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The Origin of the X-Ray Emission in Heavily Obscured Compact Radio Sources

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Compact Symmetric Objects (CSOs)

CSOs are a subset of active galaxies known for their **very young radio structures** (a few hundred to a few thousand years old). Their radio emission is dominated by compact symmetric lobes/hotspots with sizes smaller than 1 kpc (see Fig. 1).

Why are they interesting?

Their very young radio structures provide a unique opportunity to study the initial stages of active galactic nuclei evolution.

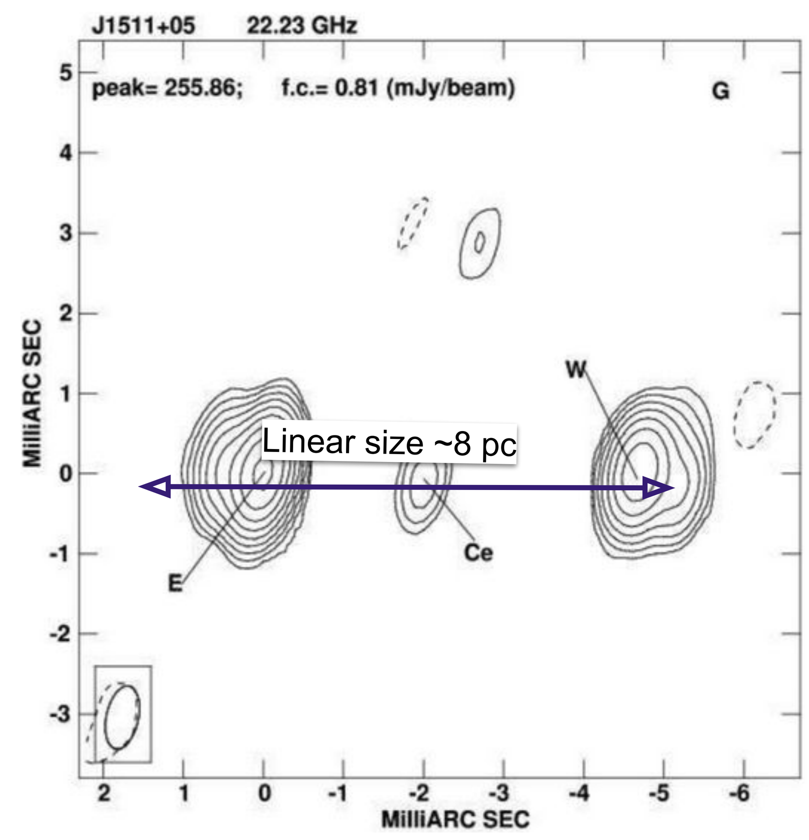

Figure 1. Radio VLA map at 22.23 GHz frequency of the CSO J1511+0518. CSO linear sizes are <1 kpc (Orienti et al. 2006).

Compact Radio Lobes as an X-ray Emission Source?

We propose that the compact lobes of CSOs may serve as a source of X-ray continuum emission, as they constitute a reservoir of relativistic electrons that produce high-energy radiation through the Comptonization of IR and UV photons. During the earliest stages of the jet's lifetime, this emission is then reflected from the torus, adding fluorescent Fe Kα lines and the reflection component (see the cartoon in Fig. 2).

Spectral Energy Distribution (SED) modelling

We employed the model by Stawarz et al. (2008) to investigate the source of high-energy emission in three heavily obscured CSOs: J1511+0518, OQ208, and J2021+6136, characterized by a Fe Kα line in the X-ray spectrum and radio sizes in the 7–25 pc range. The model self-consistently describes the broad-band emission of the lobes based on:

- The dynamical model for the expansion of double-double radio sources (Begelman & Cioffi, 1989).
- Various prescriptions for the energy spectrum of ultra-relativistic electrons injected into the lobes at the terminal hotspots.
- Adiabatic energy losses and radiative cooling due to synchrotron emission and inverse Compton scattering of soft photon fields originating from the obscuring torus (IR), accretion flow (UV), and starlight (optical/visual).

Model parameters and how to get them:

SED modeling constraints
Must reproduce the radio emission
↓
Electron energy spectrum:
- Low- and high-energy slopes
- Min and max Lorentz factor
- Lorentz factor of the break
- Jet kinetic power

SED modeling constraints
Must model well the X-ray and gamma-ray emission
↓
- UV emission
- Magnetic field and electron energy density fractions, ISM density.

Observational constraints
↓
- IR emission
- Linear size of the radio source
- Radio turn-over frequency
- Advance velocity of radio lobes
- X-ray absorption

We calculate characteristic ISM densities corresponding the X-ray absorbing matter concentrated in either the source size (n_{high}), Chandra extraction region (n_{low}) and an intermediate value (n_{int}).

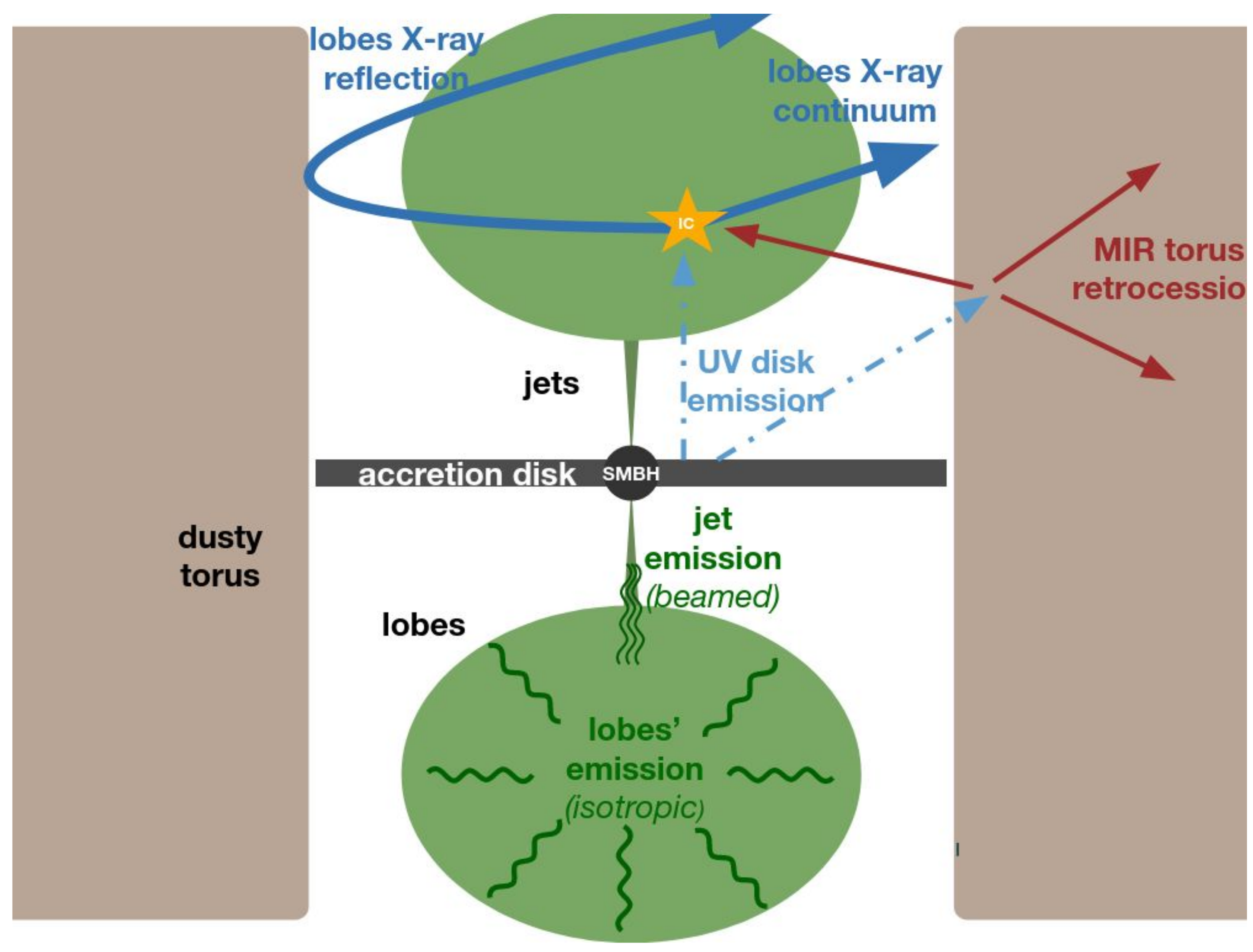

Figure 2. schematic view of a young radio source, where the X-ray continuum emission is produced within compact radio lobes (Król et al. 2024).

Results: Origin of X-ray Emission and ISM Density Constraints

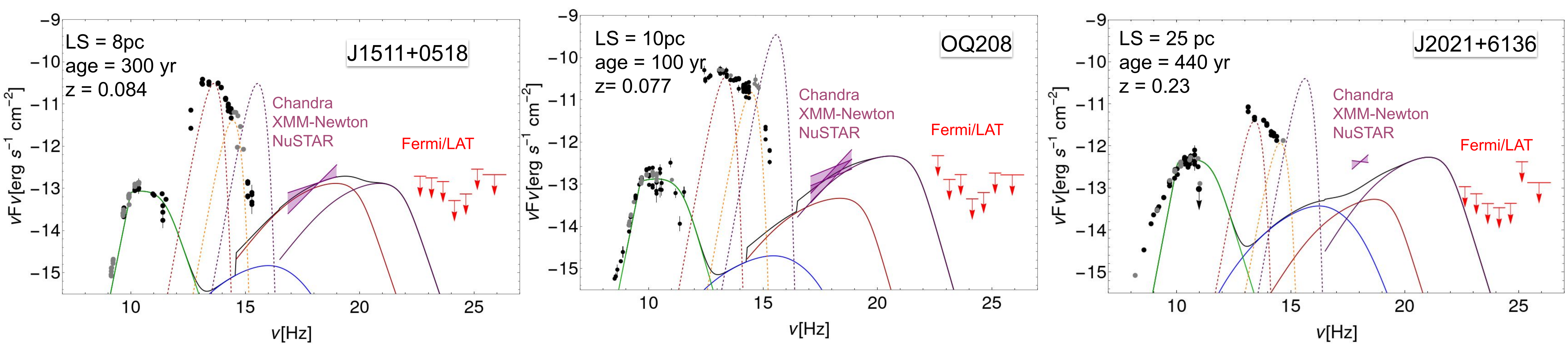

Figure 4. SEDs of the X-ray obscured CSOs. Green - synchrotron radio emission. Blue - synchrotron self-Compton. Red - IC scattering of the IR emission. Purple - IC scattering of the UV emission.IC scattering of the visible light is negligible. Models assume Ue=10UB (Ue - electron energy density, UB - magnetic field energy density) and the ISM density corresponding to the X-ray absorption occurring on the scales comparable to the linear sizes of the radio structures.

The origin of the X-ray emission:

- In two sources, X-rays can be fully explained as due to the the radio lobe emission (IC of infrared in J1511, and IC of UV in OQ208).
- In J2021 (the X-ray brightest of the three), an additional X-ray component is required (for example an X-ray corona or an X-ray jet). Its luminosity depends on the Ue/Ub ratio and the ISM density. Lobes closer to equipartition and/or expanding in a denser ISM require a more luminous jet/corona.

The ISM density surrounding the expanding radio lobes:

- J1511: ISM density $n_0 \sim 4{,}000\ cm^{-3}$.
- OQ208: either high ISM density $n_0 \sim 20{,}000\ cm^{-3}$ or that the radio lobes are close to equipartition (Ue ~ UB).

The radio data require a **steep high-energy slope of the electron energy distribution**, which results in all three sources being quiet in gamma-ray frequencies.

For a detailed description of the modeling procedure and a comprehensive discussion of the results, see:
Król, D. Ł., et al. (2024), ApJ, Vol. 966.

Bibliography
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