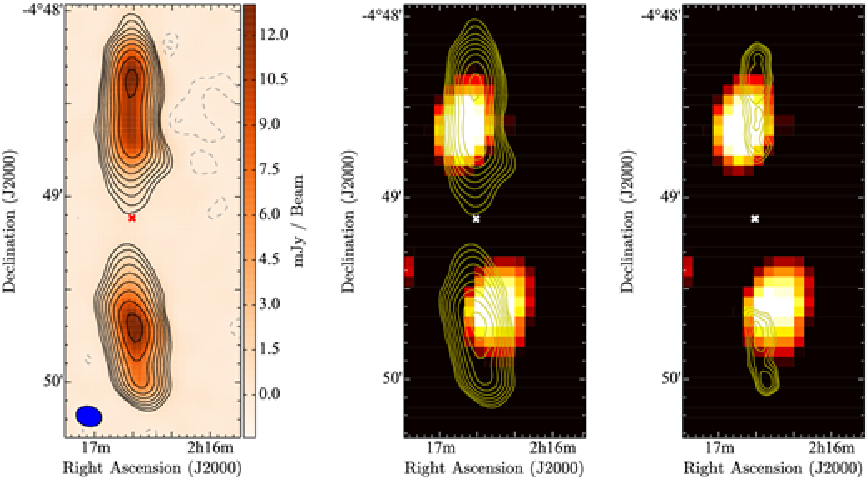
Extragalactic Astronomy II

Lecture 8

Yogesh Wadadekar

Apr-June 2021

High z radio galaxies - X-ray emission from lobes



Why is there X-ray emission from the lobes?

Tamhane et al. (2015)

CMB photons

How does the space density of CMB photons change with redshift?

CMB photons

How does the space density of CMB photons change with redshift?

$a(z) = a_0/(1+z)$

CMB photons

How does the space density of CMB photons change with redshift?

$a(z) = a_0/(1 + z)$

How does the energy of a single photon change with redshift?

CMB photons

How does the space density of CMB photons change with redshift?

$a(z) = a_0/(1+z)$

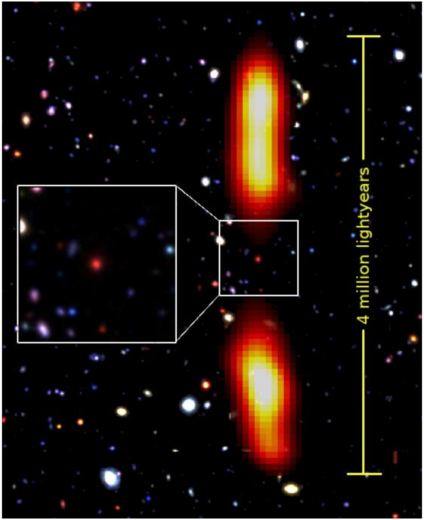
How does the energy of a single photon change with redshift?

$\nu_o = (1+z)\,\nu_e$

At $z = 1.3$, the redshift of the Tamhane et al. (2015) galaxy, we have

$(1+z)^4 \approx 28$

Identifying optical counterparts can be challenging in relic



Tamhane et al. (2015)

Can we determine the age of the lobe in some some fashion?

Spectral ageing makes the following assumptions:

- the magnetic field strength is constant Observed to change

Can we determine the age of the lobe in some some fashion?

Spectral ageing makes the following assumptions:

- the magnetic field strength is constant Observed to change
- no mixing; each segment or slice of the lobe is regarded as a discrete element of plasma evidence for backflows

Can we determine the age of the lobe in some some fashion?

Spectral ageing makes the following assumptions:

- the magnetic field strength is constant Observed to change
- no mixing; each segment or slice of the lobe is regarded as a discrete element of plasma evidence for backflows
- the radiative lifetime of the synchrotron particles in the plasma is much longer than the age to measured Mostly true

Can we determine the age of the lobe in some some fashion?

Spectral ageing makes the following assumptions:

- the magnetic field strength is constant Observed to change
- no mixing; each segment or slice of the lobe is regarded as a discrete element of plasma evidence for backflows
- the radiative lifetime of the synchrotron particles in the plasma is much longer than the age to measured Mostly true
- each element of plasma has a power law distribution in energy measurements across many frequencies show that there is curvature.

If these assumptions are true then...

a break appears in the radio spectrum of each element of the plasma which evolves with time as

$$\nu_B \propto \frac{1}{B^3 t^2}$$

where B is the magnetic field strength within the element and t is the time elapsed since the energy distribution was accelerated to its deemed power law distribution. A correction is made to account for the effect of CMB IC effects on the equivalent magnetic field.
But the characteristic frequency is $\nu_c \propto B\gamma^2$. At a fixed observing frequency we observe either low B, high γ sources or vice versa.

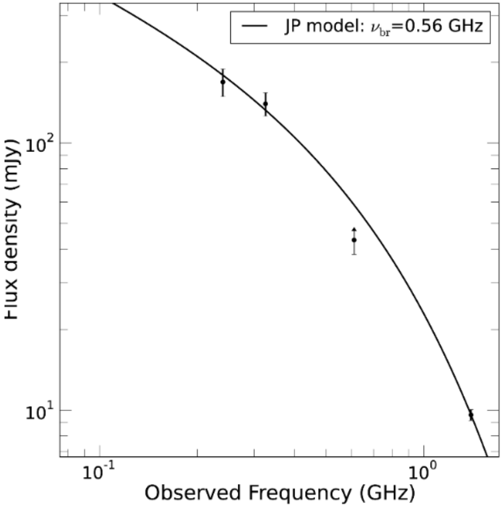
How do we measure the magnetic field?

- using polarisation. But is it strong enough to be measured reliably? Also the length scale on which the magnetic field is aligned, determines our ability to measure it.

How do we measure the magnetic field?

- using polarisation. But is it strong enough to be measured reliably? Also the length scale on which the magnetic field is aligned, determines our ability to measure it.
- energy equipartition between energy of cosmic rays and the magnetic field.This too has problems because it requires us to know the ratio of the total energy of cosmic ray protons to synchrotron emitting electrons (or positrons). From radio polarisation observations of spiral galaxies, we know that equipartition holds only roughly.

Spectral ageing



KP model (Kardashev 1962; Pacholczyk 1970). JP model; Jaffe & Perola 1973

How ageing models work

Assuming the 4 assumptions are valid and for various assumption like "Continuous injection", passive evolution etc. of the lobes, and a measurement of the magnetic field, and multiband flux measurements spanning a large range of radio frequency, it is possible to determine a break frequency and thereby an age for the lobes. Given the many uncertainties, the modeled age is only a rough indicator of the true age.

Question

What are the mechanisms by which electrons can loose energy in the lobes?

Question

What are the mechanisms by which electrons can loose energy in the lobes?

- synchrotron 'cooling'
- IC losses
- adiabatic cooling

Which of these change the shape of the radio spectrum?

Assignment 1

will be put on the website early next week. You will have 3 weeks to submit it. I will send you an email when the assignment is uploaded.

Eddington ratio

For matter to be able to fall in, the condition for energy production – the radiation force must be smaller than the gravitational force. For each electron there is a proton, and these two kinds of particles are electromag- netically coupled. The gravitational force per electron-proton pair is given by:

$$F_{grav} = \frac{GM_{BH}m_p}{r^2}$$

For accretion to happen,

$$F_{rad} < F_{grav}$$

$$\frac{\sigma_T L}{4\pi r^2 c} < \frac{GM_{BH}m_p}{r^2}$$

Eddington limit - an upper limit on luminosity

$$L < \frac{4\pi G c m_p}{\sigma_T} M_{BH}$$

$$L_{edd} \approx 1.26 \times 10^{38} \left(\frac{M_{BH}}{M_{\odot}}\right) \mathrm{erg\ s}^{-1}$$

Since σ_T is independent of photon frequency, the luminosity above is the bolometric luminosity.

Eddington limit - an upper limit on luminosity

$$L < \frac{4\pi G c m_p}{\sigma_T} M_{BH}$$

$$L_{edd} \approx 1.26 \times 10^{38} \left(\frac{M_{BH}}{M_\odot}\right) \mathrm{erg\ s}^{-1}$$

Since σ_T is independent of photon frequency, the luminosity above is the bolometric luminosity.

Our galaxy has a radio luminosity of 10^{37} erg s^{-1}, how far is it from Eddington luminosity?

Eddington mass - a lower limit on mass

$$M_{edd} = \frac{\sigma_T}{4\pi G c m_p} L \approx 8 \times 10^7 \left(\frac{L}{10^{46} \mathrm{erg/s}} \right) M_\odot$$

For luminous AGNs, like QSOs, typical masses are $M \gtrsim 10^8 M_\odot$, while Seyfert galaxies have lower limits of $M \gtrsim 10^6 M_\odot$.

Assumption about radiation

In our calculation of the Eddington luminosity of AGN, we have have made an implicit assumption which may not be true. What is this assumption?

Assumption about radiation

In our calculation of the Eddington luminosity of AGN, we have have made an implicit assumption which may not be true. What is this assumption?

We assumed that the emission of radiation is isotropic. Luminosities exceeding the Eddington luminosity can be obtained, if the emission is highly anisotropic. A geometrical concept for this would be, for example, accretion through a disk in the equatorial plane and the emission of a major part of the radiation along the polar axes. Models of this kind have indeed been constructed. It was shown that the Eddington limit may be exceeded by this, but not by a large factor. Due to SR effects, measured luminosity may depend on the direction of observation.

Eddington accretion rate

$$\dot{m} = \frac{L}{\epsilon c^2} \approx 0.18 \frac{1}{\epsilon} \left(\frac{L}{10^{46} \mathrm{erg/s}} \right) M_{\odot}/\mathrm{yr}$$

maximum efficiency is of order 0.1, this implies accretion rates of typically several Solar masses per year for very luminous QSOs.
We can define

$$\dot{m_{edd}} = \frac{L_{edd}}{\epsilon c^2} \approx \frac{1}{\epsilon} 2 \times 10^{-9} M_{BH} \mathrm{yr}^{-1}$$

Also, by definition $\dot{m} L_{edd} = \dot{m_{edd}} L$

How fast can be the SMBH grow?

$$\frac{M_{BH}}{\dot{m}} \approx \epsilon \left(\frac{L}{L_{edd}} \right)^{-1} 5 \times 10^{8} \mathrm{yr}$$

Assuming $\epsilon \sim 0.1$, the mass of an SMBH can be built up rapidly.

Is there any other way to grow a SMBH?