# BLACK HOLES IN THE UNIVERSE

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# THE IDEA OF BLACK HOLE

## First proposed by John Michell in 1783

(Philosophical Transactions of the Royal Society)

## IN THE CONTEXT OF CORPUSCULAR THEORY OF LIGHT:

"…suppose the particles of light to be attracted

in the same manner as all other bodies…"

## THERE SHOULD EXIST BLACK HOLES:

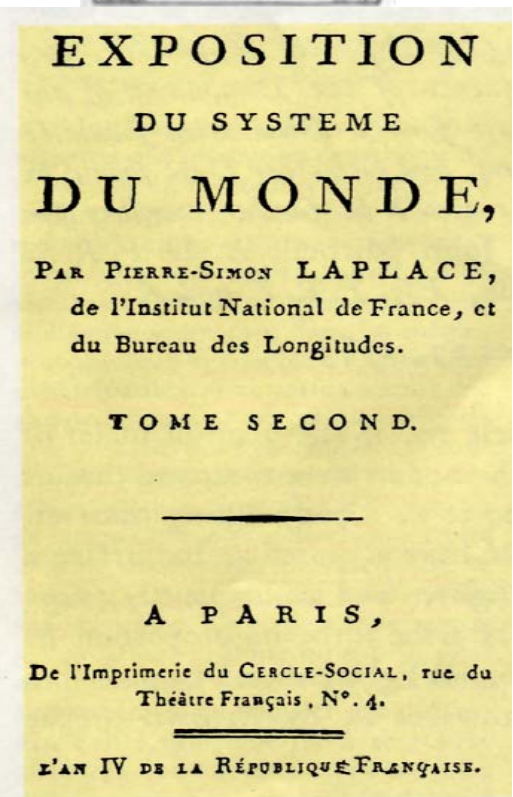
"…there should exist in nature bodies from which light could not arrive at us…"

## CAN BE DETECTED BY THE MOTION OF COMPANION STARS:

"…we might still perhaps from the motions of these revolving bodies infer the

existence of the central objects with some degree of probability…"

# SUPERMASSIVE BLACK HOLES



EXPOSITION

DU SYSTEME

DU MONDE,

PAR PIERRE-SIMON LAPLACE,
de l'Institut National de France, et
du Bureau des Longitudes.

TOME SECOND.

A PARIS,

De l'Imprimerie du CERCLE-SOCIAL, rue du
Théâtre Français, N°. 4.

L'AN IV DE LA RÉPUBLIQUE FRANÇAISE.

(in the context of Newtonian physics)

## BLACK HOLES MAY EXIST:

"…tous ces **corps devenus invisibles**…"

## IN VERY LARGE NUMBERS:

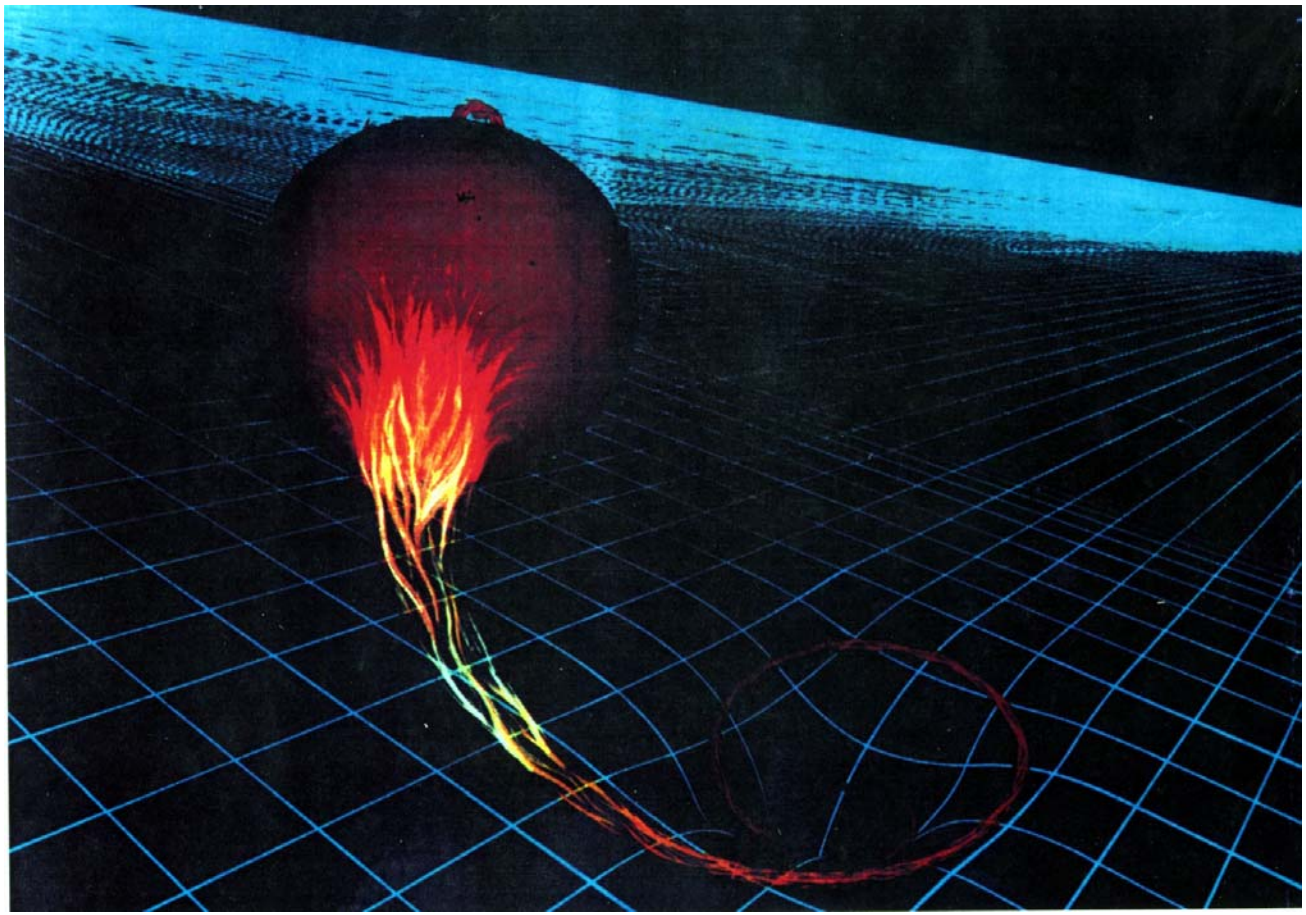
"…Il existe donc dans les espaces celestes, des corps obscurs aussi considerables, et peut etre en aussi grand nombre, que les etoiles."

## THE LARGEST OBJECTS IN THE UNIVERSE:

"…ne lesserait en vertu de son attraction, parvenir aucun de ses rayons jusq'a nous; il est donc possible que les plus grands corps lumineux de l'univers, soient par cela meme, invisibles."

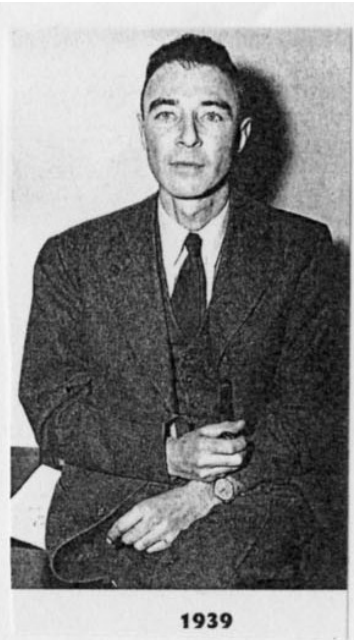
Idea remained silent due to the ondulatory theory of light

# RELATIVISTIC GRAVITY



LIGHT IS DEFLECTED AND λ MODIFIED IRRESPECTIVE OF THE CORPUSCULAR OR WAVE THEORY OF LIGHT

# RELATIVISTIC THEORY OF BLACK HOLES

| Einstein | Schwarzchild | Eddington | Chandrasekhar | Oppenheimer |
|---|---|---|---|---|
|  1916 |  1916 |  1924 |  1930 |  1939 |
| Theory of gravitation: black holes should exist | Horizon: $R_s = 2\,G\,M/c$ ~3 M/ $M_\odot$ km | White dwarfs: $R_{wd} = R_T$ | Limit of mass for white dwarfs: $M_{wd} < 1.4\,M_\odot \Rightarrow$ | Neutron stars: $M > 1.4\,M_\odot$ R ~ 20 km Black holes: $M > 3\,M_\odot$ |

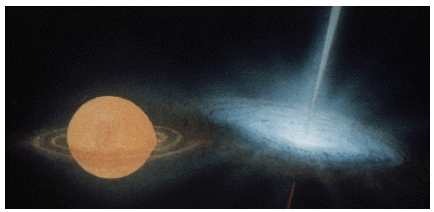
**Black holes have mass, angular momentum, charge (?), but no material surface**

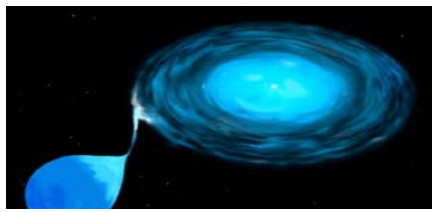
# OBSERVATION OF STELLAR-MASS BHs

## DISCOVERED AS X-RAY SOURCES

(Giacconi et al. 1962)

**High Mass and Low Mass X-Ray Binary Systems**

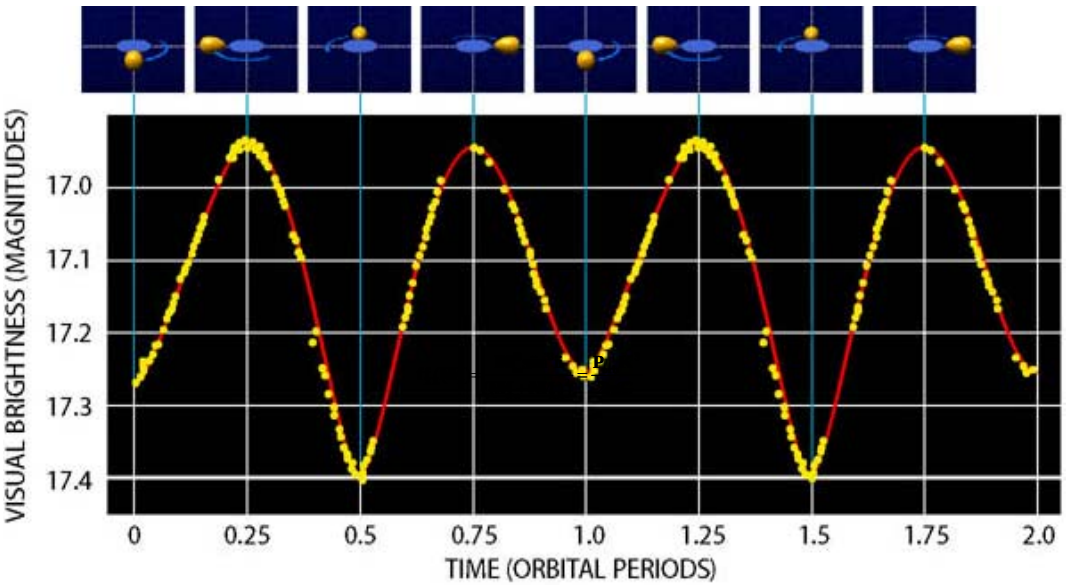




IN BINARY STELLAR SYSTEMS:

as predicted by Michell (1783)

$M > 3\ M_{\odot} \Rightarrow$ BLACK HOLE




- 20 BHs known in binaries and other 20 additional candidates
- Estimated population in the Galaxy ~ $3 \times 10^8$ $\Rightarrow$
- Assuming ~10 $M_{\odot}$ this form of dark mass is ~ 4% of total baryonic mass of the Galaxy
- Outweighs the supermassive black hole at Galactic Centre by a factor of $10^3$

**Fonction de masse:** $$f_X(M) = \frac{M_n^3 \sin^3 i}{(M_n + M_X)^2} = \frac{P_{orb} K}{2\pi G}$$

***Minimum de masse de l'objet compact***

$K = (V_{max} - V_{min}) / 2$ ; $f < M_n$

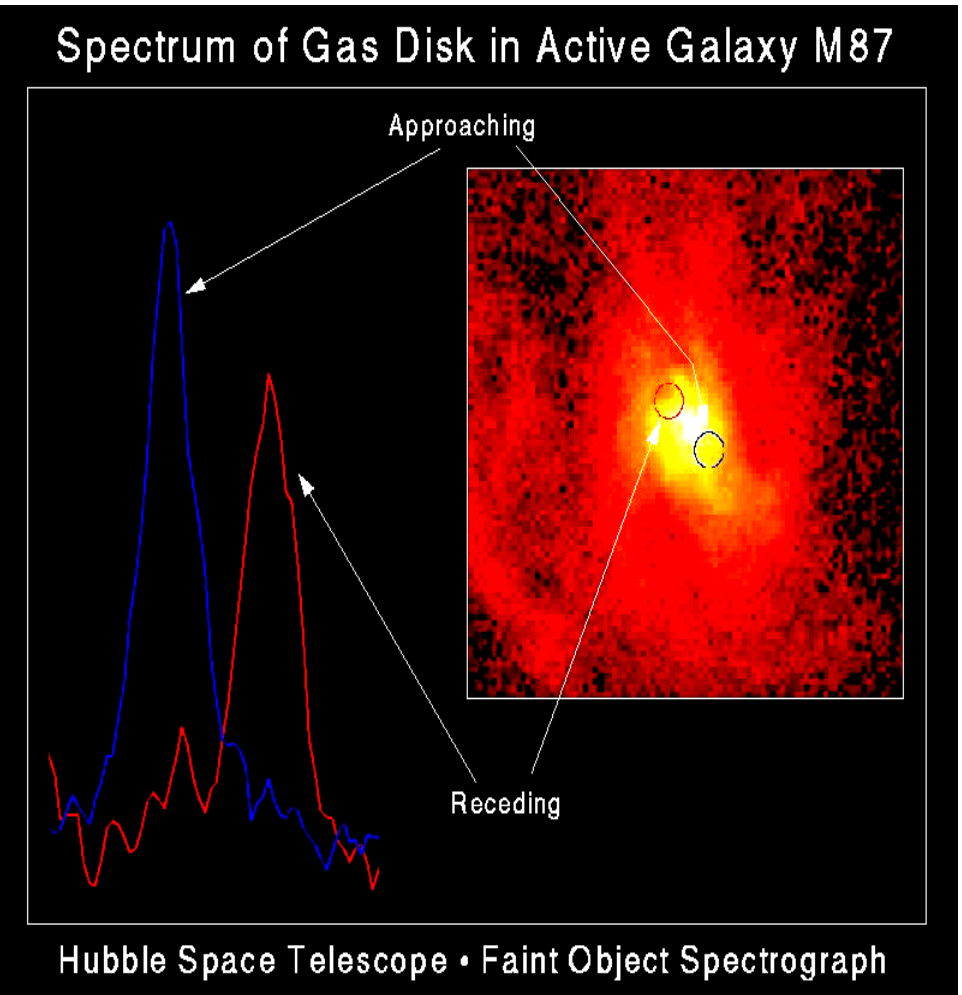
# SUPERMASSIVE BLACK HOLES IN THE UNIVERSE

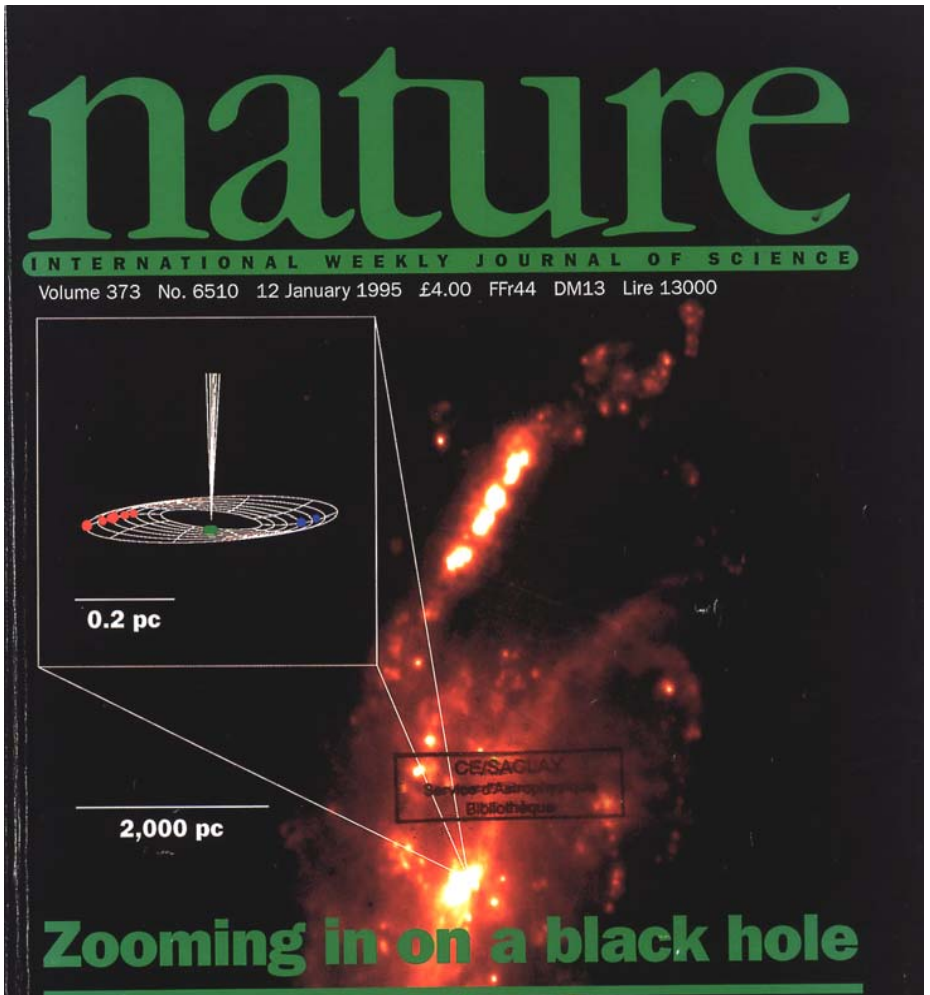
Kinematics of the $H_\alpha$ line with HST

$\Rightarrow M_{BH} \sim 10^8 M_\odot$ in M 87

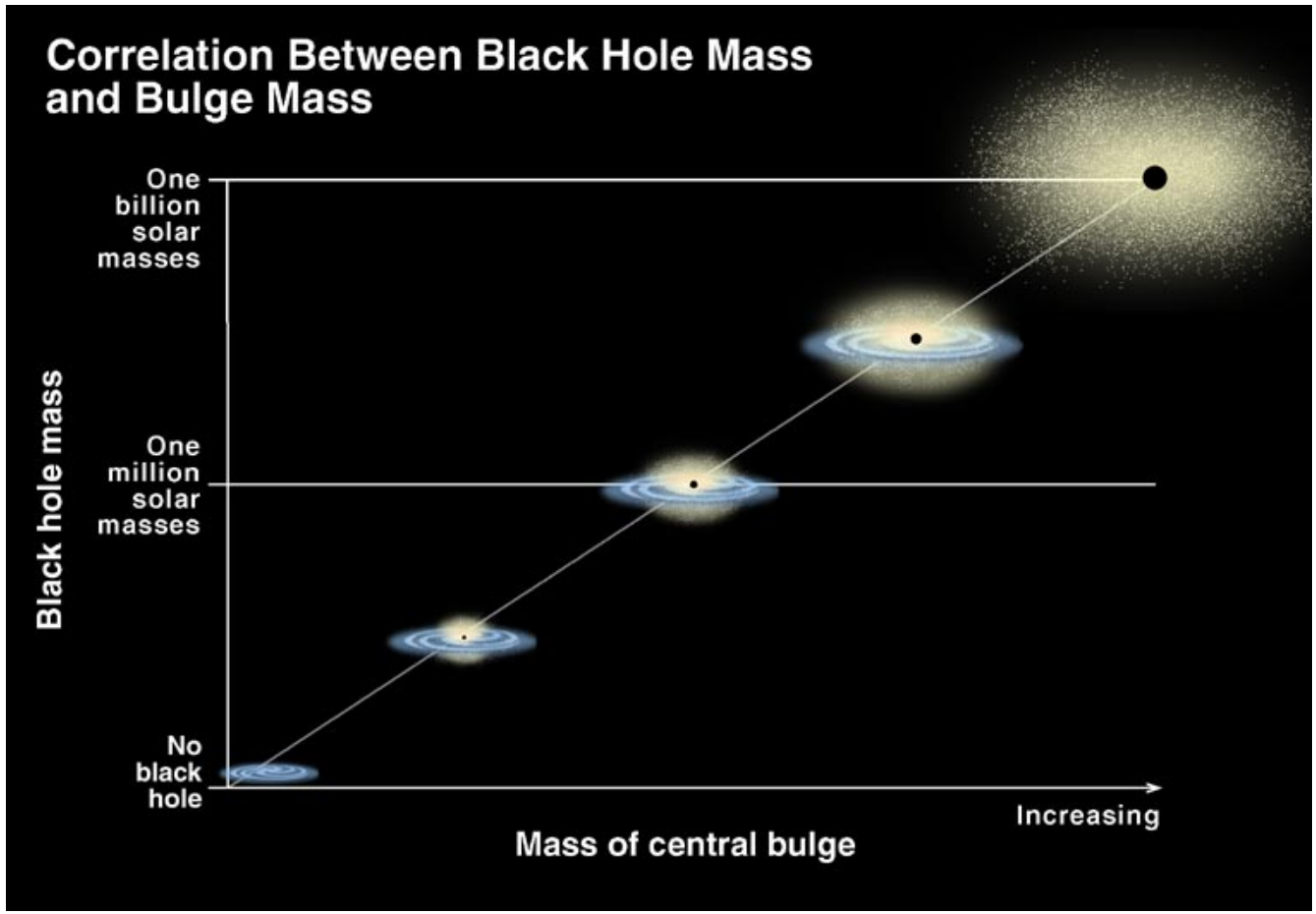
$H_2O$ masers with VLBA

$\Rightarrow M_{BH} \sim 10^7 M_\odot$ in NGC 4258



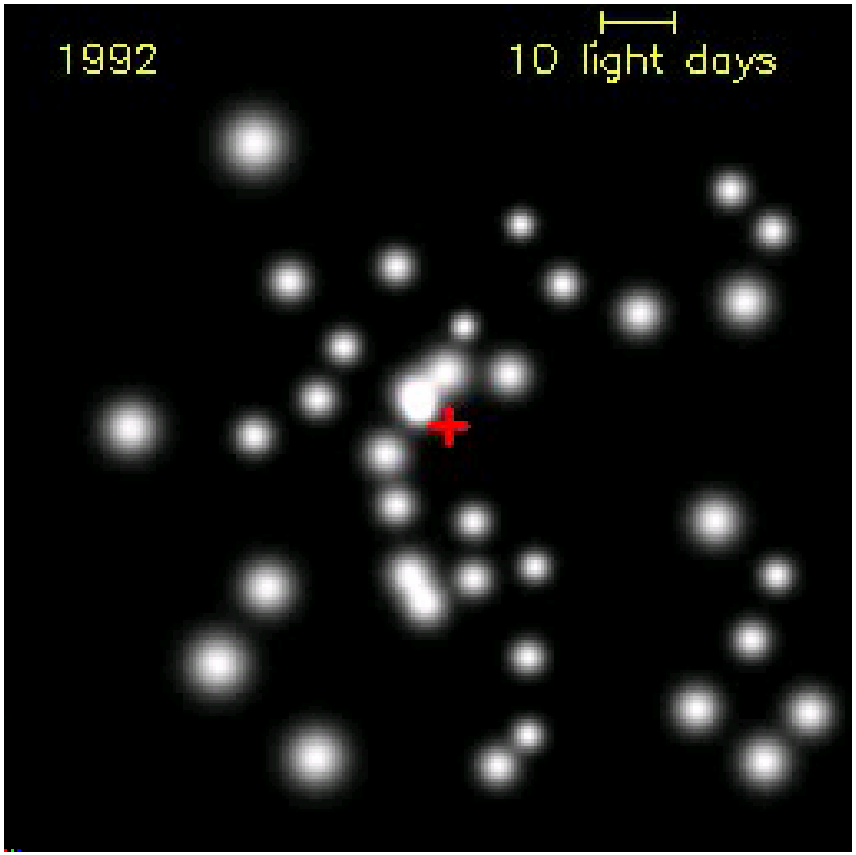
# MASSIVE GALAXIES HOST SUPERMASSIVE BLACK HOLES



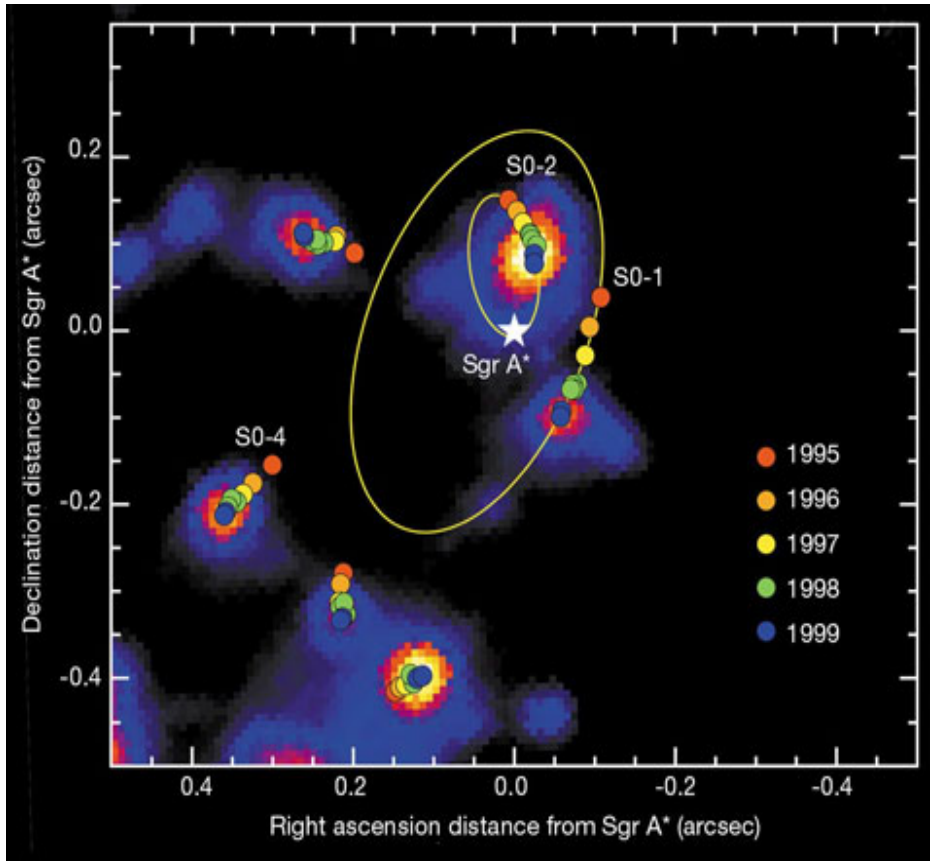

- **HOW ARE SUPERMASSIVE BLACK HOLES FORMED ?**
- **ARE THERE BHs OF INTERMEDIATE MASS ($10^2$- $10^4$ $M_\odot$) ?**

# BLACK HOLE IN THE GALACTIC CENTRE

Eckart & Genzel (IR with VLT-ESO)




Ghez, Morris et al. (IR with Keck)

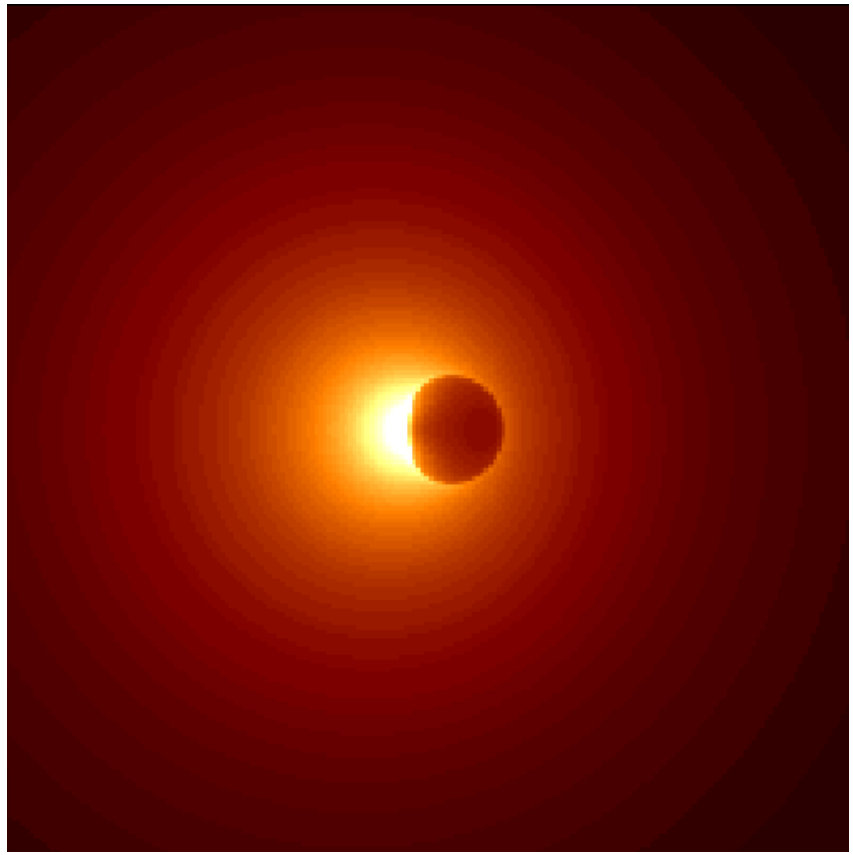



- Must be a single object with $M_{BH} \sim 3 \times 10^6 M_\odot$
- Black Hole in Andromeda $M_{BH} \sim 10^8 M_\odot$ (Bender et al. 2005)
- How stars < $10^7$ yr old can exist in such environments ?
- But this is an indirect evidence of black hole

# CAN WE OBTAIN A DIRECT IMAGE OF Sgr A* ?

## "HORIZON": DEFINING CONCEPT OF BLACK HOLE

J.P. Luminet

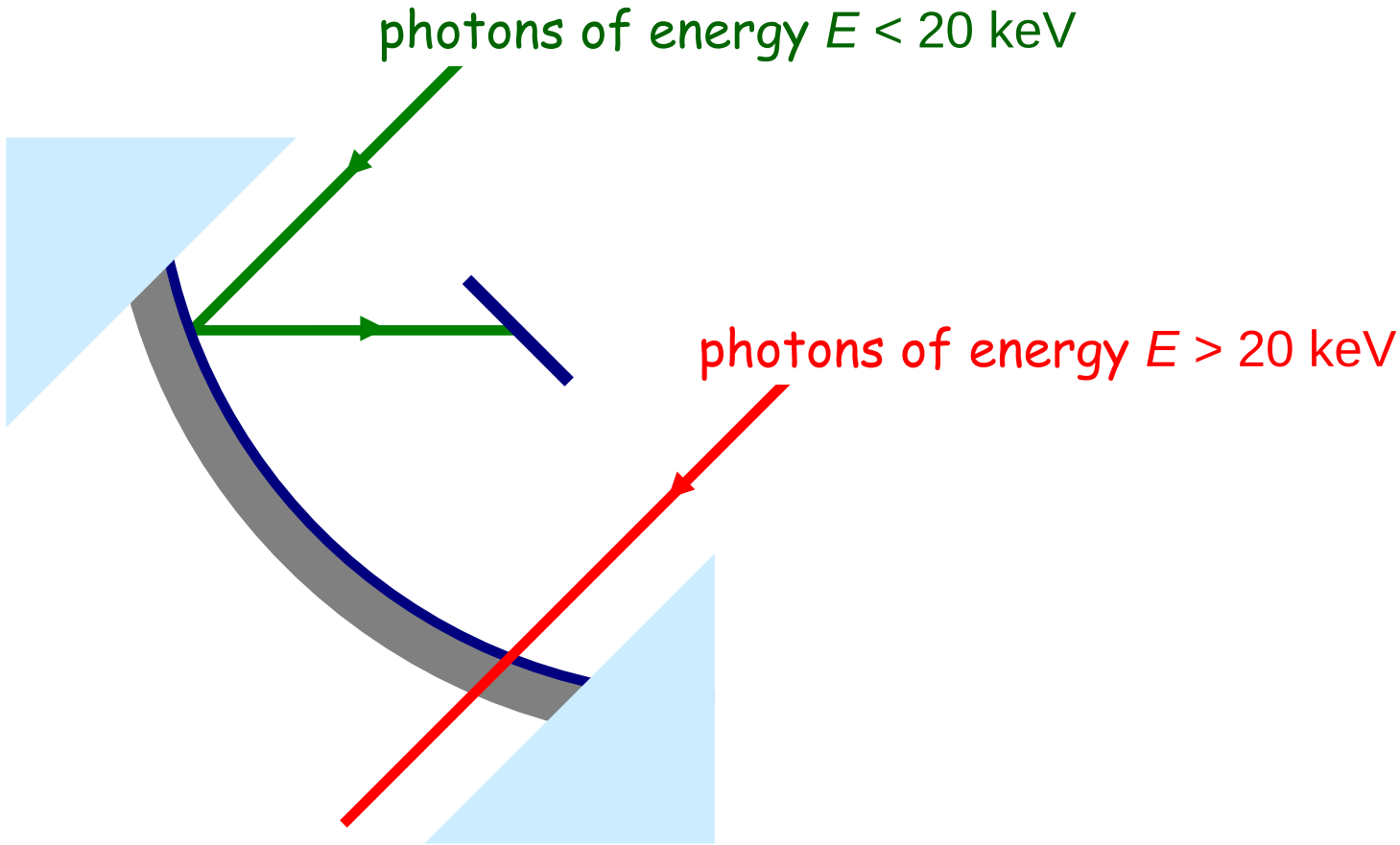


- Dark circle caused by radiation from sources behind that are being swallowed by the event horizon.
- Bright ring due to rays deflected by BH
- Shadow is off-centre due to flung of photons in the direction of BHs' rotation

- **3 x $10^6$ $M_\odot$ confined in a region enclosed by the orbit of the Earth**
- **D = 30 μarcsec to be imaged with VLBI at sub-millimeter or X-rays**

Is Sgr A* an annihilation source of e+e- at 511 keV ?

# OBSERVATIONAL LIMITATIONS IN HIGH ENERGY ASTROPHYSICS

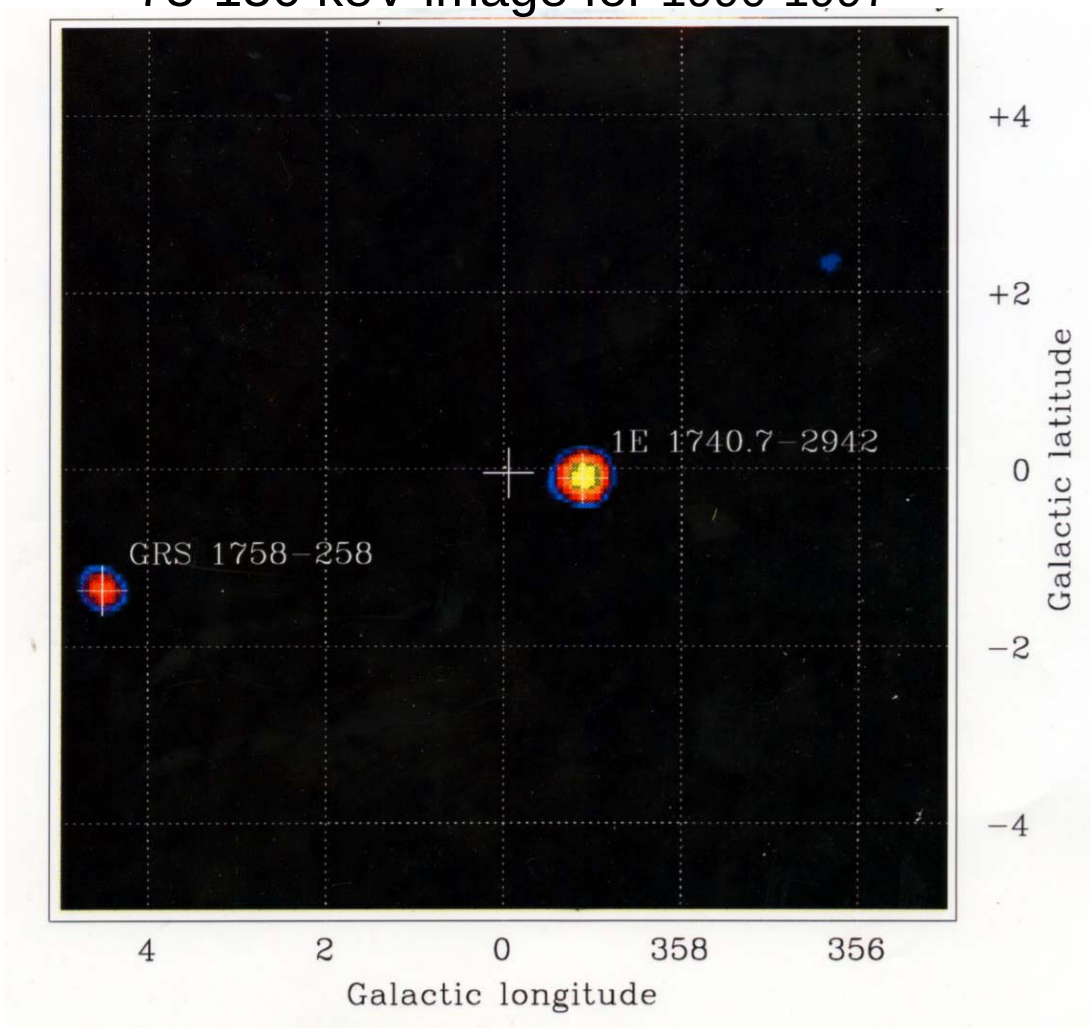



- The imaging at E > 20 keV is done with coded mask techniques which can provide positions for the sources with resolutions of a few arcmin
- Focusing photons with energy *E* > 20 keV, a challenge for the future

# GRANAT SURVEY OF THE GALACTIC CENTRE


with a simultaneous multiwavelength approach


75-150 keV image for 1990-1997

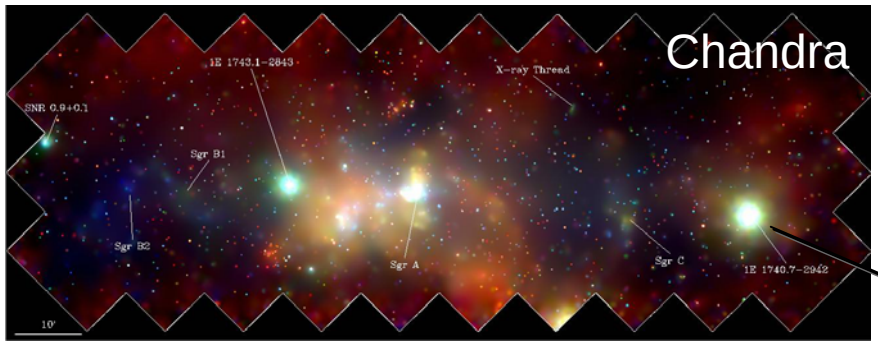



**In 1990-97 Sgr A* was silent (Goldwurm et al.) ⇒ ADAF (Narayan et al.)**

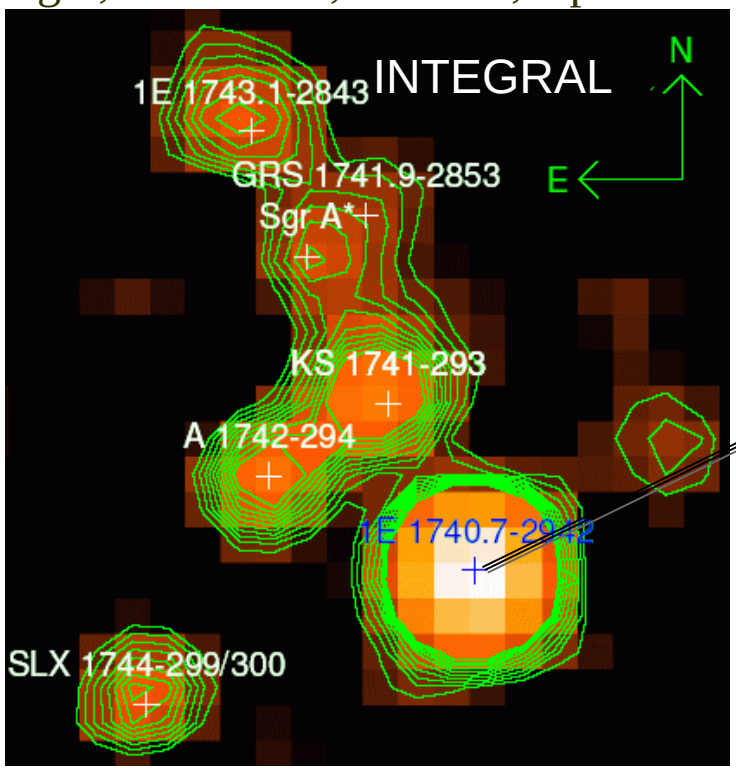
**In 2002-5 Chandra & XMM detected flares at energies <10 keV**

# HIGH ENERGY SOURCES IN THE GALACTIC CENTRE

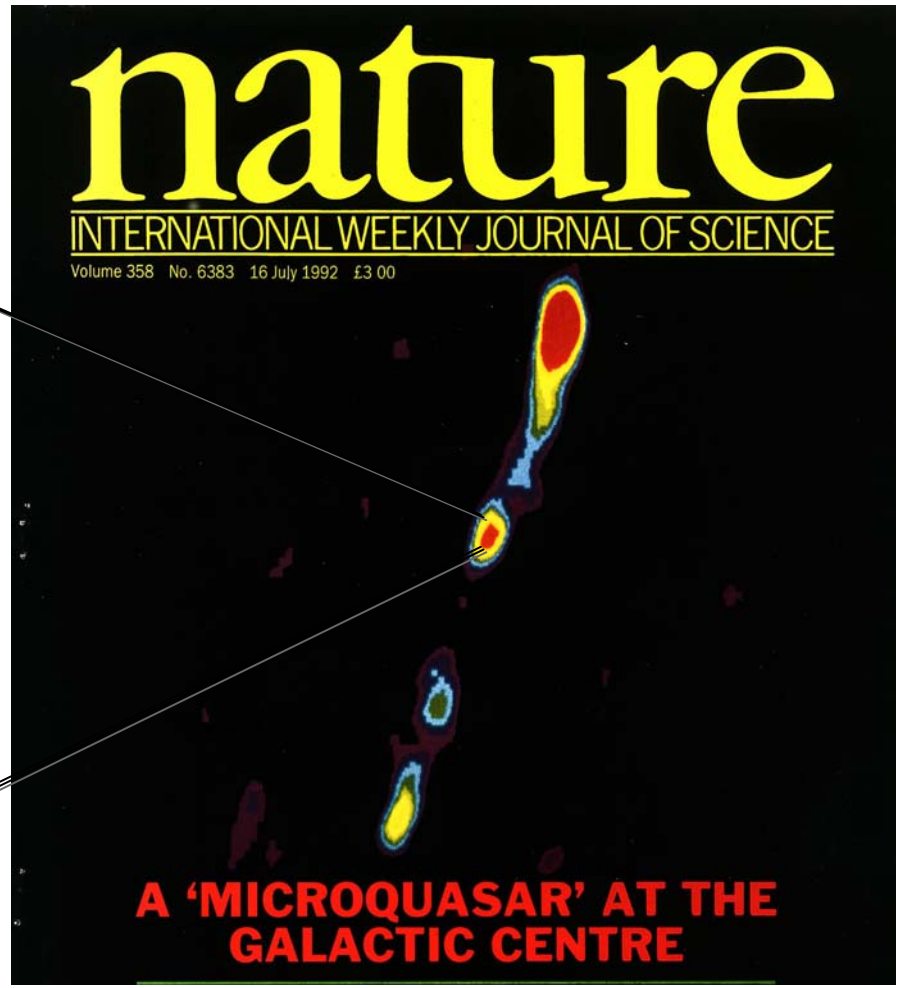
Wang et al. ApJ 2002




Belanger, Goldwurm, Goldoni, ApJ 2003

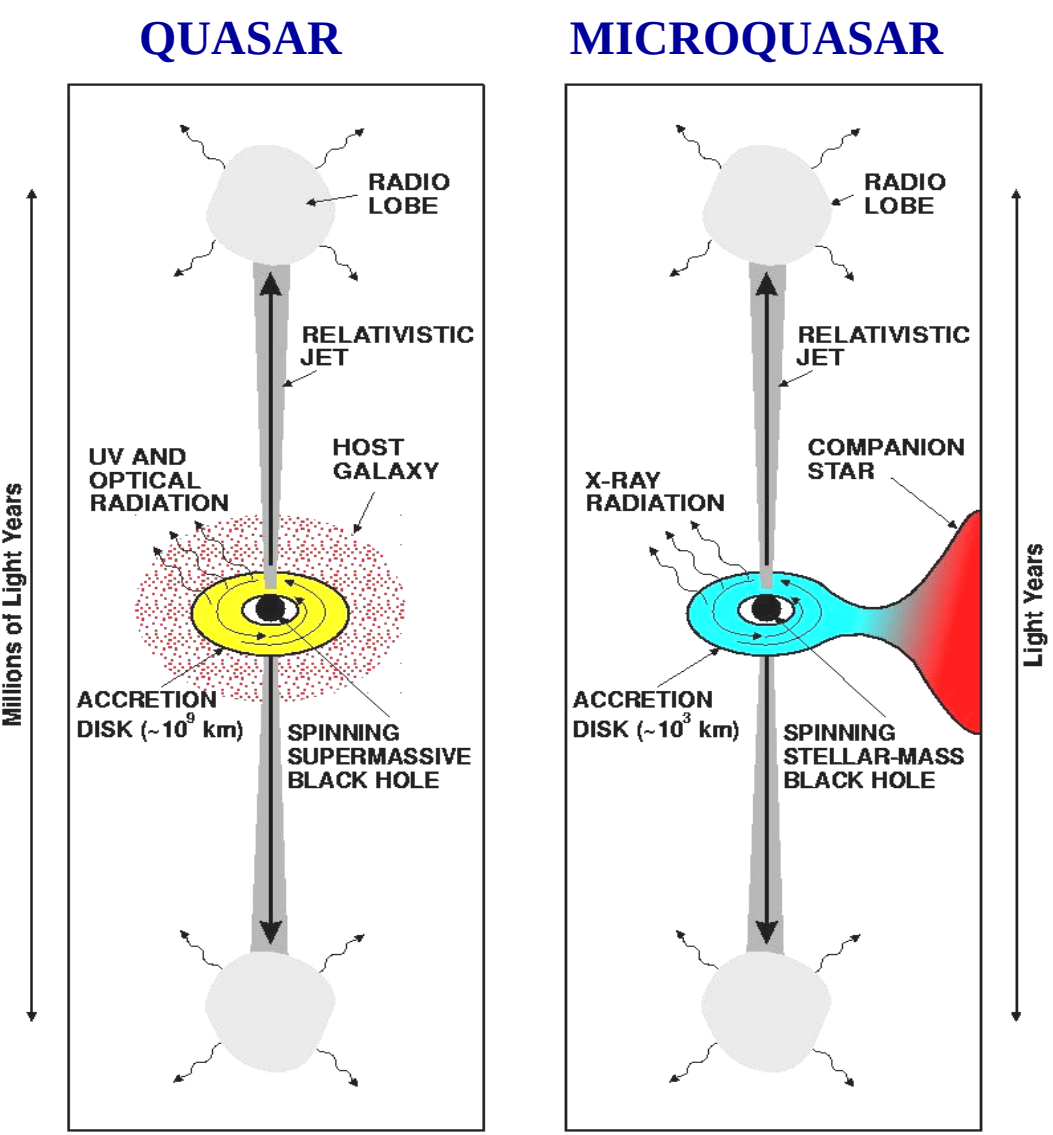



M., Rodriguez, et al, 1992




Five international workshops

# QUASAR-MICROQUASAR ANALOGY




M. & Rodriguez; Nature 1998

**The scales of length and time are proportional to $M_{BH}$**

$$R_{sh} = 2GM_{BH}/c^2 \; ; \; \Delta T \, \alpha \, M_{BH}$$

**Unique system of equations:**

The maximum color temperature of the accretion disk is:

$$T_{col} \, \alpha \, (M/\, 10M_{\odot})^{-1/4}$$

(Shakura & Sunyaev, 1976)

Waited era of space astronomy

For a given accretion rate:

$$L_{Bol} \, \alpha \, M_{BH} \; ; \; l_{jet} \, \alpha \, M_{BH} \; ;$$

$$\varphi \, \alpha \; M_{BH}^{-1} \; ; \; B \, \alpha \, M_{BH}^{-1/2}$$

(Sams, Eckart, Sunyaev, 96; Rees 04)

APPARENT SUPERLUMINAL MOTIONS IN μQSOs AS IN QSOs ?