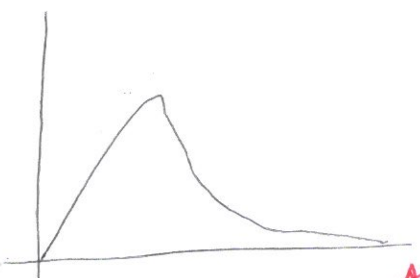
Quasars and Beyond

The Third Cambridge Catalogue of Radio Sources (3C) was published in 1959, it is an astronomical survey of the sky at 159 MHz. ~~It~~ ~~discovered~~ two sources, 3C 48 and 3C 273, with no corresponding visible object were known. 3C discovered hundreds more. WHAT COULD THESE BE? ~~Further stuc~~



Black-body radiation suggests that if object/phenomenon is not a main sequence star if it only radiates in radio.

★ Maybe some cloud? The hydrogen line is 21-cm = 1420 MHz.

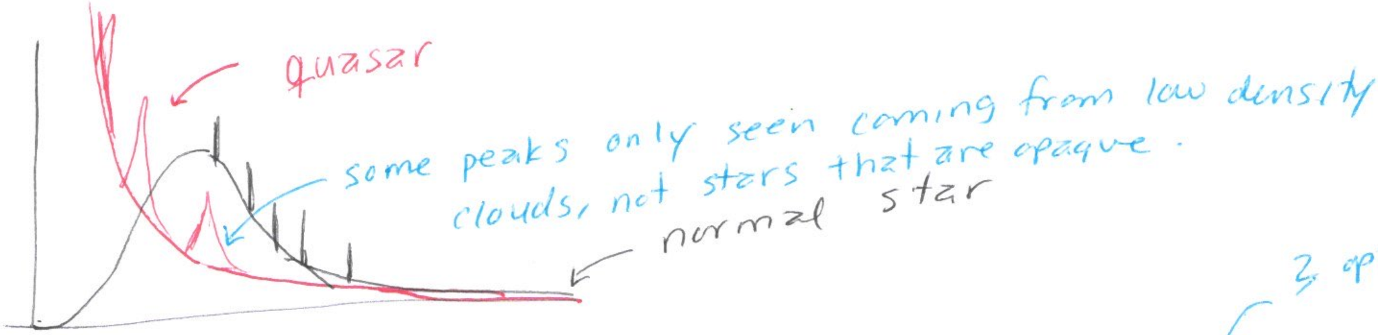
Using several radiotelescopes with interferometry techniques it was determined that the sources were compact regions unresolved by the radiotelescopes (points).

Likely not clouds which tend to extend for pc or kpc.

In 1963, a faint blue "star" was identified as the optical ~~analogue~~ counterpart of 3C 48.

In 1962, using occultations by the moon, the optical counterpart of 3C 273 was found.

The objects had a light spectrum with unknown <u>and broad</u> emission lines.



2 options

In 1963 it was shown that the emission lines were that of hydrogen but redshifted by 16%. [among the farthest objects known at the time, or moving away at 5×10^7 m/s, which makes no sense from the distribution of star velocities]

Considering expanding Universe

1. Object moving away ridiculously fast with no apparent explanation, plus does not explain spectrum.
2. Object ridiculosly far away (but at least we knew of objects that were also really far away).
   It could explain the spectrum, but object had to be both i) brighter than a whole galaxy (by then the brightest object we knew of) and ii) way more compact.
3. New laws of nature

They were first called QUASi-stellAR objects (quasars) in a 1964 Physics Today article.

In 1964 two more optical counterparts were found and in 1965 five more, all of them with extreme redshifts.

The optical counterpart of 3C 273 is bright enough to be in archival telescope observations, some from the 1900s. Its luminosity varies on yearly timescales. This provides further support that they are "compact" objects, less than 1 ly.
Also, they don't move with respect to the background of the universe, this supports the hypothesis that they are really far away.

FACTS: Object radiates strongly in the radio, faint in the visible.

Object is compact

Emission lines are redshifted to the extreme

They don't move

HYPOTHESIS 1: Object is in our galaxy or close to it, extreme redshift due to very strong gravity.

PRO: Power output can be explained by known phenomena

CONS: A star of mass as large as needed to produce the redshift would be unstable, some emission lines could only be observed if produced by low density gases (opacity)

HYPOTHESIS 2: Object is very far away from our galaxy, extreme redshift due to large velocity

PRO: Explains redshift and spectrum and lack of apparent motion, also "forbidden" emission lines.

CONS: No know mechanism (at the time) to explain power output.

HYPOTHESIS 3: It is not aliens, until it is. (Although some people prefer "it is never aliens).

white hole end of worm hole, matter-antimatter interaction, supernovae chain reaction

Edwin Salpeter and Yakov Zeldovich (independently) proposed that the radiation was produced by matter in an accretion disk falling into a supermassive black hole. Nobody believed them since the community didn't believe black holes existed (and there was no evidence).

PRO: Explains "forbidden" emission lines (the accretion disk is of low density at least in some regions)

Explains power spectrum and provides an origin.

Explains lack of apparent motion and redshift (far away)

Explains point-like source (compact object)

Bonus: * Explains the large broadening of the emission lines

The large broadening is due to the large acceleration and hence large velocity range of particles in the accretion disk.

CON: Nobody had detected a black hole.

~~Best~~ #1 x-ray source in the constellation of Cygnus

Cygnus X-1 was discovered in 1964 by a suborbital rocket launched from White Sands with a Geiger counter.

The first surveys were performed by suborbital rockets rotating with a Geiger counter and identified 8 sources, including Cygnus.

Main sequence stars do not produce x-rays ~~in~~ with high luminosity, the ~~biggest~~ most massive ones produce UV (strömgren spheres)

X-rays are produced in supernova explossions, but these are transient events, lasting a few days.

Cygnus X-1 continually produces x-rays.

NASA launched the satellite Uhuru (which means "freedom" in Swahili) in 1970 and it was operational for 3 years. It was the first x-ray observatory and showed variations in the x-ray intensity in the sub-second scale.

This limits the maximum size of the object. In 1971 an optical counterpart and radio was found, a ~~giant~~ blue giant. (blue giant can't produce x-rays)

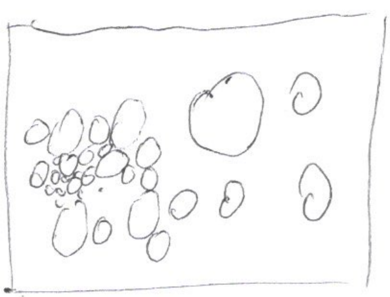
Also in 1971, using Doppler shift, it was discovered that the blue giant had a binary partner, not visible, and with a mass 14 - 16 $M_\odot$ (too high to be a neutron star).

This starting turning the tide and by the mid 1970's it was deemed possible that Cygnus X-1 was a black hole with an accretion disk (sometimes called micro quasars), and that it was a feasible energy production mechanism. Along with computer simulations and better instruments, the mechanism behind quasars was broadly accepted by the scientific community.

★ WHY IS THE NIGHT SKY DARK?

Olbers's paradox

Consider a universe that is infinite in size and static (infinite in time) and homogeneous.



Every line of sight would end at the surface of a star.

One or more assumptions are wrong.

The density of galaxies is $10^{-2}/Mpc^3$ and each galaxy has about 10^{10} stars, so the star density in the Universe is $10^{10} \cdot 10^{-2}/Mpc^3 = 10^8/Mpc^3$

$$\frac{10^8}{1\,\cancel{Mpc}^3} \cdot \frac{1\,\cancel{Mpc}^3}{1\times10^{18}\,\cancel{pc}^3} \cdot \frac{1\,\cancel{pc}^3}{34.6\,\cancel{ly}^3} \cdot \frac{1\,\cancel{ly}^3}{8.46\times10^{47}\,m^3}$$

3.4×10^{-60} stars/m^3

The cross-section of a star is $\sigma \doteq \pi R_\odot^2$.

$$\sigma = \pi\left(7\times10^8\,m\right)^2 = 1.5\times10^{18}\,m^2$$

The mean free path is then $l = \frac{1}{n\sigma} = \frac{1}{(3.4\times10^{-60}/m^3)(1.5\times10^{18}\,m^2)}$

$$l = \frac{1}{5.2\times10^{-42}\,\text{star}/m} = 1.9\times10^{41}\,m/\text{star}$$

$$l = 1.9\times10^{41}\,m \cdot \frac{1\,ly}{9.46\times10^{15}\,m} = 2\times10^{25}\,ly$$

This means that the Universe is either $\ll 2\times10^{25}\,ly$

or $c = \frac{l}{t} \Rightarrow t = \frac{l}{c} = \cancel{2\times10^{25}}\ \frac{1.9\times10^{41}\,m}{3\times10^8\,m/s} = 6.35\times10^{32}\,s$

$$\frac{365.25\text{ days}}{1\text{ year}} \cdot \frac{86400\,s}{1\text{ day}} = 3.15\times10^7\,s/\text{year}$$

$$6.35\times10^{32}\,s \cdot \frac{1\text{ year}}{3.15\times10^7\,s} \ll 2\times10^{26}\text{ years}$$

Hubble's law $v = H_0 D$ Made by Lemaître

Empirical observation

v ← speed at which galaxy is moving

H_0 ← Hubble's constant

D ← distance from our galaxy

The Hubble constant is not quite a constant, it changes with time, its current value is $H_0 = 70 \pm 5 \ \mathrm{km/s\,Mpc}$

This of course implies that at some point, the distances between galaxies was zero.

This happened about $t_0 = \dfrac{1}{H_0}$

$$H_0 = \frac{70 \ \cancel{\mathrm{km}}}{1\mathrm{s}\ 1\cancel{\mathrm{Mpc}}} \cdot \frac{1000 \ \cancel{\mathrm{m}}}{1 \ \cancel{\mathrm{km}}} \cdot \frac{1 \ \cancel{\mathrm{Mpc}}}{1\times10^{6}\ \cancel{\mathrm{pc}}} \cdot \frac{1 \ \cancel{\mathrm{pc}}}{3.2 \ \cancel{\mathrm{ly}}} \cdot \frac{1 \ \cancel{\mathrm{ly}}}{9.46\times10^{15}\ \mathrm{m}}$$

$$H_0 = \frac{70000}{3\times10^{22}\ \mathrm{s}} = 2.31\times10^{-18}/\mathrm{s}$$

$$t_0 = \frac{1}{2.31\times10^{-18}/\mathrm{s}} = 4.32\times10^{17}\ \cancel{\mathrm{s}}\ \frac{1 \ \mathrm{year}}{3.15\times10^{7}\ \cancel{\mathrm{s}}} = 1.4\times10^{10}\ \mathrm{yr}$$