Pleasantness Review*

Department of Physics, Technion, Israel

Jets in supernovae and supernova remnants

La Réunion Island 2017

Noam Soker

Collaborators: Aldana Grichener, Ealeal Bear, Avishai Gilkis

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

Noam = Pleasantness
Soker = Review

A short summary

JETS

See review Soker, N., 2016, New Astronomy Review 75, 1
(arXiv:160502672):

“The jet feedback mechanism (JFM) in stars, galaxies and clusters (a review)”

A long summary

I think that all core collapse supernovae are exploded by jets operating in a negative jet feedback mechanism

See review Soker, N., 2016, New Astronomy Review 75, 1
(arXiv:160502672):

"The jet feedback mechanism (JFM) in stars, galaxies and clusters (a review)"

A note

The formation of a magnetar would be accompanied by jets that carry more energy than the magnetar

Soker, N. 2016, New Astronomy, 47, 88
(paper accepted to the Journal before is was accepted by astro-ph)

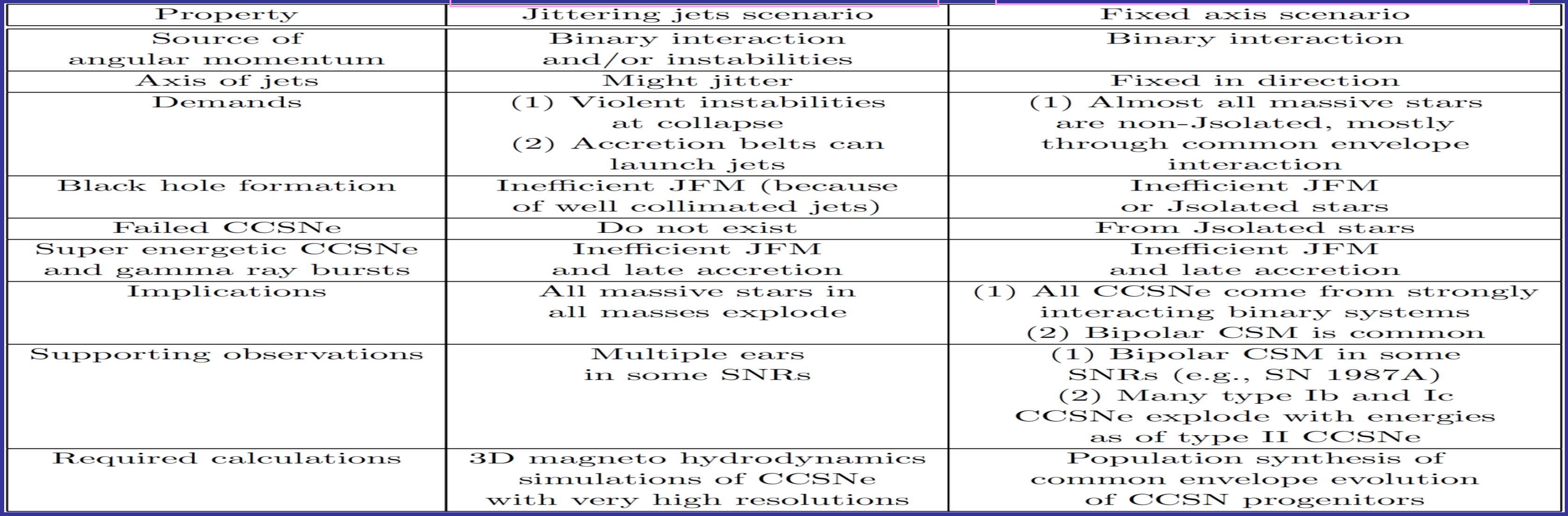
Soker, N. 2017, accepted by the desk of the referee (arXiv:1612.01912)

The two most promising scenarios to explode supernovae:

Both operate in a negative feedback mechanism

The jittering jets scenario

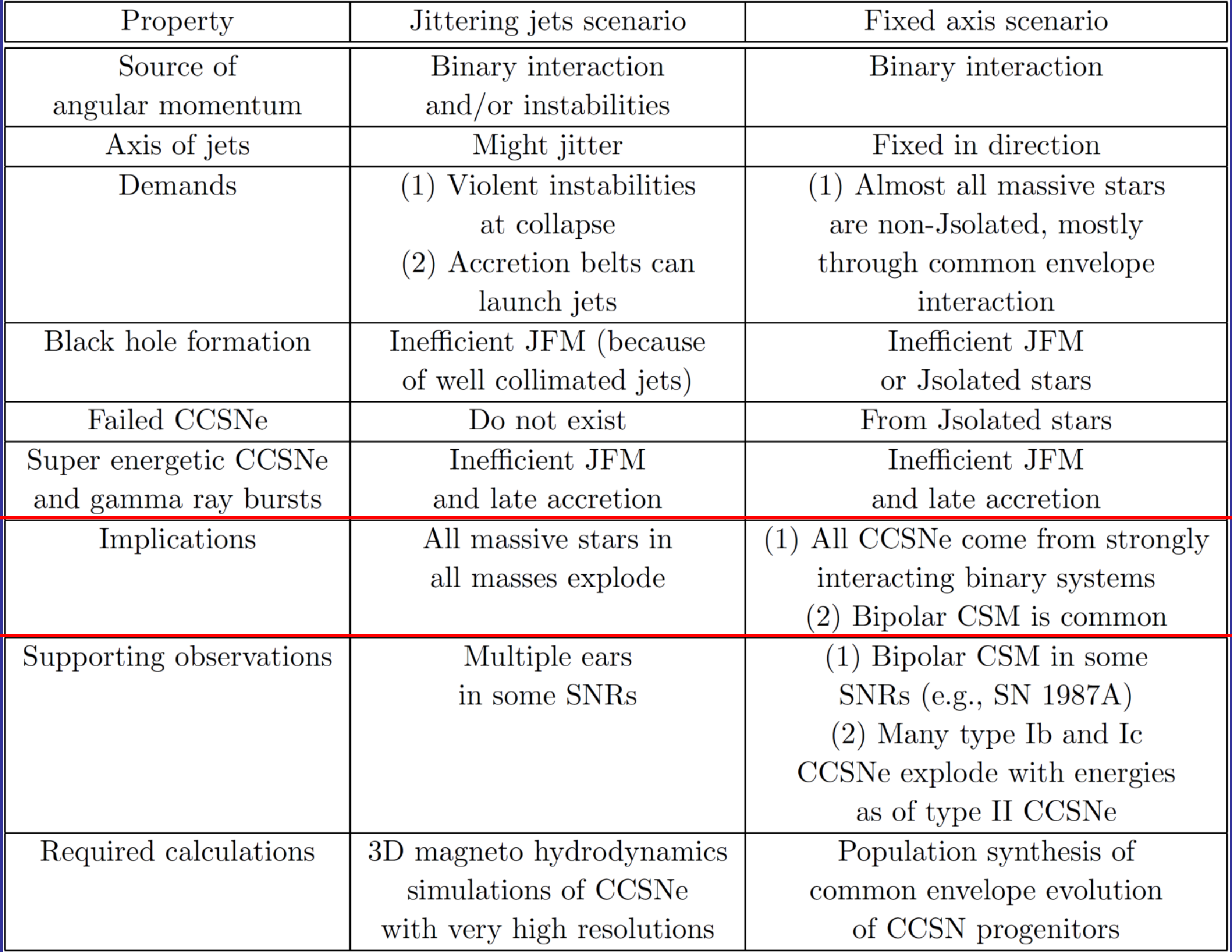
The fixed axis scenario



Property	Jittering jets scenario	Fixed axis scenario
Source of angular momentum	Binary interaction and/or instabilities	Binary interaction
Axis of jets	Might jitter	Fixed in direction
Demands	(1) Violent instabilities at collapse (2) Accretion belts can launch jets	(1) Almost all massive stars are non-Jsolated, mostly through common envelope interaction
Black hole formation	Inefficient JFM (because of well collimated jets)	Inefficient JFM or Jsolated stars
Failed CCSNe	Do not exist	From Jsolated stars
Super energetic CCSNe and gamma ray bursts	Inefficient JFM and late accretion	Inefficient JFM and late accretion
Implications	All massive stars in all masses explode	(1) All CCSNe come from strongly interacting binary systems (2) Bipolar CSM is common
Supporting observations	Multiple ears in some SNRs	(1) Bipolar CSM in some SNRs (e.g., SN 1987A) (2) Many type Ib and Ic CCSNe explode with energies as of type II CCSNe
Required calculations	3D magneto hydrodynamics simulations of CCSNe with very high resolutions	Population synthesis of common envelope evolution of CCSN progenitors

Soker, N. 2017, accepted for publication by astro-ph (arXiv:1702.03451)

The two most promising scenarios to explode supernovae

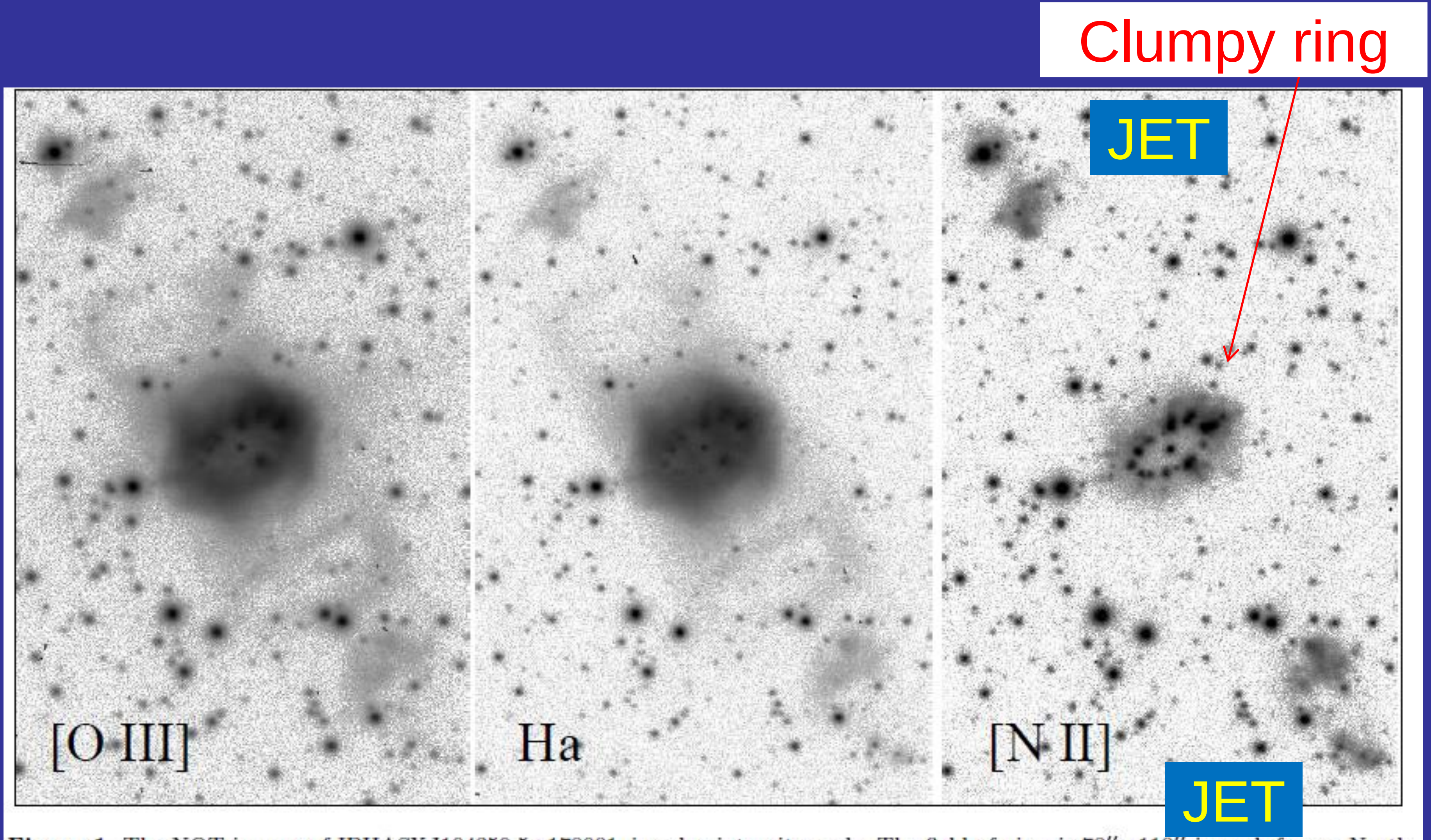


Property	Jittering jets scenario	Fixed axis scenario
Source of angular momentum	Binary interaction and/or instabilities	Binary interaction
Axis of jets	Might jitter	Fixed in direction
Demands	(1) Violent instabilities at collapse (2) Accretion belts can launch jets	(1) Almost all massive stars are non-Jsolated, mostly through common envelope interaction
Black hole formation	Inefficient JFM (because of well collimated jets)	Inefficient JFM or Jsolated stars
Failed CCSNe	Do not exist	From Jsolated stars
Super energetic CCSNe and gamma ray bursts	Inefficient JFM and late accretion	Inefficient JFM and late accretion
Implications	All massive stars in all masses explode	(1) All CCSNe come from strongly interacting binary systems (2) Bipolar CSM is common
Supporting observations	Multiple ears in some SNRs	(1) Bipolar CSM in some SNRs (e.g., SN 1987A) (2) Many type Ib and Ic CCSNe explode with energies as of type II CCSNe
Required calculations	3D magneto hydrodynamics simulations of CCSNe with very high resolutions	Population synthesis of common envelope evolution of CCSN progenitors

Soker, N. 2017, accepted for publication by astro-ph (arXiv:1702.03451)

The Necklace planetary nebula (Form Romano Corradi et al. 2011):

A binary central star with P=1.16 days.



Clumpy ring

JET

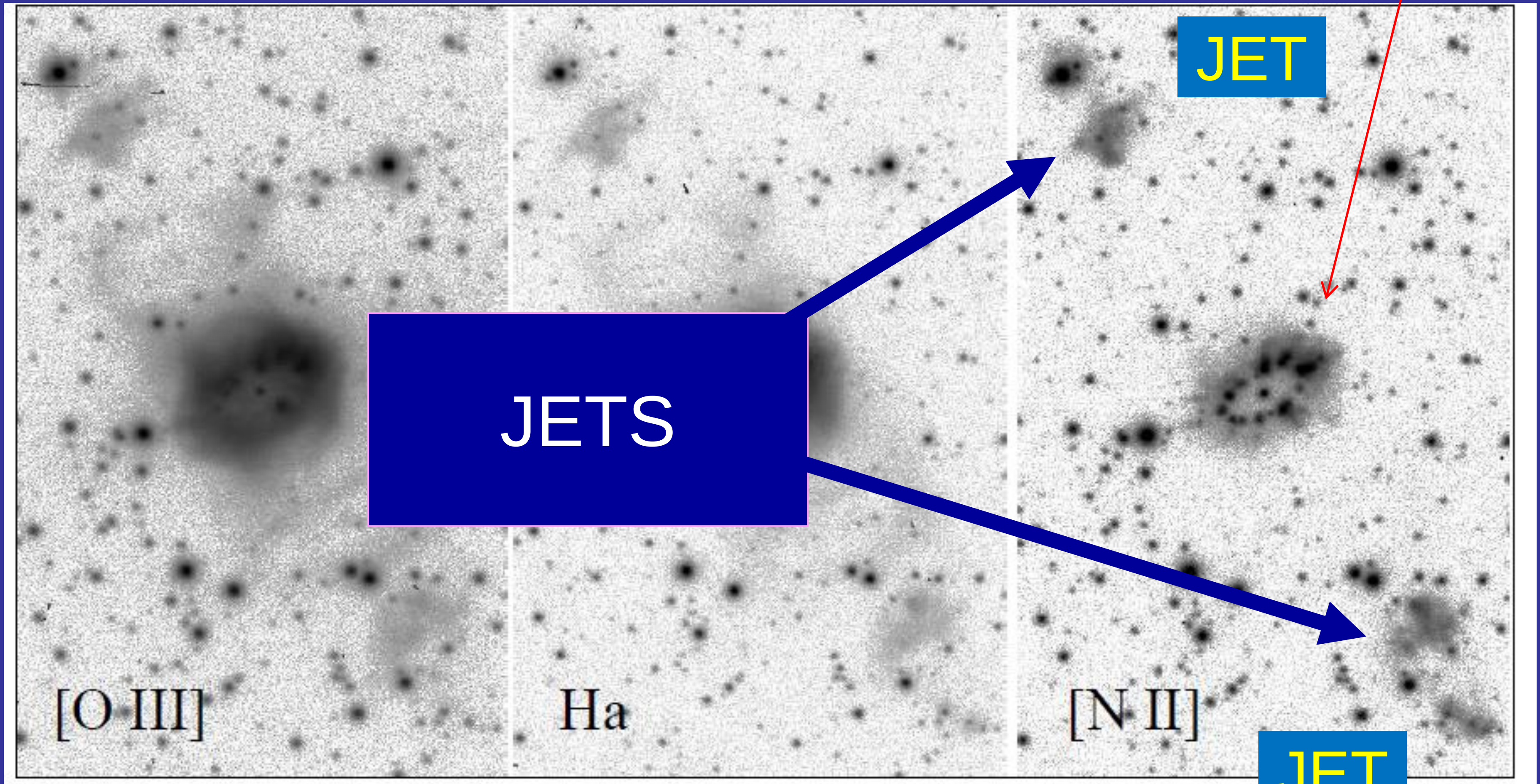
JET

Figure 1. The NOT images of IPHASXJ194359.5+170901 in a log intensity scale. The field of view is 70″×110″ in each frame. North is up and East is left.

The Necklace planetary nebula (Form Romano Corradi et al. 2011):

A binary central star with P=1.16 days.

Clumpy ring



JET

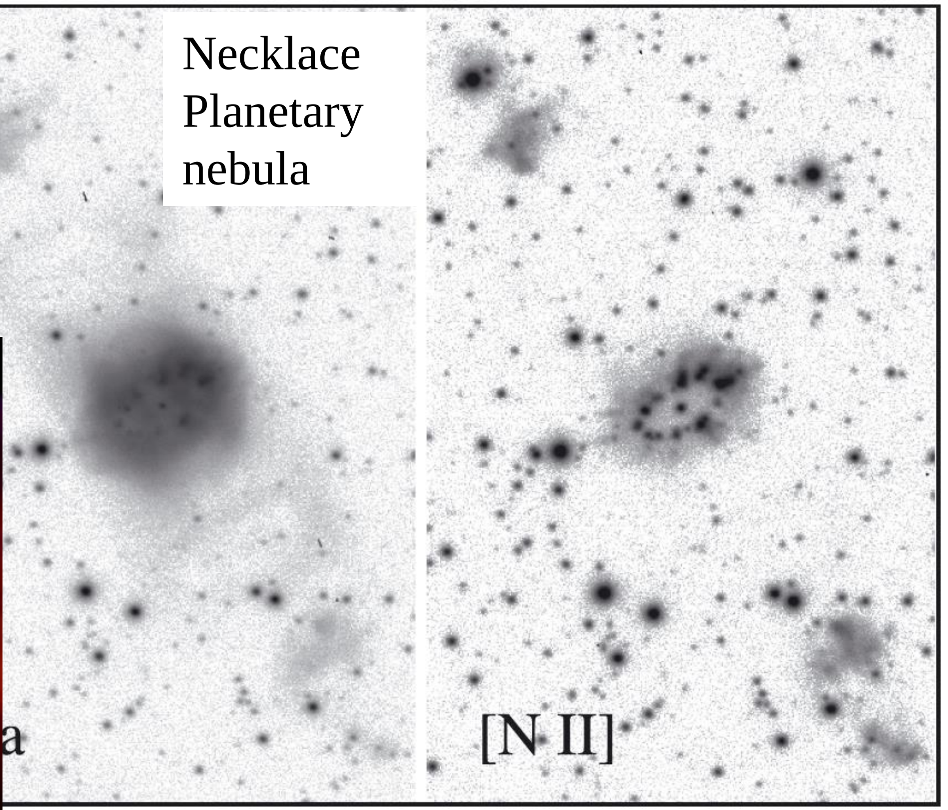
JETS

JET

Figure 1. The NOT images of IPHASXJ194359.5+170901 in a log intensity scale. The field of view is 70″×110″ in each frame. North is up and East is left.

An equatorial dense and clumpy ring

Necklace Planetary nebula

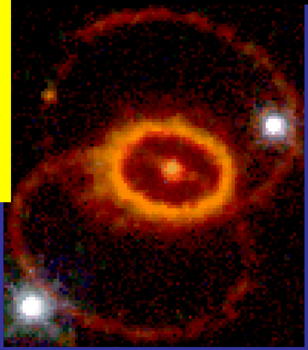


n a log intensity scale. The field of view is 70 × 110 arcsec^2 in each frame. North is up and east

Inner ring in 2004 (HST)

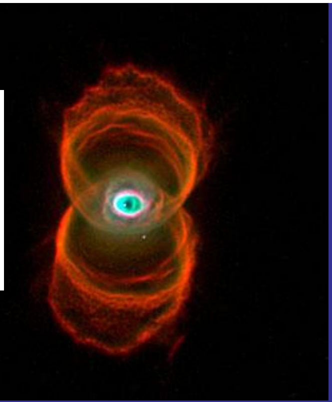
SN 1987A

Supernova remnant



MyCn 18

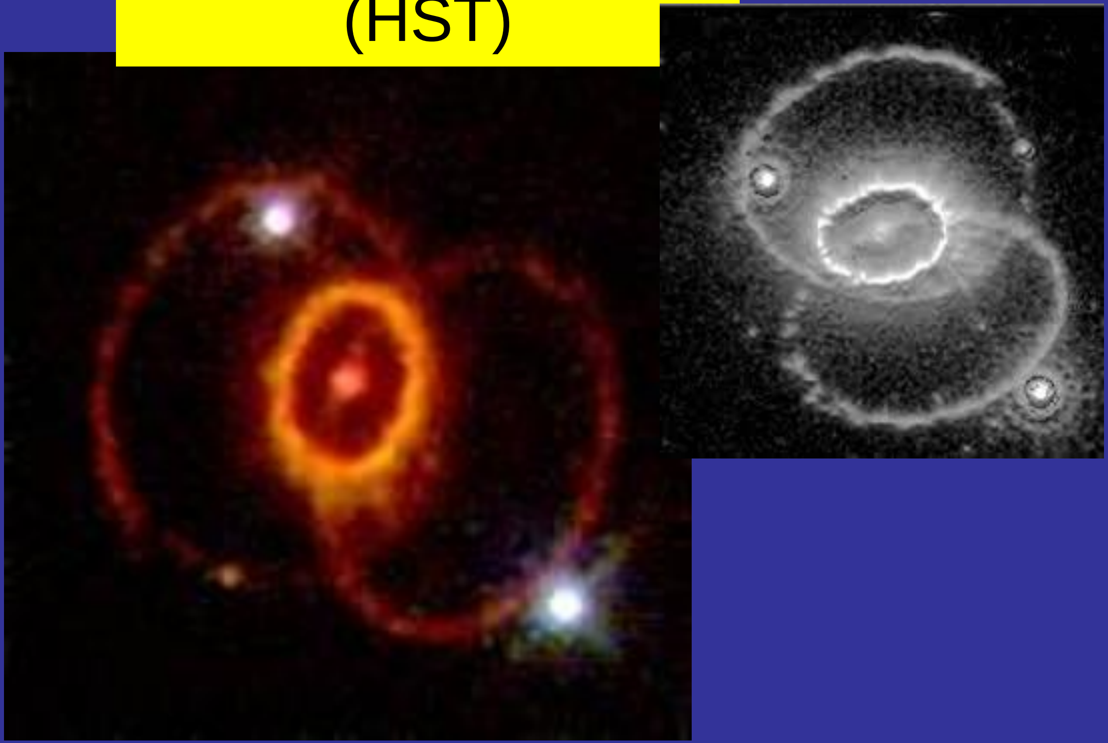
Planetary nebula



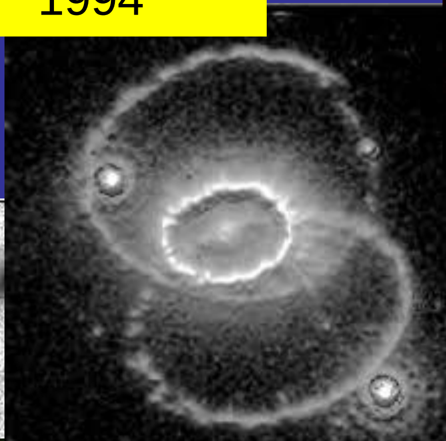
Supernova 1987A evolution (Philipp Podsiadlowski et al.) and the rings (Soker et al.) require binary merger.

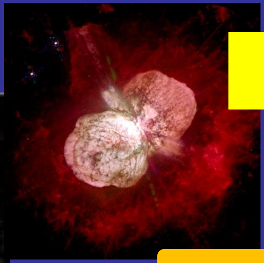
Inner ring in 2004
(HST)

The 3 rings in 1994
(HST)



The 3 rings in 1994



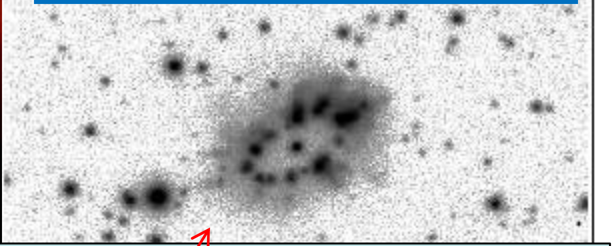


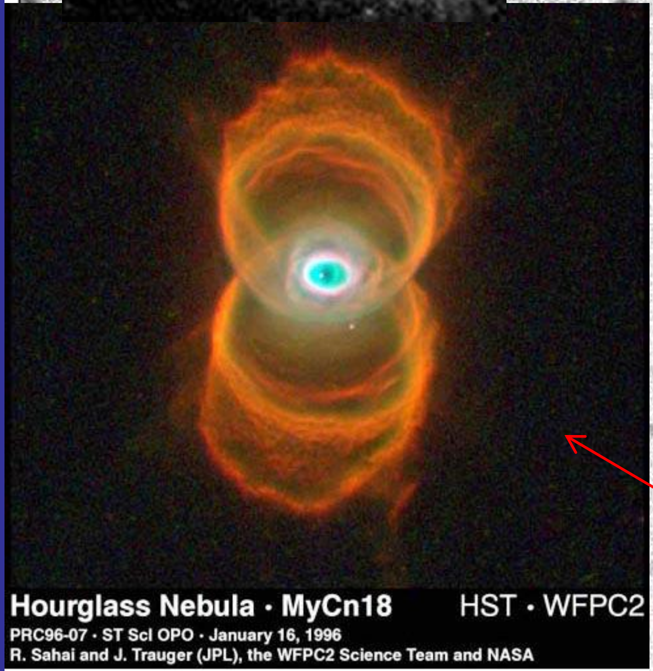
Eta Carinae

Inner ring in 2004

The Necklace planetary nebula

A binary central star with P=1.16 days





Hourglass Nebula · MyCn18 HST · WFPC2

PRC96-07 · ST ScI OPO · January 16, 1996

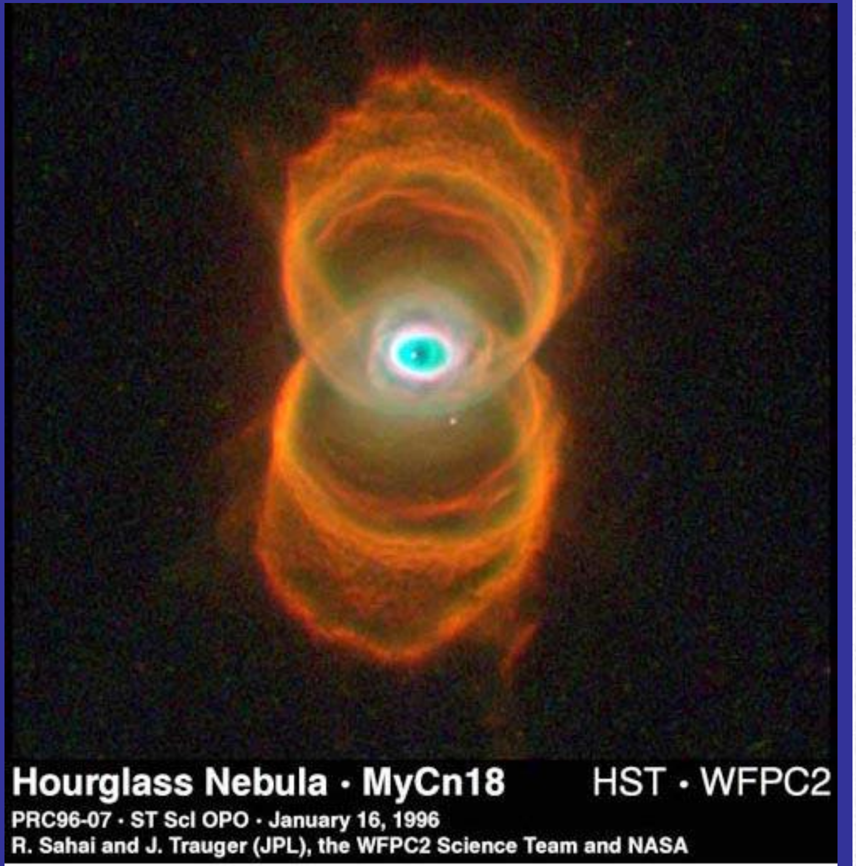
R. Sahai and J. Trauger (JPL), the WFPC2 Science Team and NASA

MyCn18 G307.5-04.9 13 39 35.12 -67 22 51.5, R:G:B = unknown
Sahai, Trauger, WFPC2 GTO, HST/WFPC2/PC?, N is NOT up
ref: hubblesite.org/gallery/album/entire_collection/pr1996007a/
ref: Sahai, R., et al., 1999 AJ 118 468

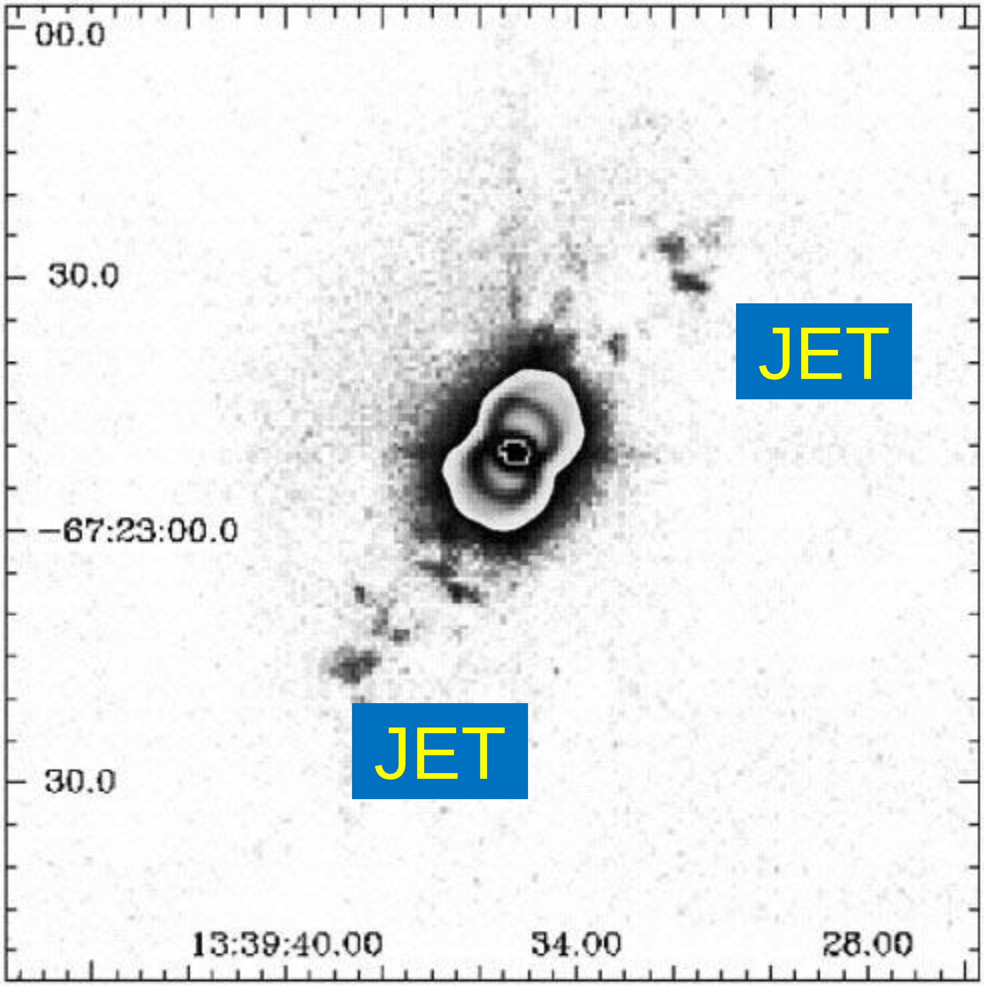
is up and East is left.

planetary nebulae

MyCn18 planetary nebula (Form Sahai et al and O’Connor et al.).

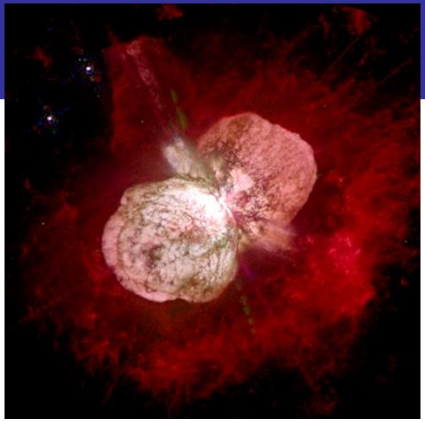


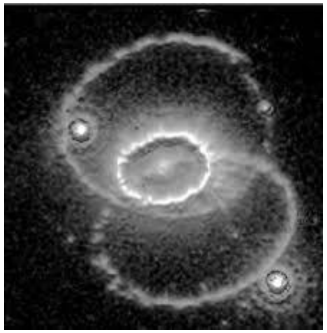
MyCn18 G307.5-04.9 13 39 35.12 -67 22 51.5, R:G:B = unknown
Sahai, Trauger, WFPC2 GTO, HST/WFPC2/PC?, N is NOT up
ref: hubblesite.org/gallery/album/entire_collection/pr1996007a/
ref: Sahai, R., et al., 1999 AJ 118 468



MyCn 18 G307.5-04.9 13 39 35.12 -67 22 51.5 Ha + [NII]
Ref: O'Connor, J.A., Redman, R.P., Holloway, A.J, Bryce, M., Lopez, J.A. &
Meaburn, J. 2000, ApJ, 531, 336

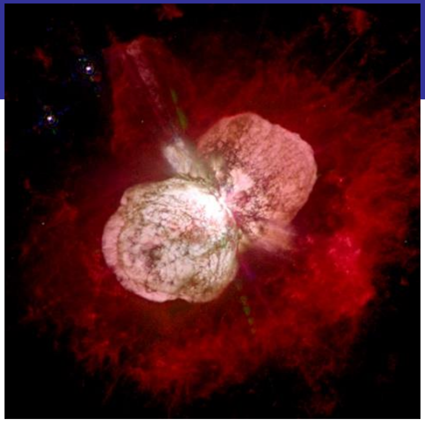
* The outer rings of 1987A and Eta Carinae were shaped by jets.



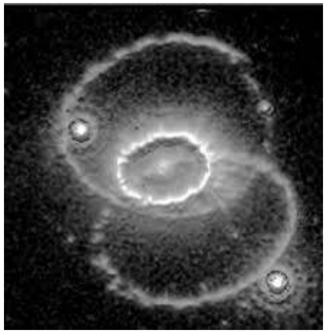


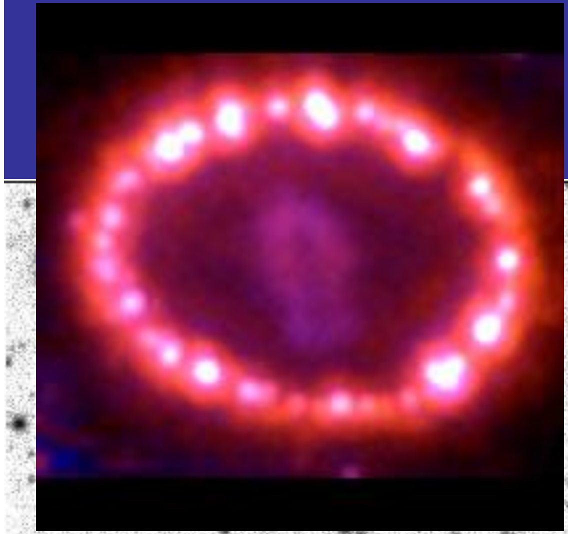
A main sequence companion accretes mass and launches opposite jets (in some planetary nebulae and in symbiotic nebulae the companion is a WD)

* The outer rings of 1987A and Eta Carinae were shaped by jets.



* Inner ring:





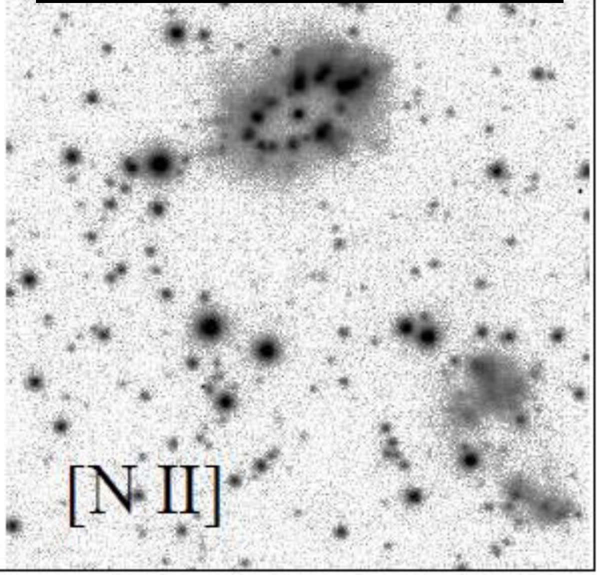
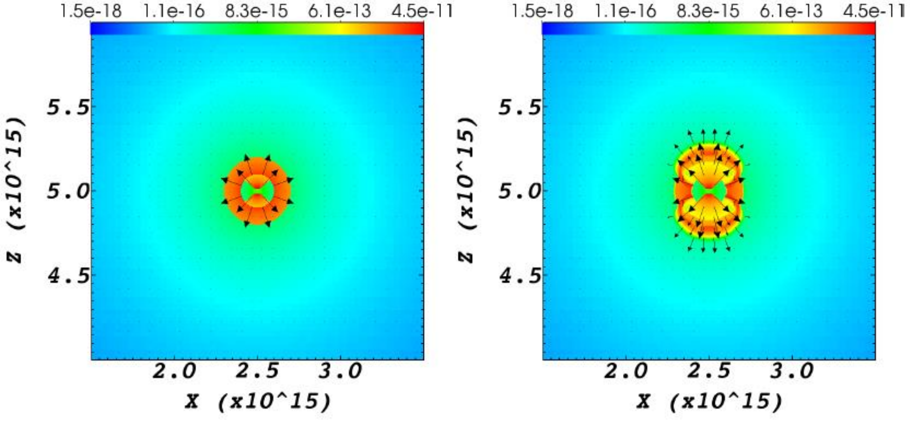


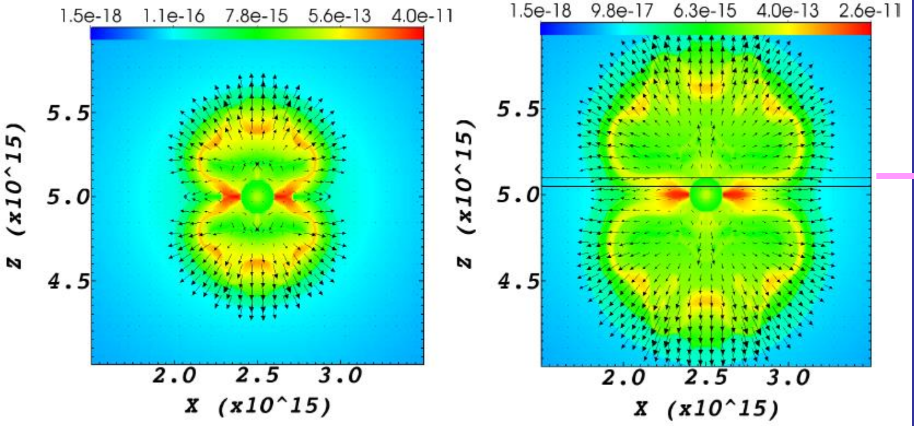
Figure 1. The NOT images of IPHASXJ194359.5+170901 in a log intensity scale. The field of view is 70″×110″ in each frame. North is up and East is left.

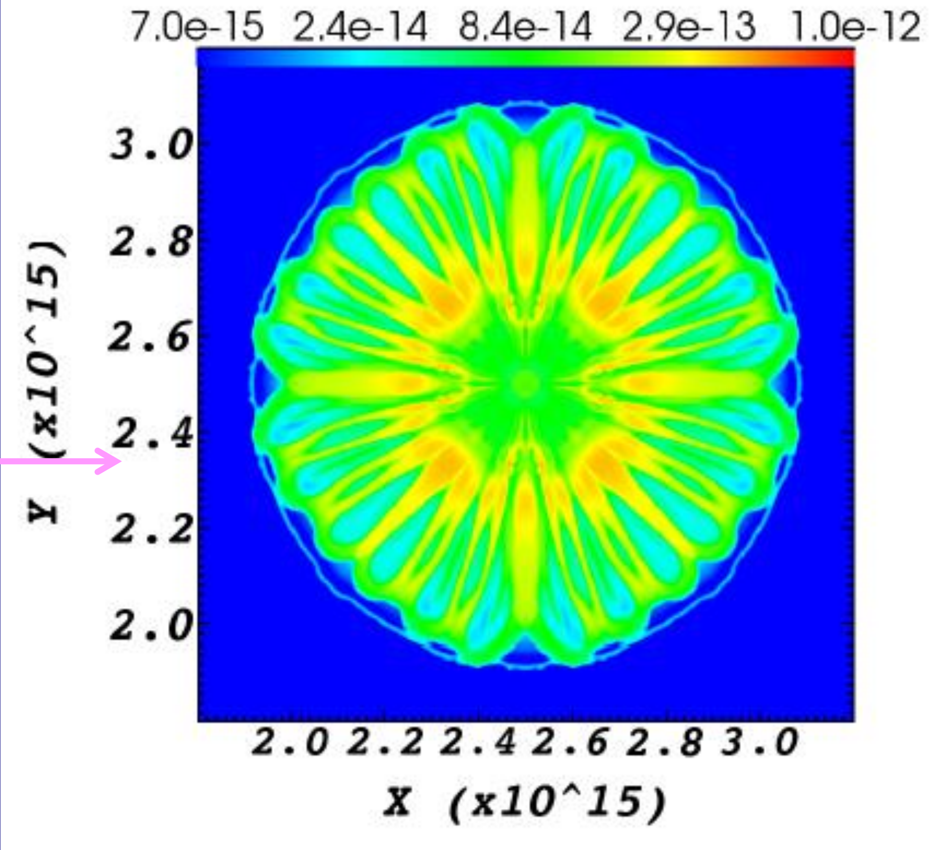
Instabilities in the plane will lead to the formation of clumps



(a) $t = 0$days

(b) $t = 47$days

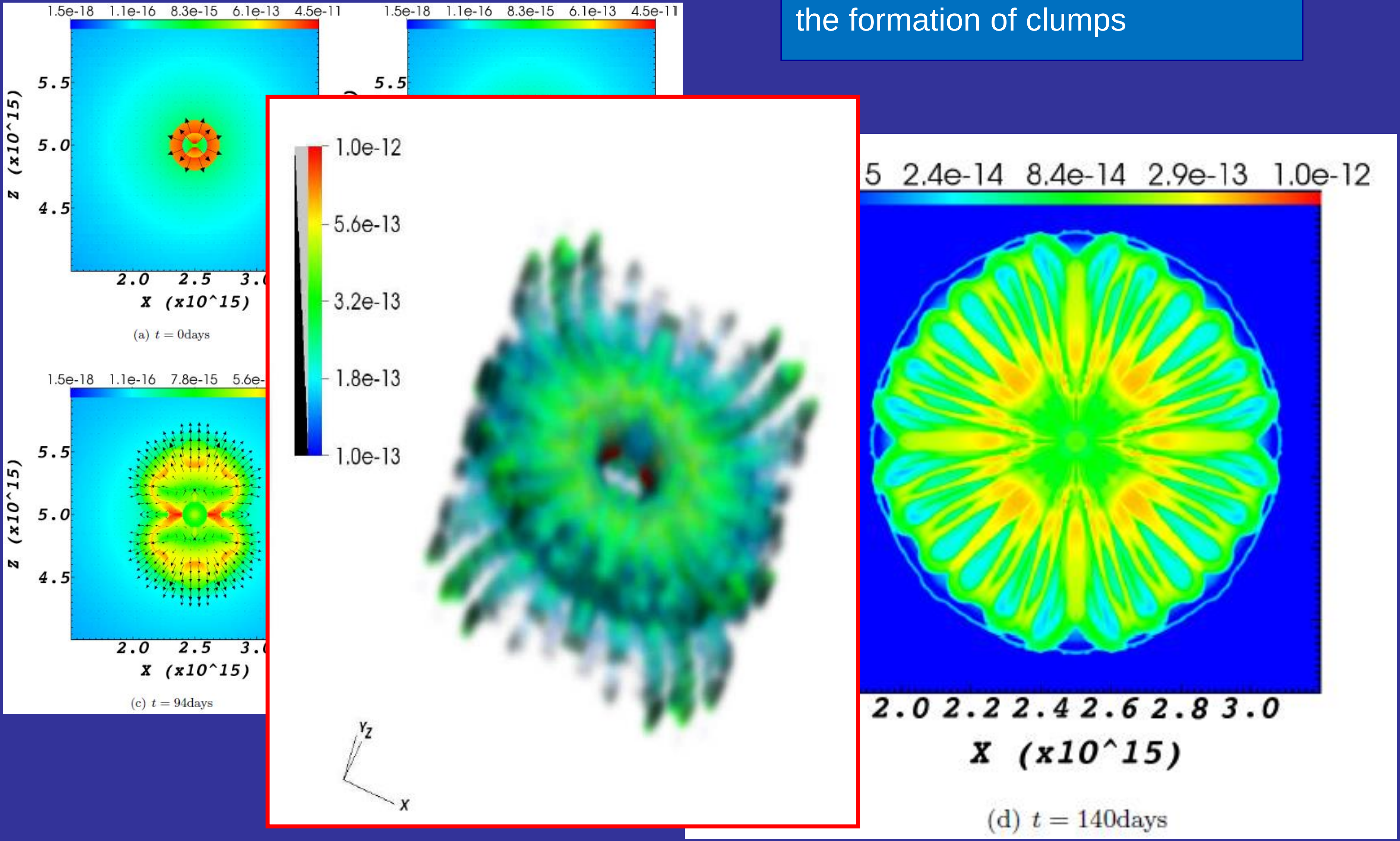




(d) $t = 140$days

Full 3D simulations of jets. (Muhammad Akashi et al. , 2015, MNRAS, 453, 2115).

Instabilities in the plane will lead to the formation of clumps



(a) $t = 0$days

(c) $t = 94$days

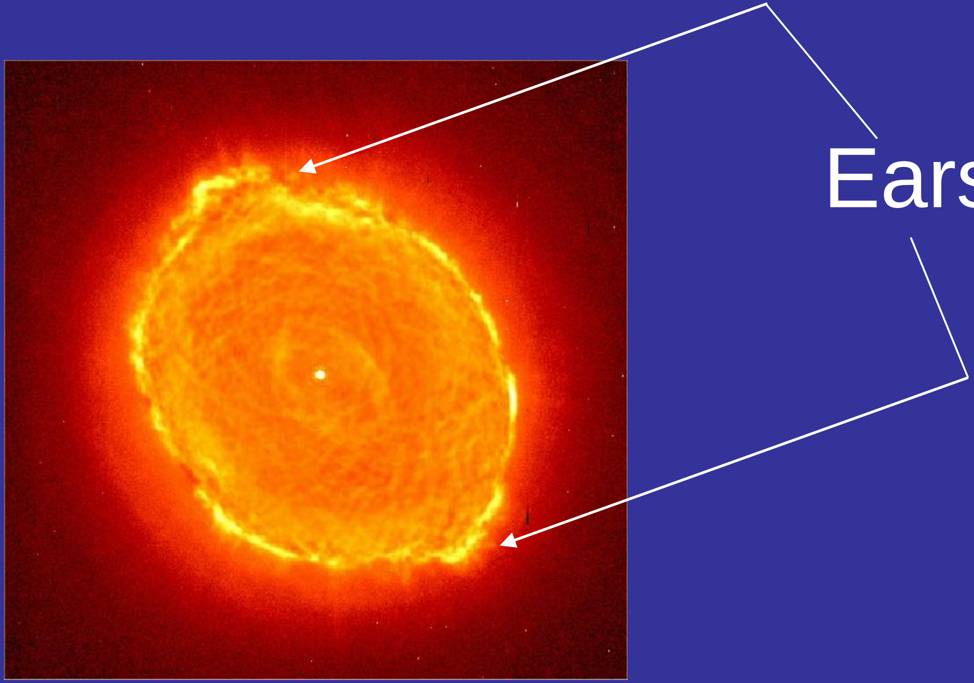
(d) $t = 140$days

To take home:

Jets can be active before the explosion

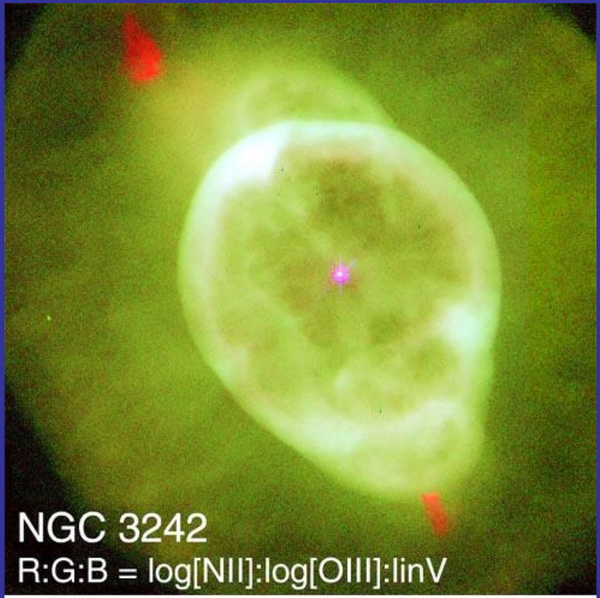
Ears in
Supernova remnants

Ears in
A planetary nebulae

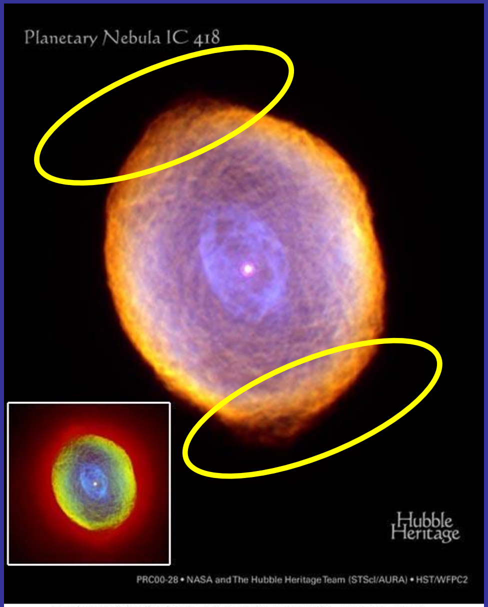


Ears

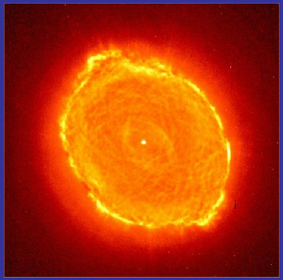
Ears in planetary nebulae



NGC 3242 G261.0+32.0 10 24 46.11 -18 38 32.6, R:G:B = log[NII]: log[OIII]: linear V
HST/WFPC2/PC1 N is NOT up. credit: Hajian et al (unpublished)
HST archives, GO 7501/8390/8773



IC 418 G215.2-24.2 05 27 28.20 -12 41 50.3, R:G:B = [NII], Ha, [OIII]
Hubble Heritage Team, HST/WFPC2/PC?, N is NOT up
ref: hubblesite.org/gallery/album/nebula_collection/pr2000028a/
inset: R:G:B = deep log[NII]:log [NII]:log[OIII] Hajian, HST archives GO7501

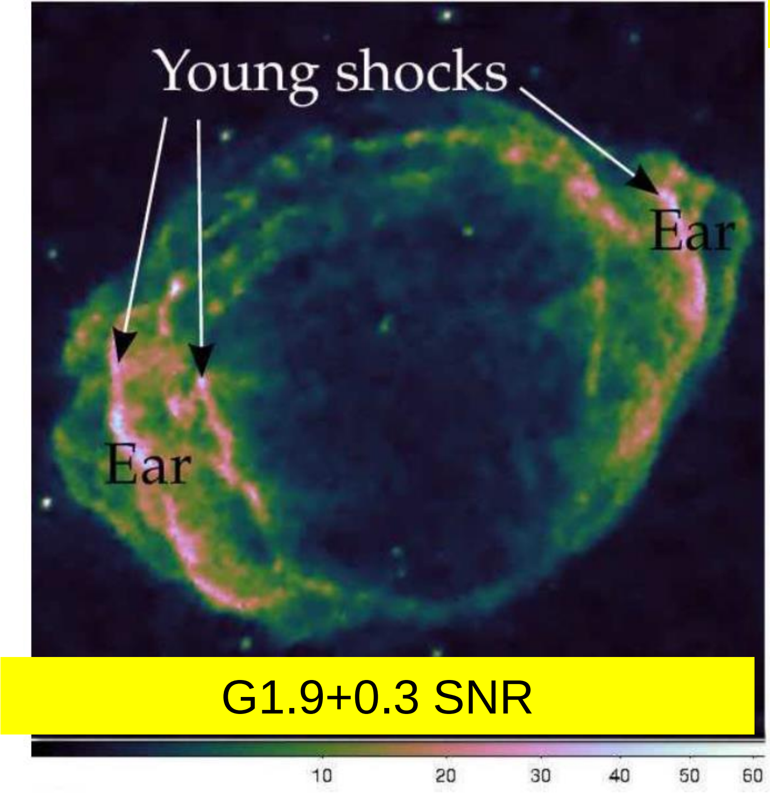


NGC 7139 G104.1+07.9 21 46 08.59 +63 47 29.4, R:G:B = unknown
credit: Gert Gottschalk and Sibylle Froehlich/Adam Block/NOAO/AURA/NSF
source: http://www.noao.edu/outreach/aop/observers/n7139.html

NGC 6563 G358.5-07.3 18 12 02.75 -33 52 07.1, R:G:B=log(Ha+[NII]),both,log[OIII]
ref: Schwarz, H.E., Corradi, R.L.M., Melnick, J 1992 A&A Suppl, 96, 23
image files courtesy R Corradi.   N is NOT up. See ref for orientation.

IC 2448 G285.7-14.9 09 07 06.26 -69 56 30.7, R:G:B = log[NII]: log[OIII]: linear V
HST/WFPC2/PC1 N is NOT up. credit: Hajian et al (unpublished)
HST archives, GO 7501/8390/8773

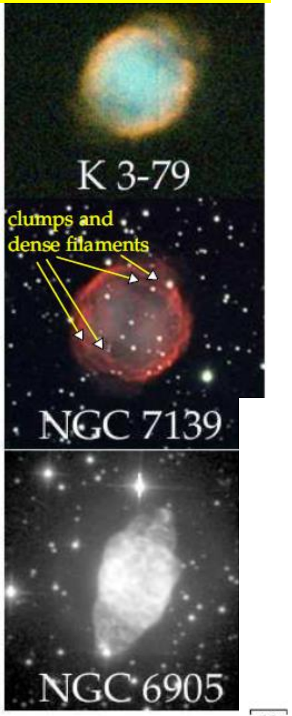
Ears in Type Ia SNRs



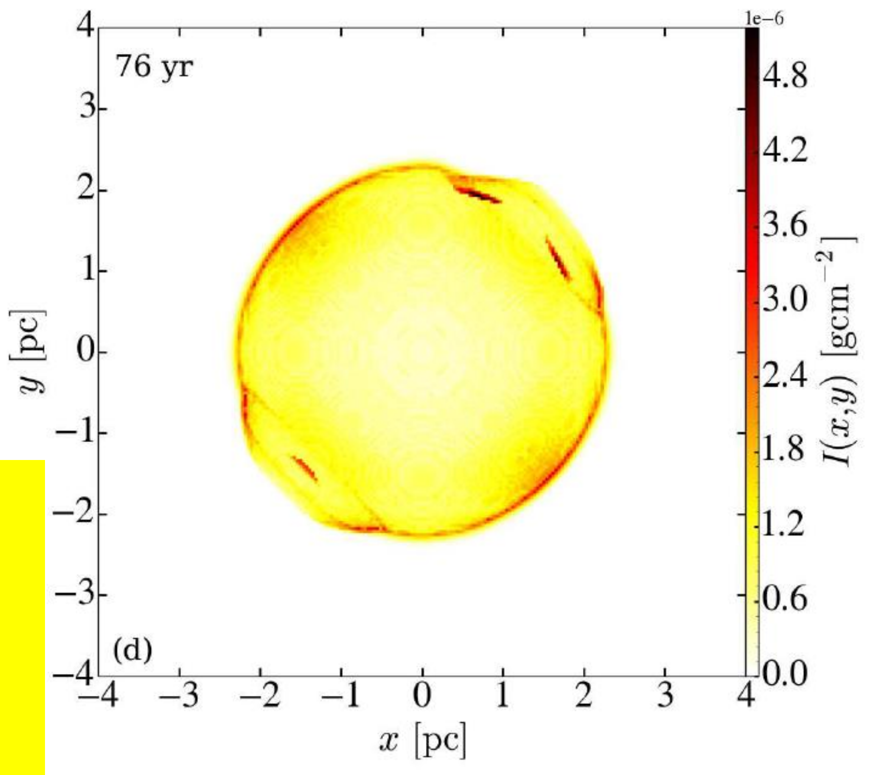
G1.9+0.3 SNR

Fig. 1.— Left: Chandra X-ray image of G1.9+0.3 from 2011 (Borkowski et al. 2

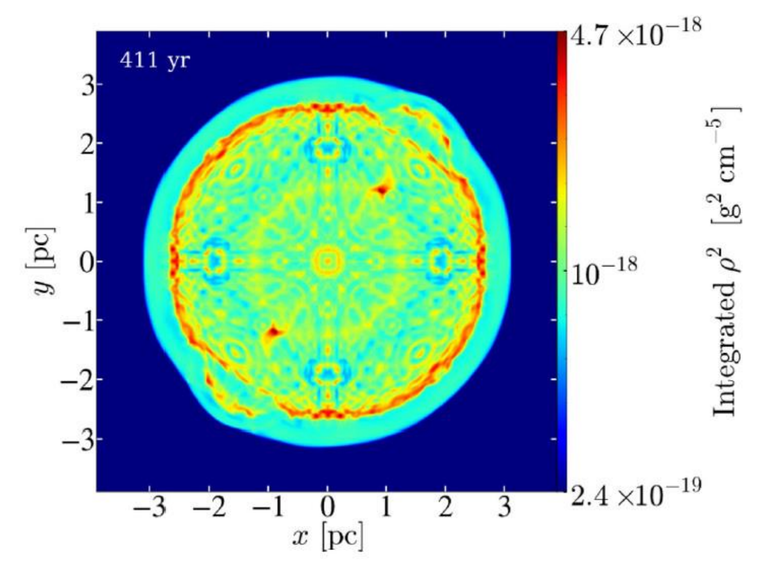
Planetary nebulae

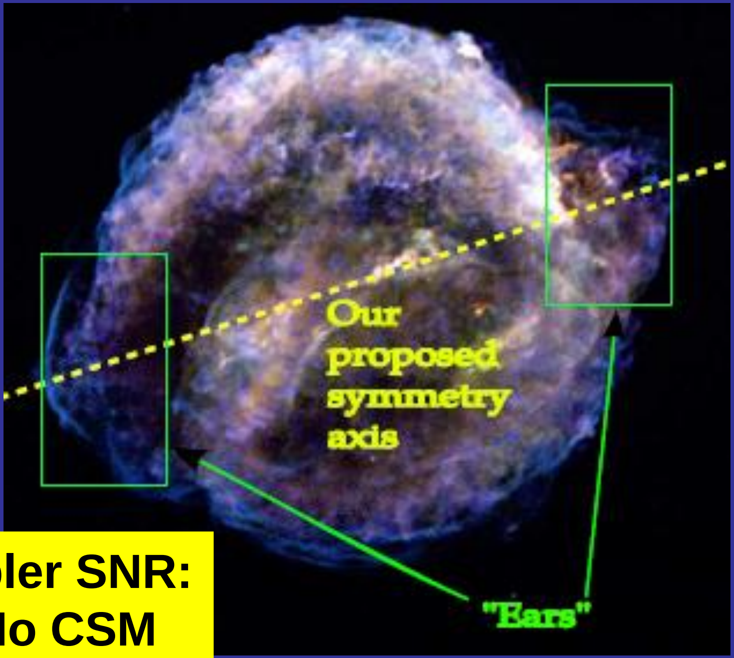


Numerical simulations of a
SN Inside a **P**lanetary nebula
(SNIP)
(from Tsebrenko, D. & Soker, N. 2015)

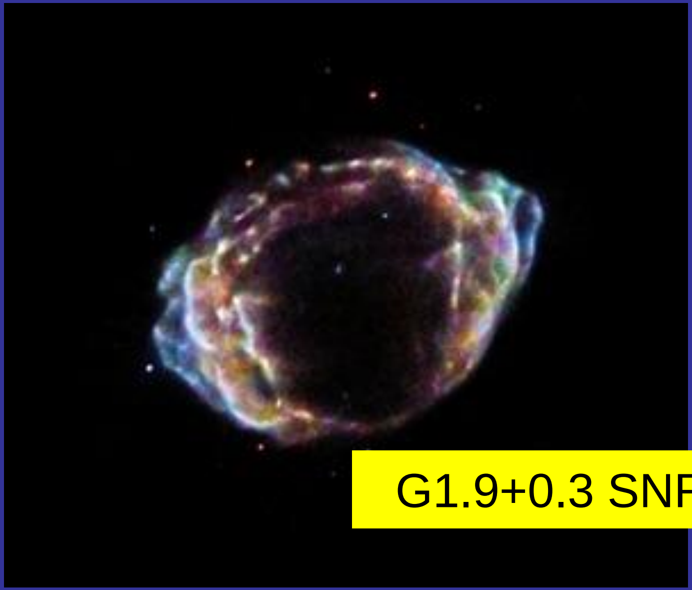


Ears in Type Ia SNRs

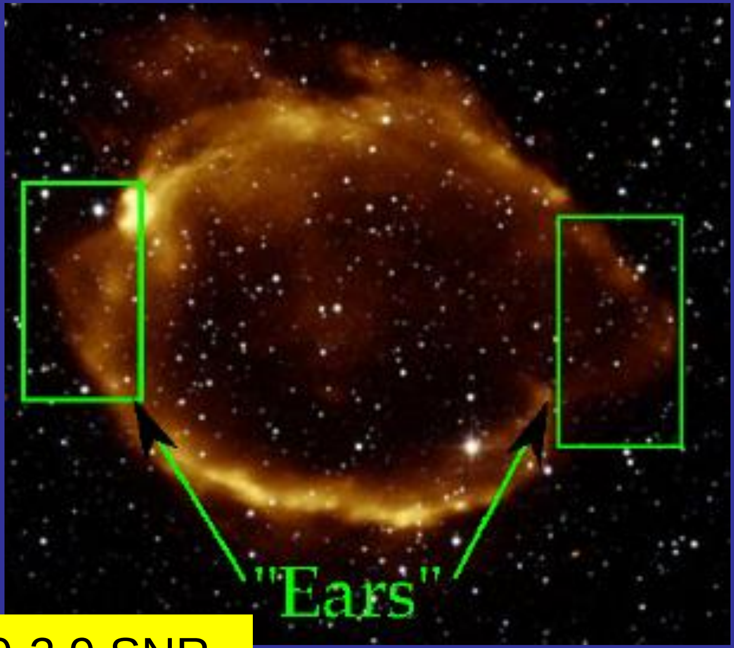




Kepler SNR: ~1Mo CSM

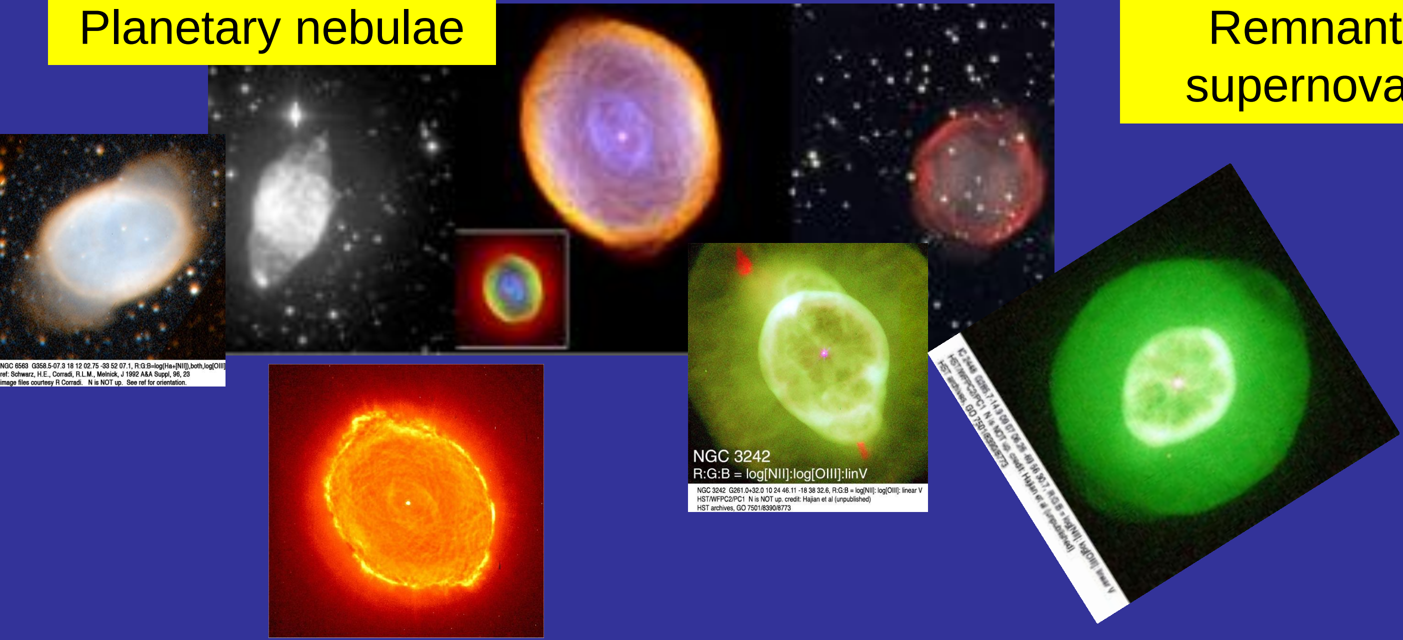


G1.9+0.3 SNR

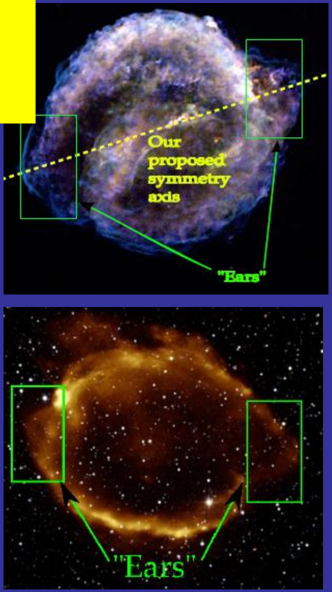


G299-2.9 SNR

Planetary nebulae



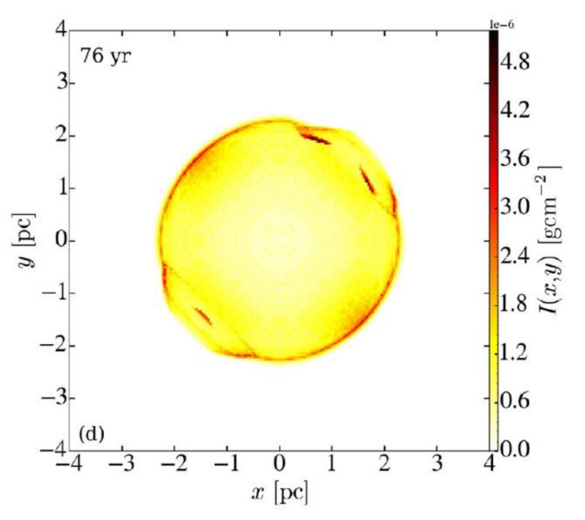
Remnants of supernovae Ia



Jets might be common in pre - SN Ia,

(Tsebrenko & Soker 2013, 2015a)

SNIP: Supernovae Inside Planetary nebulae



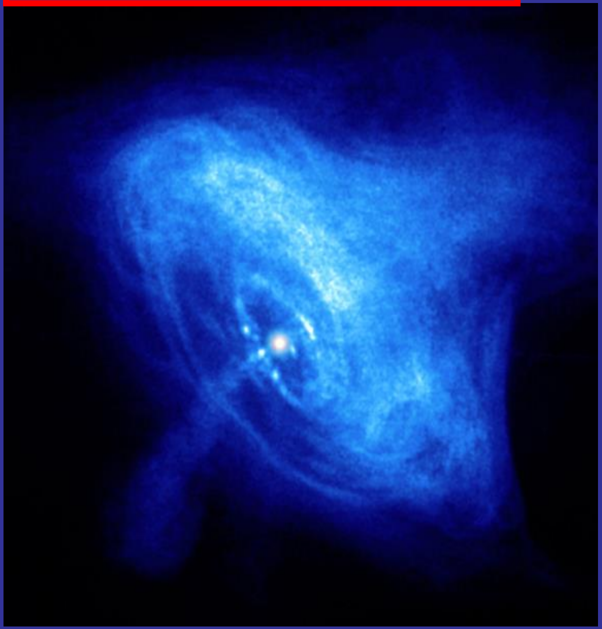
Ears in
Core collapse
supernova remnants

Grichener, A. & Soker, N. 2017, arXiv:1610:09647

Bear, E. & Soker, N. 2017, arXiv:1611:07327

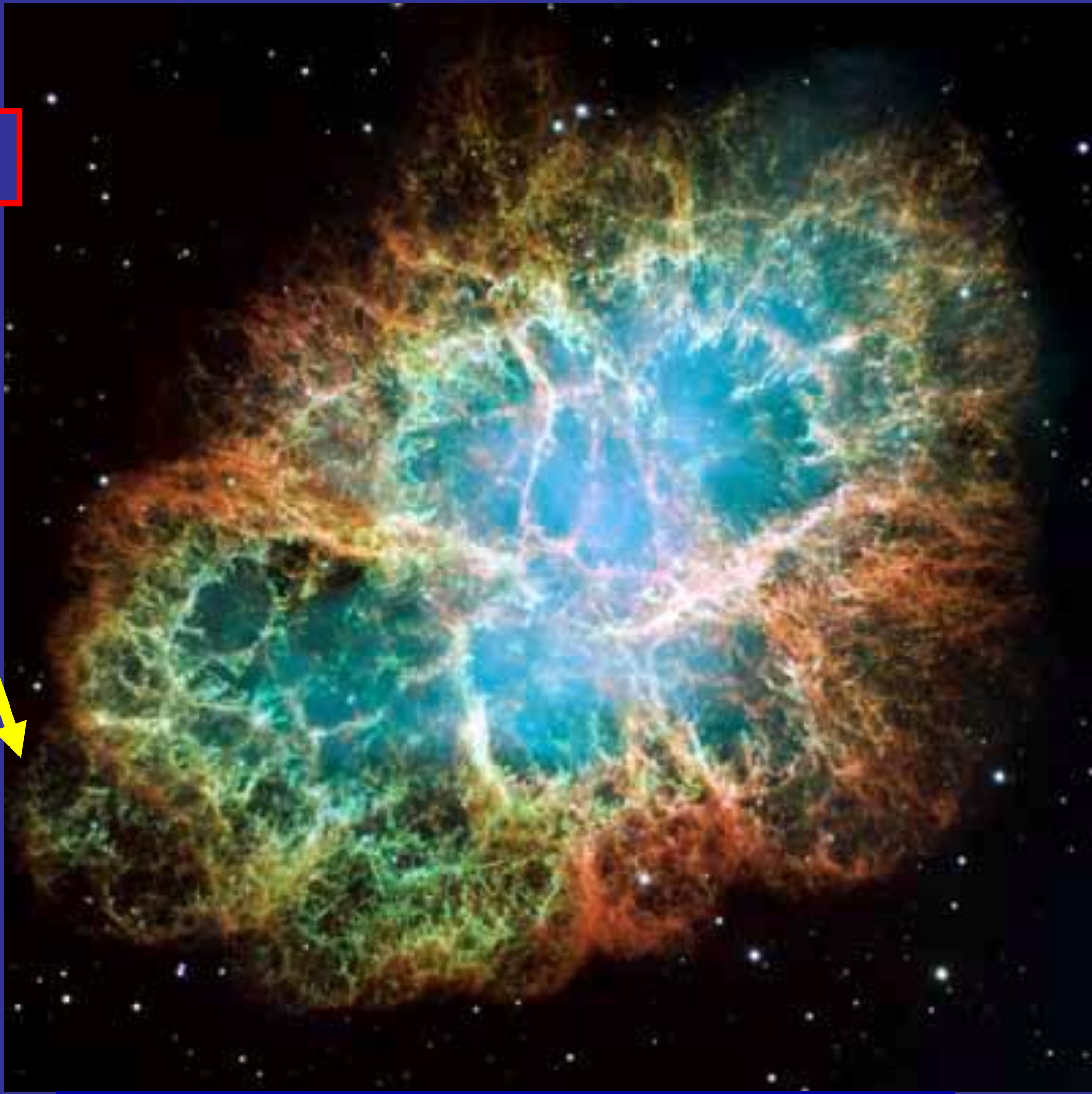
Crab Nebula

A neutron star with its jets



Credit: NASA/CXC/ASU/J.Hester et al

An ear



Credit: NASA, ESA, J. Hester, A. Loll (ASU);
Acknowledgement: Davide De Martin (Skyfactory)

Simeis 147

(V. V. Gvaramadze 2006)

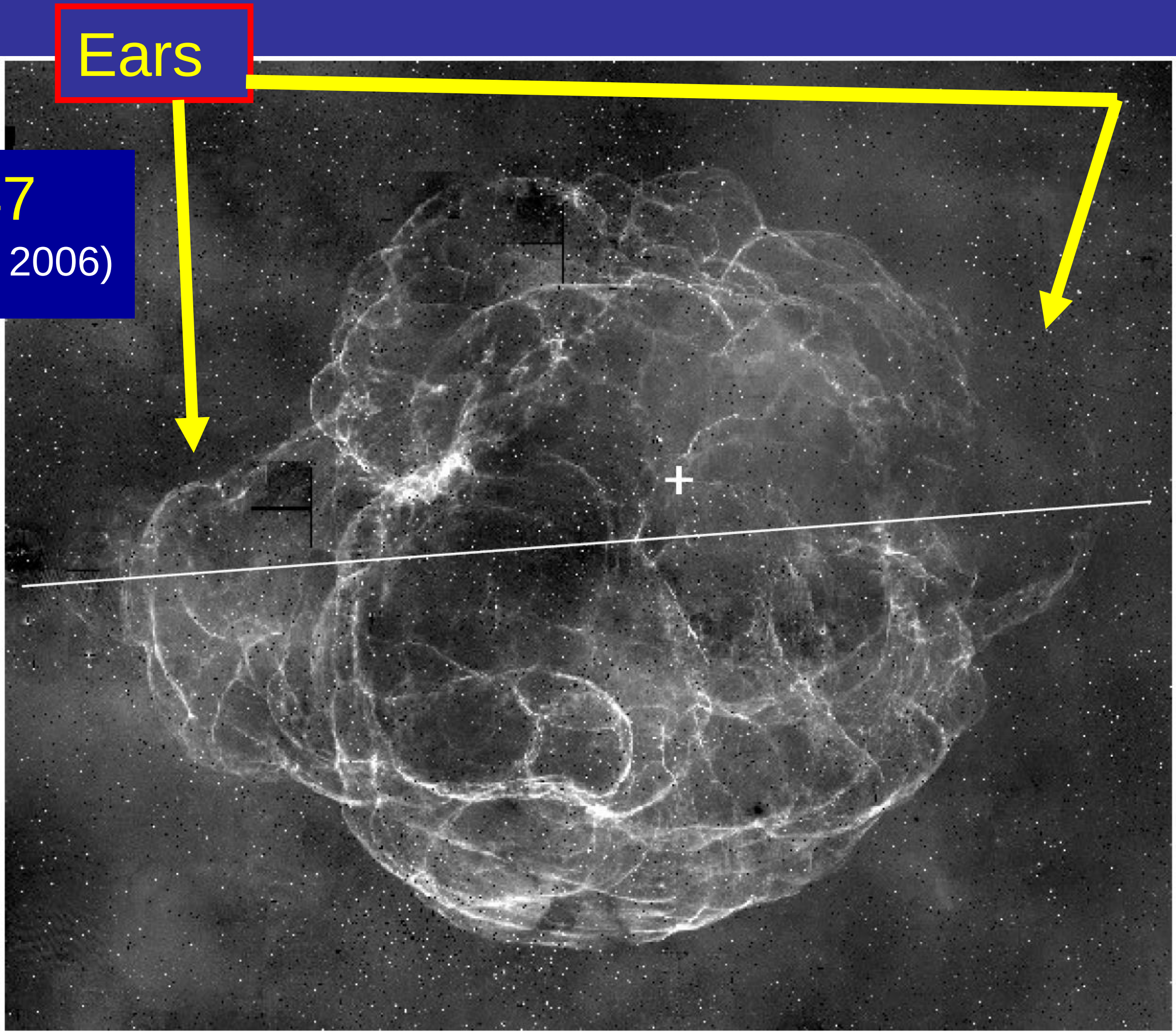
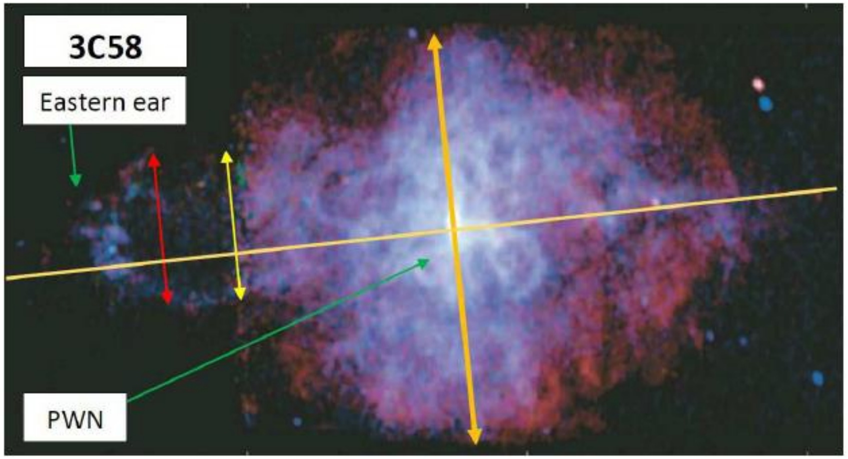
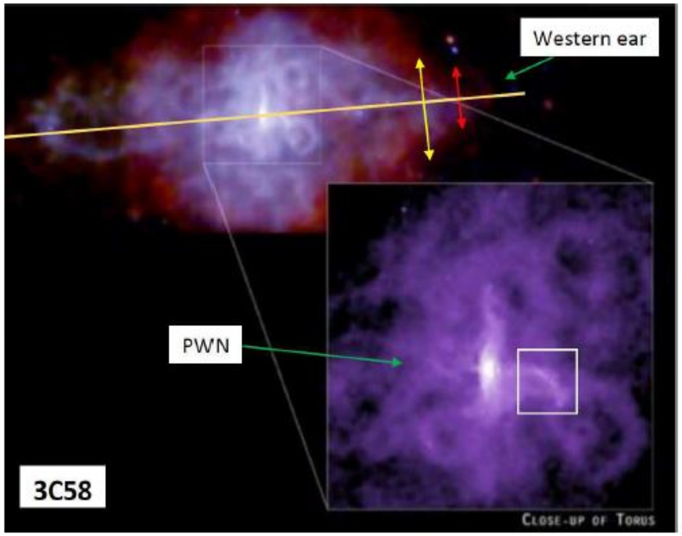
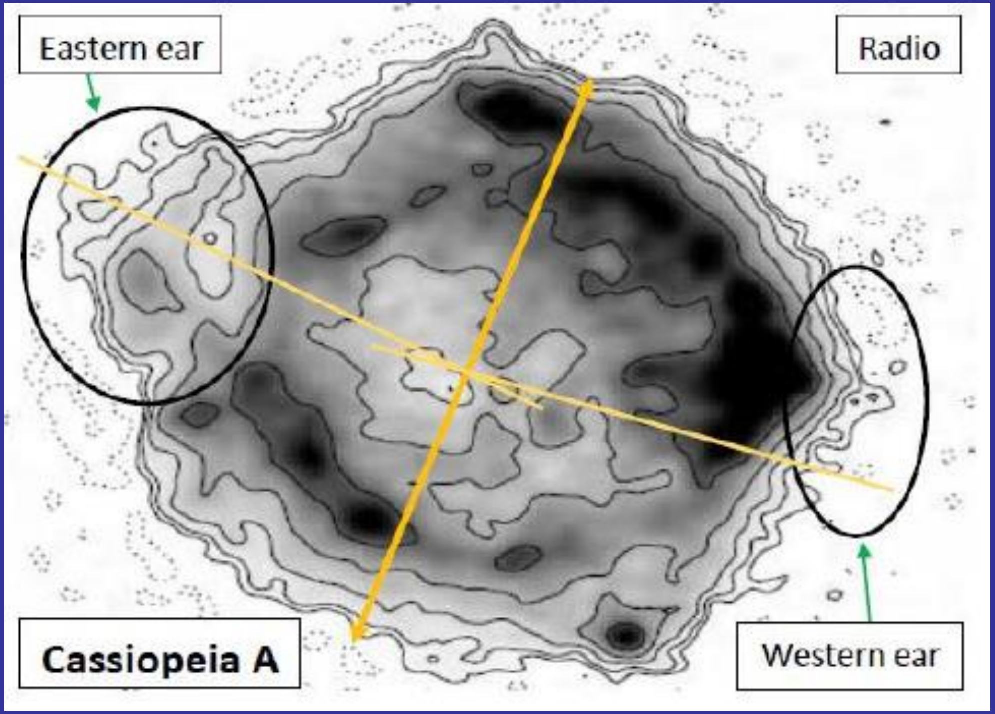
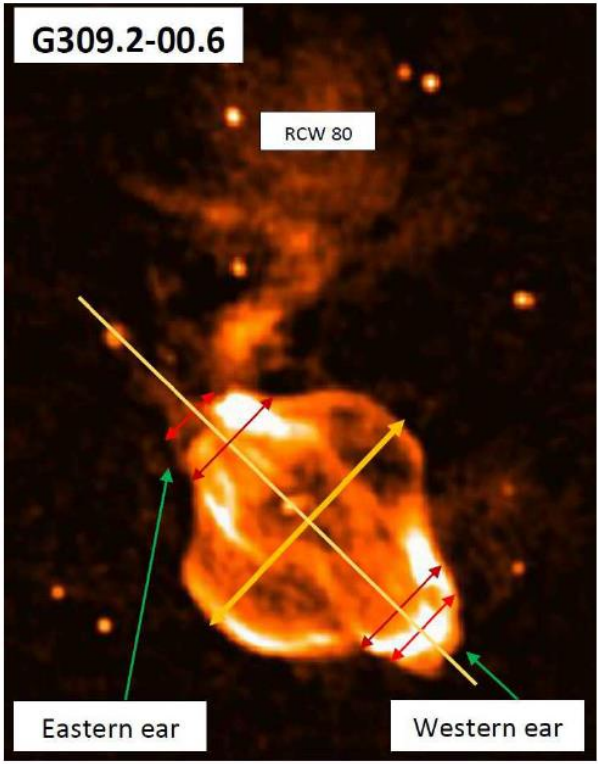


Fig. 1. The H_{α} image of the supernova remnant S 147 (Drew et al. 2005; reproduced with permission of the IPHAS collaboration). Position of the pulsar PSR J 0538+2817 is indicated by a cross. The line drawn in the east-west direction shows the bilateral symmetry axis (see text for details). North is up, east at left.

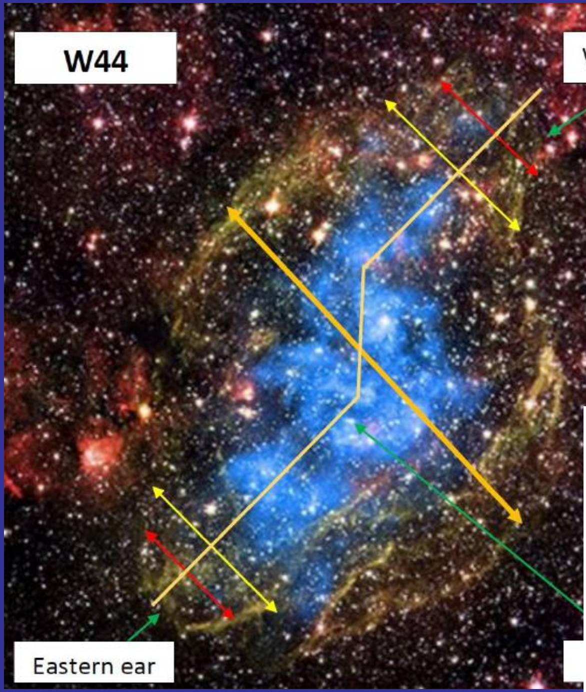

3C58
Eastern ear
PWN

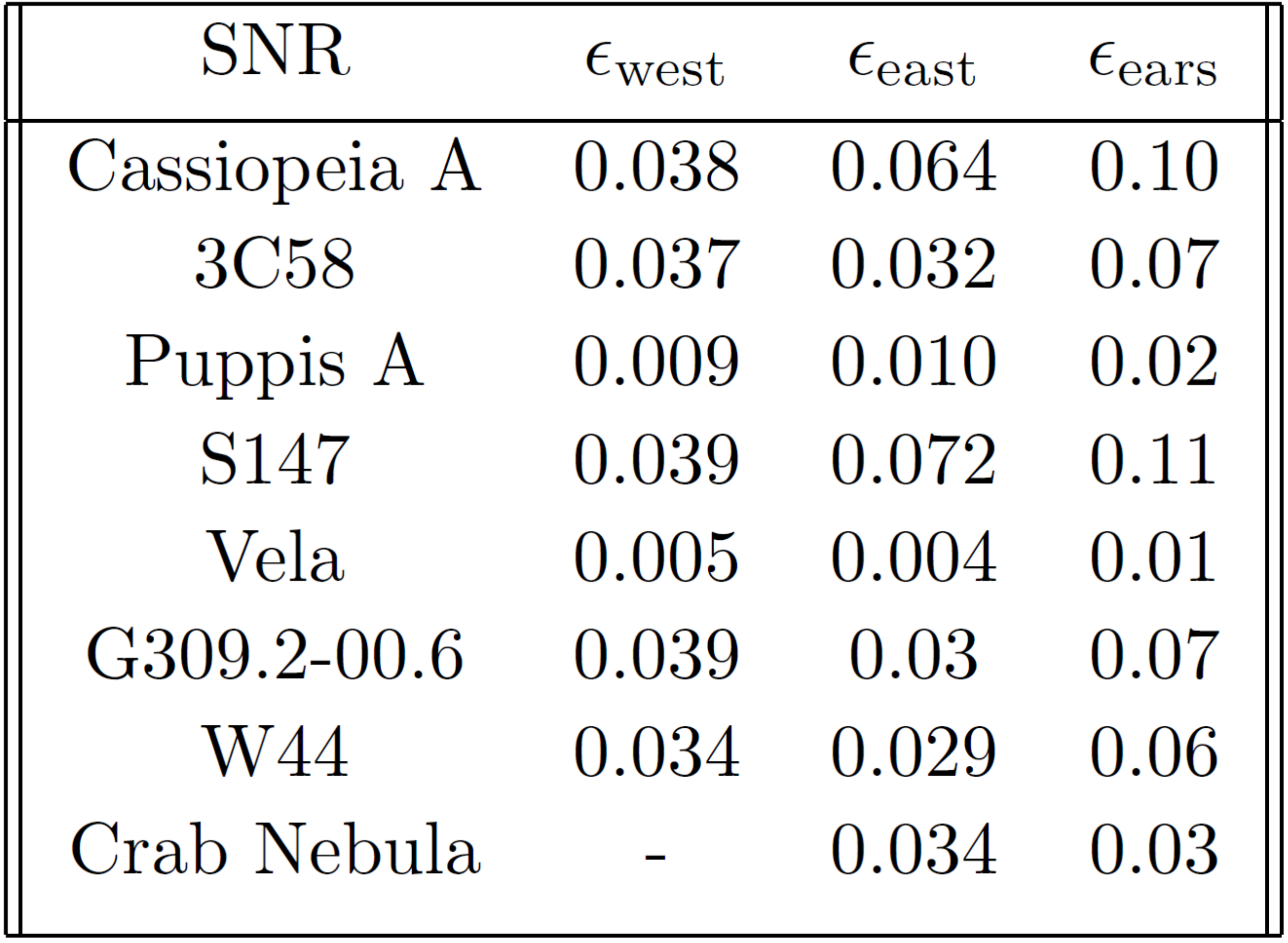

Western ear
PWN
3C58
CLOSE-UP OF TORUS


Eastern ear
Radio
Cassiopeia A
Western ear


G309.2-00.6
RCW 80
Eastern ear
Western ear

Relative energy to inflate the ears





SNR	$\epsilon_{\rm west}$	$\epsilon_{\rm east}$	$\epsilon_{\rm ears}$
Cassiopeia A	0.038	0.064	0.10
3C58	0.037	0.032	0.07
Puppis A	0.009	0.010	0.02
S147	0.039	0.072	0.11
Vela	0.005	0.004	0.01
G309.2-00.6	0.039	0.03	0.07
W44	0.034	0.029	0.06
Crab Nebula	-	0.034	0.03

To take home:

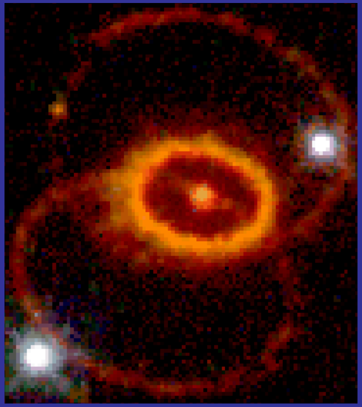
- About 40% core collapse supernova remnants have ears.

- The energy of the jets that inflated the ears is 5-15 % of the explosion kinetic energy.

Grichener, A. & Soker, N. 2017, arXiv:1610:09647

Bear, E. & Soker, N. 2017, arXiv:1611:07327

Formation of Ears: I think they are formed by jets



The ears can be formed before the explosion.

This requires a binary companion.

+ A bipolar circumstellar gas is seen in SN 1987A →
+ S147 had a massive binary companion (e.g., Dincel et al. 2015).

The ears can be formed during the explosion.

This *might* occur in the jet-feedback mechanism. In the last episode jets are launched after the core was exploded. These jets freely expand and form the ears.

+ Expected in the explosion mechanism.
+ Can have 5-10% of the explosion energy.
+ Same angular momentum spins-up the newly born neutron star.

The ears can be formed after the explosion.

+ We observe jets from the pulsar at the center (A note about magnetars).
? Does the pulsar have 5-10% of the explosion energy released in jets? (In 3C58 only ~1e49 erg in the pulsar.)

Cassiopeia A

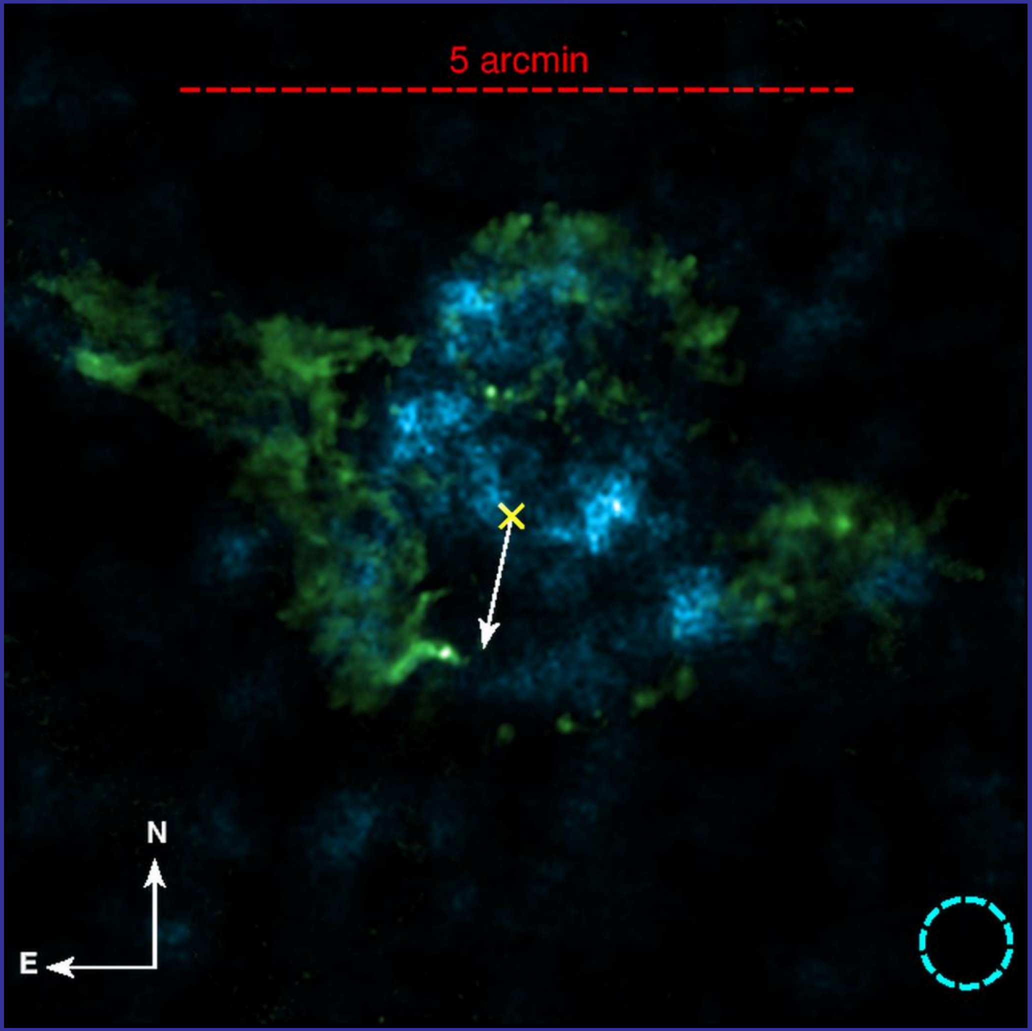
In blue: 44Ti

In Green: Si

A possible explanation in the frame of the jittering jets scenario.

- The 44Ti is formed at early times — first several jets. 44Ti spreads sporadically in inner regions.

- The last jets-launching episode did not collide with dense core gas, hence no 44Ti is formed. These jets expand to large distances.



(Grefenstette et al. 2014)

Final summary

There are two scenarios within the jet feedback mechanism.

Soker, N. 2017, accepted for publication by astro-ph
(arxiv:1702.03451)