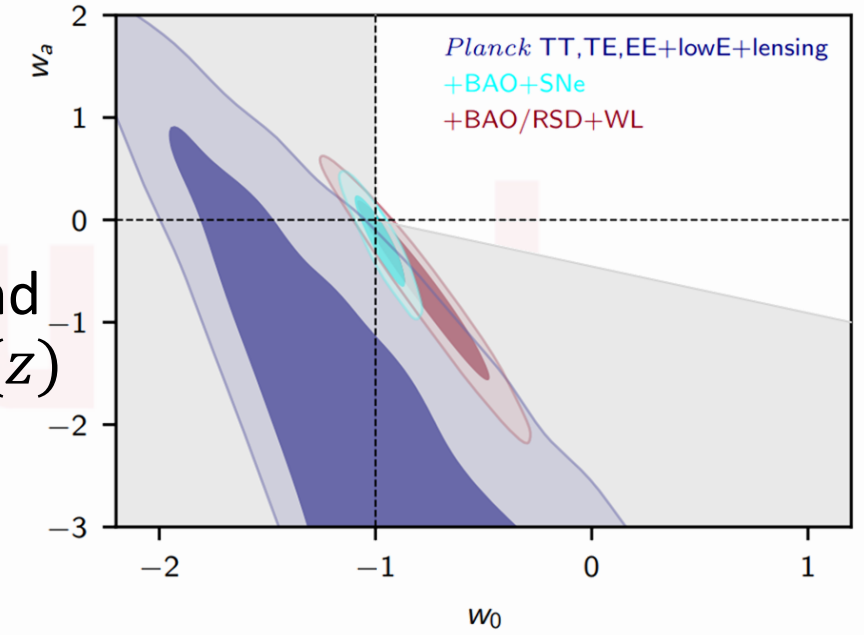
Q1: Dark Energy

- Is cosmic acceleration produced by a cosmological constant or by an evolving scalar field?
  - Evolving equation of the state of DE: $w(a) = p(a)/\rho(a)$

$$w(a) = w_0 + w_a(1-a) + \cdots$$

- Measure the expansion history of the Universe $H(z)$ and its content to high accuracy $\rightarrow$ DE equation of state: $w(z)$
  - Baryon Acoustic Oscillation (BAO): scale of BAO in the clustering pattern of galaxies as a standard ruler
  - Weak Gravitational Lensing (WL): shape distortions maps matter distribution

Planck Coll. 2018, VI

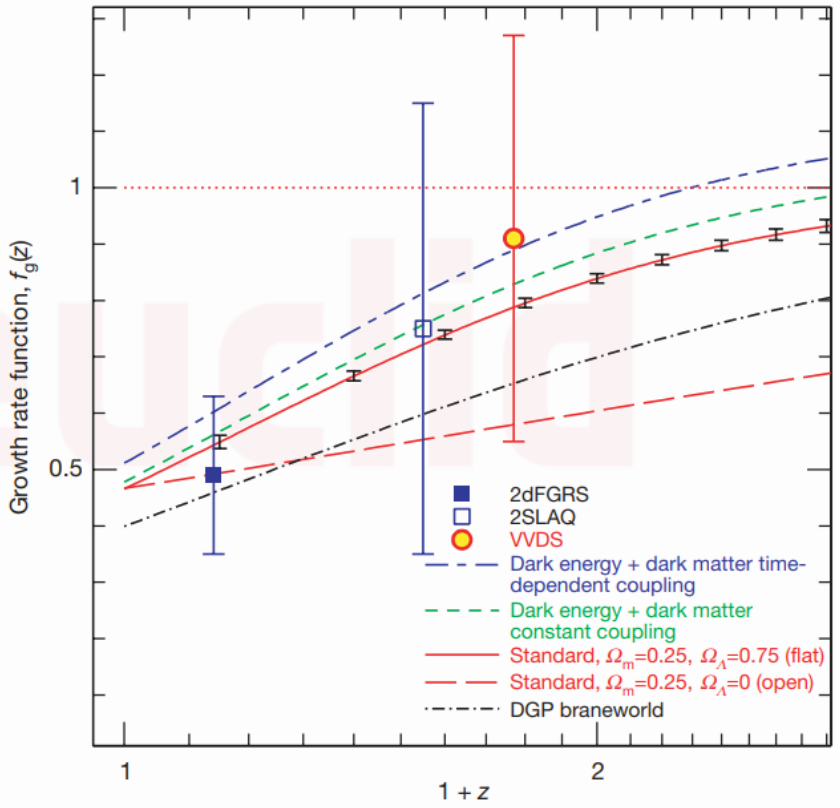


Q2: General Relativity or Modified Gravity?

- Does General Relativity still work on cosmological scales? Modified Gravity instead of Dark Energy…?
  - Structure's growth rate: $f(z) = [\Omega_m(z)]^\gamma$
    - General Relativity predicts $\gamma = 0.55$
    - Do we need Modified Gravity?

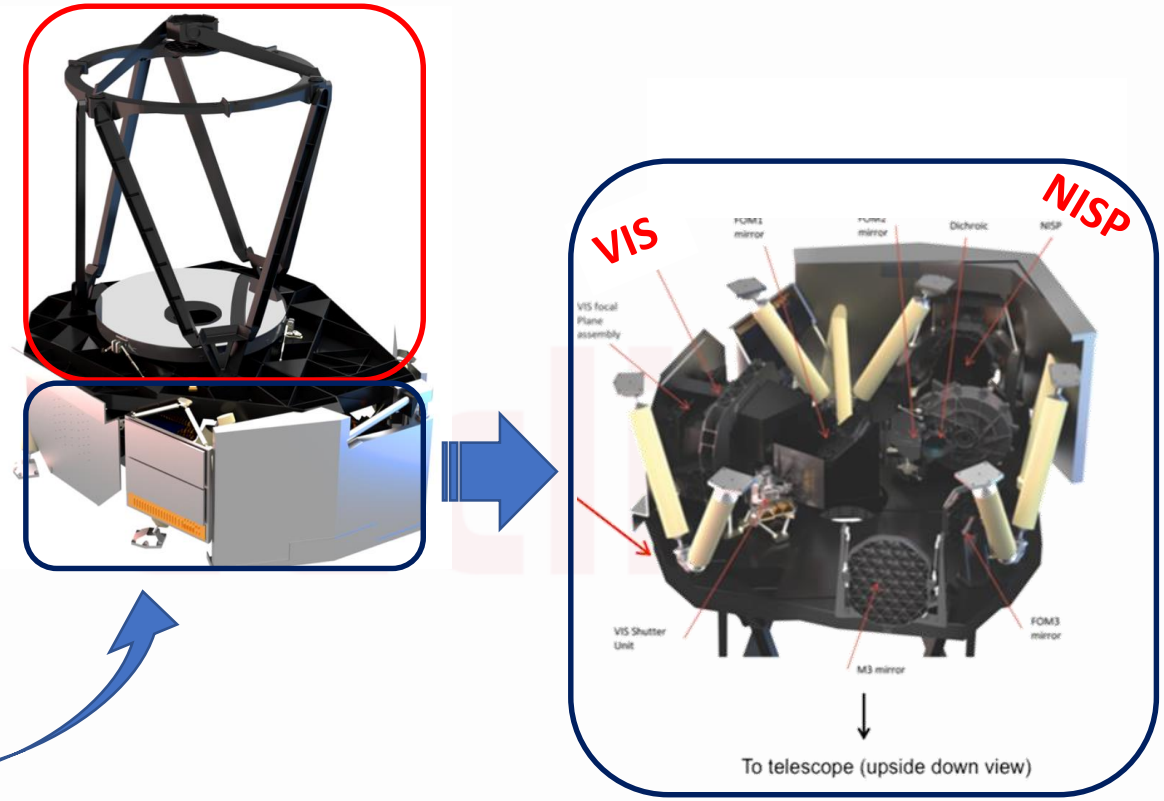
- Measure the growth rate of structures $f(z)$ $\rightarrow$ detect modifications of gravity
  - Redshift Space Distortions (RDS)
  - Weak Gravitational Lensing (WL) tomography

Nature **451,** 541–544 (2008)



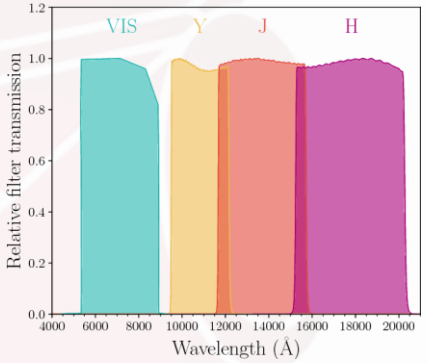
Spacecraft

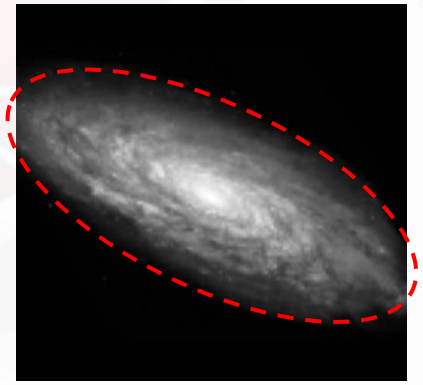
- Mass: ~ 2020 kg
- Size: 4.5 x 3 x 3 m^3
- Telescope: **1.2 m aperture Korsch** configuration
- Mirror and structure in Silicon Carbide (rigidity and stability)
- **850 Gbit** (K-band) downlink in 4 hour/day
- Two instruments:
  - **Visible CCD** [VIS]
  - **Near Infrared Spectro-Photometer** [NISP]

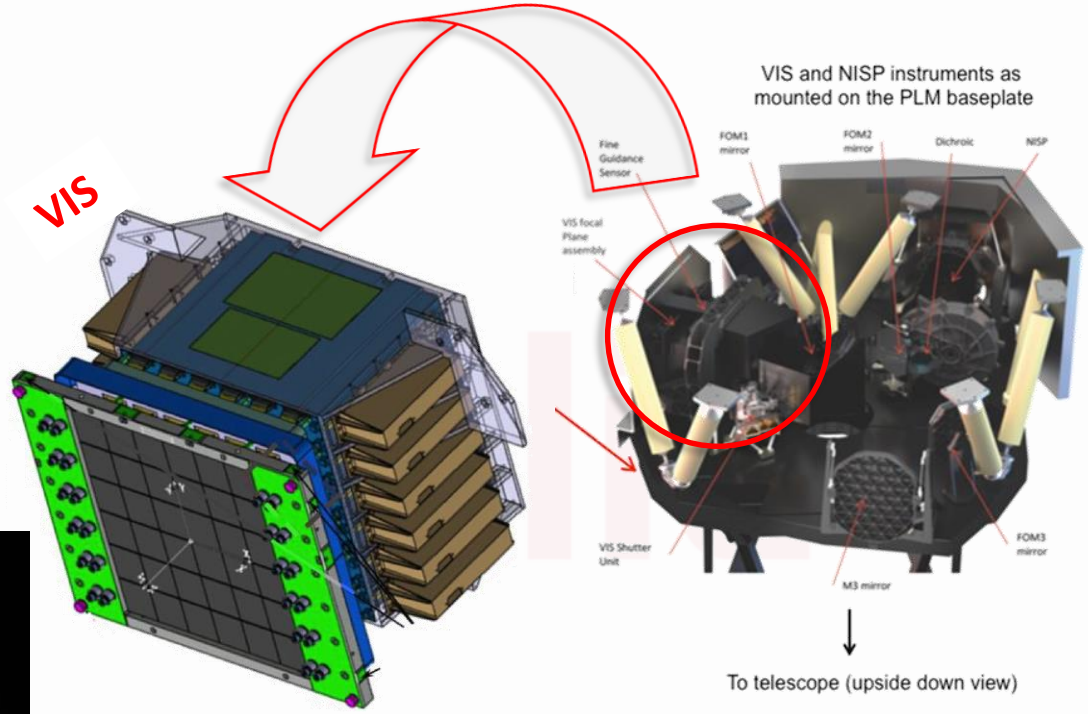


Visible CCD

- 36 (4k x 4k) CCDs, 12 μm pixel
- Resolution: 0.1 arcsec
- Field of view: 0.54 deg^2
- Very broad band filter [550 nm – 900 nm]
- 1.5 x 10^9 galaxy shape down to 24.5 mag with S/N > 10

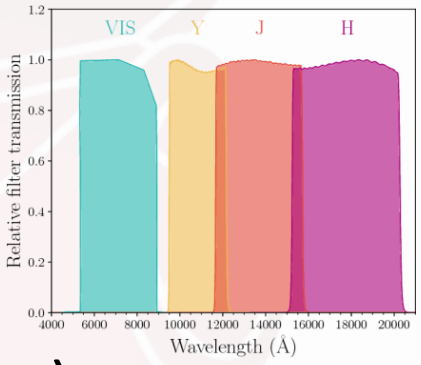


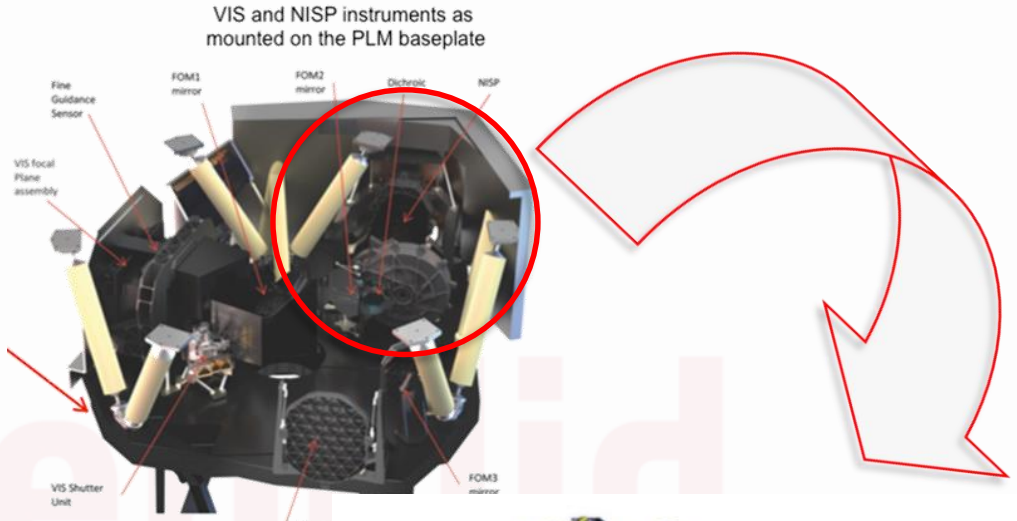


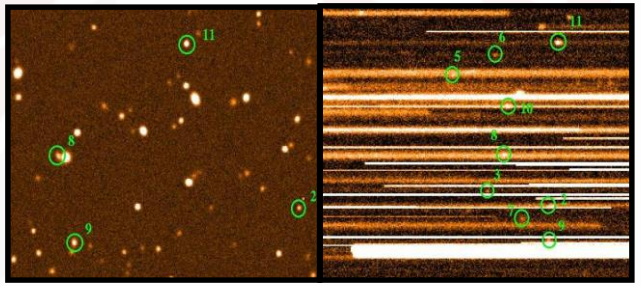


Near Infrared Spectro-Photometer

- 16 (2k x 2k) H2RG (HgCdTe), 18 μm pixel
- Resolution: 0.3 arcsec
- Field of view: 0.55 deg^2
- 3 filters: Y, J, H
- 4 grism: 1xB (920-1350 nm); 3xR (1250-1850 nm)
- ~ 3 x 10^7 photometric and spectroscopic galaxy redshifts down to 24 mag with S/N > 5

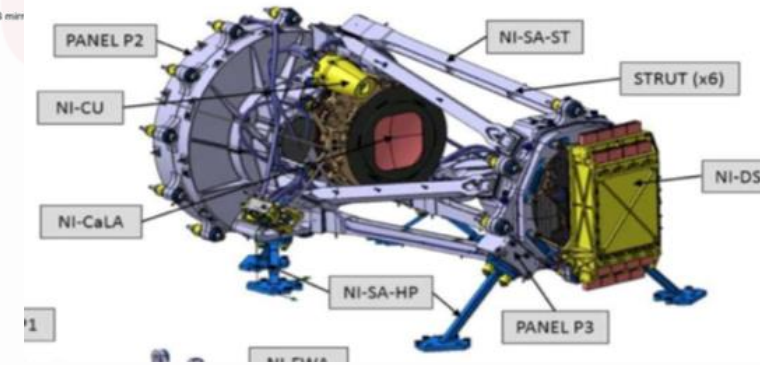






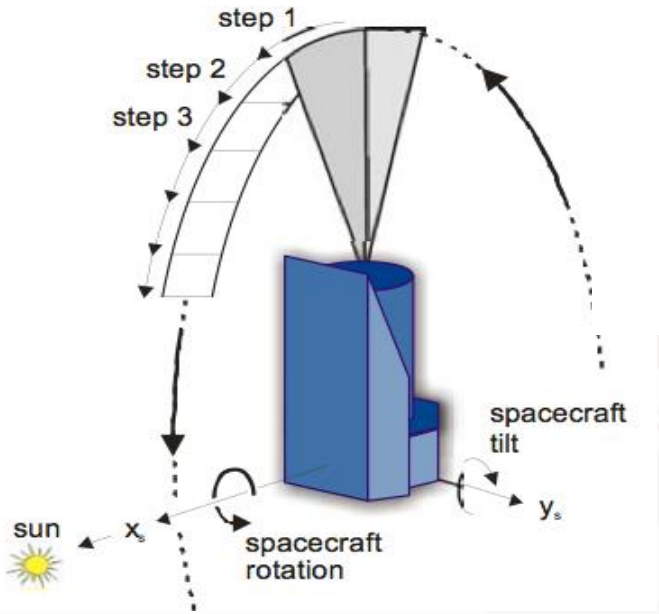
photometry with filters

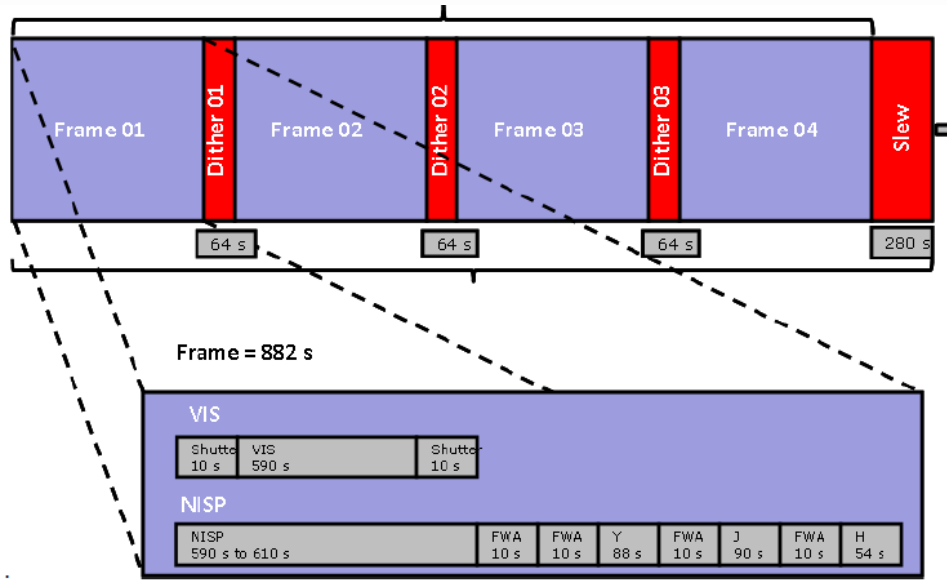
spectroscopy with grisms



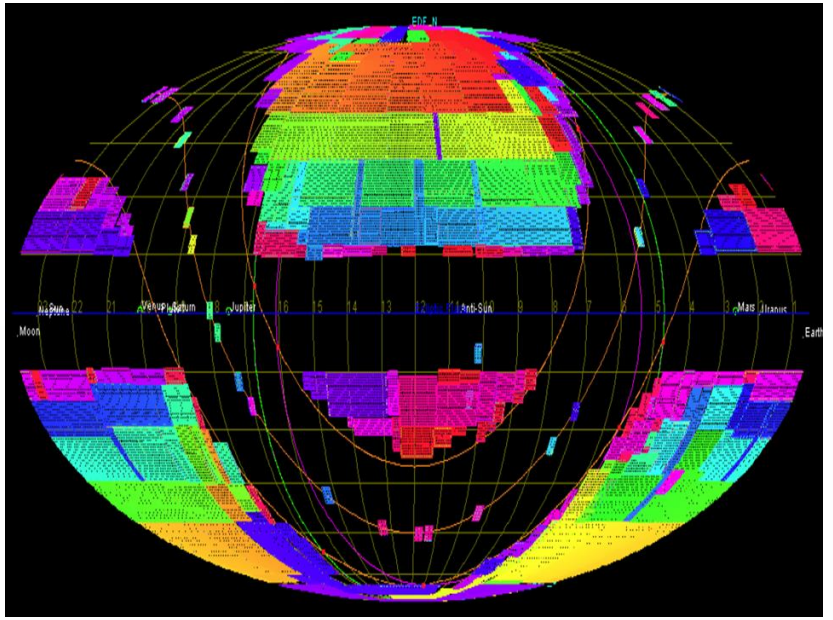
Scanning Strategy

Stare and step with 4 dither pointings per step

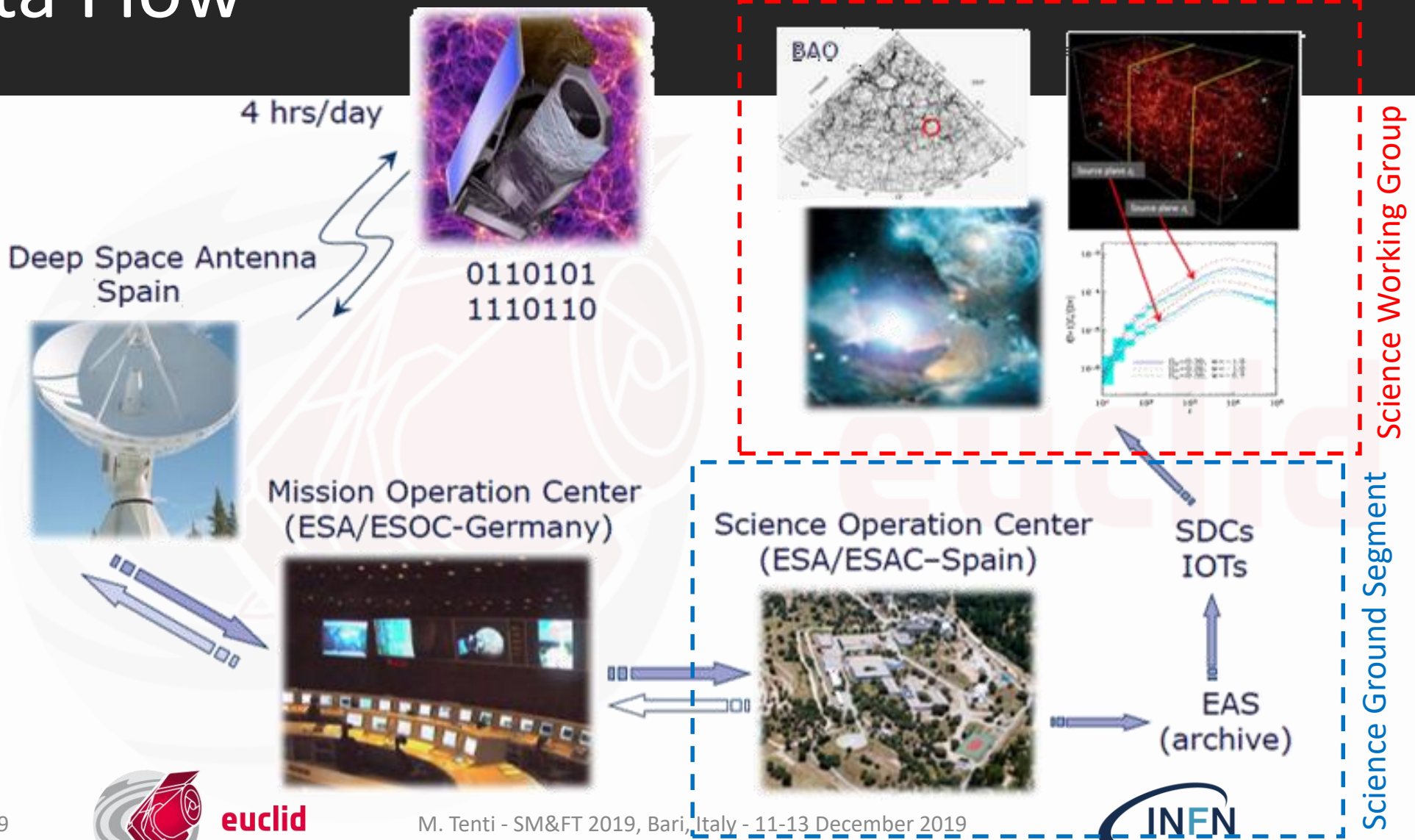




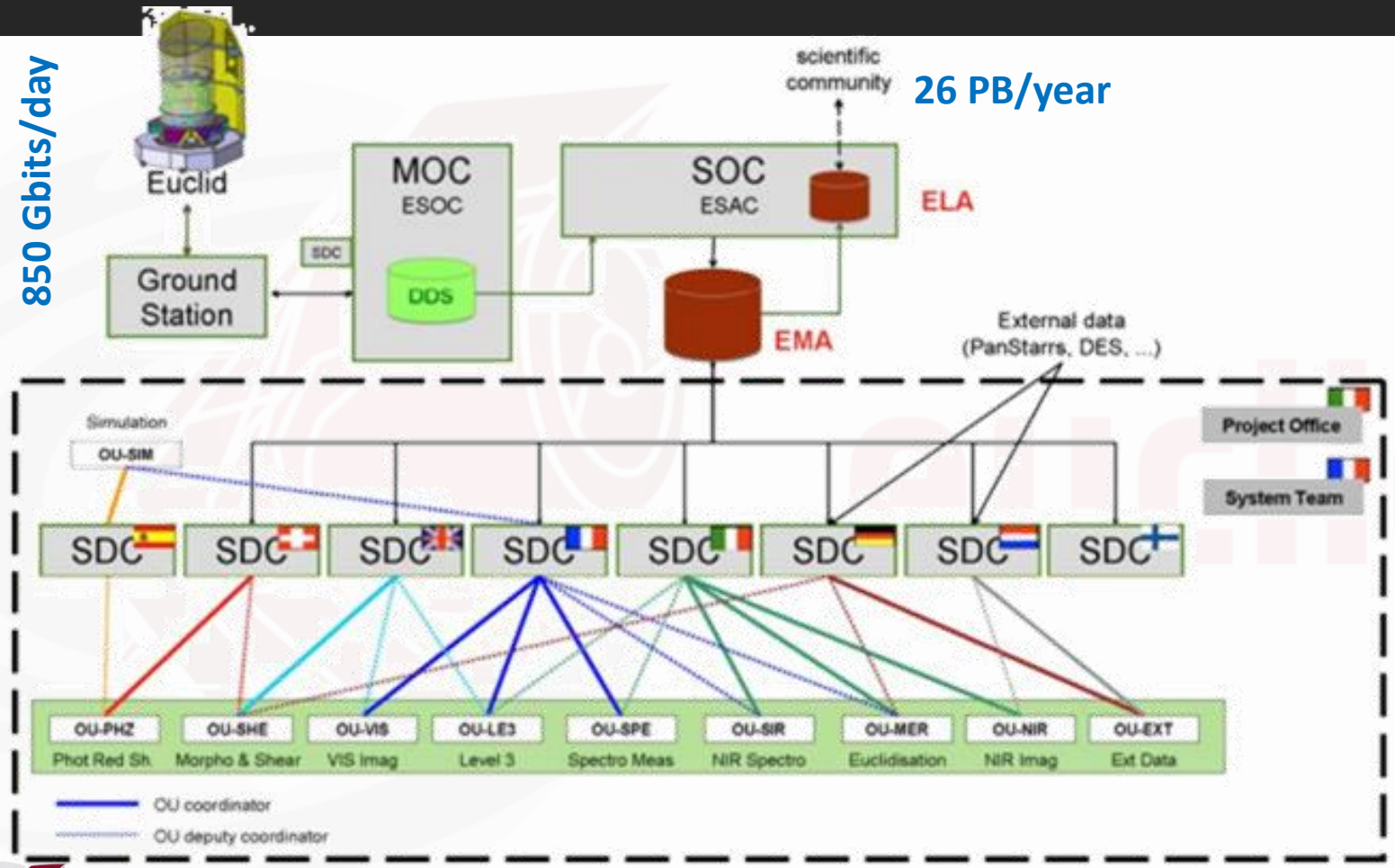
Complete survey:
~ 15.000 deg^2 (**1/3 full sky**)



Data Flow


4 hrs/day
Deep Space Antenna
Spain
0110101
1110110
Mission Operation Center
(ESA/ESOC-Germany)
Science Operation Center
(ESA/ESAC–Spain)
BAO
SDCs
IOTs
EAS
(archive)
Science Working Group
Science Ground Segment

Science Data Center



Data Pipeline

- Data are organized in different levels:
  - Raw data from satellite
  - Level 1: edited telemetry
  - Level 2: calibrated signal from instruments
  - Level 3: physical observables (redshift, shear) reconstruction

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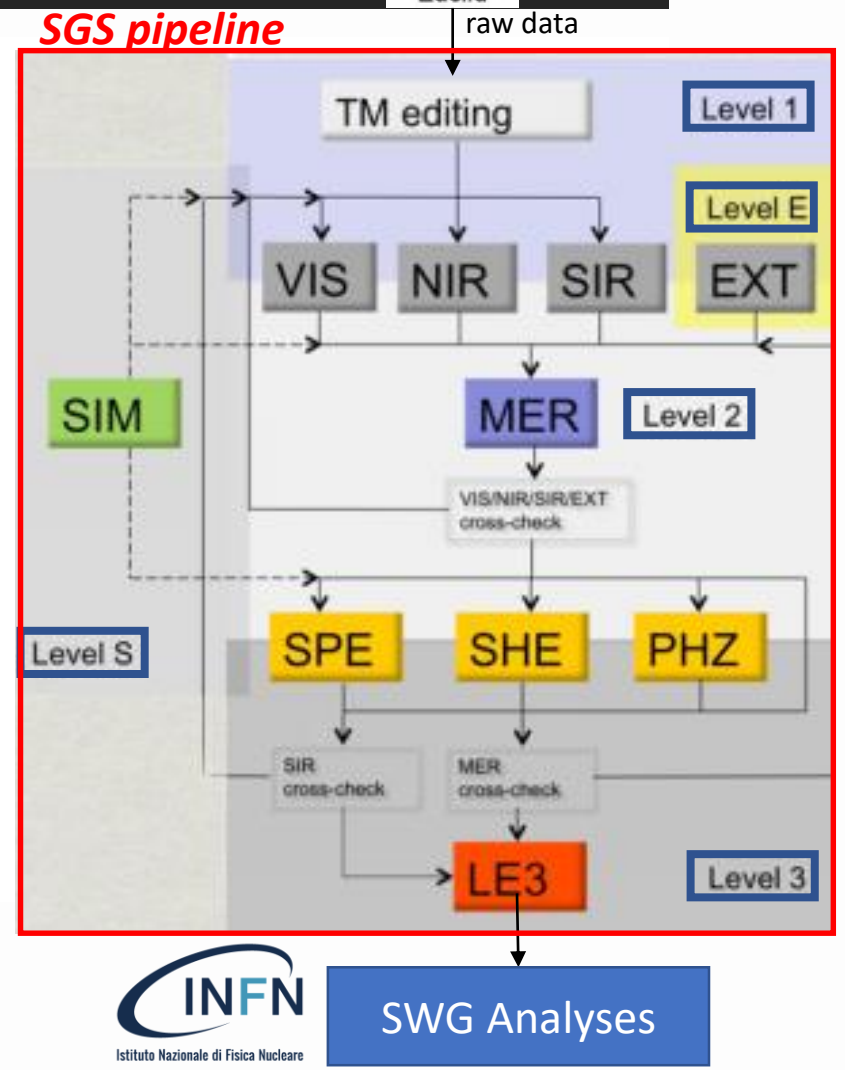
  - Level Q: quick release
  - Level E: external data from ground based experiment
  - Level S: simulation

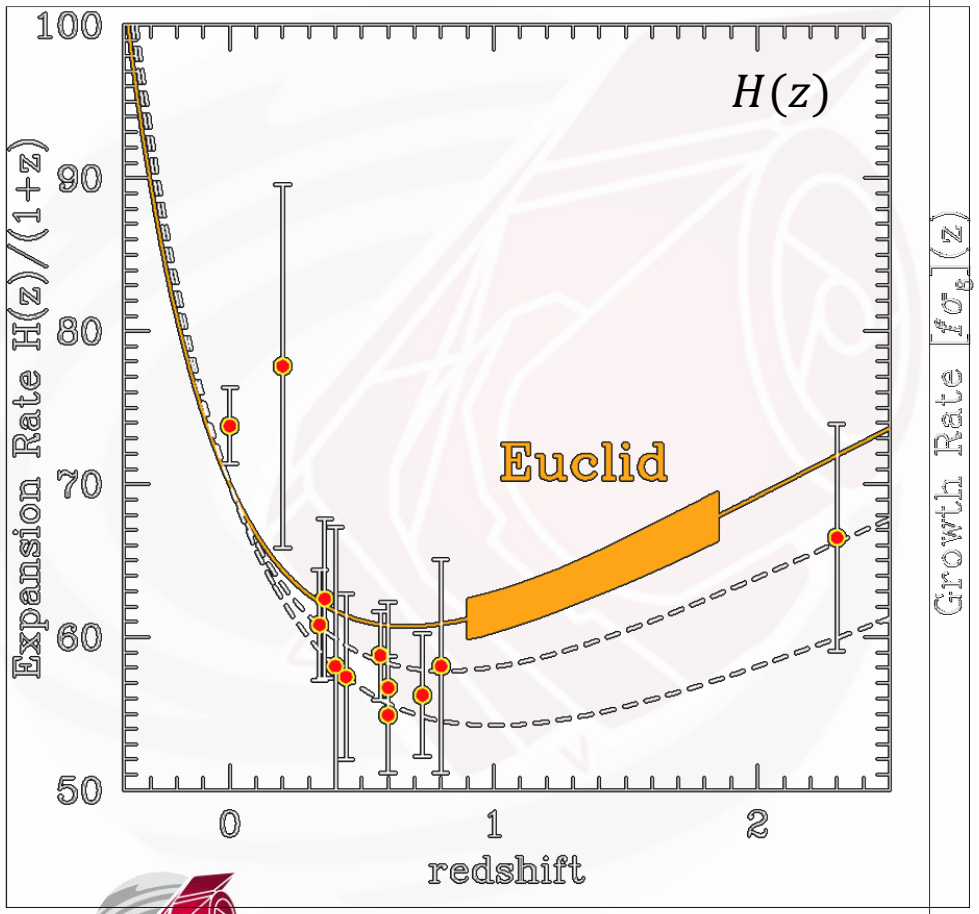


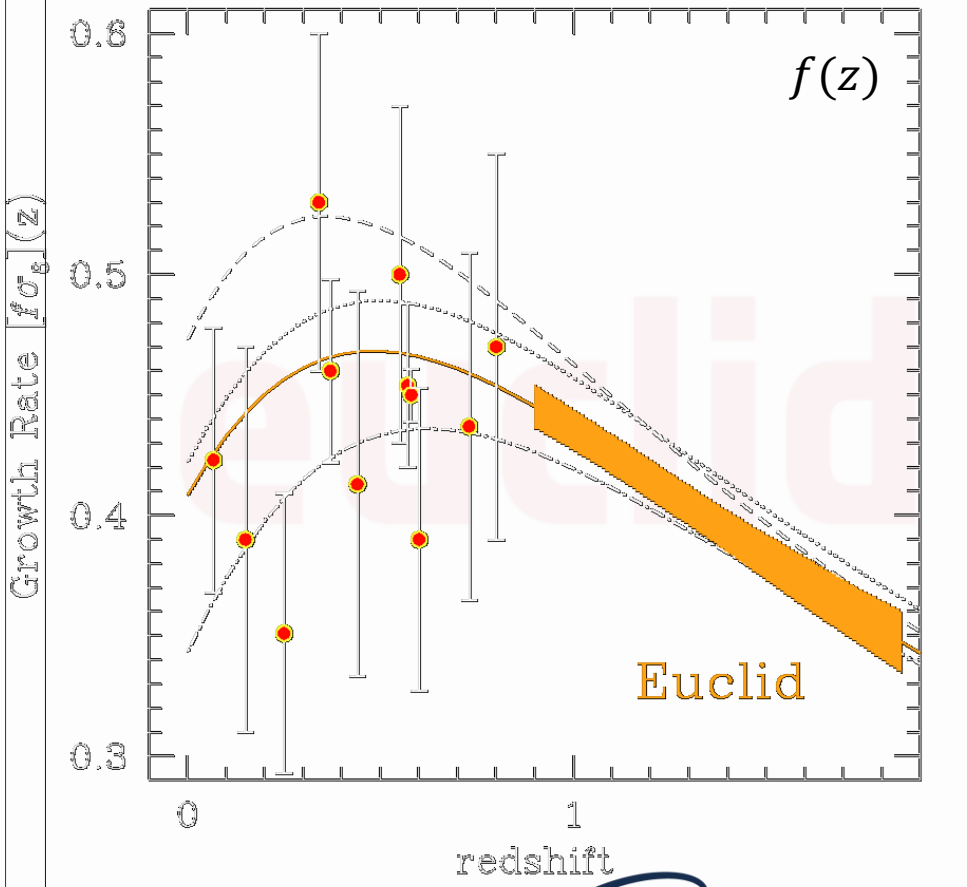
Science Working Group

- The science activities performed by Science Working Groups [using Level 3 data].
- People involved in science analyses participate to different Working Groups, having a specific task.

Forecasts: $H(z)$ and $f(z)$

From Guzzo and SWG-GC group 2016





Forecast: $w(z)$

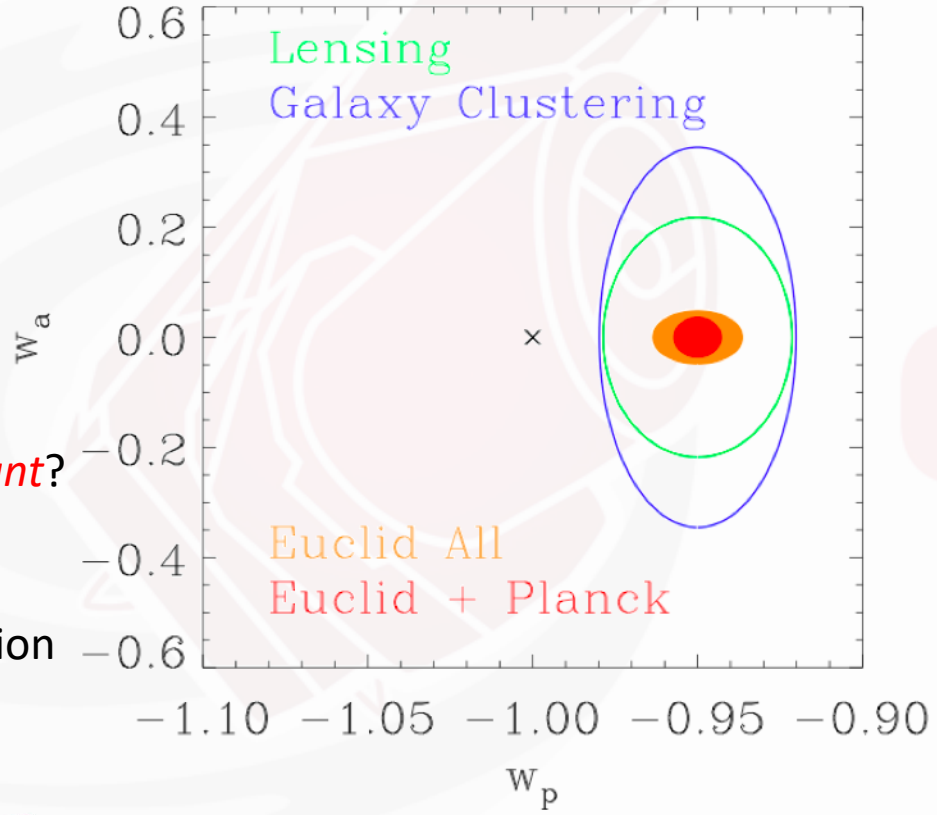
$$w(a) = w_p + w_a(1-a)$$

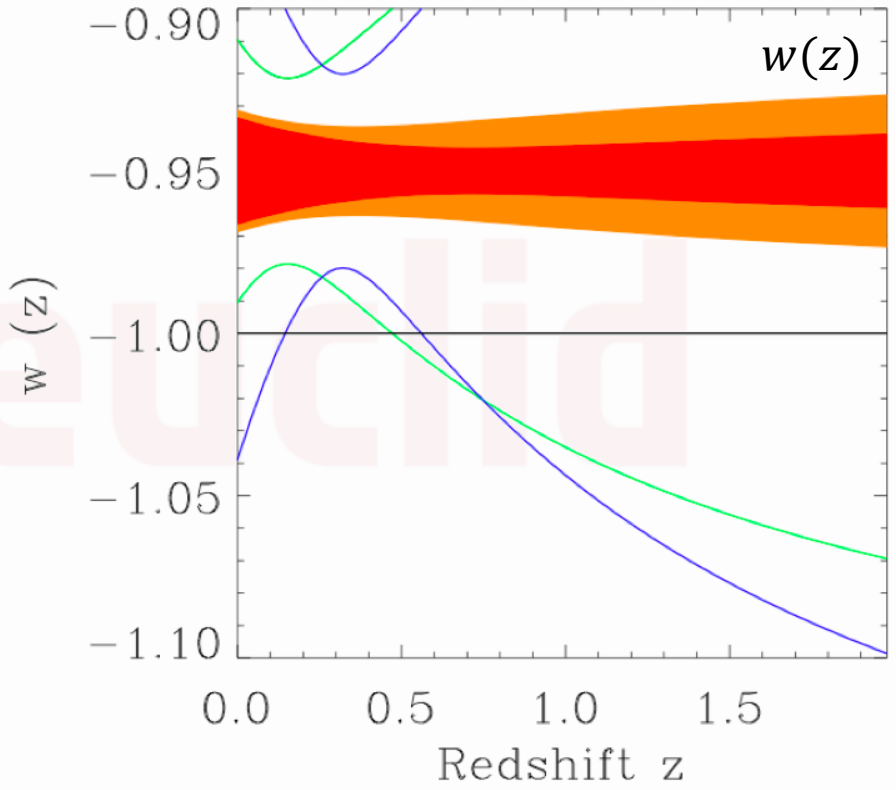
Laureijs et al., Euclid RedBook ESA/SRE(2011)12

DE eos from:
Weak Lensing and
Galaxy Clustering,
clusters, ISW (orange)

Is Dark Energy described by a simple *cosmological constant*?

Or it is a *field evolving dynamically* with the expansion of the Universe?





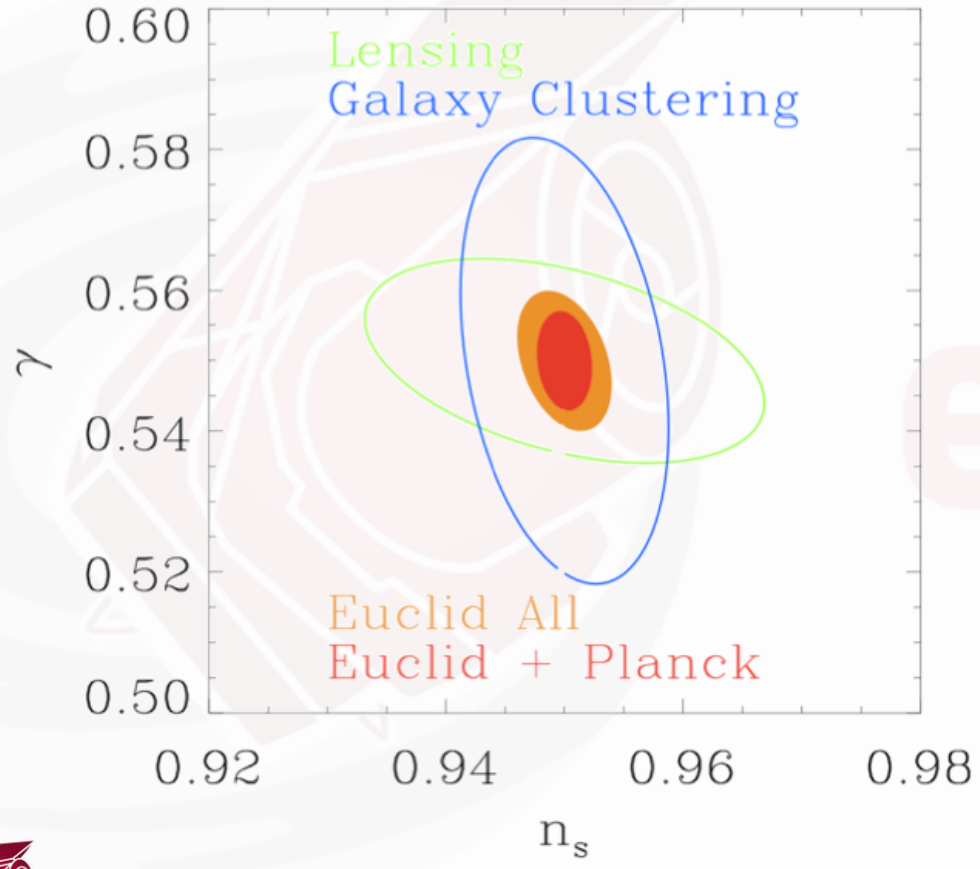
Forecast: γ

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

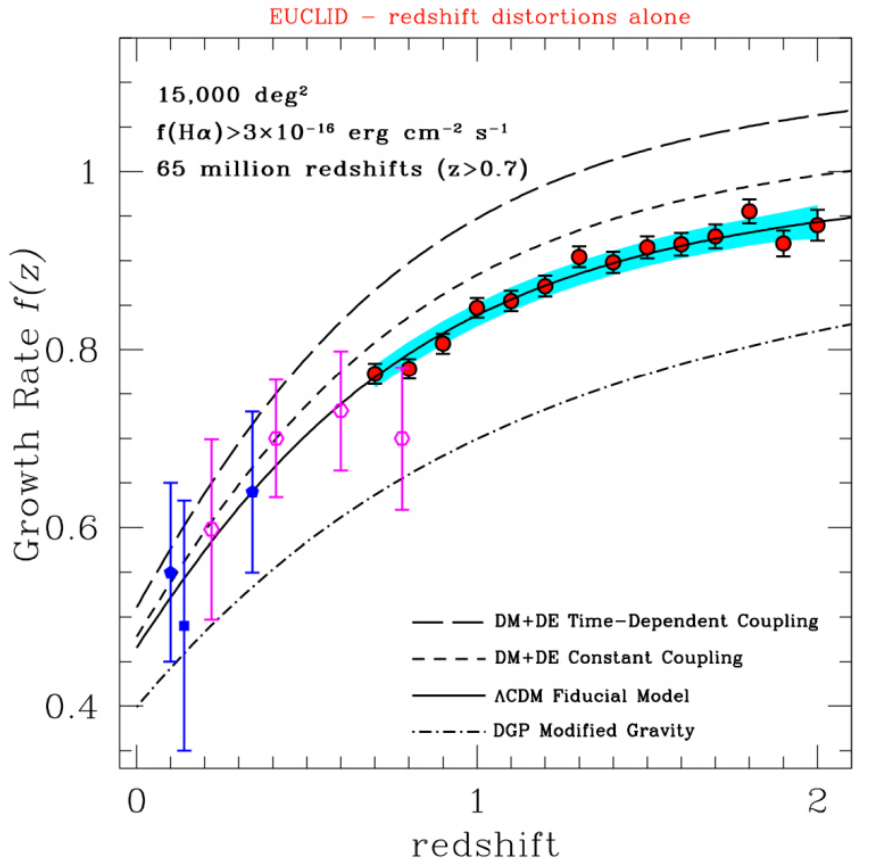
Growth rate
of structure from:
Weak Lensing,
Galaxy Clustering,
clusters, ISW (orange)

Is *General Relativity* valid at cosmic scales?

Do we need a *Modified Gravity*?



Laureijs et al., Euclid RedBook ESA/SRE(2011)12



Expected accuracy

- Controlling systematics to an unprecedented level of accuracy
- Synergy with Planck:
  - Different cosmic epochs and high accuracy results
- Different probes:
  - Degeneracies between parameters are broken or mitigated

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

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

Euclid computing: a comparison

Requirements	Planck [1603.09303]	Euclid [1701.08158]
Computing [core-hours/year]	~ 10M – 100M	~ 1G – 10G
Storage (disk) [PB]	~ 1	~ 100

Scientific analysis of data will require many medium-size N-body simulations

With respect to Planck satellite mission:
- 1 order of magnitude more in core-hours needs
- 2 order of magnitude more in disk space needs

Euclid-Italy

Italian Participation

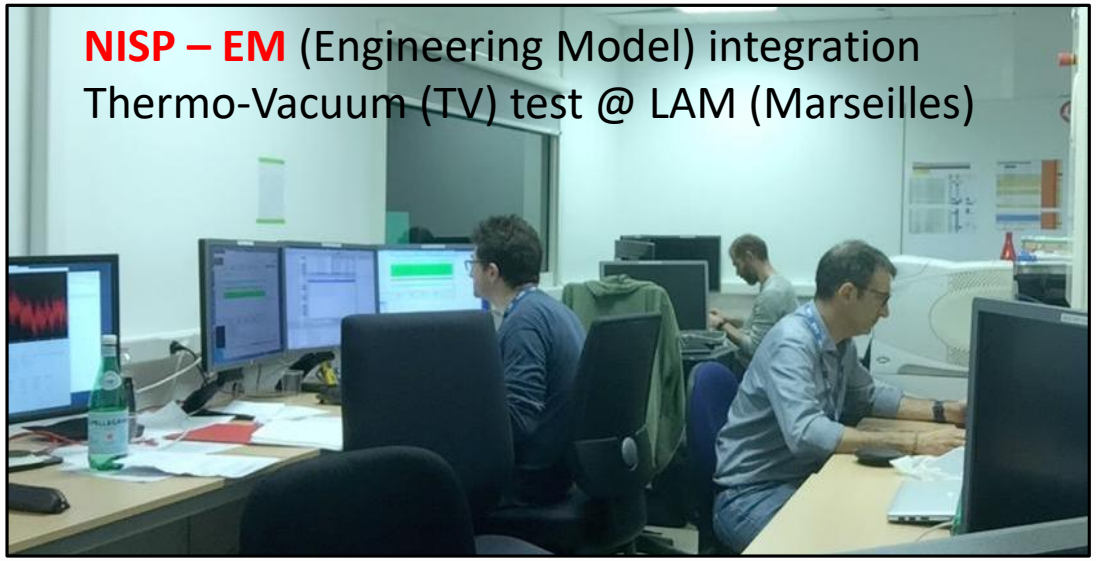
- ~ 400 members
- Financial support from ASI, partly from MIUR (PRIN), INFN
- Universities: Bologna, Milano, Napoli, Padova, Roma1, Roma2, Roma3, Trieste, SISSA, SNS (Pisa)
- INAF: OABO, OABrera, OACT, OAA, OANA, OAPD, OARM, OATO, OATS, IASFBO, IASFMI, IAPS
- INFN: Bologna, Ferrara, Genova, Lecce, Milano, Padova, Roma1, Torino

euclid

Istituto Nazionale di Fisica Nucleare

«Euclid-INFN» Team

- Assembly, Integration and Verification of the NISP warm electronic modules
- Simulations: before the launch (2022)
- Analyses: after the launch (2022)
- Main scientific interests:
  - *Equation of state of DE*
  - *Sum of Neutrino masses*
- Several probes under study:
  - Cosmic Voids
  - CMB Cross-Correlations
  - …



Cosmological simulations

- *N-body simulation*:
  - Standard and non-standard cosmologies
  - With massive neutrino
- Typical medium-size simulation of $O(10^3)$ particles in a $O\left(\left[\frac{Gpc}{h}\right]^3\right)$ volume with a $O([10^3]^3)$-cells mesh and ~ 50 snapshots requires:
  - 1M core-hours
- And produces:
  - ~ 100 TB of data

Computational requirements

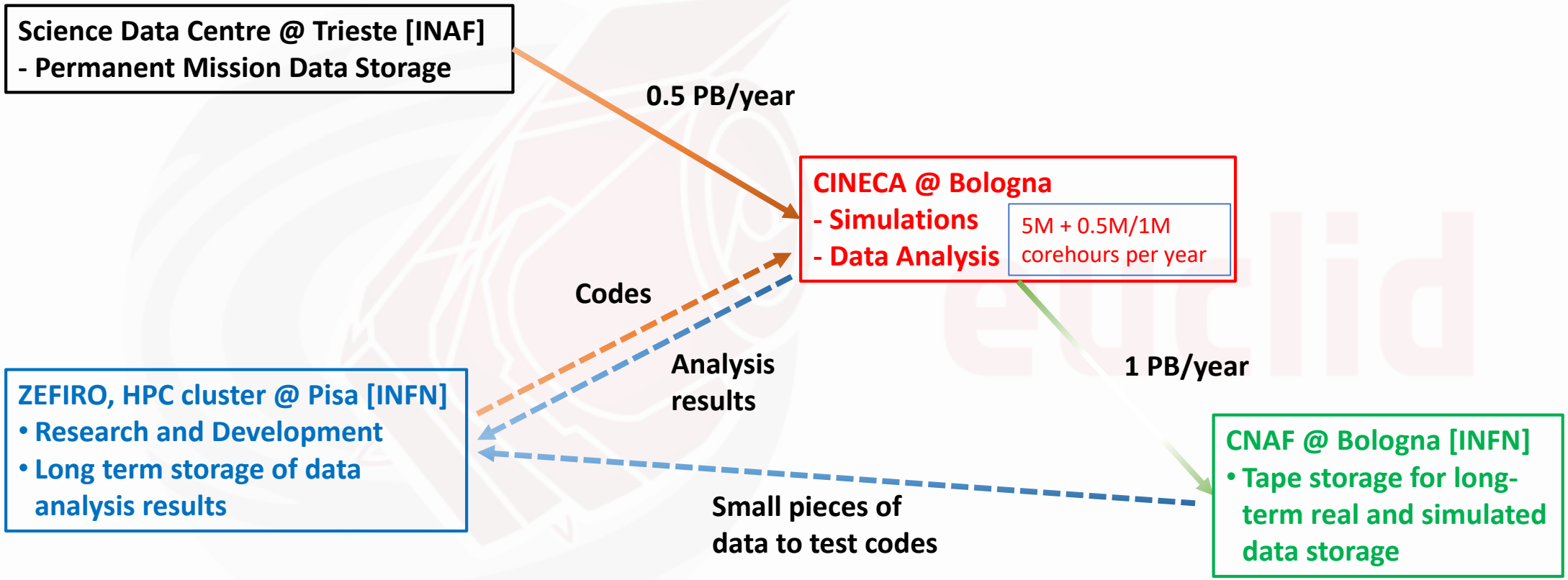
- Present requirement (for developing and [partial] optimization of the data analysis codes):
  → Dedicated HPC/MPI farm with:
  - *high-speed low-latency communication*
  - *~1000 cores*
  - *8 GB RAM/core*
  - *~1 PB disk storage*

- It is critical a reliable *long-term large space disk storage* to store both real and simulated

- *High bandwidth connection* with Euclid Legacy Archive
  (only part of data are needed at a time)

- The use of large *HPC facilities* (like CINECA) is mandatory!

Computing Model

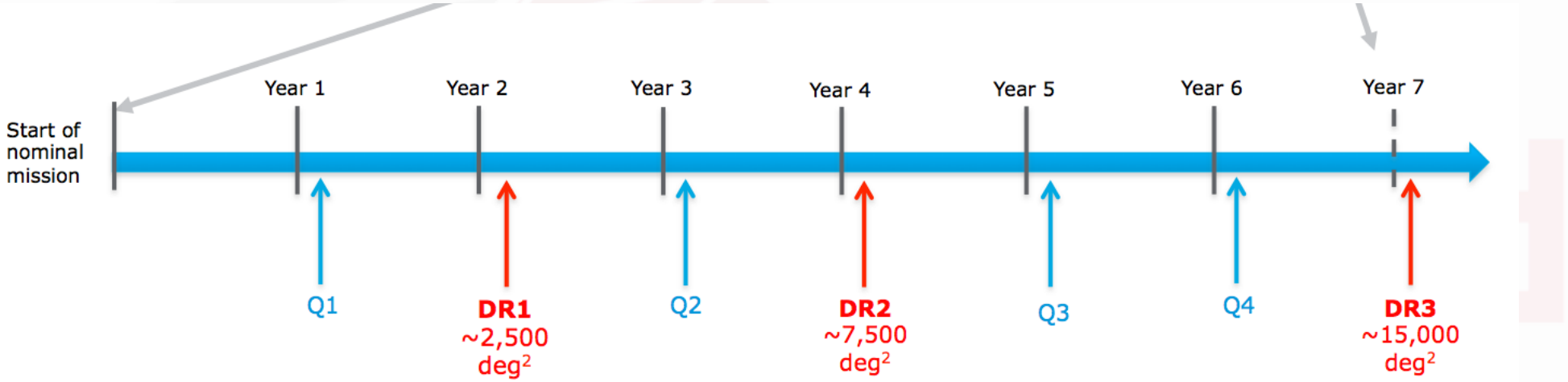


Summary

- The origin of **cosmic acceleration** is one of the most compelling problems in cosmology and physics
- **Euclid** is an experiment combining GC and WL: an unprecedented match of an imaging and redshift survey from space
- unique **control over systematics** effects will push **errors to percent-level** on the dark energy equation of state $w(a)$ and growth index γ
- Tight **constraints** on dark energy and gravitation
- **Large amount of data and computing** needed
- An **HPC-based computing scheme** has been defined in the context of Euclid-INFN team and its set-up is in progress

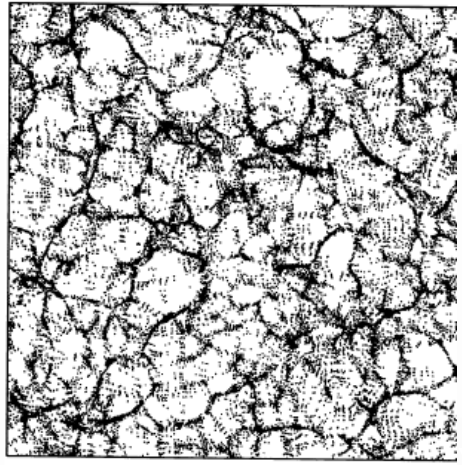
Backup

Data release

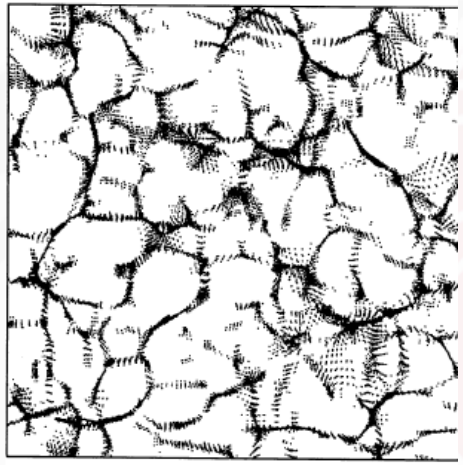


Dark Matter and neutrino effect on structure formation

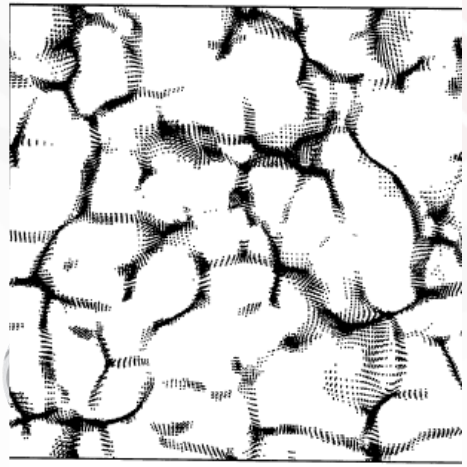
CDM



WDM



HDM



- Light DM particles suppress the collapse of structures on small scales (free streaming)
- Galaxy clustering can constrain the mass of light DM particles
- E.g.: standard neutrino (mass, hierarchy, number of species, BB relic background), WDM candidates with m~keV (sterile neutrino, gravitino)

- Neutrino oscillations $\rightarrow \Delta m^2$
  for Normal Hierarchy $\Sigma m_\nu < 0.06$ eV

- Cosmological measurements $\rightarrow \Sigma m_\nu$

(current : Σm_ν <0.15 eV if w=-1, or Σm_ν <0.49 eV if w ≠ -1)

Euclid expected accuracy on $\Sigma m_\nu \leq 0.05$ eV
→ Crucial information on neutrino absolute scale (not accessible to laboratory experiments) and two mass hierarchies

Istituto Nazionale di Fisica Nucleare

Colombi et al. 1996