Jitter radiation as an alternative mechanism for the nonthermal emission in Cassiopeia A.

A diagnostic tool to measure magnetic turbulence downstream the shock

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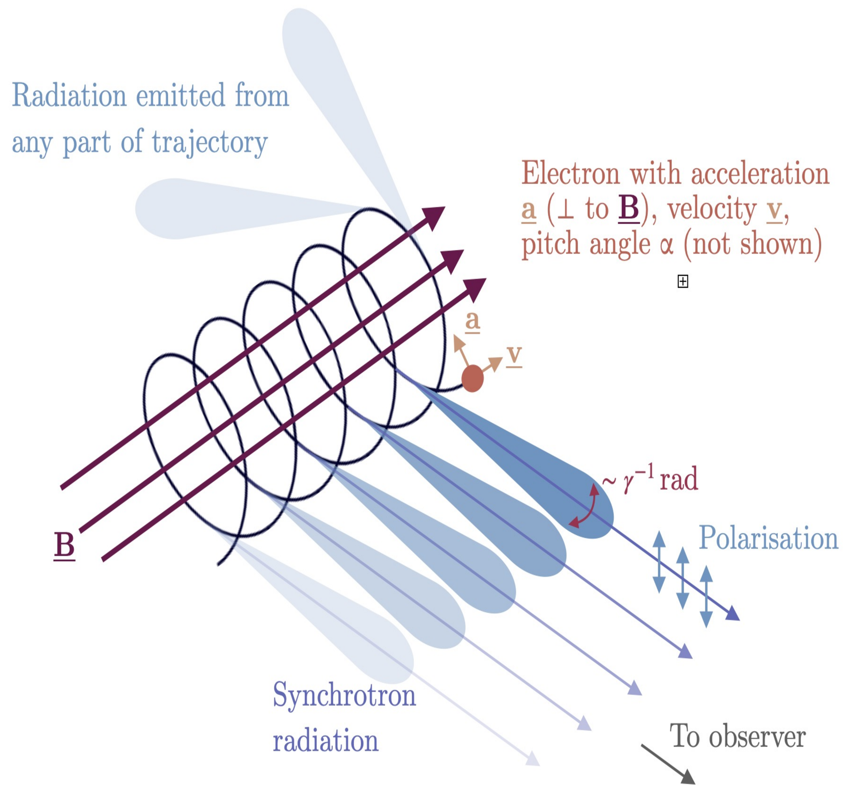
SCAN ME

Turbulence: a flaw in the current synchrotron radiation paradigm?

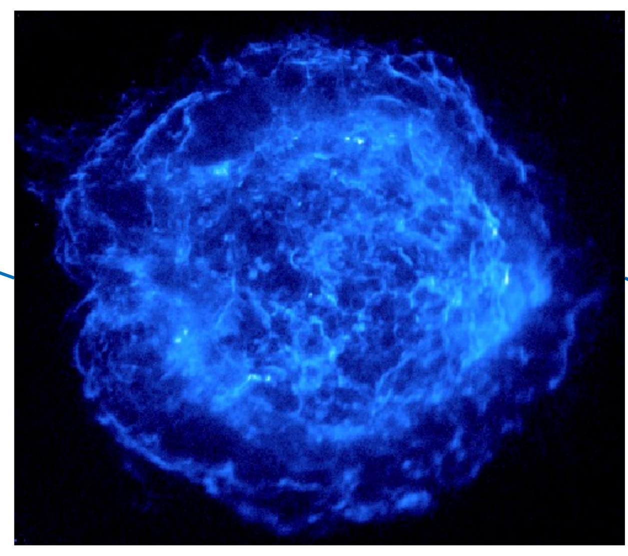
Through Diffusive Shock Acceleration (DSA) electrons are accelerated to TeV energies [1] and emit **synchrotron radiation**



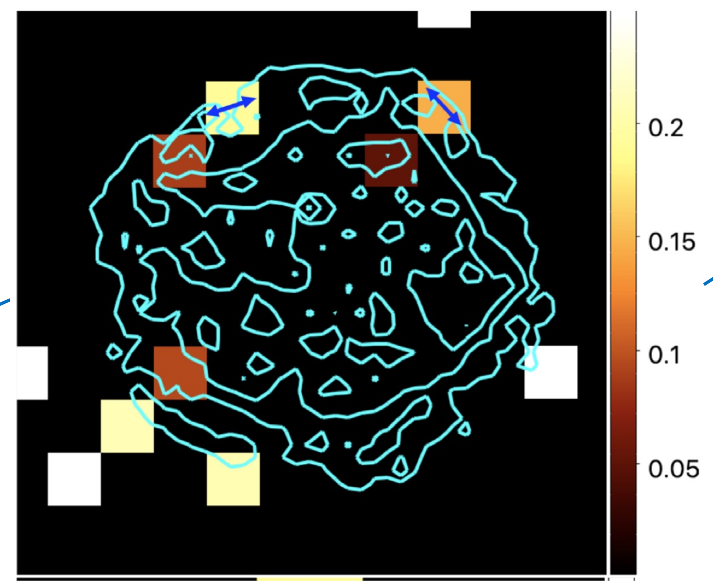
In order to be efficient, DSA **requires high level of magnetic turbulence** [1]

Synchrotron radiation is typically studied **between 4-6 keV**

Chandra image of Cassiopeia A in the 4-6 keV band



Low polarization degree suggests **high magnetic turbulence**



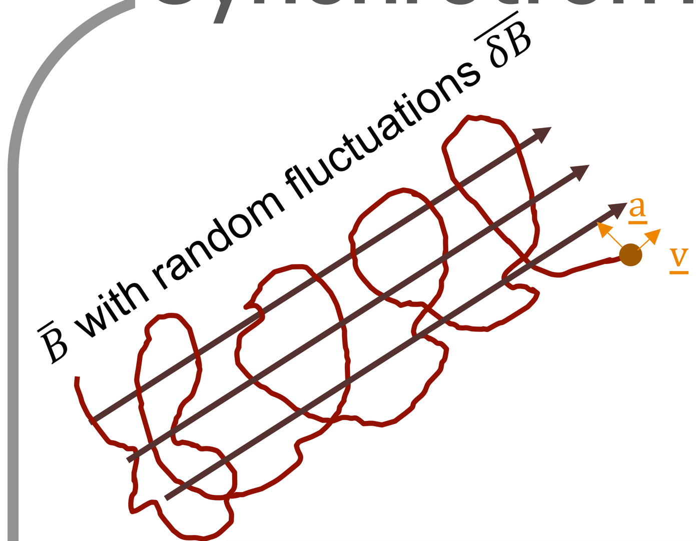
IXPE polarization degree map of Cassiopeia A [2]

Most popular synchrotron spectral models **srcut** [3] and **loss-limited** [4] assume uniform magnetic field

High **turbulence is necessary** for DSA, **is supported** by polarization results but is **not included** in the spectral fitting!

References:
[1] Bell, A. R. 1978, MNRAS, 182, 147
[2] Vink, J., Prokhorov, D., et al. 2022b, ApJ, 938, 40
[3] Reynolds, S. P., & Keohane, J. W. 1999, ApJ, 525, 368
[4] Zirakashvili, V. N., & Aharonian, F. 2007, A&A, 465, 695

Synchrotron in a highly turbulent environment: jitter radiation



Jitter radiation is the extension of synchrotron radiation in the case of **highly turbulent medium**, self-consistently accounting for the effect of magnetic turbulence in the shape of the emitted photons' spectra. If the turbulence scale-size λ is lower than the gyroradius ($\lambda \ll 170\ (B/100\ \mu G)^{-1}$ km) the electrons become sensitive to the fluctuations of the magnetic field and randomly jitter

References:
Toptygin, I. N., & Fleishman, G. D. 1987, Ap&SS, 132, 213; Kelner, S. R., Aharonian, F. A., & Khangulyan, D. 2013, ApJ, 774, 61

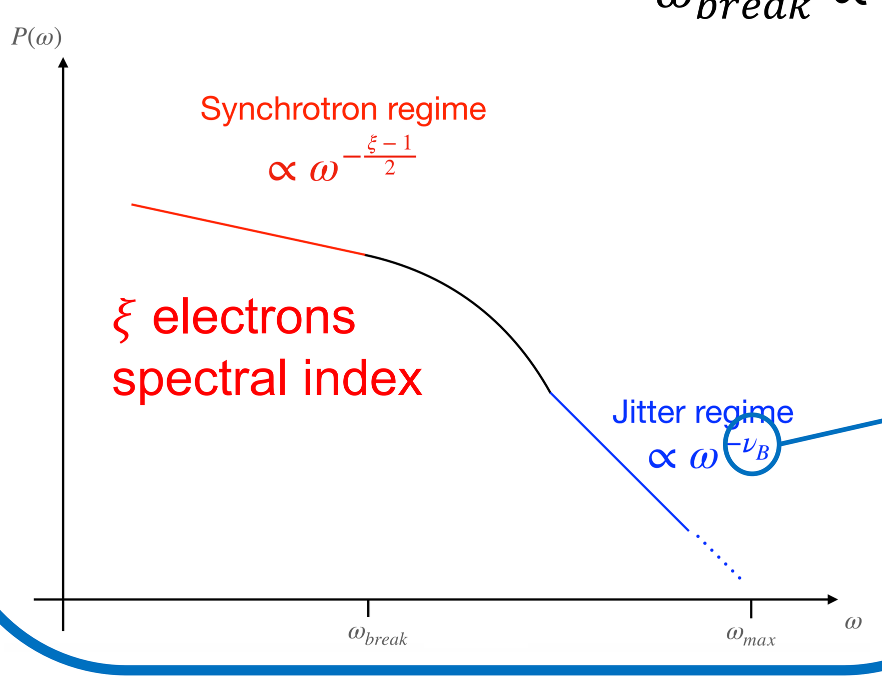
Broken power-law

Jitter spectrum $P(\omega)$ is a broken power-law with a smooth break at $\omega \sim \omega_{break}$:

$\omega < \omega_{break}$: standard synchrotron

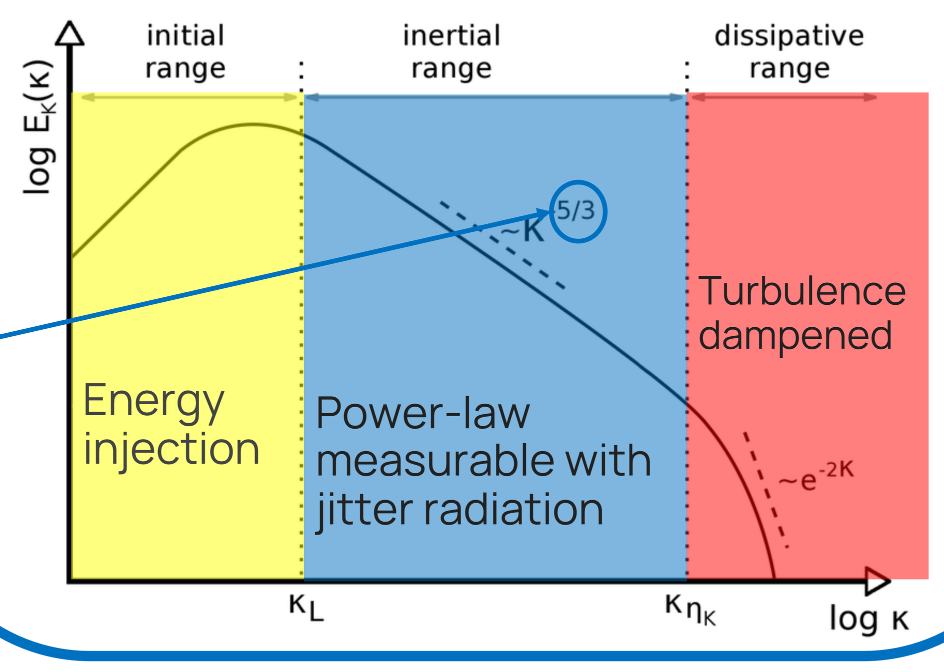
$\omega > \omega_{break}$: jitter regime

$\omega_{break} \propto \lambda^{-1}$



Depends on turbulence spectrum

Slope of the jitter component is directly linked to the slope of the turbulence spectrum ν_B (e.g. Kolmogorov $\nu_B = 5/3$)



Depends on turbulence scale

Maximum frequency to which the jitter component extends is limited by the minimum turbulence scale-size $\omega_{max} \propto \lambda^{-3}$

Intrinsically unpolarized

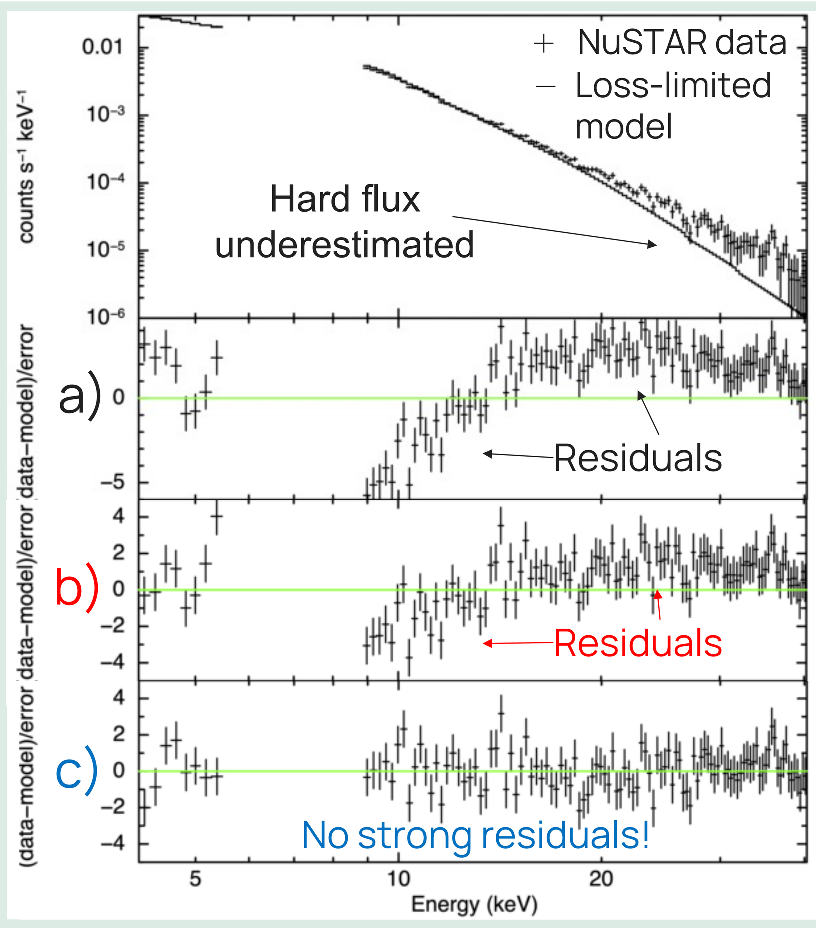
Random motion leads to polarization components canceling each other out

Detecting **jitter radiation** in X-ray spectra of **young SNRs** would provide unprecedented information **on magnetic turbulence**

X-ray Jitter radiation in Cassiopeia A

- Spatially resolved spectral analysis of X-ray data of Cas A reveals that **jitter model fits** the 4-40 keV spectra **better** than any standard synchrotron model
- **Slope of turbulence spectrum** inferred ν_B = 2-2.4 across different regions
- **Minimum scale** of turbulence found to be $\lambda < 100$ km
- Natural explanation for **low polarization** level detected

6-9 keV band excluded since dominated by Fe K line



NuSTAR spectrum from region North fitted with a) **loss-limited**, b) **srcut** and c) **jitter** models

Jitter radiation is likely at work in the outer shell of Cassiopeia A and we constrain, for the first time, the spectral distribution and scale-size of downstream magnetic turbulence in a young SNR