particle acceleration and magnetic fields: looking at the nw rim of rcw 86 with chandra

sne-grb workshop
kyoto
oct 2013

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collaborators

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special credit to joe depasquale at cxc for imaging help

outline

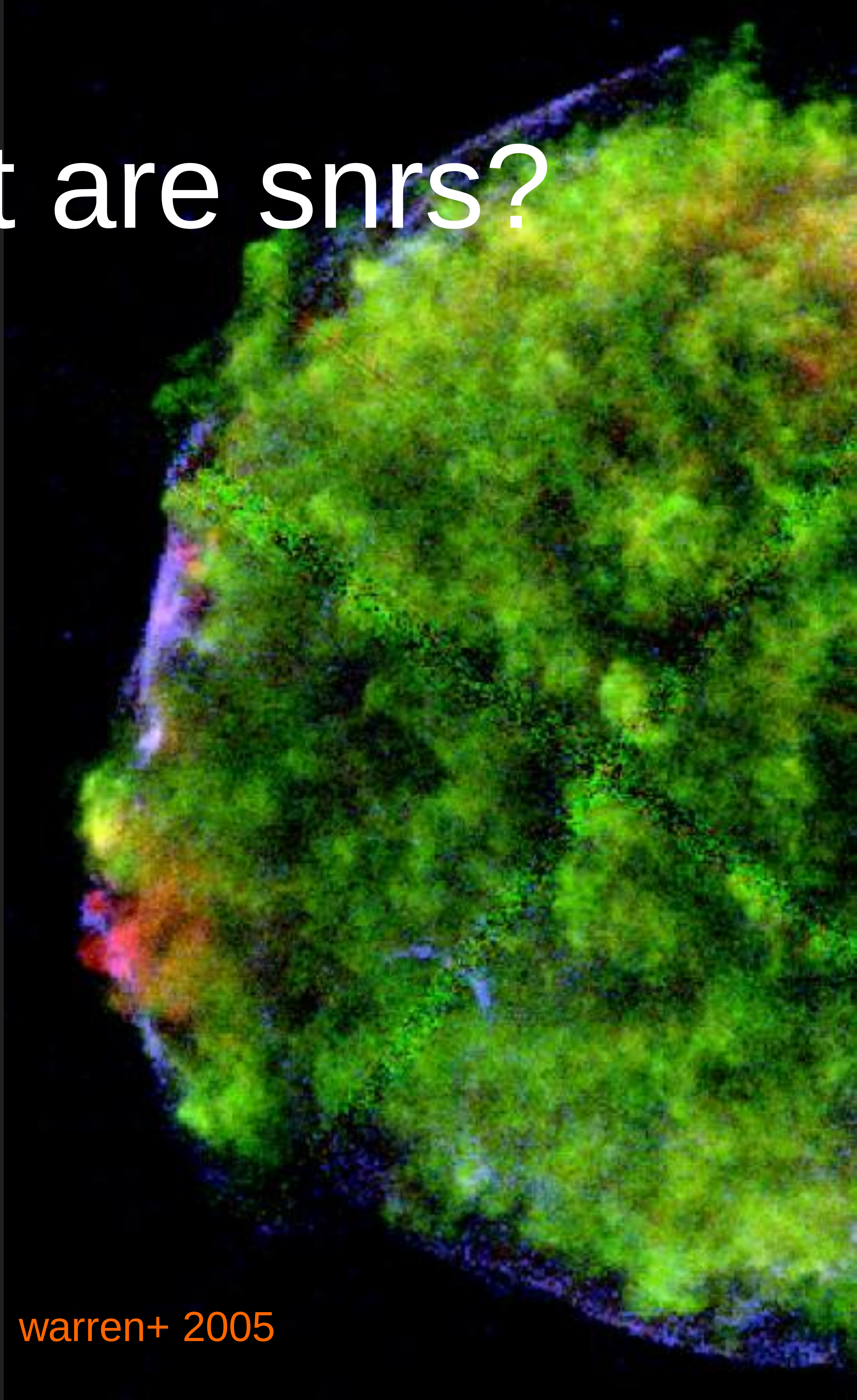
what evidence is there that SNRs accelerate cosmic rays?

how does the magnetic field get amplified? and how do we know it does?

what have we learnt studying rcw 86 with chandra?

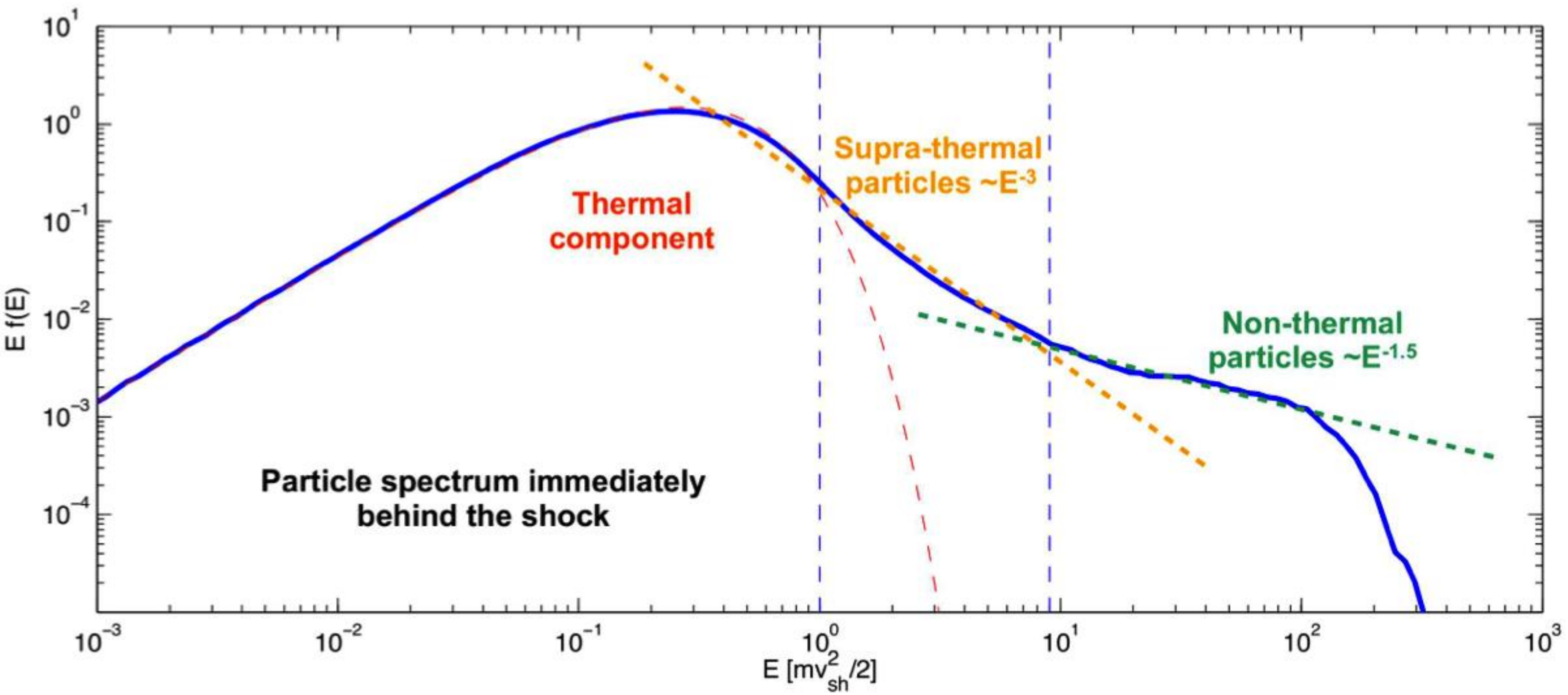
0. primer: what are snrs?

- explosive end of a star
- two types:
  - core-collapse
  - thermonuclear
- material ejected with ~10^{51} erg kinetic energy
- shock wave forms & sweeps up ISM/CSM



warren+ 2005

0. primer: what are snrs?



e.g. caprioli 2012

i. evidence

what evidence is there that SNRs accelerate cosmic rays?

i. evidence

- non-thermal X-rays
- γ-ray emission
- dynamical properties
- structure

koyama+ 1995

i. evidence

- non-thermal X-rays
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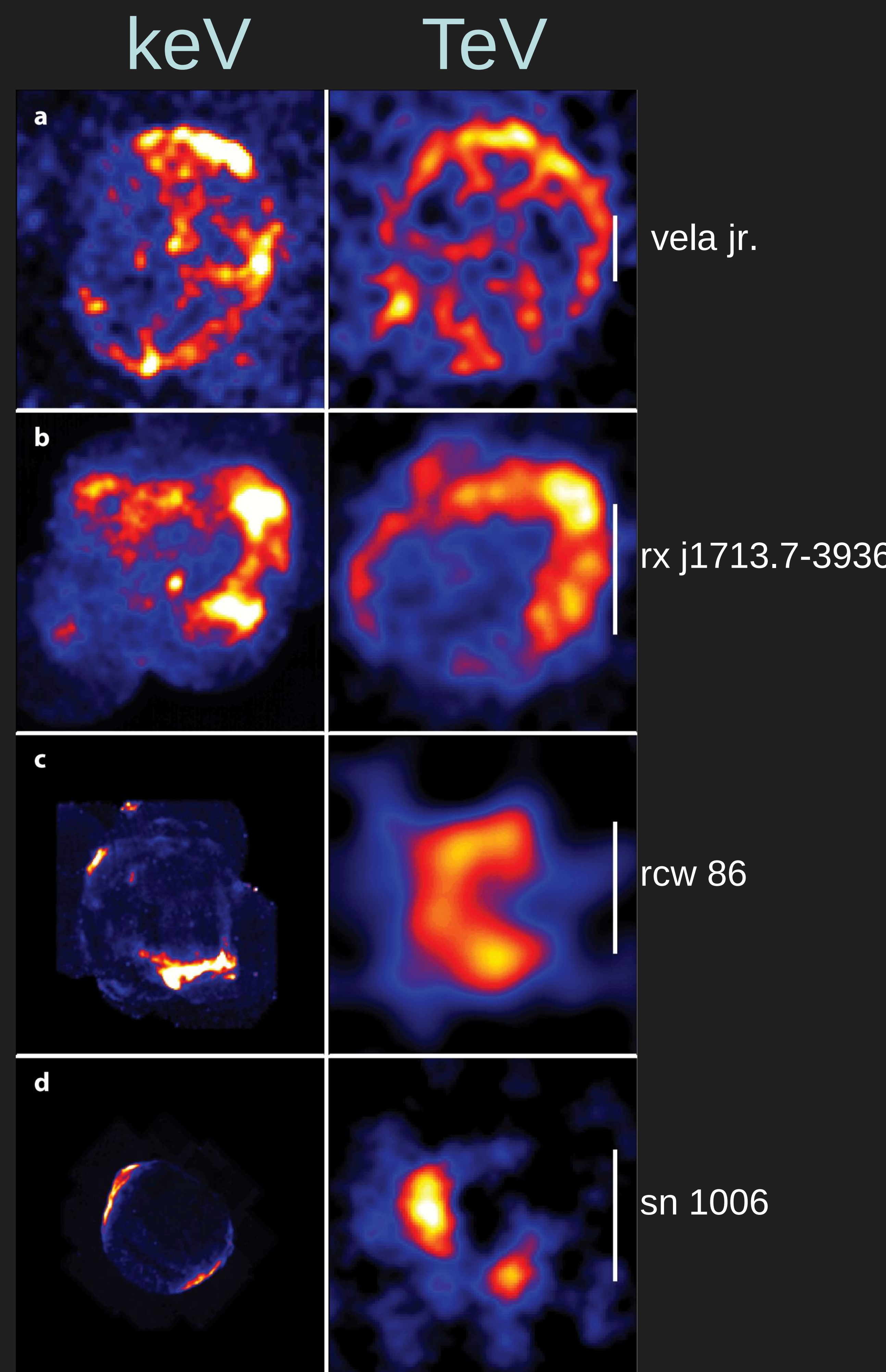
hinton & hofmann 2009
uchiyama+ 2002
aschenbach 1998
vink+ 2006
aharonian+ 2006, 2007,2008
naumann-godo+ 2006



i. evidence

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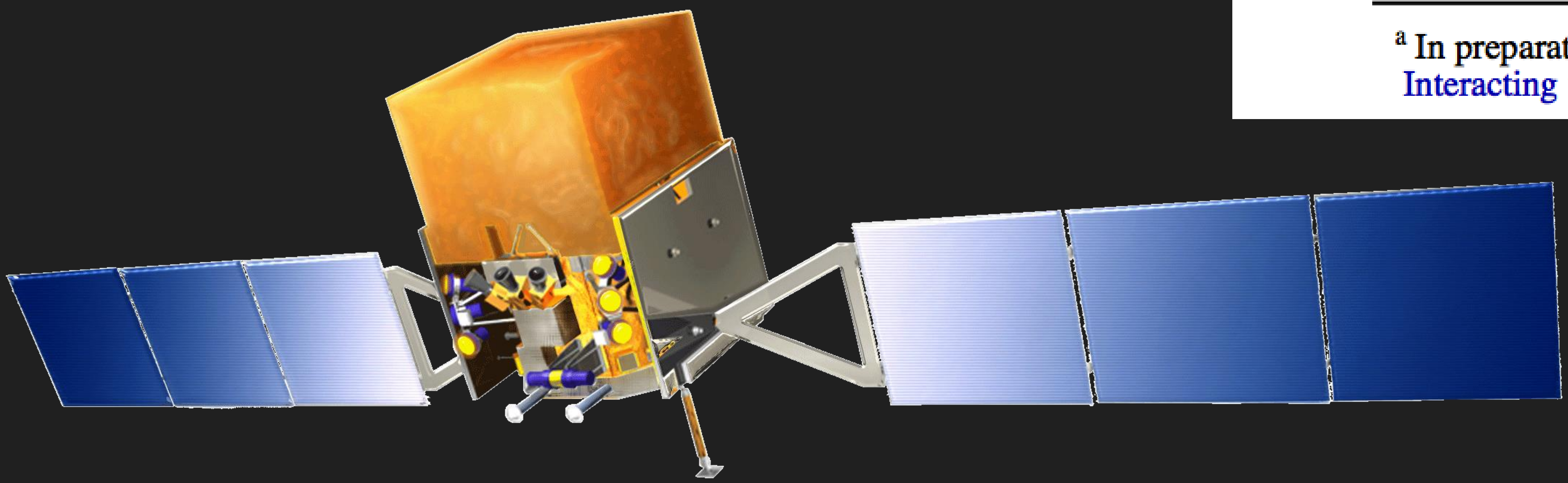
Table 1
SNRs Observed with the *Fermi*-LAT

Galactic l (°)	b (°)	Name	Reference
6.4	-0.1	W28	Abdo et al. (2010a)
8.7	-0.1	W30	Castro & Slane (2010)
23.3	-0.3	W41	Castro et al. (2013a)
31.9	0.0	3C 391	Castro & Slane (2010)
33.6	0.1	Kes 79	Auchettl et al. (2013)[a]
34.7	-0.4	W44	Abdo et al. (2010c)
43.3	-0.2	W49b	Abdo et al. (2009)
49.2	-0.7	W51C	Abdo et al. (2009)
74.0	-8.5	Cygnus Loop	Katagiri et al. (2011)
78.2	2.1	γ-Cygni SNR	Lande et al. (2012)
89.0	4.7	HB 21	Reichardt et al. (2012)
109.1	-1.0	CTB 109	Castro et al. (2012)
111.7	-2.1	Cas A	Abdo et al. (2010b)
120.1	1.4	Tycho	Giordano et al. (2012)
180.0	-1.7	S147	Katsuta et al. (2012)
189.1	3.0	IC443	Abdo et al. (2010d)
260.4	-3.4	Puppis A	Hewitt et al. (2012)
266.2	-1.2	Vela Jr.	Tanaka et al. (2011)
304.6	0.1	Kes 17	Wu et al. (2011)
337.0	-0.1	CTB 33	Castro et al. (2013a)
337.8	-0.1	Kes 41	Castro et al. (2013b)[a]
347.3	-0.5	RX J1713.7 3946	Abdo et al. (2011)
348.5	0.1	CTB 37A	Castro & Slane (2010)
349.7	-0.5	G349.7-0.5	Castro & Slane (2010)
357.7	-0.1	MSH 17-39	Castro et al. (2013a)

[a] In preparation
Interacting with MCs



LAT SNR catalog (sometime in the next 12 months)

i. evidence

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- γ-ray emission
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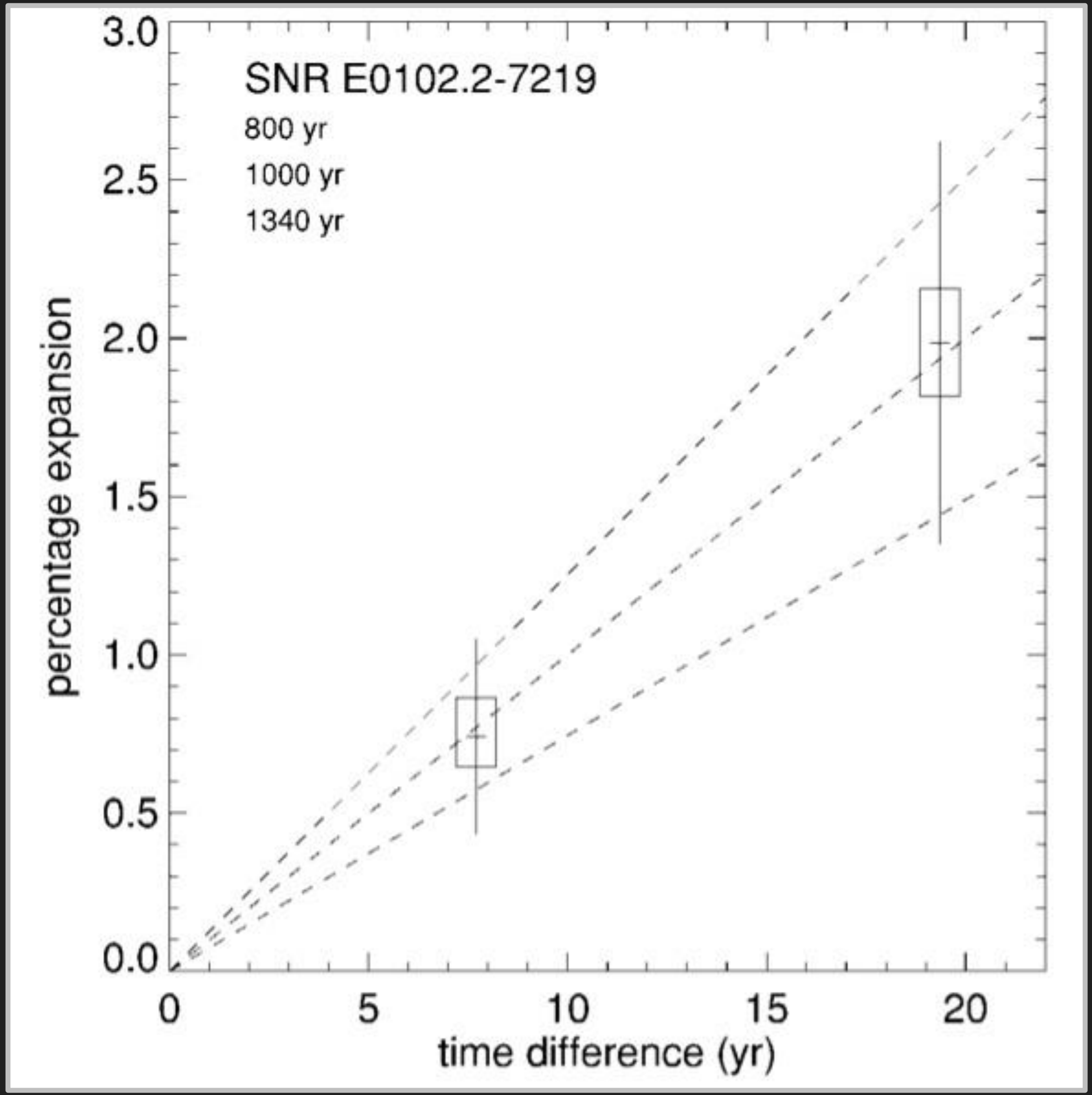

hughes+ 2000

i. evidence

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- γ-ray emissi
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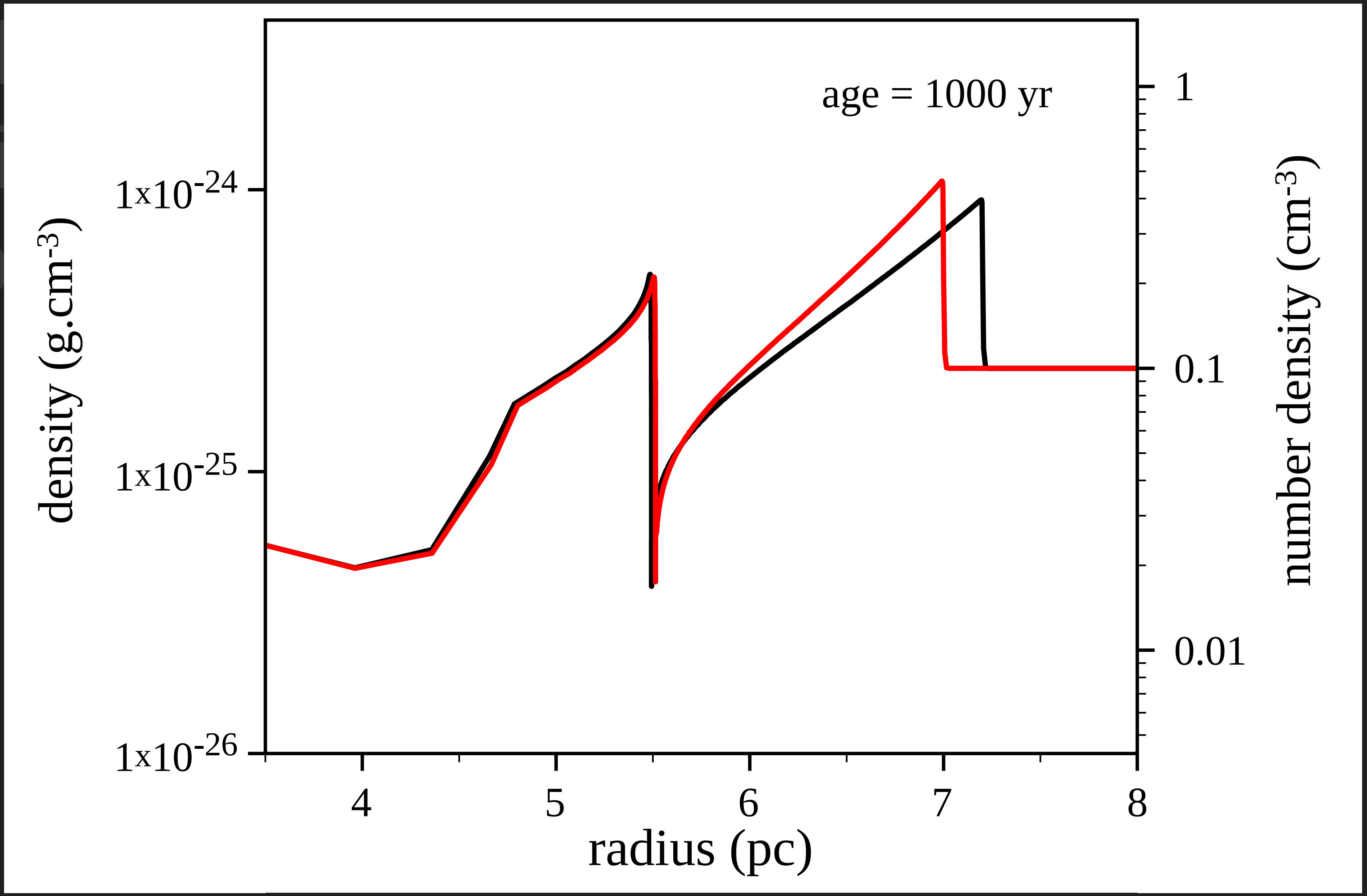

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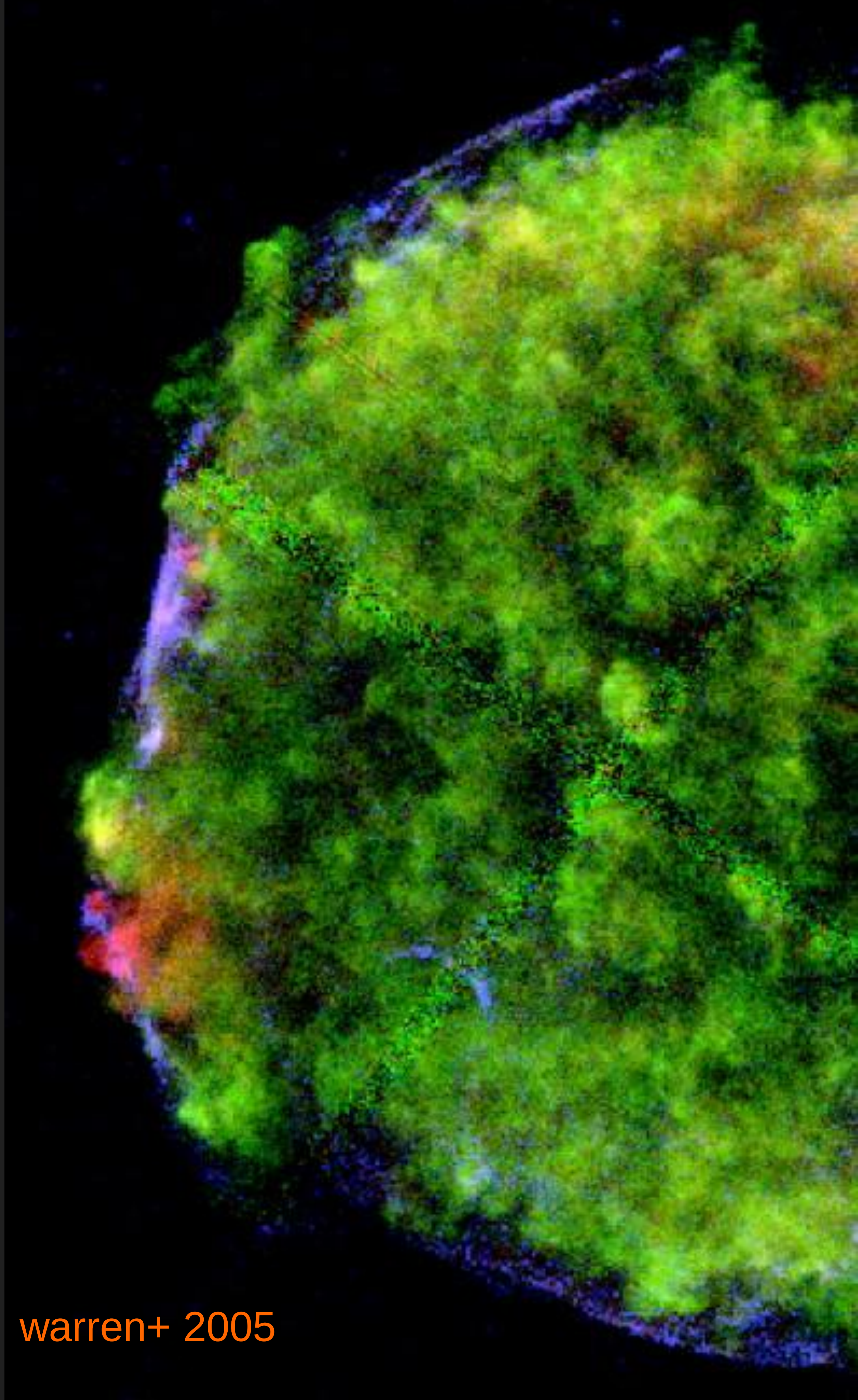

warren+ 2005

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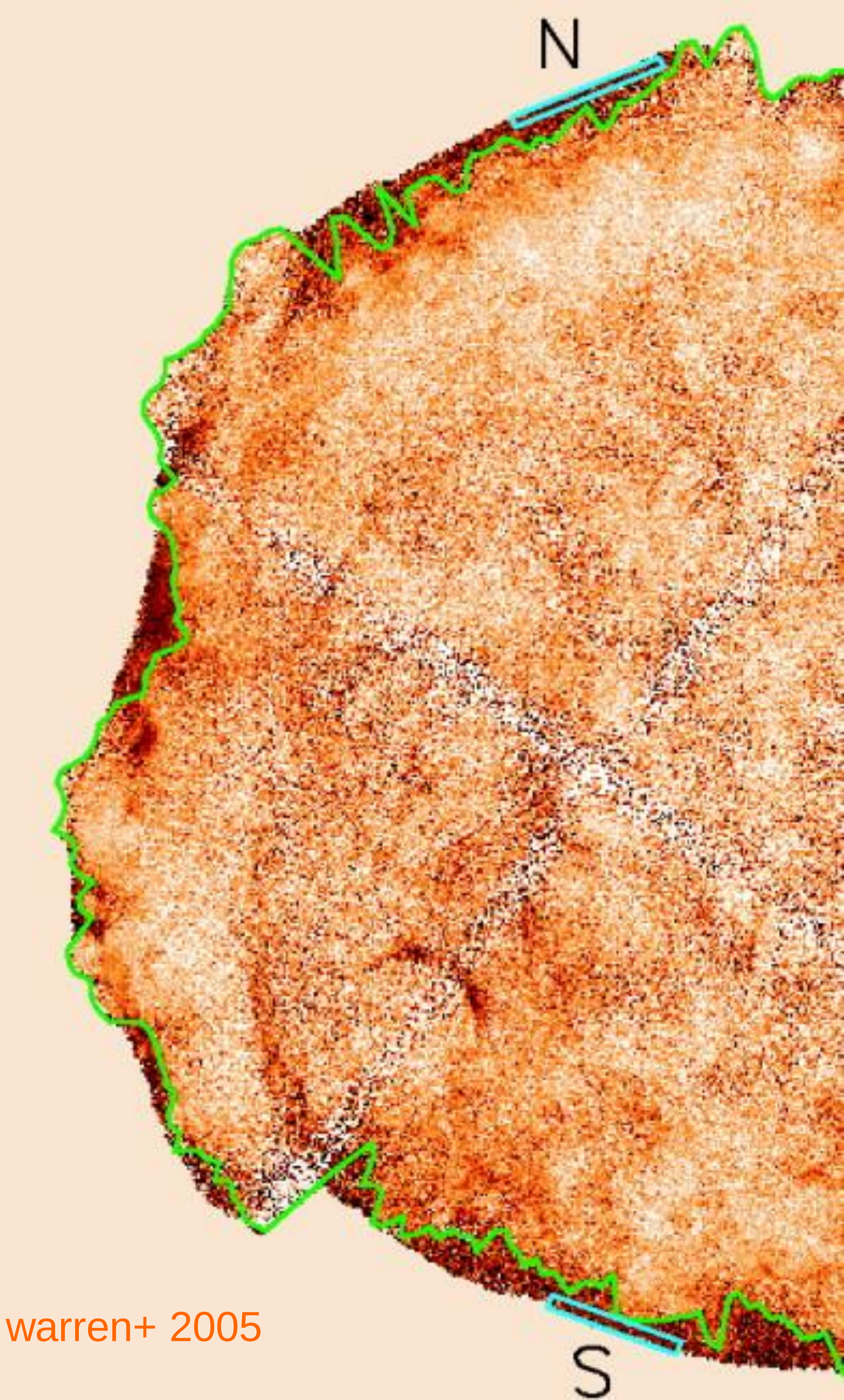
- γ-ray emission
- dynamical properties
- structure



warren+ 2005

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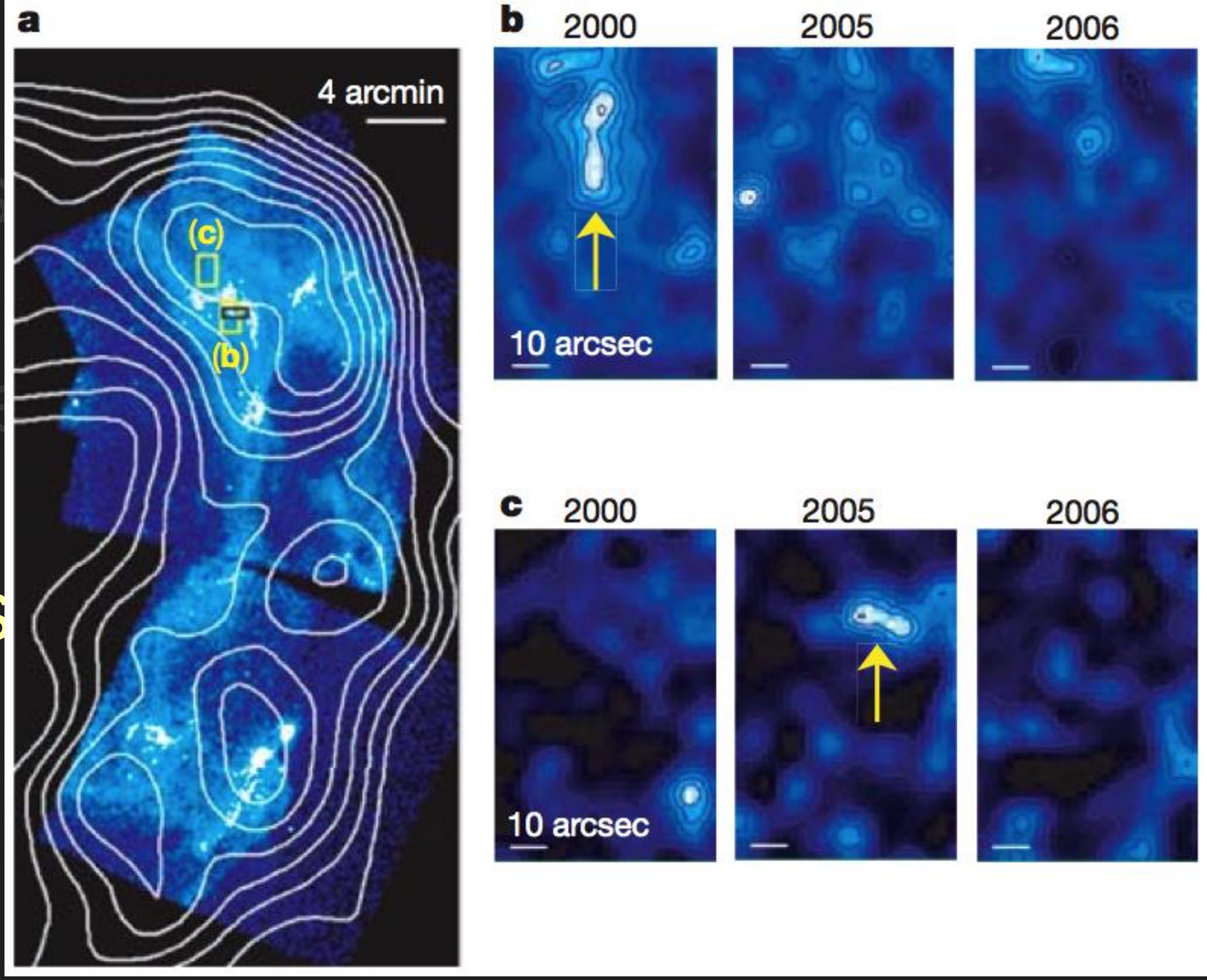
- non-thermal X-rays



uchiyama+ 2007

ii. magnetic field amplification

how does the magnetic field get amplified? and how do we know it does?

ii. magnetic field amplification

how

.resonant cosmic ray streaming instability e.g. zirakashvili 2000

.bell's non-resonant instability bell 2004

.non-resonant long-wavelength instability bykov & toptygin 2005

.others…

ii. magnetic field amplification

evidence

.spectral curvature in radio emission (a little iffy)

.broad-band fits of synchrotron emission between radio and non-thermal X-rays

.rapid variability of nonthermal X-ray emission from bright filaments in SNRs

.sharp X-ray edges

ii. magnetic field amplification

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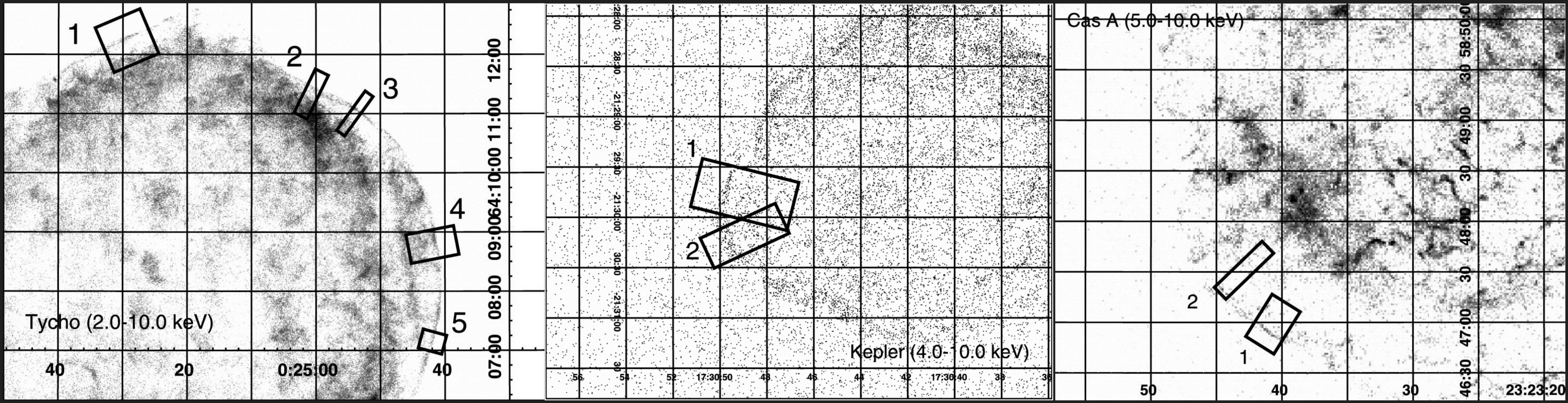


bamba et al. 2005

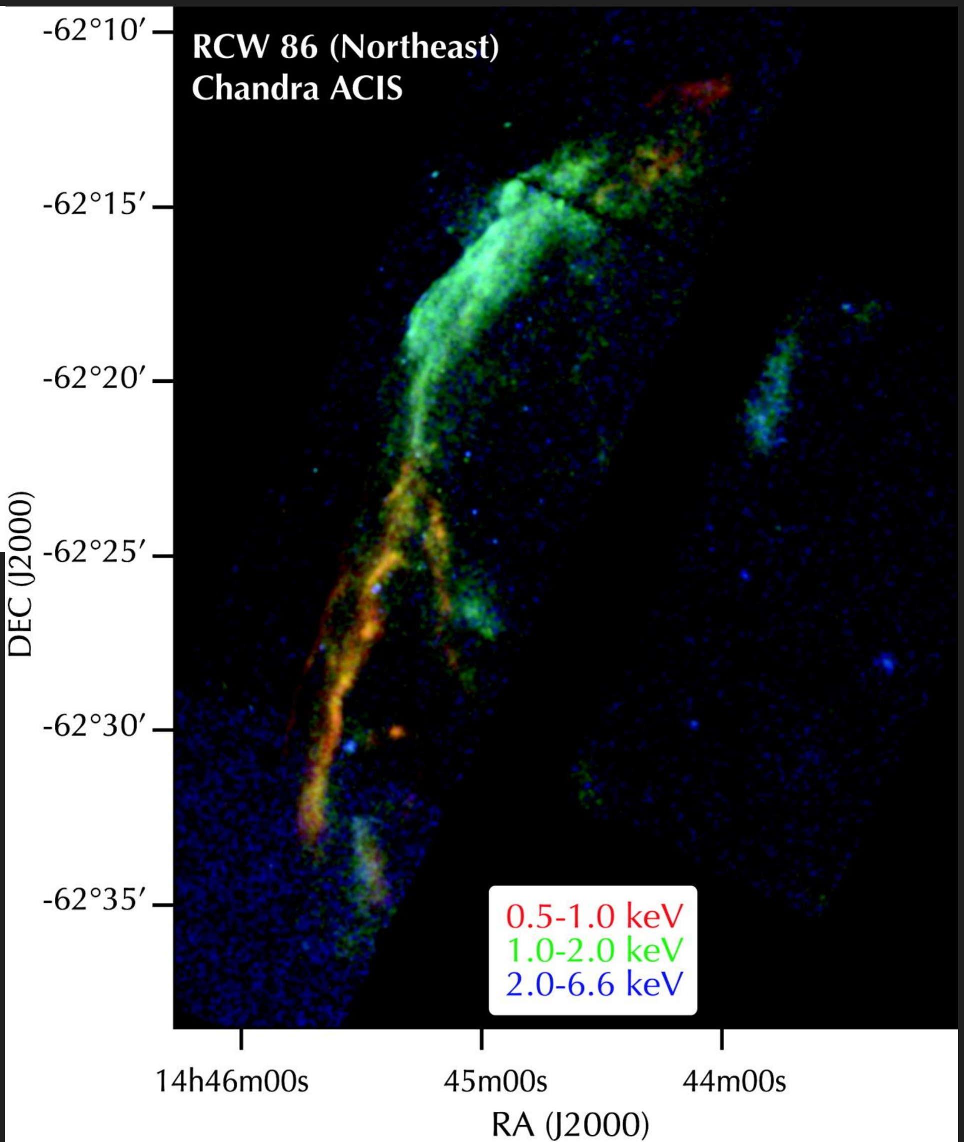
ii. magnetic field amplification

.sharp x-ray edges

vink et al. 2006

SNR	Dist kpc	V_s km s^{-1}	n_0 cm^{-3}	width $''$	B_{loss} μG	B_{diff} μG
Cas A	3.4	5200	3	0.5	249	299
Kepler	4.8	5300	0.35	1.5	97	113
Tycho	2.4	4500	0.3	2	113	165
SN1006	2.2	4300	0.1	20	30	39
RCW86	2.5	3500	0.1	45	24	14

vink 2006



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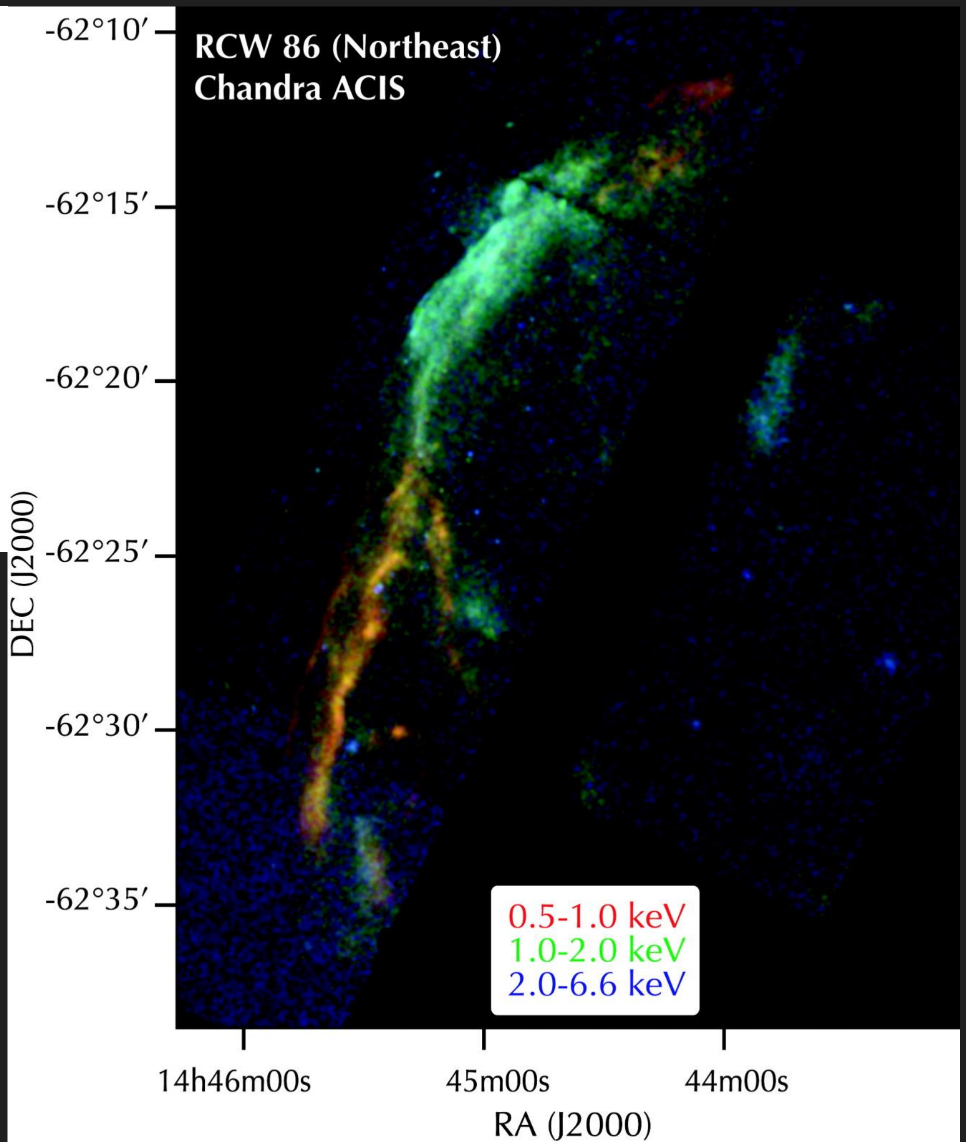
vink 2006

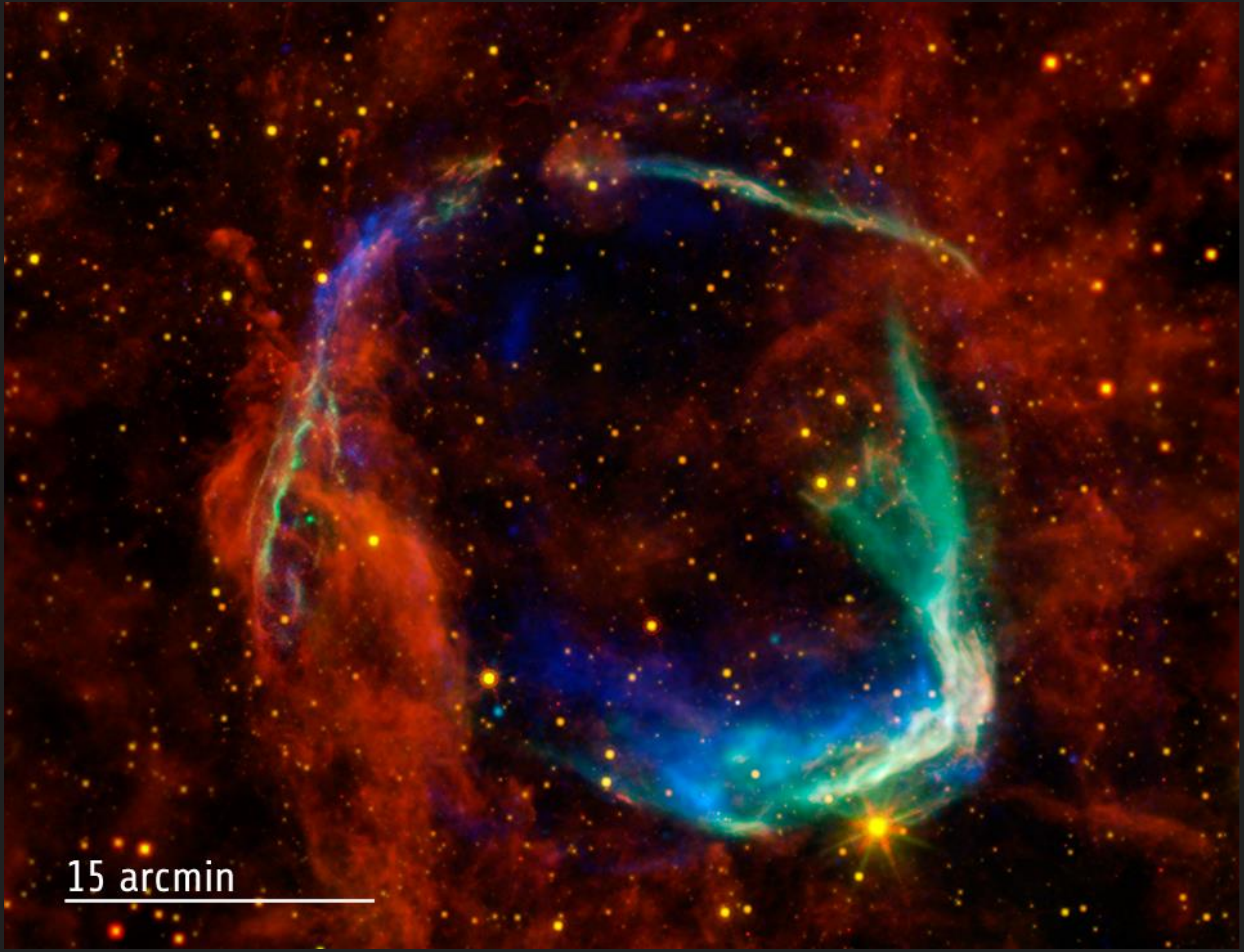
actually helder+ 2013 find vs~700-2000 km/s



iii. rcw 86

what have we learnt studying rcw 86 with chandra?

iii. rcw 86

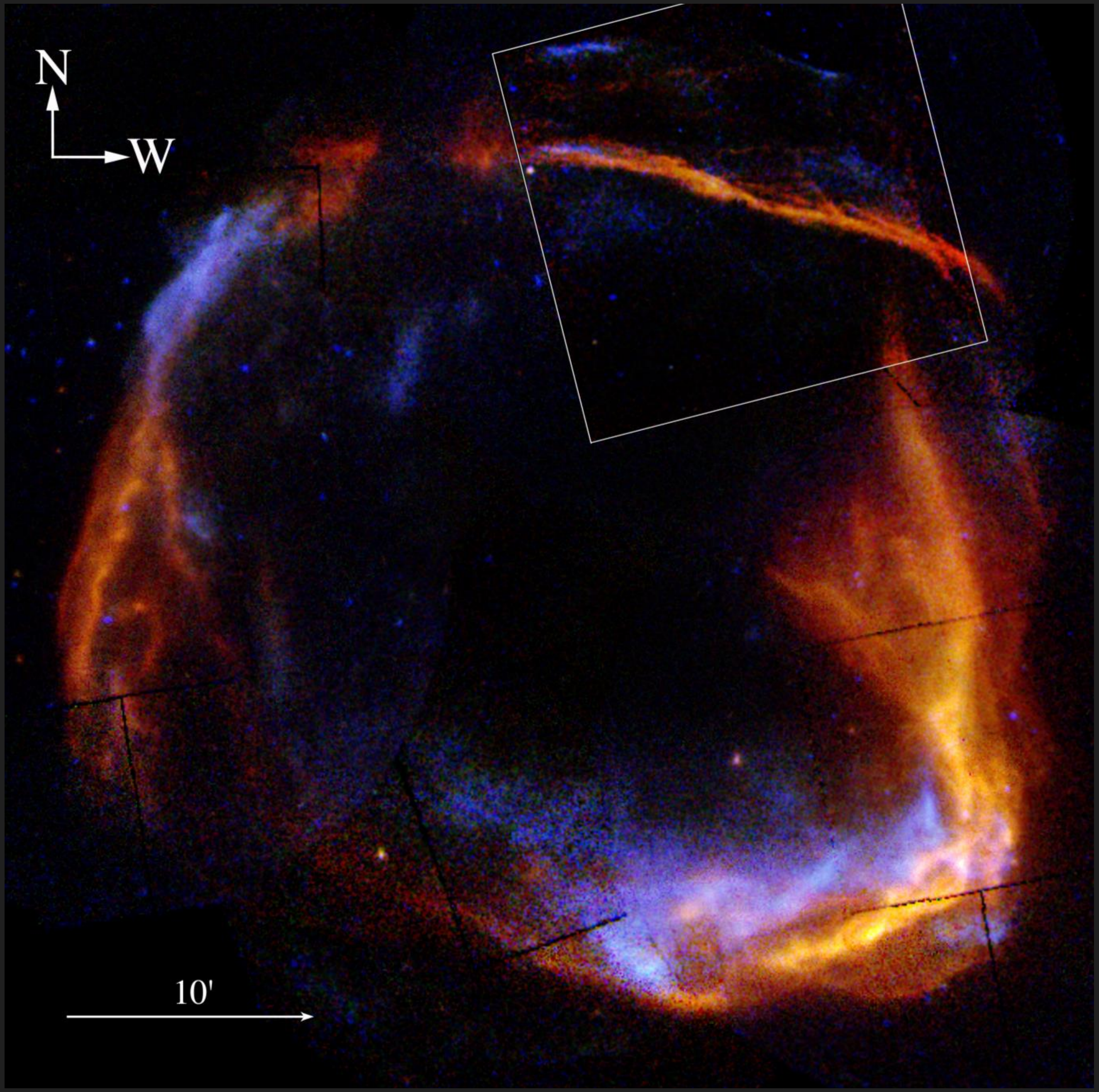


red: spitzer 24 microns
(wise 22 microns)

chandra and xmm
green:0.5-1.95 keV
blue: 1.95-6.8 keV

x-ray: nasa/cxc/sao & esa; infared: nasa/jpl-caltech/b. williams (ncsu)

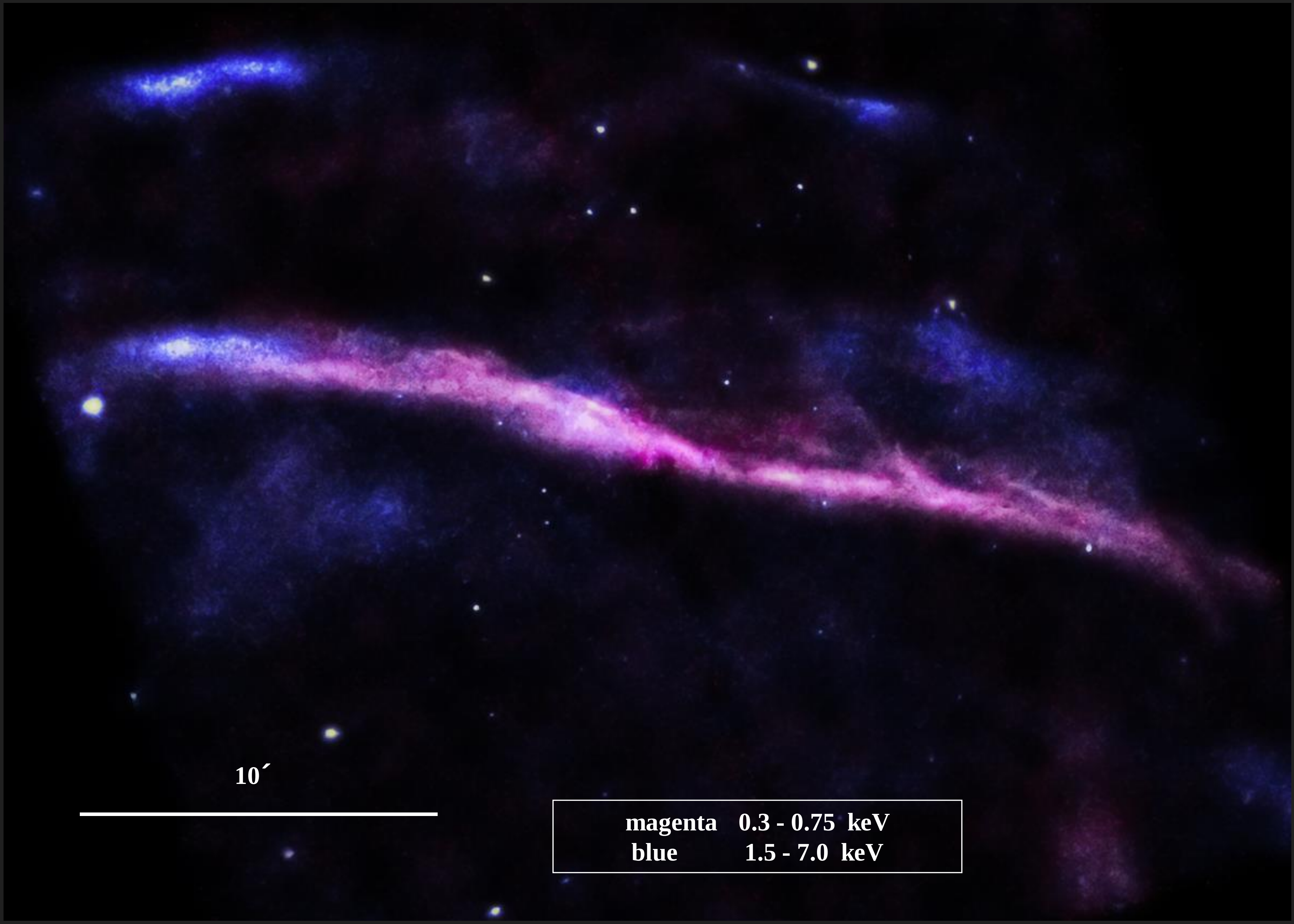
iii. rcw 86



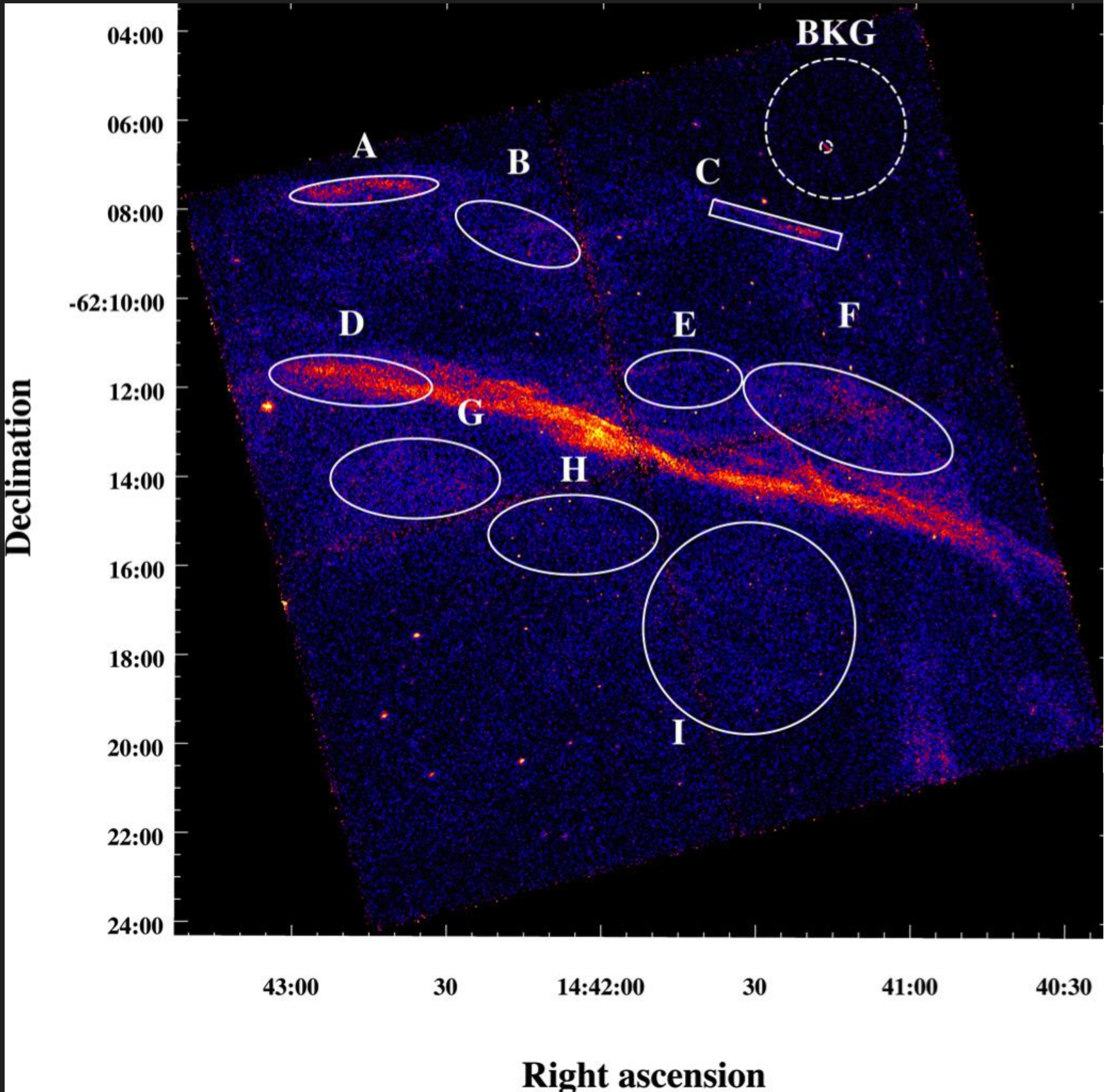
chandra and xmm

red: 0.5 - 1 keV
green: 1.5 - 2 keV
blue: 2 - 8 keV

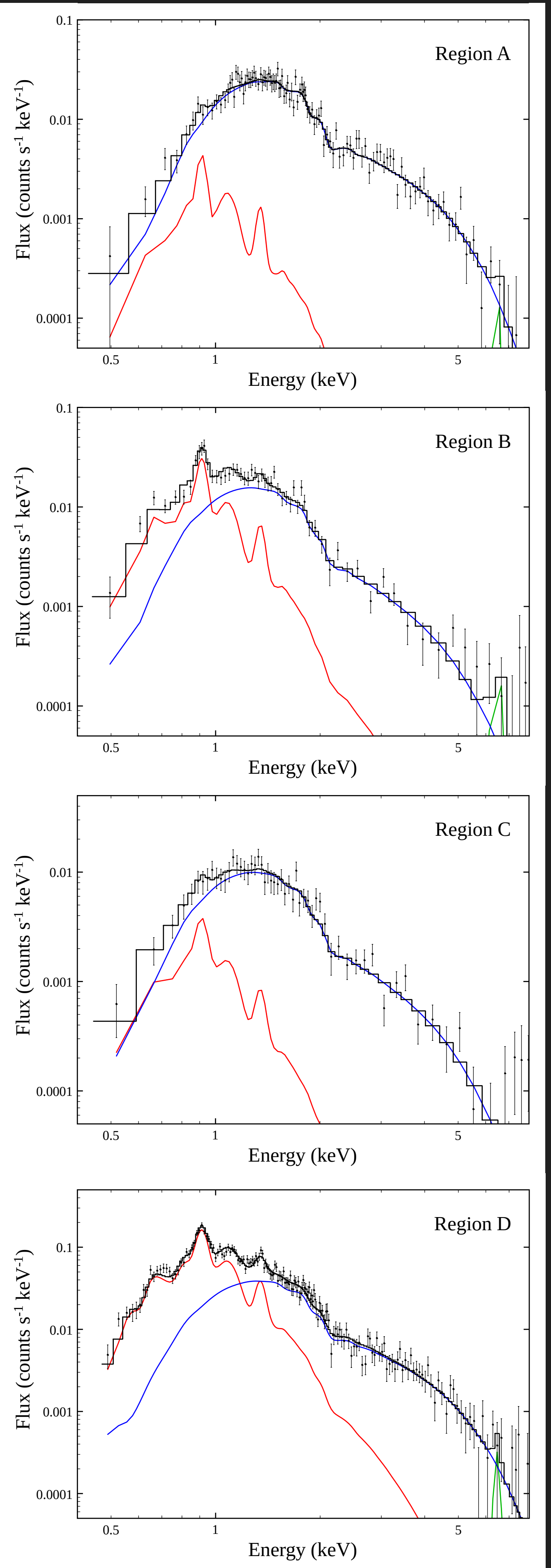
iii. rcw 86



iii. rcw 86



BKG
A
B
C
D
E
F
G
H
I
04:00
06:00
08:00
-62:10:00
12:00
14:00
16:00
18:00
20:00
22:00
24:00
Declination
43:00
30
14:42:00
30
41:00
40:30
Right ascension



Region A
Region B
Region C
Region D
Flux (counts s⁻¹ keV⁻¹)
Energy (keV)
0.1
0.01
0.001
0.0001
0.5
1
5

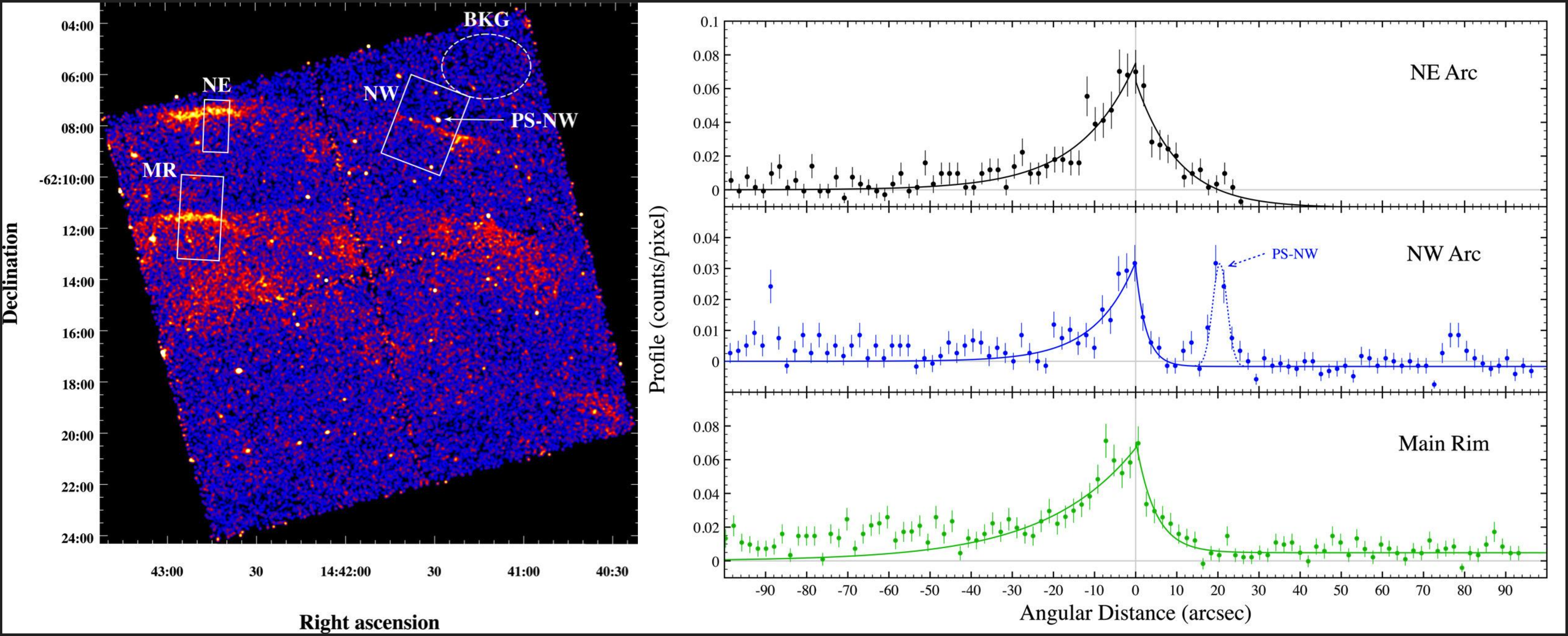
iii. rcw 86

Region	SRCUT				Power-Law			
	$h\nu_{\text{roll-off}}$ (keV)	F_{srcut}[a] (10^{-13} erg cm^{-2} s^{-1})	F_{nei}[a] (10^{-13} erg cm^{-2} s^{-1})	χ^2/dof	Γ	F_{powerlaw}[a] (10^{-13} erg cm^{-2} s^{-1})	F_{nei}[a] (10^{-13} erg cm^{-2} s^{-1})	χ^2/dof
A...........	$0.37^{+0.05}_{-0.06}$	1.93	0.004	108.2/106	$2.65^{+0.06}_{-0.06}$	1.92	0.003	110.3/106
B...........	$0.12^{+0.03}_{-0.02}$	0.68	0.023	57.4/55	$3.1^{+0.1}_{-0.1}$	0.71	0.021	58.6/55
C...........	$0.17^{+0.06}_{-0.04}$	0.54	0.003	47.1/54	$2.9^{+0.1}_{-0.1}$	0.56	0.003	47.1/54
D...........	$0.28^{+0.03}_{-0.05}$	2.39	0.147	190.8/166	$2.78^{+0.06}_{-0.06}$	2.44	0.144	190.5/166
E...........	$0.6^{+0.3}_{-0.2}$	0.72	0.026	63.8/53	$2.5^{+0.1}_{-0.1}$	0.74	0.025	64.4/53
F...........	$0.46^{+0.06}_{-0.09}$	3.32	0.080	173.9/162	$2.59^{+0.06}_{-0.06}$	3.40	0.077	171.5/162
G...........	$0.32^{+0.06}_{-0.04}$	3.03	0.016	167.7/143	$2.68^{+0.05}_{-0.05}$	3.05	0.012	167.8/143
H...........	$0.8^{+0.2}_{-0.2}$	1.76	0.018	134.9/87	$2.43^{+0.08}_{-0.08}$	1.76	0.016	131.1/87
I...........	$0.27^{+0.05}_{-0.04}$	4.03	0.052	149.2/125	$2.75^{+0.06}_{-0.06}$	4.14	0.047	150.4/125

iii. rcw 86

from Bamba+ 2003

$$f(x) = \begin{cases} A \exp\left(-\left|\frac{x_0 - x}{l_{\rm up}}\right|\right) & x > x_0 \\ A \exp\left(-\left|\frac{x_0 - x}{l_{\rm down}}\right|\right) & x < x_0 \end{cases}$$



iii. rcw 86

advection

$$l_{\rm adv} = v_{\rm adv}\tau_{\rm syn}$$

$$B_{\rm adv} \approx (83\ \mu{\rm G}) \left(\frac{l_{\rm adv}}{0.01\ {\rm pc}}\right)^{-2/3} \left(\frac{V_{\rm S}}{1000\ {\rm km\ s^{-1}}}\right)^{2/3}$$

diffusion

$$l_{\rm diff} = D/v_{\rm diff}$$

$$B_{\rm diff,d} \approx (700\ \mu{\rm G}) \left(\frac{l_{\rm diff,d}}{0.01\ {\rm pc}}\right)^{-2/3} \left(\frac{V_{\rm S}}{1000\ {\rm km\ s^{-1}}}\right)^{-2/3}$$

$$B_{\rm diff,u} \approx (280\ \mu{\rm G}) \left(\frac{l_{\rm diff,u}}{0.01\ {\rm pc}}\right)^{-2/3} \left(\frac{V_{\rm S}}{1000\ {\rm km\ s^{-1}}}\right)^{-2/3}$$

joint

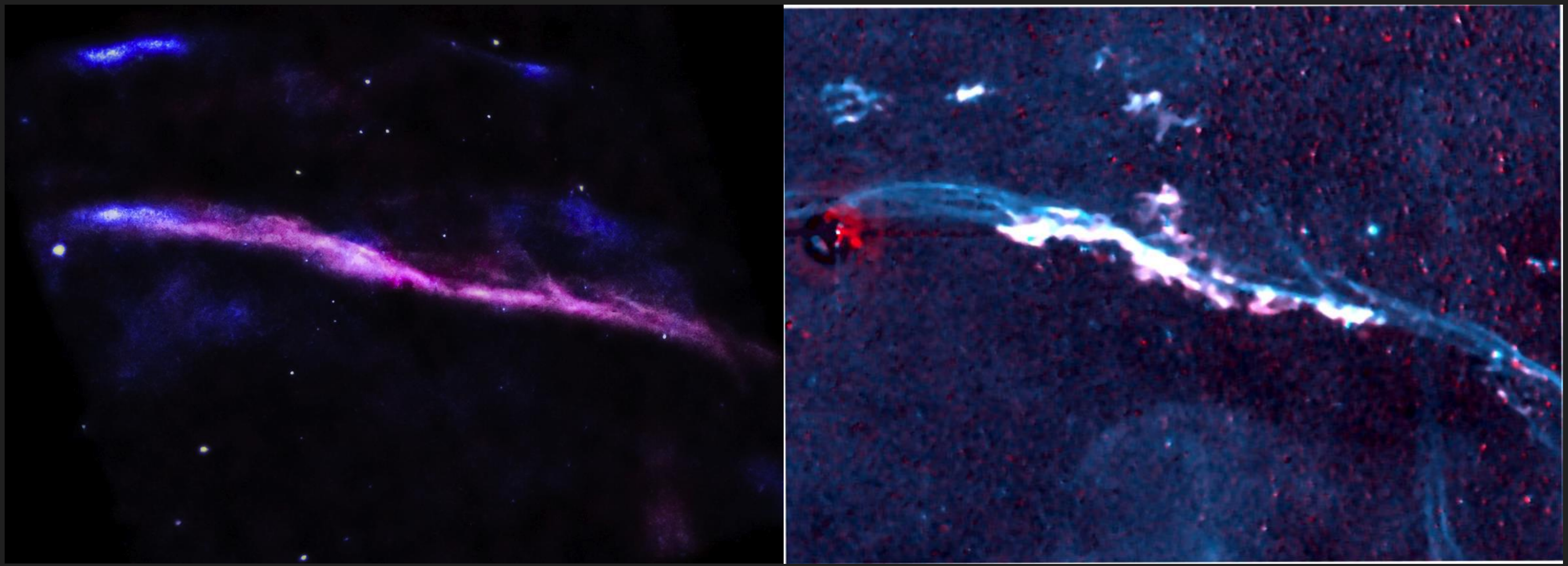
$$l_{\rm adv} \approx l_{\rm diff}$$

$$B_{\rm joint} \approx (240\ \mu{\rm G}) \left(\frac{l_{\rm adv}}{0.01\ {\rm pc}}\right)^{-2/3}$$

PROFILE FIT PARAMETERS AND MAGNETIC FIELD ESTIMATES

Region	$l_{\rm down}$ (arcsec)	$l_{\rm up}$ (arcsec)	χ^2/(dof)	$l_{\rm down}$ (pc)	$l_{\rm up}$ (pc)	$V_{\rm s}$[a] (km s^{-1})	$B_{\rm adv}$[b] (μG)	$B_{\rm diff,d}$[c] (μG)	$B_{\rm diff,u}$[c] (μG)	$B_{\rm joint}$[d] (μG)
NE Arc	14 ± 2	10 ± 3	60 / (59)	0.17 ± 0.03	0.13 ± 0.04	810 ± 150	27	300	140	110
NW Arc	10 ± 2	3 ± 1	94 / (74)	0.12 ± 0.02	0.03 ± 0.02	810 ± 150	33	370	360	140
Main Rim	22 ± 2	5 ± 1	75 / (65)	0.27 ± 0.03	0.06 ± 0.01	650 ± 120	17	250	280	80

iii. rcw 86



ghavamian et al. 2001

PROFILE FIT PARAMETERS AND MAGNETIC FIELD ESTIMATES

Region	l_{down} (arcsec)	l_{up} (arcsec)	$\chi^2/(dof)$	l_{down} (pc)	l_{up} (pc)	V_s[a] (km s^{-1})	B_{adv}[b] (μG)	$B_{diff,d}$[c] (μG)	$B_{diff,u}$[c] (μG)	B_{joint}[d] (μG)
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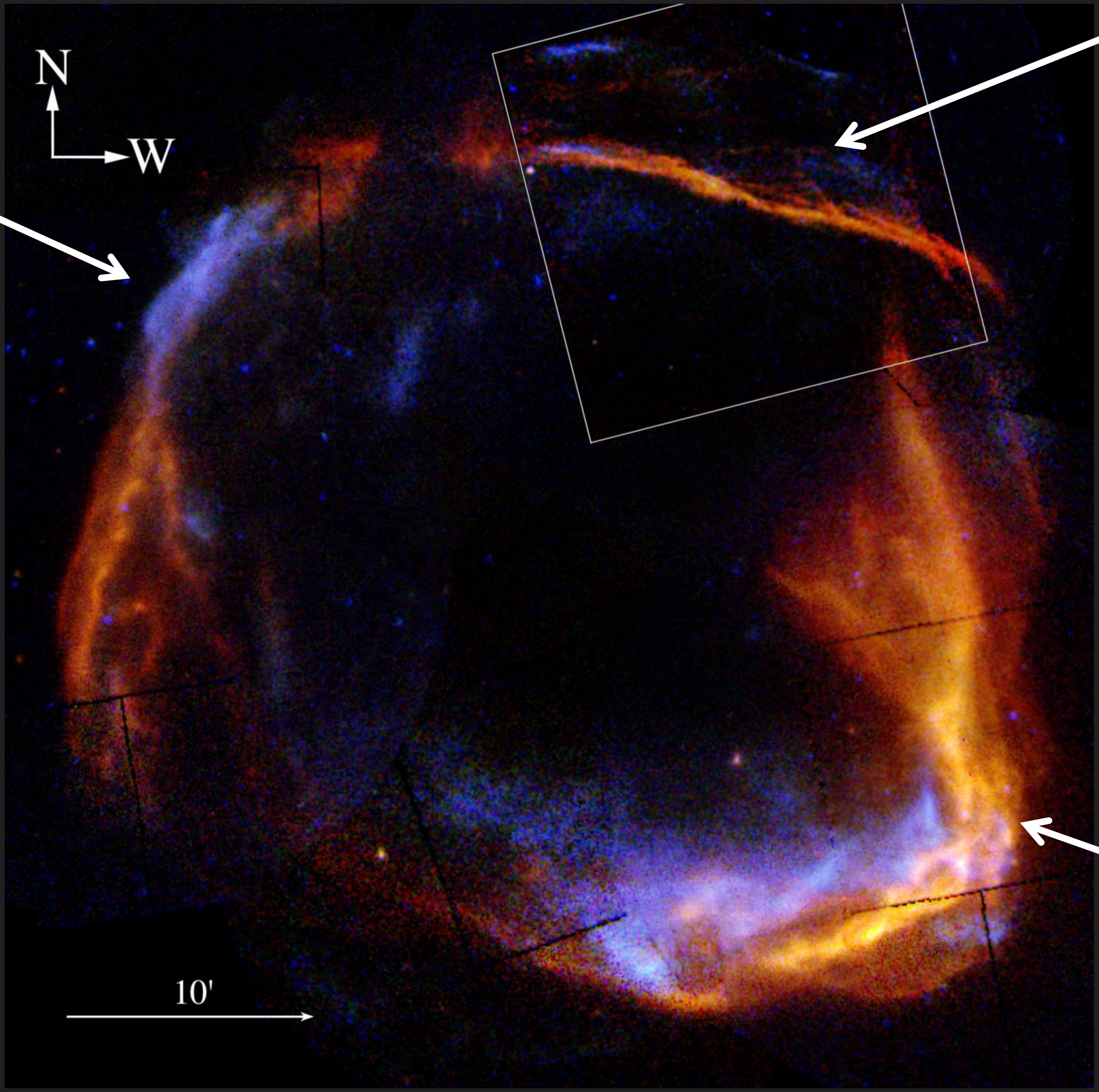
iii. rcw 86: next step



chandra obs

chandra obs

chandra obs

the end

.thin nonthermal x-ray rims observed in the nw of rcw 86

.high magnetic fields derived using filament widths

.shock velocity derived from balmer line profiles (optical observations) appears too low