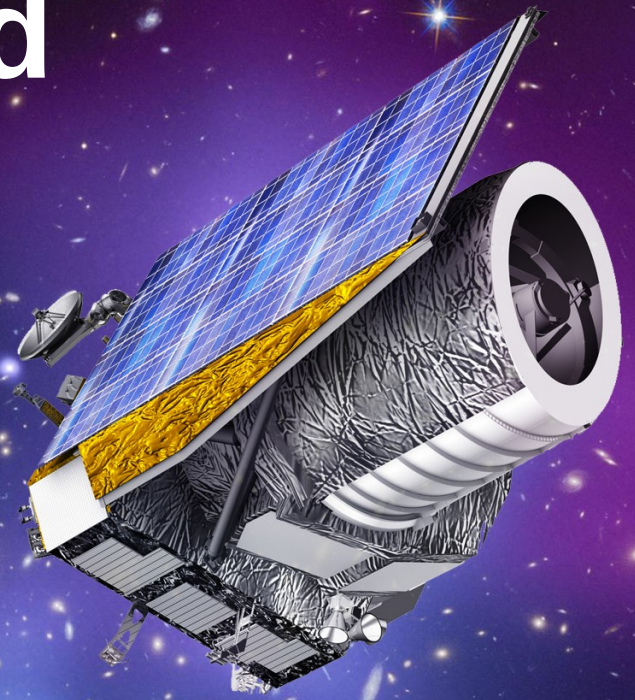
Exploring the Dark Universe with Euclid



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Département d'astronomie

esa

Euclid consortium

Outline

- Cosmology (in two slides)
- Cosmological probes
- The Euclid mission
- Photometric redshifts for Euclid

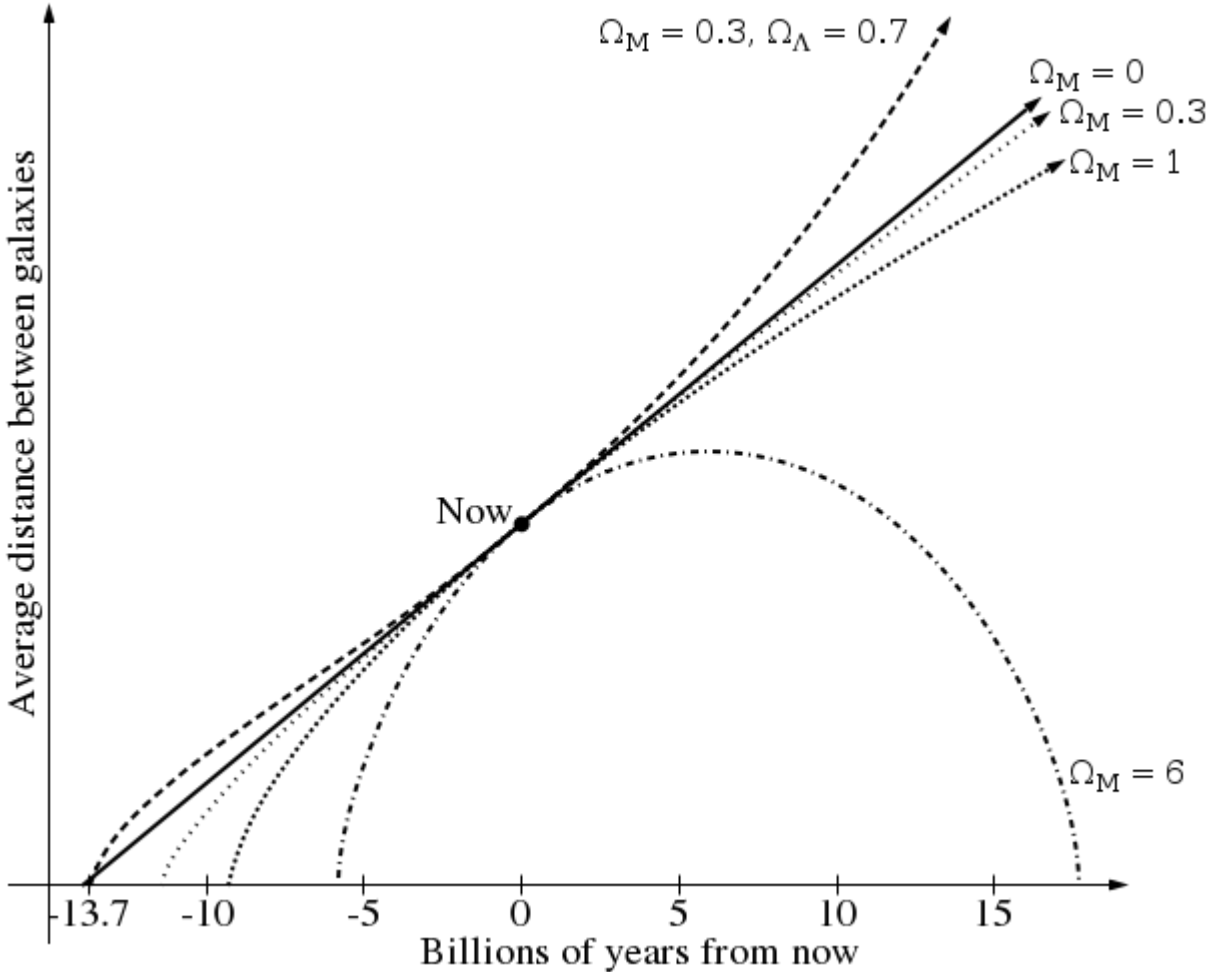
Friedmann Equation

- With $H = \dot{a}/a$ the Hubble parameter (flat universe), where a is the scale parameter

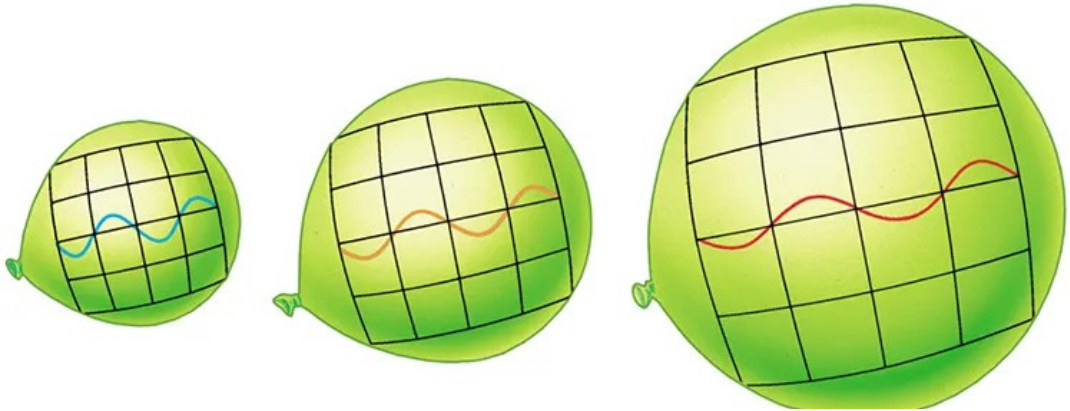
$$\frac{H(t)^2}{H_0^2} = \Omega_{0,R} a(t)^{-4} + \Omega_{0,M} a(t)^{-3} + \Omega_{0,k} a(t)^{-2} + \Omega_{0,\Lambda} a(t)^0$$

  - Ω_X is the density relative to critical density of energy component X
  - 0 means now

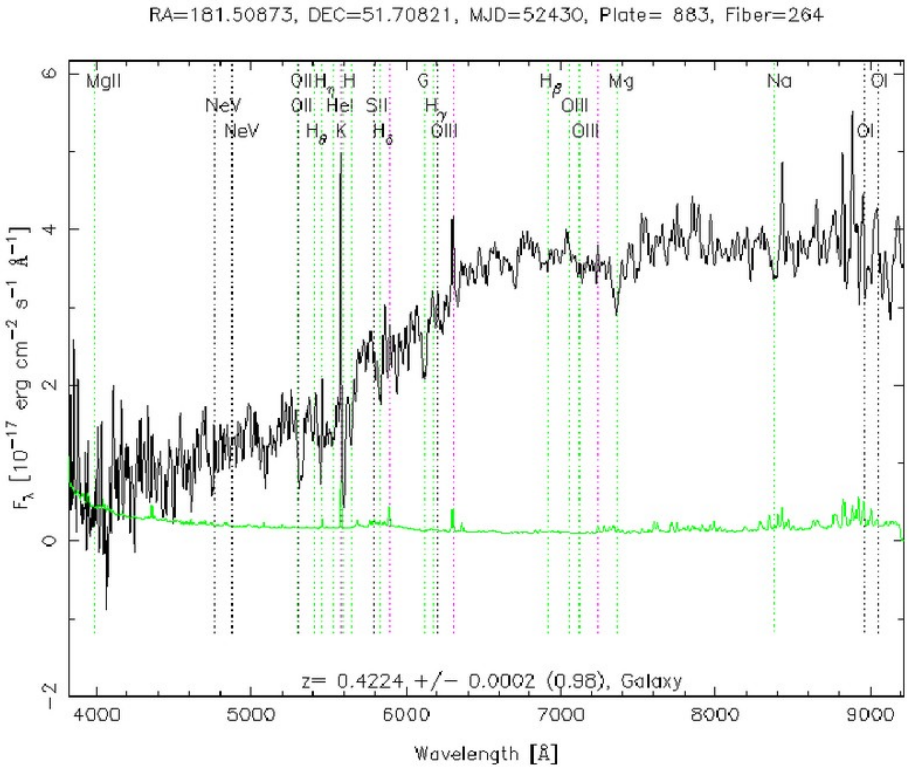
Expansion history of the universe



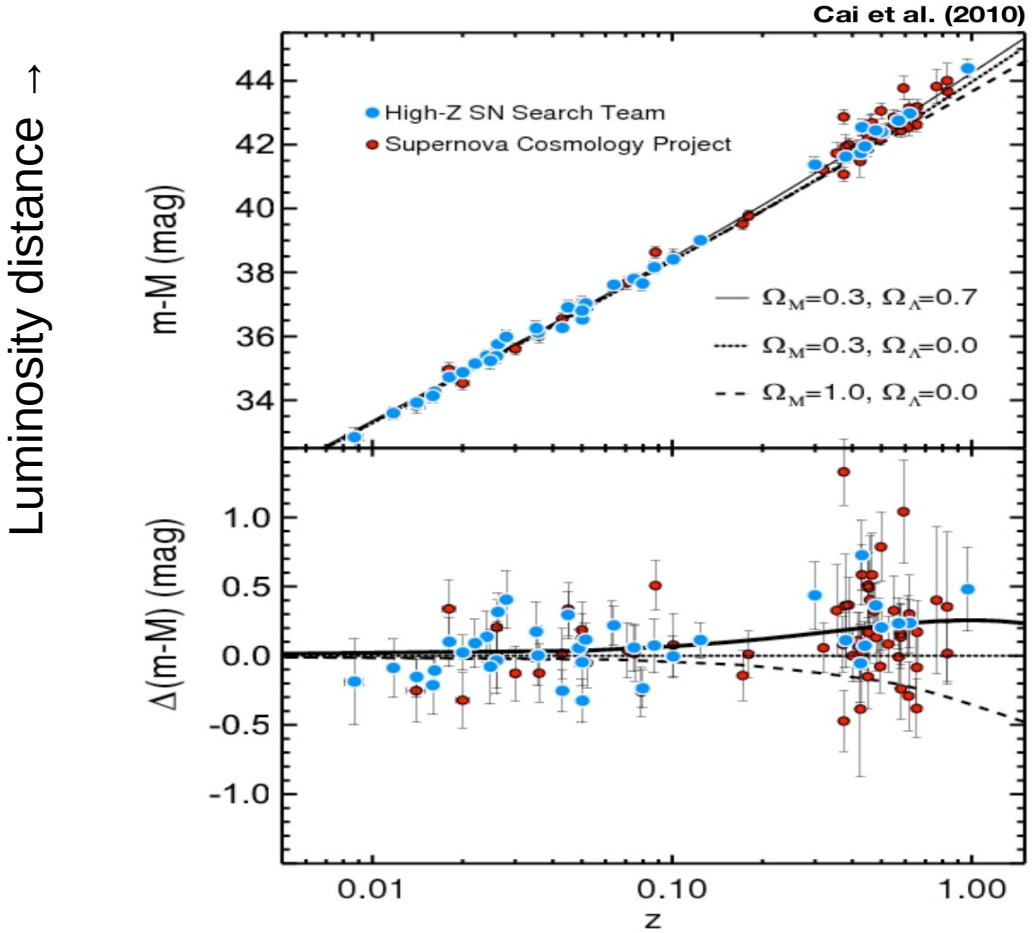
Cosmological redshift



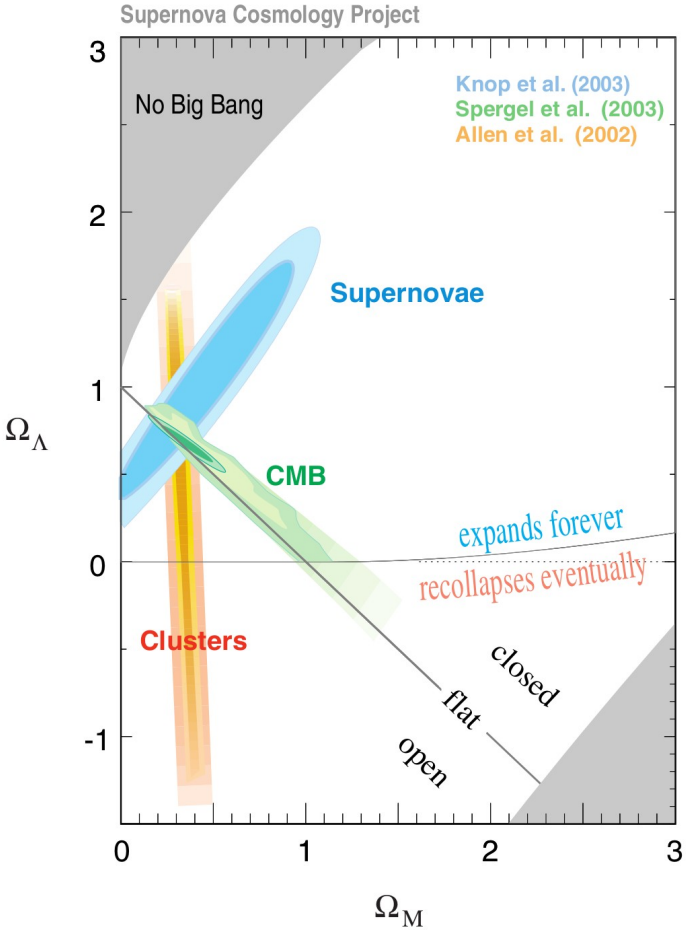
$$1+z=\frac{a(t_0)}{a(t_1)}=\frac{\lambda_0}{\lambda_1}$$

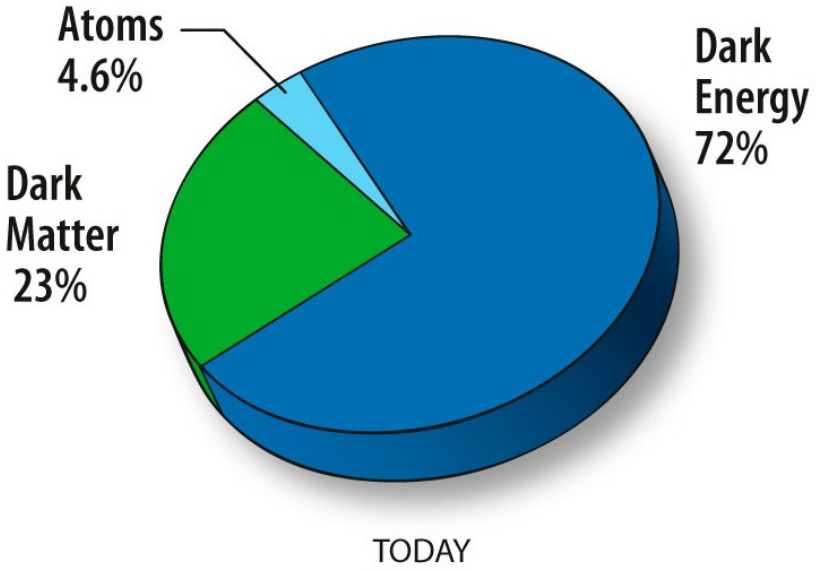


z-distance relation of supernovae

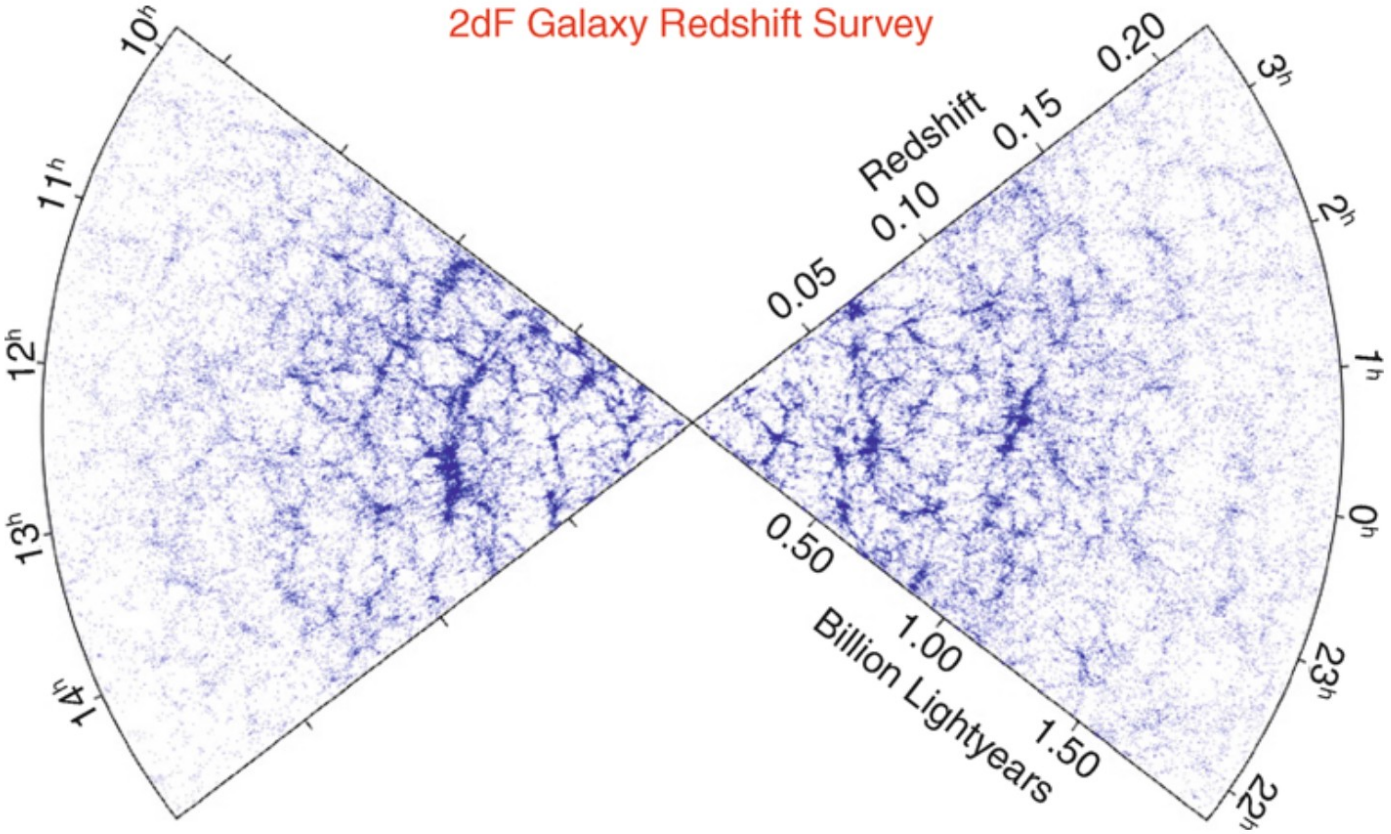


Concordance model



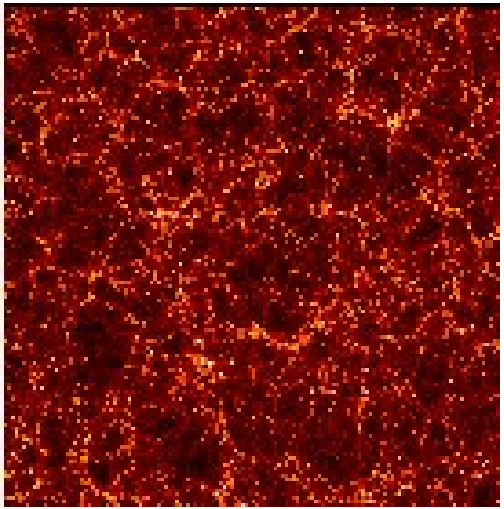


Large-scale structure

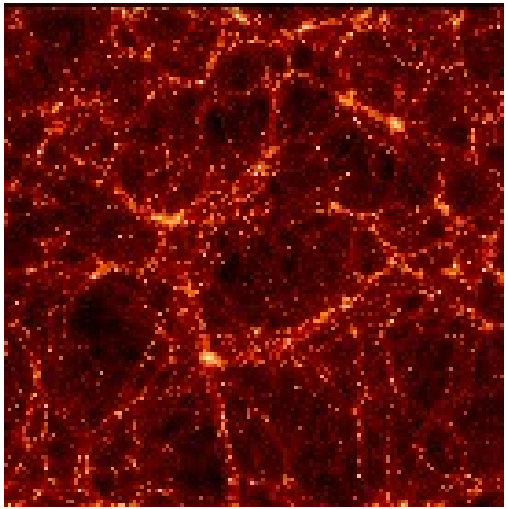


Influence of cosmological parameters in the LSS

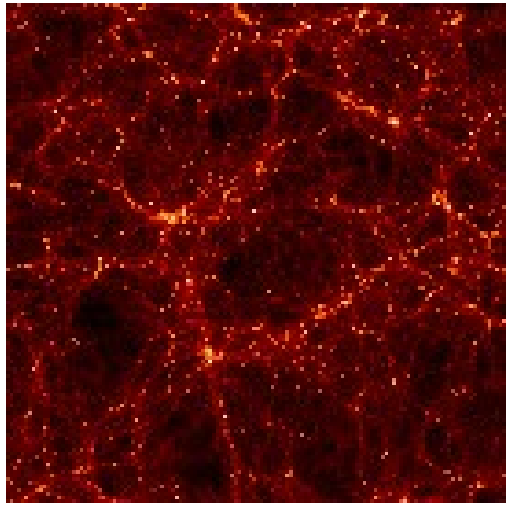
Virgo Simulations (MPA)



Flat Universe,
$\Omega_M = 1$

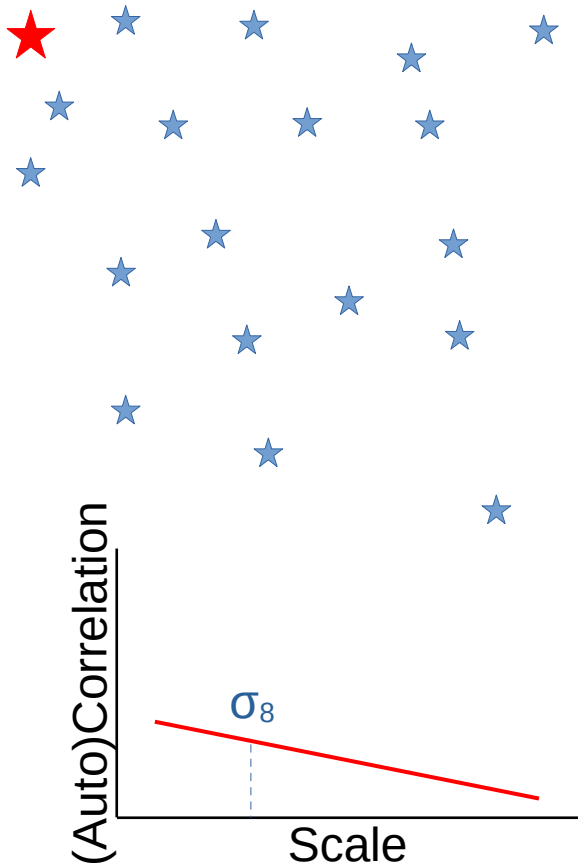


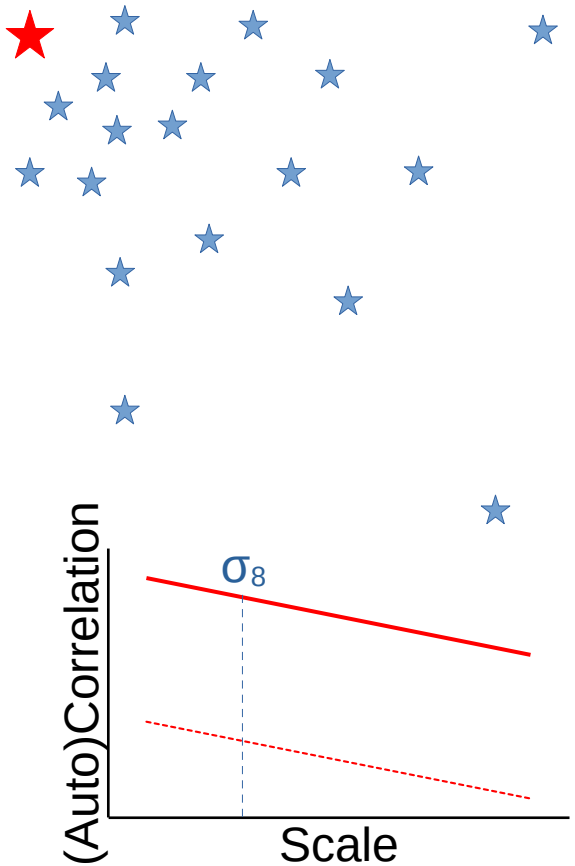
Flat Universe,
$\Omega_\Lambda=0.7$, $\Omega_M=0.3$



Open Universe,
$\Omega_M = 0.3$

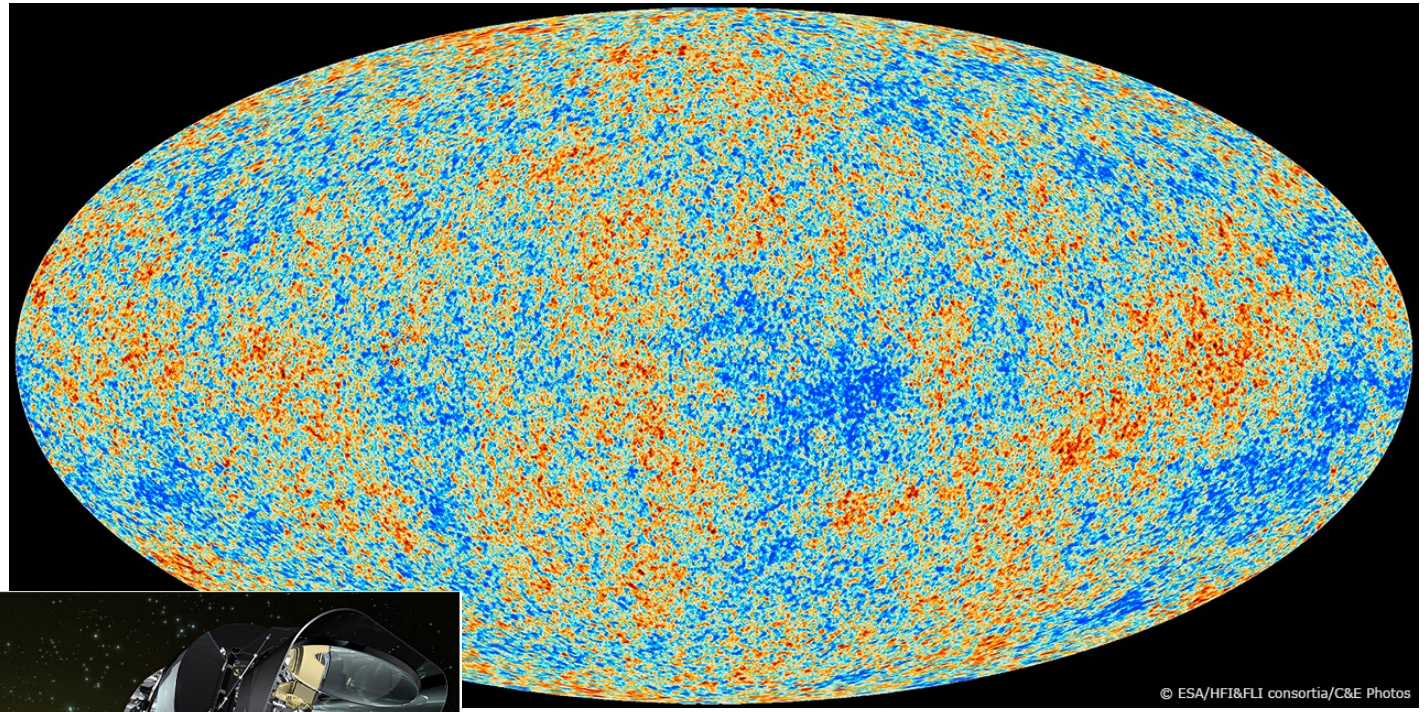
Clustering

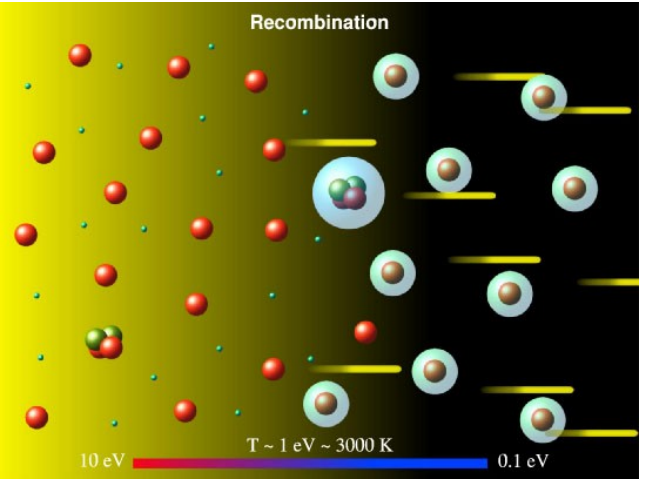


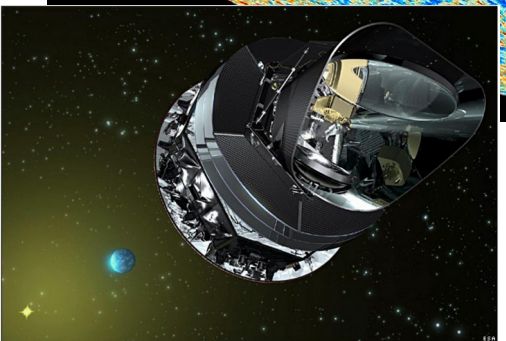


σ_8 : normalisation factor of the power spectrum

The Cosmic Microwave Background

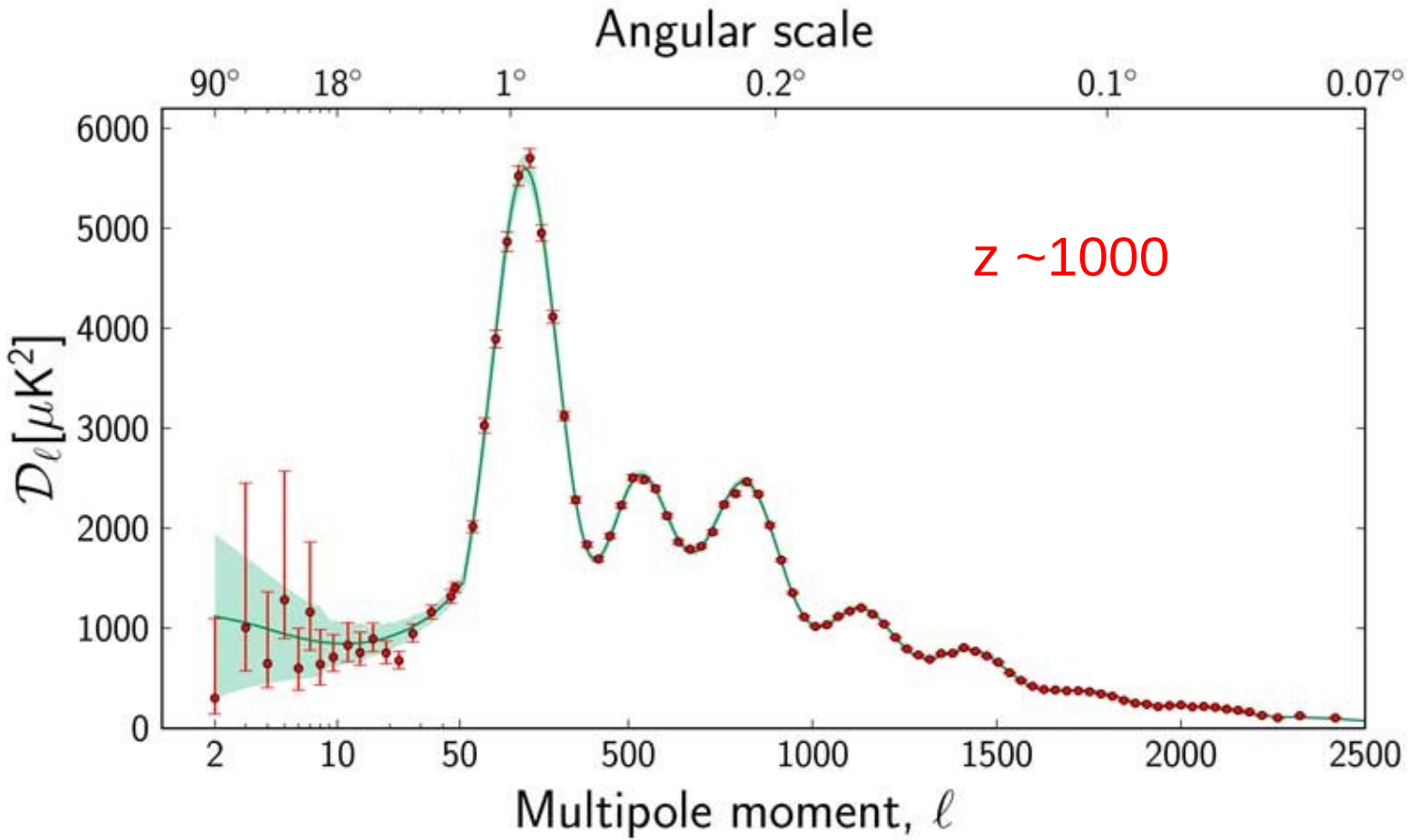






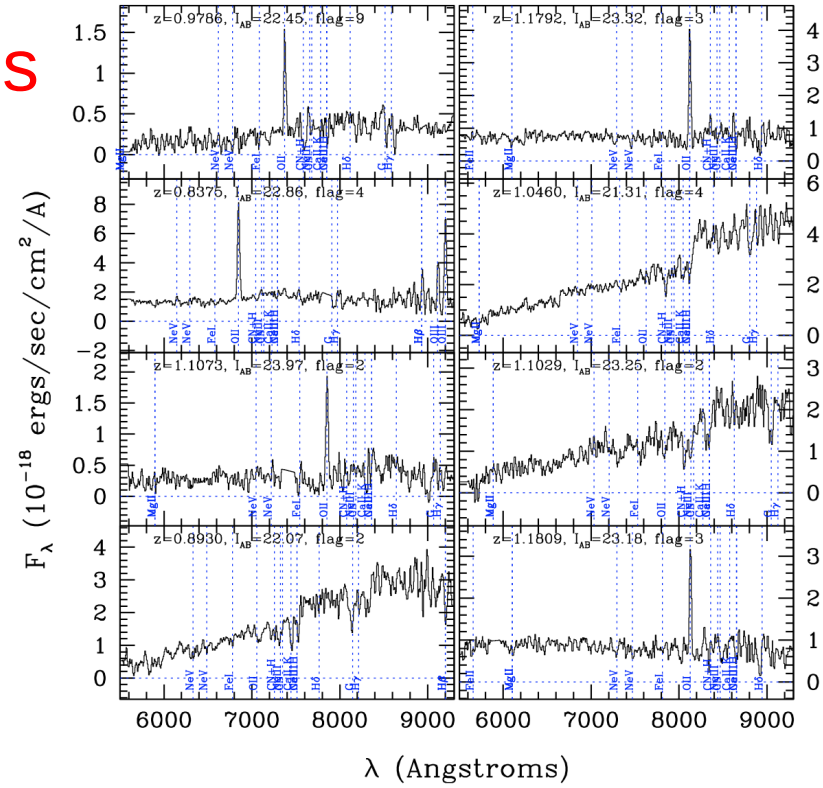
planck esa

CMB power spectrum



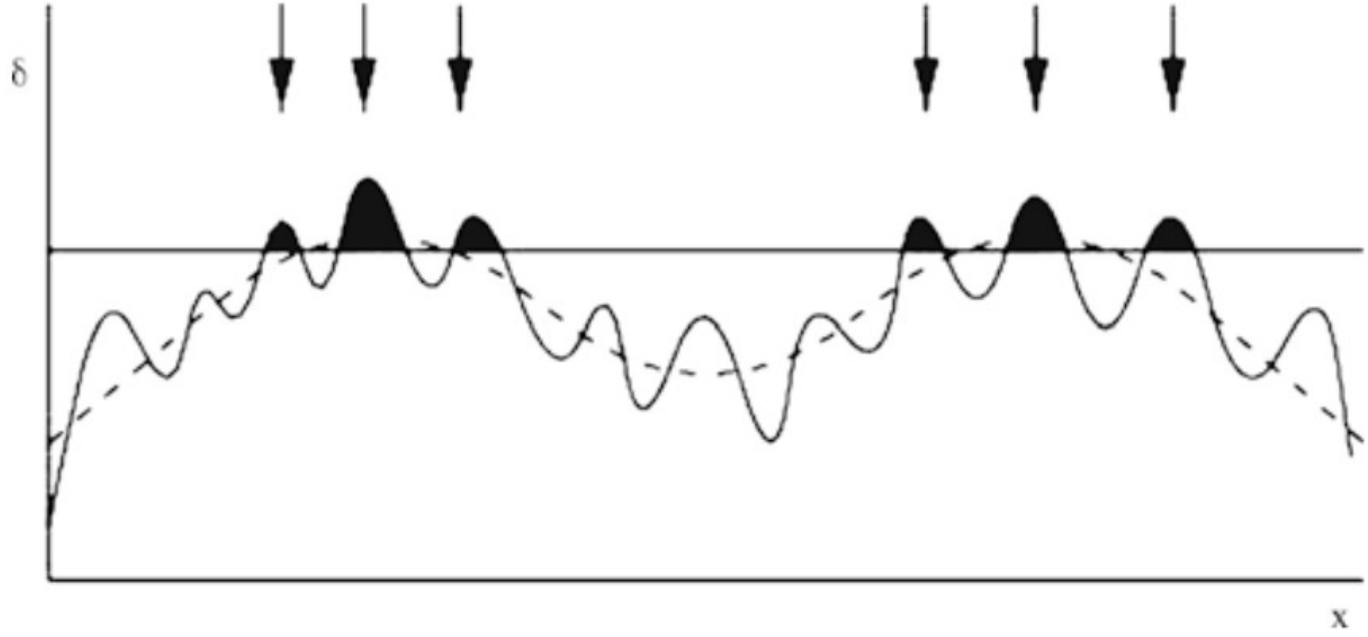
Galaxy clustering

- Matter can be traced by galaxies
- *z* can be determined with spectroscopy
- Large spectroscopic surveys
  - eBoss, DESI, PFS, HETDEX, 4MOST, …
  - ~1000 deg²
  - Also Euclid



Limitations of galaxy clustering

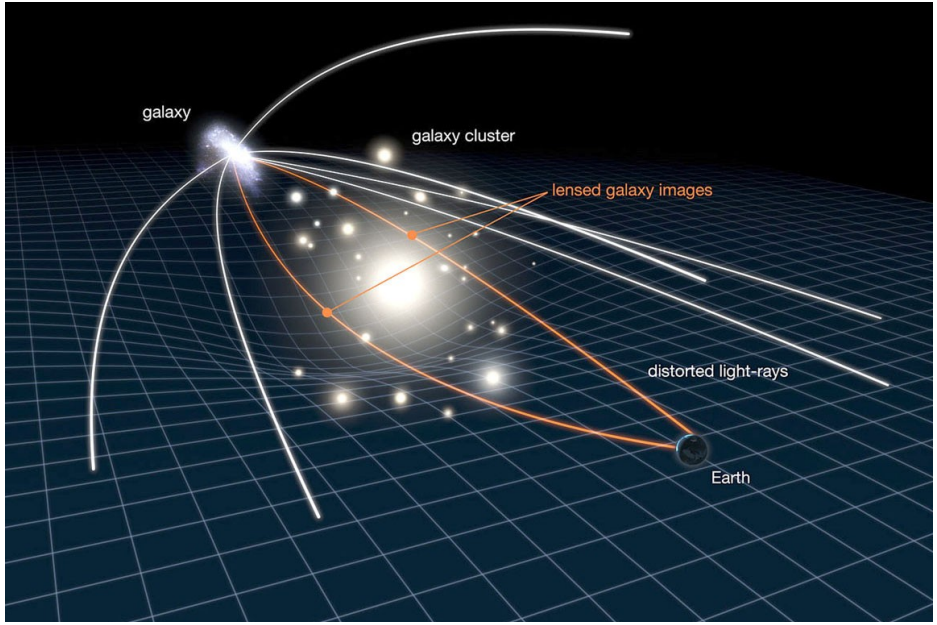
- Only a small fraction of the matter is visible
- Details of galaxy formation: baryonic processes

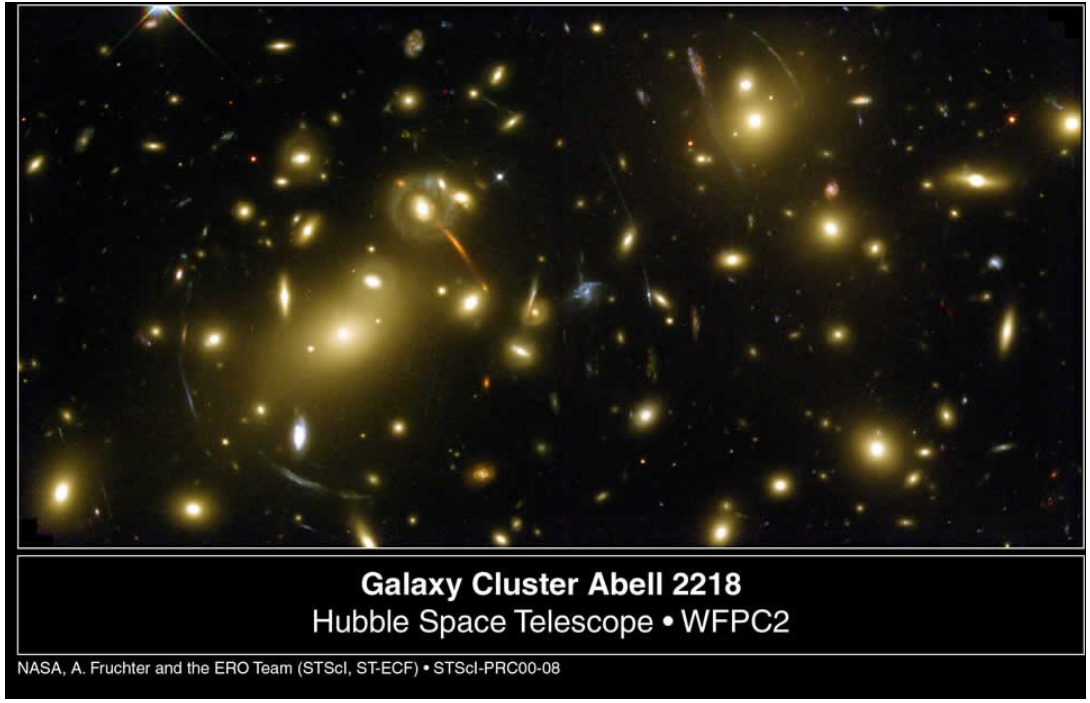


Matter clustering?

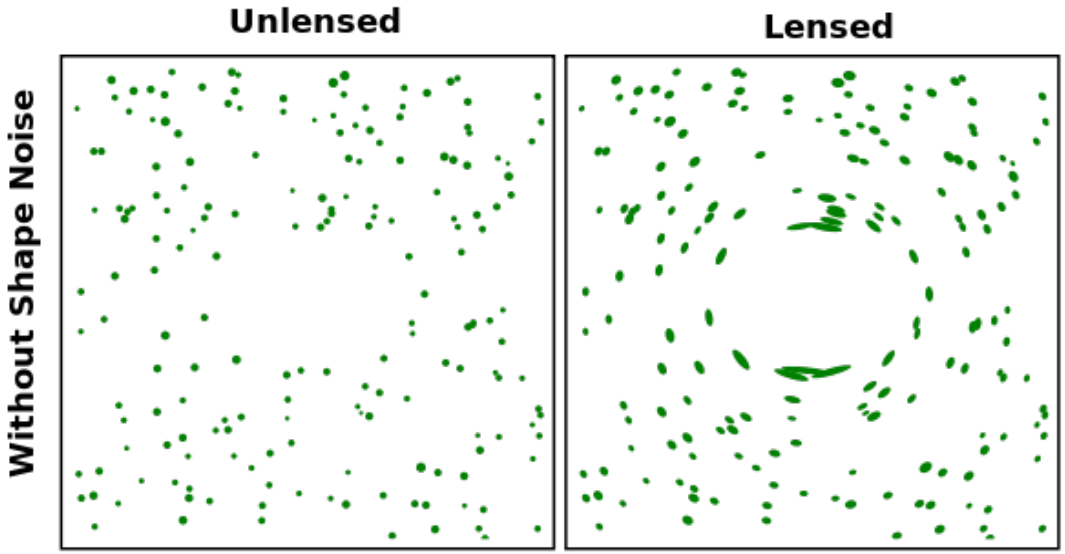
- Ideally one want a probe of the LSS that:
  - Is sensitive to all matter
  - Does not depend (so much) on baryonic processes

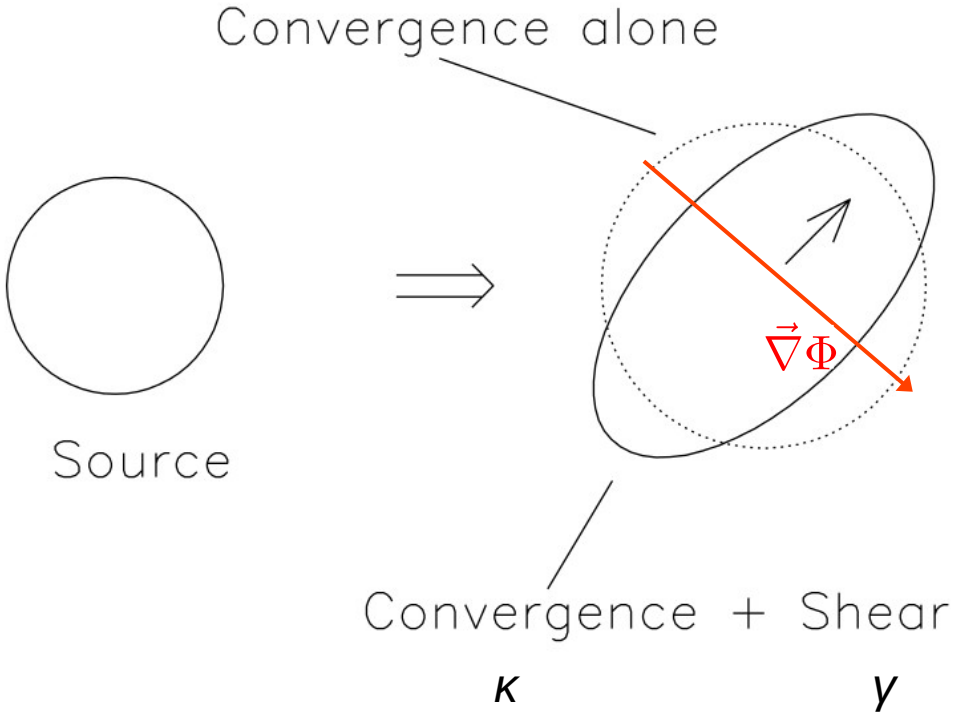
Gravitational lenses





Convergence and shear





Matter, convergence and shear

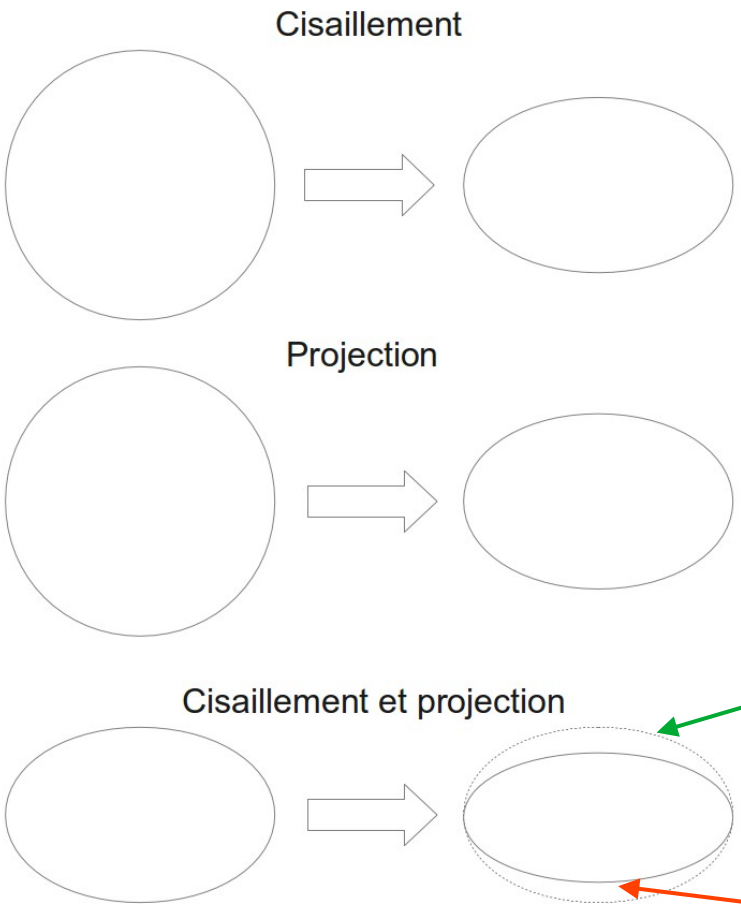
- Convergence is easily related to matter density:

$$\kappa = \frac{1}{2}\triangle\psi_\theta \sim \triangle\Phi = 4\pi G\rho$$

- But difficult to use: size and brightness distributions of galaxies?
- But one also have:

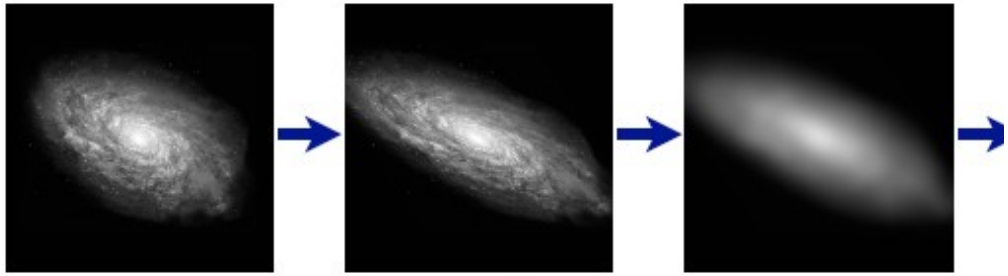
$$\tilde{\kappa}(\vec{\ell}) \sim \tilde{\gamma}(\vec{\ell})$$

Determination of the shear

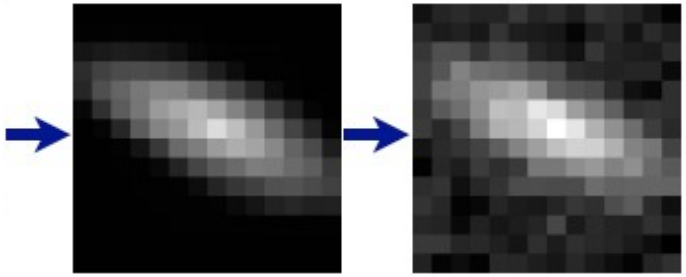


γ determined statistically only

Sub-% effect

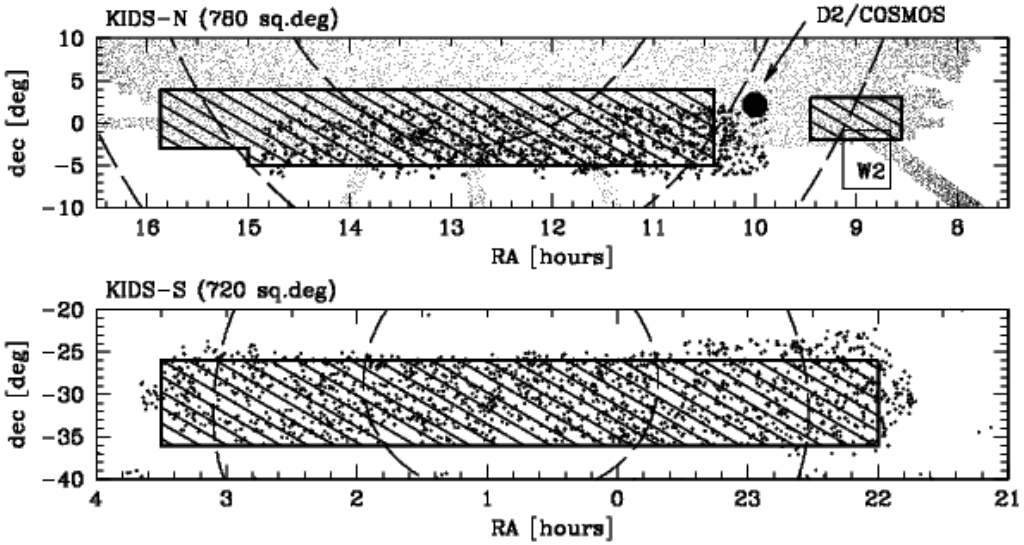


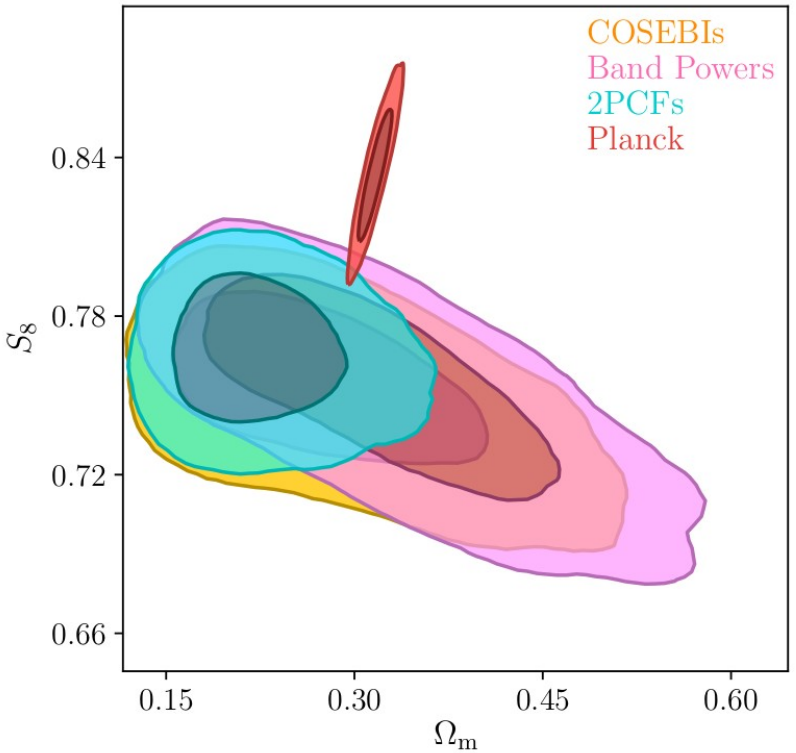
Intrinsic galaxy (shape unknown) → Gravitational lensing causes a ***shear (g)*** → Atmosphere and telescope cause a convolution



Detectors measure a pixelated image → Image also contains noise

Kilo-Degree Survey



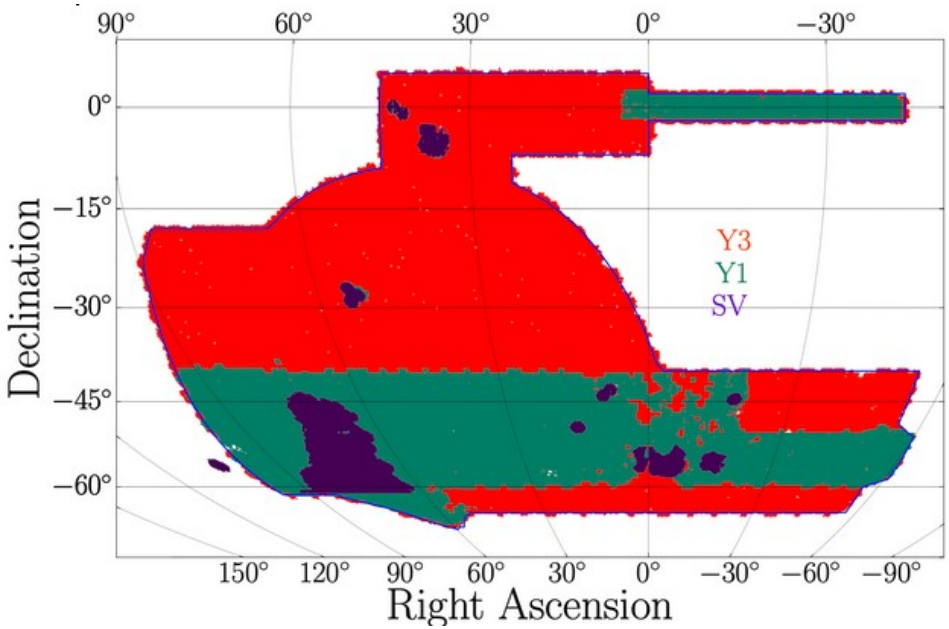


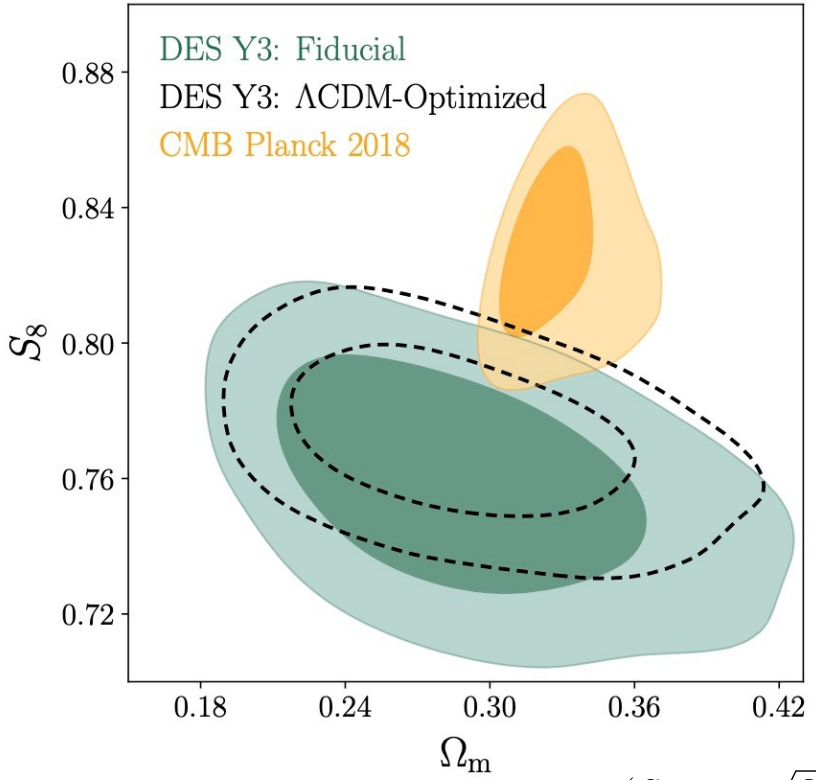
- ~1500 deg² (1000 completed)
- 2.6m ground-based telescope

$(S_8 = \sigma_8 \sqrt{\Omega_M/0.3})$

Asgari et al. 2021

Dark Energy Survey





$(S_8 = \sigma_8 \sqrt{\Omega_M/0.3})$

Amon et al. 2022

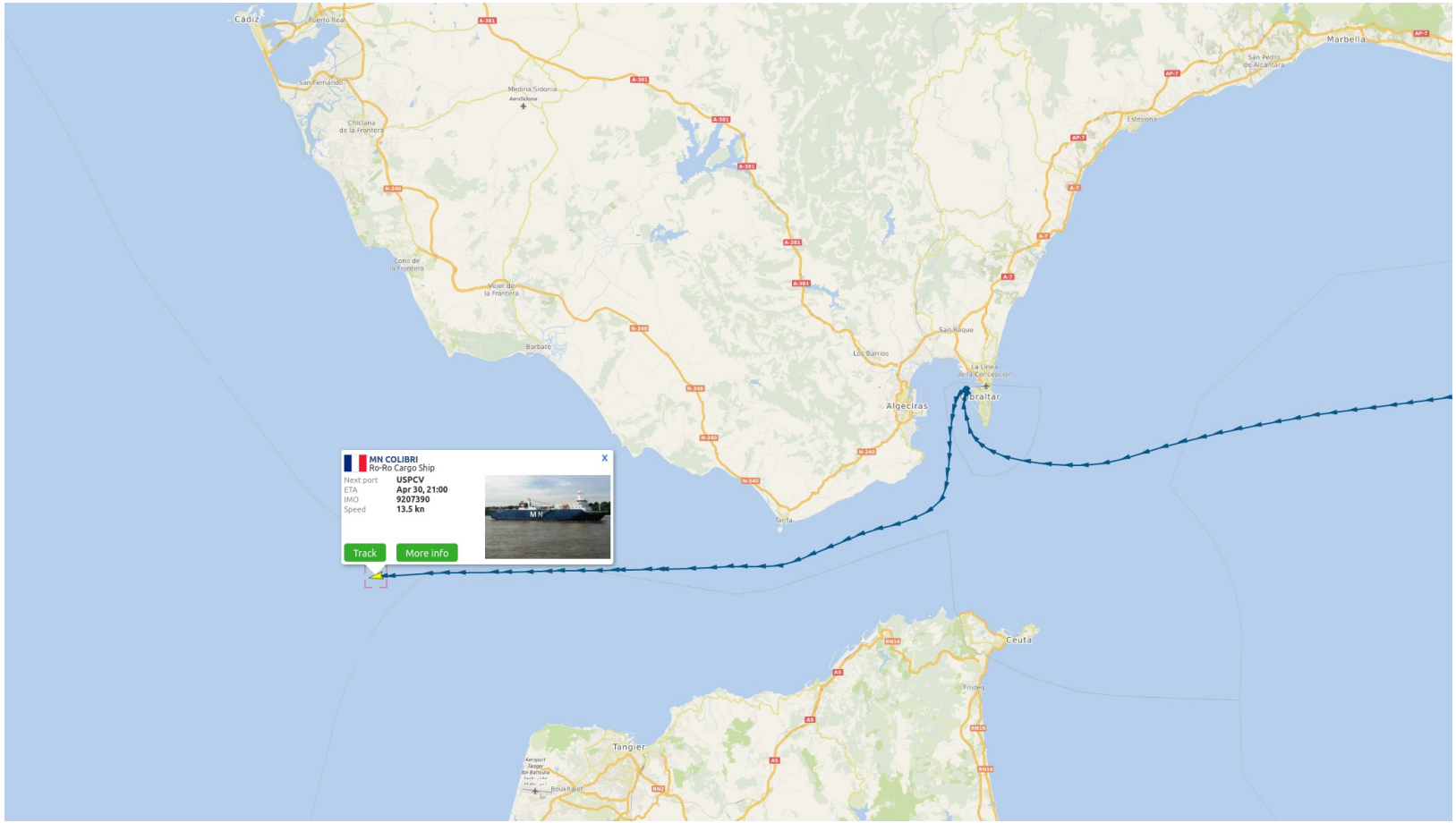
- ~4000 deg²
- 4m ground-based telescope

Euclid

- Medium-size mission (1 B€)
- 1.2m wide-field telescope: 0.5 deg² 2.5xMoon 0.2; >100xHST or JWST
- Destination: 2nd Lagrangian point
- Mission duration: 6-7 years
- Two payload instruments:
  - VIS
  - NISP

Euclid launch is getting close: July 2023!

Euclid today



Euclid main science goals

- Equation of state of dark energy: $w_0 = 1 \pm 0.016$? $w_r = 0 \pm 0.16$?

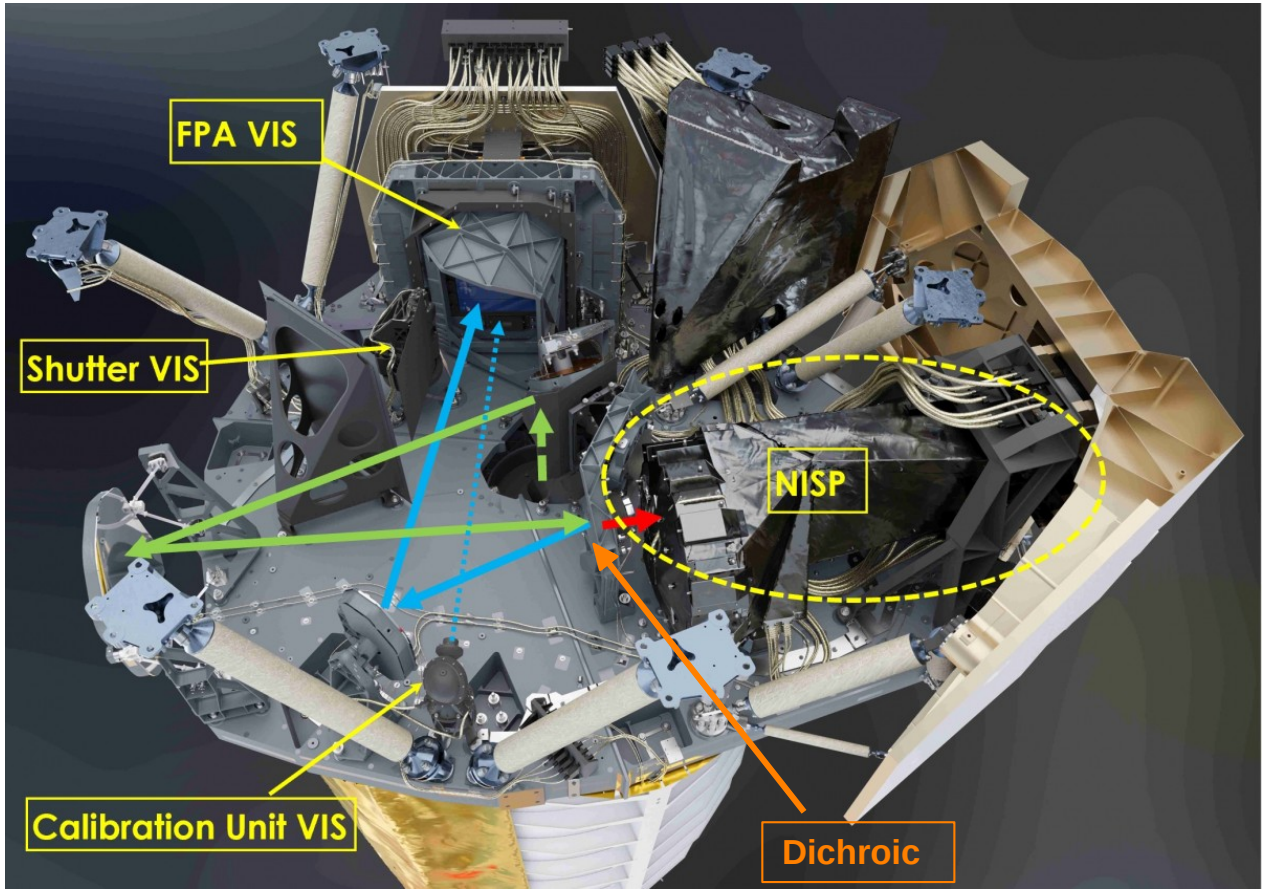
$$p = w\rho c^2$$

$$w(r) = w_0 + (1 - r)w_r, \qquad r = \left(\frac{1}{1+z}\right)$$

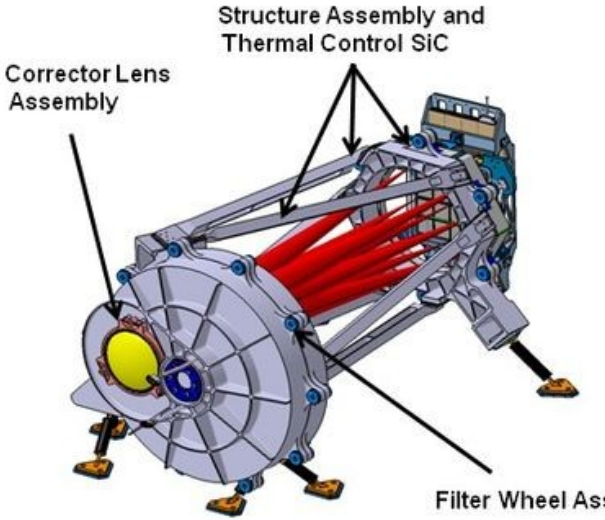
- Growth rate of density fluctuations: $\gamma = 0.55 \pm 0.02$?

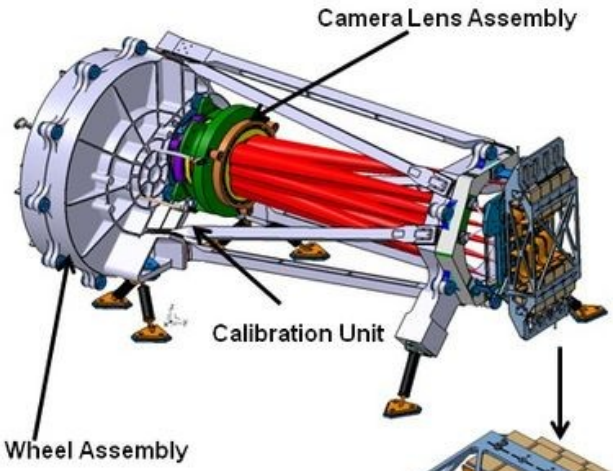
$$f(z) = \Omega_{\mathrm{m}}^{\gamma}$$

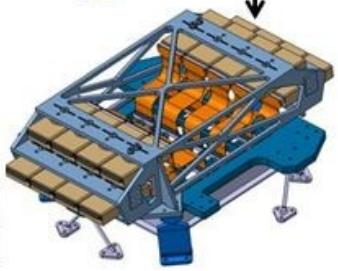
Euclid Payload Module



NISP: Near-Infrared Photometer and Spectrometer





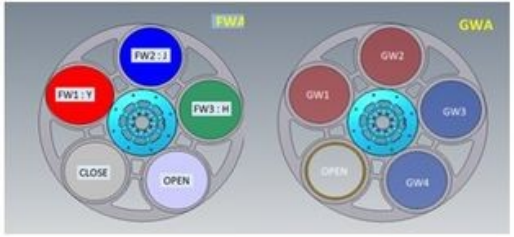


16 H2GR detectors

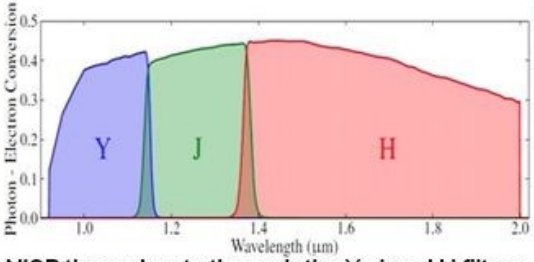
4x4 matrix of 2kx2k HgCdTe detectors

Imaging photometry in three bands Y, J, H

Low-resolution spectra 1.25-1.85 μm (+0.9-1.25 μm)

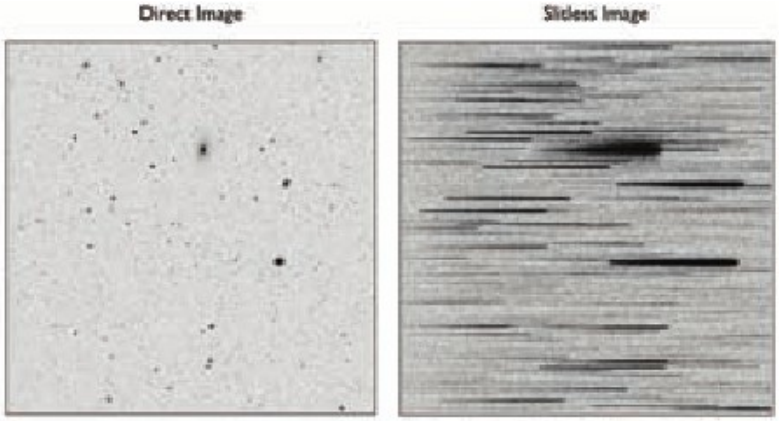


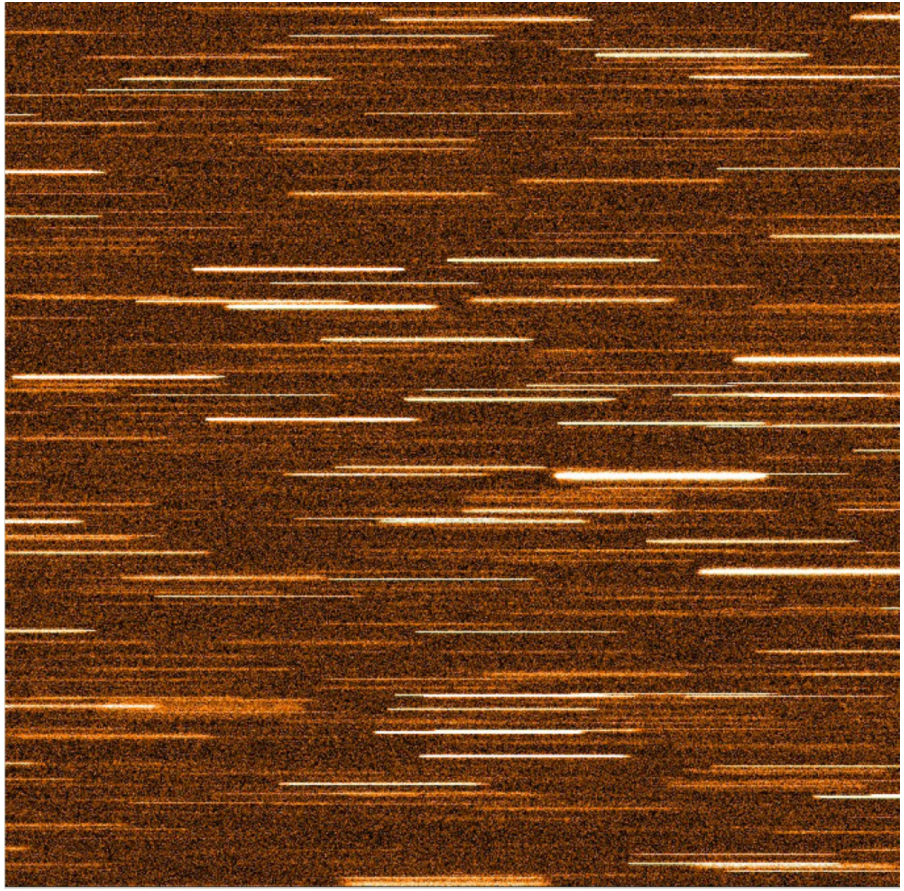
Filters and grisms positions in wheels



NISP throughputs through the Y, J and H filters

Slitless spectroscopy



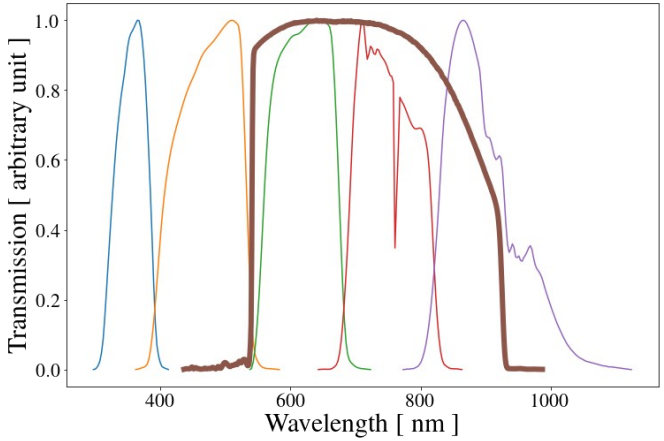


Advantages:
- Simplicity
- No source preselection

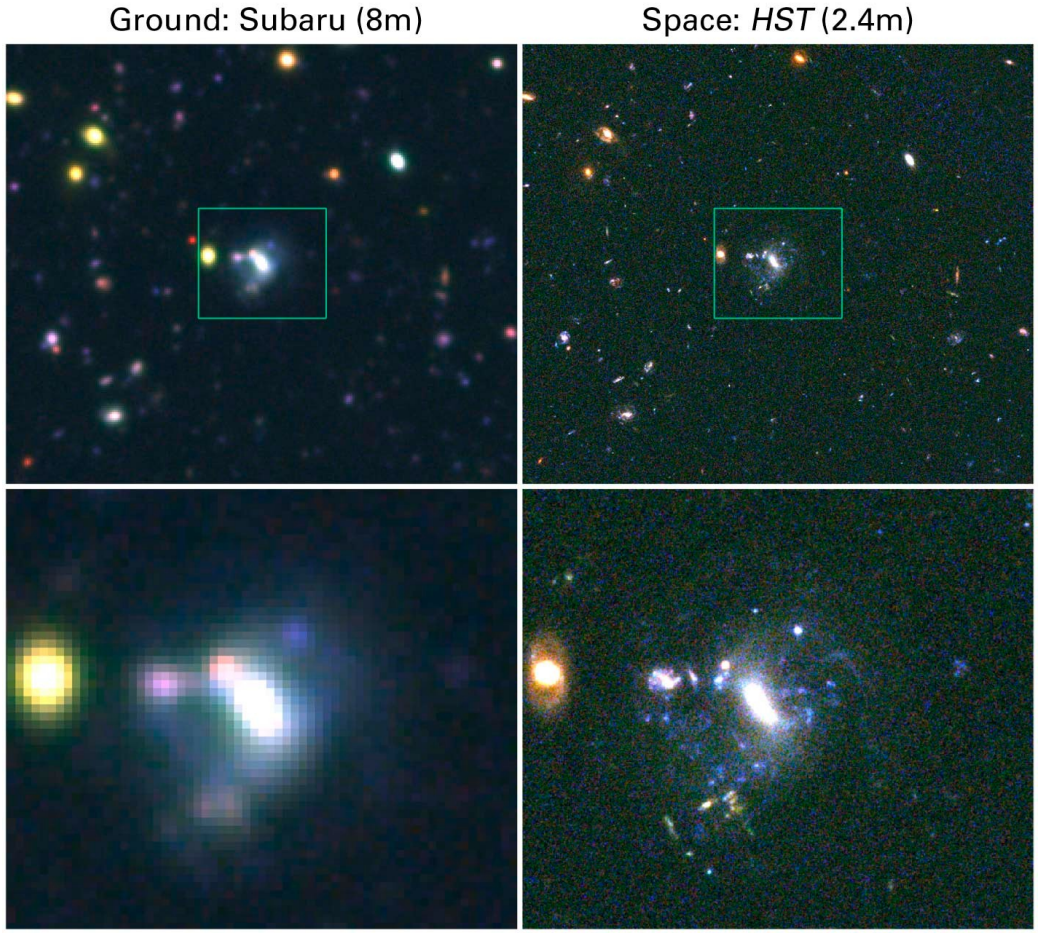
Disadvantages:
- Source overlap
- Complex sky background

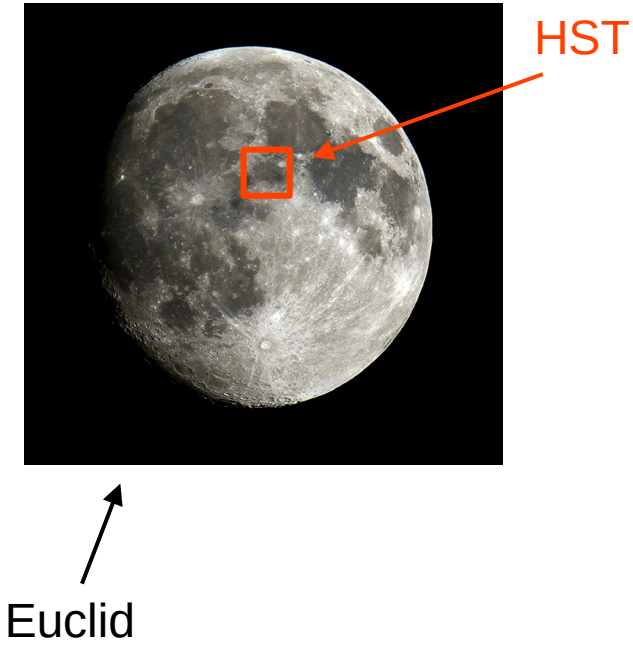
The VIS imager

- 6x6 matrix of 4kx4k CCDs
- One broad-band filter
- 0.15 arcsec resolution

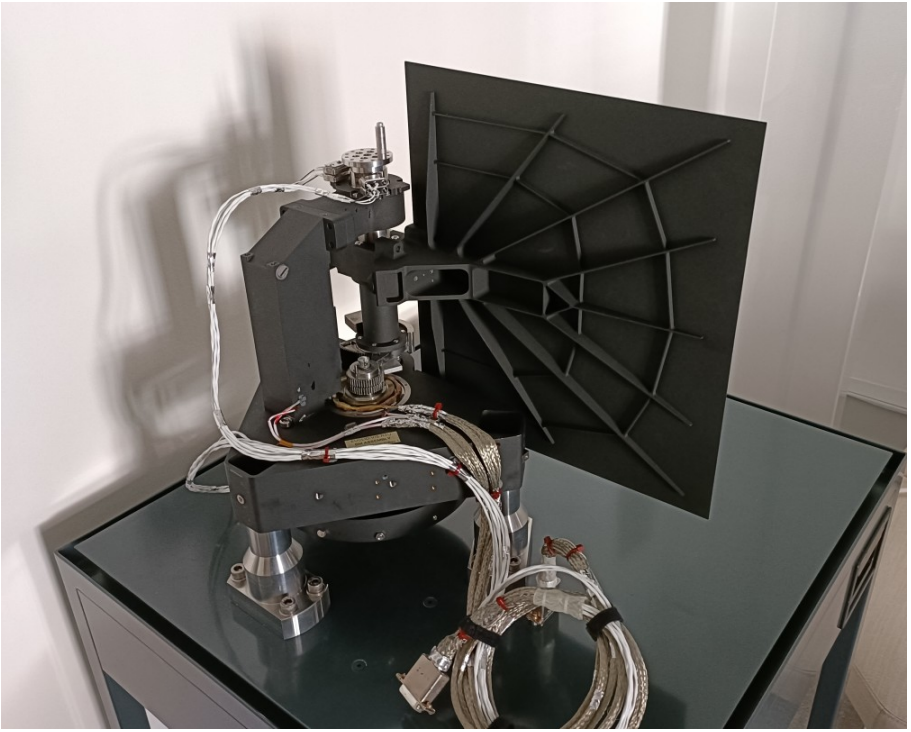


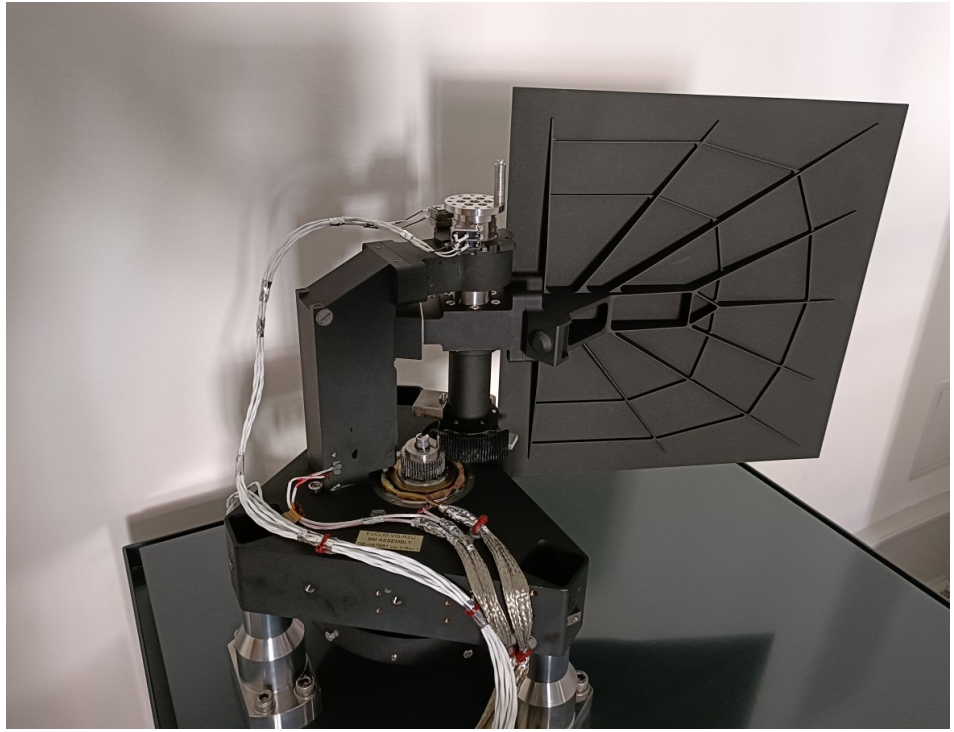
Euclid VIS images





The Readout Shutter unit for VIS





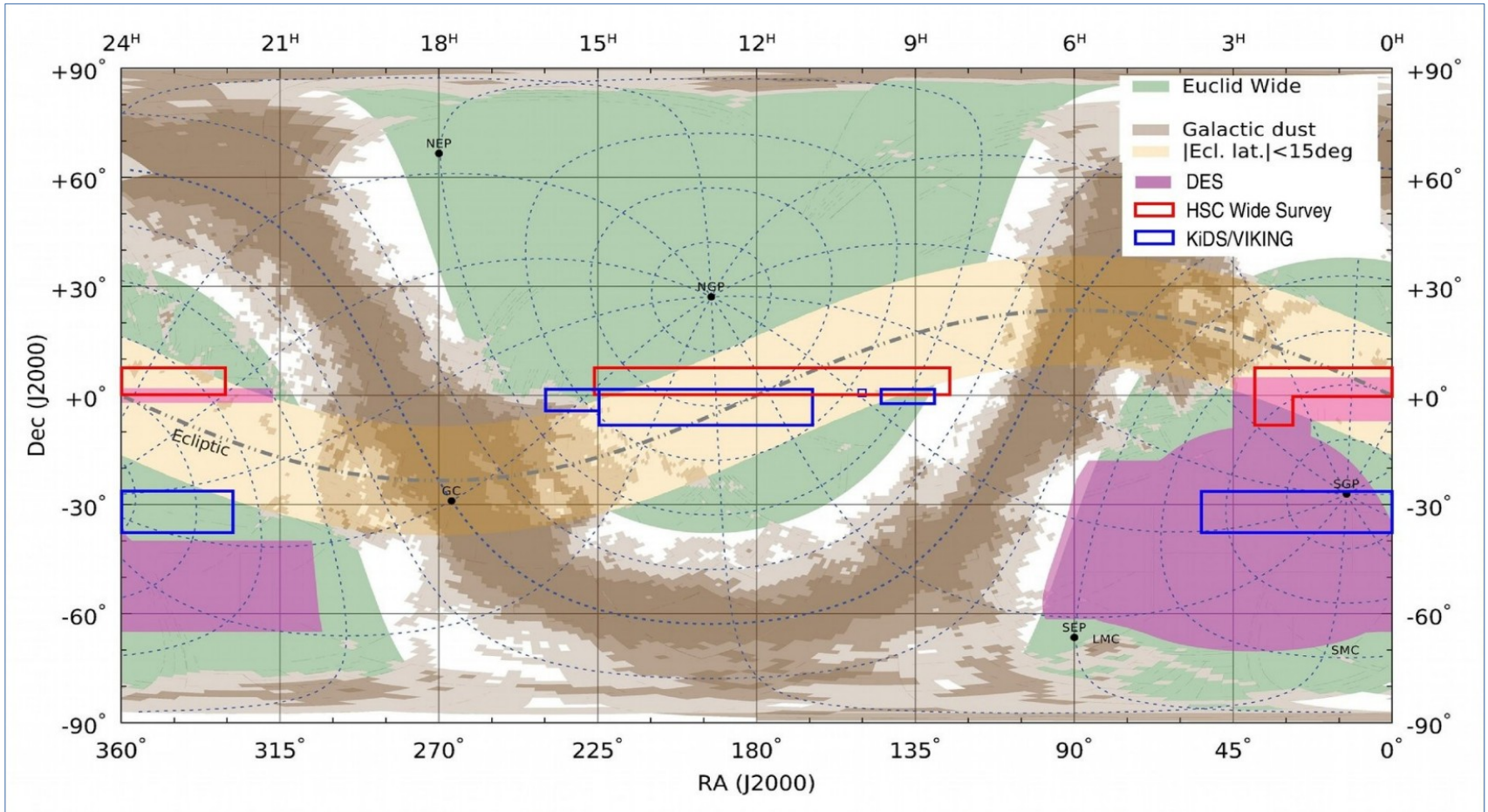
– Cold (170 K) – 14 kg – Highly reliable (500’000 operations)
– No exported momentum and torque – No microvibrations

APCO TECHNOLOGIES

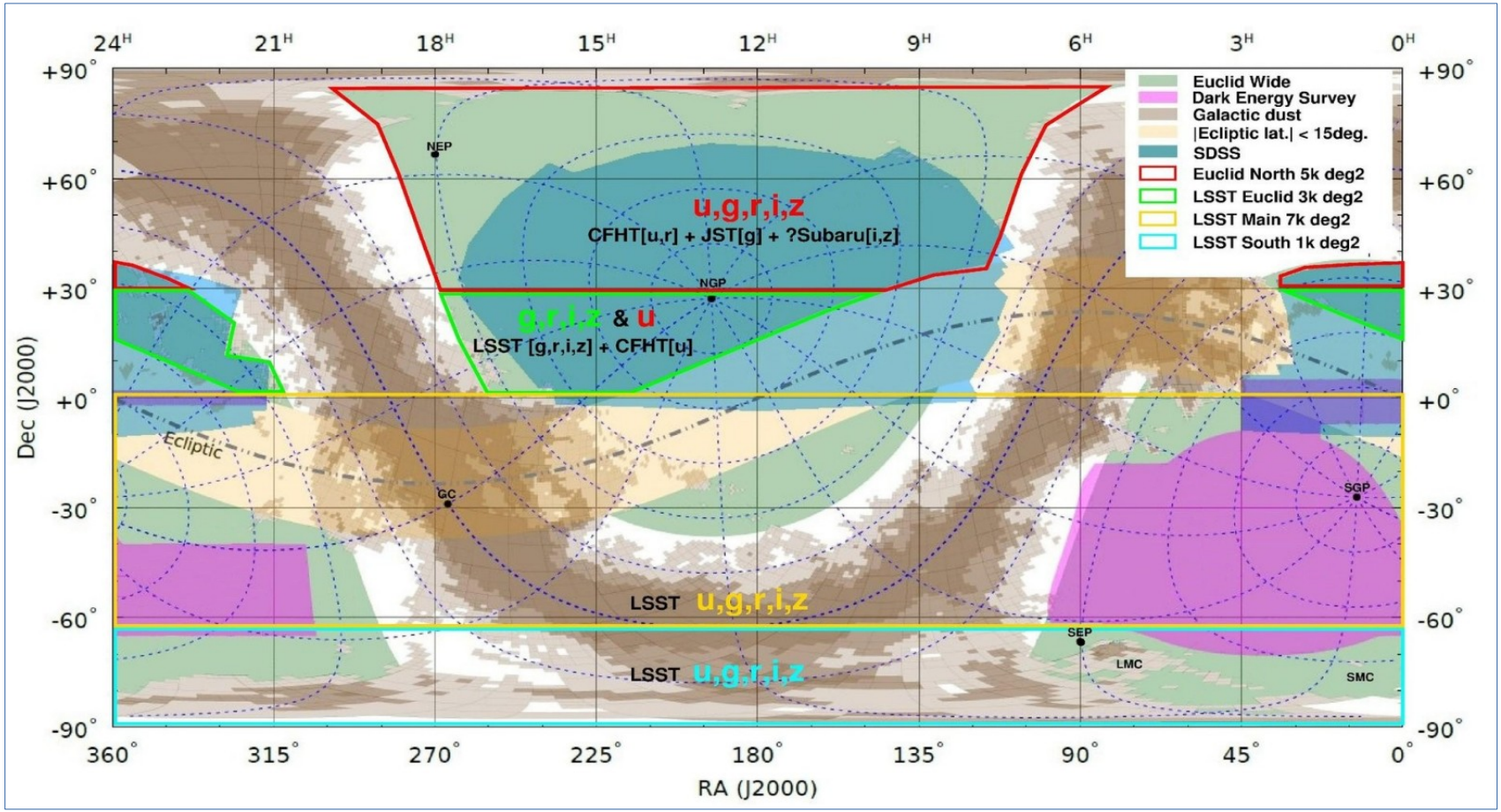
What Euclid will provide

- Sky area: 15’000 deg² (x4-10)
  - 10 billion galaxies for weak lensing
  - 30 million galaxies with spectroscopy
- Image resolution: 0.15 arcsec (x5)
- Near-infrared:
  - $z \rightarrow 2$ (x2-3)
  - Tomography: clustering over 80% of the age of the Universe

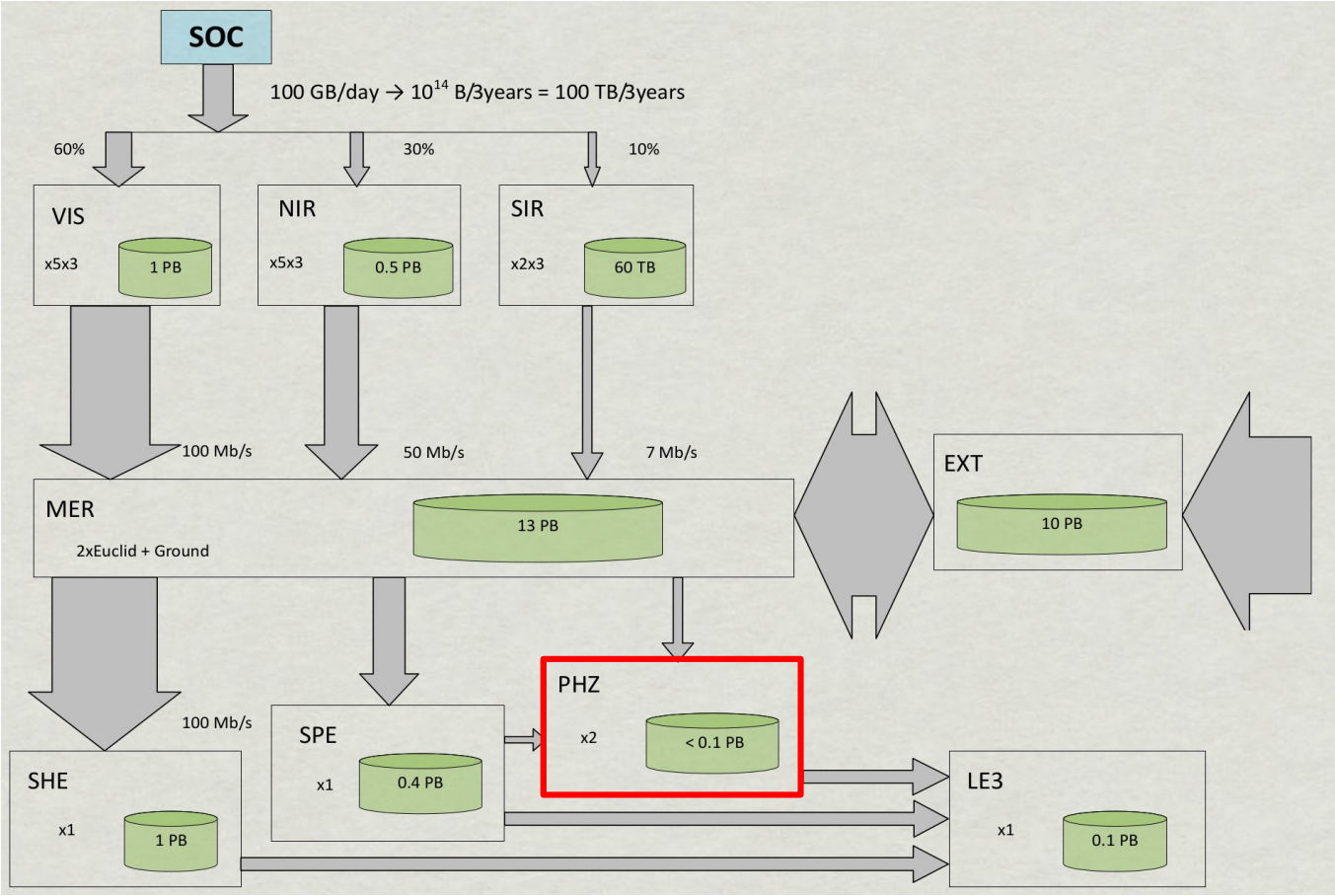
The Euclid wide survey



Ground-based optical survey



The Euclid pipeline



- 30-50 PB of data
- 10 data centers
  - All SDC process all data
  - SDC-CH @ ASTRO
- 20’000 cores
  - 1300 on Yggdrasil
- PHZ is the Swiss (UNIGE) main responsibility

Photometric redshifts

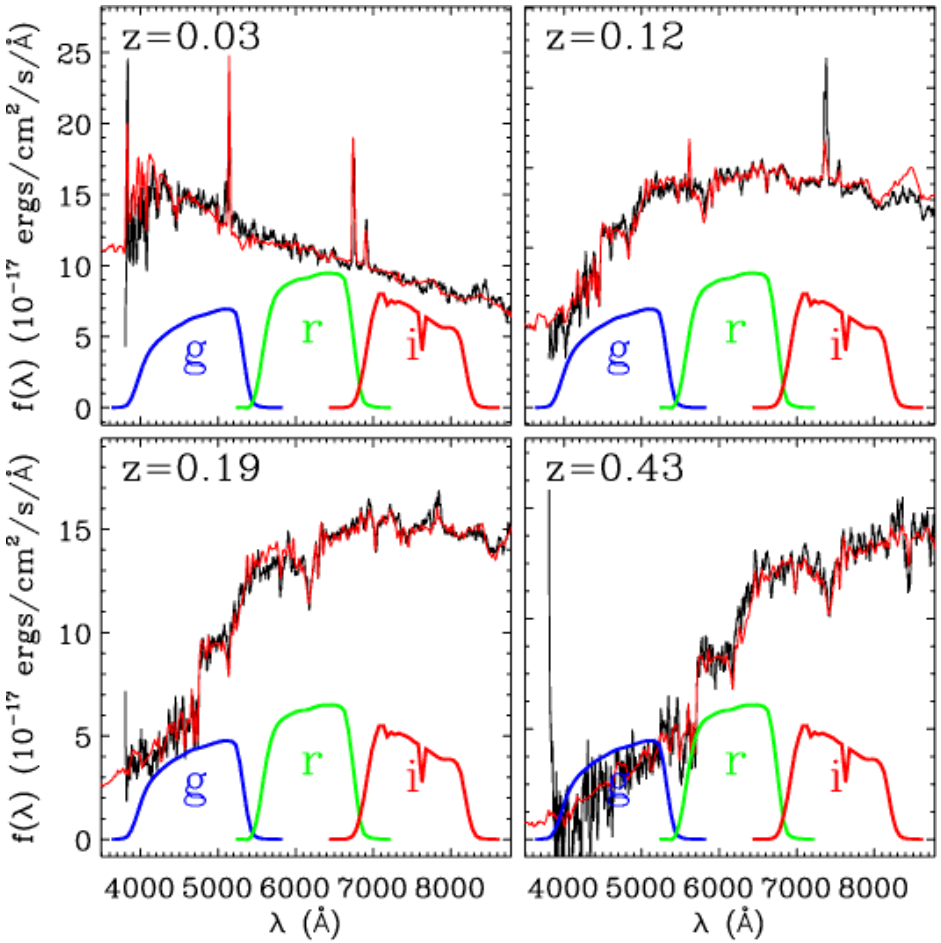
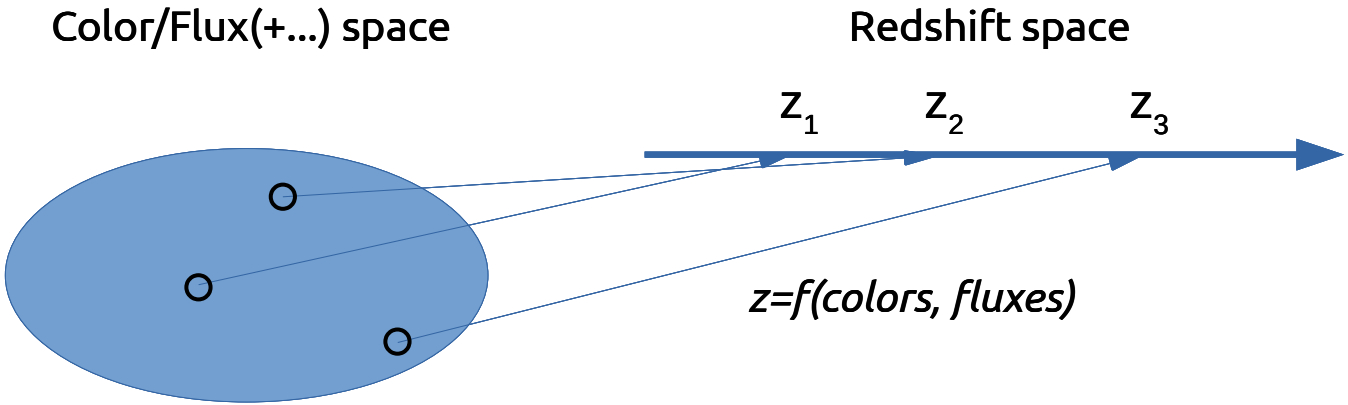


Photo-z as a mapping problem



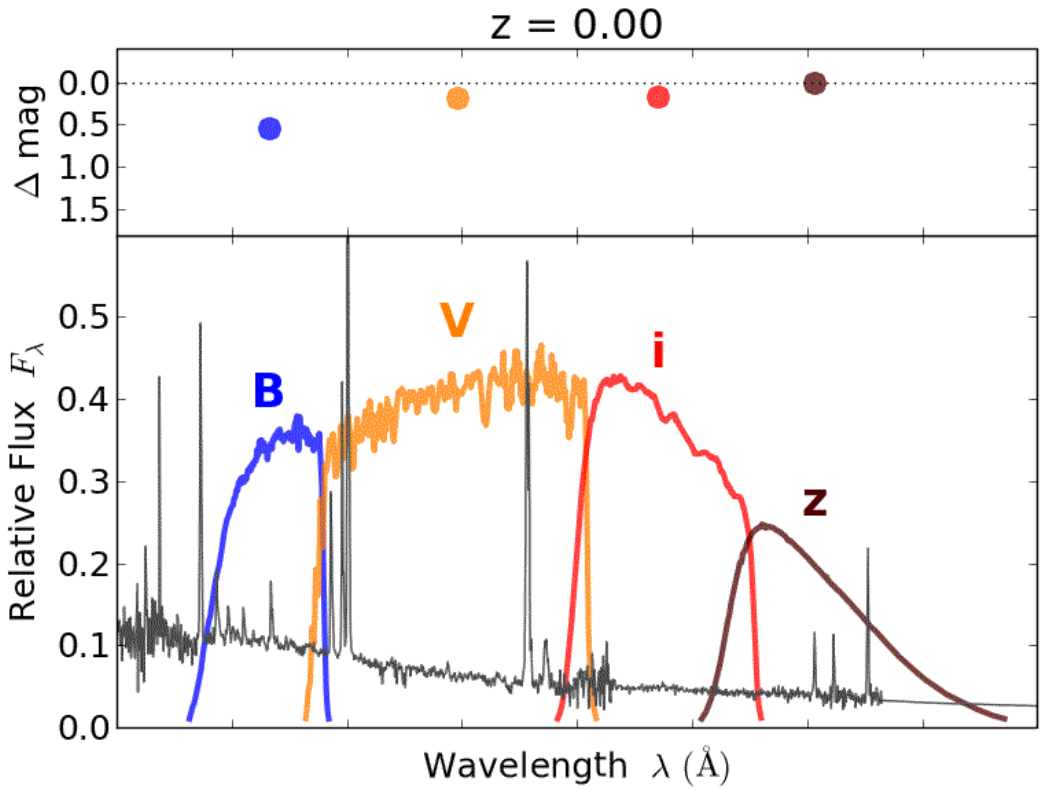
Mapping *f* can be constructed based on prior astrophysical knowledge :

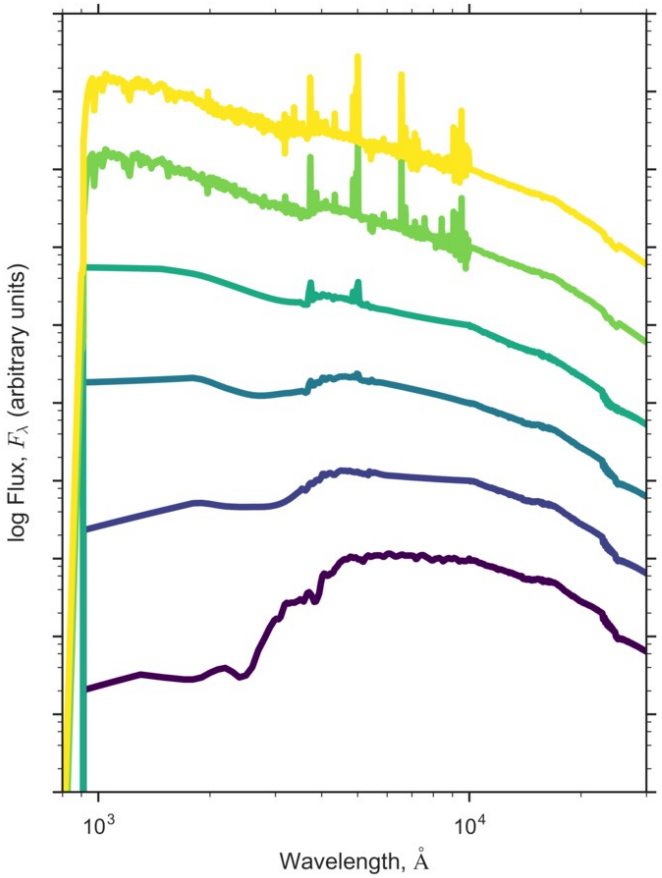
- Template-fitting: Hyper-Z, Le Phare, BpZ, Phosphoros,…

Or it can be discovered using known (spectroscopic) redshifts:

- Machine-learning: Nearest neighbours, Perceptron, Support vector regression, Random Forest, Adaboost, Gaussian Processes, …

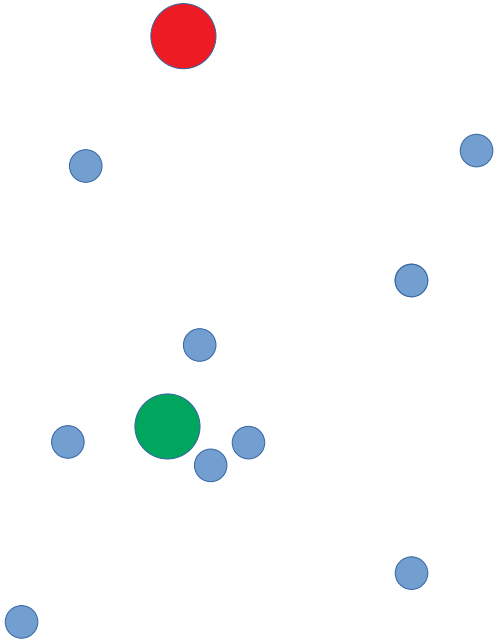
Template-fitting



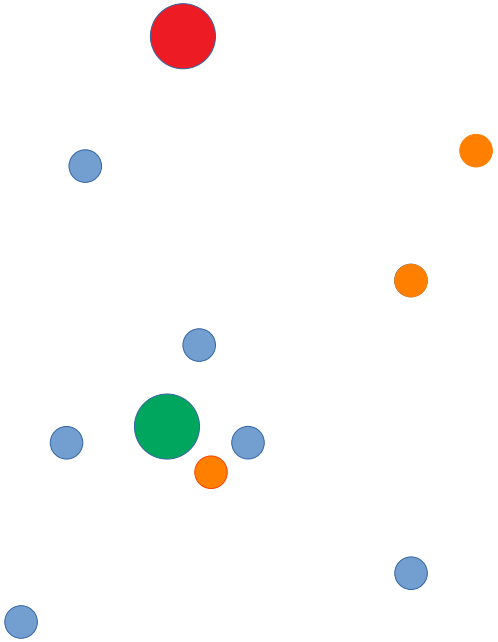


Machine learning issues

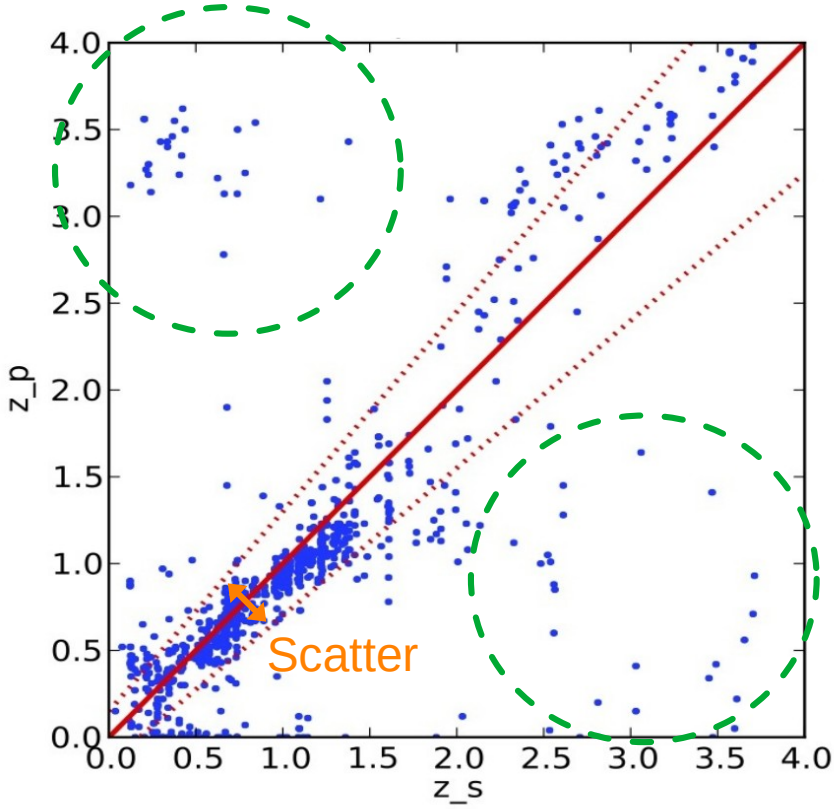
Incompleteness of training sample



Degeneracy



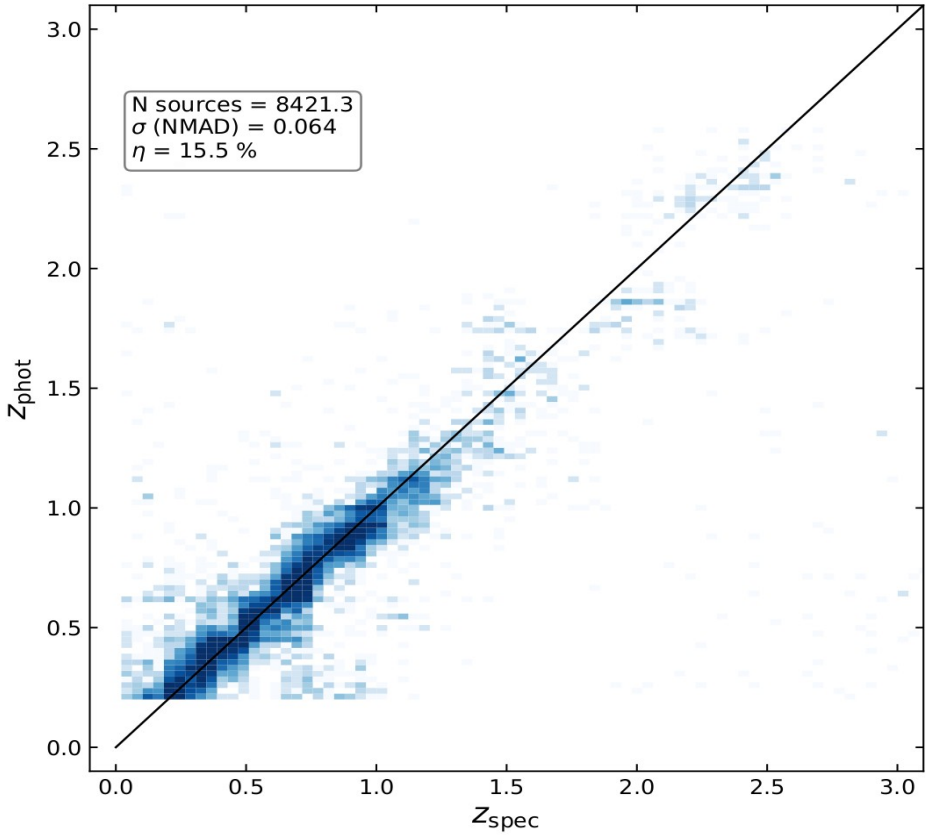
Photometric redshift quality

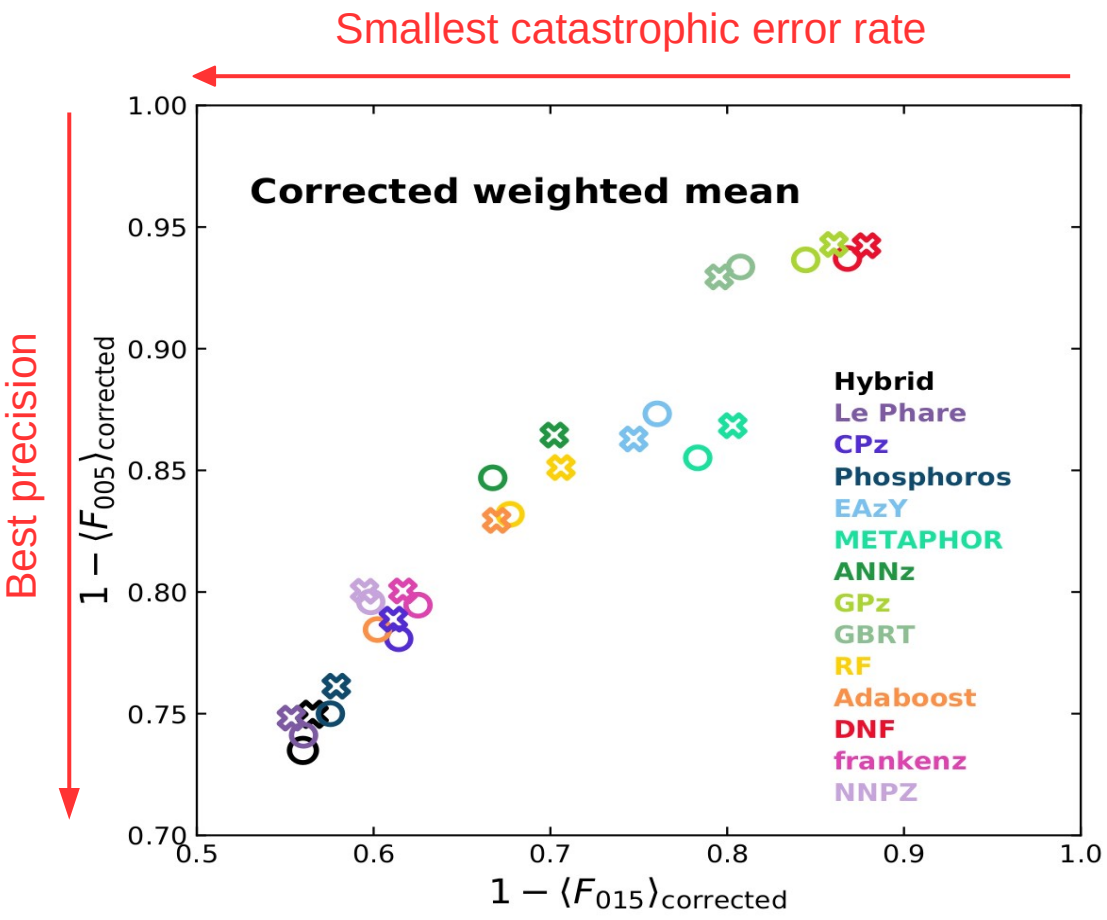


Catastrophic failures

Data Challenge

EC, Desprez et al. 2020





NNPZ: Probabilistic nearest-neighbour

Reference Sample
10^6 high-quality objects
PDZs from Phosphoros

Euclid Sample
10^{10} objects
Unknown PDZs

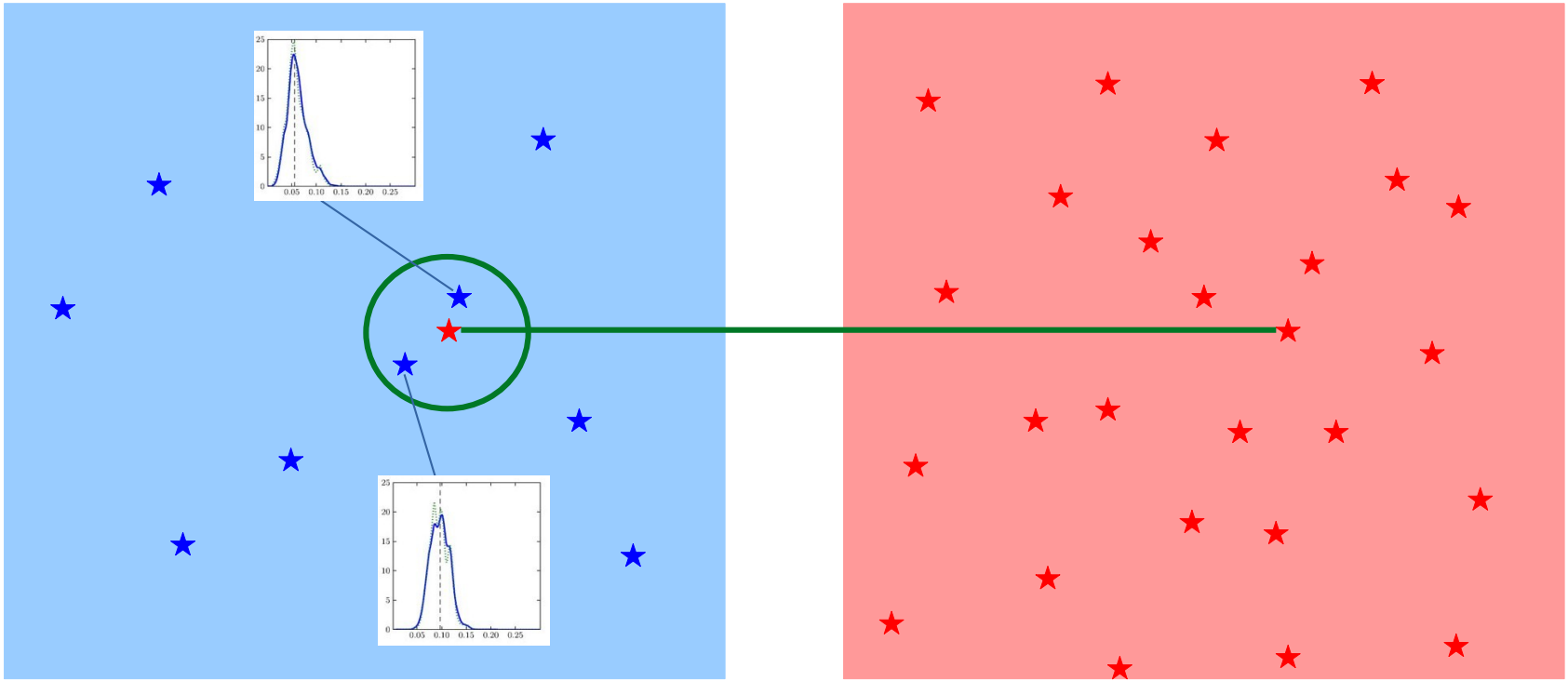
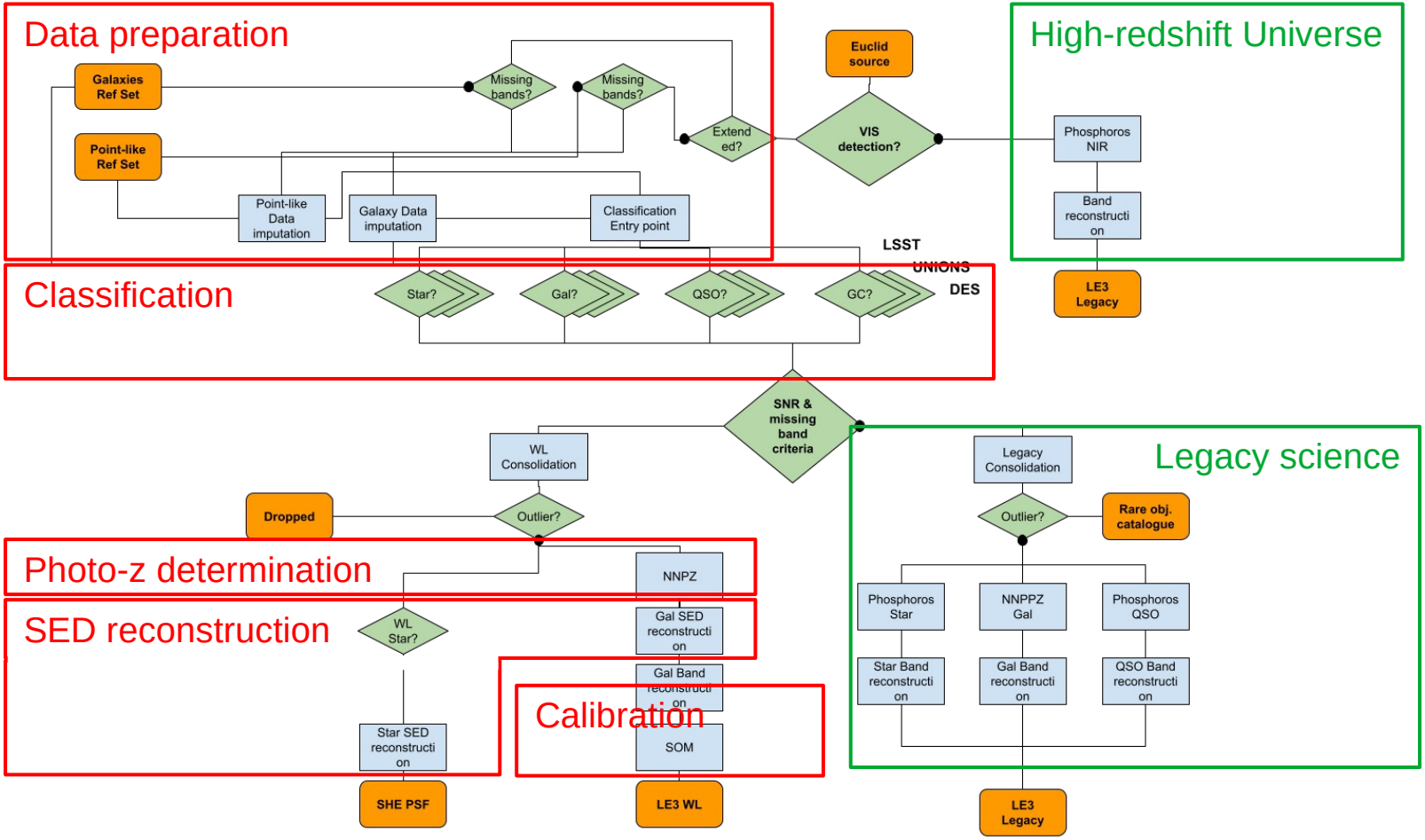
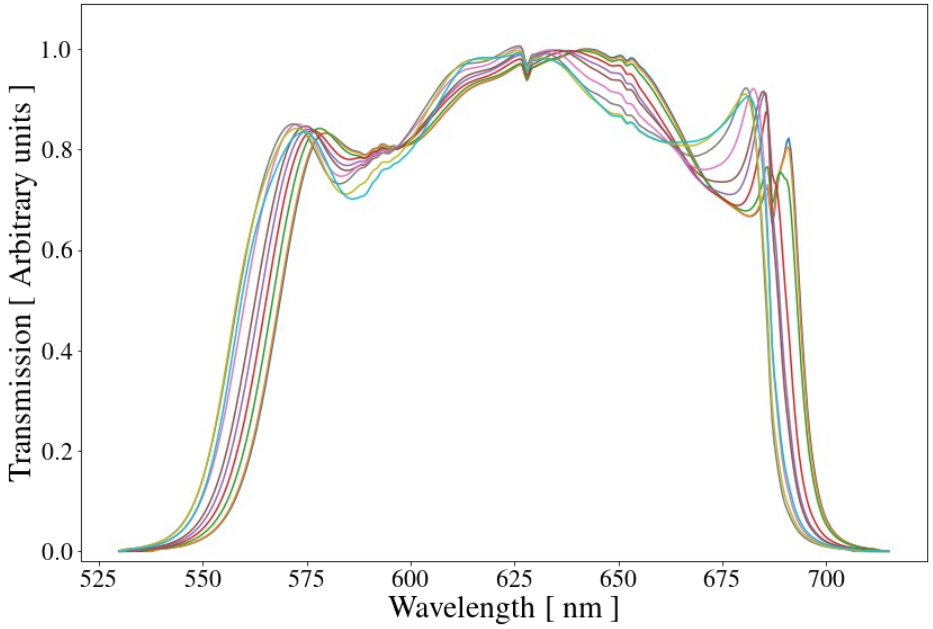
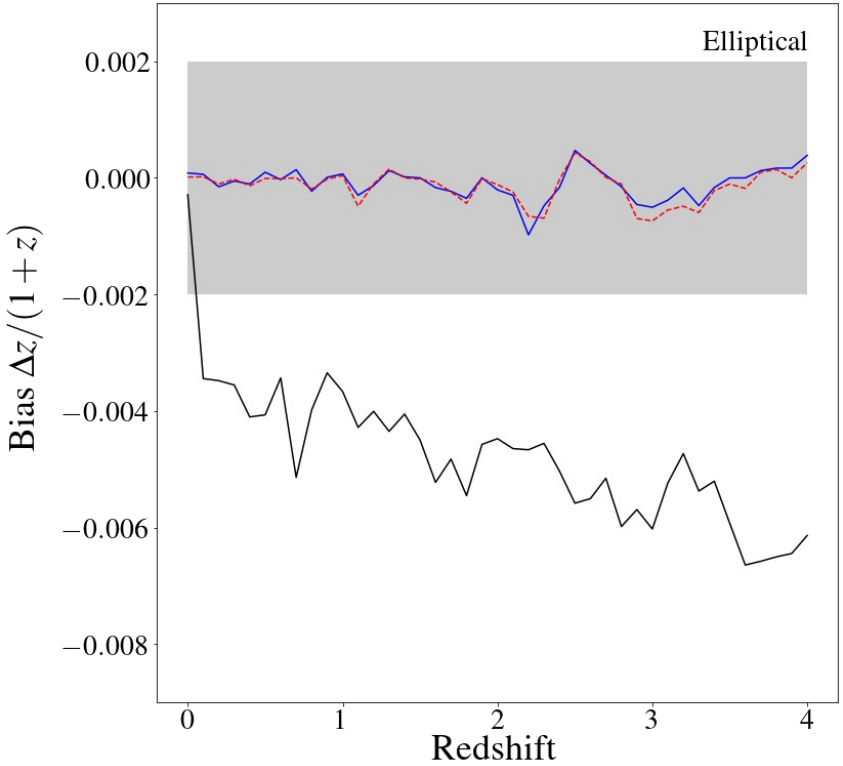


Photo-z pipeline



Filter variations





Big issue for ML!

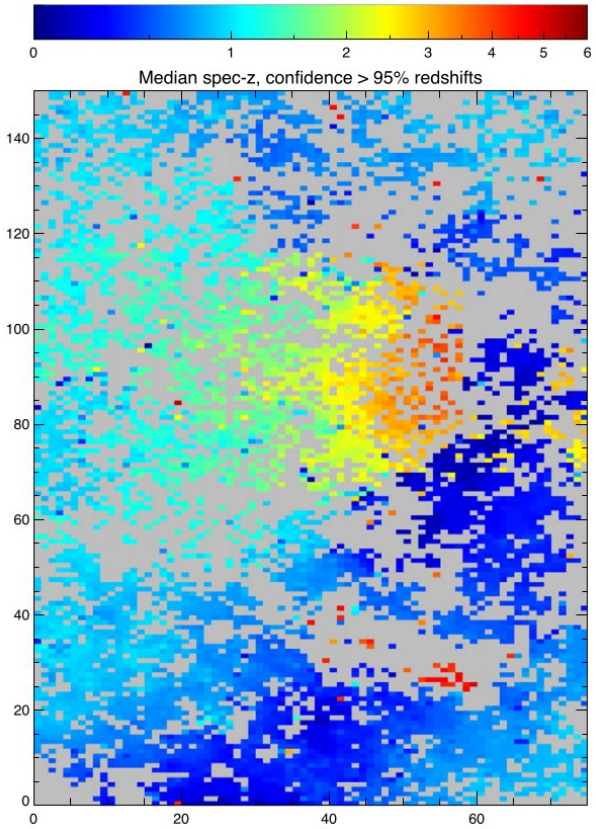
EC, SP et al.

Classification

- Identification of stars vs galaxies, but also active supermassive black holes
- Images cannot be used!
- Colour-based classification
  - Machine-learning: Probabilistic Random Forest

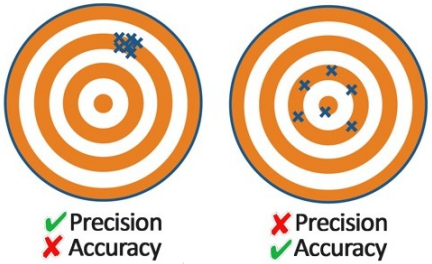
EC, Fotopoulou, Tucci et al.

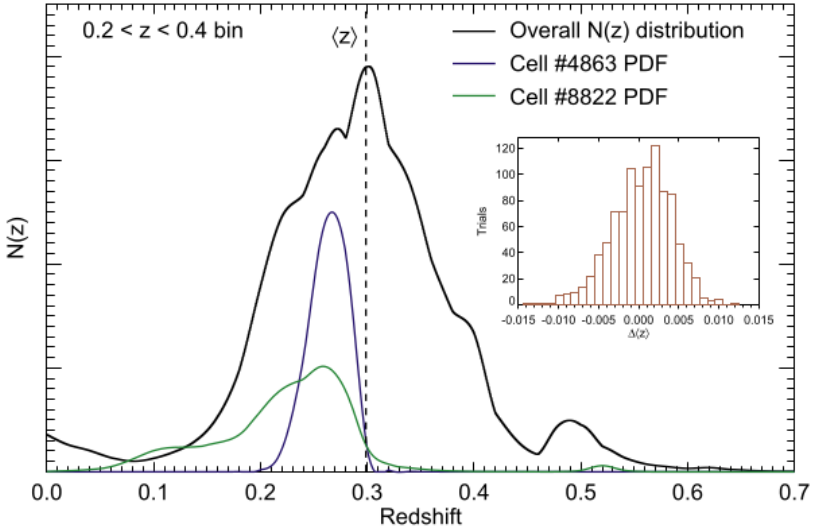
Calibration



Self-organizing map of all galaxies in 8D colour space → **C3R2**

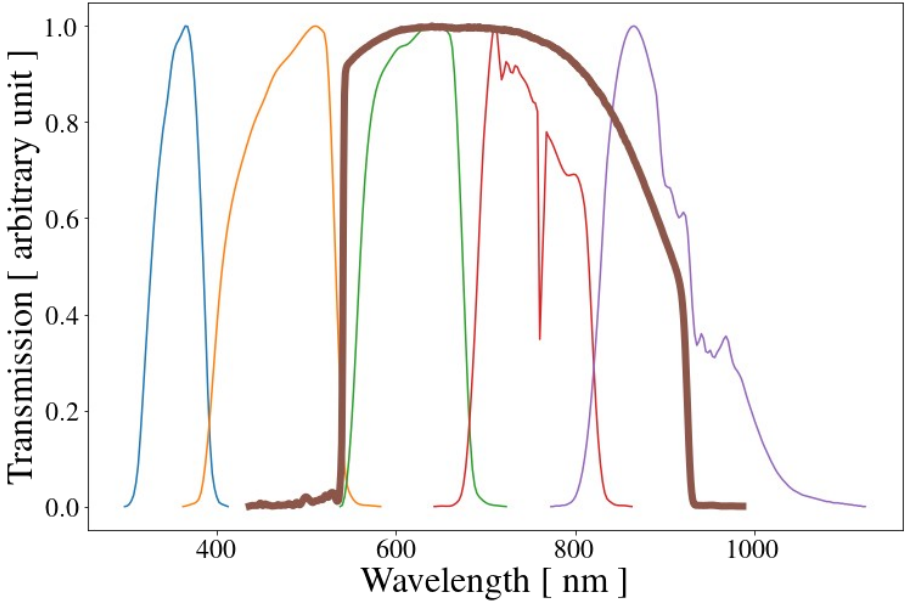
Bias requirement: $\Delta z < 0.002(1+z)$

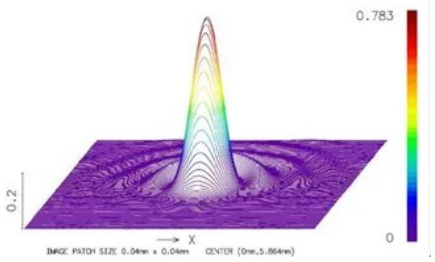




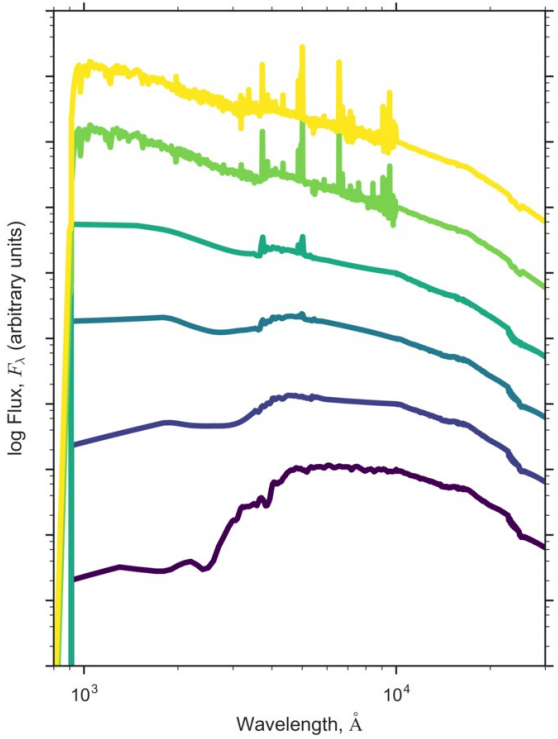
Masters et al. 2015 ++

Point Spread Function

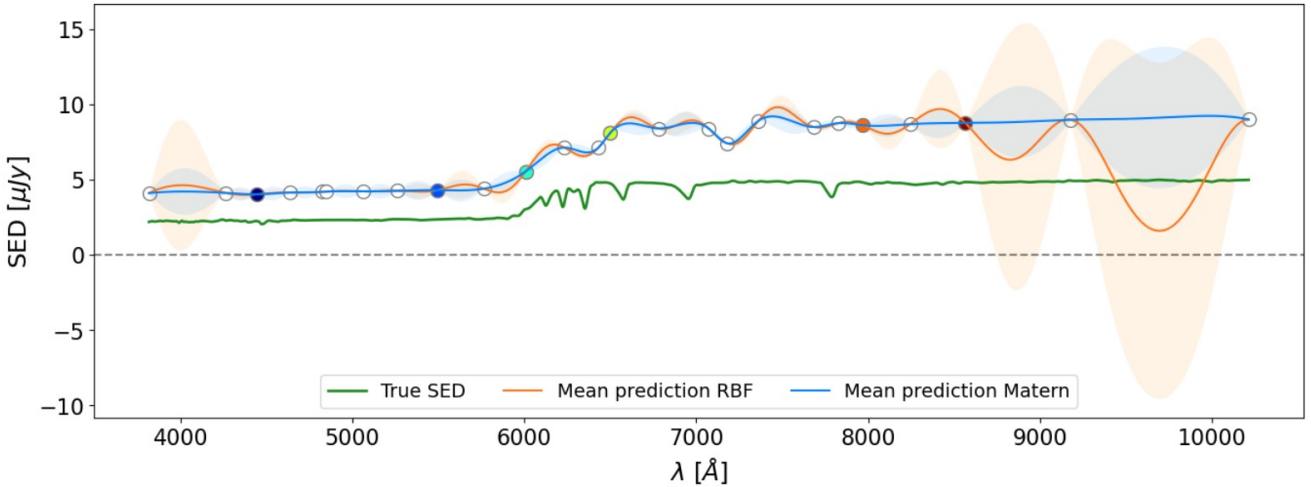


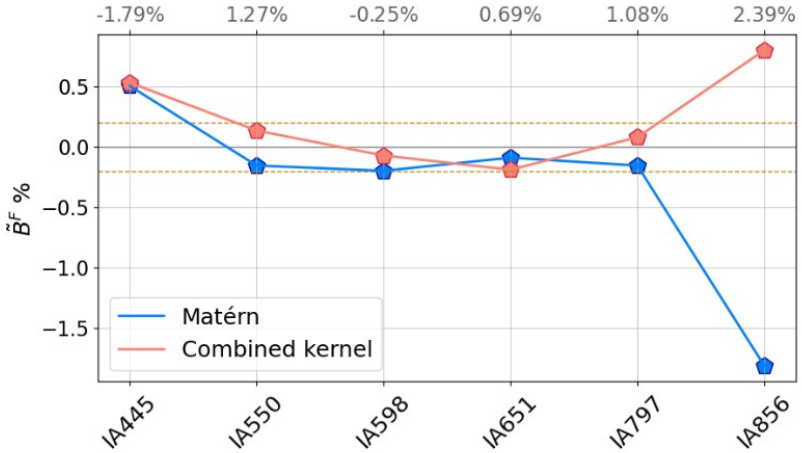


PSF ~ λ



SED reconstruction



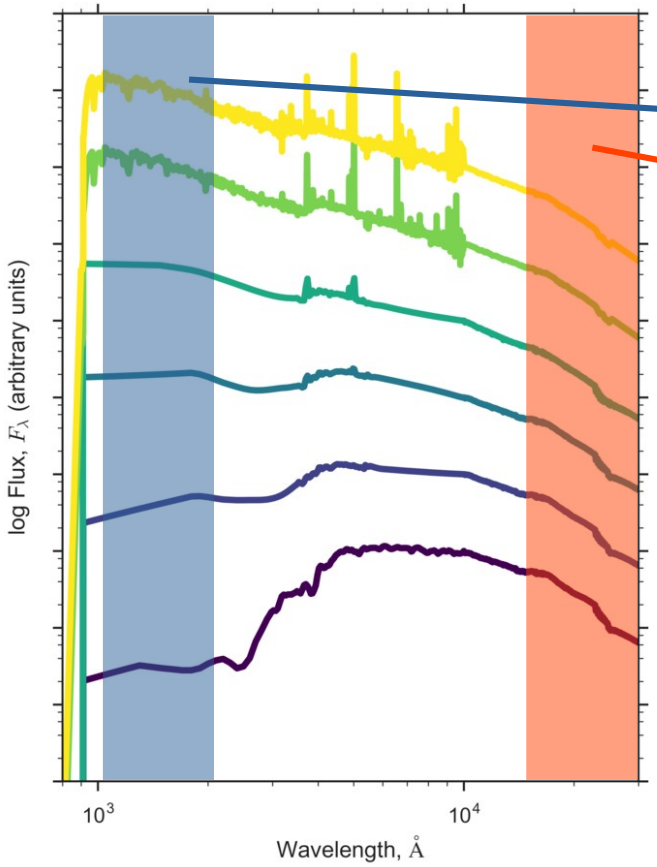


Gaussian process with Matérn kernel
ν controls smoothness

$$k(x_i, x_j) = \frac{1}{\Gamma(\nu)2^{\nu-1}} \left(\frac{\sqrt{2\nu}}{l} d(x_i, x_j) \right)^{\nu} K_\nu \left(\frac{\sqrt{2\nu}}{l} d(x_i, x_j) \right)$$

EC, Tarsitano et al.

Legacy science



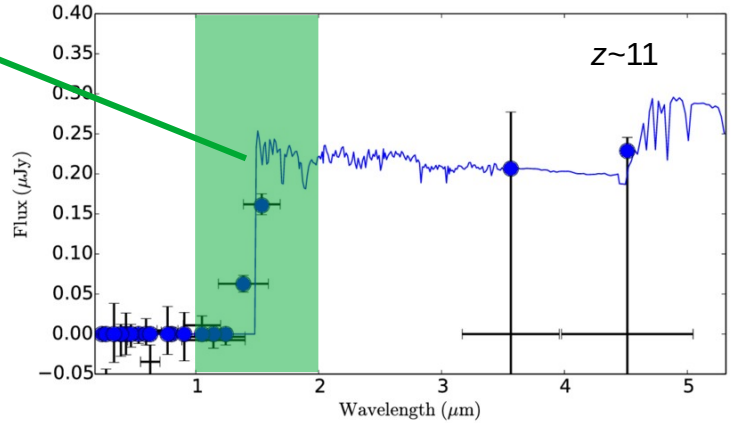
Primordial universe

Star formation rate

Stellar mass

Also:

- Luminosity
- Extinction
- Metallicity
- Nuclear activity

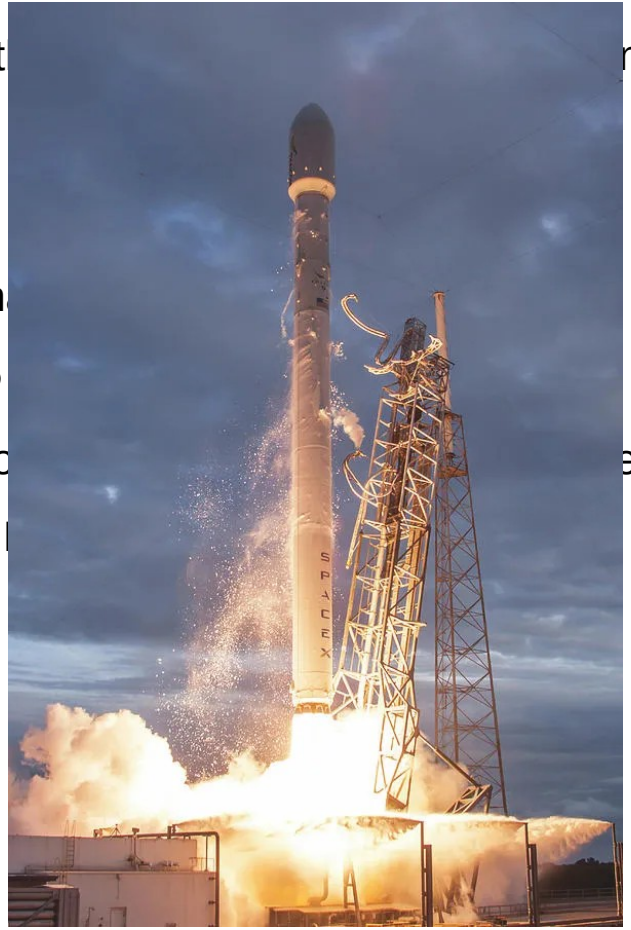


Physical parameters of billions of galaxies:

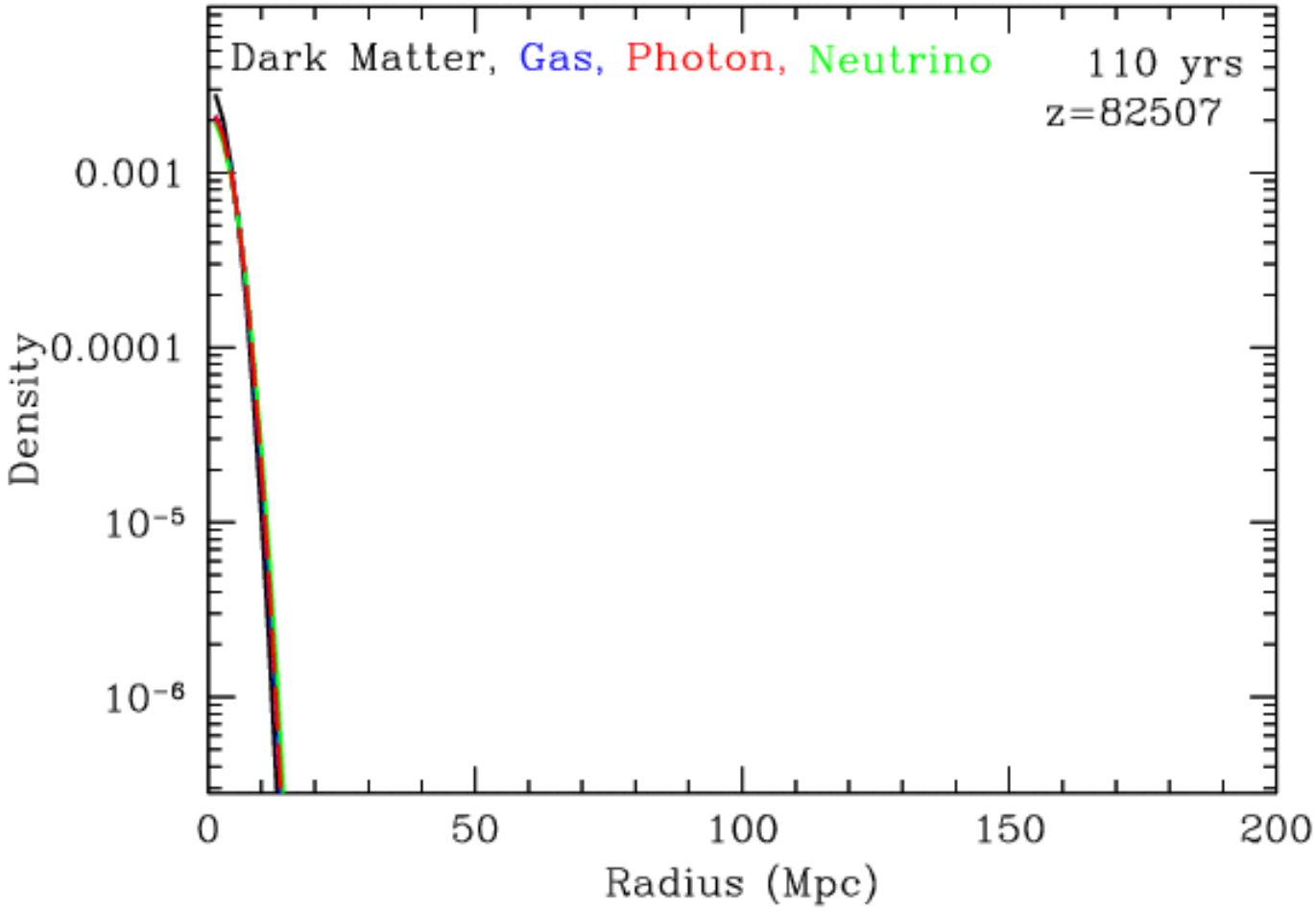
- Galaxy formation
- Galaxy evolution
- Growth of supermassive black holes
- …
- …
- …

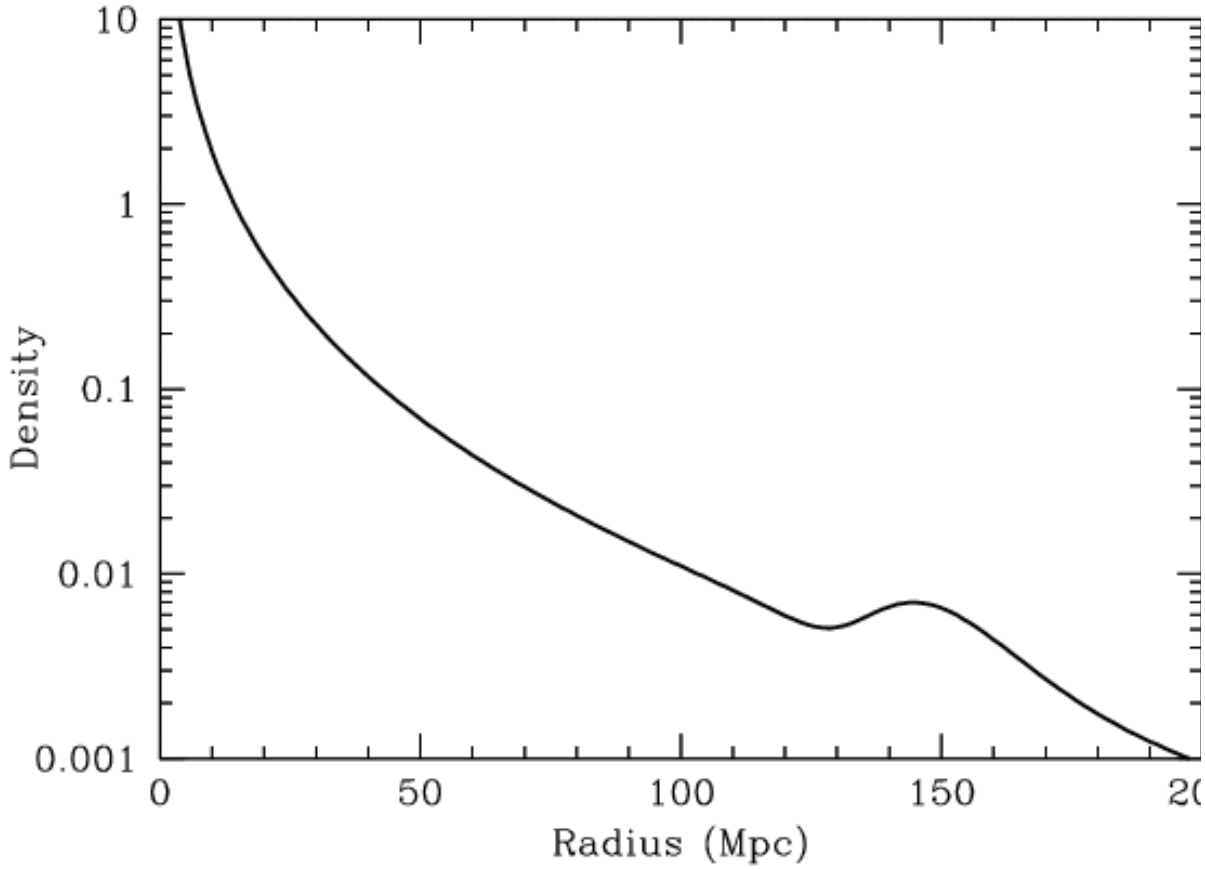
Conclusions

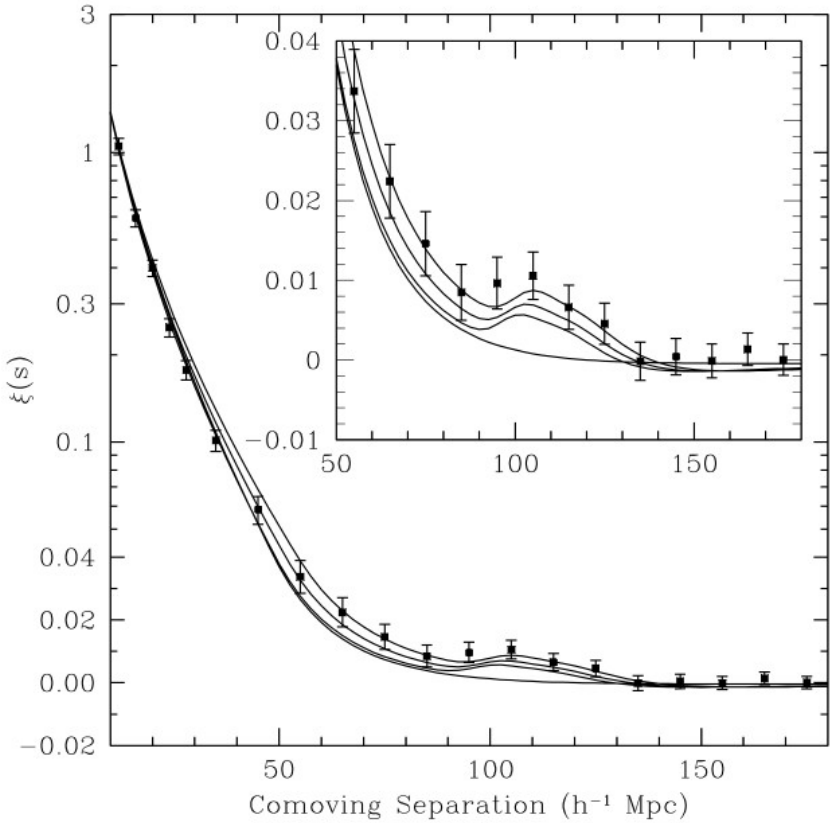
- Euclid shall answer some of t n physics:
  - Nature of dark energy
  - Nature of gravity
- Data analysis is extremely ch
  - What if we get w = -1.05
- Legacy science will largely do erms of number of papers!
  - But not in term of Nobel
- Launch is now imminent!



Additional slides


Dark Matter, Gas, Photon, Neutrino
110 yrs
z=82507
0.001
0.0001
10^{-5}
10^{-6}
Density
0
50
100
150
200
Radius (Mpc)





Eisenstein et al. 2005