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Scientific Visitor Programme in Garching

Please consult the Garching Scientific Visitor Programme.

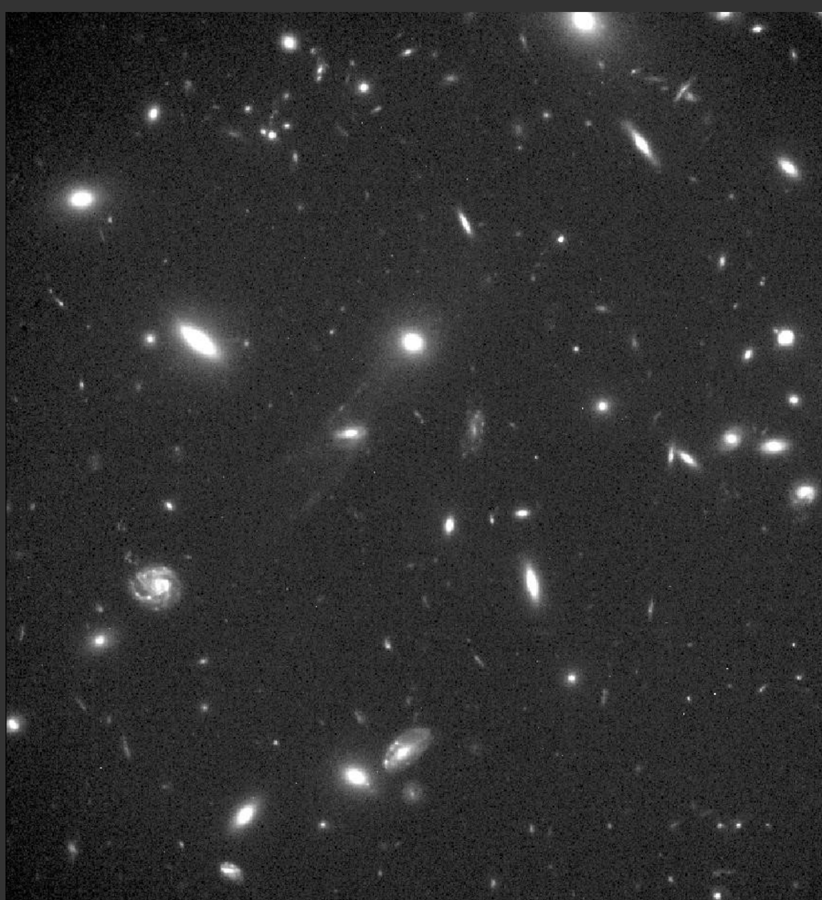
http://www.eso.org/sci/activities/santiago/personnel/visitors.html

Morphological transformation in galaxy clusters

-> interpreted as the result of galaxy harassment (Moore et al. 1996).

Harassment = 1 encounter/Gyr with an L* galaxy, within 50kpc

CL0939 @z=0.41



Coma cluster @z=0.0023

Morphological transformation in the

Local Group?

or...

The true identity of NGC 205

Ivo Saviane
European Southern Observatory

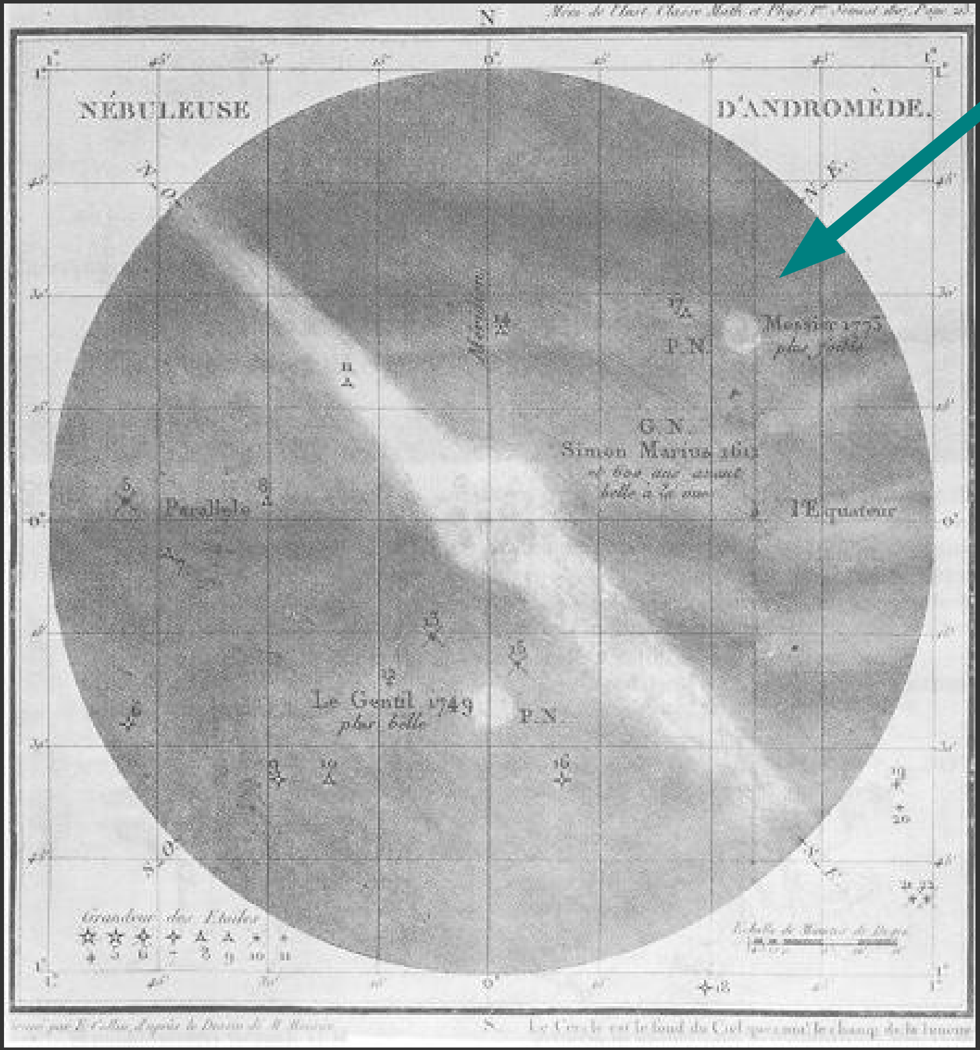
And

L. Monaco
Universidad de Concepcion

S. Perina
M. Bellazzini
A. Buzzoni
L. Federici
F. Fusi Pecci
S. Galleti
INAF - Osservatorio Astronomico di Bologna

Tony Hallas
astrophoto.com

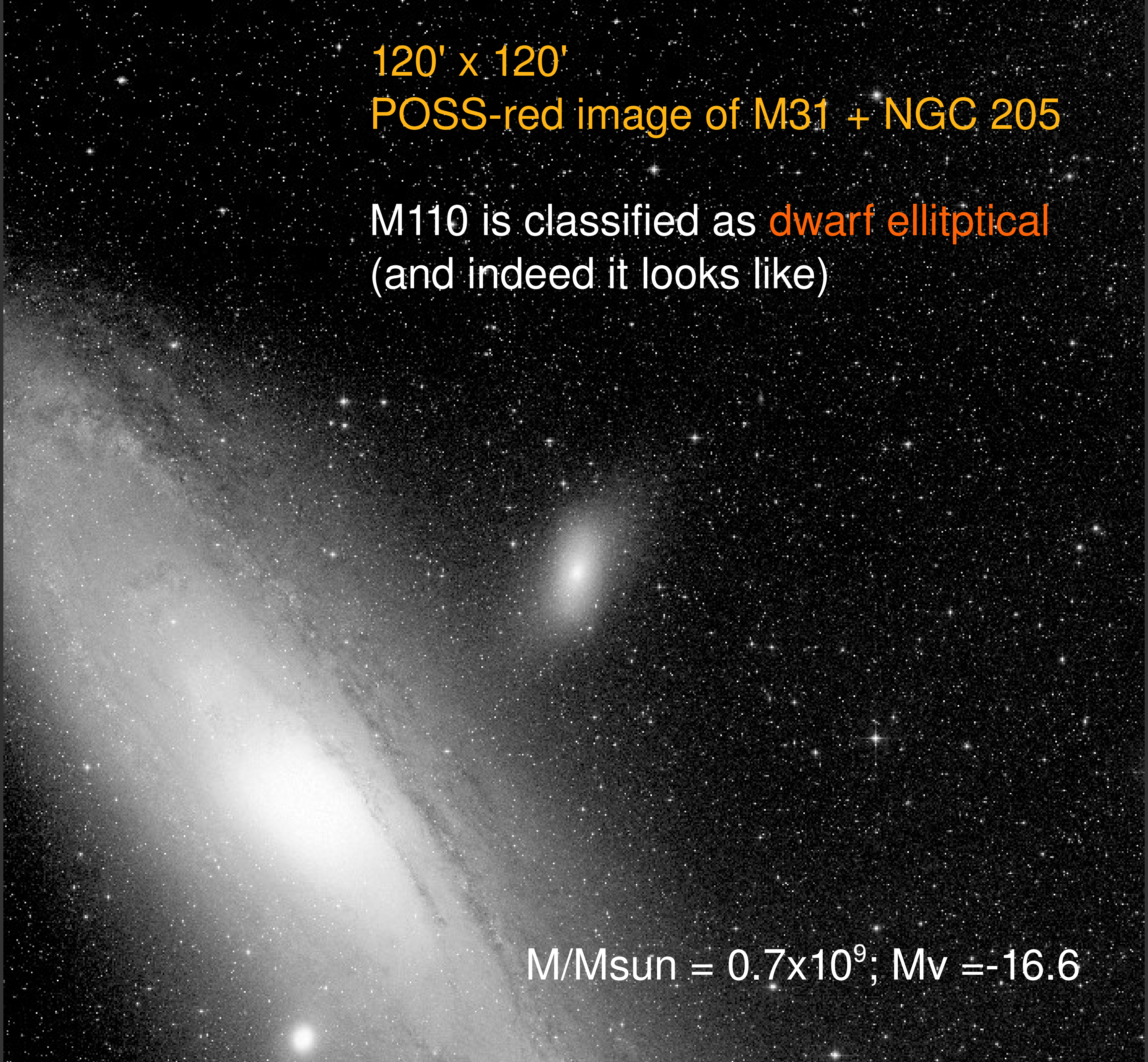
NGC 205 was discovered by Messier in 1773



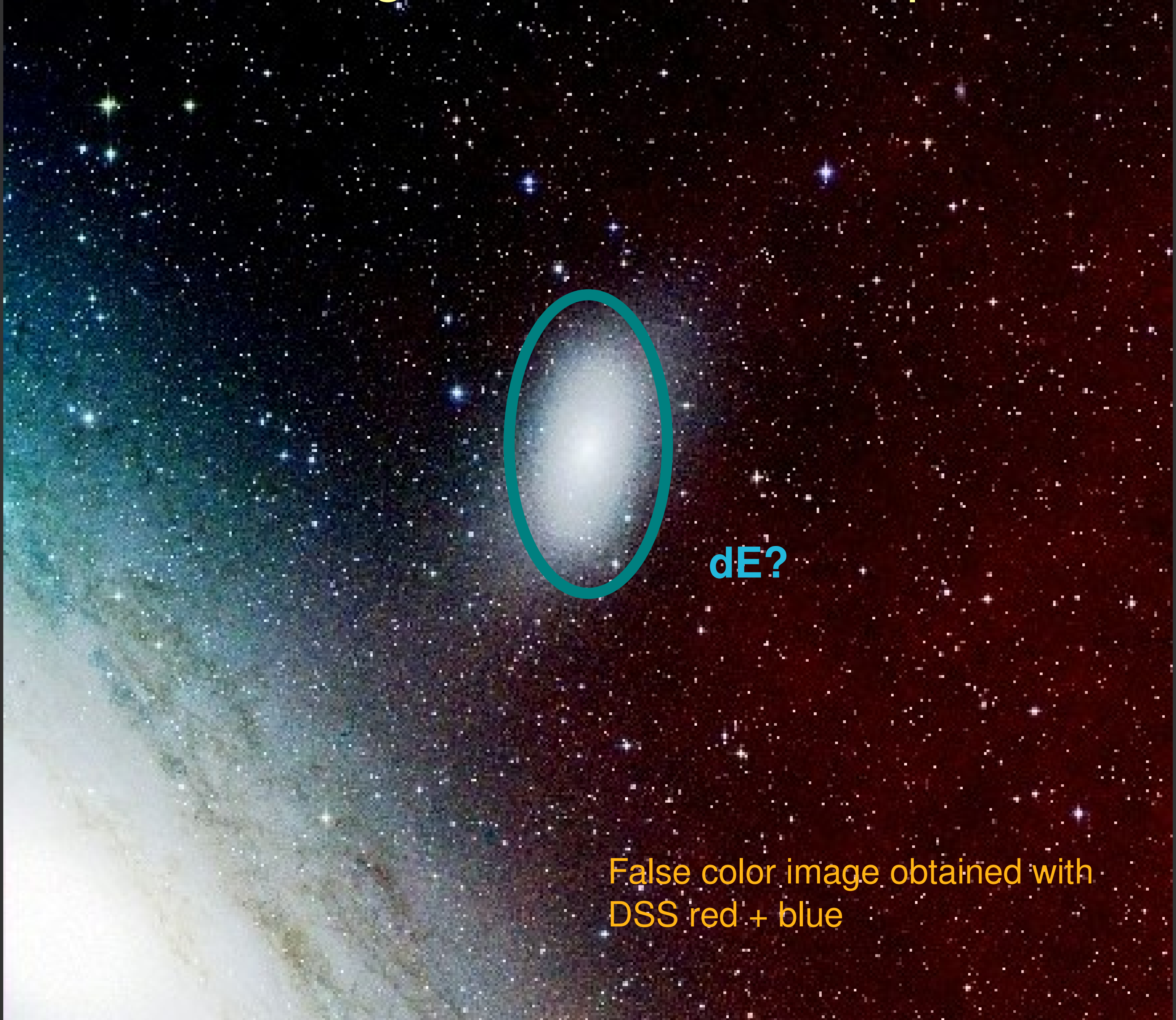
But was included in the catalog only in 1966

It's M110, the last object of the list

First resolved by Baade (1944)


120' x 120'
POSS-red image of M31 + NGC 205
M110 is classified as dwarf ellitptical
(and indeed it looks like)
M/Msun = 0.7x10^9; Mv =-16.6

Zooming in confirms the impression



False color image obtained with
DSS red + blue


Zooming in confirms the impression
But also that there is something peculiar

It's not the only peculiarity

- specific frequency of GCs is SN = 1.8
  (Harris & van den Bergh 1981; Sharina et al. 2006),
  in the regime of spiral galaxies

- The large scale dynamics shows
  partial rotational support
  (De Rijcke et al. 2006; Geha et al. 2006)

- 11 +/- 5 km/sec along major axis

The Astronomical Journal, 131:332–342, 2006 January

Ⓔ

LOCAL GROUP DWARF ELLIPTICAL GALAXIES. I. MAPPING THE DYNAMICS OF NGC 205 BEYOND THE TIDAL RADIUS

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Received 2005 July 20; accepted 2005 September 18

ABSTRACT

NGC 205 is the nearest example of a dwarf elliptical galaxy and the prototype of this enigmatic galaxy class. Photometric evidence suggests that NGC 205, a close satellite of the M31 galaxy, is tidally interacting with its parent galaxy. We present stellar radial velocity measurements out to a projected radius of 20′ (5 kpc) in NGC 205 based on Keck DEIMOS multislit spectroscopic observations of 725 individual red giant branch stars. Our kinematic measurements extend from the center out to 6 times the effective radius of NGC 205, well past the expected tidal radius. The contamination in our kinematic sample from M31 field stars is estimated to be a few percent based on maximum likelihood fits to the distribution of stars in position-velocity space. We measure a maximum major-axis rotation speed for the body of NGC 205 of 11 ± 5 km s^{-1} and note that this is based on observing a definite turnover in the rotation curve; this is the first dE galaxy in which the maximum rotation velocity has been measured. Combined with the velocity dispersion, we conclude that NGC 205 is supported by a combination of rotation and anisotropic velocity dispersion. At a major-axis distance of 4′.5 (1 kpc), the velocity profile of NGC 205 turns over; stars beyond this radius are moving counter to the rotation of the inner part of the galaxy. The turnover radius is coincident with the onset of isophotal twisting and the estimated tidal radius, suggesting that the outer kinematics of NGC 205 is dominated by gravitational interactions with the nearby M31 galaxy. The motion of stars beyond a radius of ∼4′.5 implies that NGC 205 is in a prograde encounter with its parent galaxy, M31.

Key words: galaxies: dwarf — galaxies: individual (NGC 205) — galaxies: interactions — galaxies: kinematics and dynamics

Online material: color figure, machine-readable table

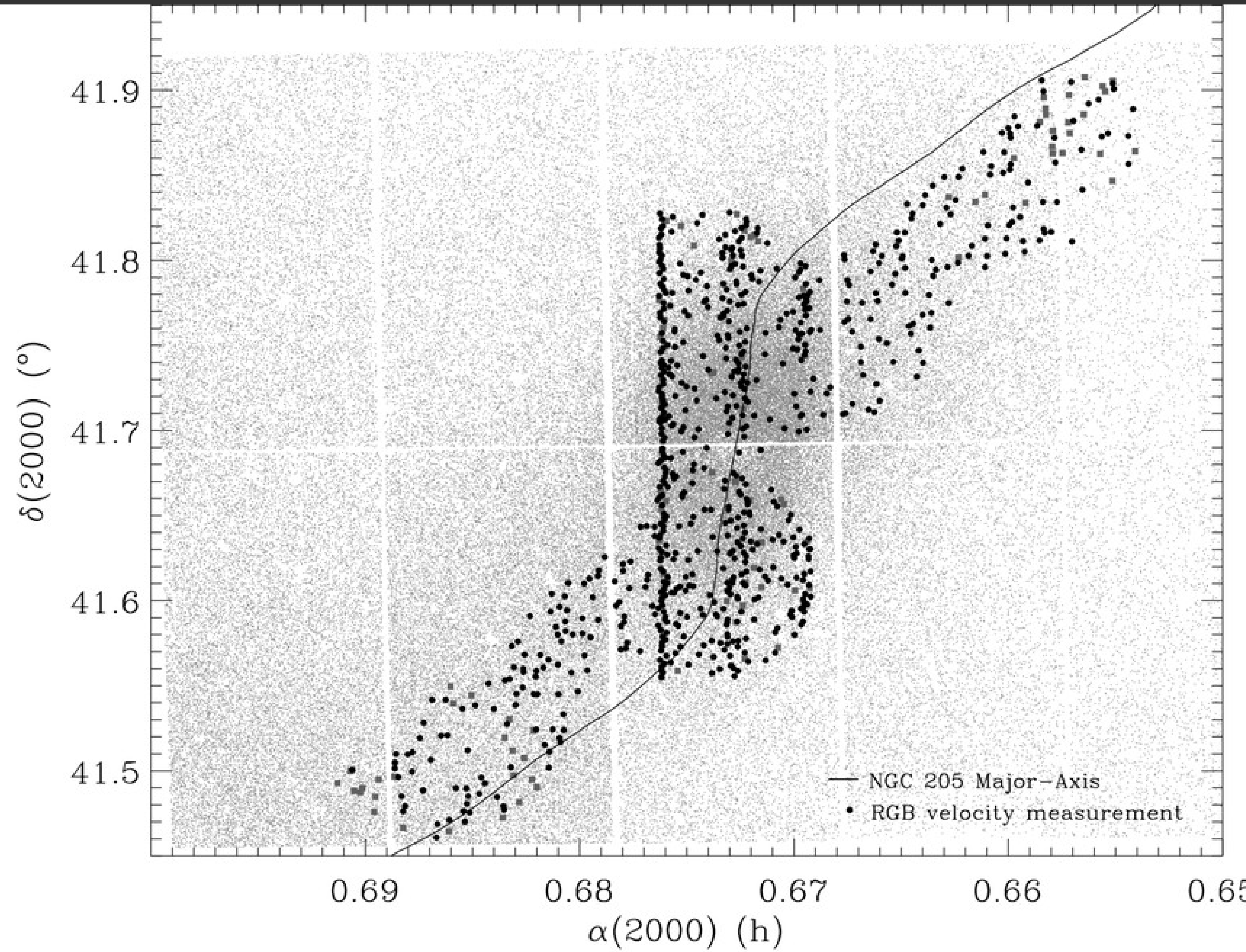


Fig. 3.—Spatial distribution of stars in NGC 205 (*small gray dots*) from Demers et al. (2003) photometry. Large circles indicate objects targeted for DEIMOS spectroscopy; the tiered pattern of slitlets can be seen in the central mask. The solid curve shows the major axis of NGC 205 determined from Choi et al. (2002) photometry.

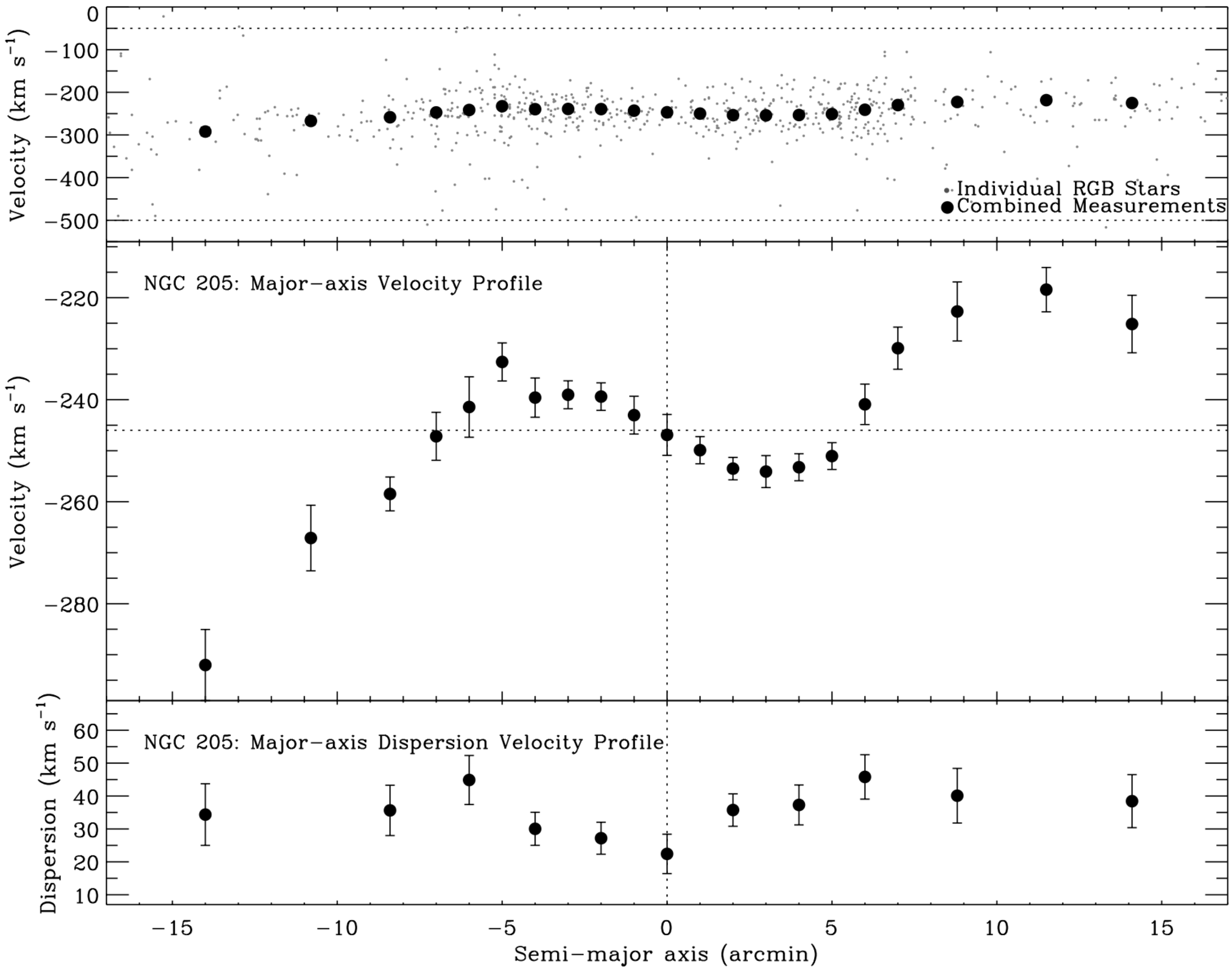


FIG. 6.—Major-axis velocity profile for NGC 205. *Top*: Small gray dots indicate Keck DEIMOS velocity measurements of individual RGB stars, and large black circles indicate the combined velocity measurements based on Gaussian fits to the velocity distribution in each radial bin. Dotted lines indicate the limits inside which the combined measurements are determined. *Middle*: Combined velocity measurements (*circles*) with a finer velocity scale. The vertical dotted line is plotted at the galaxy center, and the horizontal dotted line is plotted at the measured systemic velocity of NGC 205. *Bottom*: Velocity dispersion profile for NGC 205 determined using a coarser binning scheme than for the velocity profile.

- There is a significant amount of rotating molecular and atomic gas (Welch et al. 1998) (10^6 Msun)

- and dust (Marleau et al. 2006).

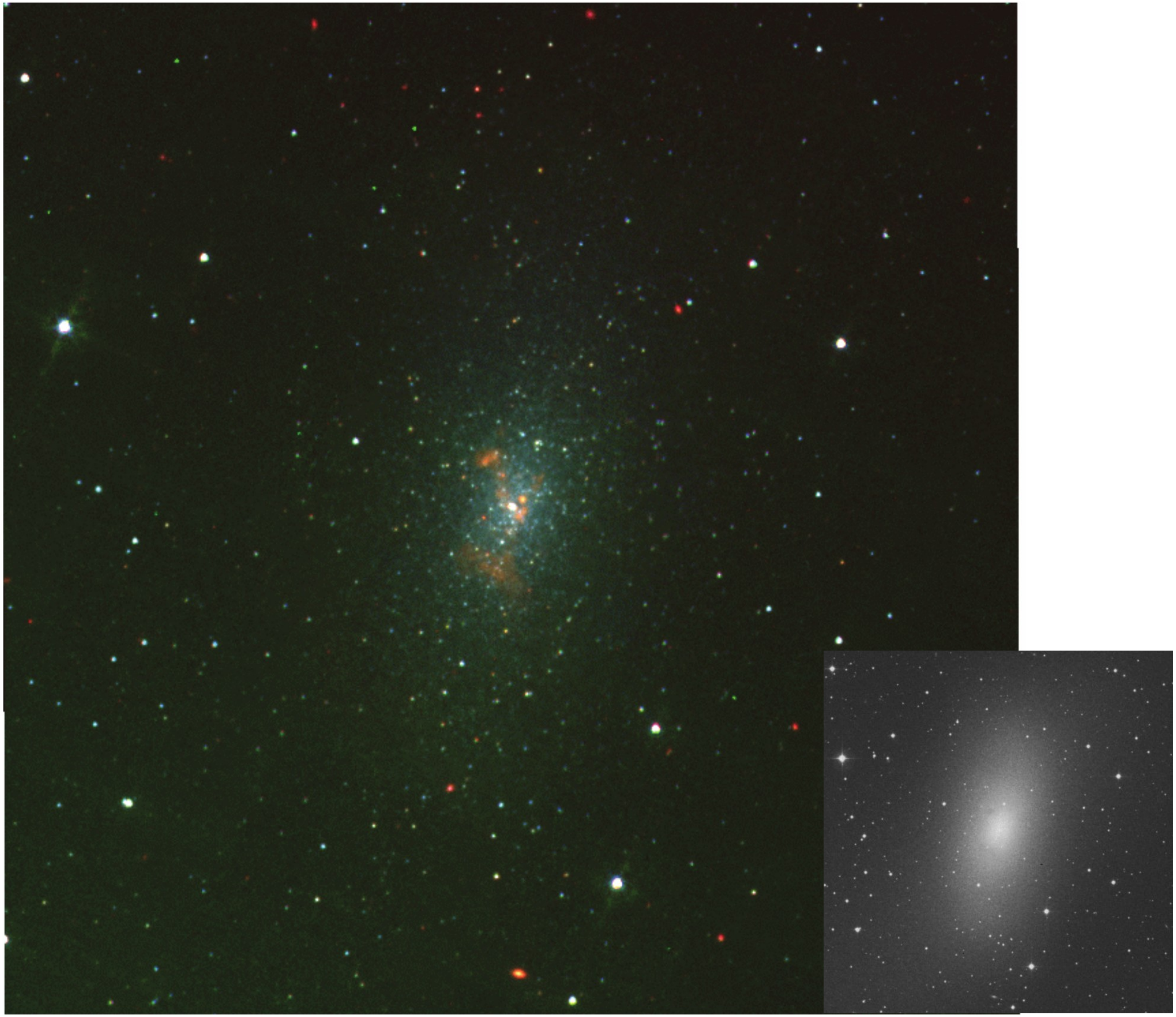


FIG. 3.—Three-color image of NGC 205 as seen by IRAC at 3.6 (*blue*), 5.8 (*green*), and 8 μm (*red*). The image emphasizes the dust cloud distribution seen at longer wavelengths over a $15' \times 15'$ region, with north up and east to the left.

- NGC 205 harbors a fairly complex stellar population

- especially in the central regions

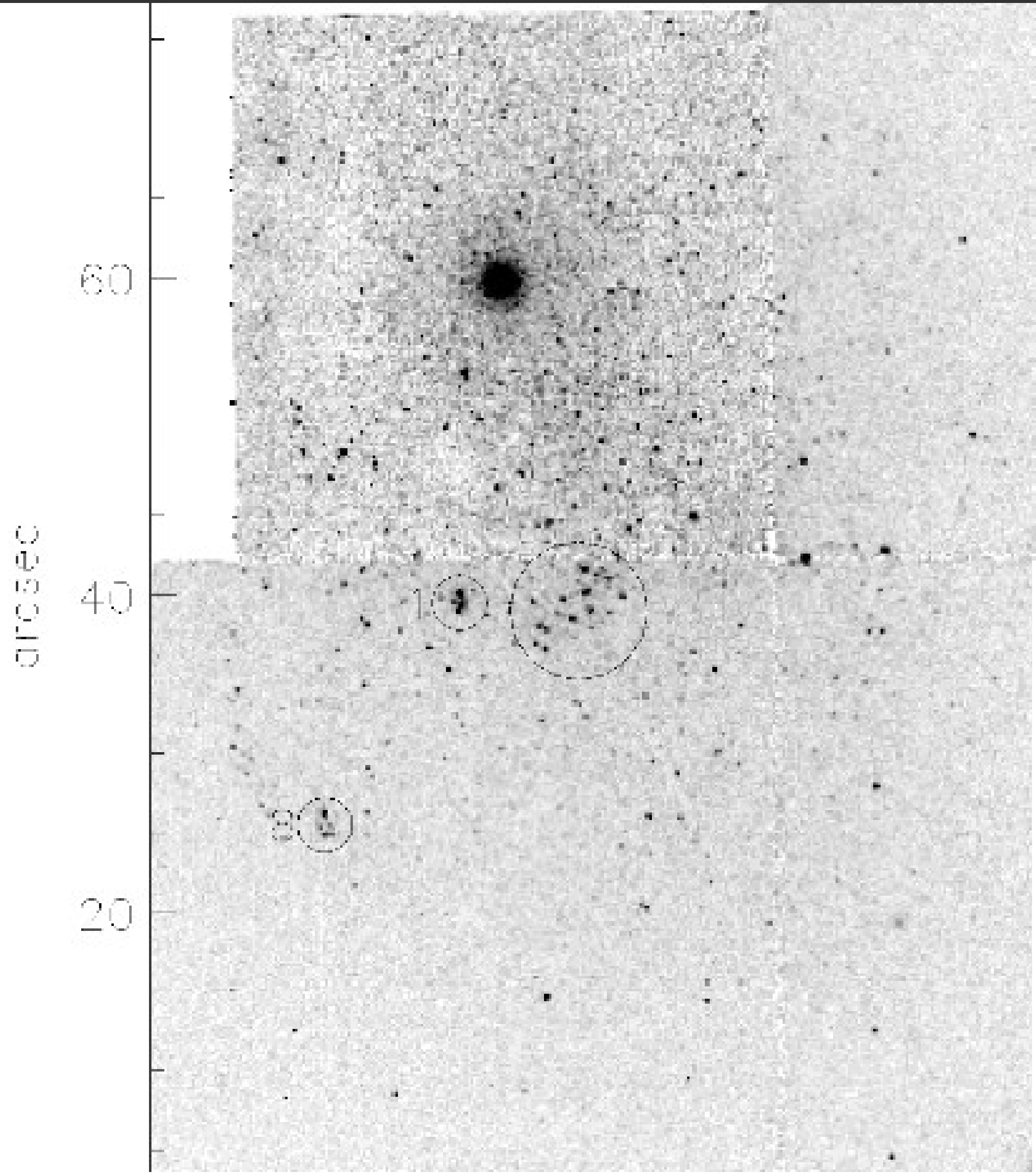
- the presence of bright O and B stars in the center is known since Baade (1951).

- Bica et al. (1990) from integrated spectrum of nucleus:

  mean age: 100—500 Myr

  metallicity: -1< [m/H] <-0.5
  (max [m/H]=-0.5)

- (Cappellari et al. 1999), wfpc2 observations
- Baade's “stars” are actually multiple systems
- ages of 50 and 100 Myr for two clusters
- This centrally concentrated blue population likely represents the last episode of star formation in NGC 205



The question as to where this gas came from is not easy to answer. Possibly, as in our Galaxy, high-velocity H I clouds may be orbiting M31, and one such cloud might have been captured by the potential well of NGC 205 and squeezed above star formation threshold.

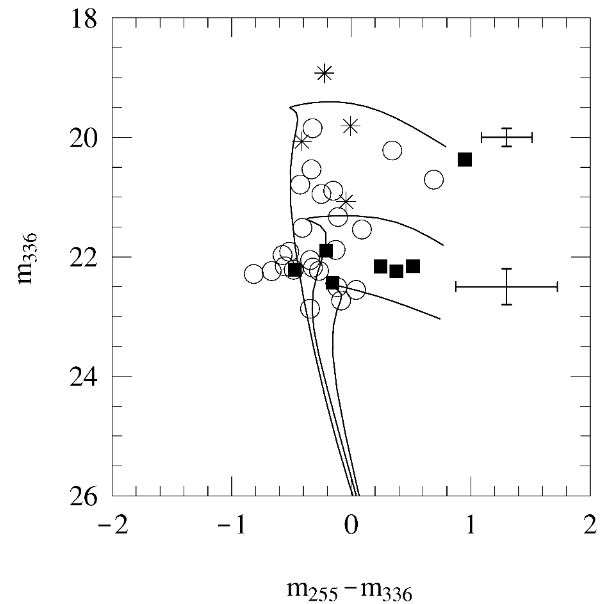


FIG. 4.—Color-magnitude diagram (m_{336} vs. $m_{255} - m_{336}$) of clusters 1 (*asterisks*) and 8 (*filled squares*) and of the Archipelago (*open circles*). Note that only the four brightest stars of cluster 1 have been included in this diagram, since the photometry of the fainter stars recognizable in Fig. 1 is affected by large errors. Mean photometric errors are shown by the error bars to the right. Overplotted are the theoretical isochrones from Bertelli et al. (1994) for the metallicity $Z = 0.02$ and ages of 20, 50, and 100 Myr, respectively. These isochrones have been transformed into the STMAG magnitude system, by adopting a true distance modulus of 24.6 mag and a reddening $E(B-V) = 0.18$. The post–main-sequence part of the isochrones has been truncated at $T_{\rm eff} = 8000$ K.

The C99 clusters/associations are not the only young population

A young 'field' population is revealed by ACS/HRC in the central region

Monaco, Saviane et al. (2009, A&A, 502, L9)

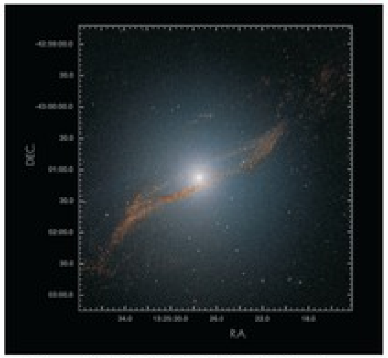
HIGHLIGHTS: this week in A&A

Volume 502-2 (August II 2009)

In section 1. Letters to the Editor

"Uncovering the kiloparsec-scale stellar ring of NGC5128", by J.T. Kainulainen et al., A&A 502, p. L5

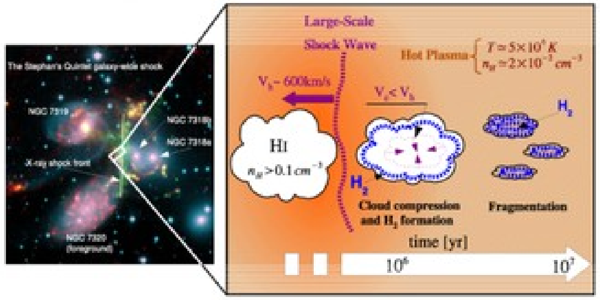
A 0.1" resolution near-infrared image of NGC 5128 (the "hamburger" galaxy Centaurus A) has been obtained with NACO on VLT. It reveals a dust-free image of a nuclear ring of 1kpc size. The ring is decomposed into thousands of separate, mostly point-like sources, the most luminous identified as red supergiants or low-mass star clusters.



In section 4. Extragalactic astronomy

"H_2 formation and excitation in the Stephan's quintet galaxy-wide collision", by P. Guillard, F. Boulanger, G. Pineau des Forets, P.N. Appleton, A&A 502, p. 515

Extremely powerful mid-IR H2 line emission has been detected towards a large-scale inter-galactic shock, corresponding to a 900km/s galaxy collision in the Stephan's Quintet (SQ) galaxy group. There is no accompanying star formation, and it appears that the H2 lines are in fact the main coolant of the post-shock gas. To explain this puzzling situation, the authors propose a scenario where two flows of multiphase dusty gas collide. The H2 gas coexists with a hot X-ray emitting plasma, but radiates more than the X-ray gas, because it is the main coolant. Dust is destroyed, soon after having catalyzed the formation of H2 molecules. While the 900km/s shock heats the diffuse gas and creates the X-ray plasma, denser gas is also formed by high pressure, experiencing slower 20km/s MHD shocks and exciting the H2 lines. This multi-phase scenario can apply to many other similar situations in galaxy collisions, or cooling flow clusters, where H2 lines dissipate the mechanical energy effectively.



In section 1. Letters to the Editor

"The young stellar population at the center of NGC 205", by L. Monaco et al., A&A 502, p. L9

Using high-resolution deep imaging with the ACS, this paper reports the discovery of a young (< 0.7 Gyr) stellar population in the nuclear region of NGC 205. This dE is notable for its abundance of gas and indications of a rotationally supported disk. The authors find that the rate of star formation is consistent with a recently initiated event, relative to the evolutionary timescale for the old population and possible continued bursting on a timescale of tens of Myr. The present blue population is consistent with a triggering event, possibly after first passage of the galaxy by M31.

Astronomy & Astrophysics

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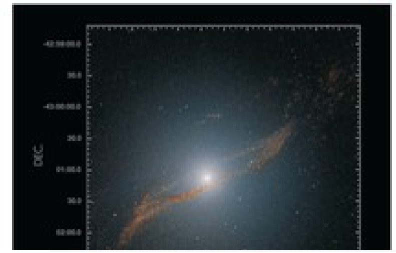

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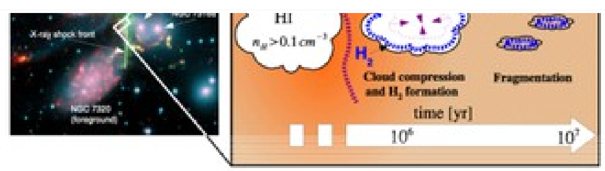

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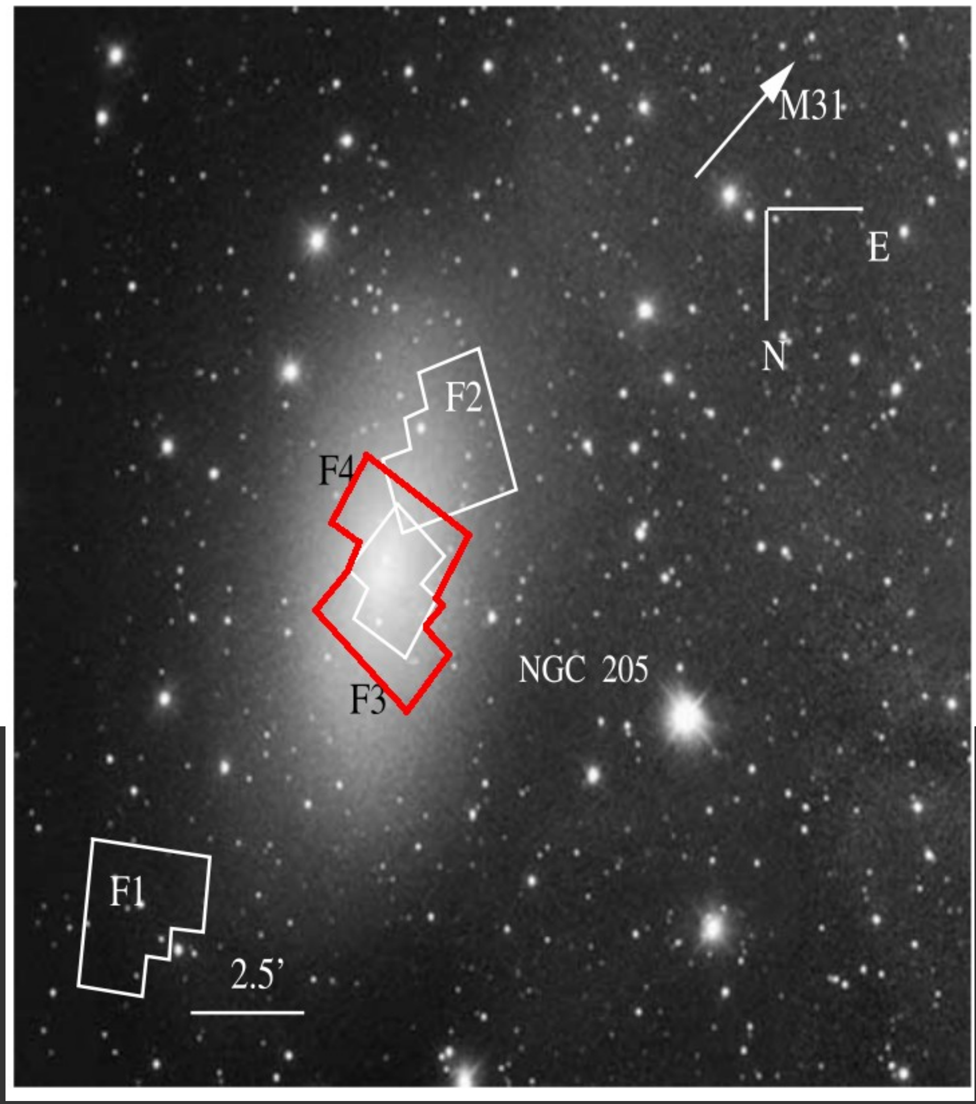
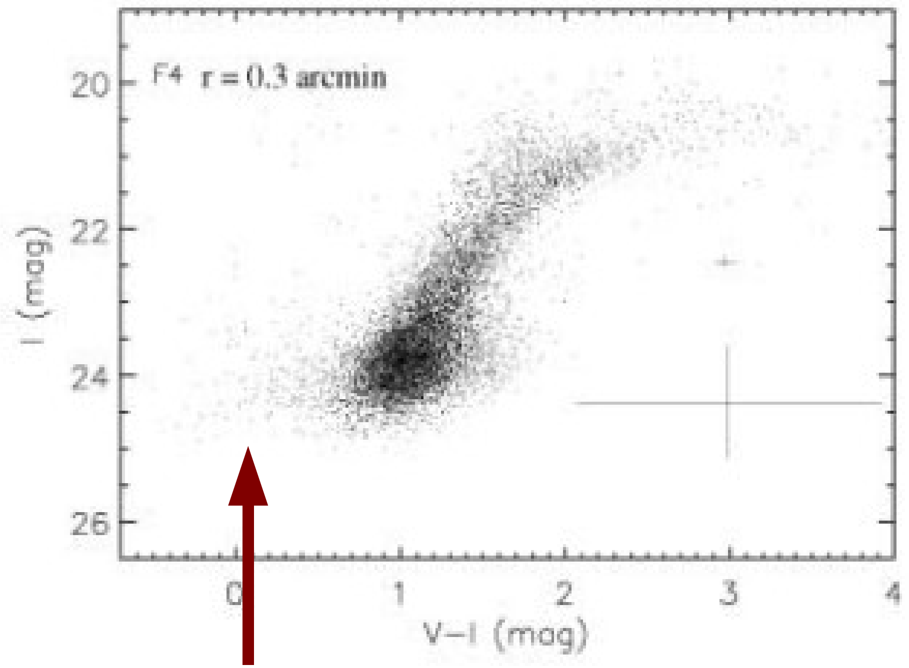
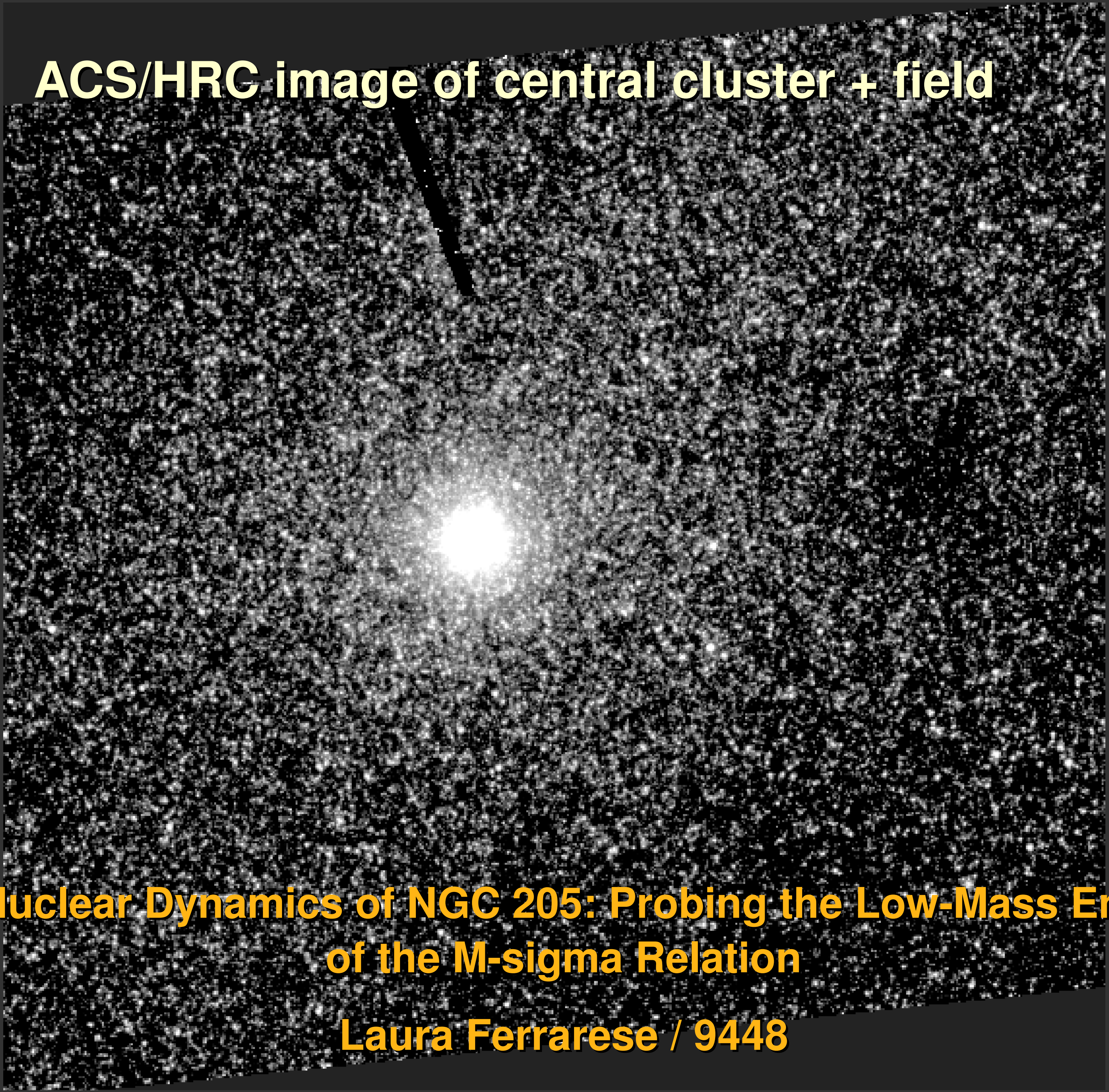
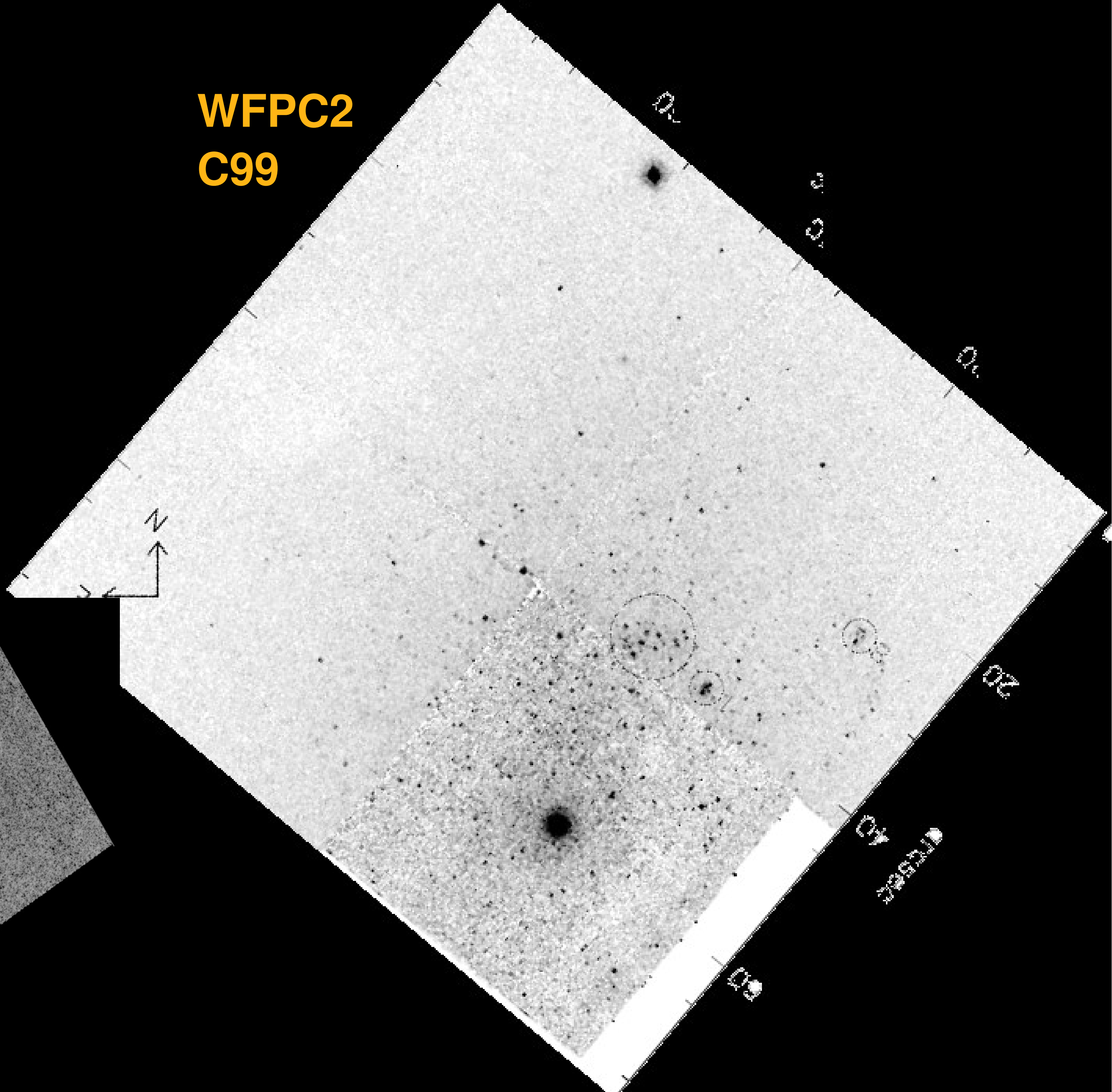
Some hint in Butler & Martinez-Delgado (2005)



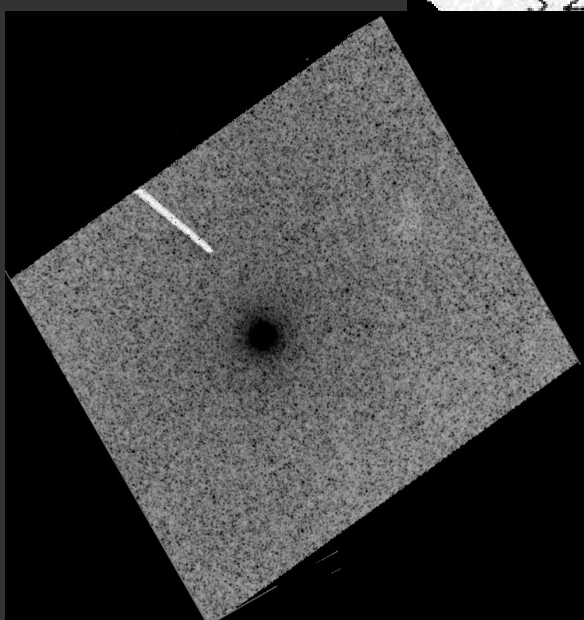


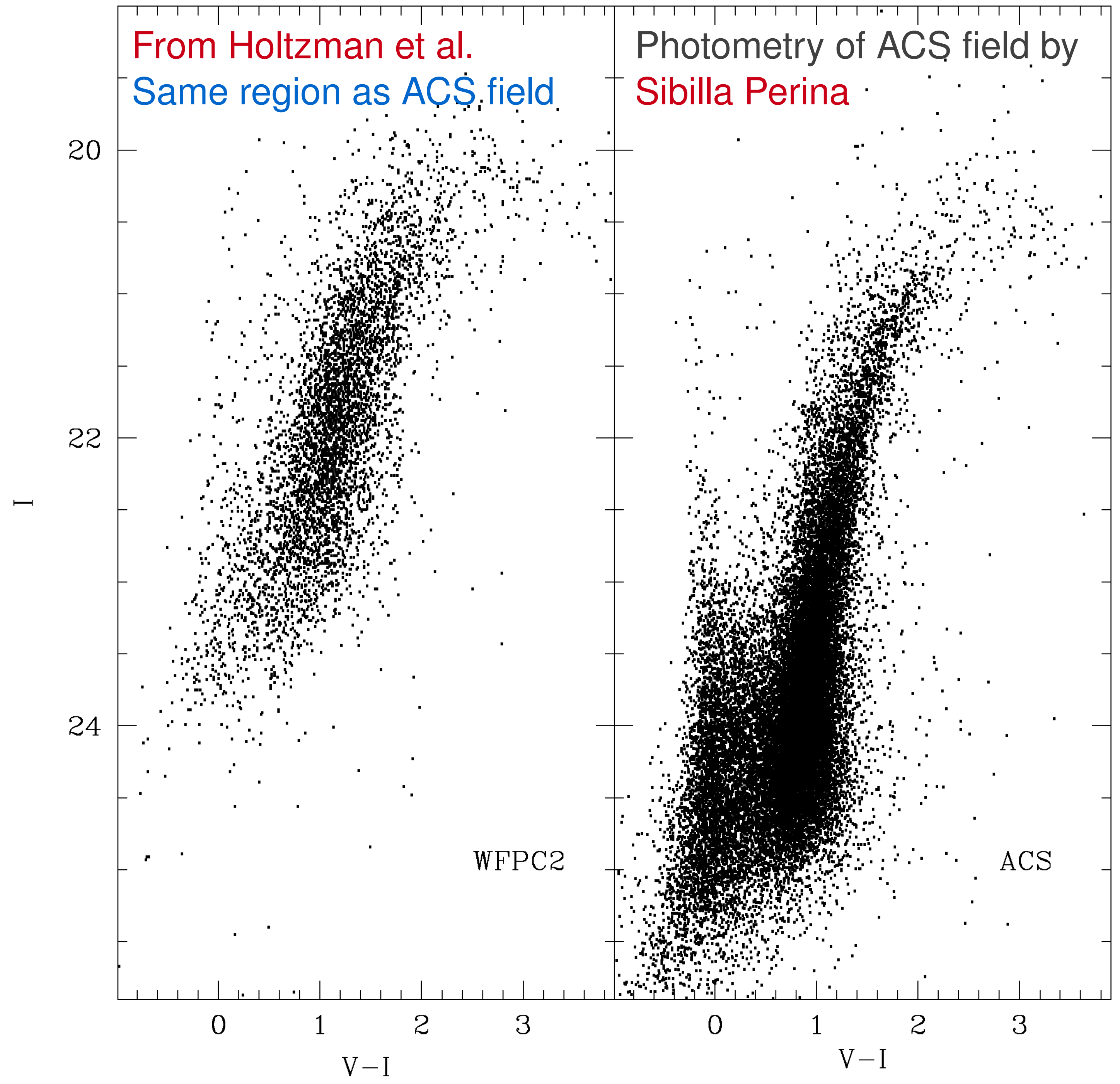

ACS/HRC image of central cluster + field
Nuclear Dynamics of NGC 205: Probing the Low-Mass End of the M-sigma Relation
Laura Ferrarese / 9448

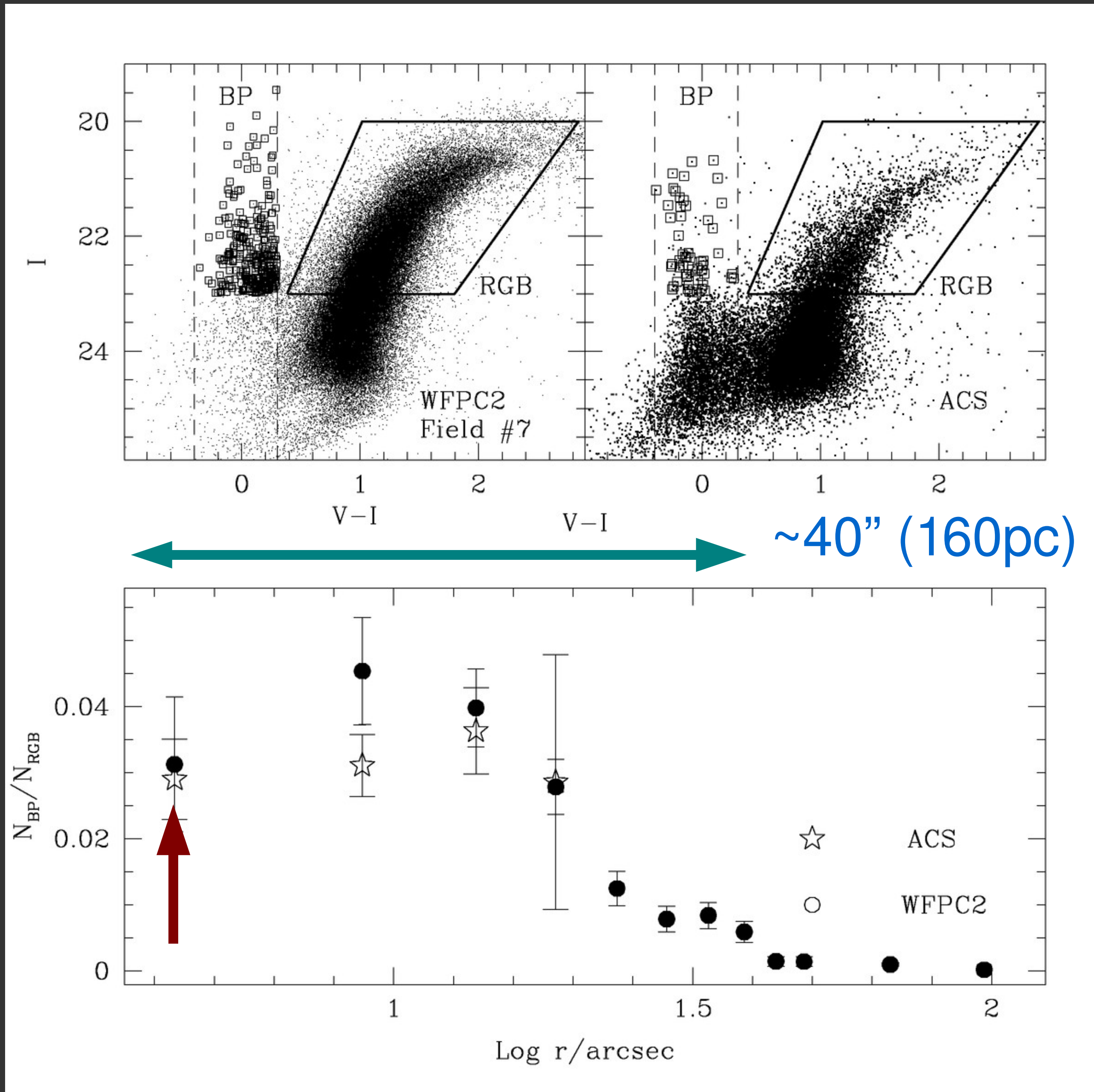
WFPC2
C99

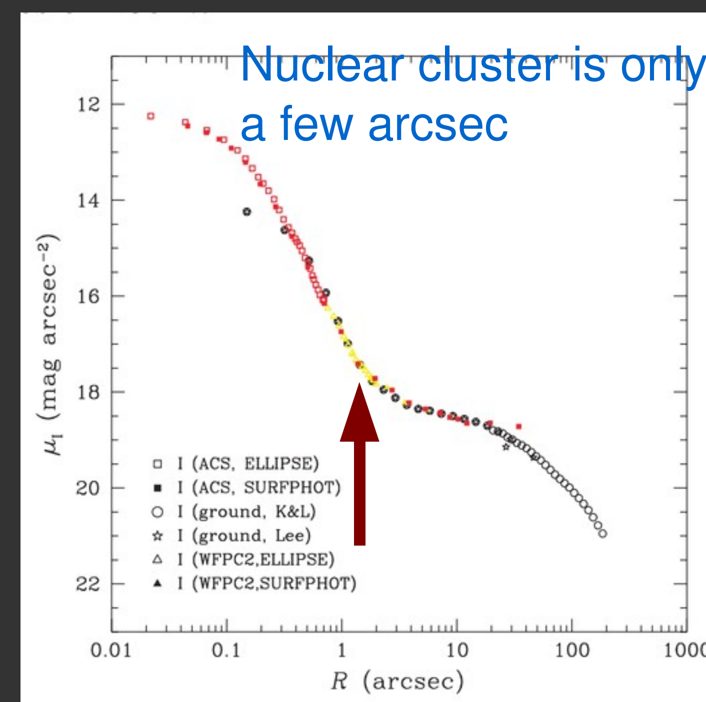


ACS
(PI=Ferrarese)



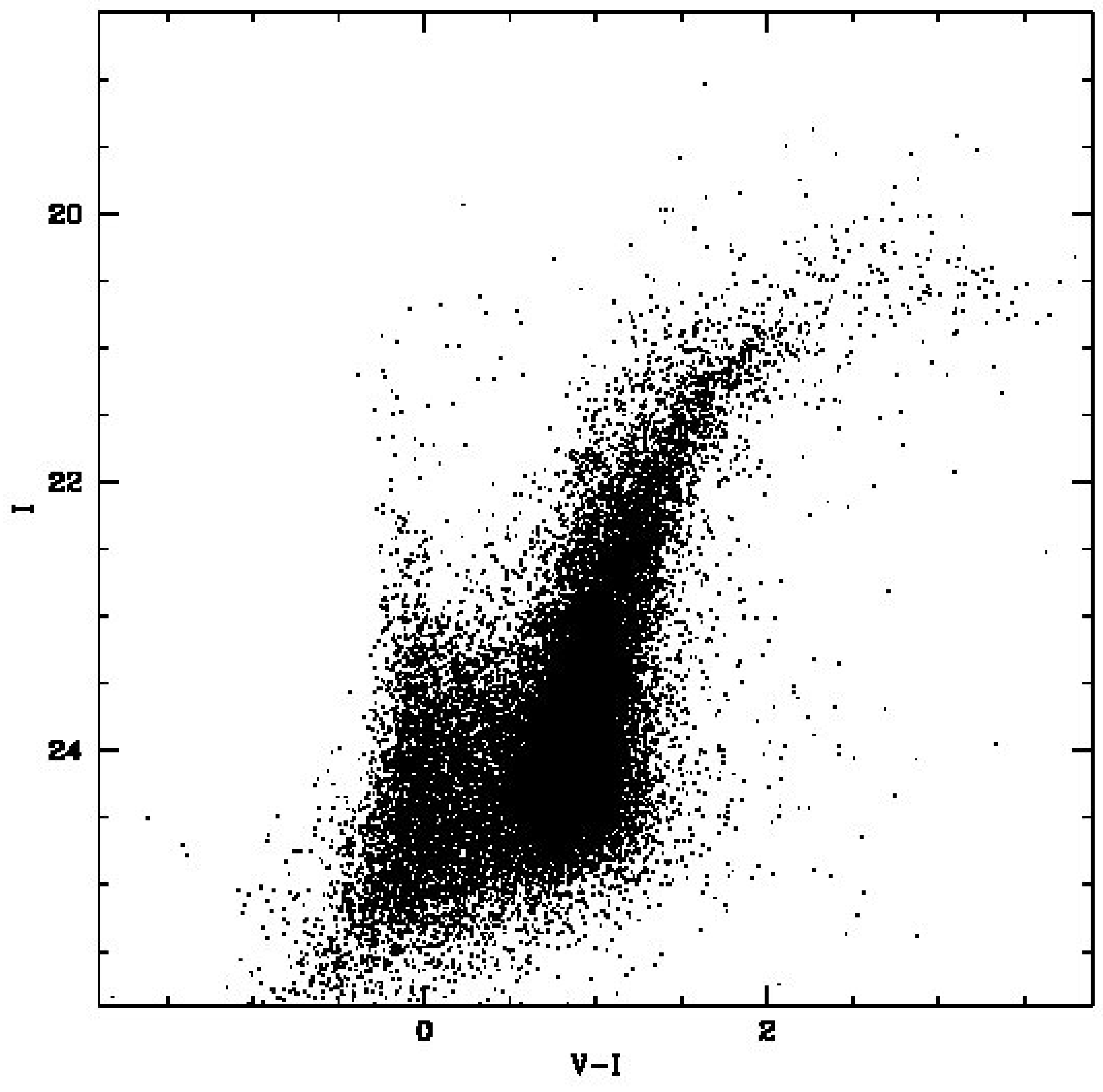

From Holtzman et al.
Same region as ACS field
Photometry of ACS field by
Sibilla Perina
WFPC2
ACS
I
V−I
20
22
24
0
1
2
3



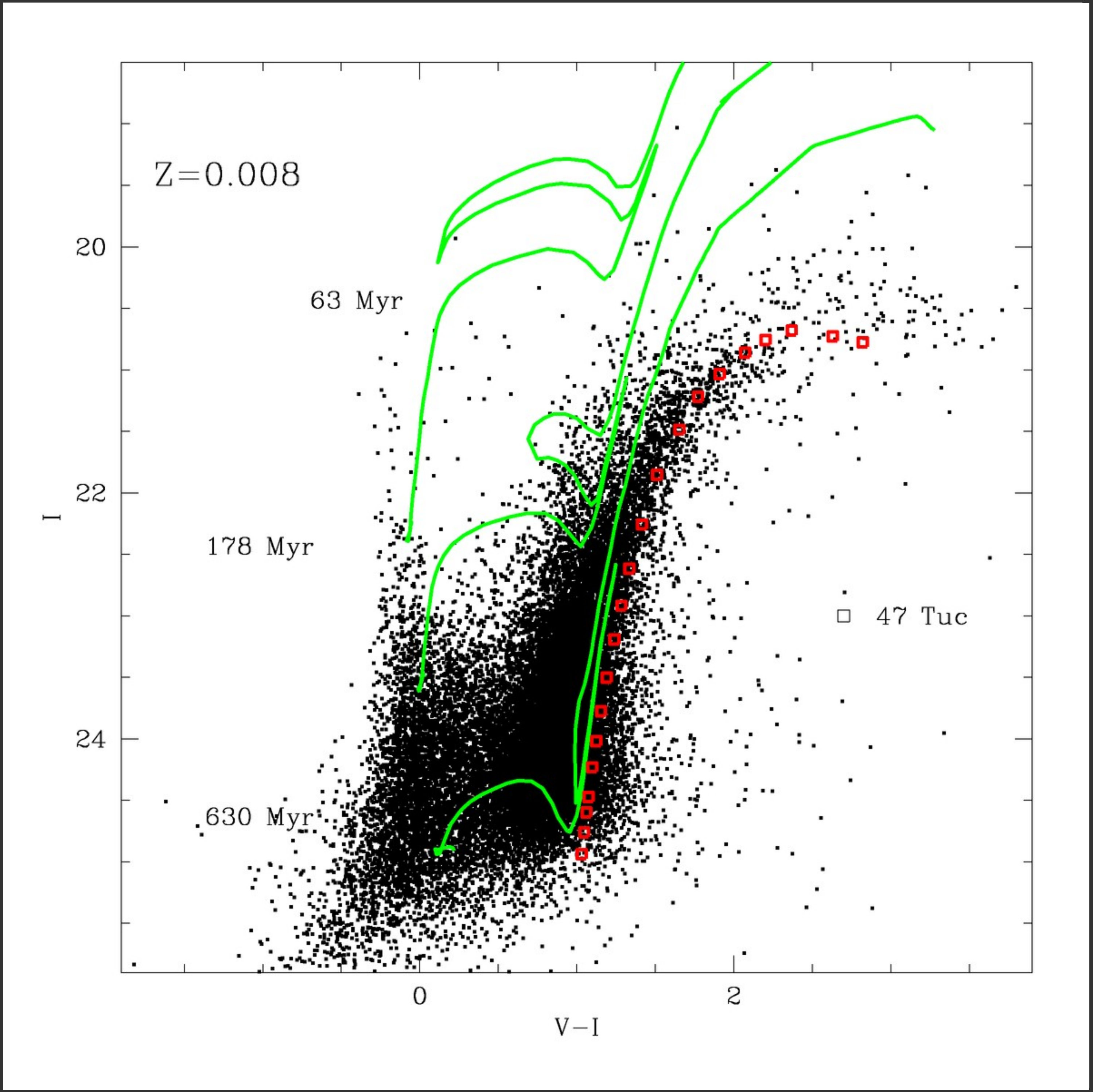


S.B. Profile from Valluri, Ferrarese et al. (2005)

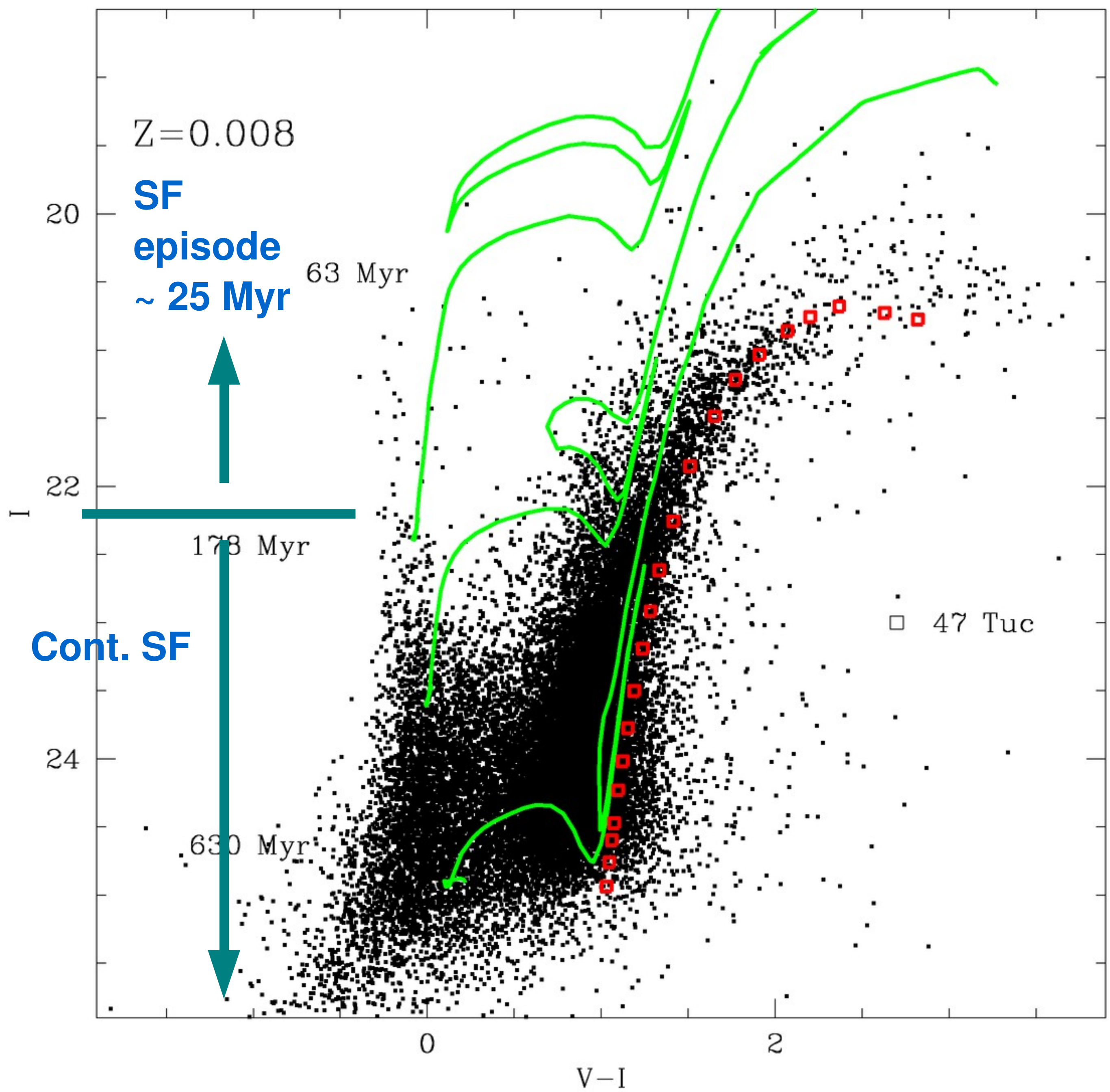
FIG. 4.—Surface brightness profile of NGC 205 in the I band, obtained by combining the *HST* ACS observation discussed in this paper with the ground-based data of Kim & Lee (1998) and Lee (1996). The radius is the effective radius, given by $r = r_{SMA}[1 - \epsilon(r)]^{1/2}$, where r_{SMA} is the galaxy semimajor axis and ϵ is the ellipticity.



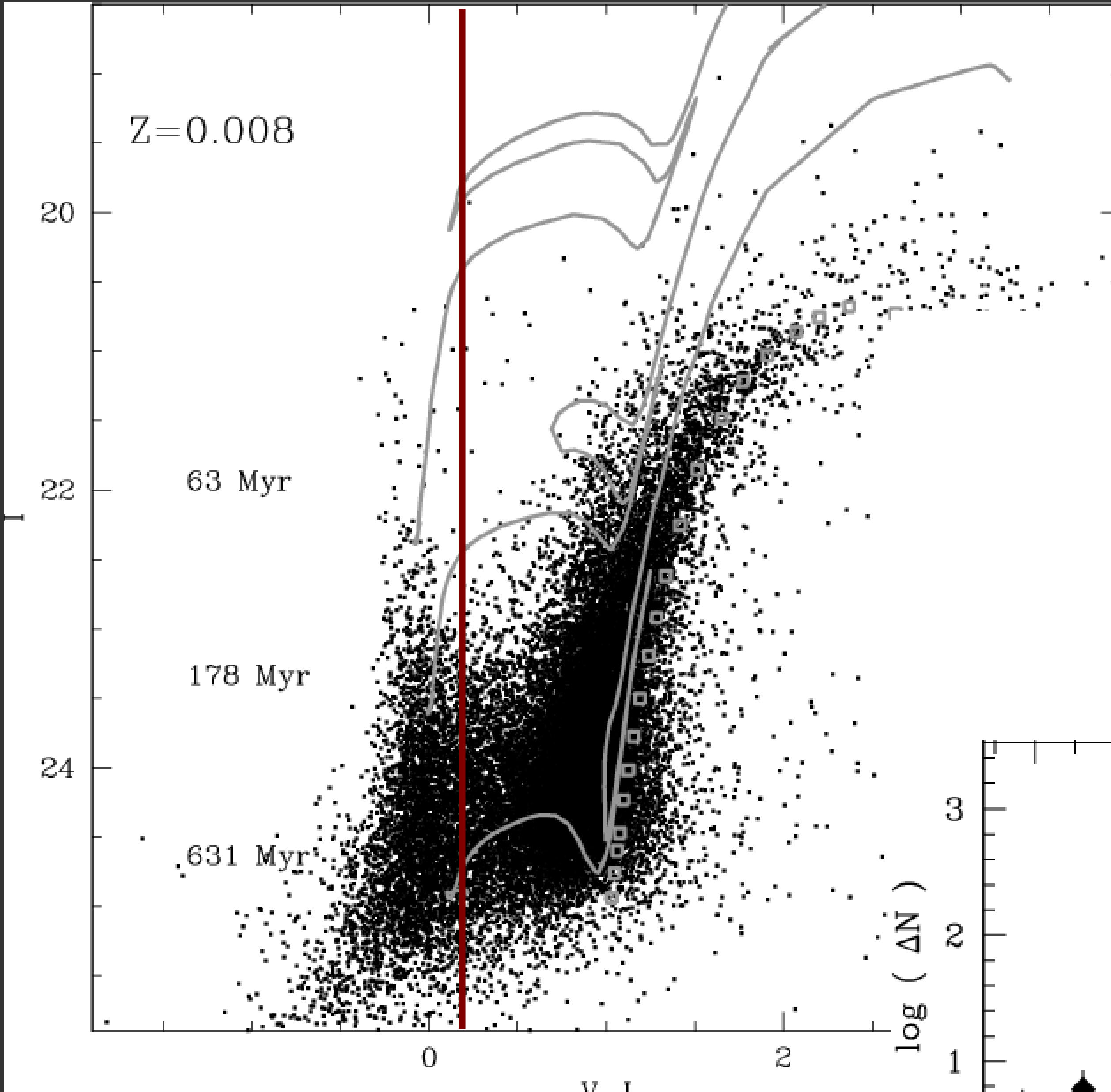
20
22
24
I
0
2
V−I

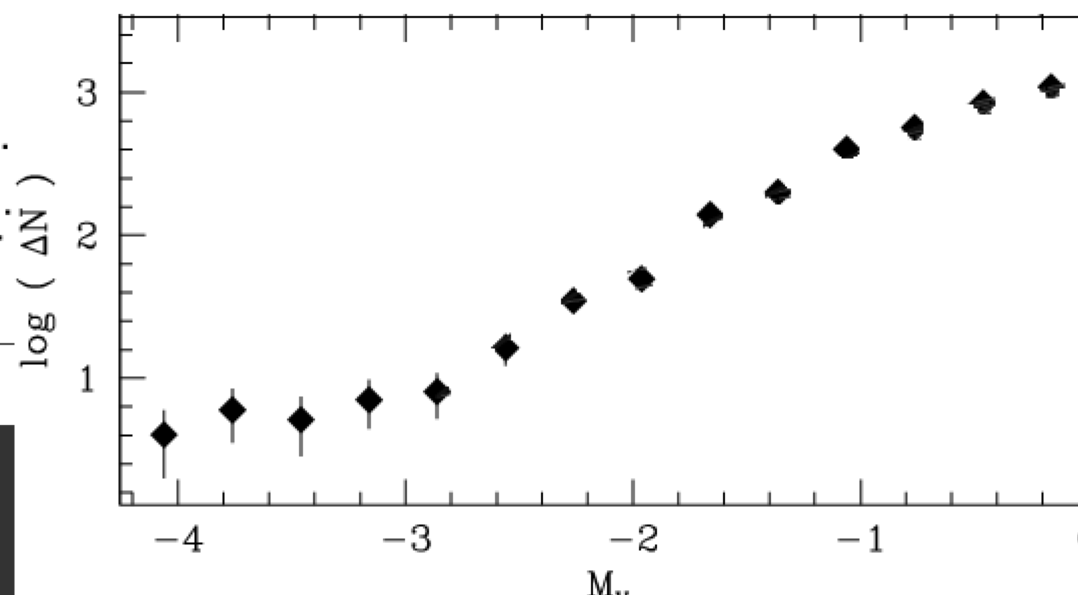


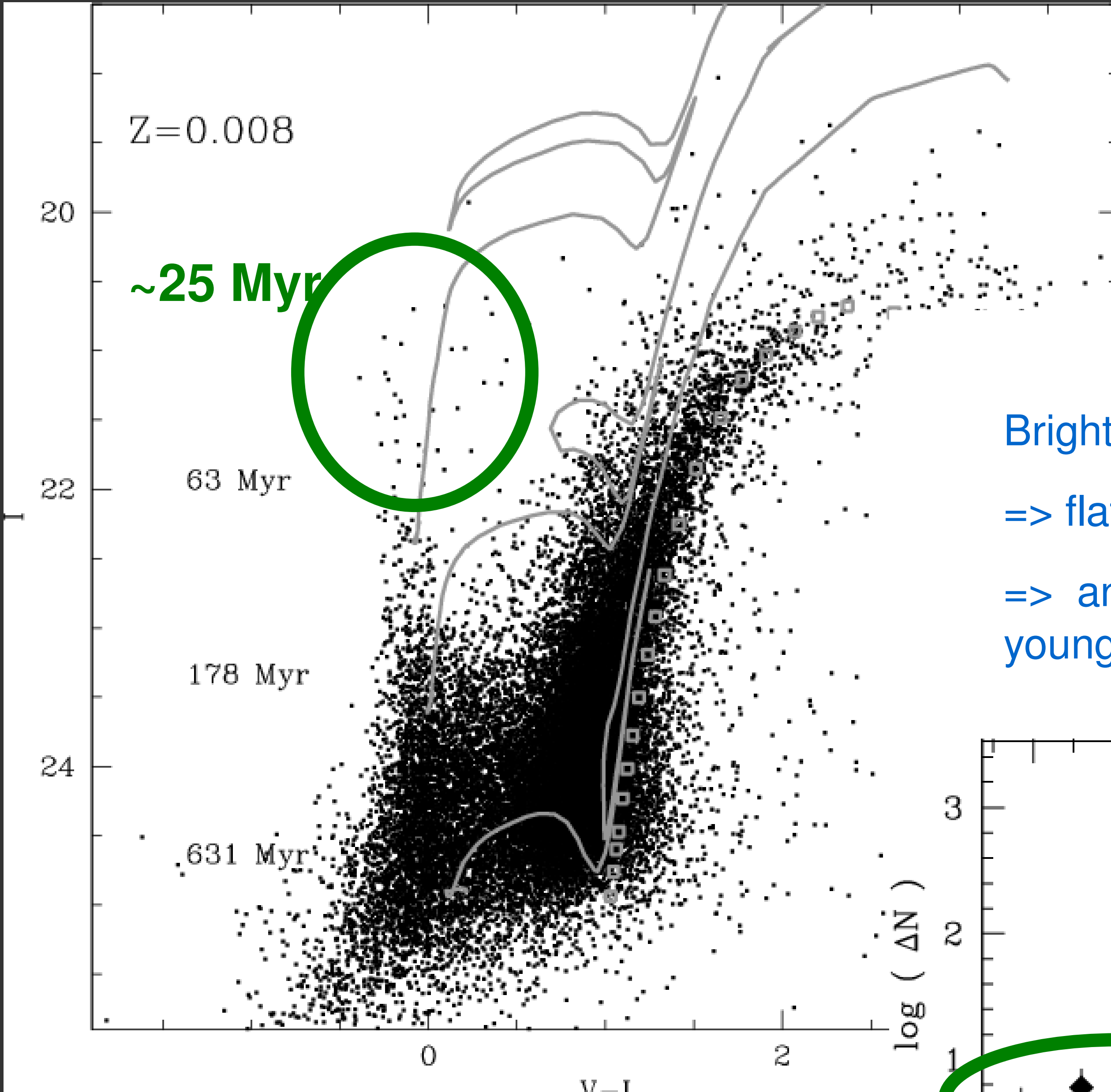
Z=0.008
63 Myr
178 Myr
630 Myr
47 Tuc
20
22
24
0
2
I
V−I



Z=0.008
SF
episode
~ 25 Myr
63 Myr
178 Myr
Cont. SF
630 Myr
47 Tuc
20
22
24
I
0
2
V−I


Z=0.008
63 Myr
178 Myr
631 Myr
I
20
22
24
0
2
V−I

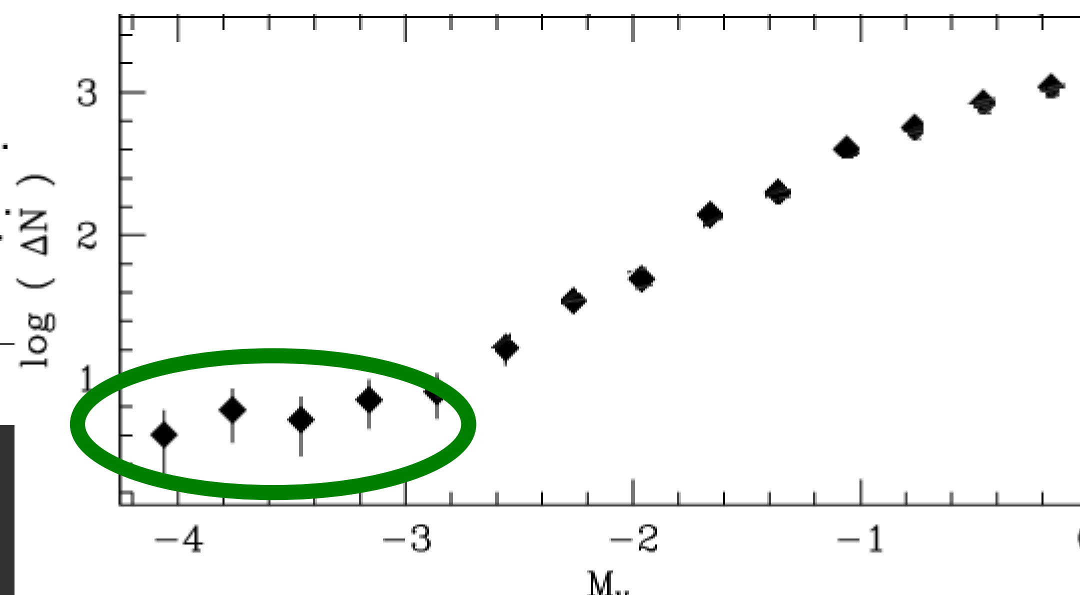

log (ΔN)
1
2
3
−4
−3
−2
−1
0
M_V

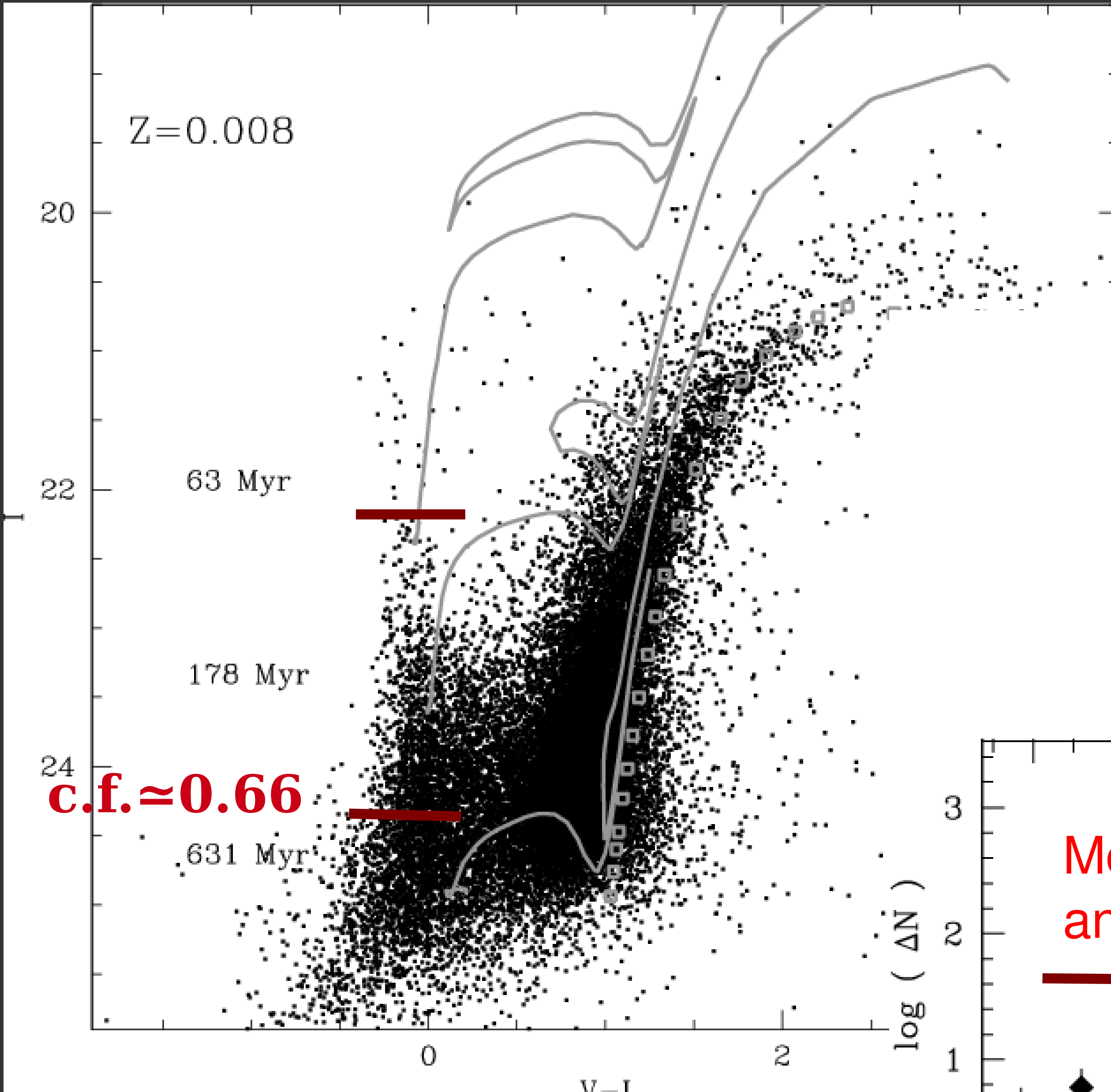


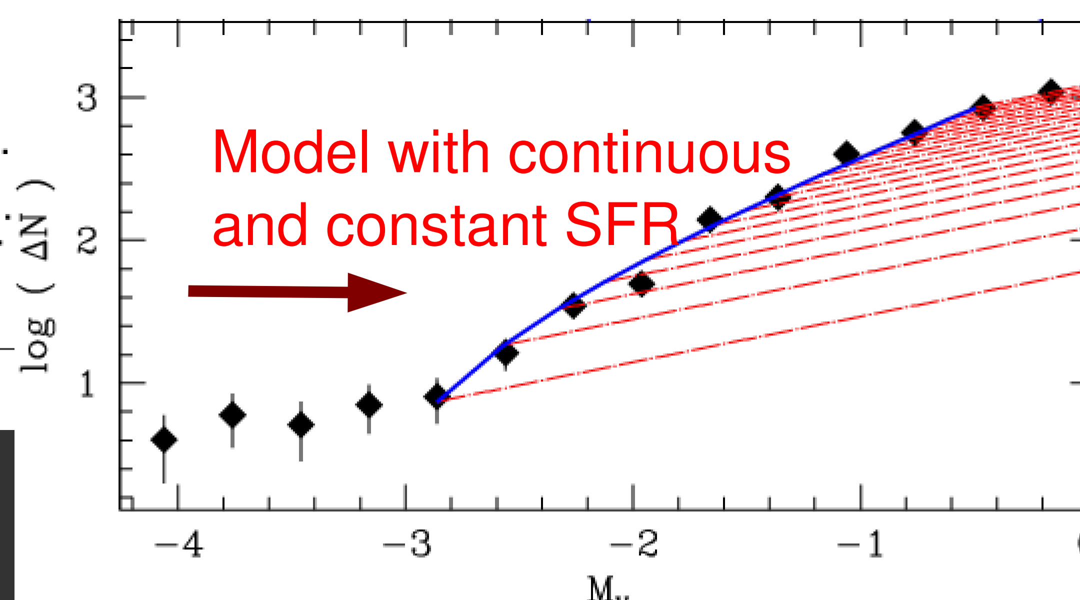
Brightest portion of MS

=> flatter LF

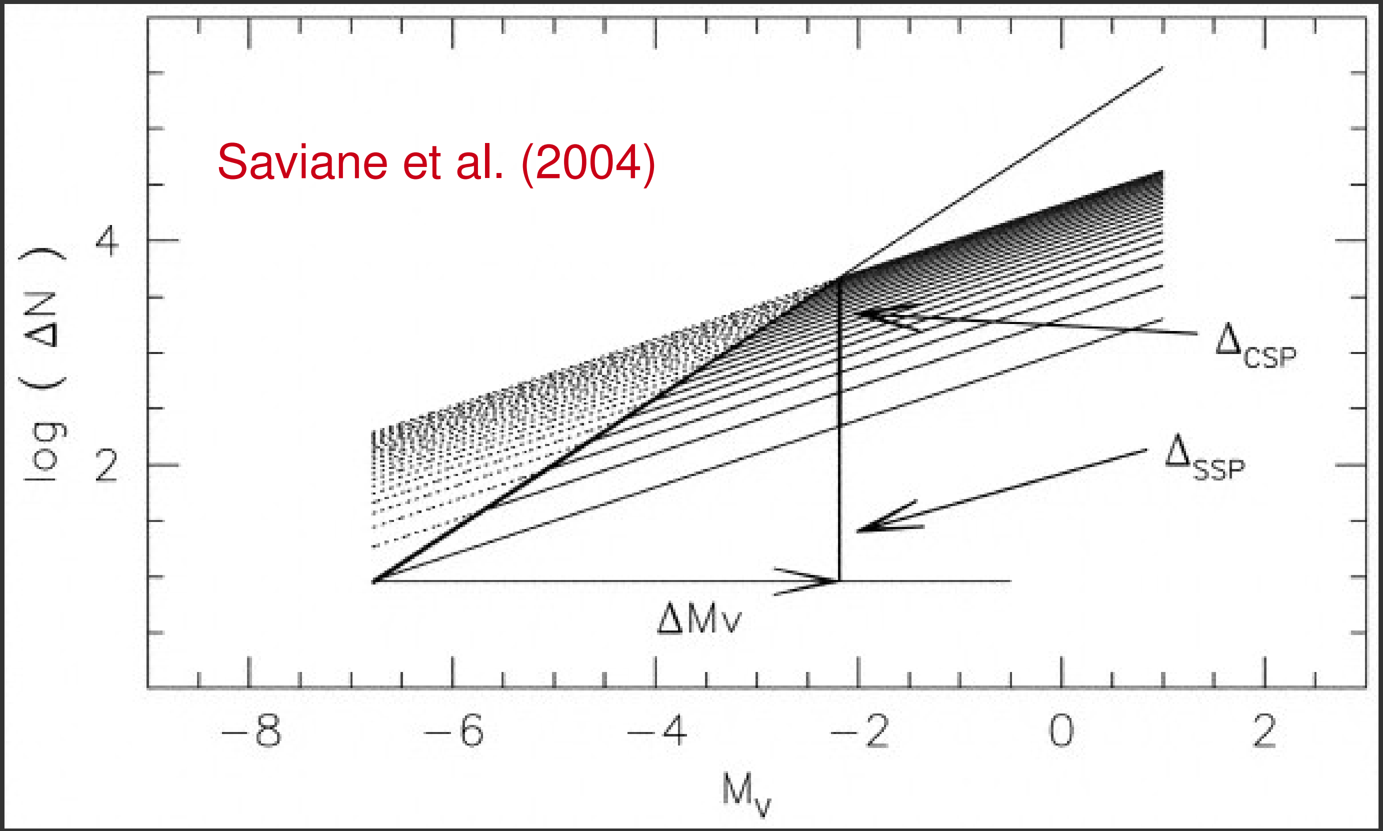
=> an isolated SF episode slightly younger than C99 clusters




Z=0.008
20
22
24
I
63 Myr
178 Myr
631 Myr
c.f.≃0.66
0
2
V−I


Model with continuous
and constant SFR
log (ΔN)
3
2
1
−4
−3
−2
−1
0
M_V

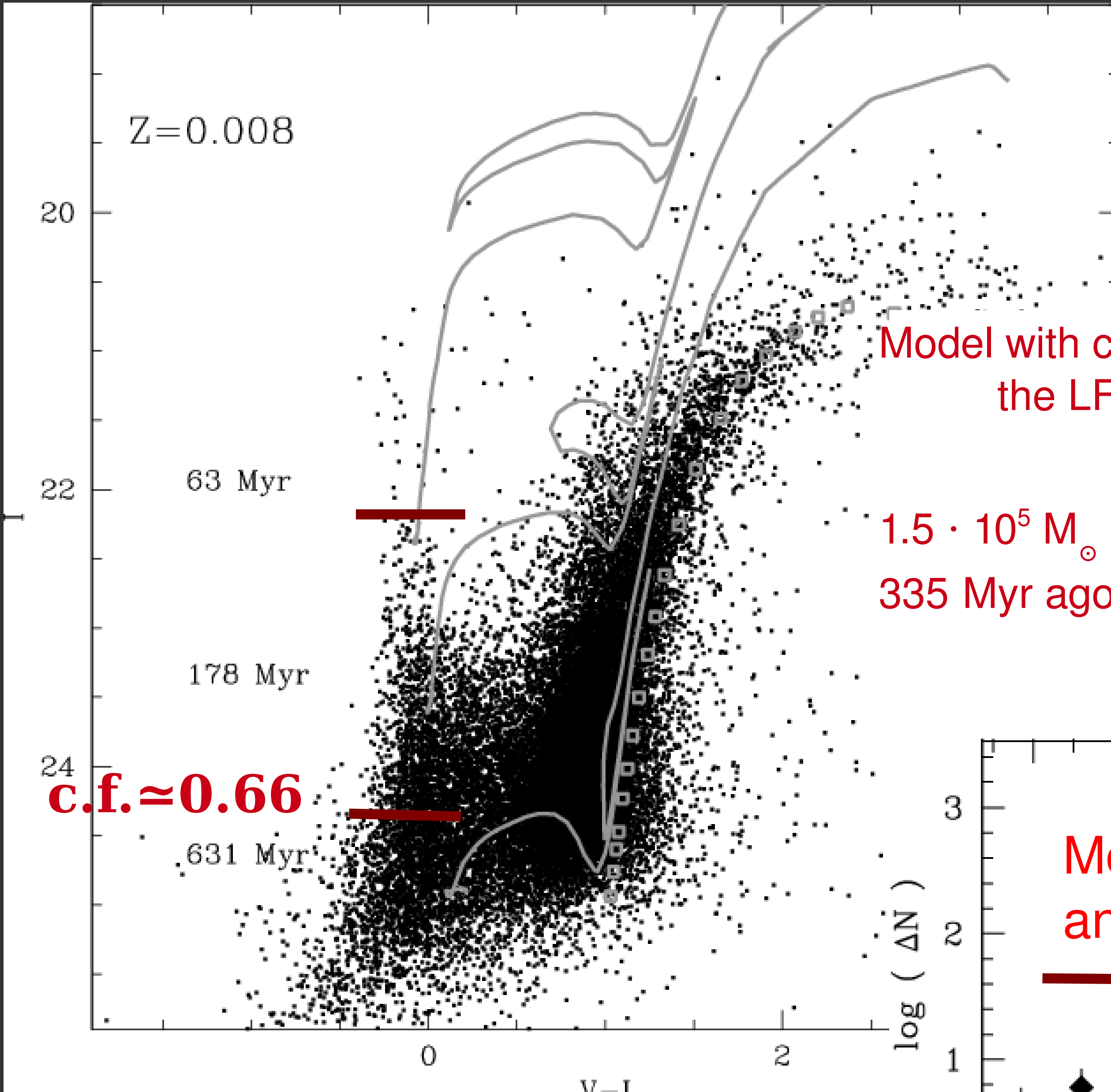
The LF of the MS can be used to derive the mass in young stars and the SFR at late epochs in the central region of NGC 205



$$\log \dot{n}_{\rm SSP} = (\alpha_{\rm CSP} - \alpha_{\rm SSP})\Delta M_V - \log \Delta t, \qquad \text{(B2)}$$

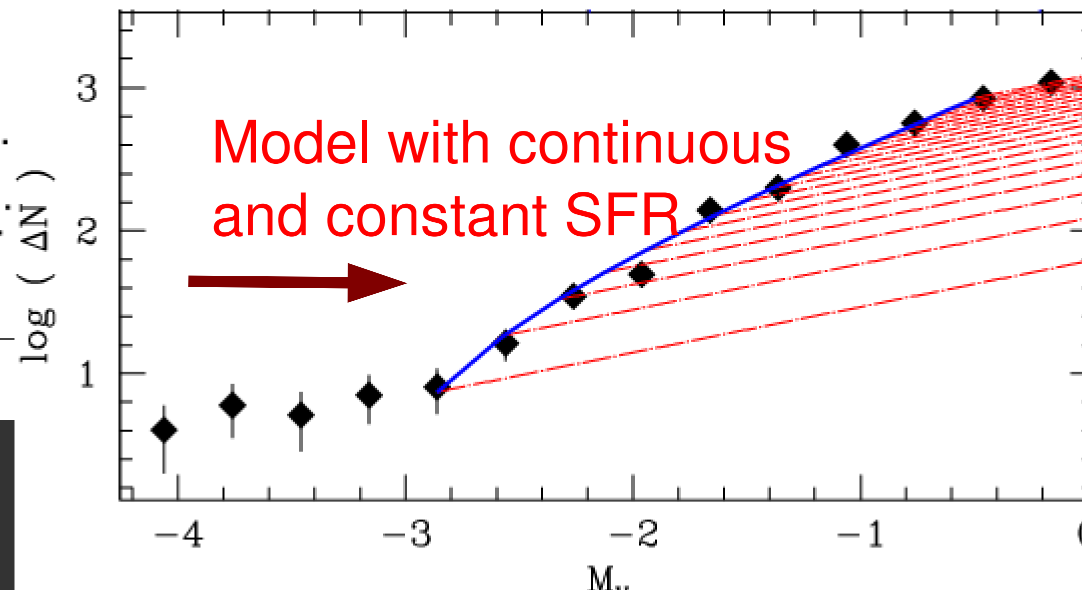
$$M_V^{\rm TMS} = 3.29 \log t - 28.51, \qquad \text{(B1)}$$

$$\alpha_{\rm CSP} = \alpha_{\rm SSP} + \frac{\Delta_{\rm CSP}}{\Delta M_V} = \alpha_{\rm SSP} + \frac{\log\left[\dot{n}_{\rm SSP}(t_{\rm max} - t_{\rm min})\right]}{3.29 \log\left(t_{\rm max}/t_{\rm min}\right)}.$$



Model with continuous and constant SFR:
the LF is reproduced by the sum of 20 SSP.

$1.5 \cdot 10^5\ M_\odot$ produced between ~62 Myr and 335 Myr ago, i.e. SFR $= 7 \cdot 10^{-4}\ M_\odot$/yr



Cepa & Beckman 1988

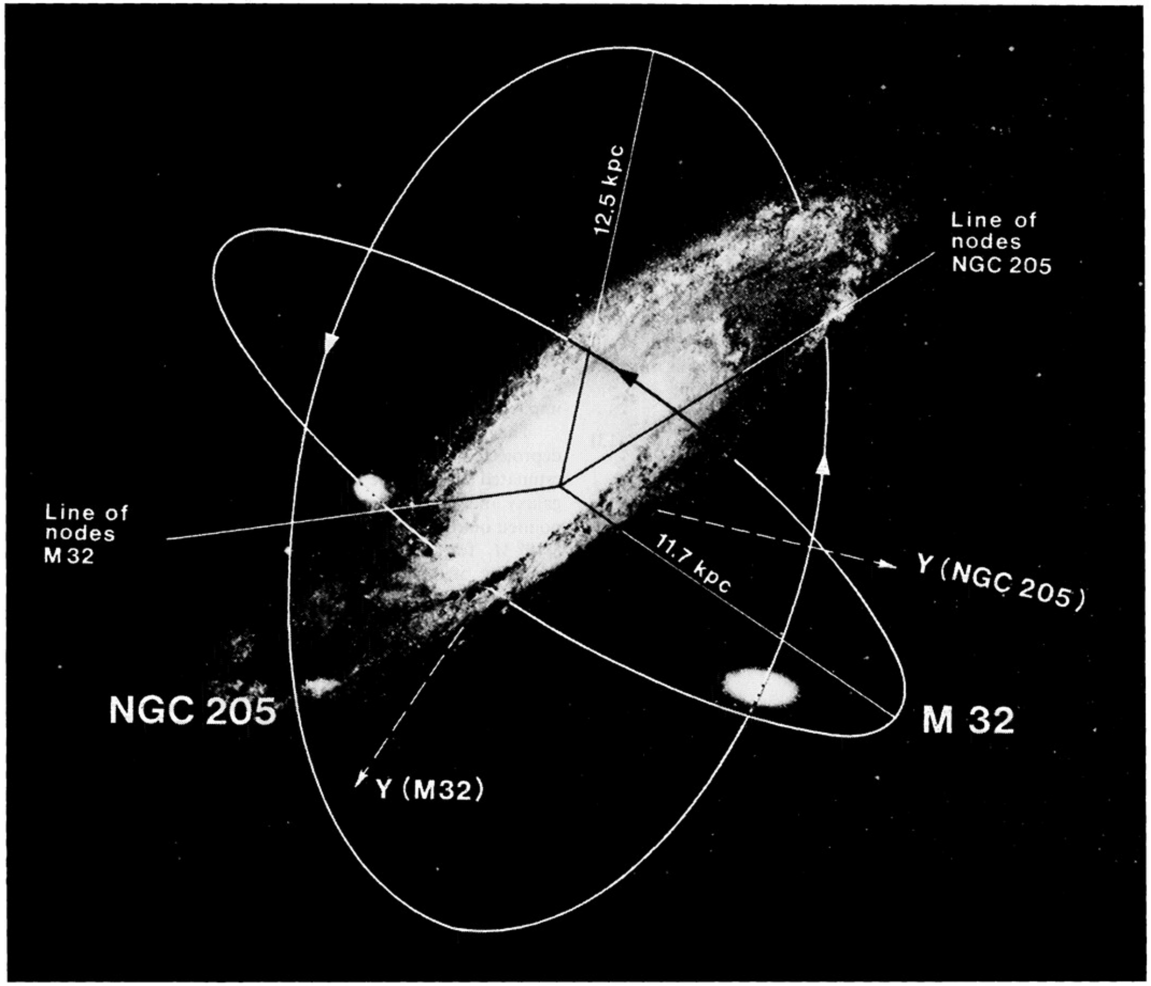


Fig. 2. Calculated orbits of M 32 and NGC 205 shown superposed on the Palomar Sky Survey print of M 31

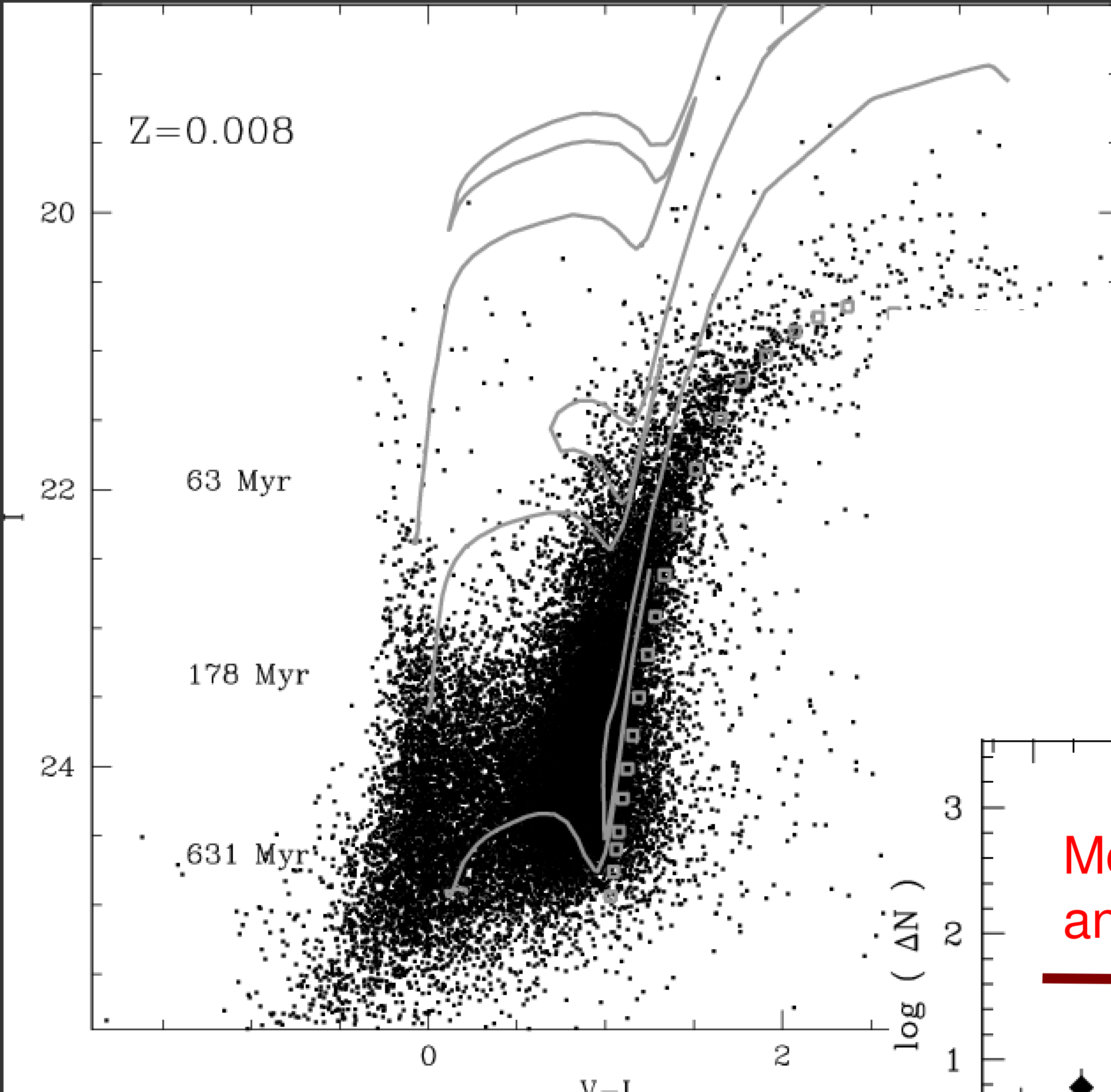
Table 1. Data assumed for the orbits of M 32 and NGC 205

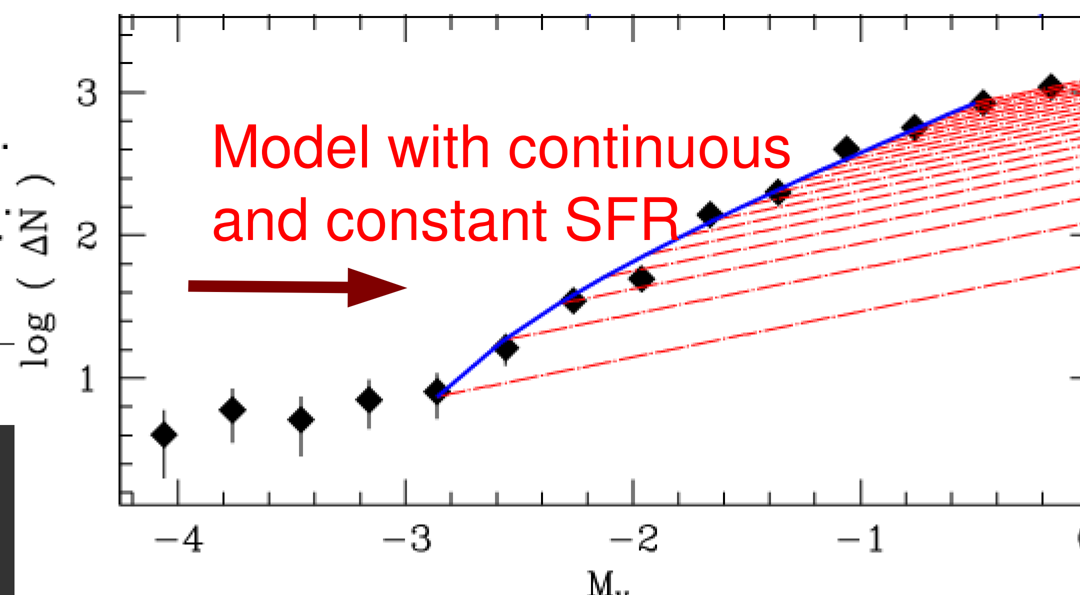
Galaxy	Mass ($M_\odot$)	$r^{a,b}$ (kpc)	χ(°)	V_r [a] (km s^{-1})	r_t [a,b,c] (kpc)
M 32	$8\ 10^{8}$ [d]	5.4	306	+82	0.84
NGC 205	$8\ 10^{9}$ [e]	7.9	173	+60	1.93

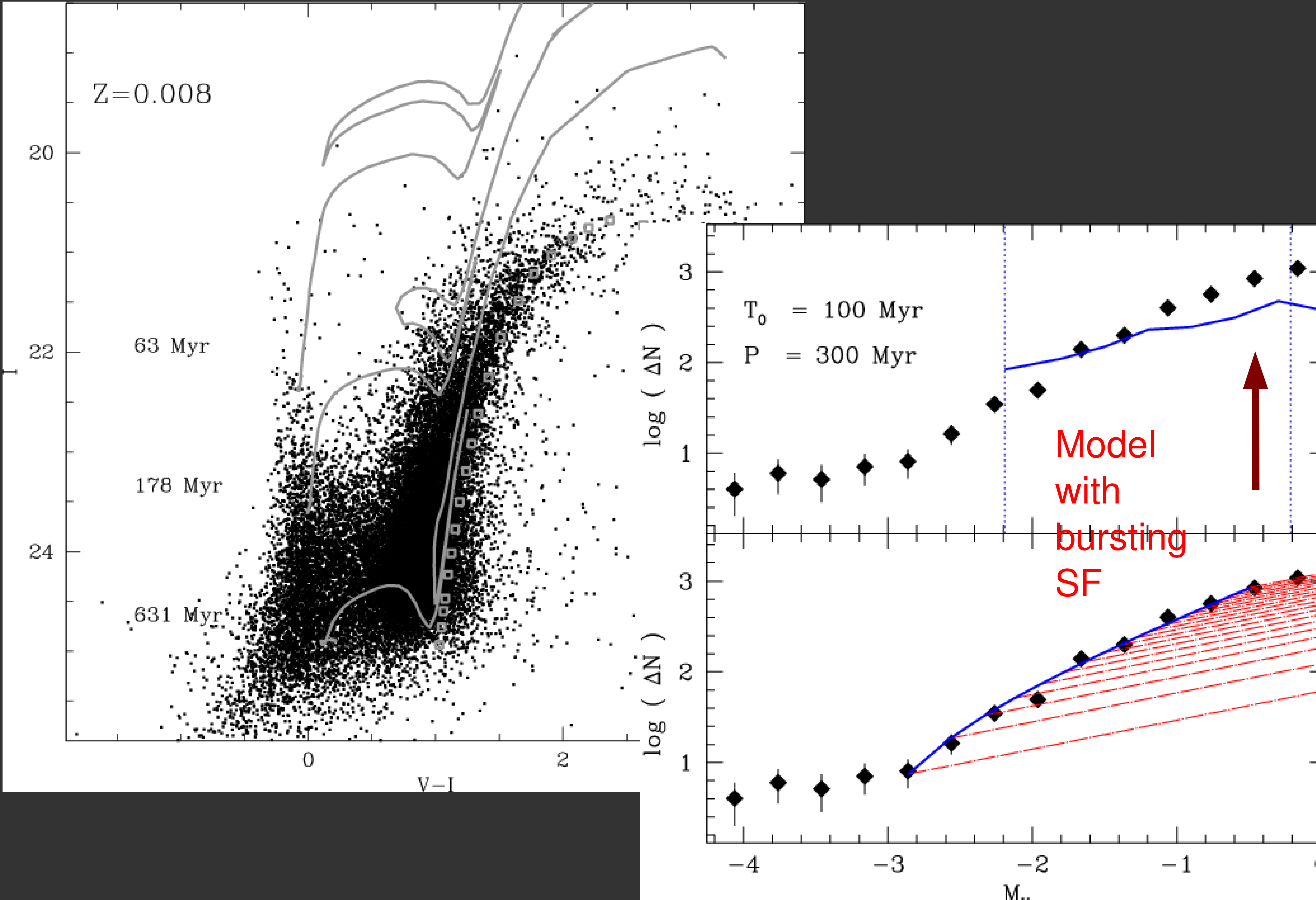
[a] From de Vaucouleurs et al. (1976)
[b] Using a distance to M 31 of 765 kpc given by Hodge (1981)
[c] Radius to isophote at 25 mag arcsec^{-2}
[d] From Nolthenius et al. (1986)
[e] Allen (1976)

Table 3. Orbital parameters of M 32 and NGC 205. T and t_0 represent, respectively, the orbital period and the time elapsed since the last crossing of the plane of M 31

Galaxy	R (kpc)	V (km s^{-1})	T (yr)	α (°)	ϕ (°)	γ (°)	β (°)	t_0 (yr)
M 32	11.7	261.7	$2.7\ 10^{8}$	70.3	70.6	−95.3	74.7	$1.3\ 10^{8}$
NGC 205	12.5	260.2	$2.9\ 10^{8}$	53.9	73.4	121.9	140.2	$9.3\ 10^{7}$


Z=0.008
63 Myr
178 Myr
631 Myr
20
22
24
I
0
2
V−I

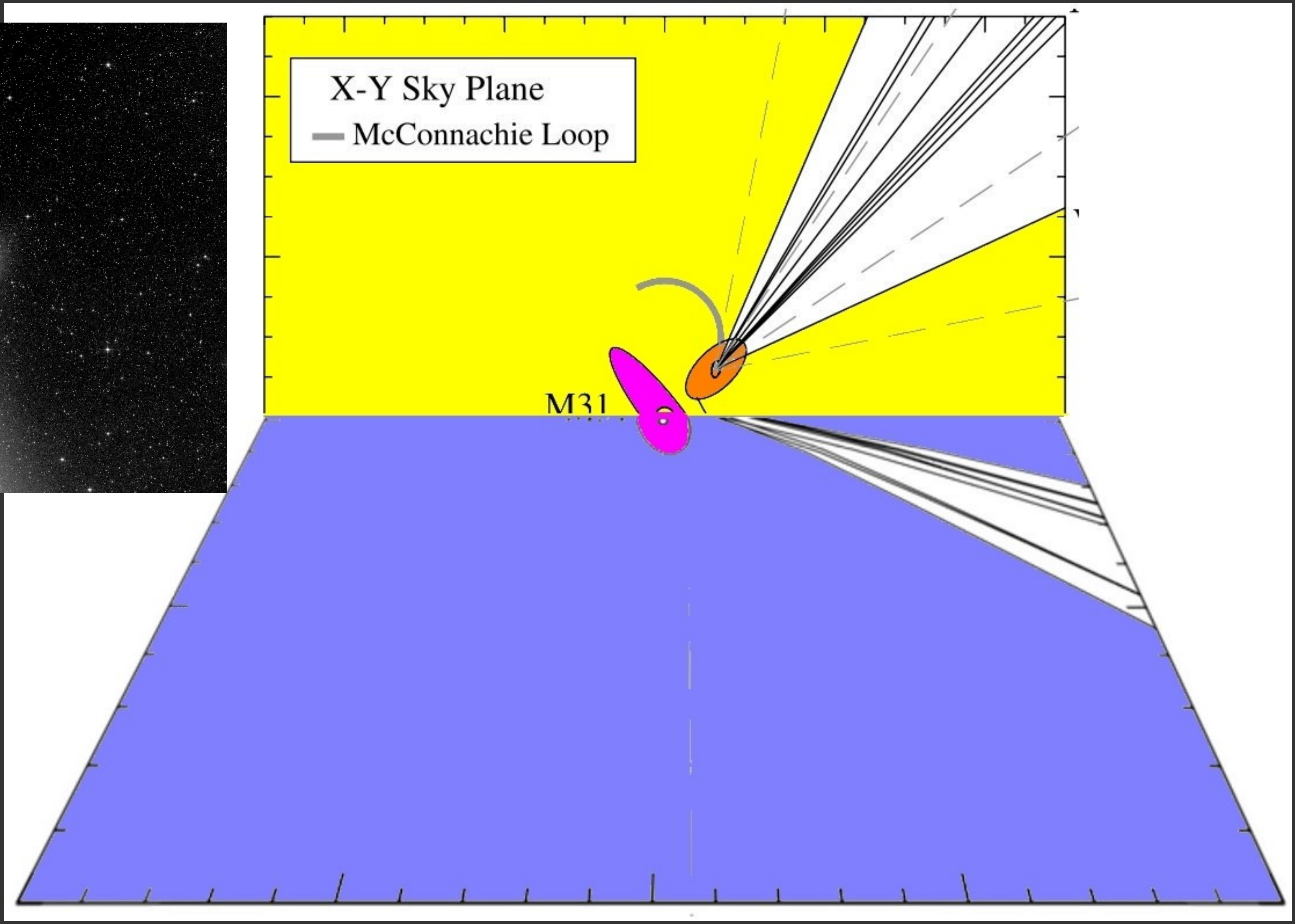

Model with continuous
and constant SFR
log (ΔN)
1
2
3
−4
−3
−2
−1
0
M_V



Z=0.008
20
22
24
I
63 Myr
178 Myr
631 Myr
0
2
V−I
T_0 = 100 Myr
P = 300 Myr
log (ΔN)
3
2
1
Model
with
bursting
SF
−4
−3
−2
−1
0
M_V

Our photometry does NOT lend support the hypothesis of a tidally triggered SF at late epochs in NGC 205.

Rather, a continuous SF may be consistent with NGC 205 being in its first interaction with M 31, as recently proposed by Howley et al. (2008).

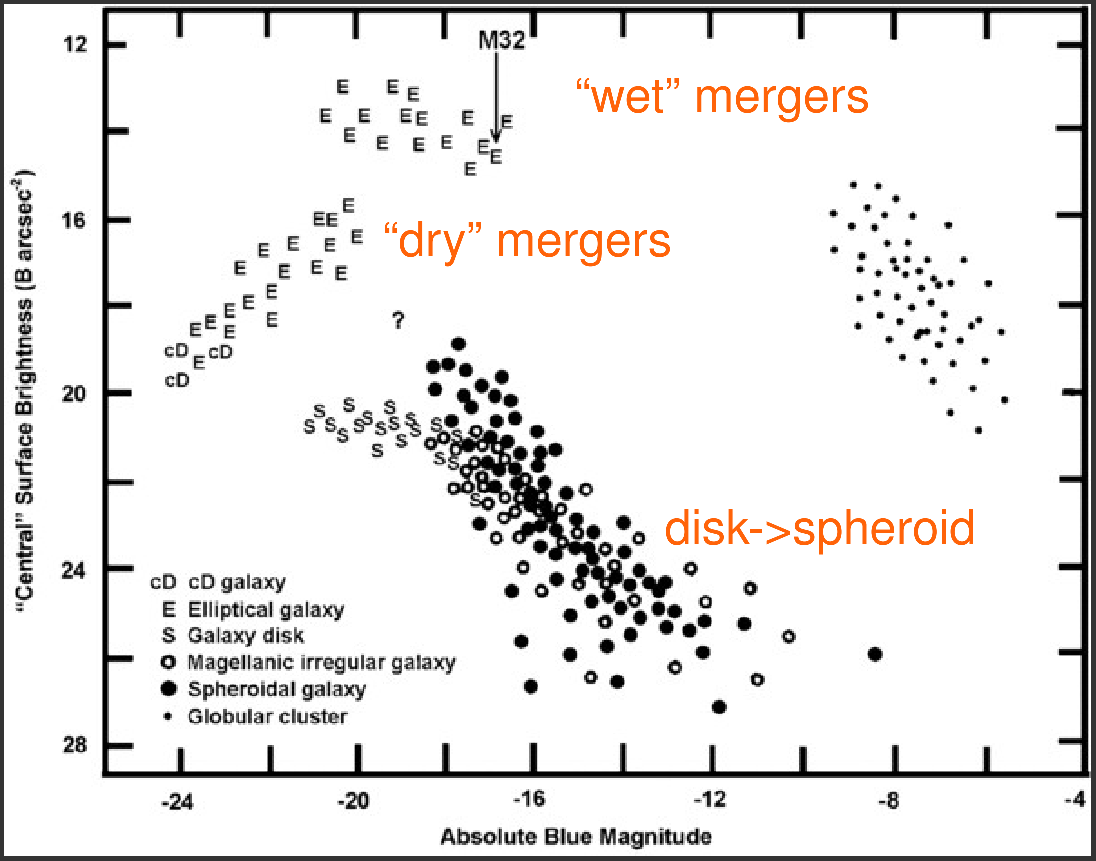


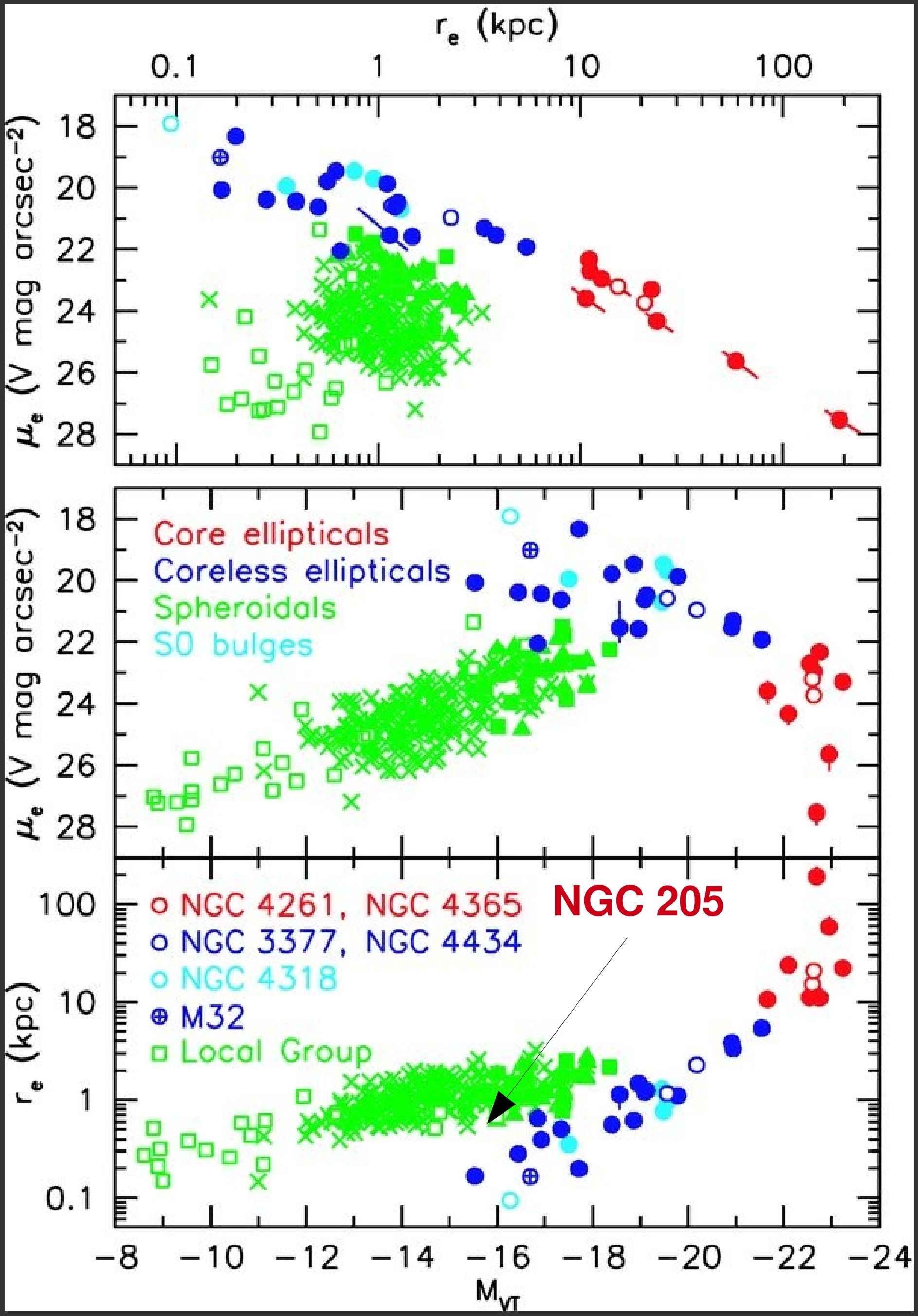
The bigger picture

Kormendy et al. (2009)

-- E-E dichotomy

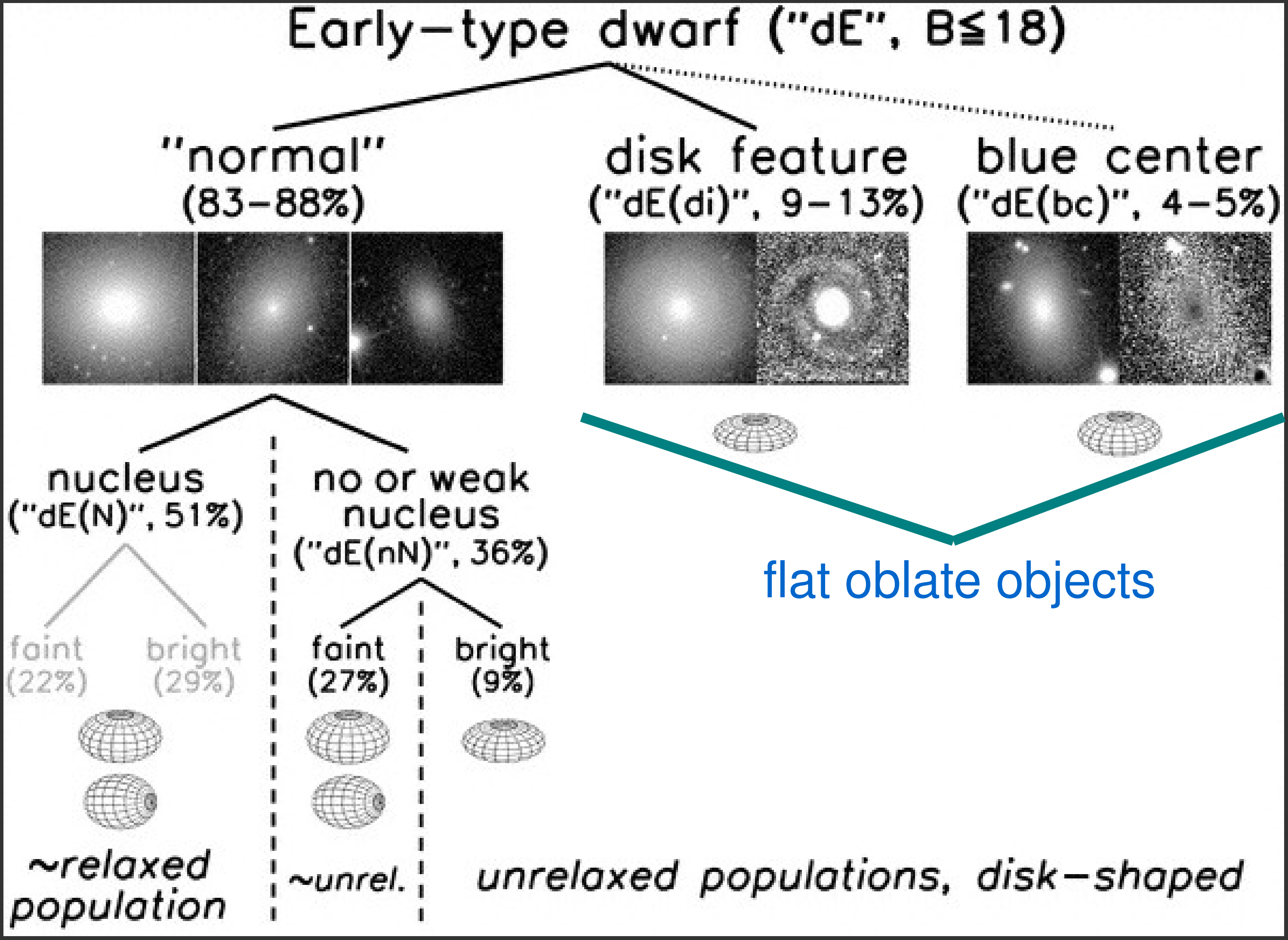
-- E-Sph dichotomy





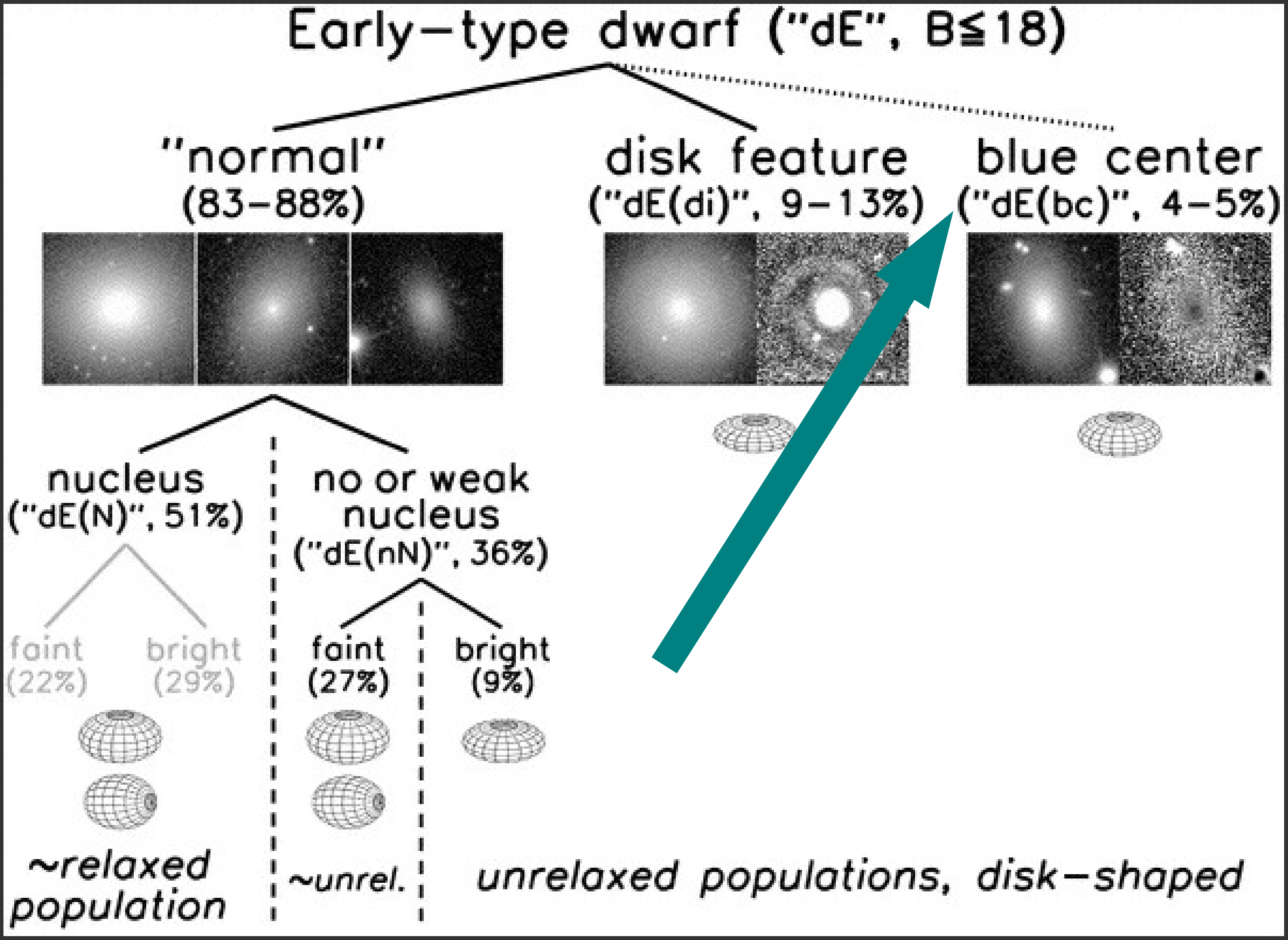
Lisker et al. (2007)

[...] dEdis are not spheroidal galaxies that just have an embedded disk component but are instead a population of genuine disk galaxies. [...]



Lisker et al. (2007)

[...] dEdis are not spheroidal galaxies that just have an embedded disk component but are instead a population of genuine disk galaxies. [...]



Galaxy threshing

(Bekki et al. 2001)

M32: from disk to spheroid

n-body/smoothed particle hydrodynamics simulations

Started several Gyr ago as a low-luminosity spiral galaxy (M/Msun=4e9

later stripped of its outer stellar and gaseous disk by M31's tidal field

In the course of the transformation, gas rapidly transferred to the central region

nuclear starburst is triggered =>
=> central high-density, more metal-rich stellar populations
=> with relatively young ages

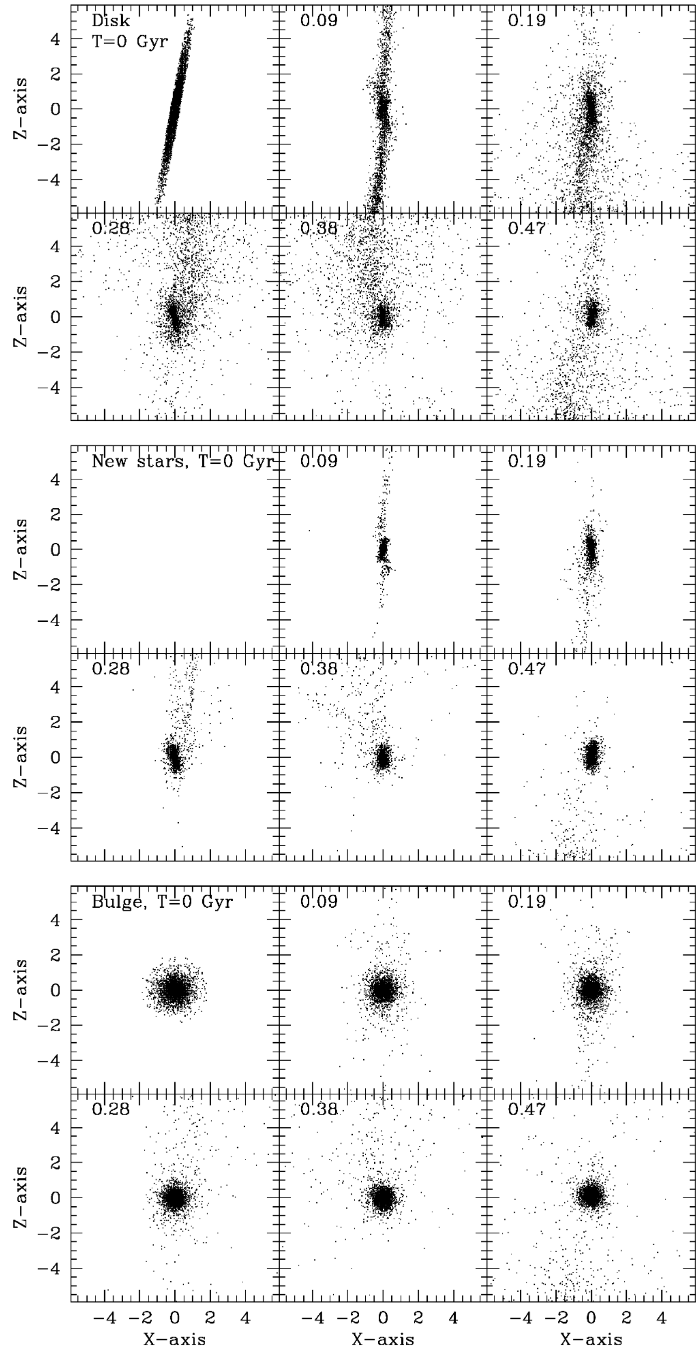


FIG. 2.—Morphological evolution projected onto the *x*-*z* plane (edge-on) for the stellar disk (*top six panels*), the new stars formed from gas (*middle six panels*), and the bulge (*bottom six panels*) in the simulated spiral galaxy. The time indicated in the upper left-hand corner of each frame is given in gigayears, and each frame measures 9.4 kpc on a side.

Disk stars

New stars

Bulge

Tidal stirring

Mayer et al. 2001, 2006, 2007

Klimentowski et al. 2008

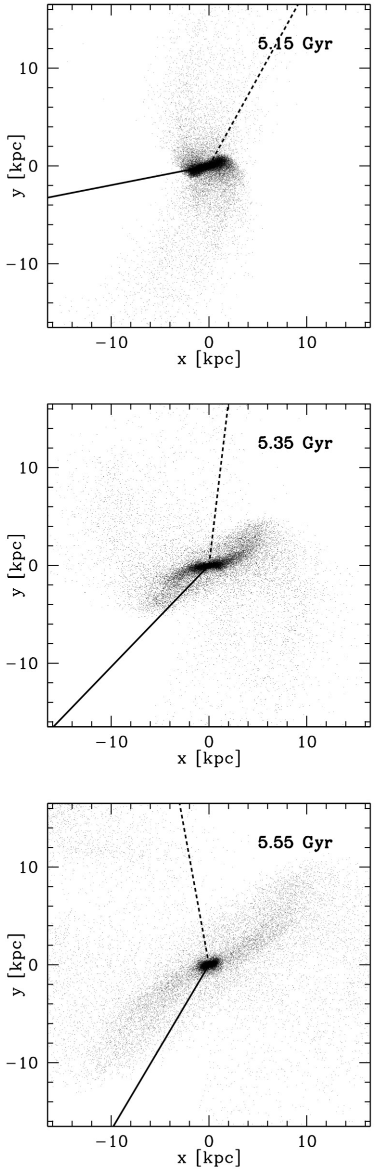


Figure 13. Tidal tail flipping. The three panels show three snapshots from the simulation at 5.15, 5.35 and 5.55 Gyr from the start. Only the positions of stellar particles are shown projected onto the orbital plane. The solid line indicates the direction to the host galaxy while the dashed one is parallel to the velocity vector. Old tidal tails oriented almost along the orbit decay and new ones pointing radially towards the host galaxy are formed.

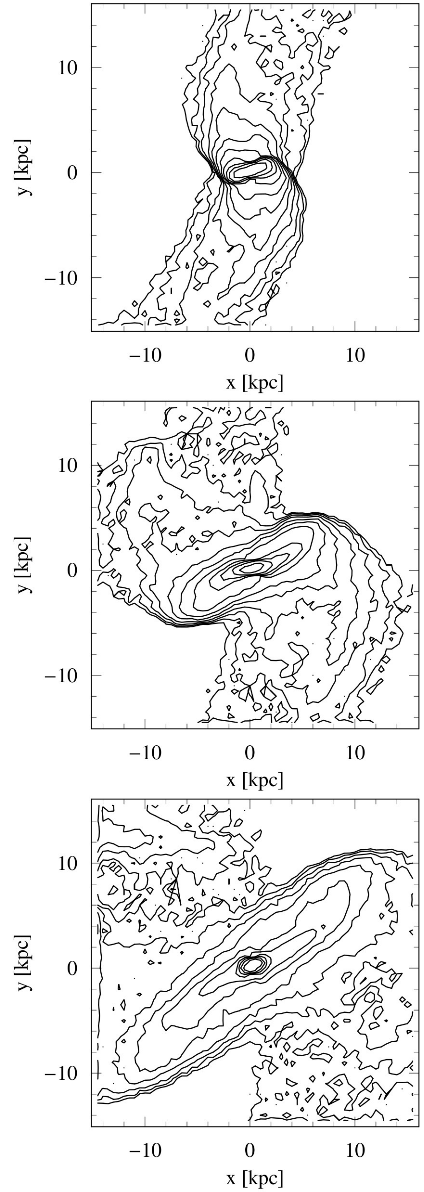
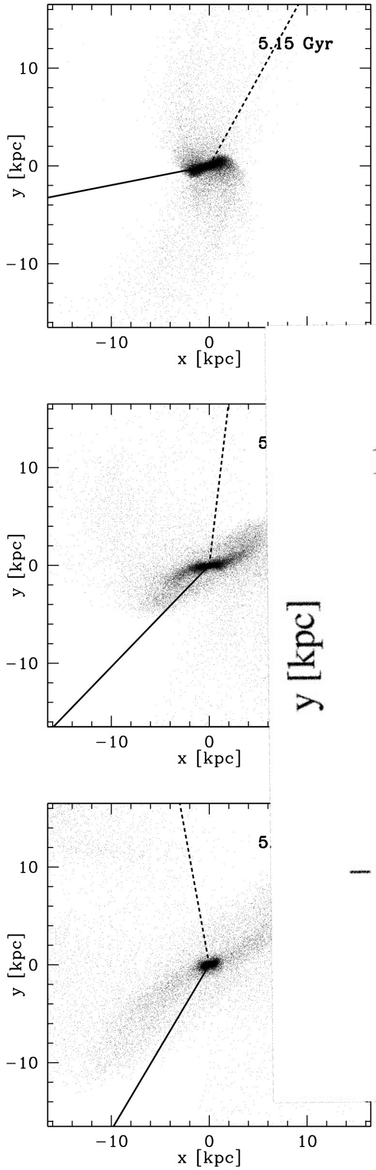


Figure 14. Contour plots of the surface density of stars corresponding to the three stages shown in Fig. 13. Each contour marks the density twice lower than the previous one. Assuming the stellar mass-to-light ratio of 3 solar units, the innermost contour corresponds to 2 $L_\odot$ pc^{-2}, while the outermost to 0.002 $L_\odot$ pc^{-2}.



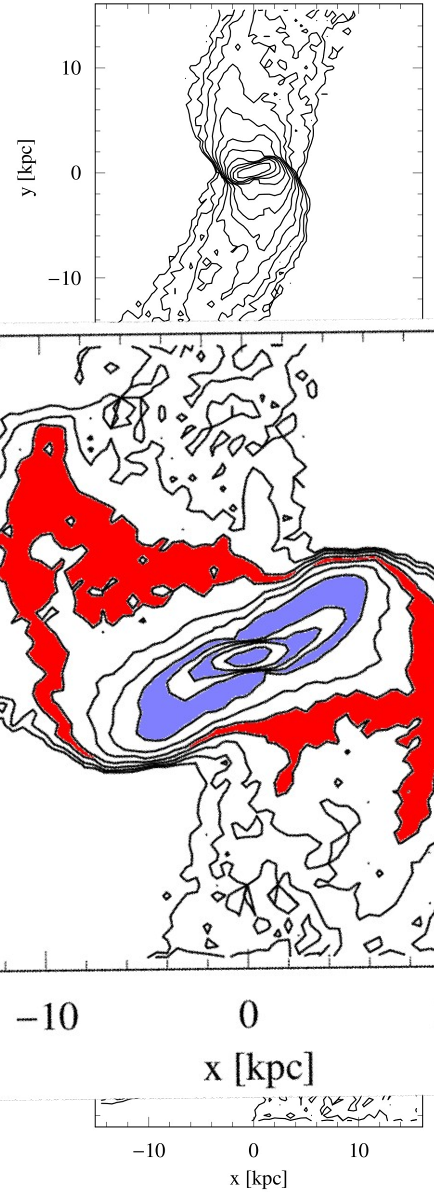


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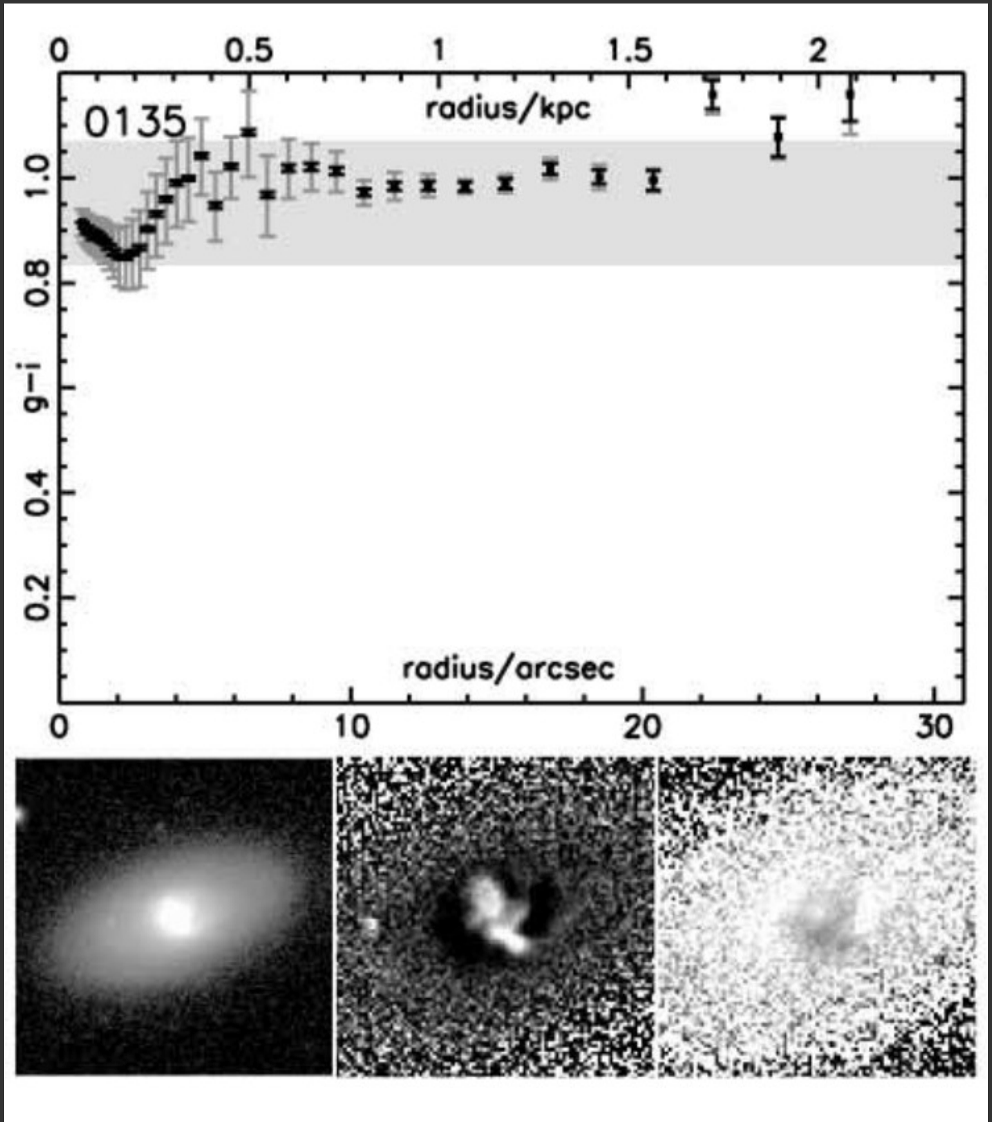
Figure 14. Contour plots of the surface density of stars corresponding to the three stages shown in Fig. 13. Each contour marks the density twice lower than the previous one. Assuming the stellar mass-to-light ratio of 3 solar units, the innermost contour corresponds to 2 $L_\odot$ pc^{-2}, while the outermost to 0.002 $L_\odot$ pc^{-2}.

One might expect to see relics of the original disk, and indeed some dE(bc) show them

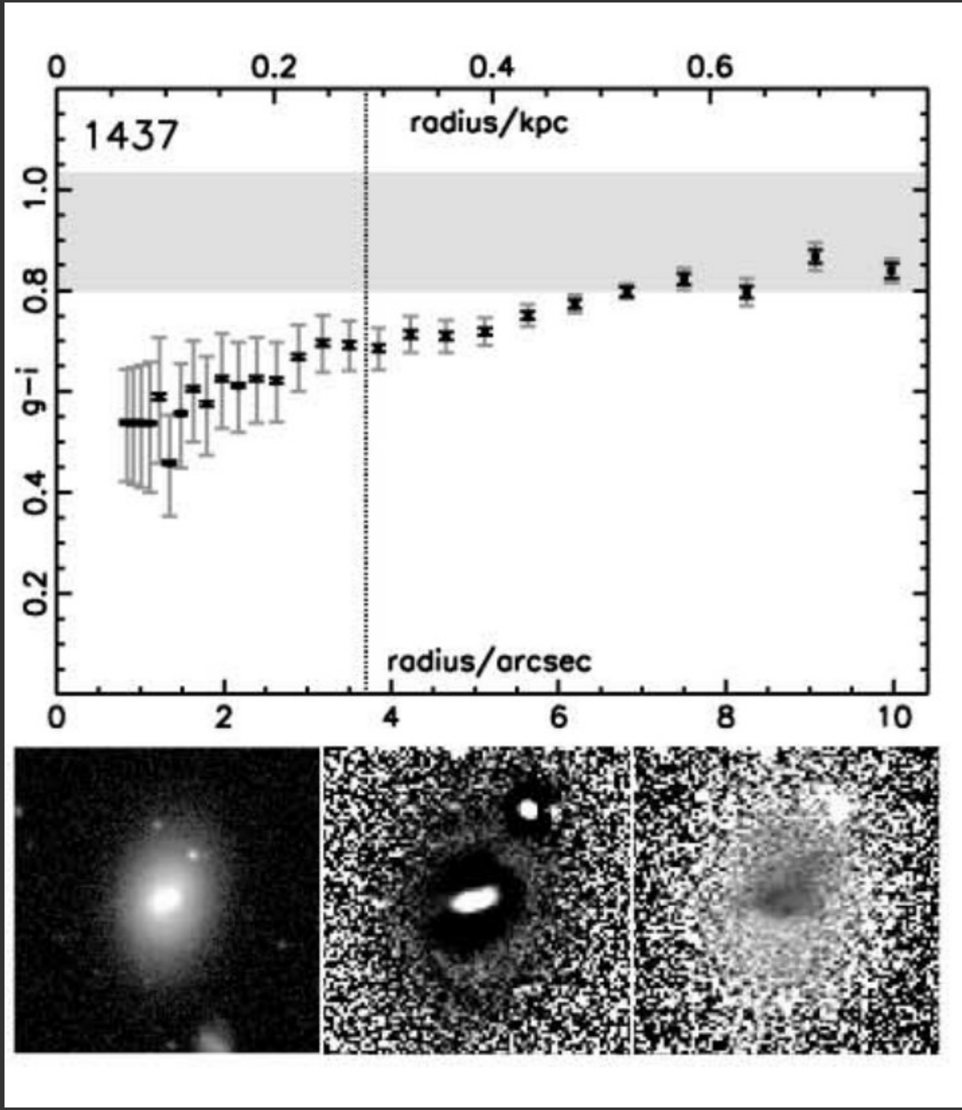
(perhaps even NGC 205)

Lisker et al. (2006)

VCC 0135: possibly spiral arms



VCC 1437: possibly spiral arms and a bar



APOD, Jan 24, 2008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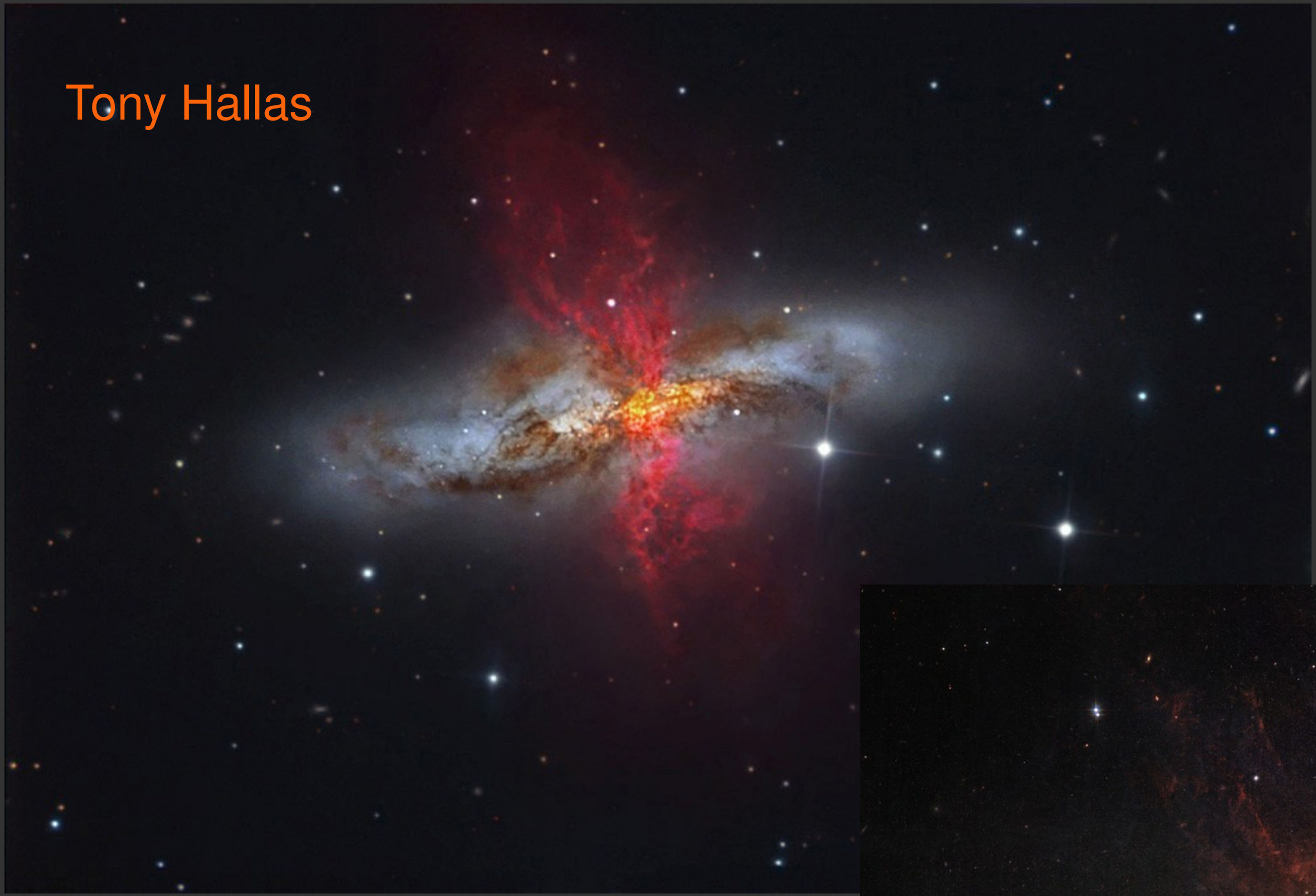
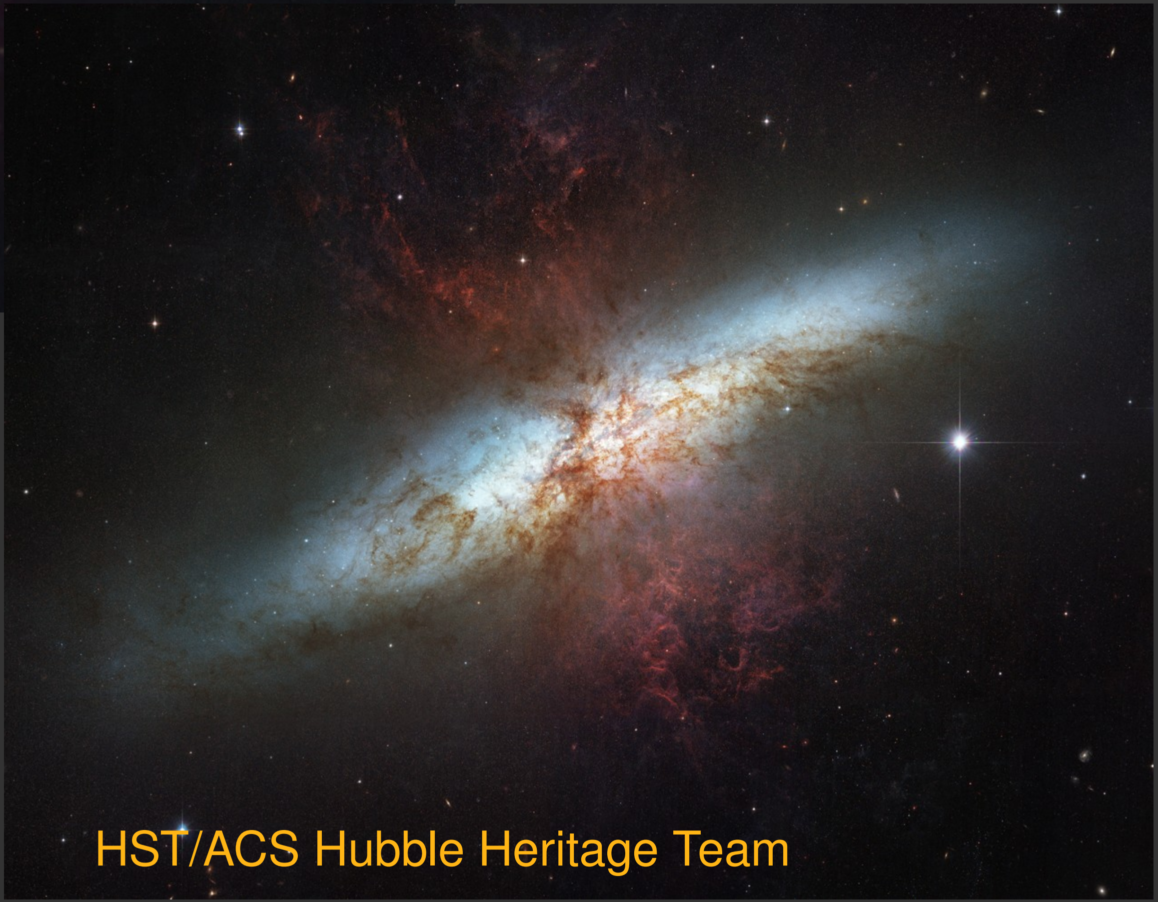
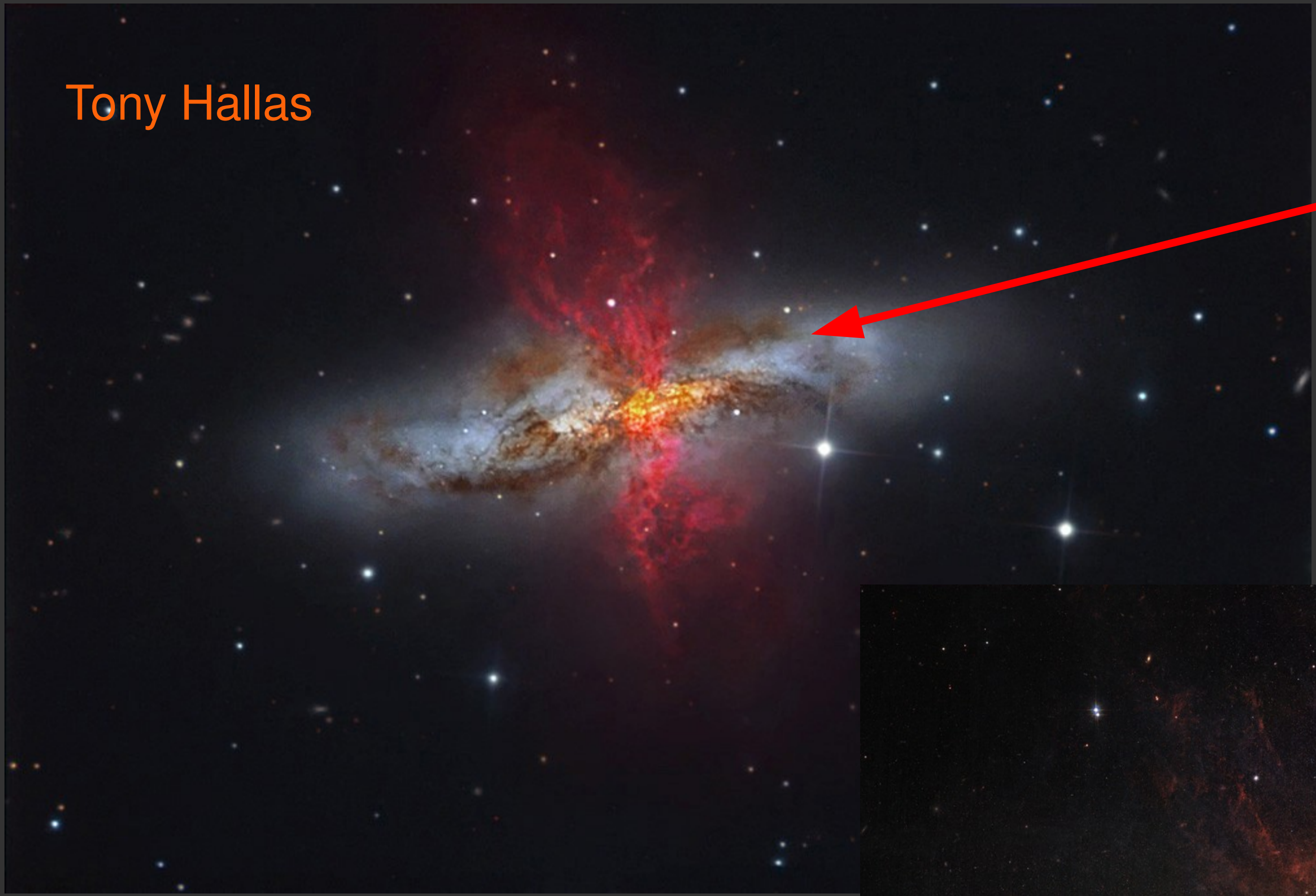
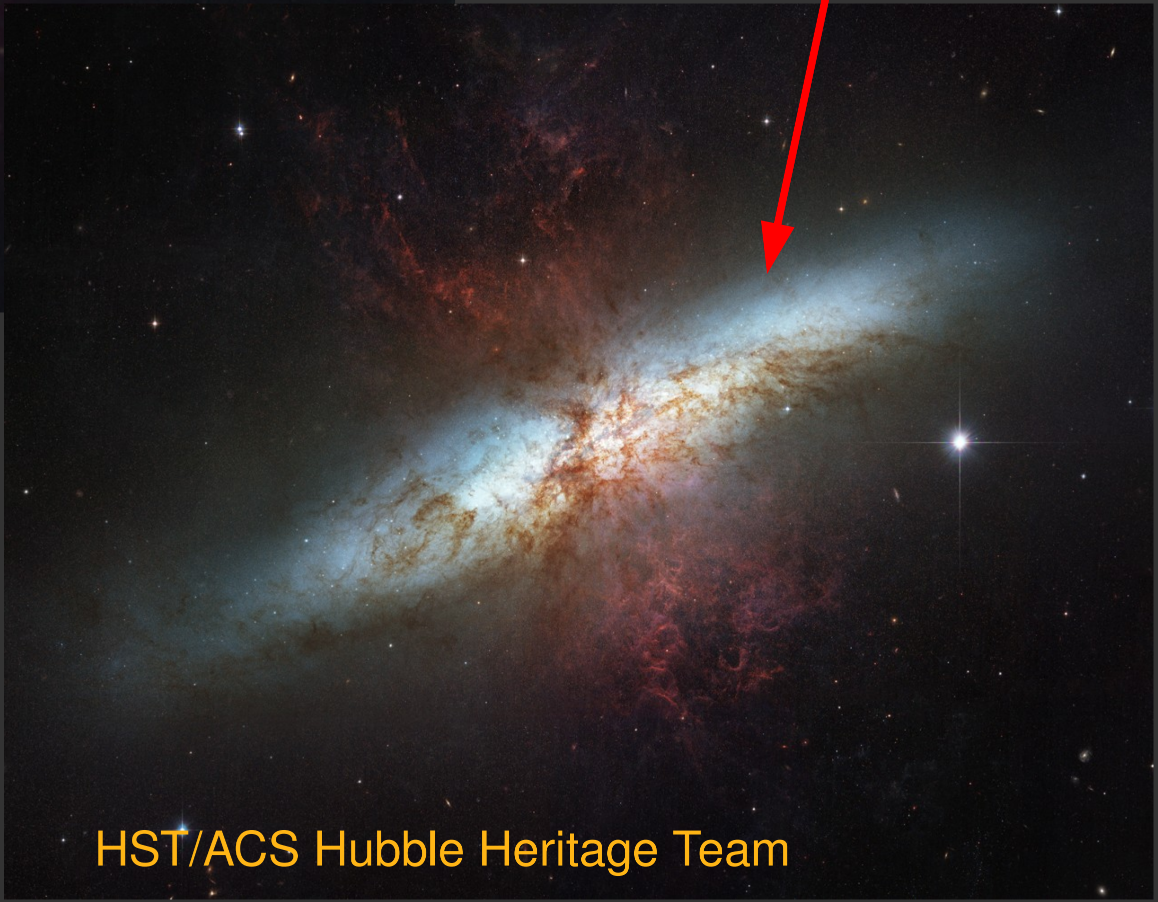
M 82


Tony Hallas


HST/ACS Hubble Heritage Team





Dust features better revealed in the groundbased image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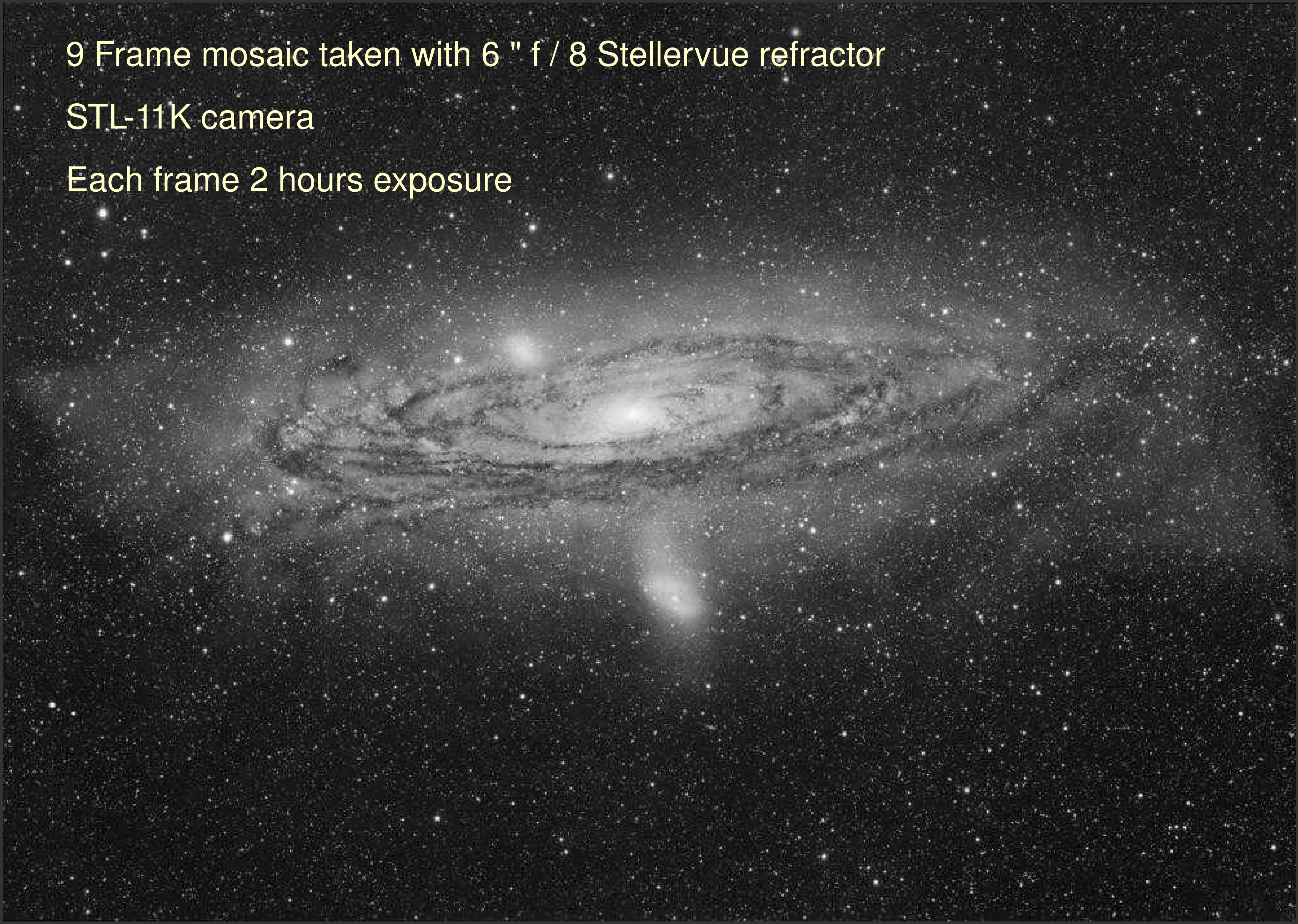
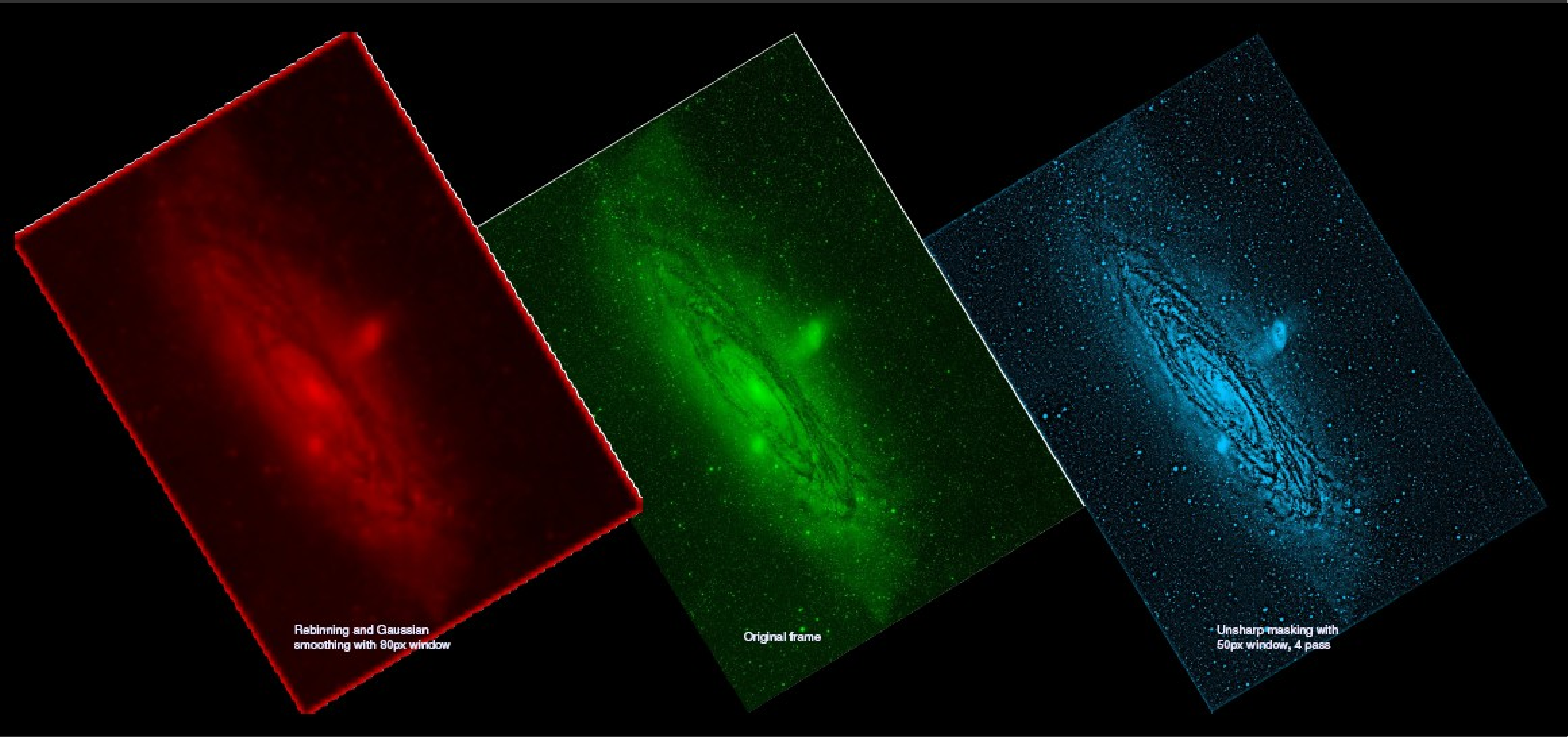
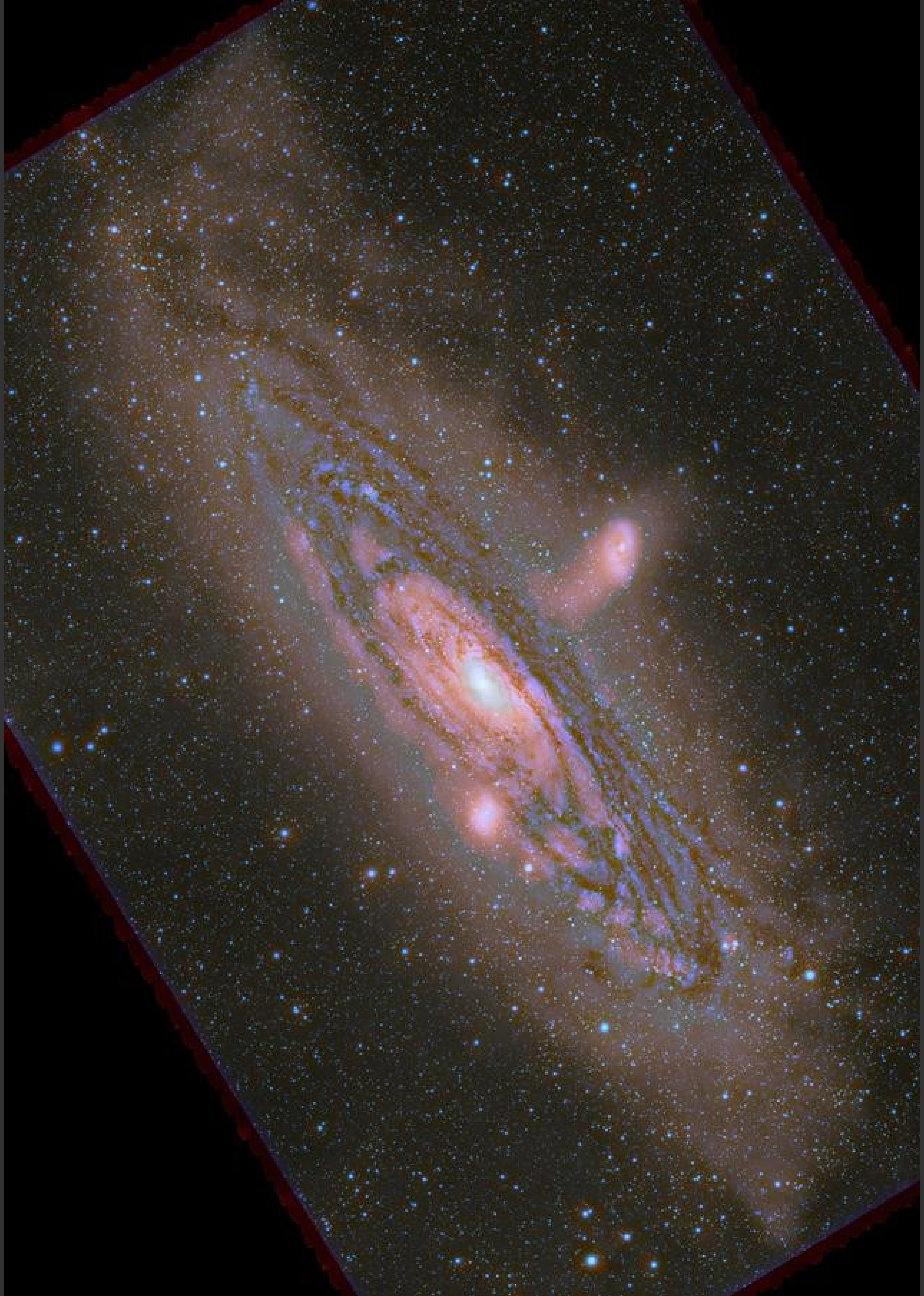
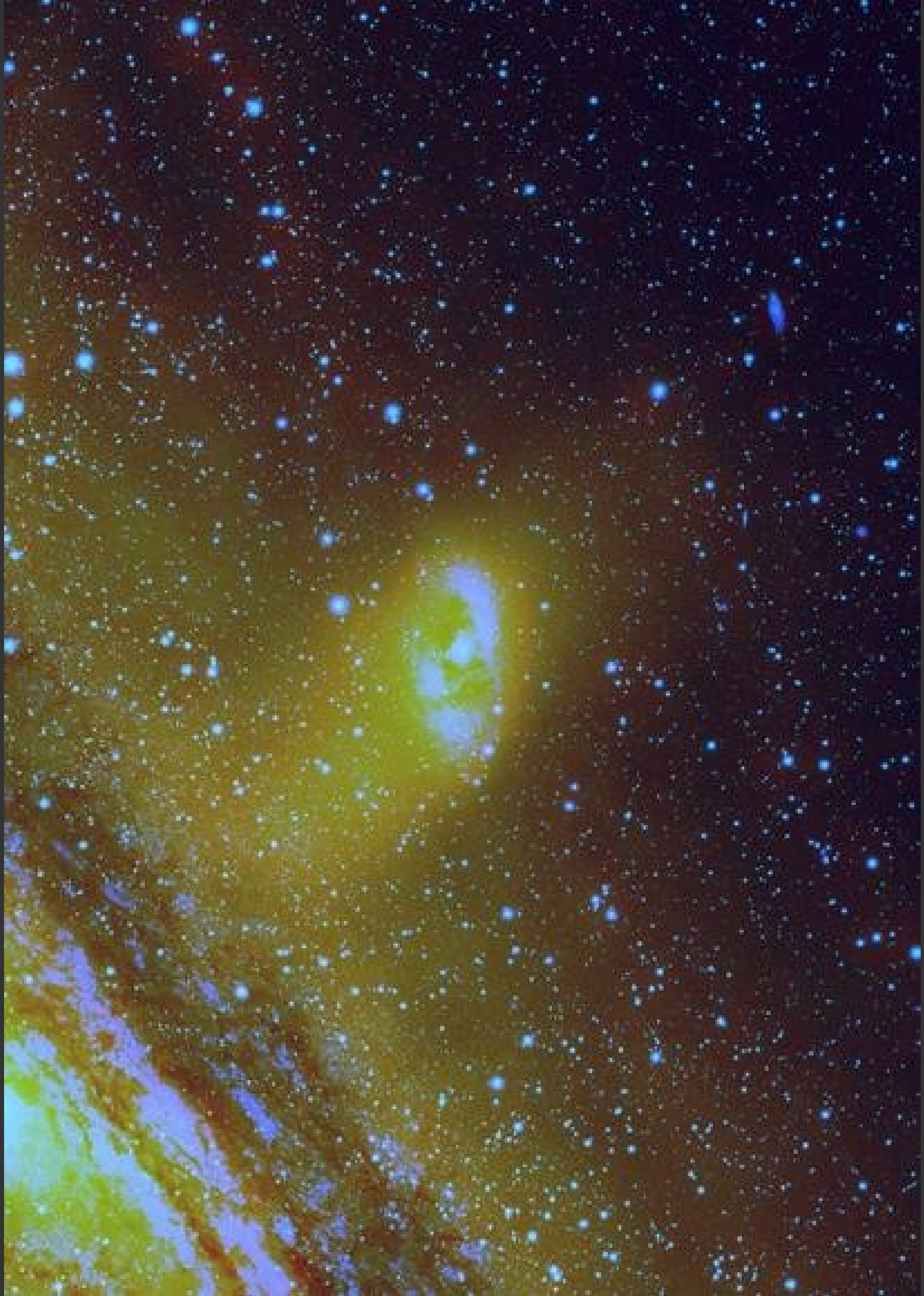
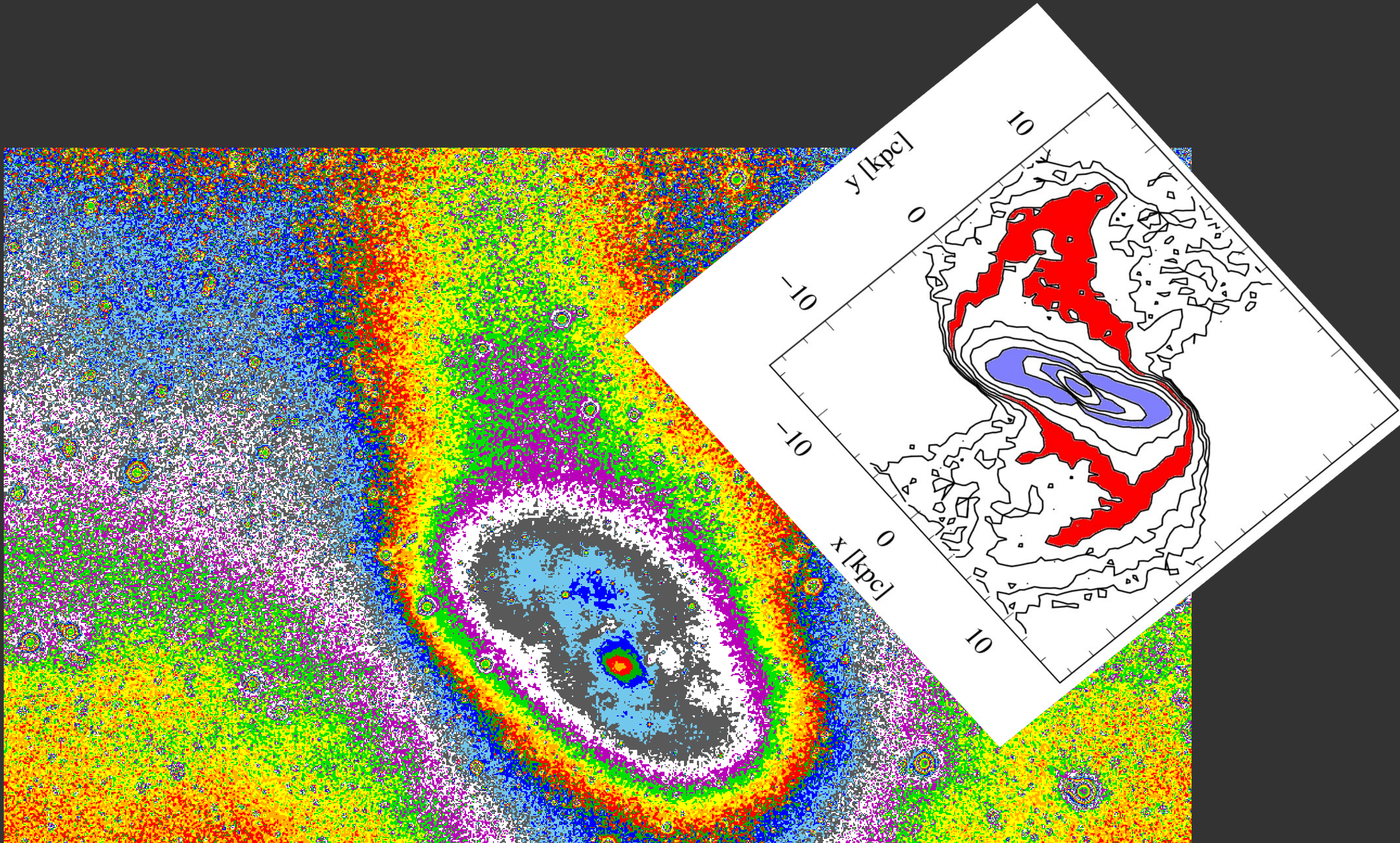

9 Frame mosaic taken with 6 " f / 8 Stellervue refractor
STL-11K camera
Each frame 2 hours exposure


Rebinning and Gaussian
smoothing with 80px window
Original frame
Unsharp masking with
50px window, 4 pass






y [kpc]
10
0
−10
x [kpc]
−10
0
10

In any case, the interaction with M31 is clear

Davidge (2003):

- multiple episodes of star formation in the most central region

- with a time spacing compatible with the putative NGC 205 orbital period (Cepa & Beckman 1988)

Demers et al. (2003)
-> extra-tidal carbon stars

Ibata et al. 2001; McConnachie et al. 2004
-> tidal streams of stars in M31 halo
- possibly related with NGC 205 and/or M32

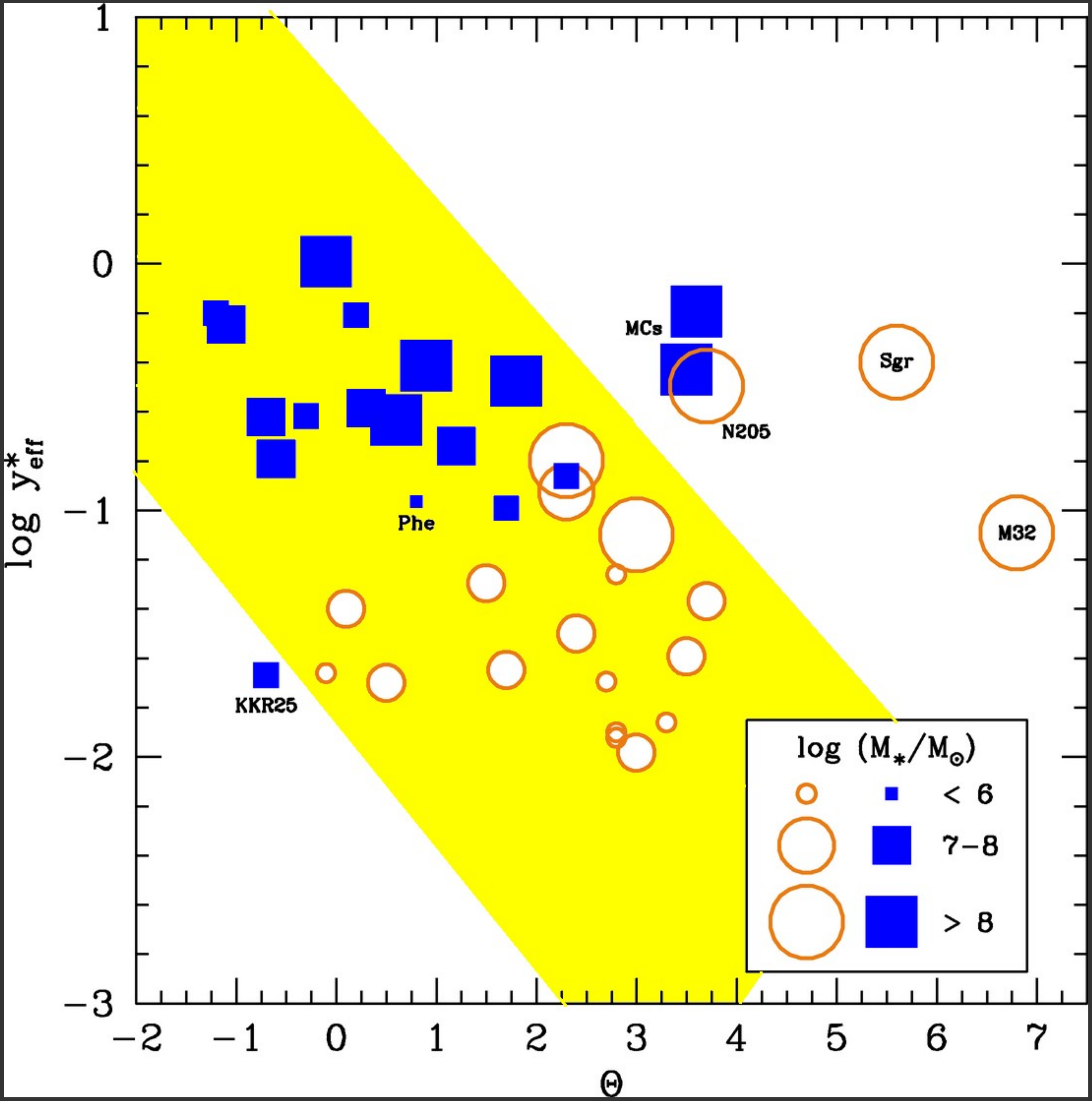
Hodge 1973; Choi et al. 2002
-> isophotes twisted at radii larger than ~ 4'
- incipient tidal tails

De Rijcke et al. 2006; Geha et al. 2006
- stars beyond that radius are apparently moving in the opposite direction with respect to the inner galaxy

Note that NGC 205 is also the prototype of nucleated dwarf ellipticals
-> usually considered as tracers of high density environments (interactions favor the nucleation process)

The four nucleated galaxies in the Local Group (M33, Sagittarius, M32, and NGC 205; Kormendy & McClure 1993; Majewski et al. 2003; Ibata et al. 2001; McConnachie et al. 2004) have all been suggested to be in the process of tidal disruption

From Henry Lee et al. (2009)



Conclusion

- NGC 205 might be a case of morphological transformation happening right here in the Local Group

- Wide-field, panoramic imaging is needed to confirm this hypothesis (e.g. spiral arms vs. dust lane)

What next...

Wide-area, deep imaging:

- HST/ACS
- LBT/LBC
- Subaru/SuprimeCam