Relativistic Jets From Supermassive Black Holes

(Radio Galaxies : One kind of exotic objects in the sky)

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Galaxies and their formation

1. Galaxy forms by gravitational collapse of a rotating protogalactic gas cloud.

2. The structure of galaxies are formed by the Galactic Dynamics.

3. There are three types of galaxies:
   a) spiral galaxies, b) elliptical galaxies and c) irregular galaxies

4) We live in a galaxy called the Milkyway Galaxy. This is a spiral galaxy.

5) All massive galaxies have a SuperMassive Black Hole (SMBH).

6) Our galaxy Milkyway has a SMBH of mass ~ 4 x 10^6 M_sun

Elliptical galaxy form via the merger of spirals

Irregulars are just irregulars

Various kinds of spiral and elliptical galaxies

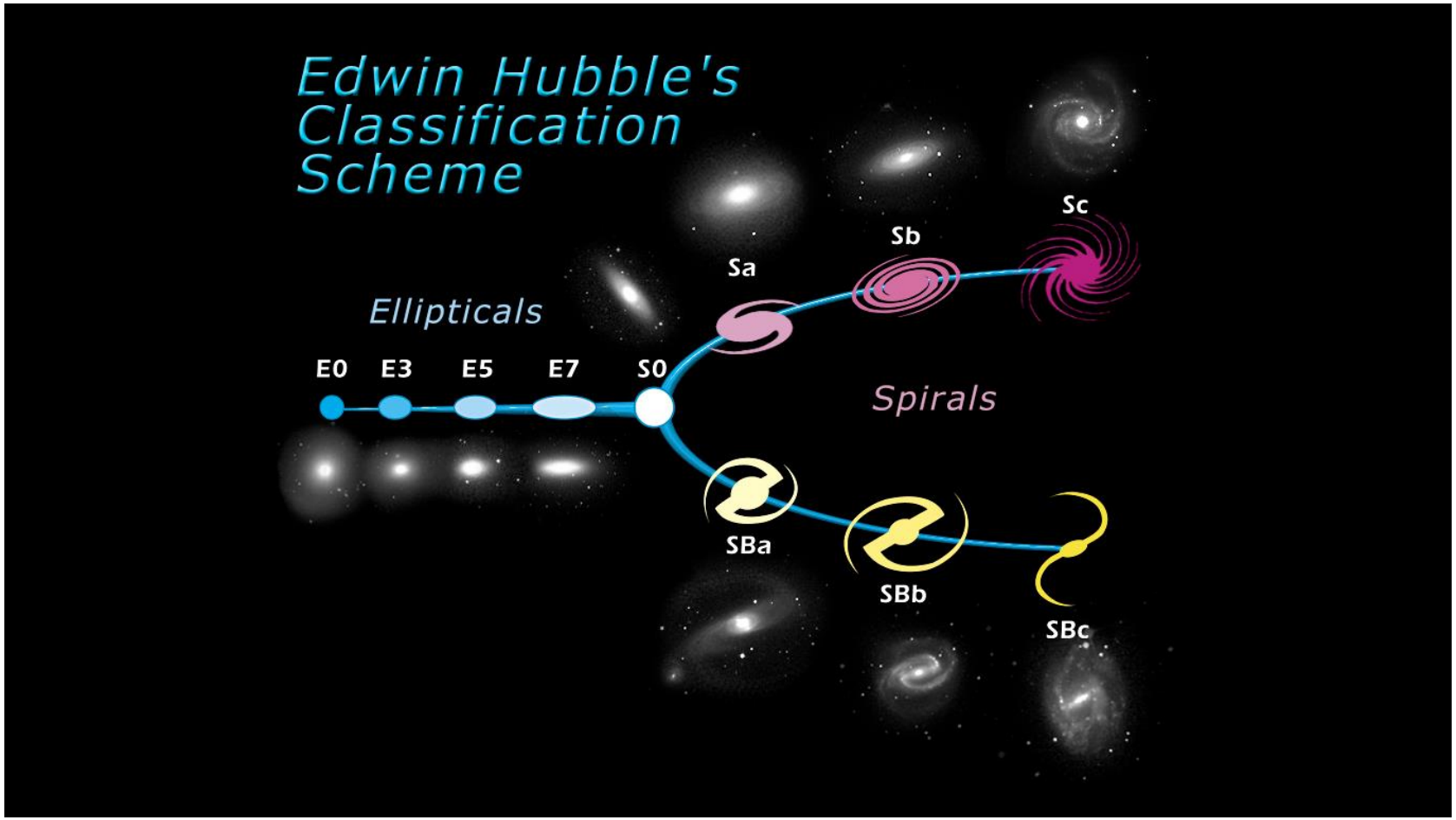
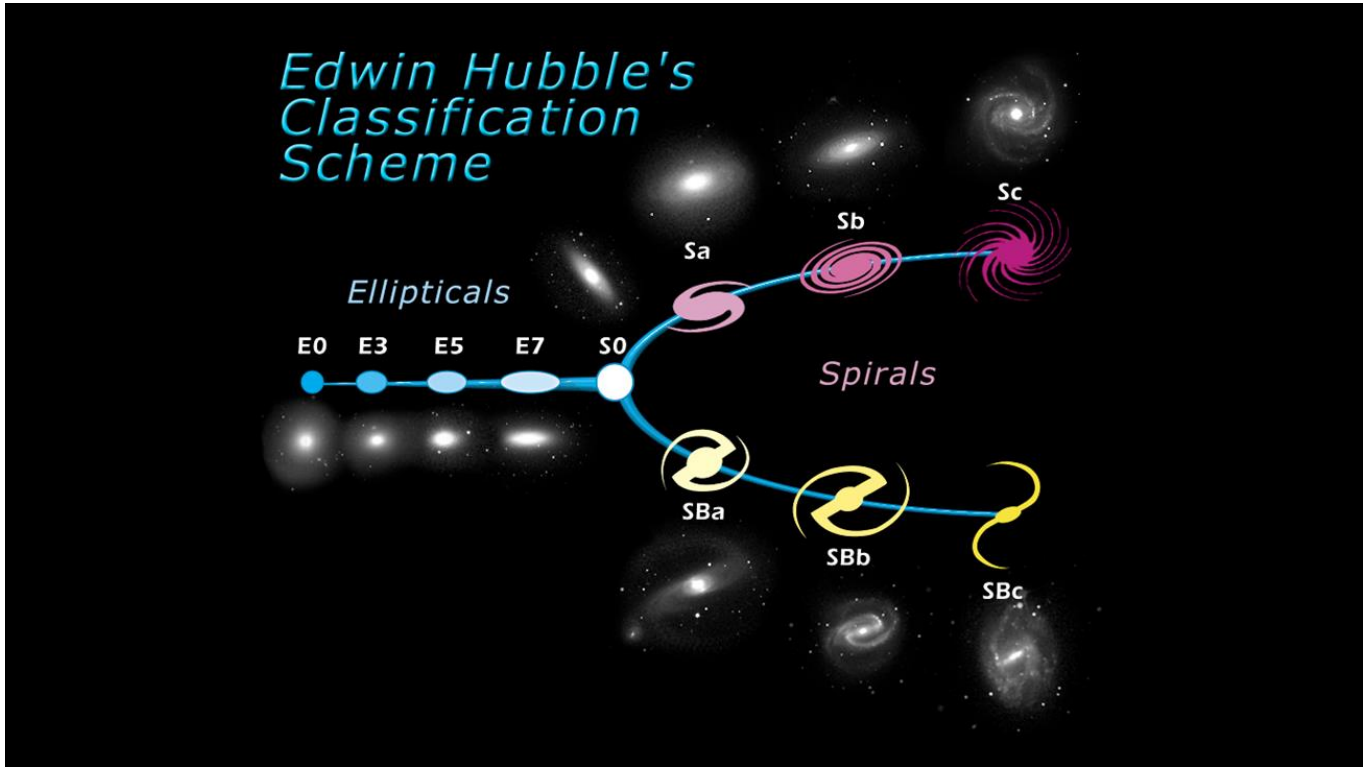


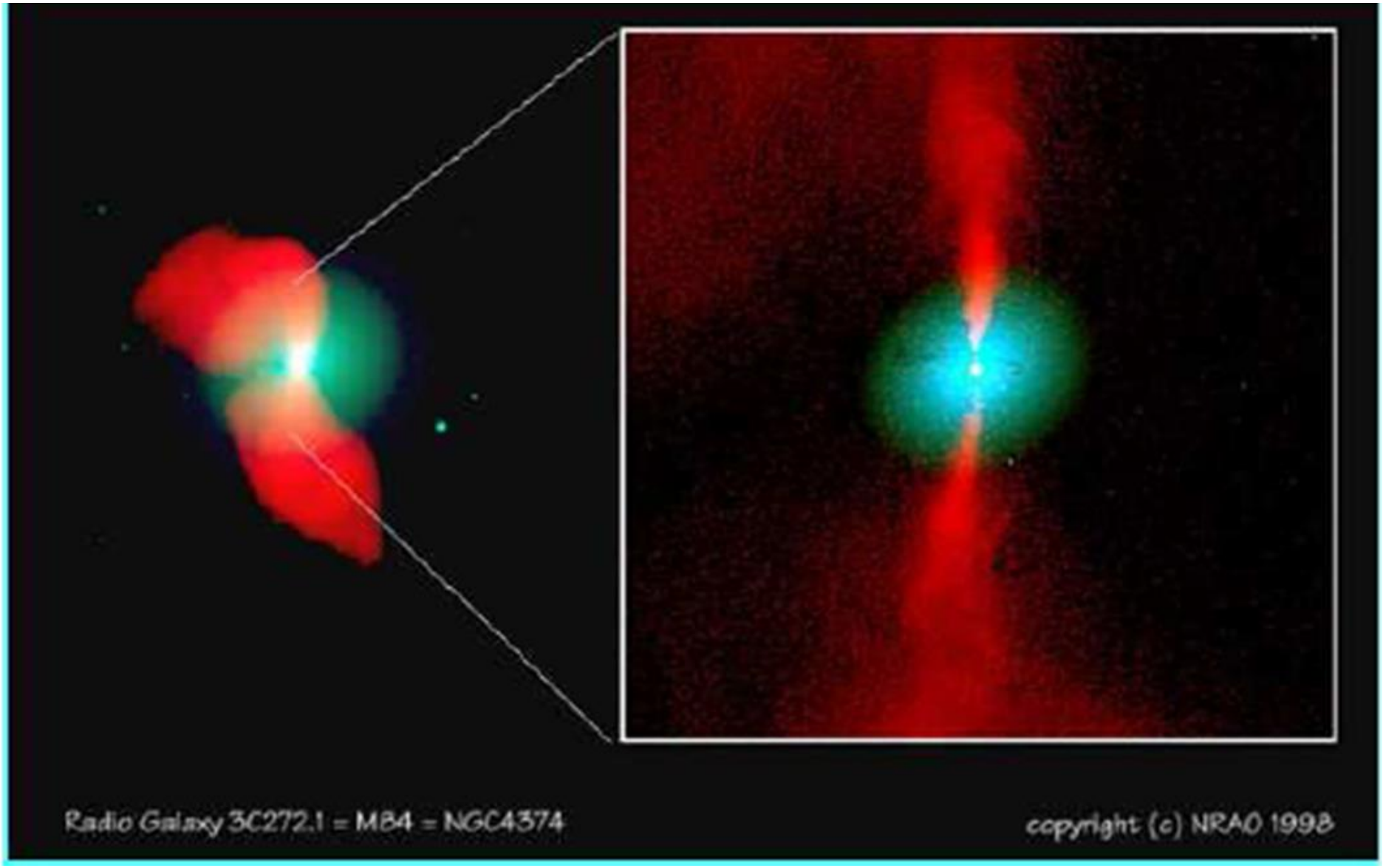
Image credit: Wikipedia

Elliptical galaxies are formed by the mergers of spirals

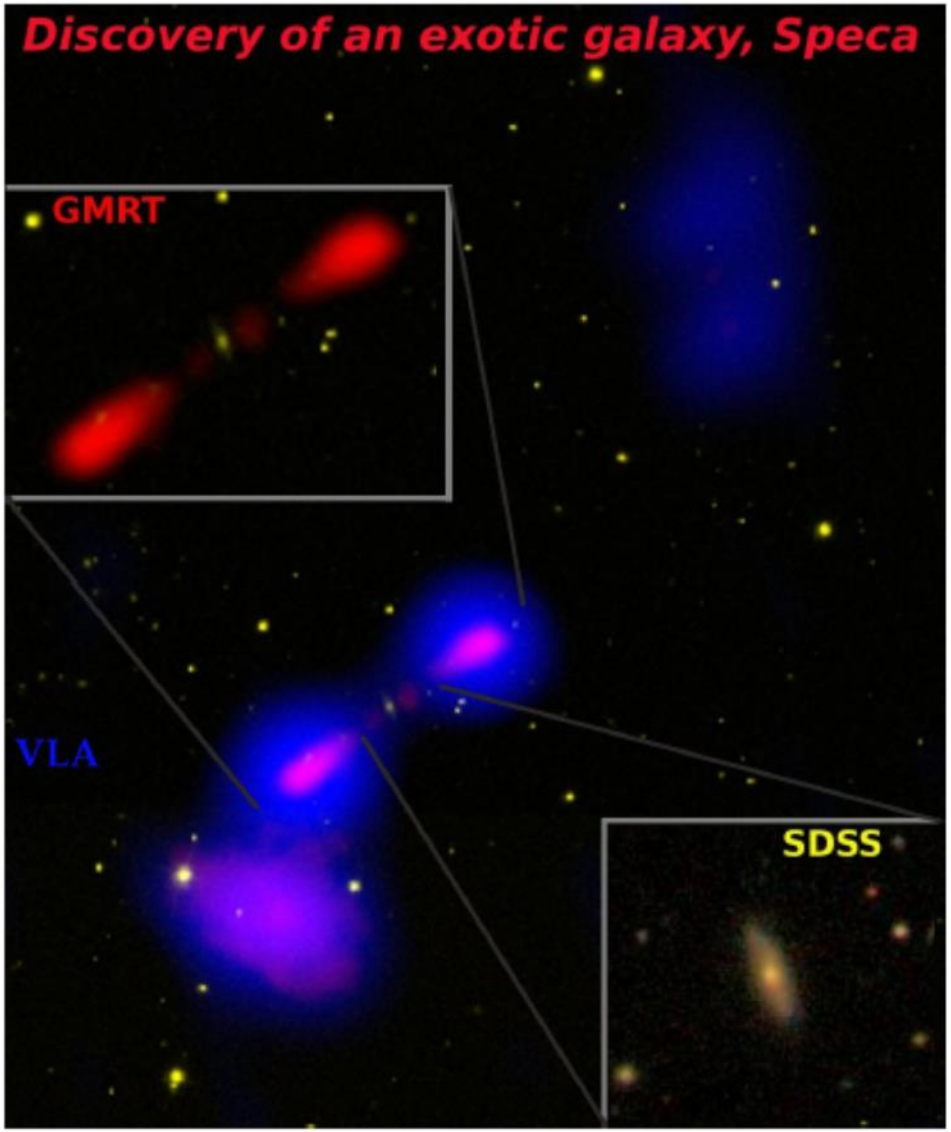


1. Initially we knew that only ellipticals launches radio galaxy phenomenon
2. Ledlow, Owen, Keel (1998), then Hota,..,.., Konar et al. (2011) showed that even spirals creates radio galaxy phenomenon. Relatively rare. Why?
3. Now the question is why RGs are not created by the barred spirals.
   (If citizen scientists find RGs in barred spiral, then the question is half solved.
   only rarity has to be explained.)

Most of the radio galaxies are hosted by the elliptical galaxies



Radio galaxy created by a spiral (disk) galaxy discovered by Hota,..,..,Konar et al. (2011)



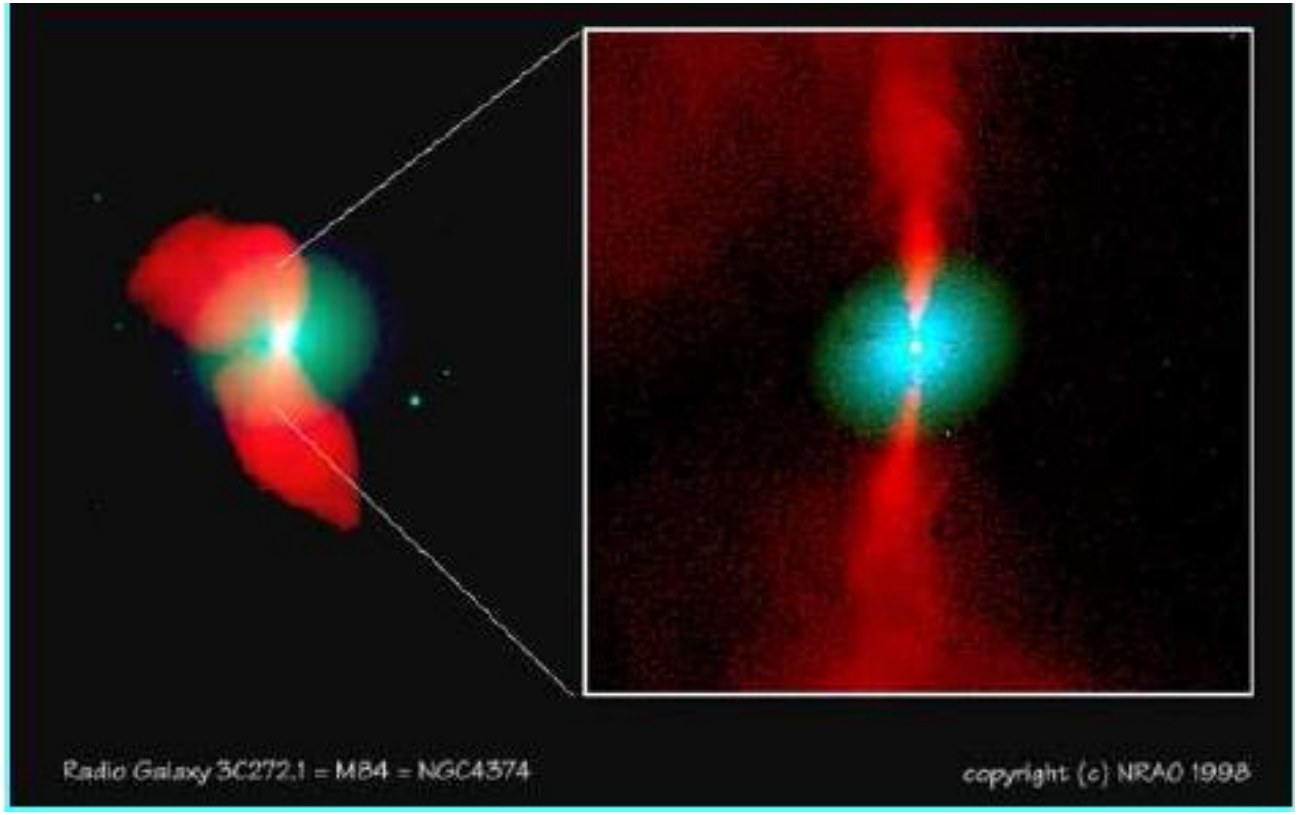
Spiral host radio galaxy: SPECA

What is basically a radio galaxy?

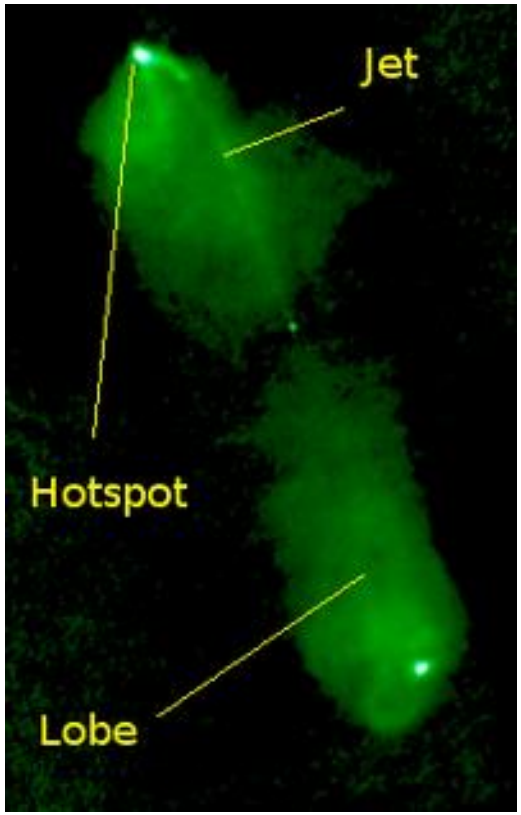
When

- the accretion is in suitable mode (as all AGNs don't form RGs)
- $M_{\bullet} >= 10^{8}\ M_{\odot}$ (Chiaberge & Marconi, 2011)
- the SMBH perhaps has the right amount of spin: ??

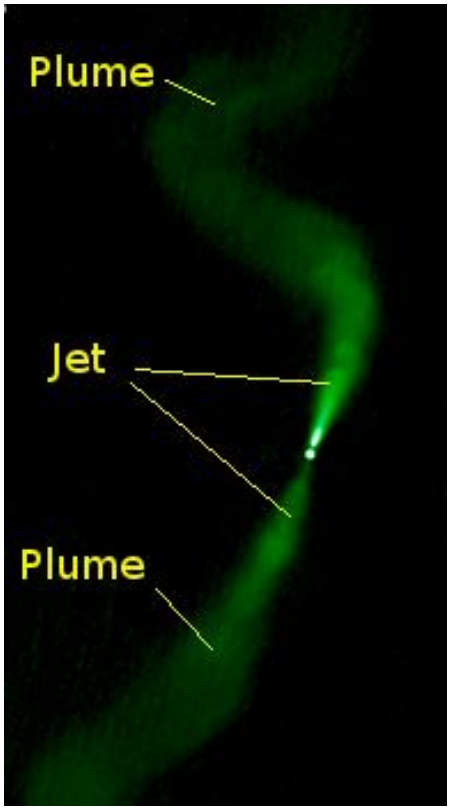
SMBH in ellipticals launches 100-kpc scale jets.



Radio galaxies: two types depending upon the collimation and the speed of the jets



3C 98 (FR-II RG)

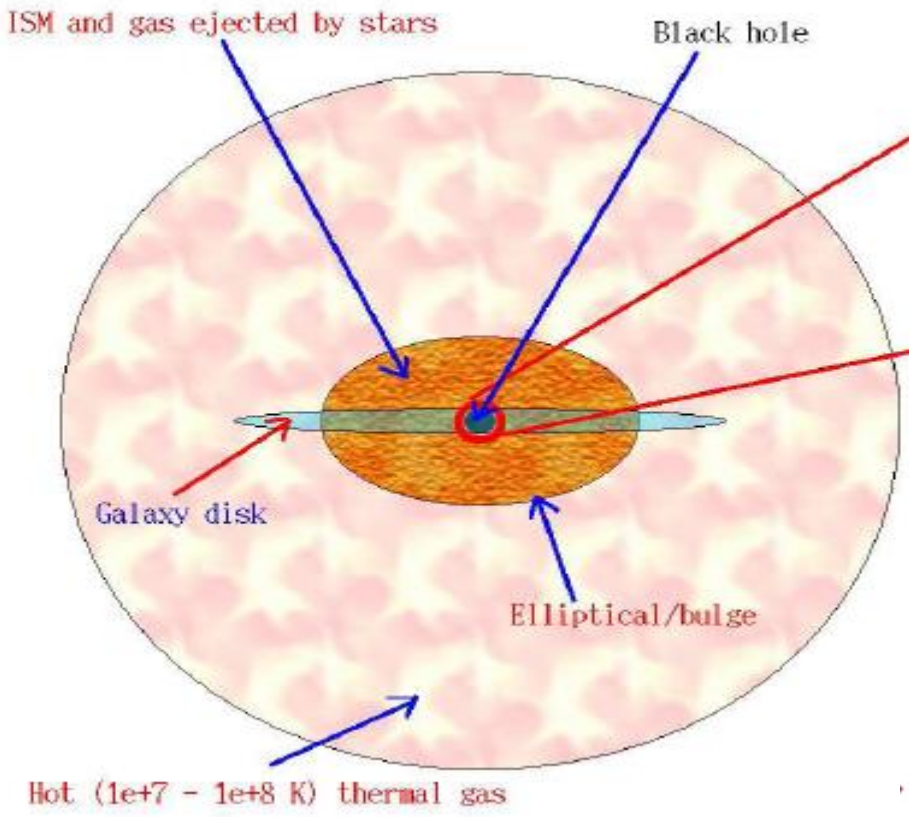


3C 31 (FR-I RG)

(Image courtesy: M.J. Hardcastle)

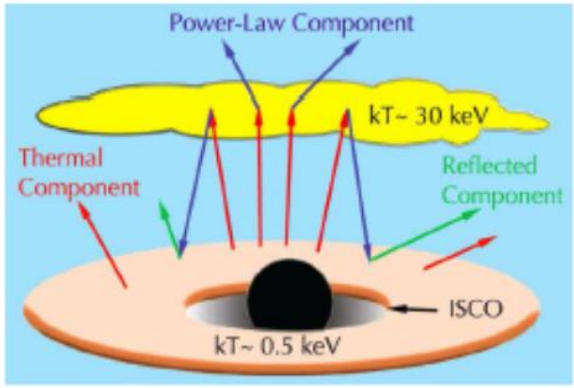
1. Hotspots are jet termination shocks
2. No such shocks in FR-I
3. Jet Lorentz factor is up to 10 (speed is close to c)
4. Core is the base of the jet
5. Lobe/plumes consists of electron-positron plasma. There are some protons that goes into plumes/lobes from the environment

The Central Engine System



$\beta-$model amb medium:

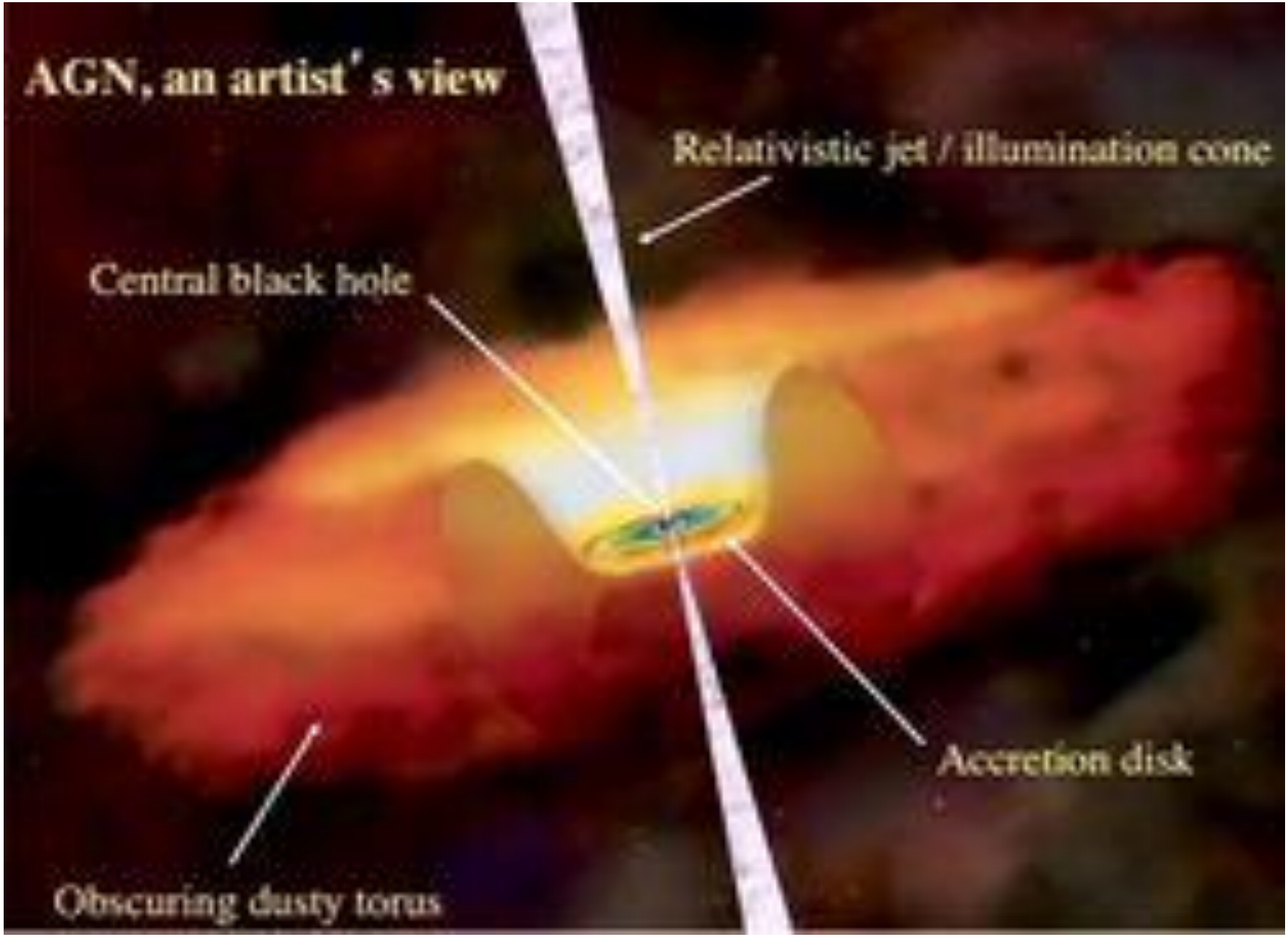
$$n_{\rm p}(r) = (1+\frac{r^2}{r_c^2})^{-\frac{3\beta}{2}}$$



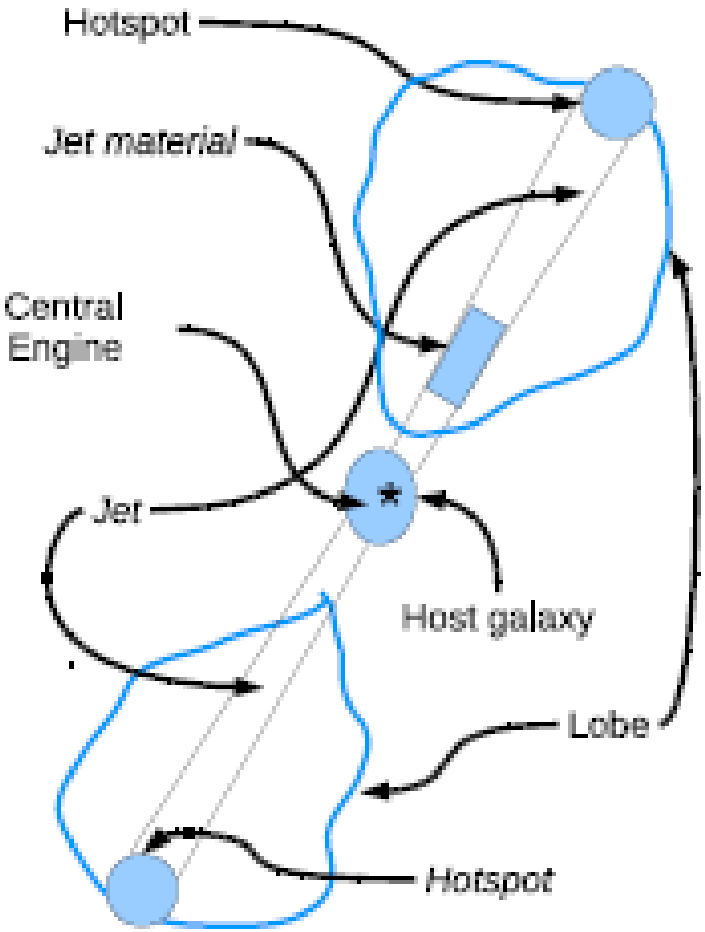
Keplerian motion: standard disk

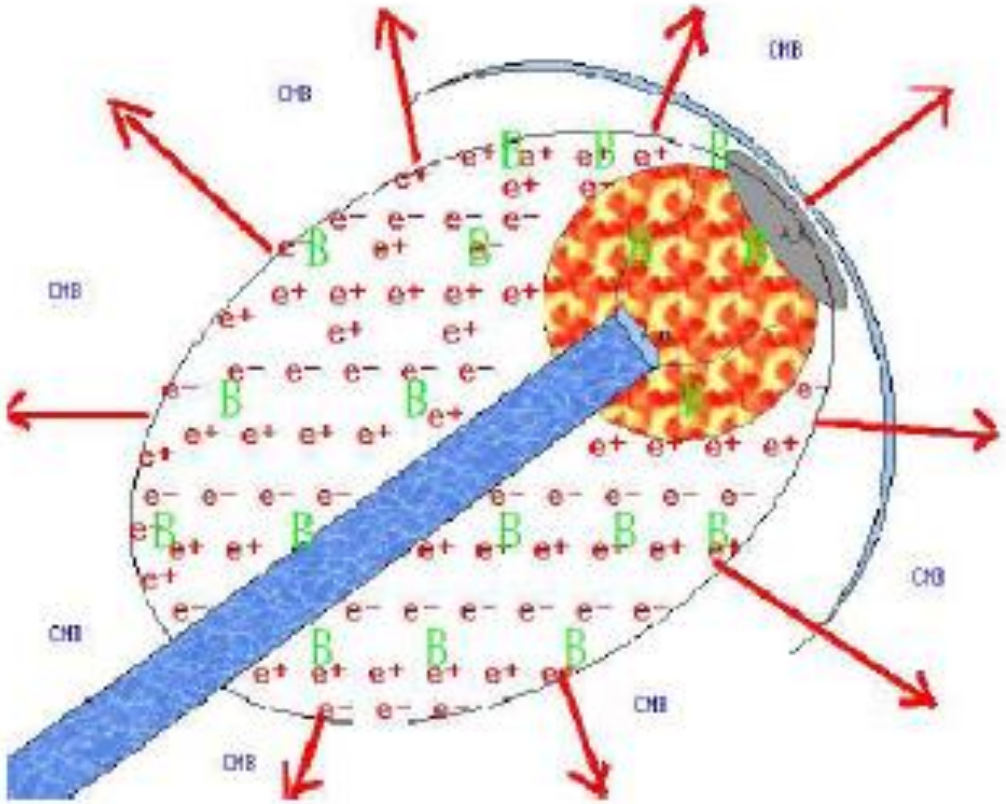
At the centre, there is (1) molecular torus, (2) Accretion disk and (3) SMBH

Schematic Picture of Central Engine of Radio Galaxies



Components and radiations

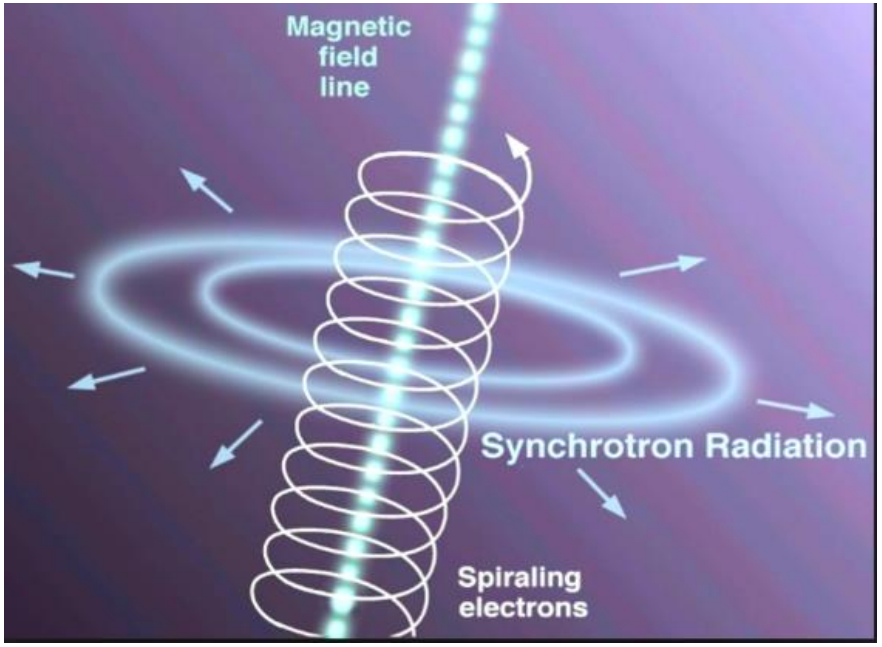


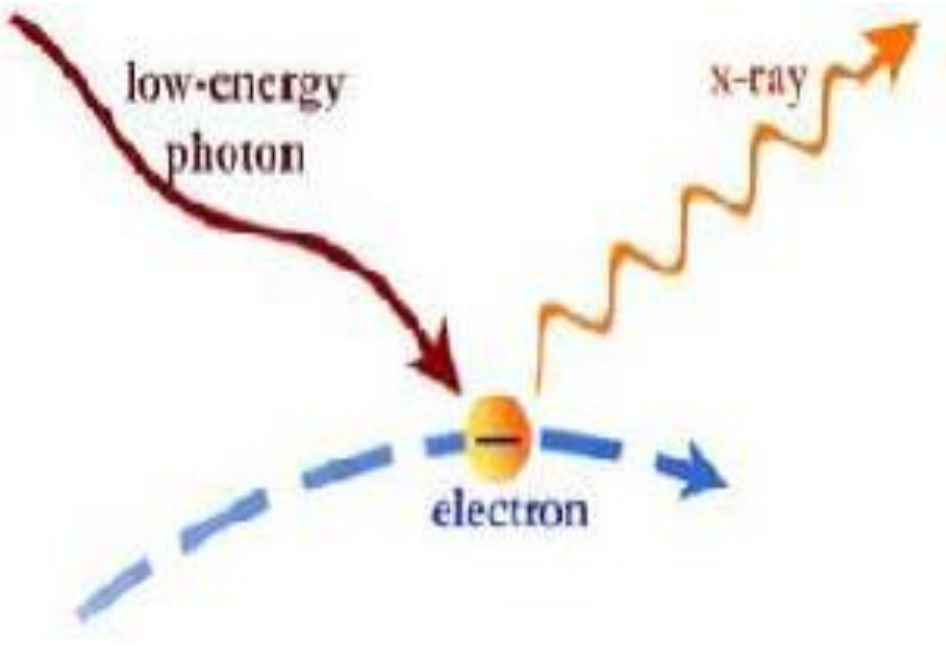


$$J_{\nu,\mathrm{syn}} = J_{\nu}(n_0, U_B)$$

$$J_{\nu,\mathrm{IC}} = J_{\nu,\mathrm{IC}}(n_0, U_{CMB})$$

Equipartition condition in the radio lobes can be checked





In Lobes

Typical no. density of particle = 10^{-4} - 10^{-10} cm^{-3}

N(E)dE = N_0 E^{-p} dE → power law distribution

The particles are not in equilibrium. We cannot define temperature in thermodynamic sense. However, energy density can be determined.

u = 10^{-7}- 10^{-11} erg cm^{-3}

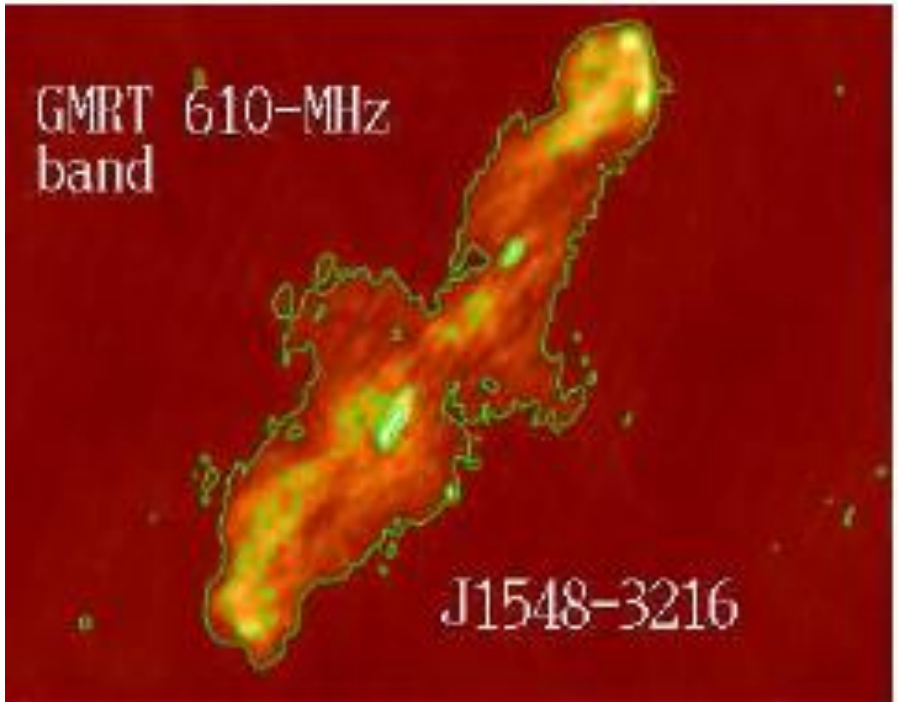
P_J = 10^{44}- 10^{46} erg/s

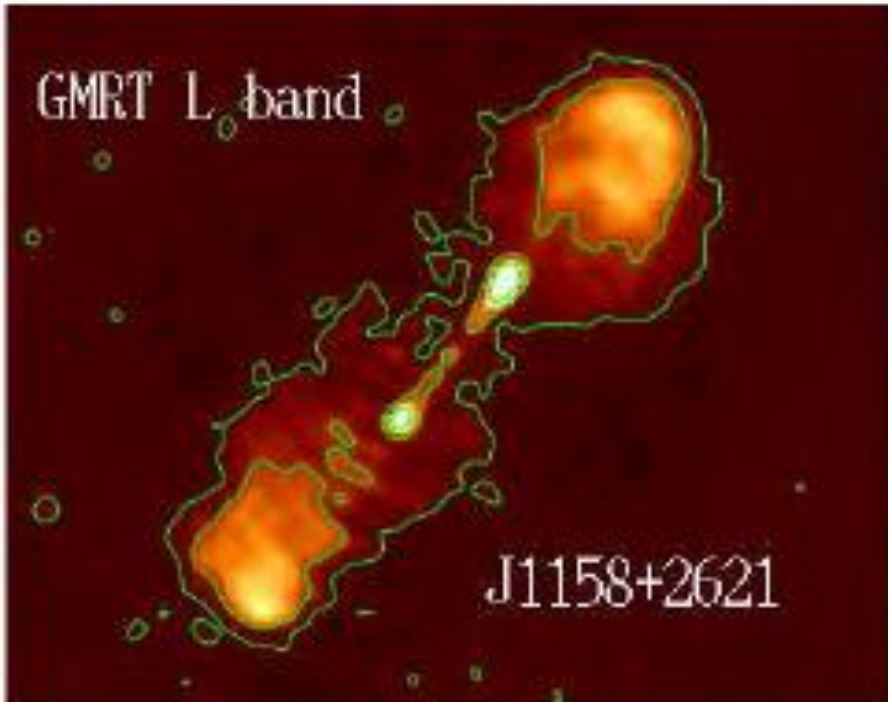
The jet formation from the SMBHs is episodic in nature

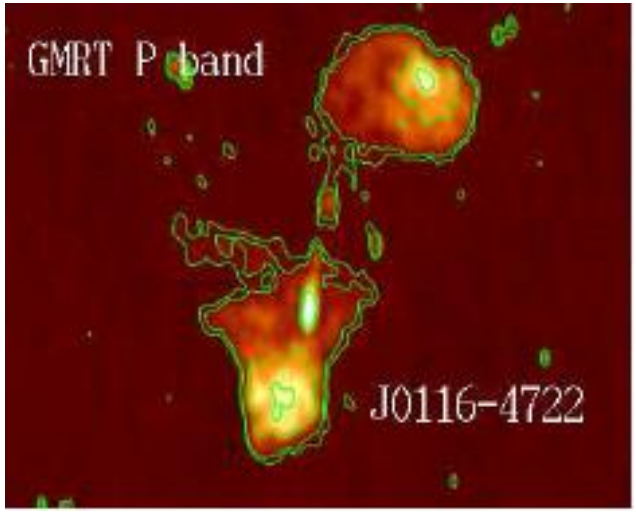
Multiple episodes gives rise to various kinds of morpho-logy of radio galaxies.

They are called double-double radio galaxies, triple-double Radio galaxies etc.

These are called DDRGs or Episodic Radio Galaxies







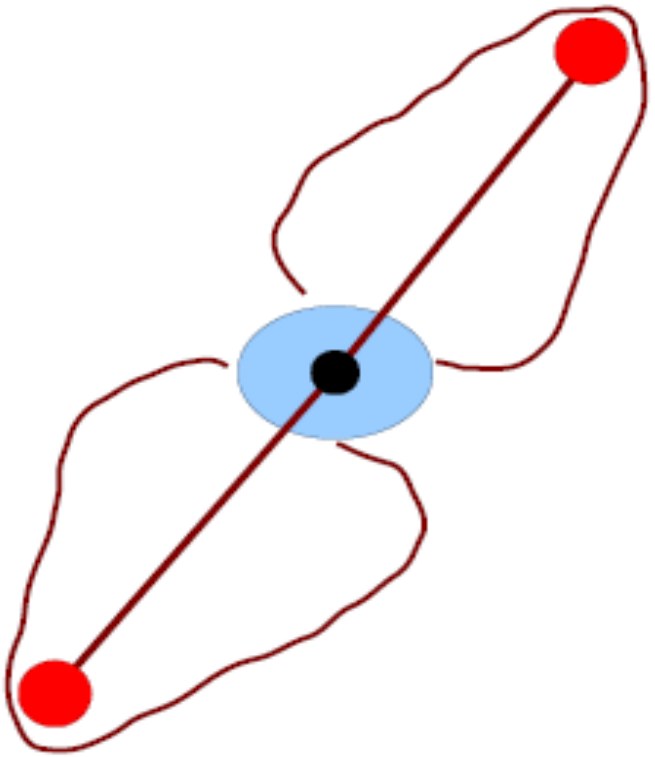
There are Triple Double Radio Galaxies also. That Means there are three episodes of jet activity.

How Episodic Radio Galaxies form

- A massive galaxy with SMBH

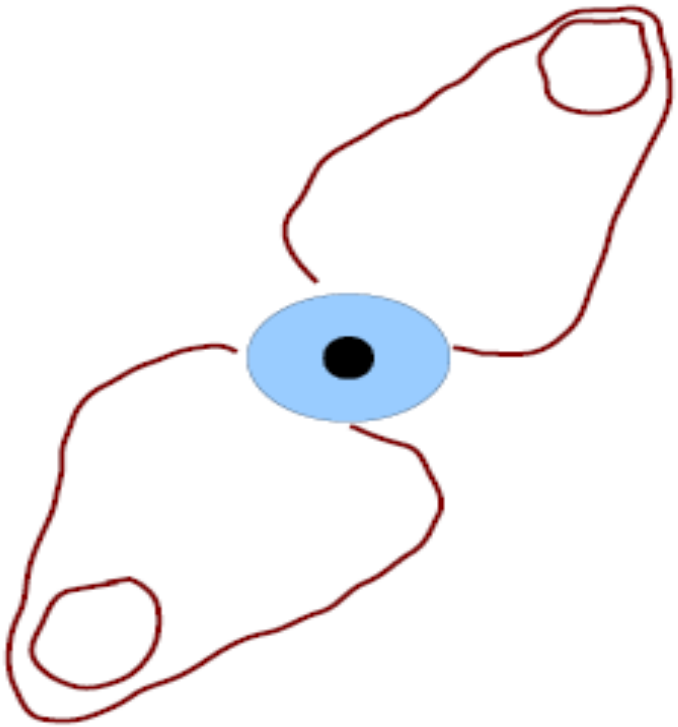
How Episodic Radio Galaxies form

- A massive galaxy with SMBH
- Launches kpc-Mpc scale jets



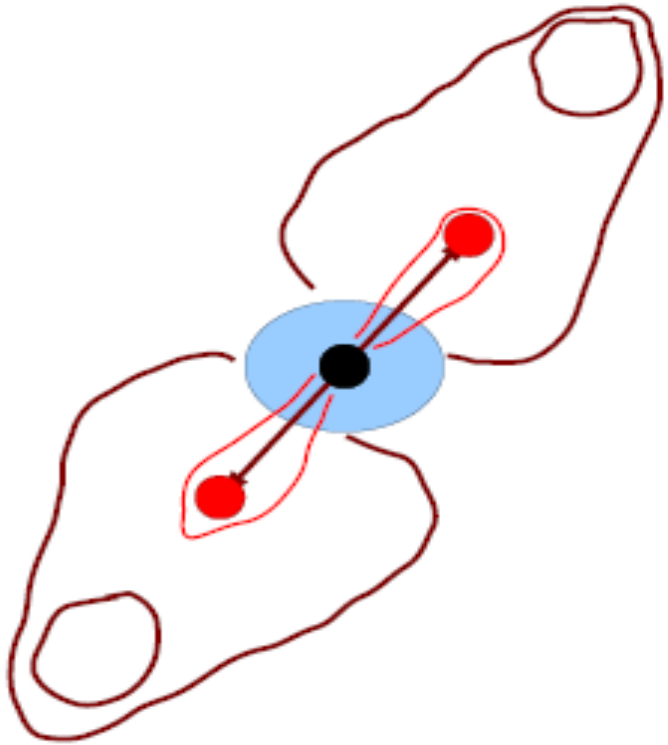
How Episodic Radio Galaxies form

- A massive galaxy with SMBH
- Launches kpc-Mpc scale jets
- Jet switches off, HS–>WS



How Episodic Radio Galaxies form

- A massive galaxy with SMBH.
- Launches kpc-Mpc scale jets.
- Jet switches off, HS–>WS.
- New jets starts, propagates thru cocoon matter of outer lobes.
- new jets forms JTS inspite of the tenuous ambient medium.
- Inner lobes seems to have back flow.



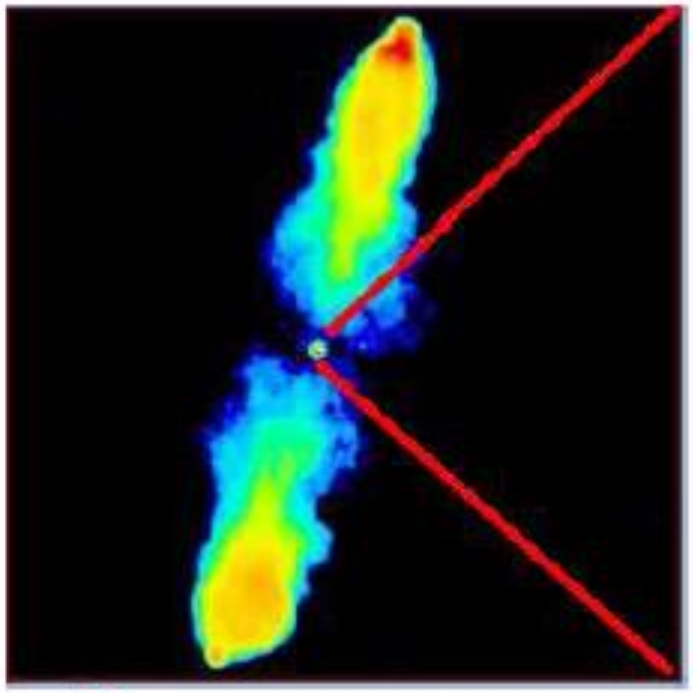
Mode of accretion in radio galaxies

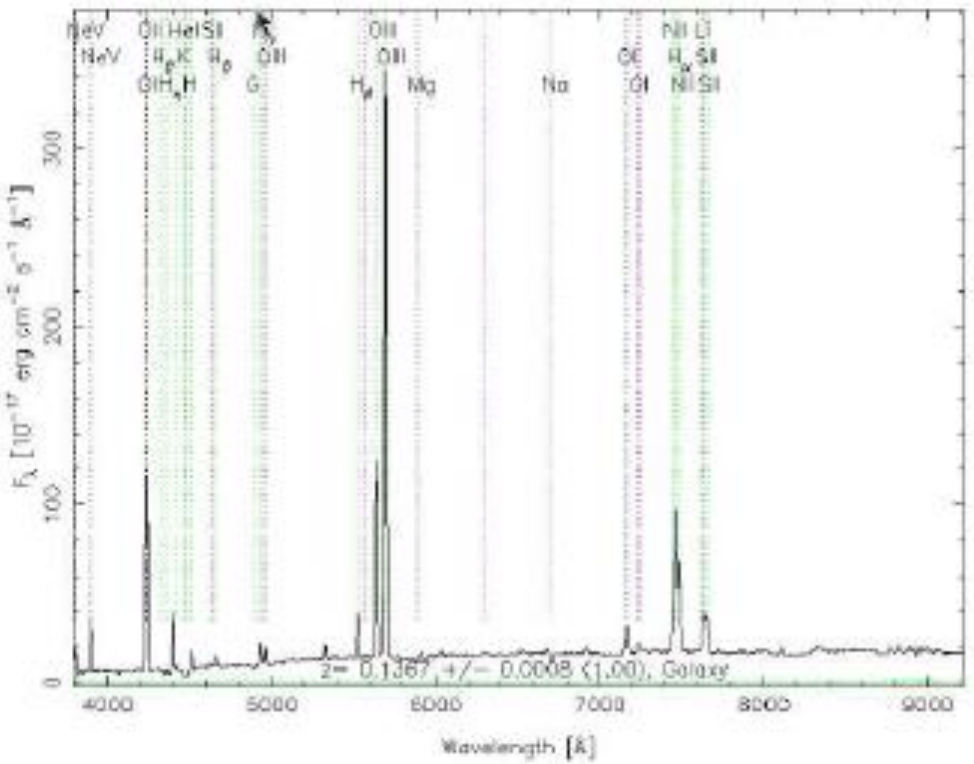
(See Hardcastle+, 2006, 2007; Allen+, 2006)

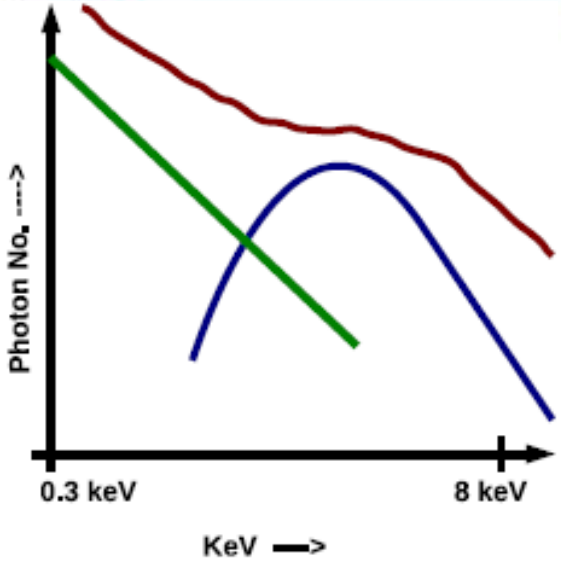
Two types of Radio Galaxies in terms of mode accretion:

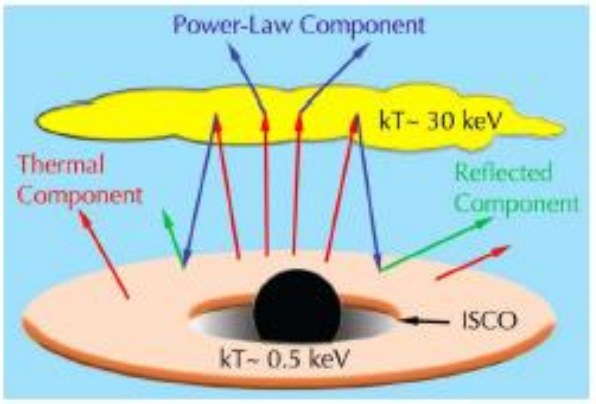
1) HERG
2) LERG

HERG: cold mode accretion



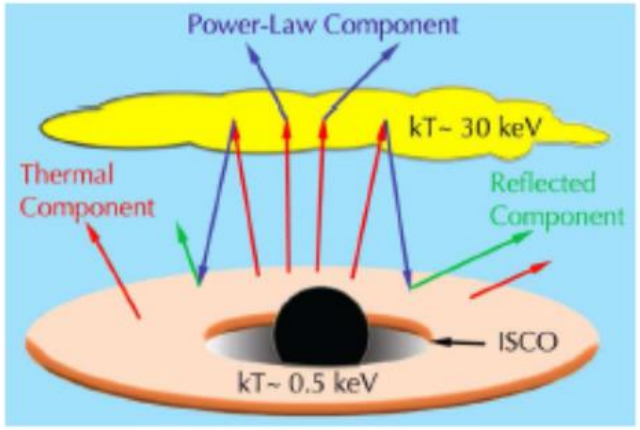




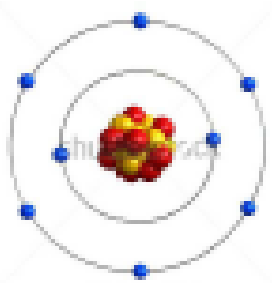


Keplerian motion: standard disk

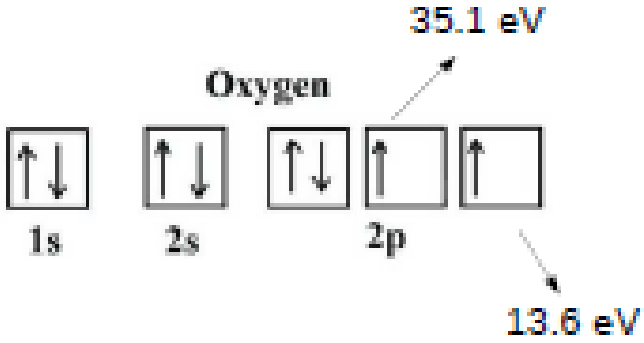
HERG: cold mode accretion



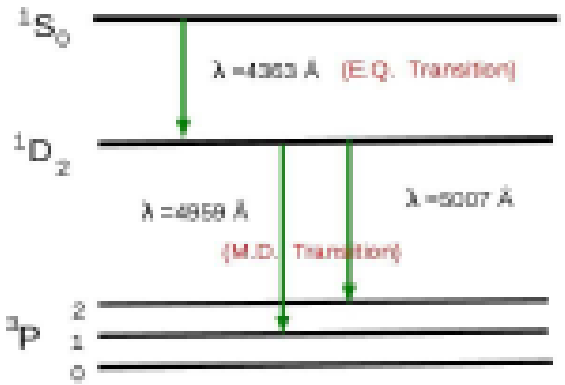
Keplerian motion: standard disk



Oxygen atom



Forbidden lines

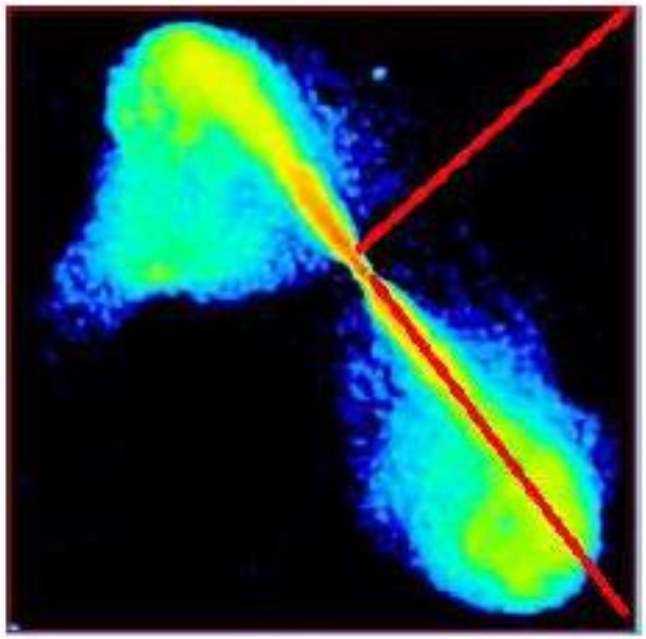


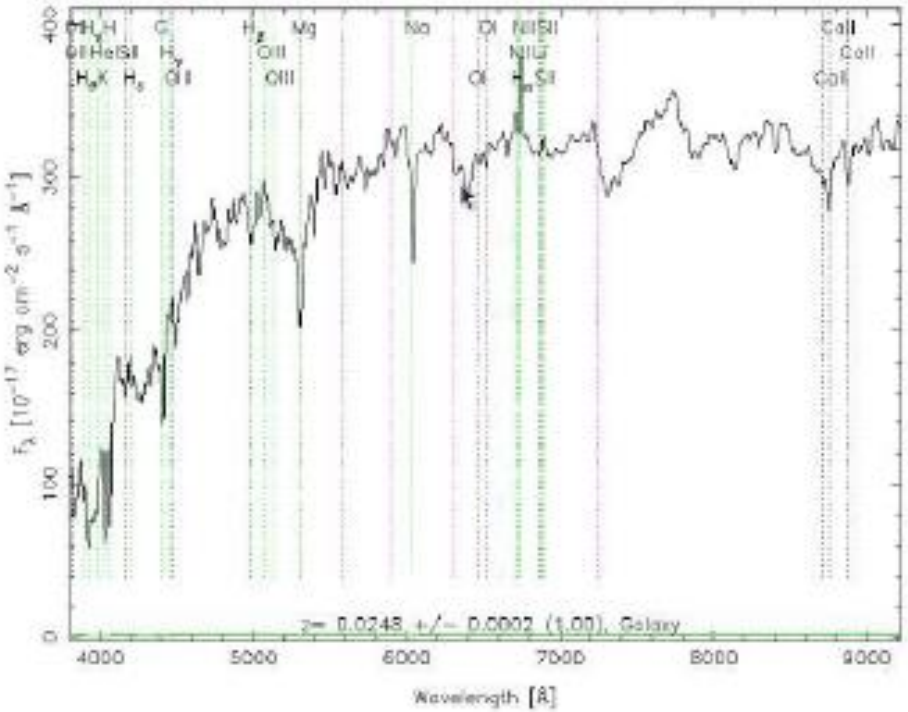
Lamda_1 = 4363 Angstrom

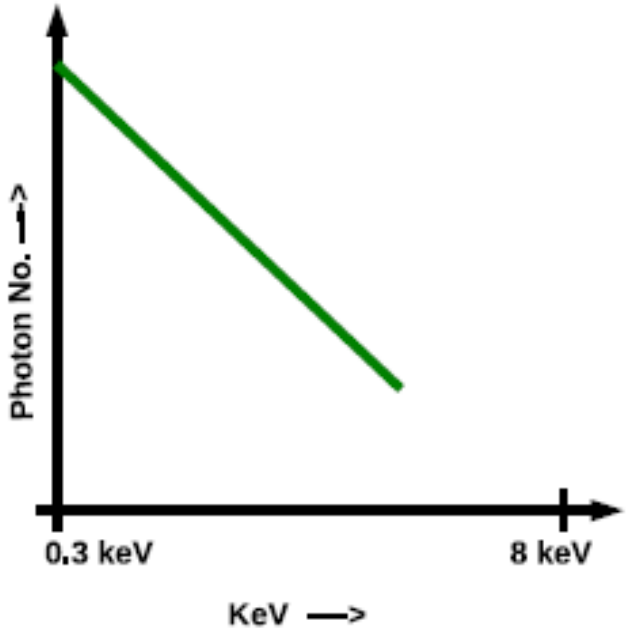
Lamda_2 = 4959 Angstrom

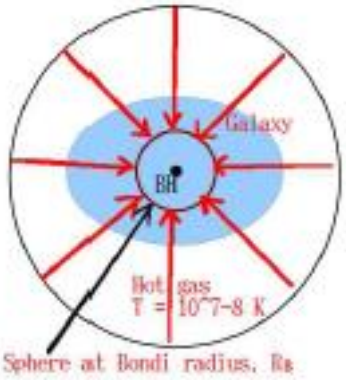
Lamda_3 = 5007 Angstrom

LERG: hot mode accretion









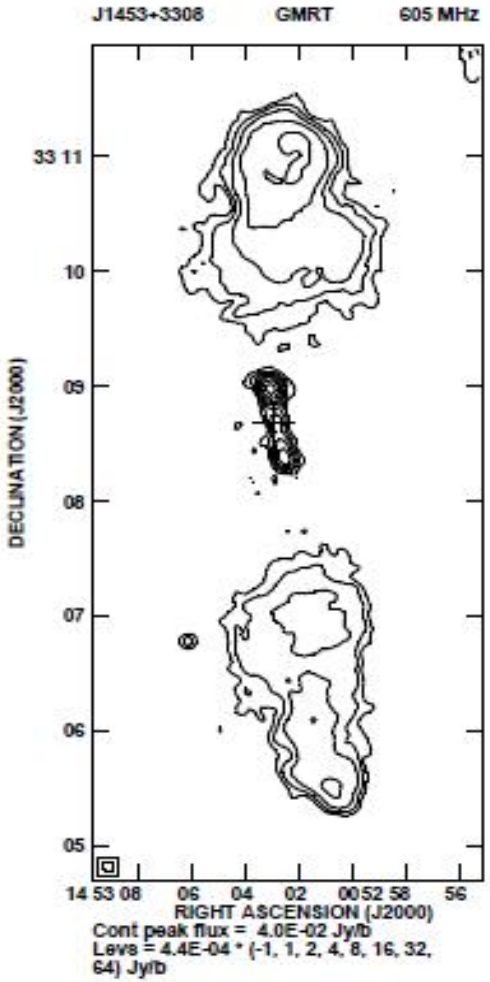
$R_B = 2GM_\bullet/C_s^2$

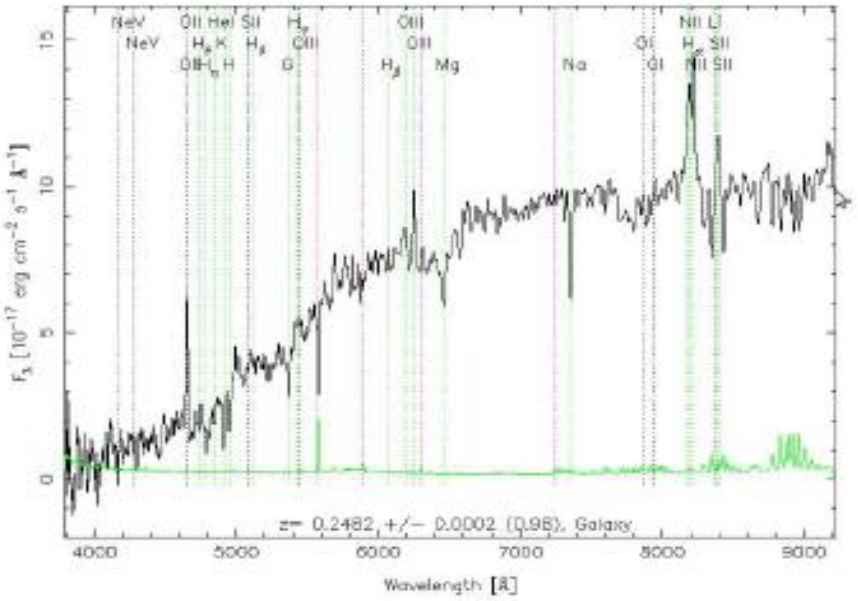
$$\frac{dM_B}{dt} = \frac{4\pi G^2 M_\bullet^2}{C_s^3}$$

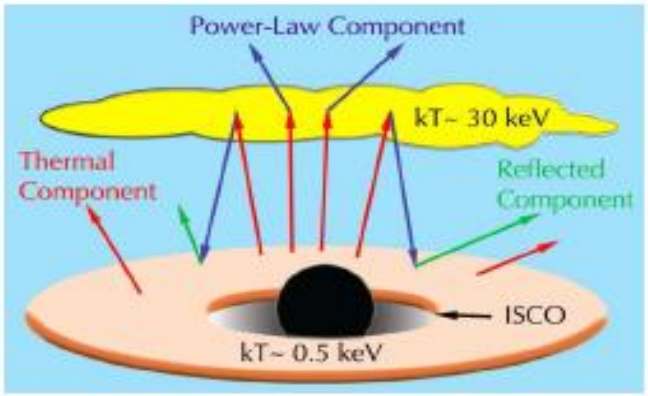
Sub Keplerian accrn flow: RIAF

Episodic Radio Galaxies show both the modes of accretion

Episodic HERG

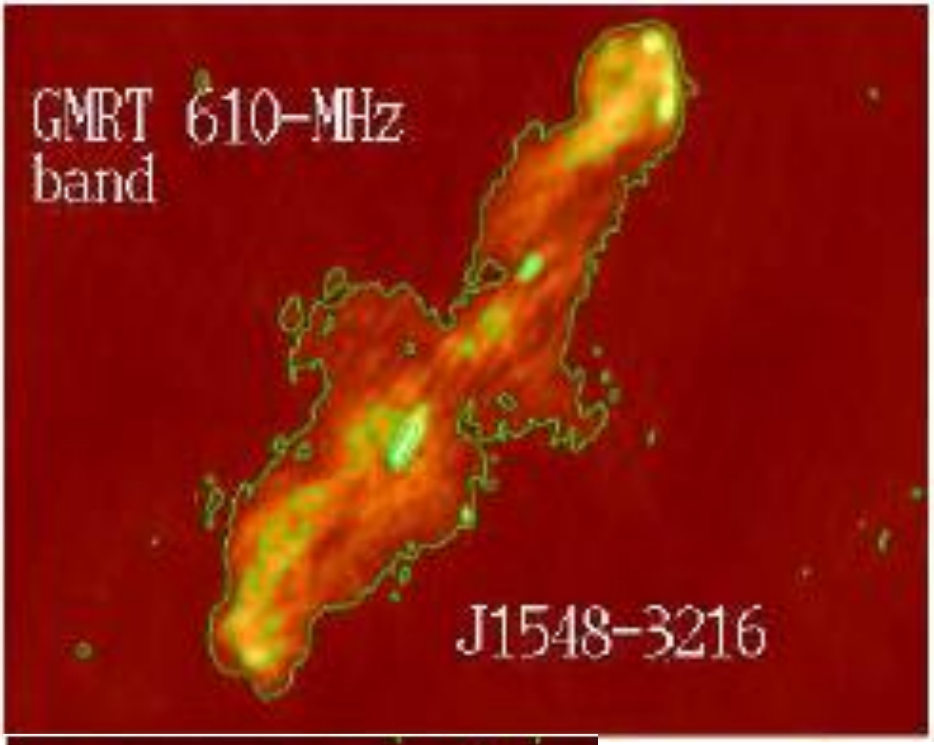


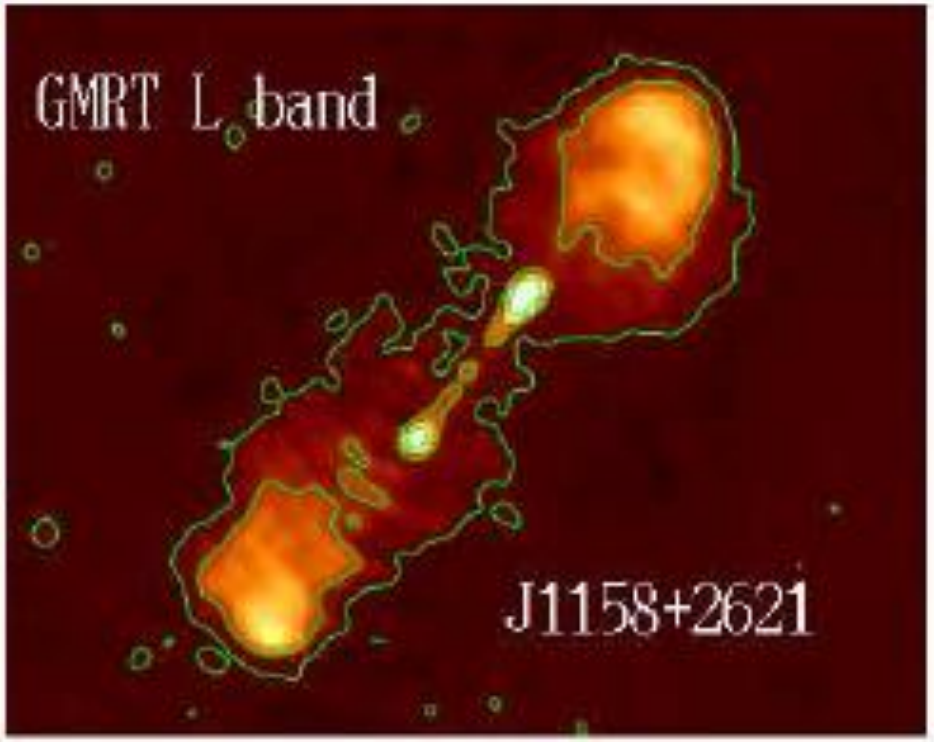


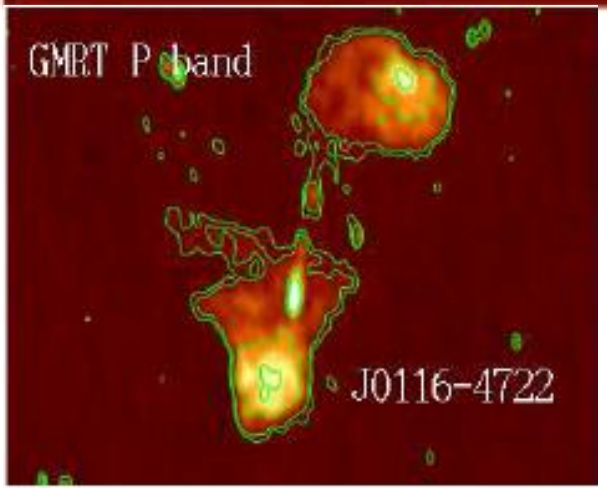


Keplerian motion: standard disk

Episodic LERG







(Z=0.1082, 0.1121, 0.1461)
No [OIII] lines, no hard power laws
Konar+, 2017, in prep

SUMMARY

1) A collection of stars form a galaxy (10^11 to 10^12 stars in a galaxy)

2) All massive galaxies are found to have evidence of BHs at their centres.

3) Mostly elliptical galaxies host radio galaxies, though a few spirals have been discovered to host radio galaxies.

4) Radio galaxies can be of two types in terms of morphology (FR-I & FR-II).

5) Radio galaxies can be of two types in terms of mode of accretion at the central engine (HERGs & LERGs)

6) Radio galaxies can be episodic in nature (DDRGs & TDRGs).

7) Episodic RGs can also be classified as FR-I/FR-II and HERG/LERG.

THANKS