Elliptical galaxies

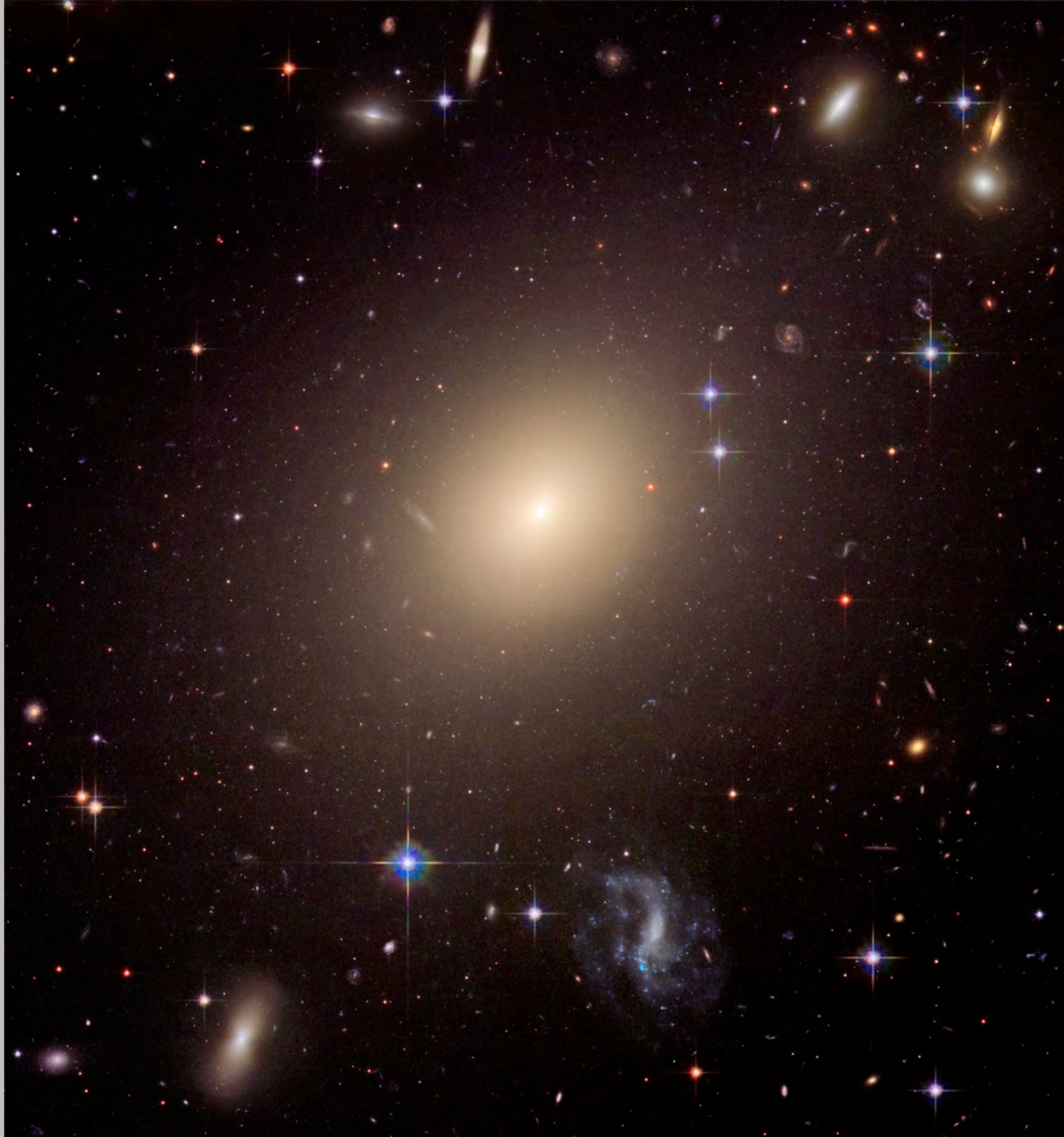
E’s span a wide range of luminosity and have a correspondingly wide range of structural properties.

We can measure surface brightness profile, 2D shape, integrated colors:

- spheroids, not thin exponential disks
- round to moderately flattened ($b/a \approx 0.5 - 1.0$)
- typically red ($B - V \approx 0.7 - 1.1$)
- generally smooth and “featureless”: no internal substructure
- not much cold atomic or molecular gas
- old stellar populations, little on-going star formation.

⇒ “red and dead” *(maybe....?)*

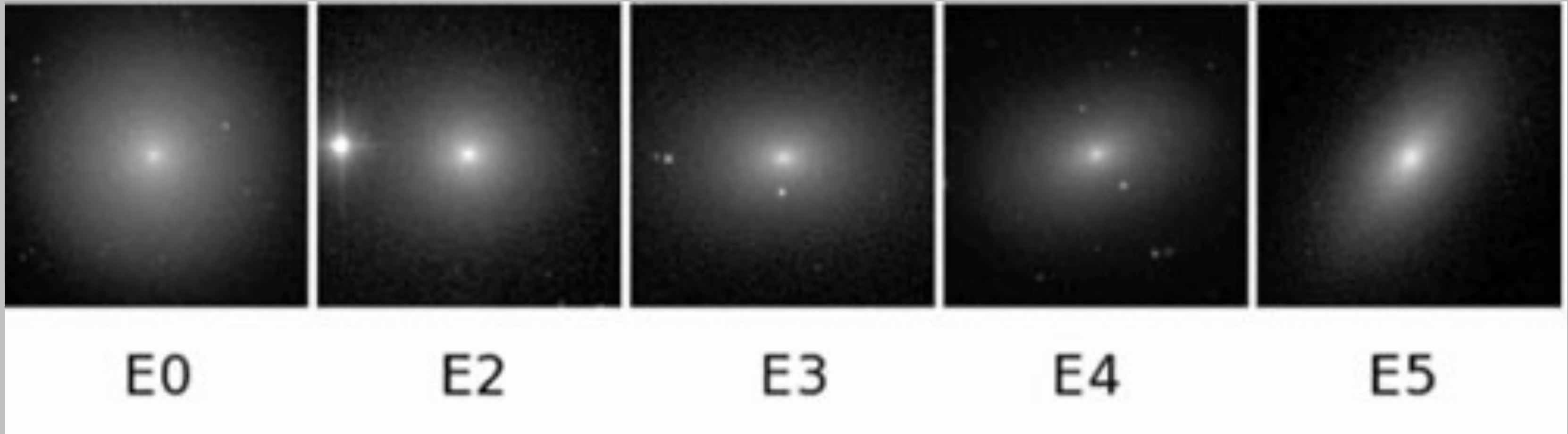
Here we will mostly be talking about regular/giant ellipticals. Dwarf ellipticals (dE’s) and dwarf spheroidals (dSph’s) are different animals entirely!



Elliptical Galaxies: Ellipticity

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

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

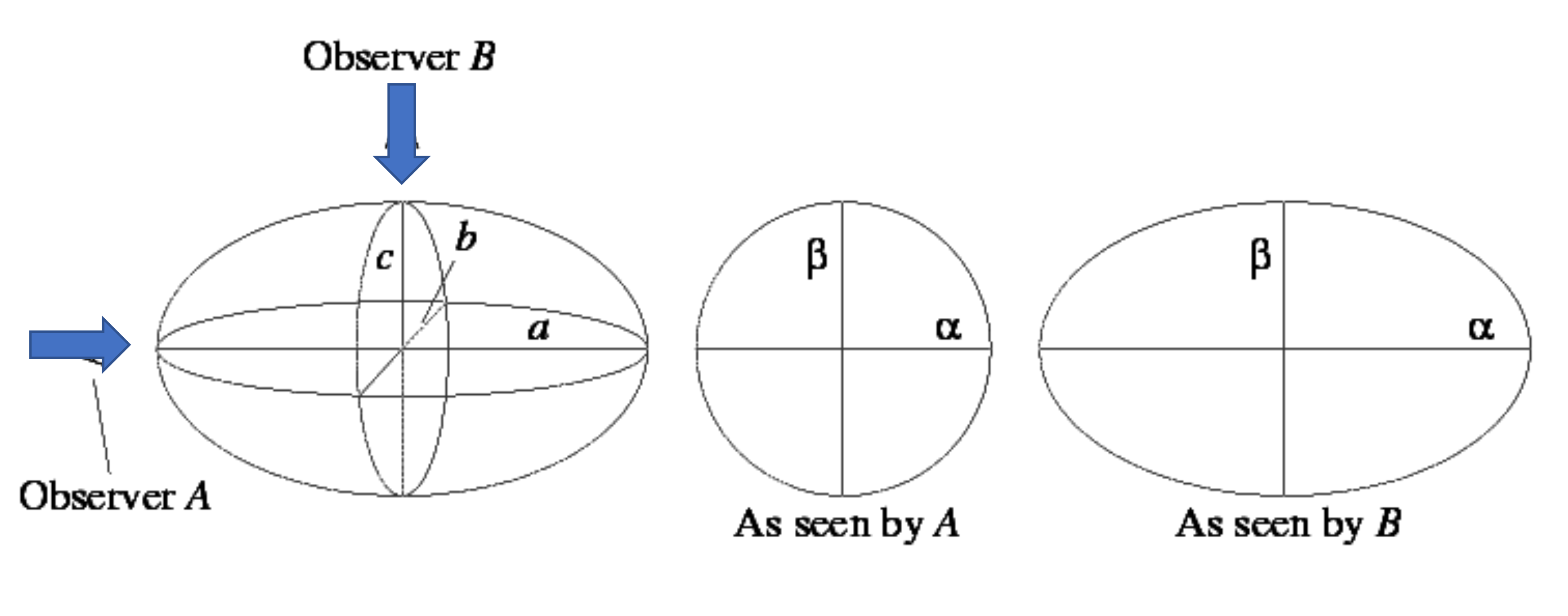


$b/a = 1$ $b/a = 0.8$ $b/a = 0.7$ $b/a = 0.6$ $b/a = 0.5$

*Beware: **observed** axis ratio 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: Luminosity Profiles

First, remember disk galaxies: Exponential luminosity profiles ($I = I_0 e^{-R/h}$) which turn into linear profiles ($\mu(R) \sim R$) when plotted as logarithmic surface brightness. But ellipticals are not exponential.

Originally defined by Gerard deVaucouleurs to have profiles that behave like $\mu(R) \sim R^{1/4}$. Known as an "R-to-the-quarter law" or a "deVaucouleurs profile".

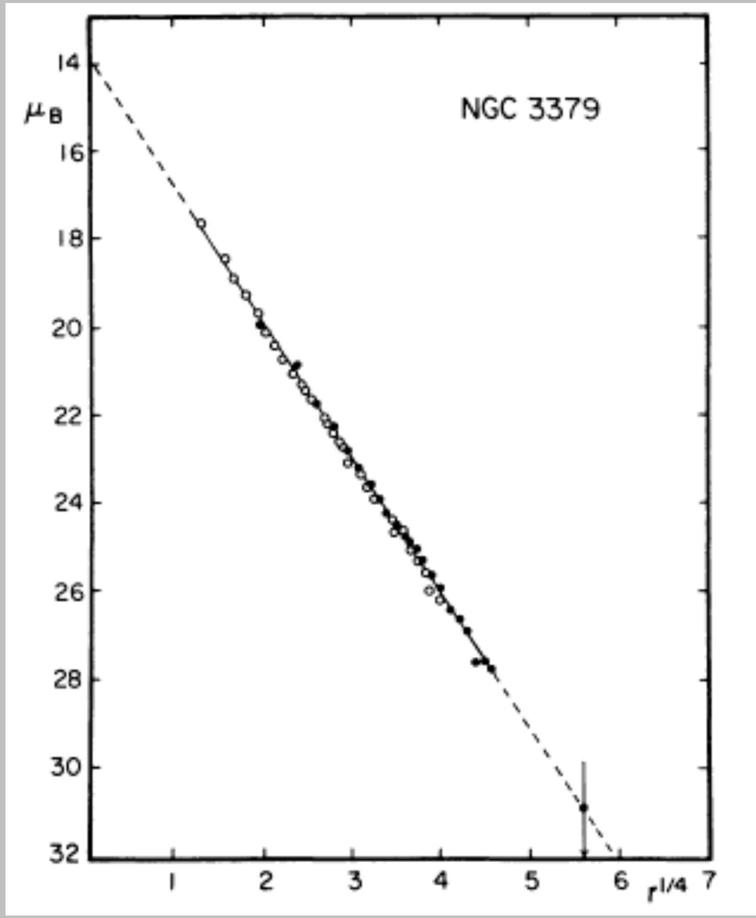
Since $R^{1/4}$ laws don't have a natural radial scale length like exponential profiles do, we characterize the size of an elliptical by the radius containing half the total light of the galaxy.

This is known as the half-light radius or effective radius (R_e).

And instead of a central surface brightness, we talk about the average surface brightness within the effective radius: $\langle \mu \rangle_e$ or $\langle I \rangle_e$

mag/arcsec^2

$L_\odot/pc^2$



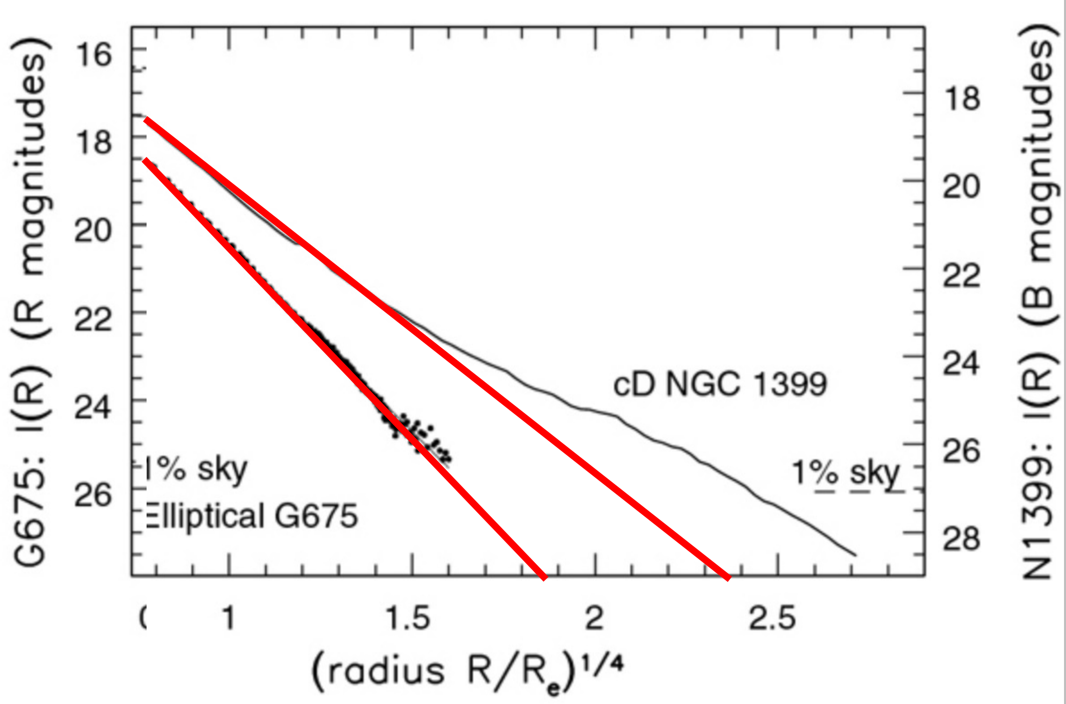
Elliptical Galaxies and the Sersic profile

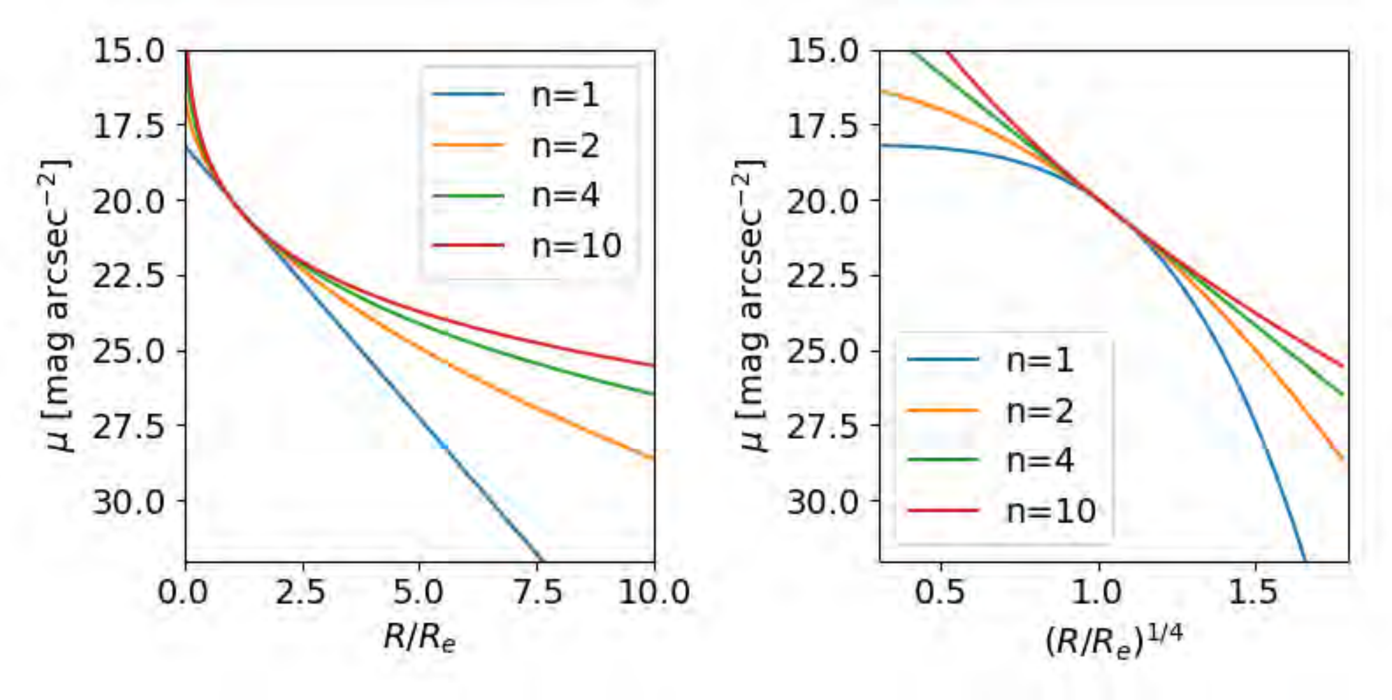
But elliptical galaxies show a range of profile types, not always $R^{1/4}$ $\Rightarrow$

This has led to the definition of a more general profile shape, called a Sersic profile of index n:

$$\mu(R) \sim R^{1/n}$$

- $n = 1$: pure exponential, $\mu(R) \sim R$
- $n = 4$: de Vaucouleur law, $\mu(R) \sim R^{1/4}$
- Ellipticals a wide range of n values





Compared to disk galaxies, ellipticals typically have more light at both large and small radius.

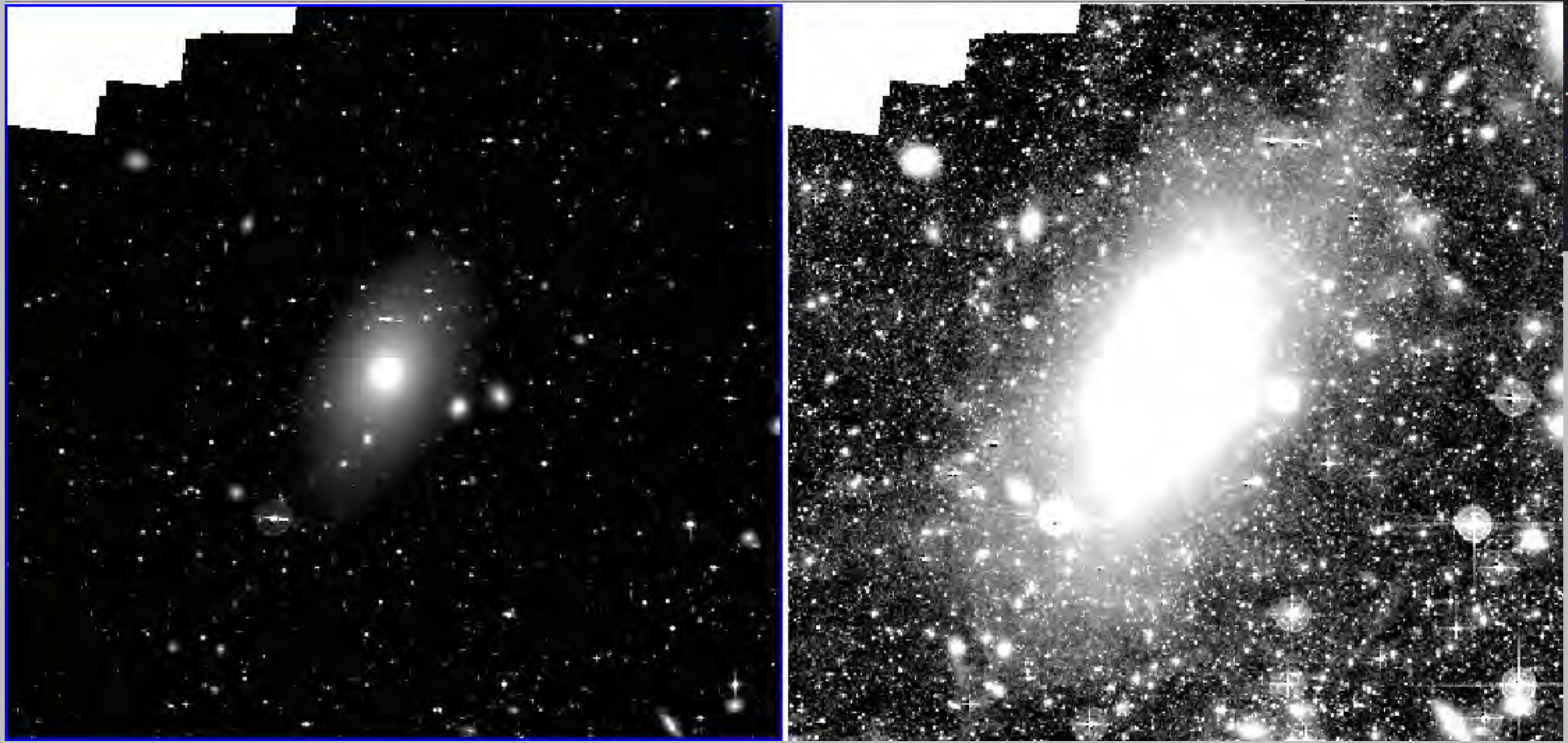
Sersic n roughly correlates with luminosity:
Luminous ellipticals ($L \approx 10^9 - 10^{10}\ L_\odot$) : $n \approx 4$
Massive cD ellipticals ($L >$ few $\times 10^{10}\ L_\odot$): $n > 4$
Dwarf ellipticals ($L \lesssim 10^9\ L_\odot$) : $n \approx 1$

exponential, but not disks!

Ellipticals at low and high luminosity

NGC 205
dwarf elliptical
$n \approx 1$
(John Chumack)

M87
Giant cD galaxy
$n \approx 10$
(Mihos+17)



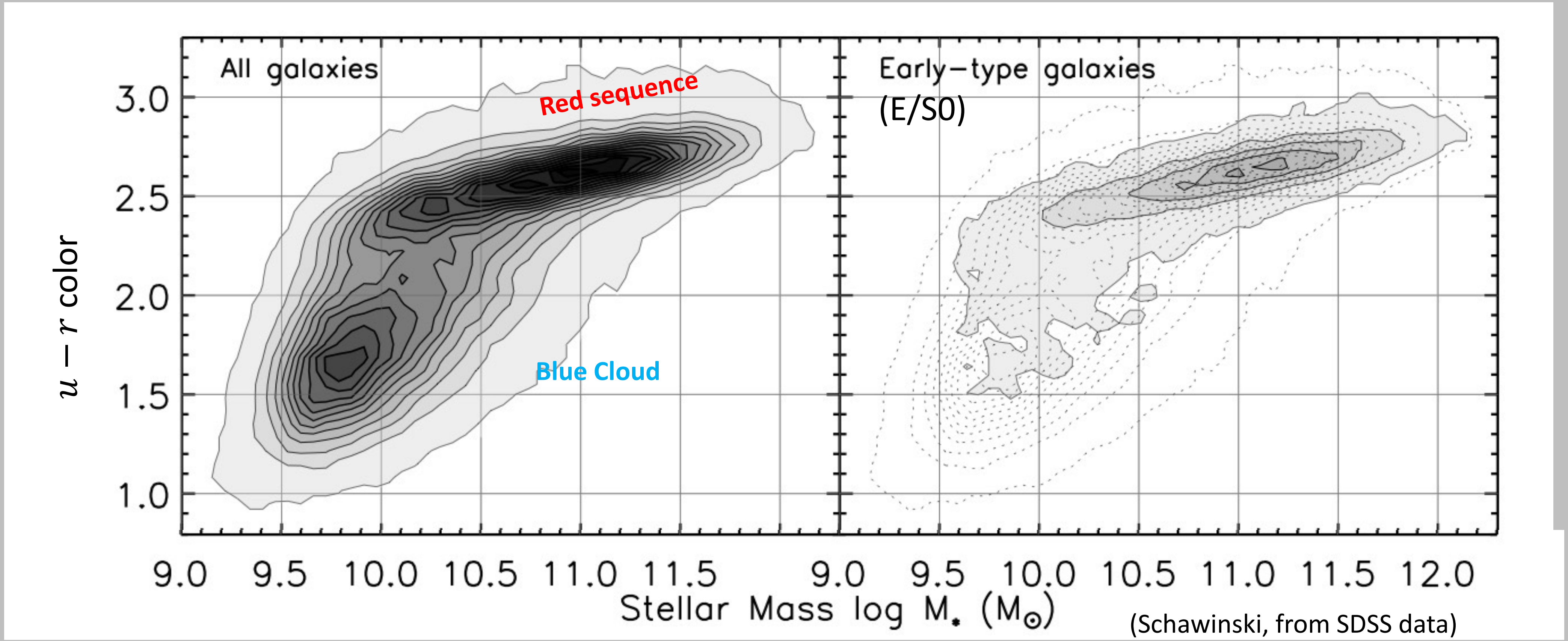
Elliptical Galaxies: Colors and stellar populations

Galaxies tend to segregate into two color groups:

- **red sequence** (old ellipticals and S0s)
- **blue cloud** (star forming disks and irregulars)

Three important take-aways:

1. The most massive galaxies are ellipticals.
2. Ellipticals are red: generally old stellar populations
3. Ellipticals follow a mass-color relationship: massive ellipticals are redder, lower mass ellipticals are (slightly) bluer.



(Schawinski, from SDSS data)

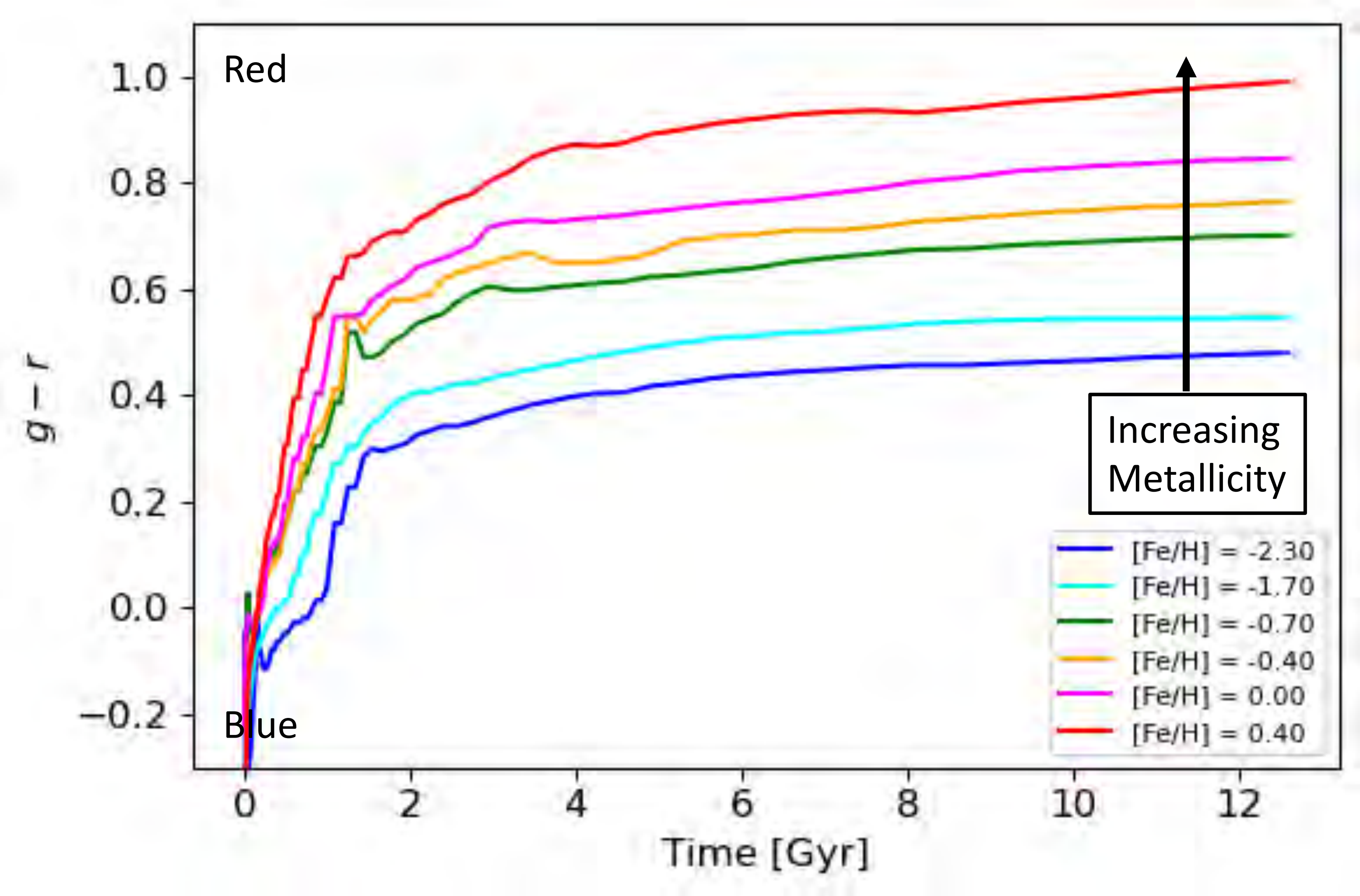
Elliptical Galaxies: Colors and stellar populations

Remember that for old stellar ages, color is much more sensitive to metallicity differences than age differences.

The color spread along the red sequence would imply an age spread of 2 – 15 billion years, which is nonsense.

Instead we are seeing a metallicity sequence: **the mass-metallicity relationship**. More massive ellipticals have more metal-rich stellar populations (and are thus redder).

This is confirmed by spectroscopic studies of elliptical galaxies which show stronger absorption lines due to metal-rich stars.



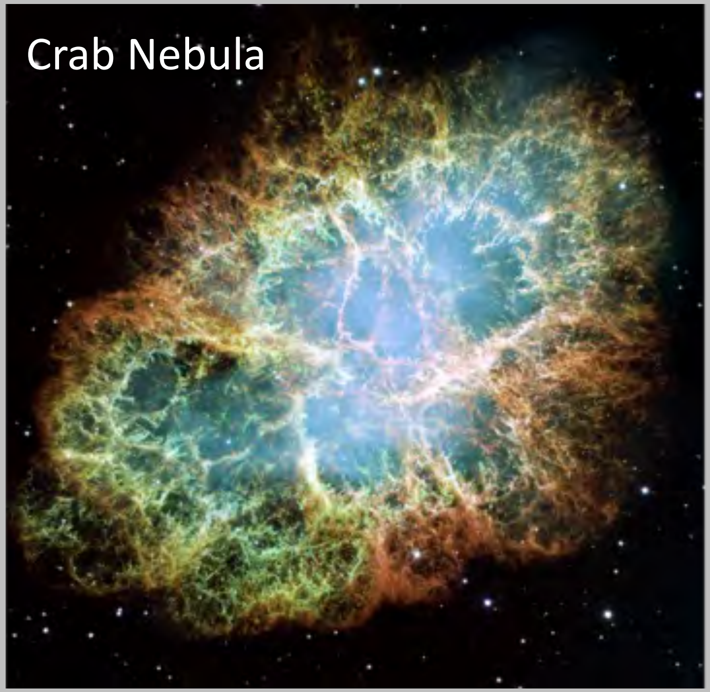
What drives the mass-metallicity relationship

Remember **chemical evolution**: stars make heavy elements ("metals") in their cores and then eject them into the surrounding gas for subsequent star formation to create more metal-rich stars.

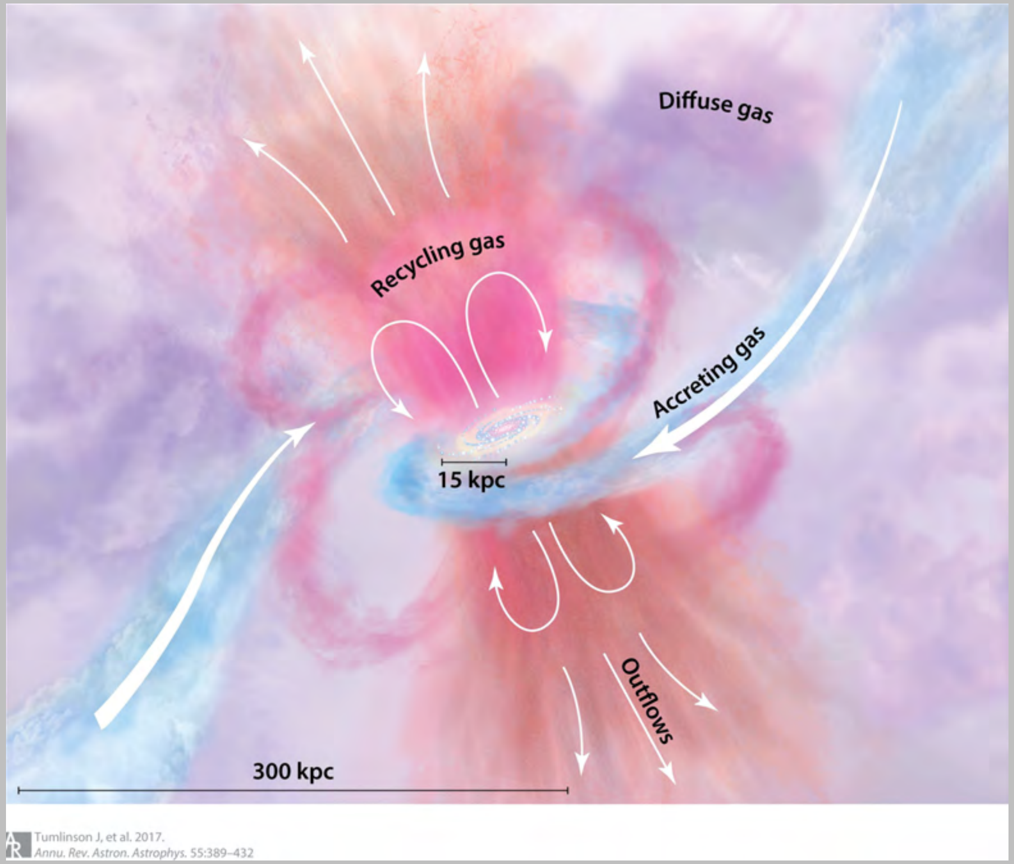
These metals are often ejected at high speed during supernovae events.

One possibility is that if the ejection speed exceeds the escape velocity for a galaxy, those metals will be lost to intergalactic space and won't be incorporated into subsequent generations of stars.

It's easier to escape from low mass galaxies than massive galaxies, so only more massive galaxies could build up stars with high metallicity.

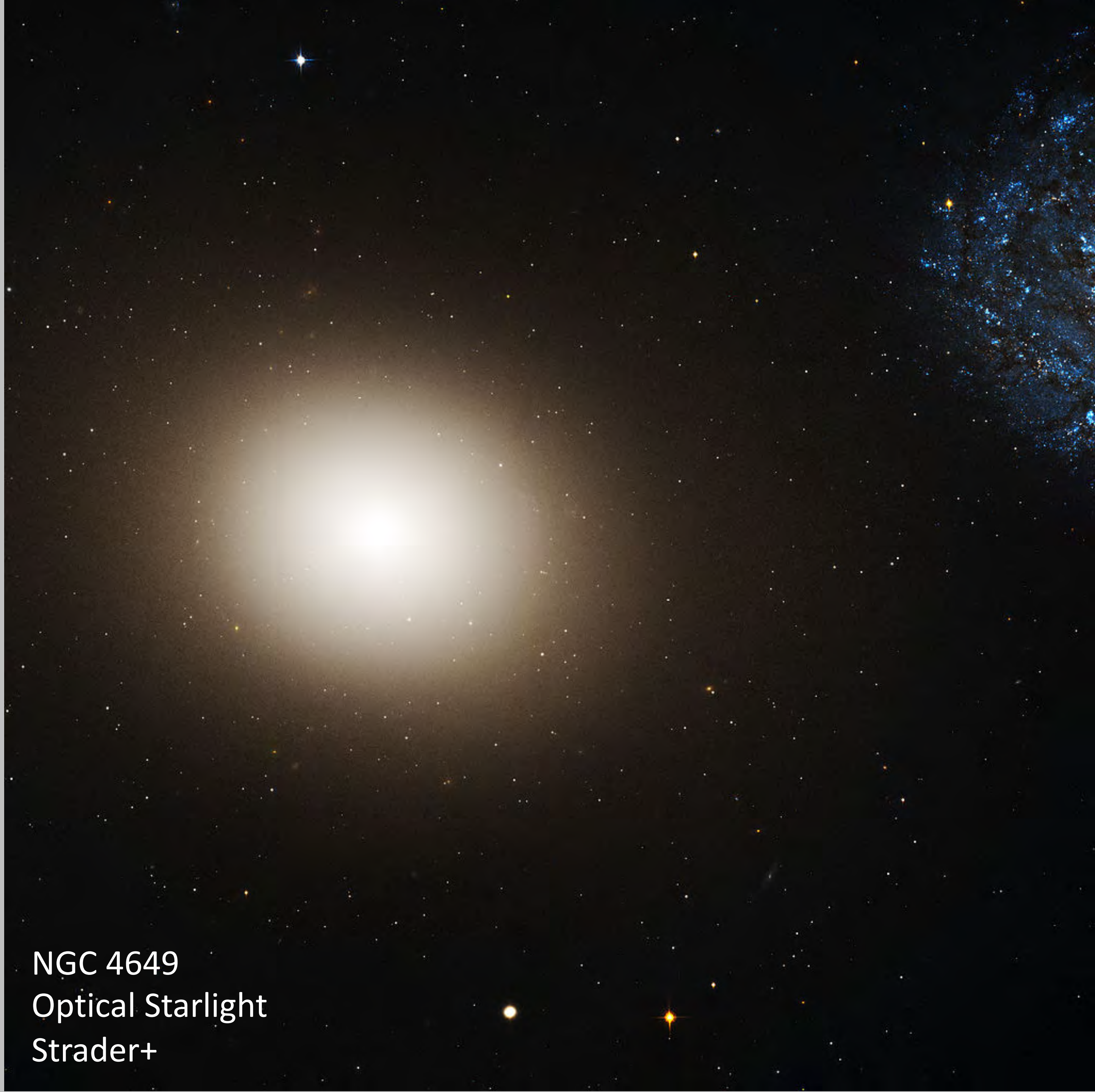


Sounds plausible,
but is far from proven!



Hot gas in elliptical galaxies

Ellipticals generally have very little cold atomic or molecular gas. But if we look in X-rays....



Hot gas in elliptical galaxies

Ellipticals generally have very little cold atomic or molecular gas. But if we look in X-rays....

... we see lots of diffuse X-ray emission: free-free (Bremsstrahlung) emission from ionized gas.

How hot is this gas? Set the X-ray photon energy equal to the thermal energy:

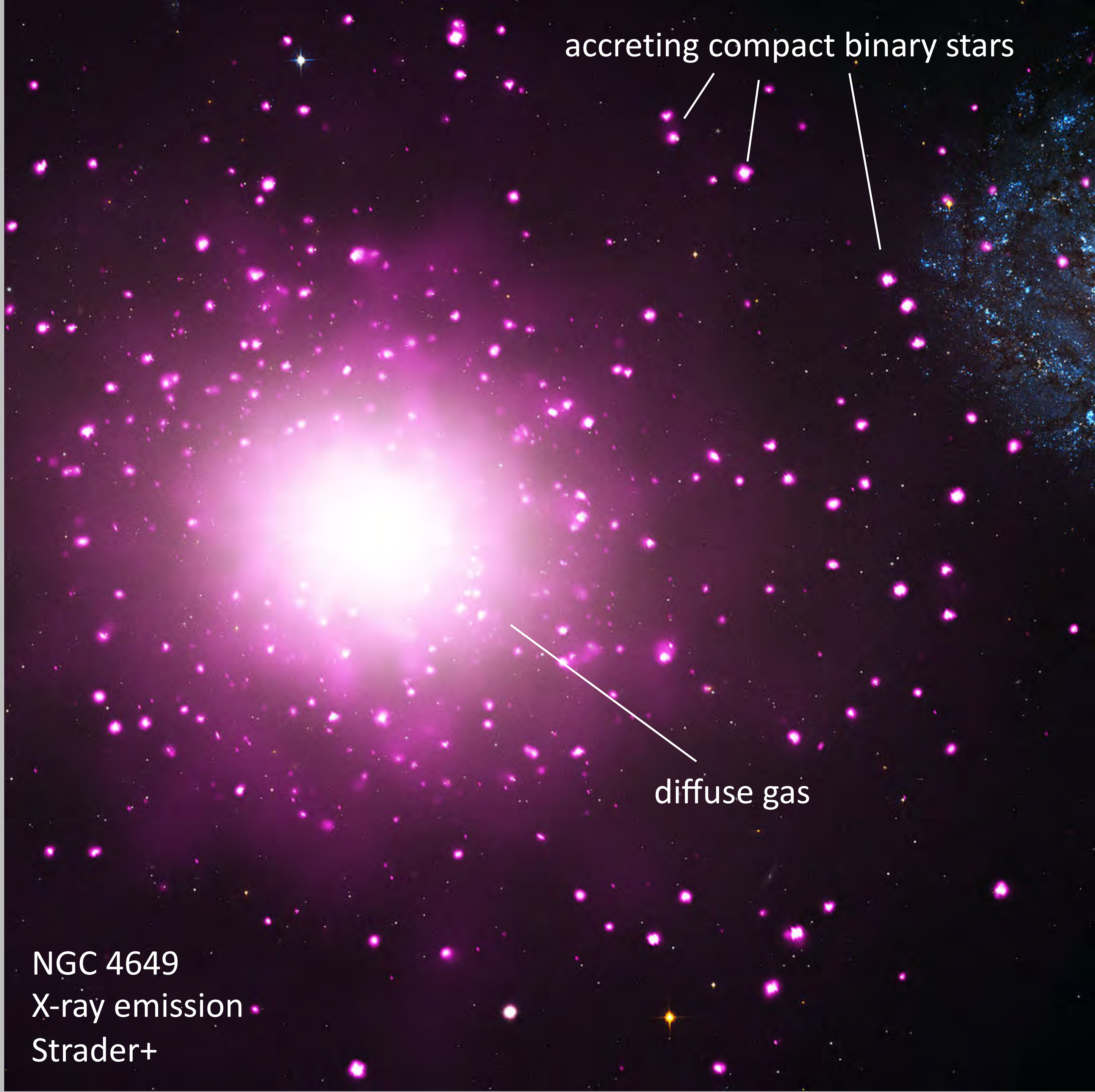
$$h\nu \approx kT$$

and solve for temperature: $T \approx h\nu/k \approx 10^6$ K

The gas is hot and diffuse and cannot form stars. But there's a fair bit of it! $\mathcal{M}_{gas} \approx 10^8 - 10^9 \mathcal{M}_\odot$.

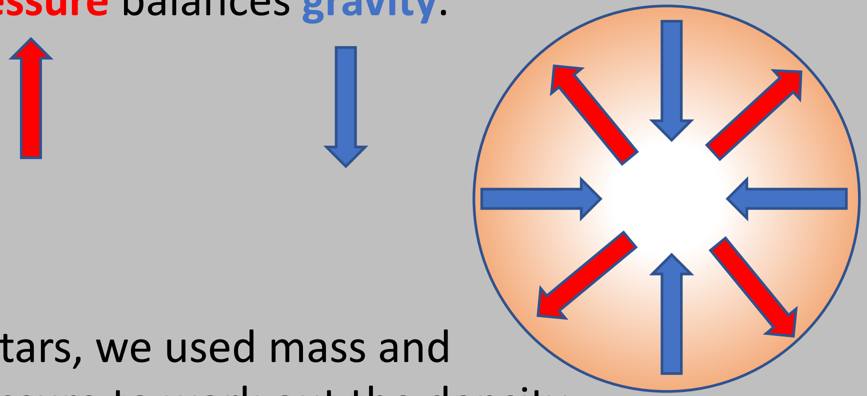
Metallicity is low, about 1/3 solar.

What's going on?



Hot gas in elliptical galaxies

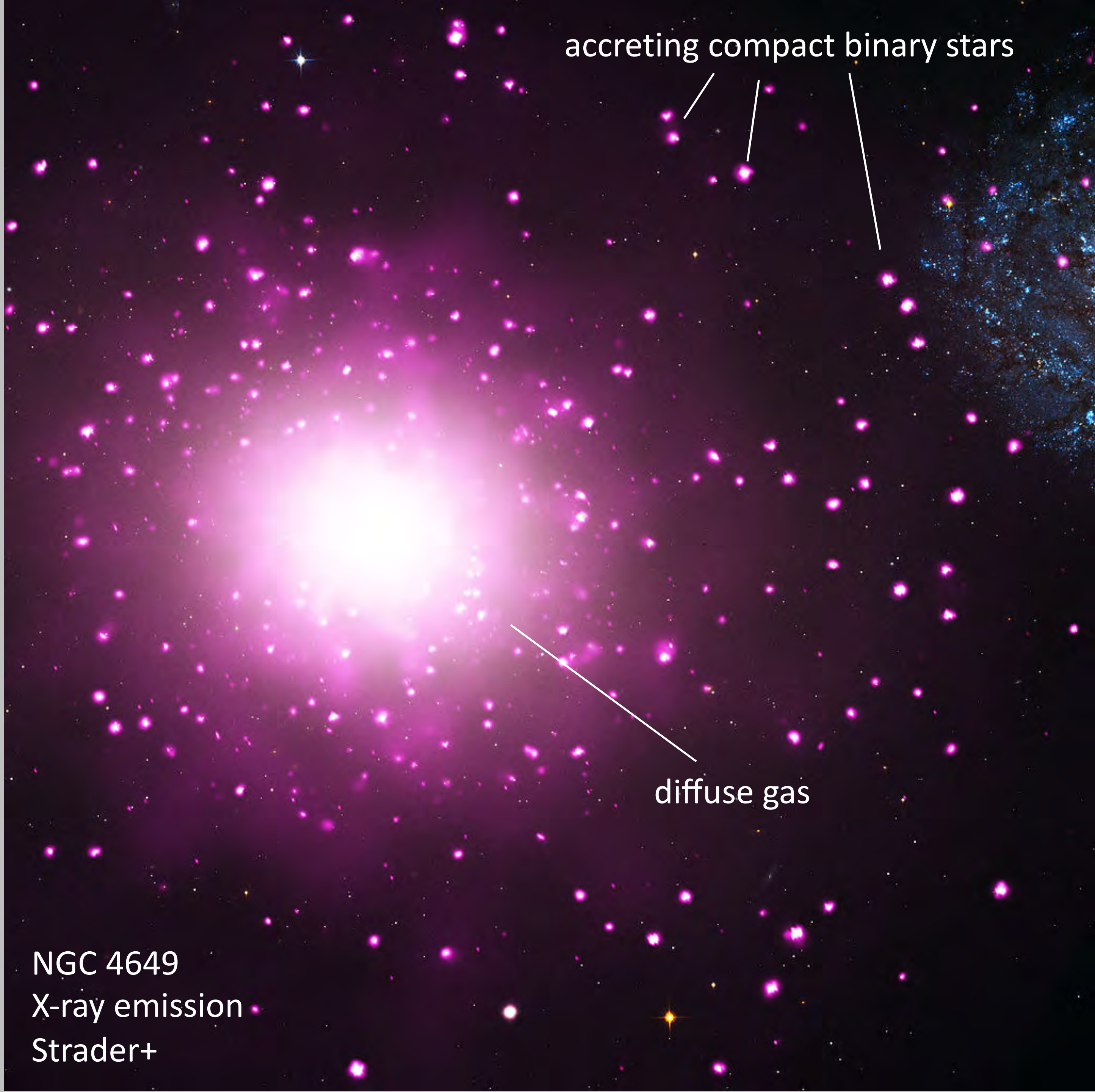
Remember hydrostatic equilibrium.
Pressure balances **gravity**.



In stars, we used mass and pressure to work out the density and temperature structure of the star.

Here, we can measure density and temperature of the gas and work out the mass of the galaxy.

A big elliptical might have a mass of $\approx 10^{12}\mathcal{M}_\odot$, much more than gas+star mass. ⇒ ***Dark matter!***

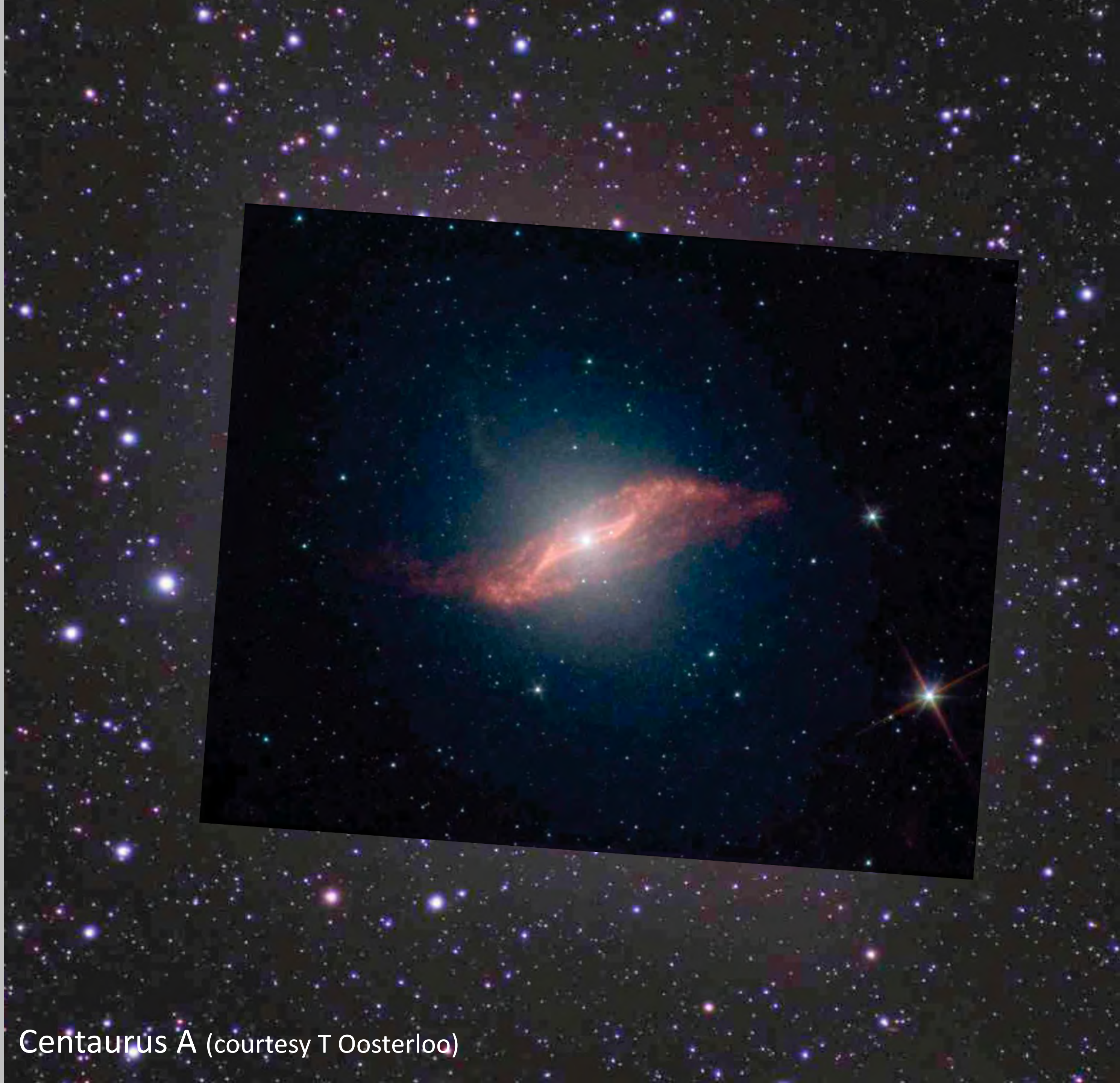


Cold gas in elliptical galaxies

Some ellipticals have a bit of cold neutral hydrogen gas.

Typically morphologically peculiar ellipticals like Centaurus A.

Color image: Visible starlight
Contours: 21-cm HI emission
Overlay: mid-IR dust emission



Centaurus A (courtesy T Oosterloo)