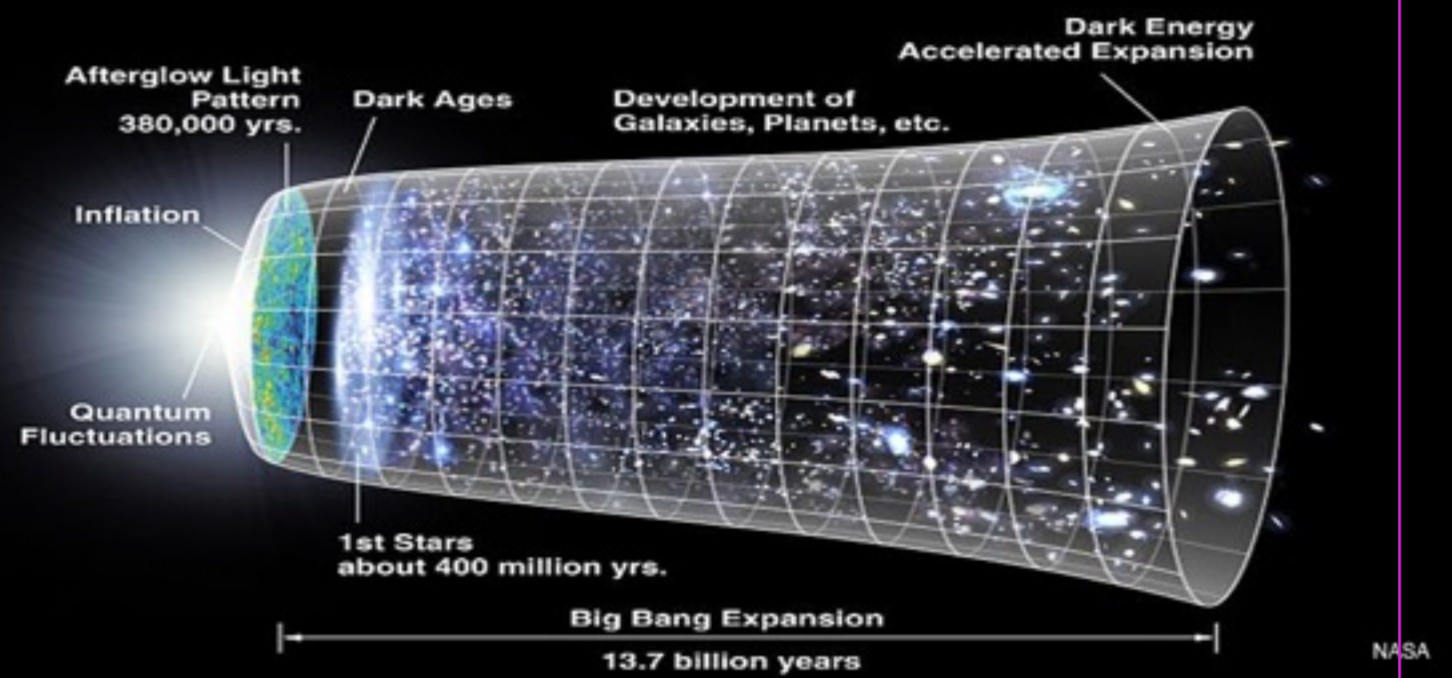
High-Energy Emission from Astronomical Transients

Raffaella Margutti

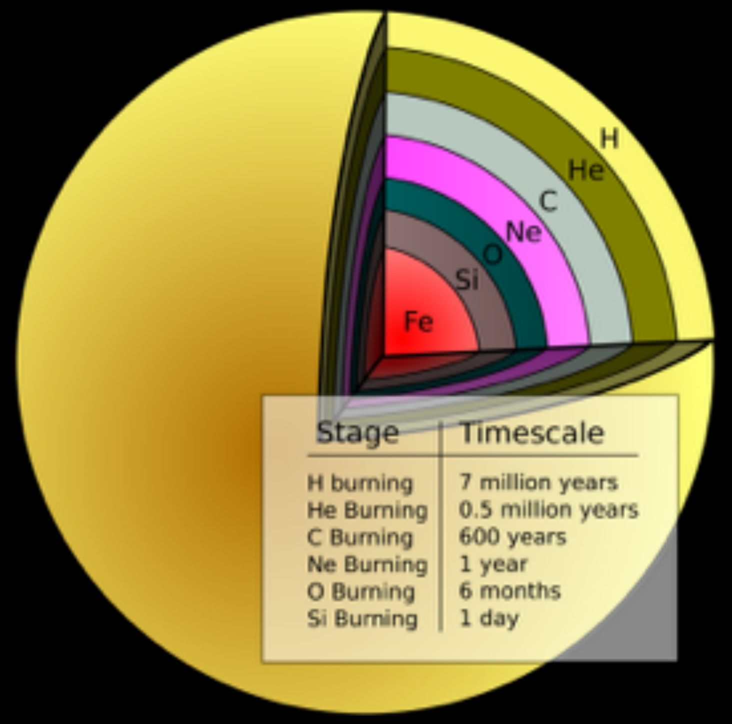
“We always find something, eh Didi, to give us the impression we exist?”

Cosmology:
Distance Ladders

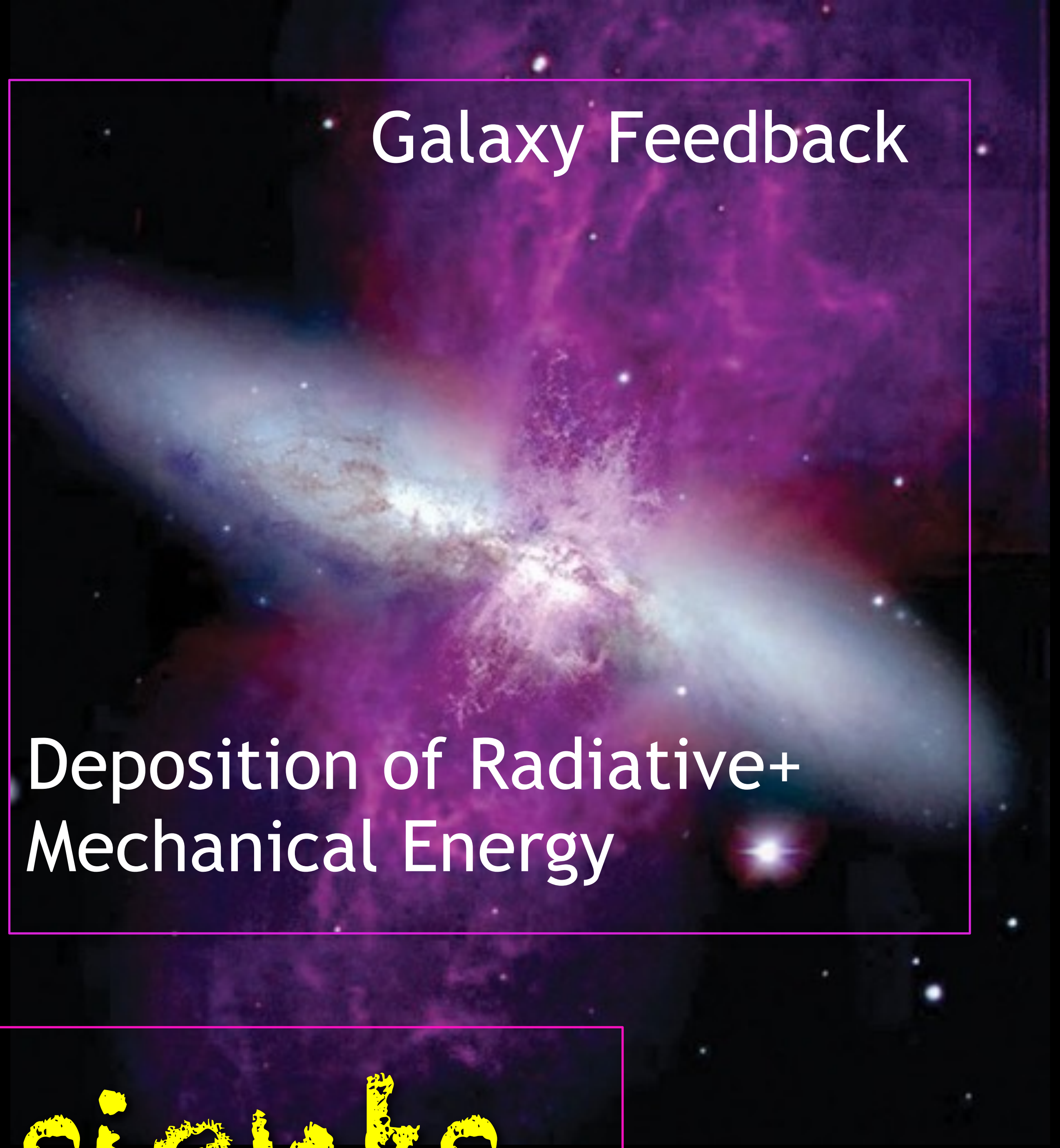


First sources of ionizing photons

Chemical Enrichment



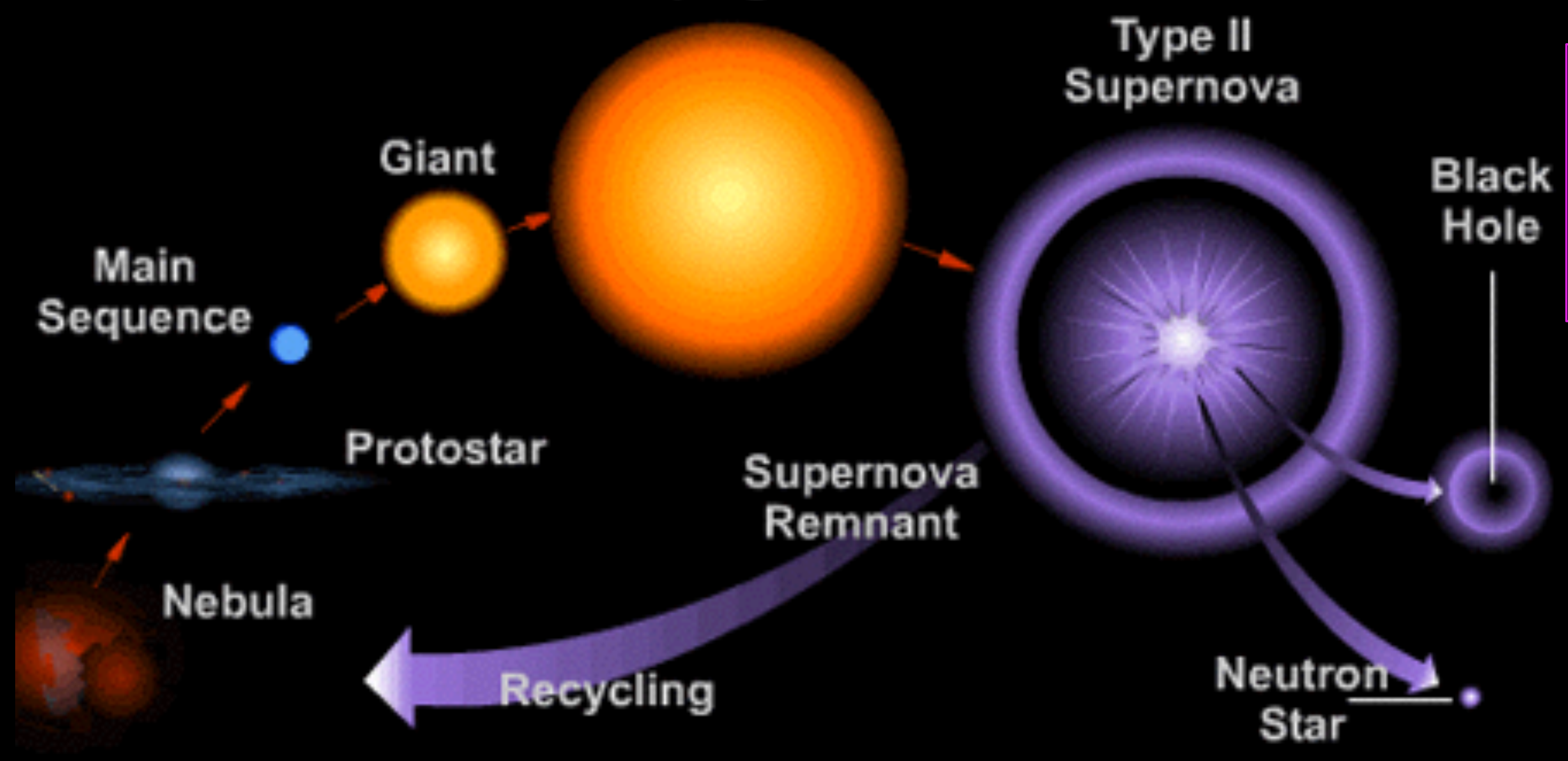
Galaxy Feedback



Deposition of Radiative+
Mechanical Energy

Explosive Transients

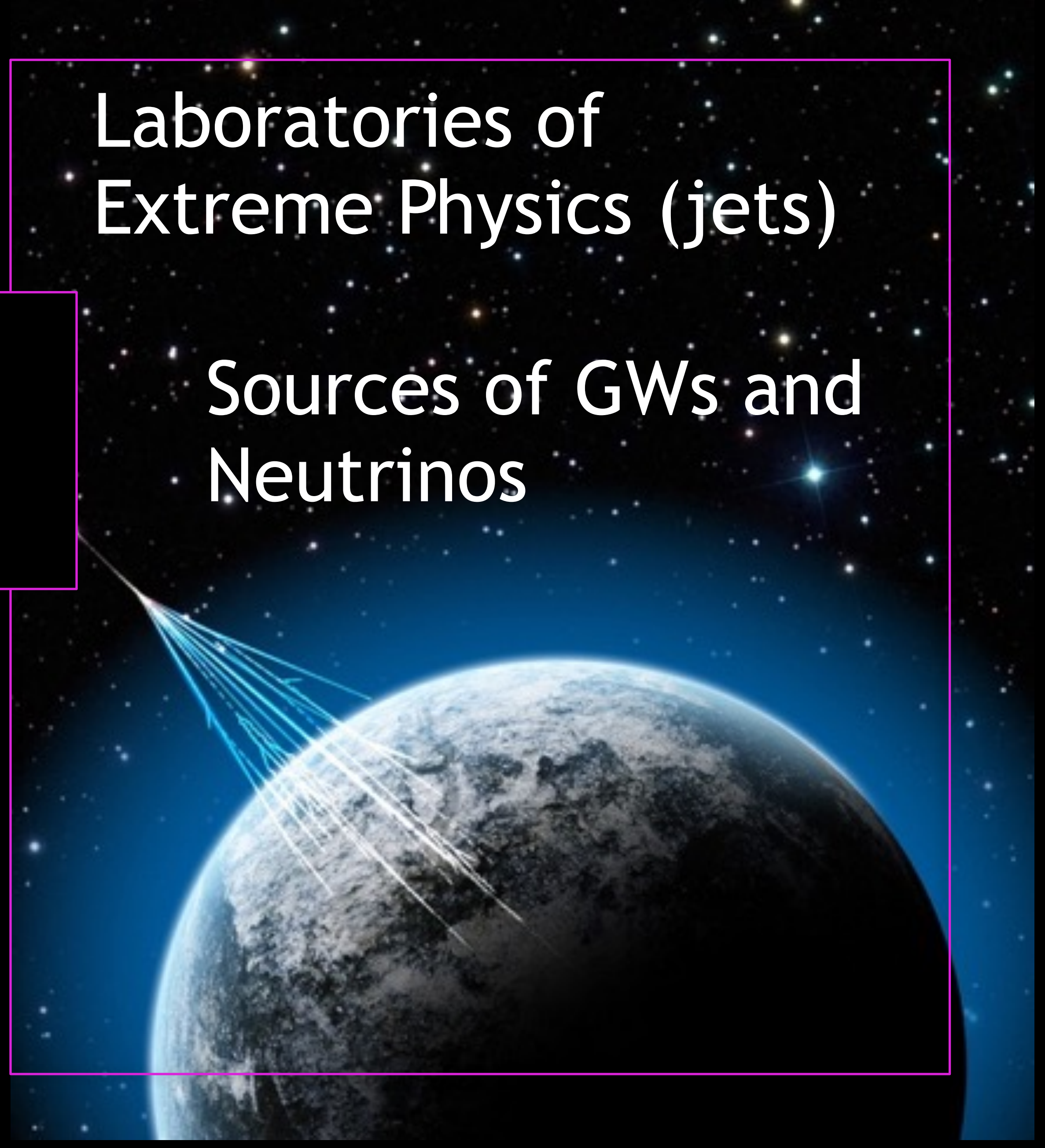
Endpoint of Stellar Evolution



They produce the
most Extreme
Objects

Laboratories of
Extreme Physics (jets)

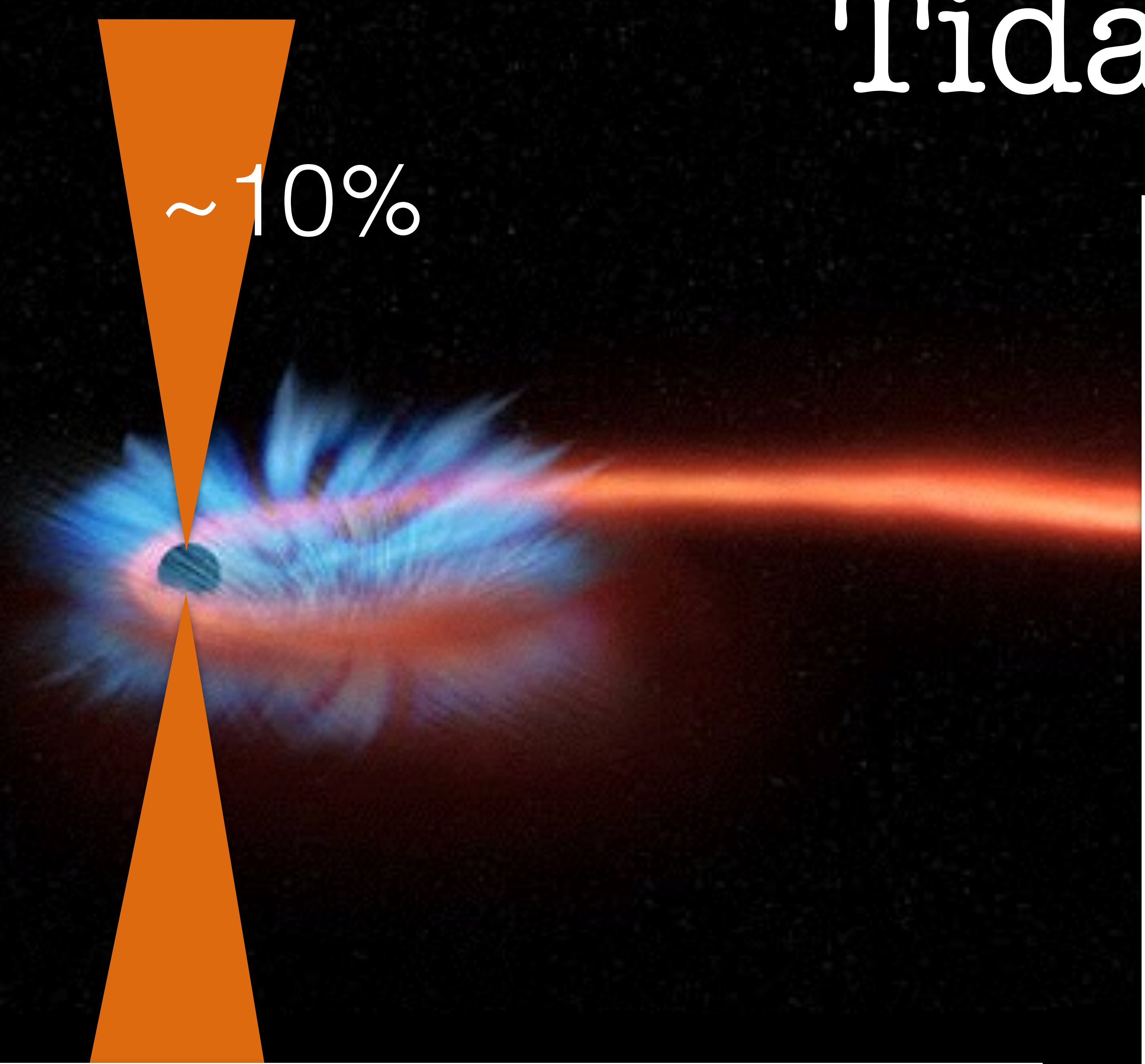
Sources of GWs and
Neutrinos

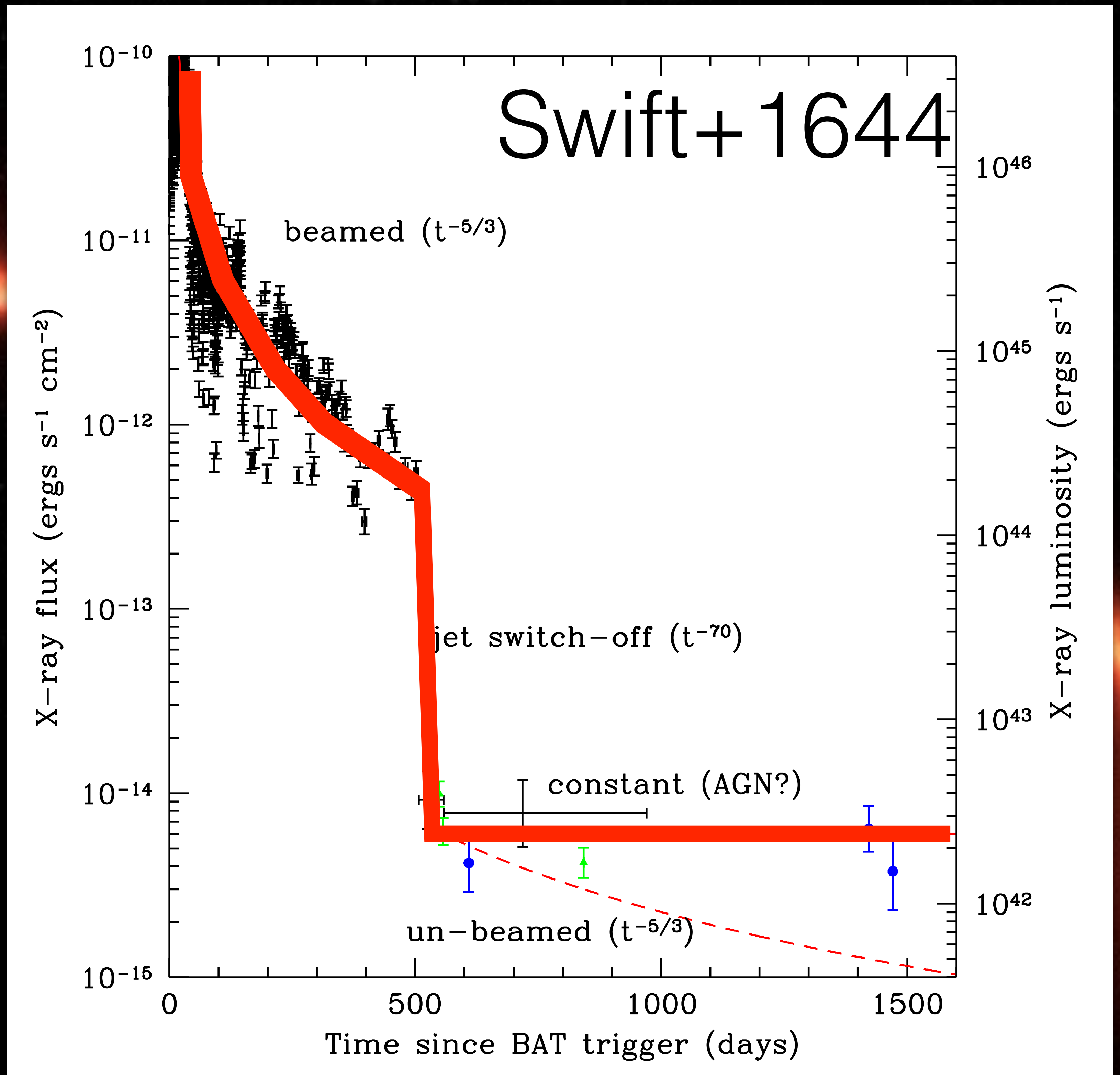


High-Energy emission from Transients

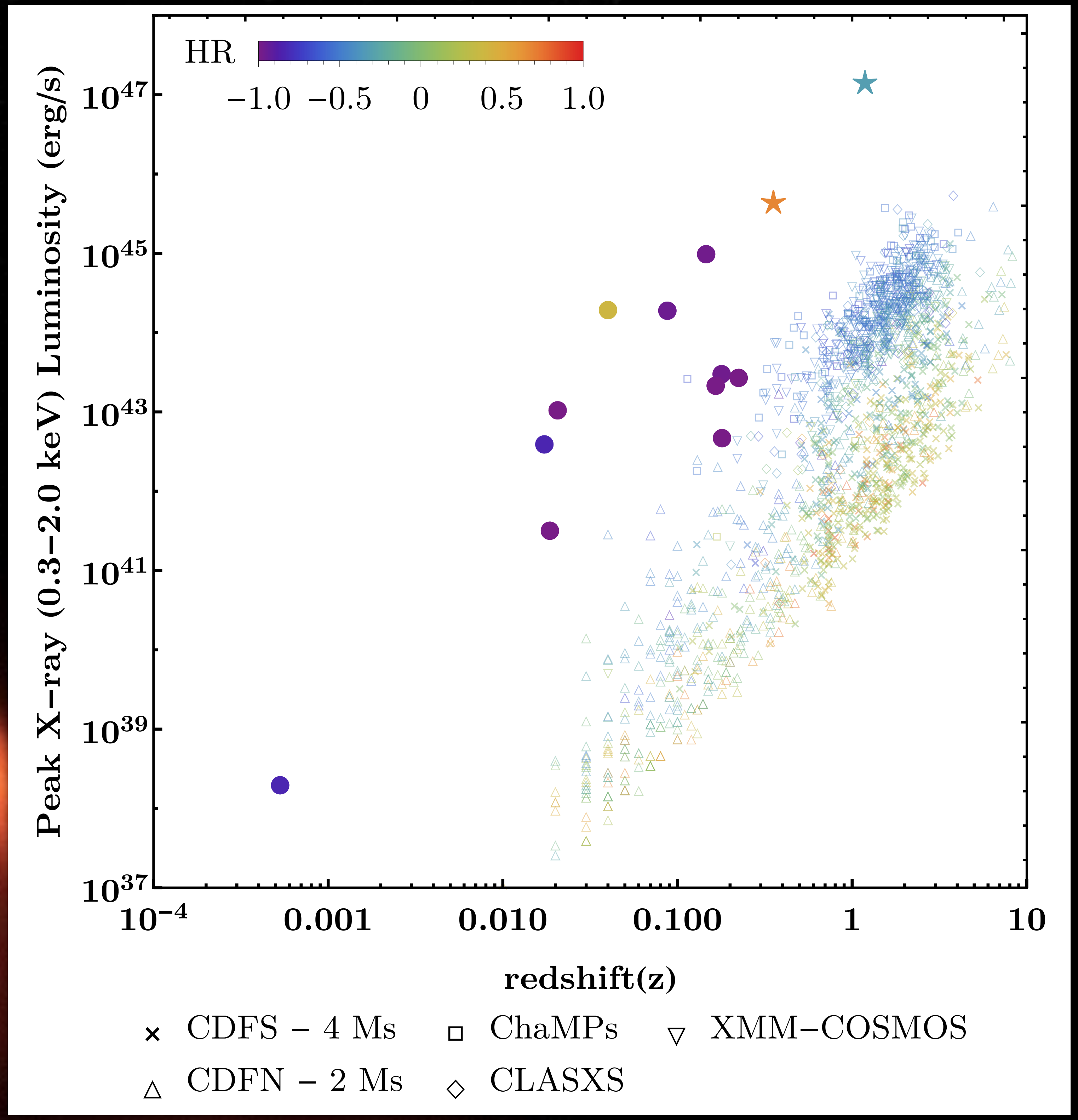
- Tidal Disruption Events
- Engine-Driven SNe / GRBs
- Strongly Interacting SNe
- SuperLuminous SNe

Tidal Disruption Events

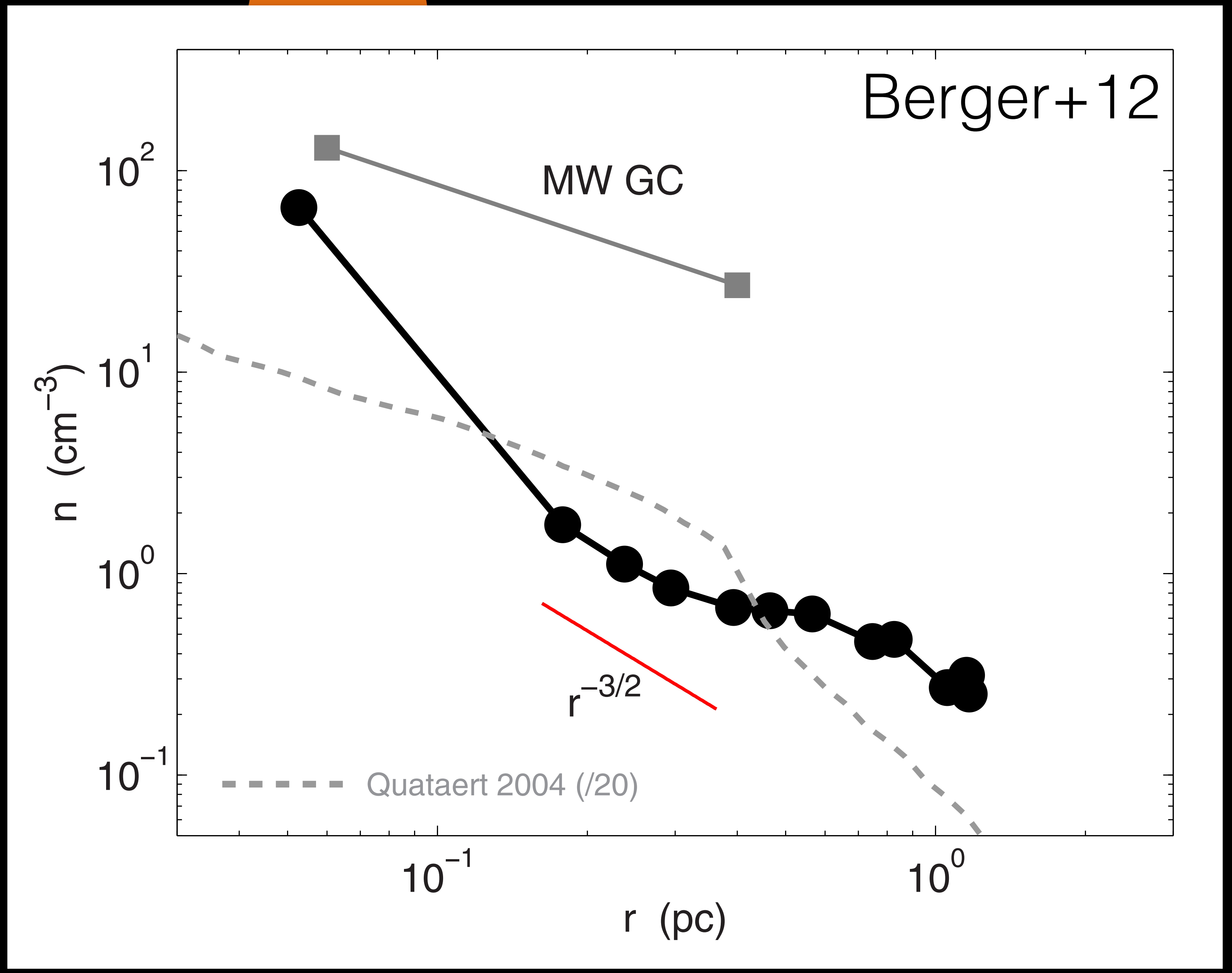




Levan+16



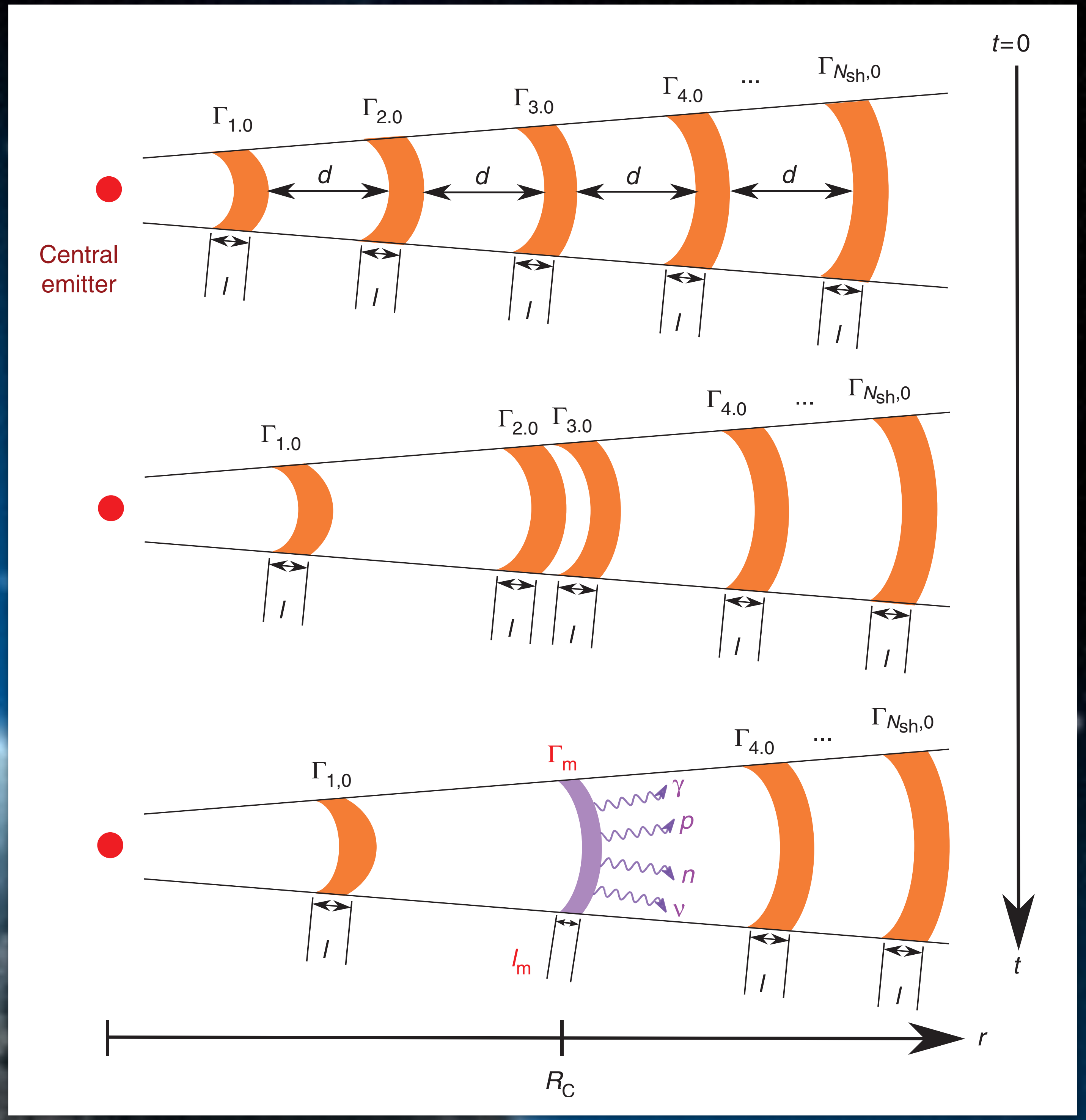
Auchettl+17

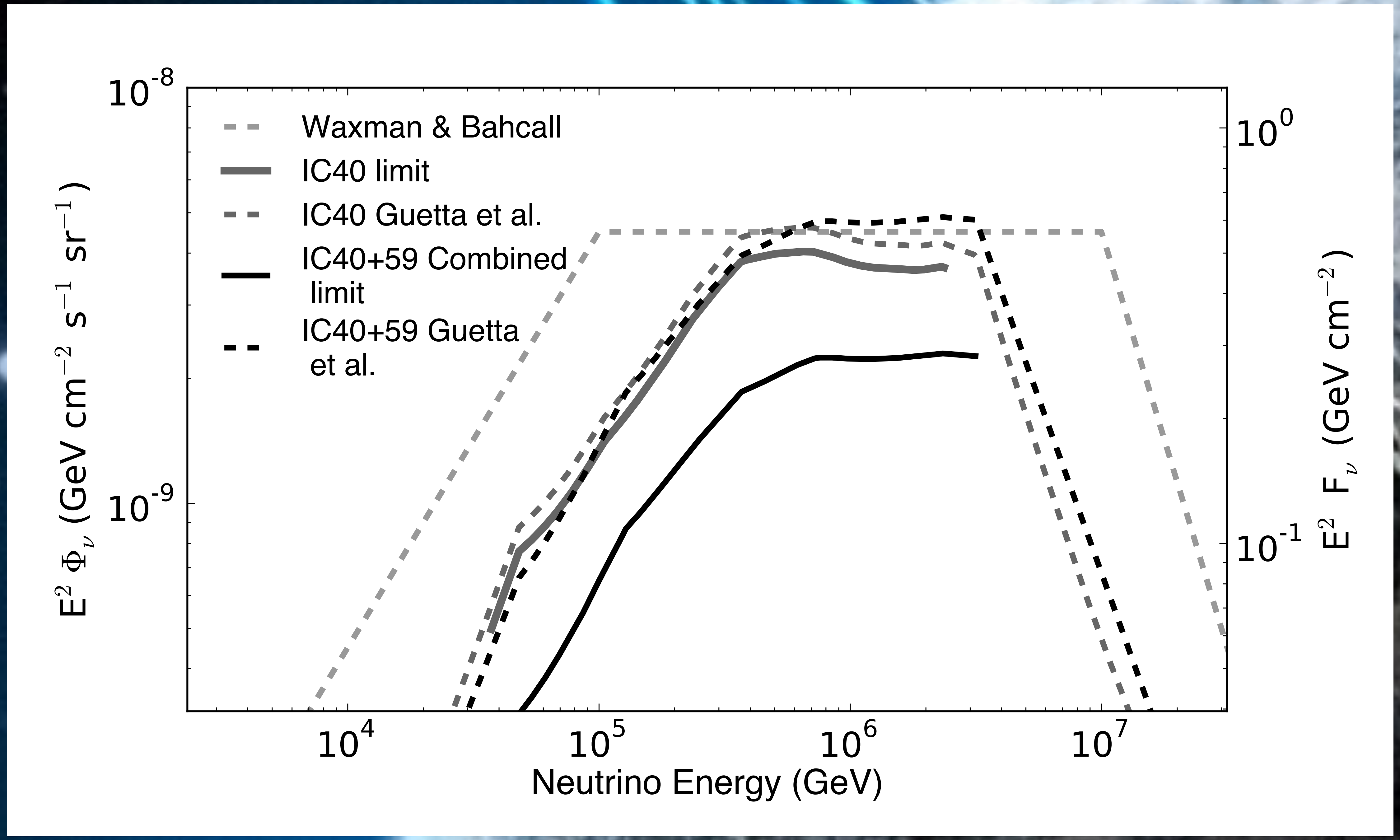


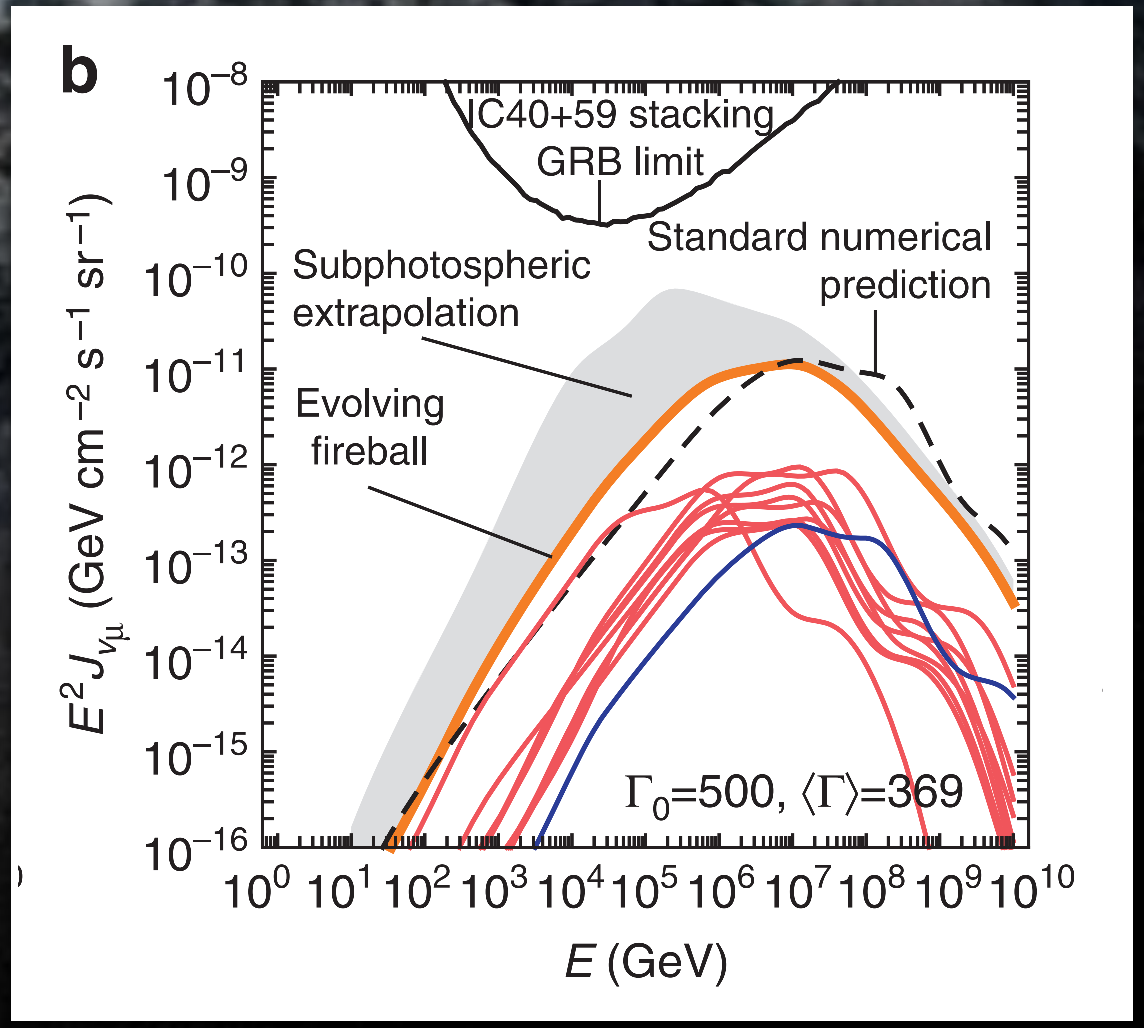
Credit: NASA

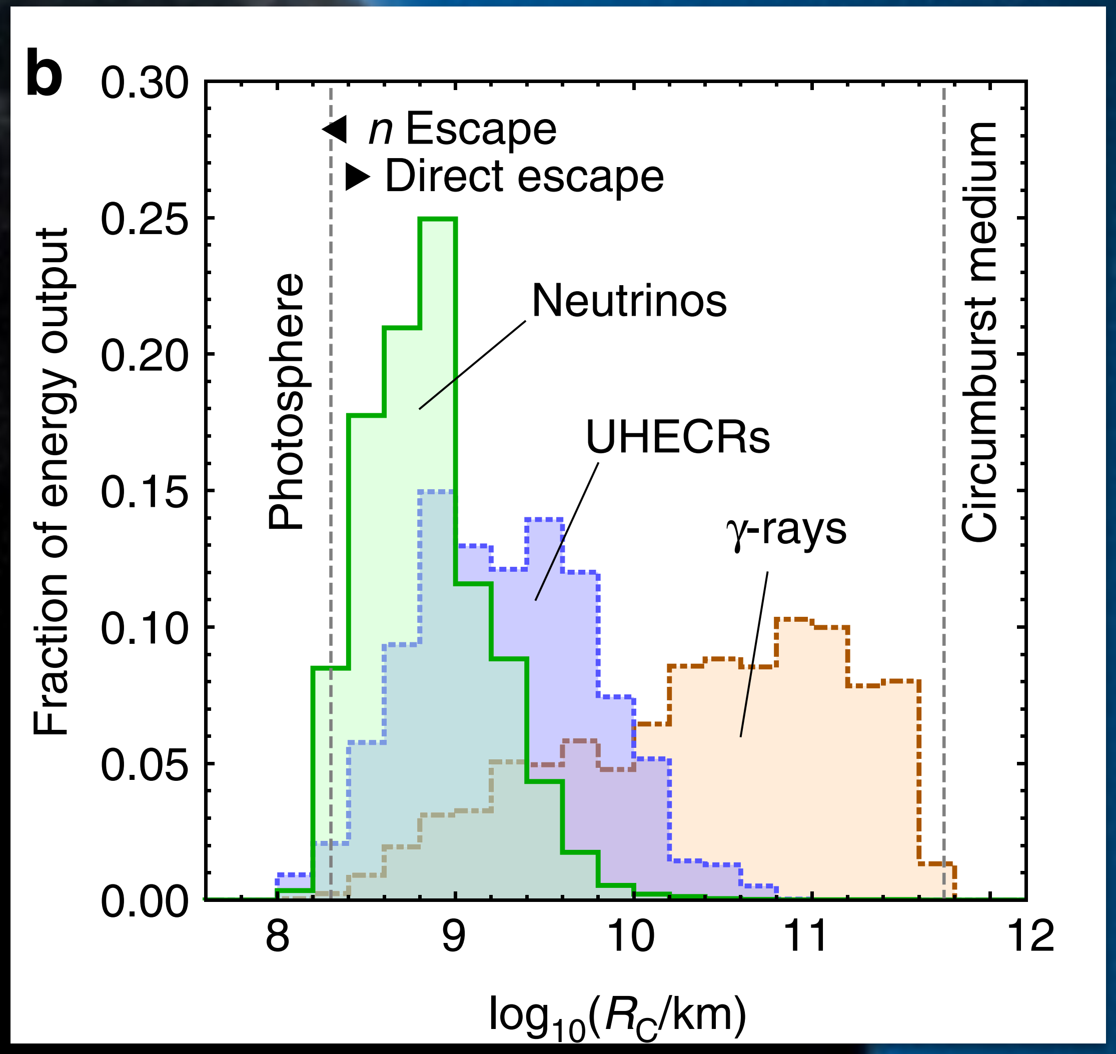
Engine-driven SNe/GRBs

Bustamante+Nature Com 2015









IceCube, Nature 2012

Credit: NSF/J. Yang

High-Energy emission from Transients

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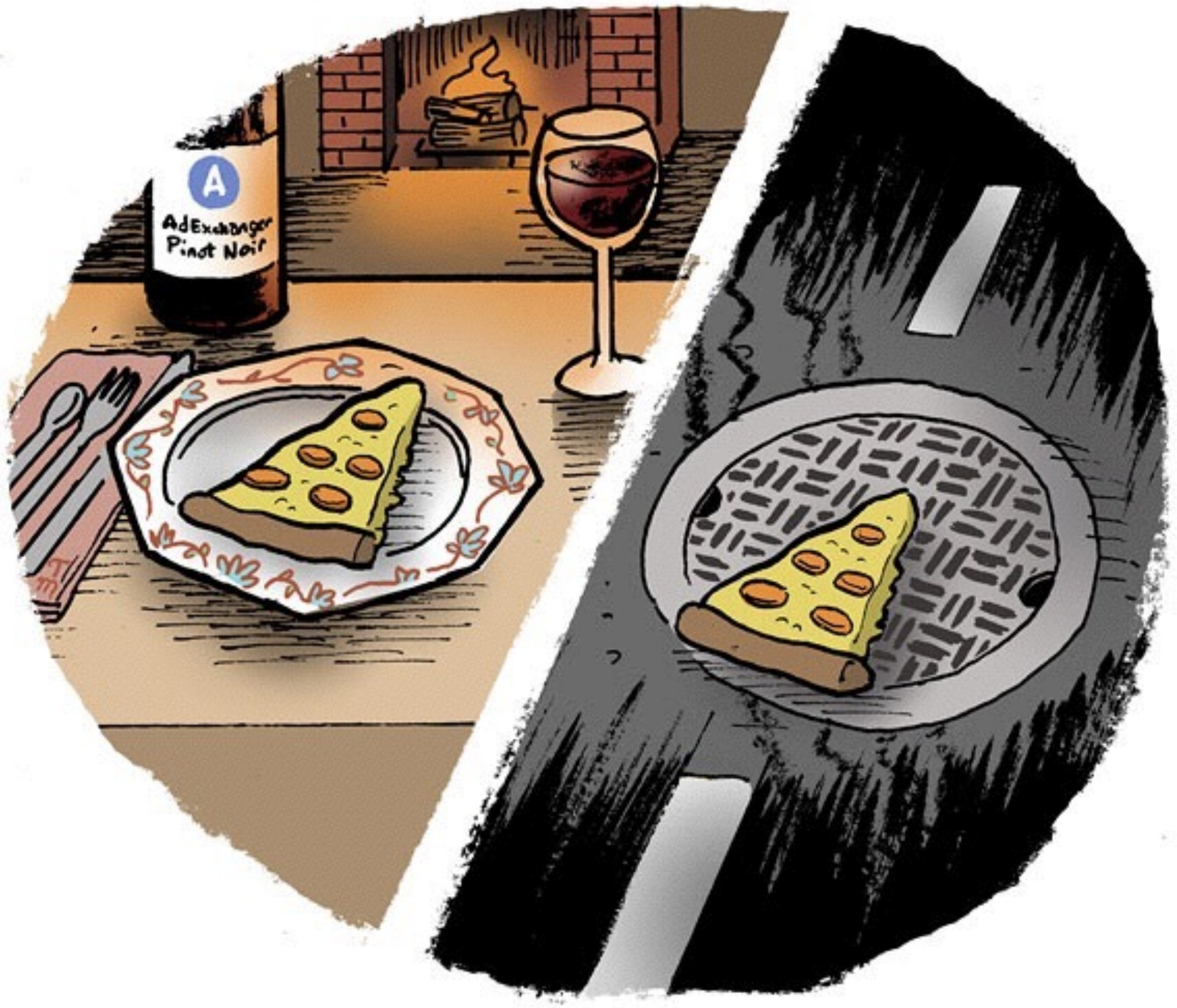
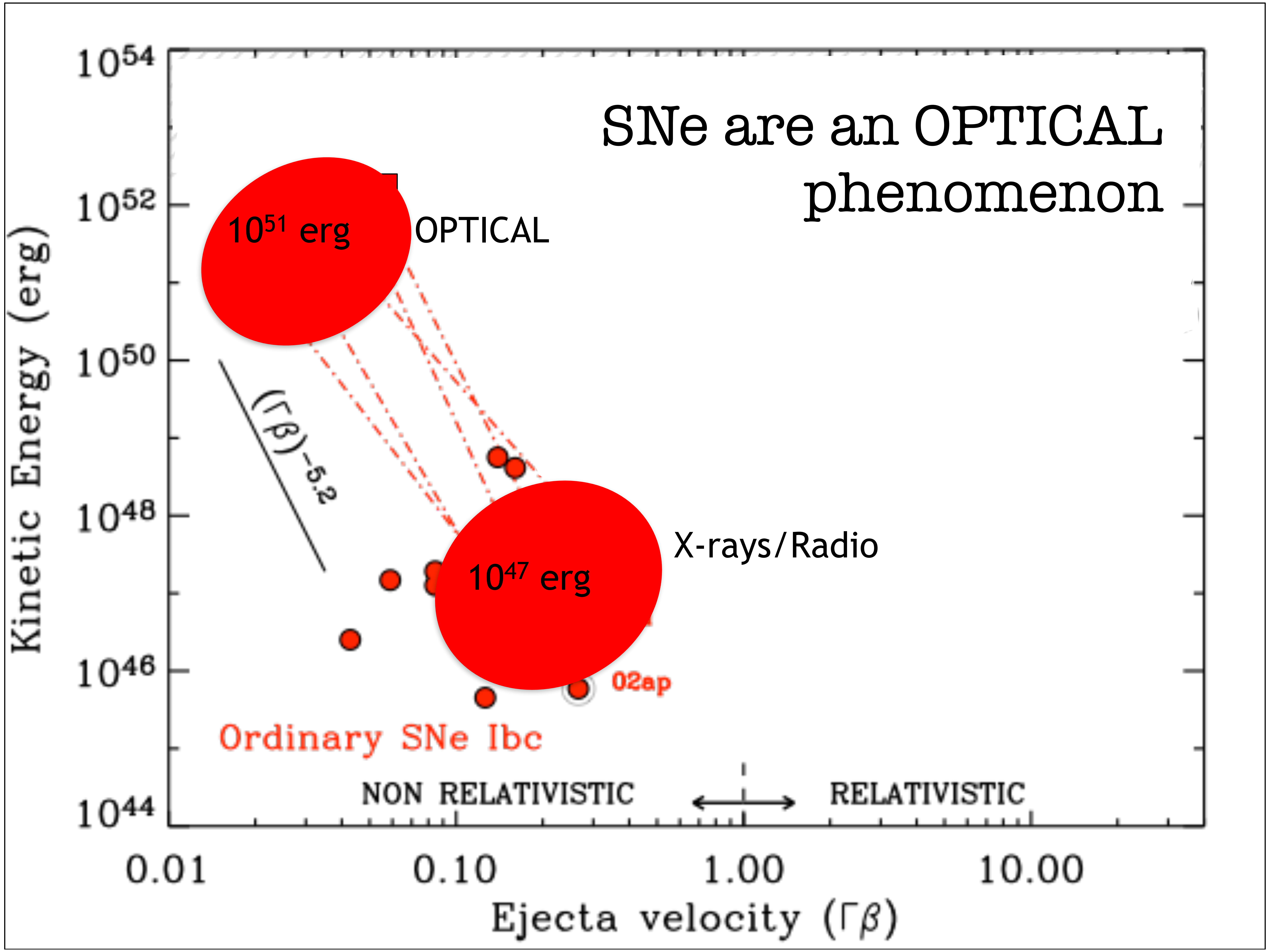
- Engine-Driven SNe / GRBs
- Strongly Interacting SNe
- SuperLuminous SNe



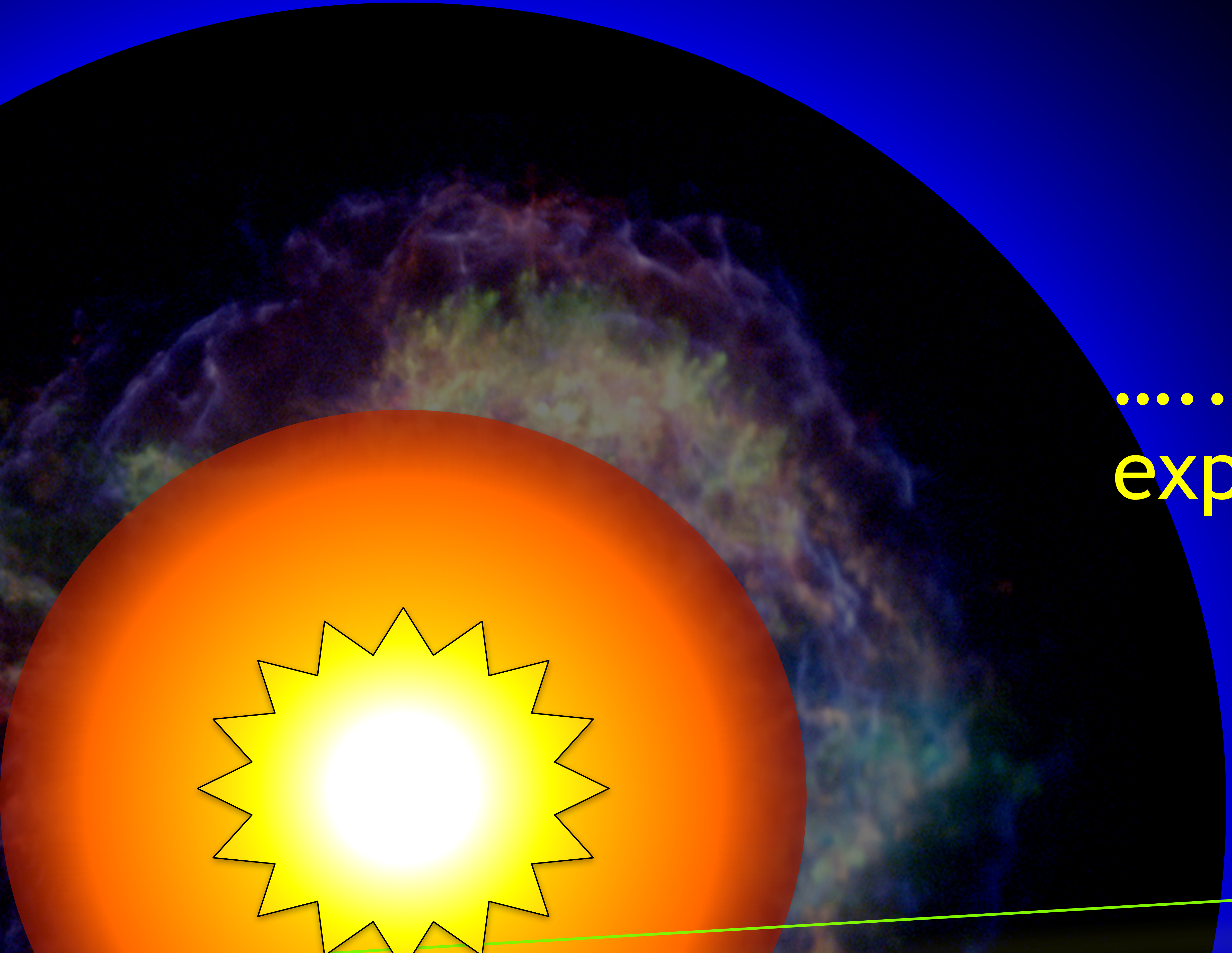
Context Matters

Energy partitioning



Margutti +13, +14; Kamble +13; Soderberg +06, +10

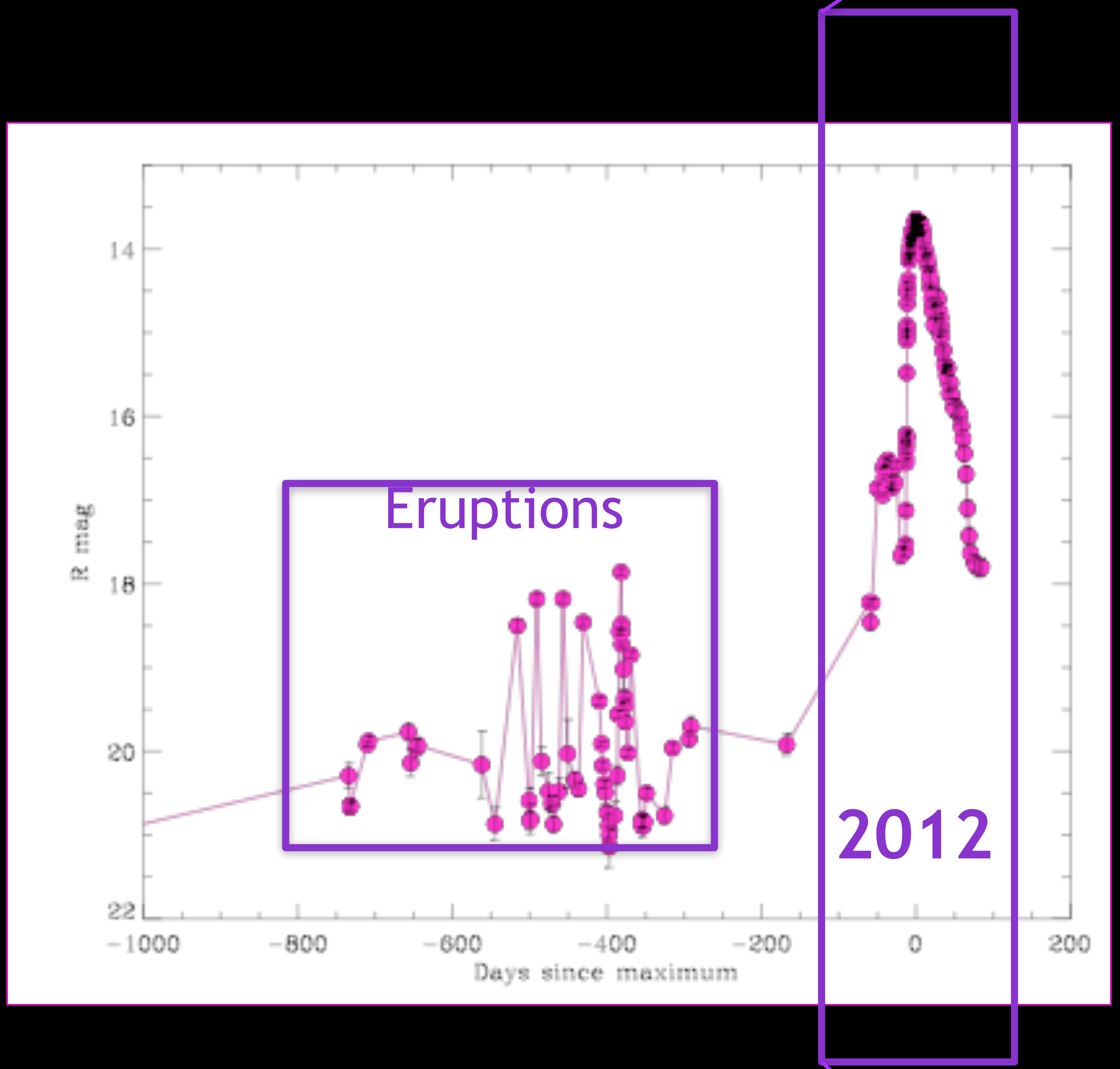
The restless SN2009ip

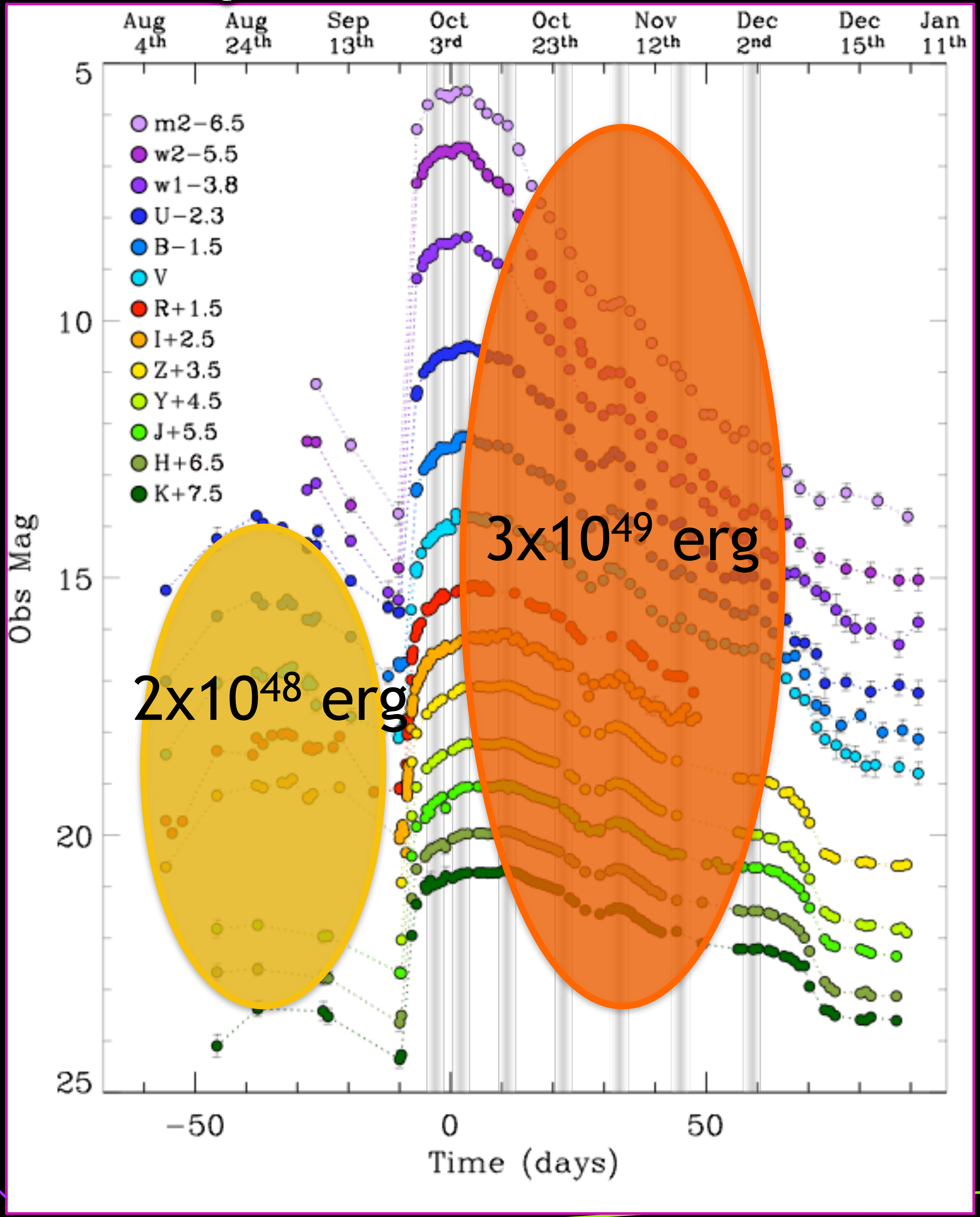


.....Once upon a time SNe exploded once....

★Distance of 24 Mpc
★In the outskirts of NGC7259
★Sub-solar metallicity environment 0.4<Z<0.9 Zsun
HST/WFPC2
F606W
1999
5 kpc
NGC 7259
N
15"
1.75 kpc
Discovery
~~Supernova~~
Outburst
Outburst
Supernova Impostor
Explosion1
Supernova
Aug 2009
Jul 2010
Sep 2010
May 2011
Oct 2011
Aug 2012
Sep 2012
Now

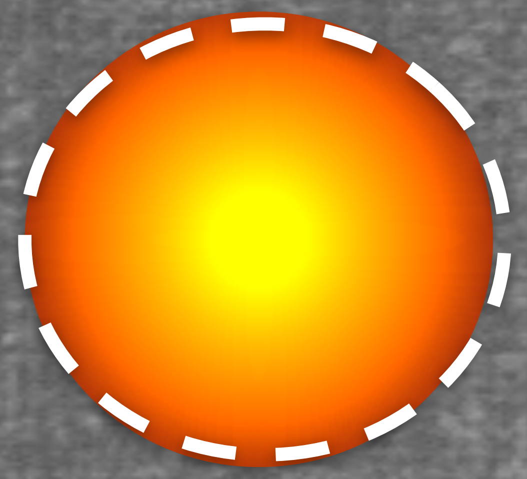
UV-Optical-NIR Light-curve





Margutti+ 2014

Expected Evolution from Stellar tracks:



Supergiant

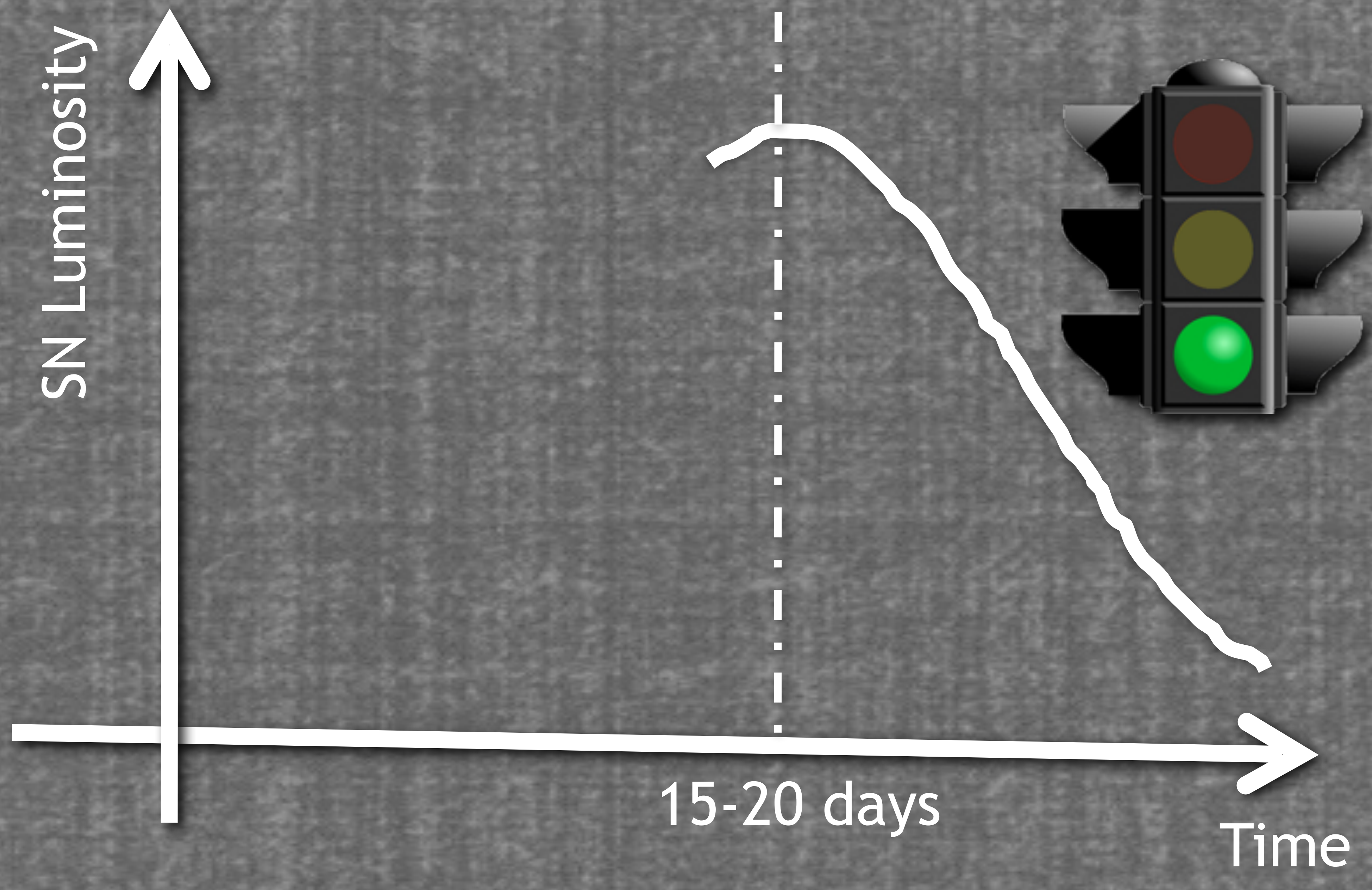
Luminous Blue Variable

(Eruptions)

Wolf-Rayet

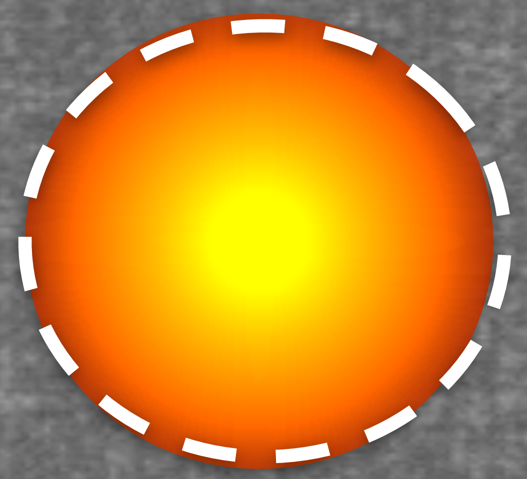
~10^4-10^5 yrs

SN Explosion

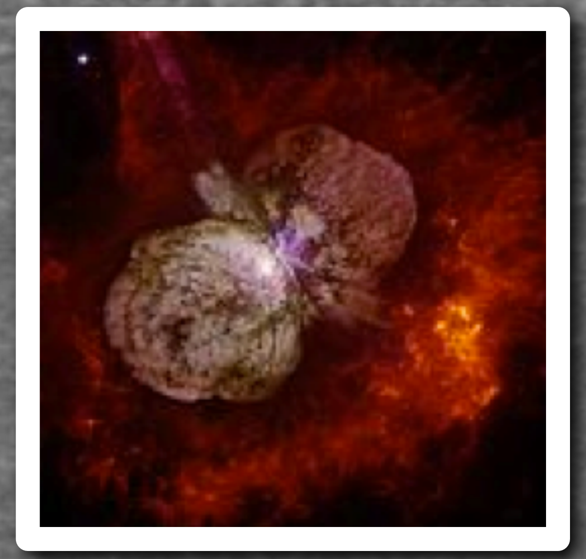


MASS LOSS– Massive Stars

A new channel of Explosive Mass Loss in evolved massive stars



Supergiant



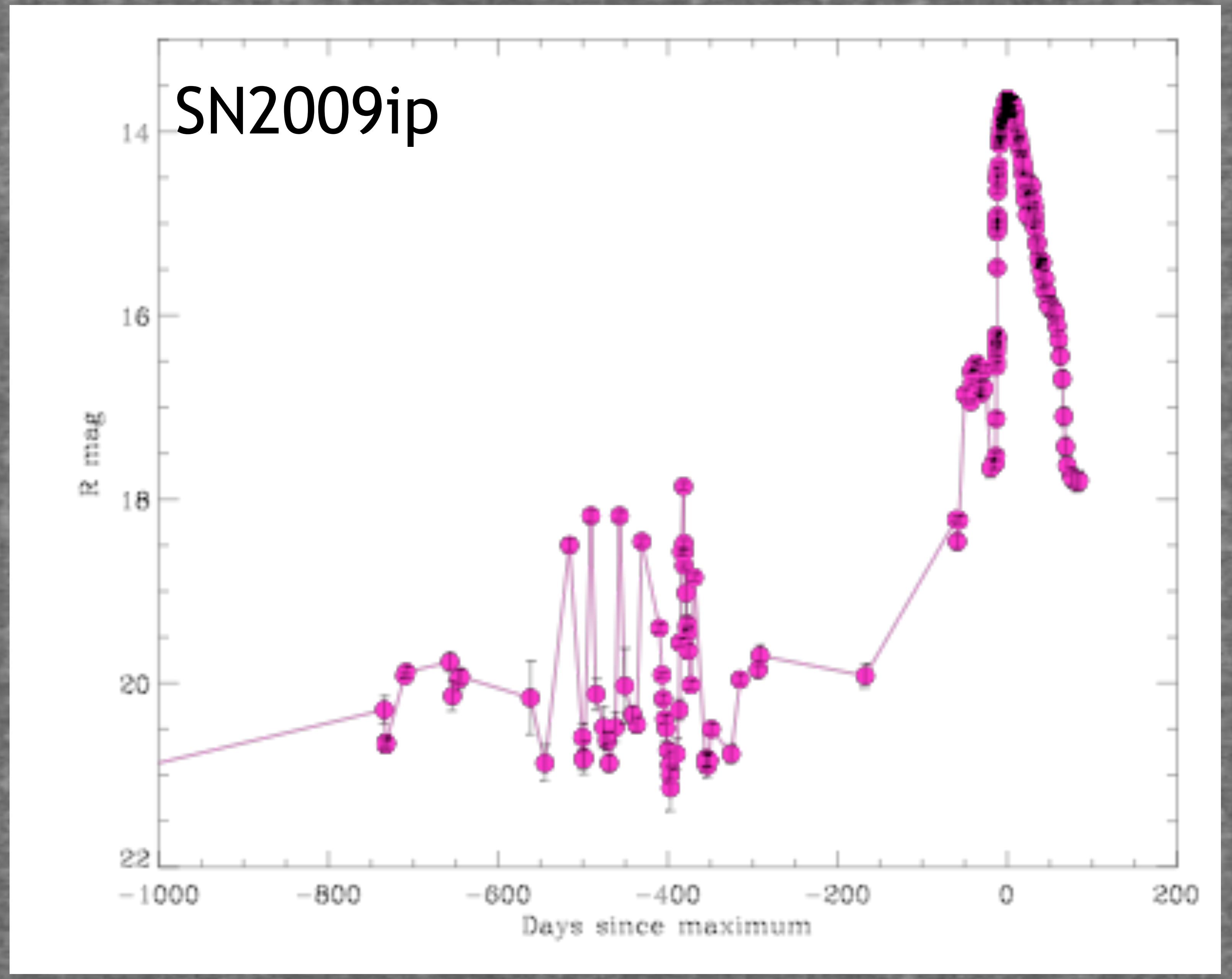
Luminous Blue Variable
(Eruptions)

Wolf-Rayet
~10^4-10^5 yrs

SN Explosion

SN2009ip

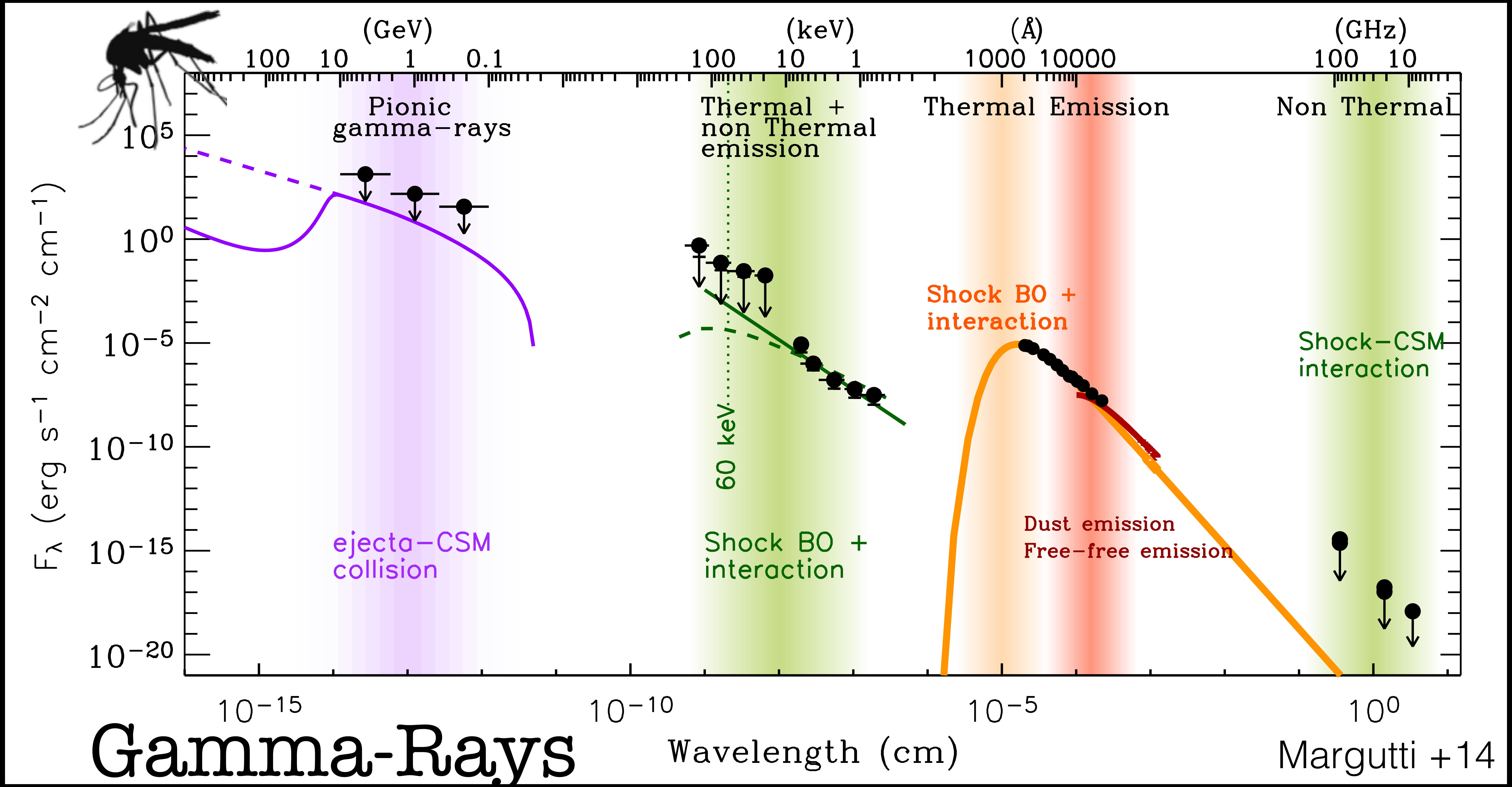
Margutti Astronomy Magazine

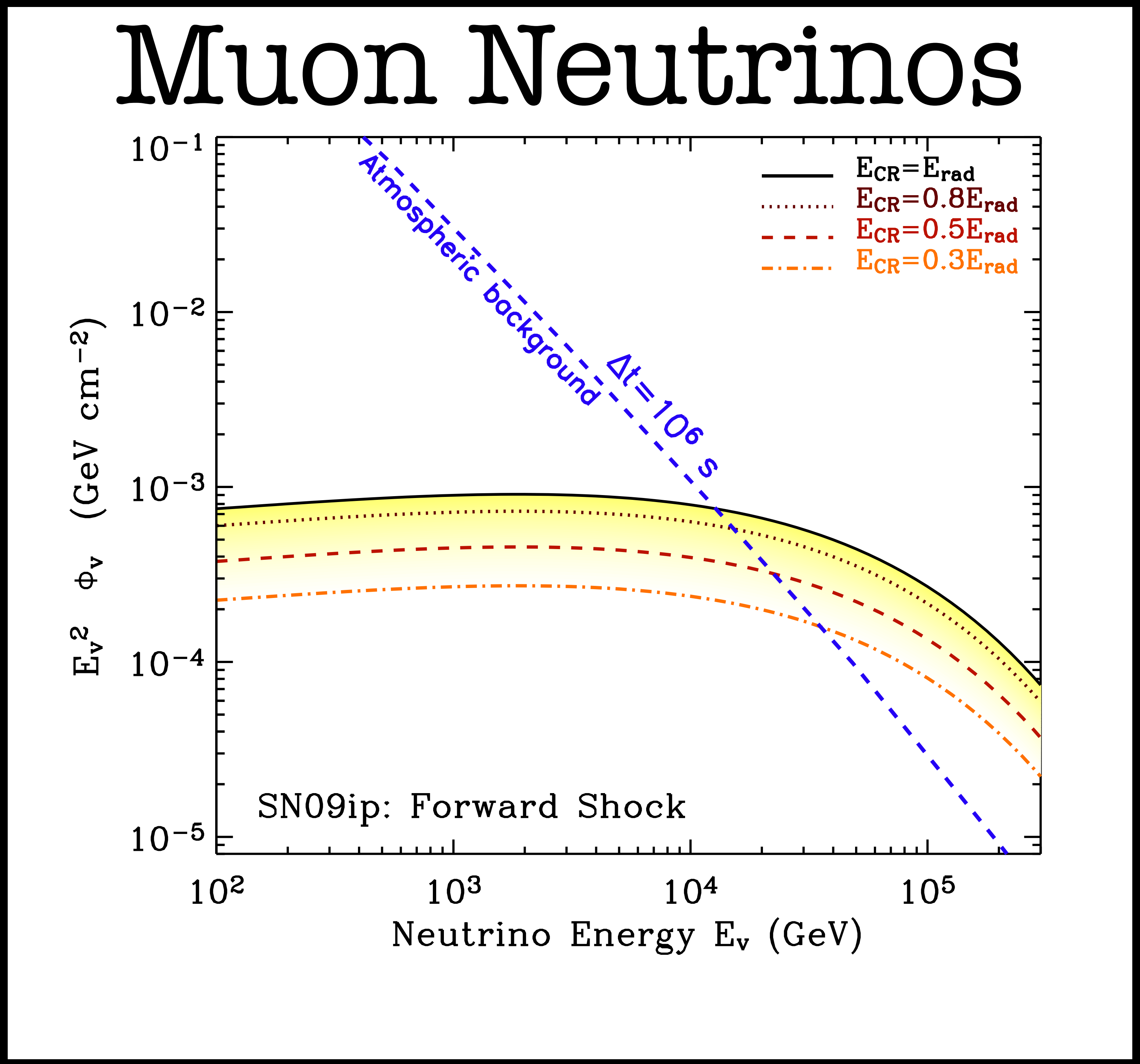


Margutti +14

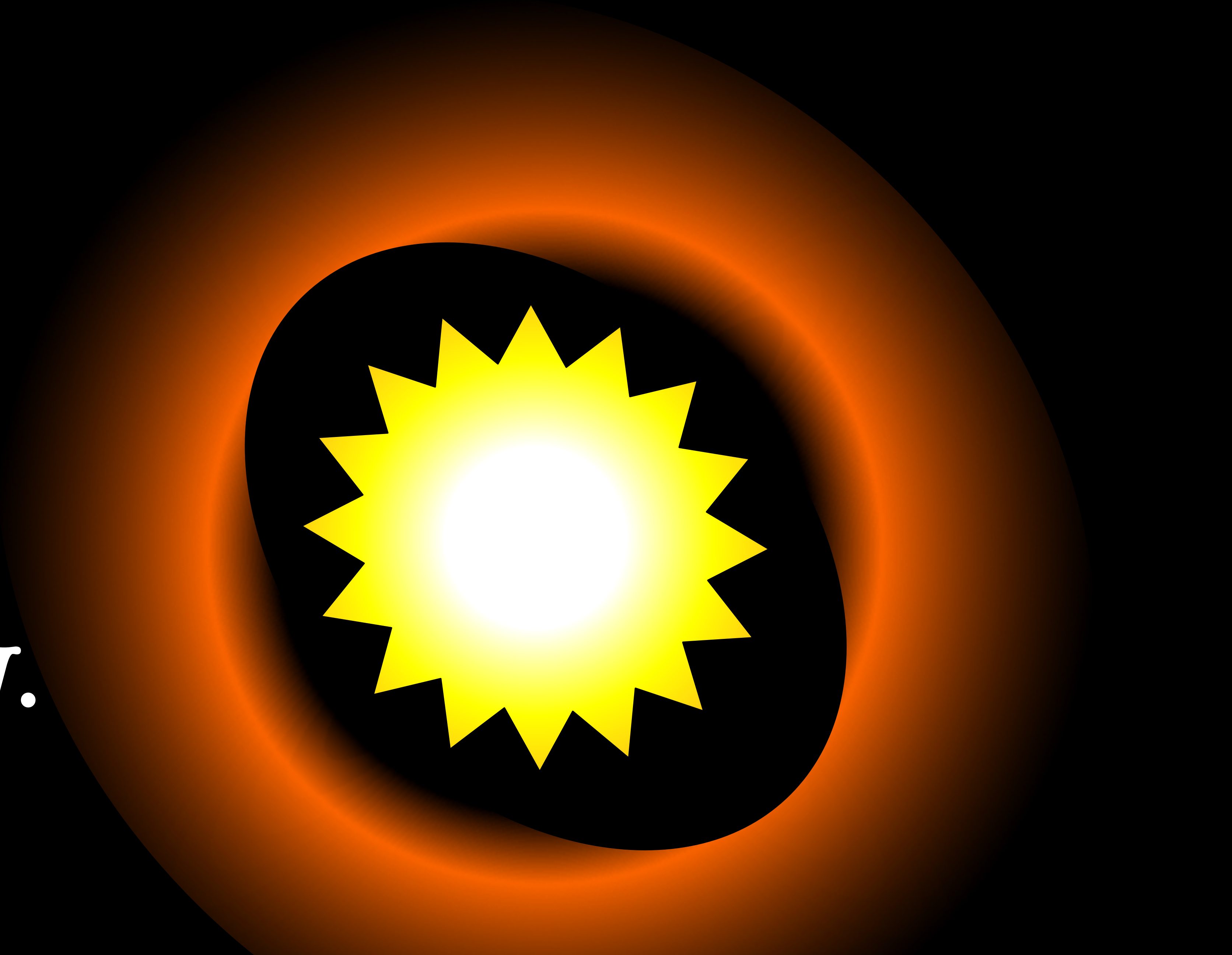
"It sort of makes you stop and think, doesn't it."

Broad-band SED of SN2009ip at peak

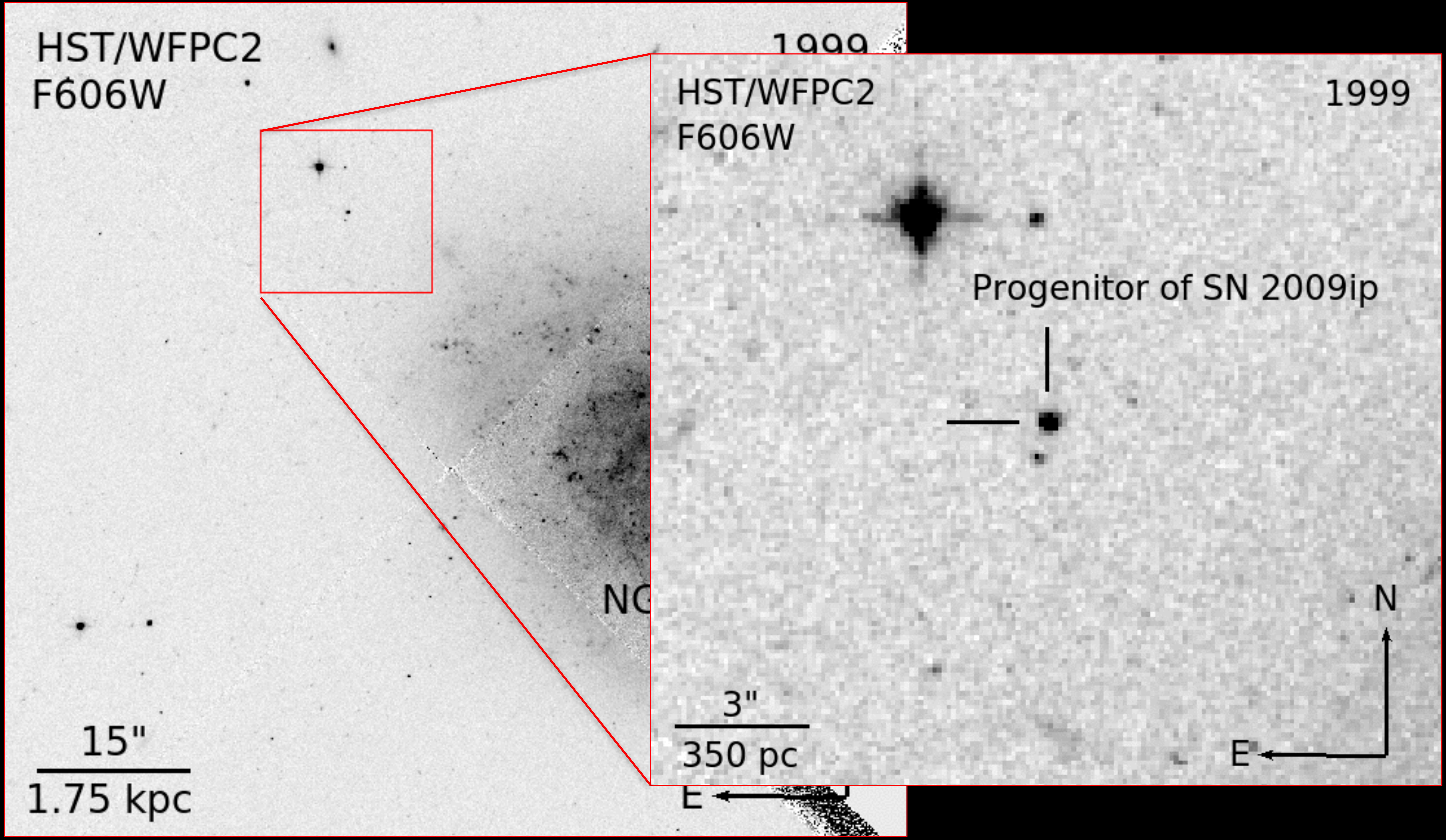




SN shock strong interaction w. medium



See Murase+ 2011



Massive star: M> 60 Msun

Smith et al, 2010; Foley et al., 2011

Developing STRONG interaction….

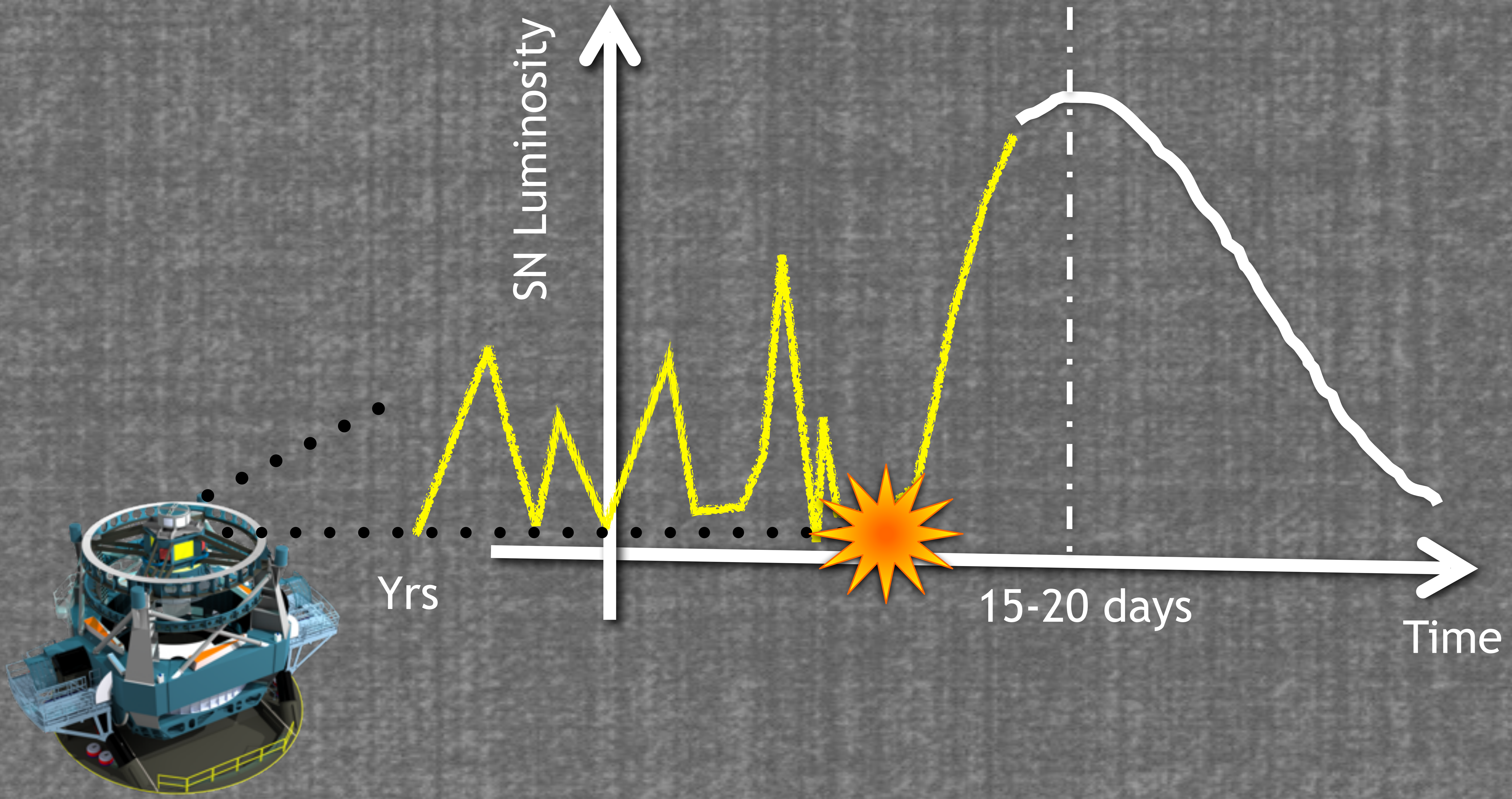
…in real-time…

Enhanced and Episodic Mass-Loss

Direct Observations

Flash Spectroscopy

Shock Interaction



Enhanced and Episodic Mass-Loss

Direct Observations

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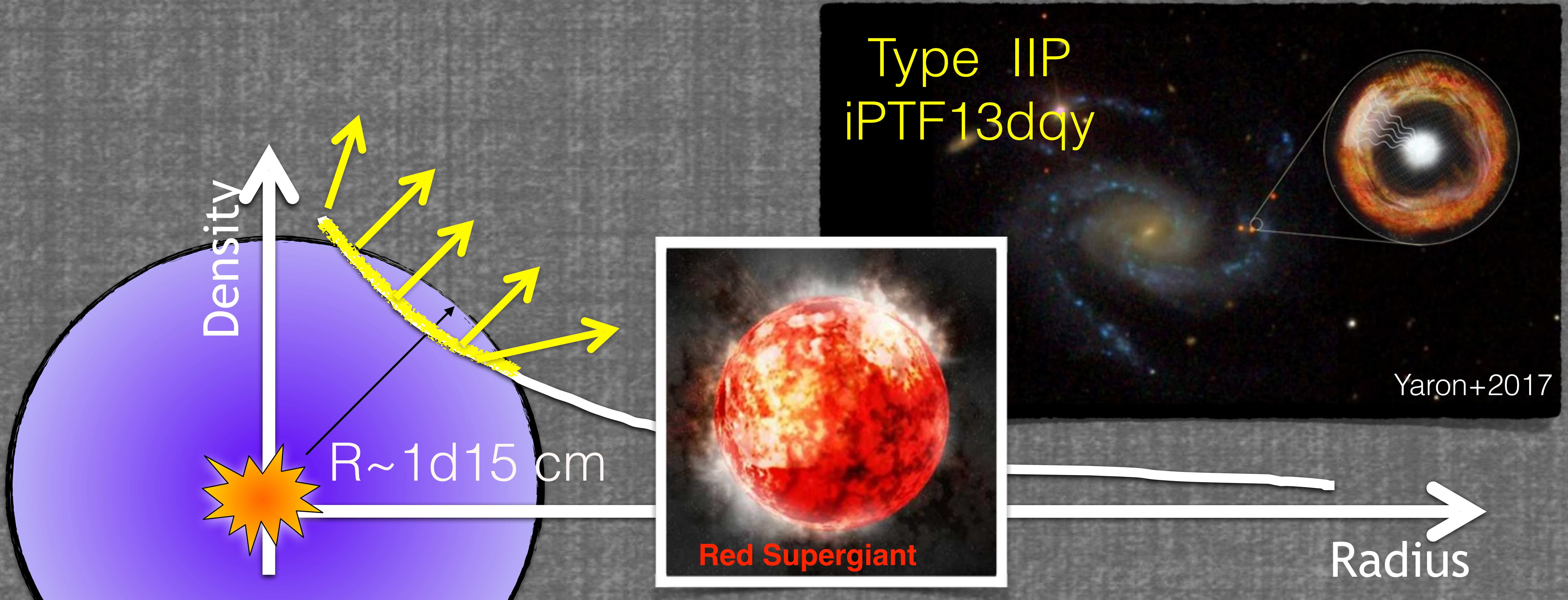

Enhanced and Episodic Mass-Loss

Direct Observations

Flash Spectroscopy

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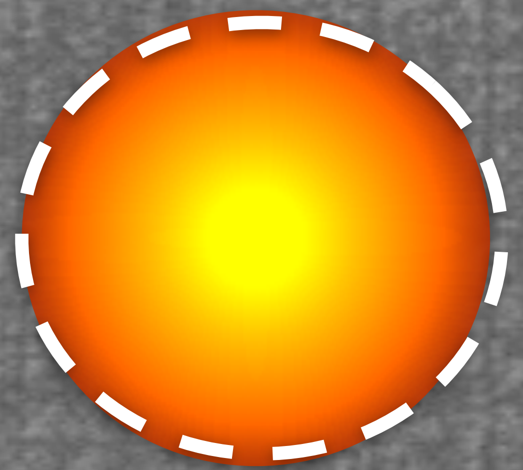


Supergiant

Wolf-Rayet

~10^4-10^5 yrs

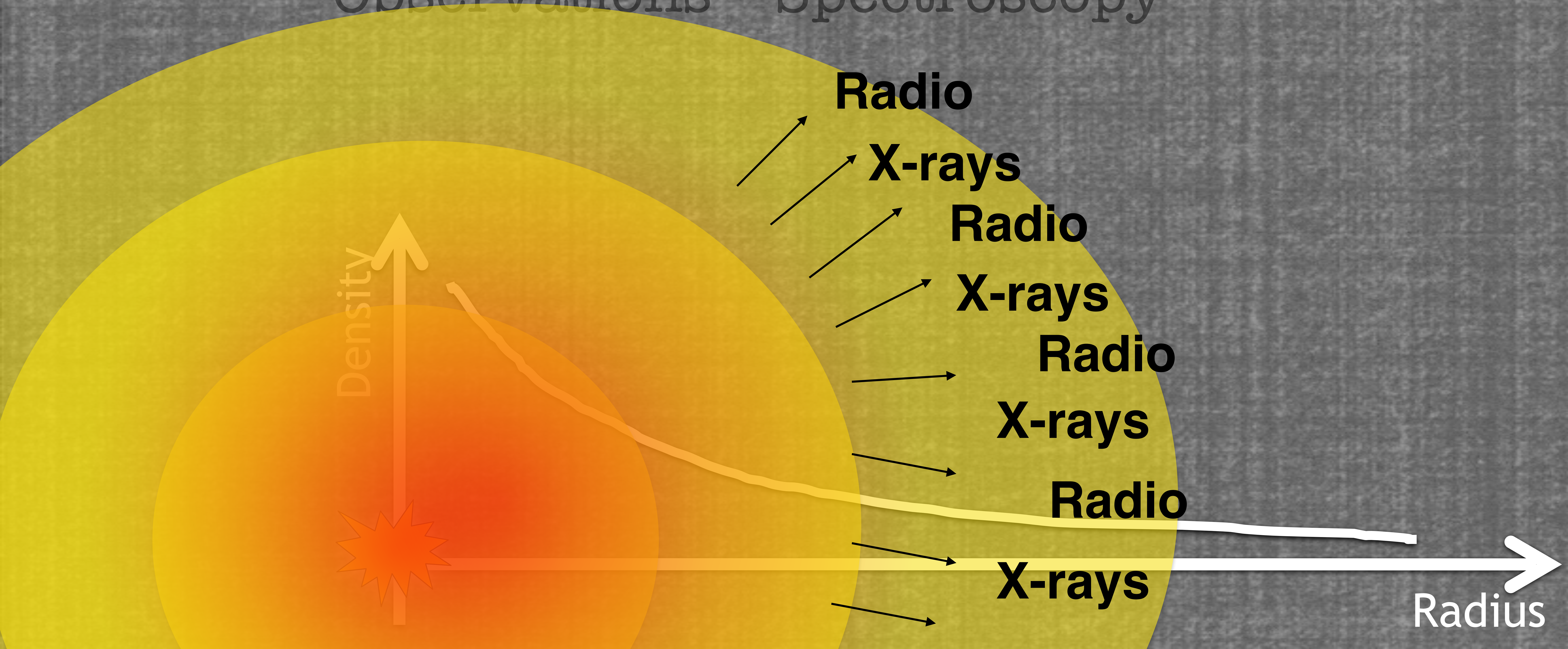
SN Explosion

Enhanced and Episodic Mass-Loss

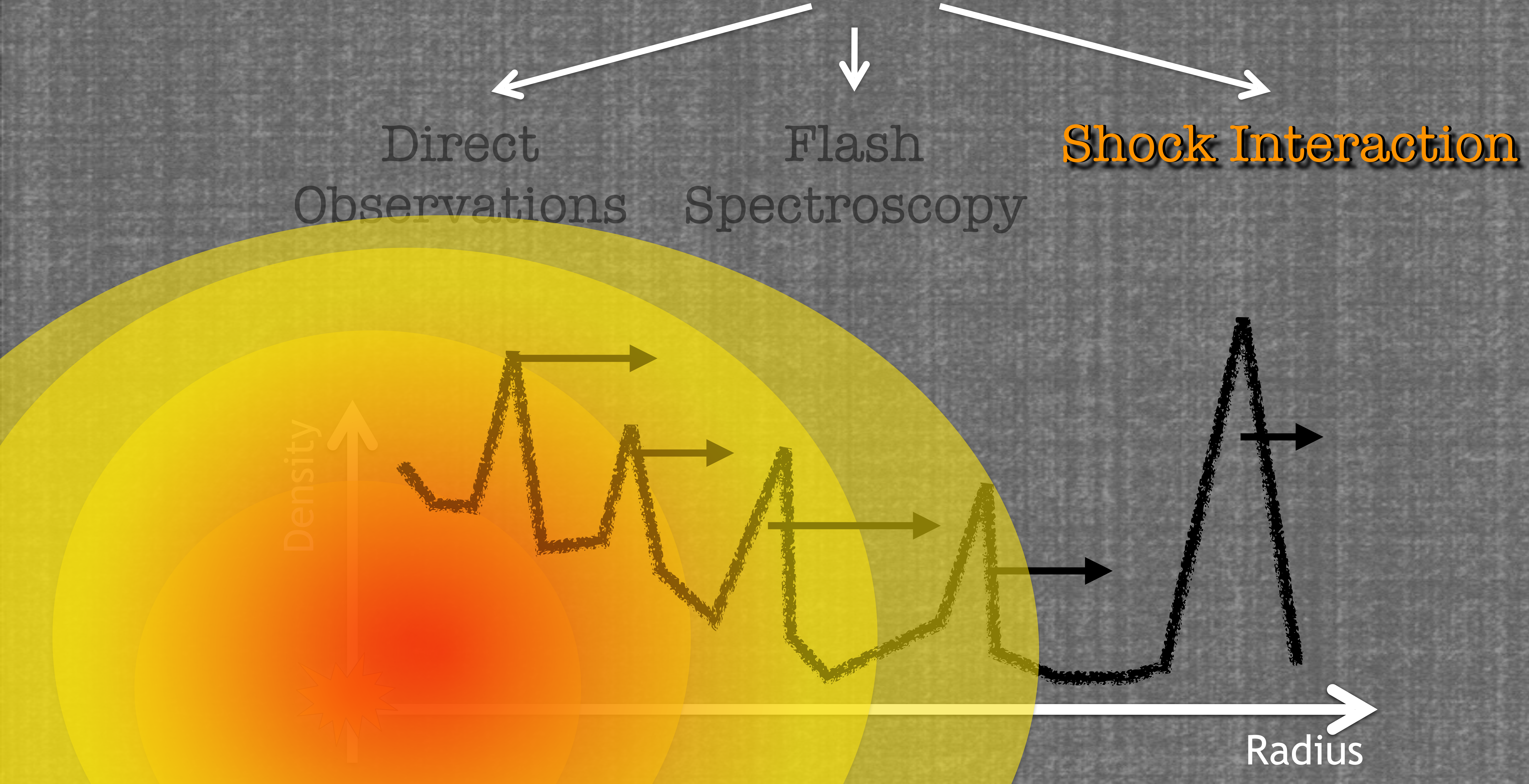
Direct Observations

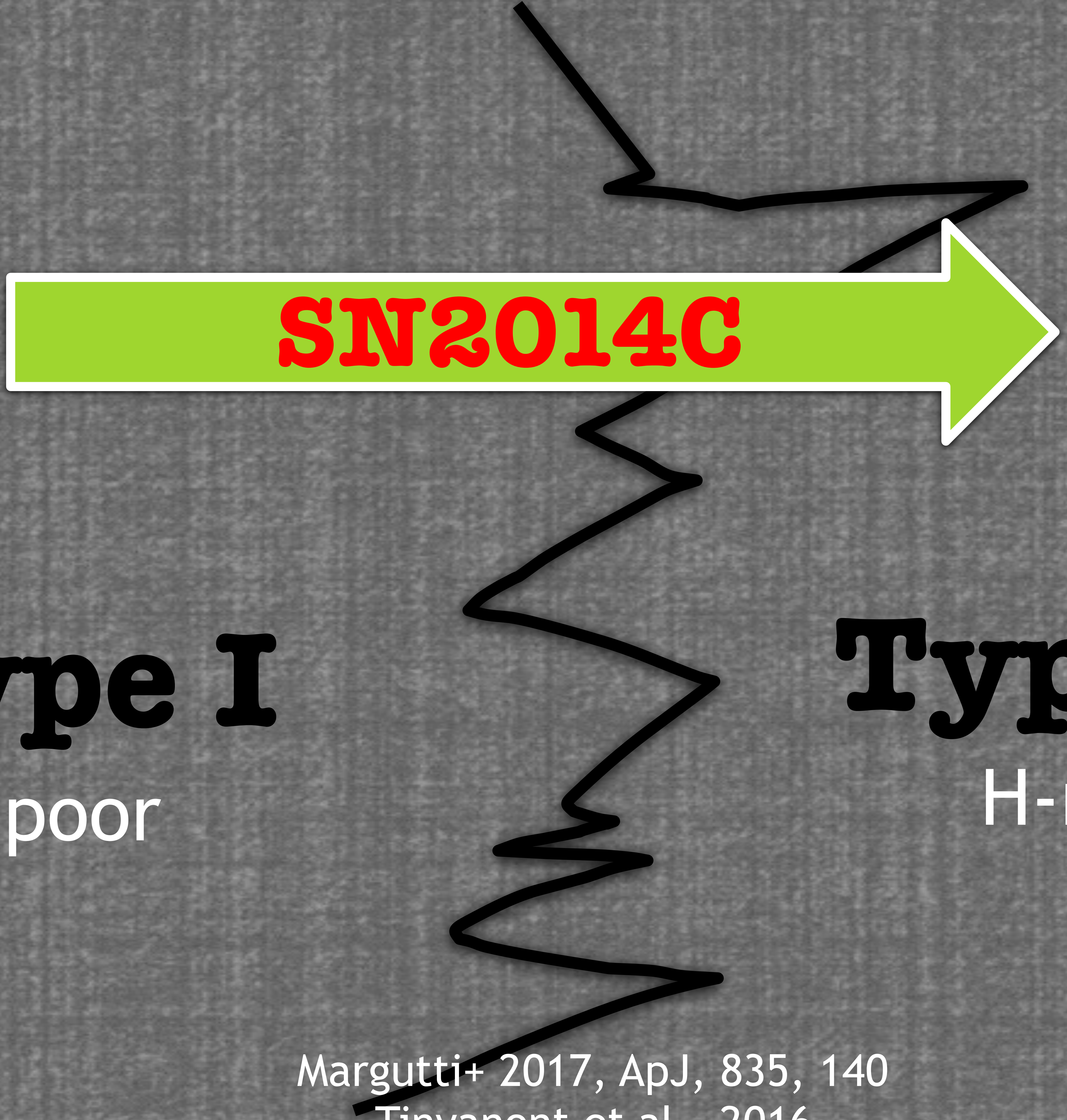
Flash Spectroscopy

Shock Interaction



Enhanced and Episodic Mass-Loss





Type I

H-poor

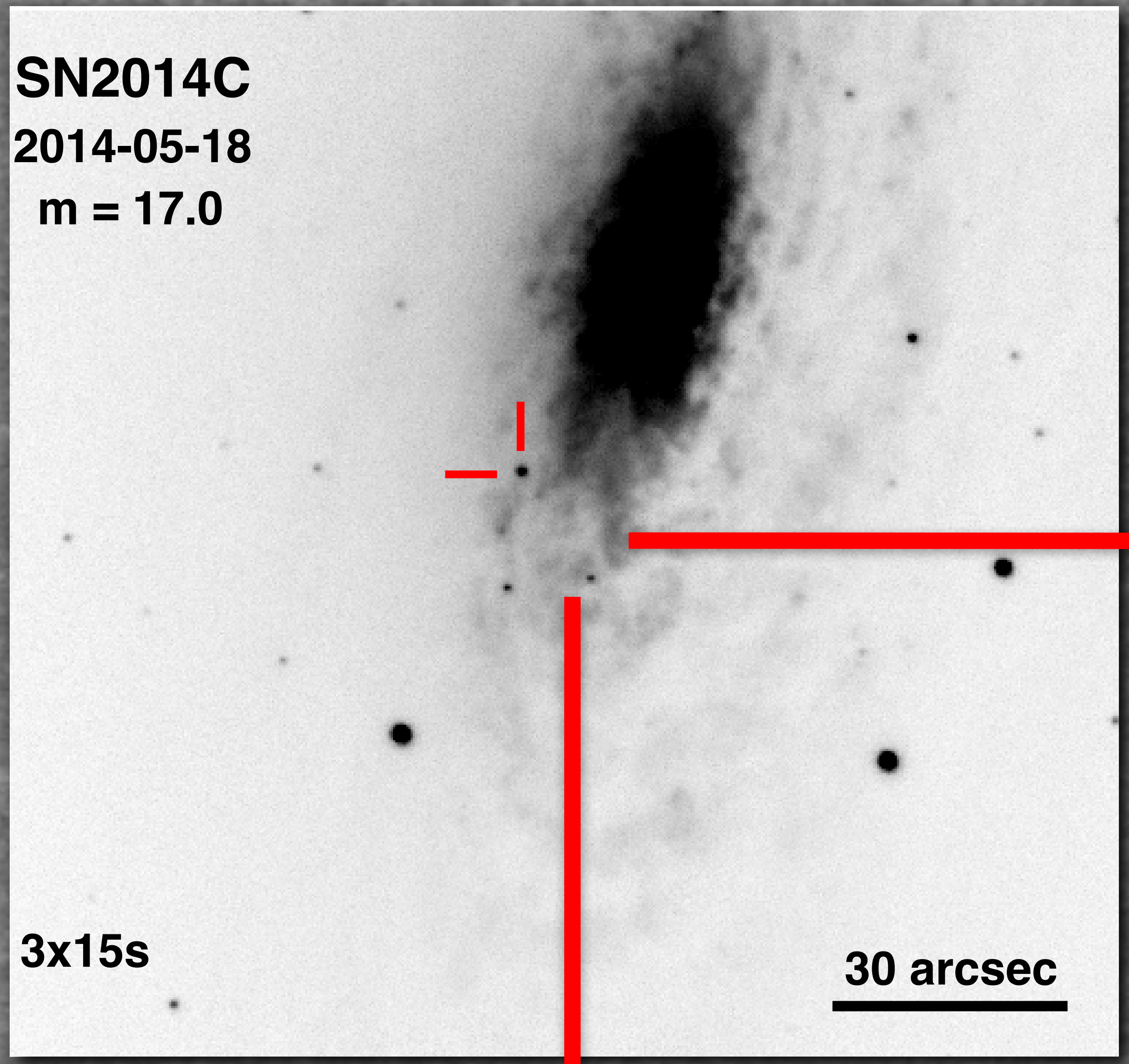
Type II

H-rich

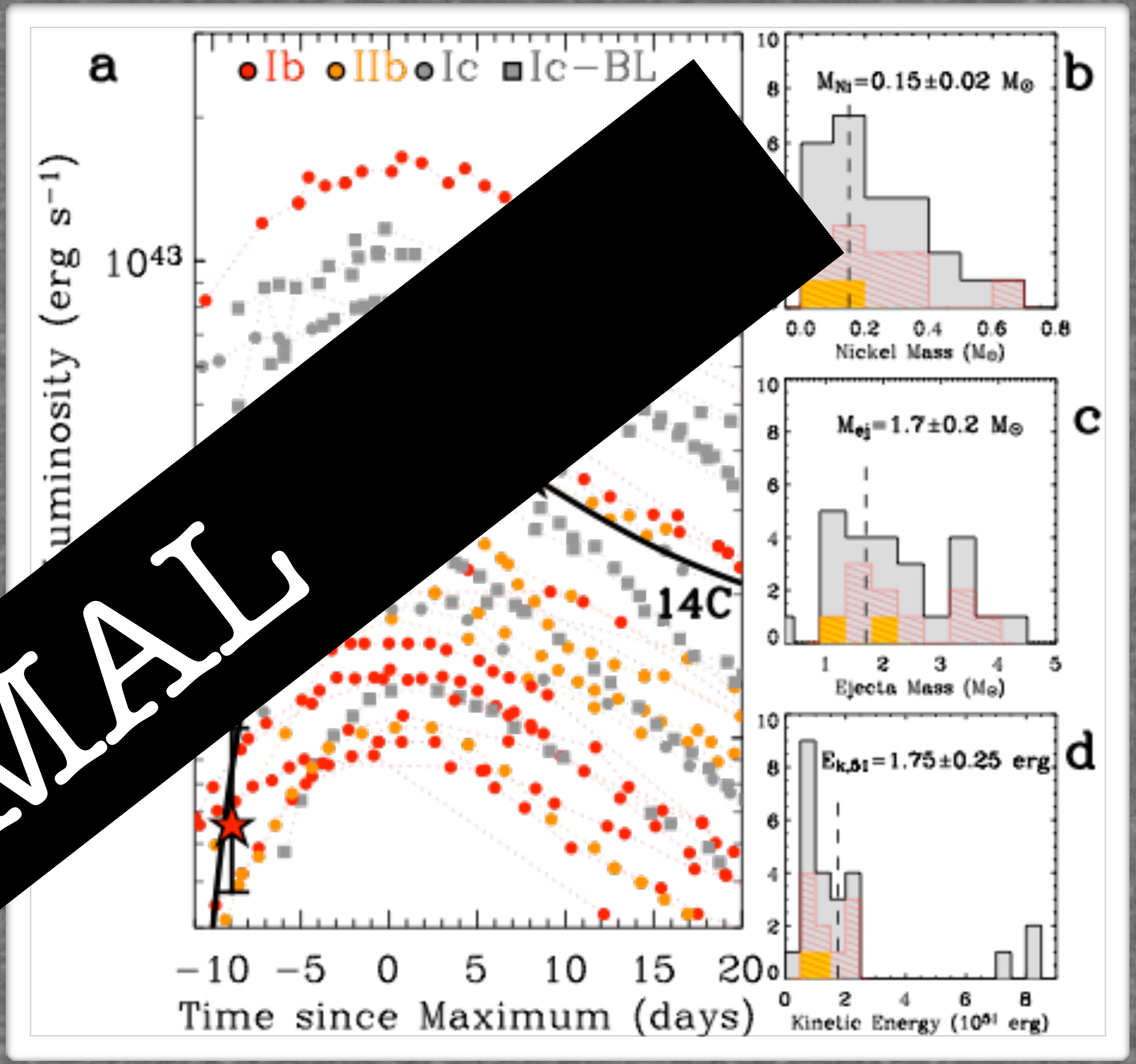
Margutti+ 2017, ApJ, 835, 140
Tinyanont et al., 2016
Anderson et al., 2016
Milisavlejvic, RM et al., 2015, ApJ, 815, 120

SN2014C: a normal Ib SN

dist=15.7 Mpc



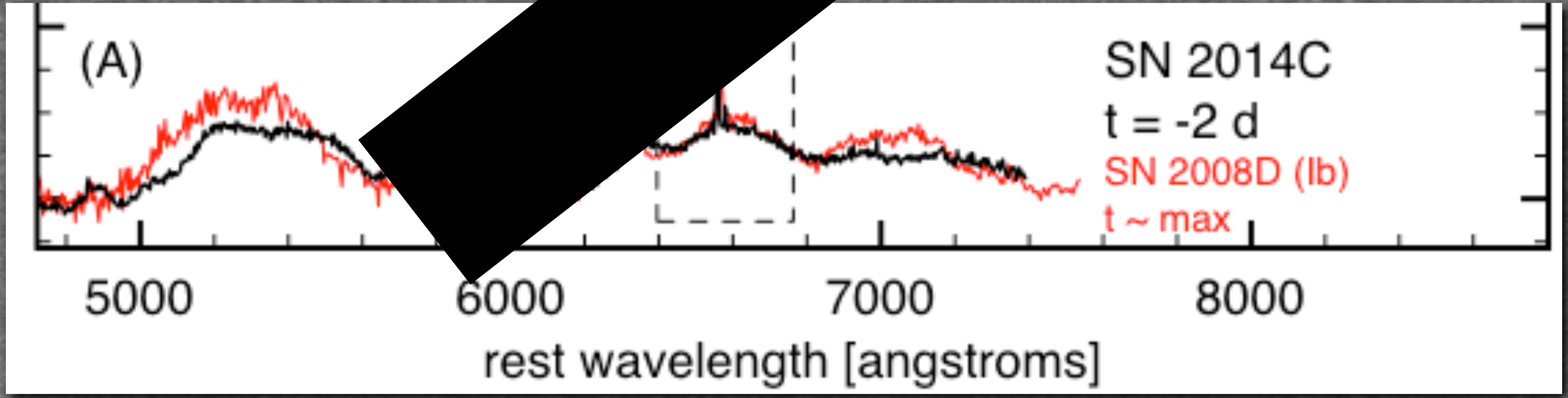
Bolometric Luminosity



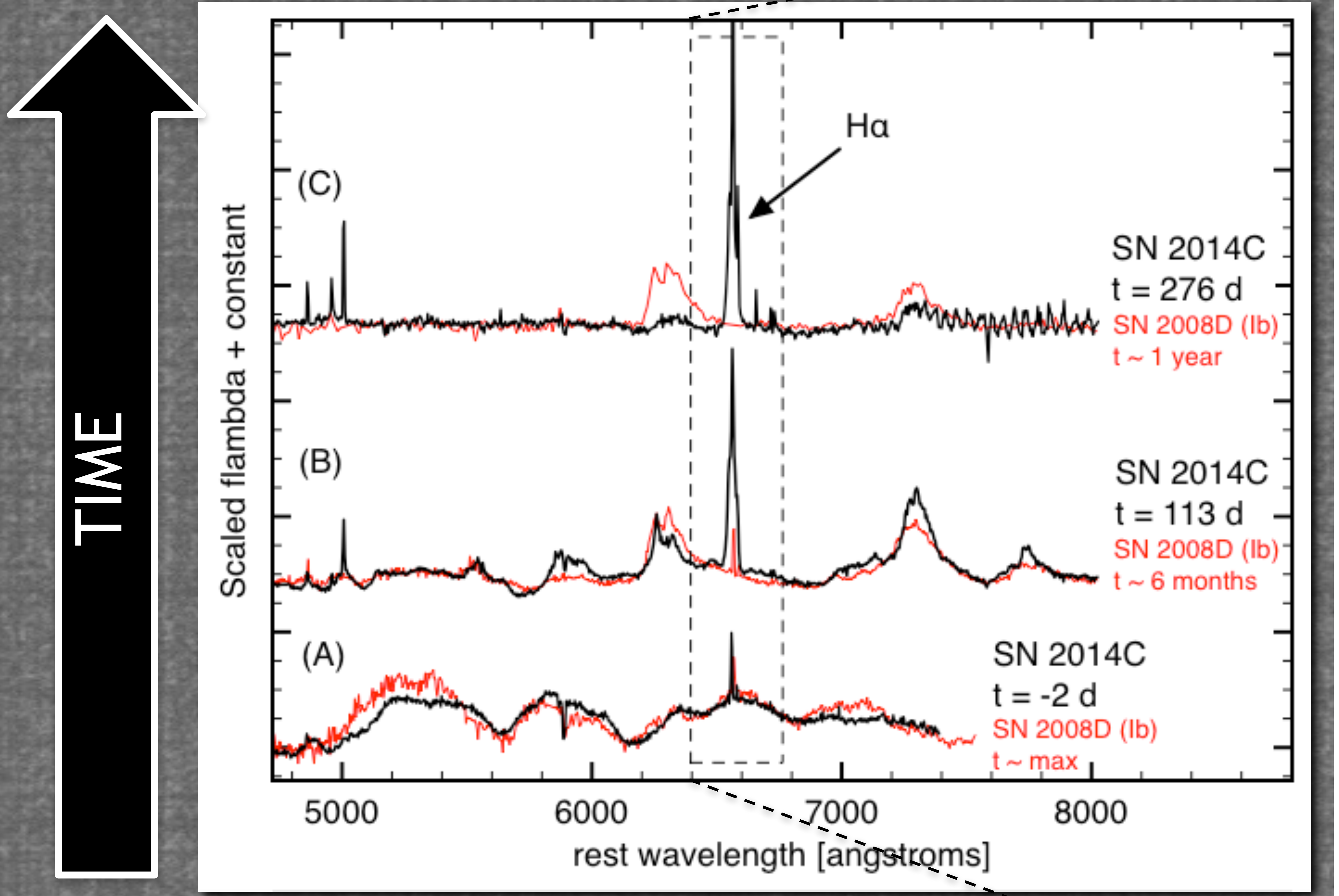
RM+16

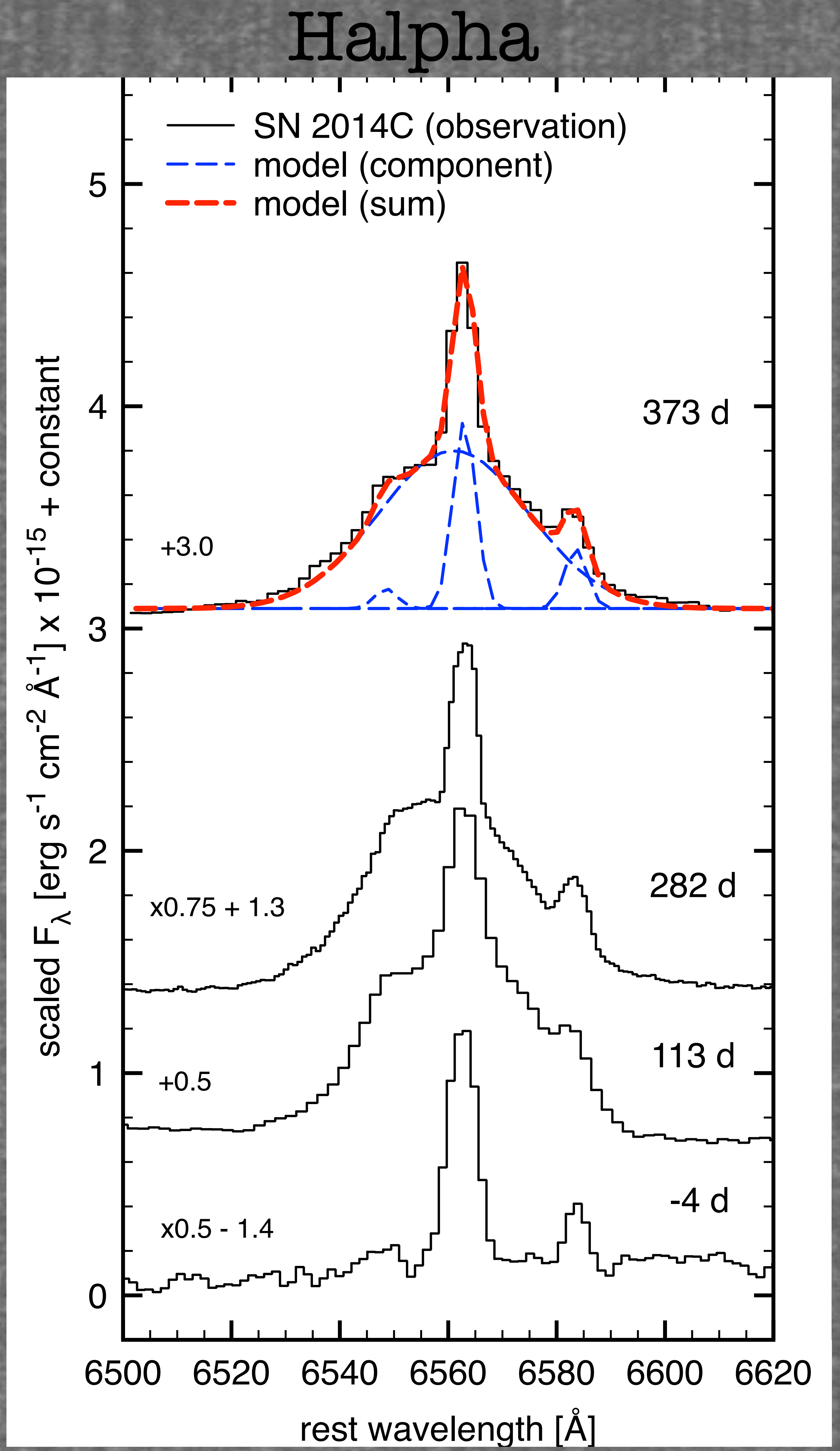
NORMAL

Optical Spectrum at



SN2014C-Optical

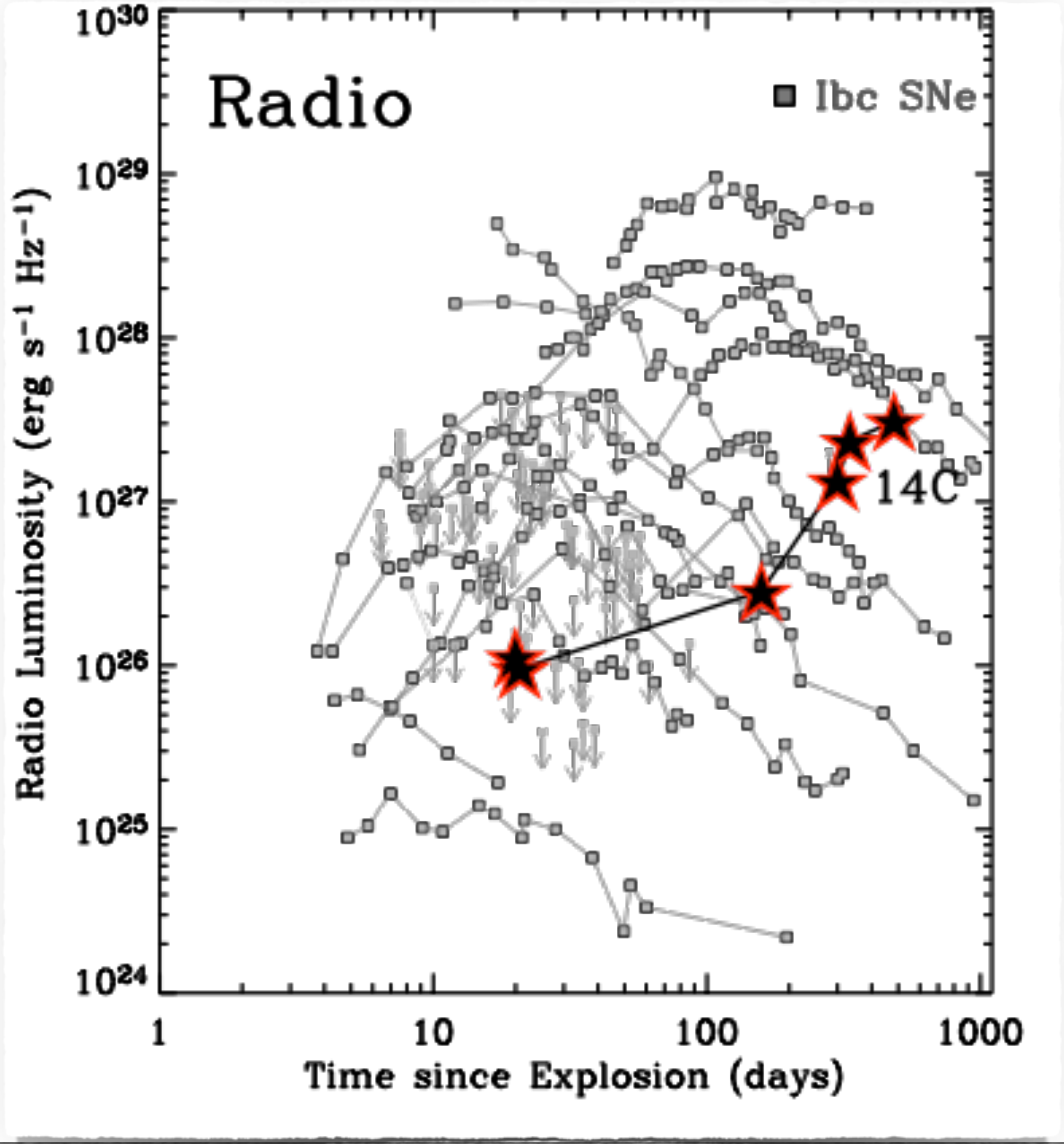




Milisavljevic, RM+16

Development of H-features with time

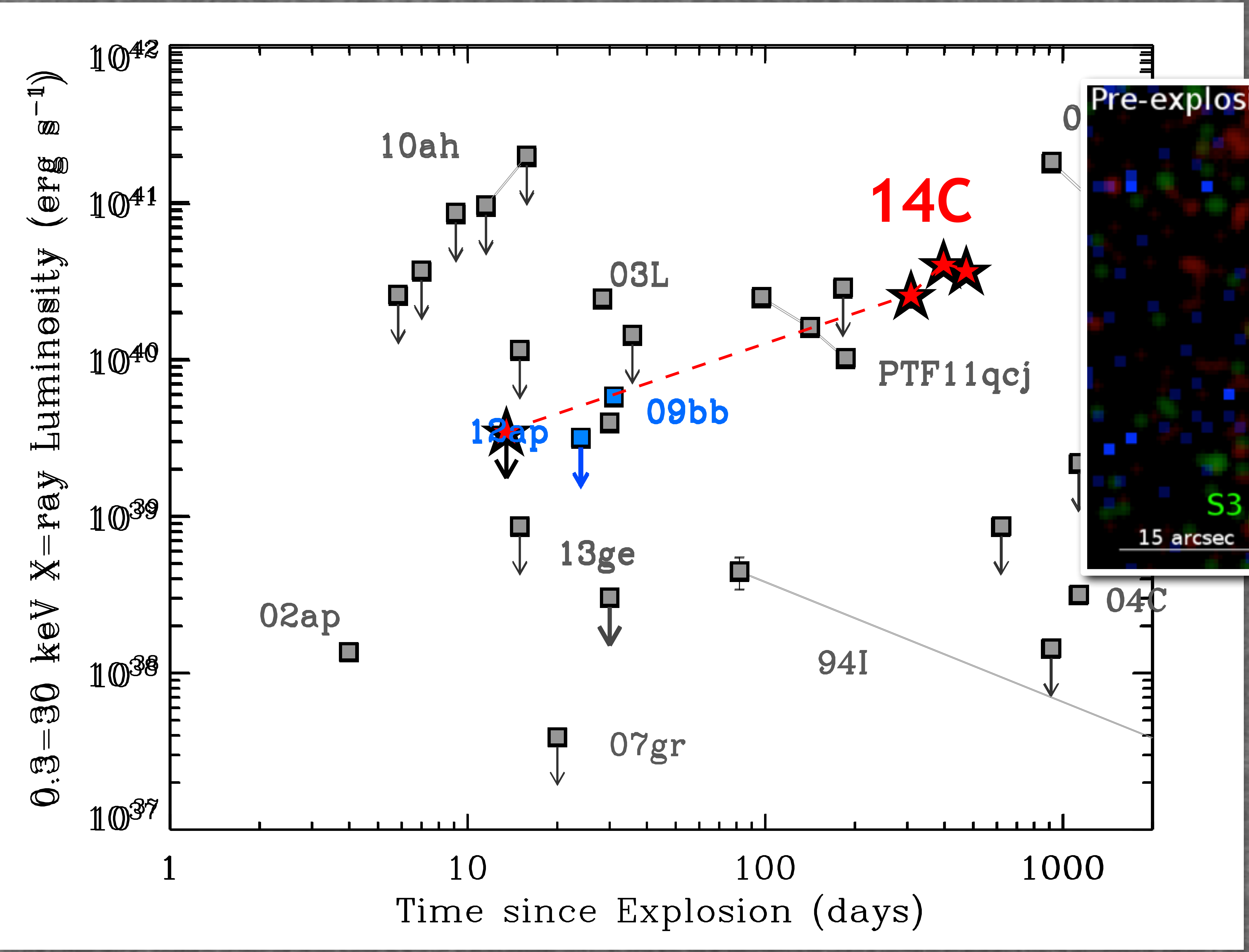
SN2014C-Radio

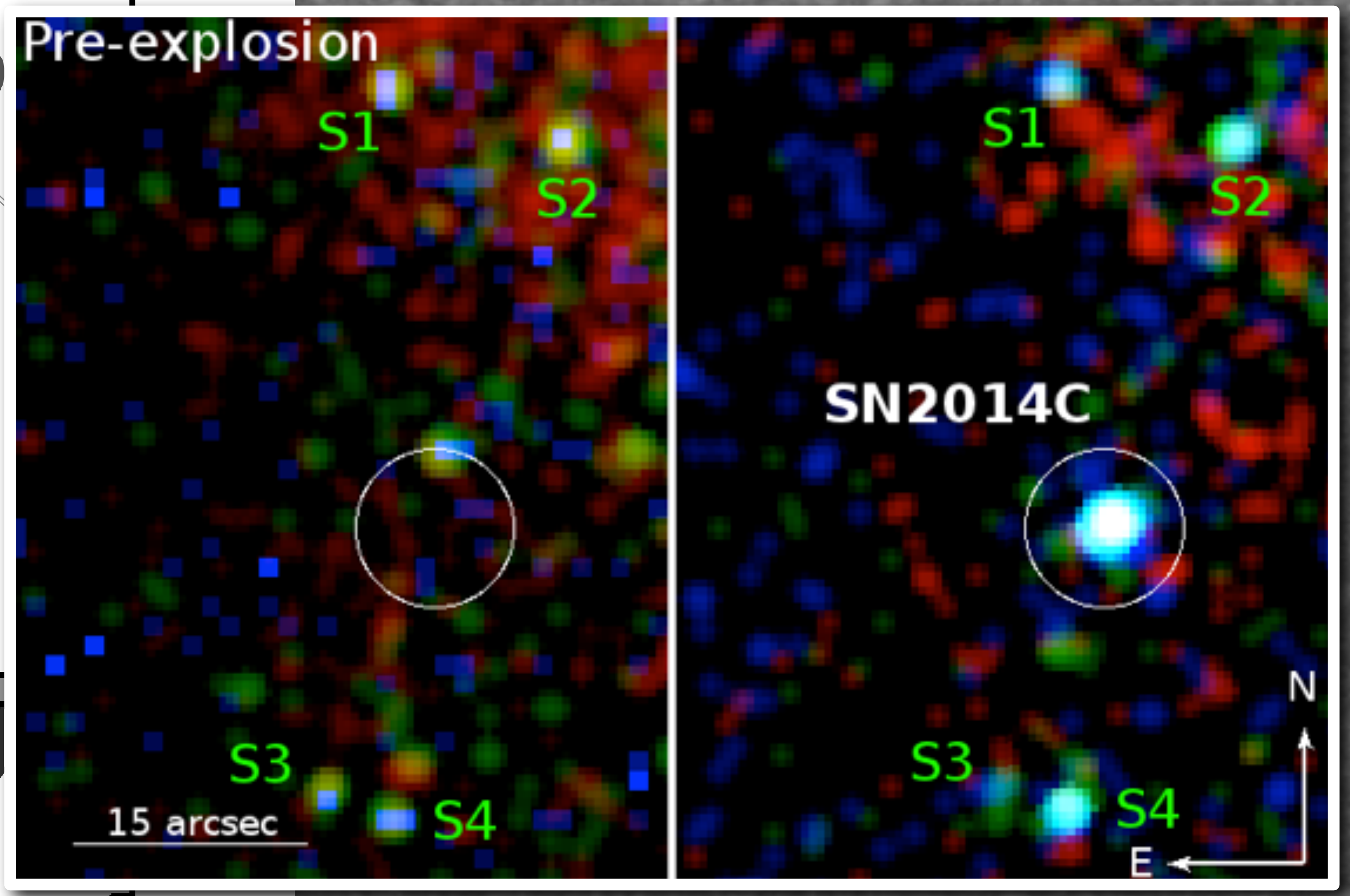


RM+16

Radio Luminosity INCREASES w. time!

SN2014C-X-rays (soft+hard)

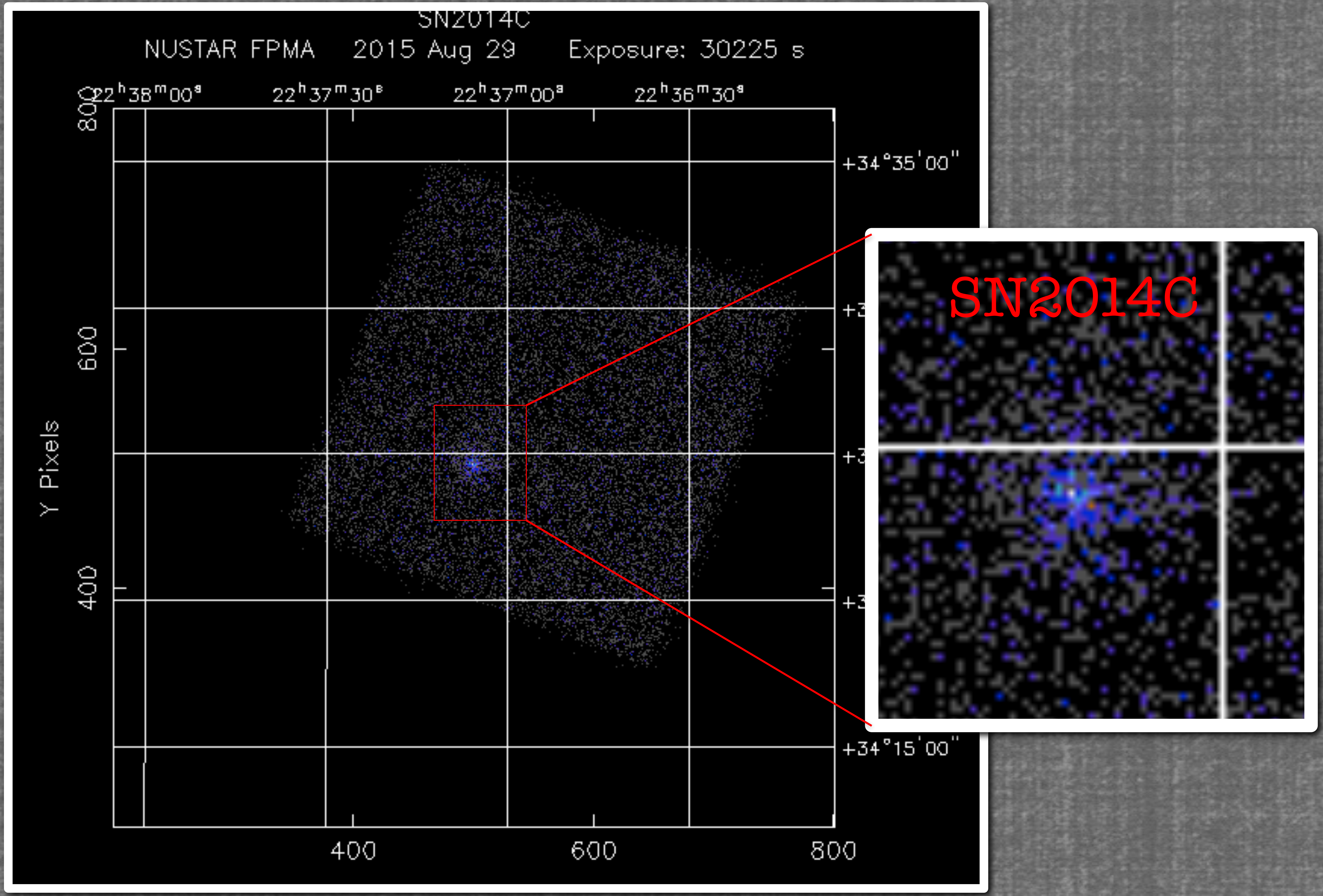




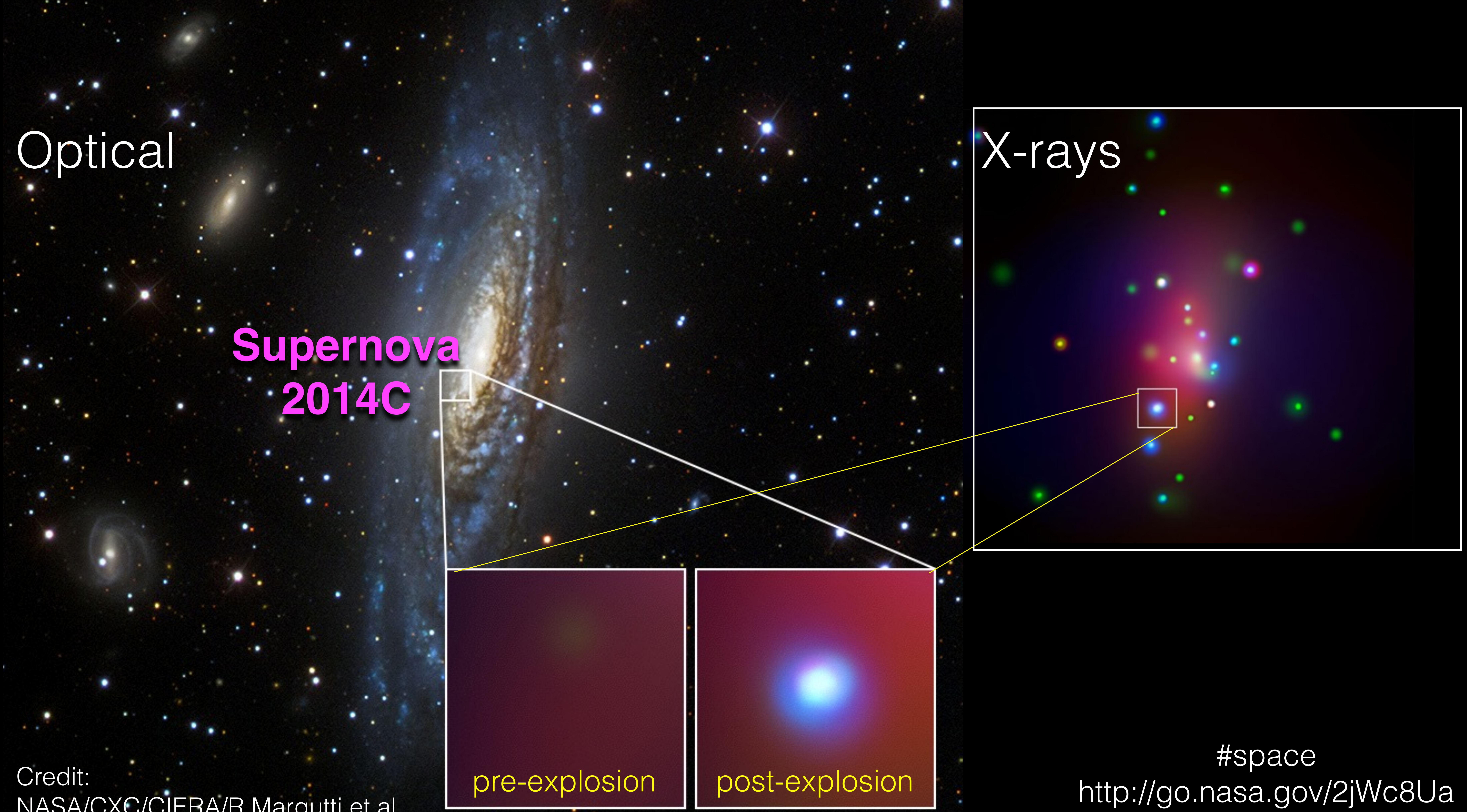
RM+16

Rising X-ray Luminosity!

NuSTAR (3-80 keV)

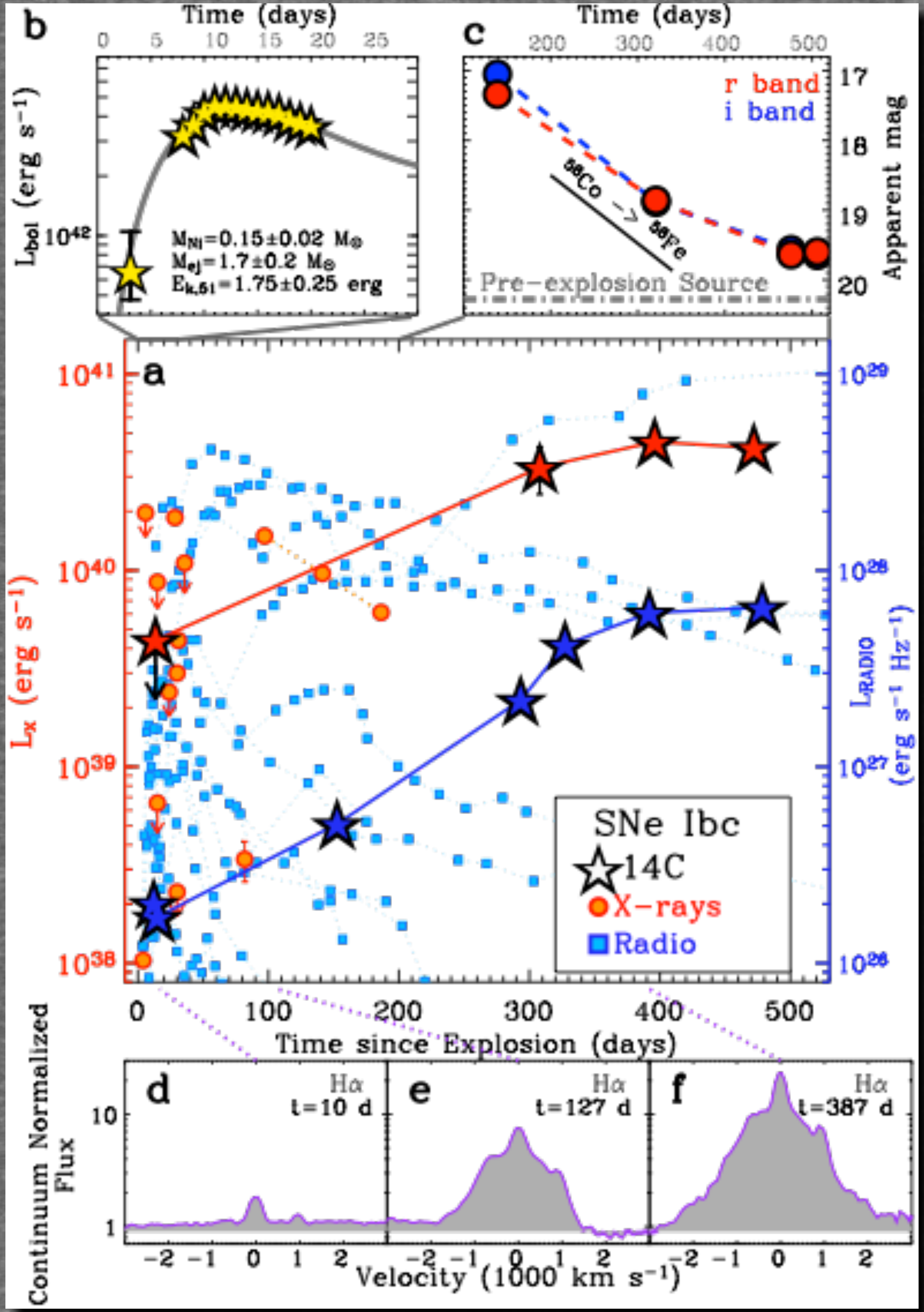


Exploding Star challenges decades-long understanding of how massive stars evolve and die



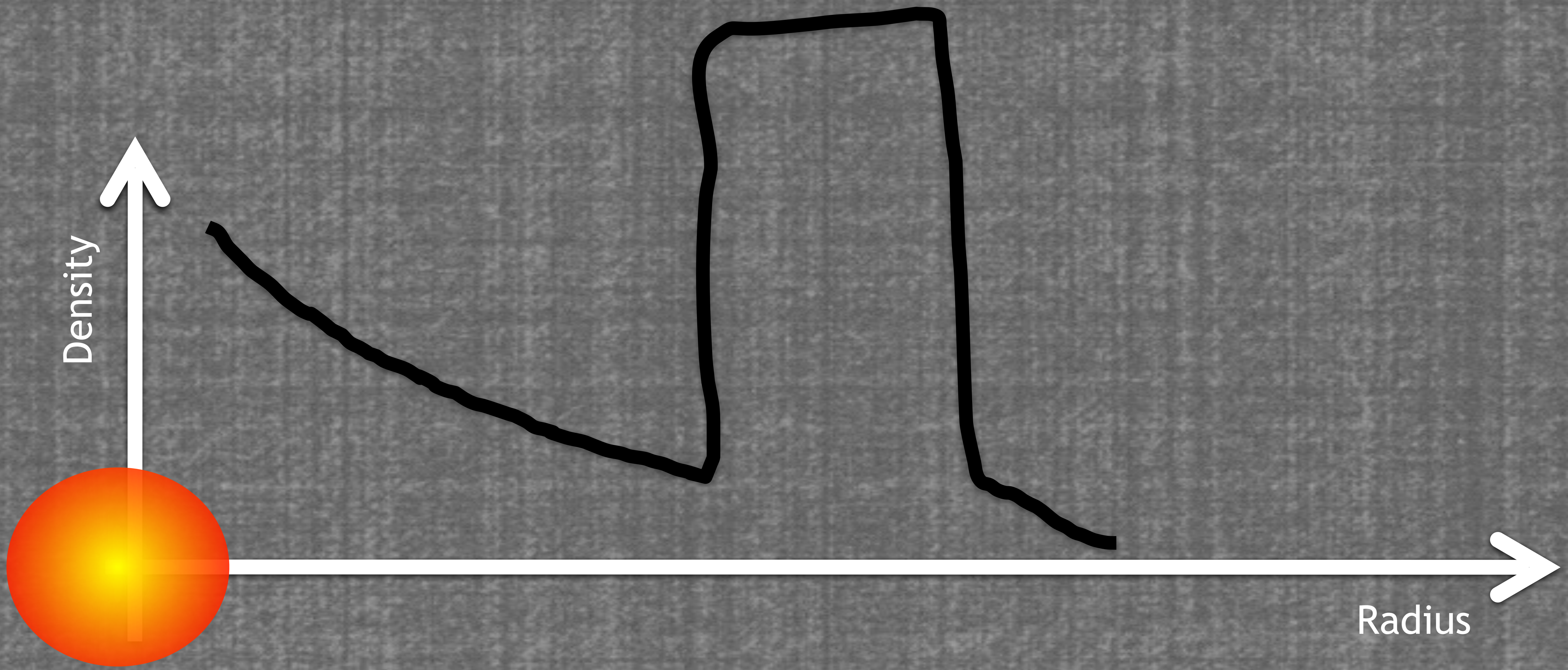
Credit:
NASA/CXC/CIERA/R.Margutti et al

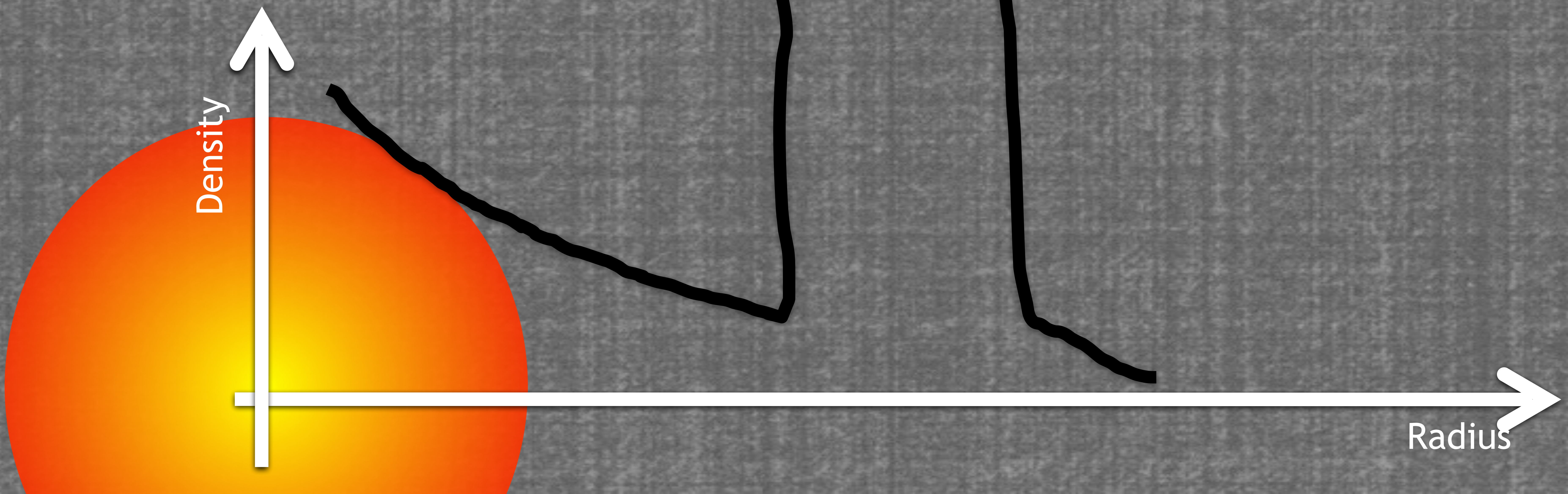
#space
http://go.nasa.gov/2jWc8Ua

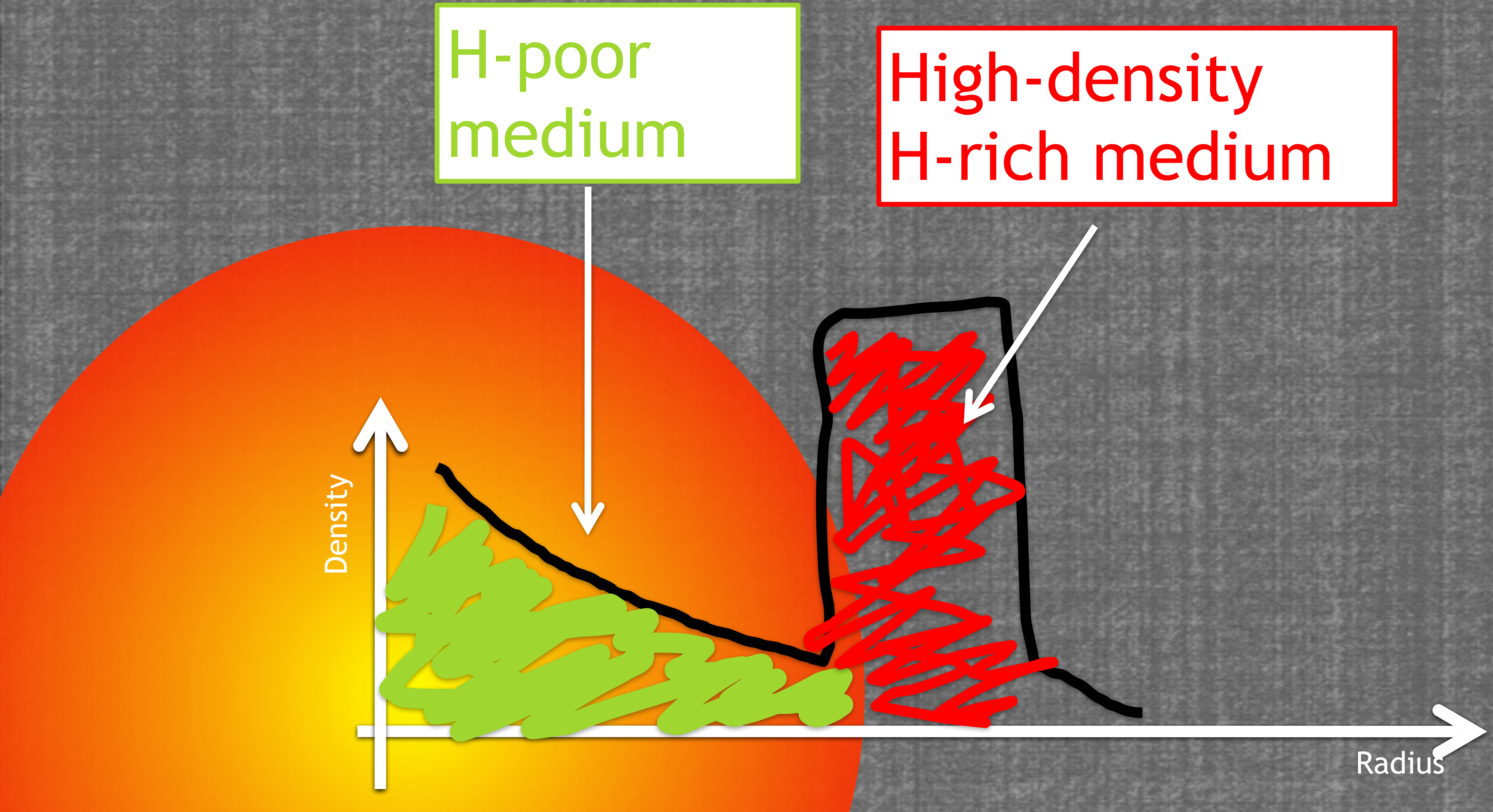


RM+16

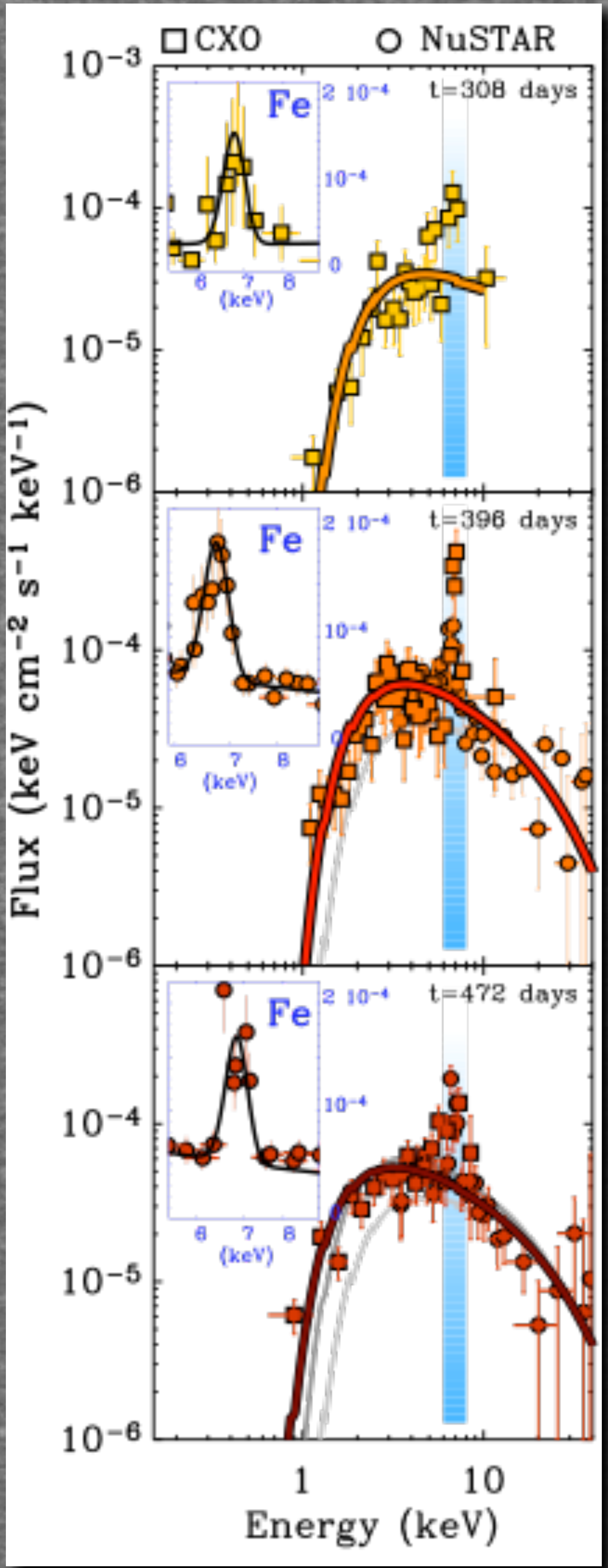
Type I SN → Type II SN


Density
Radius


Density
Radius

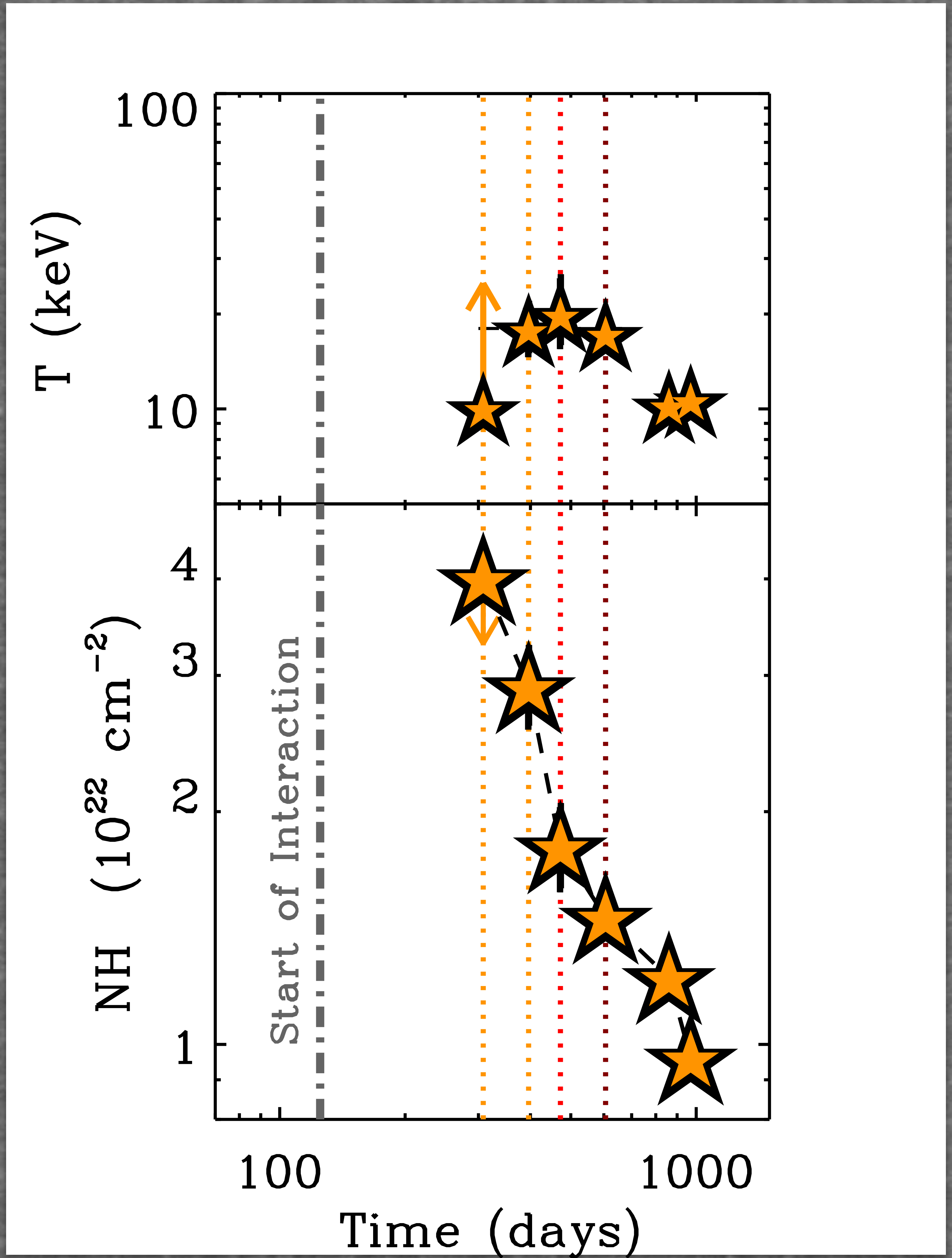

H-poor medium
High-density H-rich medium
Density
Radius

Chandra+NuSTAR



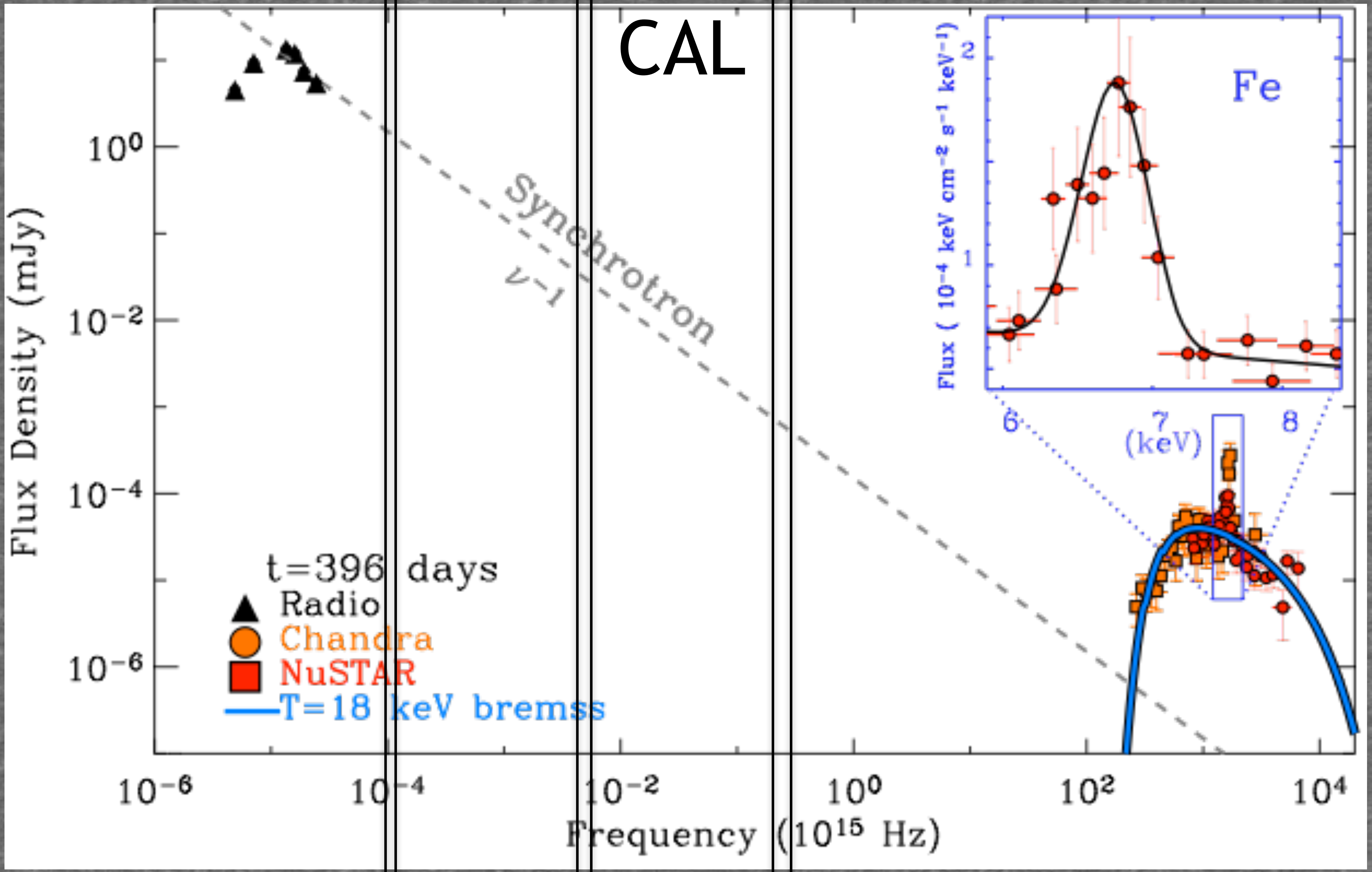
RM+16

=



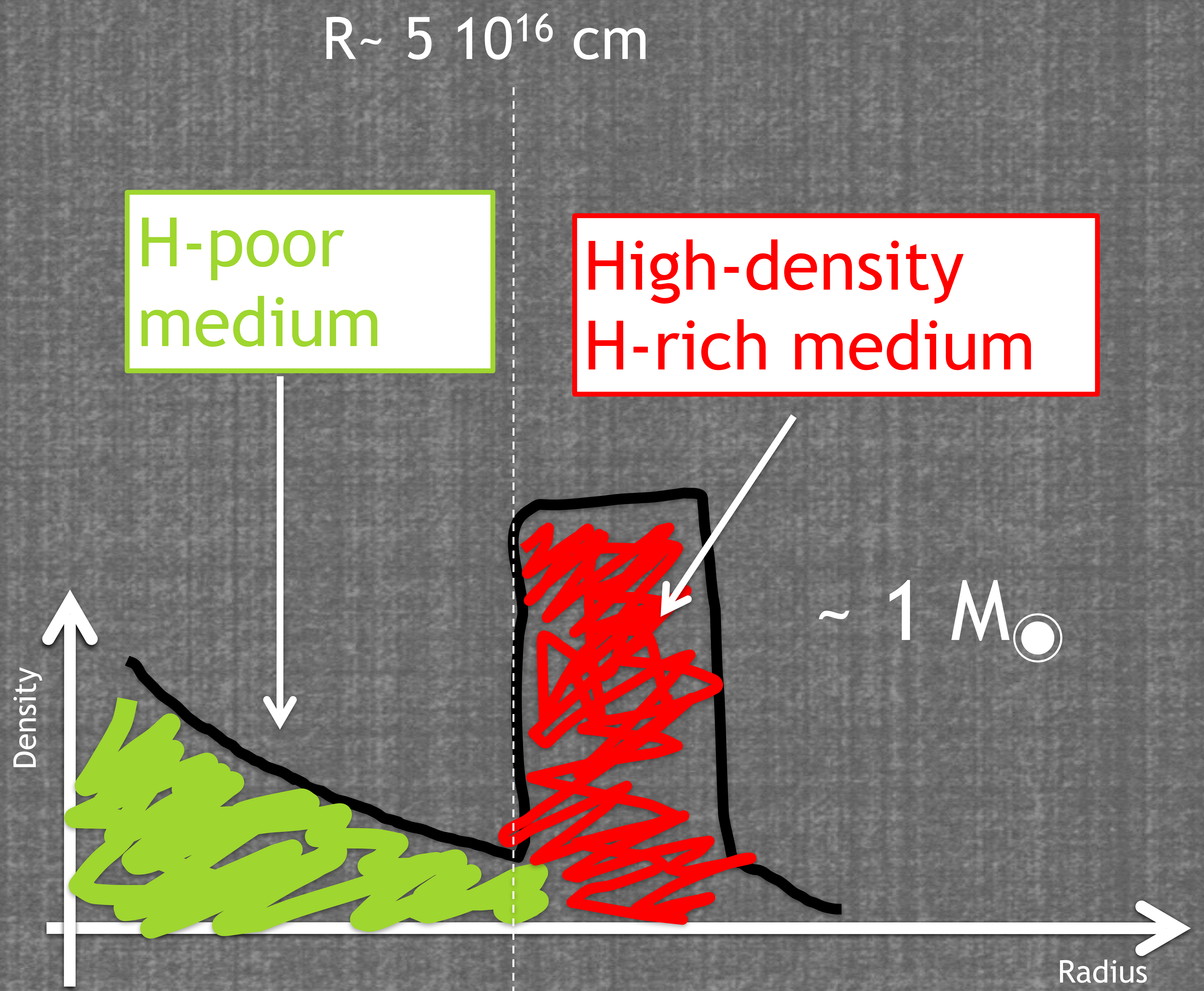
Direct Constraints on the shock dynamics!

RADIO NIR OPTICAL X-RAY



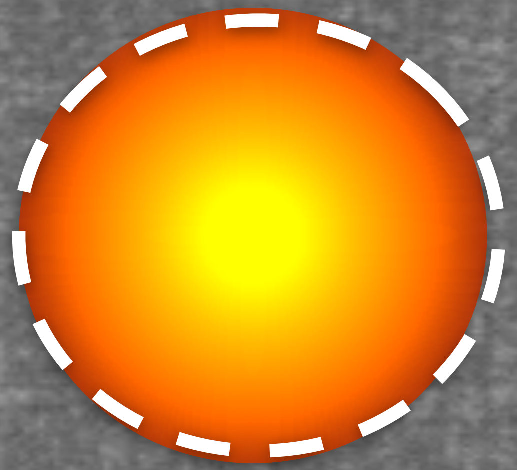
Synchrotron

Bremsstrahlung



R~ 5 10^16 cm
H-poor medium
High-density H-rich medium
~ 1 M☉
Density
Radius

Expected Evolution from Stellar tracks:

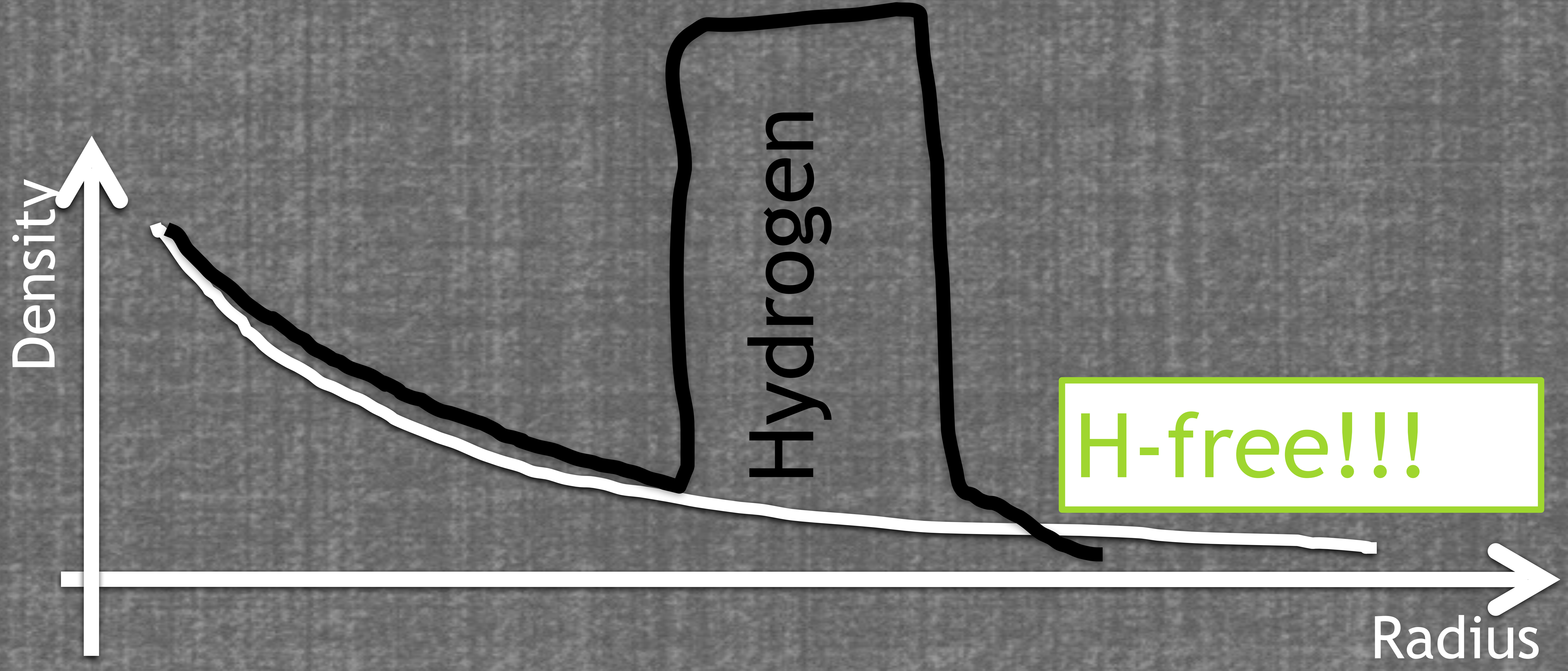


Supergiant

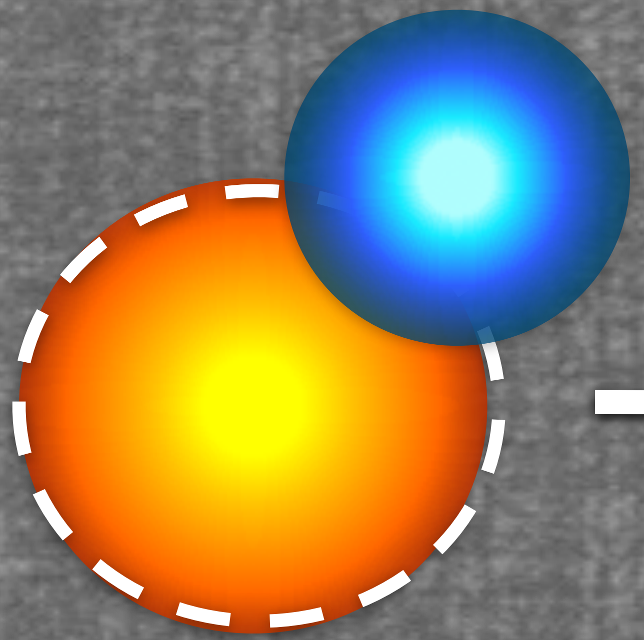
Wolf-Rayet

~10^4-10^5 yrs

SN Explosion



Expected Evolution from Stellar tracks:

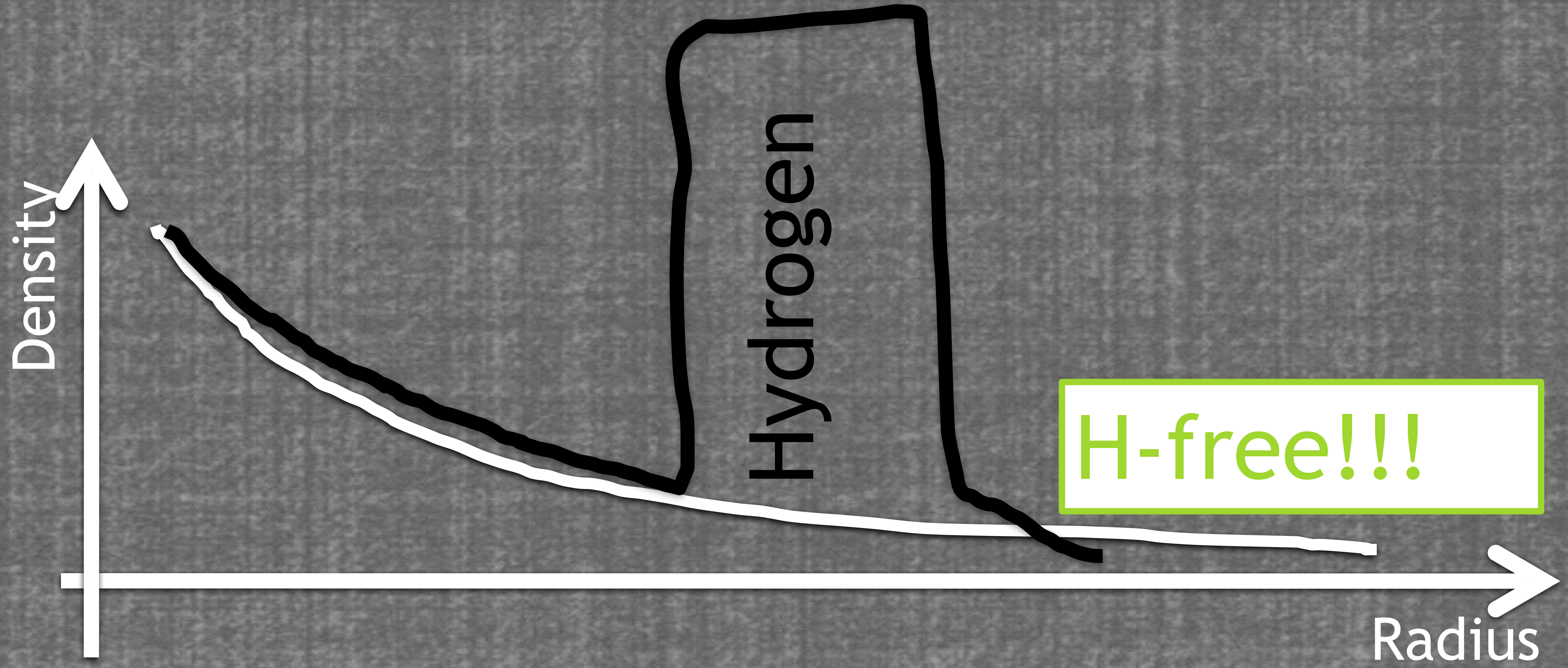


Supergiant

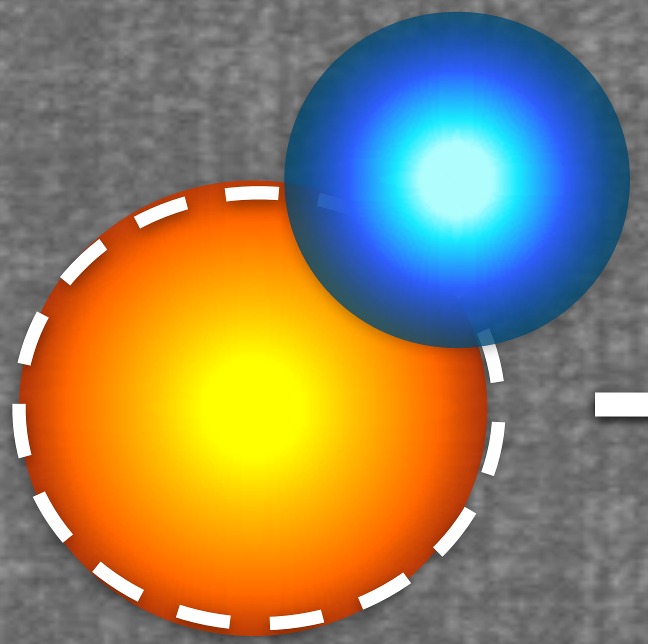
Wolf-Rayet

SN Explosion

~10^4-10^5 yrs



Expected Evolution from Stellar tracks:



Supergiant

Wolf-Rayet

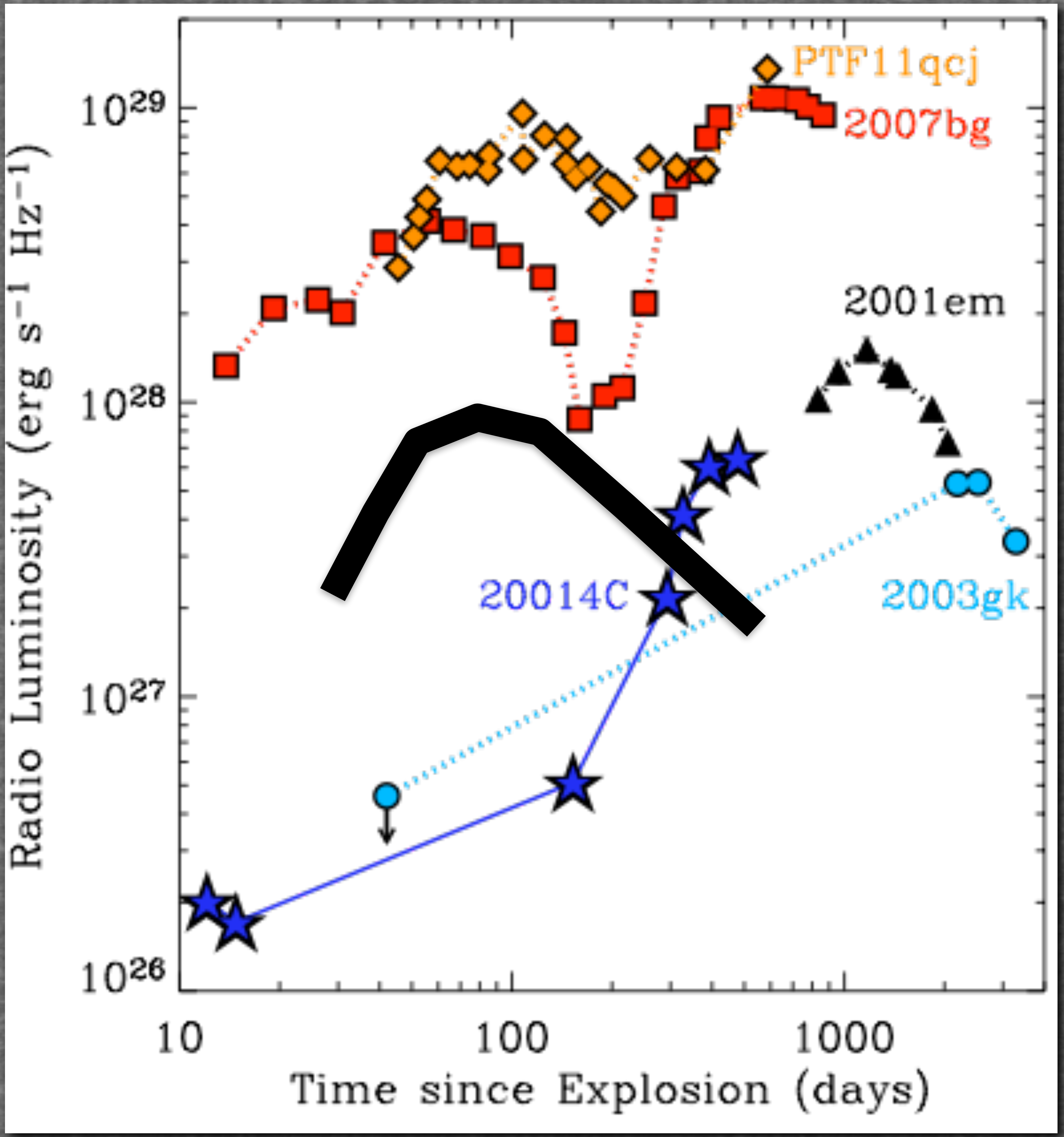
~10^4-10^5 yrs

1000 yrs

SN Explosion

Nuclear Burning Instabilities

Non thermal Radio emission Ibc



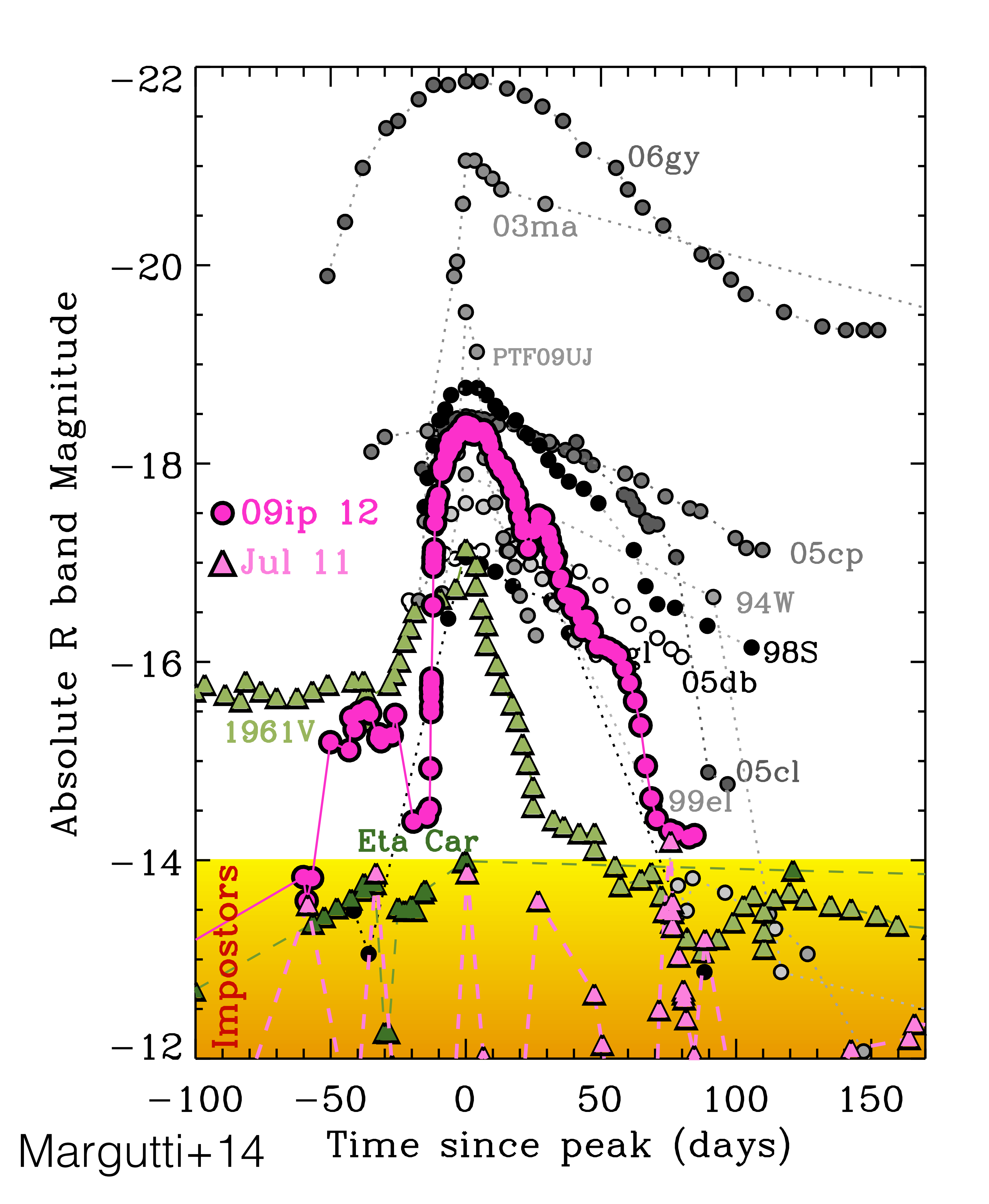
} 10%

RM+16

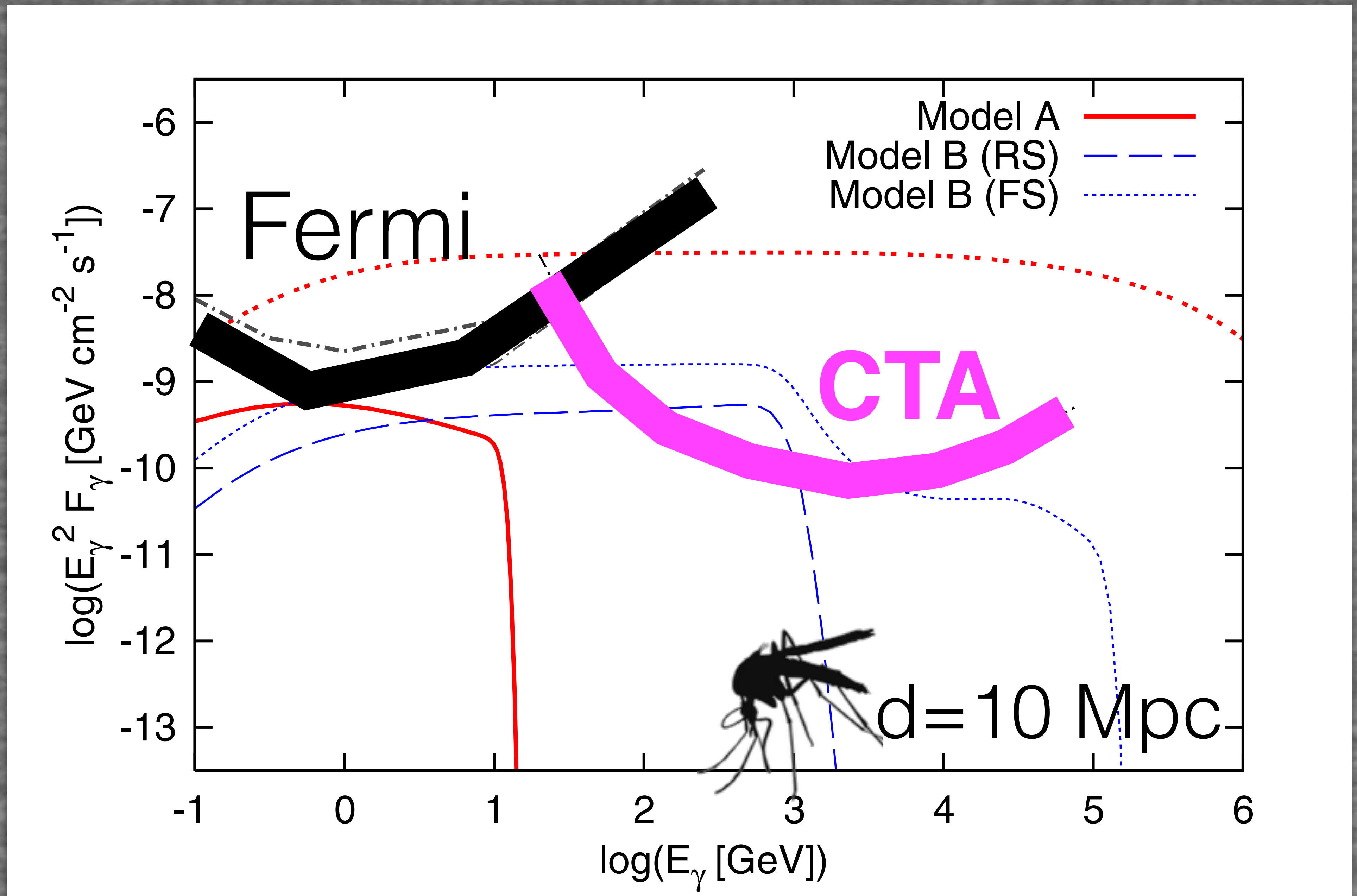
PHYSICAL REVIEW D **84,** 043003 (2011)

New class of high-energy transients from crashes of supernova ejecta with massive circumstellar material shells

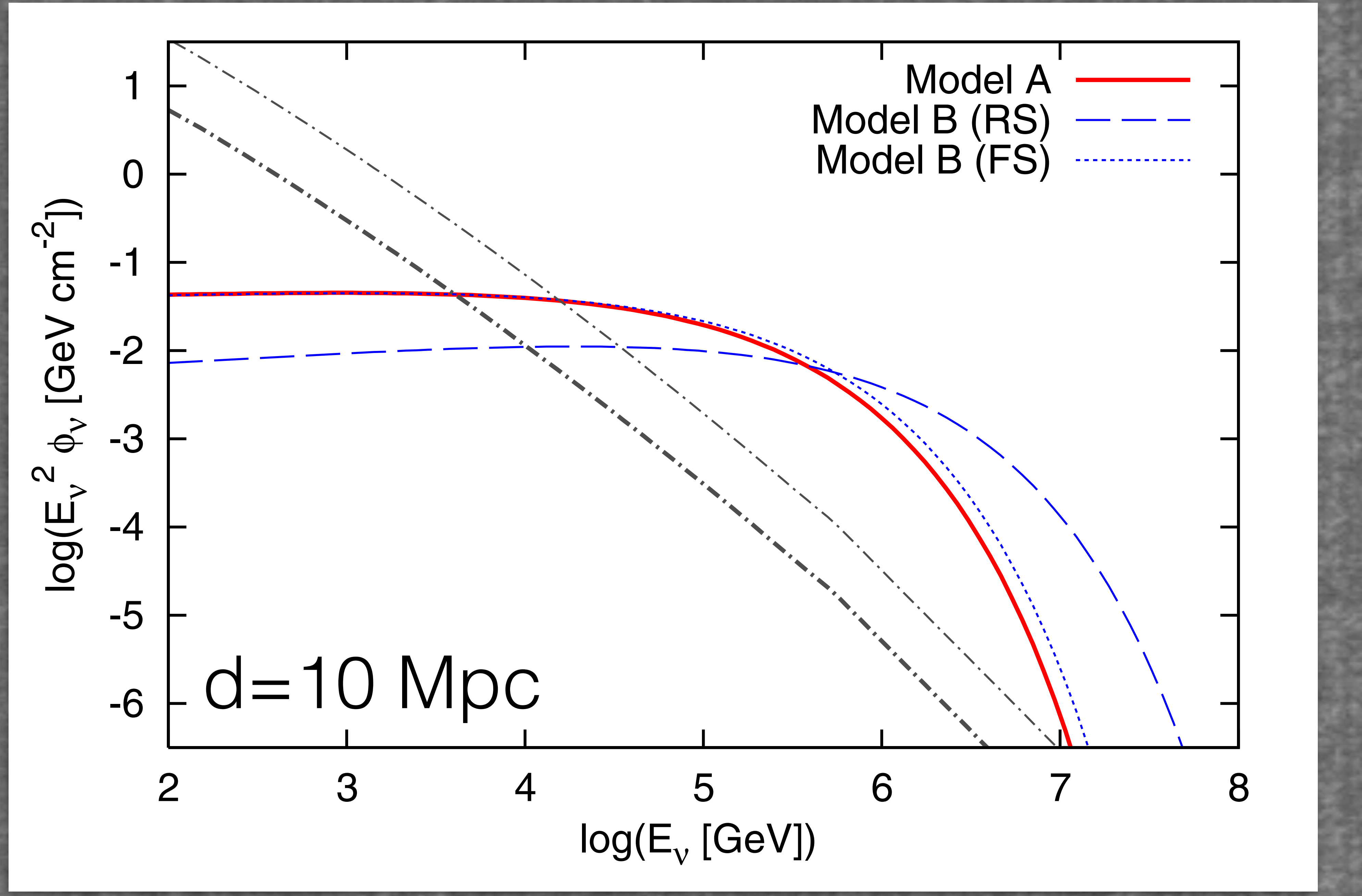
Kohta Murase,[1,2] Todd A. Thompson,[1,3] Brian C. Lacki,[1,3] and John F. Beacom[1,2,3]



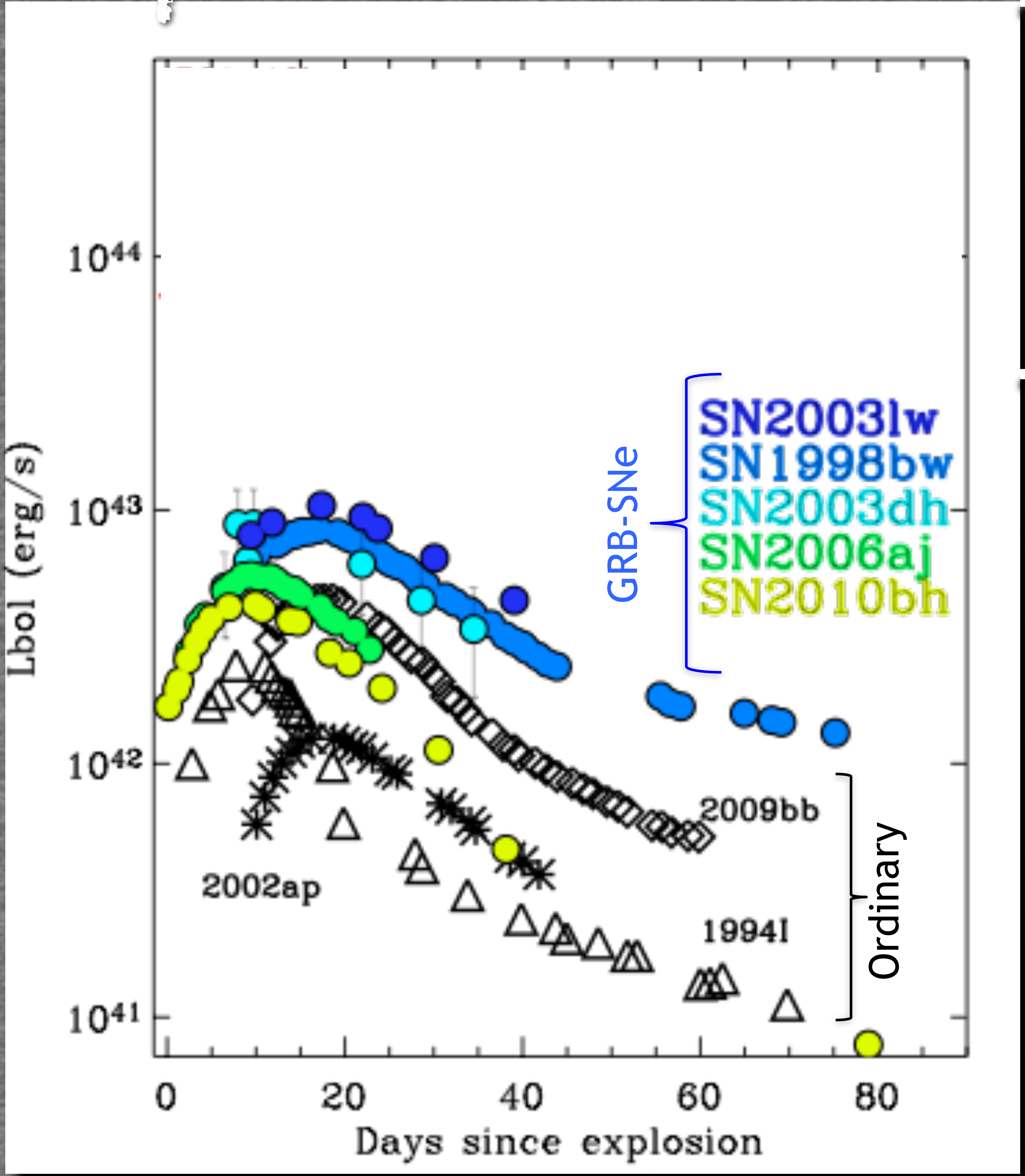
High-energy photons



Neutrinos



Super-Luminous SNe



$E_{rad} = 10^{51}$ erg

$E_K = 10^{52}$ erg

What Source of Energy powers SLSNe

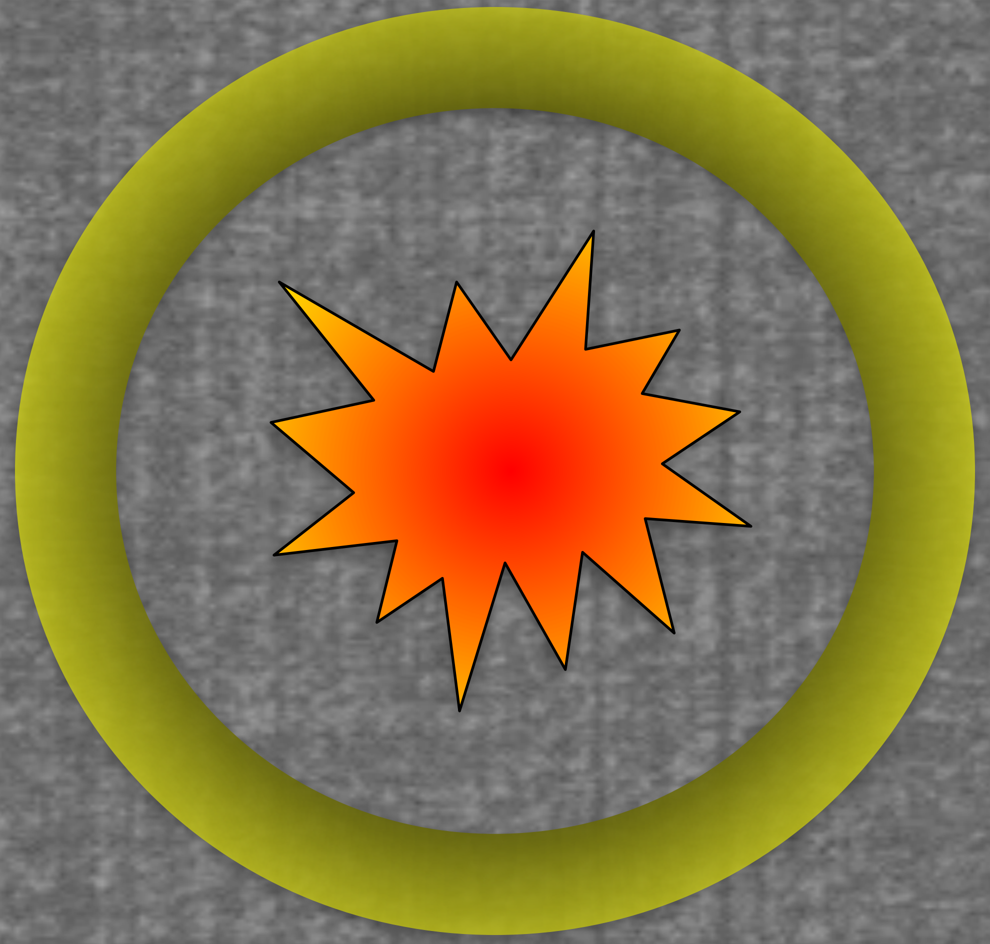
?

ENERGY SOURCE- SUPERLUMINOUS

What powers SLSNe?

Interaction

E.g. Chevalier 2011
Pan & Loeb 2013



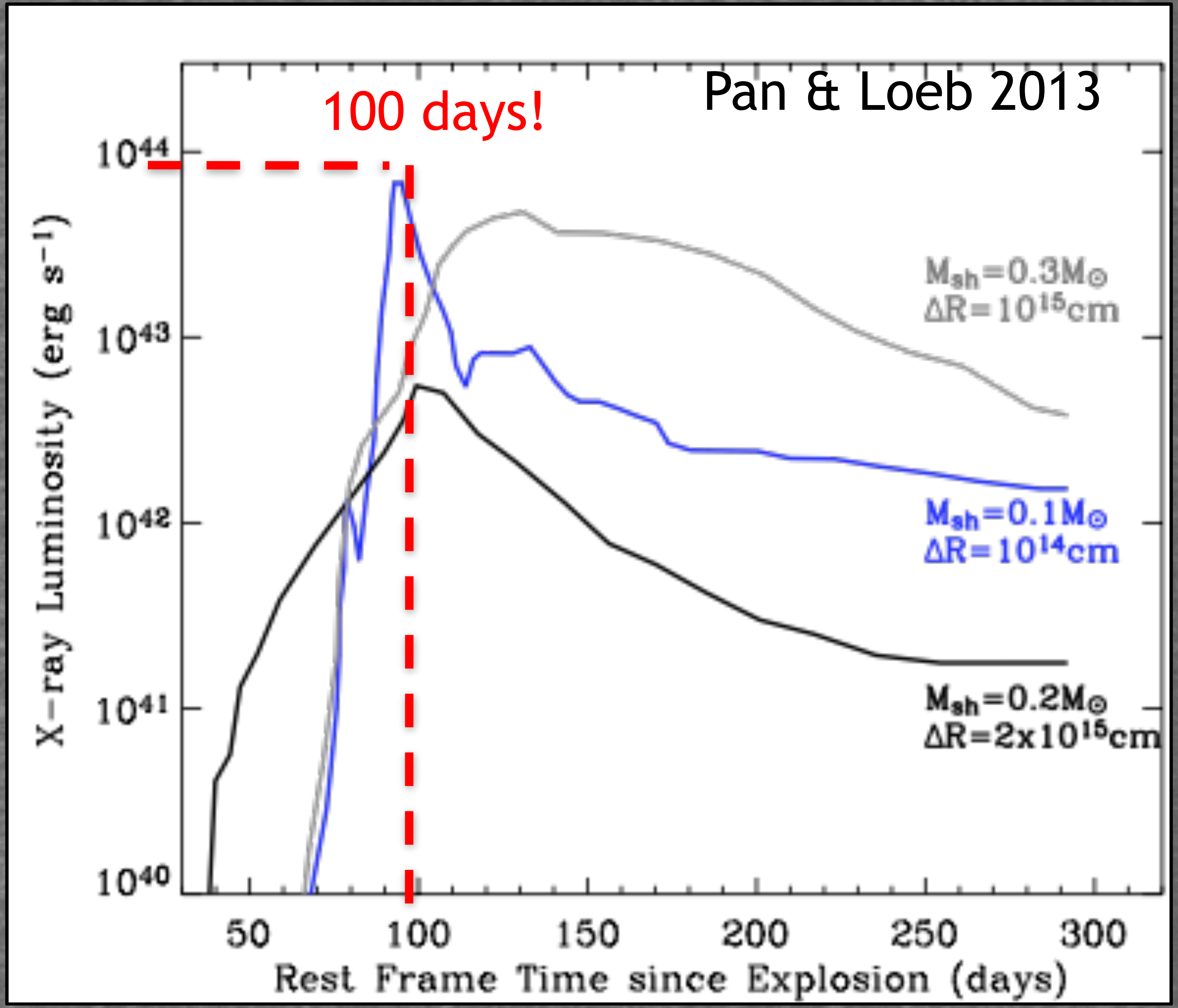
Increased Efficiency

^{56}Ni

Gal-Yam 2009

Magnetar

Kasen & Bildsten 2010
Woosley 2010



What powers SLSNe?

Interaction

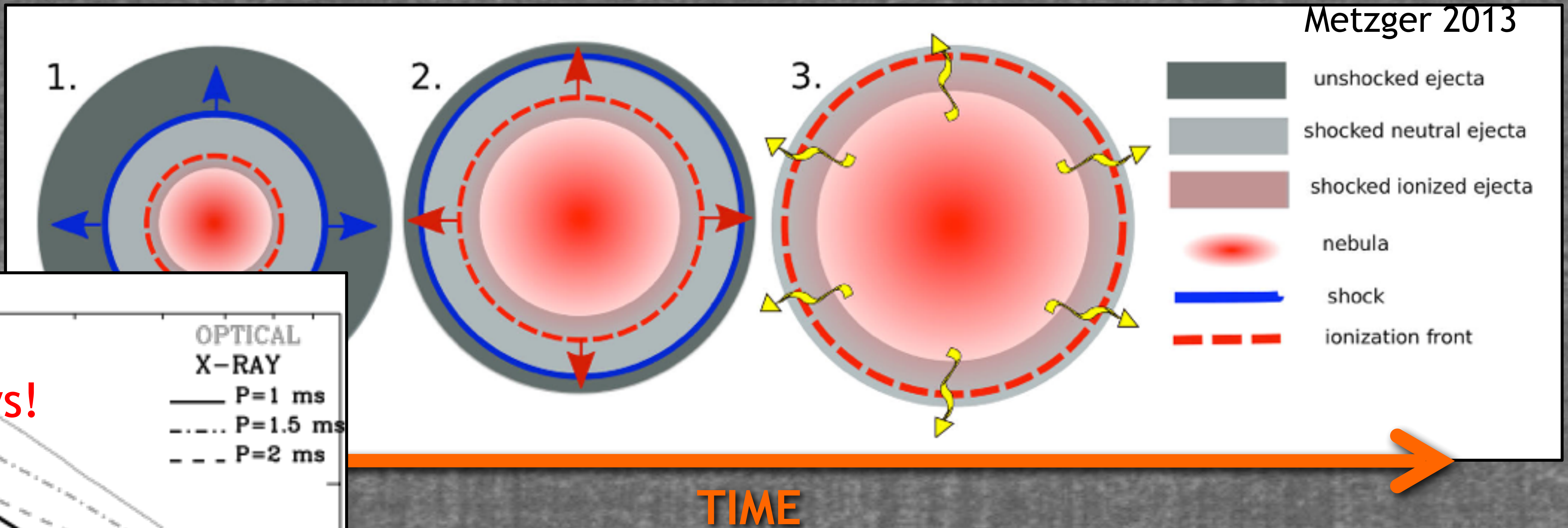
E.g. Chevalier 2011
Pan & Loeb 2013

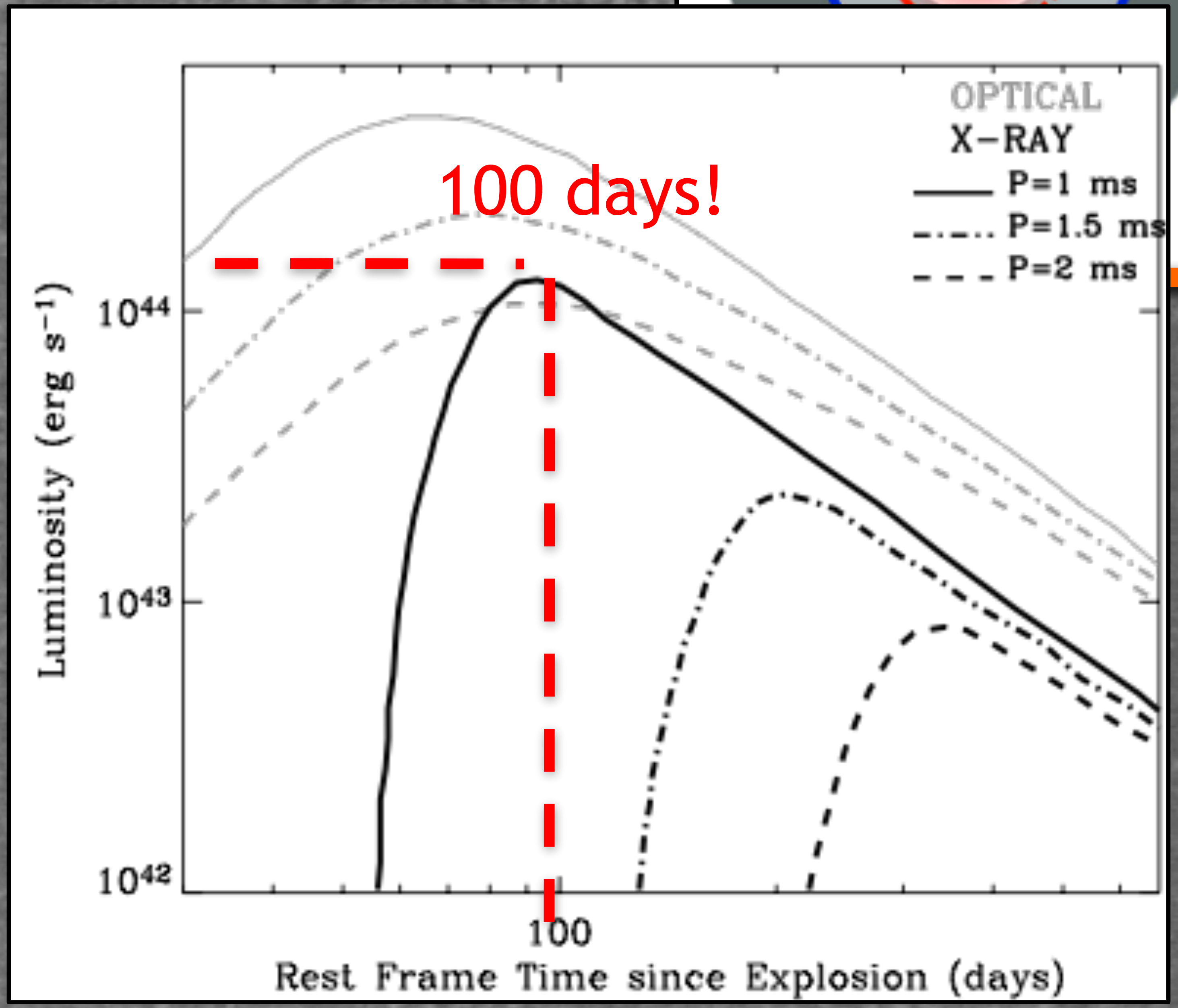
^{56}Ni

Gal-Yam 2009

Magnetar

Kasen & Bildsten 2010
Woosley 2010





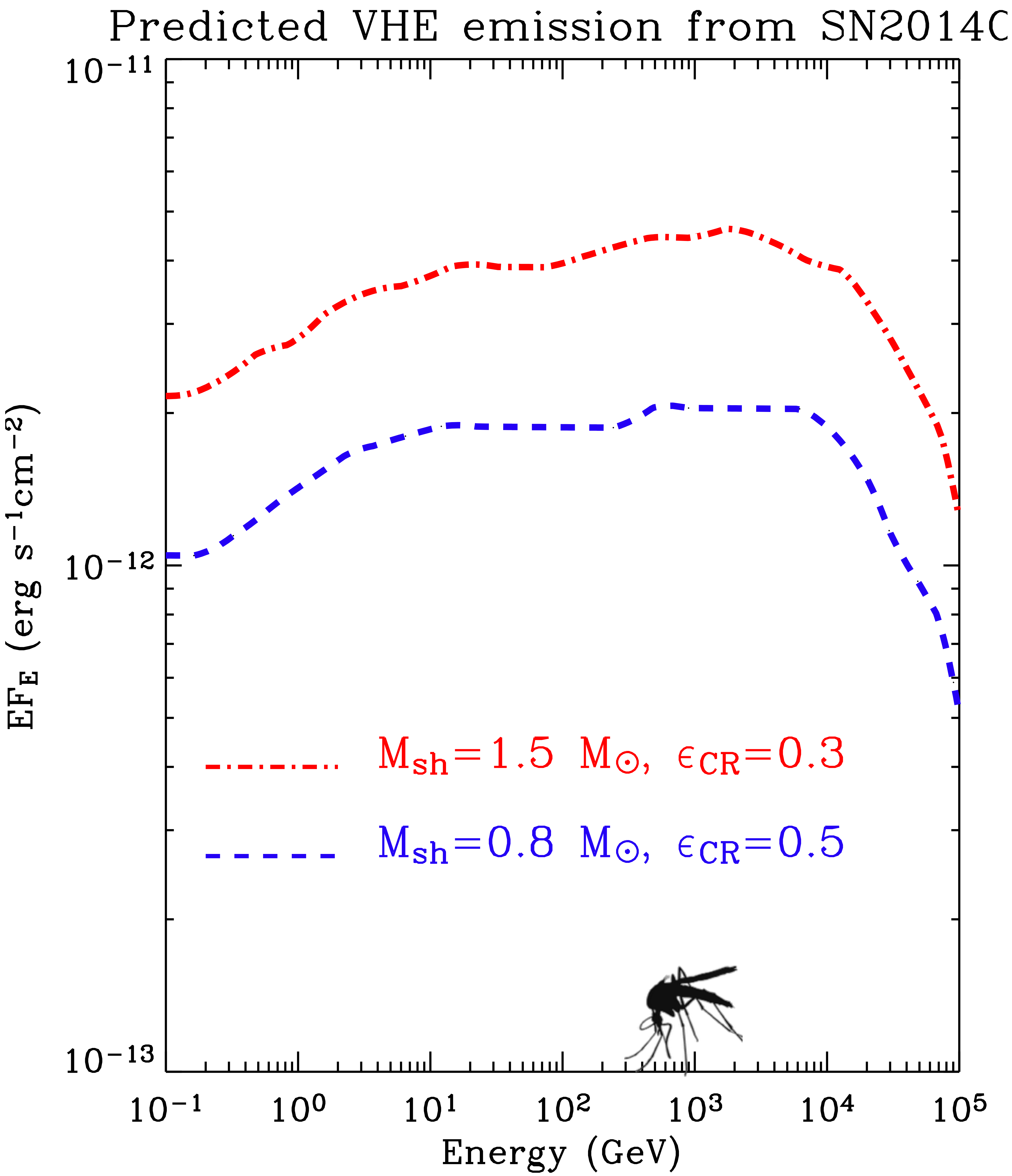
"The problem is completely specified by the properties of the pulsar and of the ejecta"
Metzger 2013

Strongly Interacting SN shocks at VHE:

(1) Environment
(2) CR efficiency of acceleration

VERITAS **Observing Proposal 2015/2016**

Proposal Title : A new window of investigation on strongly interacting SN shocks: VERITAS observations of SN2014C
Science Group : DM-Aspen
Authors : M. Cerruti, W. Benbow (Harvard), R. Margutti (NYU), K. Murase (Penn State U), N. Omodei (Stanford U.), T. Cheung (Naval Research Lab.), D. Milisavljevic (SAO), A. Kamble, J. Parrent, A. Zauderer, (Harvard), R. Chornock (Ohio U), W. Fong (Arizona U)



Predictions from K. Murase

"…The END

is where we start from…"

The Little Gidding by T. S. Eliot

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