



## Active Galactic Nuclei

Jörn Wilms

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Office: Dr. Karl Remeis-Sternwarte, Bamberg  
email: joern.wilms@sternwarte.uni-erlangen.de  
Tel.: (0951) 95222-13

<http://astro.uni-tuebingen.de/~wilms/teach/agn>

Friedrich-Alexander-Universität  
Erlangen-Nürnberg



## What are AGN?

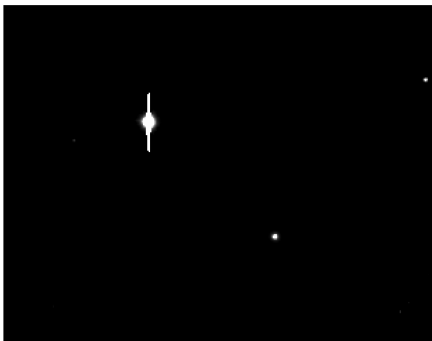
Observational characteristics of AGN:

- (Normally) high luminosity
- Emission throughout the electromagnetic spectrum (radio to keV, MeV, TeV)  
⇒ spectrum is “nonthermal”
- flat  $\nu f_\nu$  spectra: similar emission per frequency decade
- strong variability (days to years)
- radio loud sources: relativistic jets, which can be superluminal  
( $v_{\text{apparent}} \gg c$ )
- broad optical lines ( $v_{\text{characteristic}} \sim \text{several } 1000 \text{ km s}^{-1}$ )

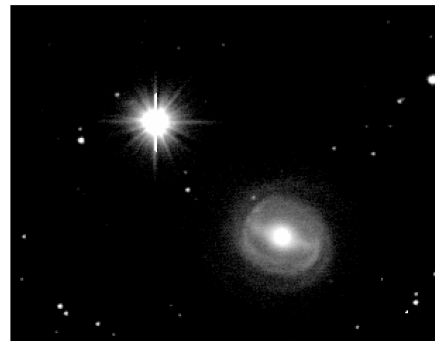
What are AGN?



## What are AGN?



NGC 3783: *linear* intensity scale



*logarithmic* intensity scale

**Active Galactic Nuclei** (AGN): supermassive black holes ( $M \sim 10^{6..8} M_\odot$ ),  
accreting  $1 \dots 2 M_\odot/\text{yr}$   
⇒ luminosity  $\sim 10^{10} L_\odot$  (comparable to galaxy luminosity)



## Outline

- 16 Oct Introduction, History
- 23 Oct AGN Taxonomy, Unification
- 30 Oct Accretion
- 6 Nov Measurement Methods
- 13 Nov Continuum Emission
- 20 Nov Line Diagnostics
- 27 Nov Broad-line Region
- 4 Dec **no lecture**
- 11 Dec Narrow-line Region
- 18 Dec Broad Fe  $K\alpha$  lines and Black Hole Paradigm
- 8 Jan Radio loud AGN
- 15 Jan Jets
- 22 Jan AGN Environment: Host galaxies
- 29 Jan Cosmology: Quasar Surveys
- 5 Feb AGN Evolution
- 12 Feb Summary



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### Textbooks on AGN

PETERSON, B.M., 1997, *An Introduction to Active Galactic Nuclei*, Cambridge: Cambridge Univ. Press, 254pp., \$45

Undergraduate level introduction to Active Galactic Nuclei, level is slightly lower than ours.

KROLIK, J., 1999, *Active Galactic Nuclei: From the Central Black Hole to the Galactic Environment*, Princeton: Princeton Univ. Press, 632pp., \$57.50

The most comprehensive textbook on AGN available, covers much more material than what is possible here.

KEMBHAVI, A.J. & NARLIKAR, J.V., 1999, *Quasars and Active Galactic Nuclei: An Introduction*, Cambridge: Cambridge Univ. Press, 476pp., \$50

Graduate level textbook, similar to Krolik, but often explains things from a somewhat different point of view.

Literature

1



2-1

### *History of AGN research*



1-8

### Other Textbooks

BRADT, H., 2003, *Astronomy Methods: A Physical Approach to Astronomical Observations*, Cambridge: Cambridge Univ. Press, 458pp., €57.50

Summary of many technical details that are useful to know if you want to become a professional astronomer. Detectors, radiation processes, etc.

PADMANABHAN, T., 2000, *Theoretical Astrophysics: Volumes 1-3*, Cambridge: Cambridge Univ. Press, ~ 500pp. each, ~€60 per volume

Introduction to the (theoretical) physics of astrophysics. Short, concise, great. Graduate level, but understandable, although not for the faint hearted. . .

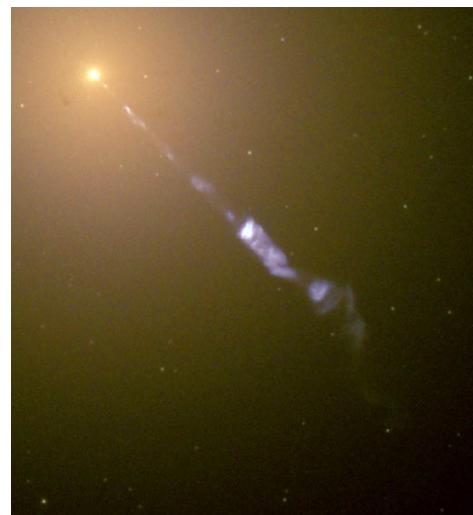
FRANK, J., KING, A., RAINE, D., 2002, *Accretion Power in Astrophysics*, 3rd edition, Cambridge: Cambridge Univ. Press, 398pp., €55.90

The standard textbook on accretion, covering all relevant areas of the field, including AGN.



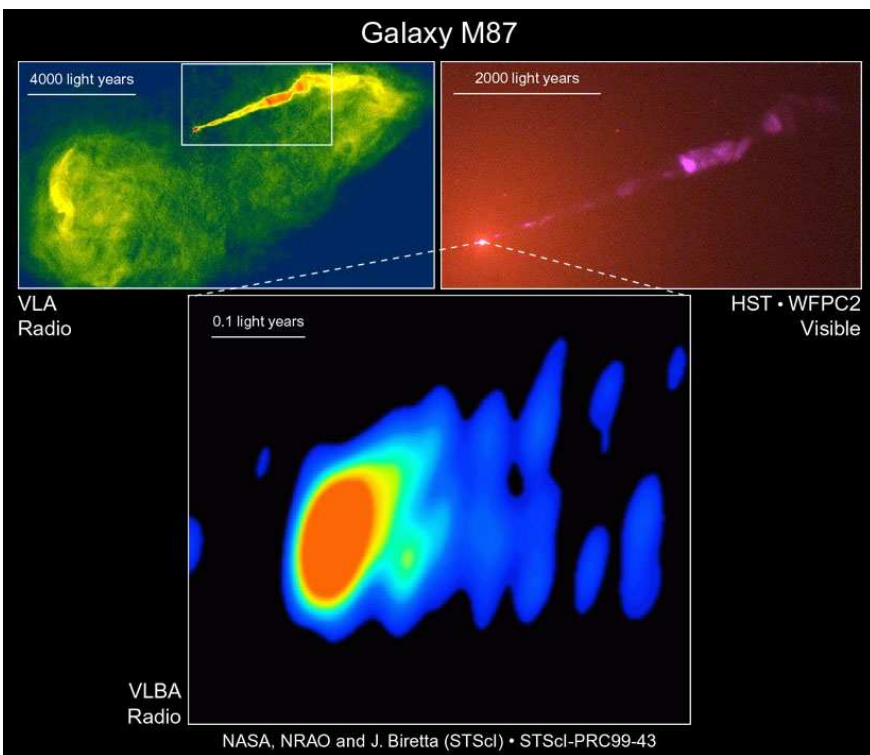
2-4

### 1918: H. Curtis



HST

1918: Heber D. Curtis: “[M87 exhibits] a curious straight ray. . . apparently connected with the nucleus by a thin line of matter”.  
 ⇒ M87 contains an optical jet



1943: C. Seyfert

NUCLEAR EMISSION IN SPIRAL NEBULAE\*

CARL K. SEYFERT†

ABSTRACT

Spectrograms of dispersion 37–200 Å/mm have been obtained of six extragalactic nebulae with high-excitation nuclear emission lines superposed on a normal G-type spectrum. All the stronger emission lines from  $\lambda$  3727 to  $\lambda$  6731 found in planetaries like NGC 7027 appear in the spectra of the two brightest spirals observed, NGC 1068 and NGC 4151.

Apparent relative intensities of the emission lines in the six spirals were reduced to true relative intensities. Color temperatures of the continua of each spiral were determined for this purpose.

The observed relative intensities of the emission lines exhibit large variations from nebula to nebula. Profiles of the emission lines show that all the lines are broadened, presumably by Doppler motion, by amounts varying up to 8500 km/sec for the total width of the hydrogen lines in NGC 3516 and NGC 7469. The hydrogen lines in NGC 4151 have relatively narrow cores with wide wings, 7500 km/sec in total breadth. Similar wings are found for the Balmer lines in NGC 7469. The lines of the other ions show no evidence of wide wings. Some of the lines exhibit strong asymmetries, usually in the sense that the violet side of the line is stronger than the red.

In NGC 7469 the absorption K line of Ca II is shallow and 50 Å wide, at least twice as wide as in normal spirals.

Absorption minima are found in six of the stronger emission lines in NGC 1068, in one line in NGC 4151, and one in NGC 7469. Evidence from measures of wave length and equivalent widths suggests that these absorption minima arise from the G-type spectra on which the emissions are superposed.

The maximum width of the Balmer emission lines seems to increase with the absolute magnitude of the nucleus and with the ratio of the light in the nucleus to the total light of the nebula. The emission lines in the brightest diffuse nebulae in other extragalactic objects do not appear to have wide emission lines similar to those found in the nuclei of emission spirals.

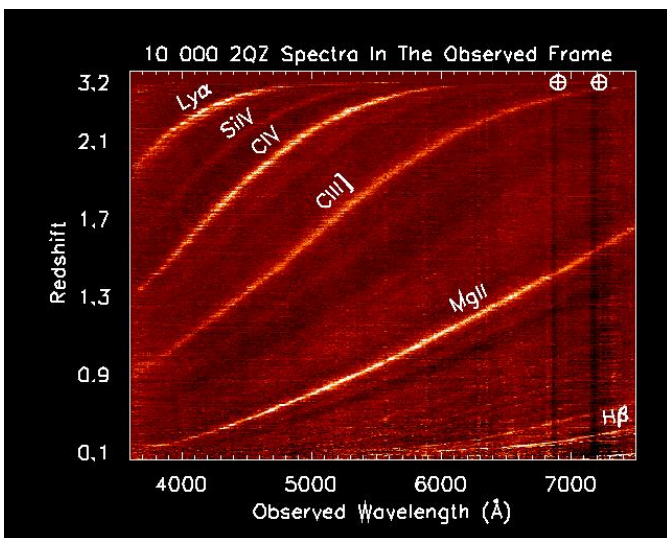
(Seyfert, 1943)

1943: Carl Seyfert: Recognition of spiral galaxies with optical emission lines as a class  $\Rightarrow$  Seyfert galaxies

History



1926: E. Hubble



1926: Edwin Hubble:

- Emission lines in NGC 1068, NGC 4051, NGC 4151
- Spectral features in nebulae are redshifted  $\Rightarrow$  nebulae are extragalactic!

Reminder:  $z = \Delta\lambda/\lambda = v/c$ ,  
 $v = Hd$  where  
 $H \sim 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$ .

courtesy 2DF survey



1954: W. Baade and R. Minkowski



W. Baade (Mt. Wilson)

IDENTIFICATION OF THE RADIO SOURCES IN CASSIOPEIA, CYGNUS A, AND PUPPIS A

W. BAADE AND R. MINKOWSKI  
 MOUNT WILSON AND PALOMAR OBSERVATORIES  
 CARNEGIE INSTITUTION OF WASHINGTON  
 CALIFORNIA INSTITUTE OF TECHNOLOGY  
 Received June 19, 1953

ABSTRACT

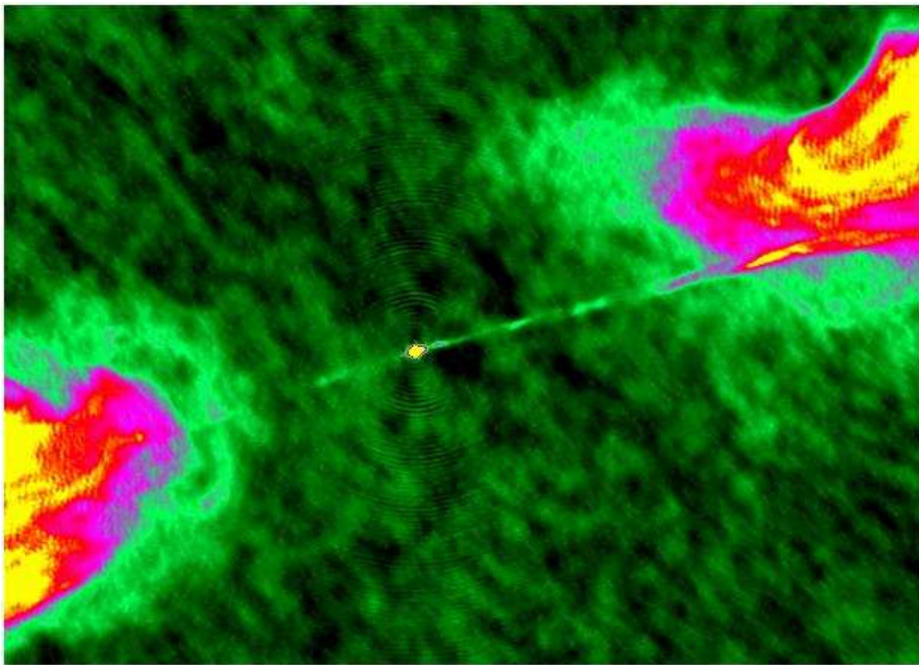
The radio sources in Cassiopeia and Puppis A are identified with a new type of galactic emission nebula. The outstanding features of these nebulosities are very large internal random velocities. The radio source Cygnus A is an extragalactic object, two galaxies in actual collision.

Only very few individual sources of cosmic radio emission have been identified with conspicuous astronomical objects.<sup>1</sup> Although the sources in Cassiopeia<sup>2</sup> and Cygnus A<sup>3</sup>

(Baade & Minkowski, 1954)

1954: Walter Baade and Rudolph Minkowski: optical counterparts to radio sources Cyg A (NGC 5128), Vir A (M87), Per A (NGC 1275).

Cyg A: First ultra-luminous AGN (2nd brightest radio source in the sky;  $L \sim 10^{45} \text{ erg s}^{-1}$ ).



Cyg A in radio ( $\lambda = 6$  cm, VLA, Perley, Dreher & Cowan 1984)

Data in Cygnus\_A: I::6cm:pd1984.fits, u30x0108bt.fits, and dss2\_red.19.59.28.3+40.44.02.0.fits



1963: M. Schmidt

1950s and 1960s: Radio surveys  $\implies$  large lists of (unknown) radio sources

Most important surveys:

$\implies$  Cambridge:

- "Third Cambridge Catalogue" (Edge et al., 1959):  $f = 159$  MHz, 471 sources  $> 8$  Jy for  $-22^\circ < \delta < +71^\circ$ .
- "Revised Third Cambridge Catalogue" (Bennett, 1962):  $f = 178$  MHz,  $-22 < \delta < +90^\circ$ , same numbering scheme

Objects have names like 3C273, 3C279, 3C405 (aka Cyg A), sometimes "3CR" is used.

$\implies$  Parkes surveys (Bolton, Gardner & Mackey, 1964; Price & Milne, 1965; Day et al., 1966),  $f = 408, 1410, \text{ and } 2650$  MHz,  $\sim 900$  sources with  $F > 1$  Jy and  $-90^\circ < \delta < +20^\circ$ .

Sources have names such as PKS 2155-304 (a blazar) or PKS 405-385 (intra-day variable source).

1 Jansky = 1 Jy =  $10^{-26}$  W m<sup>-2</sup> Hz<sup>-1</sup>

History

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1959: L. Woltjer

EMISSION NUCLEI IN GALAXIES

L. WOLTJER\*

Yerkes Observatory, University of Chicago

Received February 16, 1959

ABSTRACT

Some galaxies which show wide emission lines in the spectra of their nuclei are discussed. It is shown that, on statistical grounds, the nuclear emission must last for several times  $10^8$  years at least. The nuclei are extremely narrow, of the order of 100 parsecs, and, if a normal mass-to-light ratio applies, extremely massive. The width of the emission lines, which indicates velocities of a few thousand kilometers per second, is probably due to fast motions, circular or random, in the gravitational fields of the nuclei. The high star density in the nuclei may provide a source of excitation. In the nucleus of our own Galaxy the radio source Sagittarius gives evidence of strong magnetic fields and large amounts of relativistic particles. A mass of a few times  $10^8$  solar masses is needed to prevent disintegration of the source. The Andromeda Nebula has a nucleus with a somewhat smaller mass. The occurrence of dense nuclei may be a common characteristic of many galaxies.

(Woltjer, 1959)

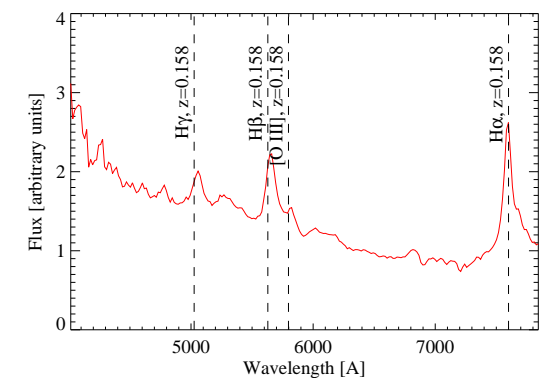
1959: Lodewijk Woltjer: AGN have huge masses.



1963: M. Schmidt



M. Schmidt (Caltech)



3C273 (Rondi et al., Pic du Midi)

1963: Maarten Schmidt: 3C273 has  $z = 0.158 \implies$  AGN are far away!

shortly later: 1963: J. Greenstein and Th. Matthews: 3C48 has  $z = 0.368$

Nomenclature: Quasar/QSO (from "quasi stellar radio source": radio emitting AGN)