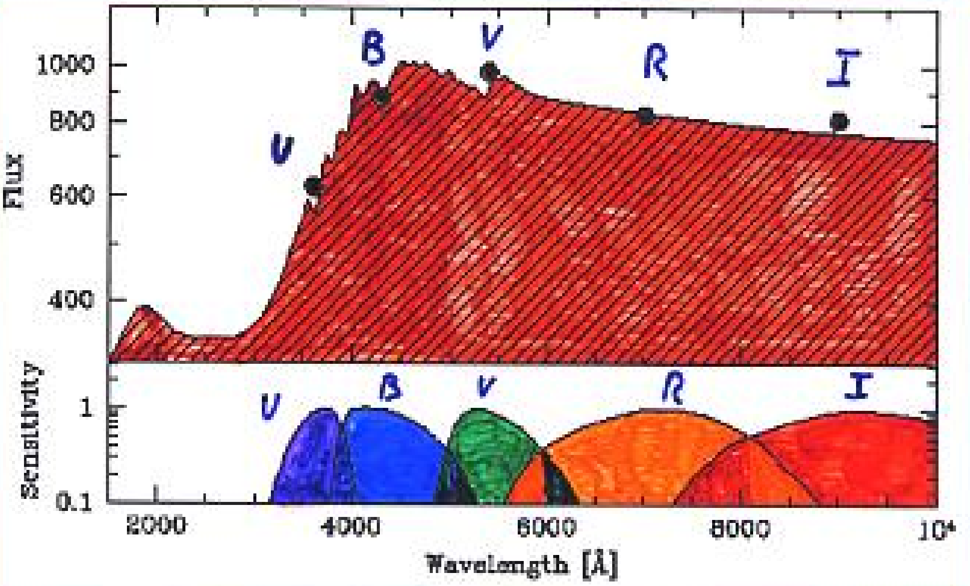
Evoluzione spettrale delle Galassie

Materiale didattico per gli studenti

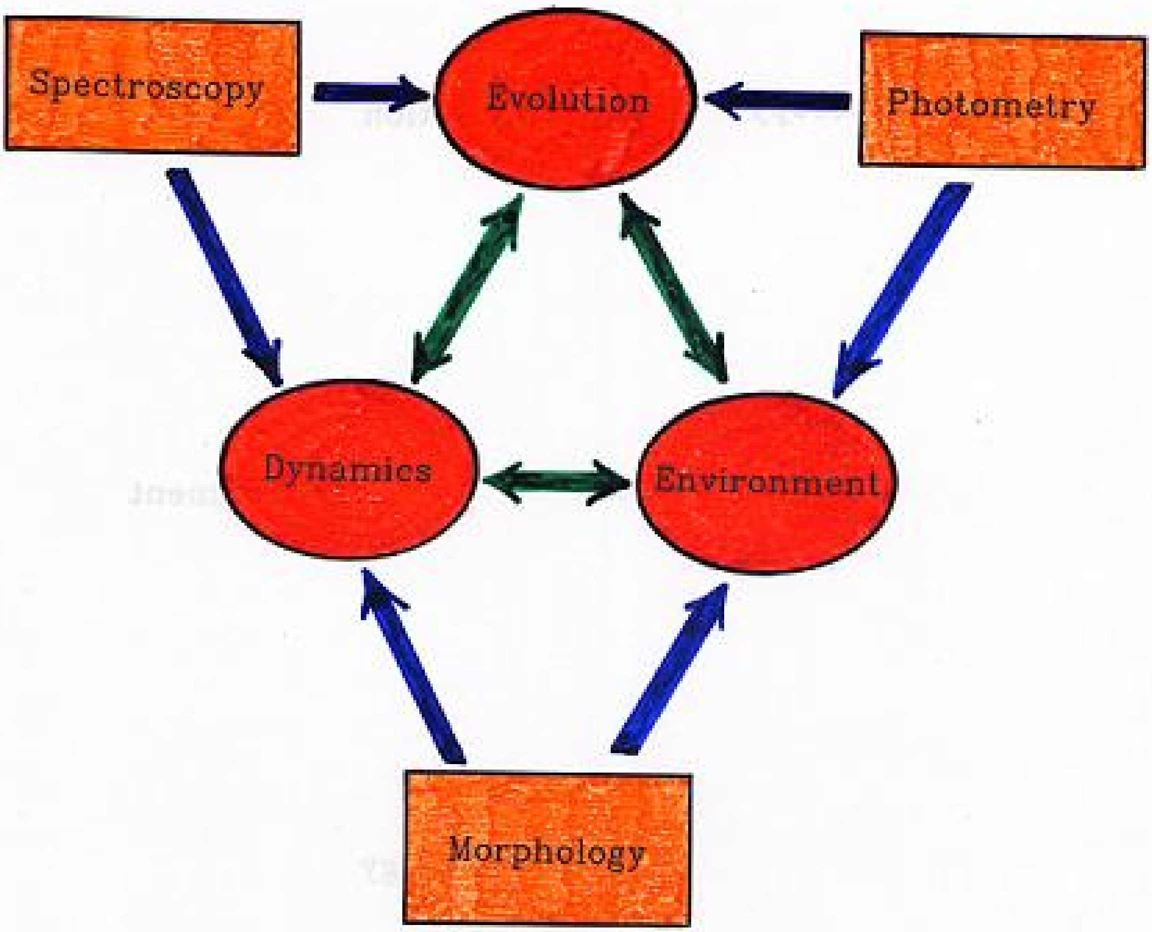
A.A. 2016/17 - Laurea Magistrale in Astrofisica e Cosmologia

Prof. Alberto Buzzoni

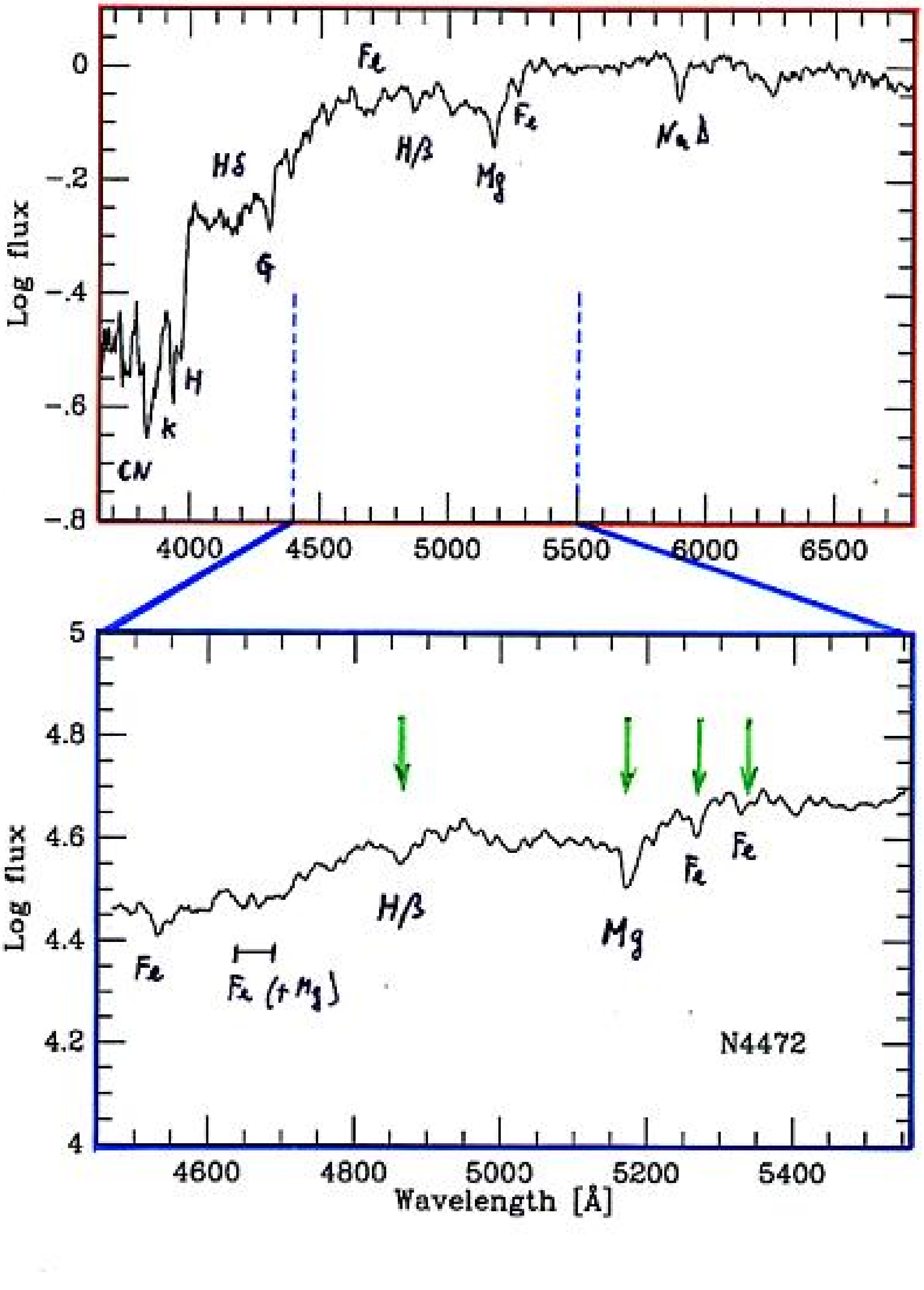
MORPHOLOGY



PHOTOMETRY


Spectroscopy
Evolution
Photometry
Dynamics
Environment
Morphology

SPECTROSCOPY



Humason et al. (1956)

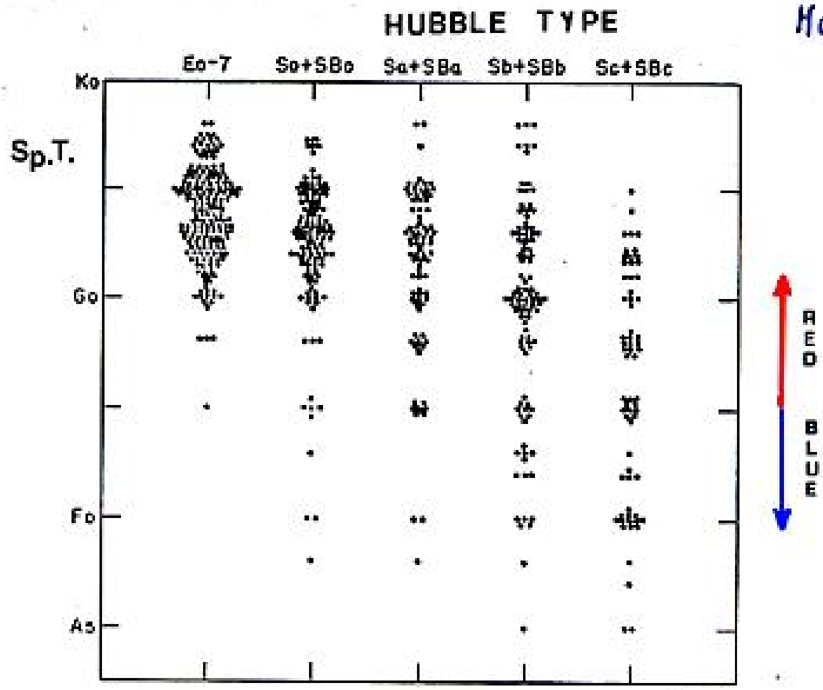
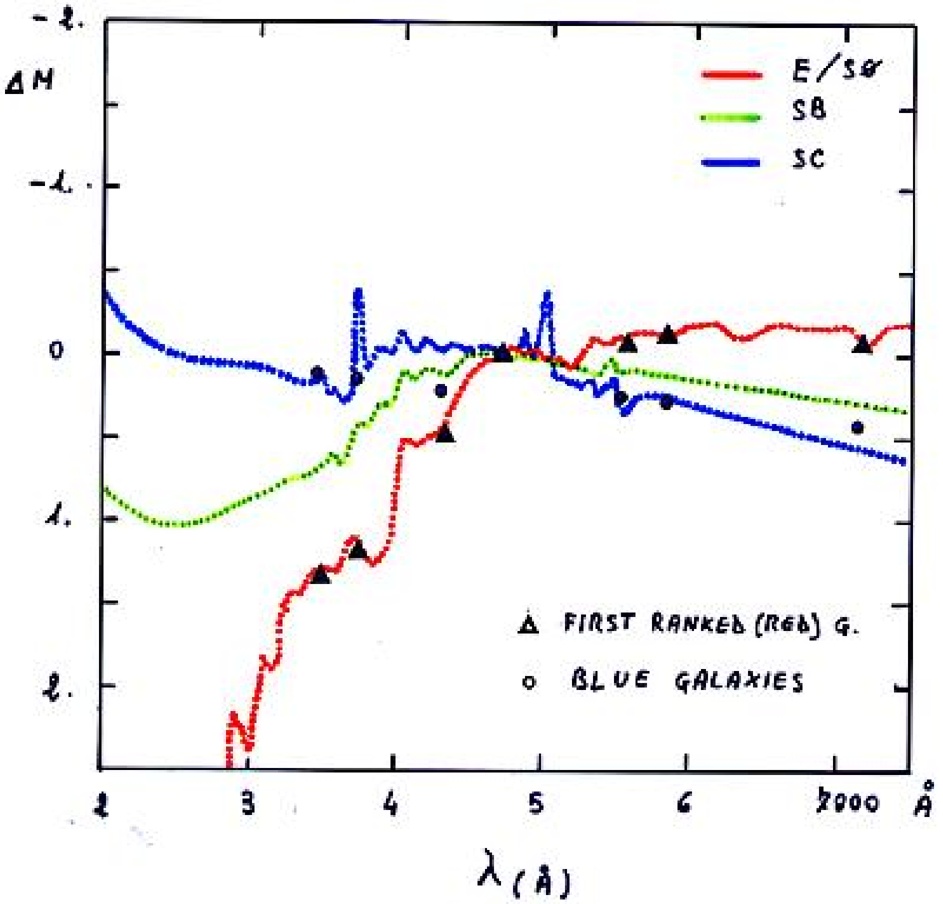
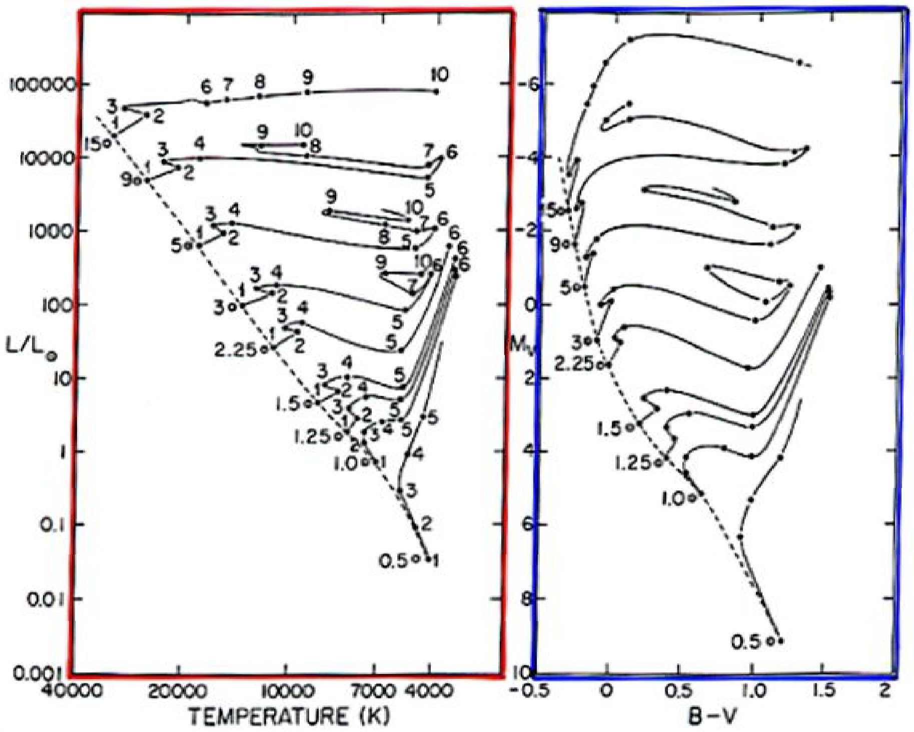


Figure 2. The distribution of spectral type as a function of nebular type for 546 nebulae from Tables I and II.



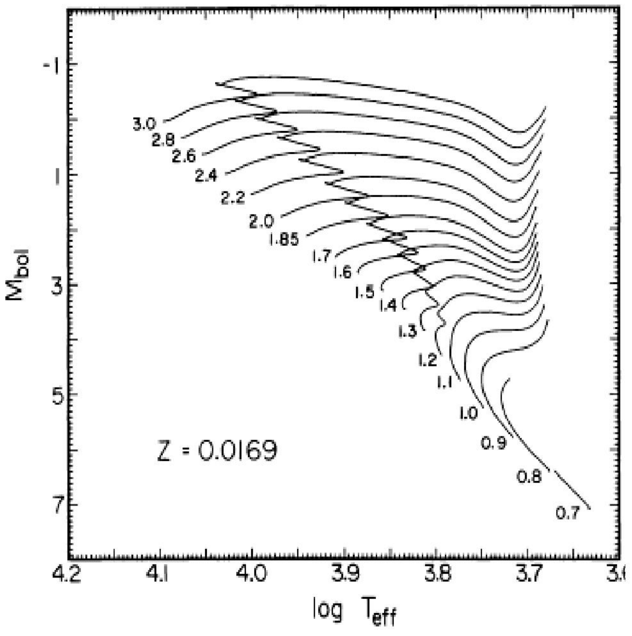
Stellar Evolution

Le prime tracce evolutive

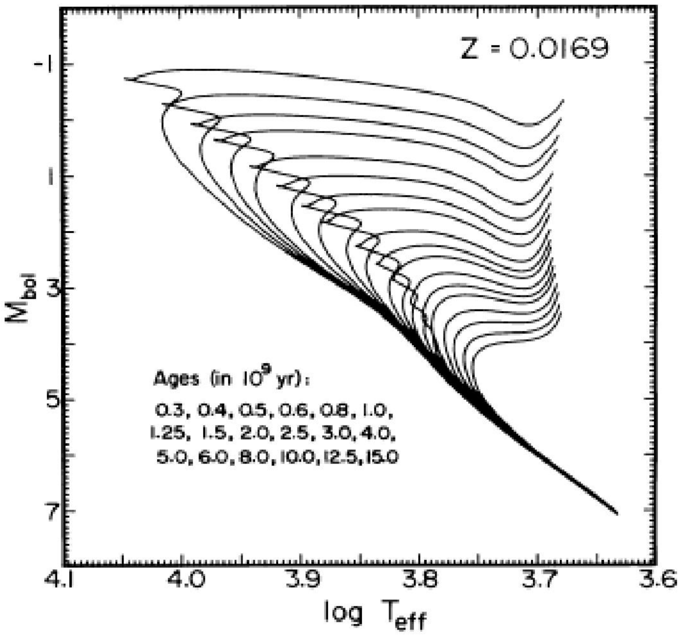


Iben (1967)

Tracce stellari



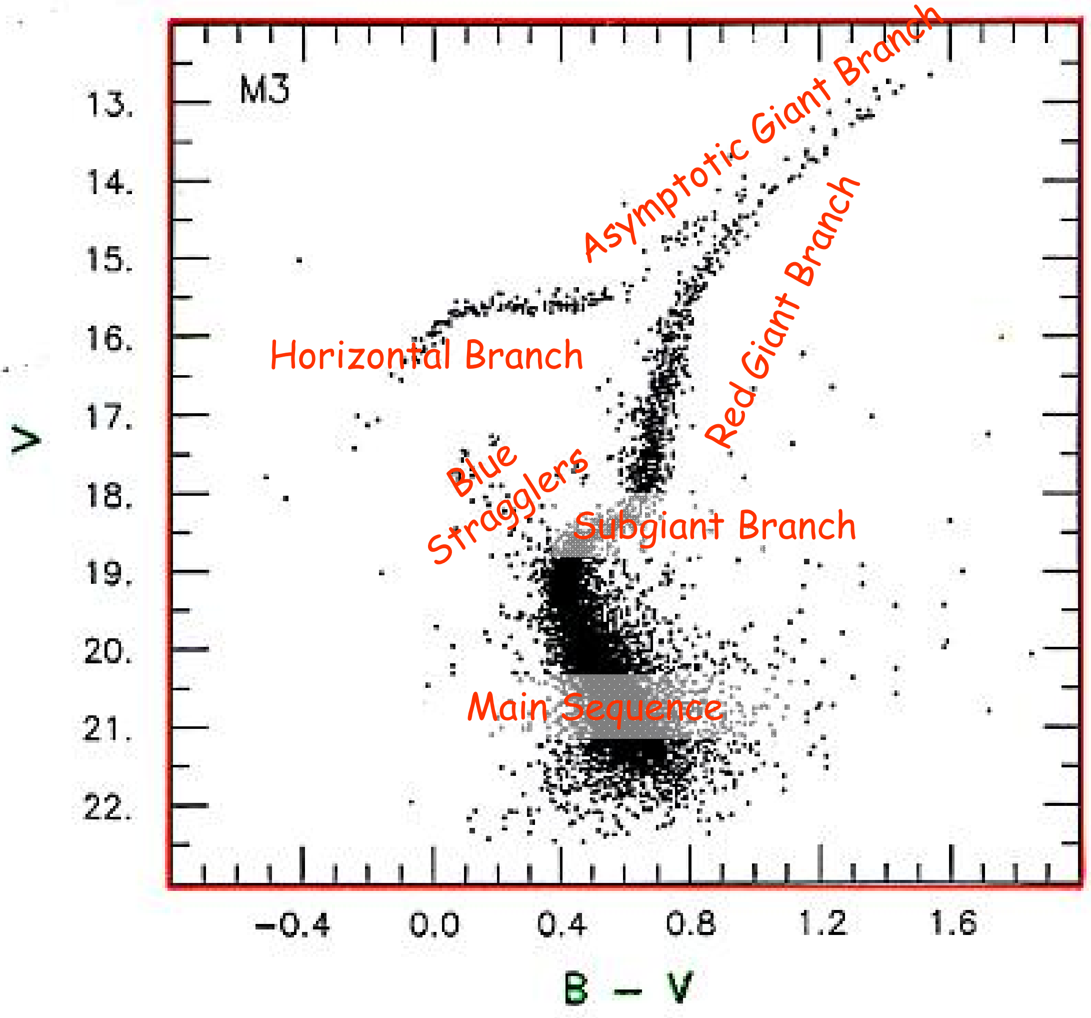
Isocrone



Vandenberg (1985)

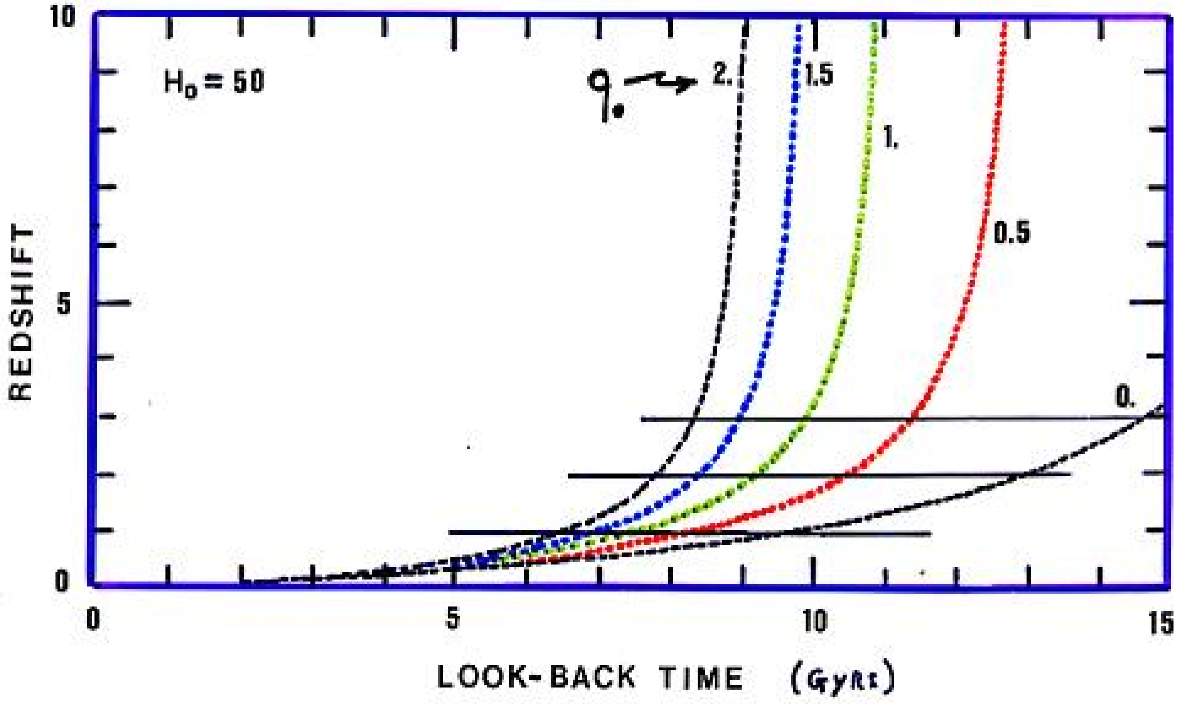
Un diagramma colore-magnitudine tipo (l'ammasso globulare M3)

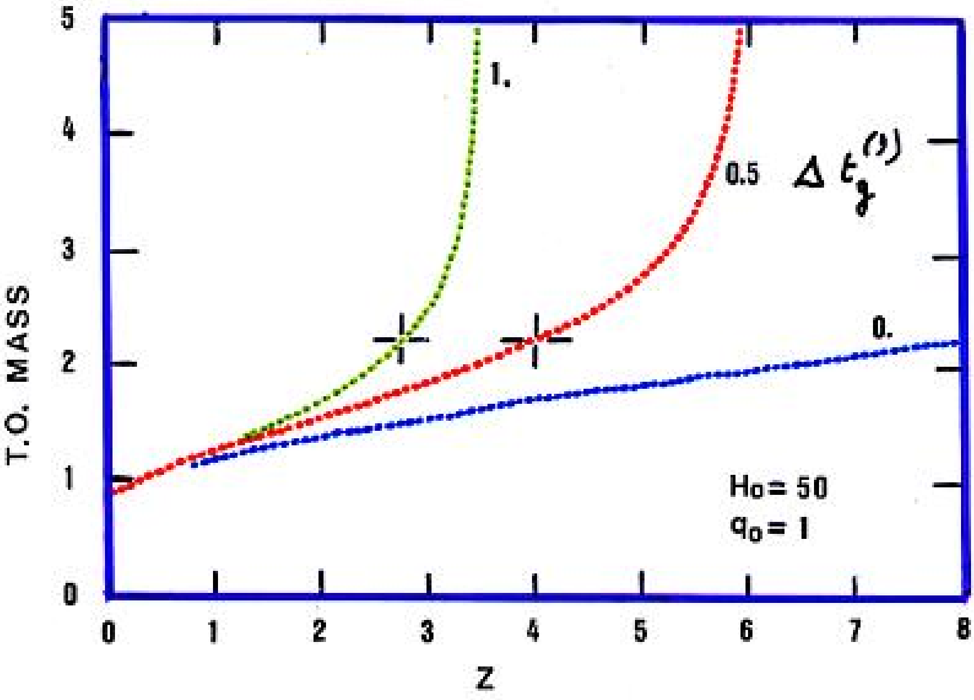
M3 (11,000 *)



Buonanno et al. (1994)

Cosmologia & Look-back time





http://en.wikipedia.org/wiki/Distance_measures_(cosmology)

$$\left\{\begin{array}{lll} * & 1) & \nabla P = -\rho g \Longrightarrow \frac{P}{R} \propto \rho \frac{M}{R^2} \Longrightarrow P \propto \rho \frac{M}{R} \\ & 2) & \nabla M = 4\pi R^2 \rho \\ & 3) & \nabla L = 4\pi R^2 \varepsilon \\ * & 4) & \nabla T = -\frac{3\rho k L}{16\pi a c T^3 R^2} \Longrightarrow \frac{T}{R} \propto \frac{\rho L}{T^3 R^2} \Longrightarrow T^4 \propto \frac{\rho L}{R} \\ * & 5) & P = \frac{\rho k T}{\mu H} \Longrightarrow P \propto \rho T \end{array}\right.$$

$$\rho T \propto \rho \frac{M}{R}$$

$$\Downarrow$$

$$\left\{\begin{array}{l} T \propto \frac{M}{R} \\ T^4 \propto \frac{\rho L}{R} \end{array}\right. \Longrightarrow \frac{M^4}{R^4} \propto \frac{M}{R^4} L \Longrightarrow \boxed{L \propto M^3}$$

$$L t \propto M$$

$$\Downarrow$$

$$\left\{\begin{array}{l} t \propto \frac{M}{L} \\ L \propto M^3 \end{array}\right. \Longrightarrow \boxed{\begin{array}{l} t \propto M^{-2} \\ t \propto L_{T.O.}^{-2/3} \end{array}}$$

http://en.wikipedia.org/wiki/Stellar_structure

Relazioni di scala per le stelle in Sequenza Principale

$$\begin{cases}\nabla P = -\rho g \\ P = \dfrac{\rho k T}{\mu H}\end{cases} \Rightarrow \frac{\cancel{\rho} k T}{\mu H \cancel{R}} \propto -\cancel{\rho}\,\frac{GM}{R^{\cancel{2}}}$$

$$\Downarrow$$

$$\boxed{T \propto \frac{M}{R}\,\mu}$$

$$\nabla T = \frac{-3\rho\tilde{K}L}{16\pi a c R^2 T^3}$$

$$\Downarrow$$

$$\frac{T^4}{\cancel{R}} \propto \frac{M}{R^3}\,\frac{\tilde{K}L}{R^{\cancel{2}}} \qquad \frac{M^{\cancel{4}\,3}}{\cancel{R^4}}\,\mu^4 \propto \frac{\cancel{M}}{\cancel{R^4}}\,\tilde{K}L$$

$$\Downarrow$$

$$\boxed{L \propto M^3\,\frac{\mu^4}{\tilde{K}}}$$

$$\begin{cases}T \propto \dfrac{M}{R}\,\mu \\ L \propto R^2 T^4\end{cases} \Rightarrow R \propto \frac{L^{1/2}}{T^2} \qquad \cancel{T} \propto \frac{M\,T^{\cancel{2}}}{L^{1/2}}\,\mu$$

$$\Downarrow$$

$$\left(\frac{M^{\cancel{3}}\,\mu^{\cancel{4}\,2}}{\cancel{M^2}\,\tilde{K}\,\cancel{\mu^2}}\right)^{1/2} \Leftarrow \frac{L^{1/2}}{M\mu} \propto T$$

$$\boxed{T \propto \sqrt{\frac{M}{\tilde{K}}}\,\mu}$$

$$\begin{cases}L \propto \dfrac{M^3\mu^4}{\tilde{K}} \\ T \propto \dfrac{M^{1/2}\mu}{\tilde{K}^{1/2}}\end{cases} \Rightarrow L \propto T^6\left(\frac{\tilde{K}}{\mu}\right)^2$$

http://en.wikipedia.org/wiki/Mass-luminosity_relation

Clocks

$$L\,t = E$$

$$\boxed{\text{KELVIN-HELMHOLTZ} \qquad E = \frac{GM^2}{R}}$$

$$t_\odot \sim \frac{E}{L} \sim \frac{GM^2}{RL} \sim \frac{6\,10^{-8}\,(2\,10^{33})^2}{7\,10^{10}\;\;4\,10^{33}}\ \text{sec.}$$

$$t_\odot \sim \frac{6\;10^{25}}{7\;10^{10}\;\;3\,10^{7}}\ \text{yr} \Rightarrow \boxed{\frac{2}{7}\,10^{8}\ \text{yr}}$$

$$\boxed{\text{NUCLEARE} \qquad E = \underset{\substack{\downarrow \\ 0.007}}{\alpha}\, M c^2}$$

$$t_\odot \sim \frac{E}{L} \sim \frac{\alpha M c^2}{L} \sim \frac{7\,10^{-3}\;2\,10^{33}\;9\,10^{20}}{4\,10^{33}}\ \text{sec.}$$

$$t_\odot \sim \frac{63}{2}\,\frac{10^{17}}{3\,10^{7}}\ \text{yr} \sim \frac{63}{6}\,10^{10} \sim \boxed{10^{11}\ \text{yr}}$$

$$\boxed{\text{DIPENDENZA DALLA CHIMICA}}$$

$$\left\{\begin{array}{l} t \propto \dfrac{M}{L} \\[2ex] L \propto \dfrac{M^3 \mu^4}{\tilde{K}} \end{array}\right. \Rightarrow \quad t \propto \frac{\cancel{M}\,\tilde{K}}{M^{\cancel{3}\,2}\mu^4} \propto \boxed{\frac{1}{M^2}\left(\frac{\tilde{K}}{\mu^4}\right)}$$

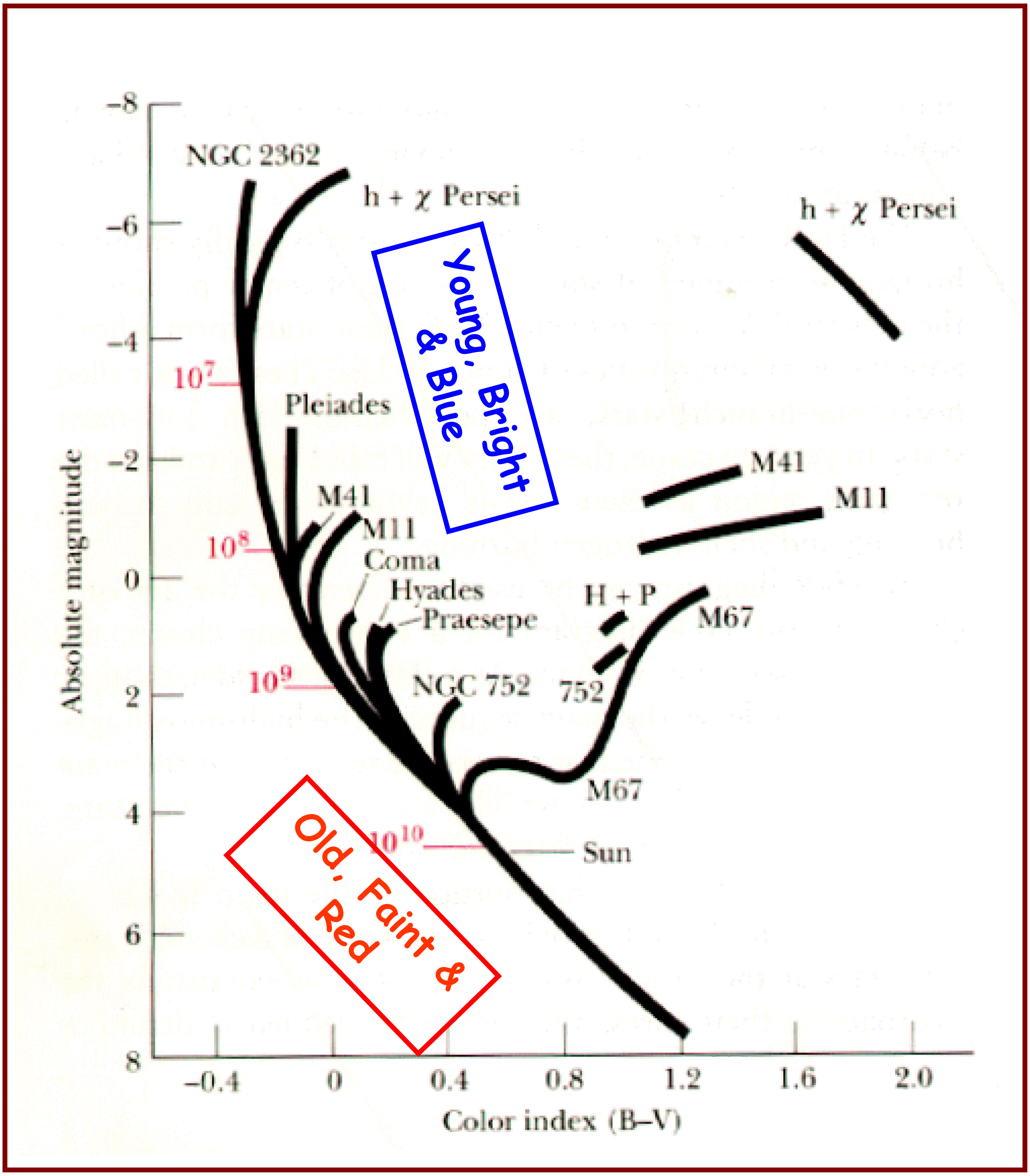
quindi: se $M = \text{fix}$ $\quad t \nearrow$ se $Z \nearrow$

$t \downarrow$ se $Y \nearrow$

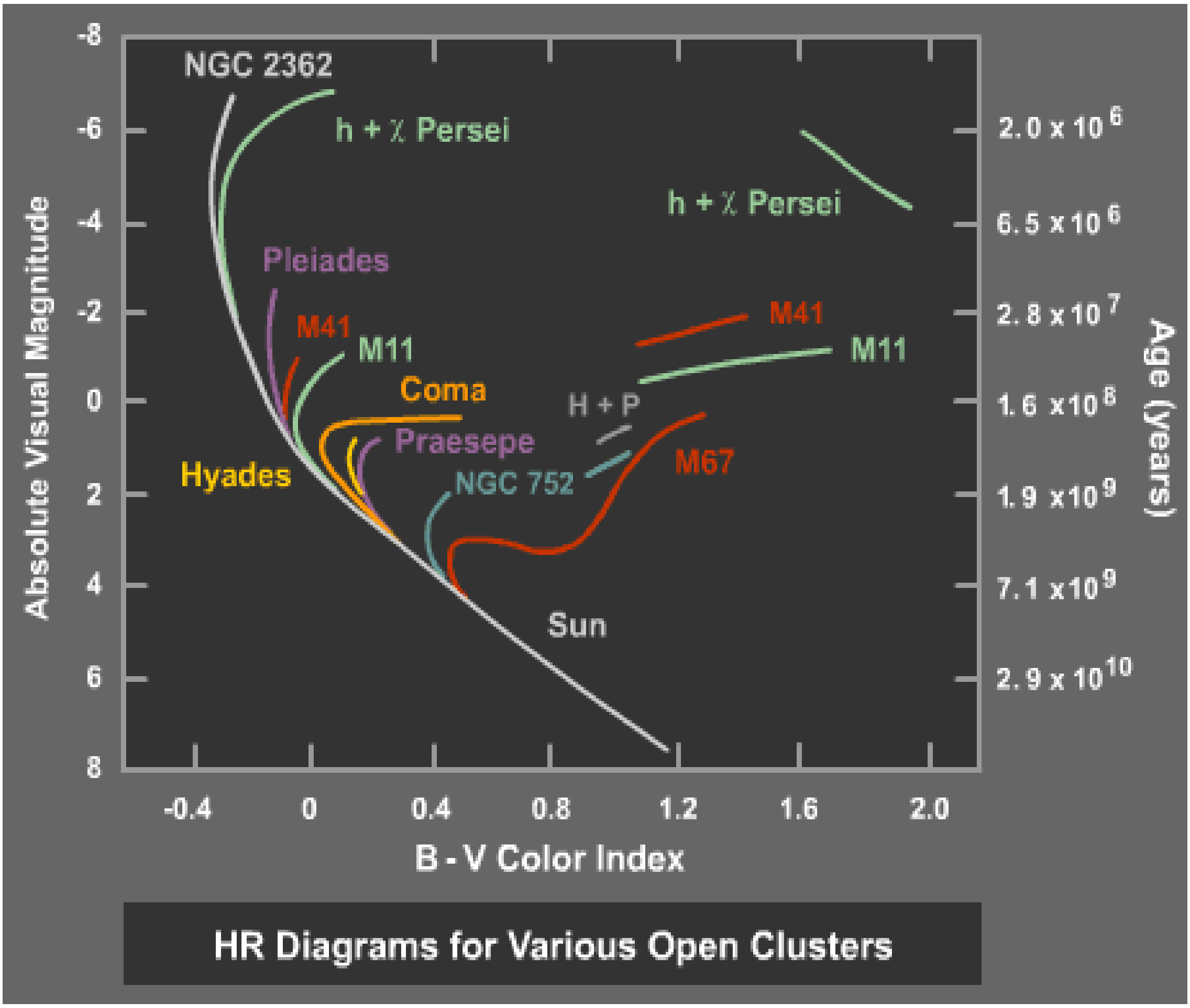
se $t = \text{fix}$ $\quad M_{TO} \nearrow$ se $Z \nearrow$

$M_{TO} \downarrow$ se $Y \nearrow$

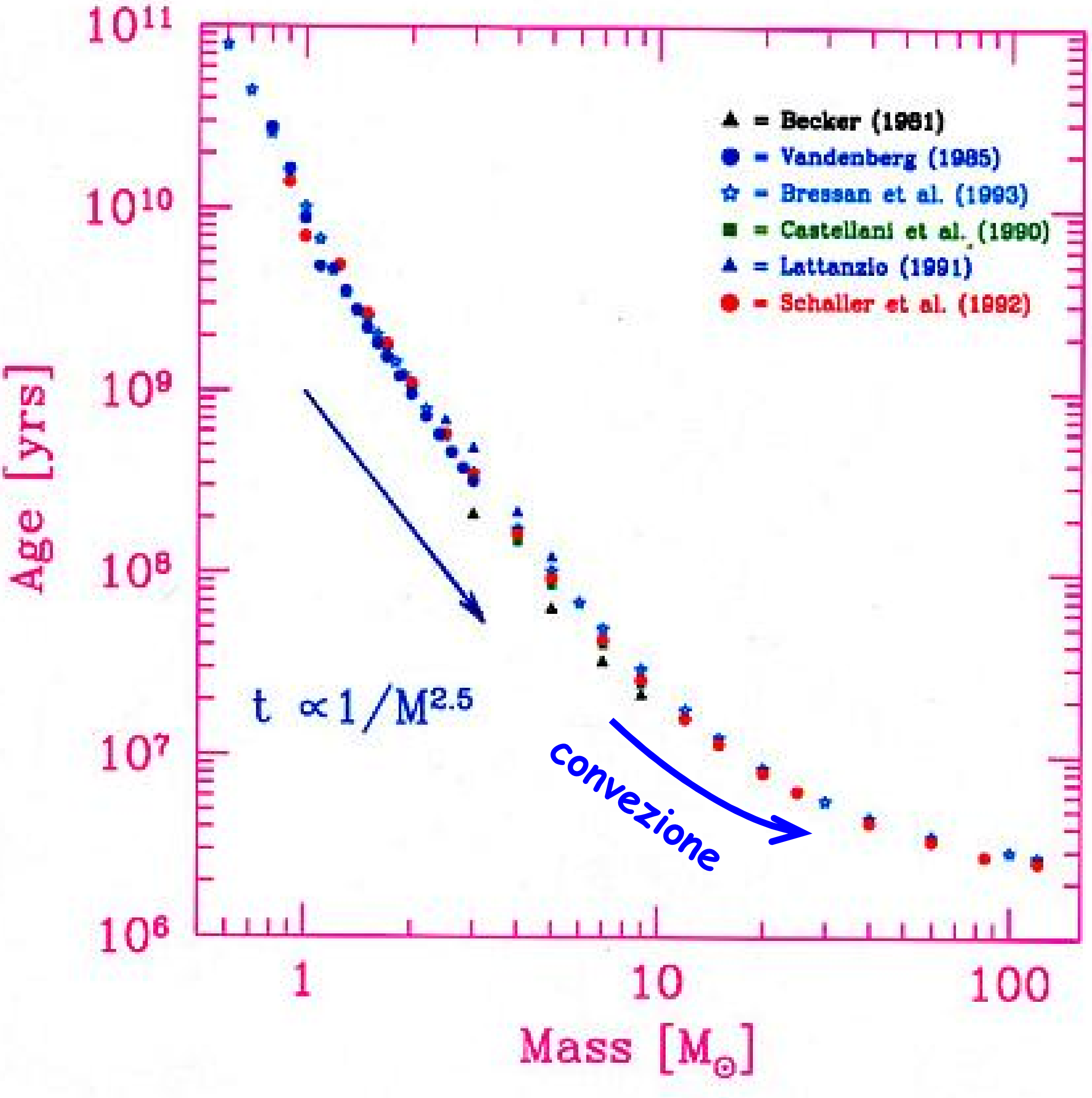
Il punto di Turn Off come indicatore di eta'



Il punto di Turn Off come indicatore di eta’



The Clock



Age [yrs]
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
Mass [$M_\odot$]
1
10
100
▲ = Becker (1981)
● = Vandenberg (1985)
☆ = Bressan et al. (1993)
■ = Castellani et al. (1990)
▲ = Lattanzio (1991)
● = Schaller et al. (1992)
$t \propto 1/M^{2.5}$
convezione

Peso Molecolare Medio

$$\mu = \frac{\sum n_j m_j}{\sum n_j}$$

$\forall$ j = tutte le specie chimiche

GAS NEUTRO

$$\mu_N = \frac{\rho X + \rho Y + \rho Z}{\frac{\rho X}{H} + \frac{\rho Y}{4H} + \frac{\rho Z}{2\mathcal{Z} H}} \sim \boxed{\frac{H}{X + \frac{Y}{4} + \underset{\sim 0}{\underset{\Downarrow}{\frac{Z}{2\mathcal{Z}}}}}}$$

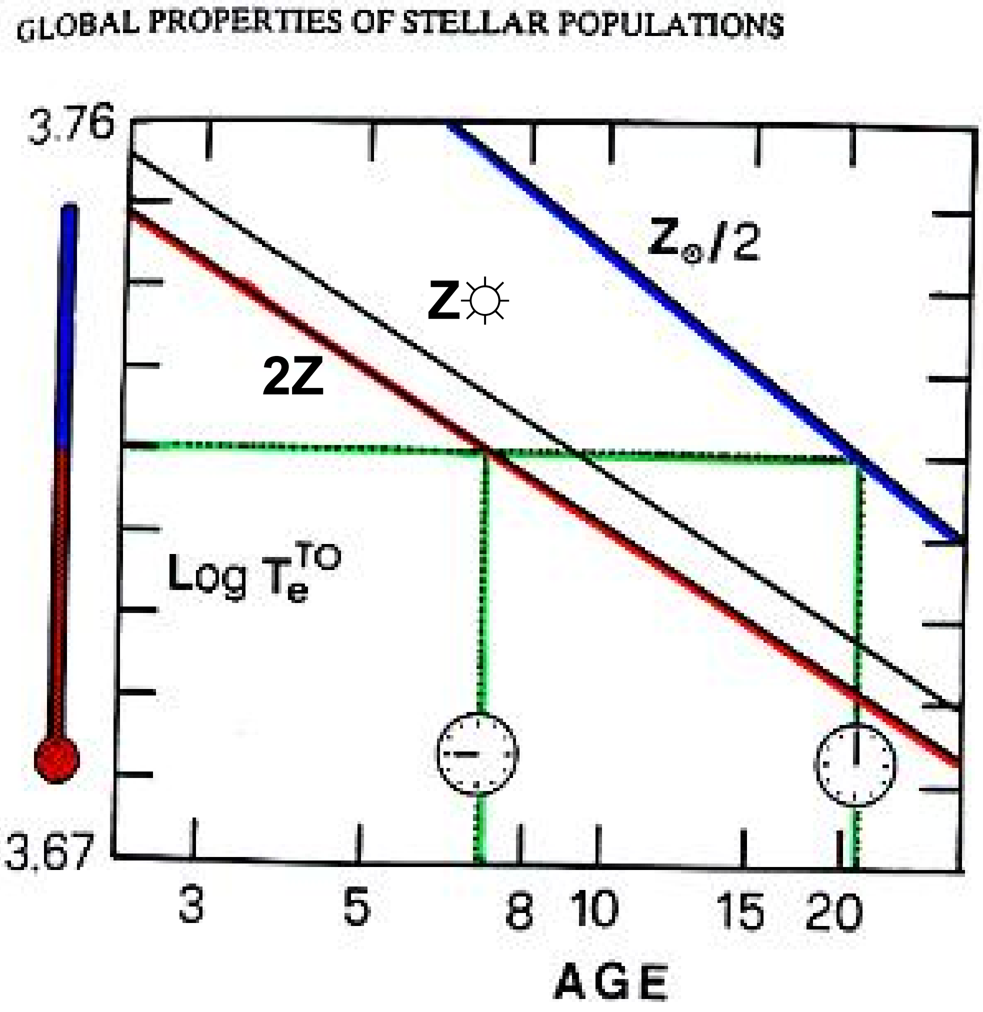
PLASMA TOT IONIZZATO

$$\mu_i = \mu_N + \frac{\rho}{\frac{\rho X}{H} + \frac{2\rho Y}{4H} + \frac{\mathcal{Z}\rho Z}{2\mathcal{Z}}} = \mu_N + \frac{H}{X + \frac{Y}{2} + \frac{Z}{2}}$$

$$\mu_i = \frac{H}{\left(X + \frac{Y}{4} + \frac{Z}{2\mathcal{Z}}\right) + \left(X + \frac{Y}{2} + \frac{Z}{2}\right)} = \frac{H}{2X + \frac{3}{4}Y + \underbrace{\left(1 + \frac{1}{\mathcal{Z}}\right)}_{\Downarrow \atop \sim 1}\frac{Z}{2}}$$

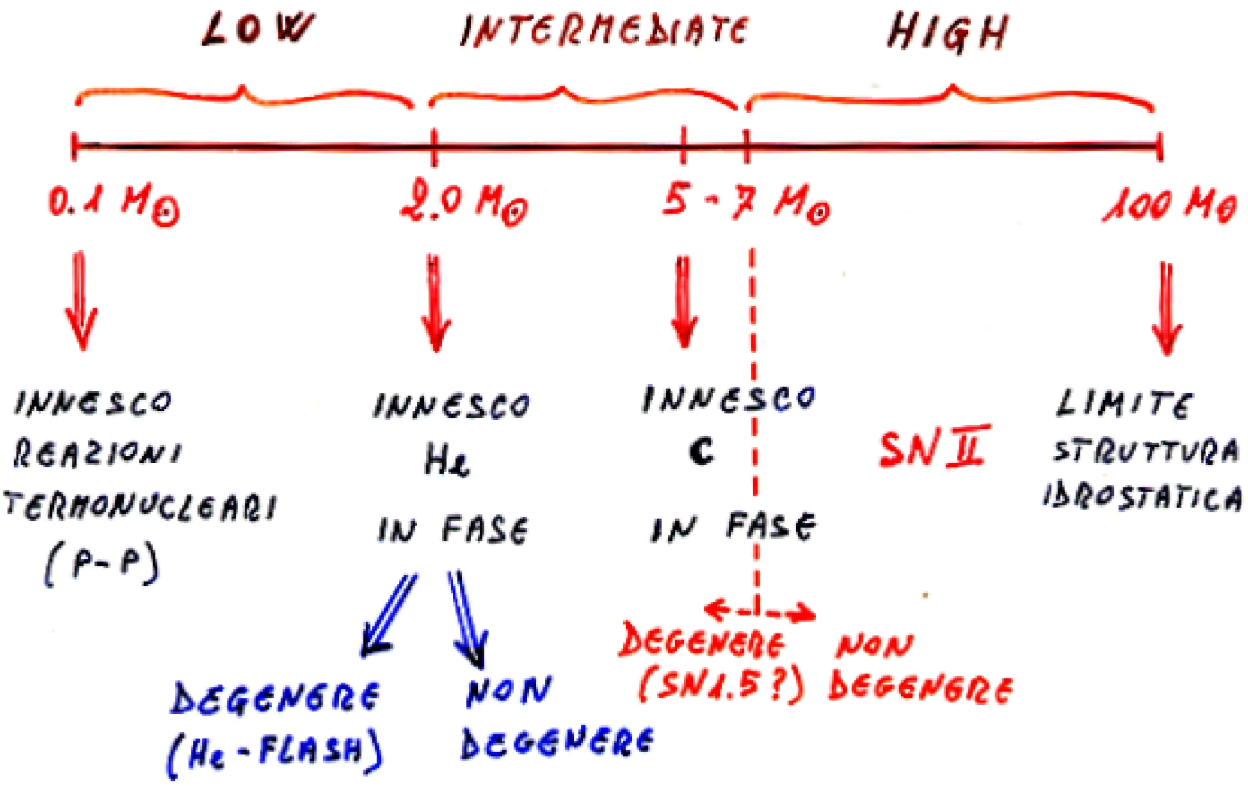
$$\boxed{\mu_i \sim \frac{H}{2X + \frac{3}{4}Y + \frac{Z}{2}}}$$

Thermometers & Clocks
(effetto della metallicita')



Renzini & Buzzoni (1986)

STELLAR MASSES

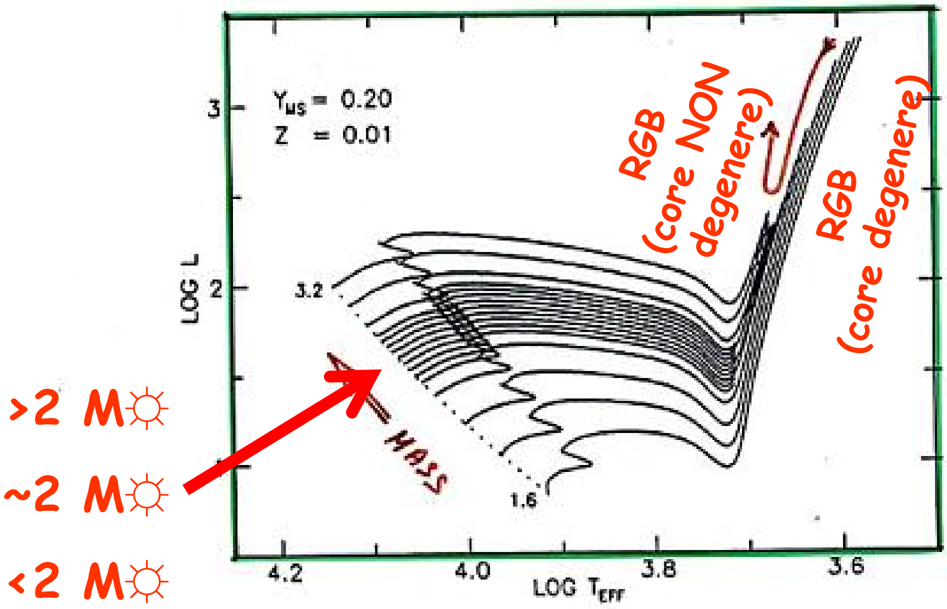


FASE	LOW-MASS	HIGH-MASS
CORE H-BURNING	MS	MS
SHELL H-BURNING	SGB RGB	1-ST GB
CORE He-BURNING	HB	1-ST BLUE LOOP
DOUBLE (MULTIPLE) SHELL BURNING	AGB	2-ND, 3-RD etc. GBs

http://it.wikipedia.org/wiki/Formazione_stellare

L'effetto della "transizione di fase" in RGB

SWEIGART, GREGGIO & RENZINI
(1989)



RENZINI & BUZZONI
(1986)

GLOBAL PROPERTIES OF STELLAR POPULATIONS

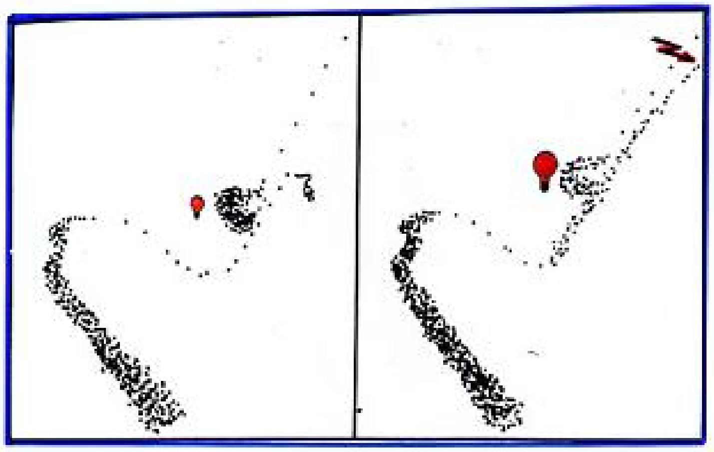


Figure 14. An artist view of the RGB phase transition. On the left panel the HR diagram of a cluster slightly younger than $t(M_{HeF})$. On the right panel the same cluster when slightly older than $t(M_{HeF})$. Note the virtual identity of the main sequences, and, by contrast, the development of the RGB. The plug indicates the point when helium ignites (non degenerately). The jagged arrow indicates the helium flash location. The growing light bulb emphasizes the brightening of the clump giants across the RGB phase transition. The AGB stays nearly the same across the transition.

DISTINCTIVE PARAMETERS IN A STELLAR POPULATION

1) AGE $\Rightarrow$ t

2) CHEMICAL COMPOSITION $\Rightarrow$ Z, $[Fe/H]$

3) STAR MASS DISTRIBUTION $\Rightarrow$ IMF

4) STAR FORMATION HISTORY $\Rightarrow$ SFR

CANONICAL ASSUMPTIONS

1) IMF $N_{(M)} \propto M_*^{-s}$ $(s = 2.35)$

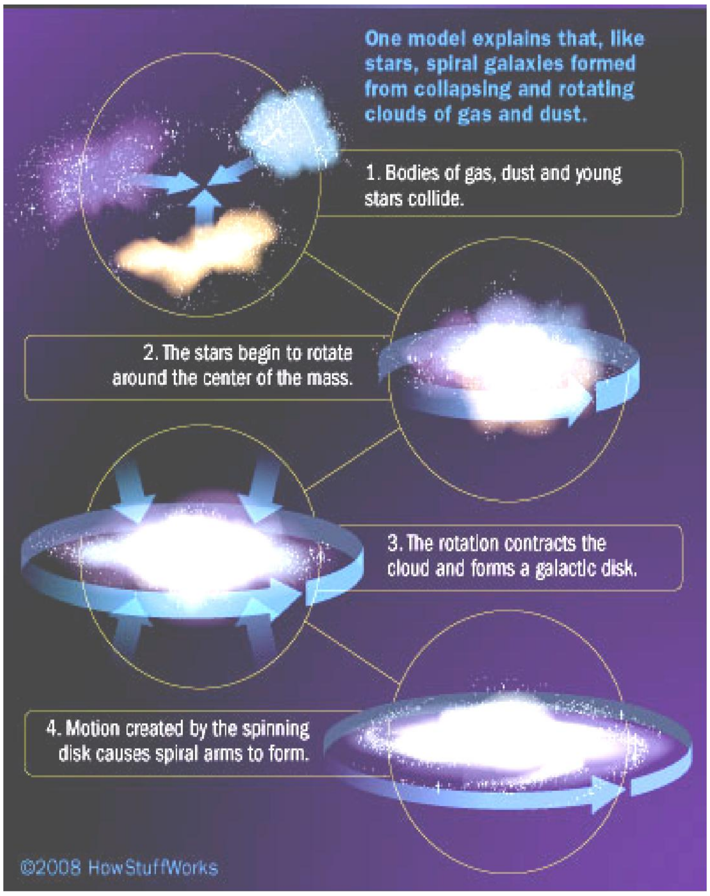
2) SFR

- $\delta(0) \rightarrow$ SSP
- $f(t) \rightarrow$ CSP.

Articoli consigliati (vedi Webpage):
http://www.bo.astro.it/~eps/lezioni/lezioni.html

- SSPs (Tinsley)
- SSPs (Renzini & Buzzoni)
- M/L clusters (Girardi)
- Galaxy Colors (Buzzoni)
- Galaxy Spectral Atlas (Kennicutt1)
- Galaxy Spectral Atlas (Kennicutt2)
- Chemical evolution of spiral galaxies (Buzzoni)

Come nascono le galassie?



One model explains that, like stars, spiral galaxies formed from collapsing and rotating clouds of gas and dust.

1. Bodies of gas, dust and young stars collide.

2. The stars begin to rotate around the center of the mass.

3. The rotation contracts the cloud and forms a galactic disk.

4. Motion created by the spinning disk causes spiral arms to form.

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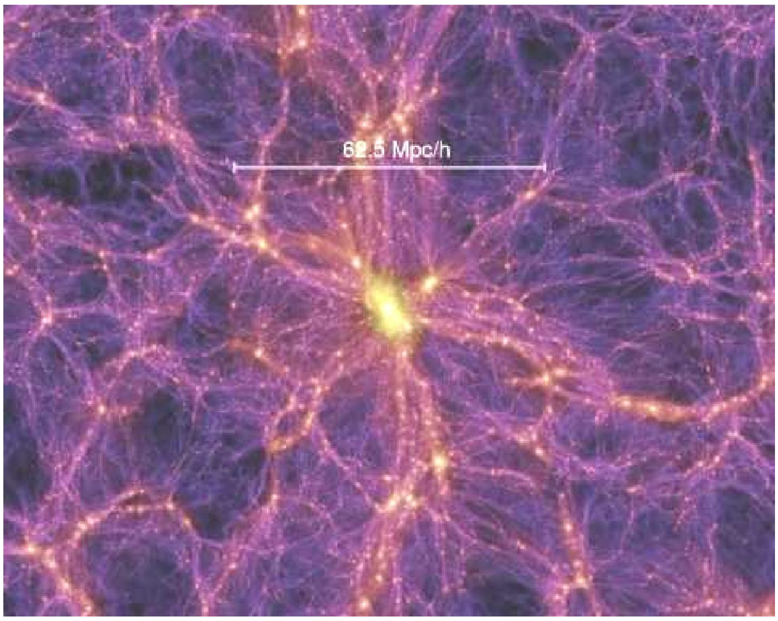
Scenario “monolitico”

(Larson 1974,1975)

Scenario “gerarchico”

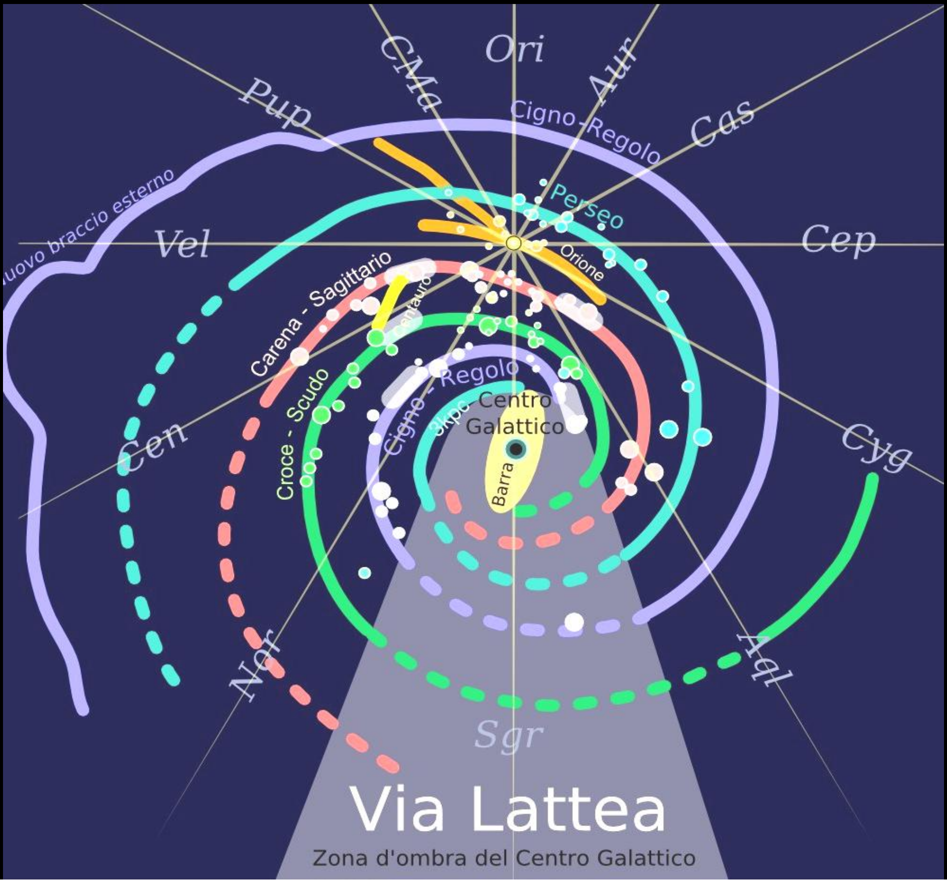
(Kauffmann & White 1993)



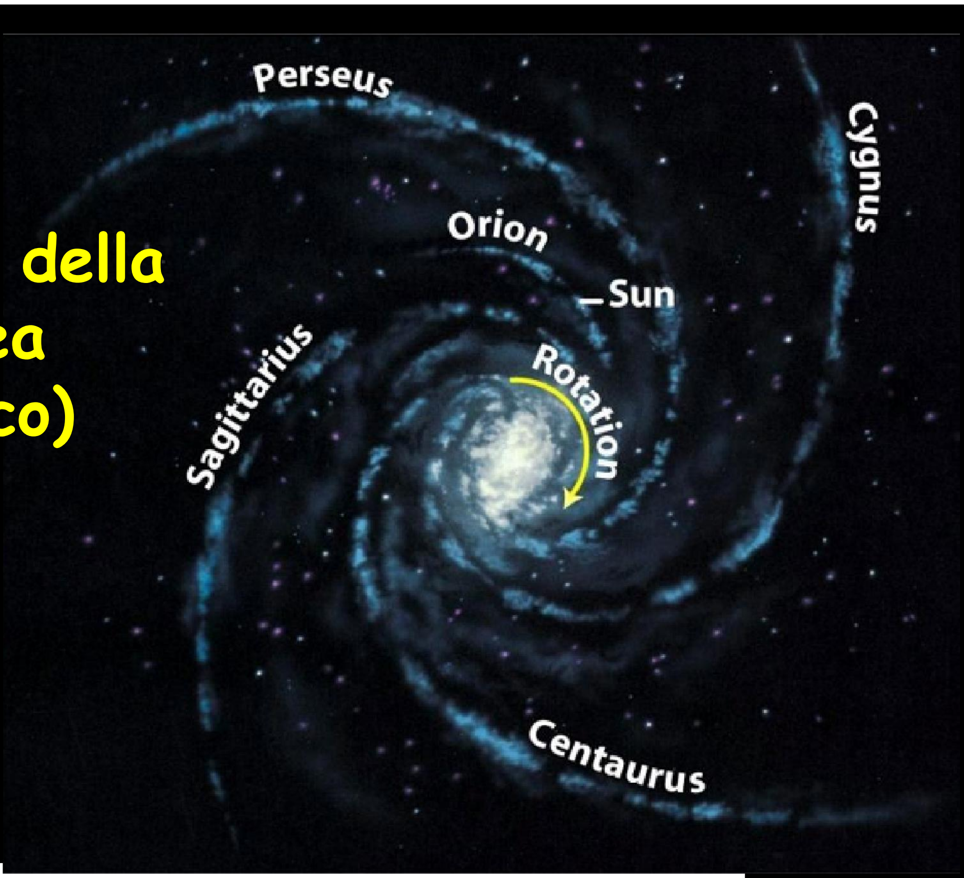
http://en.wikipedia.org/wiki/Galaxy_formation_and_evolution

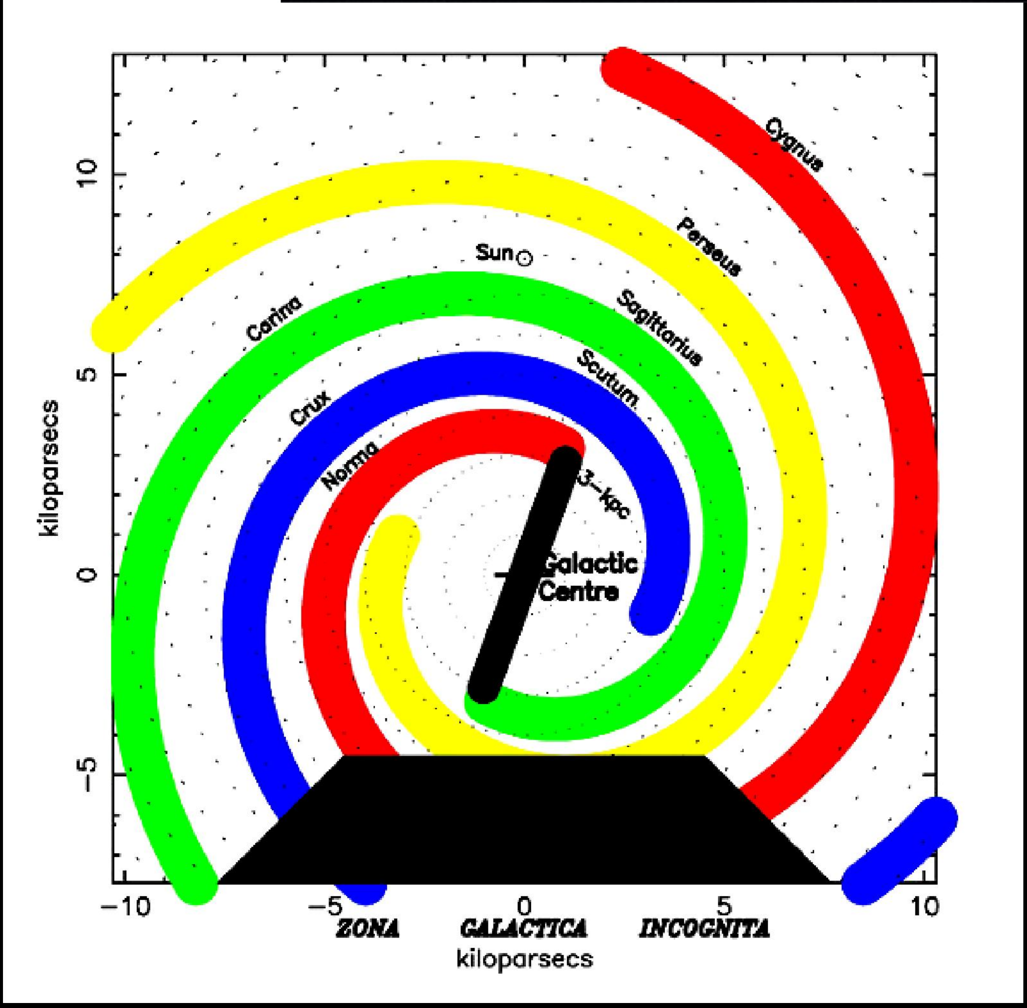
http://en.wikipedia.org/wiki/Dwarf_galaxy_problem http://it.wikipedia.org/wiki/Via_Lattea

La Via Lattea



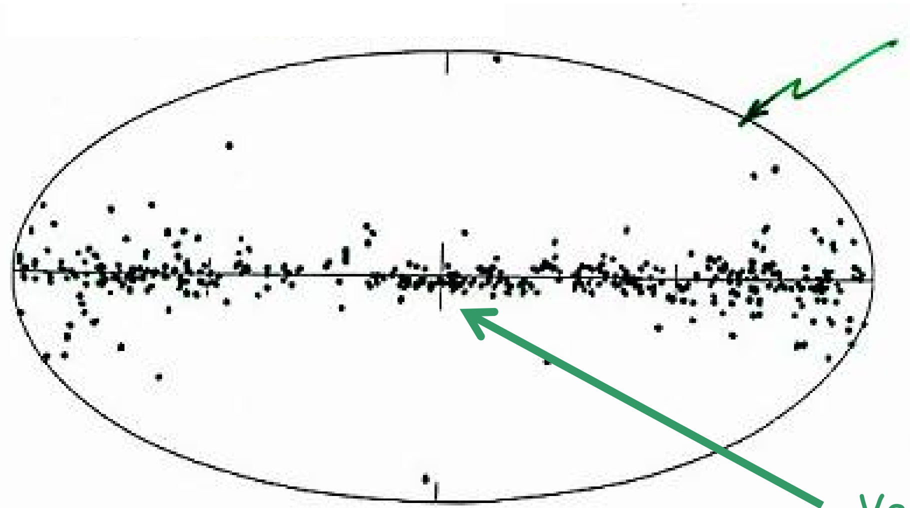
I vari bracci della Via Lattea (schematico)





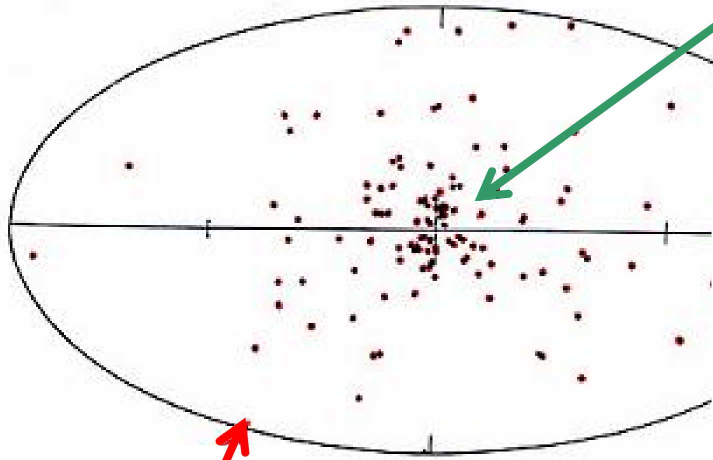
Vallée (2005)

I diversi sistemi stellari nella Via Lattea



Ammassi aperti

Verso il centro galattico



(da “dentro”)

(in sezione)

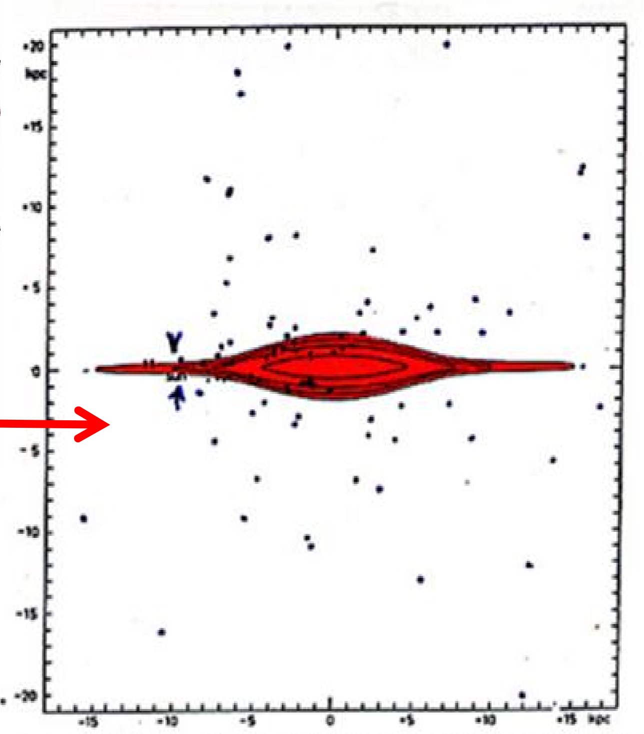
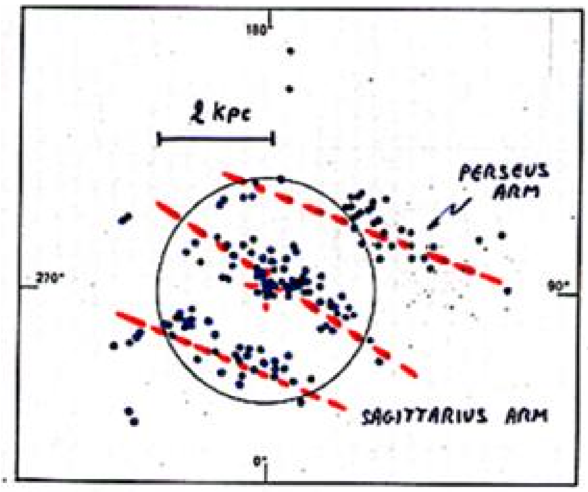


Fig. 23.6: Il *sistema galattico*: distribuzione spaziale degli ammassi globulari, proiettata su di un piano passante per il sole e perpendicolare al piano galattico, ed aree di uguale densità (riferite alle vicinanze del sole). Nel piano galattico è rappresentato, punteggiato, il sottile strato di materia interstellare con popolazione I estrema (braccio della spirale) (secondo J. H. Oort).

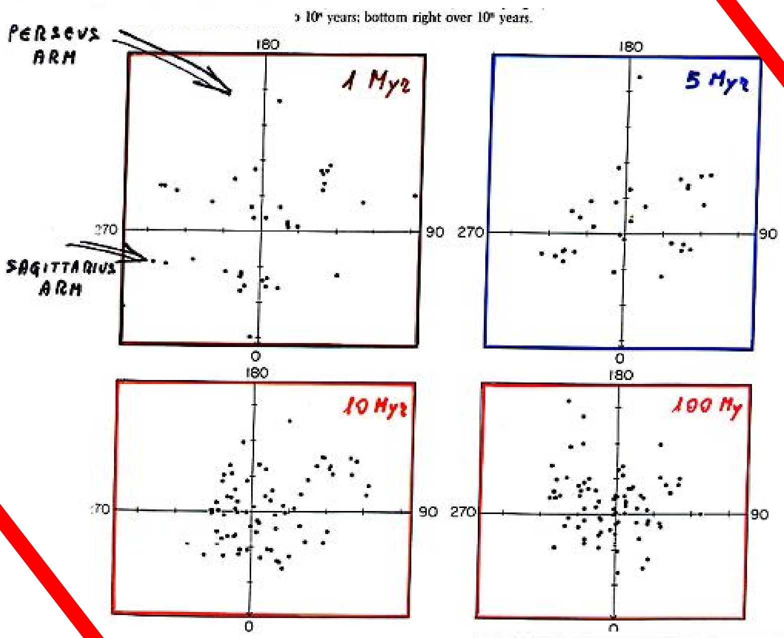
Ammassi globulari

http://en.wikipedia.org/wiki/Globular_cluster

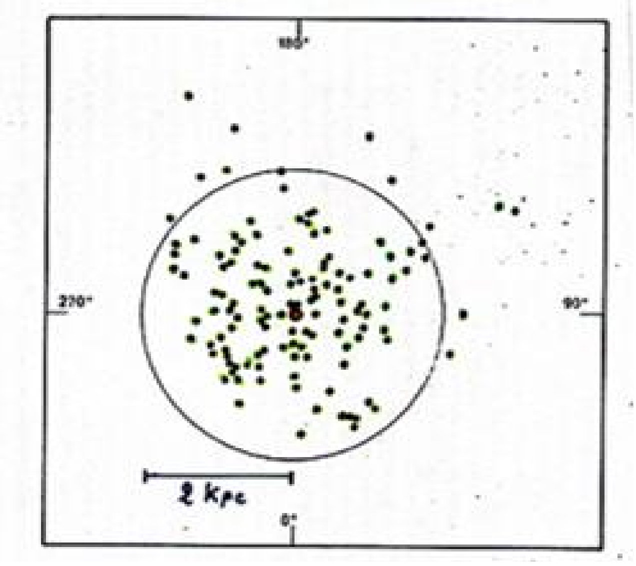
Gli ammassi aperti come traccianti dei bracci a spirale



Associazioni O-B (<1Myr)



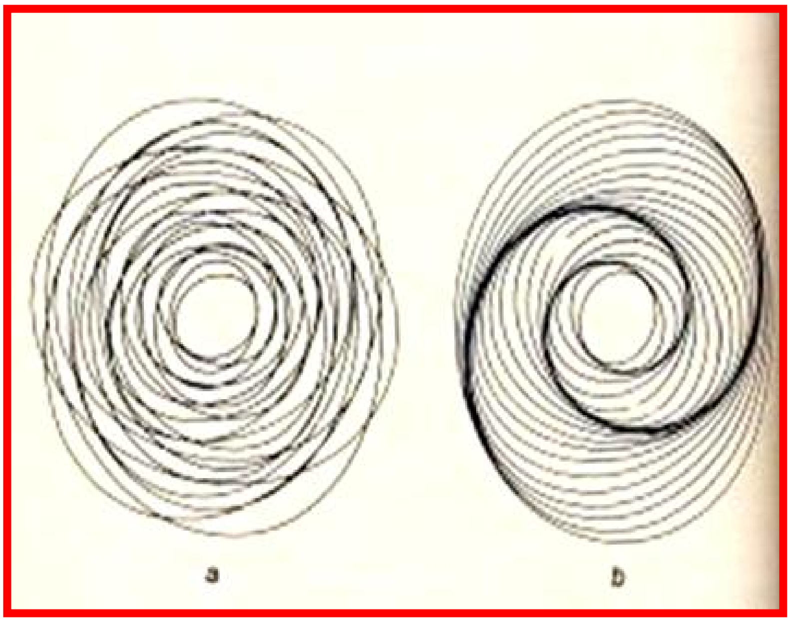
Eta'

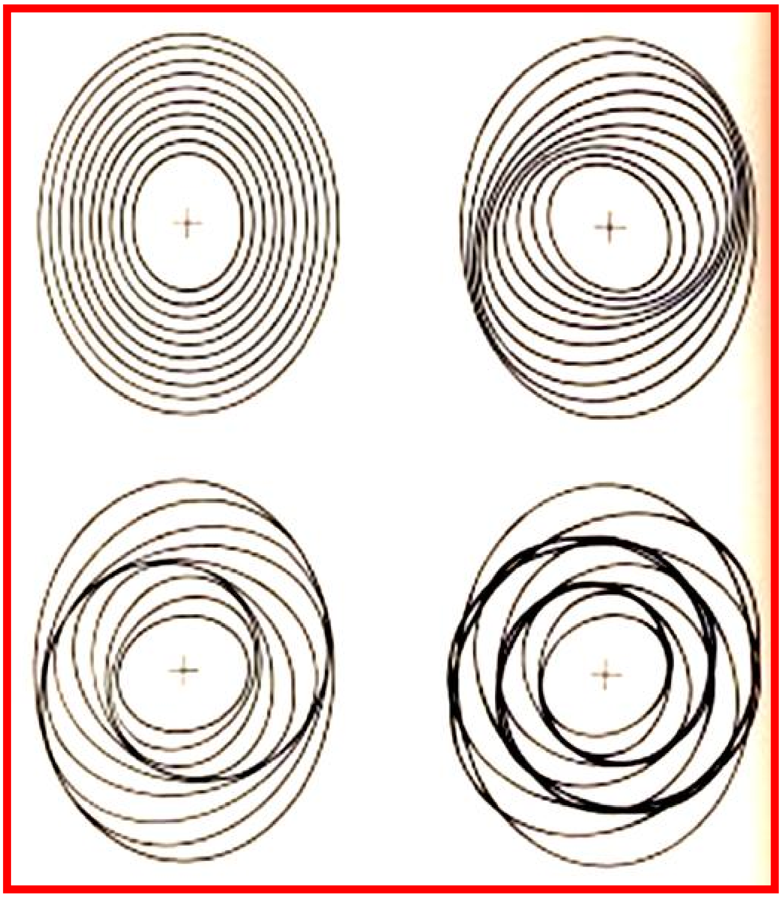


Ammassi aperti (>1Gyr)

http://it.wikipedia.org/wiki/Ammasso_aperto

Risonanze orbitali & genesi delle braccia a spirale





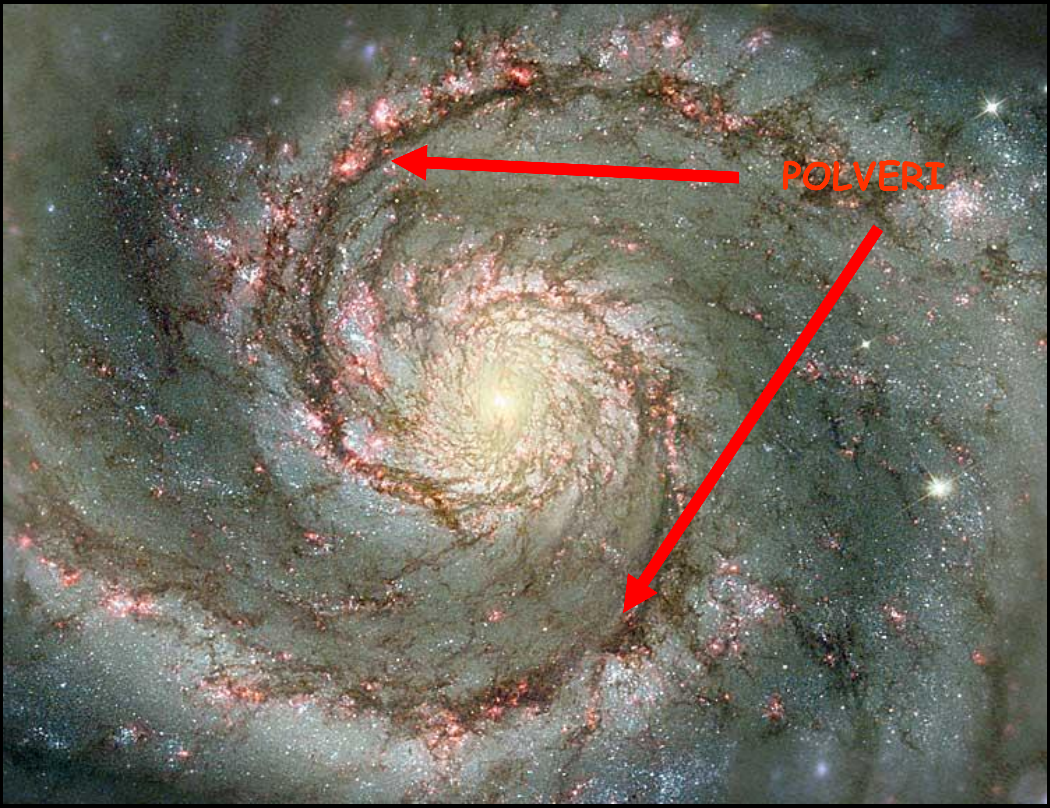
Kalnajs
(1986)

http://en.wikipedia.org/wiki/Density_wave_theory

Il meccanismo di formazione stellare

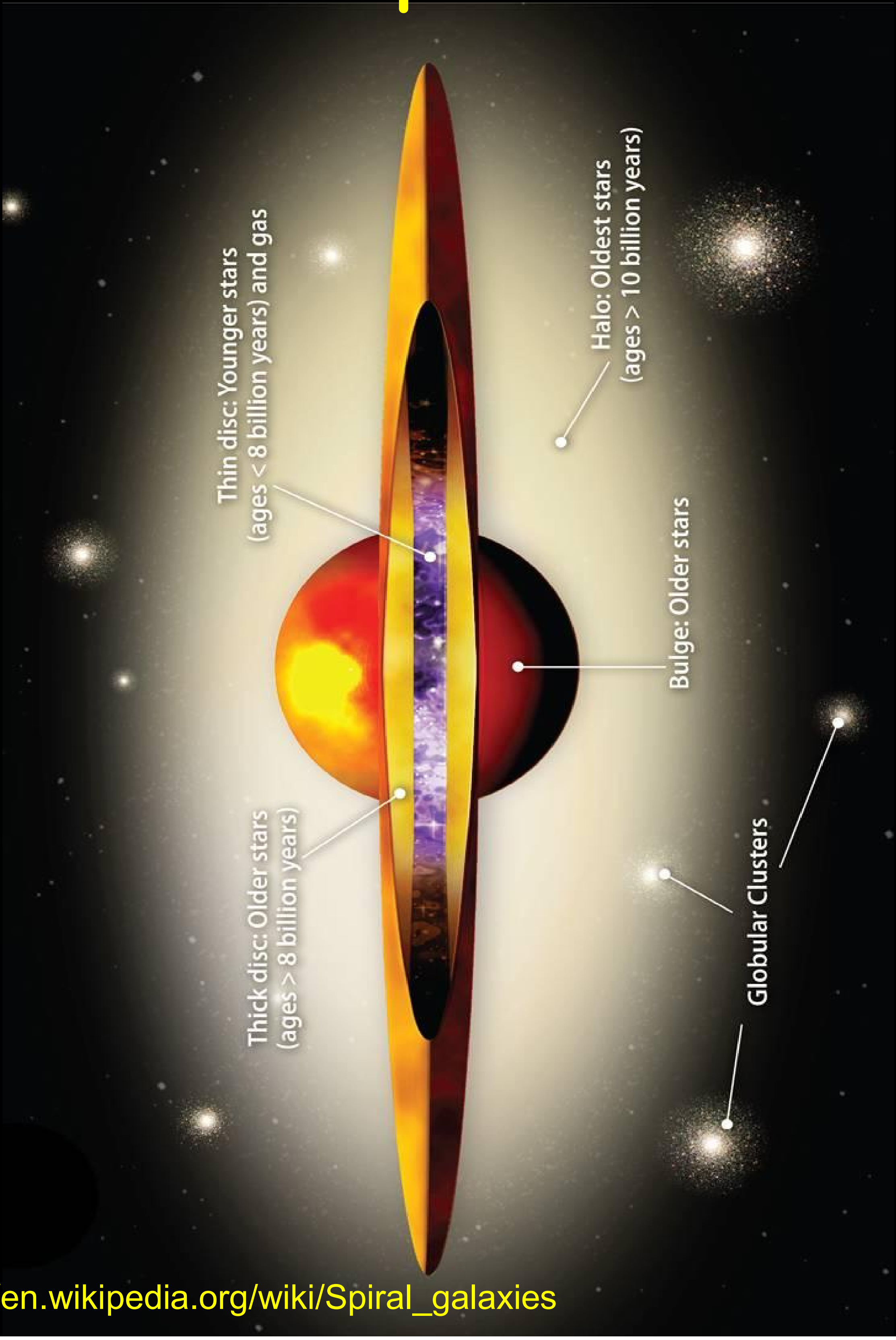
Il caso di M51

Ottico



Ultravioletto

Struttura delle galassie a spirale



http://en.wikipedia.org/wiki/Spiral_galaxies

Il Diagramma di Bottlinger e la diagnostica delle popolazioni stellari

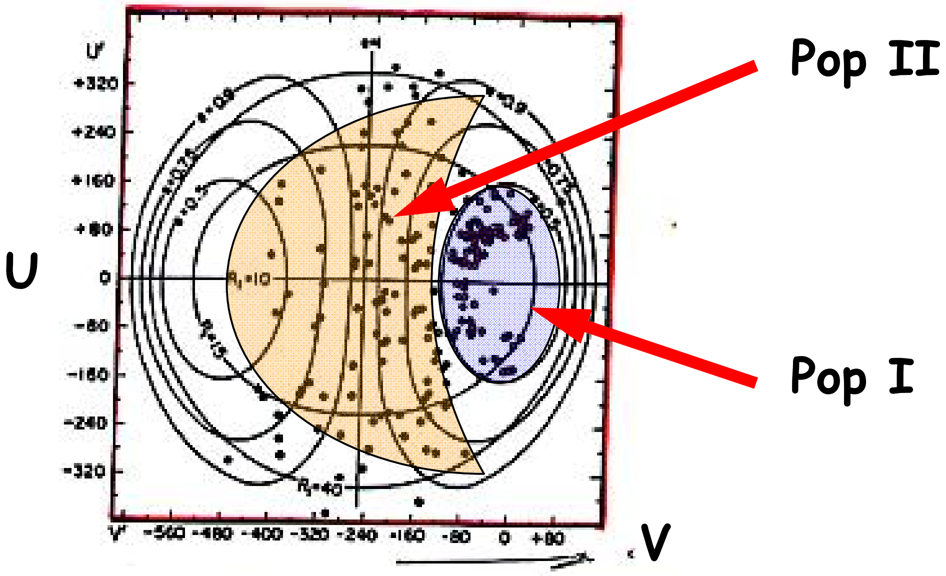
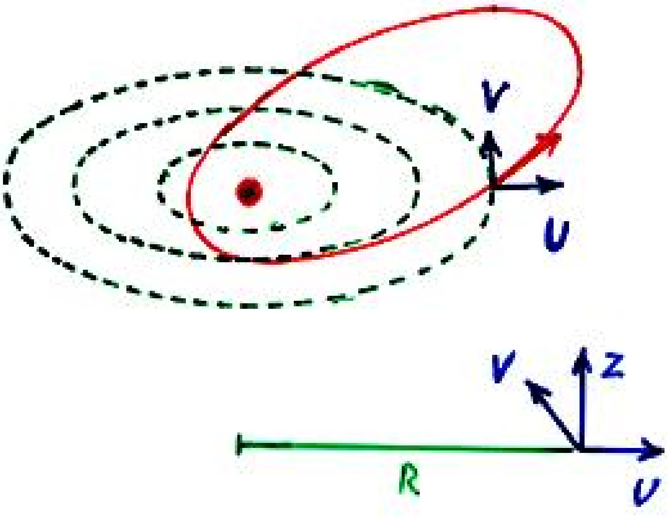
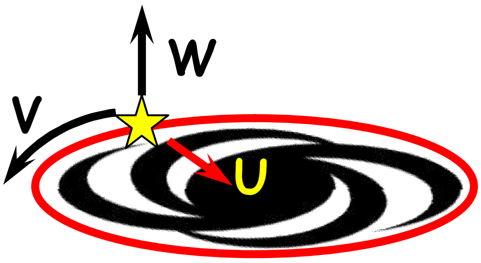
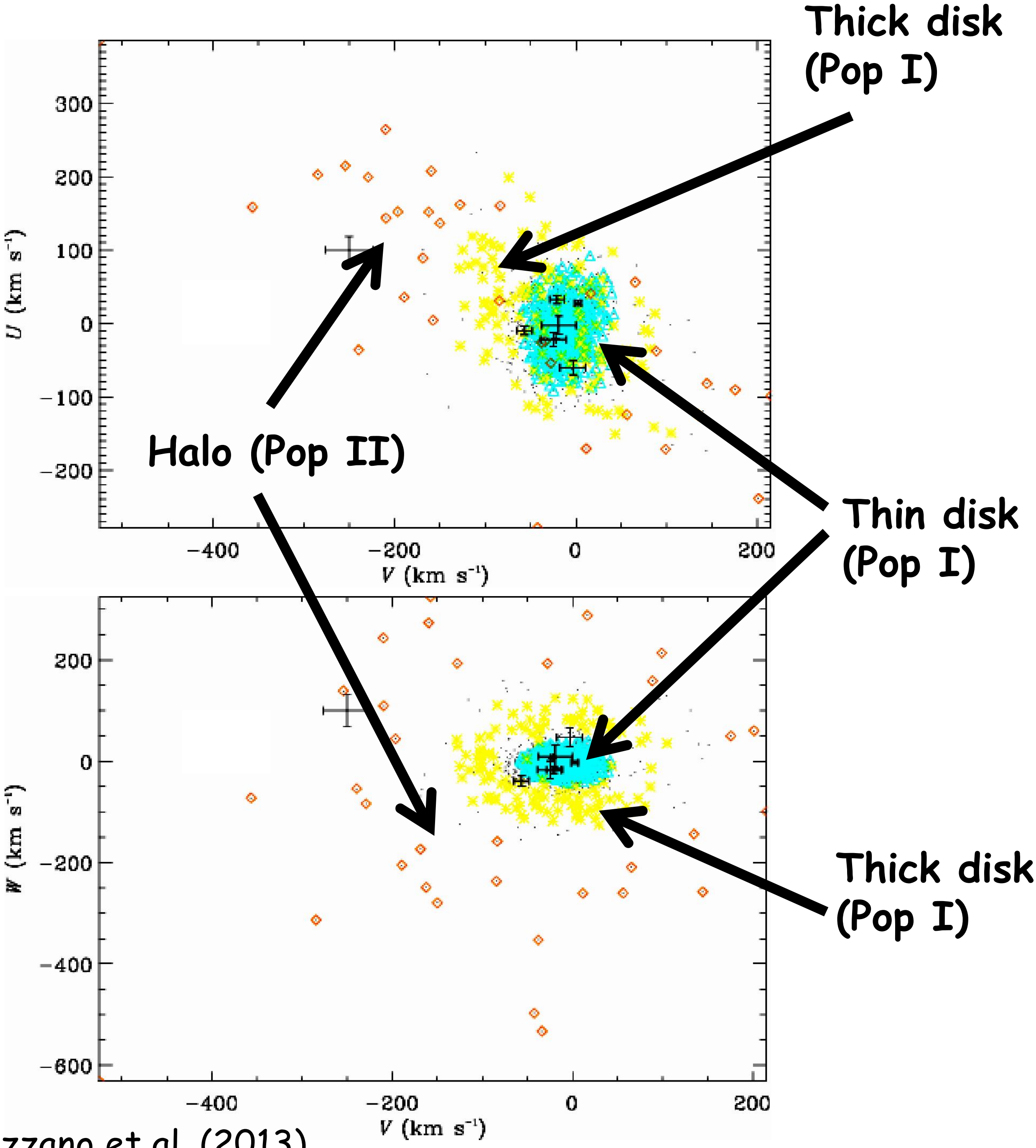


Fig. 23.10: *Diagramma di Bottlinger*. Sono riportate le componenti delle velocità galattiche *U'* (verso l'anticentro) e *V'* (nel senso della rotazione) relative ai dintorni del sole. Gli assi ortogonali rappresentano le *U* e *V* assolute. Per ogni curva è data l'eccentricità orbitale *e* e la distanza apogalattica R_1 in kpc. Nel capitolo 27 diremo sulle stelle (segnate con ●) aventi un eccesso nell'ultravioletto $\delta(U-B) > +0^m.16$, cioè le stelle povere di metalli della popolazione II di « halo ». Queste sono, incidentalmente, stelle veloci con grande velocità spaziale. Con ○ sono segnate le stelle con $\delta(U-B) < +0^m.16$, le quali costituiscono una transizione dalla popolazione II di halo alla popolazione del disco galattico, con orbite meno eccentriche (secondo O. J. Eggen).



Il Diagramma di Bottlinger - 2





Thick disk
(Pop I)

Halo (Pop II)

Thin disk
(Pop I)

Thick disk
(Pop I)

Gazzano et al. (2013)

La struttura verticale del disco

SANDAGE (1987)

SANDAGE & FOUTS (1987)

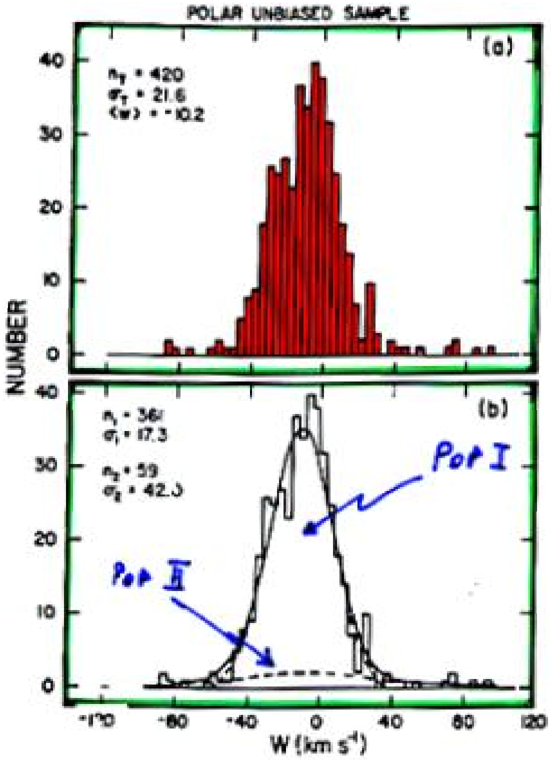


FIG. 2. (Top) Distribution of W velocities from Table VI for the 420-star sample, binned in 4 km s^{-1} intervals. (Bottom) Two-Gaussian fit to the observed distribution. The $\langle W \rangle_2$ and σ_2 values for the high-velocity component have been assumed.

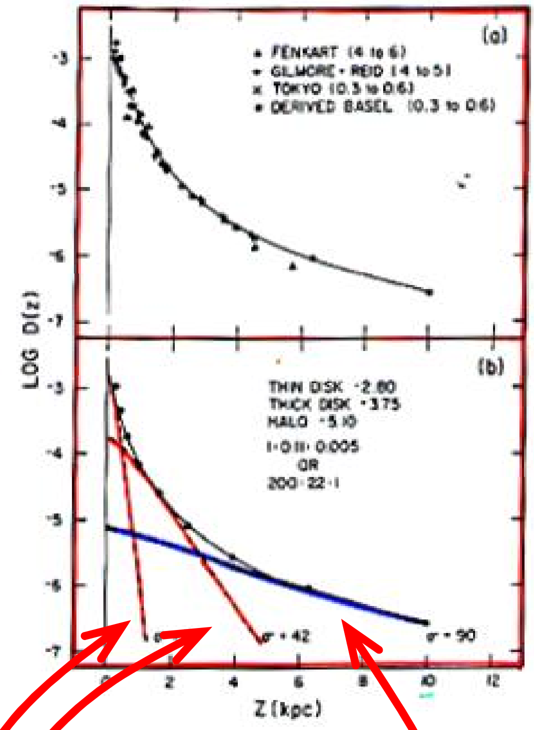


FIG. 2. (Top) The density $D(Z)$ perpendicular to the galactic plane for the four data sets listed in Table II, III, and V. (Bottom) Decomposition of the observed log $D(Z)$ function into three components using the calculated densities shown in Fig. 1.

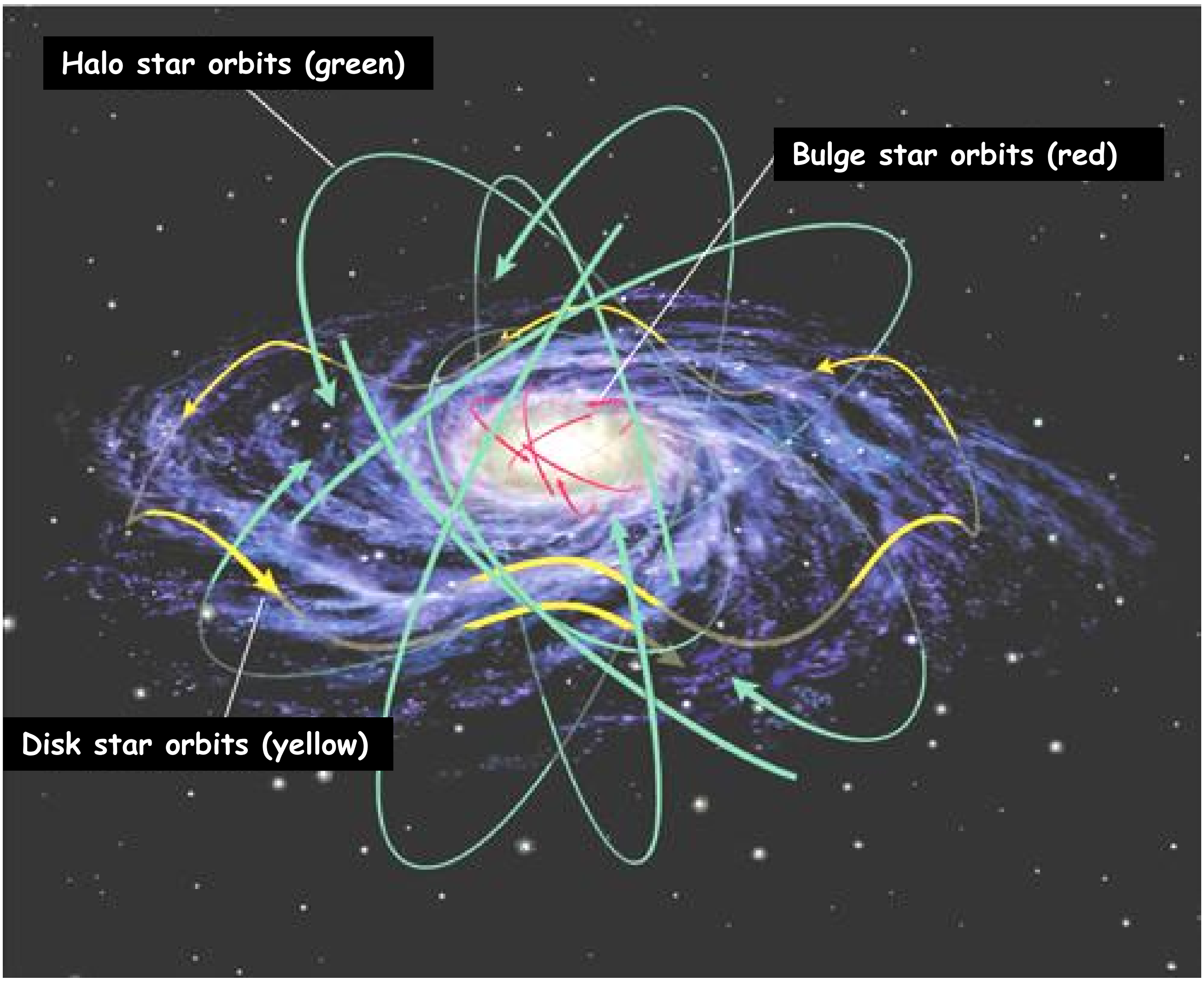
HALO 1 ■

THICK DISK 22 ■

THIN DISK 200 ■

ρ/ρ_{HALO}

Le orbite delle Pop I e Pop II



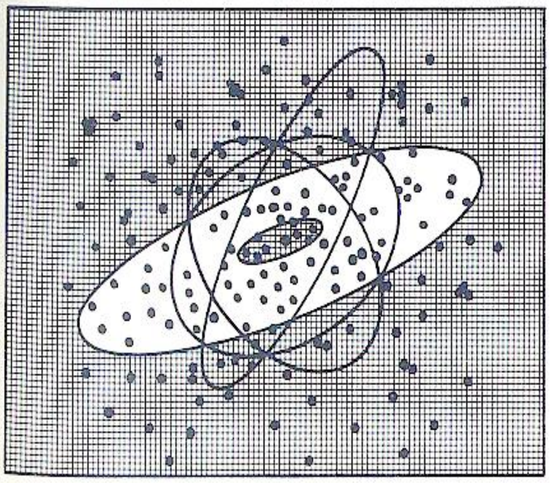
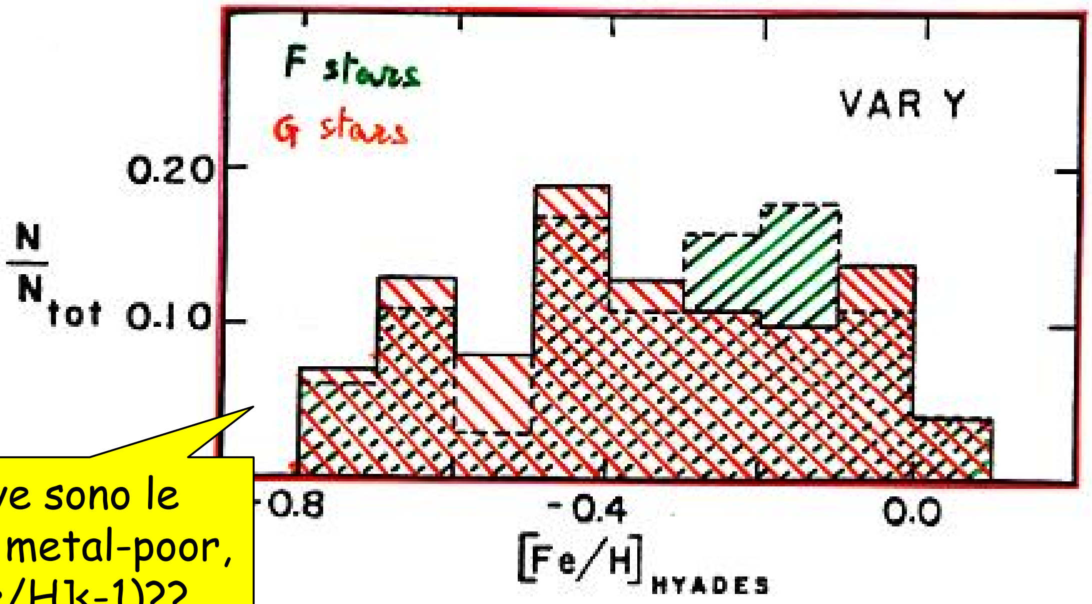


Fig. 11 Schema della costituzione della Galassia. Sono indicate alcune tipiche orbite delle stelle e degli ammassi dell'alone.

Castellani (1986)

Thick & Thin disk:
The G-dwarf problem

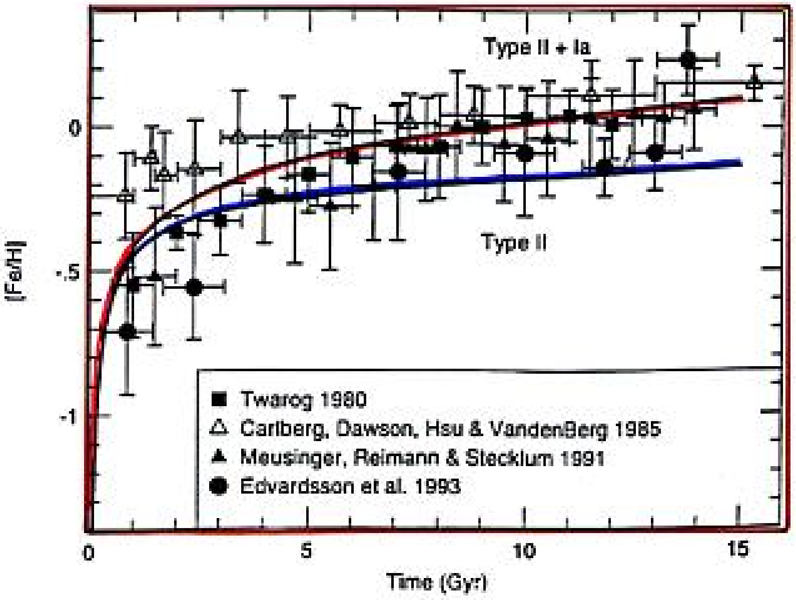
TWAROG (1980)



Dove sono le stelle metal-poor, ([Fe/H]<-1)??

FIG. 8.—F dwarf metallicity distribution (*dashed line*) including corrections for stellar evolution and scale height effects which produce a constant SFR compared to the G dwarfs (*solid line*).

TIMMES et al. (1995)



Thick & Thin disk e SFR

PARDI & FERRINI (1994)

SFR

$[M_\odot/pc^2/yr]$

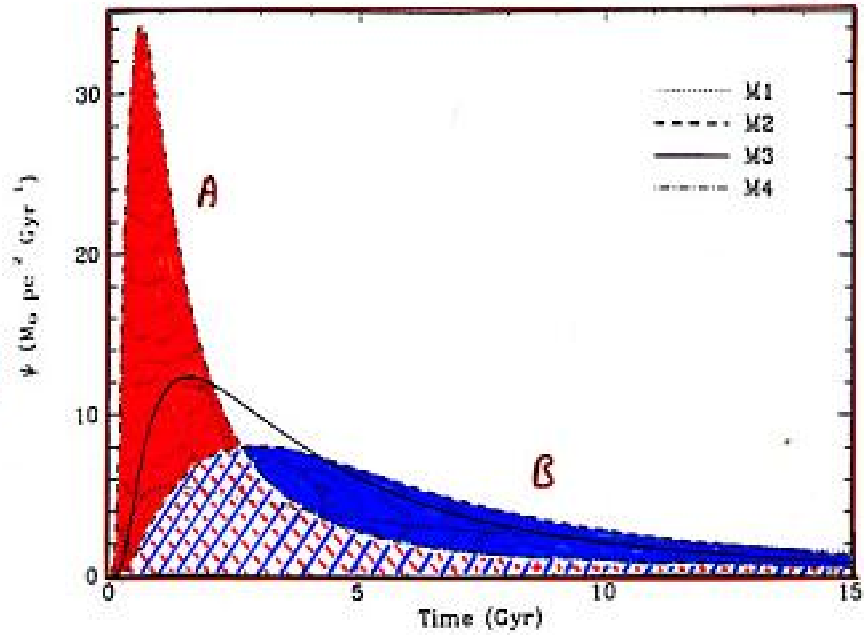


FIG. 3.—SF rate vs. time (M1–M4)

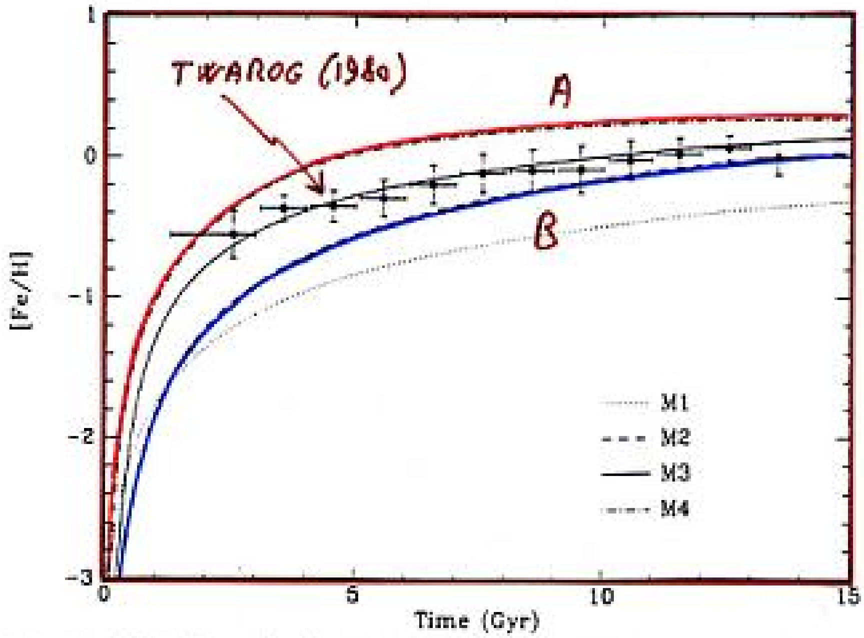
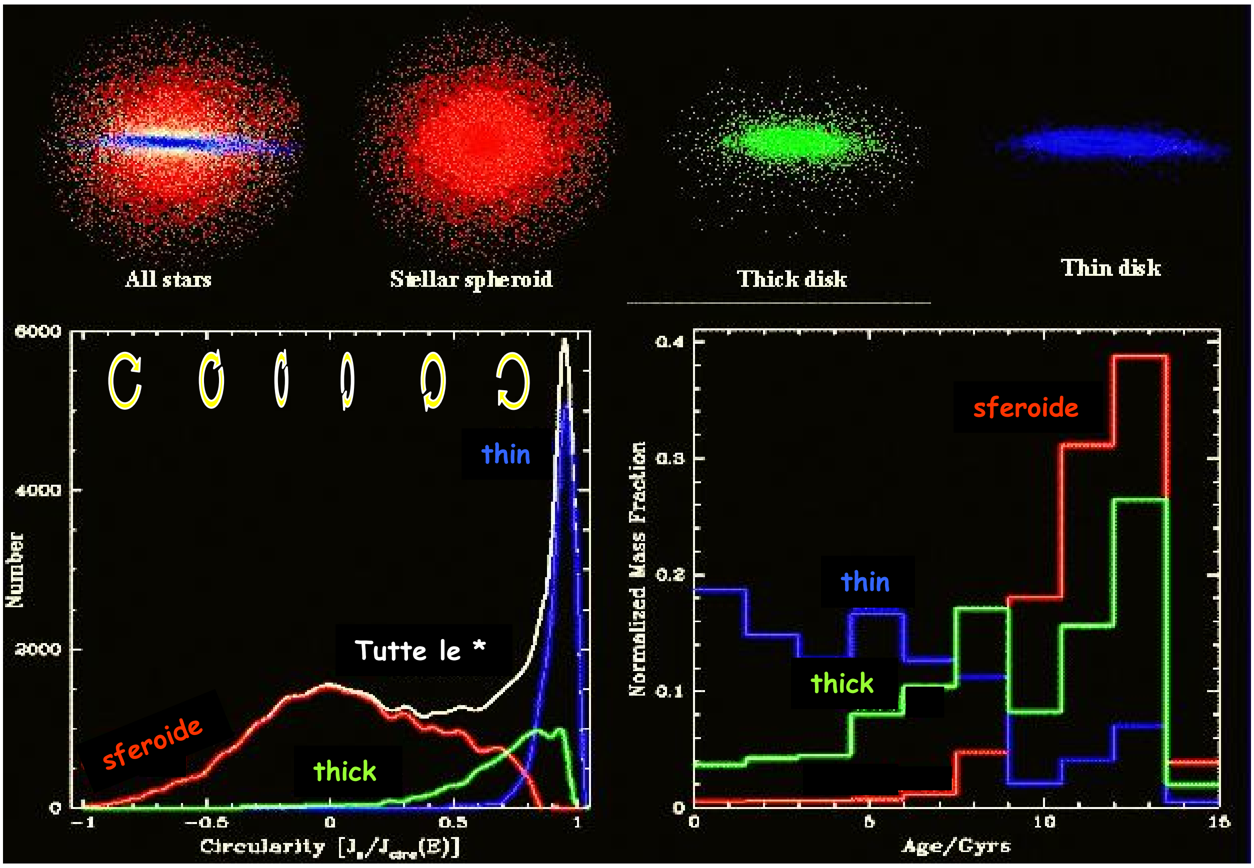
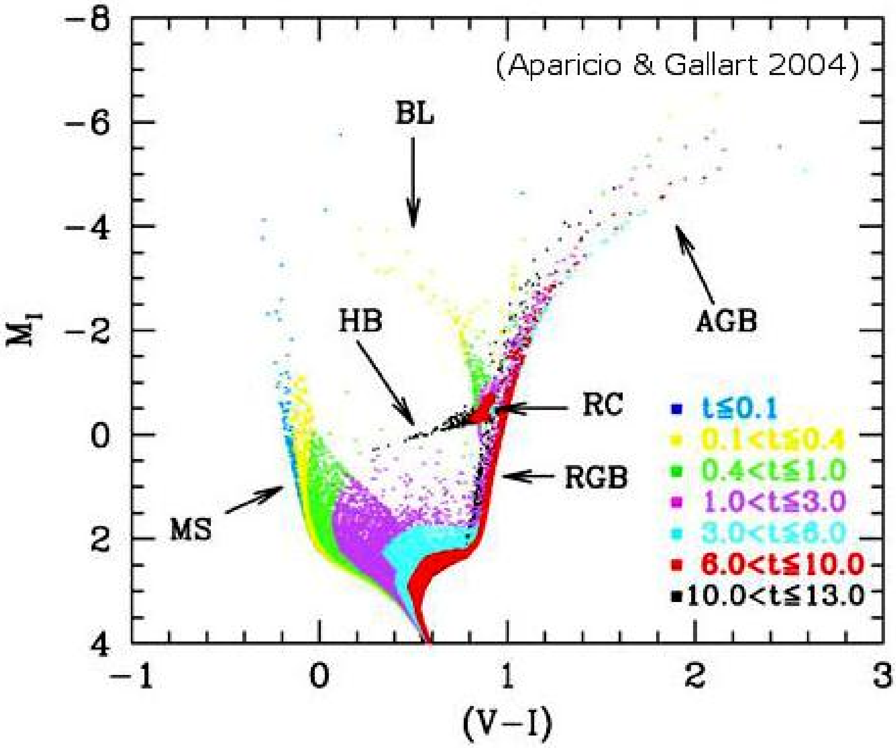


FIG. 4.—[Fe/H] vs. time for the same models of Fig. 3, superposed on data of Twarog (1980).

Le popolazioni stellari composite nel disco di M31



Collins & the RAVE coll. (2010)



M_I apparente

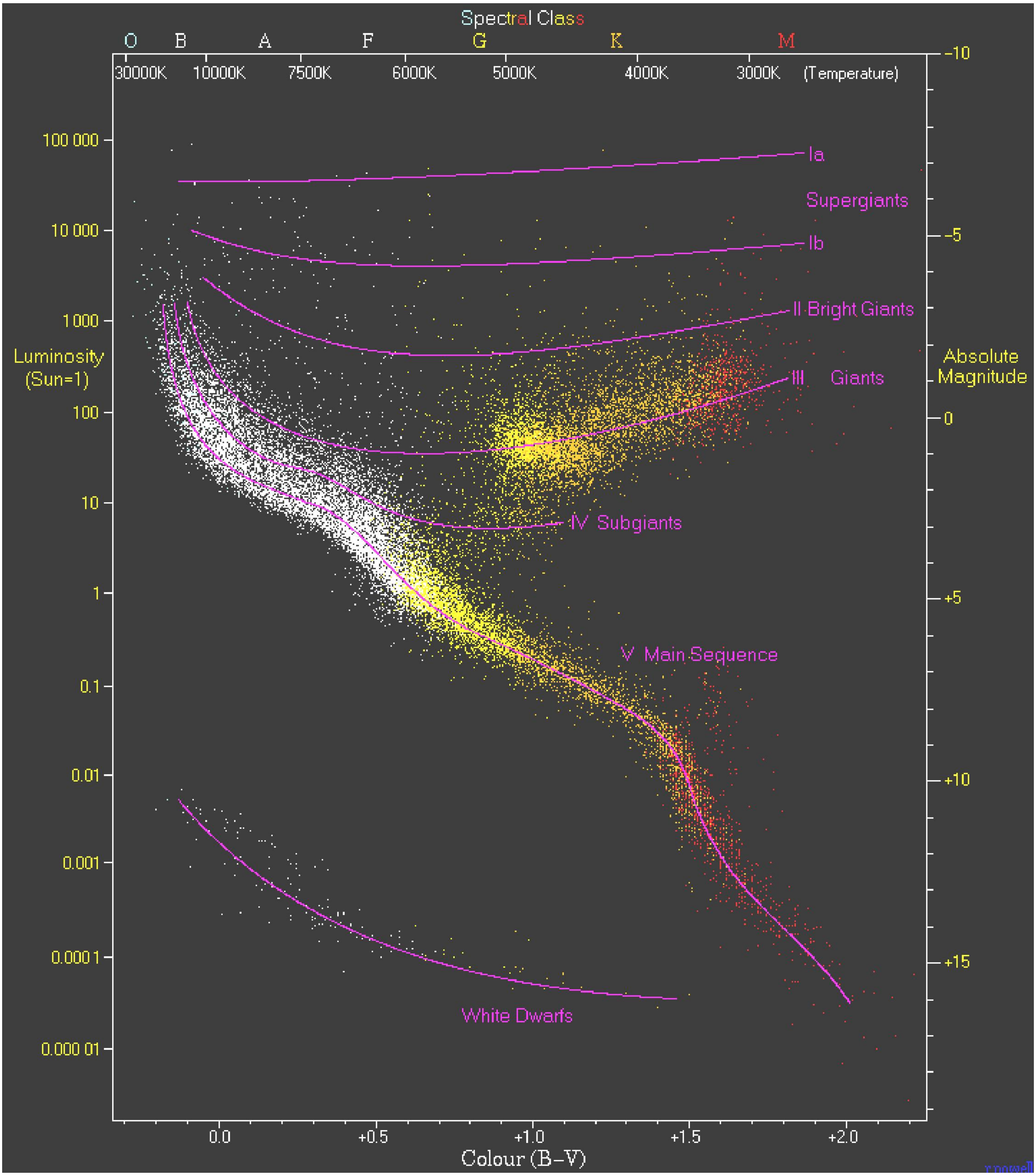
+21.0

+23.0

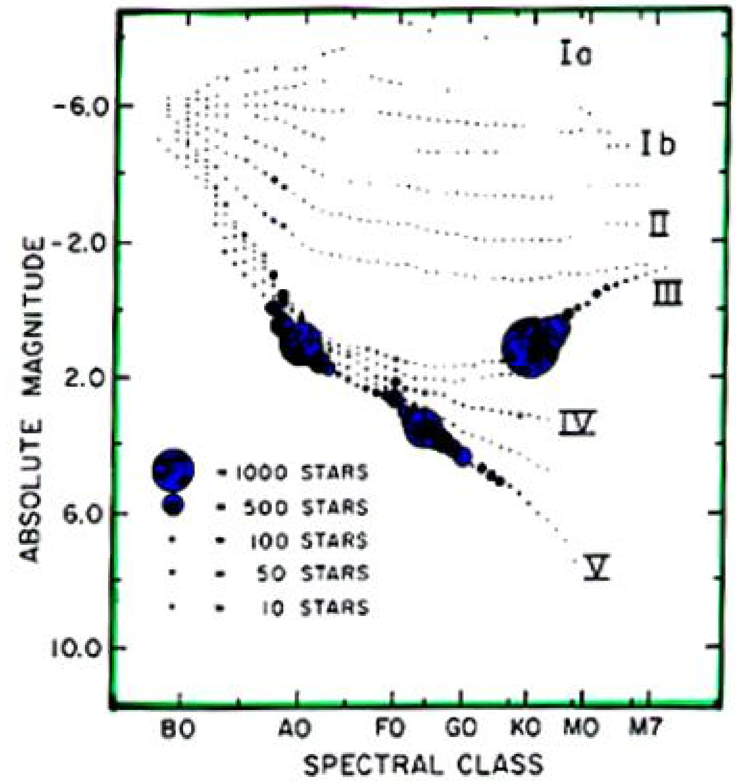
+25.0

+27.0

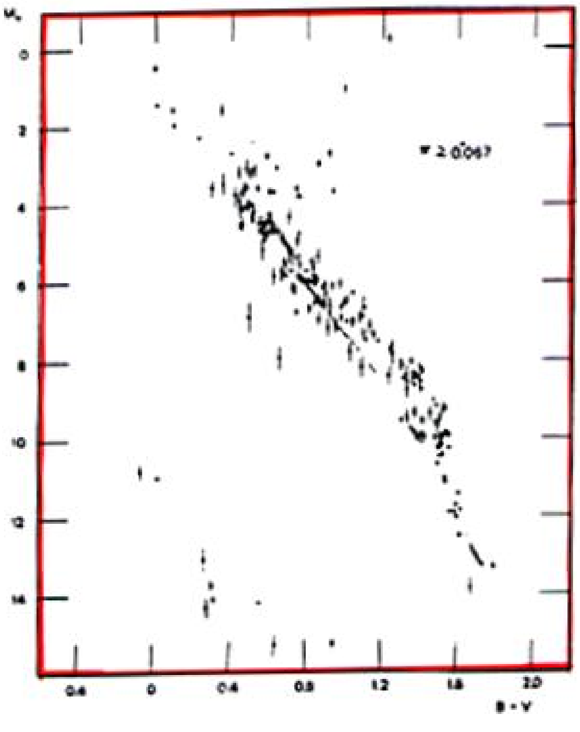
Hipparcos (1993) (22,000 stars)



I conteggi stellari e la determinazione della IMF

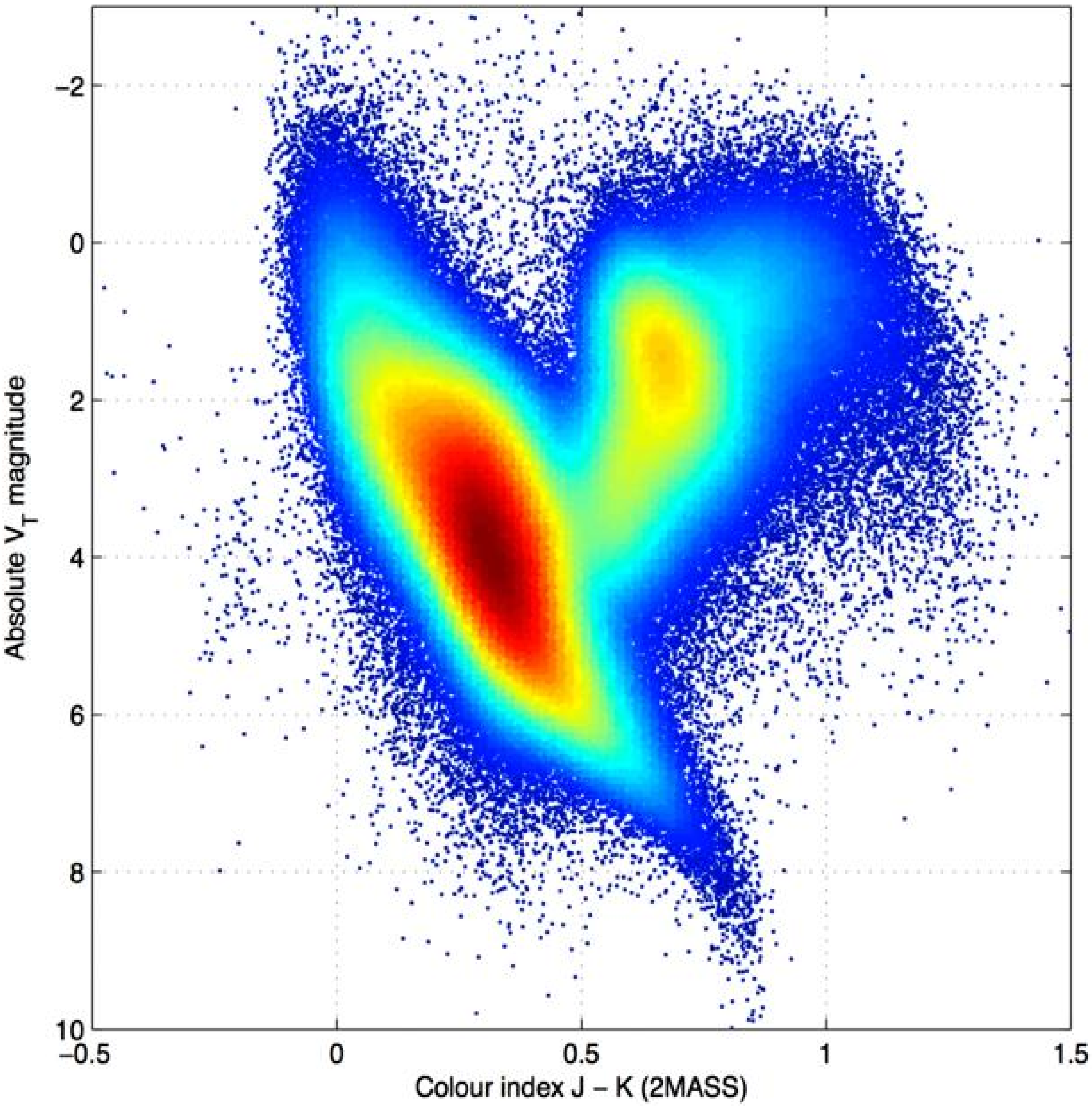


App. Mag. limited



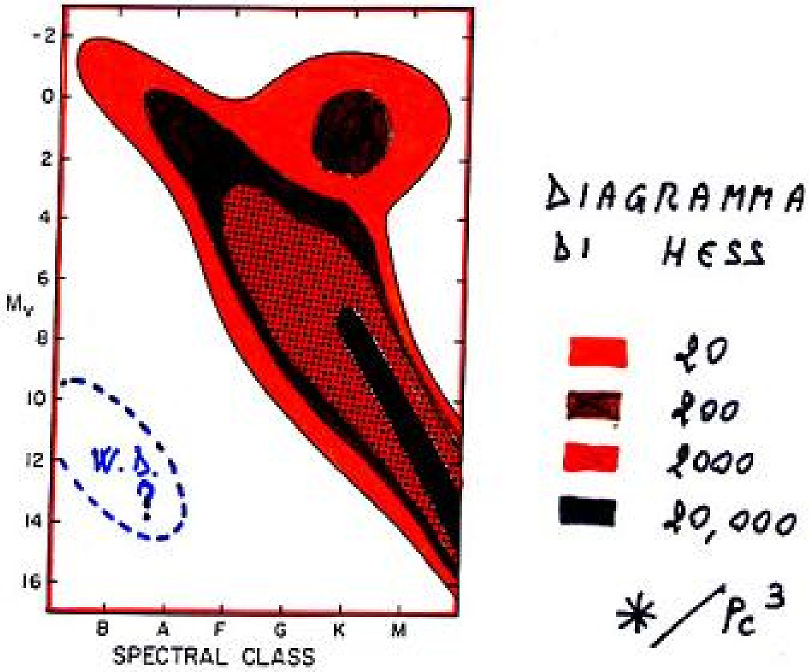
Distance limited

GAIA'S FIRST HERTZSPRUNG-RUSSELL DIAGRAM (~10^6 stars) (2015)

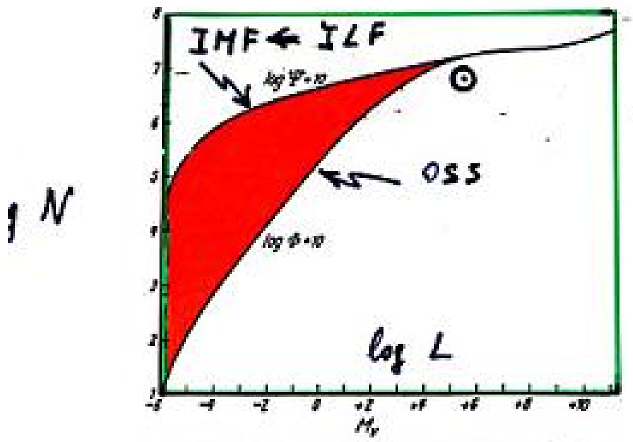


Il diagramma di Hess

Figure 5.2. Schematic Hess diagram for stars in our neighborhood. Numbers of stars per cubic parsec are shown by contours which refer to 20, 200, 2000, and 20,000 stars. The main sequence runs along the ridge. Probably the peak is reached at about the bottom right corner of the diagram, with about 40,000 stars per cubic parsec. Statistics for fainter stars do not permit us to say how fast the slope falls off from there. The contours for white dwarfs are not shown; these stars populate a moderately high ridge, roughly parallel to the main ridge and separated from it by a deep valley.



Statistica stellare. Funzione di luminosità

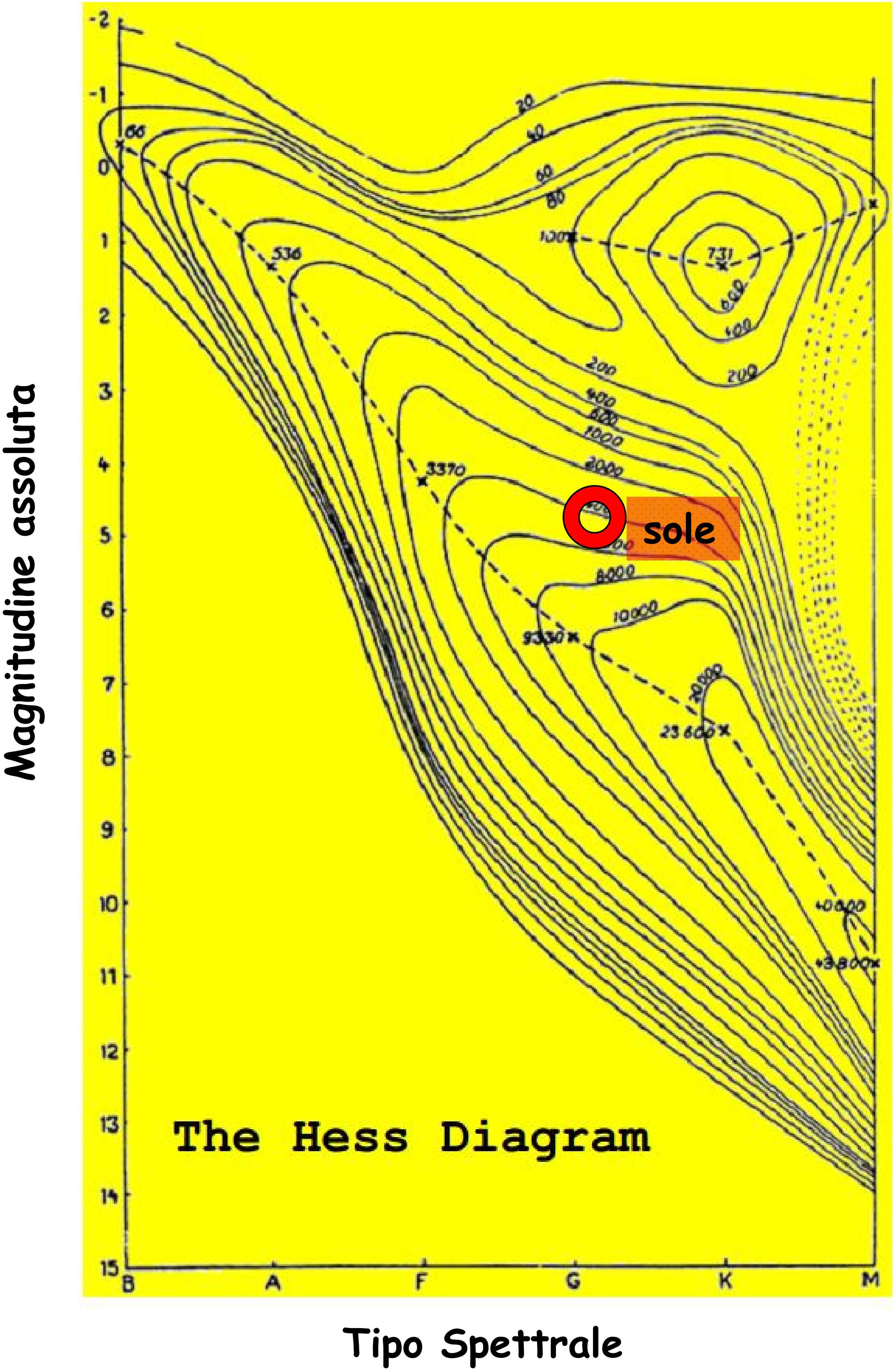


KAPTEYN & VAN RHIJN '20

SALPETER (1953)

Fig. 26.8: Funzione di luminosità $\Phi(M_v)$ e funzione iniziale di luminosità $\Psi(M_v)$, per stelle della sequenza principale nei dintorni del sole. La Φ e la Ψ dànno rispettivamente il numero osservato di stelle per pc^3 comprese fra $M_v - 1/4$ ed $M_v + 1/4$, e di quelle formatesi a partire dalla formazione della Galassia.

Il diagramma di Hess (2)



La IMF

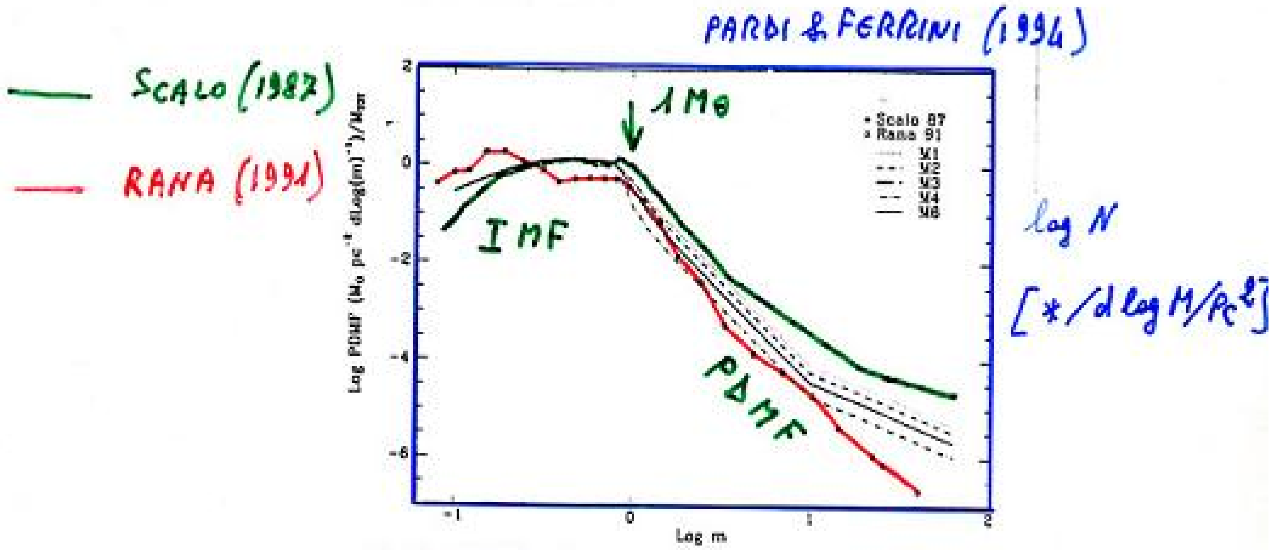
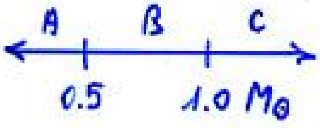


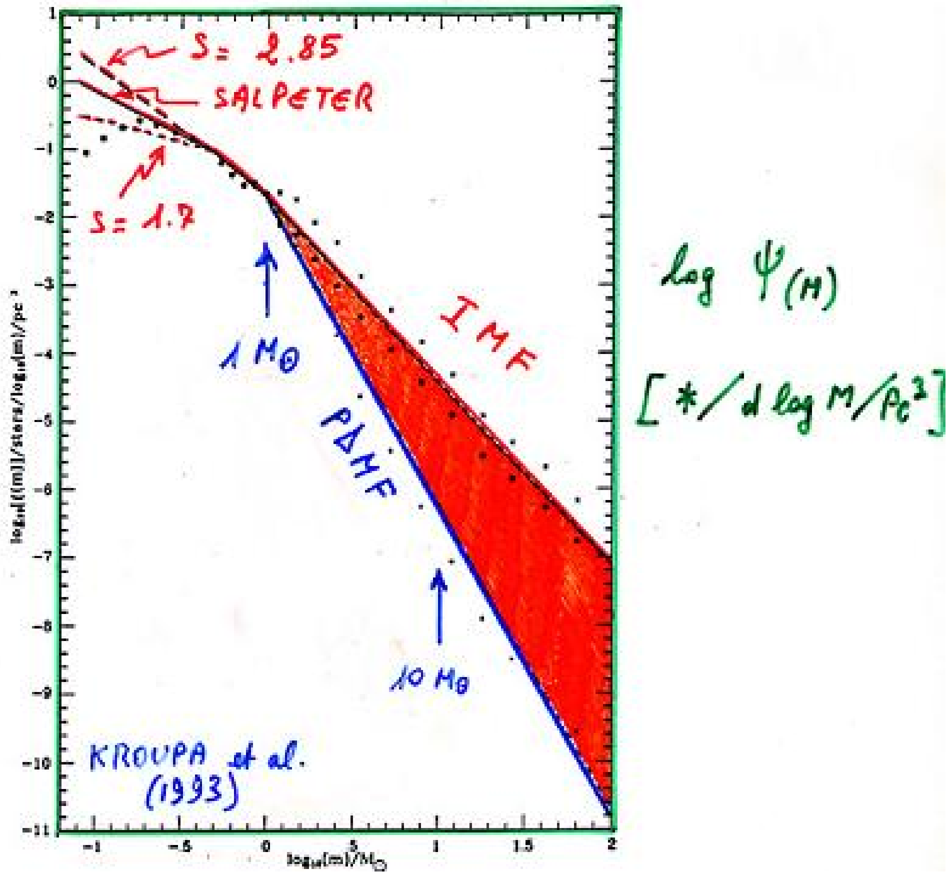
FIG. 12.—PDMFs predicted by the model in cases M1–M4 and M6 superposed on data of Scalo (1987 [*triangles*]) and Rana (1991 [*squares*]).

A) $\psi_{(M)} \propto M^{-1.3}$

B) $\psi_{(M)} \propto M^{-2.2}$

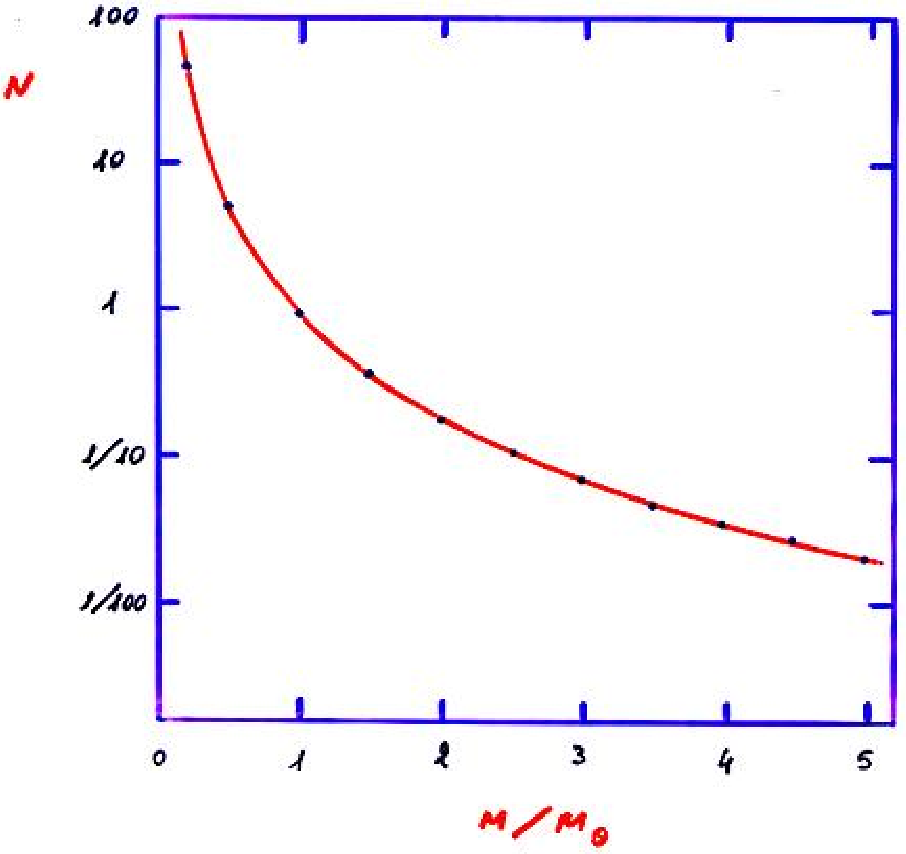
C) $\psi_{(M)} \propto M^{-2.7}$





http://en.wikipedia.org/wiki/Initial_mass_function

La IMF (2)



0.1 ← M → 100

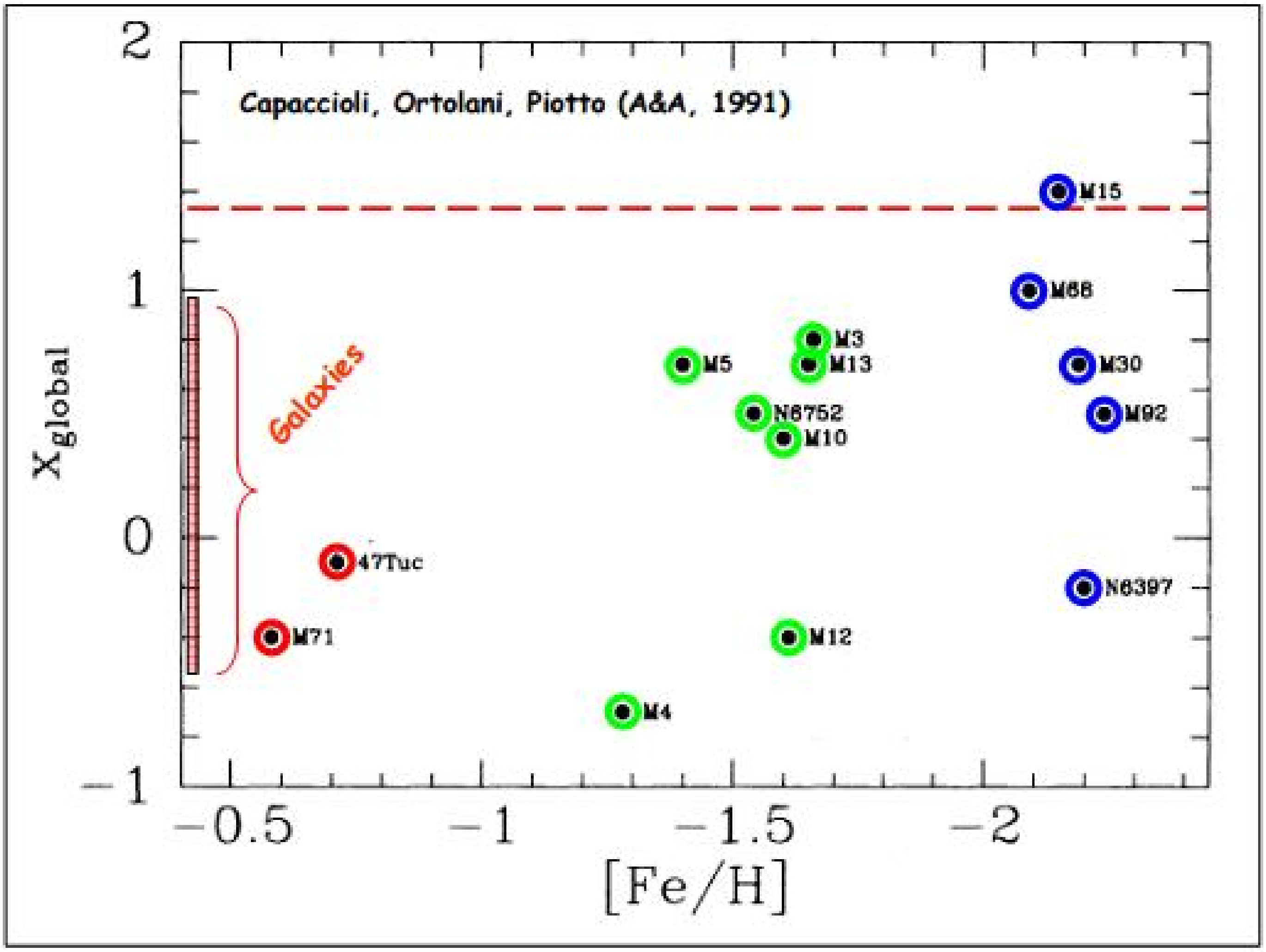
INNESCO REAZIONI TERMONUCLEARI

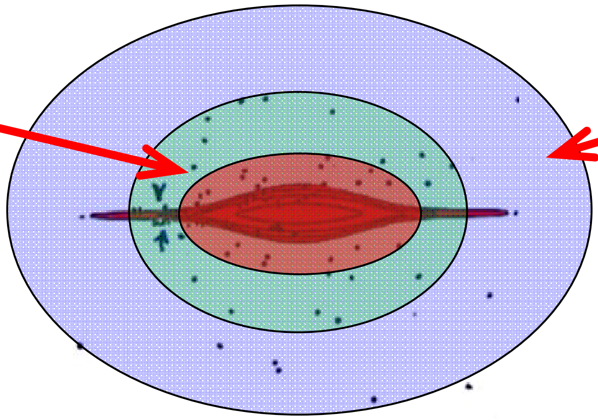
INSTABILITA' STRUTTURALI

M	L	N
0.1	0.0001	220
0.5	0.06	5
1	1	1
2	16	1/5
5	625	1/40
10	10'000	1/220
50	$6\,10^6$	1/10'000

La IMF negli ammassi globulari galattici

Metal rich **Metal poor**


Capaccioli, Ortolani, Piotto (A&A, 1991)



Ammassi metal-rich

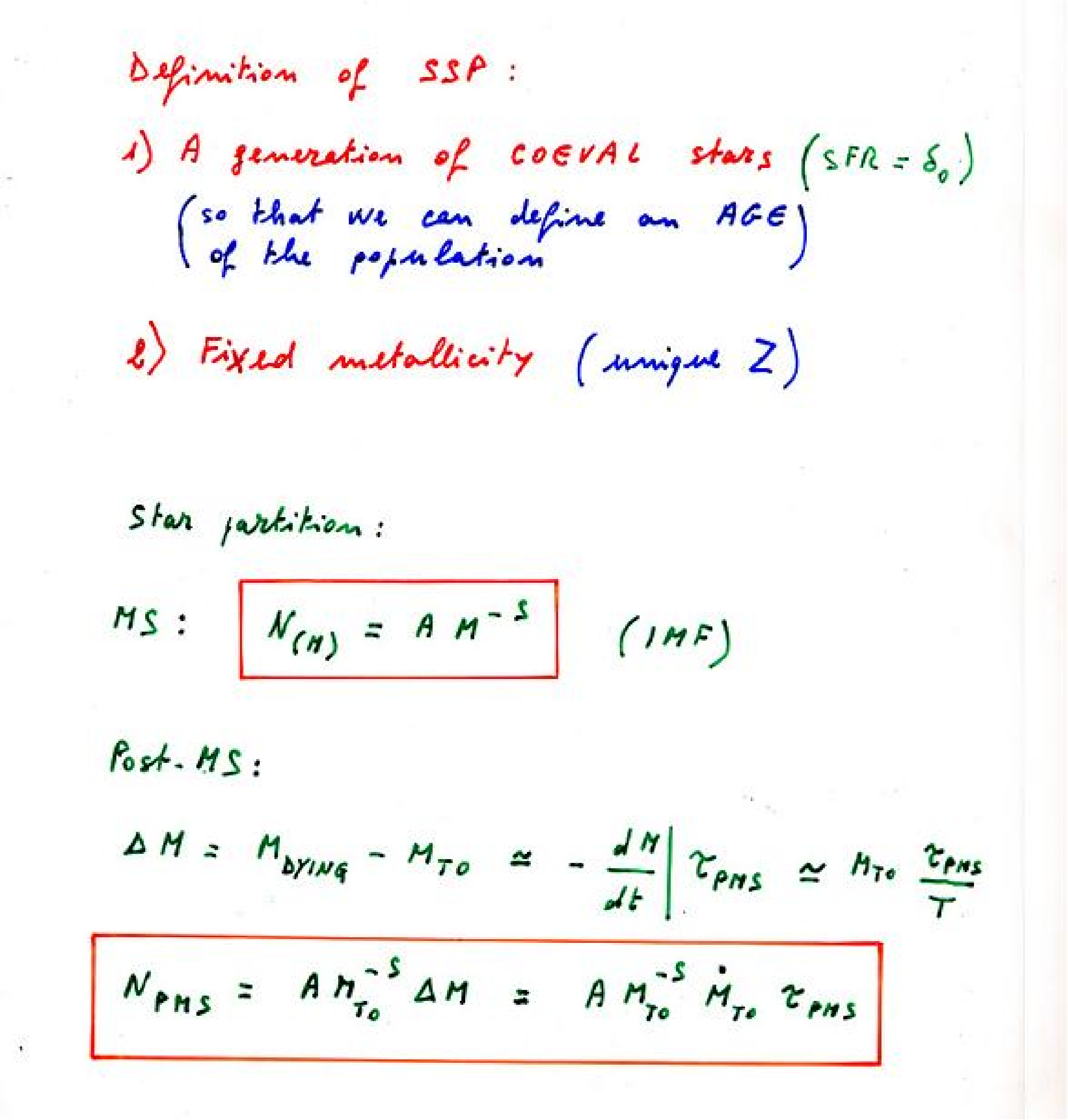
Ammassi metal-poor

Articoli consigliati (vedi Webpage):
http://www.bo.astro.it/~eps/lezioni/lezioni.html

- Galaxy Colors (Buzzoni)
- Sandage (Disco MW)
- Sandage & Fouts (Bottlinger)
- Bottlinger
- SFR (Kennicutt)
- SFR (Ryder & Dopita)
- SFR (Schmidt)
- IMF (Miller & Scalo)
- IMF (Kroupa)
- IMF (Kalirai 2013)
- IMF (Weidemann)
- Chemical evolution of spiral galaxies (Buzzoni)

Teoria delle Popolazioni Stellari Semplici (SSPs)

Renzini & Buzzoni (1986)



Definition of SSP :

1) A generation of COEVAL stars ($SFR = \delta_0$)

(so that we can define an AGE of the population)

2) Fixed metallicity (unique Z)

Star partition:

MS : $\boxed{N_{(M)} = A\, M^{-s}}$ (IMF)

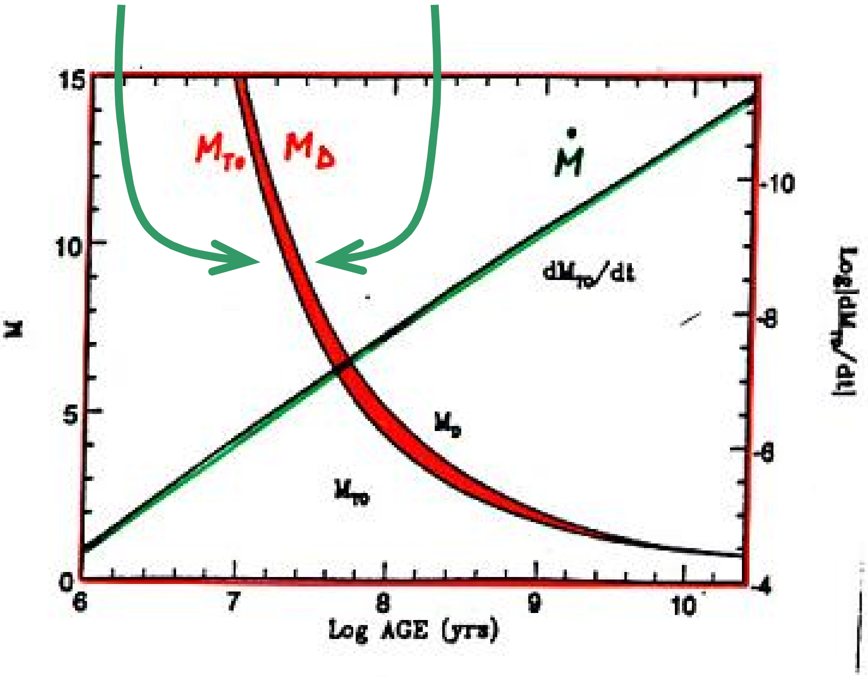
Post-MS:

$$\Delta M = M_{DYING} - M_{TO} \simeq - \left.\frac{dM}{dt}\right| \tau_{PMS} \simeq M_{TO} \frac{\tau_{PMS}}{T}$$

$$\boxed{N_{PMS} = A\, M_{TO}^{-s}\, \Delta M = A\, M_{TO}^{-s}\, \dot{M}_{TO}\, \tau_{PMS}}$$

Massa al
Turn Off

Massa finale
(Nane Bianche)



Renzini & Buzzoni
(1986)

Flusso evolutivo specifico

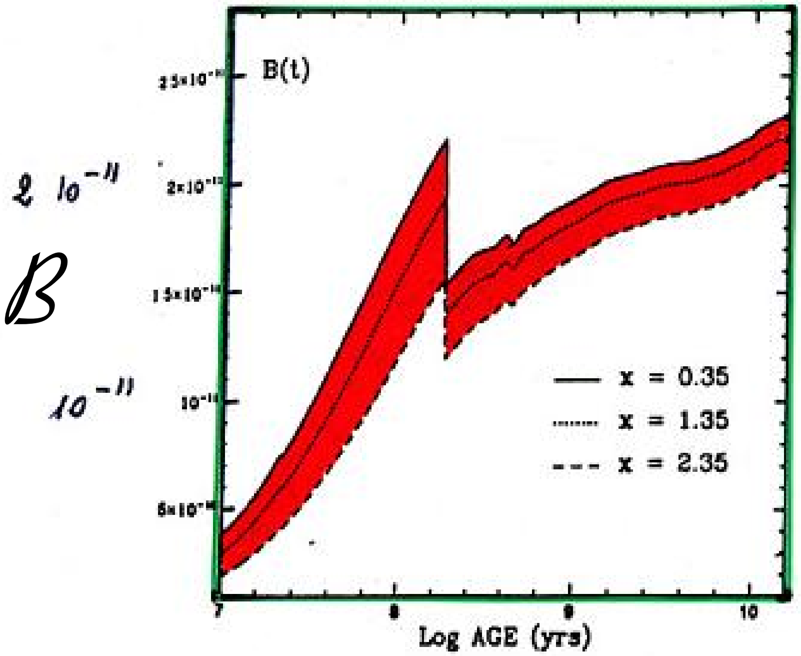


Fig. 1.3: The specific evolutionary flux B(t) as a function of age for three IMF slopes (1 + x).

$\mathcal{B}$ = (b/Ltot)

$$N_{PMS} = \underbrace{A\, M_{TO}^{-s}\, \dot{M}}_{b\, =\, B\, L_{TOT}}\ \tau_{PMS}$$

$$\boxed{N_{PMS} = B\, L_{TOT}\, \tau_{PMS} = 1.7\, 10^{-11} \left(\frac{L}{L_{\odot}}\right)\left(\frac{\tau}{yr}\right)}$$

$\Downarrow$

specific Evolutionary Flux

LUMINOSITY

$$L_{MS} = A \int_{0}^{TO} \ell_* M^{-s}\, dM \qquad \begin{cases} \ell_* \propto M^{3} \\ t_* \propto M^{-2} \end{cases}$$

$$\boxed{\begin{aligned} &L_{MS} \simeq \frac{A}{4-s}\, M_{TO}^{4-s} \qquad (s<4) \\ &L_{MS} \propto t^{-\frac{4-s}{2}} \sim t^{-0.85} \end{aligned}}$$

$$L_{PMS} = \int^{PMS} \ell_*\, dN = A\, M_{TO}^{-s}\, \dot{M}_{TO} \underbrace{\int^{PMS} \ell_*\, d\tau}_{\text{fuel} \sim \text{const.}}$$

$$\boxed{L_{PMS} \propto t^{-\frac{3-s}{2}} \sim t^{-0.35}}$$

$$\frac{L_{PMS}}{L_{MS}} \propto \frac{t^{-\frac{3-s}{2}}}{t^{-\frac{4-s}{2}}} \propto \sqrt{t}$$

Conclusion: MS always dominates with decreasing time

Corollary: Total SSP luminosity is a DECREASING function of time

Model evolutionary rate at different bands

$$L_{BOL} \propto t^{-0.75}$$

$$L_B \propto t^{-0.95}$$

$$L_V \propto t^{-0.86}$$

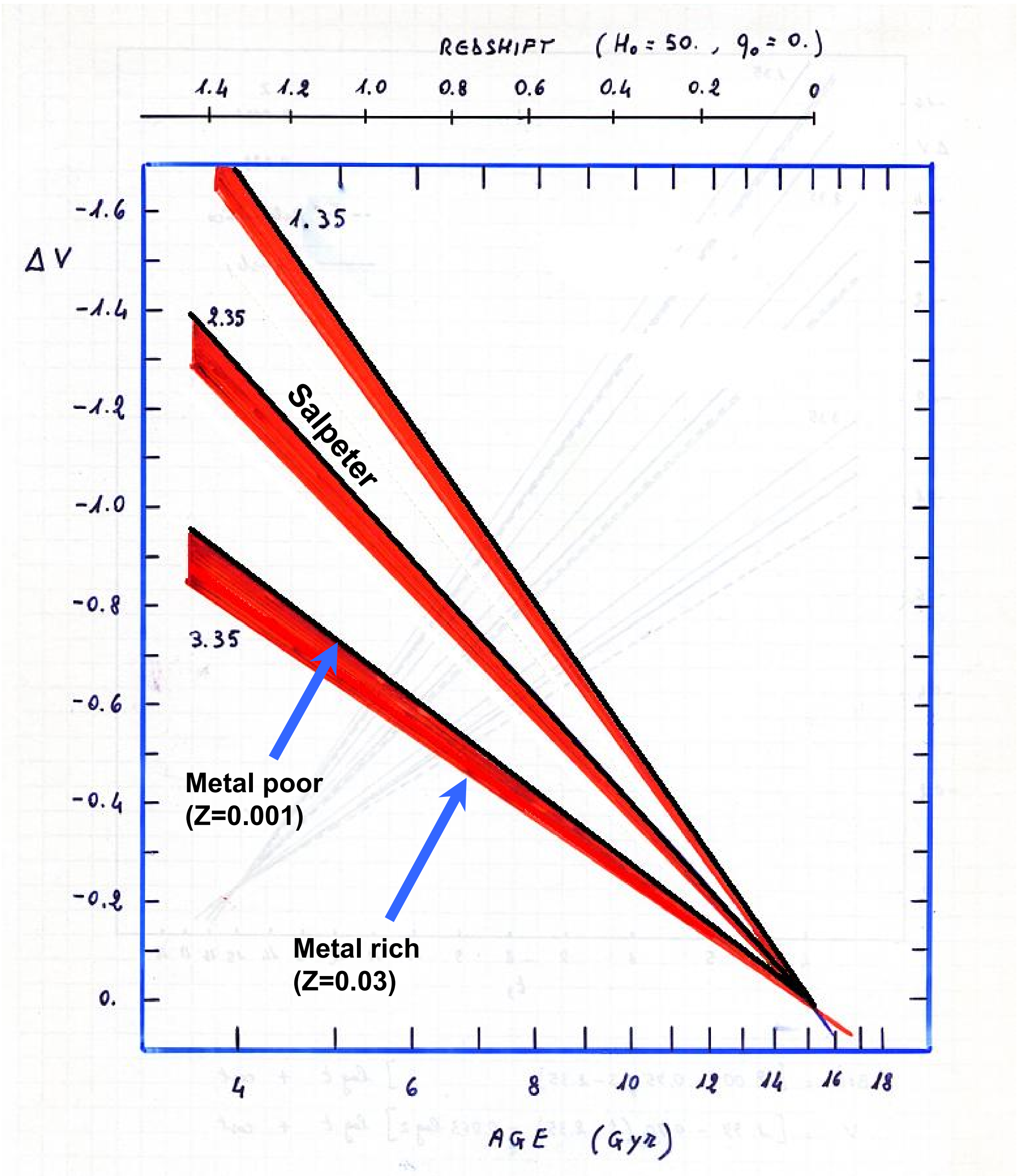
$$L_I \propto t^{-0.75}$$

$$L_K \propto t^{-0.71}$$

$Z = Z_\odot$

$s = 2.35$

Buzzoni (2005)



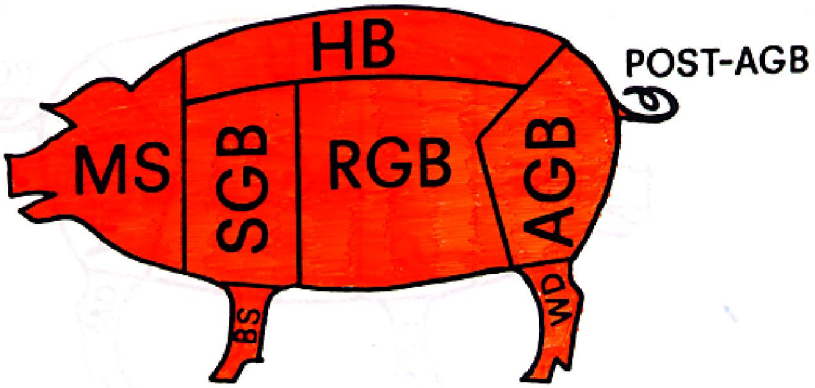
$$t \propto \frac{1}{M^2}\frac{\tilde{k}}{\mu^4}$$

$$L_* \propto M^3 \frac{\mu^4}{\tilde{k}}$$

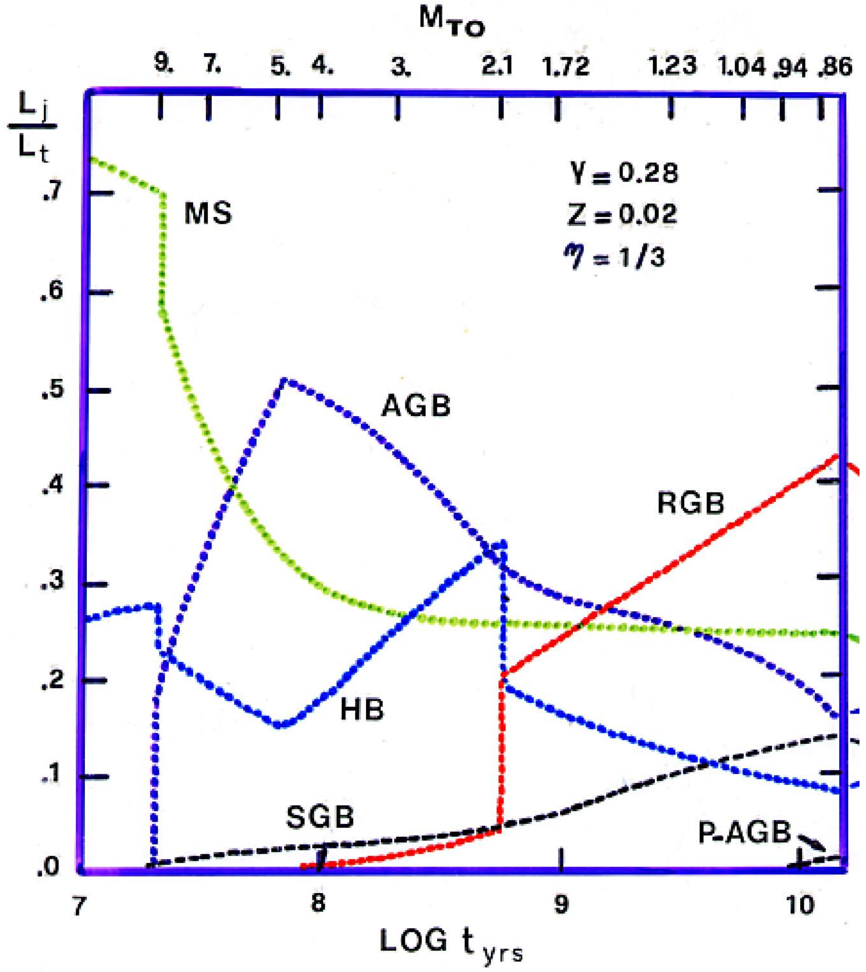
$$\longrightarrow \quad \frac{dt}{t} = -\frac{2}{3}\frac{dL_*}{L_*} + \frac{1}{3}\frac{d\tilde{k}}{\tilde{k}} - \frac{4}{3}\frac{d\mu}{\mu}$$

Quindi, la stessa variazione di luminosita' dL/L, avviene su tempi piu' lunghi (dt/t) se k ↑(ovvero se Z ↑)

SSP
Contributi bolometrici



All the cuts of a stellar population.



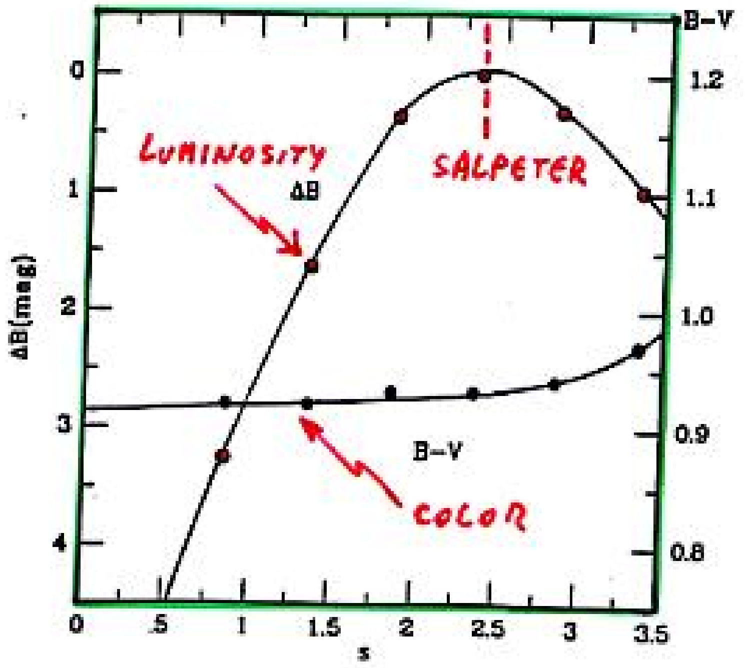
Renzini & Buzzoni (1986)

Articoli consigliati (vedi Webpage):
http://www.bo.astro.it/~eps/lezioni/lezioni.html

- SSPs (Tinsley)
- SSPs (Renzini & Buzzoni)
- Galaxy Colors (Buzzoni)
- IMF (Miller & Scalo)
- IMF (Kroupa)
- IMF (Kalirai 2013)
- IMF (Weidemann)

IMF e Luminosita' totale

Una IMF alla Salpeter permette alla SSP di rilasciare la max luminosita' per unita' di massa



BUZZONI (1995)

$$M_{TOT} = A \int M\, M^{-s} = \frac{A}{2-s}\left[M_u^{2-s} - M_l^{2-s} \right]$$

$s > 2$ DWARF - DOMINATED SSP

$s < 2$ GIANT - DOMINATED SSP

Una IMF alla Salpeter permette alla SSP di rilasciare la max luminosita' per unita' di massa: DIMOSTRAZIONE

$L_{tot} \propto A \dot{M} M_{TO}^{-s}$ Solo "A" e M_{TO}^{-s} dipendono da "s"

$$M_{TOT} = A \int M_*^{-s} M_* \, dM_* = \frac{A}{2-s}\left[M_*^{2-s}\right]_{low}^{up}$$

Assumiamo $s > 2$ e vediamo se esiste soluzione all'interno di questo dominio

$$\forall s > 2 \qquad A = \frac{M_{TOT}(2-s)}{M_{low}^{2-s}}$$

$$L_{tot} \propto \frac{M_{TOT}(2-s)}{M_{low}^{2}} \left(\frac{M_{TO}}{M_{low}}\right)^{-s}$$

(non dipende da "s")

$$\left(\frac{L}{M}\right) \propto \cancel{\frac{1}{M_{low}^{2}}} (2-s) \left(\frac{M_{TO}}{M_{low}}\right)^{-s}$$

$$\frac{\partial (L/M)}{\partial s} = 0 \Longrightarrow -1 \cancel{\left(\frac{M_{TO}}{M_{low}}\right)^{-s}} = (2-s) \ln\left(\frac{M_{TO}}{M_{low}}\right) \cancel{\left(\frac{M_{TO}}{M_{low}}\right)^{-s}}$$

$$2 - s_{MAX} = \frac{1}{\ln\left(\frac{M_{low}}{M_{TO}}\right)}$$

$$\boxed{s_{MAX} = 2 - \frac{1}{\ln\left(\frac{M_{low}}{M_{TO}}\right)}}$$

$M_{low} \sim 0.1 \, M_\odot$

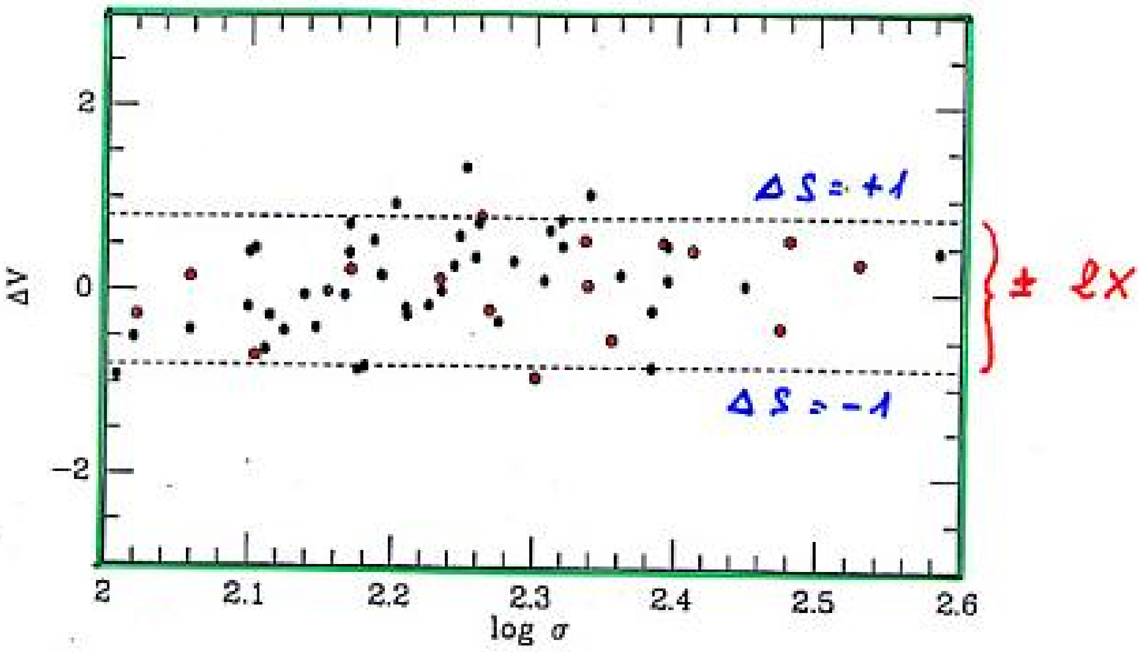
$\forall M_{TO} \rightarrow 0.01 \lesssim \frac{M_{low}}{M_{TO}} \lesssim 0.1$

$$\boxed{2.2 \lesssim s_{MAX} \lesssim 2.4}$$

Dispersione della IMF fra le galassie ellittiche

● = 16 galx VIRGO
● = 43 galx COMA

Bowen, Lucy & Ellis (1992)



same σ ⇒ same Mass ⇒ same [Fe/H]

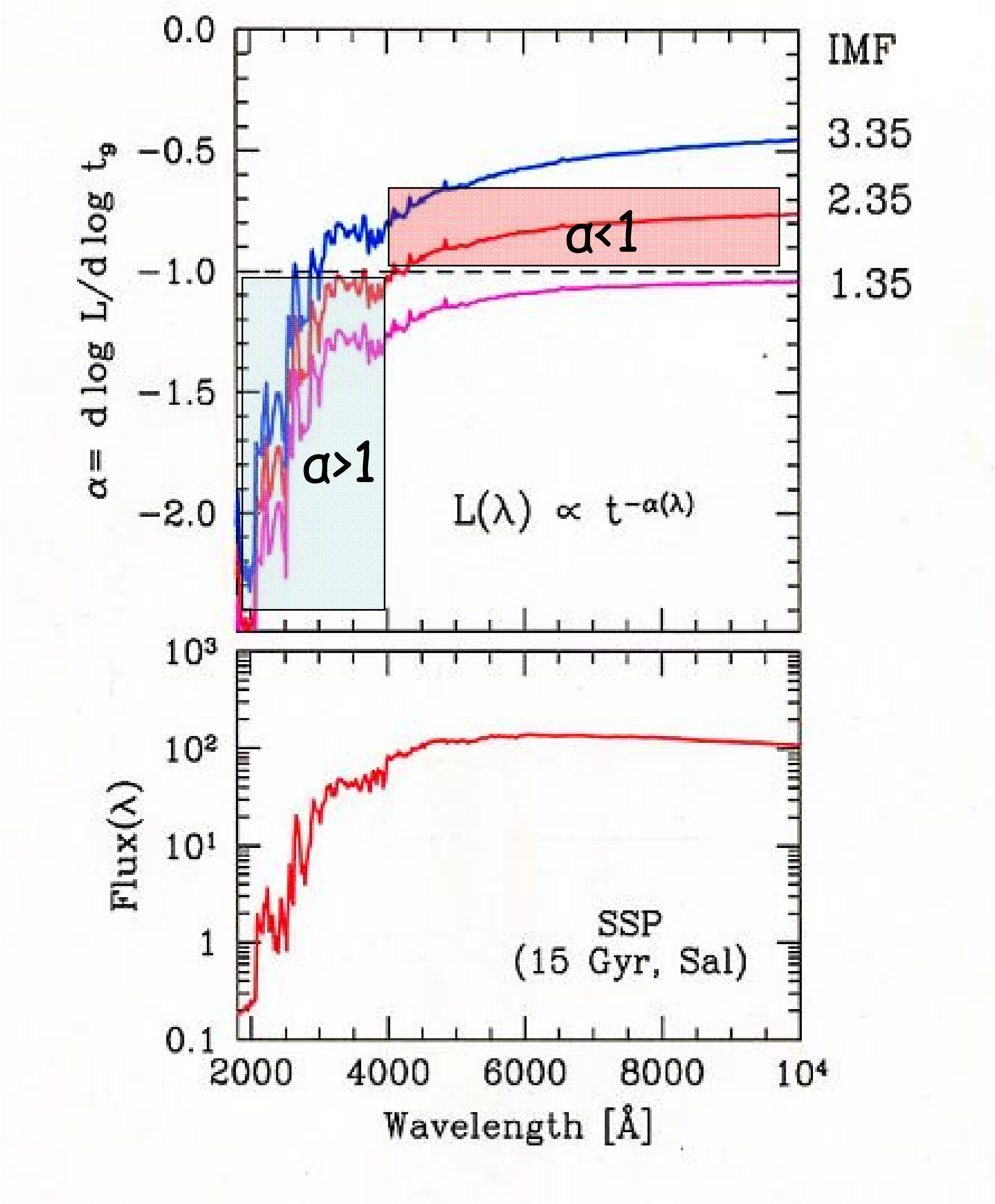
IF (AGE = CONST)

THEN ⇒ ΔV_{mag} ⟺ ΔS

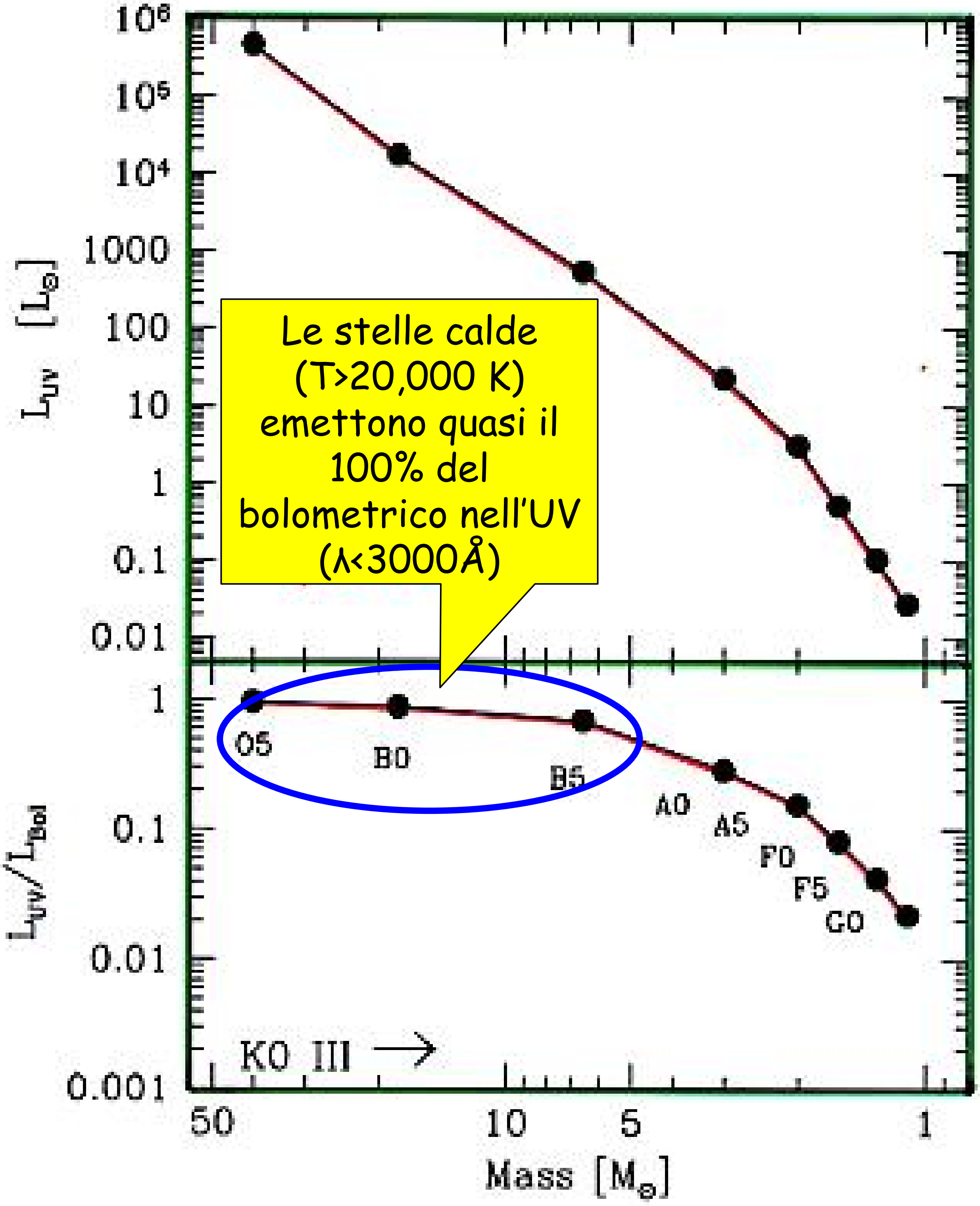
Articoli consigliati (vedi Webpage):
http://www.bo.astro.it/~eps/lezioni/lezioni.html

- IMF (Miller & Scalo)
- IMF (Kroupa)
- IMF (Kalirai 2013)
- IMF (Weidemann)

Evoluzione fotometrica delle SSP: dal bolometrico al monocromatico



L'evoluzione fotometrica delle SSPs nell'UV avviene piu' veloce di t^{-1} !! Dunque, in una CSP, l'UV traccia la SFR recente.

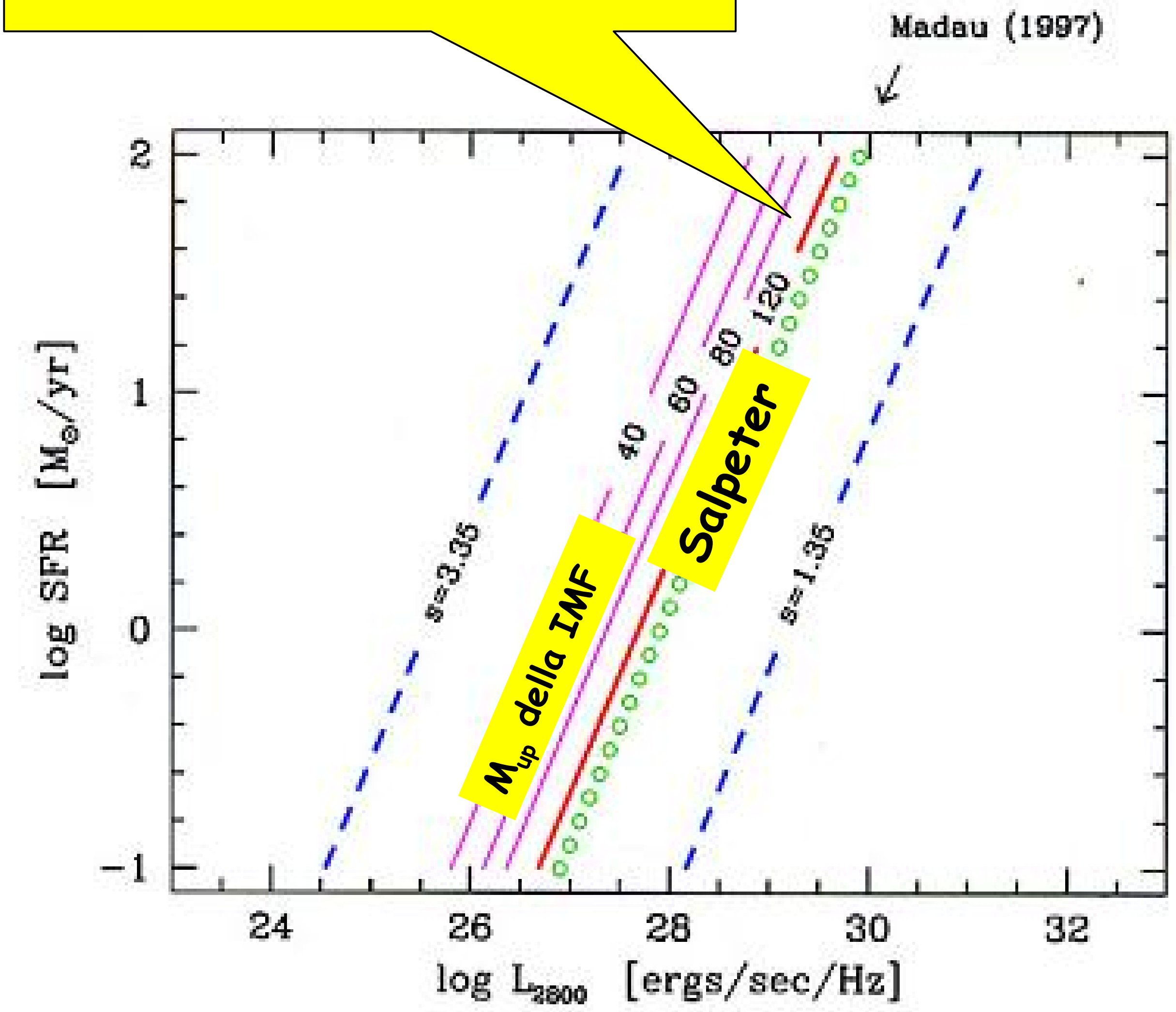


Le stelle calde (T>20,000 K) emettono quasi il 100% del bolometrico nell'UV (λ<3000Å)

Buzzoni (2002)

$L_{UV} \rightarrow$ SFR

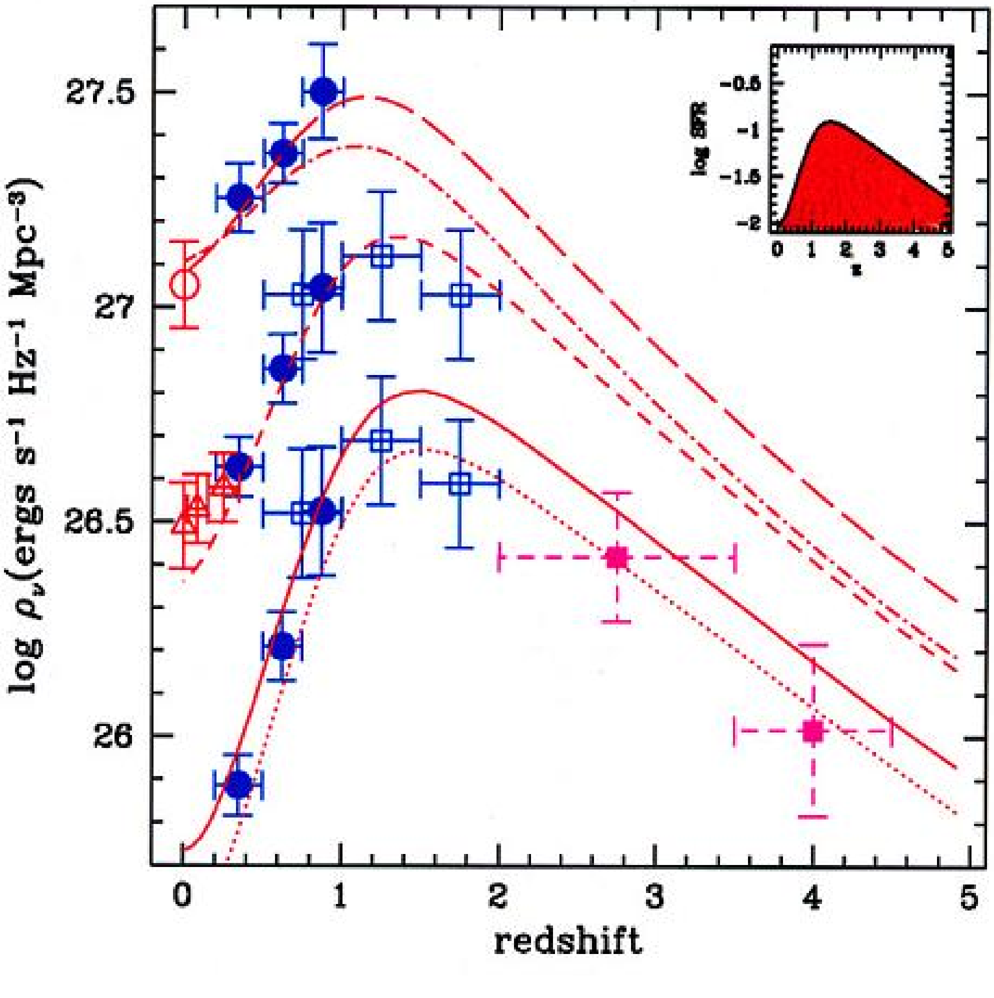
Deve esserci corrispondenza lineare fra L_{UV} e SFR



(Buzzoni 2002)

Il "Madau Plot" e la Storia della Formazione Stellare Cosmica

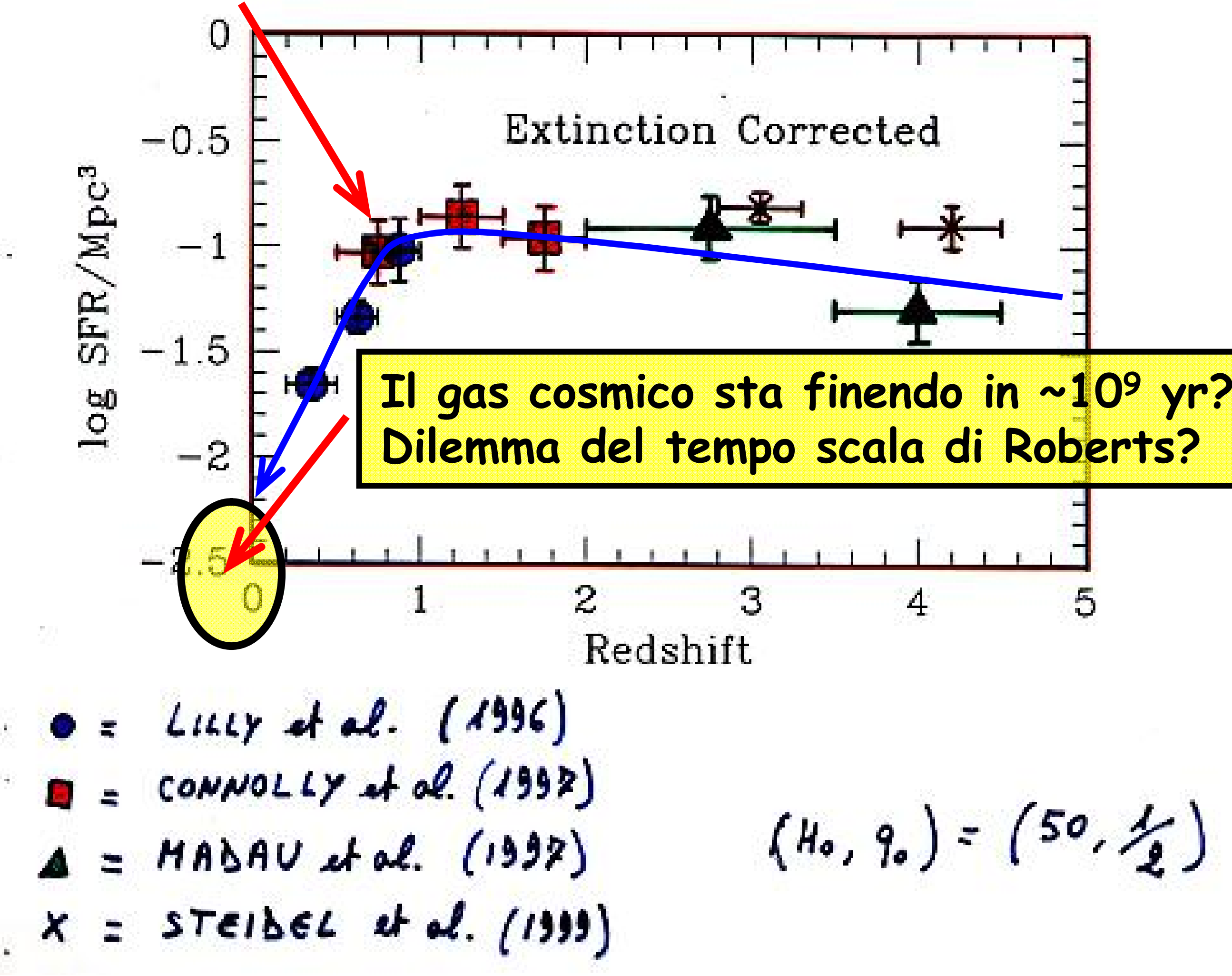
(Madau 1997)



Evoluzione del Madau plot

(includendo incompletezza, assorbimento polveri etc.)

Cosa e' successo qui?



Il gas cosmico sta finendo in ~10^9 yr?
Dilemma del tempo scala di Roberts?

Tempo di Roberts: $t_R \sim \frac{f_{gas} M_{gal}}{SFR_{now}}$ ma (vedi dopo) $b = \frac{SFR_{now}}{M_{gal}} t_{gal}$

Combinandole: $\frac{t_R}{t_{gal}} = \frac{f_{gas}}{b} \sim \frac{\sim 0.1}{\sim 1}$ Quindi $\boxed{t_R \text{ ~1-2 Gyr max}}$

Articoli consigliati (vedi Webpage):
http://www.bo.astro.it/~eps/lezioni/lezioni.html

- SSPs (Tinsley)
- SSPs (Renzini & Buzzoni)
- Galaxy Colors (Buzzoni)
- Dropout galaxies (Madau)
- Madau Plot
- SFR (Kennicutt)
- SFR (Ryder & Dopita)
- SFR (Schmidt)
- IMF (Kalirai 2013)
- Balmer break (Hamilton)

Teoria delle Popolazioni Stellari Composite (CSPs)

Buzzoni (2005)

Definition:

$$\boxed{[CSP] = \int [SSP] \otimes SFR}$$

A relevant case: SFR = const

$$\mathcal{L}_{CSP} = \int_0^T \underset{\substack{\downarrow \\ t^{-\alpha}}}{L_{SSP}}\, d\tau$$

$(\alpha < 1)$

$$\boxed{\mathcal{L}_{CSP}\Big|_T = \frac{T^{1-\alpha}}{1-\alpha}} \qquad \boxed{\mathcal{L}_{CSP} \propto t^{0.15}}$$

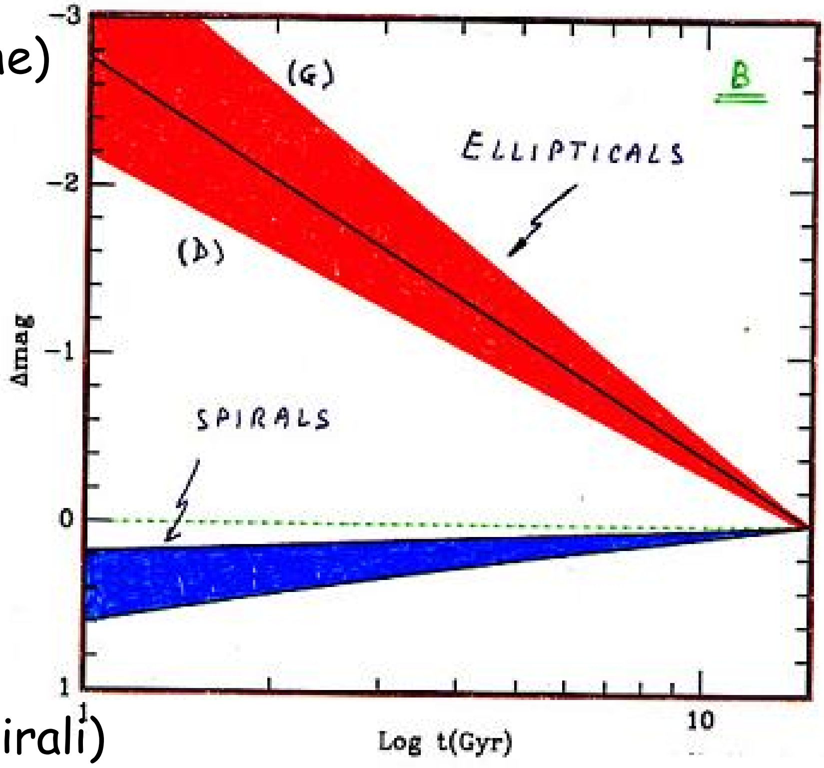
Conclusion: Total luminosity in a CSP is an INCREASING function of time

Color evolution:

SSP	CSP
$\begin{cases} L_B \propto t^{-\alpha_B} \\ L_V \propto t^{-\alpha_V} \end{cases}$	$\begin{cases} \mathcal{L}_B \propto t^{1-\alpha_B} \\ \mathcal{L}_V \propto t^{1-\alpha_V} \end{cases}$

SAME LAW! $\frac{L_B}{L_V} \propto t^{-(\alpha_B - \alpha_V)}$

LUMINOSITY EVOLUTION



SSPs
(≈ Ellittiche)

CSPs
(≈ Dischi Spirali)

Ellipticals	$L_t \propto t^{-\alpha} \sim \boxed{t^{-0.8}}$
Spirals (disk)	$L_t \propto t^{1-\alpha} \sim \boxed{t^{+0.2}}$

Star Formation Rate
(Leggi di Schmidt)

$$SFR = -\frac{d\, f_{gas}}{d\, t}$$

$$PDMF_{(M,t)} = \int_0^{\tau \le T} SFR \times IMF_{(M)}\, dt$$

$\Downarrow$

OBSERVED $\qquad 0 \le \tau \le T$

ASSUMED $\qquad SFR \propto f_{gas}^{m} \qquad m = 2$ SCHMIDT LAW

$m = 1 \qquad SFR = k f = -\dot{f} \qquad SFR = k\, e^{-kt}$

$m = 2 \qquad SFR = k f^{2} = -\dot{f} \qquad SFR = \dfrac{k}{(1+kt)^{2}}$

$k = 1/\tau$ (star formation timescale)

$\lim k \to \infty \qquad \tau \to 0 \qquad \Longrightarrow \qquad SSP$

$SFR \to \delta(0)$

Star Formation Rate
(Leggi di Schmidt)

Soluzioni:

$\boxed{n = 1}$

$$\left\{\begin{aligned} SFR &= \dot{f}_* = -\dot{f}_{gas} \\ \dot{f}_* &= k f_{gas} \end{aligned}\right\} \rightarrow \quad k f_{gas} = -\frac{d f_{gas}}{dt}$$

$$\frac{d f_{gas}}{f_{gas}} = -k\, dt \quad \text{integro:} \quad f_{gas}(t) = f_{gas}(0)\, e^{-kt}$$

posso assumere $k = \frac{1}{\tau} \leftarrow$ tempo scala

Quindi, alla fine ho:

$$\boxed{\left\{\begin{aligned} f_{gas} &= e^{-kt} \\ SFR &= k e^{-kt} \end{aligned}\right. \qquad b = \frac{SFR_0}{\langle SFR \rangle} = \frac{k e^{-kt}}{\frac{k}{t}\int_0^t e^{-kz}\, dz} = \frac{kt}{e^{+kt} - 1} \qquad 0 \leq b \leq 1}$$

$\boxed{n = 2}$ (Legge di Schmidt canonica)

$$\left\{\begin{aligned} SFR &= -\dot{f}_{gas} \\ SFR &= k f_{gas}^2 \end{aligned}\right\} \rightarrow \quad k f_{gas}^2 = -\frac{d f_{gas}}{dt}$$

$$\frac{d f_{gas}}{f_{gas}^2} = -k\, dt \quad \text{integro:} \quad \frac{1}{f_g(0)} - \frac{1}{f_g(t)} = -kt$$

$$\boxed{\left\{\begin{aligned} f_{gas} &= \frac{1}{1+kt} \\ SFR &= \frac{k}{(1+kt)^2} \end{aligned}\right. \qquad b = \frac{k}{(1+kt)^2}\, \frac{t}{\int \frac{k}{(1+kt)^2}} = \frac{1}{1+kt} \qquad 0 \leq b \leq 1}$$

Star Formation Rate
(Power Law)

Soluzione:

Assumo che l'efficienza del meccanismo di formazione stellare sia un parametro intrinseco della galassia, che solo dipende dalla sua morfologia.

Ne consegue che:

$$\begin{cases} SFR = k t^{-\beta} \\ SFR = -\dot{f}_{gas} \end{cases} \longrightarrow \quad k t^{-\beta} = -\frac{df_{gas}}{dt}$$

k ha le dimensioni di $\tau^{+(\beta-1)}$

$$df_{gas} = -k t^{-\beta} dt \rightarrow 1 - f_{g(t)} = \frac{k}{1-\beta} t^{1-\beta}$$

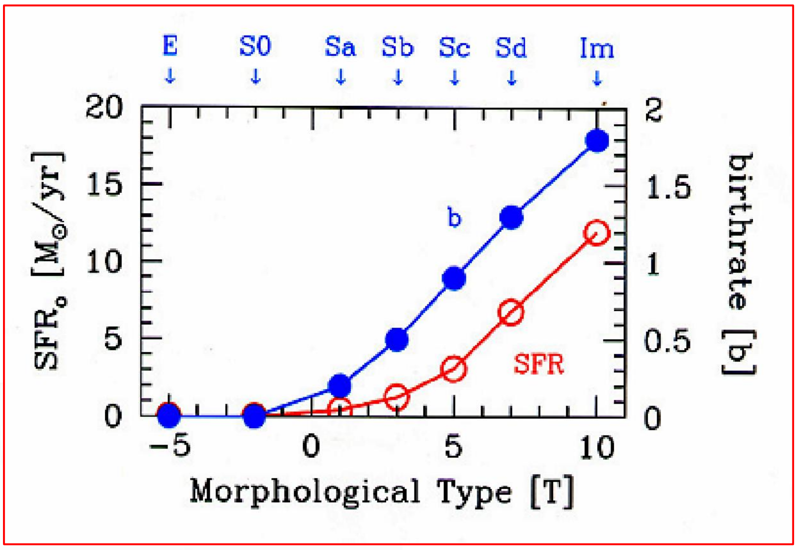
$$\boxed{\left.\begin{cases} f_{g(t)} = 1 - \dfrac{k t^{1-\beta}}{1-\beta} \\ SFR(t) = k t^{-\beta} \end{cases}\right\} \quad b = \frac{k t^{-\beta}}{\dfrac{k}{t(1-\beta)} t^{1-\beta}} = (1-\beta) \quad \forall t}$$

Quindi il Birthrate è indipendente dal tempo.

Il gas si esaurisce in un tempo finito:

$$\boxed{t_{MAX} = \left(\frac{1-\beta}{k}\right)^{\frac{1}{1-\beta}}}$$

SFR & Birthrate



Buzzoni (2002)

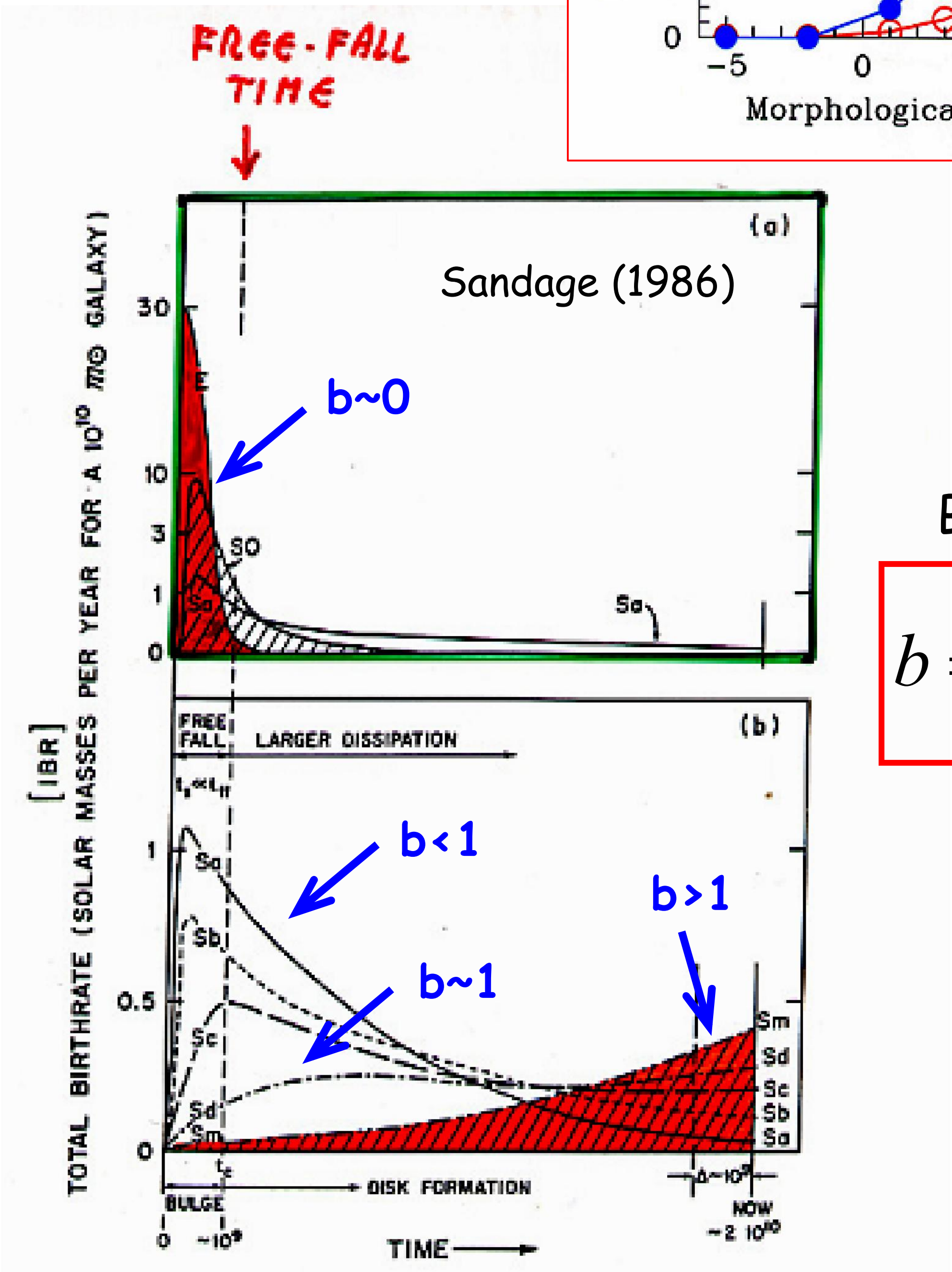
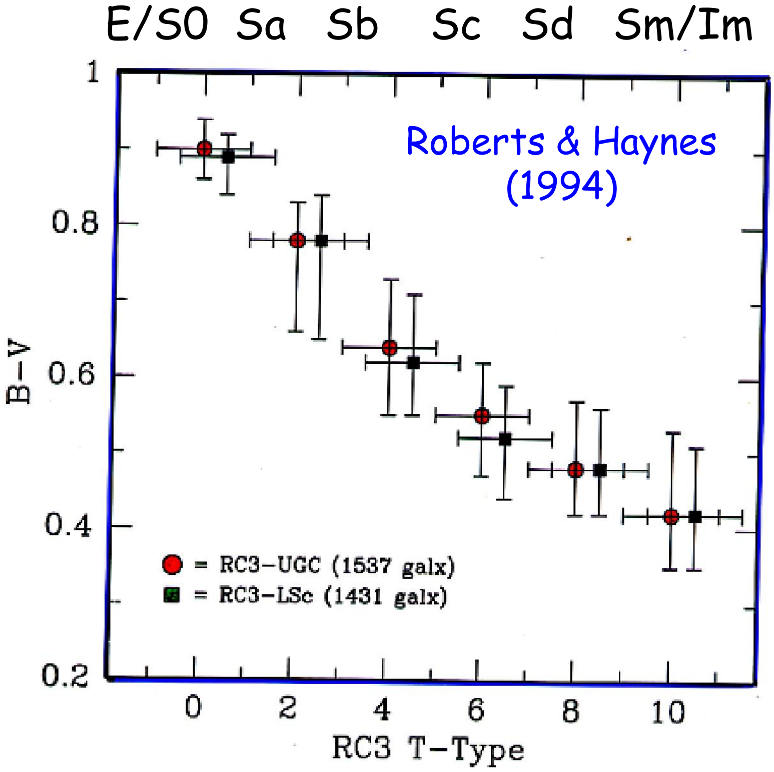


Fig. 10. Same as Fig. 9 with later Hubble types shown in the lower panel. The integral under the Sm curve is shaded for illustration. The curves are only schematic showing the trends that have been established by Gallagher et al. (1984)

Birthrate

$$\boxed{b = \frac{SFR_o}{< SFR >}}$$

Eta' media delle popolazioni e colore integrato delle galassie



Nel caso di una SFR a legge di potenza:

$$SFR = k\, t^{-\beta}$$

$$\mathcal{L}_{(t)} = k' \int^{t} \tau^{-\alpha} (t-\tau)^{-\beta} d\tau = k' \frac{\Gamma_{(1-\alpha)}\Gamma_{(1-\beta)}}{\Gamma_{(2-\alpha-\beta)}}\, t^{1-\alpha-\beta}$$

$$b = \frac{SFR(t)}{<SFR>} = \frac{k\, t^{-\beta}(1-\beta)\, t}{k\, t^{(1-\beta)}} = (1-\beta) \qquad \forall t$$

Etá media delle SSP componenti (pesate con la luminositá)

$$<t> = \frac{k' \int \tau\, \tau^{-\alpha}(t-\tau)^{-\beta} d\tau}{k' \int \tau^{-\alpha}(t-\tau)^{-\beta} d\tau} = \frac{\int \tau\, \mathcal{L}_{(\tau)}}{\mathcal{L}_{(t)}}$$

Ricordando che $\Gamma_{(1+n)} = n!\, \Gamma_{(n)}$

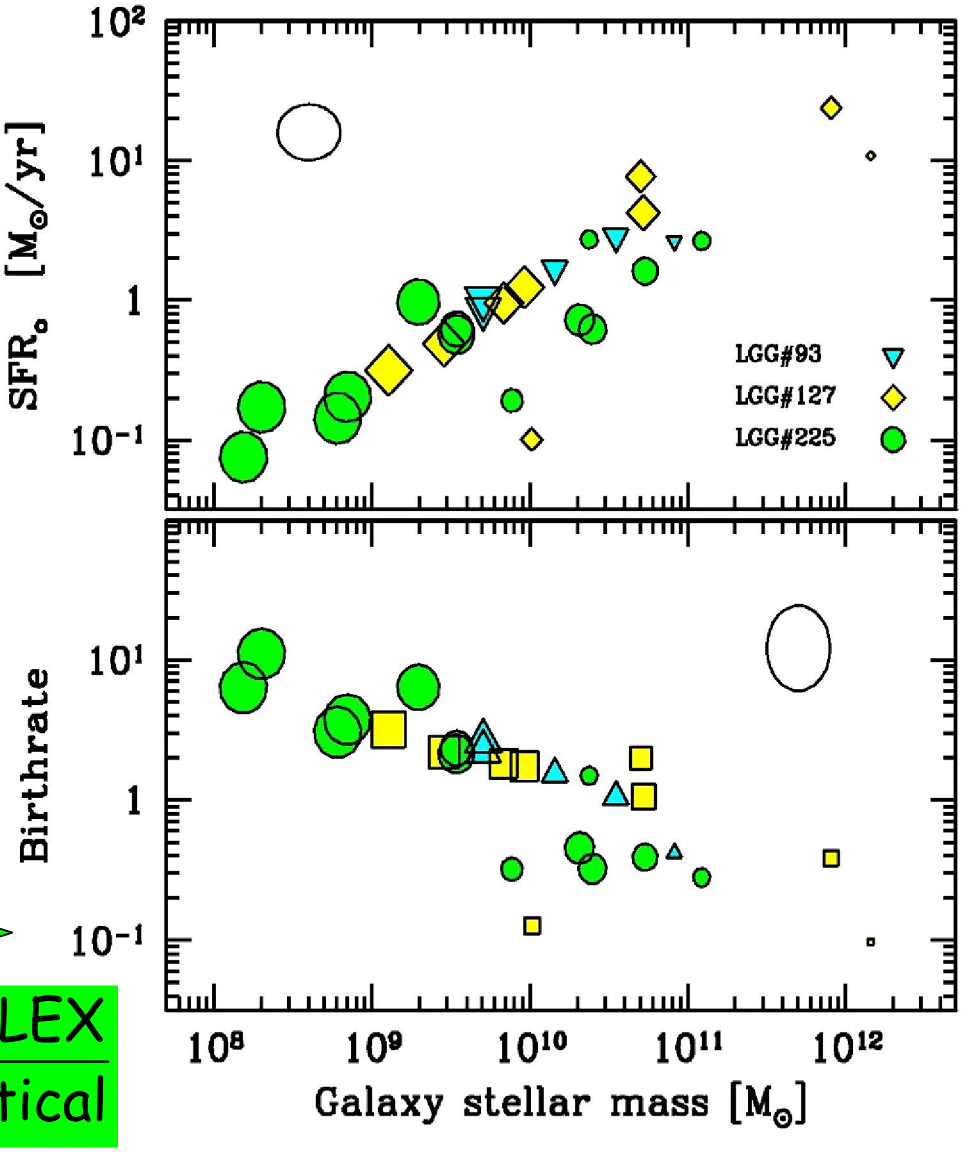
$$<t> = \frac{\Gamma_{[1+(1-\alpha)]}\, \Gamma_{(1-\beta)}}{\Gamma_{[2+(1-\alpha)-\beta]}} \; \frac{\Gamma_{(2-\alpha-\beta)}}{\Gamma_{(1-\alpha)}\, \Gamma_{(1-\beta)}} \; \frac{t^{2-\alpha-\beta}}{t^{1-\alpha-\beta}}$$

$$\boxed{<t> = \frac{1-\alpha}{2-\alpha-\beta}\, t} \qquad \boxed{\frac{<t>}{t} << 1 \quad \text{se} \quad b >> 0}$$

Birthrate & Downsizing

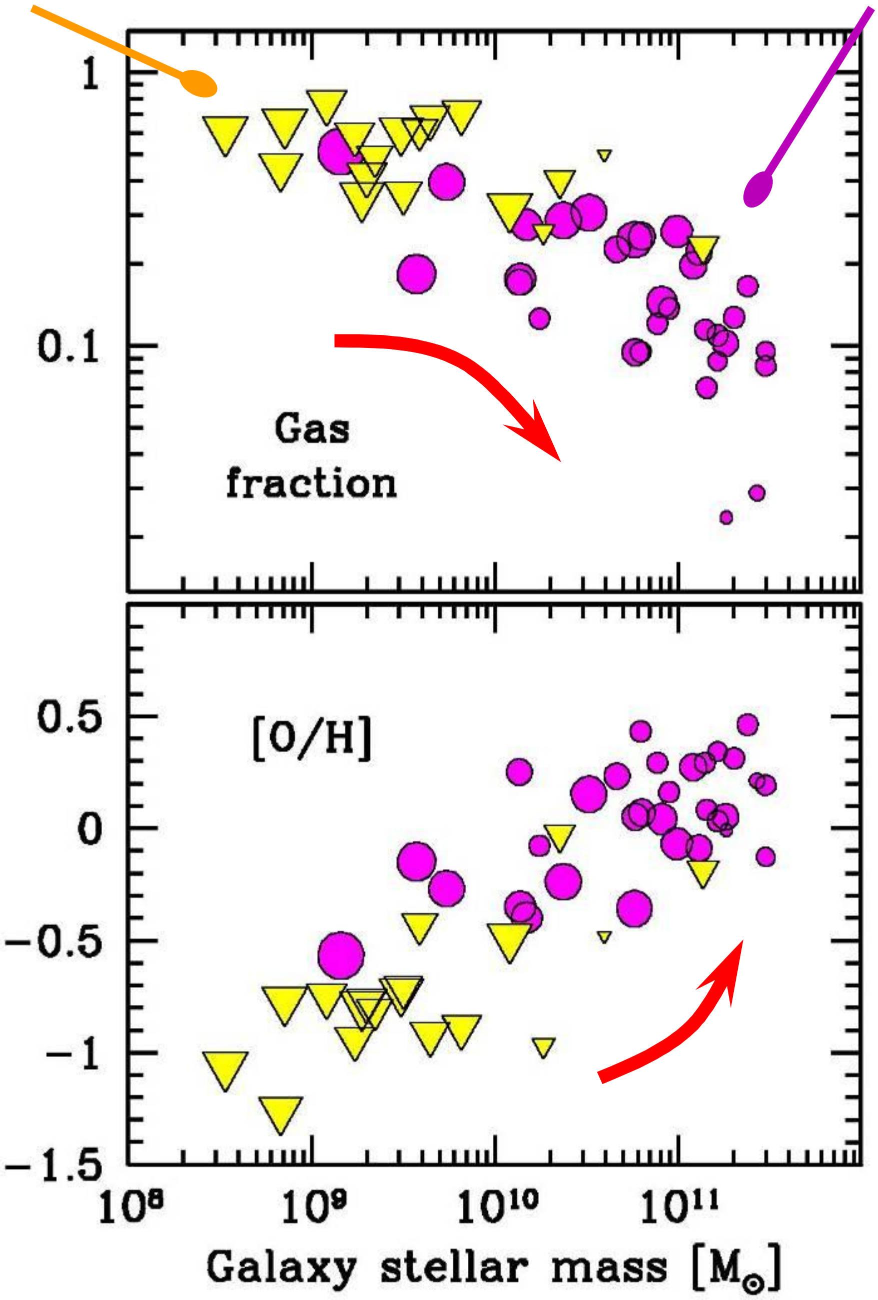
Buzzoni (2011) – Marino et al. (2009)

GALEX



$$b=\frac{SFR}{\langle SFR\rangle}=\frac{GALEX}{Optical}$$

Gas fraction & ISM Metallicity



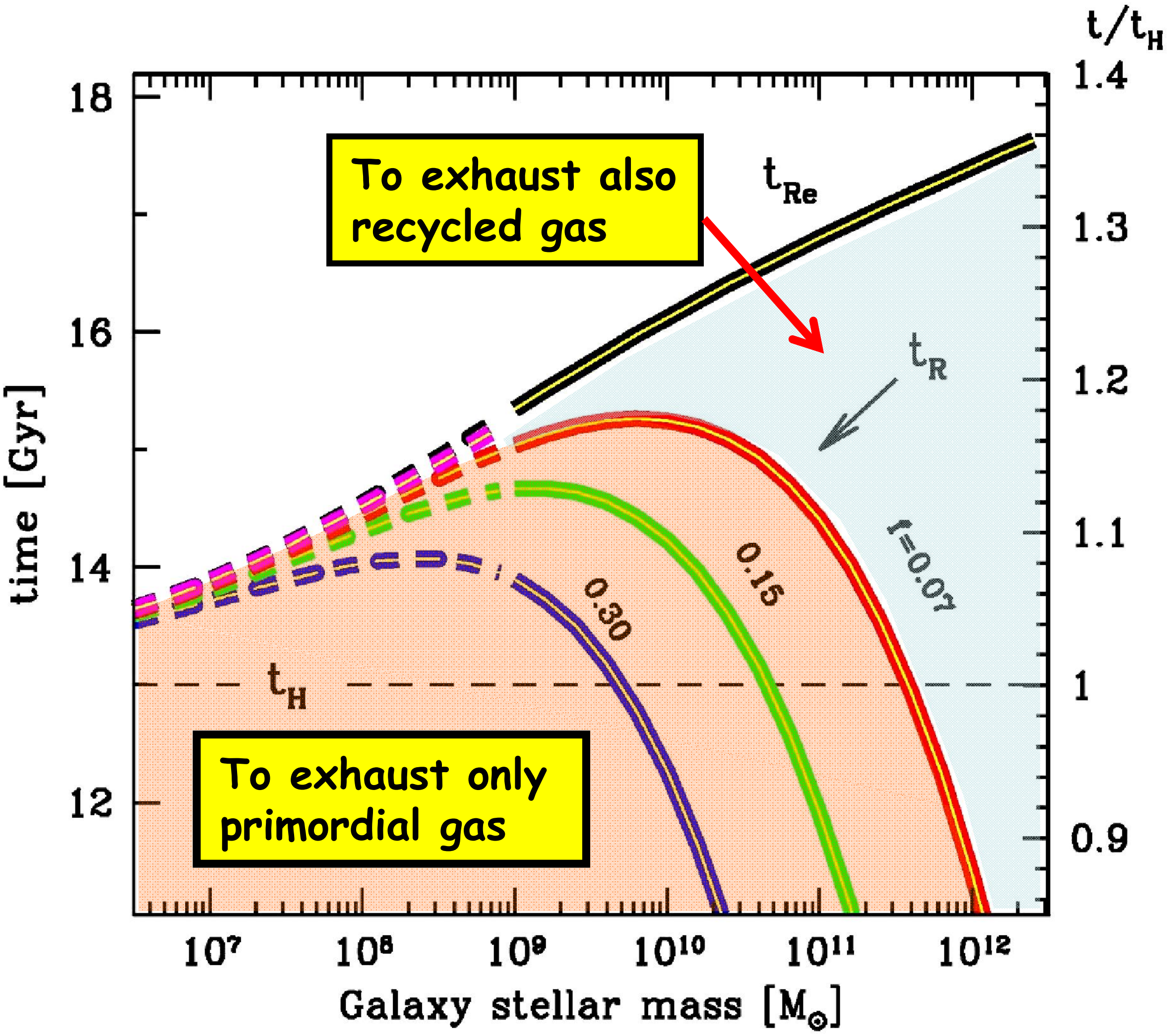
Kuzio de Naray et al. (2004)

Garnett (2002)

The Roberts time
(hurry up: the party is over!)

Tempo di Roberts: $t_R \sim \frac{f_{gas} M_{gal}}{SFR_{now}}$ ma (vedi dopo) $b = \frac{SFR_{now}}{M_{gal}} t_{gal}$

Combinandole: $\frac{t_R}{t_{gal}} = \frac{f_{gas}}{b} \sim \frac{\sim 0.1}{\sim 1}$ Quindi $\boxed{t_R \text{ ~1-2 Gyr max}}$



To exhaust also recycled gas

To exhaust only primordial gas

We are (so embarrassingly) close to the final death of galaxies as star-forming systems in the Universe!!

Energetica nucleare e rapporto M/L delle galassie

METAL ABUNDANCE

$X + Y + Z = 1$

HYDROGEN HELIUM "OTHERS"

$$\left[\frac{Fe}{H}\right] = \log \frac{Fe}{Fe_\odot} - \log \frac{H}{H_\odot}$$

IF $Fe \propto Z$

$$\left[\frac{Fe}{H}\right] = \log \frac{Z}{0.017} - \log \frac{1-Z-Y}{0.71} \approx \lg Z + 1.8$$

$$(X, Y, Z)_\odot = (0.70,\ 0.28,\ 0.017)$$

$$\underbrace{1\,gr\ H \rightarrow 1\,gr\ Z}_{6.6\ 10^{18}\ ergs}$$

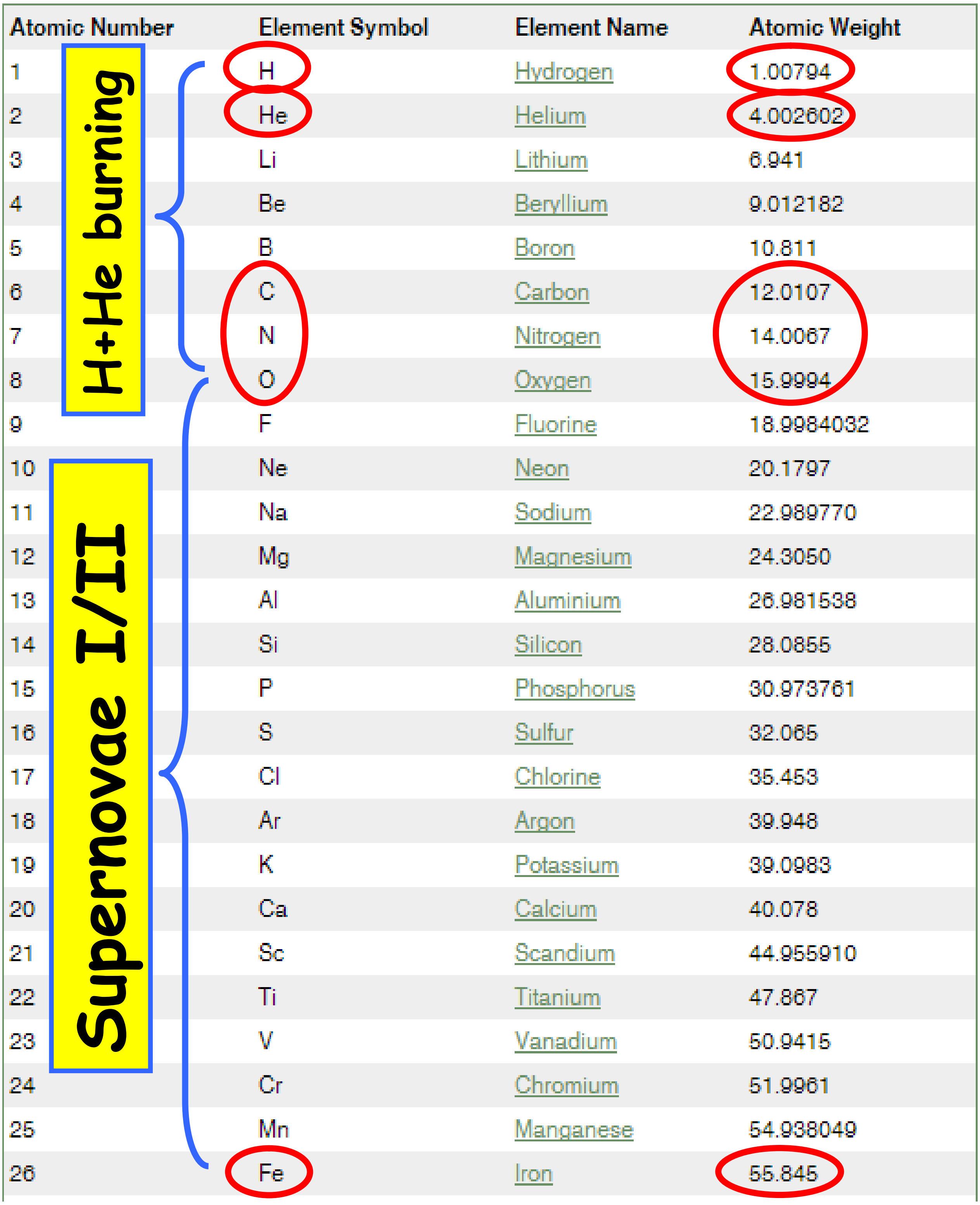
ENERGETICS

IN A GALAXY: $M_Z \sim 2\ 10^{9}\ M_\odot \sim 4\ 10^{42}\ gr$

$$M_Z = \frac{\int L \times t}{6.6\ 10^{18}} \sim \frac{\langle L \rangle\ 10^{10} yr}{6.6\ 10^{18} ergs}$$

$\langle L \rangle \sim 2.2\ 10^{10}\ L_\odot$ $\frac{M}{L} \lesssim 5$ in primordial galx

Energetica nucleare e tempi scala evolutivi



Atomic Number	Element Symbol	Element Name	Atomic Weight
1	H	Hydrogen	1.00794
2	He	Helium	4.002602
3	Li	Lithium	6.941
4	Be	Beryllium	9.012182
5	B	Boron	10.811
6	C	Carbon	12.0107
7	N	Nitrogen	14.0067
8	O	Oxygen	15.9994
9	F	Fluorine	18.9984032
10	Ne	Neon	20.1797
11	Na	Sodium	22.989770
12	Mg	Magnesium	24.3050
13	Al	Aluminium	26.981538
14	Si	Silicon	28.0855
15	P	Phosphorus	30.973761
16	S	Sulfur	32.065
17	Cl	Chlorine	35.453
18	Ar	Argon	39.948
19	K	Potassium	39.0983
20	Ca	Calcium	40.078
21	Sc	Scandium	44.955910
22	Ti	Titanium	47.867
23	V	Vanadium	50.9415
24	Cr	Chromium	51.9961
25	Mn	Manganese	54.938049
26	Fe	Iron	55.845

Energetica nucleare e tempi scala evolutivi

H burning: 4 H → 1 He

4 x 1.00794 u → 4.002602 u + ε/c²

$$\mathrm{E} = \frac{4.03176 - 4.002602}{4.002602} c^2 = 6.6 \cdot 10^{18}\, erg/gr$$

He burning: 4 He → 1 C^{12}

3 x 4.002602 u → 12.0107 u + ε/c²

$$E = \frac{12.007806 - 12.010700}{12.010700} c^2 = 0.2 \cdot 10^{18}\, erg/gr$$

4 He → 1 O^{16}

4 x 4.002602 u → 15.9994 u + ε/c²

$$E = \frac{16.010408 - 15.994000}{15.994000} c^2 = 0.9 \cdot 10^{18}\, erg/gr$$

Analytic fundamentals

Luminosity of a Composite Stellar Population:

$$\mathcal{L}_{\mathrm{CSP}} = \int \ell_{\mathrm{SSP}} \otimes \mathrm{SFR}\ \mathrm{dt}$$

Output energy after "t" years:

$$\mathcal{E}(t) = \int_0^t \mathcal{L}_{\mathrm{CSP}}(\tau)\, d\tau$$

Analytic fundamentals (2)

Metal enrichment:

$$\frac{M_{yZ}}{M^*} = \frac{K^{-1}\varepsilon}{\int SFR} = \frac{\varepsilon_o}{KM_o}\left(\frac{t}{t_o}\right)^{0.23}$$

"Yield Metallicity" of processed mass scales with time as a power law:

$$\mathcal{Z} \propto \frac{M_{yZ}}{M^*} \propto \left(\frac{t}{t_o}\right)^{0.23}$$

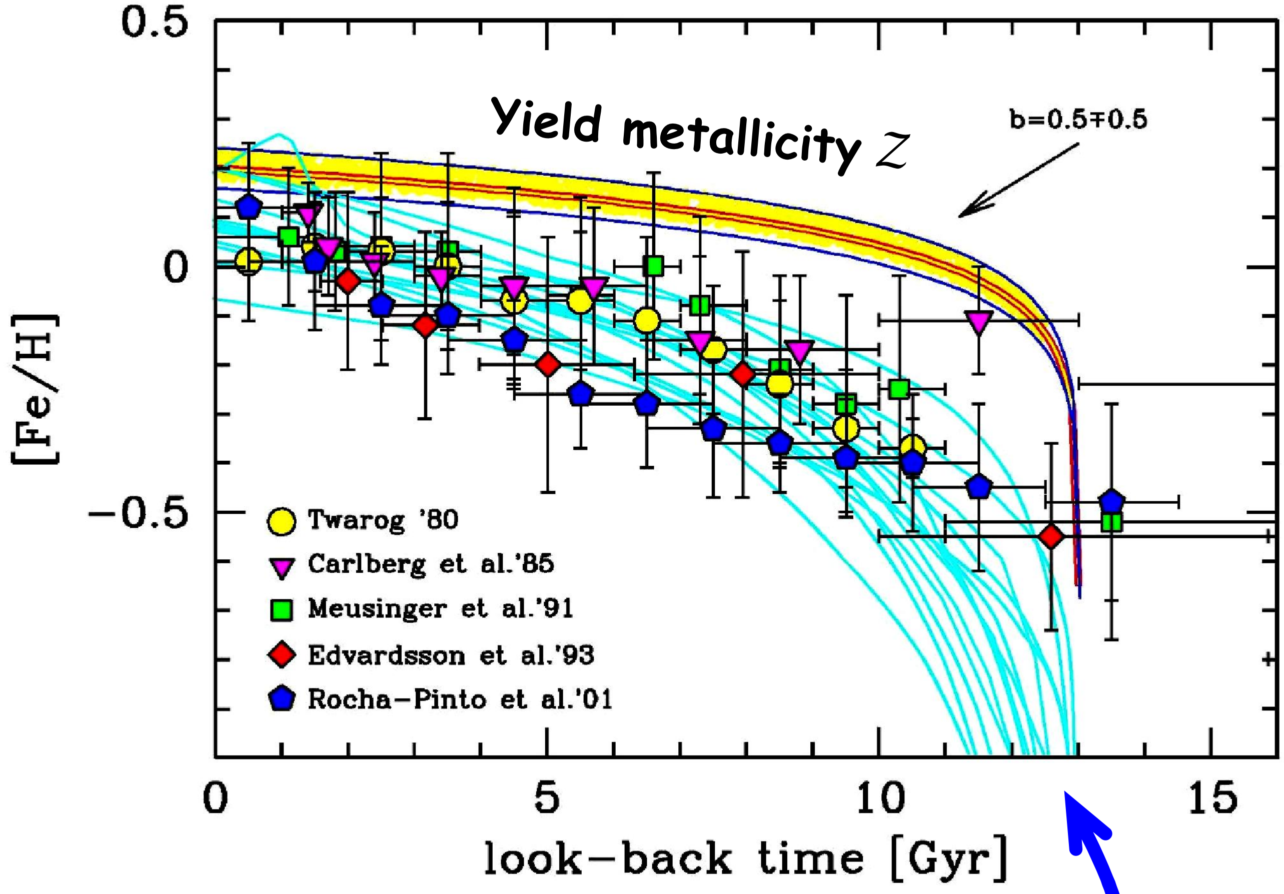
Mass energetic exploitation does (nearly) NOT depend on the galaxy SFR:

$$\mathcal{F} = \frac{\varepsilon_o}{KM_o}$$

~ 10 -13%

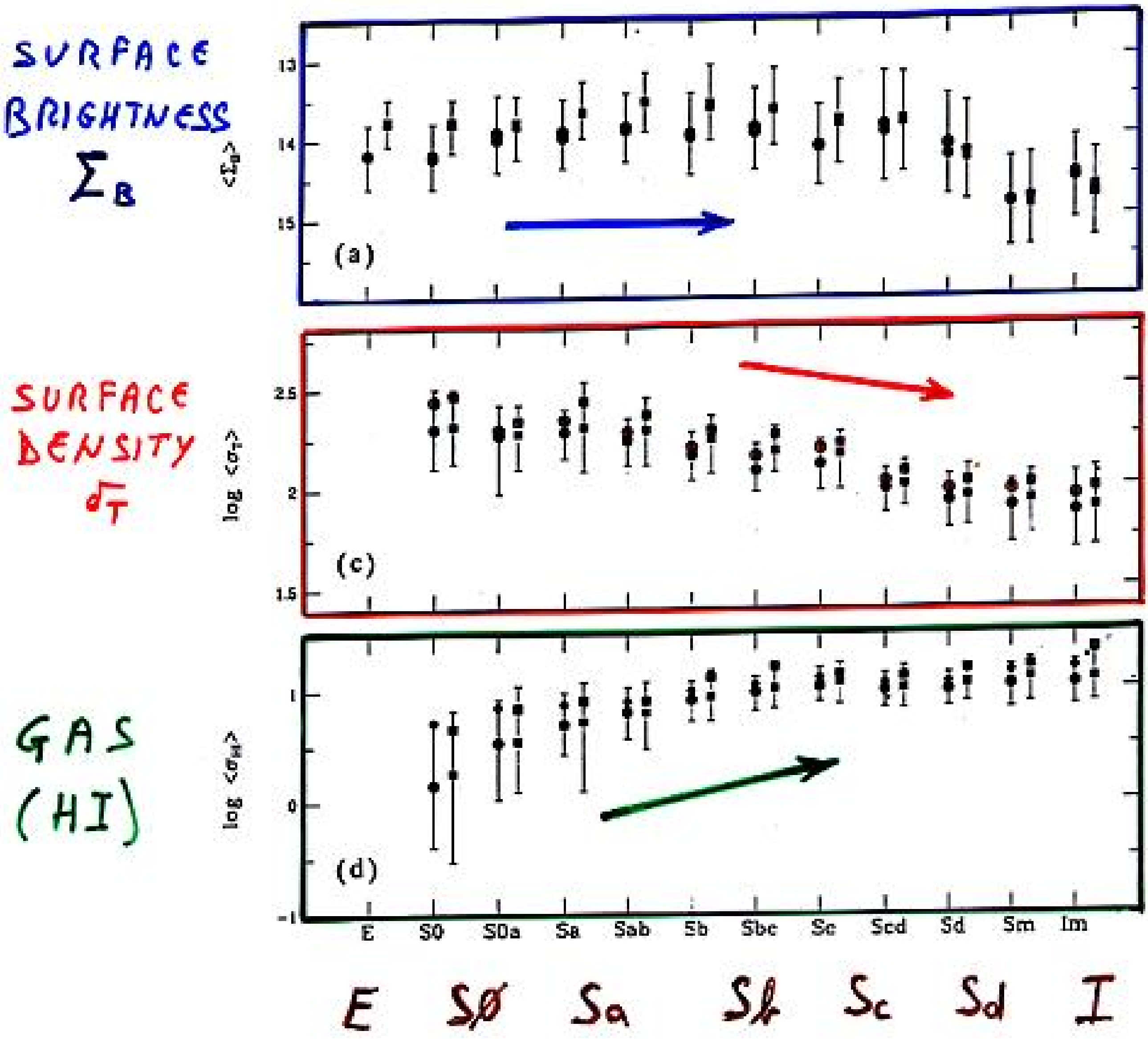
The Age-metallicity relation (AMR)

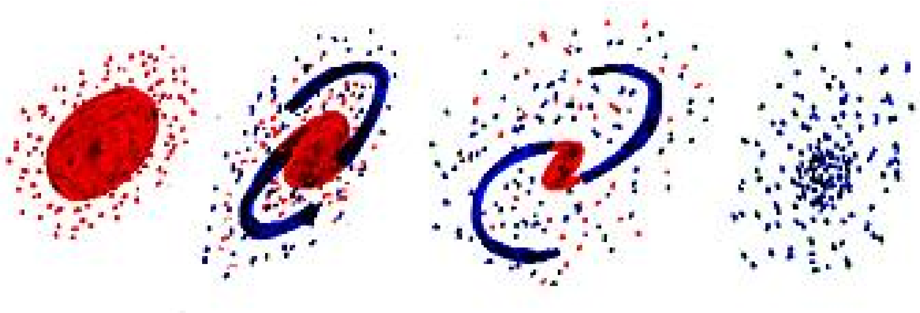
Buzzoni (2011)



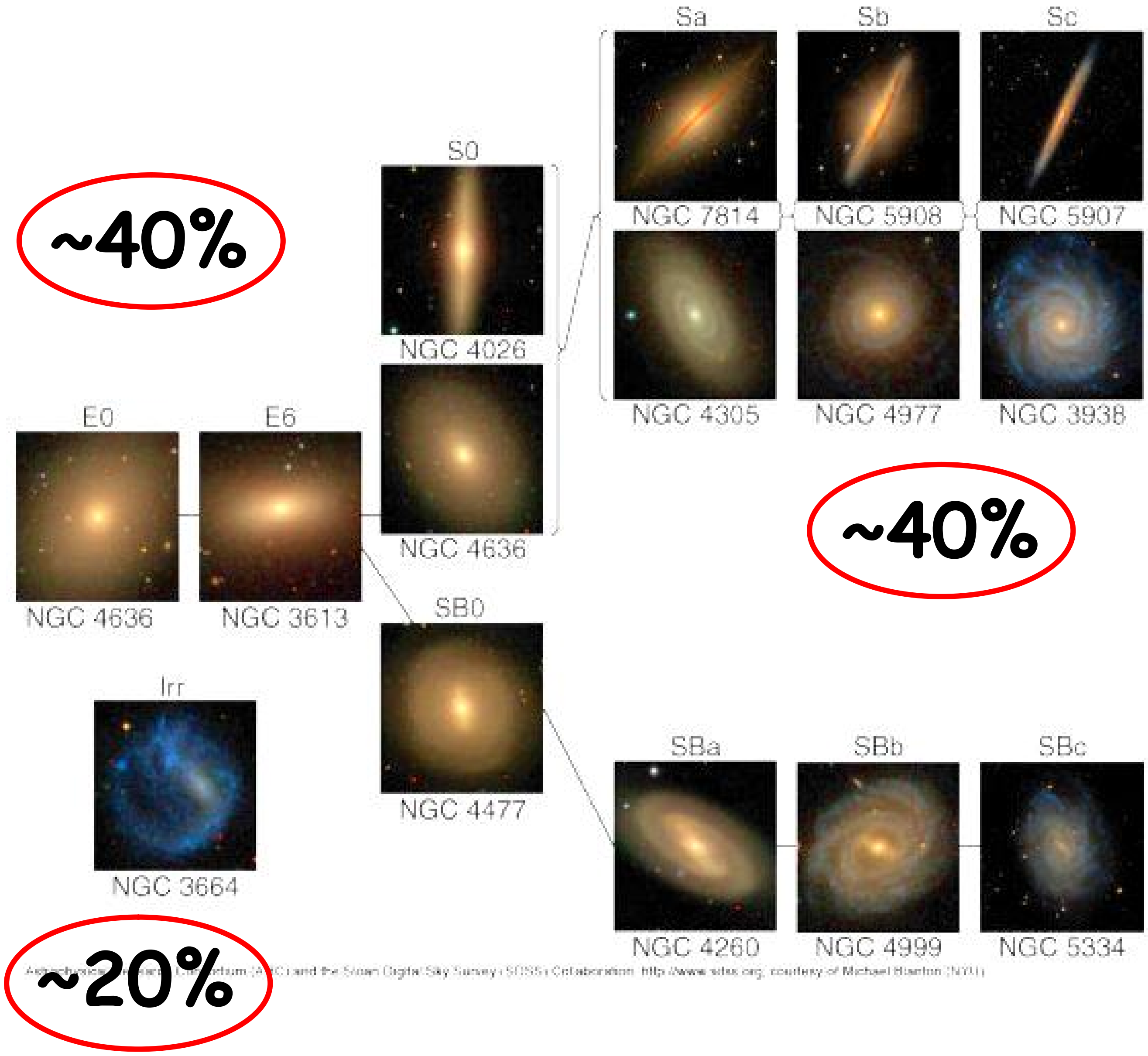
"explicit" chemical evolution (models)

Matteucci & Francois 89 // Wyse & Silk 89 // Carigi 94 // Pardi & Ferrini 94 // Prantzos & Aubert 95 // Timmes et al. 95 // Giovagnoli & Tosi 95 // Pilyugin & Edmunds 96 // Mihara & Takahara 96 // Chiappini,et al. 97 // Portinari et al. 98 // Boissier & Prantzos 99 // Alibes et al. 01


SURFACE BRIGHTNESS
Σ_B
SURFACE DENSITY
σ_T
GAS (HI)
$\langle\Sigma_B\rangle$
13
14
15
(a)
log $\langle\sigma_T\rangle$
2.5
2
1.5
(c)
log $\langle\sigma_{HI}\rangle$
1
0
-1
(d)
E
S0
S0a
Sa
Sab
Sb
Sbc
Sc
Scd
Sd
Sm
Im
E
S0
Sa
Sb
Sc
Sd
I

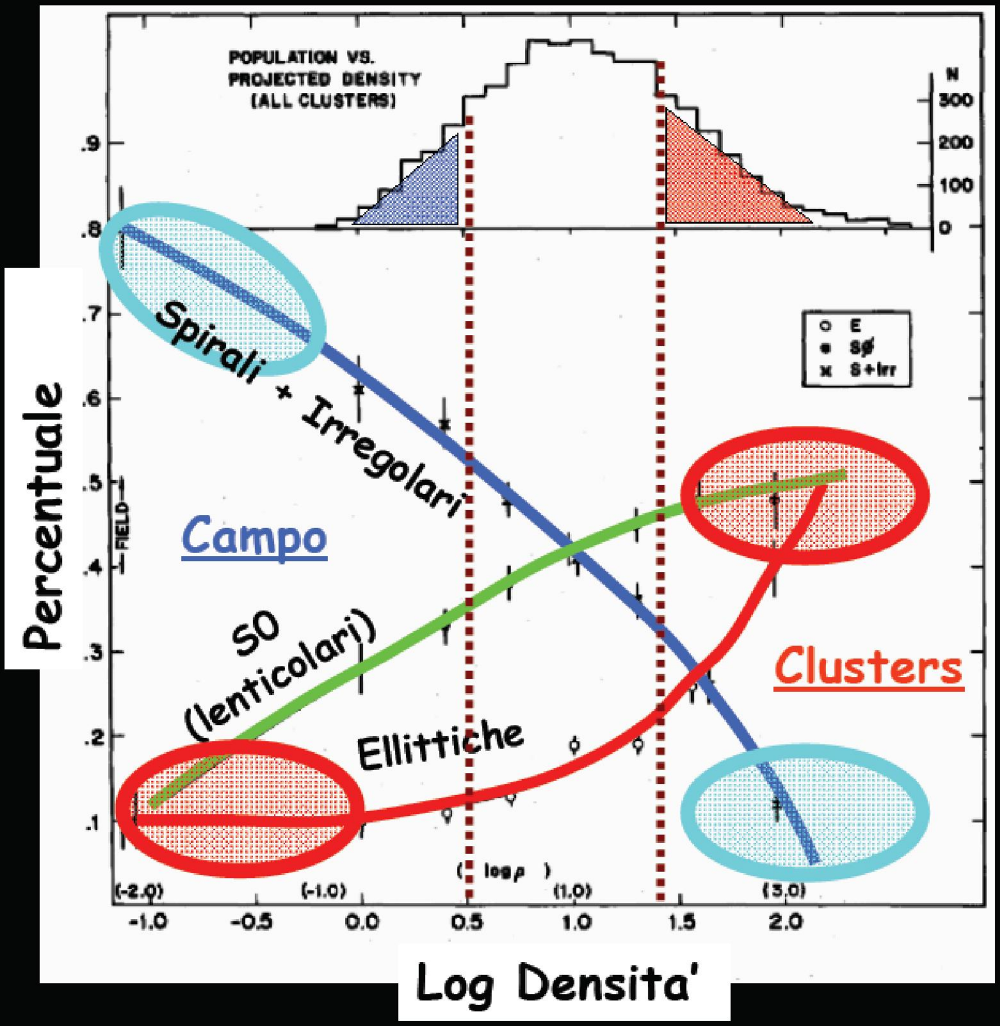


Classificazione Morfologica di Hubble



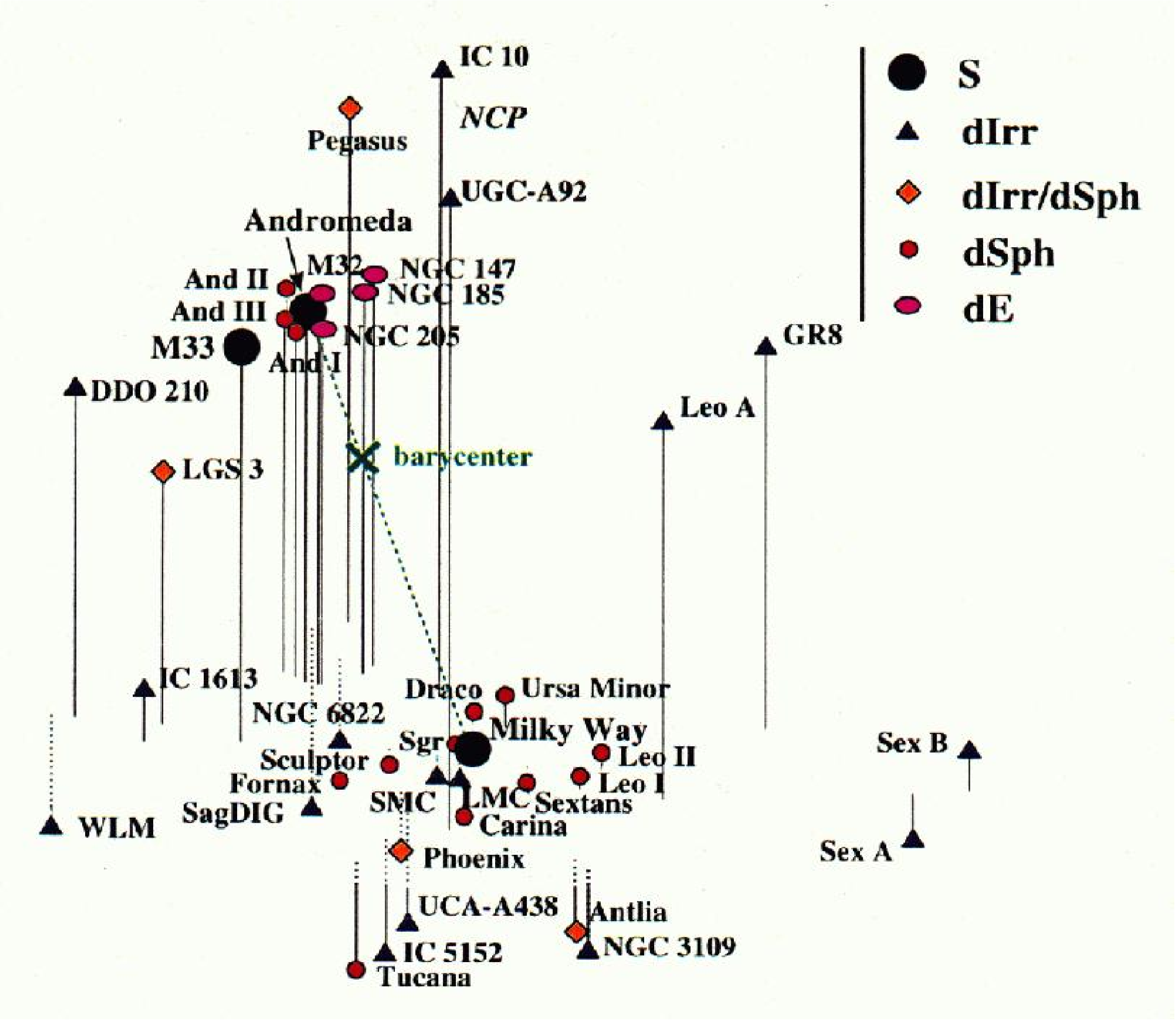
http://en.wikipedia.org/wiki/Galaxy_morphological_classification

Distribuzione galattica e tipo morfologico (Segregazione morfologica)



Dressler (1980)

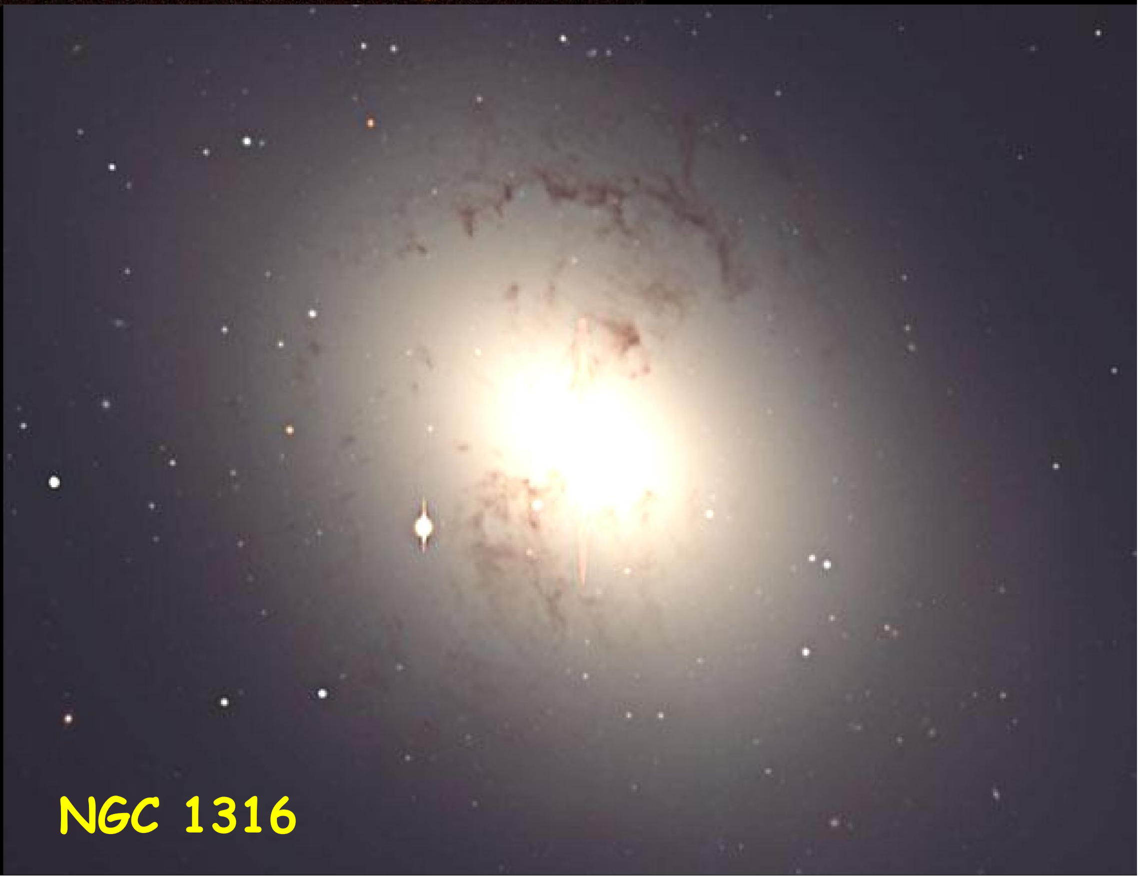
Il Gruppo Locale



http://it.wikipedia.org/wiki/Gruppo_Locale

Galassie Ellittiche

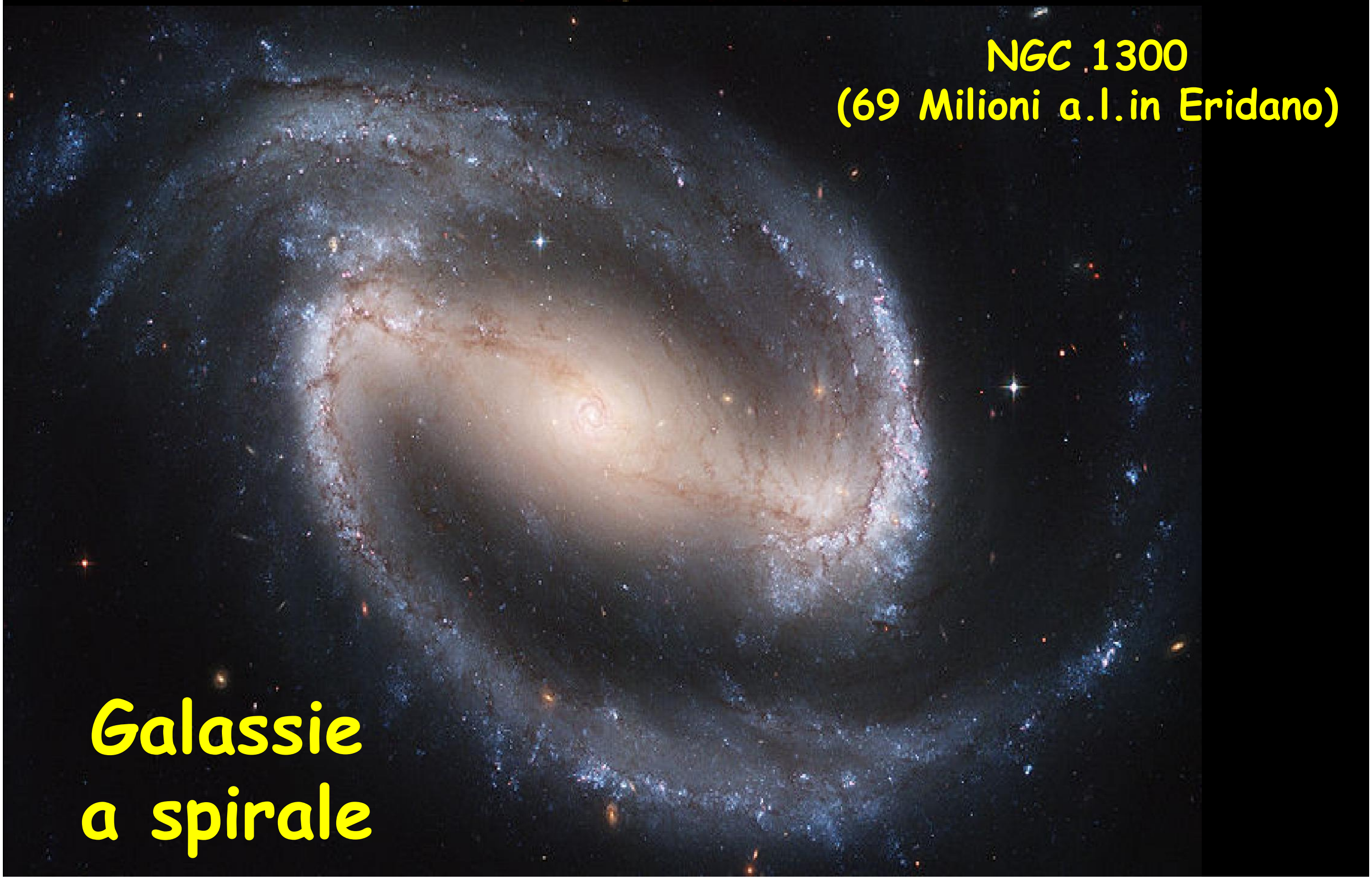
NGC 5044
(~120 Milioni a.l.)



NGC 1316

Galassie ellittiche

M104
El Sombrero



NGC 1300
(69 Milioni a.l.in Eridano)

Galassie a spirale

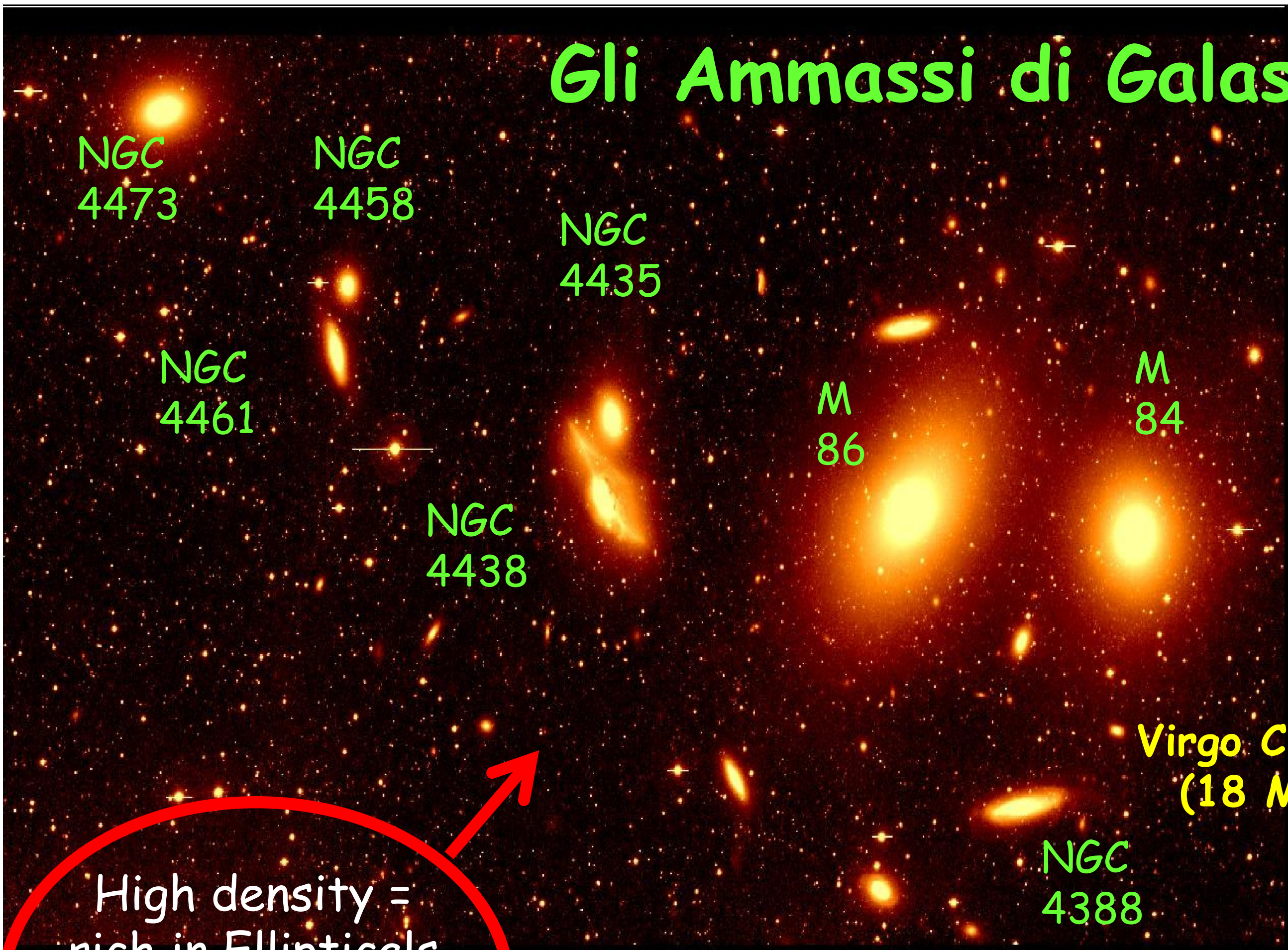
Galassie Irregolari

NGC 55 (~LMC)
6 Milioni a.l.

Sferoidali nane

La sferoidale nana in Fornax (Gruppo Locale)

Gli Ammassi di Galassie



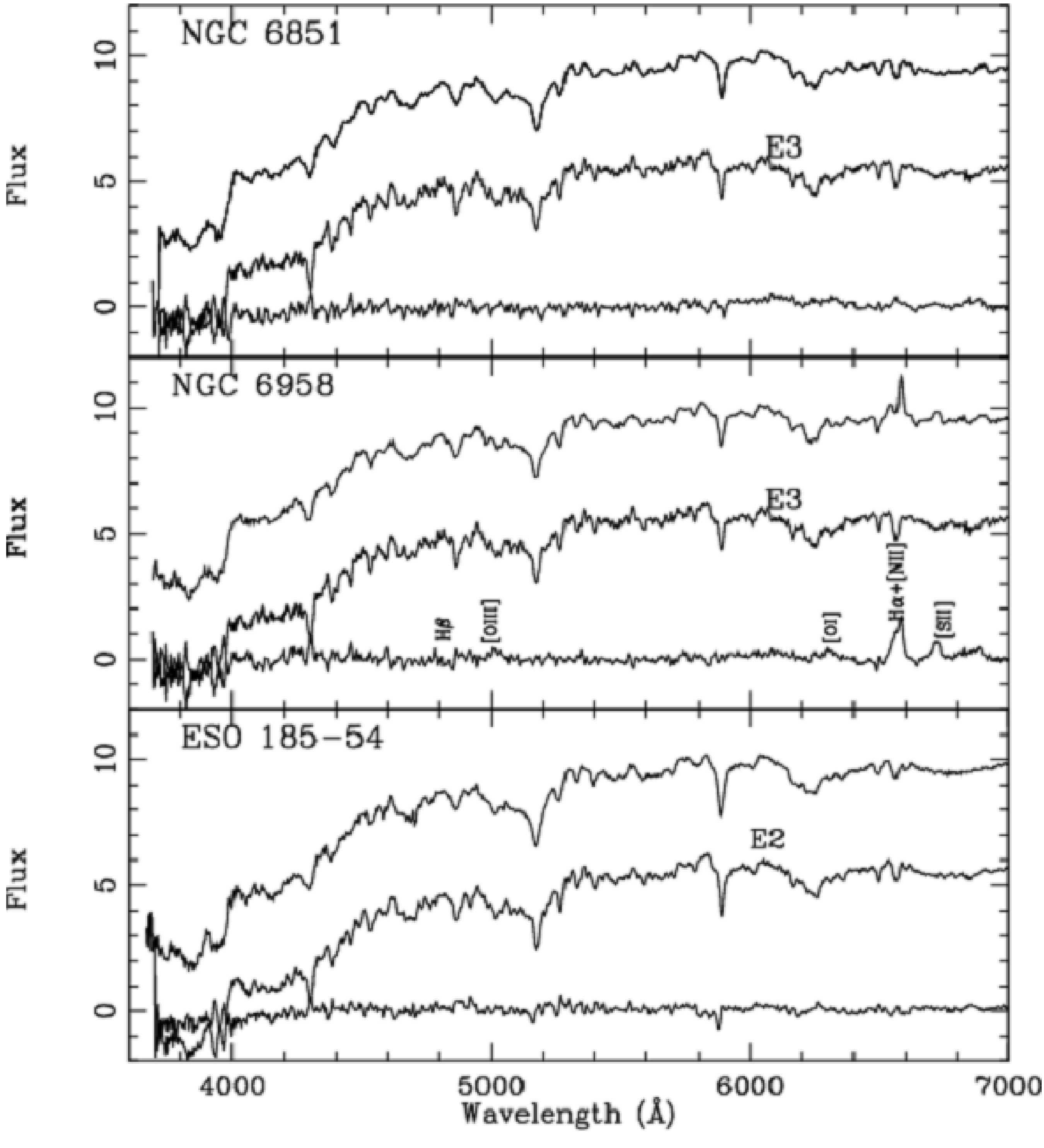
Virgo Cluster
(18 Mpc)

High density =
rich in Ellipticals

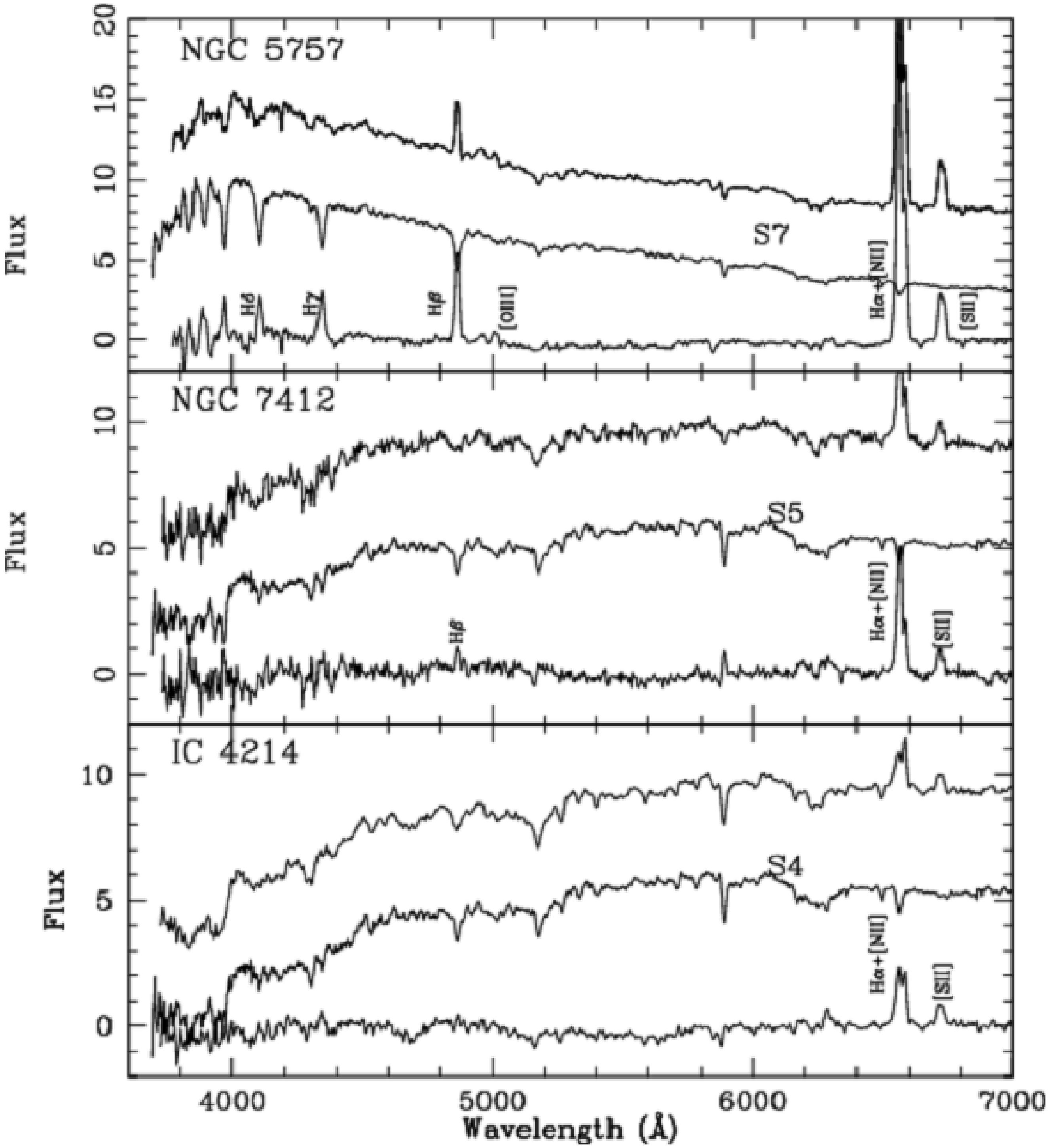
Low density =
rich in Spirals

Hercules cluster
(156 Mpc)

Lo spettro delle Ellittiche



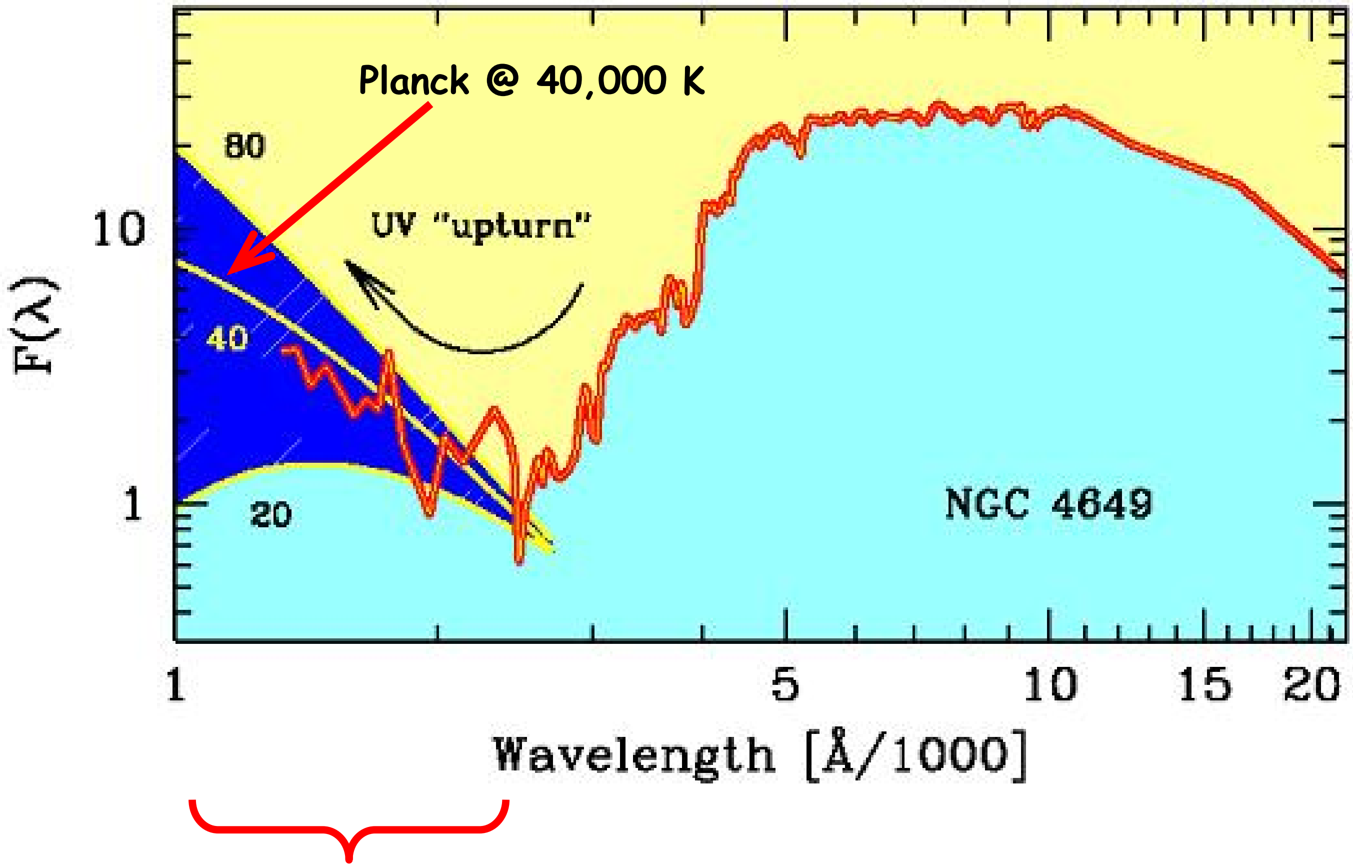
Lo spettro delle Spirali



Articoli consigliati (vedi Webpage):
http://www.bo.astro.it/~eps/lezioni/lezioni.html

- SSPs (Tinsley)
- SSPs (Renzini & Buzzoni)
- Galaxy Colors (Buzzoni)
- Galaxy Spectral Atlas (Kennicutt1)
- Galaxy Spectral Atlas (Kennicutt2)
- SFR (Kennicutt)
- SFR (Ryder & Dopita)
- SFR (Schmidt)
- Balmer break (Hamilton)
- Lick indices (Worthey)
- UV indices (Fanelli)
- Energetica e metallicita' (Buzzoni)
- Chemical evolution of spiral galaxies (Buzzoni 2011)

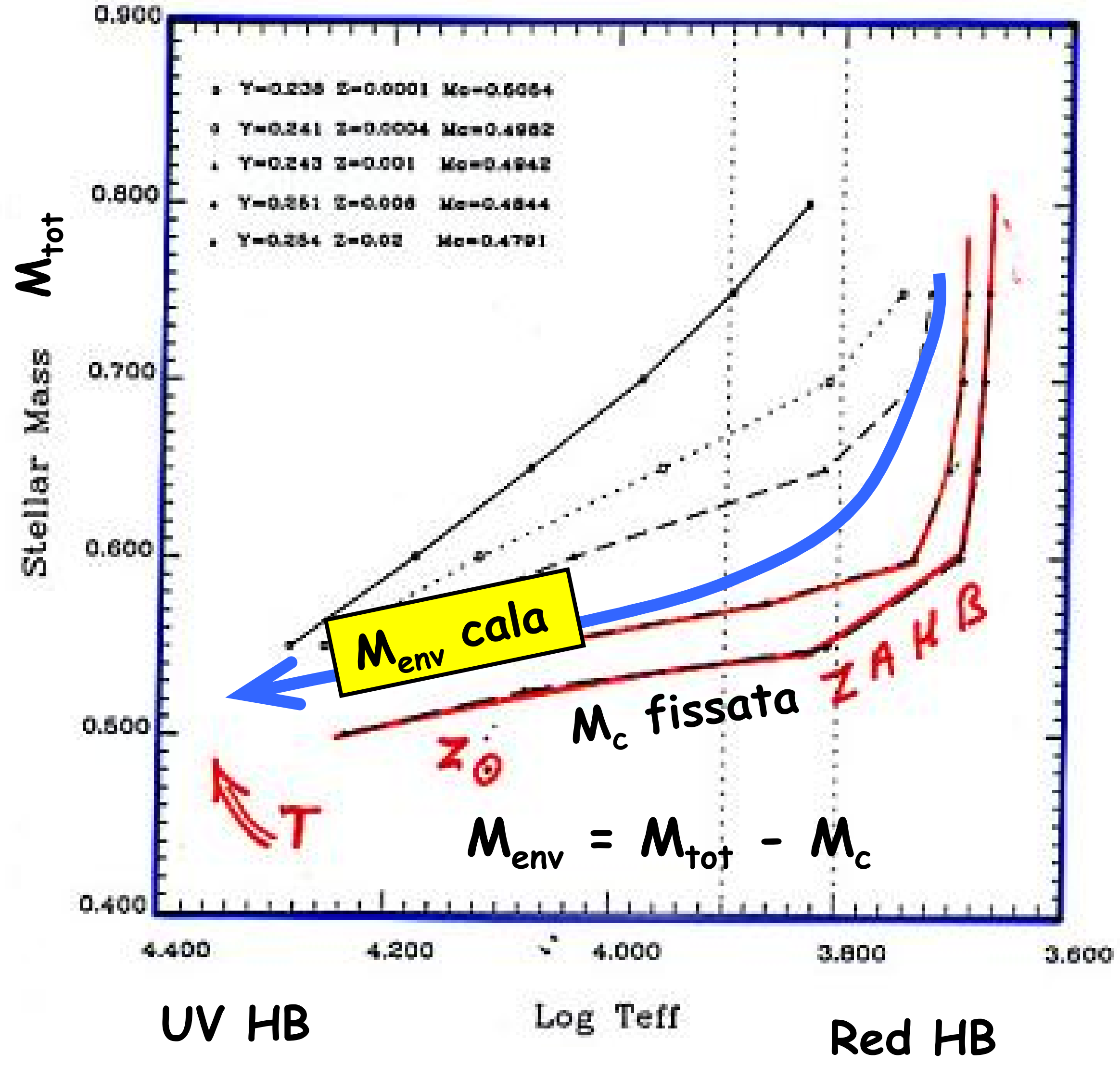
L’emissione UV nelle SSPs: l’UV Upturn nelle galassie ellittiche



	20,000	40,000	80,000 K
$\left(\frac{\text{Integrale Planck}}{\text{Bolometrico}}\right) =$	**1.4%**	**2.1%**	**6.0%**

Il meccanismo della Massa di core in HB

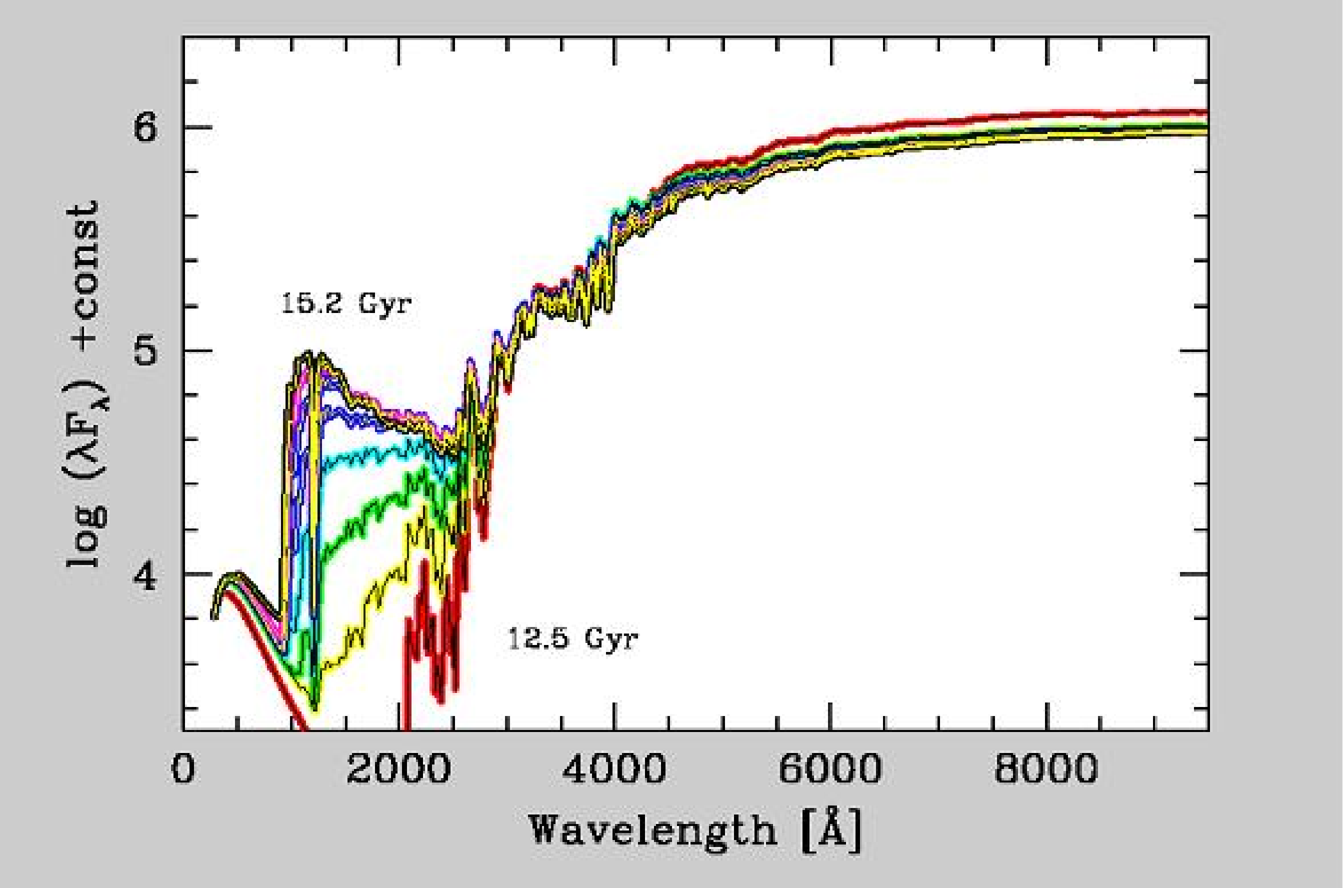
Castellani (1991)



M_{env} cala se

1) Aumenta Mc (= Y ↑ perche' Z↑)
2) Aumenta la "mass loss" (= Z↑ ??)

Evoluzione spettrale dell'UV upturn



A parita' di efficienza del meccanismo che modula M_{env}, se aumenta M_{TO} possiamo aspettarci che aumenti anche M_{HB}. Siccome la T_{HB} e' molto sensibile a M_{HB}, se t ↑ allora M_{TO} ↑ e M_{HB} ↑. Quindi M_{env} ↑ e T↓. Quindi il Braccio Orizzontale tende velocemente al rosso e l'UV upturn scompare:

$$\frac{dt}{t} \approx -2\frac{dM_{TO}}{M_{TO}} \approx -2\frac{dM_{HB}}{M_{HB}}. \quad \text{Se} \quad \frac{dM_{HB}}{M_{HB}} \approx 0.1 \Rightarrow \frac{dt}{t} \approx 0.2$$

Quindi, andando indietro di circa 2-3 Glyr (z~0.2-0.3) l'effetto dovrebbe scomparire.

M. CASTELLANI et al. (1994)

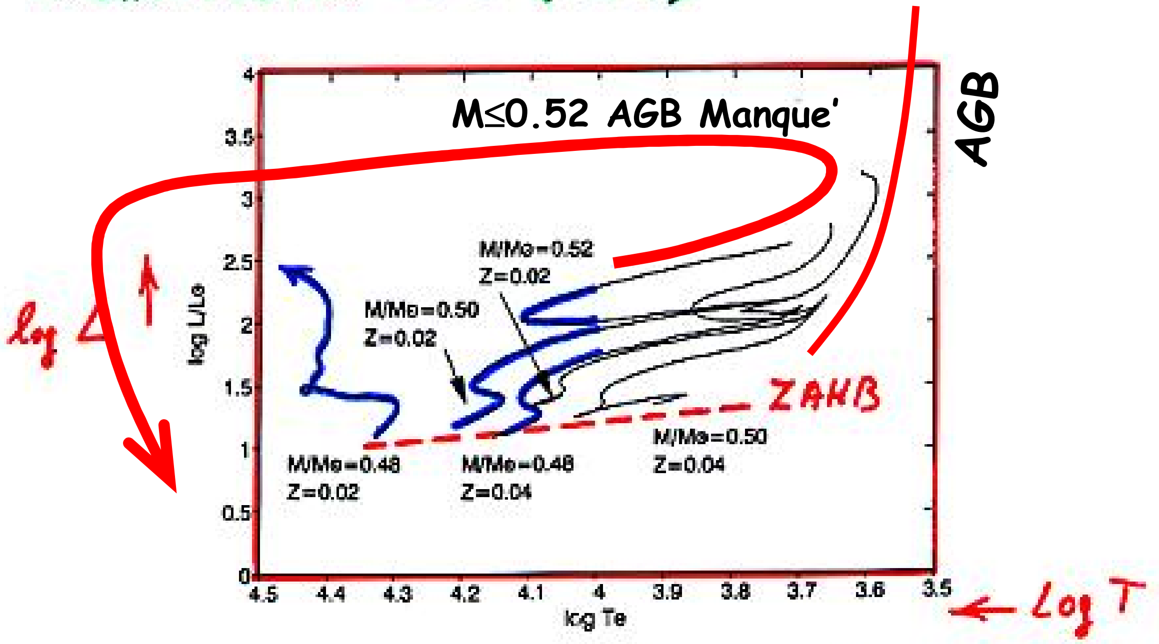


FIG. 1.—The H-R diagram of the models evolved at constant mass covering the central He-burning phase and (in some models) the initial He shell–burning phases.

V. CASTELLANI & TORNAMBÉ (1992)

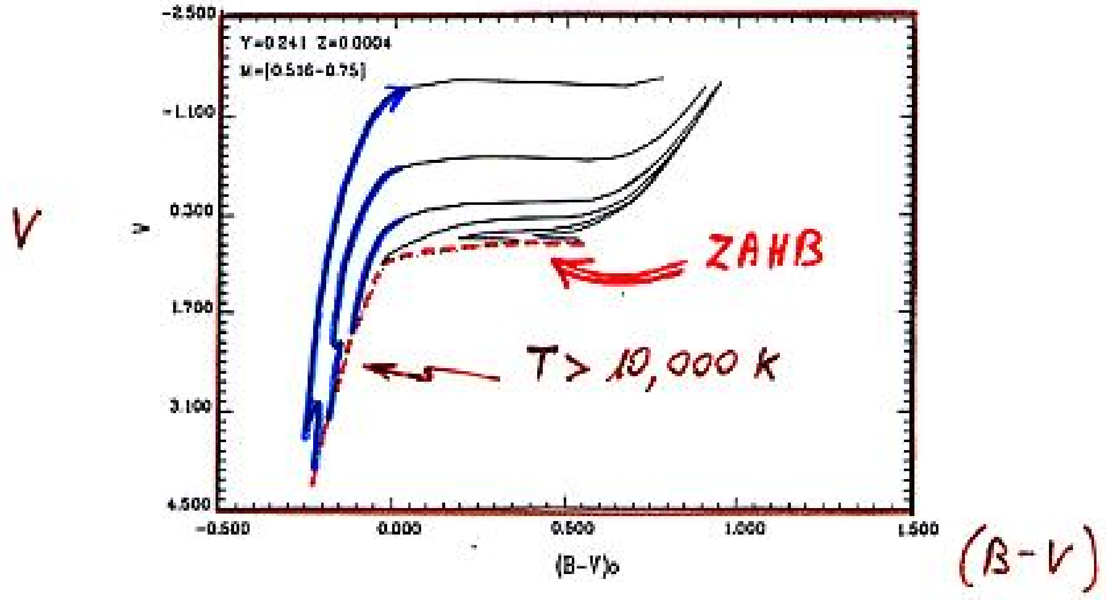
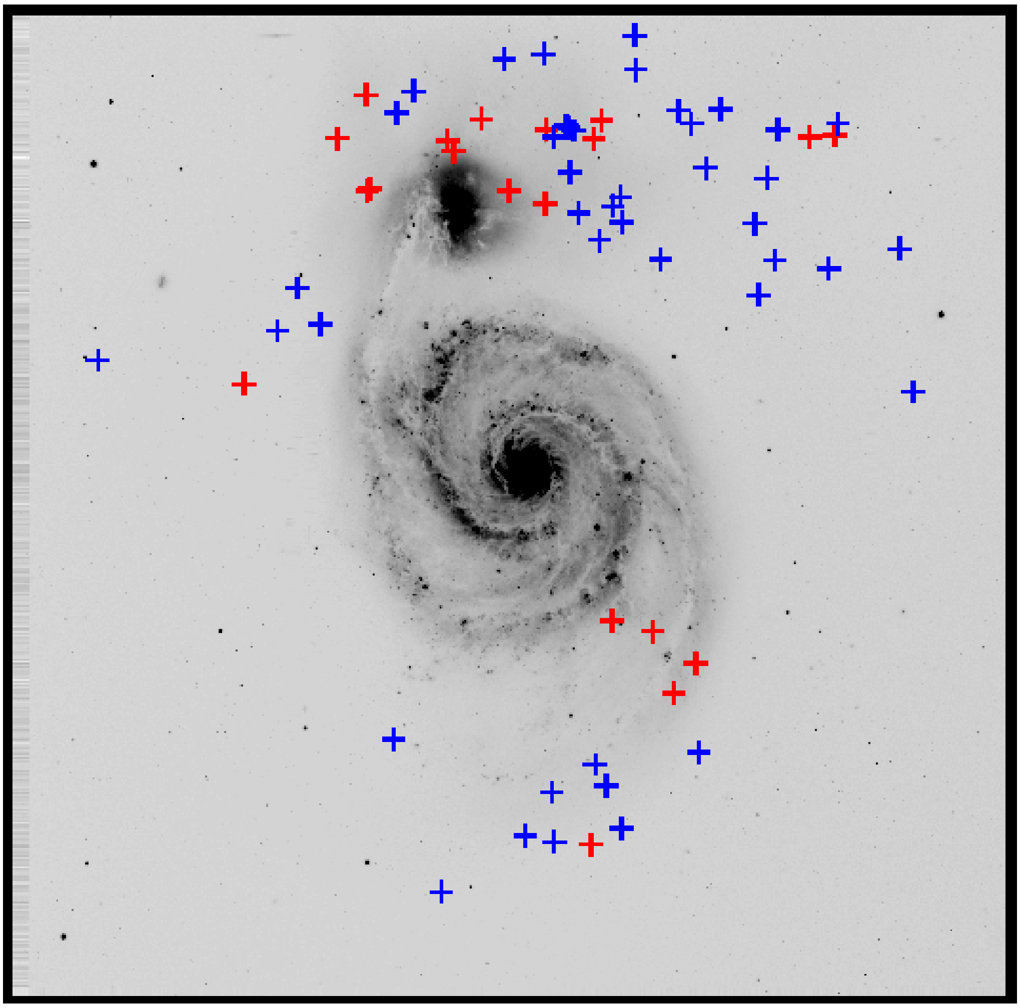


Fig. 5. The evolutionary paths in the V, $B - V$ plane of HB models with $Z = 0.0004$ and for selected values of the stellar mass in the labeled range of masses

Articoli consigliati (vedi Webpage):
http://www.bo.astro.it/~eps/lezioni/lezioni.html

- SSPs (Tinsley)
- SSPs (Renzini & Buzzoni)
- Galaxy Spectral Atlas (Kennicutt1)
- Galaxy Spectral Atlas (Kennicutt2)
- UV Upturn (Brown)
- UV Upturn (Dorman)
- UV Upturn (OConnell)
- UV Upturn (Yi)
- Balmer break (Hamilton)
- Lick indices (Worthey)
- UV indices (Fanelli)

Le Nebulose Planetarie



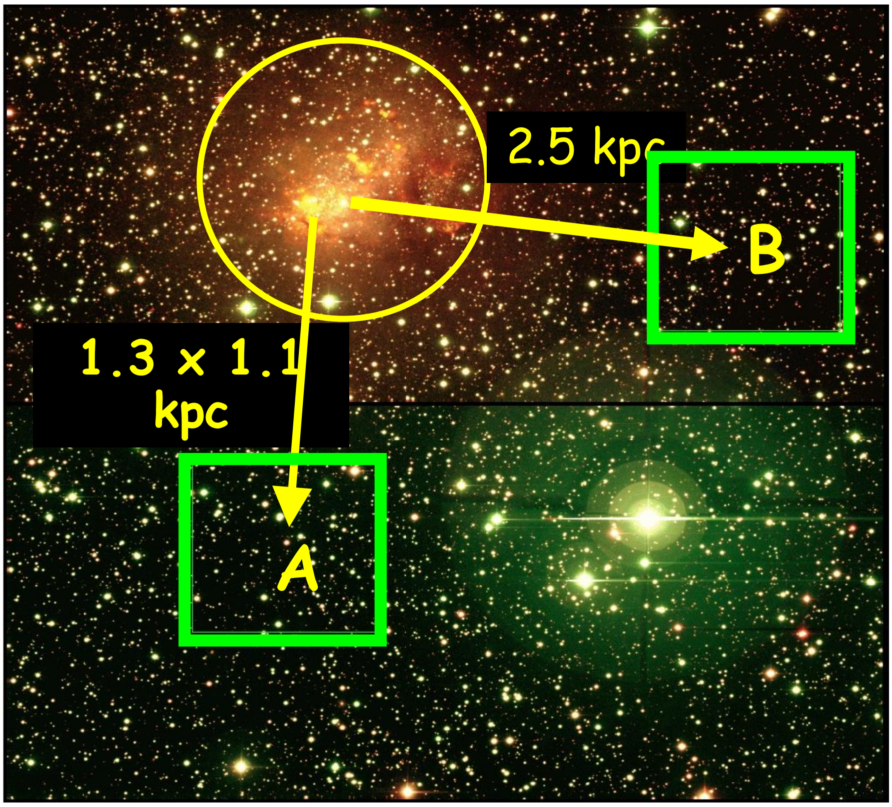
Feldmeier, Ciardullo & Jacoby (1997)

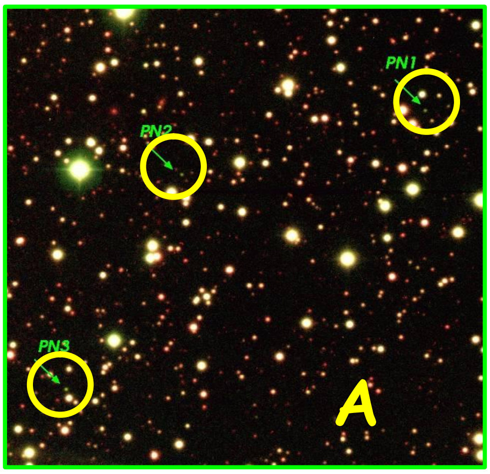
Planetary Nebulae follow Luminosity not surface brightness!

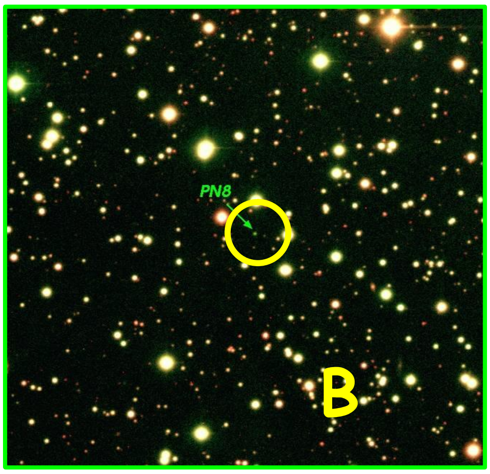
Stars can exist at great distances from luminous galaxies

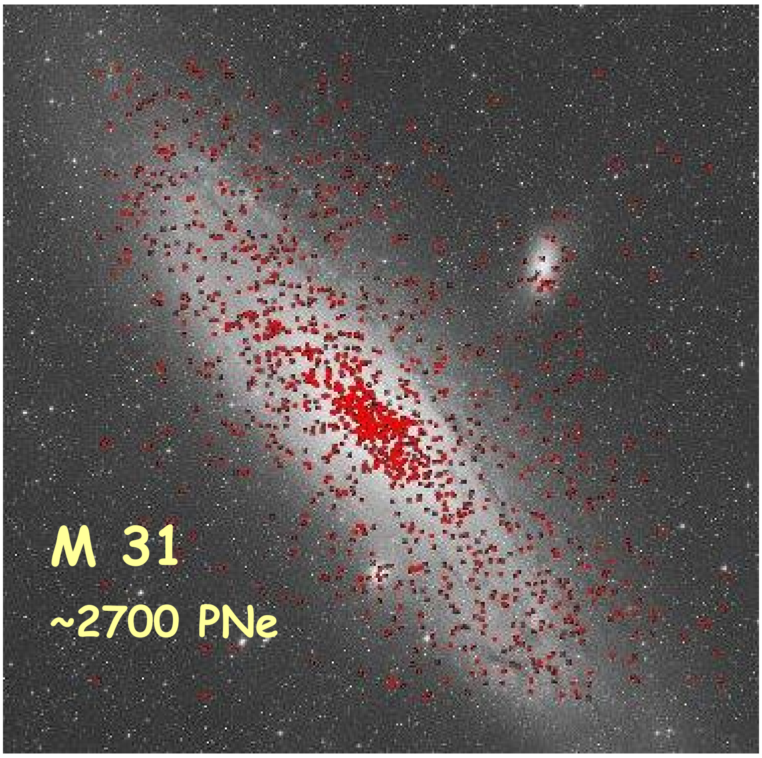
Il censimento delle PNe nelle galassie del Gruppo Locale

Magrini et al. 2003 A&A 407 51

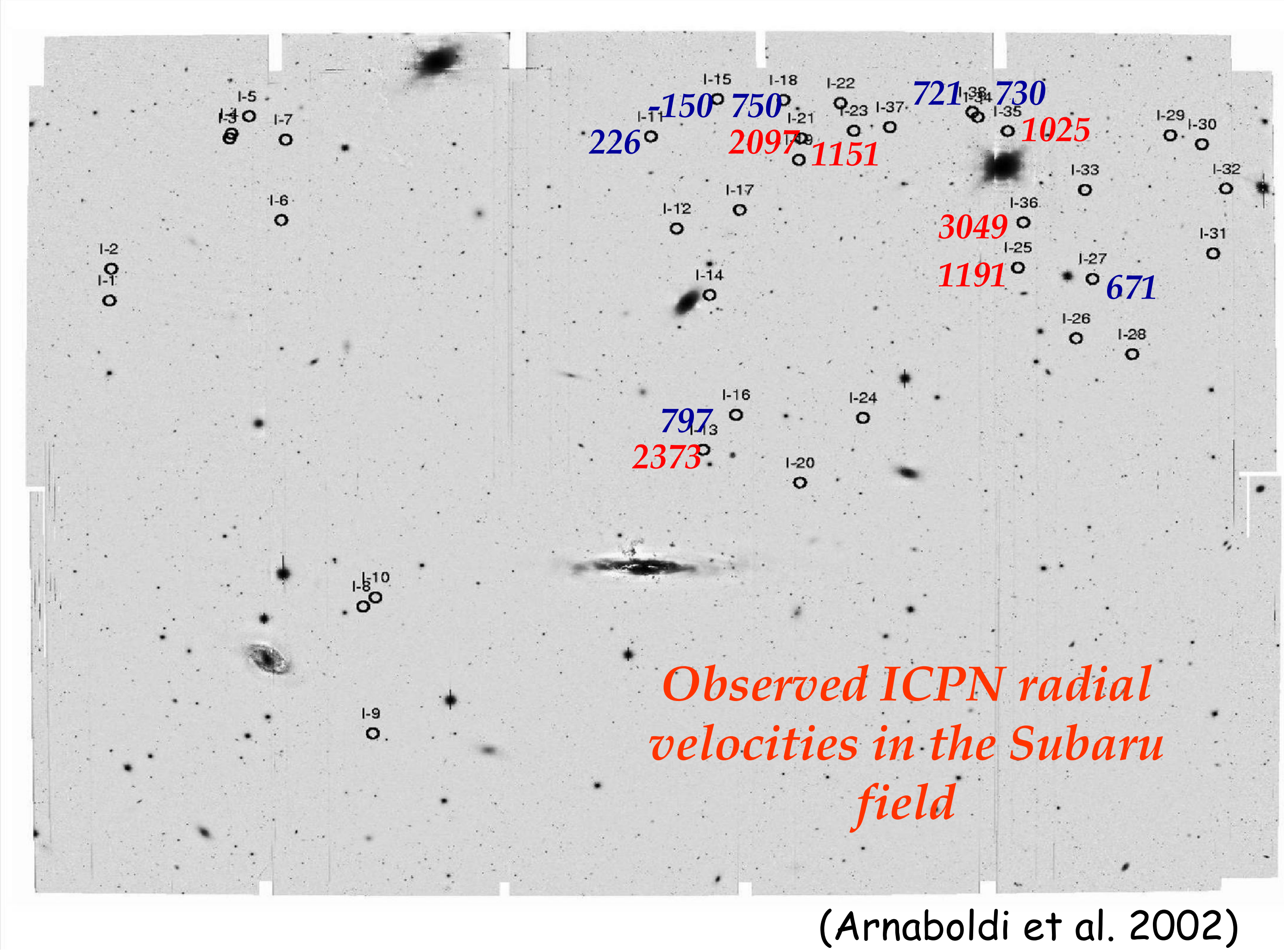








Planetarie intra-galattiche nell'Ammasso della Vergine



(Arnaboldi et al. 2002)

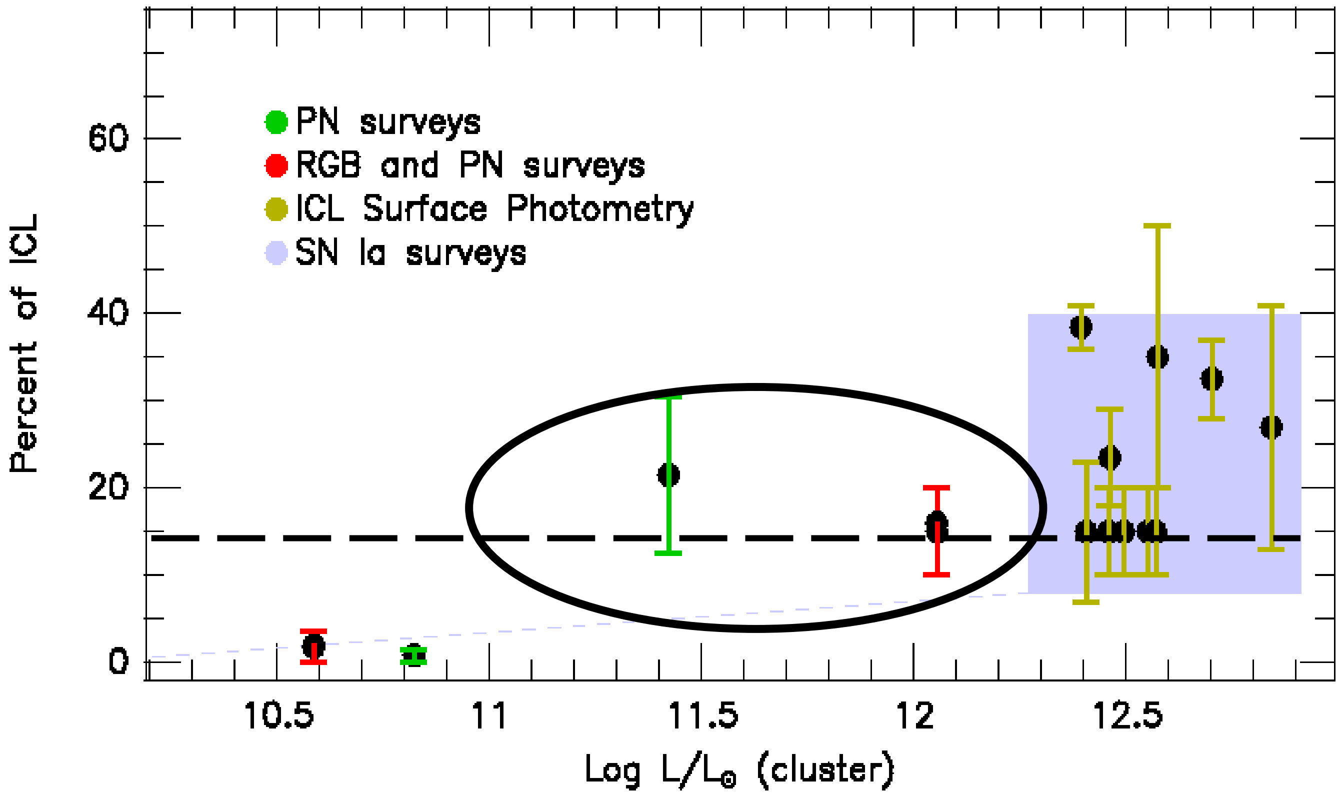
$$N_{PN} = B L_{tot} \tau_{PN} \quad \longrightarrow \quad \alpha = \frac{N_{PN}}{L_{tot}} = B \tau_{PN}$$

quindi $\alpha = \frac{N_{PN}}{L_{tot}} \approx 2 \times 10^{-11} \times 3 \times 10^{4} = 6 \times 10^{-7}$

Ovvero, 1 PN campiona: $L_{tot} \approx \frac{1}{\alpha} \approx 1.7 \times 10^{6} L_{sun}$

PNe e Intra-Cluster Luminosity (ICL)

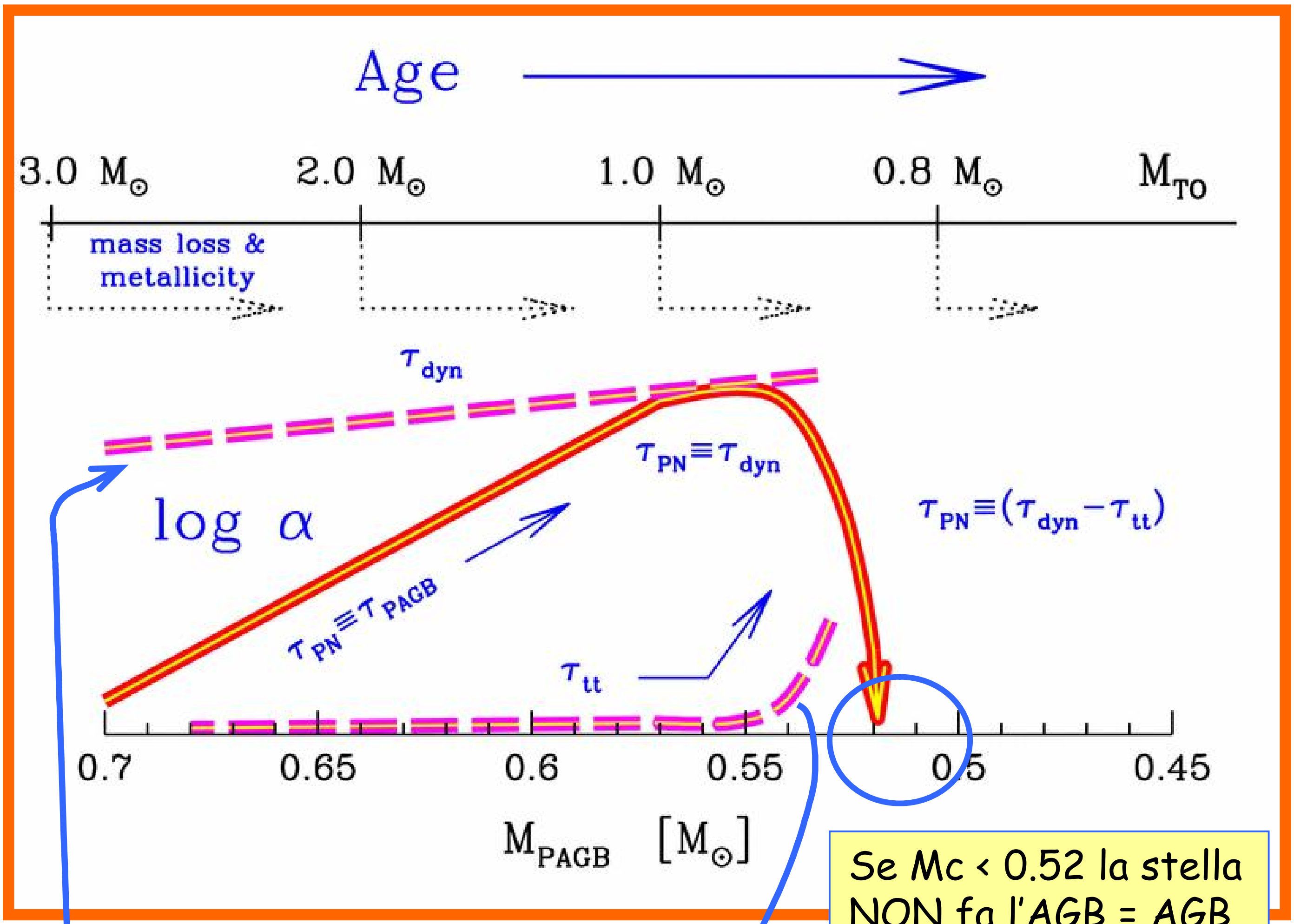
(Ciardullo et al. 2003)



Per l'Ammasso della Vergine, si valuta una ICL dell'ordine del 15% della L dell'intero ammasso.

Tempi scala di visibilita' delle PNe

Buzzoni, Arnaboldi & Corradi (2006)



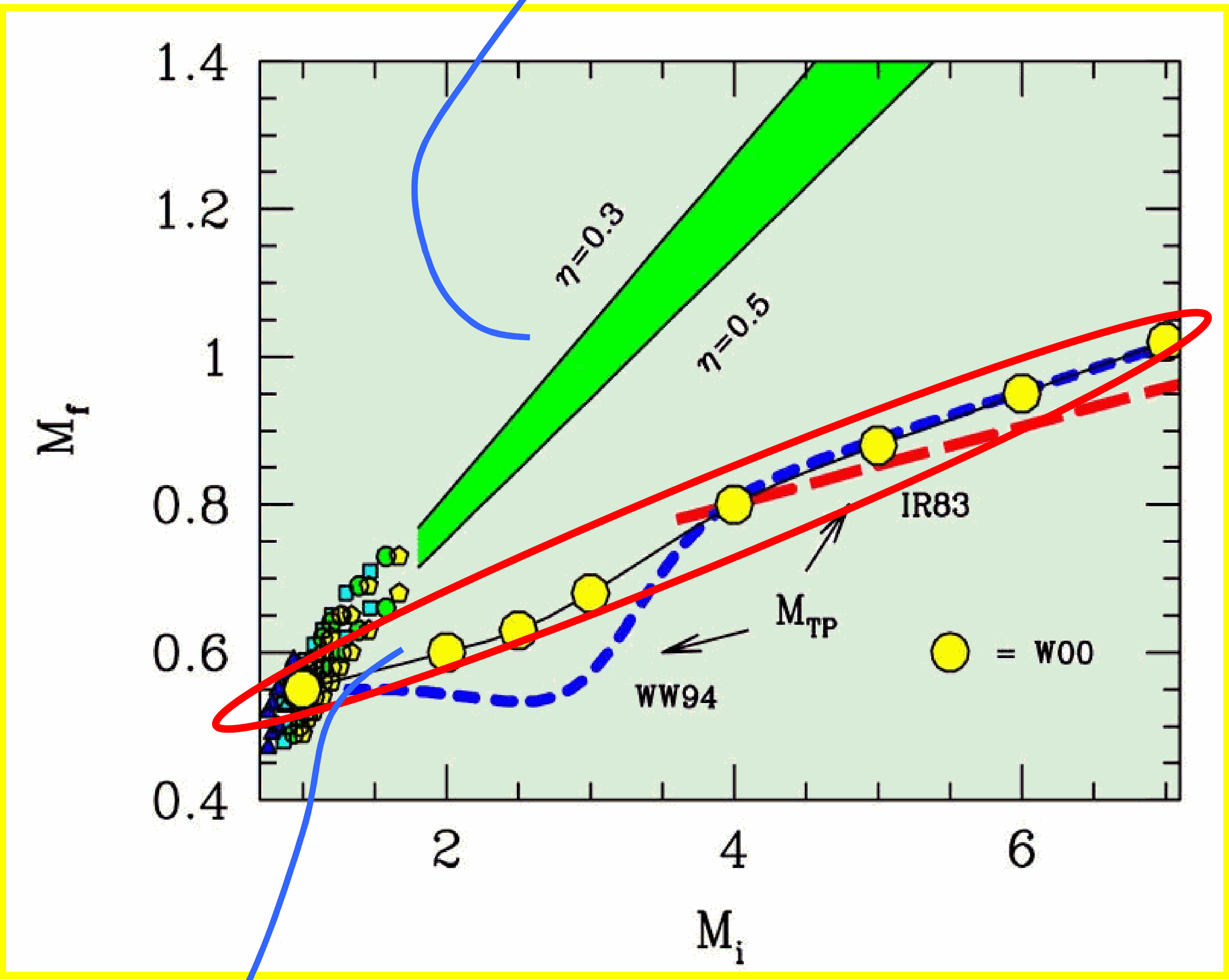
Se Mc < 0.52 la stella NON fa l'AGB = AGB Manque' e quindi non ci sono PNe

Tempo dinamico
(evaporazione inviluppo)
V~10 km/sec

Tempo di transizione
da AGB freddo a
T~50,000 K

Massa iniziale e finale delle stelle

Formula di Reimers (1975)

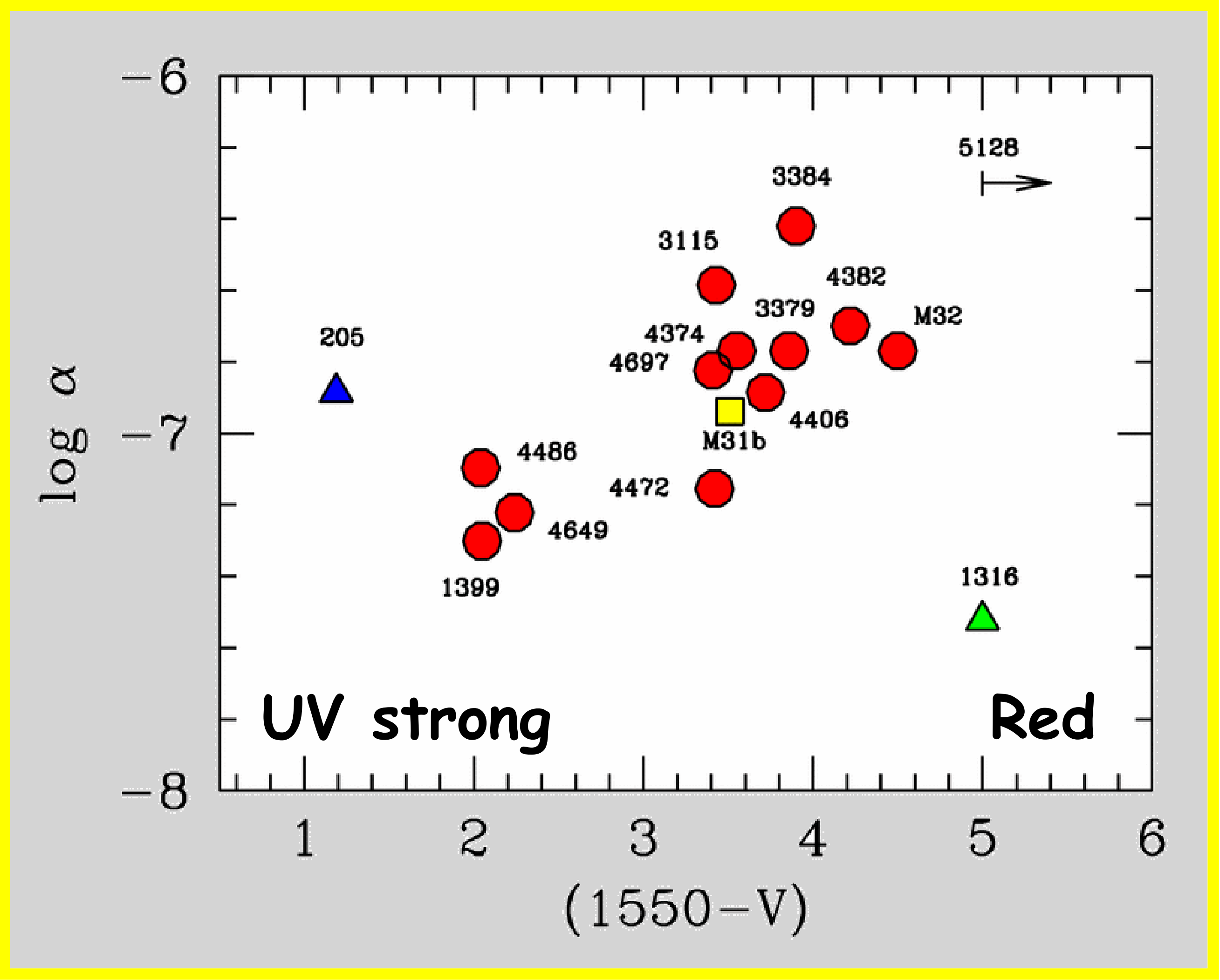


Buzzoni, Arnaboldi & Corradi (2006)

Osservazione empirica di Weidemann (2000) dagli ammassi aperti Galattici, dove $M_i = M_{TO}$, e $M_f = M_{WD}$

Si vede che le PNe devono avere sempre una massa << $1M_{sun}$

PNe e UV upturn nelle galassie ellittiche



Buzzoni, Arnaboldi & Corradi (2006)

Un forte UV da stelle HB implica molte stelle AGB manque' e quindi α↓

Articoli consigliati (vedi Webpage):
http://www.bo.astro.it/~eps/lezioni/lezioni.html

- SSPs (Renzini & Buzzoni)
- Nebulose Planetarie (Arnaboldi)
- Nebulose Planetarie (Feldmeier)
- Nebulose Planetarie (Buzzoni)
- IMF (Weidemann)

Entropia Fotometrica

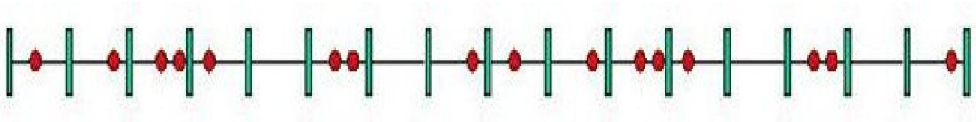
What a Photometric Entropy theory is for?

Entropy is a measure of the intrinsic "variance" of a stellar aggregate along the different spectral range of observation.

- Surface-brightness Fluctuations
- Crowding
- Diagnostics from Narrow-band Spectroscopy

Some Fundamentals

$$p(x) = \frac{e^{-\lambda}\,\lambda^{x}}{x!} \quad \text{for } \lambda > 0 \text{ and } x = 0, 1, 2\ldots$$

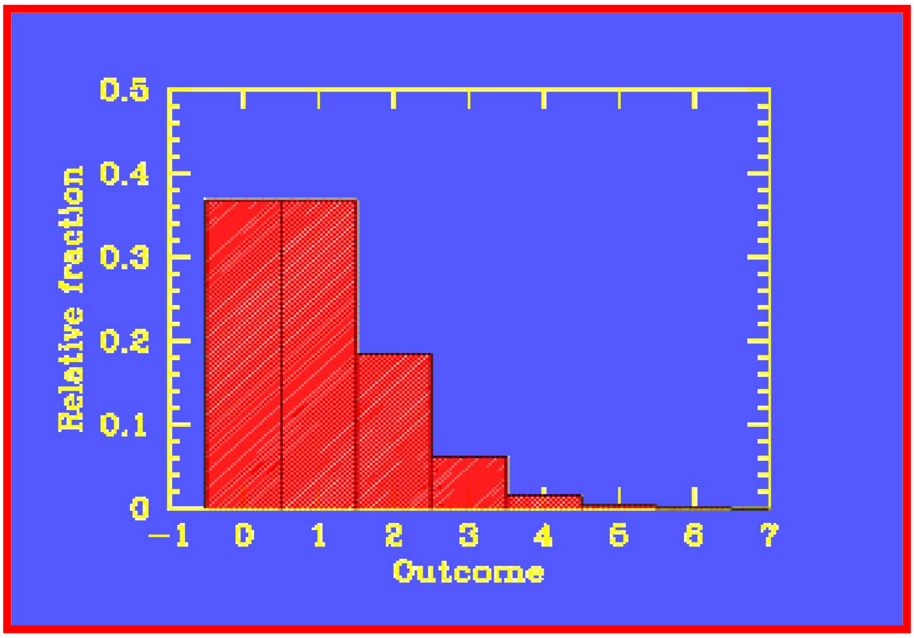


1, 2, 3, ... N_{tot}

→ N= 1± 1 for each cell $L_{tot} = \Sigma\, \ell_* = N_{tot}\, \ell_*$

$\sigma(N_{tot}) = \sqrt{\Sigma 1} = \sqrt{N_{tot}}$ $\sigma(L_{tot}) = \sqrt{\Sigma \ell_*^2} = \ell_* \sqrt{N_{tot}}$

$\sigma(L_{tot})/L_{tot} = 1/\sqrt{N_{tot}}$



More generally, if ℓ_* is NOT a constant, we can still define

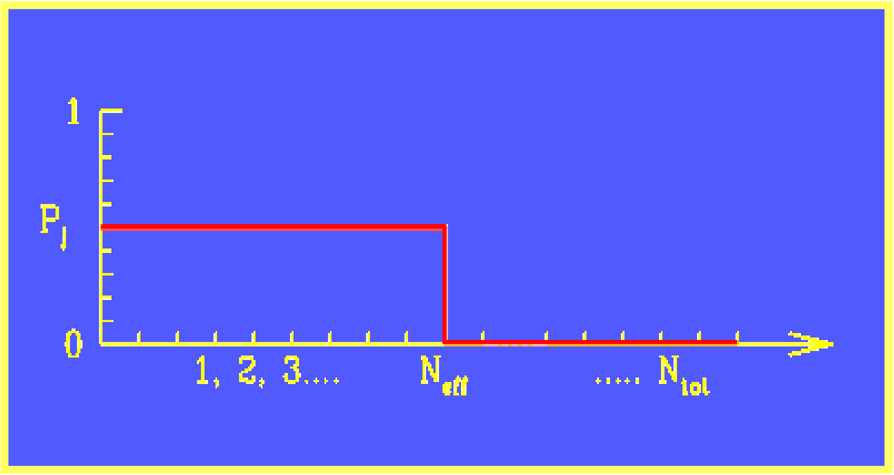
$$\sigma(L_{tot})/L_{tot} = 1/\sqrt{N_{eff}}$$

where, always,

$$N_{eff} \leq N_{tot}$$

N_{eff} will depend on λ as ℓ_* depends on λ

$$S = \mathrm{Log}\,(N_{eff}/N_{tot})$$



Quite importantly,

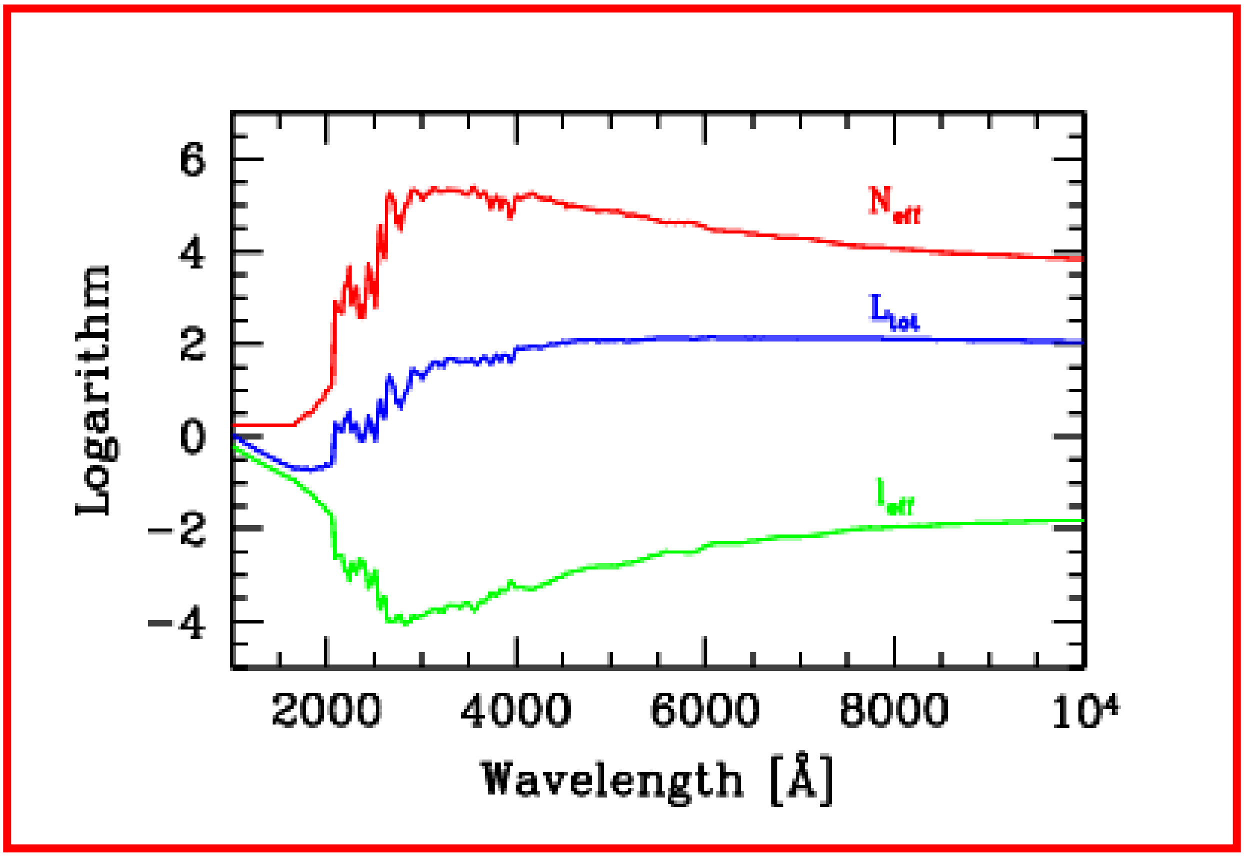
$$S = S(\lambda)$$

In order to fix N_{eff} (and Entropy) we need a photometric argument

$$\sigma^2(L_{tot}) \,/\, L_{tot} = \Sigma \ell_*^2 \,/\, \Sigma \ell_* = \ell_{eff}$$

At every λ, it must be:

$$N_{eff} \times \ell_{eff} = L_{tot}$$



Buzzoni (1993), A&Ap, 275, 433

Cerviño et al. (2002), A&Ap, 381, 51

Teoria dettagliata

CASO A) N stelle di fissata luminosità l_*

$$L_{TOT} = \sum^N l_* = N\, l_*$$

$$\sigma_{L_{TOT}} = \left(\sum_j^N \sigma_j^2\right)^{\frac{1}{2}} \qquad \forall * \quad m = 1 \pm 1 \quad (\text{Poisson})$$

$$\downarrow$$

$$\left(\sum (l_* \cdot 1)^2\right)^{\frac{1}{2}} \rightarrow \left(N\, l_*^2\right)^{\frac{1}{2}} \rightarrow l_* \sqrt{N}$$

Quindi
$$\boxed{\frac{\sigma_L}{L_{TOT}} = \frac{l_* \sqrt{N}}{l_*\, N} = \frac{1}{\sqrt{N}}}$$

CASO B) N stelle tutte diverse

$$L_{TOT} = \sum^N l_j = N \langle l \rangle \qquad \text{dove } \langle l \rangle = \frac{\sum l_j}{N}$$

$$\sigma_{L_{TOT}} = \left(\sum l_j^2\right)^{\frac{1}{2}} = \sqrt{N} \langle l^2 \rangle \qquad \text{dove } \langle l^2 \rangle = \frac{\sum l_j^2}{N}$$

media quadratica

$$\frac{\sigma_{L_{TOT}}}{L_{TOT}} = \frac{\sqrt{N} \langle l^2 \rangle^{\frac{1}{2}}}{N \langle l \rangle} = \frac{K}{\sqrt{N}} \qquad \text{dove } K = \left[\frac{\langle l^2 \rangle}{\langle l \rangle^2}\right]^{\frac{1}{2}}$$

$K \geq 1$ perché $\langle l \rangle^2 \leq \langle l^2 \rangle$

$$\frac{K}{\sqrt{N}} = \frac{1}{\sqrt{N_{eff}}} \Rightarrow \boxed{\frac{N_{eff}}{N} = \frac{1}{K^2}}$$

Quindi è sempre $N_{eff} \leq N$

Definiamo
$$\boxed{\begin{array}{c}\text{ENTROPIA FOTOMETRICA:} \\ S = -2 \log K = \log \dfrac{N_{eff}}{N}\end{array}}$$

Analisi della varianza

$$\sigma_{L_{TOT}}^2 = \sum l_i^2$$

$$\frac{\sigma_L^2}{L_{TOT}} = \frac{N\langle l^2\rangle}{N\langle l\rangle}$$ → Questo rapporto ha le dimensioni di una luminosità

quindi $$\boxed{l_{eff} = \frac{\langle l^2\rangle}{\langle l\rangle} = \frac{\sum l^2}{\sum l}}$$

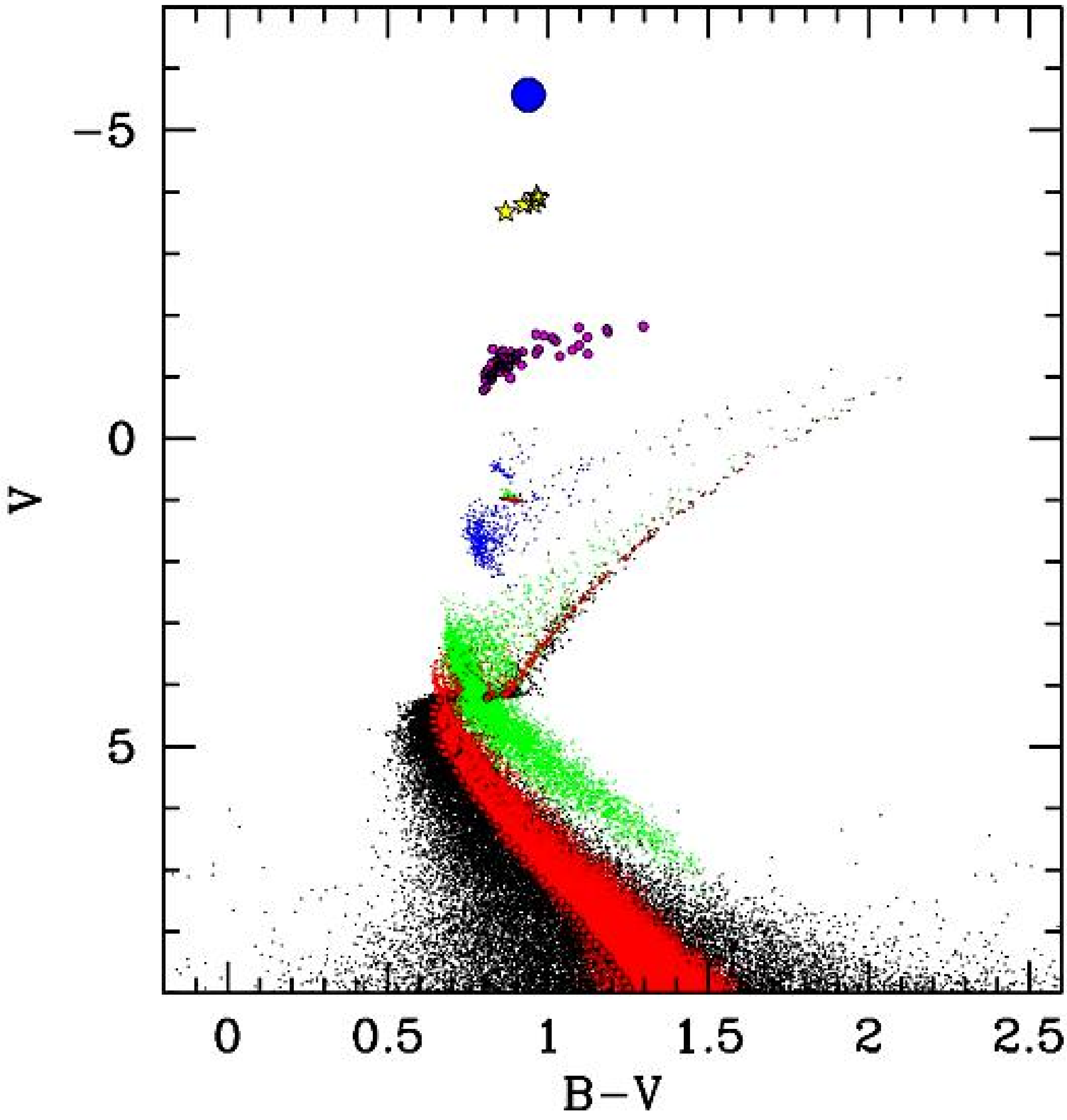
Che relazione c'è fra N_{eff} e l_{eff} ?

$$N_{eff} \cdot l_{eff} = \frac{N}{k^2}\frac{\langle l^2\rangle}{\langle l\rangle} = \frac{N\cancel{\langle l^2\rangle}\langle l\rangle^{\cancel{2}}}{\cancel{\langle l^2\rangle}\cancel{\langle l\rangle}} = N\langle l\rangle$$

$$\downarrow$$

$$N\frac{\sum l}{N}$$

Quindi $$\boxed{N_{eff} \times l_{eff} = L_{TOT}}$$



SSP

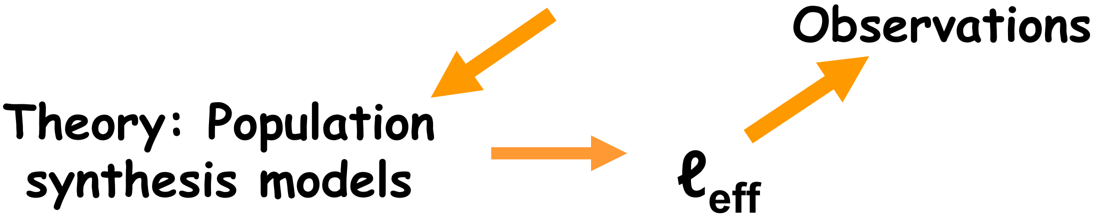
(Age, [Fe/H], IMF)

(15 Gyr, 0.0, Salpeter)

Surface-Brightness Fluctuations: an alternative approach for the case of M53

First application of the theory to galx's: Tonry & Schneider (1988) and Tonry (1991)

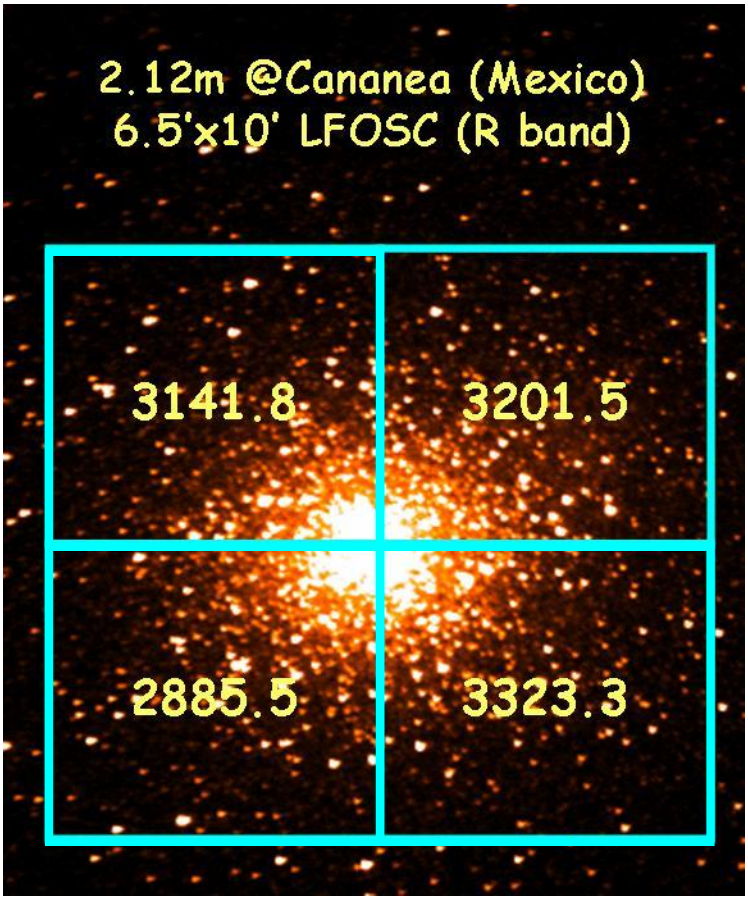
$$\sigma^2(L_{tot}) / L_{tot} = \Sigma \ell_*^2 / \Sigma \ell_* = \ell_{eff}$$



Observations

Theory: Population synthesis models

ℓ_{eff}

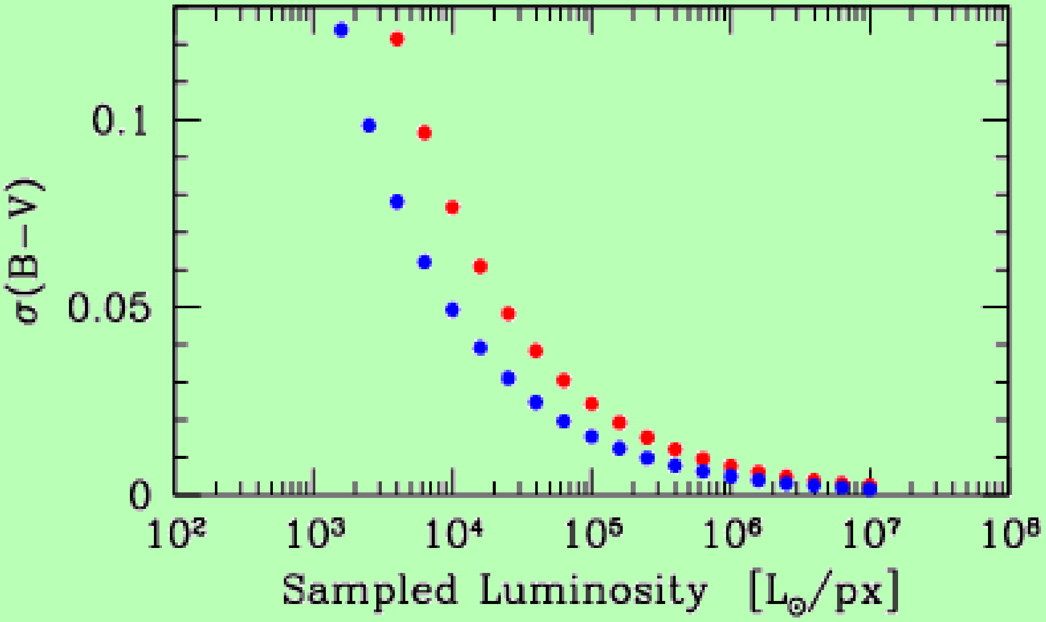


$L_{(quad)}$ = 3138 ± 184

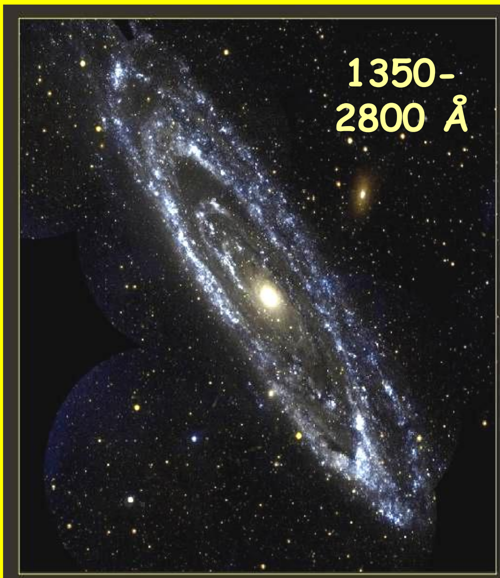
Luminosity Sampling and Intrinsic Color Fluctuations

$$\Delta mag = \sigma(L_{tot})/L_{tot} = 1/\sqrt{N_{eff}}$$

$$\sigma\,(B-V) = [\sigma(B)^2 \pm \sigma(V)^2\,]^{1/2} = (1/\,N_{eff}^{B} \pm 1/\,N_{eff}^{V})$$



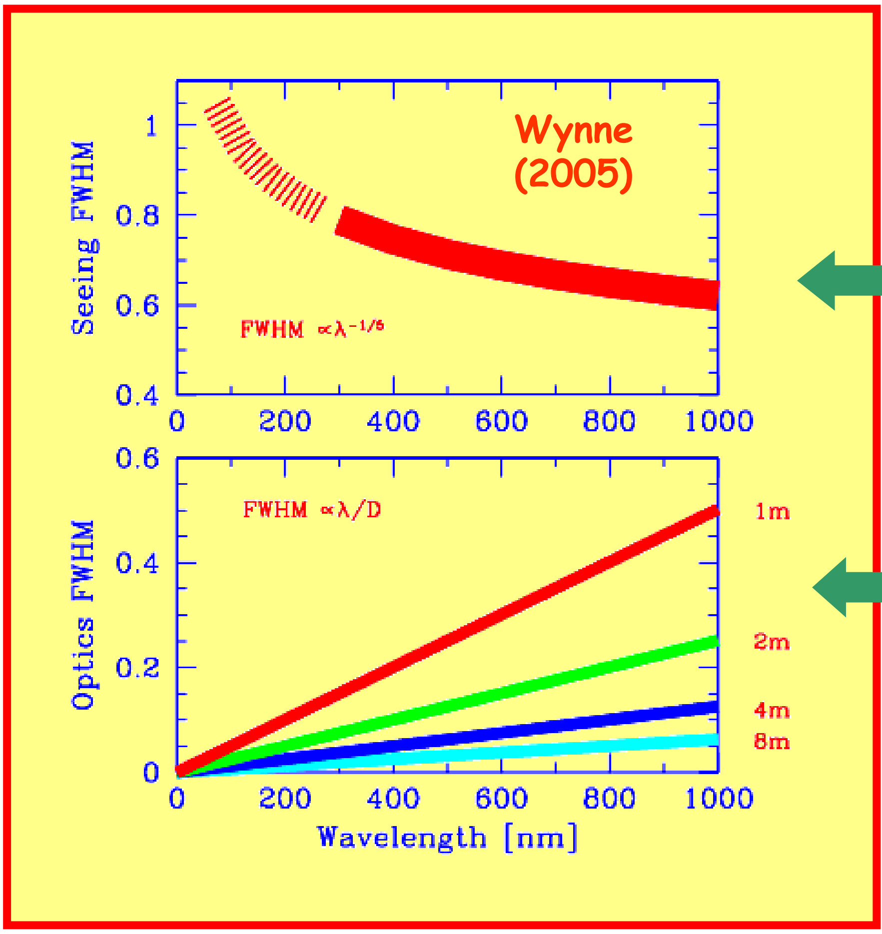
Crowding & Optical opacity



Andromeda Galaxy
GALEX

Thilker et al. (2005)

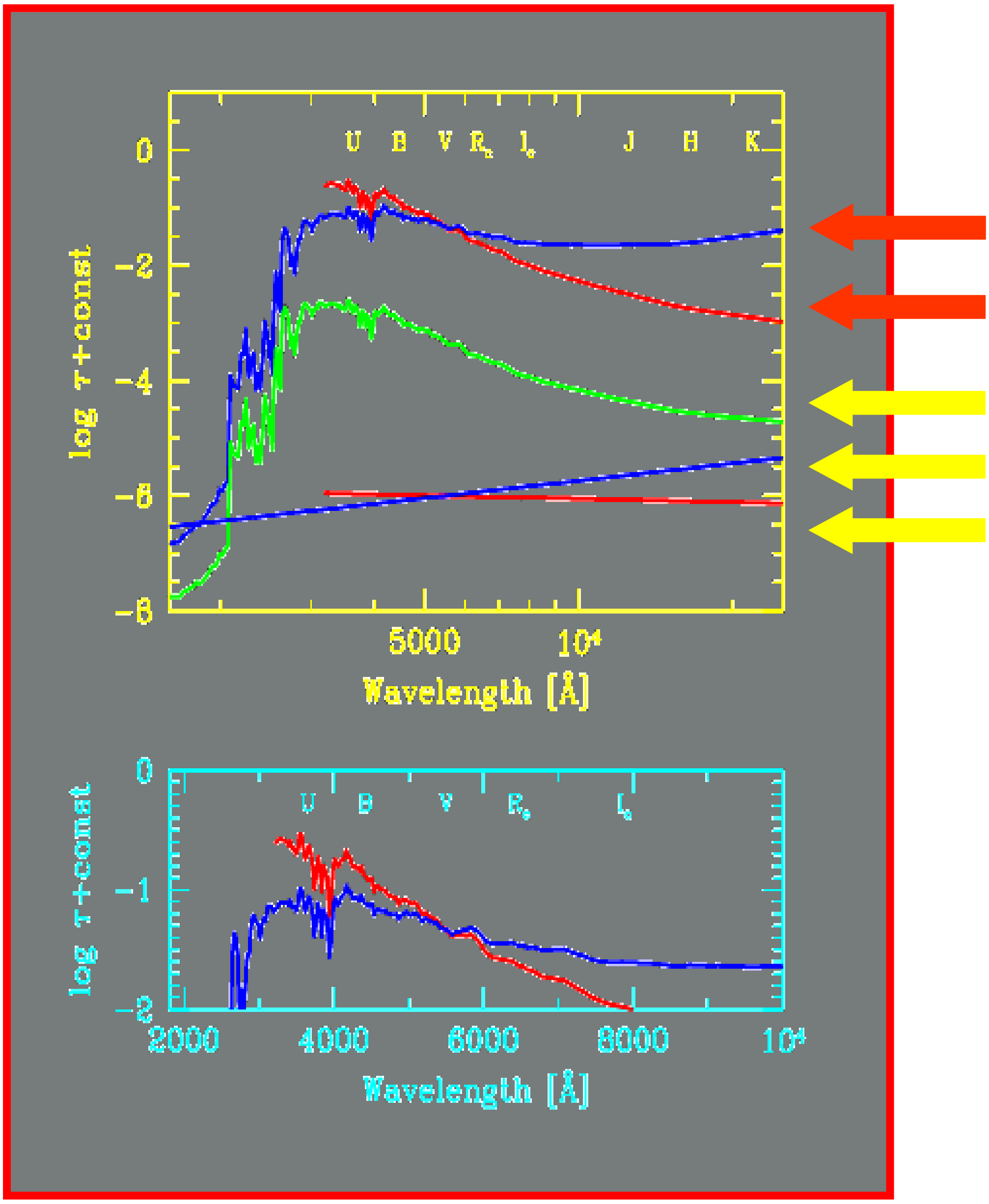
Andromeda Galaxy
Visible light image (John Gleason)



Seeing

Diffraction

Crowding & Opacity



from Space

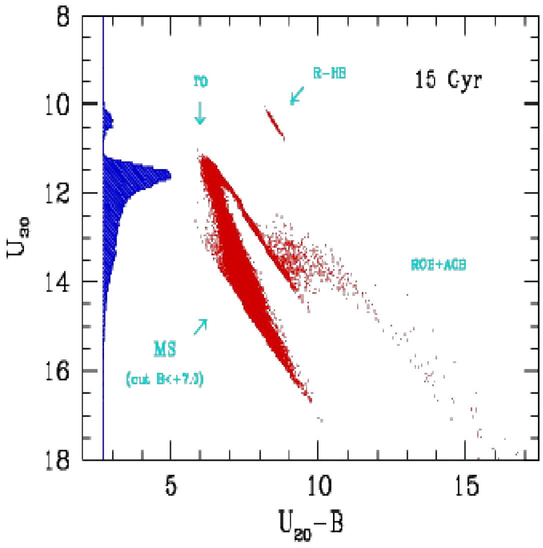
from Ground

Entropy (N_{eff})

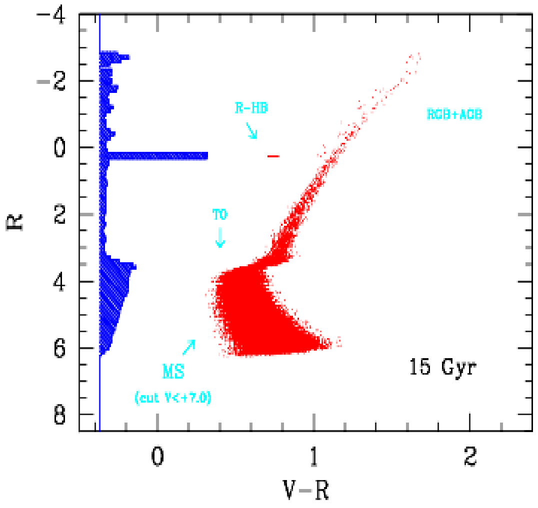
Diffraction

Seeing

Oligarchy vs. Democracy

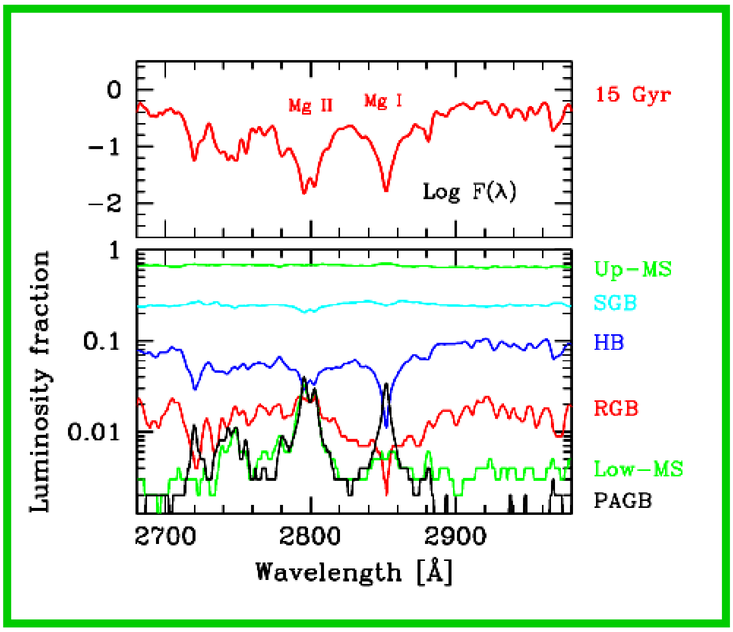


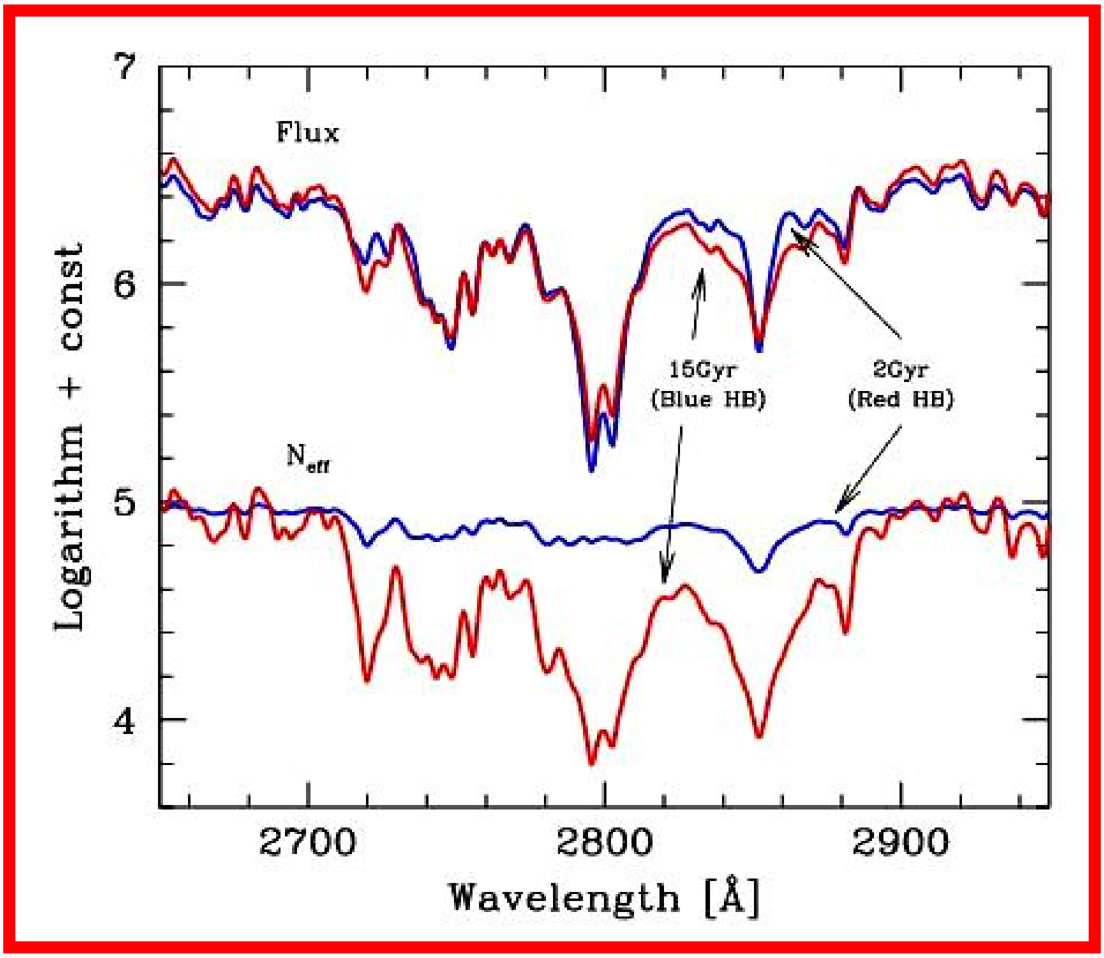
2000 Angstroms



7000 Angstroms

Recovering the Age-Metallicity degeneracy





Articoli consigliati (vedi Webpage):
http://www.bo.astro.it/~eps/lezioni/lezioni.html

- Entropia Fotometrica (Buzzoni)
- Photometric Entropy (Cerviño & Luridiana)
- SBF (Buzzoni)
- SBF (Tonry & Schneider)

I principi della spettroscopia (Diffrazione & Interferenza)

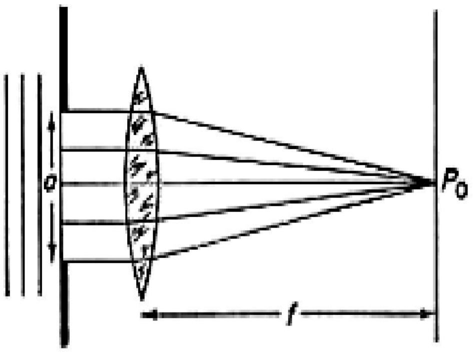


Figura 2. *Massimo centrale nella diffrazione di Fraunhofer.*

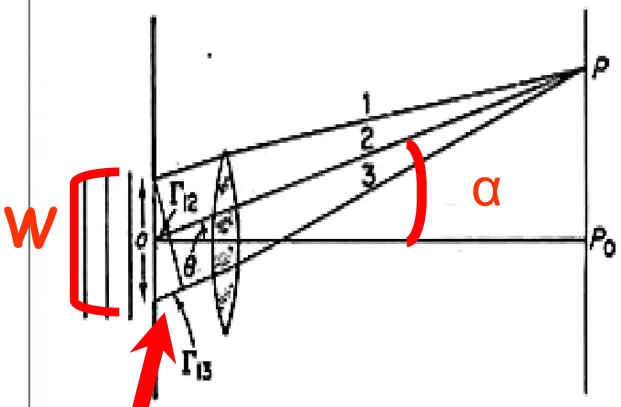


Figura 3. *Diffrazione di Fraunhofer.*

$$\boxed{\frac{W}{2}\sin\alpha = \frac{m}{2}\lambda} \longrightarrow \boxed{\alpha \cong m\frac{\lambda}{W}}$$

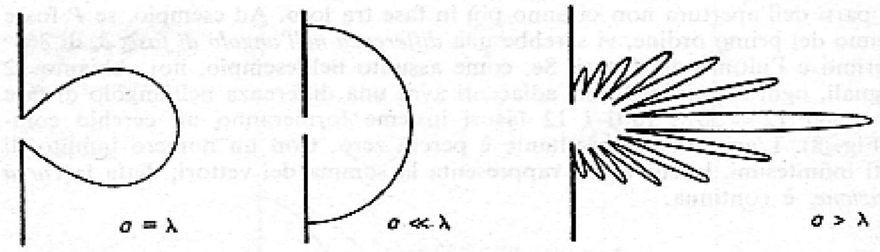
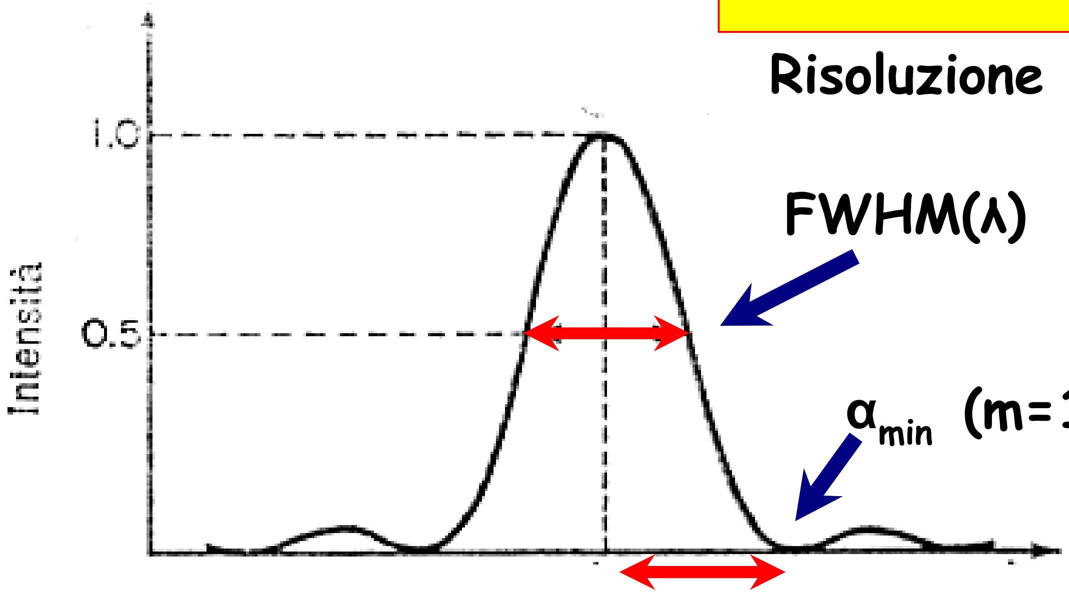


Figura 5. *Distribuzioni d'intensità dietro un'apertura di larghezza* a = λ *(a sinistra), dietro un'apertura estremamente piccola (al centro), e dietro un'apertura più larga (a destra).*

Risoluzione vs. Dispersione

$$\alpha_{\min} \cong m\frac{\lambda}{W}$$

Risoluzione



FWHM(λ)

α_{min} (m=1)

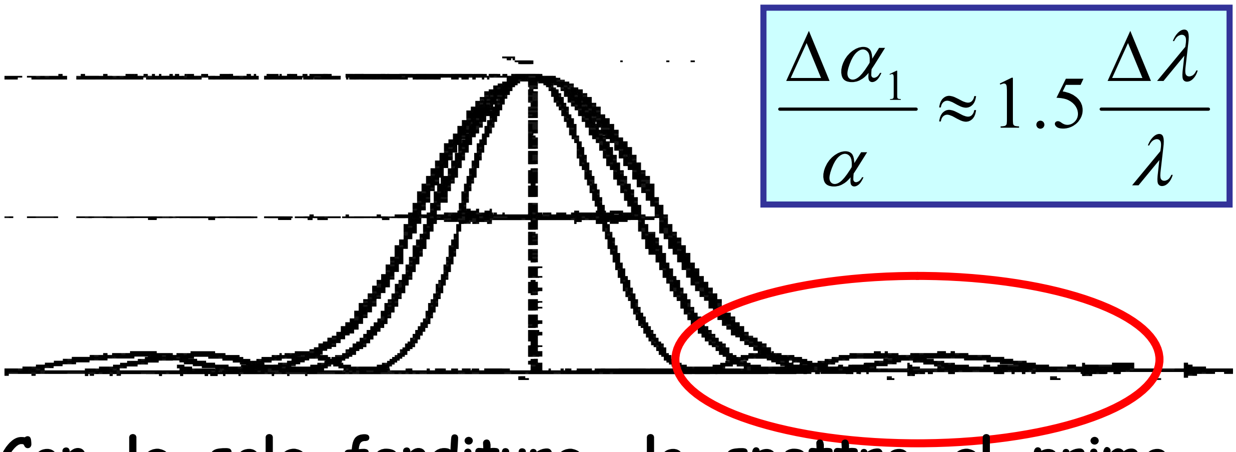
sin(α) ~ α

$$\alpha_{\max 1} \approx 1.5\frac{\lambda}{W}$$

$$\Delta\alpha_1 \approx \frac{1.5}{W}\Delta\lambda$$

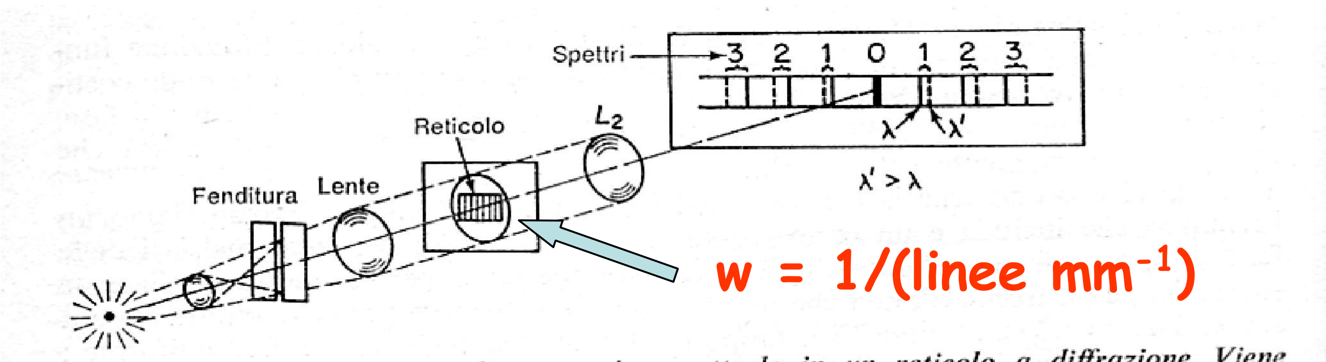
Dispersione

$$\frac{\Delta\alpha_1}{\alpha} \approx 1.5\frac{\Delta\lambda}{\lambda}$$



Con la sola fenditura, lo spettro al primo ordine sarebbe totalmente confuso dalla figura di diffrazione all'ordine zero, e quindi inutilizzabile

Reticoli di diffrazione



w = 1/(linee mm^{-1})

Figura 2. *La formazione di una riga spettrale in un reticolo a diffrazione. Viene mostrato lo spettro di una sorgente che emette su due lunghezze d'onda λ e λ'.*

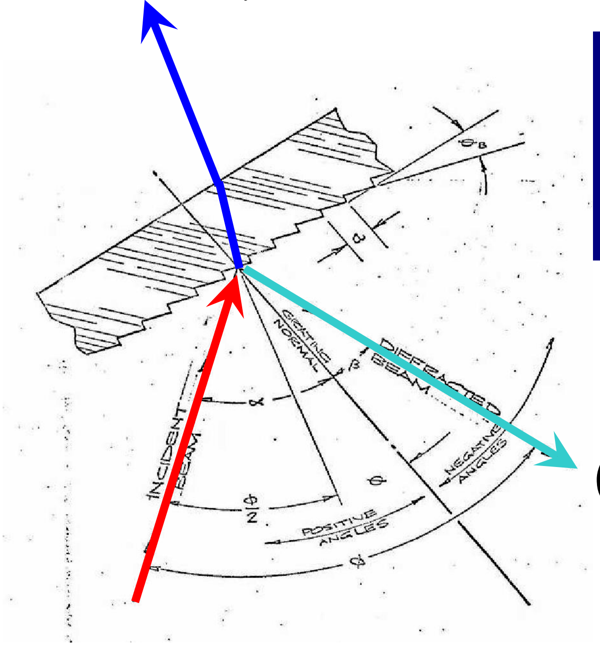
risoluzione

$$\alpha_{\min} \cong m \frac{\lambda}{W}$$

dispersione

$$\Delta\alpha_1 \approx \frac{1.5}{w} \Delta\lambda$$

"Grism"
(per rifrazione)



$$\frac{\Delta\alpha}{\alpha} \approx 1.5 \left(\frac{W}{w} \right) \frac{\Delta\lambda}{\lambda}$$

"Grid"
(per riflessione)

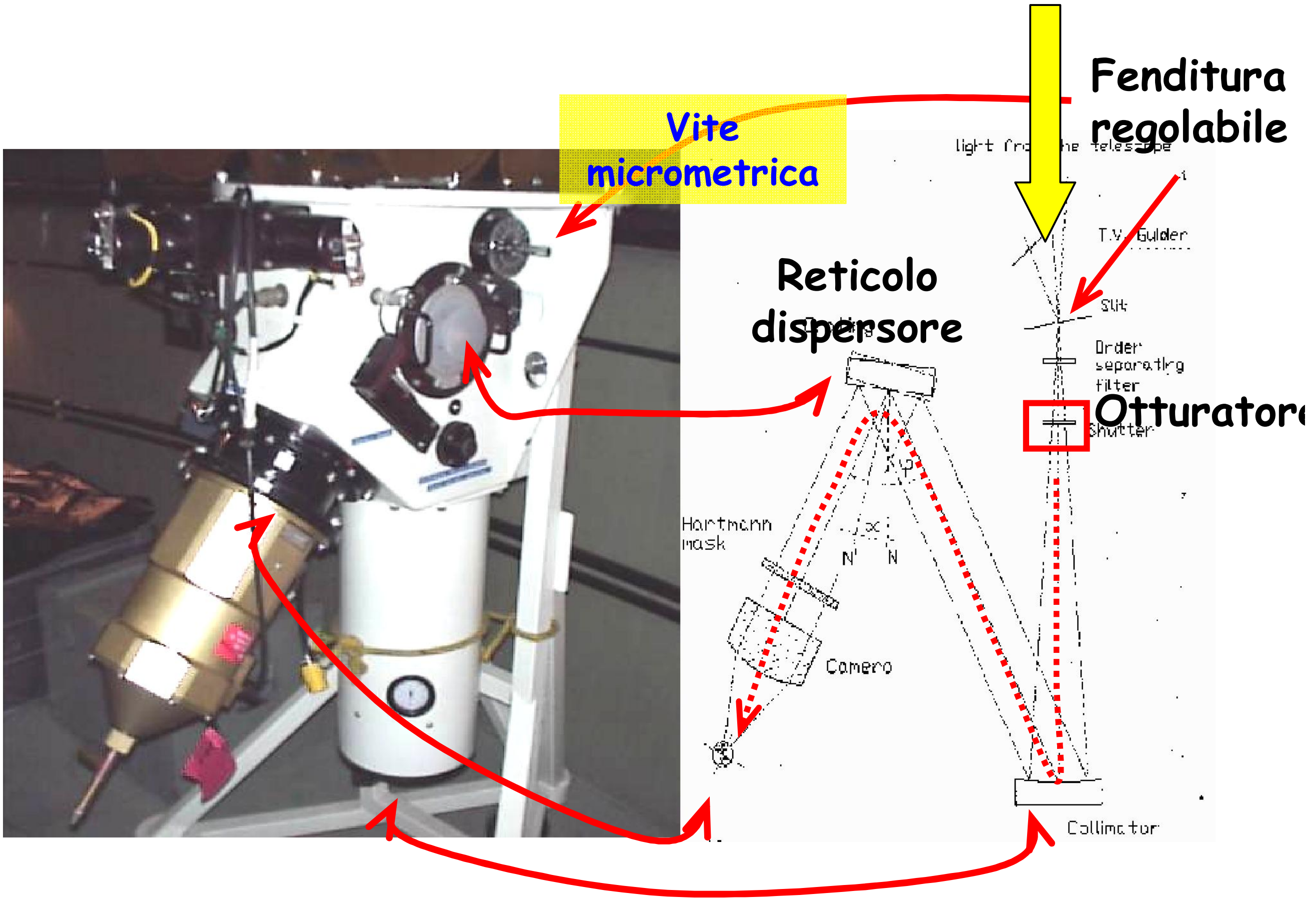
Quindi:

1) l'ampiezza della fenditura determina la <u>RISOLUZIONE</u>

2) La frequenza di linee del grism/grid determina la <u>DISPERSIONE</u>

Gli spettrografi a riflessione

Luce dal telescopio



Fenditura regolabile

Vite micrometrica

Reticolo dispersore

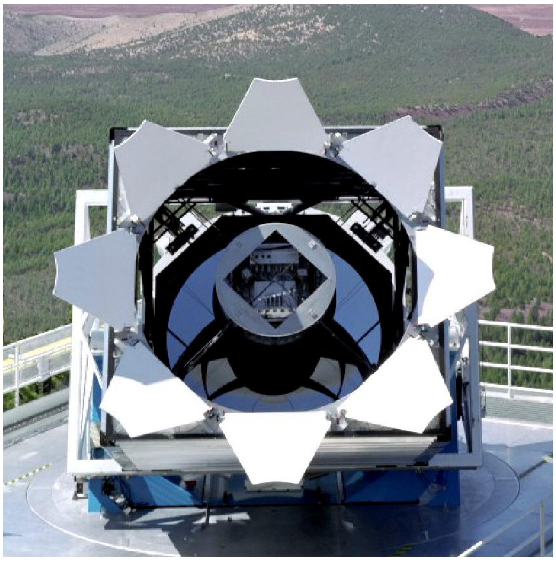
Otturator

Specchio collimatore

Böller & Chivens

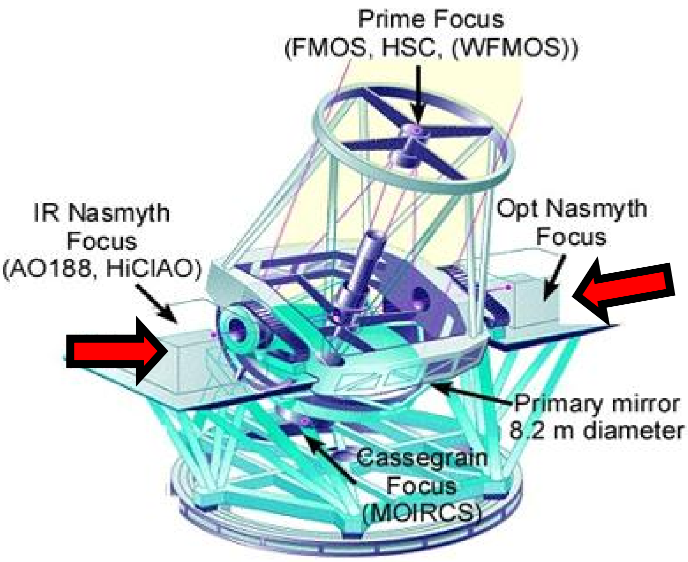
Gli spettrografi a fibre ottiche

Hydra @KPNO (3.8m) USA



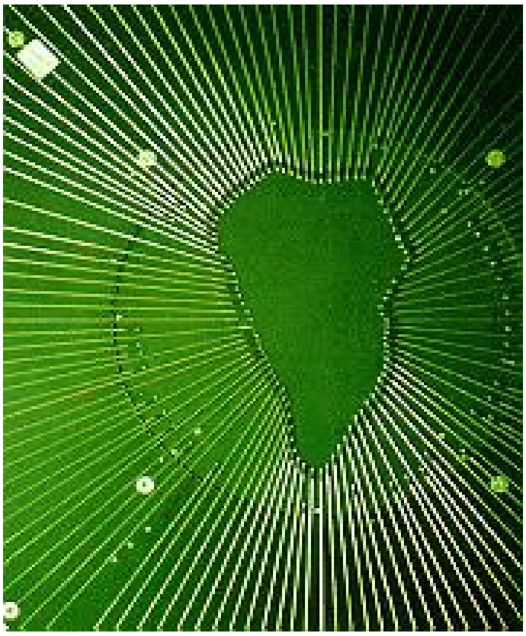
The Sloan Digital Sky Survey's
2.5-meter telescope at Apache
Point Observatory, New Mexico

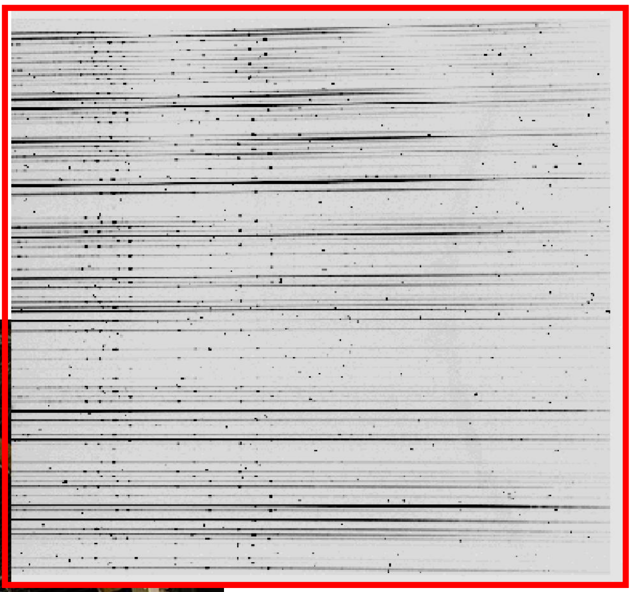
Spettrografi da "banco"



Subaru (8.3m) Japan

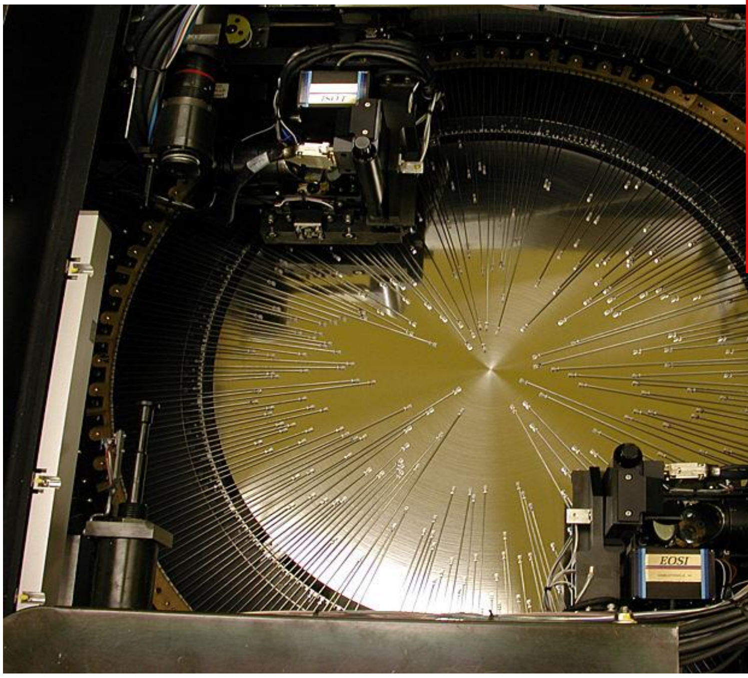
Autofib@WHT (4.2m) UK



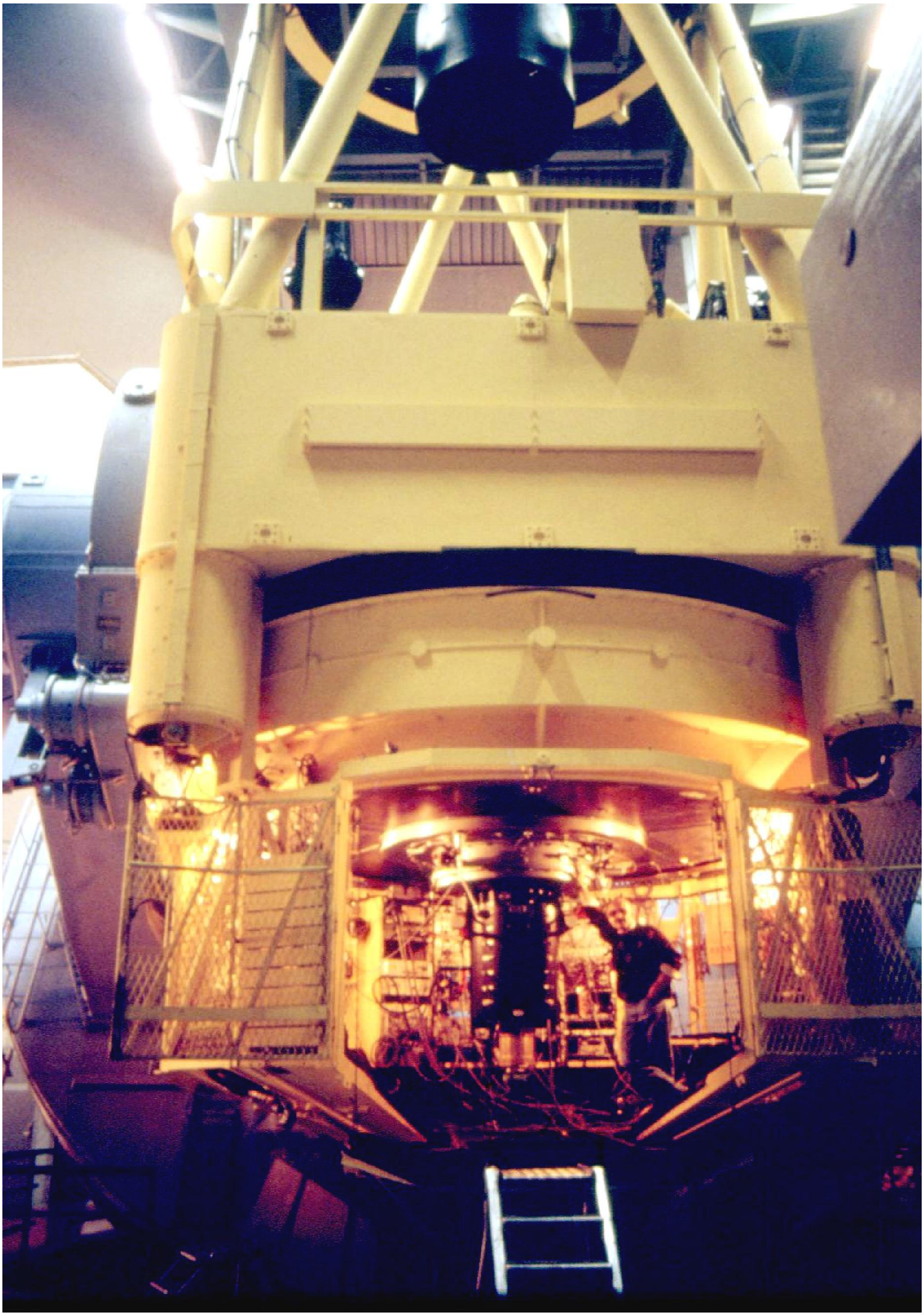


Esempio di uscita spettrografo a fibre

HECTOSPEC@MMT (6.5m)
Arizona (USA)



Le camere FOSC



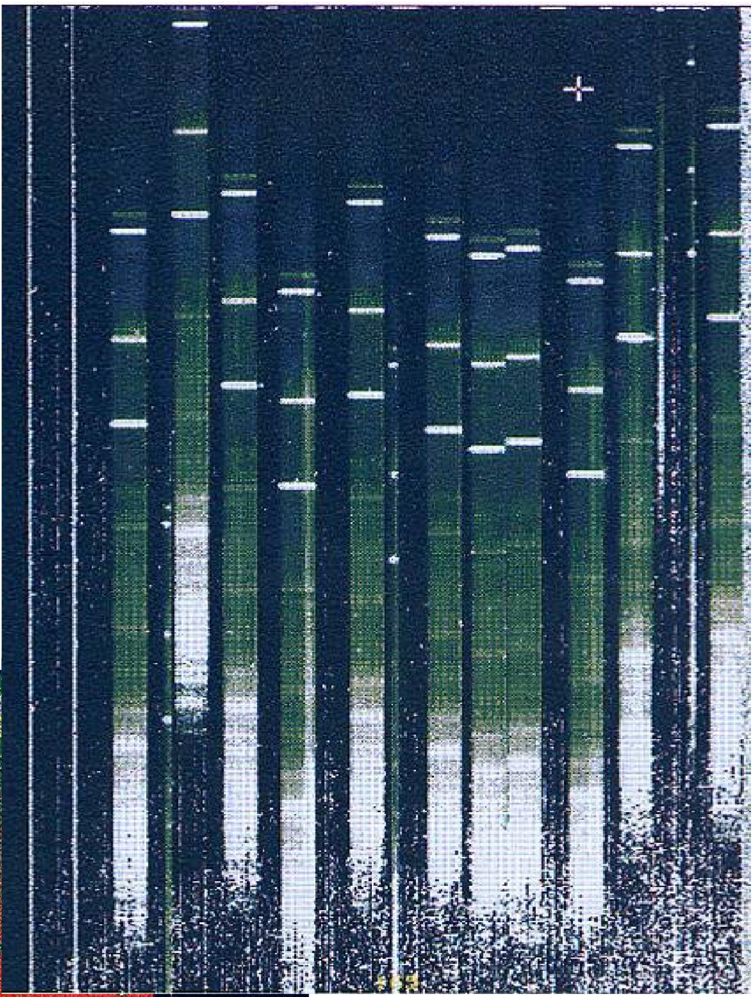
Spettroscopia "MOS"
(multiobject)

Spectral resolution

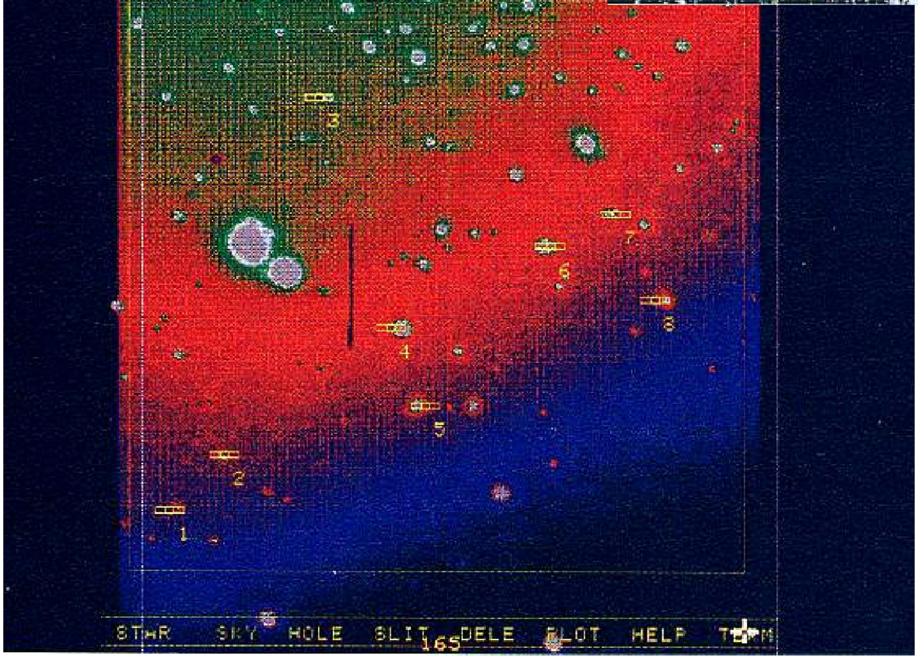
FWHM ~ 2.5 ÷10Å

Resolving power

$$R = \frac{\lambda}{\Delta\lambda} = 500 \Leftrightarrow 2000$$

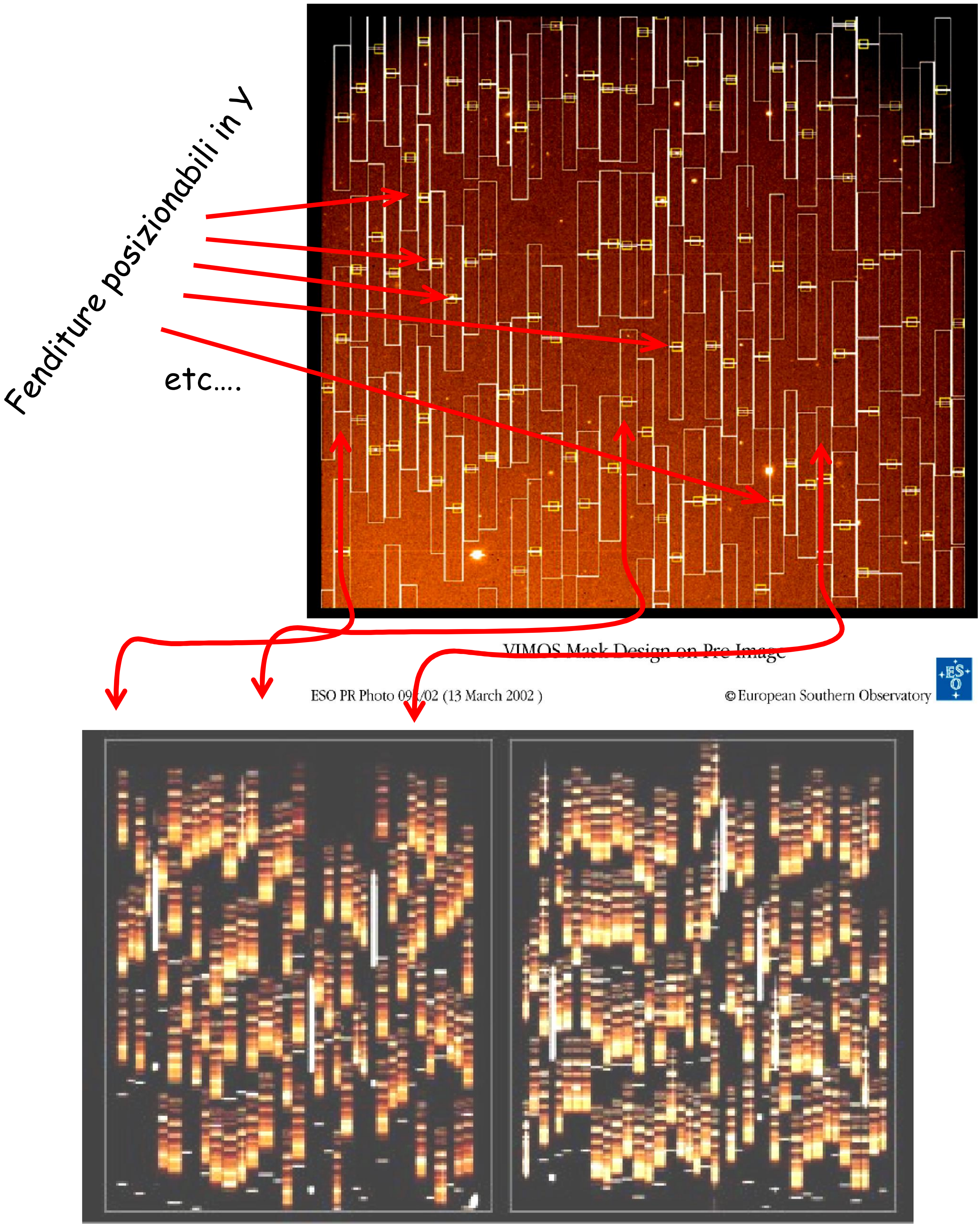


Esempio di uscita spettrografo MOS FOSC



Pre-imaging
(per vedere gli oggetti da puntare)

VIMOS@VLT (ESO) 8.2m, Chile



VIMOS Mask Design on Pre-Image

ESO PR Photo 09[illegible]/02 (13 March 2002)

© European Southern Observatory

Legge di Wien :

$$\boxed{\lambda_{\max} T \propto const}$$

$$\frac{\lambda_{\max}}{5500} = \frac{5780}{T_K} \Longrightarrow \lambda_{\max} \approx \frac{3\,10^{7}}{T_K} \quad [\text{Å}]$$

T_K	λ_{max}	[eV]
100,000	300 Å	raggi γ
10,000	3000 Å	UV
6,000	5000 Å	Ottico
3,000	10,000 Å	MIR
1,000	30μm Å	FIR

Equipartizione dell'energia :

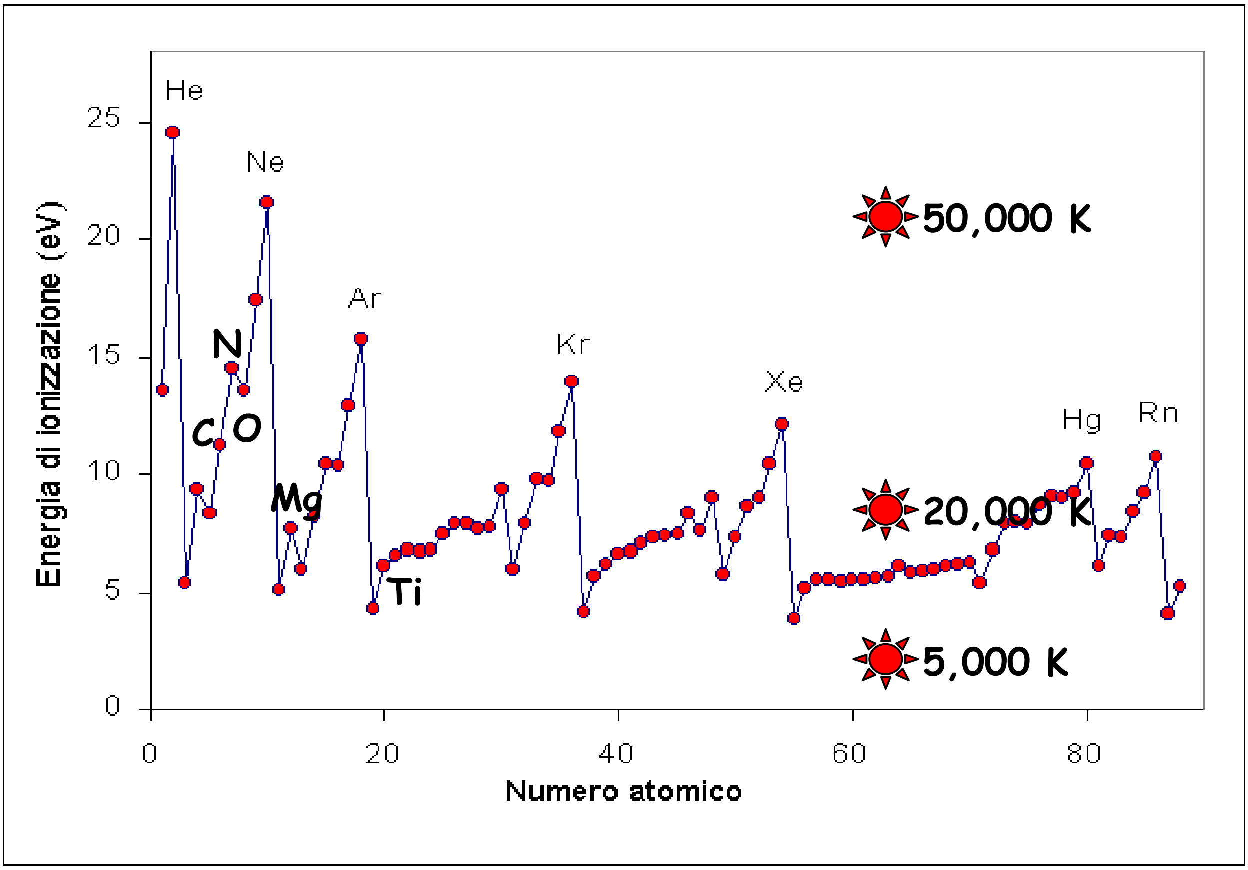
$$E \approx 3kT = 4.2\,10^{-16}\,T_K \approx h\nu = \frac{hc}{\lambda}$$

$$\langle\lambda\rangle \approx \frac{hc}{kT} = \frac{6.6\,10^{-27}\times 3\,10^{10}}{4.2\,10^{-16}\,T_K\,(10^{-8})} = \boxed{\frac{4.7\,10^{7}}{T_K}} \quad [\text{Å}]$$

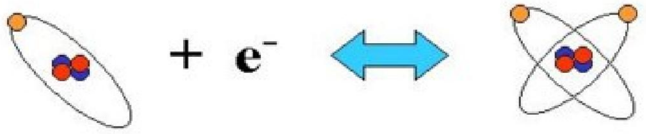
$$\boxed{T_K \approx 2400\ E_{eV}}$$

Il potenziale di ionizzazione dell'H e' di 13.6eV. Quindi sono necessarie temperature superiori a circa 35,000 K

Gruppo Periodo	1	2	13	14	15	16	17	18
1	H 13.59844							He 24.58741
2	Li 5.39172	Be 9.32263	B 8.29803	C 11.26030	N 14.53414	O 13.61806	F 17.42282	Ne 21.56454
3	Na 5.13908	Mg 7.64624	Al 5.98577	Si 8.15169	P 10.48669	S 10.36001	Cl 12.96764	Ar 15.759
4	K 4.34066	Ca 6.11316	Ga 5.99930	Ge 7.899	As 9.8152	Se 9.75238	Br 11.81381	Kr 13.99961
5	Rb 4.17713	Sr 5.69484	In 5.78636	Sn 7.34381	Sb 8.64	Te 9.0096	I 10.45126	Xe 12.12987
6	Cs 3.89390	Ba 5.21170	Tl 6.10829	Pb 7.4167	Bi 7.2855	Po 8.41671	At 9.2	Rn 10.74850
7	Fr 4.0712	Ra 5.27892						



Popolazioni ionizzate



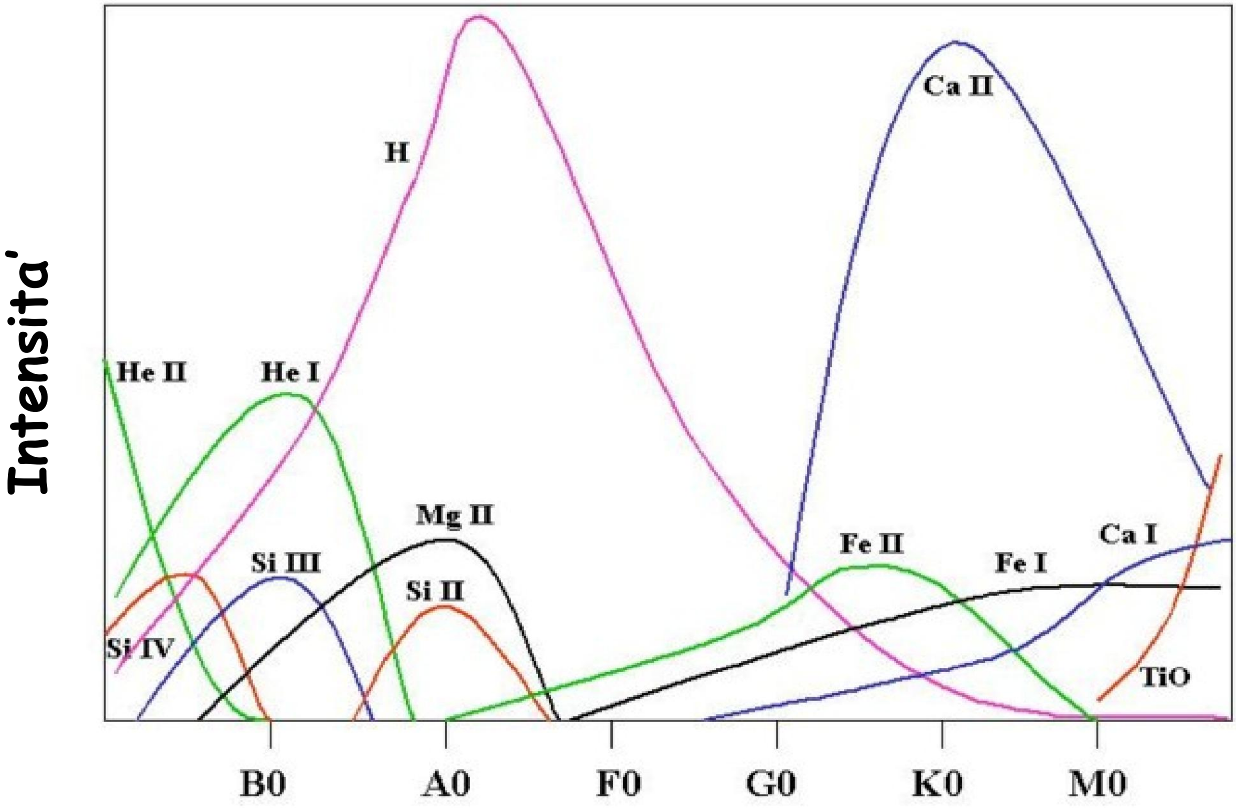
$$\log \frac{n_{r+1} P_e}{n_r} = -E_I \frac{5040}{T} + 2.5 \log(T) - 6.48 + \log \frac{2u_{r+1}}{u_r}$$

where:

$$u_r = g_0 + \sum_i g_i \cdot e^{-\frac{E_{ii}}{KT}}$$

Equazione di Saha

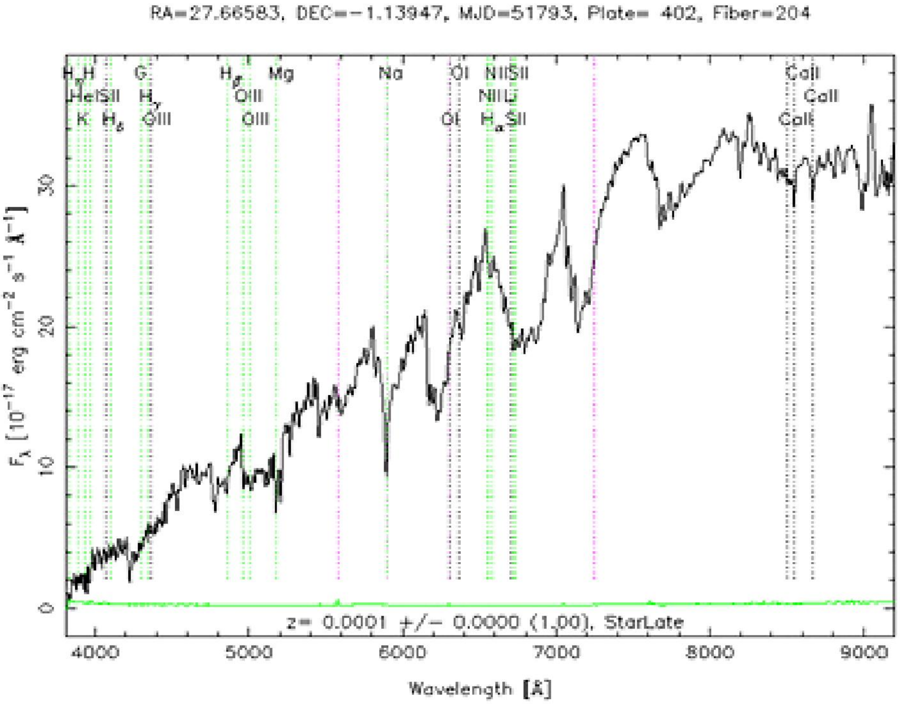
E_i in eV
P_e in atm



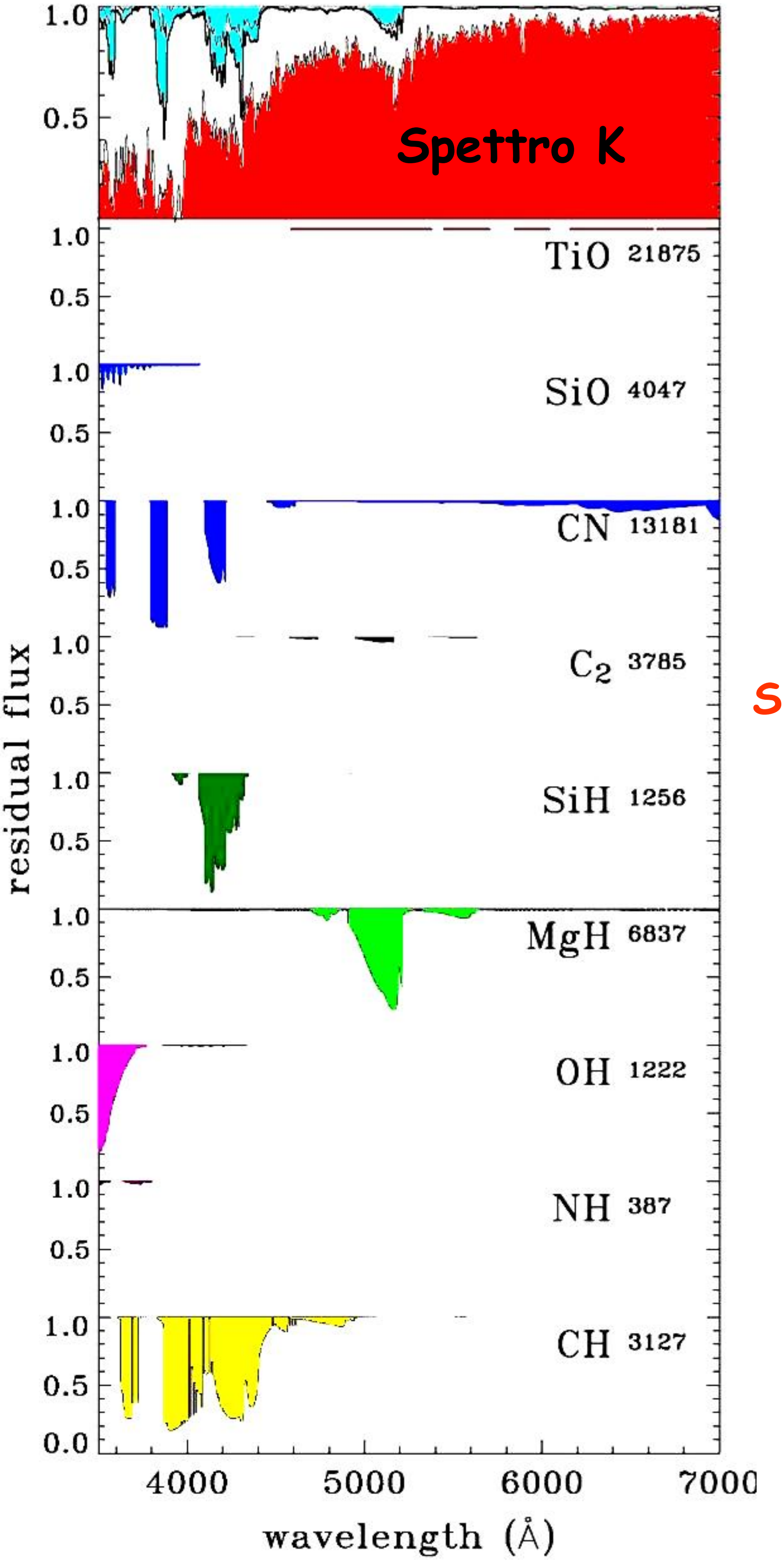
Le molecole

Aspetti generali

- La meccanica quantistica è generalmente in grado di prevedere le proprietà delle molecole (configurazione d'equilibrio, energia di legame, spettri)
- I calcoli per fare queste previsioni sono molto complicati ("quantum chemistry")
- Le regole di selezione sono meno (= più transizioni consentite) che negli atomi
- Gli spettri risultanti sono generalmente più complicati che quelli degli atomi
- Si distinguono spettroscopie vibrazionali/rotovibrazionali (IR e Raman) ed elettroniche (assorbimento visibile/UV e fluorescenza)



Molecole



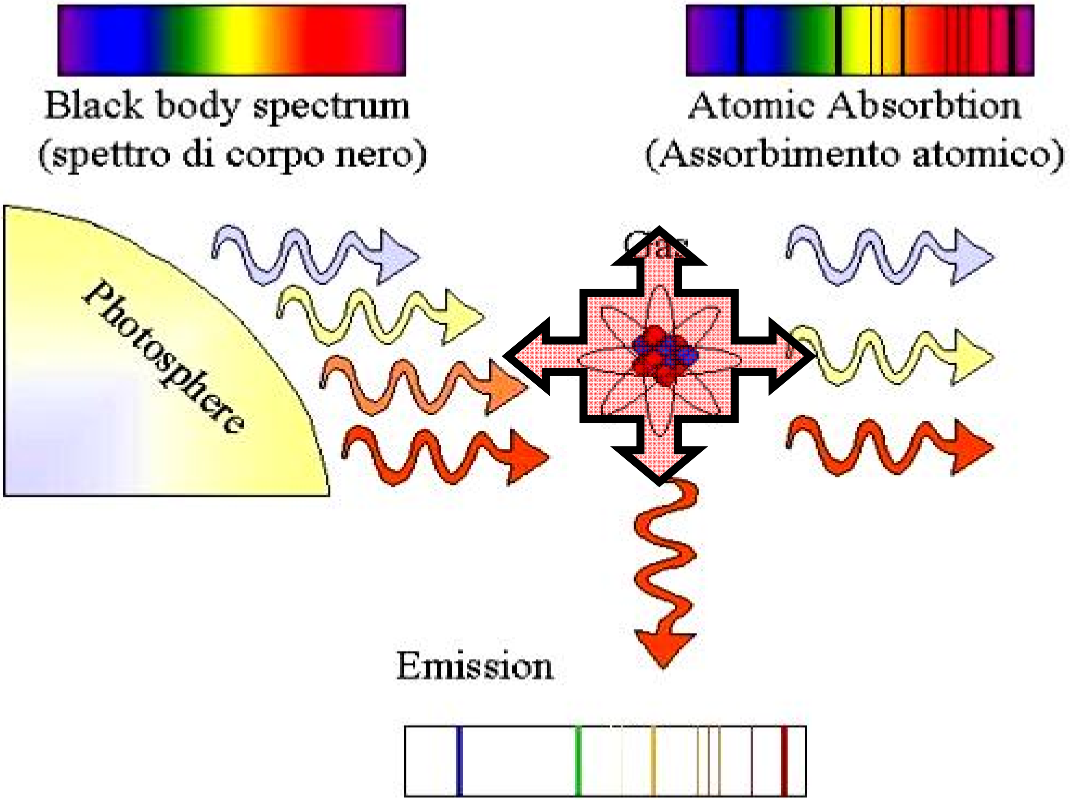
4000 > Teff > 3000 K

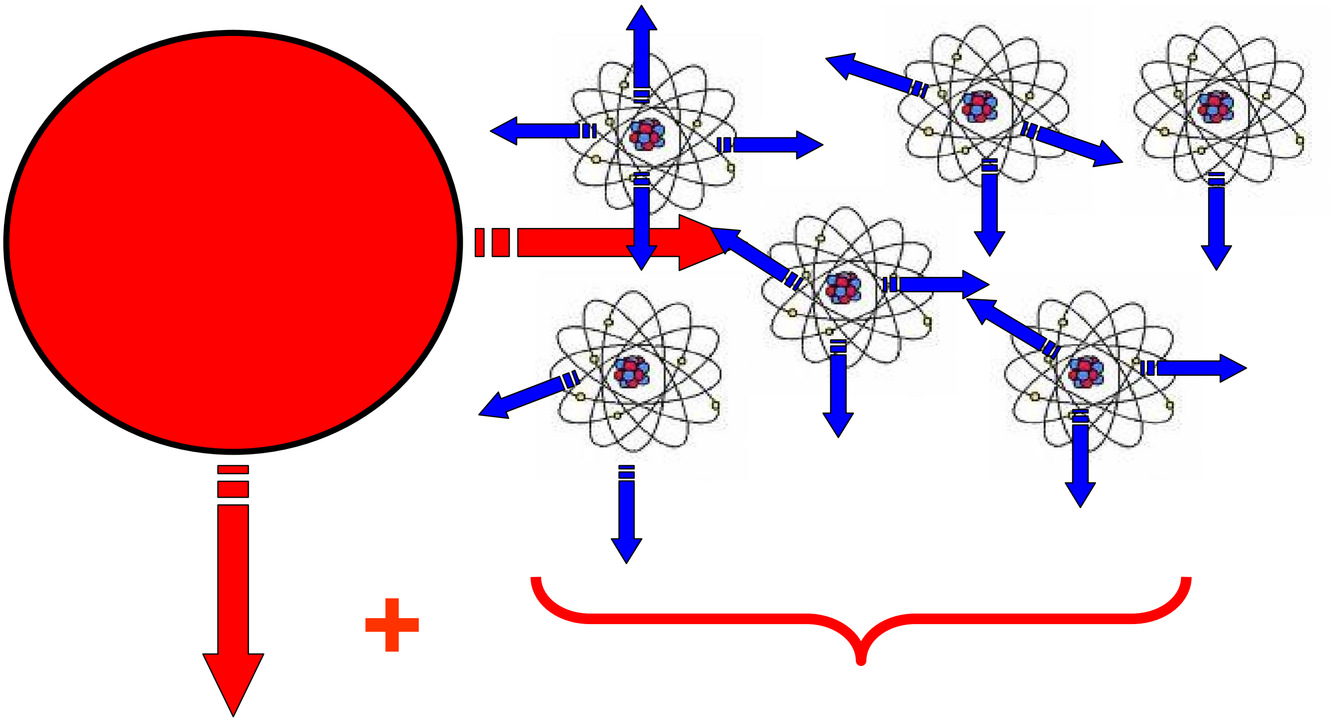
Diatomic molecules
(i.e. TiO, SiO,CN,
SiH, MgH, OH, CH….)

3000 K > Teff

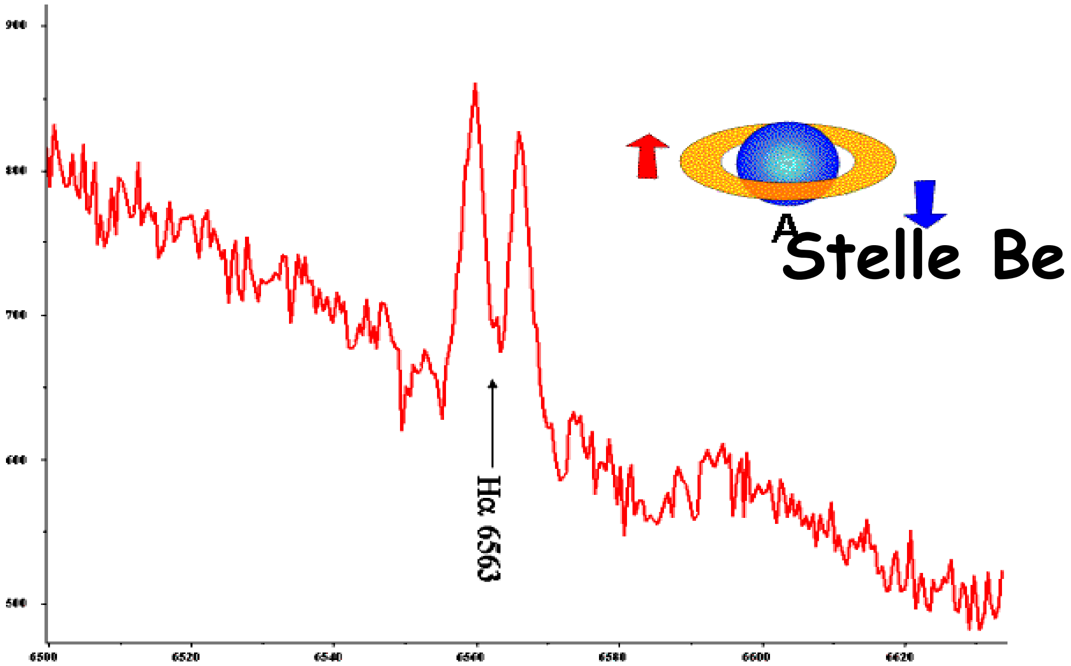
Triatomic molecules
(Water!)

Emissione & Assorbimento

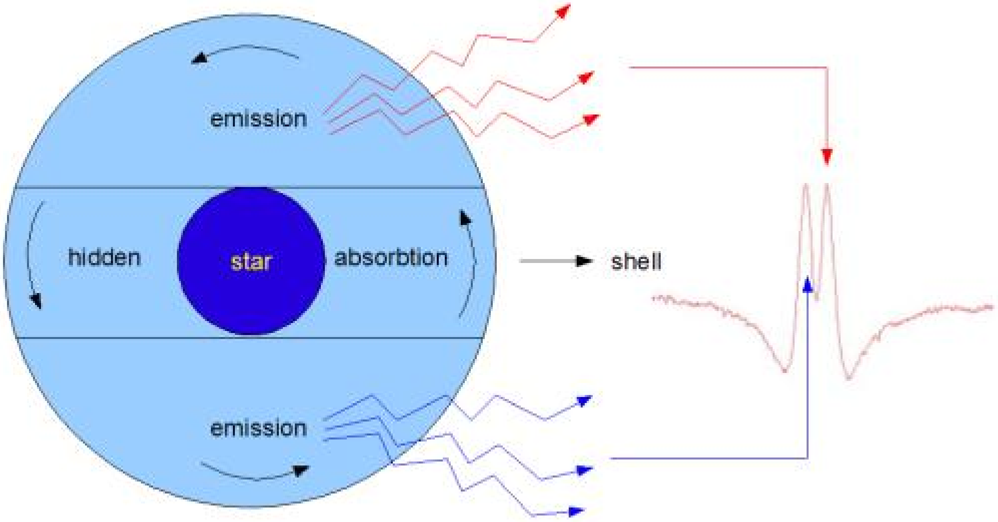




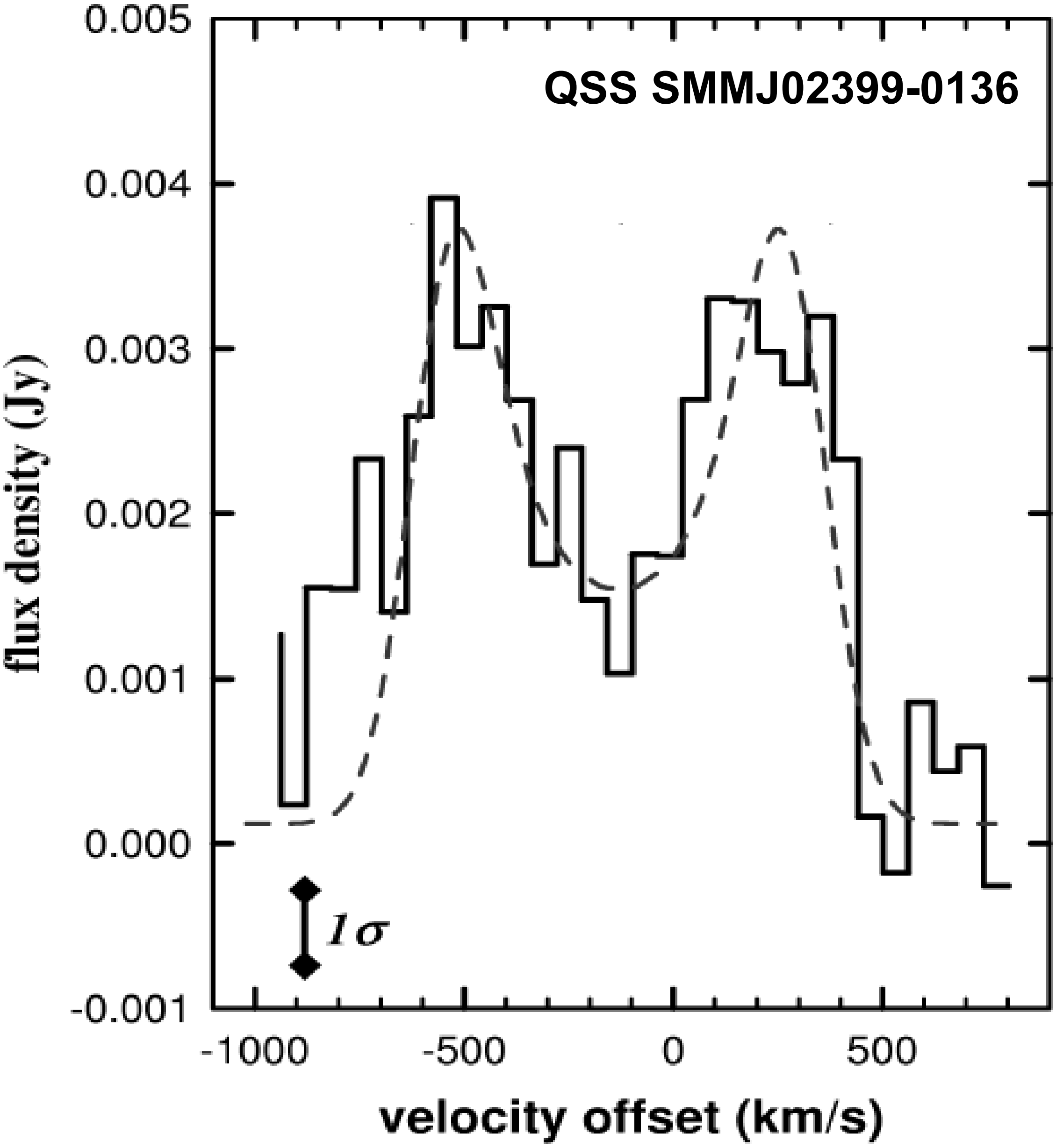
Effetti della rotazione (emissione)



Stelle Be



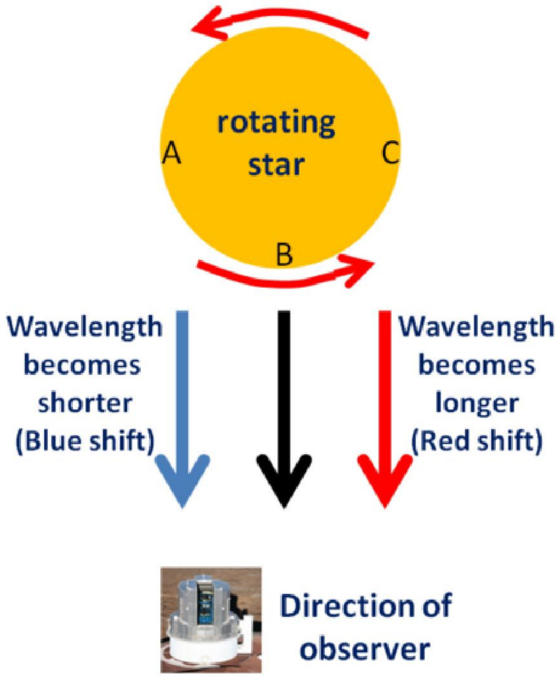
Effetti della rotazione (emissione)



“SMMJ02399-0136 appears to contain a massive molecular ring/disk which rotates about a buried type 2 QSO. Its dynamical mass of $>3.10^{11}$ Msun within a radius of 8 kpc”

A Very Massive Submillimeter Galaxy at z = 2.8 (Genzel et al. 2003)

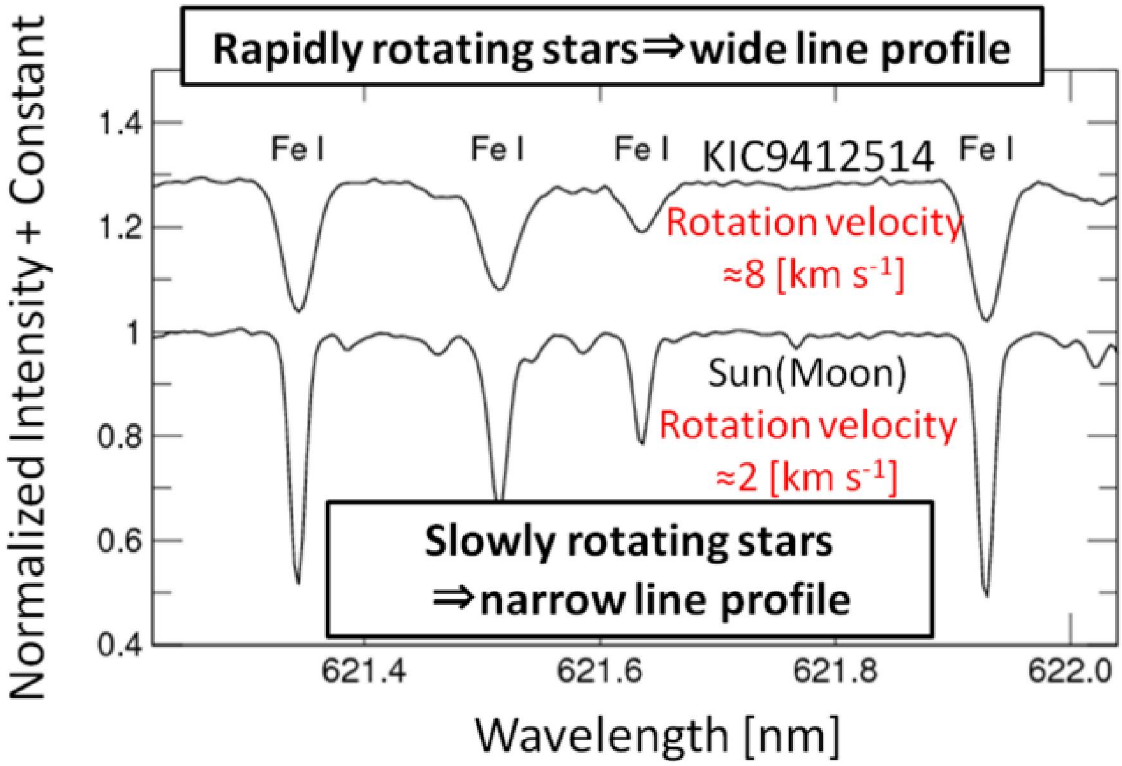
Effetti della rotazione (assorbimento)



Wavelength becomes shorter (Blue shift)

Wavelength becomes longer (Red shift)

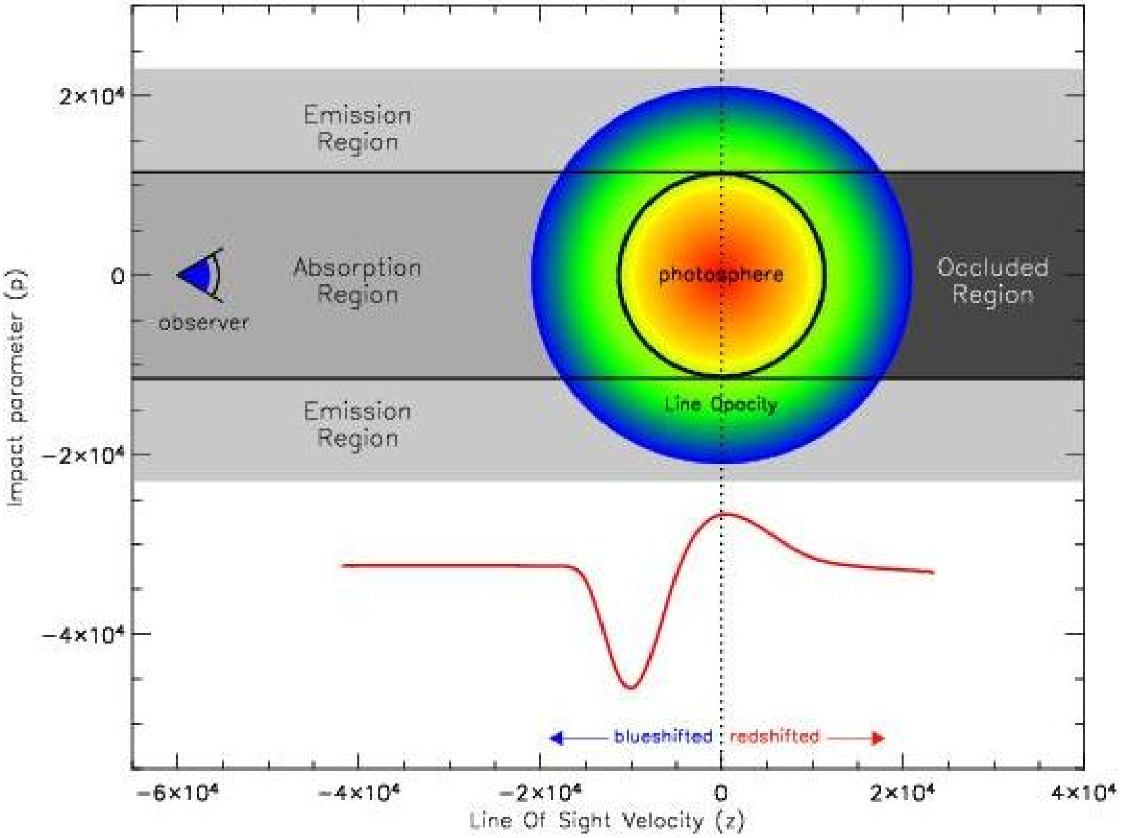
Direction of observer

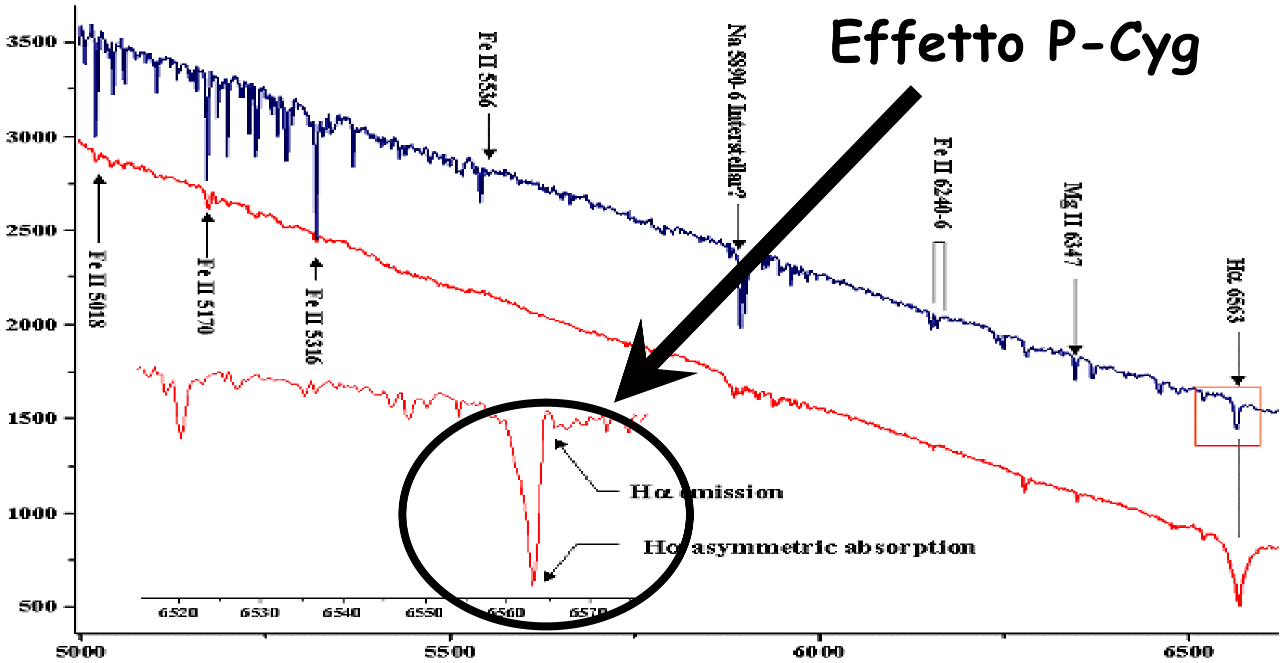


Rapidly rotating stars⇒wide line profile

Slowly rotating stars ⇒narrow line profile

L'effetto P Cygni

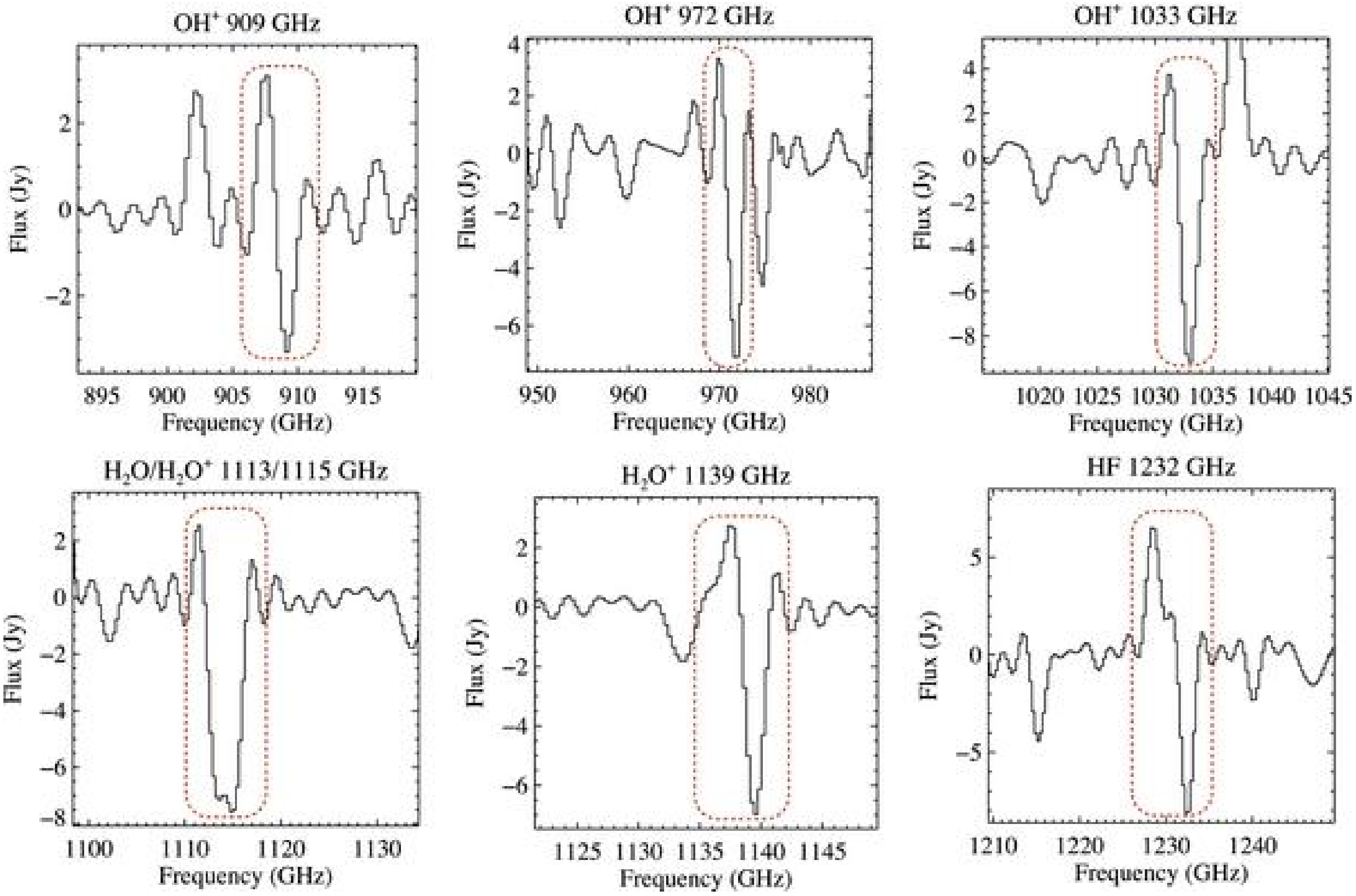




Effetto P-Cyg

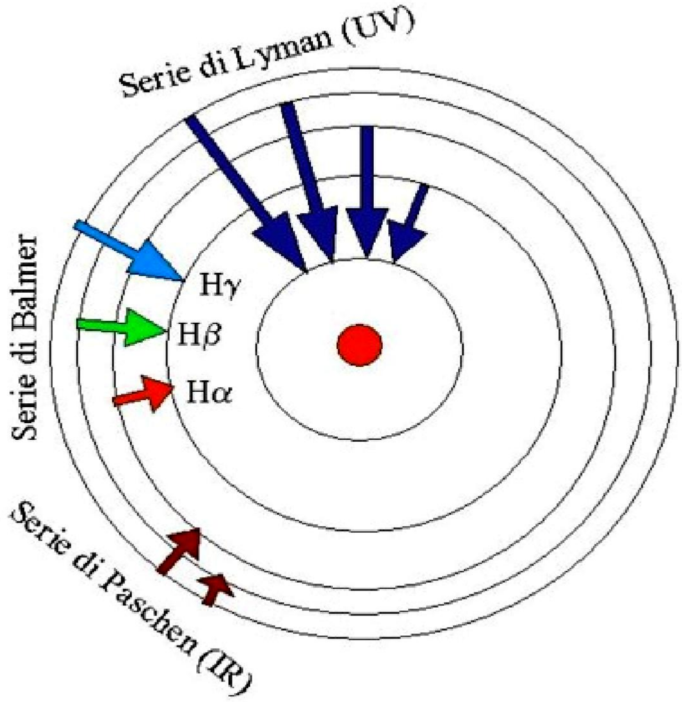
L'effetto P Cygni

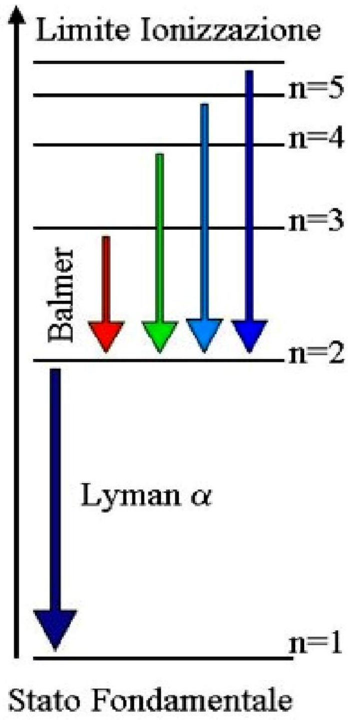
(Arp 220)



Arp 220 is the nearest Ultra Luminous Infrared galaxy (ULIRG) at a distance of about 77 Mpc and *z* ~ 0.0181. It has *L*FIR ~ 10^{12} *Lsun*, and is one of the most popular templates for studies of high-*z* dusty galaxies. (Rangwala et al., 2011)

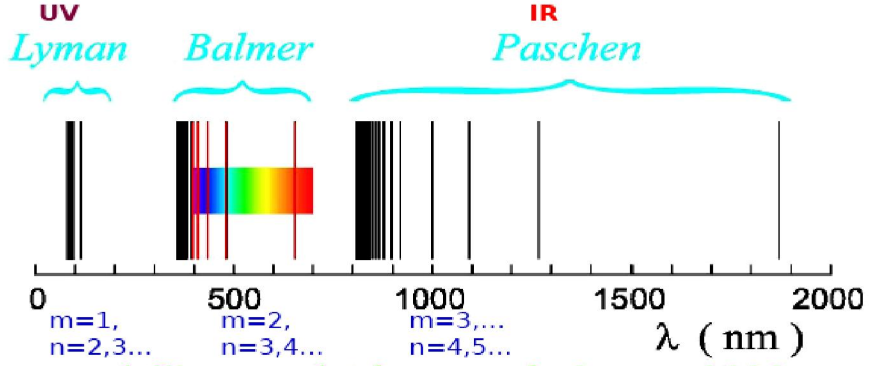
Le righe dell'Idrogeno





Righe emesse non solo nel visibile

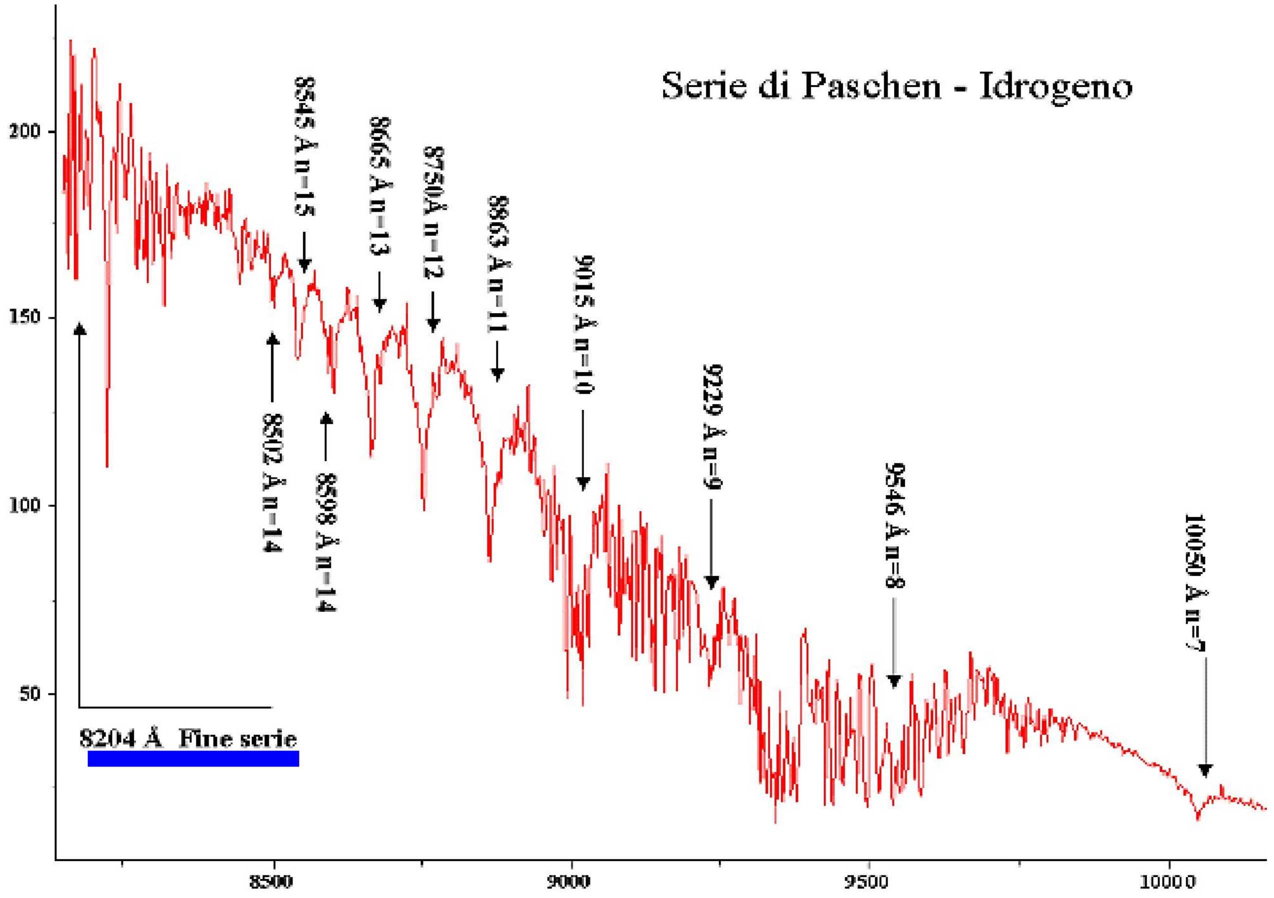
$$\frac{1}{\lambda}=R\left(\frac{1}{m^2}-\frac{1}{n^2}\right) \quad m=1,2,3,\ldots \quad n=m+1,\ldots.$$



Spettro dell'atomo di idrogeno da 0 nm a 2000 nm

Le serie di righe

Nome della serie	Anno della scoperta	m nella formula di Rydberg	Limite della serie (nm)	λ_{max} ($n=m+1$) (nm)	Regione spettrale
Lyman	1906-1914	1	**91.126**	**121.5**	UV lontano
Balmer	(1885)	2	**364.506**	**656.1**	Visibile-UV
Paschen	1908	3	**820.14**	**1874.6**	Infrarosso
Brackett	1922	4	**1458.03**	**4050.1**	Infrarosso
Pfund	1924	5	**2278.17**	**7455.8**	Infrarosso
Humphreys	1953	6	**3280.56**	**12365.1**	Infrarosso
Hansen-Strong	1973	7	**4465.21**	**19051.5**	Infrarosso



Spettri & masse delle galassie

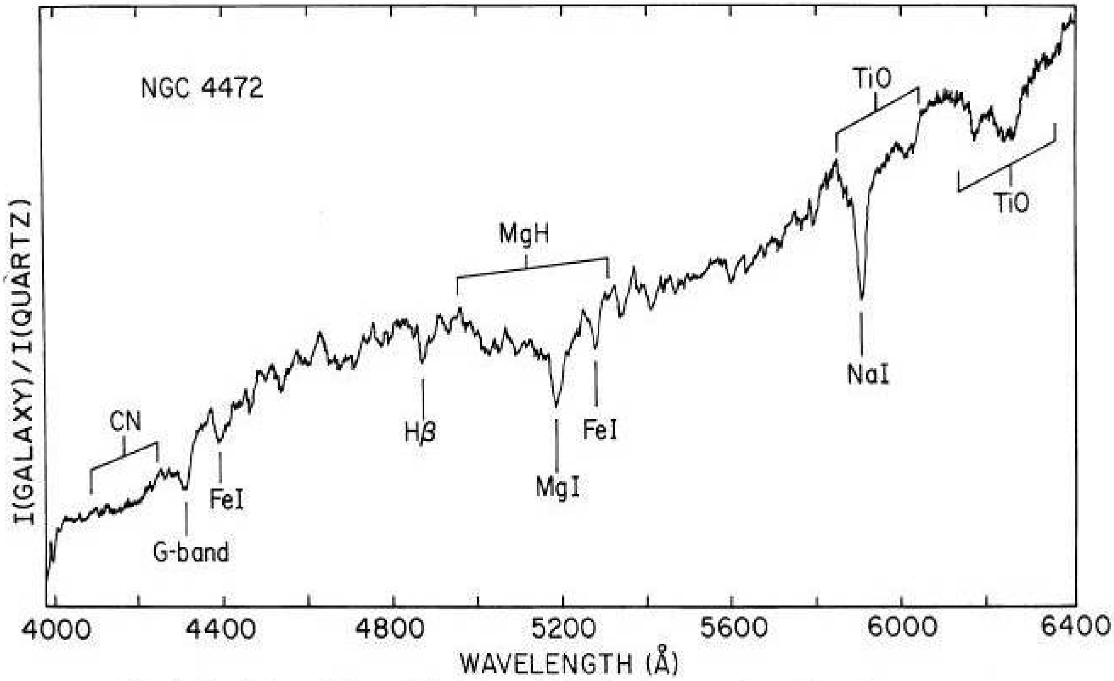


FIG. 1.—Typical scan of giant elliptical galaxy, divided by the tungsten lamp (denoted by "quartz")

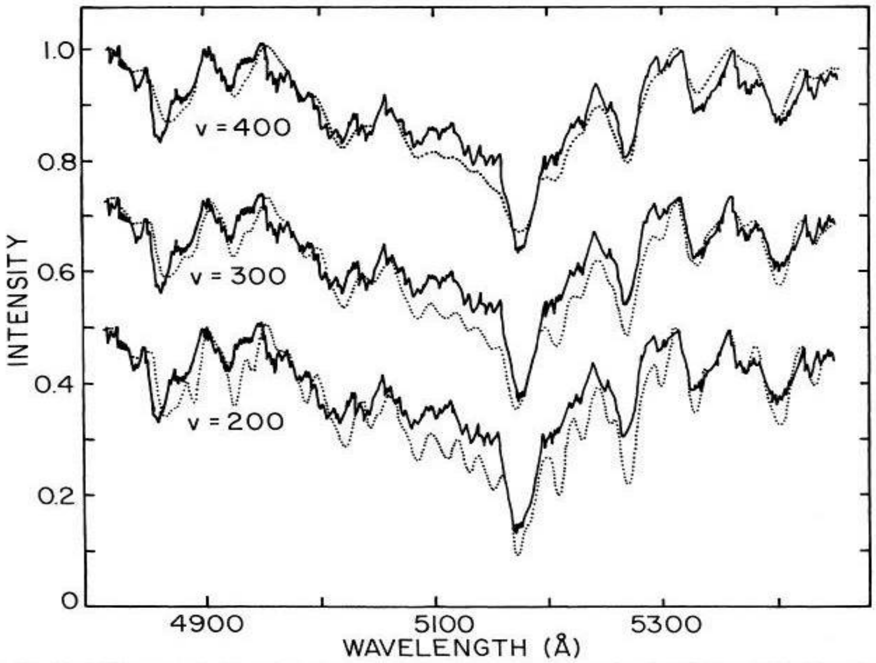


FIG. 3.—NGC 4472 compared with standard star HR 1805 (K3 III), broadened by various line-of-sight velocities (*dotted line*)

La legge di Faber-Jackson (1976)

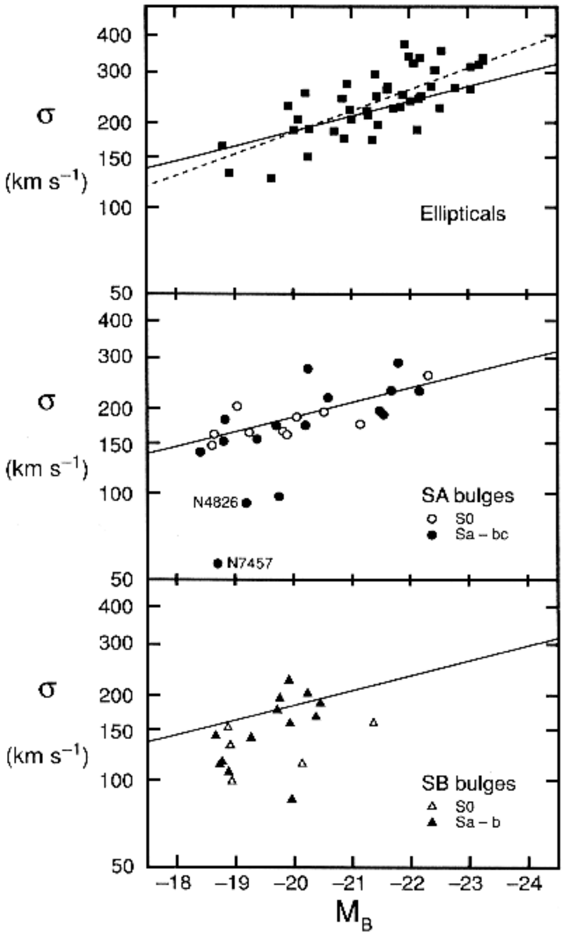


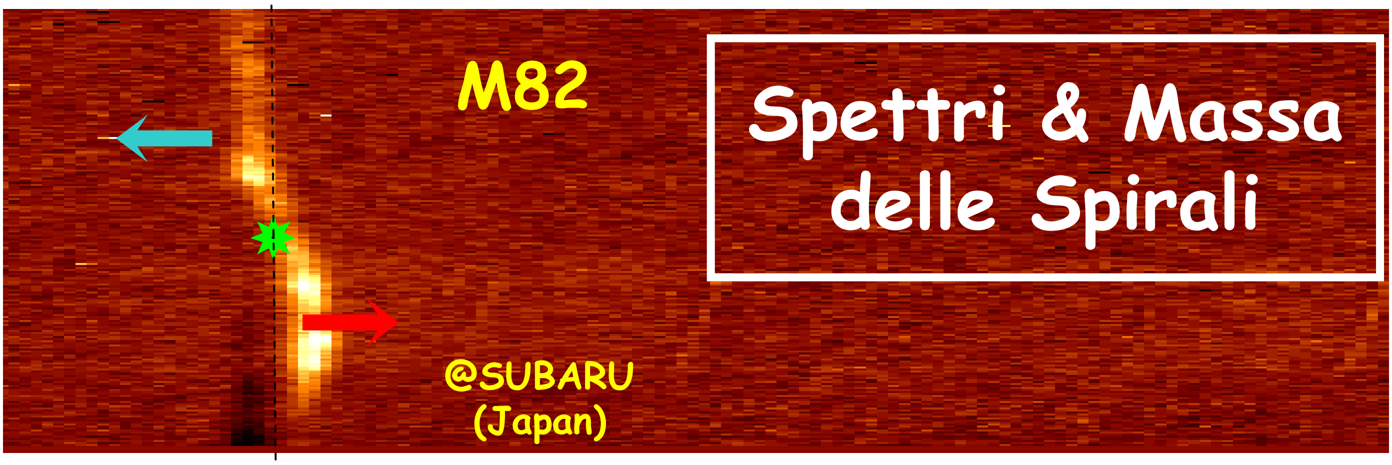
Fig. 6. Correlation between central velocity dispersion σ and absolute magnitude M_B for elliptical galaxies and for bulges of unbarred (SA) and barred (SB) disk galaxies. The solid line is a fit to the galaxies in the middle panel; the dashed line is a fit to the ellipticals. Except for the NGC 4826 point, this figure is from Kormendy and Illingworth (1983).

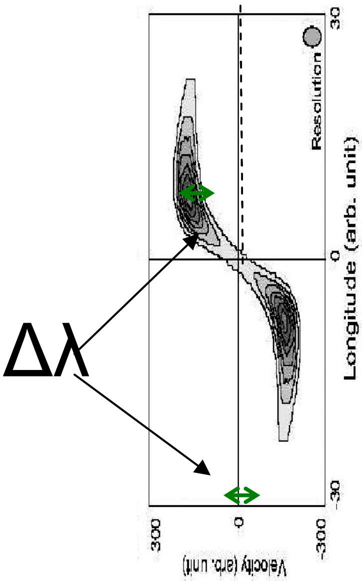
$$\left\{\begin{array}{l} v^2 \approx \dfrac{GM}{R} \\[2ex] \mu = \dfrac{L}{\pi R^2} \approx \text{const} \\[2ex] \left(\dfrac{M}{L}\right) = \text{const} \end{array}\right\}$$

Se il moto e' caotico, allora $v^2 \equiv \sigma^2$

$$\boxed{\sigma^4 \propto \mu L}$$

Spettri & Massa delle Spirali



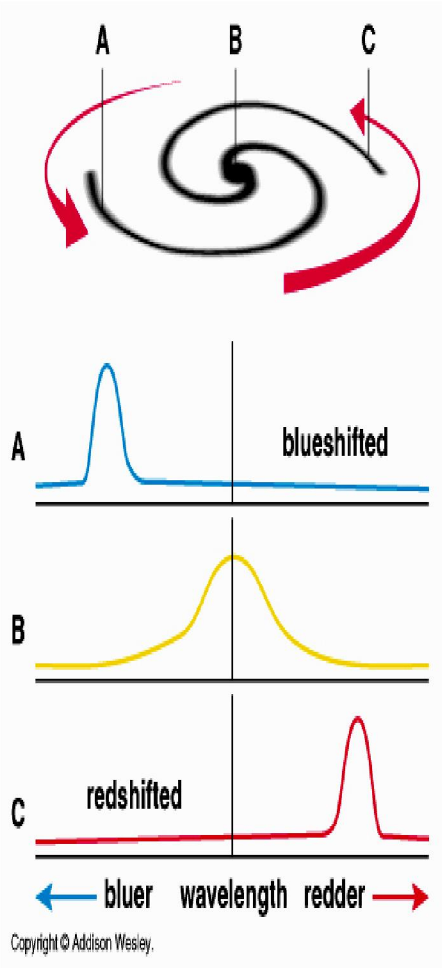


$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

$$\frac{v^2}{R} = \frac{GM}{R^2}$$

Acc. centrifuga

Acc. gravitazionale



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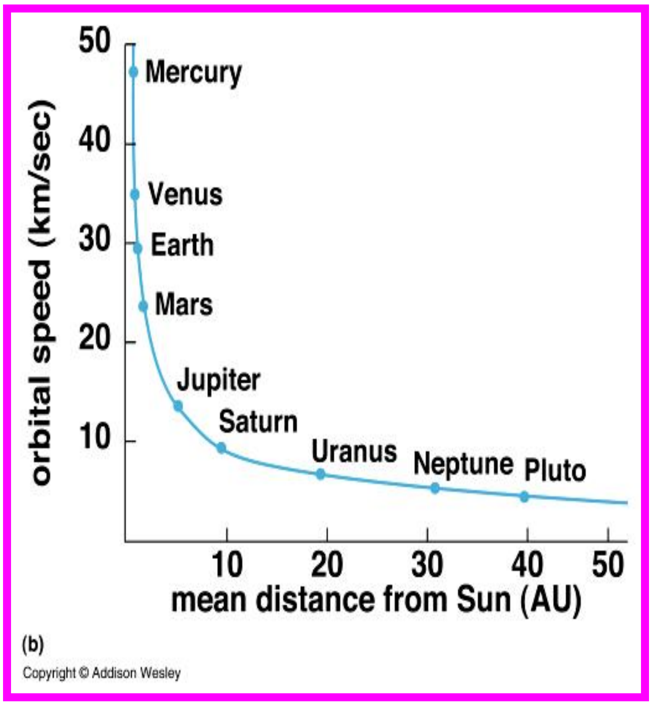
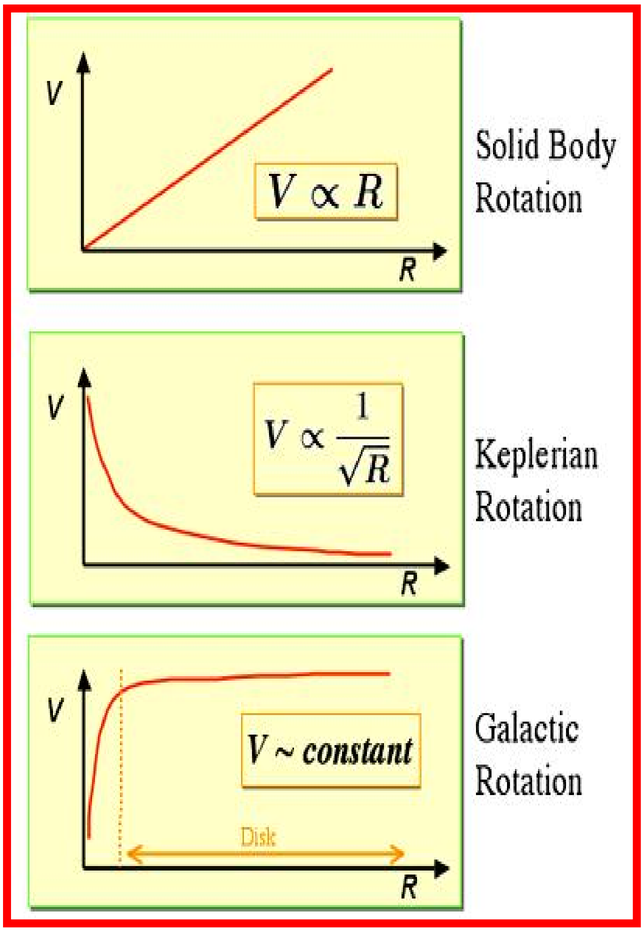
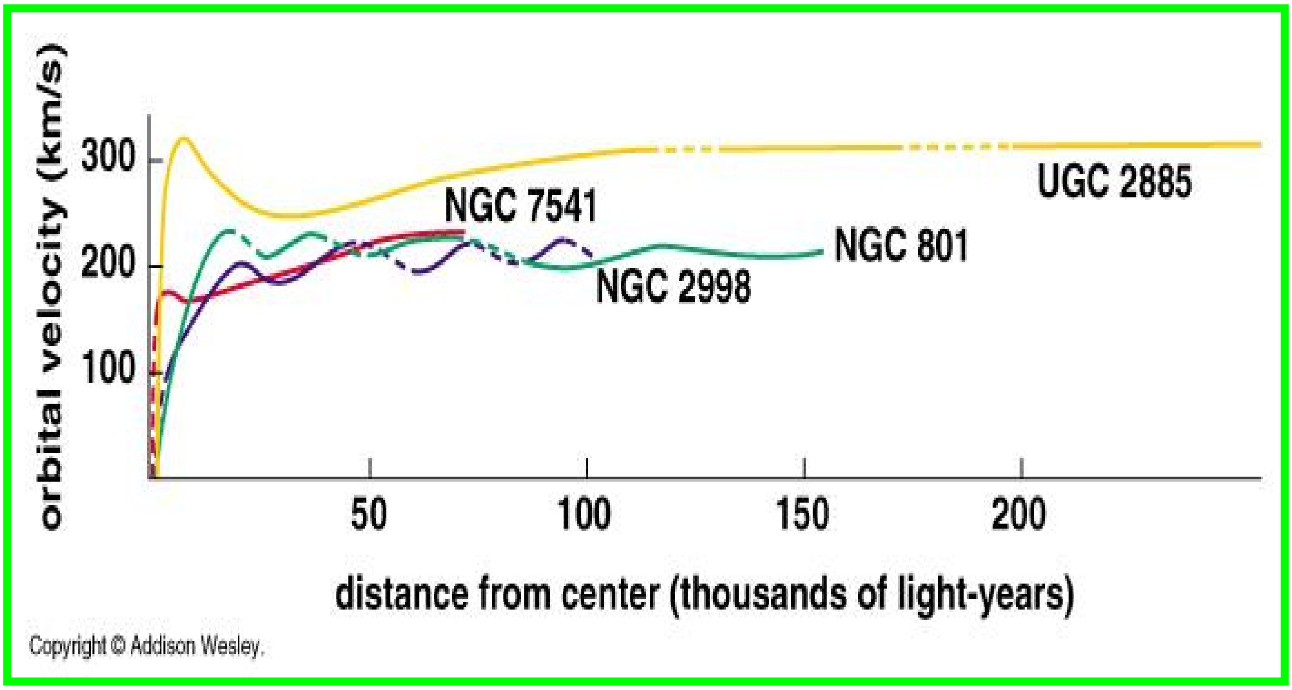
La materia oscura



Copyright © Addison Wesley





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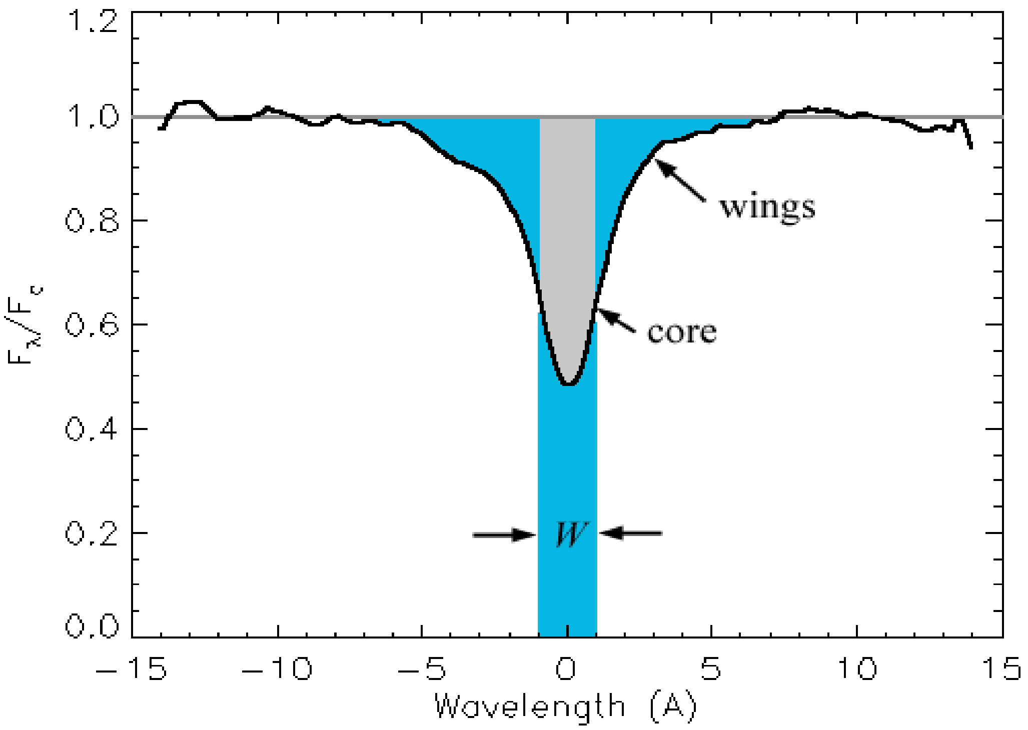
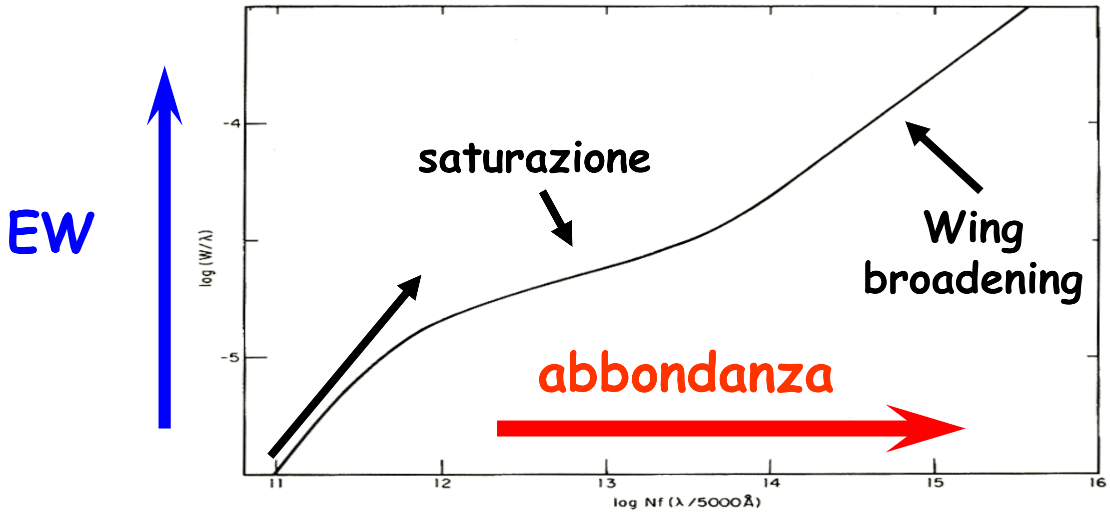
Forza di indice e Ampiezza equivalente



$$EW = \int \frac{f_c - f_f}{f_c} d\lambda$$

a T_{eff} fissato!!



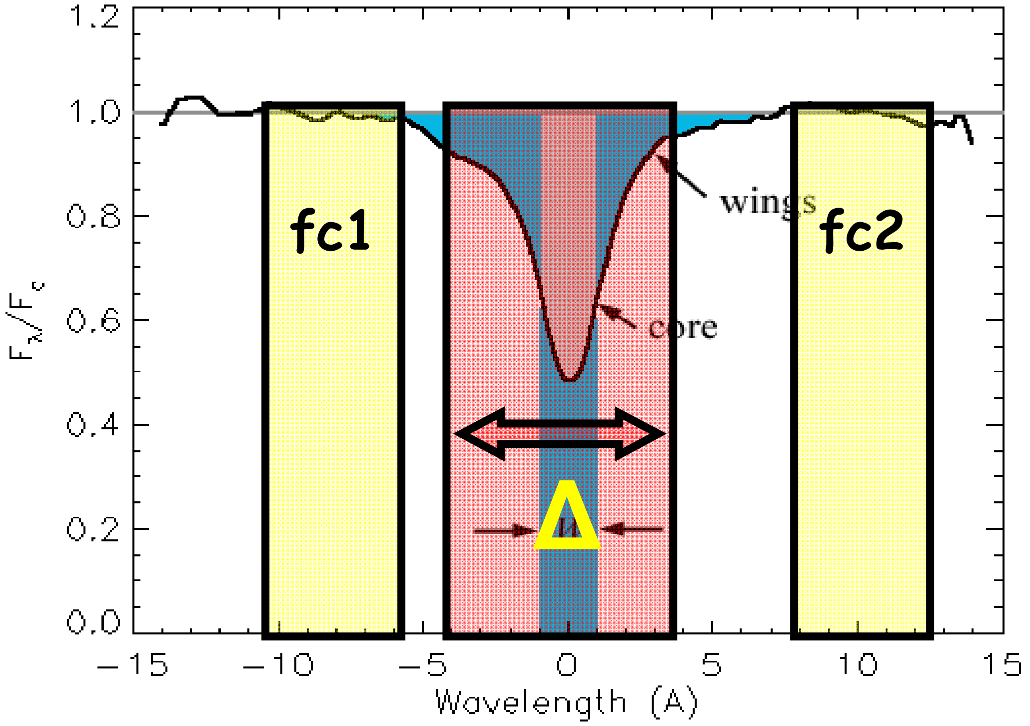
EW

saturazione

Wing broadening

abbondanza

Indici in EW e in magnitudini



Tipicamente,

- se la riga e' **atomica**, l'indice si misura in **EW**
- se la banda e' **molecolare** si misura in **mag**

$$I_A = \Delta \frac{(f_c - f_f)}{f_c}$$

$$I_{mag} = -2.5 \log \left[1 - \left(\frac{I_A}{\Delta} \right) \right]$$

$$I_{mag} = -2.5 \log \left(\frac{f_f}{f_c} \right)$$

$$I_A = \Delta \left[1 - 10^{-0.4 I_{mag}} \right]$$

Gli indici di Fanelli (Far-UV)
(1987)

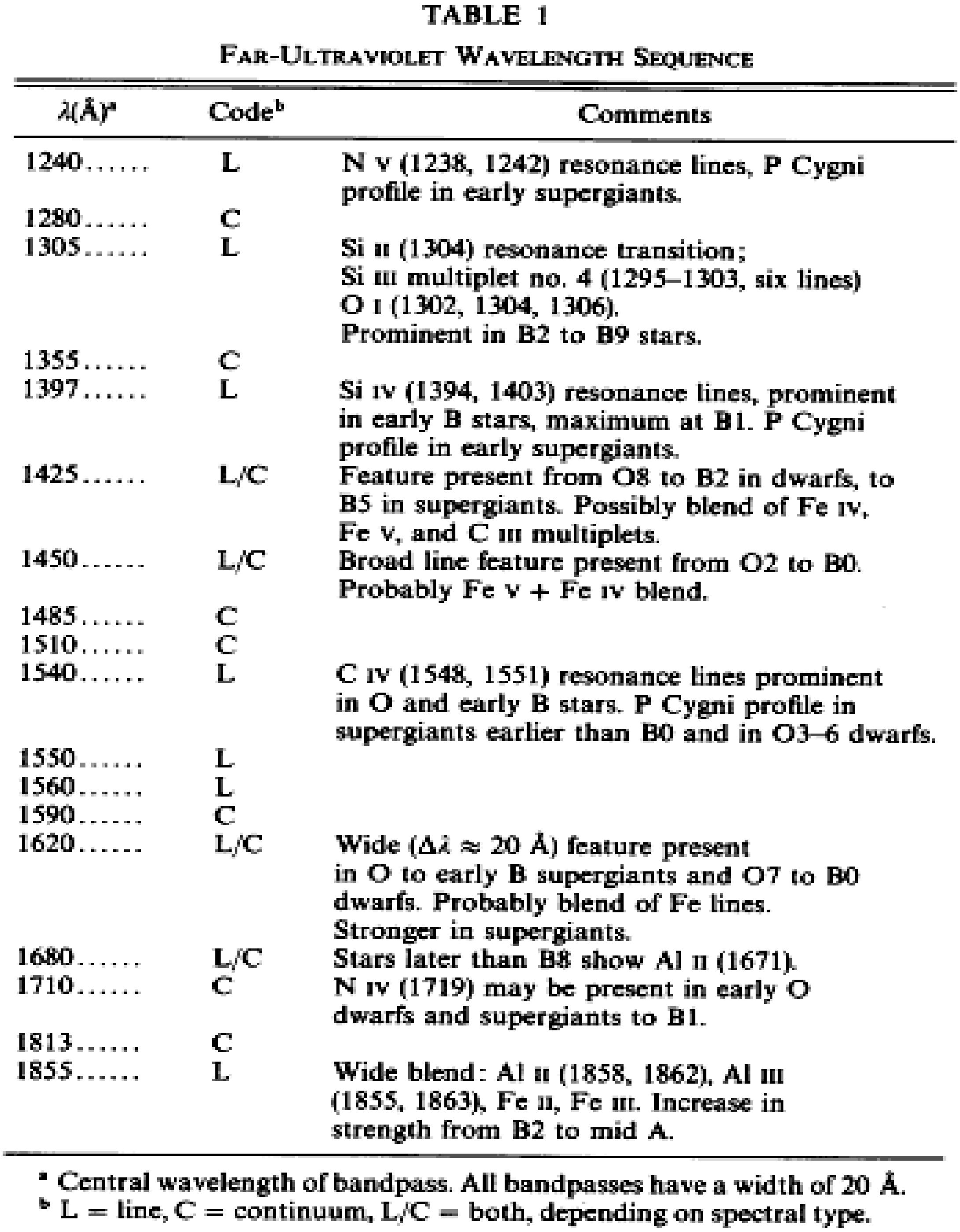


TABLE 1

FAR-ULTRAVIOLET WAVELENGTH SEQUENCE

λ(Å)[a]	Code[b]	Comments
1240......	L	N v (1238, 1242) resonance lines, P Cygni profile in early supergiants.
1280......	C	
1305......	L	Si ii (1304) resonance transition; Si iii multiplet no. 4 (1295–1303, six lines) O i (1302, 1304, 1306). Prominent in B2 to B9 stars.
1355......	C	
1397......	L	Si iv (1394, 1403) resonance lines, prominent in early B stars, maximum at B1. P Cygni profile in early supergiants.
1425......	L/C	Feature present from O8 to B2 in dwarfs, to B5 in supergiants. Possibly blend of Fe iv, Fe v, and C iii multiplets.
1450......	L/C	Broad line feature present from O2 to B0. Probably Fe v + Fe iv blend.
1485......	C	
1510......	C	
1540......	L	C iv (1548, 1551) resonance lines prominent in O and early B stars. P Cygni profile in supergiants earlier than B0 and in O3–6 dwarfs.
1550......	L	
1560......	L	
1590......	C	
1620......	L/C	Wide (Δλ ≈ 20 Å) feature present in O to early B supergiants and O7 to B0 dwarfs. Probably blend of Fe lines. Stronger in supergiants.
1680......	L/C	Stars later than B8 show Al ii (1671).
1710......	C	N iv (1719) may be present in early O dwarfs and supergiants to B1.
1813......	C	
1855......	L	Wide blend: Al ii (1858, 1862), Al iii (1855, 1863), Fe ii, Fe iii. Increase in strength from B2 to mid A.

[a] Central wavelength of bandpass. All bandpasses have a width of 20 Å.

[b] L = line, C = continuum, L/C = both, depending on spectral type.

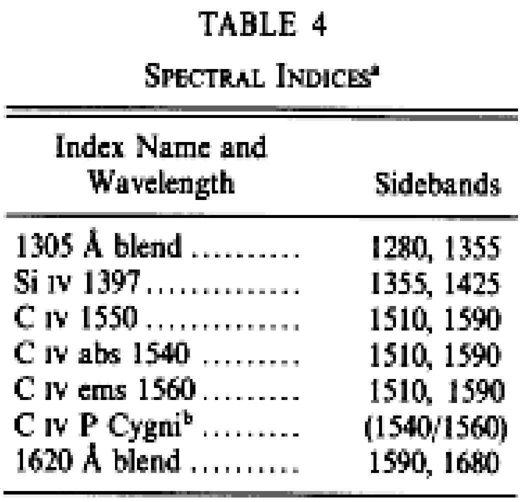


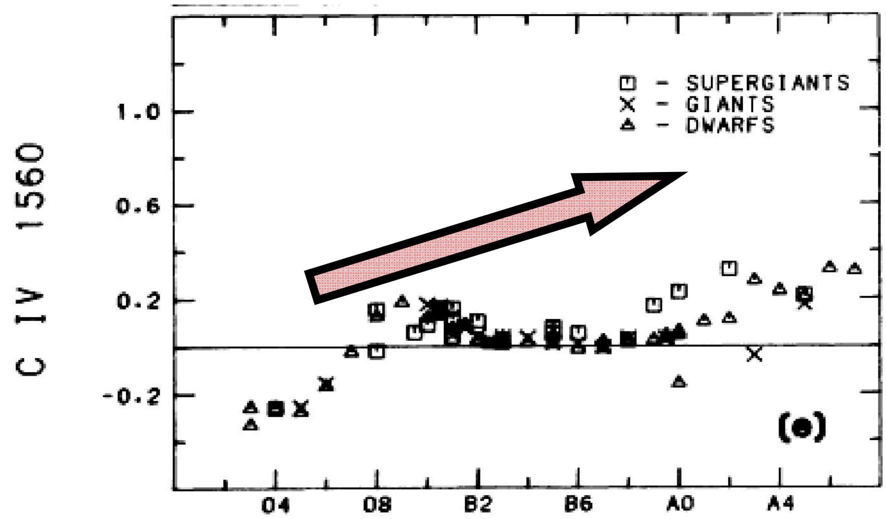
TABLE 4

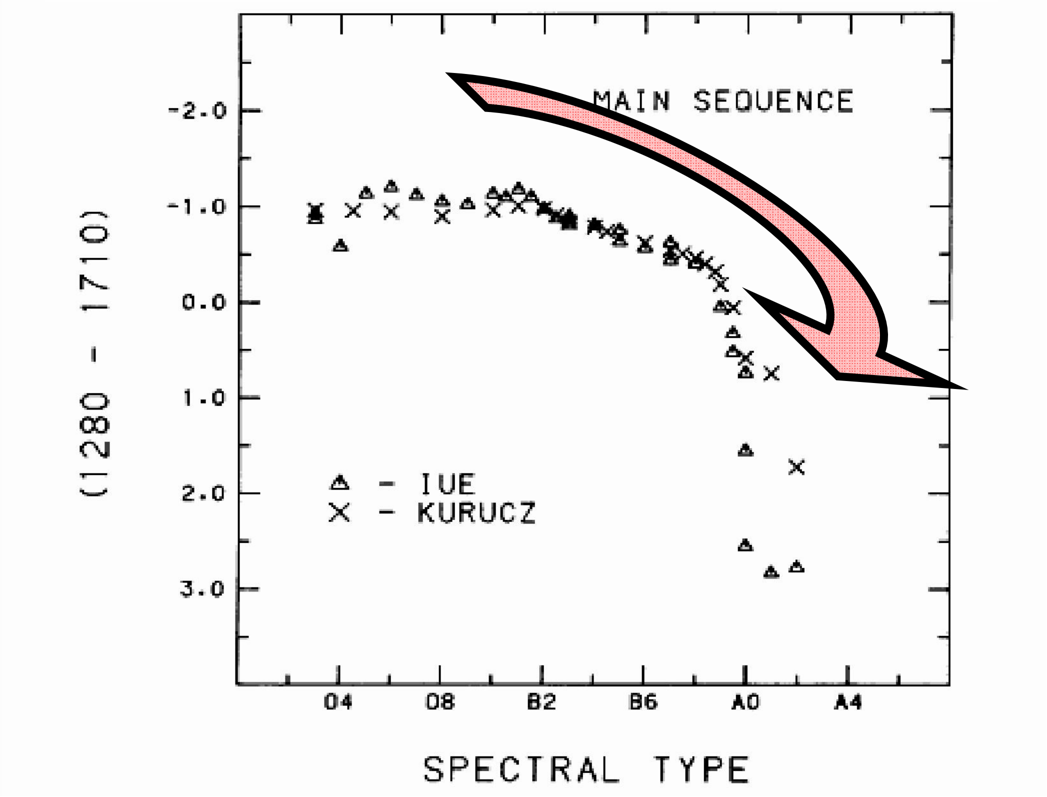
SPECTRAL INDICES[a]

Index Name and Wavelength	Sidebands
1305 Å blend	1280, 1355
Si IV 1397..............	1355, 1425
C IV 1550	1510, 1590
C IV abs 1540	1510, 1590
C IV ems 1560	1510, 1590
C IV P Cygni[b]	(1540/1560)
1620 Å blend	1590, 1680

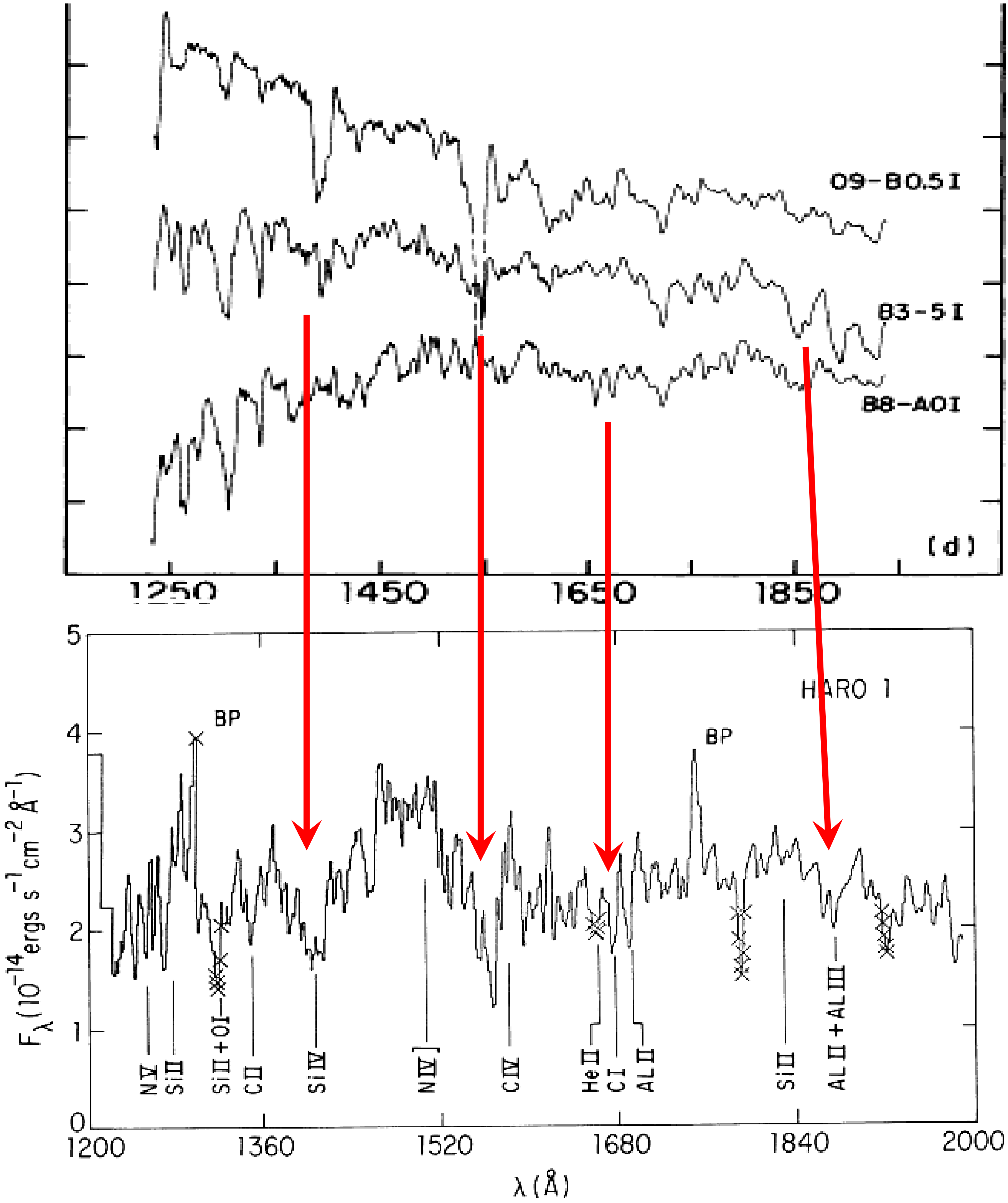
Indici di (pseudo)-continuo & linea

FWHM = 6Å





UV indices & diagnostica di Star-forming galaxies



Indici di Mid-UV

(1990)

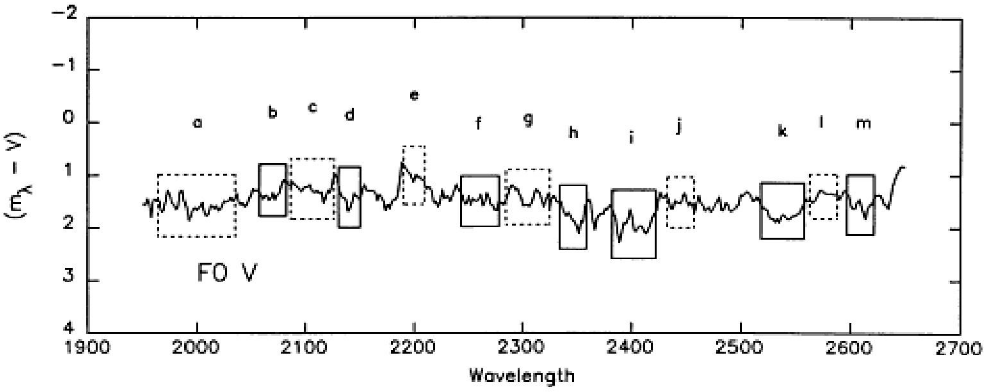


FIG. 3*a*

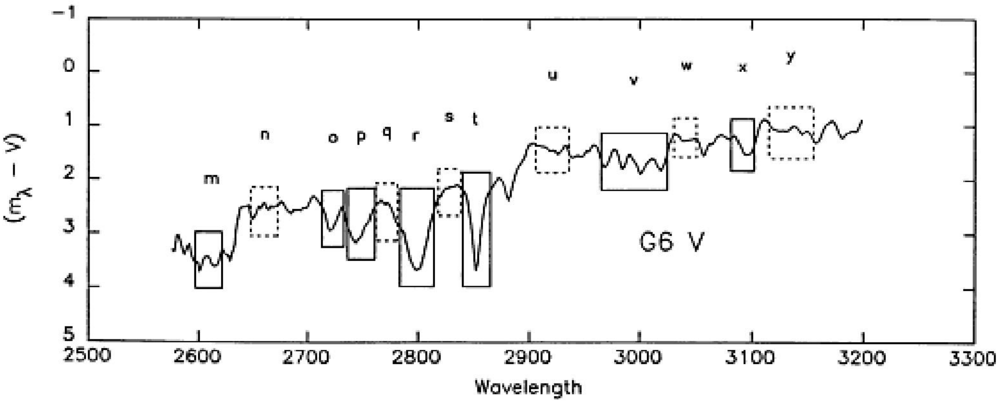


TABLE 3

MID-ULTRAVIOLET WAVELENGTH SEQUENCE

ID (1)	λ_i (2)	λ_f (3)	$\Delta\lambda$ (4)	Code[a] (5)	Comments (6)
a	1965	2035	70	C	
b	2057	2083	26	L	
c	2087	2127	40	C	
d	2131	2151	20	L	
e	2190	2210	20	C	
f	2243	2279	36	L	
g	2285	2325	40	C	
h	2333	2359	26	L	Fe II (3), 2338.0, 2344.3, 2343.5, 2348.3
i	2382	2422	40	L	Fe II (2), blend of ~10 lines
j	2432	2458	26	C	
k	2520	2556	36	L	Uncertain, Fe I?
l	2562	2588	26	C	
m	2596	2622	26	L	Fe II (1), blend of ~10 lines
n	2647	2673	26	C	
o	2713	2733	20	L	
p	2736	2762	26	L	Fe I, 2744.1, Fe II 2747.0, 2746.5, Cr I 2748.3
q	2762	2782	20	C	
r	2784	2814	30	L	Mg II (1) 2795.5, 2802.7
s	2818	2838	20	C	
t	2839	2865	26	L	Mg I (1) 2852.1
u	2906	2936	30	C	
v	2965	3025	60	L	Fe I 2967.0, 2973.3, 2994.4, 3020.6
w	3031	3051	20	C	
x	3086	3106	20	L	Al I 3092.7, Fe I 3091.6, Ni I?
y	3115	3155	40	C	

[a] C = continuum; L = line.

Il Magnesio (MgII & MgI)

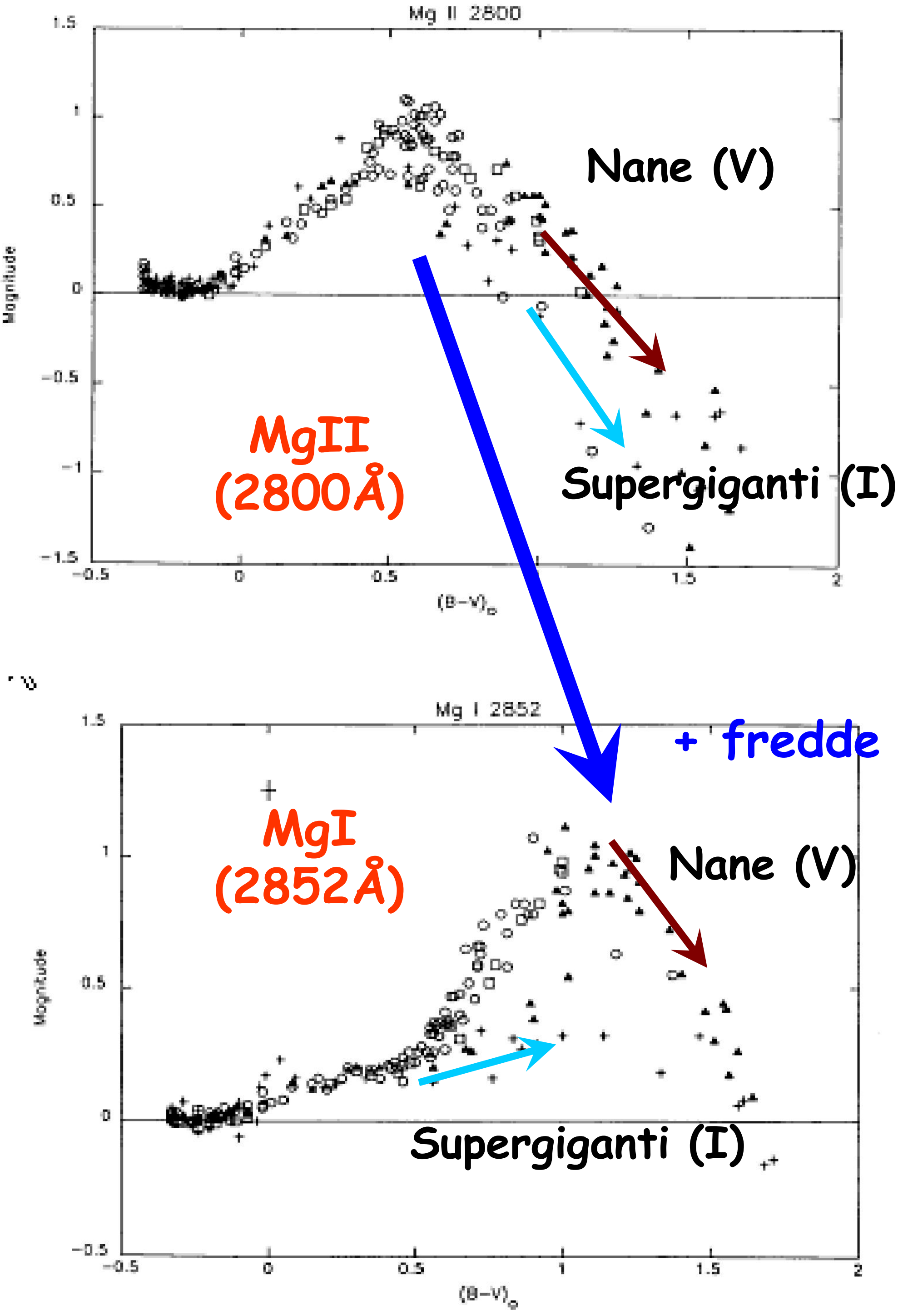


FIG. 5d

Il sistema di Lick

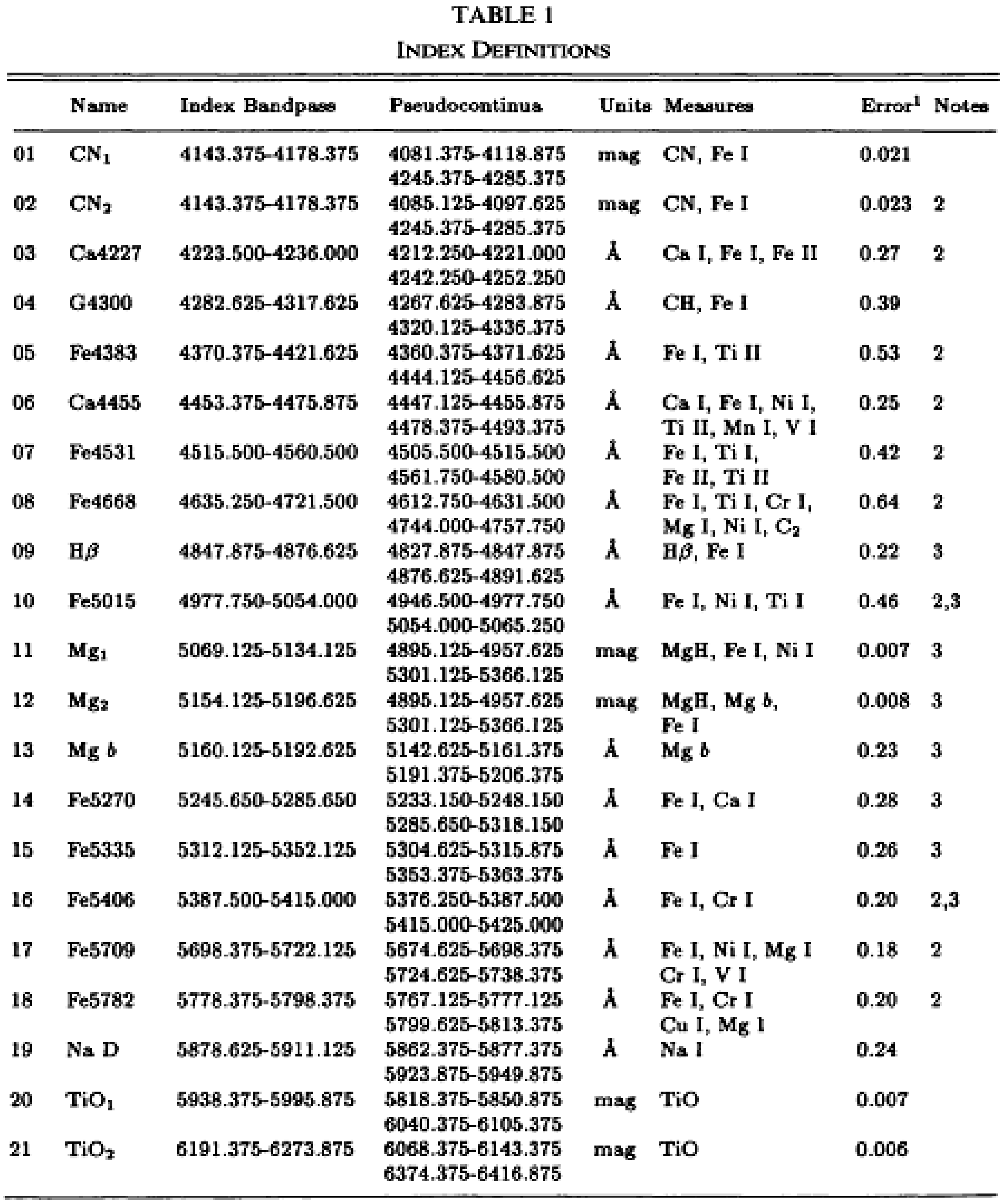


TABLE 1

INDEX DEFINITIONS

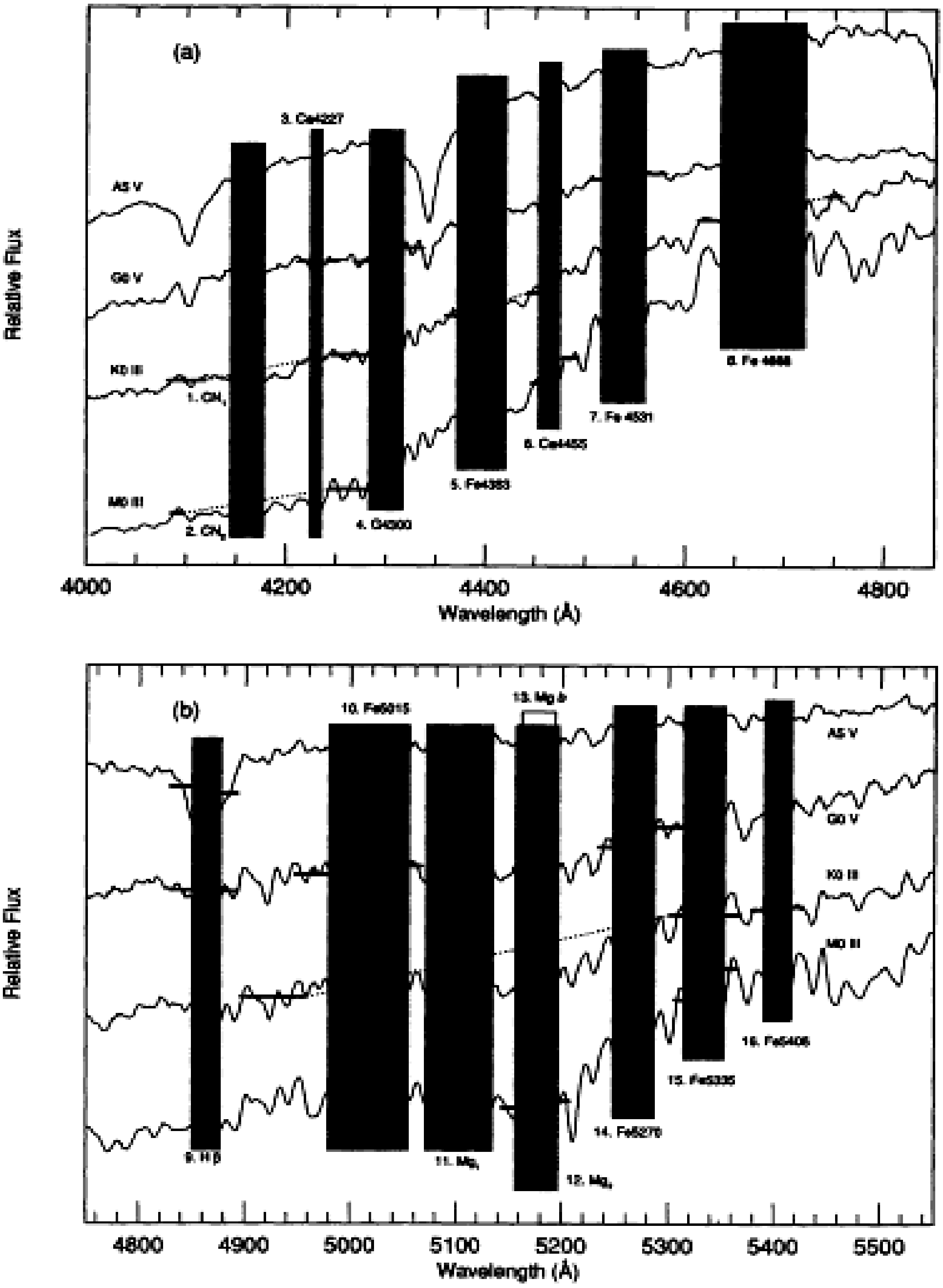
	Name	Index Bandpass	Pseudocontinua	Units	Measures	Error[1]	Notes
01	CN$_1$	4143.375-4178.375	4081.375-4118.875 4245.375-4285.375	mag	CN, Fe I	0.021	
02	CN$_2$	4143.375-4178.375	4085.125-4097.625 4245.375-4285.375	mag	CN, Fe I	0.023	2
03	Ca4227	4223.500-4236.000	4212.250-4221.000 4242.250-4252.250	Å	Ca I, Fe I, Fe II	0.27	2
04	G4300	4282.625-4317.625	4267.625-4283.875 4320.125-4336.375	Å	CH, Fe I	0.39	
05	Fe4383	4370.375-4421.625	4360.375-4371.625 4444.125-4456.625	Å	Fe I, Ti II	0.53	2
06	Ca4455	4453.375-4475.875	4447.125-4455.875 4478.375-4493.375	Å	Ca I, Fe I, Ni I, Ti II, Mn I, V I	0.25	2
07	Fe4531	4515.500-4560.500	4505.500-4515.500 4561.750-4580.500	Å	Fe I, Ti I, Fe II, Ti II	0.42	2
08	Fe4668	4635.250-4721.500	4612.750-4631.500 4744.000-4757.750	Å	Fe I, Ti I, Cr I, Mg I, Ni I, C$_2$	0.64	2
09	Hβ	4847.875-4876.625	4827.875-4847.875 4876.625-4891.625	Å	Hβ, Fe I	0.22	3
10	Fe5015	4977.750-5054.000	4946.500-4977.750 5054.000-5065.250	Å	Fe I, Ni I, Ti I	0.46	2,3
11	Mg$_1$	5069.125-5134.125	4895.125-4957.625 5301.125-5366.125	mag	MgH, Fe I, Ni I	0.007	3
12	Mg$_2$	5154.125-5196.625	4895.125-4957.625 5301.125-5366.125	mag	MgH, Mg b, Fe I	0.008	3
13	Mg b	5160.125-5192.625	5142.625-5161.375 5191.375-5206.375	Å	Mg b	0.23	3
14	Fe5270	5245.650-5285.650	5233.150-5248.150 5285.650-5318.150	Å	Fe I, Ca I	0.28	3
15	Fe5335	5312.125-5352.125	5304.625-5315.875 5353.375-5363.375	Å	Fe I	0.26	3
16	Fe5406	5387.500-5415.000	5376.250-5387.500 5415.000-5425.000	Å	Fe I, Cr I	0.20	2,3
17	Fe5709	5698.375-5722.125	5674.625-5698.375 5724.625-5738.375	Å	Fe I, Ni I, Mg I Cr I, V I	0.18	2
18	Fe5782	5778.375-5798.375	5767.125-5777.125 5799.625-5813.375	Å	Fe I, Cr I Cu I, Mg I	0.20	2
19	Na D	5878.625-5911.125	5862.375-5877.375 5923.875-5949.875	Å	Na I	0.24	
20	TiO$_1$	5938.375-5995.875	5818.375-5850.875 6040.375-6105.375	mag	TiO	0.007	
21	TiO$_2$	6191.375-6273.875	6068.375-6143.375 6374.375-6416.875	mag	TiO	0.006	

FWHM = 8.5Å

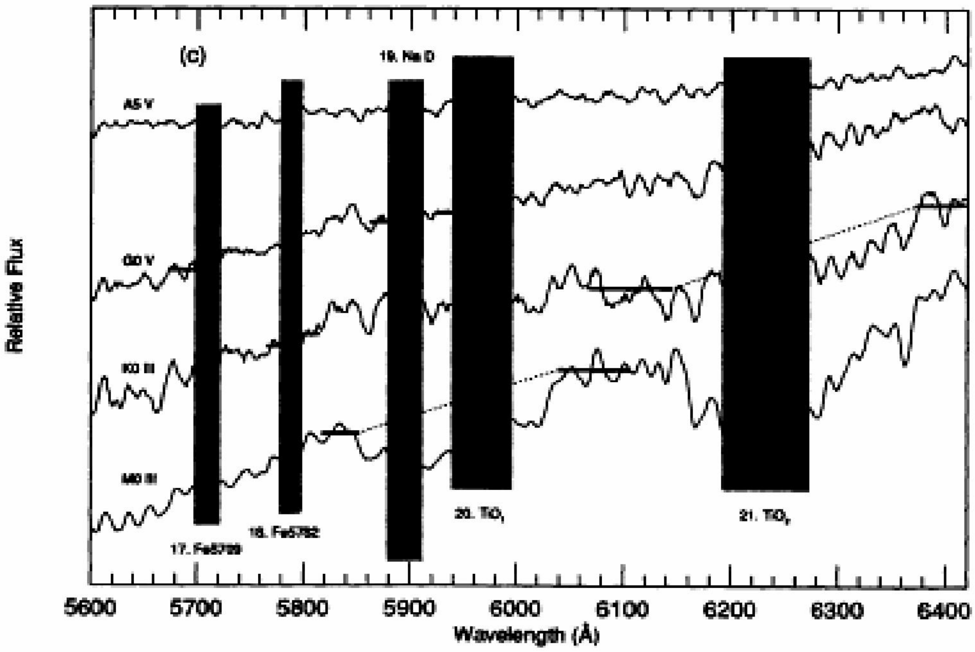
Worthey et al. (1994)

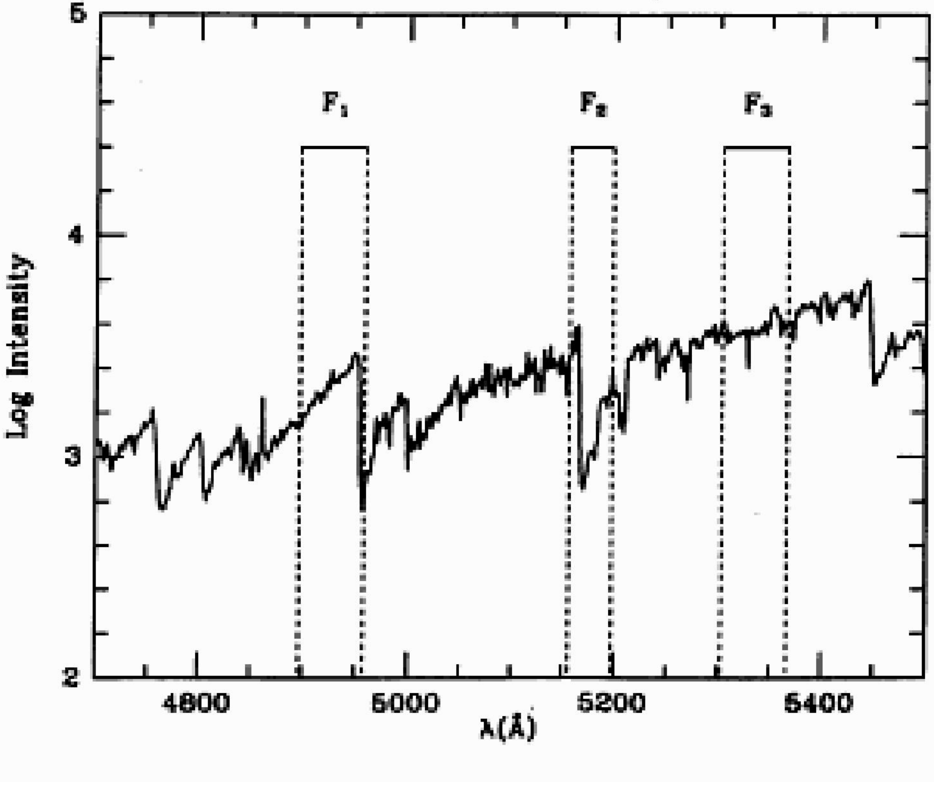
+ Trager et al. (1998)

Indici Blu-Vis

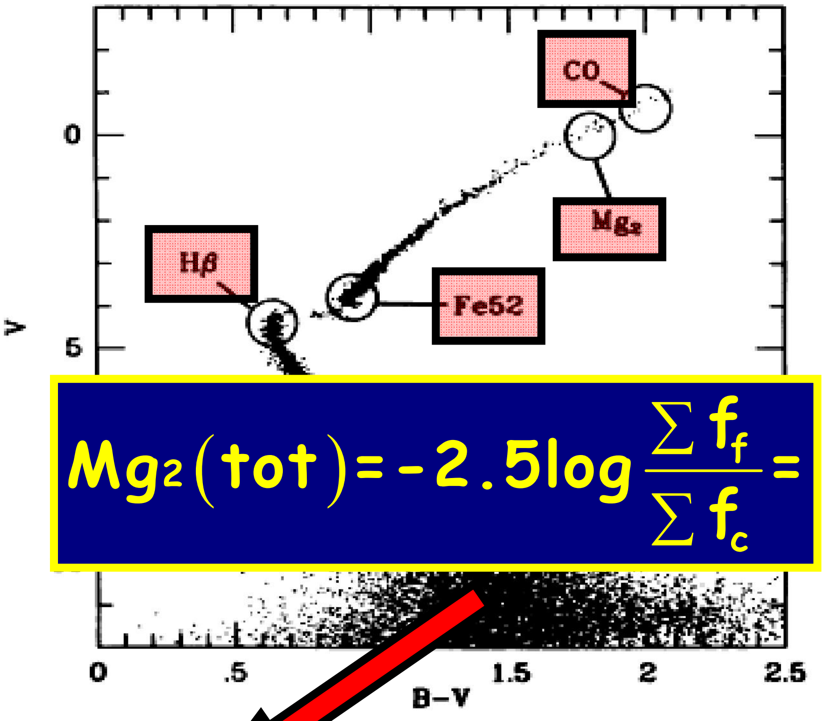


Indici Rossi

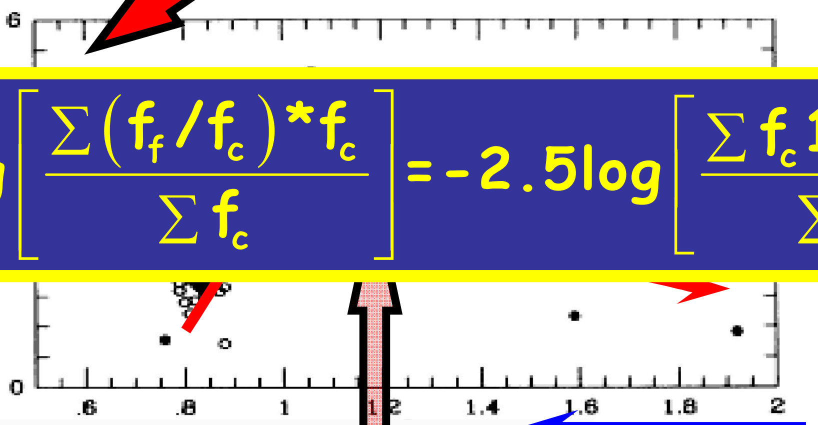




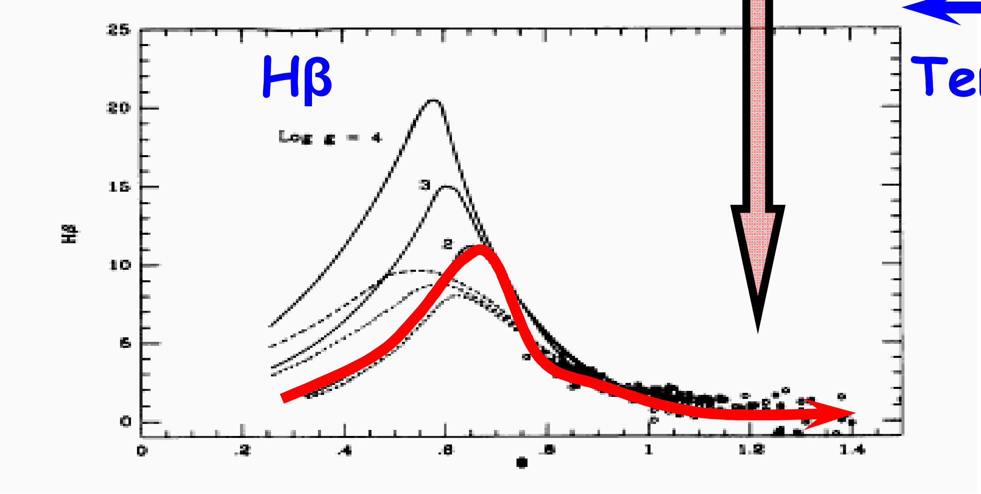
Indici e analisi "tomografica" delle pop stellari



$$Mg_2(tot) = -2.5\log\frac{\sum f_f}{\sum f_c} =$$

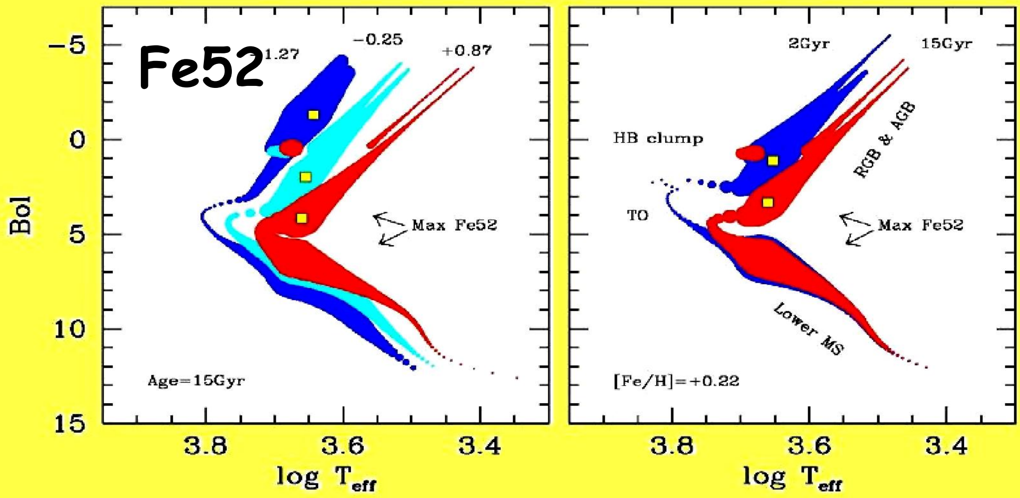


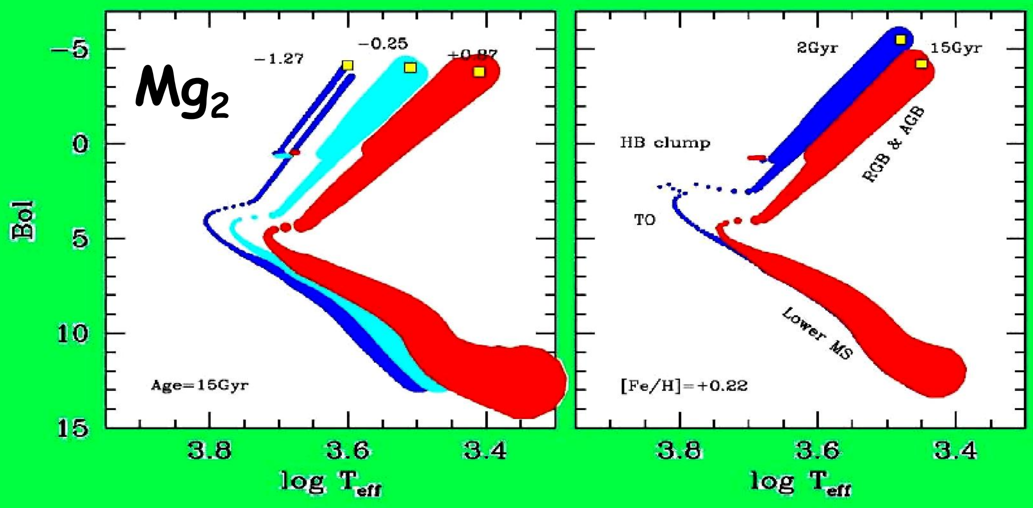
$$I_{tot} = -2.5\log\left[\frac{\sum (f_f/f_c)*f_c}{\sum f_c}\right] = -2.5\log\left[\frac{\sum f_c 10^{-0.4I}}{\sum f_c}\right]$$

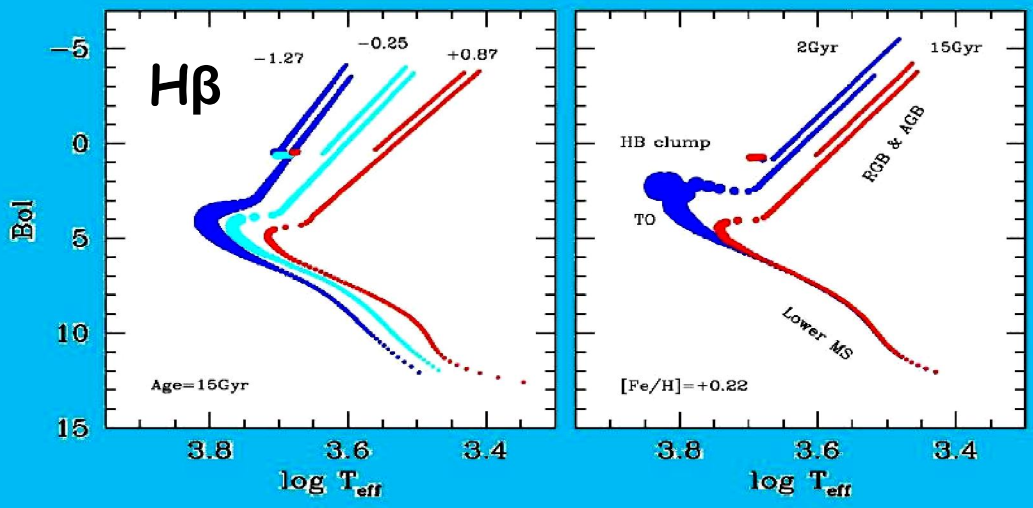


Temperatura

Narrow-band indices & SSP tomography







Articoli consigliati (vedi Webpage):
http://www.bo.astro.it/~eps/lezioni/lezioni.html

- Galaxy Spectral Atlas (Kennicutt1)
- Galaxy Spectral Atlas (Kennicutt2)
- Balmer break (Hamilton)
- Lick indices (Worthey)
- UV indices (Fanelli)
- Faber & Jackson
- M/L clusters (Girardi)

Il bias di Malmquist

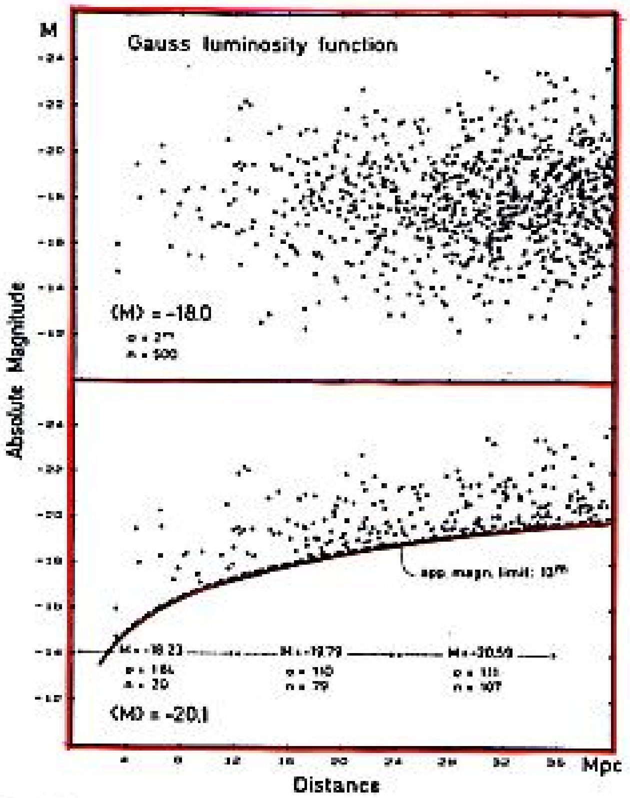
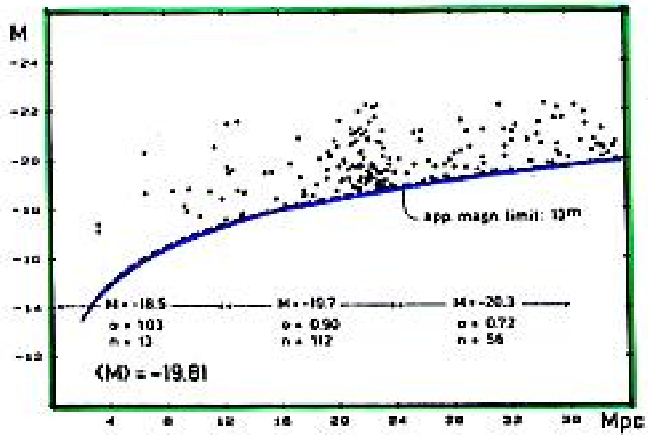


Fig. 1. Upper panel: Monte Carlo distribution in distance and absolute magnitude of 500 galaxies within 38 Mpc. Constant space density and a mean absolute magnitude of $\langle M \rangle = -18^m$ with a Gauss standard deviation of $\sigma_M = 2^m$ are assumed. Lower pannel: The same sample cut by an apparent-magnitude limit of $m = 13^m0$. Note the increase of the galaxian luminosities with increasing distance and the small effective (observable) scatter σ_M within individual distance intervals.

THE VALUE OF H_0 333

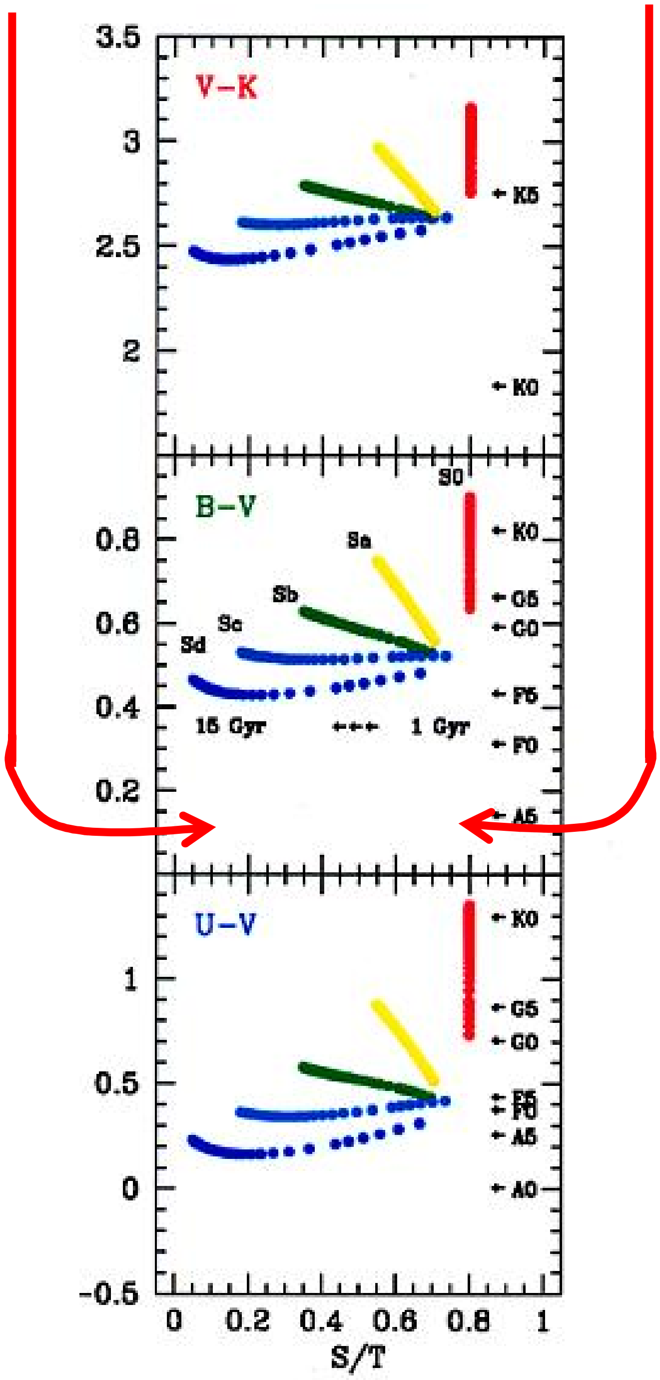


http://en.wikipedia.org/wiki/Malmquist_bias

Bias morfologico &
Bias fotometrico

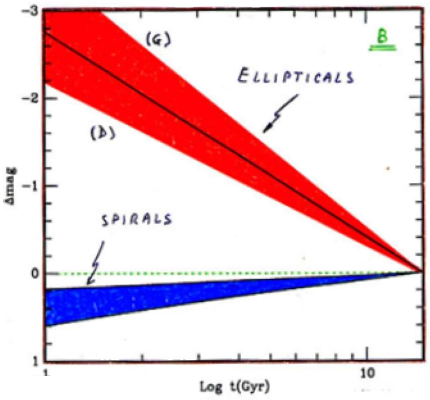
Disk-dominated

Bulge-dominated



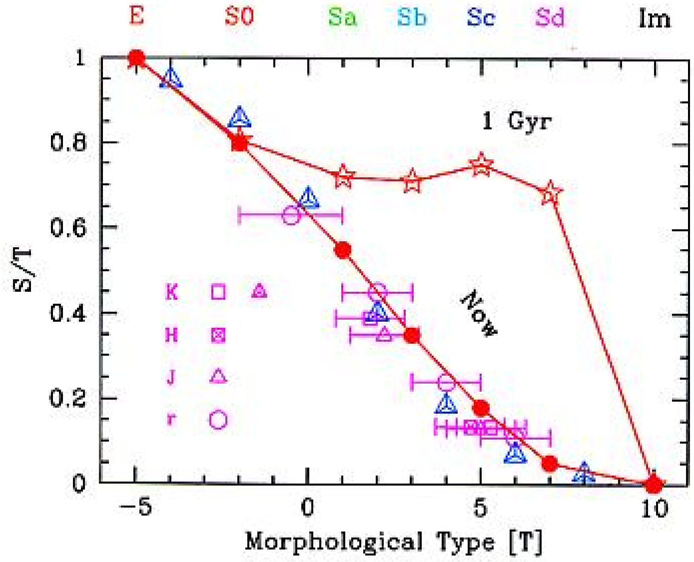
L(Spheroid)/L(Tot)

Bias Morfologico

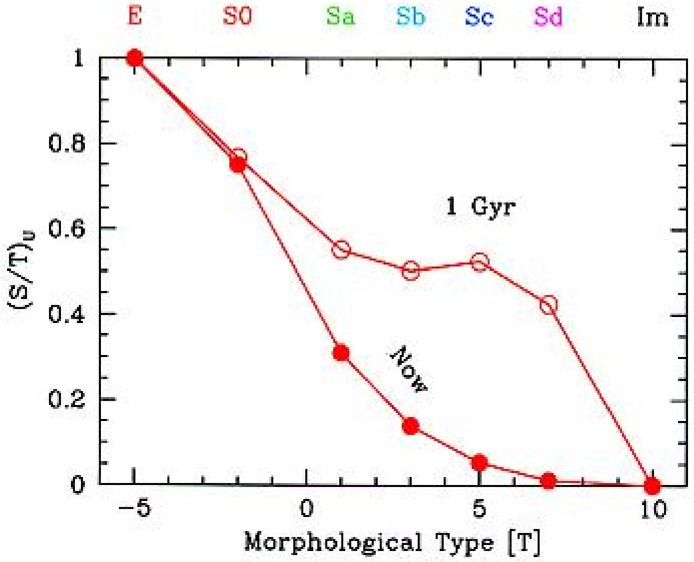


All'aumentare del redshift

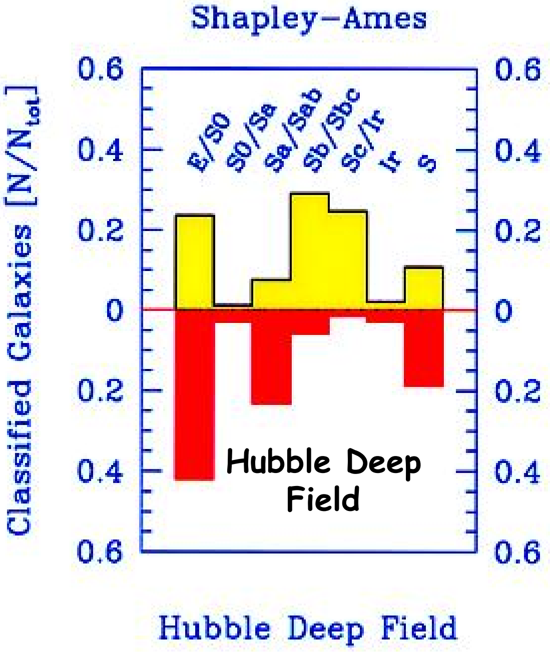
1) Andiamo indietro nel tempo (bulge +luminoso e disco –luminoso)
2) La morfologia tende ad essere quella nell'Ultravioletto



Buzzoni (2005)

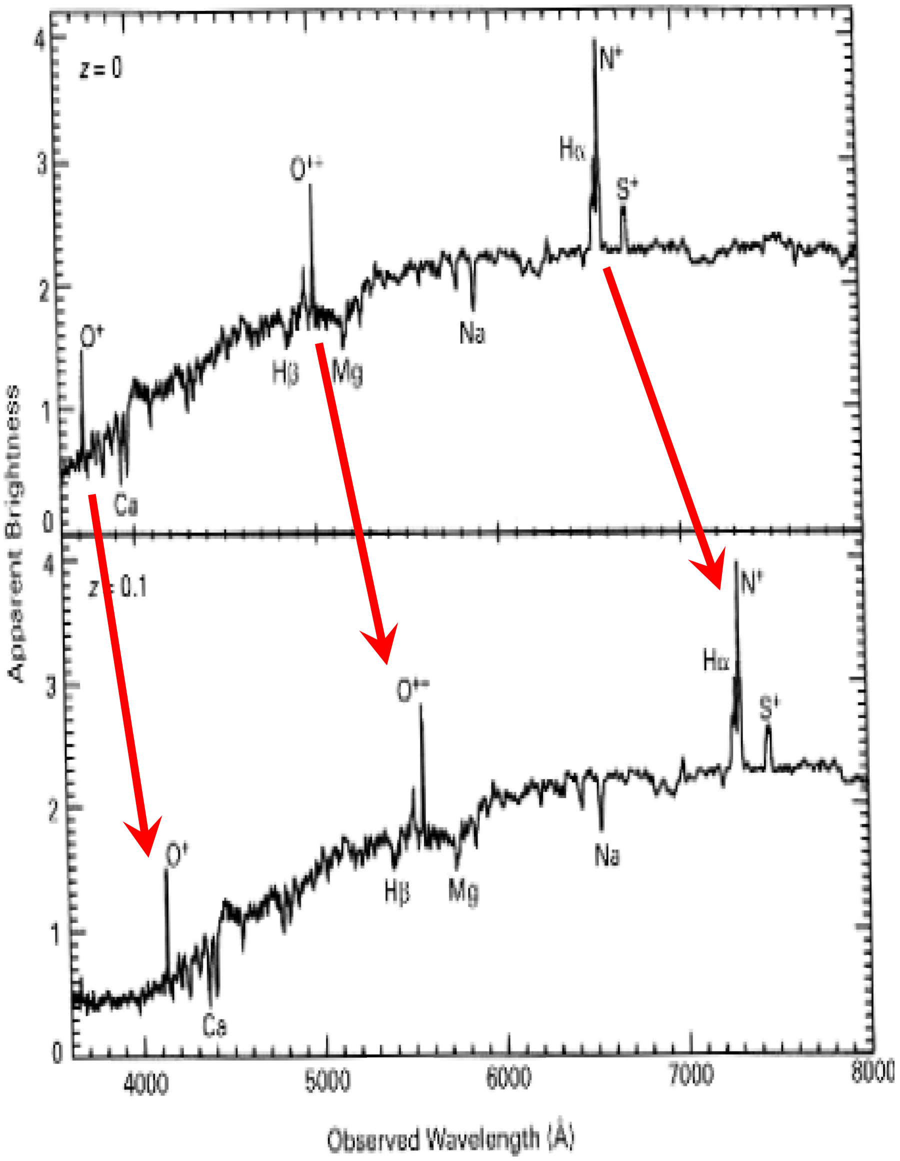


Galassie locali



Van den Bergh et al. (1996)

Il Redshift

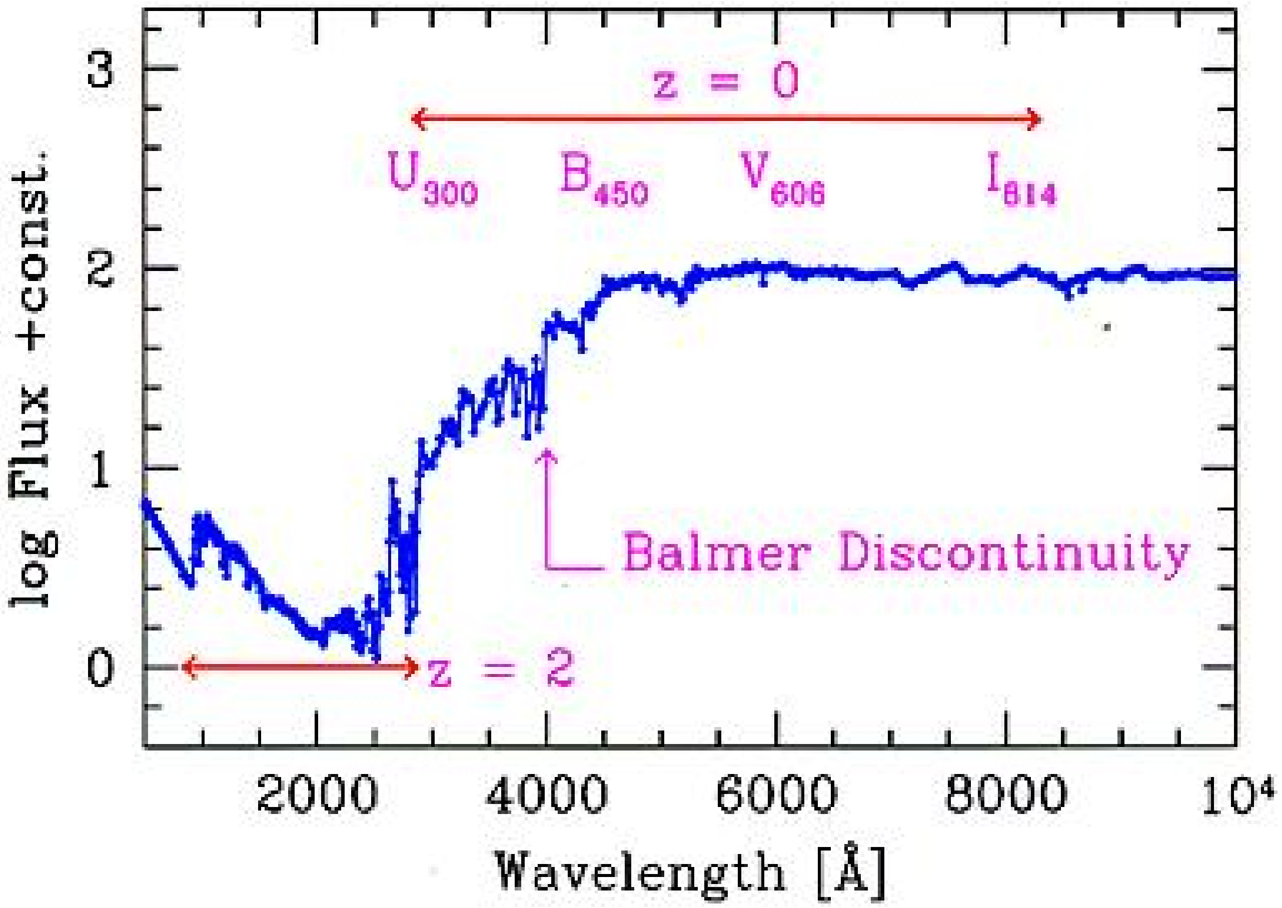


$$\frac{\lambda_{oss} - \lambda_{lab}}{\lambda_{lab}} = z$$

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c} = z$$

$$\frac{\lambda_{oss}}{\lambda_{lab}} = (1+z)$$

L'effetto di "streching"



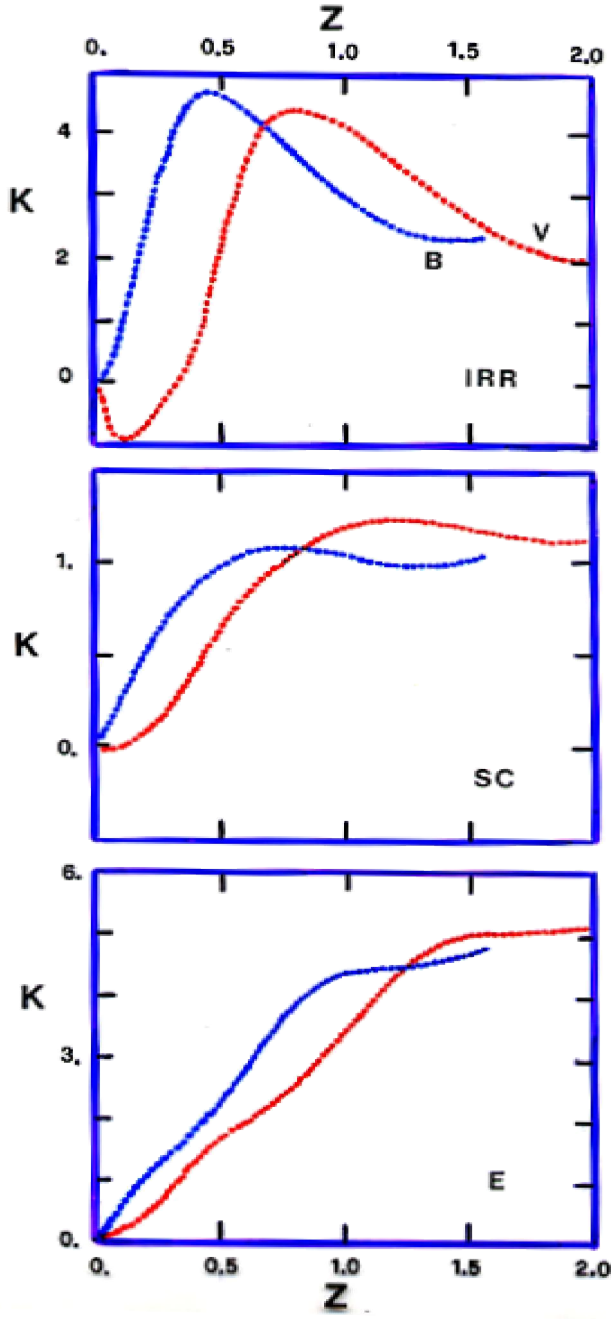
Massarotti et al. (2001)

Correzione k

$$M - M_0 = 5\,\mathrm{Log}\,\ell/\ell_0 + K(z) + e(z)$$

$$K(z) = 2.5\,\mathrm{Log}(1+z) - 2.5\,\mathrm{Log} \int F_{\underline{\underline{(\lambda/1+z)}}} R_\lambda\, d\lambda \Big/ \int \underline{\underline{F_\lambda}}\, R_\lambda\, d\lambda$$

$$e(z) = -2.5\,\mathrm{Log} \int F(\lambda/1+z\,; \underline{\underline{t_z}})\, R_\lambda\, d\lambda \Big/ \int F(\lambda/1+z\,; \underline{\underline{0}})\, R_\lambda\, d\lambda$$



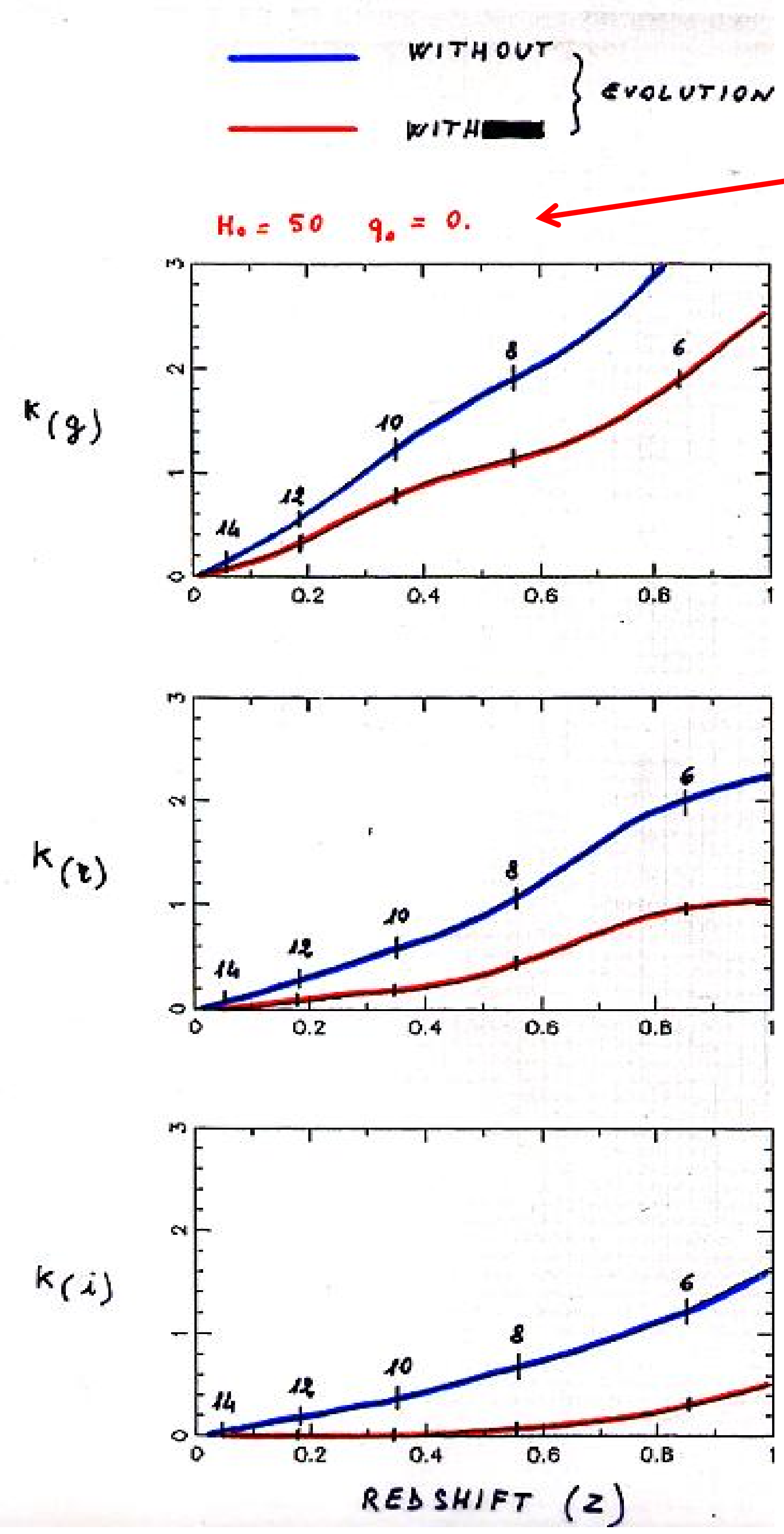
Notare che ∀ morfologia

$$\lim_{z\to 0} k = +2.5 Log(1+z)$$

Dato che F(Λ/(1+z) → F(Λ)

http://arxiv.org/abs/astro-ph/0210394

Esempi di correzione k passiva (k) ed evolutiva (k+e)



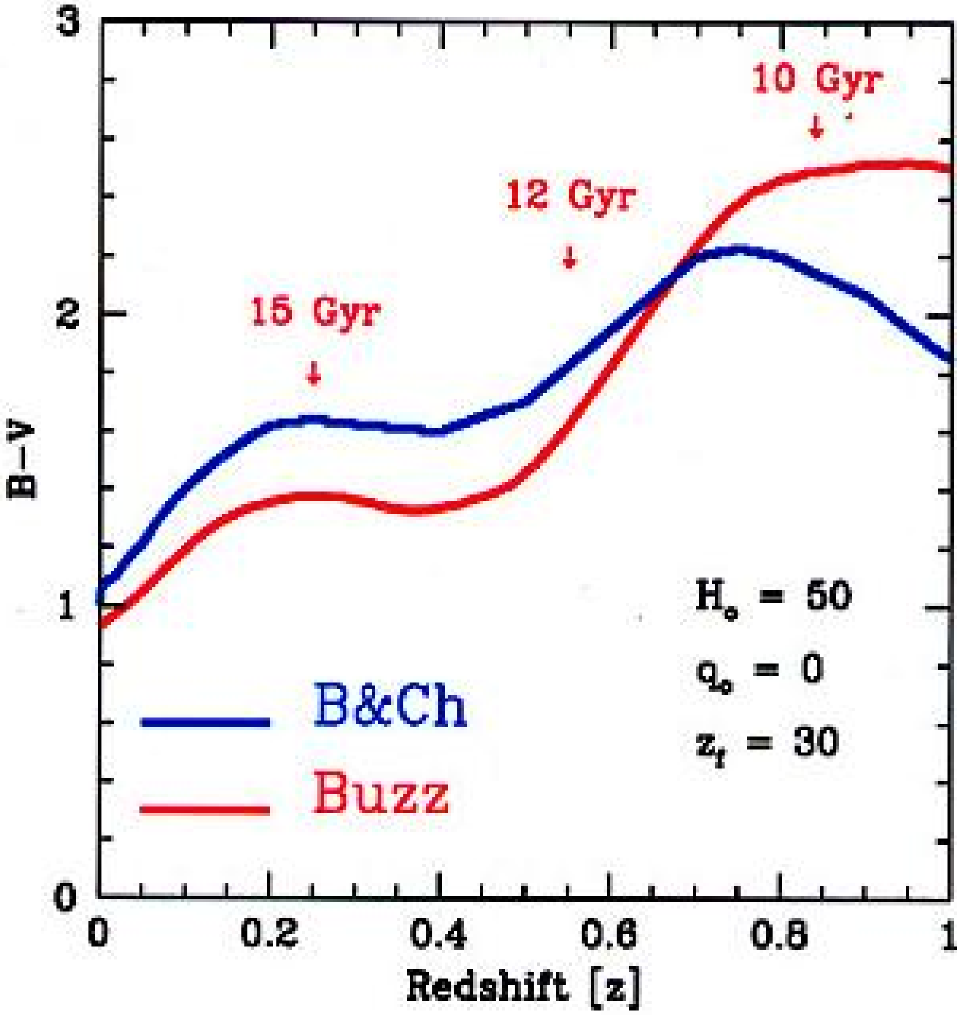
Importante!:

La correzione evolutiva e(z) dipende dal modello cosmologico assunto

k(z)

k(z)+e(z)

Apparent Color vs. Redshift



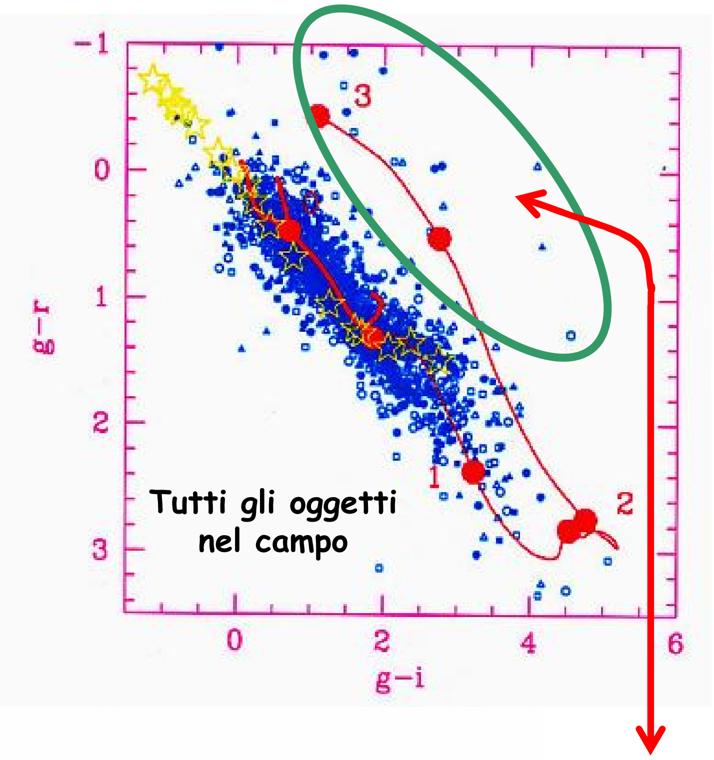
$$(B-V)_z = (B-V)_o + (k_B - k_V) + \underbrace{(e_B - e_V)}$$

Colore apparente

Colore restframe

Opzionale, nel caso si voglia/possa tenere in conto della evoluzione con z

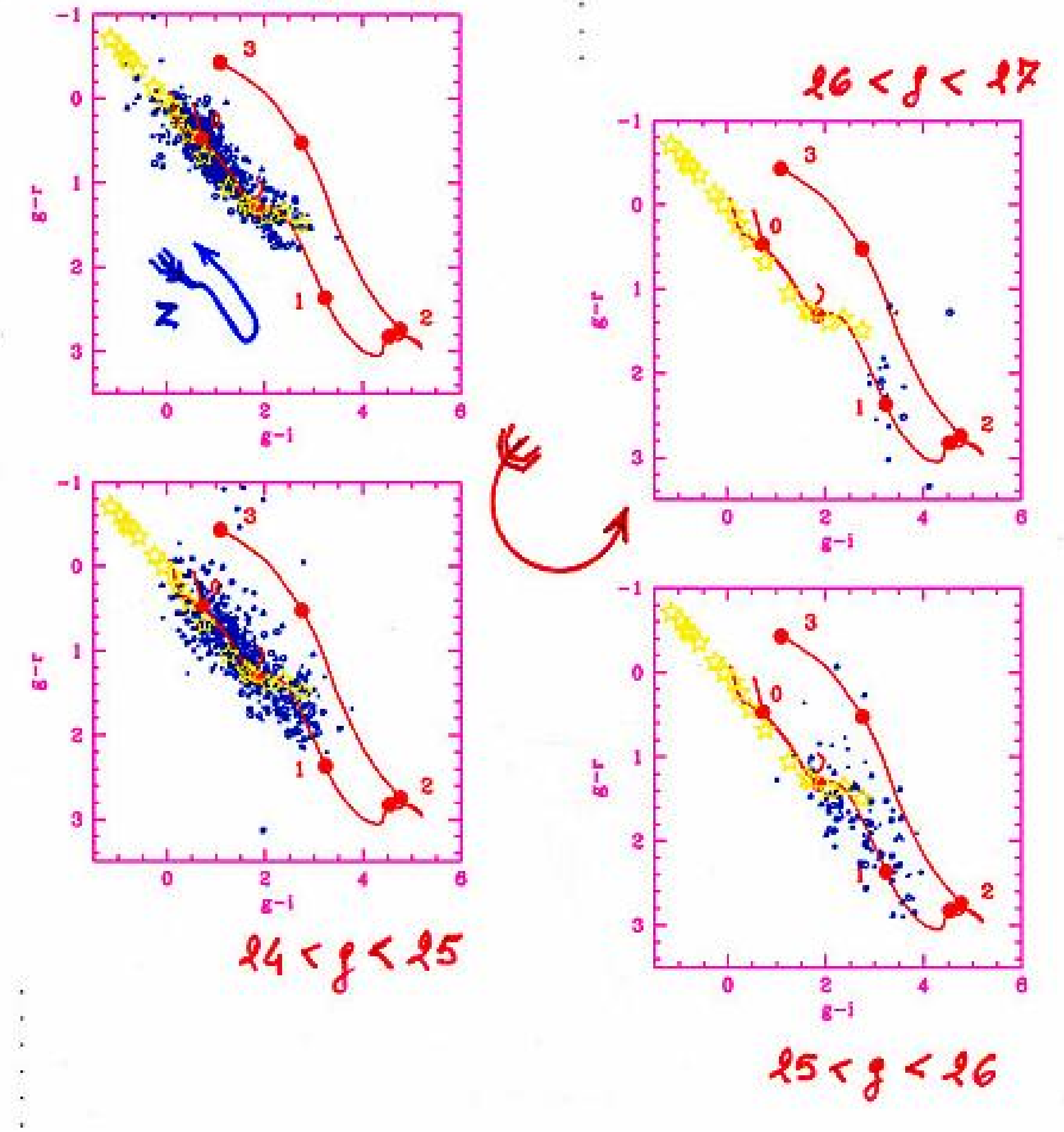
Selezione fotometrica delle galassie ad alto redshift: un esempio



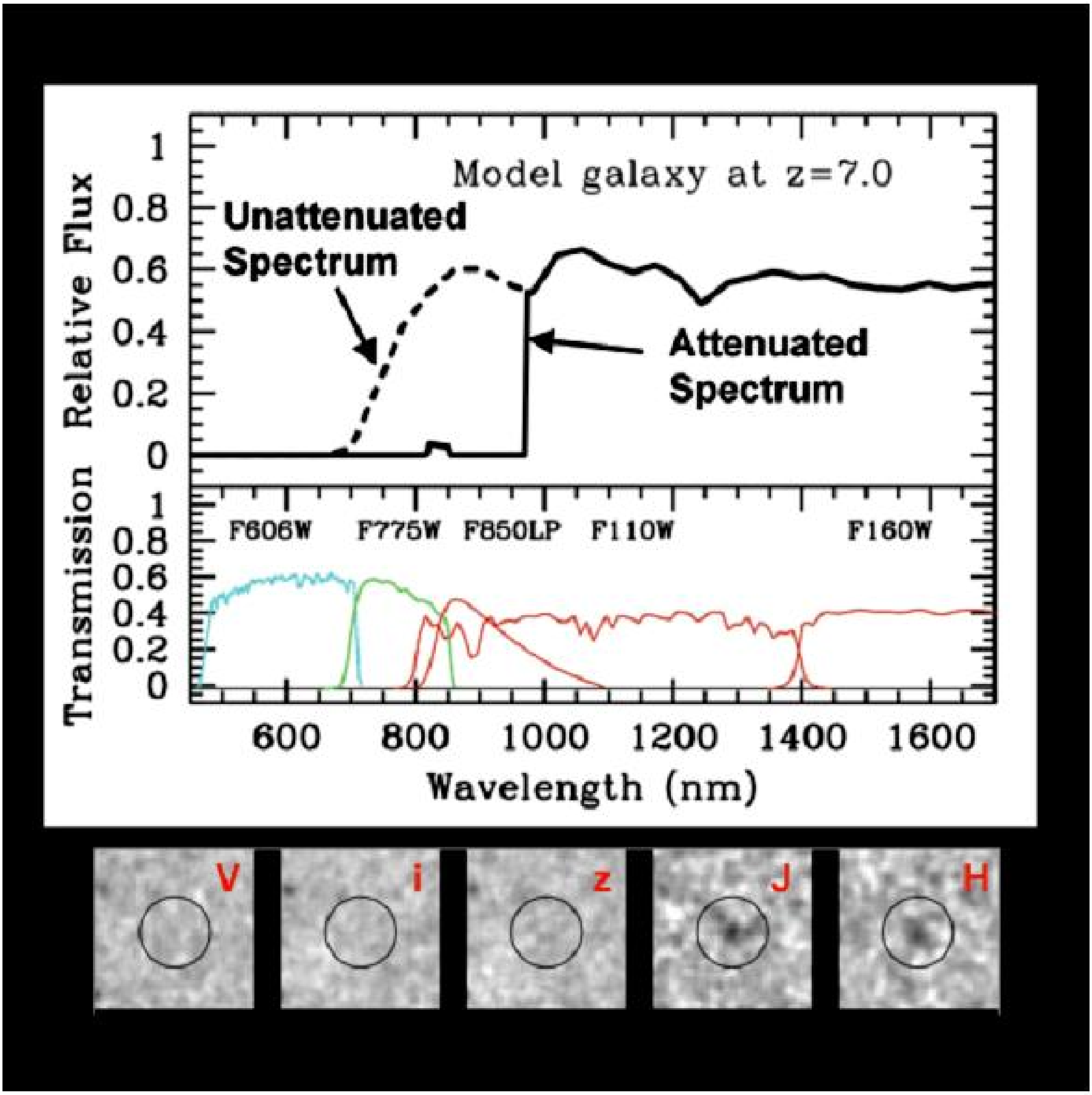
Tutti gli oggetti nel campo

Galassie ellittiche a z>2

23 < g < 24



Selezione fotometrica delle galassie ad alto redshift: “Dropout galaxies”



Steidel et al. (1996)

Articoli consigliati (vedi Webpage):
http://www.bo.astro.it/~eps/lezioni/lezioni.html

- Faber & Jackson
- M/L clusters (Girardi)
- Galaxy Colors (Buzzoni)
- K-correction (Hogg et al.)
- Dropout galaxies (Madau)
- Galaxy Spectral Atlas (Kennicutt1)
- Galaxy Spectral Atlas (Kennicutt2)
- Balmer break (Hamilton)