Introduction to Astronomy and Astrophysics I

Lecture 14

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Scaling relations

There are a number of correlations between the global parameters of galaxies: **Luminosity; Size; Surface Brightness; Rotation Velocity**. Such relations are called **Scaling Relations**.
They are important for several reasons:

- They reveal the internal properties of galaxies
- They must arise naturally in theories of galaxy formation.

In the case of disk galaxies, the most important is between $V_{\rm rot}$ and Luminosity

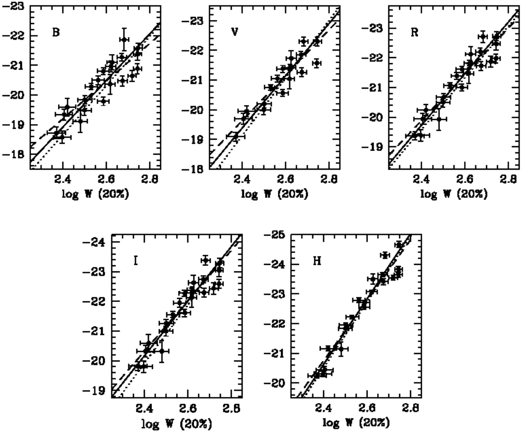
Tully Fisher relation

Tully & Fisher (1977) recognised that $V_{\max}$ correlates with galaxy luminosity $L \propto V_{\max}^{\alpha}$ where $\alpha \sim 3 - 4$

Scatter in T-F relation smaller at longer wavelengths.

Tully Fisher relation is an important distance indicator. How to measure distance with TF relation?

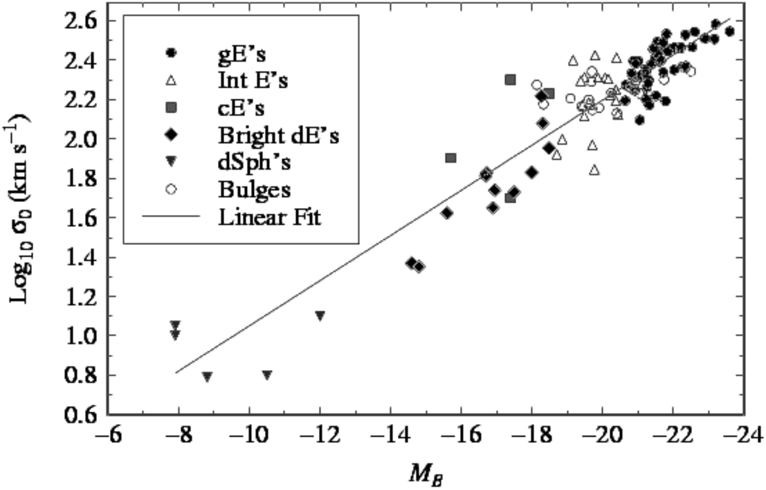
The Tully Fisher relation



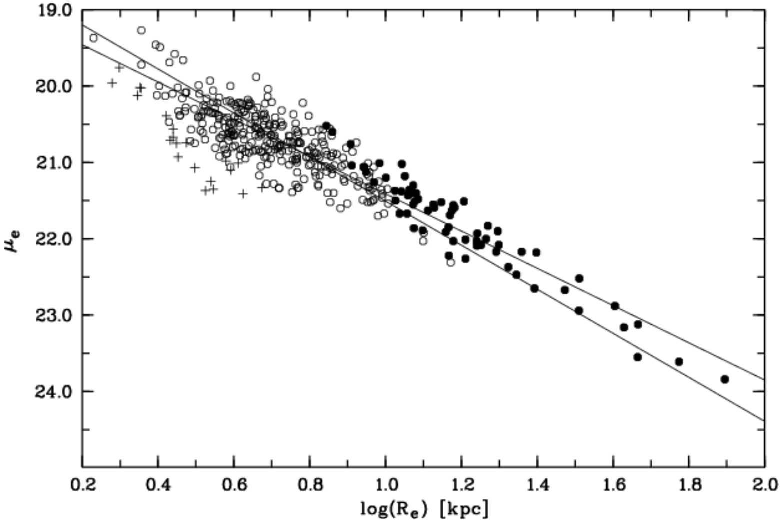
Why is the TF relation so special?

- it connects a property of the dark halo - the maximum circular speed - with the product of the net integrated star formation history, i.e., the luminosity of the disk. This implies: Halo-regulated galaxy formation/evolution?
- The scatter is remarkably low. There is some important feedback mechanism involved, which we do not understand yet. The TFR offers some important insights into the physics of disk galaxy formation.

Faber Jackson relation



Kormendy relation



This relation tells us something about galaxy formation!

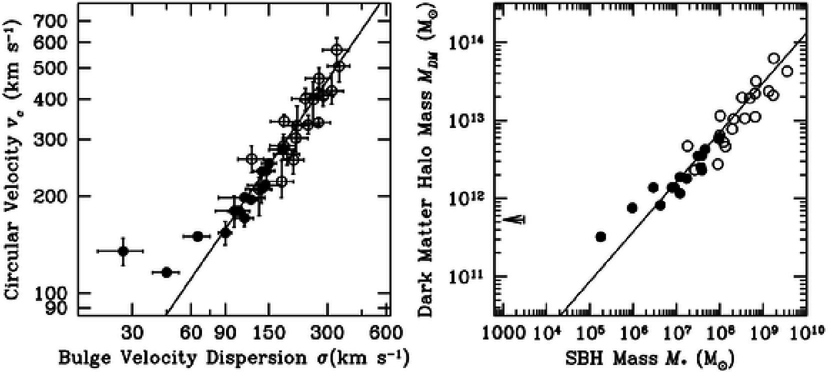
Dissipationless less merging or dissipational collapse?

From virial theorem, the dynamical $M \propto R\sigma^2$.
Luminosity $L \propto IR^2$ where I is the mean surface brightness
If M/L is constant, then $M \propto IR^2 \propto R\sigma^2$ and $IR \propto \sigma^2$
If ellipticals formed via dissipationless (dry) merging, kinetic energy per unit mass ($\sim \sigma^2$ remains constant), implying $R \propto I^{-1}$
If ellipticals formed via dissipative collapse of gas, then $I \propto MR^{-2}$, implying $R \propto I^{-0.5}$
Kormendy relation gives $R \propto I^{-0.8}$. What does this imply?

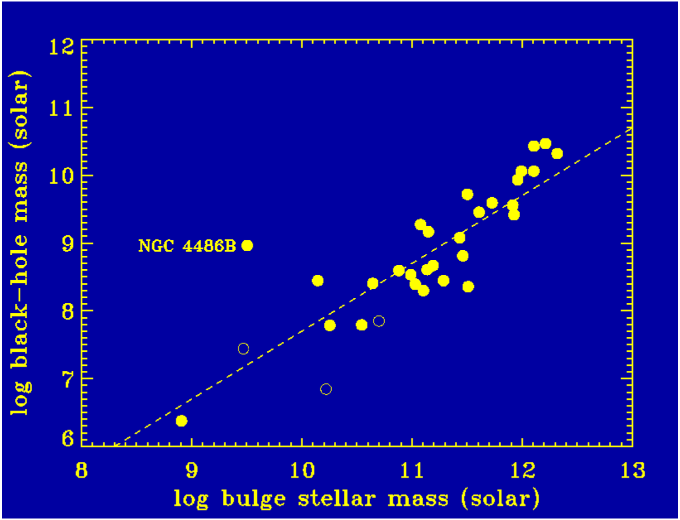
Final exam

10am-12:15pm on Fri. 27 September in NCRA Lecture Hall. 50% weightage.
Short answer questions based on all lectures, with most questions from Lecture 7 onwards. Closed notes, closed book. **Please bring a scientific calculator**

Central black hole and the bulge



and most interestingly



Dark matter haloes

- Many of galaxy scaling relations may be driven by the properties of their dark halos
- It is possible to infer their properties from detailed dynamical profiles of galaxies and some modeling
- Numerical simulations suggest a universal form of the dark halo density profile (NFW = Navarro, Frenk & White):

$$\rho(r) = \frac{\rho_0}{(r/r_s)(1 + r/r_s)^2}$$

where ρ_0 and the scale radius r_s are parameters that vary from halo to halo.

Dark matter discovered in 1937 by Zwicky

He calculated the mass of the Coma cluster using the virial theorem. $M_{\rm cl} = \sigma^2 R_{\rm cl}/G$. For typical clusters $\sigma \sim 500 - 1500$ km s^{-1},$R{\rm cl} \sim 3 - 5$ Mpc. This gives $M_{\rm cl} \sim 10^{14} - 10^{15} M_{\odot}$. Typical clusters have 100-1000 galaxies and $L_{\rm cl} \sim 10^{12} L_{\odot}$ and $(M/L) \sim 200 - 500$ in solar units.
Besides dark matter, Zwicky was also not aware of the existence of the dominant baryonic component of clusters. What is this?

Dark matter candidates

- Massive neutrinos: Known to exist and to have mass, but how much?
- Weakly Interacting Massive Particles (WIMPs): Not found yet, but possible . A generic category, e.g., the neutralino = the least massive SUSY particle; also include gravitinos, photinos, and higgsino. Possible masses > 10 GeV
- Axions: predicted in some versions of quantum chromodynamics, Could interact electromagnetically, Possible masses 10^{-12} eV to 1 MeV
- Many (many!) other speculative possibilities ...

Two types of dark matter

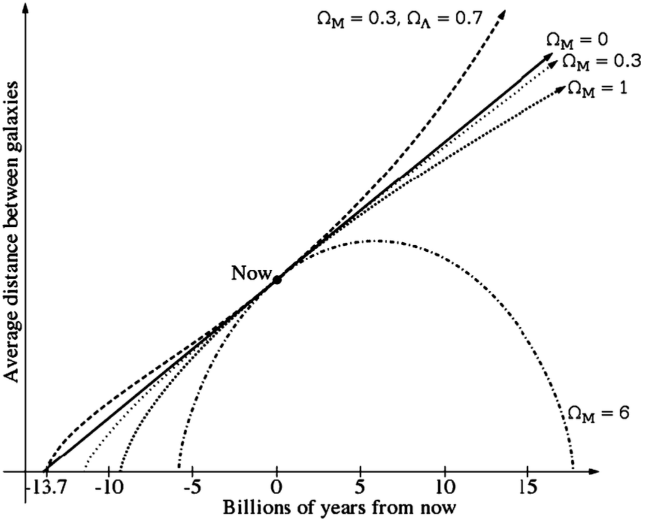
- Hot (HDM): matter is relativistic, so must involve low-mass particles such as neutrinos. Their streaming erases the small-scale density fluctuations, so big structures form first, then later fragment. This is “top-down” structure formation
- Cold (CDM): matter moves more slowly; includes exotic as yet unknown particles such as axions, WIMPs, etc. Density fluctuations at all scales survive. Small fluctuations collapse first, then larger ones (pulling in the littler ones along the way). This is “bottom-up” structure formation and this is the best match to what we observe.
- There is probably a little bit of HDM and a lot of CDM

Cosmology Independent Equations

Definition of Redshift: $\lambda_o = (1+z)\lambda_e$
Scale Factor $a(z) = \frac{1}{1+z}$
Volume $V(z) = \frac{1}{(1+z)^3}$
CMB Temperature $T(z) = T(0)(1+z)$
Time interval $\Delta t = (1+z)\Delta t(0)$
CMB Photon Energy $\propto (1+z)$
CMB Energy Density $\propto (1+z)^4$
Hubble Parameter: $H(t) = \frac{\dot{a}(t)}{a(t)}$, H_0 is the value of the Hubble Parameter today.

Can we write an expression for $a(t)$ or $z(t)$ independent of cosmological parameters?

Scale Factor Variation with time



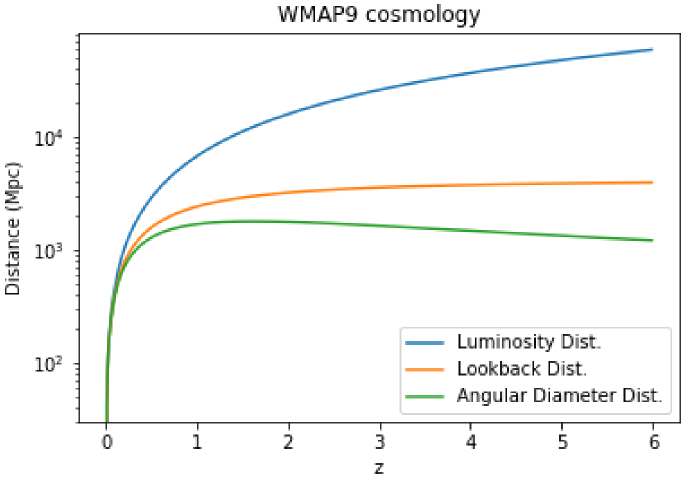
Critical Density

$$\rho_{cr} = \frac{3H_0^2}{8\pi G}$$

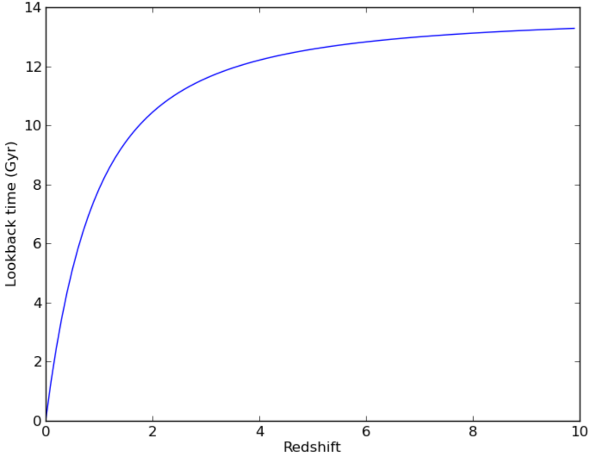
Distances in cosmology

- Luminosity Distance $D_L = \sqrt{L/4\pi S}$
- Angular Diameter Distance $D_A = \sqrt{R^2\pi/\omega}$ and $D_L(z) = (1+z)^2 D_A(z)$
- Lookback Distance

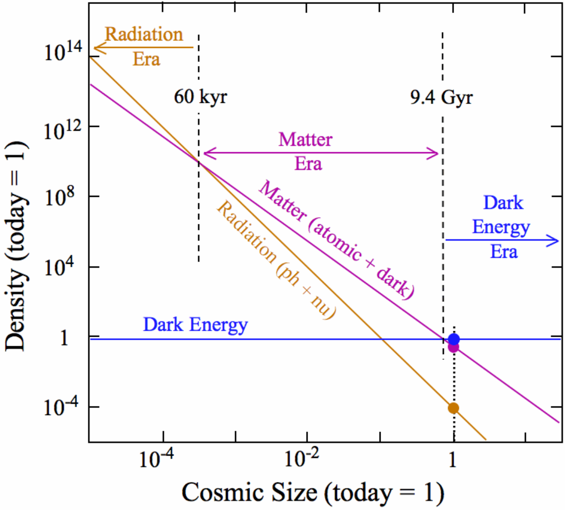
Distances with WMAP9 cosmology



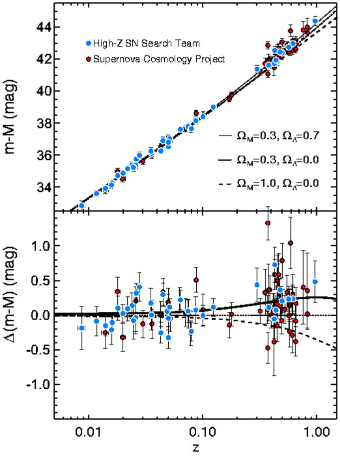
Lookback time WMAP9 cosmology



Mass-energy Density Evolution with Scale Factor



The Accelerating Universe



Active galactic Nuclei

- emission from the hot accretion disk (can emit in many wavebands) around the SMBH and sometimes, from relativistic (sometimes beamed) jets and lobes.

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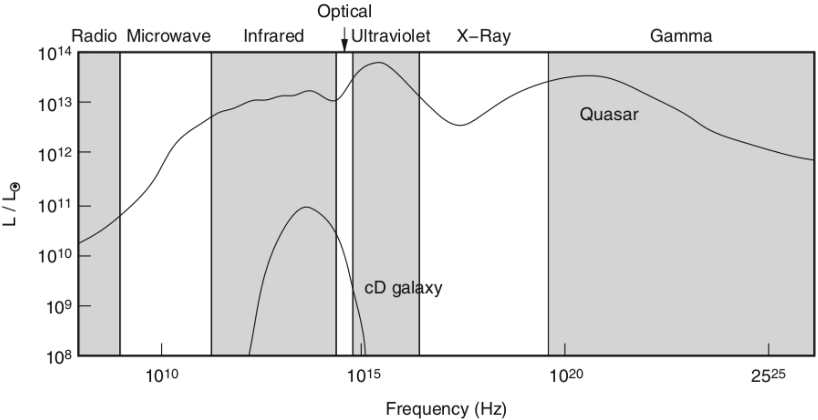
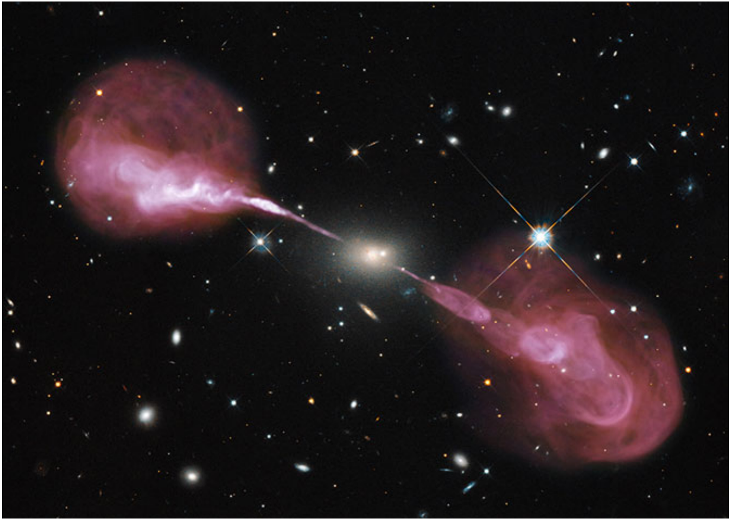
- about 10% of massive galaxies are AGN or perhaps all galaxies are AGN 10% of their lifetime.
- optical AGN spectra have strong blue continuum and many emission lines
- many flavours - Seyfert 1, Seyfert 2, QSO or quasars (blazars, BL Lacs), radio galaxies, Type 2 QSOs etc.

3C273 Quasar spectrum

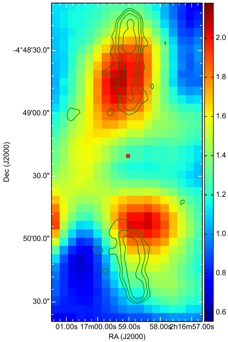


Schneider (2015)

Radio Galaxy - usually hosted by ellipticals

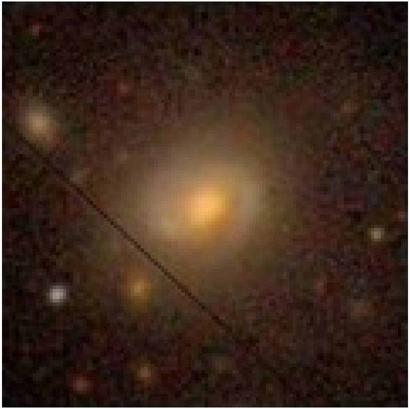


High Redshift radio galaxies - ICCMB

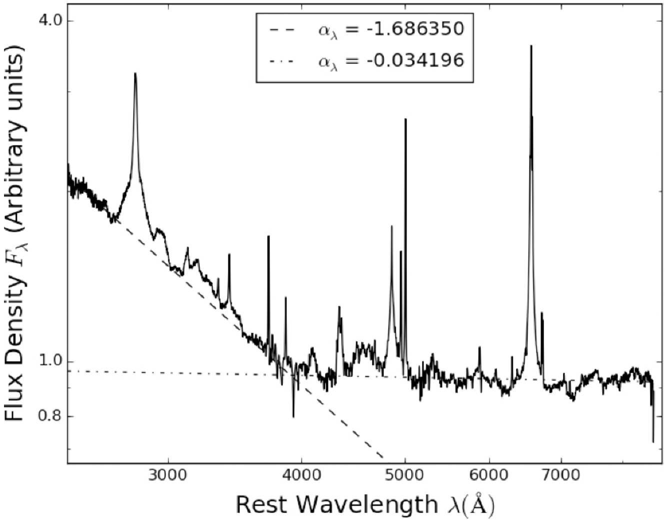


Tamhane et al (2015)

Seyfert 1 galaxy

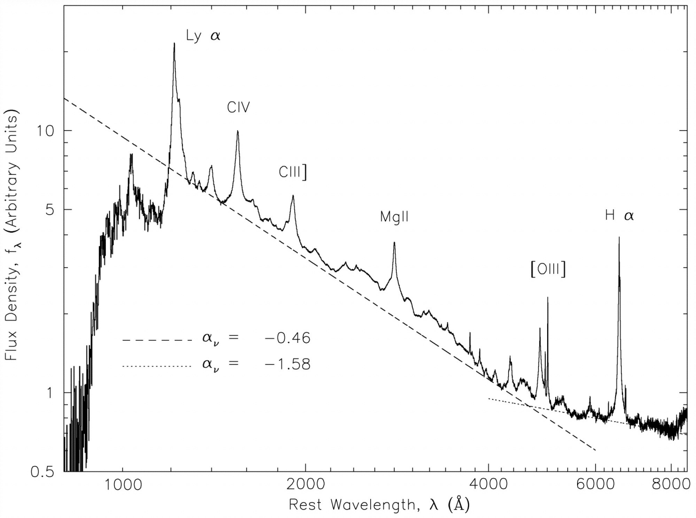


Composite Seyfert 1 Spectrum



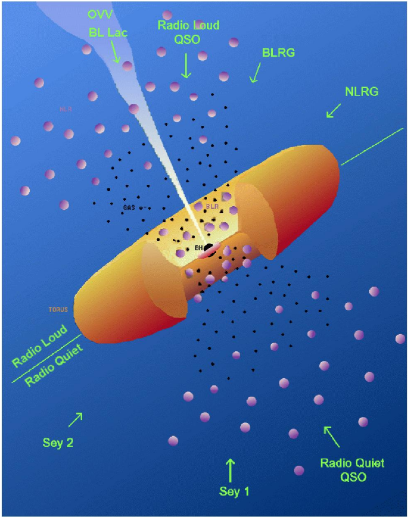
Pol & Wadadekar (2016)

Composite Quasar Spectrum

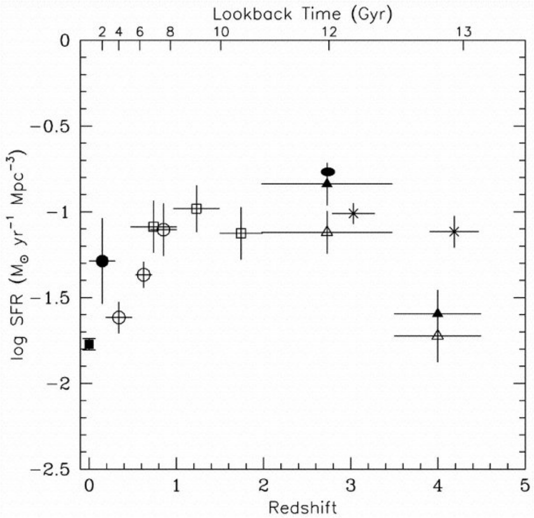


Vanden Berk et al. (2001)

AGN Unification



Star-formation History and the Quasar age



Wadadekar et al. (2006)

The official syllabus

Earth-solar system - The Sun as a star - Stellar structure and evolution - The HR diagram - Colours, magnitudes, Spectral classification - White dwarfs, neutron stars, black holes - Binaries - ISM - Structure of Milky Way - Stellar population and galactic structure - Cosmology - Brief description of Galaxy morphology and evolution - Active Galaxies - Clusters of Galaxies.

Exoplanets

[All these topics will come up for detailed study later; the aim of this course will be to connect physics with astrophysics at an order-of-magnitude level and to introduce conventions and jargons of A & A to a physics student].