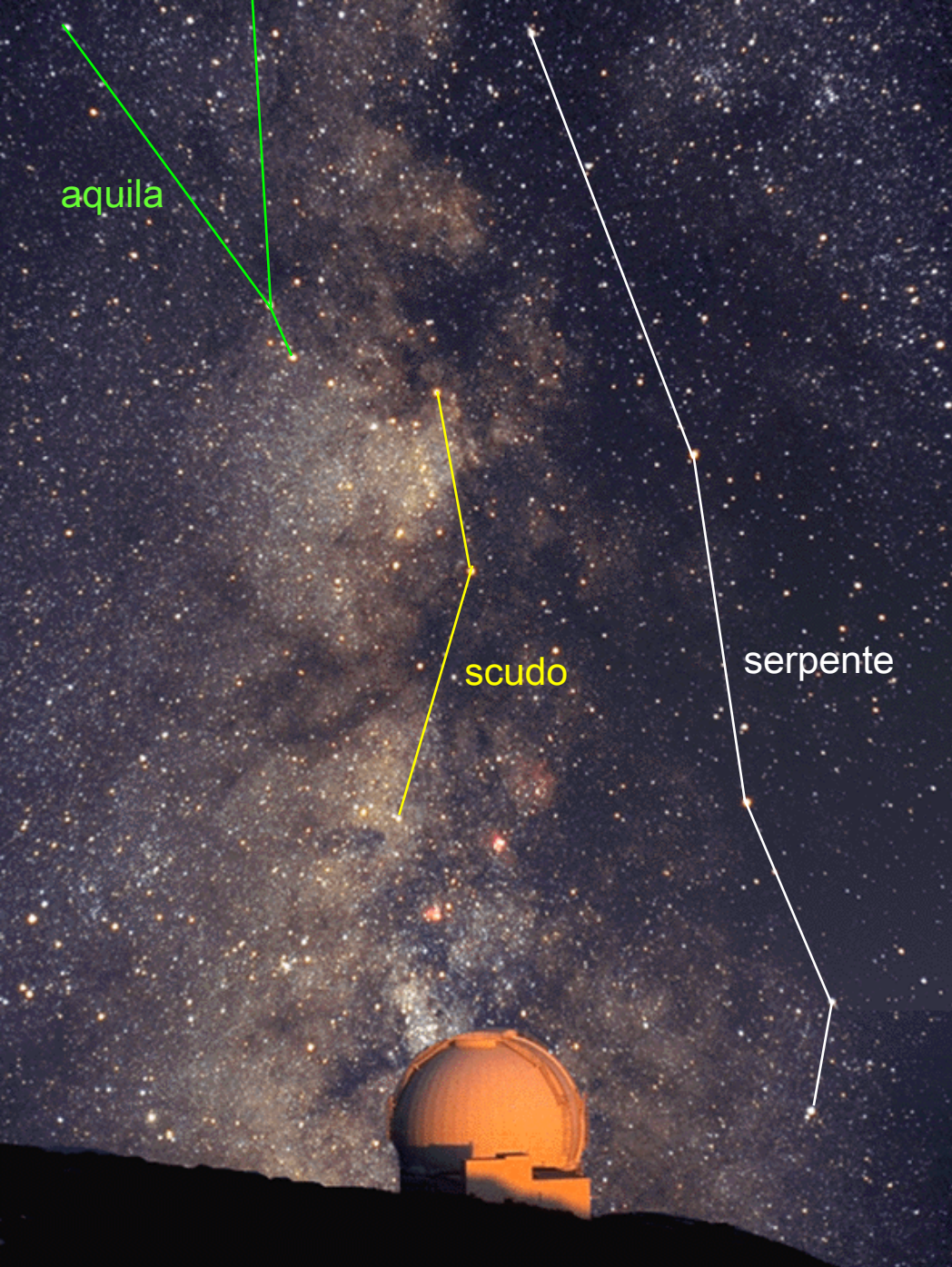
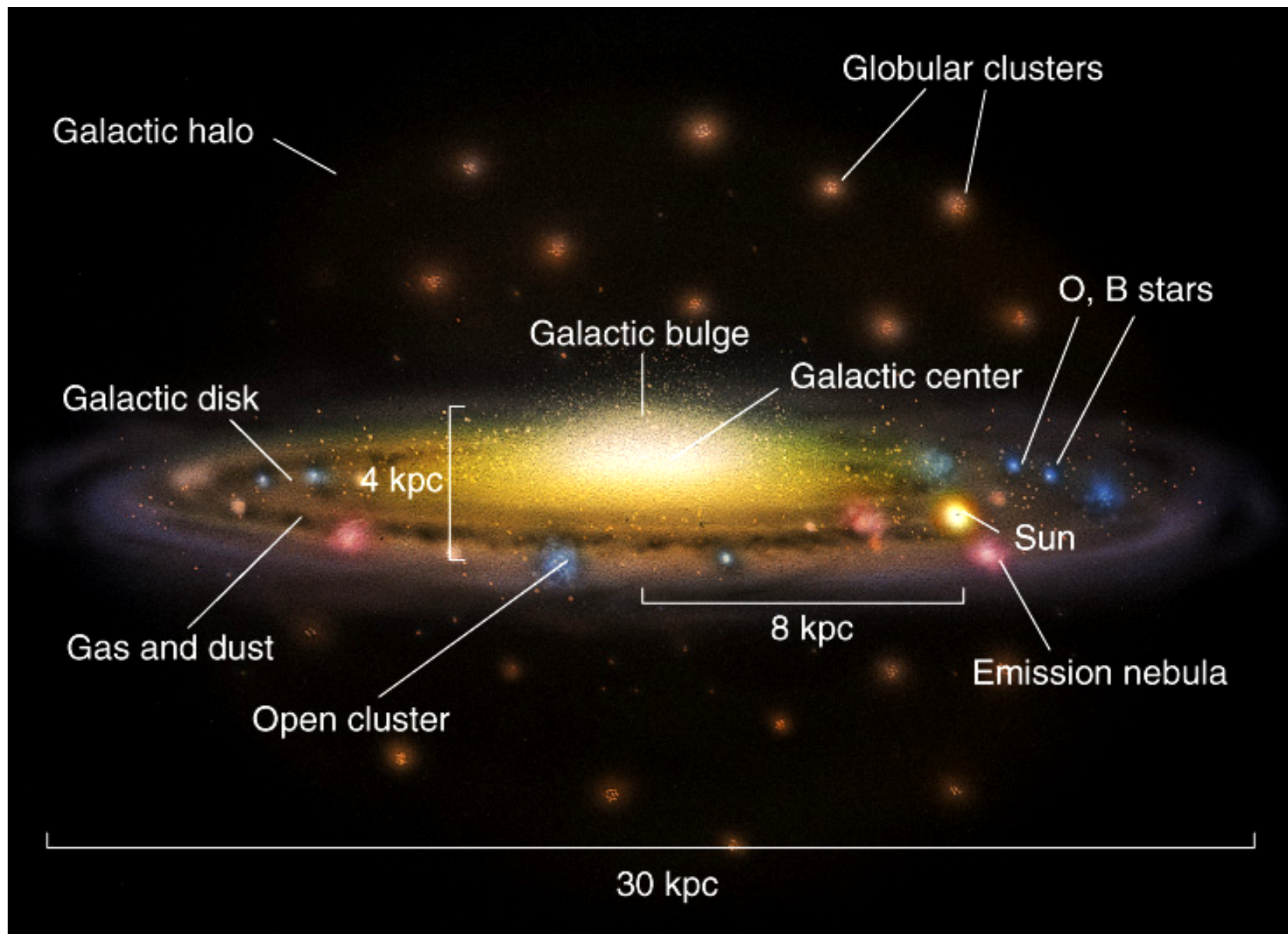




Le galassie

La Via Lattea





Via Lattea – Scheda

Luminosità $\sim 2 \times 10^{10} L_{\odot}$

Massa $\sim 2 \div 6 \times 10^{11} M_{\odot}$

$\varnothing$ disco $\sim 10^5$ anni-luce

$h_{\odot}$ disco $\sim 10^3$ anni-luce

No. di stelle $\sim 4 \times 10^{11}$

Densità media di stelle $\sim 1 \star$ per 125 anni-luce³

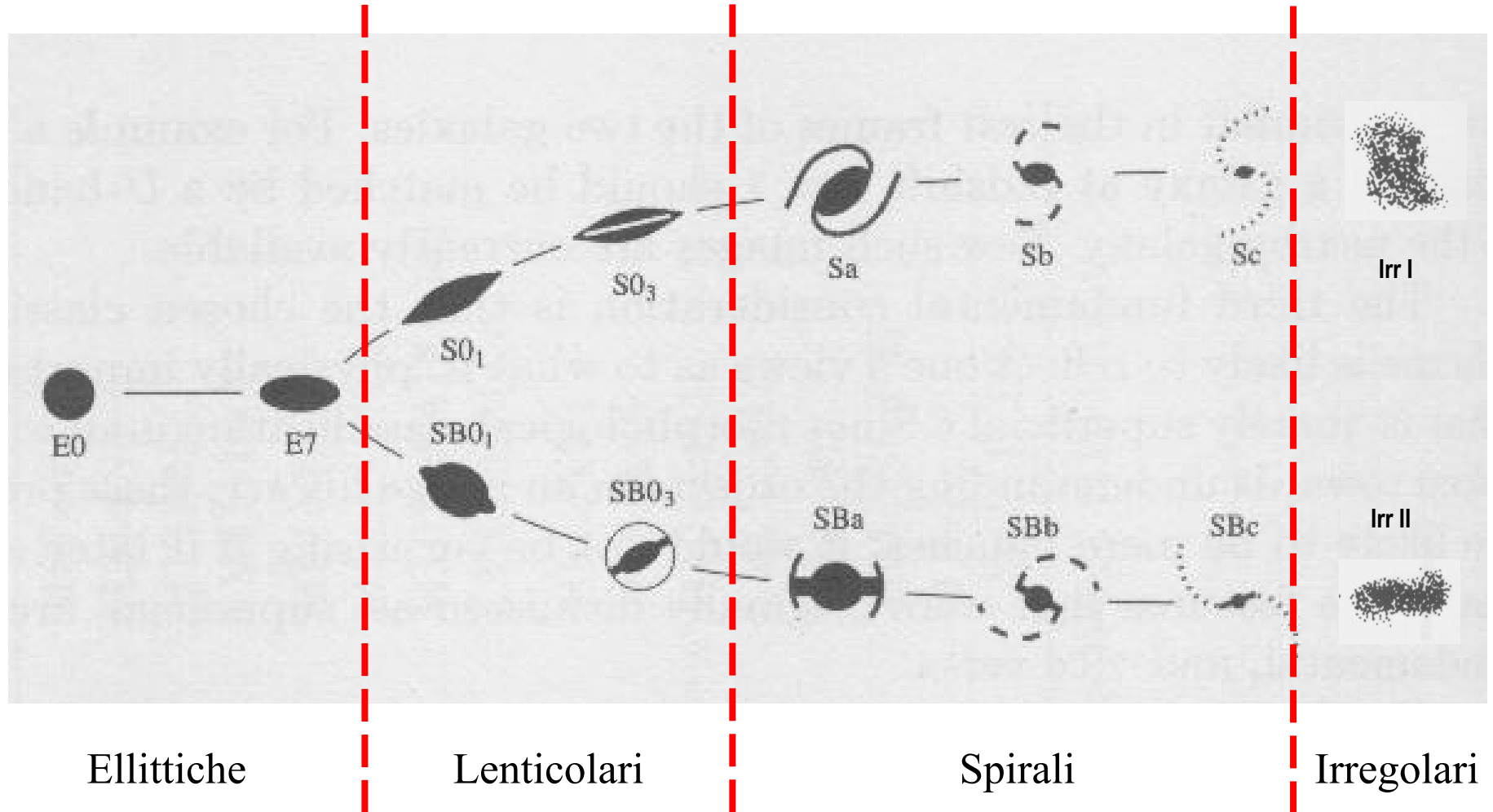
Separazione media fra stelle ~ 5 anni-luce

La stella più vicina al Sole, Proxima Centauri, si trova a ~ 4.3 anni-luce

Classificazione morfologica



Diagramma di Hubble

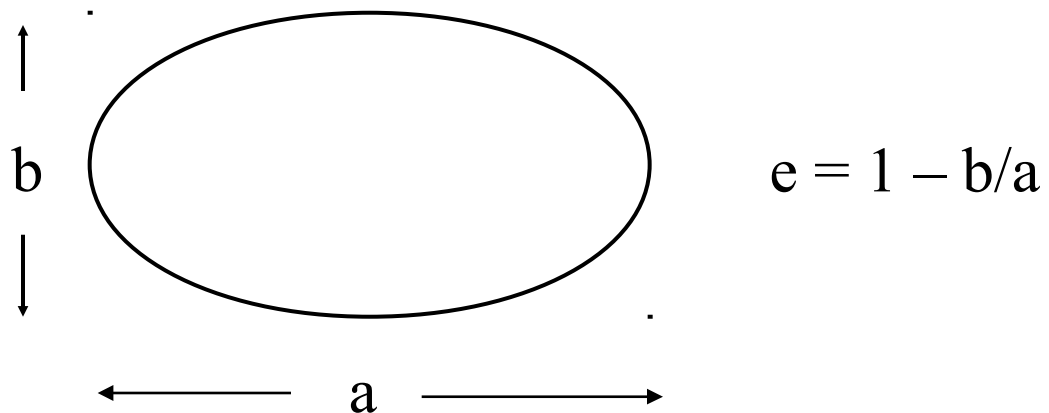


Galassie ellittiche

- Forma (apparente) ellittica
- Struttura diffusa con poca evidenza di gas e polveri
- I sottotipi sono definiti sulla base dello schiacciamento apparente (ellitticità, e)

E_n , $n=0,1,\dots,7$

con $n = 10e = 10(1-b/a)$

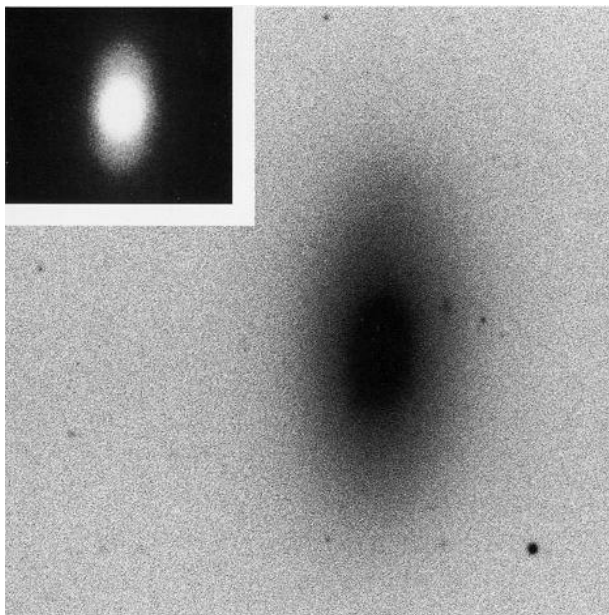




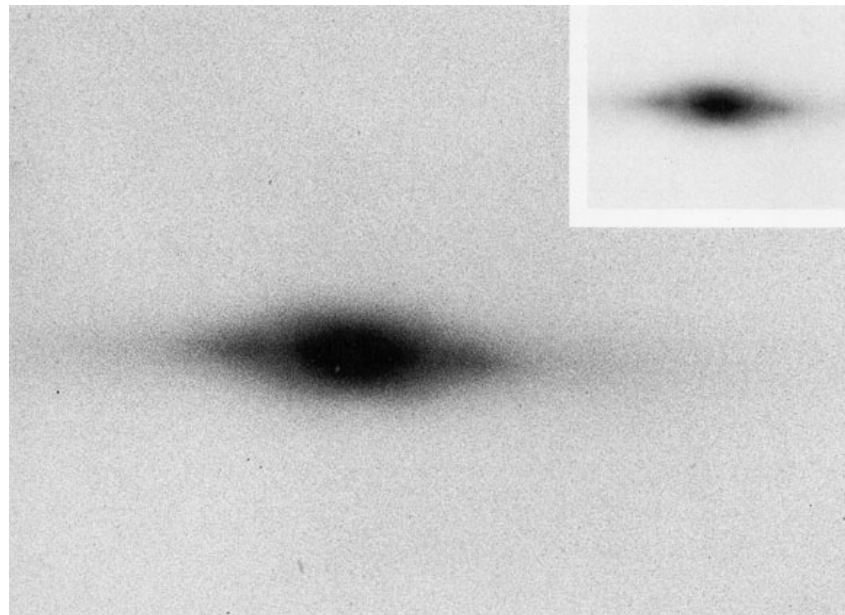
b/a	1	0.7	0.5	0.3
1-b/a	0	0.3	0.5	0.7
tipo	E0	E3	E5	E7

Galassie lenticolari

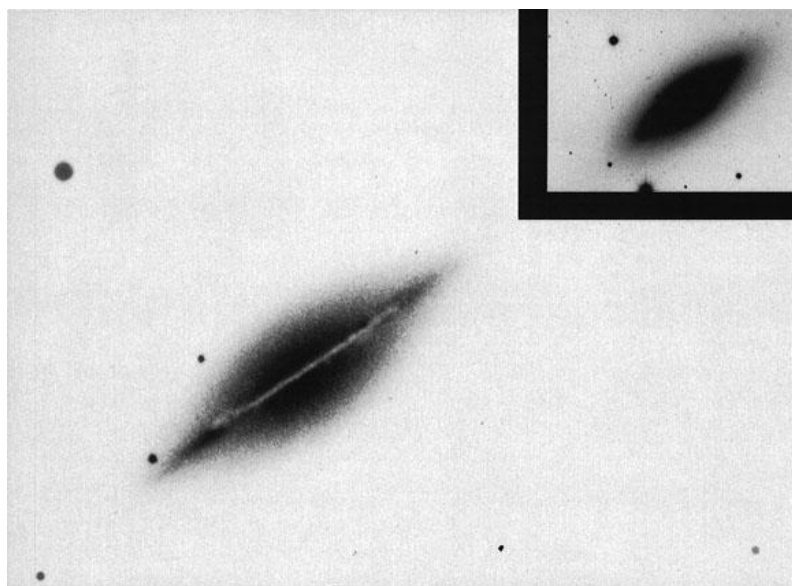
- Due componenti: **sferoide** centrale (**bulge**) e **disco** senza evidenza di bracci di spirale
- Due sottoclassi: **normali** (S0) e **barrate** (SB0)
- I sottotipi S0₁, S0₂, S0₃ sono definiti dalla prominenza delle polveri nel disco
- I sottotipi SB0₁, SB0₂, SB0₃ sono definiti dalla prominenza delle polveri e della barra



NGC 3245 S0₁



NGC 4111 S0₂



NGC 5866 S0₃

Galassie a spirale

- Due componenti: **sferoide** centrale (bulge) e **disco** caratterizzato dalla presenza dei **bracci di spirale**
- Due sottoclassi: **normali** (S) e **barrate** (SB)
- I sottotipi Sa, Sb, Sc sono definiti da tre criteri:
 - prominenza del bulge rispetto al disco
 - avvolgimento/apertura dei bracci a spirale
 - risoluzione del disco in stelle, nodi, regioni HII

Galassie “di taglio” (= molto inclinate)



Sa

- Bulge molto prominente



Sc

- Bulge poco prominente/assente

Galassie “di faccia” (= poco inclinate)



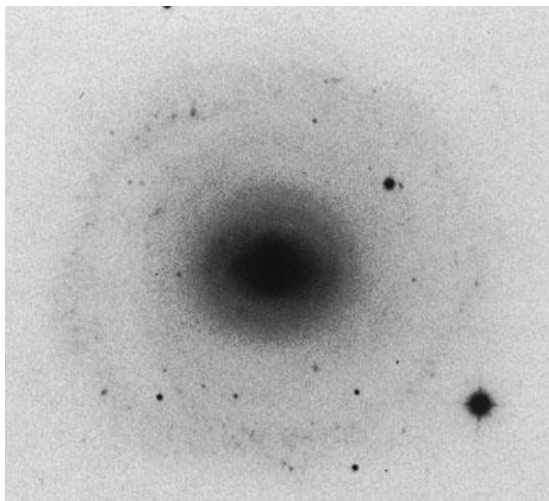
Sa

- Bulge molto prominente
- Bracci molto avvolti
- Bracci poco risolti

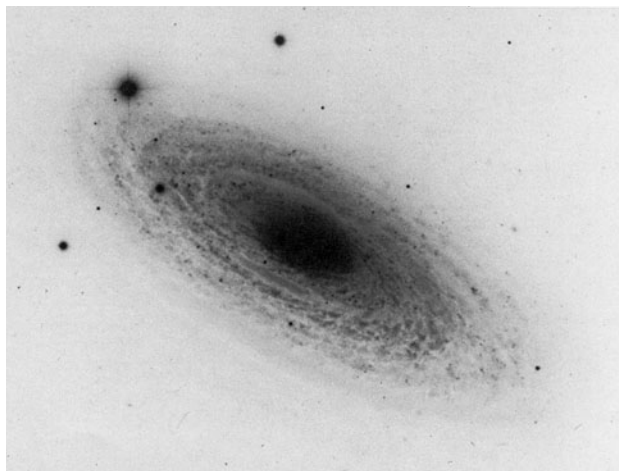


Sc

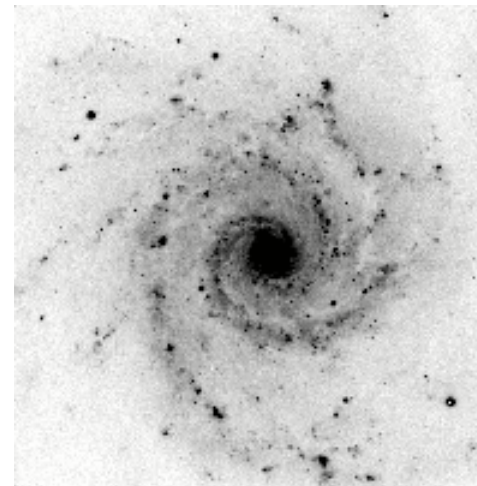
- Bulge poco prominente
- Bracci poco avvolti
- Bracci molto risolti



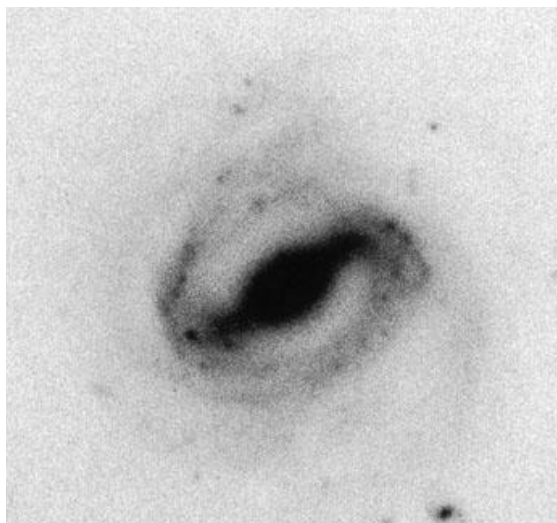
NGC 1302 Sa



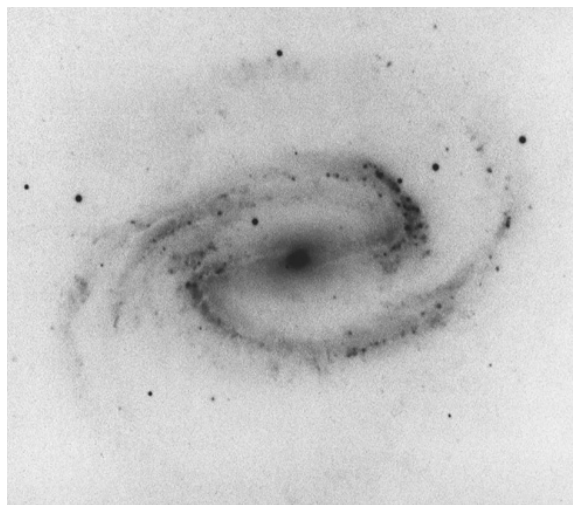
NGC 2841 Sb



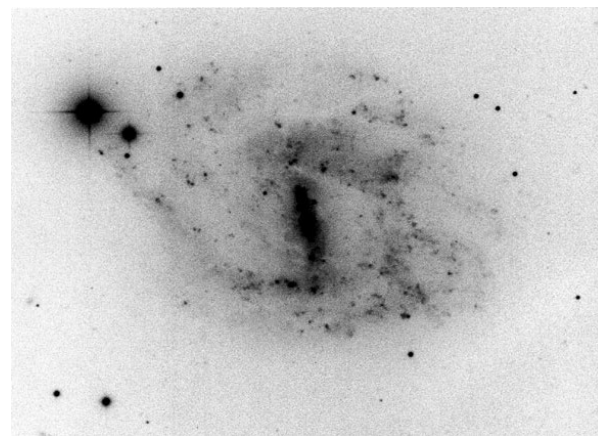
NGC 628 Sc



NGC 175 SBa



NGC 1300 SBb

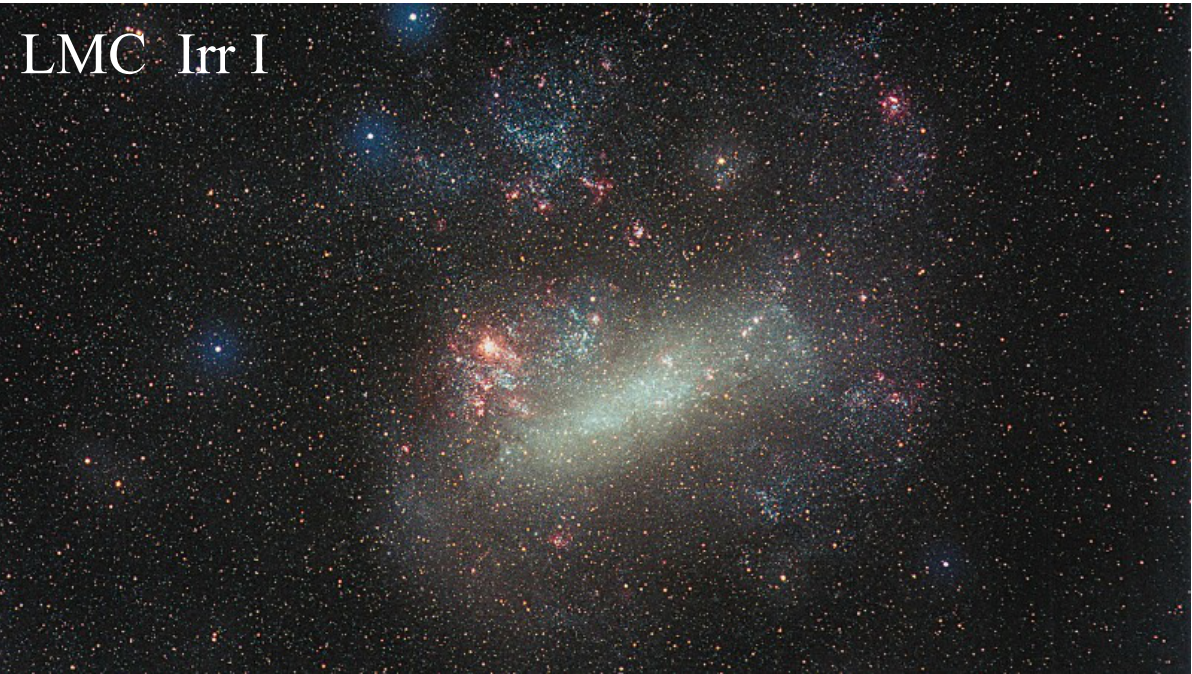


NGC 7741 SBc

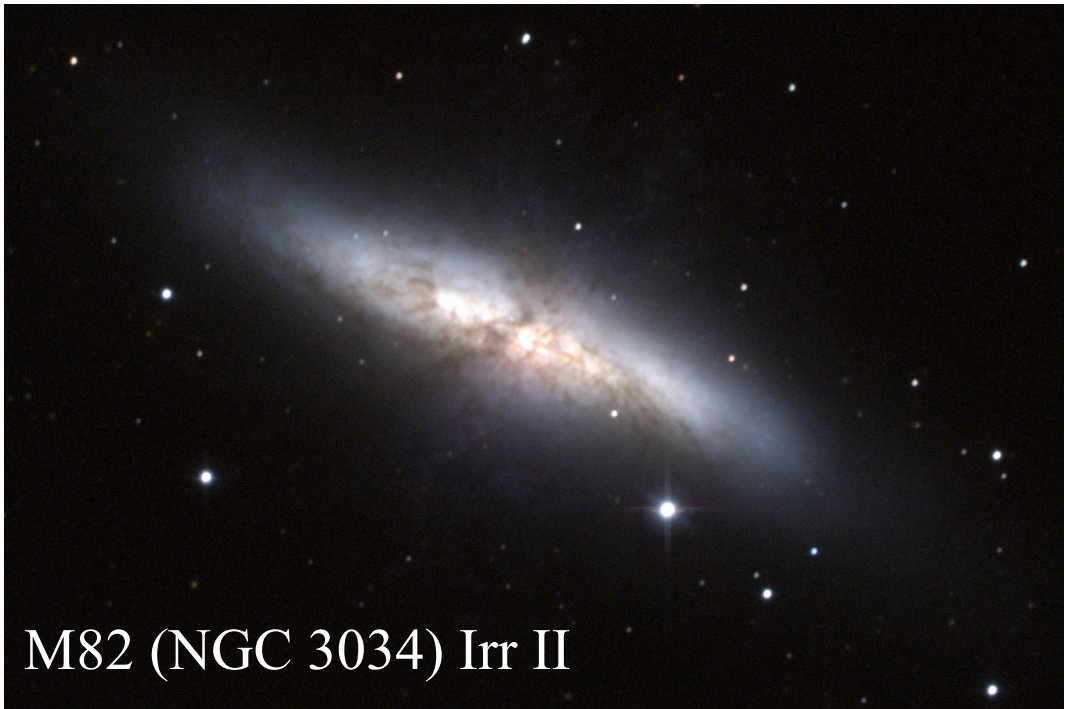
Galassie irregolari

- Poca o nessuna simmetria
- Due sottoclassi: **tipo I** (Irr I) e **tipo II** (Irr II)
 - Irr I: fortemente risolte in stelle (a.e. LMC)
 - Irr II: caotiche e disturbate (a.e. M82)

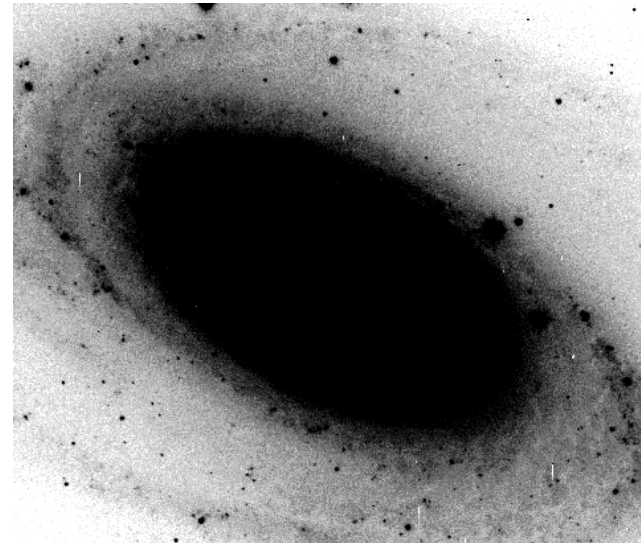
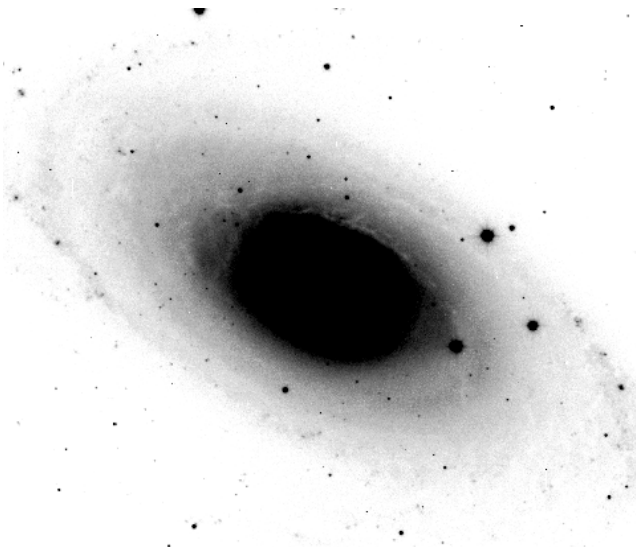
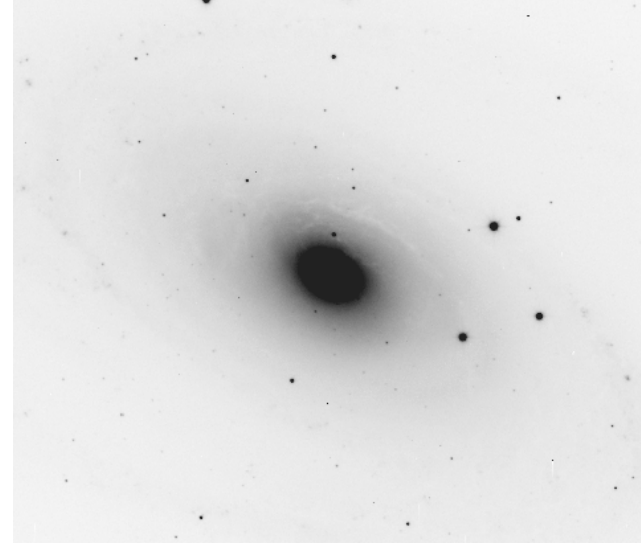
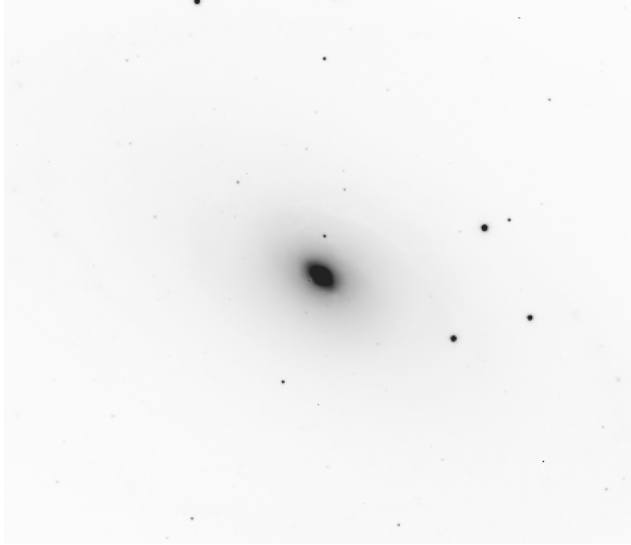
LMC Irr I



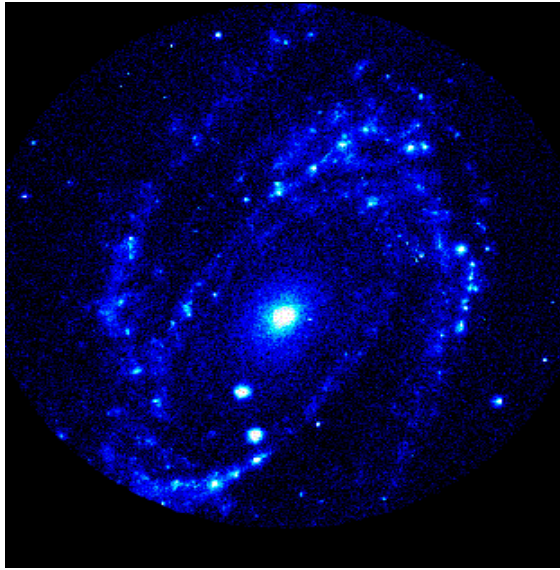
M82 (NGC 3034) Irr II



Limiti delle classificazioni morfologiche



Limiti delle classificazioni morfologiche



UV

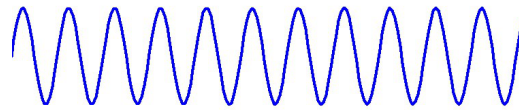


Visibile

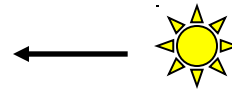


IR

Effetto Doppler



$$\nu > \nu_0$$



$$\nu < 0$$



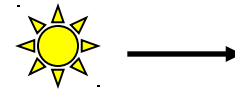
$$\nu = \nu_0$$



$$\nu = 0$$



$$\nu < \nu_0$$



$$\nu > 0$$

$$\nu = \frac{\nu_0}{1 + \frac{v}{c}}$$

Redshift

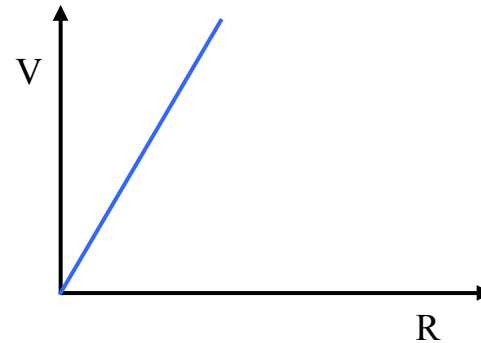
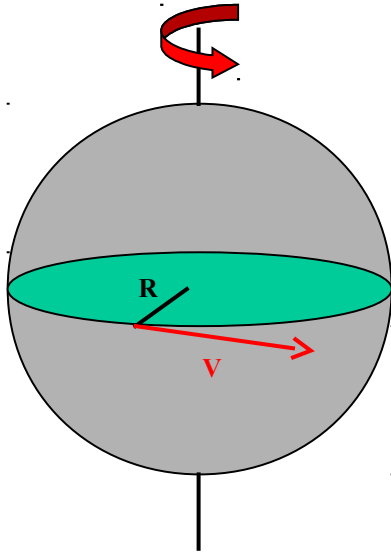
$$\frac{c}{\lambda} = \frac{\frac{c}{\lambda_0}}{1 + \frac{v}{c}} \Rightarrow \lambda = \lambda_0 \left(1 + \frac{v}{c} \right) \Rightarrow \boxed{z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{v}{c}}$$

$v \ll c$

Quando invece $v \leq c$:

$$z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{\sqrt{1 + \frac{v}{c}}}{\sqrt{1 - \frac{v}{c}}} - 1$$

Rotazione rigida o di corpo solido



$$V = \omega R \Rightarrow V \propto R$$

Rotazione kepleriana

3^a Legge di Keplero

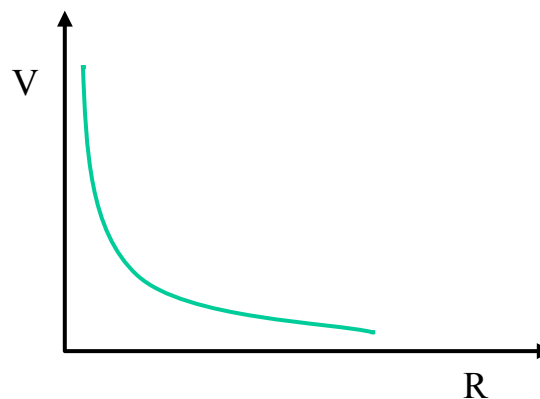
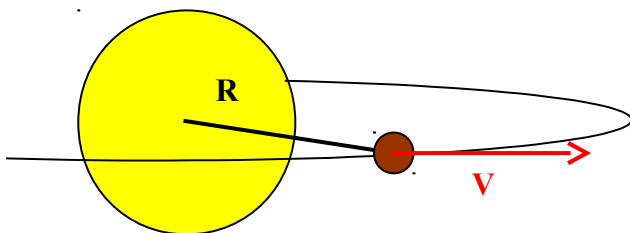
$$\frac{R^3}{T^2} = k$$

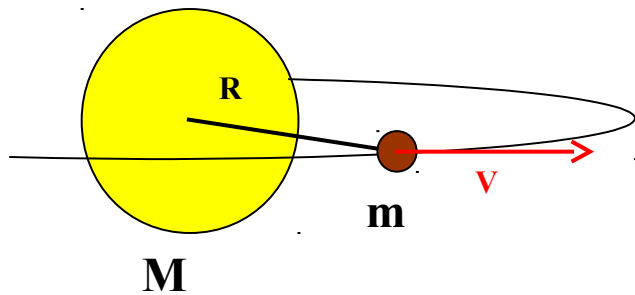


$$\left(\frac{R}{T}\right)^2 R = k$$

$$V^2 R = k$$

$$V \propto R^{-1/2}$$





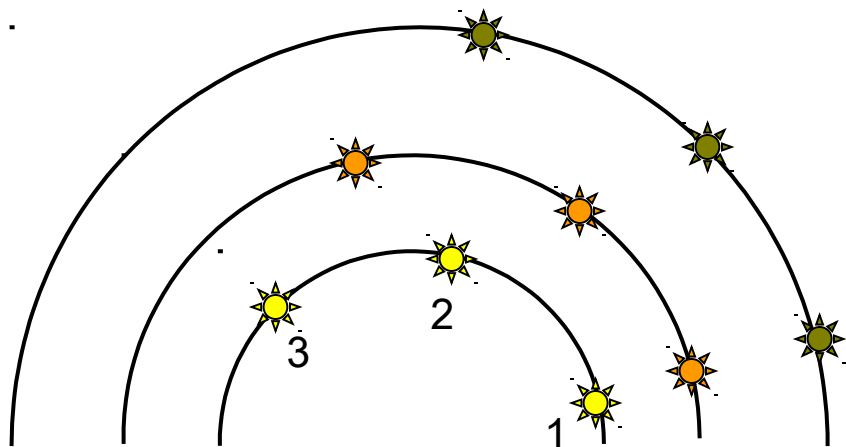
$$F_g = F_c$$

$$G \frac{Mm}{R^2} = m \frac{V^2}{R}$$



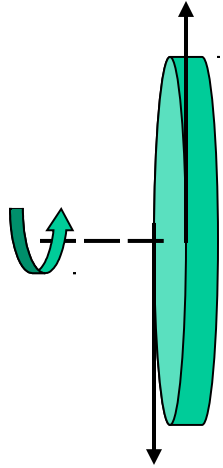
$$M = \frac{R V^2}{G}$$

$$G = 6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$$

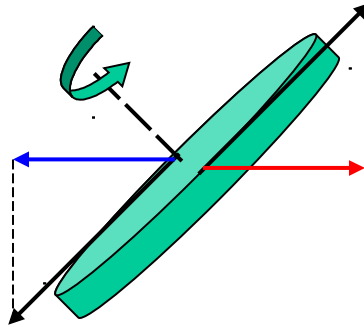


Rotazione differenziale

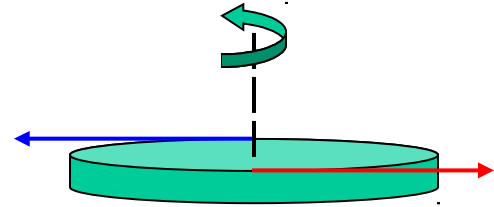
Effetto di inclinazione



$$i = 0^\circ$$



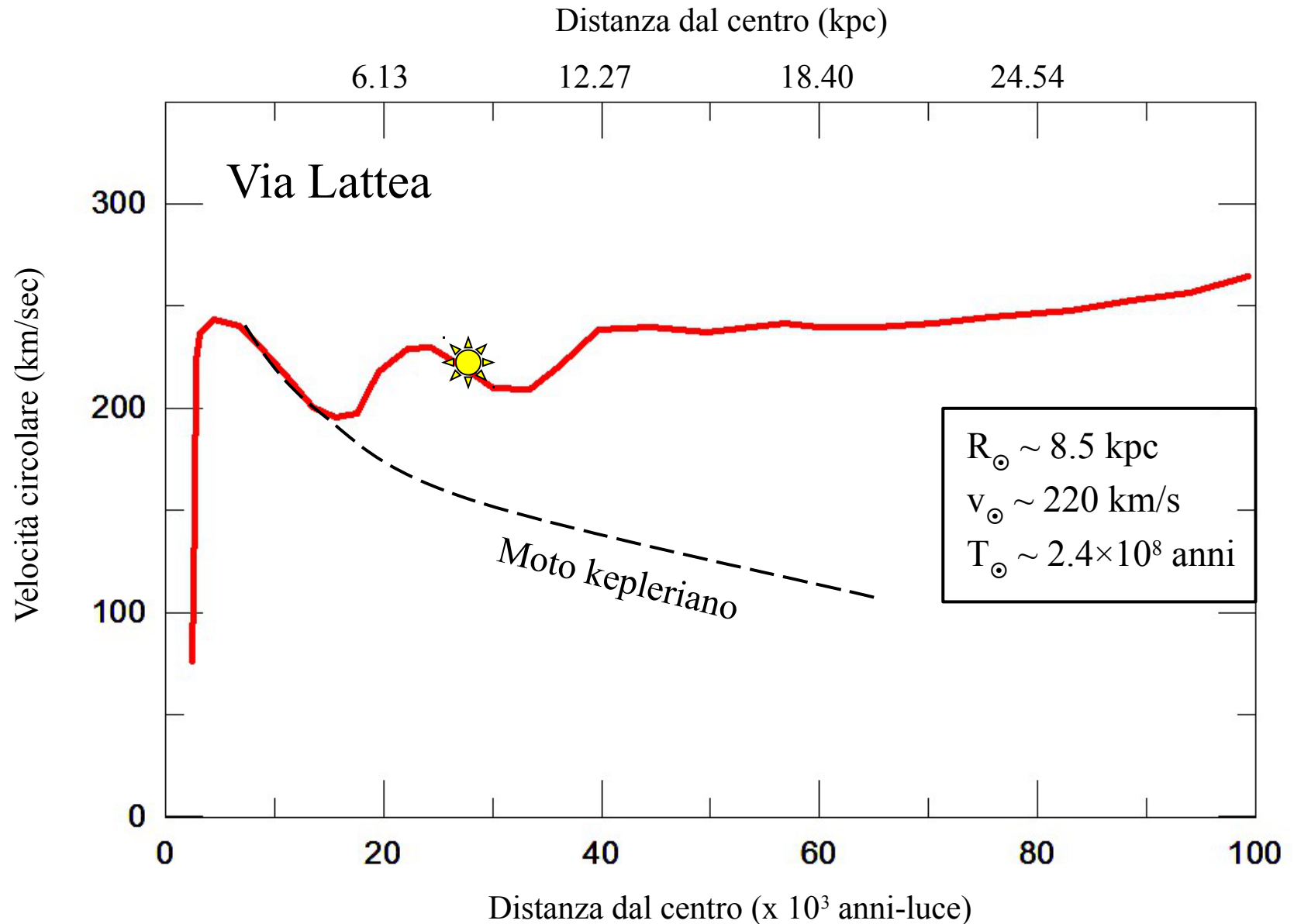
$$i = 45^\circ$$

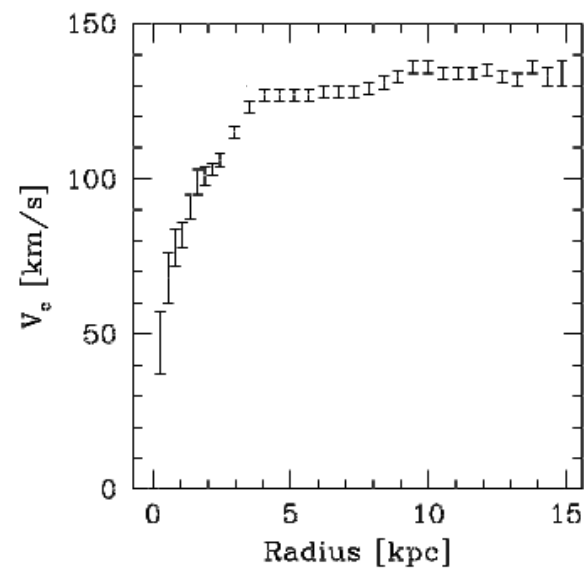
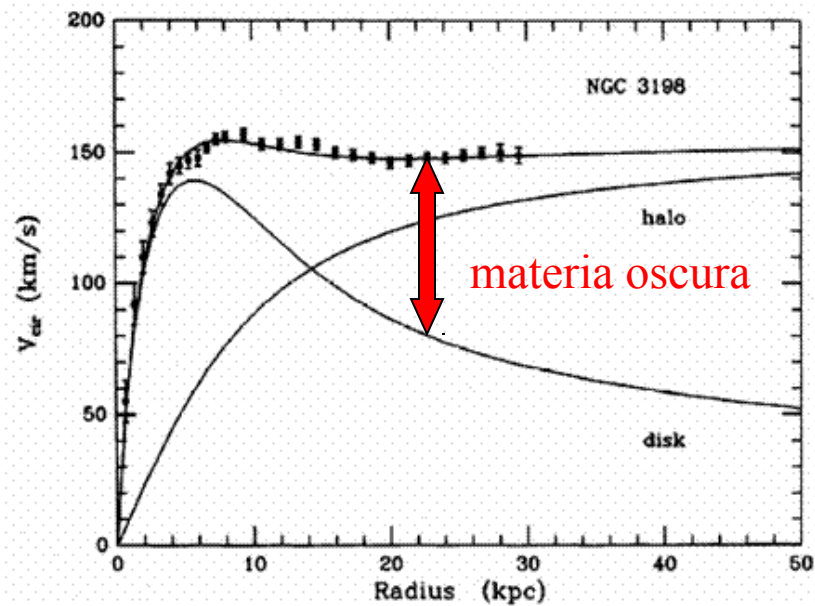
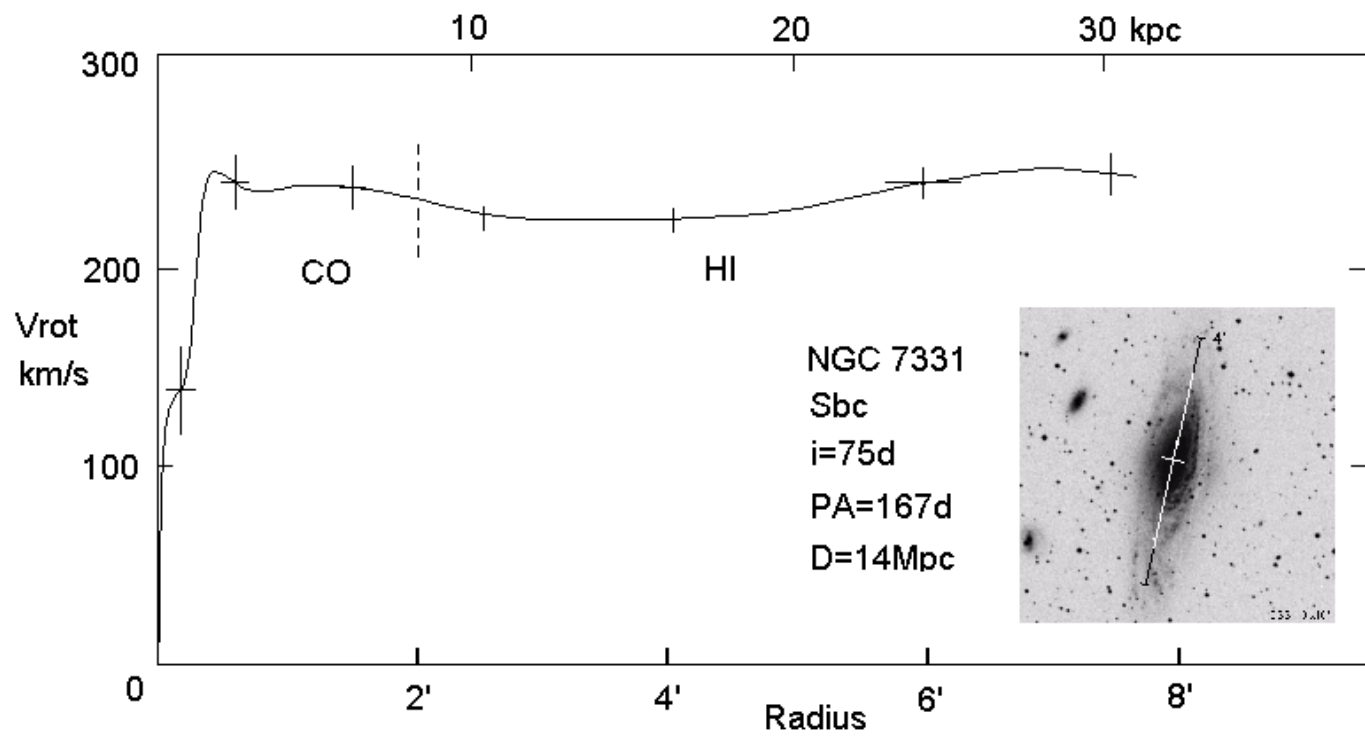


$$i = 90^\circ$$

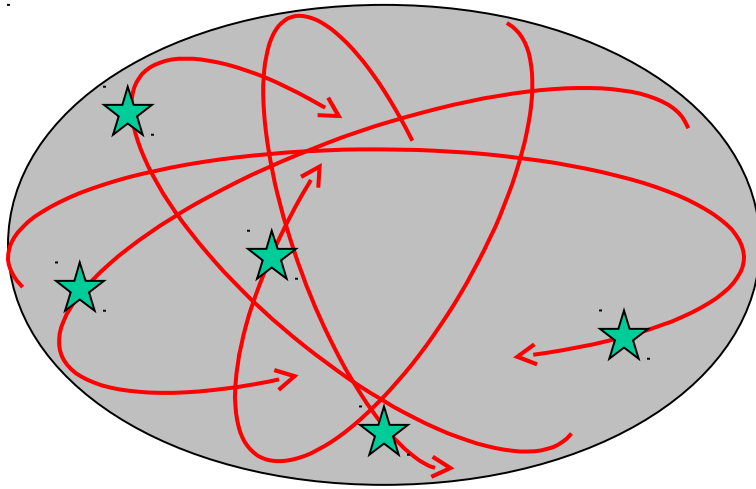
$$v_{\text{oss}} = v \sin i$$

Cinematica delle spirali





Cinematica delle ellittiche



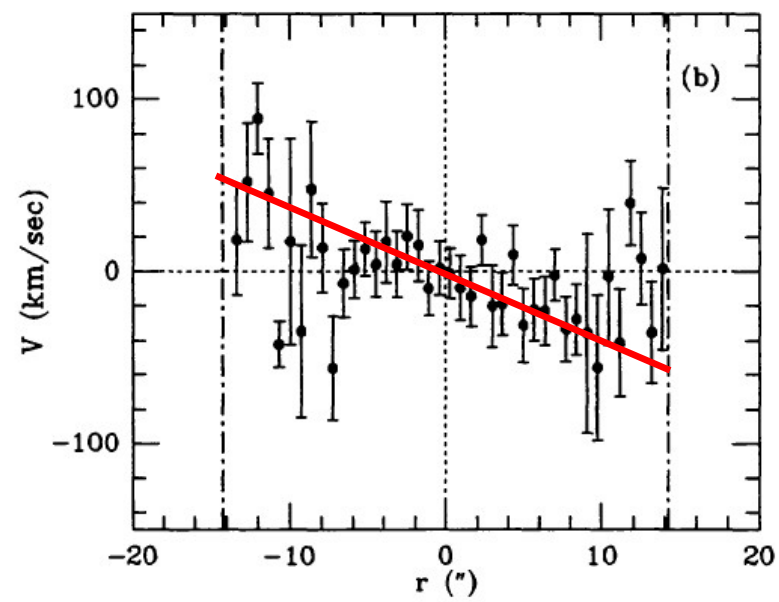
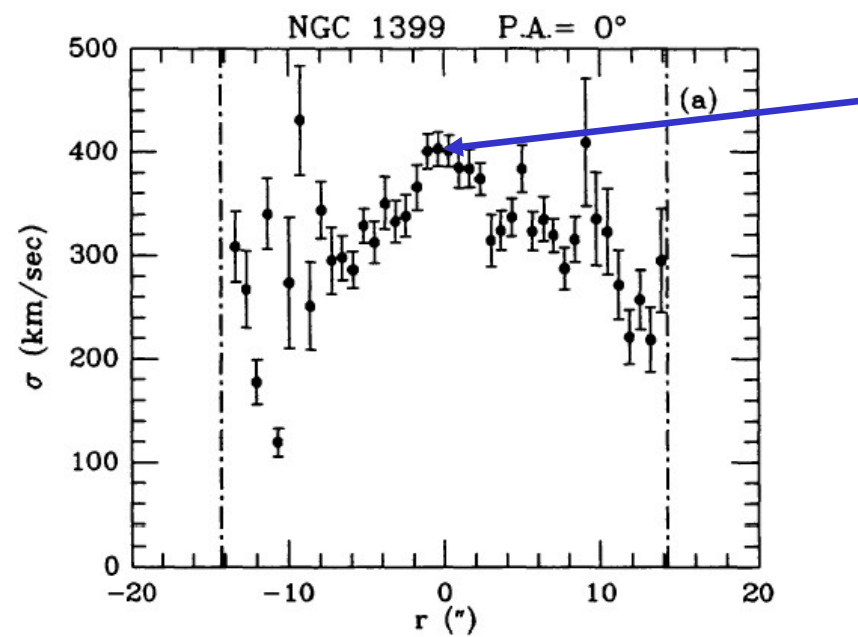
Velocità media

$$\bar{v} = \frac{\sum_{i=1}^N v_i}{N}$$

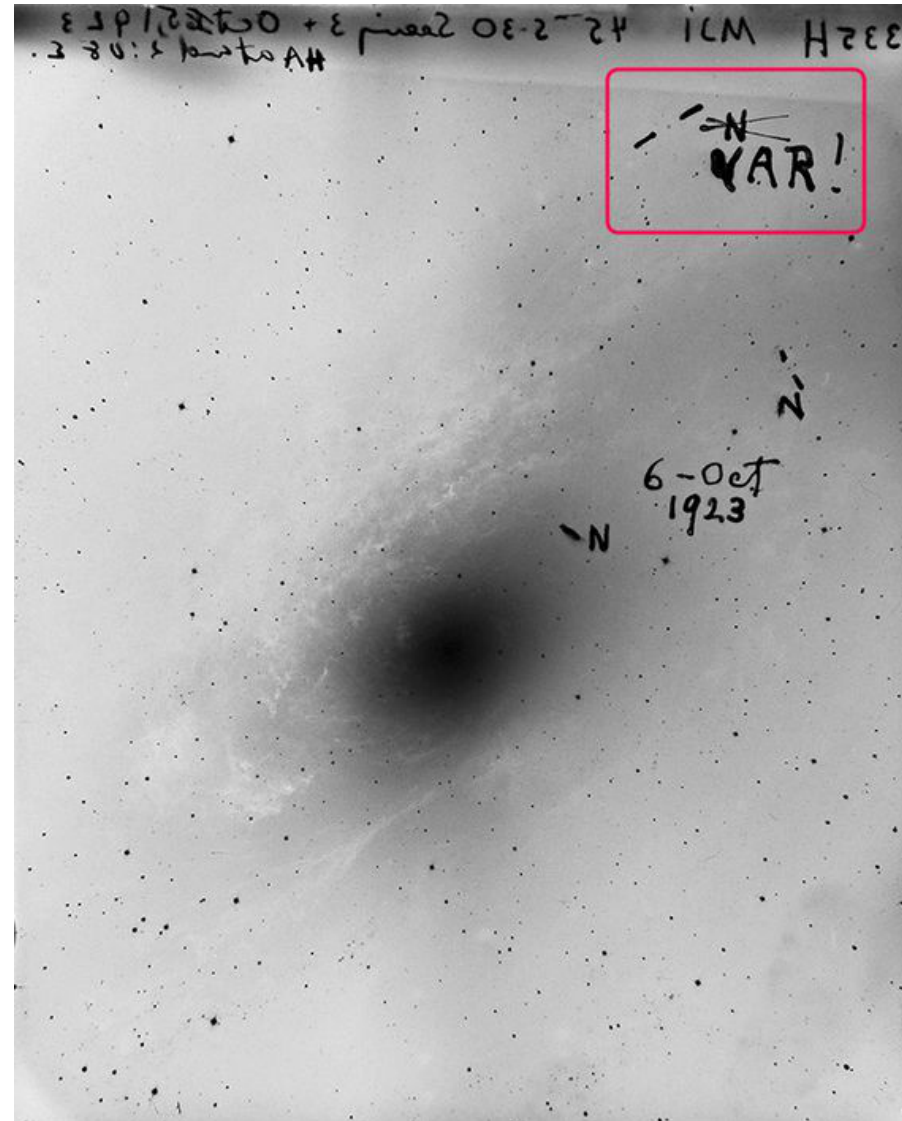


Dispersione di velocità

$$\sigma = \sqrt{\frac{\sum_{i=1}^N (v_i - \bar{v})^2}{N-1}}$$



Distanza delle galassie



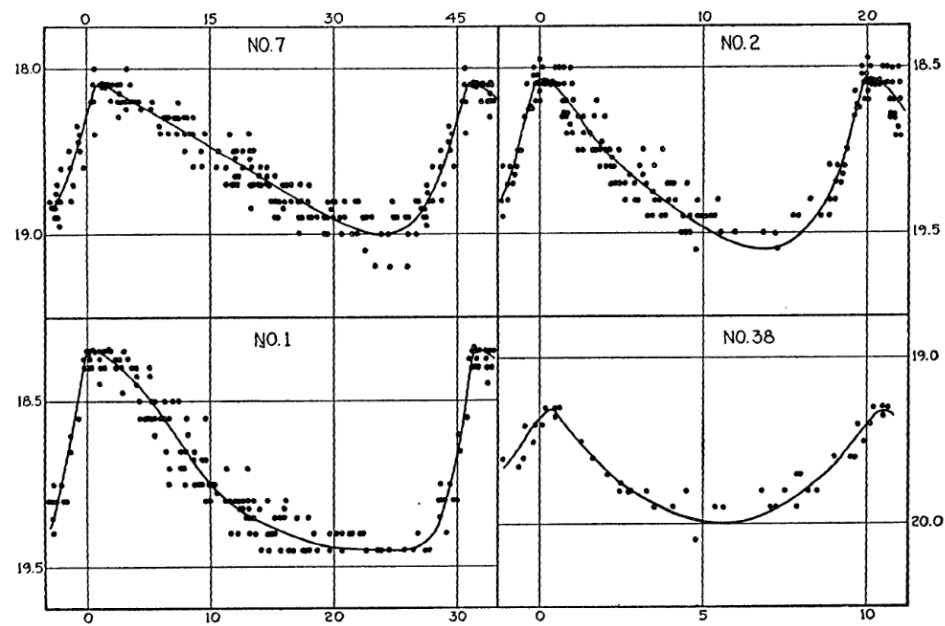


FIG. 1.—Light-curves of four Cepheids in M 31; ordinates, photographic magnitudes; abscissae, days.

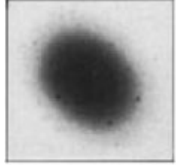


NGC6822 = 214 kpc (**520**) = 700 000 a.l. (1925)

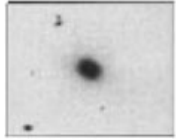
M33 = 263 kpc (**870**) = 850 000 a.l. (1926)

M31 = 275 kpc (**780**) = 900 000 a.l. (1929)

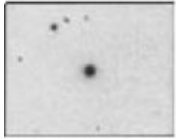
Cluster
nebula in



Virgo



Ursa Major



Corona
Borealis



Boötes



Hydra

Redshifts

H+K

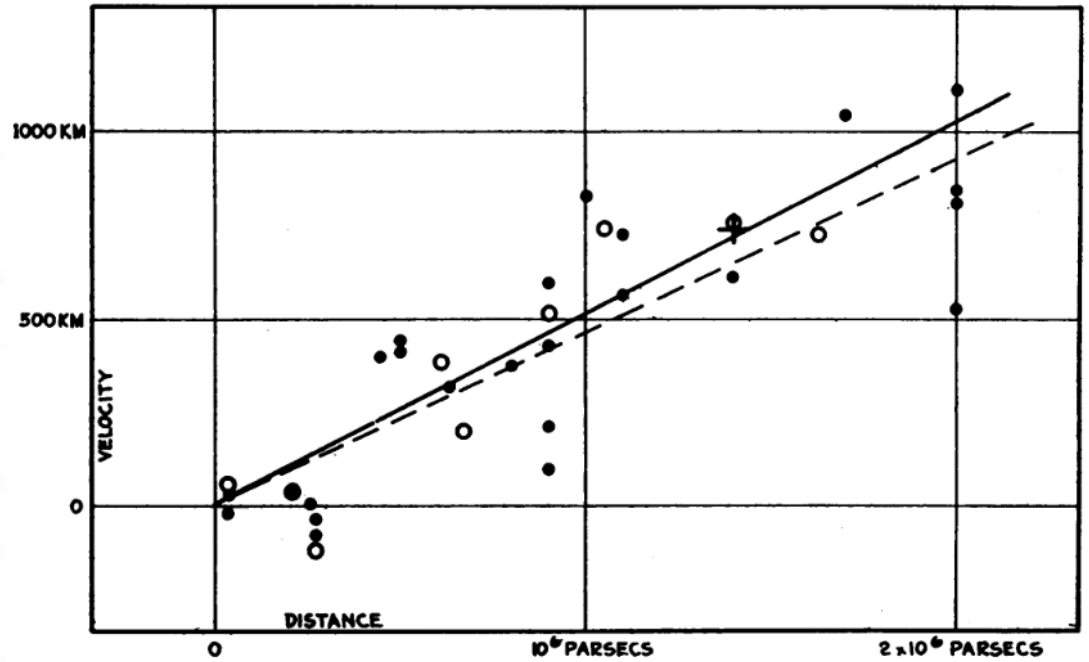
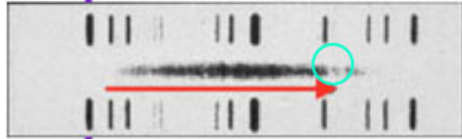
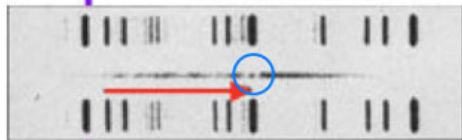
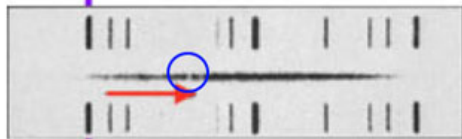
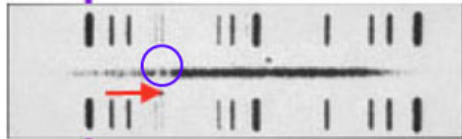
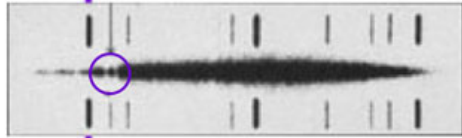


FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

$$v = K \times d$$

$$K = 465 \pm 50 \text{ km s}^{-1} \text{ Mpc}^{-1} \quad (H_0 = 73 \pm 2)$$

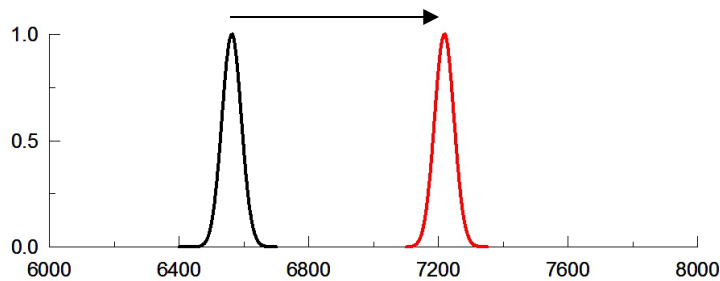
$$z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{v}{c} = \frac{H_0 \times d}{c} \quad \Rightarrow \quad \boxed{d = \frac{c}{H_0} \times z} \quad (\text{Mpc})$$

se $v \ll c$

$$z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{\sqrt{1 + \frac{v}{c}}}{\sqrt{1 - \frac{v}{c}}} - 1 \quad \Rightarrow \quad \boxed{d = \frac{c}{H_0} \times \frac{(z+1)^2 - 1}{(z+1)^2 + 1}} \quad (\text{Mpc})$$

se $v \leq c$

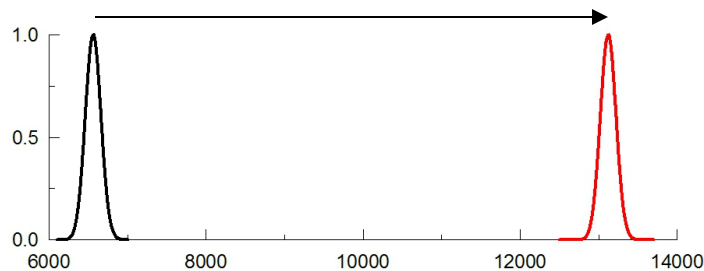
Come si determina un redshift



$$\lambda_0 = 6563 \text{ Å}$$

$$\lambda = 7912 \text{ Å}$$

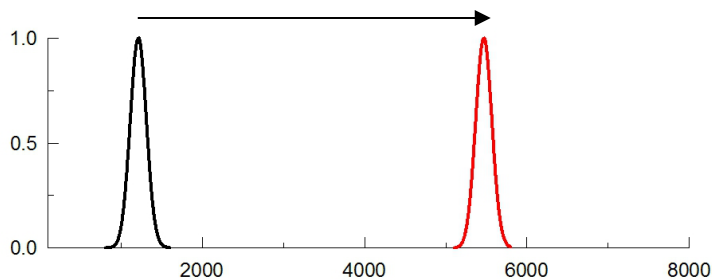
$$z = \frac{\Delta\lambda}{\lambda} = 0.1 \Rightarrow d = 396 \text{ Mpc}$$



$$\lambda_0 = 6563 \text{ Å}$$

$$\lambda = 13126 \text{ Å}$$

$$z = \frac{\Delta\lambda}{\lambda} = 1 \Rightarrow d = 2500 \text{ Mpc}$$



$$\lambda_0 = 1216 \text{ Å}$$

$$\lambda = 5472 \text{ Å}$$

$$z = \frac{\Delta\lambda}{\lambda} = 3.5 \Rightarrow d = 3775 \text{ Mpc}$$

$$d = \frac{v}{H_0} \quad (\text{Mpc})$$

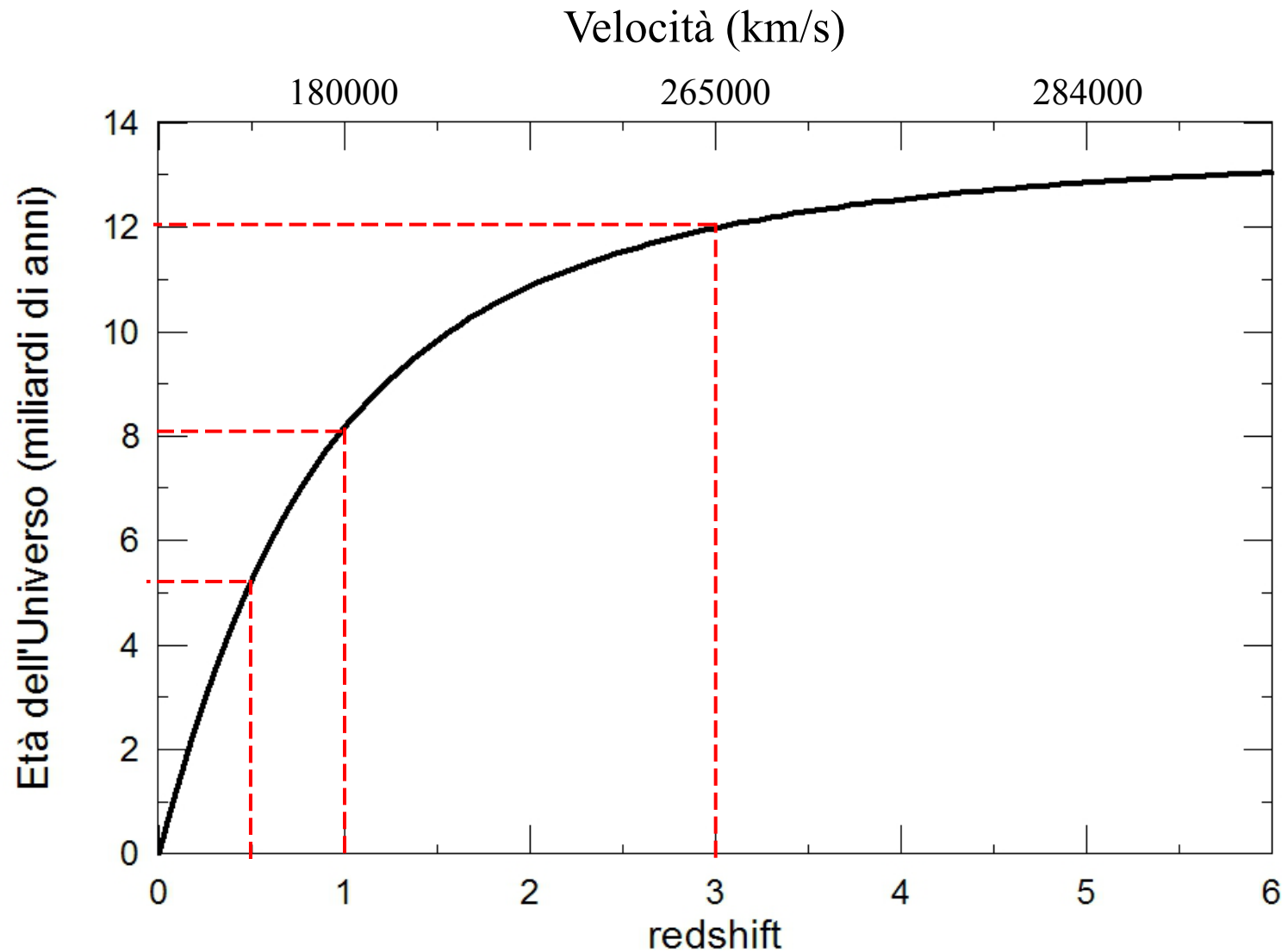


Età dell'Universo

$$\frac{1}{H_0} = \frac{1}{73} \cdot \frac{3.09 \times 10^{19}}{3.15 \times 10^7} = 13.4 \times 10^9 \text{ anni}$$

lontano nello spazio = indietro nel tempo

La scala dei tempi



Morfologia ad alto redshift

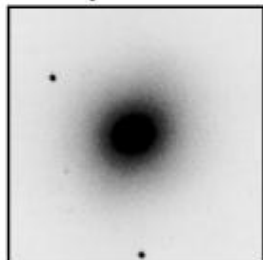
Age of the Universe

Today: 14 Billion Years

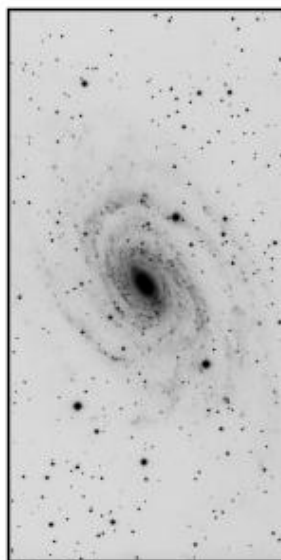
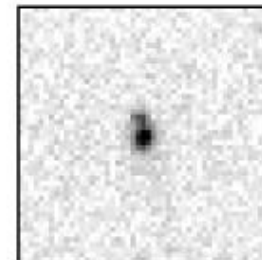
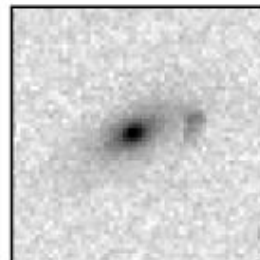
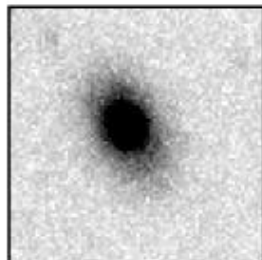
9 Billion Years

5 Billion Years

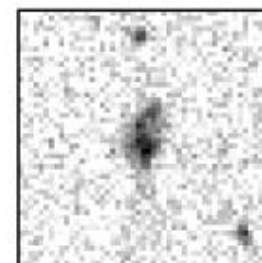
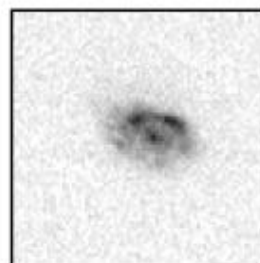
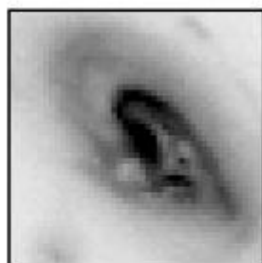
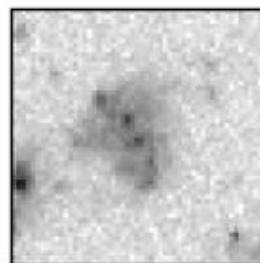
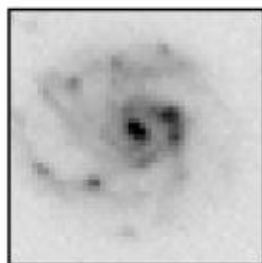
2 Billion Years



Elliptical



Spiral

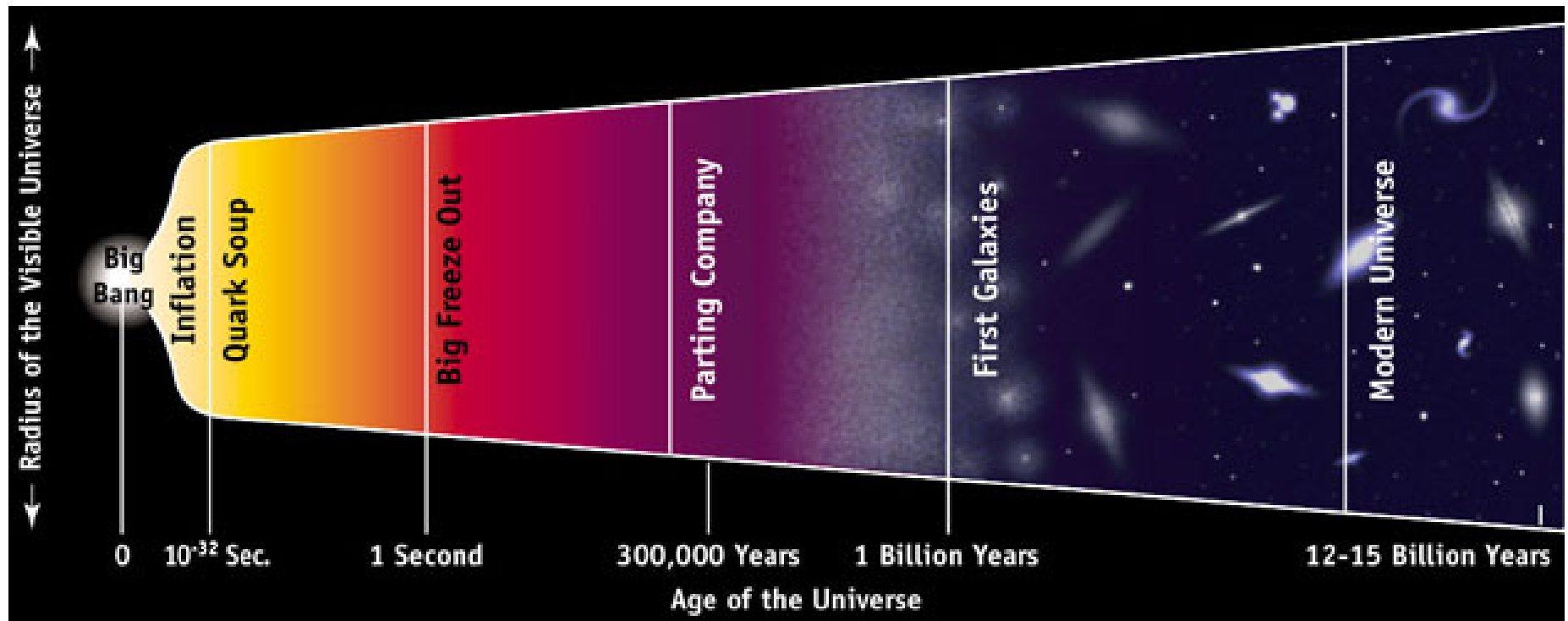


Galaxies: Snapshots in Time

HST • WFPC2



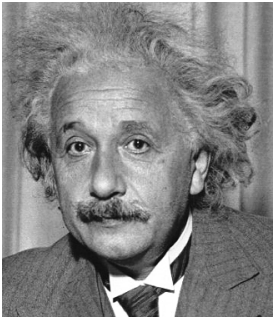
La teoria del Big Bang



Quale futuro per l'Universo?



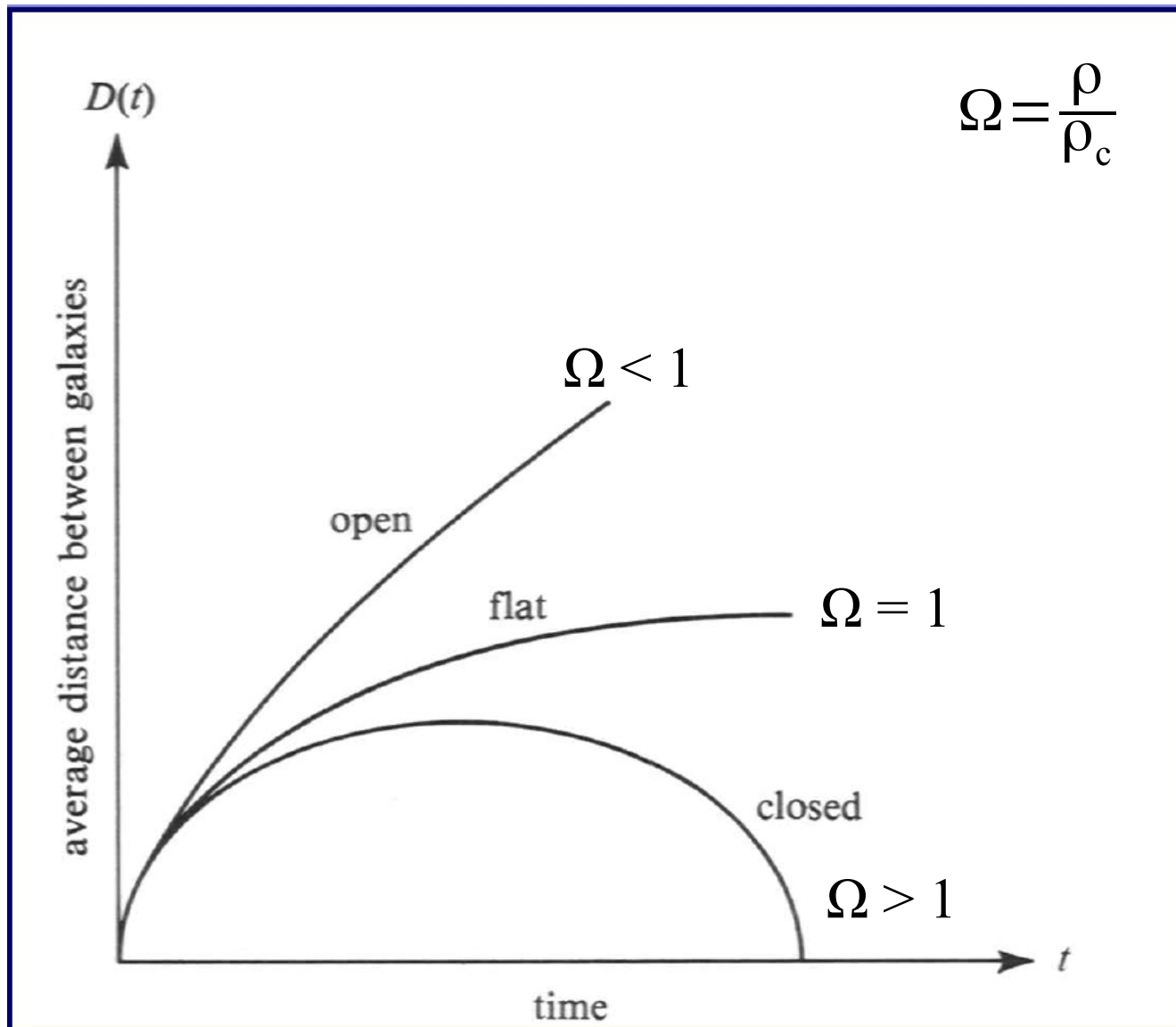
Alexander Friedmann (1922): assumendo che l'Universo su larga scala appaia lo stesso in ogni direzione e da ogni punto e utilizzando le equazioni della Relatività Generale di Einstein → **l'Universo si espande!!**



Einstein: impossibile, l'Universo è **statico**
→ **costante cosmologica Λ**



Hubble: l'Universo è **in espansione**
→ **Einstein cancella la costante Λ**



$$\rho_c = \frac{3H_0^2}{8\pi G} \simeq 9.7 \times 10^{-30} \text{ g/cm}^3$$

Qual è il nostro Universo?

Osservazioni BOOMERanG, WMAP, Planck $\rightarrow$

$$\Omega = 1$$

$$\left. \begin{array}{l} \text{Stelle e galassie} \rightarrow \Omega \approx 0.05 \\ \text{Materia oscura} \rightarrow \Omega \approx 0.27 \end{array} \right\} \Omega_{\text{M}} \approx 0.32 \quad \begin{array}{l} \text{Universo} \\ \text{aperto} \end{array}$$

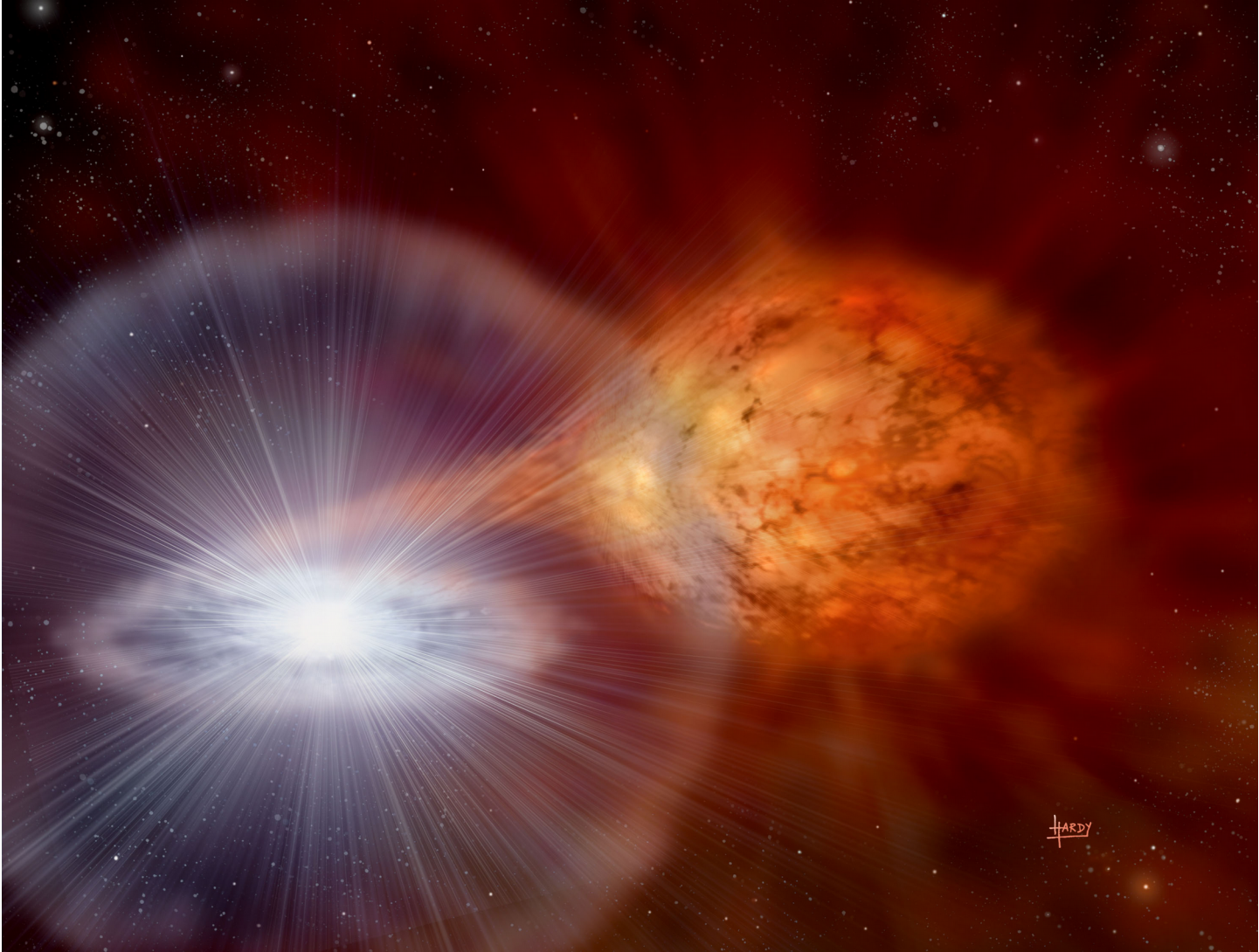


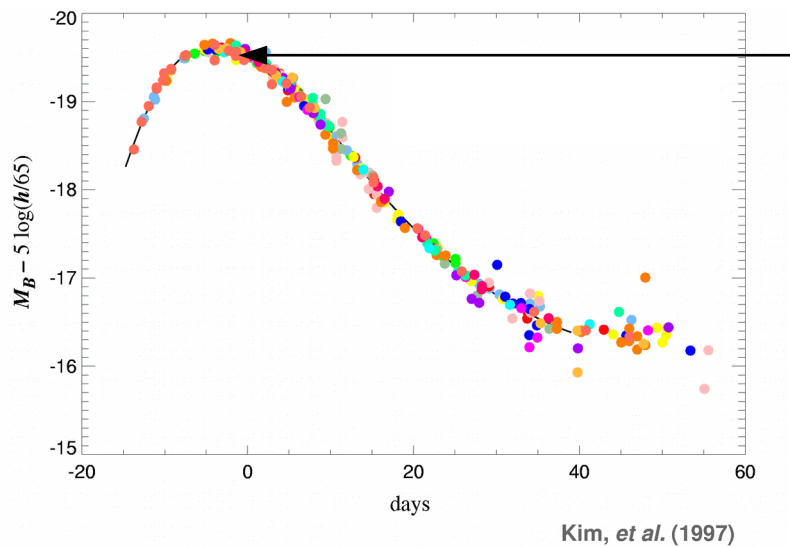
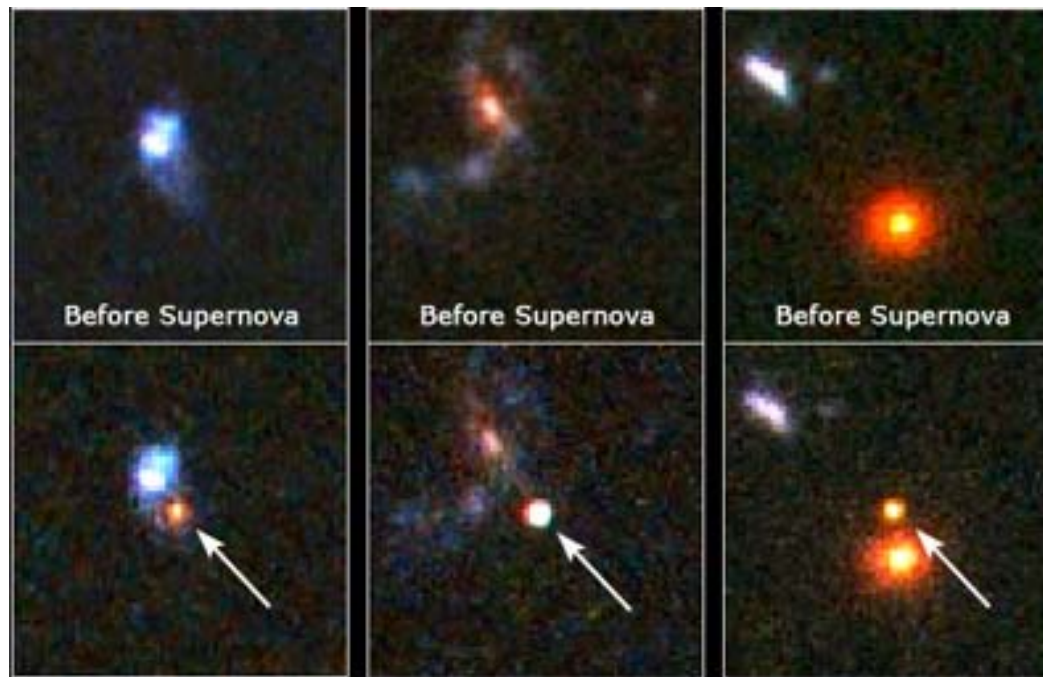
Manca il 68% del parametro di densità $\rightarrow \Omega_{\Lambda} \approx 0.68$

Dati di Planck (2016) $\rightarrow H_0 = 67 \text{ km s}^{-1} \text{ Mpc}^{-1}$

Dati di HST (2018) $\rightarrow H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$

Supernovae Ia



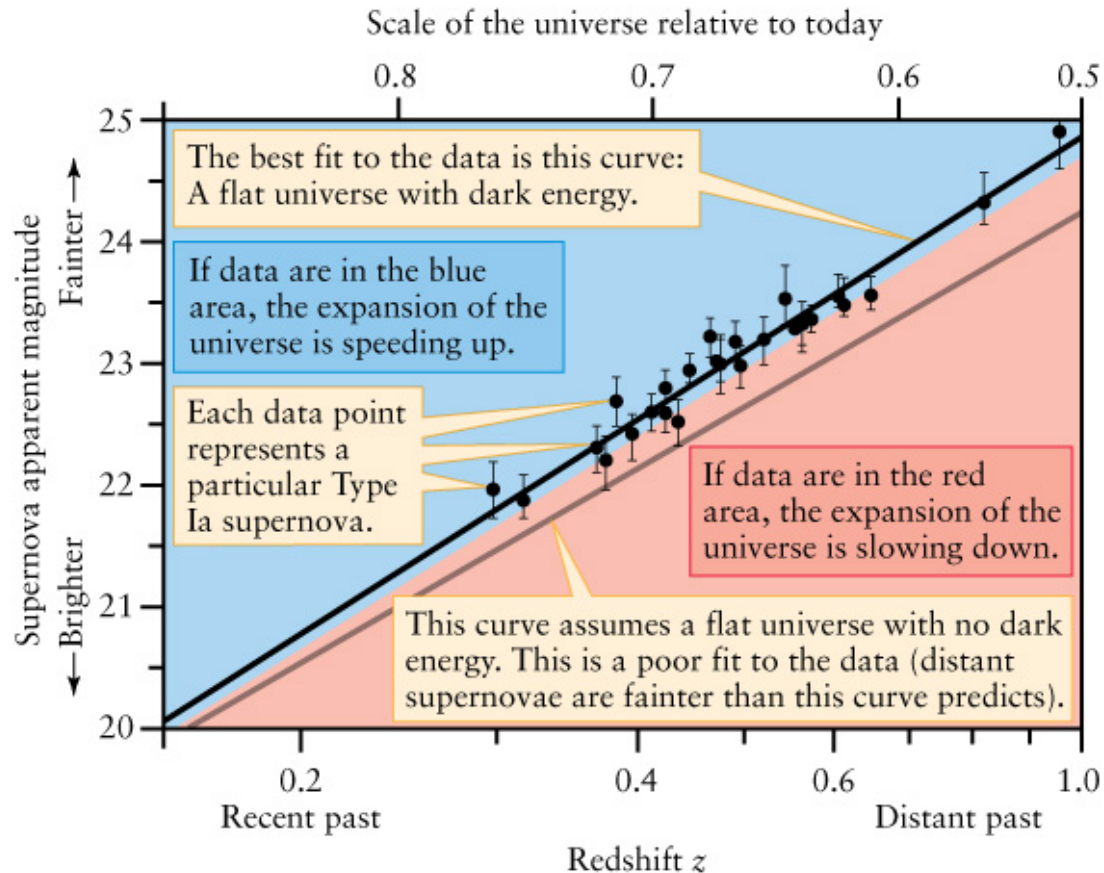


$$M_B = -19.5 \pm 0.1$$



$$d = 10^{\frac{m_B - M_B + 5}{5}} \text{ (pc)}$$

L'Universo è in fase di accelerazione (1998)



Premio Nobel 2011

Per poter accelerare, l'Universo deve essere sottoposto a una sorta di “forza gravitazionale repulsiva” ossia una forza di **pressione** che superi l'attrazione gravitazionale → **Energia Oscura**

$\Omega_{\Lambda} \rightarrow$ ritorna la costante Λ

