Extragalactic Astronomy II

Lecture 1

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Apr-June 2021

Course Website

http://www.ncra.tifr.res.in/∼yogesh/agn2021/

Best way to reach me is by email at *yogesh@ncra.tifr.res.in*
The PDF file for each lecture will be put on the website immediately after it is given. So, don't bother copying stuff that is already on the slide.

Introductions

Please introduce yourself stating your name, where you are from and where you did your master's degree and if you are a student of IUCAA/NCRA/University.

Assessment

- 60% weightage for 2 assignments to be given to you at the end of the third week and the sixth week. Roughly 2.5 weeks time to hand in each assignment.
- 30% weightage for an online seminar towards the end of the course
- 10% for class participation. Asking and answering questions

Assignments

Assignments gain you the majority of marks. So spend enough time on them. Some assignment problems will require modest amount of computer scripting and use of some plotting software. Make sure that you are comfortable with computer programming. Good time to learn, if not!

I strongly recommend Python for programming – specifically numpy for fast array computation and matplotlib for plotting

Seminar

The purpose of the seminar is to pick one seminal paper in the field of AGN which you will explain to the rest of us in about 20 minutes. Each one will speak about a different paper. I will provide a list of papers to choose from, on the website.
The seminars will be held towards the end of the course (end June).

The official syllabus

Phenomenology of AGNs (Seyferts, Quasars, Radio Galaxies, LINERS, BL Lacs) with a survey of continuum, emission and absorption features of spectra - Black hole and accretion disc models for AGNs - Emission line regions (BLR, NLR) - Physics of jets and hot spots.

I will cover all of these topics, but also go a bit beyond to talk about the implications of AGN physics to galaxy evolution. Will focus more on areas being worked upon at NCRA and IUCAA.

This course has linkages to several astronomy courses

Obviously to galaxies, Electrodynamics and radiative processes, GR and SR, ISM/IGM and some radio techniques.

Textbooks and reference material

- I will put up a list of some textbooks and review articles on the website.
- I put in a lot of effort to make slides for my talks. Use these as your starting point and remember to stop me and ask questions if you don't understand something at any point. Don't wait till the end of the lecture.
- Some of the slides will cite papers which you are encouraged to read to know more. This is particularly important for this course, where the extant literature is very vast.

Questions about the course content and organisation?

Light from normal galaxies

For normal galaxies in the optical and near infrared, part of the spectrum is dominated by **stars**, with smaller contributions from gas and dust. This radiation is thermal i.e. it can be well approximated by the Planck spectrum. Spectrum of a galaxy is well described by a linear superposition of black body spectra (with temperatures spanning 1 dex), modulated by dust.

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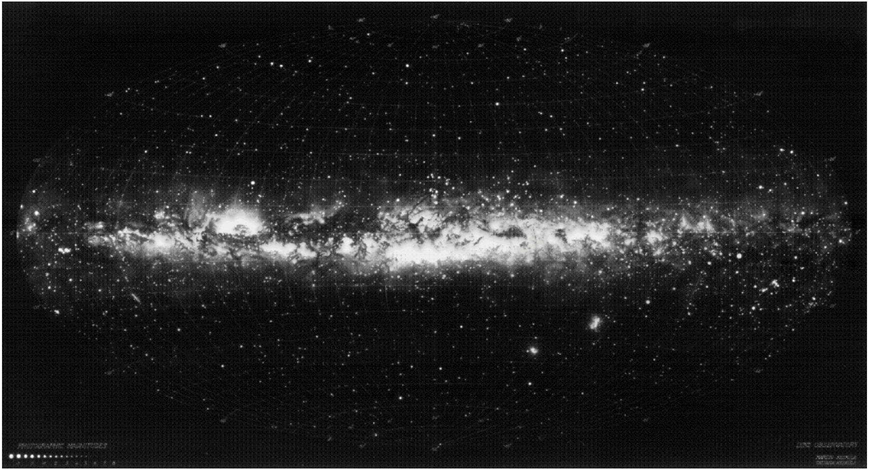
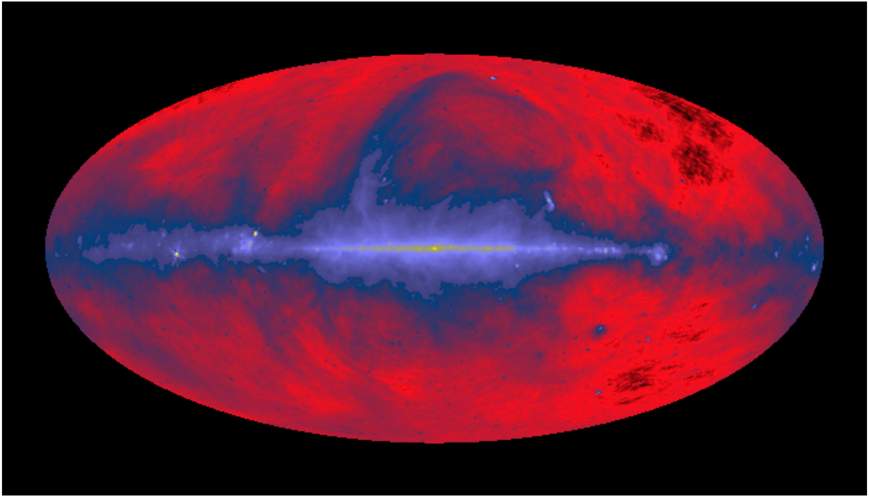
For AGN, light is a mix of both thermal and non-thermal processes.

The optical sky



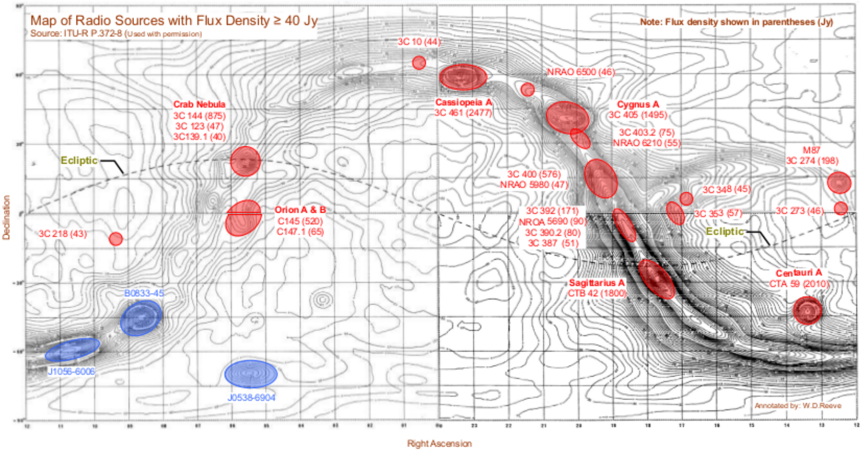
dominated by stars, ionised gas, dust (absorbtion)

The radio sky at 408 MHz



dominated by pulsars, supernova remnants, star-forming regions, and active galaxies - e.g. NGC 5128, Sagittarius A*.

The brightest radio sources



Cas A, Crab Neb, Vela - Supernova remnant; Orion A - star-forming region; Sag A - Milky Way Centre; M87, Cen A, Cyg A - AGN

What are AGN?

- AGN are galaxies that have strong emission component emanating from their nuclear region. This "additional" component is now universally accepted to be due to an actively accreting central supermassive ($\gtrsim 10^6 M_\odot$) black hole (SMBH). The mass of the SMBH may be as high as $6 \times 10^{10} M_\odot$

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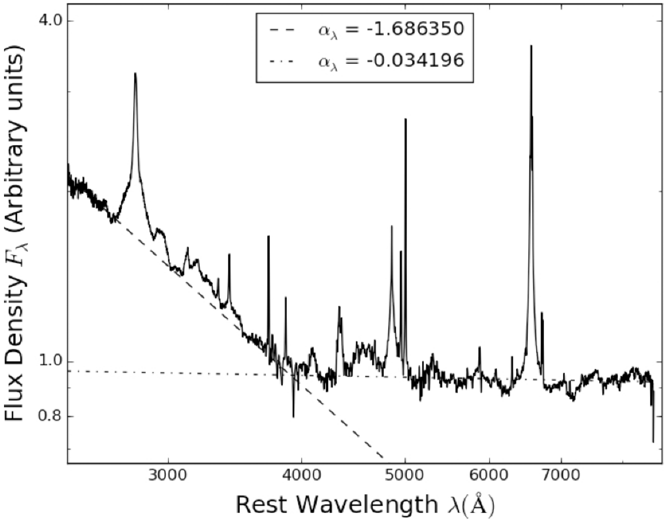
- very high luminosities (up to $L_{bol} \sim 10^{48}$ erg s^{-1})
- small emitting regions in most bands (of the order of a milliparsec)
- strong evolution of the luminosity functions with time
- broad-band emission covering the entire electromagnetic spectrum
- since they are detected at all wavelengths, the same AGN may receive multiple classifications

The main AGN classes - many subclasses in the AGN zoo

Class/Acronym	Meaning	Main properties/reference
Quasar	Quasi-stellar radio source (originally)	Radio detection no longer required
Sey1	Seyfert 1	FWHM $\gtrsim 1,000$ km s^{-1}
Sey2	Seyfert 2	FWHM $\lesssim 1,000$ km s^{-1}
QSO	Quasi-stellar object	Quasar-like, non-radio source
QSO2	Quasi-stellar object 2	High power Sey2
RQ AGN	Radio-quiet AGN	see ref. 1
RL AGN	Radio-loud AGN	see ref. 1
Jetted AGN		with strong relativistic jets; see ref. 1
Non-jetted AGN		without strong relativistic jets; see ref. 1
Type 1		Sey1 and quasars
Type 2		Sey2 and QSO2
FR I	Fanaroff-Riley class I radio source	radio core-brightened (ref. 2)
FR II	Fanaroff-Riley class II radio source	radio edge-brightened (ref. 2)
BL Lac	BL Lacertae object	see ref. 3
Blazar	BL Lac and quasar	BL Lacs and FSRQs

Seyfert galaxies studied in 1943 by K. Seyfert



Pol & Wadadekar (2017)

Physics of Seyferts - Woltjer (1959)

- The nuclei are unresolved, so the size of the nucleus is less than 100 pc.

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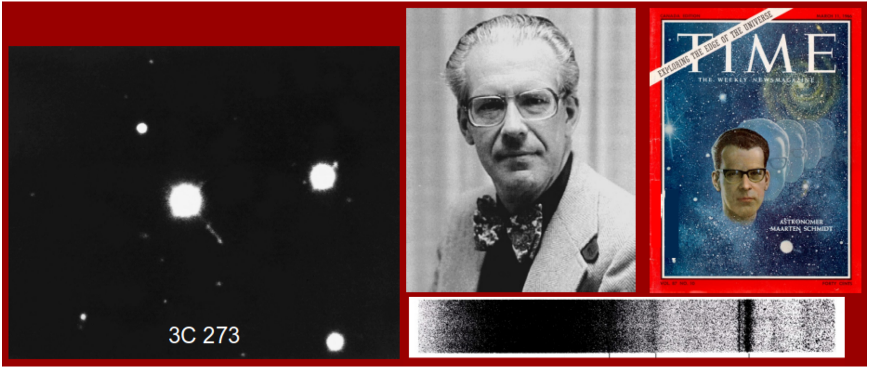
- The nuclei are unresolved, so the size of the nucleus is less than 100 pc.
- The nuclear emission must last more than 10^8 years, because Seyfert galaxies constitute about 1 in 100 spiral galaxies. One extreme scenario is that galaxies which are Seyferts are always Seyferts, in which case their lifetime is the age of the Universe (10^{10} years). The opposite extreme is one where all spirals pass through a Seyfert phase (or phases) - since 1 spiral in 100 is currently in the Seyfert phase, it must last of order 10^{10} / 100 = 10^8 years.

Physics of Seyferts - Woltjer (1959)

If the material in the nucleus is gravitationally bound, the mass of the nucleus must be very high. This is a simple virial argument, i.e. $M \sim v^2 r/G$. The velocity dispersion is obtained from the widths of the emission lines and is of order 10^3 km s^{-1}. We have an upper limit to the size of the nucleus ($r \sim 100$ pc) from the fact that it is spatially unresolved. The emission lines are characteristic of a low-density gas, which effectively provides a lower limit $r \sim 1$ pc. Thus, the mass of the nucleus can be inferred to be in the range $M \sim 10^{9\pm1} M_{\odot}$. Why is this a problem?

Discovery of Quasars



Maarten Schmidt (1963)

Setting the AGN size Scale

What is the Schwarzschild radius of a $10^6 M_\odot$ SMBH. And a $10^9 M_\odot$ one?

Hint: What is the Schwarzschild radius of the Sun?