Supernovae

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warning

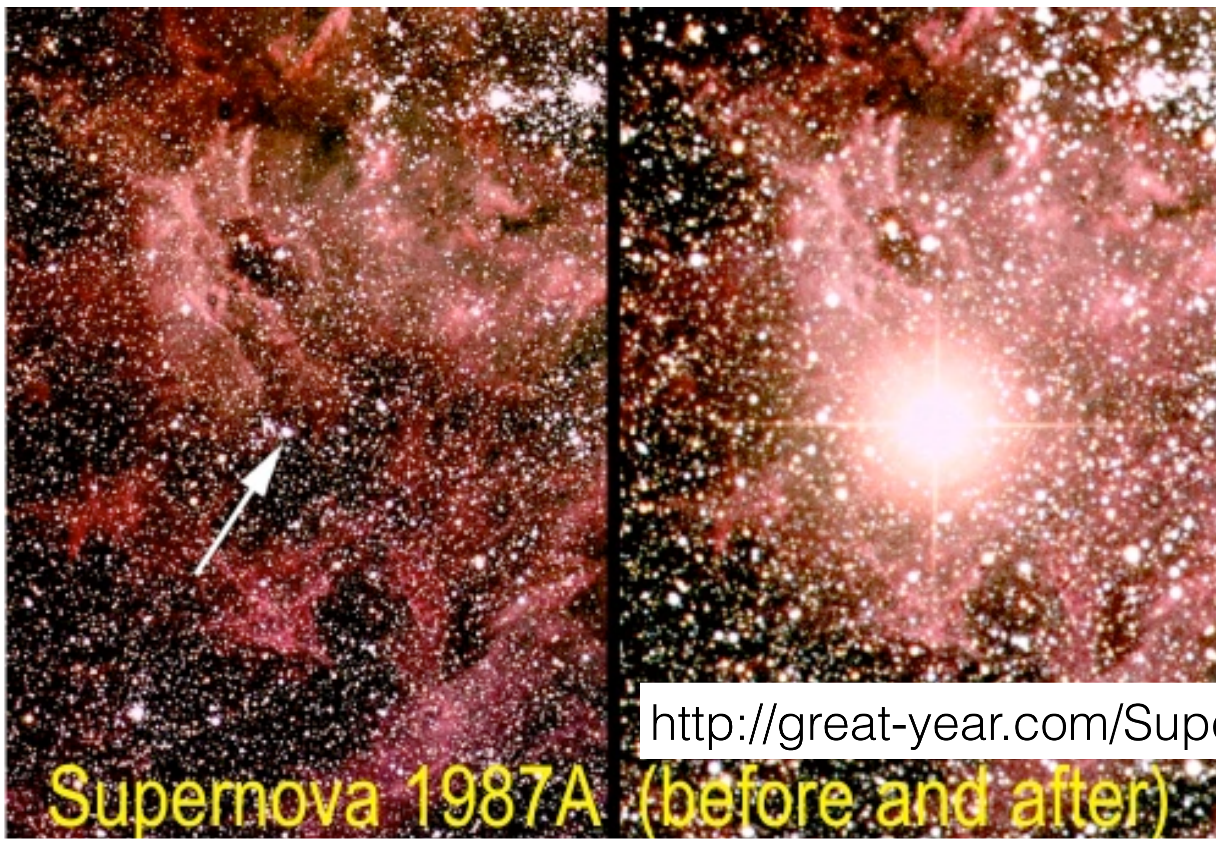
I'm *not* at all supernova expert; just a few thoughts about how supernova play a critical role in understanding disparate aspects of physics!

February 11, 2016   LIGO Press Announcement
(Kip Thorne speaking)

https://www.youtube.com/watch?v=aEPIwEJmZyE

April 7, 1987   New York Times on Supernova 1987A

THE nearby explosion of a star and a lucky succession of scientific accidents are combining to create a new branch of astronomy, in which new instruments sensitive to streams of neutrino particles could serve as the counterparts of light-gathering telescopes.



http://great-year.com/Supernova_1987A.jpg

April 7, 1987 New York Times on Supernova 1987A

"Theories of stellar evolution predict that supernova explosions should occur fairly often ... we should be able to detect the neutrino signature of about one relatively nearby supernova every ten years."

(late) John Bahcall

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Take all (legitimate!) press/public releases of scientific information with a grain of salt…

Supernovae

3 Vignettes

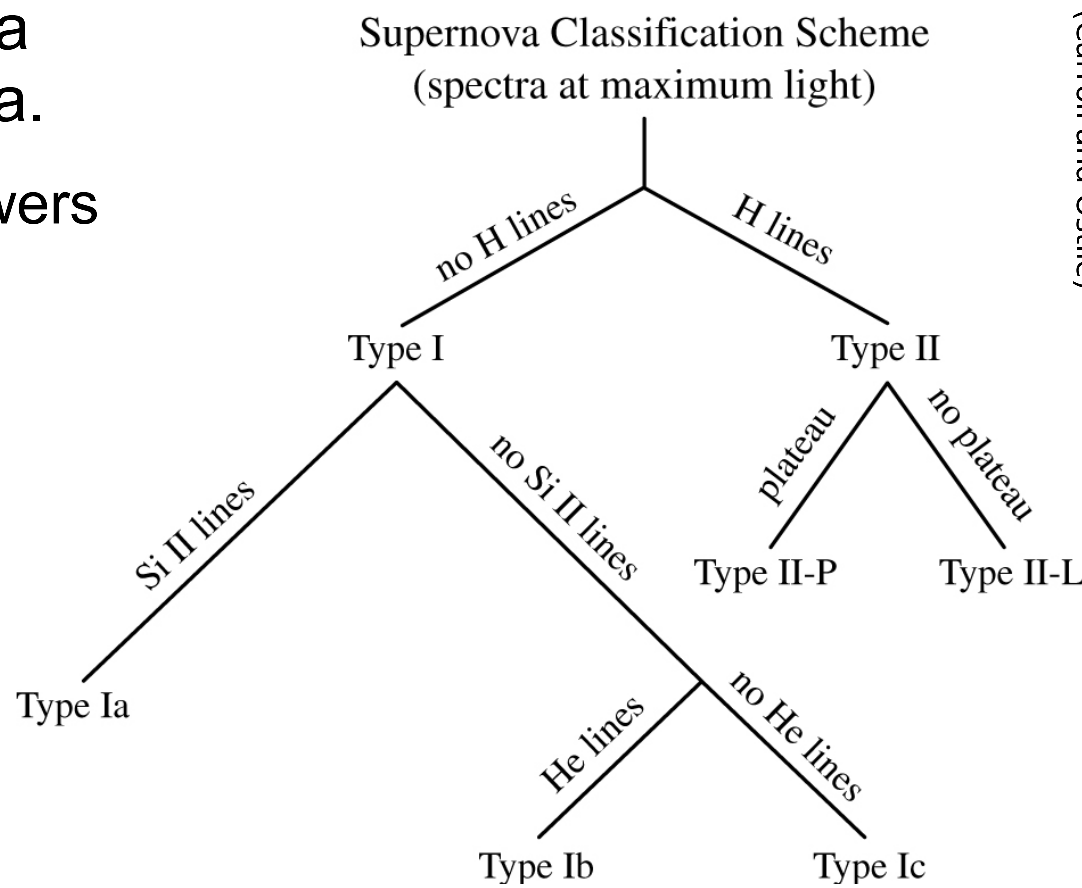
- 1987A - neutrinos!
- “Type II” supernovae and “heavy” elements
- “Type Ia” supernovae and cosmology

Supernovae

Type II, Ib, and Ic supernova are core-collapse supernova.

Gravitational collapse powers the explosion.

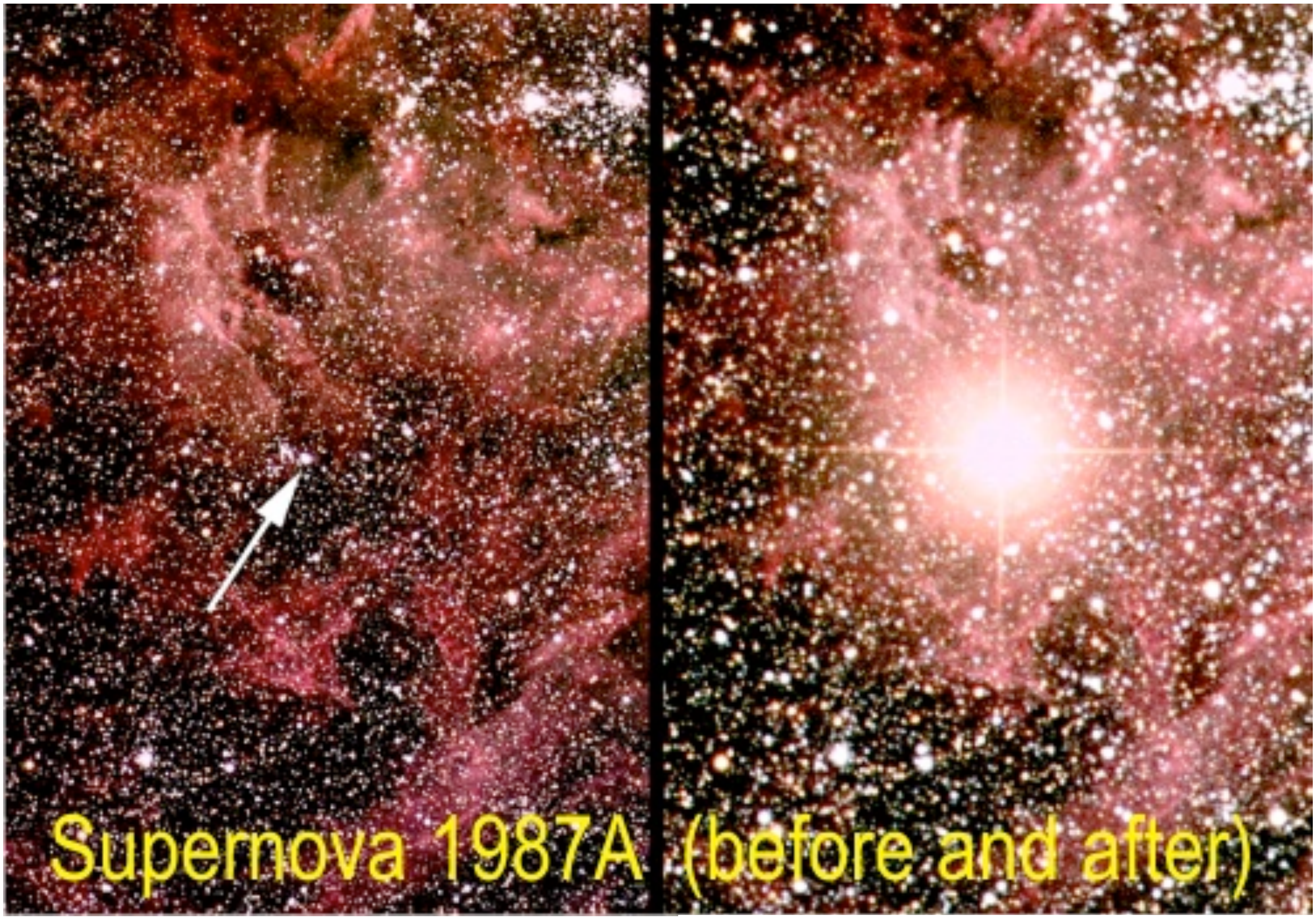
Type Ia supernovae are themonuclear explosions.



(Carroll and Ostlie)

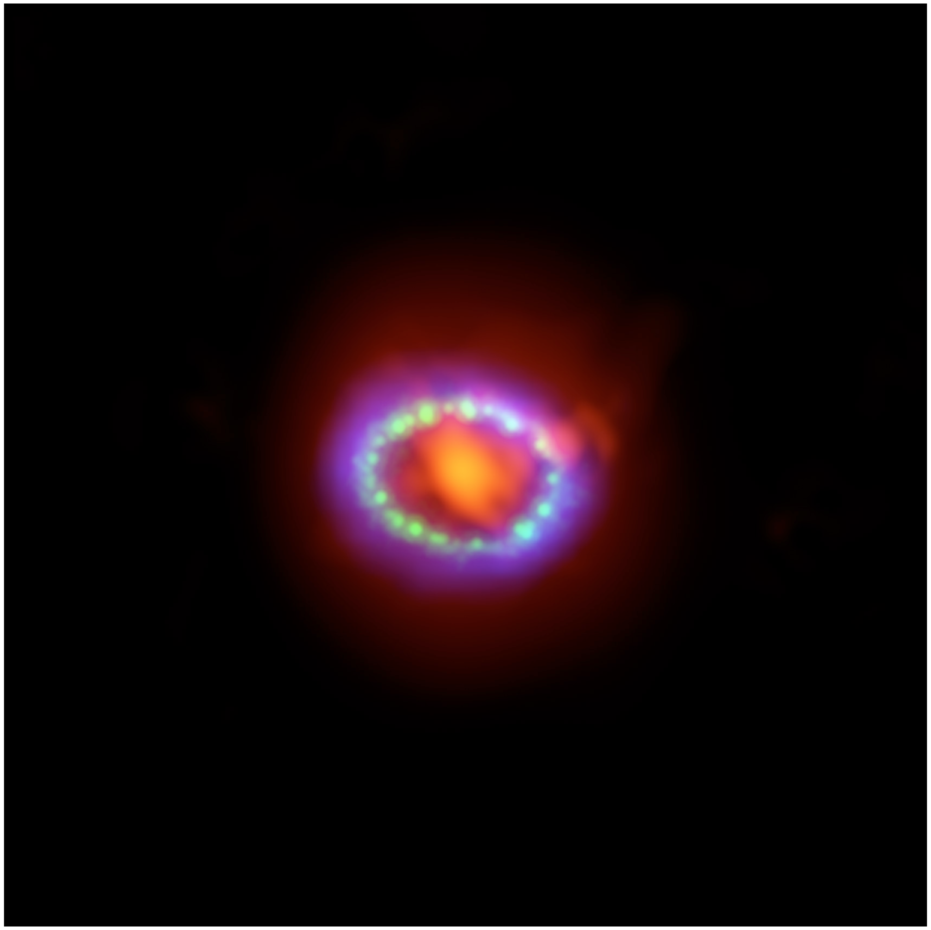
http://www.astro.sunysb.edu/lattimer/AST301/SNela_ast301.pdf

Supernova 1987A



http://great-year.com/Supernova_1987A.jpg

Supernova 1987A



This image shows the remnant of Supernova 1987A seen in light of very different wavelengths. ALMA data (in red) shows newly formed dust in the centre of the remnant. Hubble (in green) and Chandra (in blue) data show the expanding shock wave.

https://upload.wikimedia.org/wikipedia/commons/a/af/Composite_image_of_Supernova_1987A.jpg

PBS NOVA program

(late) Stirling Colgate

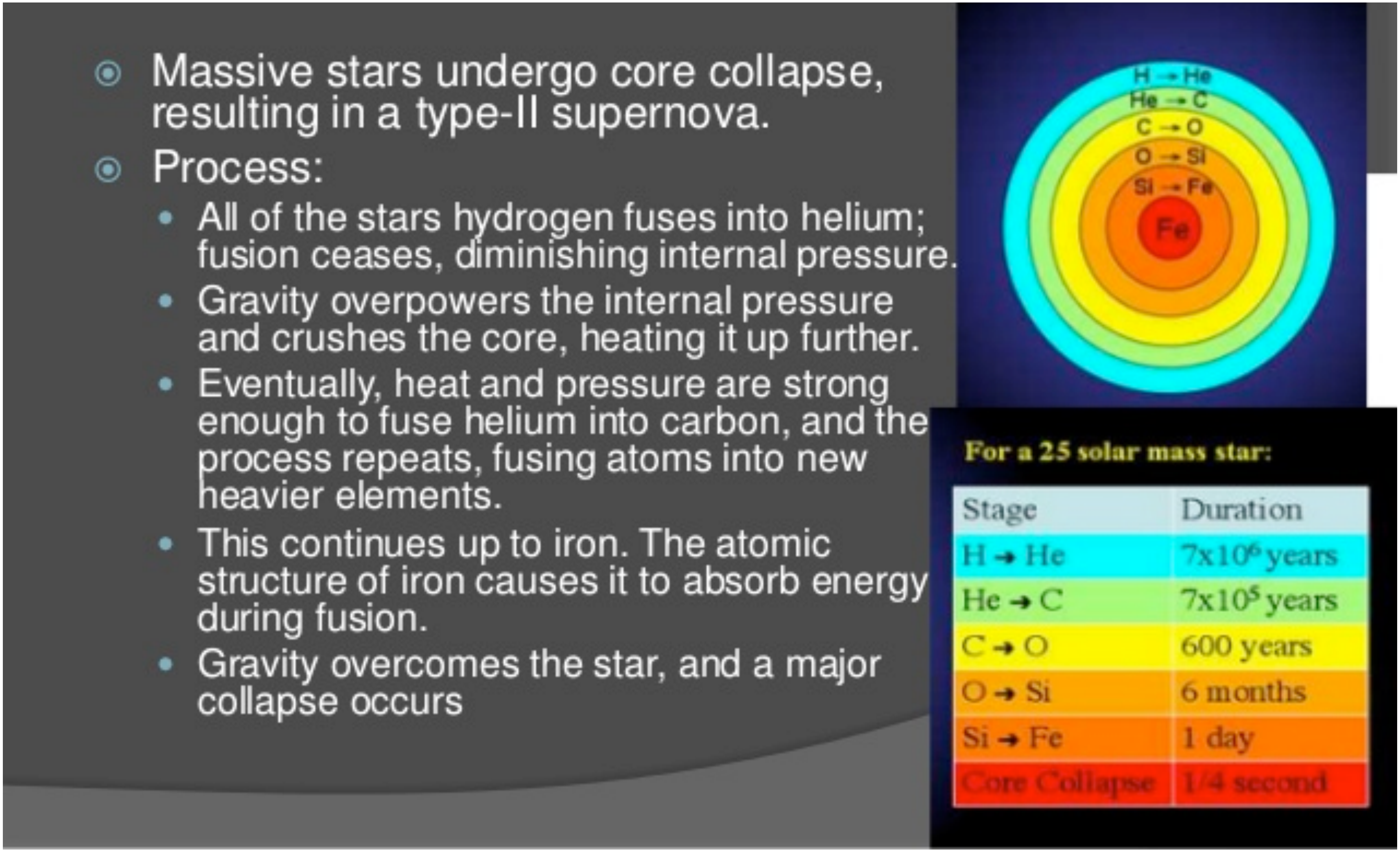
https://www.youtube.com/watch?v=ubDjB-gHfsw

PBS NOVA program

Stan Woosley

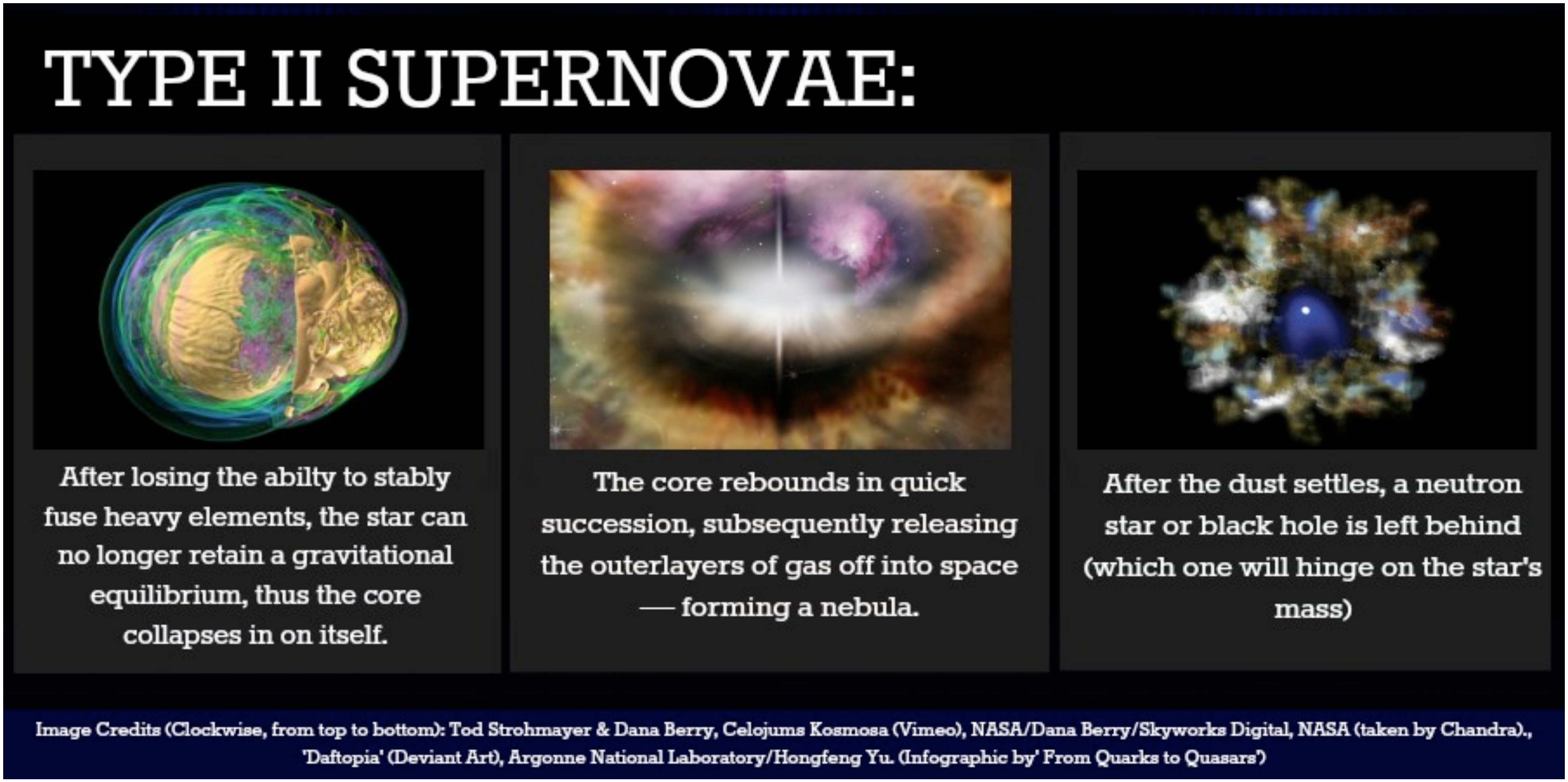
https://www.youtube.com/watch?v=ubDjB-gHfsw

Type II (Core Collapse) Supernova



http://image.slidesharecdn.com/conleycis100pptassignment-121119223233-phpapp01/95/conley-cis100-pptassignment-8-638.jpg?cb=1353364436

Type II (Core Collapse) Supernova



http://futurism.com/wp-content/uploads/2014/02/Supernova-Types-Infographic-From-Quarks-to-Quasars.png

Neutrinos

$$p + e^- \rightarrow n + \nu_e$$

Lawrence Krauss

https://www.youtube.com/watch?v=gcZqqTffjJ0

PBS NOVA program - neutrino observation

https://www.youtube.com/watch?v=ubDjB-gHfsw

Neutrino data

Arnett, Bahcall, Kirshner, Woosley.
Published in Ann.Rev.Astron.Astrophys. 27 (1989) 629-700

Table 3 Measured properties of neutrino events observed in water Cherenkov detectors[a]

Event	Event time (s)	Electron energy (MeV)	Electron angle (degrees)
Kamiokande II:			
1	0.0	20.0 ± 2.9	18 ± 18
2	0.107	13.5 ± 3.2	40 ± 27
3	0.303	7.5 ± 2.0	108 ± 32
4	0.324	9.2 ± 2.7	70 ± 30
5	0.507	12.8 ± 2.9	135 ± 23
6	0.686	6.3 ± 1.7	68 ± 77
7	1.541	35.4 ± 8.0	32 ± 16
8	1.728	21.0 ± 4.2	30 ± 18
9	1.915	19.8 ± 3.2	38 ± 22
10	9.219	8.6 ± 2.7	122 ± 30
11	10.433	13.0 ± 2.6	49 ± 26
12	12.439	8.9 ± 1.9	91 ± 39
IMB:			
1	0.0	38 ± 7	80 ± 10
2	0.41	37 ± 7	44 ± 15
3	0.65	28 ± 6	56 ± 20
4	1.14	39 ± 7	65 ± 20
5	1.56	36 ± 9	33 ± 15
6	2.68	36 ± 6	52 ± 10
7	5.01	19 ± 5	42 ± 20
8	5.58	22 ± 5	104 ± 20

[a] The first events were detected on February 23, 1987, at about 7 hr 36 m UT. The angle in the last column is relative to the direction of the LMC. The errors are estimated 1σ uncertainties.

Simulating the Explosion Mechanism (Do they blow up?)

- The type-II supernova explosion mechanism: Despite 50 years of intensive investigation, we still do not understand exactly how massive stars blow up. Models of increasing complexity and dimensionality exist but still do not adequately predict such fundamentals as the explosion energy and mass cut (including fallback). They are thus unable to predict with necessary precision the mass of neutron stars or the products of explosive silicon burning. Uncertainty in the explosion mechanism as well as the nuclear equation of state makes it difficult to predict which stars will leave neutron stars as remnants and which will leave black holes.

Woosley, Heger, Weaver,
Rev.Mod.Phys. 74 (2002) 1015

Predicted Elemental Abundances (from one 25 solar mass Type II)

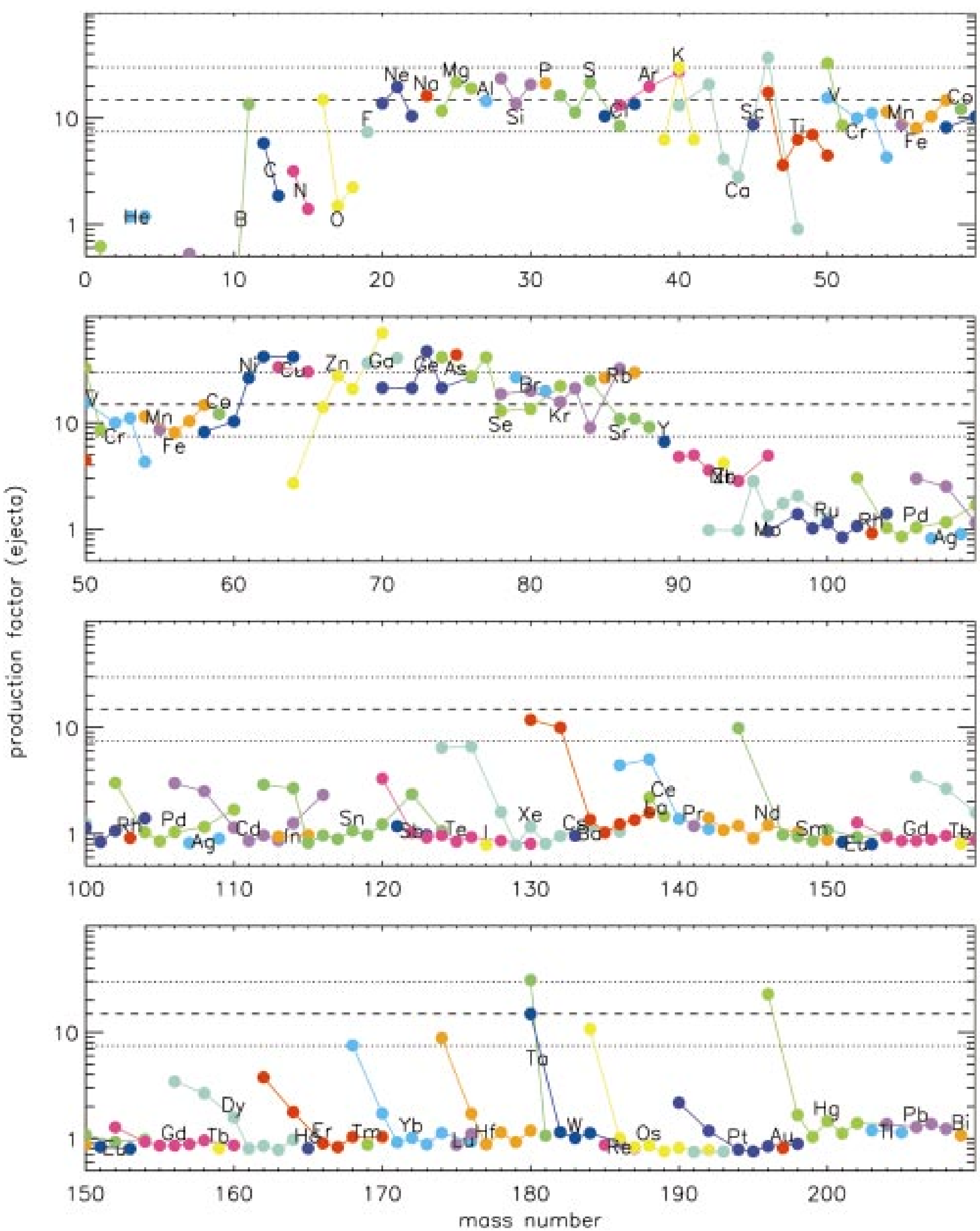


FIG. 27. Final nucleosynthesis from a $25M_{\odot}$ supernova compared to solar abundances (Heger, Woosley, Rauscher, and Hoffman, 2002). Isotopes of a given element are all the same color and are connected by lines. All ejecta, including the wind, are included. A possible *r* process in the neutrino wind is not taken into account here. The production factor is the ratio of the mass fraction in the ejecta divided by the mass fraction in the sun [Color].

Woosley, Heger, Weaver, Rev.Mod.Phys. 74 (2002) 1015

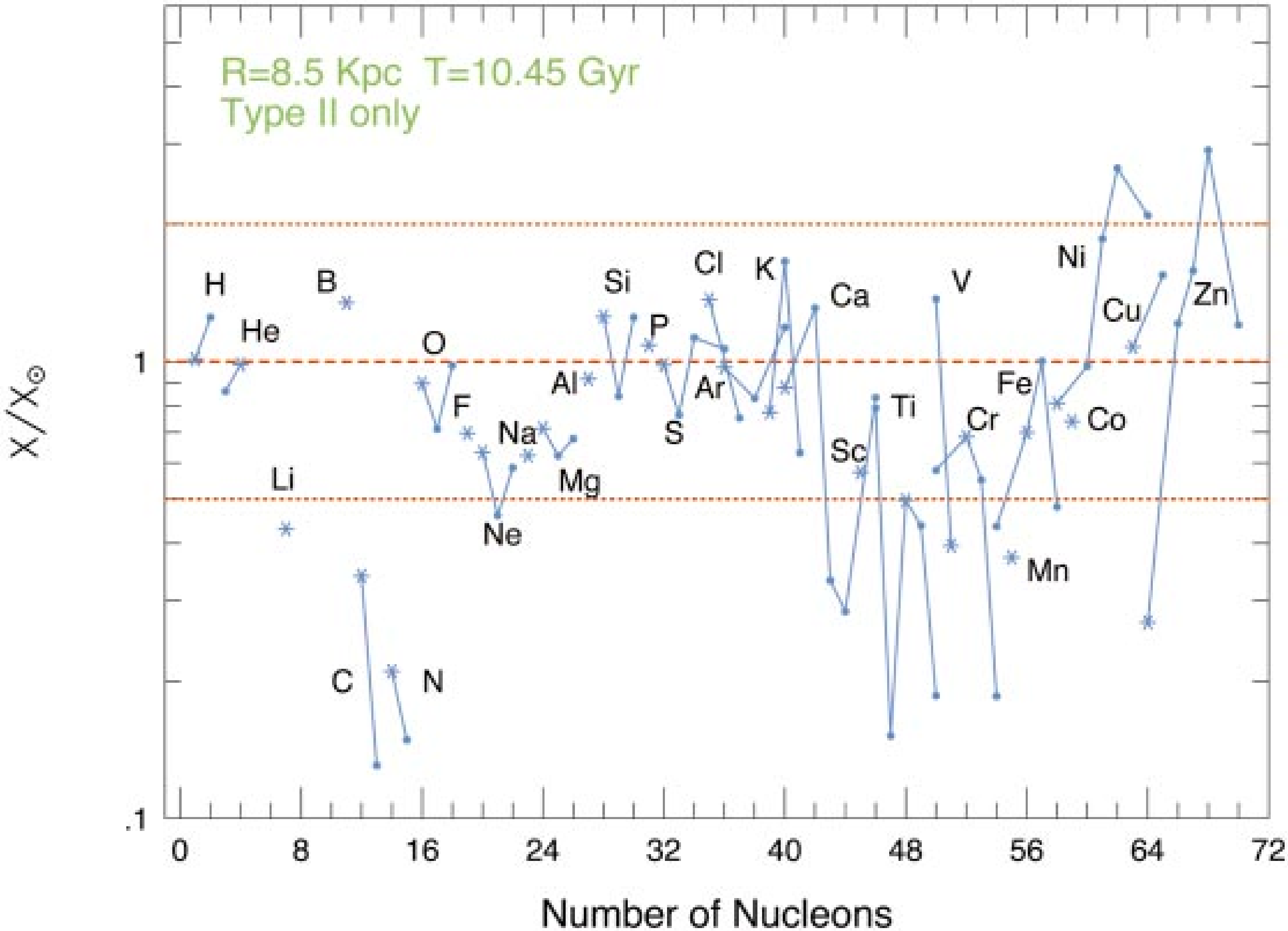


FIG. 28. Integrated nucleosynthesis from a grid of massive stars ($11\text{–}40 M_\odot$) of various metallicities ($0 Z_\odot$, $10^{-4} Z_\odot$, $0.01 Z_\odot$, $0.1 Z_\odot$, and $1 Z_\odot$) compared to the solar abundances (Timmes, 1996). This figure also includes contributions from the big bang (hence ^{2}H) but not from low-mass stars (especially ^{12}C and ^{14}N) or type-Ia supernovae (especially ^{55}Mn, ^{54,56}Fe, and ^{58}Ni) or novae (^{15}N, ^{17}O). The overproduction of Zn and Ni isotopes may reflect an overly large rate for $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ during the *s* process [Color].

Woosley, Heger, Weaver,
Rev.Mod.Phys. 74 (2002) 1015

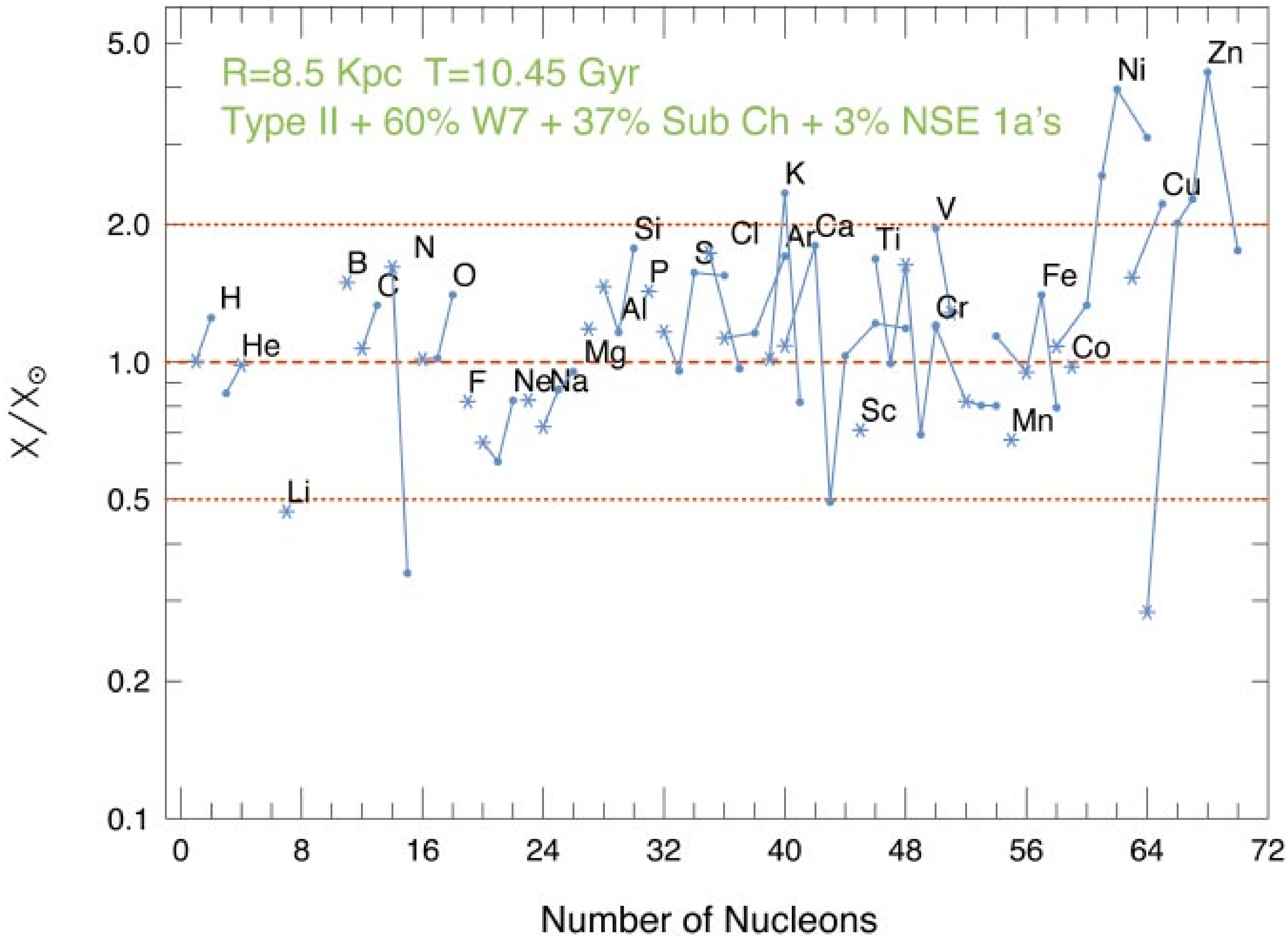
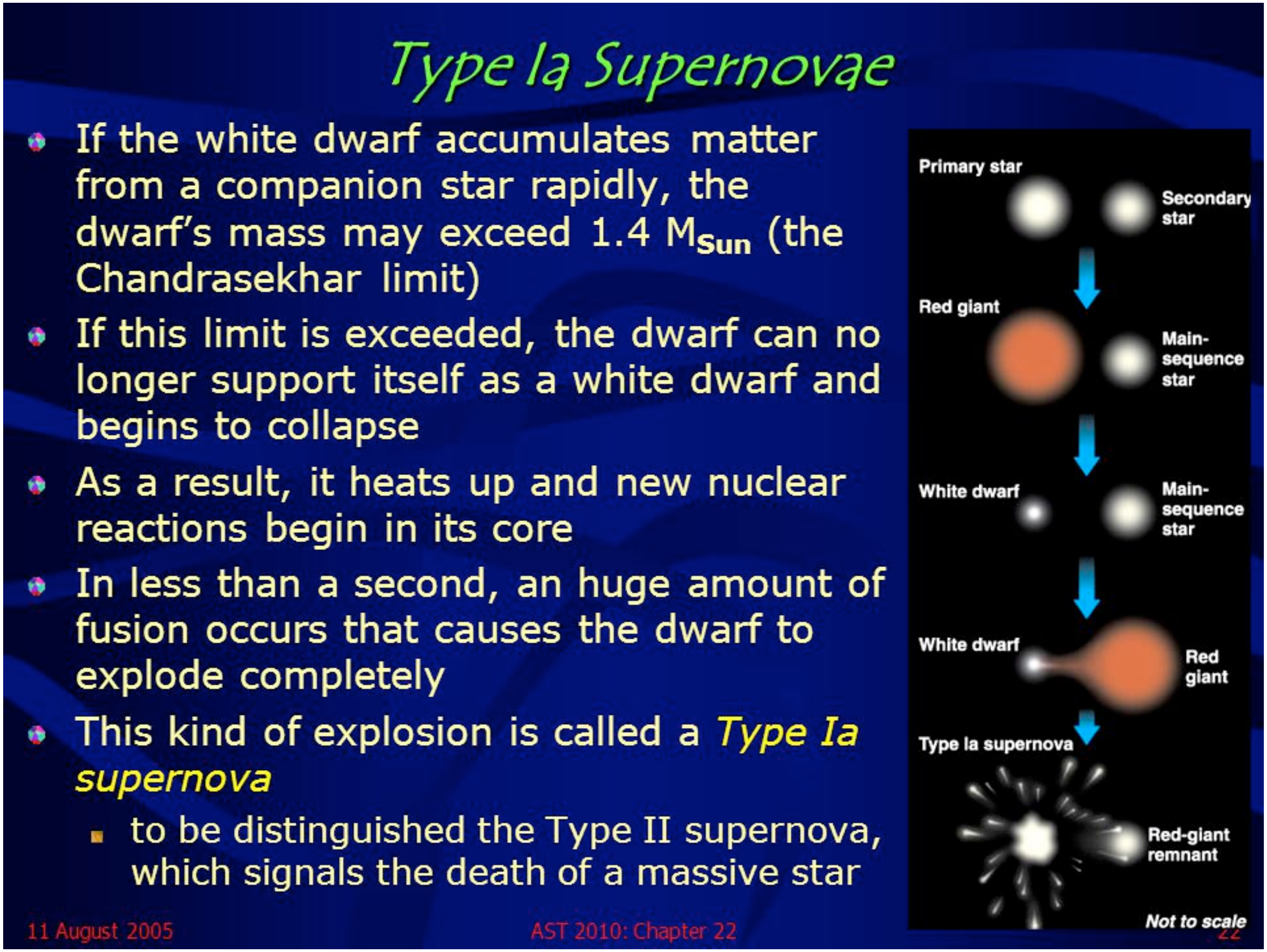


FIG. 29. The agreement in Fig. 28 is greatly improved if one includes the iron-group production from three varieties of type-Ia supernovae (see text and Table III) as well as classical novae (Timmes, 1996) [Color].

Woosley, Heger, Weaver,
Rev.Mod.Phys. 74 (2002) 1015

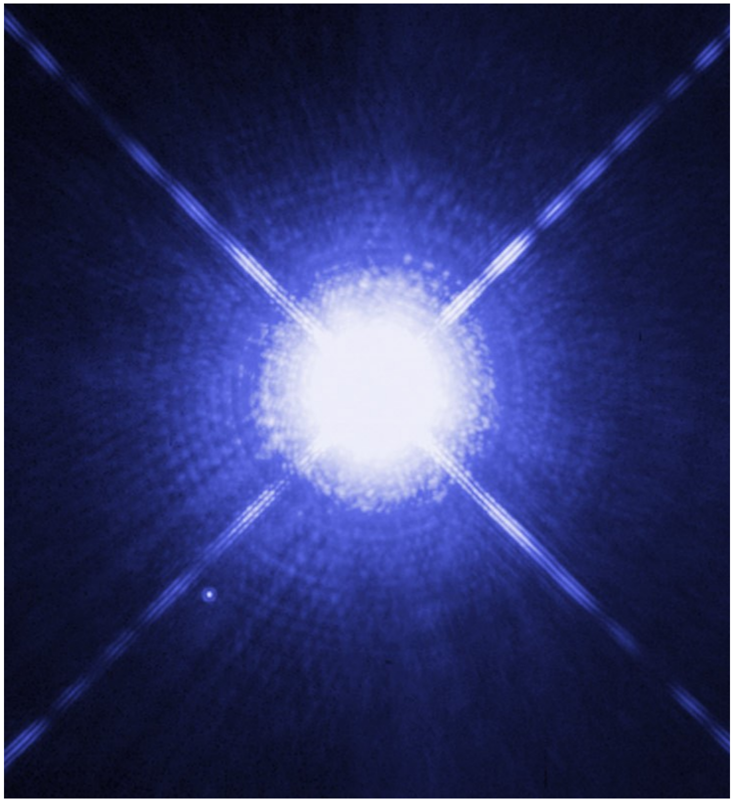
Type Ia (Explosive) Supernova



http://slideplayer.com/slide/3852659/

Type Ia (Explosive) Supernova

- Best model for SNe Ia: thermonuclear explosion of a carbon/oxygen white dwarf
  - Electron degeneracy pressure provides support
    - Very different than thermal pressure
    - Heisenberg uncertainty principle + Pauli exclusion principle at work
- Chandrasekhar showed maximum mass supported by electron degeneracy pressure is 1.4 times the mass of the sun.
  - This maximum mass provides the robustness we are looking for.



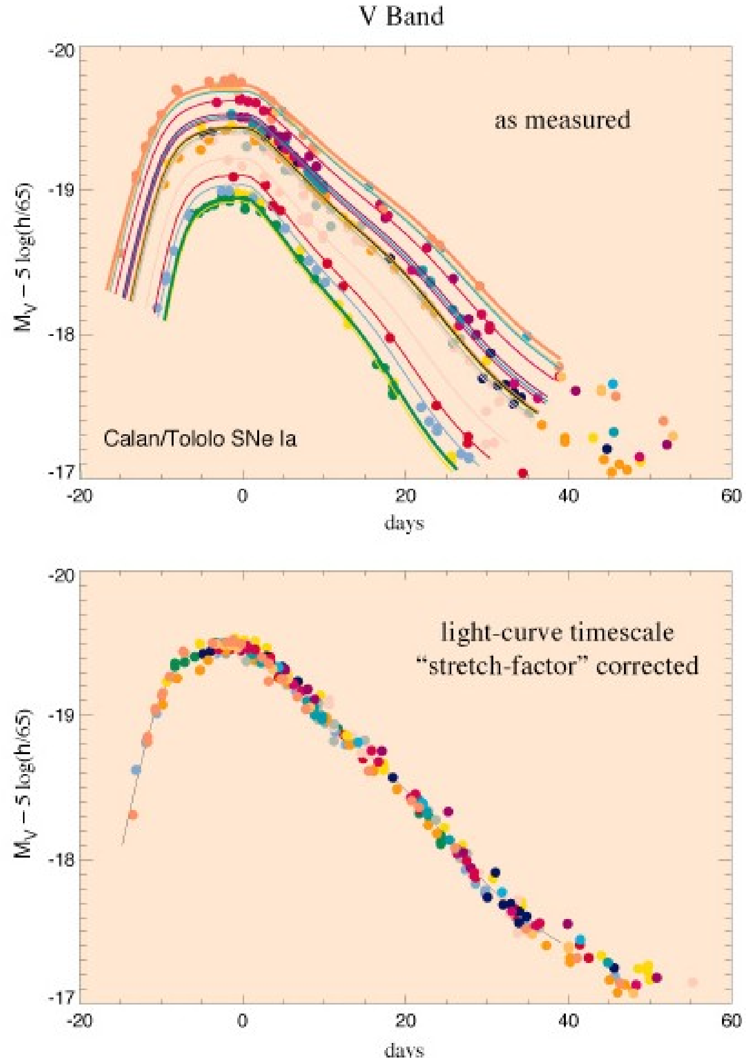
Sirius A and its white dwarf companion Sirius B (NASA/HST)

http://www.astro.sunysb.edu/lattimer/AST301/SNela_ast301.pdf

Type Ia Supernovae Observations

One of the main observables for SNe Ia is the lightcurve. Observations of nearby events have shown that the variation in the lightcurves can be corrected for. In this way SNe Ia act as standard candles.

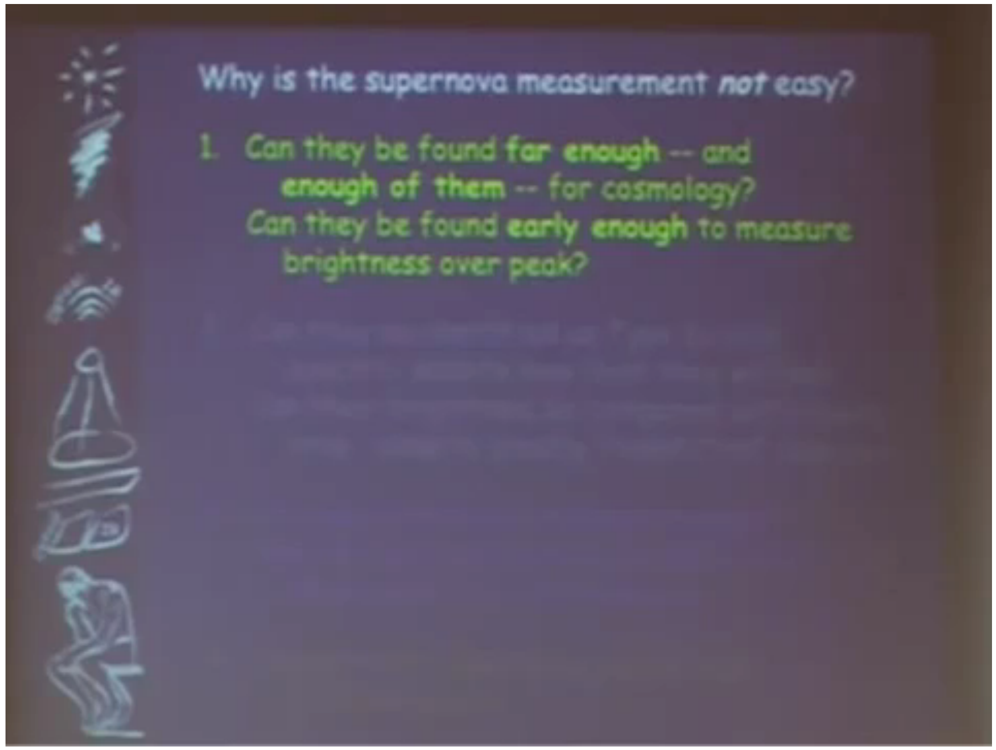
If we know how bright these explosions are intrinsically, and we measure how bright they appear to us, then we can measure their distance.



Phillips (1993), Perlmutter et al. (1997)

http://www.astro.sunysb.edu/lattimer/AST301/SNeIa_ast301.pdf

Saul Perlmutter Nobel Lecture



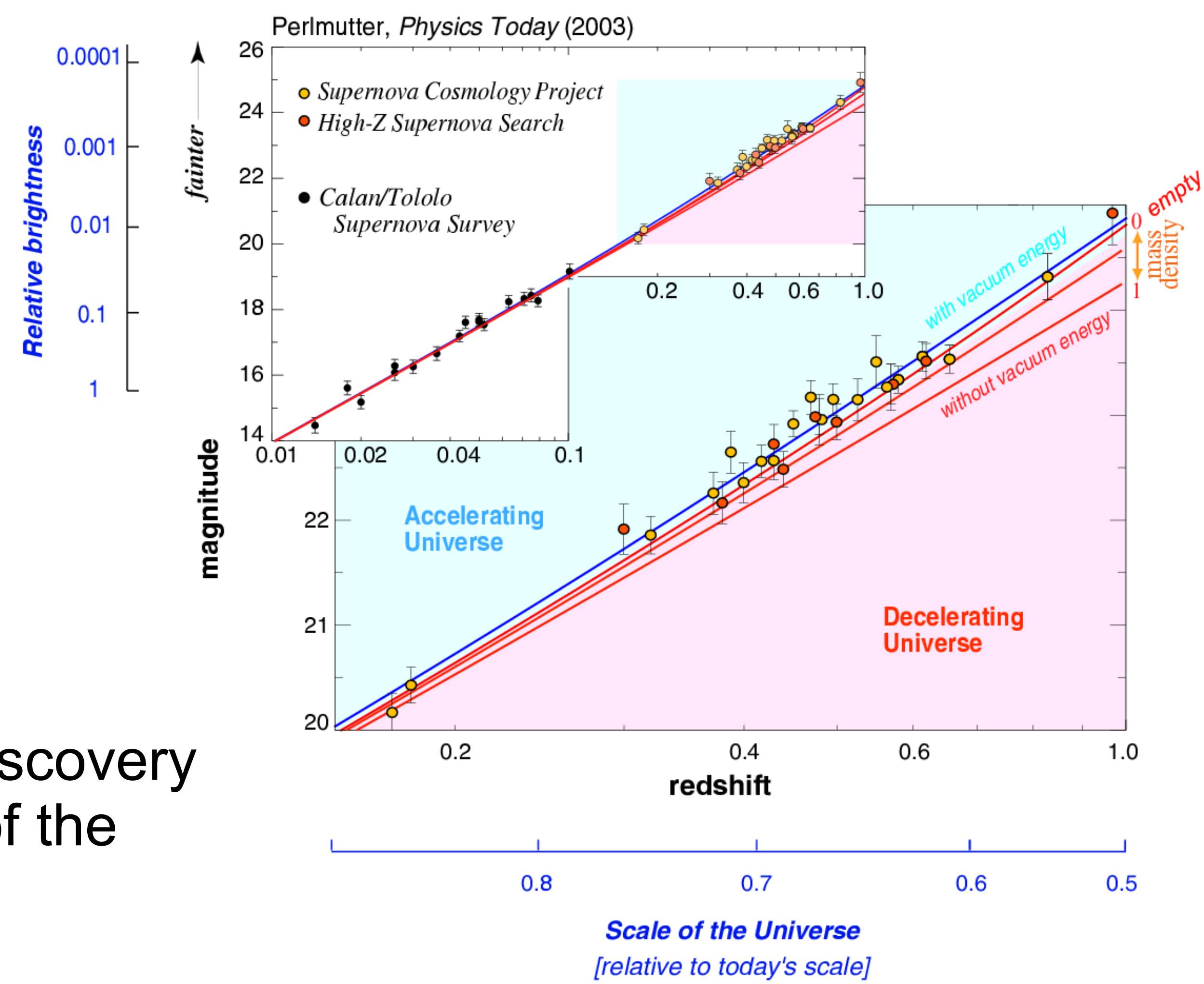
https://www.youtube.com/watch?v=z31rTvGyBh0

Type Ia Supernovae Observations

Plotting the distance verse redshift produces a Hubble diagram.

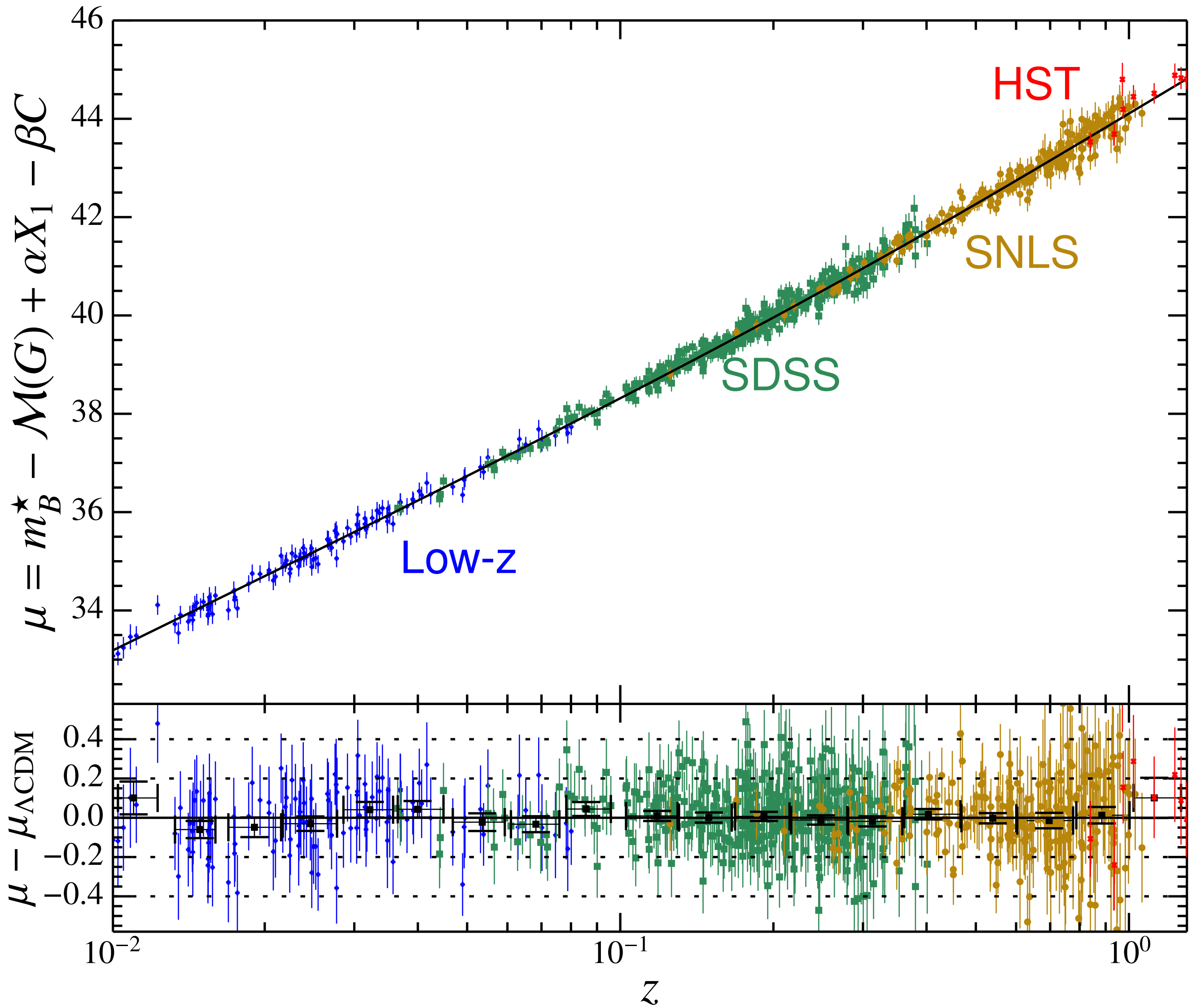
Distance supernovae allow us to determine the cosmological parameters.

In 1998, this led to the discovery that the expansion rate of the Universe is accelerating.



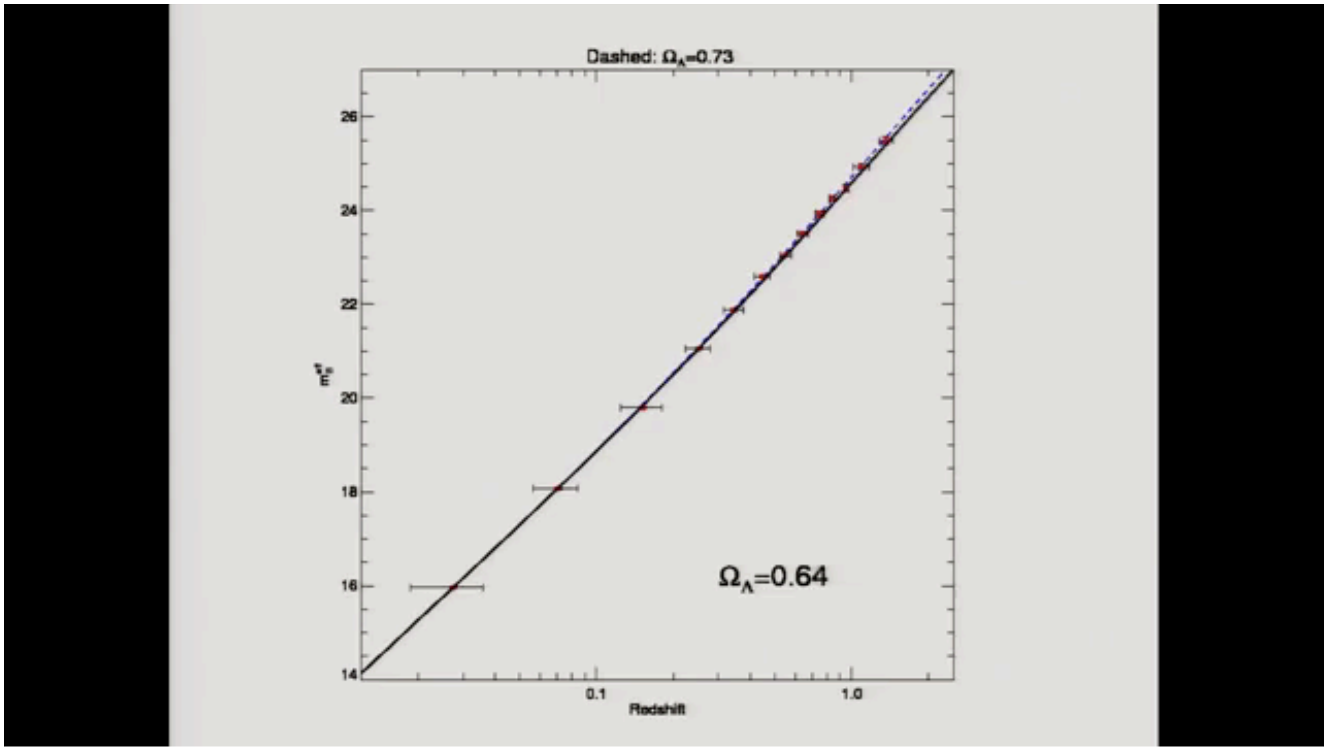
http://www.astro.sunysb.edu/lattimer/AST301/SNela_ast301.pdf

Supernova Observations versus Redshift



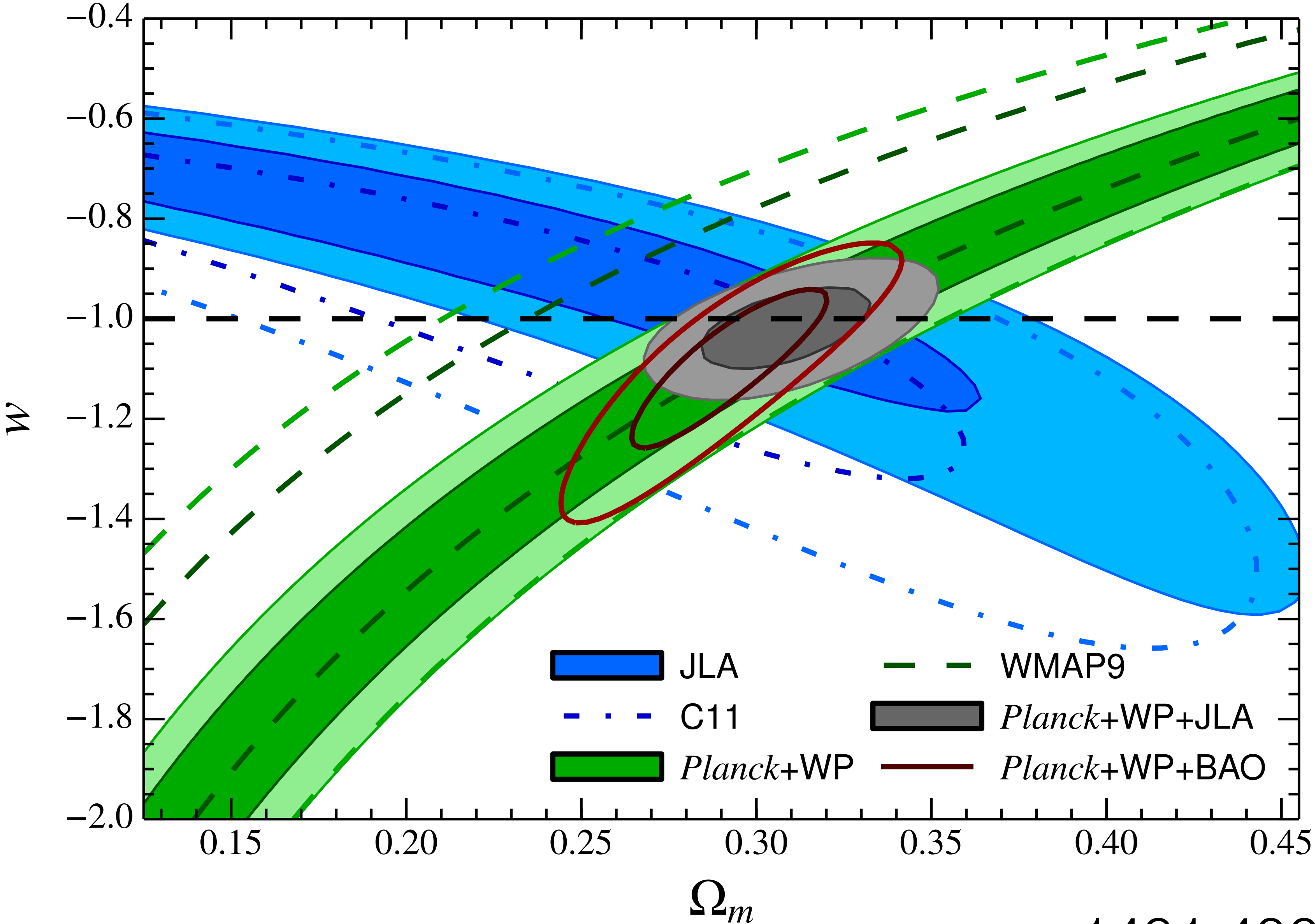
1401.4064

Robert Kirshner explains…



https://www.youtube.com/watch?v=wNMBVF2lncM

ΛCDM model



1401.4064

Big mystery remains!   w=-1 is cosmological constant

Steven Weinberg

https://www.youtube.com/watch?v=g-y3DPJRVhE