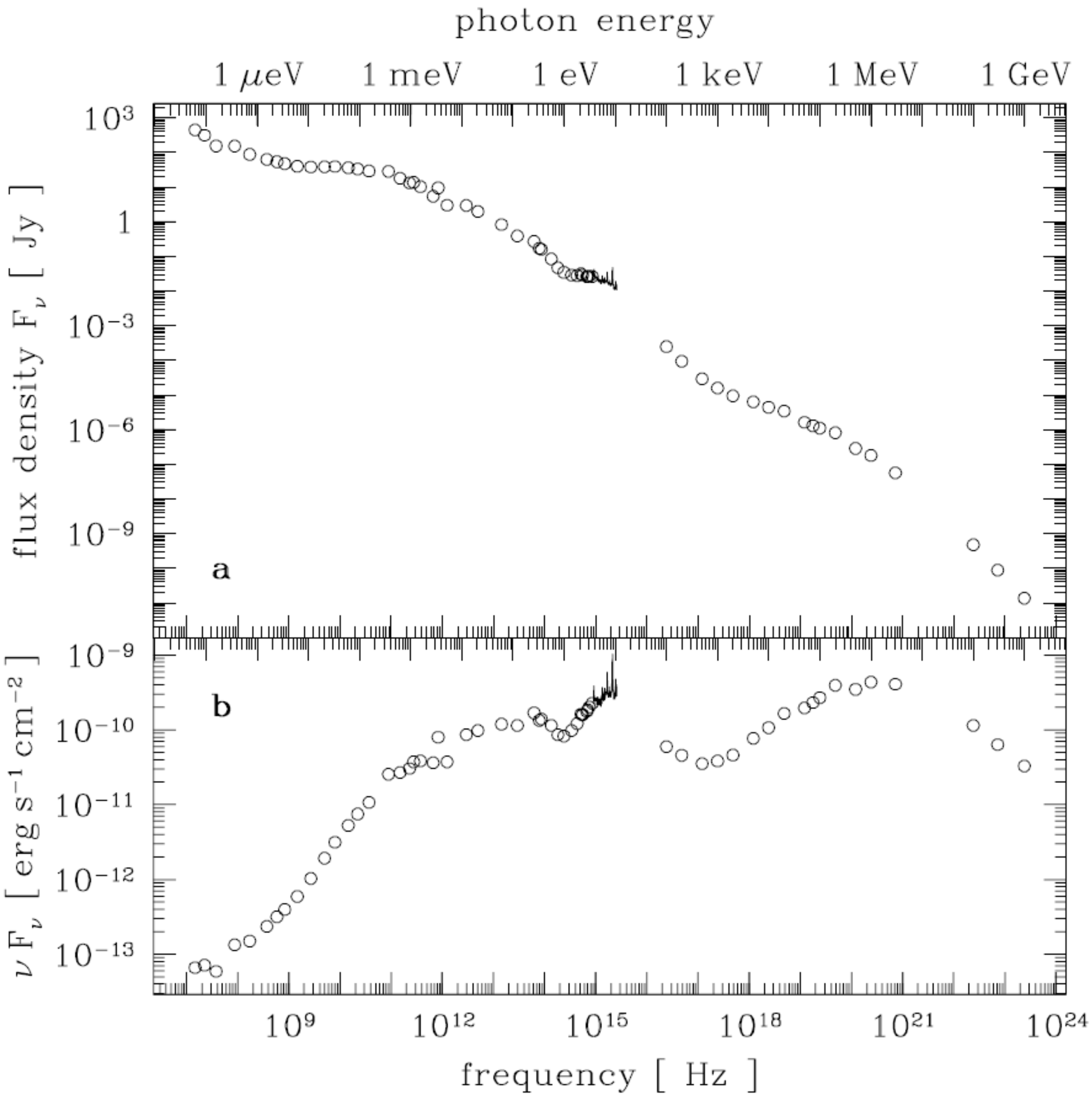
Active galactic nuclei

Observable quantities

Spectral appearance

- Classification of sources done based on their energy spectrum
- In νF_ν plot, equal graph area corresponds to equal energy
- Example: 3C 273, the 1st quasar
  - Peak power at low-E γ-rays
  - Narrow lines weak



Spectral appearance

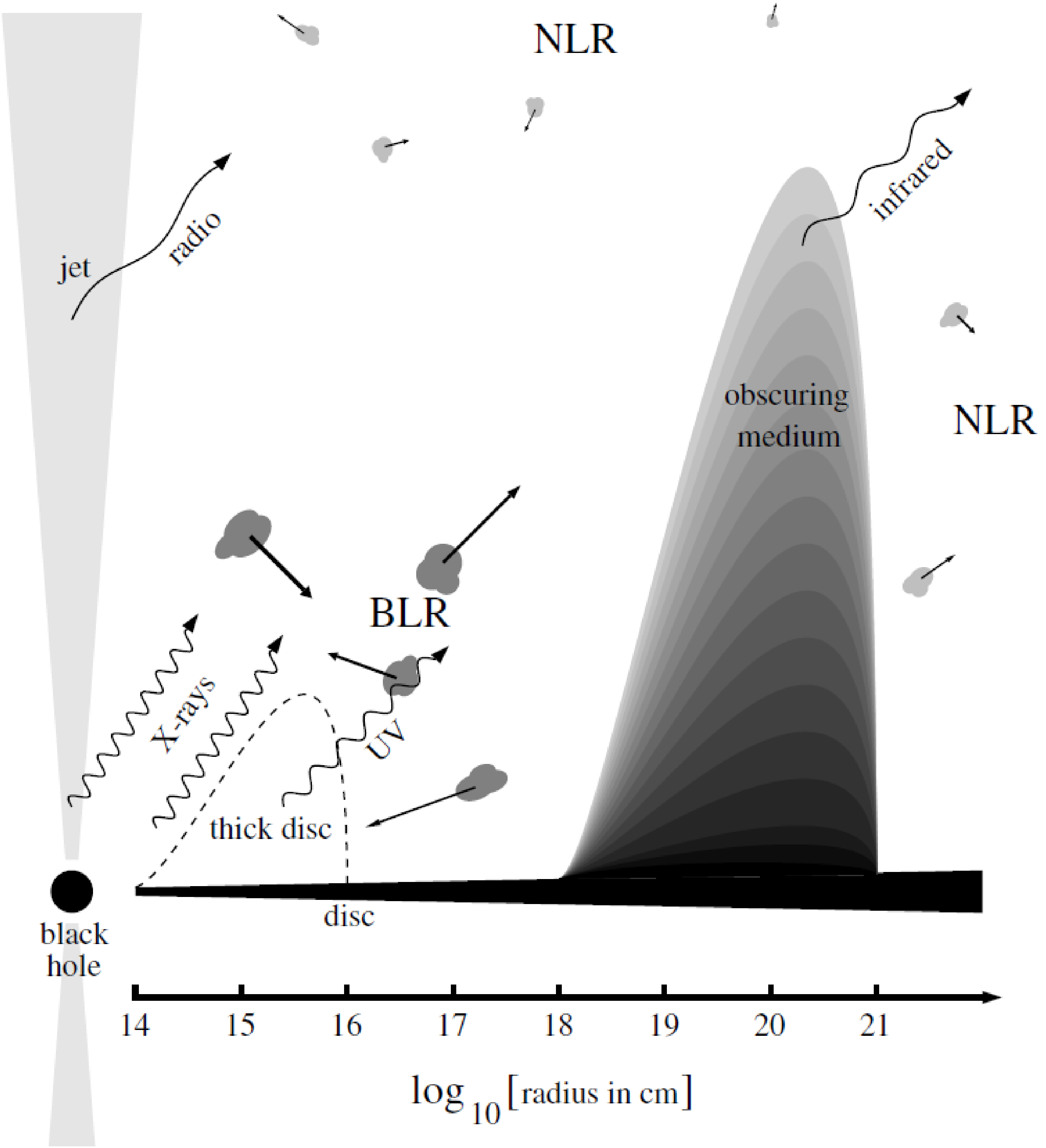
- Radio emission has been an important characteristic for quasars
  - 10 % of quasars show strong radio emission
  - Still the major energy output in other wavelengths, i.e. IR or X-rays and γ-rays
- Radio-loud galaxies tend to be associated with elliptical galaxies while radio-quiet occur mostly in spirals
- Structures visible in radio VLBI, such as double lobes and jets, are important for the study of AGNs

Spectral appearance

- Strong emission lines of two types usually observed:
  - Broad lines ($0.05 < \delta v/v < 0.1$ base of the line): in quasars and Seyfert 1 galaxies
  - Narrow lines ($\delta v/v \sim 0.002$ FWHM): Seyfert 2 only show narrow lines
- Recognized lines allow for the redshift to be measured $z=(\lambda_o-\lambda_e)/\lambda_e$
  - Redshift also determines, which shifted lines are seen within the fixed optical band (from H Balmer to originally UV lines of e.g. C or Mg)
- Objects, where there are no lines or they are weak, are called BL Lacs
  - Variability and polarization measurements help in classification
- Absorption lines also present in spectra, originating to either AGN outflows or the intergalactic medium

Unified model

- Radio-loud quasars are radio galaxies seen end-on
- Seyfert galaxies:
  - Emission lines come from reprocessing clouds, whose velocities determine the line widths
  - There is an outer dust torus which may block the view to the central region
  - Thus, Seyfert 1 are such systems seen more face-on while Seyfert 2 more edge-on



Distances

- Redshift: cosmological origin largely accepted
- Luminosity distance $d_L = cH_0^{-1}(z + 0.5(1-q_0)z^2 +...)$, where q_0 is the deceleration factor for cosmic expansion
  - Gives the diminution in total flux $F=L/4\pi d_L^2$
  - Therefore, based on the measured fluxes, intrinsic luminosities should have the energy of hundreds of galaxies in a volume million times smaller

Distances: arguments supporting cosmic interpretation

- Quasars appear associated with galaxy clusters of similar redshifts
- Continuity in object luminosities: from high-L Seyferts to low-L quasars
- Absorption line ratios are related to the size of the photoionized system, which should be that of intervening galactic haloes
- Gravitational lensing: light from a distant quasar may be seen as several lensed images (identical spectra&redshift, but variability may have delay)

Sizes

- optical: unable to see much, so the structures are probably ~1pc (indirect evidence from line-emitting regions suggests similar scales)
- radio: VLBI, size from angular size: $l=\theta cz/H_0$ (excluding relativistic corrections), giving ~1pc at 100 Mpc (z=0.03)
- variability from seconds to years observed: variable emission region constrained by light travel time: $l<ct_{var}$
  - X-ray flaring on hour timescale is common: $l<10^{15}$ cm
  - relativistic motions, however, mean that the timescales are longer in the source rest frame and the sizes are underestimated
  - Thus, 10^{15} $(M/\ 10^8\ M_{sol})$ cm estimated upper limit for the central engine size, while the minimum radius, 3 Schwarzschild radii, is ~ 10^{14} $(M/\ 10^8\ M_{sol})$ cm

Mass determination

- Based on luminosity: matter is converted into energy so $M = L\Delta t/\eta c^2$
  - Assuming very efficient: $\eta \sim 1/10$
  - Source time can be estimated from radio lobes, measuring how fast the jet material pushes into the intergalactic medium: $v \sim 10^3$ km/s
    - e.g. Cyg A with lobe separation 80 kpc has $\Delta t \sim 4\times10^7$ yr, resulting in $M \sim 10^8\ M_{sol}$
  - Since 1% of galaxies are active, another time estimate got by taking 0.01 galaxy lifetime (10^{10} yr)
    - Activity time 10^8 yr with a high luminosity 10^{47} erg/s gives $M \sim 10^{10}\ M_{sol}$

Mass determination

- Alignment time of rotational axes: $\Delta t_l > L/\eta\Delta Mc^2$ so $M > L/\eta c^2\Delta\, t_l$ (where L is angular momentum), giving $10^8\ M_{sol}$
- Luminosity constrained by the Eddington limit $L_{Edd} = 1.3\times10^{38}\ (M/M_{sol})$ erg/s, so AGNs require M at least in range 10^6-10^{10} (assuming spherical accretion)
- Variability and light-crossing time: $t \geq R/c \geq 2GM/c^3 = 0.98\times10^{-5}\ (M/M_{sol})$ s
  - In case of periodic motion, orbital time $t_K \geq 8.8\times10^{-5}\ (M/M_{sol})$ s

Mass determination

- A central mass affects the distribution and movement of the stellar population
  - Connecting brightness to mass is difficult
  - Velocity dispersion gives a better estimate, and often a compact central object is needed to explain results
  - Direct observation of stellar orbits in our Galactic centre indicate the presence of a massive BH