LECTURE III

CLOSED ORBITS IN NON INERTIAL FRAMES

- # OSCILLATIONS PER ORBIT ABOUT GAL. CENTRE $\hat{=}$ (epicycle frequency κ): (orbital angular speed Ω)

$$\frac{\kappa}{\Omega} = \text{INTEGER} \Rightarrow \text{CLOSED ORBIT}$$

MOST NOT CLOSED $\Rightarrow$ ROSETTE PATTERN

- REFERENCE FRAME ROTATING WITH LOCAL ANGULAR PATTERN SPEED: $\Omega_{Lp} = \Omega$

$\Rightarrow$ PATH OF STAR: CLOSED ORBIT, RETROGRADE CENTRED AT R_m

(COORDINATE SYSTEM OF EPICYCLE)

CLOSED ORBIT: STAR COMPLETES n ORBITS IN ROTATING FRAME WHILE EXECUTING m EPICYCLE OSCILLATION

(n, m): INTEGER

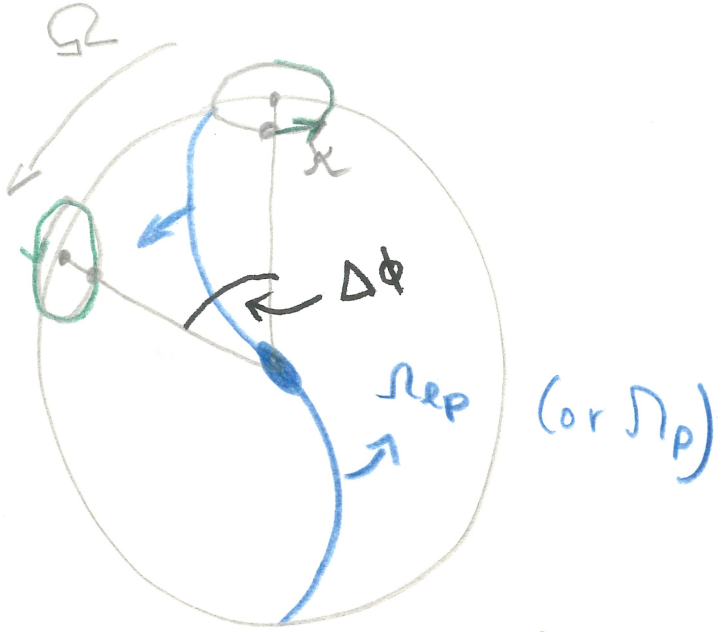
(REF. FRAME NOT LOCAL PATTERN)

i.e. $m(\Omega - \Omega_{Lp}) = n\kappa$

$$\Rightarrow \Omega_{Lp}(R) = \Omega(R) - \frac{n}{m}\kappa(R)$$

$\longrightarrow$ EXPLAIN

CONSIDER LIKE THIS



FOR ONE EPICYCLE: $T_r = \frac{2\pi}{\kappa}$

$\Rightarrow$ IN THIS TIME ANGLE CHANGES BY

$$\Delta\phi = \Omega \cdot T_r$$

IN THIS TIME (LOCAL) PATTERN MOVES BY

$$\phi_p = [\text{redacted}] = \Omega_{Lp} \cdot T_r$$

HENCE DIFFERENCE OF STAR TO LOCAL PATTERN:

$$\Delta\phi_p = \Delta\phi - \Omega_{Lp} \cdot T_r$$

ASSUME THAT THERE ARE m SPIRALS (equi distant)

CLOSED ~~PATTERN~~ ORBIT RELATIVE TO SPIRALS

$$m \cdot \Delta\phi_p = 2\pi n \qquad (n: \text{INTEGER})$$

$$\Rightarrow \Delta\phi_p = \frac{2\pi n}{m}$$

$$\Delta\phi - \Omega_{pp} \cdot T_r = \Omega \cdot T_r - \Omega_{pp} \cdot T_r$$

$$= \frac{2\pi n}{m}$$

$$\Leftrightarrow (\Omega - \Omega_{pp}) \cdot \frac{2\pi}{\kappa} = \frac{2\pi n}{m}$$

$$\Rightarrow \Omega_{pp}(R) = \Omega(R) - \frac{n}{m}\kappa(R)$$

↑ Local!

LARGE NUMBER OF STARS AT DIFFERENT DISTANCE

REFERENCE FROM ROTATING WITH GLOBAL PATTERN: Ω_{gp}

EXAMPLE $\Omega_{LP} \leftrightarrows R \Rightarrow \Omega_{gp} = \Omega_{LP}$

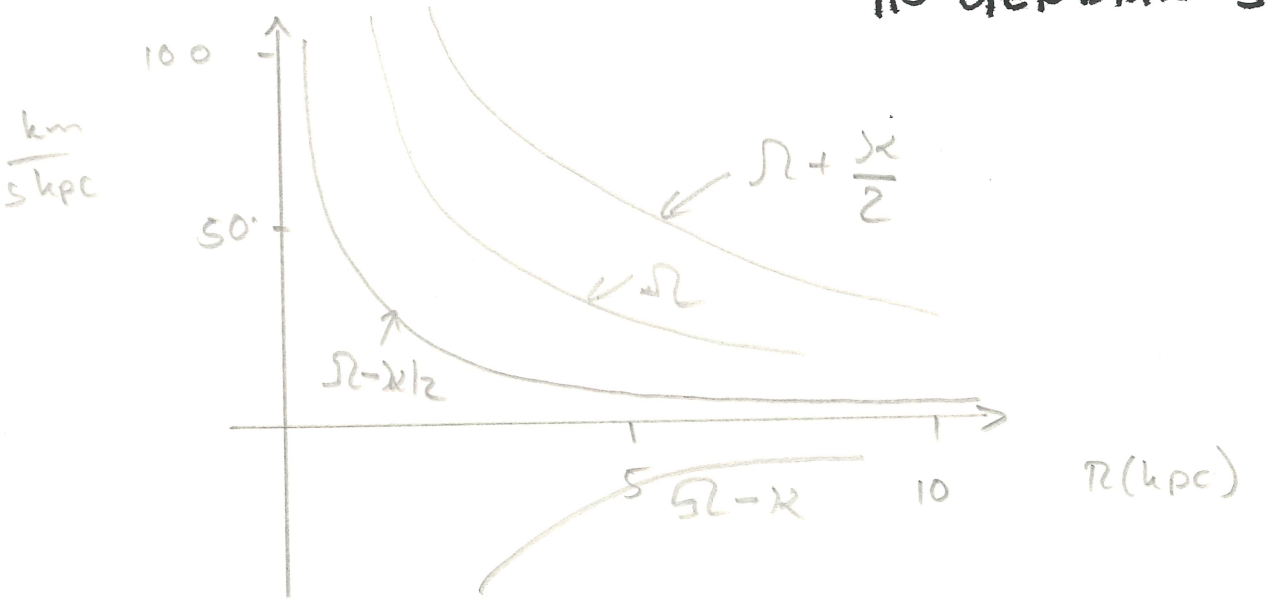
ORBITAL PATTERNS NESTED

SLIDE 22 BAR

ORIENTATION OF MAJOR AXIS ~~ROTATED~~

SLIDE 23 SPIRAL
SLIDE 24-25

MOST COMMON: PATTERNS WITH $m=2$
IN GENERAL $\Omega(R)$...



$\frac{n}{m} = \frac{1}{2}$: $\Omega - \frac{\kappa}{2}$: MOSTLY CONSTANT

⇒ EVEN FOR $\Omega(R)$

A RESONANCE CAN DEVELOP (NATURAL FREQUENCY)

⇒ AMPLIFICATION

INNER LINDBLAD RESONANCE:

$$\Omega_{gp} = \Omega - \frac{\kappa}{2}$$

OUTER LINDBLAD RESONANCE:

$$\Omega_{gp} = \Omega + \frac{\kappa}{2}$$

ELLIPTICAL GALAXIES

- FOR EARLY TYPE GALAXIES (ELLIPTICALS) HUBBLE TYPE DOES NOT CORRELATE WELL WITH PHYSICAL PROPERTIES
- ELLIPTICALS DIVERSE AND COMPLEX

MORPHOLOGICAL CLASSES OF ELLIPTICAL GALAXIES

× cD GALAXIES (central dominant)
- ALMOST 1 Mpc (M87) ← SLIDE EARLIER
- $M_B = -22 \ldots -25$ mag
- $10^{13} < M < 10^{14} M_\odot$
- CENTRAL REGIONS $\mu = 18 \frac{\text{B-mag}}{\text{arcsec}^2}$
- $\mathcal{O}(10^5)$ GLOBULAR CLUSTERS
- $\frac{M}{L} = 750 \frac{M_\odot}{L_\odot}$

× NORMAL ELLIPTICAL GALAXIES
- giant ellipticals (gE's)
- intermediate " (E's)
- compact " (cE's)
- $-15 < M_B < -23$
- $10^8 < M < 10^{13} M_\odot$
- P $1\text{kpc} < R < 200\text{kpc}$
- $7 \frac{M_\odot}{L_\odot} < \frac{M}{L} < 100 \frac{M_\odot}{L_\odot}$
- ~~1 - 10 globular clust~~

× DWARF ELLIPTICALS (dE's)

- $-13 < M_B < -19$
- $10^7 M_\odot < M < 10^9 M_\odot$
- $1\,kpc < R < 10\,kpc$

× DWARF SPHEROIDAL GALAXIES (dSph's)

- ONLY DETECTED IN VICINITY OF MILKY WAY
- $-8 < M_B < -15$
- $10^7 M_\odot < M < 10^8 M_\odot$
- $0,1 < 2R < 0,5\,kpc$

× BLUE COMPACT DWARF GALAXIES (BCD's)

- SMALL, UNUSUALLY BLUE $(M_B - M_V)$
  $\langle B-V \rangle = 0.0 - 0.3$
  (SPECTRAL CLASS 'A' STAR)
  ↳ STRONG STAR FORMATION
- $-14 < M_B < -17$
- $M \sim \mathcal{O}(10^9) M_\odot$
- $2R < 3\,kpc$
- A LOT OF GAS: $M_{HI} = 10^8 M_\odot$, $M_{HII} = 10^6 M_\odot$
- $\frac{M}{L} < 0.1 \frac{M_\odot}{L_\odot}$

SURFACE BRIGHTNESS PROFILES

- cD's + NORMAL ELLIPTICALS : $r^{1/4}$
- FOR LOWER MASSES EXPONENTIAL PROFILE,

$$\mu(r) = \mu_0 + 1.09\left(\frac{r}{h_r}\right)$$

(IN PARTICULAR dE's ; dSph's)

- DUST AND GAS, MUCH LESS THAN IN SPIRALS

FABER-JACKSON RELATION

- GENERAL RELATION FOR ALL dE's ; dSph's AND NORMAL E's (AS WELL AS BULGES OF SPIRALS)

FROM TULLY-FISHER RELATION DERIVATION

$$L \propto \sigma_0^4$$

↑ CENTRAL VALUE OF σ_r

$$\Rightarrow \log_{10} \sigma_0 = -0.1\, M_B + \text{const.}$$

SLIDE 28

FUNDAMENTAL PLANE

- SCATTER IN DATA !
- DEPENDING ON SAMPLE:

$$L \propto \sigma_0^{\alpha} \quad \text{WITH} \quad 3 < \alpha < 5$$

WITH EFFECTIVE RADIUS:

$$L \propto \sigma_0^{2,65} \, r_e^{0,65}$$

GALAXIES ON SURFACE IN 3-D PARAMETER SPACE (L, σ_0, r_e)

↳ FUNDAMENTAL PLANE

ALSO: $r_e \propto \sigma_0^{1.24} \, I_e^{-0.82}$

REPRESENTS WHOLE FAMILY OF ELLIPTICAL GALAXIES!

EFFECTS OF ROTATION

- ELLIPTICALS TYPICALLY TRIAXIAL (NOT PURE OBLATE OR PROLATE)
- MEASURE ROTATIONAL VELOCITY: V_{ROT}

$V_{ROT} \ll \sigma$

FOR MORE LUMINOUS

$\Rightarrow$ SHAPE CAUSED BY ANISOTROPIC VELOCITY DISPERSION

NGC 1600 ($M_B = -22.87$): $V_{ROT} = 1.9 \pm 2.3 \frac{km}{s}$

$$\frac{V_{rot}}{\sigma} < 0.013$$

SLIDE 29

IF ELLIPTICITY FROM IDEAL OBLATE ROTATOR WITH ISOTROPIC STELLAR VELOCITIES

$$\left(\frac{V_{rot}}{\sigma}\right)_{ISOTROPIC} \approx \sqrt{\frac{\epsilon}{1-\epsilon}}$$

NGC 1600: $\epsilon = 0.4 \Rightarrow \frac{V_{rot}}{\sigma} \approx 0.8$

DEFINE $\left(\frac{V}{\sigma}\right)^* \equiv \frac{(V_{rot}/\sigma)_{obs}}{(V_{rot}/\sigma)_{isotropic}}$

$\Rightarrow (V/\sigma)^* < 0.016$ FOR NGC 1600

ROTATIONALLY SUPPORTED GALAXIES: $(V/\sigma)^* > 0.7$

BRIGHT E's ; gE's $(V/\sigma)^* \approx 0.4$

PRESSURE SUPPORTED

(SHAPE DUE TO RANDOM MOTION)

- FOR $-20.5 < M_B < -18$

$$\left(\frac{V}{\sigma}\right)^* \gtrsim 0.9$$ ROT. SUPPORTED (CE's)

(BULGES OF SPIRALS ROT. SUPPORTED)

BOXINESS - DISKINESS

1988: BENDER, NIETO

SHAPE OF ISOPHOTAL CONTOUR:

$$a(\theta) = a_0 + a_2 \cos(2\theta) + a_4 \cos(4\theta)$$

(FOURIER)

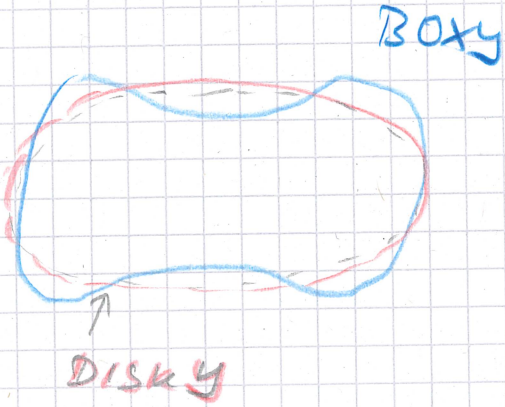
a: RADIUS OF CONTOUR

θ: ANGLE TO MAJOR AXIS

a_0: PERFECT CIRCLE

$a_4 < 0$: BOXY

$a_4 > 0$: DISKY



TYPICALLY: $\left|\frac{a_4}{a_0}\right| \sim 0.01$

- DISKY GALAXIES ROTATIONALLY SUPPORTED
- BOXY " PRESSURE "

RELATIVE NUMBER OF GALAXY TYPES

LUMINOSITY FUNCTION

$$\phi(M)\,dM$$

NUMBER OF GALAXIES WITH MAGNITUDES BETWEEN M AND M+dM

SLIDE 30

SCHECHTER: $\Phi(L)\,dL \sim L^{\alpha} e^{-L/L^*} dL$

$$\Leftrightarrow \phi(M)\,dM \sim 10^{-0.4(\alpha+1)M} e^{-10^{0.4(M^*-M)}} dM$$

α, L^* (M^*) FREE PARAMETERS

$\alpha = -1{,}0$; $M_B^* = -21$ (LOCAL)

$\alpha = -1{,}24 \pm 0.02$; $M_B^* = -21 \pm 0.7$ (VIRGO)

DEPENDING ON ENVIRONMENT

VIRGO: 12% E's, 26% SO, 62% S+Ir

COMA: 44% E's, 48% SO, 7% S+Ir

ENVIRONMENT IMPORTANT