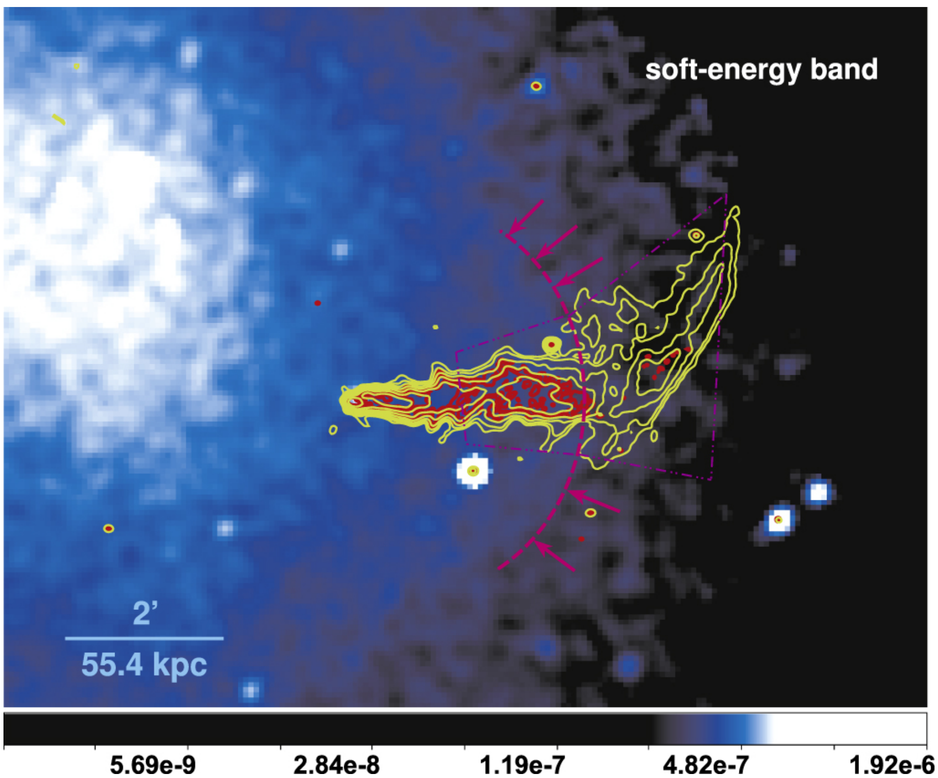
Lecture 26 : Radio Galaxies

Radio emission from an external galaxy was first detected around 1950 from the powerful galaxy Cygnus A. There was a suggestion that it was a 'double radio source'. This discovery catalyzed the quest for achieving higher angular resolution. This led to the discovery of "Aperture Synthesis" telescopes. Sir Martin Ryle in Cambridge was awarded the Nobel Prize for this discovery. Observations with high angular resolution revealed a remarkable morphology of 'Radio Galaxies'. There was a compact central source, presumed to be a super-massive black hole. There were two relativistic jets of particles emanating from the central source, and two gigantic 'lobes' of radio emission at both ends of the jet. This lecture is intended to be an introduction to the world of giant radio galaxies.



This is a low (radio) frequency image of the head-tail radio galaxy NGC 4869 in the Coma cluster obtained using the upgraded Giant Metrewave Radio Telescope (uGMRT). It shows the uGMRT images in green (250-500 MHz) and red (1050-1450 MHz), overlaid on a Chandra X-ray image. The red arrows indicate the location of the surface brightness edge. The two radio jets emanating from the apex of the host galaxy initially travel in opposite directions. As the galaxy plows through the dense intracluster gas, these jets form a trail behind the host galaxy due to interaction with the intracluster medium, forming a conical shaped feature centered on the nucleus. Subsequently, the two jets twist, wrap, overlap and eventually bend.
[Figure Credit : D. V. Lal, 2020, The Astronomical Journal, 160, 161]

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Prepared by Dr. Sushan Konar : ***sushan.konar@gmail.com***

Suggested Reading

1. Shu F.H., 1981, **The Physical Universe: An Introduction to Astronomy, Ch.13**, University Science Books
2. Burke B. F, Graham-Smith F. & Wilkinson P. N, 2019, **An Introduction to Radio Astronomy**, Cambridge University Press
3. Cart Westerhout, 1959, Sci. Am., 201, 2, 44-51
   The Radio Galaxy
4. Readhead A. C. S., 1982, Sci. Am., 246, 6, 52-61
   Radio Astronomy by Very -Long-Baseline Interferometry
5. Townes C. H. & Genzel R., 1990, Sci. Am., 262, 4, 46-55
   What is Happening at the Center of Our Galaxy?

Suggested Problems

1. **Radio Astronomy**

   Assume that the Green Bank radio telescope, with a diameter of 100 m, is observing the radio source 3C147 at a frequency of 4750 MHz. The part of the spectrum which is amplified (we call it the bandwidth) is 100 MHz wide. How much power (in Watts) is delivered to the receiver? You may assume that all radiation incident on the antenna is delivered to the receiver. In the parlance of radio astronomy, this would correspond to an aperture efficiency of 100%.

   Most cell phones send and receive 4G data at a wavelength of around 1900 MHz. The "low-power" transmitter on a cell phone can transmit up to around 2 W of power, transmitted over a bandwidth of 30 kHz. With a radio telescope on Earth observing at 1900 MHz, what flux density would you observe for an actively emitting cell phone if it is placed on the moon? (Consider the cell phone to be an isotropic emitter.)

   The angular resolution, θ, of a telescope is approximately equal to $1.22\lambda/D$, where λ is the wavelength at which it is operating and D is the diameter of the aperture (or antenna). It has been discussed in the lecture how using VLBI (very large D) at millimeter wavelengths it is possible to achieve microarcsecond resolution. Is it possible to decrease the operating wavelength indefinitely (say, go to the optical or X-ray regime)?

   Around the globe, $\sim$40 radio telescopes of (average) diameter 25 m operating since 1960. Assume that the power received by each is 10^{16} W over this time. How much energy does this amount to? Compare this to the energy released by the falling of an ash ($\sim$1 g) from a cigarette 2 cm above

2. **Relativistic Doppler Effect**

   A space probe moves away from Earth at a speed of 0.35c. It sends a radio message back to Earth at a frequency of 1.50 GHz. At what frequency is the message received on Earth?

   A source of sodium D2 line of wavelength $\lambda = 5890^{\circ}$ A is moving on a circle with a constant speed 0.1c. Find the change in wavelength for an observer at the centre.

   [The light arriving from distant galaxies is shifted toward lower frequencies. This is called "the reddening of galaxies".] an ashtray.

3. Superluminal Motion

The apparent superluminal speed, as observed by Astronomers, is basically the angular speed multiplied by the distance to the radio source which turns out to be larger than the speed of light. In the diagram below, we consider a radio galaxy at a distance D from the observer. Neglecting the source (host galaxy) motion relative to the observer, let us focus on the motion of only a single blob on a radio jet. We shall assume that that the blob and the nucleus continuously emit radio waves so that they can be observed.

The blob moves at a velocity v with respect to the galactic nucleus (and the observer) starting at time $t = 0$. Show that the observer sees the blob coincident with the galaxy source at time $t_0 = D/c$ corresponding to $t = 0$. Show also that the observer sees the blob with transverse displacement $vtsin\theta$ from the galactic nucleus at the time -

$$t_r = t + \frac{1}{c}(D - vtcos\theta) \quad (1)$$

Show that the elapsed time for the observer is -

$$t_r - t_0 = t(1 - \beta cos\theta) \quad (2)$$

where $\beta = v/c$. The apparent transverse velocity of the blob relative to the nucleus, $v_{\mathrm{apparent-transverse}}$, equals the transverse displacement divided by the time difference observed for the displacement to occur. Show that this leads to -

$$\beta_{\mathrm{apparent-transverse}} = \frac{\beta \sin\theta}{1 - \beta\cos\theta} \quad (3)$$

Plot this formula for the following values: $\beta = 0.5$ and 1.0 (a special case) and $\gamma = 2, 3, 4, 5, 7, 16$. Show that the maximum transverse velocity is obtained for $\cos\theta = \beta$ (and thus $\sin\theta = \sqrt{1-\beta^2} = 1/\gamma$), and that the maximum apparent transverse velocity is

$$\beta_{\mathrm{apparent-transverse-max}} = \frac{\beta}{\sqrt{1-\beta^2}} = \beta\gamma \quad (4)$$

and that plot (generated before) agrees with this. Note that for the critical angle and $\gamma >> 1$, the transverse speed is roughly $v_{\mathrm{apparent-transverse-max}} \simeq \gamma c$.