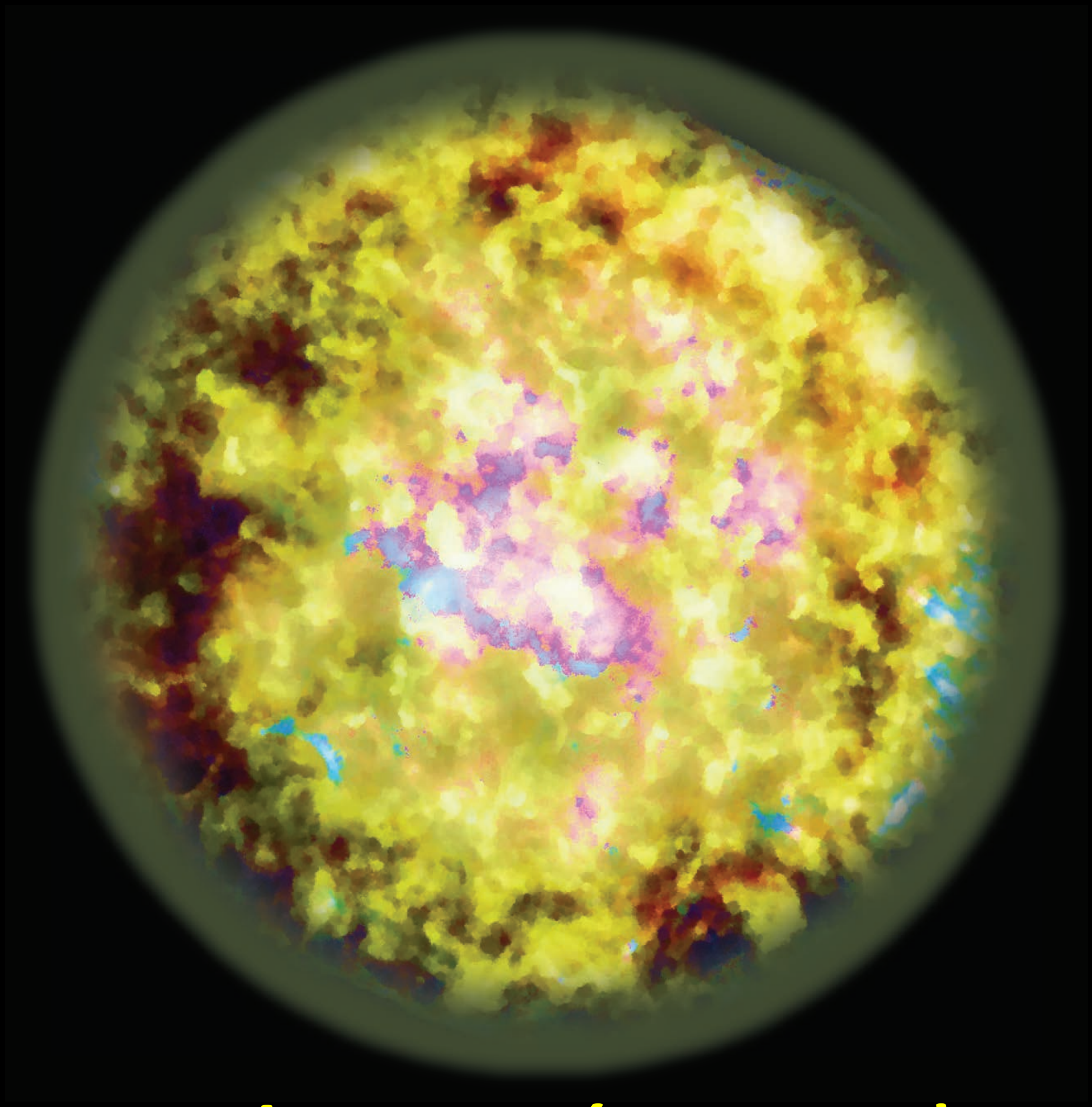
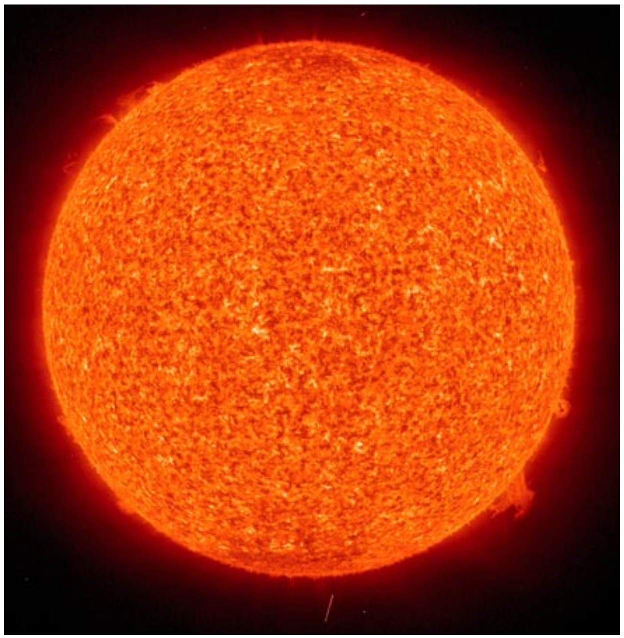
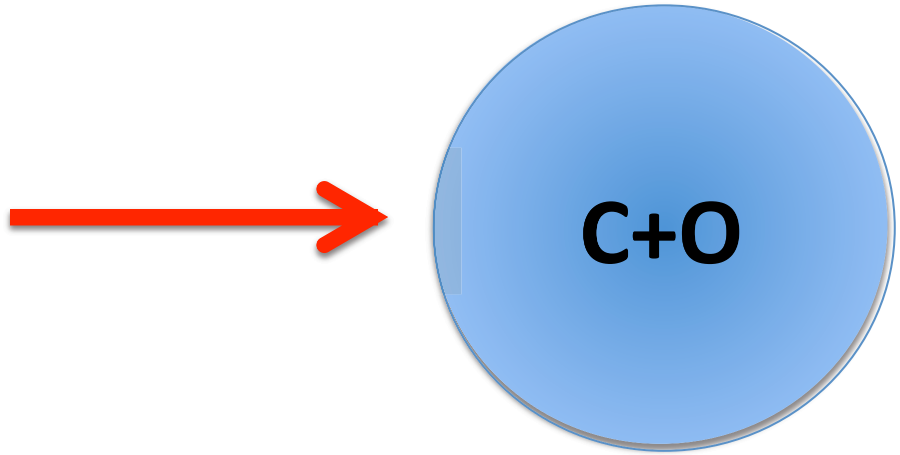
Thermonuclear supernovae with ASTROGAM



E.Churazov (MPA, IKI)

WD = End-product of stellar evolution for M<8 M_{Sun}



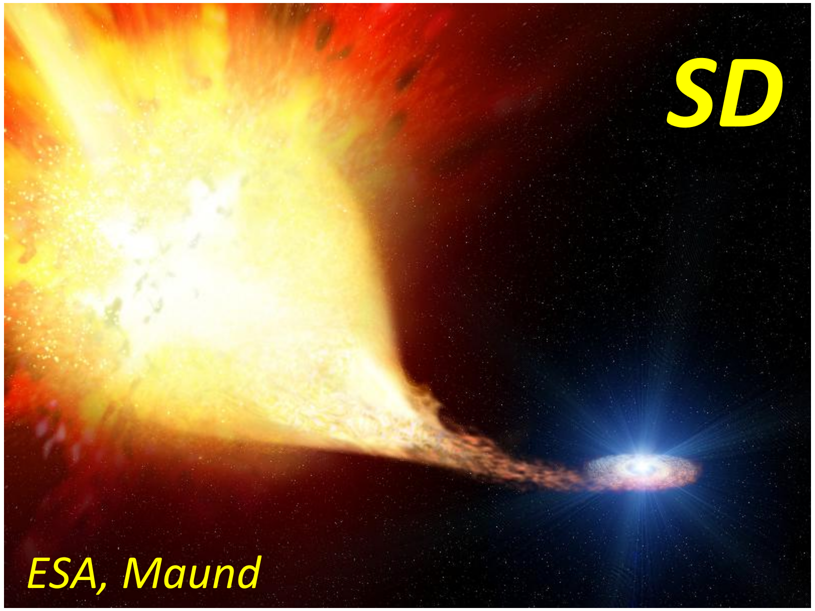


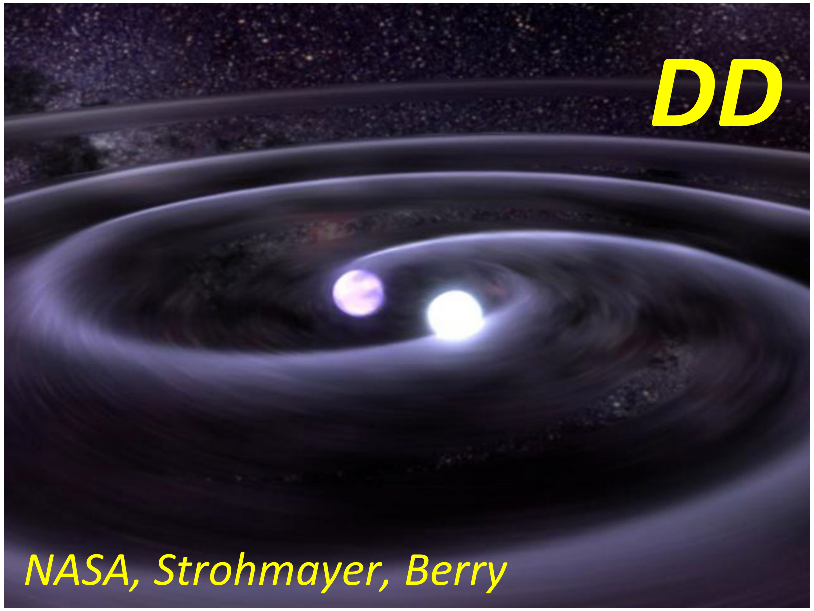
Radius ~ 10 000 km
Mass ~ 0.5 Msun
Carbon+Oxygen

WD is supported by the pressure of degenerate electron gas

Typical initial mass M_1~0.5 M_{Sun}
Maximal mass M_{Ch}~1.4 M_{sun} -- Chandrasekhar limit

Growing mass of WD





WD+ΔM

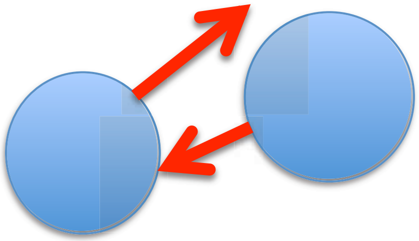
Whelan & Iben 1974

DD'

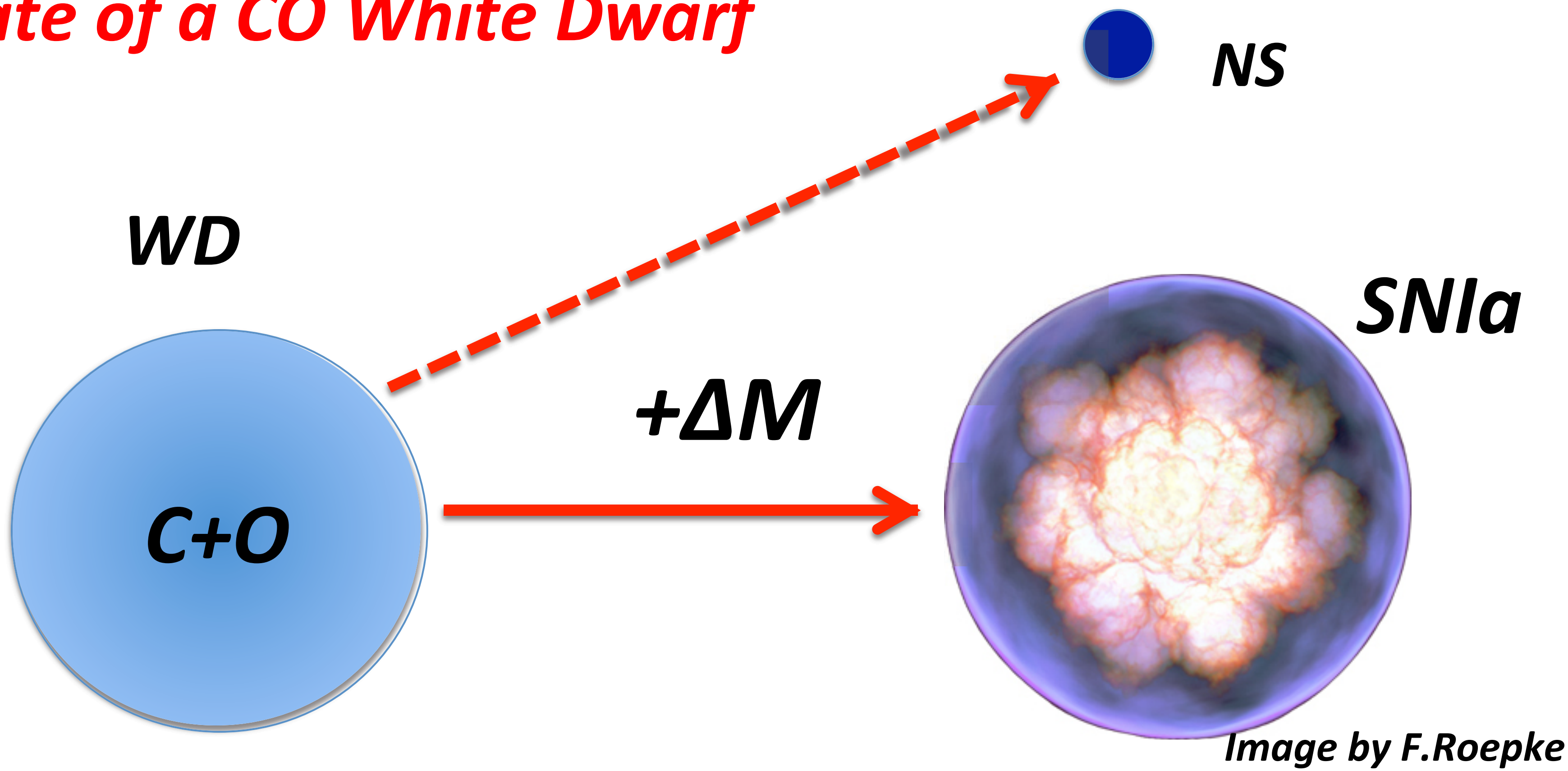
Kushnir et al., 2013

WD+WD

Iben & Tutukov 1984
Webbink 1984



Fate of a CO White Dwarf



1. Relativistic electrons
2. WD shrinks
3. Burning of CO starts
4. Detonation and Fusion of ^{56}Ni

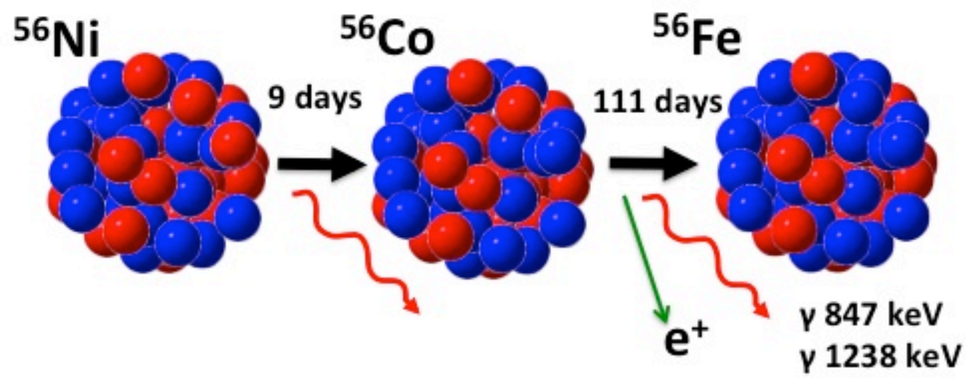
Hoyle & Fowler, 1960

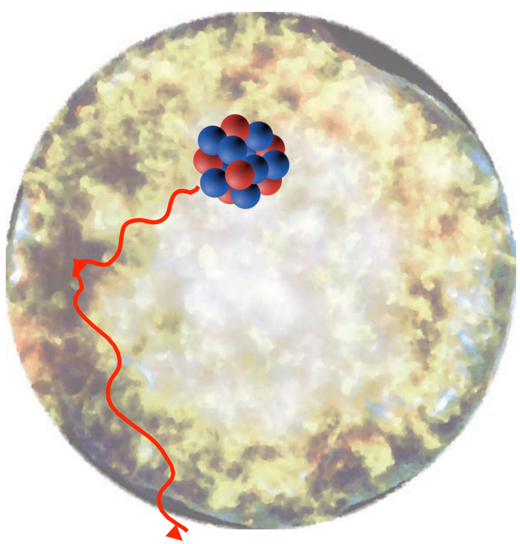
C,O → Si, Ca, Ni

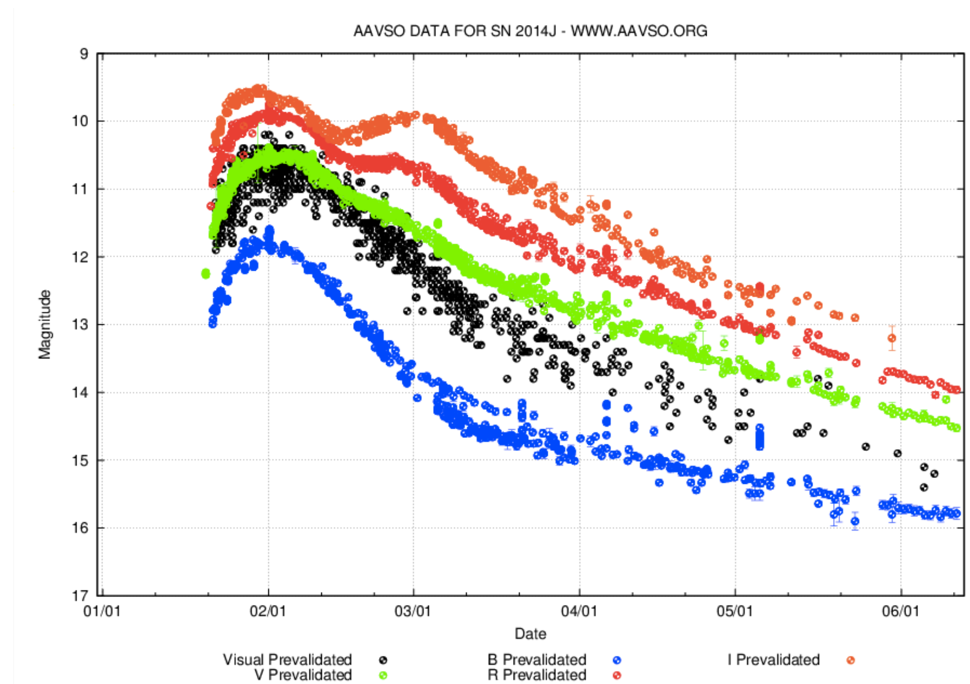
0.6-0.8 MeV/nucleon

Velocity ~ 10^4 km/s

Why we see supernovae after the explosion?







1.Direct gamma-photons

2.Reprocessed emission (optical band)

$$\tau \propto t^{-2}$$

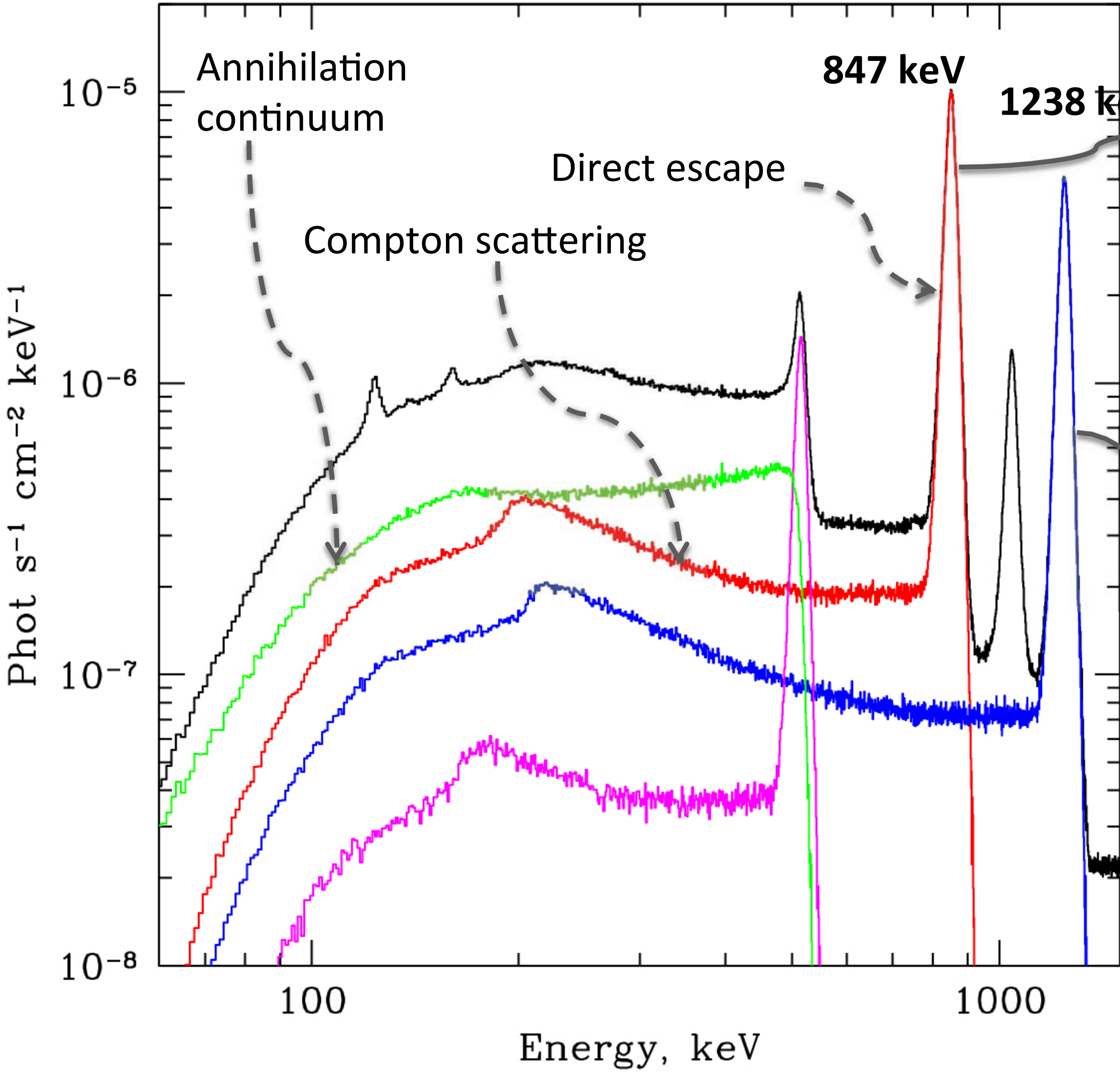
Why SNIa's are interesting?

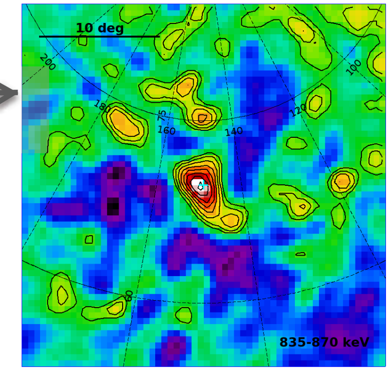
- *Standard candle? (Cosmology)*
- *Progenitors?*
- *Explosion mechanism?*
- *Source of positrons in the Galaxy?*

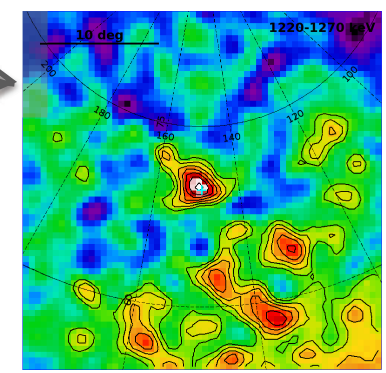
SNIa + ASTROGAM

- *Many SNIa – insights into standard candle concept*
- *Early stages – nucleosynthesis at the surface*
- *Velocity structure – progenitor/explosion mechanism*
- *Polarization – progenitor/explosion mechanism*
- *Escape and diffusion of positrons – source of positrons*

Modeling gamma-ray emission: decay+compton+absorption+envelope
MUCH simpler than in optical band





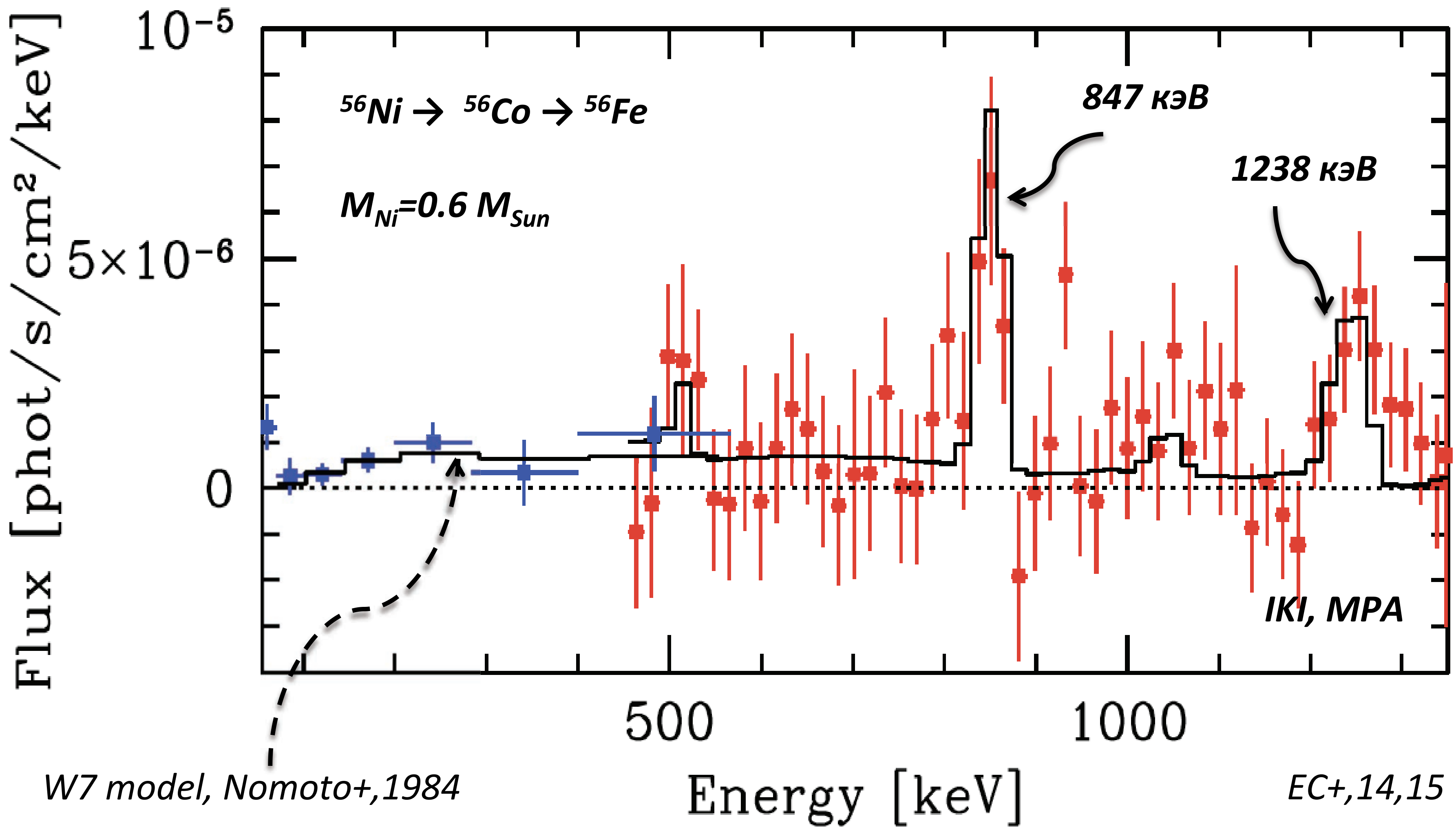


Images in γ-lines of ^{56}Co

77% of energy escapes in gamma-rays (@75 days after explosion)

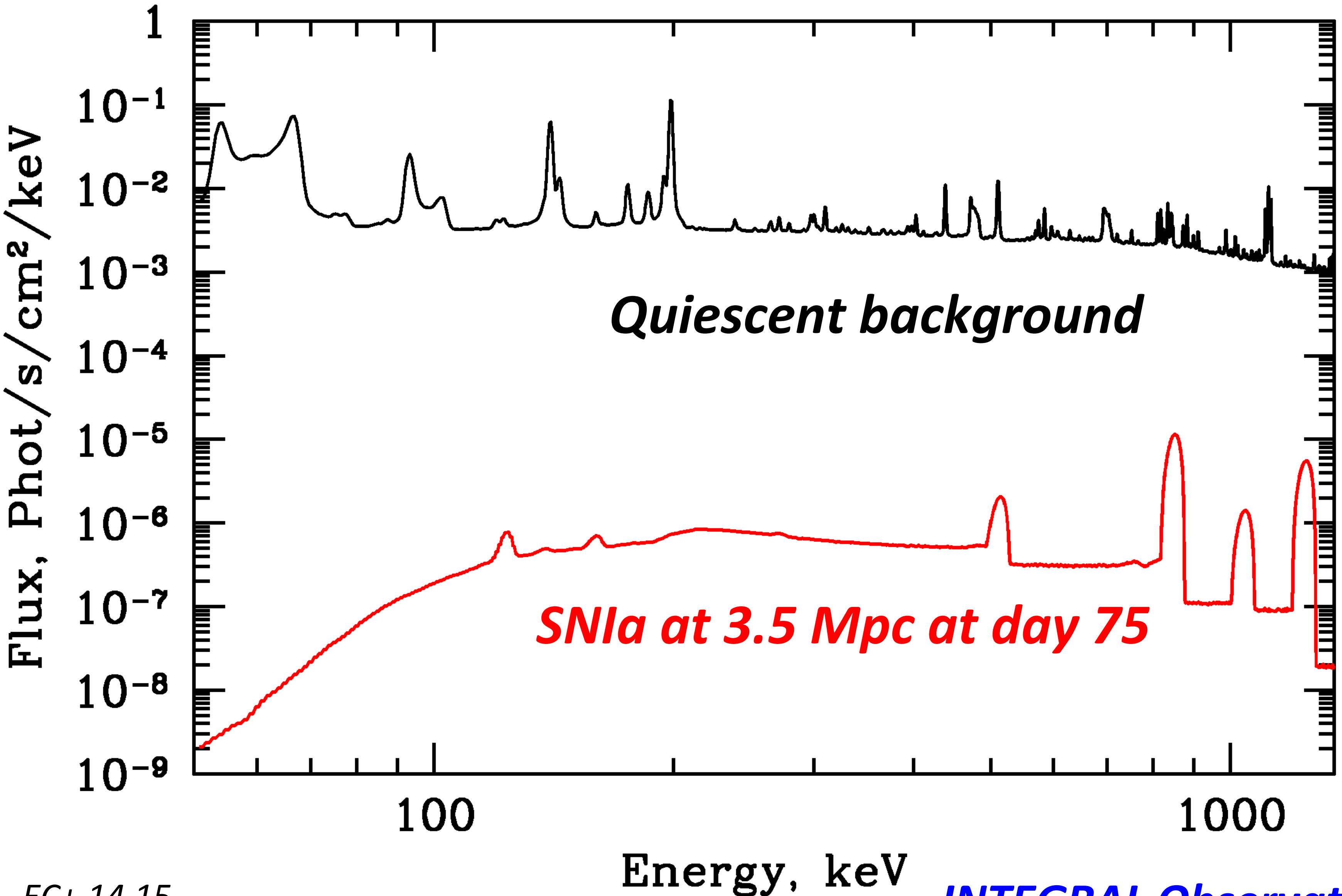
EC+,14,15

Broad band SN2014J spectrum



INTEGRAL Observatory 4 Msec; 11 σ detection

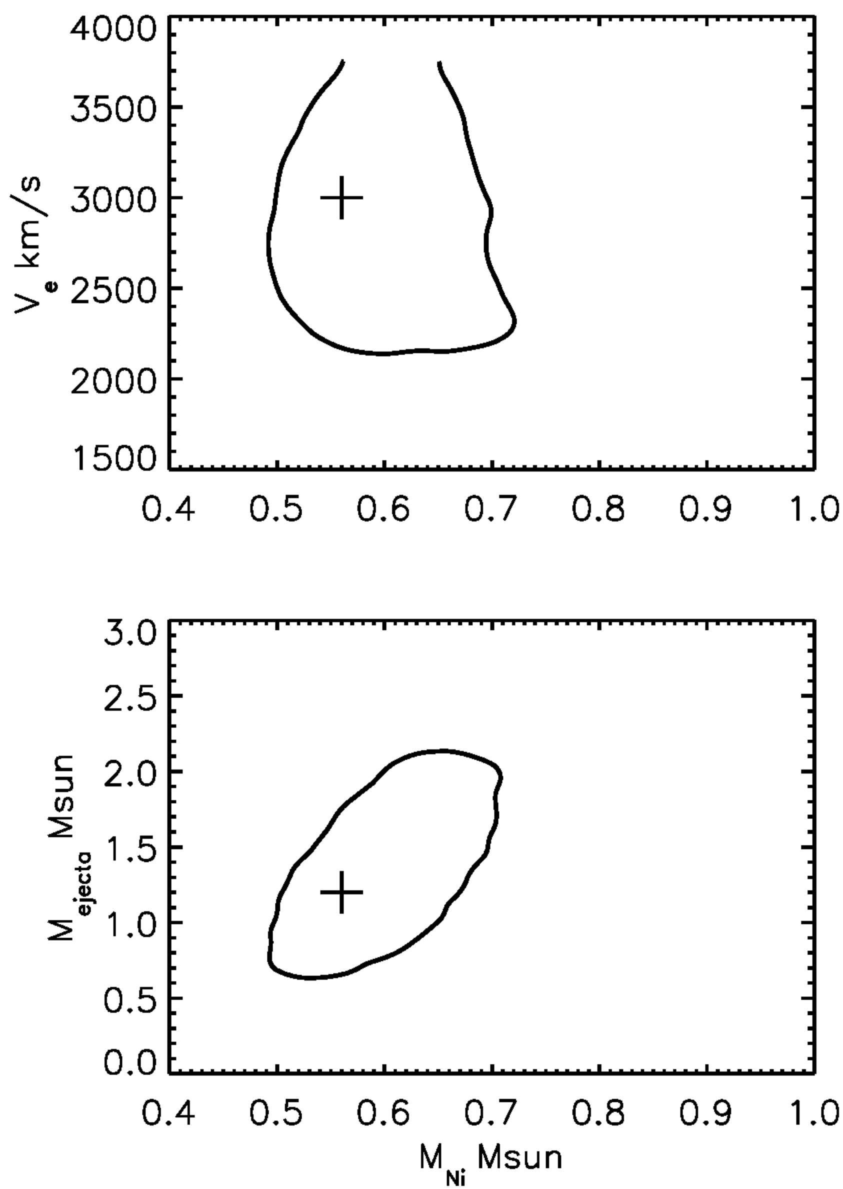
Predicted Spectrum and the Background



EC+,14,15

INTEGRAL Observatory

Best-fitting parameters of the 3PAR model

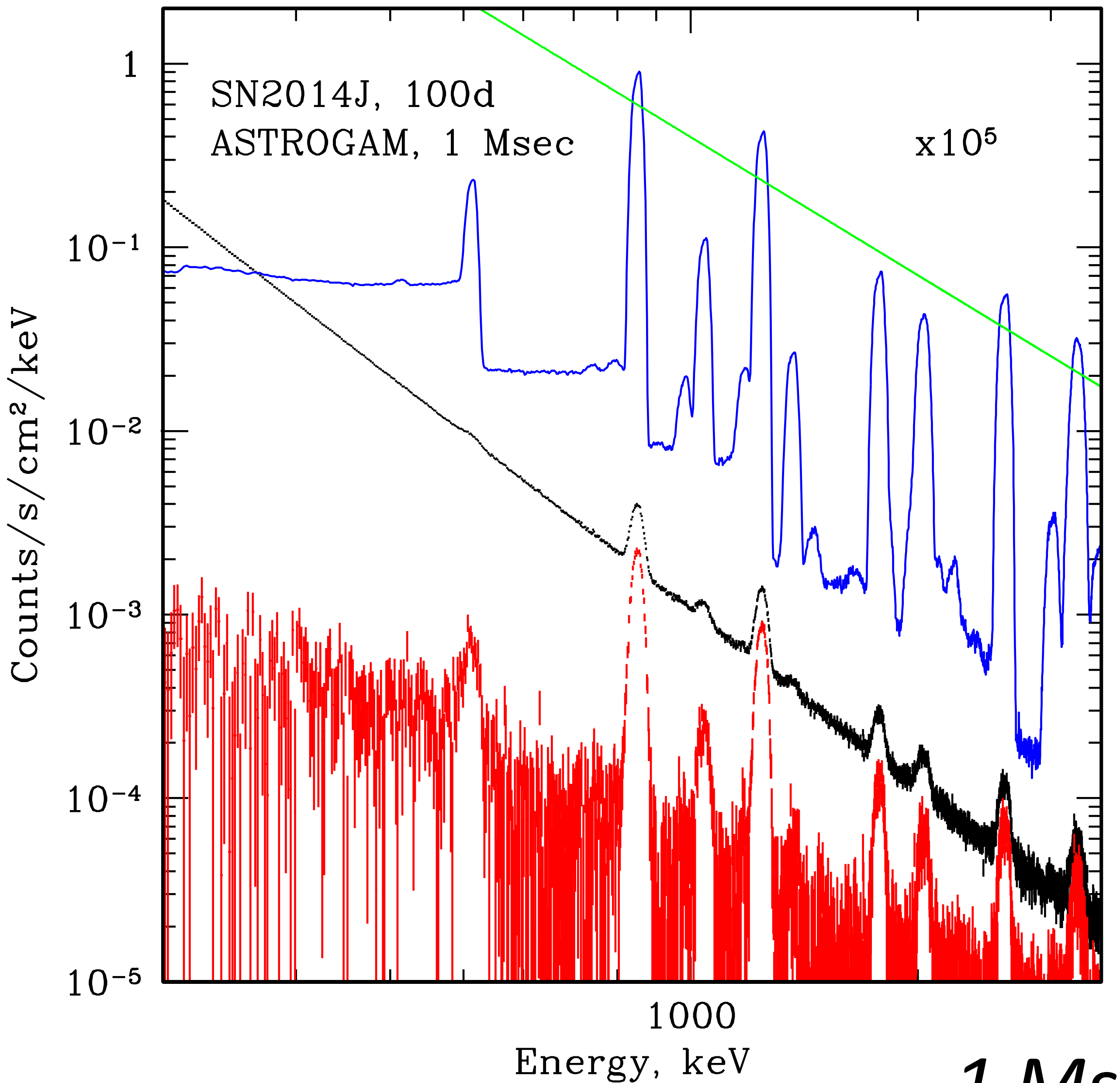


$$M_{Ni}, M_{Ejecta}, V_e$$

$$M_{Ni} \sim 0.6\, M_{Sun} \quad [\pm 0.1]$$

$$M_{Ejecta} \sim 1.3\, M_{Sun} \quad [\pm 0.7]$$

$$V_e \sim 3000 \text{ km/s} \quad [\pm 1000]$$



SN2014J, 100d
ASTROGAM, 1 Msec
x10⁵
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
Counts/s/cm²/keV
1000
Energy, keV

1 Msec; 60 σ

VIRGO SUPERCLUSTER

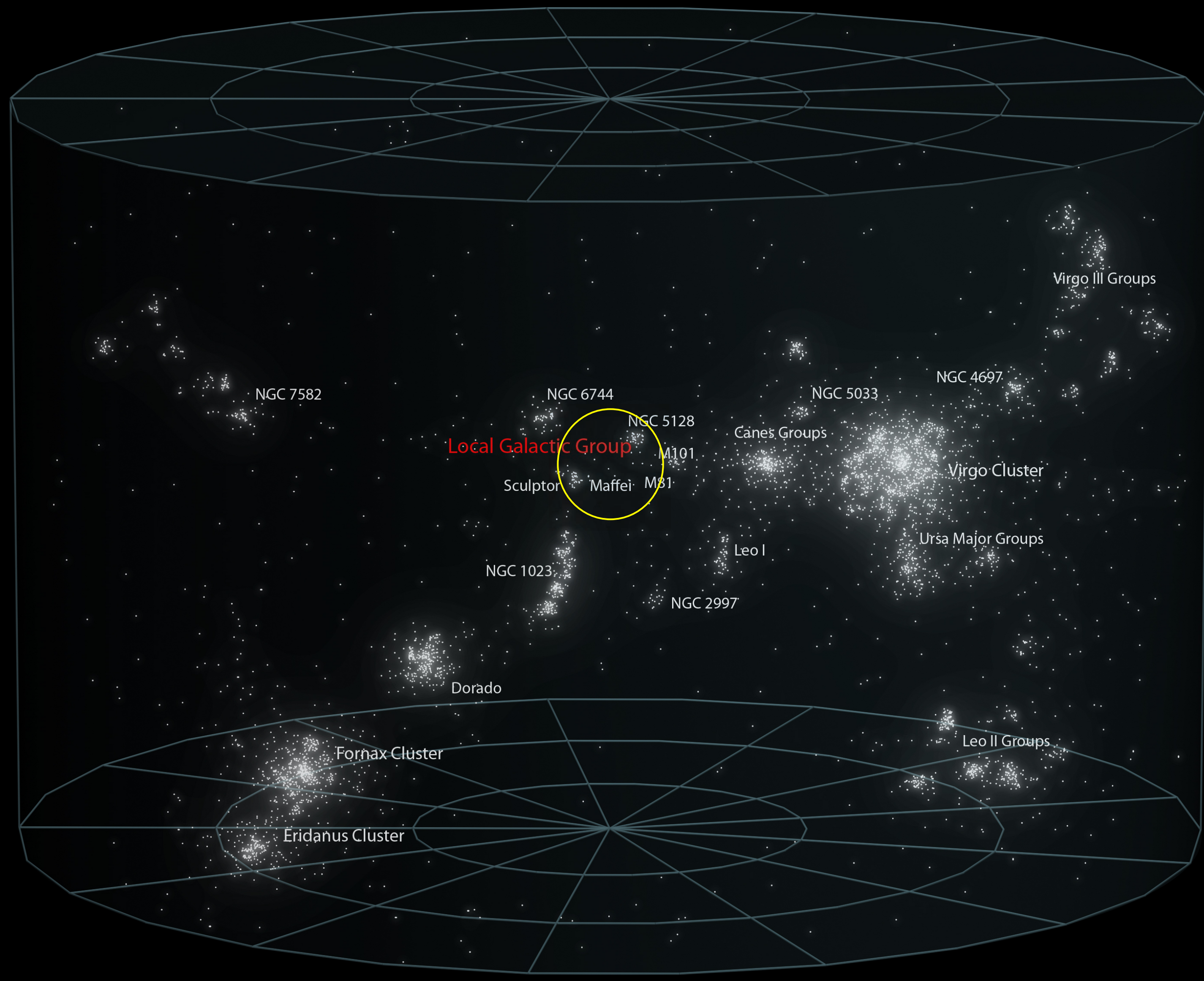
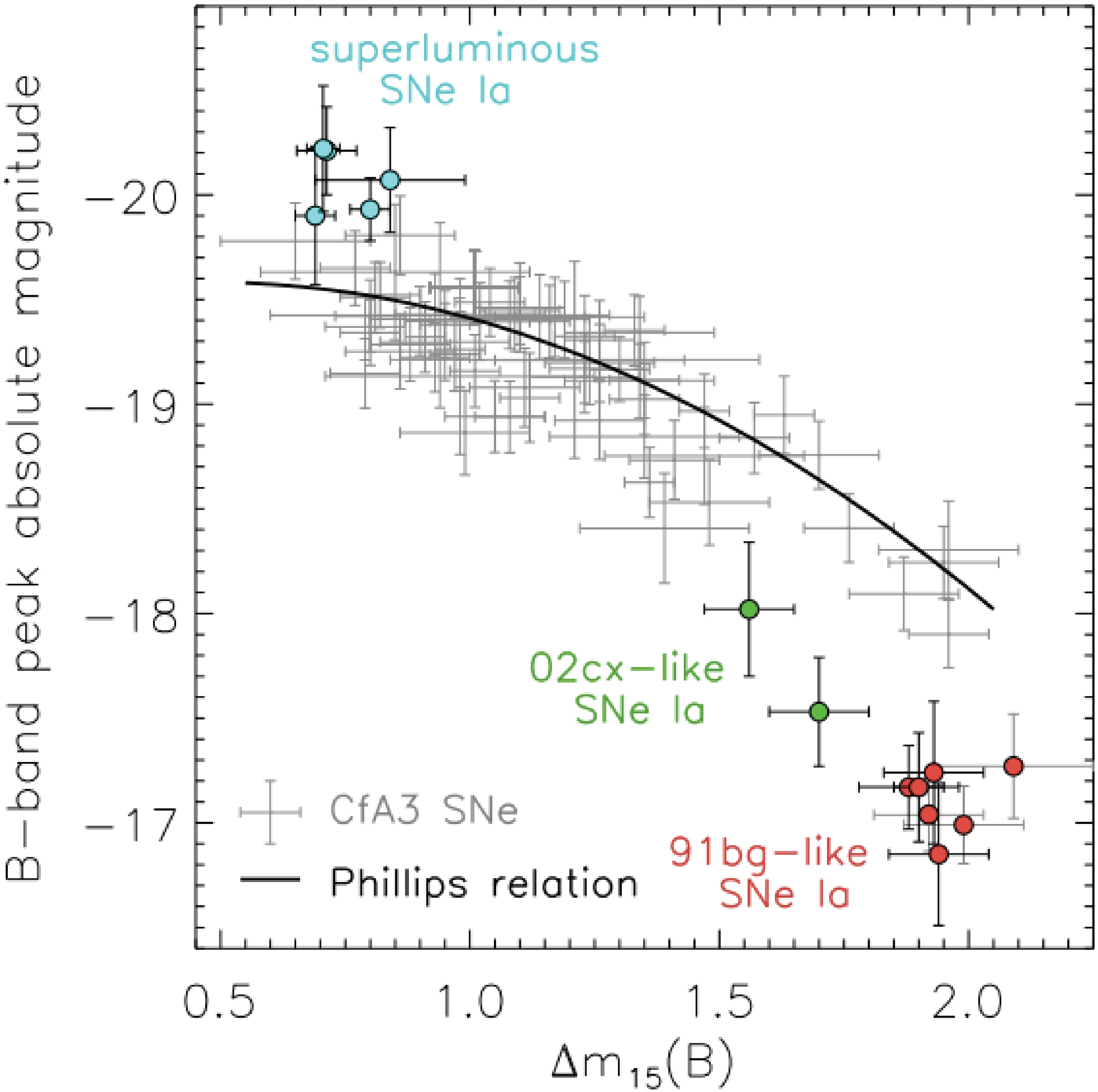


Image by Andrew Z. Colvin

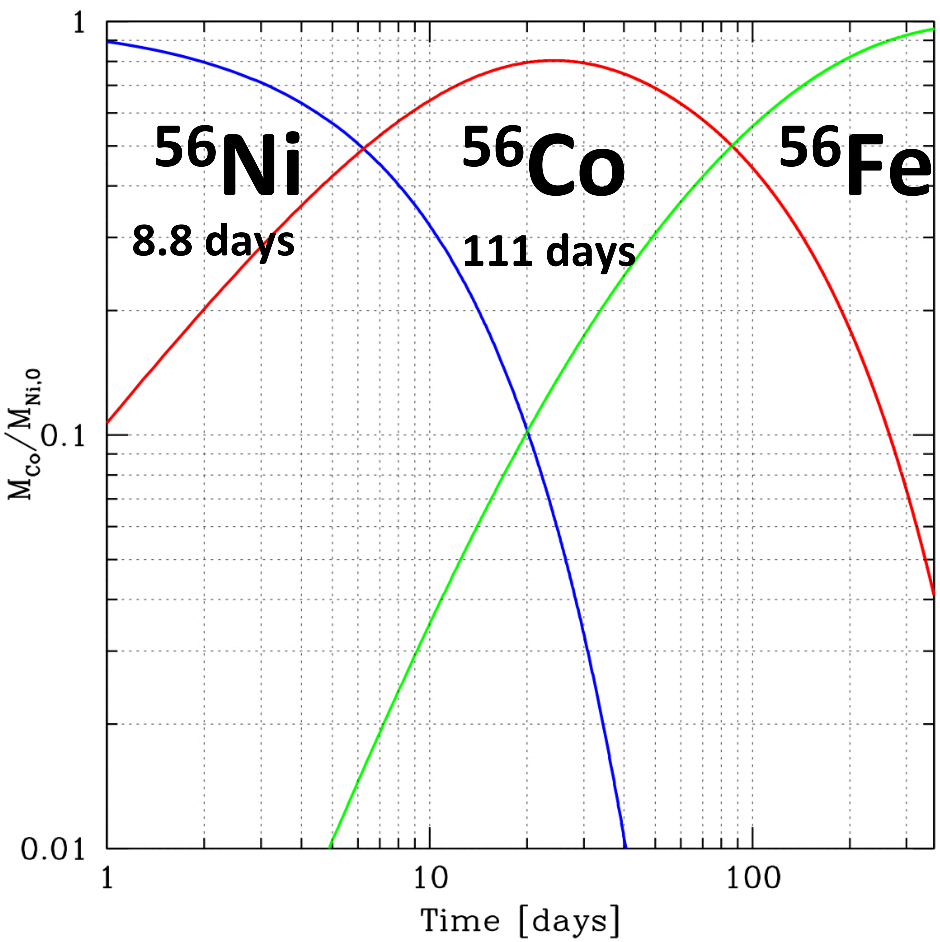
Phillips relation

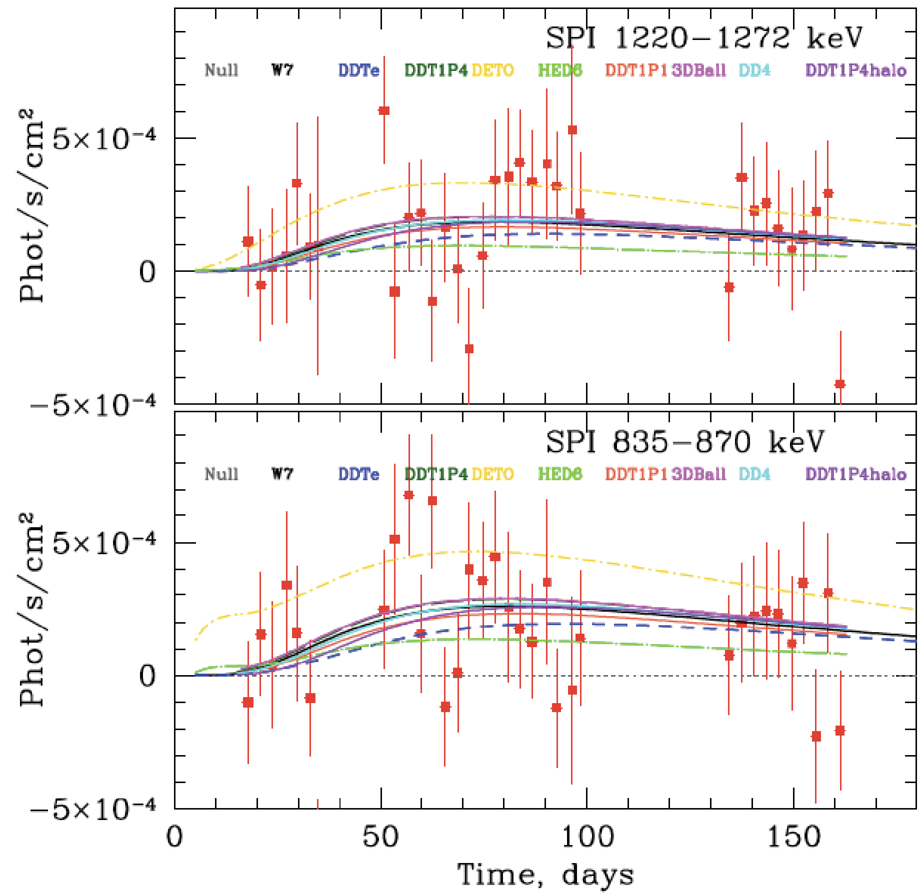


Hillebrandt+,01

Early phase (0-25 days)

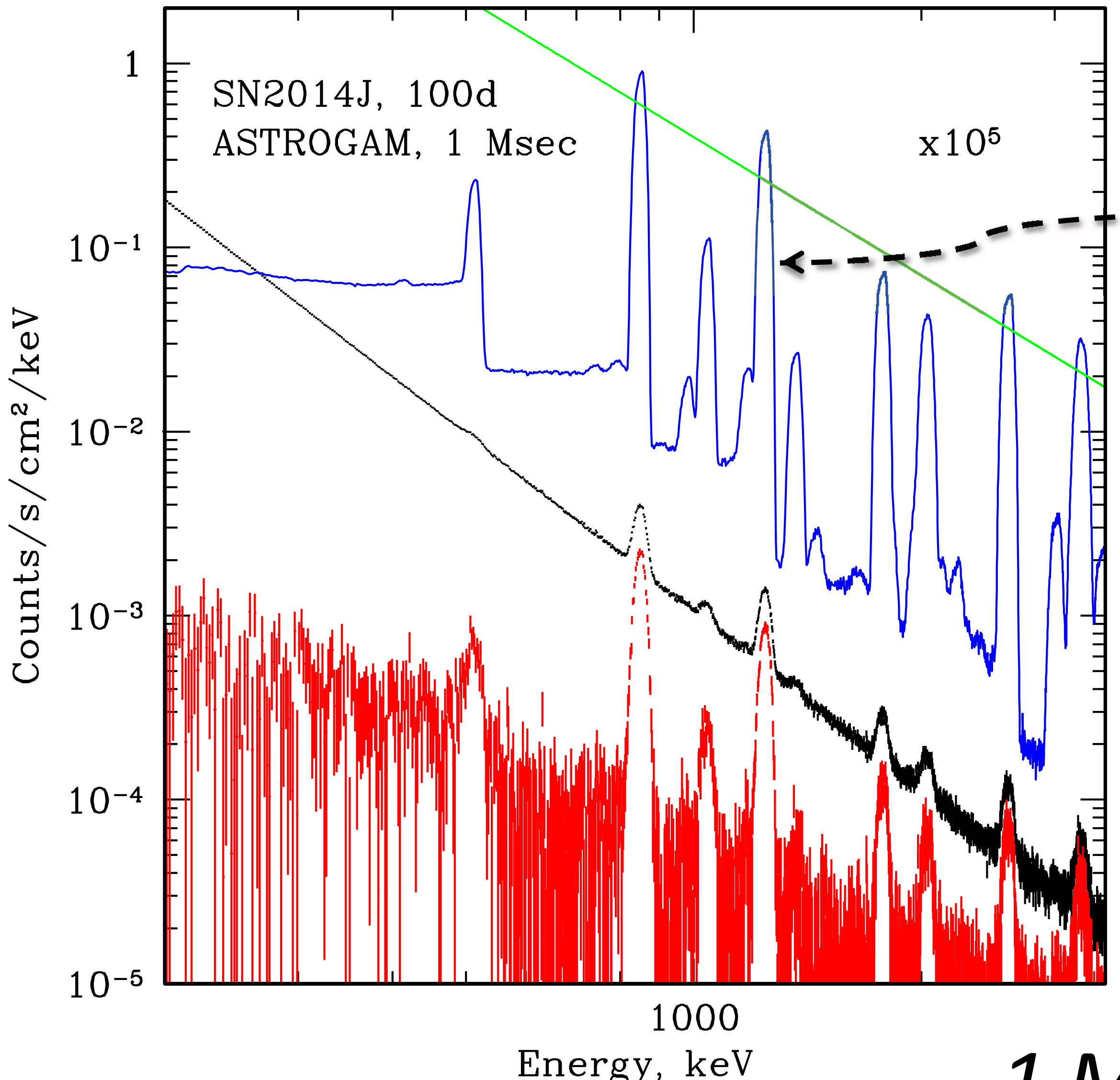
^{56}Ni decays ~12 times faster than ^{56}Co → Ni≈Co/12 by day ~25

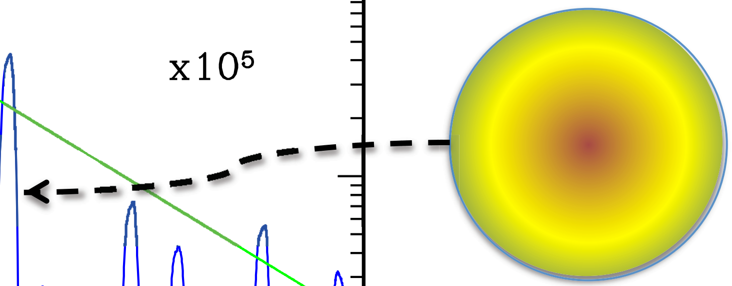




Envelope is very thick for gamma-rays → Ni has to be close to the surface

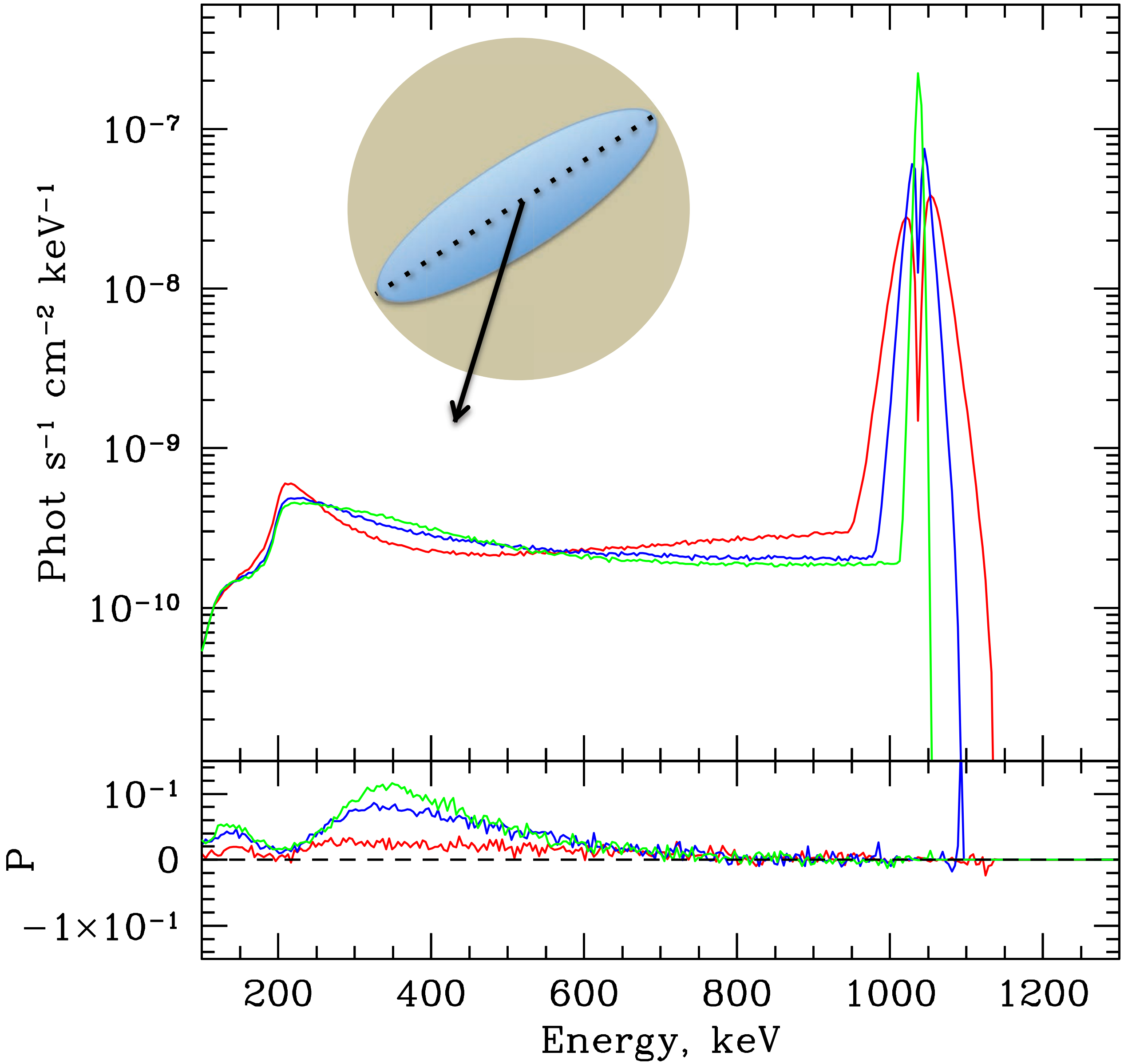
Velocity substructure and polarization





1 Msec; 60 σ

Prolate [bar of ^{56}Ni, single line]



EC+

Escape of positrons and diffusion of positrons

After 100 days most of gamma-ray escape. What about positrons?

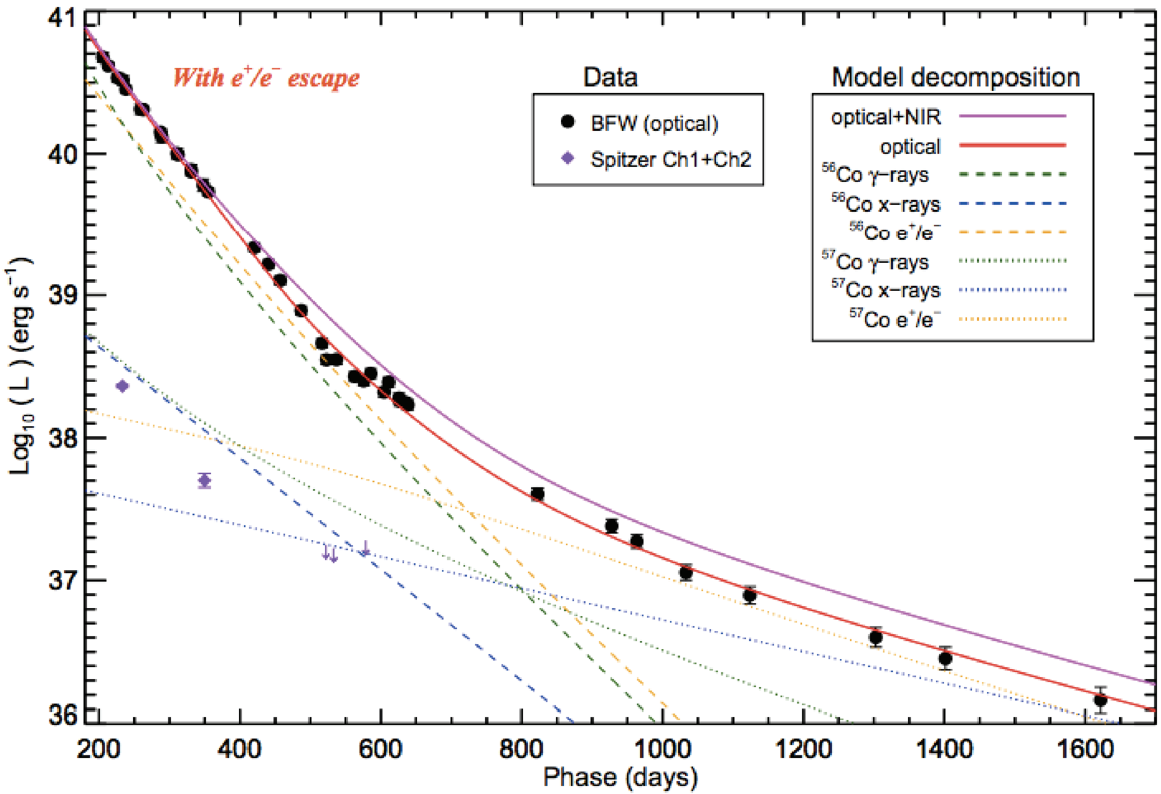
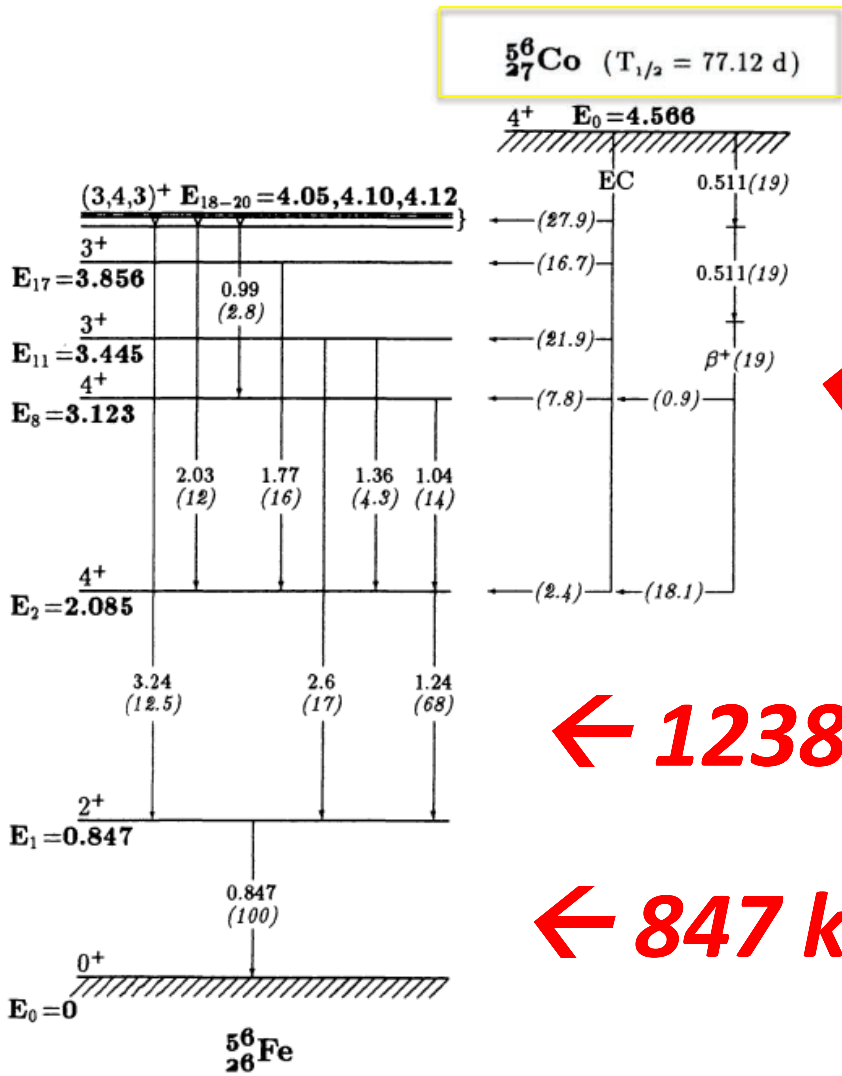


Figure 9. The pseudo-bolometric light curve of SN 2011fe shown as filled black circles; see Section 3.1 for details of the light curve construction. This figure shows the fit of the 'Case 1' model (Section 4.3), allowing for positron/electron escape and assuming that the optical light curve and near-IR corrections (Section 4.2) account for all of the emerging photons. Fig. 11 shows the fit of the 'Case 2' model, which does not allow of positron/electron escape but instead allows for luminosity to emerge at wavelengths greater than 2.5 μm.

Dimitriadis+, 2017

Gamma-ray Lines due to $^{56}Co \rightarrow {}^{56}Fe$



← e^+, 19%

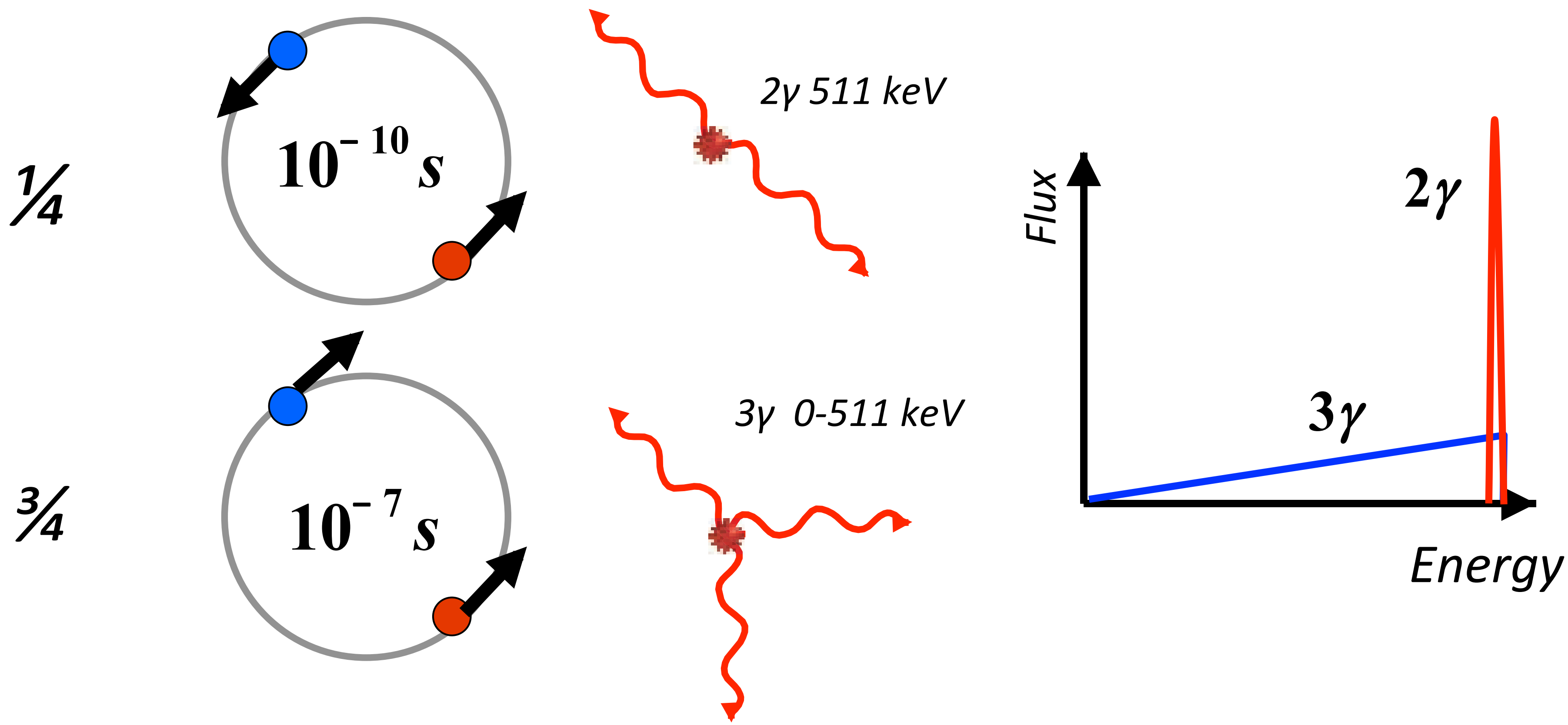
← 1238 keV, 68%

← 847 keV, 100%

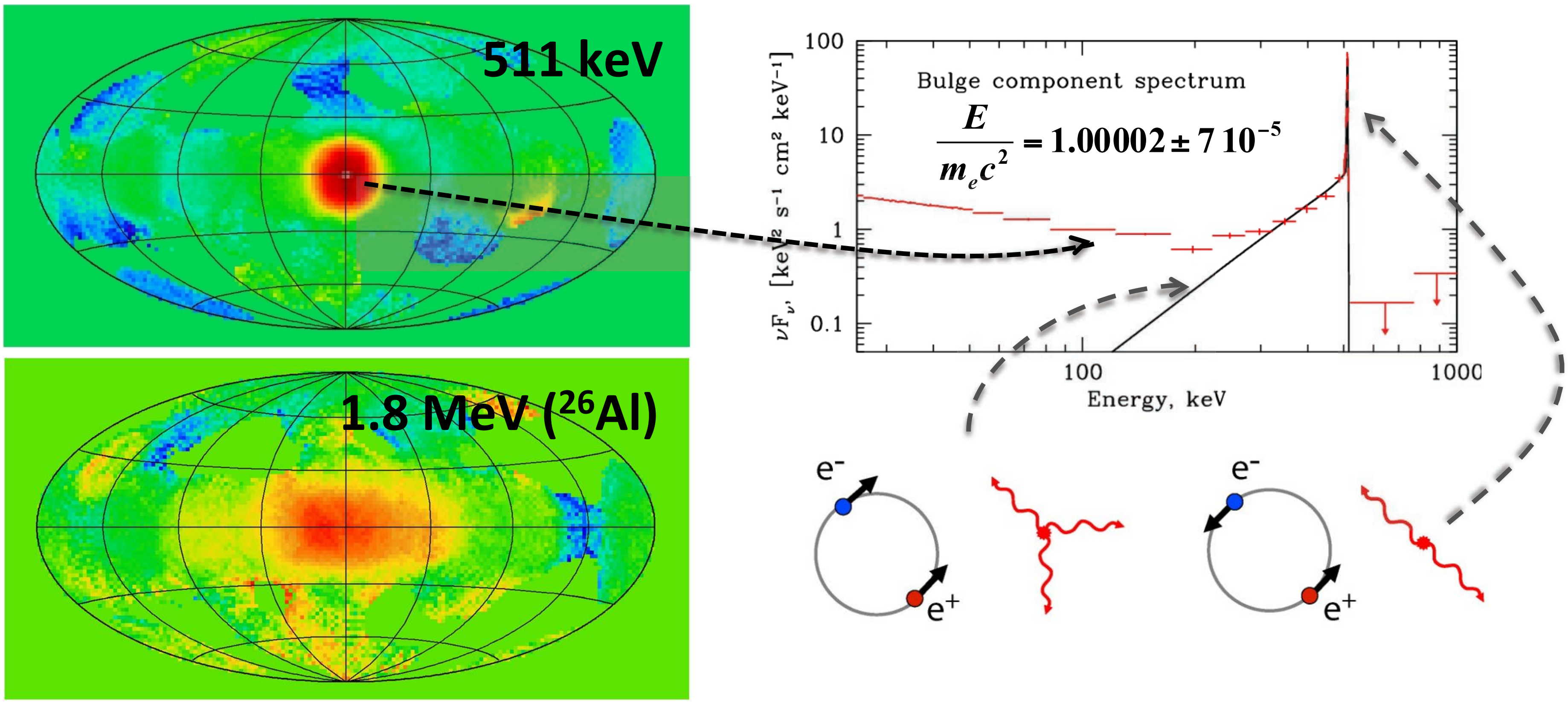
From Nadyozhin, 94

Fate of positrons (19% of decays)

Positron has initial kinetic energy ~600 keV
1) Positron slows down
2) Captures electron via charge exchange and forms positronium atom

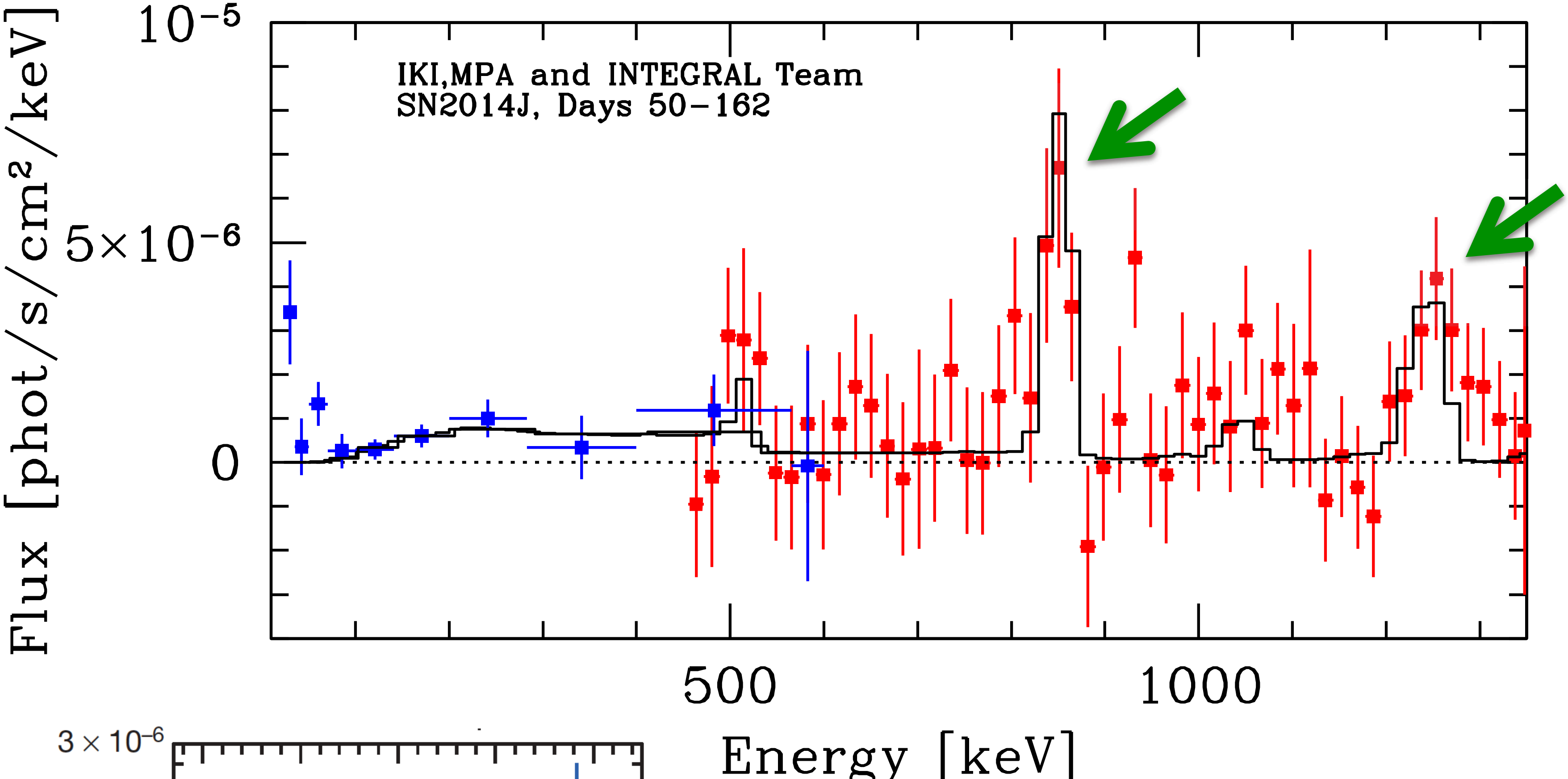


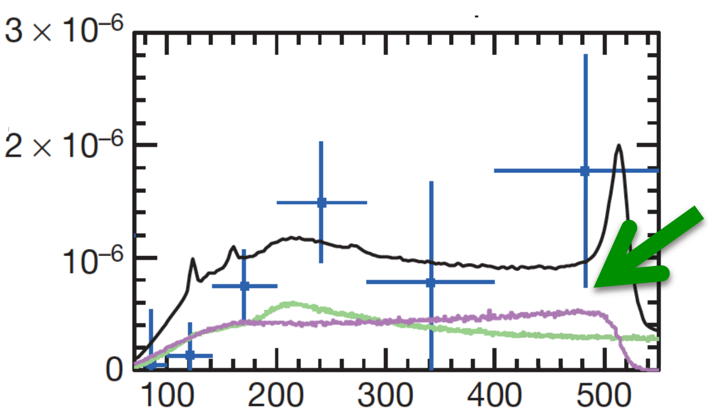
Positrons annihilation in the Milky Way



EC et al, 2005, 2011

SN2014J spectrum 50 – 1350 keV

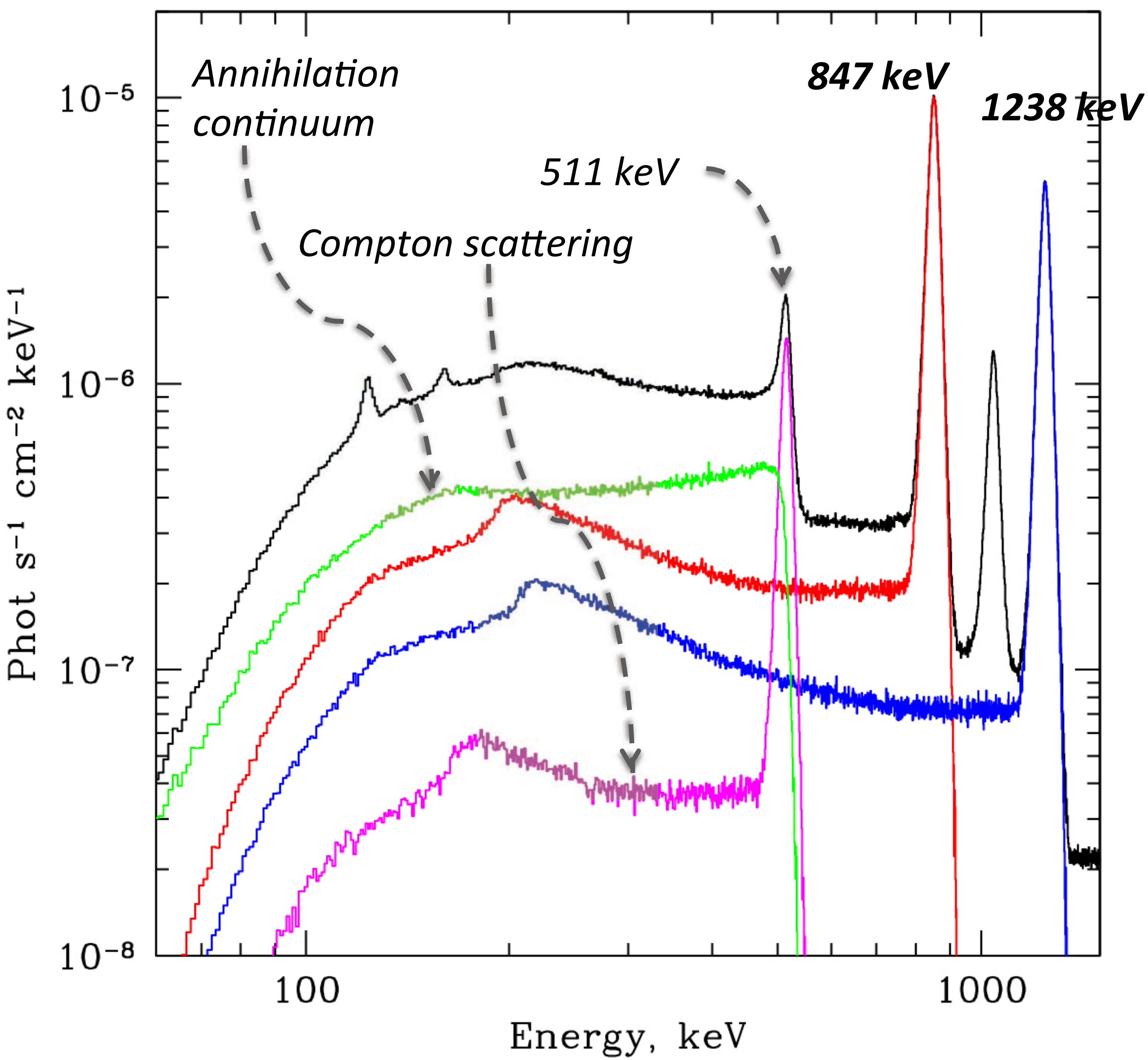




Positrons provide ~50% of the continuum

ASTROGAM can follow 511 keV for ~200 days

Contribution of positrons to Gamma-rays



77% of energy escapes in gamma-rays (@75 days after explosion)

ASTROGAM can trace 511 keV till few 100 days

Direct probe of positrons escape!

Summary

- *~10 SNIa - enough to make a sample of “normal” SNIa*
- *Accurate determination of Total Mass, Ni Mass, Energy*
- *Early phase (surface nucleosynthesis) can be studied*
- *SN2014J-type event could be traced for ~500 days*
- *Velocity substructure*
- *Polarization?*
- *Directly probe escape of positrons?*
- *Propagation of positrons (topology of the magnetic field)?*