Extragalactic Astronomy II

Lecture 2

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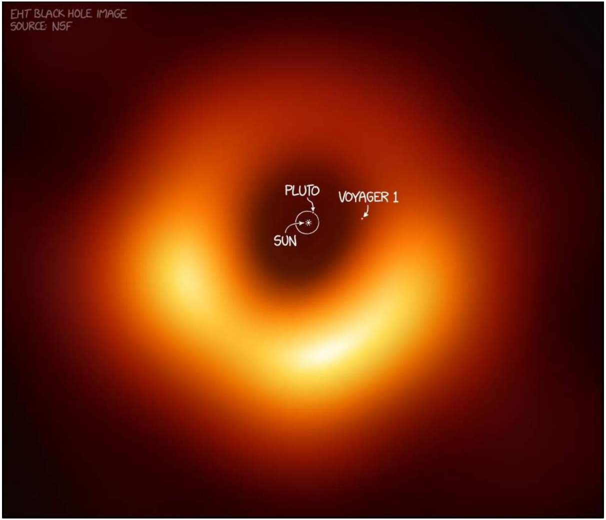
Setting the AGN size Scale

What is the Schwarzschild radius of a $10^6 M_\odot$ SMBH. And a $10^9 M_\odot$ one?
Hint: What is the Schwarzschild radius of the Sun?

Artist rendering of AGN

SMBH in M87



How are quasars powered?

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The total energy output of a quasar is at least the energy stored in its radio halo $\sim 10^{54}$ Joule.
This corresponds to 10 million $M_{\odot}$. But nuclear fusion is only about 1% efficient. This requires a starting mass of 1 billion solar masses.
Packing in 1 billion stars into a very small volume at the centre of the galaxy is difficult. But the gravitational potential energy of 1 billion Suns compressed inside a volume of the Solar System $\sim 10^{55}$ Joule.
This is the main argument for a SMBH at the AGN centre.

Gravitational potential energy powers quasars

Evidently, although our aim was to produce a model based on nuclear fuel, we have ended up with a model which has produced more than enough energy by gravitational contraction. The nuclear fuel has ended as an irrelevance.

Donald Lynden-Bell (1969)

How bright are quasars?

Take 3C 273, the first quasar discovered $z = 0.158$ With a standard concordance cosmology, we have $d_L = 760$ Mpc

$$m - M = 5\log(d_L/pc) + 5$$

plugging $m_B = 13.8$, we get $M = -25.6$. Milky Way has absolute magnitude in the B band of -21

Does this explain why quasars appear star-like?

Does this explain why quasars are invariably at a great distance?

Typical Properties of AGN

- Luminous UV emission from a compact region
- Heavily Doppler broadened emission lines
- Variability on time scales of hours to months
- Strong non-thermal emission
- Compact radio core
- Extended linear radio structures (jets, hotspots)
- X-ray, gamma-ray and TeV emission
- Cosmic ray production

Not all AGN exhibit all of these properties, but all AGN exhibit some.

Which of these may be used to discover new AGN?

Typical Properties of AGN

- Luminous UV emission from a compact region - **use UV/optical colors**
- Heavily Doppler broadened emission lines - spectroscopy is expensive
- Variability on time scales of hours to months - synoptic surveys like LSST with Rubin Observatory will enable this.
- Strong non-thermal emission - **using the radio spectral index.**
- Compact radio core - **unresolved radio sources in radio surveys, identified in optical surveys.**
- Extended linear radio structures (jets, hotspots) - from radio continuum surveys
- X-ray, gamma-ray and TeV emission - from surveys at these bands. Large surveys rare.
- Cosmic ray production - difficult to localise

Spectral Index α

$F_\nu \propto \nu^\alpha$
If $\alpha < -0.5$, spectral index is steep, else it is considered flat. Caution: Often, the sign of α may be reversed.

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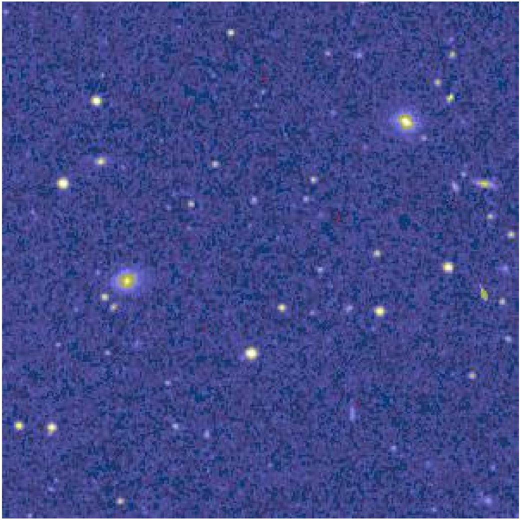
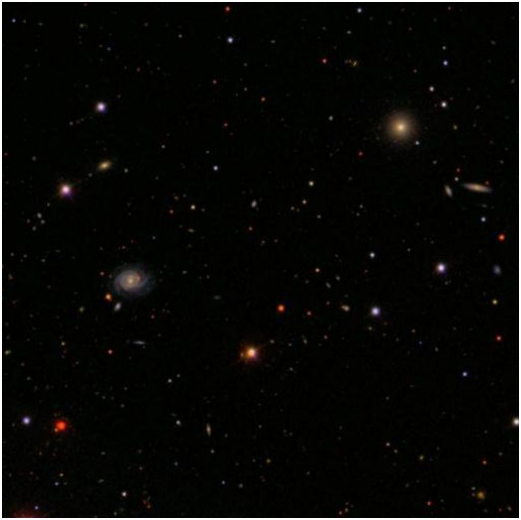
- many data products available from raw images/spectra to catalogs of measured parameters
- unlikely to be superceded for decades
- since the datasets are precisely defined and free other researchers can easily reproduce your results. This provenance greatly improves credibility.

Digitized Sky Survey



Sloan Digital Sky Survey



Basic characteristics of the original SDSS

- imaging and spectroscopic survey of π steradian (10^4 degrees) of sky using a custom designed telescope.
- near simultaneous imaging in five filters using a 120 Mpixel camera.
- follow up spectroscopy of 10^5 quasar candidates and 10^6 galaxies.
- main science goal: *Study the large scale structure of the Universe*

Major scientific discoveries made by the Sloan Digital Sky Survey

- discovery of main belt asteroid populations
- complete characterisation of large scale structure in the near universe using both galaxy clustering and absorber properties
- discovery of baryon acoustic oscillations imprinted in the early universe.
- Evidence that the universe was neutral before it got ionised by stars - Gunn-Peterson effect
- optically obscured quasars
- complex Milky way kinematics - new dwarf satelites, tidal streams, multiple galaxy mergers.
- largest sample of low redshift Type Ia supernovae compiled with many applications to supernova physics and cosmology.

How were quasars originally discovered?

- Do a radio survey and find compact, bright radio sources
- identify their optical counterparts. Shortlist those that are star-like and blue in color in the optical image
- obtain an optical spectrum

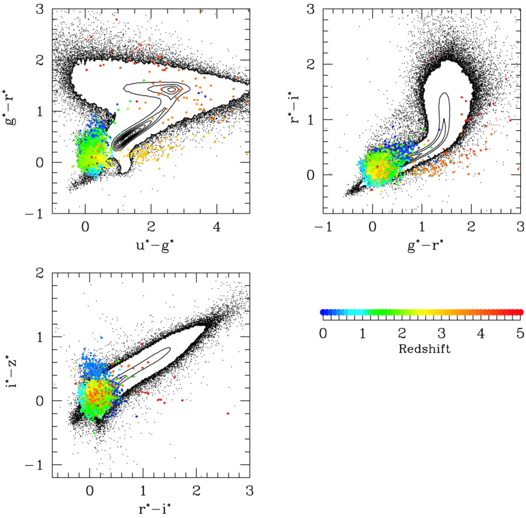
Optically selected quasars

It was quickly realised that the radio survey was redundant

- identify star-like and blue objects in an optical survey
- obtain an optical spectrum

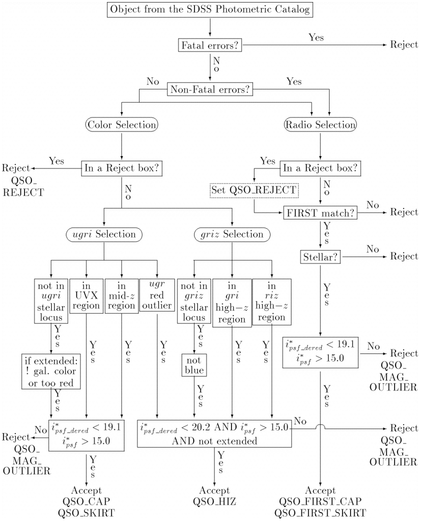
What could be a major source of contamination in such surveys?

Optically selected quasars from a color-color diagram



Color-color plots of 3040 SDSS quasars, color coded by redshift. Black dots and contours represent stars.

SDSS Quasar selection algorithm

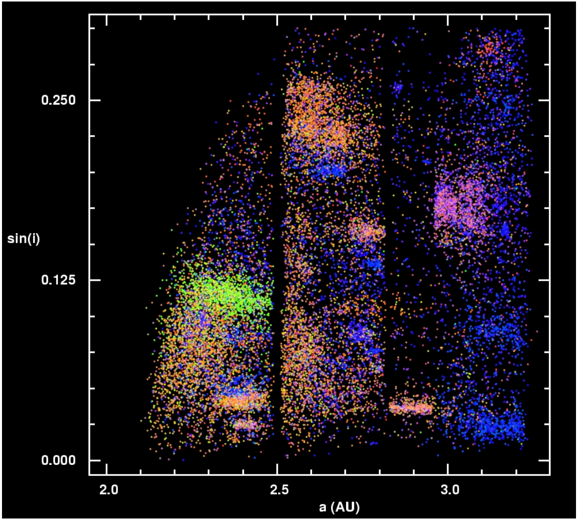


Another surprising contaminant in quasar searches

In the early days, the Sloan digital Sky survey (SDSS) team looking for quasar candidates realised that they were finding many more candidates than they expected to find. They were certainly not white dwarfs, whose numbers were included in the estimates.

What could these contaminants be?

Asteroid major axis inclination diagram



Multicolor photometry of asteroids with SDSS - Ivezic 2002

We discuss optical colors of 10,592 asteroids with known orbits selected from a sample of 58,000 moving objects observed by the Sloan Digital Sky Survey (SDSS). This is more than ten times larger sample that includes both orbital parameters and multi-band photometric measurements than previously available. We confirm that asteroid dynamical families, defined as clusters in orbital parameter space, also strongly segregate in color space. In particular, we demonstrate that the three major asteroid families (Eos, Koronis, and Themis), together with the Vesta family, represent four main asteroid color types. **Their distinctive optical colors indicate that the variations in chemical composition within a family are much smaller than the compositional differences between families, and strongly support earlier suggestions that asteroids belonging to a particular family have a common origin. We estimate that over 90% of asteroids belong to families.**