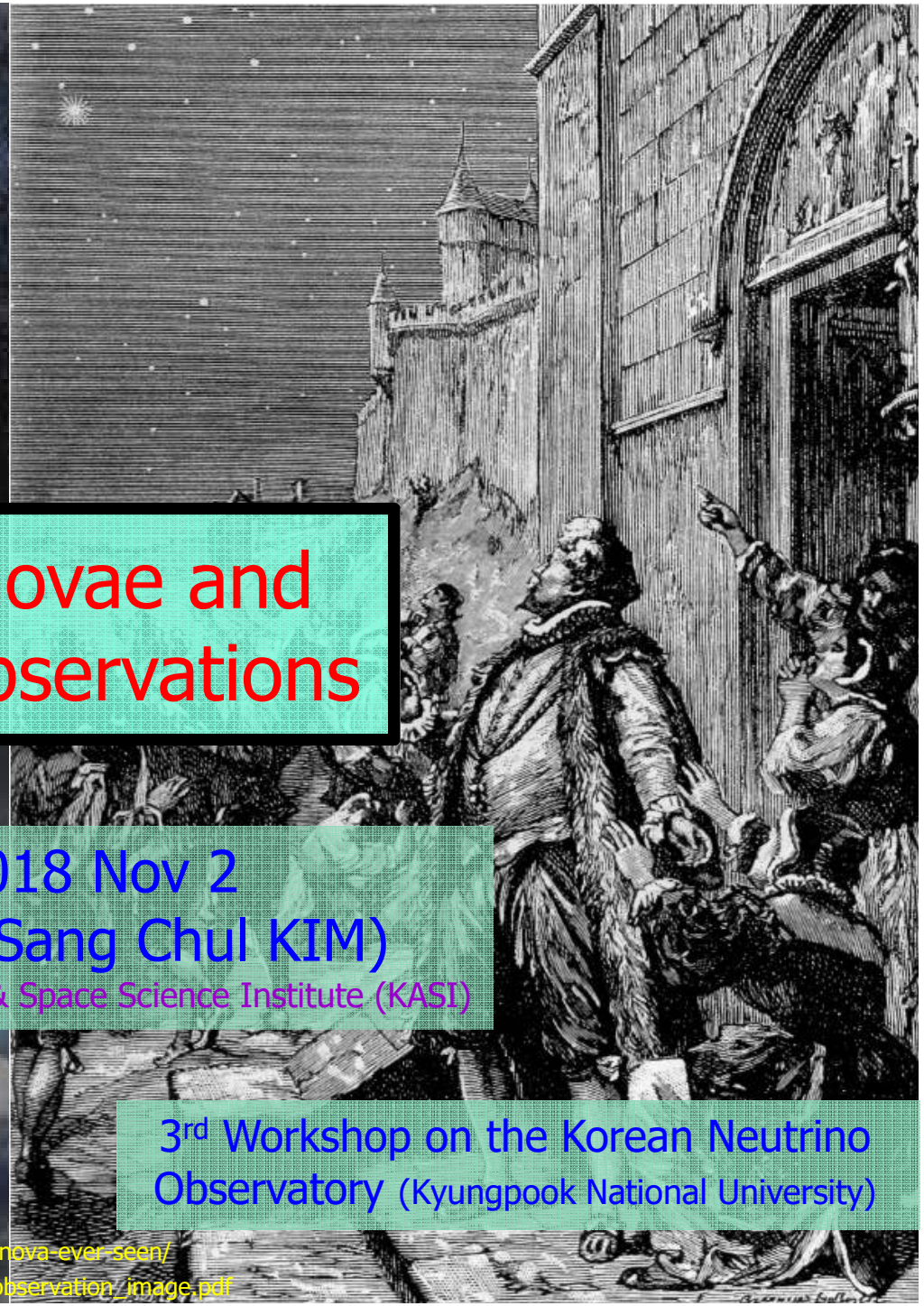


Neutrinos from Supernovae and Supernova Follow-up Observations

2018 Nov 2

김상철(Sang Chul KIM)

Korea Astronomy & Space Science Institute (KASI)

3rd Workshop on the Korean Neutrino Observatory (Kyungpook National University)

https://www.scientificamerican.com/article/found-the-most-powerful-supernova-ever-seen/

http://www2.mpia-hd.mpg.de/IRSPACE/Tycho_release/tycho1572/Tycho_observation_image.pdf

Annals of the Joseon Dynasty
(조선왕조실록, 朝鮮王朝實錄) – Kepler SN

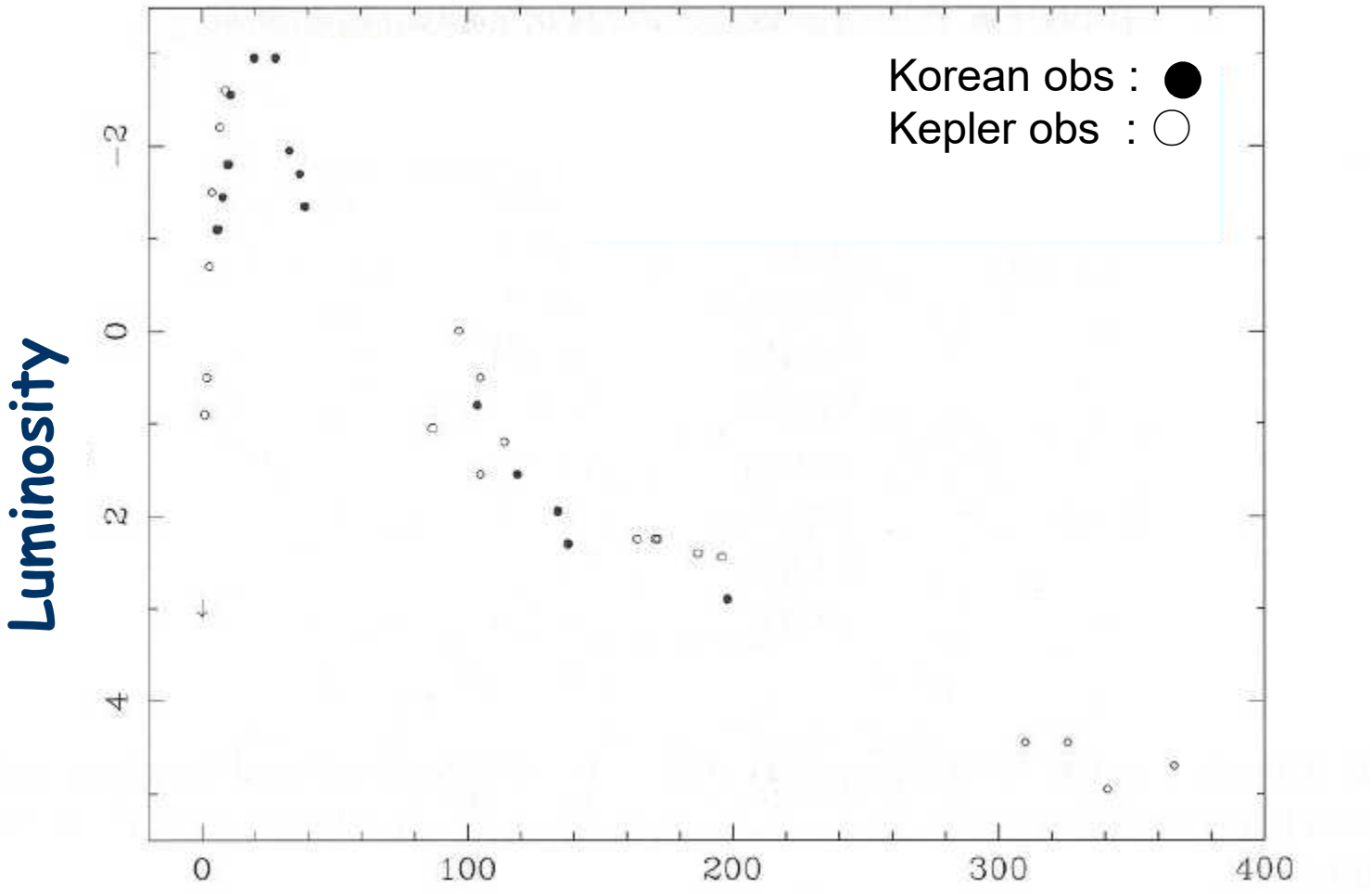
Joseon dynasty
King Sunjo yr 37
(선조 宣祖 37년)

(1604 October)

관상감(觀象監,
Joseon Royal
Observatory)

Guest star(客星)

SN 1604 (type Ia)



The Historical Supernovae (D. H. Clark & F. R. Stephenson, 1977, p. 78)

JKAS – SN 1994I

JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
28: 31 ~ 43, 1995

UBVRI CCD PHOTOMETRY OF THE TYPE Ic SUPERNOVA SN 1994I IN M51: THE FIRST TWO MONTHS

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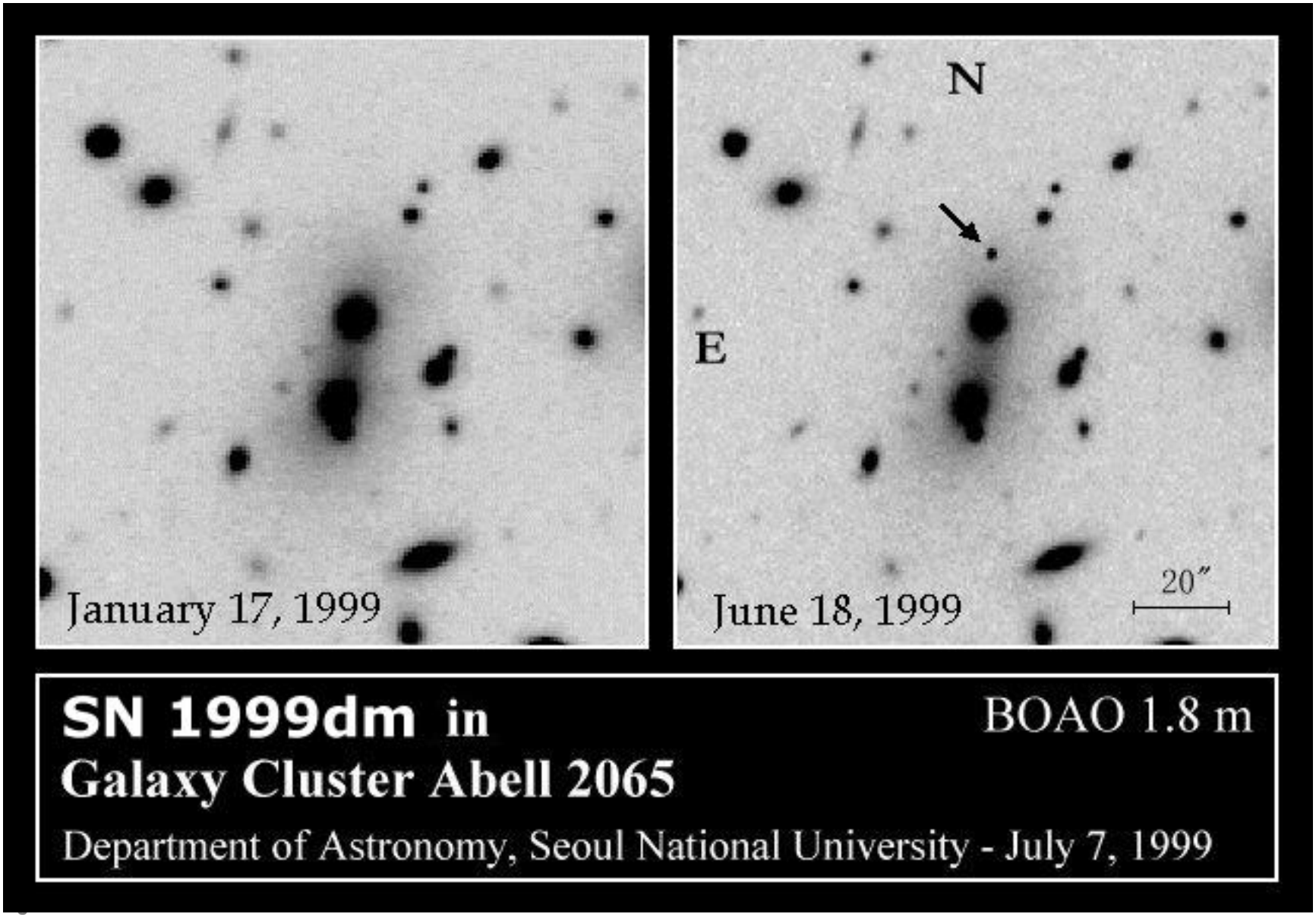
(Received Feb. 6, 1995;Accepted Feb. 23, 1995)

ABSTRACT

We present $UBVRI$ CCD photometry of the Type Ic supernova SN 1994I in M51 which was discovered on April 2, 1994 (UT). $UBVRI$ CCD photometry of SN 1994 I were obtained for the period of the first two months from April 4, 1994, using the Seoul National University Observatory 60 cm telescope. The light curves of SN 1994I show several interesting features: (a) SN 1994I reaches the maximum brightness at B-band on April 8.23 ($B = 13.68$ mag), at V-band on April 9.10 ($V = 12.89$ mag), and at I-band on April 10.32 ($I = 12.48$ mag); (b) The light curves around the maximum brightness are much narrower than those of other types of supernovae; (c) The light curves after the peak decline more steeply than those of other types of supernovae; and (d) The colors get redder from $(V-R) \approx 0.2$ mag ($(V-I) \approx 0.3$ mag, $(B-V) \approx 0.7$ mag) on April 4 to $(V-R) \approx 0.6$ mag ($(V-I) \approx 0.9$ mag, $(B-V) \approx 1.3$ mag) on April 18. Afterwards $(V-R)$ colors get bluer slightly (by ~0.005 mag/day), while $(V-I)$ colors stay almost constant around $(V-I) \approx 1.0$ mag. The color at the maximum brightness is $(B-V) = 0.9$ mag,

SN 1999dm in Abell 2065



SN 1999dm in Abell 2065

Circular No. 7241

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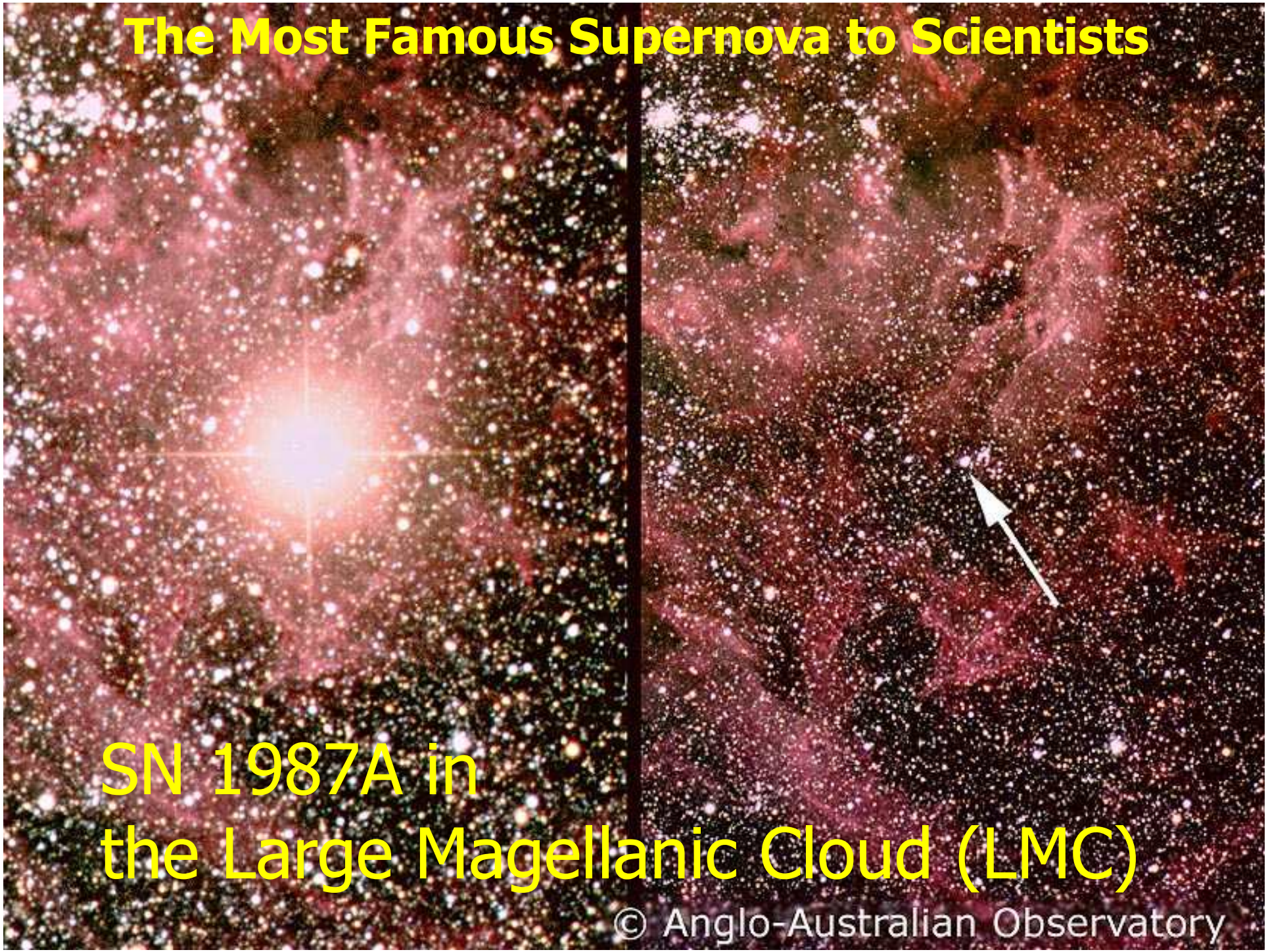
Phone 617-495-7244/7440/7444 (for emergency use only)

SUPERNOVA 1999dm IN MCG +05-36-022

Corrigenda. On IAUC 7237, the position for the nucleus of the host galaxy (MCG +05-36-022 = Abell 2065-164) of SN 1999dm was provided, rather than the supernova's position. Lee et al. provide the supernova's position as R.A. = 15h22m28s.90, Decl. = +27 42'58".0 (equinox 2000.0). The reference on line 8 was published in 1988, not 1998. On line 11, for BAO reflector read BOA reflector

M. M. M. Santangelo and S. Donati, Monte Agliale, Italy, report that their CCD patrol frames of the galaxy cluster Abell 2065 obtained on Mar. 24.09 and May 17.96 UT with the 0.51-m reflector (limiting mag R about 20.0) show nothing new near the host galaxy.


The Most Famous Supernova to Scientists
SN 1987A in
the Large Magellanic Cloud (LMC)
© Anglo-Australian Observatory

Neutrinos from stellar nucleosyntheses

Proton-proton (pp) fusion chain :

1st step : $^{1}H + {}^{1}H \rightarrow {}^{2}H + e^{+} + \nu_e$ ($\rightarrow$1.44 MeV)

2nd step : $^{2}H + {}^{1}H \rightarrow {}^{3}He + \gamma$ ($\rightarrow$5.49 MeV)

3rd step : $^{3}He + {}^{3}He \rightarrow {}^{4}He + {}^{1}H + {}^{1}H$ ($\rightarrow$12.9 MeV)

CNO Cycle :

$^{12}C + {}^{1}H \rightarrow {}^{13}N + \gamma$

$^{13}N \rightarrow {}^{13}C + e^{+} + \nu_e$

$^{13}C + {}^{1}H \rightarrow {}^{14}N + \gamma$

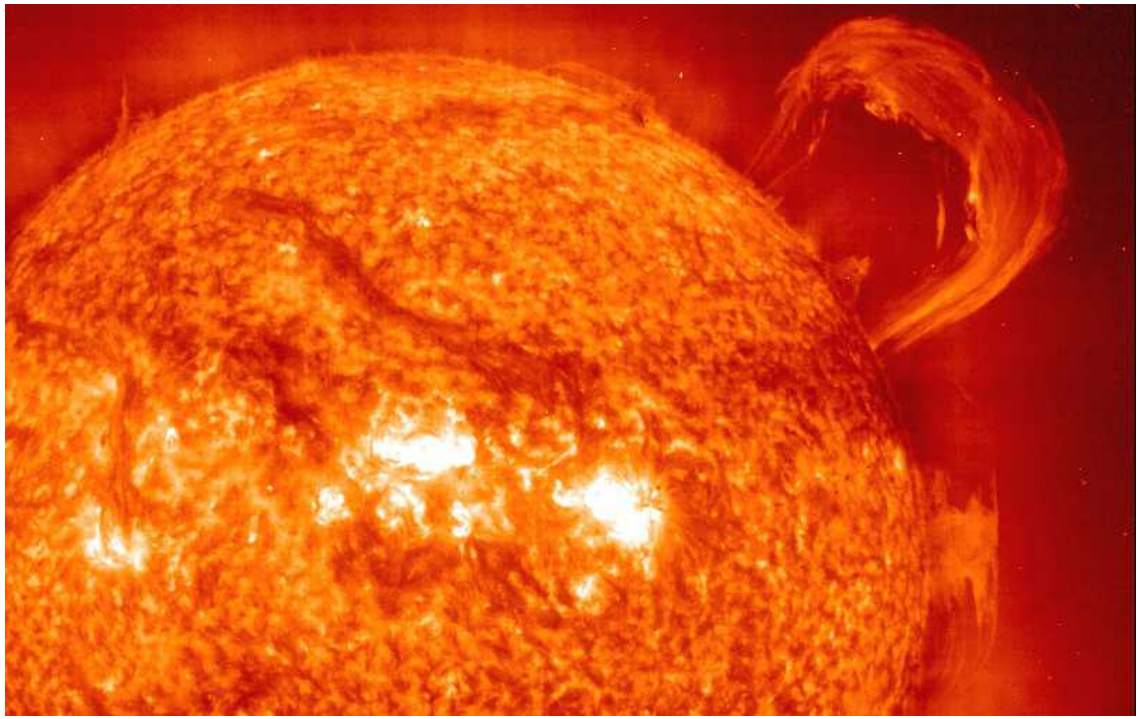
$^{14}N + {}^{1}H \rightarrow {}^{15}O + \gamma$

$^{15}O \rightarrow {}^{15}N + e^{+} + \nu_e$

$^{15}N + {}^{1}H \rightarrow {}^{12}C + {}^{4}He$

β^{+} decay : $p \rightarrow n + \beta^{+} +$

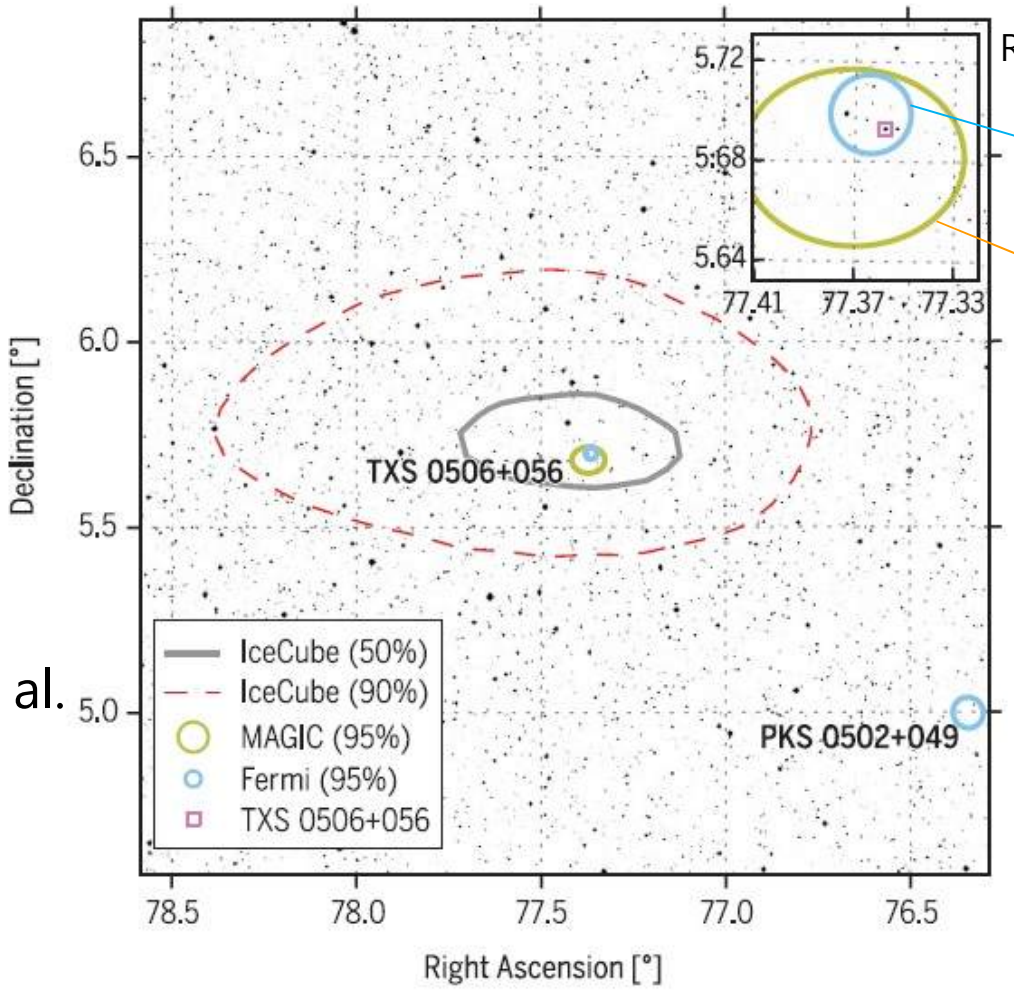
※ $\beta^{+} = e^{+}$ (positron)



The neutrino event IceCube-170922A

One neutrino event with E~290 TeV
on 22 Sep 2017 at 20:54:30.43 UT

known γ -ray blazar TXS 0506+056



R-band image

Fermi γ -ray sources

Very-high-E γ –rays detected by MAGIC (Major Atmospheric Gamma Imaging Cherenkov) telescopes

V-band image

IceCube Collaboration et al. 2018 (Science)

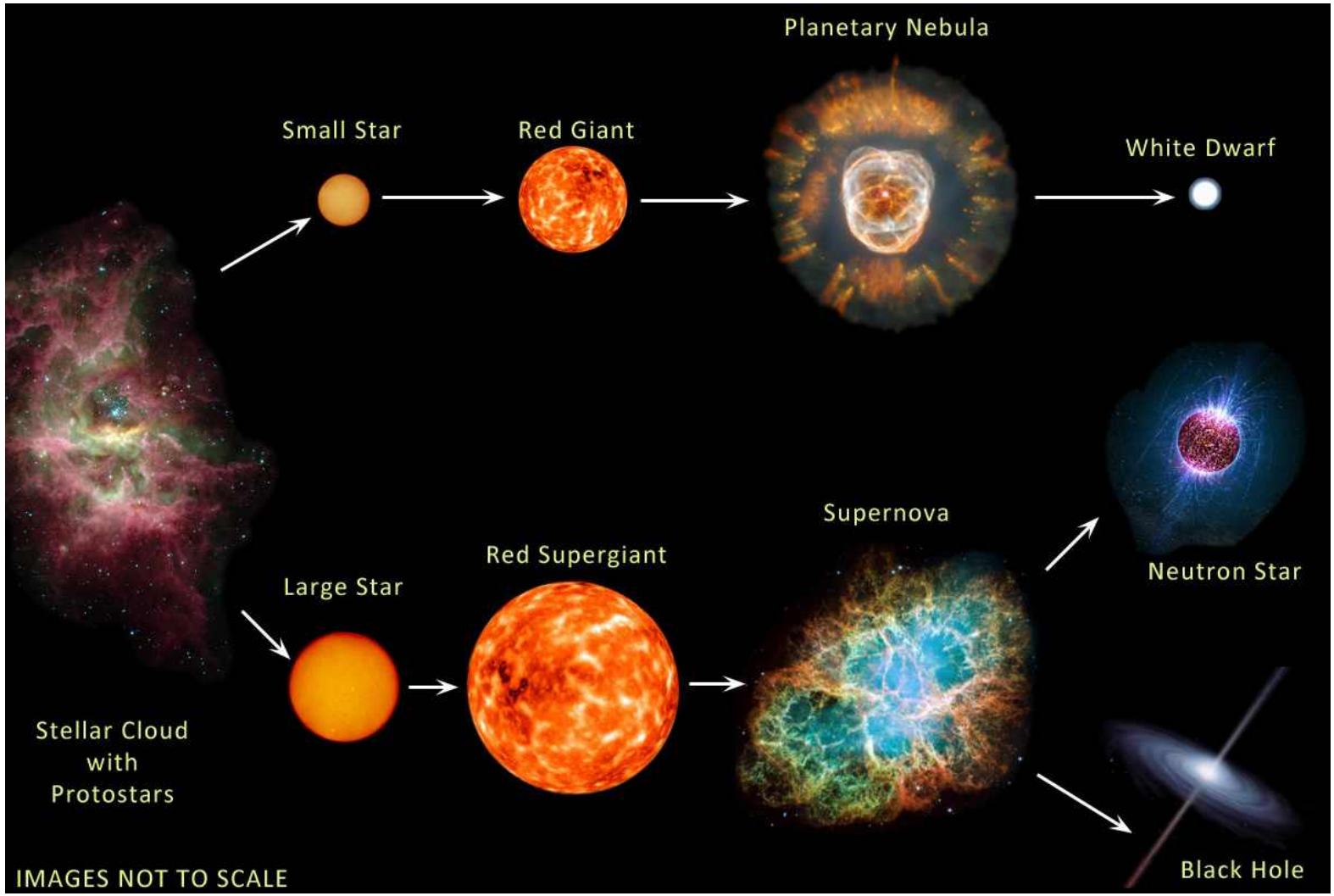
R.A. = 77.3582°, Dec. = +5.69314° (J2000)

Neutrinos from Supernovae (SNe)

- supernova energy
  - 99% comes as neutrinos
  - ~1% comes as kinetic energy
  - ~0.01% optical emission

Introduction – Stellar Evolution

- Mass → Final Stages
- Low-mass stars → White Dwarfs (WDs) → SN Ia
- Massive (≥8 $M_{\odot}$) stars → core-collapse SN



http://earthspacecircle.blogspot.kr/2013/07/stellar-evolution.html

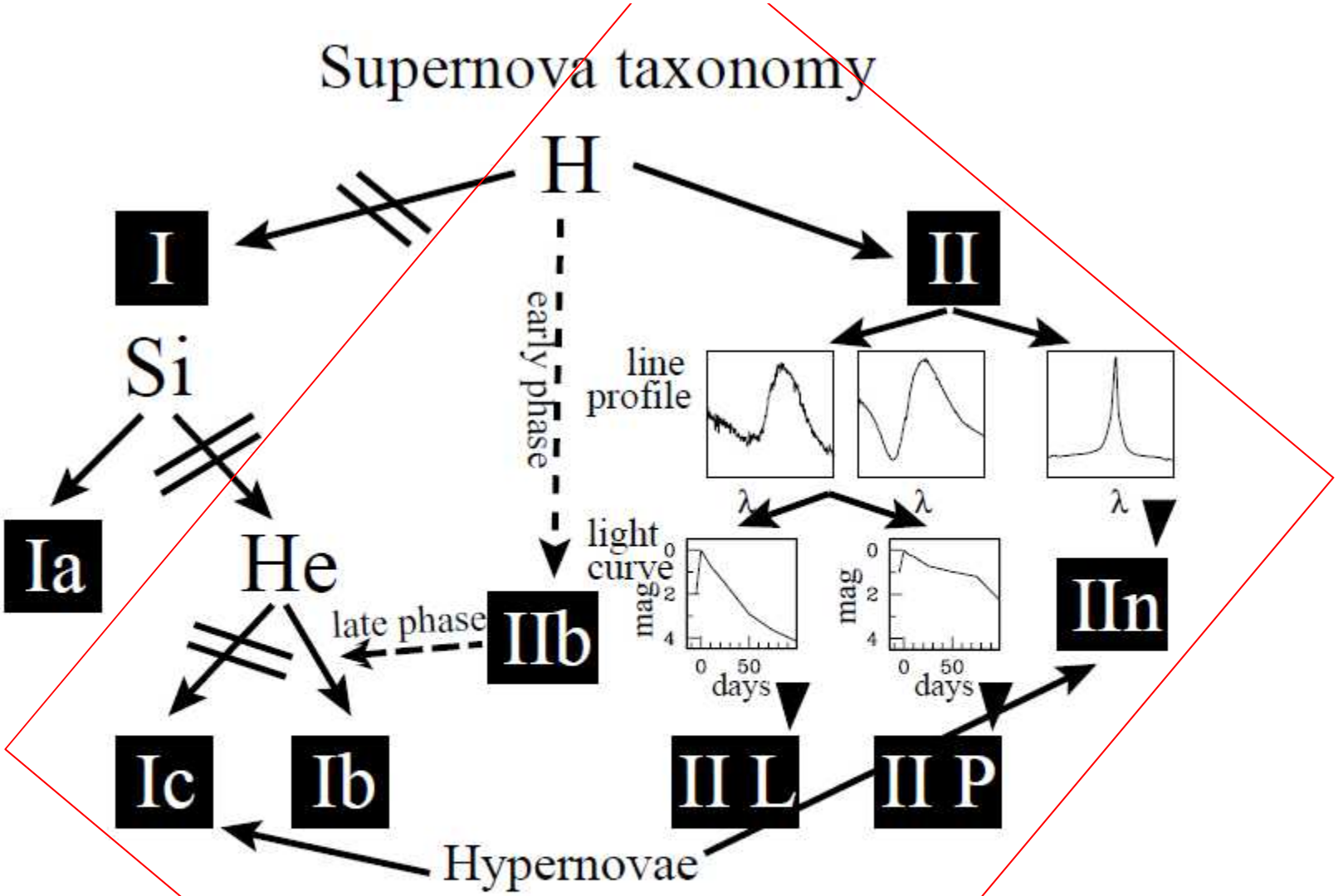


Figure 2. The detailed classification of SNe requires not only the identification of specific features in the early spectra, but also the analysis of the line profiles, luminosity and spectral evolutions

Cappellaro & Turatto (astro-ph/0012455)

SN Explosion

SN 1987A (IIP, LMC)

Tarantula Nebula

d~49.97 kpc (Pietrzynski+ 13 Natur 495 76)

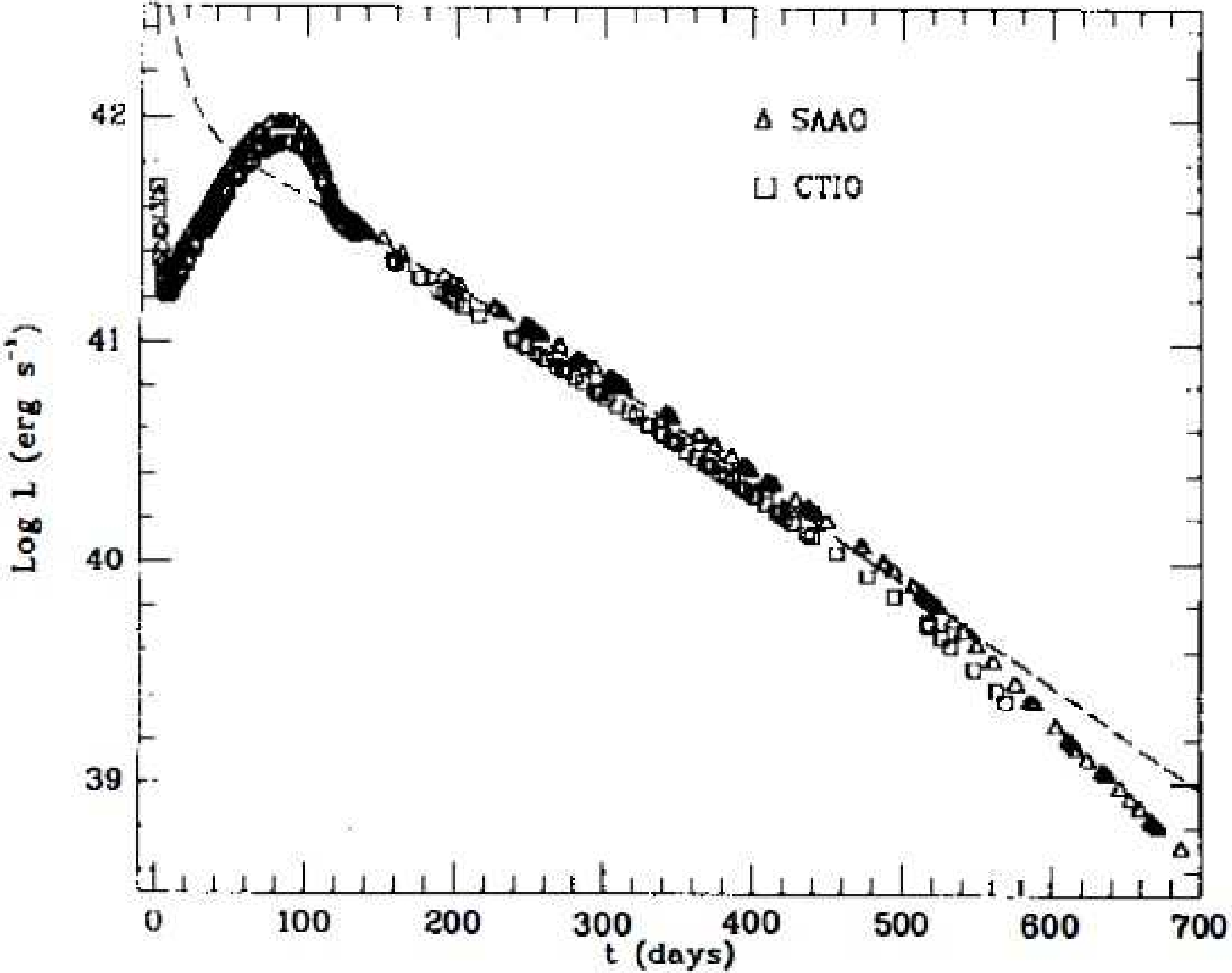
1987 Feb 23.316 (UT)

B3 supergiant

Peak : +2.9 mag

(B-V) = +0.085

SN 1987A – Bolometric Light Curve



Arnett et al. (1989, ARAA, 27, 629 – SN 1987A) – Fig 5

neutrino detector – Kamiokande II

- Upgrade → operation since 1985
- Observed solar neutrinos
- Observed 11 neutrinos from Supernova (SN) 1987A – 50 kpc (163,000 ly) away in the Large Magellanic Cloud

- Masatoshi Koshiba (小柴 昌俊) – 2002 Nobel Prize in Physics (w/Raymond Davis Jr., Riccardo Giacconi) for his work directing the Kamoka experiments, and in particular for the first-ever detection of astrophysical neutrinos

(1914-)

Raymond Davis Jr.

Prize share: 1/4

고시바 마사토시(小柴昌俊)

(1926-)

Masatoshi Koshiba

Prize share: 1/4

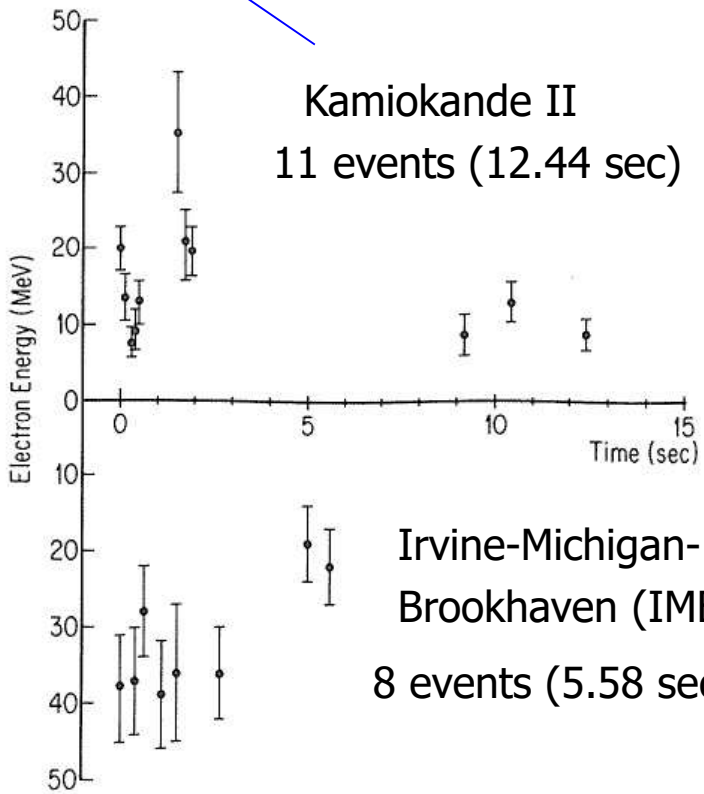
(1931-)

Riccardo Giacconi

Prize share: 1/2

Raymond Davis Jr. and Masatoshi Koshiba *"for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos"* and the other half to Riccardo Giacconi *"for*

http://www.nobelprize.org/nobel_prizes/physics/laureates/2002/



Kamiokande II

11 events (12.44 sec)

Irvine-Michigan-Brookhaven (IMB)

8 events (5.58 sec)

1987년 2월 23일 07h 35m 35s (UT)

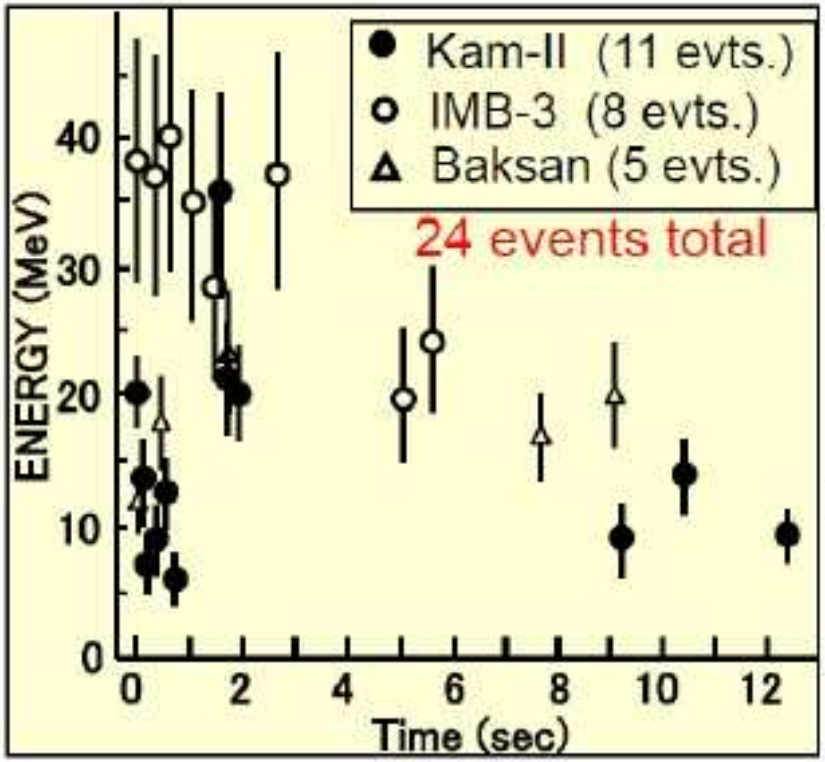
http://mulli2.kps.or.kr/~pht/11-11/021108.htm

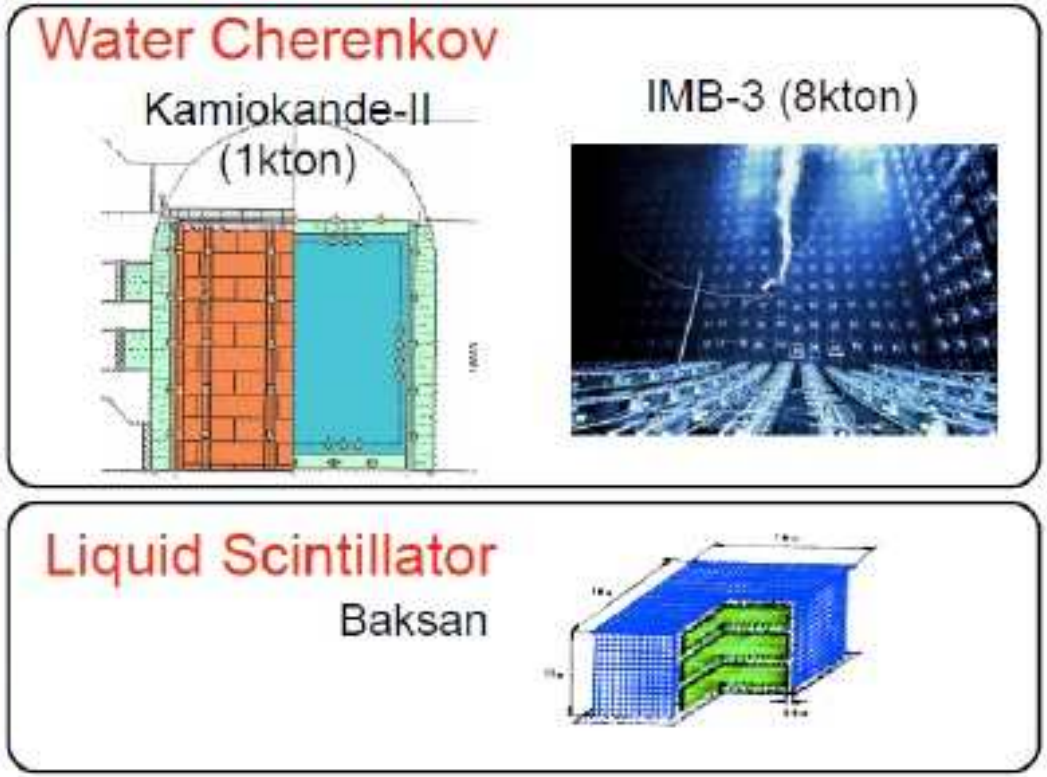
K II : Hirata+ 87 Phys. Rev. Lett. 58, 1490

IMB : Bionta+ 87 Phys. Rev. Lett. 58, 1494

SN 1987A at Large Magellanic Cloud

07:35:35 (UT), Feb. 23, 1987 @ d = 50 kpc

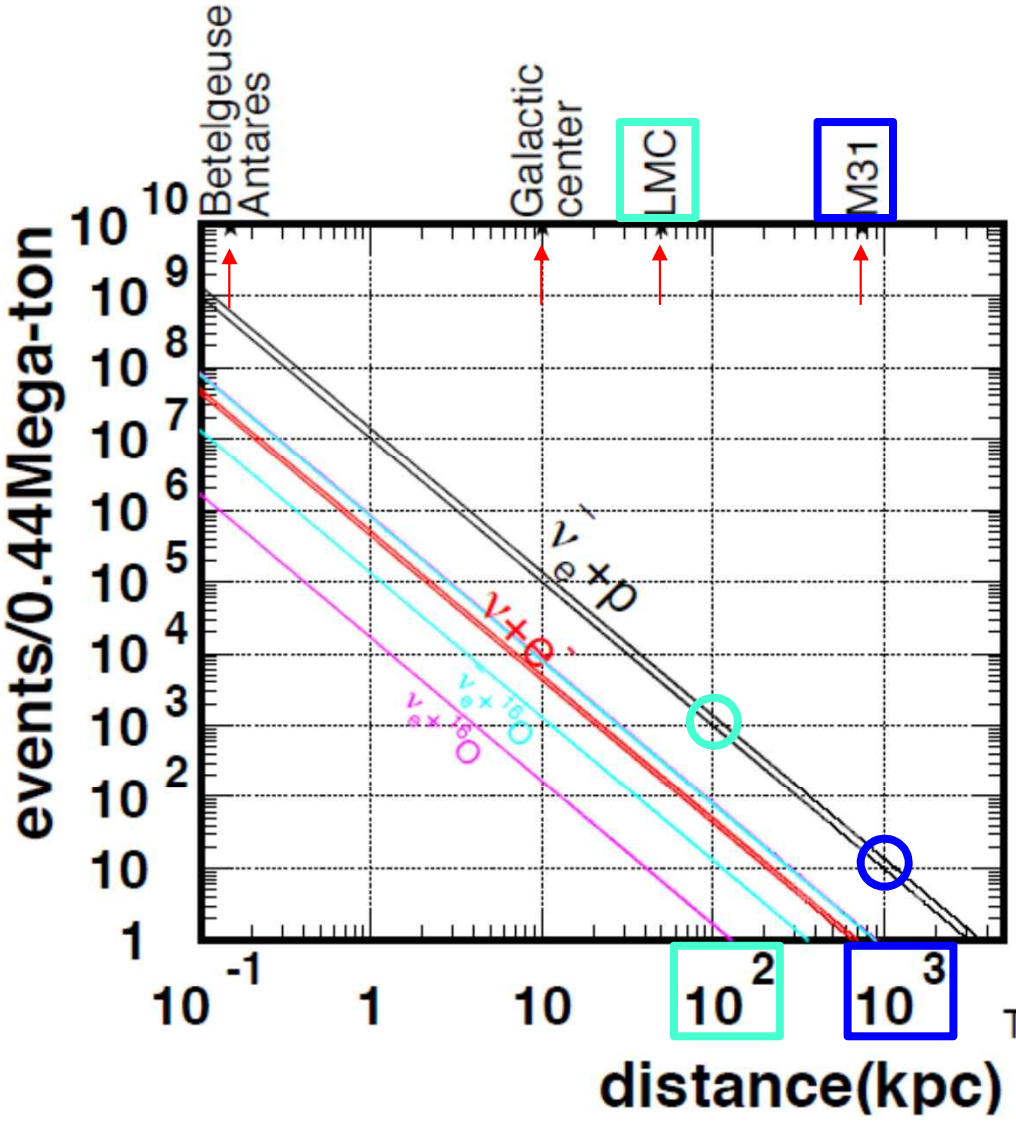


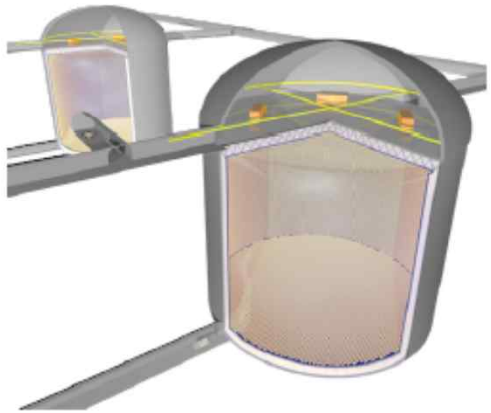


Nobel Prize 2002

Courtesy Soo-Bong Kim

SN burst observation by HK





Expected number of event

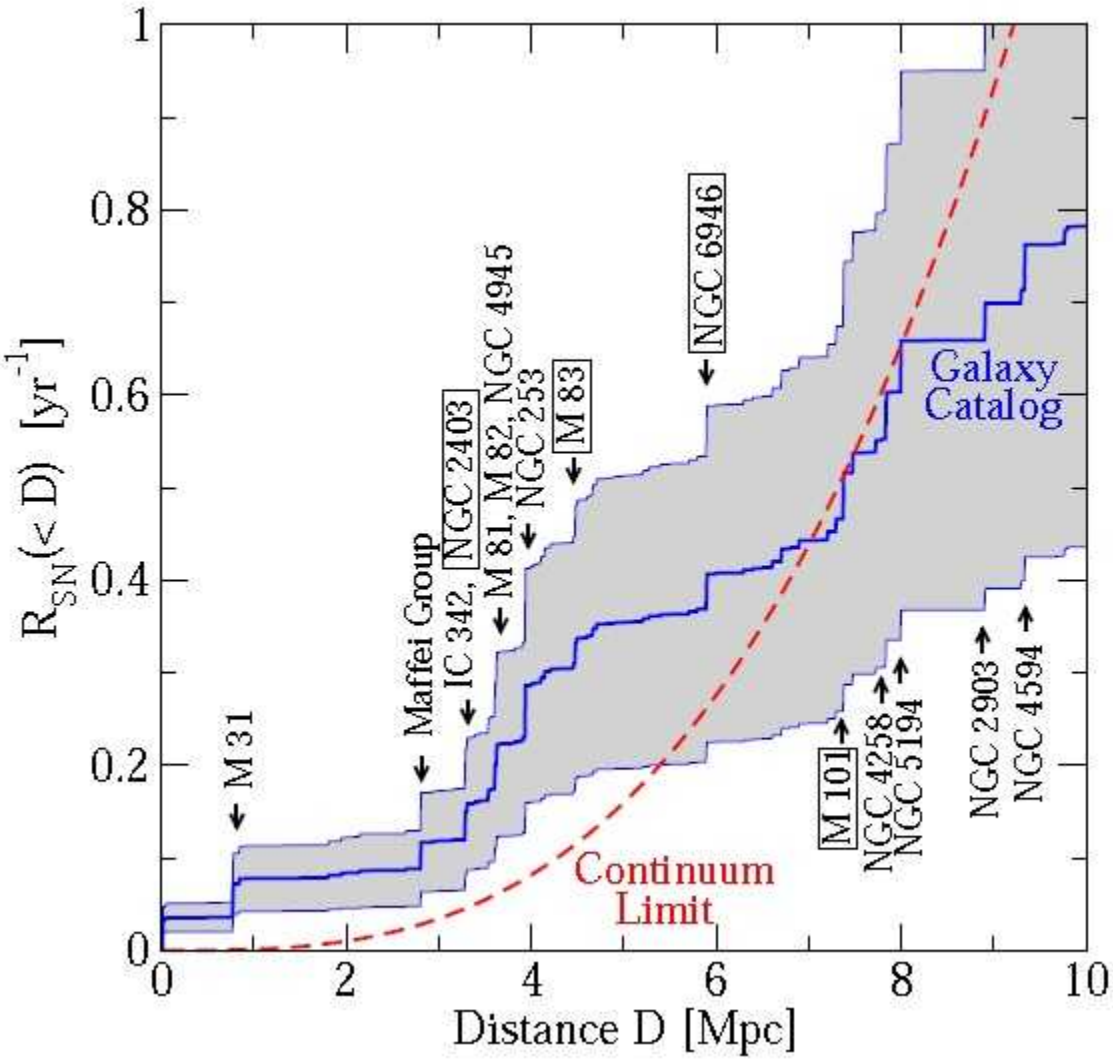
98k~136k ev (IBD)
4.2k~5k ev (νe ES)
(12~80 for neutronization)
160~8200 ev (ν_e CC)
1300~7800 ev ($\bar{\nu}_e$ CC)

at 10kpc

Livermore simulation
Totani, Sato, Dalhed, Wilson, ApJ. 496 (1998) 216

Courtesy Soo-Bong Kim

CC SN Rate

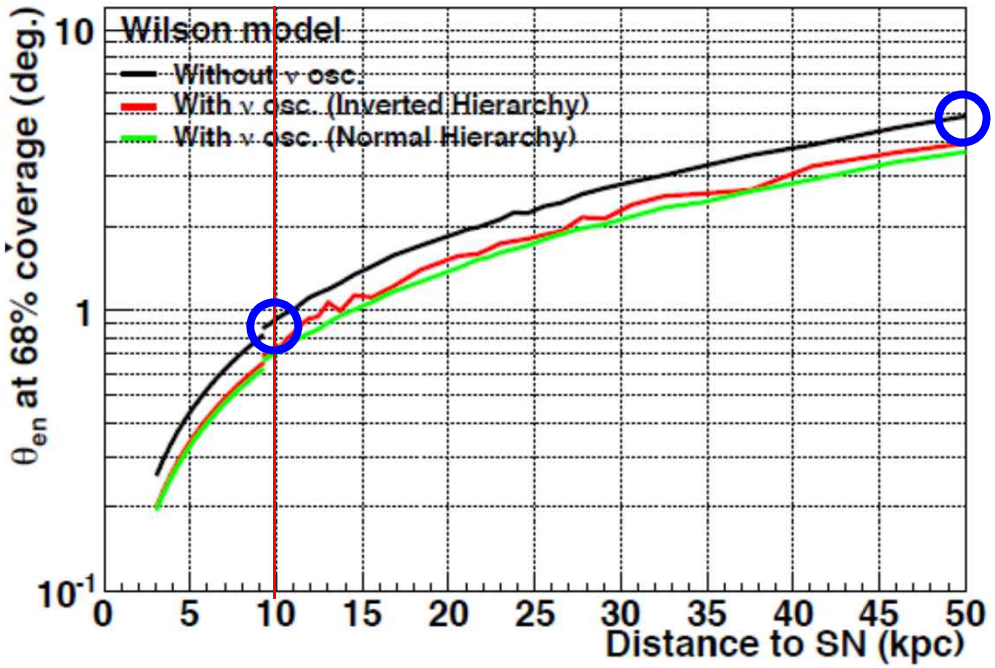


Ando et al. (2005, PRL, 95, 171101)

SN burst – Position accuracy

	SK	SK-Gd	HK	HK-Gd
Error Circle	6°	3°	1.4°	0.6°

※ Gadolinium trichloride ($GdCl_3$) addition (0.2%)
→ increases detection efficiency (J. F. Beacom & M. R. Vagins 2004 Phys. Rev. Lett. 93, 171101)

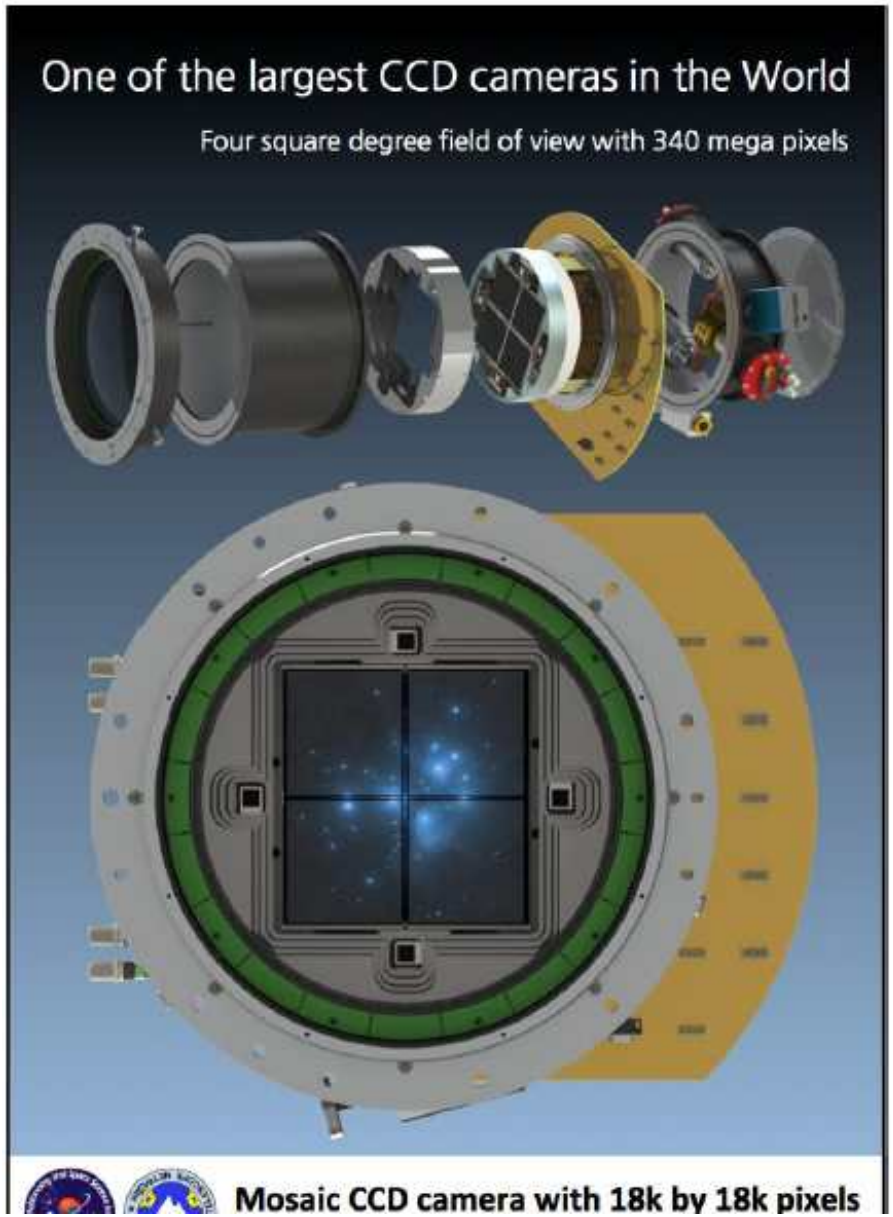


~1 degree at 10kpc

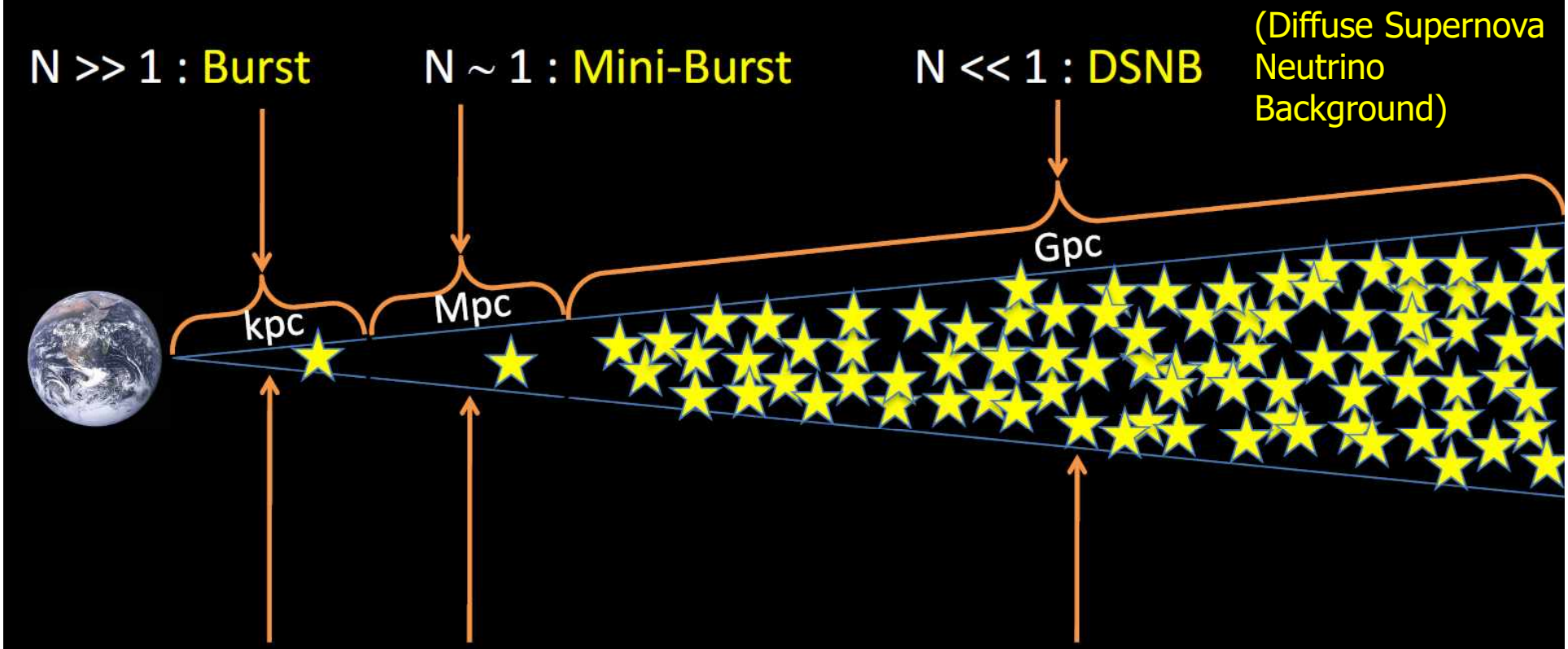
Courtesy Soo-Bong Kim

Korea Microlensing Telescope Network (KMTNet)

Wide Field CCD Imager: 2° × 2° Field of View

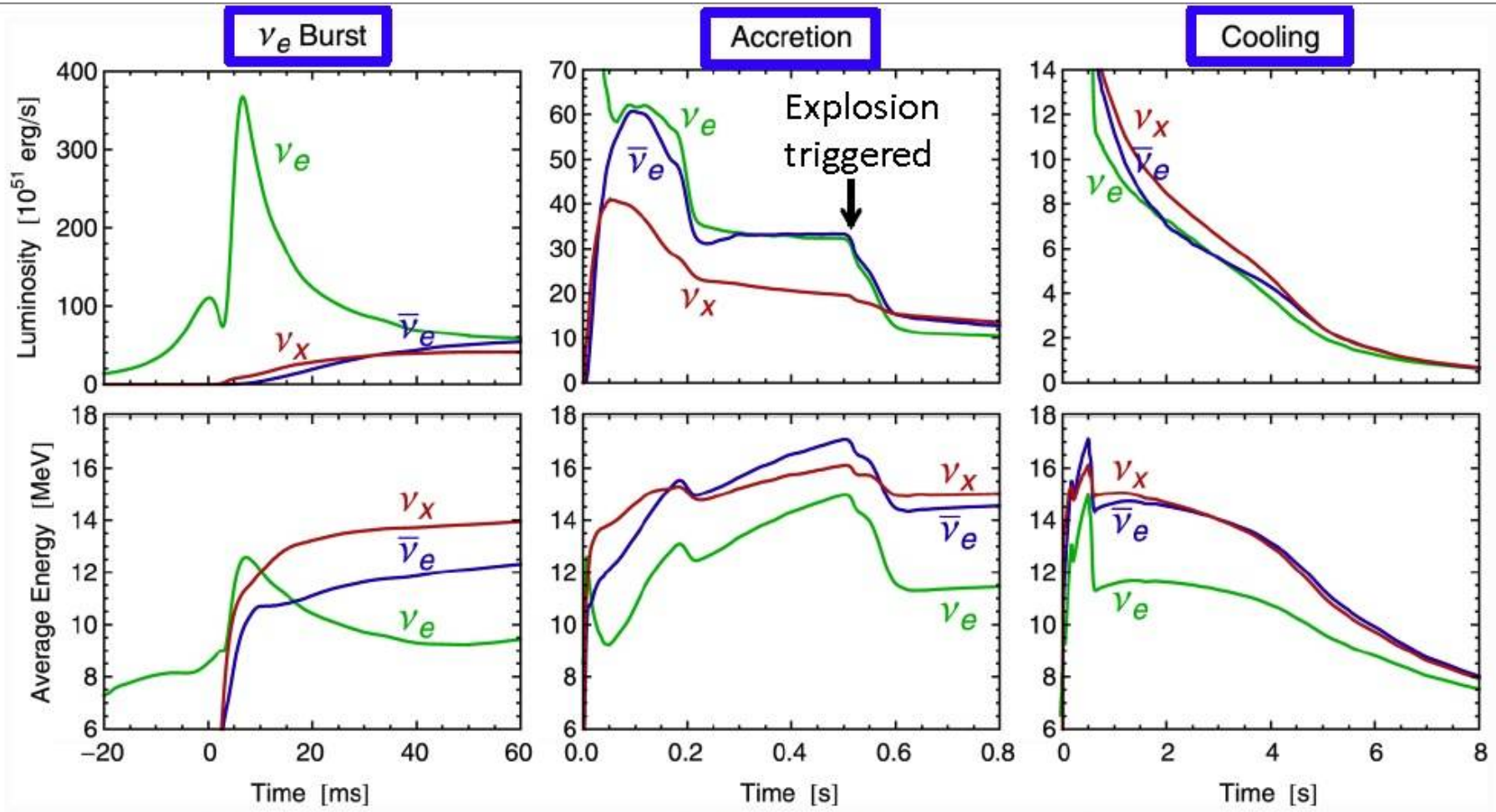


Distance Scales and Detection Strategies



Courtesy Soo-Bong Kim

Three Phases of Neutrino Emission



- Shock breakout
- De-leptonization of outer core layers

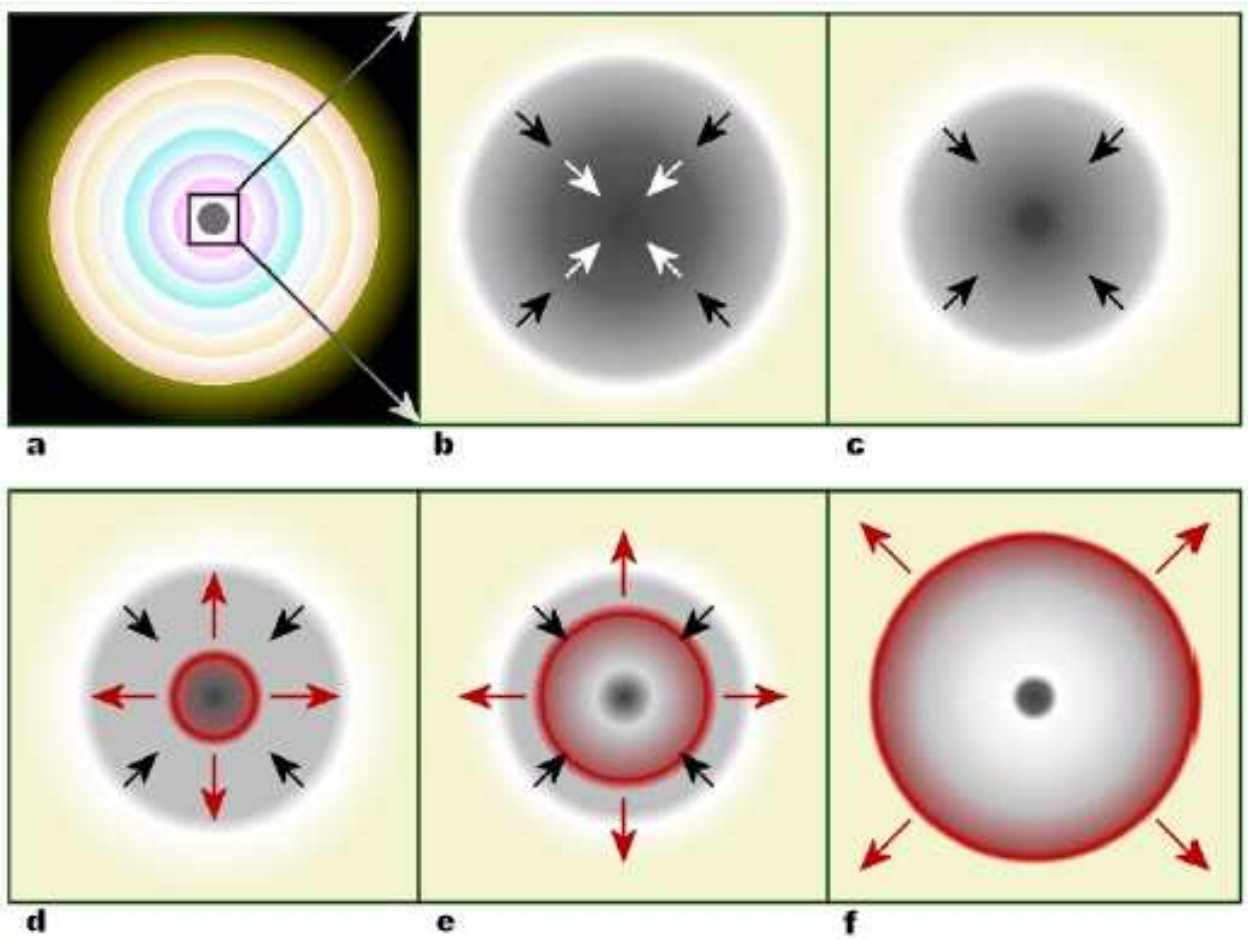
- Shock stalls ~ 150 km
- Neutrinos powered by infalling matter

Cooling on neutrino diffusion time scale

Spherically symmetric Garching model (25 $M_\odot$) with Boltzmann neutrino transport

Courtesy Soo-Bong Kim

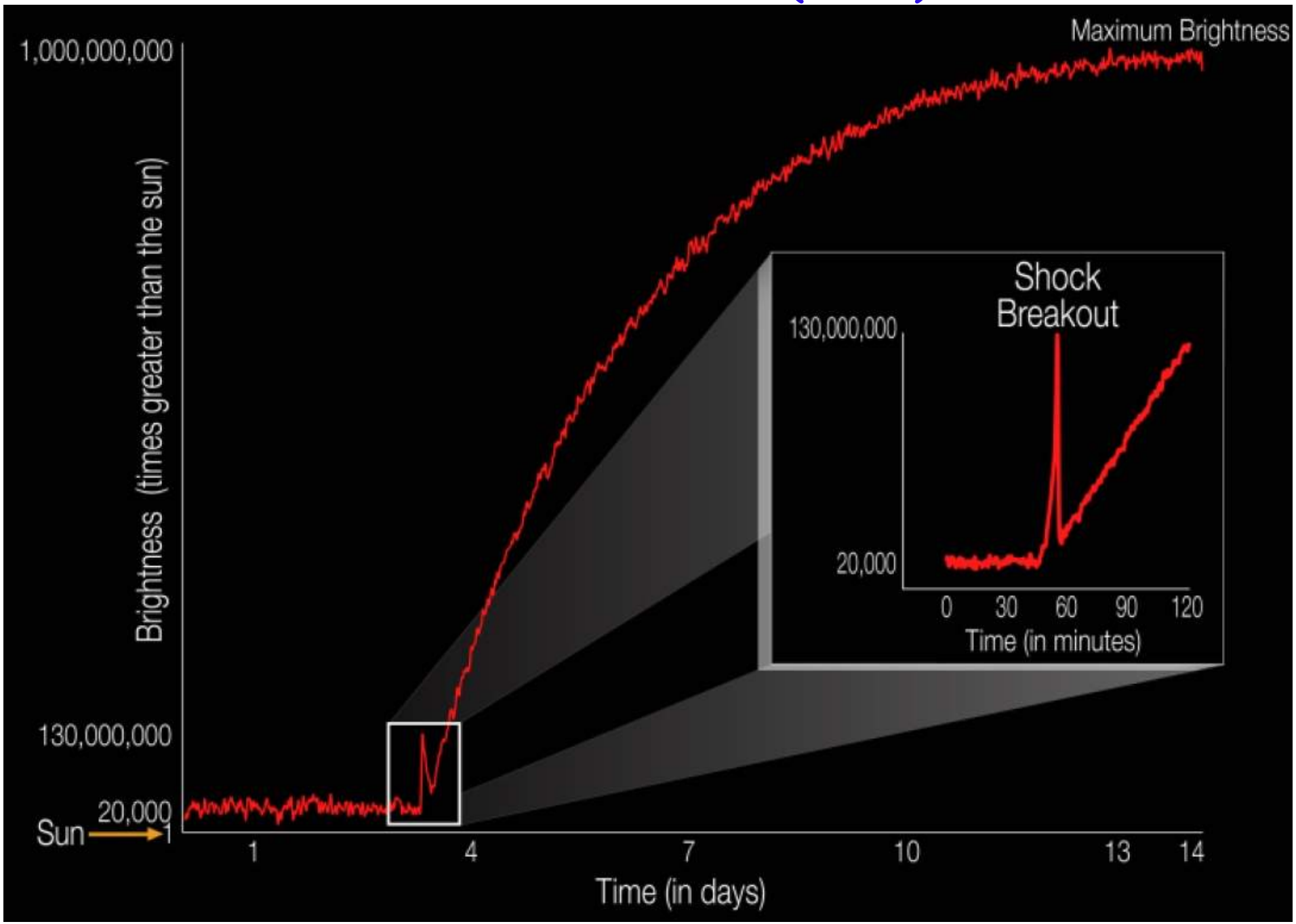
Supernova Early Observation - Shock Breakout (SBO)



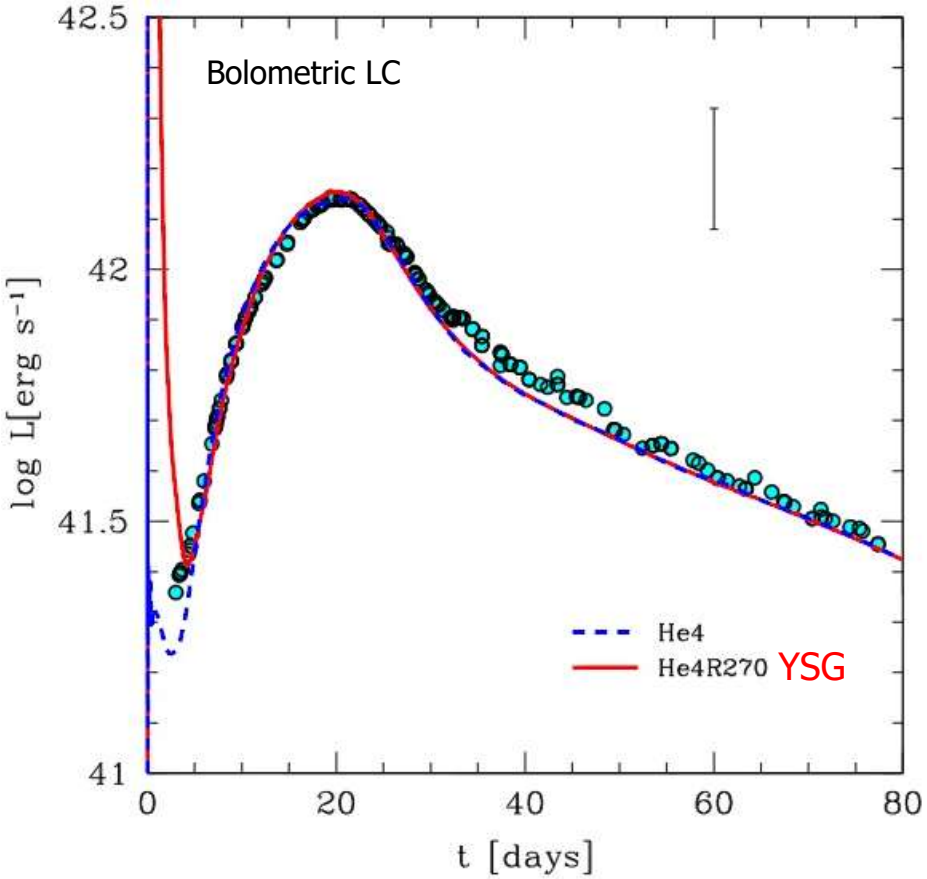
Core collapse of massive stars (>8 $M_{\odot}$)

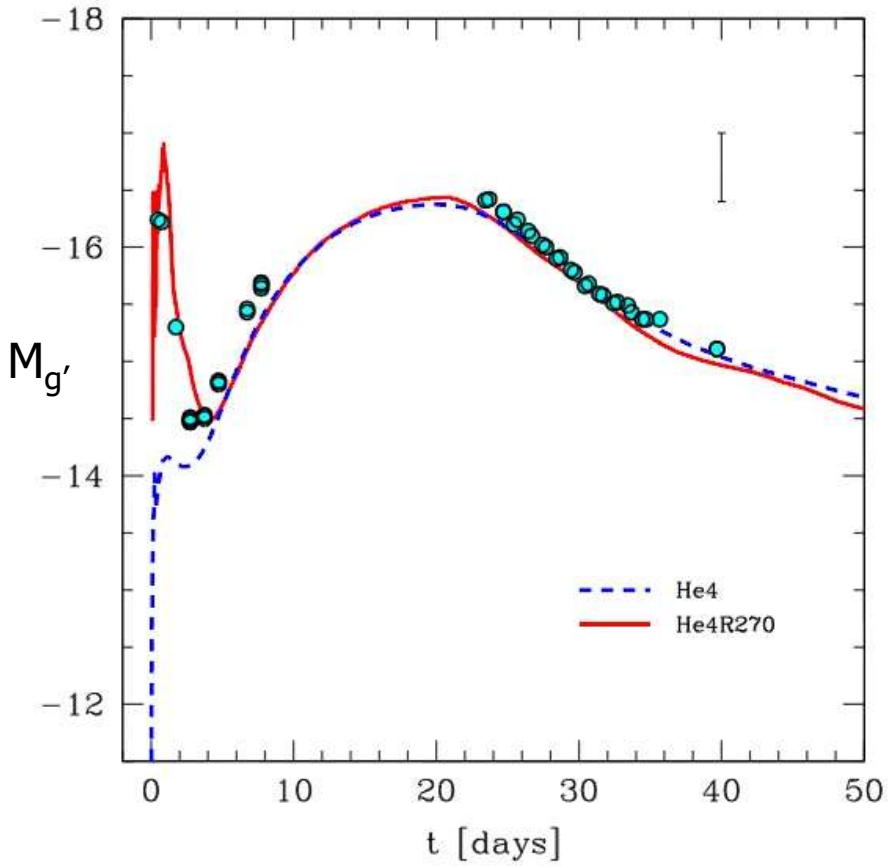
(Illustration by R. J. Hall)

Shock Breakout (SBO)



Early bolometric light curve(LC)





SN 2011dh
(IIb, M51)

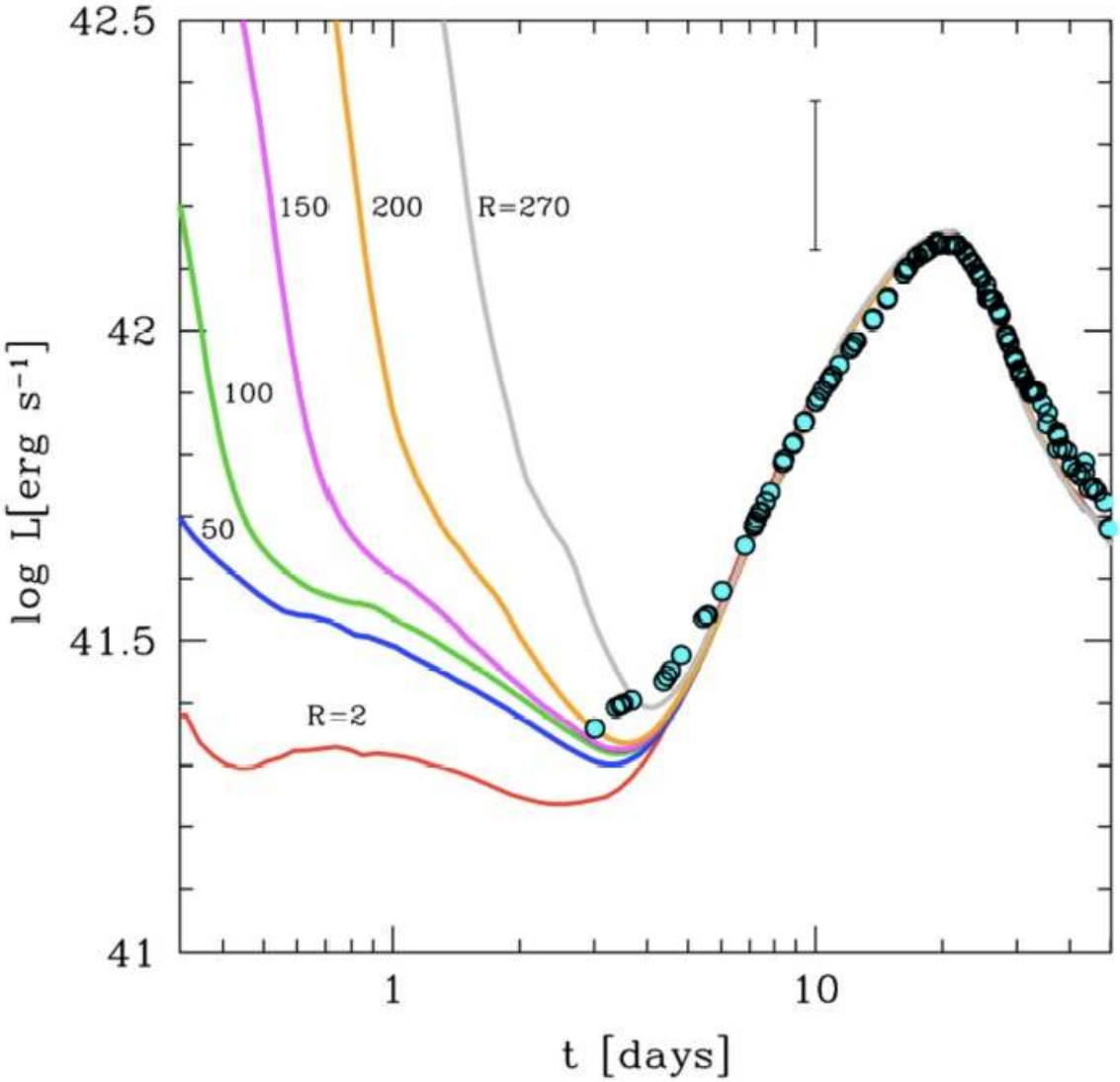
Radius effect – noticeable before t~5 days
(compact 2 $R_\odot$ vs extended 270 $R_\odot$)

Bersten+12 ApJ 757 31

Early bolometric light curve(LC)

Models
- Same explosion energy
- Different initial radius

: SN 2011dh (IIb, M51)

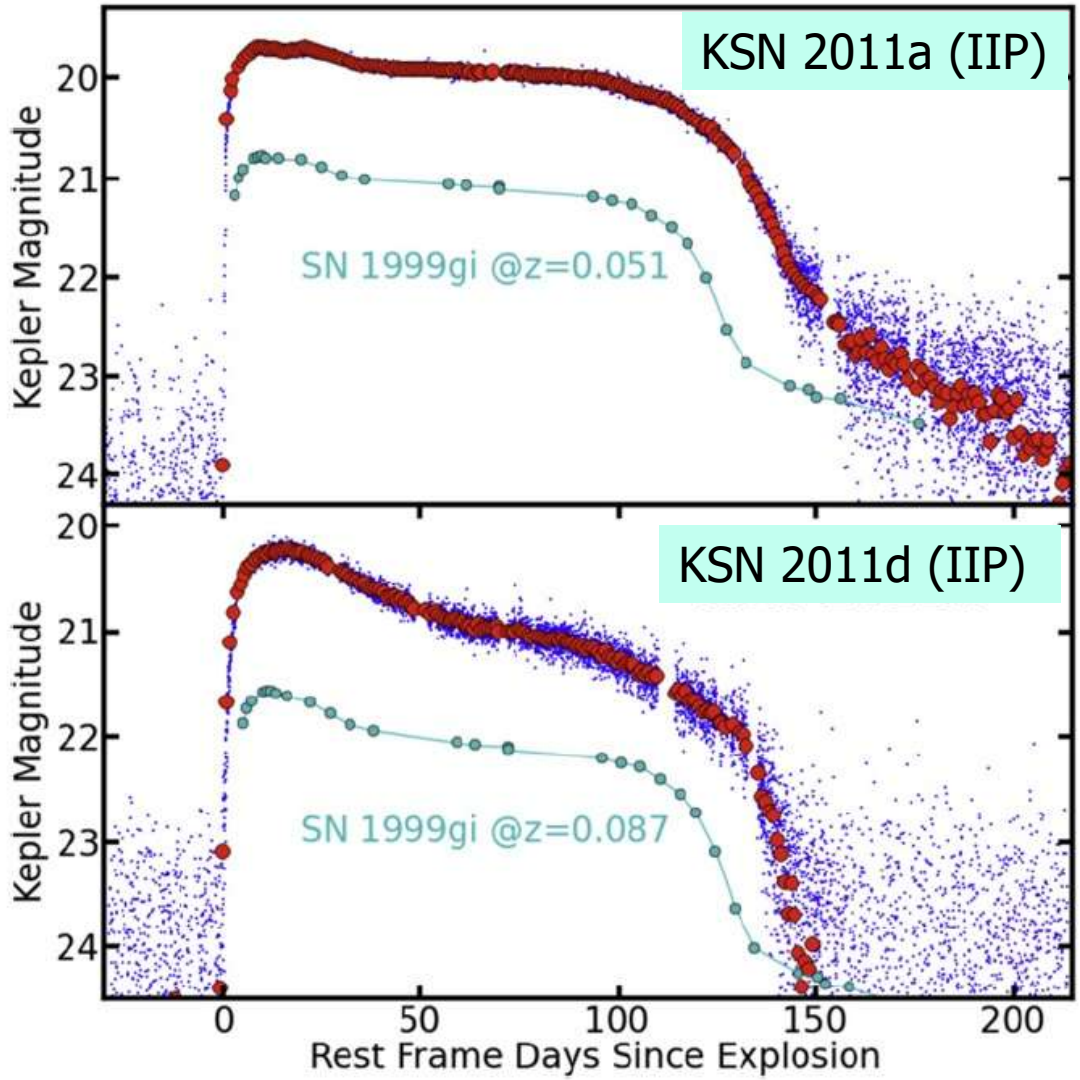


Bersten+12 ApJ 757 31

SBO - Kepler SNe

Blue points : 30-min cadence

Red dots : 1 day medians



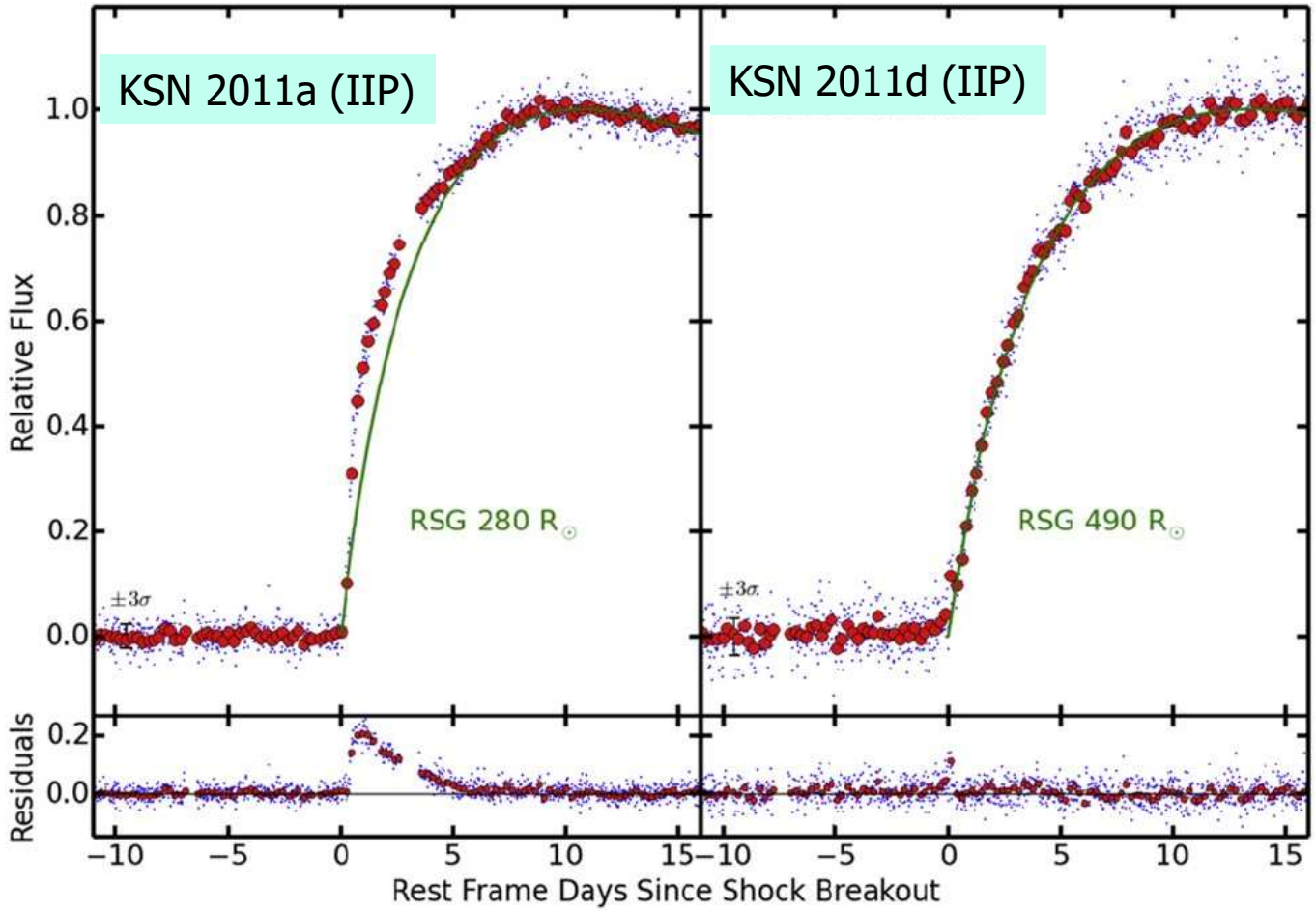
Garnavich+16 ApJ 820 23

Name[a]	Host KIC[b]	SN Type	Redshift (z)	MW A_V (mag)	Peak Kp[c] (mag)	Date of Breakout (BJD-2454833.0)	Rise Time (days)
KSN 2011a	08480662	IIP	0.051	0.194	19.66 ± 0.03	934.15 ± 0.05	10.5 ± 0.4
KSN 2011d	10649106	IIP	0.087	0.243	20.23 ± 0.04	1040.75 ± 0.05	13.3 ± 0.4

SBO – Kepler SNe

Blue points : 30-min cadence

Red dots : 6-hr medians

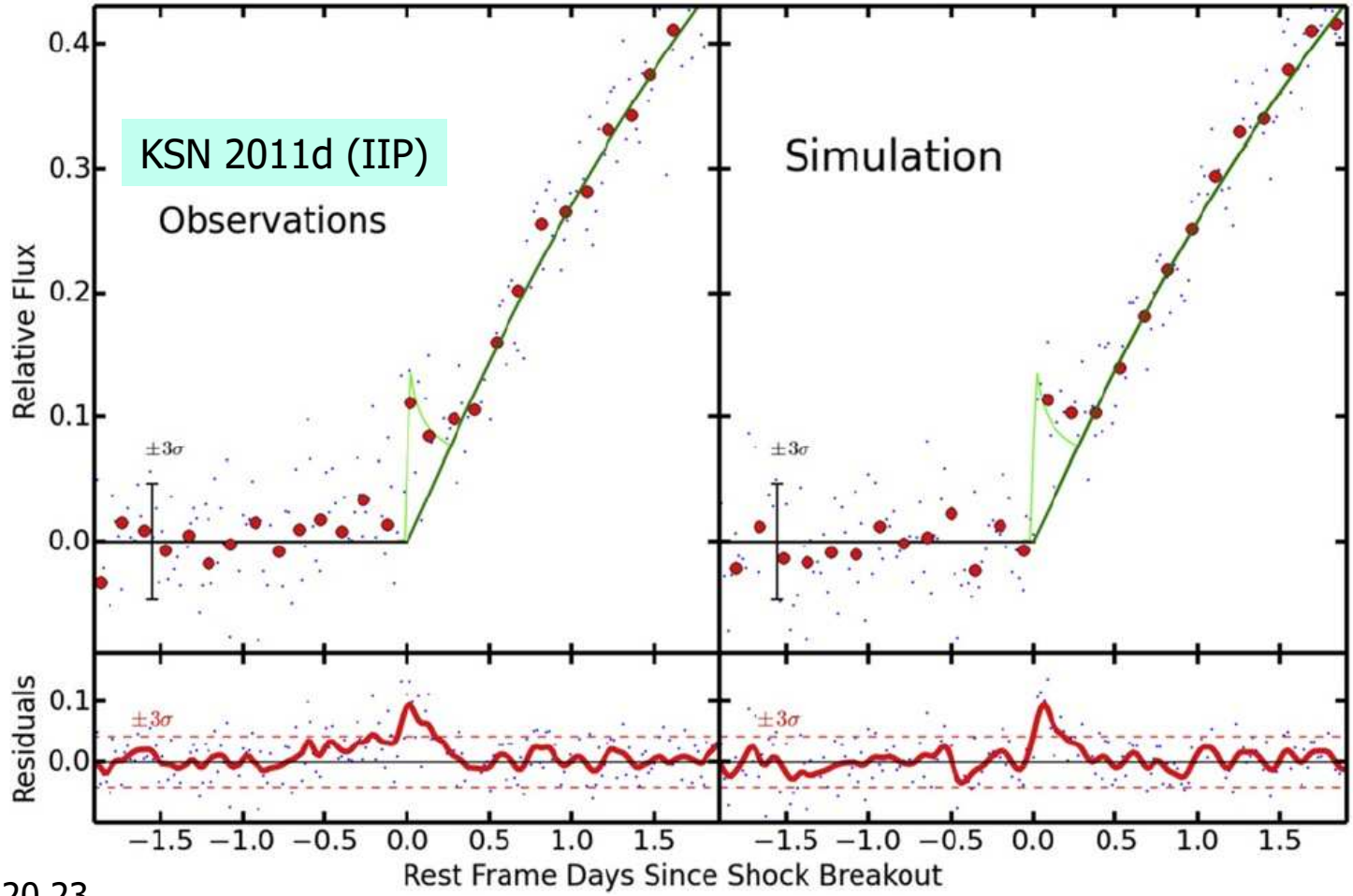


Garnavich+16 ApJ 820 23

SBO - Kepler SNe

Blue points : 30-mir cadence

Red dots : 3.5-hr medians



Garnavich+16 ApJ 820 23

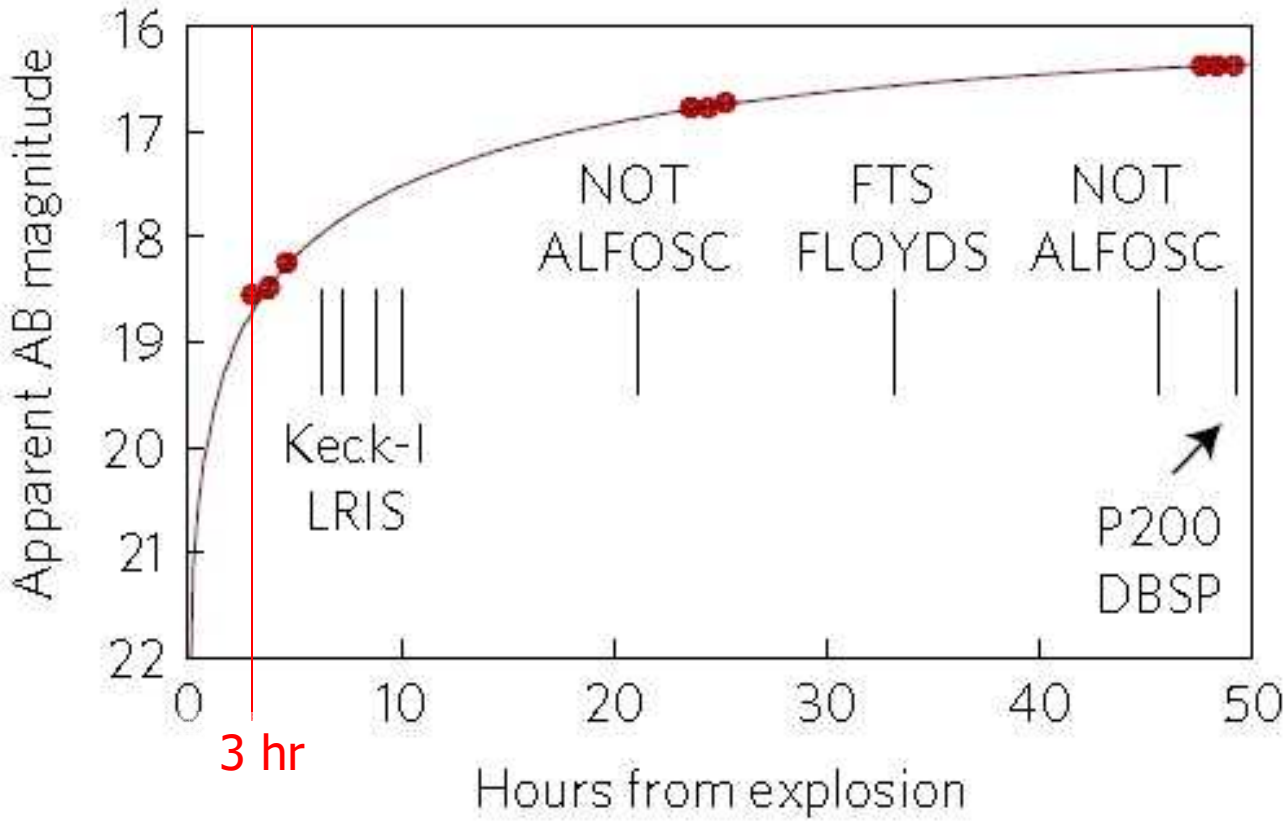
Best fit photospheric model LC

Nakar & Sari (2010) SBO model ($R=490\ R_{\odot}$)

Early detection of SN

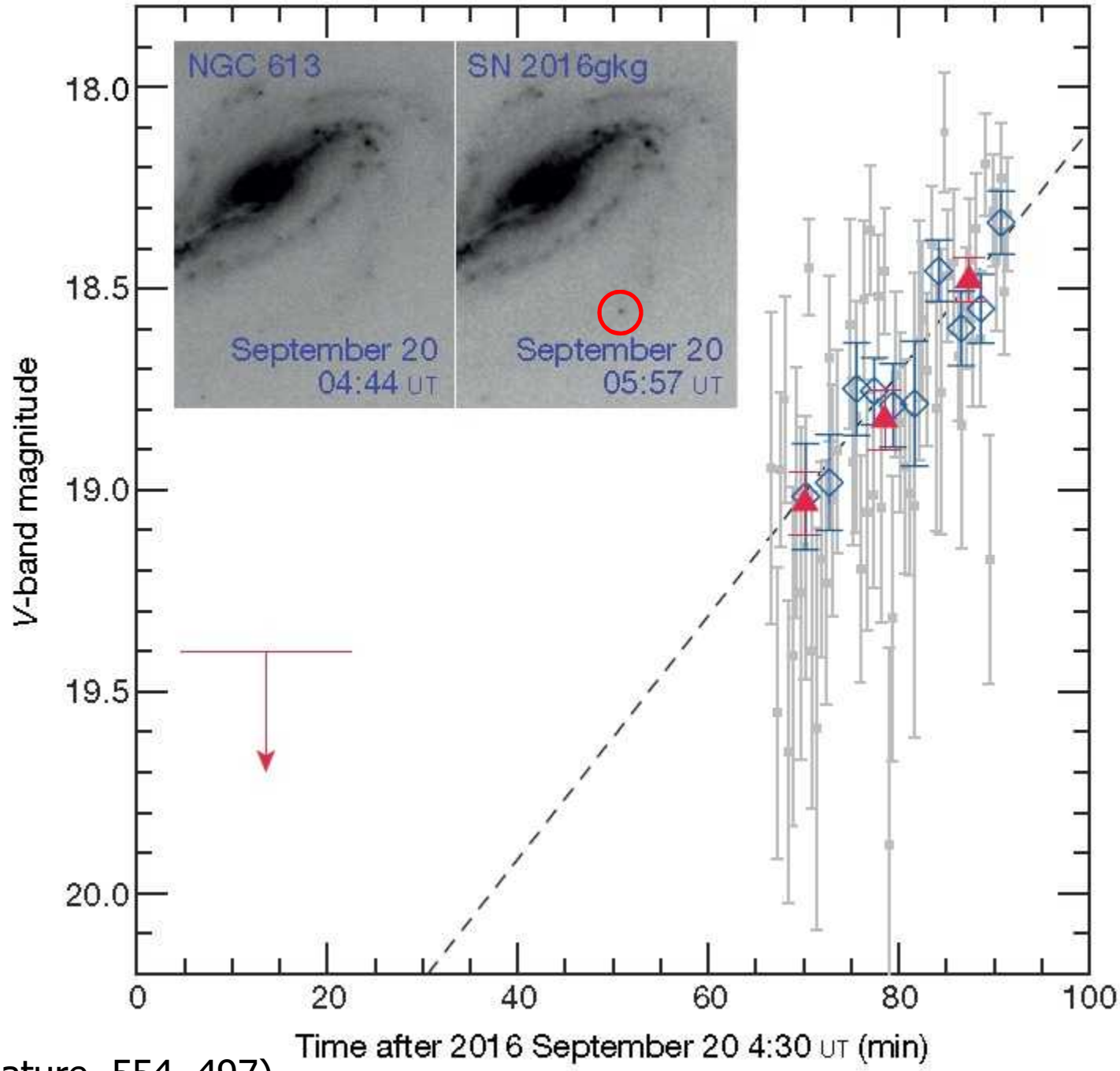
SN 2013fs (IIP, NGC 7610)

(=iPTF 13dqy)
d=50.95 Mpc

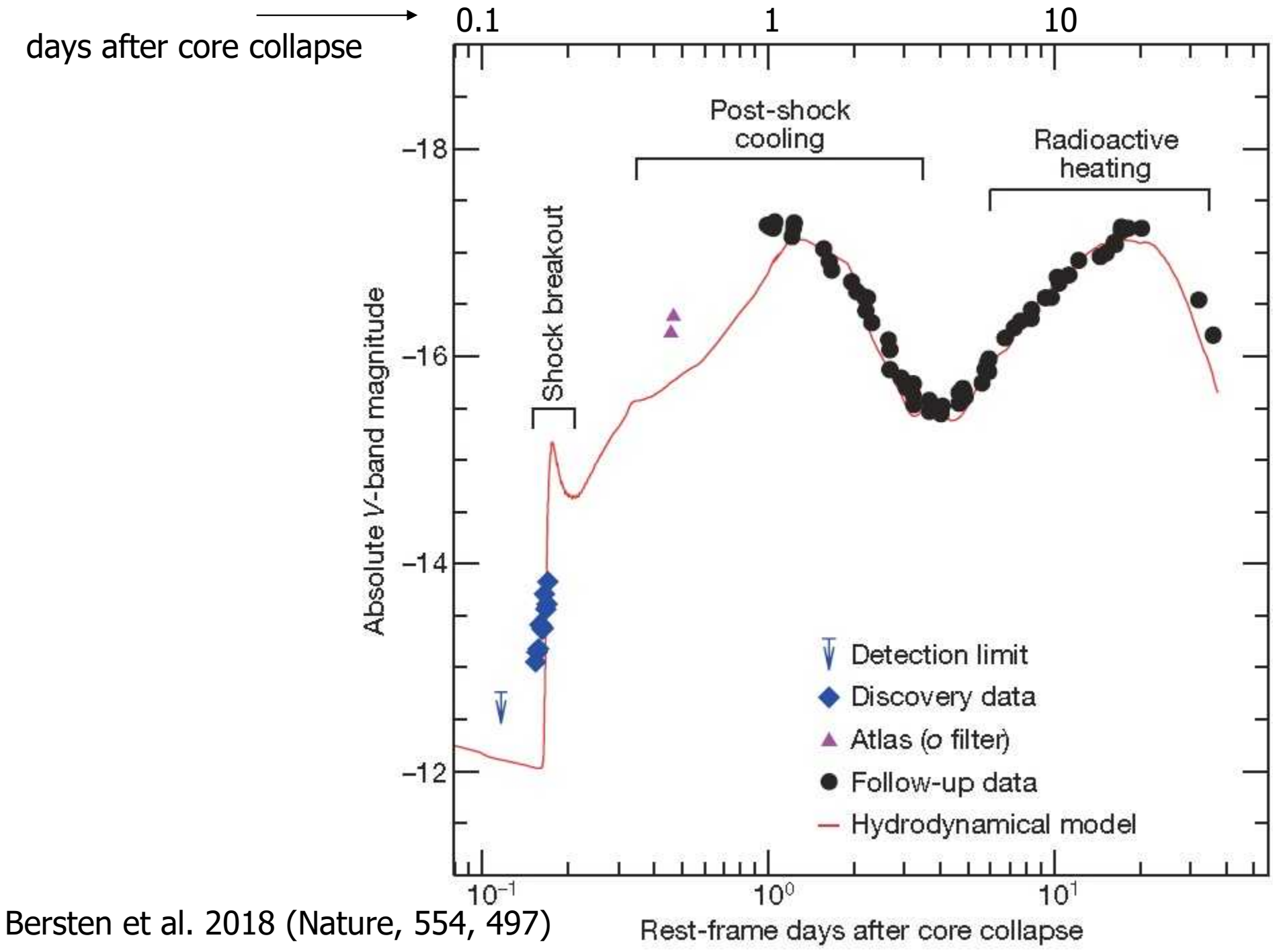


Yaron+17 NatPh, 13, 510

(NaturePhysics, arXiv: 1701.02596)



Bersten et al. 2018 (Nature, 554, 497)



Bersten et al. 2018 (Nature, 554, 497)

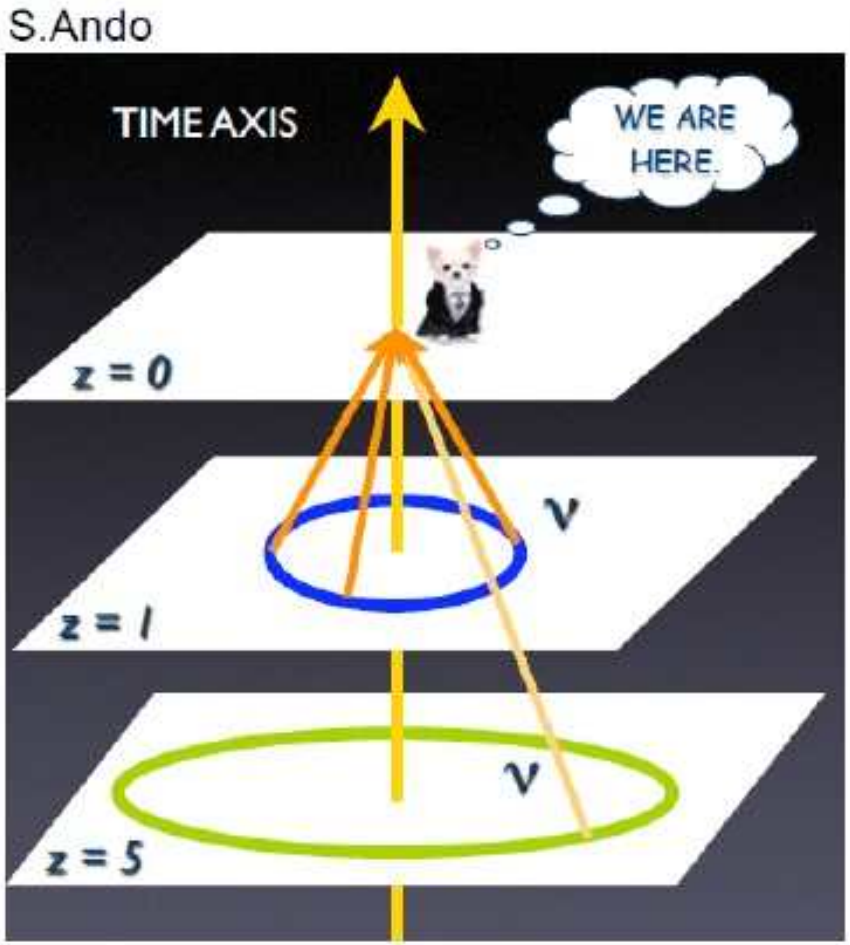
Supernova Relic Neutrino (SRN)

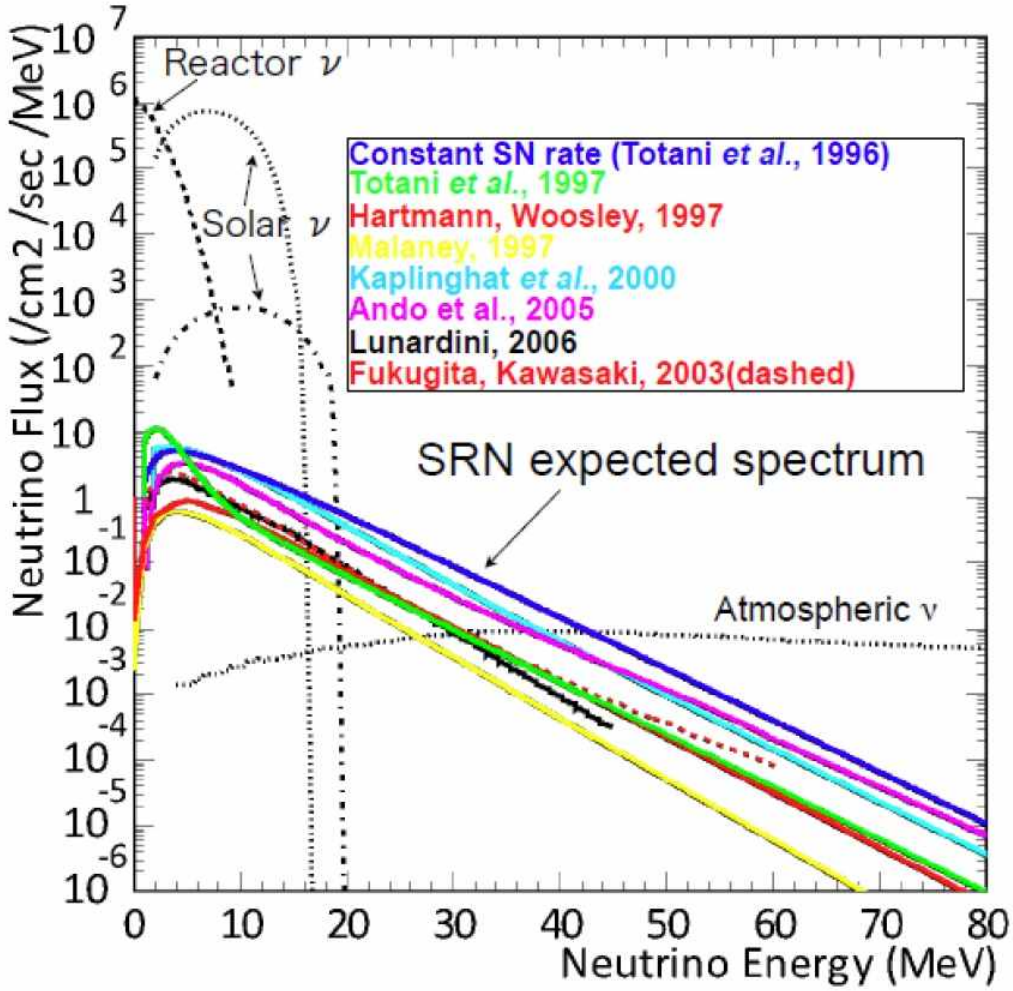
https://www.scientificamerican.com/article/found-the-most-powerful-supernova-ever-seen/
http://www2.mpia-hd.mpg.de/IRSPACE/Tycho_release/tycho1572/Tycho_observation_image.pdf

Supernova Relic Neutrino (SRN)

- SRN : Neutrinos emitted from past SNe since the beginning of the Universe – esp. below 20 MeV

  → SRN energy spectrum measurement, history of SN bursts



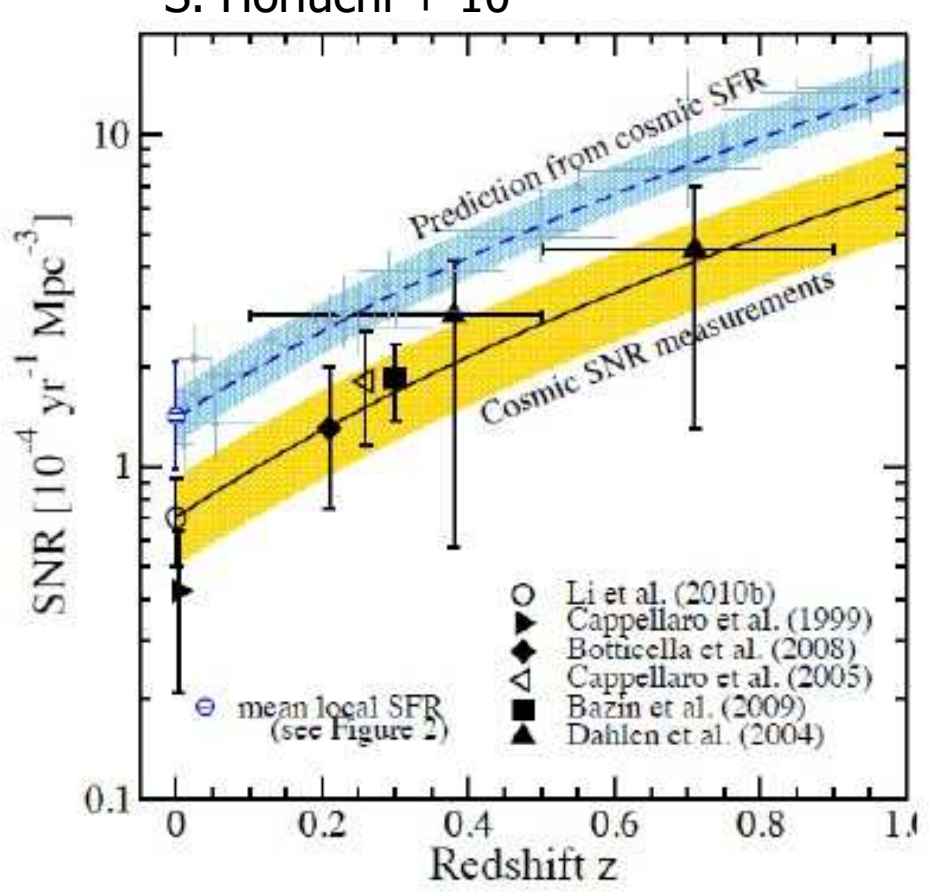


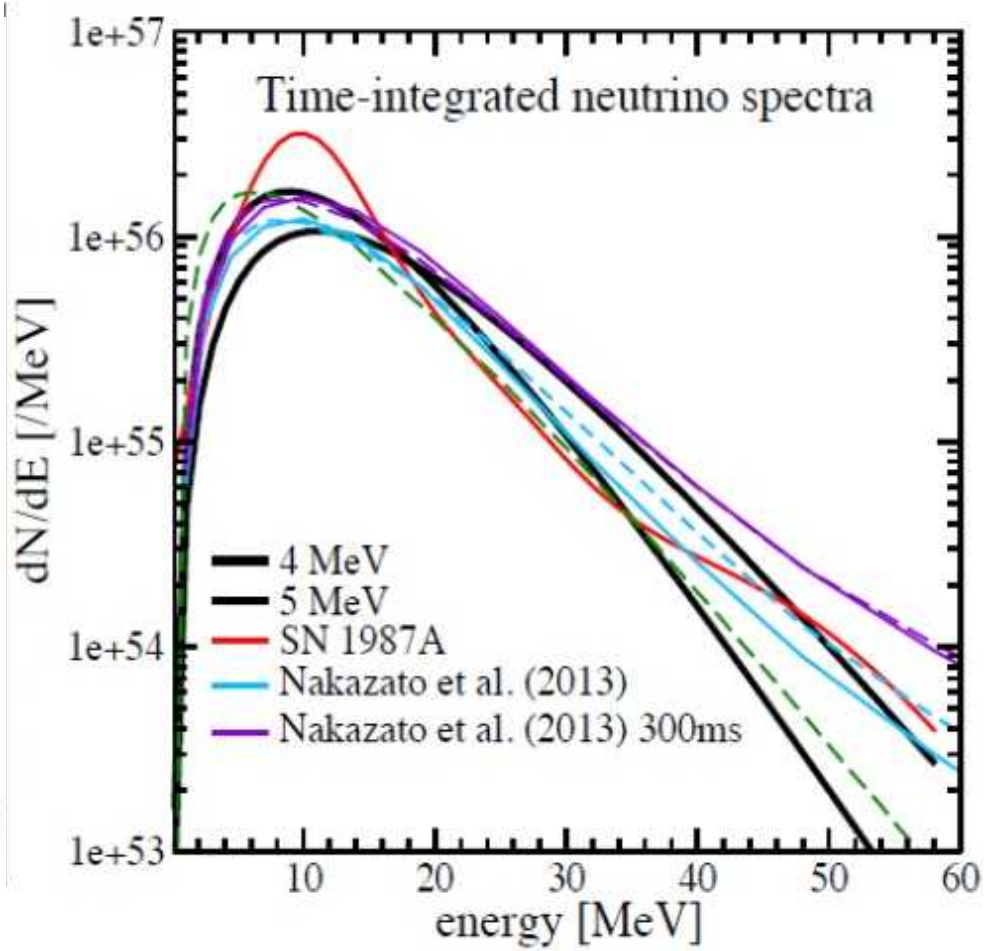
Courtesy Soo-Bong Kim

Supernova Relic Neutrino (SRN)

Physics motivation

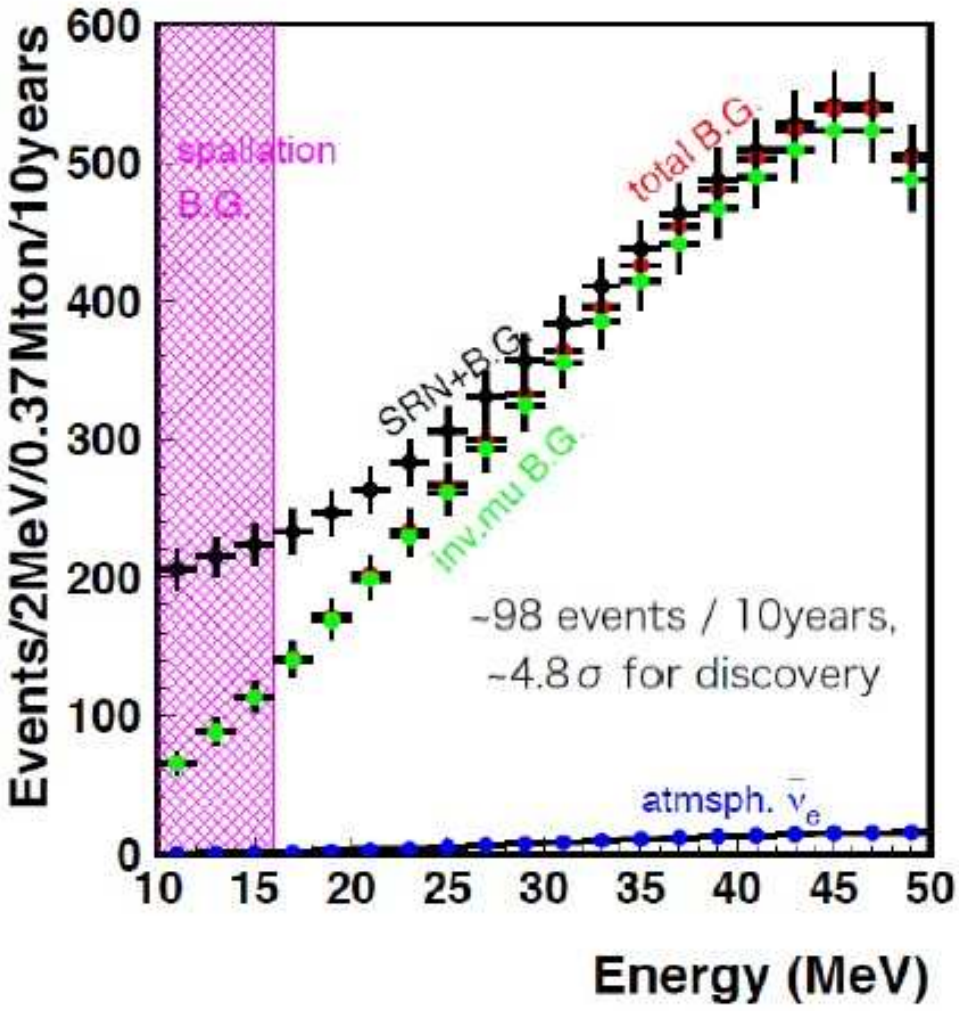
S. Horiuchi + 10

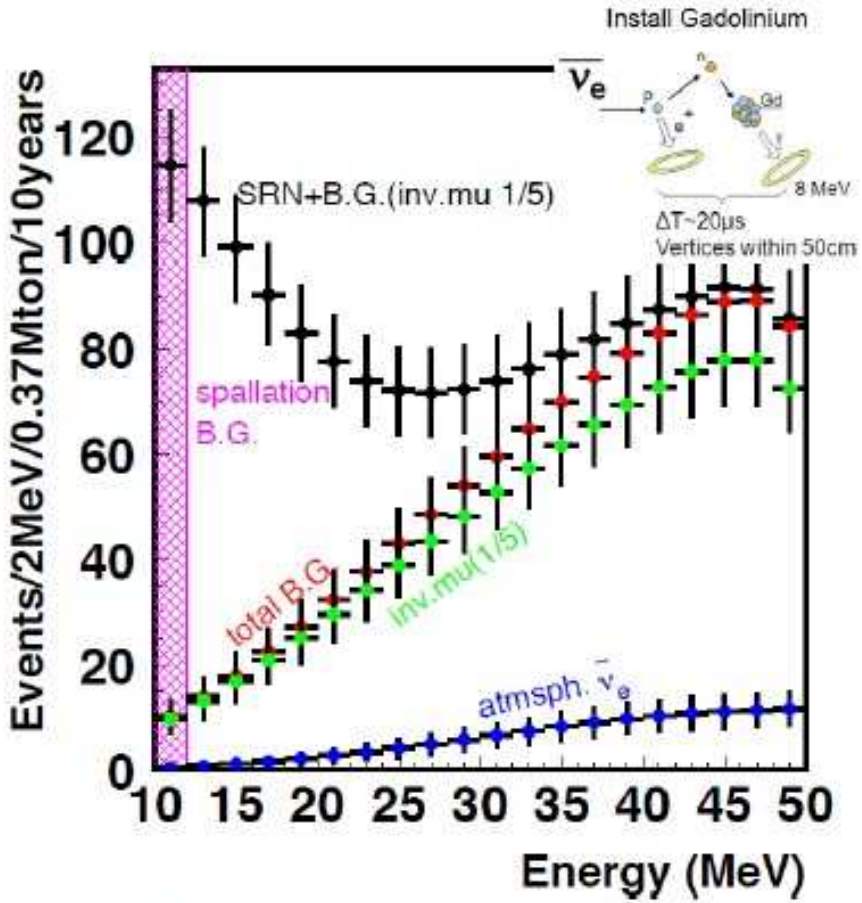




Courtesy Soo-Bong Kim

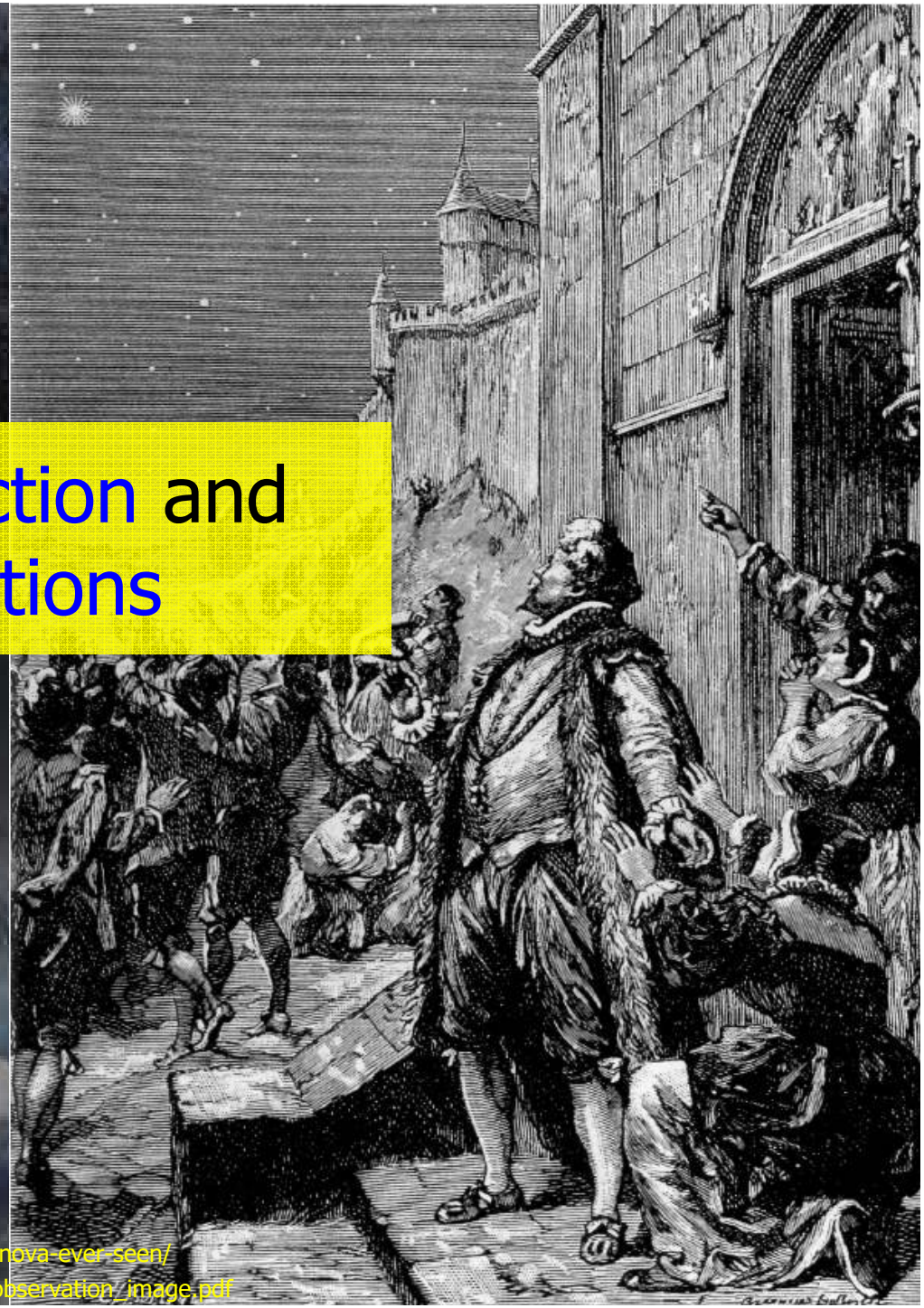
Supernova Relic Neutrino (SRN)





- Neutron tagging makes BG be drastically reduced.
- SRN spectrum can be measured

Courtesy Soo-Bong Kim



Supernova Early Detection and Follow-up Observations

https://www.scientificamerican.com/article/found-the-most-powerful-supernova-ever-seen/
http://www2.mpia-hd.mpg.de/IRSPACE/Tycho_release/tycho1572/Tycho_observation_image.pdf

SN early detection

- Sciences from SN early detection
  - progenitors
  - explosion mechanism
  - fast decay optical transients

- Neutrinos come out first from the core collapse (CC)

- Neutrino telescope can give fast alert to optical and other λ observatories

Milky Way Supernovae

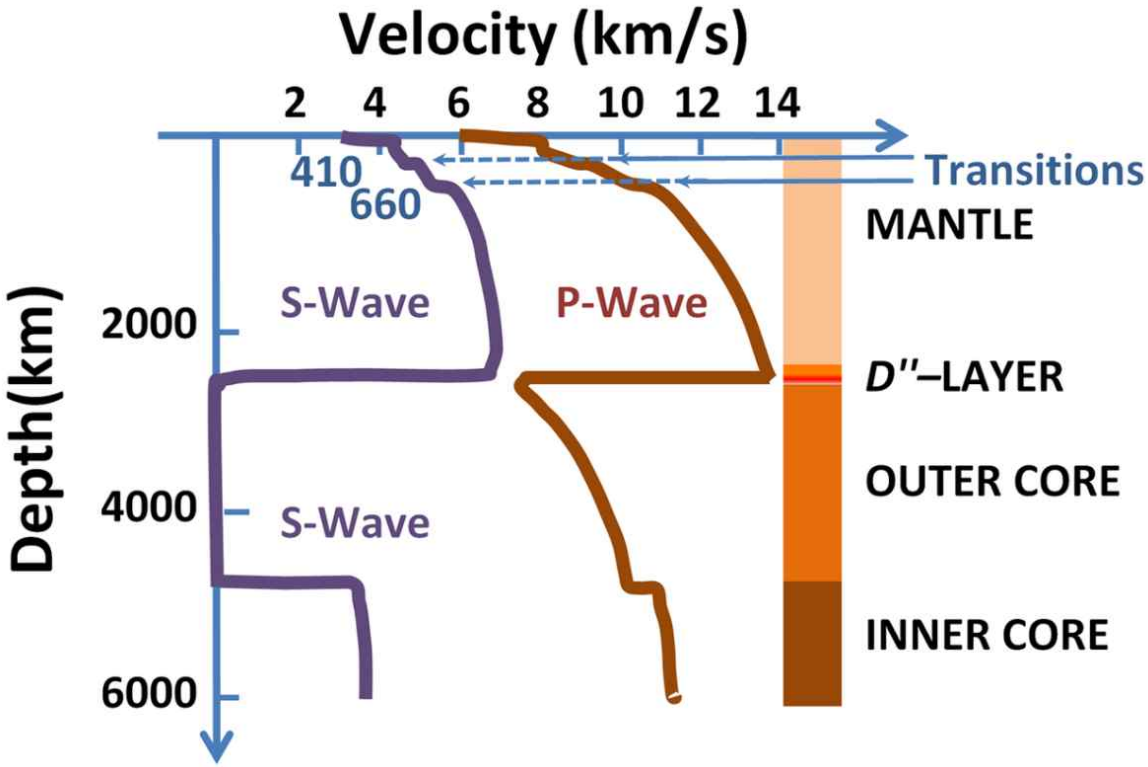
- SN rate ~ few decades - 100 years

- Last (observed) = 1604 Kepler + 관상감
- Last (known) = 1680 Cassiopeia A (Changbom Park et al. 2016 JKAS 49 233)

- The World is waiting for a new SN!

SNEWS: SuperNova Early Warning System

- Similar to "Seismic waves in(on) the Earth"



Seismic wave	파동	Speed	통과물질	피해
Primary wave	종파	**5-8 km/s**	고,액,기체	Minor
Secondary wave	횡파	3-4 km/s	고체	Huge

SNEWS: SuperNova Early Warning System

- http://snews.bnl.gov/
- A network of 7 neutrino detectors
  - Borexino, Daya Bay, KamLAND, HALO, IceCube, LVD, Super-Kamiokande
  - began automatic operation in 2005
  - reports gather + identify SNe at Brookhaven National Laboratory
    → need signals at ≥ 2 detectors within 10 seconds
- To make early warning for CC SNe from the Milky Way, or nearby galaxies (e.g. LMC, Canis Major dwarf)
- Neutrino pulses from SN 1987A – arrived 3 hours before the photons

Summary

Neutrino research - Astronomical applications

- Core-collapse supernovae in the Milky Way or Galaxies in the Local Group (~long Gamma-Ray Burst)

  - early alert, multi-λ obs, explosion mechanism, NS cooling, BH formation

  - behind the bulge, behind the Sun, w/large extinction, failed SNe

  - good sensitivity → larger distance (~Mpc)

- Supernova relic neutrinos (SRN : Neutrinos produced by all of the SN explosions since the beginning of the Universe) – esp. below 20 MeV (~100 events in 10 years)

  → SRN energy spectrum measurement, history of SN bursts


Thank you.