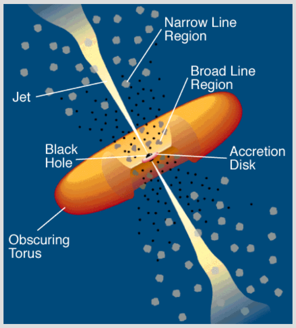
Black Holes – the supermassive species

Lecture -1- History & Overview

H. Falcke



With thanks to L. Koopmans (RUG) for producing many of the slides

Schedule

- Room: HG03.084
- Lectures: Tuesday 13.30-15:30
  - Sep. 2,
  - Sep. 9,
  - Sep. 16, no lecture self-study!
  - Sep 23 moved to Sep. 25 (Thursday, 10:30!)
  - Sep. 30 moved to Oct. 1 (Thursday, 10:30!)
  - Oct. 7
  - Oct. 14 – vacation
  - Oct. 21
- WerkCollege:
  - Woensdag, 13:30-15:30, HG00.023 (=TK023)!
- Slides on Black Board:
  - 0809 BLACK HOLES (BFCA-NM018B-8A-2008)

Tentamen

- College + self-study
- Werkcollege:
  - Programming tasks to calculate, display and fit AGN SED
  - 5 sub-tasks, 2 points for each task
- (Oral) exam
  - 0-10 points
- Final grade:
  - average of the two
  - minimum 4 pts in werkcollege
  - minimum 5 pts in exam

Course Outline

1) Introduction
2) Black Hole evidence + energetics
3) Thin and Thick Disks (self-study)
4) Jets & Lobes, superluminal motion, UHECR
5) X-rays/Gamma-rays/IC - SED
6) NLR-BLR-IR – (SED)
7) Cosmology/Surveys
8) Summary/Unification/AGN-Taxonomy

Course Outline

Course Instructor: H. Falcke (HG 03.732)

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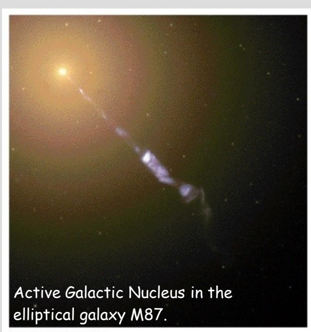
web : www.astro.ru.nl/~falcke

What are Active Galactic Nuclei?



Active Galactic Nucleus in the elliptical galaxy M87.

"AGN are the nuclei of galaxies which show energetic phenomena that can not clearly and directly be attributed to stars"

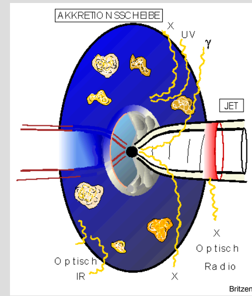
Some signs of AGN Activity

- Luminous UV emission from a compact region in the center of galaxy
- Strongly Doppler-broadened emission lines
- High Variability on time-scales of days to months
- Strong Non-Thermal Emission
- Compact Radio Core
- Extended linear radio structures (jets+hotspots)
- X-ray, γ-ray and TeV-emission
- Cosmic Ray Production

(Not all AGN show each of these, but often several of them)

The Black Hole Paradigm

- The AGN consists of
  - a supermassive **black hole** providing gravitational potential,
  - an **accretion** flow/disk providing the basic engine,
  - a relativistic **outflow** (jet) producing a lot of high-energy processes,
  - an **environment** (galaxy/gas) providing fuel and modifying AGN appearance.



Background & History

Initially two main classes of AGN hosts

typically:

- "Seyfert" Galaxies → Often Spirals ($\sim L_{gal}$) closer & fainter
- "Quasars" → Often Ellipticals (up to $\sim 100\ L_{gal}$) distant & brighter

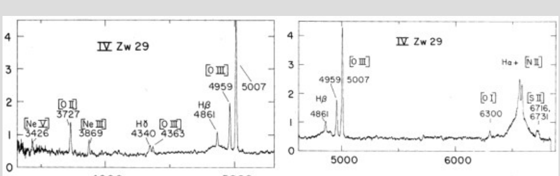
(details during the course)

First Detections of Seyfert Galaxies

1908 – Fath & Slipher detect strong emission lines similar to PNae with line-width of several hunderd km/s in NGC 1068.

Spectra of Seyfert Galaxies

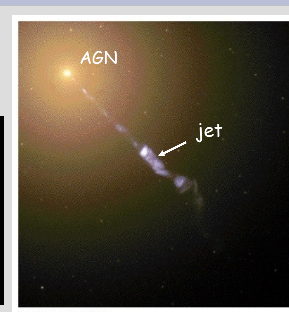
Galaxy centers show broad lines and/or high-excitation emission lines.



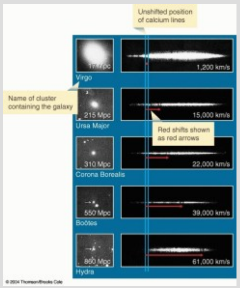
What causes these (broad) lines?

First Detections of Optical Jets

1913 – Detection of an optical jet in M87 by Curtis



"Nebulae" (Galaxies) are Extra-Galactic



1926 – Hubble finds that "nebulae" are extragalactic (galaxies)

Chepeid Distances showed that Nebulae were well outside our Milky Way.

"Re-discovery" of Seyfert Galaxies

1943 – Seyfert finds multiple galaxies similar to NGC1068
(Hence since then they are called by his name)

1955 – Detection of radio-emission from NGC1068 and NGC1275

1959 – Woltjer draws several important conclusions on "Seyfert" galaxies:

* Nuclei are unresolved (<100pc)
* Nuclear emission last for $>10^8$ years
  (1/100th spirals is a Seyfert and the Universe is 10^{10} yrs)
* Nuclear mass is very high if emission-line broadening is caused by bound material $(M \sim v^2 r/G \sim 10^9\ ^1 M_{sun})$

First Radio Surveys

Early radio surveys played a crucial role in discovering quasars

- 3C and 3CR Third Cambridge Catalog (Edge et al. 1959) at 159 Mhz (>9Jy). Basis for extragalactic radio astronomy, cosmology and *discovery of Quasars*
- PKS Parkes (Australia, Ekers 1959) survey of southern sky at 408 Mhz (>4Jy) and 1410MHz (>1Jy).
- 4C 4th Cambridge survey (today 8C). Deeper/smaller
- AO Aricibo Occultation Survey (Hazard et al. 1967). Occultation by moon (high positional accuracy)

First Radio Surveys

<u>Sources found in radio surveys</u>

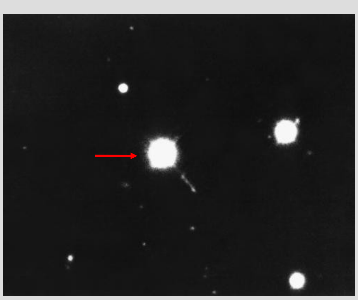
- Surveys excluded the Galactic Plane
- Mostly Normal Galaxies (e.g. Thermal emission of spiral galaxies like the MW)
- "Stars" with strange broad emission lines!

Discovery of Quasars

3C273

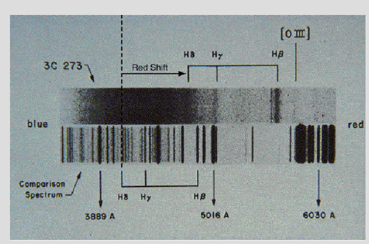
The 273rd radio source in the Cambridge Catalog

Compact radio source looks like a star except for that wisp of light!



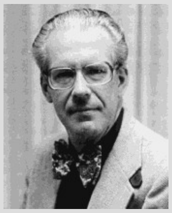
Discovery of Quasars

Broad emission lines at "strange" positions



Discovery of Quasars

Maarten Schmidt



Discovery of Quasars

1964 – Schmidt studied sufficient quasars to find:

- Star-like, accociated with radio sources
- Time-variable in continuum flux
- Large UV fluxes
- Broad emission lines
- Large redshifts

Not all quasars have these properties, although most are X-ray luminous (Elvis et al. 1978)

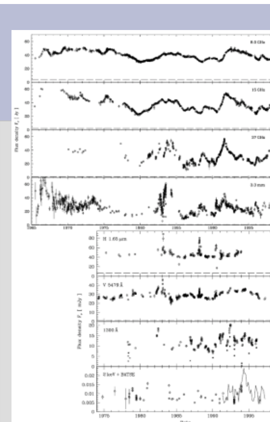
Discovery of Quasars

Why is this object at redshift of 0.158 so special?

$z = \Delta\lambda/\lambda_0$, then it follows that $d = cz/H_0 = \sim 470\ h_0^{-1}$ Mpc

$m - M = 5 \log(d/\mathrm{Mpc}) + 25$

For B =13.1th magnitude => $M_B = -23.3 + 5 \log(h_0^{-1})$
(The Milky Way has ~-19.7 =>
3C273 is $2.512^{3.6}$~30 times brighter)



30 years of multi-wavelength observations of 3C273
Astron. Astrophys. Suppl. Ser. 134, 89-101
M. Türler et al. 1998 July 28 http://obswww.unige.ch/3c273/

Quasar Variability

- Quasars are variable in every waveband and emission lines
- Variability time-scale can be days to months
- Hence size of emission regions is light-days to light-months.

Explain why?

=> The luminosity of 30 Milky Ways squeezed into less than a lighyear !

Seyfert 1 Spectrum

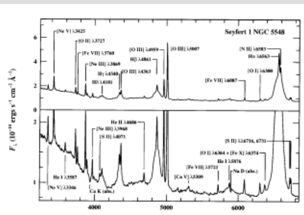
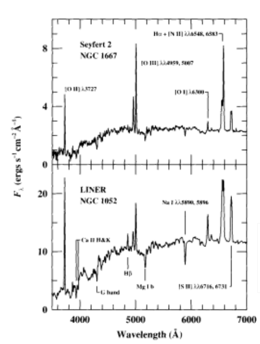


Fig. 1.1. The optical spectrum of the Seyfert 1 galaxy NGC 5548. The prominent broad and narrow emission lines are labeled, as are strong absorption features of the host galaxy spectrum. The vertical scale is expanded in the lower panel to show the weaker features. The full width at half maximum (FWHM) of the broad components is about 5900 km s^{-1}, and the width of the narrow components is about 400 km s^{-1}. The strong rise shortward of 4000 Å is the long-wavelength end of the 'small blue bump' feature which is a blend of Balmer continuum and Fe II line emission. This spectrum is the mean of several observations made during 1993 with the 3-m Shane Telescope and Kast spectrograph at the Lick Observatory. Data courtesy of A. V. Filippenko.

Seyfert 2 & LINER spectrum

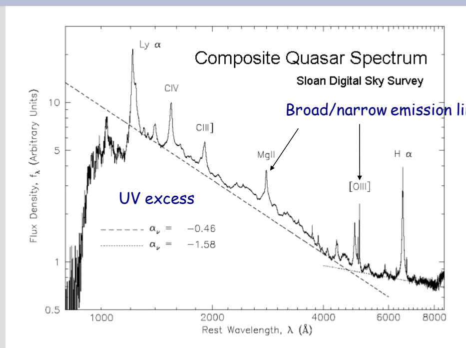


Seyfert 2
(no broad lines)

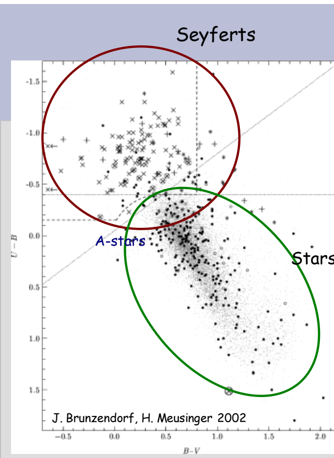
LINER
(low ionization narrow emission region)

[OIII]/Hβ is larger in Seyvert 2 while low-ionization lines ([NII] λλ6716,6731, [SII] λλ6548,6583, [OII] λ3727 and [OI] λ6300 are relatively prominent)

Quasar Composite Optical/UV Spectrum



UV Excess



- Quasars/Seyferts often have unusually blue colors relative to stars
- Bluer than most A stars
- Quasars have relatively flat spectrum from B to U

Spectral Energy Distribution of AGN

Constant value of νF_ν implies equal energy output per logarithmic bin.

More energy than an entire galaxy!

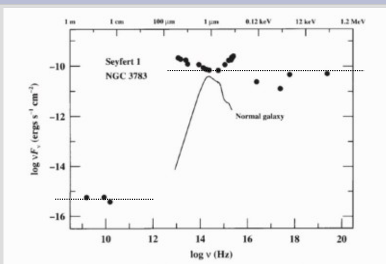
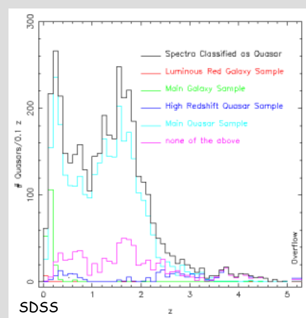


Fig. 1.3. The spectral energy distribution (SED) of the Seyfert 1 galaxy NGC 3783 (Alloin *et al.* 1995), from radio to γ-ray energies. Shown for comparison is SED for a normal (type Sbc) galaxy, from a template spectrum compiled by Elvis *et al.* (1994). The flux scale of the normal galaxy spectrum has been adjusted to give the correct relative contribution of AGN component and starlight for NGC 3783 (in mid-1992) at 5125 Å through a 5″ × 10″ spectrograph aperture.

Redshift Distribution of Quasars



- The quasar redshift distribution seems to peak around z~2.
- This is not only a selection effect, but seems real, even after bias corrections.
- This could be related to the formation of galaxies and LSS and the star-formation history.

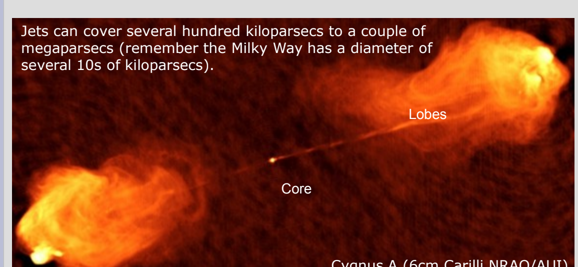
Radio Properties of Quasars

Although quasars were discovered through radio observations, most quasars are faint at radio wavelength (called QSOs).

The radio structure of quasars has often two main "components"

Compact (<1″)	Extended (double "lobes")
Flat-spectrum Optically thick Optical source	Steep-spectrum Optically thin

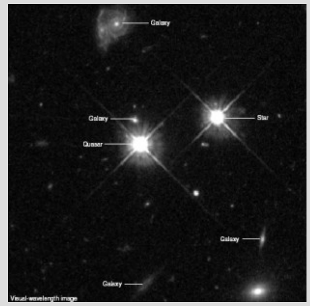
Some examples of radio-galaxies - 1



Some confusing nomeclature

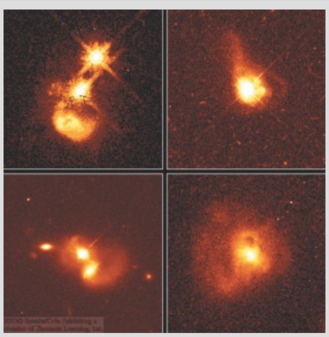
- Quasars <u>w/o</u> extended radio structure are often (but not always) called "quasars"
- "Quasars" <u>with</u> a visible galaxy and strong radio emission are often called "radio galaxies"
- Quasar with faint radio emission are often called "QSOs" (Quasi Stellar Objects), but sometimes also quasars
- "Quasars" with faint radio structure and a visible galaxy are often called Seyferts
- Seyferts/Quasars with broad lines are called "Type 1" and without "Type 2"
- Faint Seyferts are called LINERs … or LLAGN.

Some examples of QSOs - 1



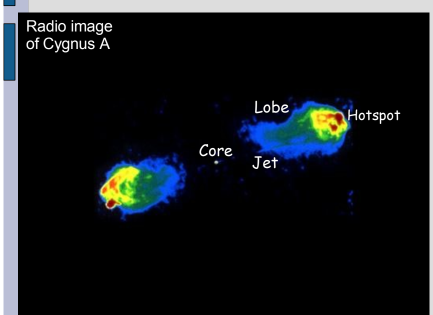
QSOs often outshine their host galaxies which can be difficult to detect!

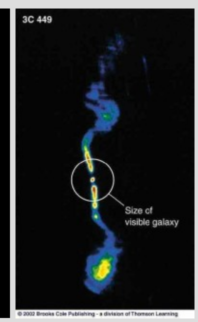
Some examples of QSOs - 2



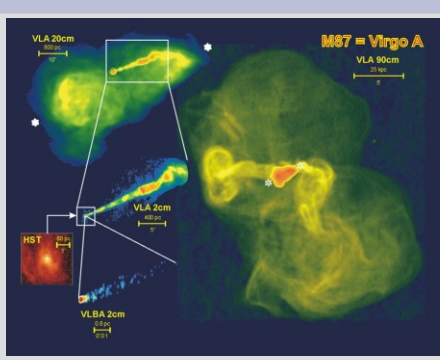
Quasars host-galaxies often show interactions

Some examples of radio-galaxies -2





Some examples of radio-galaxies -3



Classes of Radio-Galaxies

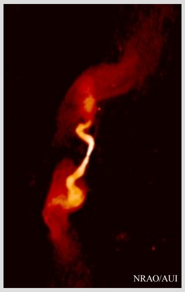
Large radio-galaxies with lobes can be divided in two types Fanaroff-Riley (1974):

- FR-I : Weaker radio sources that are bright in the center and fainter toward the edges (limb-darkened)
- FR-II : Radio structure with a faint core and bright end-points (limb-brightened)

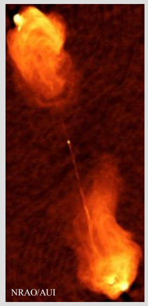
Transition around $L_{1.4GHz} = 10^{32}$ ergs/s/Hz

Classes of Radio-Galaxies

- FRI



- FRII



General Summary

- AGN show emission not easily attributable to stars
- AGN occur both in spirals and E/S0's (Seyferts/Quasars, distinghed mostly in the amount of energy emitted)
- AGN emit energy comparable or larger than all the stars in the host-galaxy, over a wide range of frequencies (including sometimes the radio).
- AGN can show linear structures (jet/lobes/hotspots) in the radio (and jet in the optical) of order ~Mpc

General Summary

- AGN show strong broad emission lines. Combined with the small emission region this indicates a high central concentration of mass.
- AGN come in many shapes and forms, with often an unclear connection to each other (Unification?)
- AGN are often highly variable (supporting the small region from which the emission eminates).