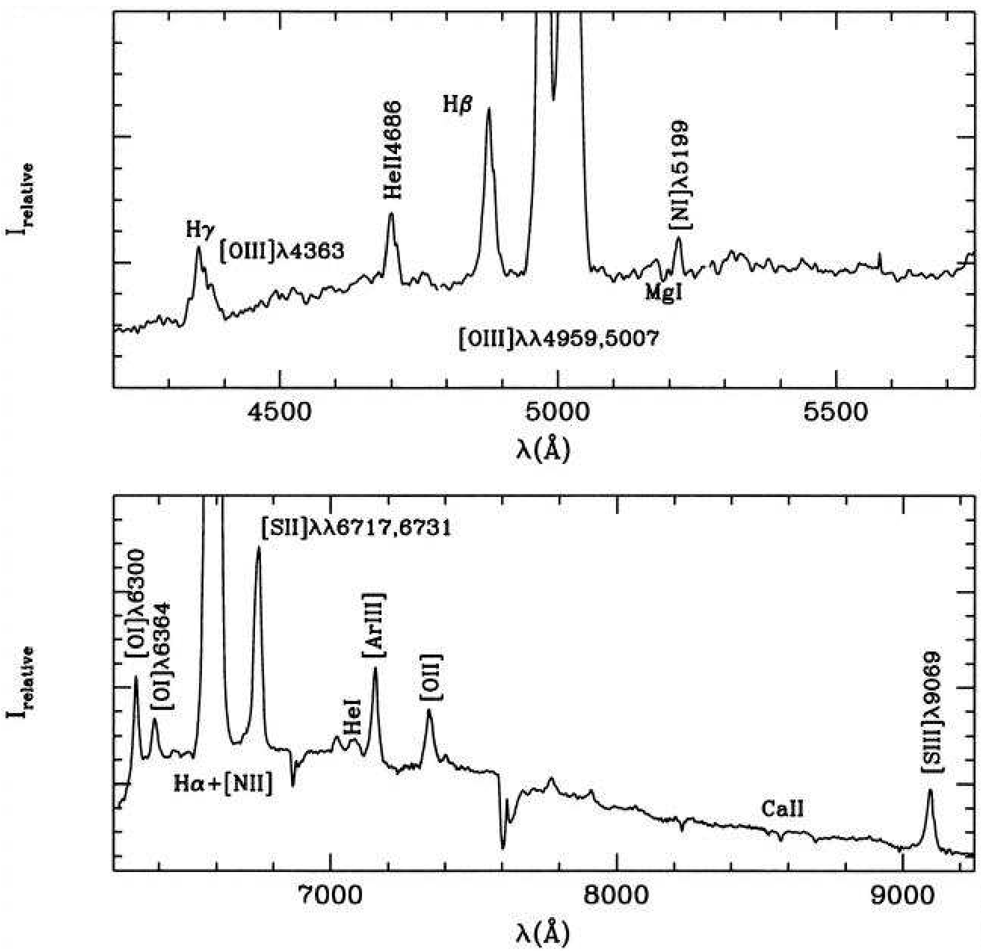
History of AGN research

NGC 1068 (M77)
courtesy Nordic Optical
Telescope

1908: E. Fath



Optical spectrum of NGC 1068

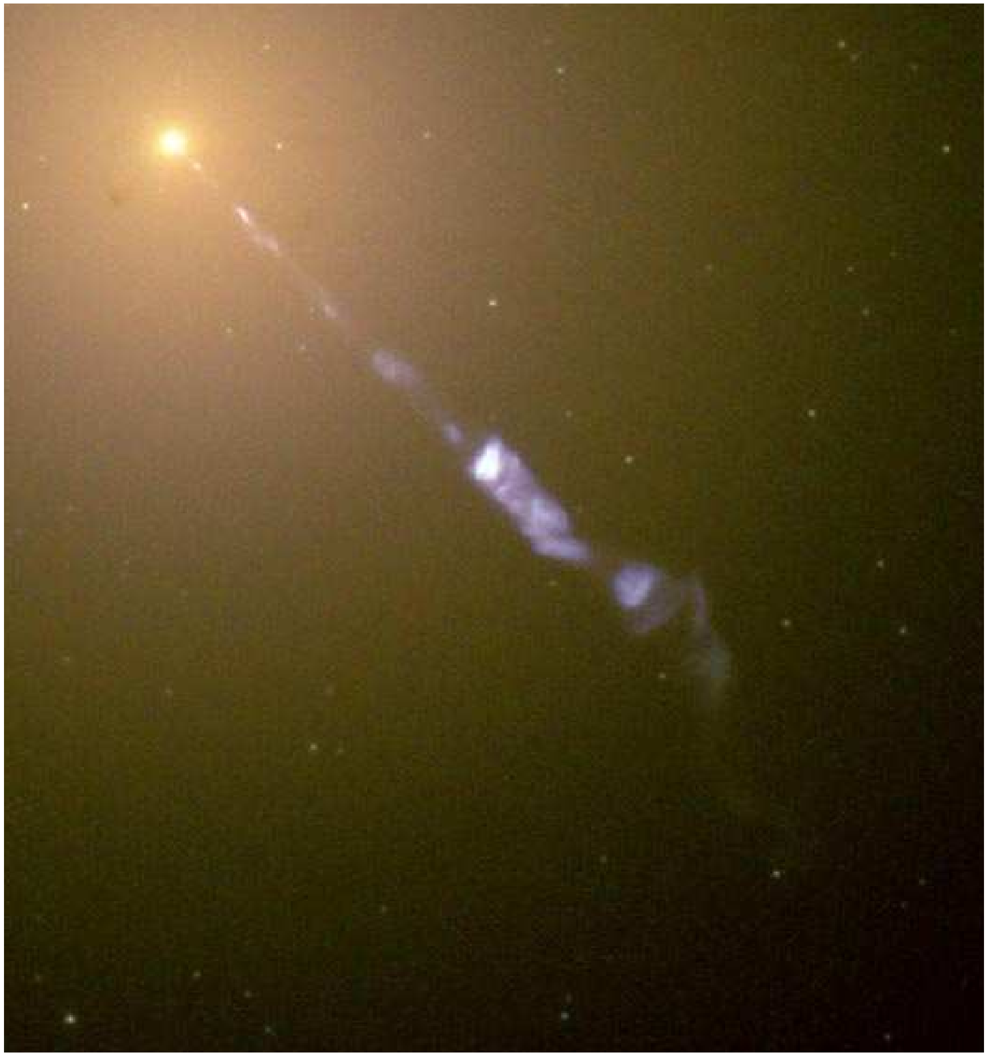
(García-Lorenzo, Mediavilla & Arribas, 1999, Fig. 4)

1908: Edward A. Fath: There are emission lines in NGC 1068, similar to planetary nebulae.

This was part of Fath's PhD!

Note: High ionization levels, large width of lines

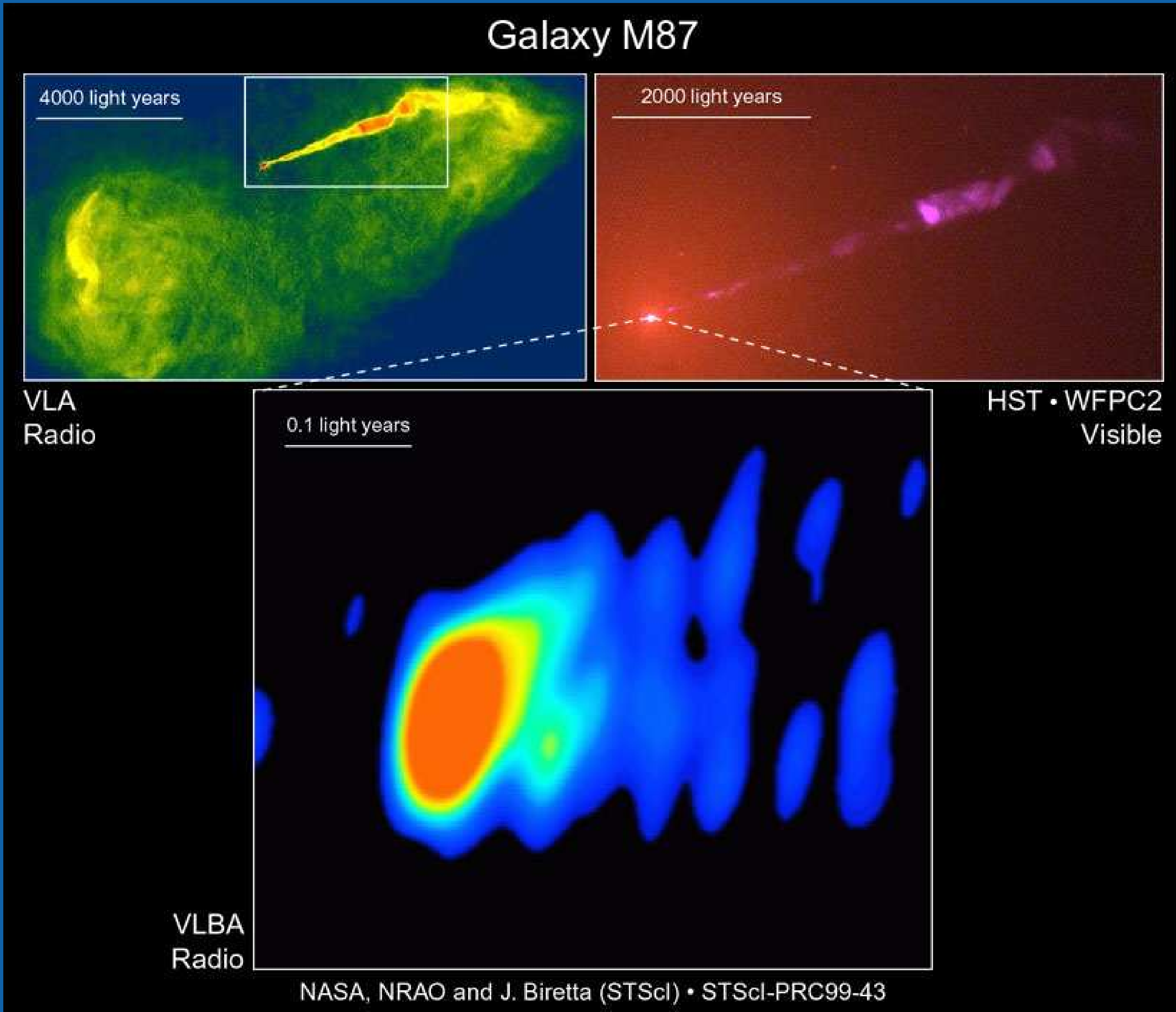
1918: H. Curtis

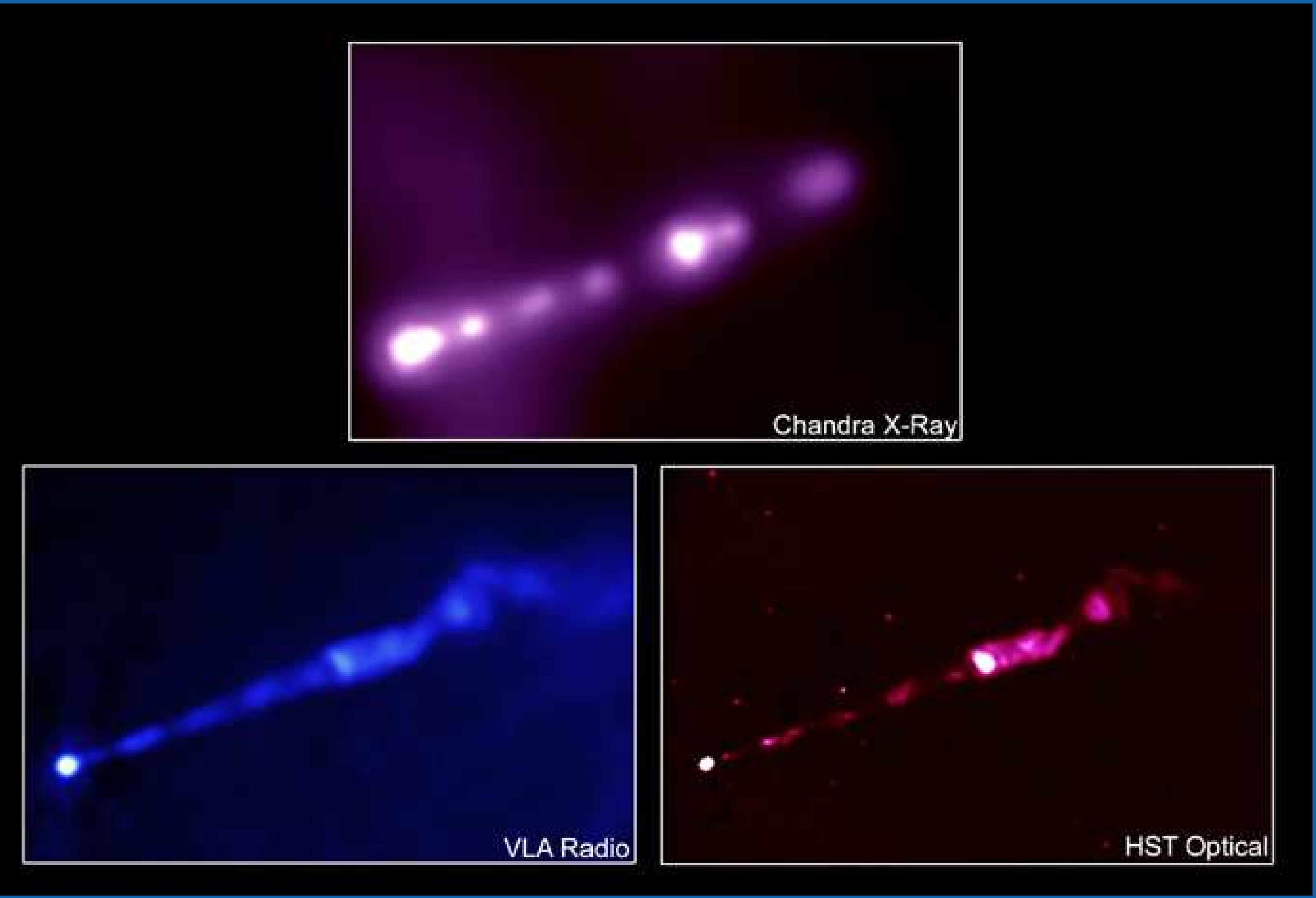


HST

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

$\Longrightarrow$ M87 contains an optical jet

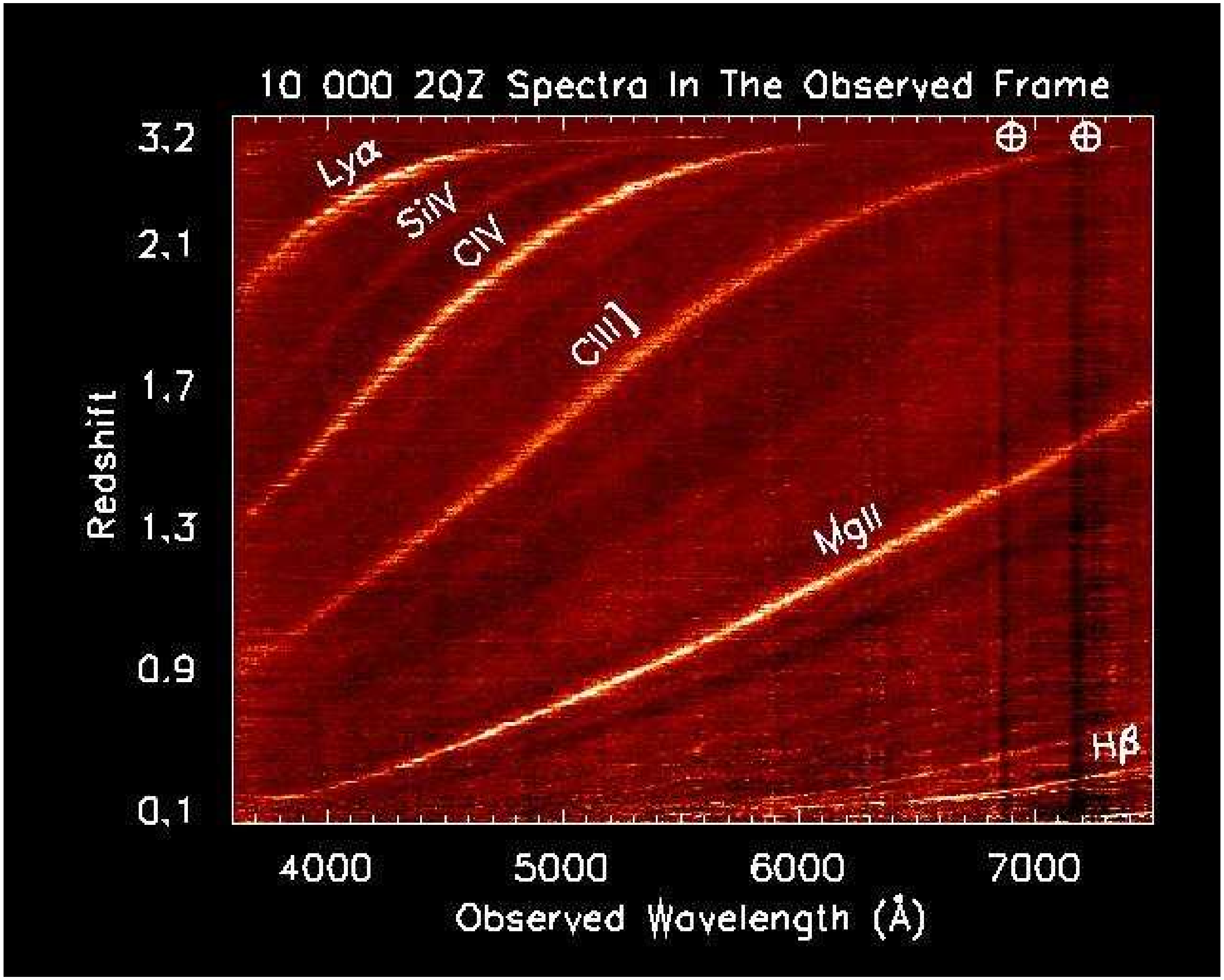

Galaxy M87
4000 light years
2000 light years
VLA
Radio
HST • WFPC2
Visible
0.1 light years
VLBA
Radio
NASA, NRAO and J. Biretta (STScI) • STScI-PRC99-43



X-ray: NASA/CXC/MIT/H.Marshall et al. Radio: F.Zhou, F.Owen (NRAO), J.Biretta (STScI)
Optical: NASA/STScI/UMBC/E.Perlman et al.

Jets are visible in all wavebands

1926: E. Hubble



courtesy 2DF survey

1926: Edwin Hubble:

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

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

1943: C. Seyfert

NUCLEAR EMISSION IN SPIRAL NEBULAE*

CARL K. SEYFERT†

ABSTRACT

Spectrograms of dispersion 37–200 A/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 λ 3727 to λ 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 A 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: Recognization of spiral galaxies with optical emission lines as a class $\Longrightarrow$ Seyfert galaxies

1954: W. Baade and R. Minkowski

W. Baade (Mt. Wilson Obs.)

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

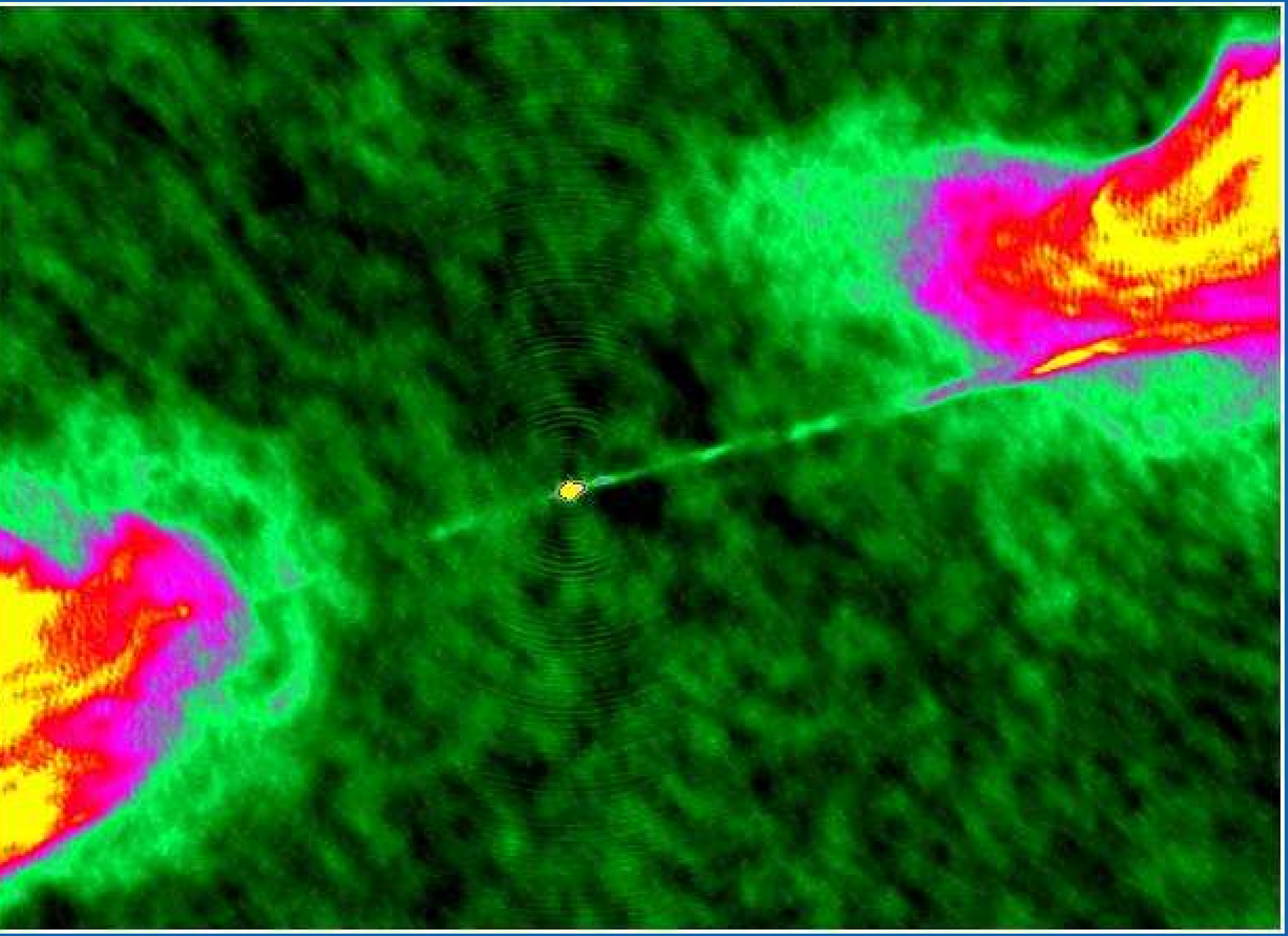
The radio sources in Cassiopeia and Puppis A are identified with a new type of galactic emission nebulosity. The outstanding features of these nebulosities are very large internal random velocities. The radio source Cygnus A is an extragalactic object, two galaxies in actual collision.

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

(Baade & Minkowski, 1954)

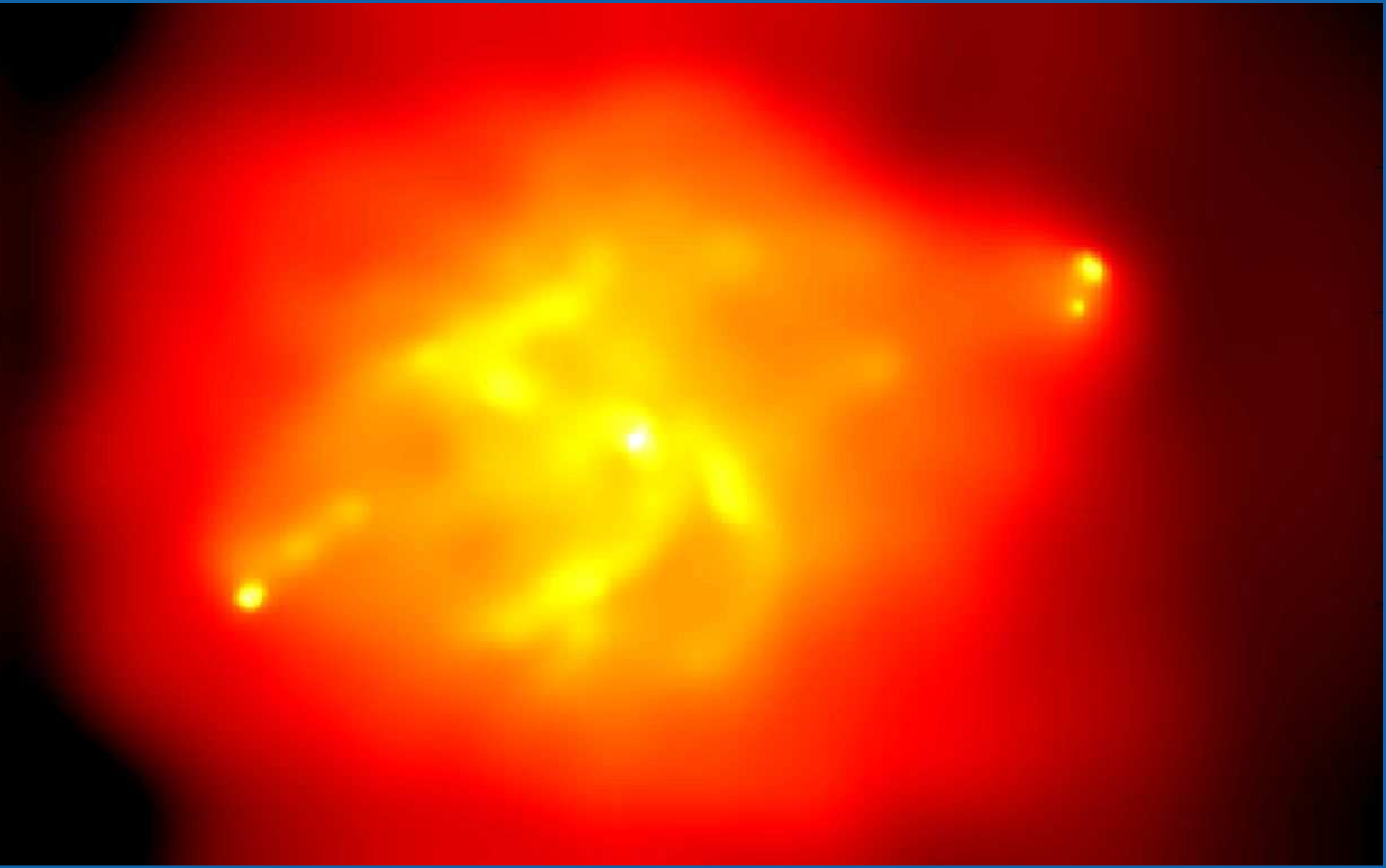
1954: Walter Baade and Rudolph Minkowski: optical counterparts to radio sources Cyg A (NGC 5128), Vir A (M87), Per A (NGC 1275).

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



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

in `Cygnus_A:I::6cm:pdc1984.fits`, `u30x0108bt.fits`, and `dss2_red.19.59.28.3+40.44.02.0.fits`



yg A in X-rays (Wilson & Young/CXC/NASA)

Hot gas in cavity produced by the radio jets $\Longrightarrow$ AGN shape their environment!

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

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

Most important surveys:

$\Longrightarrow$ Cambridge:

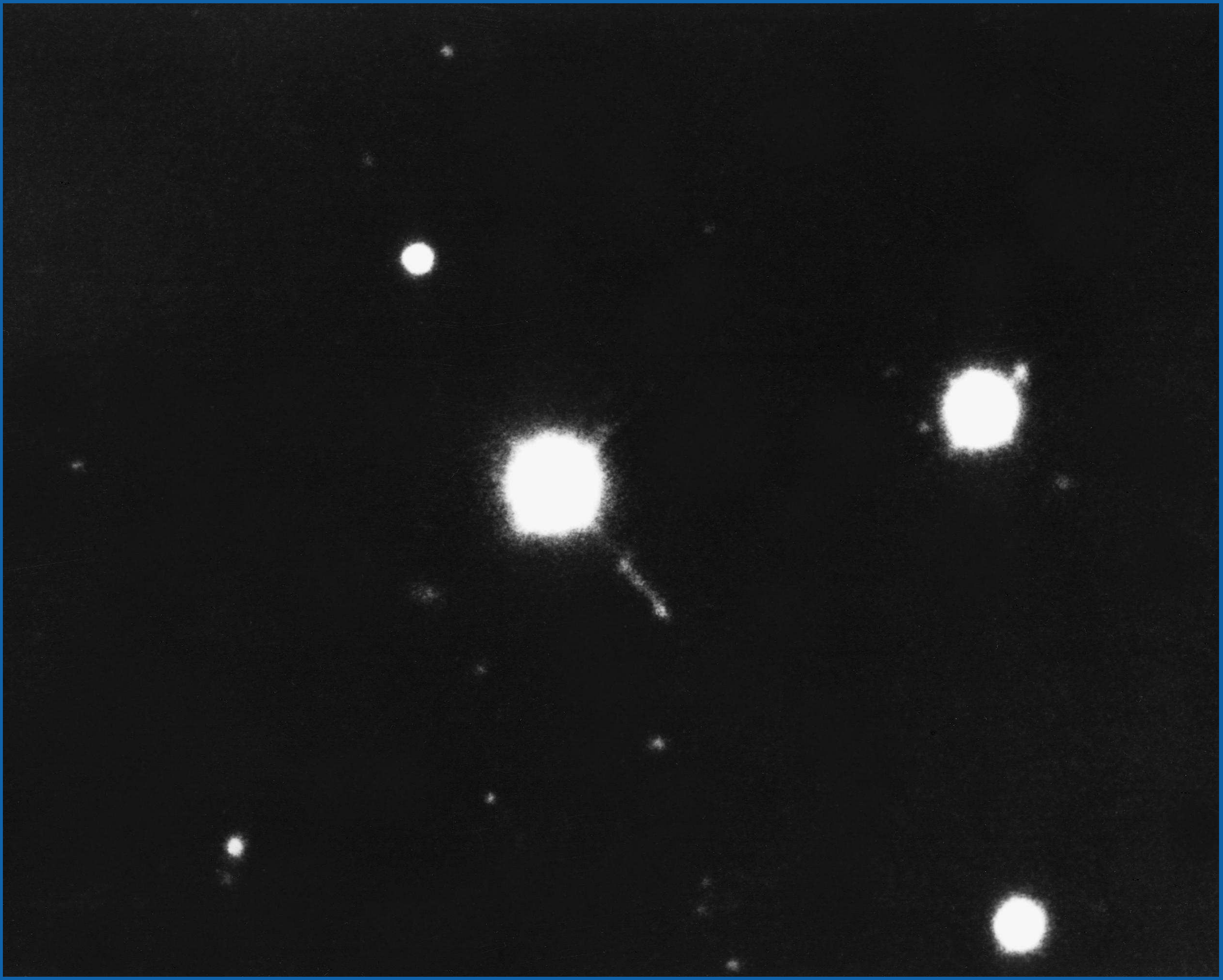
- "Third Cambridge Catalogue" (Edge et al., 1959): $f = 159$ MHz, 471 sources $>$8 Jy for $-22^\circ < \delta < +71^\circ$.
- "Revised Third Cambridge Catalogue" (Bennett, 1962): $f = 178$ MHz, $-22 < \delta < +90^\circ$, same numbering scheme

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

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

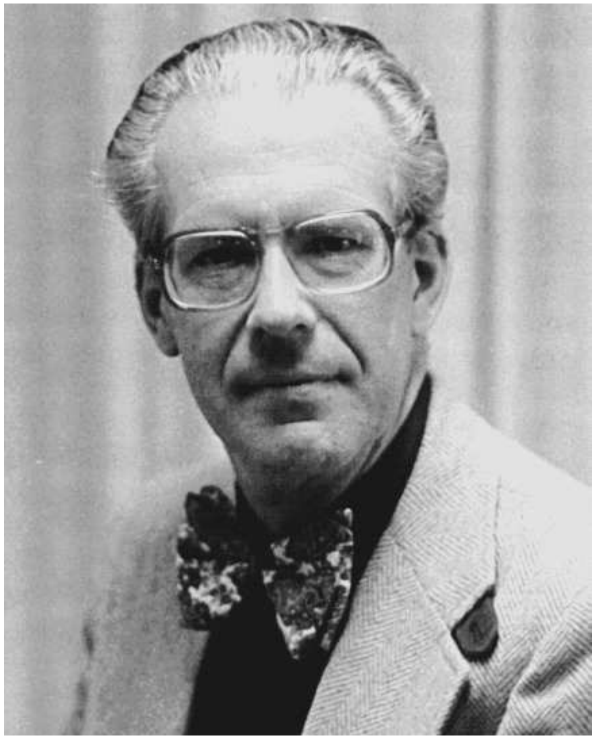
Sources have names such as PKS 2155$-$304 (a blazar) or PKS 405$-$385 (intra-day variable source).

1 Jansky $=$ 1 Jy $= 10^{-26}\,\mathrm{W\,m^{-2}\,Hz^{-1}}$

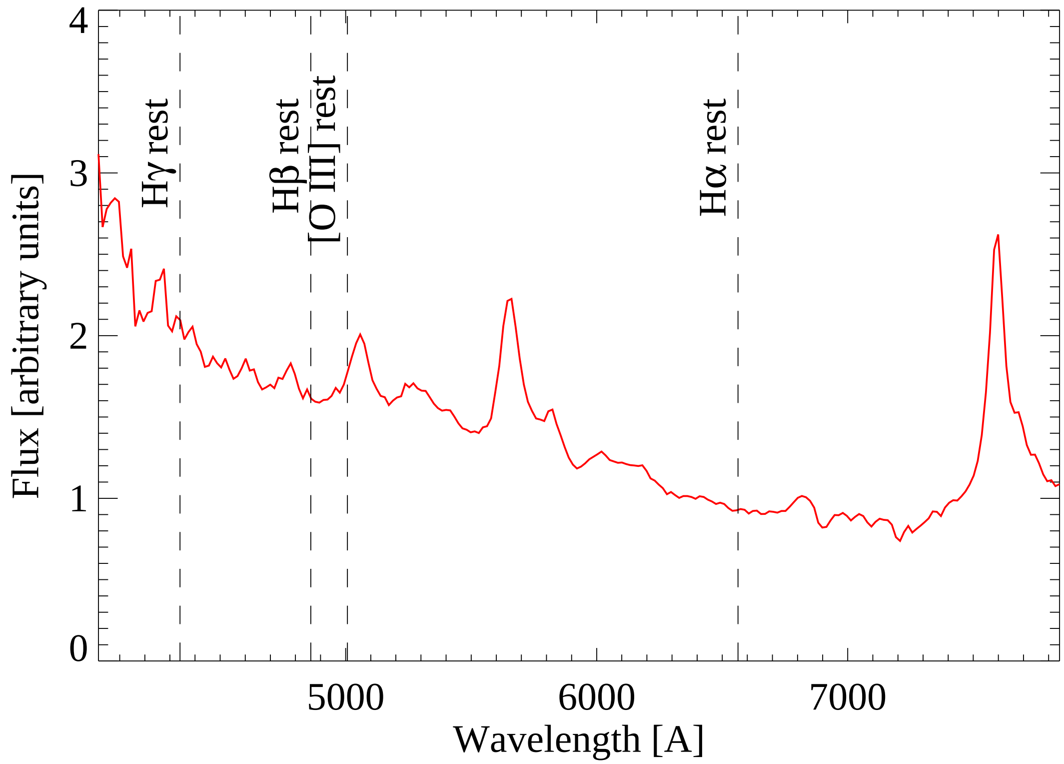


3C273 (4 m Myall telescope, NOAO/AURA/NSF)

1963: M. Schmidt

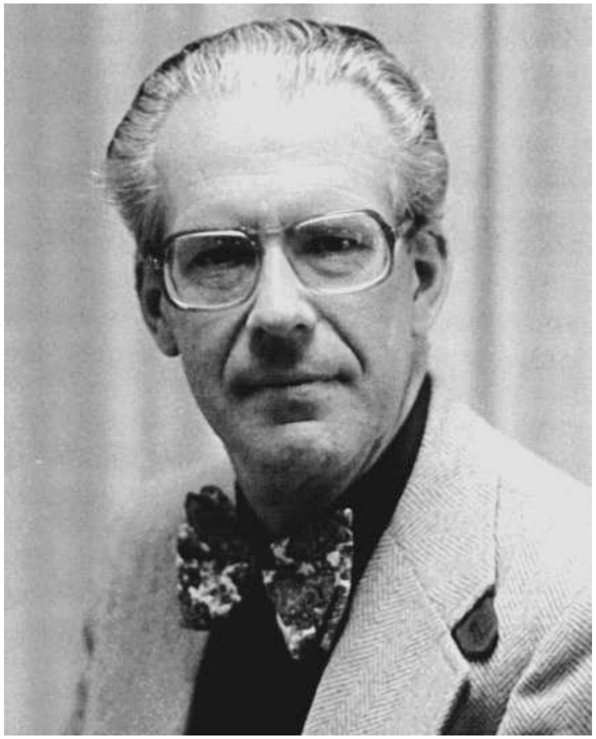


M. Schmidt (Caltech)



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

1963: M. Schmidt



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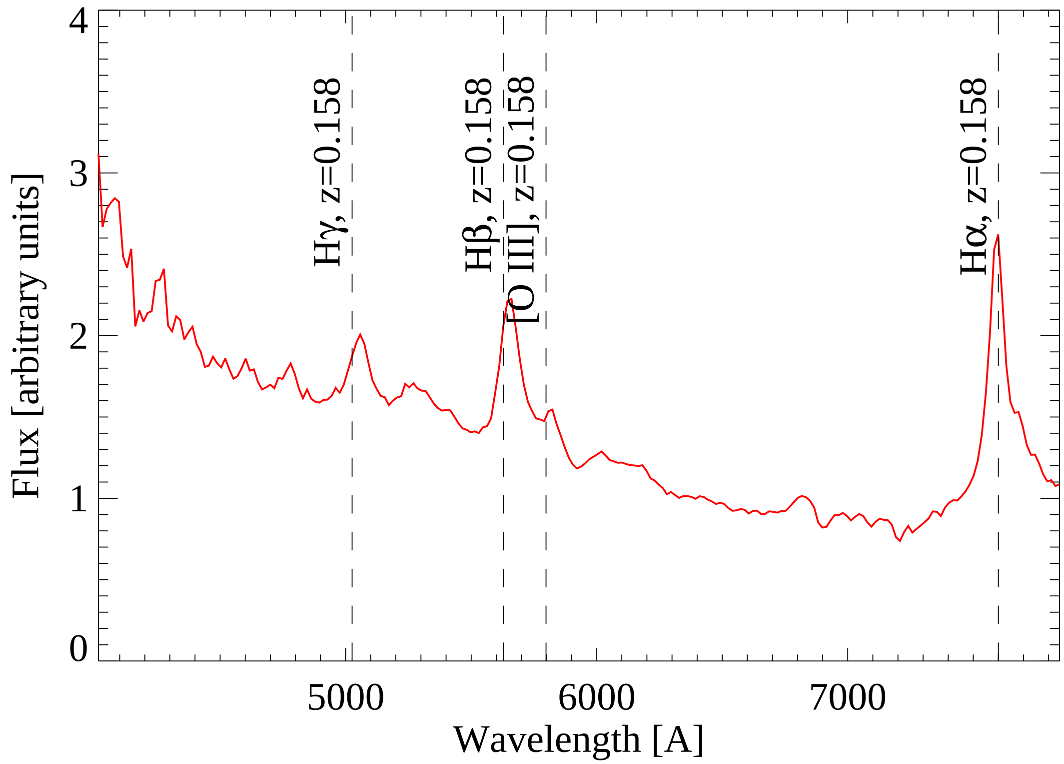

3C273 (Rondi et al., Pic du Midi)

1963: Maarten Schmidt: 3C273 has $z = 0.158 \Longrightarrow$ 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)

Interlude: Accretion Power

AGN have high luminosities: What is the energy source?

1. Nuclear Fusion

Typical reactions à la

$$4\text{p} \longrightarrow {}^{4}\text{He} + \Delta m c^2$$

Liberated energy:

Fusion produces
$\sim 6 \times 10^{18}\,\text{erg}\,\text{g}^{-1} = 6 \times 10^{11}\,\text{J}\,\text{g}^{-1}$

($\Delta E_{\text{nuc}} \sim 0.007 m_{\text{p}} c^2$)

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2. Gravitation

Accretion of mass m from ∞ onto a black hole with radius R_{S} gives

$$\Delta E_{\text{acc}} = \frac{GMm}{R_{\text{S}}} \quad \text{where} \quad R_{\text{S}} = \frac{2GM}{c^2}$$

Accretion yields
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$\Longrightarrow$ Accretion of material is the most efficient astrophysical energy source

...to power a luminous AGN, 1...2 $M_\odot\,\text{yr}^{-1}$ are sufficient.

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