Polarization in AGN

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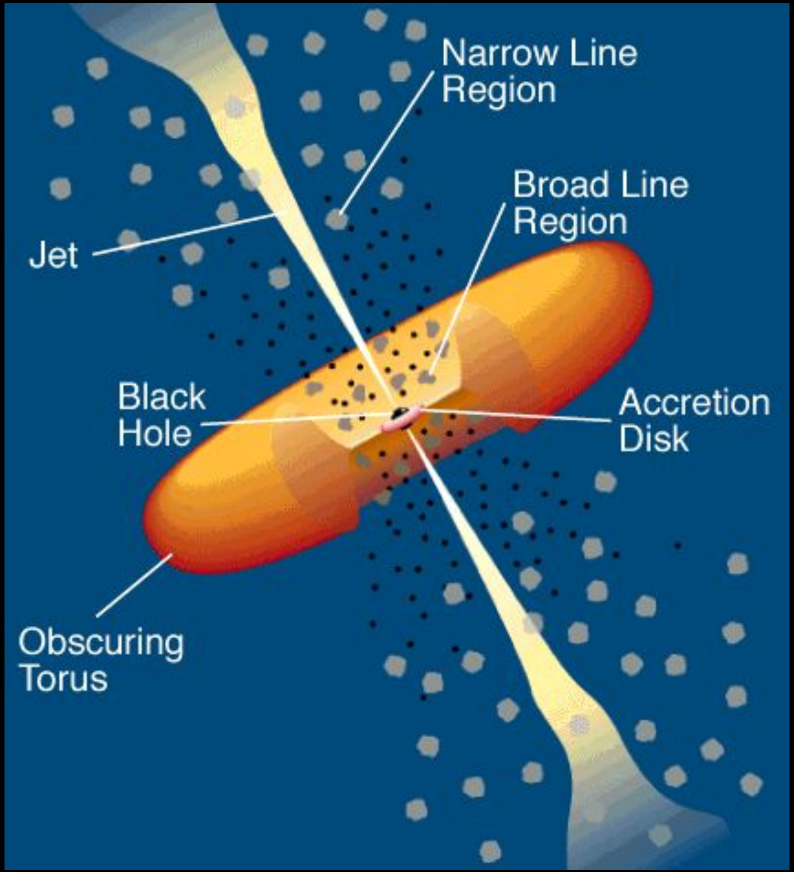
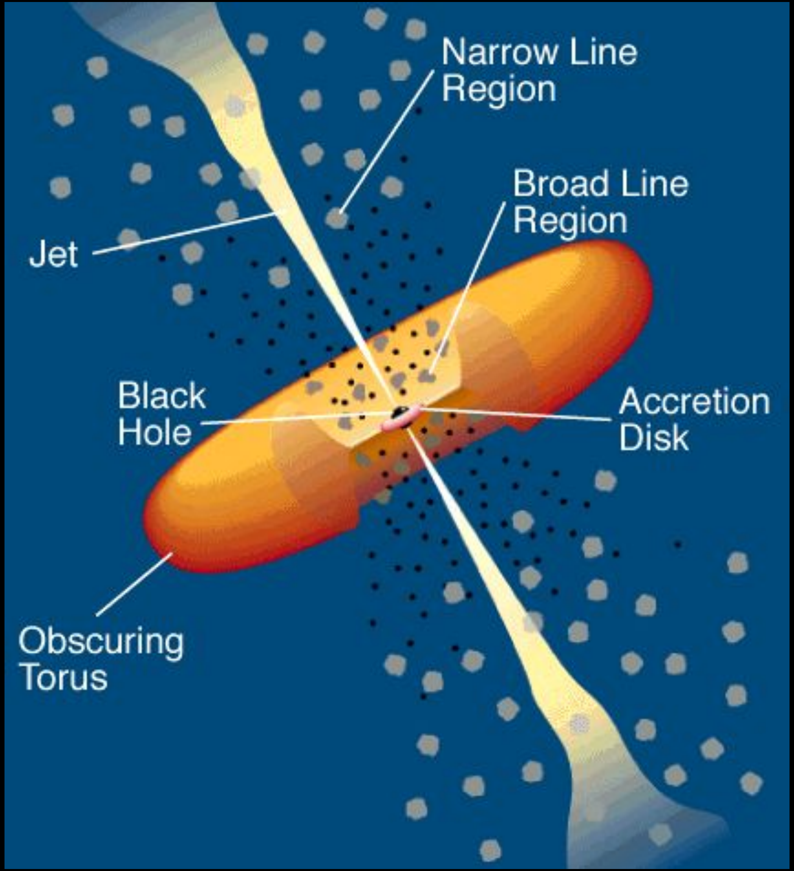
Active Galactic Nuclei

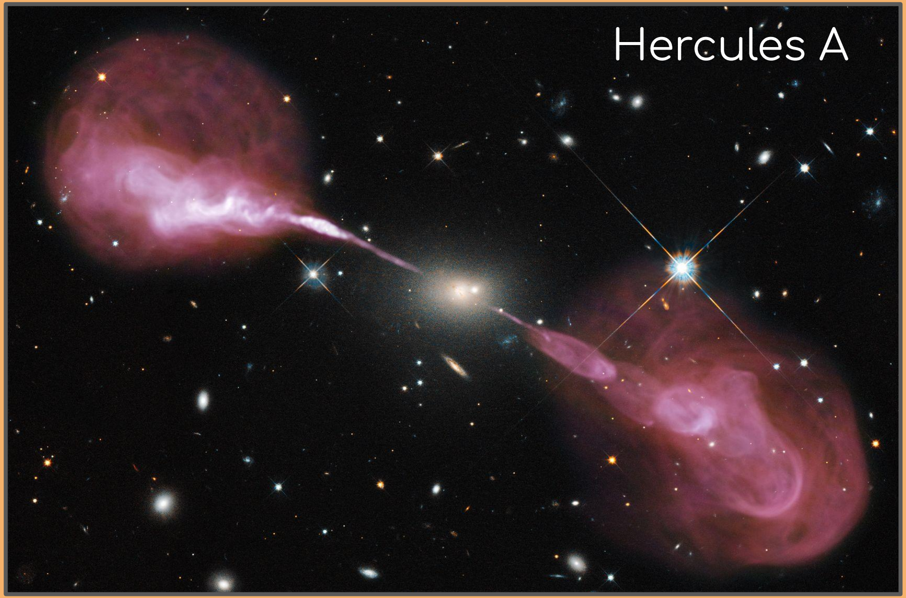


- Supermassive black hole (SMBH) ~ 10^6-10^9 $M_\odot$ powers the AGN.
- Accretion disk emits blackbody radiation in UV & X-ray.
- Broad-line regions (BLR):
  line widths ≥ 500 - 10,000 km/s
  ne ~ 10^8-10^{11} cm^{-3}
- Narrow-line regions (NLR):
  line widths ≤ 500 km/s
  ne ~ 10^3 cm^{-3}
- Dusty torus obscures BLR from certain lines of sight

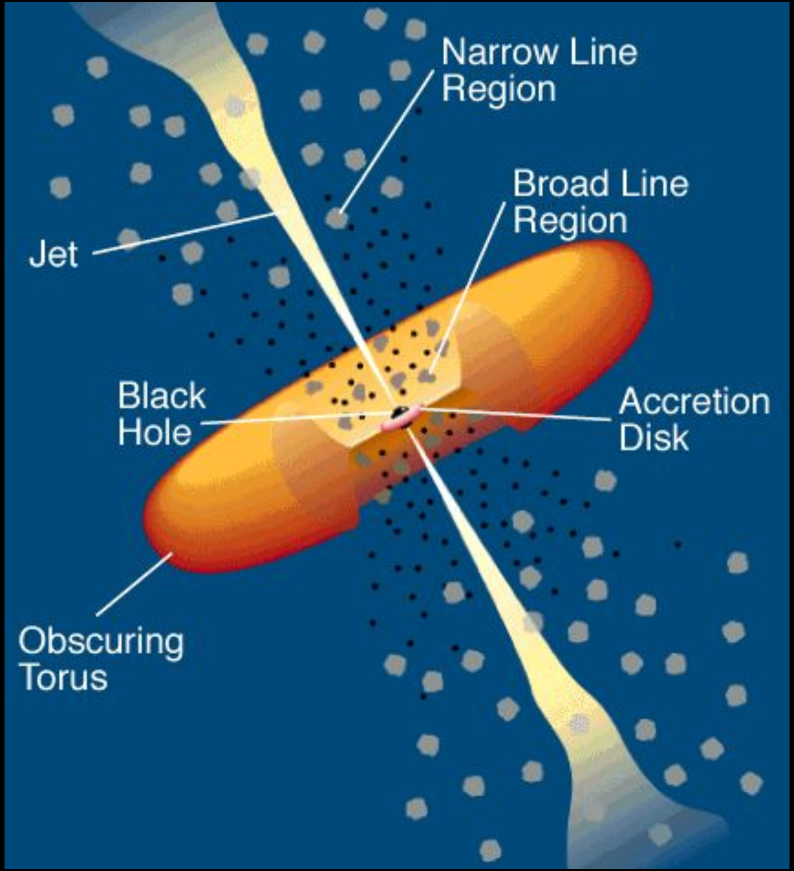
Radio jets



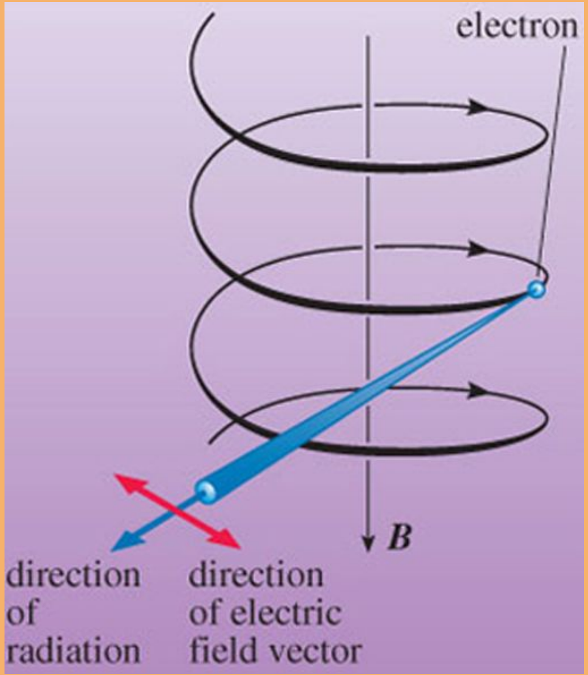
- Relativistic jets



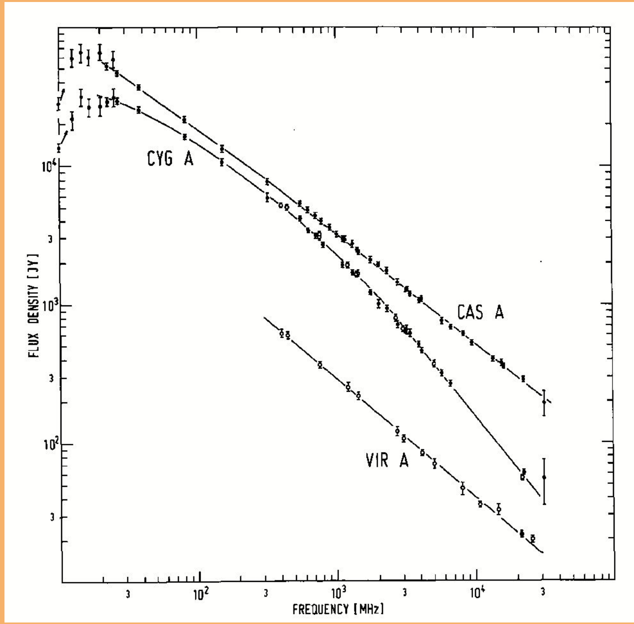
Synchrotron emission



- Relativistic jets
- Synchrotron emission in radio



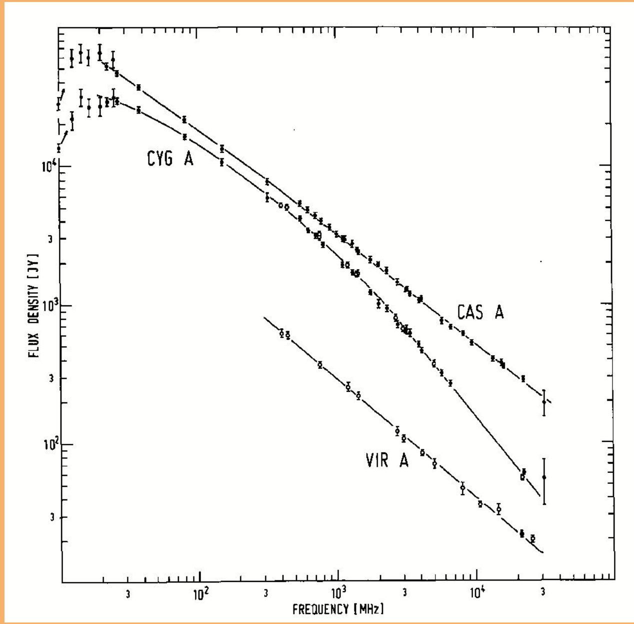
Synchrotron emission



$F_\nu \propto \nu^{-\alpha}$
$\alpha = 0.7$

$$n(E)dE \propto E^{-\gamma}\, dE$$

Synchrotron emission



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- Synchrotron emission is intrinsically linearly polarized
  (Burn 1966; Pacholczyk 1970)

$$p(\gamma) = \frac{3\gamma+3}{3\gamma+7}.$$

$\gamma = 2.5$, P = 75%

where γ is the electron energy index

$$p_i = p(\gamma)(B_0{}^2)/(B_0{}^2 + B_r{}^2)$$

Linearly polarized ≤ 75%

Depolarization

- EM wave passes through a magneto-ionized medium.
- Asymmetric interactions b/w free charges and RCP & LCP components.
- Different refractive indices, hence different speeds of propagation.
- Induces a delay ----> rotation in the plane of polarization

<u>Faraday rotation</u>

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  Faraday rotation

External depolarization

Faraday rotating medium extrinsic to radio plasma

- → Bandwidth depolarization
- → Beam depolarization

Internal depolarization

Faraday rotating medium intrinsic to radio plasma

Polarization observations

- Stokes parameters - ***I, Q, U, V***

Linear fractional polarization :

$$p_{\text{lin}} = \frac{\sqrt{Q^2 + U^2}}{I}; \qquad 0 \leq p_{\text{lin}} \leq 1$$

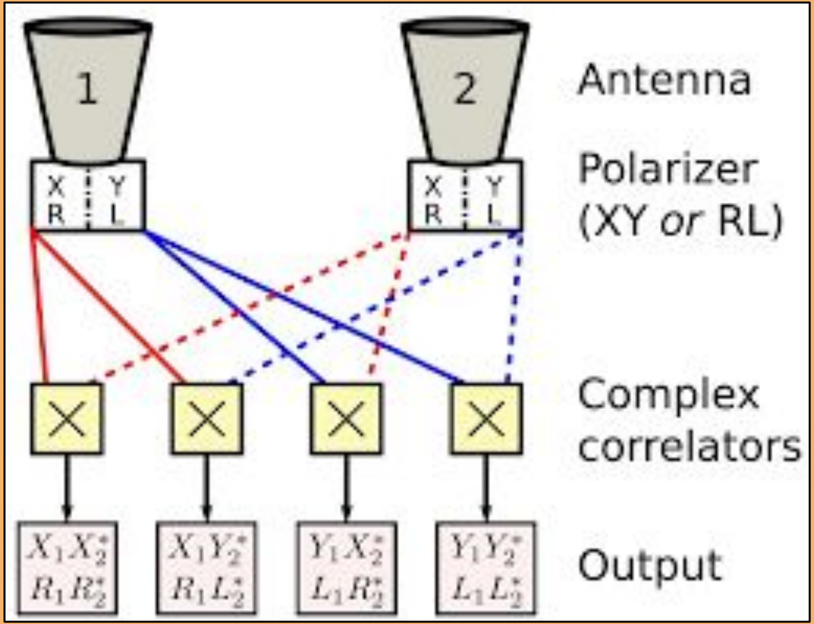
Circular fractional polarization :

$$p_{\text{cir}} = \frac{V}{I}; \qquad -1 \leq p_{\text{cir}} \leq 1$$

Polarization angle :

$$\chi = \frac{1}{2} \tan^{-1}\left(\frac{U}{Q}\right) \; ; \qquad 0^\circ \leq \chi \leq 180^\circ$$

Polarization observations



$$< R_iR_j^*(u,v) >= I(u,v) + V(u,v)$$

$$< R_iL_j^*(u,v) >= Q(u,v) + iU(u,v) = P(u,v)$$

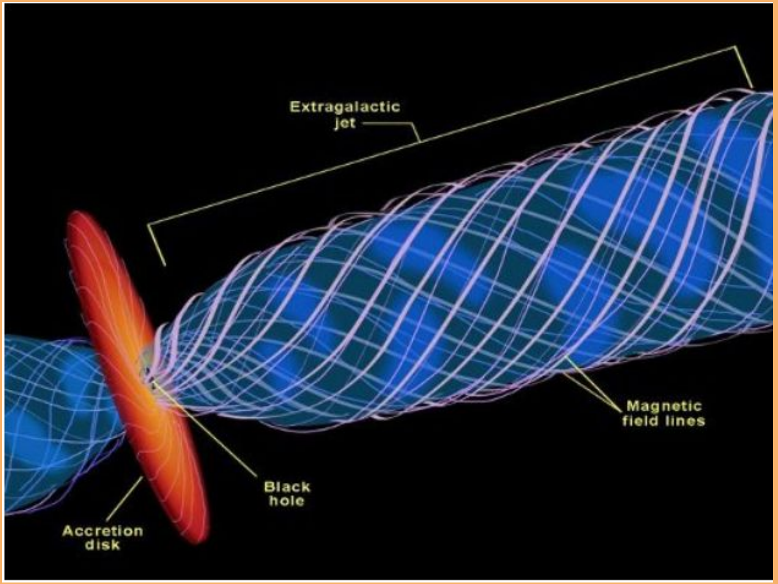
$$< L_iR_j^*(u,v) >= Q(u,v) - iU(u,v) = P^*(u,v)$$

$$< L_iL_j^*(u,v) >= I(u,v) - V(u,v)$$

- *Cross-hand delay calibration*
- *Leakage calibration*
- *Polarization angle calibration*

Polarization observations

- Linear polarization observations used to probe the degree of order & orientation of magnetic fields.



Helical B-fields in AGN jets

Toroidal component:

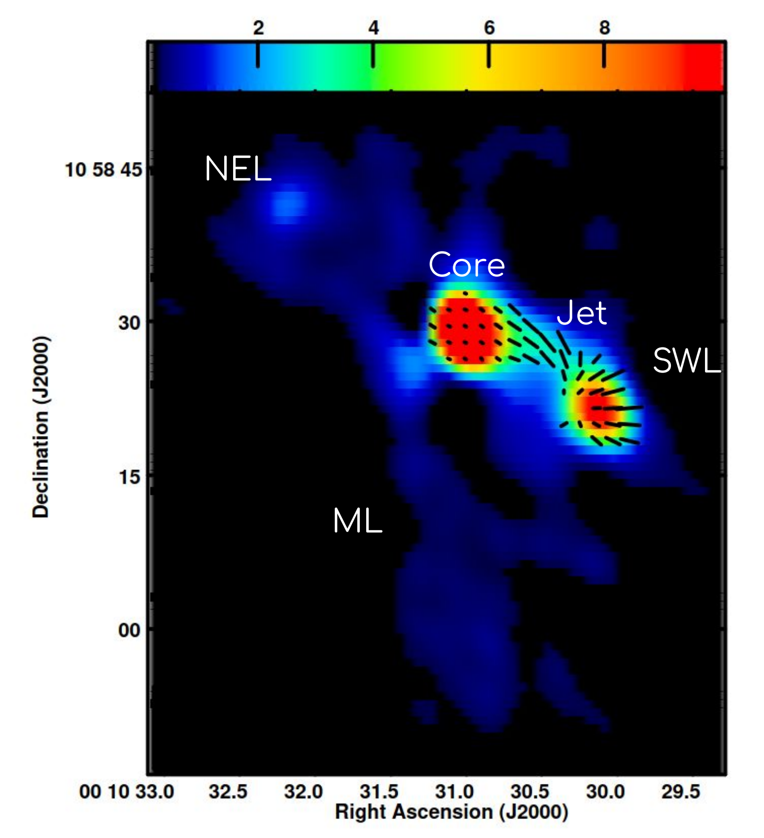
- B-field ⊥ local jet direction
- Compressed B-fields
- Shocks

Poloidal component:

- B-field // local jet direction
- Sheared B-fields

III Zw 2

uGMRT 685 MHz



Optically thin ----> B-fields ⊥ χ-vectors
Optically thick ----> B-fields // χ-vectors

- ❑ Triple radio structure
- ❑ Misaligned lobe emission
- ❑ Inferred B-fields transverse to jet
- ❑ Shocks or toroidal B-field in the jet

or

- ❑ Toroidal B-field in the wind
- ❑ 'Wind' - accretion disk wind or jet sheath

Polarization pipeline:
https://sites.google.com/view/silpasasikumar/

(Silpa et al. 2021a)