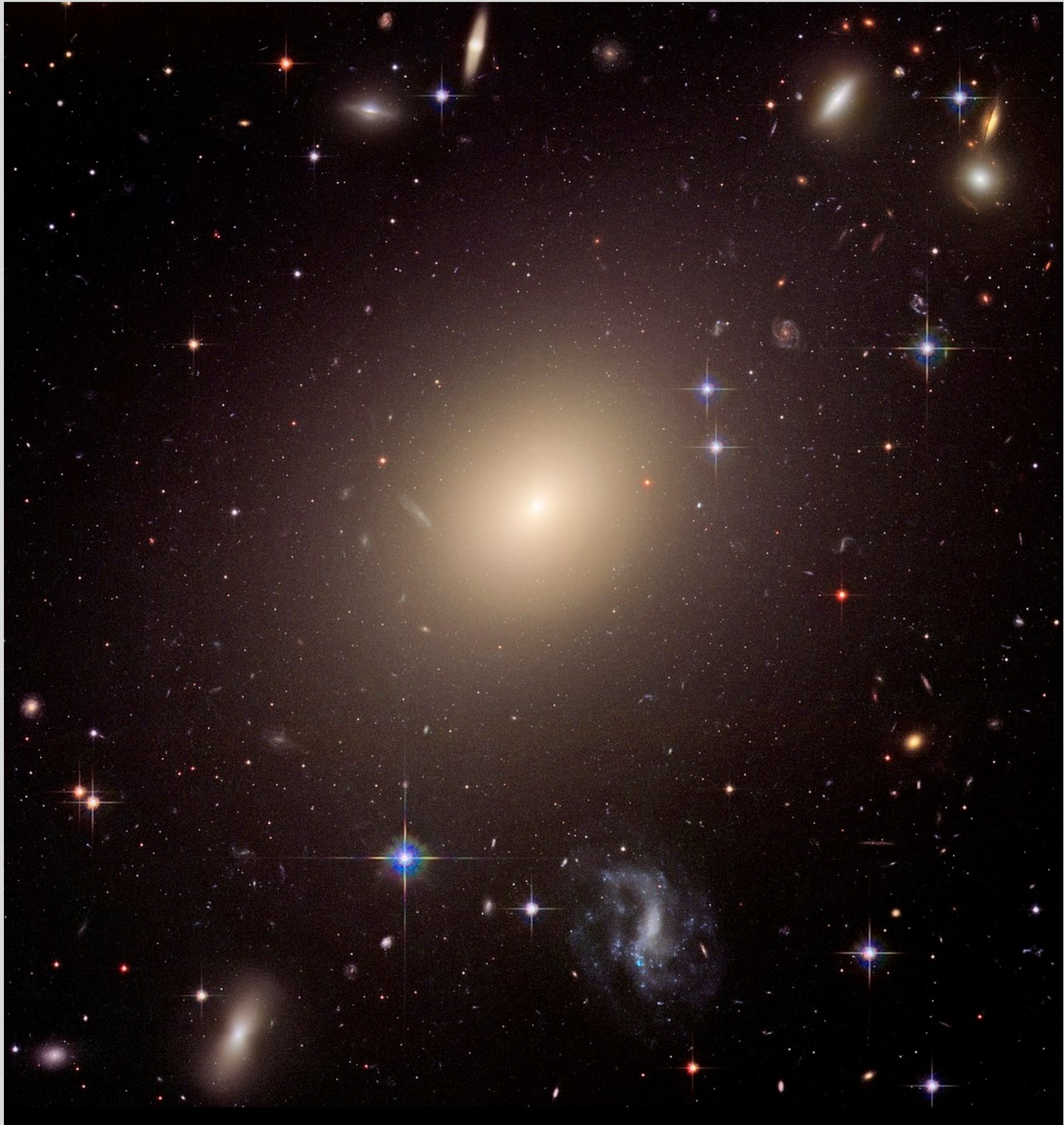
Elliptical Galaxies

E’s span a wide range of luminosity and have a correspondingly wide range of structural properties.

Surface photometry: characterize

- Surface brightness profile
- Isophotal shape/ellipticity
- Orientation (position angle)
- Deviation from ellipse (boxy/disk)



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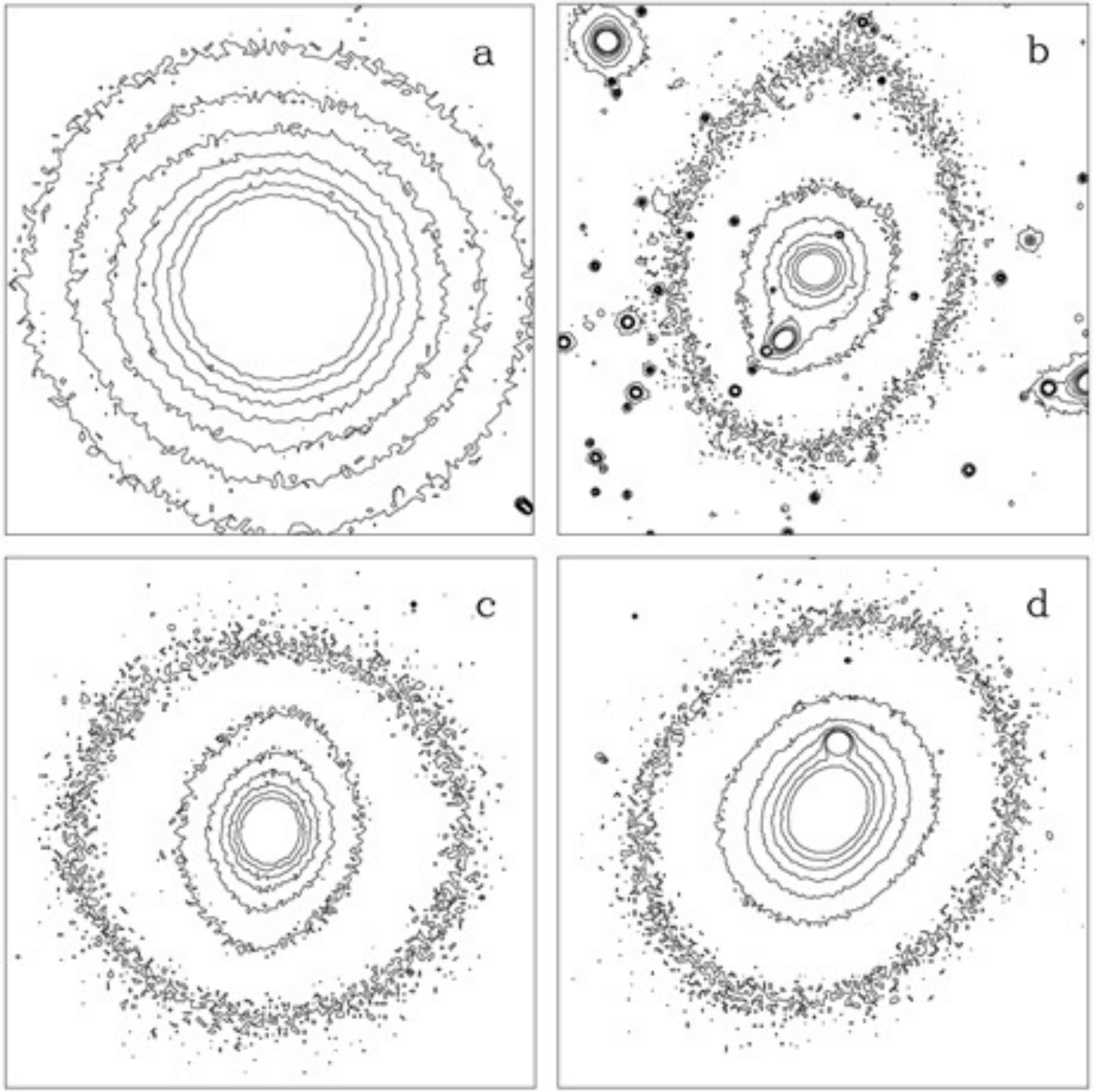


Fig 6.1 (R. de Jong) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

isophotes: contours of constant surface brightness

Elliptical Galaxies: Surface Brightness profile

Characterize the surface brightness using a Sersic profile:

$$\mu(R) = \mu_e + \frac{2.5 b_n}{\ln 10}\left[\left(\frac{R}{R_e}\right)^{1/n} - 1\right]$$

Where

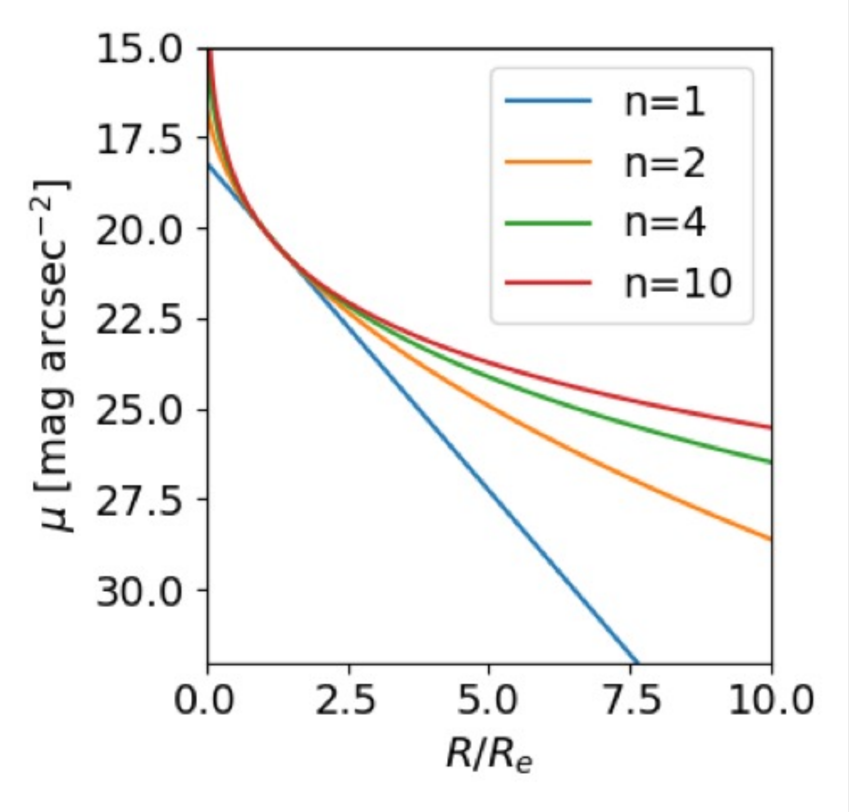
- n: Sersic index
- R_e: “effective radius”, the radius containing half the total light
- μ_e: surface brightness **at** the effective radius
- (b_n: numerical constant $\approx 1.9992n - 0.3271$)

From this, we can also derive

- m: total apparent magnitude
- $\langle\mu\rangle_e$: average surface brightness **within** R_e

Remember:

- $n = 1$: exponential decline (like disk galaxies have)
- $n = 4$: classic de Vaucouleurs $r^{1/4}$ profile
- Higher n puts more and more light in the outskirts

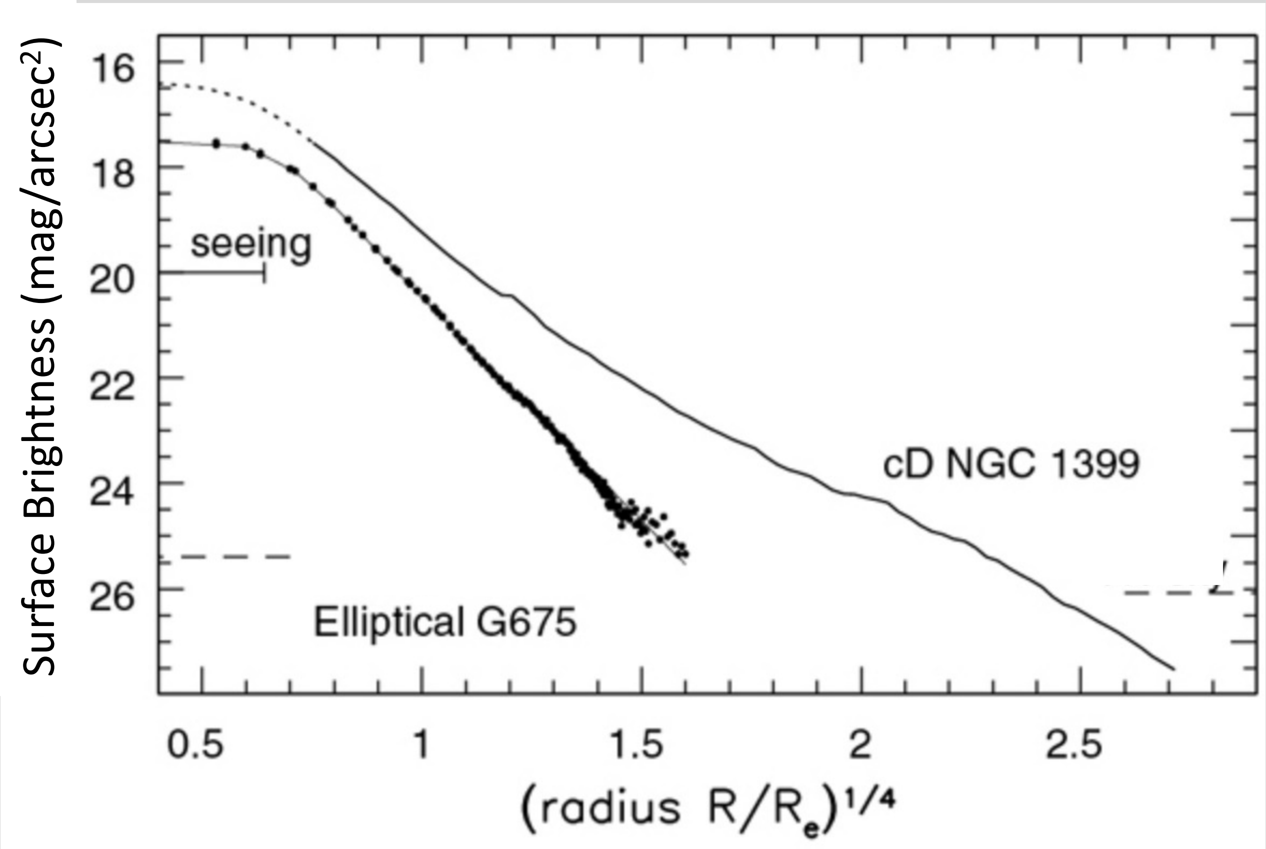


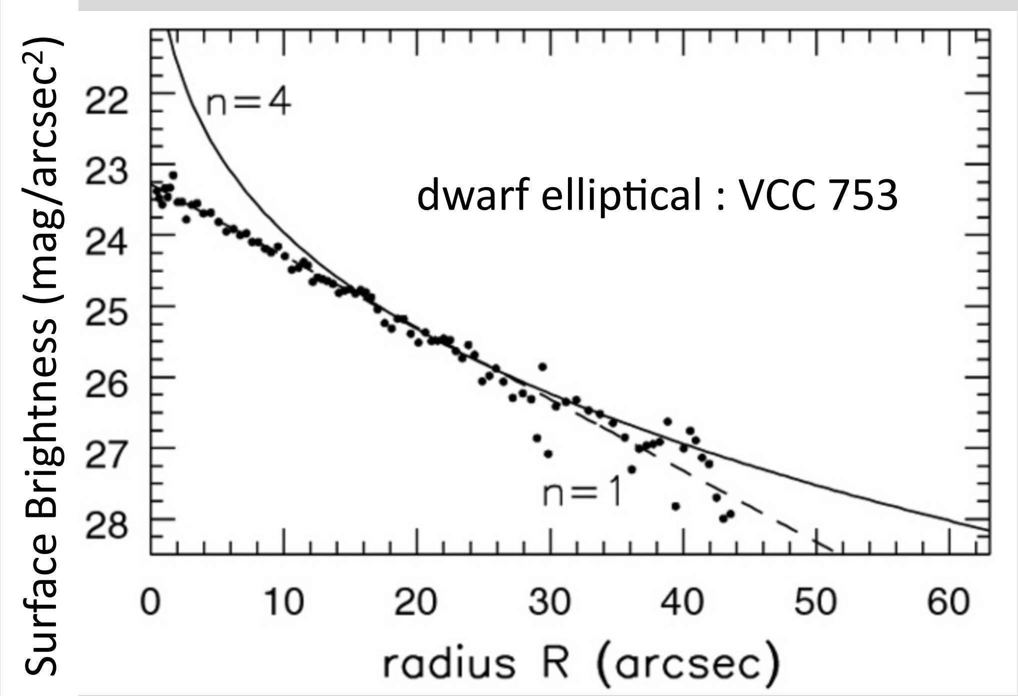
Elliptical Galaxies: Surface Brightness profile

Ellipticals are not all fit by a single value of n.

Dwarf ellipticals ($L \lesssim$ few $\times 10^9\ L_\odot$) : $n \approx 1$
(but while n=1 means an exponential profile, dE galaxies are not disk galaxies!)

Luminous ellipticals ($L \approx$ few $\times 10^9$ $-$ few $\times 10^{10}\ L_\odot$) : $n \approx 4$





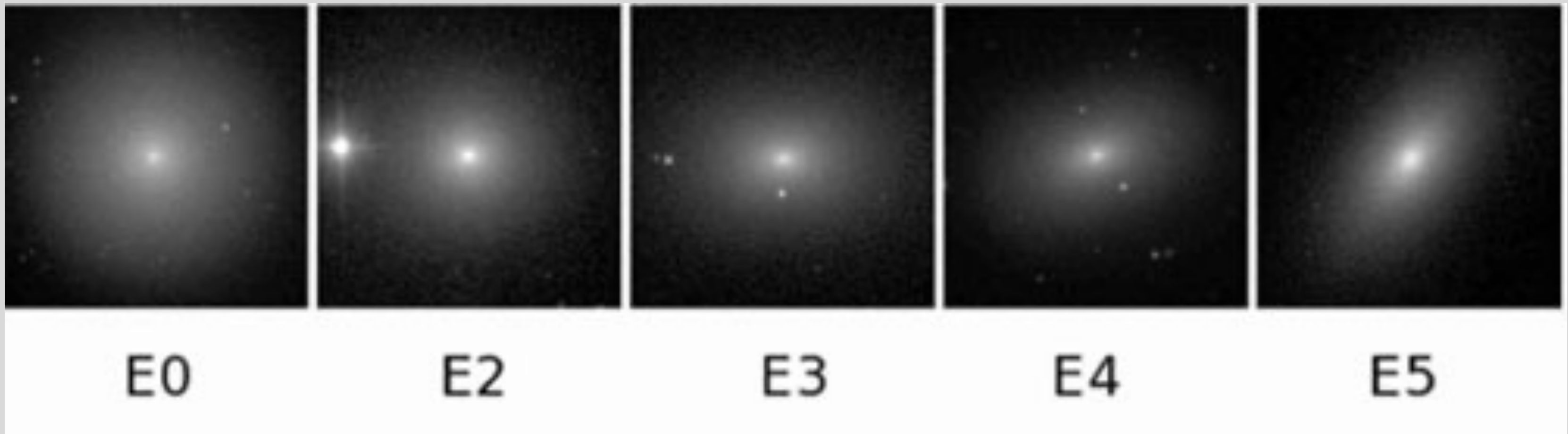
cD ("central dominant") galaxy: very luminous ellipticals at the center of big galaxy clusters.

- $L >$ few $\times 10^{10}\ L_\odot$
- Lots of excess light at large radius: $n \gg 4$
- Likely built through mergers in the cluster, with luminous envelope built from stripped galaxies.

Elliptical Galaxies: Ellipticity

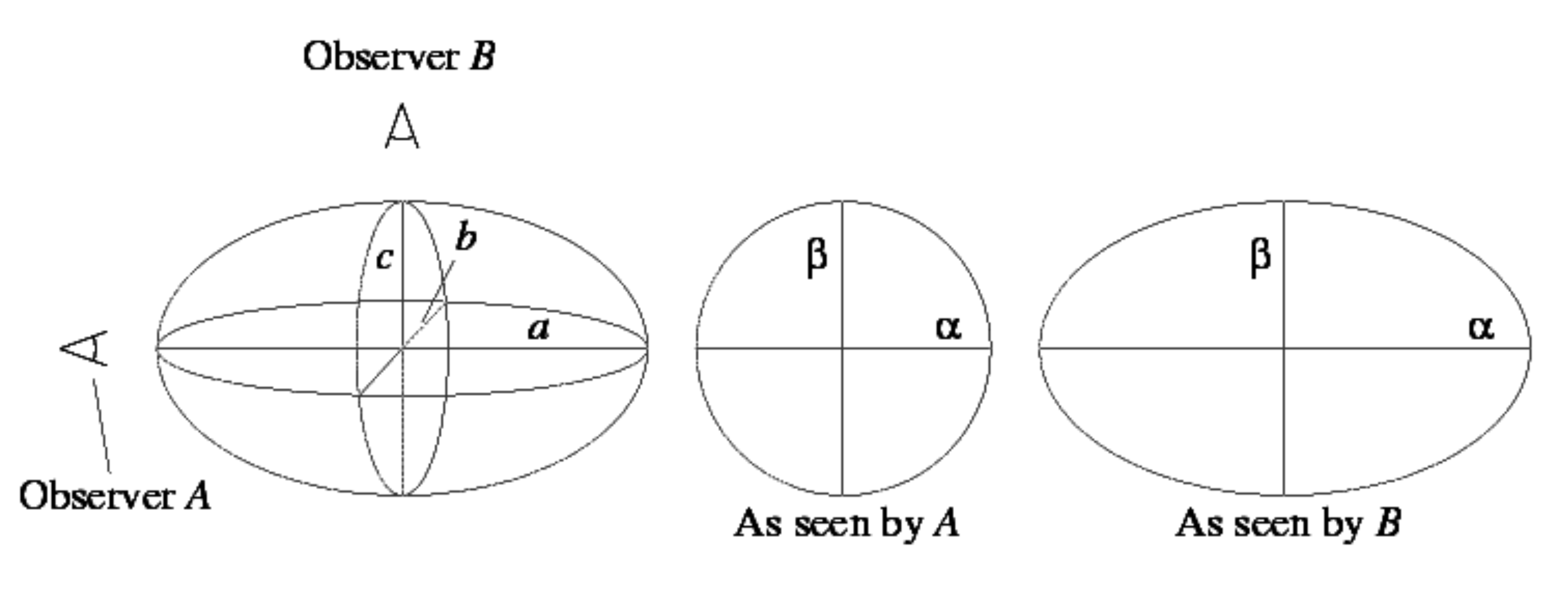
Typically defined by $\epsilon = 1 - b/a$, where a, b are the isophotal major and minor axis lengths.

Hubble scheme EN, where $N = 10\epsilon$



Beware: observed ellipticity is not the same as the true axis ratio.

Observed axis ratio is a projected version of the underlying 3D axis ratio.



3D geometry:

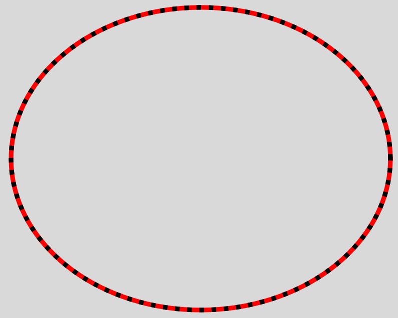
- ⚽ Spherical: $a = b = c$
- 🏈 Prolate: $a > b = c$
- 🍔 Oblate: $a = b > c$
- ?? Triaxial: $a > b > c$

Elliptical Galaxies: Disky/Boxy

Isophotes sometimes deviate from an ellipse. We can write the deviation from a perfect ellipse as

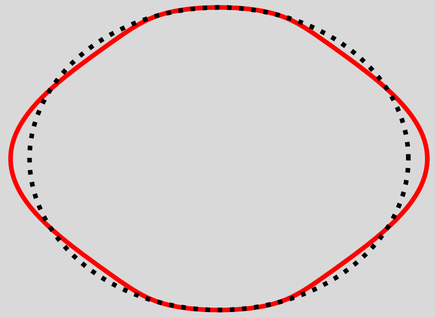
$$\Delta r(\theta) = \sum_{k\geq 3} a_k \cos k\theta + b_k \sin k\theta$$

a_4: describes disky/boxy around major axis



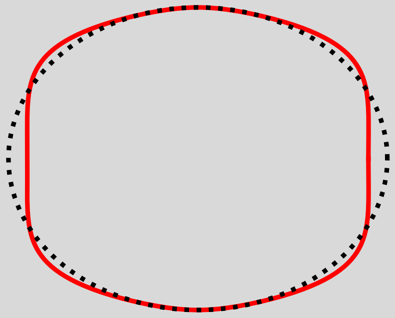
Pure ellipse

$a_4 = 0$



Disky isophotes

$a_4 = +0.1$

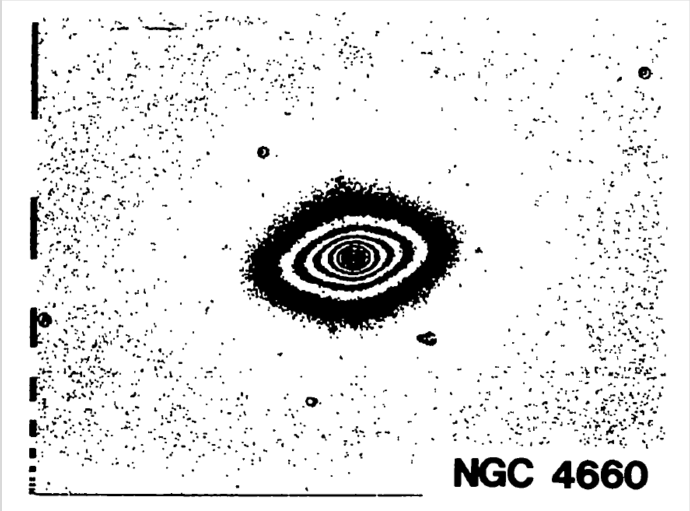


Boxy isophotes

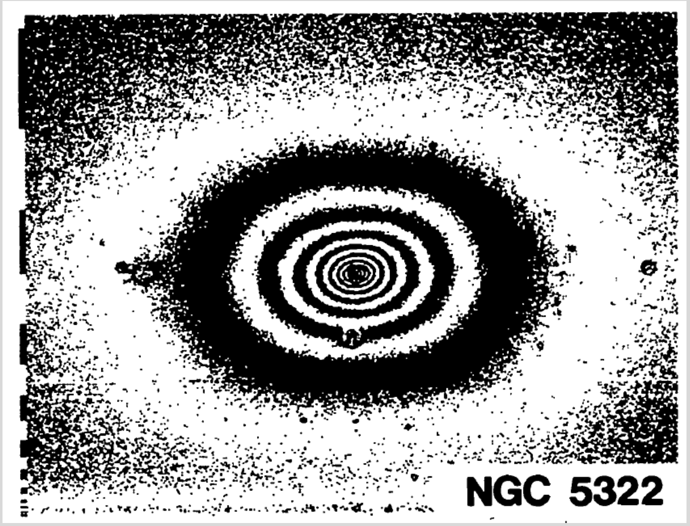
$a_4 = -0.1$

Bender+88

disky

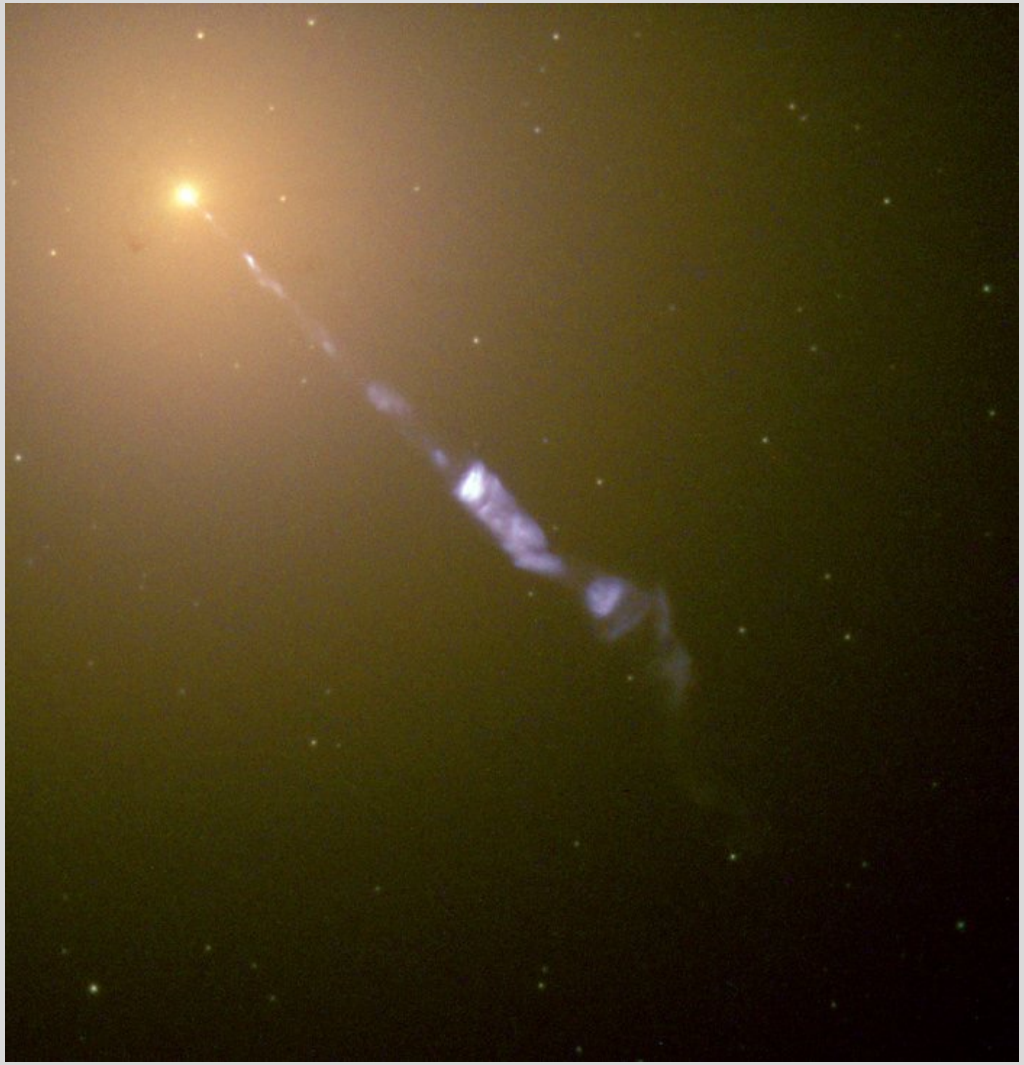


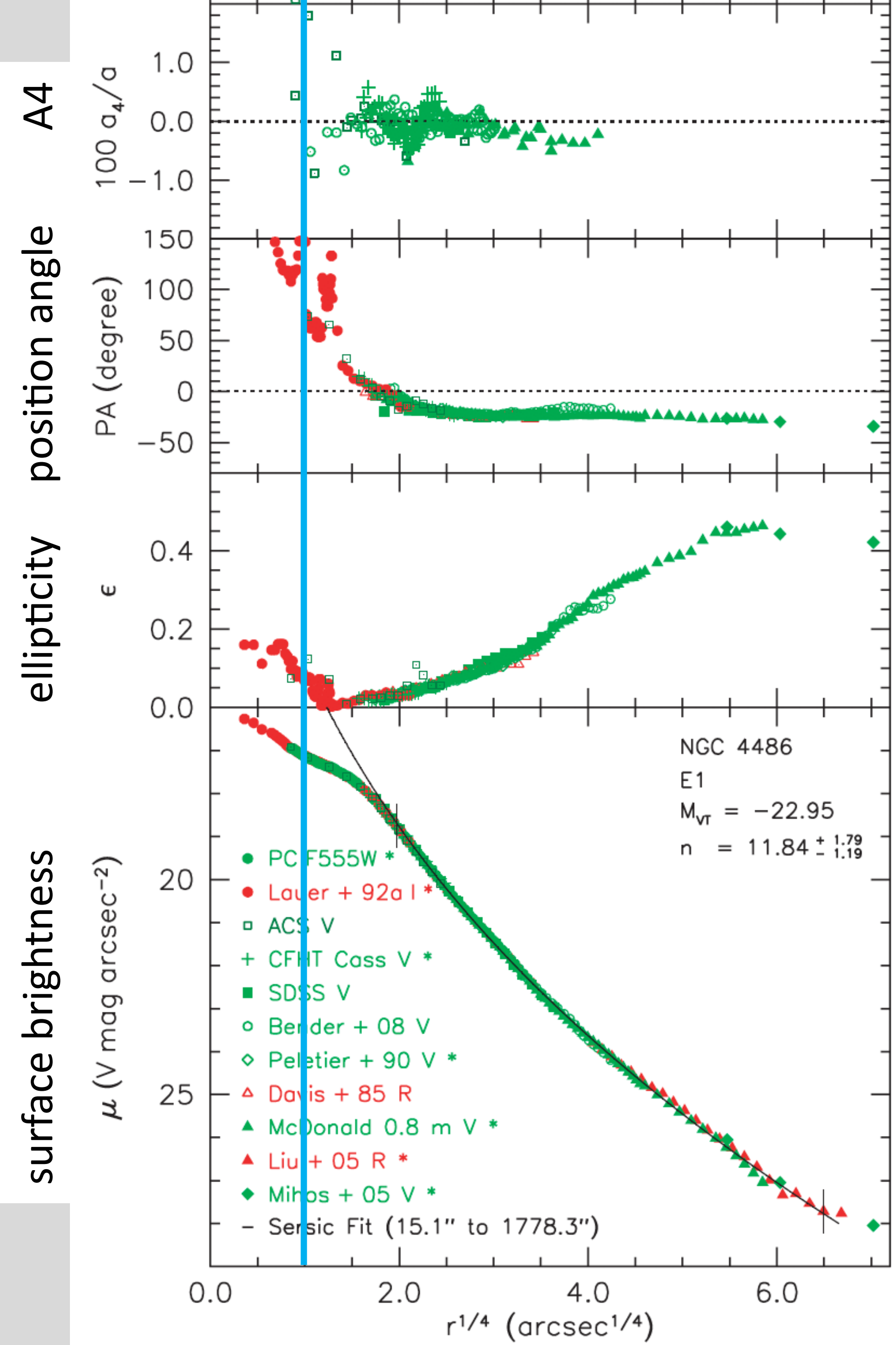
boxy



Isophotal Analysis: M87

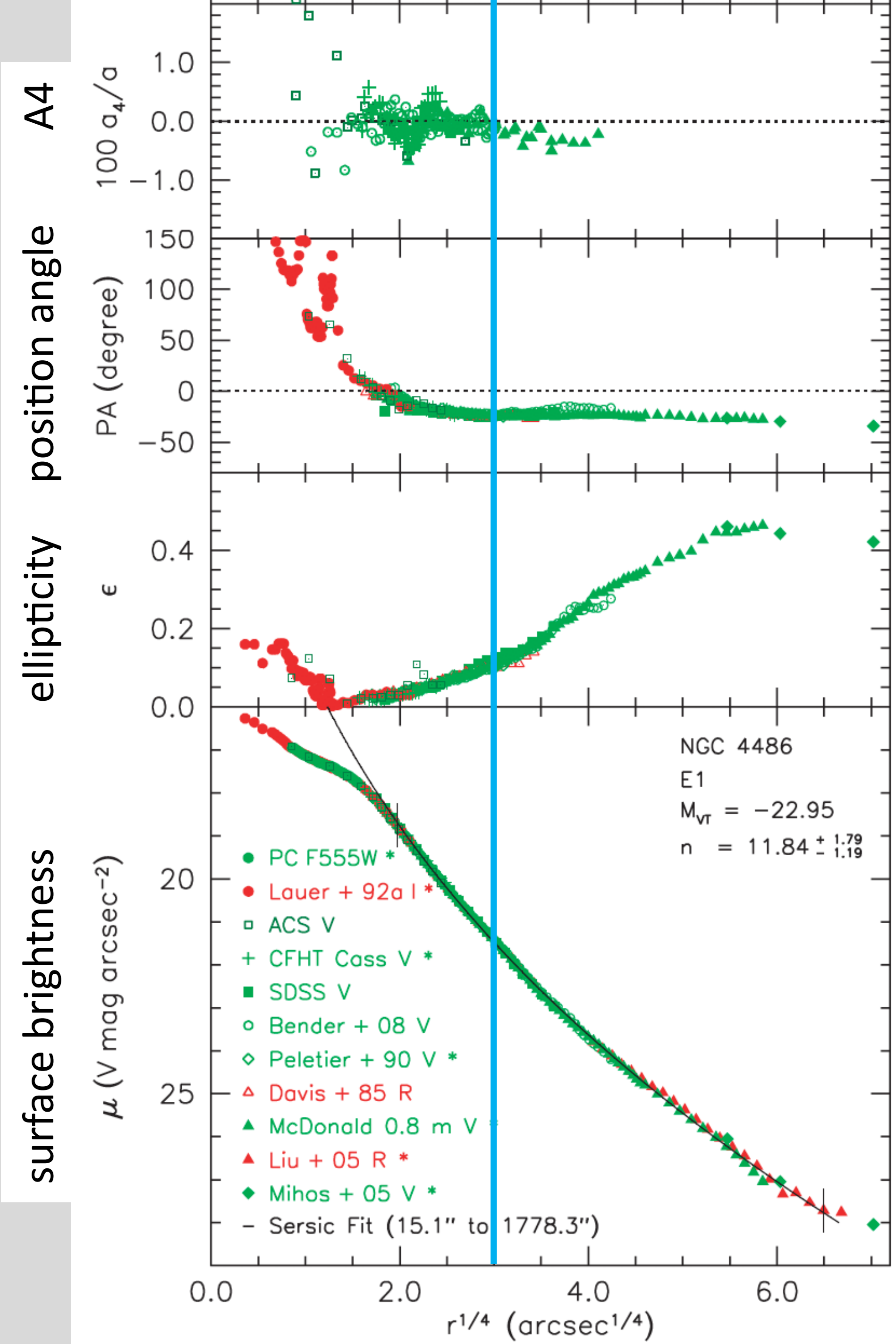
HST Image





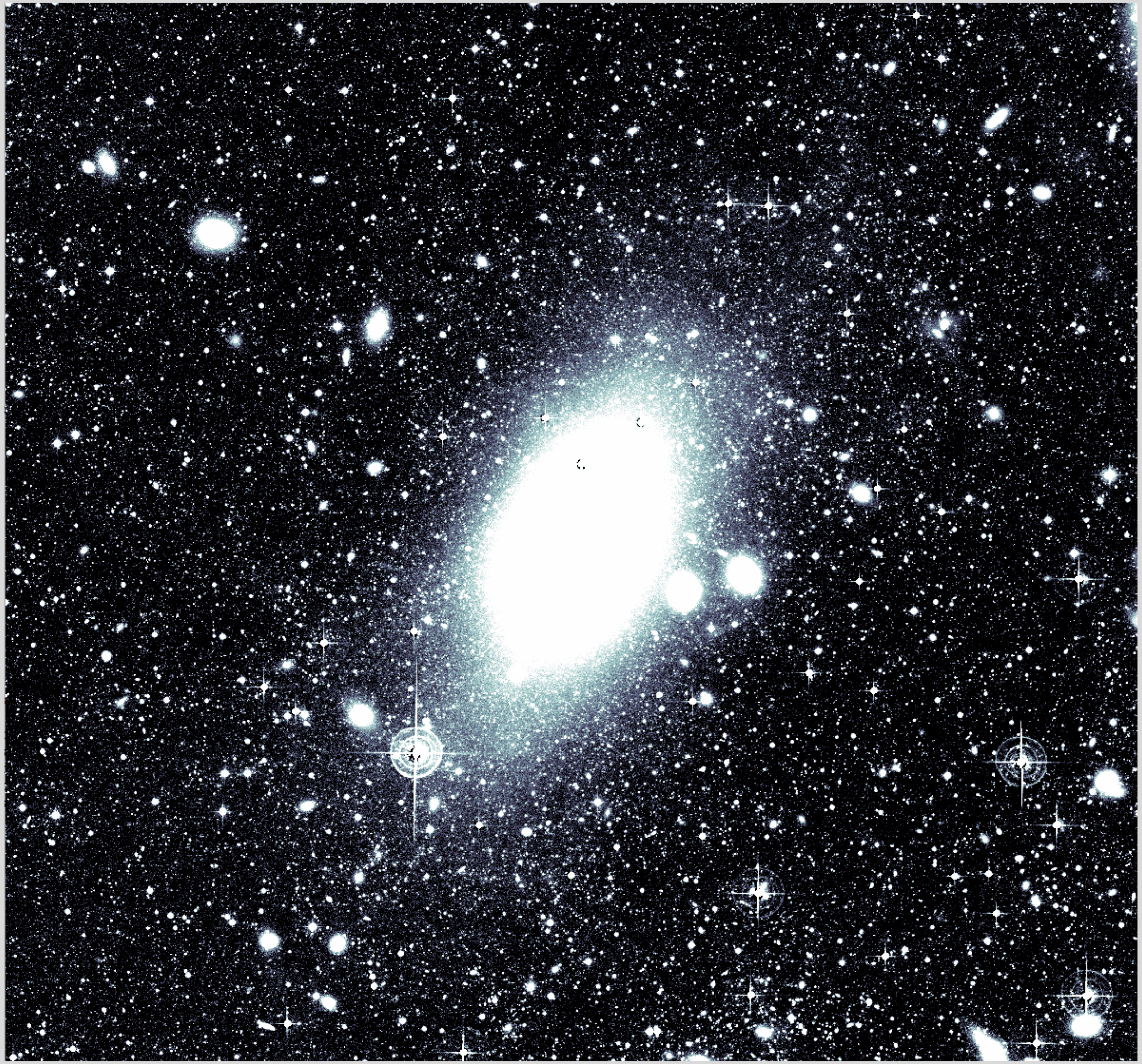
Isophotal Analysis: M87

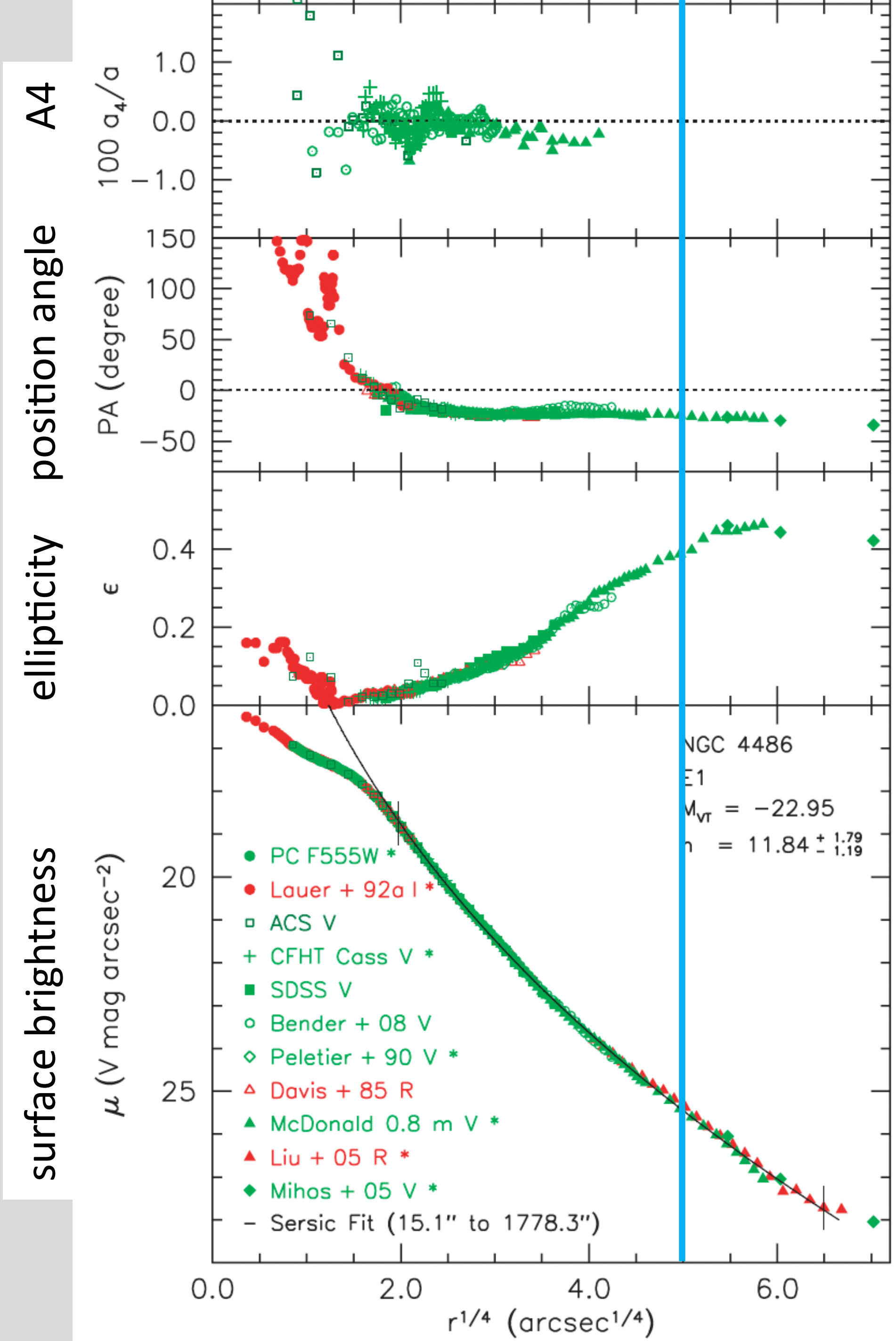
CWRU Schmidt Image



Isophotal Analysis: M87

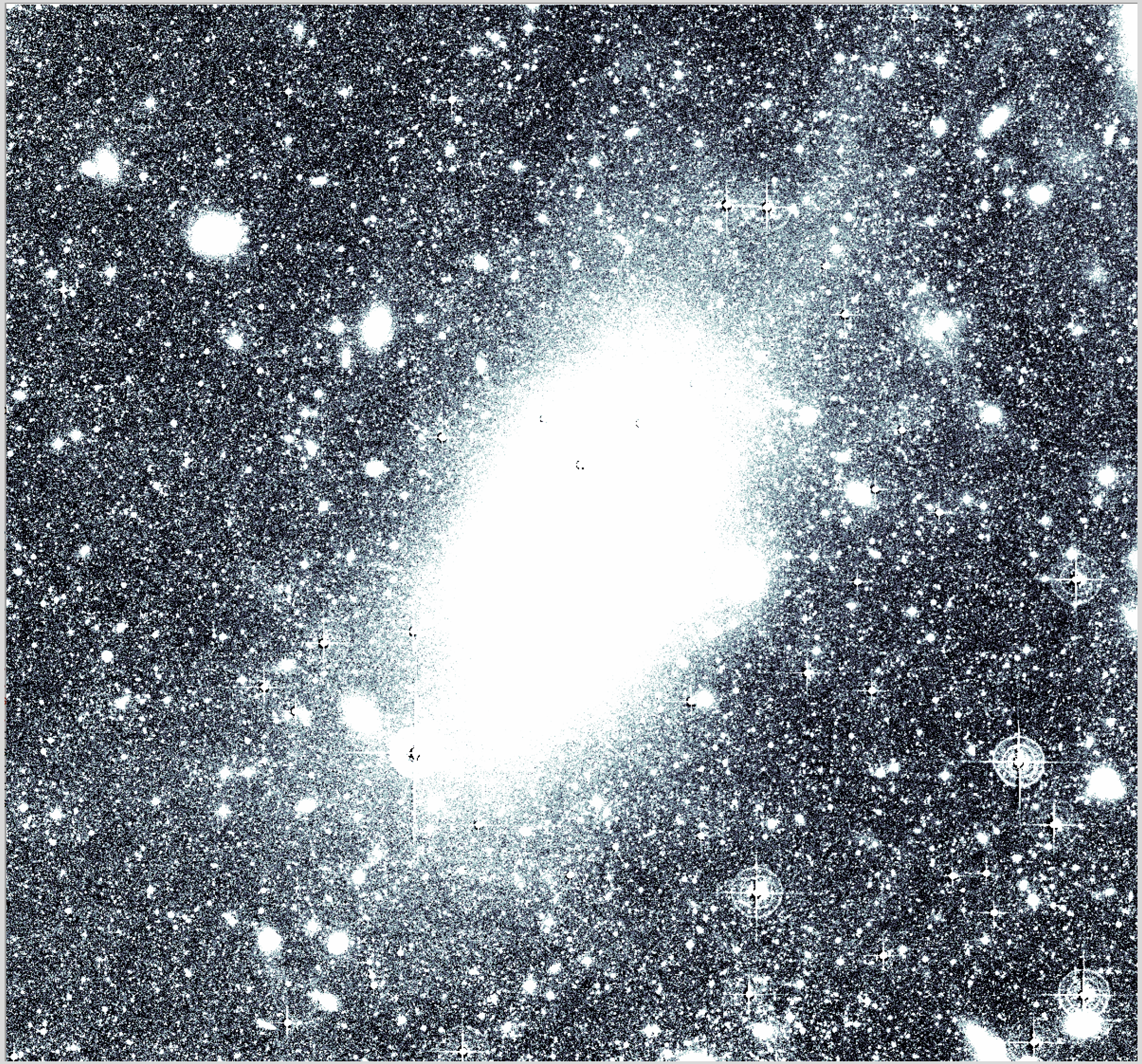
CWRU Schmidt Image

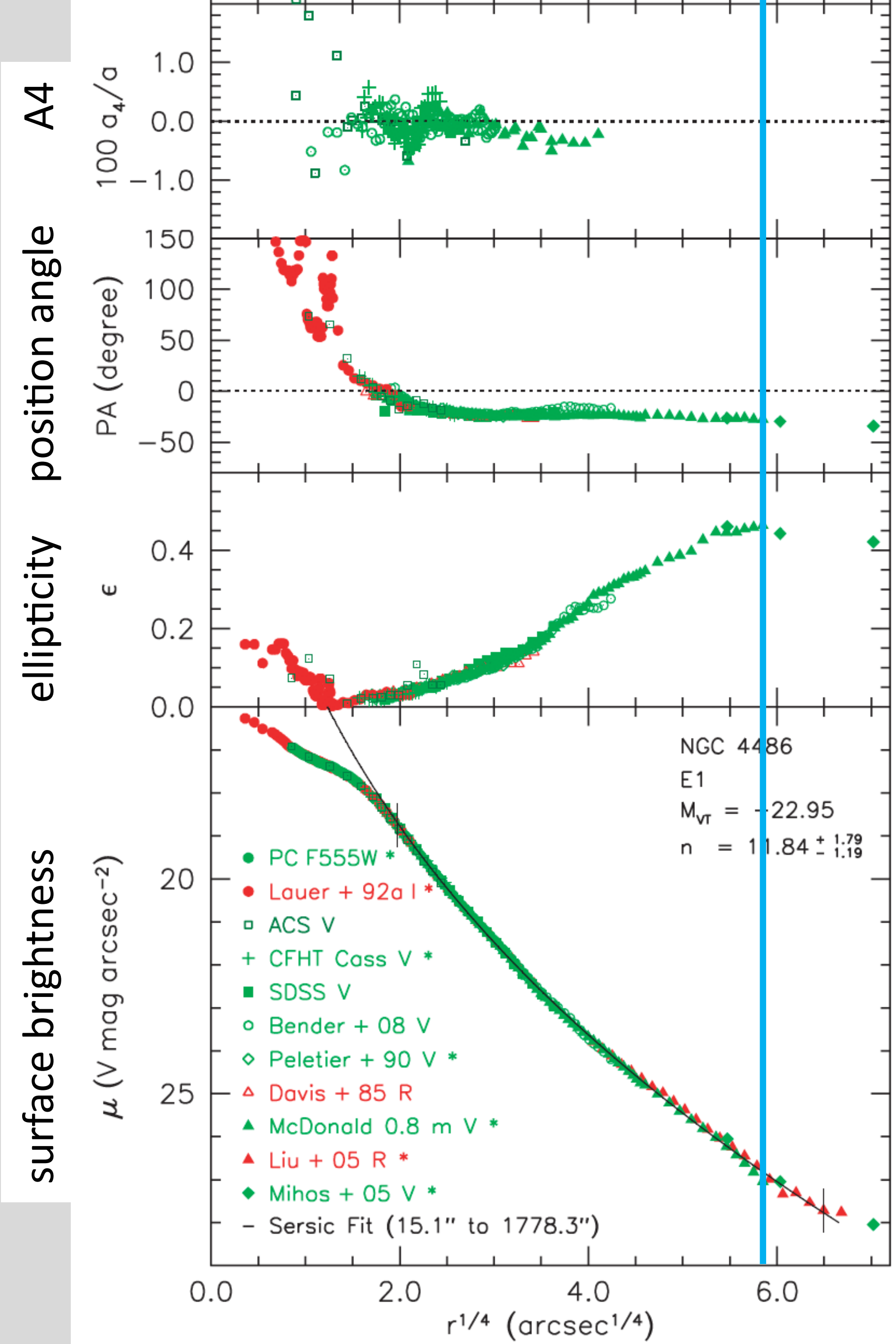




Isophotal Analysis: M87

CWRU Schmidt Image





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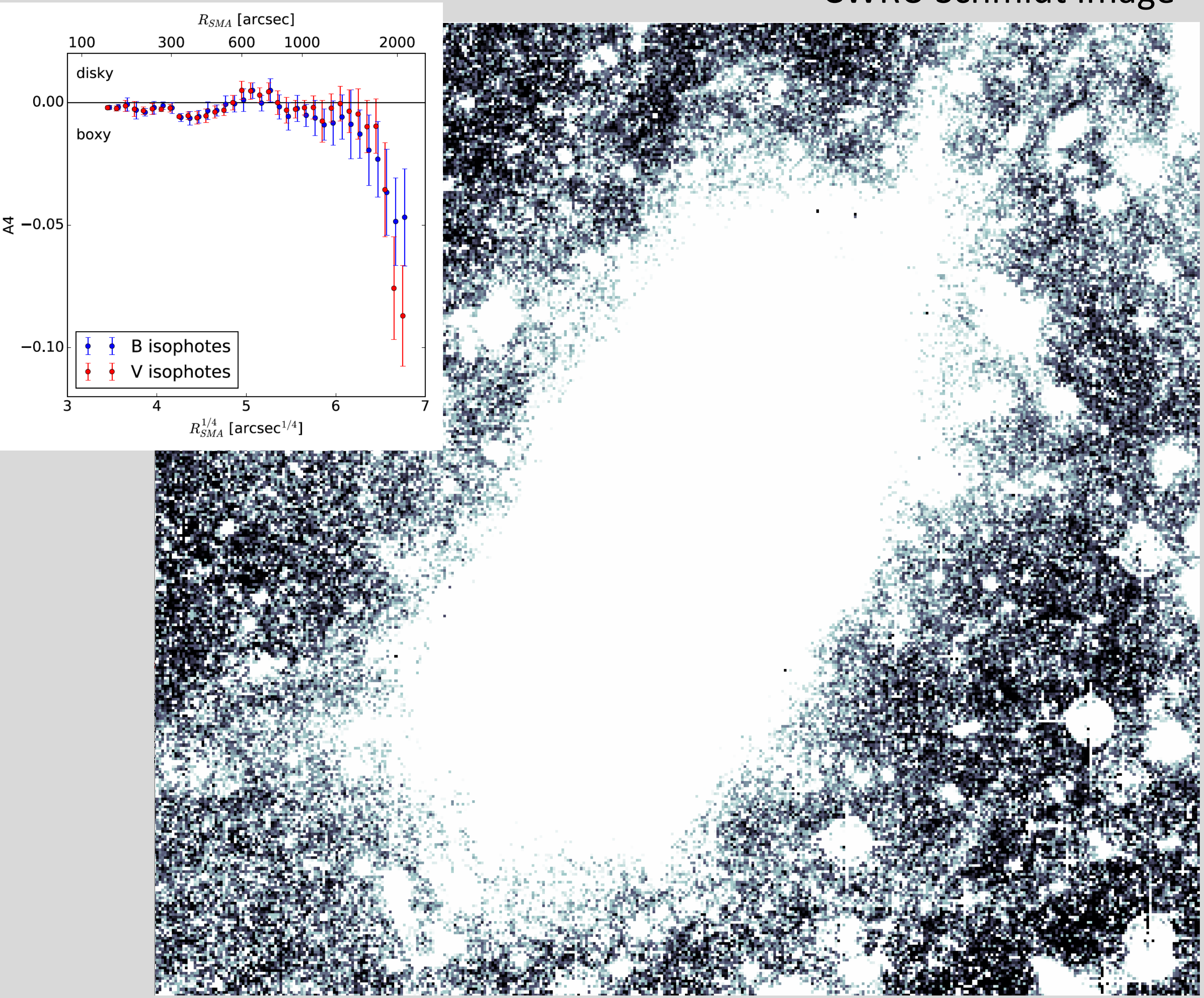

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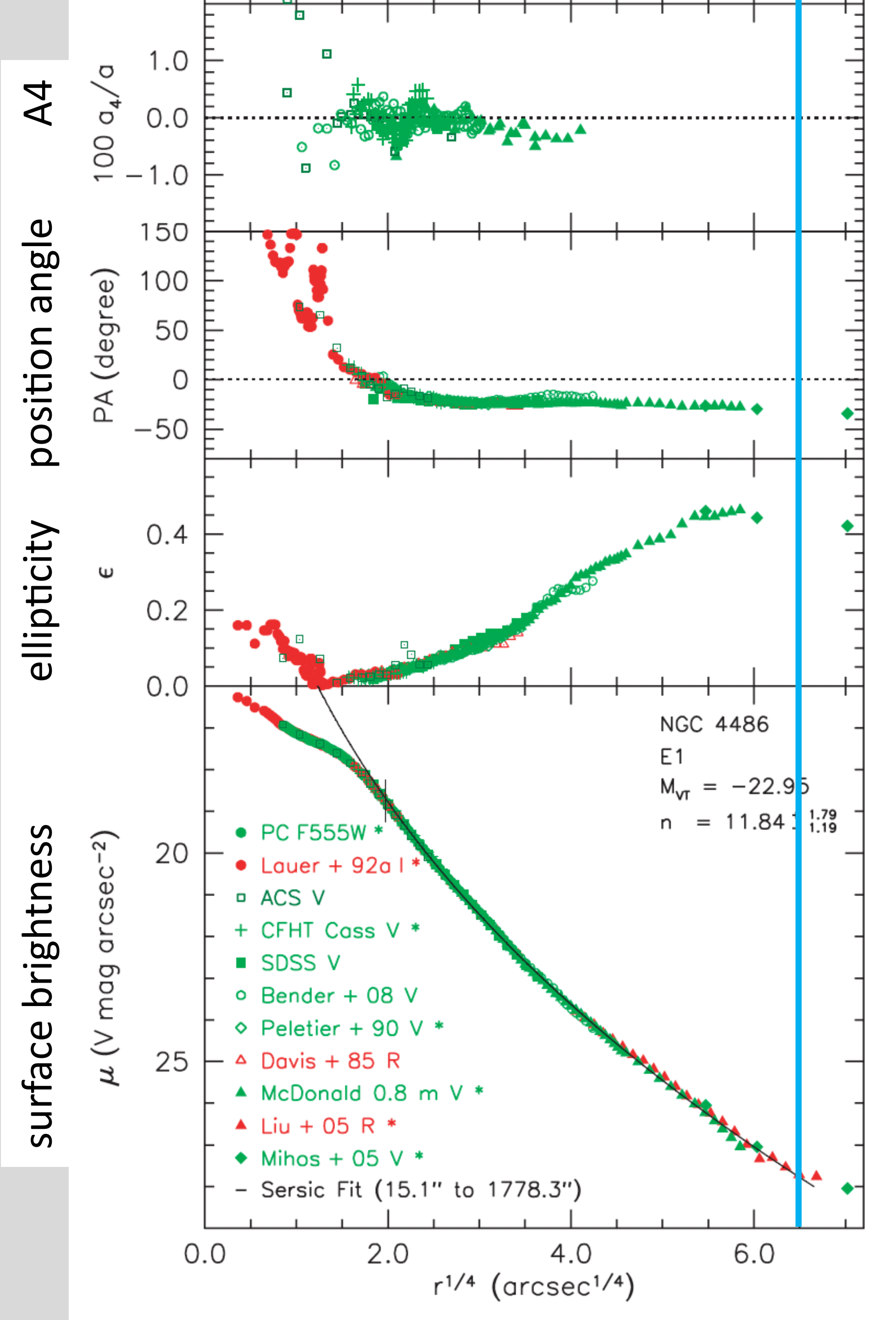
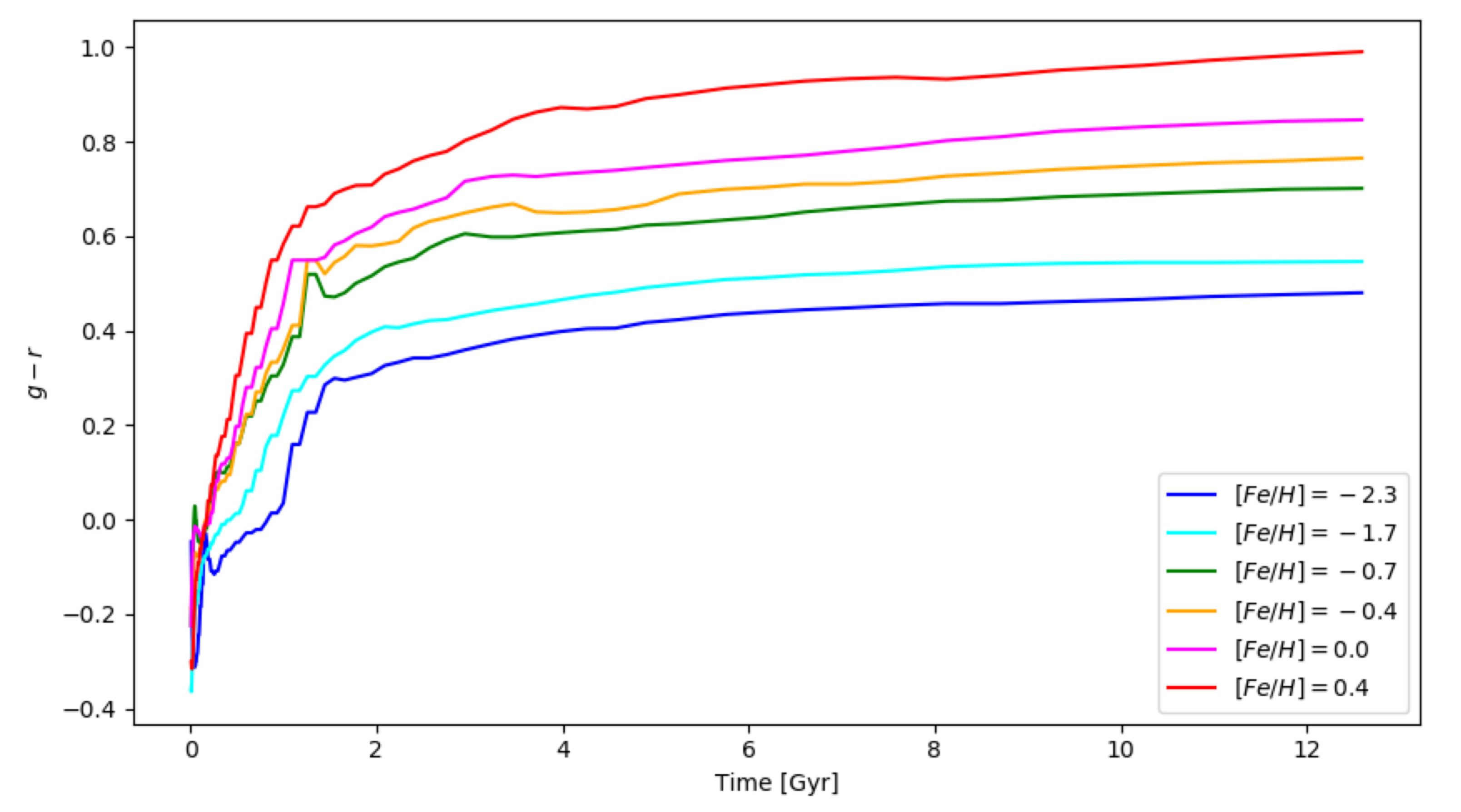


Elliptical Galaxies: Stellar Populations

Elliptical galaxies are typically ”red and dead”: old stellar populations with little or no ongoing star formation.

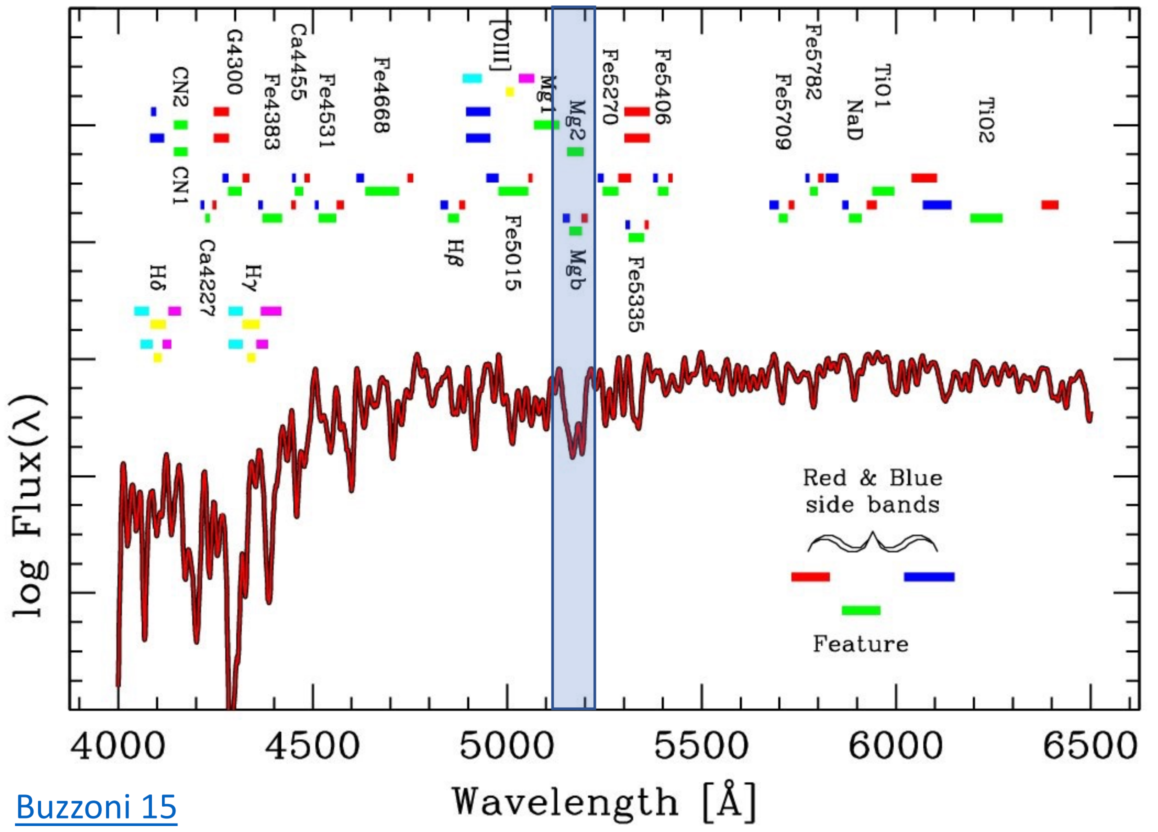
Remember: for old populations (> few Gyr), colors more indicative of metallicity than age:



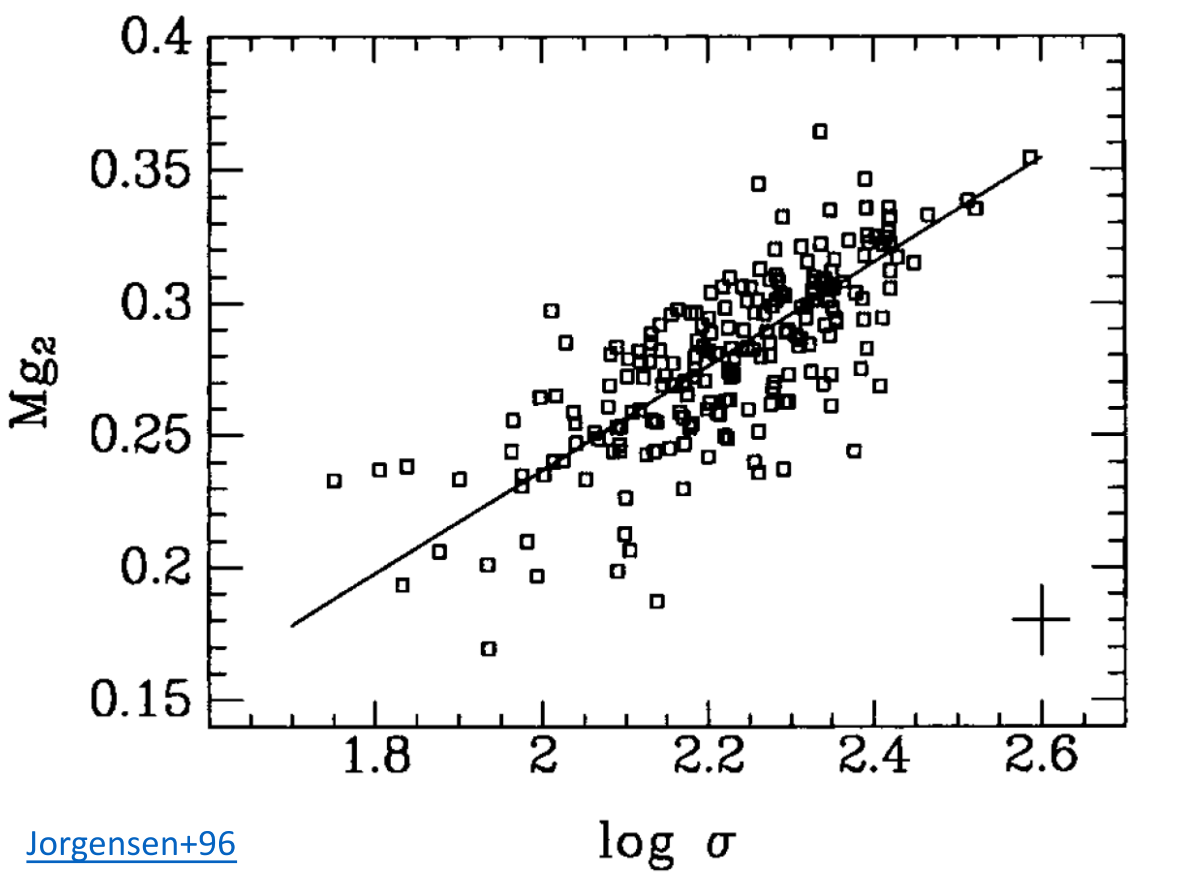
Mass-metallicity relationship

Mg2: strong absorption line in old stars (and therefore early type galaxies) which comes from magnesium ⇒ metallicity indicator

Mg2



Buzzoni 15



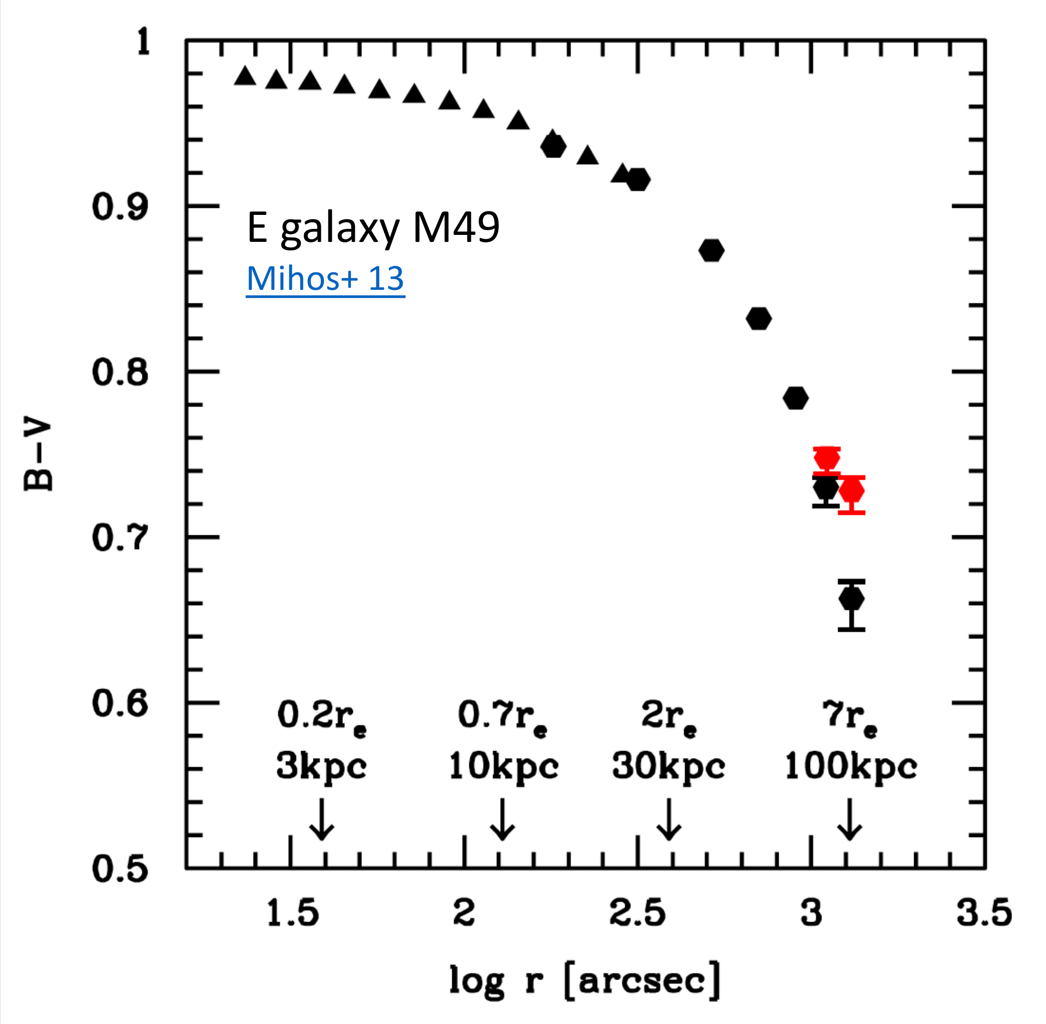
Jorgensen+96

⬆️ Strong correlation between metallicity (Mg_2) and velocity dispersion (σ) in E/S0 galaxies ⇒ **mass-metallicity relation**

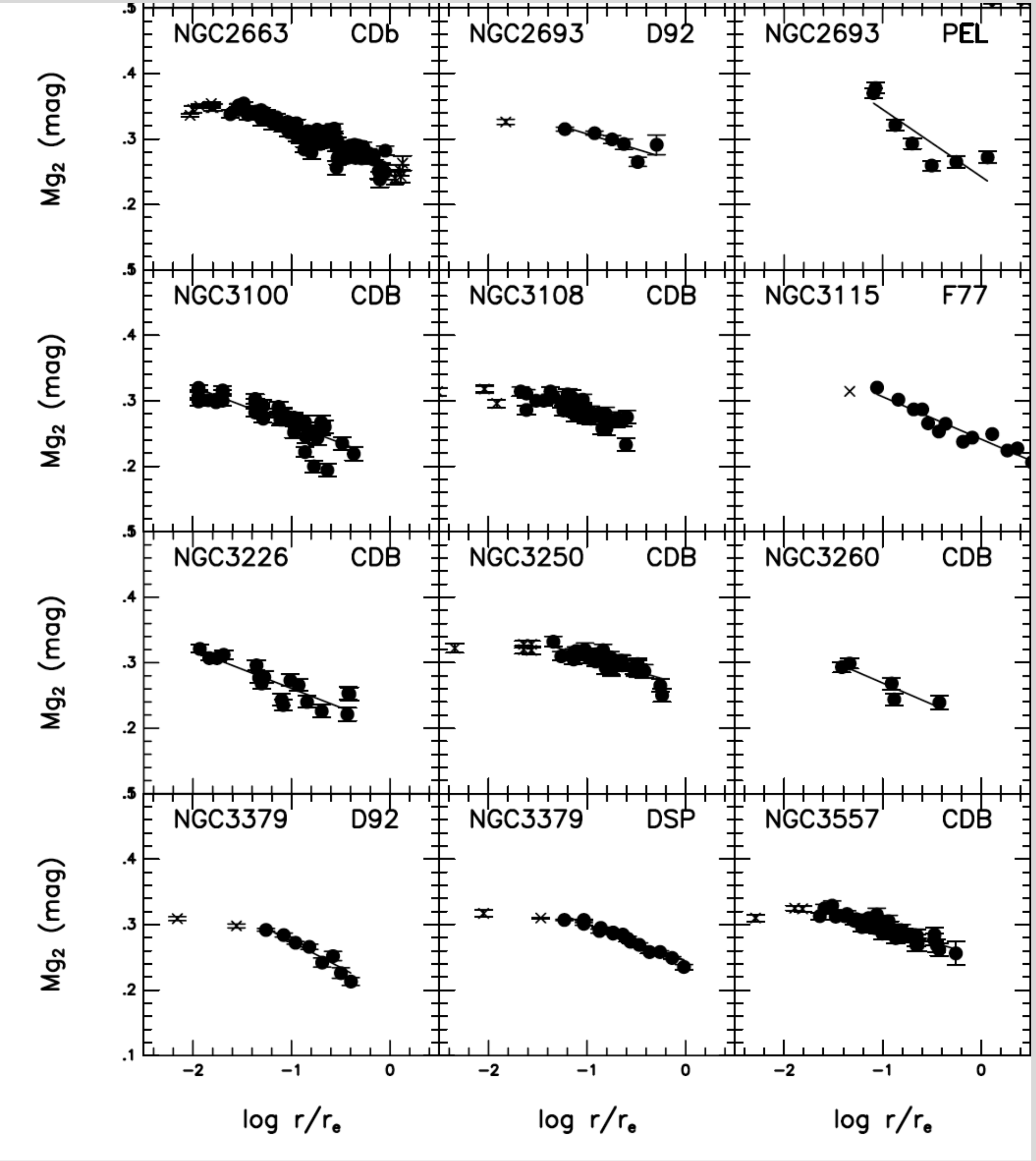
Main reason for the "tilt" (correlation between color and luminosity) in the red sequence.

Elliptical Galaxies: Stellar Populations

Elliptical galaxies show color gradients: redder interiors, bluer outskirts.



Spectroscopy confirms this is a metallicity effect.
(Mg_2 = magnesium line strength; Kobayishi & Arimoto 99)

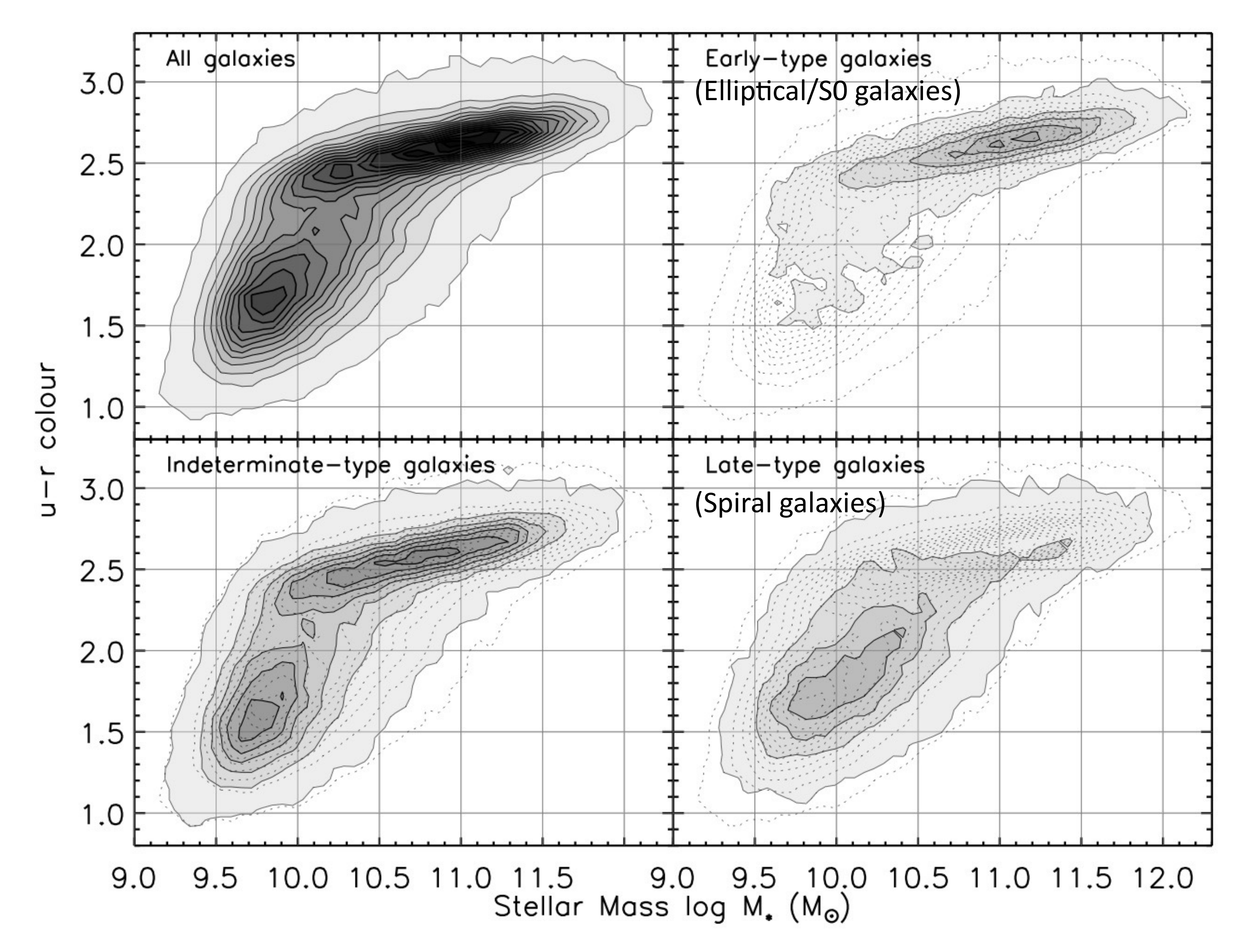


Elliptical Galaxies: Stellar Populations

courtesy K Schawinski

Similar effects give rise to the red sequence: massive ellipticals are redder because they are more metal-rich.

Note that when selected morphologically, there is a small population of ellipticals ("early-type galaxies") that fall in the blue cloud.



Elliptical Galaxies: Stellar Populations

Mass-Metallicity Relationship*: why?

One possibility: Feedback from star formation.

The combination of supernovae and stellar winds from massive stars adds lots of metals and energy to the surrounding gas in a galaxy.

More massive galaxies have deeper gravitational potential wells, so the gas cannot escape. New stars can form with higher metallicity. And so on....

Low mass galaxies have weak potential wells. The gas can escape and is lost. Since it is preferentially metal-rich, those metals are lost and any subsequent generation of stars will not be as metal-rich.

Mass-metallicity relationship holds for **all galaxy types…*

Starburst wind in M82

Elliptical Galaxies: Stellar Populations

Evidence for "*downsizing*":

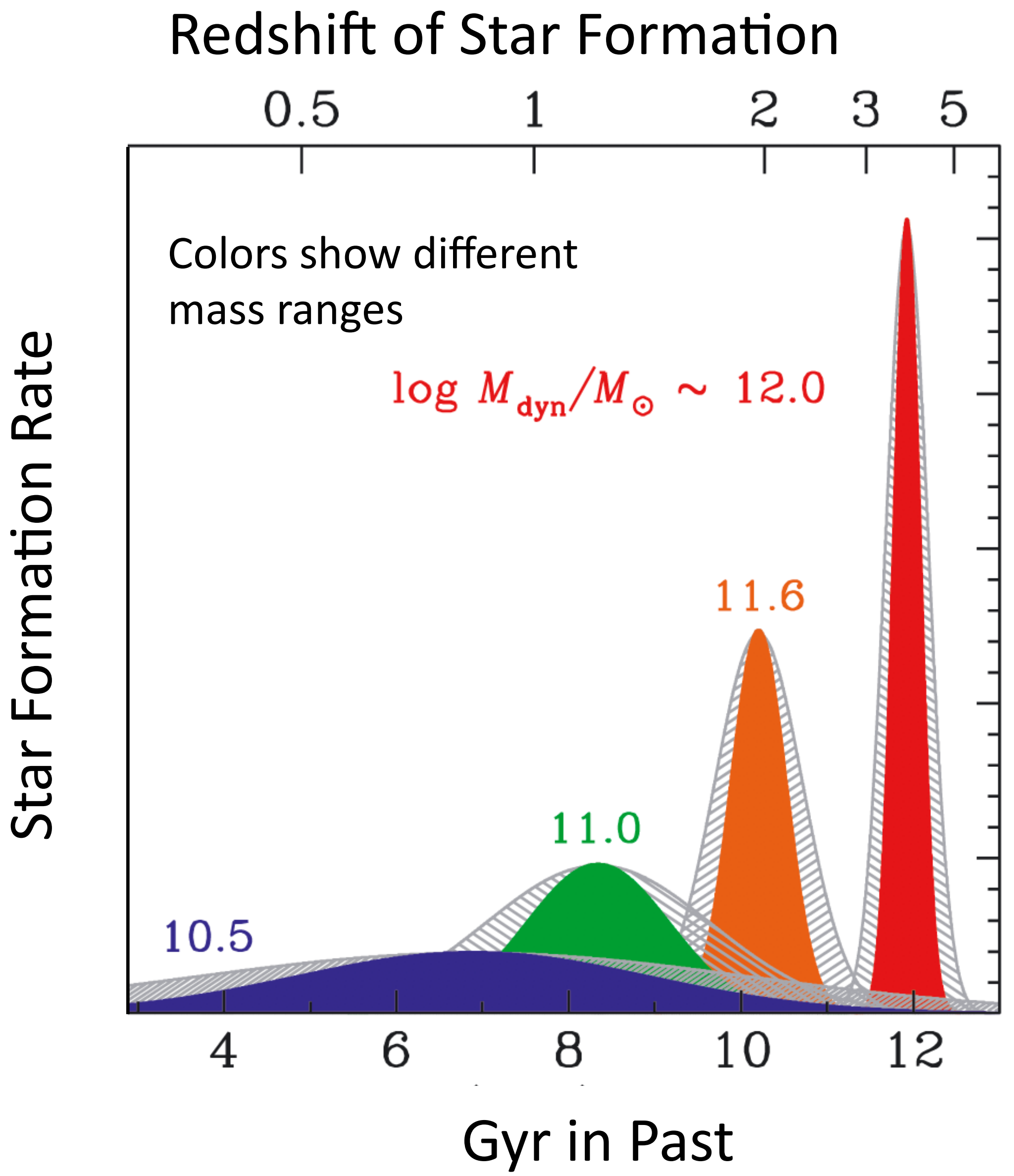
Stellar population modeling of ***nearby*** early-type galaxies in using SDSS spectroscopy.

Massive ellipticals contain stars that formed very early, less massive ellipticals show *slightly* younger populations.

Important Caveats:

- **This is not the cause of the red sequence tilt**: age differences too small to produce that much of a color change. Red sequence tilt ⇒ metallicity.
- **Age of stars is not the same as age of galaxy**. Heiarchical galaxy formation means stars can form in smaller galaxies but not merge together to form massive galaxy until later.

Thomas+ 10



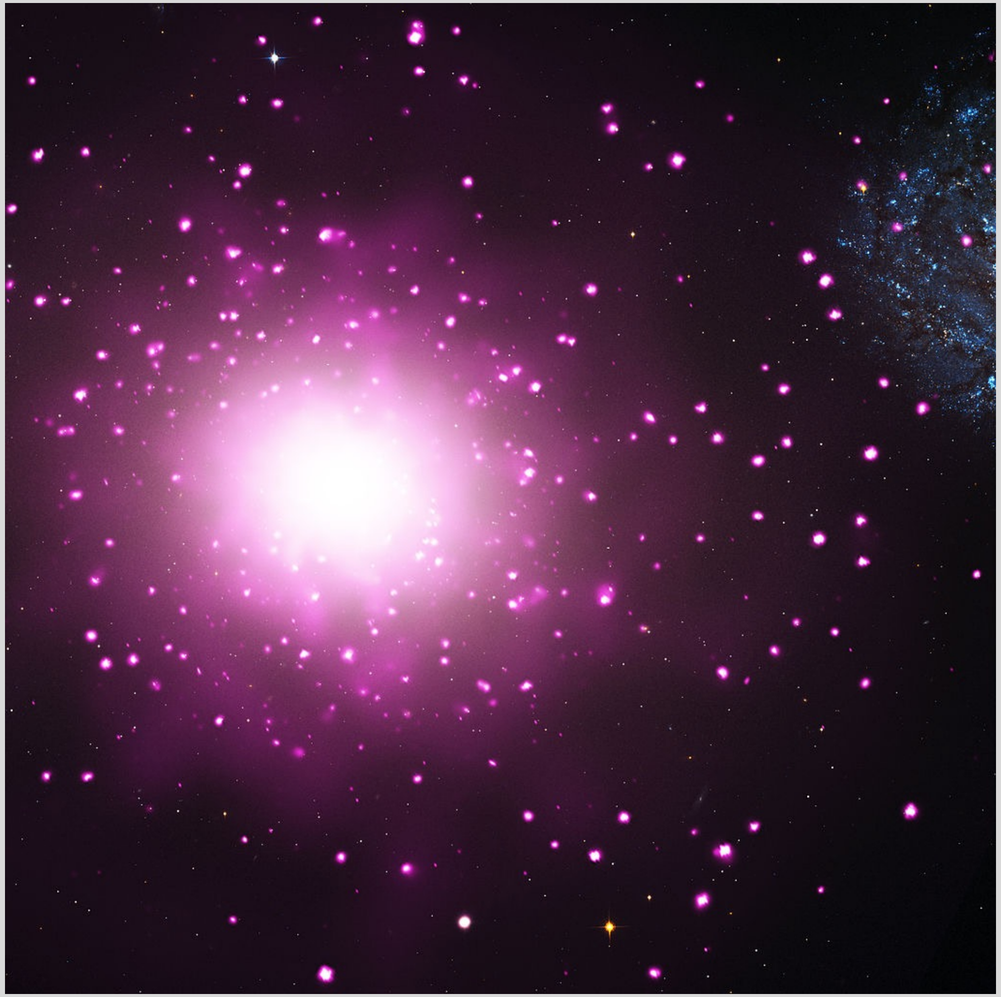
Elliptical Galaxies: Gas Content

Very little cold HI or molecular gas in elliptical galaxies.
Gas is hotter (10^7 K) and emitting X-rays.

Optical Starlight

NGC 4649
Strader+

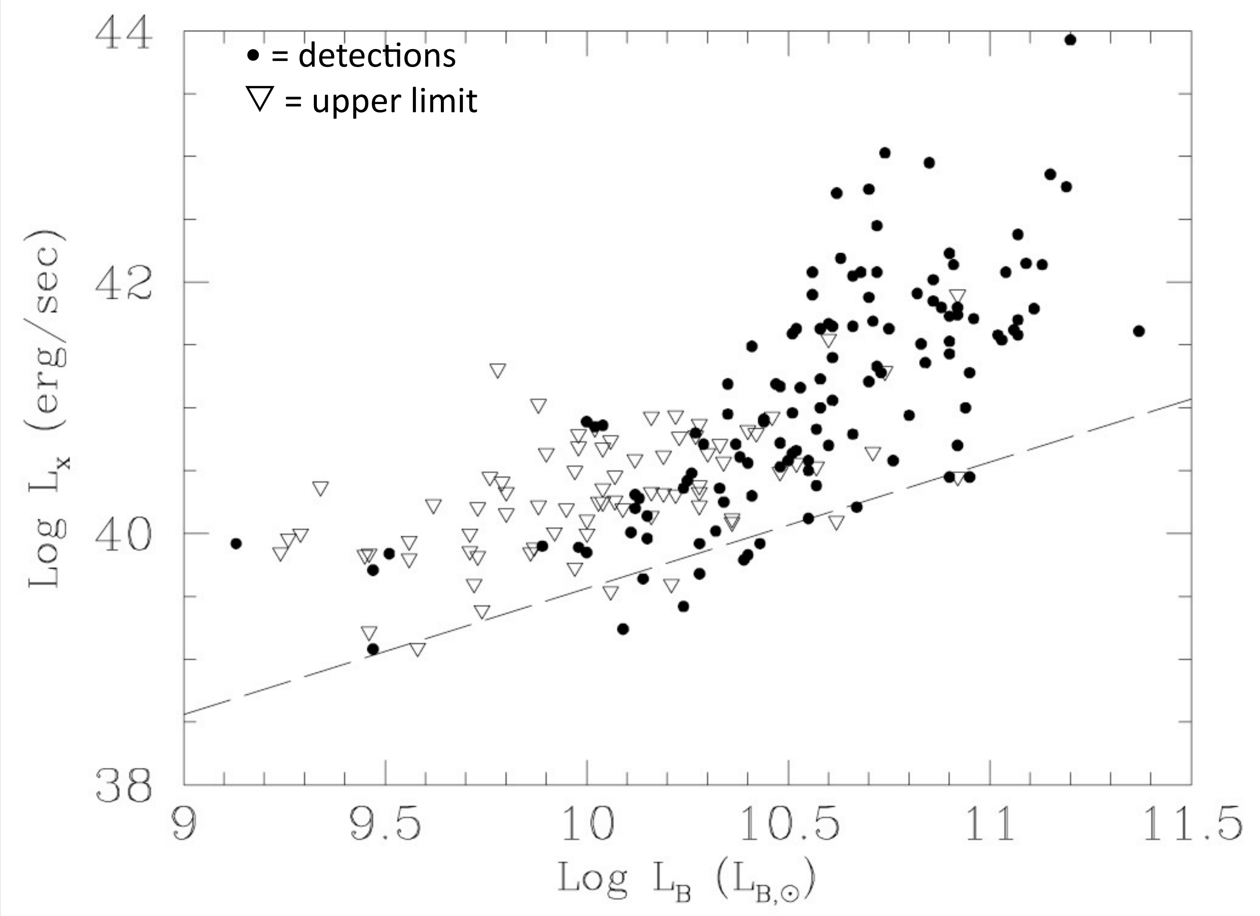
X-ray emission
diffuse emission: hot gas
point sources: accreting binary stars



Elliptical Galaxies: Gas Content

X-ray emission is significant in luminous ellipticals, inferred gas masses are $M_{gas} \approx 10^9 - 10^{11}\ M_\odot$ ($\approx 2\%$ of M_{stars})

X-ray luminosity vs optical luminosity
dashed line is expected X-ray emission for stars only
(Matthews & Brighenti ARAA 03)



Hydrostatic equilbrium: thermal pressure is in balance with gravitational potential energy:

$$\frac{dP}{dr} = -\frac{GM(r)\rho(r)}{r^2}$$

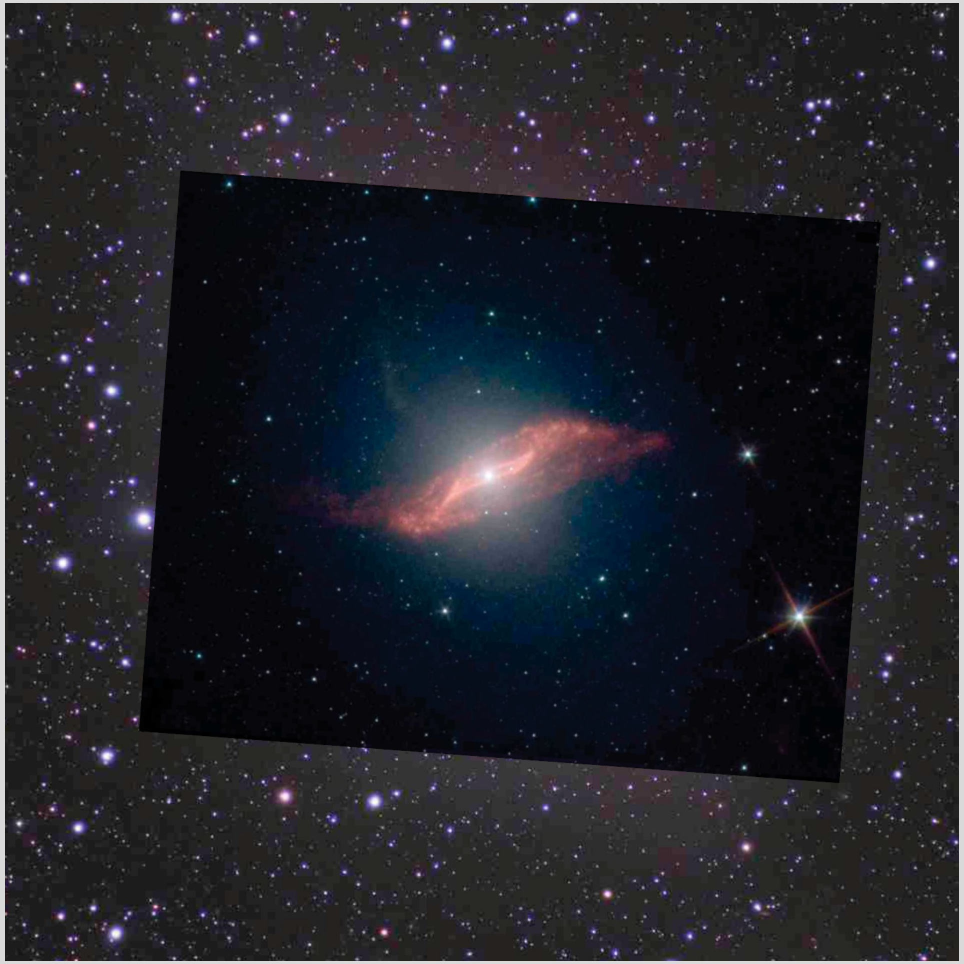
Using ideal gas law $P = \frac{\rho k T}{\mu m_p}$, we can solve for the total mass distribution:

$$M(r) = -rT(r)\frac{k}{G\mu m_p}\left(\frac{d\log\rho}{d\log r} + \frac{d\log T}{d\log r}\right)$$

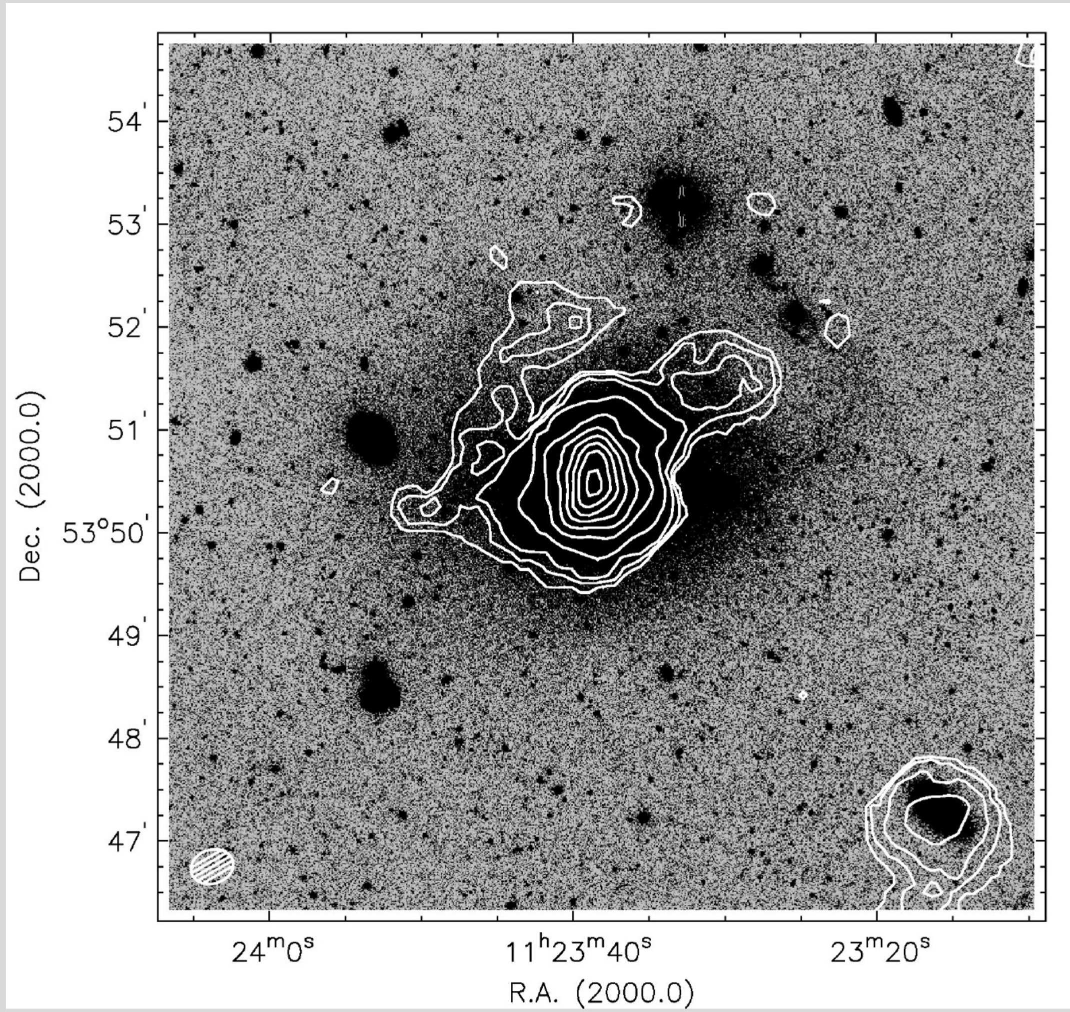
Given X-ray measures of gas density and temperature, we solve this to infer **elliptical galaxies also have massive dark matter halos**.

Elliptical Galaxies: Cold Gas

Not all elliptical galaxies are devoid of cold gas; some examples do exist. Often in morphologically peculiar ellipticals.



Centaurus A (courtesy T Oosterloo)



NGC 3656 (Balcells+ 01)

Elliptical Galaxies: Kinematics

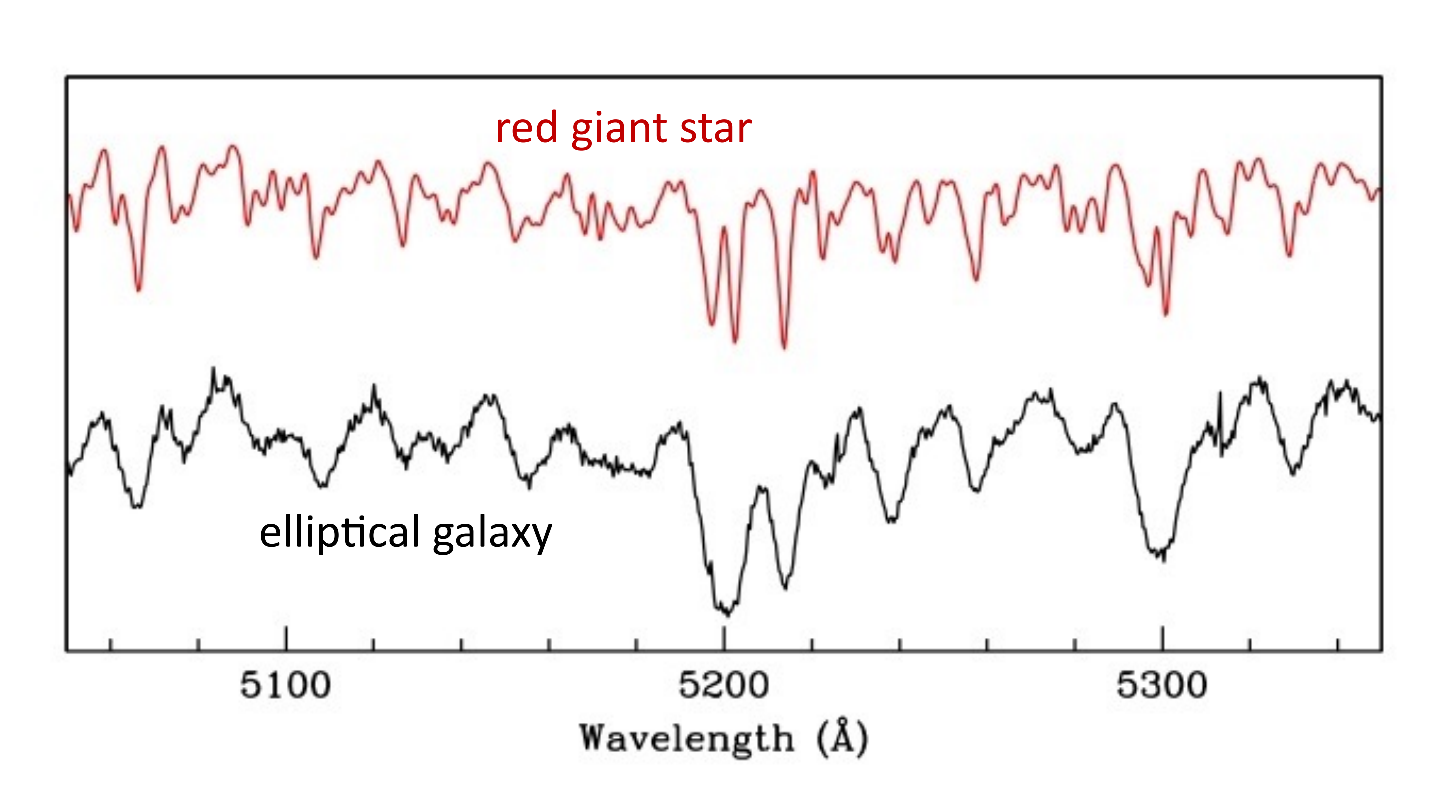
Without much cold gas or star formation, can't get kinematics from 21-cm or Hα emission lines. Must get kinematic information from stellar absorption lines, which is harder.

When we take a spectrum of an elliptical, we see projected stellar velocities, integrated along the line of sight. This broadens spectral lines.

Integrated light in ellipticals is dominated by old stellar populations: luminous red giants.

Take a red giant spectrum and broaden/shift it in wavelength to match observed galaxy spectrum.

Central wavelength and width of line gives us the mean line-of-sight velocity $\langle V \rangle$ and velocity dispersion (σ).



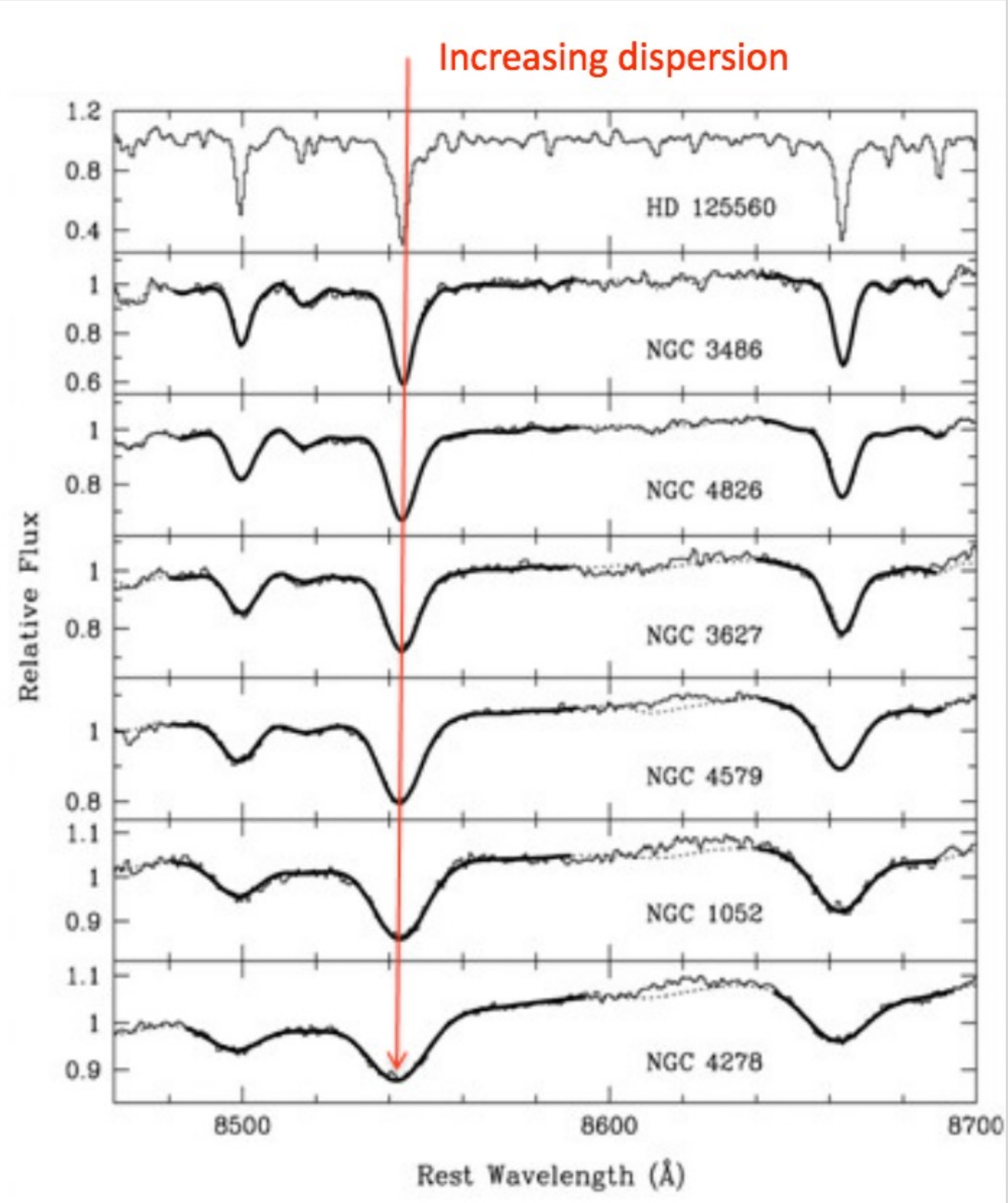
Broadening and velocity dispersion

Red giant star spectrum →

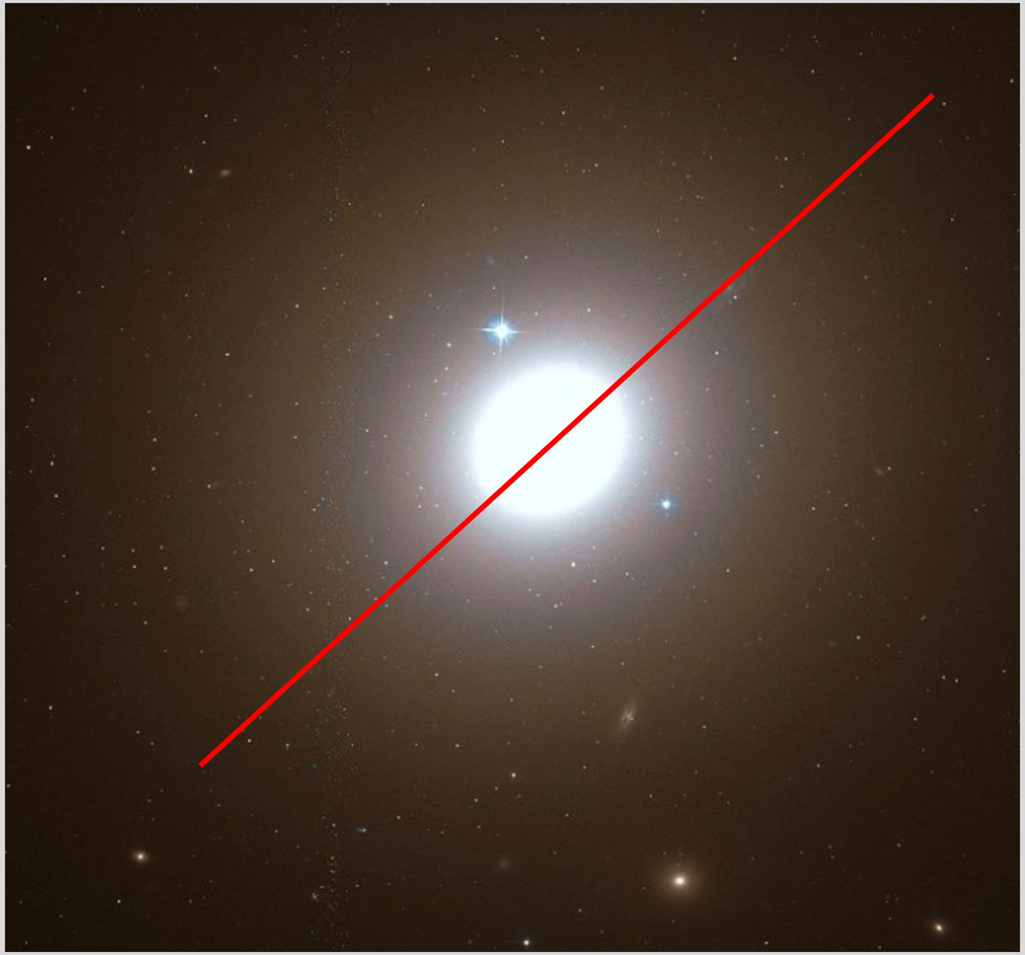
Absorption lines are broadened in wavelength, showing that ellipticals typically have low rotation (V_c) and large velocity dispersion (σ).

Elliptical galaxies are "kinematically hot" galaxies, with $V_c/\sigma < 1$.

Galaxies



Elliptical Galaxies: Major Axis Kinematics



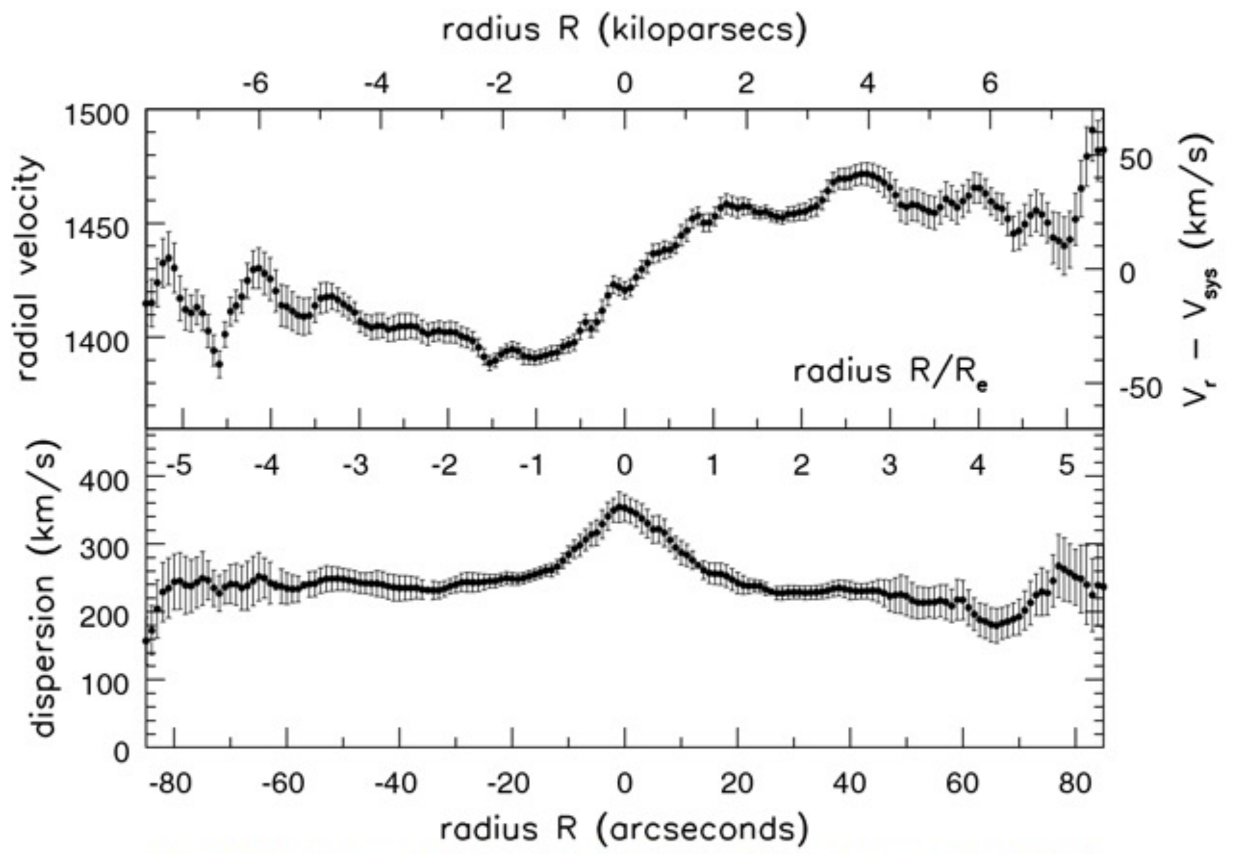


Fig 6.12 (A. Graham) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

NGC 1399: $\sigma \approx 350$ km/s, $V_c \approx 35$ km/s, $V_c/\sigma \approx 0.1$

(Compare to Milky Way disk: $\sigma \approx 30$ km/s, $V_c \approx 220$ km/s, $V_c/\sigma \approx 7.3$)