Dublin Institute for Advanced Studies
School of Cosmic Physics

Magnetic field estimates from the synchrotron X-ray shell of 30 Dor C, the first TeV superbubble

Patrick Kavanagh

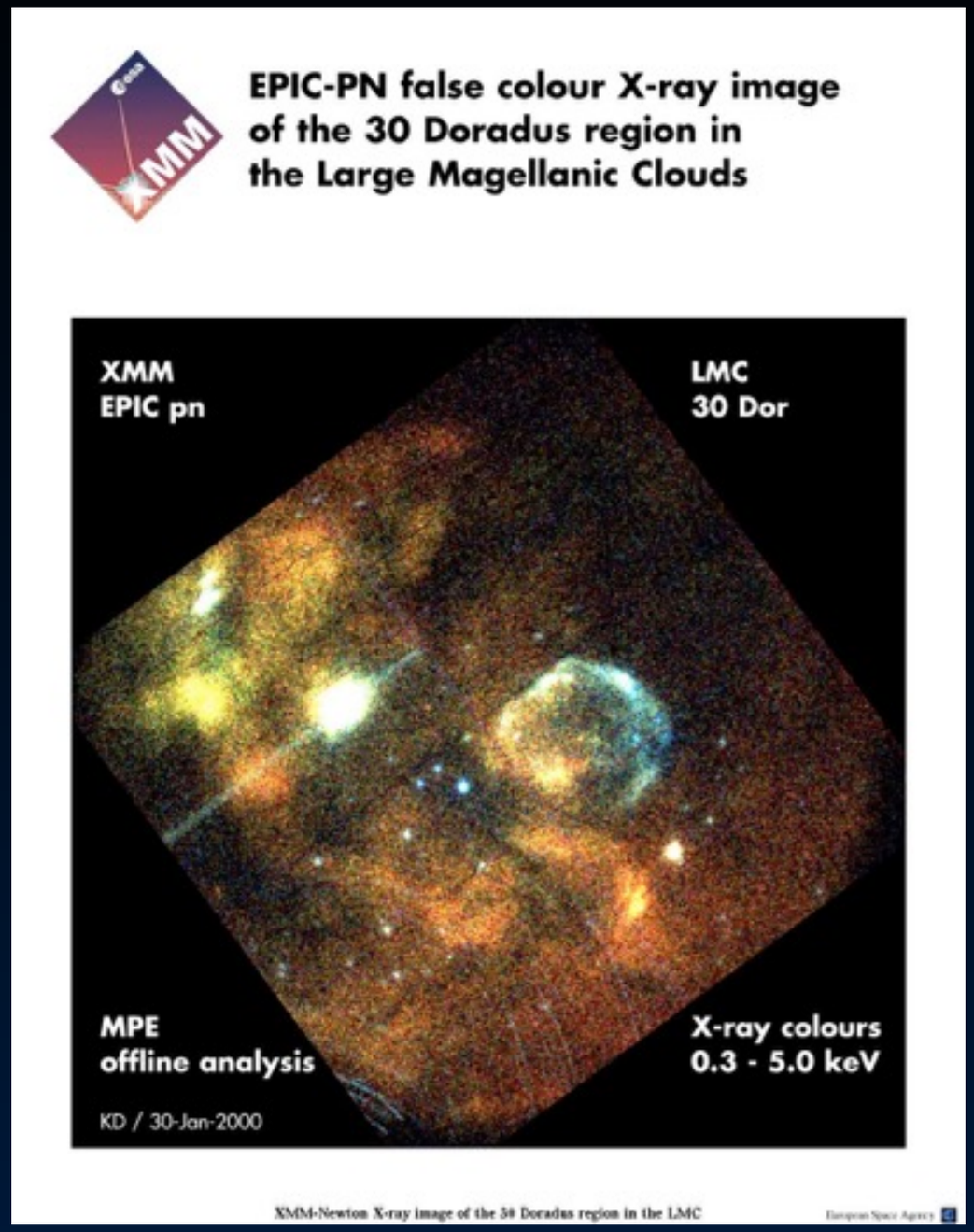
Jacco Vink (Anton Pannekoek Institute/GRAPPA)
Manami Sasaki (IAAT)
Pierre Maggi (CEA Saclay)
Frank Haberl (MPE)
Miroslav Filipovic, Luke Bozzetto (UWS)
Stefan Ohm (DESY-Zeuthen)

Outline

Aim: determine dominant TeV emission mechanism using B-fields from X-ray synchrotron region widths

- 30 Dor C
  - X-ray studies
  - TeV γ-ray detection by *H.E.S.S.*
- Analysis
  - X-ray observations
  - Synchrotron profile fitting
- Results
  - B-field estimates
  - Implications for TeV mechanism
- Future work

30 Dor C



Dennerl et al. (2001)

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

30 Dor C

X-ray studies

- ***Chandra***
Bamba et al., 2004

- ***XMM-Newton***
Smith & Wang, 2004

- ***Suzaku***
Yamaguchi et al, 2009

- ***XMM-Newton***
Kavanagh et al., 2015

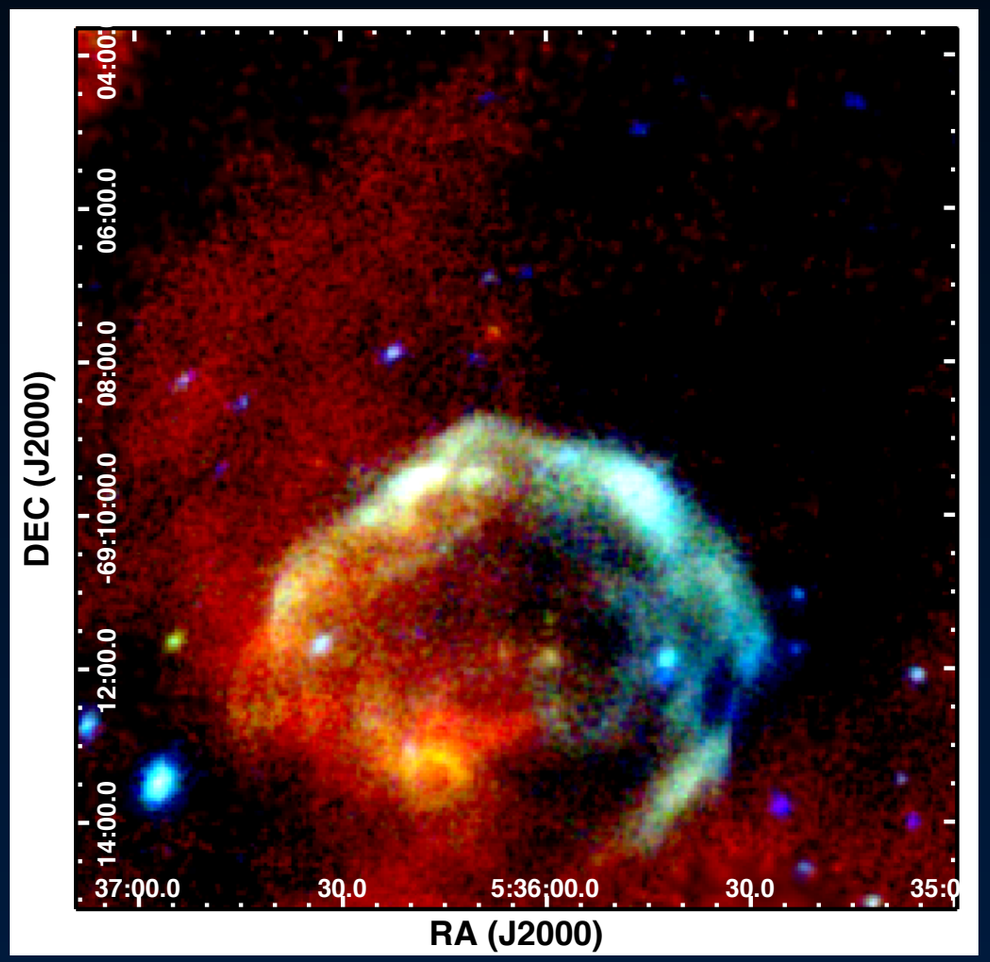
Characteristics

- Thermal emission with enhanced α-group elements

- Nearby SNR

- X-ray synchrotron shell

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

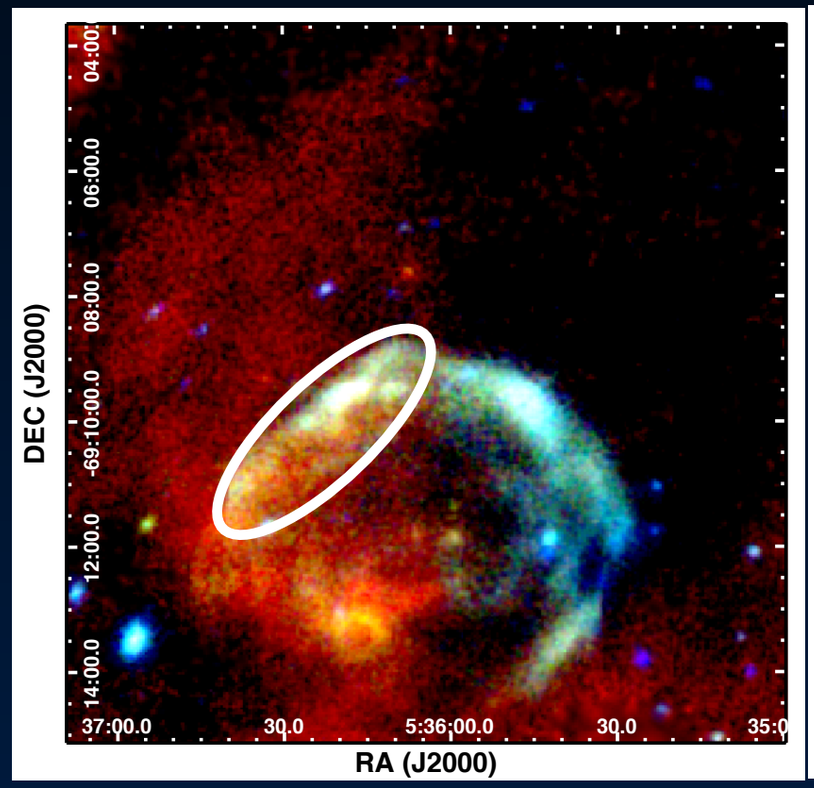


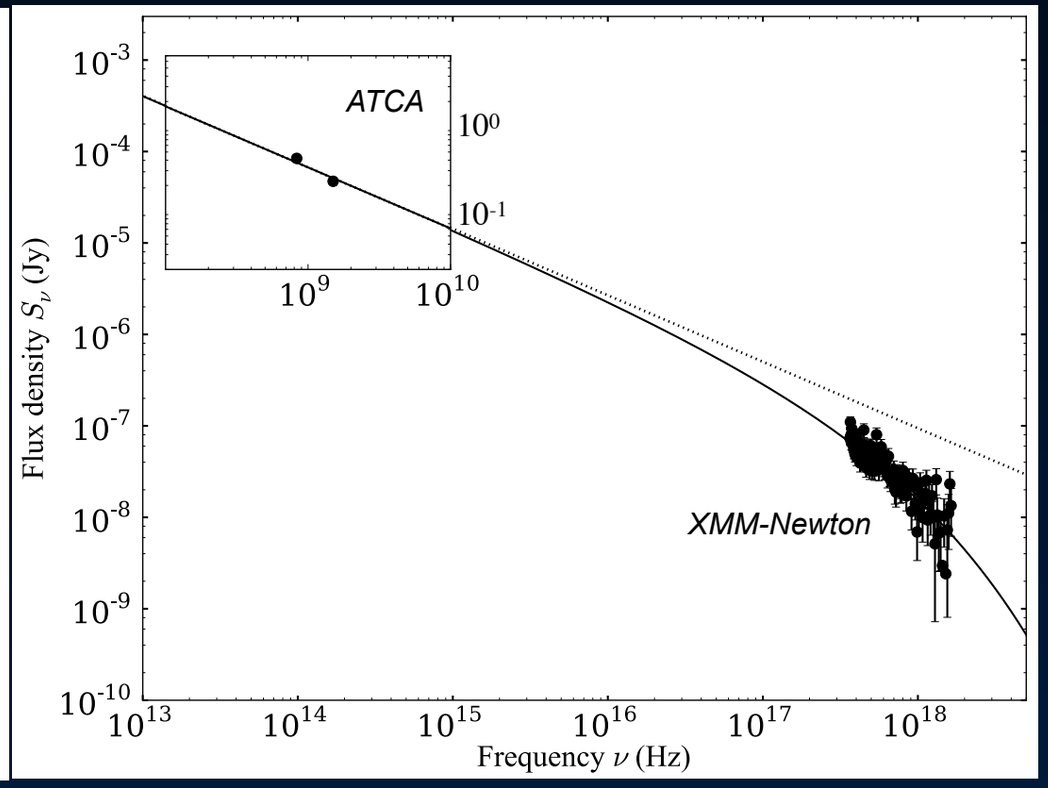
RGB: 0.3-1 keV, 1-2 keV, 2-7 keV

30 Dor C

Synchrotron shell

- large (d~100 pc!) non-thermal shell (Bamba et al., 2004)
- X-ray synchrotron in origin (Yamaguchi et al., 2009)
- ***requires shock speed ≳3000 km s^{-1}***





Kavanagh et al., 2015

H.E.S.S. detection - first TeV superbubble

H.E.S.S. Collaboration, 2015

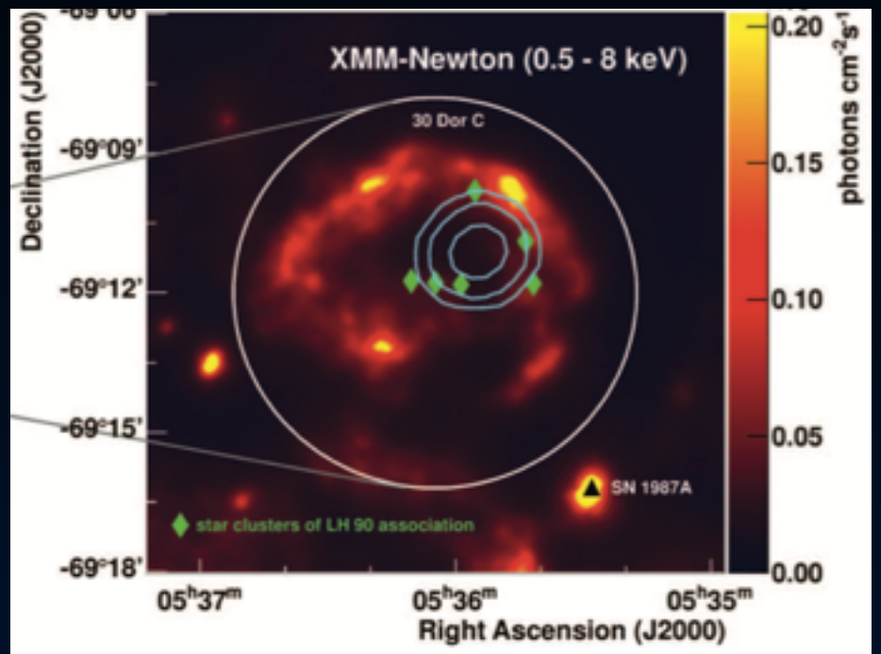
Dominant TeV emission mechanism?

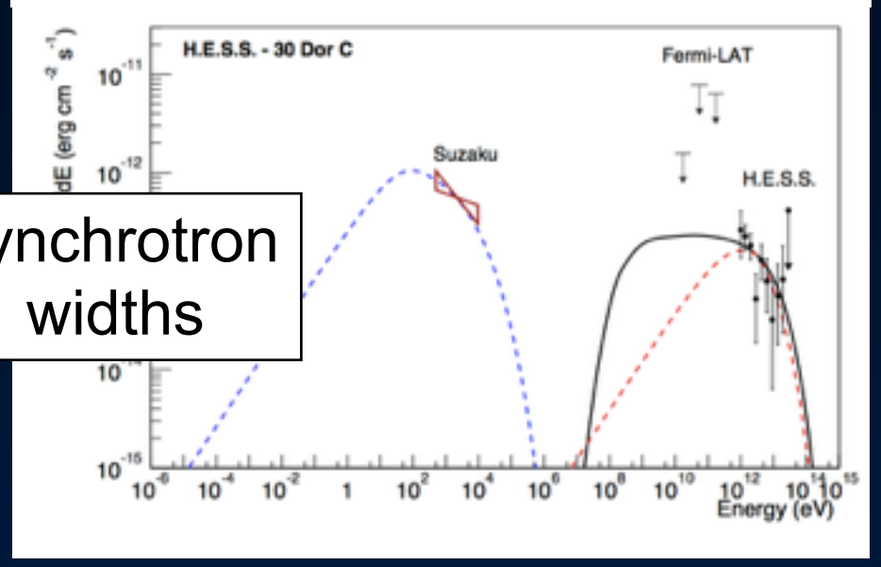
Leptonic (IC):

- same particles responsible for synchrotron shell
- requires high shock velocities, low interior densities (~10^{-4} cm^{-3})
- downstream magnetic field ~ 15 μG

Hadronic (pp):

- requires high interior densities (> 20 cm^{-3})
- high (amplified) magnetic field





synchrotron widths

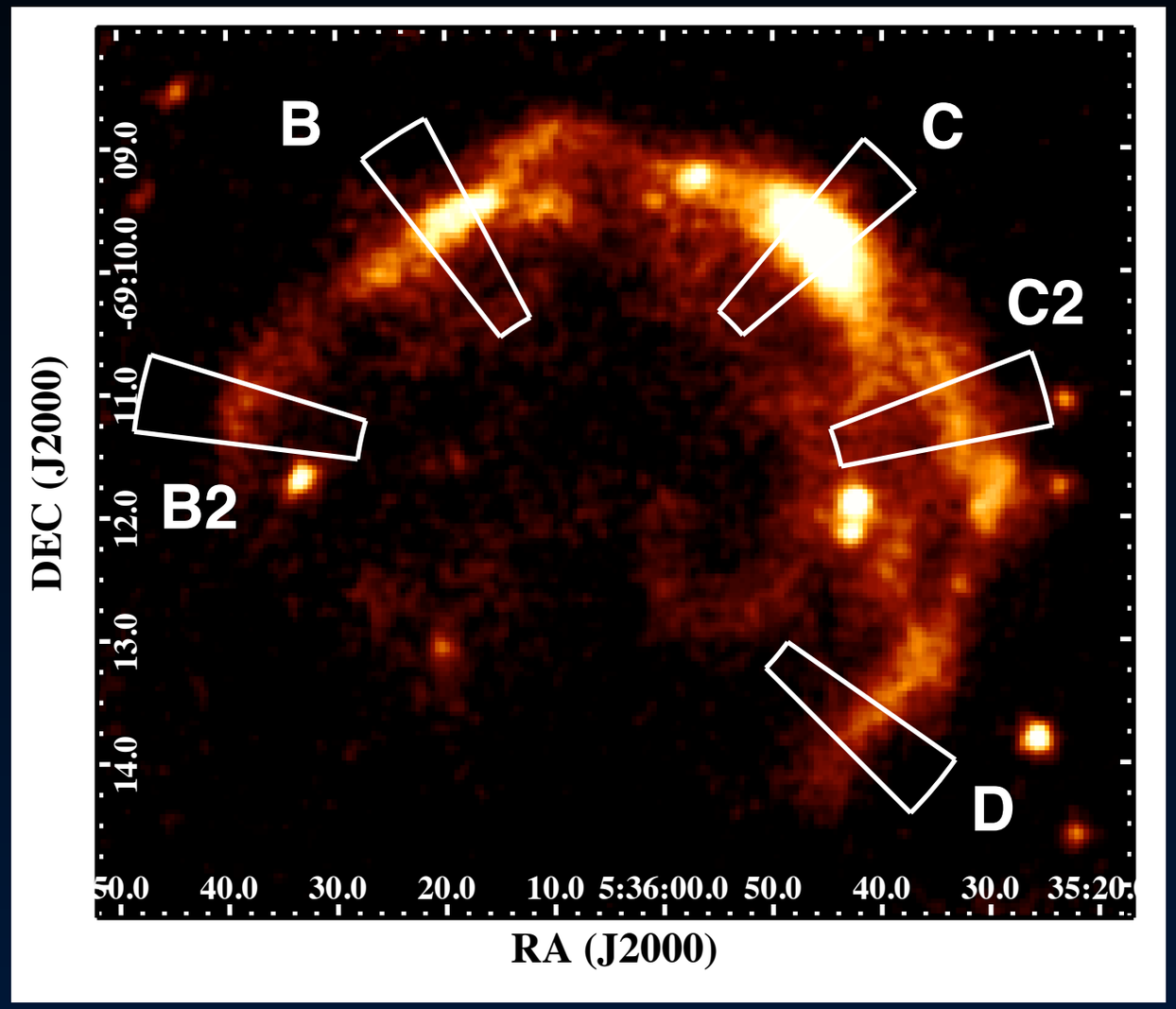
Analysis

X-ray mosaic

XMM-Newton Extended Source Analysis Software (ESAS)

- reprocessed all available data
- constructed mosaic
- particle background subtracted
- exposure corrected
- produced error image

Define and extract radial profiles



2-7 keV binned mosaic

Profile fitting

Assume model:

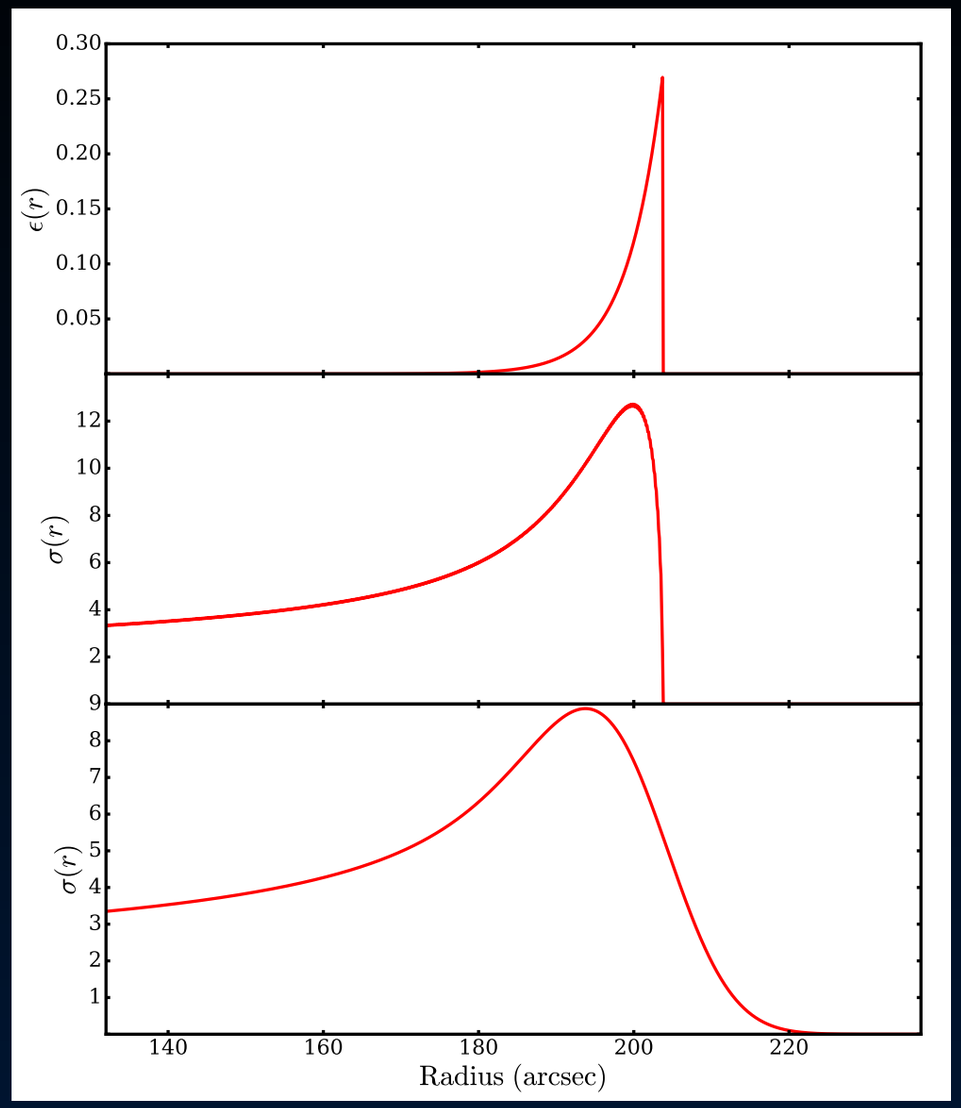
$$\epsilon(r) \propto exp(-(r-R)/l_{obs})$$

Assume spherical symmetry:
(Abel transform)

$$\sigma(r_p) = 2\int_{r_p}^{R} \frac{\epsilon(r)r}{(r^2 - r_p^2)^{1/2}} dr$$

Convolve with *XMM-Newton* PSF:

- generated using SAS task *psfgen*



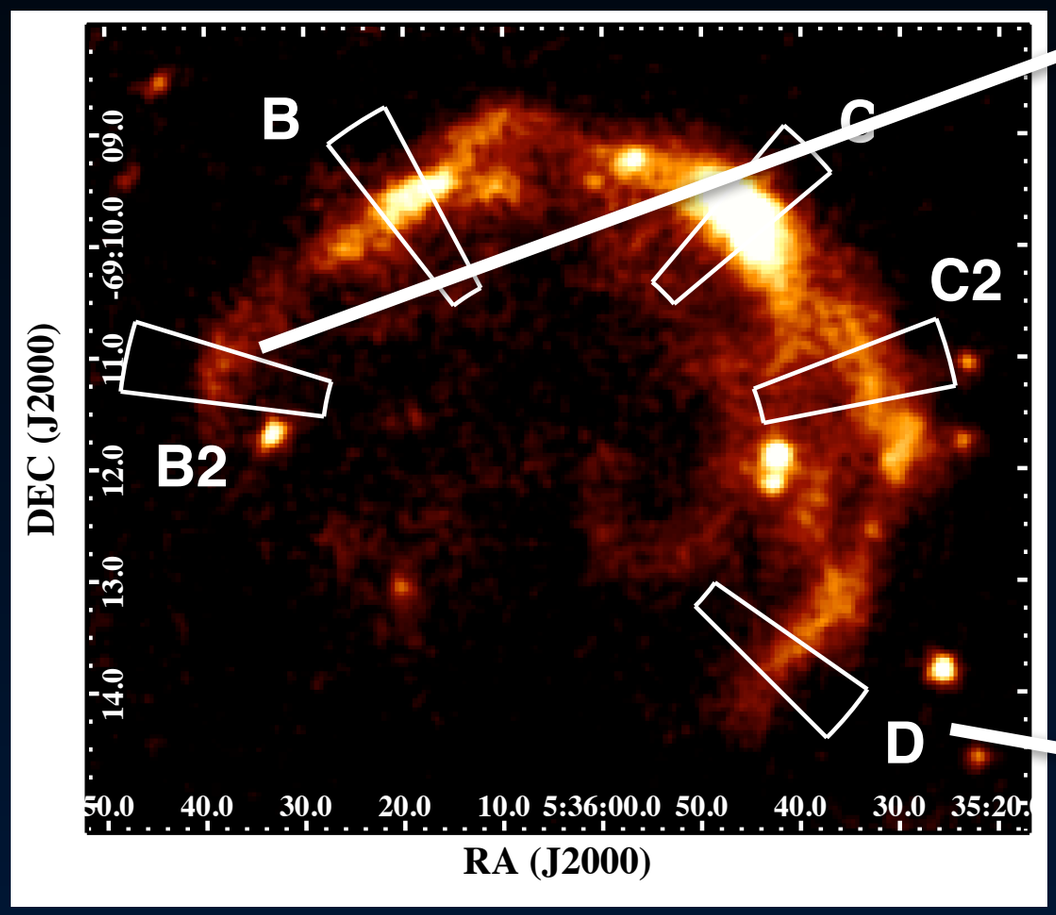
B-field estimate:
Helder et al., 2012

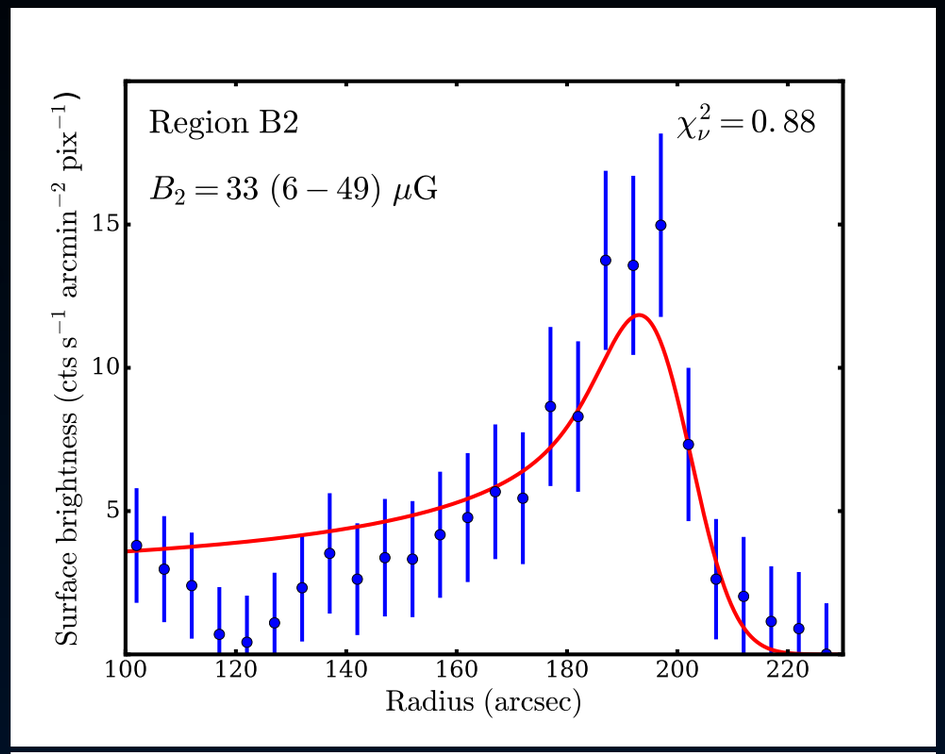
$$B_2 \approx 26 \left(\frac{l_{\rm adv}}{1.0 \times 10^{18}\ {\rm cm}}\right)^{-2/3} \eta_{\rm g}^{1/3} \left(r_4 - \frac{1}{4}\right)^{-1/3} \mu{\rm G}$$

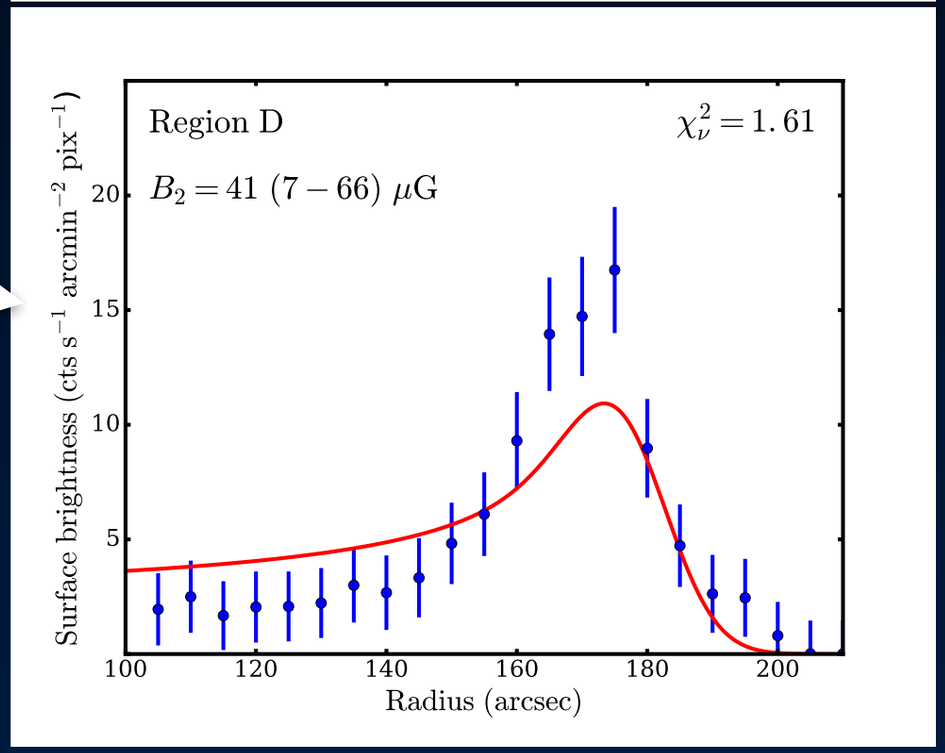
$$l_{\rm obs} \approx \sqrt{2} l_{\rm adv}$$

Results

Profile fits

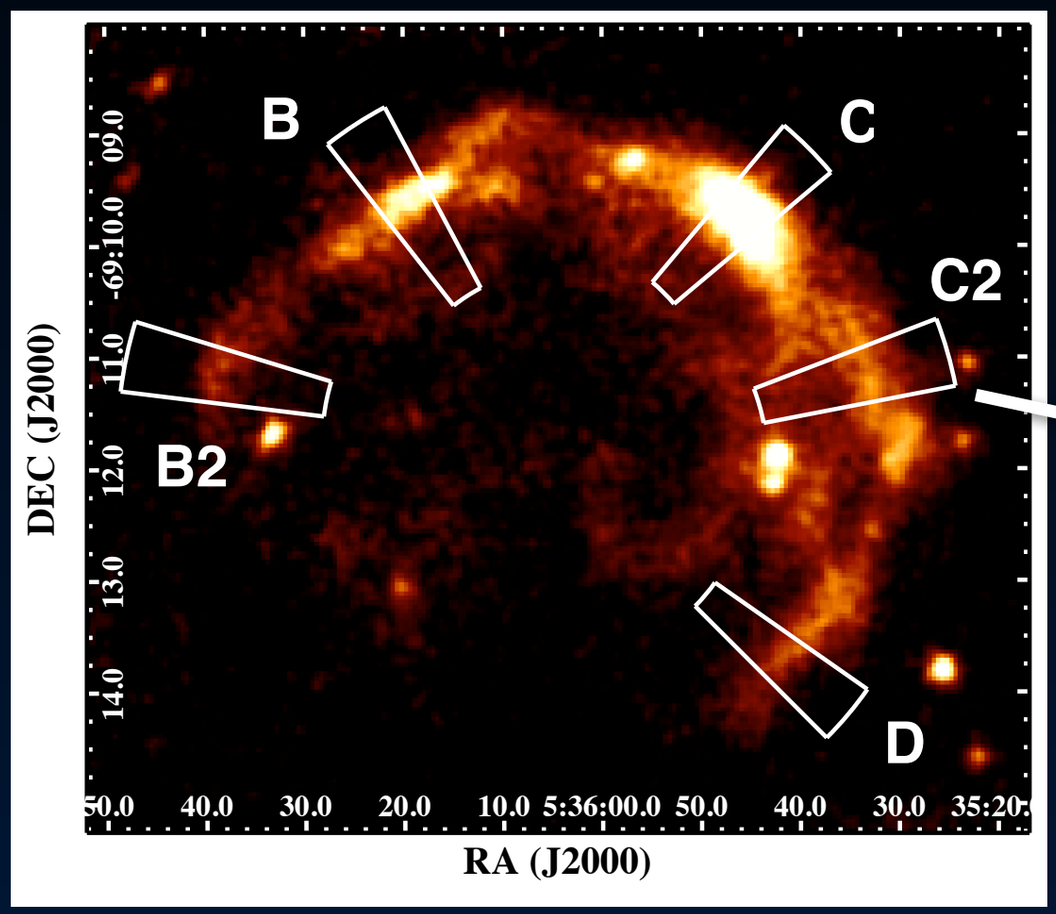


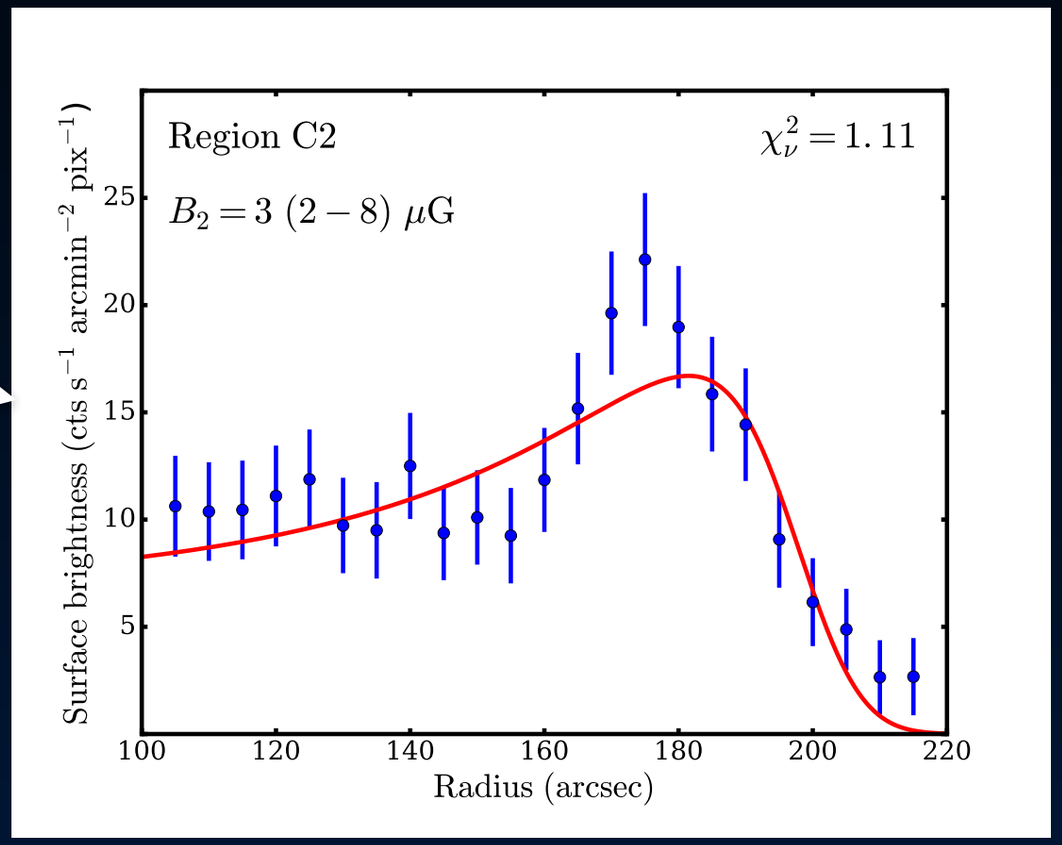




Results

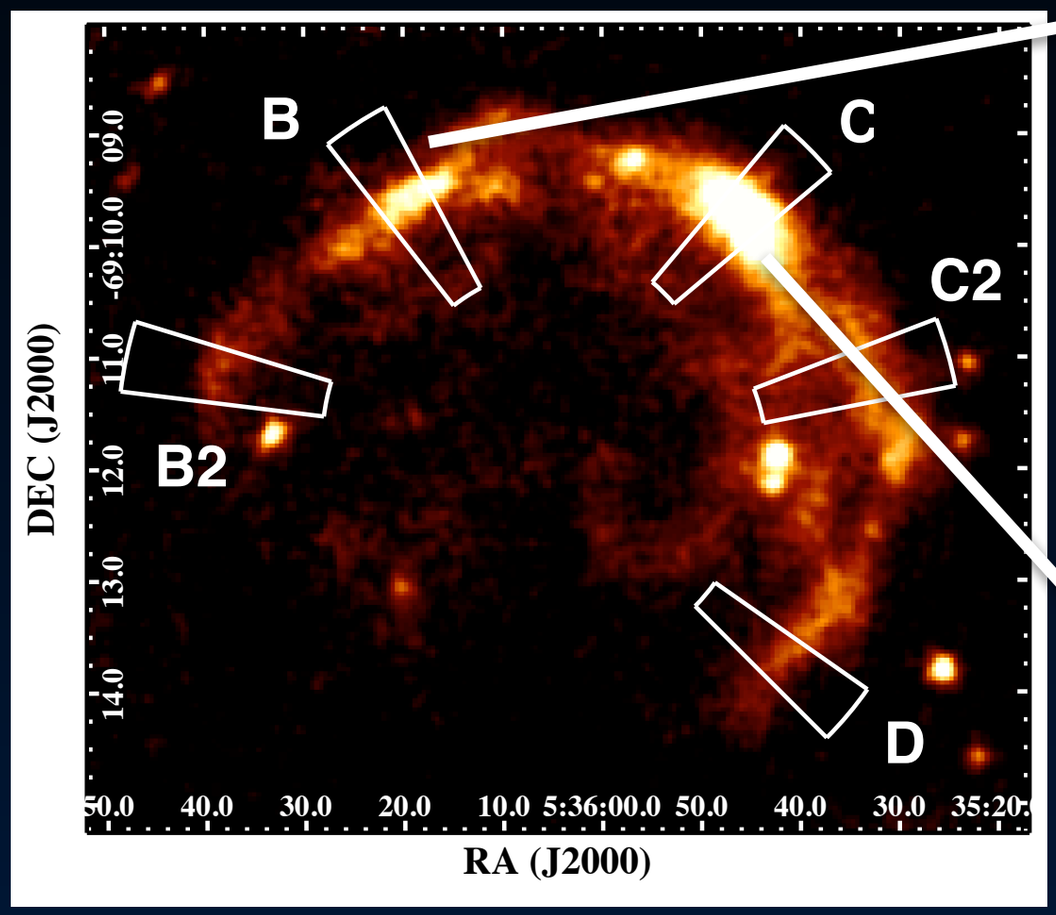
Profile fits

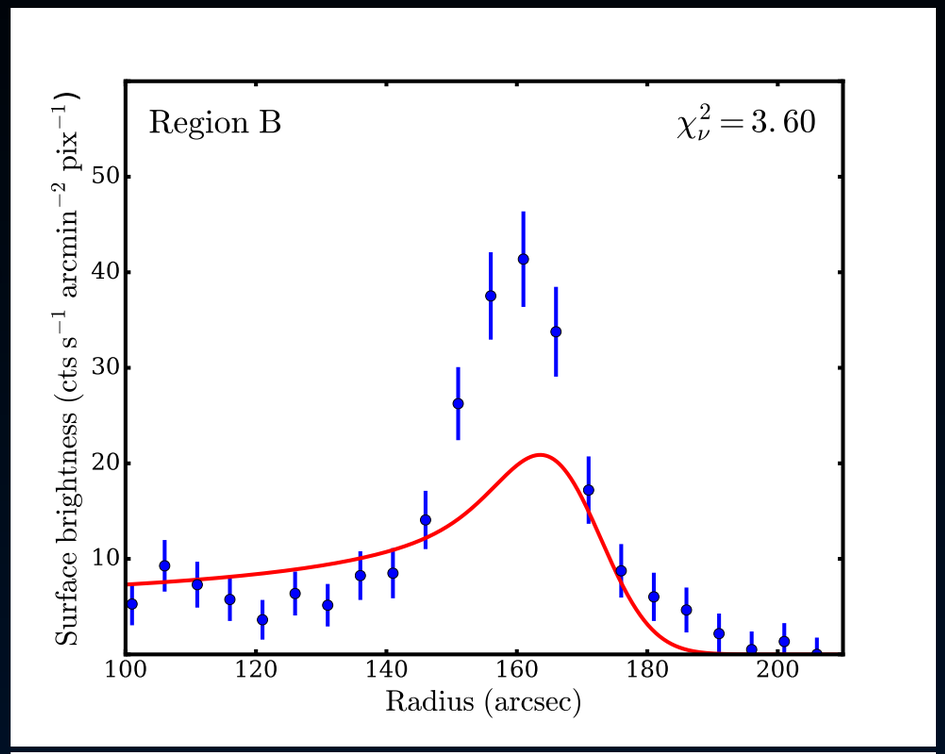


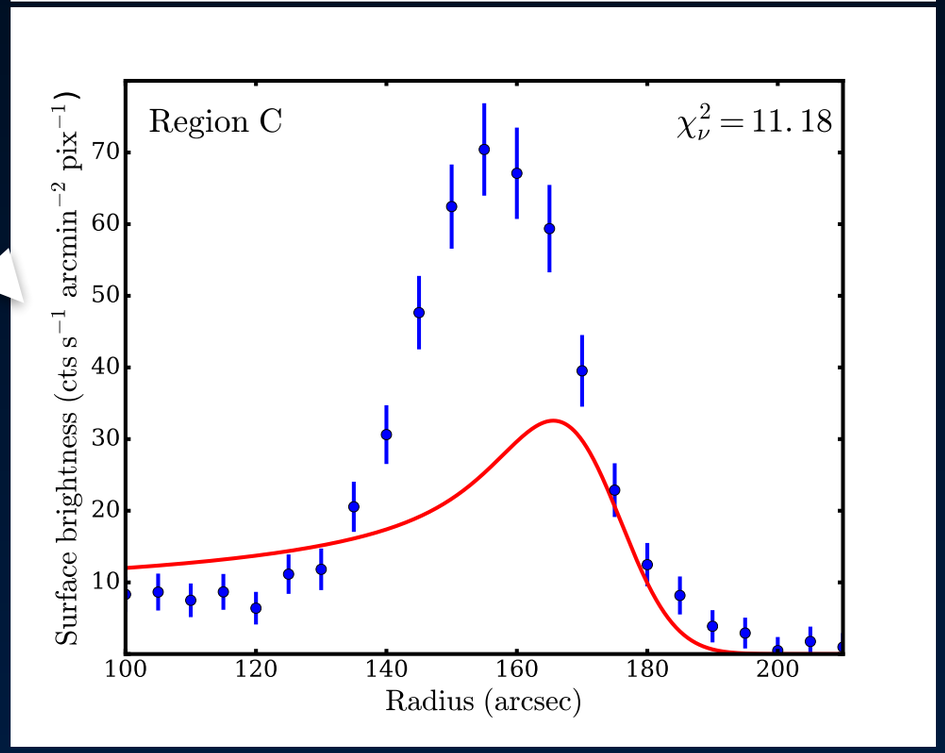


Results

Profile fits



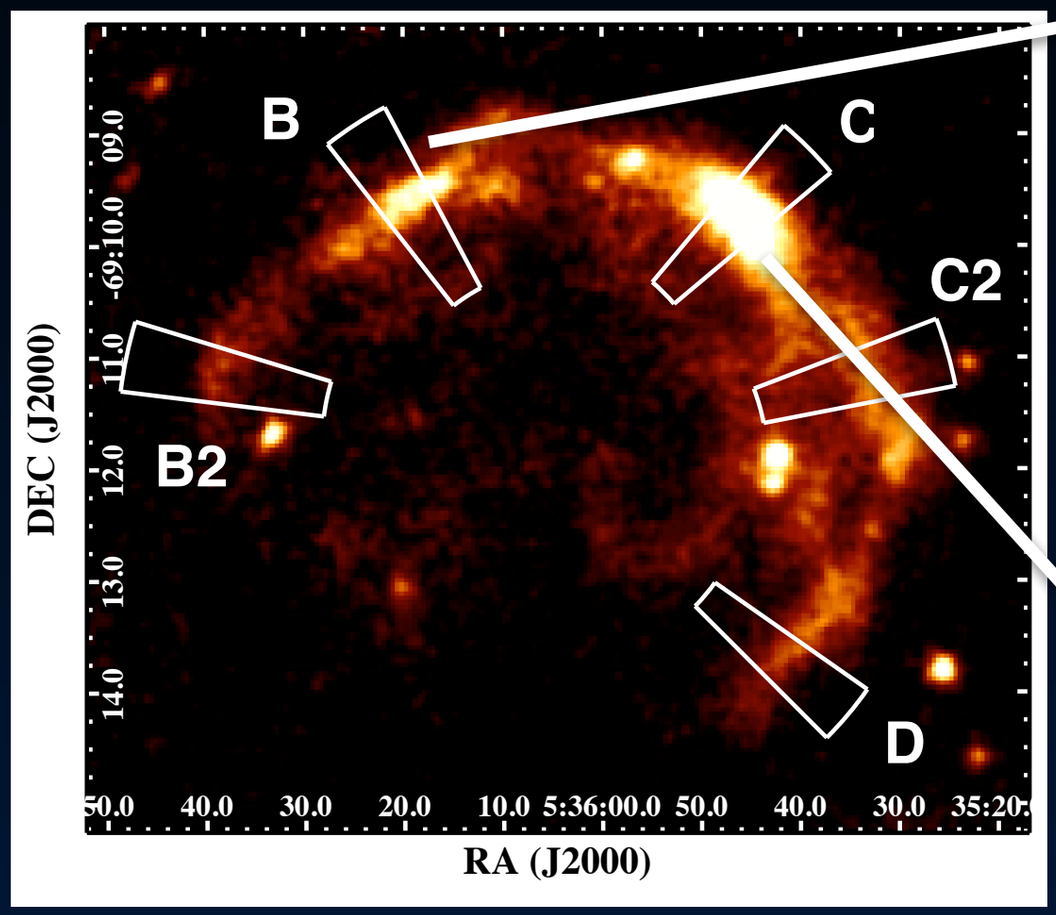


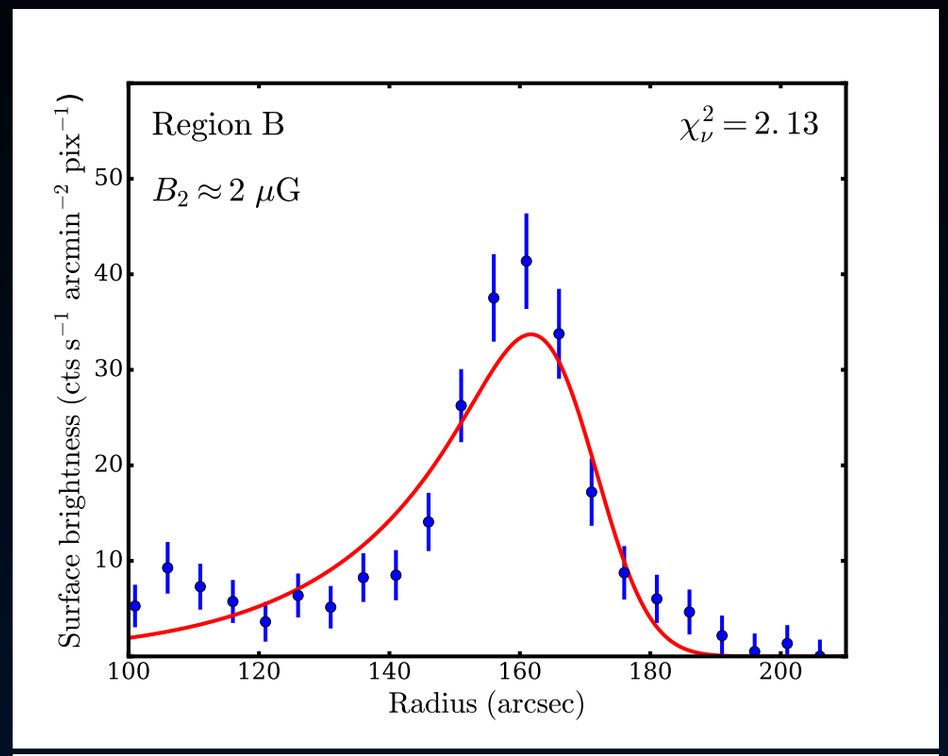


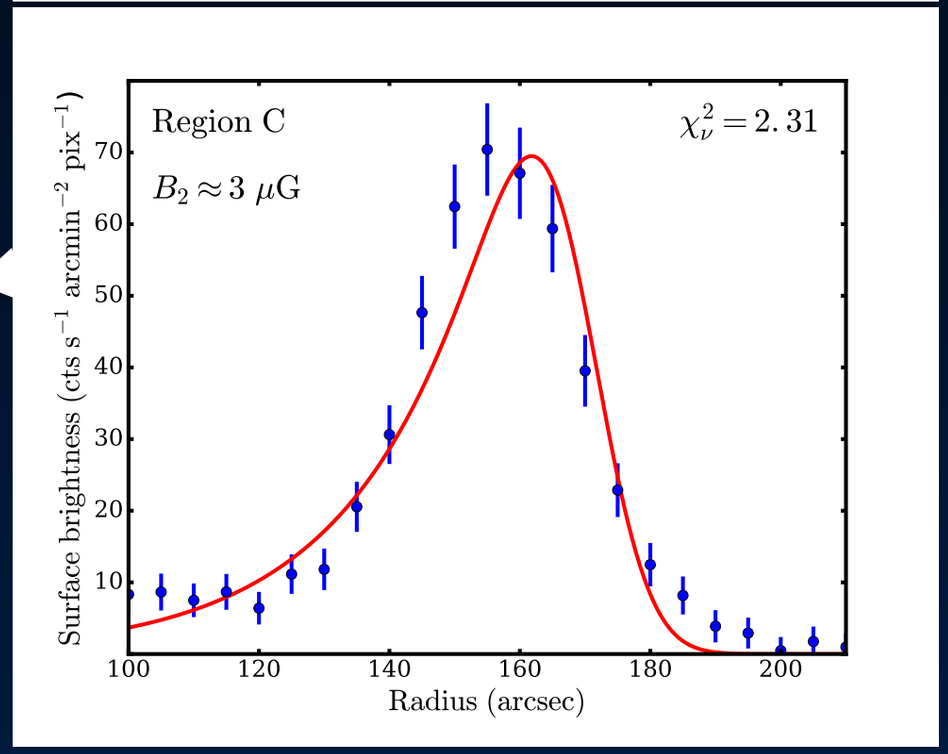
Results

Profile fits

Relax spherical symmetry







Results

Estimated B-fields

Region	B2	C2	D	B/C
B-field (μG)	33 (6-49)	3 (2-8)	41 (7-66)	~3?

Dominant TeV emission mechanism?

Hadronic:
- high (amplified) magnetic fields
- high interior density

Leptonic:
- average magnetic field ~ 15 μG
- low-interior density

TeV emission likely dominated by leptonic γ-rays

Future

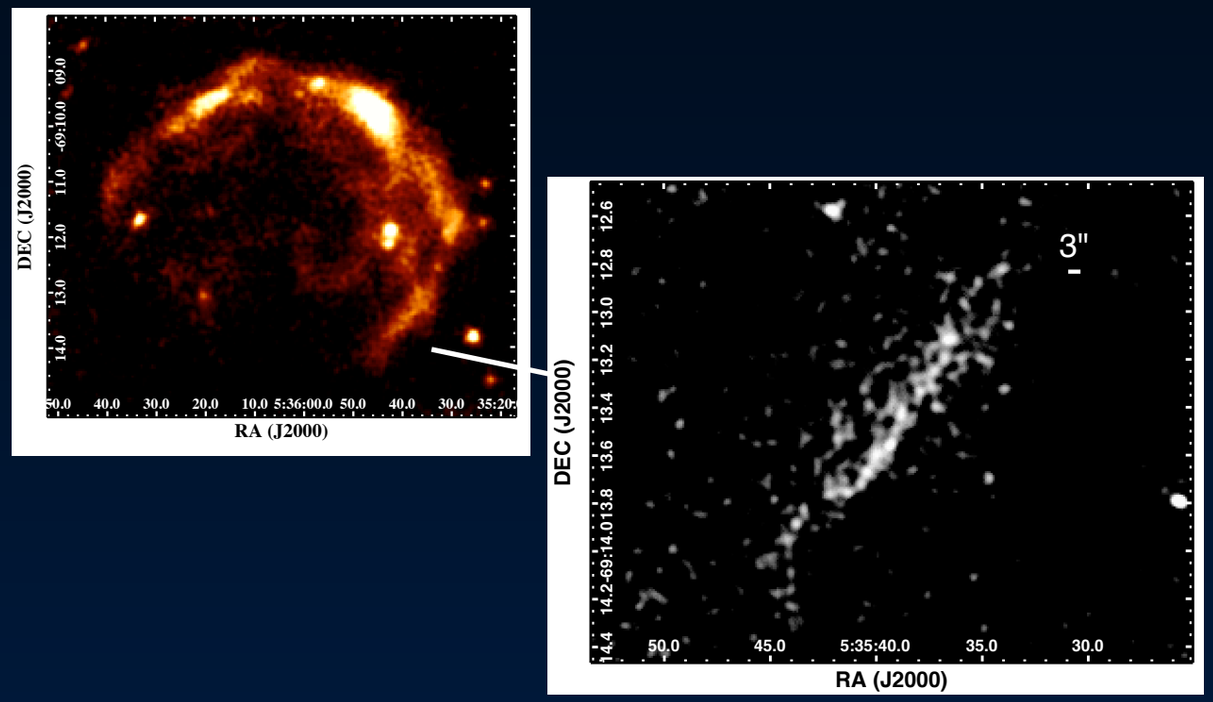
Chandra

Observation:

- 90 ks ACIS-S
- scheduled Oct 2016

Goals:

- resolve brightest synchrotron region
- refined/complete B-field estimates
- variation in B-field
- more complex profile models?
- (anti)correlation with thermal X-rays
- multi-wavelength comparison



Kavanagh et al., Chandra Cycle 17

Conclusion

- Low downstream B-field in 30 Dor C synchrotron shell
- Consistent with leptonic γ-ray dominated TeV emission
- More detailed analysis with *Chandra* to follow