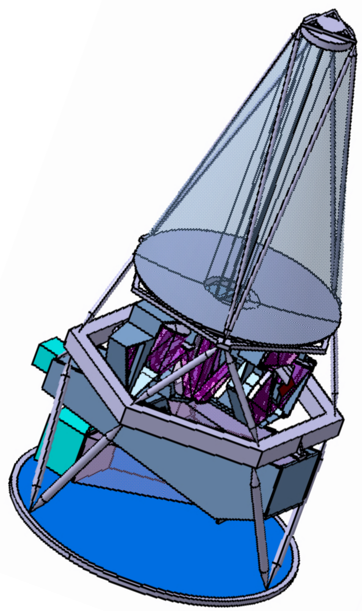
Imaging the Dark Universe with Euclid



Simon Lilly (ETH Zurich)

on behalf of

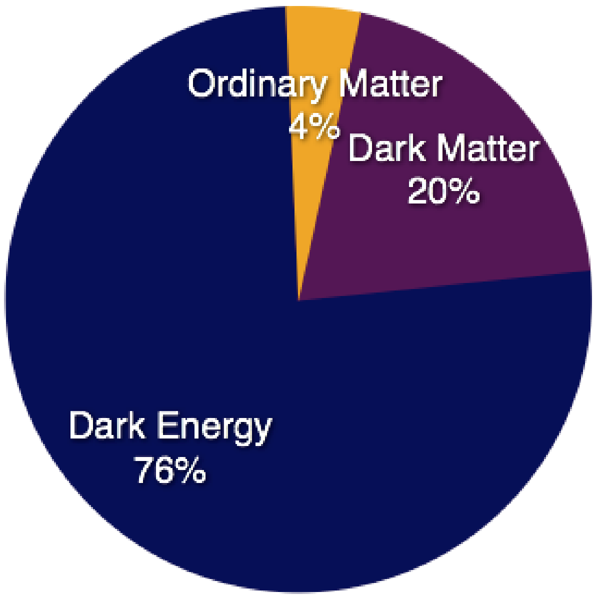
Alexandre Refregier (CEA Saclay)
for the Euclid Imaging Consortium

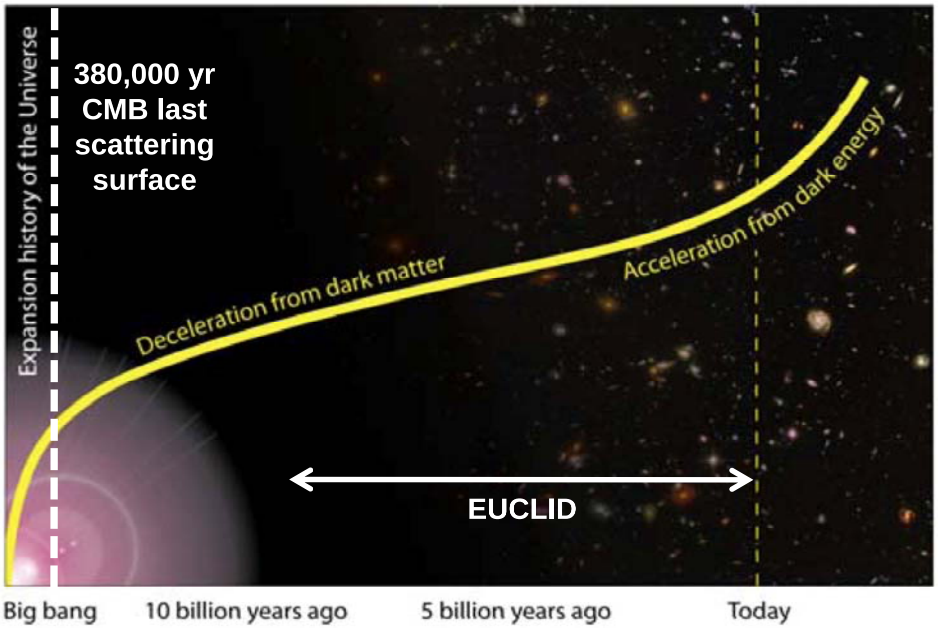
Euclid Science Objectives

Outstanding questions in cosmology:

- the nature of the Dark Energy
- the nature of the Dark Matter
- the initial conditions (Inflation Physics)
- modifications to Gravity

→ Euclid's primary science objectives
→ Secondary objectives: Legacy Science





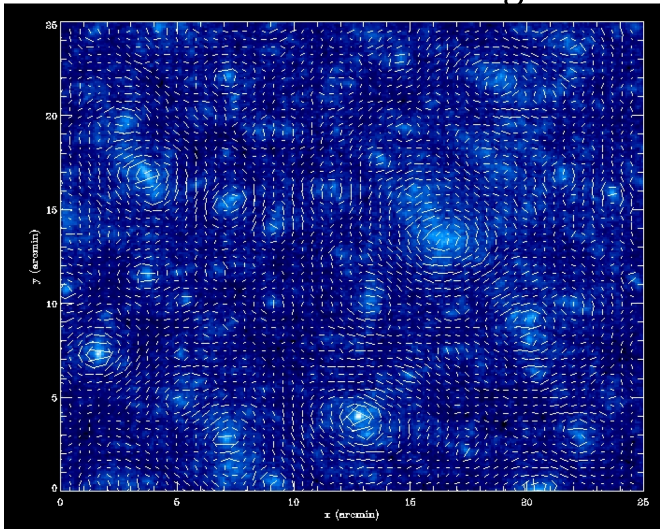
Primary Science objectives

EUCLID concept = all-sky (2π sr) Vis+NIR imaging and spectroscopic survey

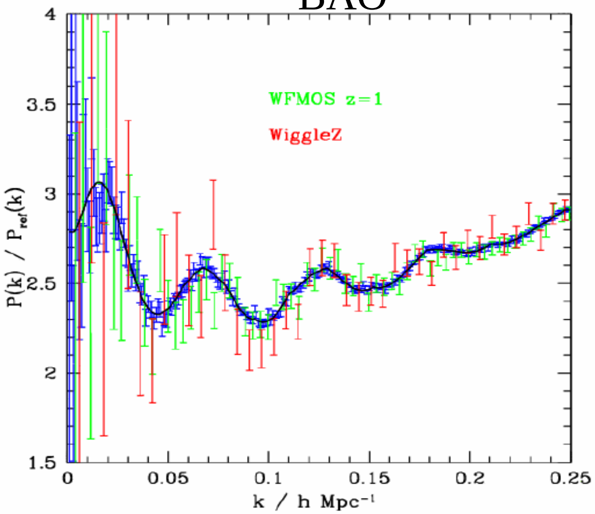
Primary EUCLID cosmological probes
- Weak Lensing Tomography
- Baryonic Accoustic Oscillations

Additional EUCLID cosmological probes:
- Cluster Counts
- Integrated Sachs-Wolfe Effect (correlation with CMB)
- Redshift space distortions

Weak Lensing

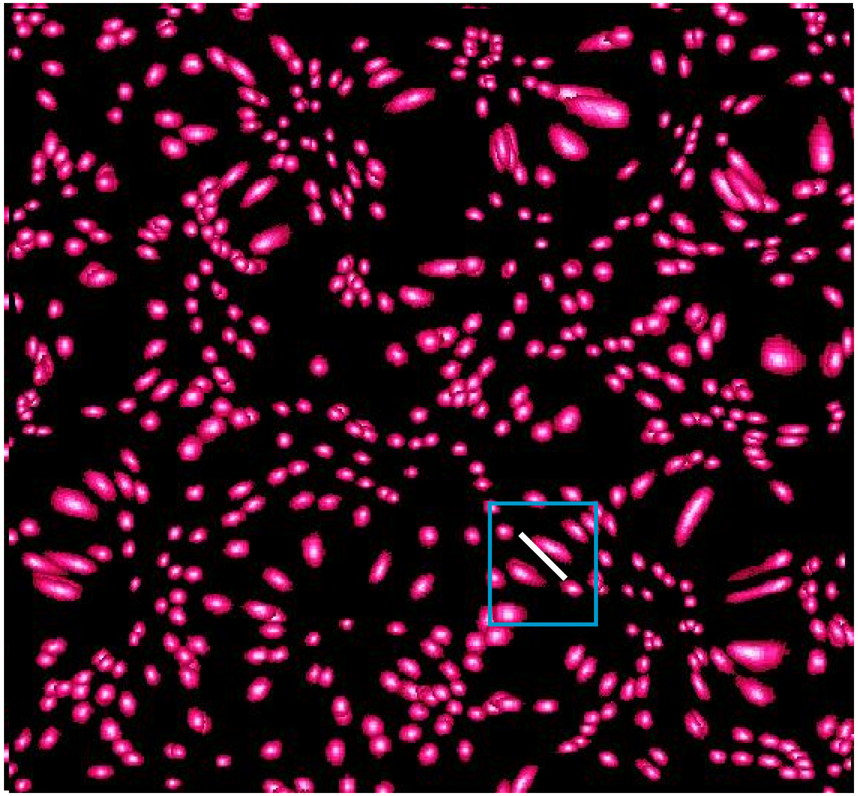


BAO

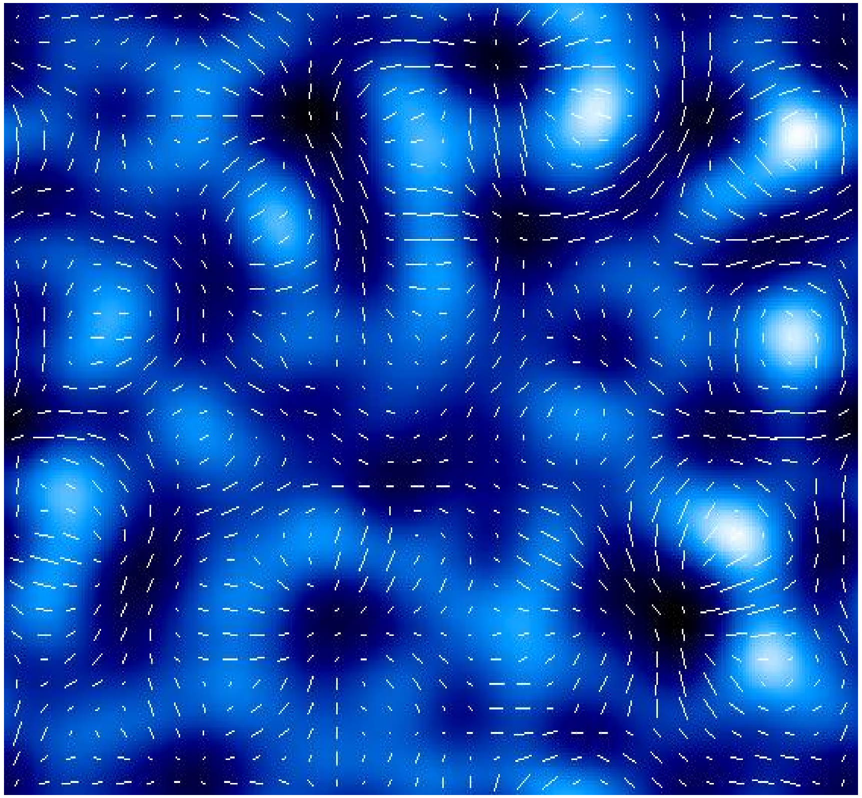


Weak Lensing Shear Measurement

Distortion matrix: $\Psi_{ij} = \frac{\partial \delta\theta_i}{\partial \theta_j} = \int dz\, g(z) \frac{\partial^2 \Phi}{\partial \theta_i \partial \theta_j}$



lensed background galaxies



mass and shear distribution

⇒ correlated image distortions on sky produce WL power spectrum $C_l(\theta,z)$

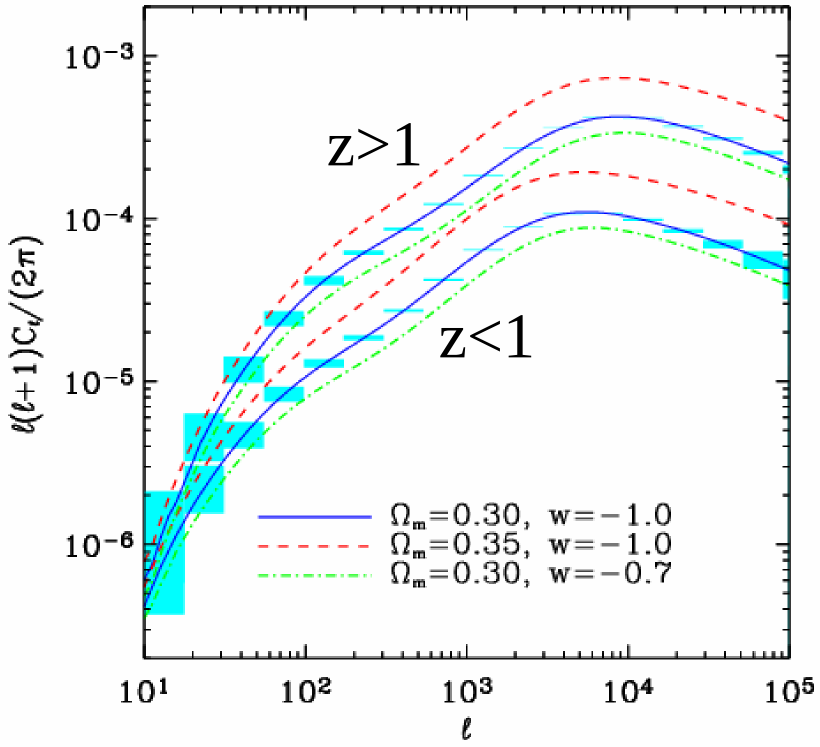
Weak Lensing Tomography

Lensing signal $C_l(\theta,z)$ depends on:

- shape of total matter density fluctuation spectrum
- angular diameter distance in lensing equation for lensing amplitude
- angular diameter distance for angular scale of density spectrum
- growth factor *g(z)* of dark matter density fluctuations

WL tomography addresses all sectors of Dark Cosmology

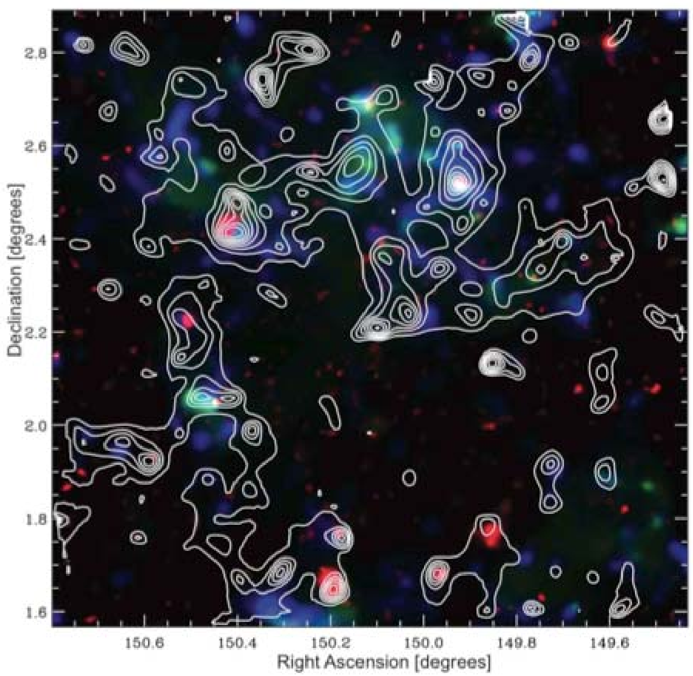
Example: WL power spectrum for each of two *z*-bins



Weak Lensing Tomography

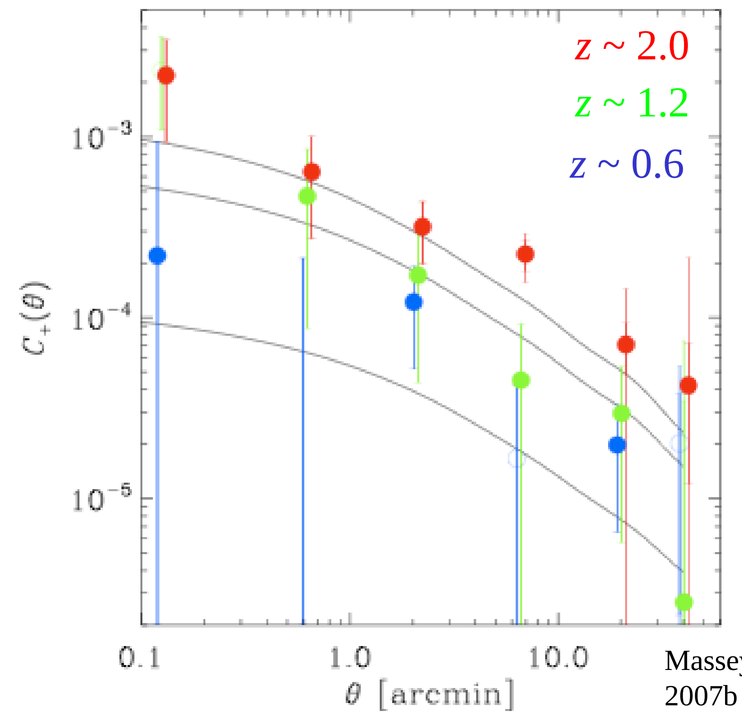
COSMOS 1.7 deg^2 HST/ACS imaging as a prototype for Euclid with 1/10,000 of area

COSMOS Dark Matter Map compared with (visible) galaxy distribution



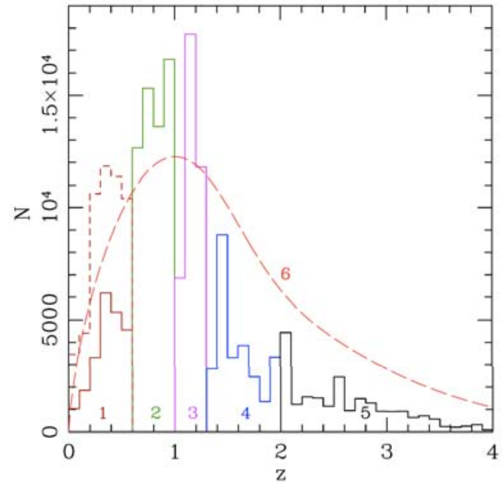
Massey et al. 2007a, Nature

WL tomography measurements:
COMBO17: Bacon et al. 2005
CFHTLS: Sembolini et al. 2006
COSMOS/HST: Massey et al. 2007b



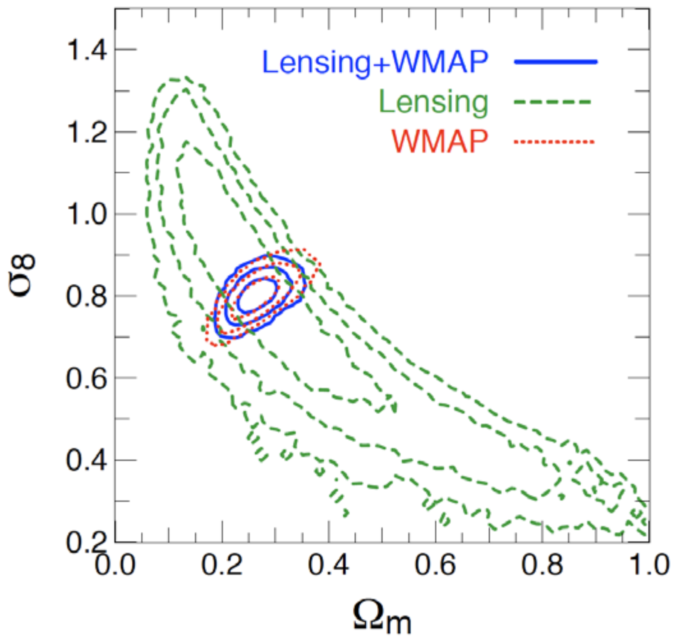
Massey et al. 2007b

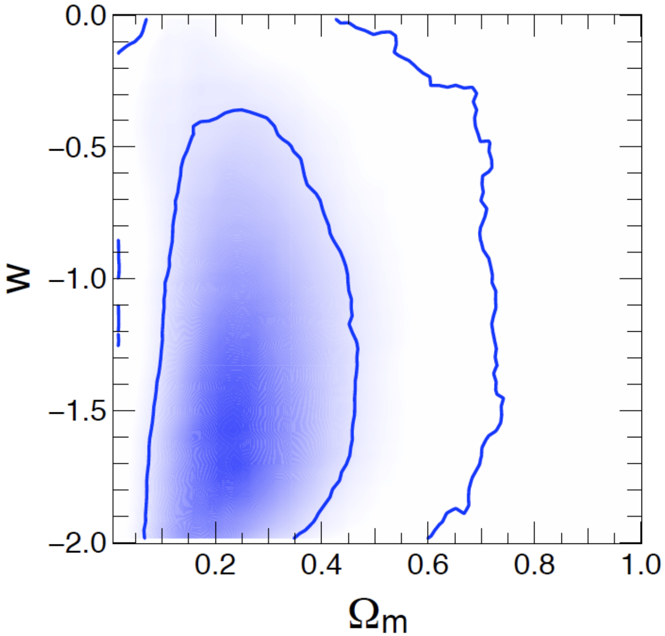
New analysis of public COSMOS data
Schrabback et al, 2009, arXiv:0911.0053



Evidence for acceleration

Agreement with WMAP5 on σ_8 and Ω_m





COSMOS alone
Euclid alone
10,000 larger

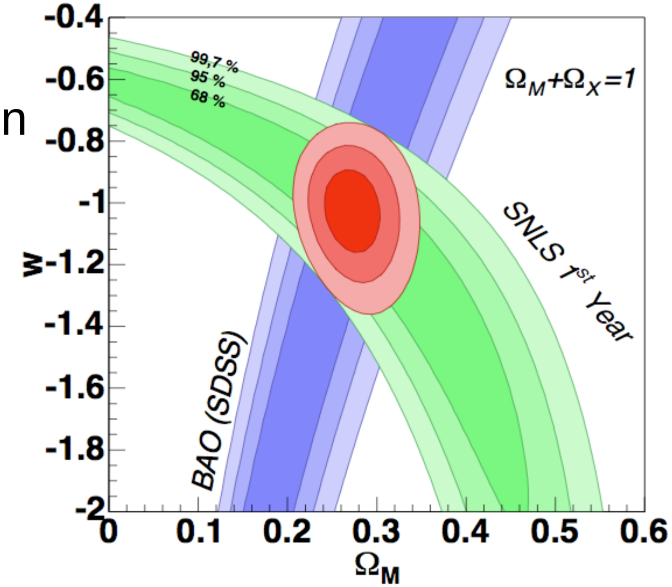
Current constraints: 10% on constant w

For definite answers on DE: need to reach a precision of 1% on (varying) w and 10% on w'

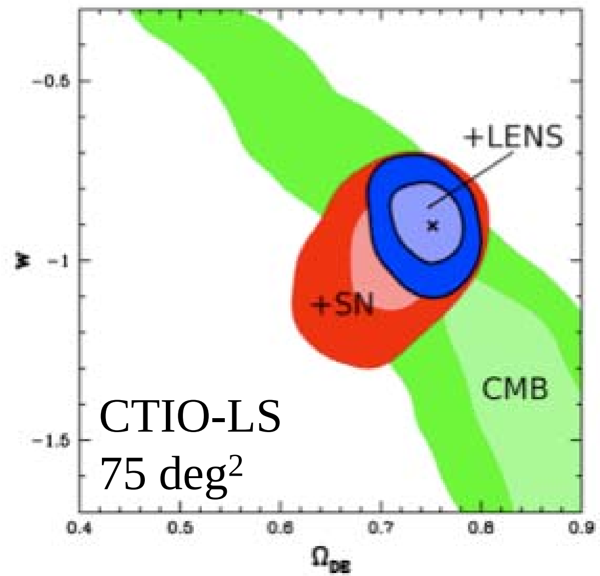
→ Objective for Euclid WL

Comparison with Other Probes

Astier et al. 2005



Jarvis et al. 2006



Requirements for precision Weak Lensing

(1) Statistics: optimal survey geometry (in a fixed survey time) is "wide rather than deep"

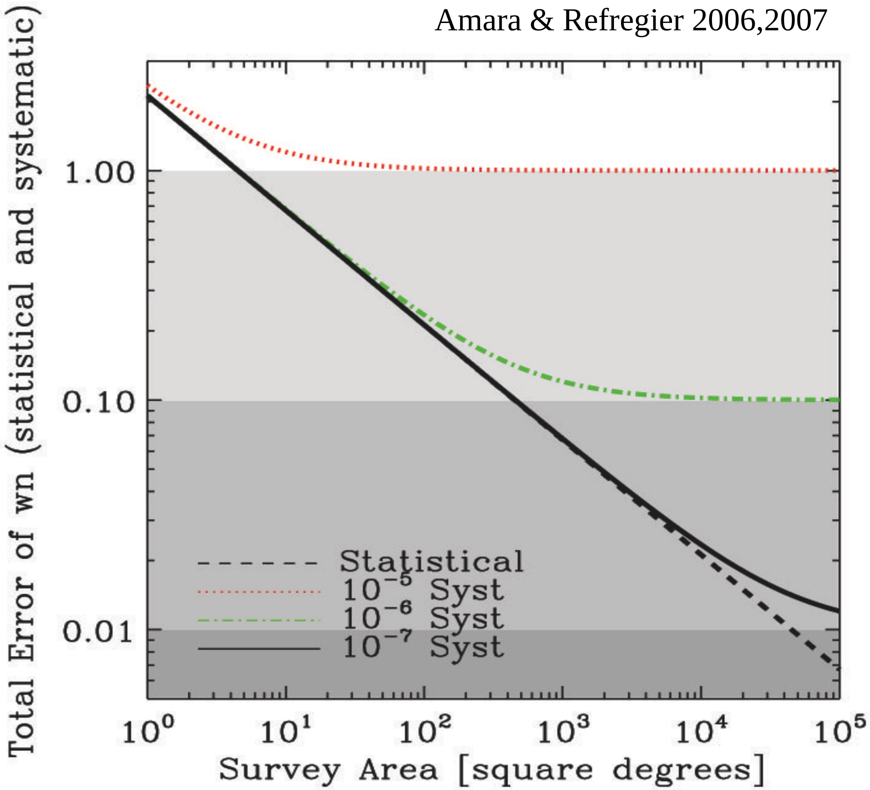
→ need 20,000 deg^2 to reach 1% precision on *w*

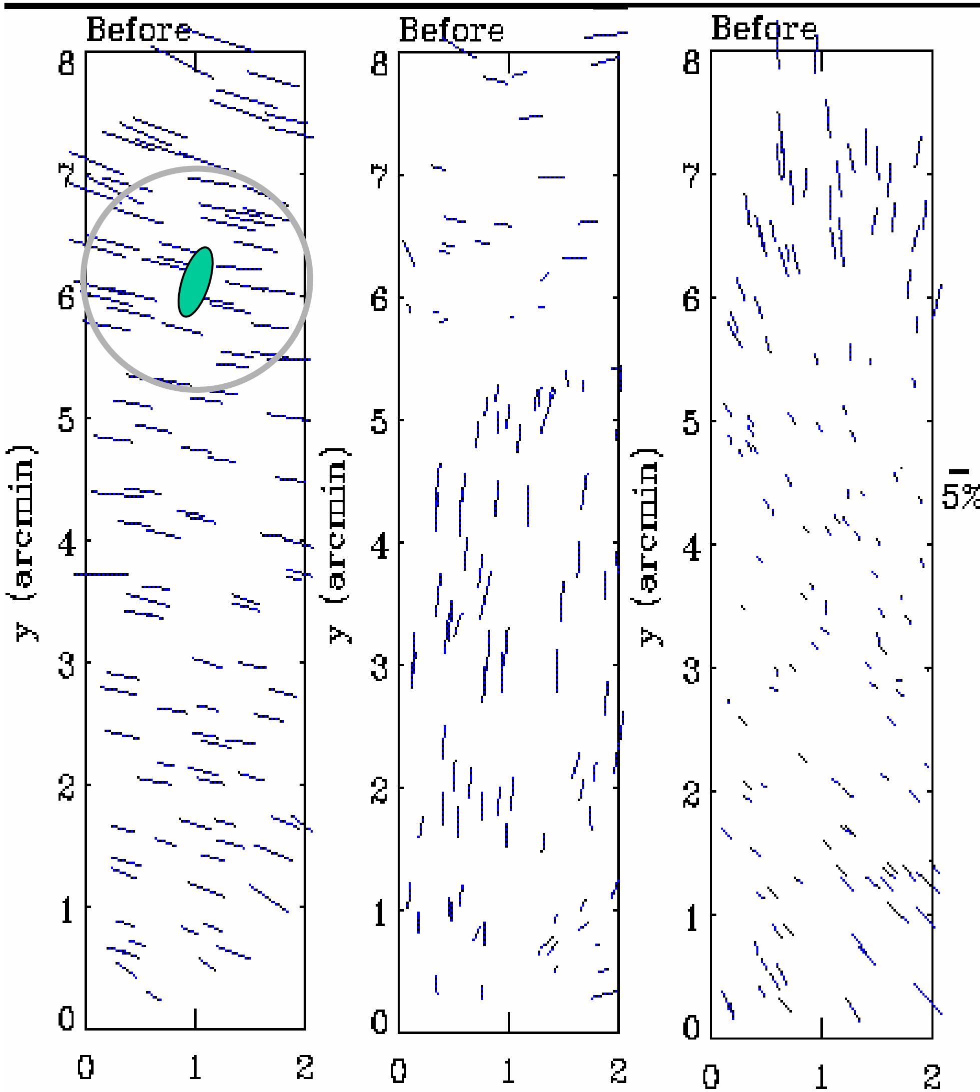
(2) Systematics: must reduce the systematics in shear measurement *by almost two orders of magnitude*

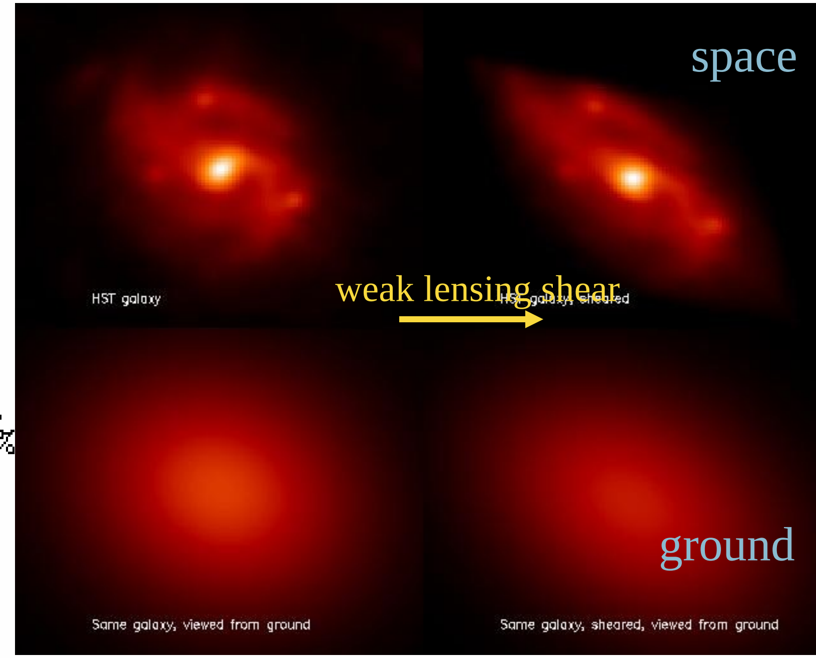
→ highly stable PSF spatially and temporally enabling 50 bright stars to calibrate PSF plus a PSF < typical ground-based seeing to use small faint galaxies

This requires access to space

Amara & Refregier 2006,2007







Space:

Stable PSF → lower residual systematics from better calibration with finite number of available stars

Smaller PSF → better resolved small galaxies → less "deconvolution"

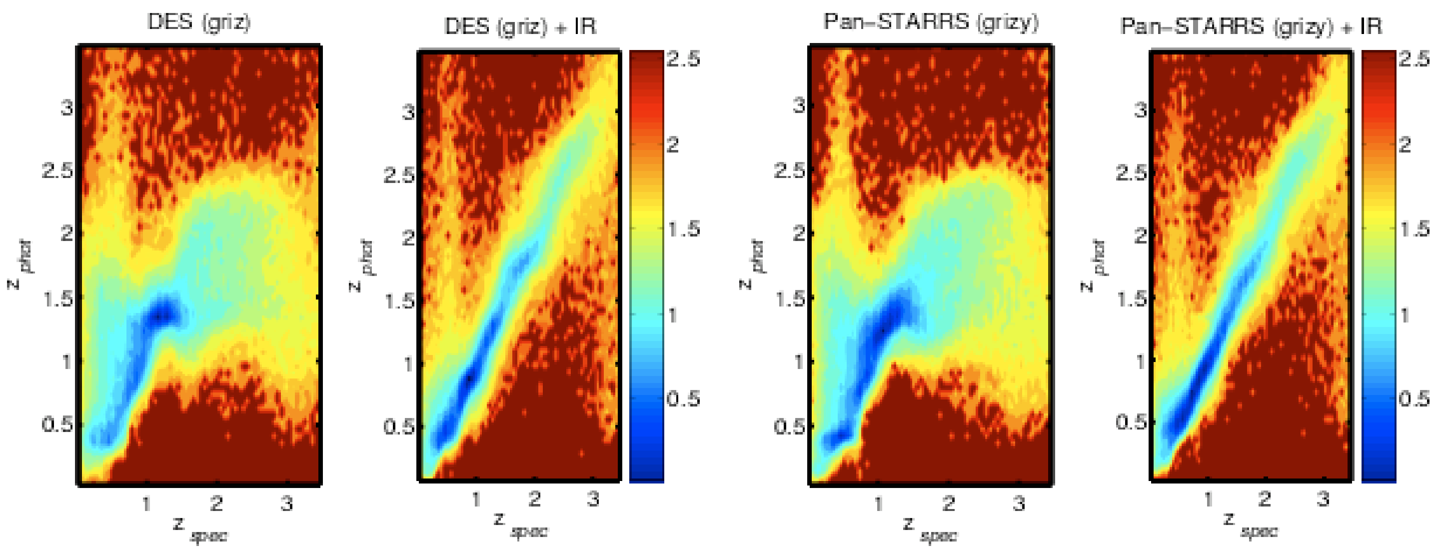
Ground PSF calibration and deconvolution

Requirements for Weak Lensing

(3) Photo-z: need redshifts *z* to make bins for tomography (and deal with intrinsic alignment effects) $\rightarrow$ $\sigma_z < 0.05(1+z)$.

•must be <u>photo-z</u> for 2 billion+ galaxies

•need photometry (AB ≥ 24 from visible to near-IR). Visible can be done from ground (at substantial cost savings), but the essential near-IR at this depth over the whole sky **<u>requires access to the low near-IR background of space</u>**.



Abdalla et al. 2007

Euclid Imaging Survey(s)

Wide Survey: Extragalactic sky (20,000 deg^2 = 2π sr)

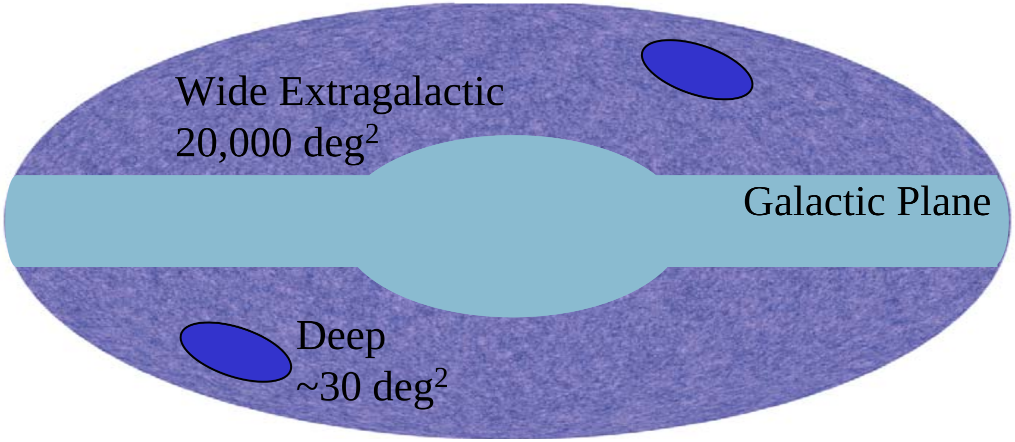
- Visible: Galaxy shape measurements to $RIZ_{AB} \leq 24.5$ (AB, 10σ) at 0.18 arcsec FWHM, yielding 35 resolved galaxies/arcmin^2, with a median redshift $<z> \sim 0.9$, for primary weak lensing tomography experiment.
- NIR photometry: Y, J, H $\leq$ 24 (AB, 5σ PS), yielding photometric redshifts $0.05(1+z)$ together with ground based complement (e.g. PanStarrs-2, DES)

Deep Survey: approx 30 deg^2 at ecliptic poles

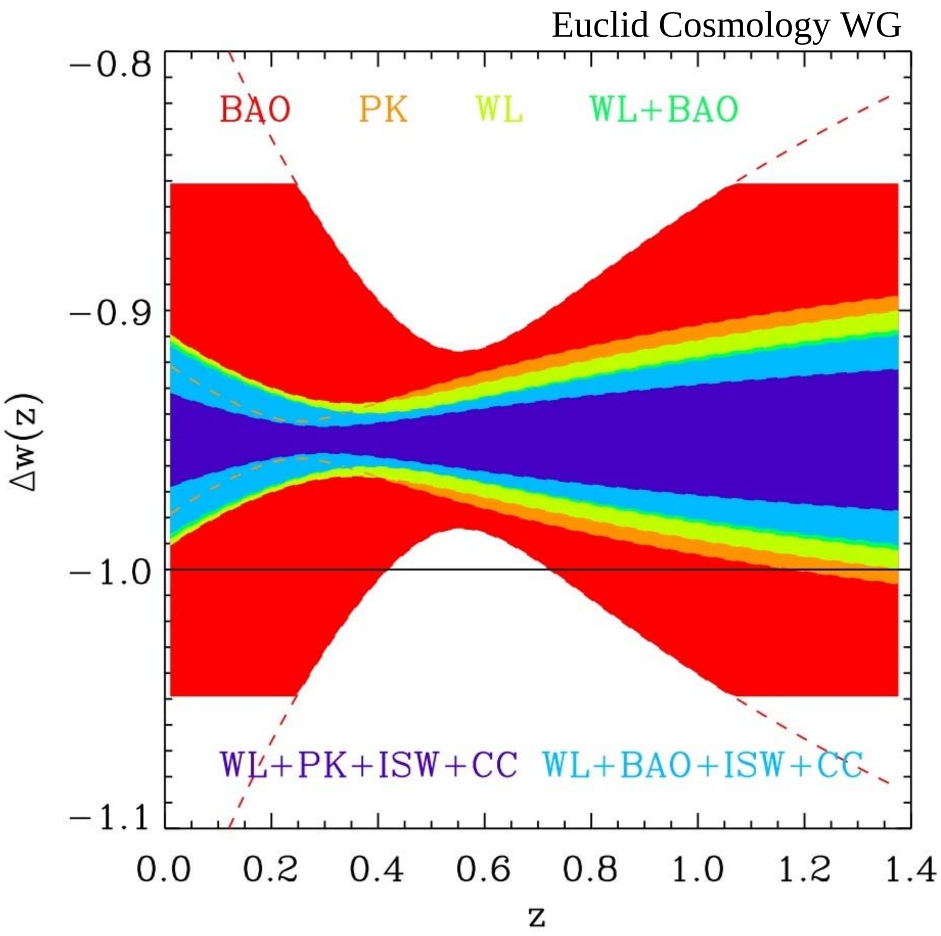
- Monitoring of PSF drift (40 repeats at different orientations over life of mission
- Produces +2 magnitude in depth for both visible and NIR imaging data.

Possible additional Galactic surveys:

Short exposure Galactic plane and high cadence microlensing extra-solar planet surveys could be easily added within Euclid mission architecture.



Complementary probes



Complementary cosmological probes within the Euclid Imaging Survey

- Cluster counts (with eRosita, Planck and other SZ surveys)
- Integrated Sachs-Wolfe effect (ISW)
- BAO/P(k) large scale structure with photo-z

Excellent complementarity with ENIS spectroscopic surveys (CAT)

- Determination of visible-DM bias *b*
- Calibration of photo-z
- Independent and better BAO/P(k) from spectroscopy
- Complementary growth of structure through redshift space distortions

Overall Impact on Cosmology

Euclid

Evolution of cosmology with Euclid imaging

	Δw_p	Δw_a	$\Delta\Omega_m$	$\Delta\Omega_\Lambda$	$\Delta\Omega_b$	$\Delta\sigma_8$	Δn_s	Δh	DE FoM
Current + WMAP	0.13	-	0.01	0.015	0.0015	0.026	0.013	0.013	~ 10
Planck	-	-	0.008	-	0.0007	0.05	0.005	0.007	-
Weak Lensing	0.03	0.17	0.006	0.04	0.012	0.013	0.02	0.1	180
EIC probes	0.018	0.15	0.004	0.02	0.007	0.009	0.014	0.07	400
EIC + Planck	0.013	0.08	0.001	0.004	0.0005	0.0016	0.003	0.002	1000

Euclid will challenge all sectors of the cosmological model:

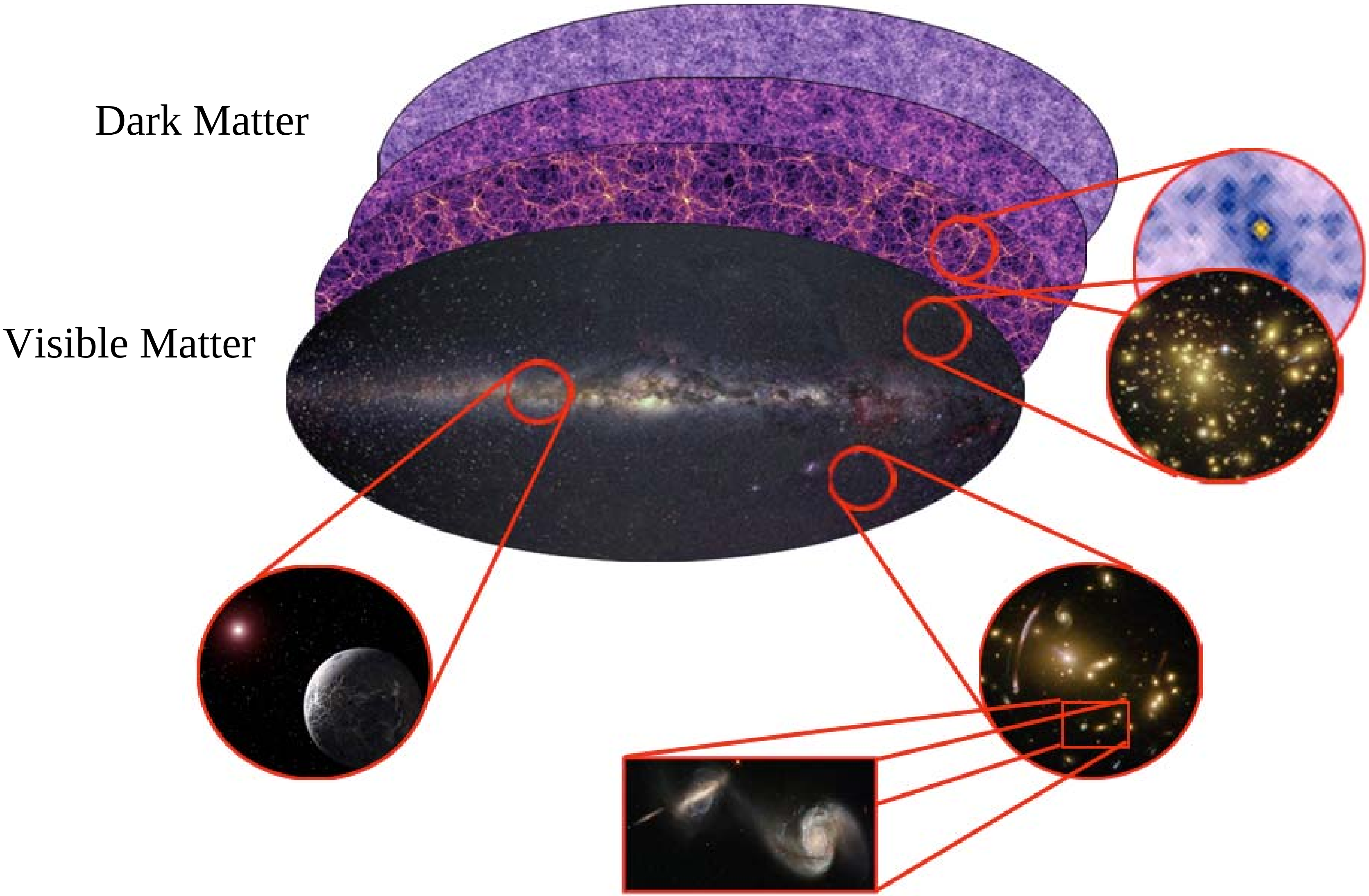
•Dark Energy: w_p and w_a with an error of 2% and 13% respectively (no priors)

•Dark Matter: test of CDM paradigm, precision of 0.04eV on sum of neutrino masses (with Planck)

•Primordial Initial Conditions: constrain amplitude, slope and higher order parameters of primordial power spectrum, constrain primordial non-gaussianity

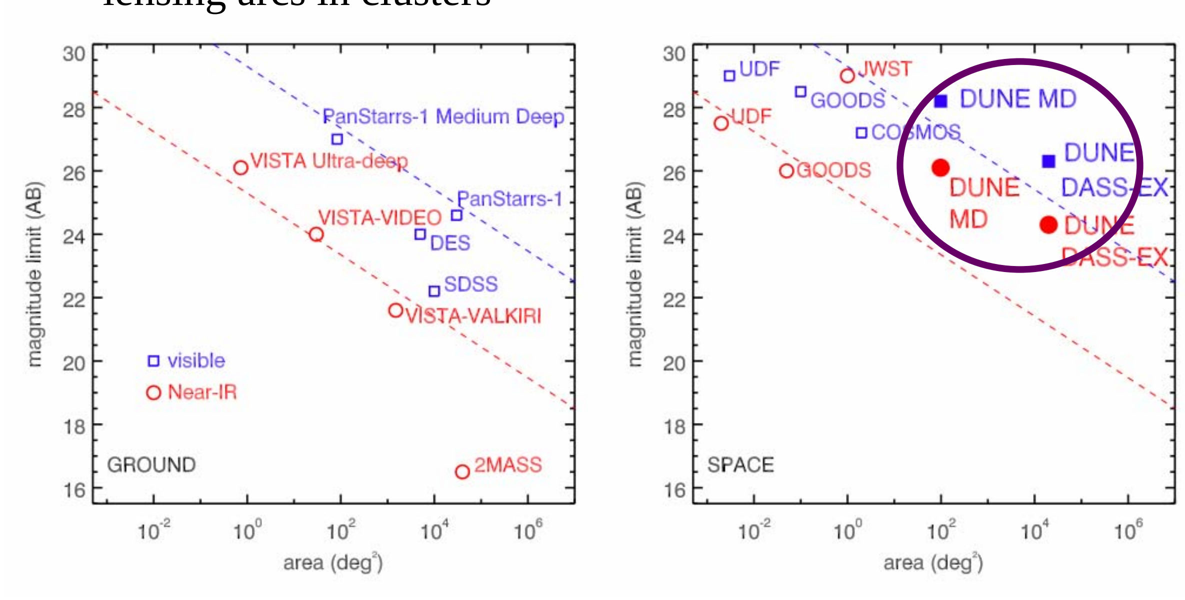
•Gravity: Distinguish GR from simplest modified Gravity theories by reaching a precision of 2% on the growth exponent γ ($d\ln\delta_m/d\ln a \propto \Omega_m^\gamma$)

Euclid Imaging Legacy: Imaging the Universe



Imaging Legacy Science

- **Map the relation between Galaxy Mass and Light**: correlation of WL mass map with galaxy distribution and properties
- **Constrain the physical drivers of star formation**: galaxy morphologies and masses; SNe rate (Detection of ~3000 Type Ia and Type II supernovae in deep survey)
- **High-z objects**: Using the Ly-dropout technique in MD survey, detect 10^{3-4} star forming galaxies at z~8, 10^{2-3} at z~10, maybe ~10 at $z \sim 12$; also detect 10^{2-4} quasars at $z \sim 7$, and 10^{1-3} at $z \sim 9$. These will be the brightest in sky for follow-up.
- **Galaxy clusters**: Mass-detection of 40,000 clusters at $0.3 < z < 0.7$, well-matched to Planck SZ and eRosita cluster sample, and NIR detection of 10^{2-3} Virgo-like clusters and 10^{3-4} $10^{13}M_\odot$ at $z > 2$,
- **Strong-lensing systems:** ~10^5 galaxy-galaxy lenses, ~10^3 galaxy-quasar lenses, 5000 strong lensing arcs in clusters

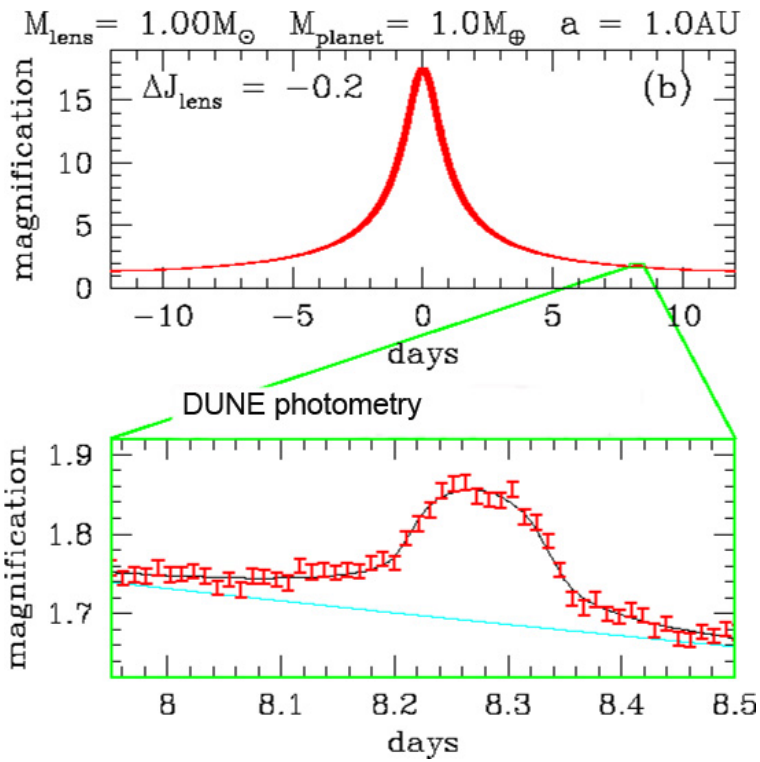


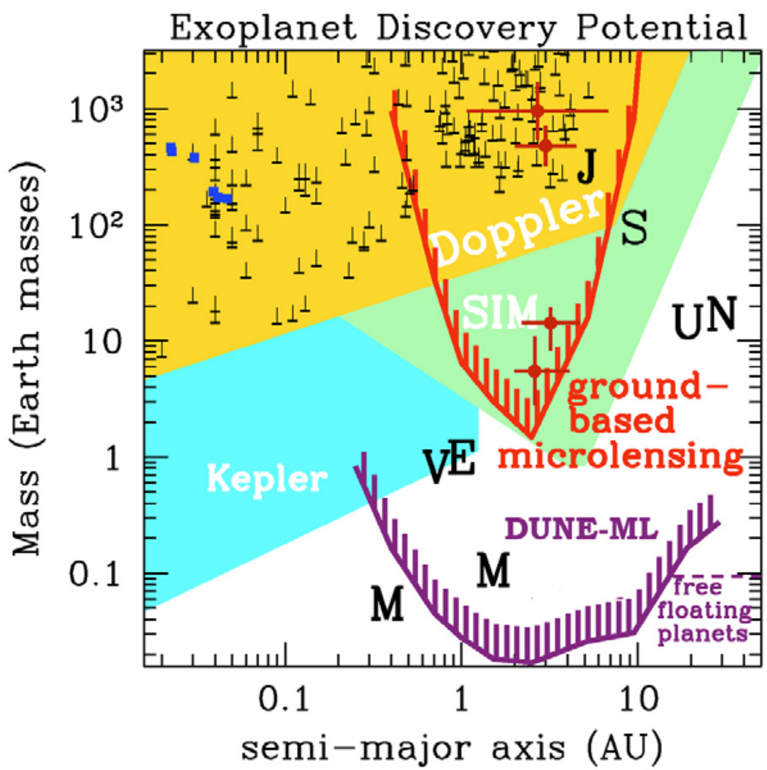
The "Genome Project" of the observable Universe ?

Add-on? Search for Planets with Microlensing Euclid

Microlensing survey: 4 deg^2 in the bulge, visited every 20 minutes over 3 months (Y,J,H ~ 22 per visit), monitor $2x10^8$ stars

→ Detect ~30 Jupiters, and ~5 Earth Mass planets in the habitable zone





Euclid Mission Baseline

Mission elements:

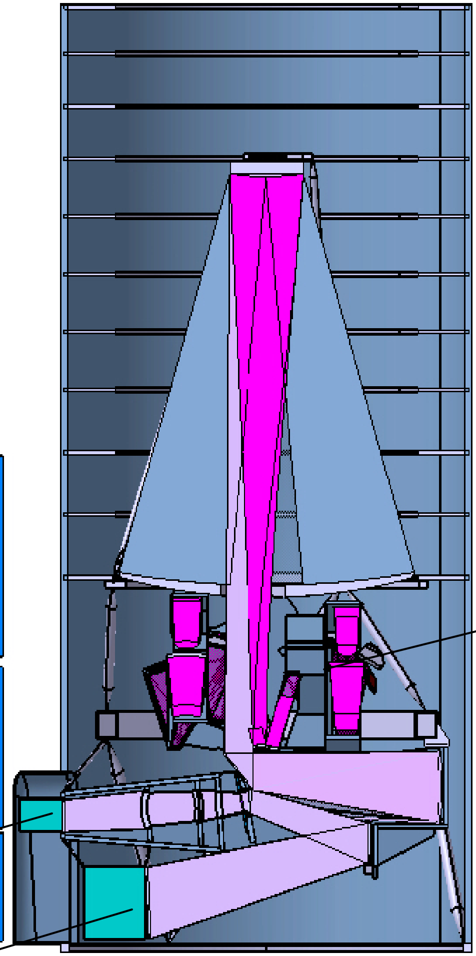
- L2 Orbit
- 4-5 year mission
- Telescope: three mirror astigmat (TMA) with 1.2 m primary
- Instruments:

– **Imaging:**
  - **Visible imaging channel: 0.5 deg², 0.10 arcsec pixels, 0.18 arcsec PSF FWHM, single broad RIZ (0.55-0.92μm), CCD detectors** → **galaxy shapes**
  - **NIR photometry channel: 0.5 deg², 0.3 arcsec pixels, 3 bands Y, J, H (1.0-1.7μm), HgCdTe detectors,** → **photometry, photo-z's**

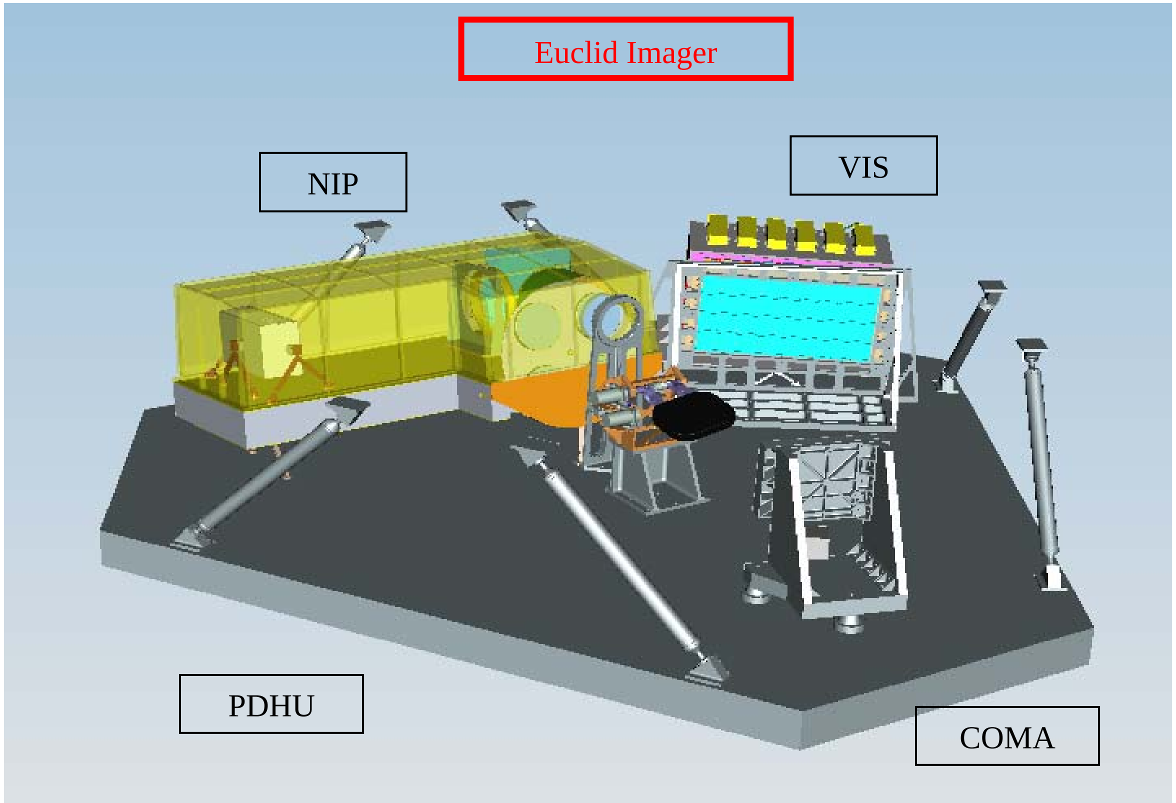
– Spectroscopy: NIR Spectroscopic channel: 0.5 deg², R=200-600, 0.9-1.7μm, → redshifts

– baseline: slitless

– option: multi-object slit-based with Digital Micro-Devices (DMD)



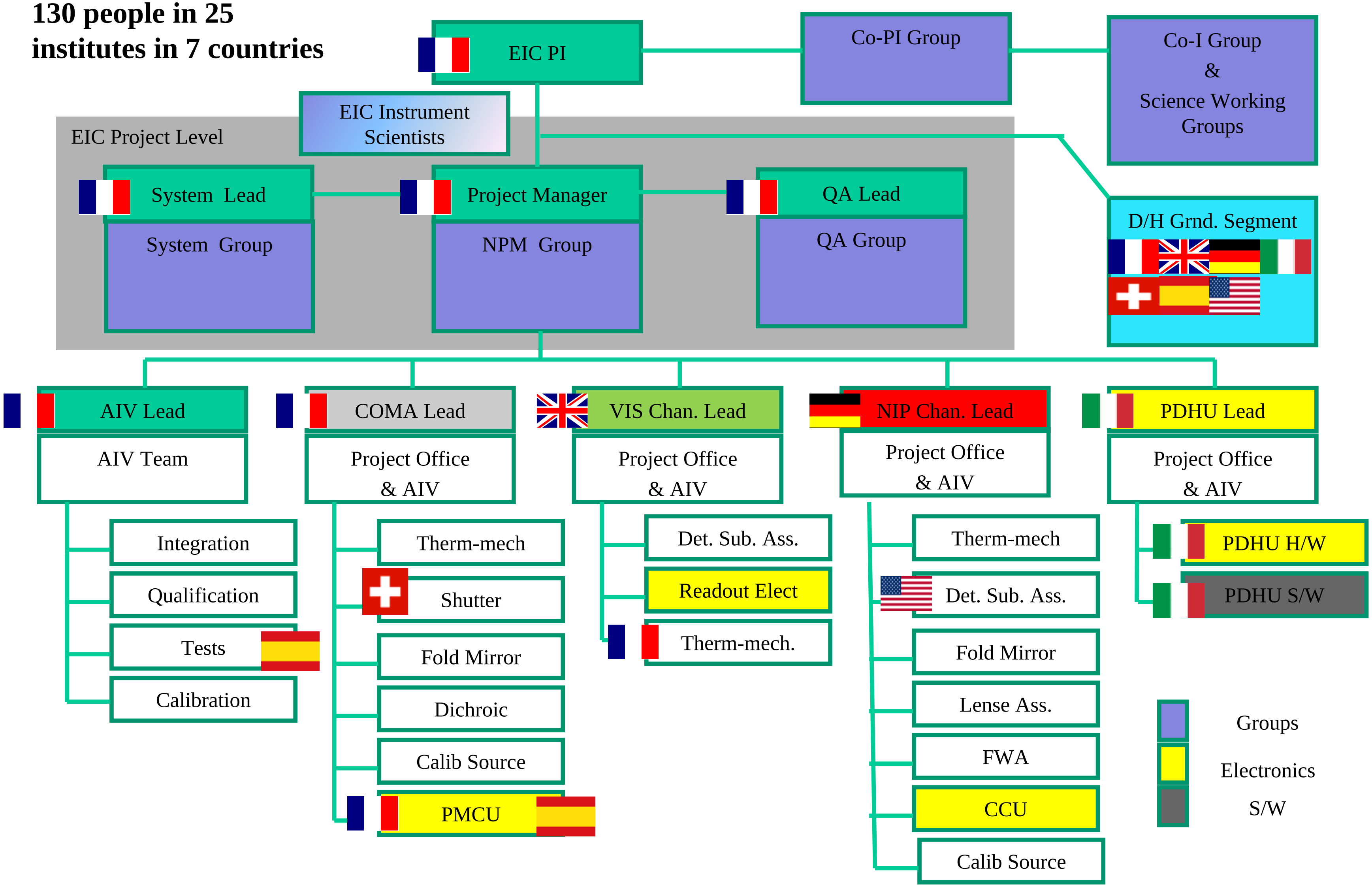
Euclid Imaging Instrument



EIC delivered data pack:
Design, Development Plan, Management & Cost + supporting Documents, EIC Science Requirements, Radiometric and NIP documents, joint EIC-ENIS ground segment document

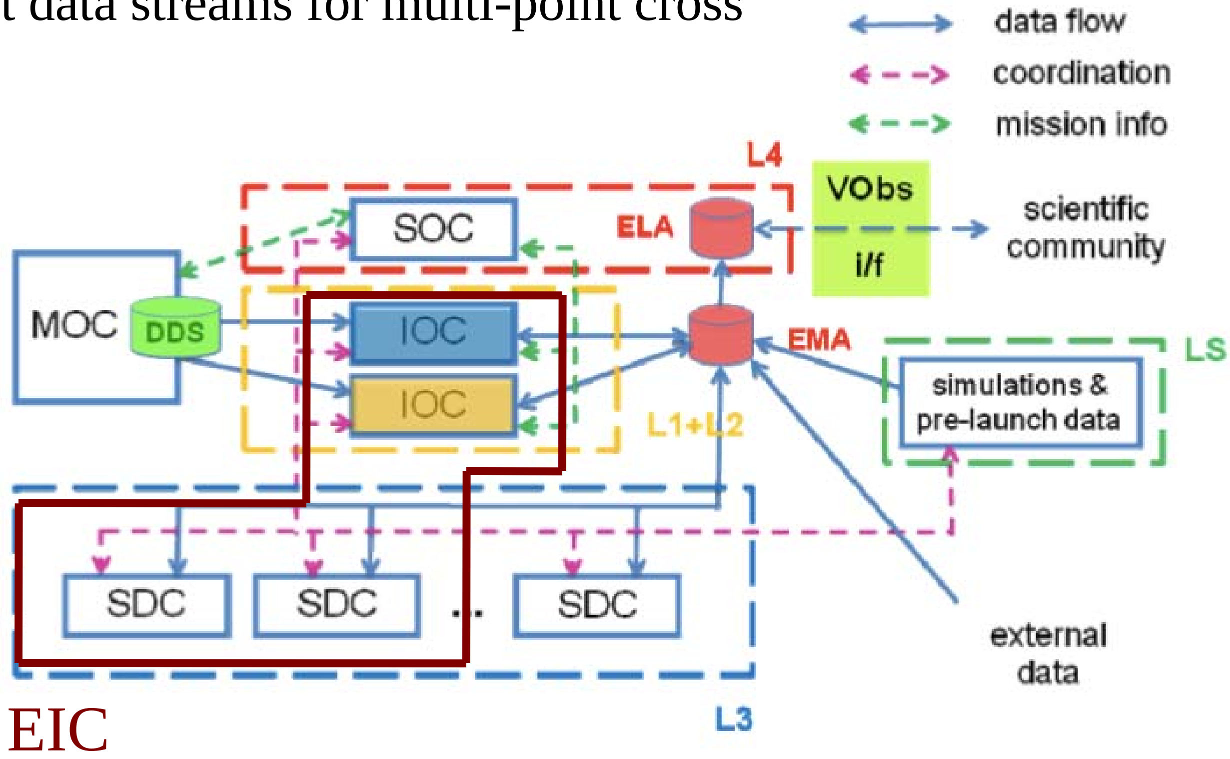
EIC Organisation

130 people in 25 institutes in 7 countries



Ground Segment

Integrated ground segment and data handling
•Intimate connection between instrument knowledge and science analysis.
•Redundant data streams for multi-point cross checking.



see EIC-ENIS Ground Segment Document

Other related EIC talks

Weak Lensing Cosmology	Adam Amara
Legacy Imaging Science	Marcella Carollo
	Isabel Hook
	Jean-Philippe Beaulieu
Photo-z requirements	Simon Lilly
Technical design	Jerome Amiaux
Image performance	Tom Kitching

Summary

- **The Euclid concept**: a high-precision cosmological survey of imaging and spectroscopy, aimed at Weak Lensing and BAO, over 2π sr, with simultaneous matched survey speeds within a 5-year M-class mission envelope.
- **Euclid Imaging Survey** is optimised to achieve definitive constraints on Dark Energy through weak lensing tomography, addressing all sectors of the cosmological model → analogous to CMB for the late-epoch DE dominated Universe $0 < z < 2$.
- **Euclid Imaging Consortium** maintains a strong link between science and instrumentation, and tight control of systematics that are essential for success in weak lensing.
- **Ground-based photometric surveys** offer cost-effective route to photo-z performance
- **Euclid ENIS spectroscopy** provides strong synergy and complementarity for both cosmological probes and photo-z calibration.
- **Euclid Legacy Surveys** from the "all-sky" and "deep" VIS/NIR imaging survey provide breakthrough resource for galaxy evolution, high-*z* objects, clusters, strong lensing and the Galactic halo, with potential survey extensions, also exoplanets and the Milky Way disk.