History of Massive Black Holes in Galaxies

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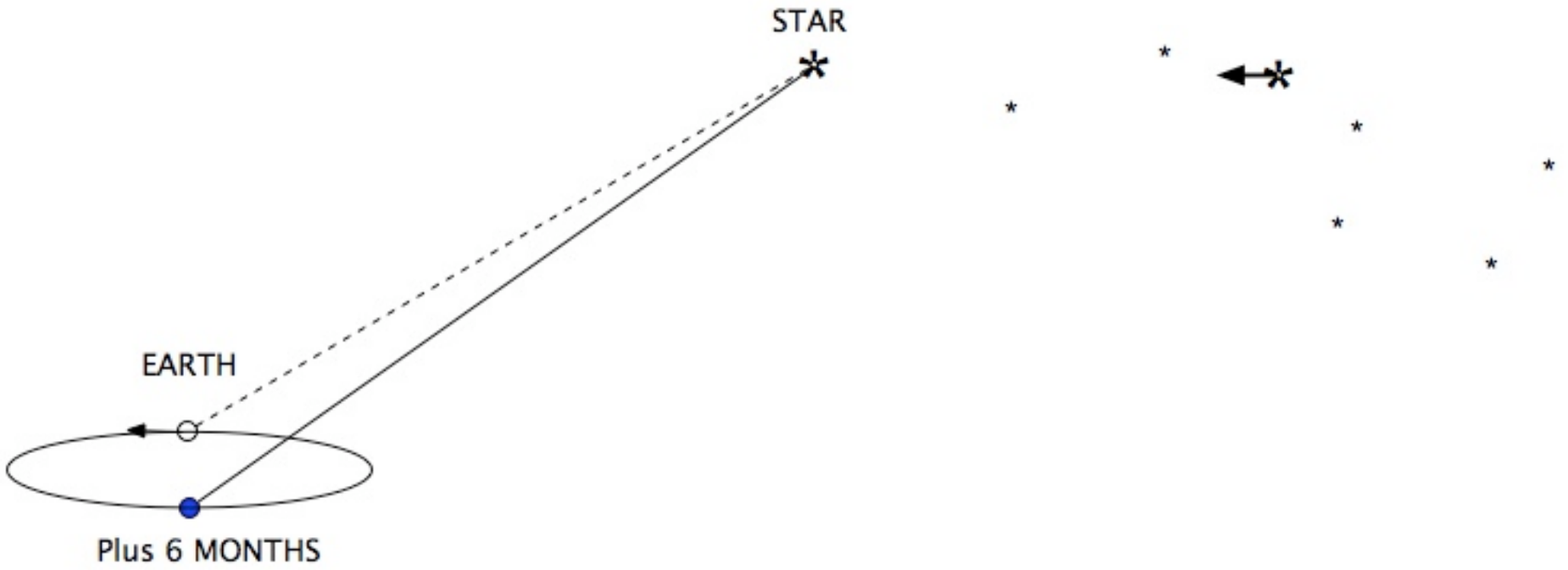
1703	Newton's	Opticks
1724	Bradley	Aberration
1780	Herschel's	bright nuclei
1783	Michell's	*Dark Stars*
1795	Laplace	popularises
1802	Young's slits	Interference
1850	Lord Rosse	Spiral galaxies
1915	Einstein's	General Relativity
1916	Schwarzschild's	Black Hole
1917	Slipher's	broad lines in1068

1939 Einstein's "Star Cluster"
1939 Oppenheimer & Snyder 'make' a BH
1953- Ryle Radio Galaxies
1958 G.Burbidge HUGE energy
1963 Kerr's Rotating BLACK HOLE
1963 Schmidt Quasars
1964 Salpeter Accretion by a moving BH
1969 Lynden-Bell BH in Galactic Centres
1970 Bardeen growth to Kerr HOLES

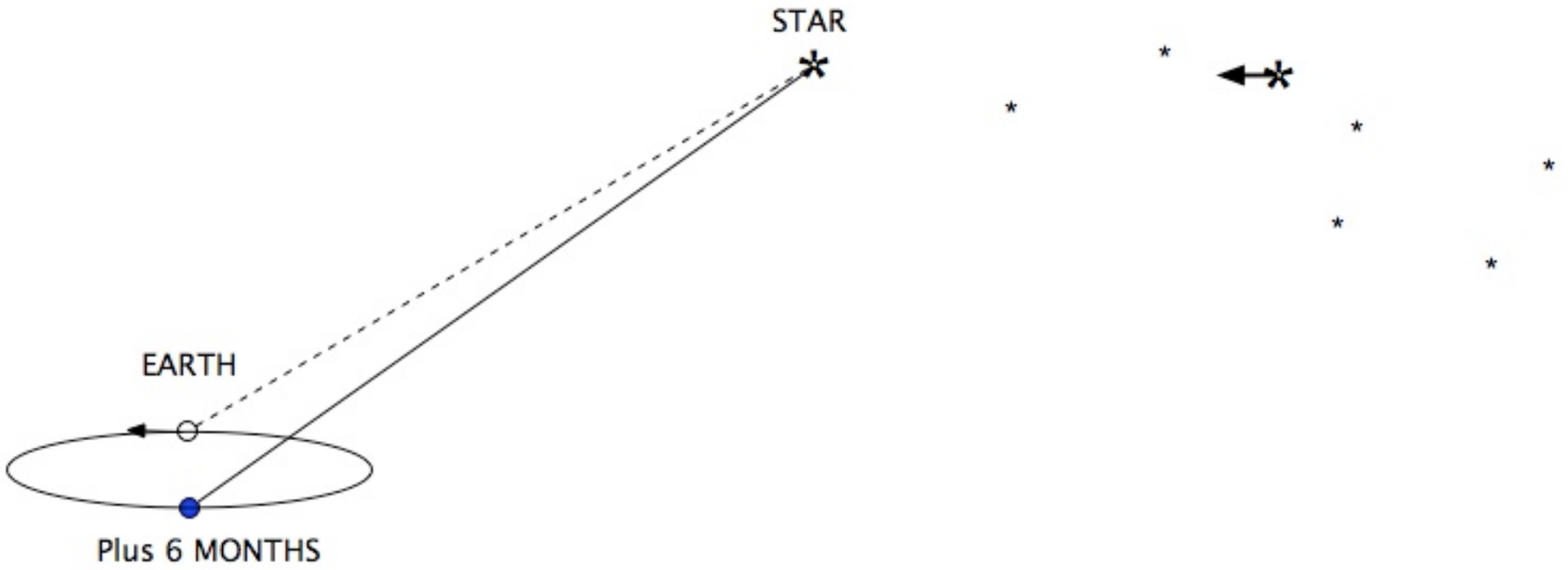
Newton 1642-1727

1703 Opticks Question 1
Do not bodies act upon light
at a distance,
and by their action bend its
rays; and is not
this action strongest at the
least distance?

Bradley 1692-1762



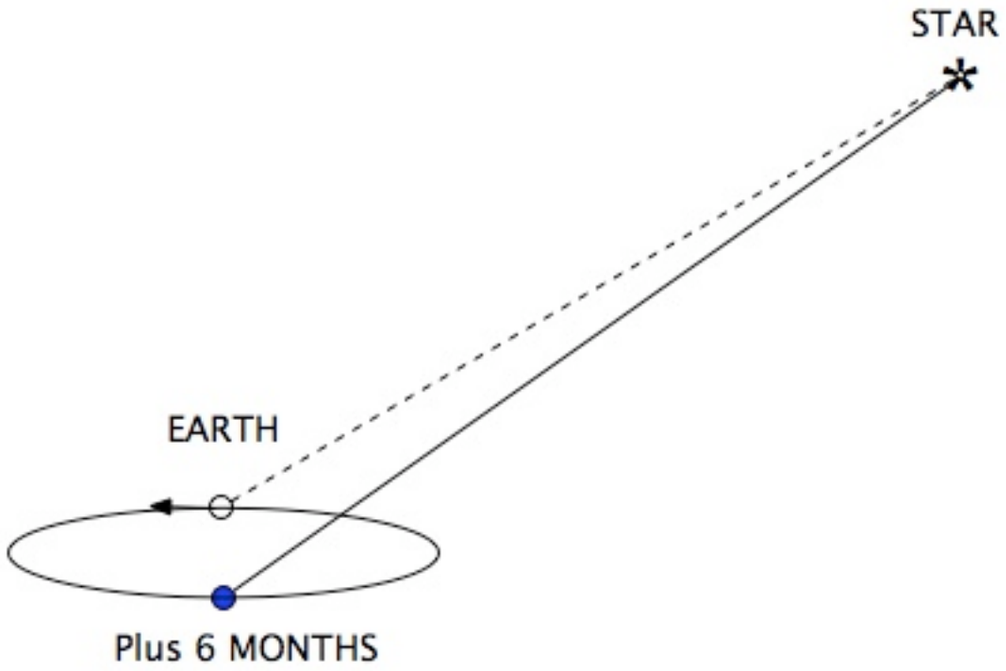
Bradley 1692-1762



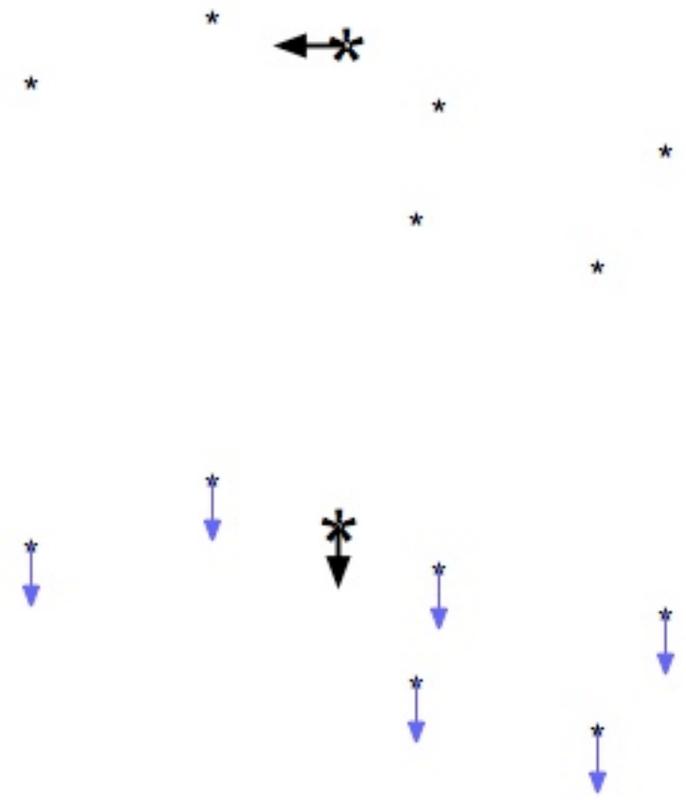
expected

observed 1728

Bradley 1692-1762



expected



observed 1728

How do the photons of light
behave when pulled back by
the Sun's gravity?

Joseph Priestley thought
they would move
VERY slightly more slowly.
(2 in 1,000,000)

ESCAPE SPEEDS

a satellite at 30,000 km/u can escape from Earth
a satellite at 650km/Sec could escape from the Sun

Michell's question
how much larger than the Sun would
a body have to be before even light could
not escape from its gravity?

Rev John Michell 1783
in a Letter to Henry Cavendish
published in Phil Trans Roy Soc 1784

If there should really exist in nature any bodies of the Sun's density whose diameters are more than 500 times the Sun's diameter then their light could not arrive at us.*

Yet if other bodies should revolve about them we could still detect them

Michell asked both the
Astronomer Royal Maskelyne
and Herschel to see if the light from
the brightest stars was slower.
They thought slower light would be
bent more easily by a prism,
but did not find that.

Cavendish calculated the bending
of light by gravity as it passes a body.

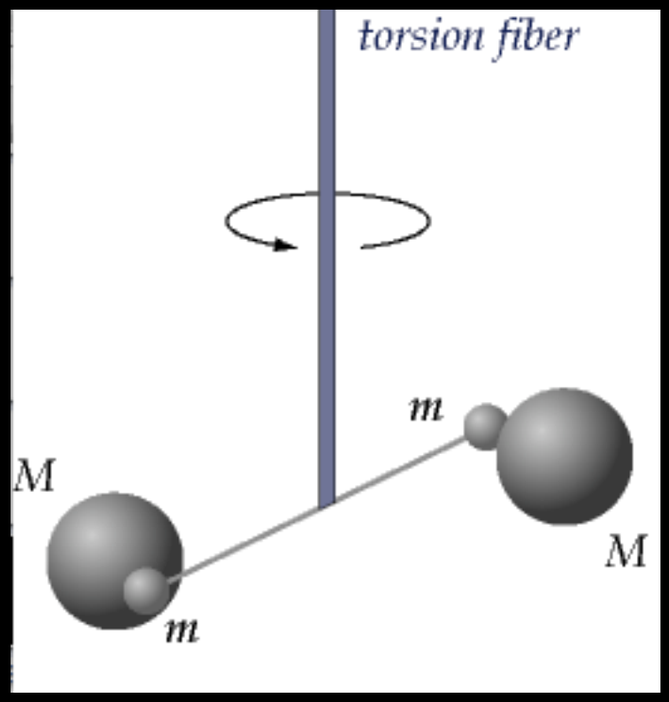
Rev. John Michell BD FRS
born Christmas day 1724 died April 29th 1793
Fellow of Queens' College Cambridge
Vicar of St. Botolph's 1760-63
Woodwardian professor of Geology 1762

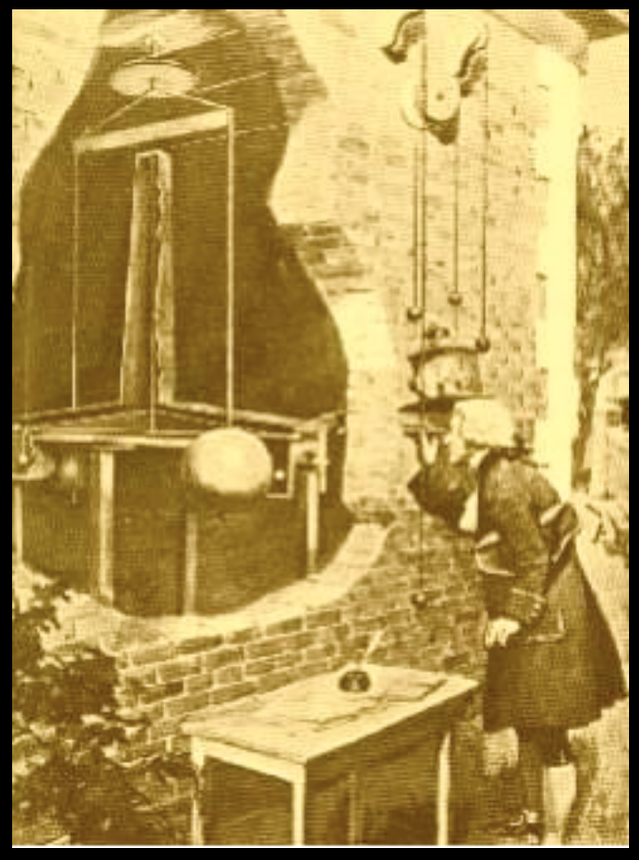
He taught Erasmus Darwin who had an
early theory of species and was grandfather
of Charles Darwin.
Rector of Thornhill Yorkshire 1767-93
friend of Joseph Priestley who discovered Oxygen
and of Henry Cavendish who discovered Hydrogen

Michell's Achievements in Science

1. Inverse square law force between magnetic poles*
2. Earthquake Waves in the Earth's Strata
3. Stars in Clusters not equally bright, held by Gravity
4. Too many double stars. Not chance coincidences
5. method for detecting the Sun's motion
6. PREDICTED GIANT BLACK HOLES 1783
7. Built himself a telescope of 72 cm aperture
8. Left a list of rock strata thicknesses in England
9. Invented the apparatus for measuring the gravitational constant. This was successfully perfected after his death by his friend Henry Cavendish.

After rebuilding Michell's apparatus Henry Cavendish measures the Gravitational Constant G

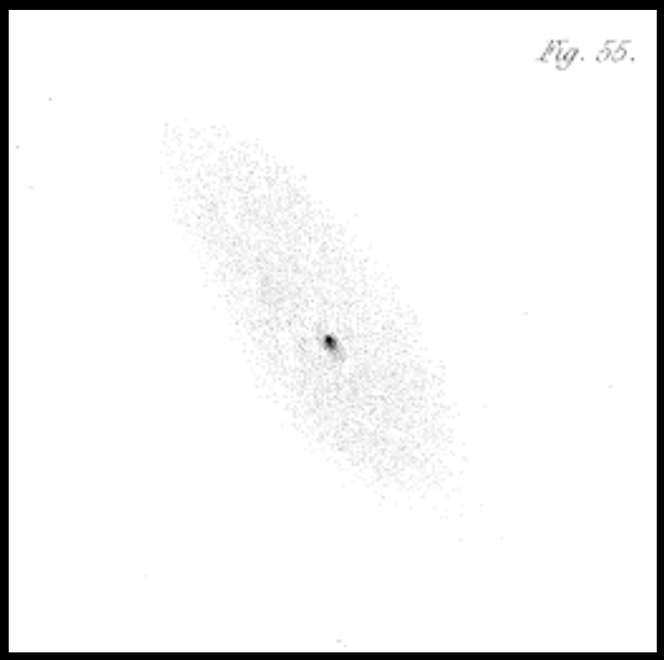




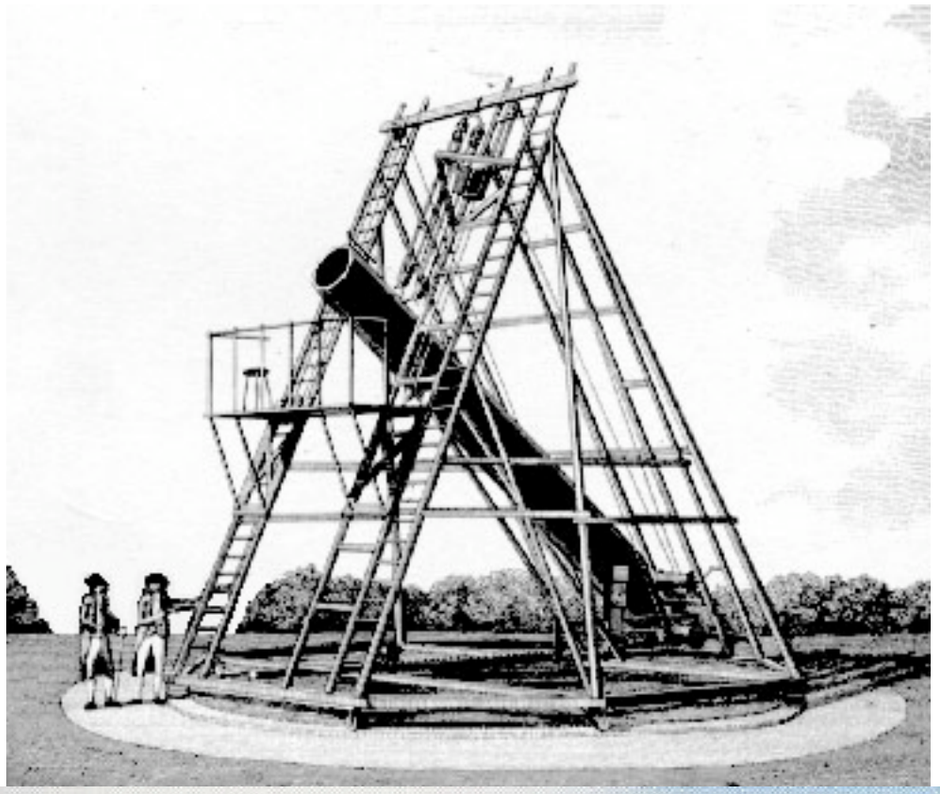
William Herschel's description:

NGC4151 very bright, small & round, very suddenly much brighter in the middle, bright nucleus.

NGC 4258



Very bright, very large, much extended at 0^0



Top: Herschel's Telescope1780 and the modern one on La Palma
Left: Lord Rosse's 1.8m telescope discovered spirals

NGC 1068

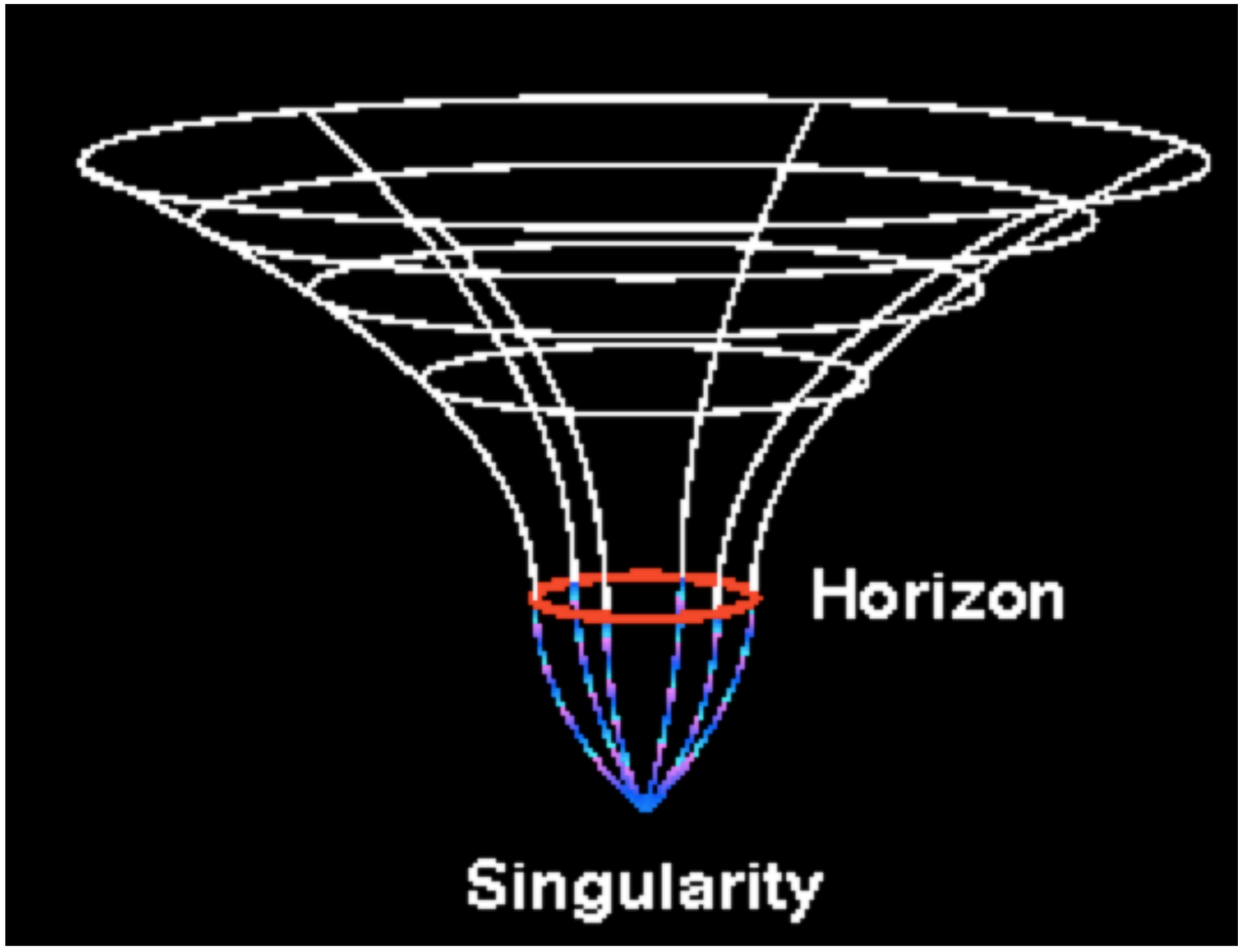
Vesto Slipher

Herschel: pretty large, irregularly round, suddenly brighter middle, partially resolved nucleus.

Vesto Slipher working at the Lowell Observatory in Flagstaff Ariz. discovered that most Galaxies move away from us at high speeds. He also found that they rotate at speeds over 150 km/sec.
In 1917 he took the spectrum of the nucleus of NGC 1068; he found the lines so WIDE that

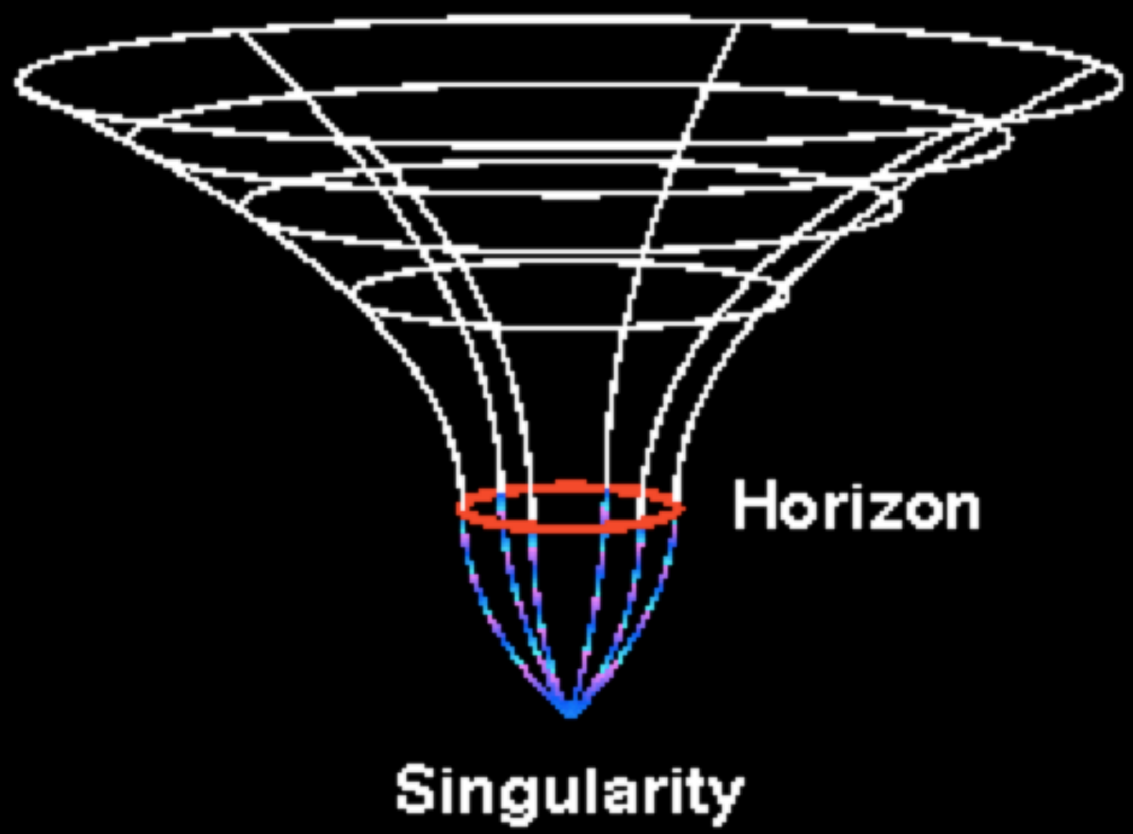
'The case hardly lends itself to the ORDINARY radial velocity interpretation'

He suggested that great pressure at the nucleus might be the cause



1916 Karl Schwarzschild Solves Einstein's equations for a static spherical body

Schwarzschild's solution came in two pieces. The outer piece was appropriate for the region outside the star where the density was zero, and an inner piece appropriate for the inside of a star.



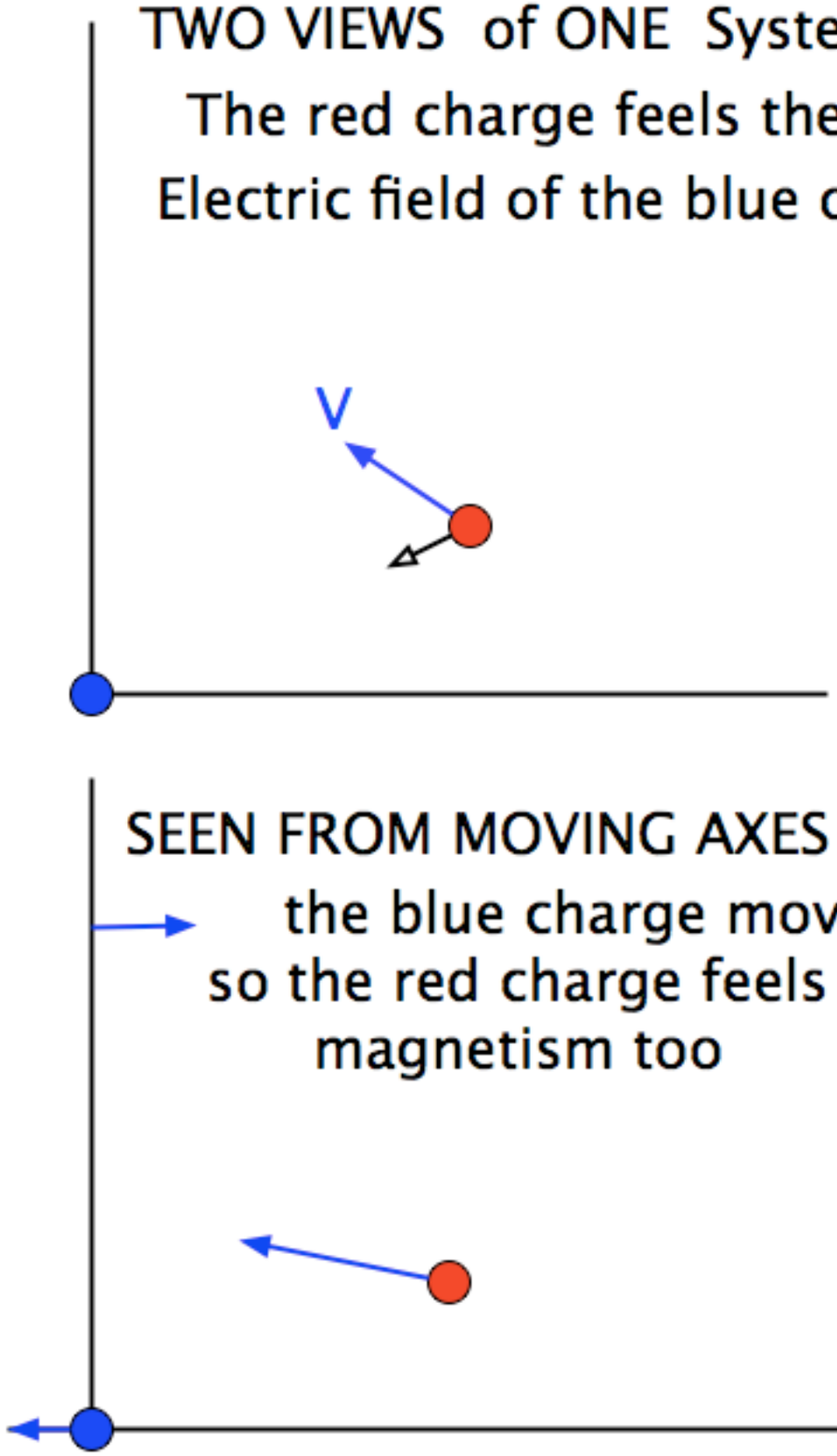
At first no one was bothered by the odd behavior of the outer solution were it to be continued inward to Michell's horizon radius from which even light could not escape

In 1924 Eddington found that Schwarzschild's exterior solution could be extended in to the centre if one allowed for a solution that was not static but falling inwards. However the point of Eddington's paper was to rebut an alternative theory of relativity put forward by the Philosopher Alfred North Whitehead.

NO-ONE NOTICED, THE EXTENSION !

By 1939 Einstein had become increasingly worried by the apparent breakdown of his equations at the Schwarzschild horizon.
To test whether this horizon was real, he made a theoretical model of a spherical star cluster in which all the stars moved in circles, but no models were smaller than the horizon.
Was the horizon unreachable?

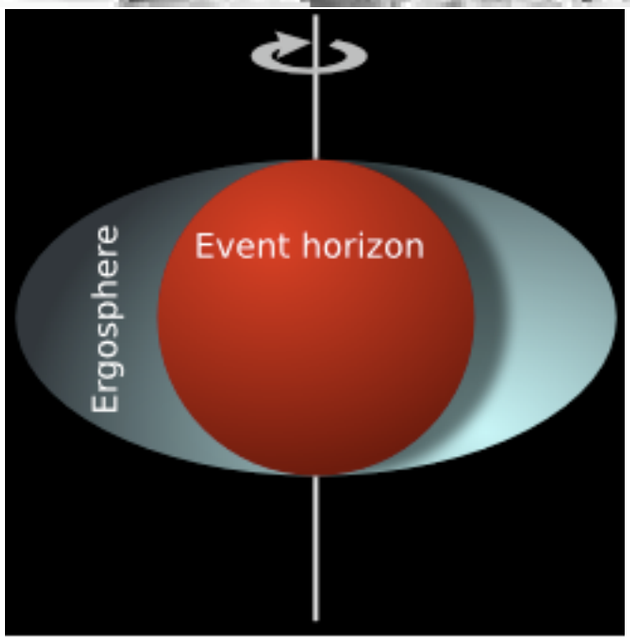
But also in 1939 Oppenheimer of Atomic bomb fame, working with Snyder showed that a perfectly cold spherical mass of gas would fall together, pass inside the horizon made by its gravity and cease to be visible.
BLACK HOLE HORIZONS CAN BE MADE!

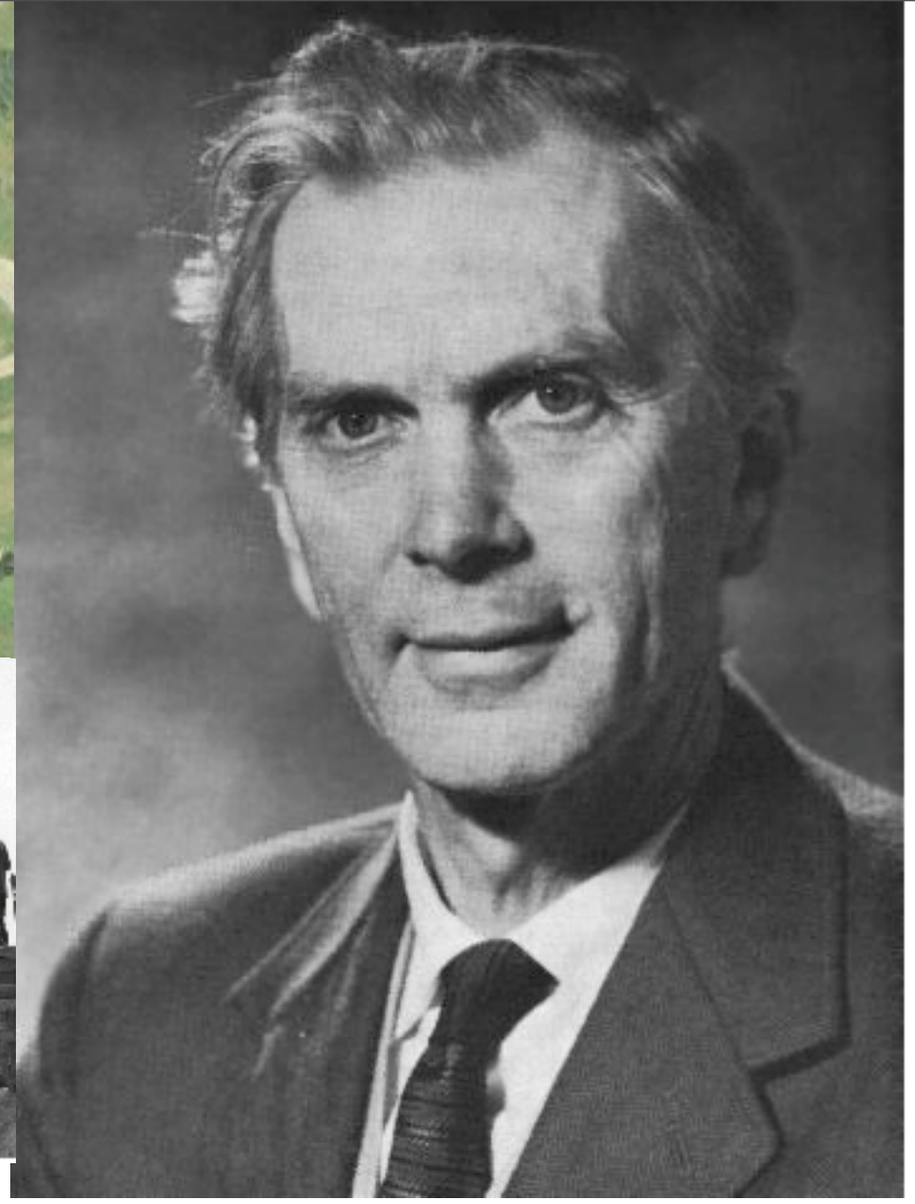


You can't have electrical forces without magnetic ones too.
By the same argument you can't have gravity without its gravo-magnetism

1963 the New Zealander Roy Kerr Solves Einstein's equations for a rotating Black Hole by a great feat of mathematical ingenuity.

Outside its horizon it has an ergosphere where the magnetic part of gravity dominates. A region never found before.



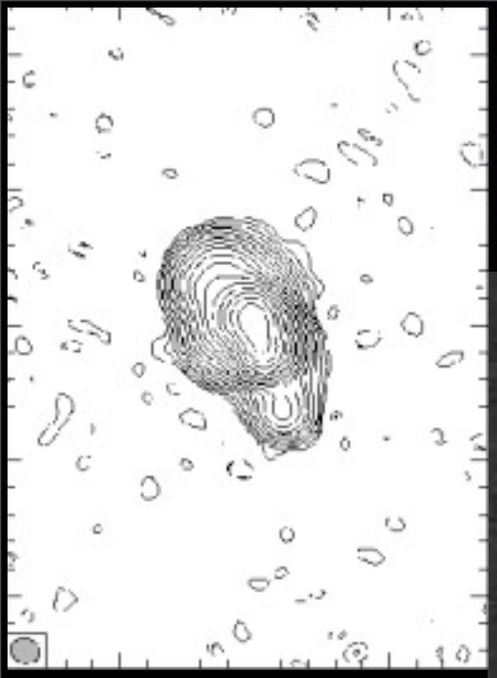


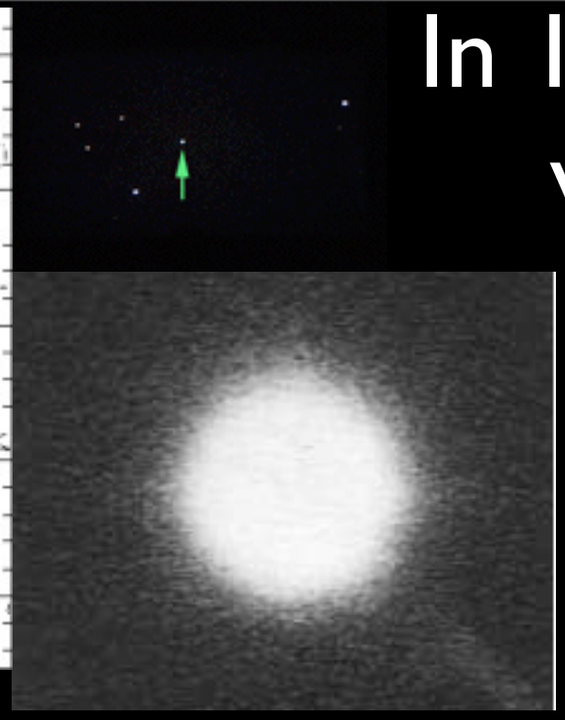
After the war some of those involved in the development of RADAR used their knowledge to develop radio astronomy. Ryle's group in Cambridge catalogued radio sources; some had small angular sizes. Geof. Burbidge showed that huge energies in fast particles and magnetic fields were needed to make the radio emissior

Henry Palmer of Jodrell Bank gave Tom Mathews of OVRO a list of small 3C sources. 3C48, 3C147 & 3C273 were among them. Mathews got Reid to refine the Cambridge N-S positions that were too crude for optical identification.

Owen's Valley Radio Observatory

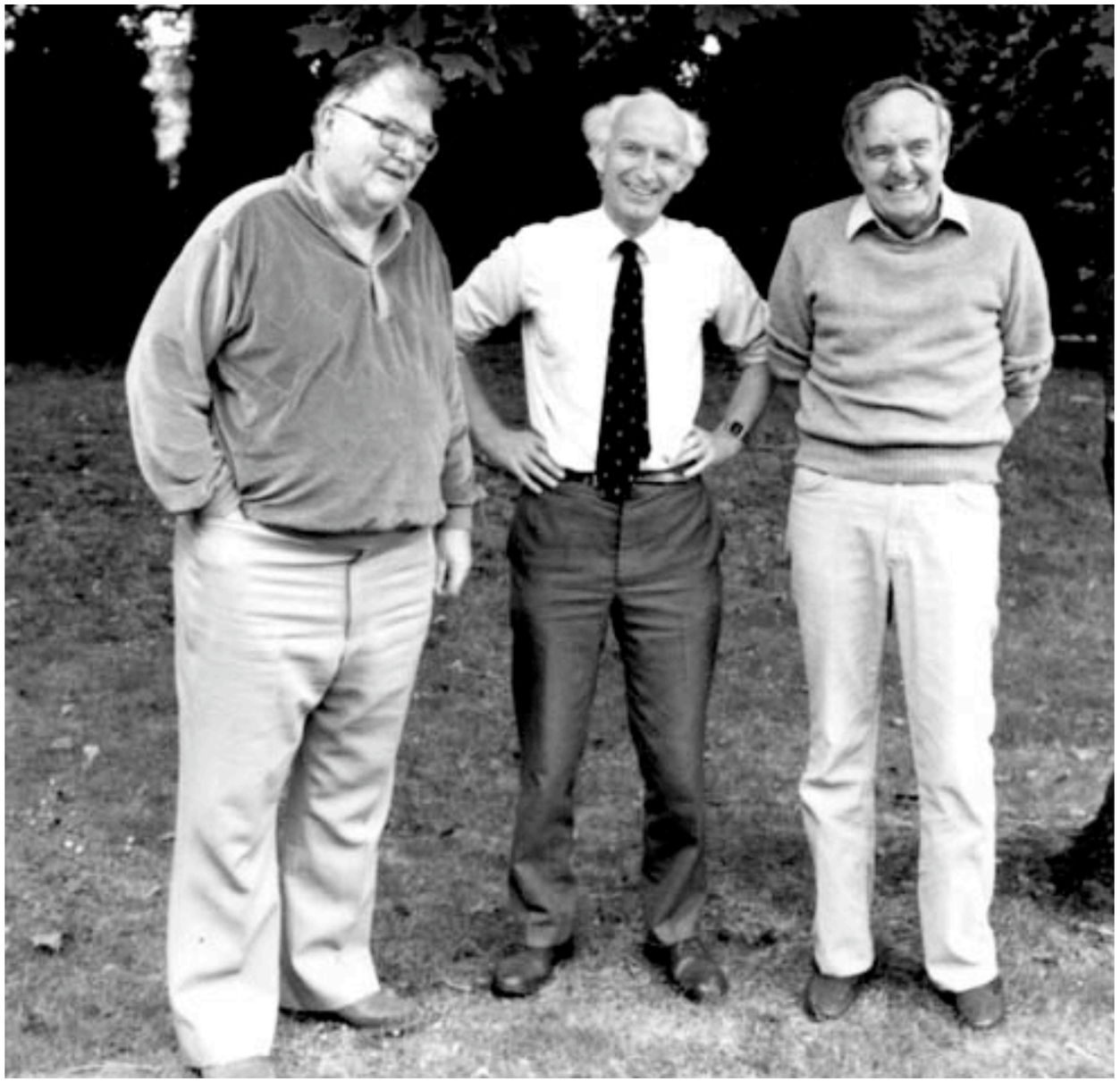
Allan Sandage photographed the fields. The Galaxies were given to Maarten Schmidt but when as for 3C48 there were just stars, he worked to identify which object was the radio source





radio 3C48 optical

In 1961 Sandage identified 3C48 with a 15th magnitude star which had a faint wisp but its spectrum, though full of spectral lines in emission, was unlike anything seen before. He asked Bowen for help in identifying the lines with known elements. Bowen could not, so he suggested Greenstein. It was just the sort of problem he liked but it defeated him too.



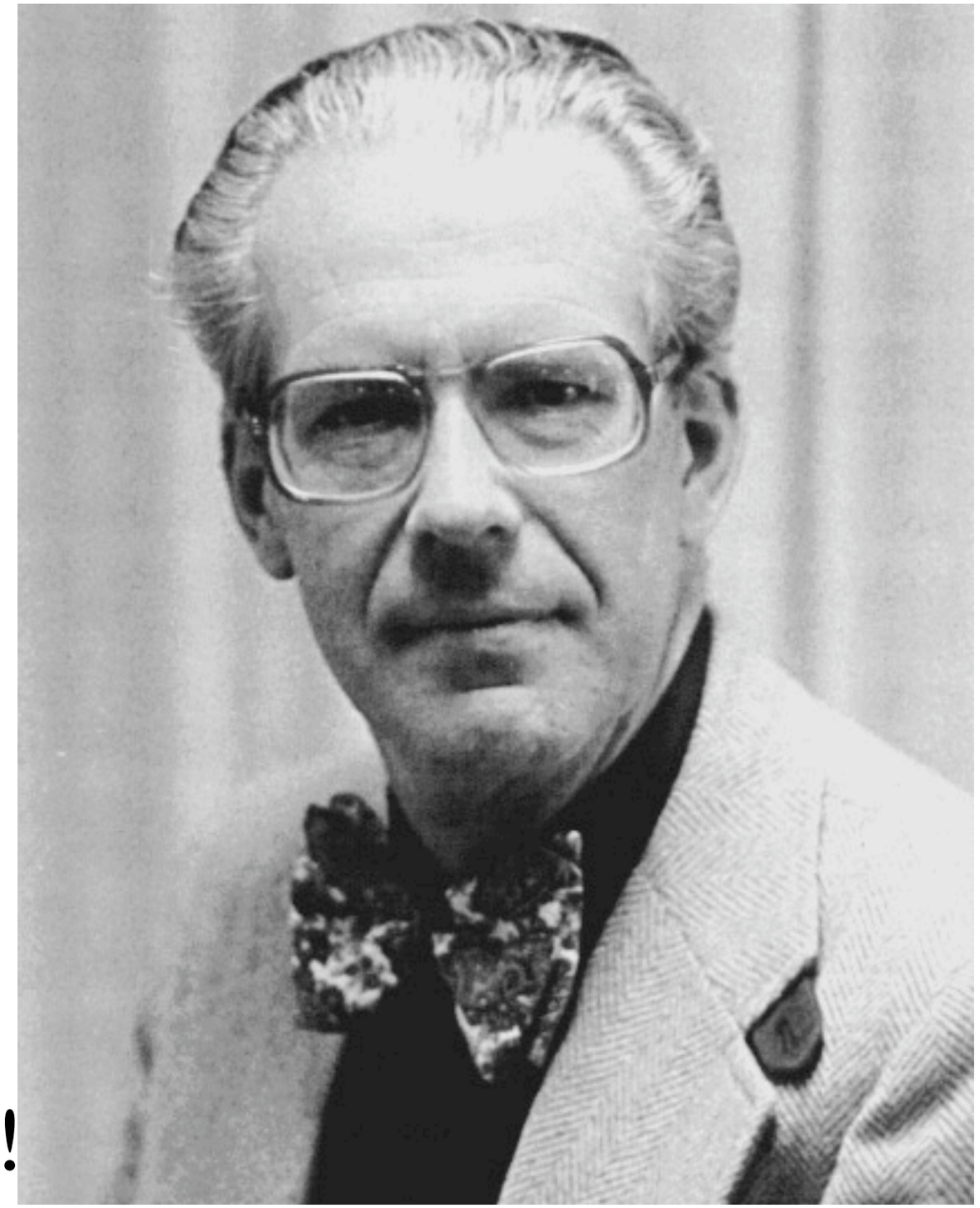
Eggen, Lynden-Bell & Sandage

In early 1962, I was working with Eggen and Sandage on something else. I remember Sandage coming down from observing with the crucial evidence; 3C48 had varied by 20% in 2 months. It must be less than a few light months in size, not 10,000 light years like a galaxy. Even if the spectrum was enigmatic it must be the first radio star!

At this time radio source positions were rather poor, about 100x worse than optical positions; this made radio sources hard to identify. Hazard realised that in 1963, the moon would pass across 3C273 as seen from the new Parkes radio telescope. It needed a bulldozer to dig a trench so that the telescope could look lower than it was designed to do, but timing disappearance and reappearance gave a good position on a 12th magnitude STAR!

Schmidt was given Hazard's position for 3C273. He was not involved in the earlier work on 3C48. Now it was his turn to be mystified by the emission lines of 3C273.

Hazard et al wanted to publish their result in Nature. Schmidt had to say something about a spectrum he could not interpret!



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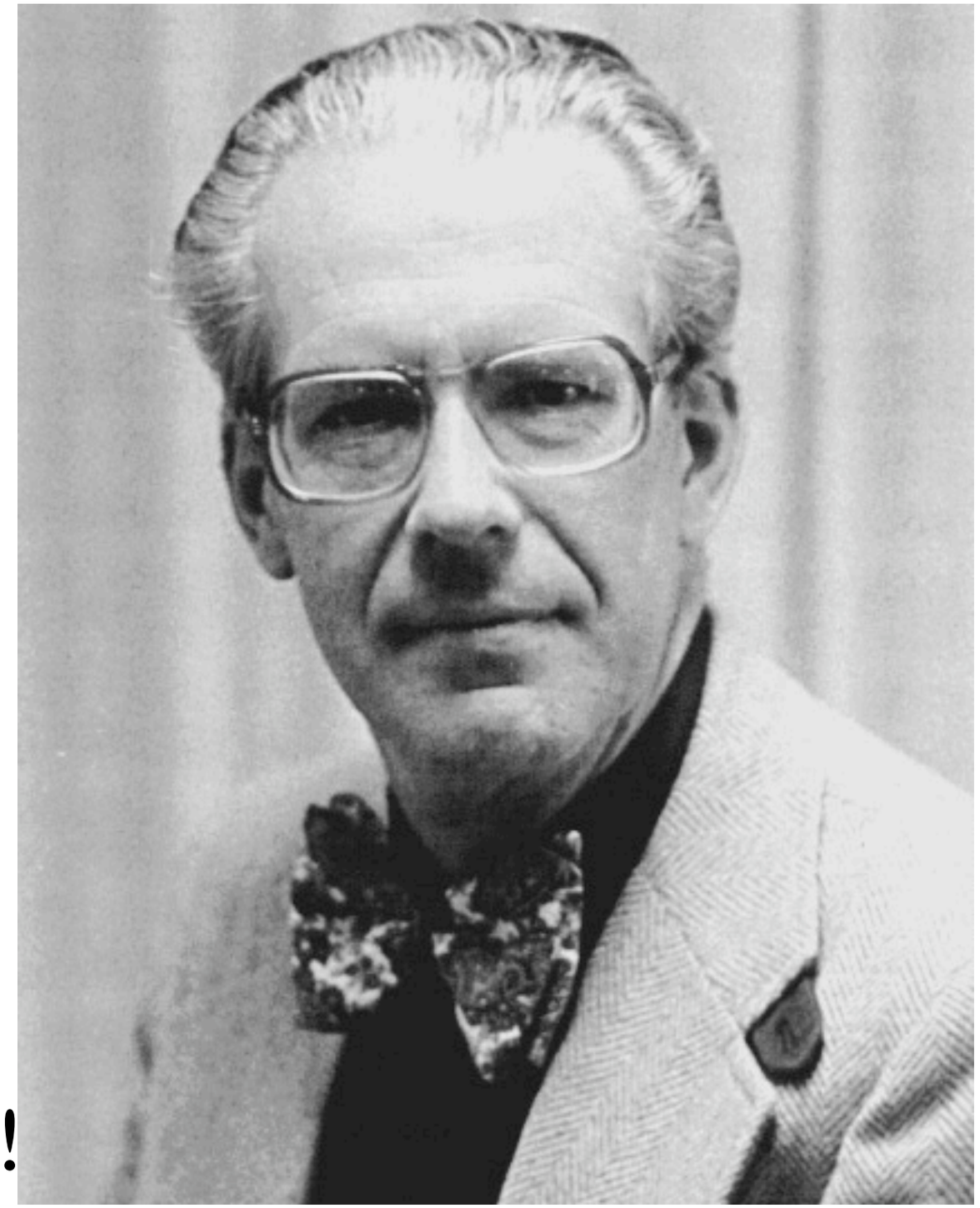

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Then he suddenly saw that if he neglected the two brightest lines the others formed a sequence.

This clue led to the solution and a mystery. The lines were hydrogen lines with much larger red-shifts than could be expected in such bright objects. There were also bright lines of other elements. The Quasi-Stellar Radio Sources (QUASARS) were 100 times as luminous as whole Galaxies, yet they must be very small to vary so quickly. WHAT WERE THESE STRANGE OBJECTS?

The first quasars did not appear to be in clusters of galaxies, nor did they cluster like galaxies. By 1964 there were many esoteric theories!

Salpeter ignored the current belief that they had nothing to do with galaxies. He worked out what would happen if a large black hole ploughed its way through a galaxy swallowing matter as it did so.

Thanks to work by Sandage and Schmidt, by 1969 we knew that radio quiet QSOs were much more numerous than the radio loud QUASARS and it was likely that they were only bright some of the time.

This led me to ask how numerous are DEAD QSO and thus how far away the nearest corpse would be. My estimate was that they might be as numerous as large galaxies like ours . Gravitational energy in these objects was more abundant than nuclear energy, but once the gravitational energy was lost the object was trapped, so its remnant black hole remained a source of gravity. These might make the Galactic Nuclei.

I predicted large mass/light and large velocities in them and surveyed the evidence in the Milky Way, M31, M32,M81,M87 & NGC4151, and gave magnetic accretion disk models of quasars.

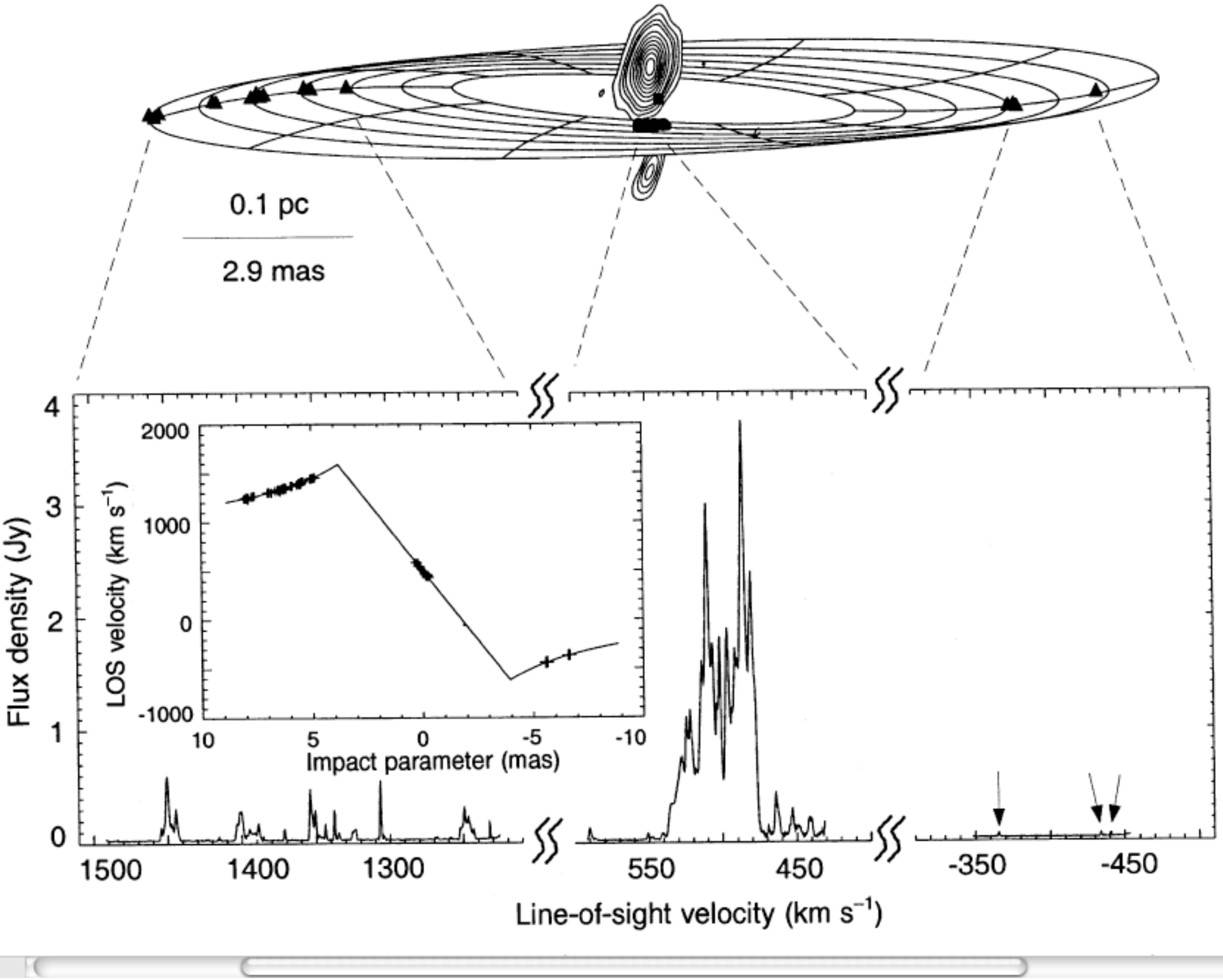
While Sandage, Schmidt and Ryle
thought well of these ideas, most
astronomers thought there was much too
little evidence for such an esoteric theory.
However those studying
general relativity liked the idea and Bardeen
found more energy was emitted
when a rotating black hole accretes.
It was 26 years before hard evidence emerged.

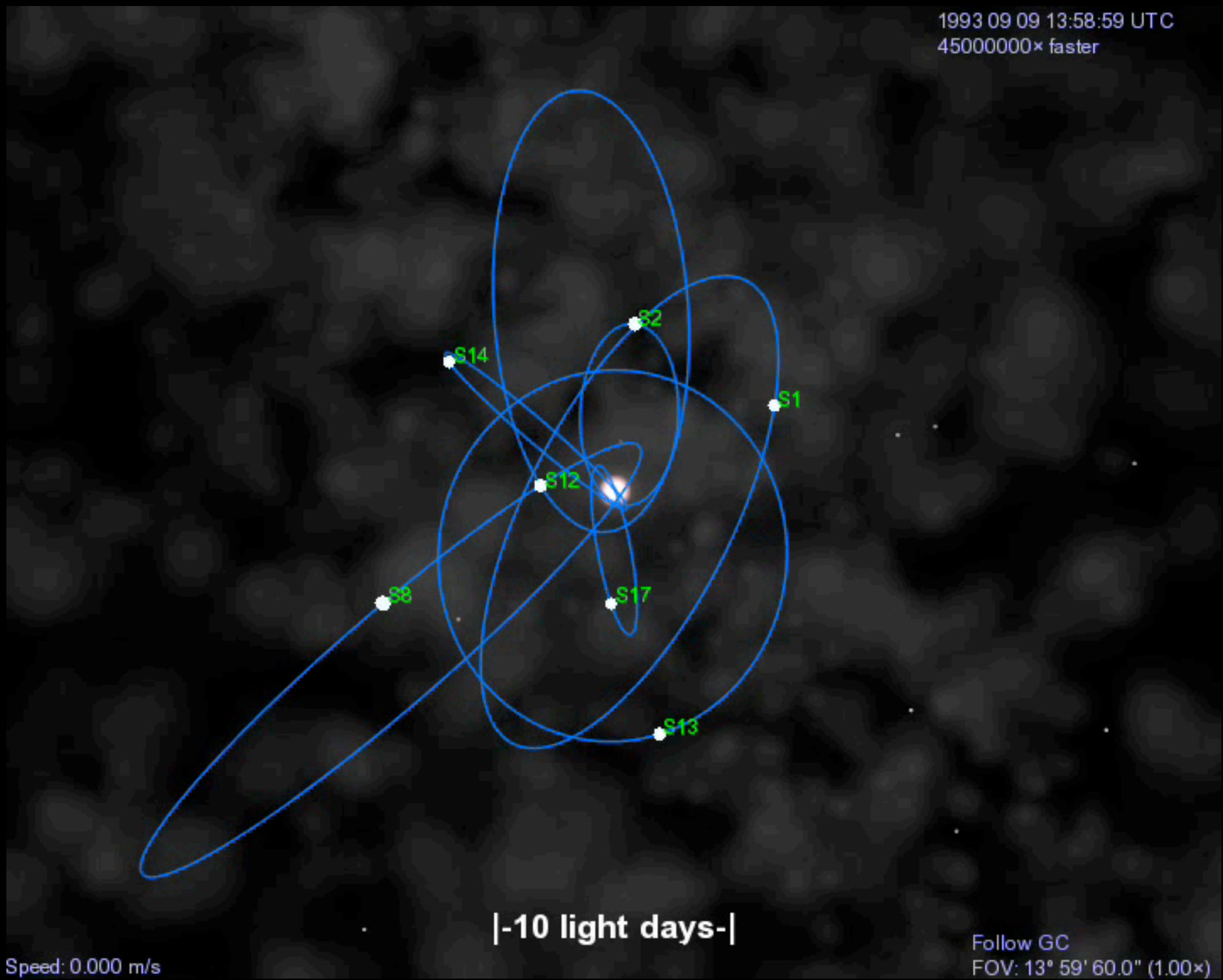
1971 UHURU flies X-ray Binary Stars
1972 Shakura and Sunyaeev's models
1974 v d Kruit, Oort & Mathewson NGC4258
1978-88 Sargent,Penston et al estimate
Black Hole masses in M 87 & 3C390.3
1988 Kormendy gets nuclear mass of NGC3115

1995 Miyoshi et al's BLACK HOLE in NGC4258

1998 Genzel the BH at the Centre of Milky Way
2000 BH Masses v speeds of stars in Galaxies
2006 RUNAWAY STARS from Galactic Centre

NGC 4258


0.1 pc
2.9 mas
Flux density (Jy)
LOS velocity (km s^{-1})
Impact parameter (mas)
Line-of-sight velocity (km s^{-1})


1993 09 09 13:58:59 UTC
45000000× faster
S2
S14
S1
S12
S8
S17
S13
|-10 light days-|
Speed: 0.000 m/s
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FOV: 13° 59' 60.0" (1.00×)