ESSENTIALS OF ASTROPHYSICS

PART II

LECTURE I

GALAXIES

Kant: IF MILKY WAY IS LIMITED

- DIFFUSE, FAINT ELLIPTICAL NEBULAE → ISLAND UNIVERSES (1750)

- CATALOGUES:
  - MESSIER (1730 - 1817)
  - DREYER (1852 - 1926): NEW GENERAL CATALOG (NGC)

    ~ 8,000 OBJECTS

- SHAPLEY - CURTIS DEBATE (1920)

  ↓ Nebulae part of Milky Way

  ↓ Extragalactic nebulae

SETTLED BY HUBBLE WITH CEPHEID DISTANCES IN 1923

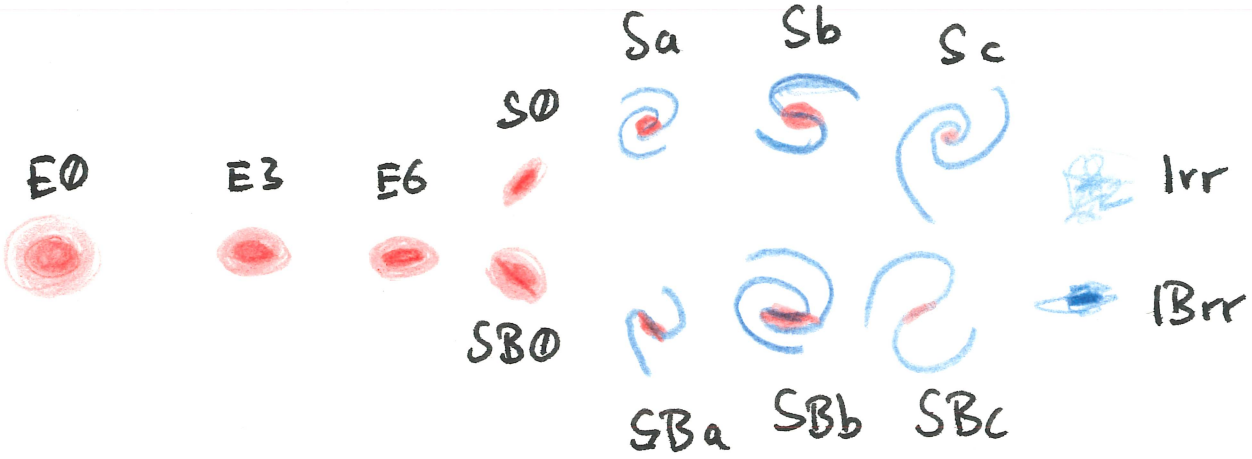
CLASSIFICATION OF GALAXIES

- SLIDE 3 -

HUBBLE 1926 : HUBBLE SEQUENCE

- MORPHOLOGY
  - ELLIPTICALS ('E')
  - SPIRALS
    - × NORMAL SPIRALS ('S')
    - × BARRED SPIRALS ('SB')
  - Irregulars
  - TRANSITIONAL CLASS : LENTICULARS
    - × S0
    - × SB0

⇒ TUNING FORK DIAGRAM



HUBBLE

ELLIPTICALS: EARLY TYPES

SPIRALS, IRR: LATE TYPES ↯ WRONG

NAMING STILL USED

WITHIN ELLIPTICALS:

ELLIPTICITY: $\epsilon \equiv 1 - \frac{\beta}{\alpha}$

α, β: APPARENT MAJOR AND MINOR AXIS

HUBBLE TYPE: 10ϵ

SPHERICAL: E0

HIGHLY FLATTENED: E7

($\epsilon > 0{,}7$ NEVER OBSERVED)

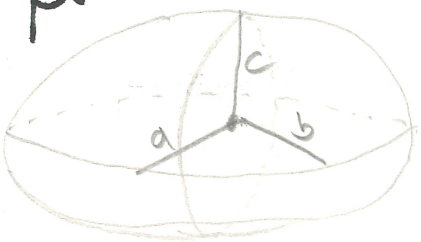
PROBLEM: DEPENDS ON LINE OF SIGHT!

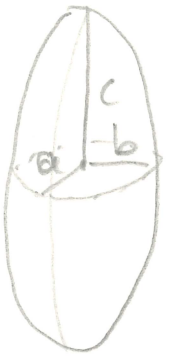
STRUCTURE OF ELLIPTICALS:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = m^2$$

OBSERVER A

OBSERVER B





OBLATE

$a = b > c$

PROLATE

$a = b < c$

~~ELLIPTICALS: N = 10 dec~~

OBSERVER A: $\frac{B}{\alpha} = 0.6 \Rightarrow E4$

OBSERVER B: $\frac{B}{\alpha} = 1 \Rightarrow E0$

PHYSICAL PROPERTIES OF ELLIPTICALS:

B MAGNITUDES: $M_B = -8$ (DIMMEST)

$M_B = -23$ (BRIGHTEST)

blue: $\lambda = 440nm$, $\Delta\lambda = 68nm$

$M \approx 10^7 - 10^{13}\ M_\odot$

$r \approx \mathcal{O}(10) - \mathcal{O}(100)$ kpc

Masses of lenticulars SIMILAR TO ELLIPTICALS

SLIDE 4 - SLIDE 6

read bh

SLIDE 7 - 8

GENERAL STRUCTURE OF

SPIRALS

- THIN, EXTENDED GASEOUS AND STELLAR DISKS WITH STAR FORMATION IN SPIRAL ARMS

  - Sa SLIDE 9

    TIGHTLY WOUND SPIRAL ARMS
    SMOOTH DISTRIBUTION OF STARS
    MASSIVE OLD RED BRIGHT BULGE: $\frac{L_{bulge}}{L_{disk}} \sim 2$

  - Sc SLIDE 10

    LOOSE OPEN ARMS
    CLUMPS OF STARS
    LOW-MASS, BLUER, YOUNGER BULGE $\frac{L_{BULGE}}{L_{disk}} \sim 0.$

  - Sb : TRANSITION FROM Sa-TO-Sc
    SLIDE 11

    ELONGATED BARS : SB

    ↳ DISK INSTABILITIES
    SLIDE 12, 13

- SPIRALS: SMALLER PHYSICAL VARIATION

$M_B = -16 \ldots -23$

$M = 10^9 - 10^{12} M_\odot$

$R_{DISK} \sim 5 \sim 100 kpc$

Irregulars: SLIDE 14

Irr I: SOME HINT OF STRUCTURE SLIDE 15

Irr II: DISORGANIZED

$M_B = \dots -13 \dots -20$

$M \approx 10^8 \dots 10^{10} M_\odot$

$R \sim 1 - 10$ kpc

CORRELATIONS OF PHYSICAL PARAMETERS WITH GALAXY TYPES

SPIRALS AND IRREGULARS

BRIGHTNESS OF GALAXIES

CORRECTIONS

ABSOLUTE MAGNITUDE OF GALAXIES:

- EXTINCTION IN MILKY WAY AND GALAXY (SEE STARS)
- EXTINCTION NEGLIGIBLE IN EMPTY SPACE BETWEEN GALAXIES
- REDSHIFT OF GALAXIES (MOTION FROM EXPANSION OF UNIVERSE)

⇒

LIGHT OF B-BAND REDSHIFTED TO LONGER WAVELENGTH

↳ K- CORRECTION

- BRIGHTNESS OF BACKGROUND SKY (SUBTRACT)

$$\mu_{sky} \approx 22 \frac{\text{B-mag}}{\text{arcsec}^2}$$

(CCD accuracy: $29 \frac{\text{B-mag}}{\text{arcsec}^2}$)

- LIGHT POLLUTION OF CITIES
- ATMOSPHERIC EFFECTS
- ZODIACAL LIGHT (REFLECTION OF SUNS LIGHT FROM INTERPLAN. DUST)
- UNRESOLVED STARS IN MW

DE VAU COULEURS PROFILE

SURFACE BRIGHTNESS $I(r) \left[\text{in } \frac{L_\odot}{pc^2}\right]$ BULGE:

$L_\odot$: SOLAR LUMINOSITY ($3.8 \cdot 10^{26}$ W)

$$\log_{10}\left[\frac{I(r)}{I_e}\right] = -3.3307\left[\left(\frac{r}{r_e}\right)^{1/4} - 1\right]$$

r_e : EFFECTIVE RADIUS

I_e : $I(r_e)$

TOTAL LUMINOSITY :

$$L = \int_0^\infty 2\pi r\, I(r)\, dr \approx 7.22\pi r_e^2 I_e \left[\text{in } L_\odot\right]$$

$$L(r \le r_e) = \int_0^{r_e} 2\pi r\, I(r)\, dr = \frac{1}{2}L$$

(DEF. OF r_e)

IN $\frac{\text{mag}}{\text{arcsec}^2}$:

$$\mu(r) = \mu_e + 8.3268\left[\left(\frac{r}{r_e}\right)^{1/4} - 1\right]$$

GENERALIZED DE VAUCOULEUR PROFILE

SERSIC PROFILE

$$\mu(r) = \mu_e + 8.3268\left[\left(\frac{r}{r_e}\right)^{1/n} - 1\right]$$

μ_e, r_e, n : FREE FITTING PARAMETERS

DISK OF GALAXY: $\mu(r) = \mu_0 + 1.09\left(\frac{r}{r_{char}}\right)$

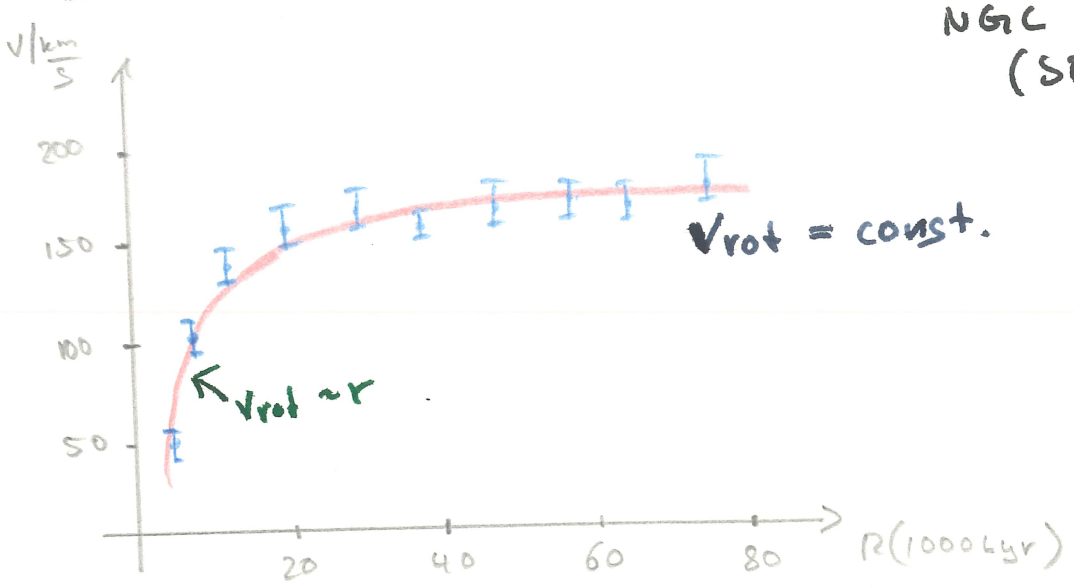
↑ char. length scale

$n=4$: DE VAUCOULEUR

$n=1$: DISK

ROTATION CURVE OF GALAXIES

NGC 3198
(SBc)

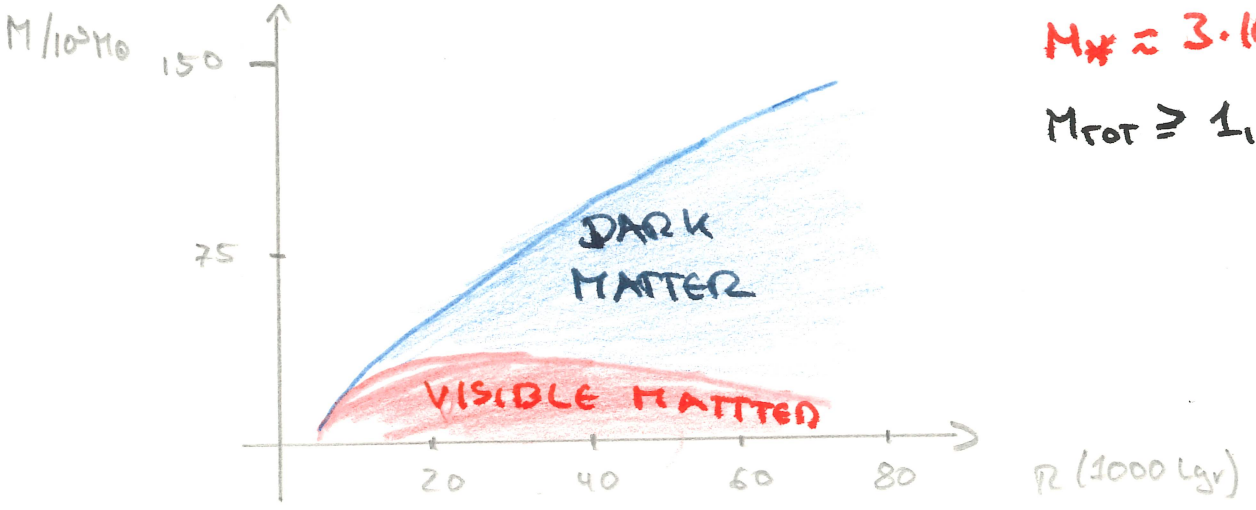


$$v_{rot}^2 = \frac{GM(r)}{r} \Rightarrow M(r) = \frac{r\, v_{rot}^2}{G}$$

$v_{rot} \sim r \Rightarrow M \sim r^3$

$v_{rot} = const. \Rightarrow M \sim r$

$$M(r) = 2.3 \times 10^9 \left(\frac{r}{kpc}\right) \left(\frac{v_{rot}}{100\ \frac{km}{s}}\right)^2 M_\odot$$



$M_* \simeq 3 \cdot 10^{10} M_\odot$

$M_{TOT} \geq 1{,}5 \times 10^{11} M_\odot$

MASS DISTRIBUTION NGC 3198

TREND WITH LUMINOSITY AND HUBBLE TYPE:

SLIDE 16

- INCREASING LUMINOSITY (L_B, M_B)
  - ⇒ ROTATION CURVE RISES MORE RAPIDLY
  - ⇒ HIGHER MAXIMUM VELOCITY
- EQUAL LUMINOSITY
  - SPIRALS OF EARLIER TYPE → HIGHER VELOCITY

BUT: ROTATION CURVES IN FORM SIMILAR

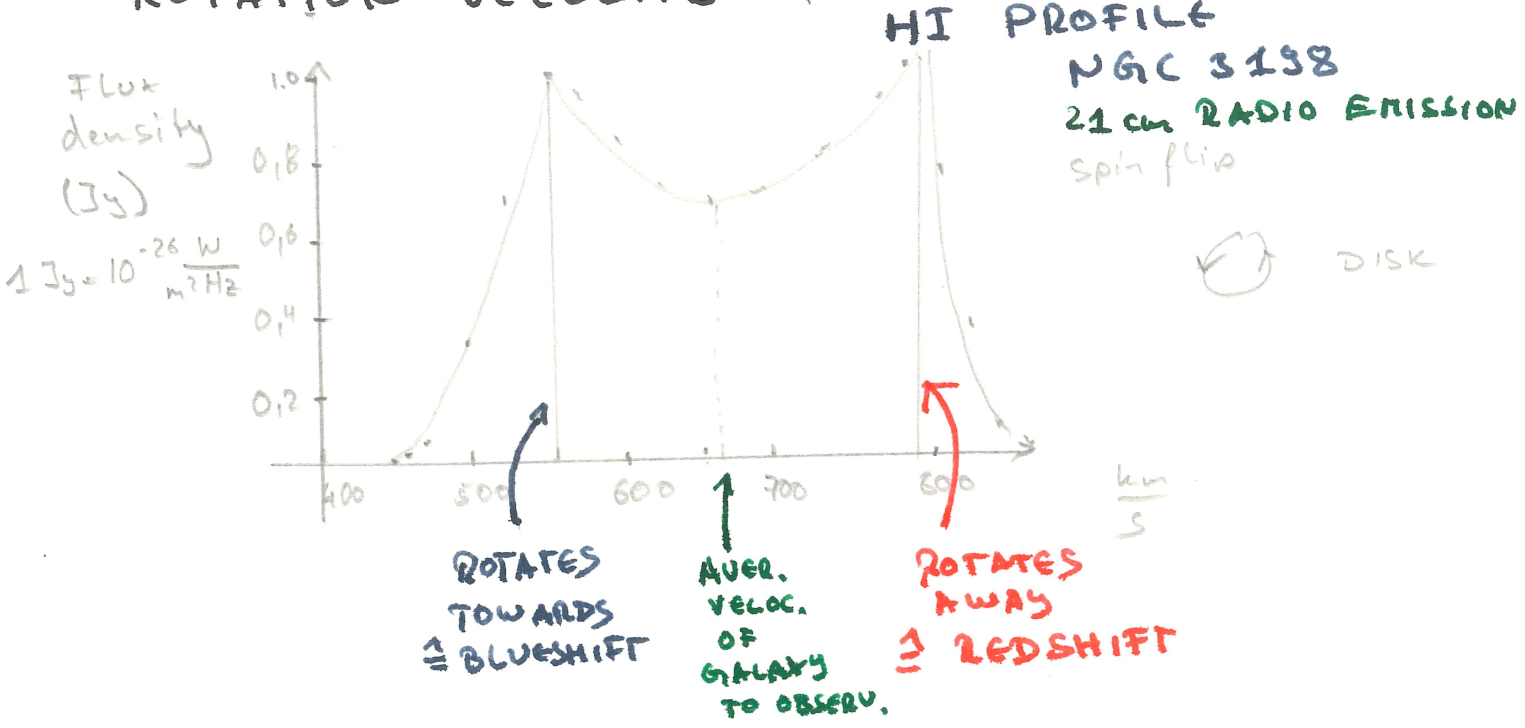
⇒ GRAVITATIONAL POTENTIAL DOES NOT FOLLOW LUMINOUS MATTER

IRREGULAR GALAXIES: $50 < V_{max} < 70 \frac{km}{s}$

MAYBE HIGH ROTATION SPEED REQUIRED FOR SPIRALS

TULLY-FISHER RELATION (1977)

RELATION BETWEEN LUMINOSITY OF SPIRAL GALAXY AND MAXIMUM ROTATION VELOCITY



$$\frac{\Delta\lambda}{\lambda_{rest}} \simeq \frac{v_r}{c} = \frac{V \sin i}{c}$$

i: INCLINATION OF LINE OF SIGHT AND DIRECTION ⊥ TO GALACTIC PLANE

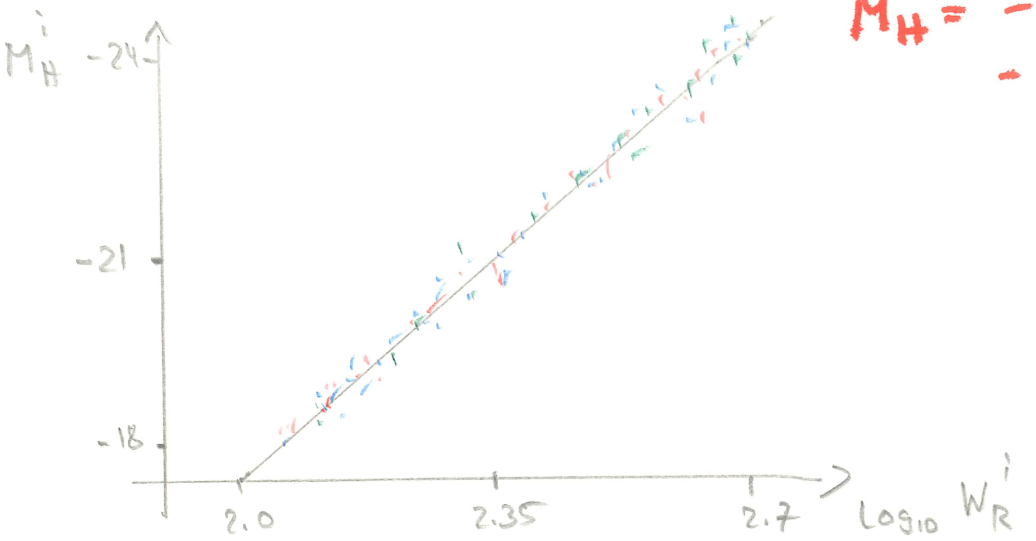
Sa: $M_B = -9.95 \log_{10} V_{max} + 3.15$

Sb: $M_B = -10.2 \log_{10} V_{max} + 2.17$

Sc: $M_B = -11.0 \log_{10} V_{max} + 3.31$

- BETTER MEASURED IN INFRARED H-BAND (1,66 μm)

$$M_H^i = -9{,}50\,(\log_{10} W_R^i - 2{,}5) - 21{,}67 \pm 0.08$$



$W_R^i = (W_{20} - W_{rand}) / \sin i$

W_{20}: ΔV (Blue – red) 20% OF PEAK

W_{rand}: Random velocity's

$$M = \frac{V_{max}^2 R}{G}$$

MASS-TO-LIGHT RATIO FOR SPIRALS:

$$\frac{M}{L} \equiv \frac{1}{C_{ML}}$$ (SAME FOR ALL SPIRALS)

$$\Rightarrow L = C_{ML} \frac{V_{max}^2 R}{G} \Rightarrow R = \frac{L G}{C_{ML} V_{max}^2}$$

ASSUME: ALL SPIRALS SAME SURFACE BRIGHTNESS AT CENTRE:

$$\frac{L}{R^2} \equiv C_{SB} \Rightarrow \frac{L\, C_{ML}^2\, V_{max}^4}{L^2 G^2} = C_{SB}$$

$$\Rightarrow L = \frac{C_{ML}^2}{C_{SB}} \frac{V_{max}^4}{G^2} = C\, V_{max}^4$$

$L \sim V_{max}^4$

ABSOLUT MAGNITUDE

$$M = M_{SUN} - 2{,}5 \log_{10}\left(\frac{L}{L_\odot}\right)$$

$$= M_{SUN} - 2{,}5 \log_{10} V_{max}^4 - 2{,}5 \log_{10} C + 2{,}5 \log_{10} L_\odot$$

$$= -10 \log_{10} V_{max} + \text{const.}$$

$\Rightarrow$ MEASURED : $\approx -9{,}5$

$\Rightarrow$ SPIRAL GALAXIES HAVE SIMILAR M/L RATIO AND ROUGHLY CONSTANT SURFACE BRIGHTNESS

($\Rightarrow$ DISTANCE TO SPIRAL GALAXY)