Supernova Observation, Detection, and SN Ia

Elsa Johnson Astr 321

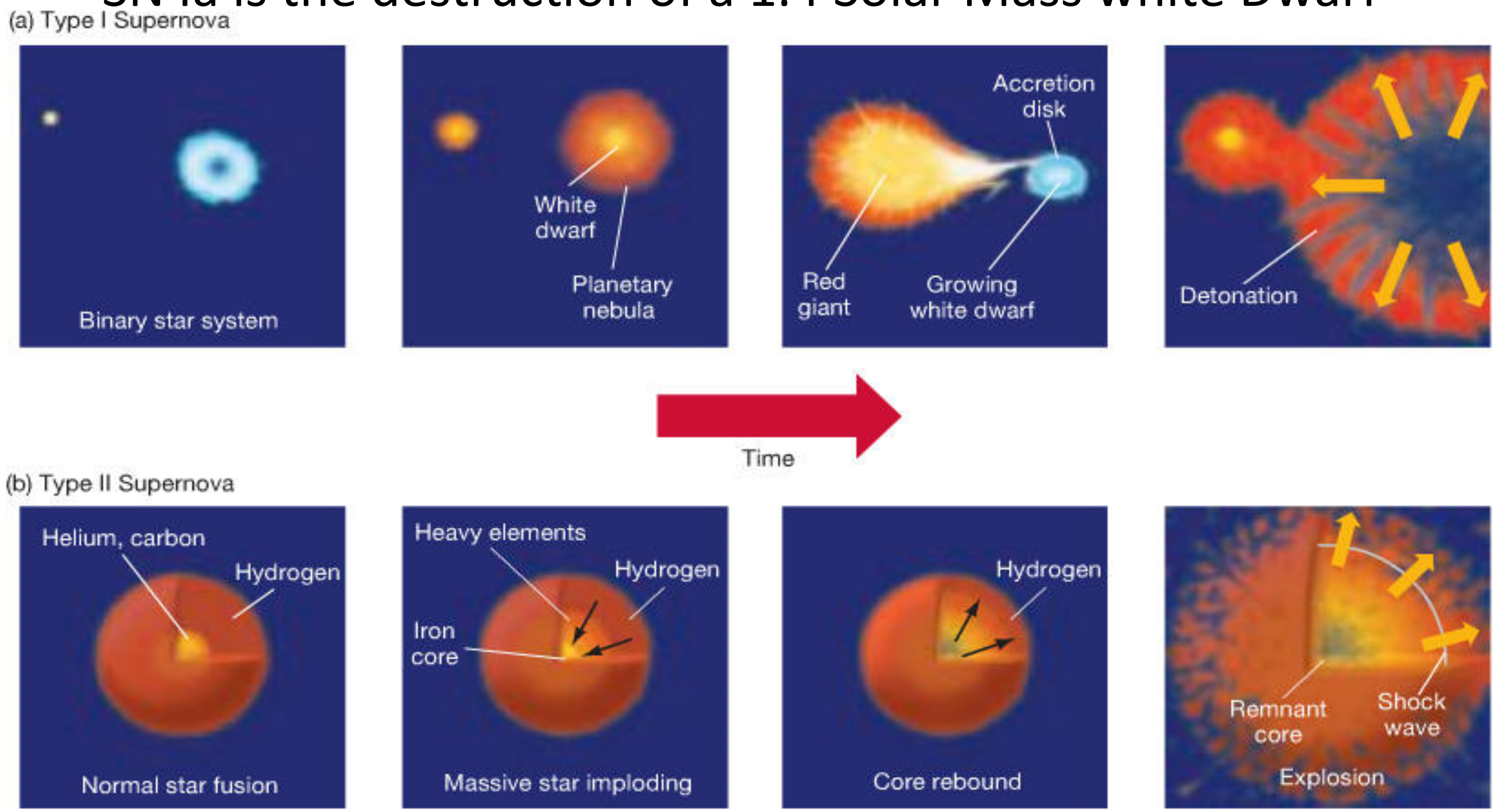
Two Possible Outcomes of Stars

- White Dwarf
- Mass of main sequence star < 8 Msolar
- Can exist as a WD for ??
- Found in all stellar populations

- Supernova
- Mass of main sequence star > 8 Msolar
- Found in star forming regions
- Some stellar remnant (Neutron star/pulsar, black hole) remains

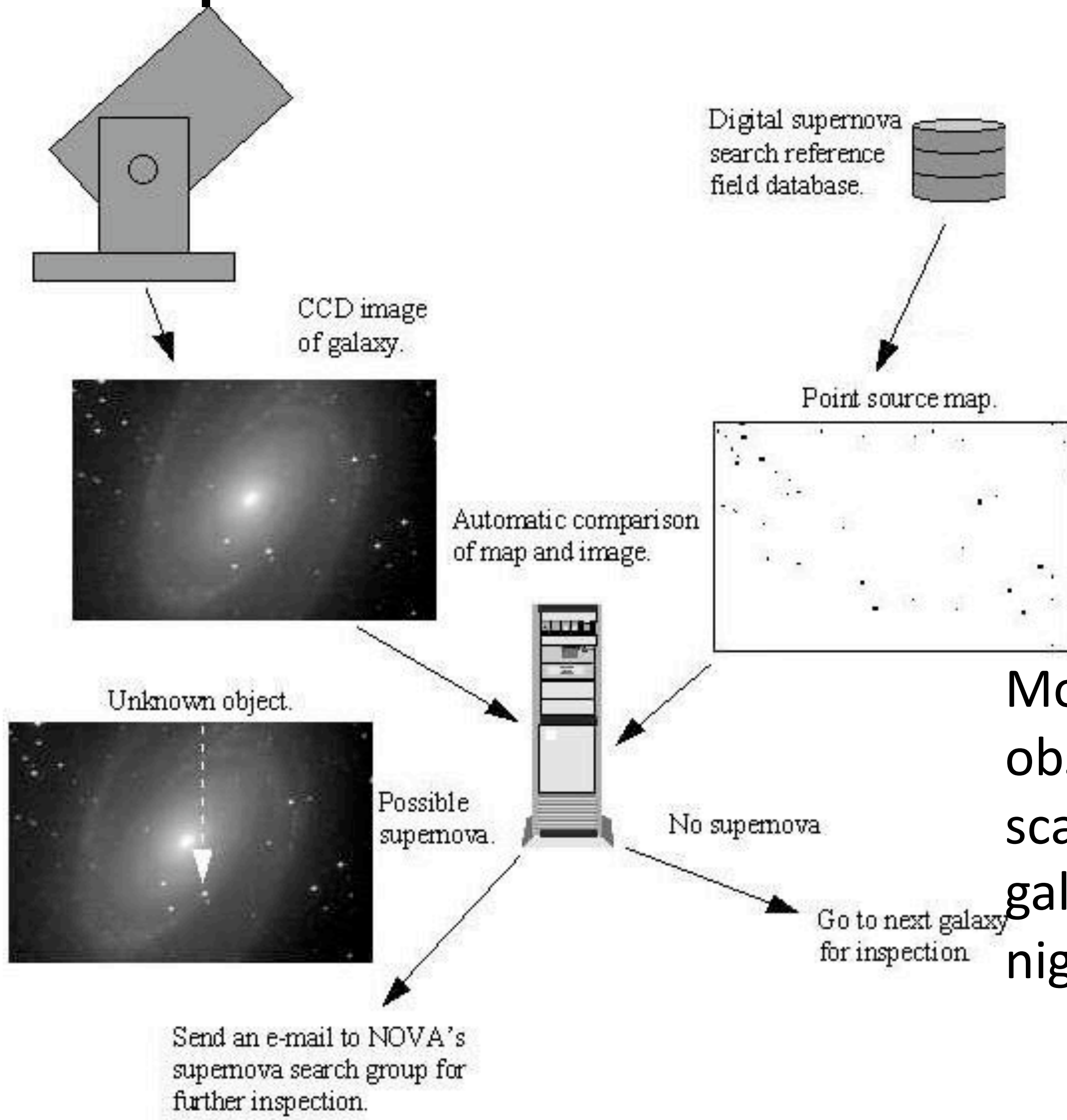
Two main categories of Supernovae

SN Ia is the destruction of a 1.4 Solar Mass white Dwarf



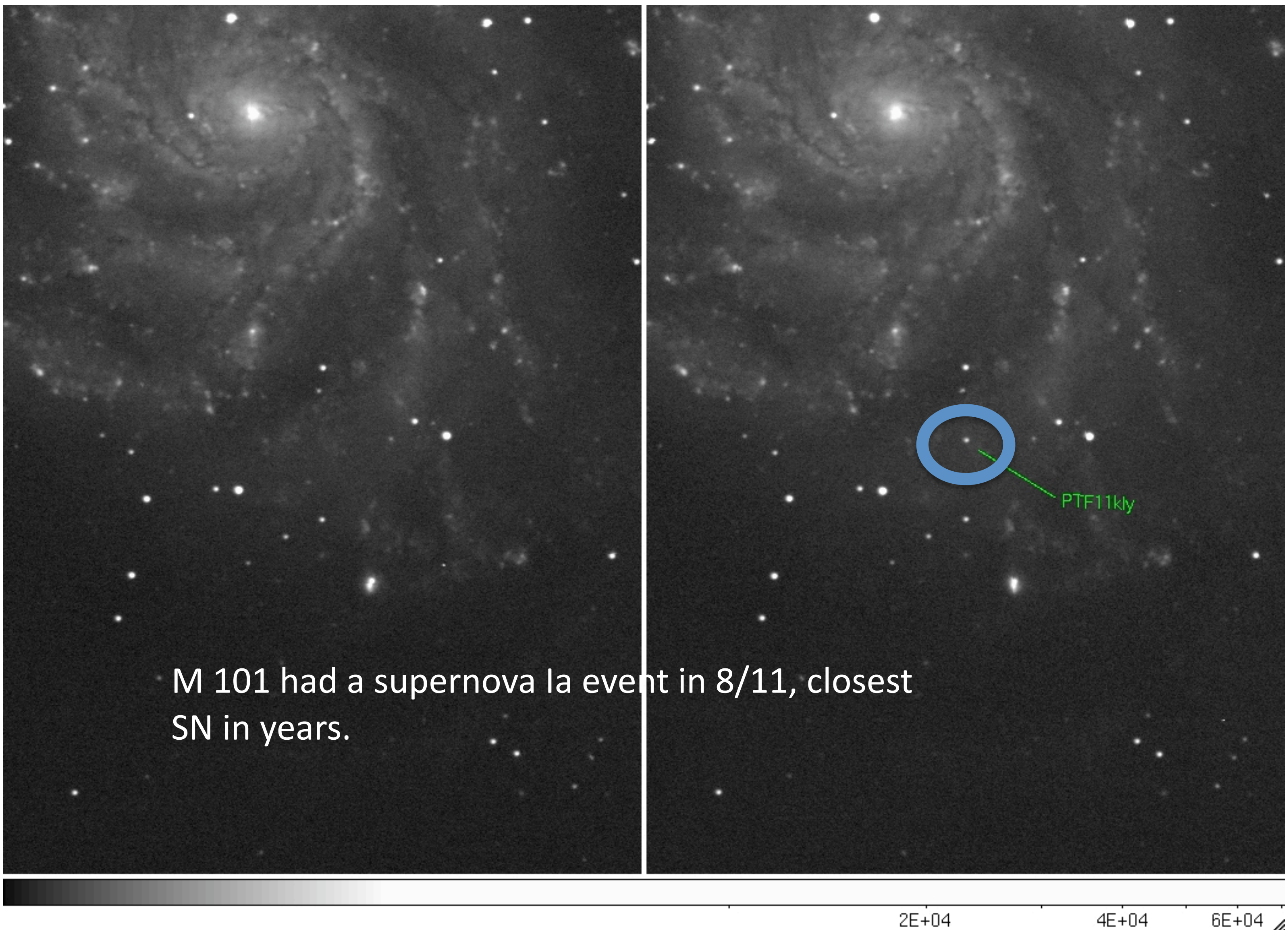
Core Collapse SNe are the explosion of massive stars

Supernova Detection

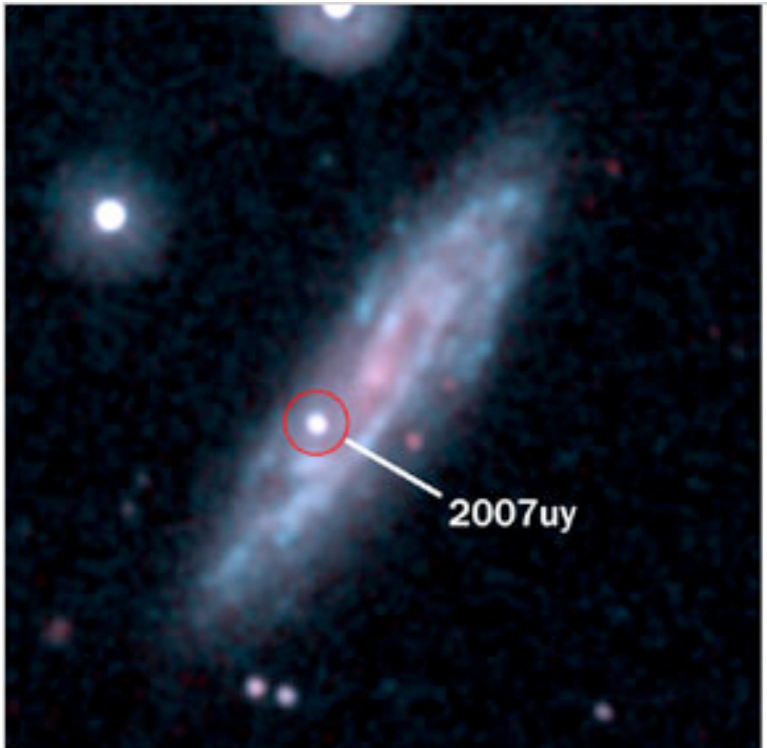
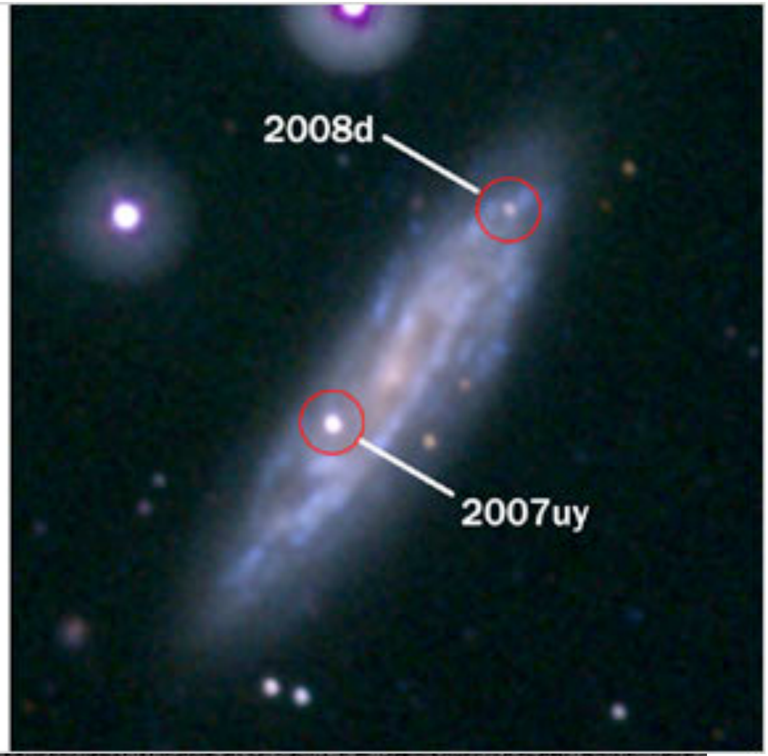
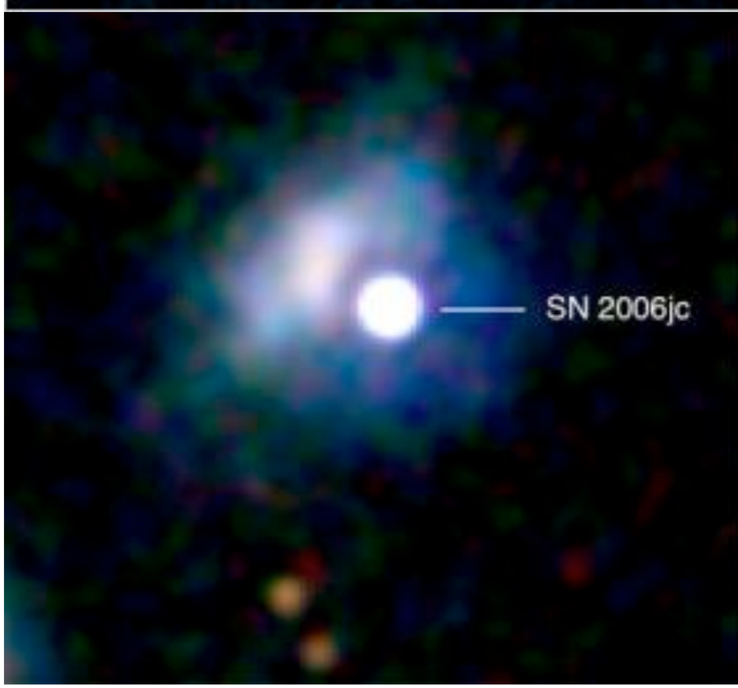
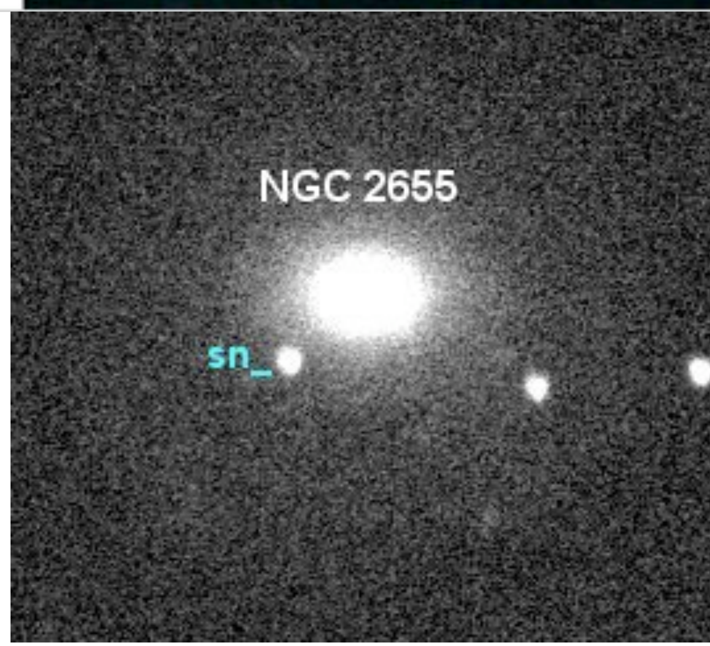


Most observatories scan ~1000 galaxies per night

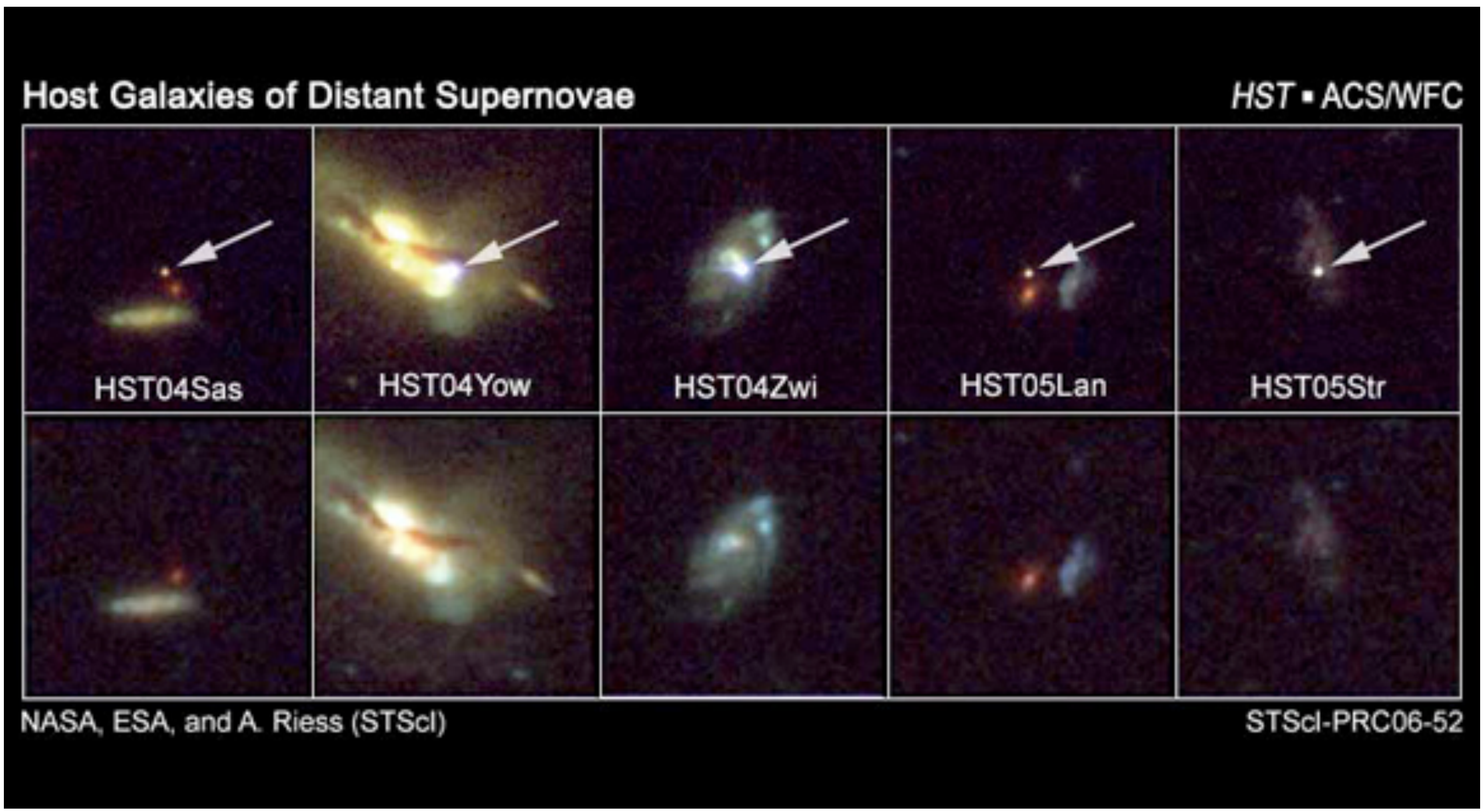
- Select some galaxies for observation
- Take images every few days
- Compare the time-spaced images



M 101 had a supernova Ia event in 8/11, closest SN in years.

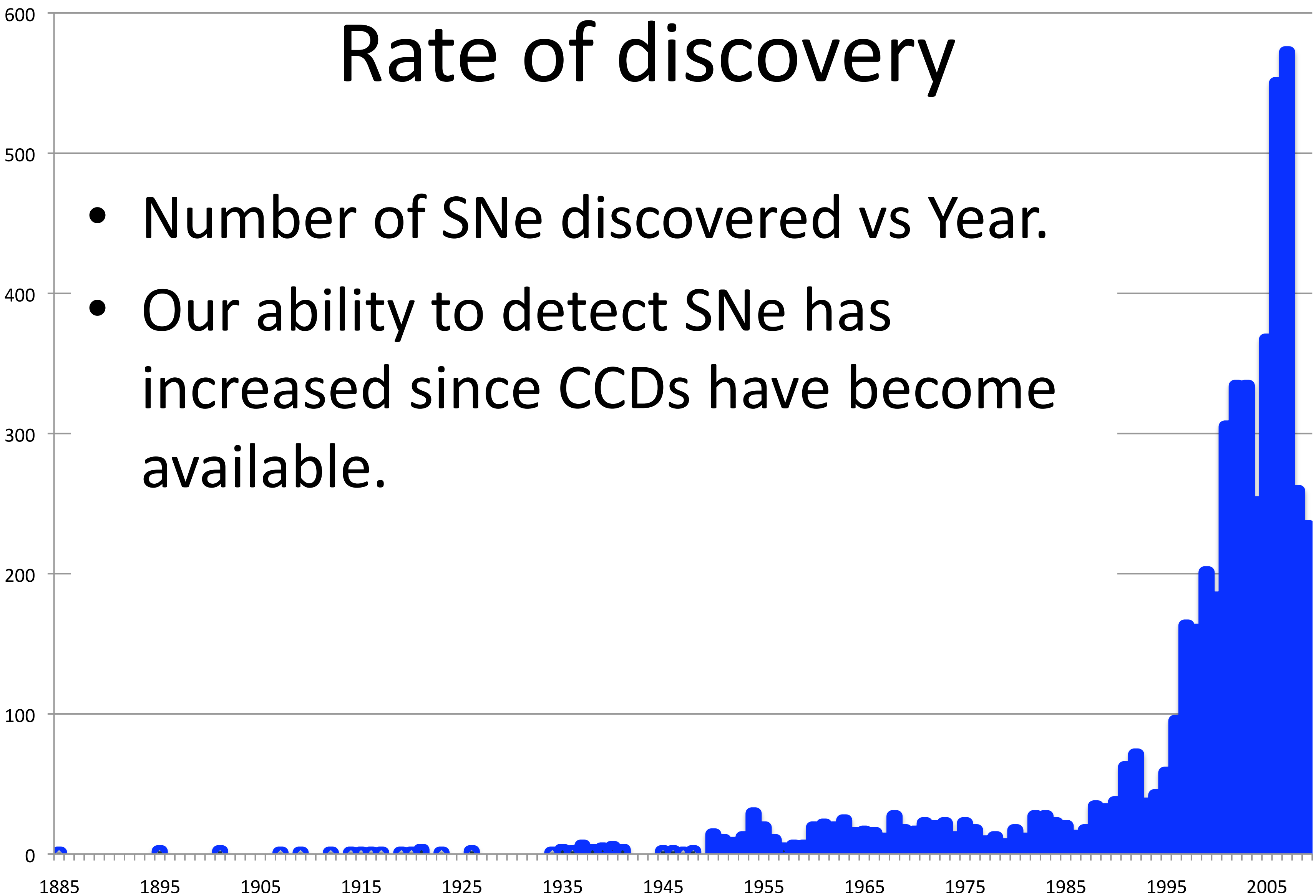

2007uy

2008d
2007uy

SN 2006jc

NGC 2655
sn_

- Brightest events are same luminosity as host galaxy.
- Bright SNe are almost always SN Ia. Core collapse SNe are typically 2-3 magnitudes dimmer.



Rate of discovery

- Number of SNe discovered vs Year.
- Our ability to detect SNe has increased since CCDs have become available.



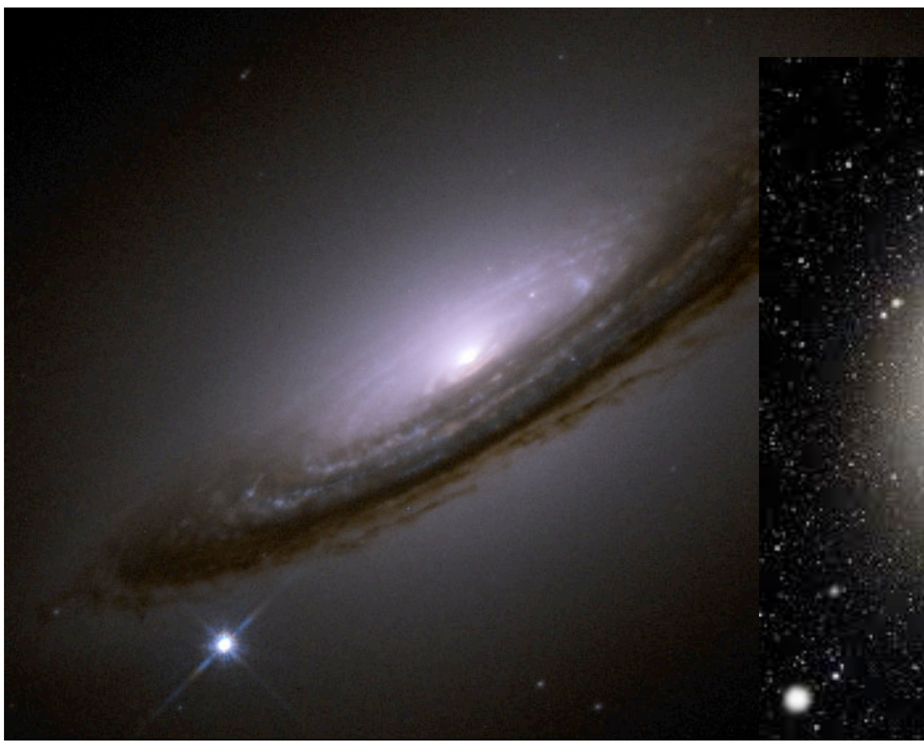
Host Galaxy Selection

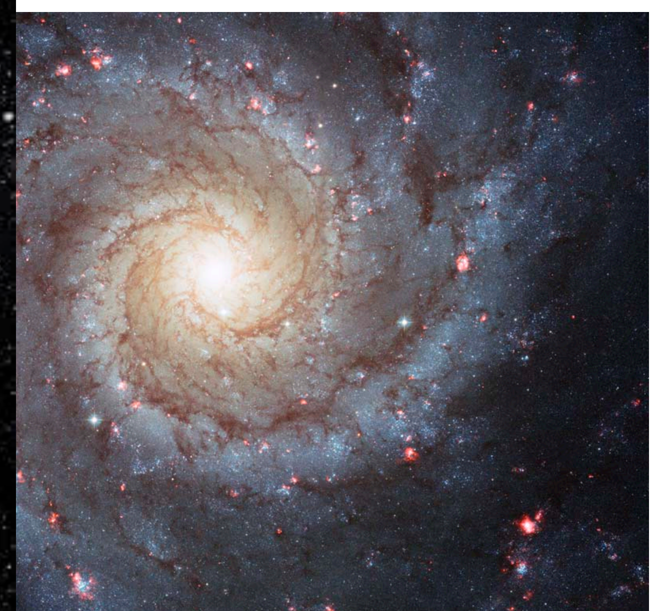
- 3 different types of searches:

1) Catalog Search (distance limited)
2) Random Sky Pointing (Magnitude limited)
3) Cluster Search

Catalog Search

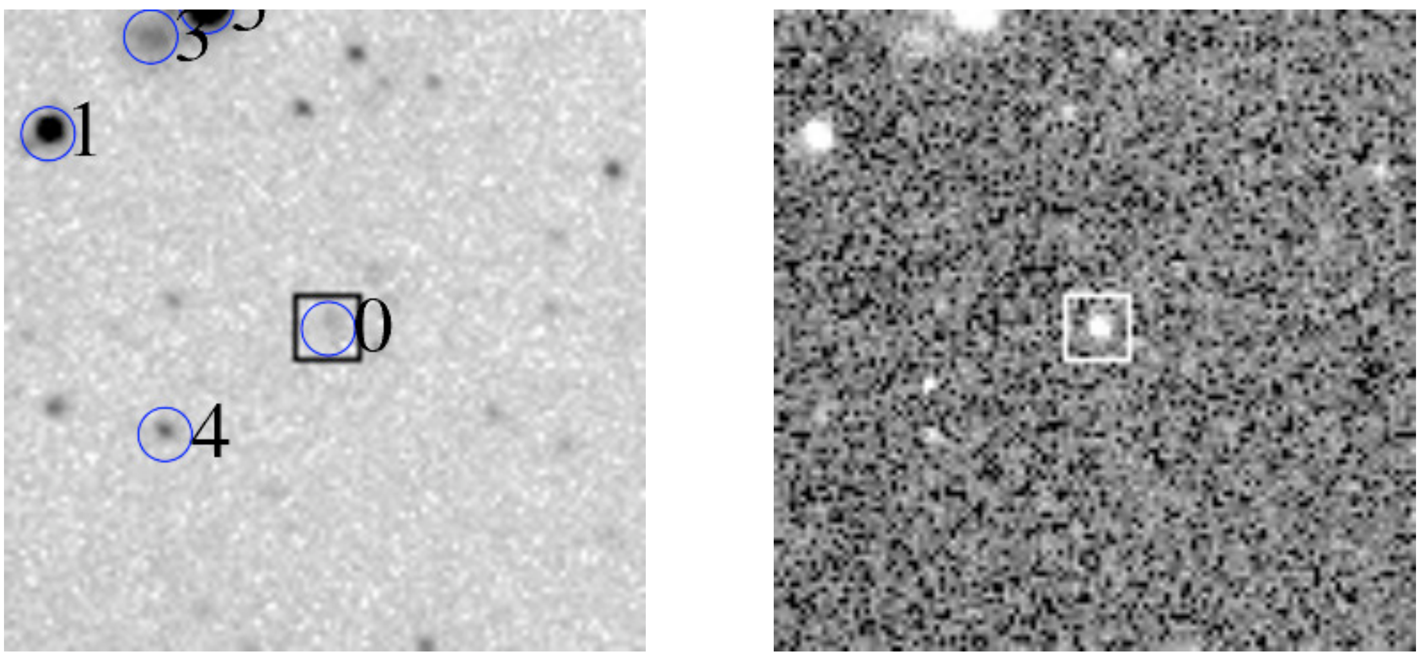
- Select galaxies from NGC/IC/MCG catalogs. These have large apparent diameters and are bright.
- These big bright catalog galaxies represent 5% of all galaxies within the same distance. Lots of star formation.





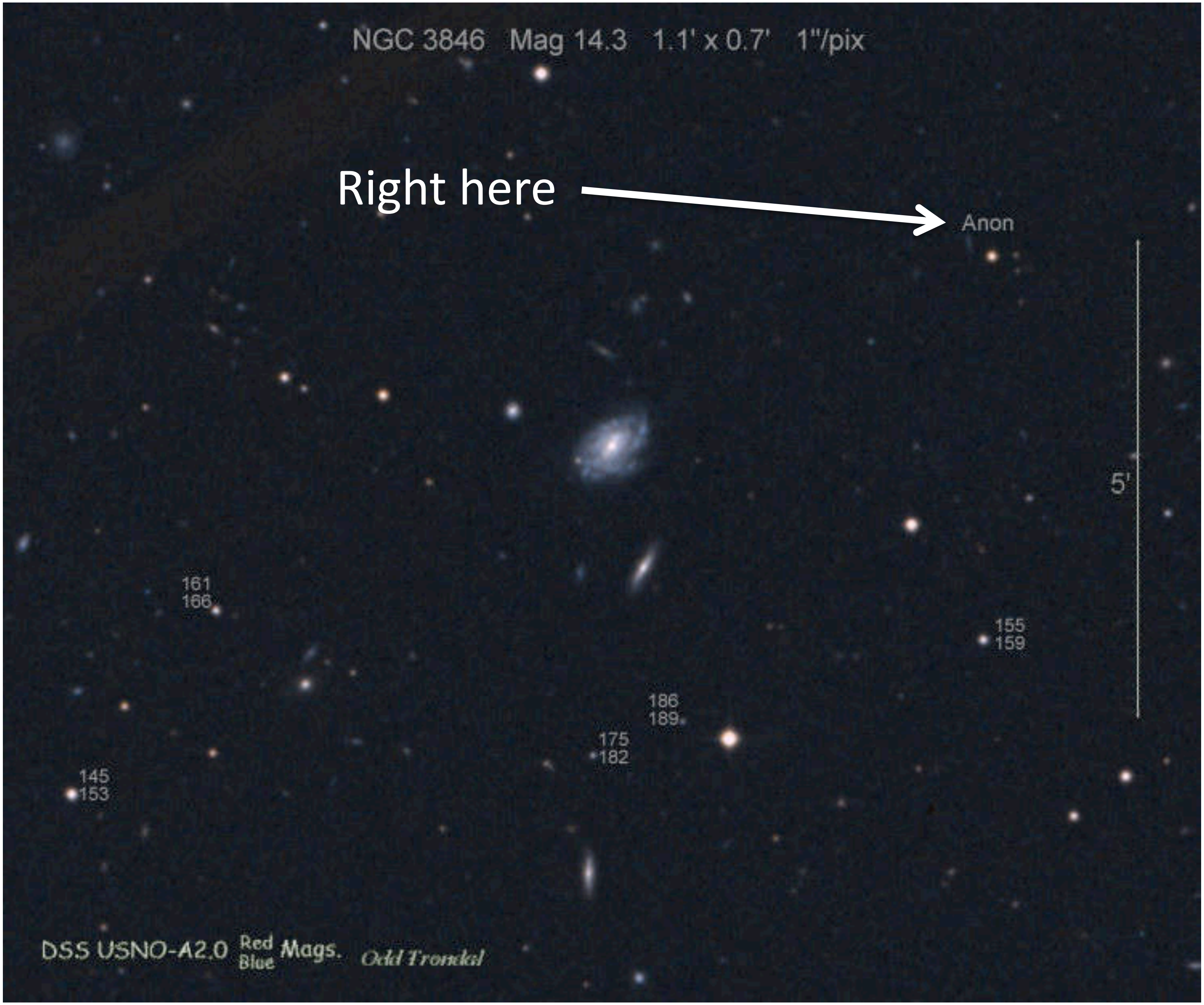
Random Pointing/Pencil Beam Search

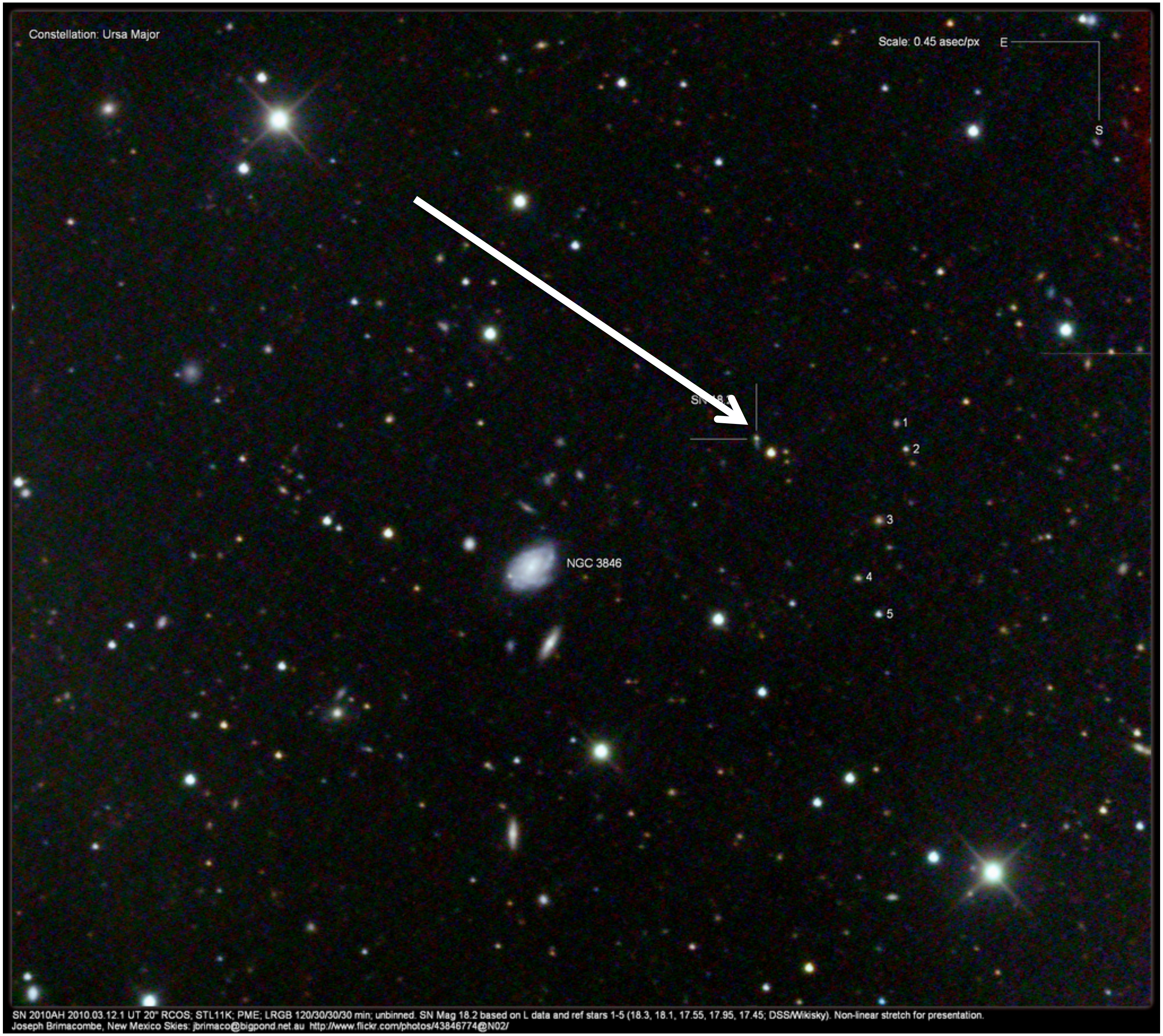
- Search looks for objects up to the detection limit of telescope. Big observatories can only do this type of search.
- Host galaxies are typically not in catalogs.
- Sometimes SN is detected before a host galaxy is found.



Example: Pre-discovery image of SN 2010dp from Catalina Real-Time Transient Survey. Host galaxy is barely visible, yet supernova is very bright (apparent magnitude = 16.7)

Guess where the supernova occurred

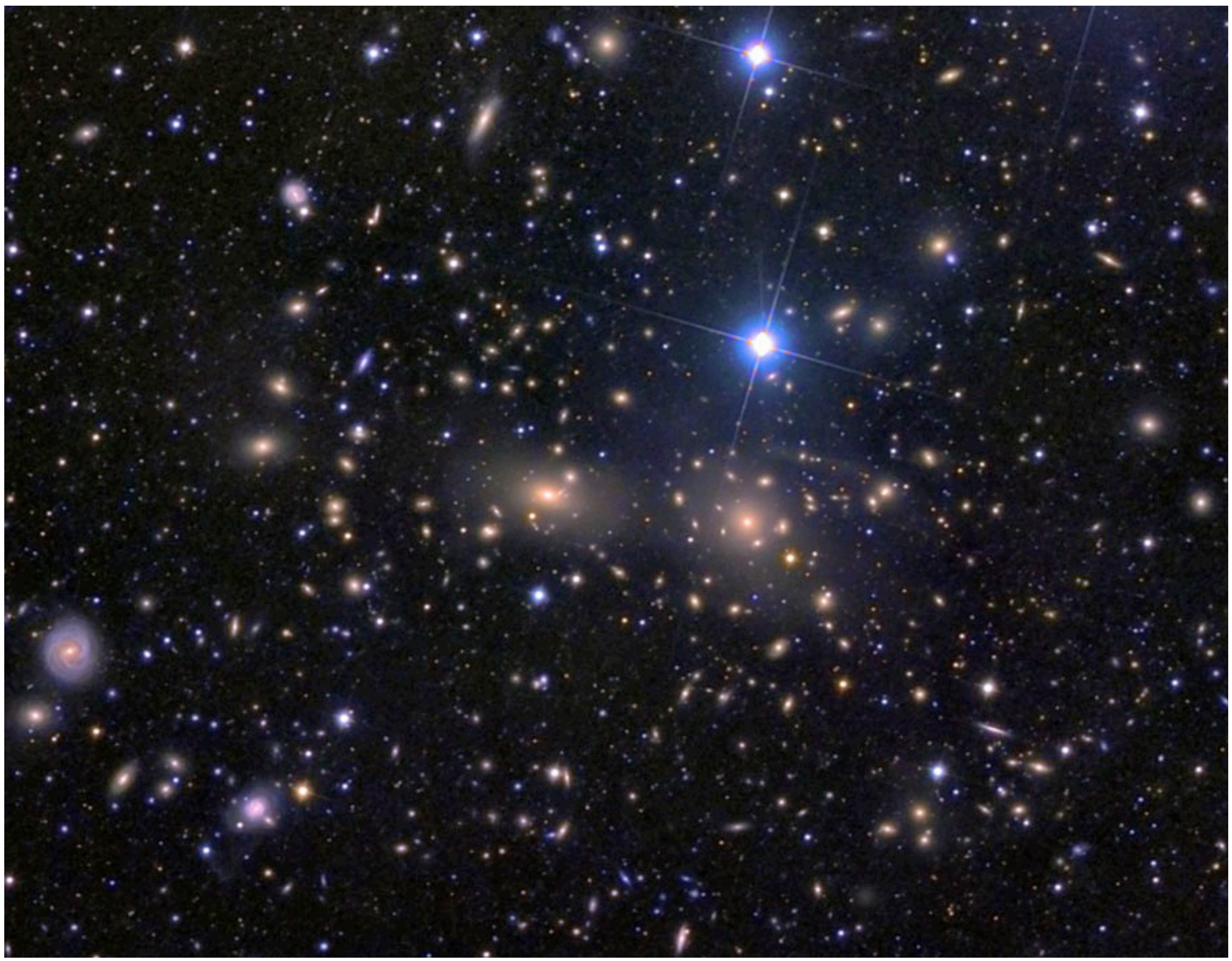

NGC 3846 Mag 14.3 1.1' x 0.7' 1"/pix
Right here
Anon
5'
161
166
155
159
186
189
175
182
145
153
DSS USNO-A2.0 Red Blue Mags.
Odd Trondal


Constellation: Ursa Major
Scale: 0.45 asec/px
E
S
1
2
3
NGC 3846
4
5
SN 2010AH 2010.03.12.1 UT 20" RCOS; STL11K; PME; LRGB 120/30/30/30 min; unbinned. SN Mag 18.2 based on L data and ref stars 1-5 (18.3, 18.1, 17.55, 17.95, 17.45; DSS/Wikisky). Non-linear stretch for presentation.
Joseph Brimacombe, New Mexico Skies: jbrimaco@bigpond.net.au http://www.flickr.com/photos/43846774@N02/

Cluster Searches

- 1000’s galaxies are located within a few degrees.
- Makes looking for SNe more convenient.
- However, supernova rates seem lower. For example: the coma cluster and NGC 6946

The Coma cluster contains 1000's of nearby galaxies within 2 degrees (10^{14} stars) and only 3 SN have been discovered in the last 50 years. (2010ai, 2008dx, 1962a)



Supernovae and detection

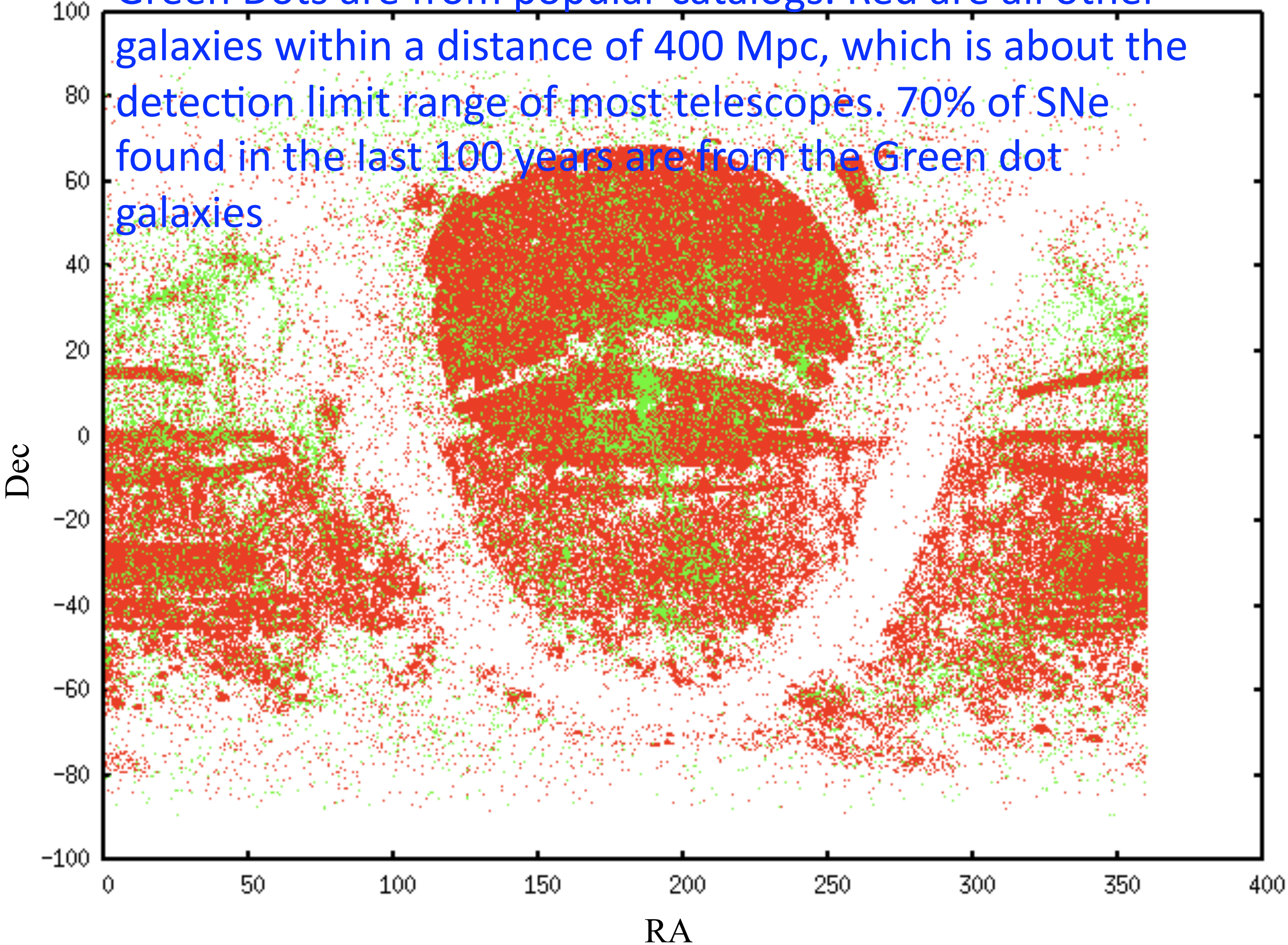
- NGC 6946 has 10^{11} stars
- had 9 SN since 1917; Rate is ~2000x greater than coma cluster
- Lots of ongoing star formation
- # of SNe depend on galaxy.

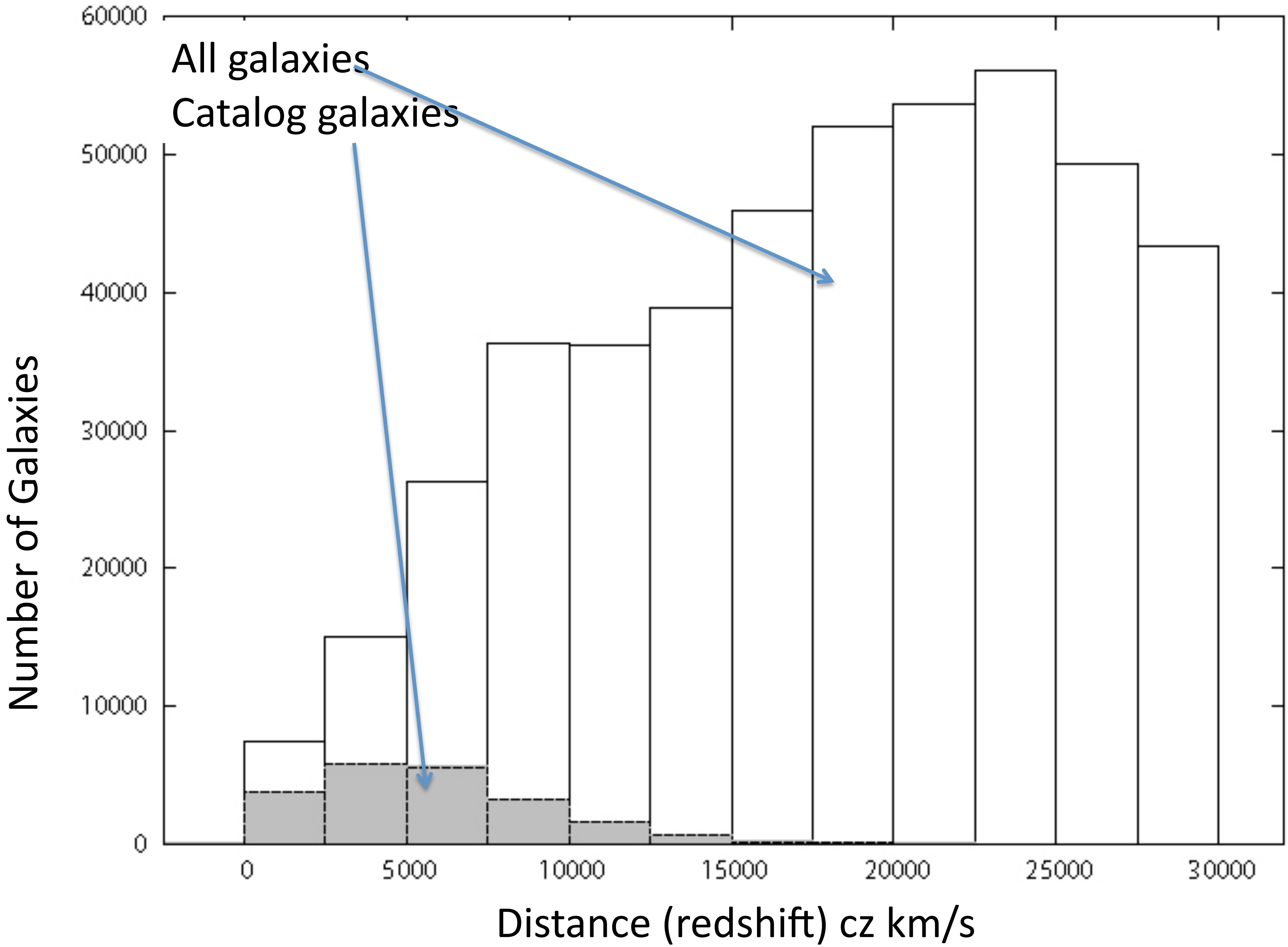
- NGC 4911 hasn’t had a supernova event in the last 100 years

Supernova Rates

- Measured in SNu – Supernova Unit
- 1 SNu = 1 SN per 10^{10} L_{Sun} per century
- Based on star formation and stellar mass.
- the more stars, the more SNe events – then how do you explain the Coma Cluster?
  - Different types of galaxies? – yes.
  - Or selection function? Are some galaxies more likely be observed than others? – yes.

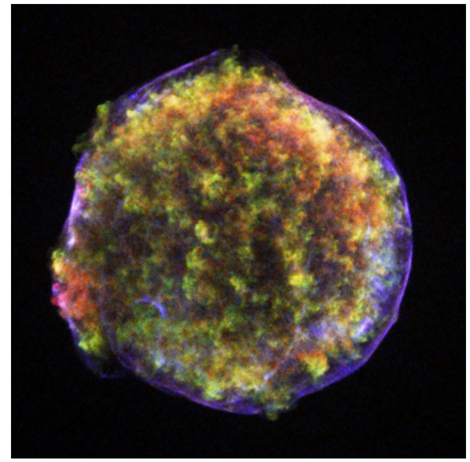
Green Dots are from popular catalogs. Red are all other galaxies within a distance of 400 Mpc, which is about the detection limit range of most telescopes. 70% of SNe found in the last 100 years are from the Green dot galaxies



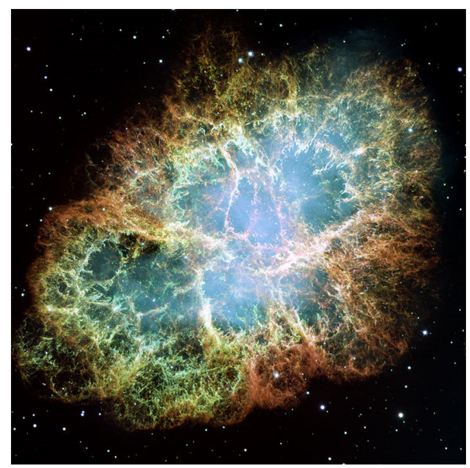

All galaxies
Catalog galaxies
Number of Galaxies
Distance (redshift) cz km/s
60000
50000
40000
30000
20000
10000
0
0
5000
10000
15000
20000
25000
30000

Supernovae in Our Galaxy

- Some SN events are recorded in history
- → Tycho Brahe's supernova event in 1572



- → Crab Nebula (SN in 1054)



Historic SNe and Pre-Supernova Stars

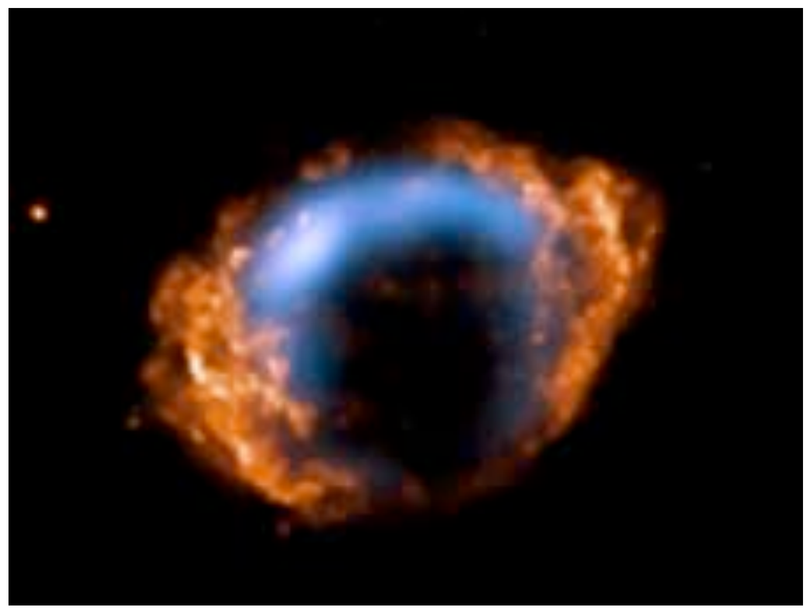
Historical Supernova In Our Galaxy

Year	Peak Mag.	Constellation	Distance Light Years
AD 185	-6	Centaurus	4500
AD 386	-3	Scorpius	16000
AD 1006	-6	Lupus	4500
AD 1054	-10	Taurus	6500
AD 1181	-1	Cassiopeia	8500
AD 1572	-4	Caseopeia	10000
AD 1604	-3	Ophiuchus	14000
AD 1671	+6	Cassiopeia	9000

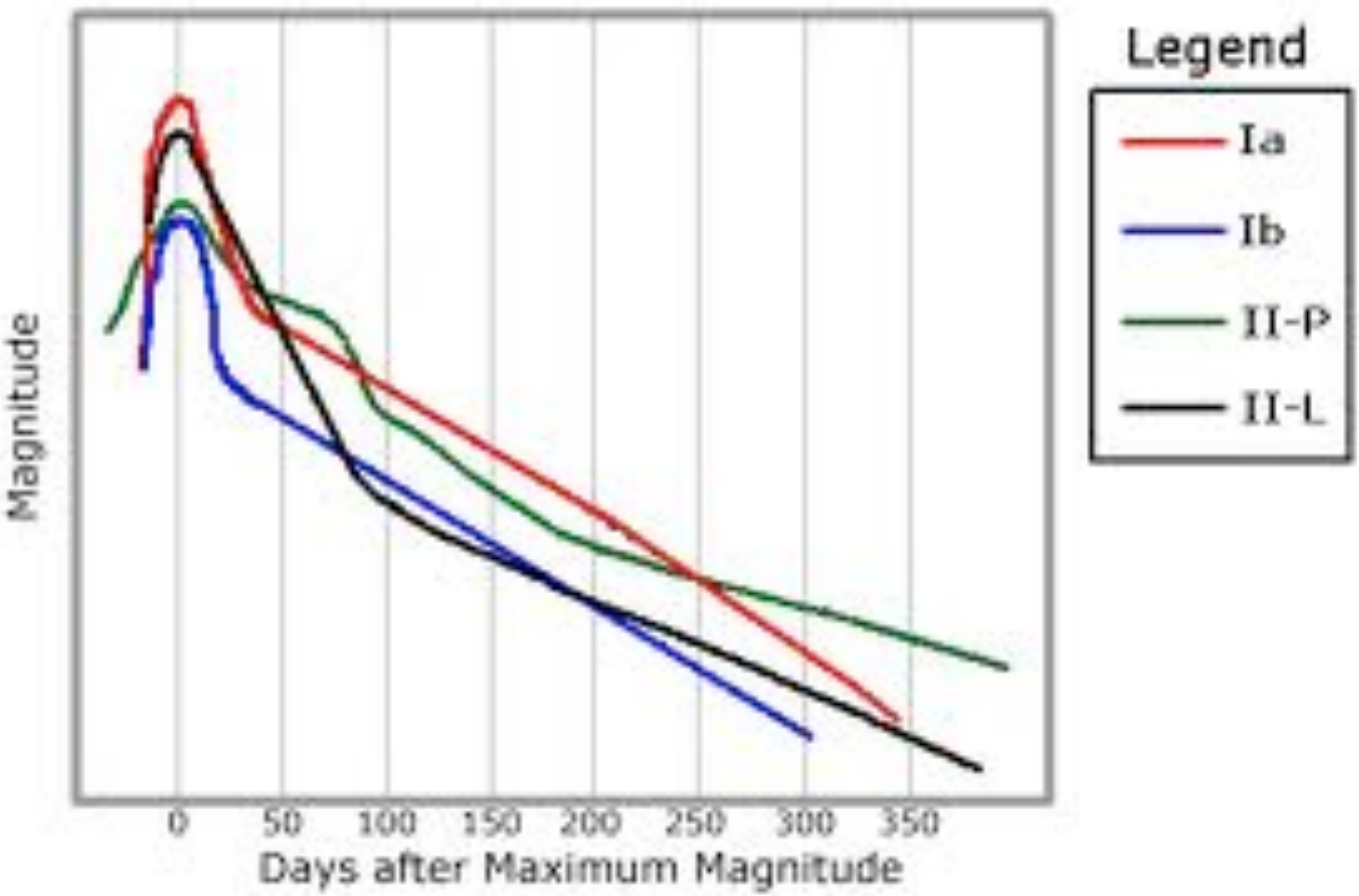
- Betelgeuse (in Orion) at 430 light years
- Antares (in Scorpius) at 600 light years
- Rasalgethi (in Hercules) at 380 light years
- Note: if Supernova creating the Crab nebula was located at Betelgeuse's distance, it would be as bright as the full moon.

- Theoretically, the Milky Way SN rate should be 2 SNe every 100 Years (2 SNu).
- Observationally, the rate is 0.75 SNe every 100 years.
- Selection effect or true rate?

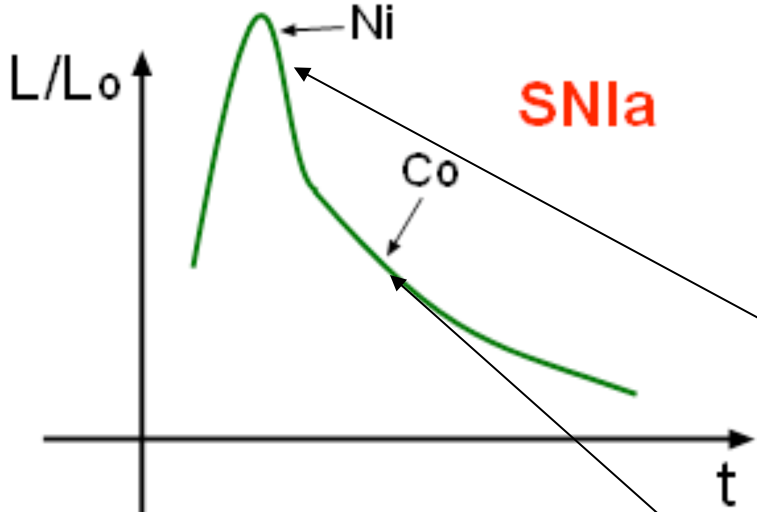
Youngest supernova remnant in MW. SN peaked in 1800's.



Supernova Light Curves



Supernova Ia Brightness over Time



Brightness depends on which isotope is decaying.

$$^{56}_{28}\mathrm{Ni} \rightarrow {}^{56}_{27}\mathrm{Co} + e^{+} + \nu_e + \gamma$$

Ni ½ life = 6.1 Days

$$^{56}_{27}\mathrm{Co} \rightarrow {}^{56}_{26}\mathrm{Fe} + e^{+} + \nu_e + \gamma$$

Co ½ life = 77 Days

Supernova Ia

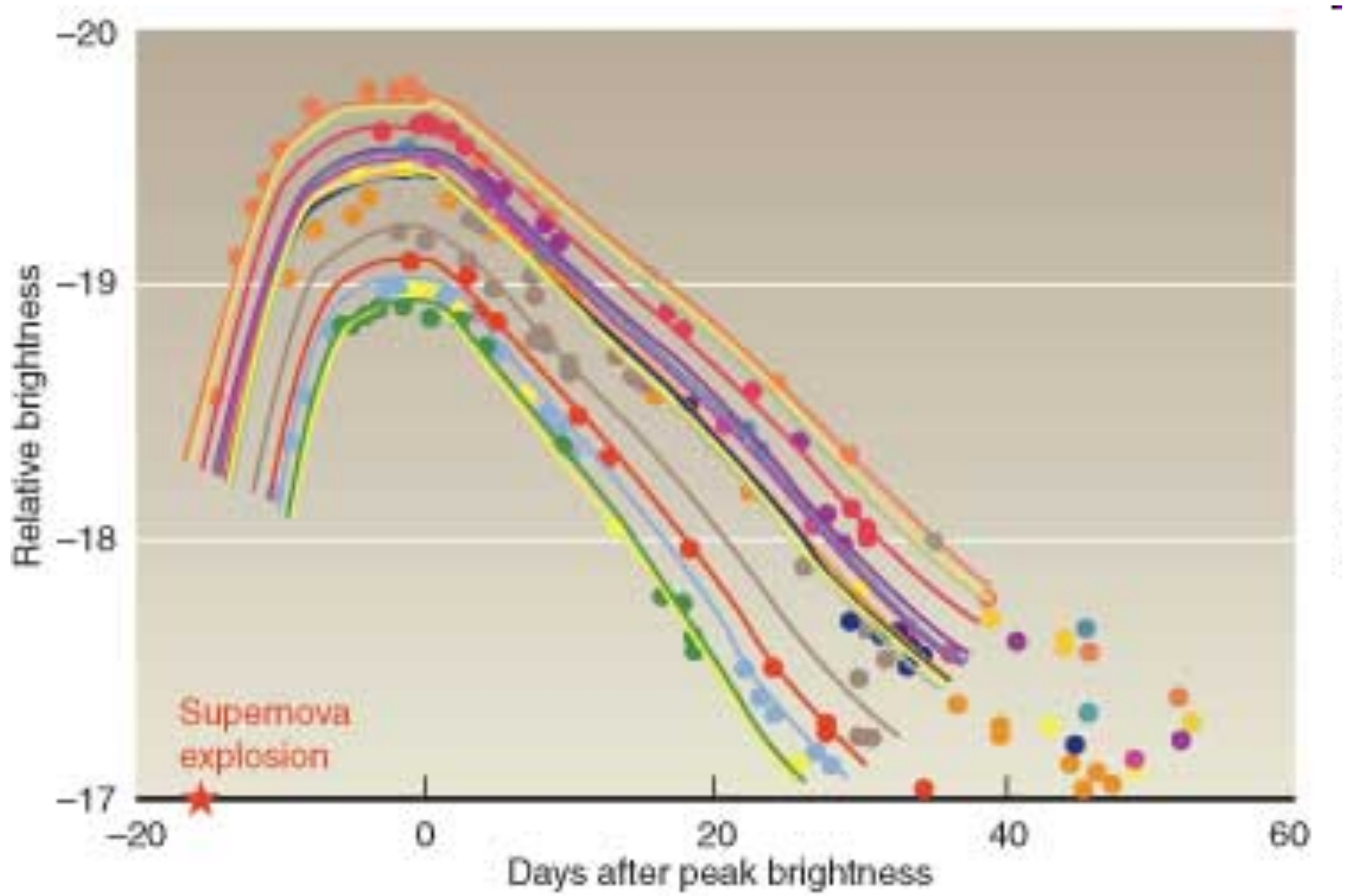
- SN Ia are theorized to be a white dwarf that explodes when it reaches it's limiting mass ~1.4 solar masses.
- Reaches this mass from accreting material from another star
- **SN Ia supposedly all have the same luminosity, when they explode due to this mass limit.**
- Used as measuring sticks

These **measuring sticks are called** **Standard Candles**. We can determine how far these objects lie by comparing their **known (assumed)** intrinsic brightness to their **measured** brightness.

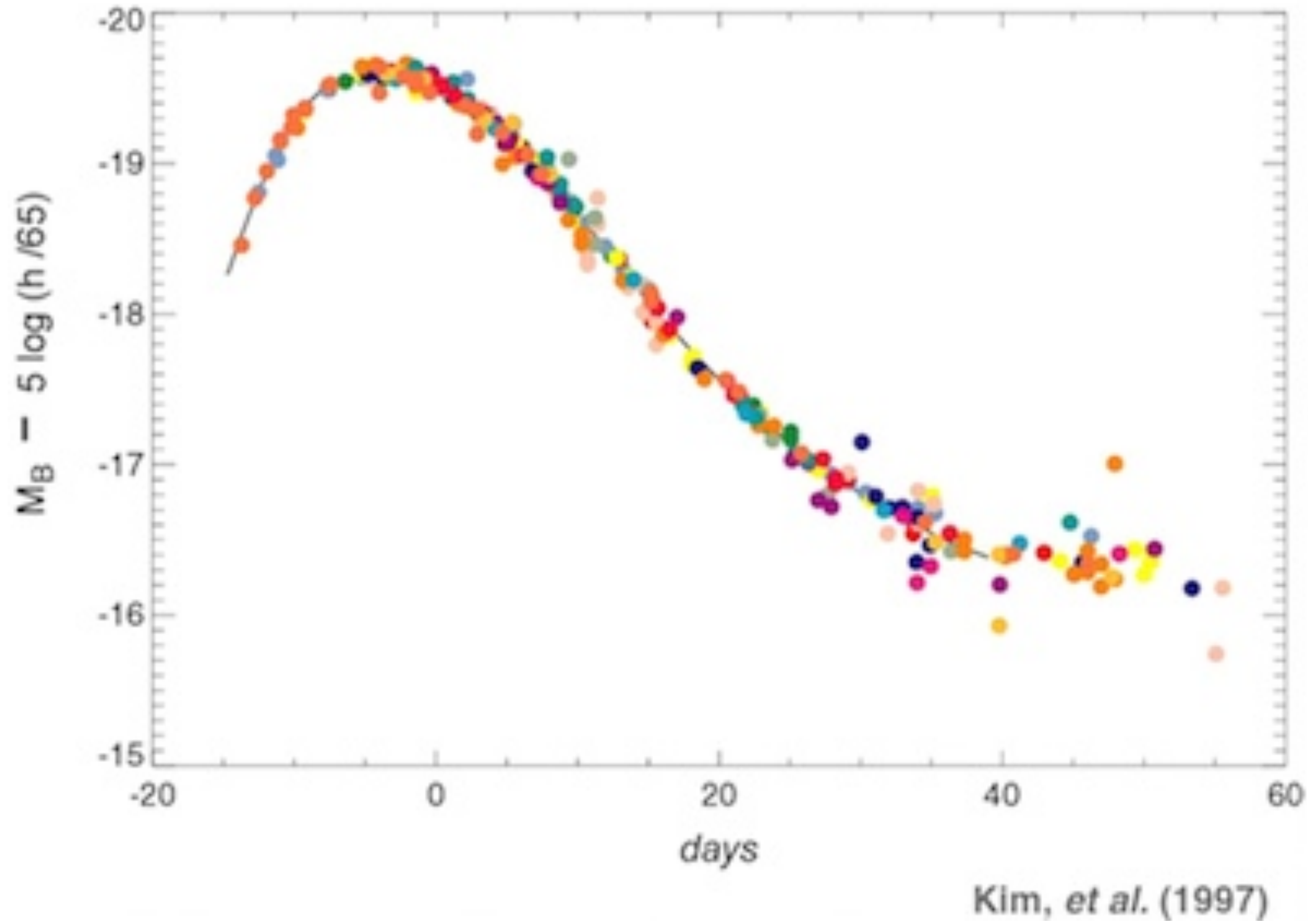
At larger distances, the host galaxy is difficult to detect, but the SN is visible

Flux **decreases** as **1/distance(cosmology)^2**

The peak is not constant. In fact it spans over a range. Curves are calibrated empirically….



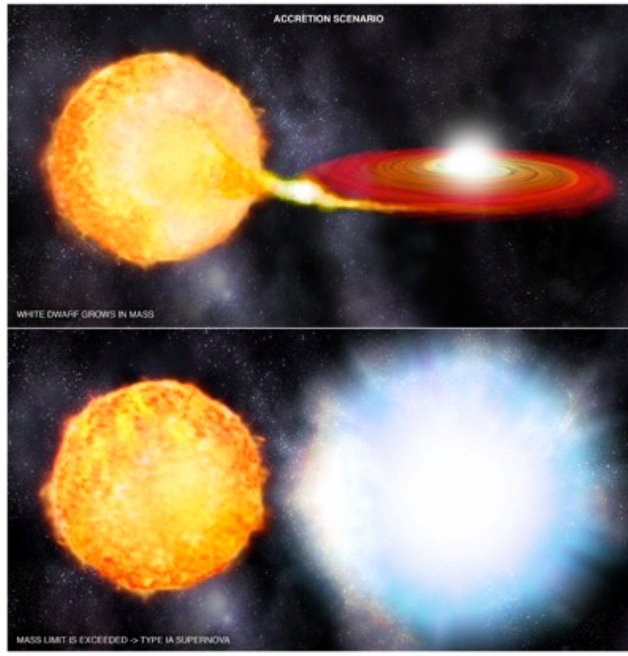
…to this, by relating the peak luminosity to the width of the light curve



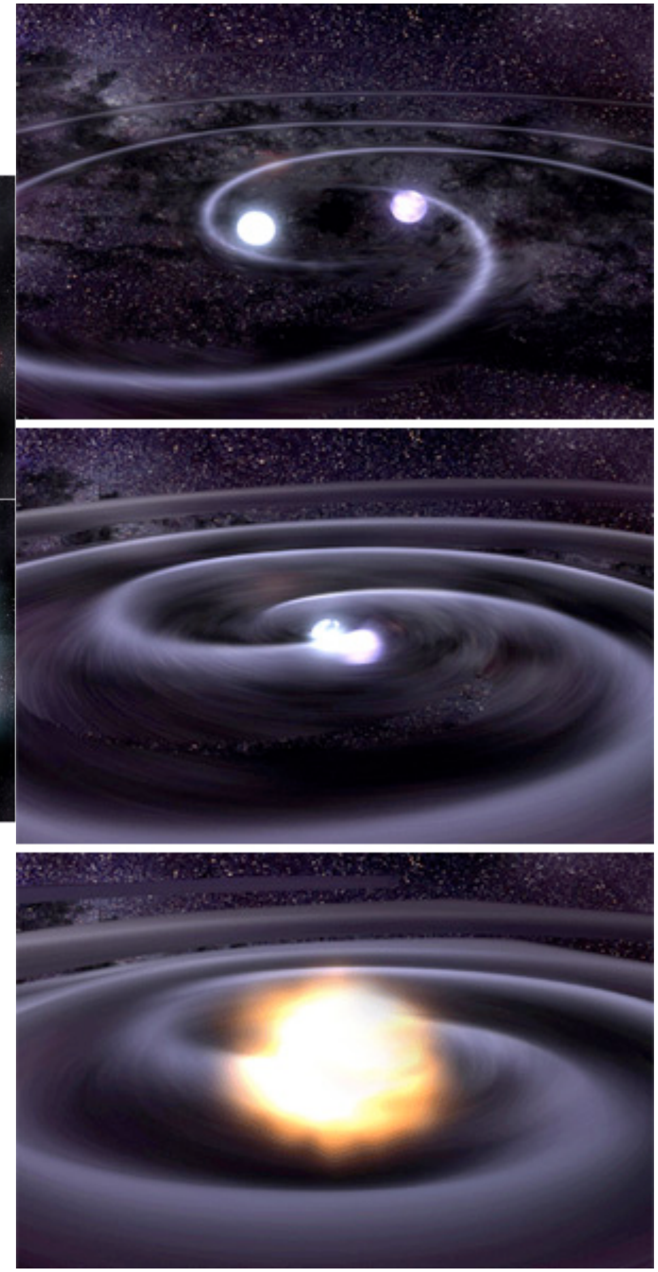
- If you believe that this parameterization works, then you can make assumptions about other SNe that don't fit this curve – yes this happens.
  - Over luminous events are considered to have Masses > 1.44 (2003fg, 2007if),
  - Light curves that have a different shapes, such an excess of red light, are assumed to be dusty.
  - Under luminous Ia, (-17mag) don't fit this parameterization

What is a "normal" SN Ia?

- We don't know.
- Different models of the progenitor
- Contradictory observations/ theories…



Accretion scenario
Image: NASA/CXC/M Weiss.

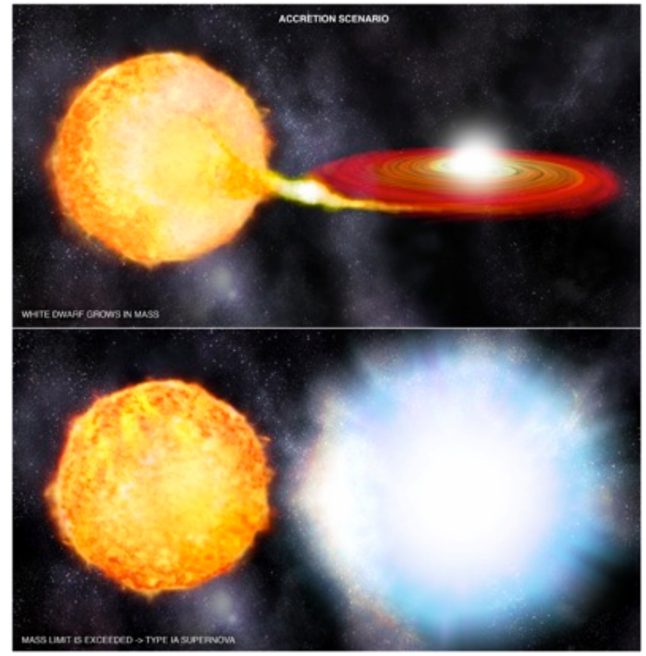


WD-WD Merger Scenario
(c) NASA/Dana Berry, Sky Works Digital

Supernova Ia as a standard candle: Unresolved Issues

- Never observed a SN Ia progenitor
- Models can’t describe observed light curve, abundance of metals produced, nor can they simulate from the progenitor to resulting light curve.
- Most characteristics of SNe Ia are based in nearby galaxies. Are these same as all (distant) galaxies?

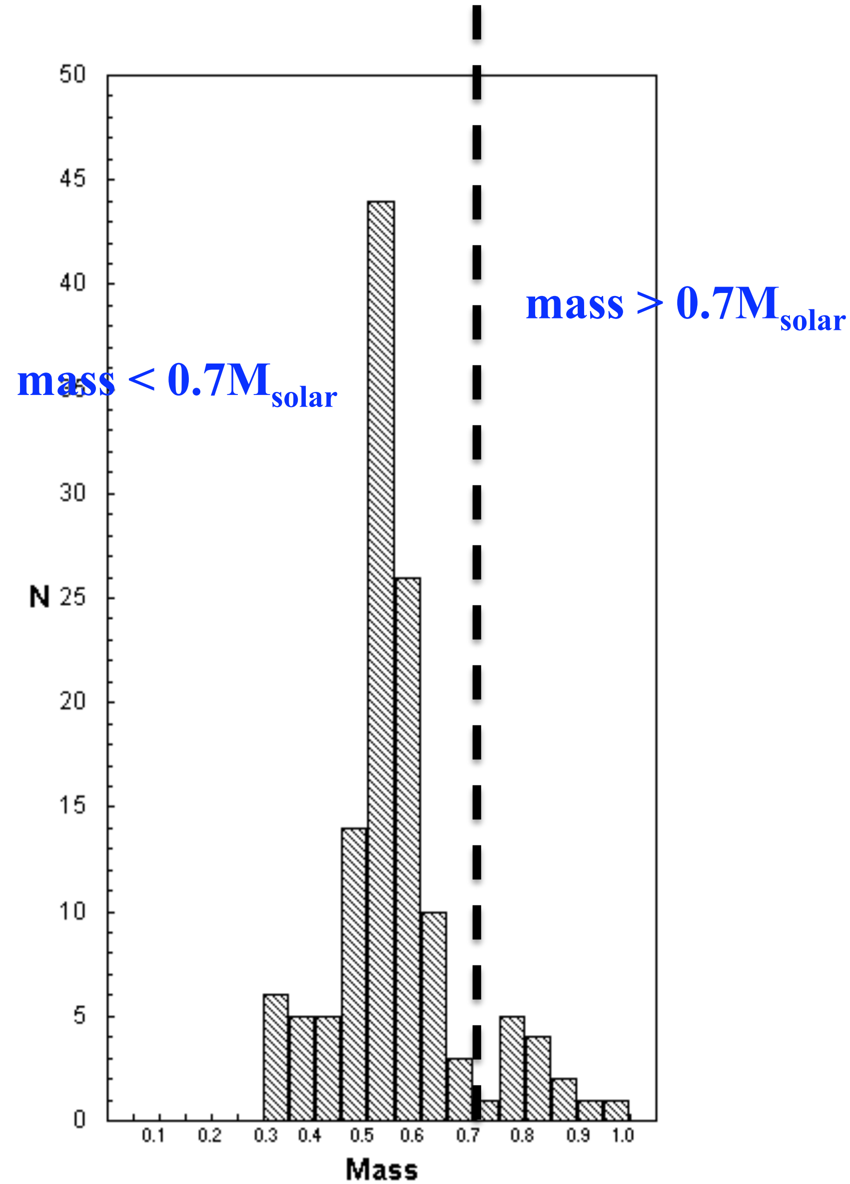
Progenitors as WD and Main Sequence Star?



1. Accreted mass should be pure hydrogen, yet not present in SN Ia spectrum.
2. Accretion requires special conditions and high mass WD (M>.9 Msolar) → very rare.
3. Accretion leads to off center explosions and different brightnesses.

Supernova Ia Progenitor Unresolved Issues

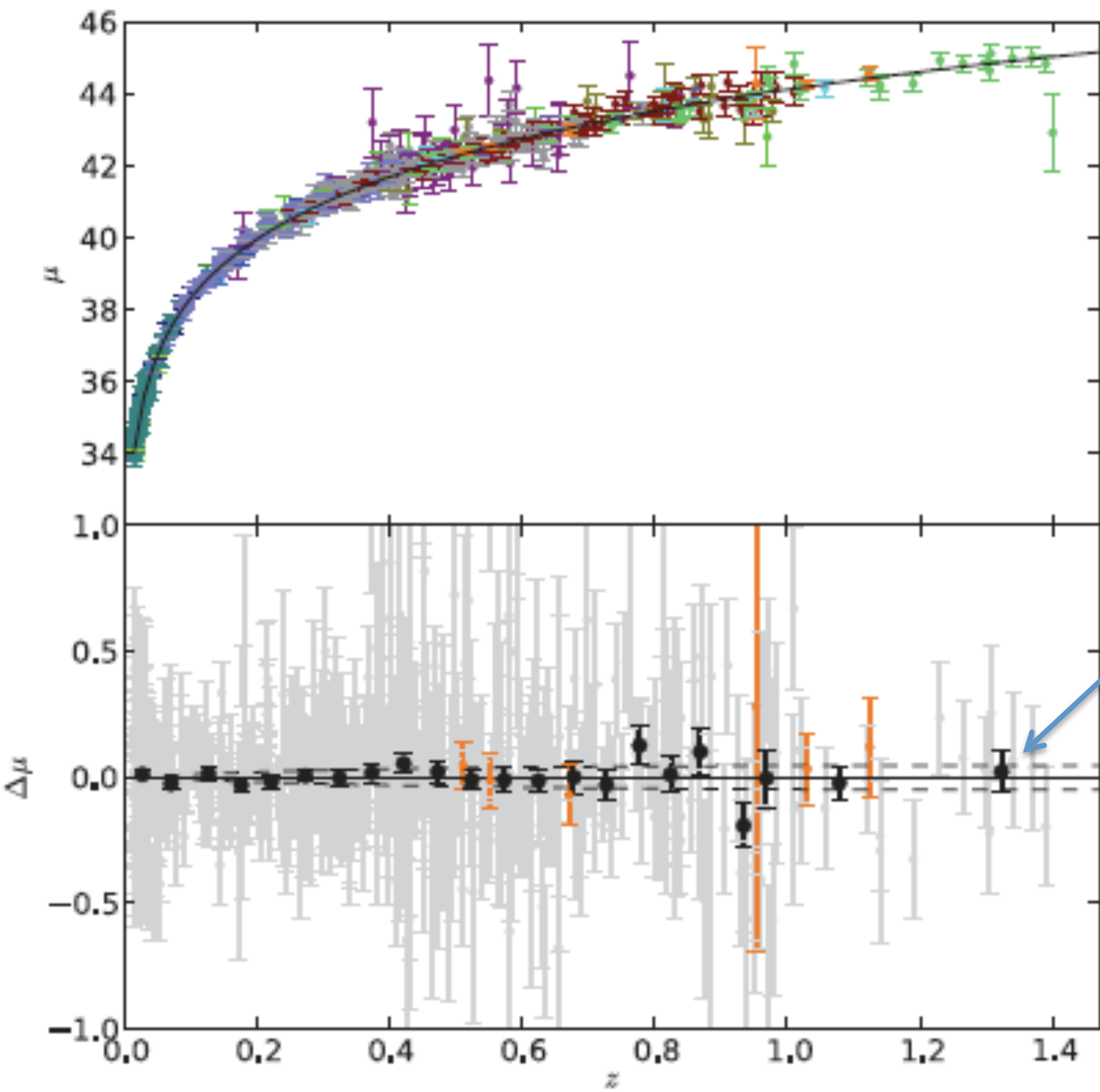
- Do we have enough WD-WD pairs in the universe with total mass =>1.44 to produce the observed rate?
- Based on the nearby white dwarf mass distribution, the SN Ia rate would be **1 every 10,000 years (observed 3 every 1000 years)**.
- Inconsistent!



Alternatives

- Both types of progenitor scenarios are probably both valid.
- White dwarfs explode at sub-chandrasekhar masses, some models show this as possible. More likely to occur.
- If true, then how can SNe Ia be used as standard candles?

- Then the use of SNe Ia in high precision cosmology becomes questionable.



Error bars in SN data are at least as large as the difference between different models of Dark Energy.

Amanullah et al 2010