Astr 8400 - Resources

• Course web page:
  http://www.astro.gsu.edu/~crenshaw/astr8400.html

• Electronic papers:
  http://adsabs.harvard.edu/abstract_service.html

• NASA Extragalactic Database:
  http://nedwww.ipac.caltech.edu

• Level 5: Extragalactic Knowledgebase:
  http://nedwww.ipac.caltech.edu/level5

• General astronomy numbers and facts:
A Little (Extragalactic) Background

At low z (after correcting for peculiar velocities):
\[ v_r = cz = H_0 d \quad (H_0 = 73 \pm 5 \text{ km s}^{-1} \text{ Mpc}^{-1}) \]

\[ z \equiv \frac{\Delta \lambda}{\lambda} = \frac{\lambda_{\text{obs}} - \lambda_{\text{lab}}}{\lambda_{\text{lab}}} = \frac{v_r}{c} \]

At high z:
From Special Relativity:

\[ 1 + z \equiv \frac{\lambda_{\text{obs}}}{\lambda_{\text{lab}}} = \sqrt{\frac{1 + \beta}{1 - \beta}} \], where \( \beta = \frac{v_r}{c} \)

\[ z = \sqrt{\frac{1 + \beta}{1 - \beta}} - 1 = \sqrt{\frac{c + v_r}{c - v_r}} - 1 \]

It can be shown that:

\[ \beta = \frac{v_r}{c} = \frac{(1 + z)^2 - 1}{(1 + z)^2 + 1} \]
Observations of Active Galactic Nuclei (AGN)

- General Characteristics
- History
- AGN Terminology
- AGN Surveys and Samples
AGN – What are they?

Active galactic nucleus – compact object in the gravitational center of a galaxy that shows evidence for a strong nonstellar continuum

Practically speaking – AGN are active supermassive black holes

AGN are typically characterized by:

• High luminosity
• Continuum radiation over a broad $\lambda$ range – radio to $\gamma$-rays
• Rapid variability (time scales of days or even hours)

AGN tend to have:

• Unusually blue colors / strong UV excess
• Emission lines with significant widths ($\geq 300$ km/sec)

Basic problem:

• What physical mechanism generates so much luminosity ($L_{\text{bol}} > 10^{43}$ ergs s$^{-1}$) in such a small volume (radius $< 10$ light days?)
A Brief History of AGN

• E.A. Fath (1908): discovered strong emission lines in the spiral “nebula” (now galaxy) NGC 1068

• C.K. Seyfert (1943, ApJ, 97, 28) obtained high dispersion spectra of 6 spiral galaxies with high excitation nuclear emission lines
  – NGC 1068, 1275, 3516, 4051, 4151, 7469
  – broad emission lines (~5000 km/s) attributed to Doppler motions

• Various radio surveys (1950s; 3C, PKS, etc.) discovered sources identified optically as quasi-stellar radio sources (quasars)

• M. Schmidt (1963) realized that broad lines in the quasar 3C 273 were redshifted nebular lines (z = 0.158)

• Eventually, it was realized that quasars (and optically discovered QSOs) are distant, high-luminosity analogs of Seyfert galaxies

• Khachikian and Weedman (1974): two types of Seyfert galaxies:
  – Seyfert 2: narrow permitted and forbidden emission lines
  – Seyfert 1: Same lines as Seyfert 2s plus broad permitted emission lines
Optical Spectra of Seyfert Galaxies
(HST/FOS spectra)

Seyfert 1

Seyfert 2

broad emission line (Hβ)

narrow emission line ([O III])

continuum
Terminology – AGN Components

Seyfert 1
(Type 1 quasar)

Seyfert 2
(Type 2 quasar)

scattering
region

“torus”

Narrow-line Region
(NLR)

Broad-Line Region
(BLR)

Supermassive Black Hole
(SMBH),
Accretion disk,
X-ray Corona

radio jet
Terminology – AGN types

- Originally classified according to the appearance of their optical spectra, luminosity, radio power, etc.
  - **Seyfert galaxies** (including subtypes)
  - Broad-line radio galaxies (**BLRG**)
  - Narrow-line radio galaxies (**NLRG**)
  - Quasi-stellar radio sources (**radio-loud quasars, RLQ**)
  - Quasi-stellar objects (**QSOs or radio-quiet quasars, RQQ**)
  - **Blazars: BL Lacs** and Optically Violent Variables (**OVVs**)
  - Low-ionization nuclear emission-line regions (**LINERs**)
- Ultraluminous IR galaxies (**ULIRGs**) – extreme starburst galaxies, some (most?) contain AGN
- **Fanaroff-Riley (Radio)Types**
  - **FR I** (lower luminosity, brighter at their centers)
  - **FR II** (higher luminosity, brighter at their edges)
Fanaroff-Riley (FR) Types

FR I

FR II

3C175

core

jet

lobe

M84

Quasar 3C175
YLA 6cm image (c) NRAO 1996
AGN Surveys and Samples – Radio

• Quasars first discovered in the radio
  – but only 5 – 10% of AGN are radio loud, so these are special

• 3C, 3CR, 4C: third, revised, and fourth Cambridge catalogs
  – 1950 – 1960s, 178 MHz, north of declination -22°, flux > 2 Jy
    (Note: 1 Jy = 10^{-23} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ Hz}^{-1})

• PKS: Parkes survey of southern hemisphere in 1960s
  – 408 MHz (> 4Jy), 1410 MHz (> 1Jy), 2650 MHz (>0.3 Jy)
  – Later surveys of H I 21-cm (1420 MHz) emission

• NVSS (NRAO VLA Sky Survey)
  – Modern 1.4 GHz, Very Large Array (VLA), D configuration (compact),
    resolution = 45'', detection limit = 2.5 mJy, north of declination −40°

• FIRST (Faint Images of the Radio Sky at Twenty Centimeters)
  – 1.4 GHz survey, NRAO Very Large Array (VLA), B configuration ,
    resolution = 5’’; detection limit = 1 mJy, North Galactic Cap

Note: Nearly all surveys require follow-up spectroscopy at \( R = \lambda/\Delta\lambda \geq 500 \)
to identify AGN and determine their types.
AGN Surveys and Samples – Optical

• **Objective Prism Surveys**
  – **First Byurakan Survey** (Markarian Galaxies): extended objects with *blue* (“UV excess”) continua in the northern hemisphere; most are starburst (H II) galaxies, ~10% are Seyferts
    
      There is now a [digitized version](#) of this 1960s – 1970s survey.

  – **Tololo** surveys: galaxies with *emission lines* in southern hemisphere, ~10% are Seyferts

• **Variability**
  – **Palomar Quest Survey**: Palomar 48-in Schmidt + CCDs, 4-band photometry in drift-scan mode, 23,000 quasars (Bauer et al. 2009)
  – Followed by Palomar Transient Factory and Zwicky Transient Facility
  – Large Synoptic Survey Telescope (**LSST**) aka Vera C. Rubin Observatory: image southern sky every few nights
AGN Surveys and Samples – Optical

• Broad-band imaging \(\rightarrow\) color selection
  – **Palomar Green (PG)** Survey: 18-in Schmidt + photographic plates, objects showing UV excess, mostly hot subwarfs and white dwarfs, 5% are QSOs (Green et al. 1986)
  – **2DF**: spectroscopic survey of galaxies, previously identified in UK Schmidt images
  – Sloan Digital Sky Survey (**SDSS**): 2.5-m telescope in New Mexico, 5-band photometry (ugriz), followed by multi-object spectroscopy of selected galaxies and AGN (900,000 galaxies; 225,000 stars; 120,000 quasars)

Color-color selection: black – stellar locus, colors– ugriz quasar candidates
(Netzer 2013; Richards et al. 2004)

Access to data through [SDSS web site](http://www.sdss.org) or NASA Extragalactic Database (**NED**)
AGN Surveys and Samples – IR

- Infrared Astronomical Satellite (IRAS): mid-IR survey of the entire sky at 12, 25, 60, and 100 µm, resolution ≈ 1 arcmin
  - discovered ULIRGs, “infrared cirrus” (cold dust in the Milky Way)
  - Followed by imaging and spectroscopy from ISO, Spitzer
- Wide Field Infrared Survey Explorer (WISE): all-sky survey at 3.4, 4.6, 12, and 22 µm)
  - many reddened quasars
- Two Micron All Sky Survey (2MASS): two telescopes, in northern and southern hemispheres
  - images in J (1.25 µm), H (1.65 µm), and Ks (2.17 µm) bands
AGN Surveys and Samples – X-ray

• **ROentgen SATellite (ROSAT):** Soft X-ray (0.1 – 2 keV) survey from 1990 – 1999, 5" resolution
  – Survey (scan) mode during first 6 months using PSPC
  – Pointed observations thereafter using PSPC and HRI

• **Swift/Burst Alert Telescope (BAT) Survey**
  – Hard X-rays (15 – 150 keV), field of view = 2 steradians, resolution = 17’, sensitive to obscured AGN
  – 58 month survey: 519 Seyferts, 108 Blazars (Baumgartner et al. 2010)

• **INTEGRAL Survey:** similar to BAT (20 – 100 keV) (Bassani et al. 2011)
Other AGN Samples (Shallow and Wide)

- Most “complete” samples are flux-limited
- To minimize biases:
  - Select on the basis of an “isotropic quantity”: hard X-rays, IR radiation, [O III] flux
  - Or, survey all galaxies to some distance or limiting flux, and identify those with AGN:
    - Center for Astrophysics (CfA) 48 Seyferts from redshift survey of bright galaxies (Huchra & Burg 1992)
    - Revised-Shapley Ames (RSA): 91 AGN in nearby galaxies (mostly Seyferts) with B < 13.4 mag (Maiolino & Rieke 1985)
    - Palomar survey: galaxies with B < 12.45, includes many low-luminosity AGN (e.g., LINERs) (Ho et al. 1997)
    - SDSS: Seyferts, LINERs, and starbursts from emission lines in galaxy spectra (Kauffmann et al. 2003; Kewley et al. 2006)
- Surveys in one bandpass always miss a fraction of the total AGN → use more than one wavelength region if possible
Other Surveys/Samples: Deep and Narrow

• Great Observatories Origins Deep Survey (GOODS) (Dickinson et al. 2003)
  – Multiwavelength surveys at high galactic latitudes, started with the Hubble Deep Field North and Chandra Deep Field South
  – Followed by HST, Chandra, XMM-Newton, Herschel, VLA, etc. observations
  – Probes the formation and evolution of galaxies and quasars

• Lockman hole
  – Region of very low column density in the Milky Way: Chandra, XMM, EUVE, 2MASS, VLA, etc.

• Many others
  – Hubble Ultradeep Field (HUDF), DEEP (Keck+HST), FORS (ESO VLT), MDS (HST), Groth Strip, etc. (Brandt & Hasinger 2005)

• LSST will be deep and wide (but only optical imaging)