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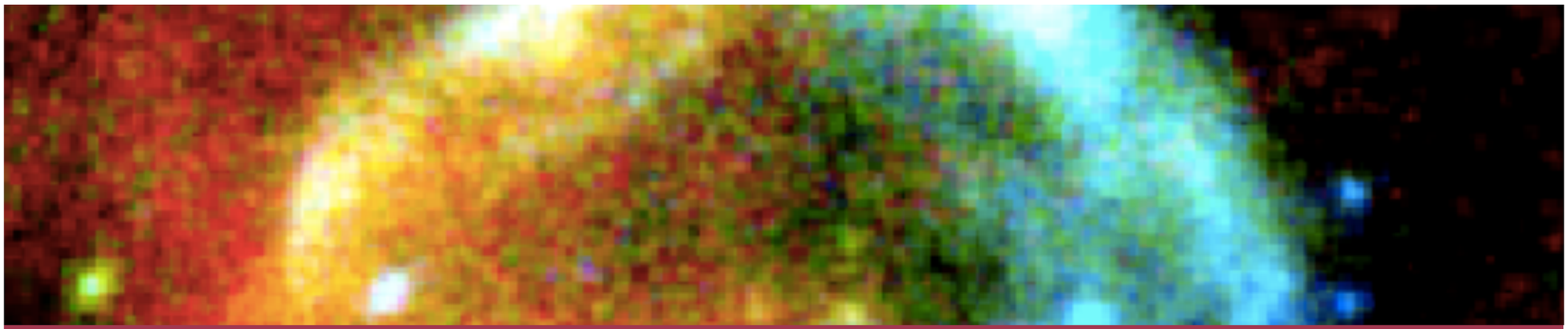
SCIENCE
Institut für Astronomie und Astrophysik



XMM-Newton observations of 30 Dor C in the Large Magellanic Cloud

Patrick Kavanagh

M. Sasaki (IAAT), L.M. Bozzetto (University of Western Sydney), M.D. Filipović (University of Western Sydney), S.D. Points (CTIO), P. Maggi (MPE), F. Haberl (MPE)

Superbubbles (SBs)

- 100-1000 pc diameter shells of swept-up interstellar material which contains a hot (10^6K) gas

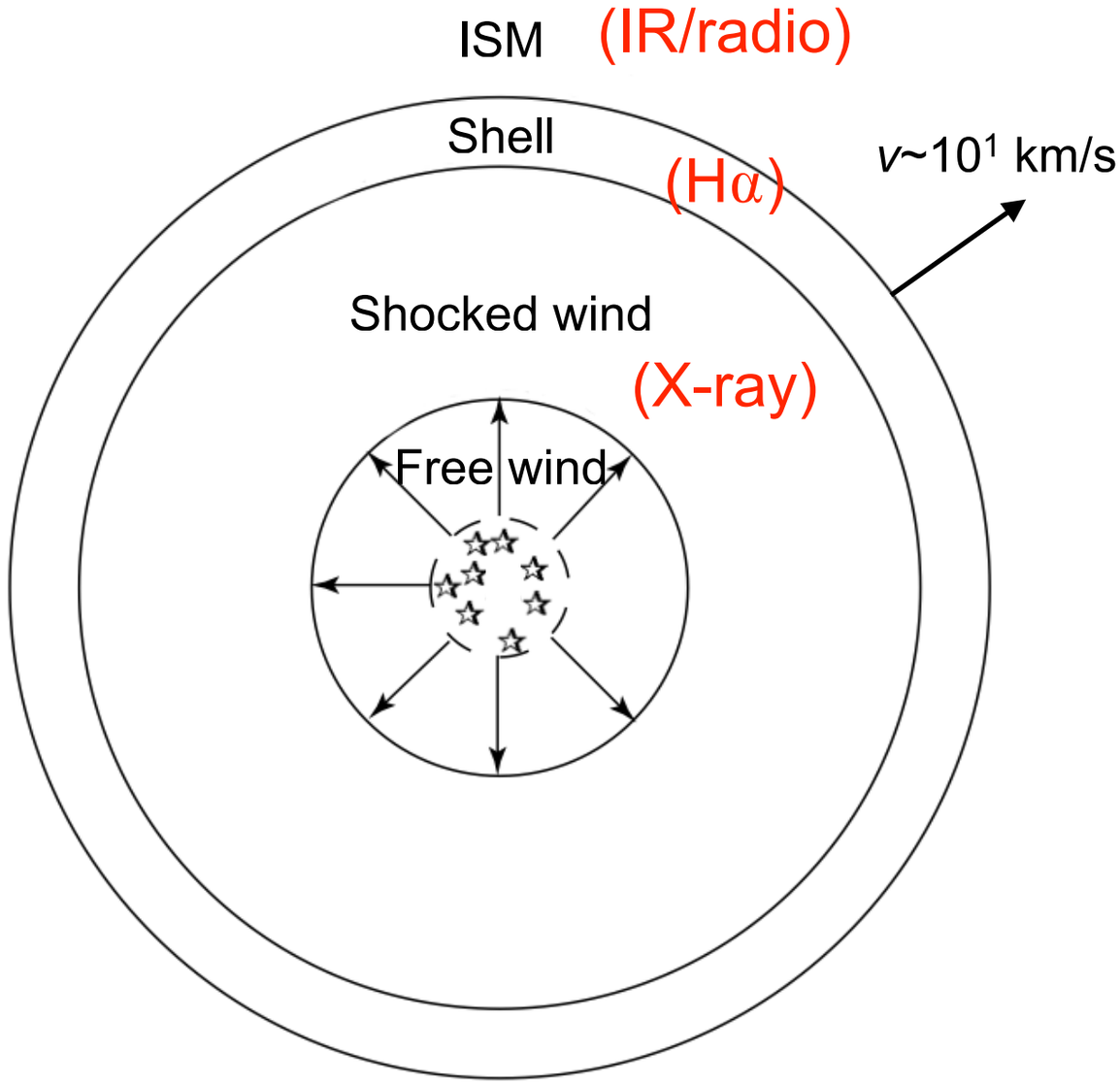
- Powered by massive stellar winds and supernova remnants

- Extragalactic non-thermally emitting SBs:

? { N11 (Maddox +, 2009;Yamaguchi +, 2010)
N51D (Cooper +, 2004;Yamaguchi +, 2010)
N70 (Rodríguez-González +, 2011;De Horta +, 2014)

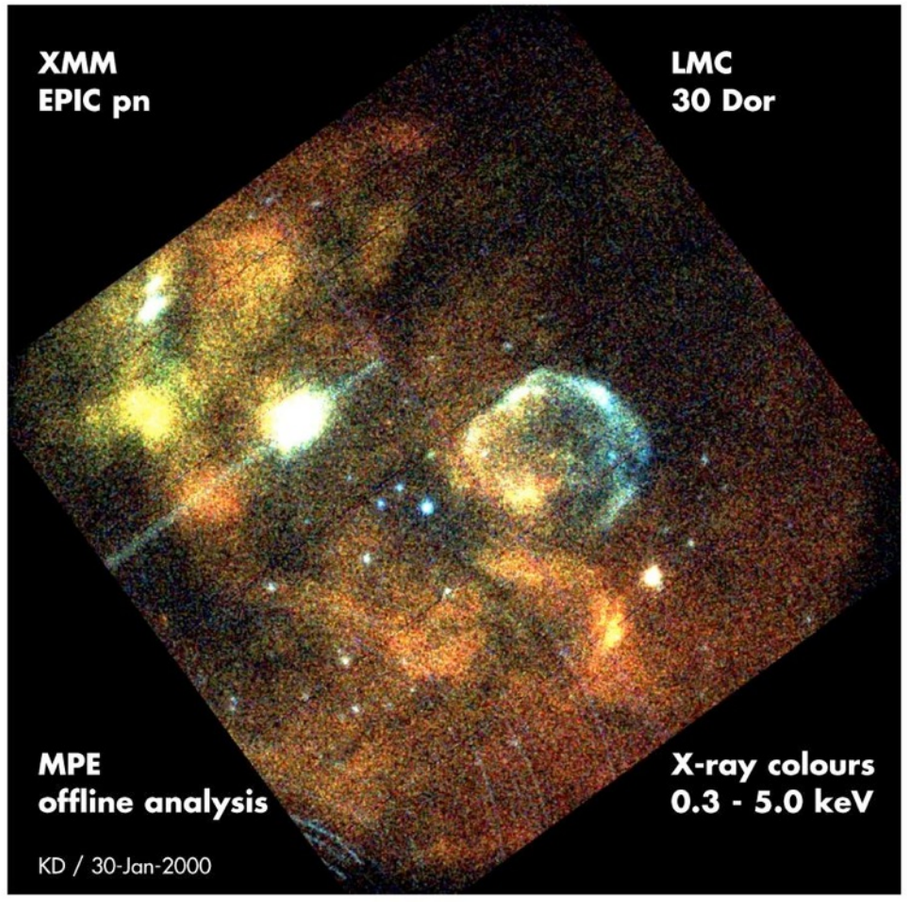
30 Dor C (Bamba +, 2004;Smith & Wang, 2004
Yamaguchi +, 2009)

IC131 (Tüllmann +, 2009)



Silich et al. (2005)

EPIC-PN false colour X-ray image of the 30 Doradus region in the Large Magellanic Clouds



XMM-Newton X-ray image of the 30 Doradus region in the LMC European Space Agency

Dennerl et al. (2001)

Press release:
http://sci.esa.int/xmm-newton/13202-30-doradus-in-lmc/

X-ray observations

- *Chandra*
  Bamba et al., 2004

- *XMM-Newton*
  Smith & Wang, 2004

- *Suzaku*
  Yamaguchi et al, 2009

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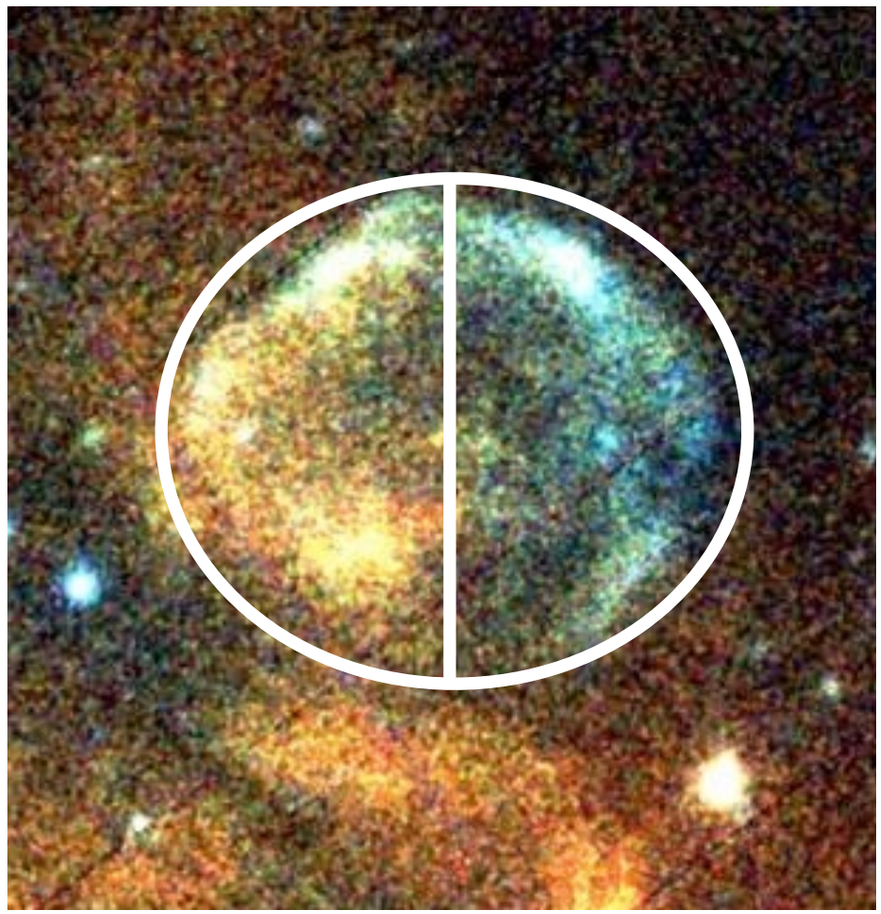

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  Smith & Wang, 2004

- *Suzaku*
  Yamaguchi et al, 2009

Dennerl et al. (2001)

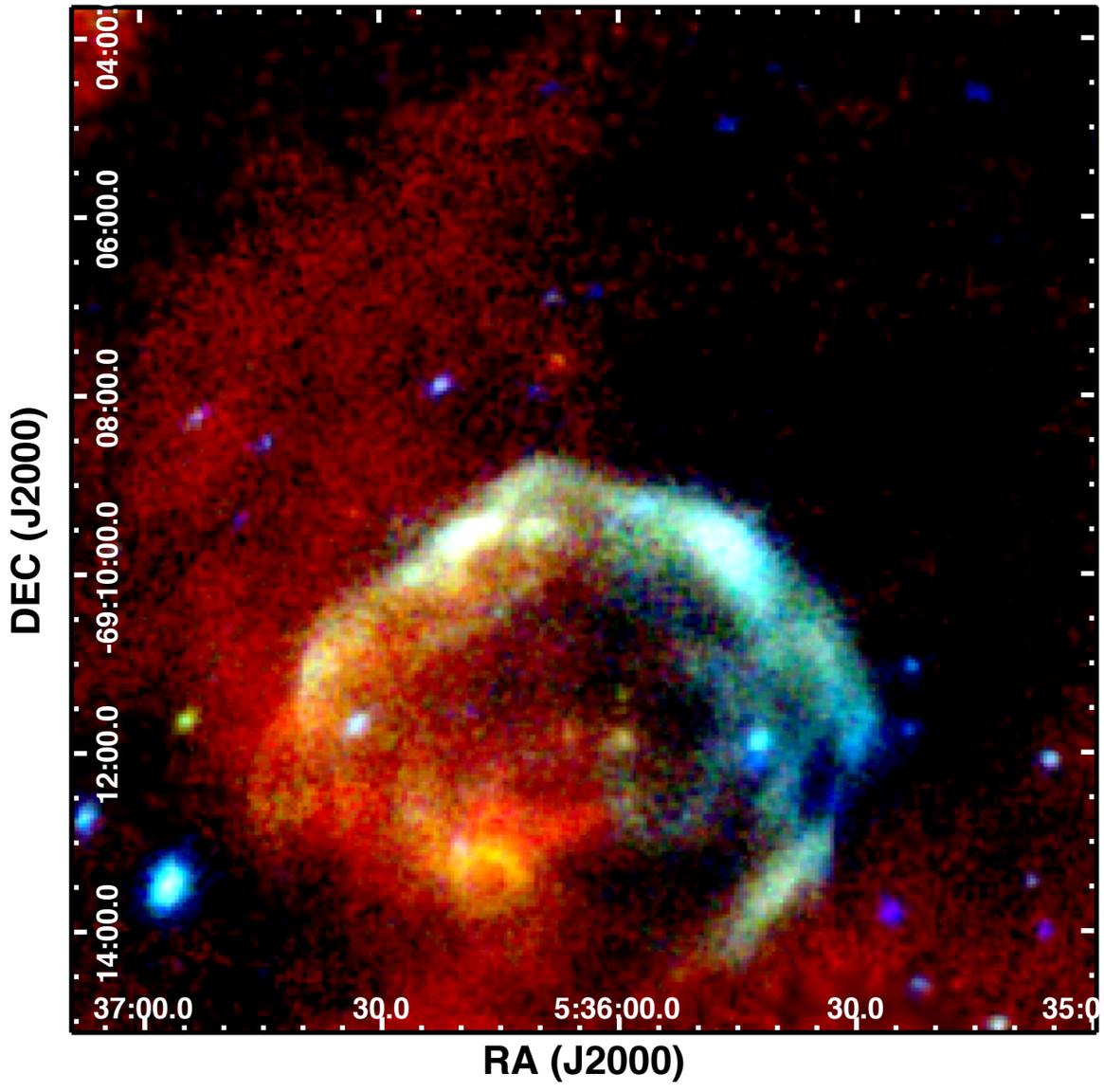
XMM-Newton SN 1987A monitoring campaign! -lmc/

XMM-Newton observations

Obs. ID	Obs. Date	Exposure time (ks)		
		pn	MOS1	MOS2
0104660101	2000-09-17	22.3	–	–
0104660301	2000-11-25	–	20.7	19.6
0113020201	2001-11-19	–	31.5	25.0
0144530101	2003-05-10	–	46.8	46.8
0406840301	2007-01-17	53.3	74.4	76.0
0506220101	2008-01-11	61.2	80.7	83.4
0556350101	2009-01-30	57.3	79.0	81.7
0601200101	2009-12-11	70.8	85.5	85.5
0650420101	2010-12-12	46.1	57.9	60.7
0671080101	2011-12-02	56.4	67.8	69.0
0690510101	2012-12-11	52.9	11.9	66.7

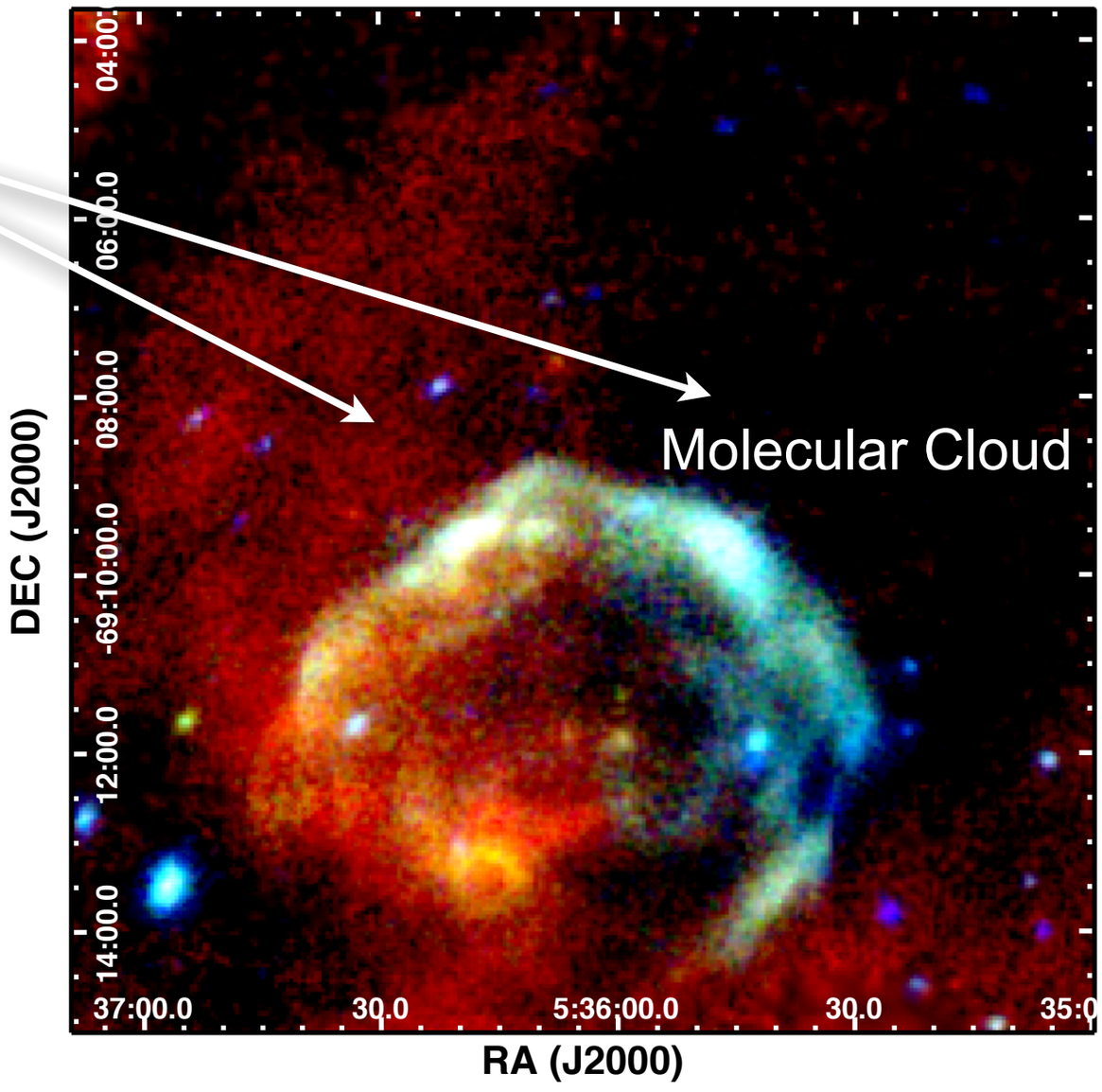
Combined, flare-filtered exposure times:

pn = 420 ks; **MOS1 = 556 ks**; **MOS2 = 614 ks**



RGB: 0.3-1 keV, 1-2 keV, 2-7 keV

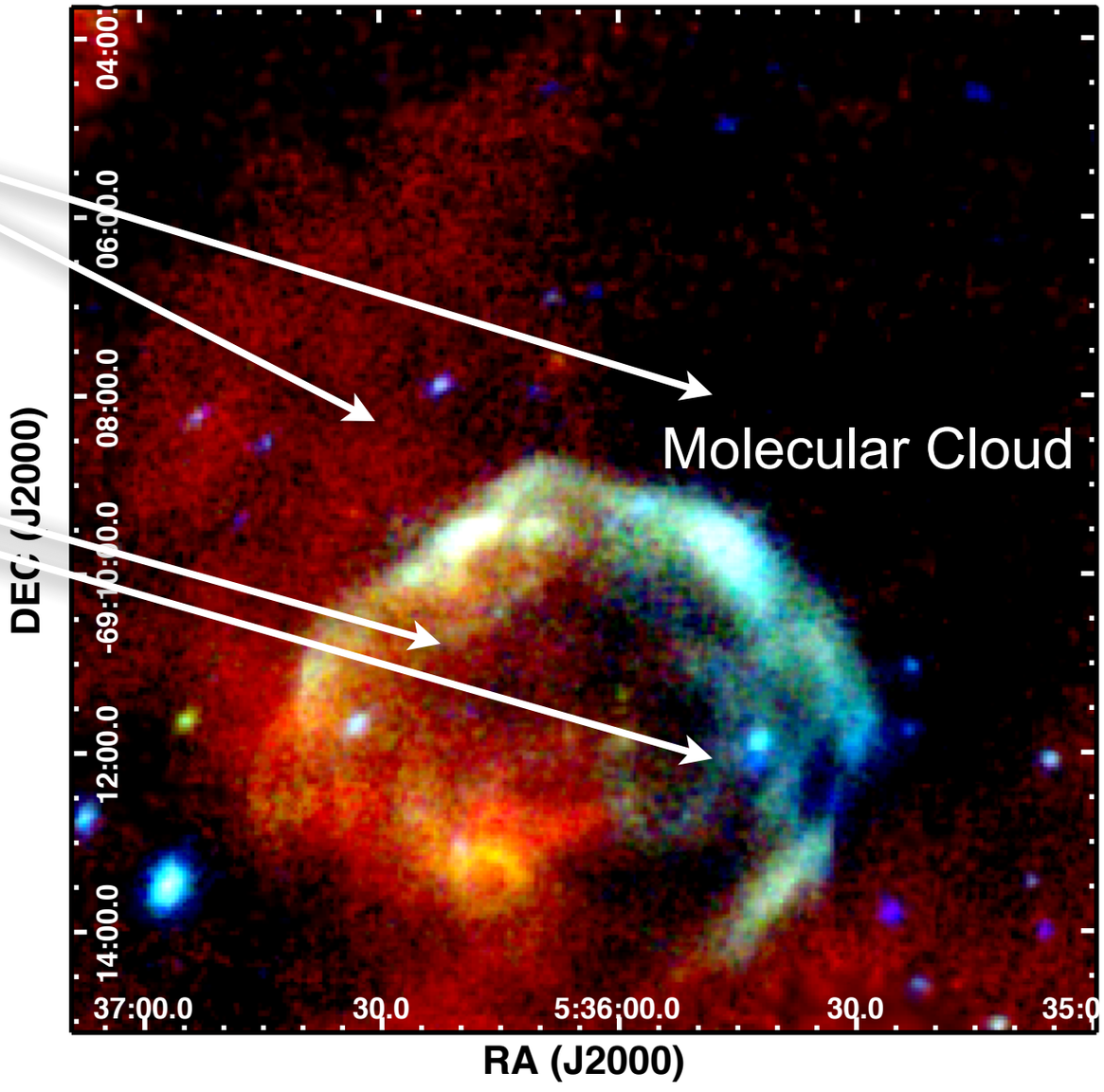
Background variation



RGB: 0.3-1 keV, 1-2 keV, 2-7 keV

Background variation

Structure in hard X-rays

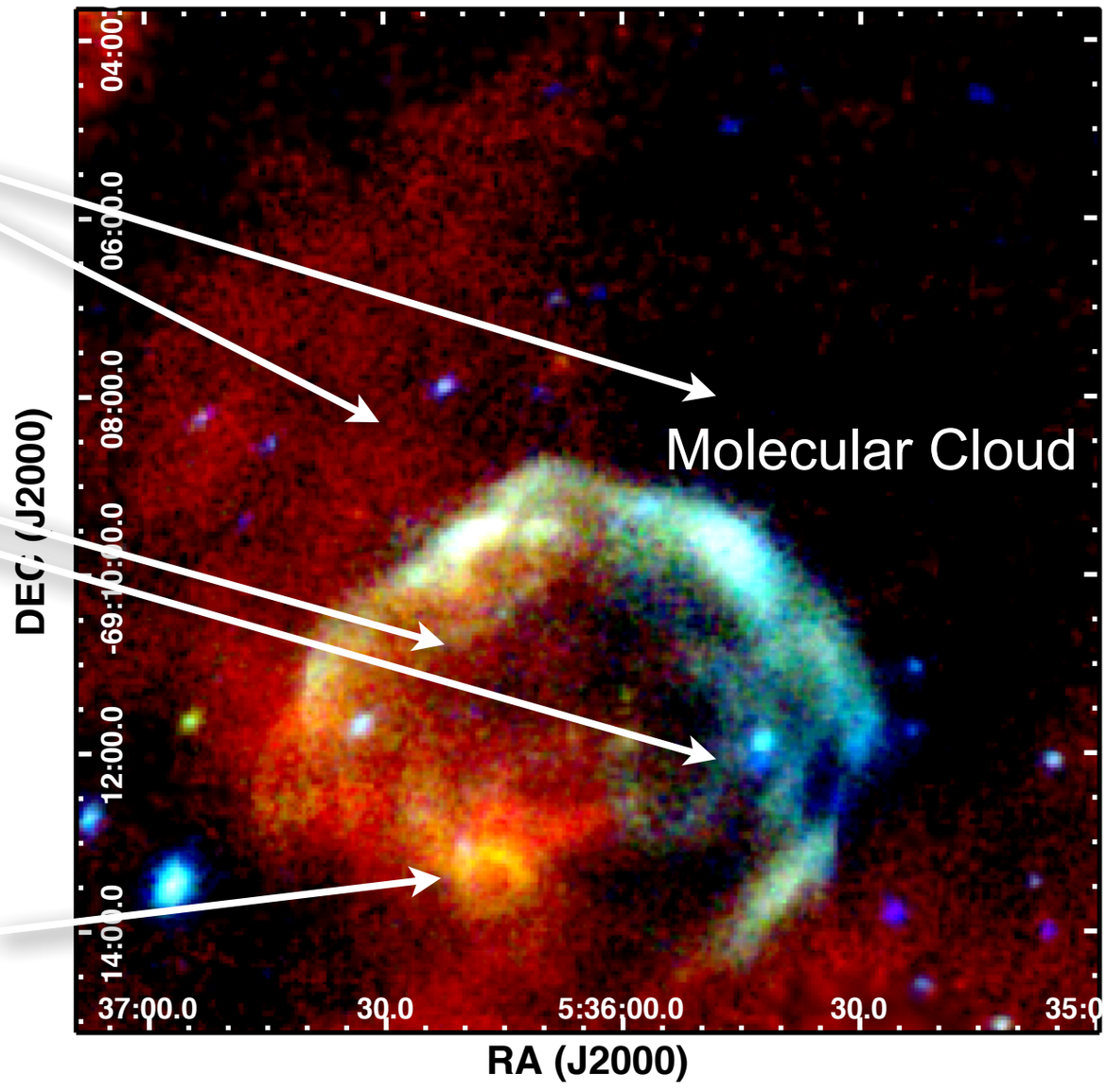


RGB: 0.3-1 keV, 1-2 keV, 2-7 keV

Background variation

Structure in hard X-rays

Brightest soft emission due to SNR



RGB: 0.3-1 keV, 1-2 keV, 2-7 keV

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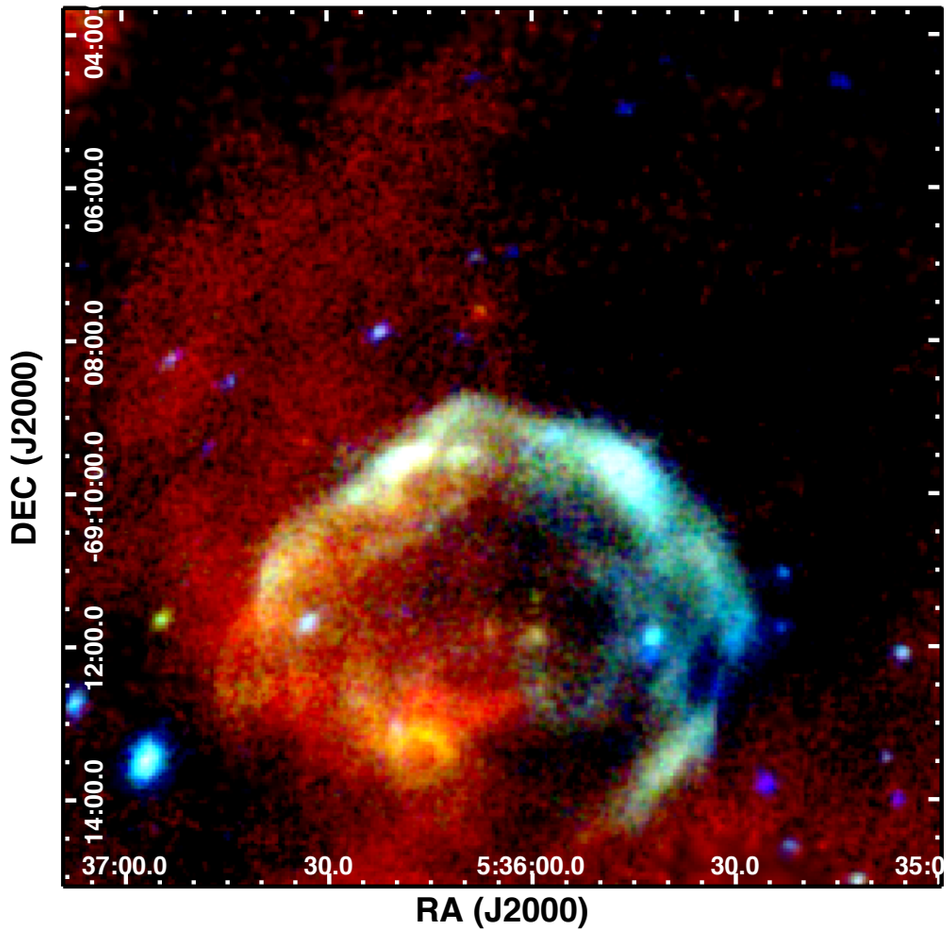
Spatially resolved spectral analysis



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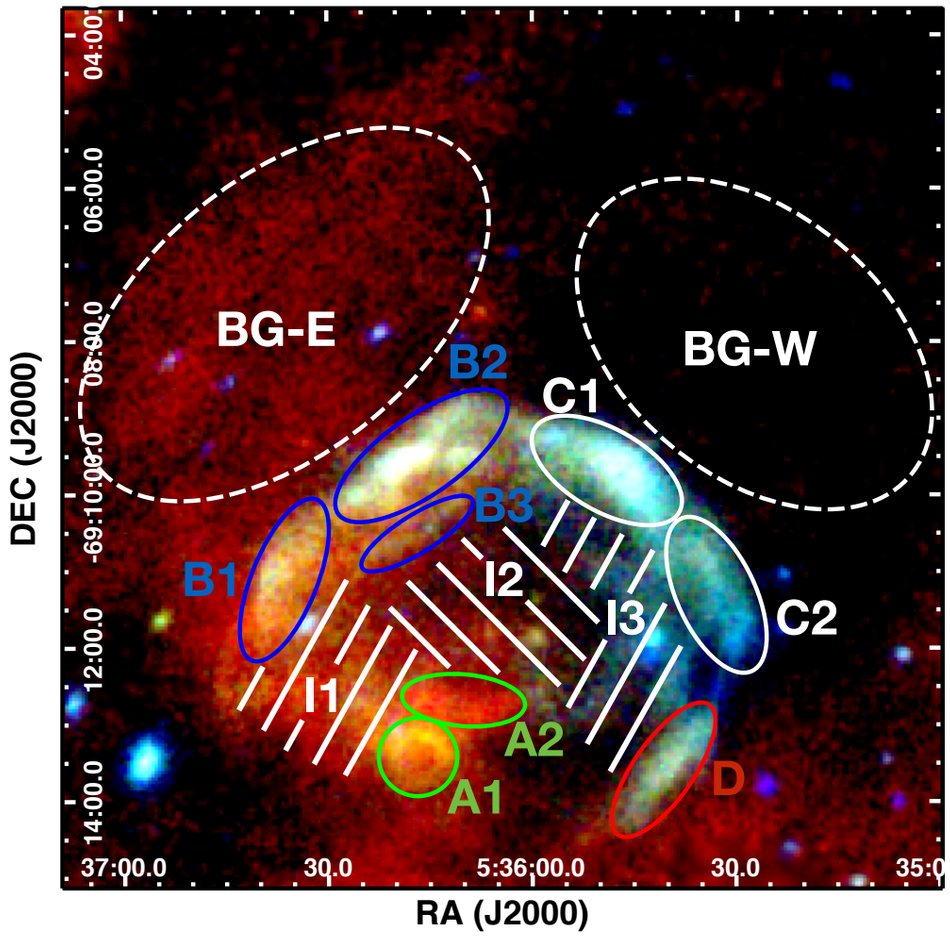
Spatially resolved spectral analysis



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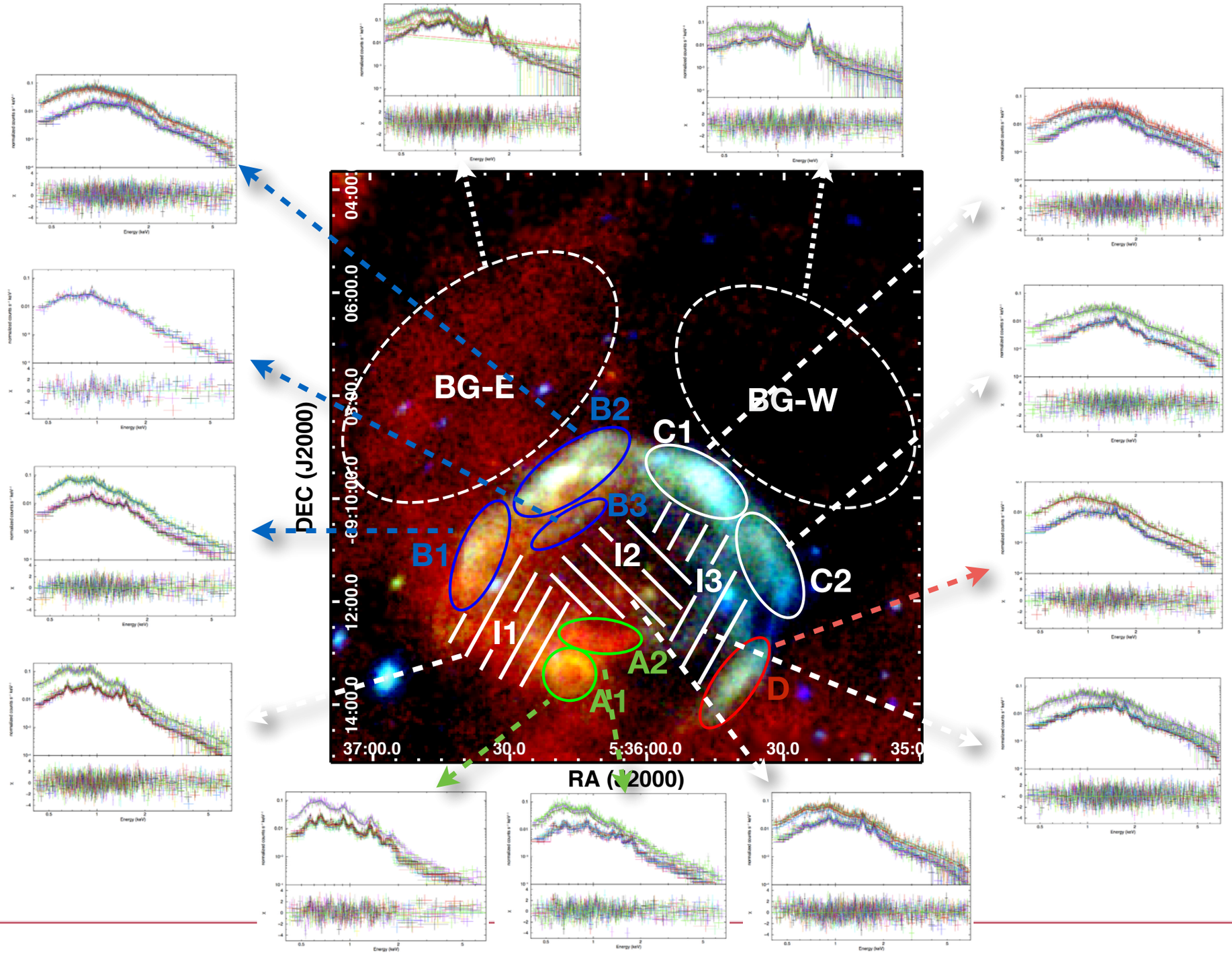
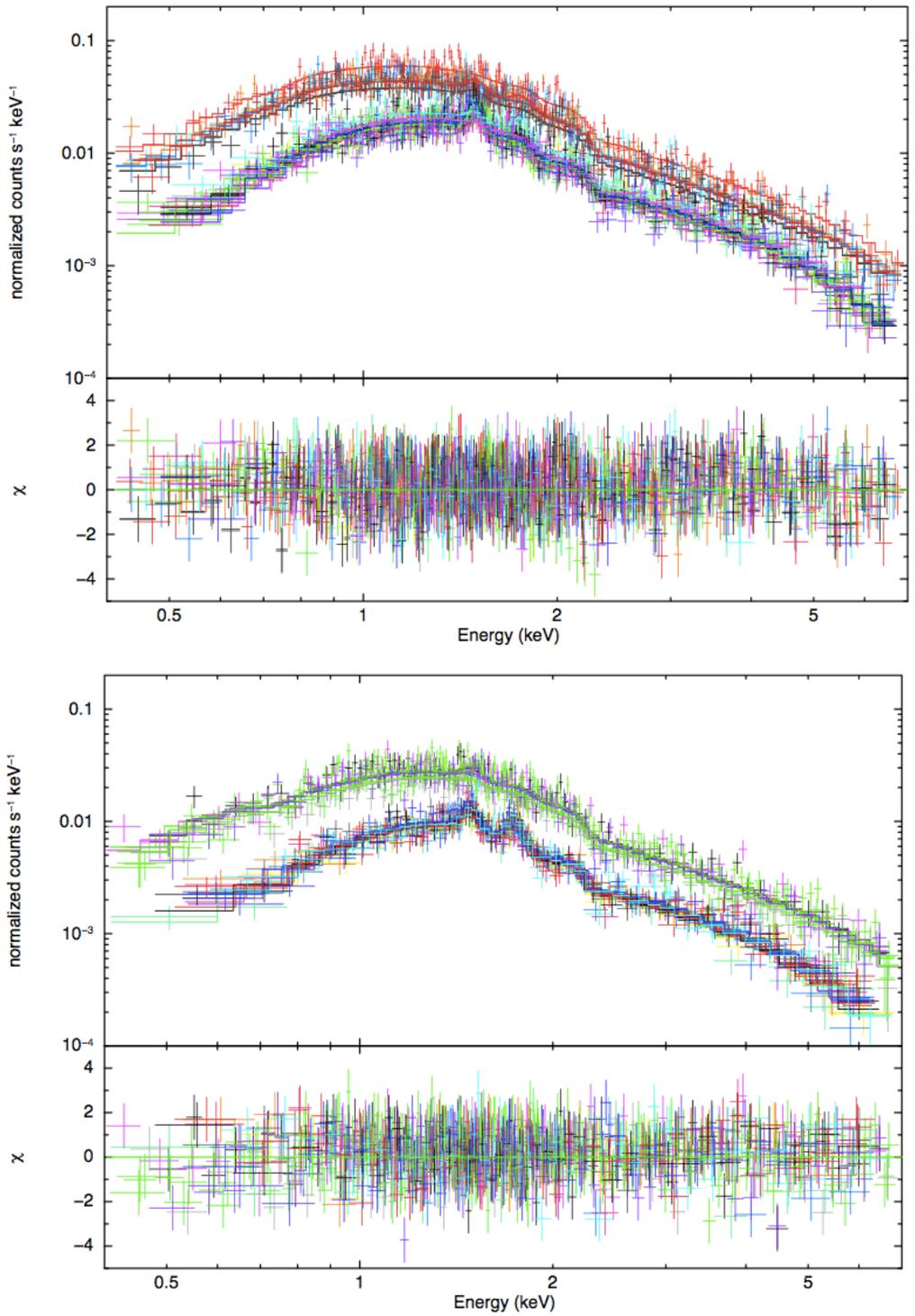
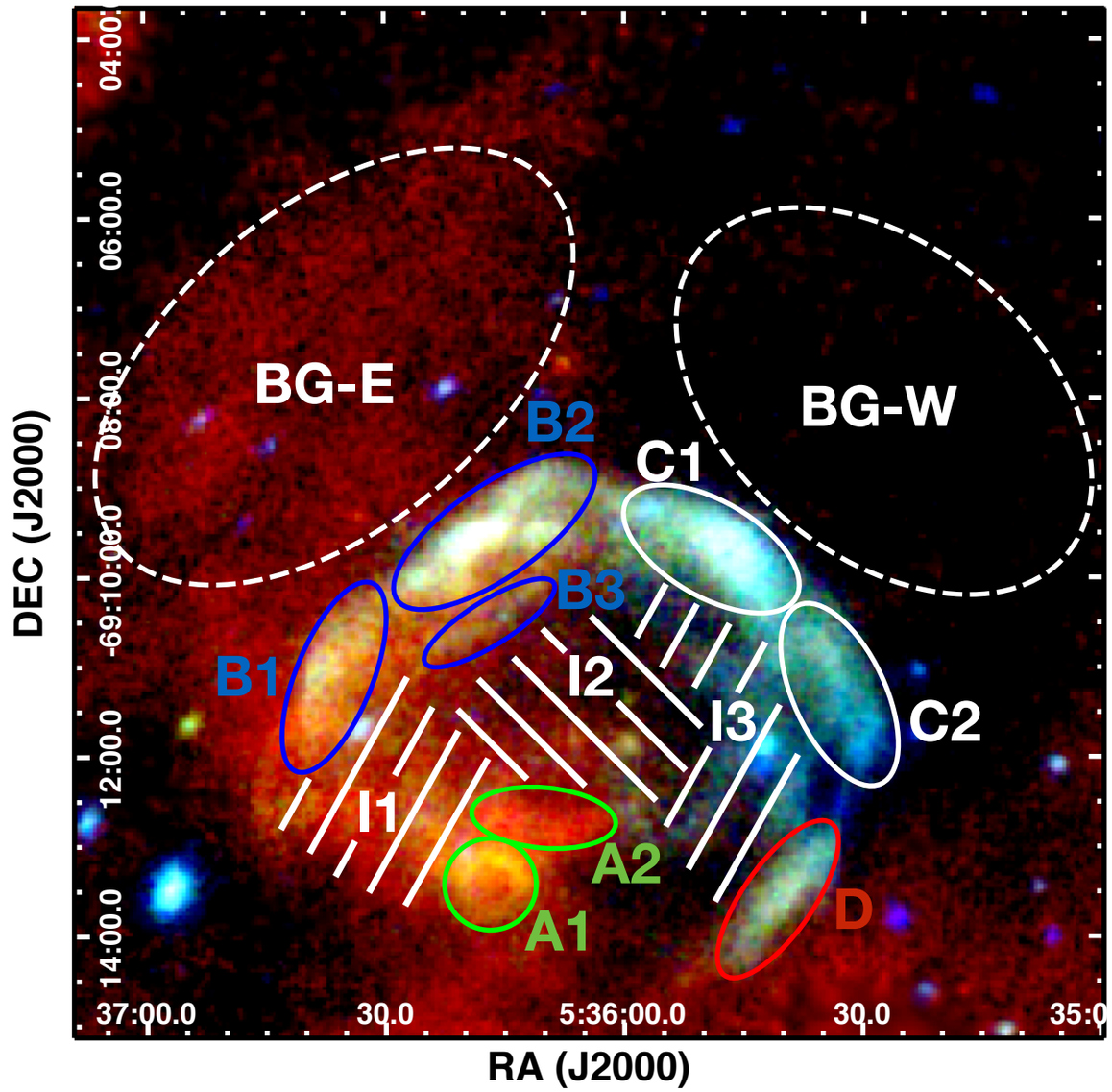
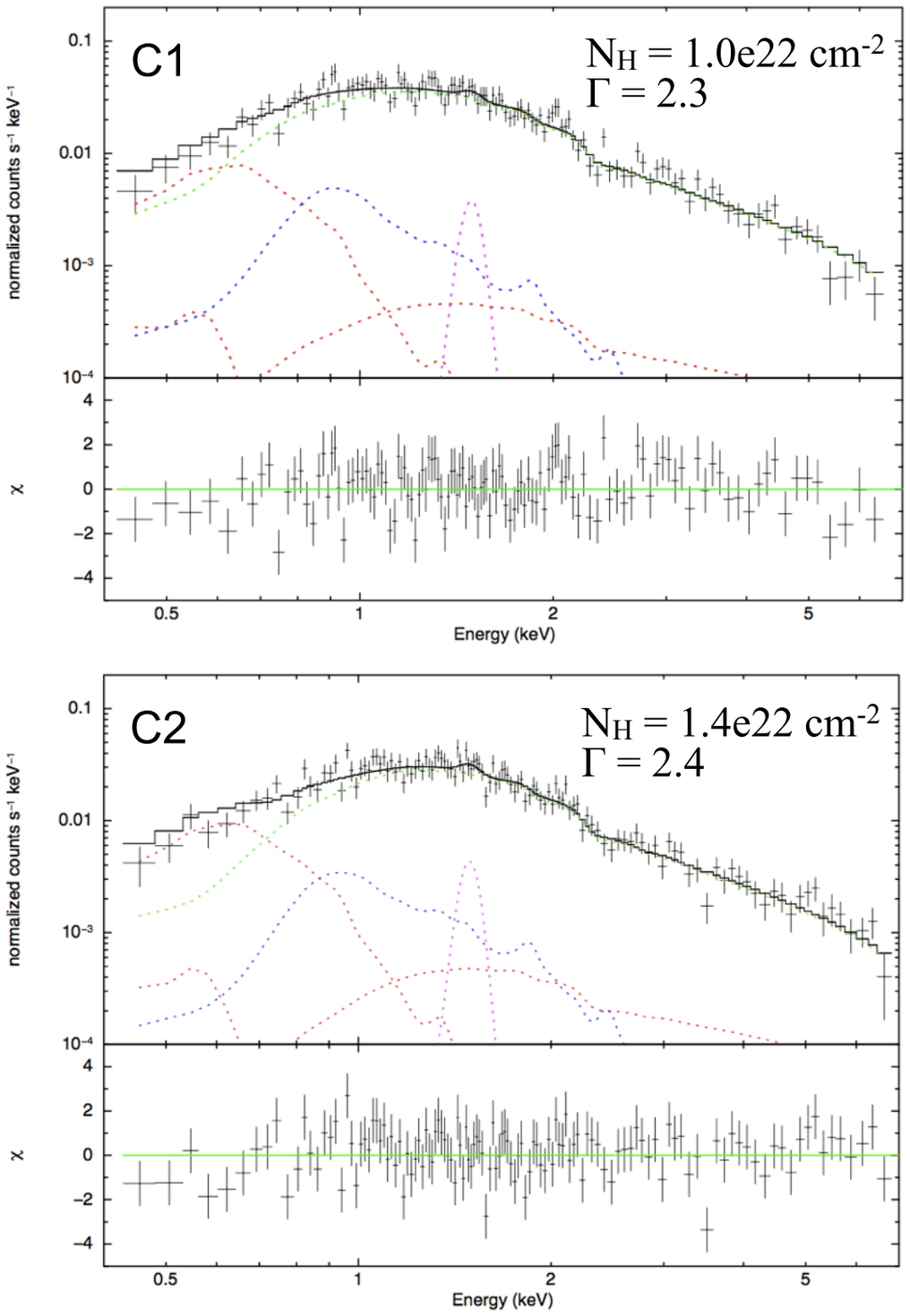
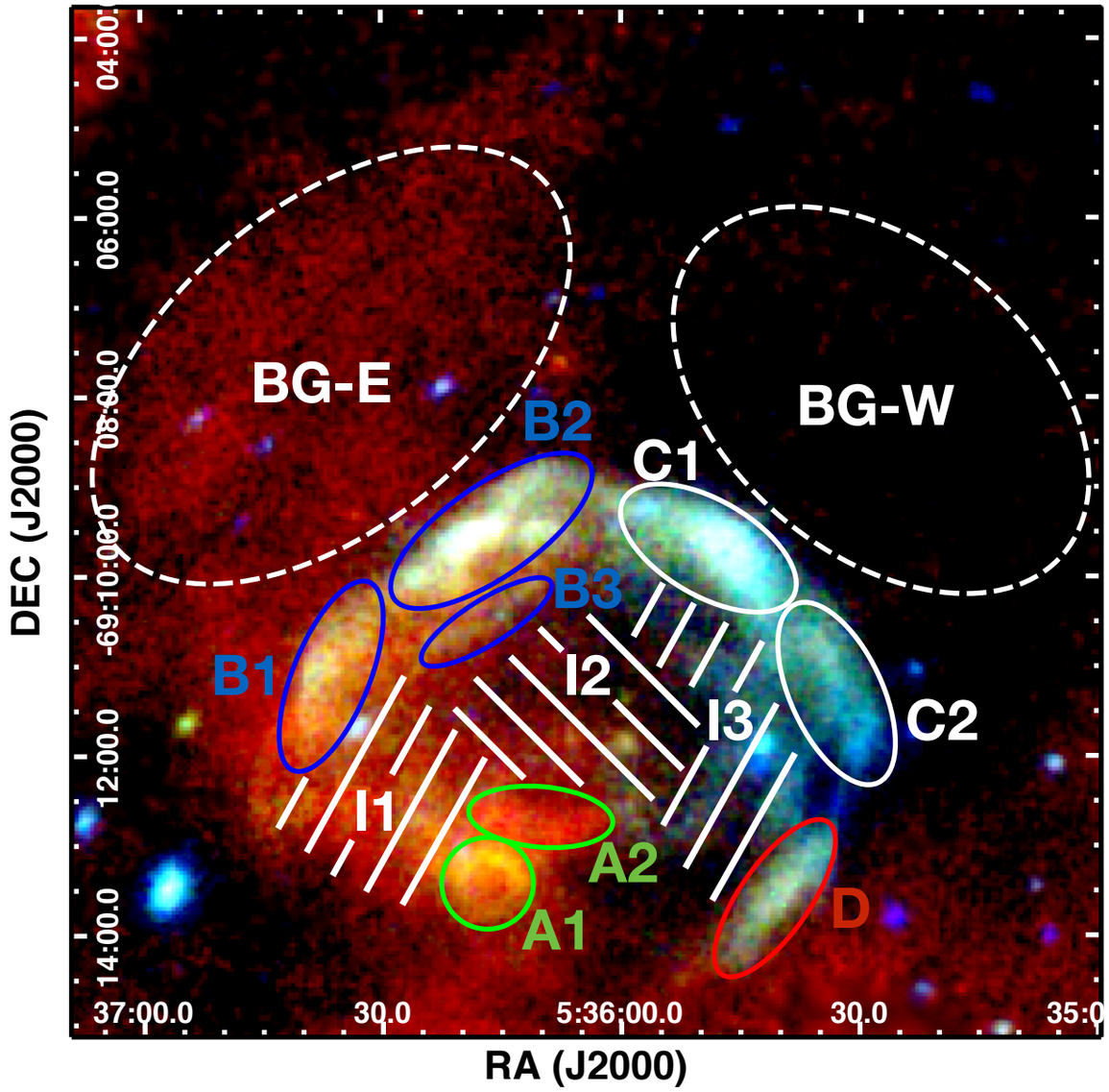
Spatially resolved spectral analysis

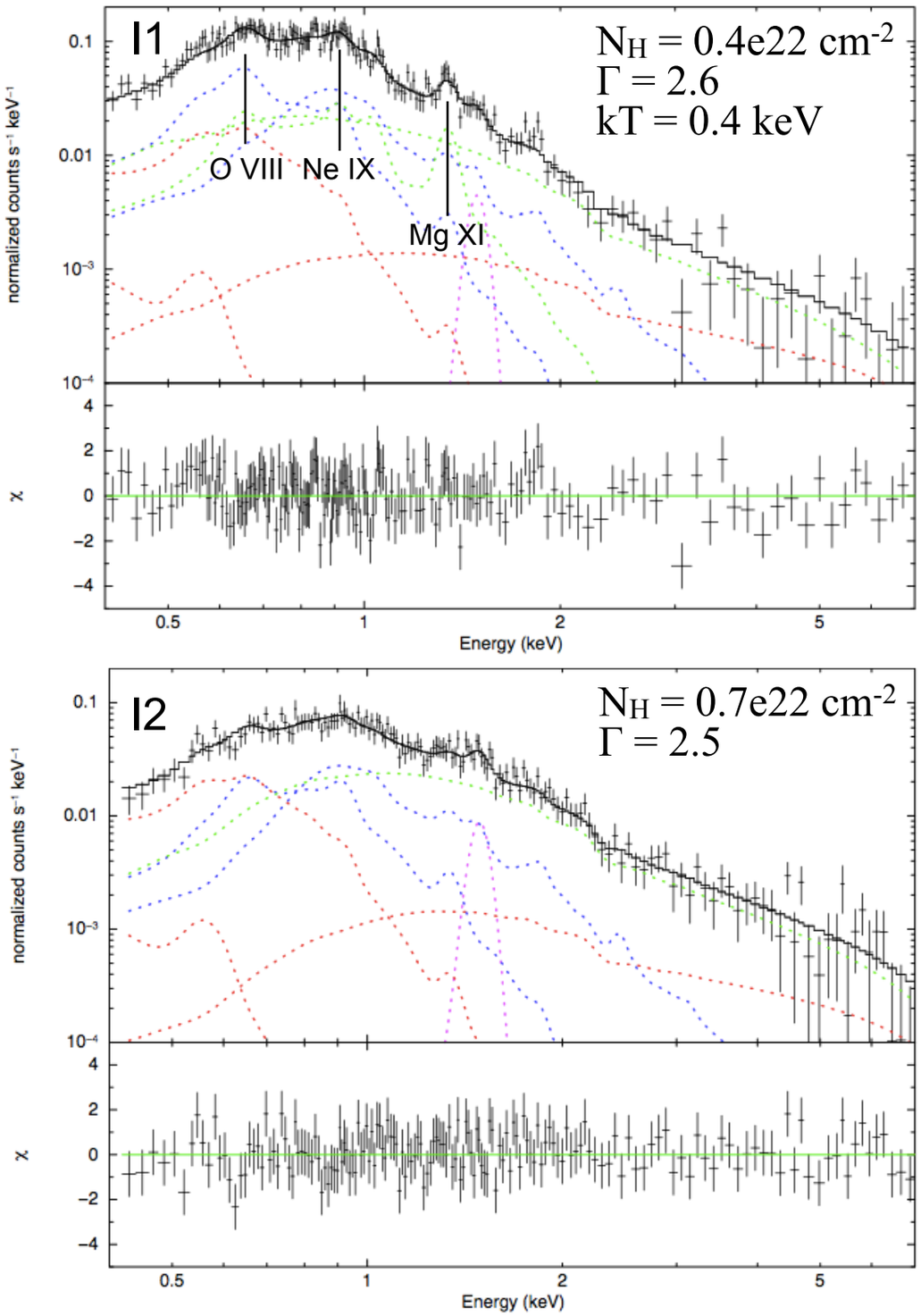


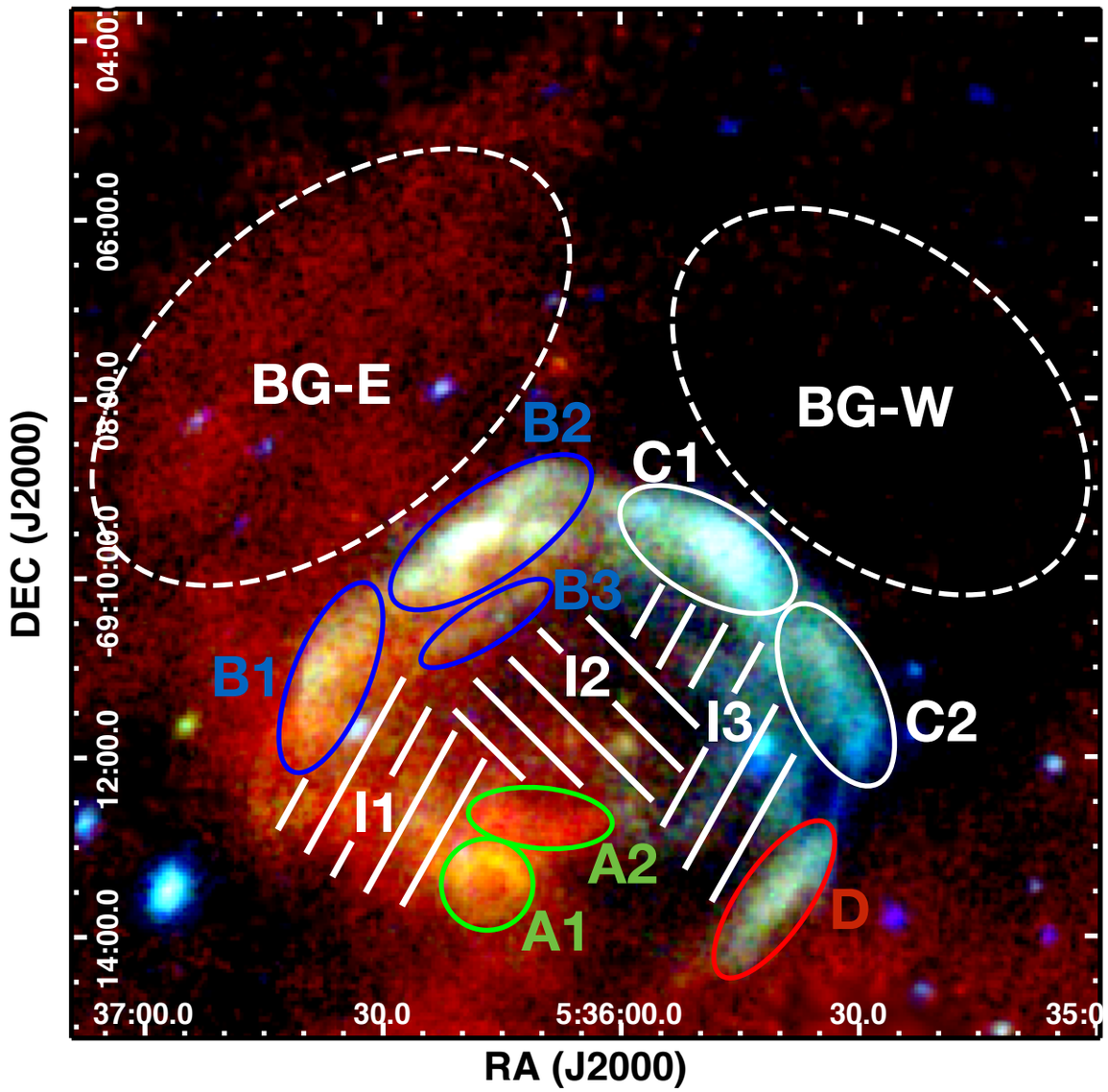

normalized counts s⁻¹ keV⁻¹
0.1
0.01
10⁻³
10⁻⁴
χ
4
2
0
−2
−4
0.5
1
2
5
Energy (keV)


BG-E
BG-W
B1
B2
B3
C1
C2
I1
I2
I3
A1
A2
D
DEC (J2000)
04:00.0
06:00.0
08:00.0
-69:10:00.0
12:00.0
14:00.0
37:00.0
30.0
5:36:00.0
30.0
35:0
RA (J2000)

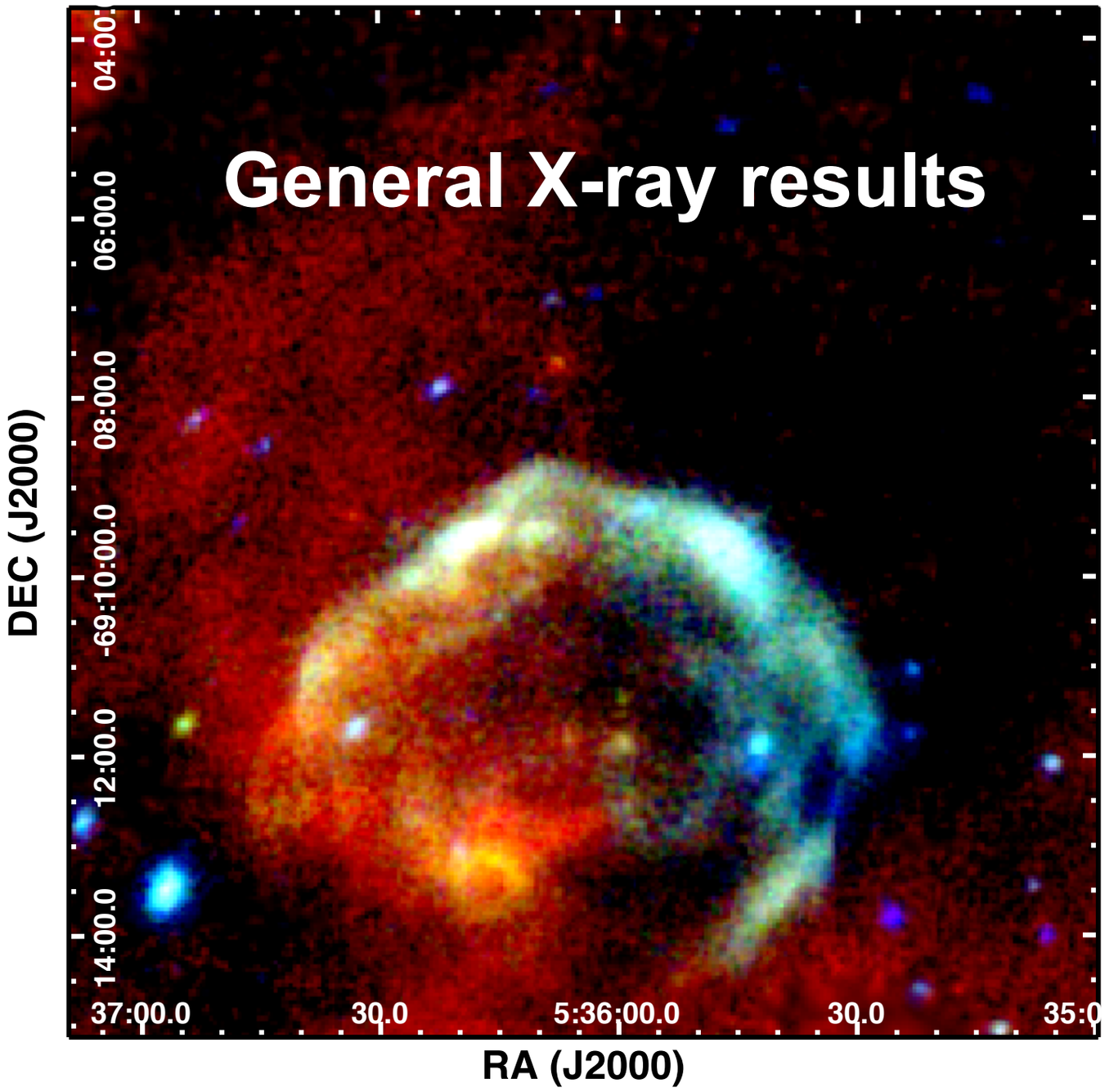

C1
N_H = 1.0e22 cm^{-2}
Γ = 2.3
normalized counts s^{-1} keV^{-1}
χ
Energy (keV)
C2
N_H = 1.4e22 cm^{-2}
Γ = 2.4
normalized counts s^{-1} keV^{-1}
χ
Energy (keV)

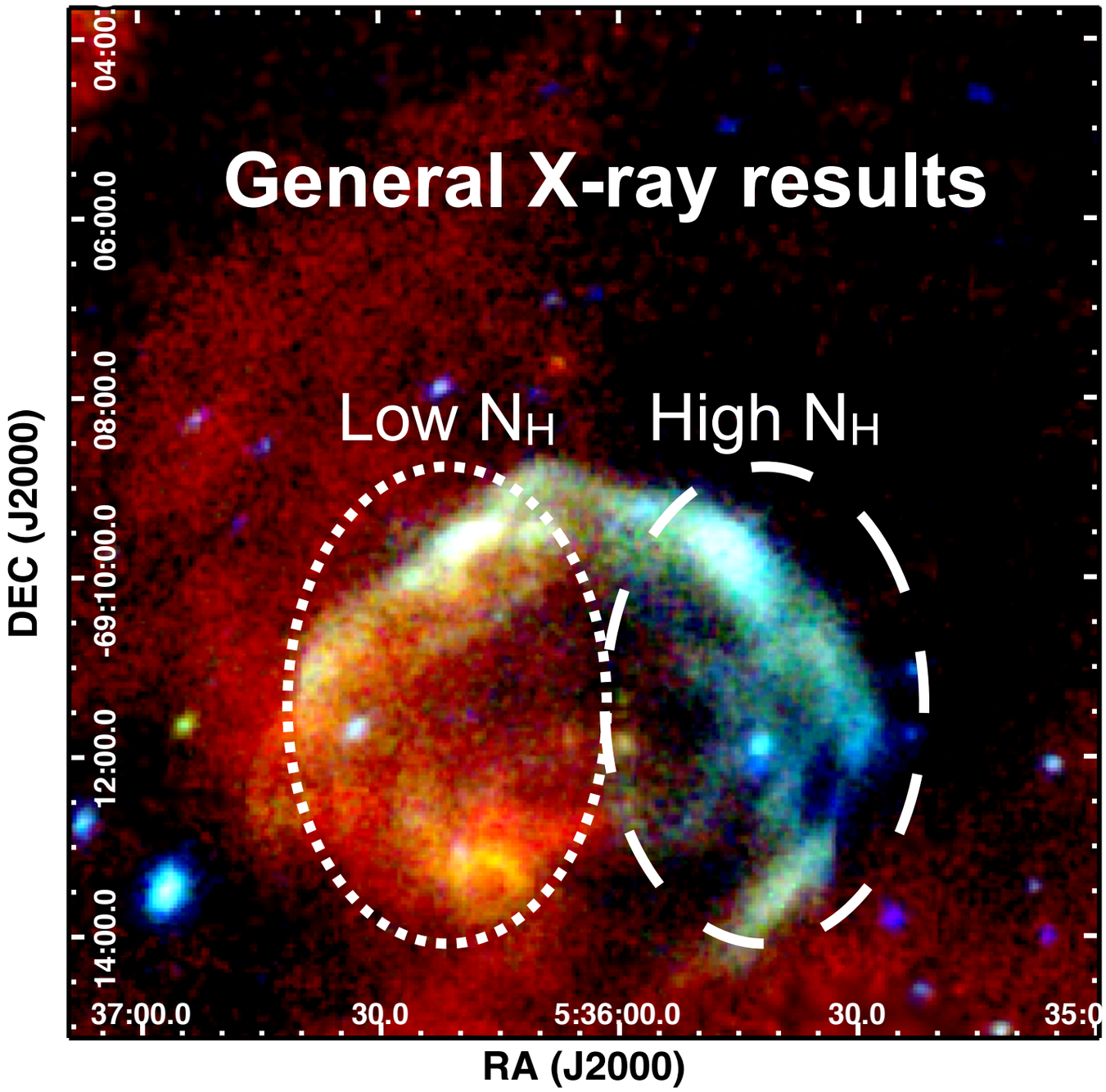

BG-E
BG-W
B1
B2
B3
C1
C2
I1
I2
I3
A1
A2
D
DEC (J2000)
RA (J2000)
04:00
06:00.0
08:00.0
-69:10:00.0
12:00.0
14:00.0
37:00.0
30.0
5:36:00.0
30.0
35:0


I1
N_H = 0.4e22 cm^{-2}
Γ = 2.6
kT = 0.4 keV
O VIII
Ne IX
Mg XI
normalized counts s^{-1} keV^{-1}
χ
Energy (keV)
I2
N_H = 0.7e22 cm^{-2}
Γ = 2.5
normalized counts s^{-1} keV^{-1}
χ
Energy (keV)

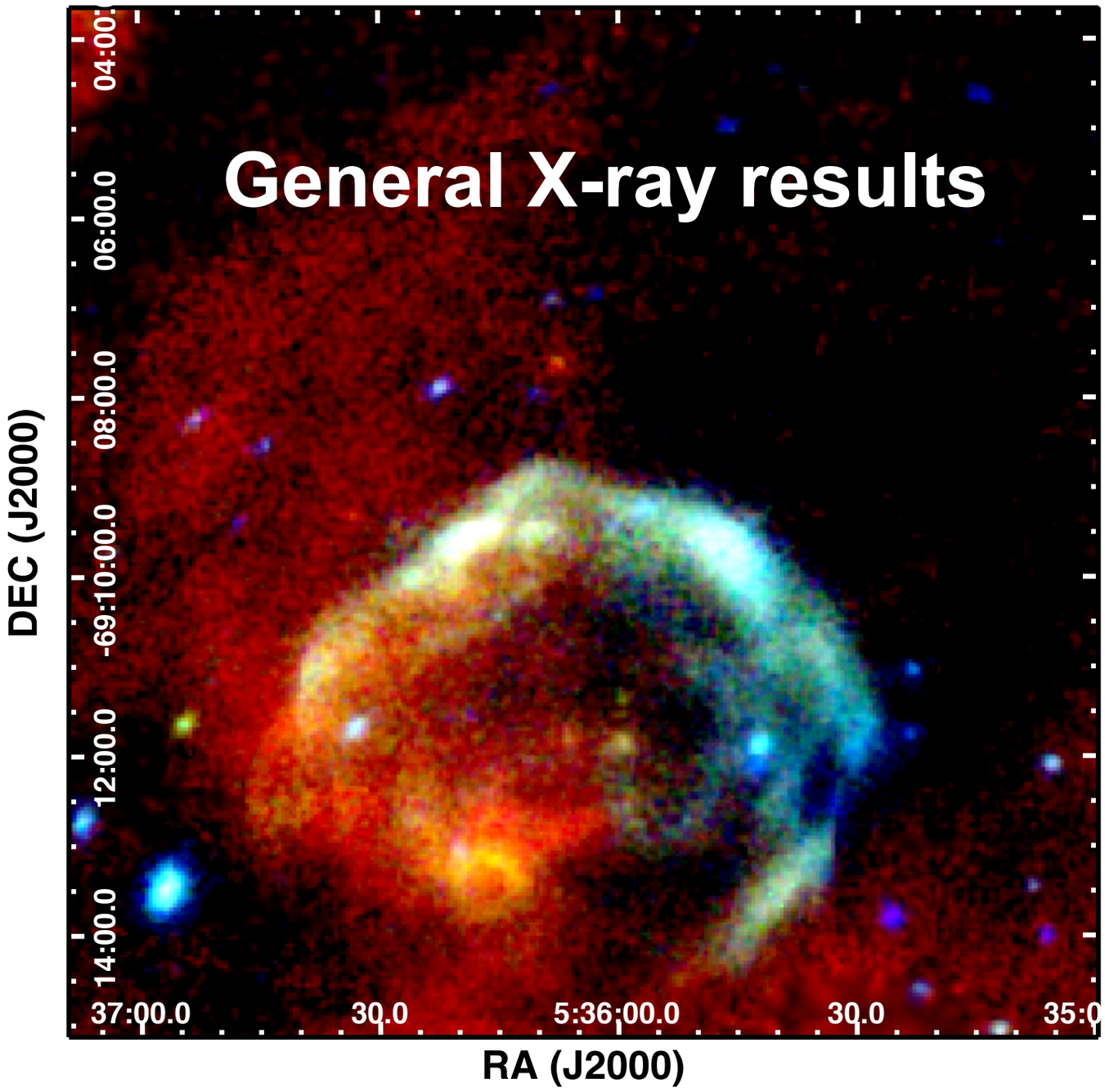

BG-E
BG-W
B1
B2
B3
C1
C2
I1
I2
I3
A1
A2
D
DEC (J2000)
RA (J2000)
04:00.0
06:00.0
08:00.0
-69:10:00.0
12:00.0
14:00.0
37:00.0
30.0
5:36:00.0
30.0
35:0

General X-ray results

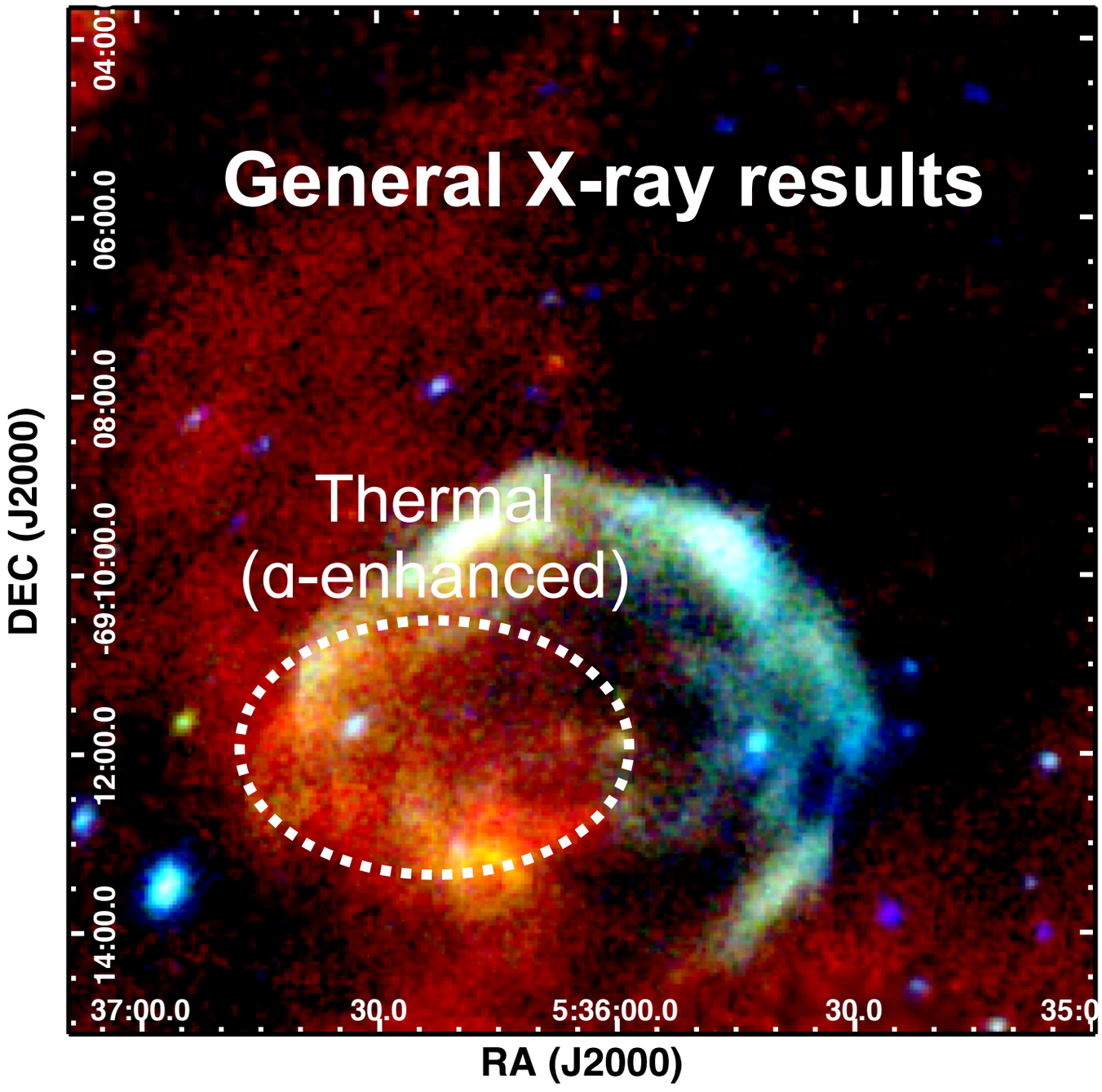



General X-ray results
Low N_H
High N_H
DEC (J2000)
-69:04:00.0
06:00.0
08:00.0
10:00.0
12:00.0
14:00.0
37:00.0
30.0
5:36:00.0
30.0
35:0
RA (J2000)

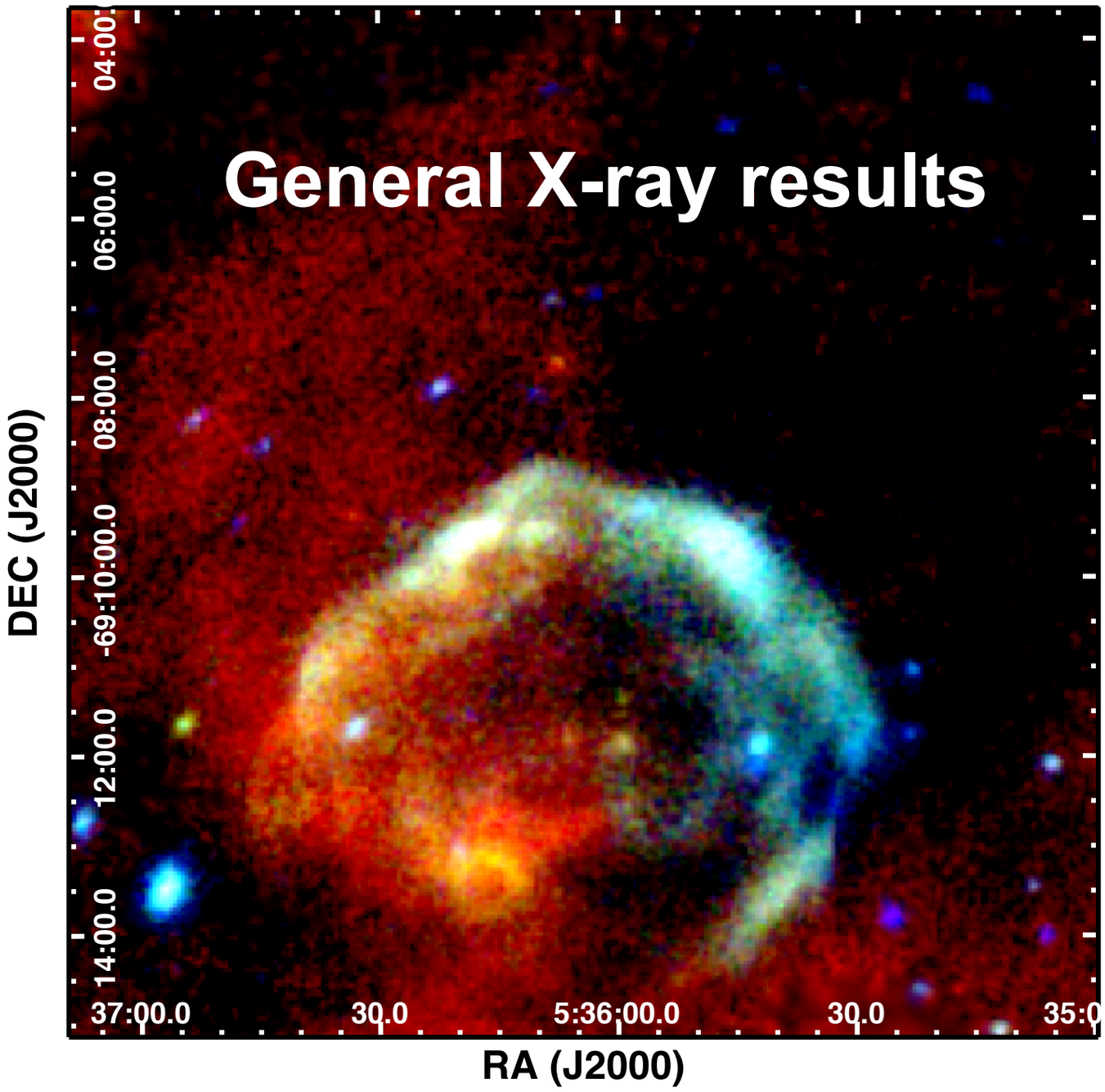
General X-ray results



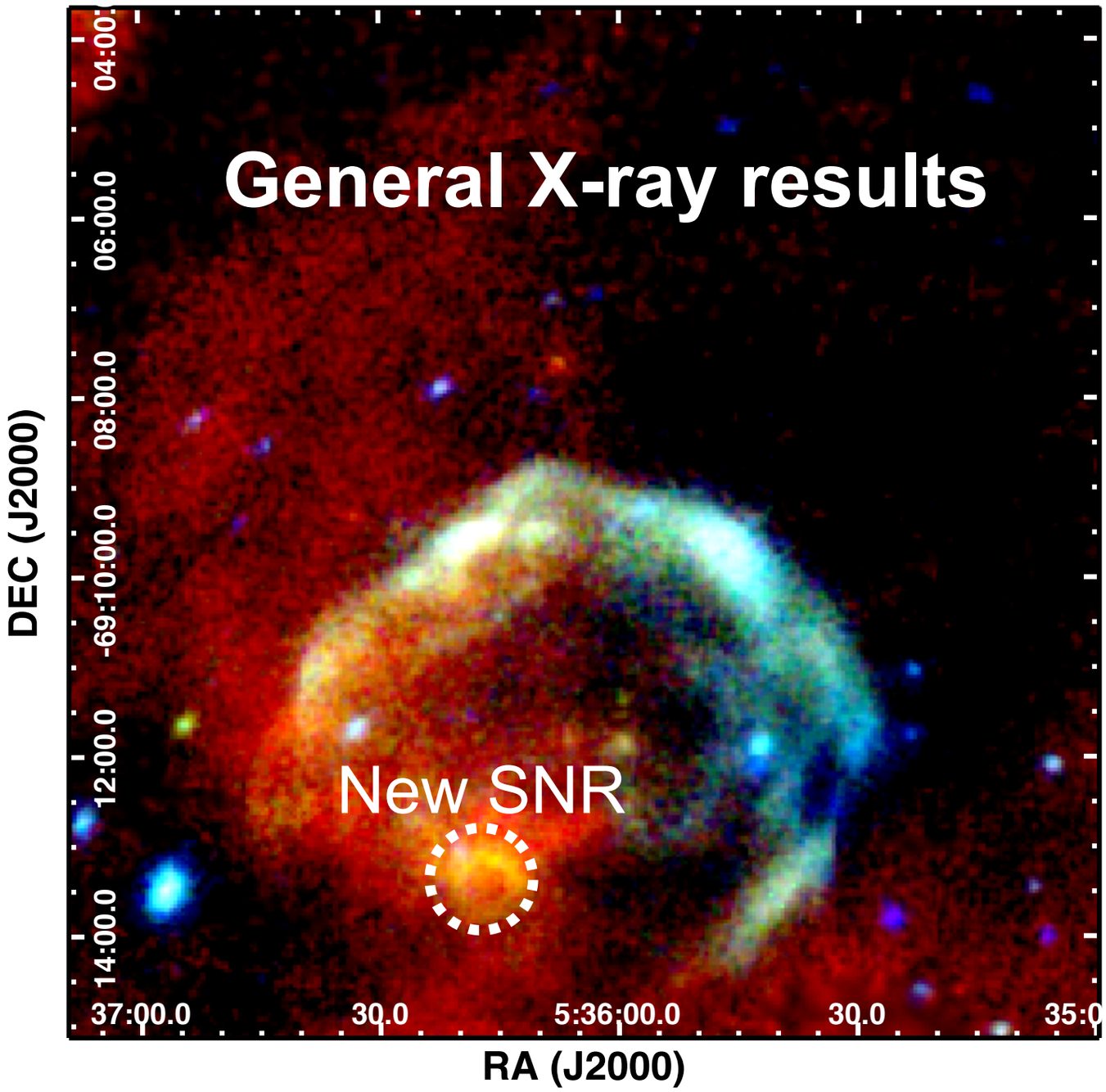
General X-ray results



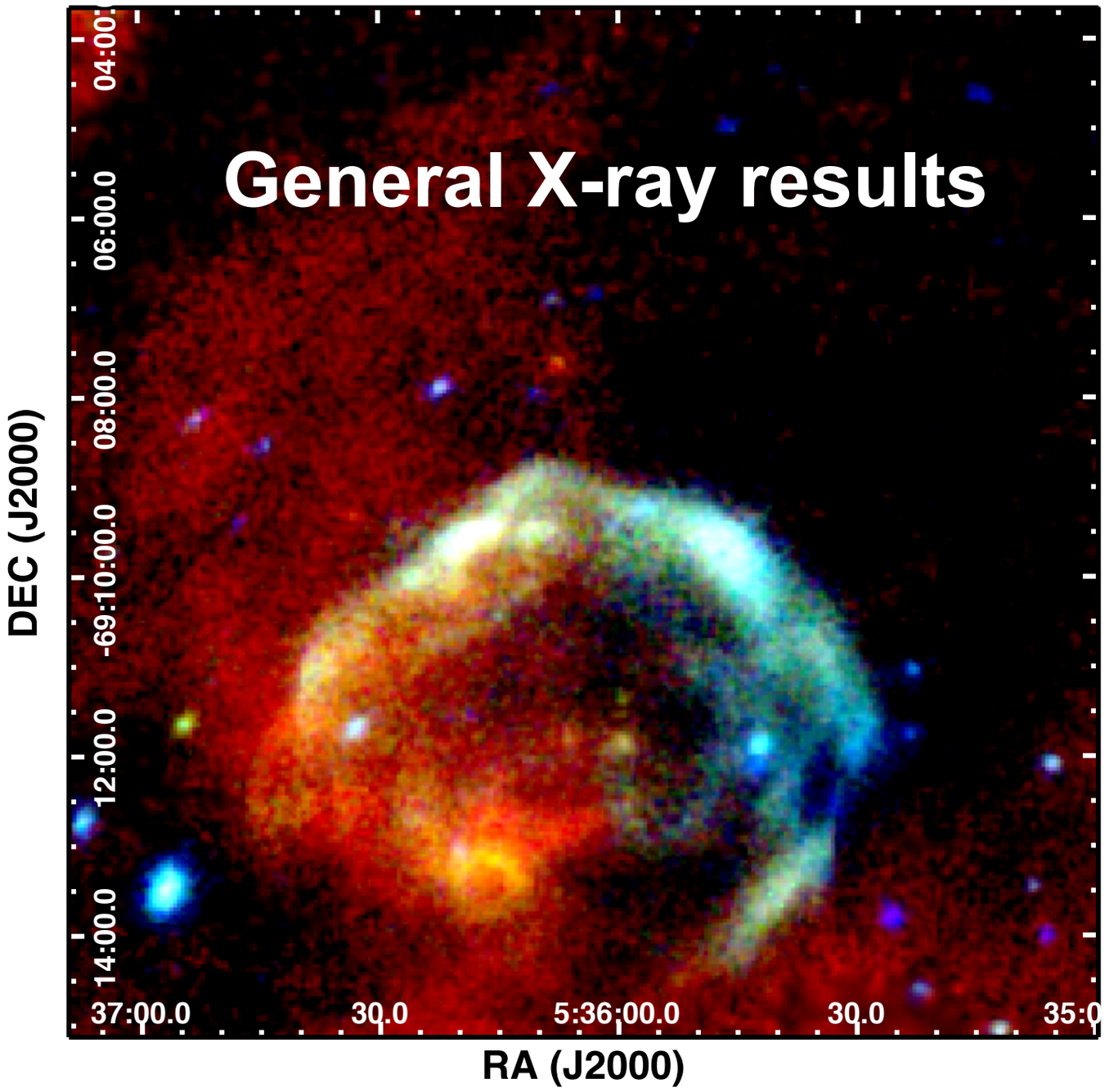
General X-ray results

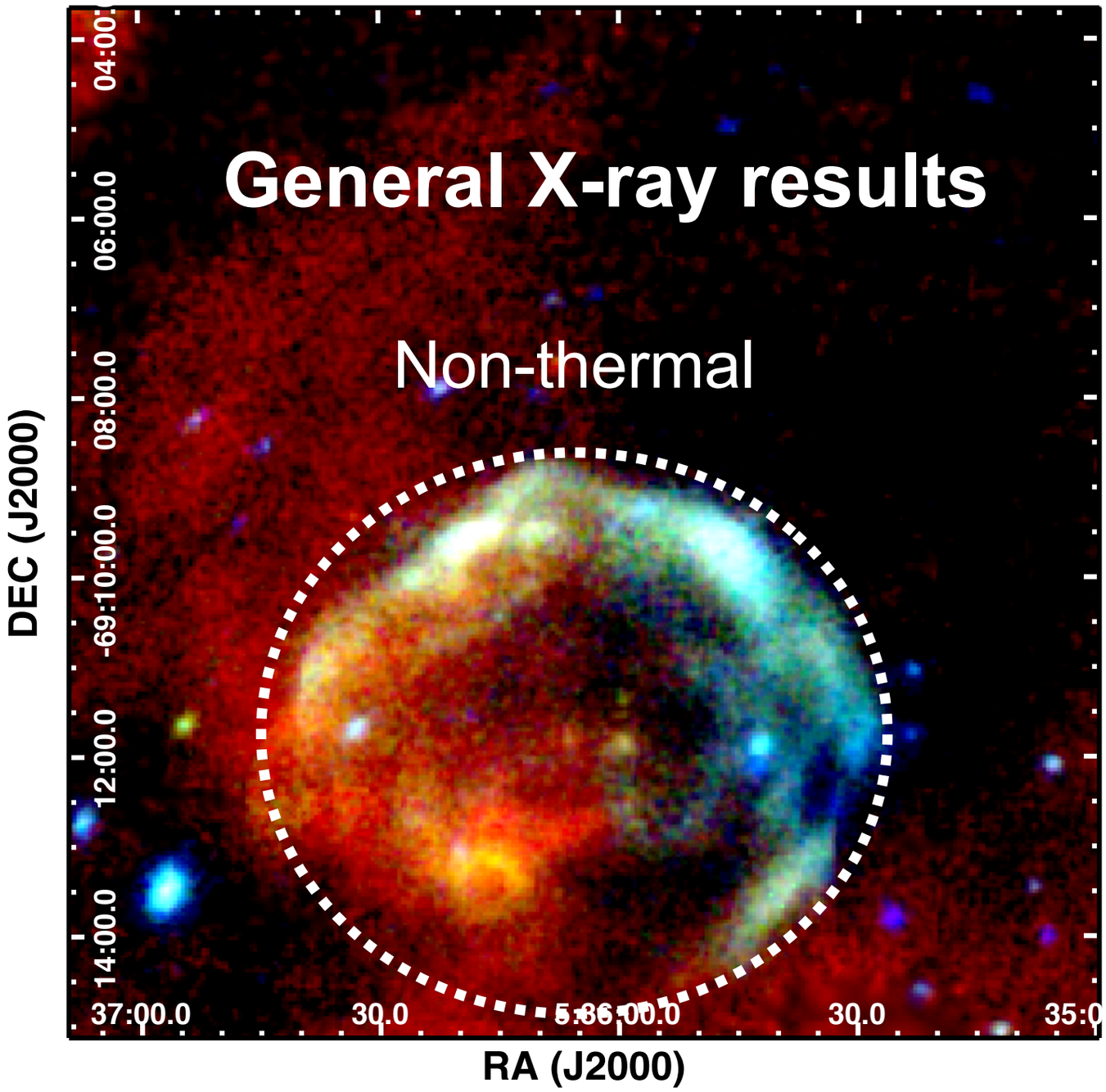


General X-ray results



General X-ray results




General X-ray results
Non-thermal
DEC (J2000)
-69:04:00.0
06:00.0
08:00.0
10:00.0
12:00.0
14:00.0
37:00.0
30.0
5:36:00.0
30.0
35:0
RA (J2000)

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MCSNR J0536-6913

- north-south gradient:
  location *outside* SB

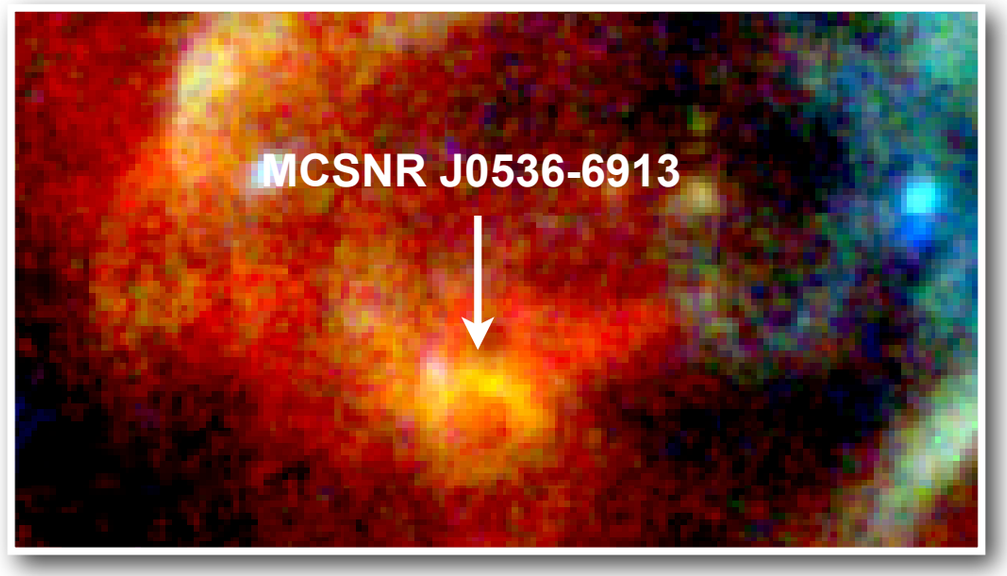
- 8 (±1) pc radius

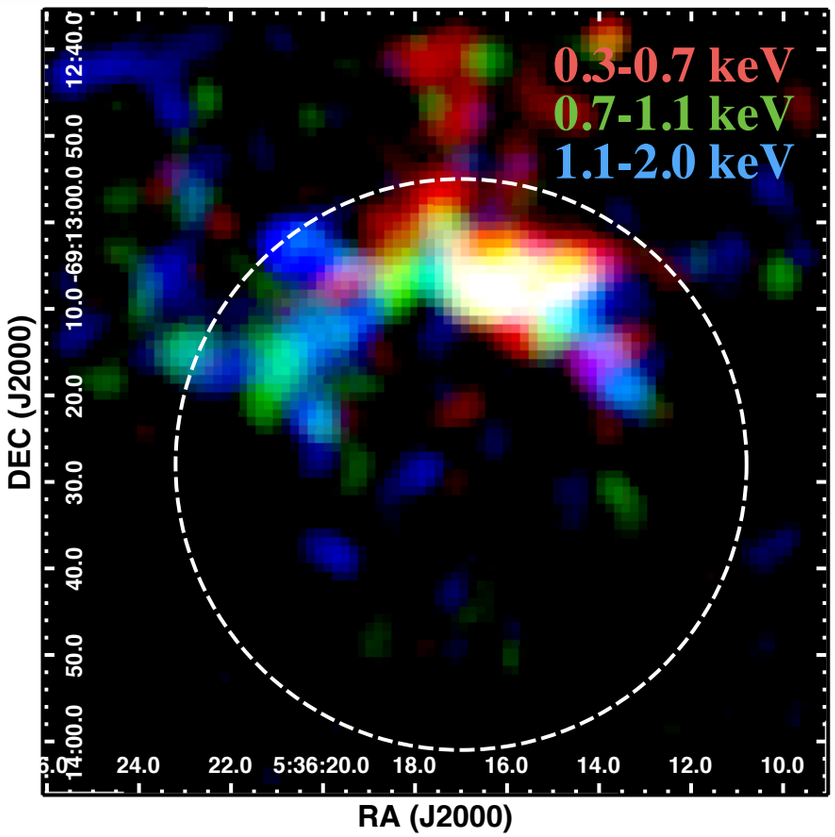
- ~ 8 x 10^{34} erg s^{-1}

- No clear optical or radio emission

- 2-5 kyr age:

Truelove & McKee (1999)
+
Fit results
+
Assumptions





~120 ks Chandra ACIS-S

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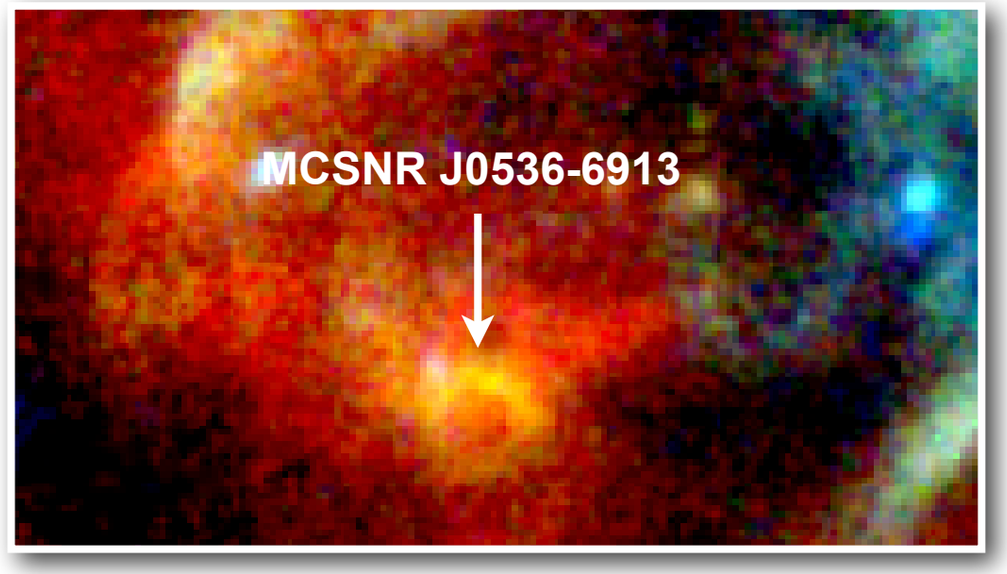
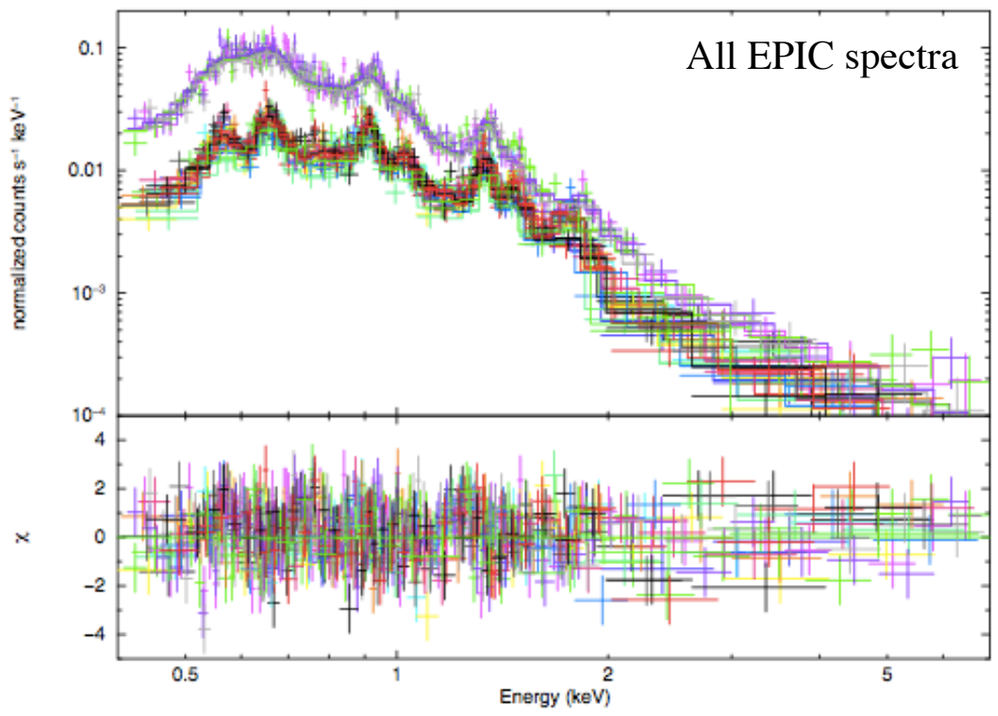
MCSNR J0536-6913

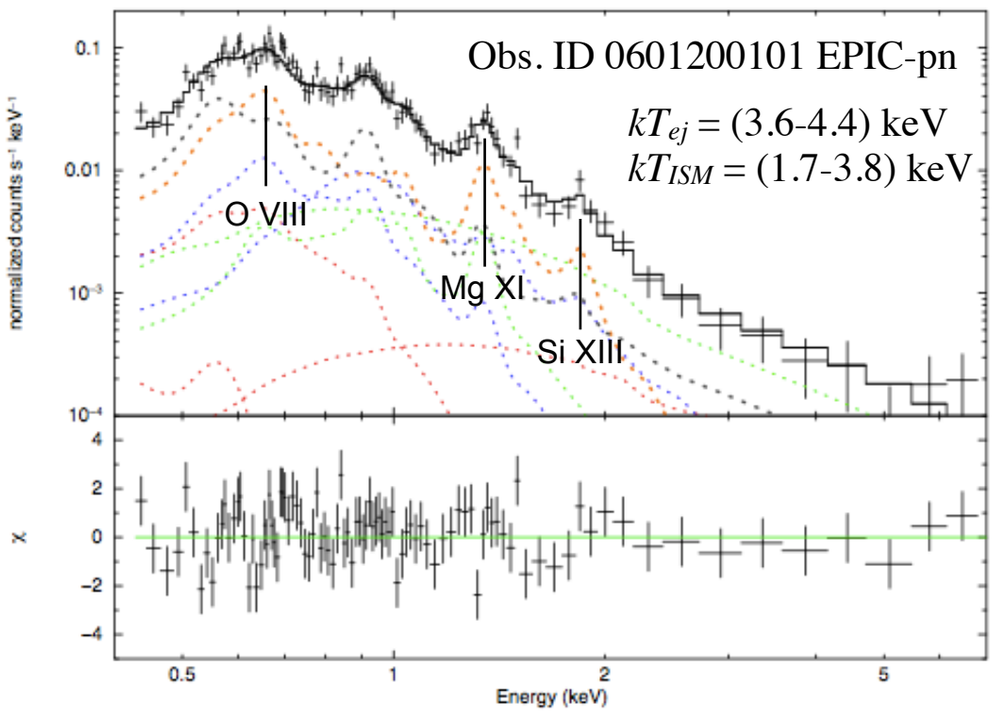
- significant contamination from 30 Dor C

- well-mixed ejecta + swept-up ISM

- Simplified approach







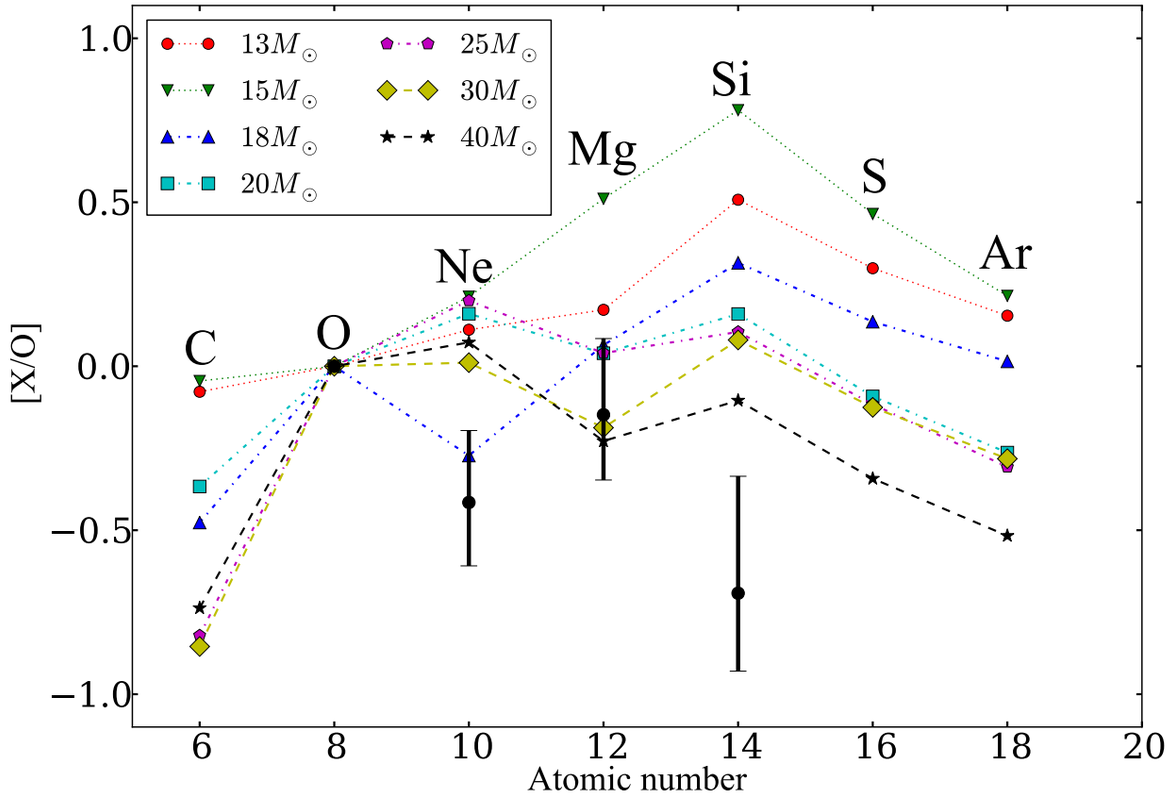
MCSNR J0536-6913

- metal abundances point to CC

- progenitor mass from SN yields

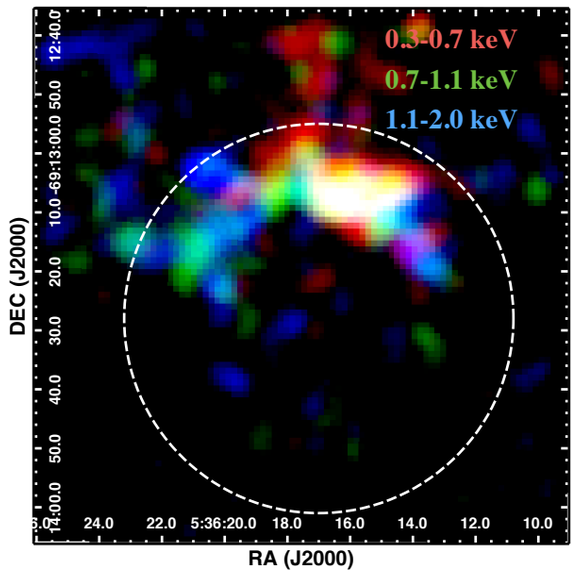
  >20 $M_\odot$ progenitor

  or >40 $M_\odot$ progenitor



Yields Table (2013)
(see also Nomoto + 2013)

- **deep *Chandra* required**



SB thermal emission

- kT = 0.2–0.4 keV; O,Ne,Mg > LMC abund.

- Correlated with the eastern Hα shell

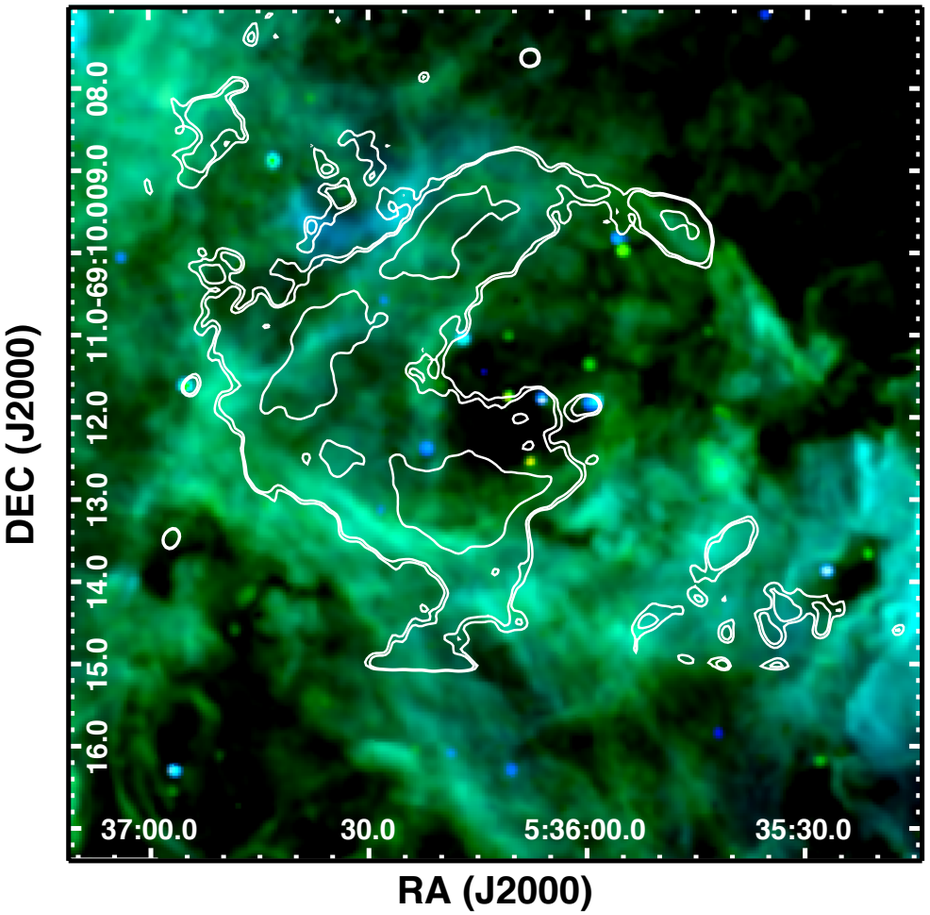
- Overabundant O, Ne, Mg suggest CC SNR

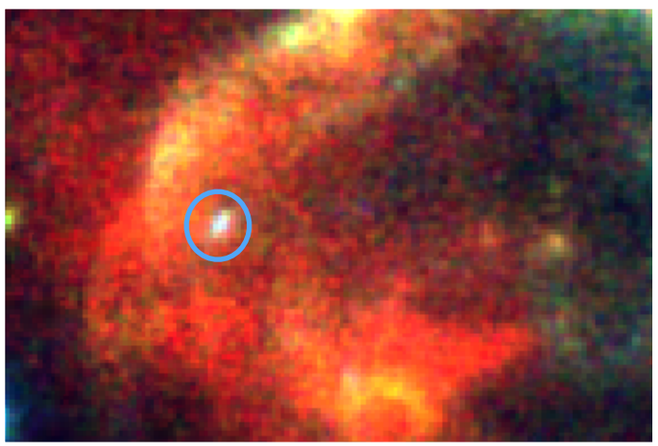
- SN must have occurred near the shell wall

- Emission from west absorbed?

- Unidentified point source as compact object?

MCELS (Winkler +, 2005)





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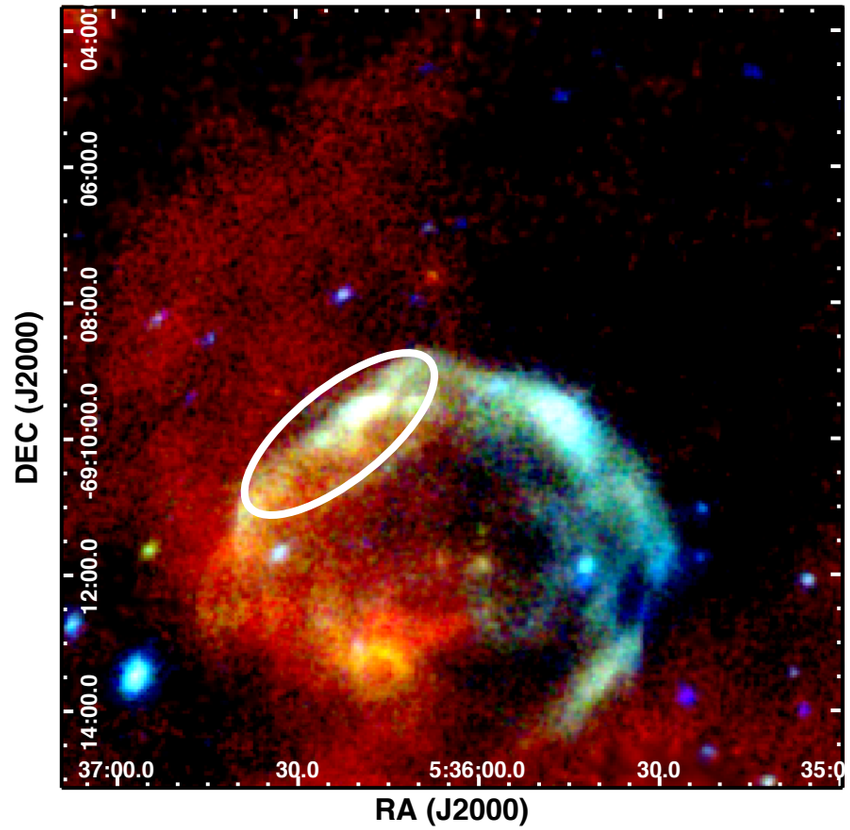
Non-thermal emission

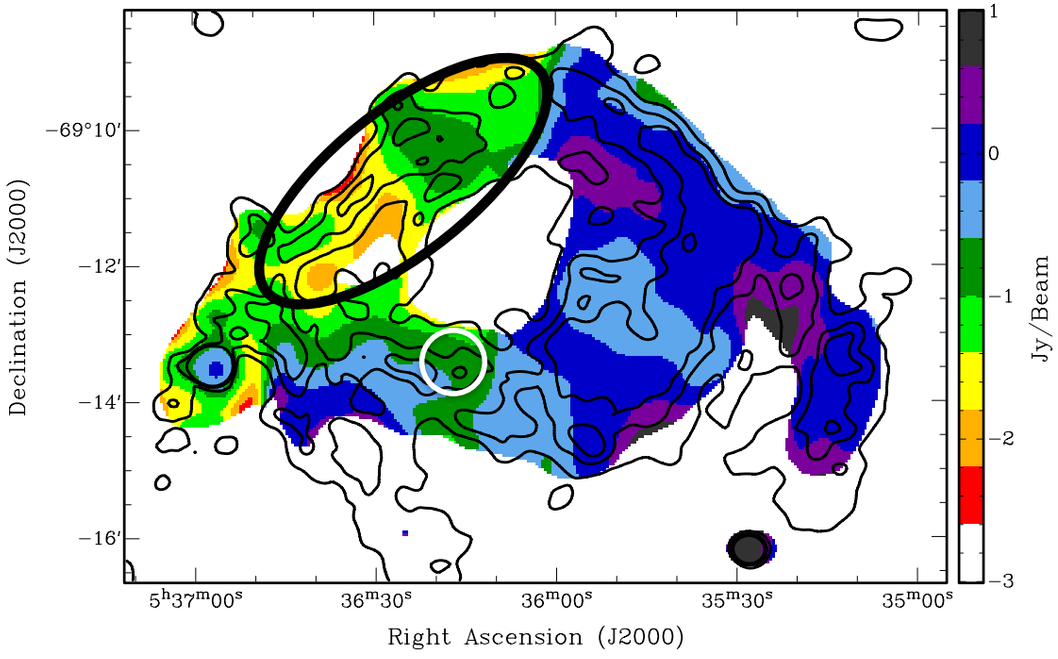
- is it synchrotron?

- *Suzaku:* Yes! (Yamaguchi +, 2009)

- *XMM-Newton:* Maybe

- X-ray and radio data available





Non-thermal emission

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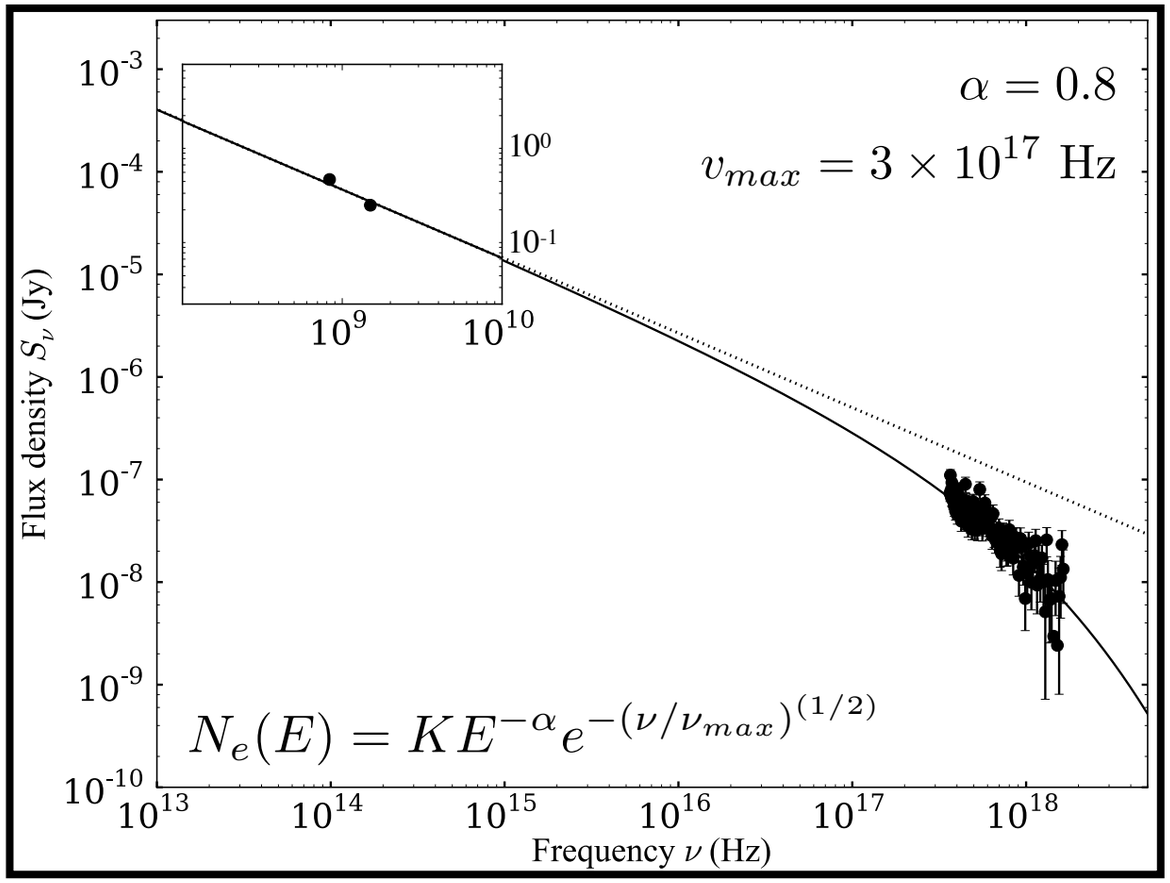
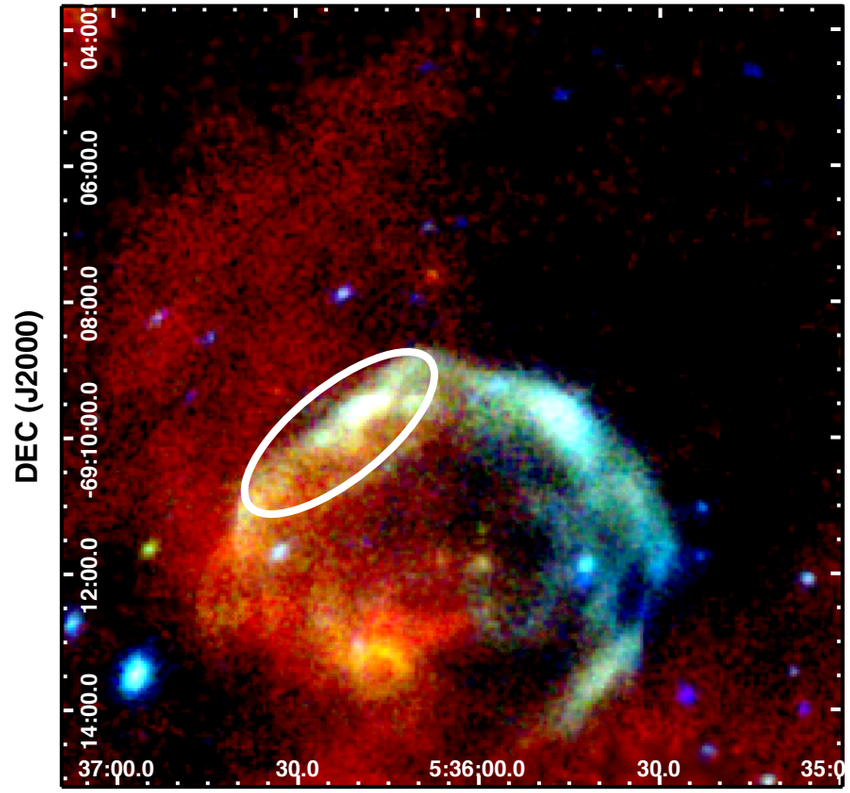
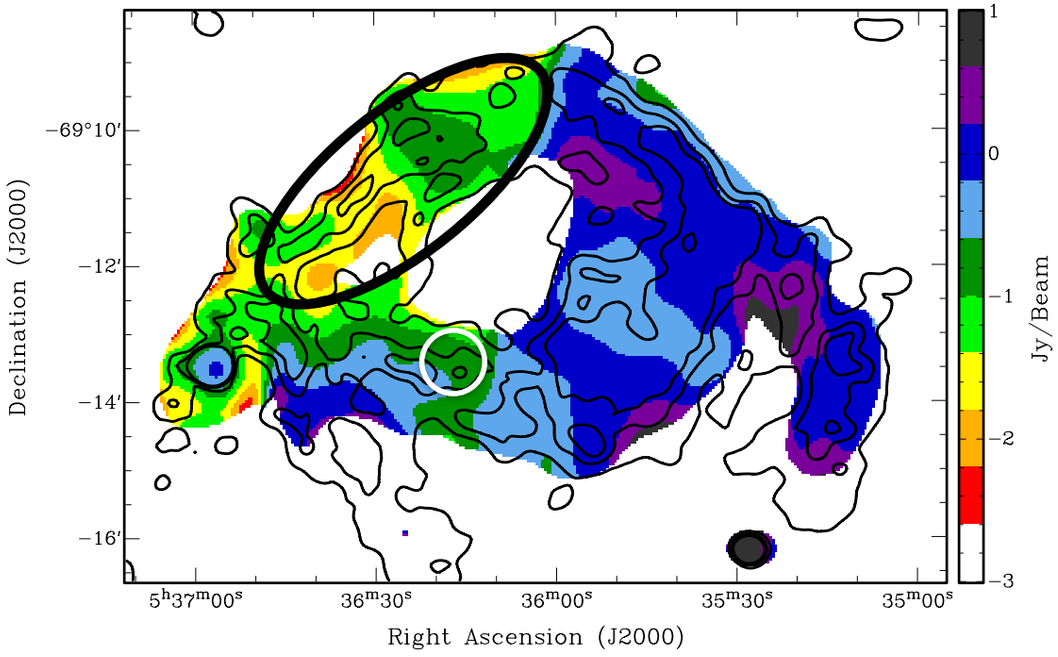
- *Suzaku:* Yes! (Yamaguchi +, 2009)







Synchrotron emission

- Problems:

SNRs do not freely expand in SB

(Mac Low & McCray, 1988; Parizot +, 2004)

no fast shocks ***(Smith & Wang, 2004)***

Where do particles come from?

- SB capable of particle acceleration
  - turbulence+MHD waves

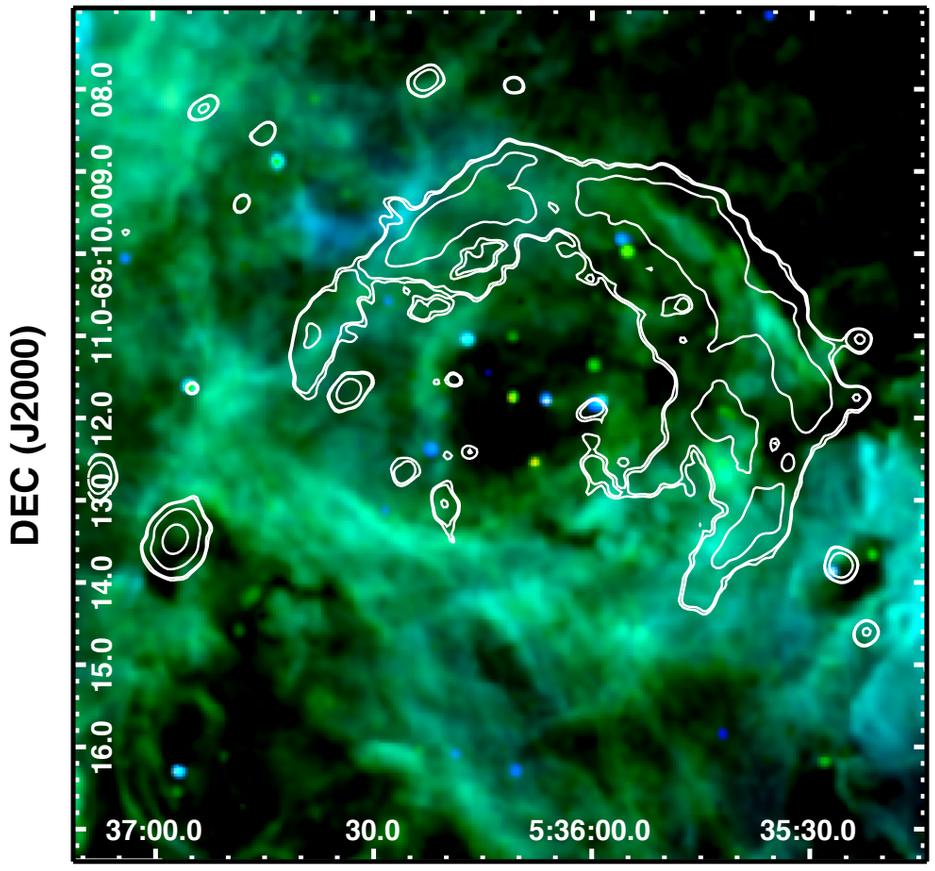
    (Bykov 2001, Parizot +,2004)
  - observed in Cygnus with *Fermi*

    (Ackermann +, 2011)

- Explanation for energy budget problem?

  (Butt & Bykov 2008)

MCELS (Winkler +, 2005)



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Synchrotron emission

Why 30 Dor C?

- 20-40% of mechanical energy converted to non-thermal particles at peak efficiency (Bykov 2001)

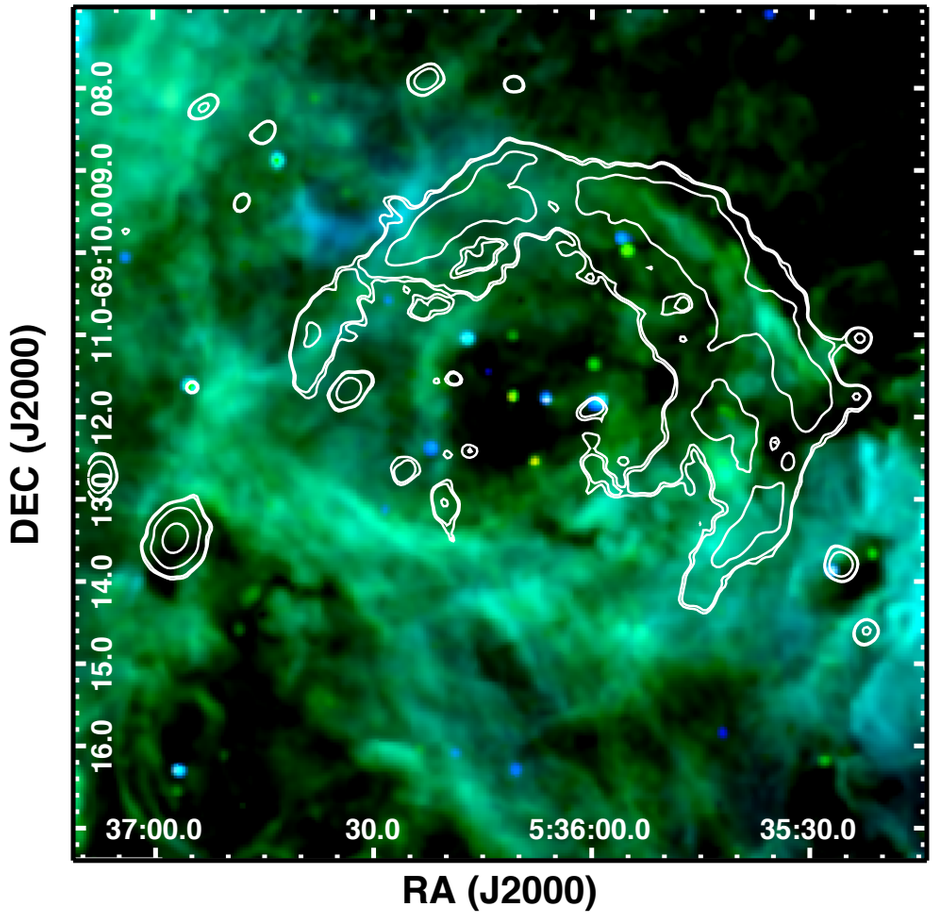
- 30 Dor C is the most powerful engine in LMC at the current epoch

- Also, potentially an SN blast wave adding to input

- 30 Dor C likely undergoing phase of non-thermal particle production

- more investigation needed

MCELS (Winkler +, 2005)



Summary

- New ejecta dominated SNR identified: MCSNR J0536-6913
  - emission lines suggest CC
  - chemical yields imply M > 20 $M_\odot$ or M > 40 $M_\odot$
  - in transition phase between free-expansion and Sedov
  - need deep *Chandra* observation!

- Eastern thermal emission with enhanced metal abundances
  - internal SNR (previously known)

- Non-thermal emission due to synchrotron mechanism
  - though no fast shocks
  - particles produced in SB itself?
  - could explain energy budget problem
  - 30 Dor C likely in phase of high particle production