Week 6

HW04 due on Thursday

Projects: http://www.astro.utah.edu/~wik/courses/astr5590spring2020/projects.html

Chapter 9: Other High Energy Processes / Radiation

Supernovae (Ch. 13)

Synchrotron Self-Absorption

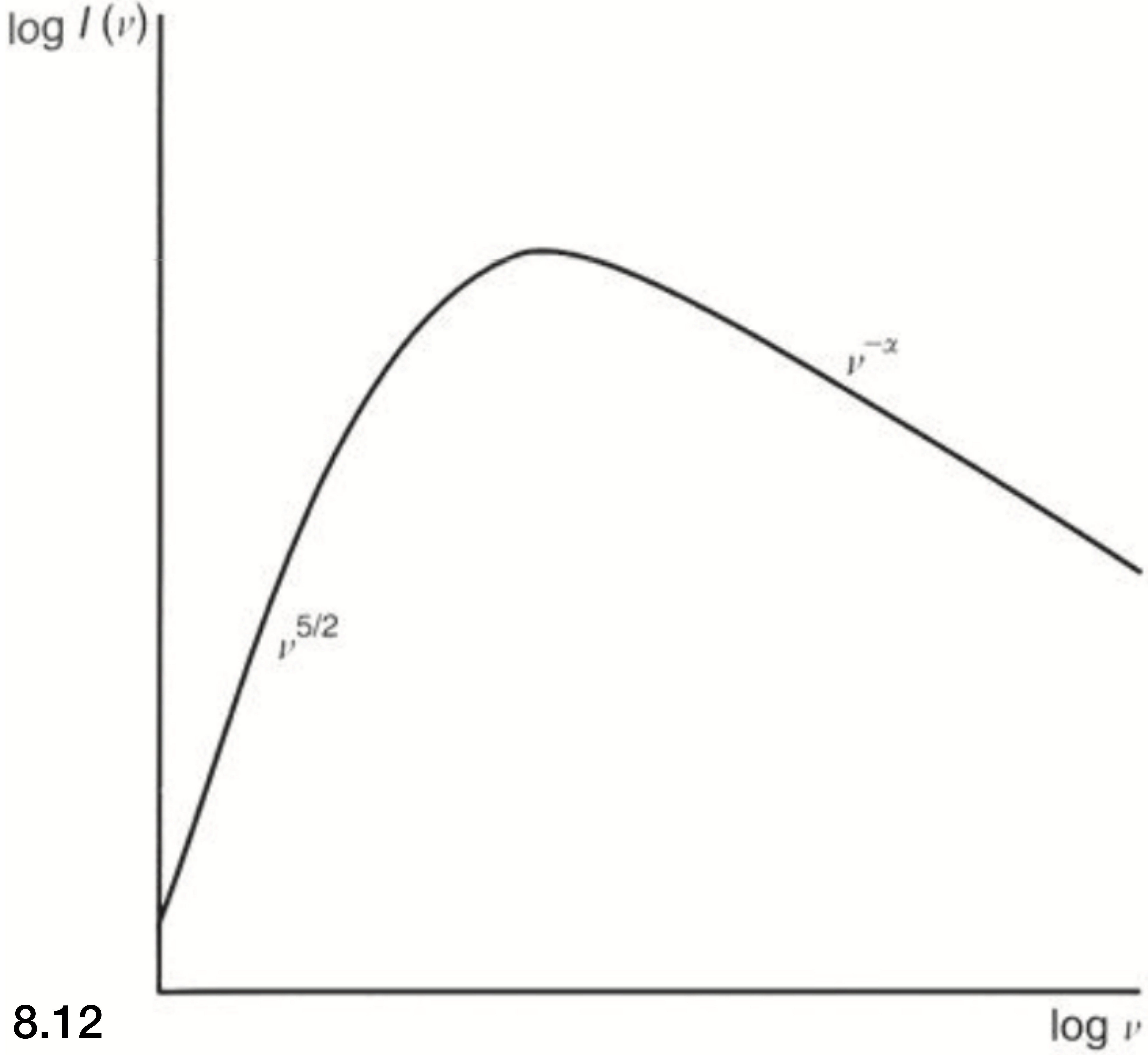


Fig. 8.12

Photoelectric Absorption

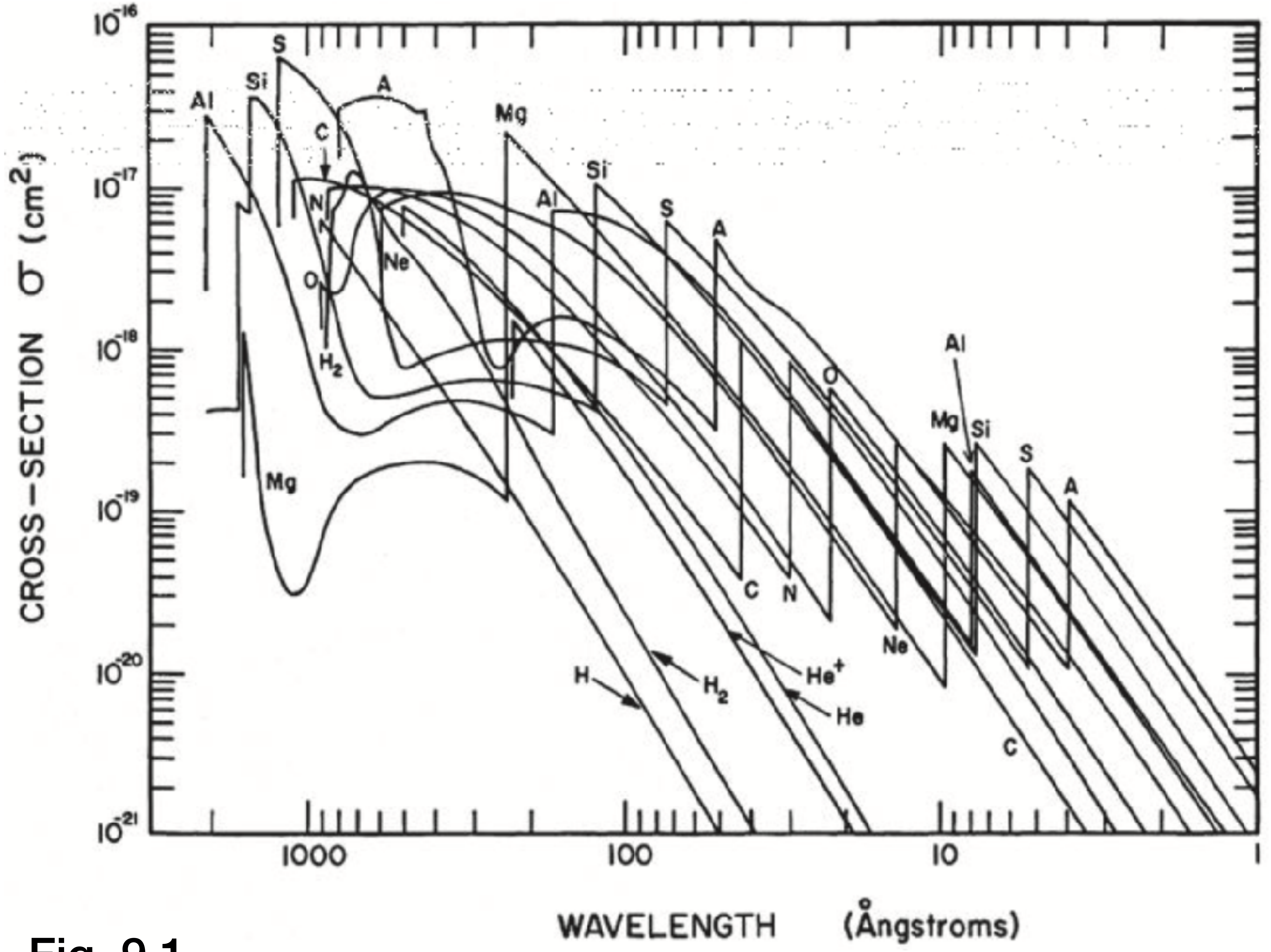


Fig. 9.1

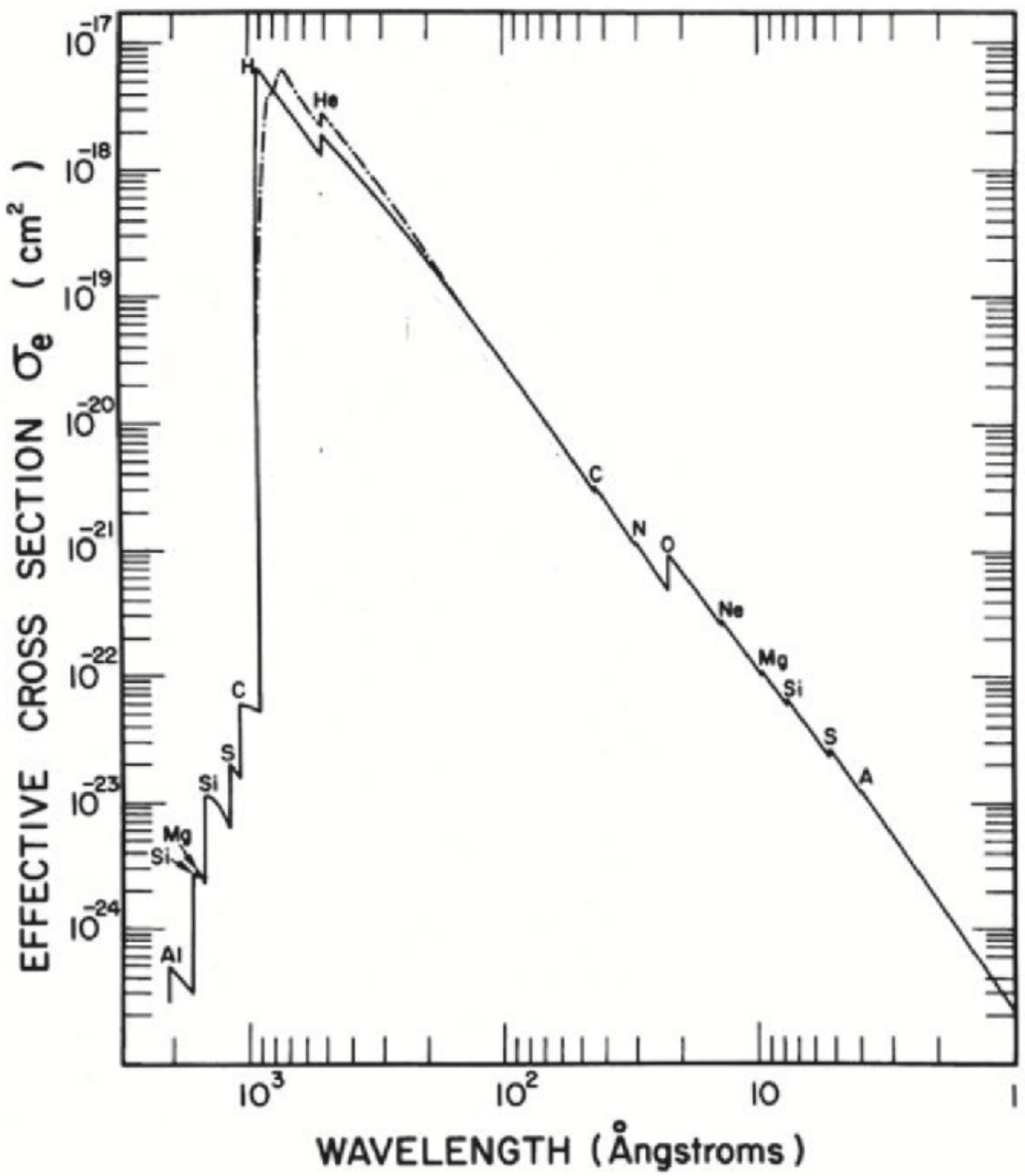
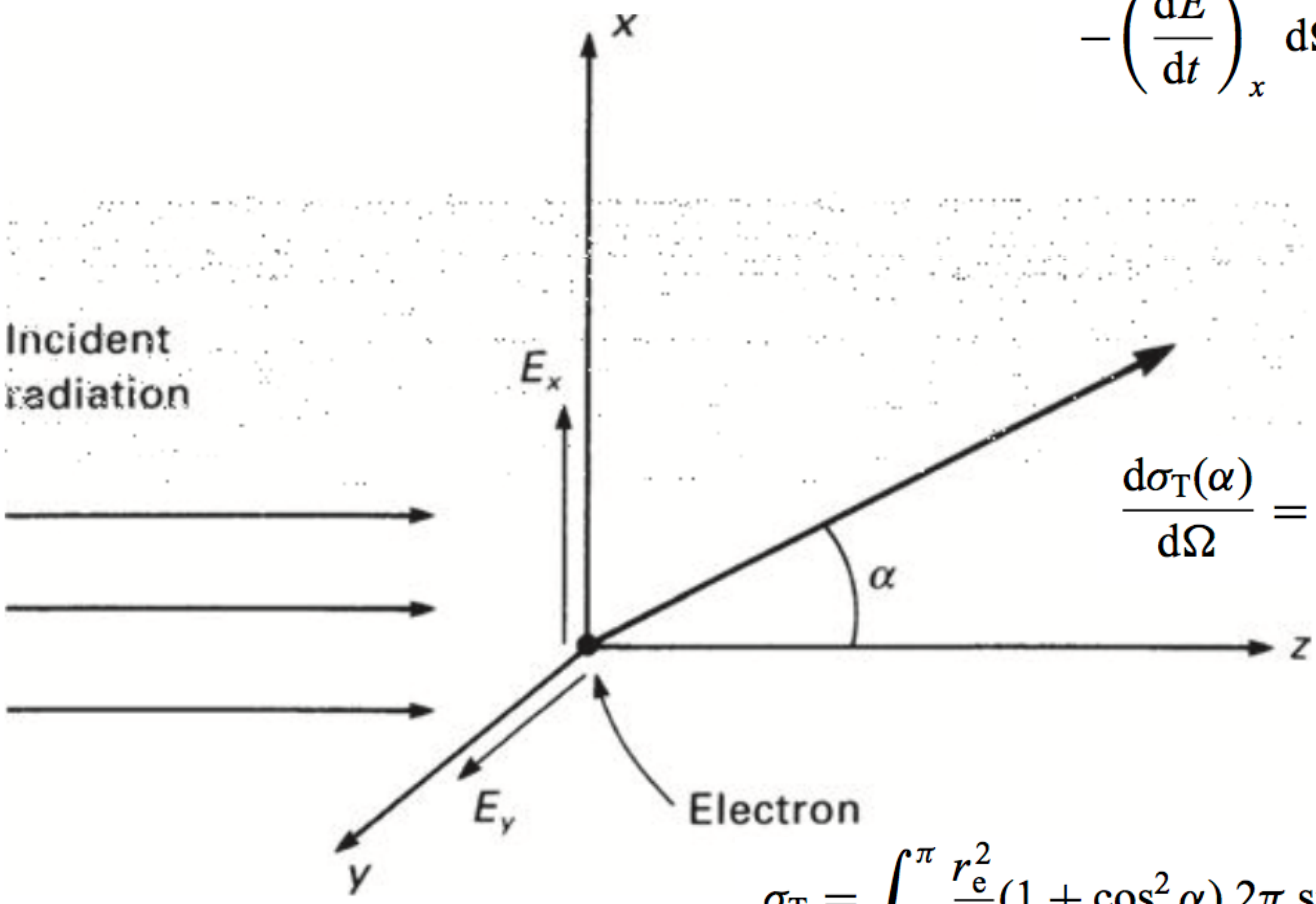


Fig. 9.2

Thomson Scattering



$$-\left(\frac{\mathrm{d}E}{\mathrm{d}t}\right)_x \mathrm{d}\Omega = \frac{e^2|\ddot{r}_x|^2 \sin^2\theta}{16\pi^2\epsilon_0 c^3}\,\mathrm{d}\Omega = \frac{e^4|E_x|^2}{16\pi^2 m_\mathrm{e}^2\epsilon_0 c^3}\cos^2\alpha\,\mathrm{d}\Omega$$

in y-direction, theta = 90 deg, so total:

$$-\left(\frac{\mathrm{d}E}{\mathrm{d}t}\right)\mathrm{d}\Omega = \frac{e^4}{16\pi^2 m_\mathrm{e}^2\epsilon_0^2 c^4}\left(1+\cos^2\alpha\right)\frac{S}{2}\,\mathrm{d}\Omega$$

$$\frac{\mathrm{d}\sigma_\mathrm{T}(\alpha)}{\mathrm{d}\Omega} = \frac{\text{energy radiated per unit time per unit solid angle}}{\text{incident energy per unit time per unit area}}$$

$$\mathrm{d}\sigma_\mathrm{T} = \frac{r_\mathrm{e}^2}{2}(1+\cos^2\alpha)\,\mathrm{d}\Omega$$

$$r_\mathrm{e} = e^2/4\pi\epsilon_0 m_\mathrm{e} c^2$$

$$\sigma_\mathrm{T} = \int_0^\pi \frac{r_\mathrm{e}^2}{2}(1+\cos^2\alpha)\,2\pi\sin\alpha\,\mathrm{d}\alpha = \frac{8\pi}{3}r_\mathrm{e}^2 = \frac{e^4}{6\pi\epsilon_0^2 m_\mathrm{e}^2 c^4} = 6.653\times10^{-29}\,\mathrm{m}^2$$

Crosssection is variable depending on relative Energies, given by Klein-Nishina formula:

$$\sigma_{K-N} = \pi r_e^2 \frac{1}{x} \left[\left(1 - \frac{2(x+1)}{x^2}\right) \ln(2x+1) + \frac{1}{2} + \frac{4}{x} - \frac{1}{2(2x+1)^2} \right]$$

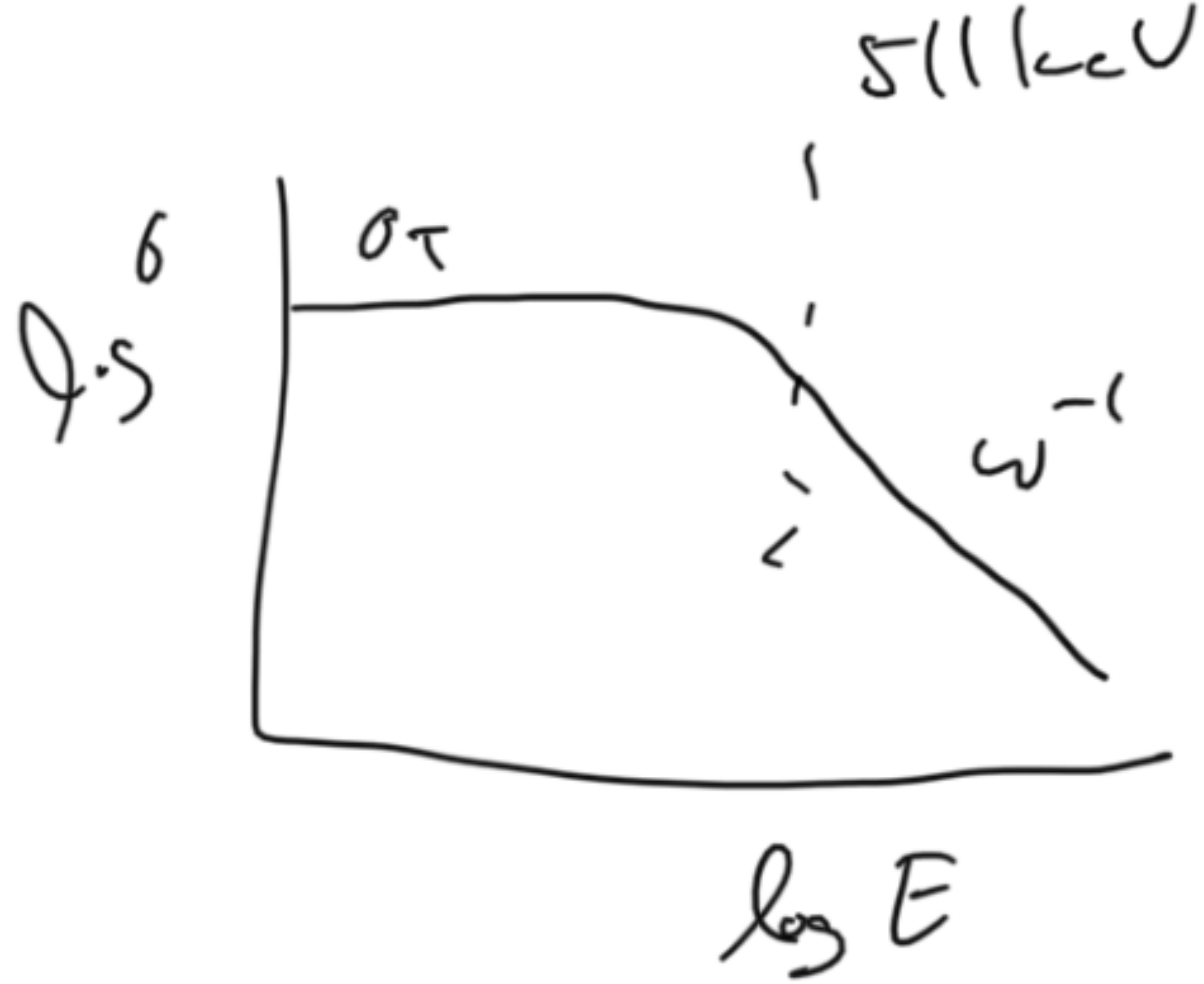
$$x = \frac{\hbar \omega}{m_e c^2}, \quad r_e = \frac{e^2}{4\pi \epsilon_0 m_e c^2}$$

Can consider ↓ & ↑ E limits

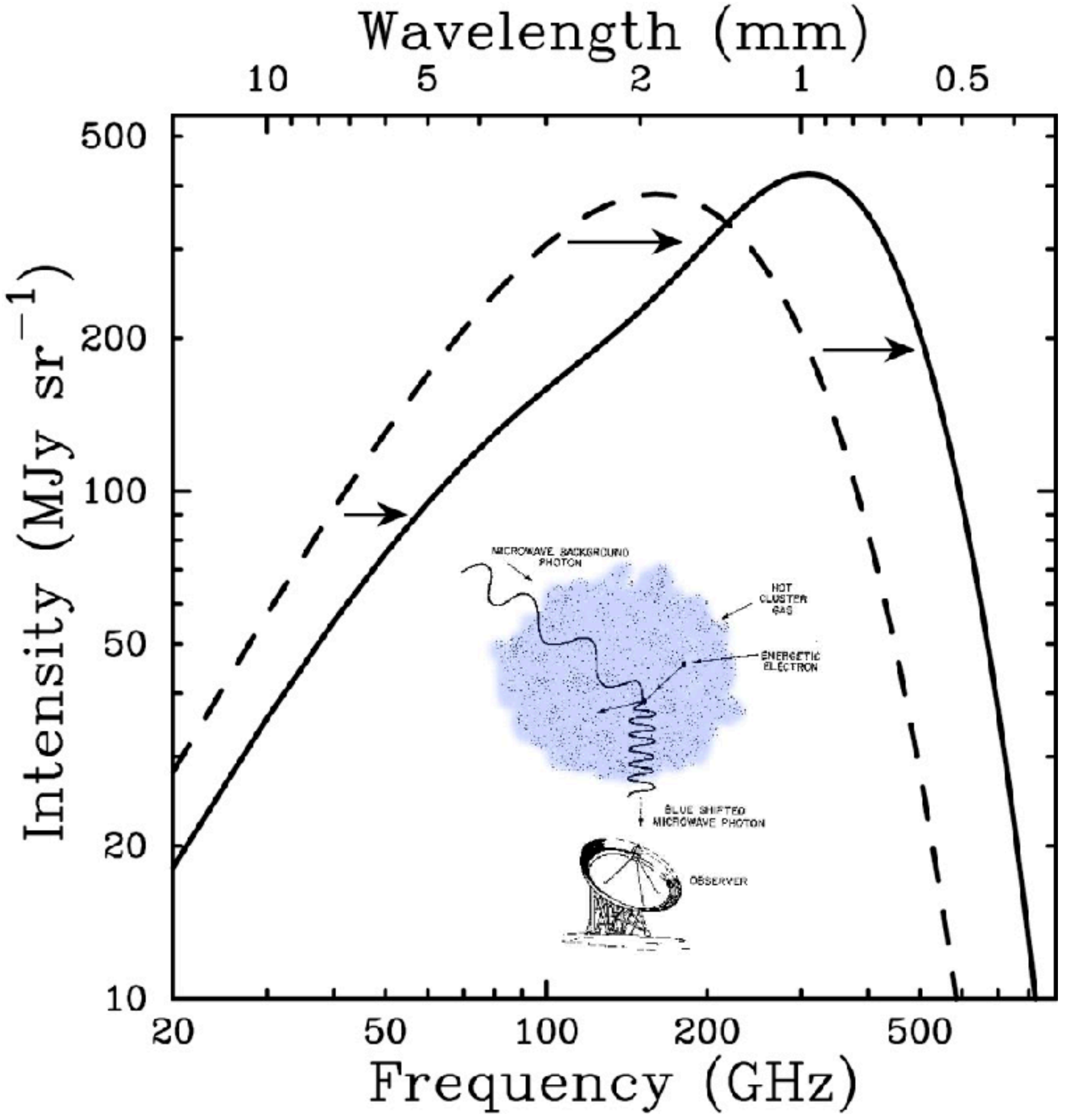
$x \ll 1$, $\sigma_{KN} \simeq \frac{8\pi}{3} r_e^2 \simeq \sigma_T$

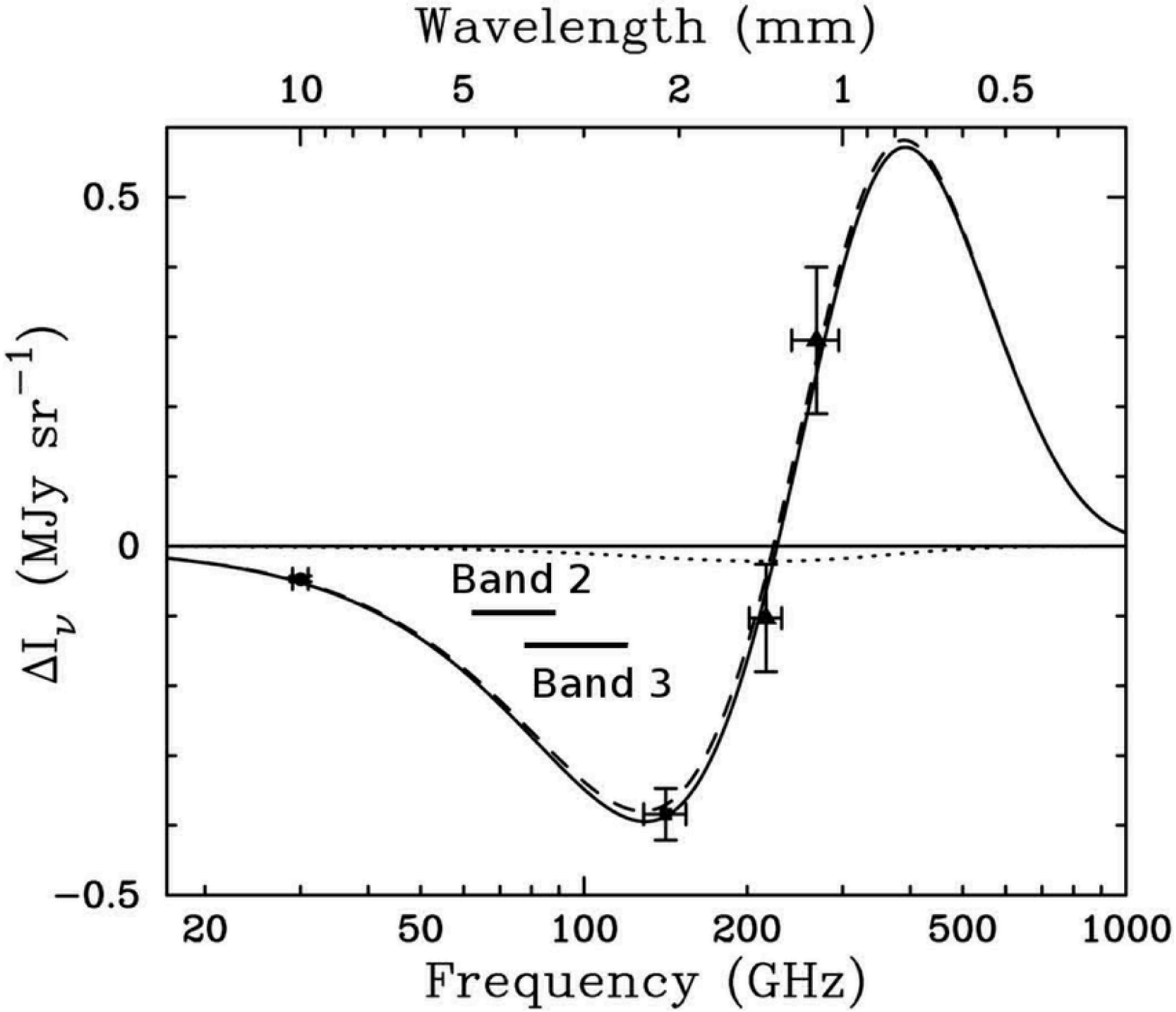
$x \gg 1$, $\propto \frac{1}{\hbar\omega}$

$x \sim 1$, $\hbar\omega \simeq 511$ keV
γ-rays

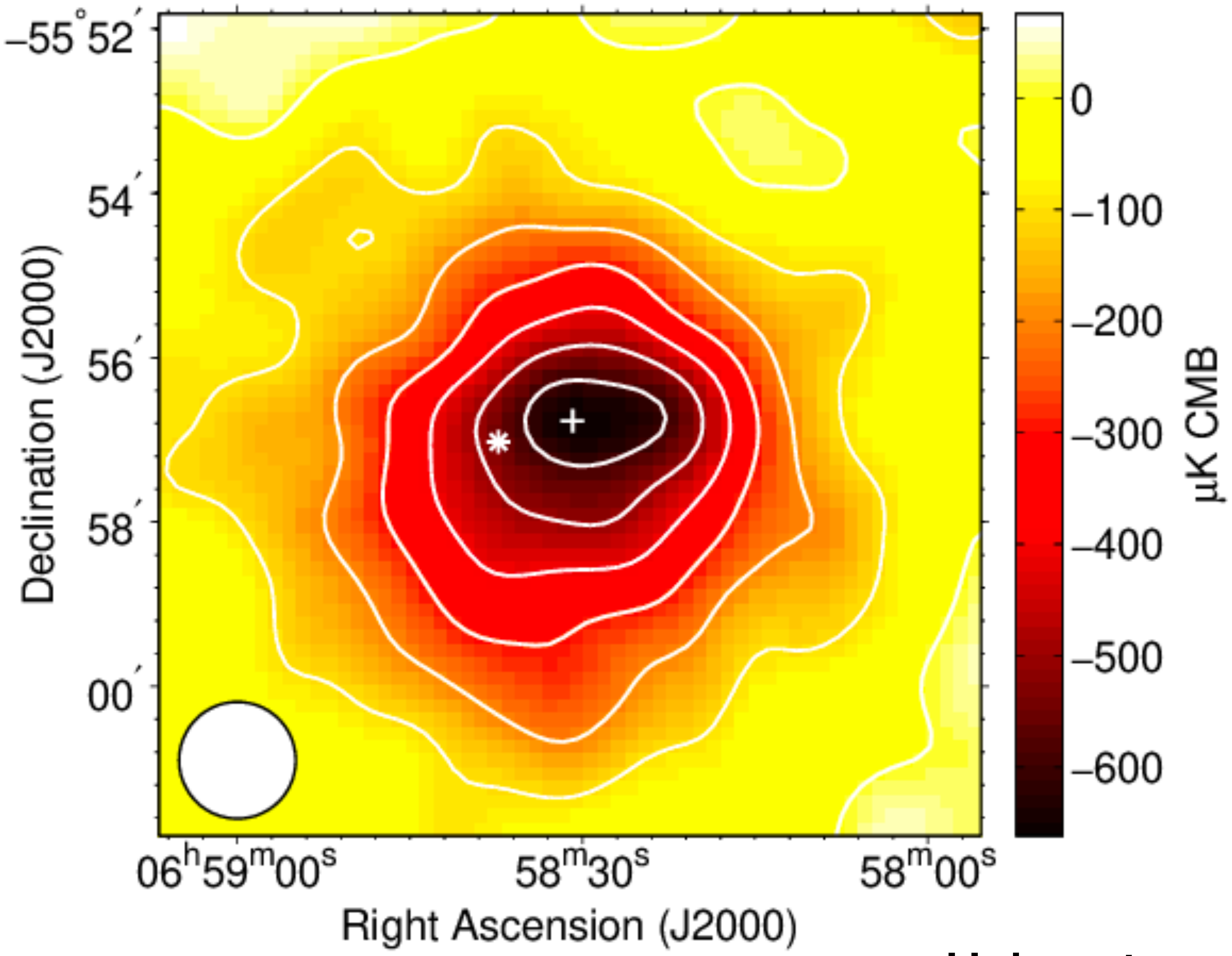


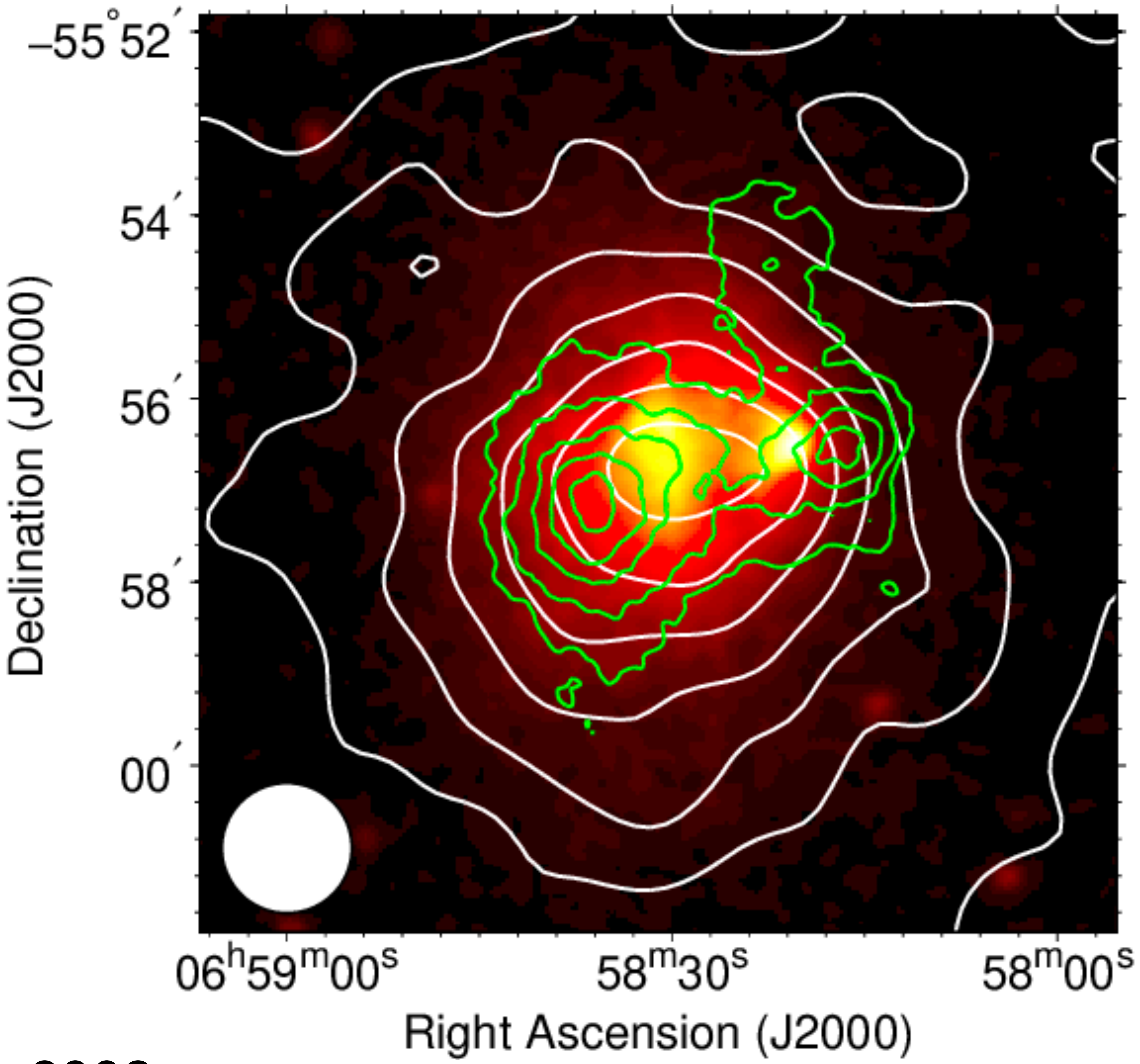
Sunyaev Zel’dovich Effect





Bullet Cluster

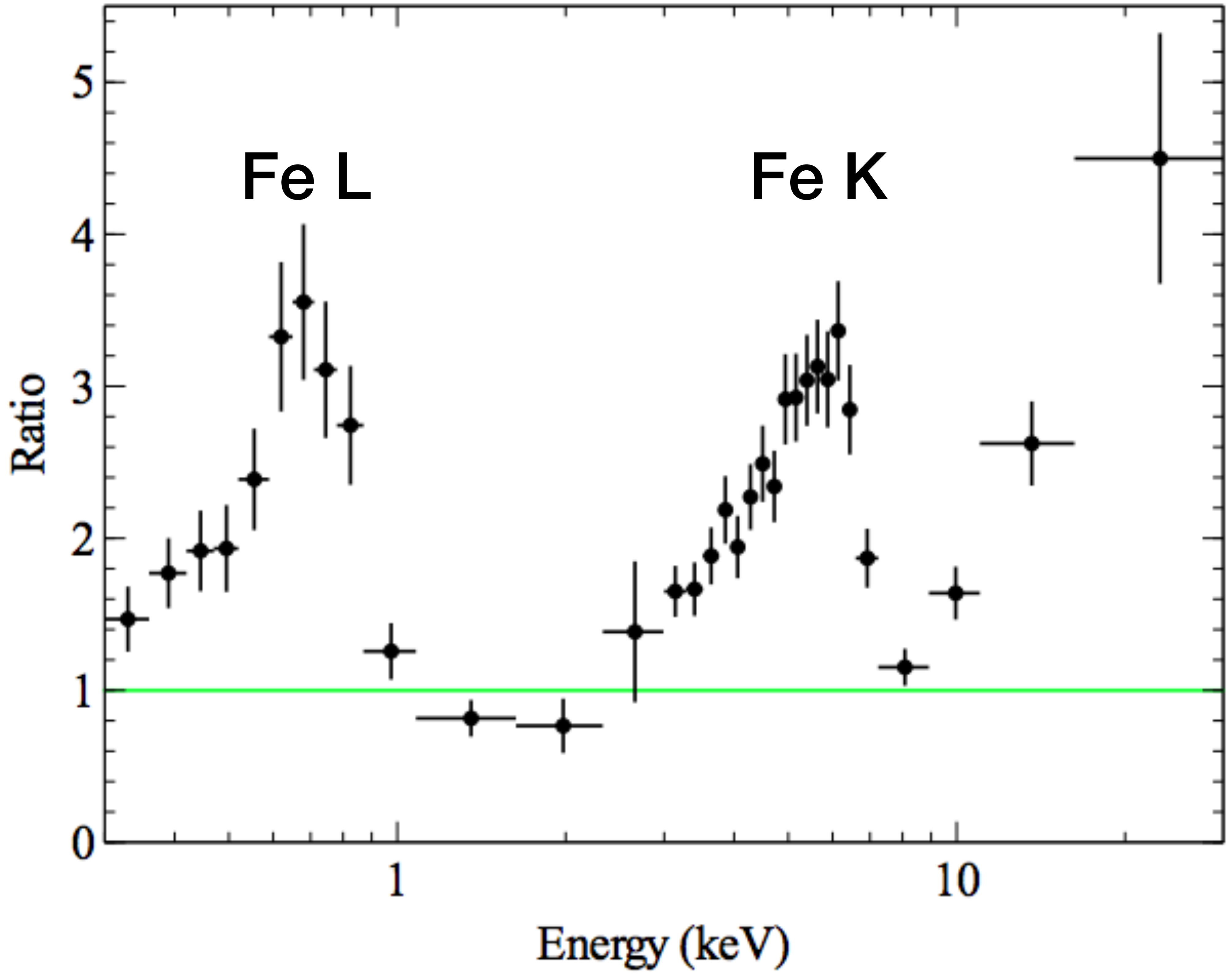




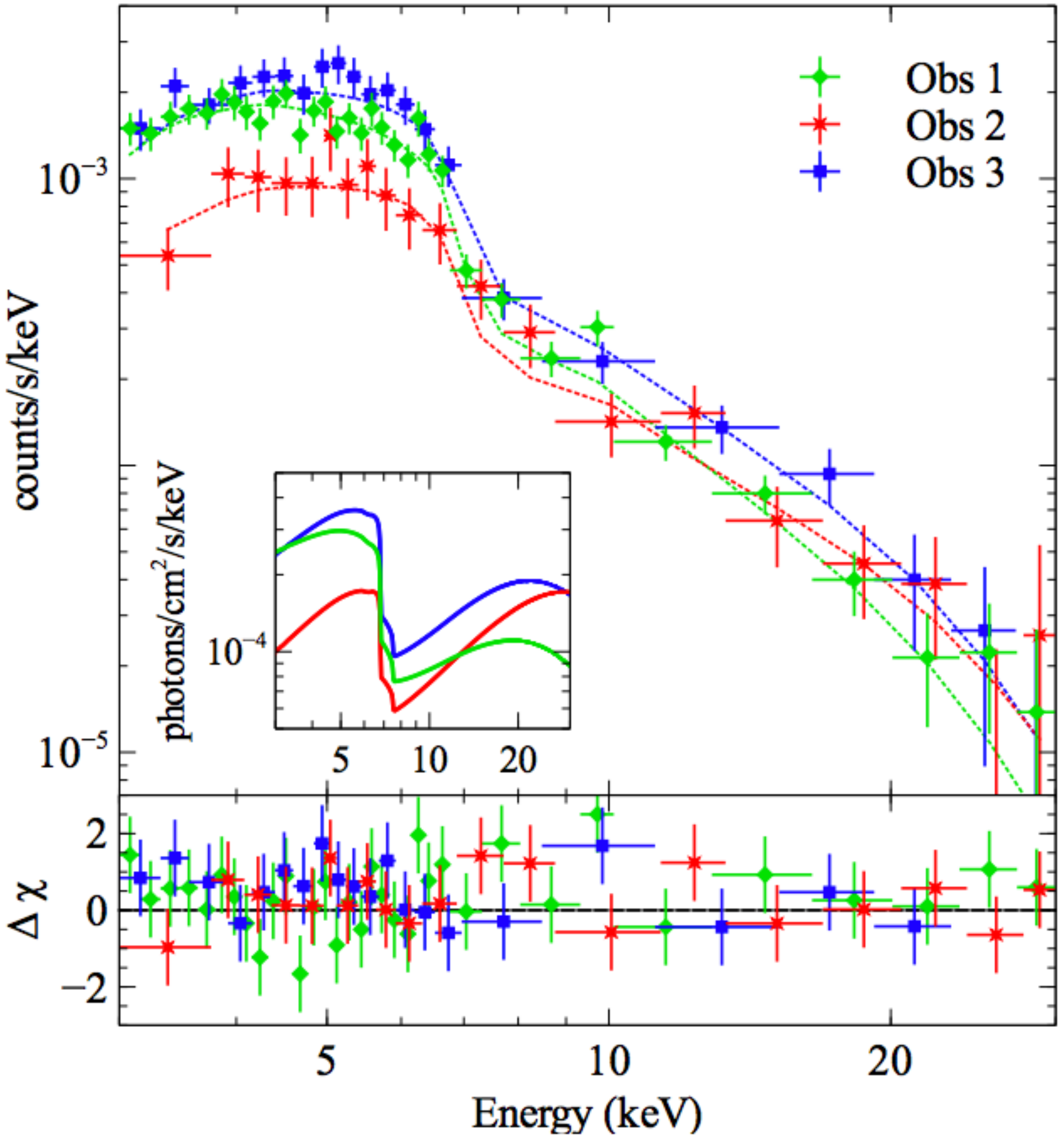
Halverston et al. 2009

Compton Downscattering

X-ray spectrum of an AGN (1H0707-495) - emission very near the BH?

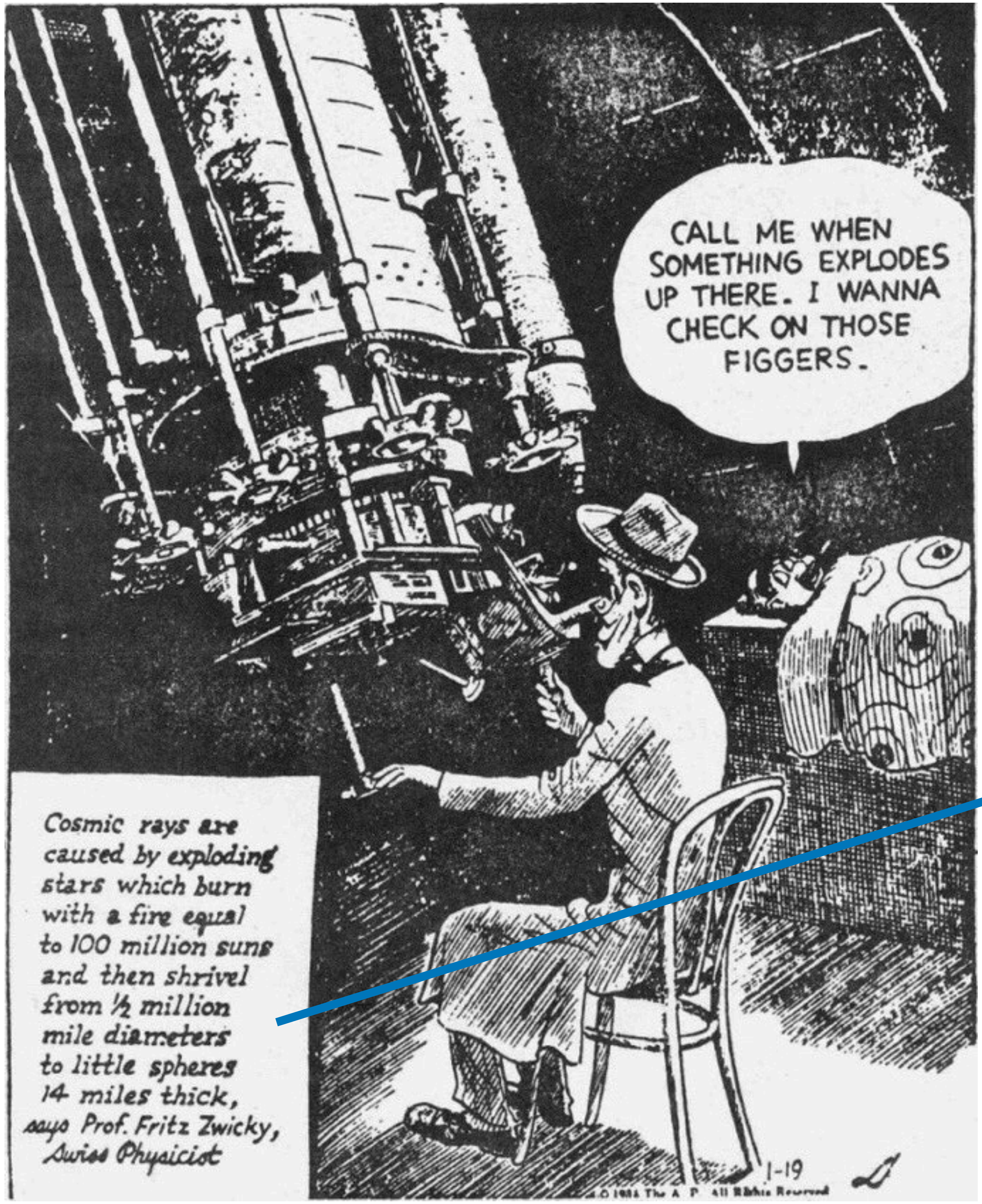


“Compton Hump”



Kara et al. 2014

Supernovae



ON SUPER-NOVAE

By W. Baade and F. Zwicky

Mount Wilson Observatory, Carnegie Institution of Washington and California Institute of Technology, Pasadena

Communicated March 19, 1934

A. *Common Novae.*—The extensive investigations of extragalactic systems during recent years have brought to light the remarkable fact

"This, in all modesty, I claim to be one of the most concise triple predictions ever made in science. More than 30 years were to pass before this statement was proved to be true in every respect."
- Fritz Zwicky, 1968

Mount Wilson Observatory, Carnegie Institution of Washington and California Institute of Technology, Pasadena

Communicated March 19, 1934

A. *Introduction.*—Two important facts support the view that cosmic rays are of extragalactic origin, if, for the moment, we disregard the possibility that the earth may possess a very high and self-renewing electrostatic potential with respect to interstellar space.

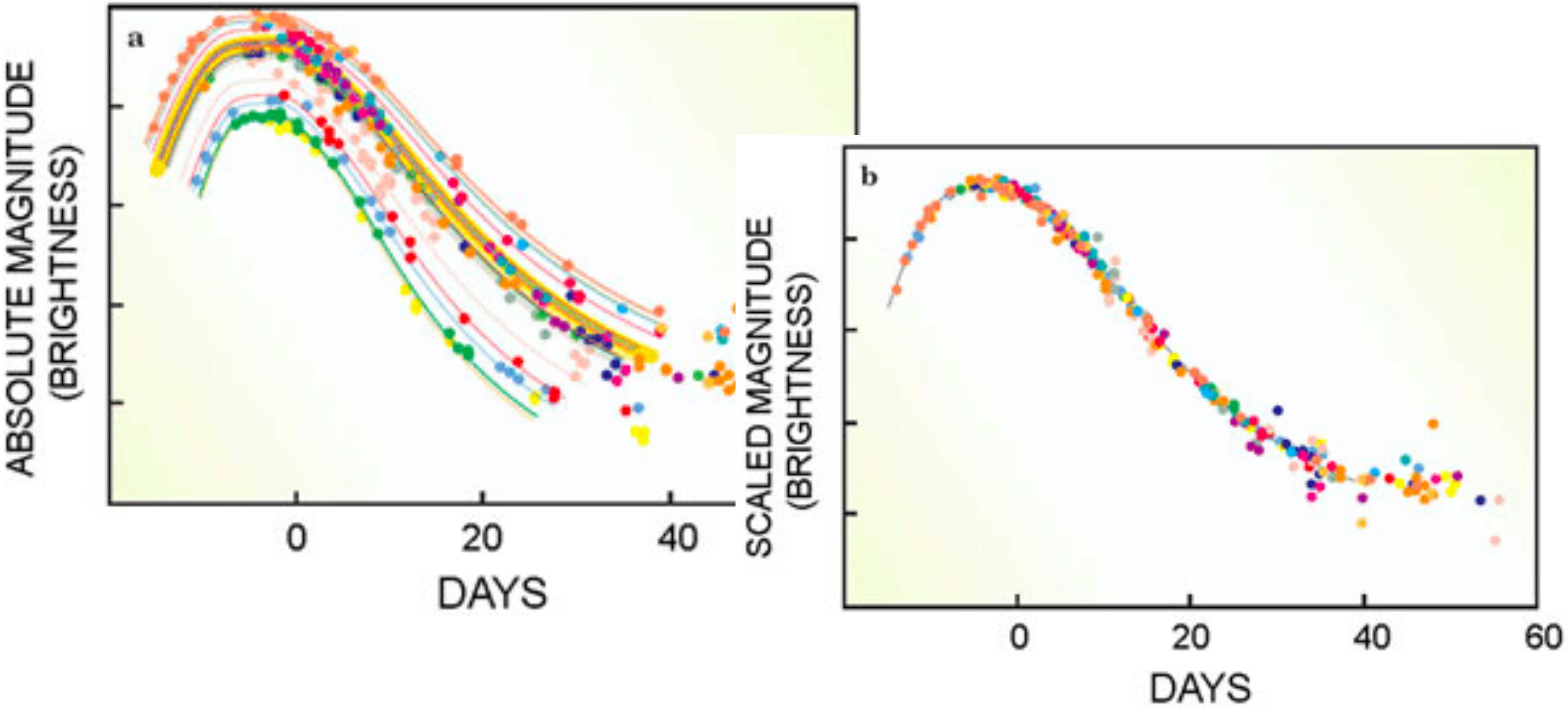
WD thermonuclear explosion (Type Ia)

Core Collapse (Type Ib through Type IIb)

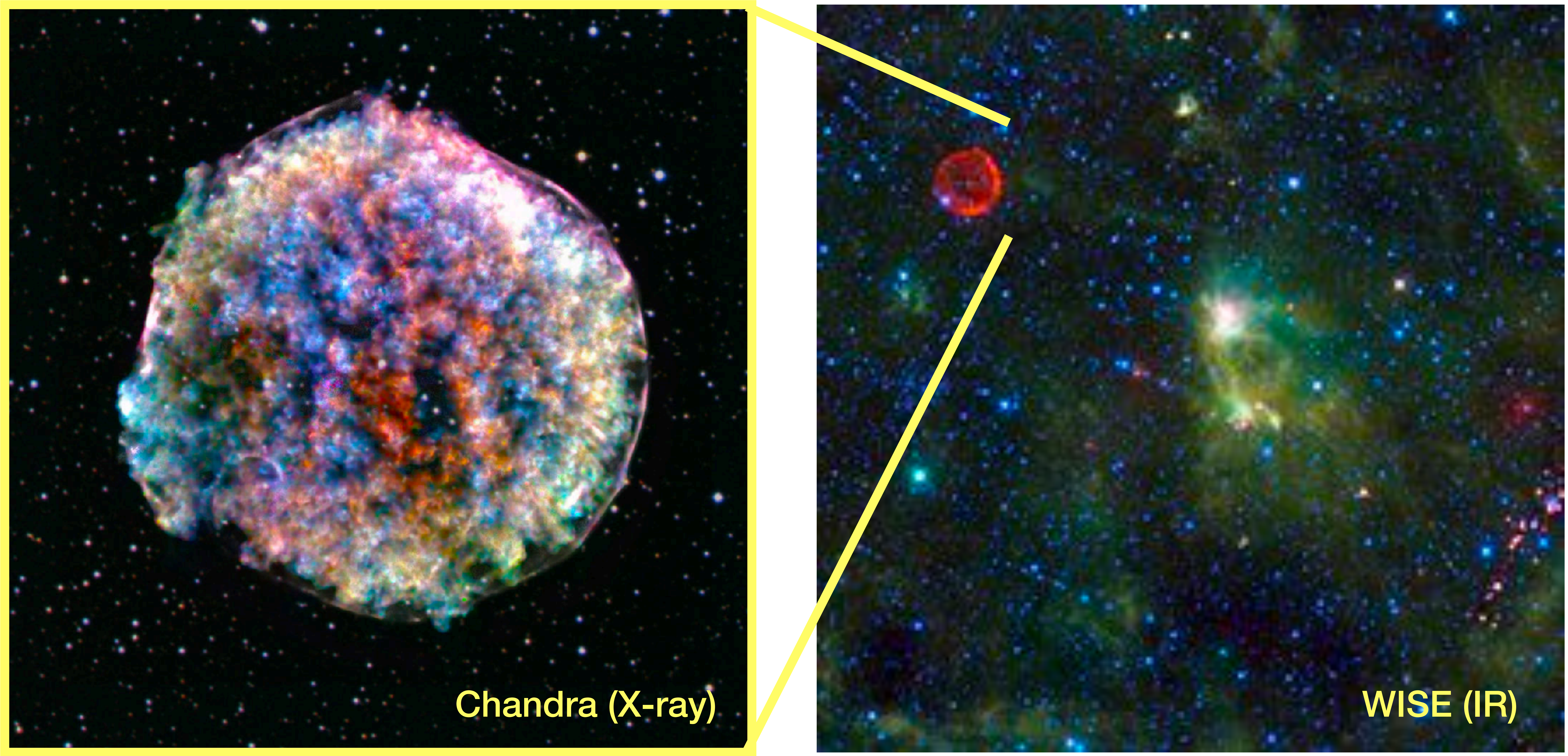
Table 13.1 Supernovae Types I and II.

Type	Characteristics
	Type I – absence of hydrogen lines in optical spectrum
Type Ia	Absence of hydrogen lines in spectrum; singly ionised silicon Si II at 615.0 nm observed near peak light.
Type Ib	Neutral helium (He I) line at 587.6 nm observed but no strong silicon absorption feature at 615.0 nm.
Type Ic	Helium lines are weak or absent; no strong silicon absorption feature 615.0 nm.
	Type II – hydrogen lines present in optical spectrum
Type IIP	Reaches a 'plateau' in its light curve.
Type IIL	Displays a linear decrease in its light curve
Type IIn	These supernovae contain relatively narrow features compared with the usual broad emission lines of Type II supernovae.
Type IIb	These supernovae have spectra similar to Type II at early times but to Type Ib/c at later times.

Supernova Type Ia light curves



Tycho SNR - SN of 1572



LiveSlides web content

To view

Download the add-in.

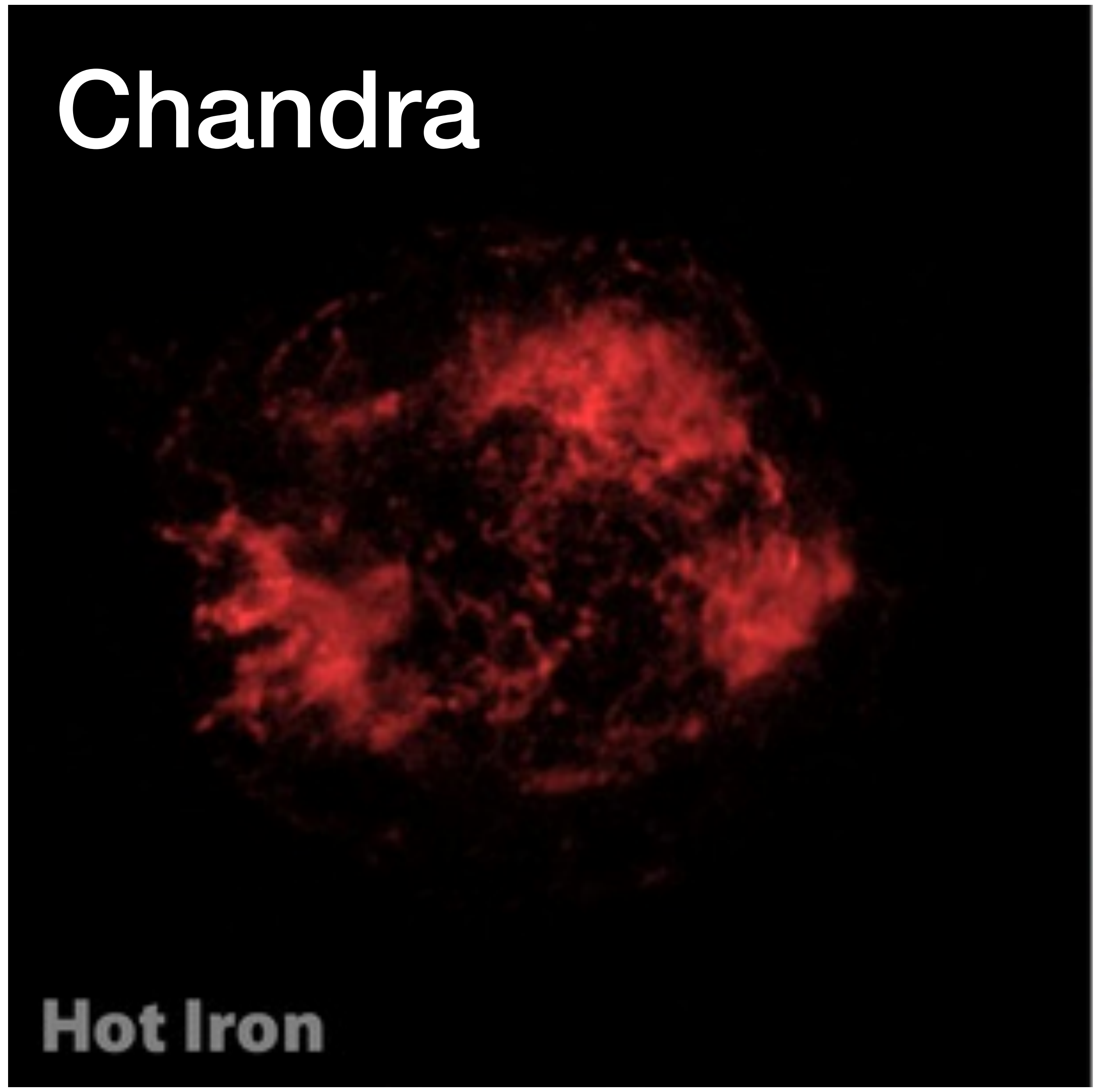
liveslides.com/download

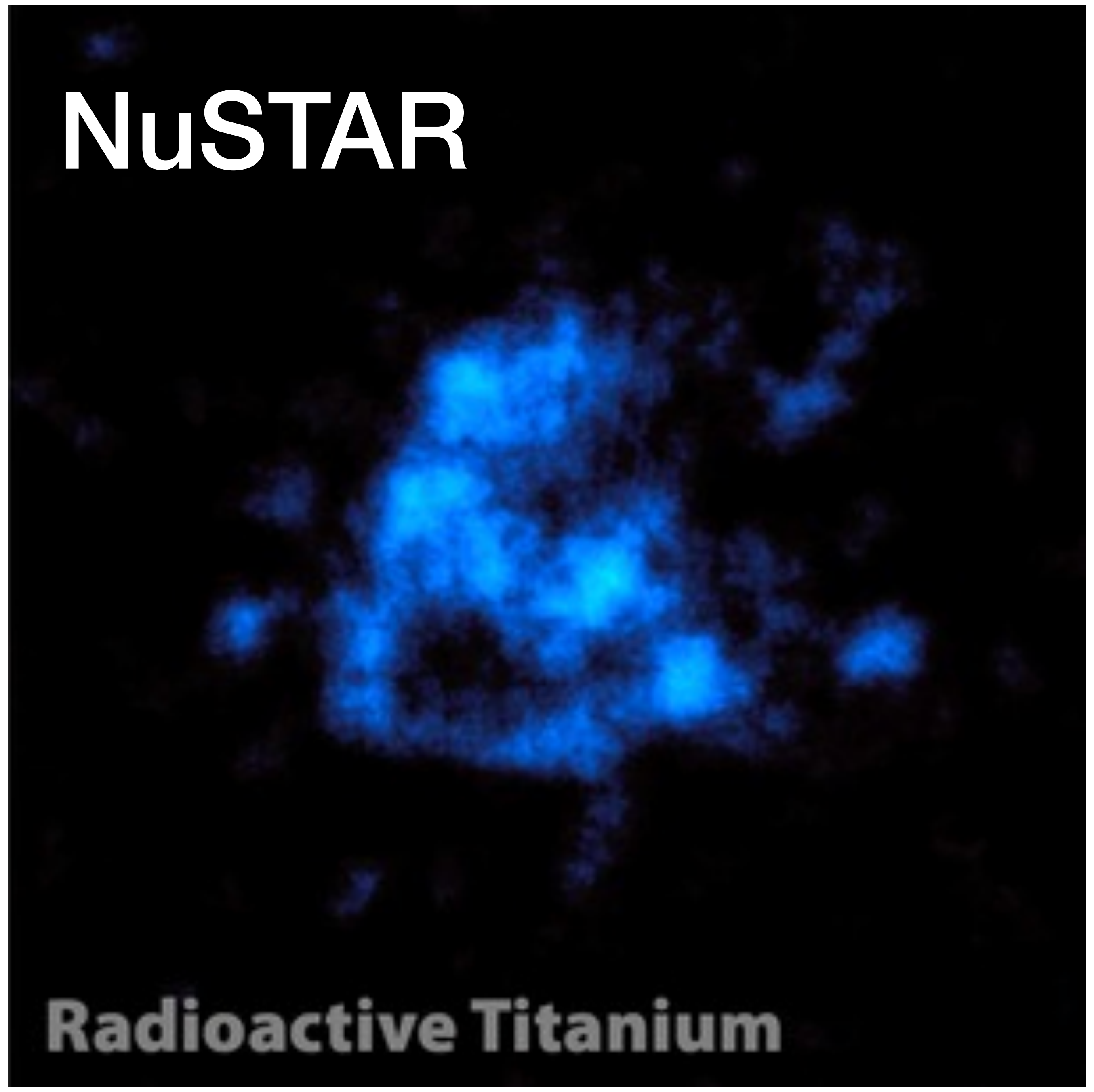
Start the presentation.

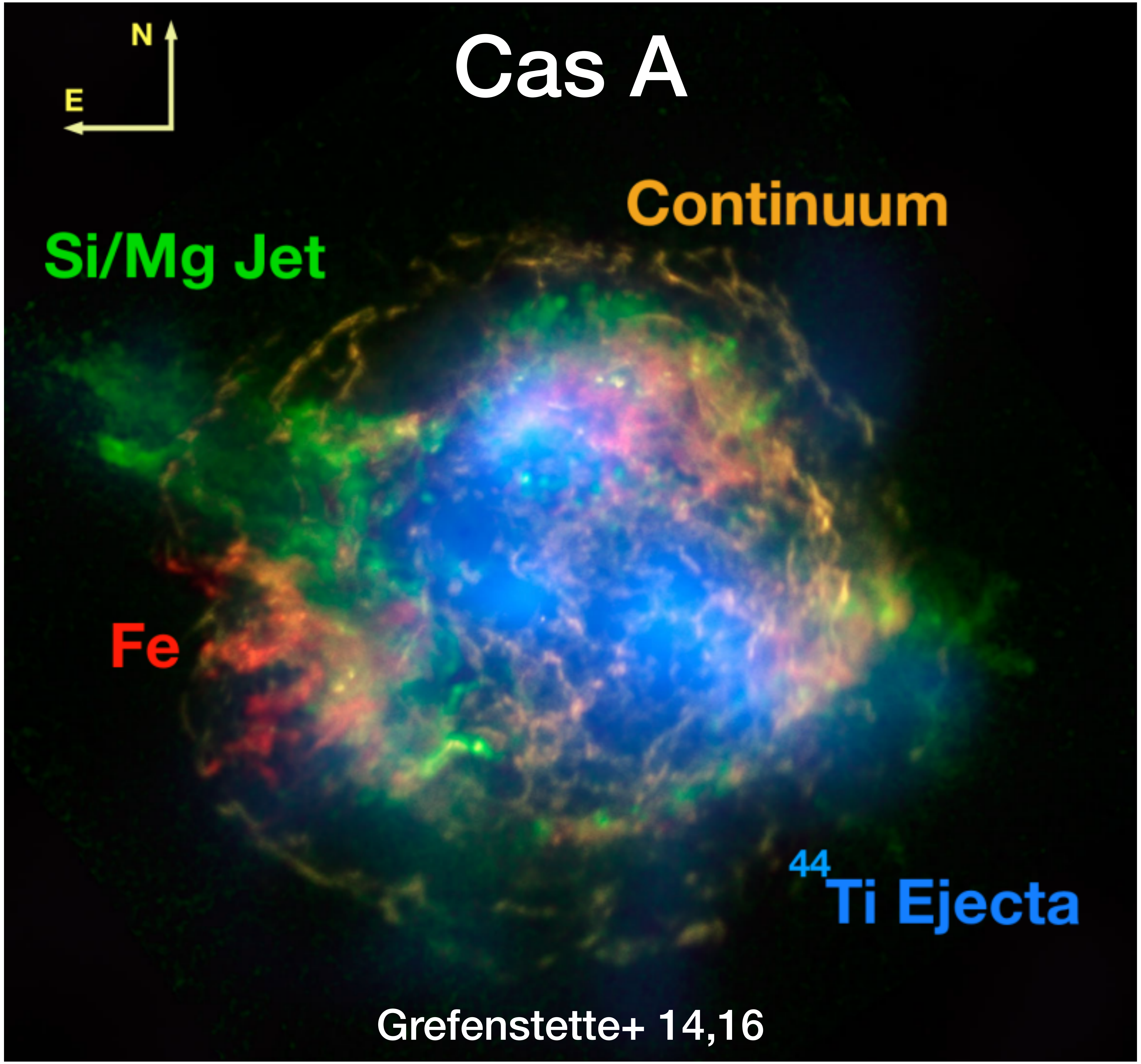
https://www.youtube.com/watch?v=pF05nG96BiM

Table 13.2 Evolution of a $15M_\odot$ star. Most of the table is from the paper by Woosley and Janda (2005), but the specific nuclear reactions are from the review by Arnett (2004).

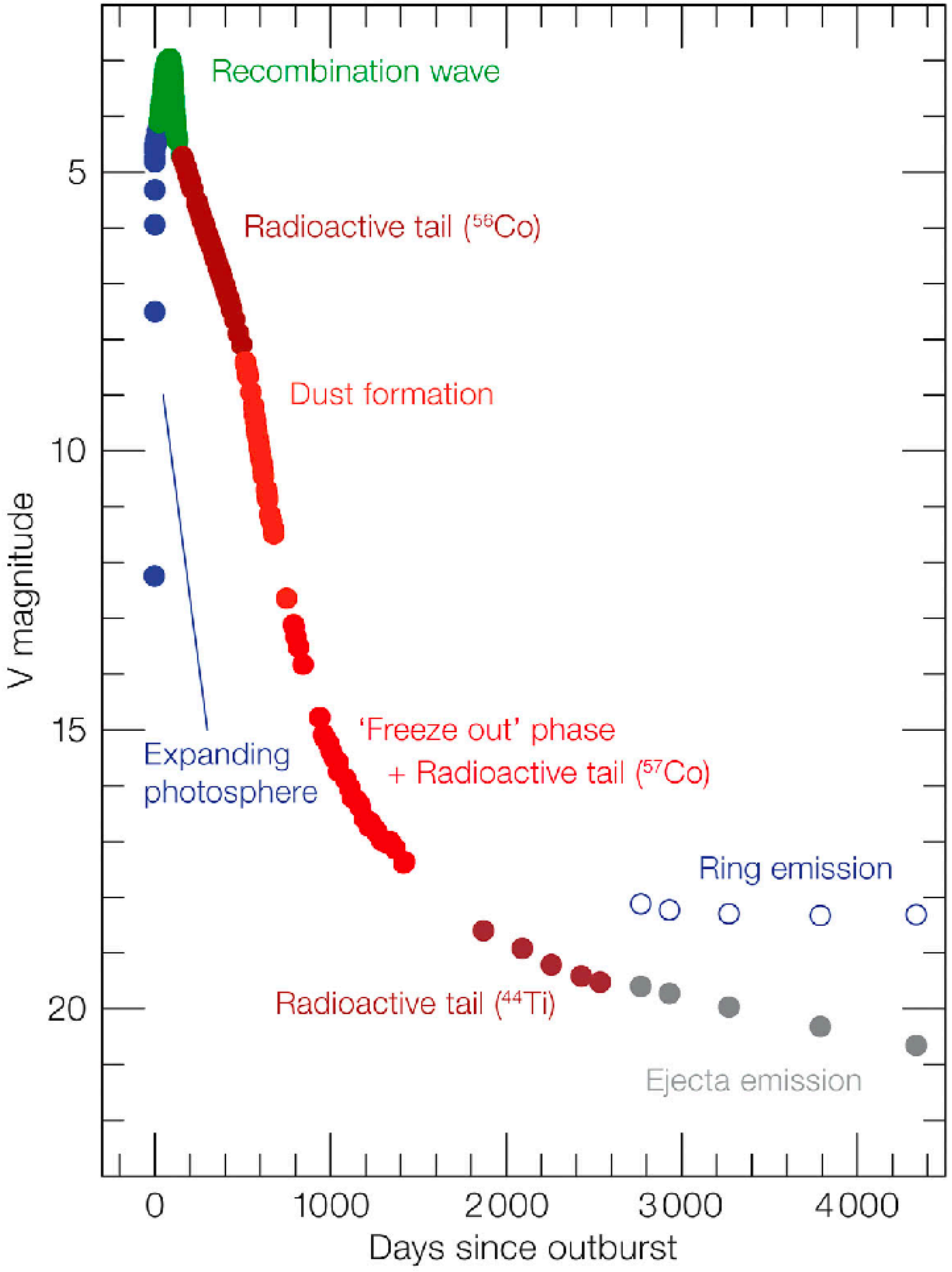
Stage	Time Scale	Reaction	Ash or product	Temperature (10^9 K)	Density (gm cm^{-3})	Luminosity (solar units)	Neutrino losses (solar units)
Hydrogen	11 My	pp	He	0.035	5.8	28,000	1800
		CNO	He, N, Na				
Helium	2.0 My	$3\alpha \rightarrow {}^{12}C$	C	0.18	1390	44,000	1900
		${}^{12}C(\alpha, \gamma){}^{16}O$	O				
Carbon	2000 y	${}^{12}C + {}^{12}C$	Ne, Na Mg, Al	0.81	2.8×10^5	72,000	3.7×10^5
Neon	0.7 y	${}^{20}Ne(\gamma, \alpha){}^{16}O$	O, Mg, Al	1.6	1.2×10^7	75,000	1.4×10^8
Oxygen	2.6 y	${}^{16}O + {}^{16}O$	Si, S, Ar, Ca	1.9	8.8×10^6	75,000	9.1×10^8
Silicon	18 d	${}^{28}Si(\gamma, \alpha)$	Fe, Ni, Cr, Ti. . .	3.3	4.8×10^7	75,000	1.3×10^{11}
Iron core collapse	1 s	Neutronisation	Neutron star	>7.1	$>7.3 \times 10^9$	75,000	$>3.6 \times 10^{15}$


Chandra
Hot Iron

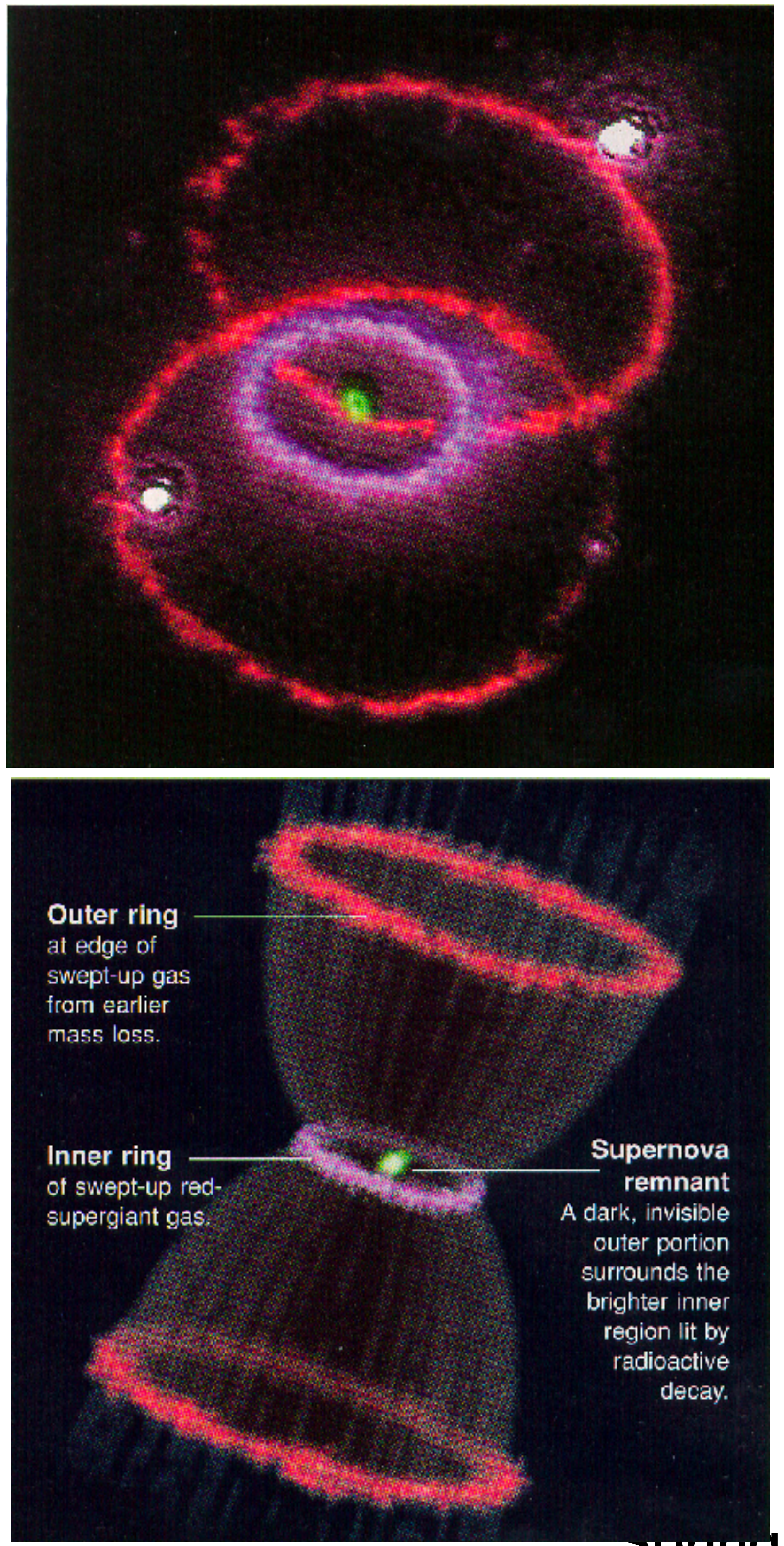

NuSTAR
Radioactive Titanium


Cas A
N
E
Continuum
Si/Mg Jet
Fe
44Ti Ejecta
Grefenstette+ 14,16

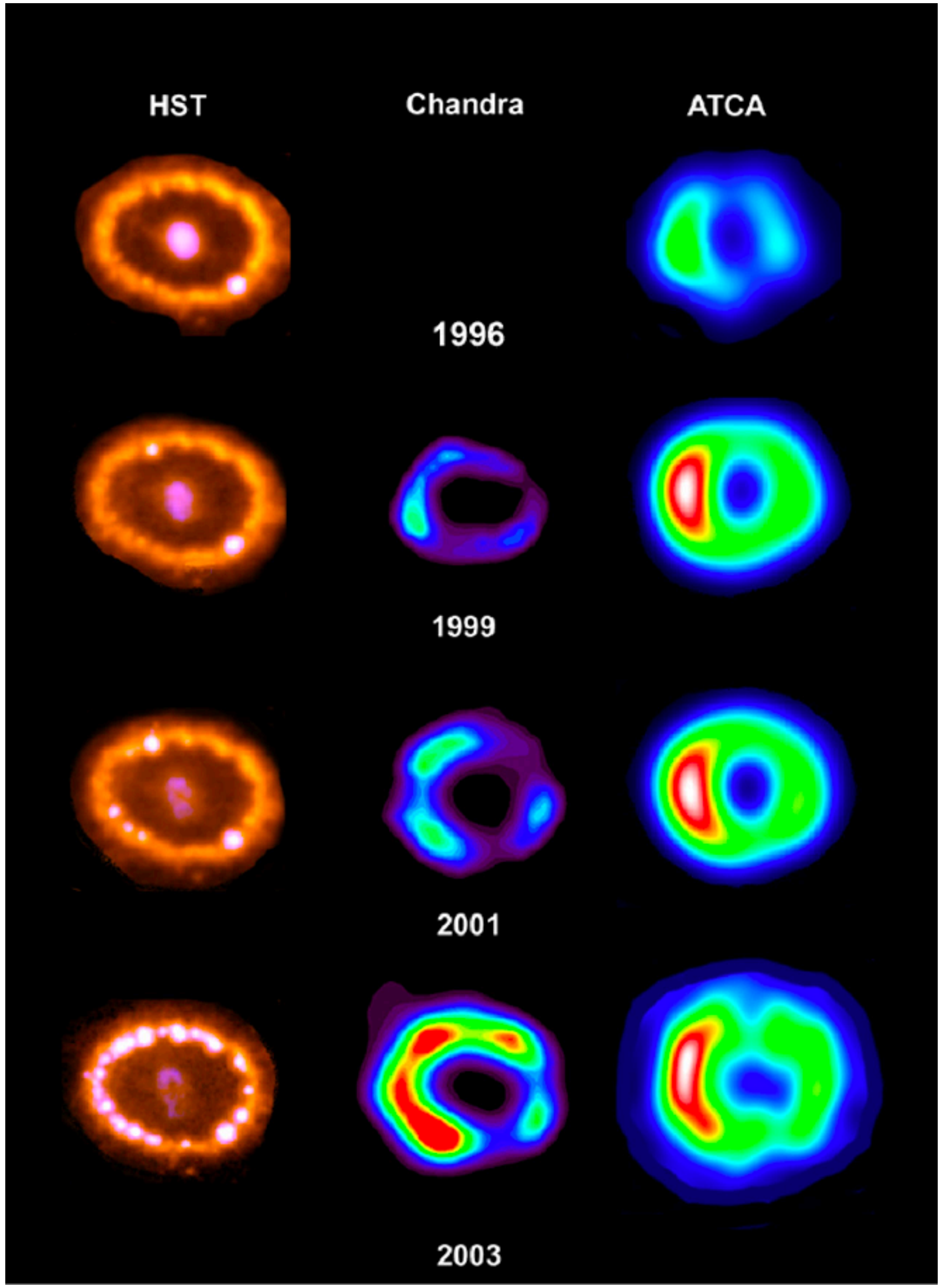
SN 1987A



Recombination wave
Radioactive tail (^{56}Co)
Dust formation
Expanding photosphere
'Freeze out' phase
+ Radioactive tail (^{57}Co)
Ring emission
Radioactive tail (^{44}Ti)
Ejecta emission
5
10
15
20
V magnitude
0
1000
2000
3000
4000
Days since outburst



Outer ring at edge of swept-up gas from earlier mass loss.
Inner ring of swept-up red-supergiant gas.
Supernova remnant
A dark, invisible outer portion surrounds the brighter inner region lit by radioactive decay.



HST
Chandra
ATCA
1996
1999
2001
2003

Supernova Remnants: Chandra