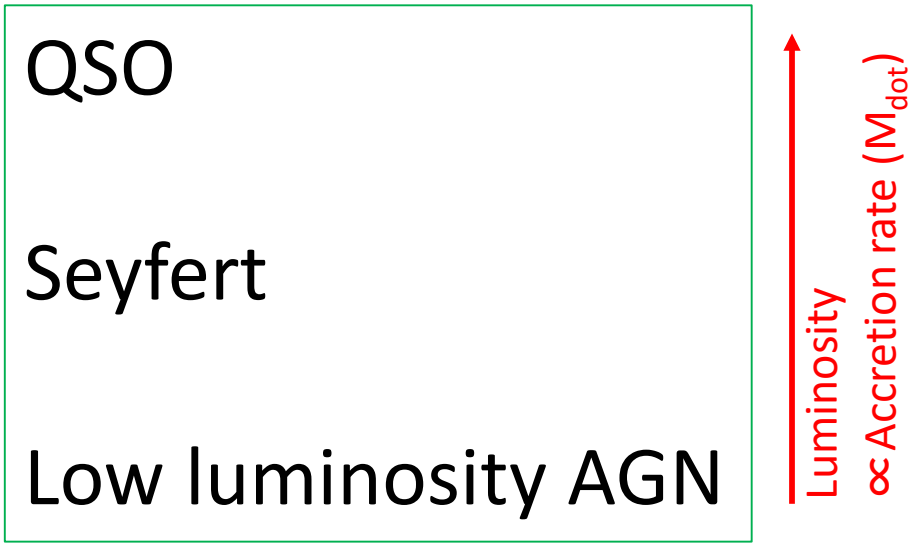
ALMA偏波観測で狙うブラックホール降着流とSPICAへの展望

永井　洋
（NAOJ）

AGN Zoo!

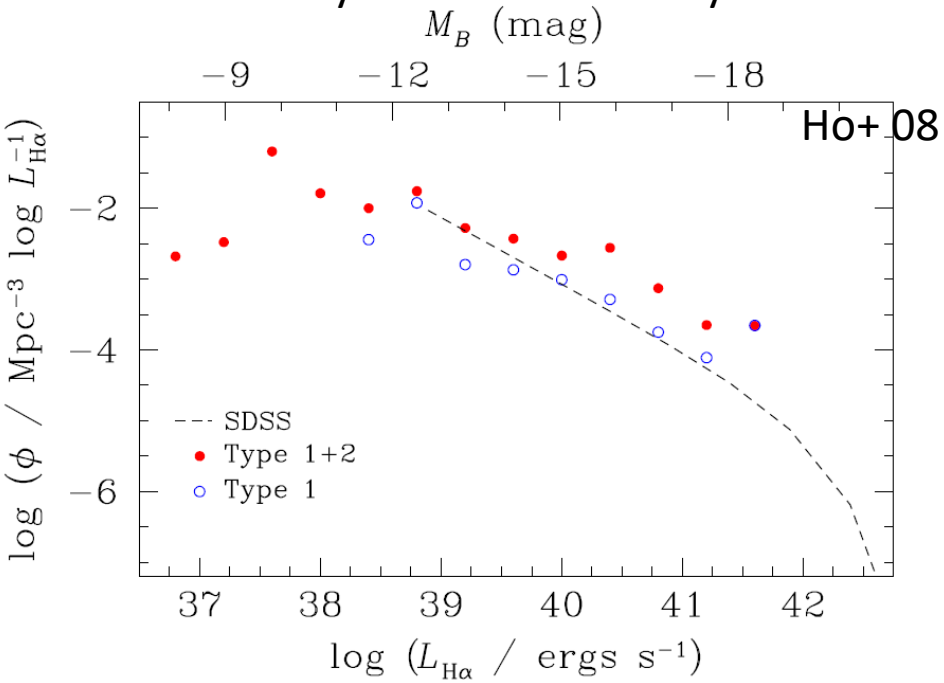
- RLQSO, RQQSO, FSRQ, HBL, IBL, LBL, Sy1, Sy2, NLSy1, OVV, BLRG, NLRG, FR1, FR2, LINER, LLAGN, GPS, CSS, CSO, MSO, BAL, UFO, …



Low Luminosity AGNs

- Hα luminosity < 10^{40} erg/s
  (X-ray core luminosity < ~10^{42} erg/s)
  - Energy output $10^{3\text{-}6}$ times smaller than in typical quasars
- Silent majority in local Universe, but not well understood the origin of their inactiveness

Luminosity function of nearby AGNs



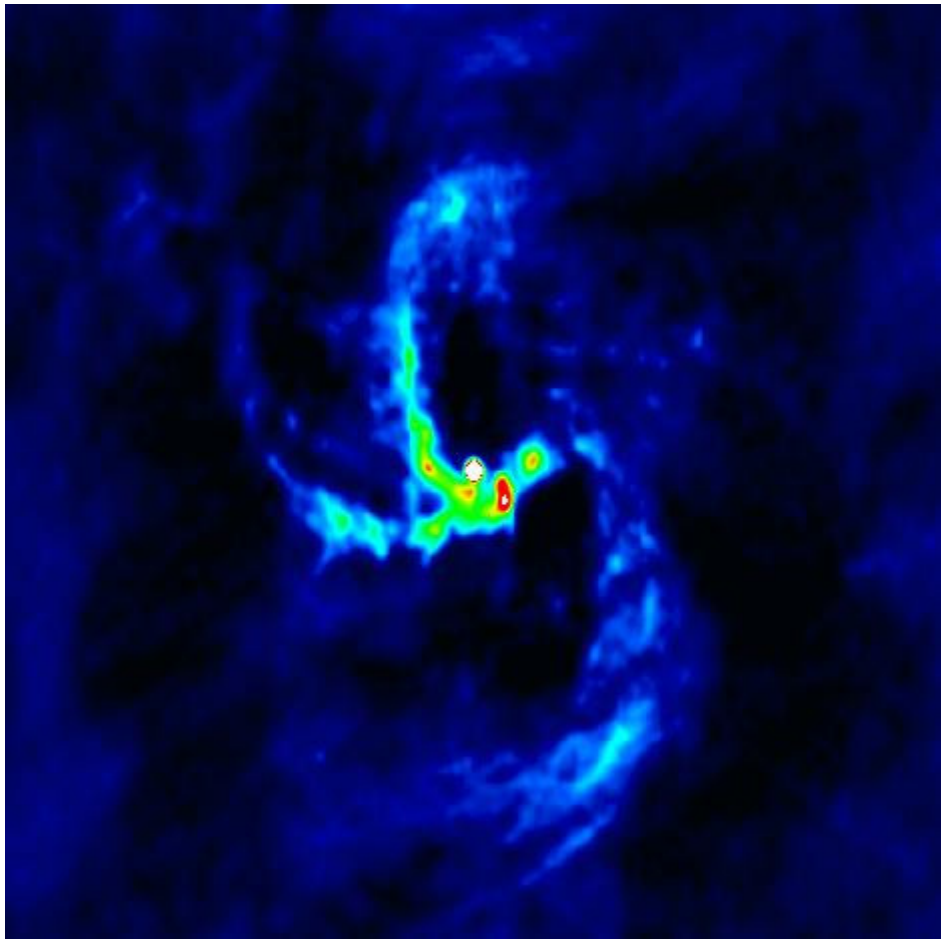
Low Luminosity AGNs

- Can be hosted by either ellipticals or spirals

Sombrero galaxy

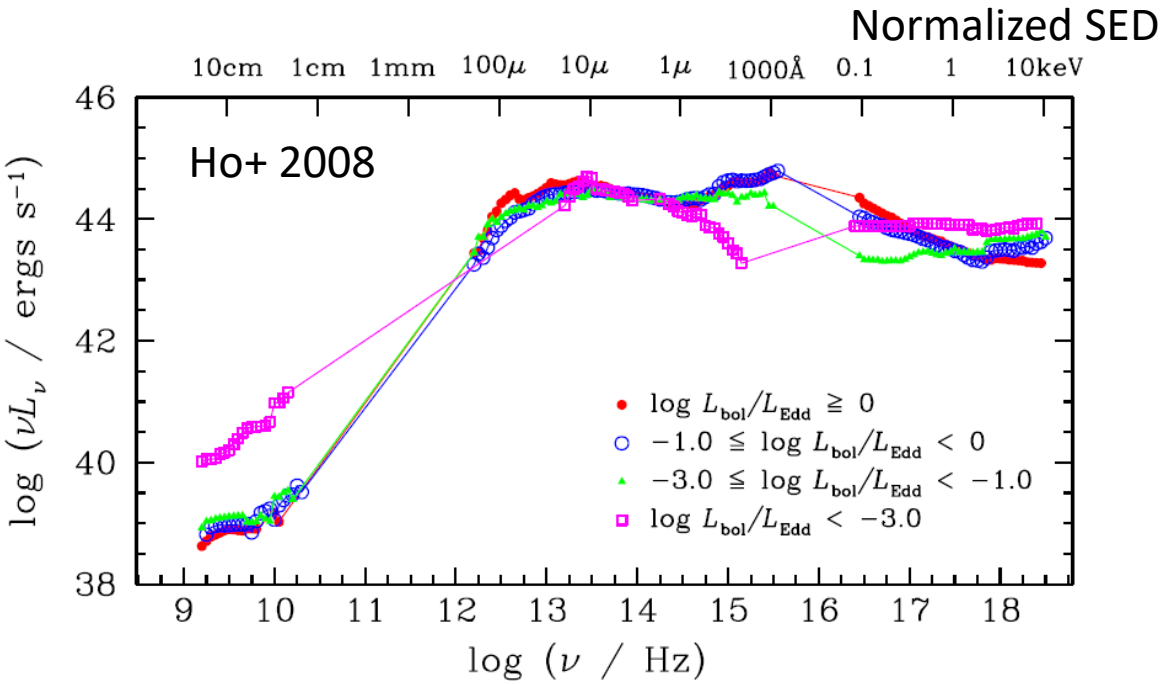
N4258

SgrA* – an extreme case of LLAGN



$L \sim 10^{35}$ erg/s = 10^{-9} L_{edd}

SED

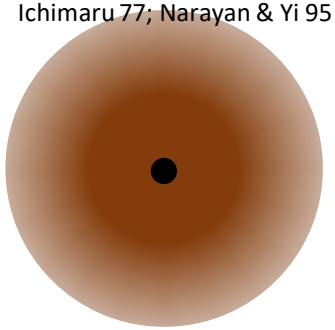


- High luminosity AGNs (L~0.1L_{edd}-1L_{edd})
  - Big blue bump (BBB) --- pseudo blackbody radiation from thin and optically-thick disk, so-called standard disk (Shakura & Sunyaev 1973)
- Low luminosity AGNs (L<~0.01L_{edd})
  - No BBB --- No standard disk
  - Hard spectrum in X-ray --- Hot accretion flow

Hot Accretion

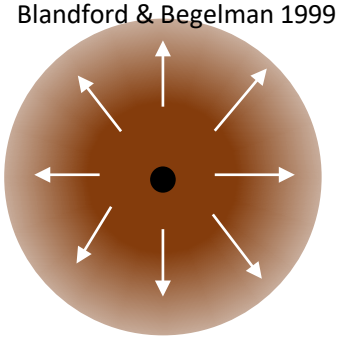
- Radiatively Inefficient Accretion Flow (RIAF)
  - Radiation cooling is inefficient
    - accretion flow remains hot (Te ~ $10^{9\text{-}10}$ K) -> Bremsstrahlung in X-ray band
    - Disk radius ~ scale height (geometrically thick)

ADAF
Ichimaru 77; Narayan & Yi 95



$\dot{M} \sim \dot{M}_B$

ADIOS
Blandford & Begelman 1999



$\dot{M} \sim \dot{M}_B (r/r_B)^{\kappa}$
$0<\kappa<1$

CDAF
Igumenshchev & Abramowicz 1999

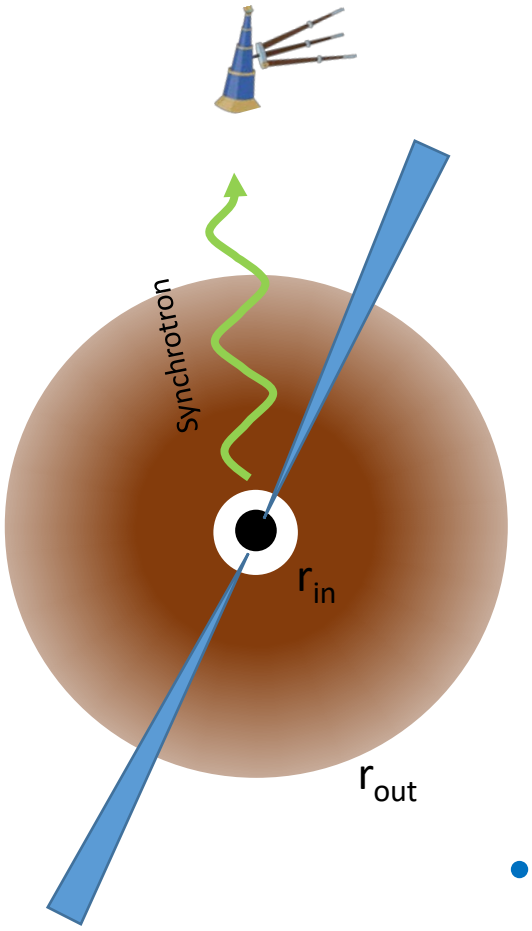
$\dot{M} \sim \dot{M}_B (r/r_B)^{\kappa}$
$\kappa=1$

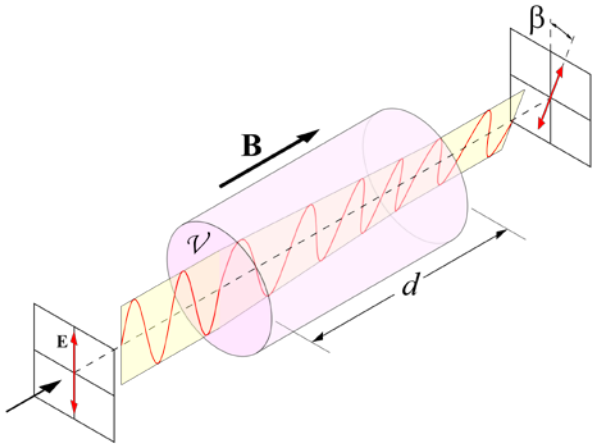
- RIAFs come into different sub models
  - Substantial decrease in accretion rate in ADIOS and CDAF

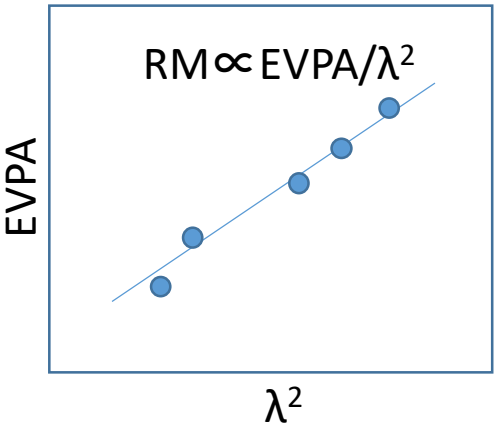
Method to Measure Accretion Rate

- SED modeling
  - $M_{dot}=L_{bol}/\eta c^2$
  - Usually assume $\eta=0.1$

Method to Measure Accretion Rate





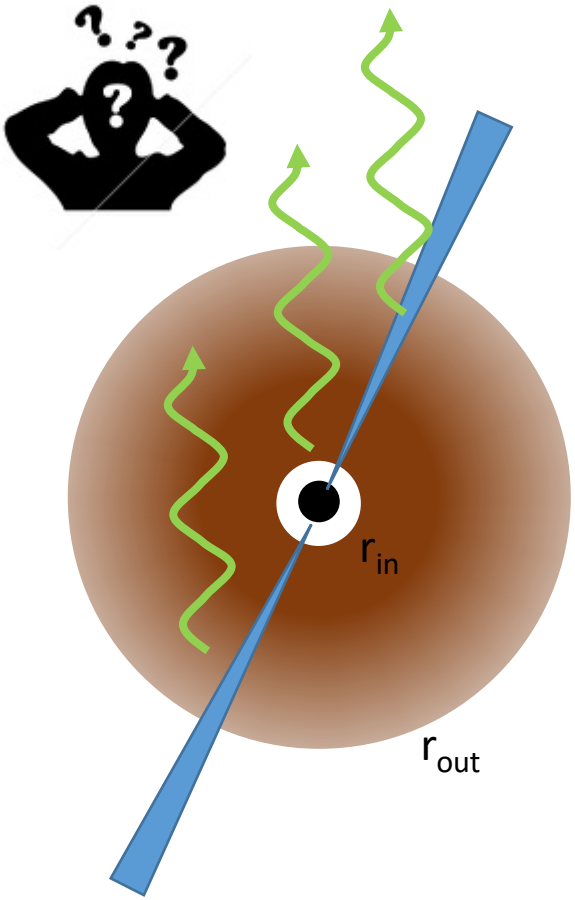


$$\dot{M} \propto \left[1 - \left(\frac{r_{out}}{r_{in}}\right)^{-\frac{3\beta-1}{2}}\right]^{-\frac{2}{3}} M_{BH}^{\frac{4}{3}} \left(\frac{2}{3\beta-1}\right)^{-\frac{2}{3}} r_{in}^{\frac{7}{6}} RM^{2/3}$$

Quataert & Gruzinov 00
Marrone+ 06
Kuo+ 14

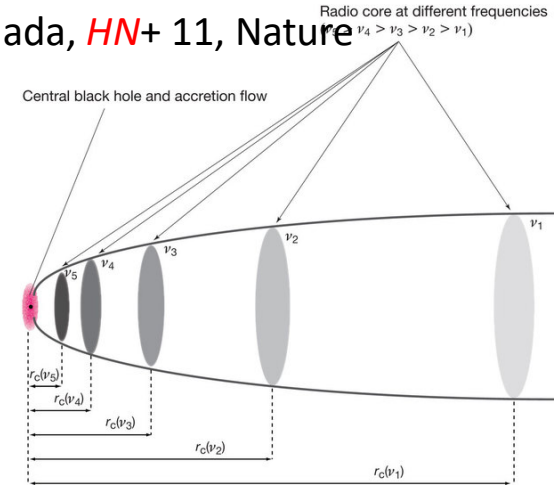
- Need geometrical structure model (r_{in}, r_{out})
  - r_{in} should be ISCO scale
  - r_{out} is not sensitive to Mdot

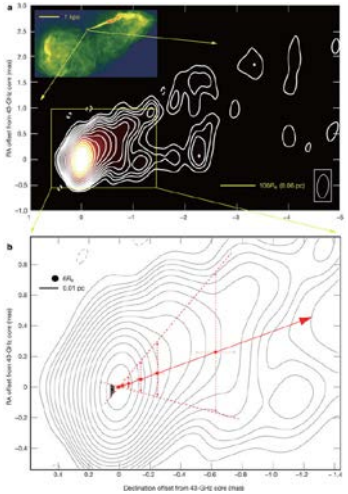
Method to Measure Accretion Rate



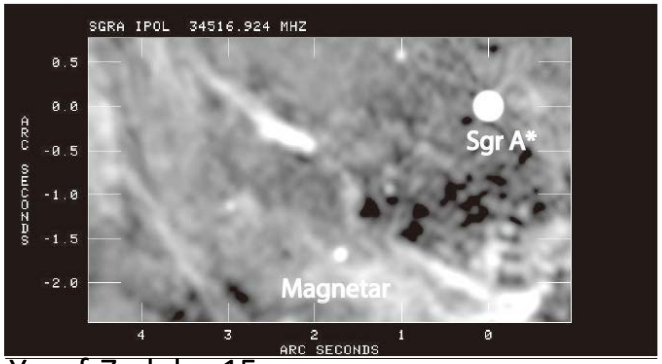
- Where is radio emission coming from?

Hada, *HN*+ 11, Nature





- RM is only sensitive to accretion flow?

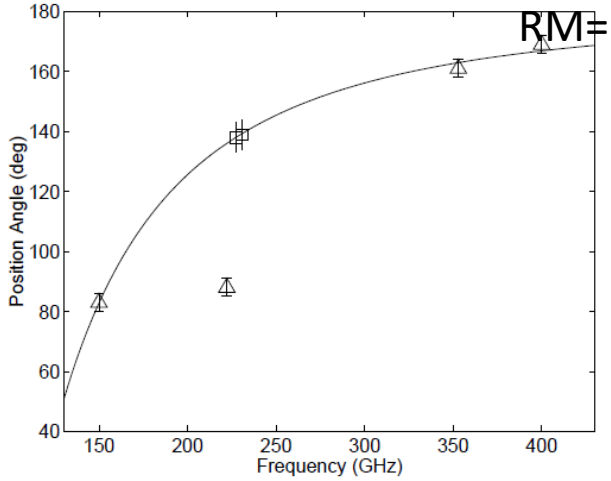


Yusef-Zadeh+ 15

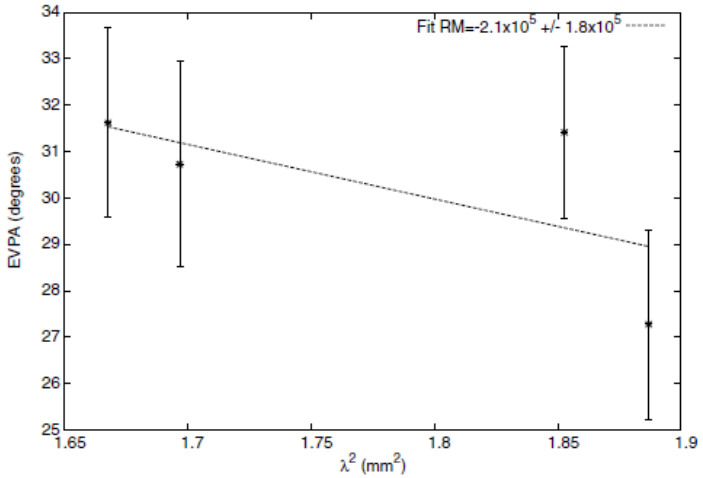
$RM_{magnetar}=0.1RM_{SgrA*}$
(Eatough+ 13; Bower+ 03)

Previous Studies

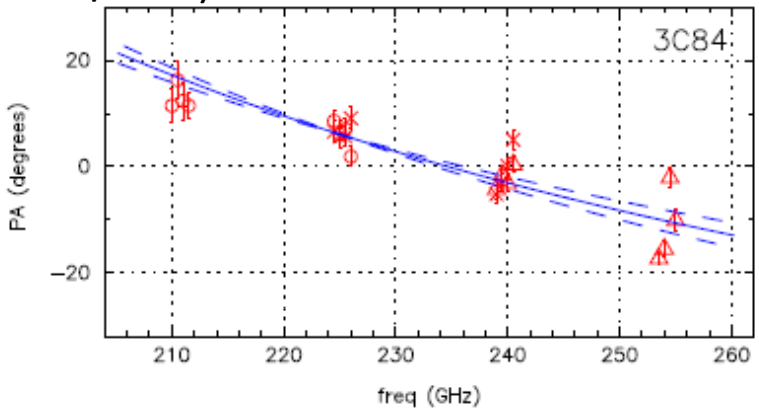
SgrA* : Bower+ 03 (BIMA)
RM=(-4.3 +/- 0.1) x 10^5 rad m^{-2}



M87 : Kuo+ 14 (SMA)
RM=(-2.1 +/- 1.8) x 10^5 rad m^{-2}



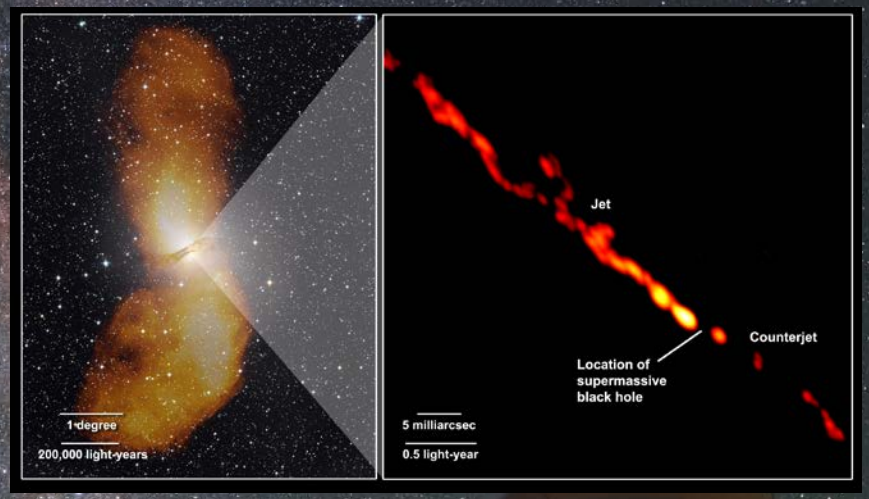
3C84: Plambeck+ 14 (CARMA) / HN+ 17 (VLBA)
RM=(8.7 +/- 2.3) x 10^5 rad m^{-2}



- SgrA* and M87 favor ADIOS/CDAF
- All models overpredict the observed RM for 3C84

ALMA Observations of Cen A

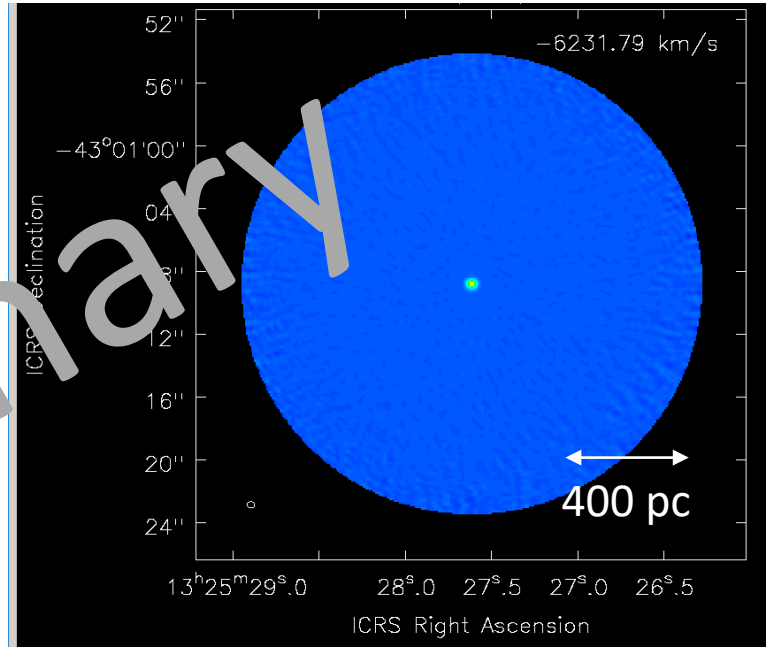
- Target: Centaurus A
  - D=3.6 Mpc
  - M_{BH}=4.5 x 10^7 M_{sun}
  - L_X=5 x 10^{41} erg s^{-1} =10^{-4} L_{edd} (Evans+ 04)



- ALMA Observations (PI: H. Nagai)
  - 2013.1.01282.S (Cycle 2)
    - 1 epoch in May, 2015
  - 2015.1.00421.S (Cycle 3)
    - 3 epochs in March-April, 2016
- ALMA Band 7 (345 GHz, 850μm)
- Beam size: ~0.4”

Results

- Stokes I emission is consistent with a point source.
- I ~8 Jy throughout 4 epochs with time variation of ~10%.
  - Variation timescale: 2 weeks
- No polarized emission with the level of >0.07% was detected.
- RM>2 x 10^6 rad m^{-2}, if no polarization arises from random fluctuations of RM within the size of emission region

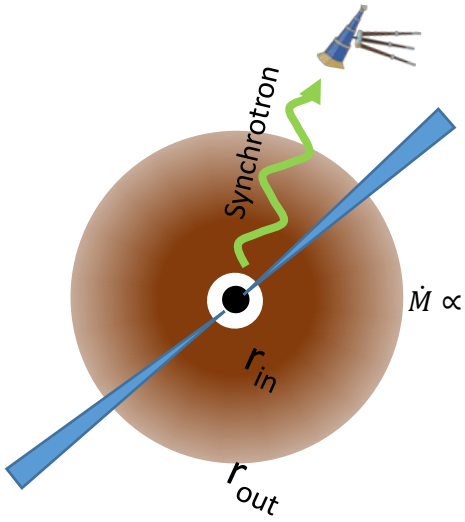


$$P(\lambda^2) = P_0 exp(-2\sigma_{\mathrm{RM}}^2 \lambda^4) < P_0 exp(-2RM^2\lambda^4).$$

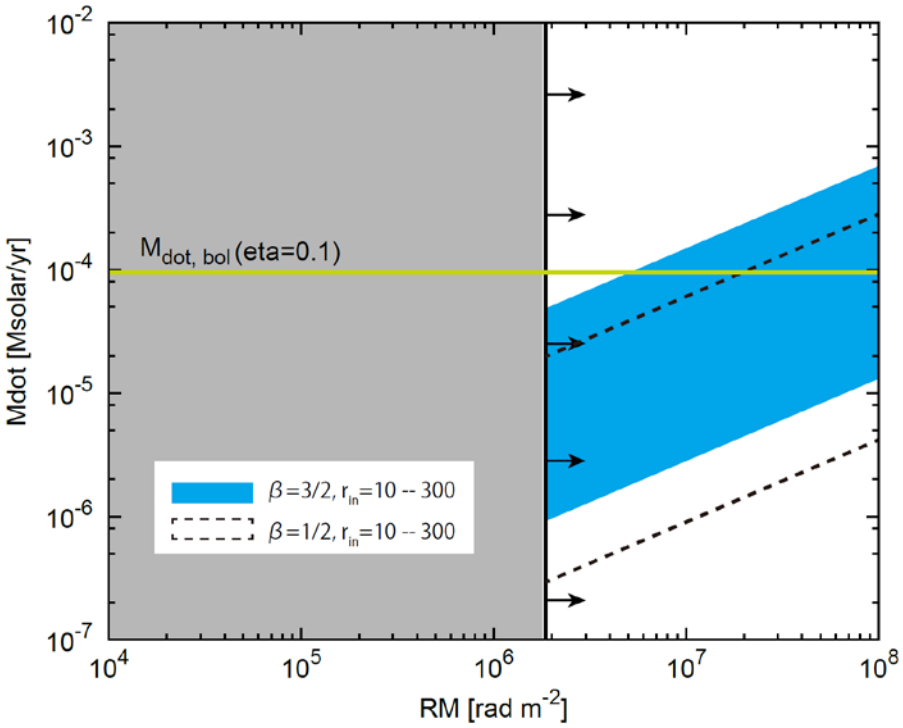
Burn 1966

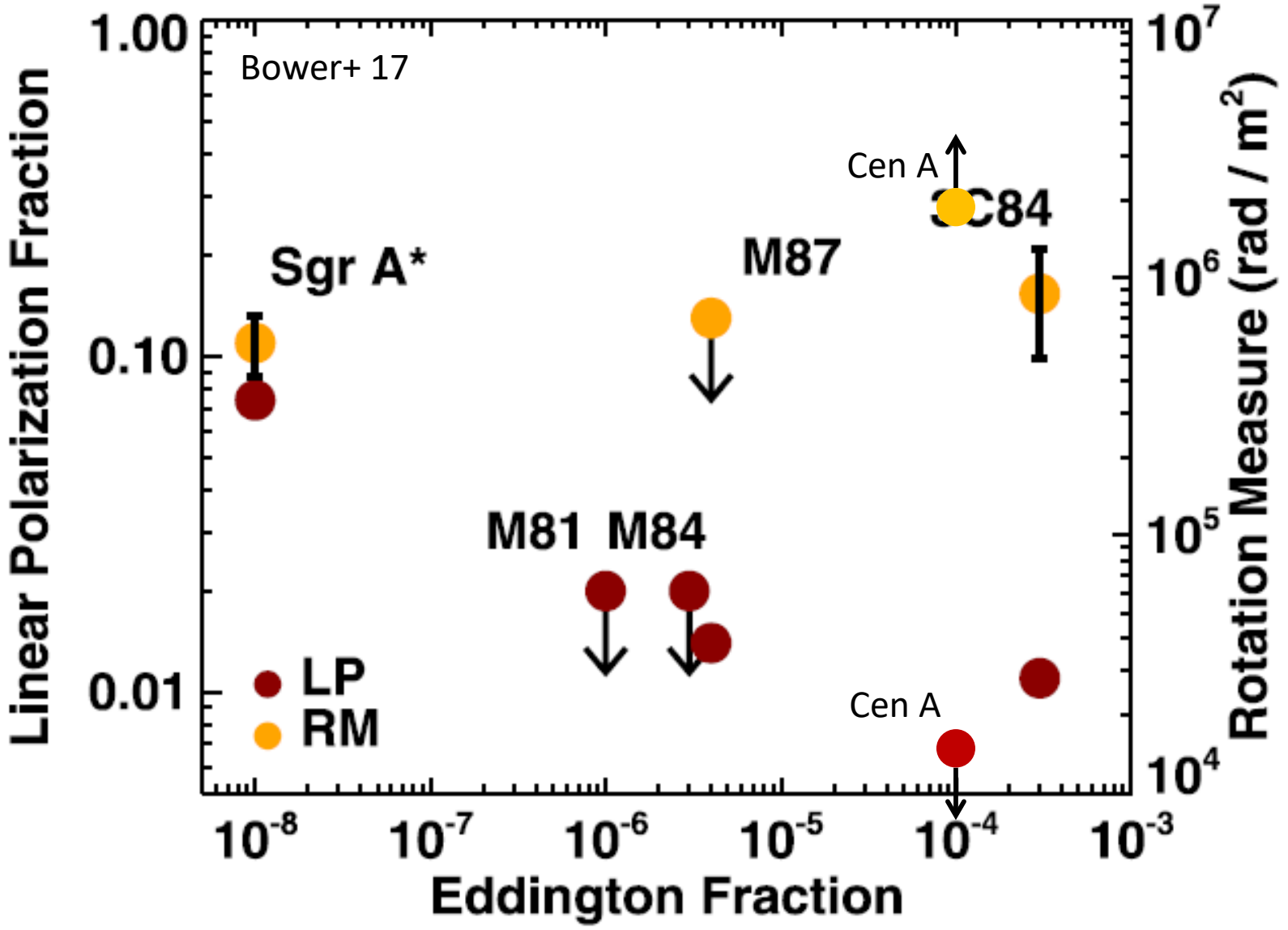
Depolarization by Faraday rotation in RIAF?

- We model the derived (lower limit of) RM using quasi-spherical accretion RIAF model (e.g., Marrone+ 06, Kuo+ 14).
- The RM upper limit constrained by ALMA is consistent with the accretion rate inferred from the bolometric luminosity
- Observations at shorter λ is necessary to detect polarization.
  - SPICA polarimetry is awaited.



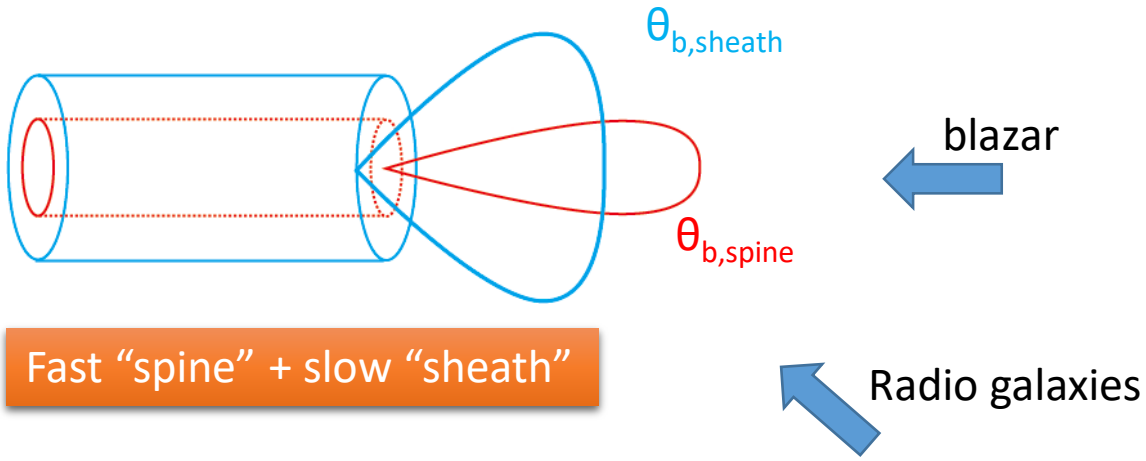
$$\dot{M} \propto \left[1-\left(\frac{r_{out}}{r_{in}}\right)^{-\frac{3\beta-1}{2}}\right]^{-\frac{2}{3}} M_{BH}^{\frac{4}{3}} \left(\frac{2}{3\beta-1}\right)^{-\frac{2}{3}} r_{in}^{\frac{7}{6}} RM^{2/3}$$



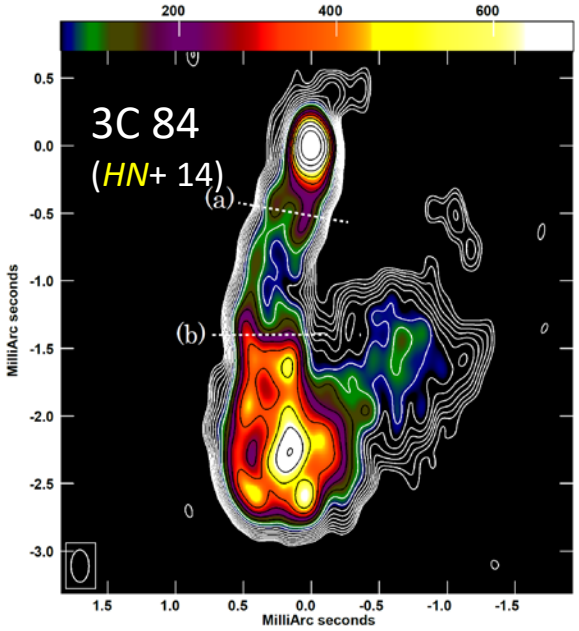

Bower+ 17
Sgr A*
M87
3C84
Cen A
M81
M84
Cen A
LP
RM
1.00
0.10
0.01
10^{7}
10^{6}
10^{5}
10^{4}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
Linear Polarization Fraction
Rotation Measure (rad / m^2)
Eddington Fraction

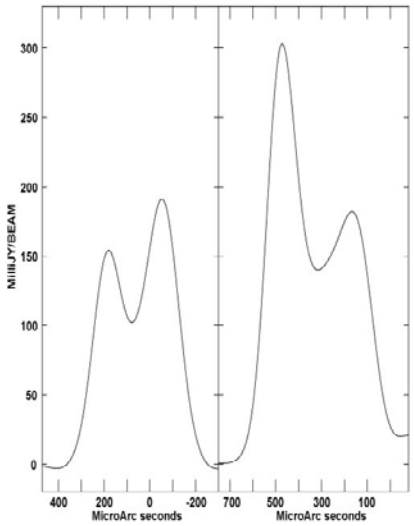
Another Possibility

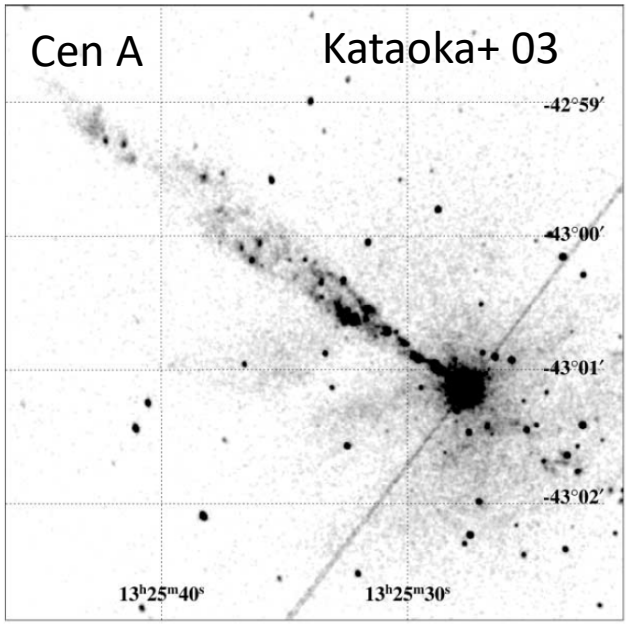
- All of sources studied so far are radio galaxies (except for Sgr A*)
  - Jet viewing angle is relatively large
- Lack of polarized emission is not related to the Faraday screen but to the nature of jet properties.
  - Spine emission: high degree of polarization
  - Sheat emission: no or little polarization



Limb-brightened jets in radio galaxies



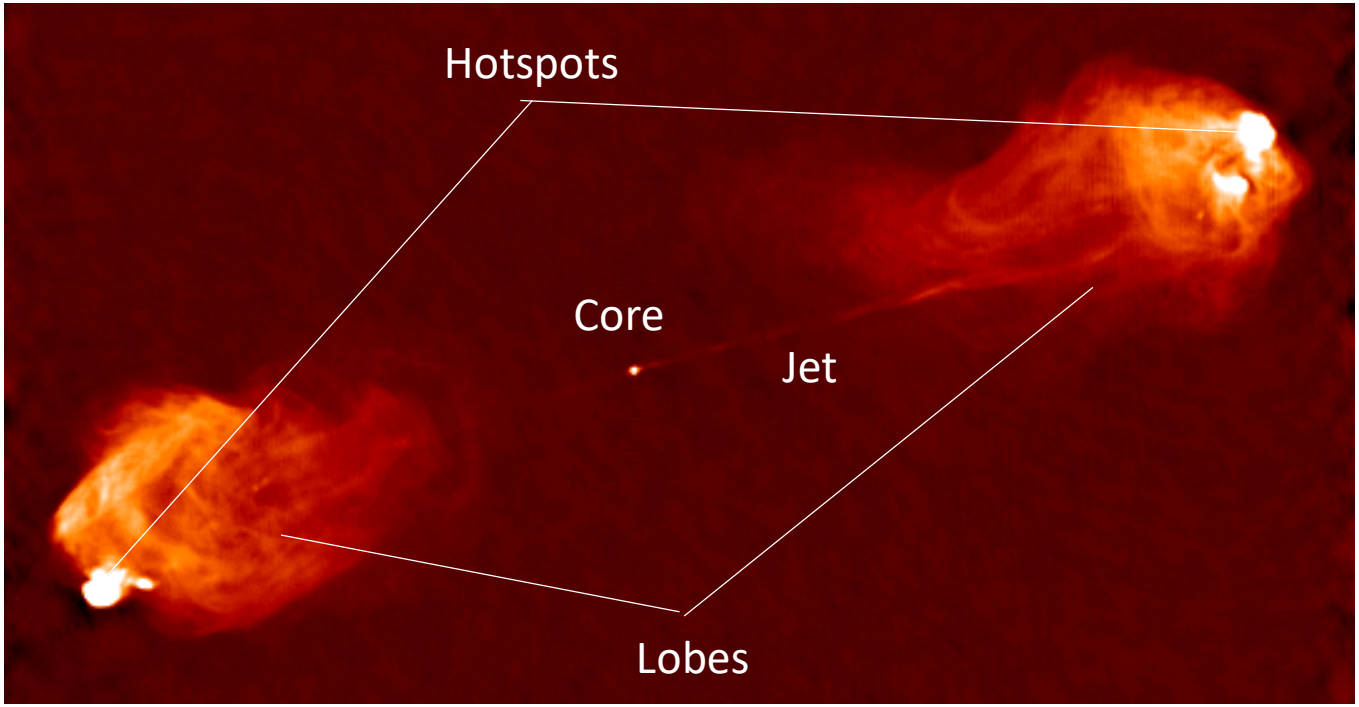




Summary and Prospects for SPICA

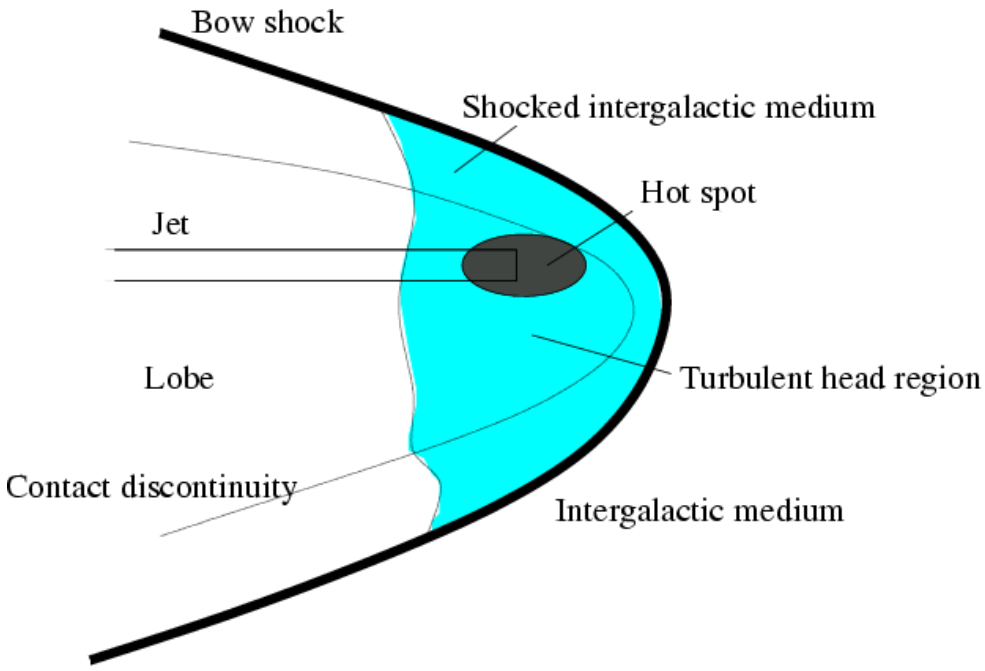
- Non-detection of polarized emission from Cen A is consistent with RIAF model if no polarization arises from random fluctuations of RM within the size of emission region.
- However, there is a clear tendency that LLAGNs/RGs show no/little polarization as compared to blazars.
- No/little polarization in LLAGNs/RGs could be explained by the jet stratification if the sheath (spine) emission is weakly (strongly) polarized.
- Polarimetry at shorter λ is crucial to distinguish two possibilities.

FRII Radio Galaxies



Hotspots

- Hot spots are bright and compact regions located up to hundred kpc or Mpc distance from the core.
- In-situ particle acceleration mainly from shocks due to jet-ICM interaction.



Shocks? Not so simple.

- Multiple spots and diffuse emission at X-ray, optical, and IR (Prieto+ 02; Orienti+ 12)
- Multiple shocks?
- Turbulent acceleration (Fermi II type) may work
  - Polarization observation is a key to probe main acceleration mechanism

3C 445

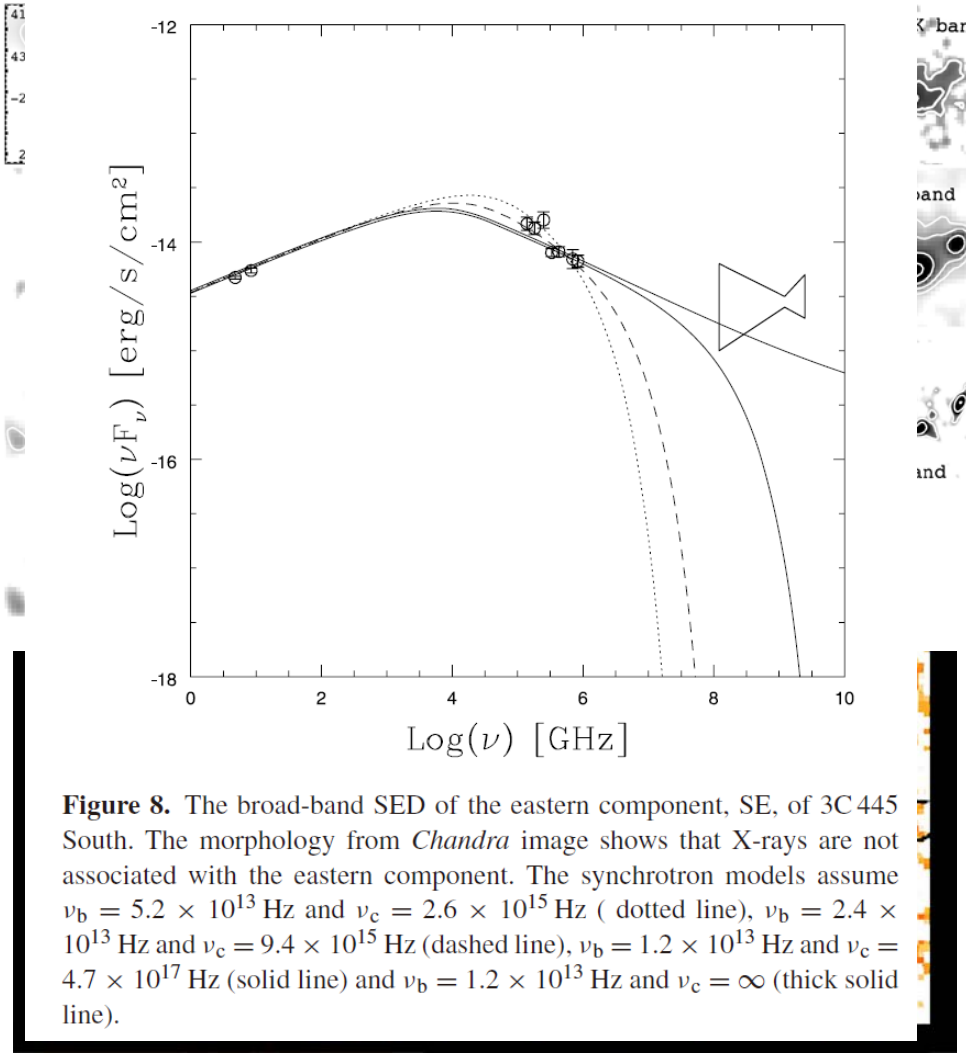


Figure 8. The broad-band SED of the eastern component, SE, of 3C 445 South. The morphology from *Chandra* image shows that X-rays are not associated with the eastern component. The synchrotron models assume $\nu_b = 5.2 \times 10^{13}$ Hz and $\nu_c = 2.6 \times 10^{15}$ Hz (dotted line), $\nu_b = 2.4 \times 10^{13}$ Hz and $\nu_c = 9.4 \times 10^{15}$ Hz (dashed line), $\nu_b = 1.2 \times 10^{13}$ Hz and $\nu_c = 4.7 \times 10^{17}$ Hz (solid line) and $\nu_b = 1.2 \times 10^{13}$ Hz and $\nu_c = \infty$ (thick solid line).

Prieto+ 2002

ALMA Obs.

- Two main spots are strongly polarized and parallel EVPA (perpendicular B-field), indicating strong shocks
- Little polarization between two main spots and northern region where the emission is visible up to IR and optical, indicating turbulent acceleration plays a role for the diffuse emission
- Similar studies by SPICA?
  - Angular resolution may not be sufficient…