Euclid space mission

(a few whys and hows)

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(Euclid Consortium, old timer,
Mission Survey Scientist,
member of the EC Board and EST)

Lots of figures and material courtesy of: EC&ESA (SciRD, CalWG, ECSURV, ESSWG, VIS, NISP, SWGs, OUs ...)

Red Book released in July 2011 (ESA web pages)

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Giga structures-years-pc-samples

Giga €...

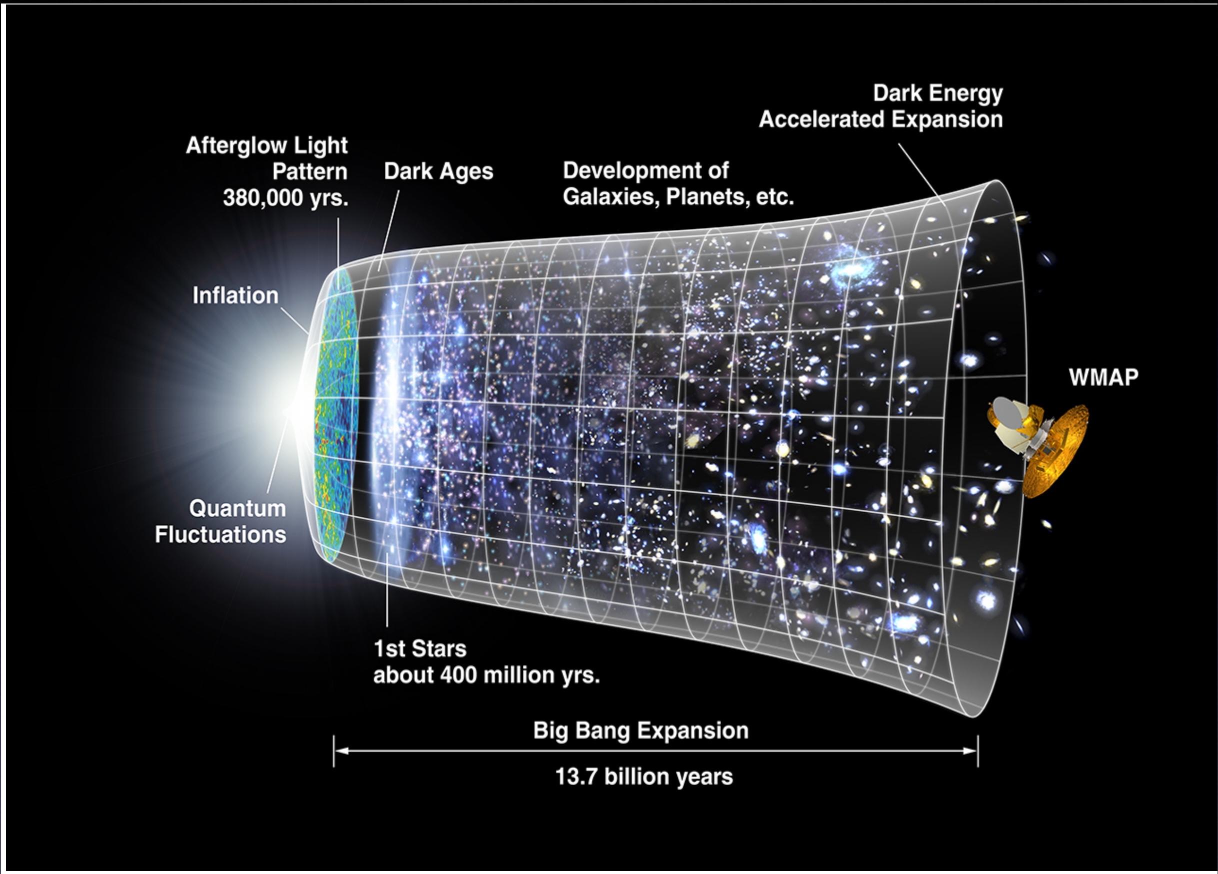
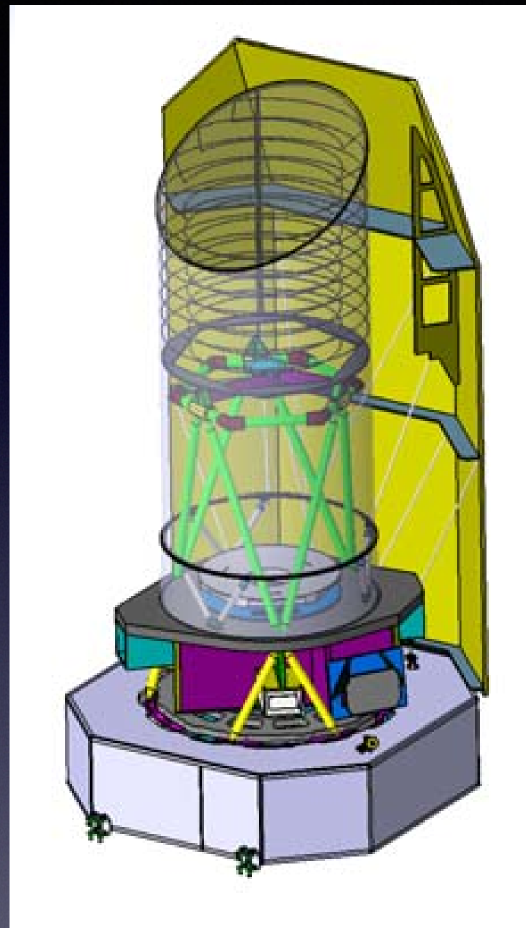


FIGURE 2-5 The cosmic timeline, from inflation to the first stars and galaxies to the current universe. The change in the vertical width represents the change in the rate of the expansion of the universe, from exponential expansion during the epoch of inflation followed by long period of a slowing expansion during which the galaxies and large scale structures formed through the force of gravity, to a recent acceleration of the expansion over the last roughly billion years due to the mysterious dark energy. Credit: NASA Wilkinson Microwave Anisotropy Probe Science Team.



Observed with a **mini** structure: mirror ~1.2 m ∅

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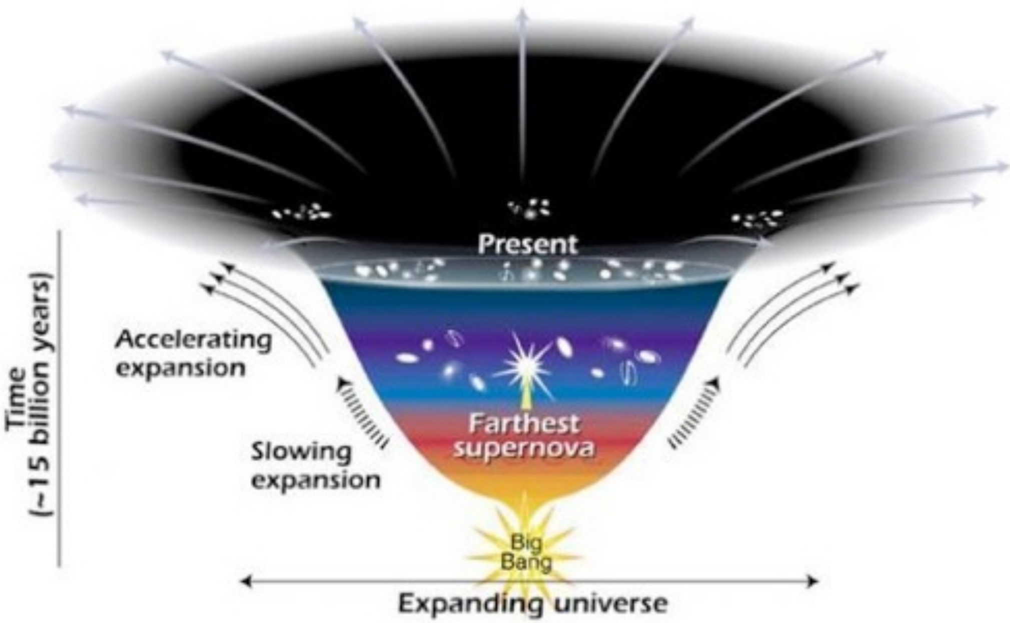
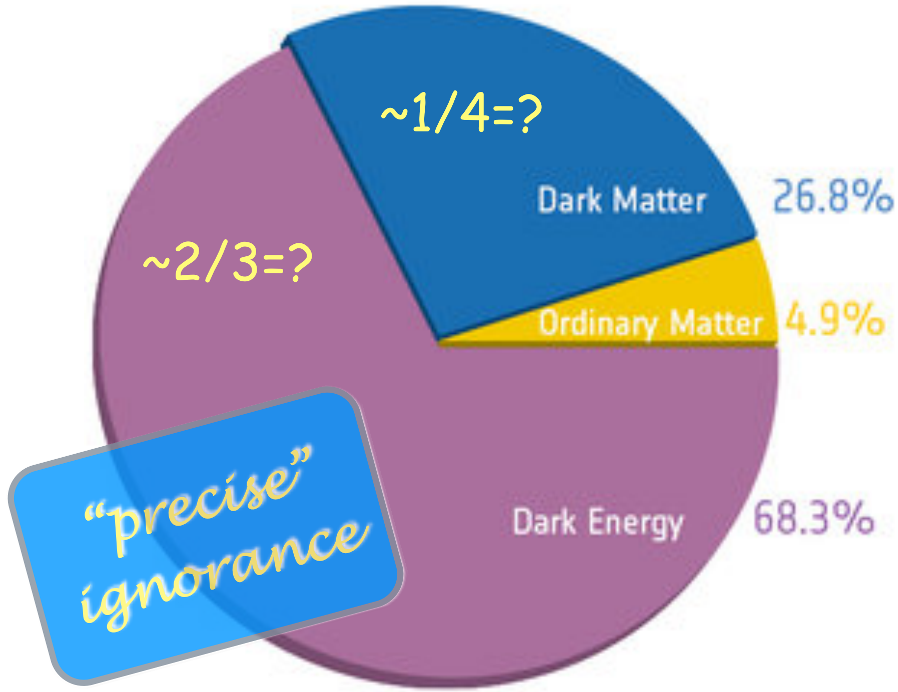
Open Questions in Cosmology

"precise" Cosmology

- Nature of the Dark Energy
- Nature of the Dark Matter
- Initial conditions (Inflation Physics)
- Modifications to Gravity
- Formation and Evolution of Galaxies

Large ignorance on ~95% of Universe content !!

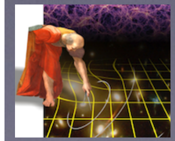




EUCLID

1. Why
2. How
3. When

1. Dark Energy & Dark Matter (Cosmology) ; Legacy
2. Space imaging (morphology & NIR) + Spectra: Grav. Lensing & BAO
3. 2020-2025+



Main Scientific Objectives
Understand the nature of Dark Energy and Dark Matter by:
• Reach a dark energy *FoM* > 400 using only weak lensing and galaxy clustering; this roughly corresponds to 1 sigma errors on w_p and w_a of 0.02 and 0.1, respectively.
• Measure γ, the exponent of the growth factor, with a 1 sigma precision of < 0.02, sufficient to distinguish General Relativity and a wide range of modified-gravity theories
• Test the Cold Dark Matter paradigm for hierachical structure formation, and measure the sum of the neutrino masses with a 1 sigma precision better than 0.03eV.
• Constrain n_s, the spectral index of primordial power spectrum, to percent accuracy when combined with Planck, and to probe inflation models by measuring the non-Gaussianity of initial conditions parameterised by f_{NL} to a 1 sigma precision of ~2.

SURVEYS

	Area (deg2)	Description
Wide Survey	15,000 (required) 20,000 (goal)	Step and stare with 4 dither pointings per step.
Deep Survey	40	In at least 2 patches of > 10 deg^2 2 magnitudes deeper than wide survey

PAYLOAD

Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	VIS	NISP			
Field-of-View	$0.787\times0.709\ deg^2$	$0.763\times0.722\ deg^2$			
Capability	Visual Imaging	NIR Imaging Photometry			NIR Spectroscopy
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	$3\ 10^{-16}$ erg cm-2 s-1 3.5σ unresolved line flux
Detector Technology	36 arrays 4k×4k CCD	16 arrays 2k×2k NIR sensitive HgCdTe detectors			
Pixel Size Spectral resolution	0.1 arcsec	0.3 arcsec			0.3 arcsec R=250

SPACECRAFT

Launcher	Soyuz ST-2.1 B from Kourou
Orbit	Large Sun-Earth Lagrange point 2 (SEL2), free insertion orbit
Pointing	25 mas relative pointing error over one dither duration 30 arcsec absolute pointing error
Observation mode	Step and stare, 4 dither frames per field, VIS and NISP common FoV = 0.54 deg^2
Lifetime	7 years
Operations	4 hours per day contact, more than one groundstation to cope with seasonal visibility variations;
Communications	maximum science data rate of 850 Gbit/day downlink in K band (26GHz), steerable HGA

Budgets and Performance

	Mass (kg)		*Nominal Power (W)*	
industry	TAS	Astrium	TAS	Astrium
Payload Module	897	696	410	496
Service Module	786	835	647	692
Propellant	148	232		
Adapter mass/ Harness and PDCU losses power	70	90	65	108
Total (including margin)	**2160**		**1368**	**1690**

All data you need to know (Red Book)

- Wide Area ($>10^4$ sq deg)
- Wide Field (FoV > 0.5 sq deg)
- Opt. imaging
- NIR photom
- NIR slitless

Two instruments:

VIS: optical imager &

NISP: NIR imager + grisms

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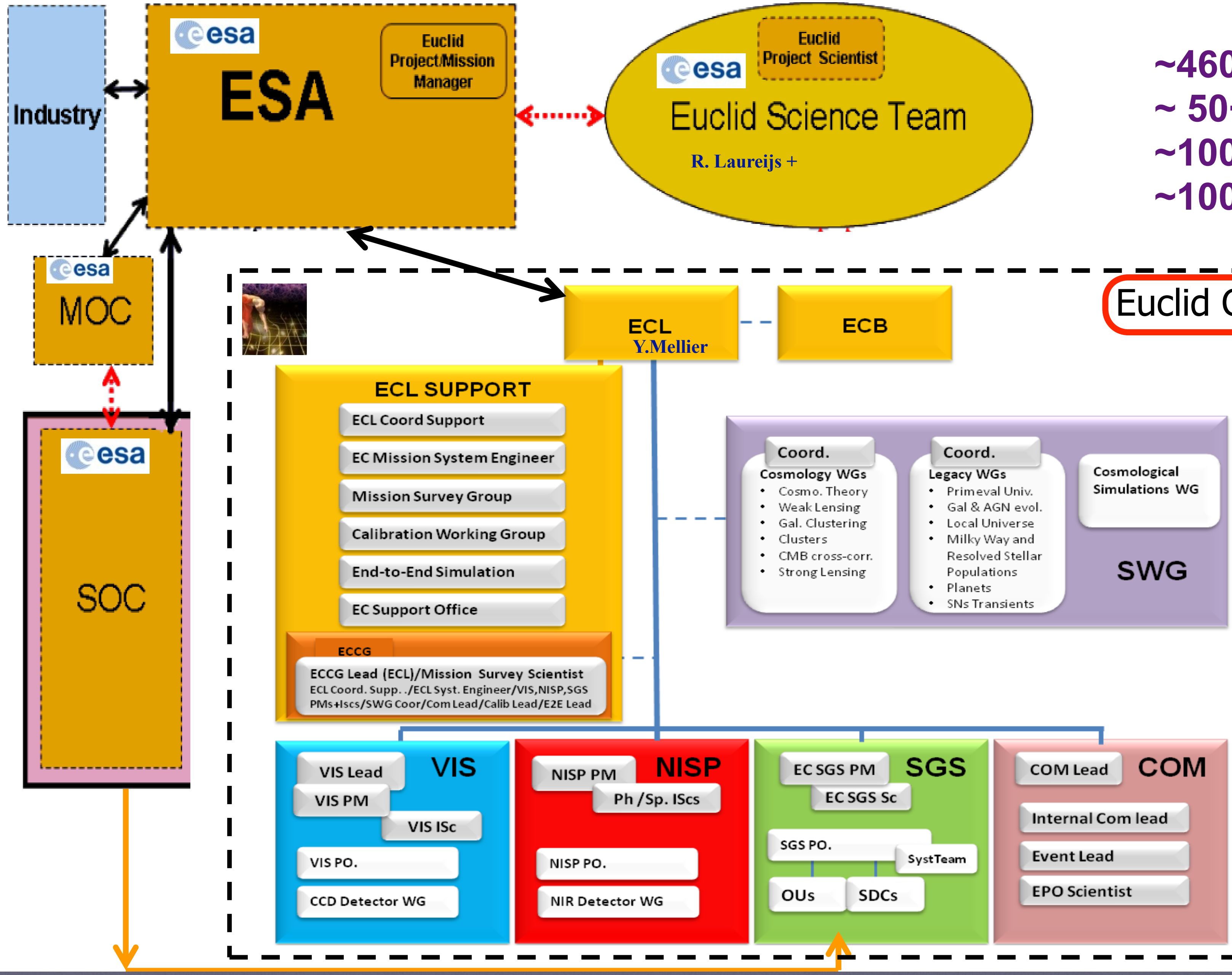

~460+ M€ (ESA)
~ 50+ M$ (NASA)
~100 M€ EC instr
~100 M€ EC Gnd Seg

Euclid Consortium

- 1100 members,
- 120 Labs
- 13 European countries:

Austria, Denmark, France, Finland,, Germany, Italy, The Netherlands, Norway, Portugal, Romania, Spain, Switzerland, UK

+ US/NASA and Berkeley labs.

Large participation of Italian community with several key roles and contributions

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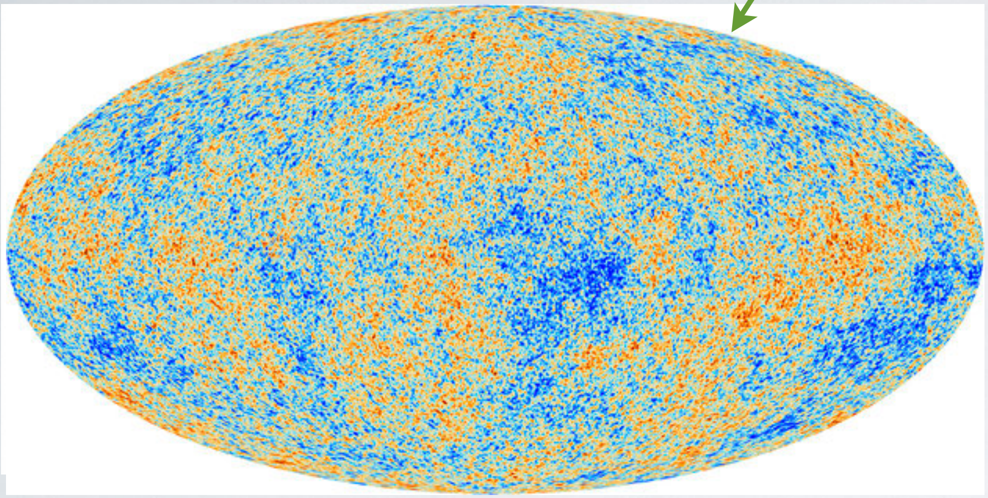
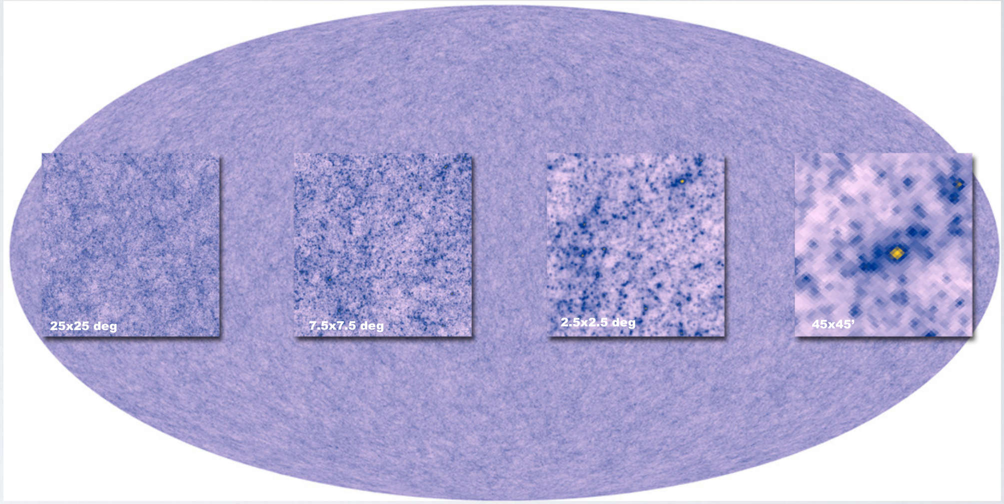
Euclid Consortium [EC] Structure and Italian role: fundamental

- Presence in the Euclid Science Team
- Presence in the Board
- Several coordinators of science WGs
- Strong presence and respnsabilities in both instruments
- SciRD team and Ubercoords
- Project Manager of the whole Ground Segment
- Project Office of the GS
- Several coordinators of GS Organizational Units
- Position of Mission Survey Scientist
- ~ 200 scientists from many INAF institutes and Universities
- Support from ASI
- Support from PRIN MIUR, EC VO, ERC, local *(hardly renewable)*

Synergy with Planck: Universe @z~1000 vs @z~1-3



R. Teyssier et al.: Full-sky weak-lensing simulation with 70 billion particles



WL sims: <1” pixels

Most of the DE effects happen at z < 3

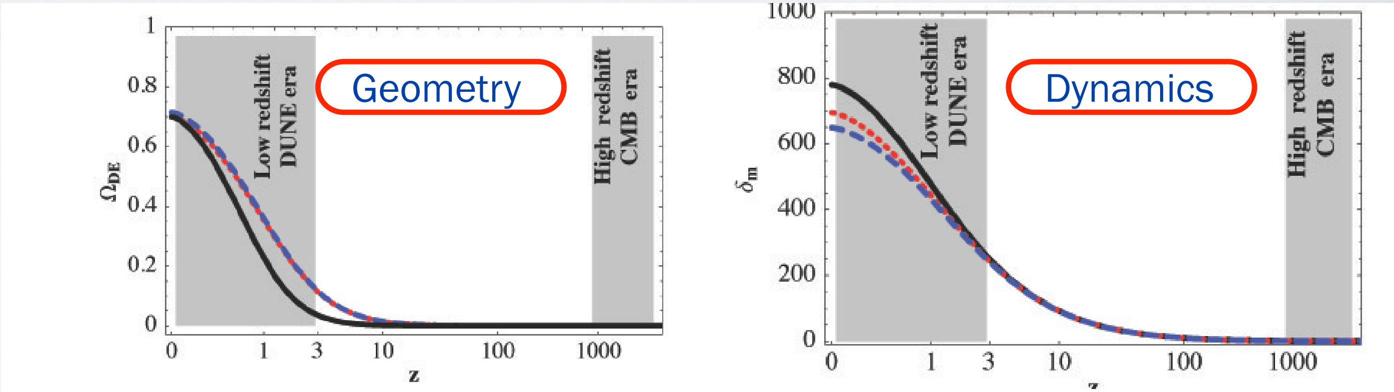
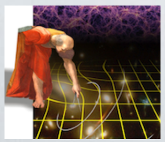
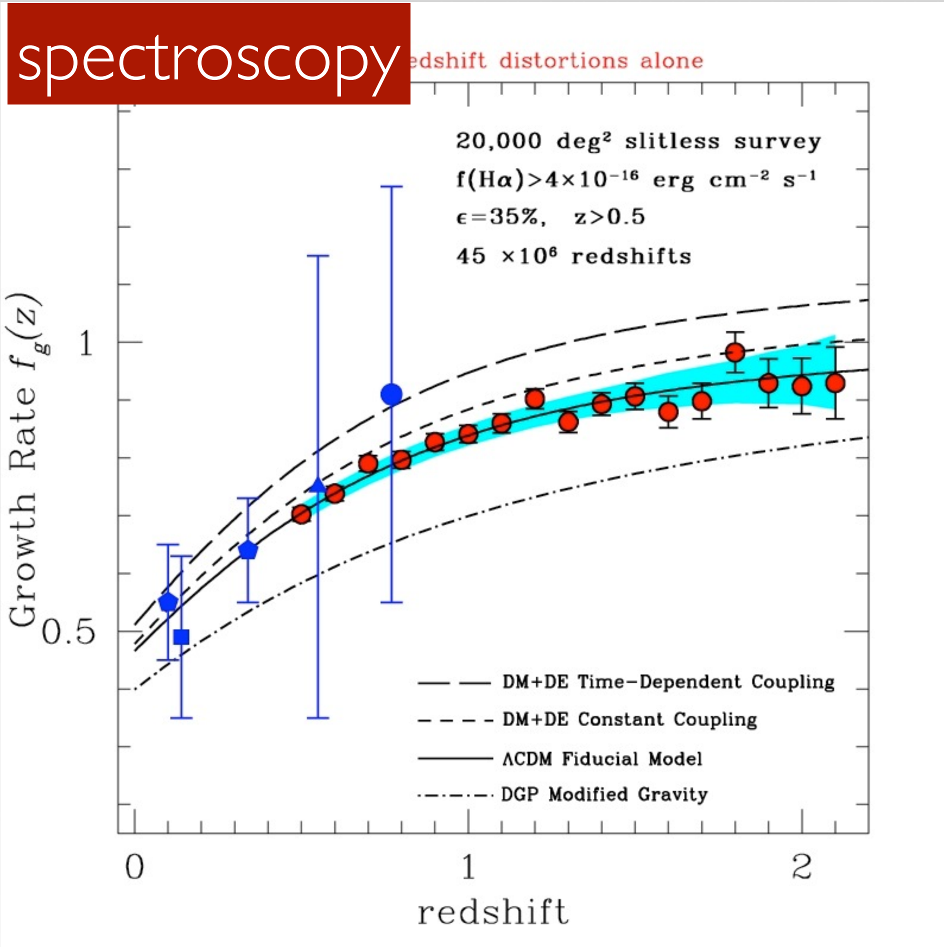


Figure C.1: *Effect of dark energy on the evolution of the Universe.* ***Left:*** *Fraction of the density of the Universe in the form of dark energy as a function of redshift z., for a model with a cosmological constant (w=-1, black solid line), dark energy with a different equation of state (w=-0.7, red dotted line), and a modified gravity model (blue dashed line). In all cases, dark energy becomes dominant in the low redshift Universe era probed by DUNE, while the early Universe is probed by the CMB.* ***Right:*** *Growth factor of cosmic structures for the same three models. Only by measuring the geometry (left panel) and the growth of structure (right panel) at low redshifts can a modification of dark energy be distinguished from that of gravity. Weak lensing measures both effects.*

Need also dynamics to further disentagle





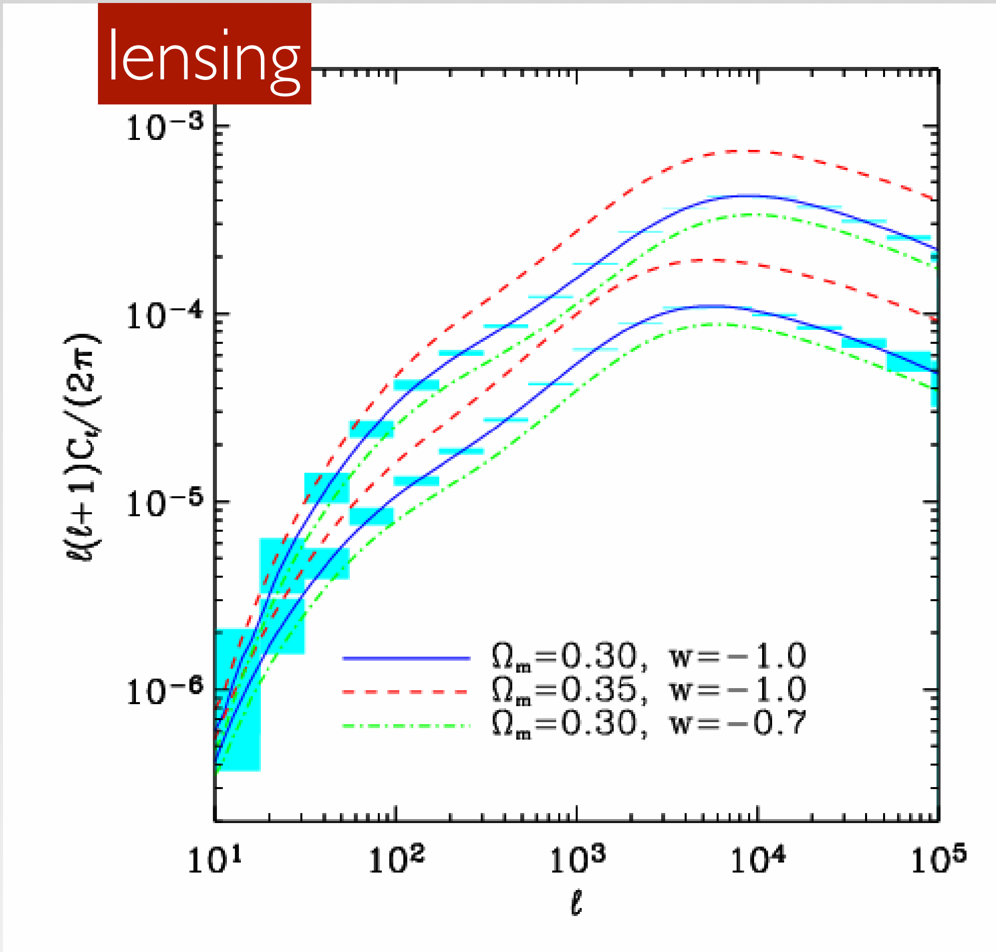


Figure 2.14: a. (left) The growth rate of matter perturbations as a function of redshift. Data points and errors are from a simulation of the spectroscopic redshift survey. The assumed ΛCDM model, coupled dark matter/dark energy modes and DGP are also shown. b. (right): The predicted cosmic shear angular power spectrum at z=0.5 and z=1 for a number of cosmological models

Can discriminate cosmology

[Dark Energy, Dark matter, non std GR]

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Want, NEED! several probes for synergies and Xchecks

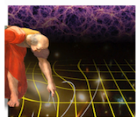
Observational Input	Probe	Description
Weak Lensing Survey	Weak Lensing (WL)	Measure the expansion history and the growth factor of structure
Galaxy Redshift Survey: Analysis of *P(k)*	Baryonic Acoustic Oscillations (BAO)	Measure the expansion history through D_A(z) and H(z) using the “wiggles-only”.
	Redshift-Space distortions	Determine the growth *rate* of cosmic structures from the redshift distortions due to peculiar motions
	Galaxy Clustering	Measures the expansion history and the growth factor using all available information in the amplitude and shape of P(k)
Weak Lensing plus Galaxy redshift survey combined with cluster mass surveys	Number density of clusters	Measures a combination of growth factor (from number of clusters) and expansion history (from volume evolution).
Weak lensing survey plus galaxy redshift survey combined with CMB surveys	Integrated Sachs Wolfe effect	Measures the expansion history and the growth

Want to measure expansion factor H(z) - *geometry* -
and growth of density perturbations - *dynamics* -

Wide survey: >15,000 sq. deg (visible: 24.5th ABmag 10σ extended; NIR: 24th ABmag 5σ; spectra: Hα line flux > 3×10^{-16} erg s^{-1} cm^{-2}, rate ~35%)

Deep Survey: ~40 sq. deg ~ 2 mags deeper (~40 visits)

Legacy



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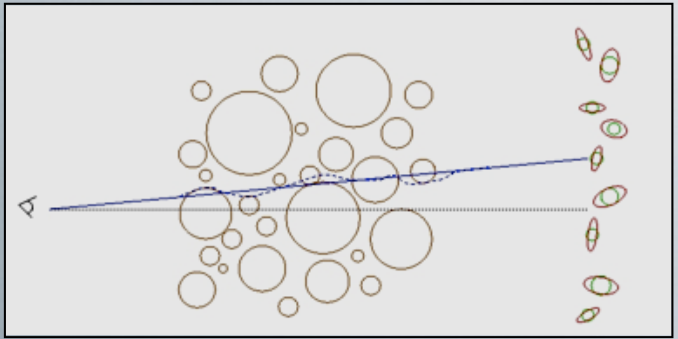
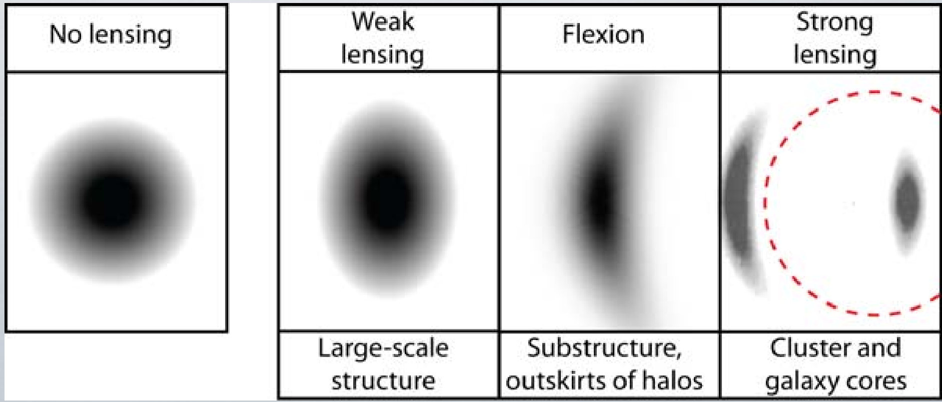
Expansion and Growth Histories through Gravitational Lensing





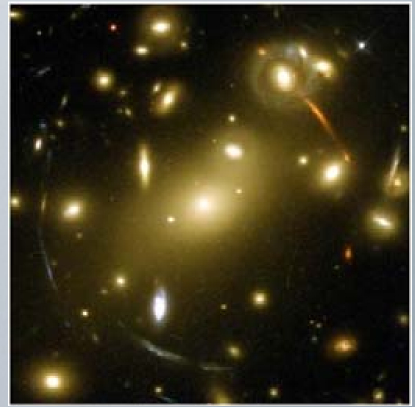


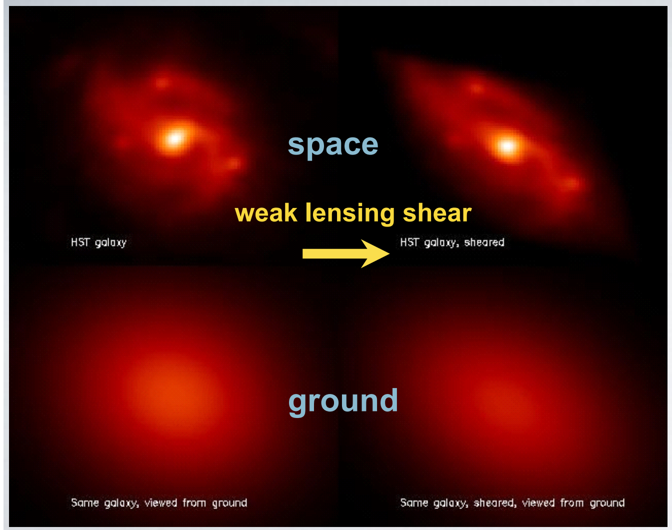
Figure 2.8: a. (Left) Illustrations of the effect of a lensing mass on a circularly symmetric image. Weak lensing elliptically distorts the image, flexion provides an arc-ness and strong lensing creates large arcs

$$\kappa = \frac{3H_0^2\Omega_m}{2c^2}\int_0^{\chi_s} d\chi \frac{D(\chi)D(\chi_s-\chi)}{\chi_s}(1+z)\delta(\chi),$$

observable

distances

density perturbation



COSMOS Dark Matter Map over 2 deg^2

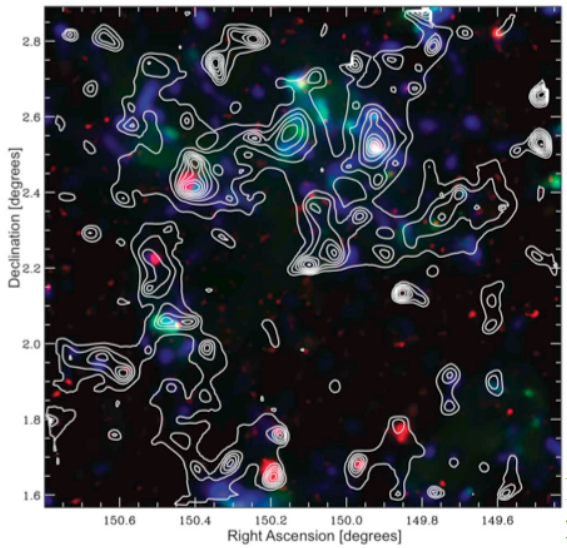
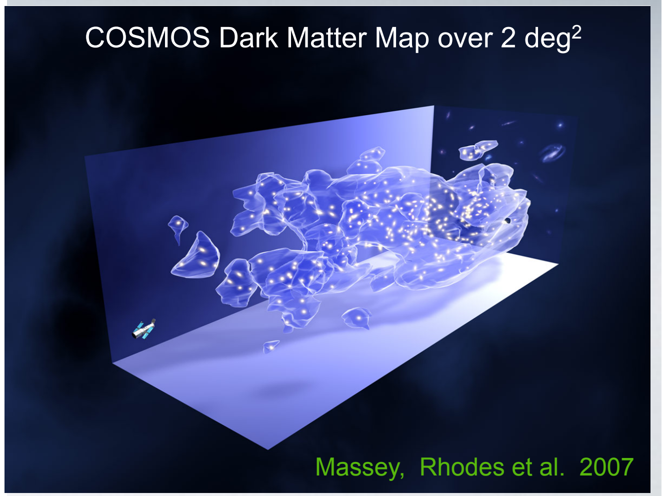
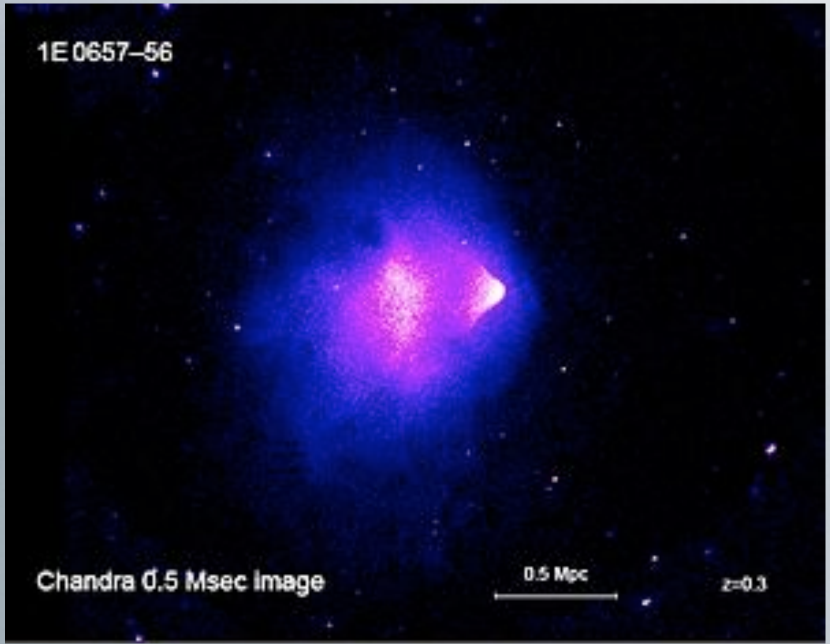


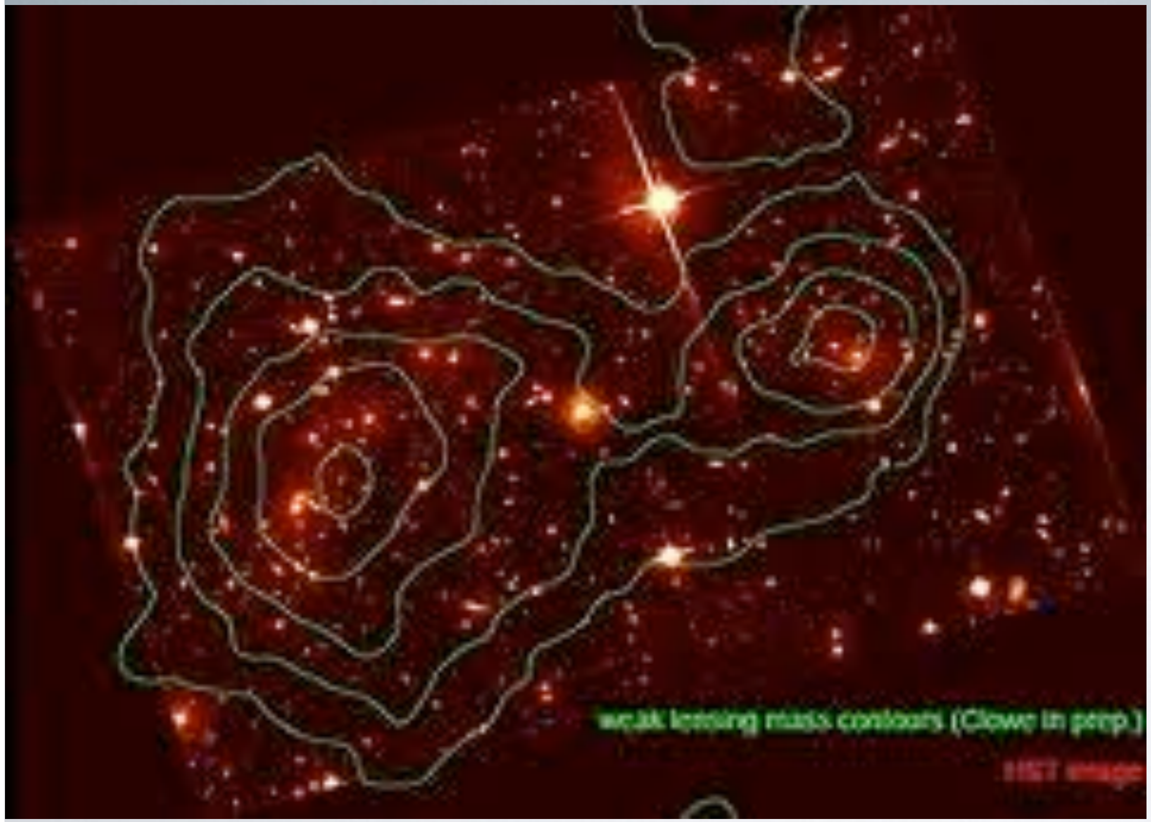
photo z

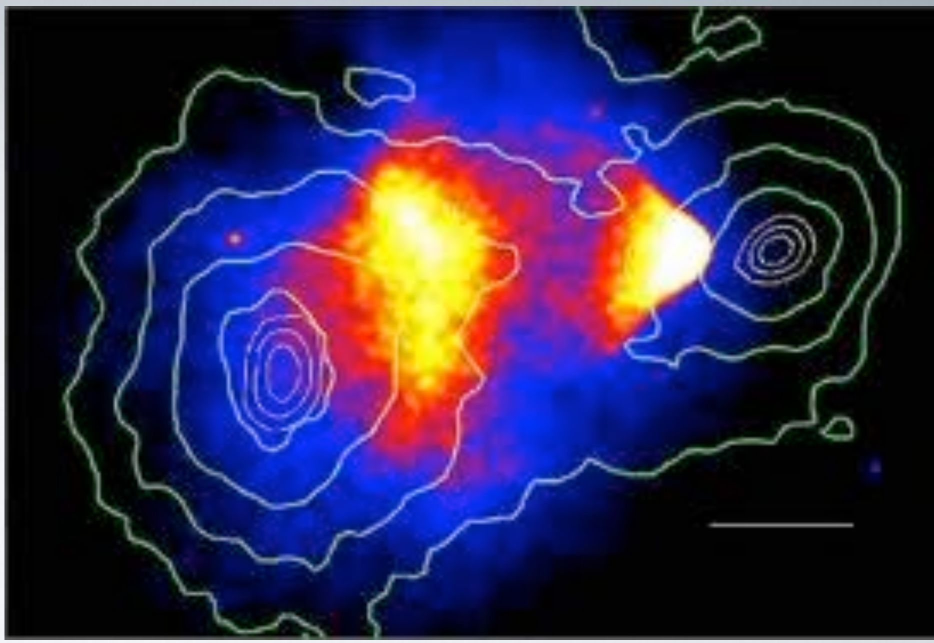
Massey et al. 2007a, Nature



Bullet Cluster: Dark Matter!







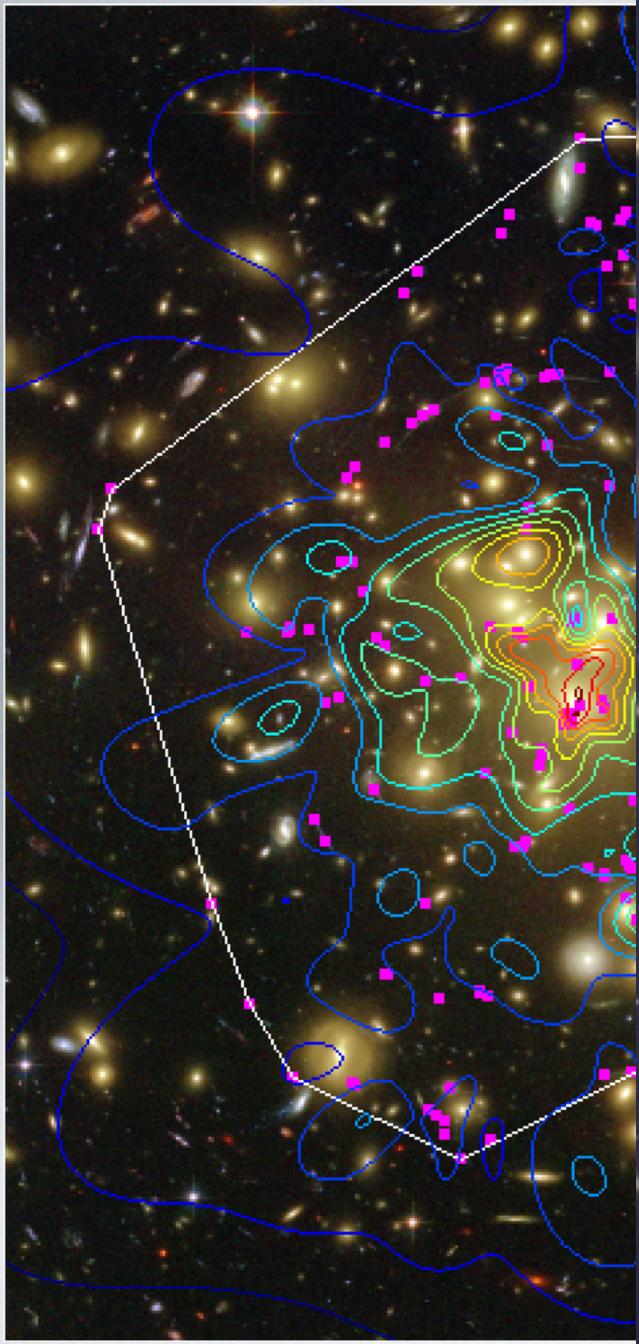
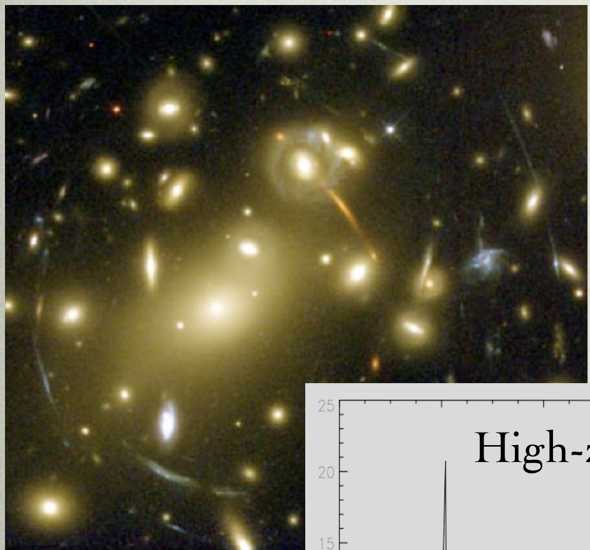


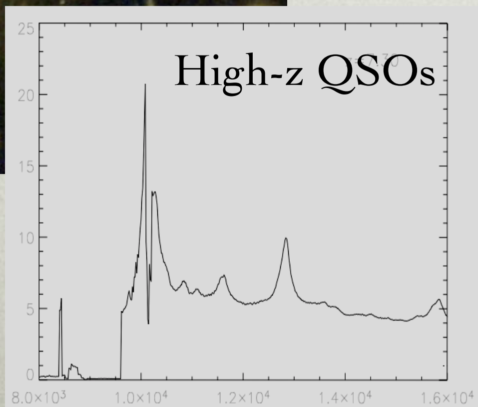
Figure 5. Mass map contours in units of $\kappa_\infty = 1/3$ laid over the 3.′2 × 3.′3 ST[…]
previous figure. Pink squares indicate the 135 multiple image positions all perfectly reproduced by our model, and the white line indicates the convex hull. Outside this region, our solution should be disregarded. This solution is not unique but was the "most physical" we found.
(A color version of this figure is available in the online journal.)

<u>*Details*</u> on Dark Matter clustering!

- ***Unique* legacy survey**: 2 billion galaxies imaged in optical/NIR to mag >24 Million NIR galaxy spectra, full extragalactic sky coverage, Galactic sources
- Unique database for **various fields in astronomy**: galaxy evolution, search for high-z objects, clusters, strong lensing, brown dwarfs, exo-planets, etc
- **Synergies with other facilities**: JWST, Planck, Erosita, GAIA, DES, Pan-STARSS, LSST, E-ELT etc (e.g. to do NIR from the ground would take several x 10^3 yr)
- **All data publicly available** through a legacy archive

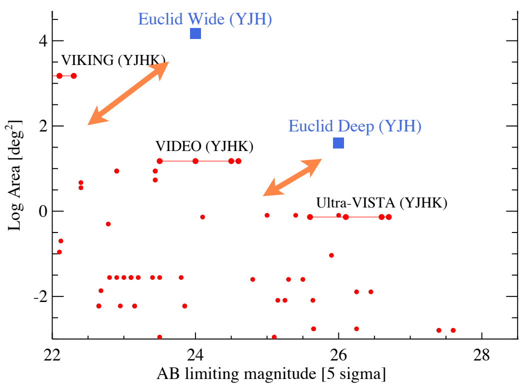
Enormous database to harvest



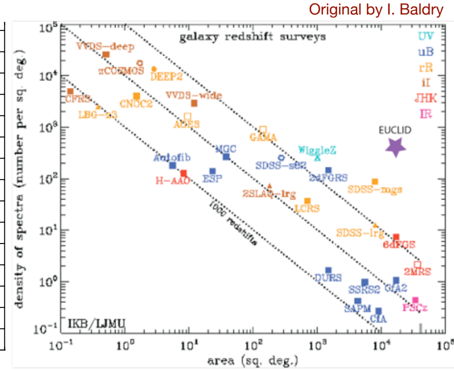


Euclid in context

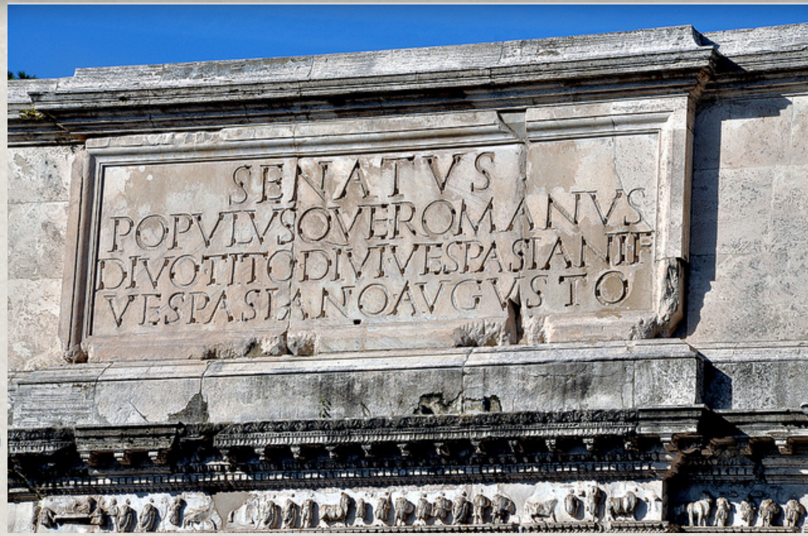
	VISTA	SASIR	Euclid
Wide survey	680 years	66 years	5 years
Deep survey	72 years	7 years	“5 years”



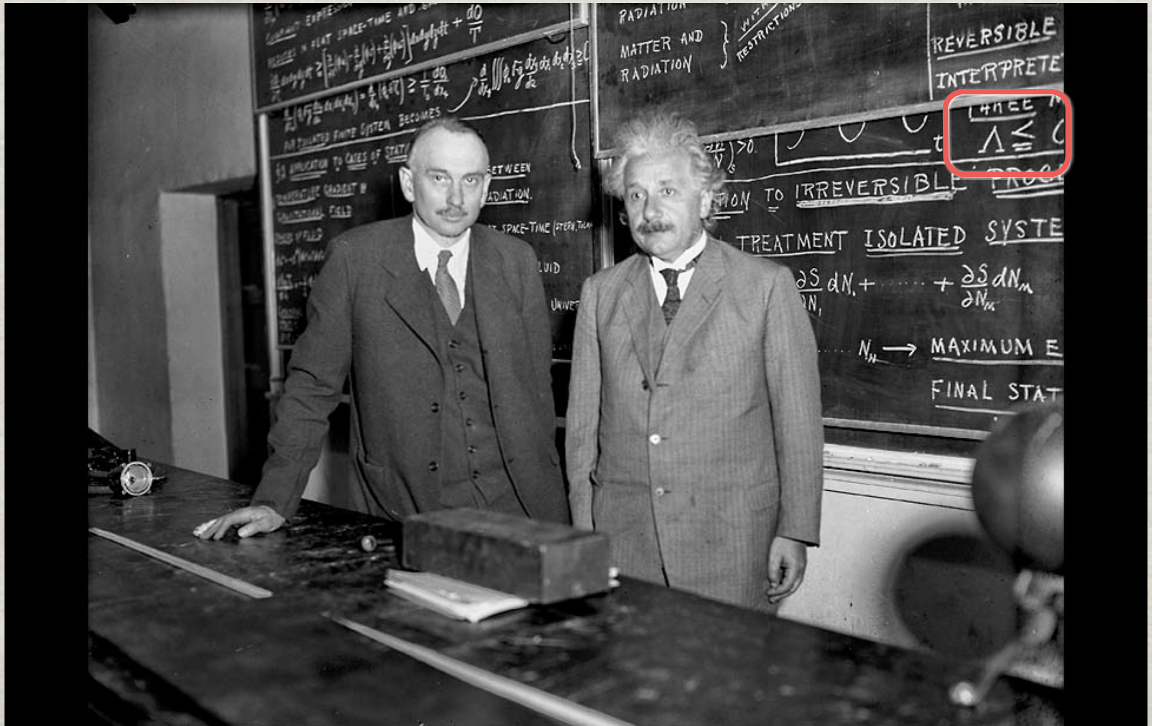
Original by I. Baldry



The ubiquitous symbol.. (hex U+039B)



one vowel,
one consonant,
one number



$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

$\varrho_{vac} = \Lambda/8\pi \quad \sim 10^{-29}\ \mathrm{g/cm^3}$

$t_{pl} = (Gh/2\pi c^5)^{1/2} = 5.4 \times 10^{-44}\mathrm{s}$

$t_U \sim 8 \times 10^{60}$

$\Lambda \sim t^{-2} \sim 10^{-122}$

Does gravity follow standard G.R.? Need experiments with high sensitivity/precision....

(cf. L. Amendola, M. Kuntz, et al Theory SWG, Living reviews)

Weak limit

The most general (linear, scalar) metric at first-order

$$ds^2 = a^2[(1+2\Psi)dt^2 - (1+2\Phi)(dx^2+dy^2+dz^2)]$$

At the linear perturbation level and sub-horizon scales

Full metric reconstruction at first order requires 3 functions

$$H(z) \quad \Phi(k,z) \quad \Psi(k,z)$$

- modified Poisson's equation $\quad k^2\Psi = -4\pi G a^2 Q(k,a)\rho_m\delta_m$
- non-zero anisotropic stress $\quad \eta(k,a) = \dfrac{\Phi+\Psi}{\Psi}$

std matter

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

Std gravity,

new matter

$$Y_{\mu\nu} = X_{\mu\nu} - G_{\mu\nu}$$

New gravity,

std matter

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

$$T^{\nu}_{\mu\,;\nu} = 0.$$

Modified Gravity at linear level

standard gravity	$Q(k,a)=1$ $\eta(k,a)=0$	
scalar-tensor models	$Q(a)=\dfrac{G^*}{FG_{cav,0}}\dfrac{2(F+F'^2)}{2F+3F'^2}$ $\eta(a)=\dfrac{F'^2}{F+F'^2}$	Boisseau et al. 2000 Acquaviva et al. 2004 Schimd et al. 2004 L.A., Kunz &Sapone 2007
f(R)	$Q(a)=\dfrac{G^*}{FG_{cav,0}}\dfrac{1+4m\frac{k^2}{a^2R}}{1+3m\frac{k^2}{a^2R}}, \quad \eta(a)=\dfrac{m\frac{k^2}{a^2R}}{1+2m\frac{k^2}{a^2R}}$	Bean et al. 2006 Hu et al. 2006 Tsujikawa 2007
DGP	$Q(a)=1-\dfrac{1}{3\beta}; \quad \beta=1+2Hr_c w_{DE}$ $\eta(a)=\dfrac{2}{3\beta-1}$	Lue et al. 2004; Koyama et al. 2006
coupled Gauss-Bonnet	$Q(a)=...$ $\eta(a)=...$	see L. A., C. Charmousis, S. Davis 2006

Galaxies, BAO

COMPLEMENTARITY

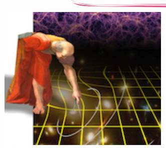
Photons, WL

massive particles respond to Ψ

massless particles respond to Φ-Ψ

$$\delta'' + (1+\frac{H'}{H})\delta = \frac{k^2}{a^2}\Psi$$

$$\alpha = \int \nabla_{perp}(\Psi - \Phi)dz$$



Need to break degeneracy: *use growth of fluctuations*

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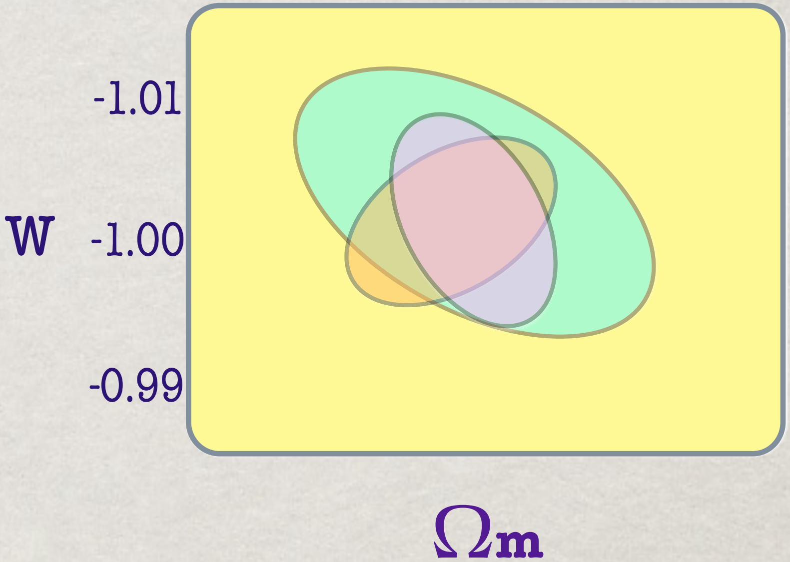
Possible outcomes.....

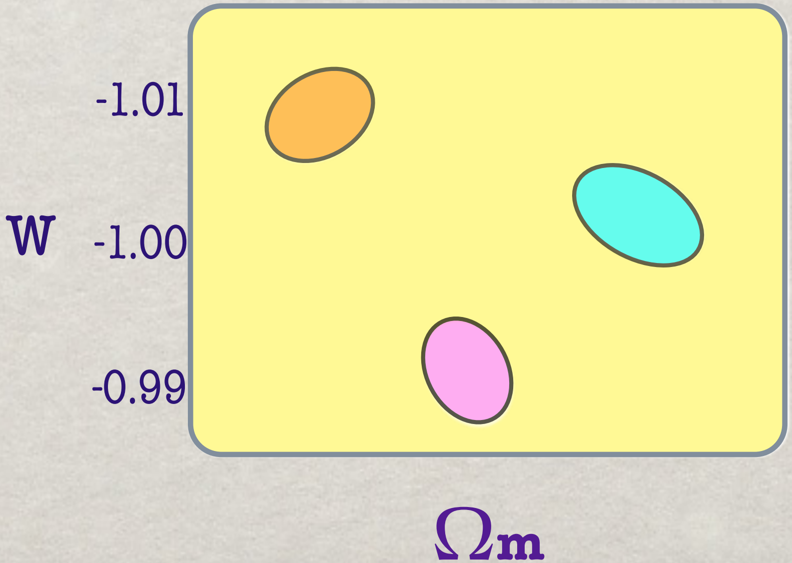
Different probes

Quite useful but
a bit dull....



Λ=const

Much more
interesting!!



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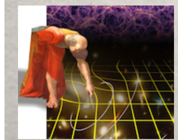

An amusing connection ….

One hundred years later… from art (vision) to science (numbers)

Euclid Futurism 2020-2030

Measuring the Universe