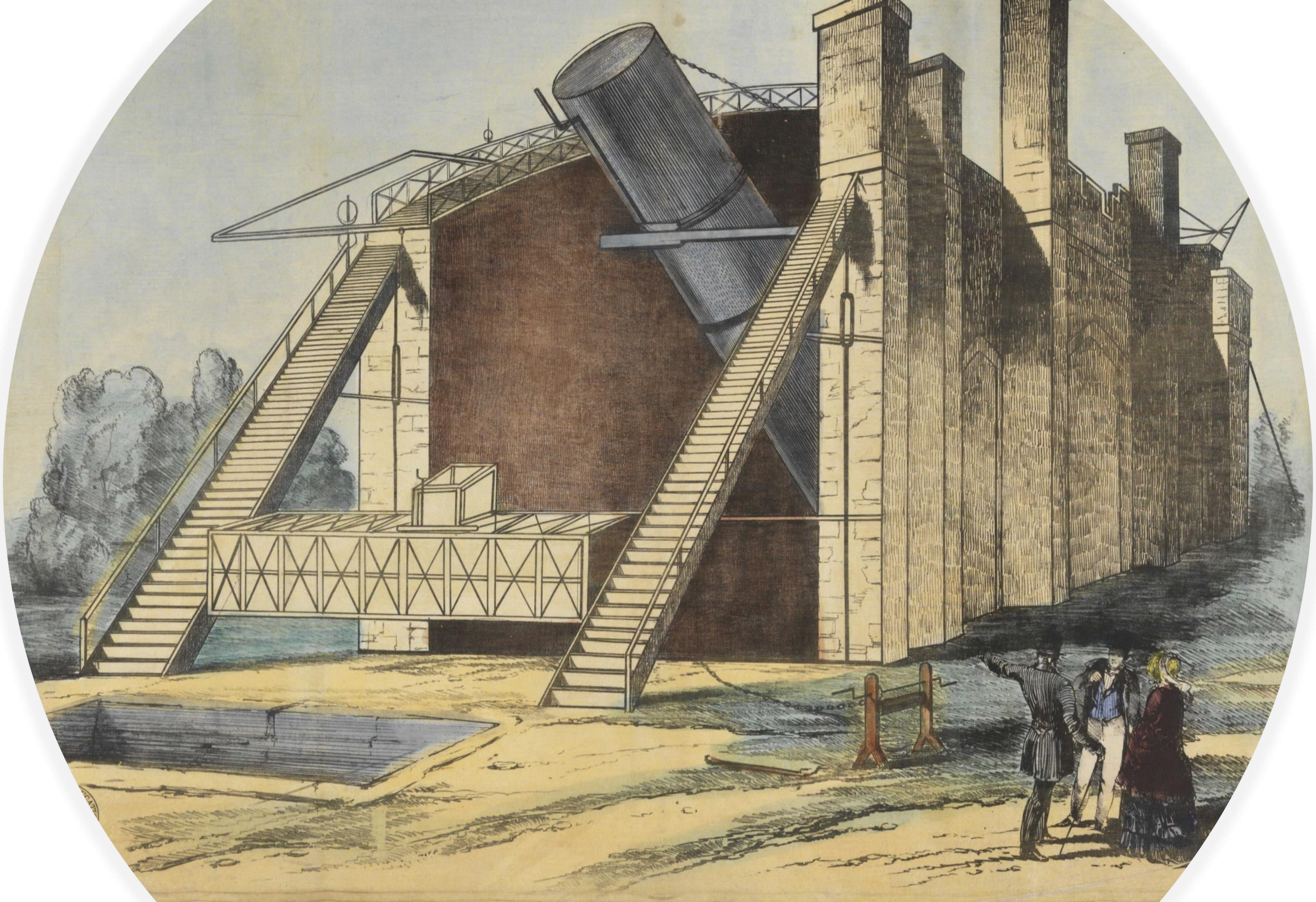
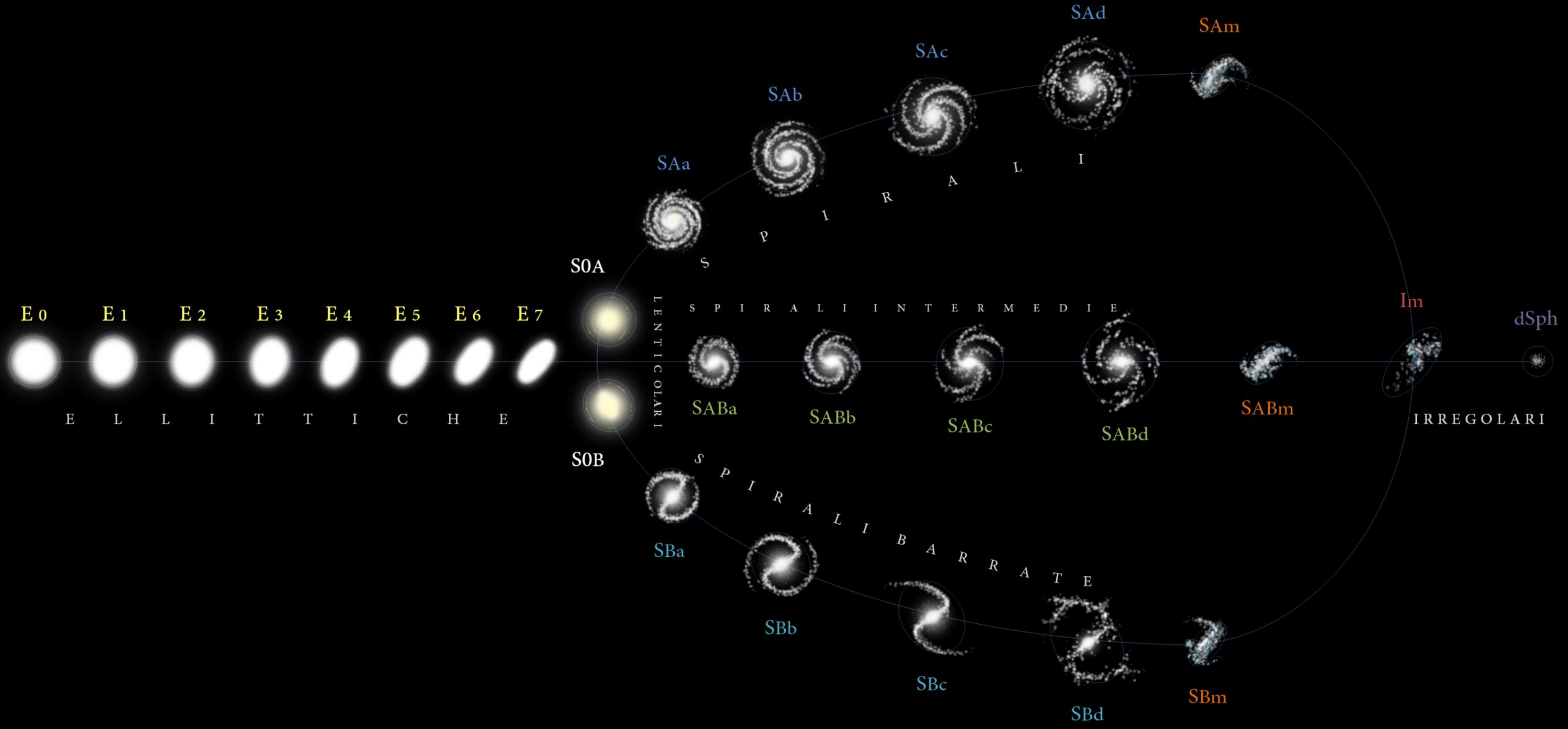
Dinamica delle galassie

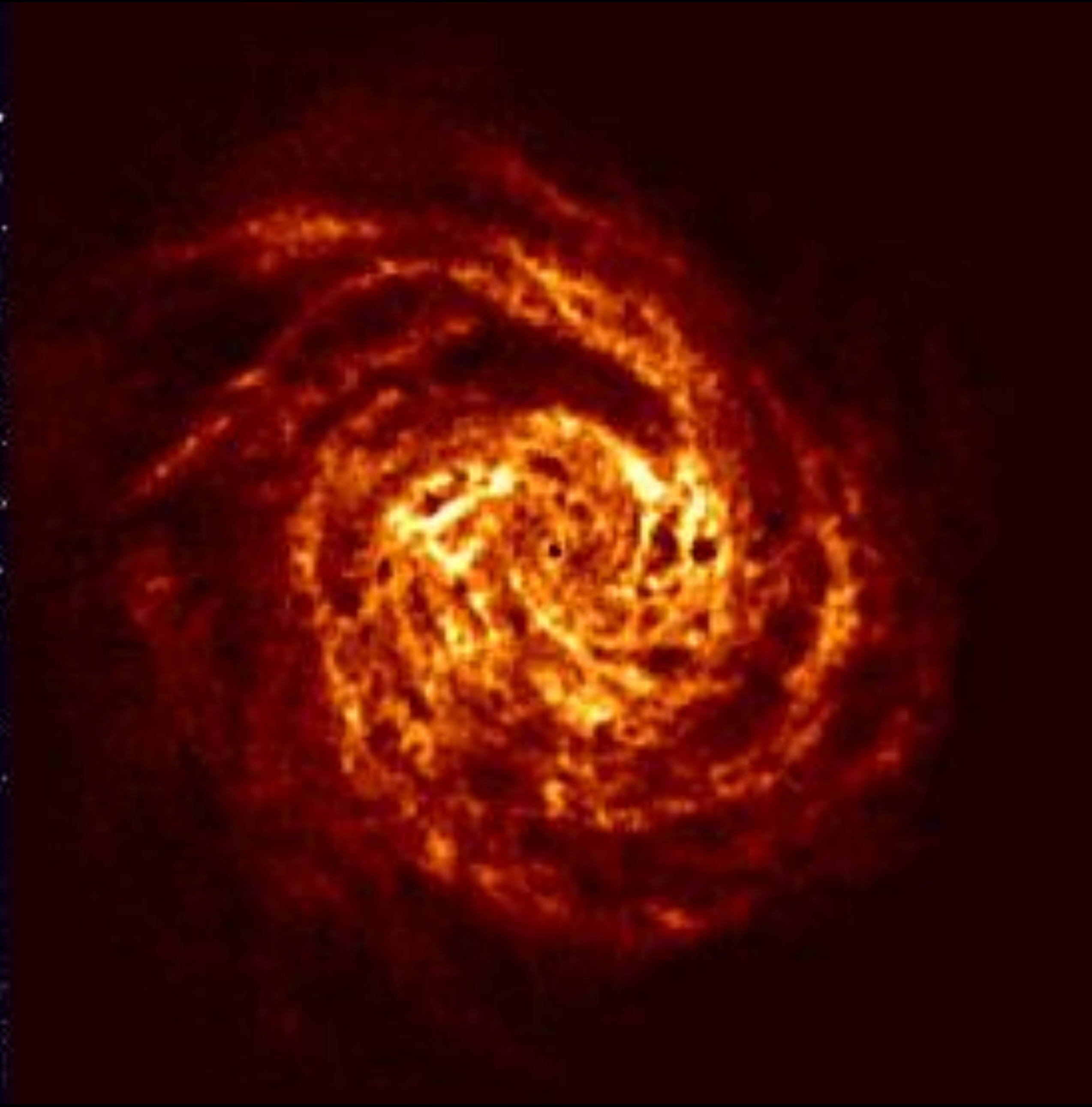
L’importanza dell’ISM e delle stelle

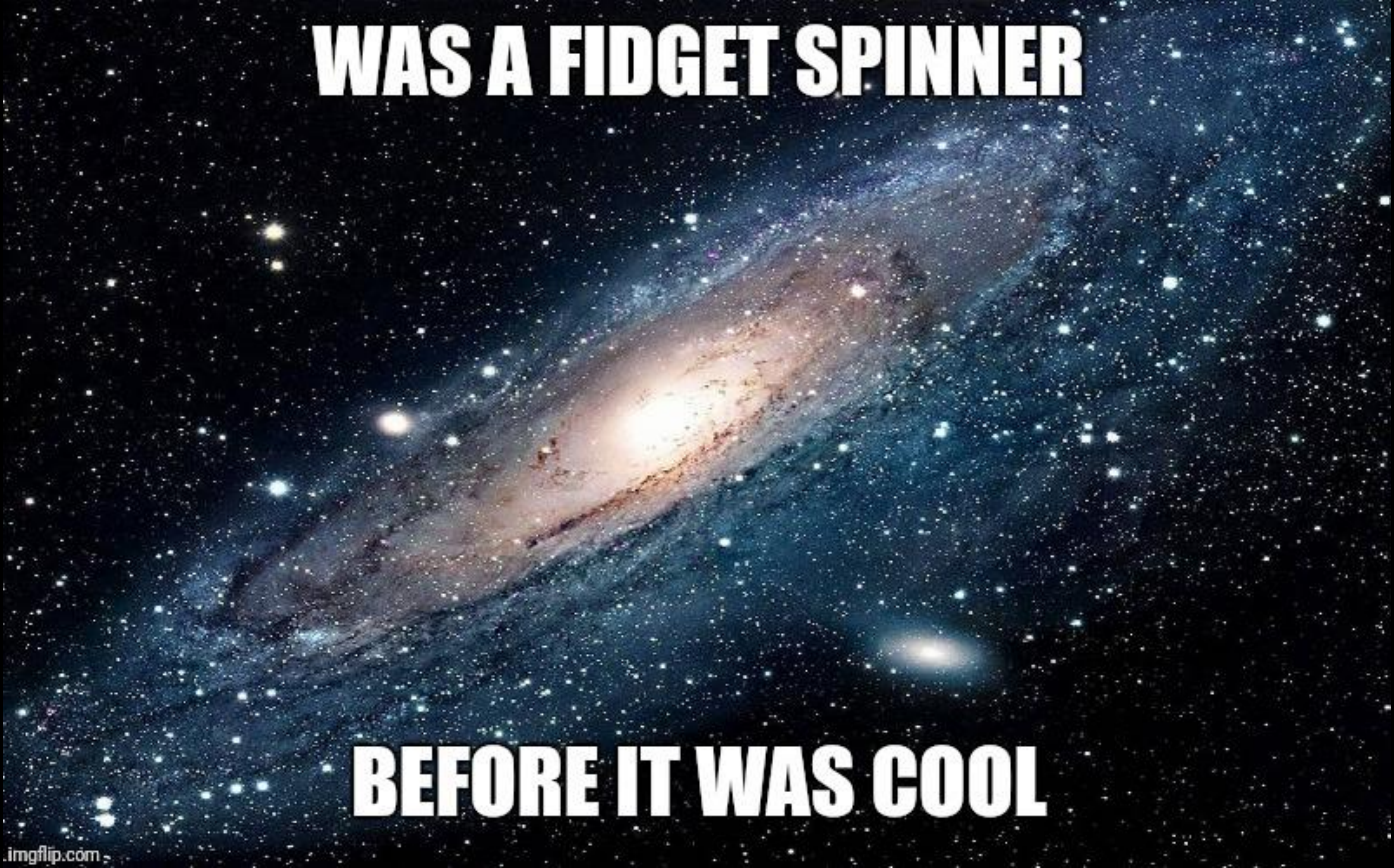


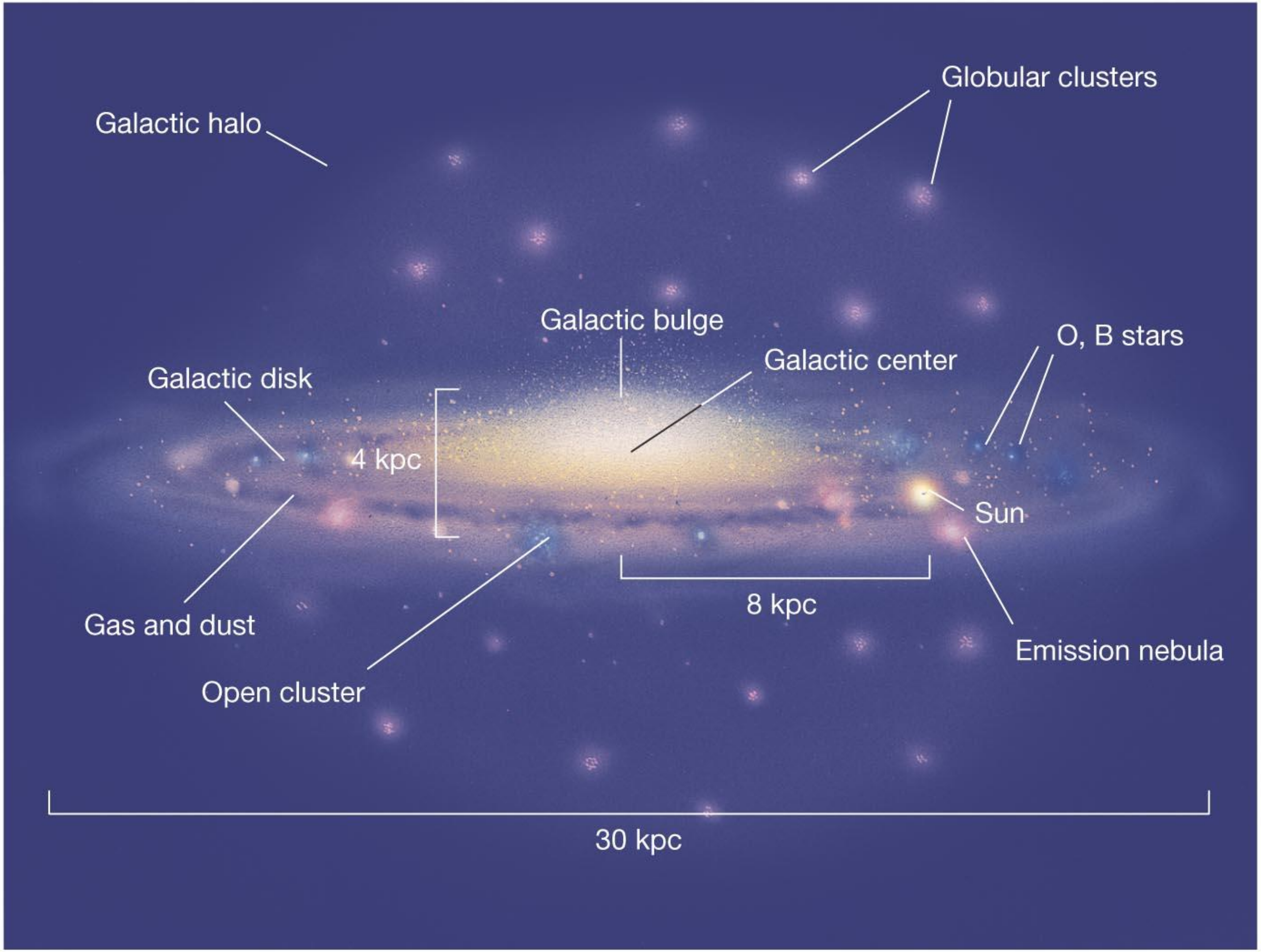
Schema Hubble – Vaucouleurs

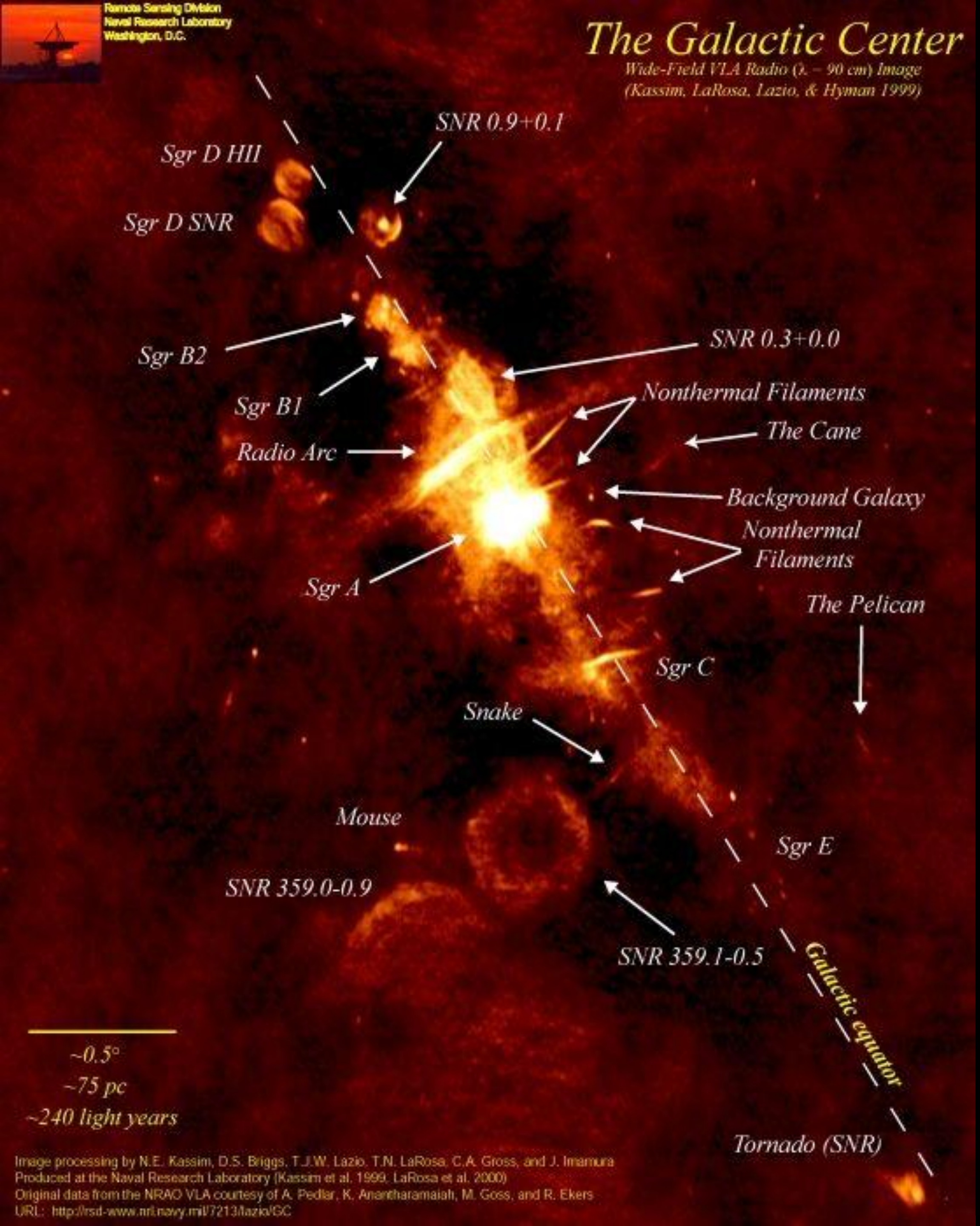


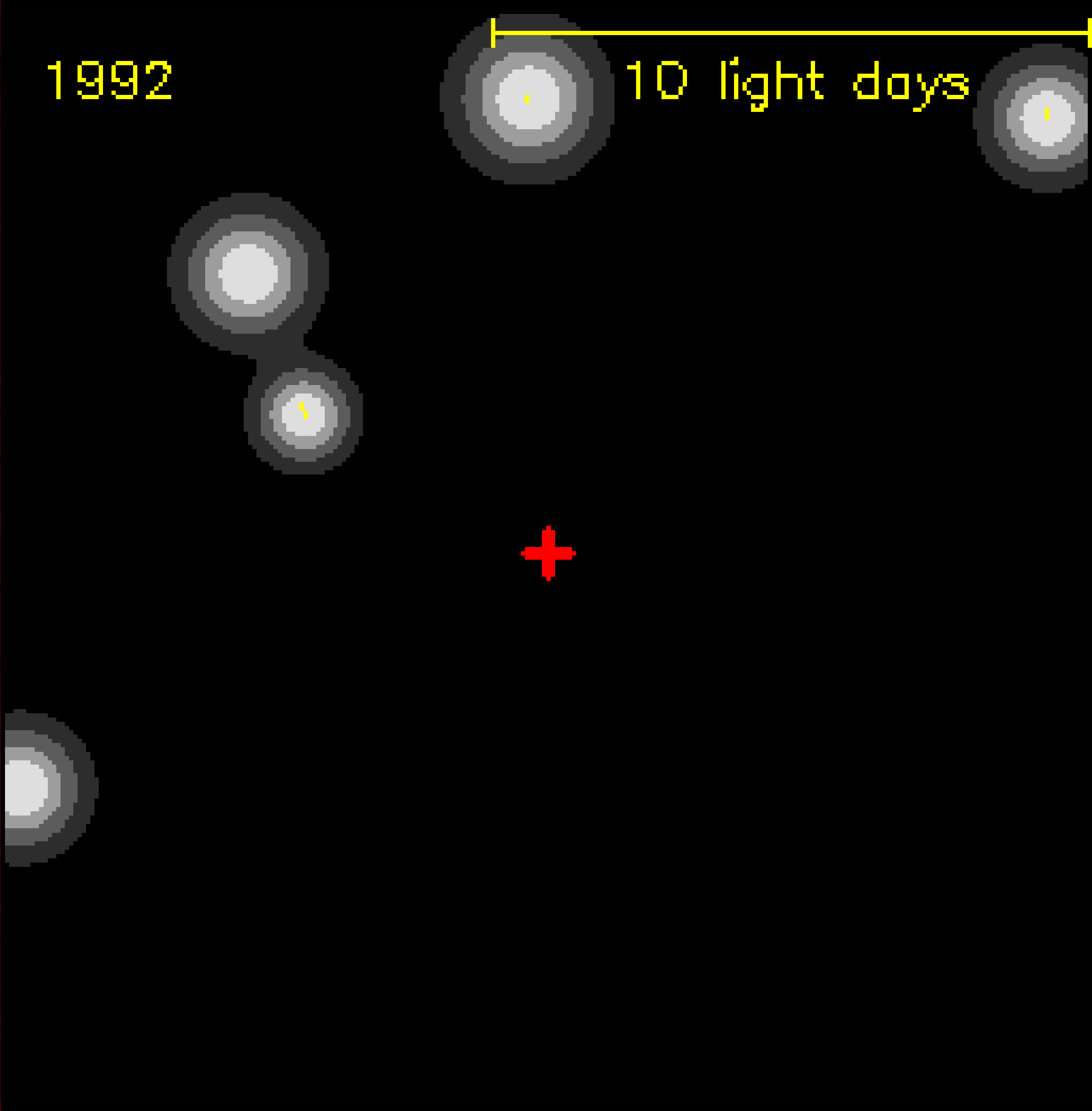
Radio
Microwave
Infrared
UV
X-Ray
Gamma Ray
Radio
60,000 nm
600 K
Infrared
1200-800 nm (10-3.6 um)
4,500 K
Optical
450-750 nm
6,000 K
Ultraviolet
400-200 nm
10,000 K
X-ray
100-10 nm
10,000,000 K
Multiwavelength Whirlpool Galaxy
COLD GAS: Radio waves reveal regions of gas cool enough for CO_2 molecules to exist.
COOL STARS: Infrared shows smaller cool red stars that make up most of the galaxy.
SOLAR STARS: Optical light comes from stars around the size of the Sun.
HOT STARS: Ultraviolet shows the larger hot blue stars that are less frequent in galaxies.
HOT GAS: X-rays are emitted from the hottest regions of gas where atoms are ionized.
COOL LOW ENERGY RADIATION
VISIBLE LIGHT
HOT HIGH ENERGY RADIATION




WAS A FIDGET SPINNER
BEFORE IT WAS COOL
imgflip.com


Globular clusters
Galactic halo
Galactic bulge
O, B stars
Galactic center
Galactic disk
4 kpc
Sun
Gas and dust
8 kpc
Emission nebula
Open cluster
30 kpc

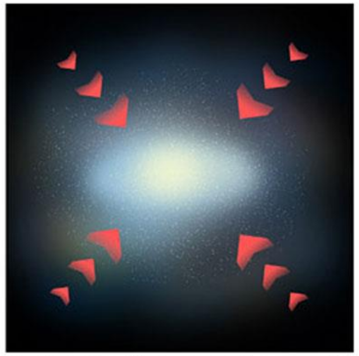

Remote Sensing Division
Naval Research Laboratory
Washington, D.C.
The Galactic Center
Wide-Field VLA Radio (λ ~ 90 cm) Image
(Kassim, LaRosa, Lazio, & Hyman 1999)
SNR 0.9+0.1
Sgr D HII
Sgr D SNR
Sgr B2
SNR 0.3+0.0
Sgr B1
Nonthermal Filaments
The Cane
Radio Arc
Background Galaxy
Nonthermal
Filaments
Sgr A
The Pelican
Sgr C
Snake
Mouse
Sgr E
SNR 359.0-0.9
SNR 359.1-0.5
Galactic equator
~0.5°
~75 pc
~240 light years
Tornado (SNR)
Image processing by N.E. Kassim, D.S. Briggs, T.J.W. Lazio, T.N. LaRosa, C.A. Gross, and J. Imamura
Produced at the Naval Research Laboratory (Kassim et al. 1999, LaRosa et al. 2000)
Original data from the NRAO VLA courtesy of A. Pedlar, K. Anantharamaiah, M. Goss, and R. Ekers
URL: http://rsd-www.nrl.navy.mil/7213/lazio/GC


1992
10 light days

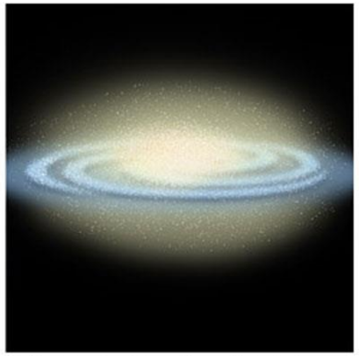
The Growth of Bulges in Spiral Galaxies
Three evolutionary scenarios

Rapid Collapse

1. Primordial hydrogen cloud.

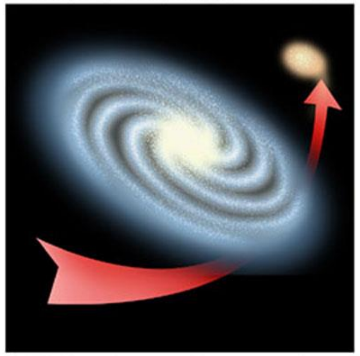


2. Cloud collapses under gravity.

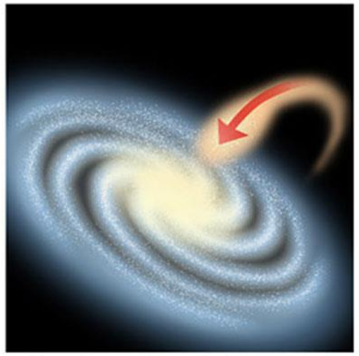


3. Large bulge of ancient stars dominates galaxy.

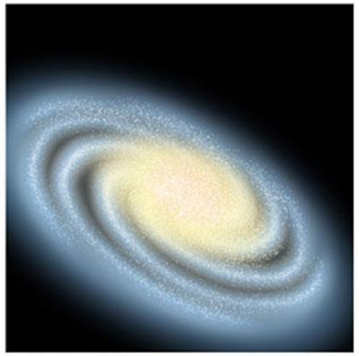
Environmental Effects



1. Disk galaxy and companion.

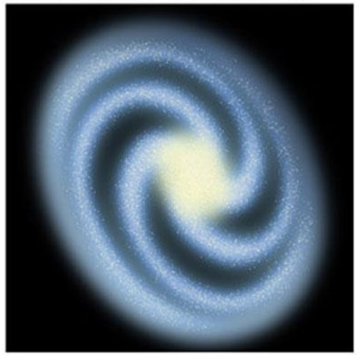


2. Smaller galaxy falls into disk galaxy.

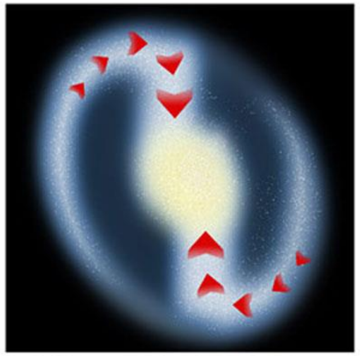


3. Bulge inflates with addition of young stars and gas.

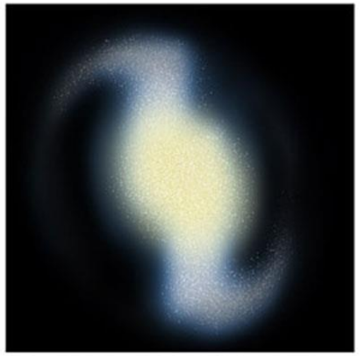
Internal Evolution



1. Disk galaxy forms around small bulge.

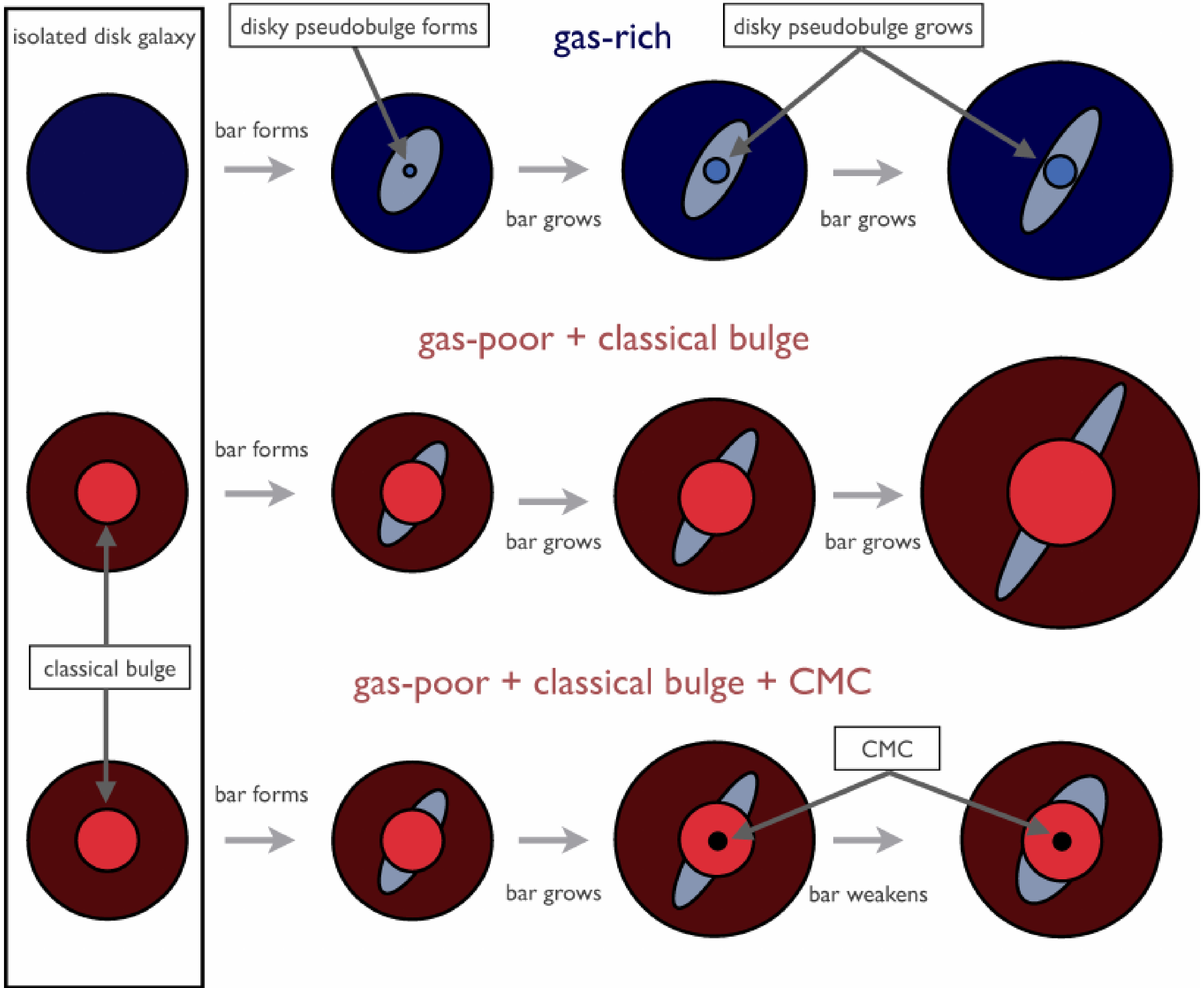


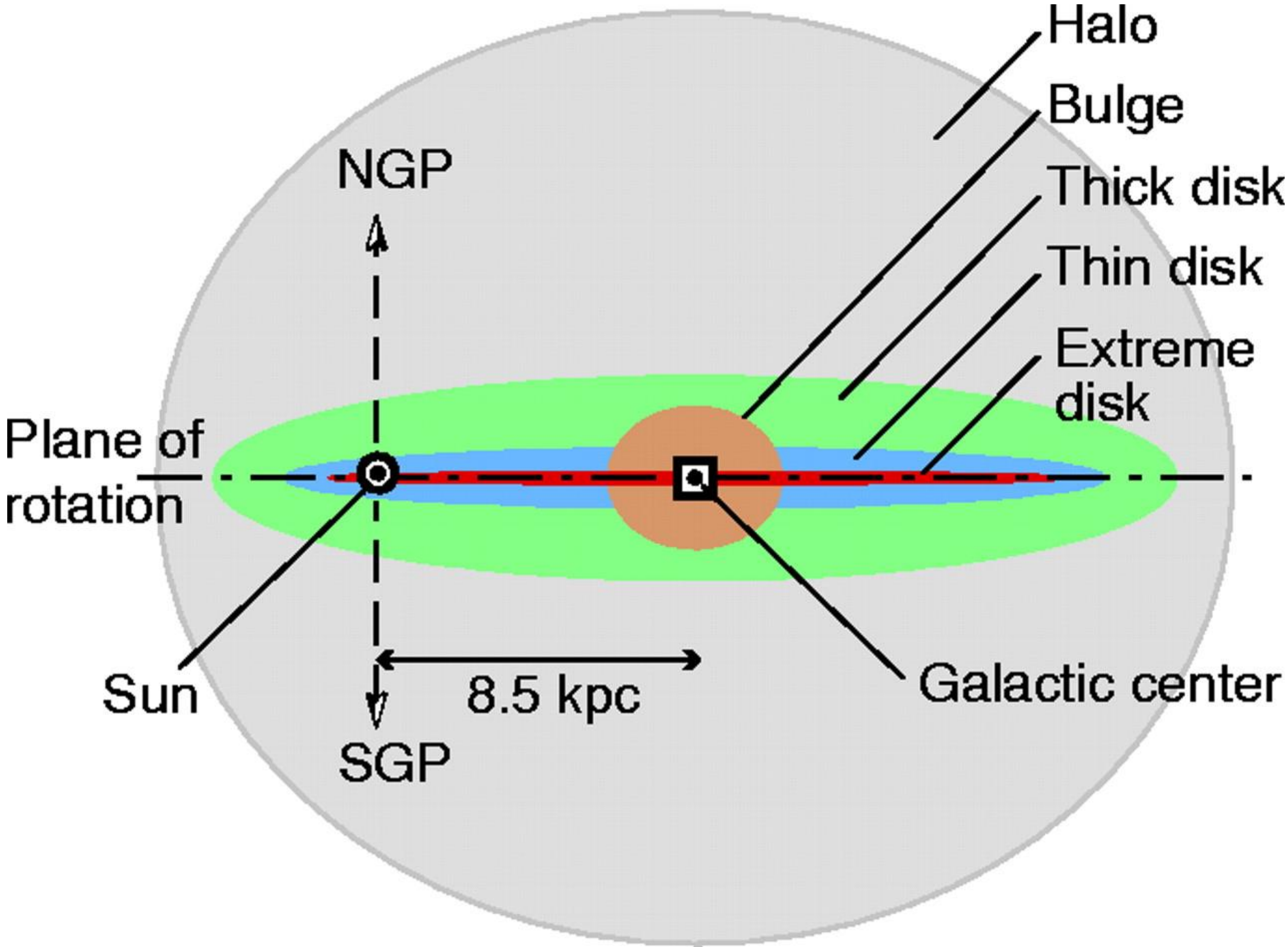
2. Disk perturbations form a bar-like structure which shovels fresh gas into the center.

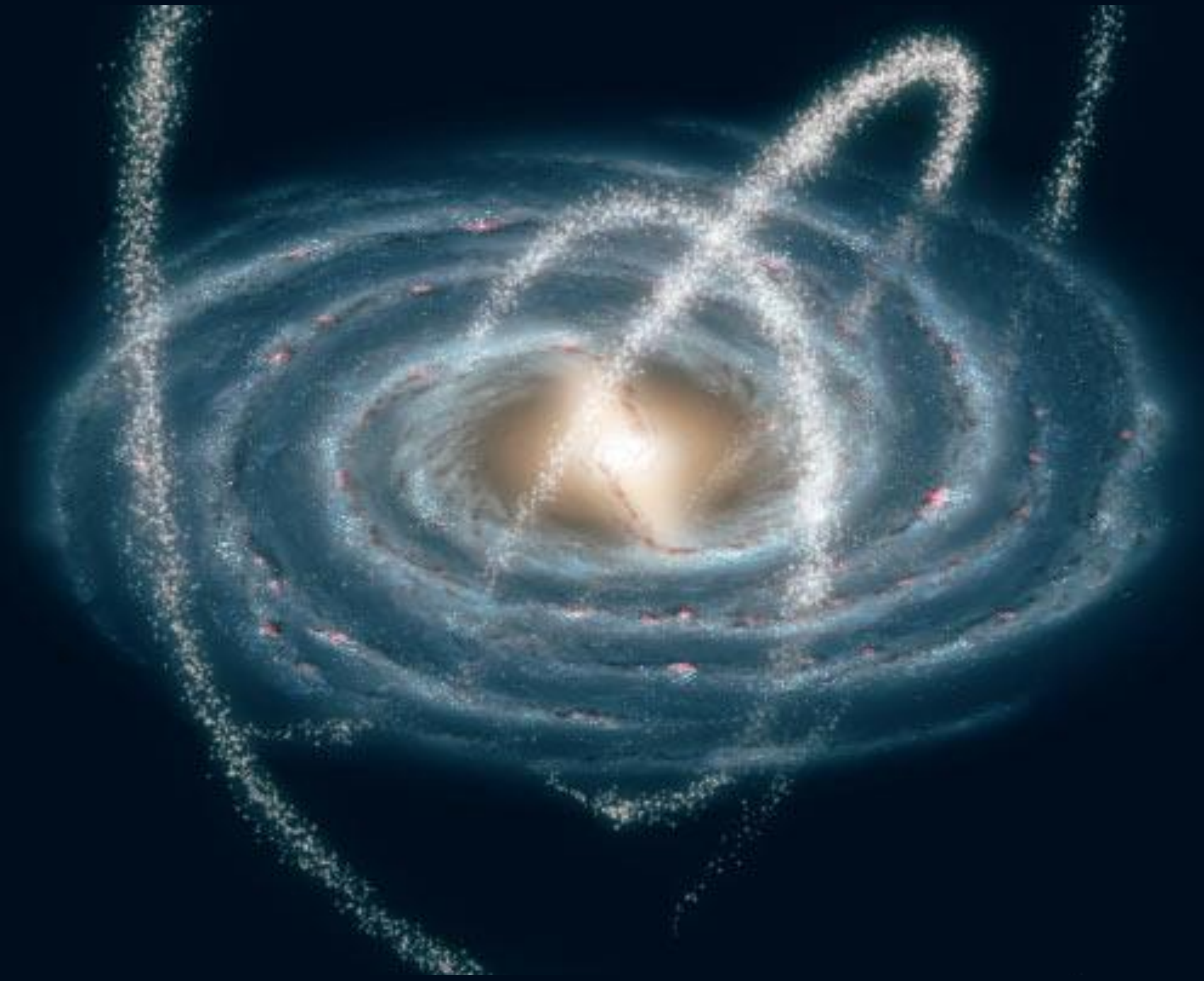


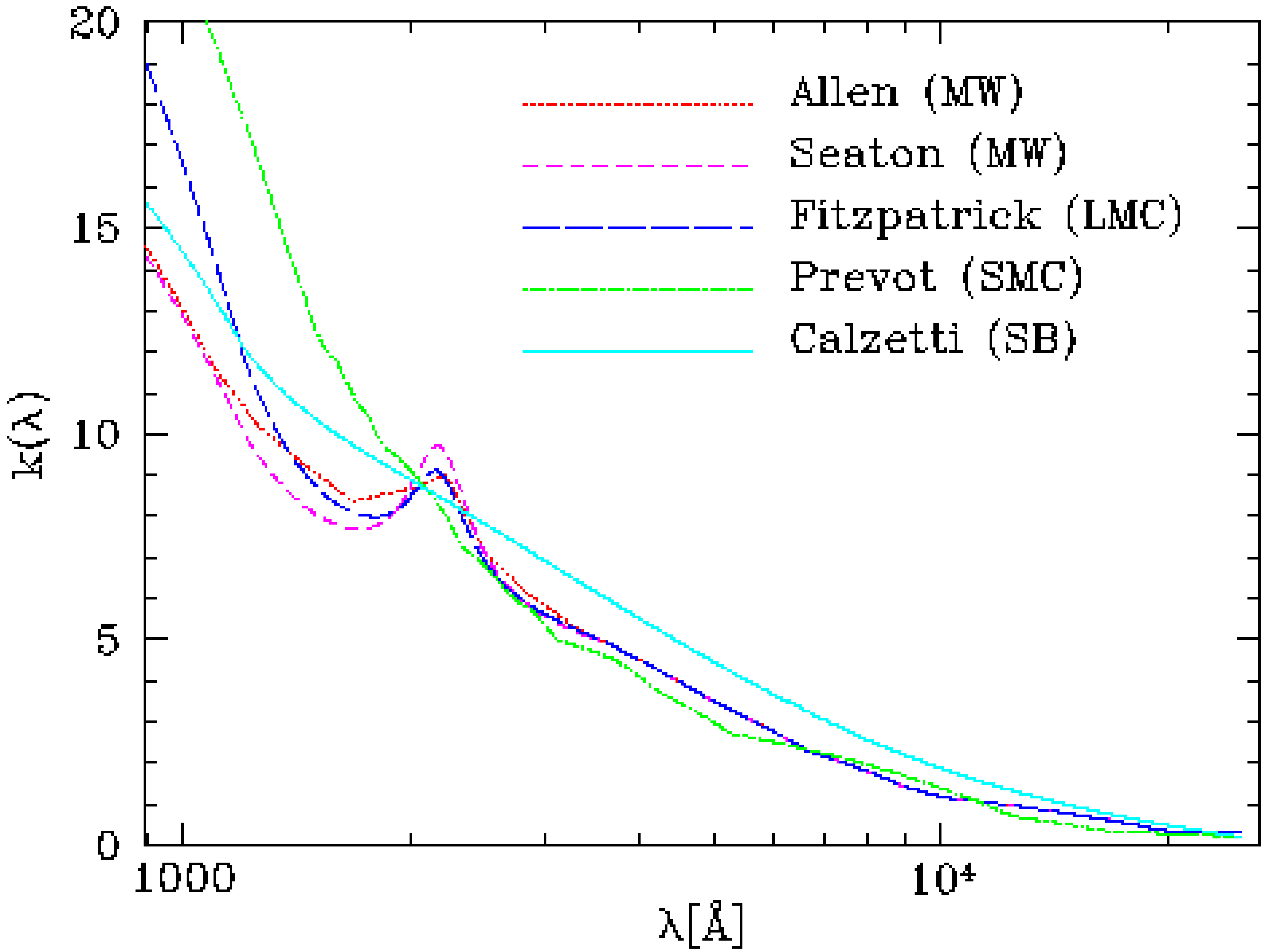
3. As bulge grows with new stars the bar is disrupted and dissipates.


Schematic of
Bar Formation and Evolution

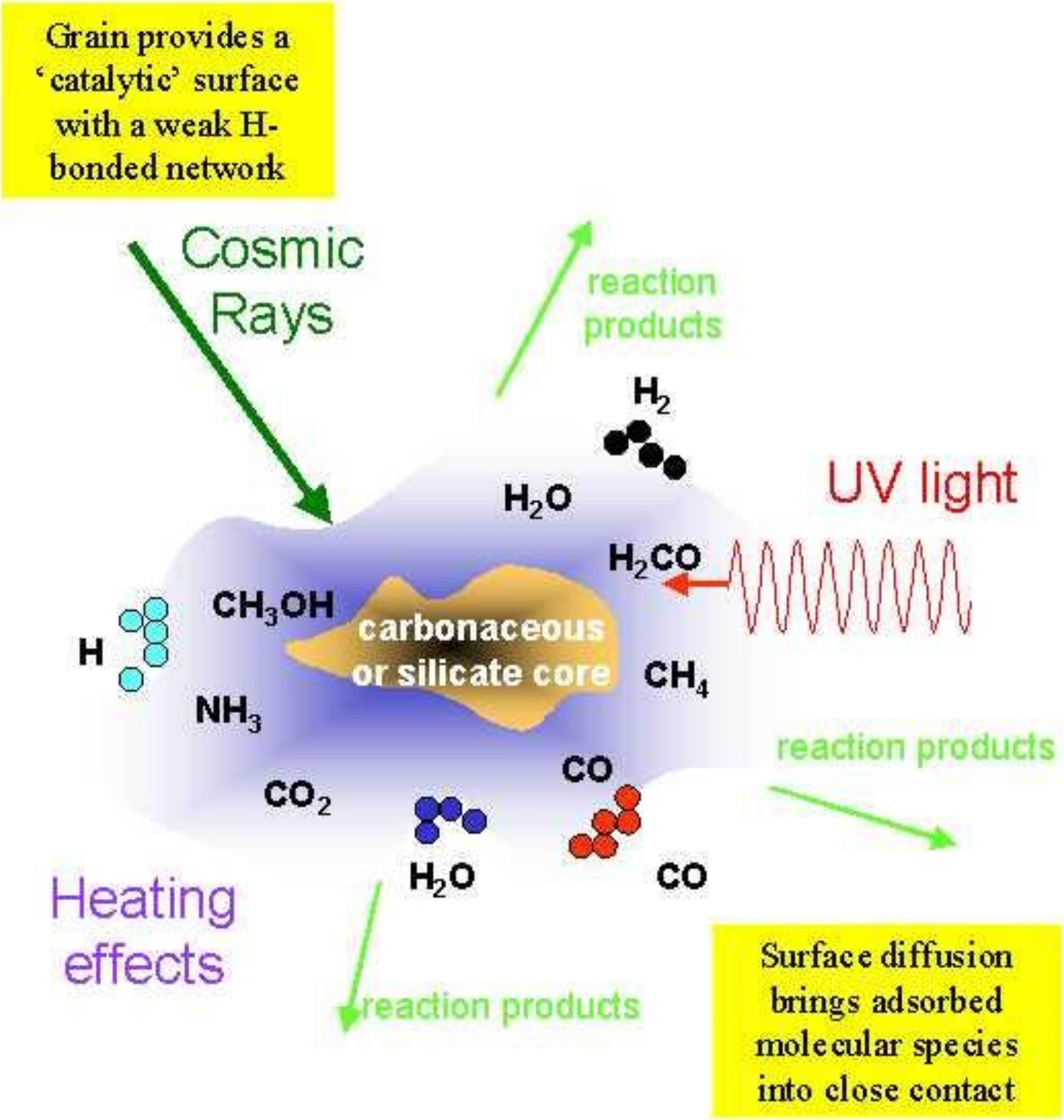



Halo
Bulge
Thick disk
Thin disk
Extreme disk
NGP
Plane of rotation
Sun
8.5 kpc
SGP
Galactic center

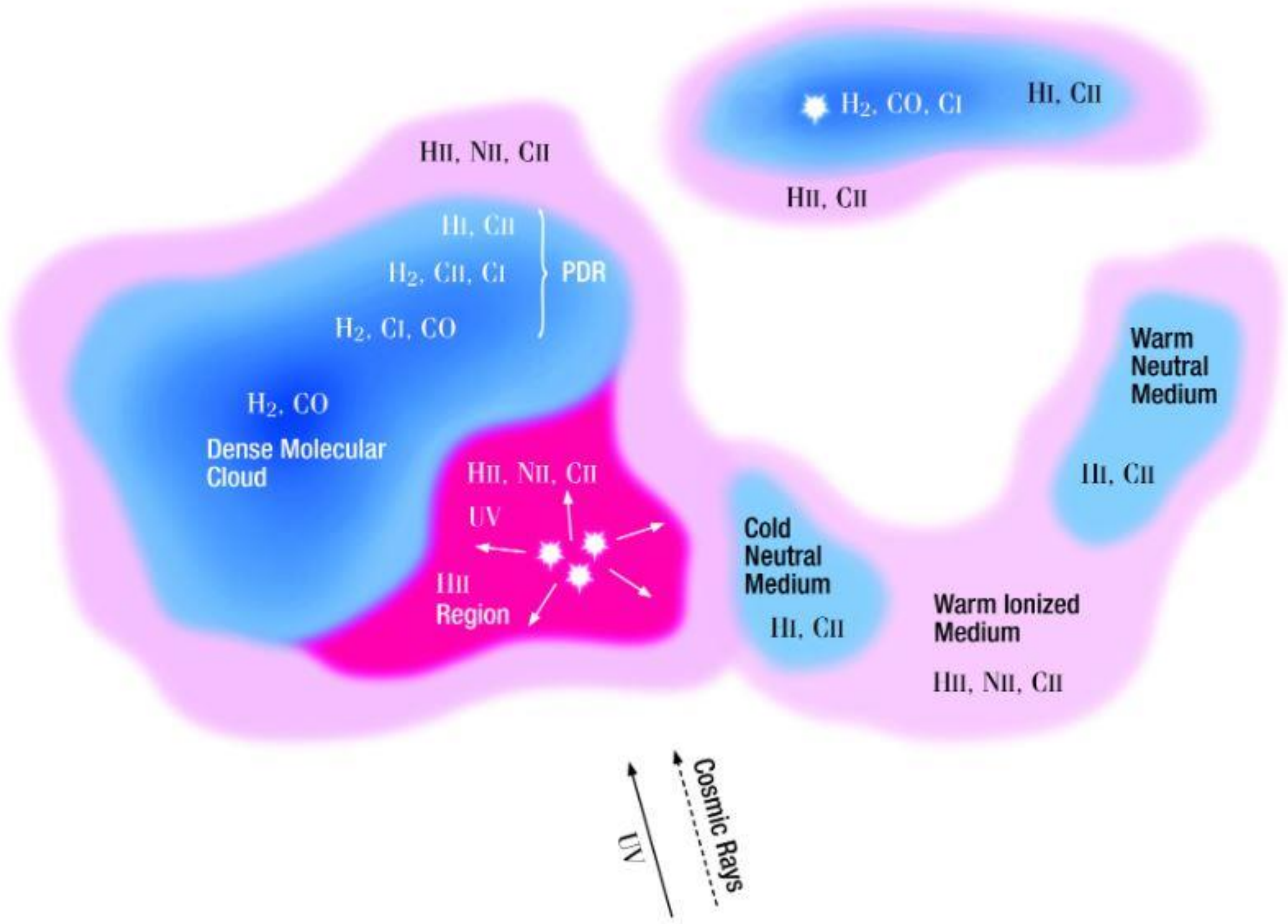




Allen (MW)
Seaton (MW)
Fitzpatrick (LMC)
Prevot (SMC)
Calzetti (SB)
20
15
10
5
0
k(λ)
1000
10⁴
λ[Å]

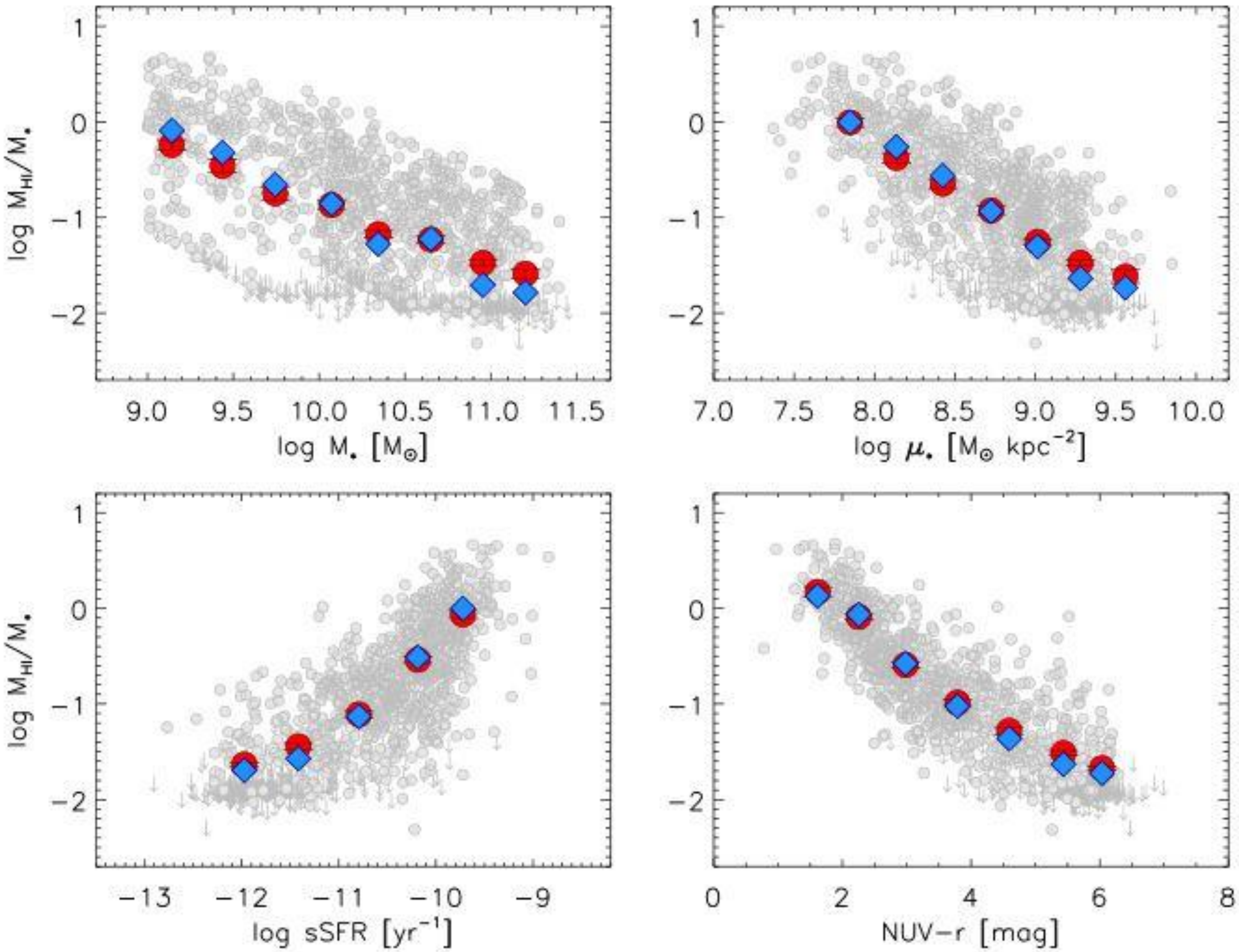


Grain provides a 'catalytic' surface with a weak H-bonded network
Cosmic Rays
reaction products
H_2
UV light
H_2O
H_2CO
CH_3OH
carbonaceous or silicate core
H
CH_4
NH_3
reaction products
CO
CO_2
H_2O
CO
Heating effects
reaction products
Surface diffusion brings adsorbed molecular species into close contact

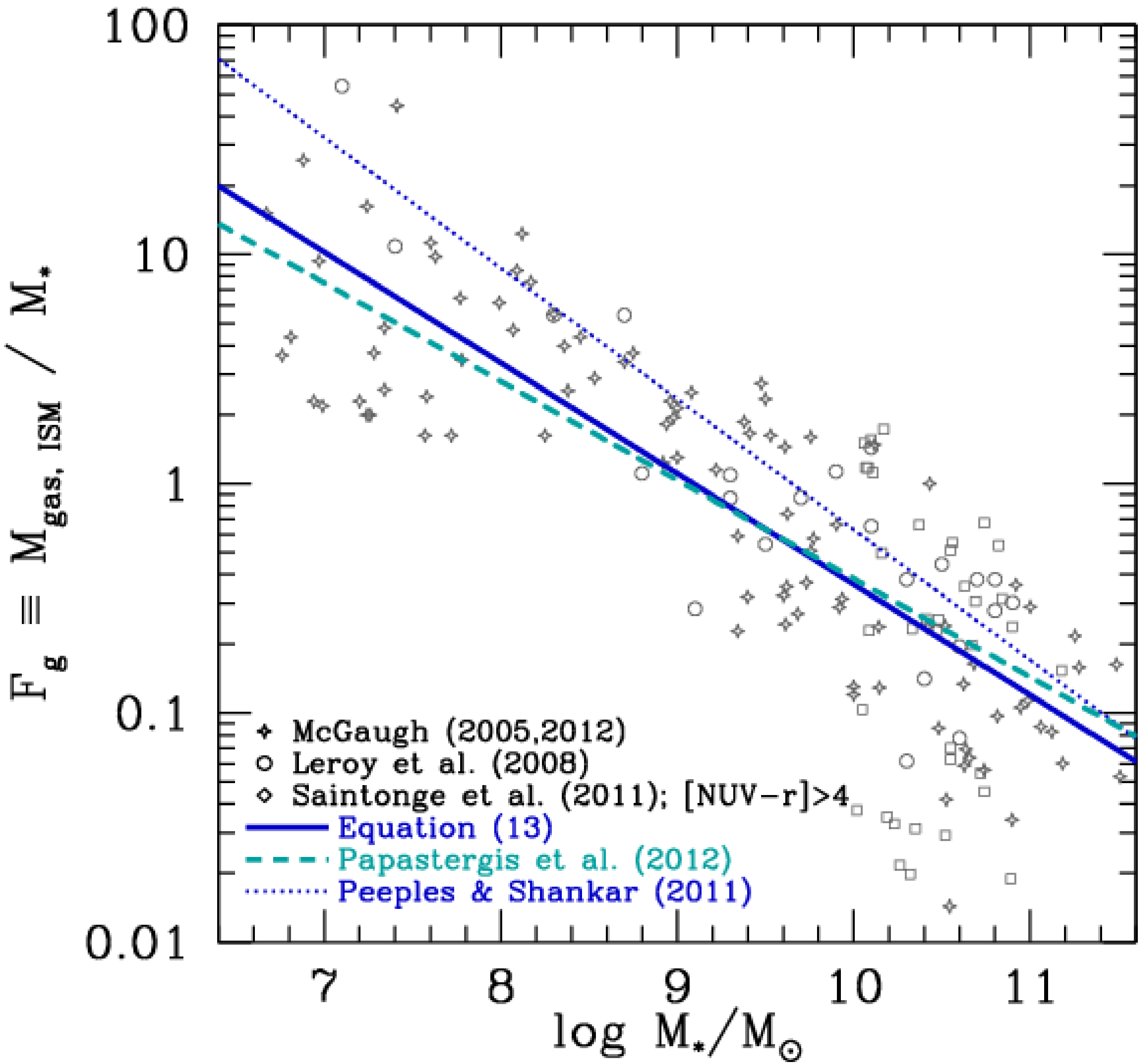


$$P(r) = \frac{\rho(r) K_B T(r)}{m}$$

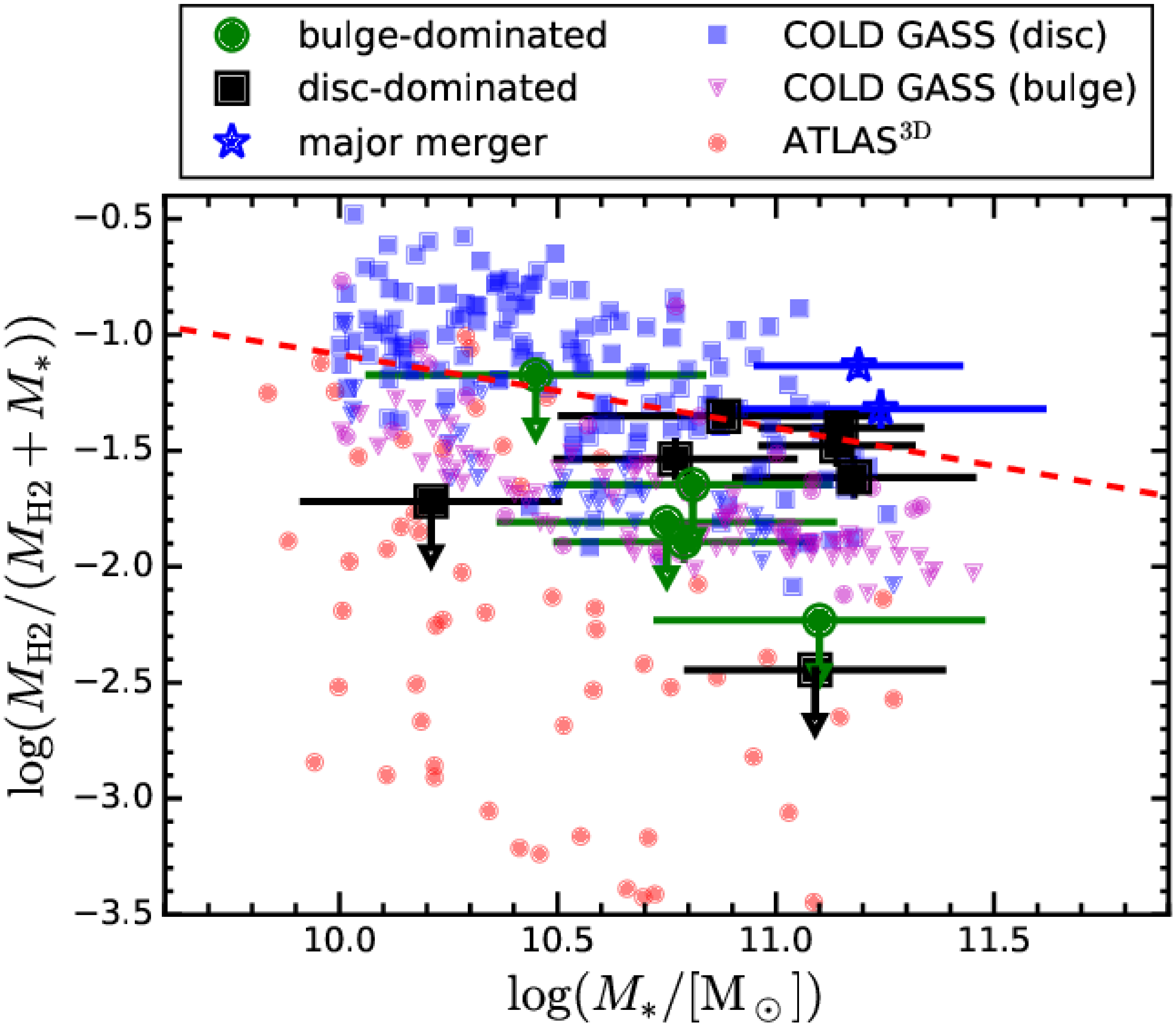
Astronomical Name	Density (cm^{-3})	Temperature (K)	β	filling factor
Molecular Cloud	$200 - \geq 10^5$	≤ 100	9×10^{-8}	0.050 %
Cold Neutral Medium (CNM)	10 - 100	~ 100	...	1 %
HII regions	5 - 10	8000	15 - 30	3×10^{-3} %
Warm Neutral Medium (WNM)	0.1 - 0.5	8000	...	30 %
Warm Ionized Medium (WIM)	0.1 - 0.5	8000	0.29	25 %
Very Local Medium (VLISM)	0.11	6700	0.27	6 - 19 %
Coronal (HIM)	5×10^{-3}	10^6	1.8	50 %



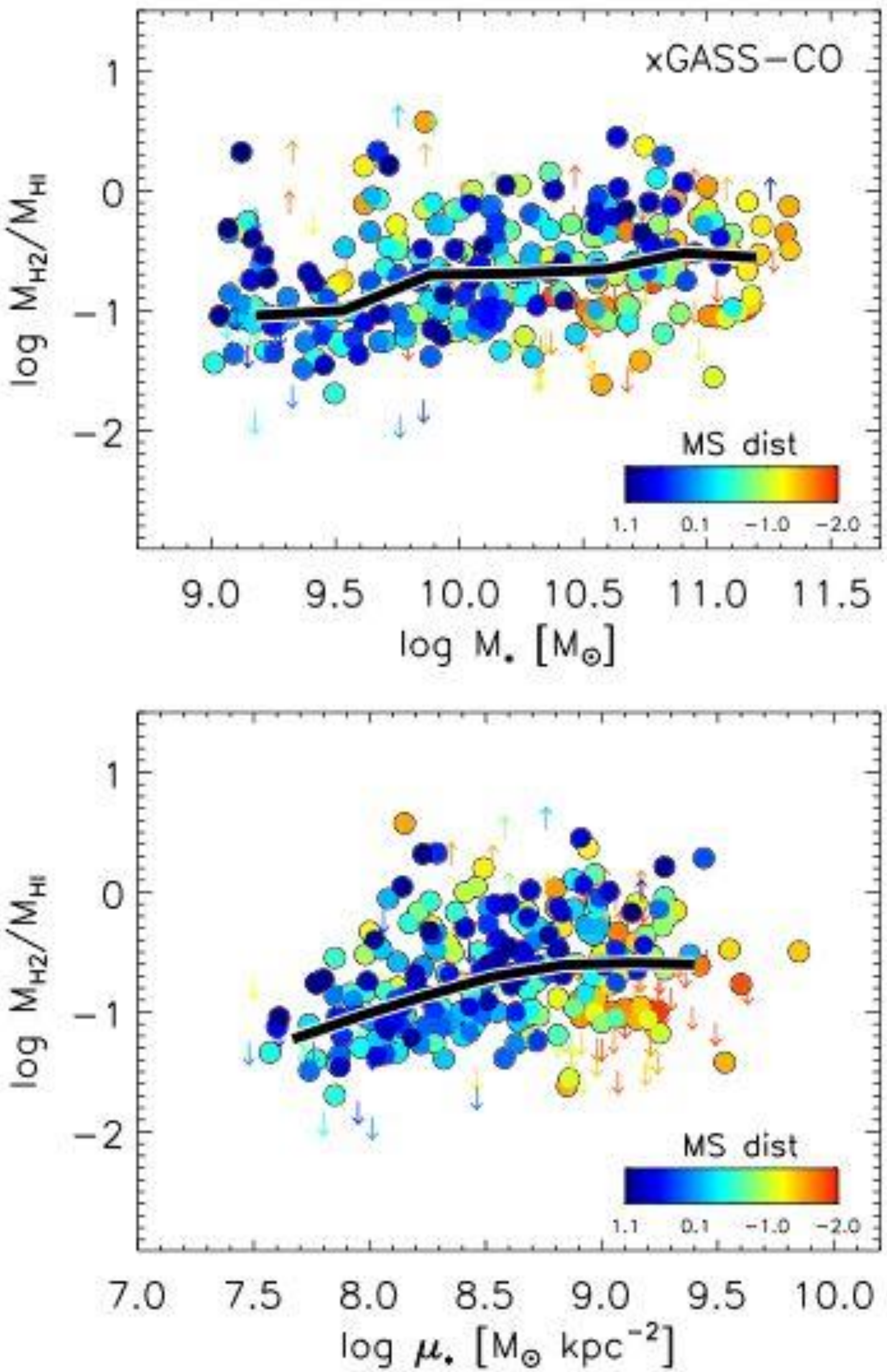
1
0
−1
−2
9.0
9.5
10.0
10.5
11.0
11.5
log M_{HI}/M_*
log M_* [$M_\odot$]
7.0
7.5
8.0
8.5
9.0
9.5
10.0
log μ_* [$M_\odot$ kpc^{-2}]
−13
−12
−11
−10
−9
log sSFR [yr^{-1}]
0
2
4
6
8
NUV−r [mag]



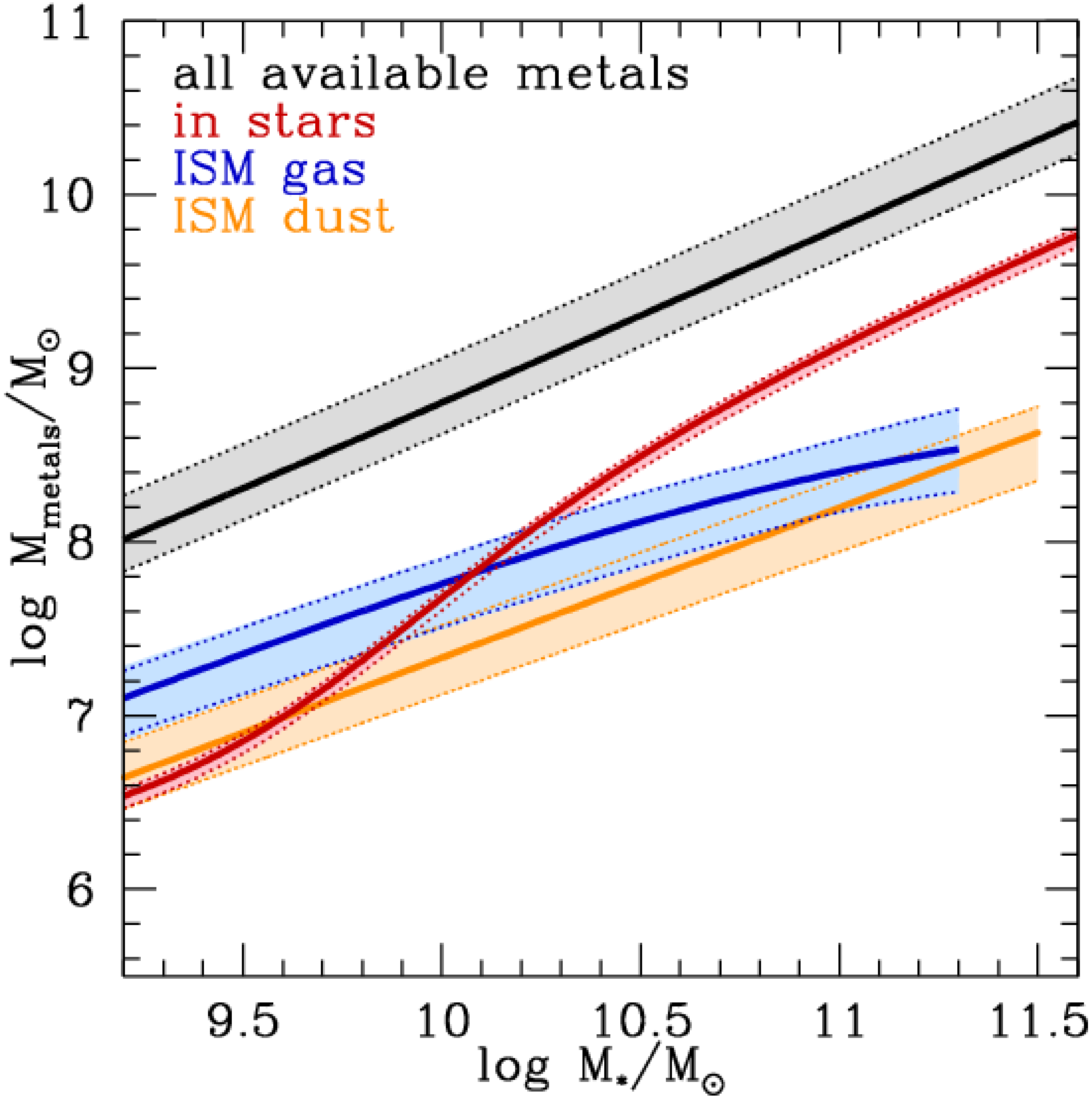
100
10
1
0.1
0.01
7
8
9
10
11
log M*/M⊙
F g ≡ M gas, ISM / M*
McGaugh (2005,2012)
Leroy et al. (2008)
Saintonge et al. (2011); [NUV-r]>4
Equation (13)
Papastergis et al. (2012)
Peeples & Shankar (2011)



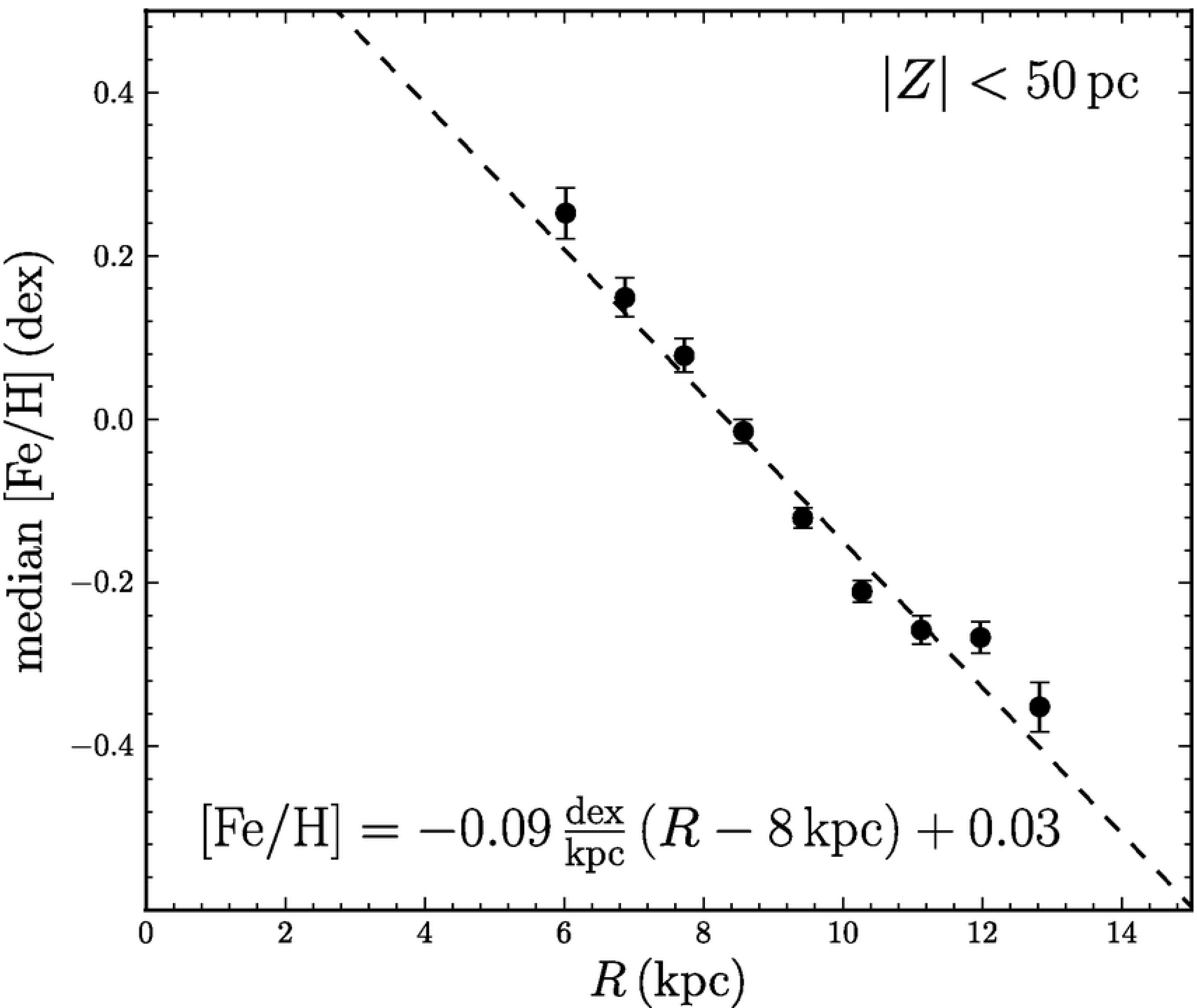
bulge-dominated
disc-dominated
major merger
COLD GASS (disc)
COLD GASS (bulge)
ATLAS^{3D}
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
10.0
10.5
11.0
11.5
$\log(M_{\mathrm{H2}}/(M_{\mathrm{H2}}+M_*))$
$\log(M_*/[\mathrm{M}_\odot])$

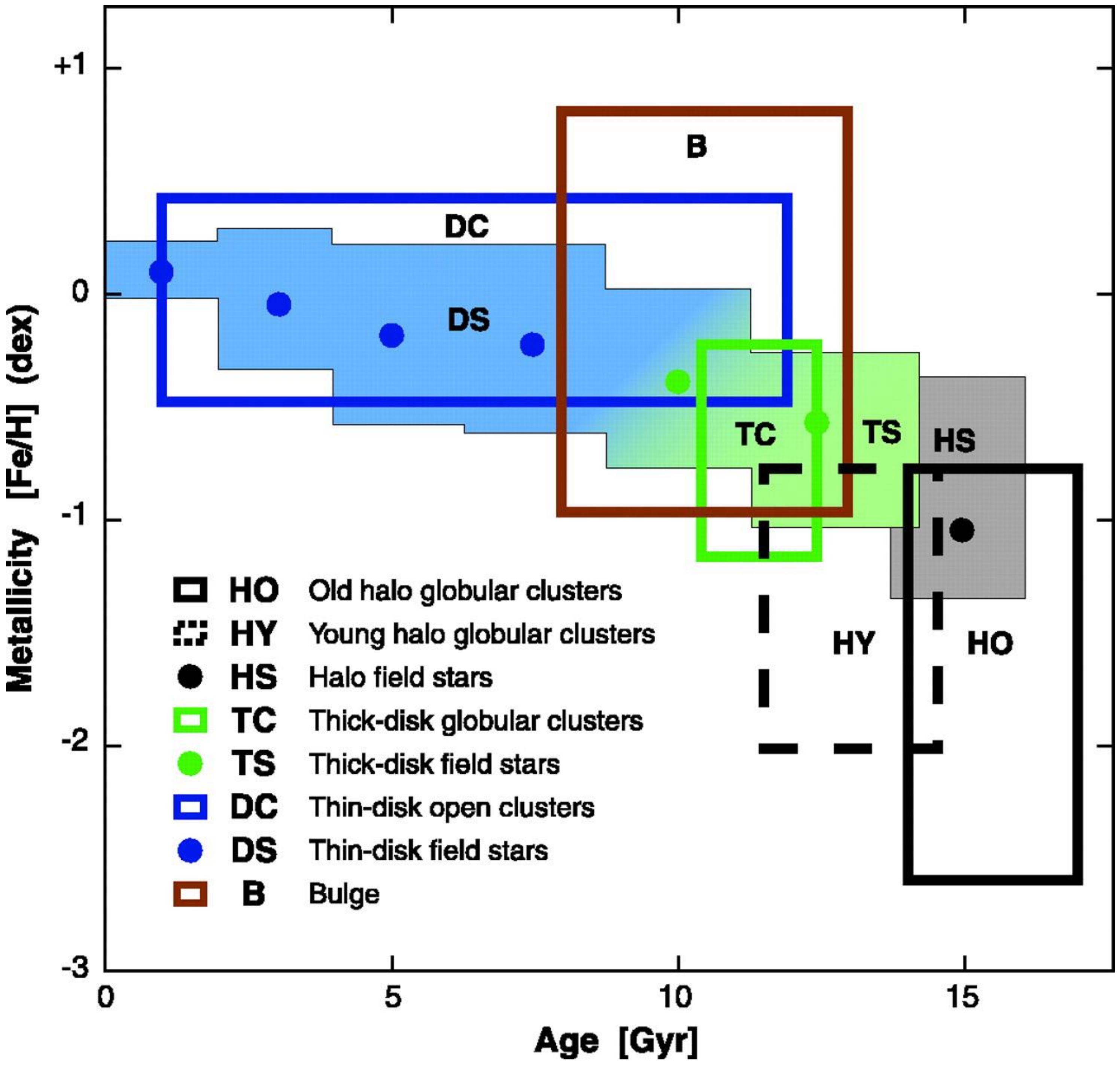


xGASS-CO
log M_{H2}/M_{HI}
log M_* [$M_\odot$]
MS dist
1.1
0.1
−1.0
−2.0
log μ_* [$M_\odot$ kpc^{-2}]



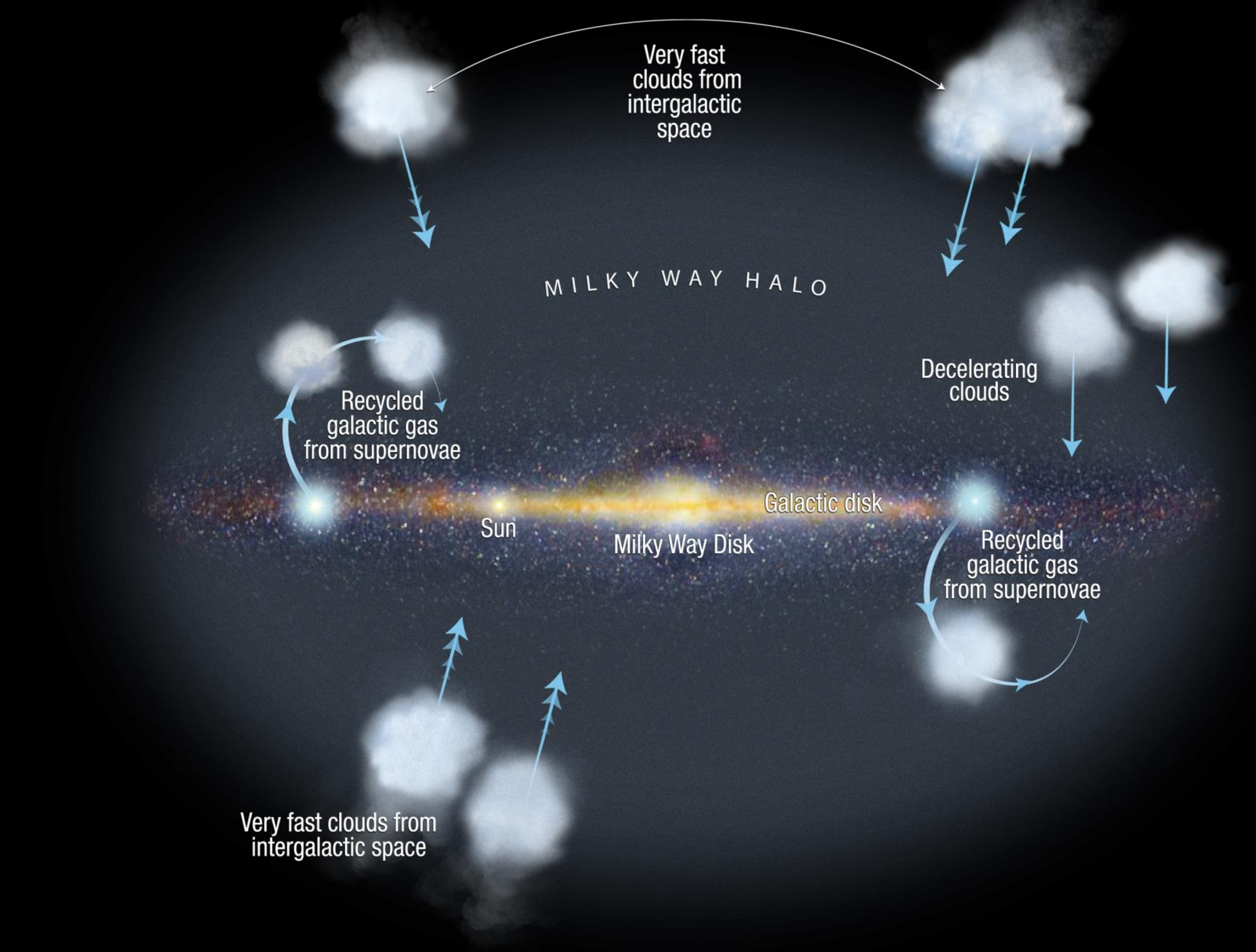
all available metals
in stars
ISM gas
ISM dust
11
10
9
8
7
6
9.5
10
10.5
11
11.5
log $M_{metals}/M_{\odot}$
log $M_{*}/M_{\odot}$

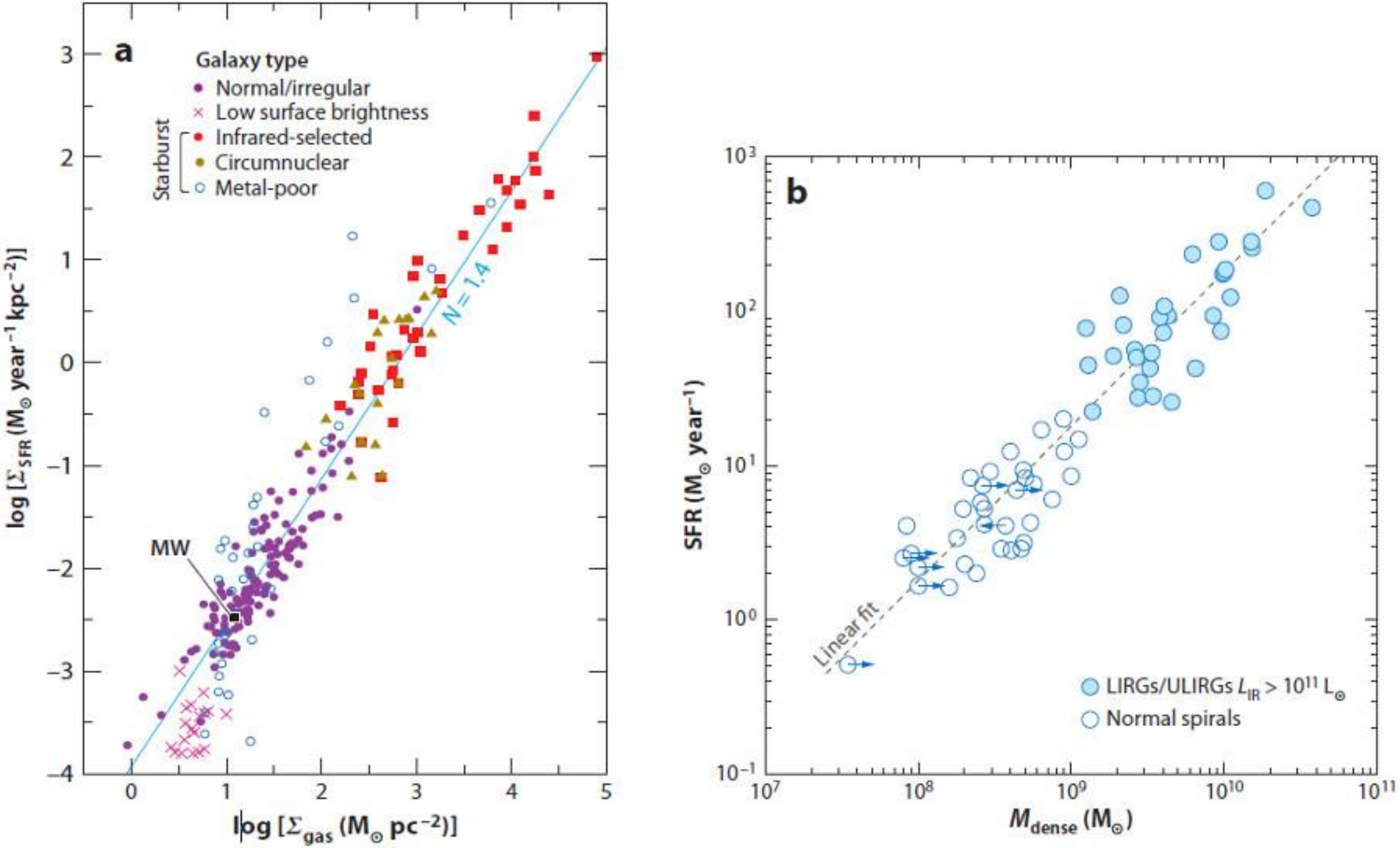

$|Z| < 50\,\mathrm{pc}$
$[\mathrm{Fe/H}] = -0.09\,\frac{\mathrm{dex}}{\mathrm{kpc}}\,(R - 8\,\mathrm{kpc}) + 0.03$
median [Fe/H] (dex)
R (kpc)
0.4
0.2
0.0
−0.2
−0.4
0
2
4
6
8
10
12
14

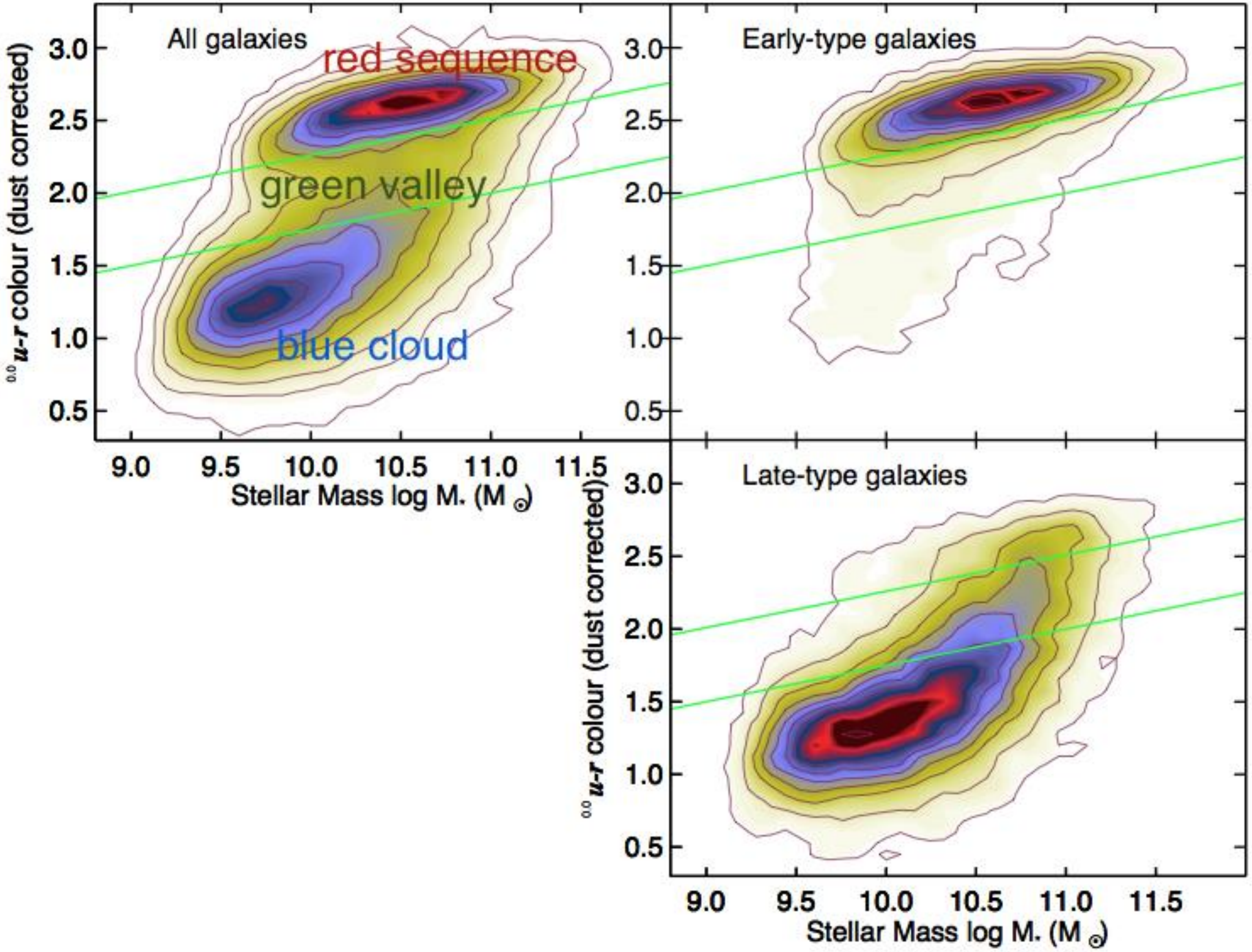


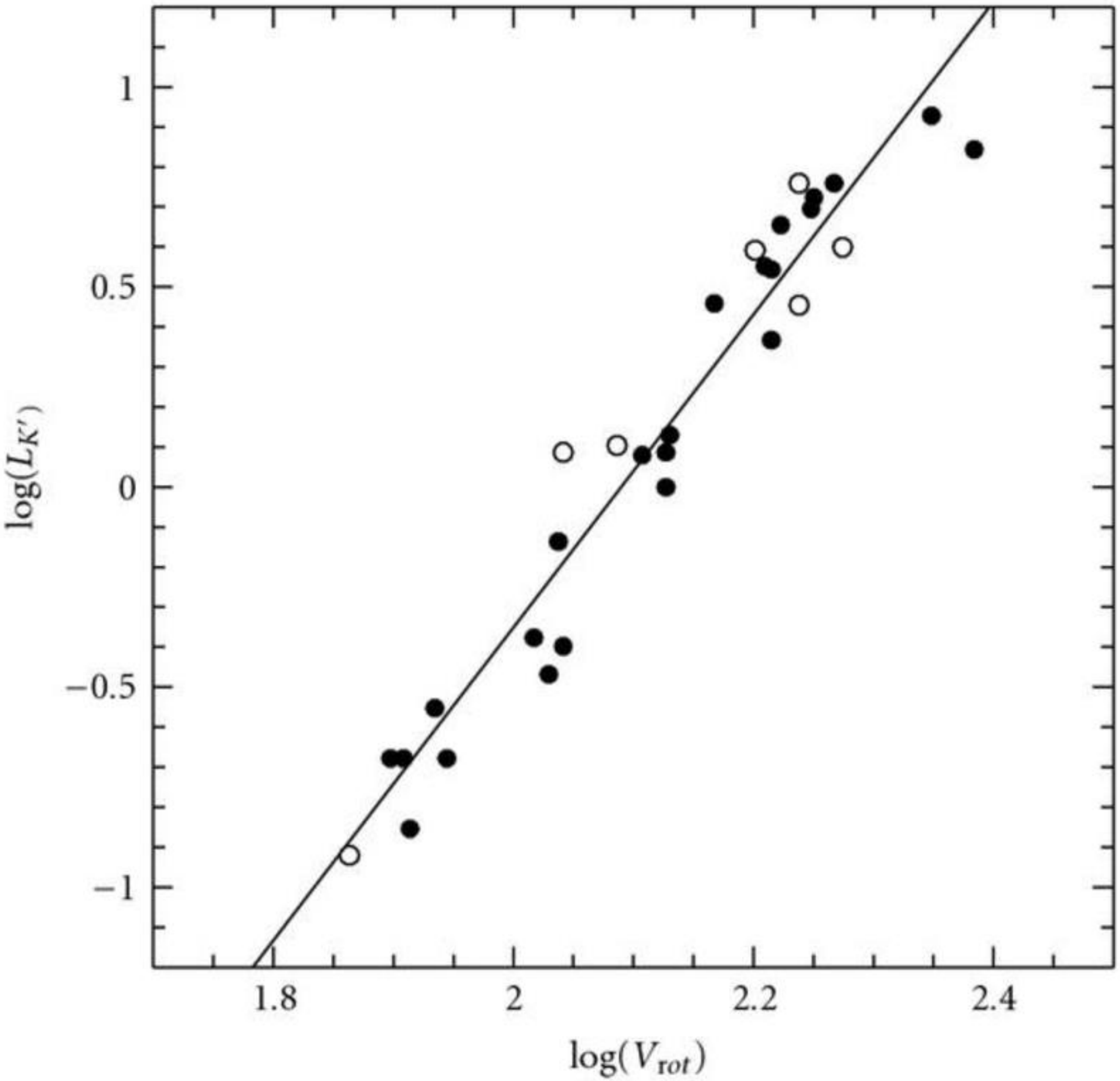
+1
0
-1
-2
-3
0
5
10
15
Age [Gyr]
Metallicity [Fe/H] (dex)
B
DC
DS
TC
TS
HS
HY
HO
HO Old halo globular clusters
HY Young halo globular clusters
HS Halo field stars
TC Thick-disk globular clusters
TS Thick-disk field stars
DC Thin-disk open clusters
DS Thin-disk field stars
B Bulge

Large-scale flows in Milky Way halo




a
Galaxy type
Normal/irregular
Low surface brightness
Starburst
Infrared-selected
Circumnuclear
Metal-poor
N = 1.4
MW
log [Σ_SFR (M⊙ year⁻¹ kpc⁻²)]
log [Σ_gas (M⊙ pc⁻²)]
b
Linear fit
LIRGs/ULIRGs L_IR > 10¹¹ L⊙
Normal spirals
SFR (M⊙ year⁻¹)
M_dense (M⊙)


All galaxies
red sequence
green valley
blue cloud
Early-type galaxies
Late-type galaxies
$^{0.0}$u-r colour (dust corrected)
Stellar Mass log M$_*$ (M$_\odot$)
3.0
2.5
2.0
1.5
1.0
0.5
9.0
9.5
10.0
10.5
11.0
11.5

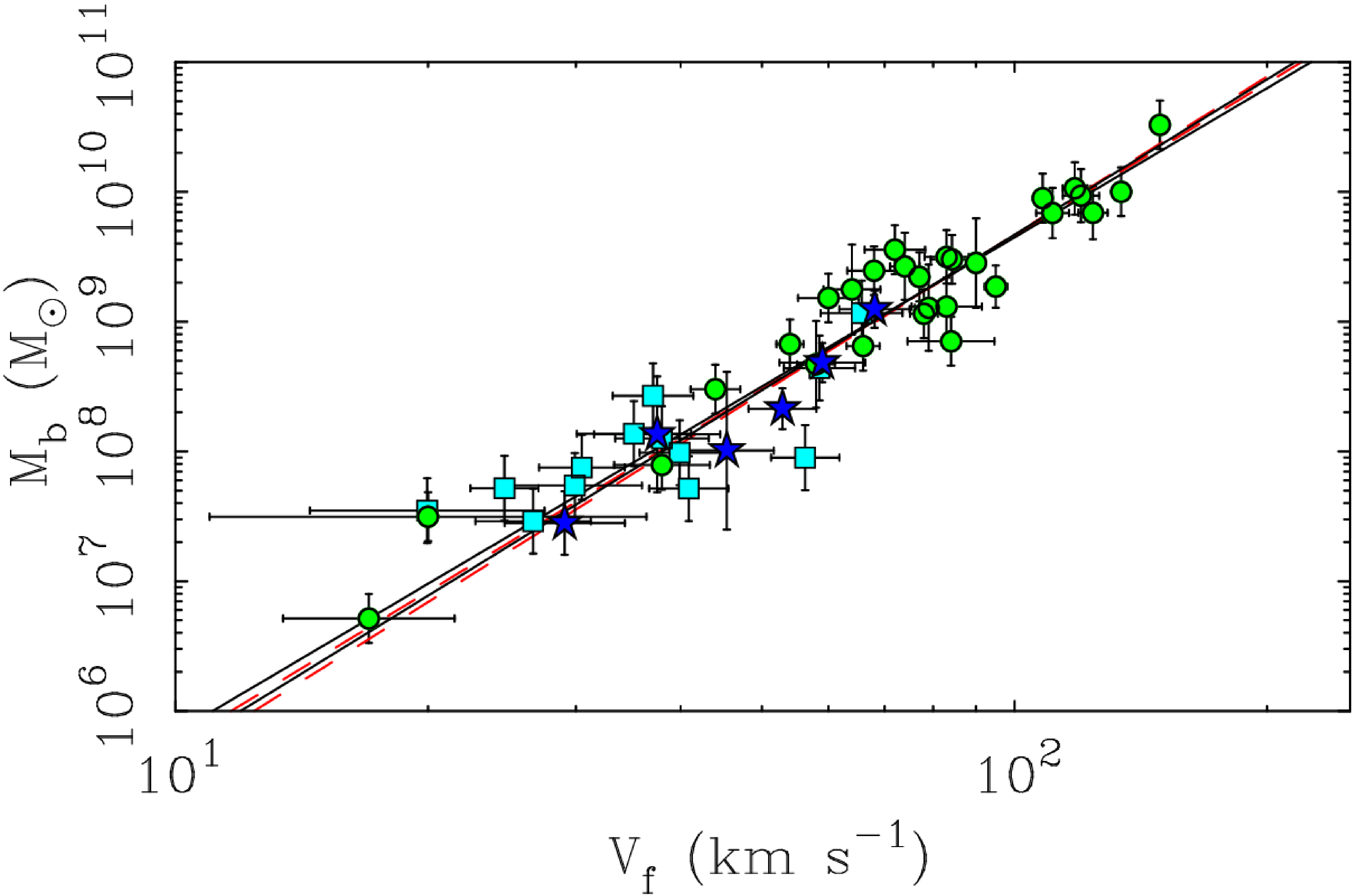


1
0.5
0
−0.5
−1
$\log(L_{K'})$
1.8
2
2.2
2.4
$\log(V_{rot})$

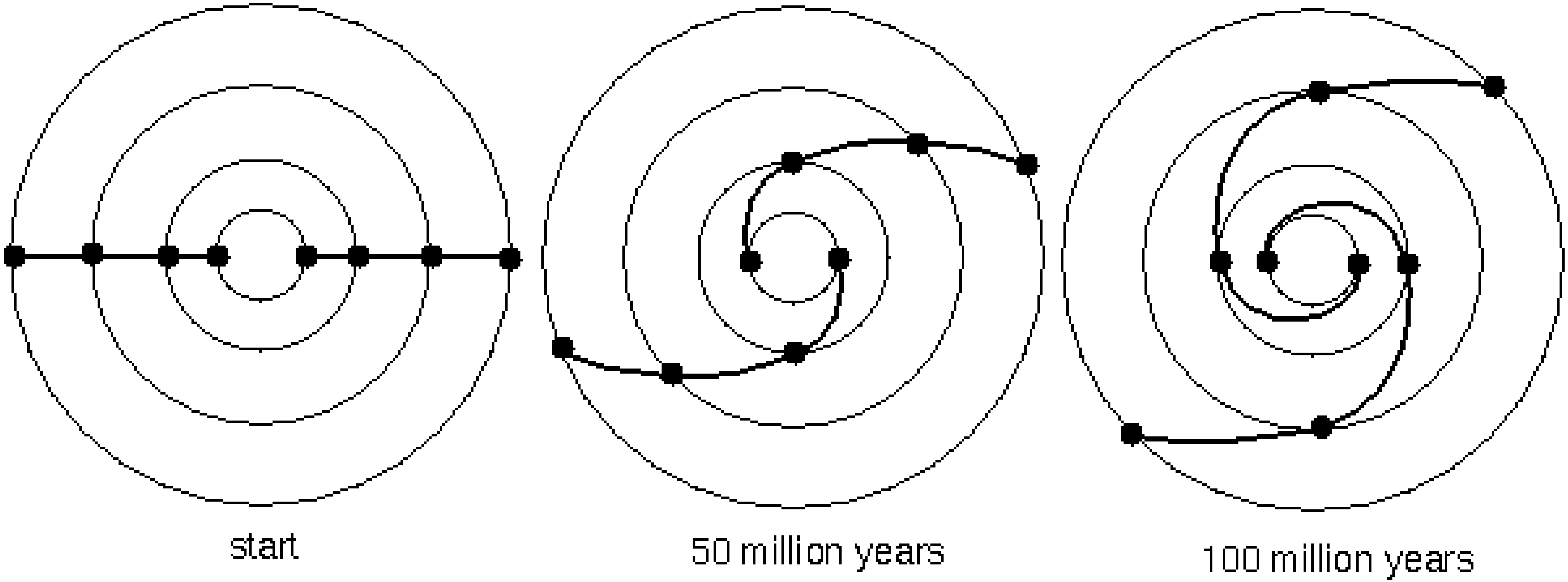
$$\text{Assunzioni:}\begin{cases}\dfrac{M}{L}=\dfrac{M_*}{L}\left(1+\dfrac{M_{\text{oscura}}}{M_*}\right)\approx \text{costante}\\ \mu_0(\text{banda B})\approx 21.7\,\dfrac{\text{mag}}{\text{arcsec}^2}\end{cases}\Rightarrow \boxed{L=kv_{\max}^4}$$

$$\begin{cases}v_{\max}^2\propto\dfrac{M}{R},\ \text{si bilanciano forza centrifuga e gravitazionale}\\ \mu_0\propto\dfrac{L}{R^2},\ \text{per definizione}\end{cases}$$

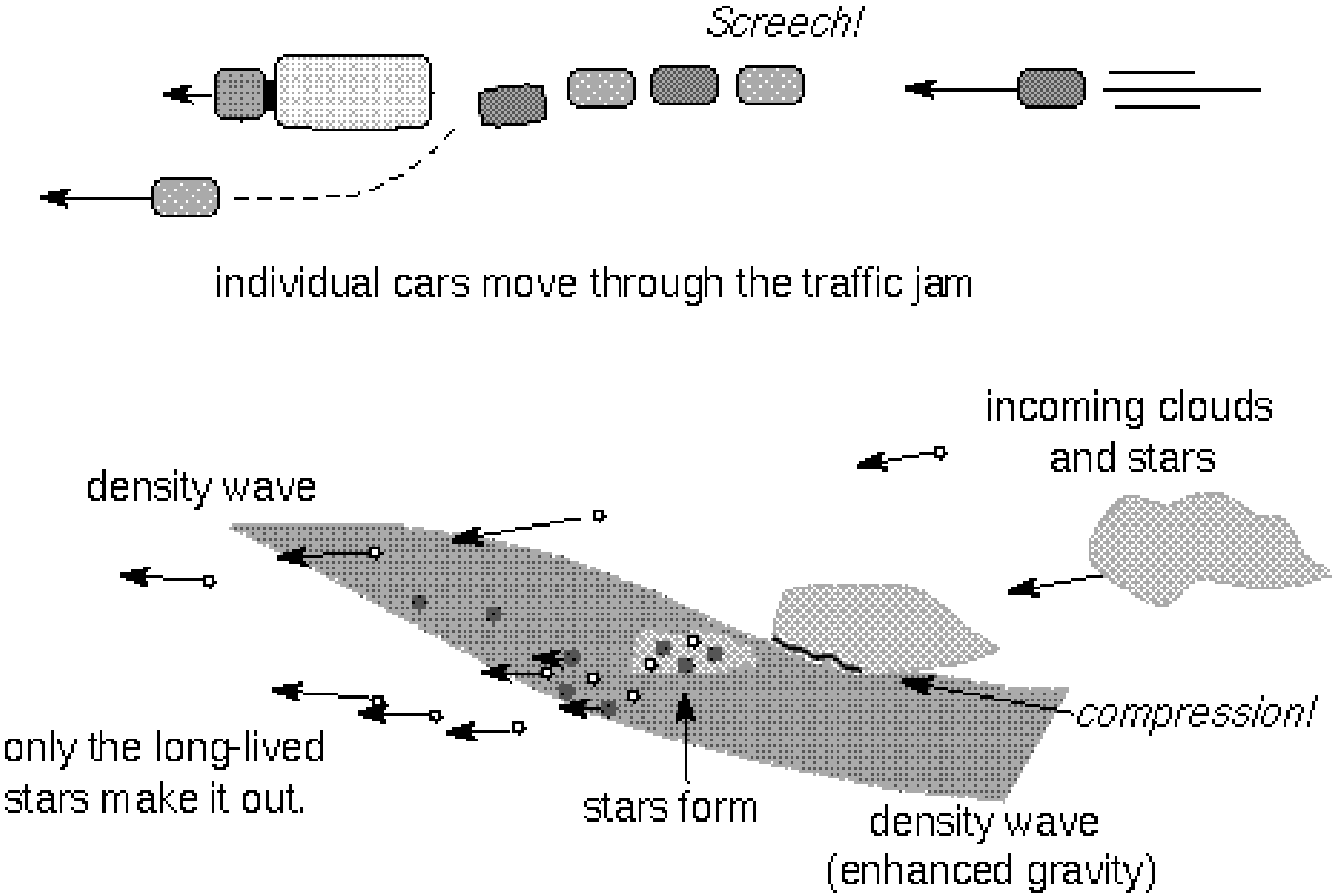
$$\left(v_{\max}^2\right)^2\propto\left(\frac{M}{R}\right)^2\propto\frac{M^2}{L}\mu_0\propto\left(\frac{M}{L}\right)^2\mu_0 L\propto L$$



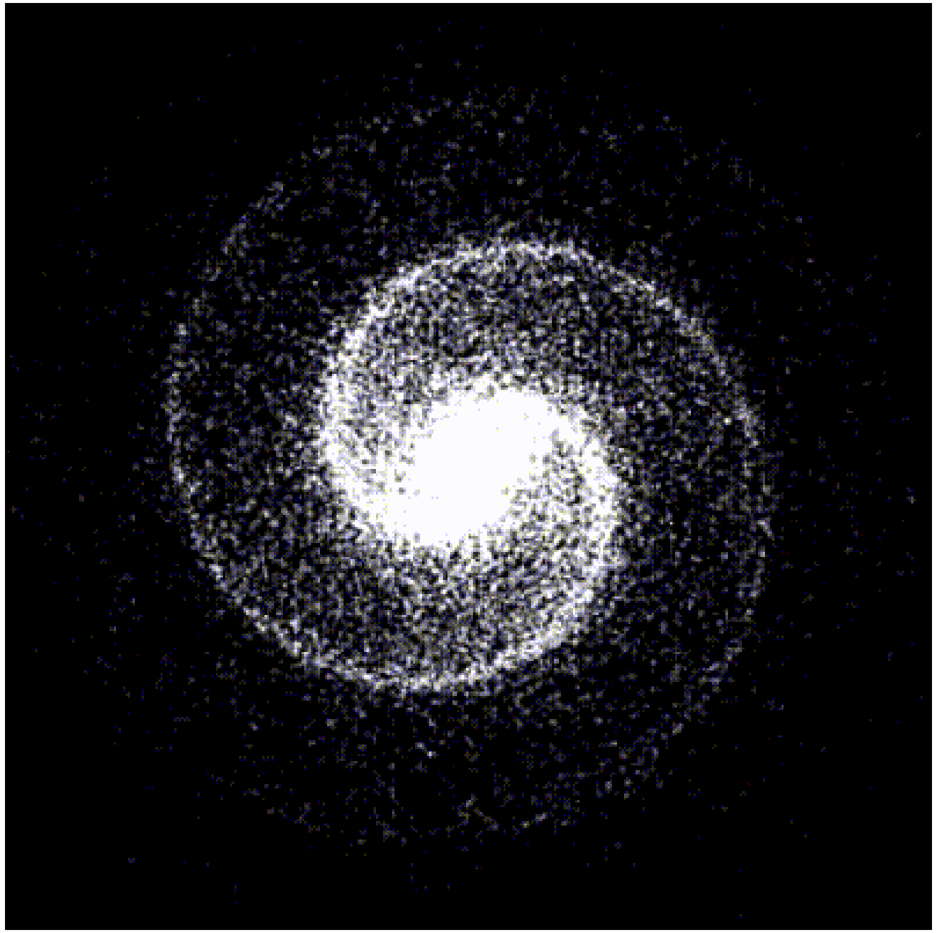
M_b ($M_\odot$)
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^1
10^2
V_f (km s^{-1})

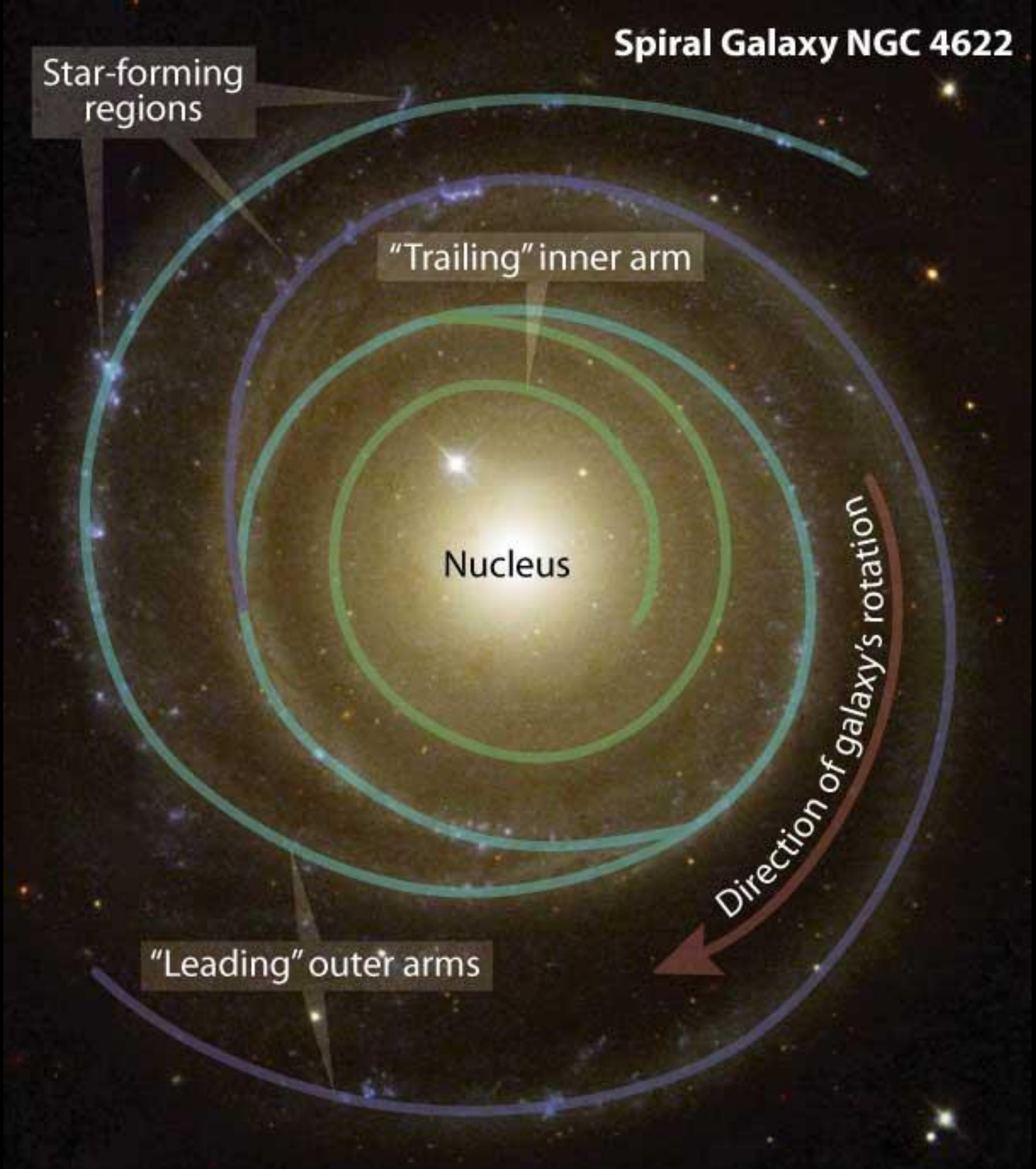


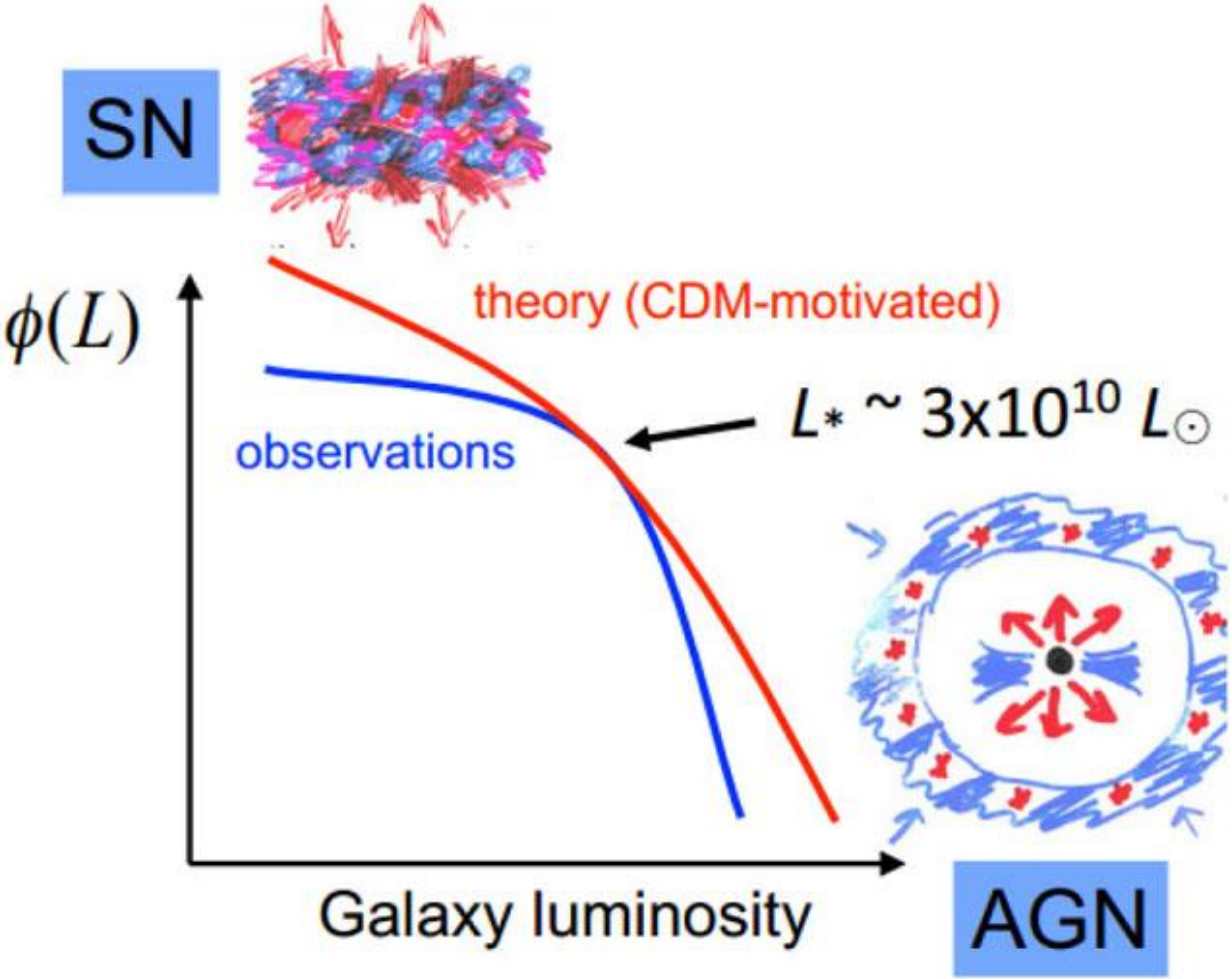
Differential rotation: stars near the center take less time to orbit the center than those farther from the center. Differential rotation can create a spiral pattern in the disk in a short time.

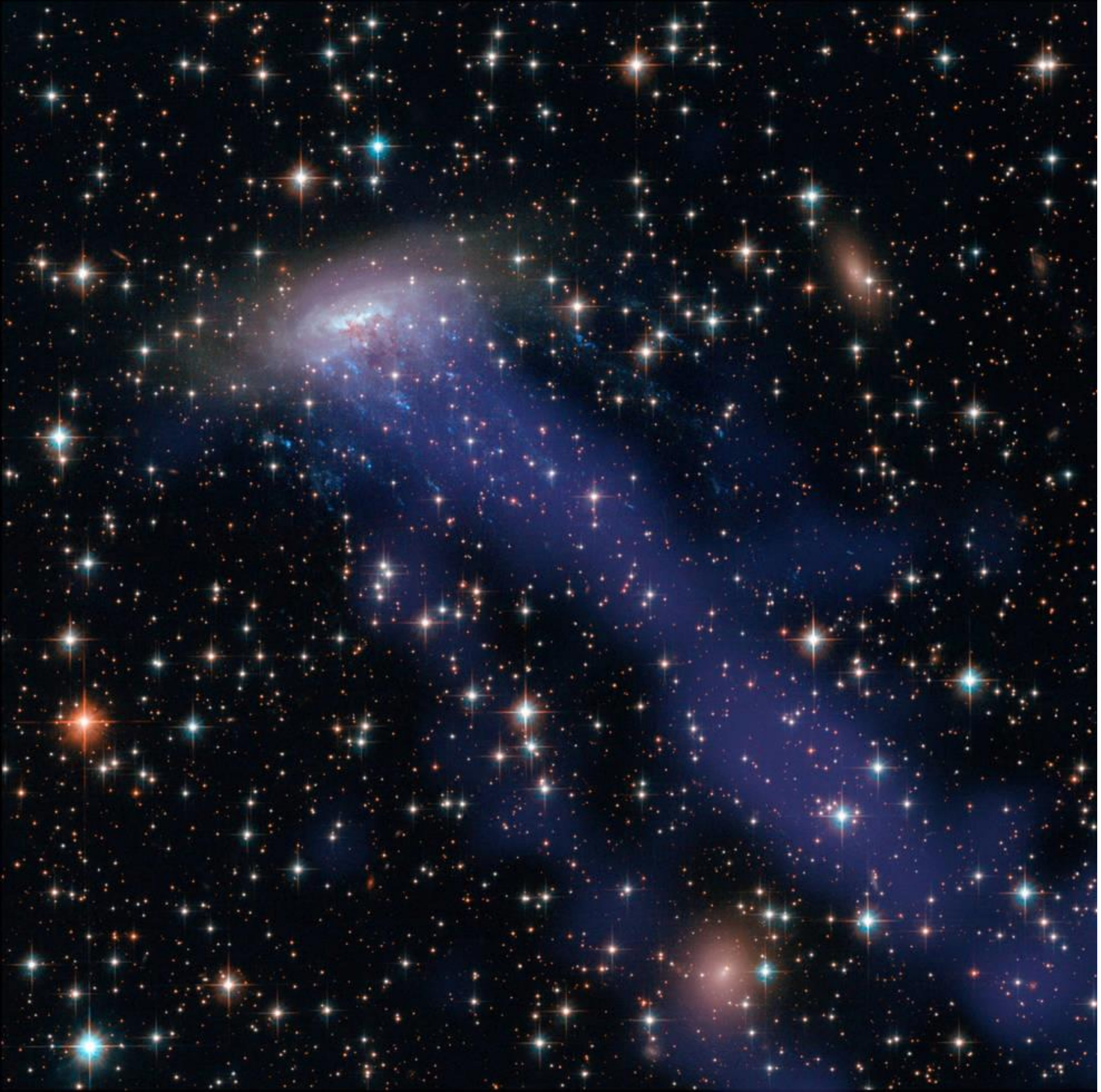


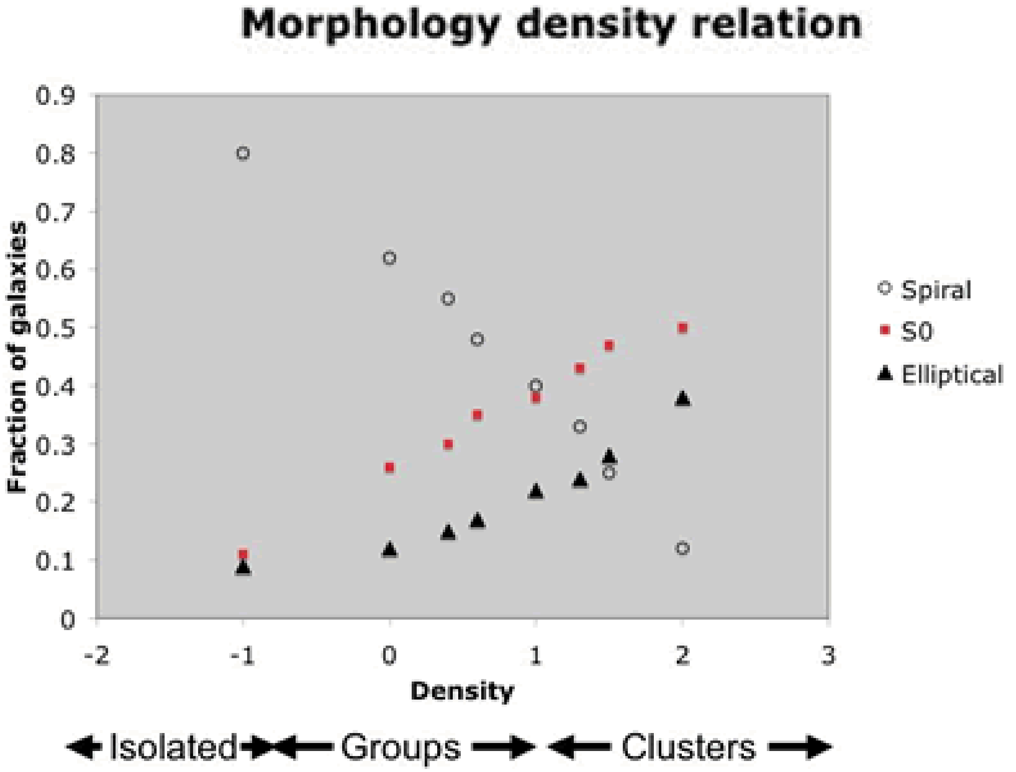
Spiral density waves are like traffic jams. Clouds and stars speed up to the density wave (are accelerated toward it) and are tugged backward as they leave, so they accumulate in the density wave (like cars bunching up behind a slower-moving vehicle). Clouds compress and form stars in the density wave, but only the fainter stars live long enough to make it out of the wave.




Spiral Galaxy NGC 4622
Star-forming regions
"Trailing" inner arm
Nucleus
Direction of galaxy's rotation
"Leading" outer arms


SN
theory (CDM-motivated)
$\phi(L)$
observations
$L_* \sim 3\text{x}10^{10}\ L_\odot$
Galaxy luminosity
AGN




Morphology density relation
Fraction of galaxies
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-2
-1
0
1
2
3
Density
Spiral
S0
Elliptical
Isolated
Groups
Clusters

Dinamica nelle ETG

Examples:

	N	R	v	τ_{cross}	τ_{relax}	age/τ_{relax}
open cluster	100	2 pc	0.5 km/s	$4 \cdot 10^6$ yrs	10^7 yrs	≥ 1
globular cluster	10^5	4 pc	10 km/s	$4 \cdot 10^5$ yrs	$4 \cdot 10^8$ yrs	≥ 10
ellipt. galaxy	10^{12}	10 kpc	600 km/s	$2 \cdot 10^7$ yrs	10^{17} yrs	10^{-7}
dwarf galaxy	10^9	1 kpc	50 km/s	$2 \cdot 10^7$ yrs	10^{14} yrs	10^{-4}
galaxy cluster	1000	1 Mpc	1000 km/s	10^9 yrs	$2 \cdot 10^{10}$ yrs	10^{-1}

Conclusion: stellar encounters will perturb a star only over τ_{relax}~10^{17} yr , or $5x10^9$ τ_{cross}

Elliptical galaxies are
collisionless system : the constituent particles move under the influence of a mean gravitational field generated by a smooth mass distribution, rather than a collection of mass points

Credit:
Pellegrini Silvia

Fast e slow rotators

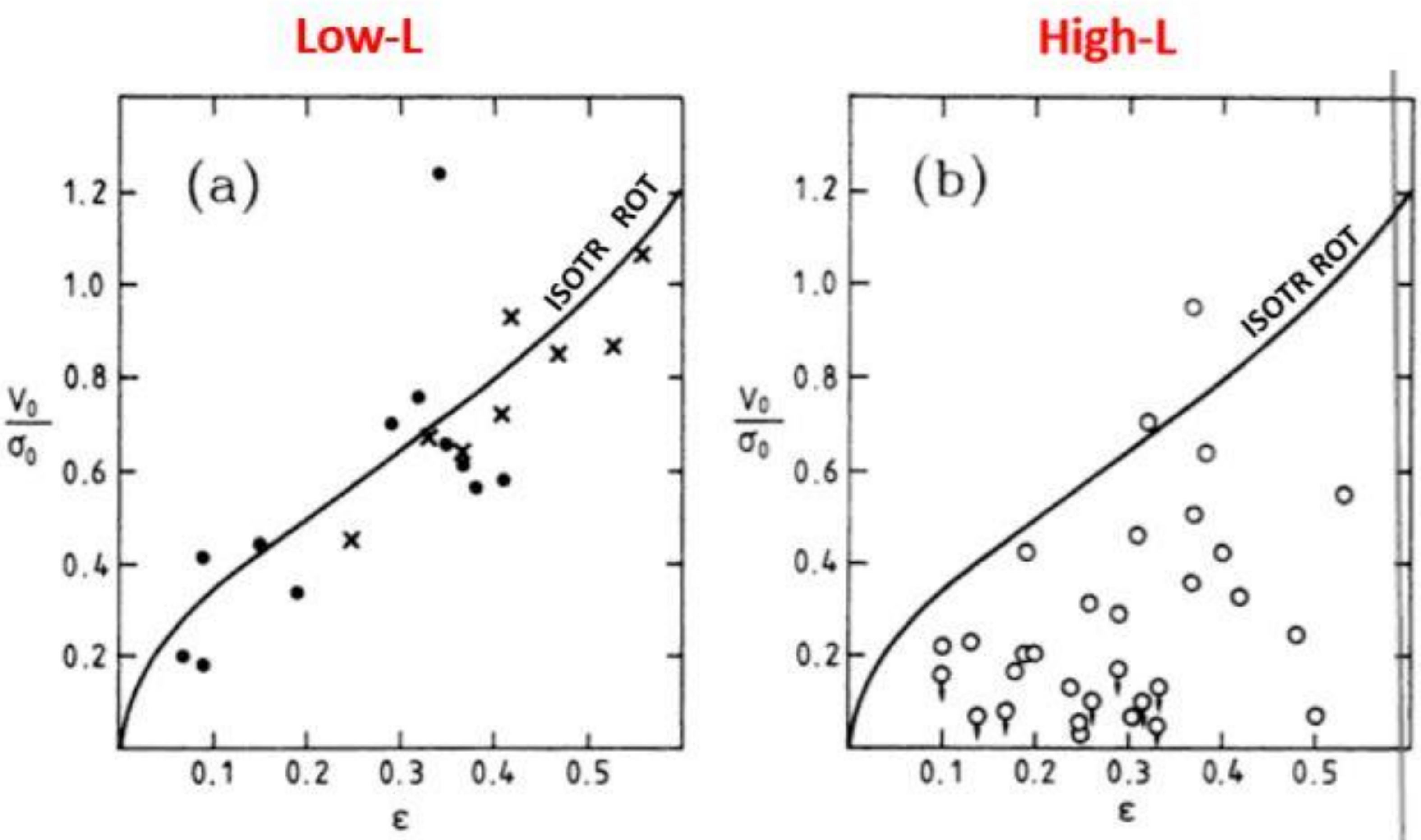
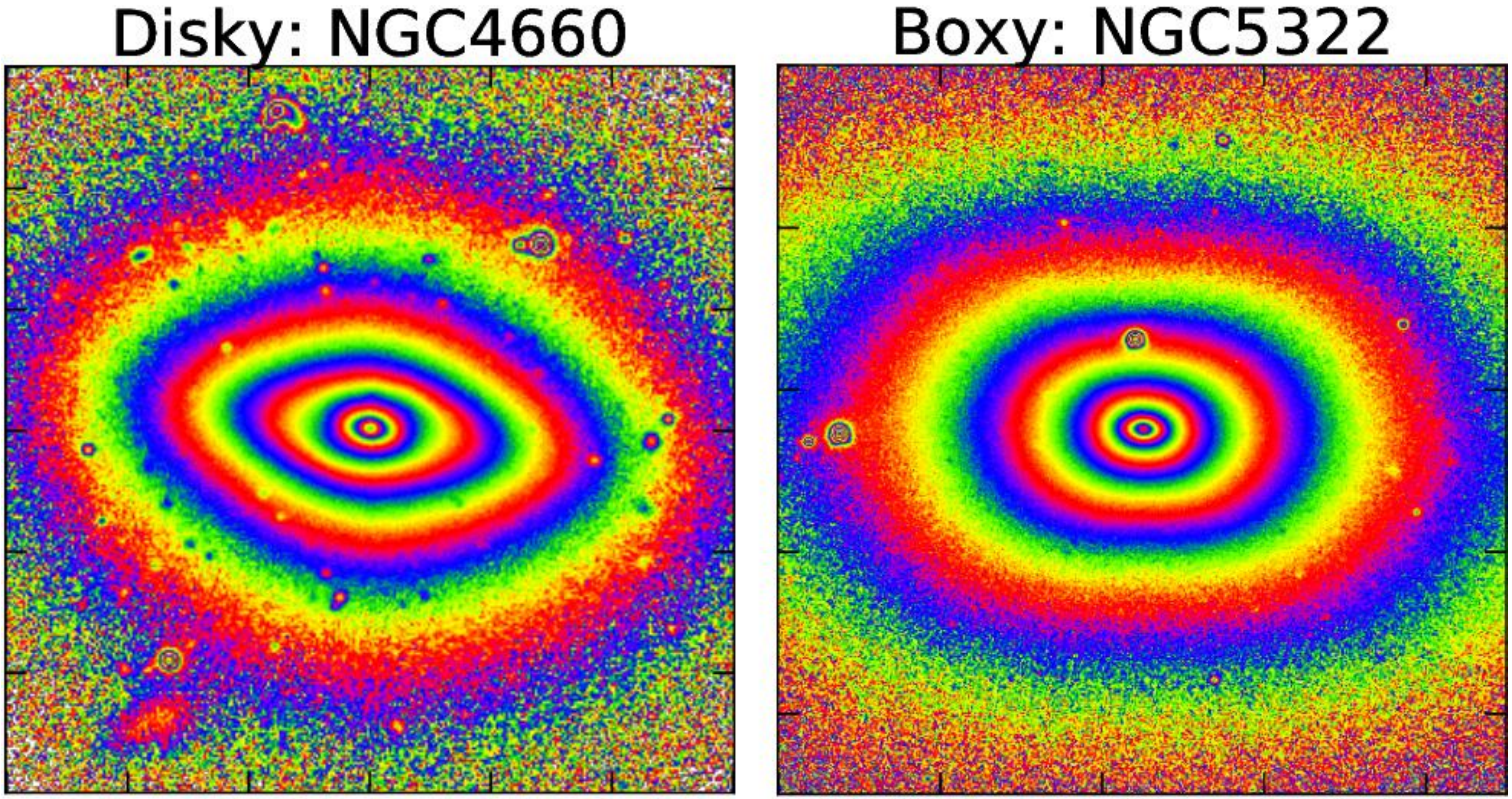
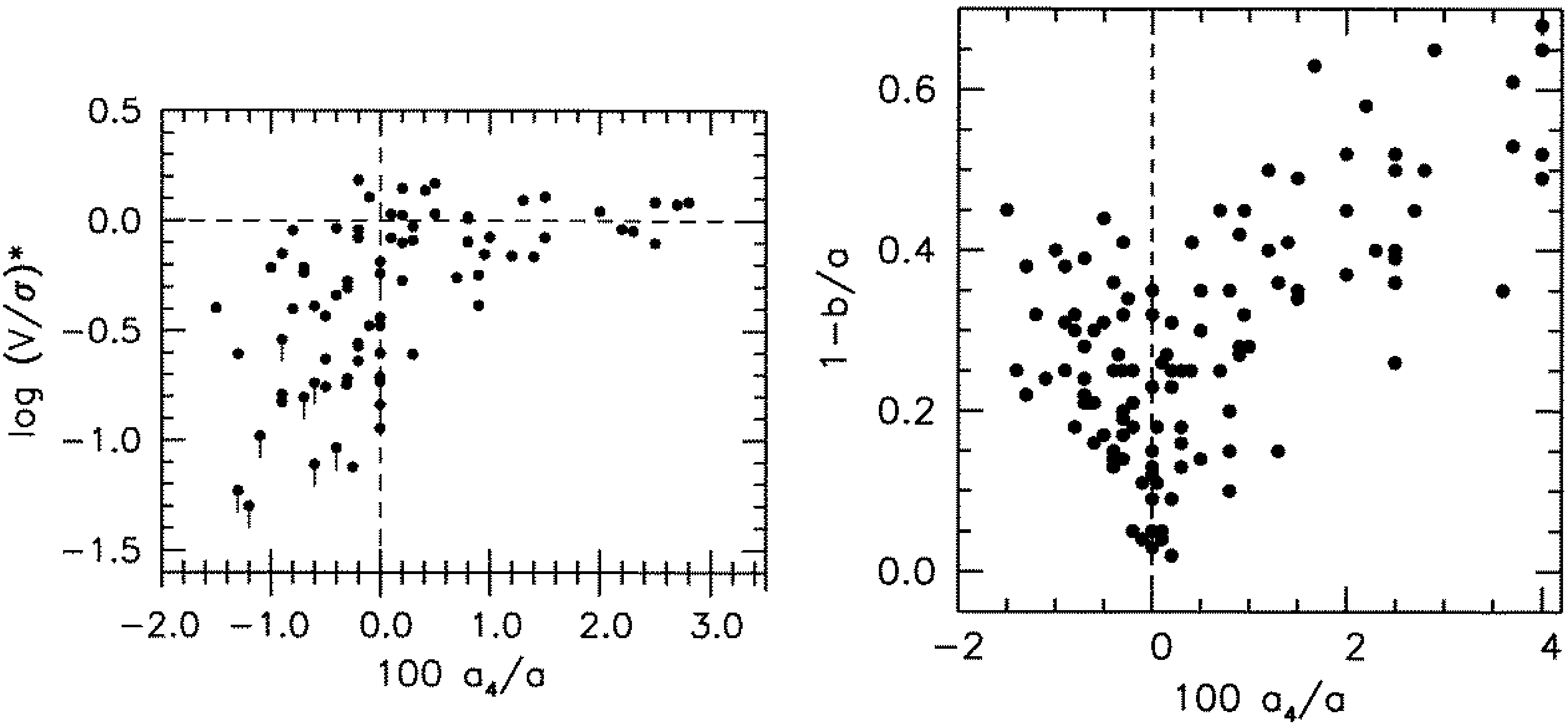


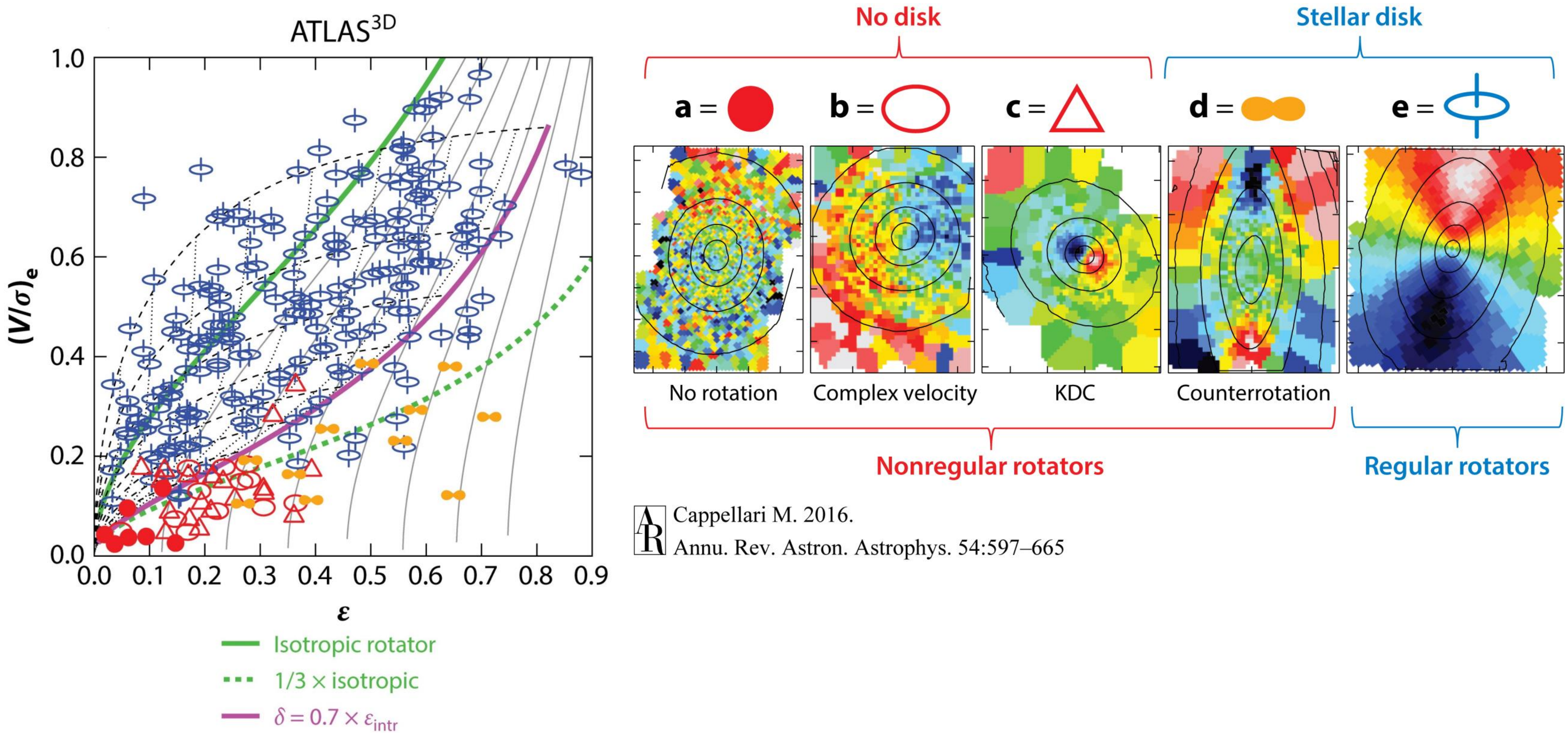
Figure 4-6. (a) The positions in the $(v/\sigma, \epsilon)$ plane of elliptical galaxies (dots), and of spheroids (crosses), that have luminosities smaller than $L = 2.5 \times 10^{10}\,L_\odot$. (b) The same as (a) but for elliptical galaxies brighter than $L = 2.5 \times 10^{10}\,L_\odot$. (After Davies et al. 1983.)

Credit:
Pellegrini Silvia

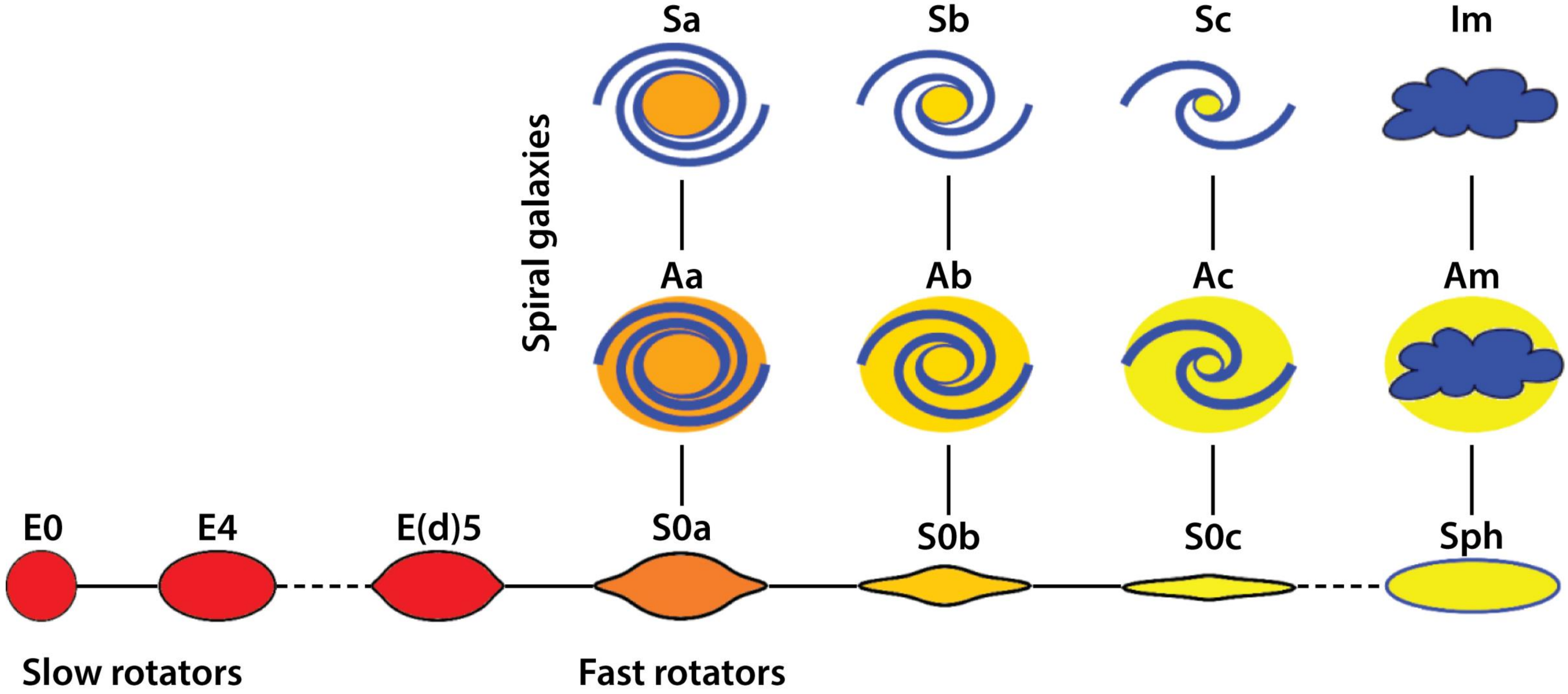

Disky: NGC4660
Boxy: NGC5322



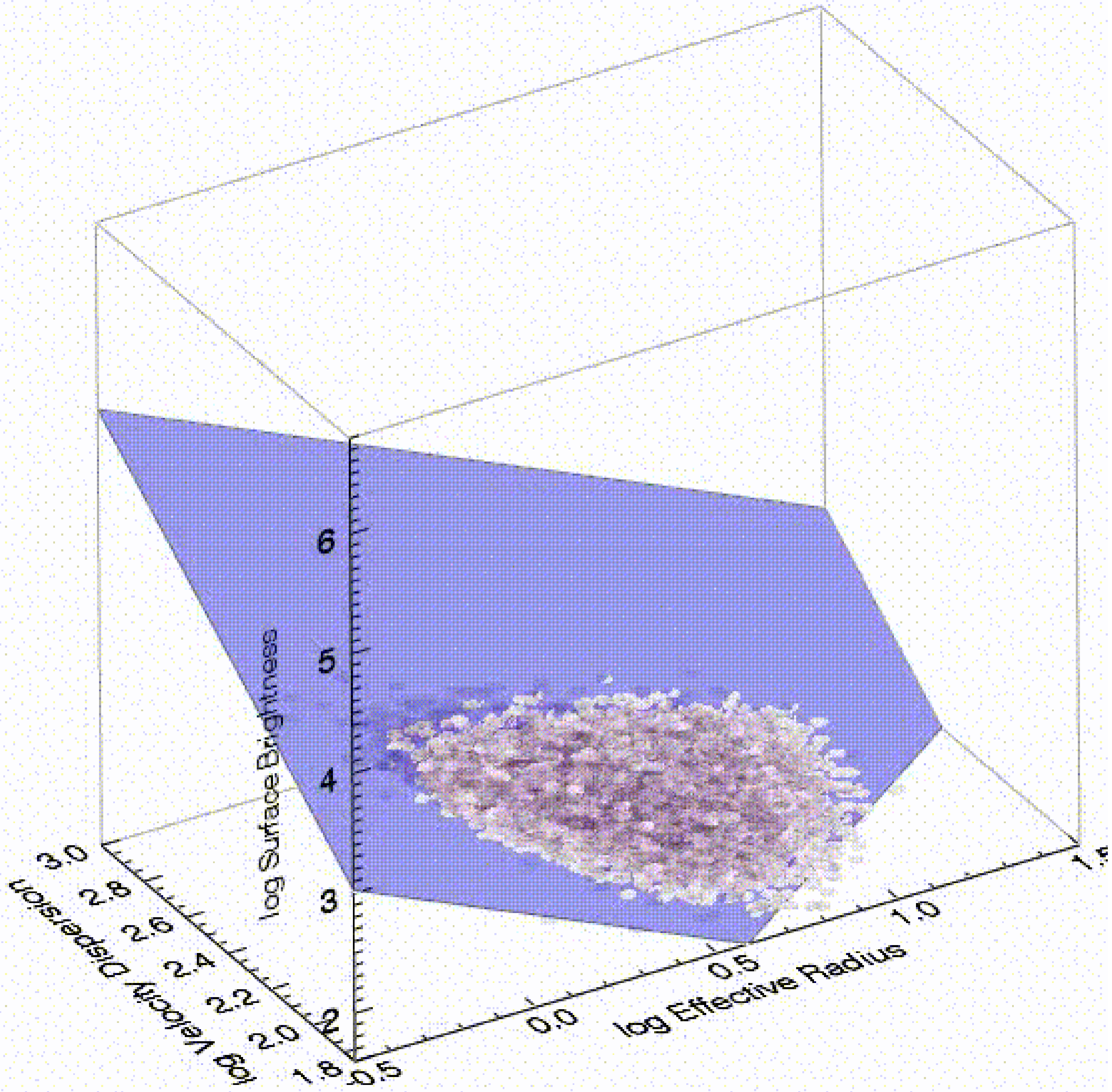
log (V/σ)*
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−1.0
0.0
1.0
2.0
3.0
100 a4/a
1−b/a
0.6
0.4
0.2
0.0
−2
0
2
4
100 a4/a



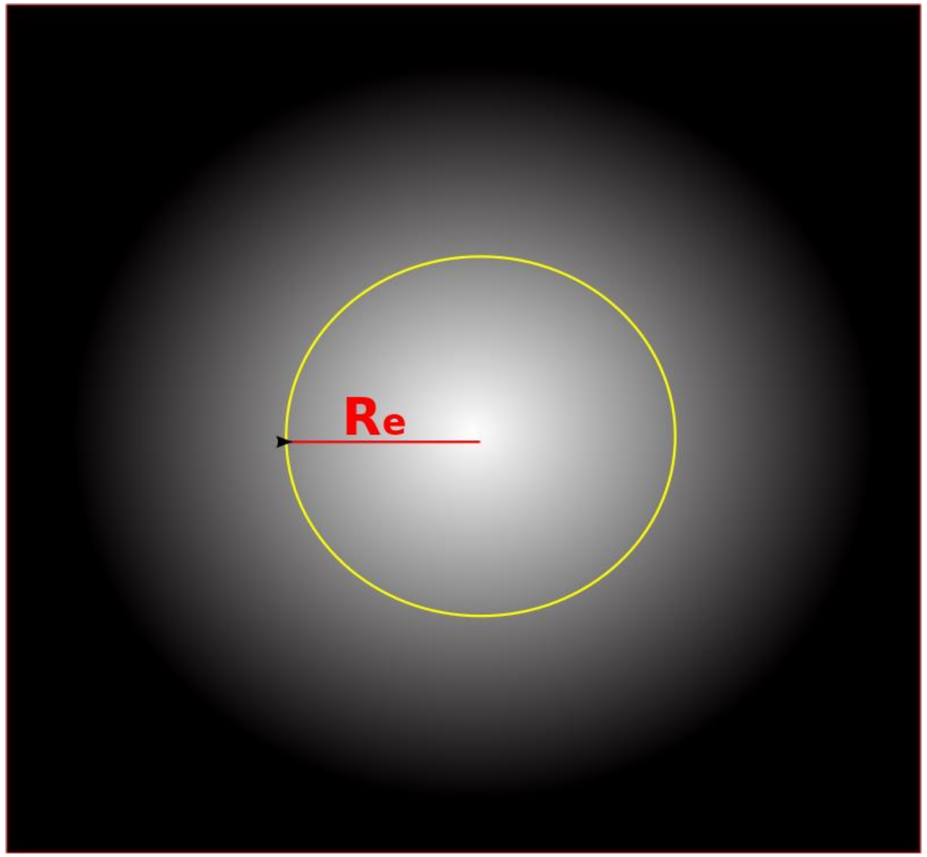
Cappellari M. 2016.
Annu. Rev. Astron. Astrophys. 54:597–665



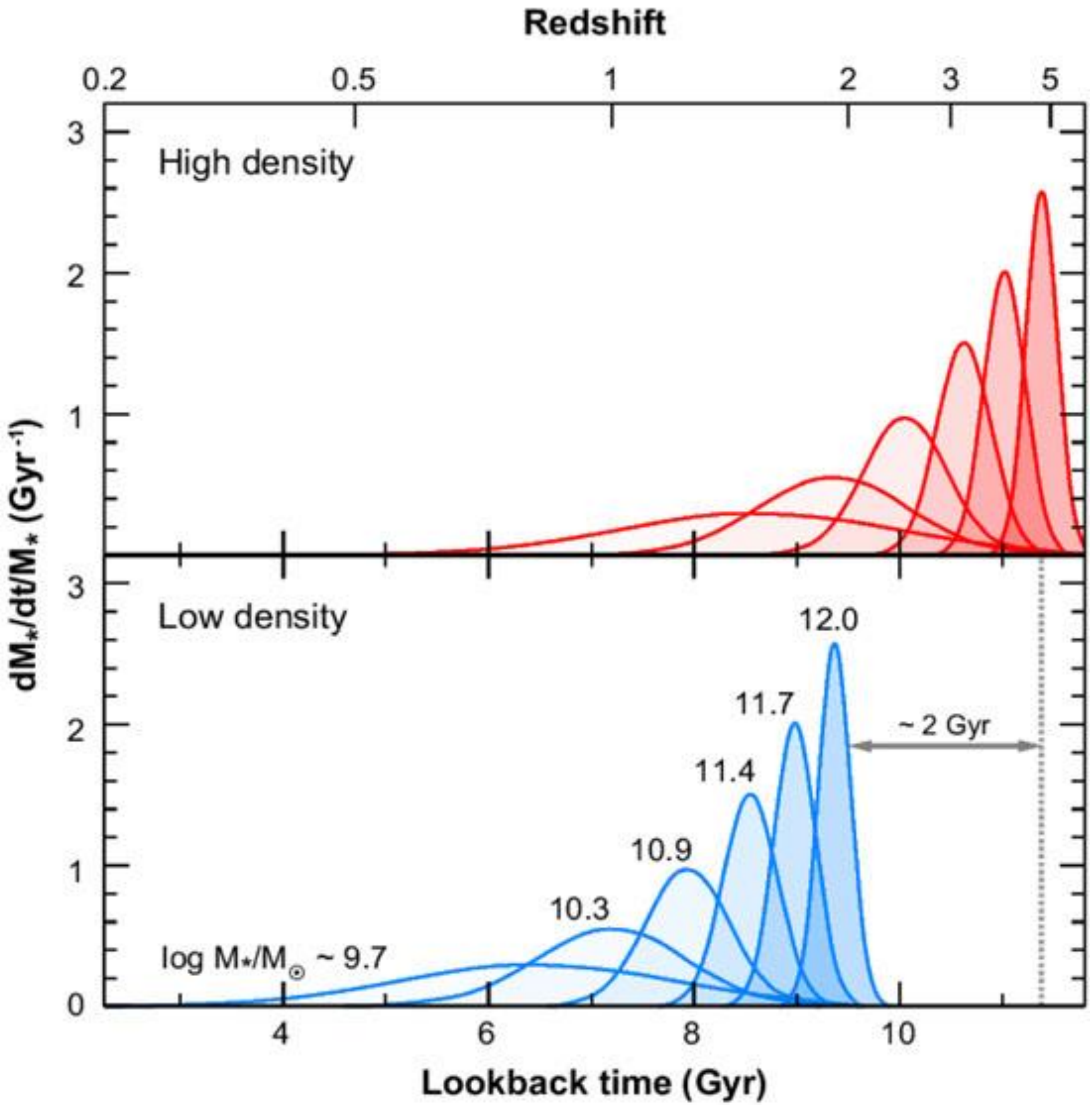
Cappellari M. 2016.
Annu. Rev. Astron. Astrophys. 54:597–665



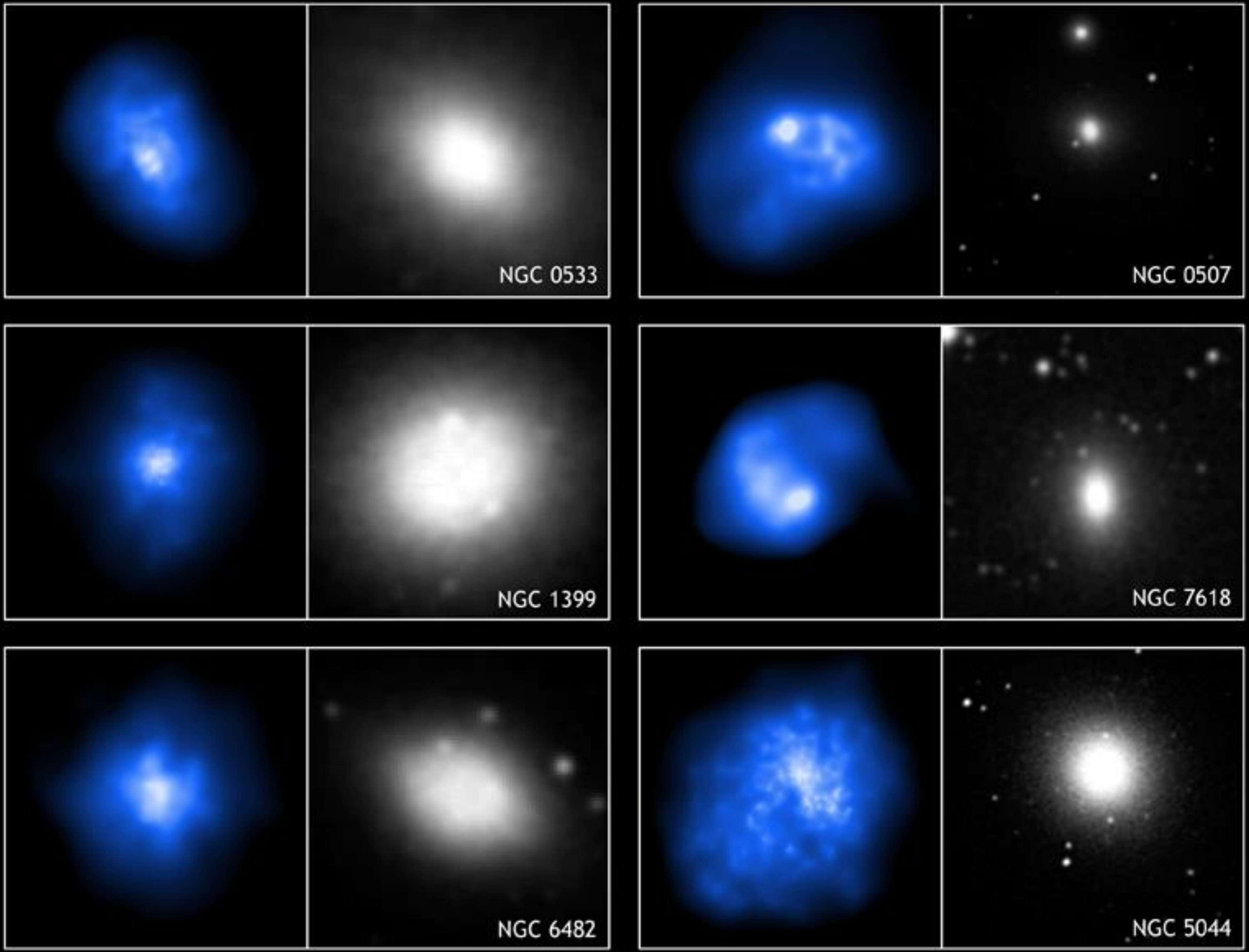
log Surface Brightness
log Effective Radius
log Velocity Dispersion
6
5
4
3
2
-0.5
0.0
0.5
1.0
1.5
1.8
2.0
2.2
2.4
2.6
2.8
3.0



Re



Redshift
0.2
0.5
1
2
3
5
High density
Low density
12.0
11.7
11.4
10.9
10.3
log M*/M⊙ ~ 9.7
~ 2 Gyr
dM*/dt/M* (Gyr⁻¹)
0
1
2
3
4
6
8
10
Lookback time (Gyr)


NGC 0533
NGC 0507
NGC 1399
NGC 7618
NGC 6482
NGC 5044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$$\frac{dP(r)}{dr} = -\rho(r)\frac{d\phi(r)}{dr} \text{ con } P(r) = \frac{\rho(r)K_B T(r)}{m}$$

$$\Updownarrow$$

$$\frac{d[\rho(r)\sigma^2(r)]}{dr} = -\rho(r)\frac{d\phi(r)}{dr}$$

$$-\frac{d\phi(r)}{dr} = g(r) = -\frac{GM(r)}{r^2} \text{ infatti } F_G = -\frac{GmM(r)}{r^2}$$

$$\begin{cases} M_T(r) = -\dfrac{r^2}{G\rho(r)} \dfrac{d[\rho(r)\sigma^2(r)]}{dr} \\ M_*(r) = 4\pi \displaystyle\int_0^r x^2 \rho(x) dx \end{cases}$$

Credit:
Pellegrini Silvia

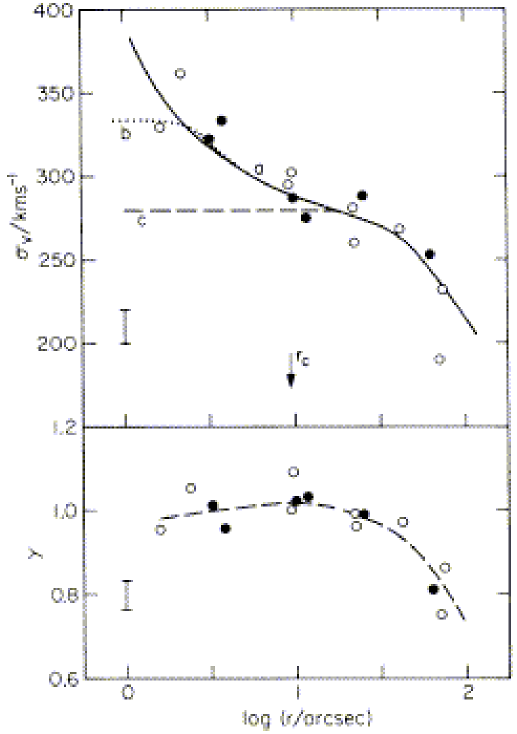


FIG. 4.—Velocity dispersions (σ_v) and the line strengths (y) for M87. The open circles (○) are points W of the nucleus, and the filled circles (●) are E. The core radius, r_c = 9″.6, of the galaxy is marked. Error bars of length 2 σ are given. Curve (a) is the velocity dispersion predicted by the black hole model fitted to the photometric data, (b) is the same model convolved with the seeing disk and slit size for the spectroscopic observations, and (c) is the King model that would prevail if the black hole were absent.

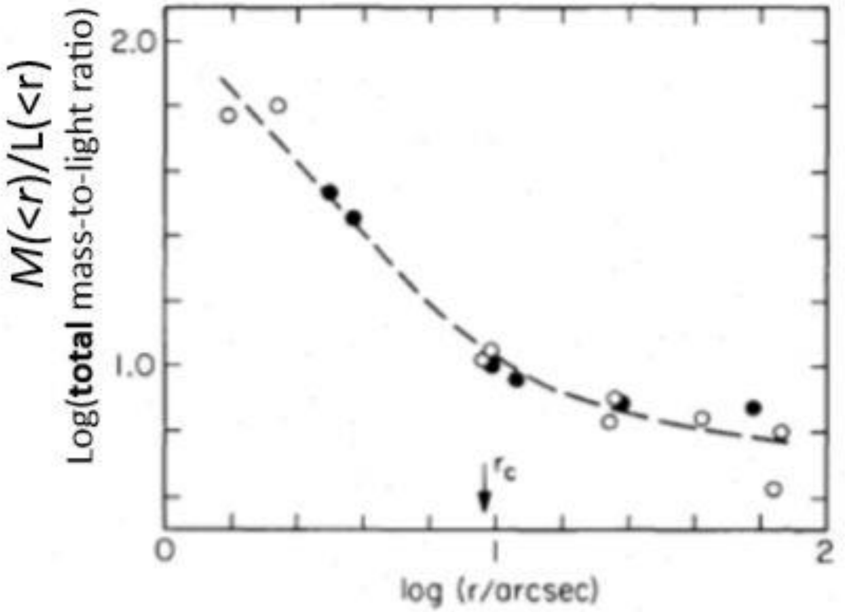


FIG. 10.—Mean mass-luminosity ratio enclosed within radius r [$\langle M/\mathscr{L}\rangle(r)$] as a function of r in M87. Open circles (○) are to the W of the nucleus, and filled circles (●) are to the E. The core radius of the galaxy, r_c = 9″.6, is marked.

M(r)/L(r)≠cost

The data require a central 5×10^9 $M_\odot$ MBH:
the total M/L is consistent with that of the stellar population ($M_\star$/L ≈constant at the value 6–7) around the core radius r_c, but steeply increases inward

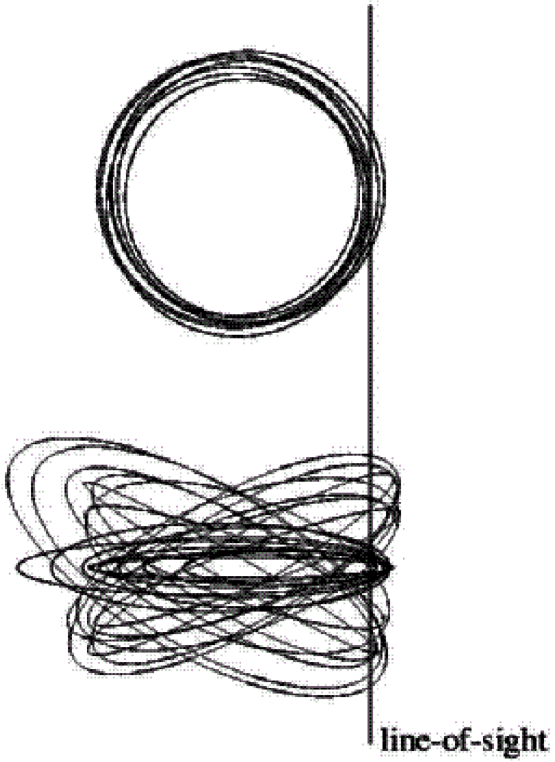
$$\frac{dP(r)}{dr} = -\rho(r)\frac{d\phi(r)}{dr} \text{ con } P(r) = \frac{\rho(r)K_B T(r)}{m}$$

$$\Updownarrow$$

$$\frac{d[\rho(r)\sigma_r^2(r)]}{dr} + \frac{2\beta(r)}{r}\rho(r)\sigma_r^2(r) = -\rho(r)\frac{GM(r)}{r^2}$$

- Assumiamo che tutta la massa sia stellare: $M(r) = M_*(r) \ \forall\, r > 0$

Parametro di anisotropia



$\beta < 0$

$\beta > 0$

Credit:
Pellegrini Silvia

ISOTROPIC modeling

at the center, M/L becomes far larger than reasonable for the stellar population

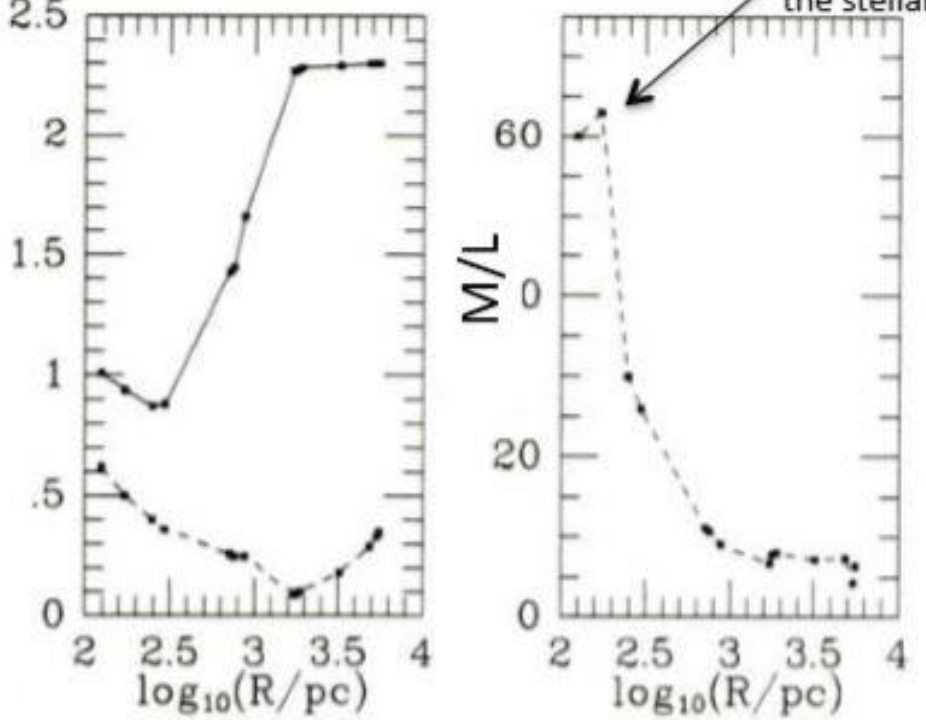
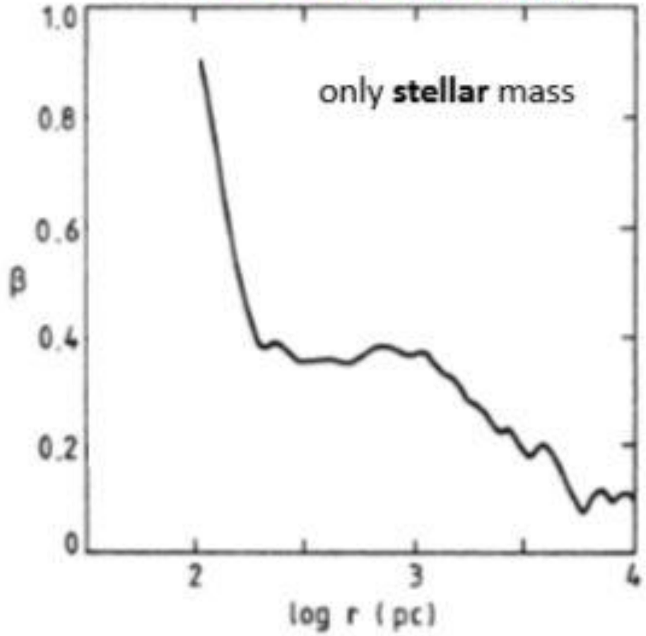


Figure 4-3. Left panel: plots of the logarithmic gradients appearing in equation (4-56) for the giant elliptical galaxy M87: full curve $|d\ln\nu/d\ln r|$; dashed curve $|d\ln\overline{v_r^2}/d\ln r|$. A distance to the galaxy of 16 Mpc has been assumed, and $\overline{v_r^2}$ has been obtained from the observed dispersion under the assumption $\beta = 0$. Right panel: the ratio $M(r)/L(r)$ derived from these data and equation (4-56). (After Sargent et al. 1978.)

ANISOTROPIC modeling with a radially varying β(r)



Bottom: the radial variation of the anisotropy parameter β in M87 if the observations on which Figure 4-3 is based are to be interpreted in terms of a constant mass-to-light ratio. (After Binney & Mamon 1982.)

β=cost=0 and M(r)/L(r)≠cost AND β(r)>0 and M/L=cost **can reproduce equally well the data**

BH **NO BH**

FINE

Libri consigliati (livello avanzato)

- Binney and Tremaine,<<Galactic Dynamics>>
- https://www.annualreviews.org/doi/10.1146/annurev-astro-082214-122432
- http://articles.adsabs.harvard.edu/pdf/1978ApJ...221..731S
- http://articles.adsabs.harvard.edu//full/1988A%26AS...74..385B/0000391.000.html
- http://articles.adsabs.harvard.edu/pdf/1988A%26A...193L...7B