Follow the Angular Momentum!

Summary talk of the April 8-12, 2013, ESO Meeting

The deaths of stars and the lives of galaxies

Noam Soker

Department of Physics, Technion

**** Biased and personal summary.**

When I mention someone, it is what I take from his/her talk/poster.

Dictionary translation of my name from Hebrew to English (real!):

Pleasantness Review

ENERGY CONSERVATION

➔~1850: Energy liberated by meteoroids hitting the sun

[Julius Robert Mayer; John James Waterston; William Thomson (Lord Kelvin)]

➔ Contraction of the sun [Waterston-1845 (paper rejected) : 9000 years; ➔ 1853 a talk heard by Herman von Helmholtz (1821-1894): 22 million year. This is known now as Kelvin-Helmholtz time.

$$\tau \approx \left(\frac{GM^2}{R}\right)\frac{1}{L}$$

1899: A geologist (T. C. Chamberlin): energy can be subatomic processes

➔1903: Radioactive decay: Ernest Rutherford

➔1915: William D. Harkins: H ➔ He

➔1919: Jean Perrin: ". .light atoms such as hydrogen, or _ _ _ _ _ ium , or helium. . . formation of heavy atoms"

Guess the element (but keep it for yourself)!!!!

ENERGY CONSERVATION

1899: A geologist (T. C. Chamberlin): energy can be subatomic processes

- 1903: Radioactive decay: Ernest Rutherford
- 1915: William D. Harkins: H → He
- 1919: Jean Perrin: ". .light atoms such as hydrogen, nebulium, or helium. . . formation of heavy atoms"
- 1920: Arthur S. Eddington (1882-1944): 4-H → He

"We can get rid of the obsession that there is no other conceivable supply besides contraction . ."

ENERGY CONSERVATION

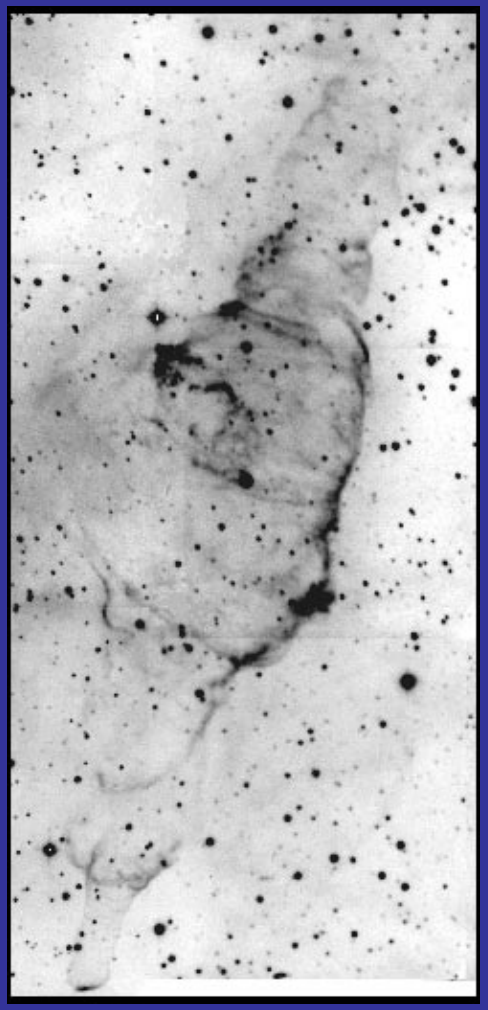
1899: A geologist (T. C. Chamberlin): energy can be subatomic processes

- 1903: Radioactive decay: Ernest Rutherford
- 1915: William D. Harkins: H → He
- 1919: Jean Perrin: ". .light atoms such as hydrogen, nebulium, or helium. . . formation of heavy atoms"
- 1920: Arthur S. Eddington (1882-1944): 4-H → He
- 1936: Robert d. Atkinson (1898-1982): $p + p \rightarrow D + e^{+}$
- 1938: Charles L. Critchfield (1910-1994): the PP chain
- 1938: Critchfield and Hans Albrecht Bethe (1906-2005) using nuclear rates calculated by Gamow and Teller, show that the energy production rate in stars works.
- 1938: Carl Friedrich von Weizsacker (1912- 2007): CNO

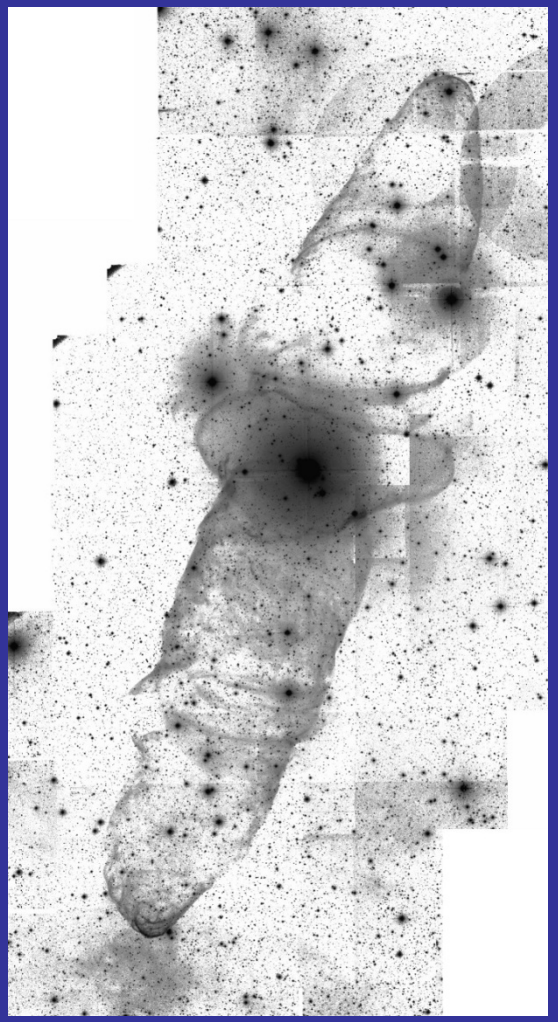
[**SN 1am**] The main open questions in stellar evolution are related to angular momentum (AM) evolution

[**SN 2am**] AM is crucial at birth and death

SN stands for Soker Noam



KjPn8
(Lopez et al. 2000)



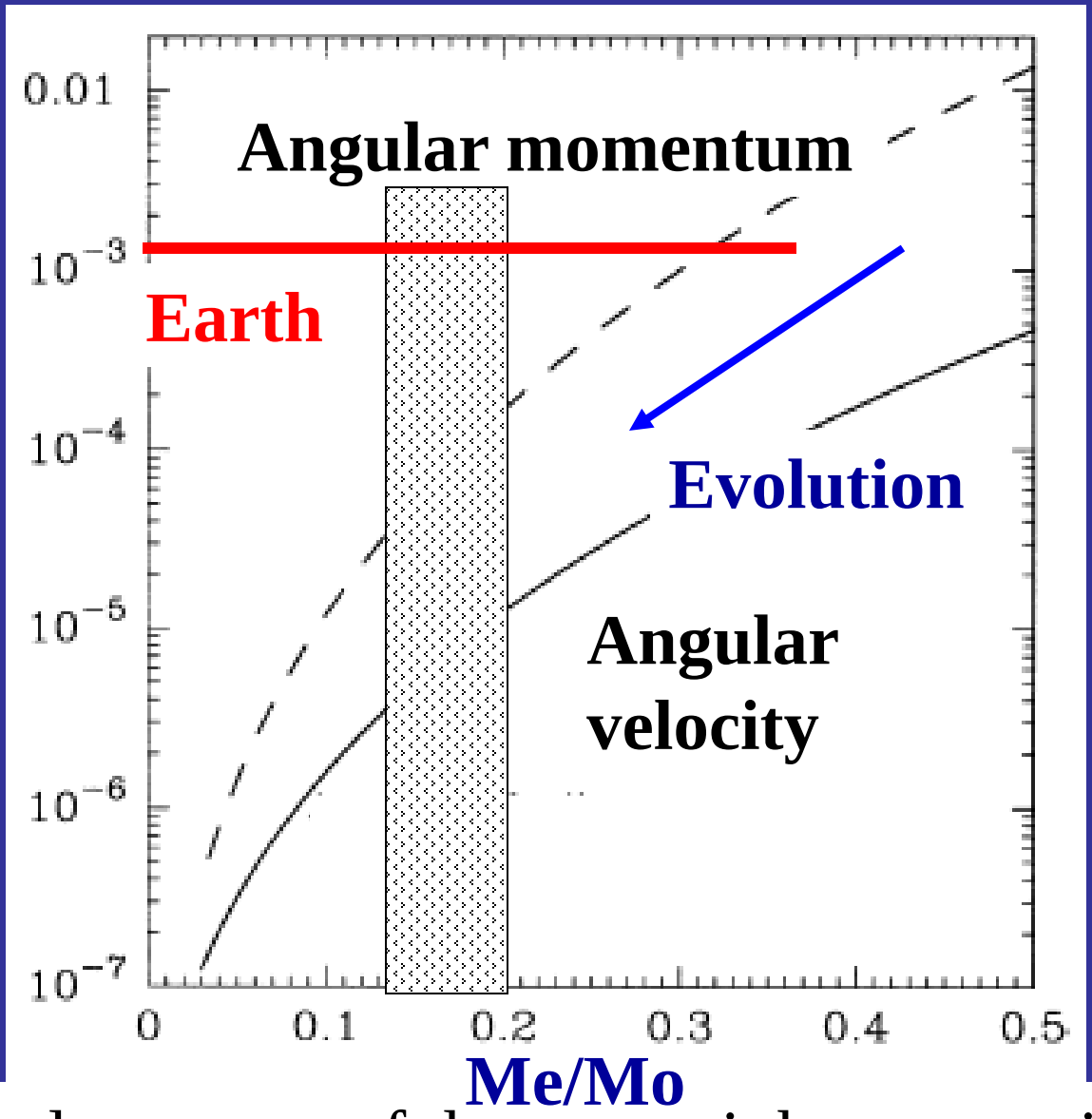
Ou4: Young stellar object
(Romano Corradi)

Angular momentum sources

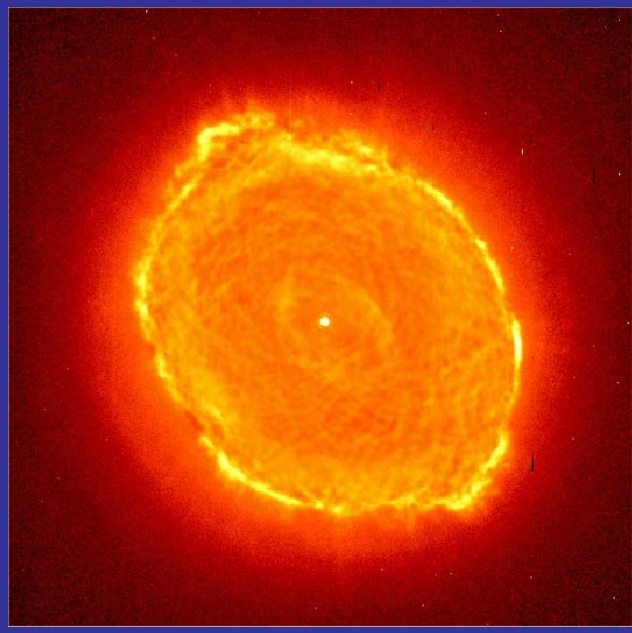
- **Contraction of a cloud/envelope: Important during birth and core collapse SNe (CCSNe)**

- **Binary companion (brown dwarf/planet)**

Even planets can do the job



IC 418: Elliptical planetary nebula



Envelope mass of the sun as it becomes giant

- **Angular momentum inside stars: Core-envelope mixing (crucial!)** ***(Falk Herwig; Amanda Karakas; Georges Meynet)*** showing in abundance ***(Adal Mesa-Delgado; Christophe Morisset)***

[SN 1b$_{ipolar}$] Peculiar central stars of PNe (CSPNe), like WR, are due to binary induced extra mixing and mass loss.

- **Abundances (e.g. *Walter Maciel*), should be able to tell us more about binarity, (e.g., PNe with symbiotic novae).**
- **Some PNe had novae. Novae can teach us about rotation-induced mixing & common envelope (after eruption) *(Claus Tappert)***

[SN 2b Due to Orsola De Marco] : In large, the occurrence of observed planetary nebulae is a binary phenomena, including BD and massive planets.

Faint circular PNe might come from single stars.

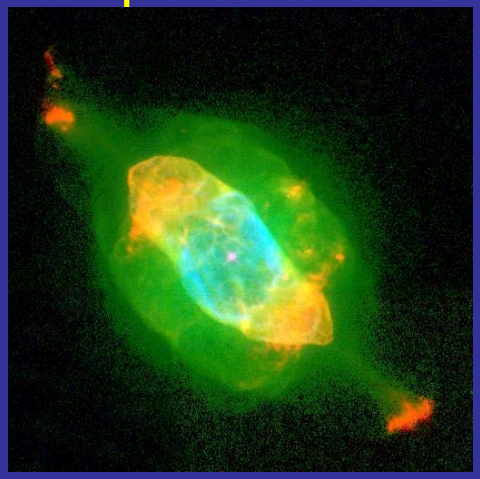
- **Jets, circumstellar and circumbinary disks, and equatorial mass loss (rings) are involved**

(Amy Tyndall; David Jones; Henri Boffin; S. Bright; R. Costa; M. Santander-Garcia)

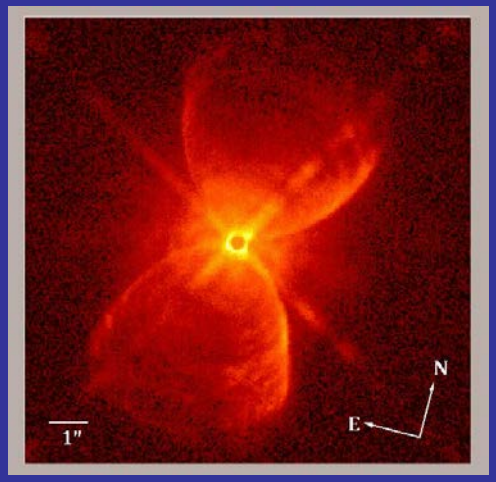
- **A comment: Many blue HB stars (have low mass envelope) have companions. Some can evolve with a nebula around them, including ISM swept-up gas.**

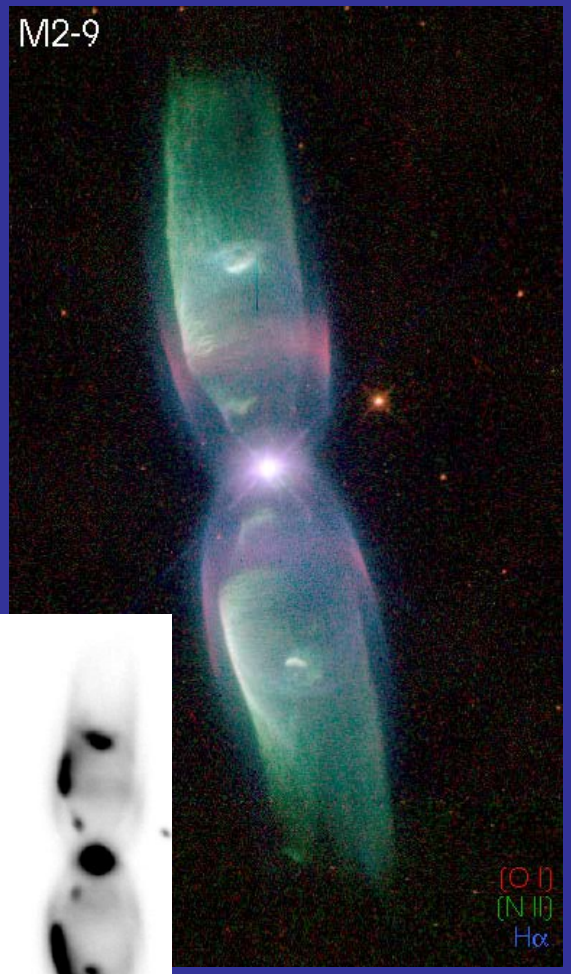
PLANETARY NEBULAE

NGC 7009:
Elliptical PN

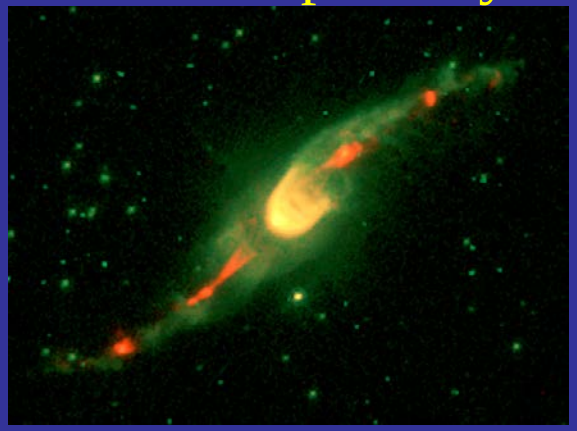


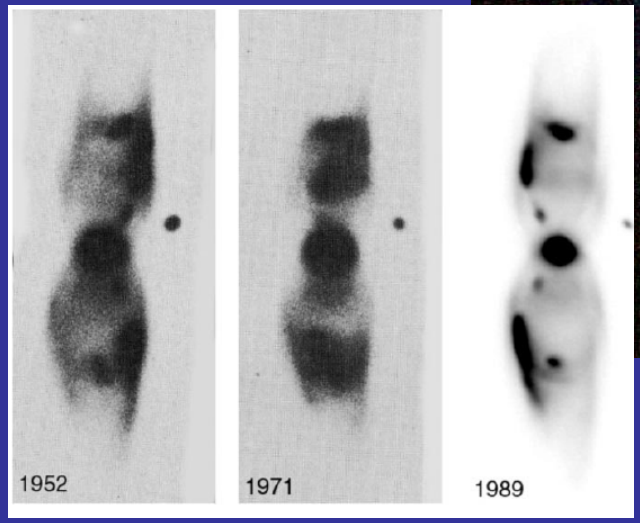
Hb 12
Bipolar PN





He 3-1475: point-symmetric





The universal bright end of the planetary nebulae luminosity function (**PNLF**) (*Magda Arnaboldi*; *Warren Reid*) is a big puzzle.
Binarity seems to be the solution . . .somehow. . .

• Binary stars are common in **massive stars**.

One cannot ignore companions in studying massive stars (*Paul Crowther*), e.g., mass loss (*Stacy Habergham; Roger Wesson*), their influence on composition of globular clusters (*Anders Thygesen; Alan Alves-Brito*), . . .

• From its morphology (*Patrick Owen*; *Nathan Smith*) the Crab nebula seems to have been shaped by a companion.

• B-field and rotation of NS tell us something *(A. Reisenegger)*

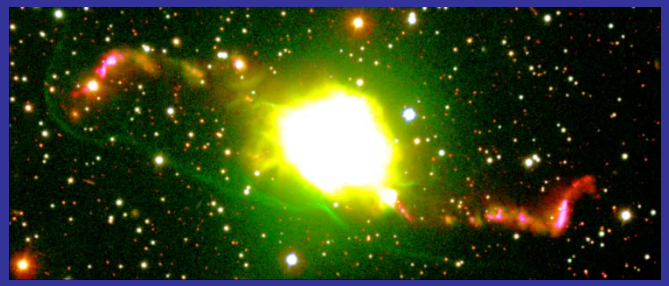
• Diversity of core collapse SN (IIn, Ib, Ic . .) and impostors must come from binary interaction J. Anderson; A. Bevan; T. de Jaeger; C. Gutirrez ; C. McEvoy; M. Soto

• B[e] stars (W.J. de Wit;)

On the low mass end, the blue horizontal branch *(V. Valcarce)* seems to require companions, *(Giovanni Carraro),*
down to planets.

- **Jets and binarity (mass transfer)**

Fleming 1
1.2 days poriod
(*Boffin* et al.)



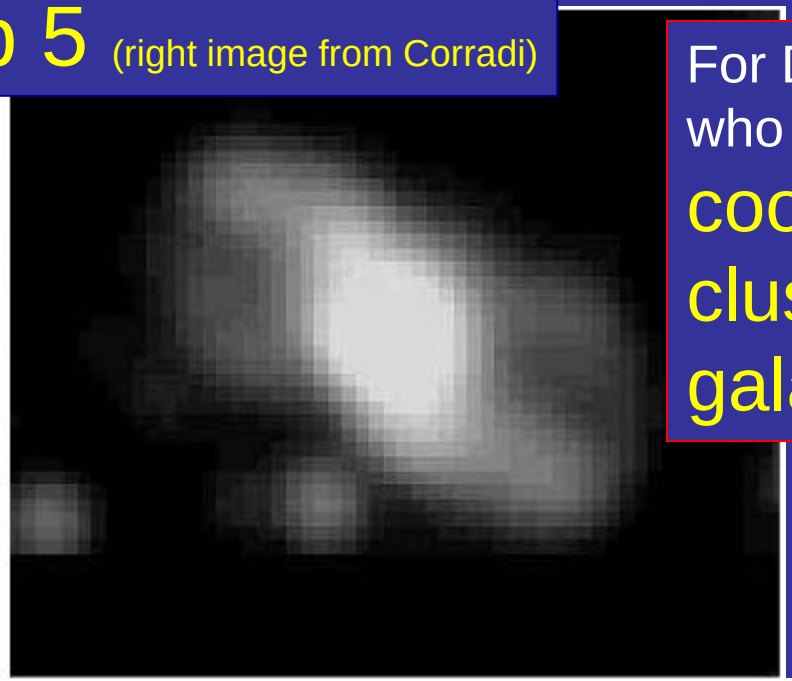
Jets can be formed before the nebular disk (David Jones), hence are **not** collimated by the nebular disk. They are formed by **accretion disk** around one of the stars (likely companion).

In too many talks the old and **wrong** idea of shaping by interacting winds was mentioned (it exist, but cannot explain most morphologies).

Jets are there even where you don’t see them.

An example:

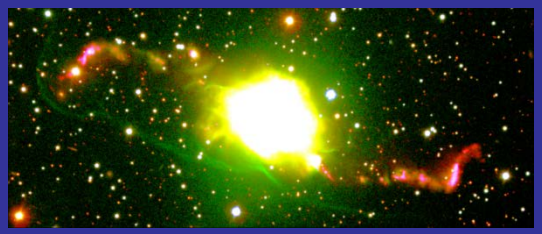
Hb 5 (right image from Corradi)

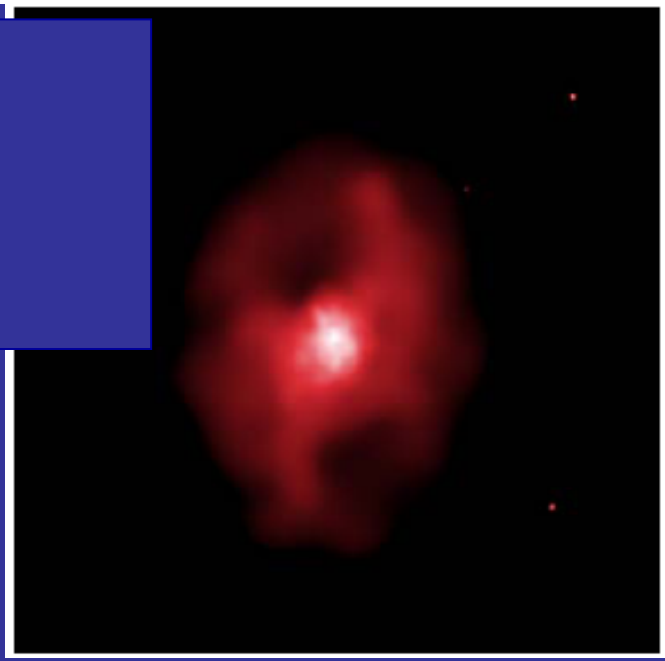


For Denise and Assaf who used to work on cooling flows in clusters of galaxies.

One million light year

Cluster of galaxies in X-ray.
Prediction: A binary black hole system





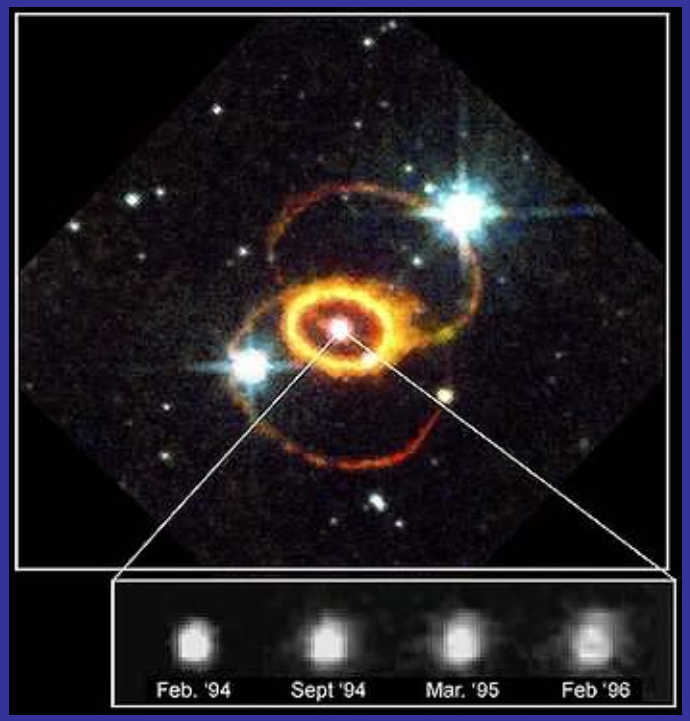
[SN 1j$_{et}$] All bipolar nebulae (PNe; Symbiotic nebulae; Eta Carinae; YSO lobes; bubbles in clusters of galaxies and in galaxies) are shaped by **Jets that are launched by an accretion disk around a compact object.**

[SN 2j] . . . Coming in a few minutes . . . . . .

Massive stars

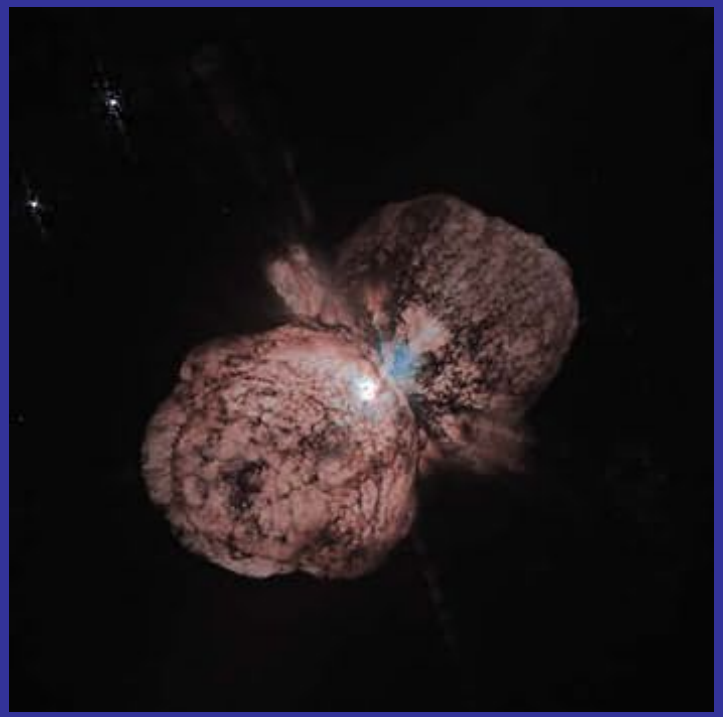
SN 1987A:

Not clear yet if jets were involved (I tend to think yes)



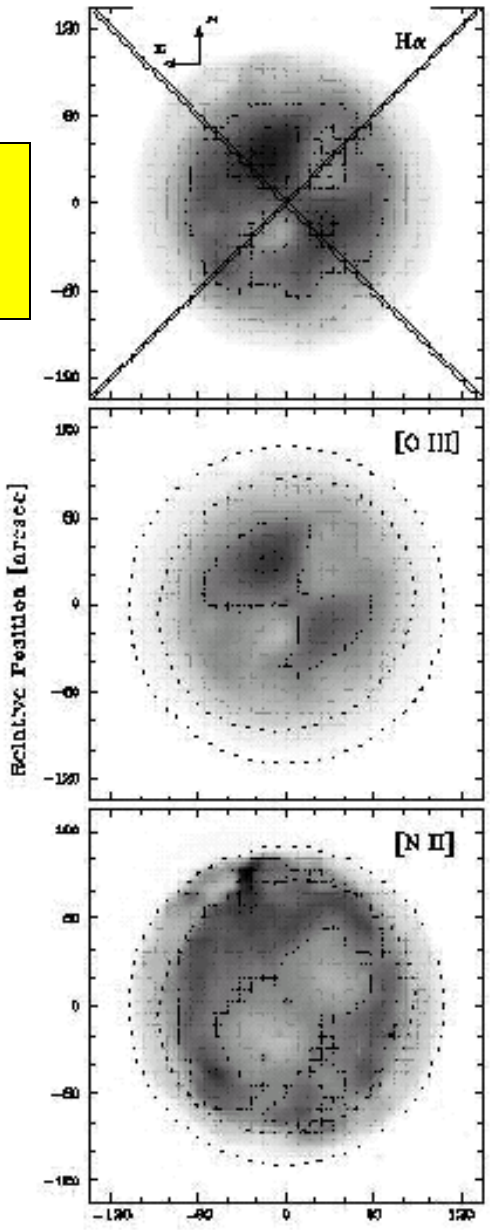
Eta Carinae:

Was shaped by jets

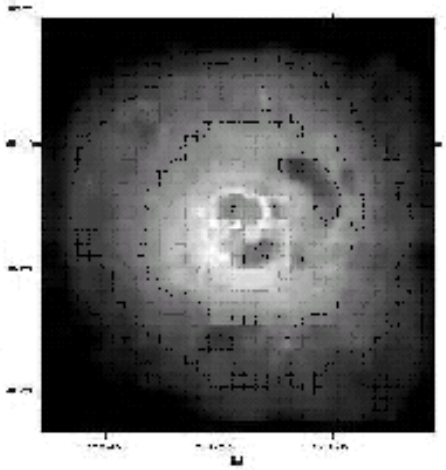


A Cluster of galaxies

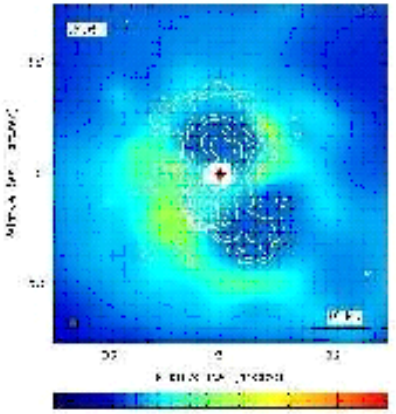
Owl Nebula
Guerrero et al.



Perseus Cluster
X-ray
Fabian et al.



A Cluster of galaxies

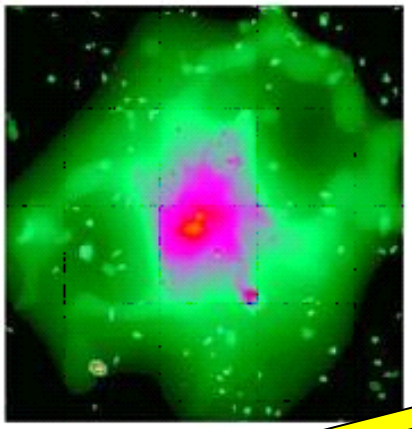


A Cluster of galaxies

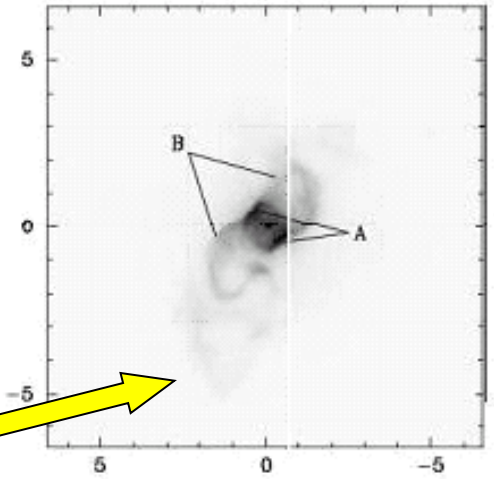
Planetary nebulae

A Cluster of galaxies

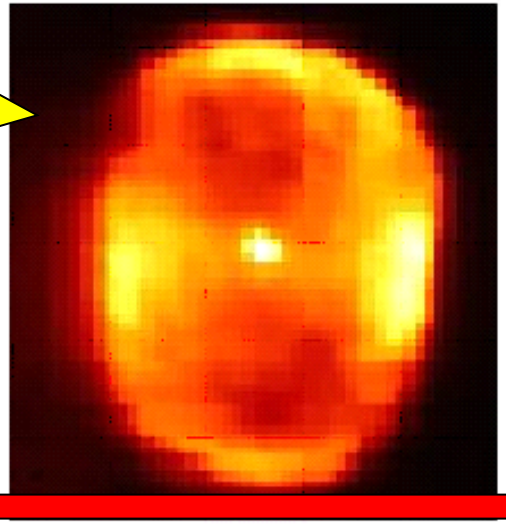
HCG 62 (X-ray)
compact galaxy group
Vrtilek et al.



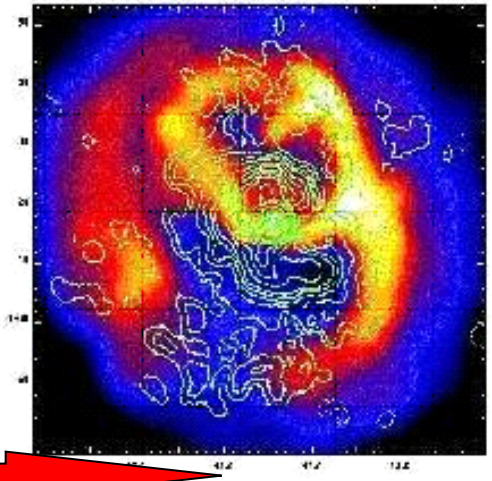
Hu 2-1
Miranda et al.

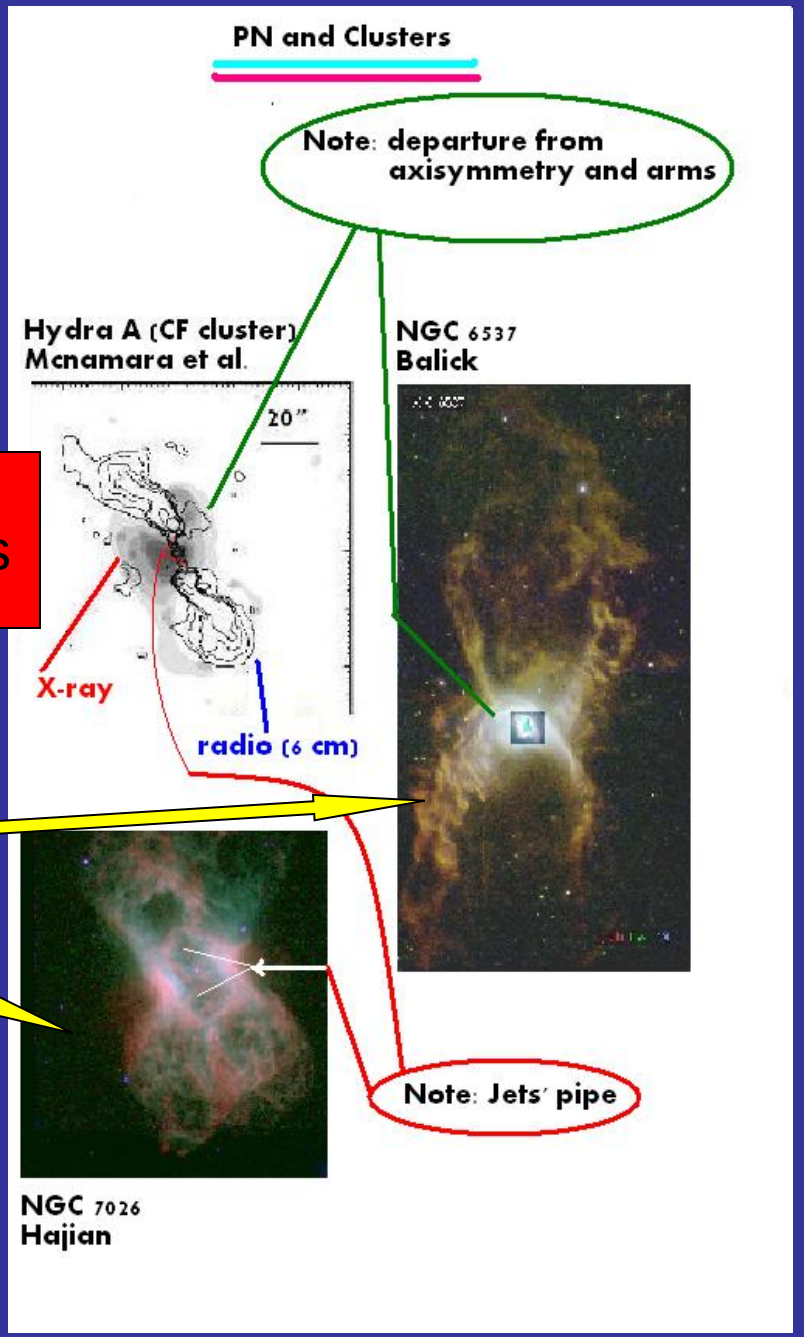


V 171 (Halpha)
Sahai



A 2052 (X-ray)
Cooling Flow Cluster
Blanton et al.





A Cluster of galaxies

Planetary nebulae

Note: In cooling flow clusters the jets and bubbles heat the gas.

During galaxy formation the **jets** from the super massive BH remove mass of about equal to the stars mass, ~1000 the SMBH mass.

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During galaxy formation the **jets** from the super massive BH remove mass of about equal to the stars mass, ~1000 the SMBH mass.

In core collapse SNe it seems to me that there are (severe) problems in exploding the star with neutrinos (this is what I take from the talks by *Thomas Janka*, *Bernhard Mueller* and *Bronson Messer*).

GRBs have jets! *(Felipe Olivares)*

So . . .here is my personal view:

[**SN 2j**] Aall core collapse SNe are exploded by jets launched from the newly formed neutron star or BH.

This is strongly supported

by my wife and three kids

[**SN 2j**] Aall core collapse SNe are exploded by jets launched from the newly formed neutron star or BH.

This is strongly supported

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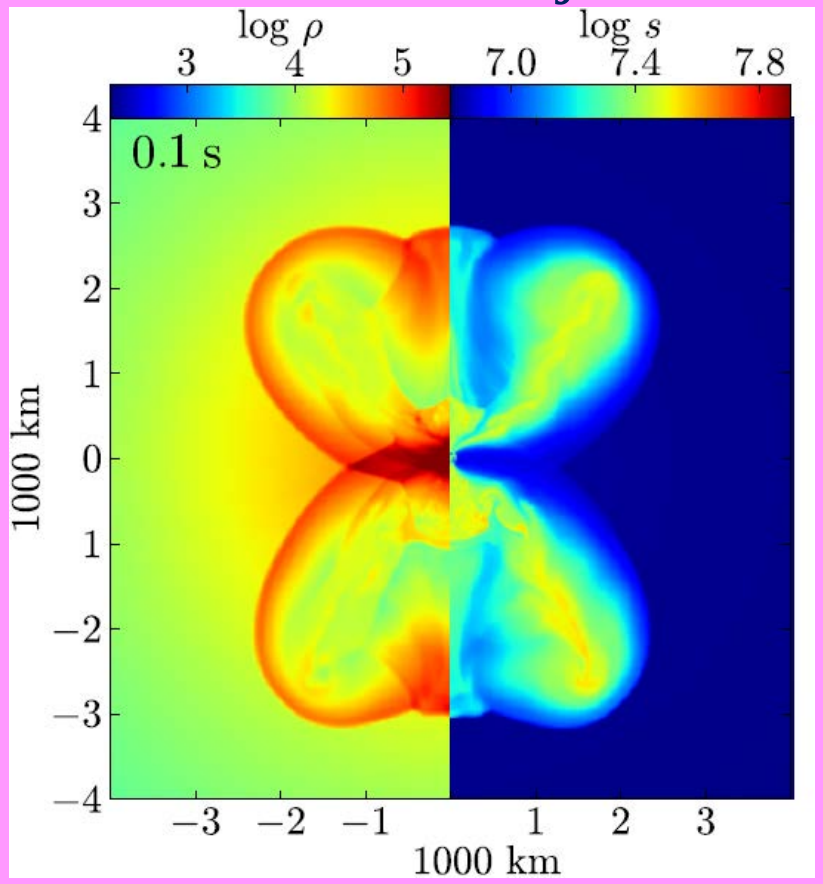
Outcome: Failed supernovae are the most violent ones.

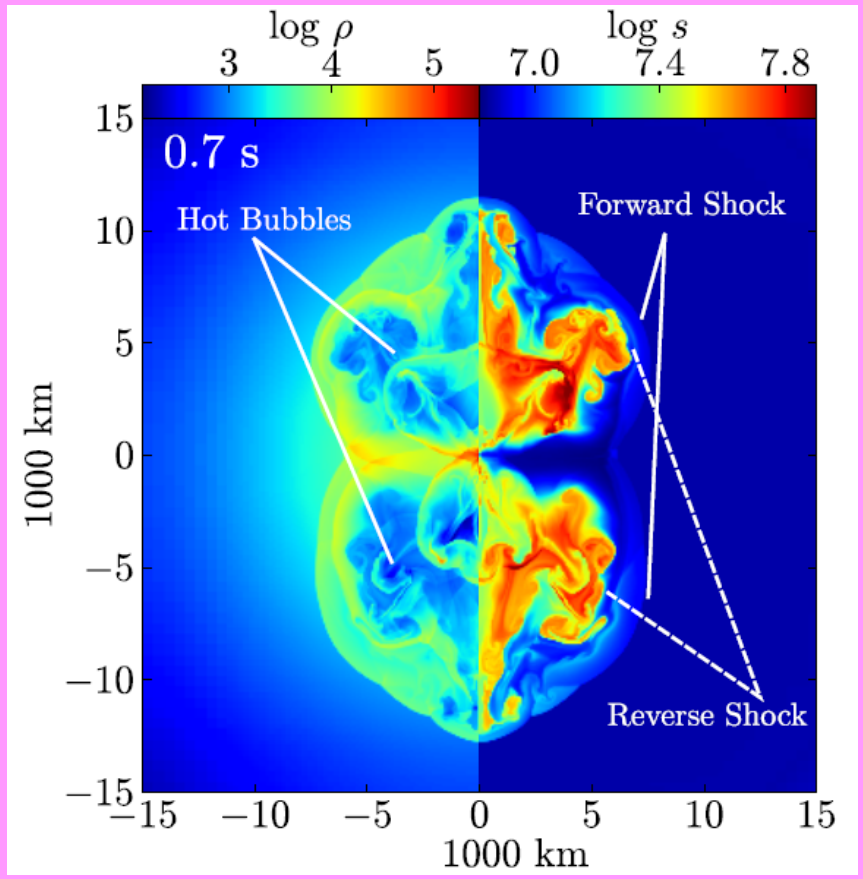
We are only starting: **jittering jets**

From *Oded Papish* (the SASI discussed by Janka & Mueller et al. is a crucial help for our scenario).

0.1 seconds of jets



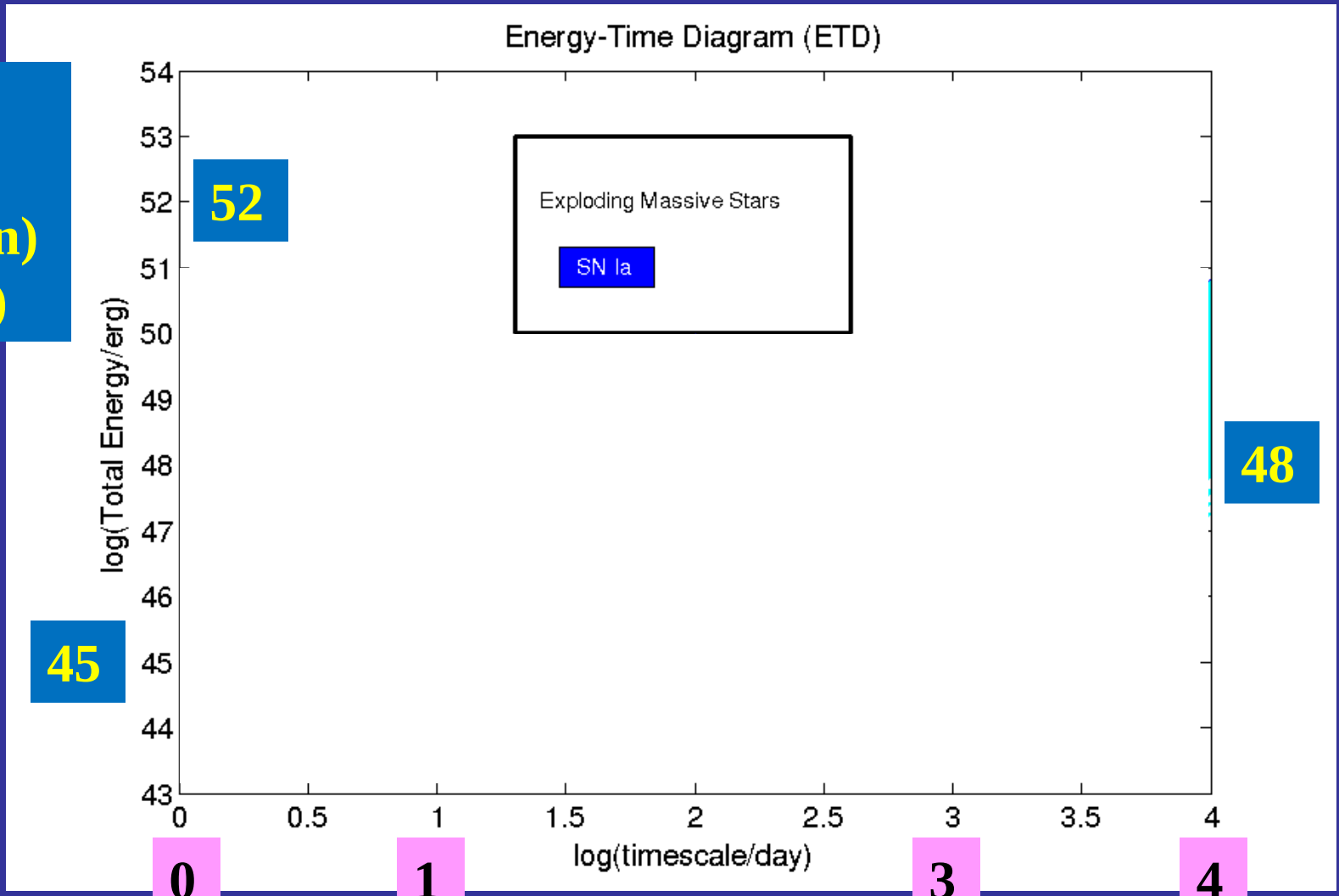
0.7 seconds of jets



Nathan Smith *and* *Olivier Chesneau* emphasized the relation of PNe and other systems (LBV, B stars, novae) as far as bipolar and binarity are concerned.

Let us try to put them on one diagram

Total (Kinetic +radiation) log(E/erg)



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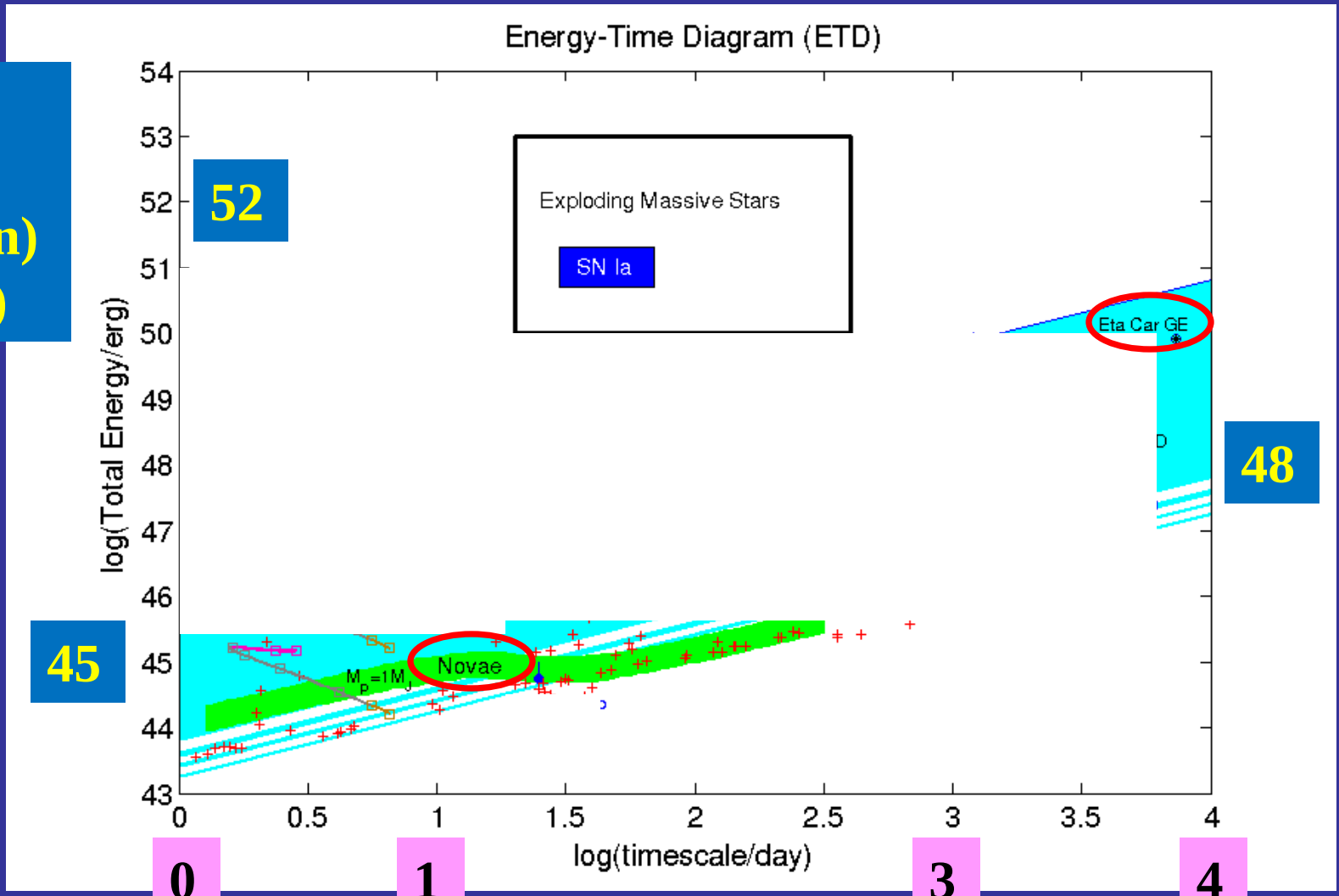
Log(time/day)

From *Amit Kashi*
Updated in:
http://physics.technion.ac.il/~ILOT/

Total (Kinetic +radiation) log(E/erg)



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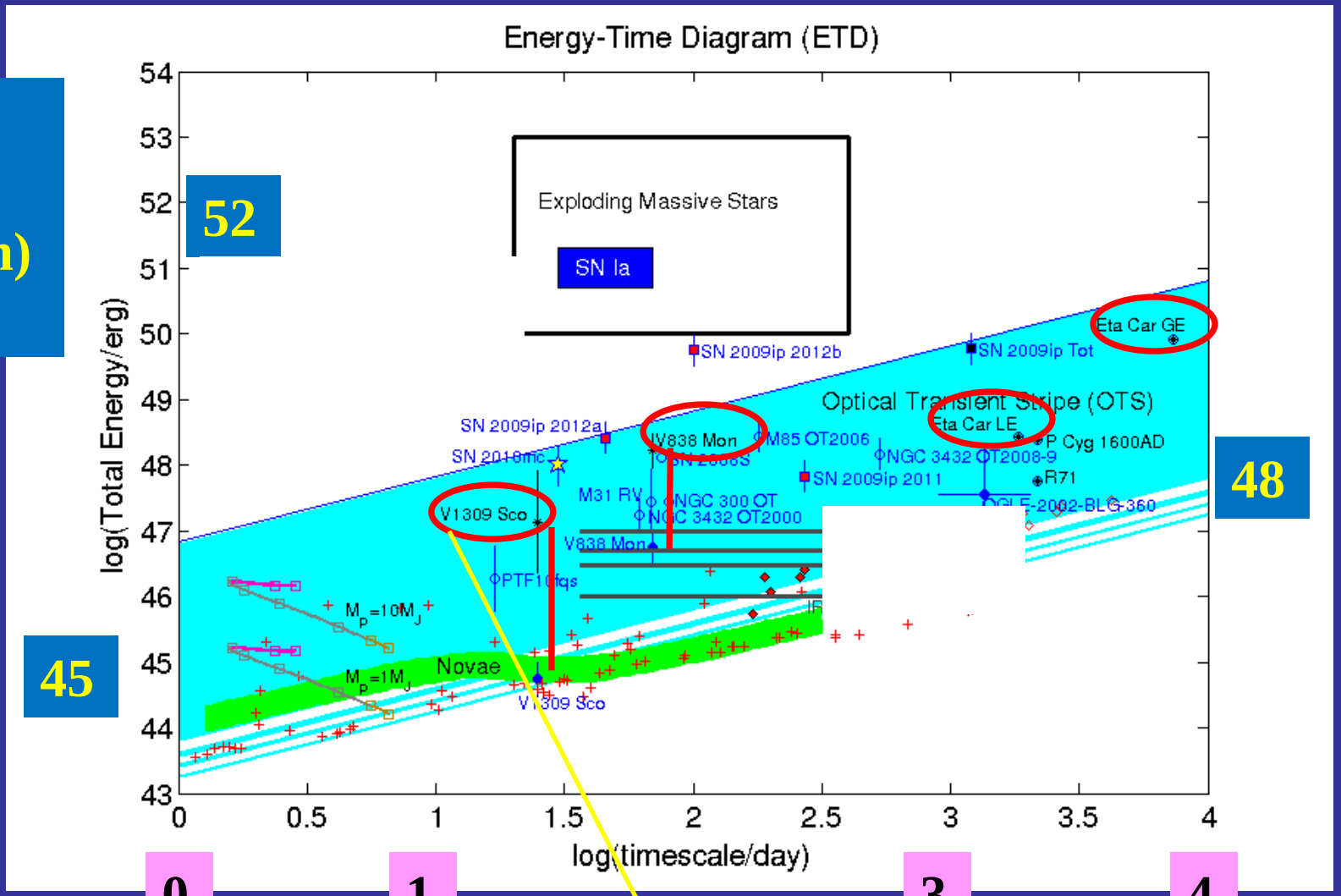

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Christine Nicholls

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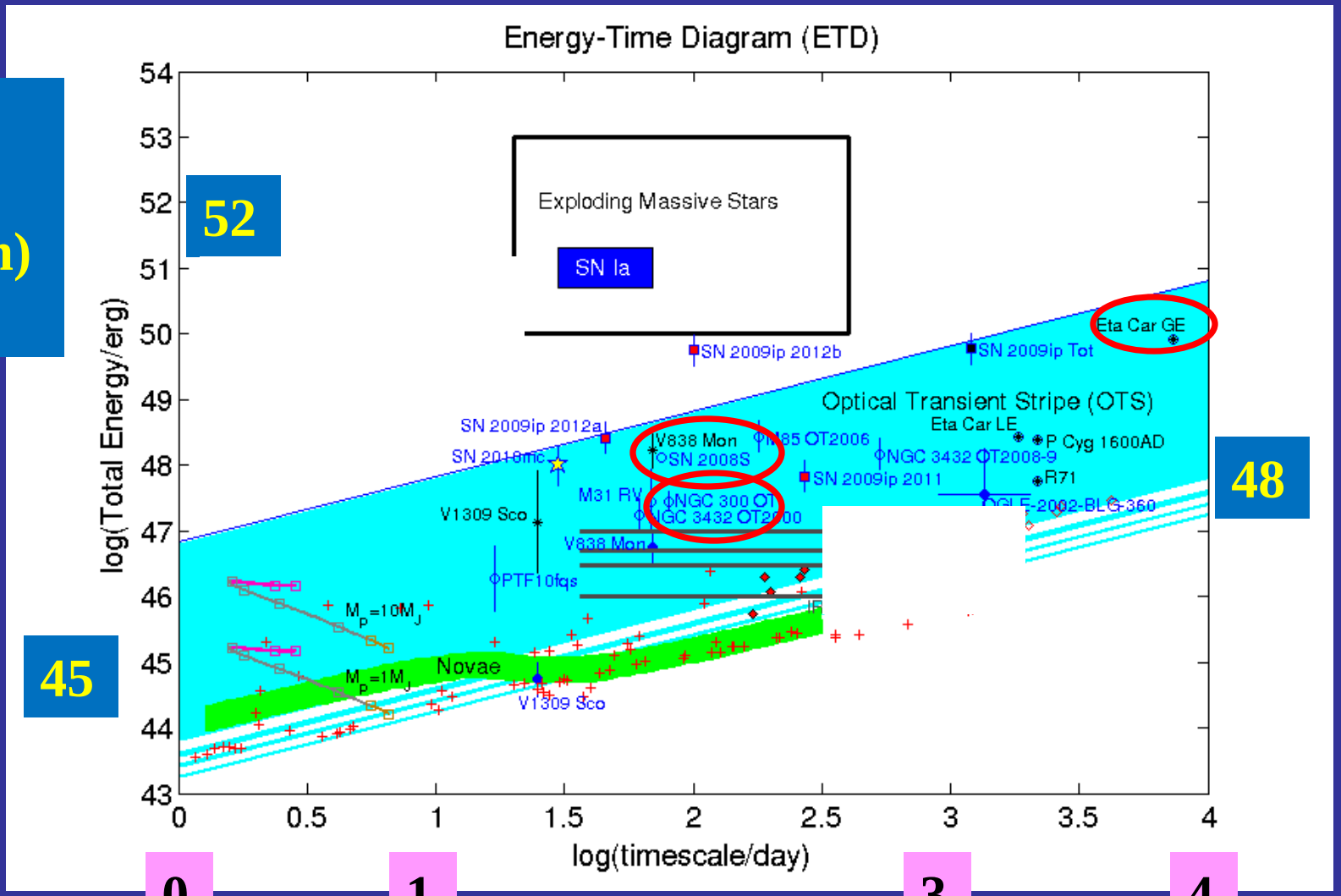

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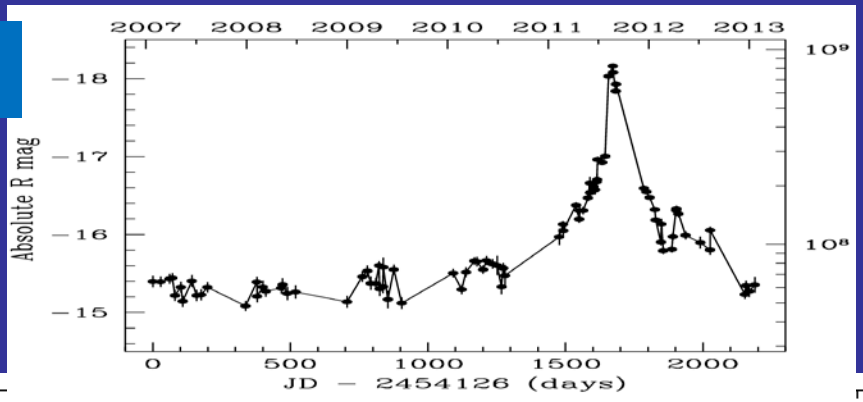
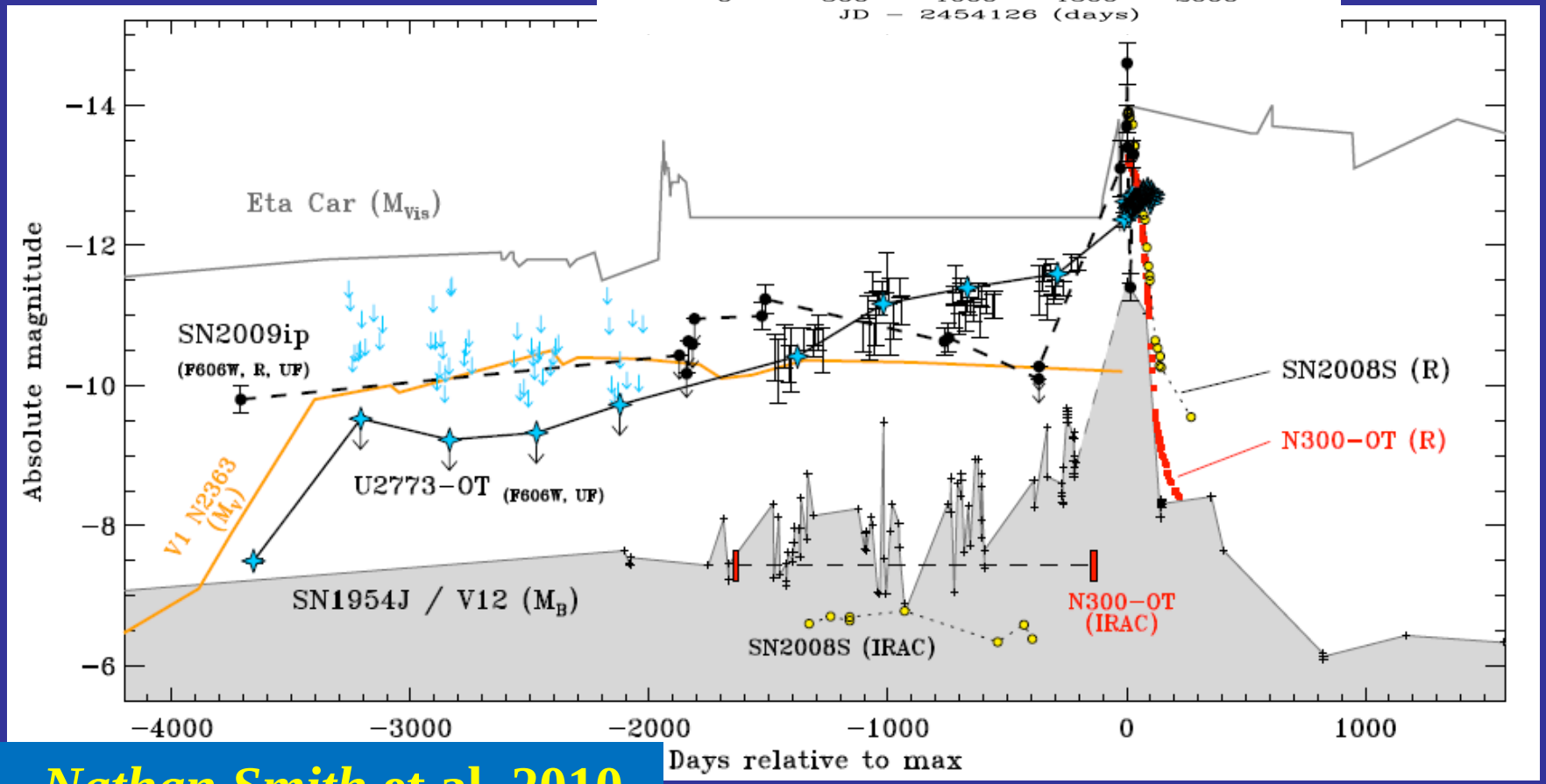
***Jose Prieto*: SN 2011fh**





- ***Nathan Smith* et al. 2010**

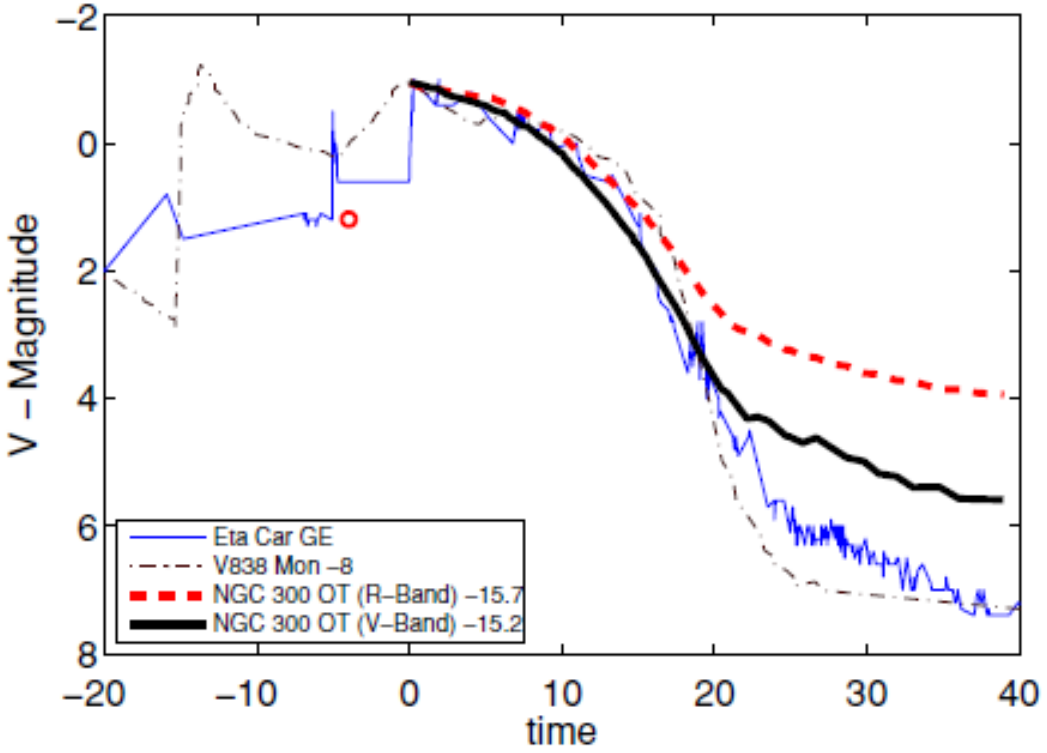
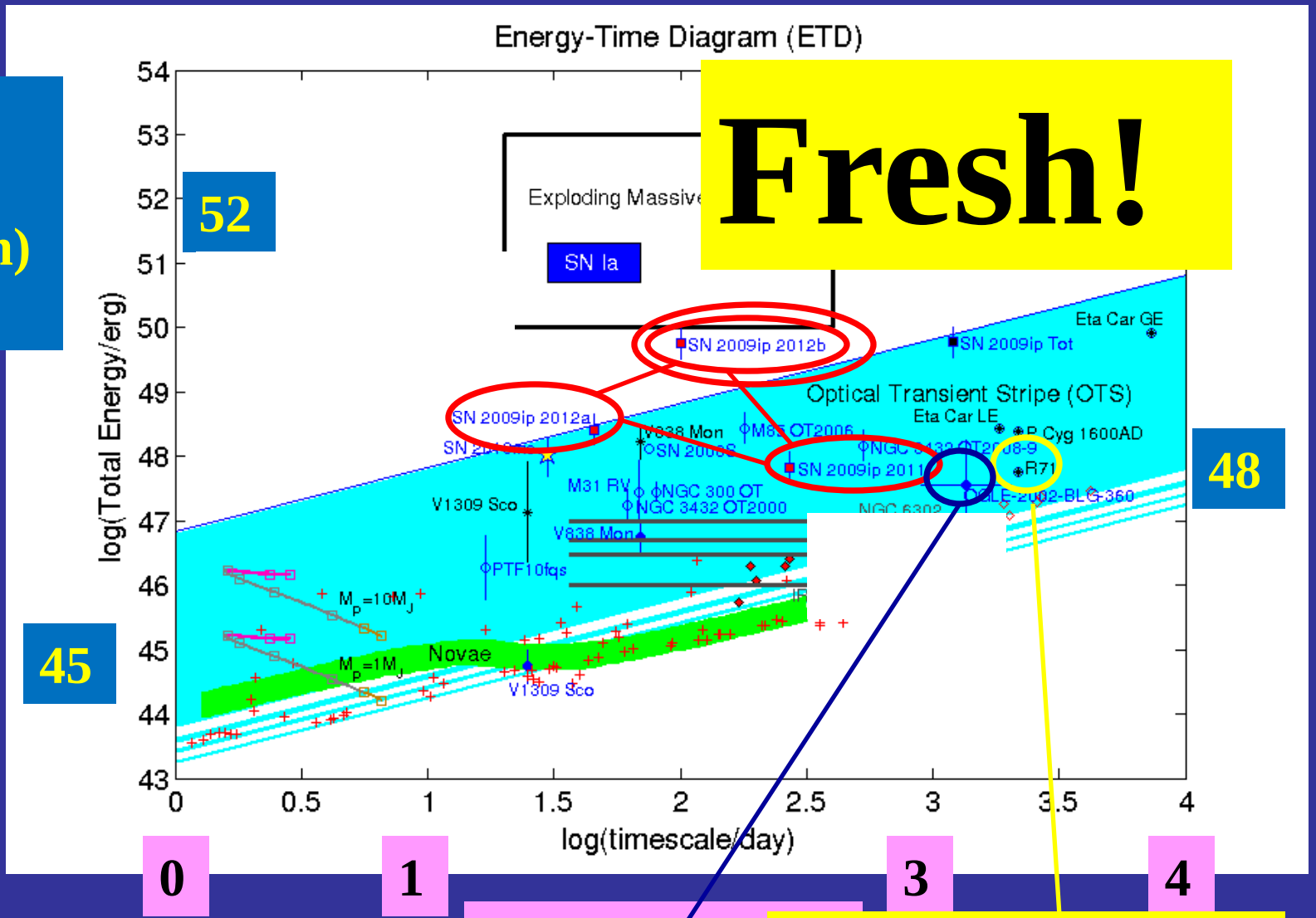


Figure 1. Comparison of the *V*-band light curves of the η Car GE, V838 Mon and NGC 300 OT. The timescale was normalized so that 1 time unit equals 1 yr for η Car GE, 2.2 days for V838 Mon, and 5.6 days for NGC 300 OT. For NGC 300 OT the *R*-band is also plotted, for which there has been one observation before the maximum (Bond et al. 2009), marked with a red circle. Top: the three separated light curves; the apparent *V*-mag axis was not rescaled. Bottom: the same curves translated vertically to bring peak luminosities to overlap (see legend for the shift values). It can be easily seen that the slope of the decline phase and its rate of change are similar for the three eruptions.

- *Kashi, Frankoski, Soker* 2010
- Time is scaled

Total (Kinetic +radiation) log(E/erg)



Fresh!

Log(time/da

R71: Andrea Mehner

OGLE-2002-BLG-360

Tylenda et al. (4 days ago on astro-ph)

From *Amit Kashi*

Updated in:

http://physics.technion.ac.il/~ILOT/

SN 2009ip:

A SN impostor in 2009—but what about 2012b?

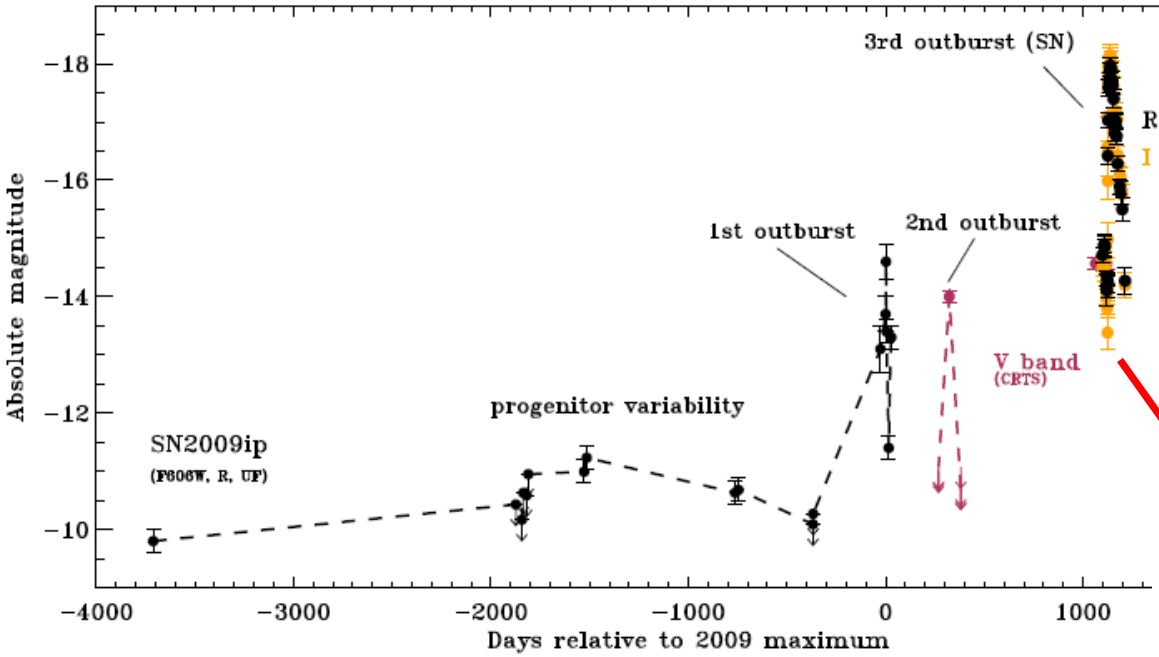
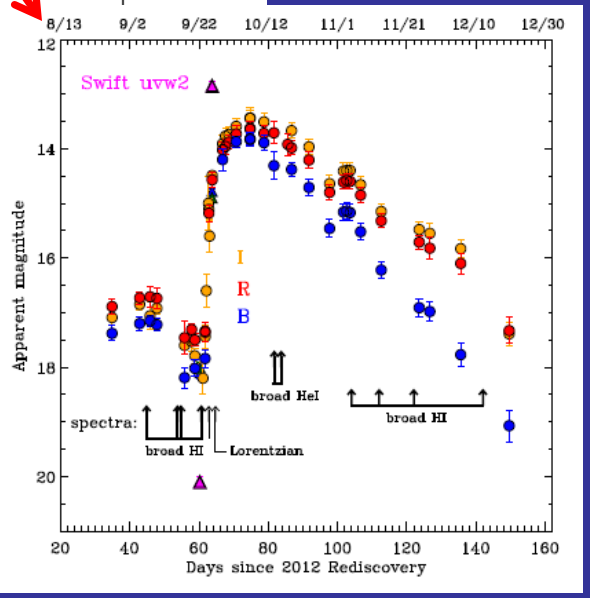
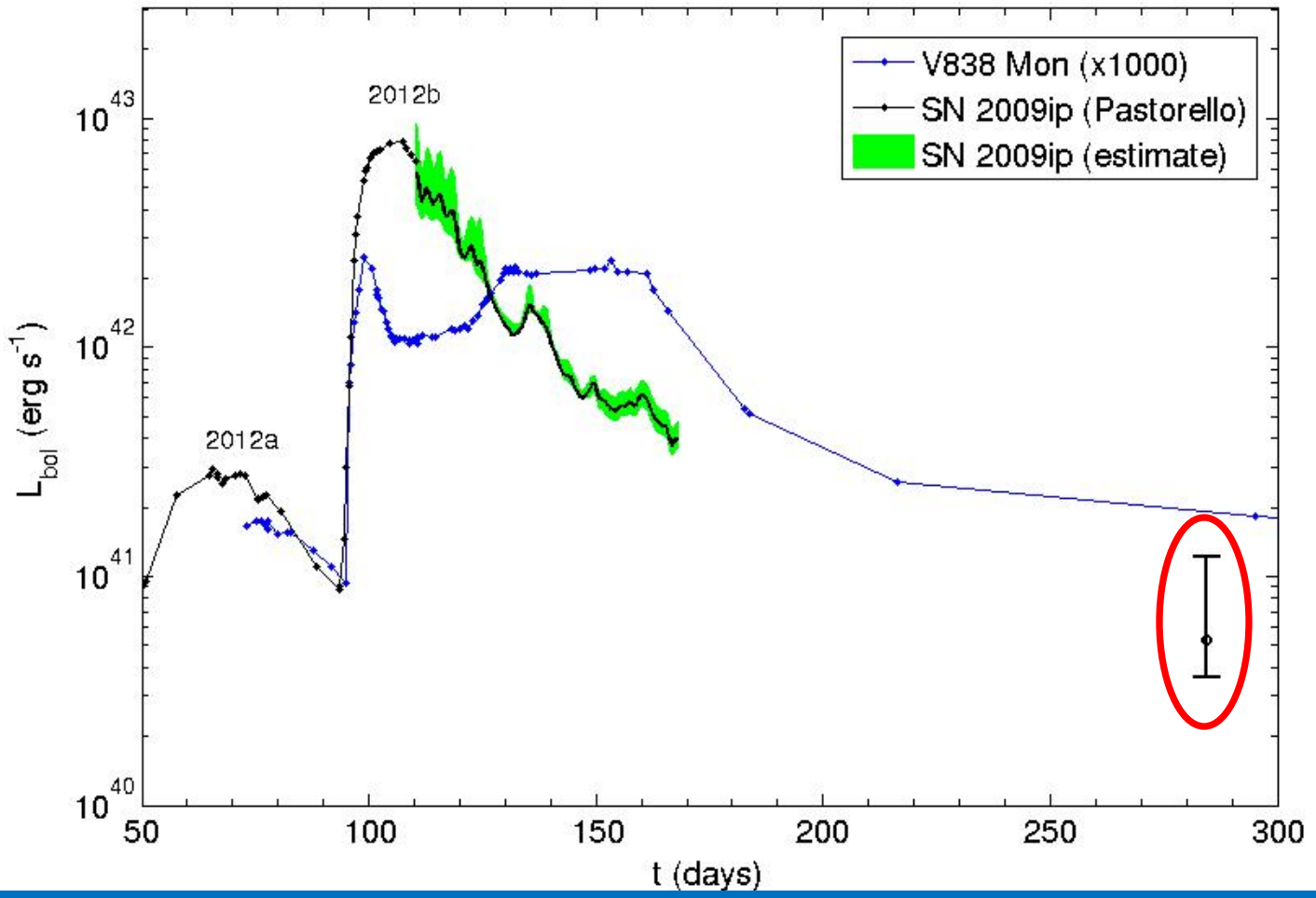


Figure 3. Absolute magnitude light curve of SN 2009ip, including archival *HST* data, and the ground-based photometry (see Smith et al. 2010b).



From Mauerhan, *Nathan Smith* et al. 2013:

- **First 2012a peak is a SN weak explosion**
- **Second 2012b large peak: ejecta-CSM**

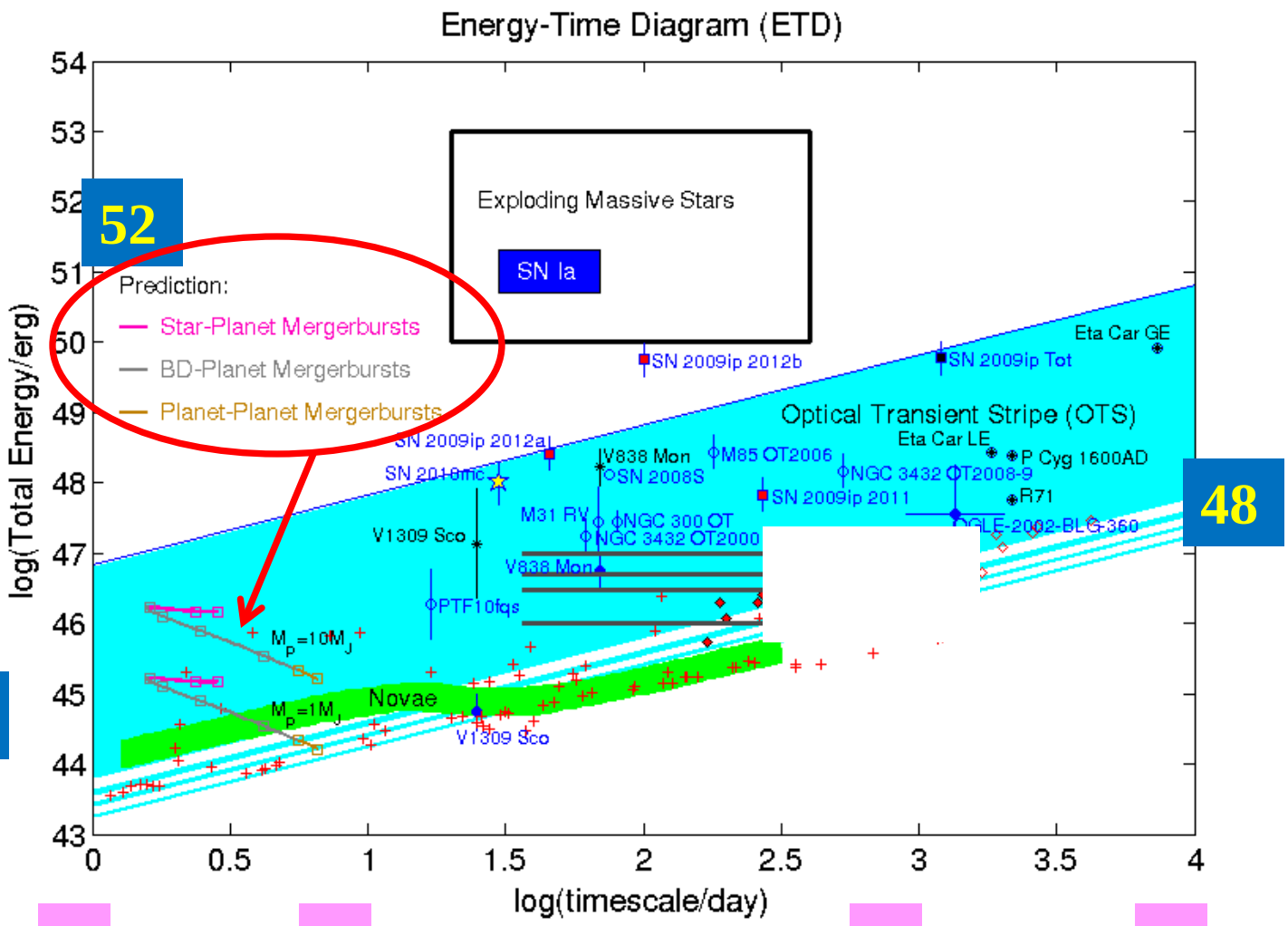


From Soker & Kashi 2013: SN2009ip

Small peaks: periastron passages.

Large peak: merger.

Total (Kinetic +radiation) log(E/erg)



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Log(time/day)

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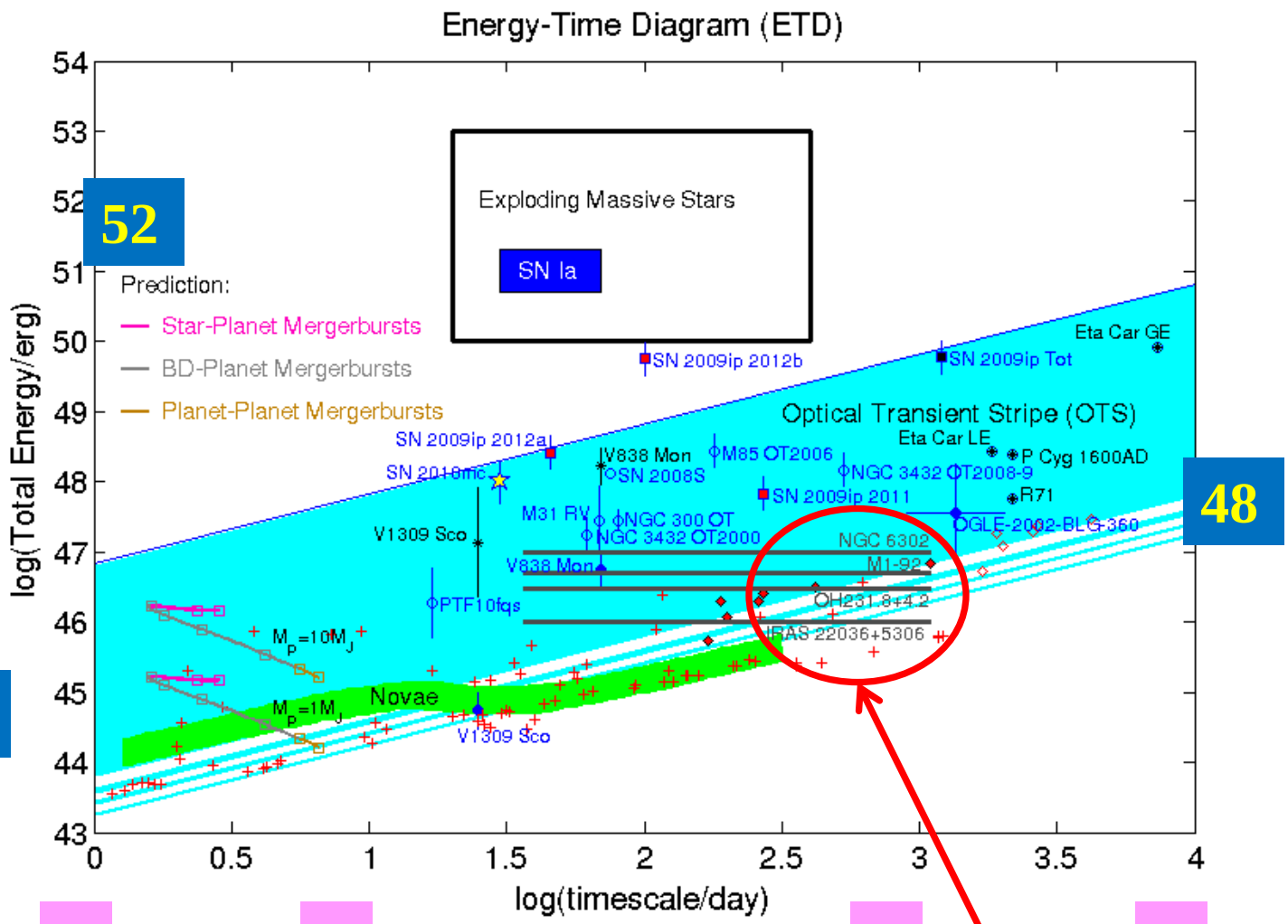

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Updated in:
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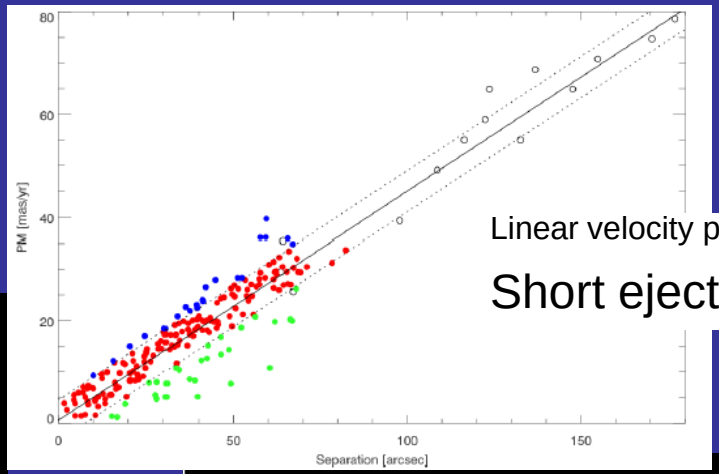
Suggestion (Kashi & soker) : Planetary nebulae and pre-PNe

NGC 6302



Linear velocity position relation:

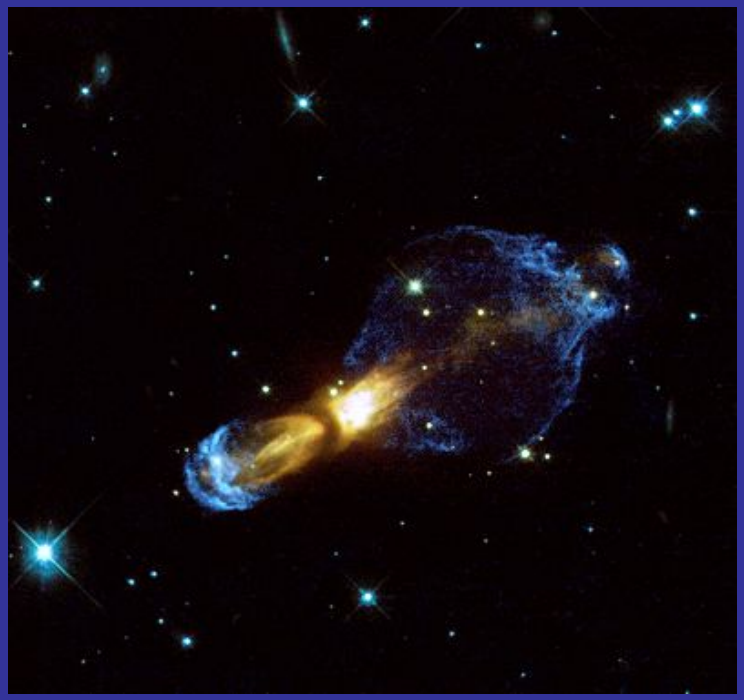
Short ejection episode.

NGC 6302 G349.5+01.0 17 13 44.21 -37 06 15.9, R:G:B = Halpha
credit: Romano Corradi
ref: http://www.iac.es/gabinete/difus/ruta/romano/imagen/n6302ha.gif

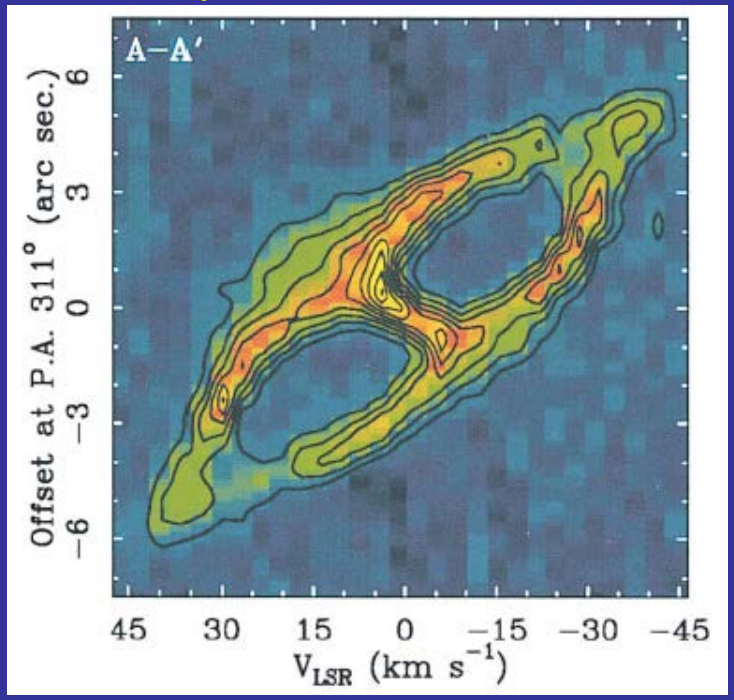
Romano Corradi

Szyszka, C.; Zijlstra, A. A.; Walsh, J

Pre-Pne that formed in a short time: ILOTs (Red Novae)?



OH231.8+4.2
(Bujarrabal et al. 1998)



M1-92 (Bujarrabal et al. 1998)

Common to all these objects in the gap is ejection of large quantities of dust

- Progenitors of PNe;
- Mergerburts;
- SN impostors;
- LBV major eruptions (that seems to be all binaries);
- Other systems with periastron activity

[SN 1Ilot] All these objects are power by gravitational energy of mass transfer, including merger, which is an extreme case of mass transfer.

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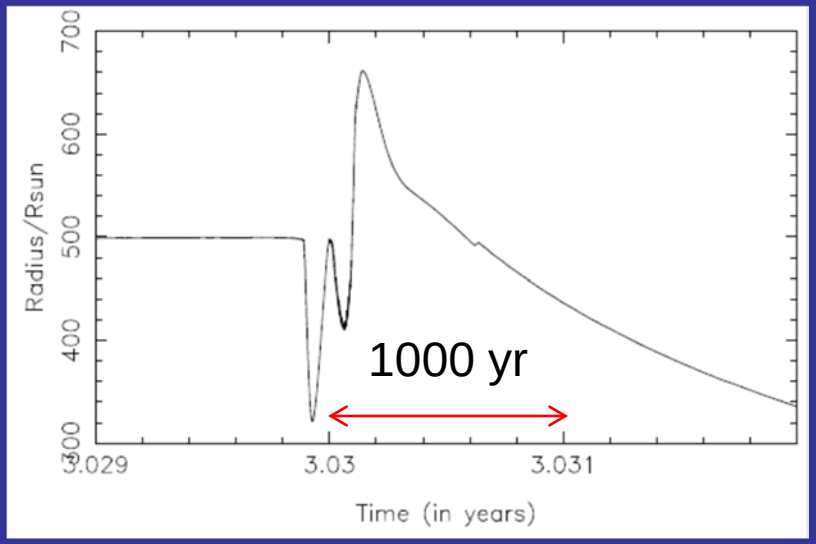


An AGB star after thermal pulse can increase its radius in several years. It will strongly interact with a companion, in particular on eccentric orbit.
(from *Amanda Karakas*)

Eccentricity important *(C. Nicholls)*

[SN 2Ilot] Binarity is behind the massive CSM dusty ejection in most (all) these objects.

I find the many talks and posters on mass loss, dust formation, chemistry, ejecta-CSM interaction, and their relation to nebular morphology, to support the above claim:
O. de Marco; H.M.J. Boffin; D. Jones; A. Tyndal; O. Chesneau; N. Smith; J. Groh; Takashi Moriya; F. Bufano ; D.R. Goncalves; L. Guzman-Ramirez; D. Ladjal; I. Cherchneff ; Mikako Matsuura; O. Jones; E. Lagadec; C. Nicholls; F. Matteucci; S. Srinivasan

Note nebula-ISM interaction which complicates structures (*Nick Cox*)

Supernova Type Ia

- **Reminder to myself 1: Try to use all time and avoid SN Ia (who needs these objects)?**
- **Reminder to myself 2: If reaching this point, make a pause to take a pill against headache, or form a support group with *Bruno Leibundgut***

Supernova Type Ia:

Traditionally the single-degenerate (a complete failure) and the double-degenerate *(Ken Shen; Ashley Ruiter)* are mentioned.

We can get rid of the obsession that these are the only two possibilities for SN Ia.

Note: I even don't refer to the mass of the WD ***(Bruno Leibundgut)***

[SN 0SNIa] If WDs knew theory, they would not have exploded as SNIa.

[SN 1SNIa] **SNIa belong to us**: to those who combine low mass (1-7 Mo) and massive (M>10Mo) stars.

(The evolution toward SNIa has almost nothing to do neither with the cataclysmic variable community nor with the cosmologiests).

- CSM in SNIa a major issue! *(Assaf Sternberg; Francisco Forster; Santiago Gonzalez)*

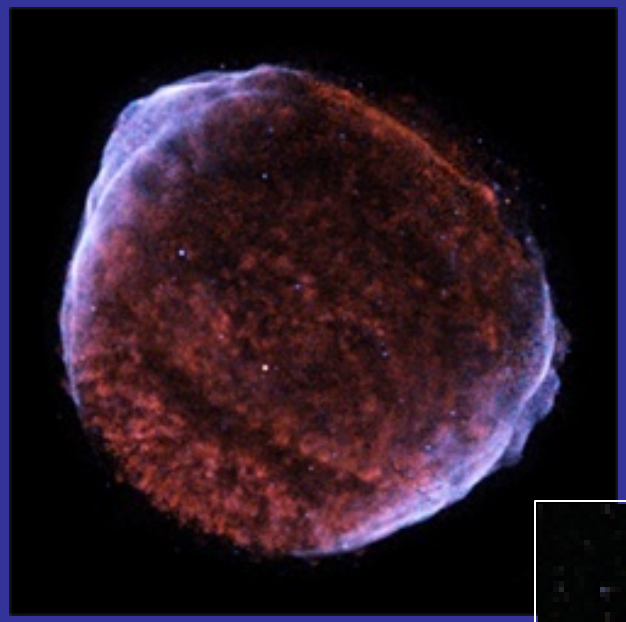
  It seems to be too massive for the SD scenario (e.g., PTF11kx; Soker et al. 2013).

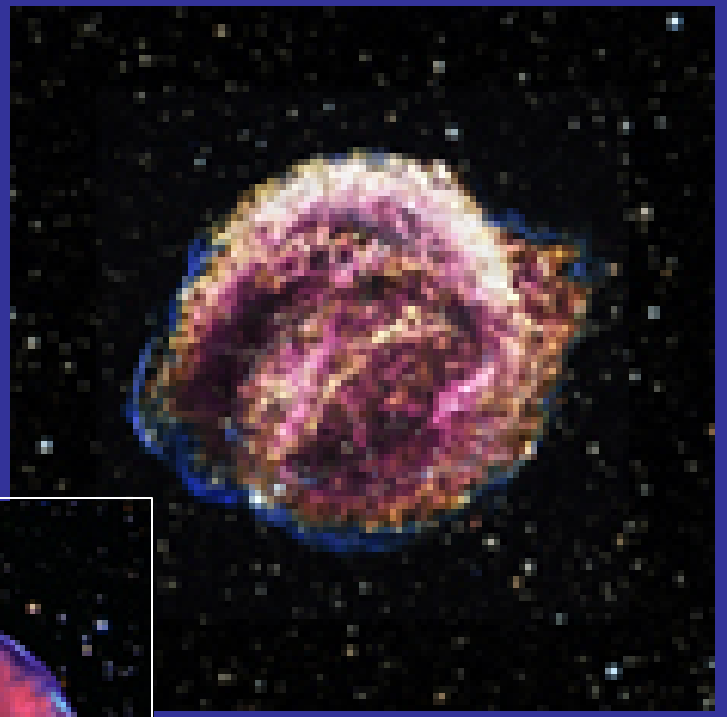
* Many binary systems avoid common envelope (CE) when the primary becomes a giant

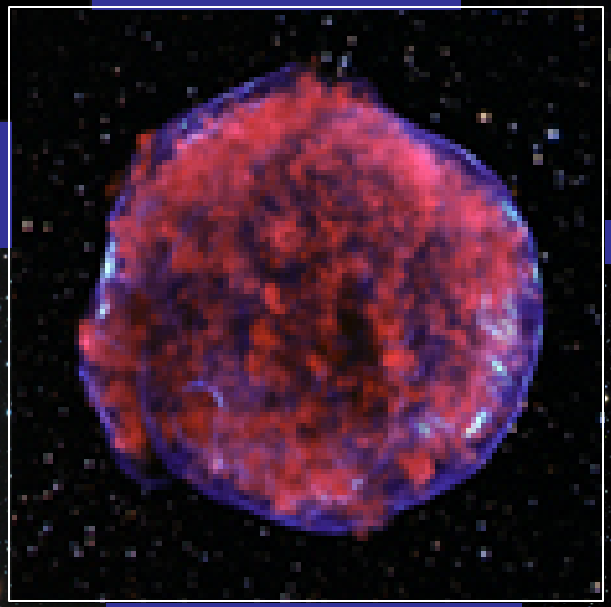
  Emphasized by *Henri Boffin* and

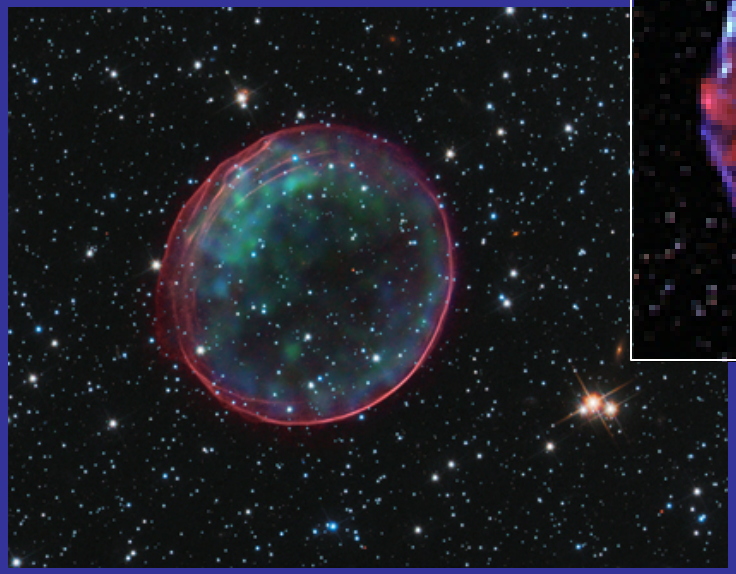
- **Crucial for SN Ia in the double-degenerate and in the core-degenerate scenarios.**

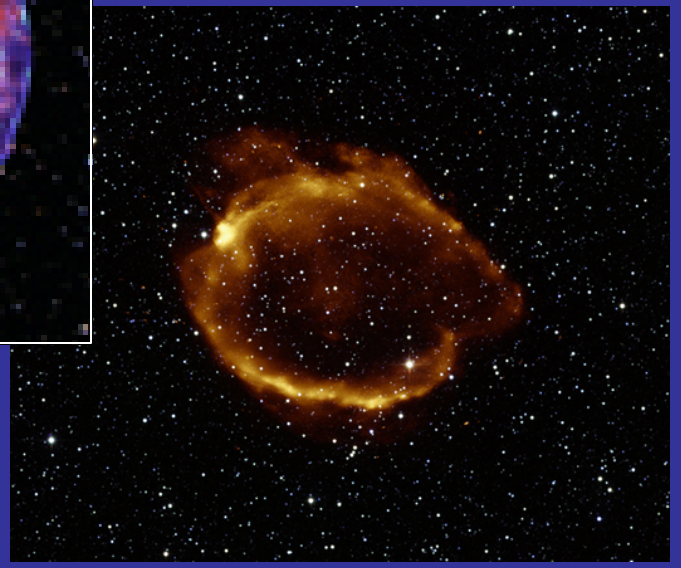
Reason: The secondary is massive enough to bring the primary to synchronization.







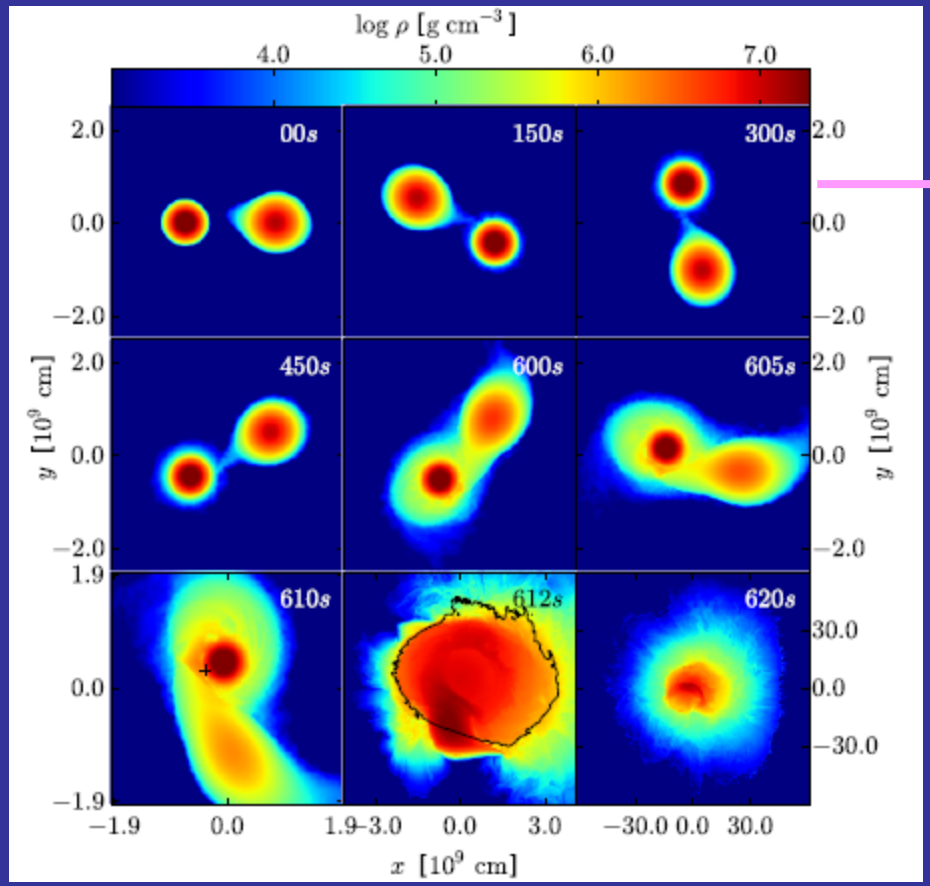


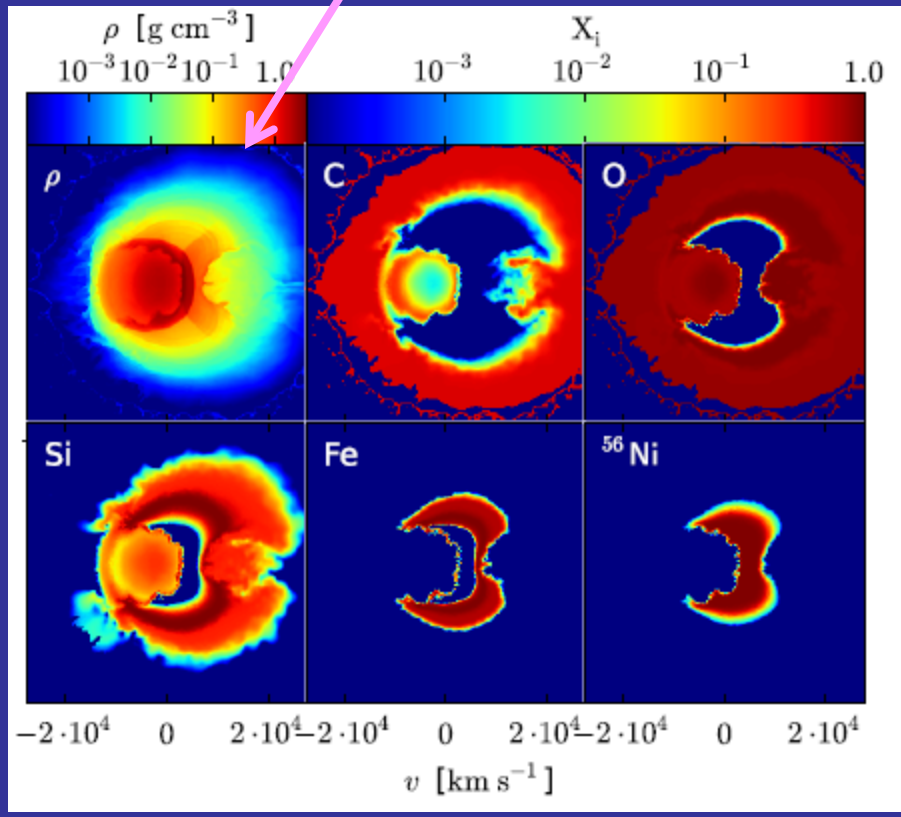


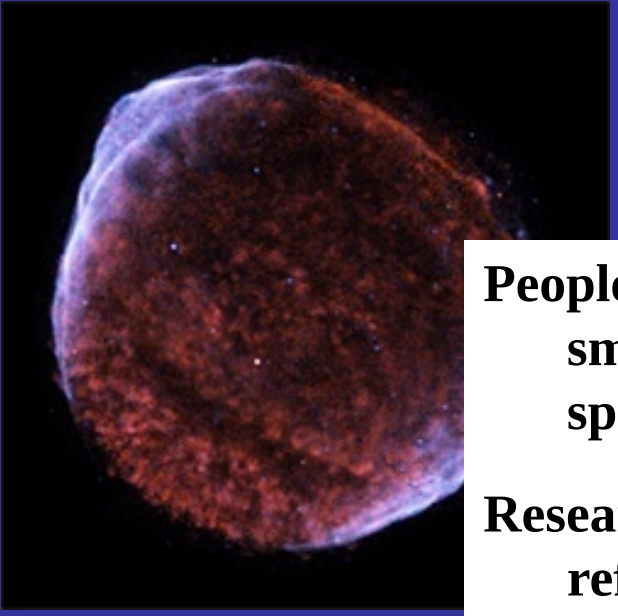
The Astrophysical Journal Letters, 747:L10 (5pp), 2012 March 1 doi:10.1088/2041-8205/

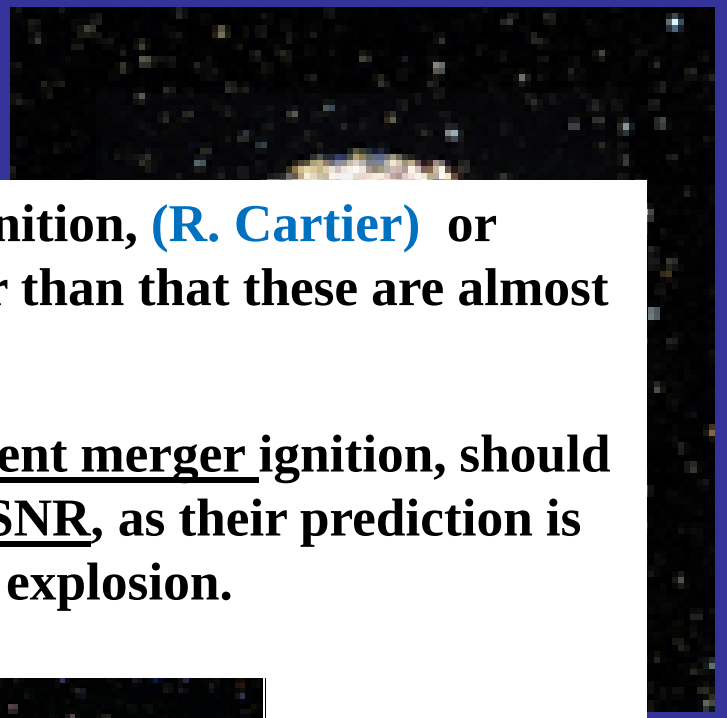
NORMAL TYPE Ia SUPERNOVAE FROM VIOLENT MERGERS OF WHITE DWARF BINARIES

R. Pakmor[1], M. Kromer[2], S. Taubenberger[2], S. A. Sim[3], F. K. Röpke[4], and W. Hillebrandt[2]





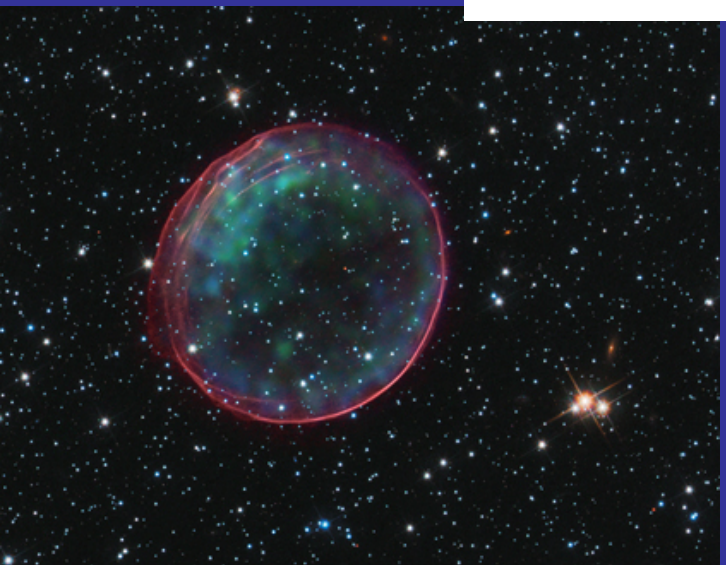


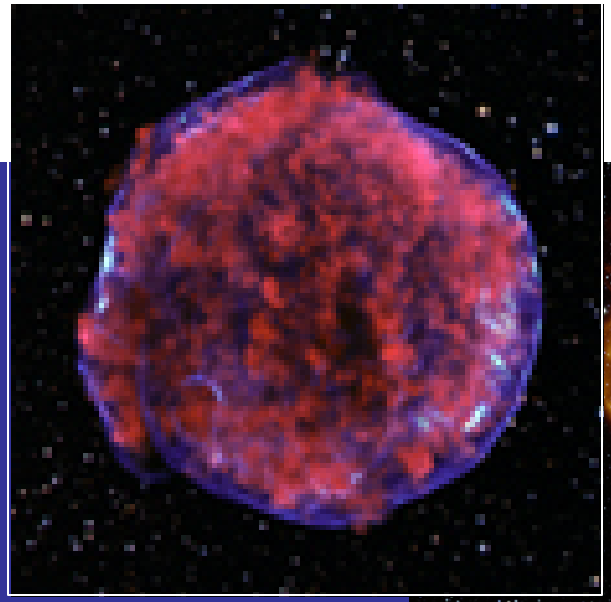


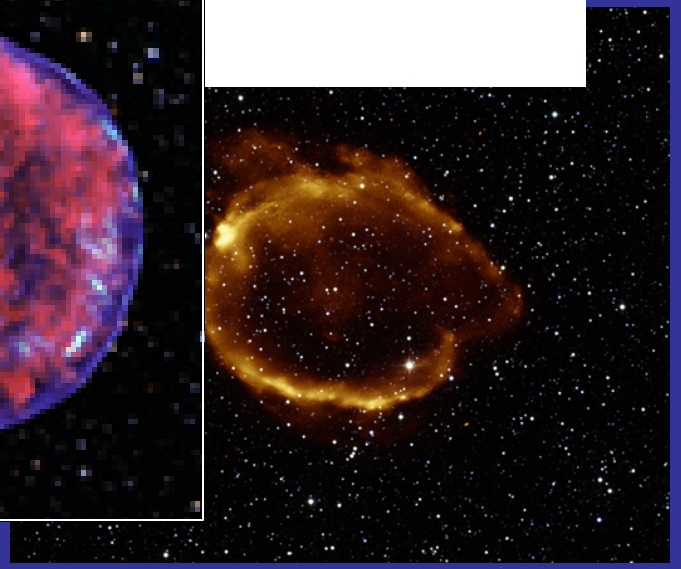
People refer to off-center ignition, (R. Cartier) or small rotation, but other than that these are almost spherical.

Researchers simulating violent merger ignition, should refer to these spherical SNR, as their prediction is for highly "egg shaped" explosion.

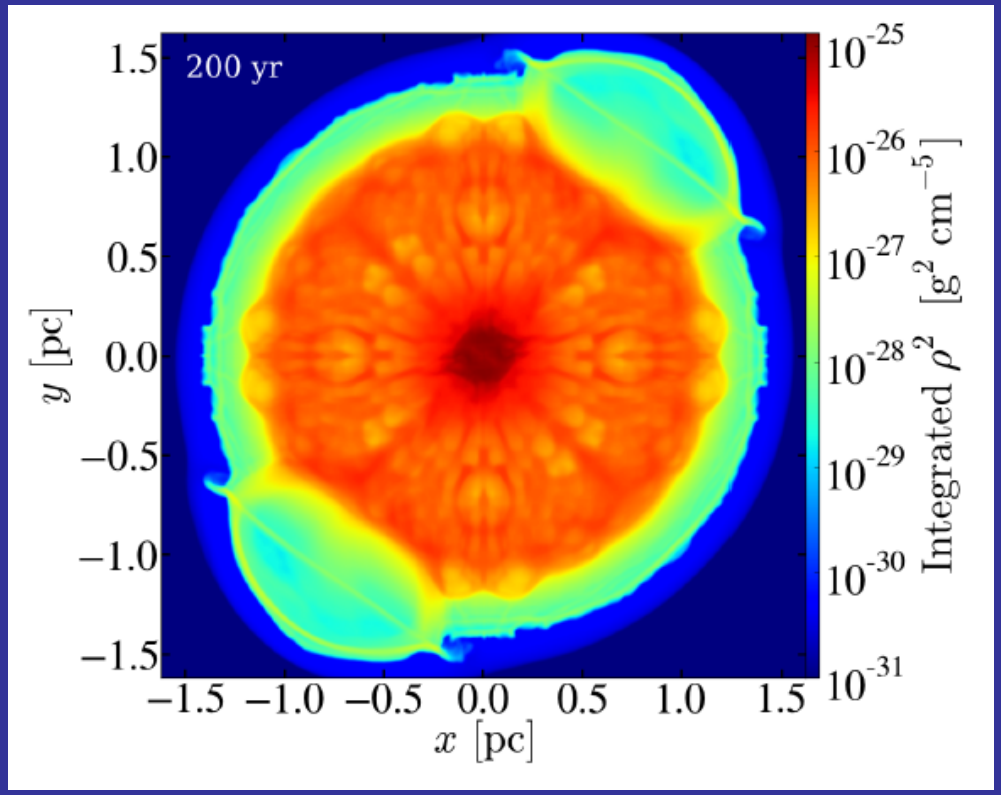
But . . .

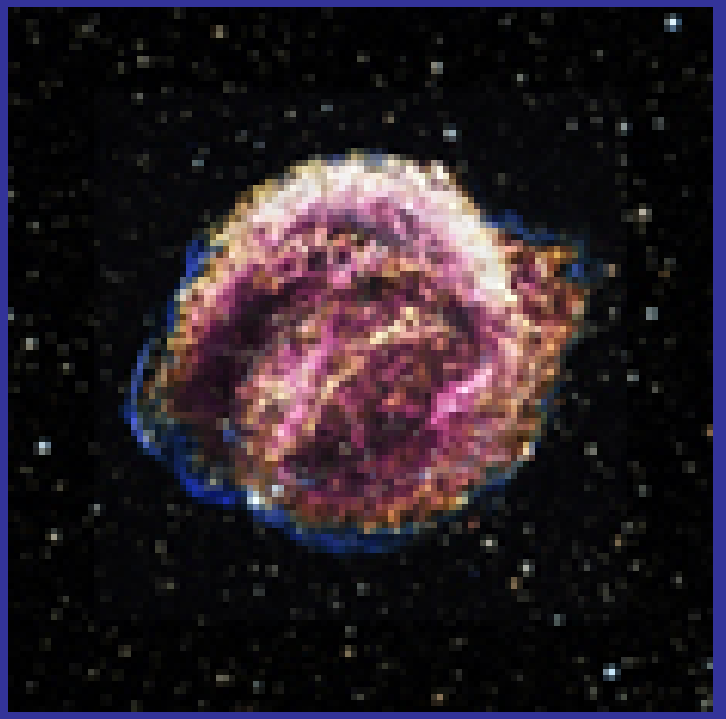






JETS !?





Simulations of jets by Danny Tsebrenko

Supernova Type Ia

[SN 2SNIa] **Not even one SNIa since the big bang came from the single-degenerate route.**

[SN 3SNIa] When it finally explodes, in most (all) cases the WD is all alone by itself, sometimes with a **disk** around it.

[SN 4SNIa] They come from massive stars (M>4Mo).

Some SN Ia have dense CSM.

Inside there is a hot WD to be exploded.

Therefore:

[SN 5SNIa] some SNIa explode inside a PN (or pre-PN like object).

Follow the Angular Momentum,

But don’t follow me!

Noam Soker