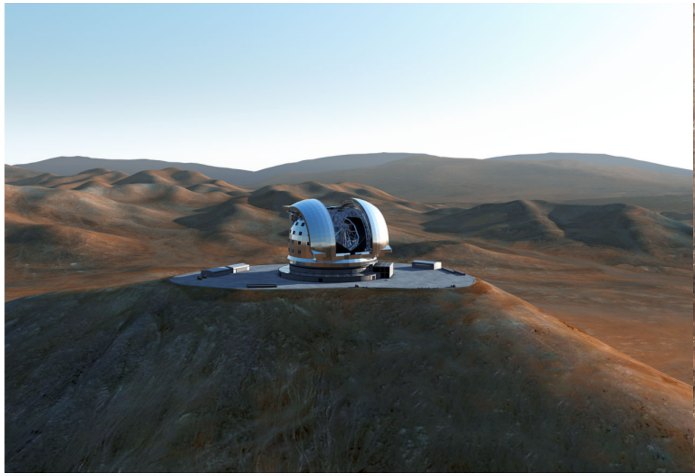
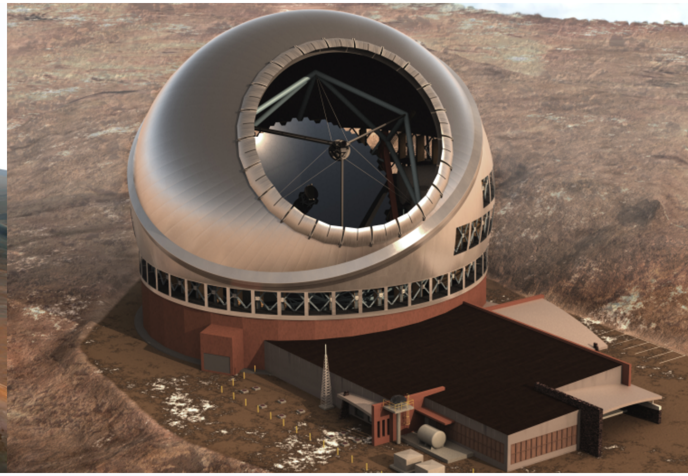
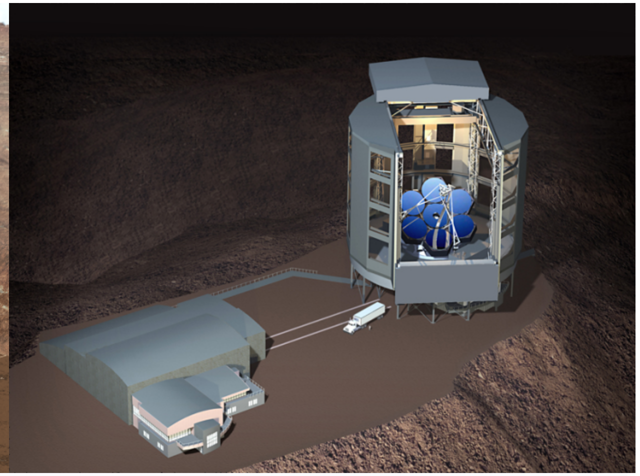
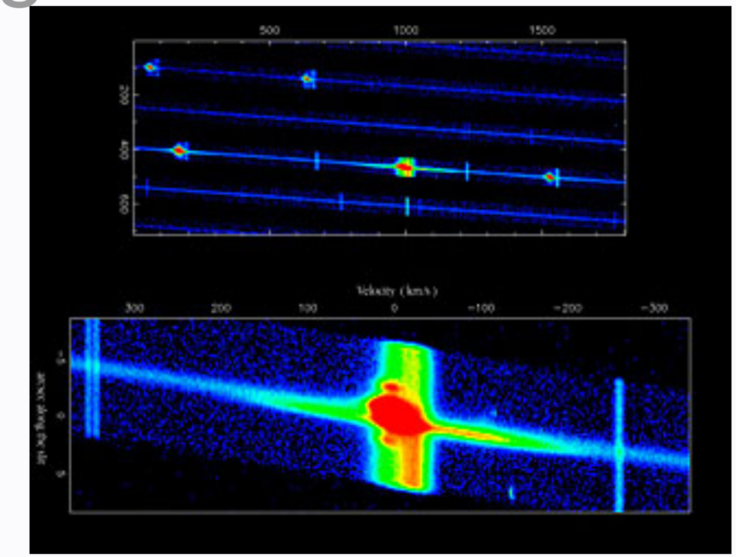
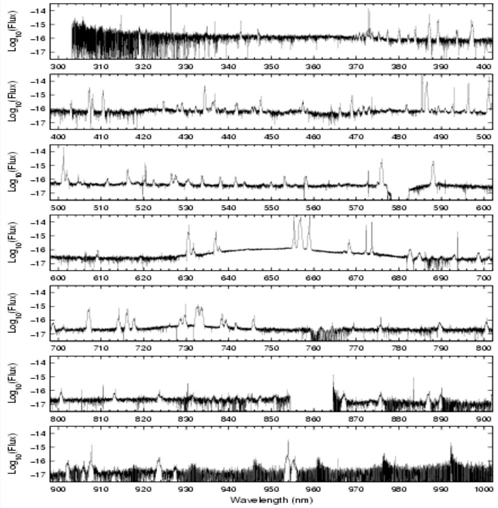




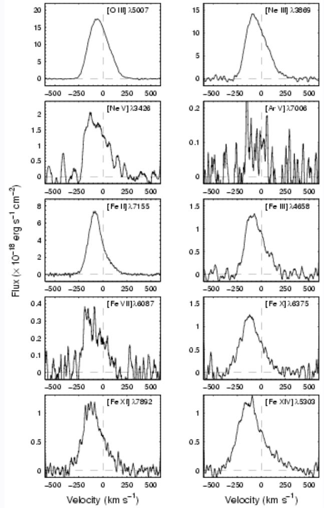
Supernova studies in the era of Extremely Large Telescopes

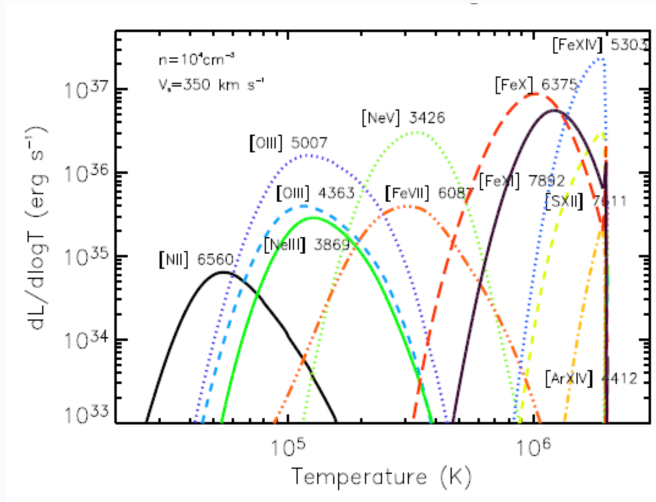
Bruno Leibundgut
ESO



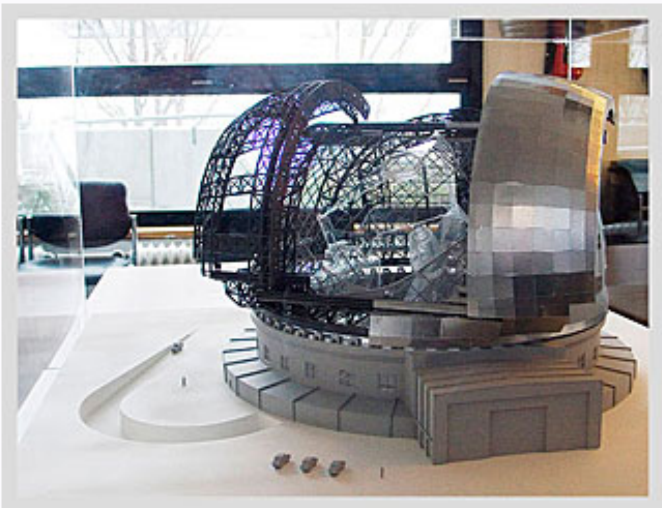
From Observations to Models

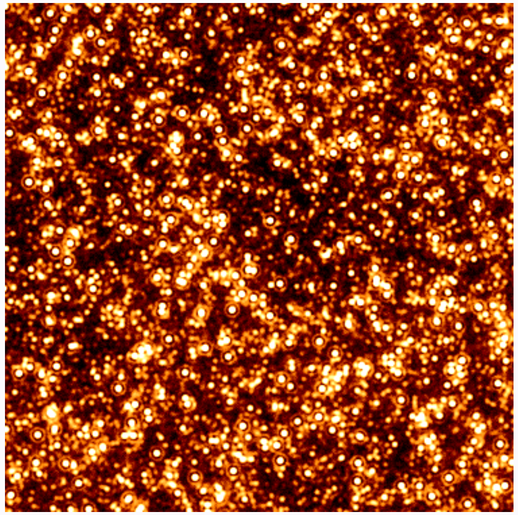






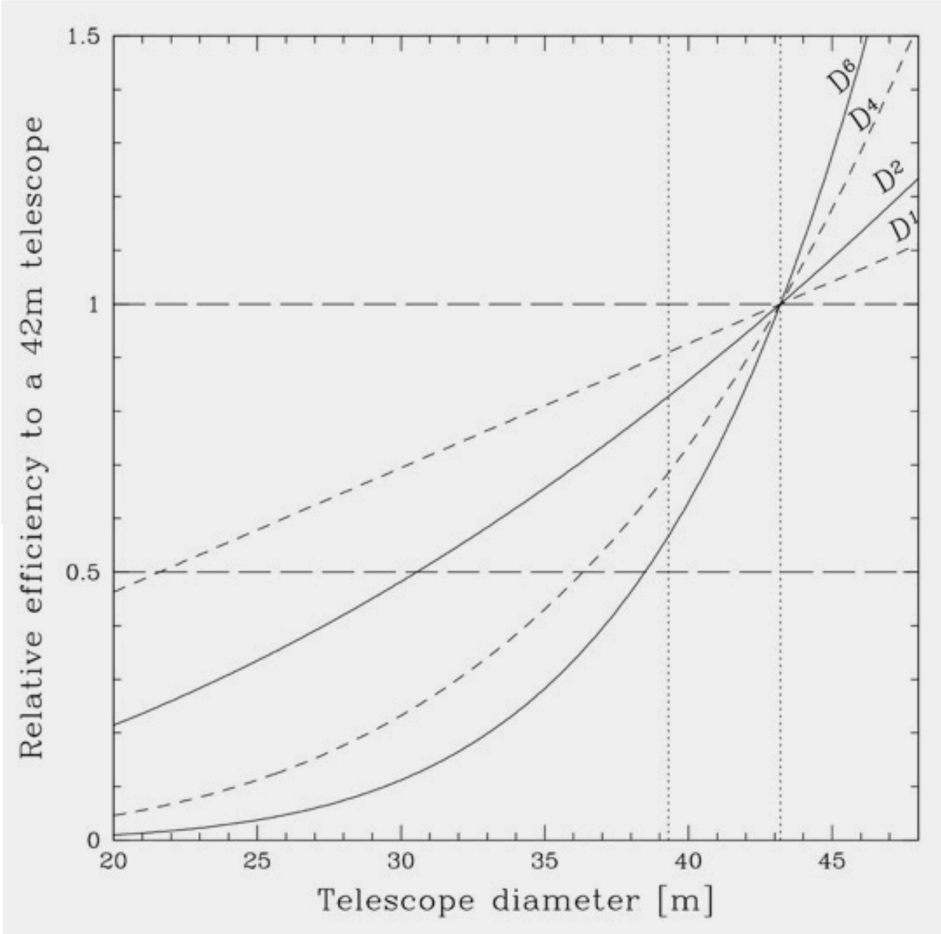
From Models to Observations

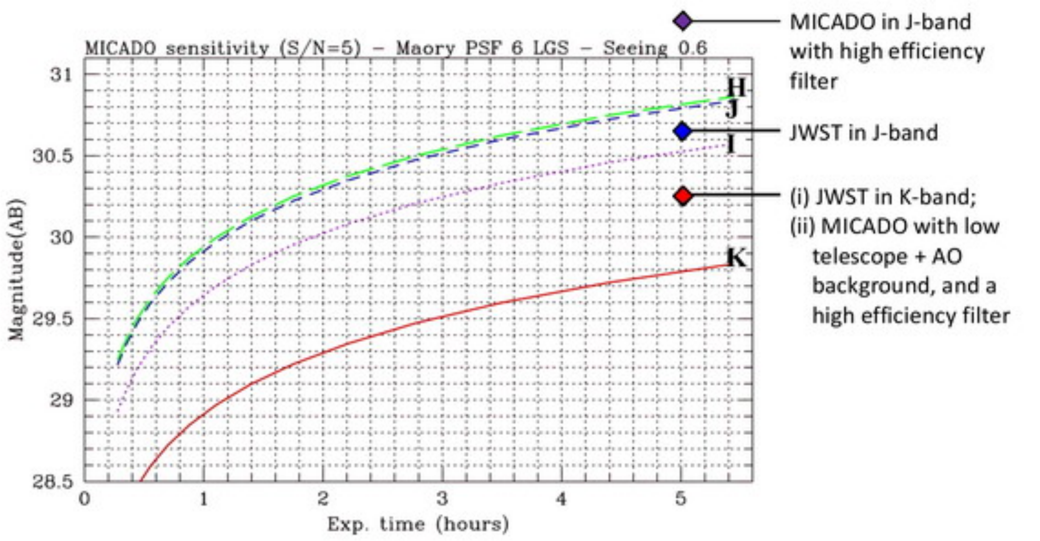




Why would you want a bigger telescope?

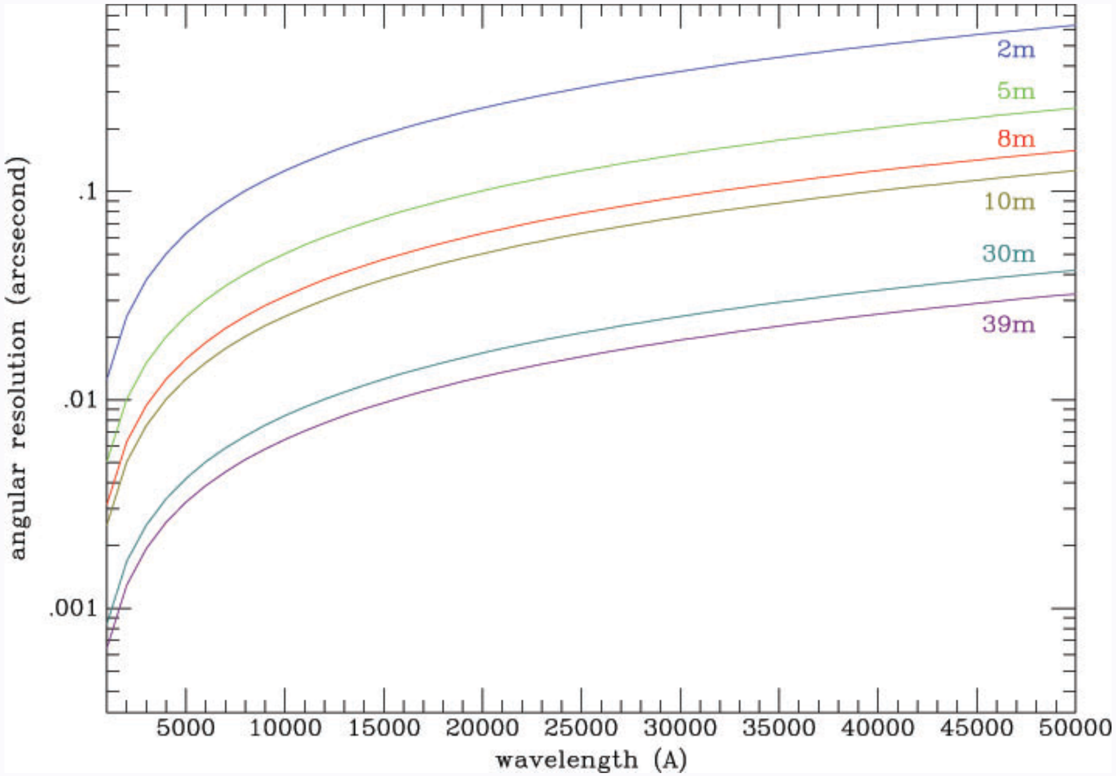
- More photons
  - D^2 for photon limited cases
  - D^4 for adaptive-optics limited cases





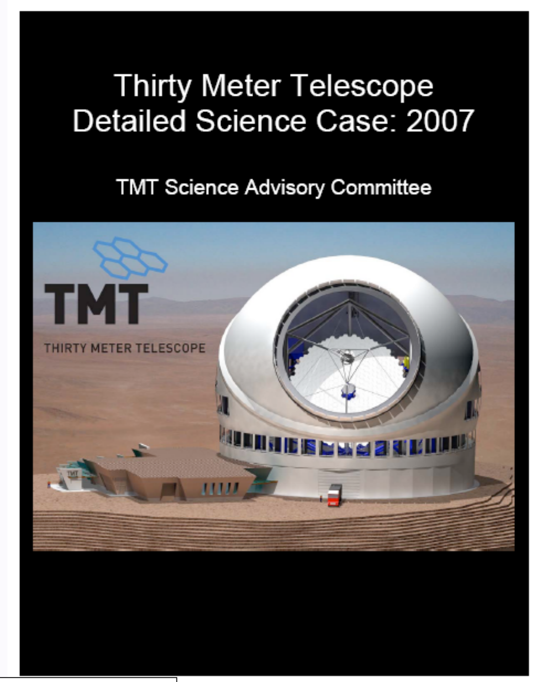
Why would you want to a bigger telescope?

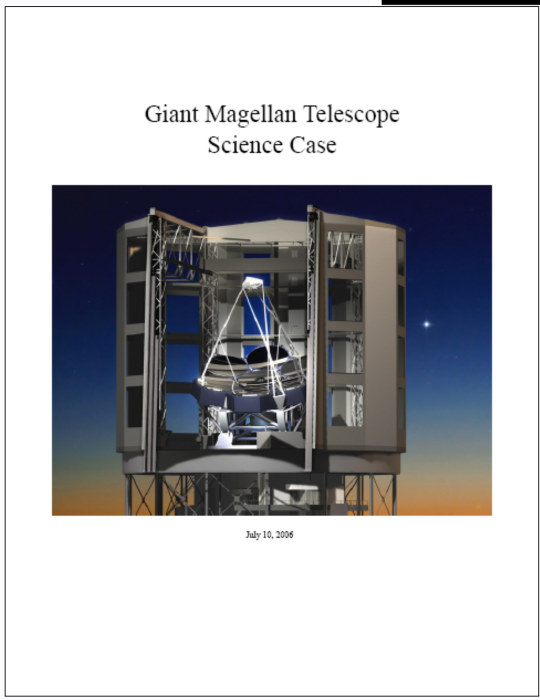
- Better angular resolution
  - requires adaptive optics from the ground
  - filled aperture essential to observe objects with complex structures



Supernovae in the ELT Science Cases

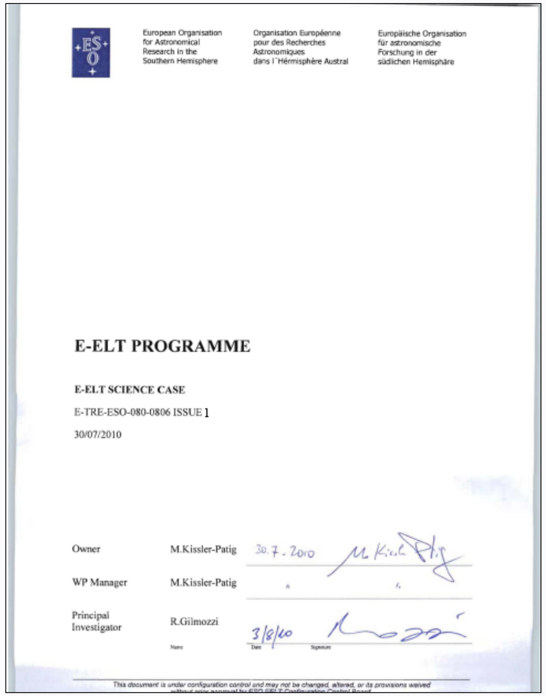
- TMT (2007)
  - physics of extreme objects
    - GRBs to z≈10
    - core collapse supernovae, in particular SNe IIn to z≈6
  - chemical enrichment
  - dark energy
- GMT (2006)
  - chemical enrichment
    - yields of SNe II
  - star formation
    - supernova feedback
  - dark energy
    - SNe at z>1





Science Cases

- E-ELT (2010)
  - star formation history through SN and GRB rates as function of z
    - GRBs to z≈15
  - chemical evolution
  - accelerating universe
    - SNe as distance indicators up to z≈4



European Organisation for Astronomical Research in the Southern Hemisphere
Organisation Européenne pour des Recherches Astronomiques dans l´Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

E-ELT PROGRAMME

E-ELT SCIENCE CASE

E-TRE-ESO-080-0806 ISSUE 1

30/07/2010

Owner	M.Kissler-Patig	30.7.2010	[signature]
WP Manager	M.Kissler-Patig		
Principal Investigator	R.Gilmozzi	3/8/10	[signature]
	Name	Date	Signature

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An ELT in the making

- ALMA now has more collecting area than any of the future E-ELT
  - 17 antennas working as array
  - 136 baselines
  - >900 proposals for Early Science (Cycle 0)

Predicting the future
or
Never look back

Supernovae and the VLT: More Light to Examine*

Bruno Leibundgut and Jason Spyromilio (1995)

* To appear in *Science with the VLT*, eds. J. Walsh, J. Danziger, (Berlin: Springer)

- 4 years before start of VLT operations
  - 5 years after VLT approval

Supernovae and the VLT (1995)

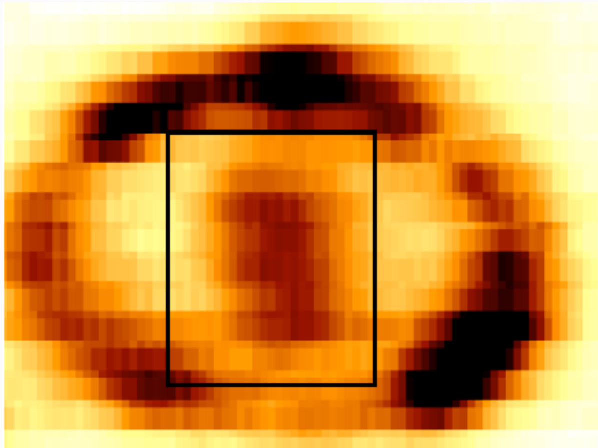
- "Current problems"
  - link between progenitor star evolution and the supernova explosion
  - Which stars blow up and what in their evolution determines the appearance of the supernova?
  - mass loss history and circumstellar interaction
  - local interstellar medium beyond the Local Group
    - selective absorption
  - H_0 will be reliably determined in the next few years

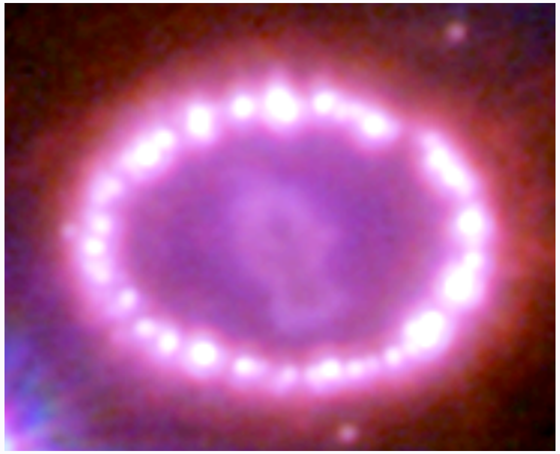
Supernovae and the VLT

- optical spectral evolution to much later phases ✓
- infrared spectroscopy
- direct measurement of the radioactive decay
  - [Co II] 10.52μm emission
  - Fe/Co ratio from [Co II] 1.547μm *vs.* [Fe II] 1.533μm ✗
- direct observations of dust formation, IR catastrophe, freeze-out ✗
- Supernovae several years past maximum ✗
- Hubble constant beyond known bulk flows ✓
- deceleration of the Universe ✓

Supernovae and the VLT

- Polarization
  - asphericities
    - work by Wang, Leonard, Patat, Maund, Chornock
  - size and orientation of interstellar dust grains
    - not done

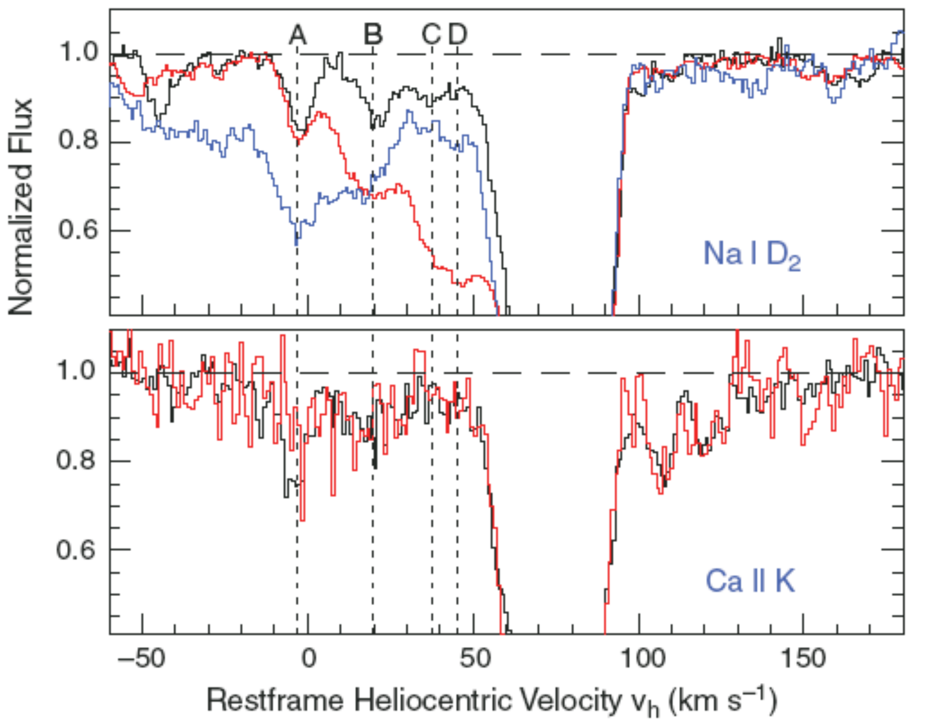




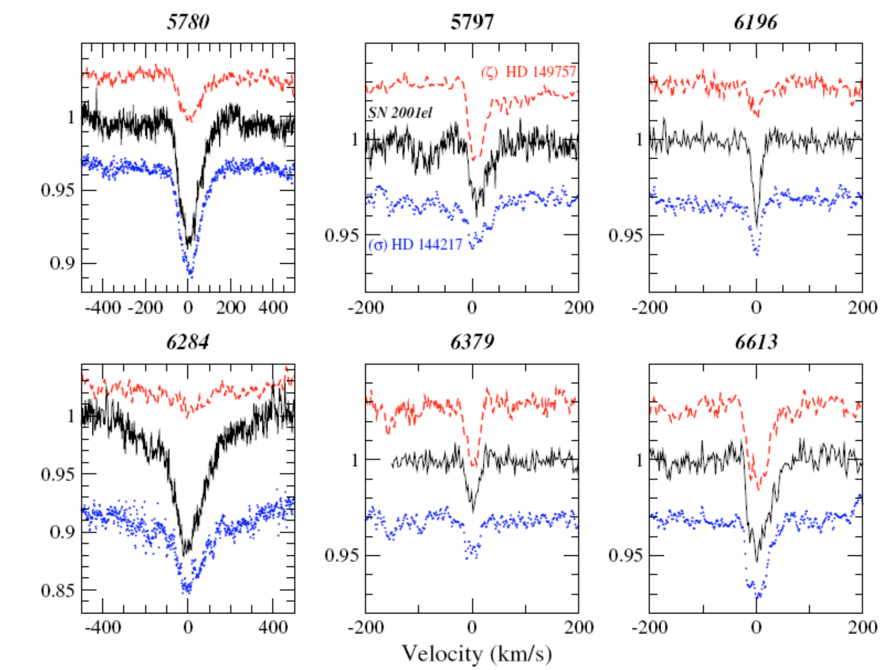
Supernovae and the VLT

- Probing the local ISM
  - Na I and Ca II (H&K)
  - diffuse interstellar bands

SN 2006X; Patat et al. 2007

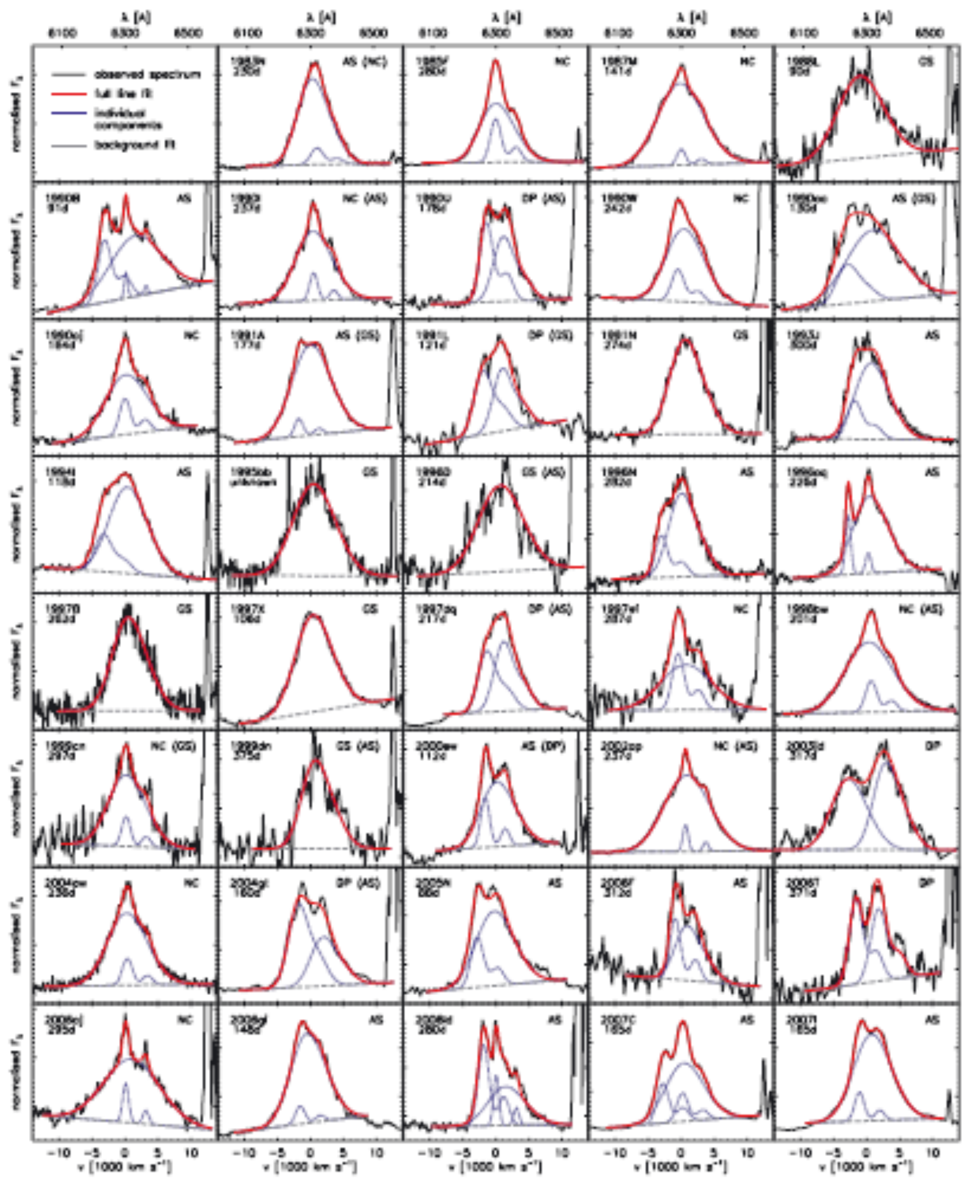


SN 2001el; Sollerman et al. 2005



Supernovae and the VLT

- Clumping in supernova ejecta
  - very high S/N of emission lines at late phases
    - "internal structure of progenitor star"



Taubenberger et al. 2009

Supernovae and the VLT

- Light echoes
  - scattering mechanisms
  - dust properties

Many of the proposed research projects reproduce observations which have been obtained for SN 1987A in the LMC and SN 1993J in M 81 for supernovae at significantly larger distances. Although this statement appears trivial

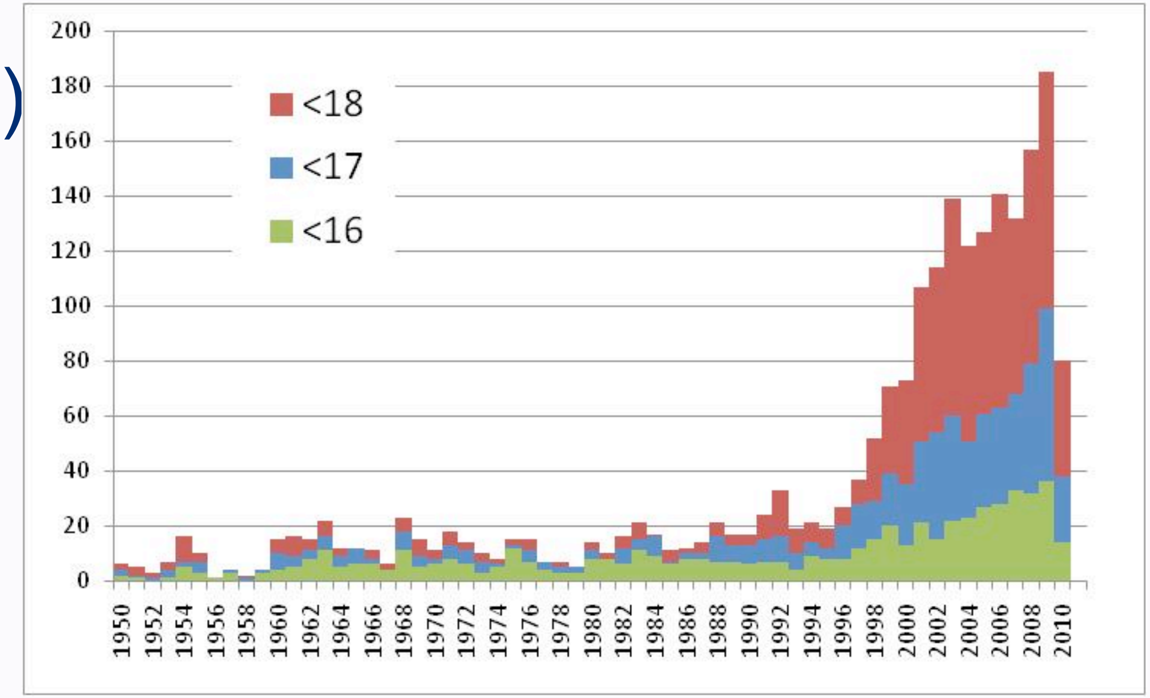
In other words, we can expect to observe a supernova with a comparable wealth of information as was gathered for SN 1987A about once every year!

What do we want to learn about supernovae?

- What explodes?
  - progenitors, evolution towards explosion
- How does it explode?
  - explosion mechanisms
- Where does it explode?
  - environment (local and global)
  - feedback
- What does it leave behind?
  - remnants
  - compact remnants
  - chemical enrichment
- Other use of the explosions
  - light beacons
  - distance indicators
  - chemical factories

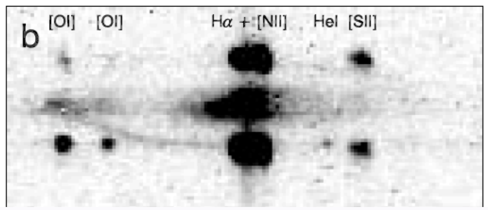
Predicting the future ...

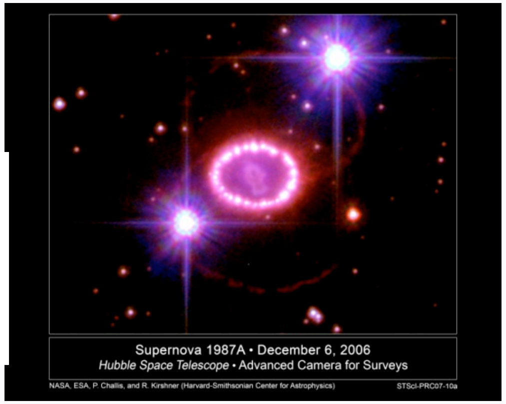
- What will we know about supernovae 10 years from now?
  - ~5400 SNe reported until end of 2009
  - expect up to 100000 SNe (?) for the coming decade



Predicting the future ...

- Future facilities
  - things we will not have any longer
    - HST
      - UV/optical high-angular resolution imaging
      - UV spectroscopy





  - new facilities
    - ALMA (mm/sub-mm)
    - LOFAR, SKA pathfinders (radio)
    - JWST (IR)
    - LSST (optical monitoring)
    - EUCLID/PLATO (IR sky survey/transiting planets)
    - SPICA (far-infrared)
    - X-ray/γ-ray observatories?

Predicting the future ...

- E-ELT capabilities
  - some optical spectroscopy
    - multi-object spectrographs
    - very high-resolution spectrographs
  - best performance in the infrared (>1μm)
    - adaptive optics supported
    - imaging
    - integral-field spectroscopy

Predicting the future ...

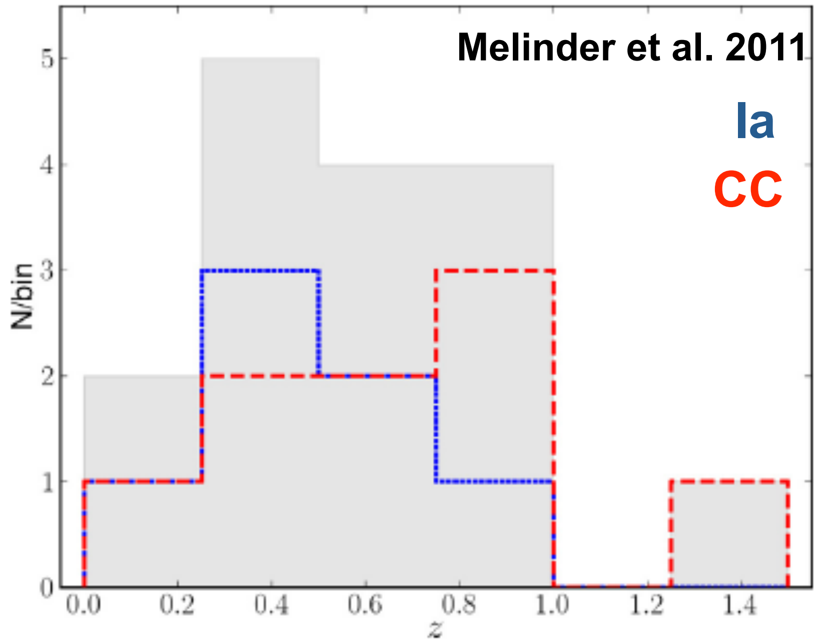
- Who will discover the supernovae?
  - two scenarios
    - follow "bright" SNe to late phases
    - observe "faint" SNe
  - small field of view of ELTs
    - difficult to find SNe with ELTs
  - LSST, PanSTARRS (and successors)
    - optical searches (to 1μm)
  - high-energy satellites?
    - eROSITA? any other?
  - JWST
    - small field; needs dedicated searches
  - EUCLID
    - time frame: EUCLID ~2018; ELT's >2020
  - radio
    - time scale not always favourable

What do we want to learn about supernovae?

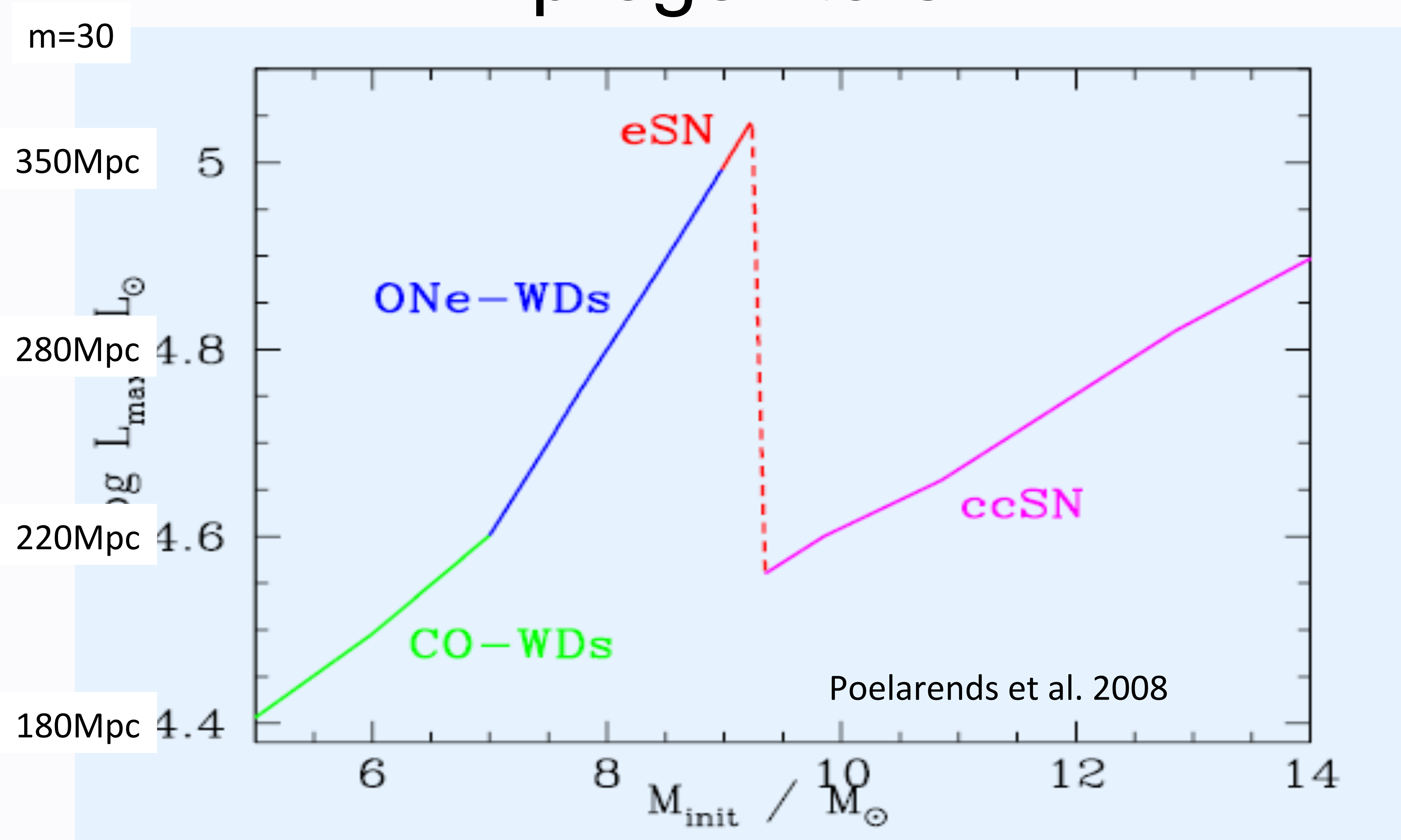
- What explodes?
  - progenitors, evolution towards explosion — deep imaging
- How does it explode?
  - explosion mechanisms — late phases?
- Where does it explode?
  - environment (local and global) — deep imaging/ integral-field spectroscopy
  - feedback
- What does it leave behind?
  - remnants — deep imaging
  - compact remnants
  - chemical enrichment
- Other use of the explosions
  - light beacons — high resolution spectroscopy
  - distance indicators — faint object photometry
  - chemical factories — faint object spectroscopy

Potential projects

- map the local stellar population of nearby supernovae
  - constrain progenitors, find companions
- find the shock breakouts at high redshift
  - help from time dilation
- find the luminous supernovae out to z≈6; GRBs out to z≈15 (through the dark ages?)
  - "first stars"?
- EUCLID follow-up
  - IR rest wavelength Hubble diagram
  - SN statistics at higher redshifts



Direct observations of SN progenitors



SN 1987A will be the first supernova that we can observe forever.

L. Woltjer

SN 1987A @ 35 years?

- Resolve ejecta and ring
  - kinematics (integral-field spectroscopy)
  - warm dust (mid-IR observations)
  - outer rings?
- (imaging with JWST)

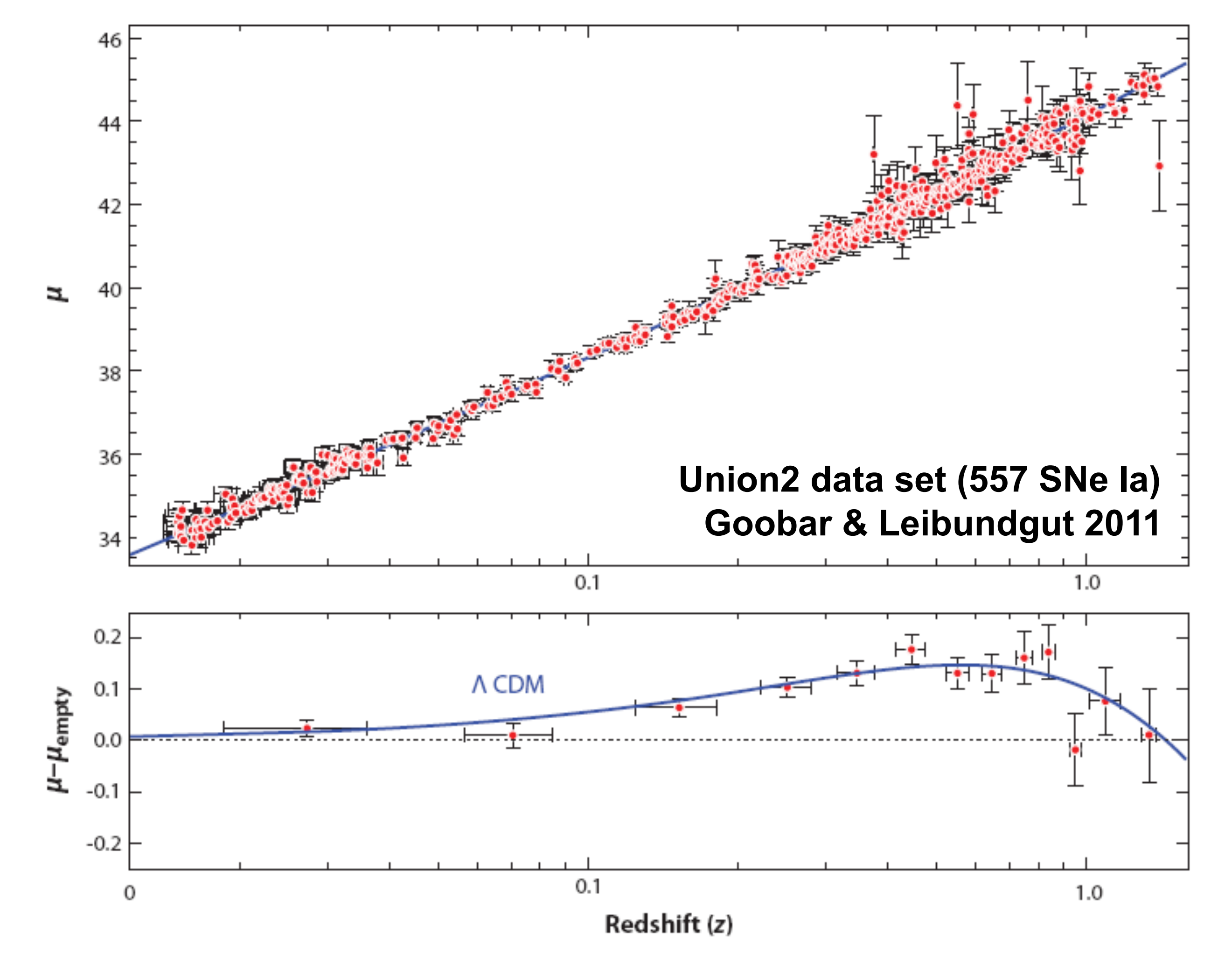
[SN 1987A] is like a box of chocolates – you never know what you're gonna get [next]

Cosmology - do we need more?

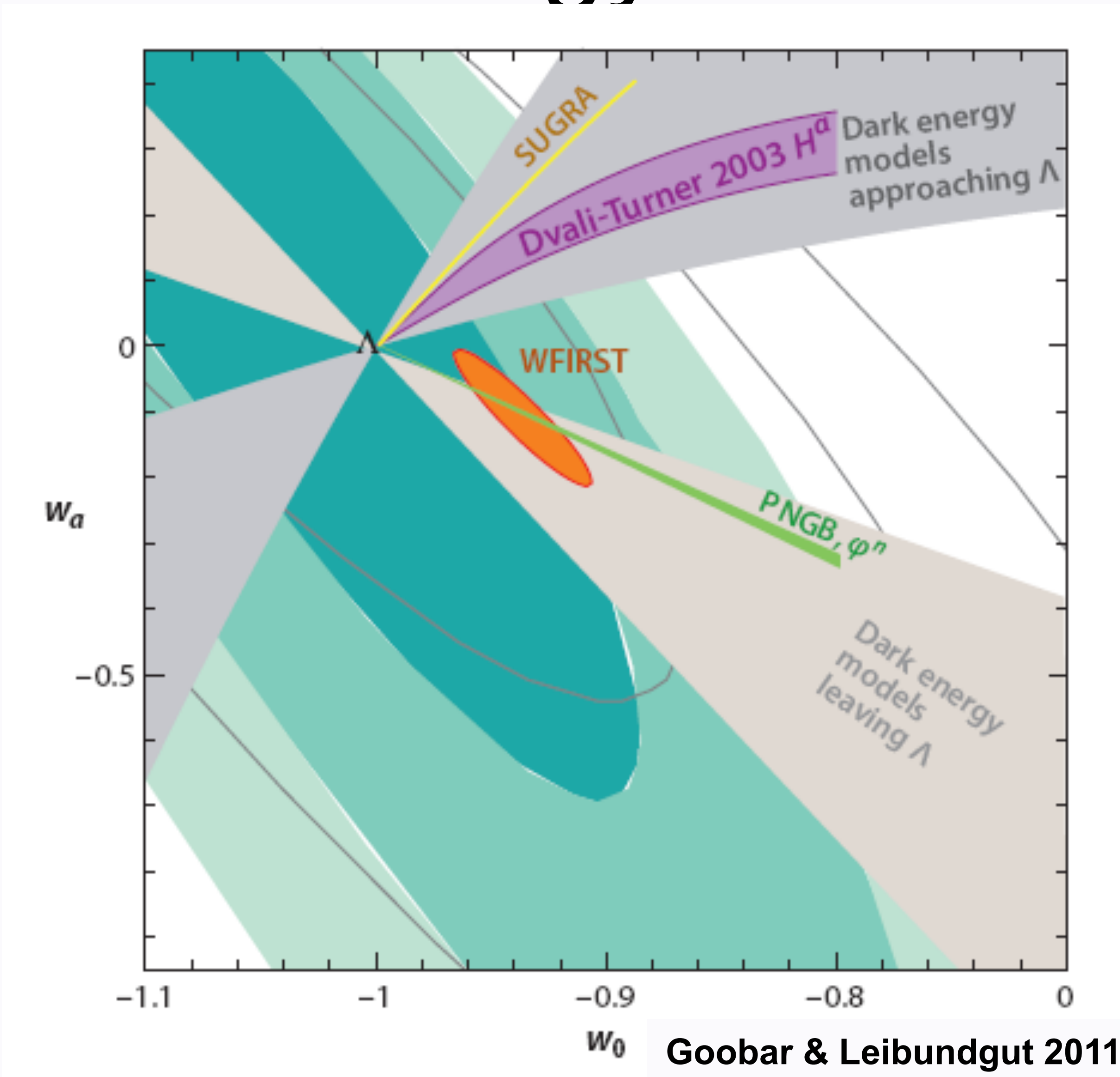
- Already in hand
  - >1000 SNe Ia for cosmology
  - constant ω determined to 5%
  - accuracy dominated by systematic effects
    - reddening, correlations, local field, evolution
- Test for variable ω
  - required accuracy ~2% in *individual* distances
  - can SNe Ia provide this?
    - can the systematics be reduced to this level?
    - homogeneous photometry?
    - further parameters (e.g. host galaxy metalicity)
    - handle >100000 SNe Ia per year?

Cosmology – more?

- Current published data set



Cosmology – more?

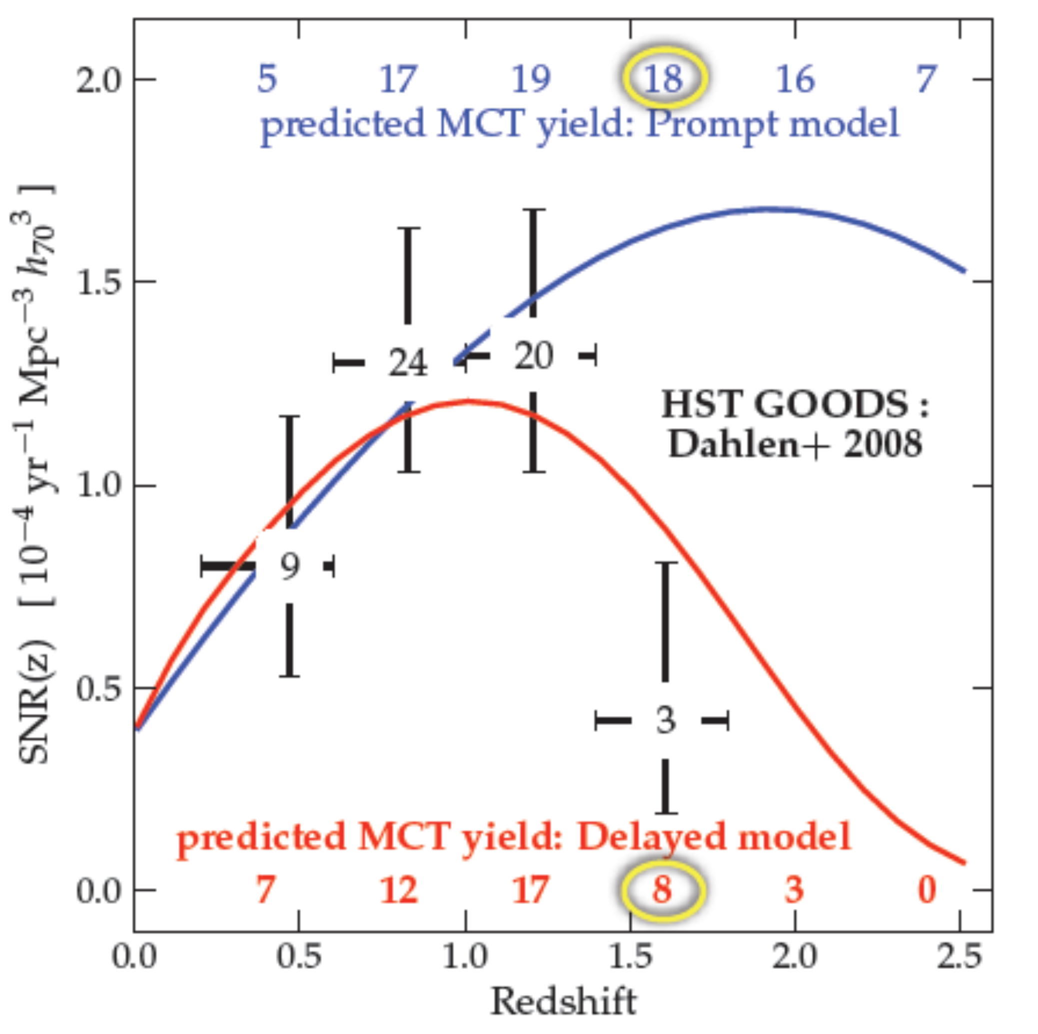


Goobar & Leibundgut 2011
(courtesy E. Linder and J. Johansson)

Distant SNe

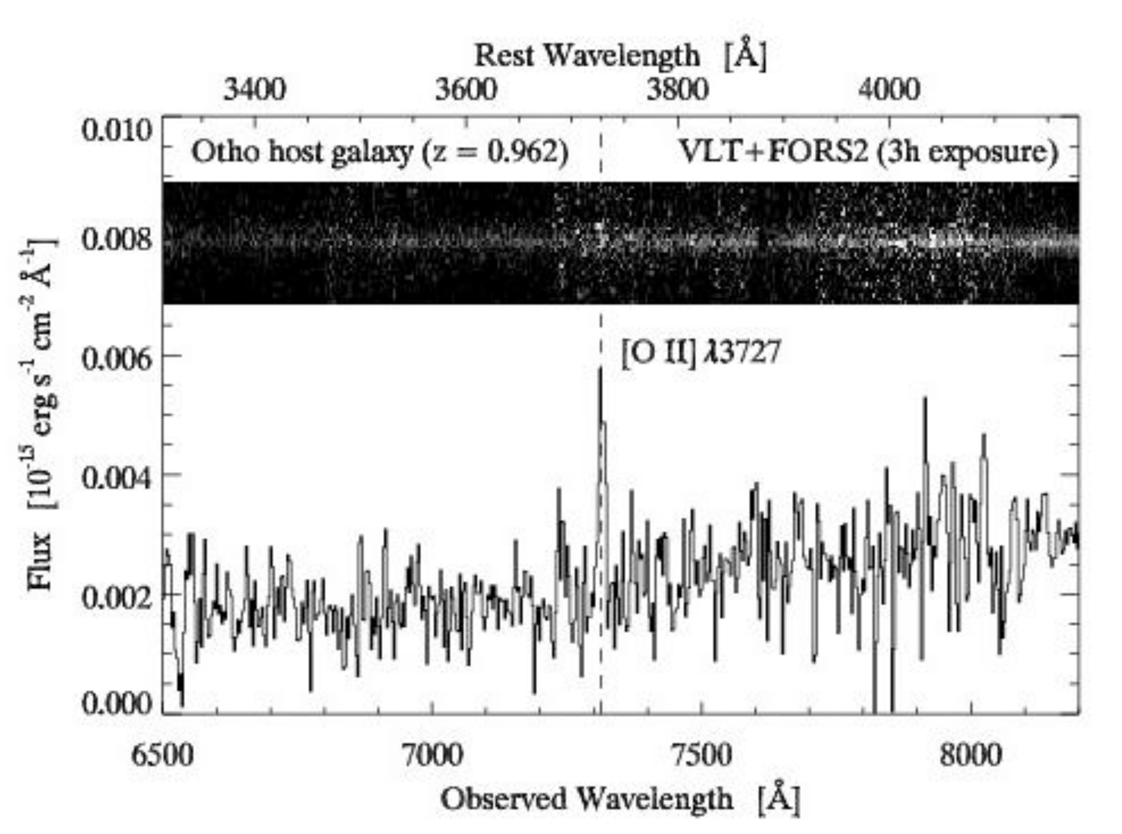
- can we do this?
  - plot assumes:
    - 100m OWL
    - SNe Ia out to z=5 (?)
    - SN II can be used as good distance indicators

Steve Rodney; MCT SN Survey



Distant SNe

- Fill the redshift range z>1
  - (will this not have been done by 2020?)



Courtesy: Stéphane Blondin

Summary

- 10 years is a long time
- 100000 SNe is a gigantic sample
- ELTs still need to be funded and built

Coming soon to a site near you