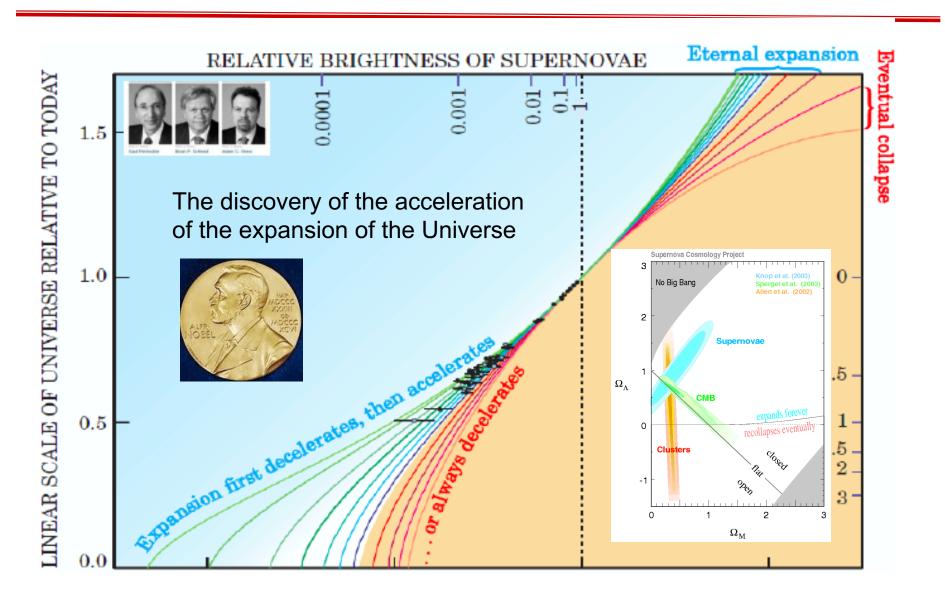


Outline

- Dark energy strategy using large surveys
- The Large structure observables
- Status of future projets
 - Space: Euclid and Wfirst
 - Ground: DESI,LSST
 - Radio : SKA

Presentation strongly biased as focusing mainly on dark energy using large structures of the Universe

Acceleration and dark energy: Supernovae



The post Planck Univers **∧CDM**

Post Planck Universe

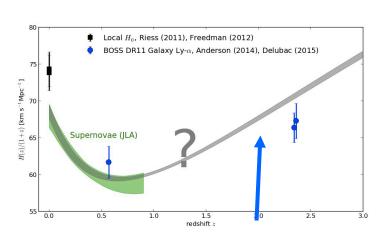
- 69.4 % dark energy
- 25.8 % dark matter
- 4.8 % baryons

25,8 %

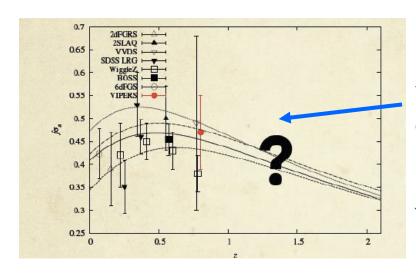
\Rightarrow Confirmation ' Λ CDM'

- \Rightarrow Cosmological constant Ω_{Λ} confirmed by Planck , supernovæ and BAO (baryonic acoustic oscillation)
- \Rightarrow No indication for a more complex explanation than Ω_{Λ_1} that can explain the acceleration of the expansion of the Universe

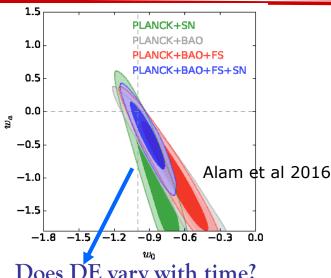
Nature of dark energy.... Where we stand...



Transition DE-DM?
Acceleration-decceleration?



No indication Or no sensitivity?

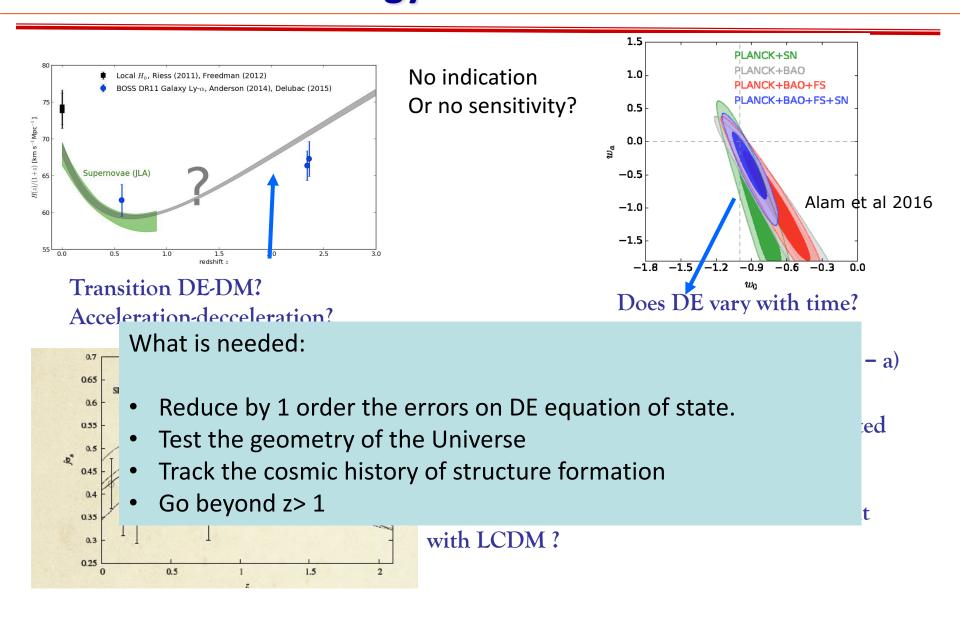


Does DE vary with time? today ...no sensitivity to wa with w(a) = w0 + wa(1 - a)

Does gravity self consistent with the accelerated expansion? (modified gravity)

=> Verify that growth of structures consistent with LCDM?

Nature of dark energy.... Where we stand...



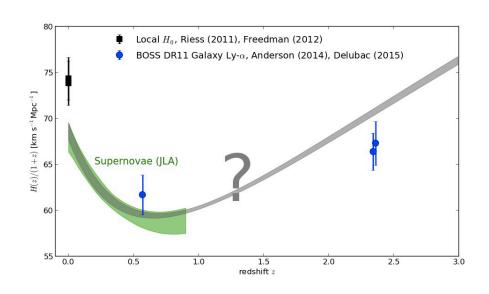
Exploring the DM/DE transition period : H(z)/D(z)

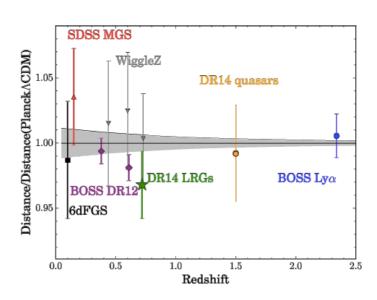
Expansion Rate (BAO):

 $H(z) = H_0 \left[\Omega_{\rm M} (1+z)^3 + \Omega_{\rm DE} \frac{\rho_{\rm DE}(z)}{\rho_{\rm DE}(0)} + \Omega_{\rm K} (1+z)^2 \right]^{1/2}$

Distance (SN, BAO, CMB):

 $D(z) = \frac{1}{(|\Omega_{\rm K}|H_0^2)^{1/2}} S_{\rm K} \left[(|\Omega_{\rm K}|H_0^2)^{1/2} \int_0^z \frac{dz'}{H(z')} \right]$





Exploring the cosmic history with structure formation

3

Growth and growth rate (WL, Clusters, RSD):

$$G'' + \left(4 + \frac{H'}{H}\right)G' + \left[3 + \frac{H'}{H} - \frac{3}{2}\Omega_{\rm M}(z)\right]G = 0$$

$$G = D_1/a$$
 ; $f = d \ln(D) / d \ln(a)$

4

Measuring the metrics: use probes that explore the 2 potentials

$$ds^2 = -(1 + 2\psi) dt^2 + (1 - 2\phi) a^2(t) dx^2$$

It is fundamental to have access to both potentials To distinguish effects

Use power spectrum

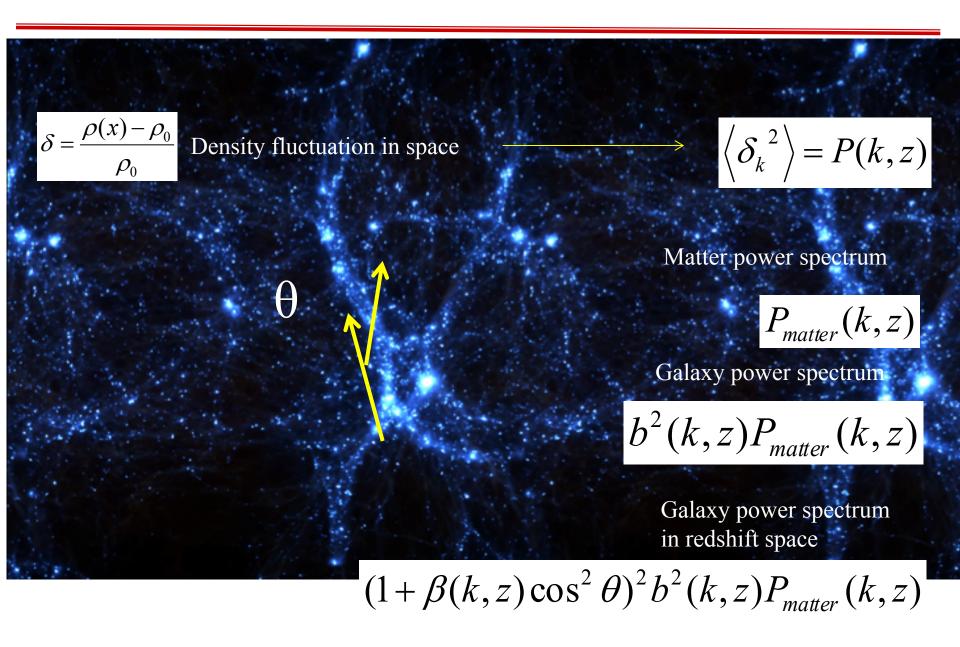
· Small scalar perturbations:

$$ds^{2} = -(1+2\psi) dt^{2} + (1-2\phi) a(t) d\vec{x}^{2}$$

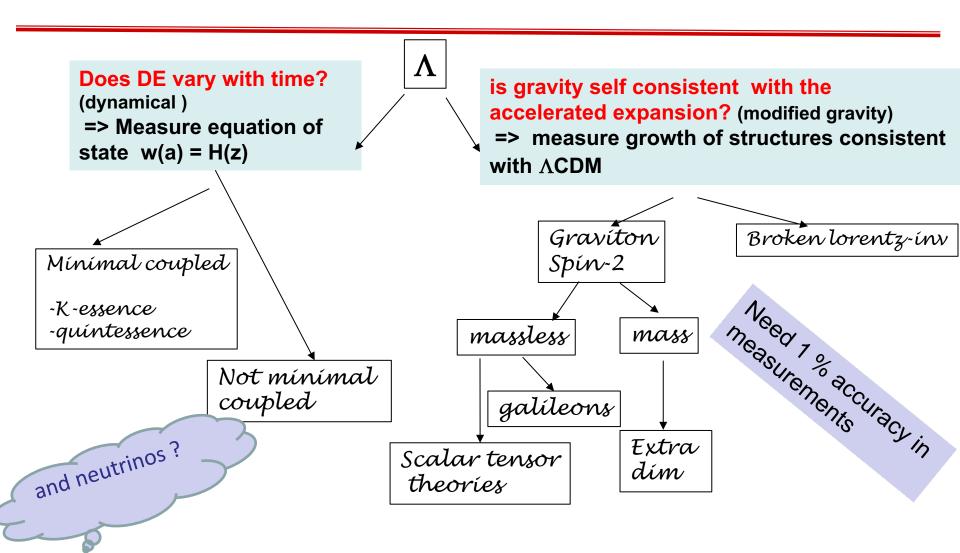
- Non relativistic particules are sensitive to: ψ
- Relativistic particules are sensitive to: $\psi + \phi$
- Standard GR + no anisotrotic stress: $\psi = \phi$
- \rightarrow Poisson equation $k^2 \phi = -4\pi G a^2 \sum \rho_i \Delta_i$
- Modified Gravity or Dynamical DE: $\psi = R\phi$
- → Poisson equation: $k^2 \phi = -4\pi G Q a^2 \sum \rho_i \Delta_i$

 $Q(k,a)_{r}R(k,a)$: imprints on clustering of DM, Gal and DE

Measurements = power spectrum



DE strategy today

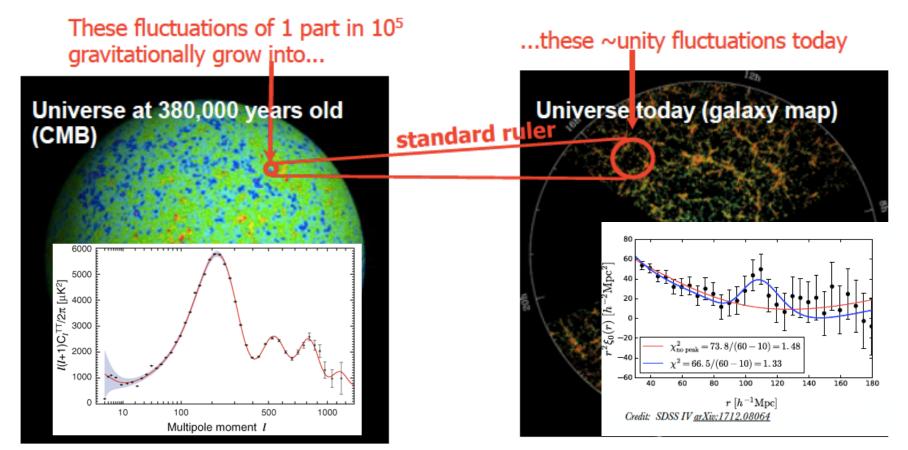


 \Rightarrow Need observations of both matter evolution (dark and baryon matter power spectrum) and Universe evolution (H(z))

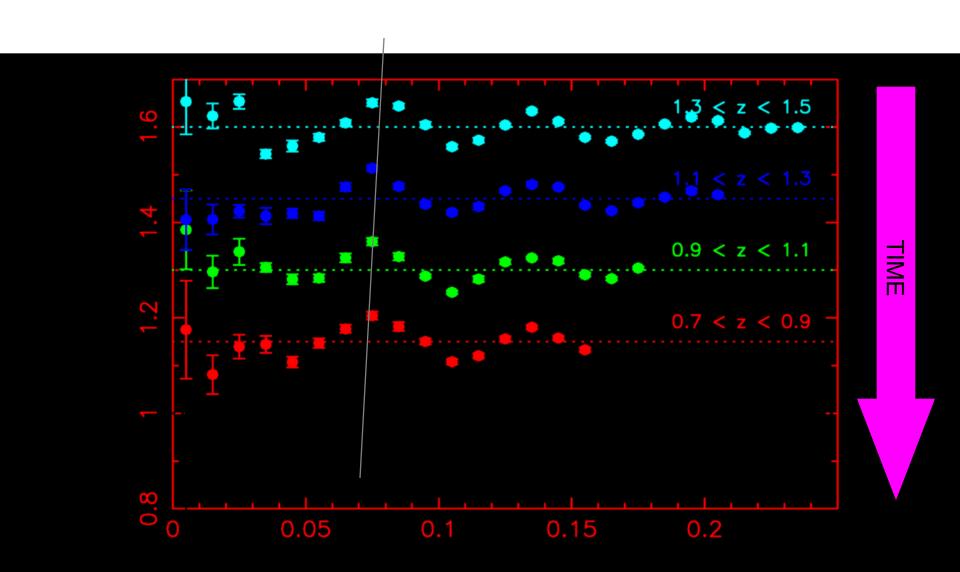
BAO and large structures (LSS)

Baryon Acoustic Oscillations (BAO) standard ruler at 147 Mpc

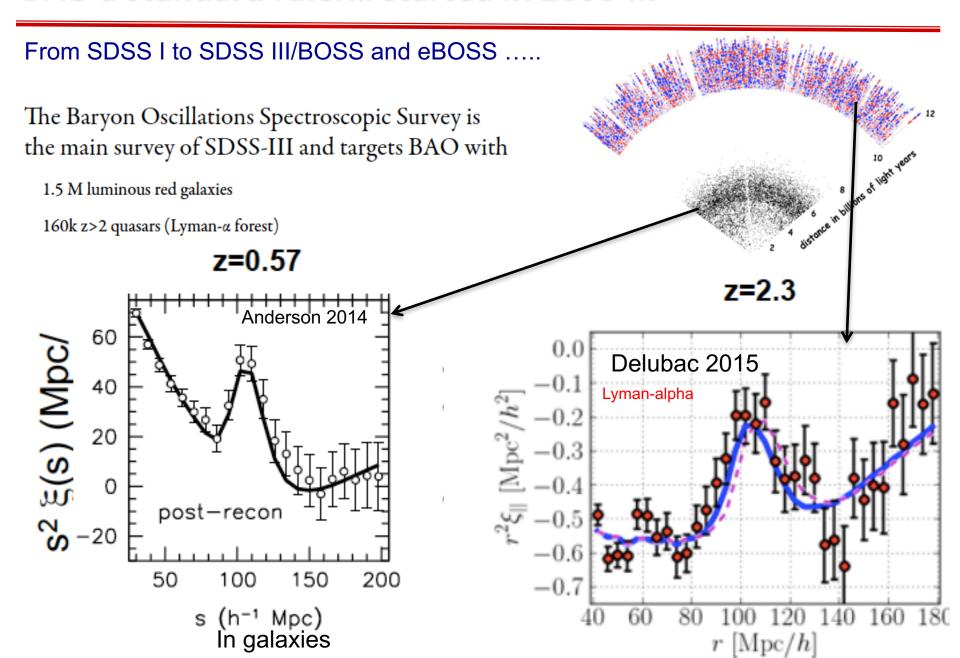
BAO imprinted in the microwave background at z=1100 ... and forever more in galaxy maps



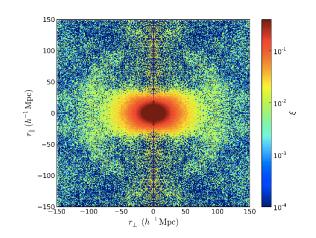
Evolution of Acoustic Oscillations



BAO a standard ruler... started in 2006!..



Smaller scales: Redshift space distorsion (RSD)



The growth factor or growth rate f(z) quantifies the efficiency with which cosmological structures can be built





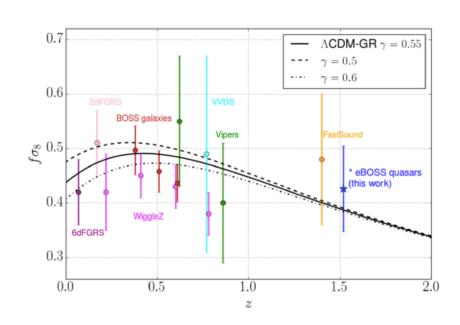
"real" space

"redshift" space

$$f(z)\sigma_8(z) \propto rac{dG}{d\log a}$$

For fixed expansion history, GR makes an unique prediction of the growth of structures

⇒ A key test of modification of the gravity



Zarrouk 2018

Using the H1 21cm Line

F=1
$$\Delta E = \frac{4}{3}\alpha^4 g_p \frac{m_e}{m_p} m_e c^2 = 5.9 \mu \text{eV} = h(1420 \text{MHz})$$

$$\lambda = 21 \text{ cm}$$

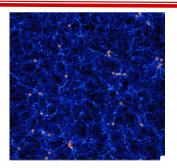
- Ground-state spin-flip hyperfine transition of neutral hydrogen
- Hydrogen: most abundant element, optically thin, simplest element
- Necessary for star formation interpretation
- Line transition: Probe 3D structure of the Universe
- Can be seen in absorption or emission against the CMB, depending on the spin temperature:

$$T_s > T_{cmb}$$
: emission (z < 10)
$$\frac{n_{F=1}}{n_{F=0}} = 3e^{-\Delta E/kT_s}$$
 $T_s < T_{cmb}$: absorption (~15? < z <~150)

Simultaneous velocities and line widths

Bias's surveys to late type galaxies Avoids some of the non-linear effects of clustering

The 21cm universe and LSS: intensity mapping

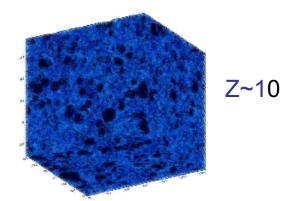


Large-scale HI temperature fluctuation; CMB-like, in 3D Observed frequency: f = 1420/(1+z) MHz

Z~1

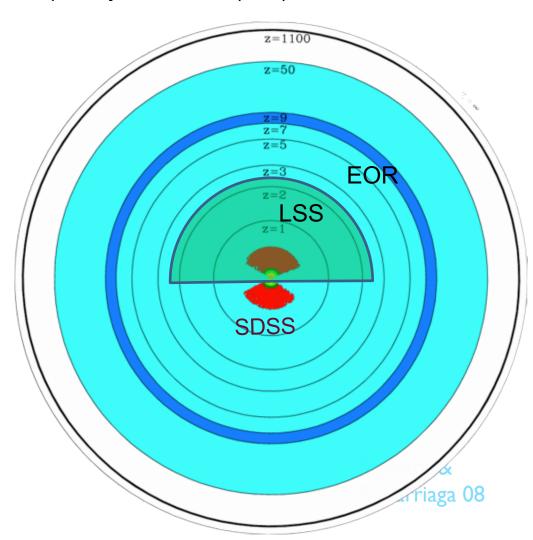
0.5<z<2.5, HI traces under-lying matter distribution, measure Baryon Acoustic Oscillations ~100 Mpc scale

=> dark energy

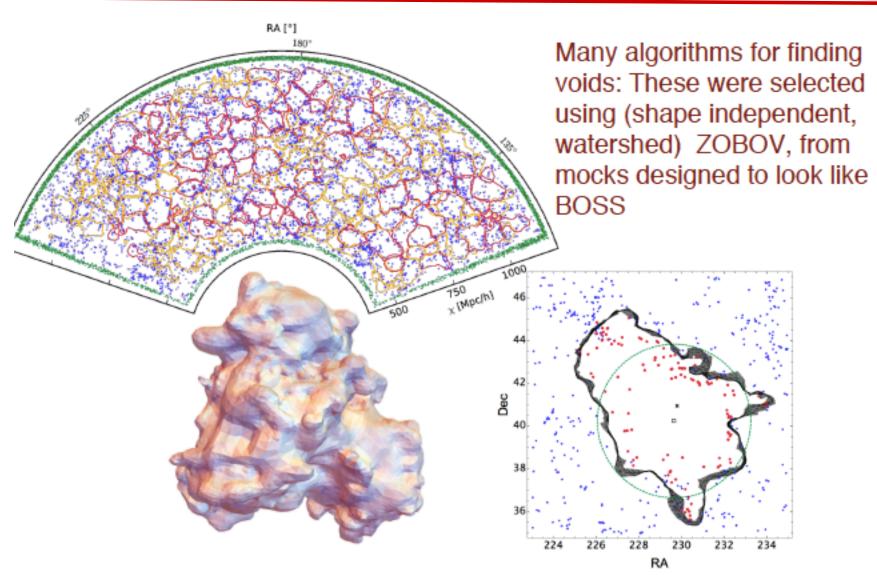


6<z<10, Epoch of Reionization, HI shows tomographic history of reionization ~20-50 Mpc scale

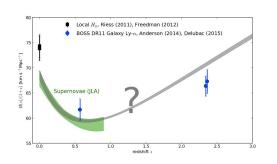
=> astrophysics



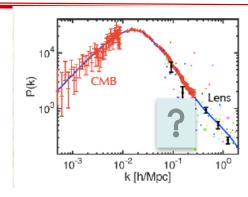
USING the structure to test the cosmic web: VOIDS and clusters



The goal: COMBINING



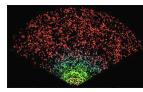






Supernovae : distance.

Photometry Multi bands



Clustering /Large scale structure (LSS) (BA0, RSD...)
distance + ordinary matter power spectrum
+ growth of structures

Spectroscopy Redshift survey



Weak gravitational shear.
distance + dark matter power spectrum,
growth of structure

Imaging Photometry



Galaxy cluster / Voids count, power spectrum

Photometry+ spectroscopy

DE strategy for > 2020 multi probes and multi projects

Goal → -reduce by 1 order of magnitude the errors on DE equation of state.
-distinguish from modified gravity

Method → Large sky Surveys & deep (24-27 mag)

Key issue → **Systematic Errors**

Combining probes

Observables

Galaxy Clustering: BAO,RSD,growth

Weak Lensing : growth of structure

Supernovae : standard candle

Cluster counts /voids

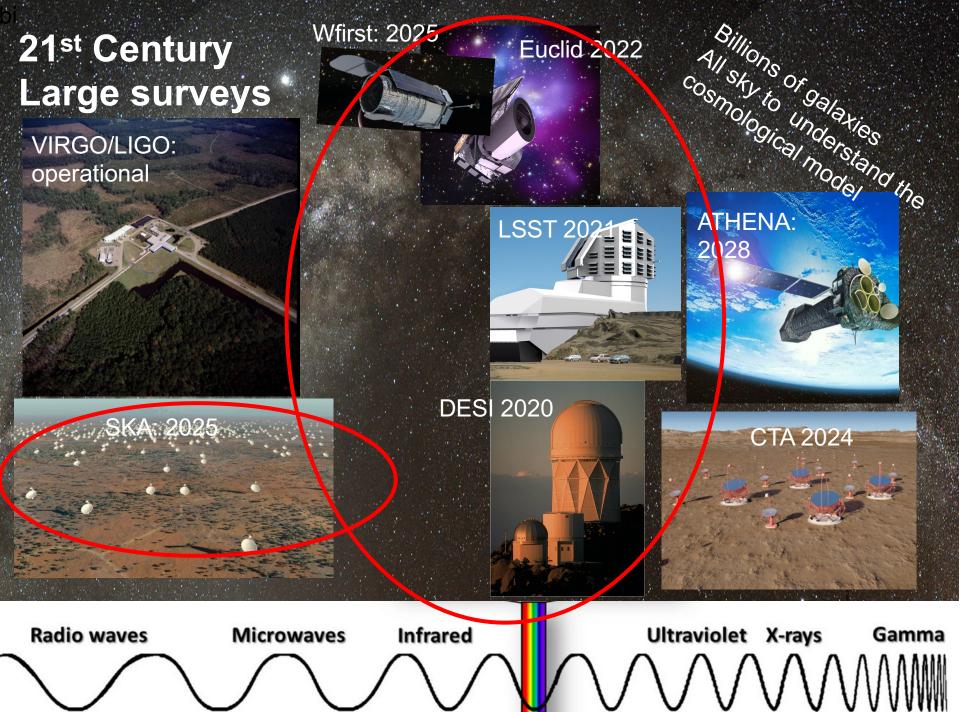
Large US ground Project DESI

A large europeen space Project selected: EUCLID.

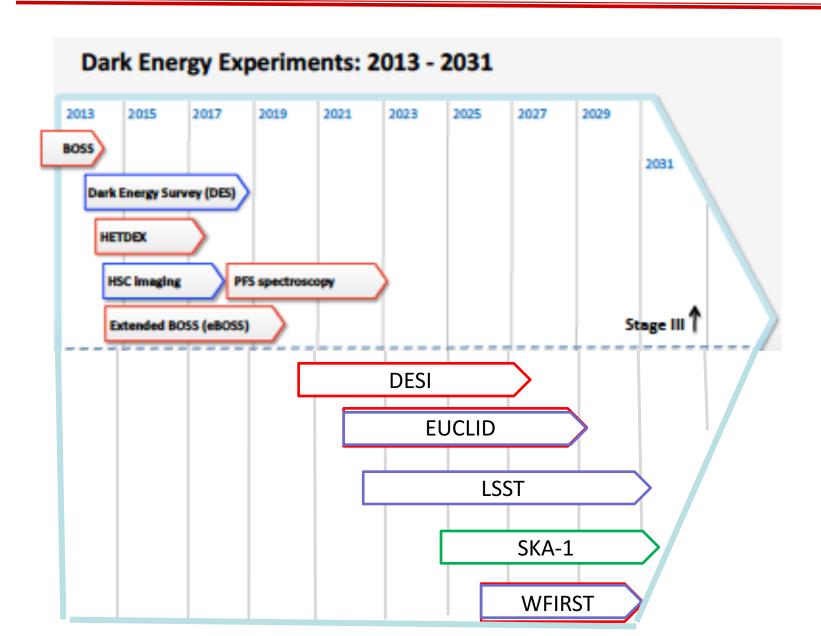
Large US ground Project LSST (photo)

A large europeen network of radio antenna SKA

- H1 survey mapping ←



The DE road map past to future



DESI: a large ground spectroscopic survey

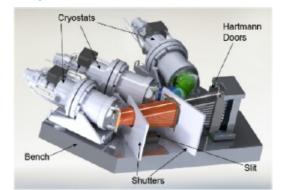
Scale up SDSS/BOSS to a massively parallel fiber-fed spectrometer at a 4-meter

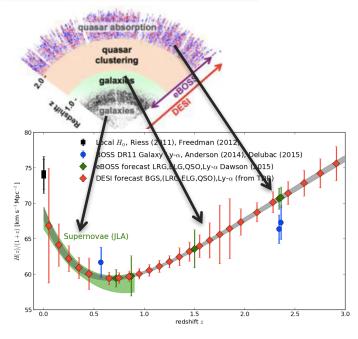
telescope.

5000 fibers in robotic actuators

- 3.2 deg. field of view
- 10 spectrographs
- 4m telecope (Mayall at Kitt peak)
- First light expected ~ 2018

- Broad range of target classes: LRG's, ELG's, QSO's
- Broad redshift range: 0.5 < z < 1.6, 2.2 < z < 3.5
- Sky area: 14,000 18,000 square degrees
- Number of redshifts: 20 30 million
- Medium resolution spectroscopy, R ~ 3000 5000
- Spectroscopy from blue to far-red





EUCLID

A space mission dedicated to understand the origin of the acceleration of the Universe

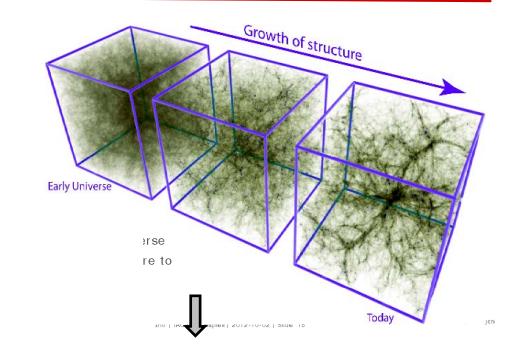
Euclid was selected by ESA in Oct. 2011, Adopted in June 2012 in the cosmic vision program as the M2 mission

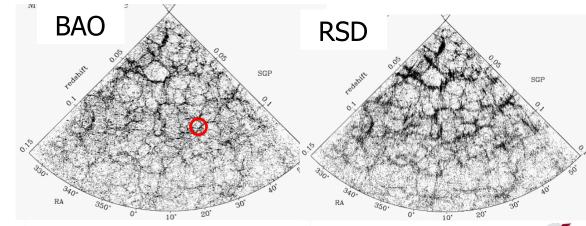
Euclid is under construction and will be launched early 2022 for a 6 year survey

Primary: Galaxy Clustering: BAO + RSD

- 3-D position measurements of galaxies over 0.9<z<2
- Probes expansion rate of the Universe (BAO) and clustering history of galaxies induced by gravity (RSD); ψ , H(z).
- Need high precision 3-D distribution of galaxies with spectroscopic redshifts from spectroscopy in NIR range.

35 million spectroscopic redshifts with 0.001 (1+z) accuracy over 15,000 deg²









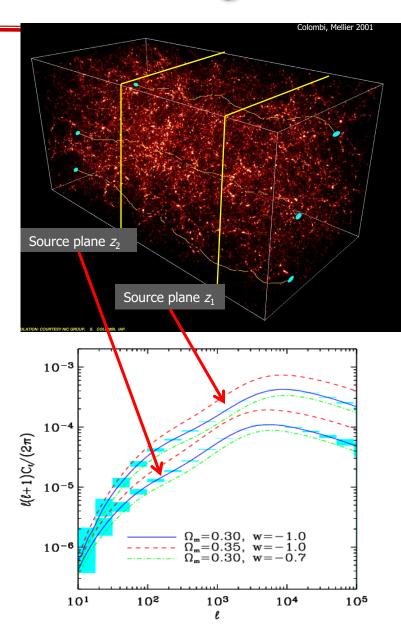
Primary probe 2: Weak Lensing

Cosmic shear over 0<z<2

- •Probes distribution of matter (Dark +Luminous): expansion history, lensing potential $\phi+\psi$.
- → Shapes+distance of galaxies: shear amplitude, and bin the Universe into slices.
- → "Photometric redshifts" sufficient for distances

Shape measurement and photo-z's from optical an NIR data

1.5 billion galaxies over 15,000 deg² †shape and photo-z's





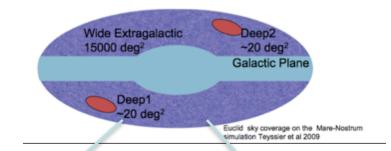


Euclid: an ESA space mission

➤ Euclid is an ESA mission with a strong scientific consortium

17 countries +US, 120 laboratories, > 1200 members

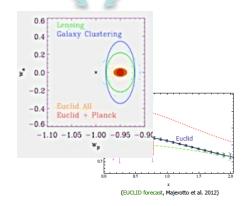
- ESA provides the telescope and detectors (via industry), the satellite, launch and operation centers
- Countries provide the 2 instruments (VIS and NISP) and the ground segment (SGS)
- The ground segment and related computing is a very expensive and challenging aspect of the project





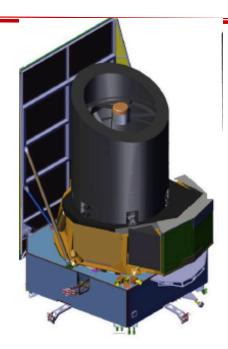
Shear

clustering



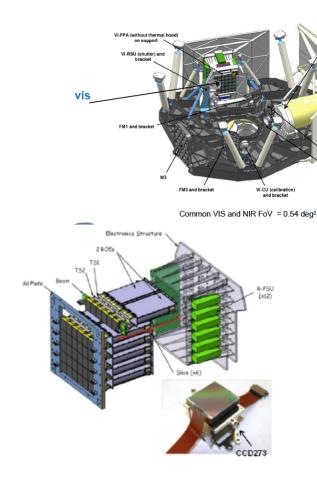


The instruments

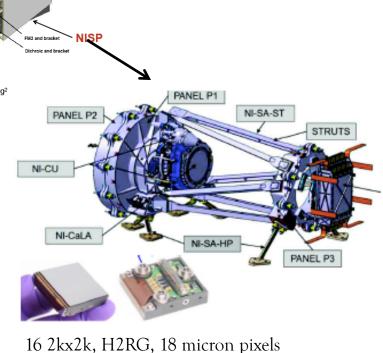


- Télescope 1,2 m: FoV: 0.54 deg²
- Miror in Silicon Carbide= ultra-stable:

Temp.: -150 deg. Stability +:- 0.05 deg.

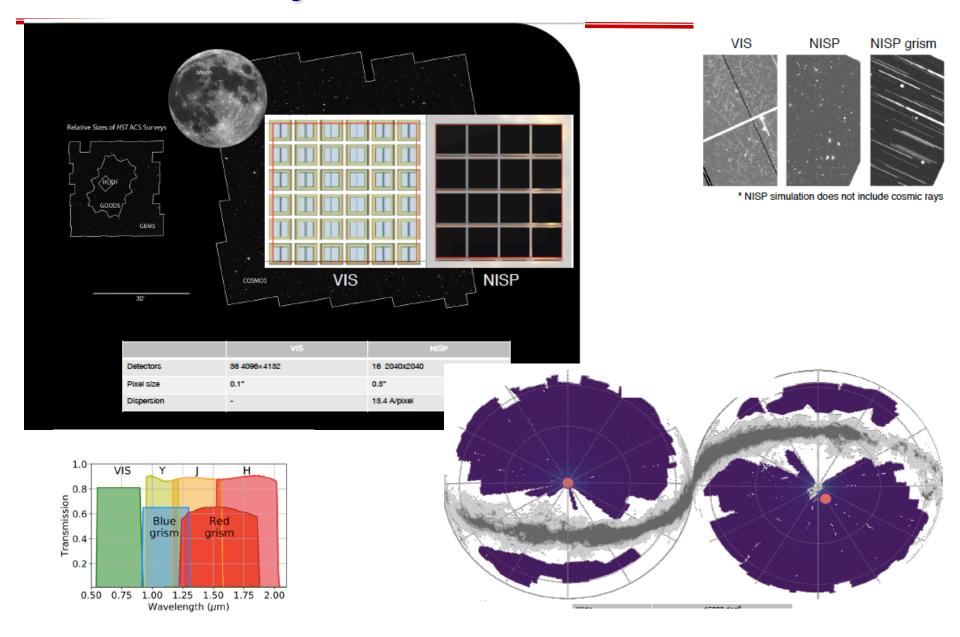


36 CCDs,4kx4k, 12 micron pixels 0,1 arcsec pixel on sky 1 filter Y(R+I+Y)
Bandpass 550-900 nm
Data volume 520 Gbit/day
Mass 135 Kg



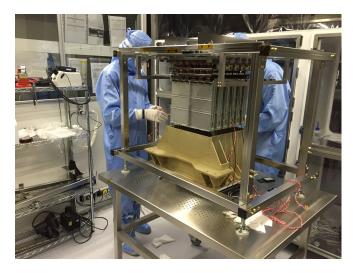
0,3 arcsec pixel on sky
3 filters Y,J,H
4 grisms 1B(920-1350),3 R(1250-1850)
Data Volume 290 Gbit/day
Mass 159 Kg

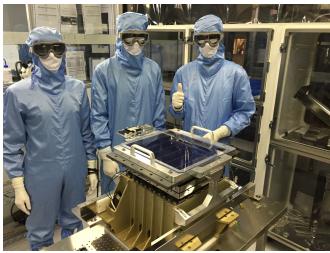
Euclid surveys



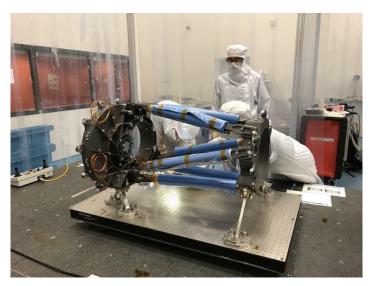
Euclid flight instruments are under construction

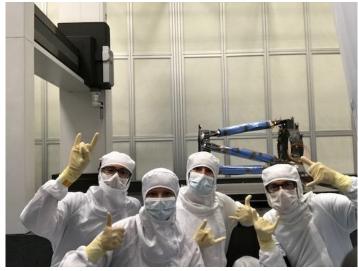
VIS integration Saclay



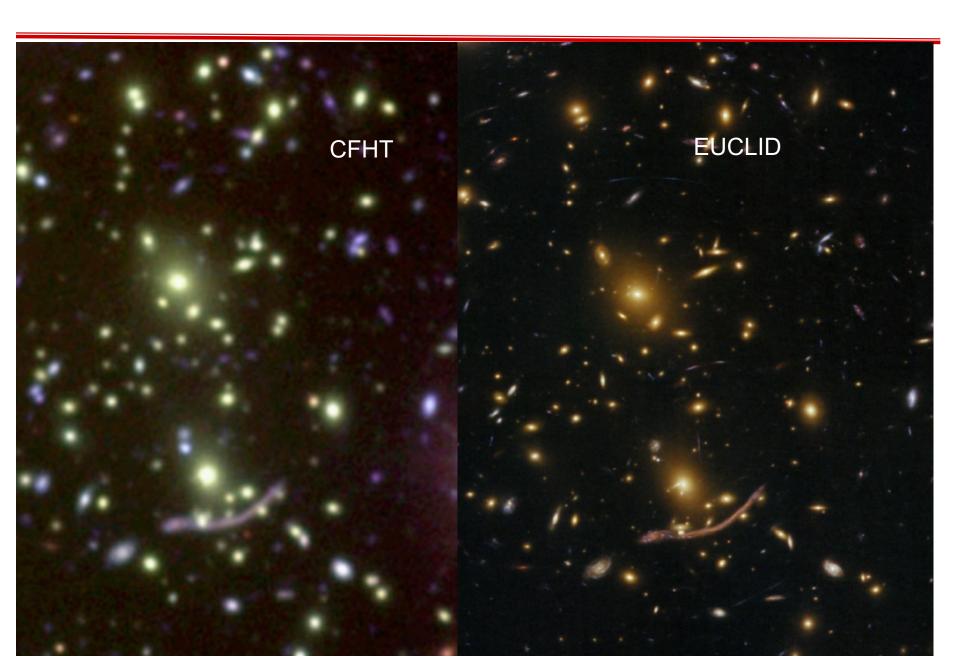


NISP integration Marseille

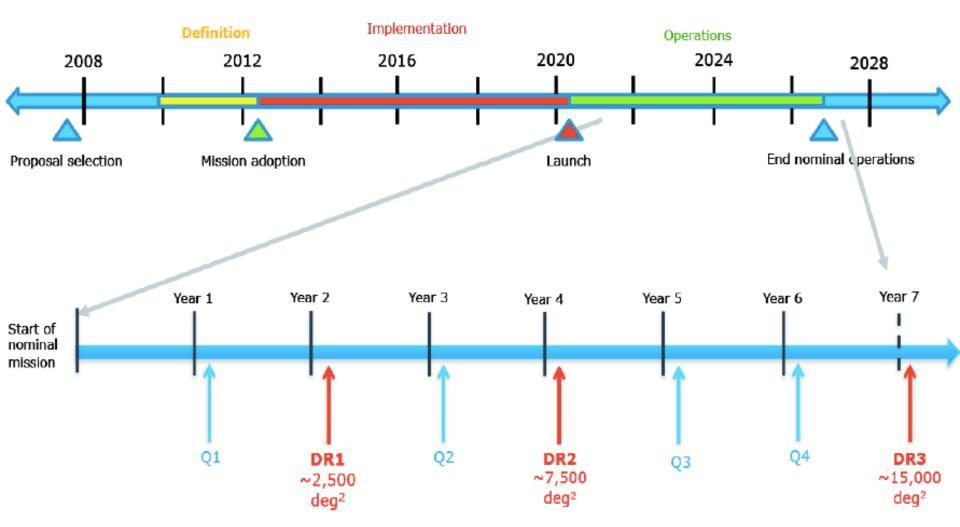




Euclid is under simulation



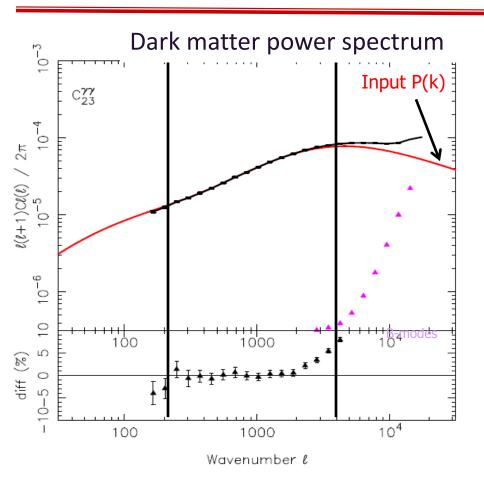
Data release



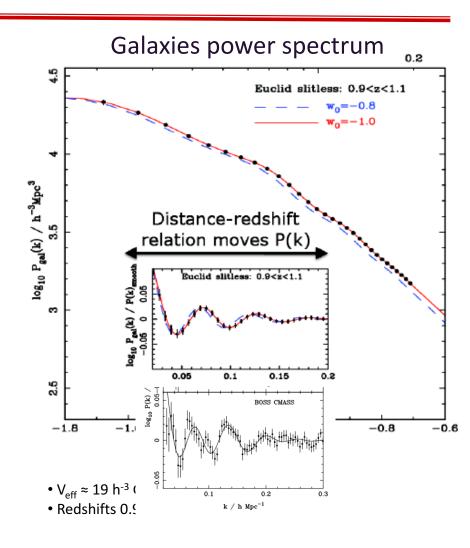
Science with Euclid will start in 2022 with Q1 and in 2023 with DR1



Euclid: Combining WL and GC power spectrum



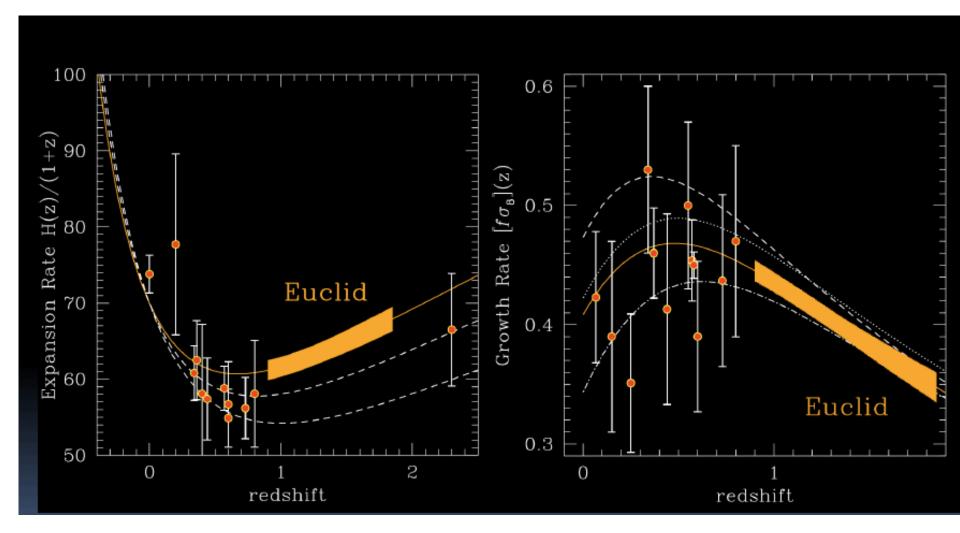
- Tomographic WL shear cross-power spectrum for 0.5 < z < 1.0 and 1.0 < z < 1.5 bins.
- Percentage difference [expected measured] power spectrum: recovered to 1% .



• Percentage difference [expected – measured] power spectrum: recovered to 1% .

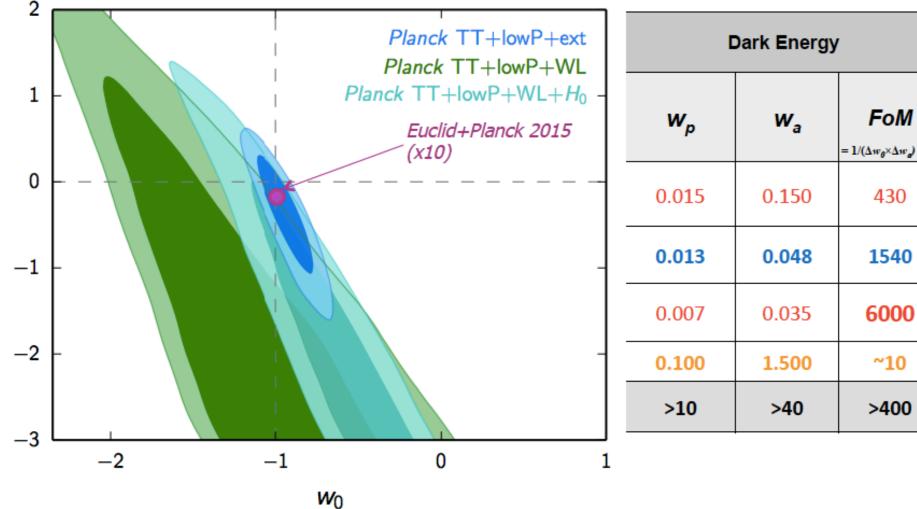
EUCLID: Exploring the DM-DE transition period

Euclid can explore the transition area with redshift survey only



Credit: G.Guzzo

Euclid Post-Planck Forecast for the Primary Program



430

1540

~10

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

From Euclid data alone, get FoM=1/($\Delta w_a \times \Delta w_p$) > 400 \rightarrow ~1% precision on w's.

WFIRSTWide-Field Infrared Survey Telescope





Wide-Field Infrared Survey Telescope Top priority of 2010 Decadal Survey

Science themes: Dark Energy, Exoplanets, Large Area

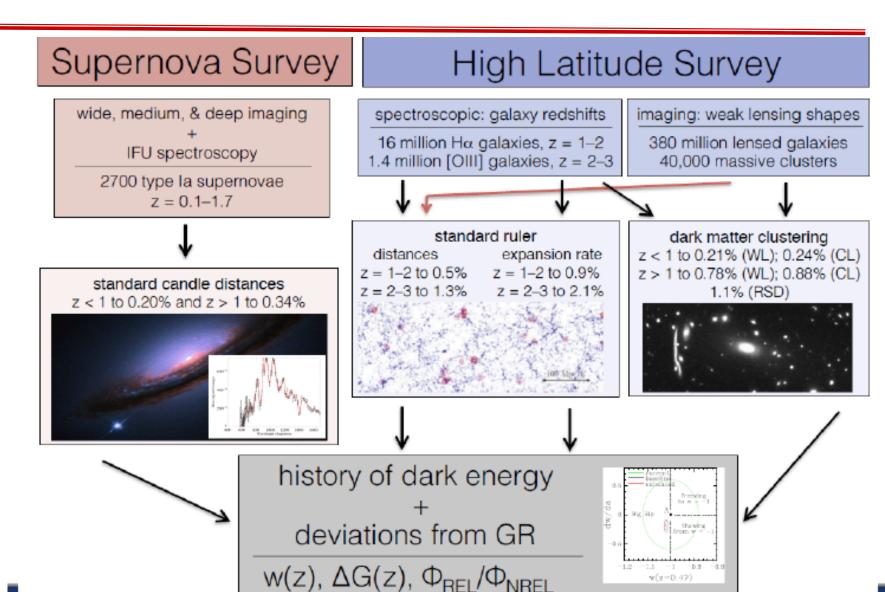
Near Infrared Surveys

Phase: Currently in Formulation (Phase A)

Hubble quality but with a field of viewx100 Telescope 4xEuclid Launch ~2025

- Mission Life: 5 years (+ ~3 month checkout)
- Mission Orbit: Sun-Earth L2
- Baseline Launch Vehicle: Falcon Heavy, Delta-IV Heavy, SLS possible
- Observatory:
 - 2.4 m primary mirror Telescope
 - Wide Field Instrument (WFI) & (IFC)
 - Coronagraph (CGI)
 - S/C Bus
 - DL Rate & Volume 290 Mbps, 11 Tbits/day
 - Pointing stability: 14 mas drift, 14 mas jitter, RMS per axis
 - Modular Serviceable Design
- Ground System: Dual site dedicated ground stations
 - Northern GS- White Sands, Southern GS- TBD

Wfirst: a strong complementarity with Euclid and LSST





LSST: a large dedicated telescope on ground lead by US

LSST selected by « Astro2010 » as The ground project for next decade

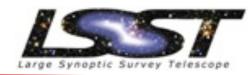
In 2012, a HEP like collaboration has been set LSST DESC (Dark Energy Science Collaboration)

LSST is in the "In FY 2014 President's budget", the agencies has started, the LSST construction in 2014

20 billions of objects!
4 billions of galaxies for cosmology
10 millions of SNs
>100 000 well measured

LSST calendar:
2021 Start of the LSST "Science Verification survey"
2023 Start of 10 years survey

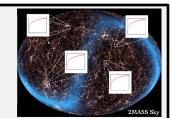
Main cosmological probes



Supernovae (SN):

distance at different epochs 0<z<1

- \rightarrow Distribution of 10⁶ SN in all sky
- \rightarrow > 100 000 SN well sampled



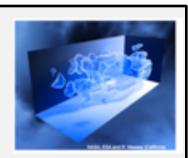
Weak lensing (WL):

Dark matter power spectrum at different epochs

- -3-D cosmic shear measurements: 0<z<2
- → Shape measurement and photo-z's

from 6 optical filter band and a multi/fast visits strategy (>100 visits)

→ 4 Billions of galaxies





Large Synoptic Survey Telescope (LSST)

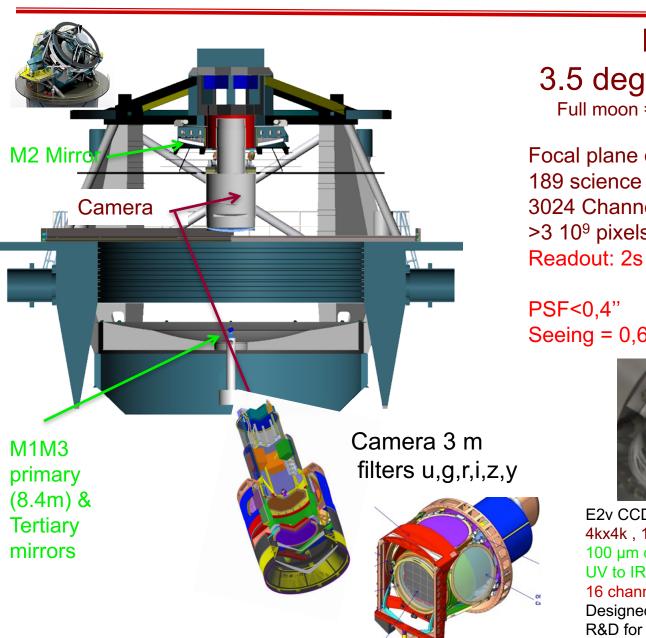




All Across the Project efforts are successfully transitioning to reality

LSST: Wide, Deep and Fast





Field of view:

 $3.5 \text{ deg} (9.6 \text{ deg}^2 = .023\% \text{ sky sphere})$

Full moon = $0.5 \text{ deg} = 4.8 \cdot 10^{-6} \text{ of sky sphere}$

Focal plane diameter: 64 cm 189 science CCD (21 rafts) 3024 Channels >3 10⁹ pixels

PSF<0,4"

Seeing = 0,6"



1 raft = 3x3 CCD150 M pixels (1/2 Megacam)

LSST a very large project

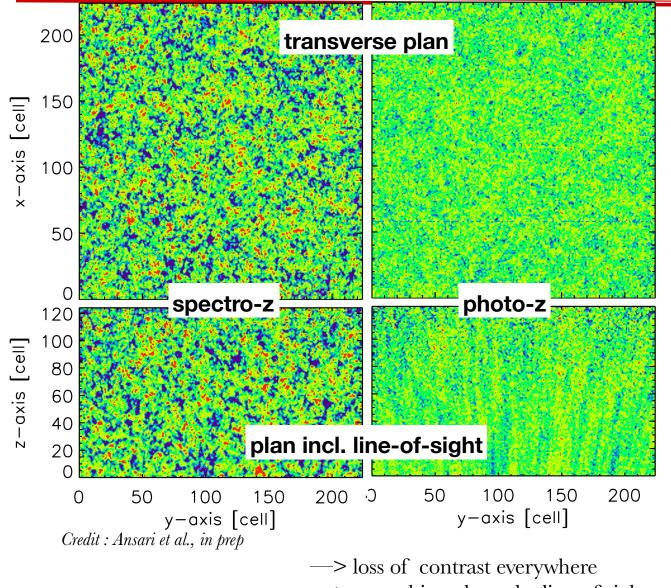




- LSST is an US project that will federate a community of ~ 900 scientists over the world
- Chile and France-IN2P3 (with in kind contributions to the camera
 - + computing) are LSST members.
 - In Europe, growing with UK, Germany, Czechy, Hungary...
 - + also Brazil, Australia, India, China
- -An internal consortium (DESC) is in place since 2012 to tackle the DE energy problem (dark energy science collaboration)
- -The data processing and computing is a major issue:
- -5 million images, a stream of 10 million of transients by night
- -37 billion of objects (20 billion of galaxies and 17 billion of stars), 15 TB of data by day.. 15 PB of data at the end.

Need large computing ressources and data access !!

LSS with photometric surveys (see DES as precursor)



not straightforward ...

But photometric surveys can have a much higher galaxy density

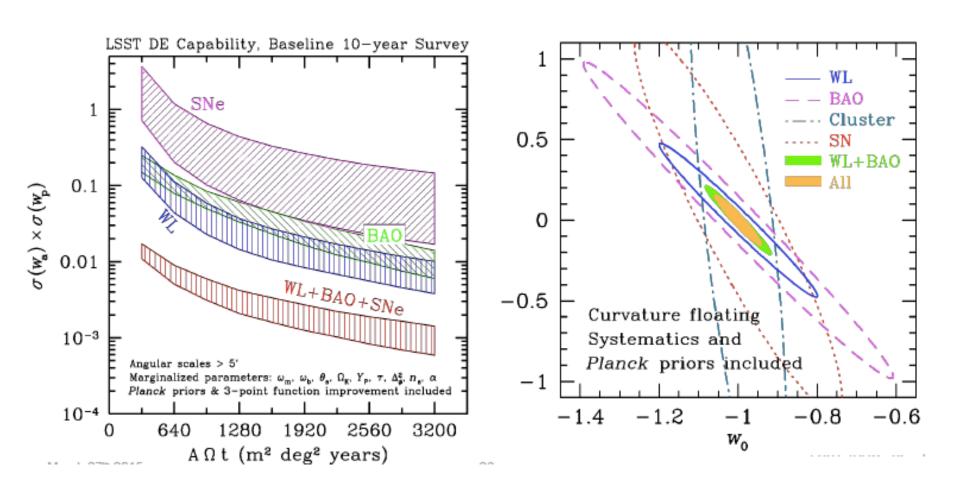
—> statistics save photo-z surveys

LSST 10y should have 30-40 gal /arc-min²

—> smoothing along the line-of-sight

Combining probes for dark energy





EUCLID and **LSST** ..complementarity



Main probes: WL & Galaxy clustering

Visible+ IR, spectro + photo

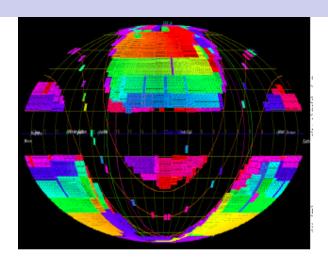
Space telescope / 1.2 m mirror

Launch : 2022

Mission length: 6 years

Survey Area: 15 000 sq deg (.36 sky)

2 billions of galaxies for cosmology! 50 millions of galaxies in spectroscopy 30 PB of data at the end.





Main probes: WL, SN, BAO (photo),

Visible, multi filters, photo

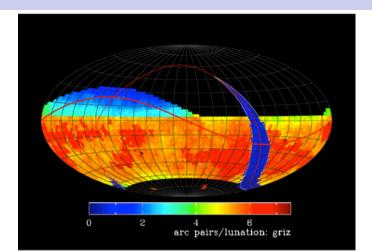
Ground Telescope / 6.5 m effective mirror

1st light: 2022

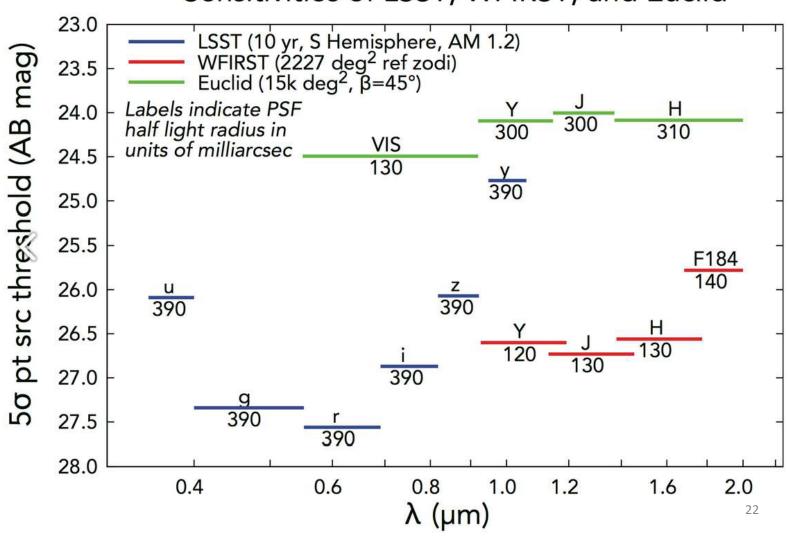
Observation length: 10 years

Survey Area : 20 000 sq dg (.48 sky)

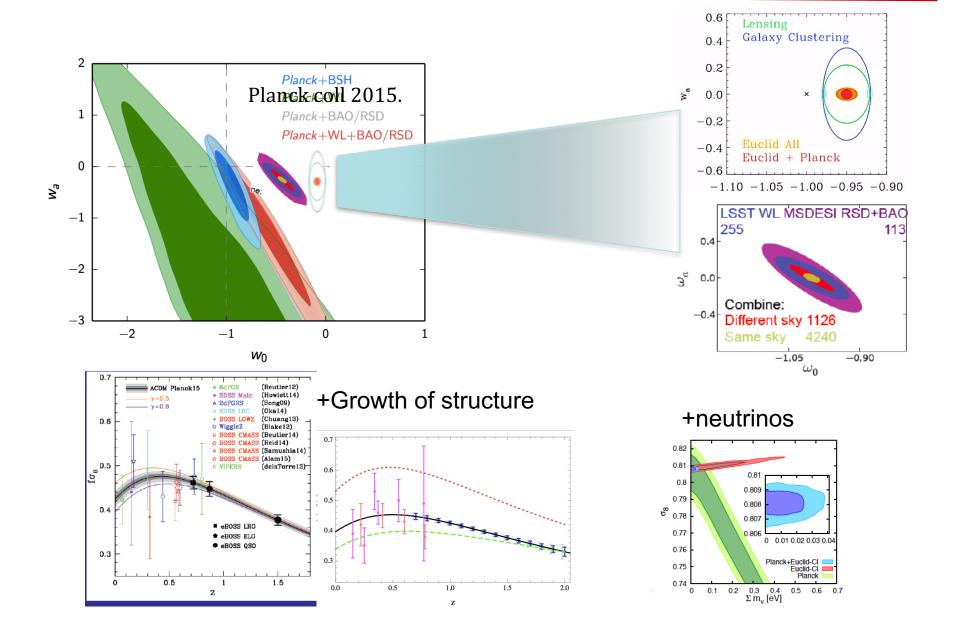
4 billions of galaxies for cosmology 10 millions of SNs, >100 000 well measured 15 TB of data by day. 400 PB all, 15 PB of final data at the end.



Sensitivities of LSST, WFIRST, and Euclid



Ultimately...need to combine all probes....



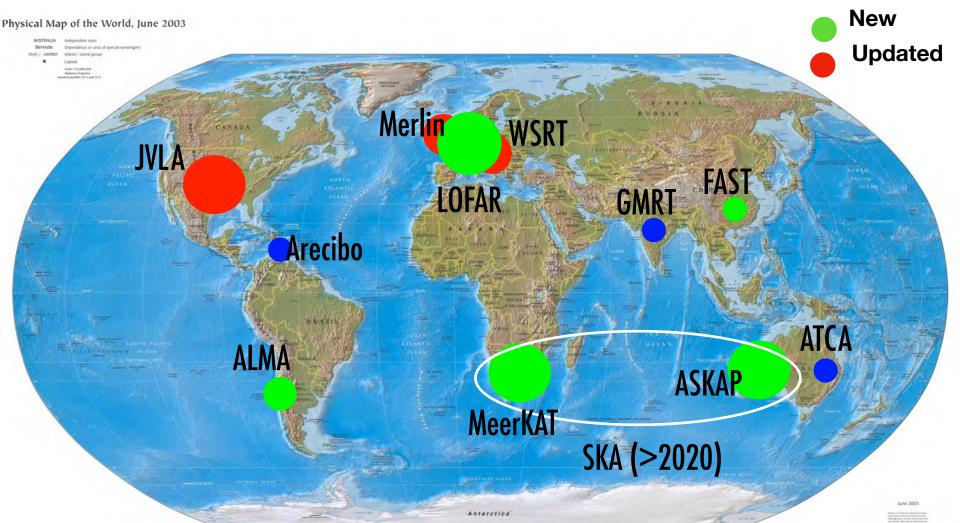
SKA

A large radio telescope for transformational science

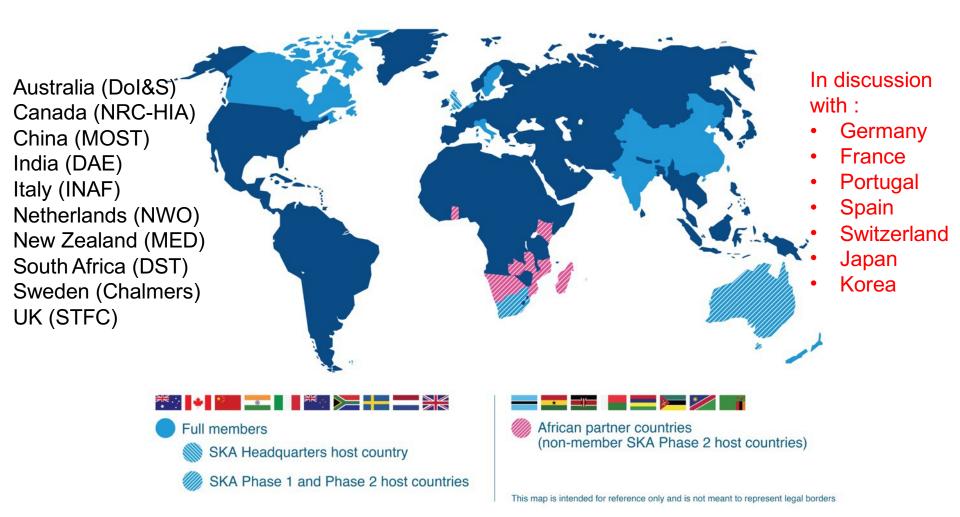
- an interferometer at frequencies from 70 MHz to 10 GHz with two or more detector technologies
- fast survey speed: field of view ~100s of sq. deg (70 to 400 MHz), >30 sq. deg (.4 to 2 GHz) and ~1 sq. deg. (2 to 10 GHz)
- connected to fast signal transport network and high performance computing system
- Can do cosmology (BAO, RSD, ISW) using HI intensity mapping, surveys HI,
 Continuum radio
- Can also be a gravitational wave detector using Pulsars

New golden age for (ground-based) radioastronomy

- Sensitive instruments x 20
- Speed x 1000
- Almost continuous coverage (in lon, lat, frequency, fields)



SKA Organisation: 10 countries, more to join



Before SKA: 2 precusors

ASKAP : Australia large FOV ->survey 0.7-1.8 GHz (HI à z=1) 30deg²

resolution 30" - 36 parabola -> **SKA 1-low**

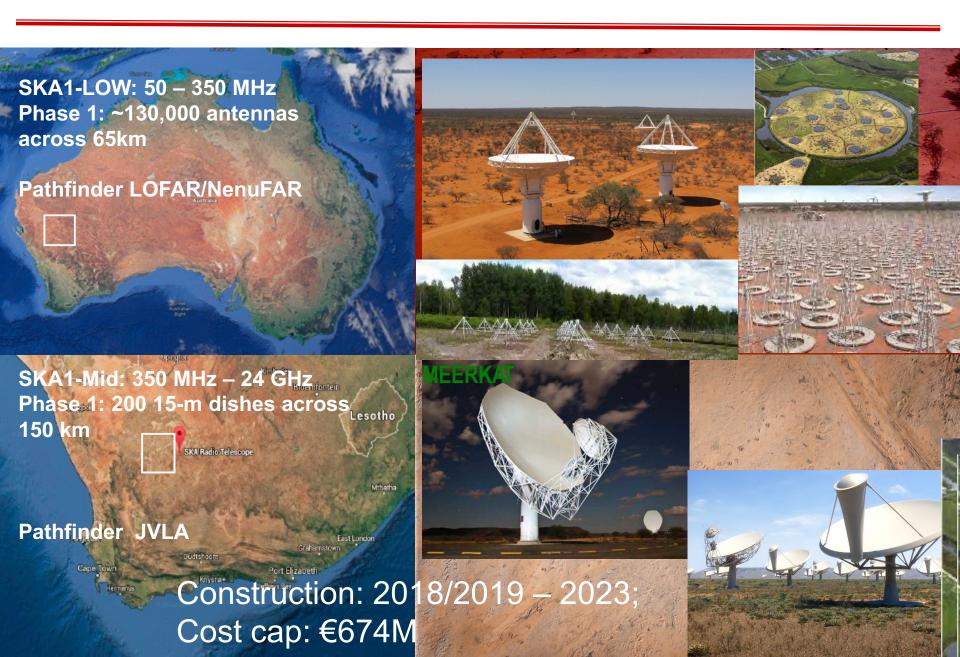
MEERKAT: South africa small FOV-> deep 0.5-10 GHz 1 deg²

resolution: 6-80" - 64 antennas deployed in March -> SKA 1- mid

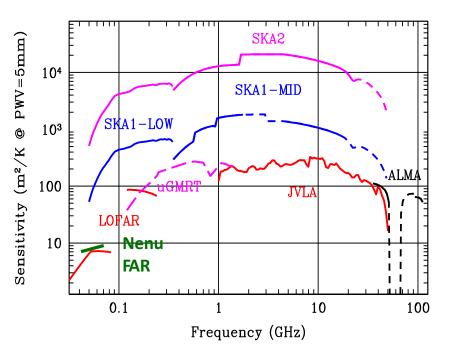


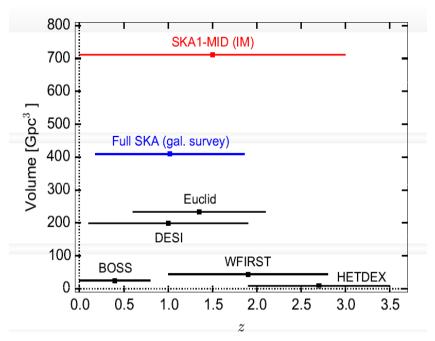


SKA: Telescopes in AUS & RSA



SKA Performance Update

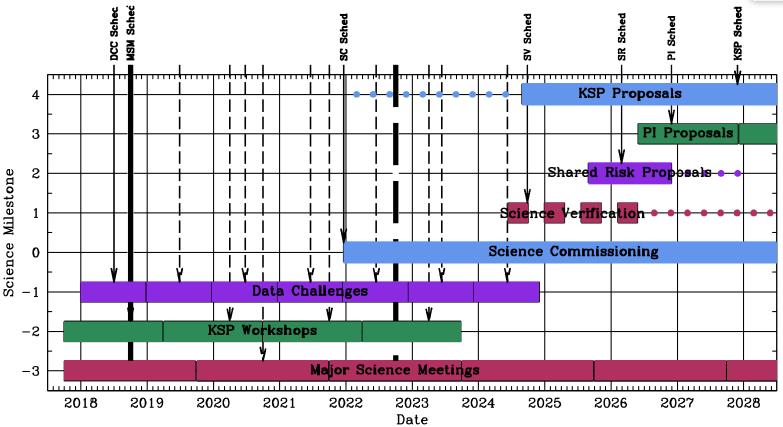




- Improved performance predictions now available at all frequencies
- Opportunity for seamless interface of SKA to ALMA capabilities

SKA1 Science Milestones





- Overview of preparatory and scientific observing activities
- KSP Preparatory Activities
 - Pilot surveys in Shared-risk and PI Proposal Cycles
 - Commissioning data to facilitate survey and pipeline design

SKA- Key Science Drivers: The history of the Universe

Testing General Relativity
(Strong Regime, Gravitational Waves)

Cosmic Dawn
(First Stars and Galaxies)

Cradle of Life
(Planets, Molecules, SETI)

Galaxy Evolution
(Normal Galaxies z~2-3)

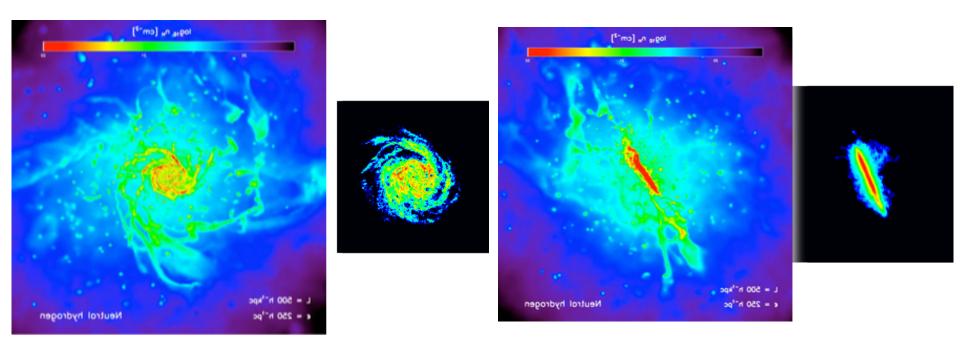
Cosmic Magnetism (Origin, Evolution)

Cosmology (Dark Energy, Large Scale Structure)

Exploration of the Unknown

Extremely broad range of science!

Galaxy HI Evolution: out to $z \sim 1$ with SKA1 and $z \sim 5$ with SKA2



(Simulations: Schaye et al. 2010, Images: Oosterloo 2014)

- Understanding galaxy assembly and the baryon cycle
 - Determine the impact of galaxy environments
 - Probe gas inflow and removal, diffuse gas N_{HI} < 10^{17} cm⁻²
 - Measure angular momentum build-up

Probing Dark Energy with the SKA

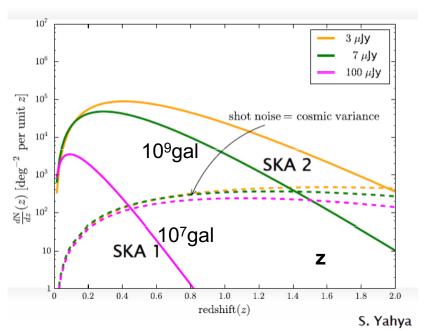
- Standard ruler based on baryonic oscillations (wriggles)
- Need to reach z ~>1
 - Current limit z = 0.2 so > x25 in sensitivity
- Optimum strategy is the survey the largest area
 - Minimise cosmic variance
- Specs call for 0.1 to 25GHz => driven by the antenna technology
- Large FoV makes this practical
- HI selection ⇒ strong bias to late type galaxies
- SKA FoV=1sq deg in 1 year
 - 10⁹ galaxies, 0 < z < 1.5 Δω = 0.01



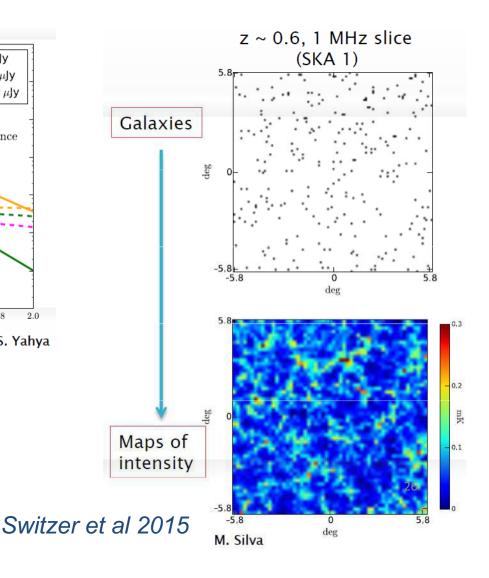
Or 1/10 area SKA phase I with FoV=100sq deg



Galaxy Survey HI vs intensity mapping



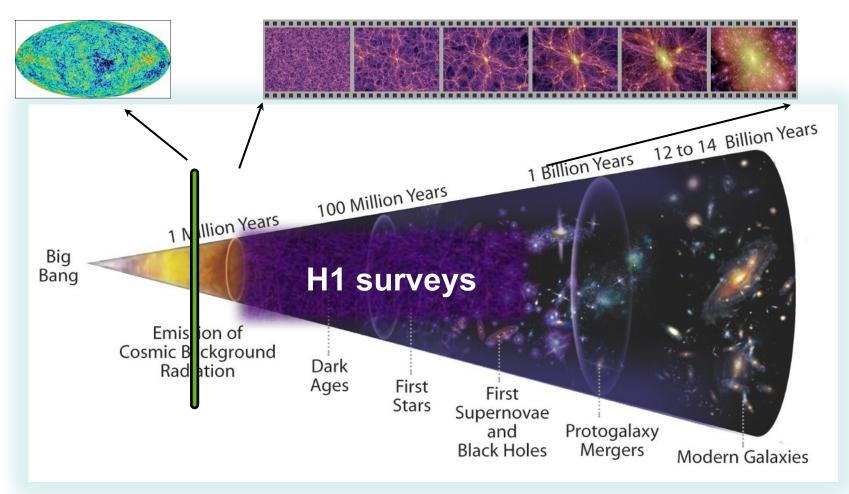
HI intensity mapping: 1000 x expected signal Less freedom in spectra



HI surveys of the EoR, Cosmic-Dawn & Dark Ages

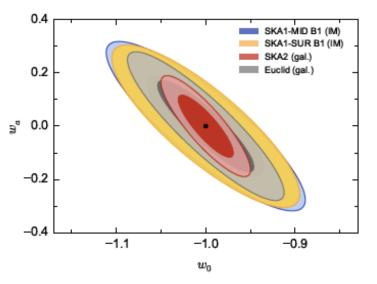
CMB displays a single moment of the Universe. Its initial conditions at ~400,000 yrs

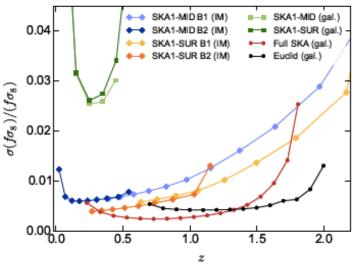
HI emission from the Dark Ages, Cosmic Dawn & EoR traces an evolving "movie" of baryonic and DM structure formation at t_{univ}<10⁹ years.



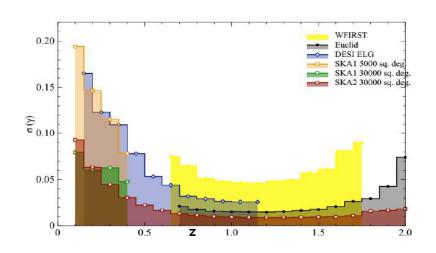
Cosmology with SKA: Baryon Acoustic Oscillations and RSD

Santos 2015



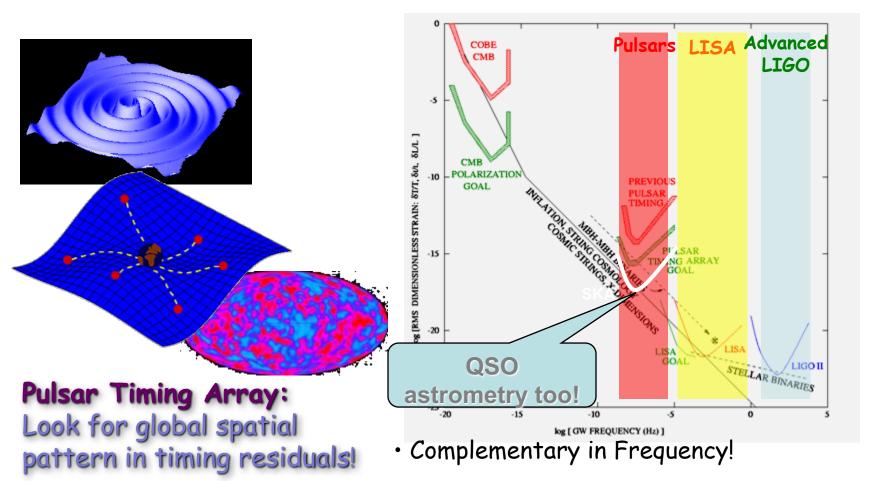


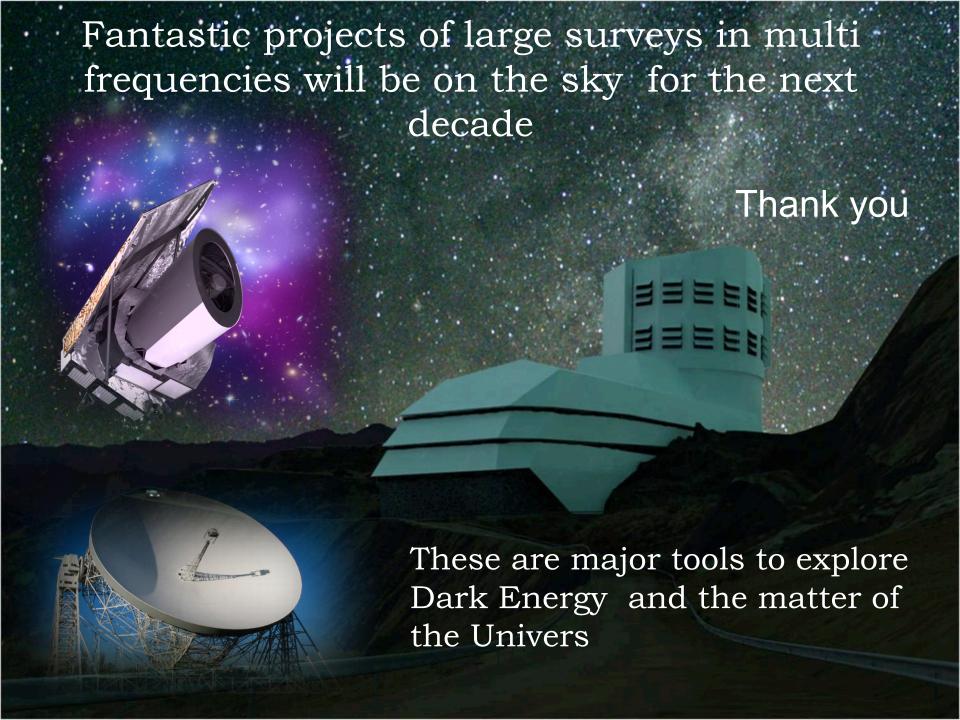
- Constraining Dark Energy models with redshift-resolved BAO measurements
- Discrete detection is complementary with SKA1, cutting edge with SKA2
- Intensity mapping is higher risk but worldclass, even with SKA1



Pulsars as Gravitational Wave Detectors

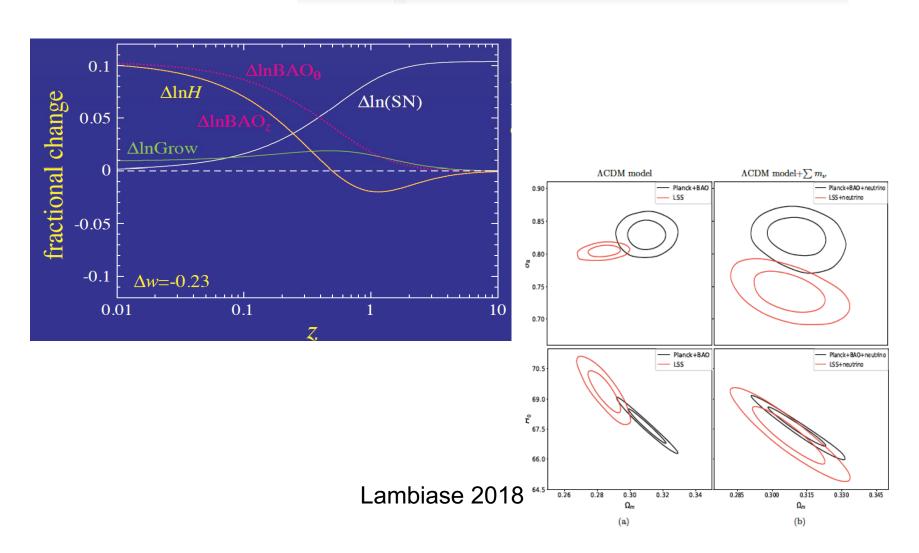
Millisecond pulsars act as arms of huge detector:



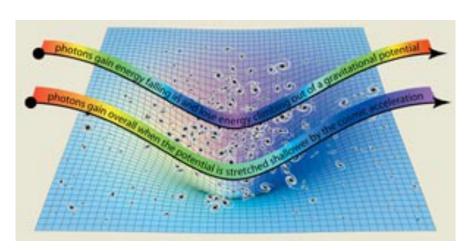


H₀. Real tension between LSS and SN?

$$H^{2}(z) = \frac{8\pi G}{3} \left[\rho_{M} (1+z)^{3} + \rho_{R} (1+z)^{4} + \rho_{DE}(z) \right] - \kappa (1+z)^{2}$$

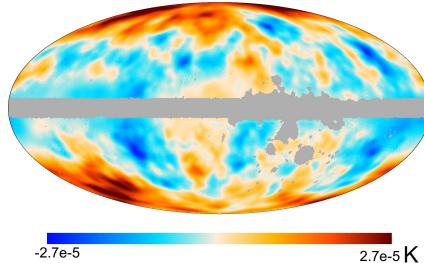


Very powerful: Cross-correlations of tracers



CMB photons traveling through a decaying potential well, such as an overdense region in the Λ CDM universe, will gain energy

- —> LSS causes secondary anisotropies in the CMB, can be measured from the correlation between galaxy overdensities and CMB T fluctuations,
- —> direct evidence for the existence of dark energy which stretches LSS



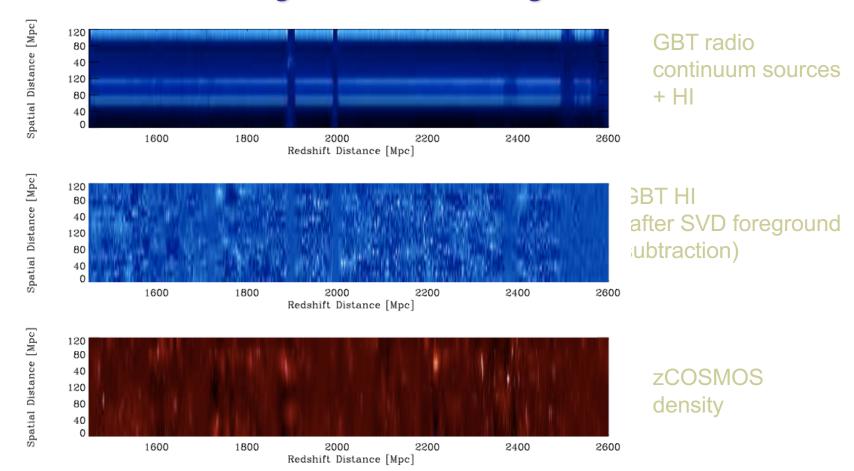
Map of the recovered Integrated Sachs-Wolf effect anisotropie from the combination of Planck SEVEM CMB map with radiosources + galaxy surveys + Planck lensing

 \longrightarrow detection at 4σ level

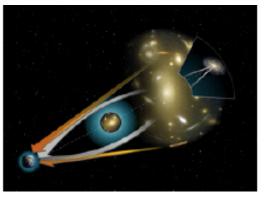
Credit: Planck 2015 XXI. The integrated Sachs-Wolfe effect

HI auto-correlation at z=0.8

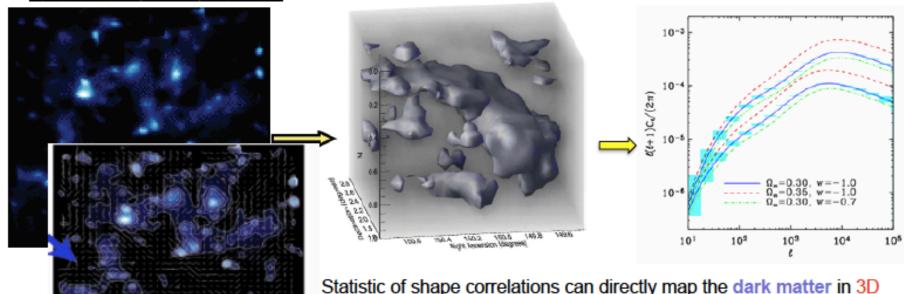
Auto- & Cross-correlating GBT HI & zCOSMOS galaxies at z ~ 0.5-1.1



Dark matter and Lensing tomography (LSST, EUClid, Wfirst)



Density fluctuations in the universe affect the propagation of light rays, leading to correlations in the shapes of neighboring galaxies.

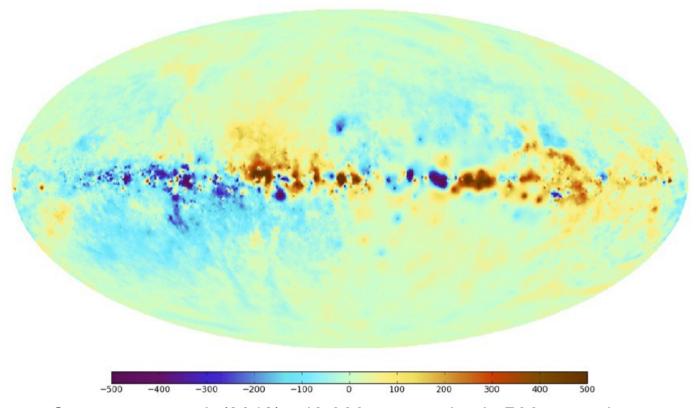


Weak lensing is sensitive to

-The expansion of Universe with z - H(z)
- The grow of structure with z - G(z)

The way these structure grow with cosmic time depend of dark energy. This is a powerful observable to constrain DE, modified gravity...

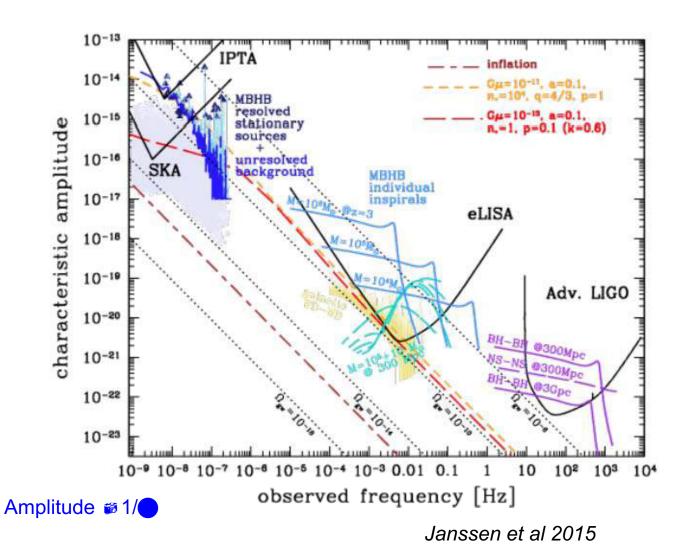
Headline Magnetism Science



Oppermann et al. (2012) ~40,000 extra-galactic RMs over 4π sr

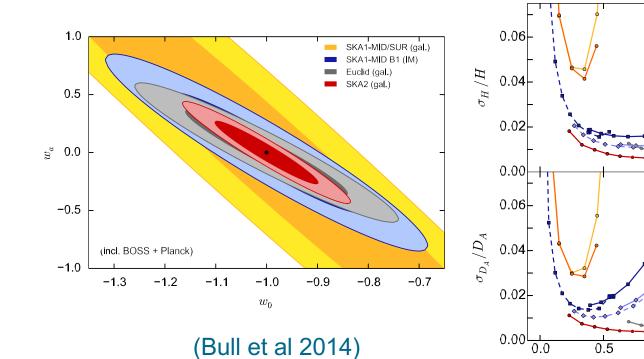
• 3D magnetic tomography of the Galaxy and distant universe; from current 1 RM deg⁻², SKA1: 300 deg⁻² to SKA2: 5000 deg⁻²

Detection of gravitational waves



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Cosmology with SKA: Baryon Acoustic Oscillations



SKA1-SUR (gal.)

SKA1-MID (gal.)

SKA2 (gal.)

Euclid (gal.)

◆ SKA1-SUR B1 (IM)

♦-♦ SKA1-SUR B2 (IM)

SKA1-MID B1 (IM)

SKA1-MID B2 (IM)

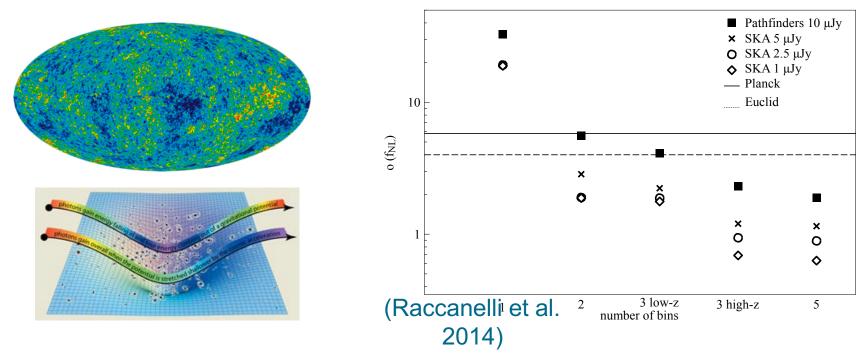
1.5

z

2.0

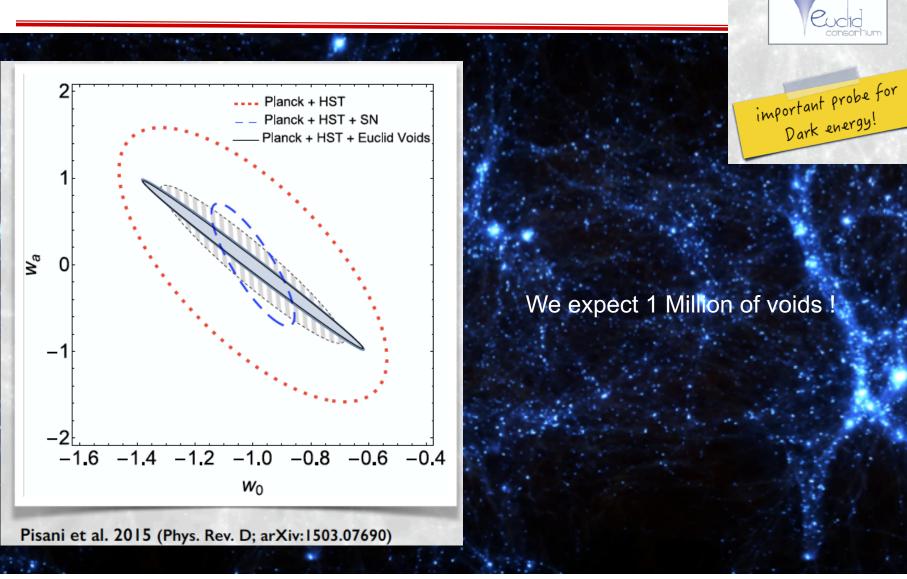
2.5

Cosmology with SKA: Integrated Sachs-Wolfe effect



- Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect: correlation of foreground source populations with CMB structures
 - Uniquely probing the largest scales

Cosmology with voids in Euclid



Dark energy!