Reading: Chapter 27, Chapter 28, Sect. 28.3 - 28.5
Observing session: tonight? Check website for instructions / weather updates
Exam 3: Tuesday, May 1, 12:00-2:00

Last time: Galaxy Distances and Motions
• By using variable stars and other “standard candles” we can measure the distance to other galaxies across the known Universe
• The Cosmic Distance Ladder
• The ‘Hubble Law’ - we live in an expanding universe

Today: Quasars, Active Galaxies, and Monster Black Holes
• Through Hubble Law we find distances to far away and exotic galaxies
• “Active Galaxies” show evidence for high-energy phenomena in and around a small central engine that drives enormous structures
• Supermassive black holes as the engine for AGN phenomena - and do all galaxies have one? They are messy eaters…

if ALL distant galaxies are moving away from us, are we at the center of the Universe?

NO!
• in an Expanding Universe
  • all galaxies move away from each other
  • farther galaxies move faster ($V \propto d$)

• Expansion gentle on small scales:
  Andromeda shows blue shift

Lookback Time
• more distant galaxies - longer time for light to reach us
• we see distant galaxies as they were when light left them
• we see the distant Universe as it was when light left that part

• cosmological redshift:
  • space has expanded between then and now
  • light from that time is “stretched” to longer wavelengths

Quasars and Active Galaxies
• 1950s: Discovery of Radio “Stars”
  • weird spectra
  • emission lines at unusual wavelengths
  • Quasi Stellar Radio Source $\rightarrow$ Quasar, or QSO

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<th>3C 273</th>
<th>470 nm</th>
<th>583 nm</th>
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**QSOs** recede at speeds approaching the speed of light...

- **The Hubble Law** says that they are at the edge of the observable universe!

- **Large Redshift + modest apparent brightness:**
  - QSOs are extremely luminous
  - \( L \approx 10^{11} \text{ to } 10^{15} \, L_{\odot} \)

- **Variability \( \rightarrow \) Small Size**
  - brightness changes in days to months
  - central engine smaller than a few light-weeks across
    \( \approx \text{a few thousand A.U.} \)
    \( \approx 0.03 \, \text{pc!} \)

**Quasar Spectral Lines:** clues to the central engine

- **Narrow Line Region**
  - \( \Delta v \approx 200 \, \text{km/s} \)
  - “normal” galaxy matter

- **Broad Line Region:**
  - \( \Delta v \approx 10,000 \, \text{km/s} \)
  - gas clouds moving at high speed near QSO center

- **Narrow Absorption Lines**
  - redshift always less than QSO
  - intervening matter closer to us than QSO

**Active Galactic Nuclei (AGNs)**

- share properties of QSOs and normal galaxies
- lots of energy from nonthermal source

- **Seyfert Galaxies:** spirals with point-like nuclei
  - \( L \approx 10^{11} \, L_{\odot} \)
  - “rapid” variations
  - broad emission lines (5000 km/s)
  - a few % of all spirals

- **BL Lac objects:** minor-league QSOs
  - stellar appearance
  - sometimes violent variability (“Blazars”)
  - no spectral lines; faint fuzz at high redshift, UV+X-ray

- **Radio Galaxies:** \( \approx 10\% \) of AGNs
  - double-lobed radio sources
  - tight jets
**Towards a Coherent Picture**

- **Common Features of AGNs:**
  - high luminosity
  - rapid variability = small size
  - → compact, efficient central engine

- **Diverse Features of AGNs:**
  - radio loud / radio quiet
  - broad lines / narrow lines
  - host galaxy / no host
  - jets / no jets
  - UV-Xray / no UV-Xray

- **Unified Model of AGNs**
  Supermassive \((10^{6-9} M_\odot)\) accreting
  BLACK HOLE
  at center of AGNs . . .

- **Material falling into BH gets**
  - compressed
  - heated
  - energy escaping as light

  \[ E_{\text{out}} \sim M_{\text{in}} c^2 \]

- Need “only” 1-10 suns / year for High Luminosity
  Chunky flow \(\rightarrow\) Variations in \(L\) \(\leftarrow\) variability!

- **Size of BH:** \(\sim 3 \times 10^{6-9} \text{ km}\)
  \(\sim 10-1000\) light-seconds \(\leftarrow\) small size!

- **Other Phenomena:** rooted in an Accretion Disk

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**“Superluminal motion” in radio jets**
(courtesy Dick McCray, U. Colorado)
Unified model of AGNs:

it’s all a matter of inclination

- **Edge-on**: see disk edge
  - Radio galaxies, Seyferts
- **Tilted**: see hot disk
  - Quasars
- **Face-on**: bore-sight on BH
  - BL Lac

- Were QSOs more active in the distant past?
- Does activity continue but at lower levels?
- Do all galaxies (including our Milky Way) have a **black hole** at their centers?
Massive black hole in MW center

X-Ray, Optical, and IR

APOD - 11/11/09

NuStar & Chandra- observations of a flare in the MW center
Massive black hole in MW center
$3 \times 10^6 \, M_\odot$

IR view from ESO

IR -adaptive optics, Keck

Fermi data reveal giant gamma-ray bubbles