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:
  Allen's Astrophysical Quantities, 4th ed.
  A.N. Cox, editor, Springer-Verlag (2000)

A Little (Extragalactic) Background

At low z (after correcting for peculiar velocities):

$v_r = cz = H_0 d$ $\quad (H_0 = 73 \pm 5 \text{ km s}^{-1} \text{ Mpc}^{-1})$

$$z \equiv \frac{\Delta\lambda}{\lambda} = \frac{\lambda_{obs} - \lambda_{lab}}{\lambda_{lab}} = \frac{v_r}{c}$$

At high z:

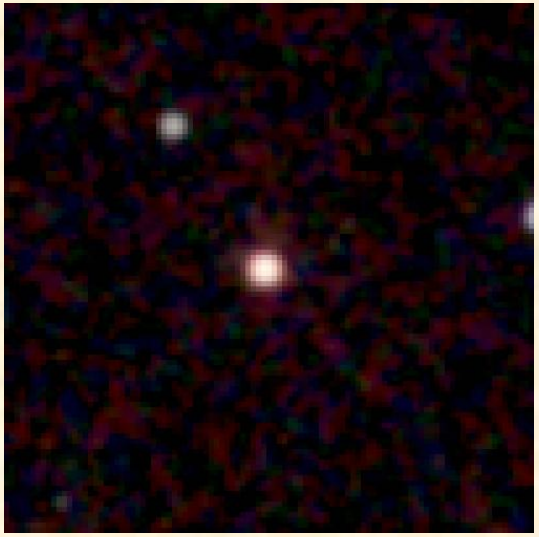
From Special Relativity:

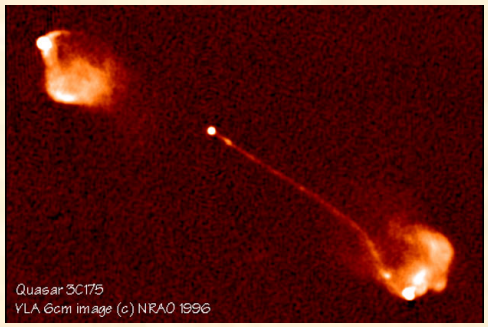
$$1 + z \equiv \frac{\lambda_{obs}}{\lambda_{lab}} = \sqrt{\frac{1+\beta}{1-\beta}} \quad , \text{ where } \beta = \frac{v_r}{c}$$

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

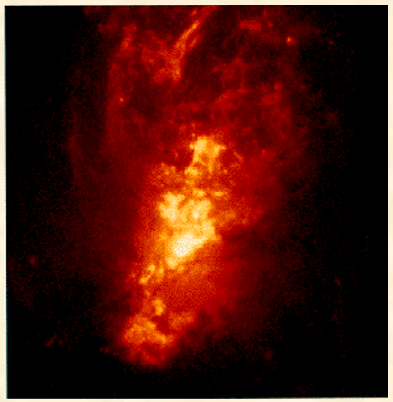
It can be shown that:

$$\beta = \frac{v_r}{c} = \frac{(1+z)^2 - 1}{(1+z)^2 + 1}$$

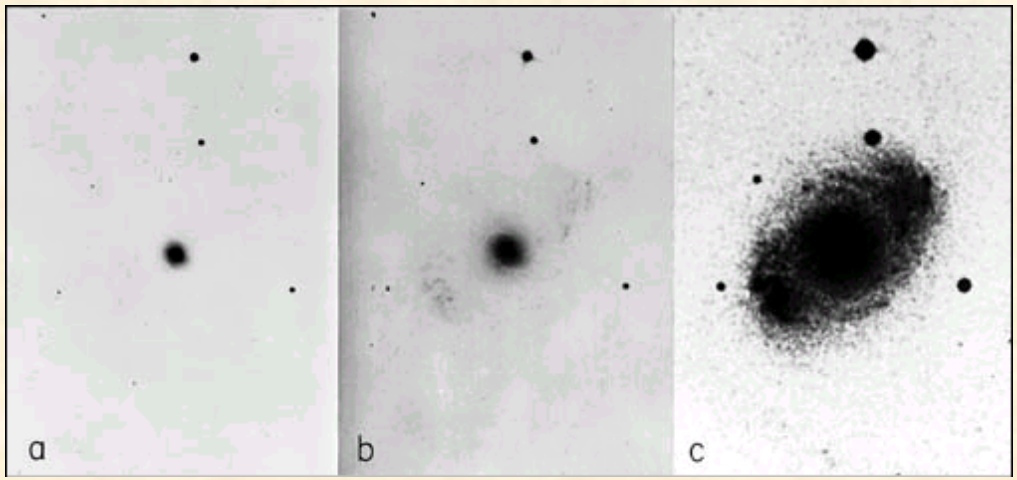




Observations of Active Galactic Nuclei (AGN)



- 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 λ range – radio to γ-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 (≥ 300 km/sec)

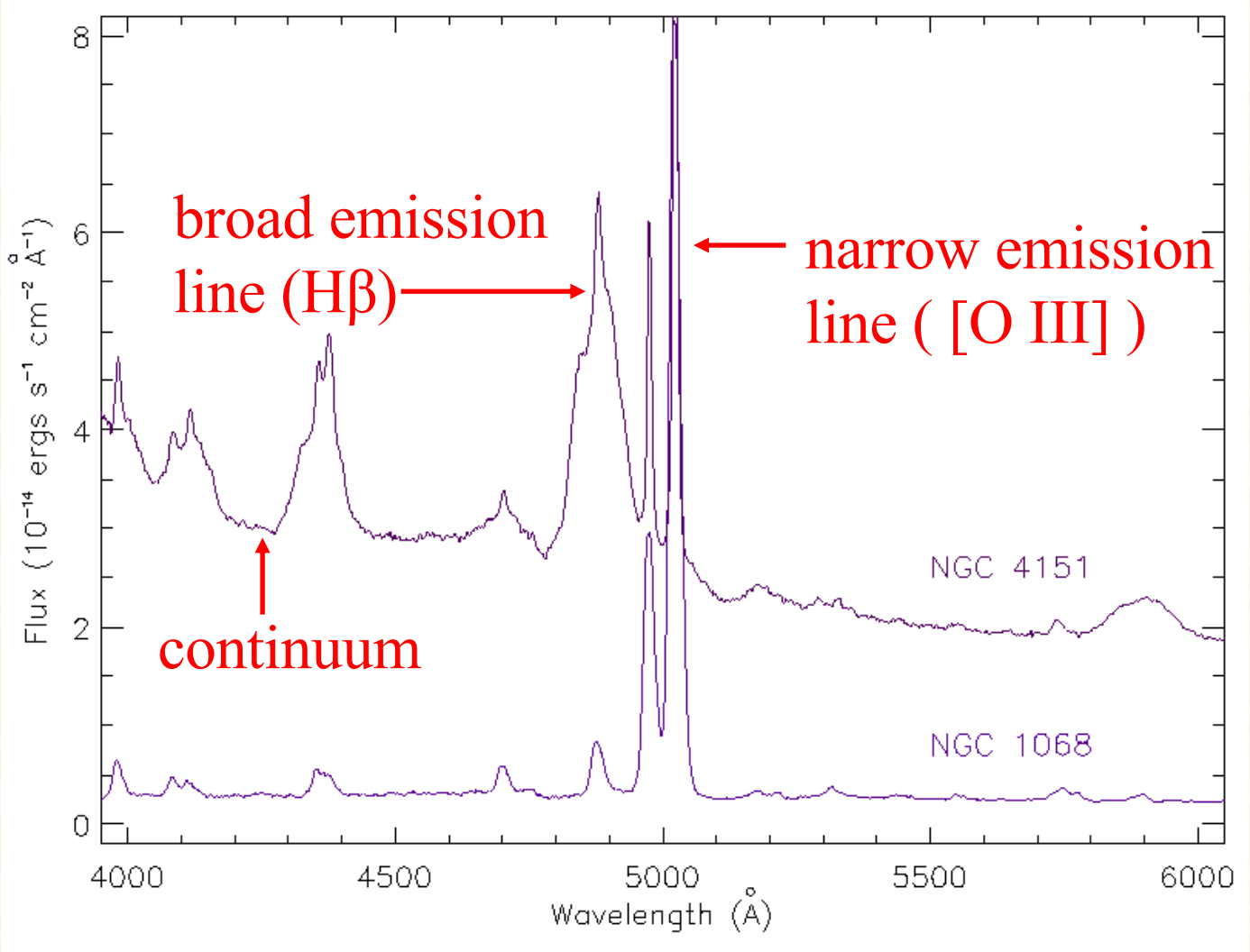
Basic problem:

- What physical mechanism generates so much luminosity ($L_{bol} > 10^{43}$ 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

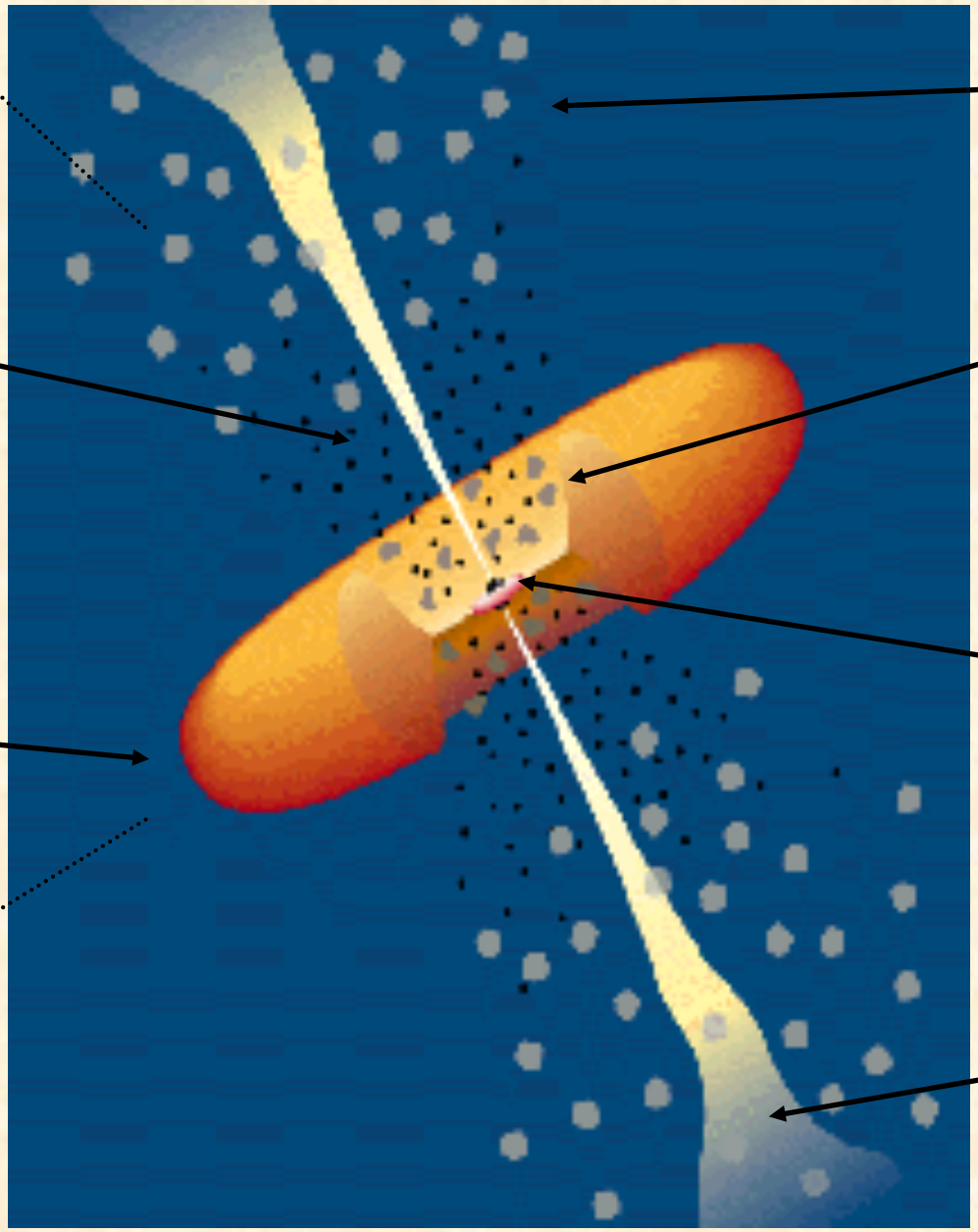
Optical Spectra of Seyfert Galaxies
(HST/FOS spectra)



Seyfert 1

Seyfert 2

Terminology – AGN Components

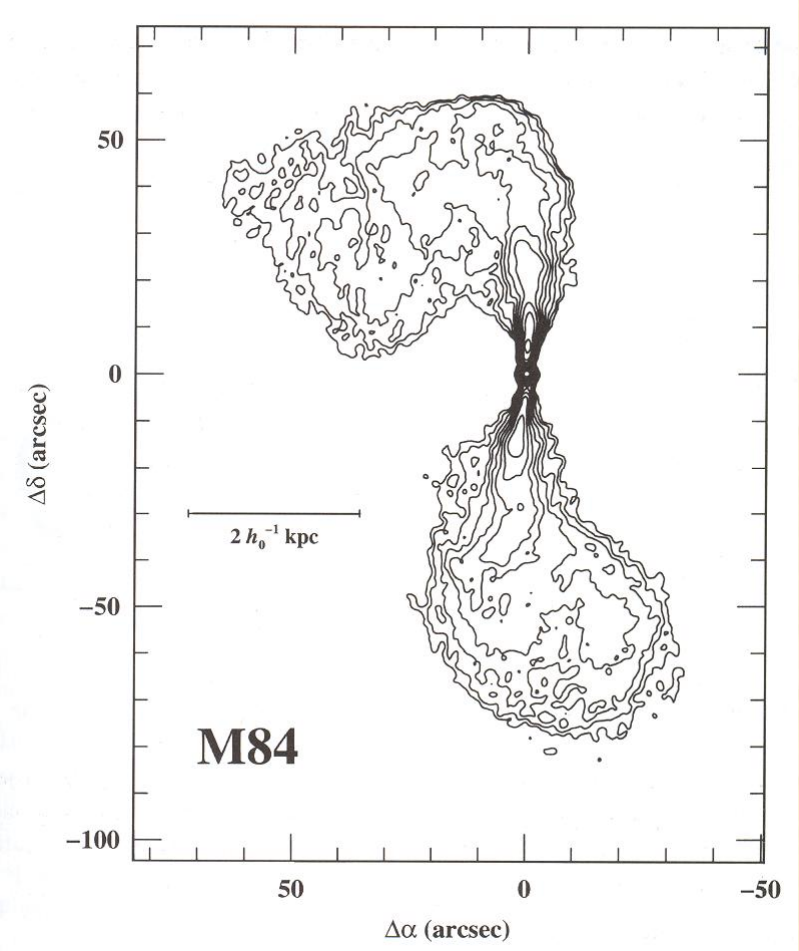


Terminology – AGN types

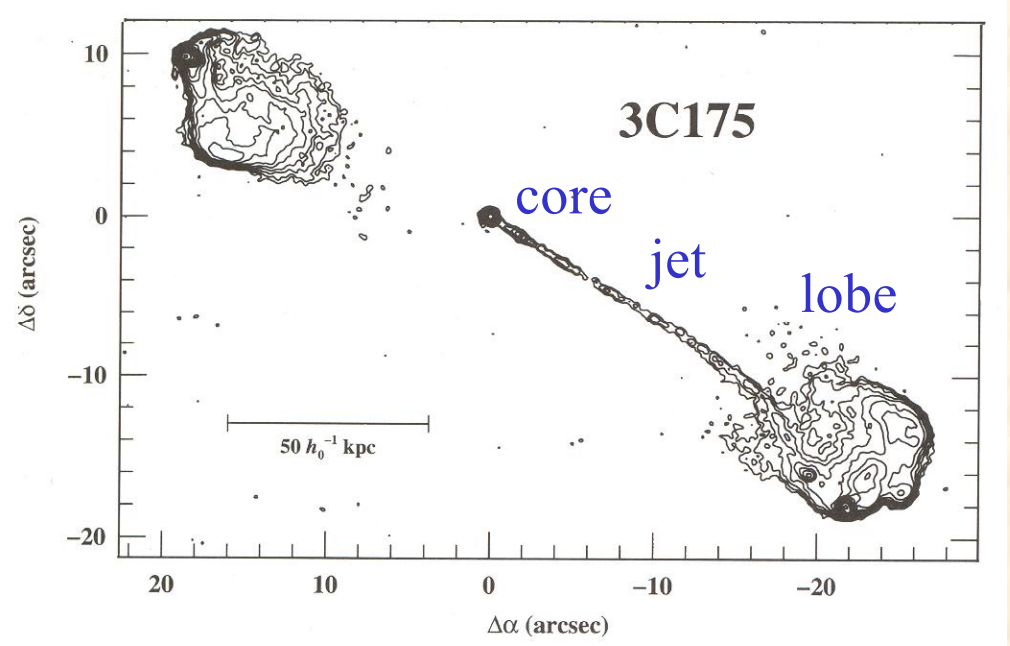
- Originally classified according to the appearance of their optical spectra, luminosity, radio power, etc.
  - **Seyfert galaxies** (including subtypes)
  - Broad-line radio galaxies (**BLRG**)
  - Narrow-line radio galaxies (**NLRG**)
  - Quasi-stellar radio sources (radio-loud quasars, **RLQ**)
  - 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)

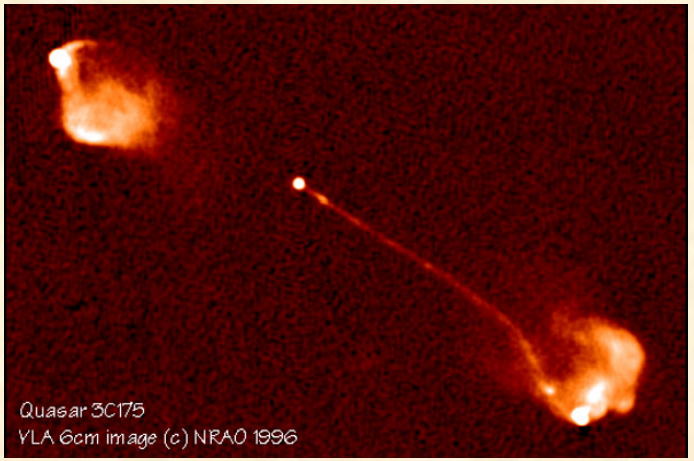
Fanaroff-Riley (FR) Types

FR I



FR II





AGN Surveys and Samples – Radio

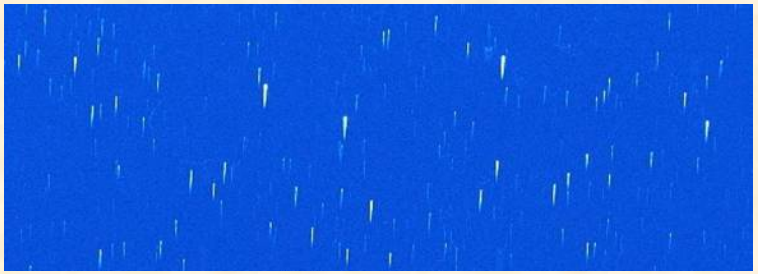
- Quasars first discovered in the radio
  - but only 5 – 10% of AGN are radio loud, so these are special
- **3C, 3CR, 4C**: third, revised, and fourth Cambridge catalogs
  - 1950 – 1960s, 178 MHz, north of declination -22° , flux > 2 Jy
    (Note: 1 Jy = 10^{-23} ergs s^{-1} cm^{-2} Hz^{-1})
- **PKS**: 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.

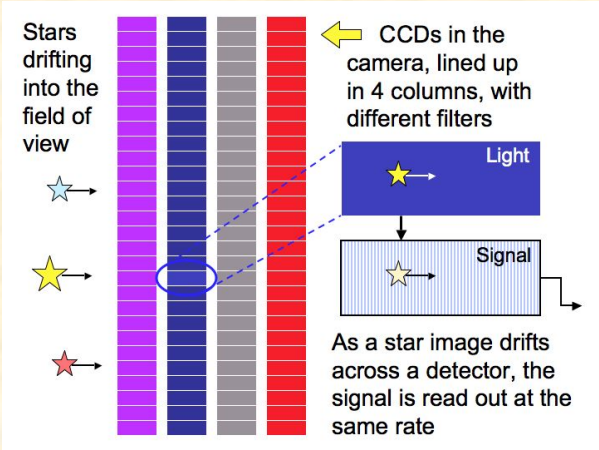
AGN Surveys and Samples – Optical

- 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

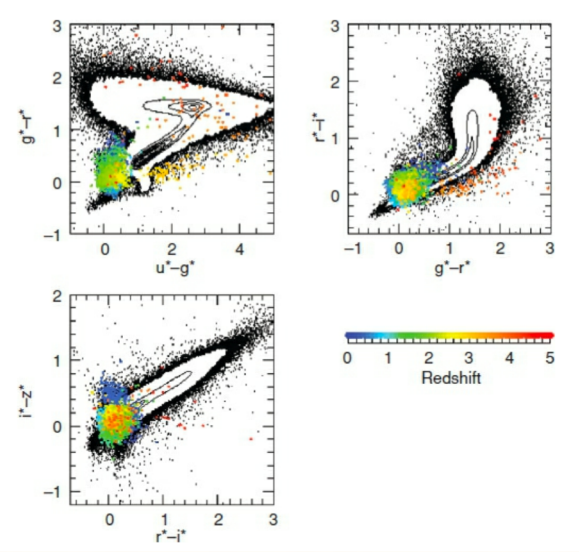


AGN Surveys and Samples – Optical

- Broad-band imaging → 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)

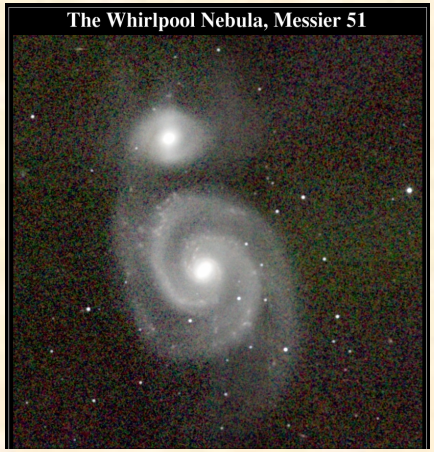
Color-color selection: black – stellar locus, colors– ugriz quasar candidates (Netzer 2013; Richards et al. 2004)

Access to data through SDSS web site or NASA Extragalactic Database (NED)



AGN Surveys and Samples – IR

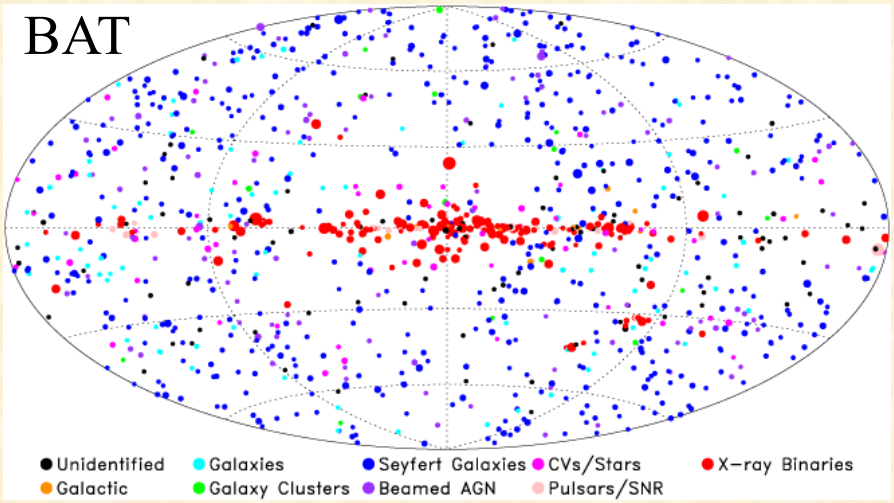
- Infrared Astronomical Satellite (**IRAS**): mid-IR survey of the entire sky at 12, 25, 60, and 100 μm, resolution ≈ 1 arcmin
  - discovered ULIRGs, "infrared cirrus" (cold dust in the Milky Way)
  - Followed by imaging and spectroscopy from ISO, Spitzer
- Wide Field Infrared Survey Explorer (**WISE**): 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 K_s (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
- **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 Blazar (Baumgartner 2010)
  - BASS Spectroscopic Survey (Koss, PI):

    https://www.bass-survey.com/index.html



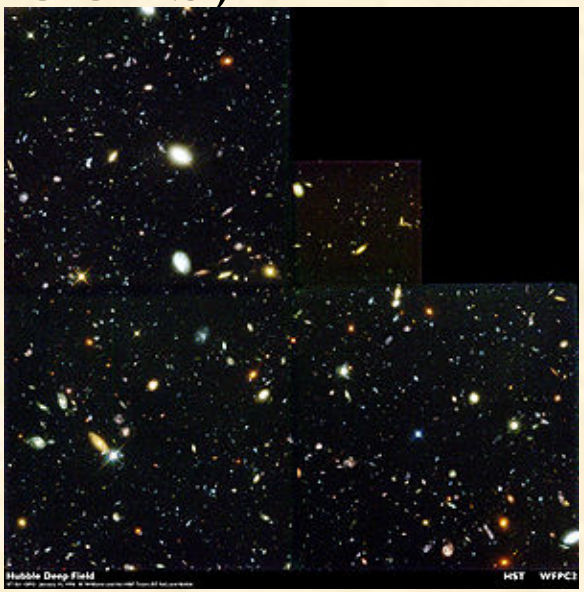
- INTEGRAL Survey: similar to BAT (Bassani et al. 2011)

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 Sefyerts) 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
  - formation and evolution of galaxies and quasars



- Many others:
  - Hubble Ultradeep Field (**HUDF**), **DEEP** (Keck+HST), **FORS** (ESO VLT), **MDS** (HST), **Groth Strip**, etc. (Brandt & Hasinger 2005);
  - JWST Systematic Mid-infrared Instrument Legacy Extragalactic Survey (SMILES; Lyu 2023)
- **Vera Rubin Observatory: deep** and **wide** (but only imaging)

Nice lecture on Multiwavelength Surveys for AGN:
https://www.youtube.com/watch?v=jnItH5jxmIA
(Brandt, W.N., IAU Symposium No. 356, 2019)