LECTURE VI

ACTIVE GALACTIC NUCLEI

NORMAL GALAXIES HAVE
- RED OR BLUE BULGES
- SOMETIMES BARS
- SPIRAL ARMS

FEW GALAXIES : UNUSUALLY BRIGHT CENTERS
(YOUNG, REMOTE)
(NOT NEARBY)
→ AGN

FIRST AGN : FATH 1908 (LICK)
NGC 1068 (SIX BRIGHT EMISSION LINES)

DISTINCT FEATURES (DIFFUSE, HOT GAS)

SEYFERT GALAXIES
- EMISSION LINES : Hβ (BROAD — DOPPLER) 1000 - 5000 km/s
- FORBIDDEN LINES OF : [OII], [OIII], [NeIII] ~500 km/s (NARROWER)

SLIDE - 51, 52 (42, 43)
LOW GAS DENS.

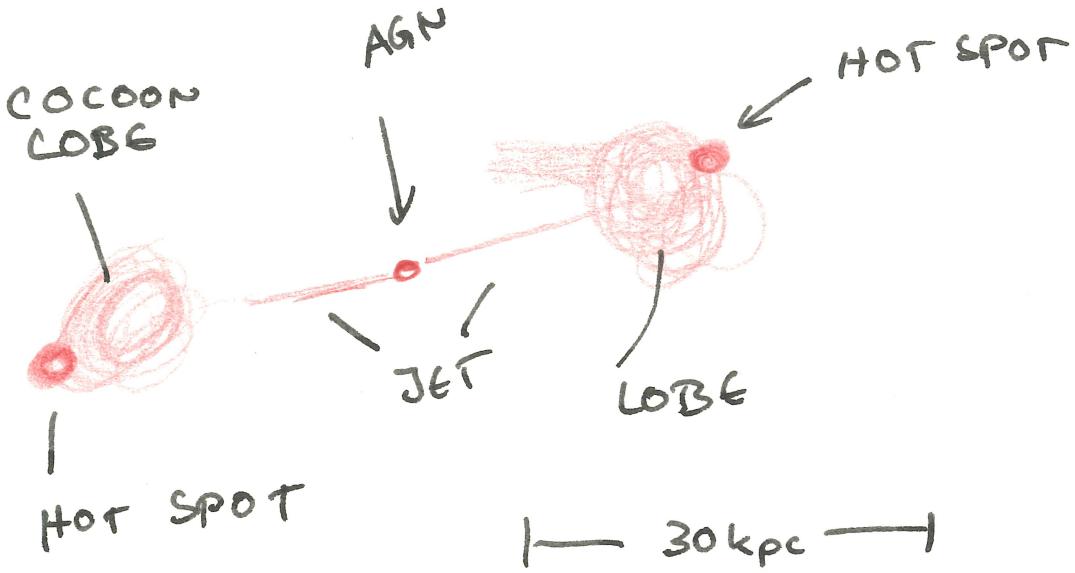
RADIO GALAXIES

1918: CURTIS (LICK) JET IN M87 OPTICAL LIGHT
SLIDE 53 (44)

- BEAMS OF MAGNETISED, RELATIVISTIC PLASMA
- RADIO EMISSION: SYNCHROTON / INVERSE COMPTON
- ABOUT 1000 KNOWN JETS IN RADIO
  30 IN OPTICAL

Cygnus A — SLIDE 54 (45)

- FIRST RADIO GALAXY
- ELLIPTICAL WITH STRONG DUST LANES



M87:
- OPTICAL JET
- CENTRAL GALAXY AT VIRGO
- RELATIVISTIC MOTION

QUASARS (& QSOs) SLIDE - 55 (46)

- SOME RADIO SOURCES ASSOCIATED WITH OPTICAL POINT SOURCES AND STRANGE EMISSION LINES
  ⇒ QUASI - STELLAR RADIO SOURCES
- MAARTEN SCHMIDT: HIGH-REDSHIFT NUCLEI OF GALAXIES SLIDE 56 (47)
- MOST HOST GALAXIES OF QUASARS HAVE BEEN IDENTIFIED

BL Lac Objects

(CONSTELLATION LACERTA) ← lizard

- BLAZARS: STRONGER EMISSION LINES
- VARIABLE "STARS" IDENTIFIED WITH RADIO SOURCES: 1968

- STRONG CONTINUUM
- HIGHLY VARIABLE RADIO EMISSION
- 3C 120: FIRST IDENTIFIED BL LAC OBJECT
- RADIO EMISSION FROM JET POINTING NEARLY TOWARD US

STRUCTURE AND PHYSICS OF AGNs

- SIZES
  - VARIABILITY of luminosity OF AGN ⇒ ESTIMATE OF SIZE ← causality
  - TIMESCALES: $\tau_{PROCESS}$:

(SYNCHROTON, HEATING, COOLING, ACCELERATION, ...)

- Δt: CROSSING TIME FOR EMISSION REGION

$$\Delta t \gg \tau_{PROCESS}$$

SIZE OF EMISSION REGION: (SPEED OF LIGHT)

$$l_{emis} = c \cdot \Delta t$$

TIME SCALE OF VARIABILITY: $\Delta t_{obs} = \tau_{PROC} + \Delta t$

$$\Rightarrow \quad c \cdot \Delta t_{obs} \sim l_{emis}$$

RADIO / OPTICAL : $\Delta t_{obs} \simeq 10\,d$

$\Rightarrow$ $l_{emis} \lesssim 0.01\,pc$

RADIO / OPTICAL : $\Delta t_{obs} \simeq 1\,d$

$\Rightarrow$ $l_{emis} \lesssim 10^{-3}\,pc$

TeV : $\Delta t_{obs} \simeq 1\,h$

$\Rightarrow$ $l_{emis} \lesssim 10^{-5}\,pc$

IN COMPARISON SCHWARZSCHILD RADIUS $R_S = 2GM_{BH}/c^2$

$M/M_\odot$	R_S
10^6	$10^{-7}\,pc$
10^8	$10^{-5}\,pc$
10^9	$10^{-4}\,pc$

$\Rightarrow$ VARIABILITY IN VICINITY OF SUPER MASSIVE BLACK HOLES ?

Zel'dovich 1963:

LUMINOSITY OF ACTIVE NUCLEI IS DUE TO ACCRETION ONTO BLACK HOLES

- TOTAL ENERGY OUT PUT FROM QUASAR AT LEAST ENERGY STORED IN ITS RADIO HALO

  $\gtrsim 10^{54}$ erg $\hat{=}$ $10^7 M_\odot$

- NUCLEAR REACTIONS HAVE AT BEST EFFICIENCY OF 0.7% (H BURNING)

  7 MeV / nucleon $\hat{=}$ 0.007 Mc^2

  $\Rightarrow$ WASTE MASS BEHIND POWERING QUASAR:

  $\gtrsim 10^9 M_\odot$

- RAPID BRIGHTNESS VARIATIONS

  TYPICAL QUASAR NOT BIGGER THAN SOLAR SYSTEM (2AU $\approx 10^{-5}$ pc)

- BUT $10^9 M_\odot$ INSIDE SOLAR SYSTEM $\hat{=}$ SMBH 10^8–$10^9 M_\odot$

  $\Rightarrow$ 10 TIMES LARGER THAN FUSION ENERGY

  SLIDE-58 (49)

$\Rightarrow$ QUASAR ENGINES ARE SUPER-MASSIVE BLACK HOLES

STANDARD MODEL OF AGNs

- AGN CONTAINS BLACK HOLE WITH MASS

$$M \approx 10^6 \ldots 10^{8.5}\, M_\odot$$

- MASS ACCRETION : $10^{-4} \ldots 10\, M_\odot / yr$ FROM DISK
- JETS AND NON-THERMAL RADIATION

ROTATING MAGNETOSPHERE OF ACCRETION DISK

LUMINOSITY FROM ACCRETION

$$L_{ACC} = \frac{1}{16} \dot{m} c^2$$

(EFFICIENCY OF HYDROGEN BURNING)

$L_{H\text{-}BURN} = 0.008\, \dot{m} c^2$

EDDINGTON LIMIT: RADIATION PRESSURE $\geq$ GRAVITATIONAL ACCELERATION PER AREA

=> LUMINOSITY:

$$L_{Edd} = \frac{4\pi G M_{BH} M_p c}{\sigma_T}$$

Hydrogen ionized

σ_T ↑ Thomson scattering

↑ MAXIMUM POSSIBLE LUMINOSITY

Eddington limit

radiation force (pressure) < grav. force

$$F_g = \frac{G M_\odot m_p}{r^2} \qquad \text{(neglect me)}$$

Radiation pressure
given by Thomson scattering σ_T

Flux: $S = \frac{L}{4\pi r^2}$

~~$\left(\frac{\gamma}{m^2 s} \doteq \frac{E}{A\,t}\right)$~~ ~~$\frac{F \cdot s}{s^2 \cdot t} = \frac{F}{s \cdot t} = \frac{m \cdot v}{s \cdot t \cdot t} = \frac{p}{s^2 \cdot t \cdot \frac{t}{s}}$~~

$$S = \frac{E}{t \cdot A}$$

pressure: $$\frac{S}{c} = \frac{E}{t \cdot A \cdot \frac{s}{t}} = \frac{E}{V} = \frac{F \cdot s}{A \cdot s} = \frac{F}{A} = \frac{m \cdot a}{A} = \frac{m \cdot v}{A \cdot t}$$

$$= \frac{\dot{p}}{A}$$

$\Rightarrow$ Force: $F_{rad} = \frac{\dot{p}}{A} \cdot \sigma_T = \frac{S \cdot \sigma_T}{c} =$

momentum transfer on electron per unit time

$$\frac{L \cdot \sigma_T}{4\pi r^2 c}$$

$$\frac{\sigma_T \cdot L}{4\pi r^2 c} \leq \frac{G M_\odot m_p}{r^2} \Rightarrow L_{edd}$$

$$L_{Edd} = 1.3 \cdot 10^{38} \frac{M_{BH}}{M_\odot} \frac{erg}{s}$$

$$\Rightarrow \quad M_{BH} \geq 10^7 M_\odot$$

↳ FOR SEYFERT GALAXIES

ACTIVE GALAXIES

$$M_{BH} \approx 10^9 M_\odot$$

↳ FOR QUASARS

efficency

$$\Rightarrow \quad \text{WITH} \quad L_{ACC} = \frac{\varepsilon}{16} \dot{m} c^2$$

$L_{ACC} = L_{edd} =$

ACCRETION RATE: $\dot{m}_{edd} = 5 \times 10^{-10} \frac{M_{BH}}{M_\odot} \left[\frac{M_\odot}{Gyr}\right]$

growth rate of BH mass

WITH $\dot{M} = \frac{M}{\tau} \Rightarrow M(t) = M_0 \exp\left(\frac{t}{\tau}\right)$

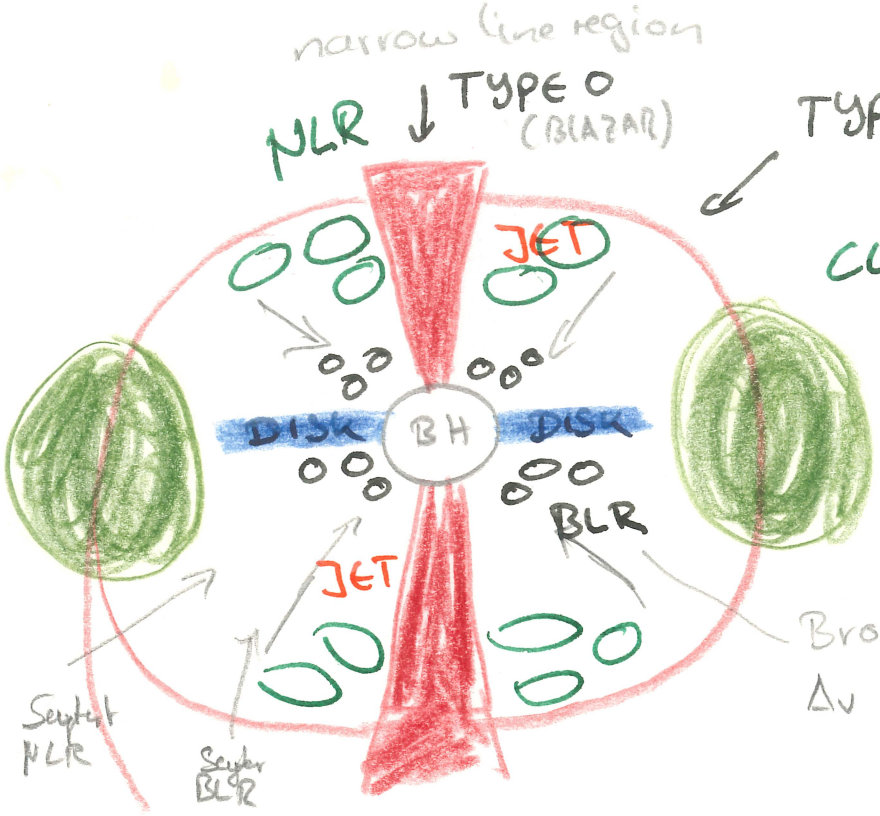
WITH $\tau \approx 2 \cdot 10^8$ yrs

FOR A SUPER MASSIVE BLACK HOLE (SMBH)

WITH $10^9 M_\odot$ IN HUBBLE TIME (AGE OF THE UNIVERSE) 10Gyr

$$M_0 = \frac{10^9 M_\odot}{\exp(5)} = 7 \cdot 10^6 M_\odot$$

STRUCTURE OF AGN



- DIFFUSE HOT CORONA; X-RAYS
- JETS
- DENSE, FAST MOVING CLOUDLETS GENERATING EMISSION LINES
- DETERMINATION OF BH MASS BY REVERBARATION MAPPING:

$$\frac{GM_{BH}}{R_{BLR}} \sim (\Delta V)^2$$

At → extend of BLR → R_{BLR}

ΔV → VEL DISPERSION

- ACCRETION DISK + TORUS
- CENTRAL SUPER MASSIVE BH

MILKY WAY BLACK HOLE

SLIDE 59 - 66
(50 - 57)

DEMOGRAPHICS OF BLACK HOLES

- ALL SPHEROIDS CONTAIN SUPER MASSIVE BLACK HOLES WITH

$$M_{BH} \sim 0.002\, M_{spheroid}$$

- PURE DISKS DO NOT CONTAIN BLACK HOLES

- TIGHT CORRELATION BETWEEN BH MASS AND SPHEROID VEL. DISPERSION:

$$M_{BH} \sim 0.1\, \sigma^4 \quad (M_\odot, \text{km/s})$$

- MORE COMPACT BULGES CONTAIN MORE MASSIVE BHS

SLIDE - 67

(58)