Active Galactic Nuclei:
a brief introduction

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The discovery of quasars

3C 273: The first AGN

March 16, 1963

INVESTIGATION OF THE RADIO SOURCE 3C 273 BY THE METHOD OF LUNAR OCCULTATIONS

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z=0.158
The power source of quasars

- The luminosity (L) of quasars, i.e. how bright they are, can be as high as \( L_{\text{quasar}} \sim 10^{12} L_{\text{sun}} \sim 10^{40} \text{W} \).

- The energy source of quasars is accretion power:
  - Nuclear fusion:
    \[
    \Delta E_{\text{nuc1}} = 0.007 mc^2 = 6 \times 10^{11} \text{W} \cdot \text{s} \cdot \text{g}^{-1}
    \]
  - Accretion power:
    \[
    \Delta E_{\text{acc}} = GMm/R = 3 \times 10^{13} \text{W} \cdot \text{s} \cdot \text{g}^{-1}
    \]

Accretion, i.e. matter falling onto a black hole is the only energy source that is powerful enough to fuel the very bright luminosity of quasars.
The discovery of quasars

3C 273: The first AGN

The First Texas Symposium on Relativistic Astrophysics - 16-18 December 1963
Active Galactic Nucleus

- Characteristics
  - Bright compact nucleus
  - Time variability

- Unified model
  - Supermassive black hole
  - Rotating accretion disk
  - Perspective to observer, accretion rate and BH mass determines the kind of AGN.
AGN
Active Galactic Nuclei
A few % of all galaxies

Radio-quiet
85-95%

Spirals
The most common class of AGN

Seyfert 1
Have both broad lines and narrow lines of ionized metals

Seyfert 2
Show only narrow lines of all species

QSOs
Quasi-Stellar Objects

Ellipticals

BL Lacs
Featureless optical spectrum

FRLs
Low peaked

FR2
High luminosity

FR1
Low luminosity

BLR
Low peaked

HBLs
High peaked

FSRQs
Flat Spectrum Radio Quasars

Radio-loud
5-15%

Blazars
<5% of all AGN
Black Holes and Relativistic jets

- Supermassive black holes: $10^6$-$10^9 \, M_{\odot}$
- Active Galactic Nuclei (AGN)
- Outflows of particles and radiation: relativistic jets.
- Aligned to our line of sight: Blazars.
- See them from radio to gamma-ray energies.
- Their emission is highly variable.

\[
\begin{align*}
\nu &\quad F_\nu \\
10^{10} &\quad 10^{-12} \\
10^{12} &\quad 10^{-11} \\
10^{14} &\quad 10^{-10} \\
10^{16} &\quad 10^{-9} \\
10^{18} &\quad 10^{-8} \\
10^{20} &\quad 10^{-7} \\
10^{22} &\quad 10^{-6} \\
10^{24} &\quad 10^{-5} \\
10^{26} &\quad 10^{-4} \\
10^{28} &\quad 10^{-3}
\end{align*}
\]

\[
\begin{align*}
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10^{22} &\quad 10^{-8} \\
10^{24} &\quad 10^{-7} \\
10^{26} &\quad 10^{-6} \\
10^{28} &\quad 10^{-5}
\end{align*}
\]
Leptonic models

- Soft photon population:
  - SSC: synchrotron photons
  - Emission from the disk
  - Broad Line Region
  - Reprocessed emission from the dust torus
Correlated variability

Krawczynski et al. 2004

1ES 1959+650

\[ \gamma \text{-} sync \]

\[ \gamma \text{-} VHE \]
Periodic variability from AGN jets

PKS 2155-204
$P_1 \sim 1.7$ years
$P_2 \sim 0.7$ years
$P_1 + P_2 \rightarrow 29\%$ var
The periodic variability could be due to two supermassive black holes orbiting around each other.
Summary

• There is a lot we don’t yet know about how supermassive black holes grow, and how they shape star formation in their host galaxies.

• Radiation from accreting supermassive black holes (AGN) is the best tracer we have of black hole evolution.

• Basic models exist that explain the radiation we observe from relativistic jets.

• Most models break down when observational data becomes more abundant and more detailed.
References

Active Galactic Nuclei - Robson
Accretion power in astrophysics - Frank, King & Raine
High Energy Astrophysics - Longair

Email me if you have further questions:
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Using python to study astrophysical catalogs

• We will now spend 15 min talking about astrophysical catalogs.

• A catalog is generally the result of a very detailed analysis of a large amount of astrophysical data.

• It differs from a single source analysis in that it aims at understanding the properties of a population of sources, rather than on individual objects.

• We will use as an example the Fermi-LAT 4FGL catalog. It summarizes the properties of all gamma-ray sources that Fermi, a gamma-ray satellite, has detected in about 10 years of operation.

• You can find and download the code that I will run here:
  - https://confluence.slac.stanford.edu/download/attachments/249335606/BL_Lacs_catalog_sample.ipynb?version=1&modificationDate=1559398718000&api=v2
The Fermi-LAT 4FGL catalog