Investigating the nature of magnetic turbulence in Tycho's SNR using X-ray observations

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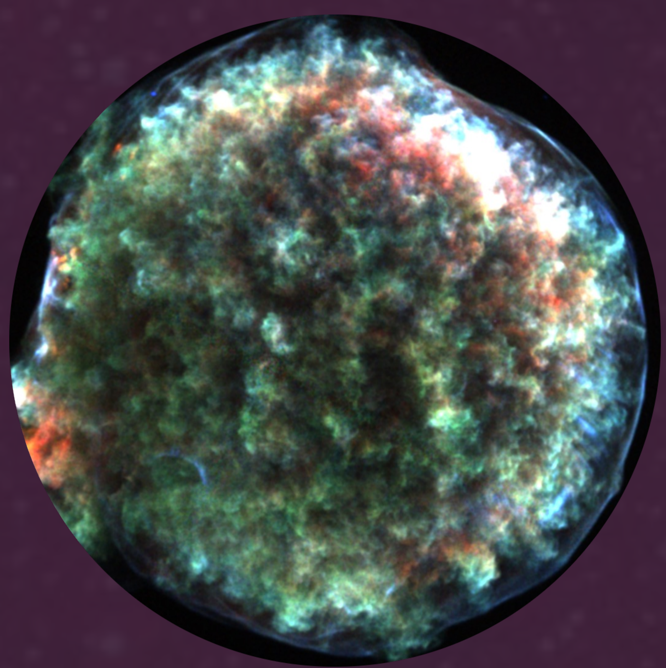


Supernova remnants (SNRs) are considered the primary sources of Galactic cosmic ray acceleration. Particles are accelerated at the shock front through the diffusive shock acceleration mechanism, where they gain energy by repeatedly crossing the shock. Magnetic turbulence plays a crucial role in scattering these particles back and forth; therefore, investigating this turbulence is essential for understanding the acceleration mechanism. The two-point correlation function can be used to study the magnetic energy spectrum using observational data, providing constraints for computational magnetohydrodynamics studies.

Two-Point Correlation

$$C_F(\lambda) = \frac{\int F(X)\, F(X')\, d^2X}{\sqrt{\int F^2(X) d^2X}\ \sqrt{\int F^2(X') d^2X}}$$

F(X) – X-ray photon flux

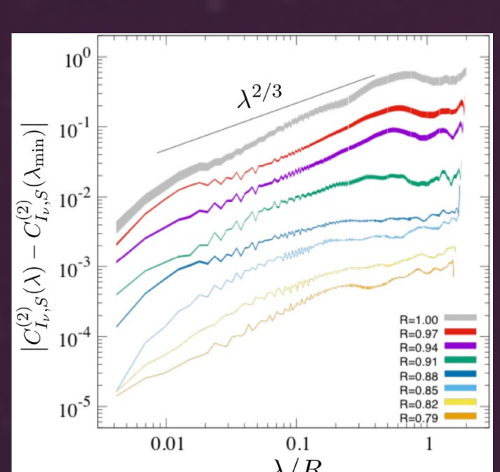
λ = X – X' (spatial separation)

Synchrotron speific intensity $(I(r)_\nu) = K\,\nu^{1-\gamma}\,B(r)^\gamma$

$$C(\lambda) = < I_\nu(X) I_\nu(X) >$$

$$< B^2(X) B^2(X') > = 4\,\bar{B}^2(X) < \Delta B(X) \Delta B(X') > +const$$

Previous work



Credits: Shimoda et al 2018

- Shimoda et al 2018 have used radio observations of Tycho SNR to study the magnetic energy spectrum with two-point statistics.

Importance for X-ray Study

- Diffusion of the electrons depends on the spectral slope of magnetic energy spectrum
- X-ray emitting electrons due to their shorter lifetimes trace the magnetic turbulence in the region of active acceleration site.

Analysis method

- We have used the X-ray data of Tycho from the Chandra X-ray observatory due to it's low spatial resolution (0.492 arcsec)
- X-ray image of Tycho's SNR consists of emission from thermal (brehmstrahlung) and non-thermal (synchrotron)
- To obtain the non-thermal image, we have used poissonian based generalized morphological component analysis method to separate thermal and non-thermal.

Acknowledgements: Hui Zhu, Adrien Picquenot

Magnetic Energy Spectrum

Region selection:

- Thickness of the concentric circle = $0.0091R_{SNR}$, R_{SNR}=253arcsec.
- X-ray photon flux is binned at minimum spatial separation (λ_{min}) of 1.968 arcsec to calculate the two-point correlation.
- Regions with X-ray photon flux > $3\sigma_{noise}$ are selected.($\sigma_{noise} = 5 \times 10^{-10}\, photon\ cm^{-2}\, s^{-1}$)

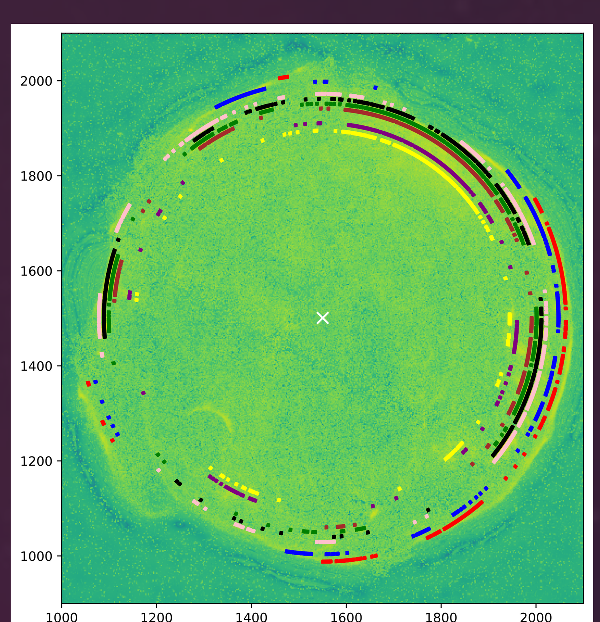


Fig.1 Tycho's SNR X-ray photon flux image (2.5-7.0KeV)

Results:

- For r≥0.9RSNR, X-ray turbulence scale is developed upto $\lambda \leq 0.1$, previous study with radio shows turbulence scale upto $\lambda \leq 0.5$.
- The slope from X-ray studies shows much steeper spectrum than radio with 0.6

Region	Slope
R_{SNR}	1.94±0.08
$0.97R_{SNR}$	1.47±0.05
$0.92R_{SNR}$	1.46±0.07
$0.90R_{SNR}$	1.36±0.06
$0.88R_{SNR}$	1.34±0.12

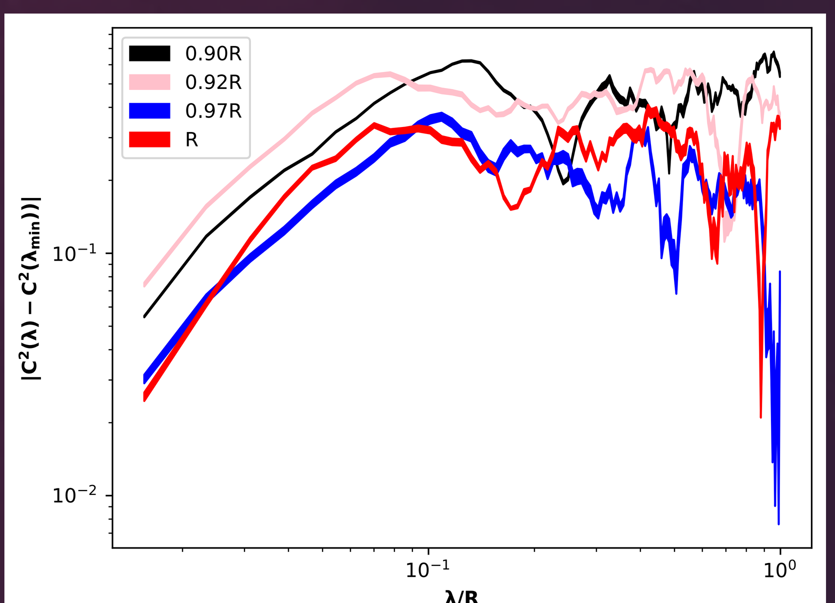


Fig 2. Magnetic energy spectrum for r≥0.9RSNR

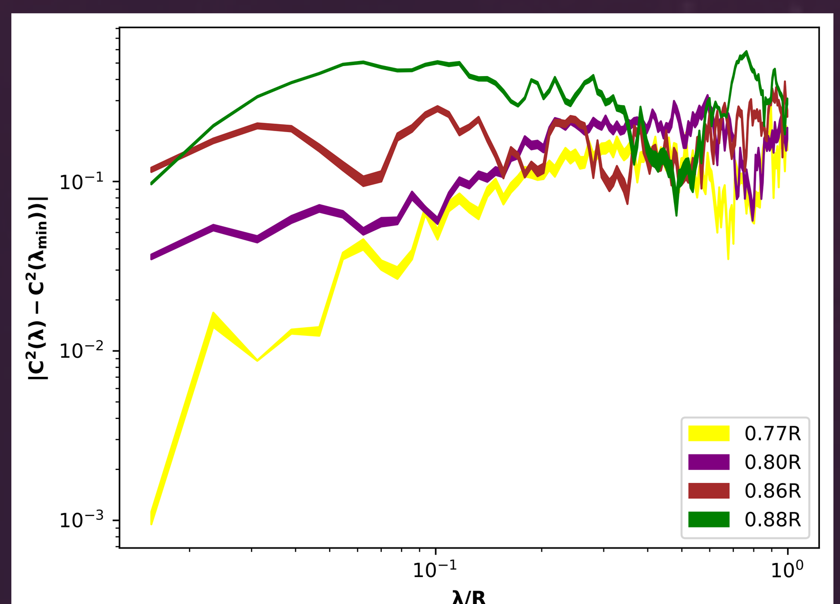


Fig 3. Magnetic energy spectrum for r<0.9RSNR

- X-ray emitting electrons might prefer regions of high magnetic field and a smaller emission volume.
- Due to smaller emission volume of higher energy electrons, number density of electrons might play a crucial role in X-ray studies.

X-ray rim thickness

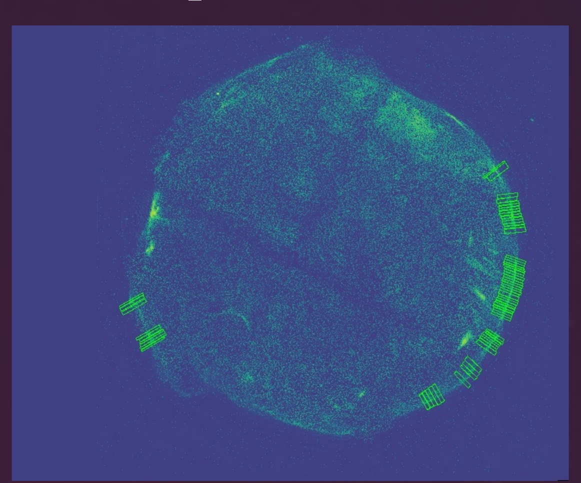


Fig 4. Tycho's SNR X-ray photon flux image (2.5-7.0KeV)

- Thin X-ray rim is formed at the shockfront due to synchrotron energy loss.
- Thickness of the X-ray rim (Δx) is directly dependent on magnetic field and is not dependent of density of electrons.

$$\Delta x = E^{(\mu-1)/2} B^{-3/2}$$

X-ray rim thickness fit:

$$\Delta x(r) = \begin{cases} A_d\, exp\left(\frac{r-r_0}{w_d}\right) + C_d\ , r < r_0 \\ A_u\, exp\left(\frac{r-r_0}{w_u}\right) + C_u\ , r \geq r_0 \end{cases}$$

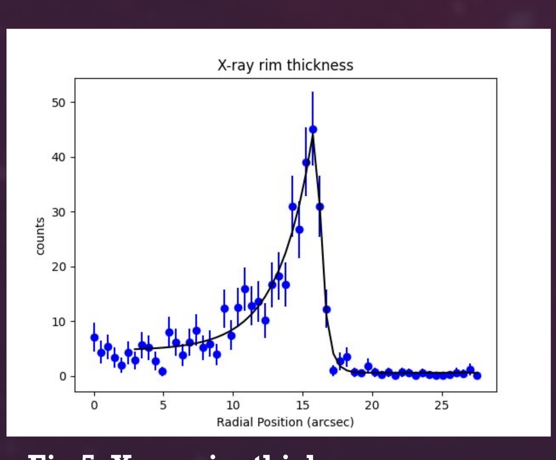


Fig 5. X-ray rim thickness

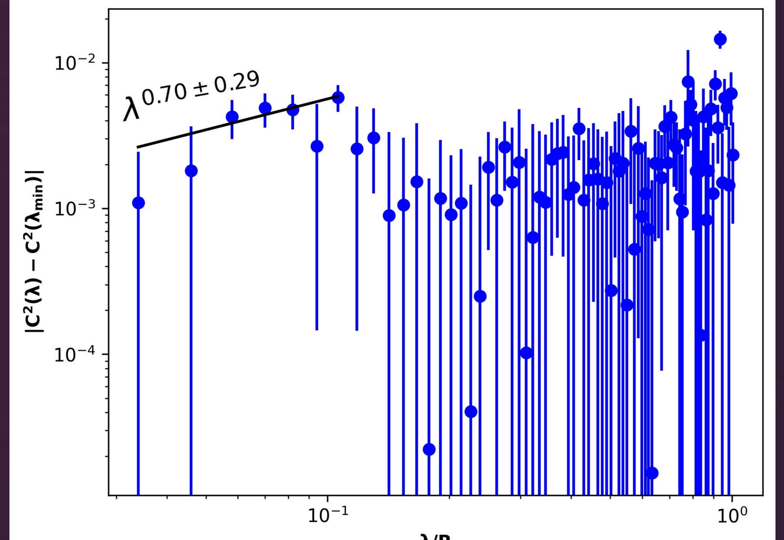


Fig 6. Magnetic energy spectrum calculated with X-ray rim thickness