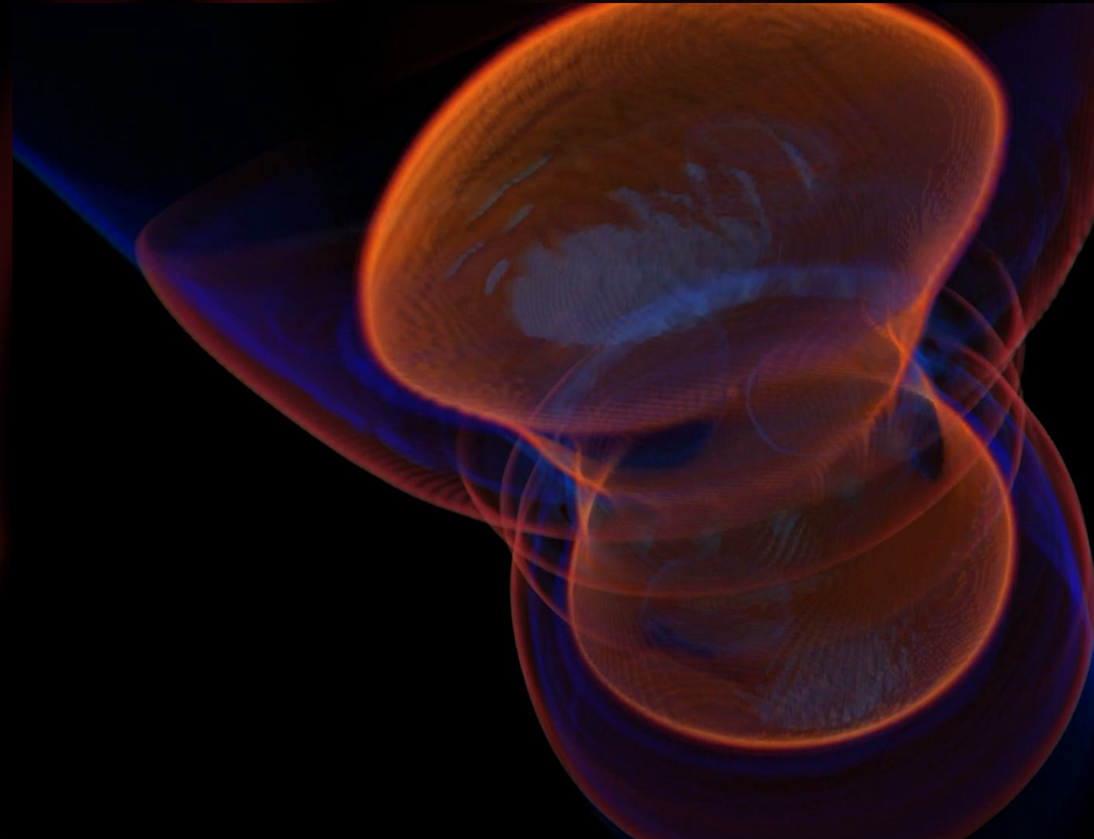
ICRAR

International Centre for Radio Astronomy Research



The Radio Remnant of Supernova 1987A - A Broader View

Giovanna Zanardo

Curtin University
THE UNIVERSITY OF WESTERN AUSTRALIA
Government of Western Australia
Department of the Premier and Cabinet
Office of Science

ICRAR

International Centre for Radio Astronomy Research

Lister Staveley-Smith

Bryan Gaensler

Dick Manchester

Tasso Tzioumis

Stephen Ng

Remy Indebetouw

Mikako Matsuura

Curtin University

THE UNIVERSITY OF WESTERN AUSTRALIA

Government of Western Australia
Department of the Premier and Cabinet
Office of Science

Radio all the way

GHz

0.07–0.2

1.4 – 1.6

1.4 – 94

84 – 116

211 – 275

275 – 373

602 – 720

m

cm

mm

μm

MWA

ATCA

ALMA

VLBI

Parkes

2013 – present

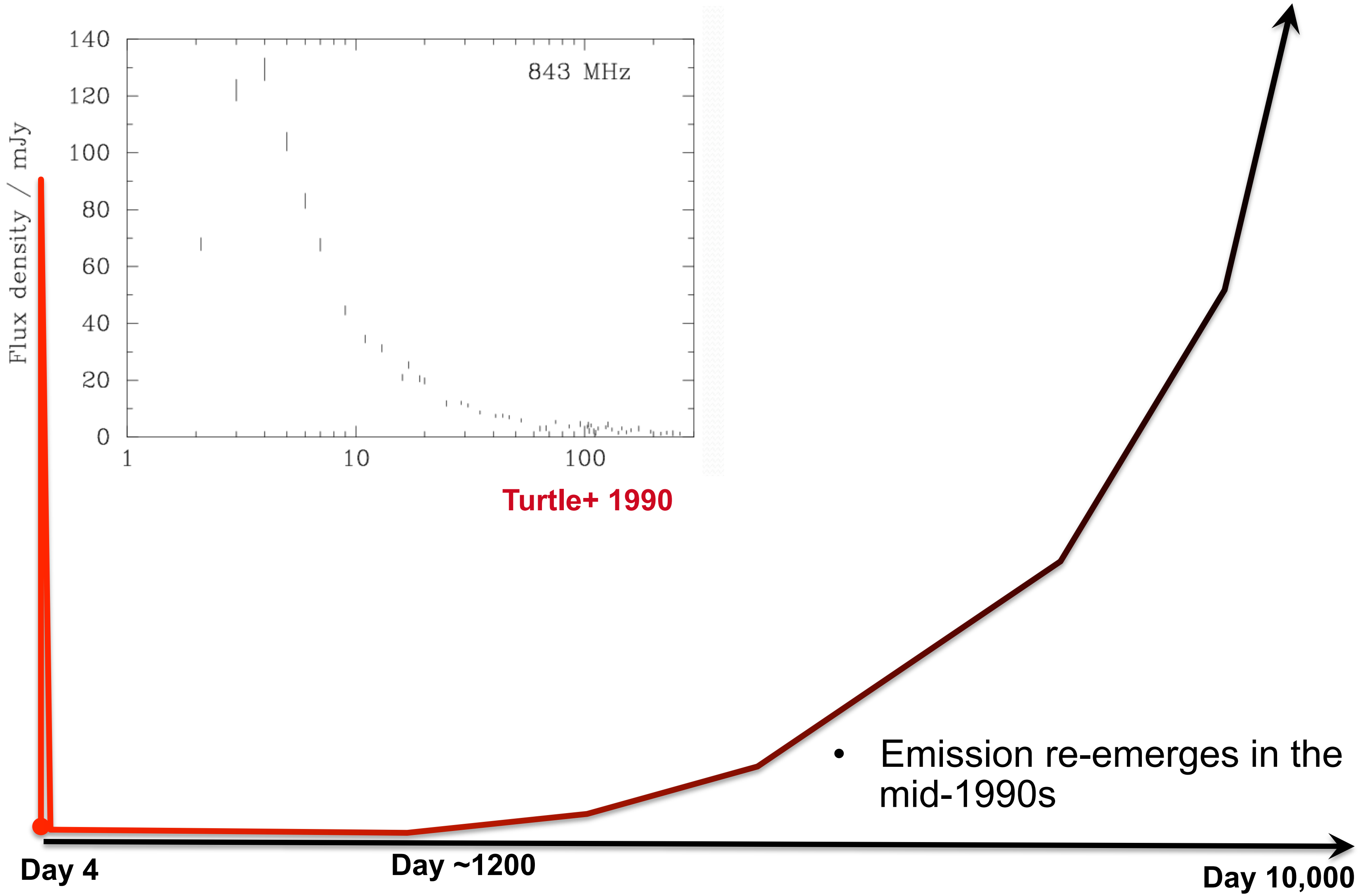
2007–2014

1987–present

2011–present

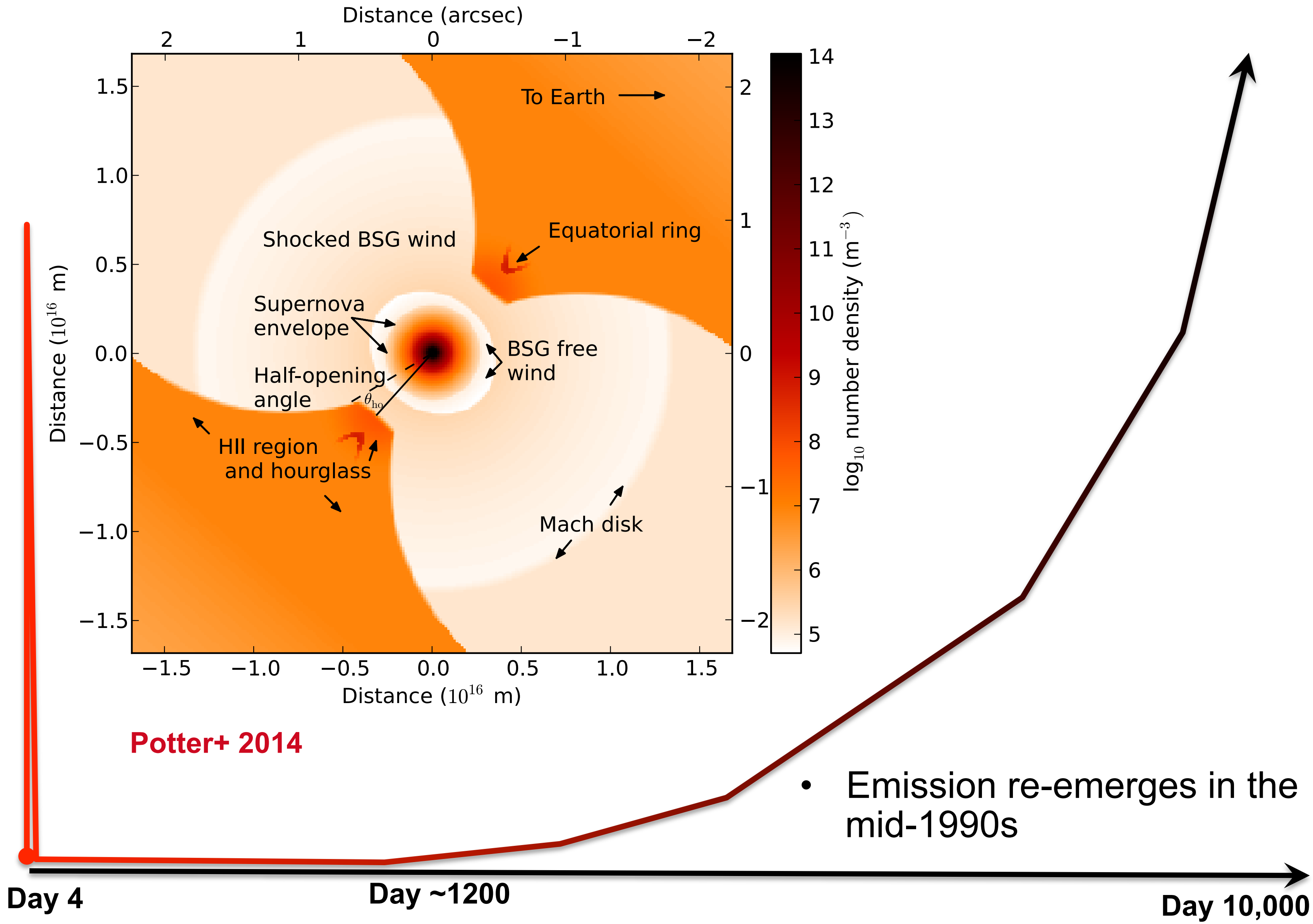
What are we observing?

What are we observing?



- Emission re-emerges in the mid-1990s

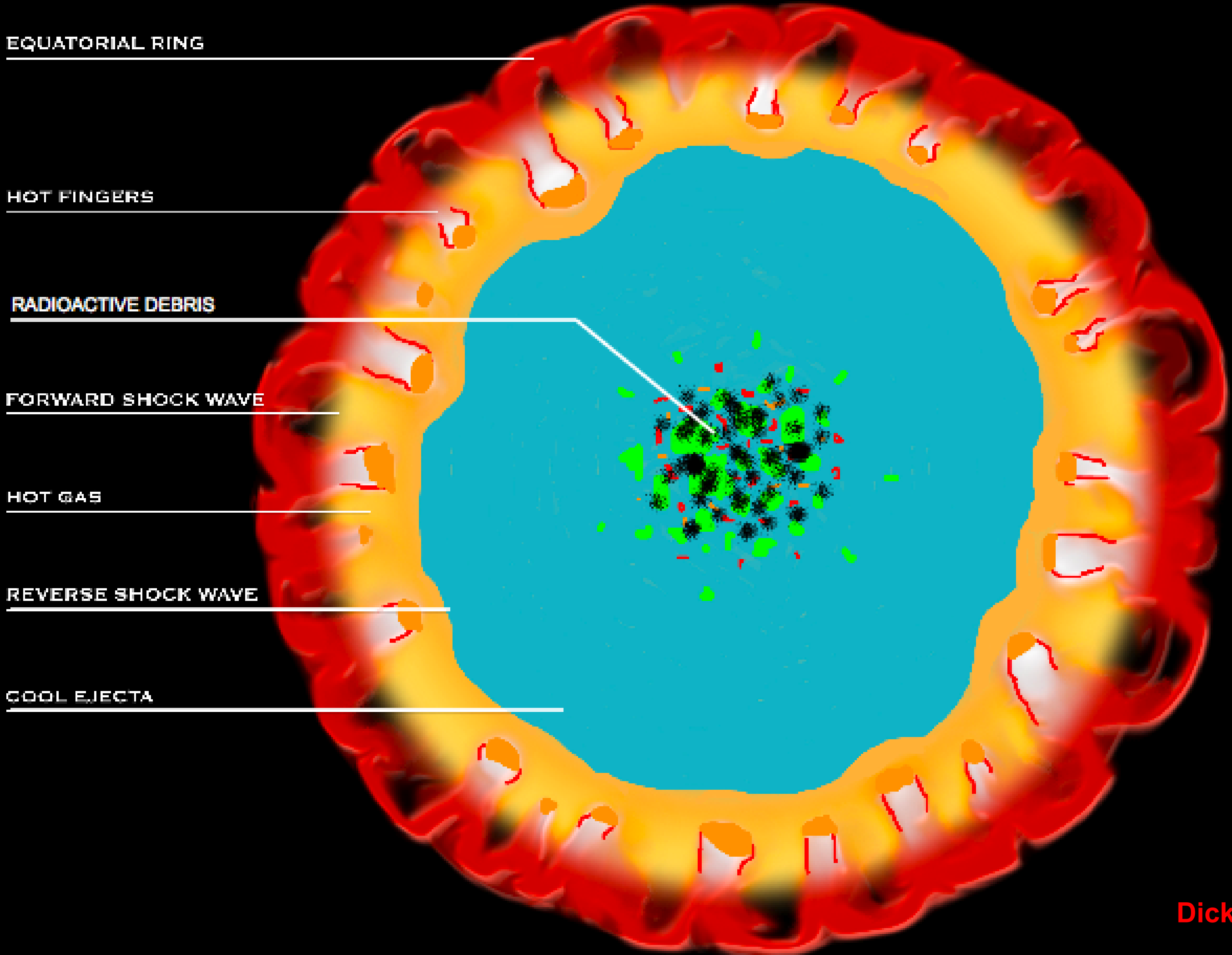
What are we observing?



Potter+ 2014

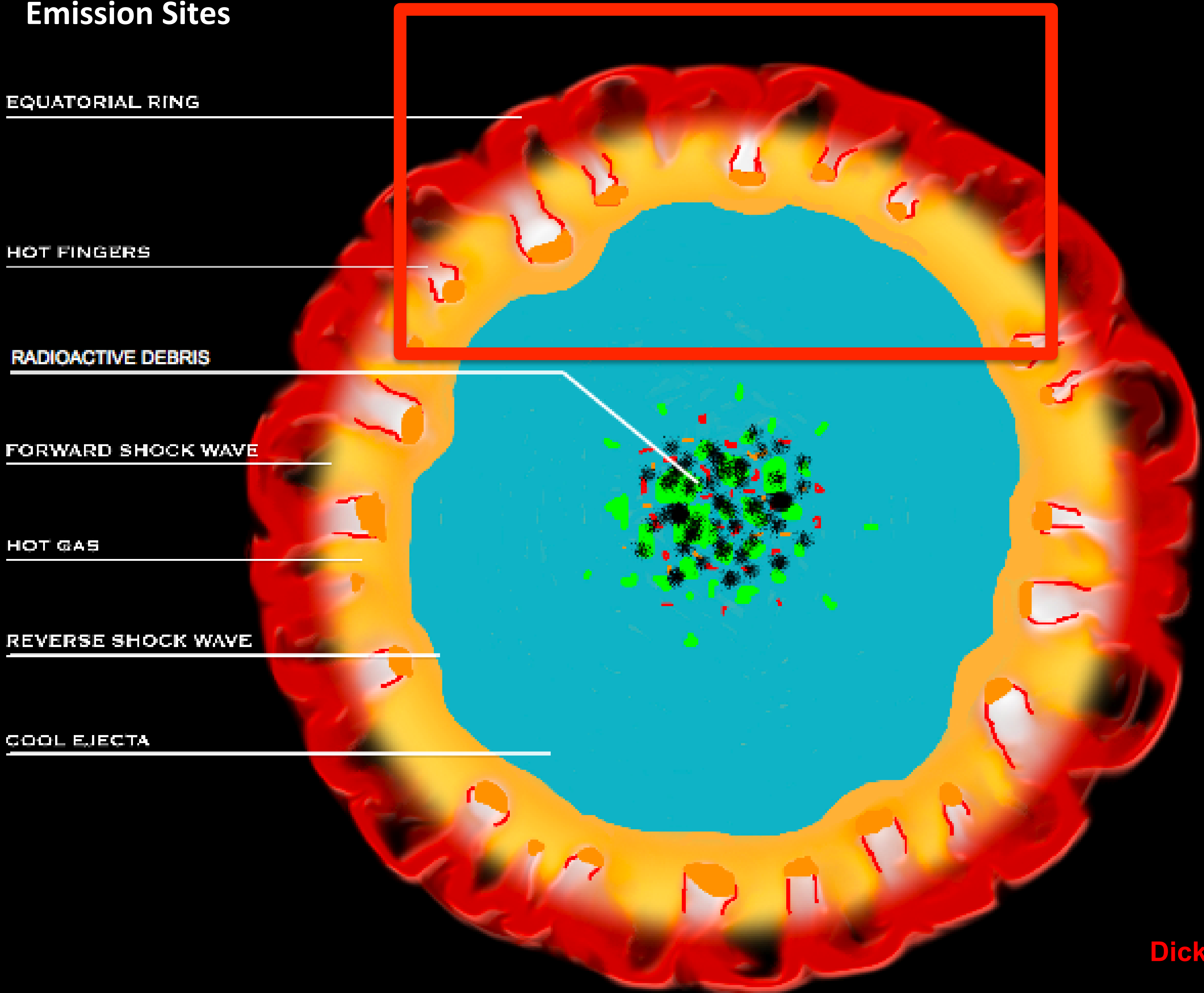
- Emission re-emerges in the mid-1990s

Emission Sites

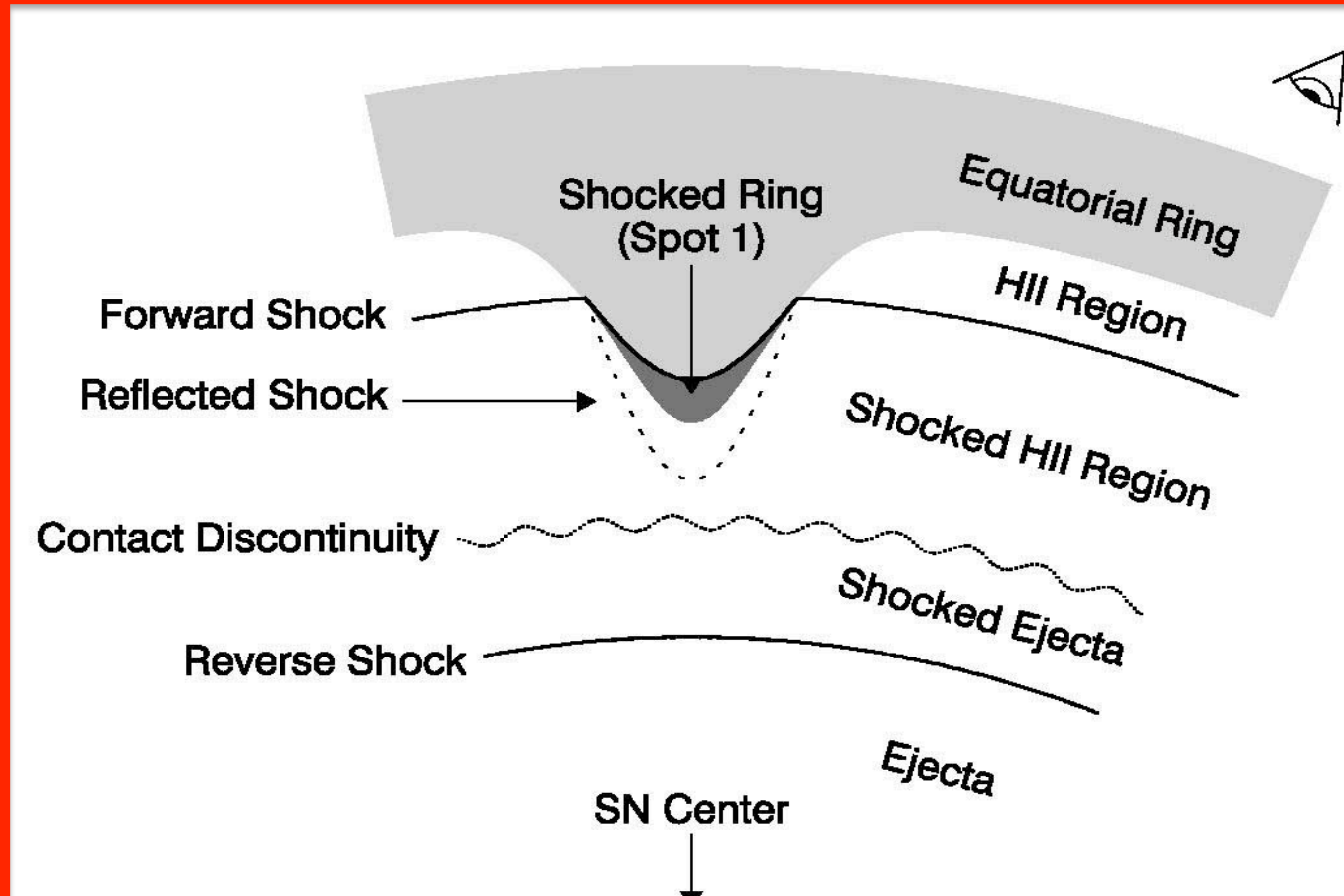


Dick McCray

Emission Sites

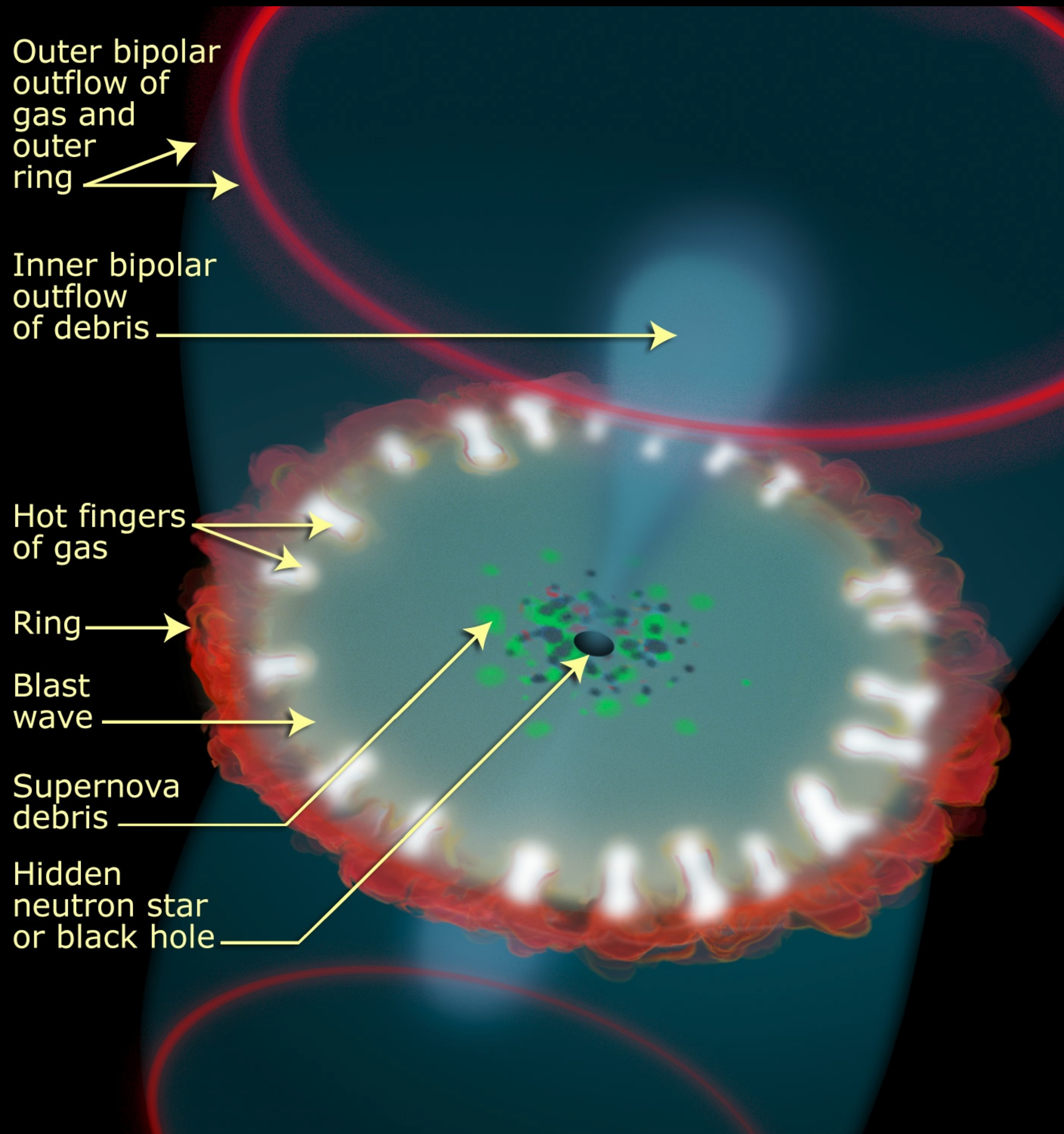


Dick McCray



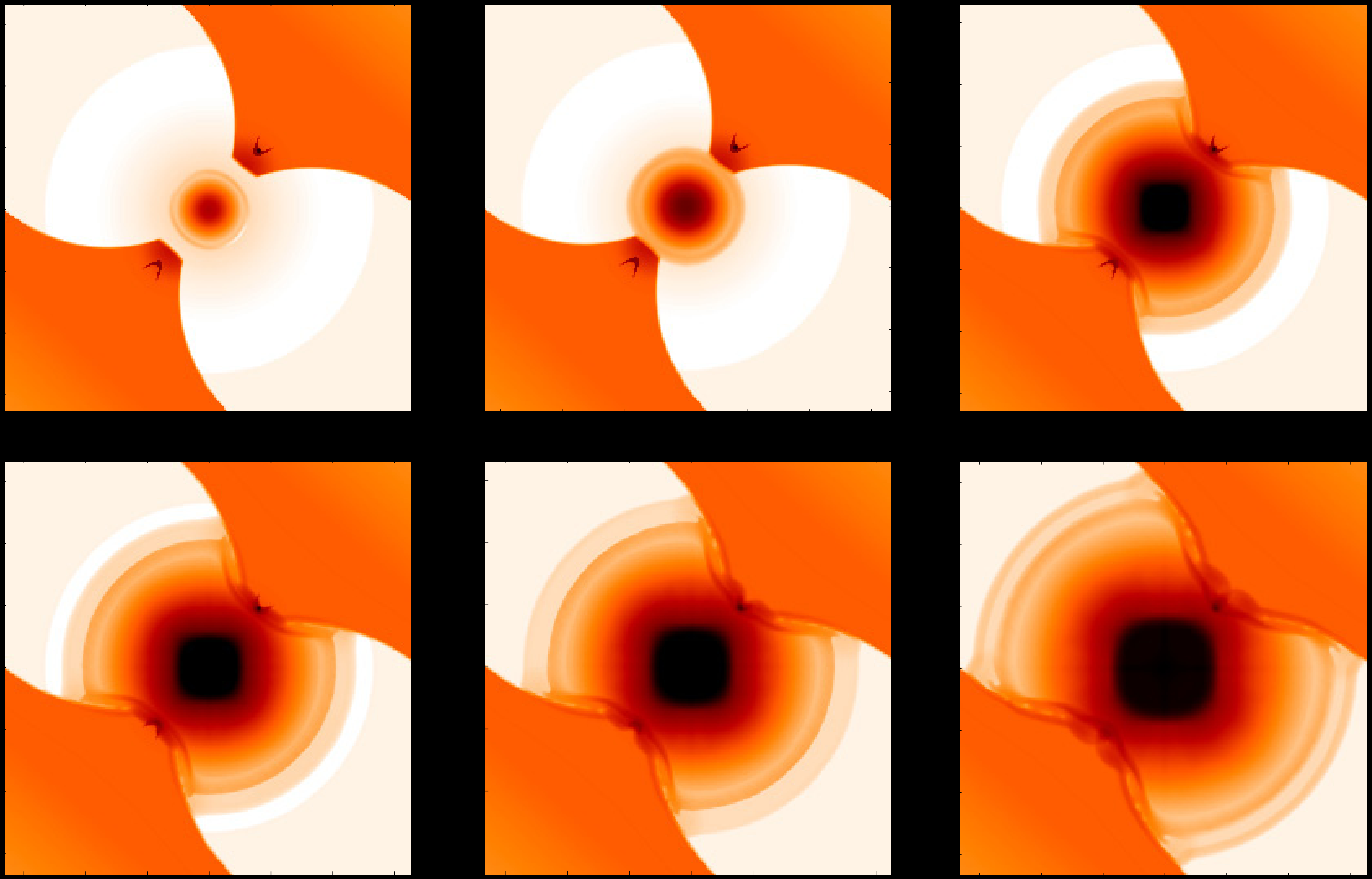
(1) the unshocked ejecta in the center;
(2) the ejecta shocked by the reverse shock;
(3) the CSM at the inner edge of the equatorial ring shocked by the reverse shock;
(4) the CSM at the outer edge of the equatorial ring shocked by the forward shock;
(5) the CSM within the inner ring radius which, after being shocked by the forward shock, have been shocked also by the reflected shock.

Emission Sites



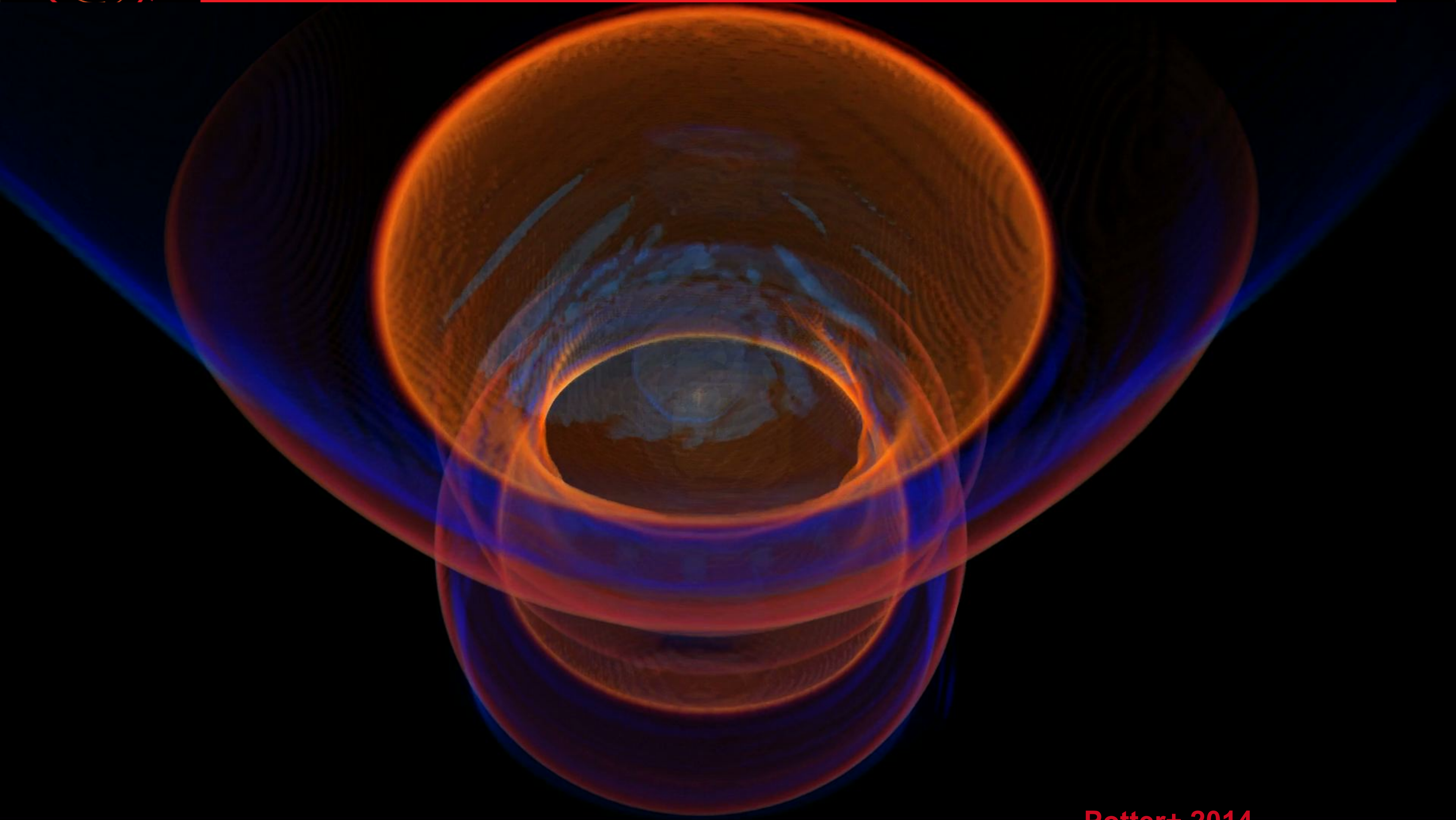
NASA/ESA, A. Field (STScI)

Remnant evolution



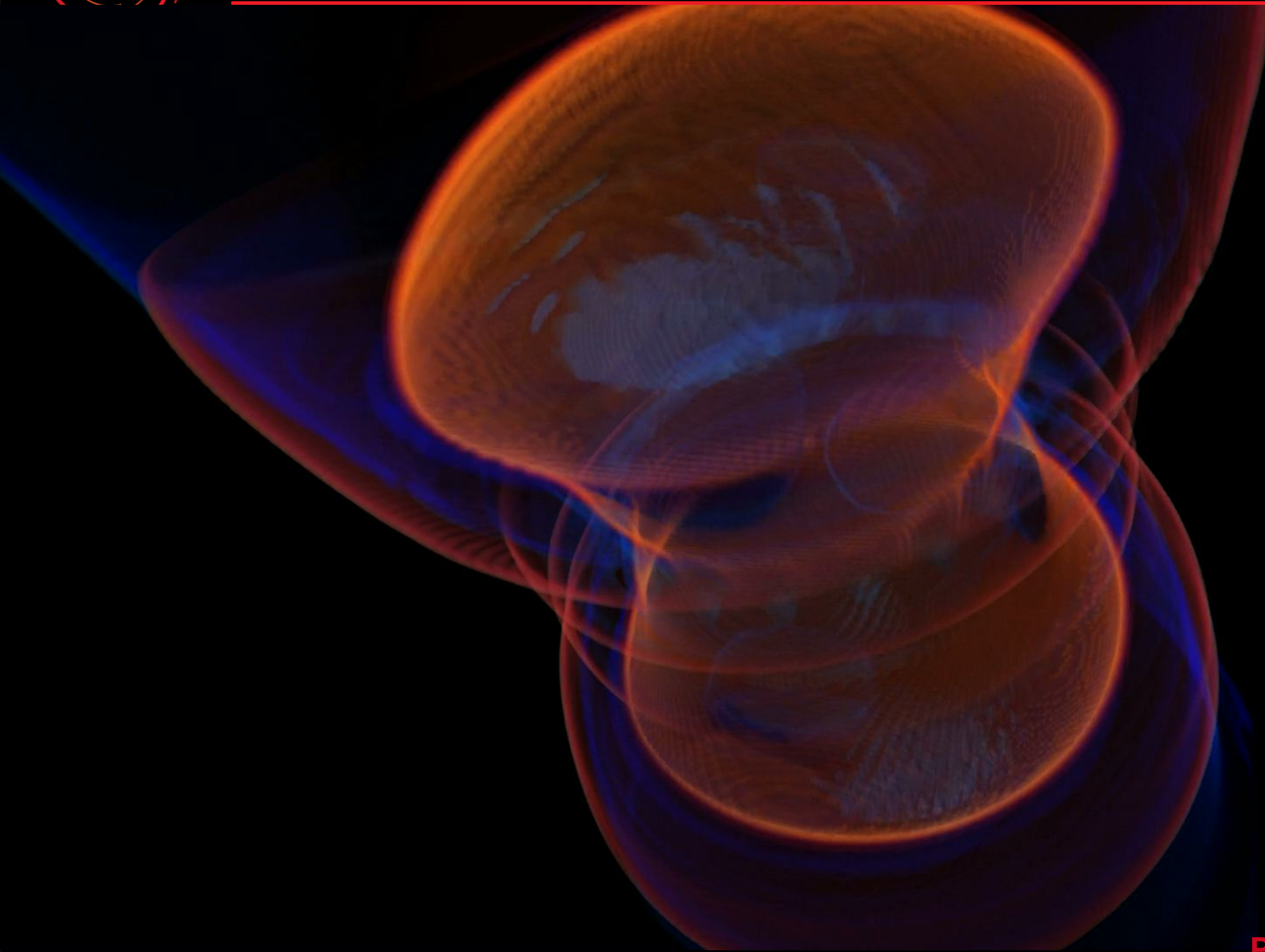
Potter+ 2014

Evolution of the radio remnant



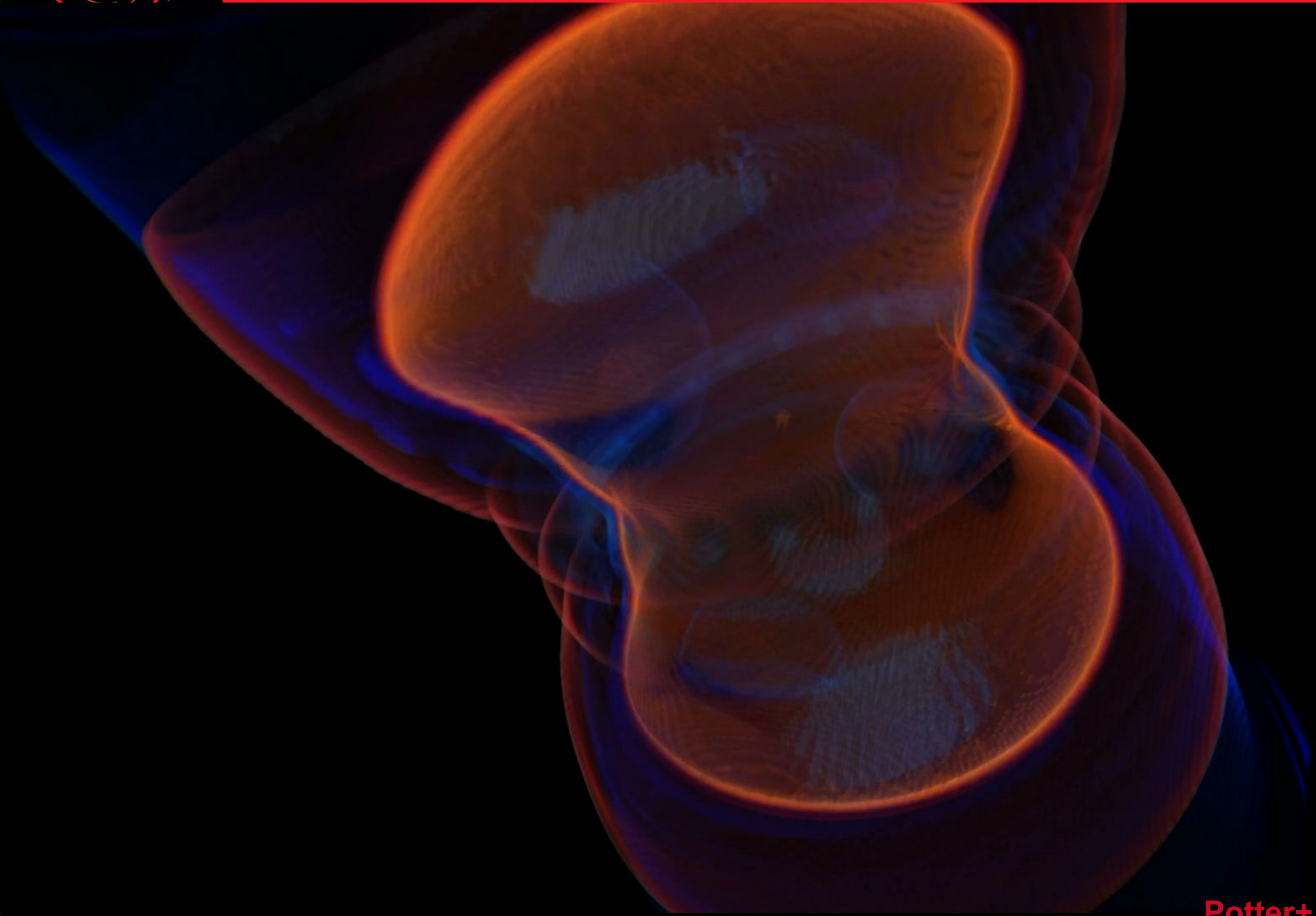
Potter+ 2014

Evolution of the radio remnant



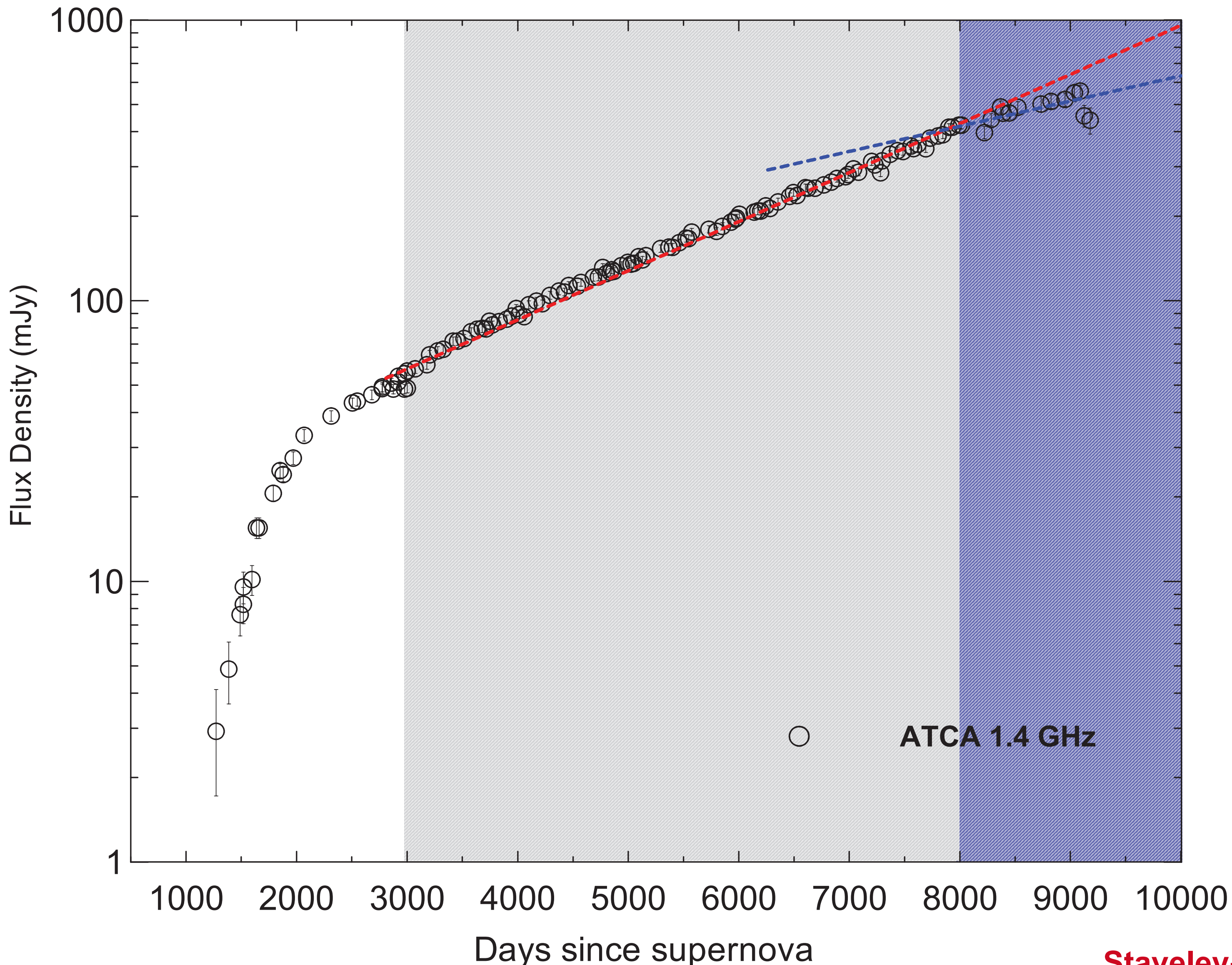
Potter+ 2014

Evolution of the radio remnant



Potter+ 2014

Evolution – Light Curve

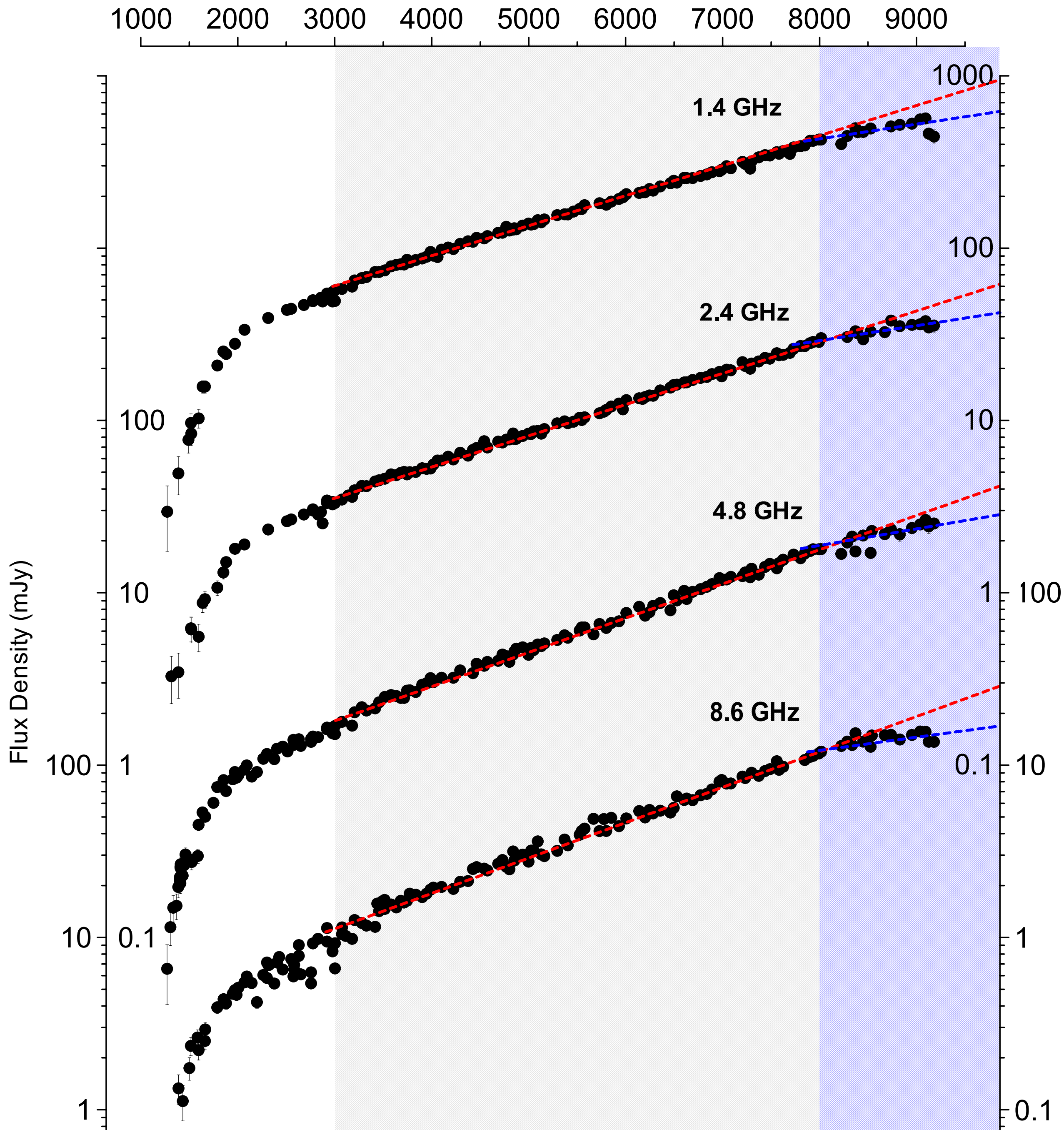


Staveley-Smith+ 2014

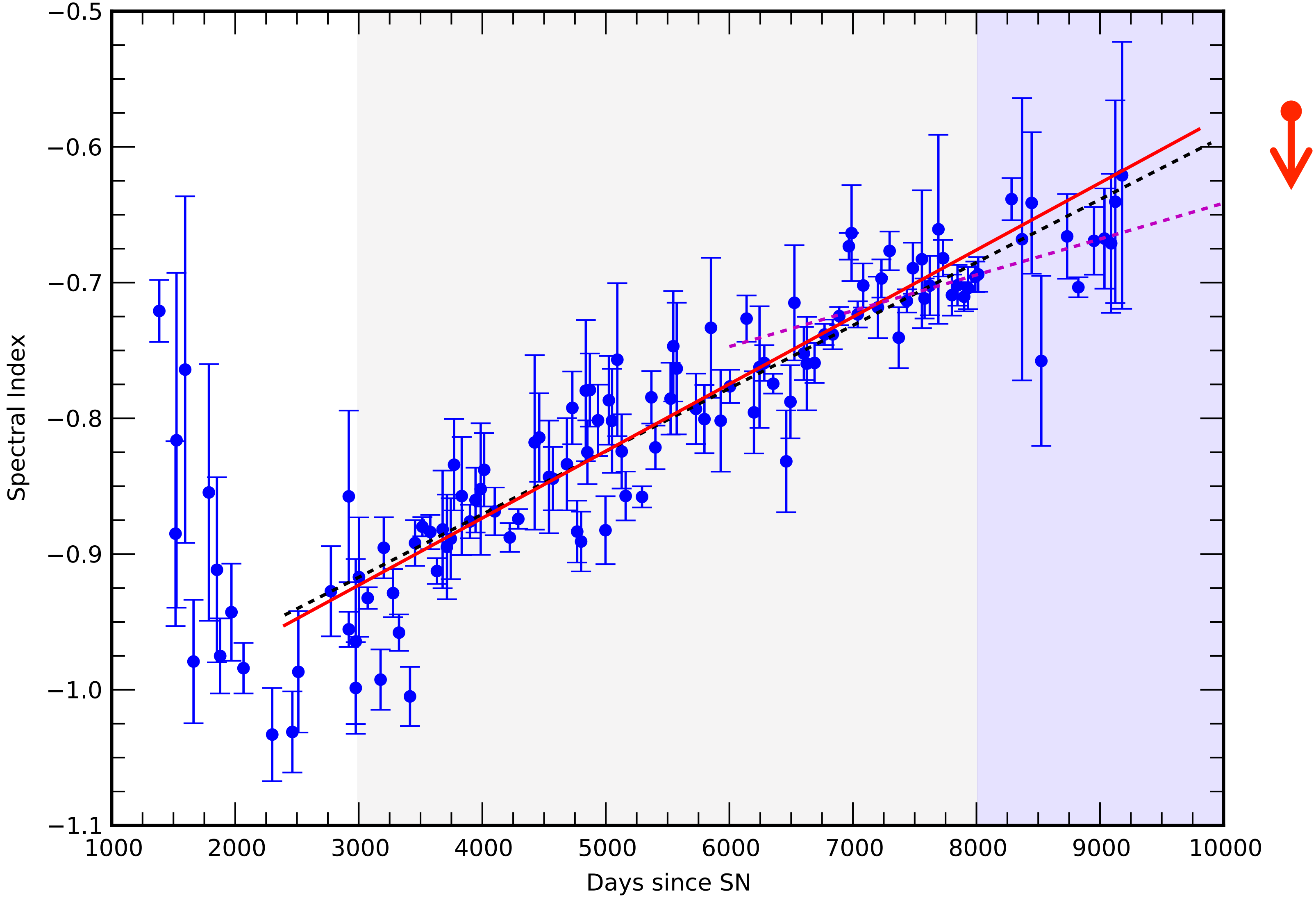
ICRAR

Evolution

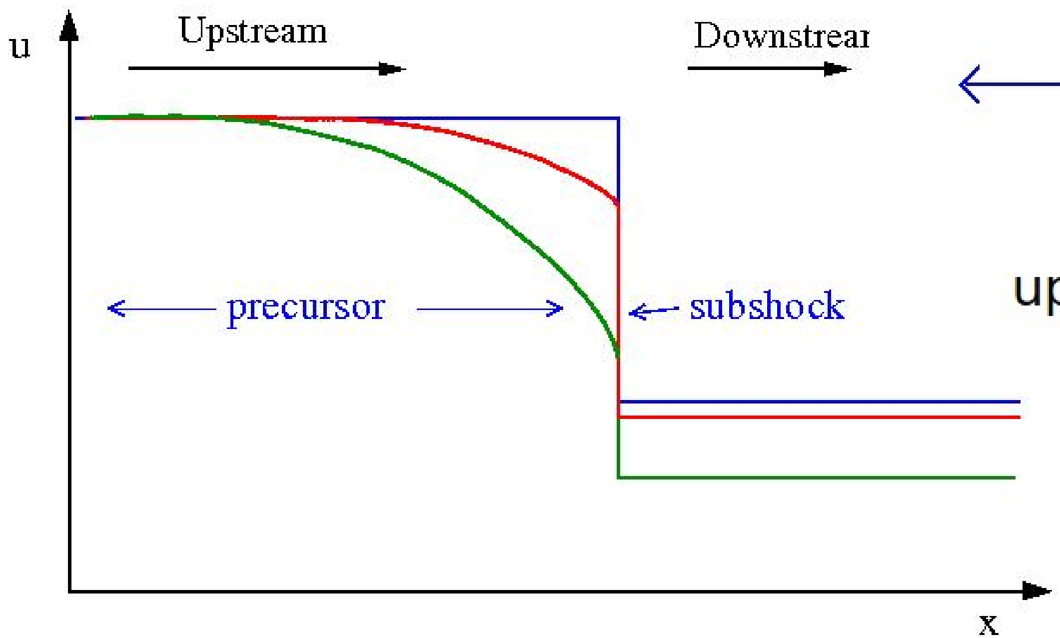
Multi-frequency Flux Monitoring

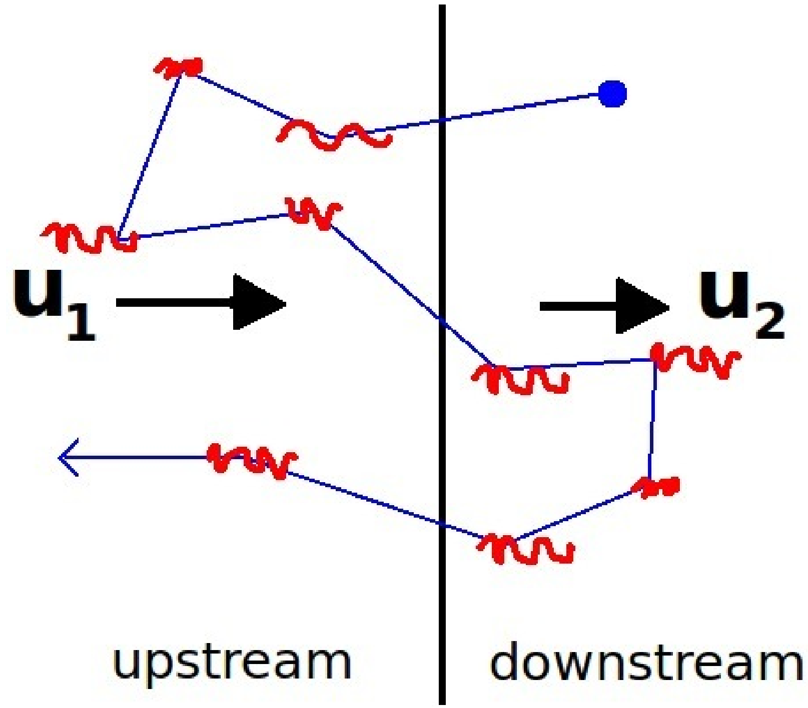


Evolution – Global spectral index



Particle acceleration by the shock front

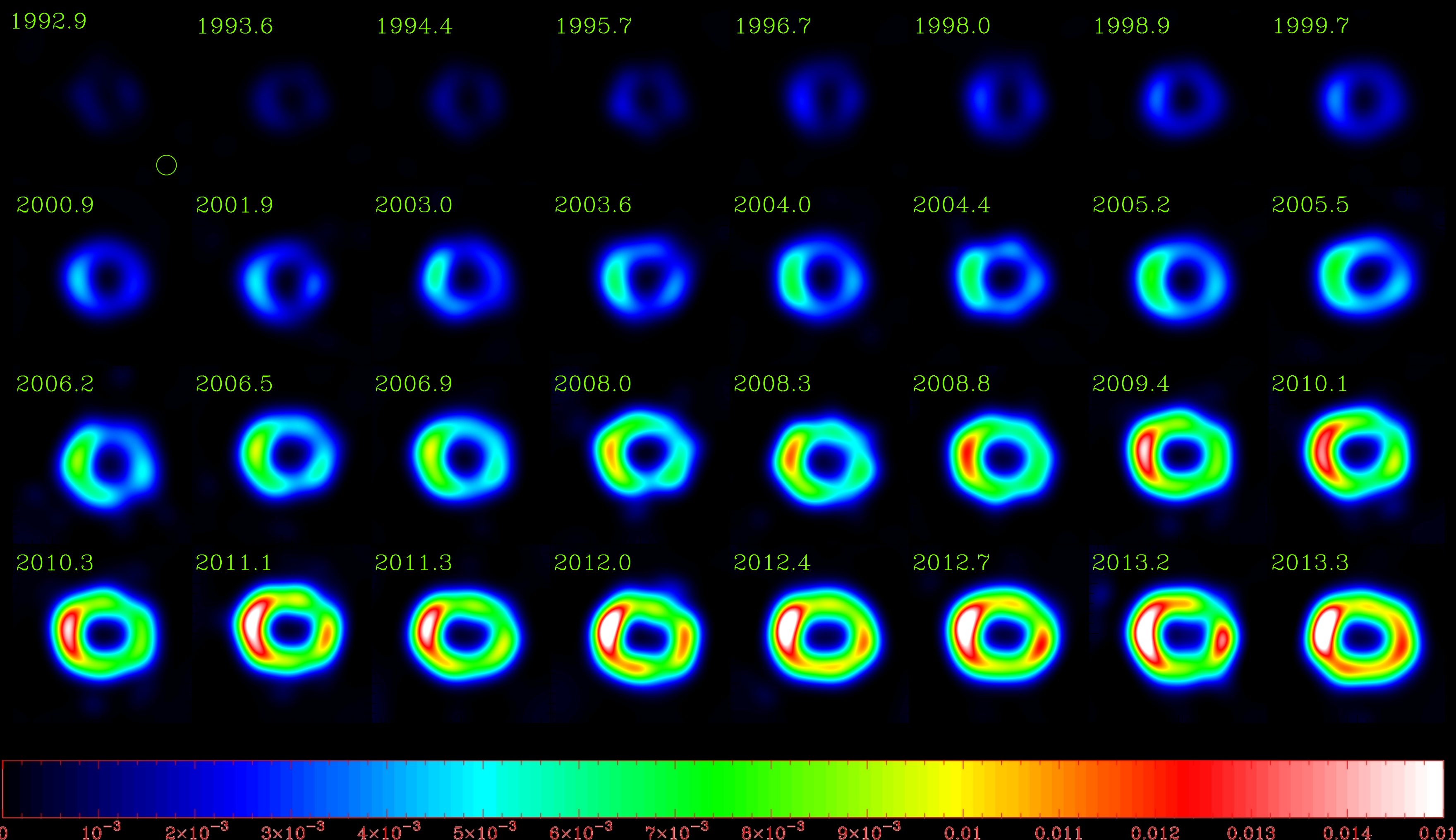




…from Brian Reville's presentation

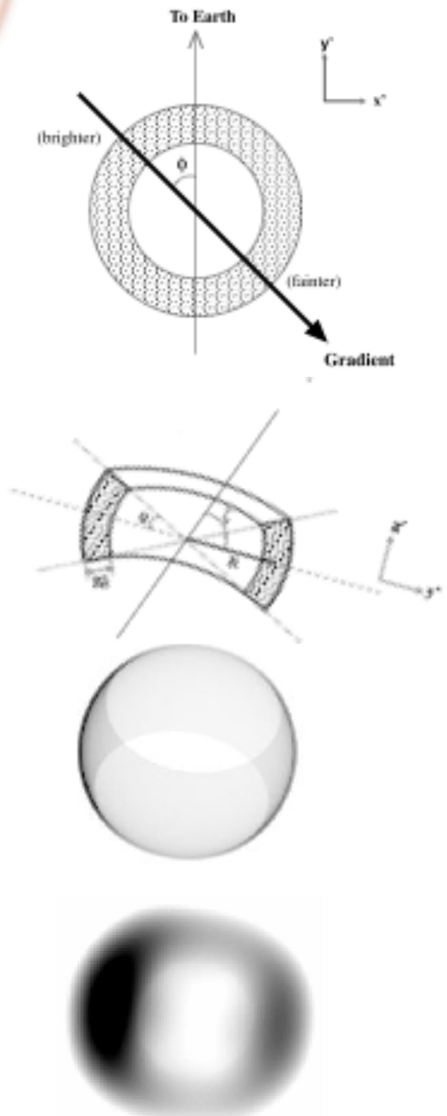
Evolution – Morphology at 9 GHz

Ng+ 2013

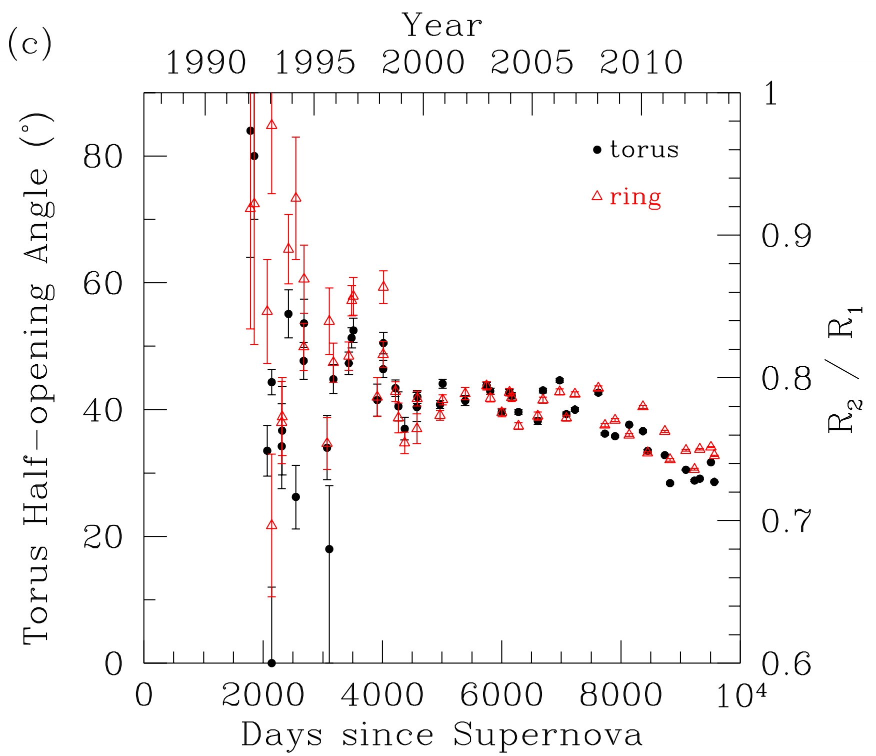


9 GHz Observations

Ng+ 2013



Geometry

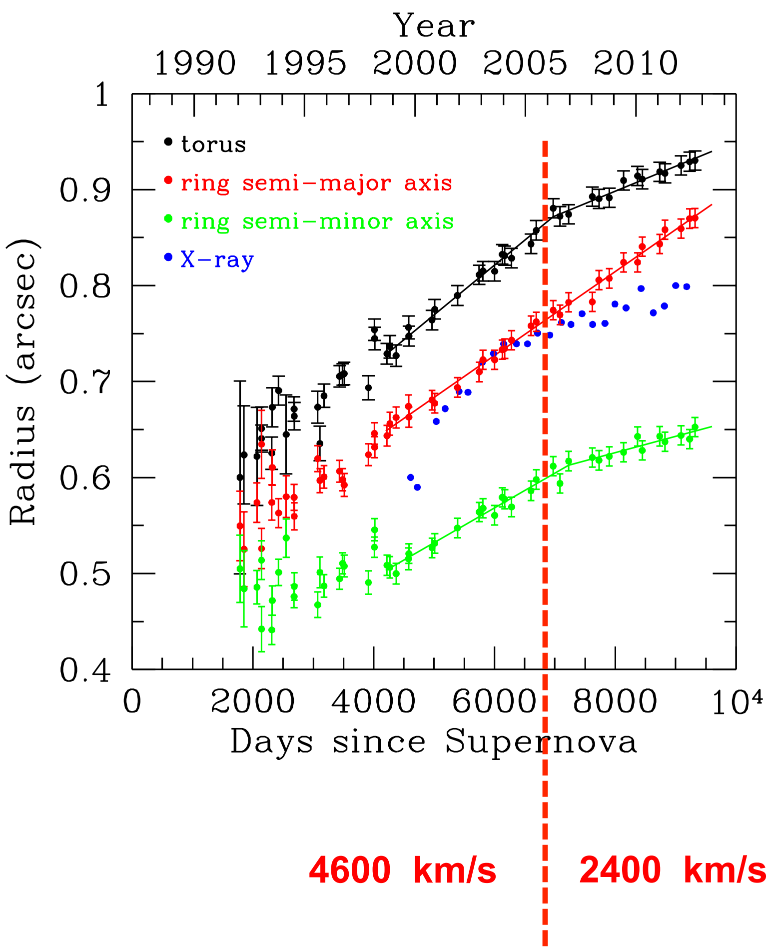


Ng+ 2008

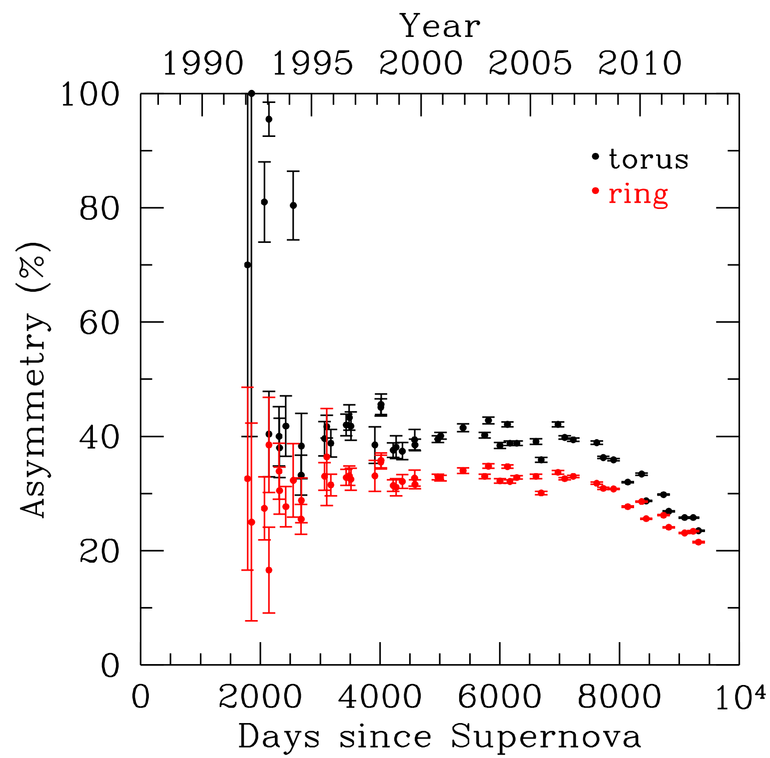
9 GHz Observations

Ng+ 2013

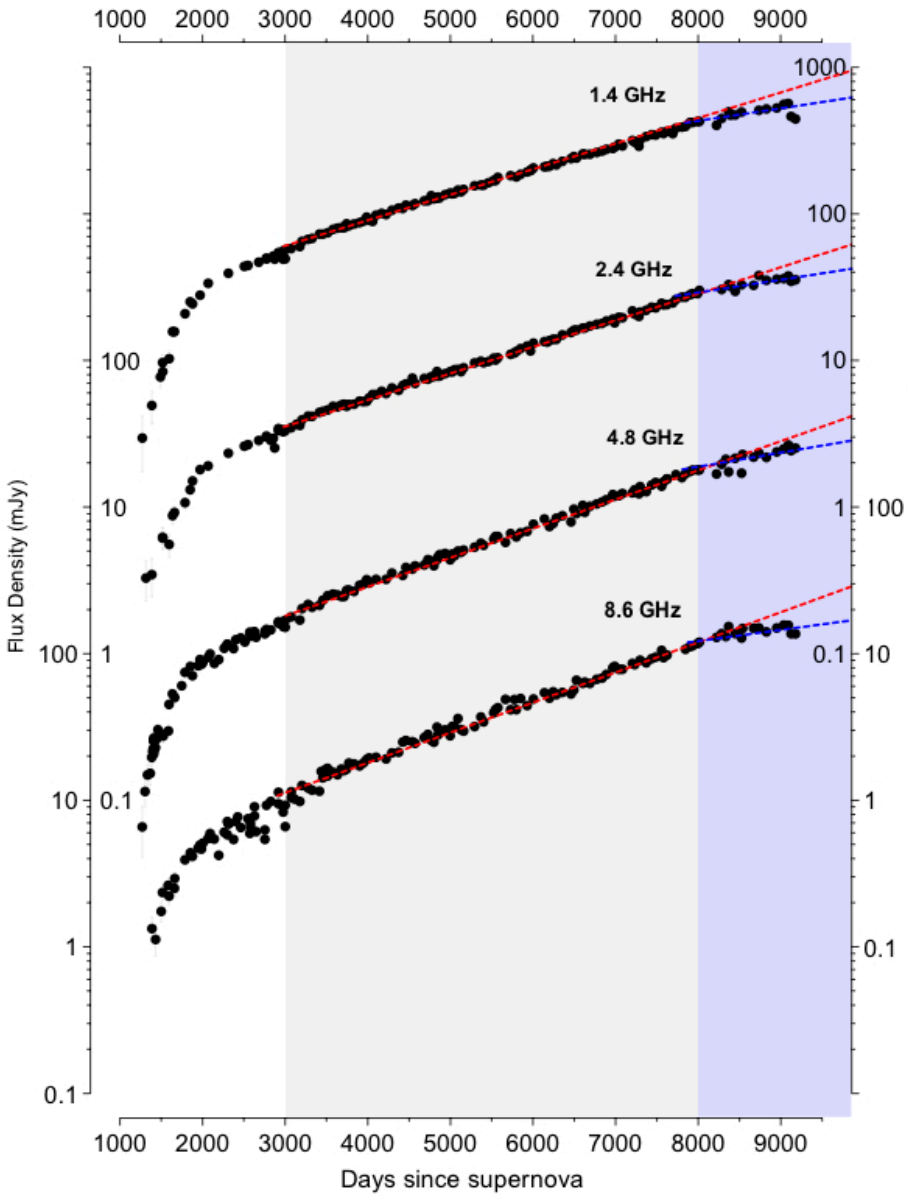
Expansion

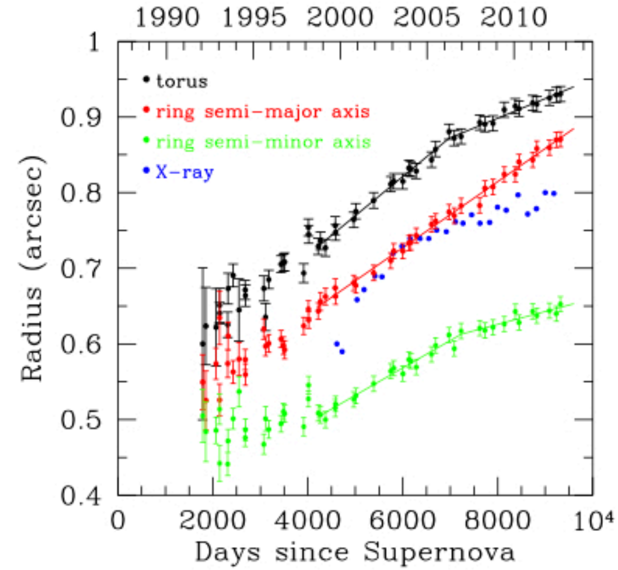


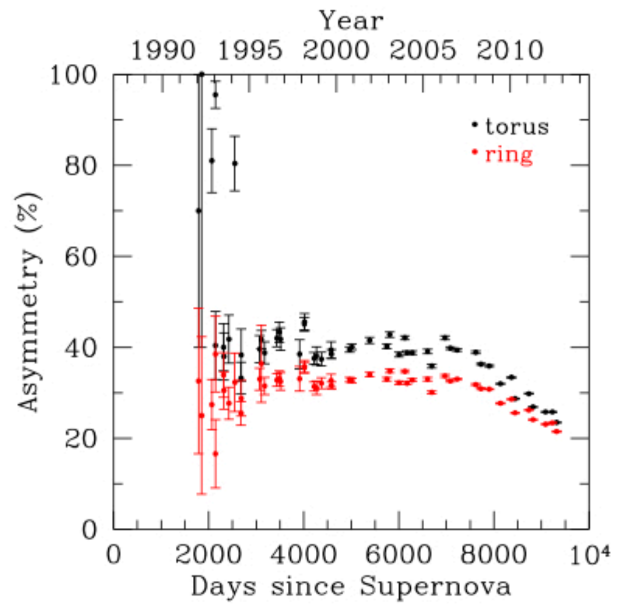
Asymmetry



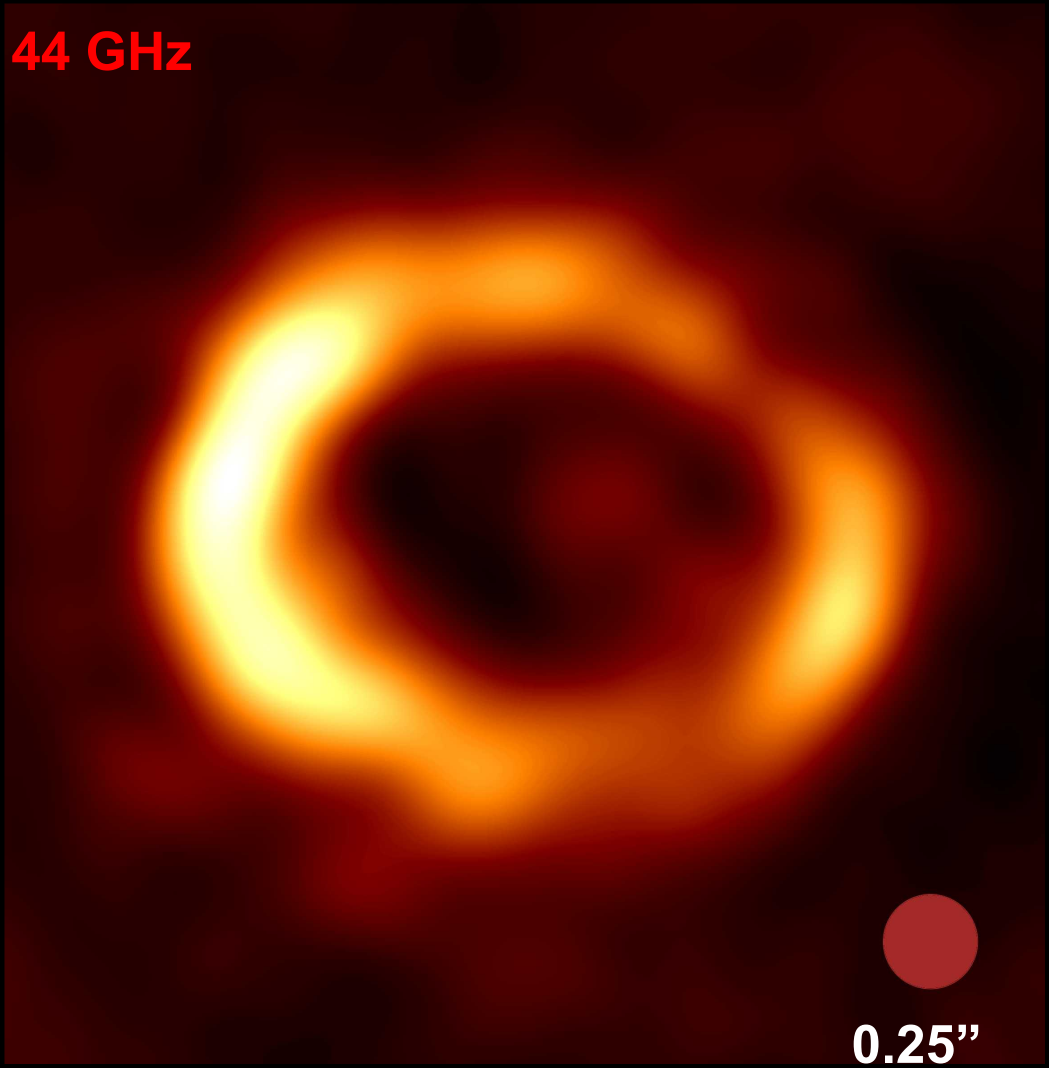
A new phase from Day ~7000-7500







Evolution – Morphology in high resolution

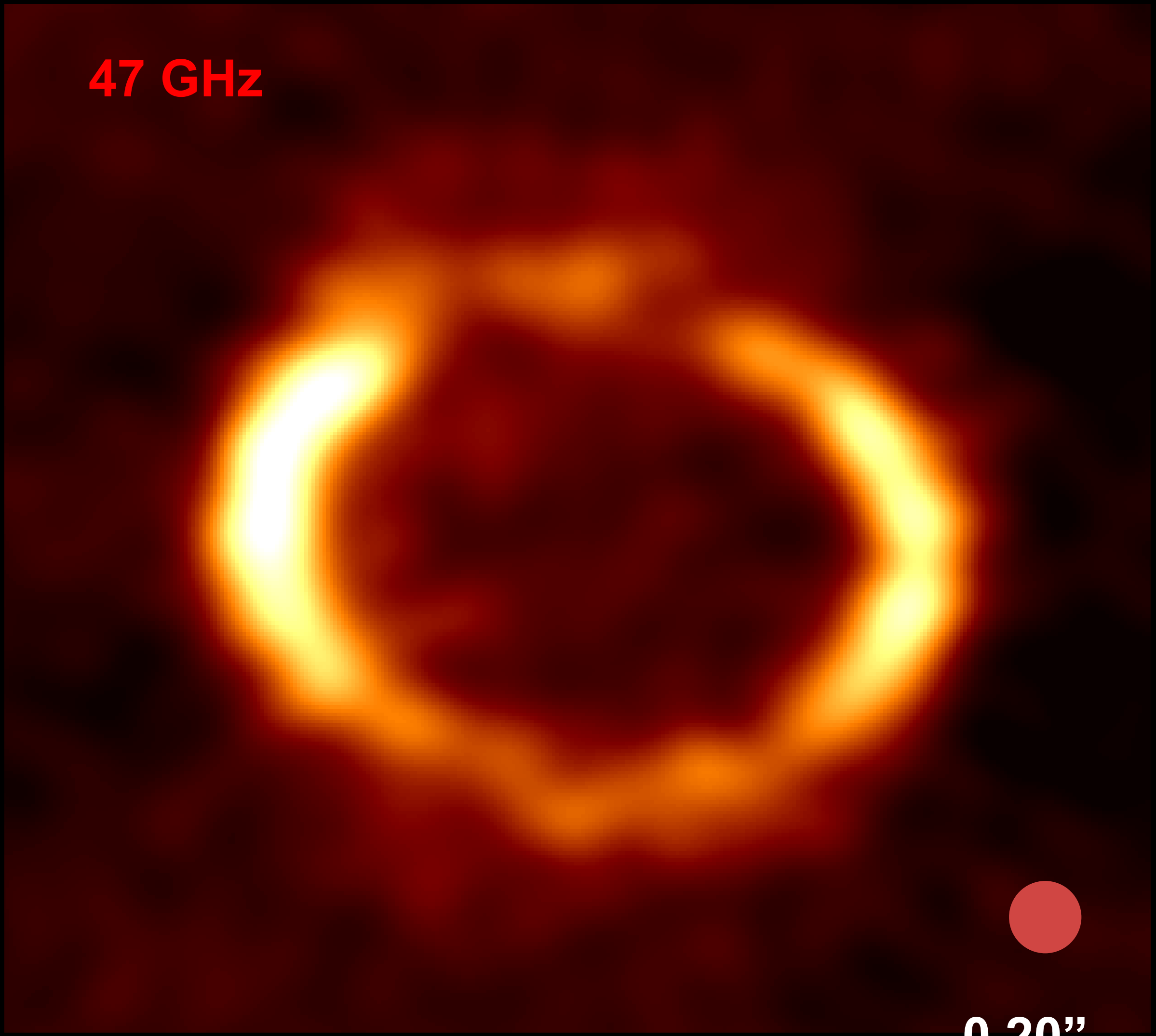


Nov 2011

Evolution – Morphology in high resolution

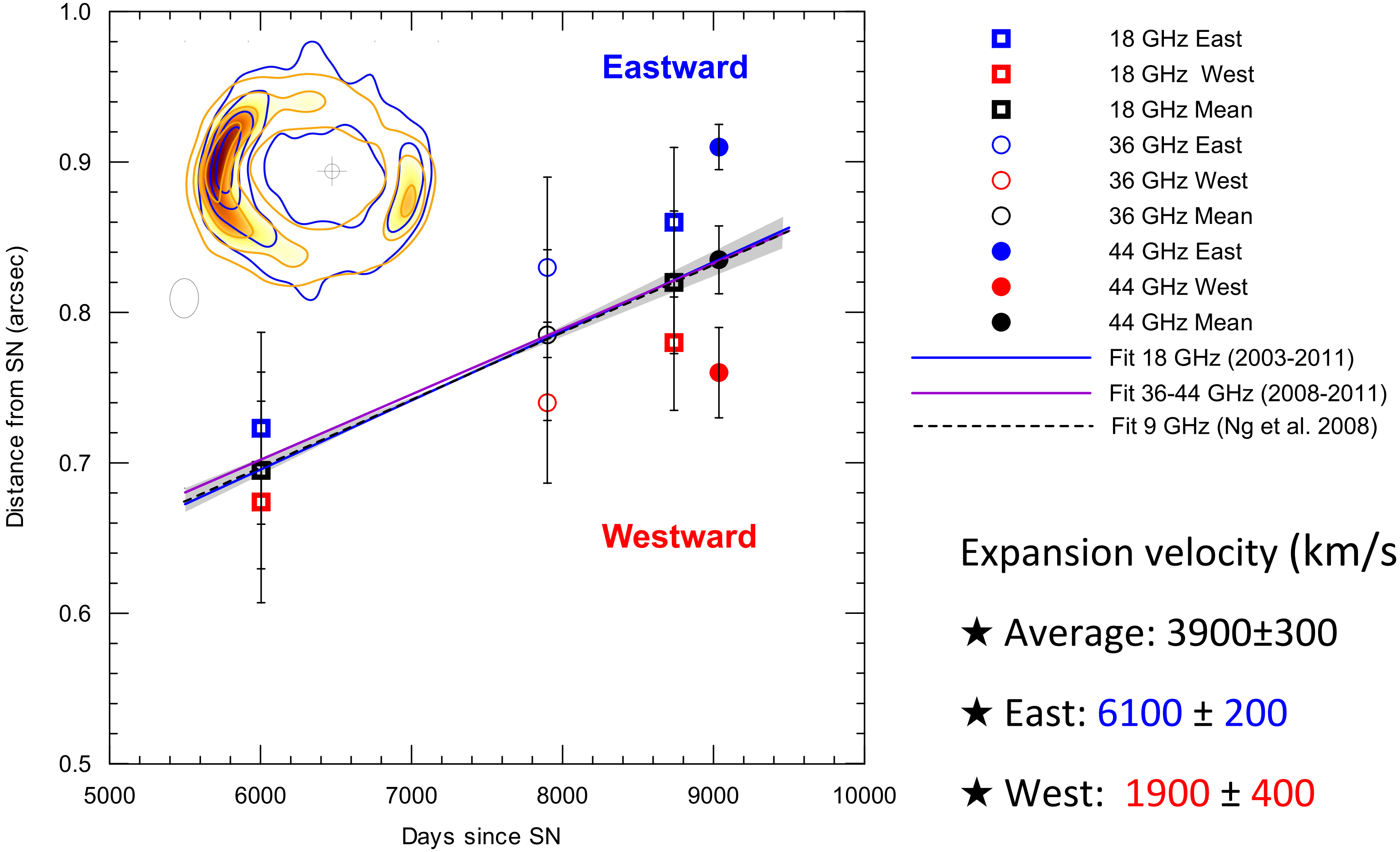
Oct 2015

Evolution – Morphology in high resolution



May 2016

Asymmetric expansion



Expansion velocity (km/s)

★ Average: 3900±300

★ East: 6100 ± 200

★ West: 1900 ± 400

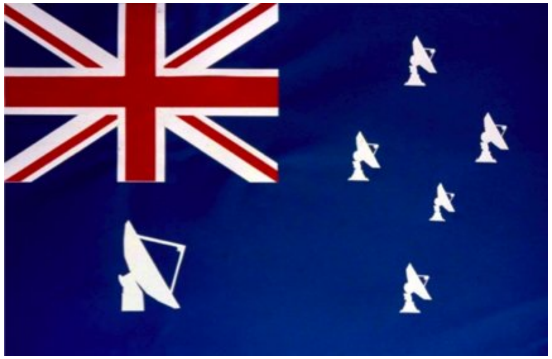
Zanardo+ 2013

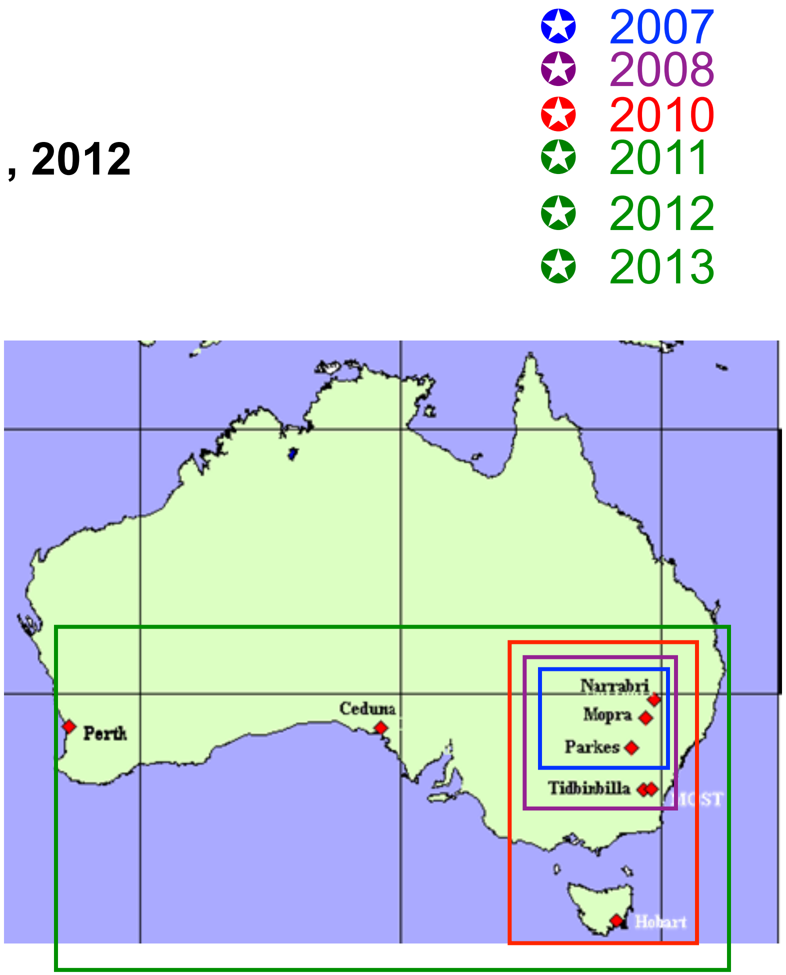
VLBI observations

LBA

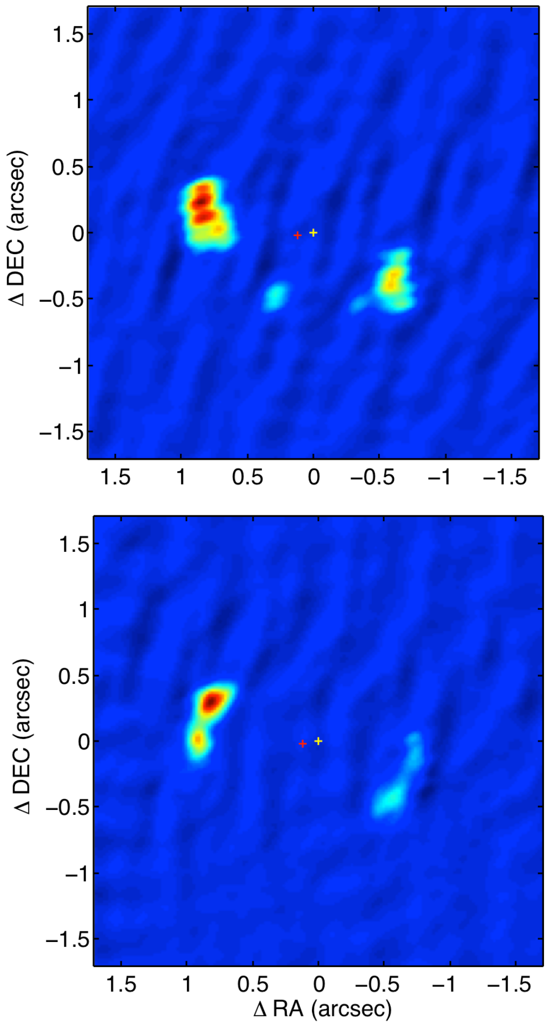
Imaging
Frequency: 1.4 GHz
Oct 2007, July 2010, Aug 2011, 2012

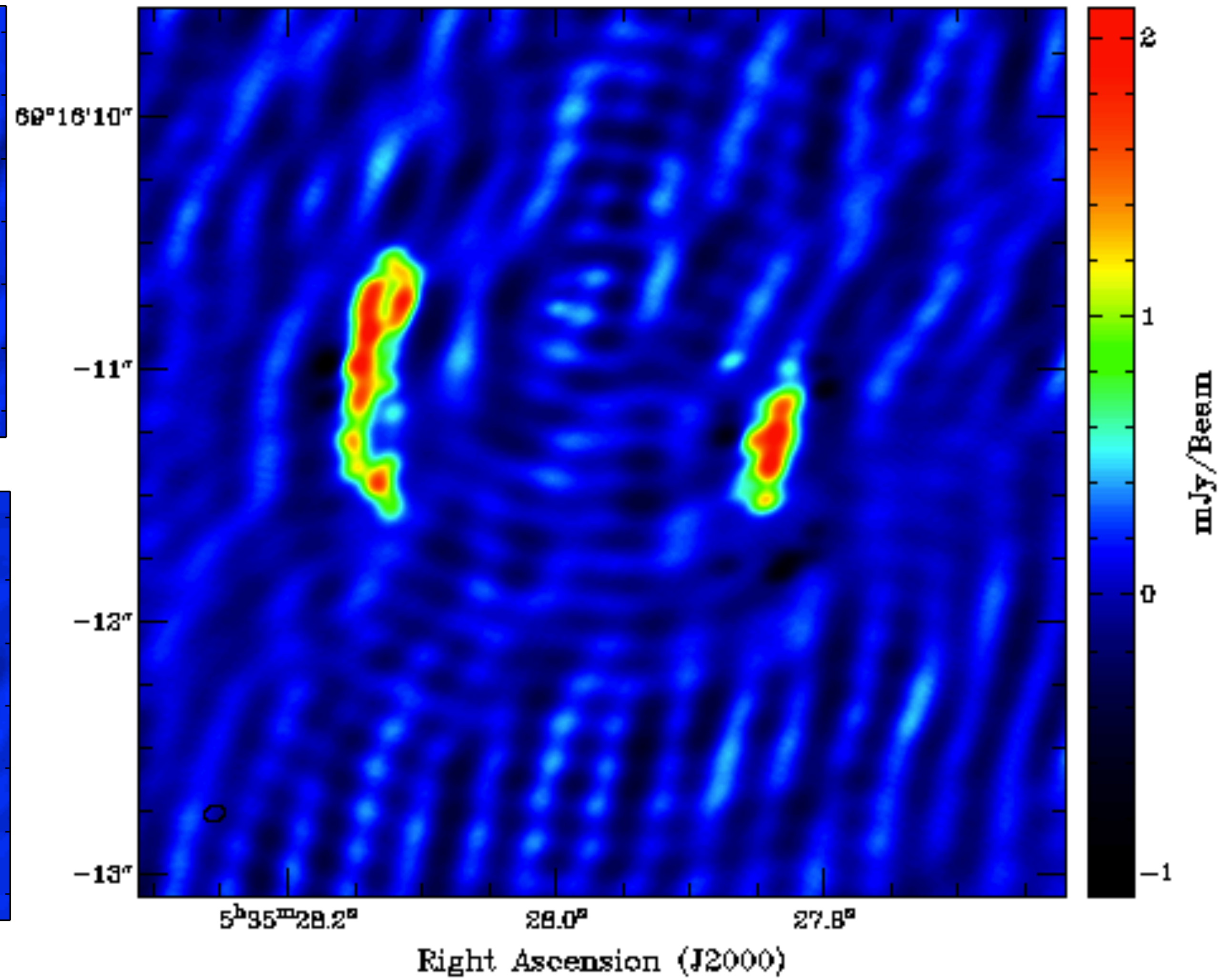
Frequency: 1.6 GHz
Nov 2008, 2013





VLBI observations

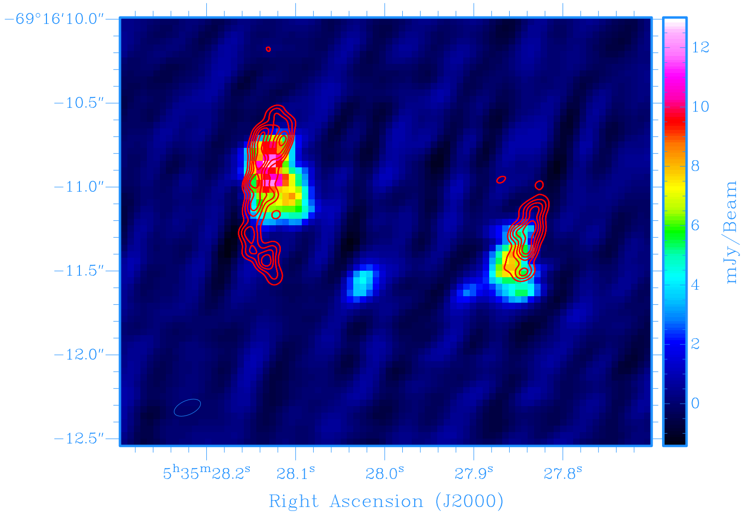


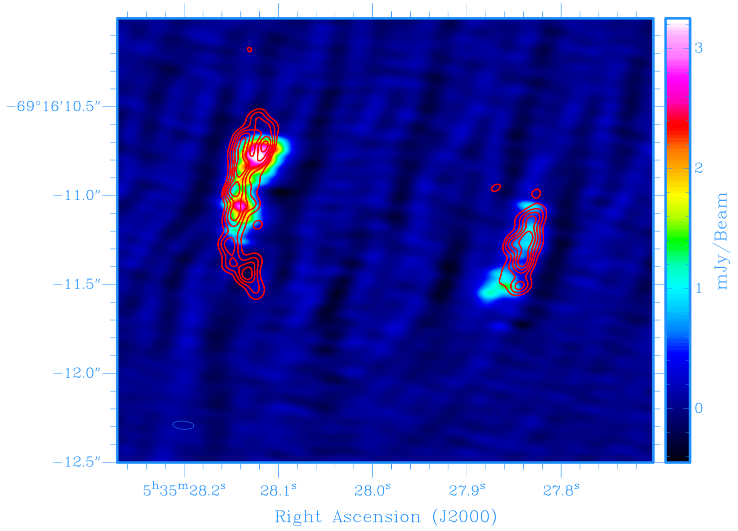


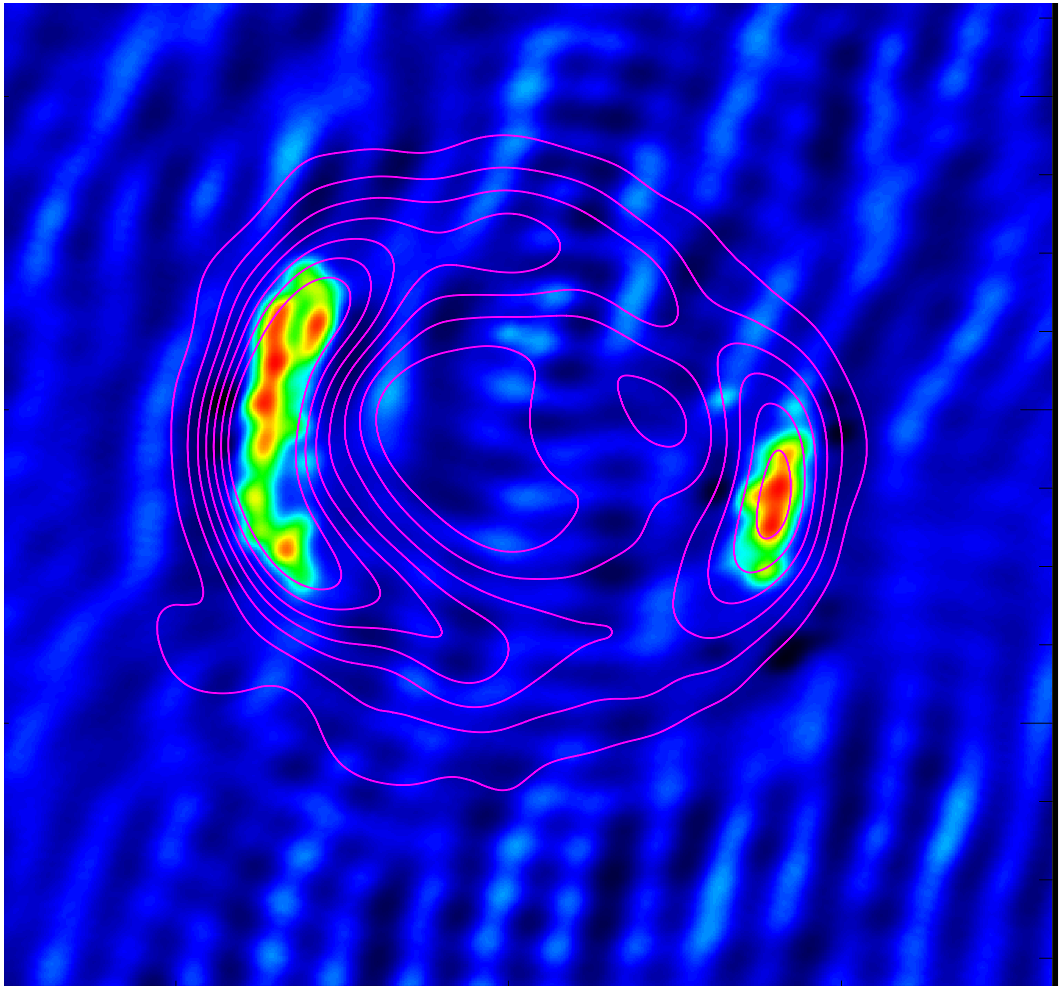
Ng+ 2011

Zanardo+

VLBI observations

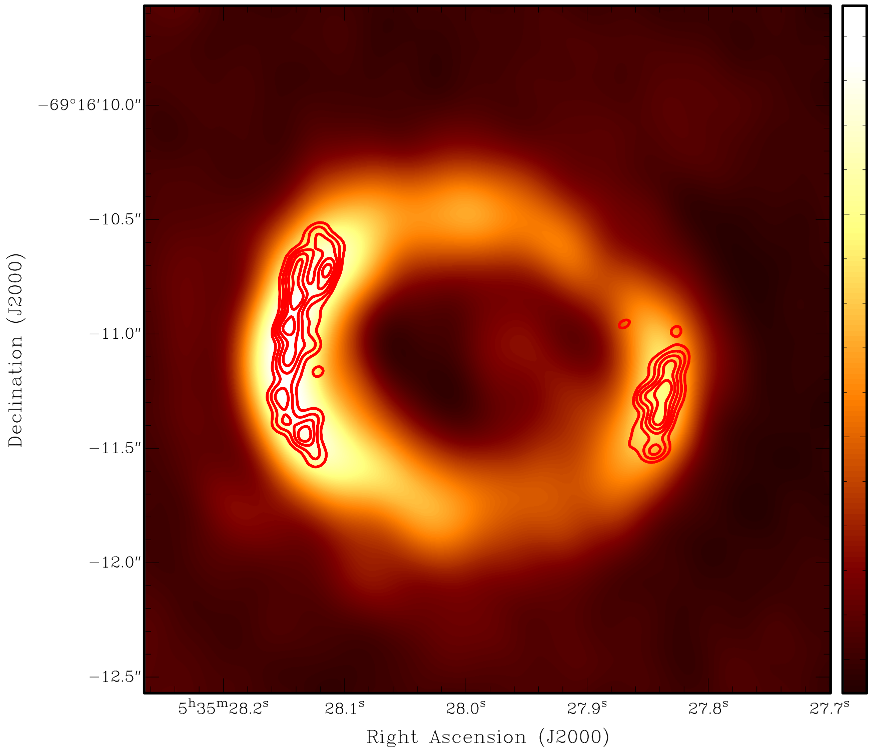


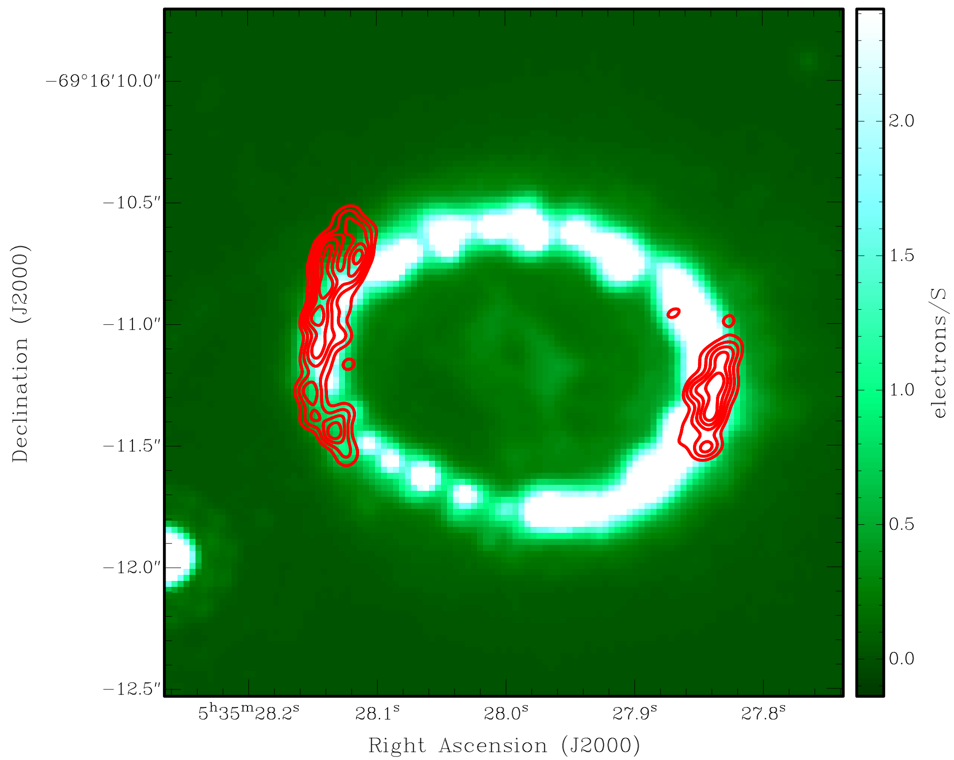




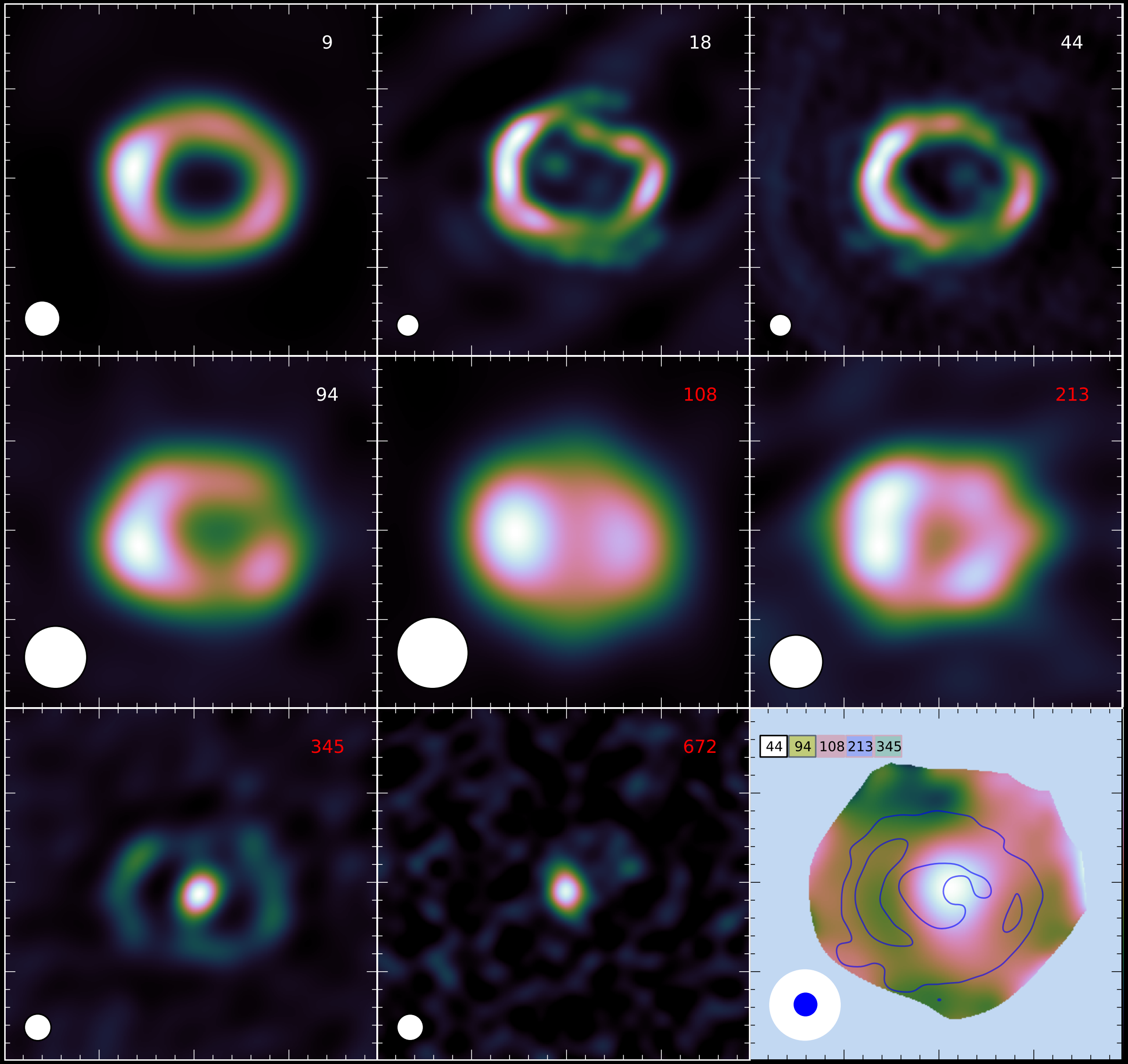
Zanardo+

VLBI - Image Alignment





ATCA + ALMA: Emission components



ATCA + ALMA: Asymmetry

Asymmetry ratio decreases at higher frequencies.

We attribute this to the shorter synchrotron lifetime at high frequencies.

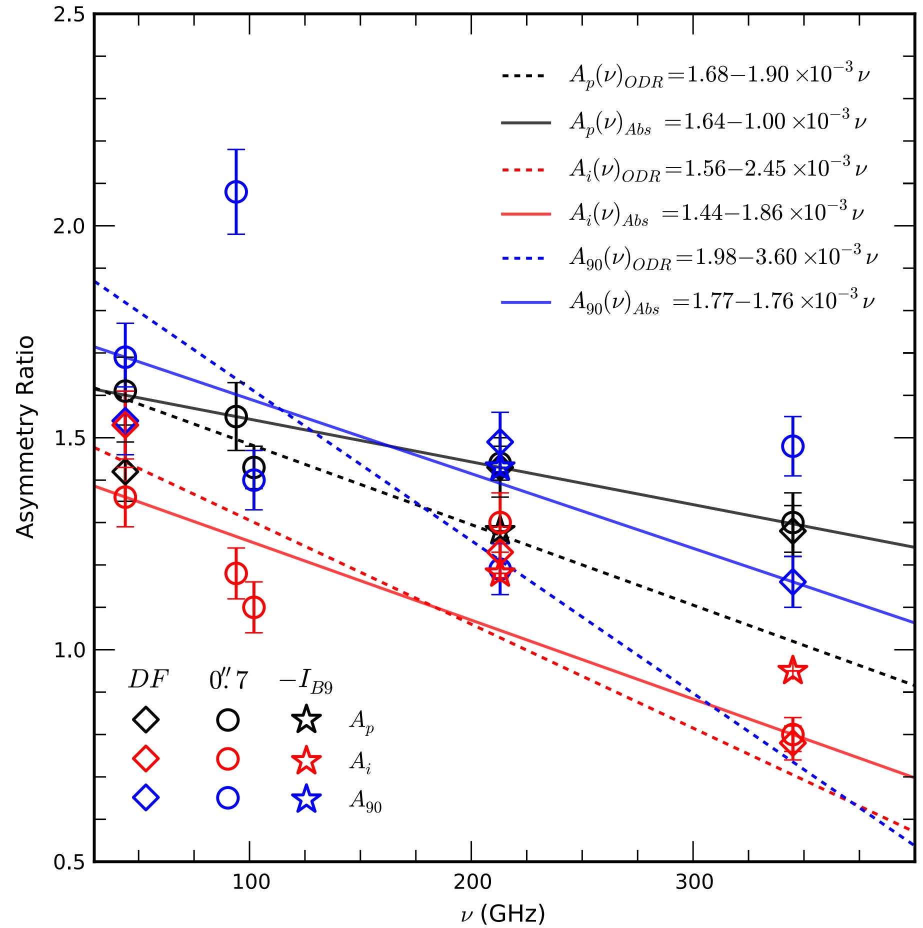


Image subtraction

Image -

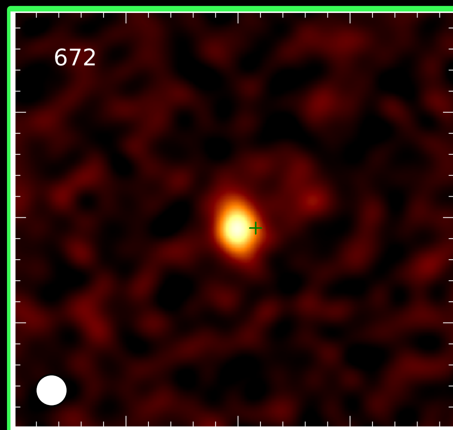


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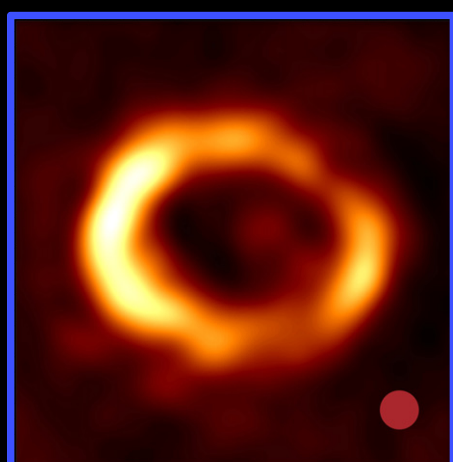
Image -



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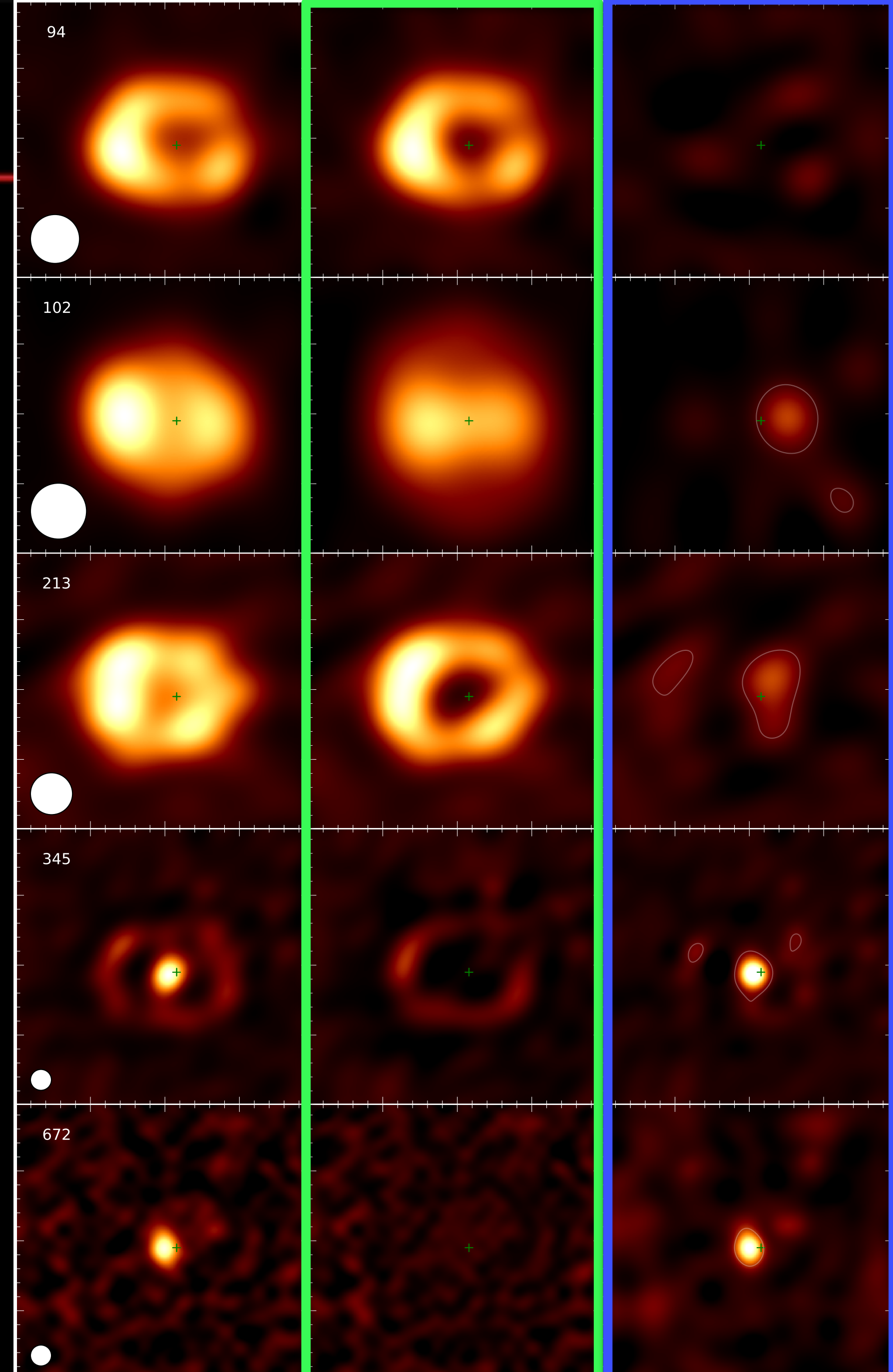
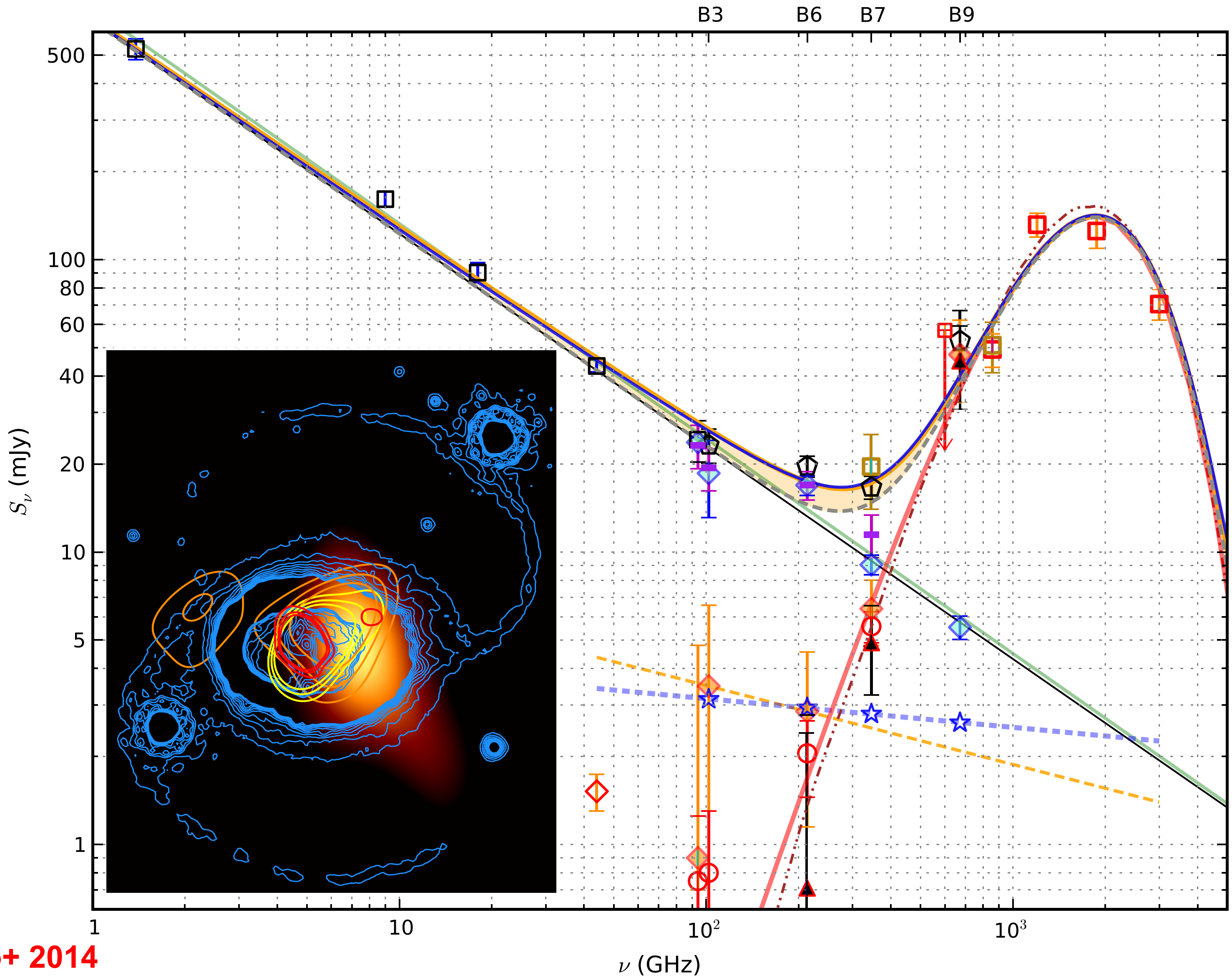


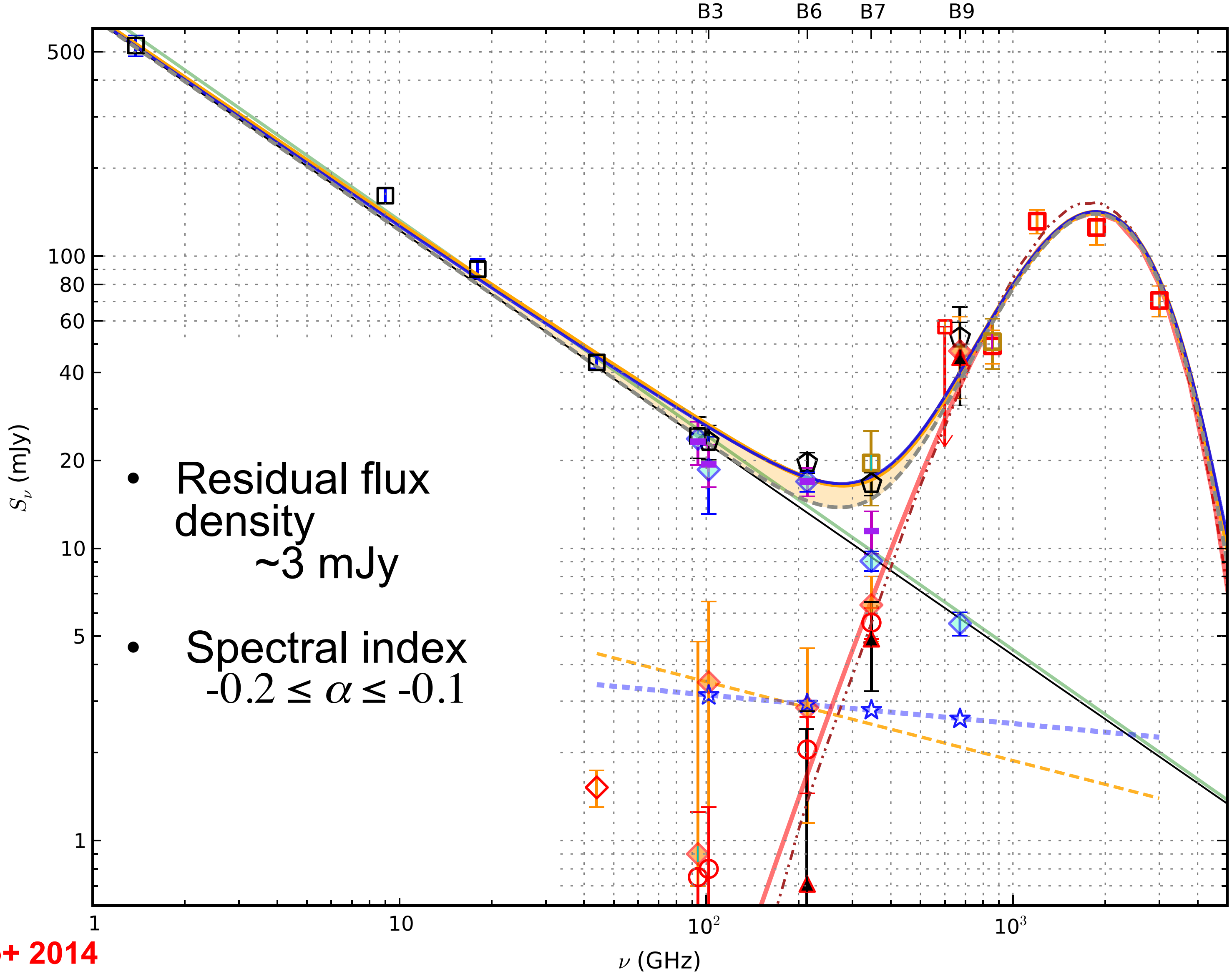
Zanardo+ 2014

ATCA + ALMA: SED & residuals



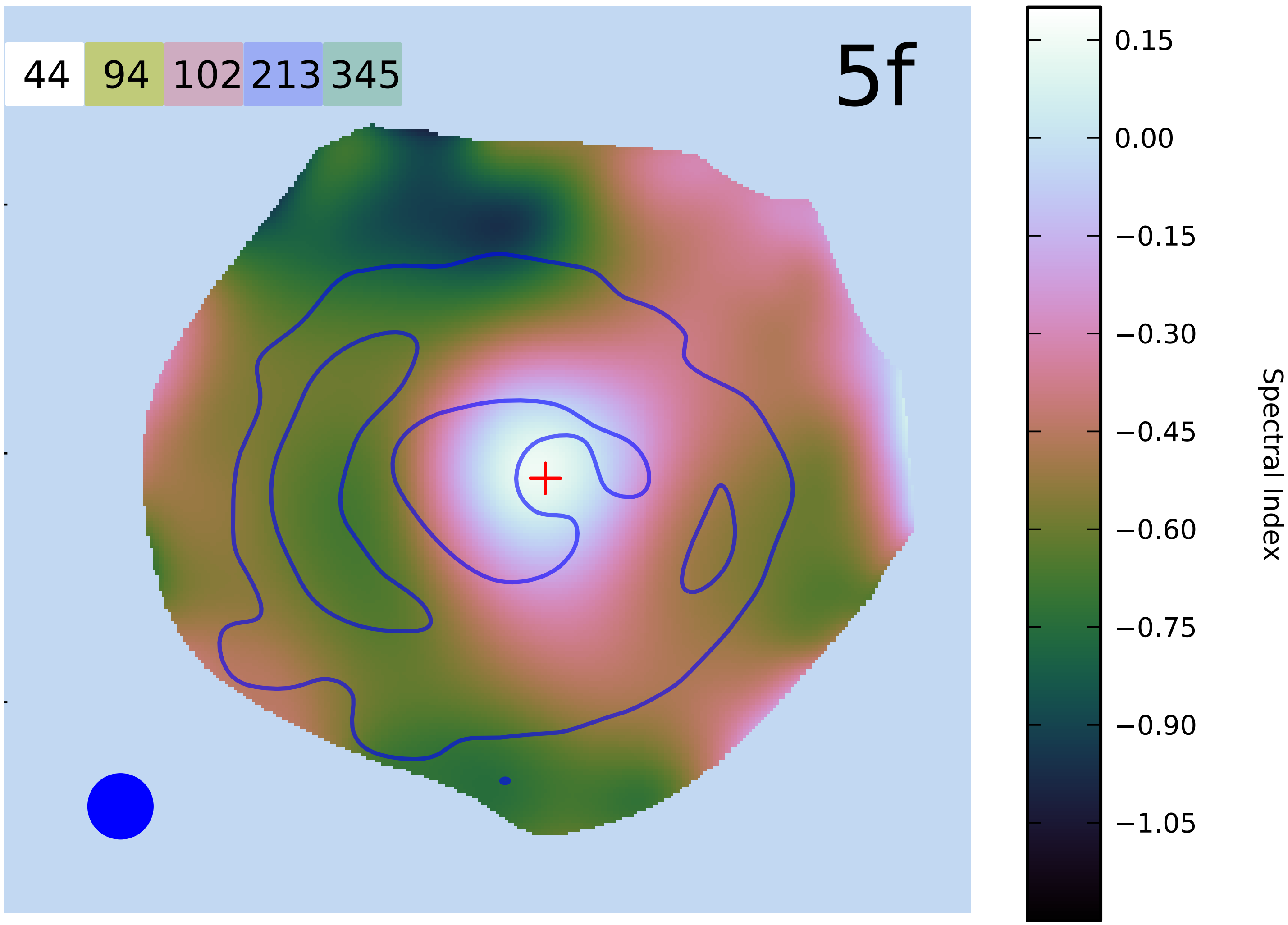
Zanardo+ 2014

ATCA + ALMA: SED & residuals



Zanardo+ 2014

Spectral index maps



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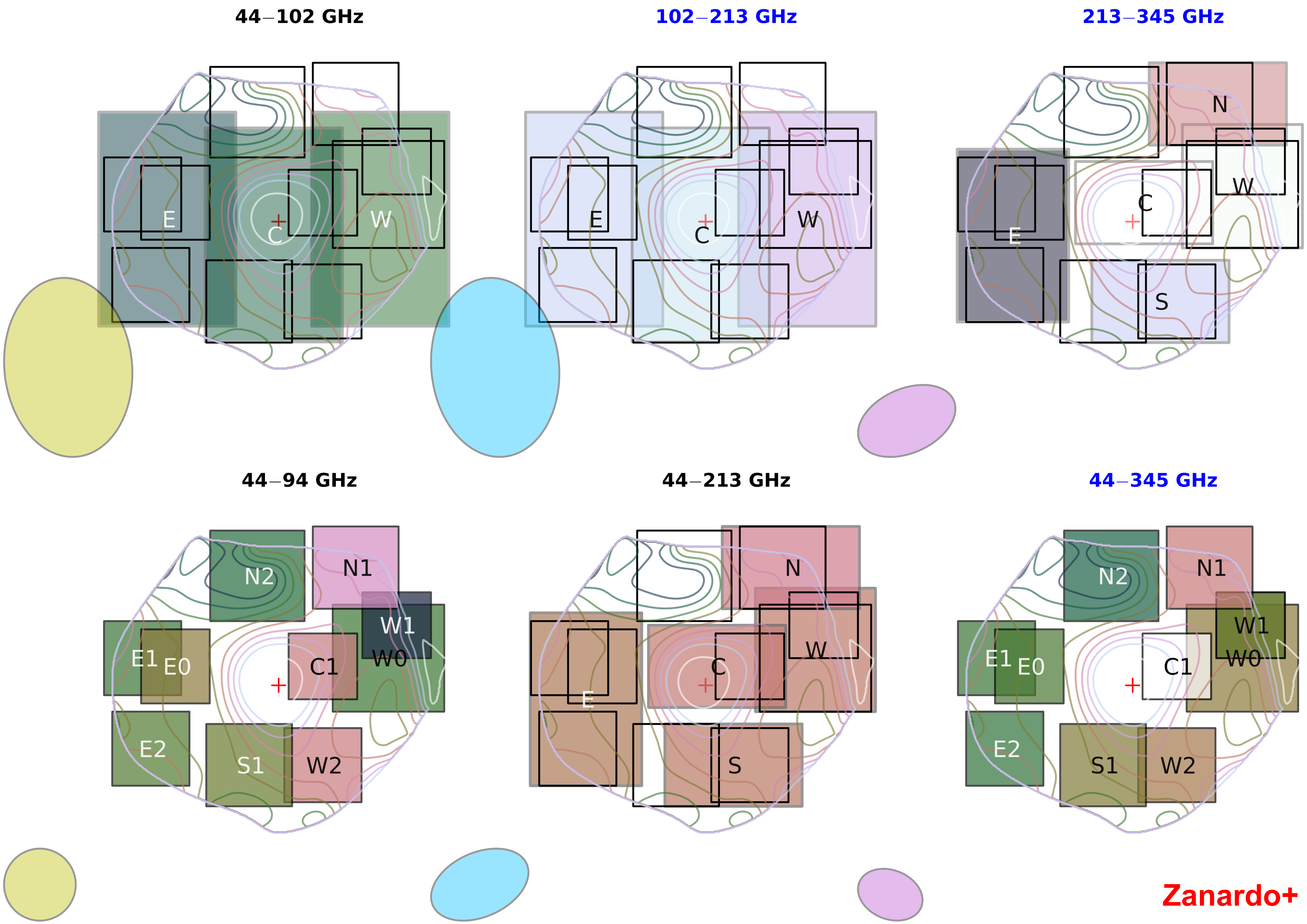
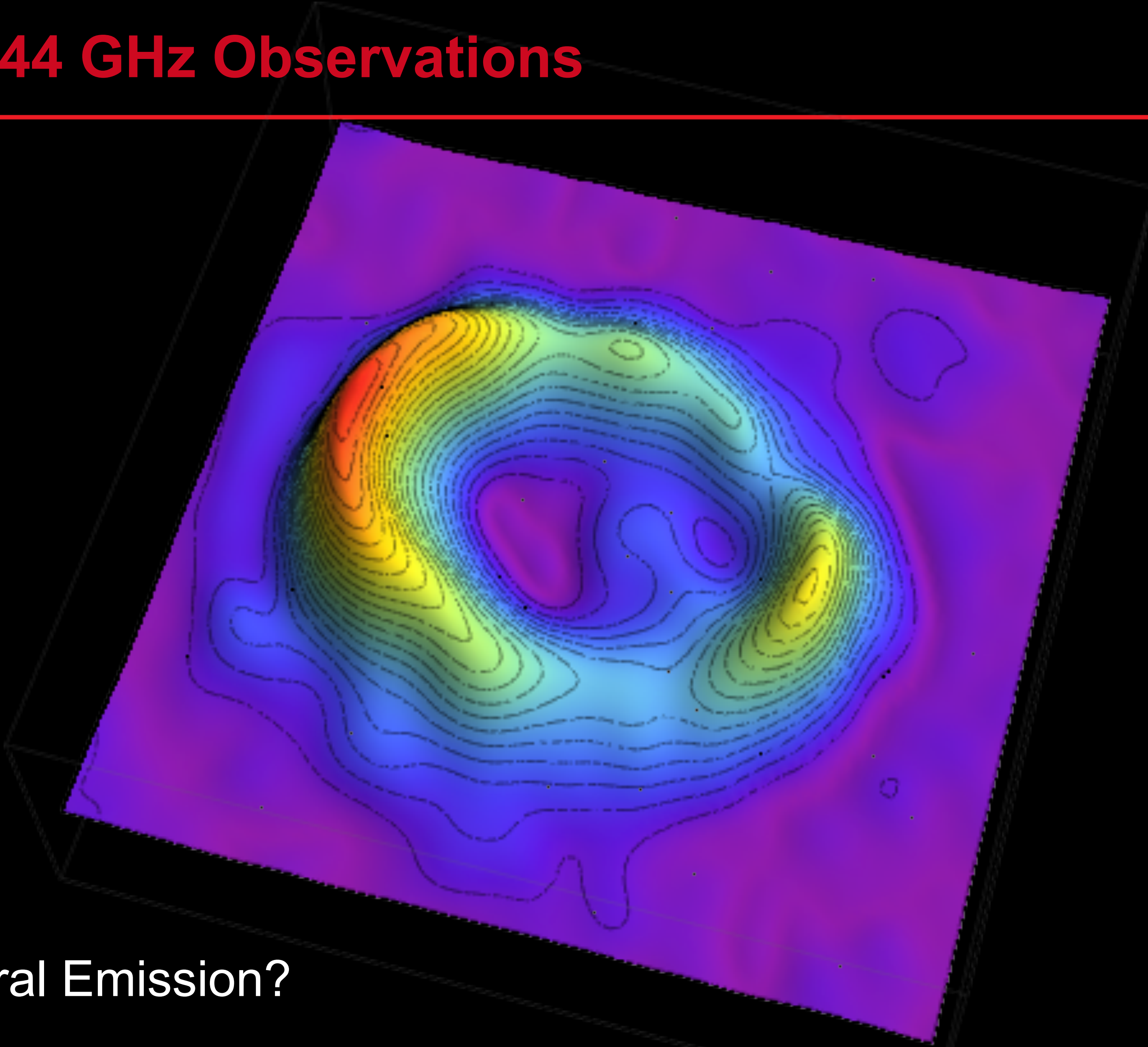
ATCA + ALMA   Spectral maps



Zanardo+ 2014

Emission from the central region

44 GHz Observations



Central Emission?

ATCA+ALMA: Possible PWN constraints

- Dispersion measure:

  $$1000 \lesssim \mathrm{DM} \lesssim 6000\ \mathrm{cm}^{-3}$$

- Swept-up velocity:

  $$260 \lesssim v_{\mathrm{PWN}} \lesssim 410\ \mathrm{km\ s}^{-1},$$

- Magnetic field strength:

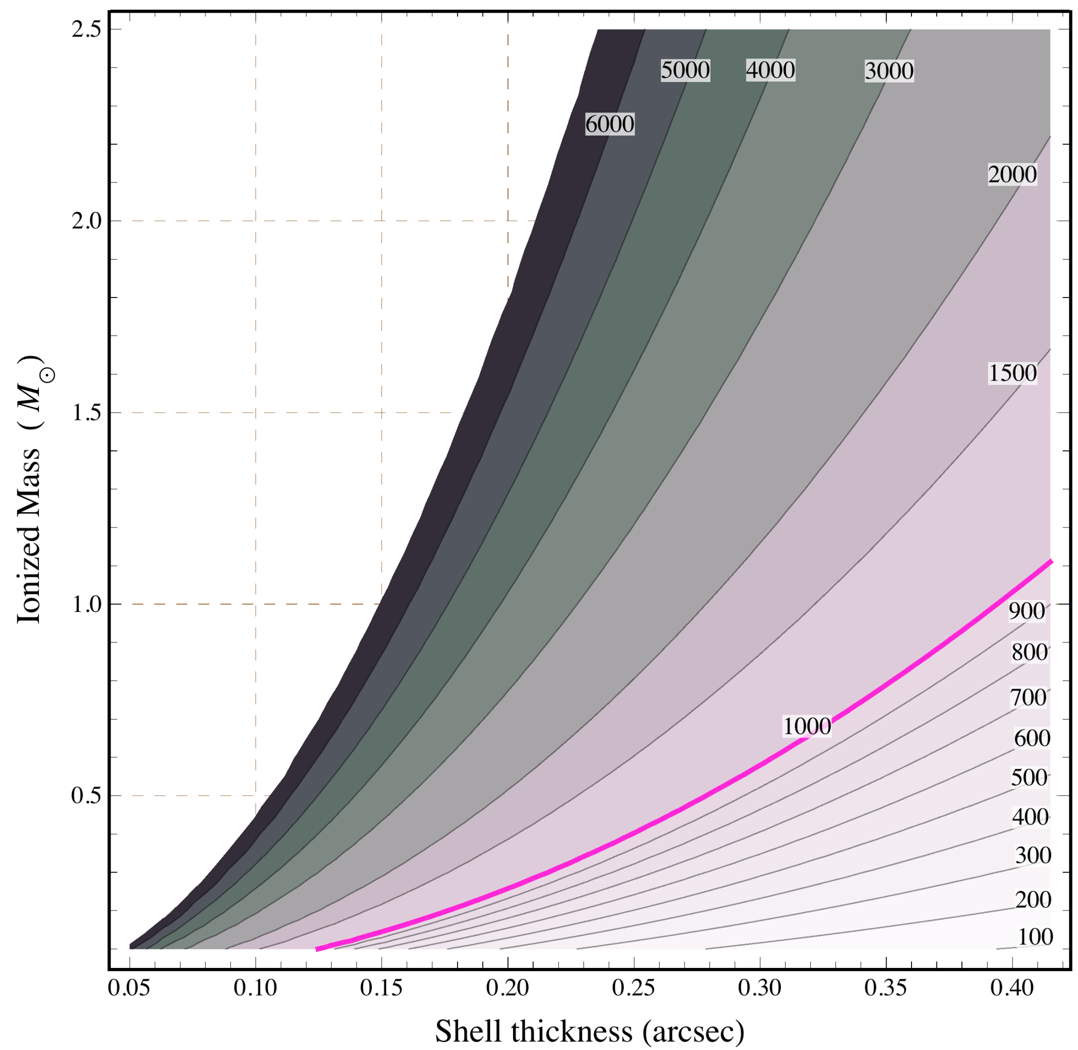
  $$1 \lesssim B_{\mathrm{PWN}} \lesssim 7\ \mathrm{mG}$$

- Period:

  P ~150 ms

- Size:

  $$0.''05 \lesssim R_{\mathrm{PWN}} \lesssim 0.''15$$

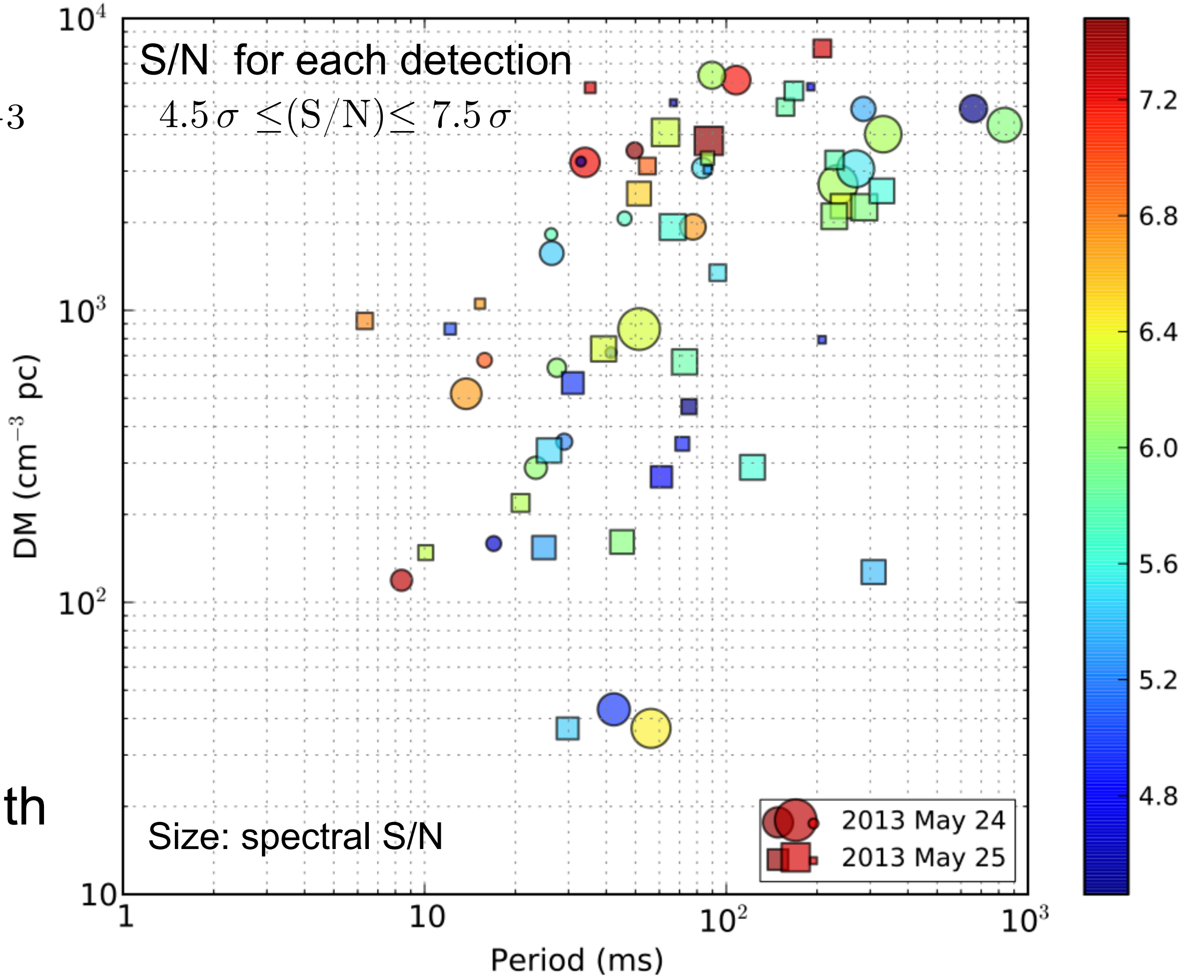


Zanardo+ 2014

Parkes: pulsar search

- Dispersion measure:

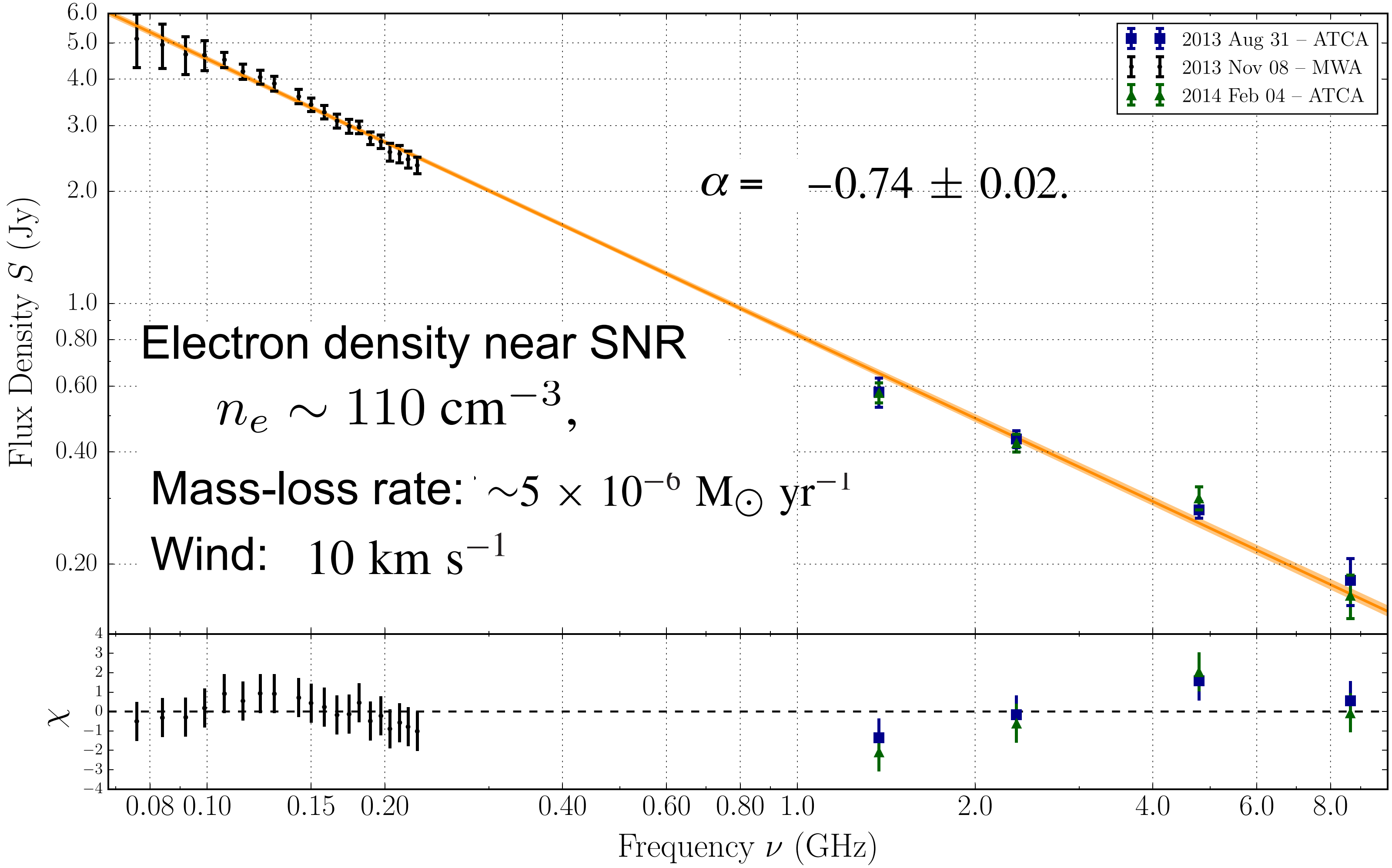
$$1000 \lesssim \mathrm{DM} \lesssim 6000\ \mathrm{cm}^{-3}$$



- Preliminary analysis:
- Possible candidates with

$$30 \lesssim P \lesssim 300\ \mathrm{ms}$$

ATCA + MWA



- Spectral break below 70 MHz, likely at ≤ 60 MHz

Callingham+ 2016

Constraints on the Magnetic field

44 GHz

- From RM, and n_e near SNR magnetic field along los

$$B_0 < 30\ \mu\mathrm{G}$$

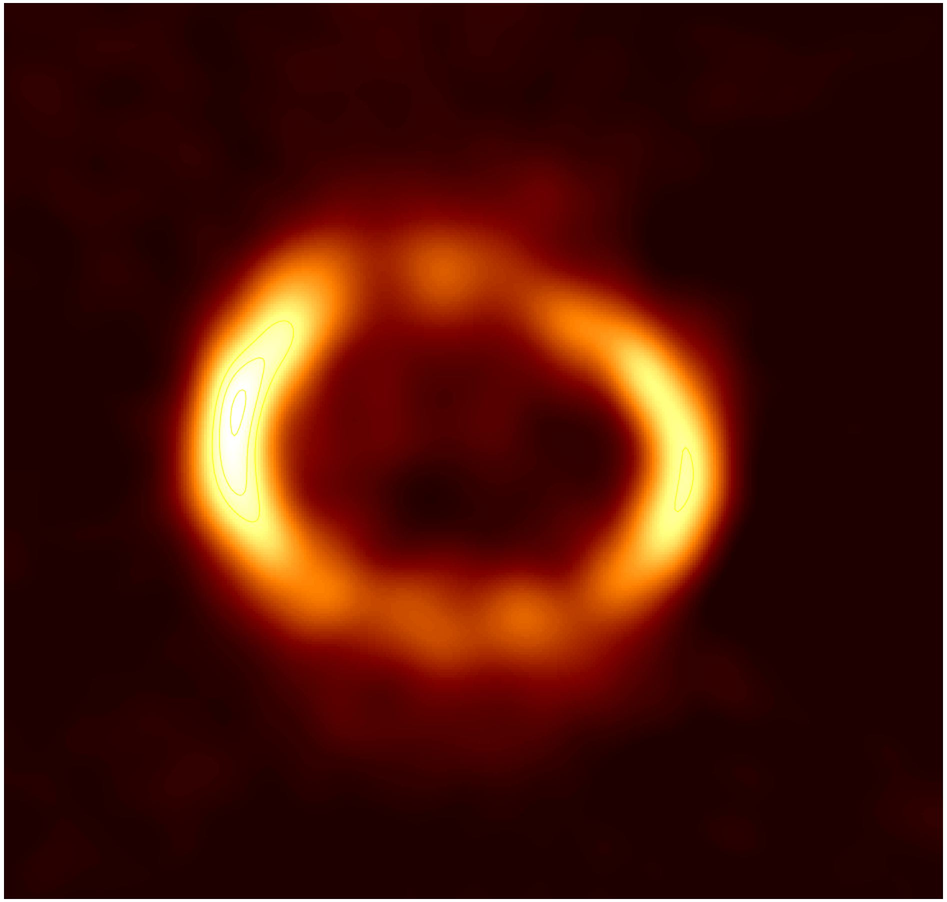
- From equipartition, magnetic field in the SNR

$$B_{\mathrm{SNR}} \sim 2\ \mathrm{mG}$$

- Likely non-linear magnetic field amplifications and high Alfenic Mach numbers

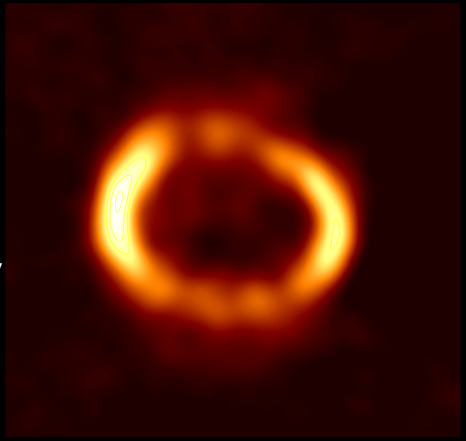
$$M_A \sim 10^3$$

- Strong fluctuations in B-field strength would invoke non-linear CR-excited turbulence.



Summary

- To date there are ongoing observing campaigns from 70 MHz to 700 GHz.
- The SNR has recently entered a new evolutionary stage. The SN is gradually moving past the high density CSM and expanding above and below the equatorial ring.



- The detection of synchrotron emission from the central region is still elusive, while the spectral indices for the inner region are consistently flat across large frequency ranges.
- Detection of polarisation with ATCA is still hampered by beam depolarisation and will be definitely more accurate with the upcoming ALMA observations.
- A radial magnetic field and a direct correlation of brightness with polarisation seems consistent with the presence of CR production.