Cosmology with supernovae

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2011 Nobel prize

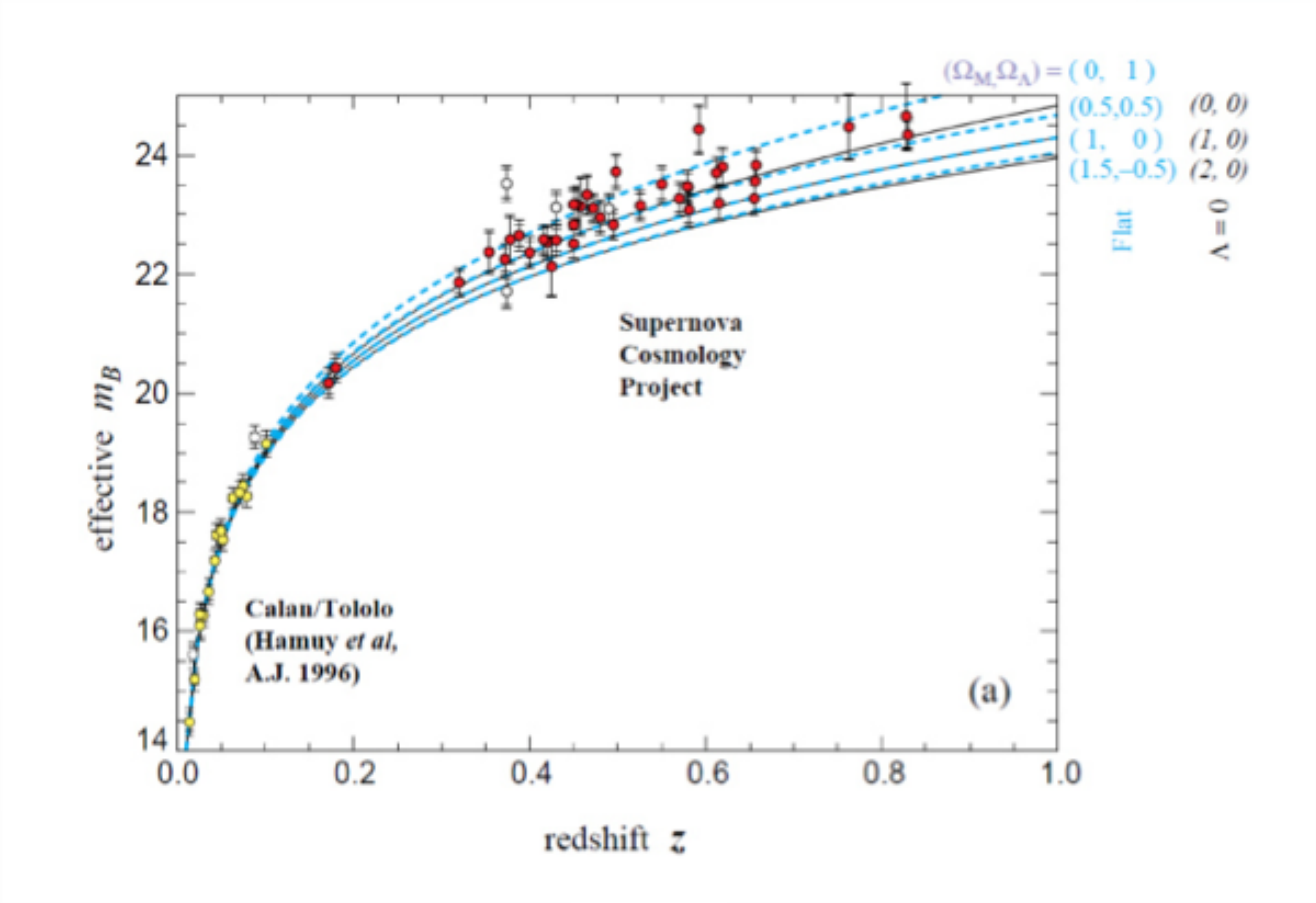
2011 Nobel Prize in Physics

Awarded to
Saul Permutter
Brian Schmidt
Adam Riess

"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae".

As described by the Chem 187S class of 2011/2012

2011 Nobel prize



This lecture : some elements to do cosmology with supernovae

- Basics on supernovae observation
- Basics on supernovae phenomenology
- Type Ia supernovae
- Measuring distances and constraints on cosmology
- State of the art
- Improving with LSST and Euclid new telescope

Cosmology with SuperNovae

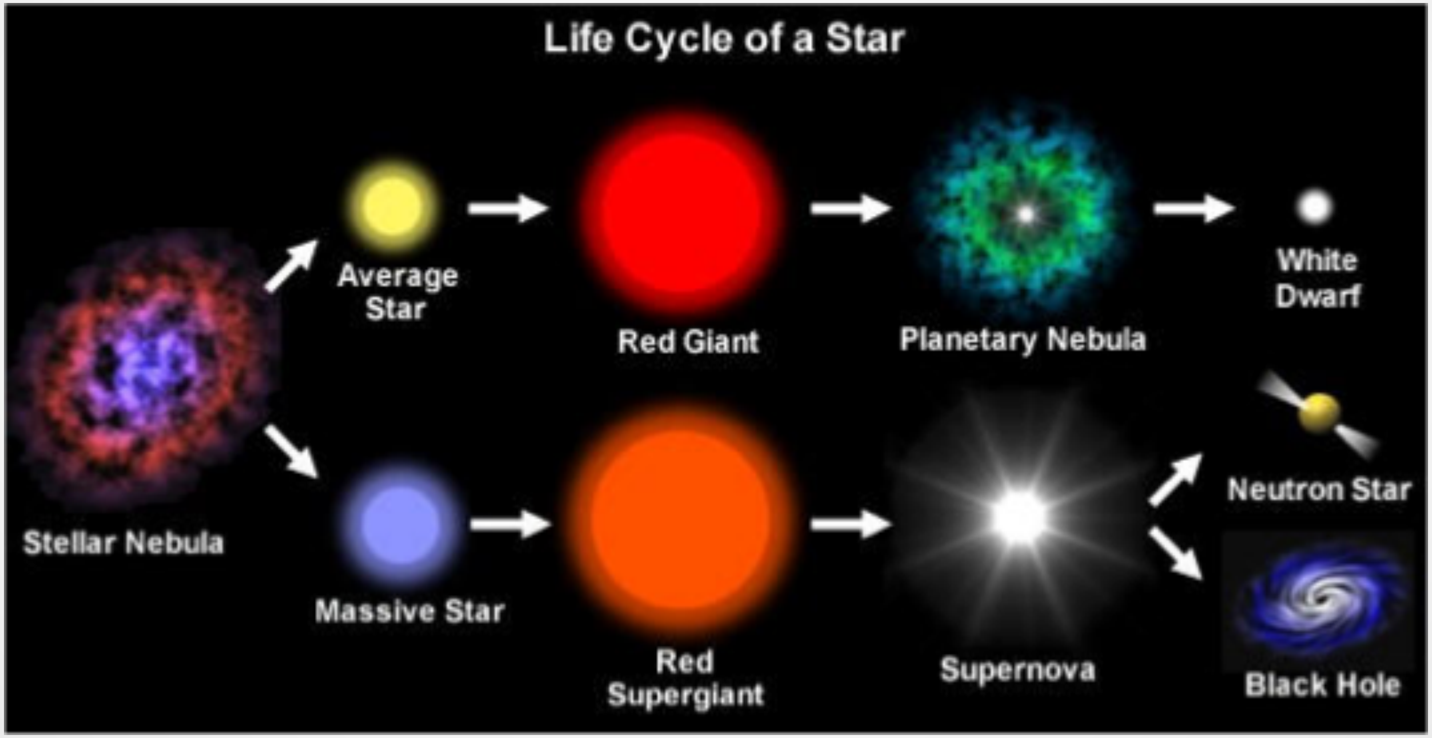
- Basics on supernova phenomenology
  - Observation
  - Supernova physics
  - Supernova diversity

Diversity of supernova observation

- Observation of supernova explosion:
  - Observation with photometry time series
  - Observation with spectroscopy
  - Observation of light echo
  - Observation of supernova remnant

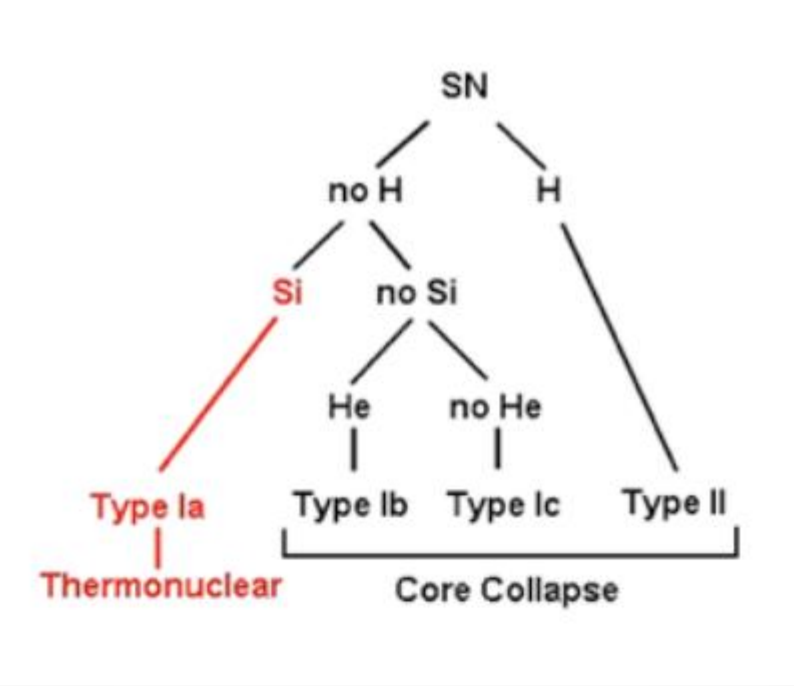
Supernova physics

- Life cycle of a star



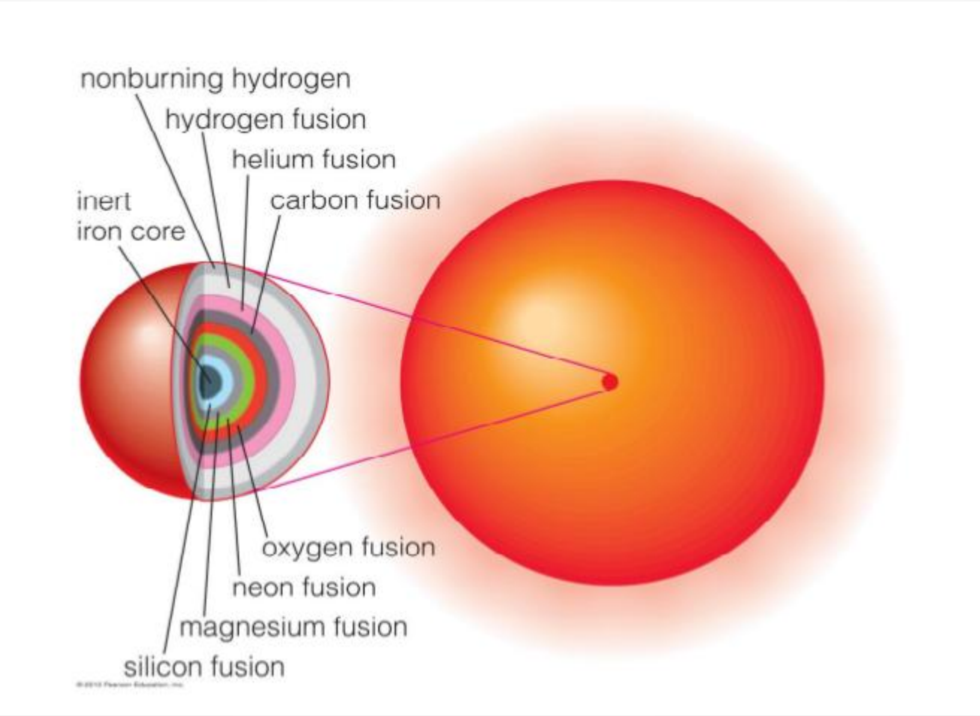
Diversity of supernova type

- Supernovae are classified from their spectroscopic observation



Supernova physics

- Explosion of massif stars
  - During it‘s life, a massive star produces heavy elements, up to iron, in an effort to produce energy to stave off the effect of gravity.



Supernova physics

- Explosion of massif stars
  - The mass of Fe in the core is now about 1.2 – 1.4M , and it must still support the weight of the rest of the star. The pressure is huge, so the atoms are degenerate: the core is, in effect, a white dwarf, embedded in the still-sputtering remnants of the star. Si in the surrounding layer continues to burn, showering Fe nuclei onto the core.
  - Once the core reaches 1.4M , degeneracy pressure can no longer support itself against gravity: the Chandrasekhar limit
  - Collapse start !

Supernova physics

- Explosion of massif stars
  - During collapse, high energetic and dense gamma rays break the iron nuclei through photodisintegration :

$$^{56}\mathrm{Fe} + \gamma \rightarrow 13\,^{4}\mathrm{He} + 4n$$
$$^{4}\mathrm{He} + \gamma \rightarrow 2\,^{1}\mathrm{H} + 2n$$

  - At dense core of neutron and proton is then created.
    -

Supernova physics

- Explosion of massif stars

  – At such density, neutron cannot decay freely, rather electron are captures by proton and when the whole core has been converted to neutron, squeezed tightly together to produce a neutron stars, where the strong nuclear force is opposed to gravity to produce a stable system.

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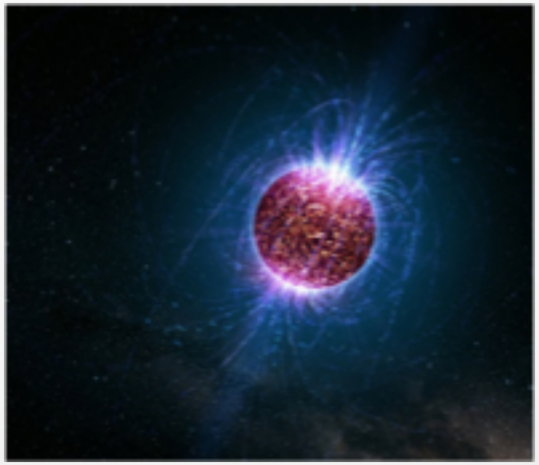
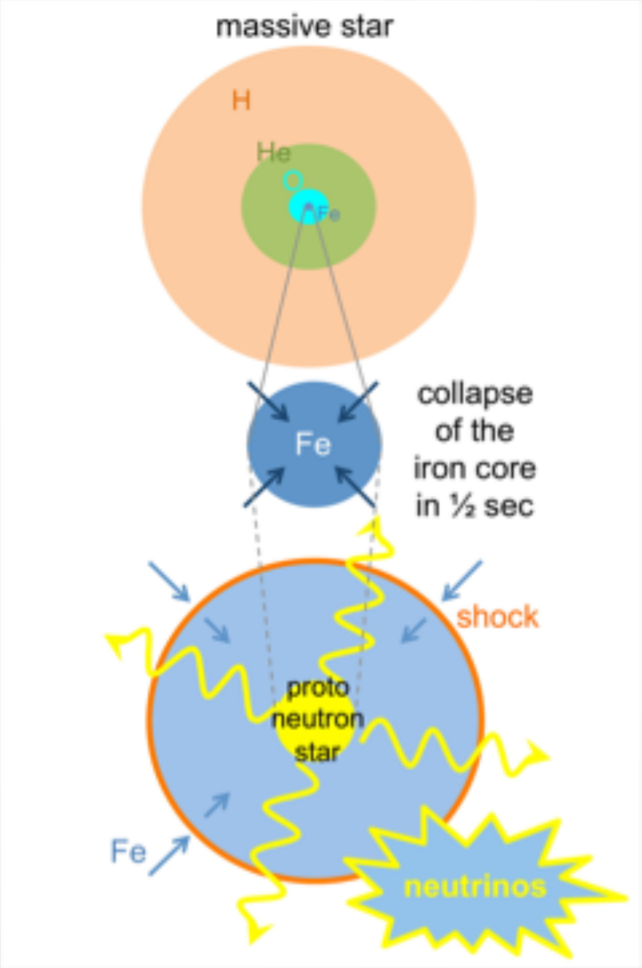


Supernova physics

- Explosion of massif stars

The core of the star bouce and shocks
With colliding envelop produce the ejection
of the envelop.

The majority of energy escape with
Neutrinos and we see about 1% which is
emitted with electromagnetic radiation



Supernova physics

- Explosion of star with a companion : Type Ia supernova

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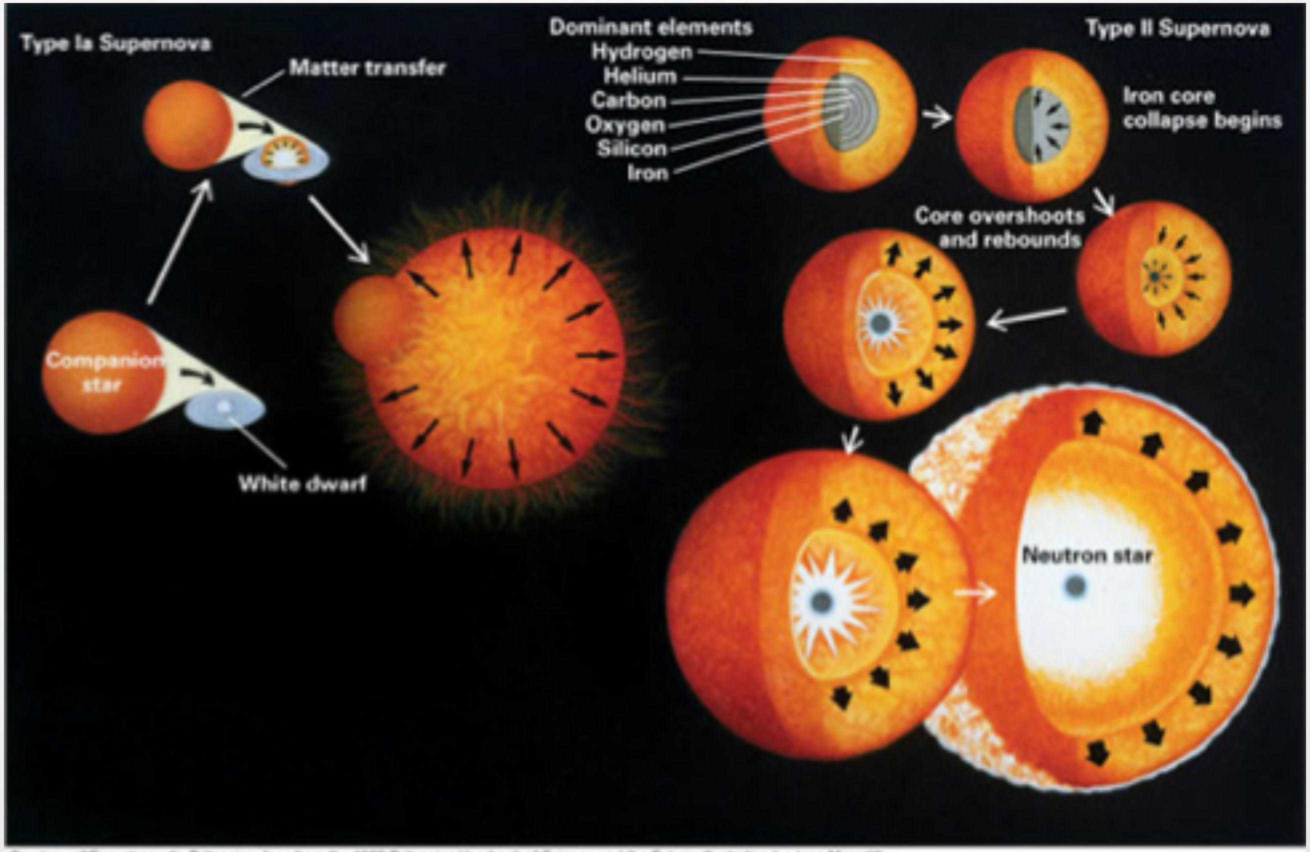

Courtesy of Encyclopaedia Britannica, Inc.; from the 1989 Britannica Yearbook of Science and the Future; illustration by Jane Meredith

Type Ia Supernova

- Explosion of star with a companion : Type Ia supernova
  - In a binary system, the white dwarf accrete the mass from its companion up to the Chandrasekhar mass
  - When the Chandrasekhar mass threshold is passed the system collapsed and produced a thermonuclear reaction with burn out all the star constituants
-

Type Ia Supernova

- Explosion of star with a companion : Type Ia supernova
  - The threshold for the explosion is fixed and all the system participate to the explosion, therefore the light emitted do not vary much between two type IA supernovae.
  - The consequence of this property is that Type Ia are close to be perfect standard candle
  - Modelisation of the explosion is a very complicated calculation

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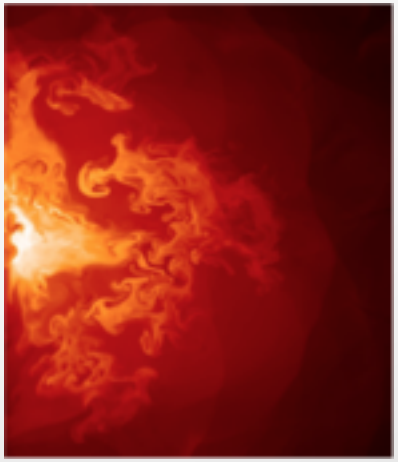

Type Ia Supernova

- Type Ia supernova :
- A closer look
  - In 2011 ,
  - a very nearby Type Ia
  - was observed:
  - SN 2011fe :
  -

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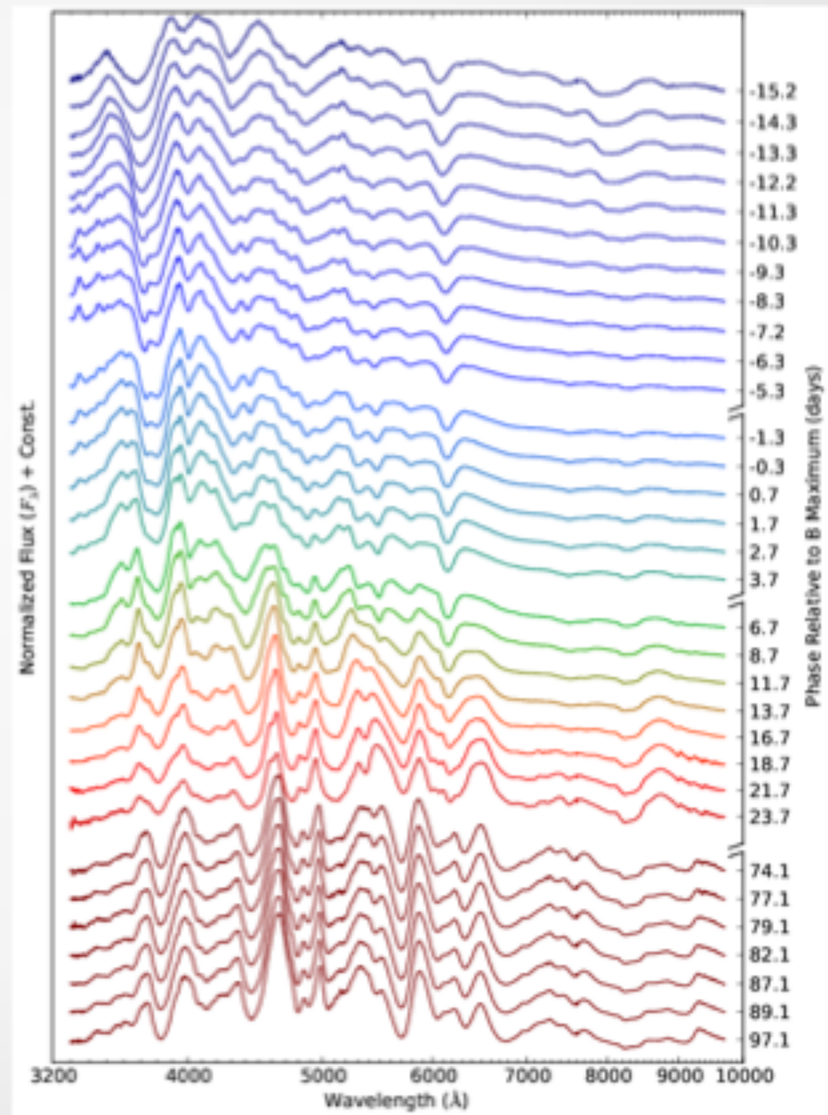

Type Ia Supernova

- Type Ia supernova :
- A closer look
  - In 2011 ,
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  -

A spectrophotometric
Time serie has been
reported
by the Sn Factory
Collaboration

Type Ia Supernova

- Type Ia supernova : Standardisable candles
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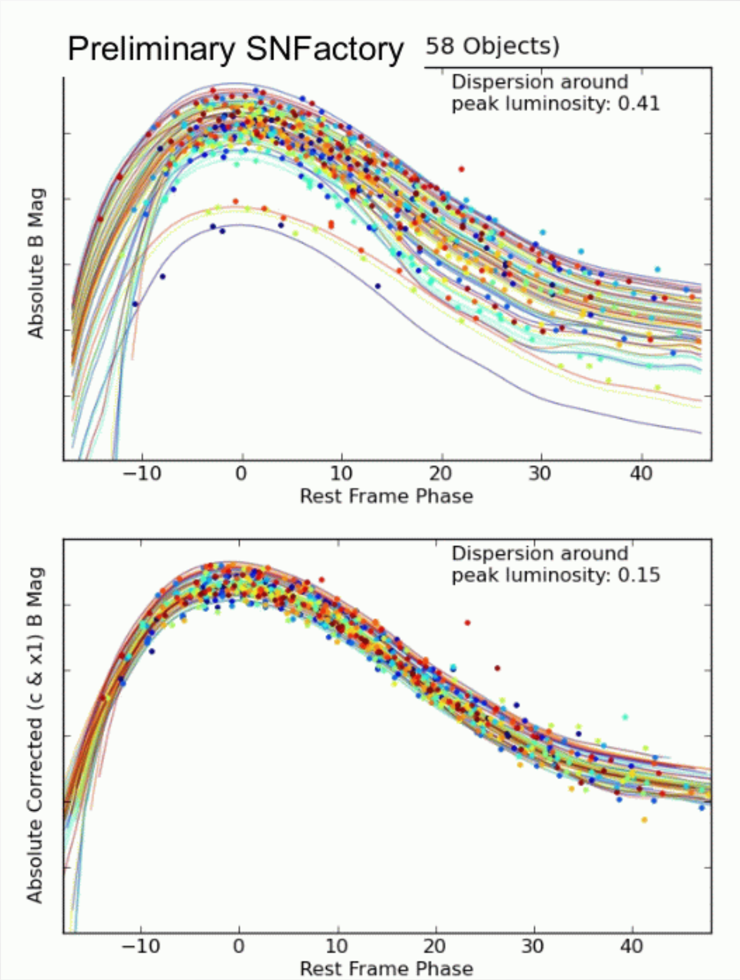
Type Ia supernovae are very good
- standard candle

Dispersion = 0.4

Standardisation = reduction of the dispersion

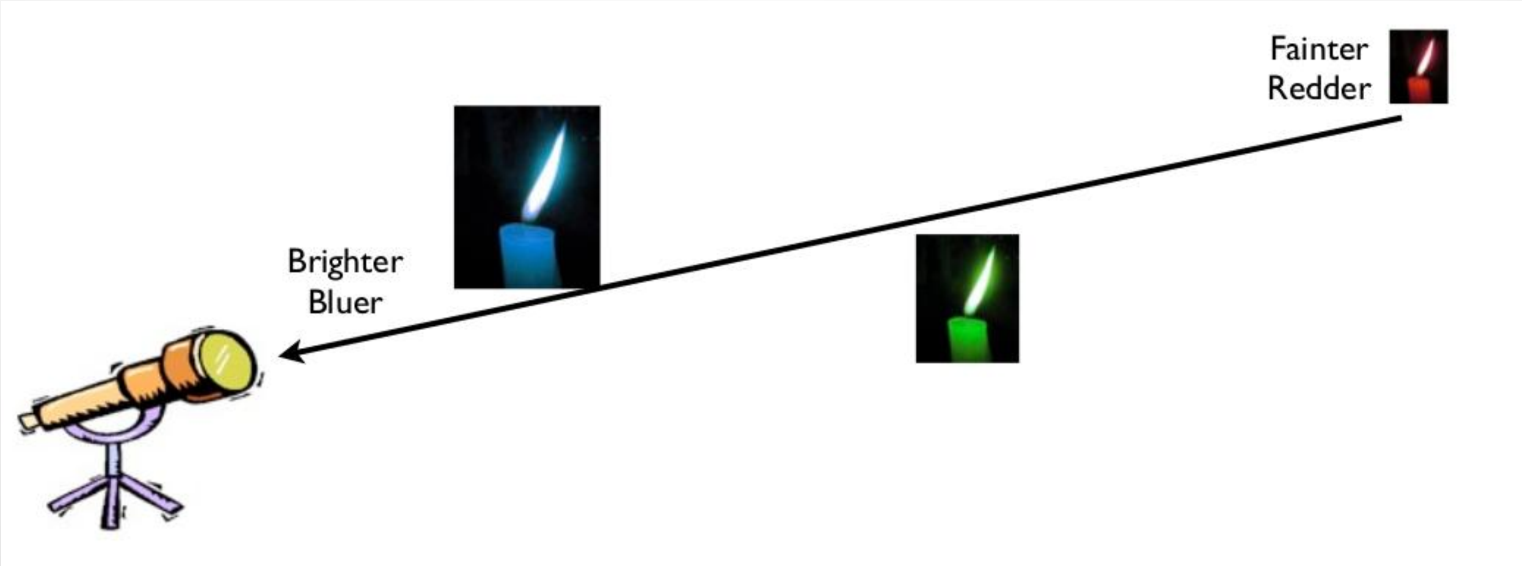
Strech + color = empirical parameters

Dispersion = 0.15



Type Ia supernovae

- Distance measurement with type IA
  - If type Ia SN is a standard candle, we can use it to measure (luminosity) distance !



supernovae

- Distance measurement with type IA
  - If type Ia SN is a standard candle of luminosity L, we have a relation between the flux and the Liminosity distance :

$$F = \frac{L}{4\pi D_L^2}$$

  - From the realtion between apparant magnitude and absolute magnitude :

$$M = m - 5(\log_{10} D_L - 1)$$

  - We define the distance modulus

$$\mu = m - M$$

SNIa as a cosmological probe

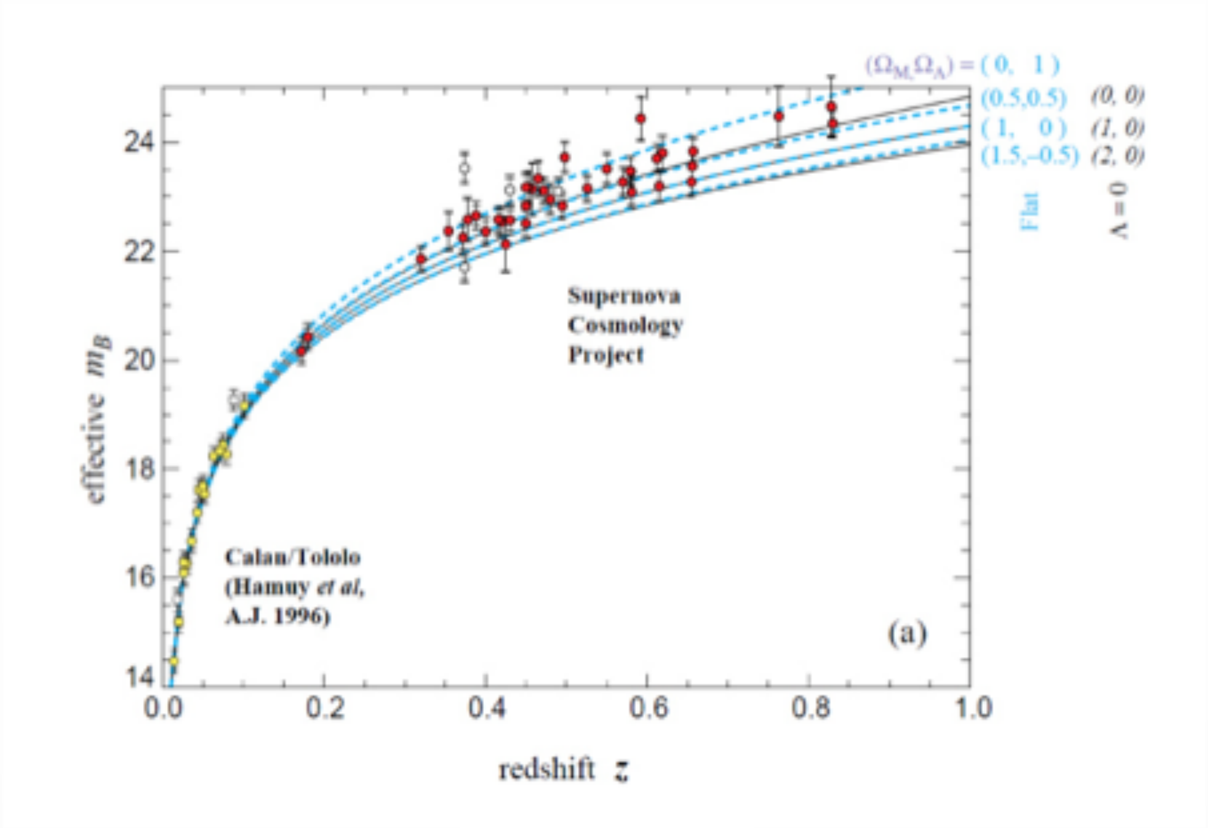
A standard candle can probe the expansion history of the universe via the luminosity distance :

$$d_L(z) = (1+z)\frac{c}{H_0}\int dz\left(\Omega_m(1+z)^3 + \Omega_x(1+z)^{3(1+w)}\right)^{-1/2}$$

It is a pure geometrical measurement, very complementary to galaxy structure probes

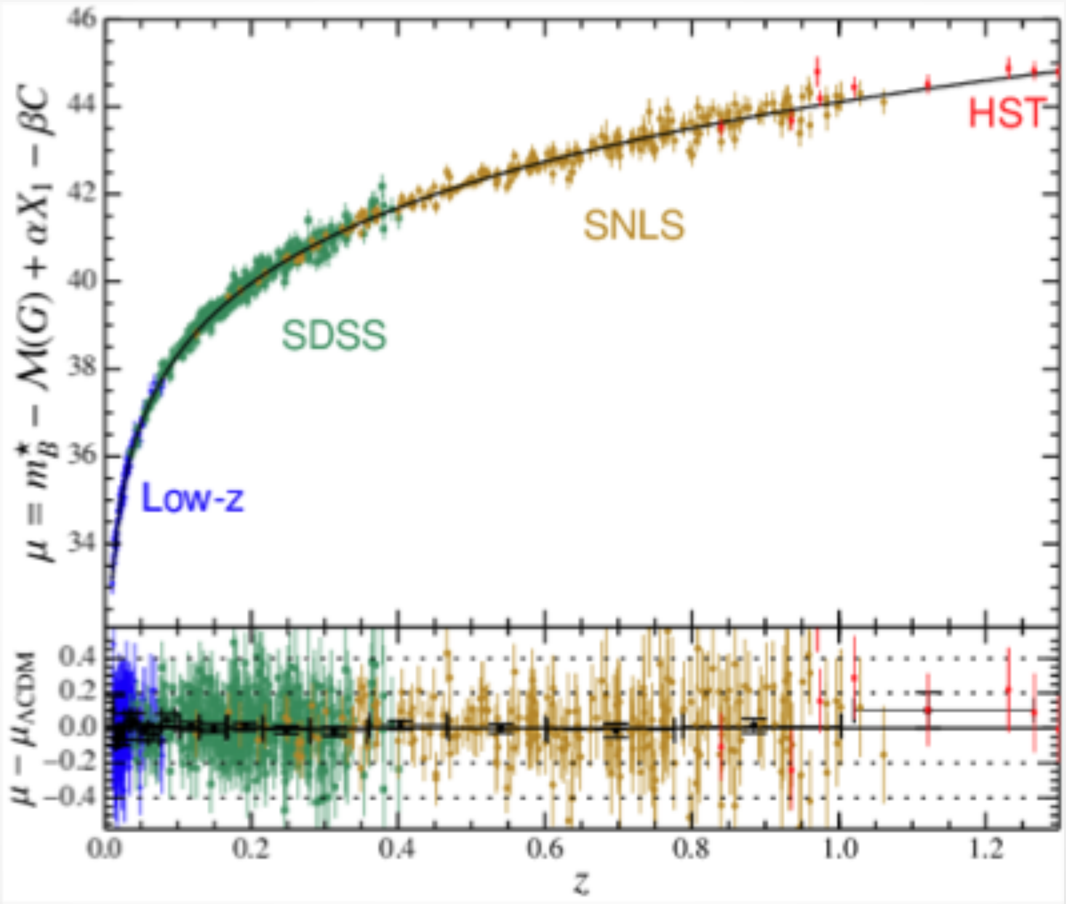
SNIa as a cosmological probe

- Hubble diagram (1998)



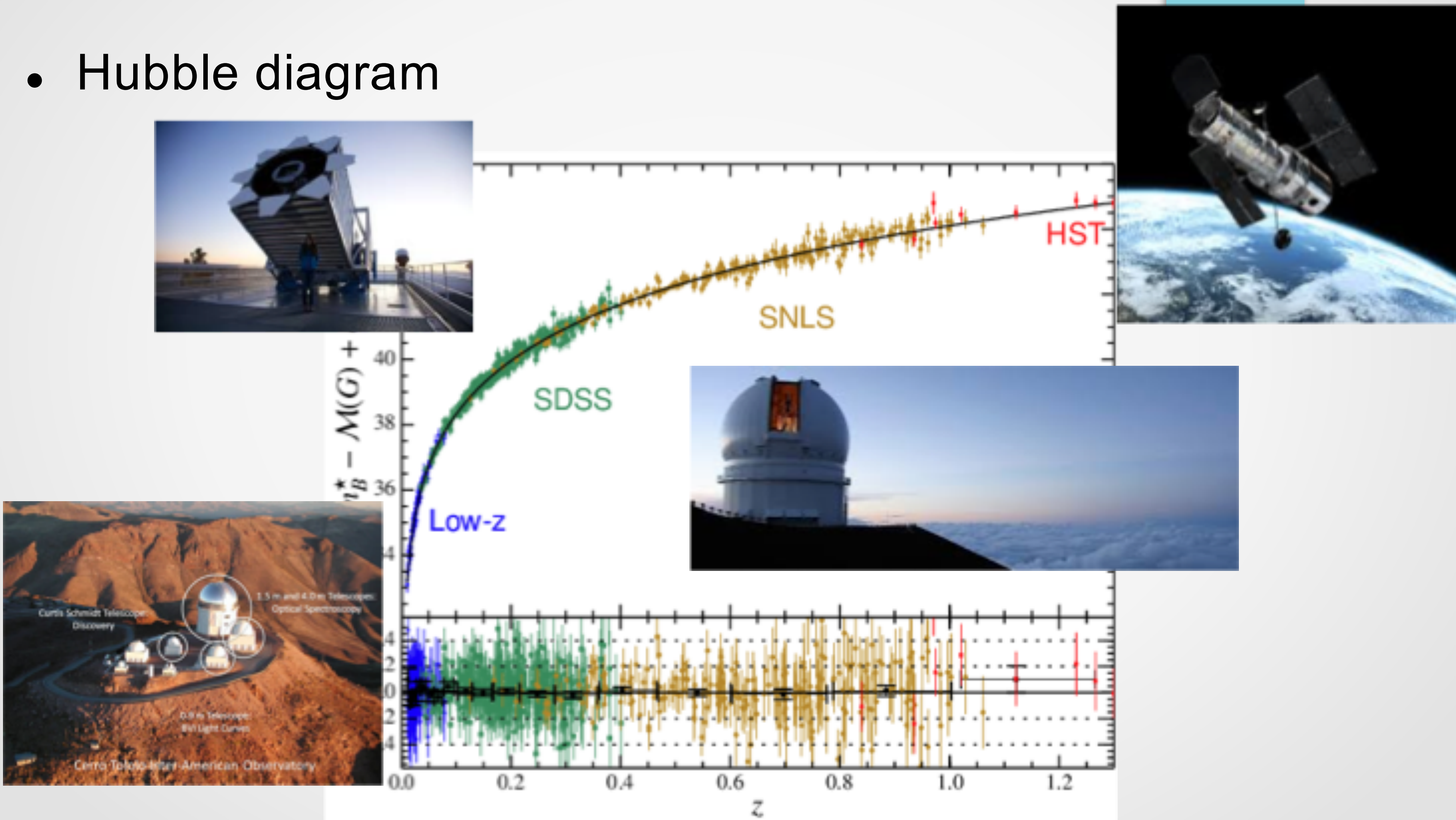
SNIa as a cosmological probe

- Hubble diagram (best current constraints)



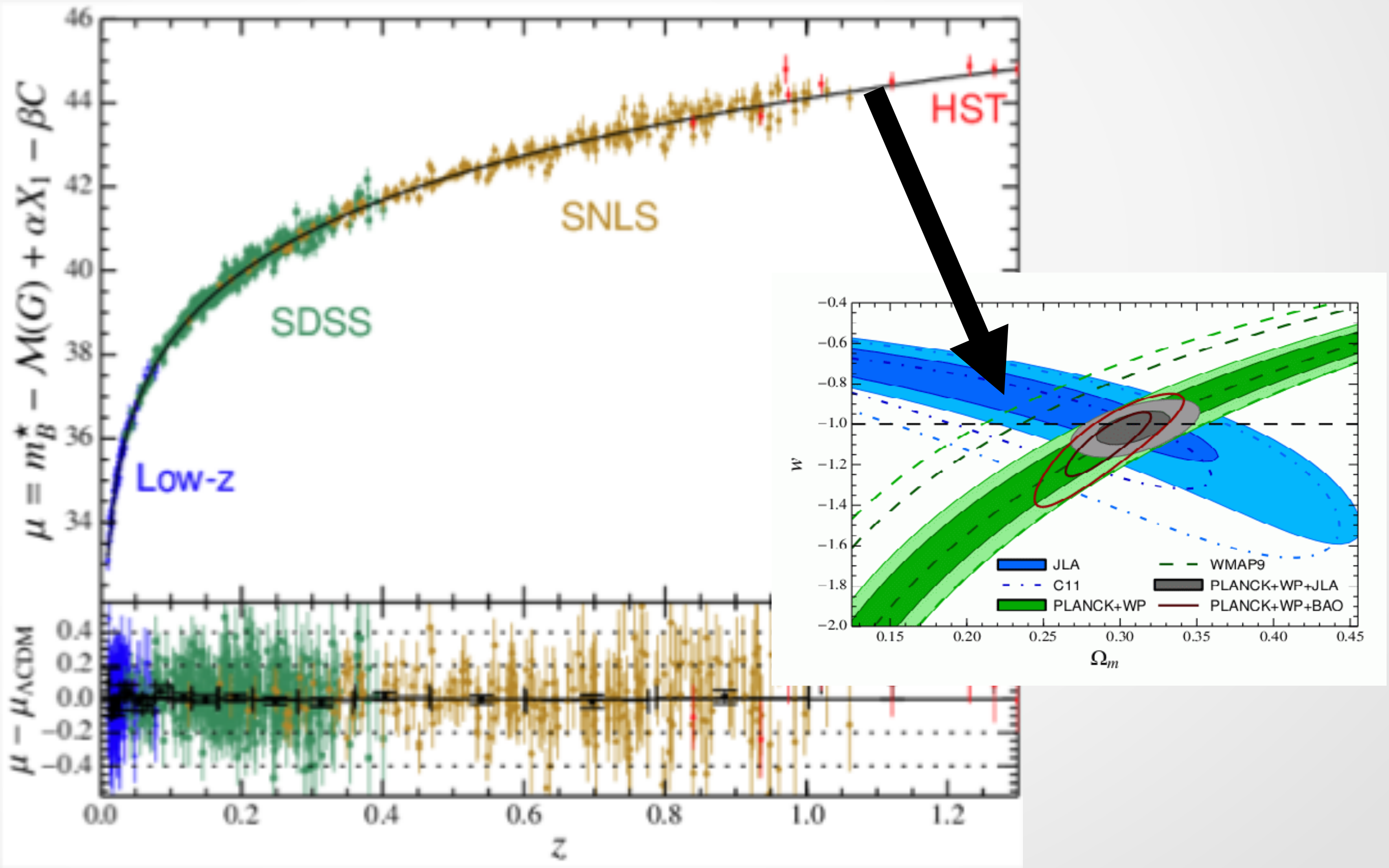
SNe as a cosmological probe

- Hubble diagram



SNIa as a cosmological probe

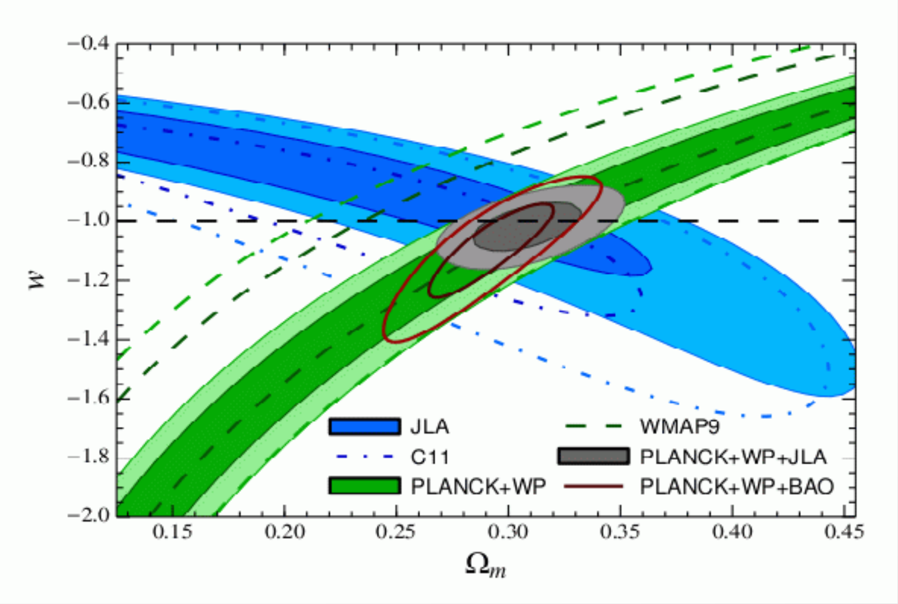
- JLA Hubble diagram



SNIa as a cosmological probe

- Precision on cosmological parameters
  - Statistic and systematics are of same amplitude !

Uncertainty sources	$\sigma_x(\Omega_m)$	% of $\sigma^2(\Omega_m)$
Calibration	0.0203	36.7
Milky Way extinction	0.0072	4.6
Light-curve model	0.0069	4.3
Bias corrections	0.0040	1.4
Host relation[a]	0.0038	1.3
Contamination	0.0008	0.1
Peculiar velocity	0.0007	0.0
Stat	0.0241	51.6

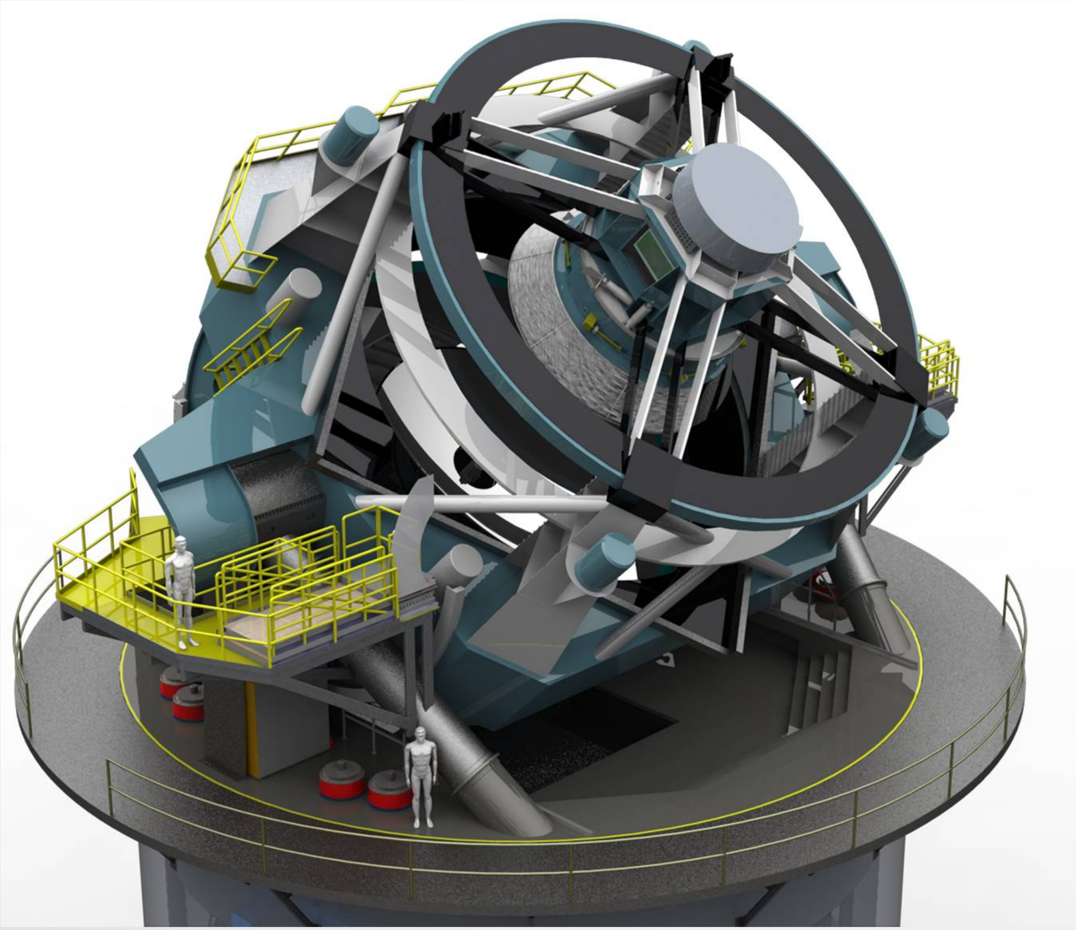


How to gain in precision ?

- Improve both statistics and systematics
- New projects are on construction
- LSST
- Euclid

LSST

- A new telescope in construction



Relevant Telescope Features
3 mirror optical design
Moving structure: 300 tons
Altitude/azimuth rotation axes
Max azimuth axis accel: 10.5 deg/sec^2
Max elevation axis accel: 5.25 deg/sec^2
Camera is cantilevered off the Top End Assembly near the center of rotation
Camera normally looks down when telescope is pointing near zenith

LSST, in a Nutshell

The LSST is an integrated survey system designed to conduct a decade-long, deep, wide, fast time-domain survey of the optical sky. It consists of an 8-meter class wide-field ground based telescope, a 3.2 Gpix camera, and an automated data processing system.

Over a decade of operations the LSST survey will acquire, process, and make available a collection of over 5 million images and catalogs with more than 37 billion objects and 7 trillion sources. Tens of billions of time-domain events will be detect and alerted on in real-time.

The LSST will enable a wide variety of complementary scientific investigations, utilizing a common database and alert stream. These range from searches for small bodies in the Solar System to precision astrometry of the outer regions of the Galaxy to systematic monitoring for transient phenomena in the optical sky. LSST will also provide crucial constraints on our understanding of the nature of dark energy and dark matter.

LSST, 4 science themes

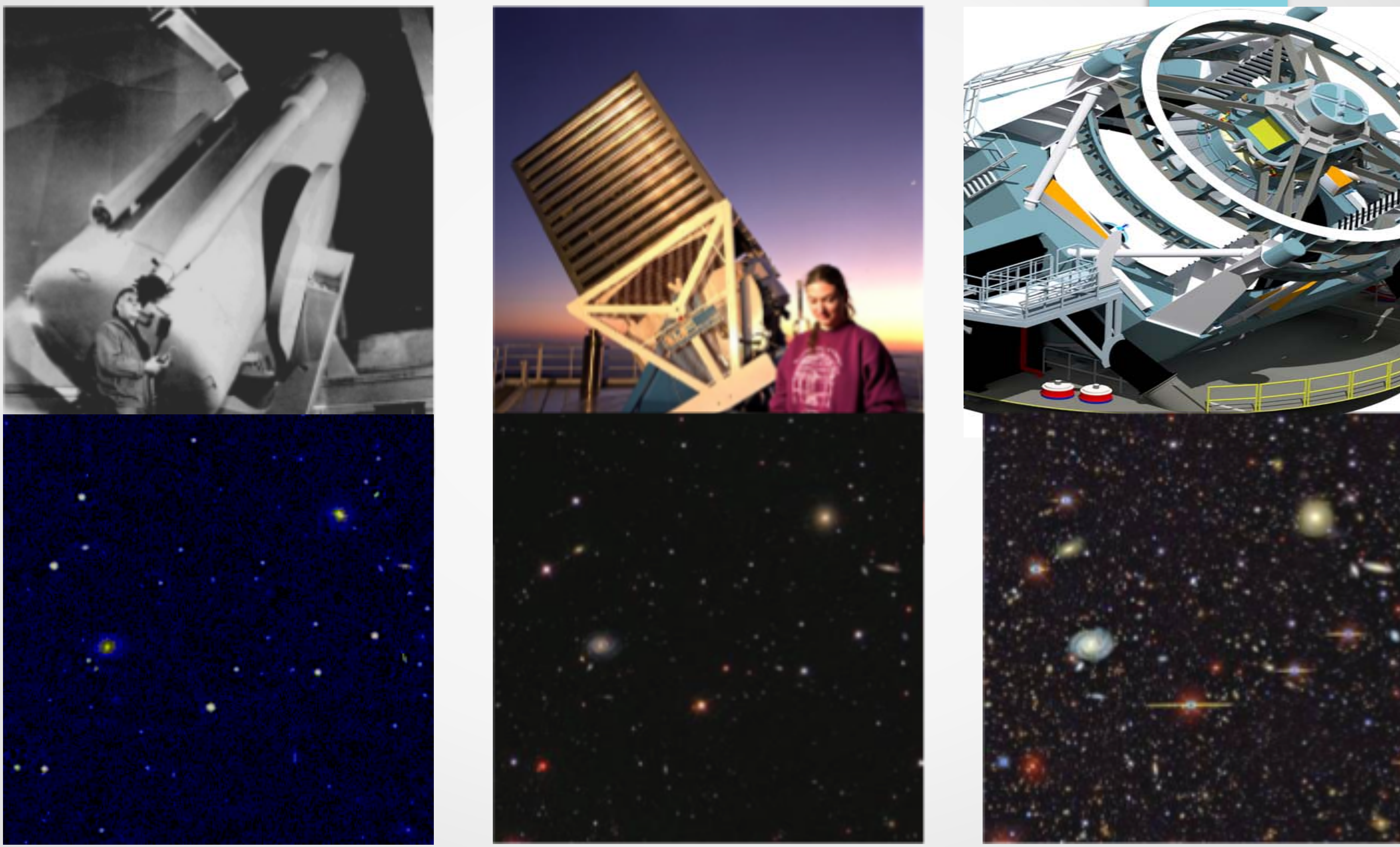
Taking a census of moving objects in the solar system.

Mapping the structure and evolution of the Milky Way.

Exploring the transient optical sky.

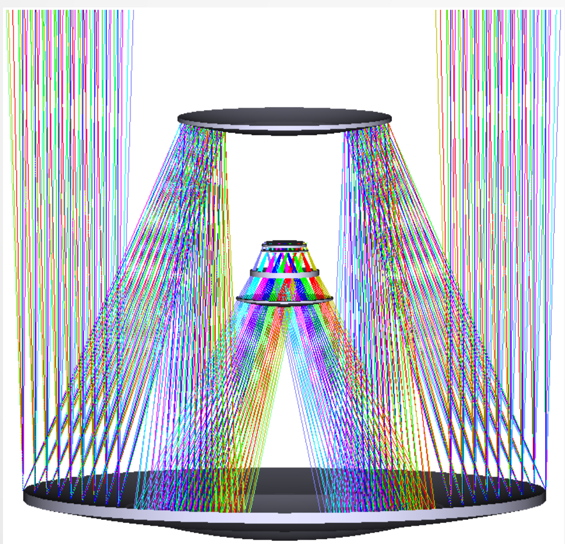
Determining the nature of dark energy and dark matter.

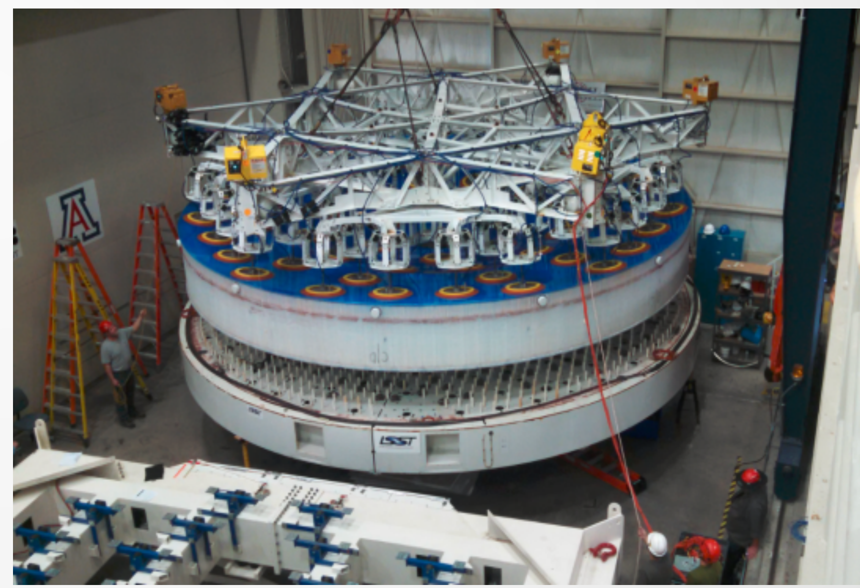
LSST, compared to precursors



LSST

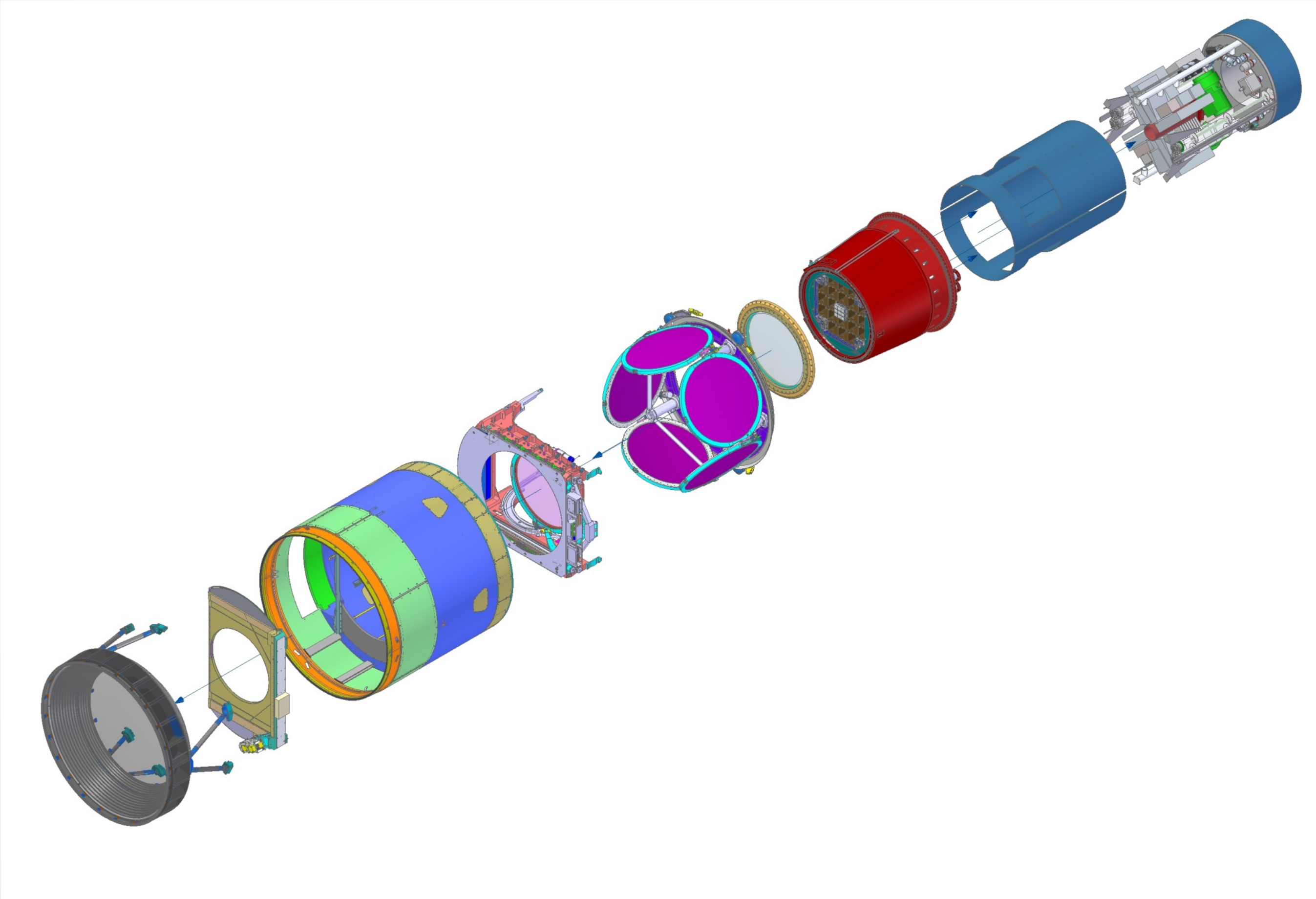
- Under contruction ! : mirrors





LSST

- Under contruction ! The camera elements



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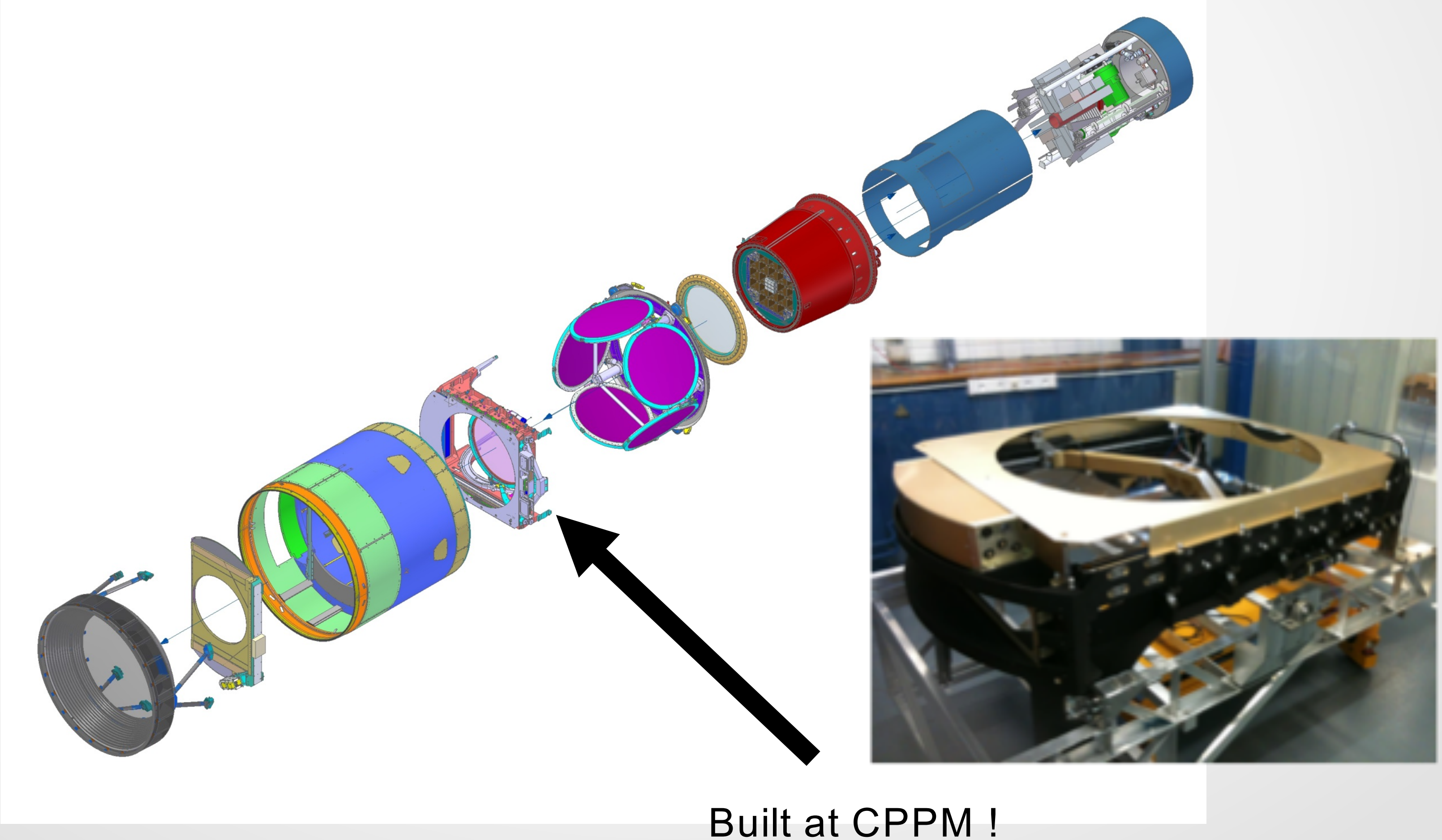


Built at CPPM !

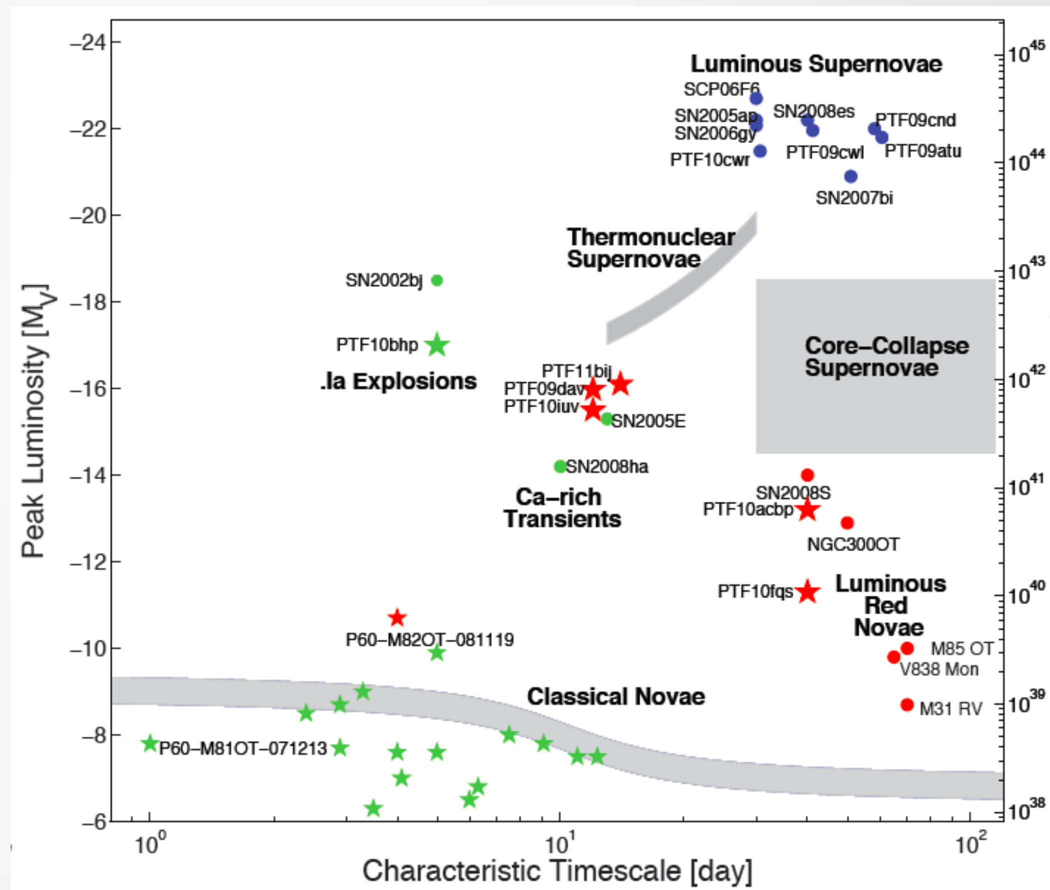
LSST is under construction !

LSST is under construction !

June 2018 !

LSST : science enabled

- Time domain science
  - Nova, supernova, GRBs
  - Source characterization
  - Instantaneous discovery
- Finding moving sources
  - Asteroids and comets
  - Proper motions of stars
- Mapping the Milky Way
  - Tidal streams
  - Galactic structure
- Dark energy and dark matter
  - Gravitational lensing
  - Slight distortion in shape
  - Trace the nature of dark energy



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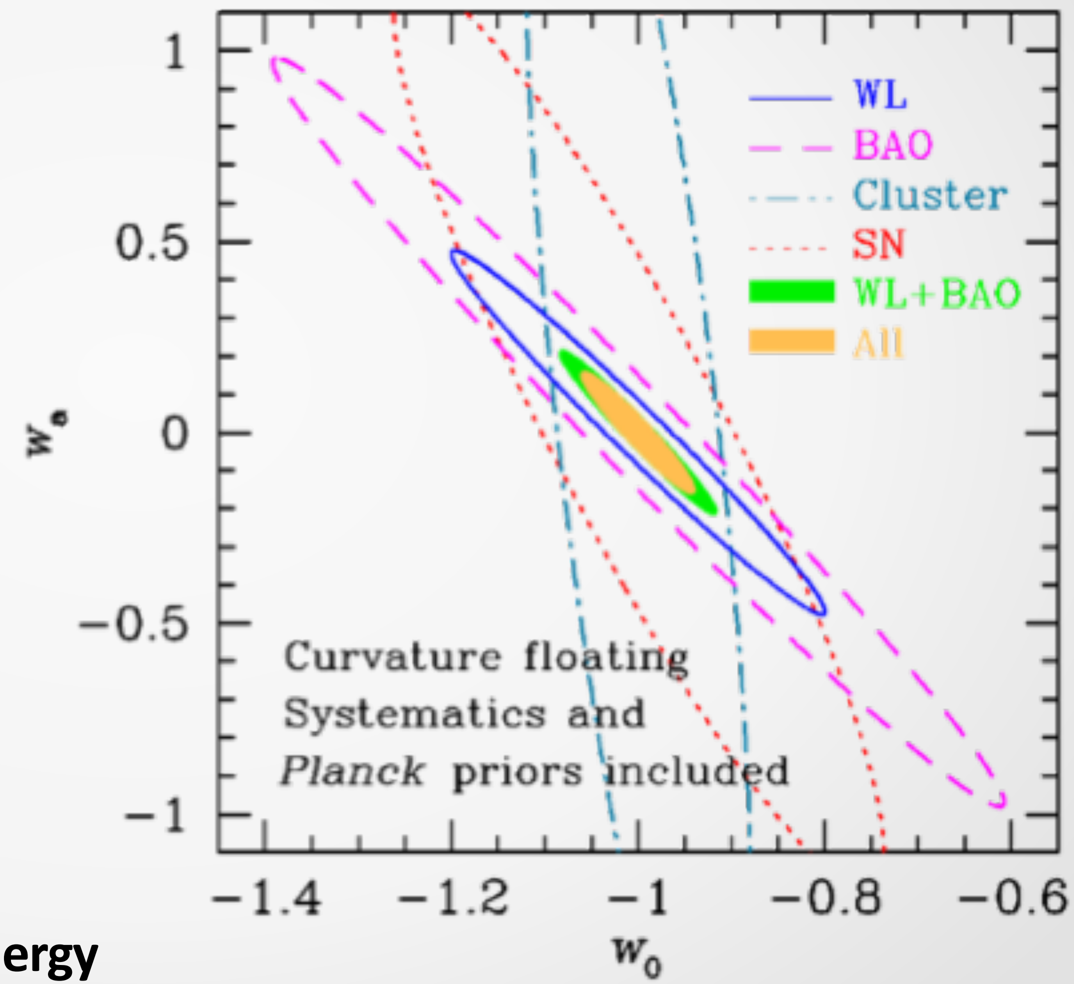
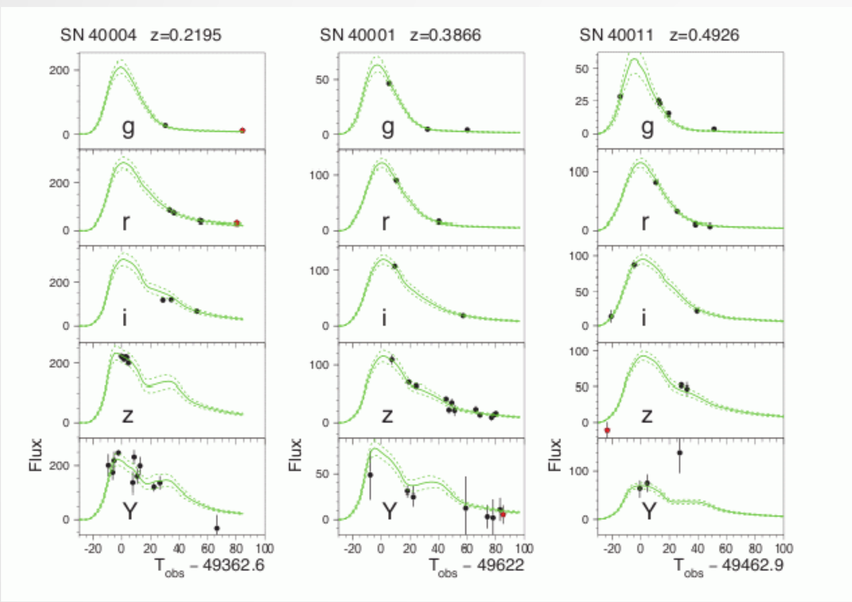


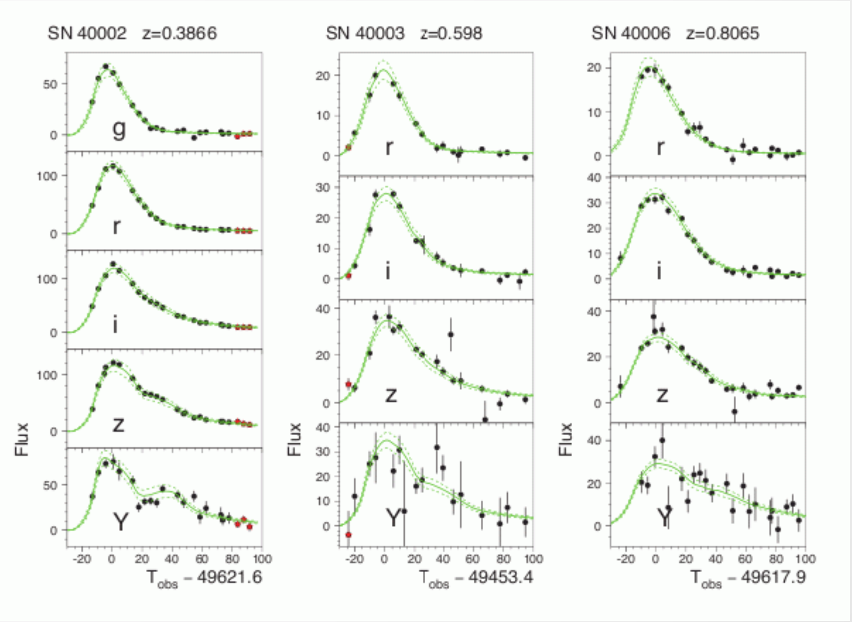
LSST, SN Program

Two surveys :

Main : 3-4 day cadence O(10^5) = 50000 SN/y

Deep drilling : < one day cadence O(10^4), deeper exposure = 800 SN/y





Constraint on cosmology

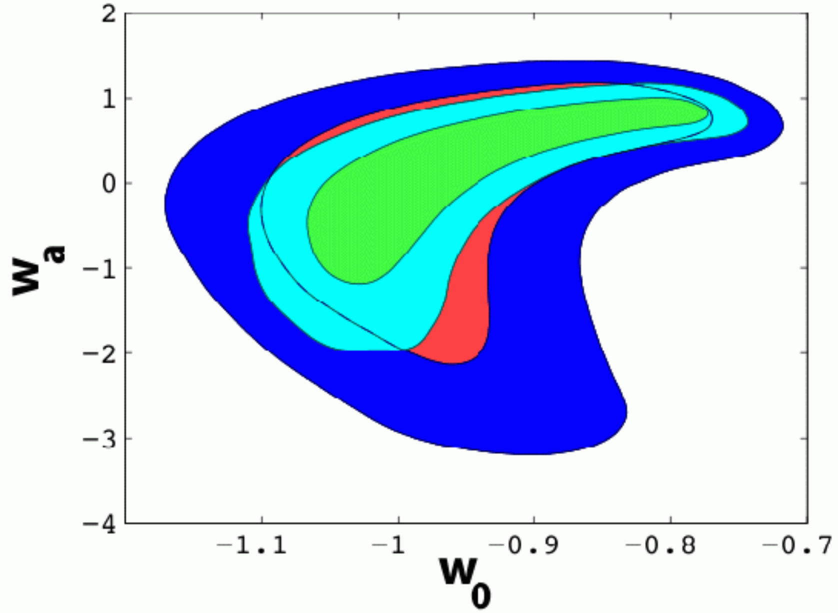
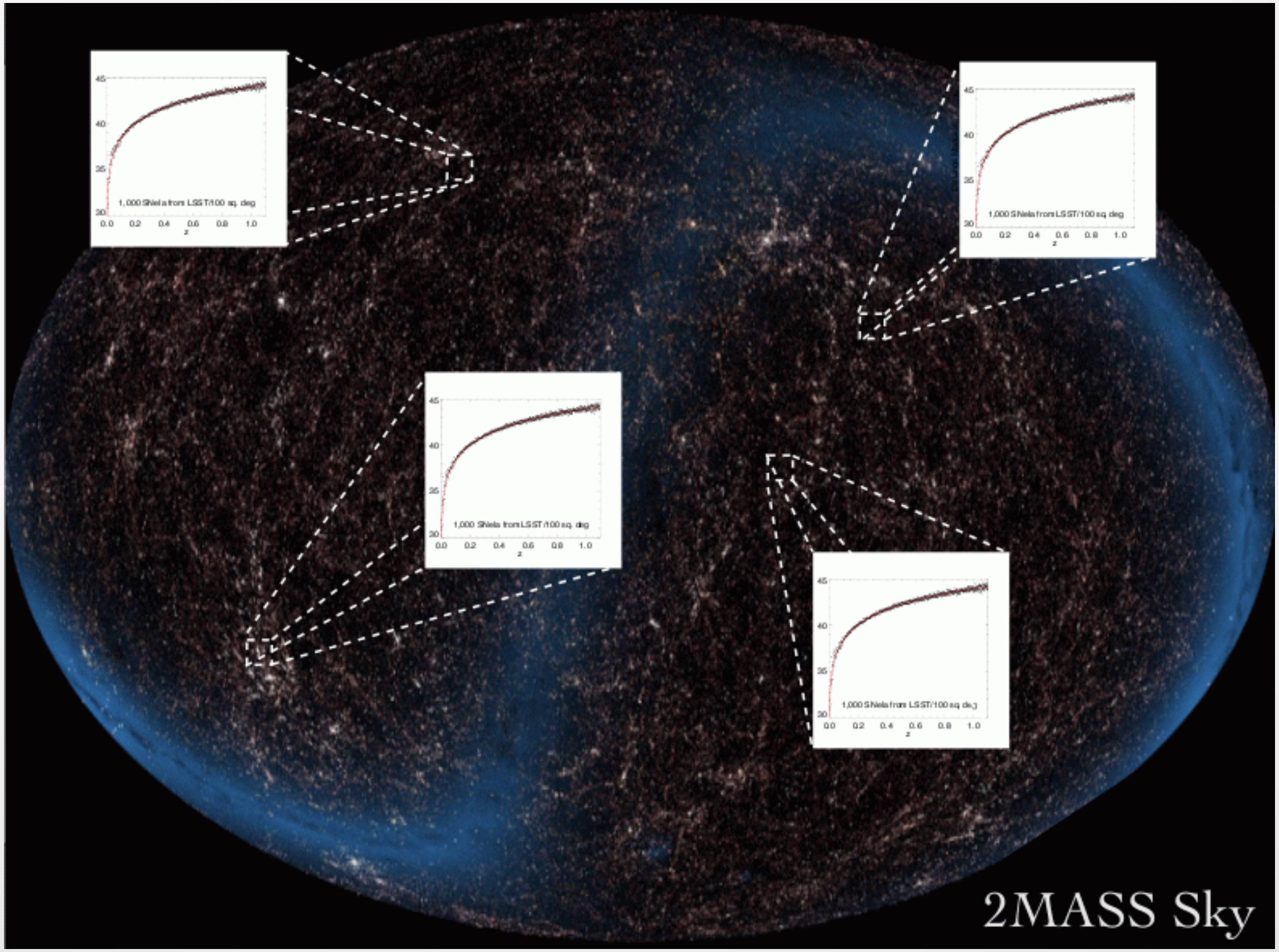


Figure 11.13: Forecast for joint posterior distribution on the parameters of a time evolving equation of state parametrized by $w(a) = w_0 + w_a(1 - a)$ in a flat cosmology from 50,000 supernovae (i.e., one year of the LSST survey). The green and cyan contours show the 68% and 95% constraints including photometric errors on redshift as a Gaussian with an error $\sigma_z = 0.01(1 + z)$, while the red and blue contours ignore photometric errors and only include an intrinsic dispersion of 0.12 mag in the distance indicator.

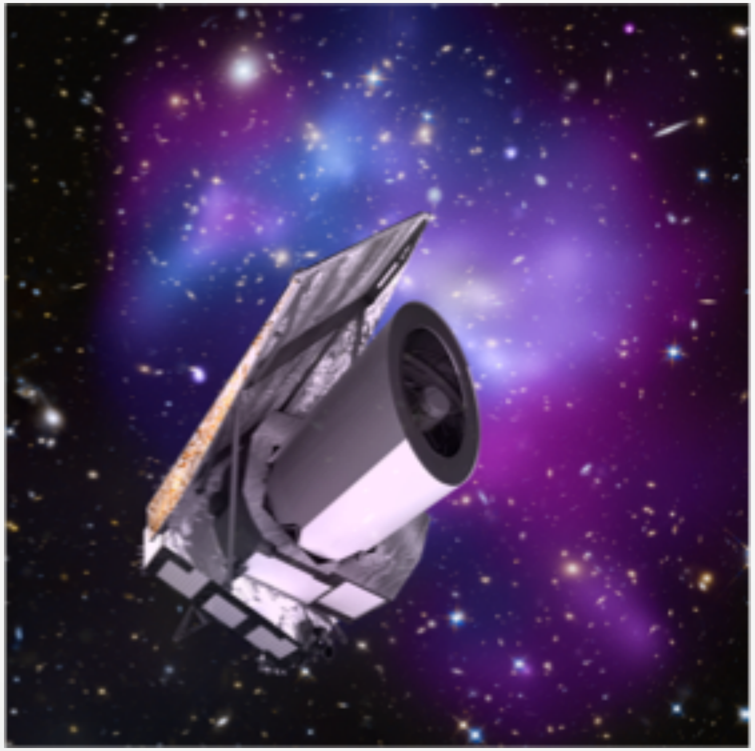
Constraint on cosmology

- Study of isotropy



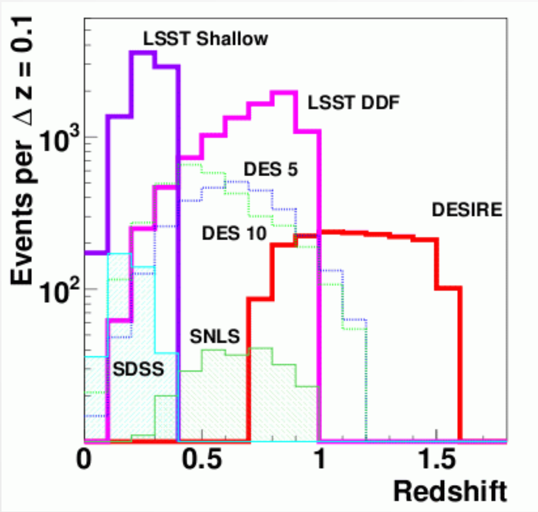
Euclid

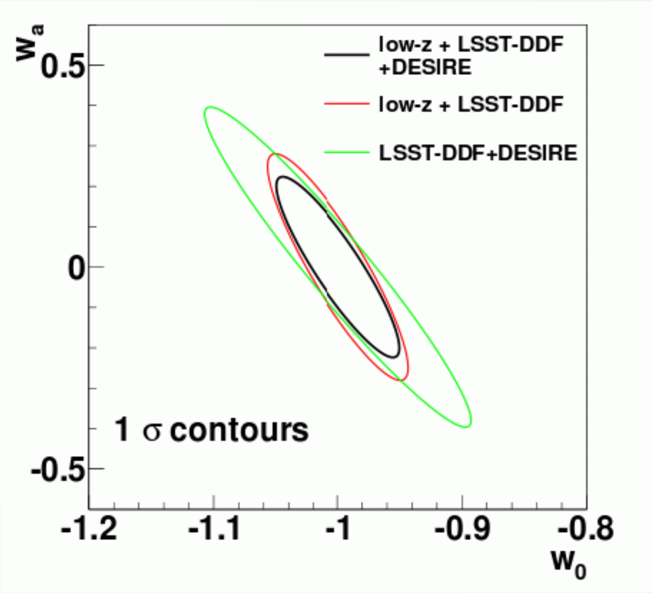
- A space telescope to study dark energy



Euclid

- A combined survey with LSST to measure supernovae is under discussion





Cosmology with supernovae

- Discovery of the accelerated universe
- Tight contraints on dark energy parameter thanks to current supernovae survey and precise analysis.
- But this is a difficult measurement
- New project will make precision even better to put new light on dark energy !