Dwarf Galaxies

Remember the luminosity function of galaxies: rising at faint magnitudes.

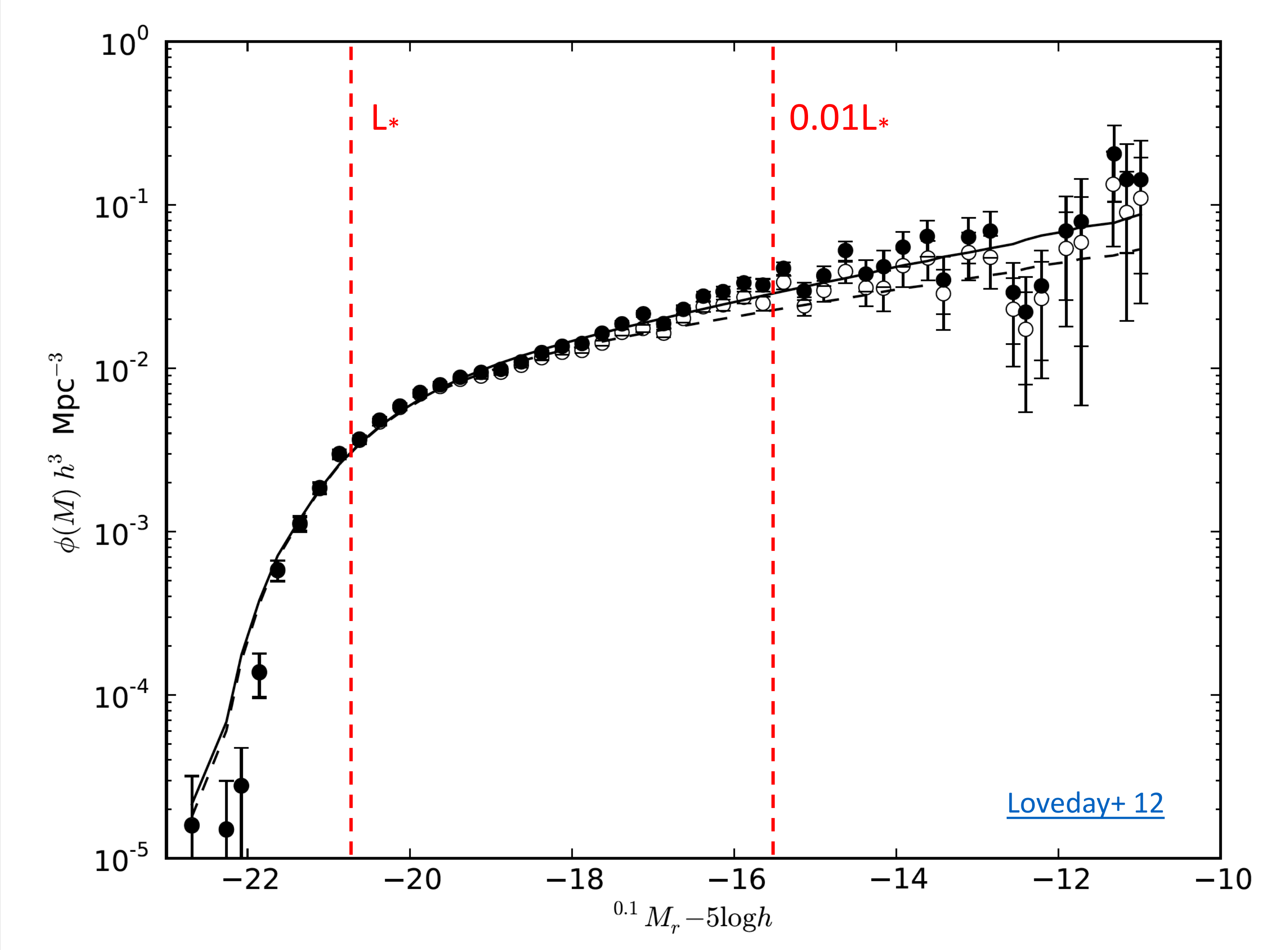
By number, low luminosity dwarfs far outnumber bright galaxies. (But luminous galaxies contain most of the stars.)

Schechter Function:

$$\Phi(L)dL = \Phi_* \left(\frac{L}{L_*}\right)^{\alpha} e^{-L/L_*} dL$$

The faint end slope (α) of the LF is:

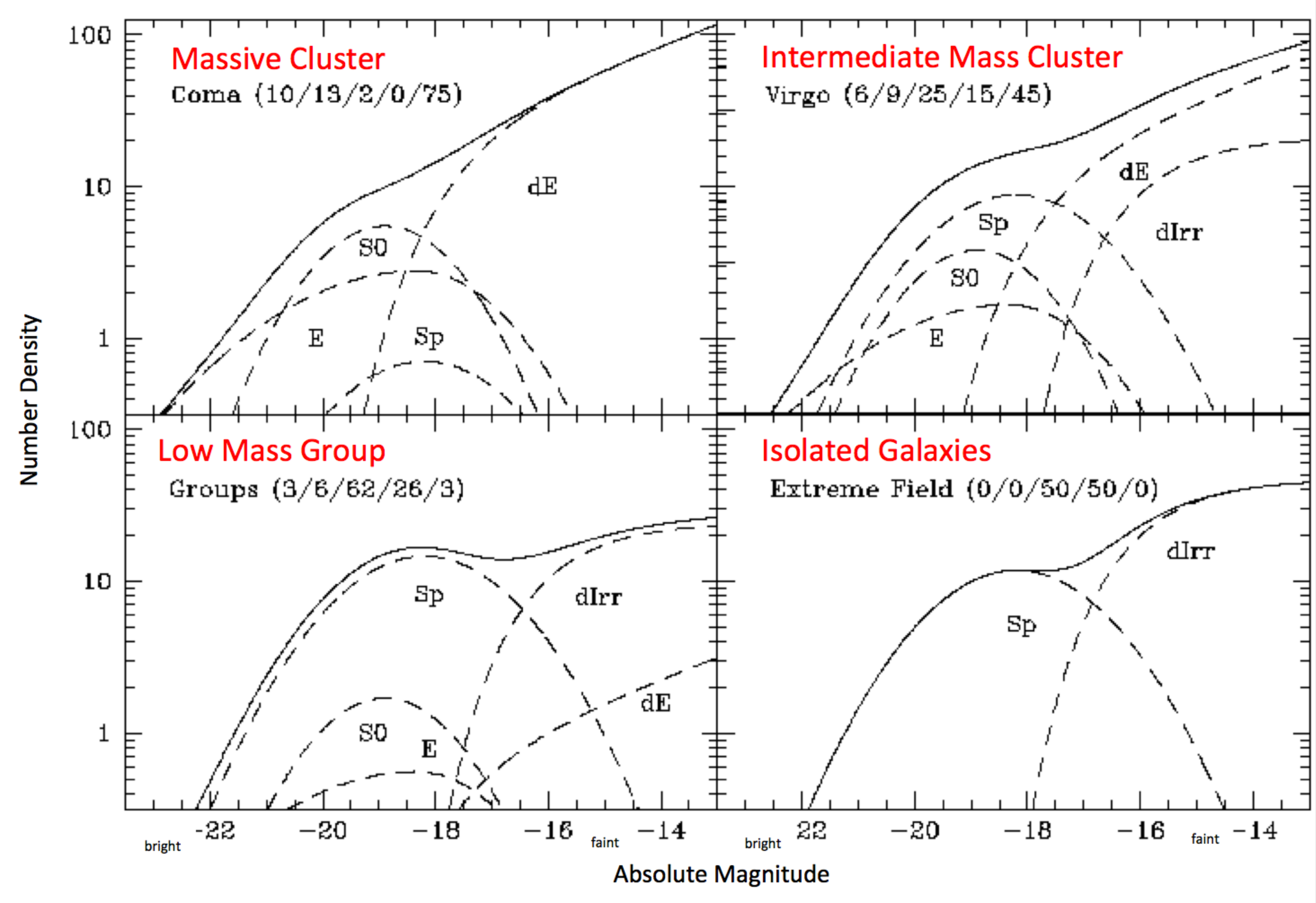
- environmentally dependent
- color dependent
- hard to measure



Galaxies: Luminosities

…and a very strong dependence on galaxy type and environment

These are schematic LFs, not real



Classical Dwarfs: Local Group Galaxies

“Dwarfs” have usually been defined by luminosity: M_V fainter than −17 or so ($L_V \lesssim 5{\times}10^8\ L_\odot$ or a few % of MW).

At fixed surface brightness, this generally also means small objects (since $L \sim R^2\Sigma$).

But as we detect more and more extremely low surface brightness galaxies, they can have low total luminosities even though they are quite big.

So definitionally, “dwarf” is a bit of a fuzzy term.

courtesy Sparke & Gallagher

Table 4.1 Galaxies of the Local Group within 1 Mpc of the Sun: the Milky Way and its satellites are listed in **boldface**; M31 and its companions are listed in *italics*

Galaxy	*Type*	d (kpc)	L_V ($10^7 L_\odot$)	$V_r(\odot)$ (km s^{-1})	l (*deg*)	b (*deg*)	$\mathcal{M}$(HI) ($10^6 \mathcal{M}_\odot$)
M31 (NGC 224)	Sb	770	2700	−299	121	−22	5700
Milky Way	Sbc	8	1500	−10	0	0	4000
M33 (NGC 598)	Sc	850	550	−183	134	−31	1500
Large MC	SBm	49	170	274	280	−33	700
NGC 205	dE	850	40	−241	121	−21	0.4
Small MC	Irr	58	34	148	303	−44	650
M32 (NGC 221)	E2	750	30	−203	121	−22	none
NGC 6822	Irr	490	30	−56	25	−18	c
IC 10	Irr	820	20	−344	119	−3	150
NGC 147	dE	760	12	−193	120	−14	none
NGC 185	dE	600	10	−202	121	−15	0.1
IC 1613 (DDO 8)	dIrr	715	10	−231	130	−61	60
Pegasus (DDO 216)	dIrr	760	8	−183	95	−44	3
WLM (DDO 221)	dIrr	970	4	−120	76	−74	80
Leo A (DDO 69)	dIrr	690	2	20	197	52	20
Fornax	dSph	120	1.4	53	237	−66	none
Sagittarius	dSph	25	1	170	6	−14	none
And I	dSph	770	0.5	−370	122	−25	none
Leo I (DDO 74)	dSph	270	0.5	285	226	49	none
And VII/Cas dSph	dSph	760	0.5	−307	110	−10	—
And II	dSph	590	0.3	−188	129	−29	—
And VI/Peg dSph	dSph	830	0.3	−341	106	−36	—
Aquarius (DDO 210)	dIrr	950	0.2	−137	34	−31	3
Sculptor	dSph	72	0.14	107	288	−83	$\lesssim$0.1c
Sagittarius DIG	dIrr	800	0.1	−78	21	−16	4
And III	dSph	770	0.1	−352	119	−26	<0.1
Phoenix	dIrr/dSph	420	0.08	56	272	−69	0.2
Cetus	dSph	775	0.08	—	101	−73	—
LGS3 (Pisces)	dIrr/dSph	810	0.06	−281	127	−41	0.2
Leo II (DDO 93)	dSph	207	0.06	76	220	67	none
Tucana	dSph	870	0.05	—	323	−47	none
Sextans	dSph	83	0.04	225	244	42	none
Carina	dSph	100	0.03	223	260	−22	none
And V	dSph	810	0.03	−387	126	−15	—
Ursa Minor	dSph	64	0.02	−247	105	45	none
Draco (DDO 216)	dSph	72	0.02	−293	86	35	none

Note: d is measured from the Sun; $V_r(\odot)$ is the radial velocity with respect to the Sun.
c: HI is confused with Galactic emission (NGC 6822) or gas of the Magellanic Stream (Sculptor).

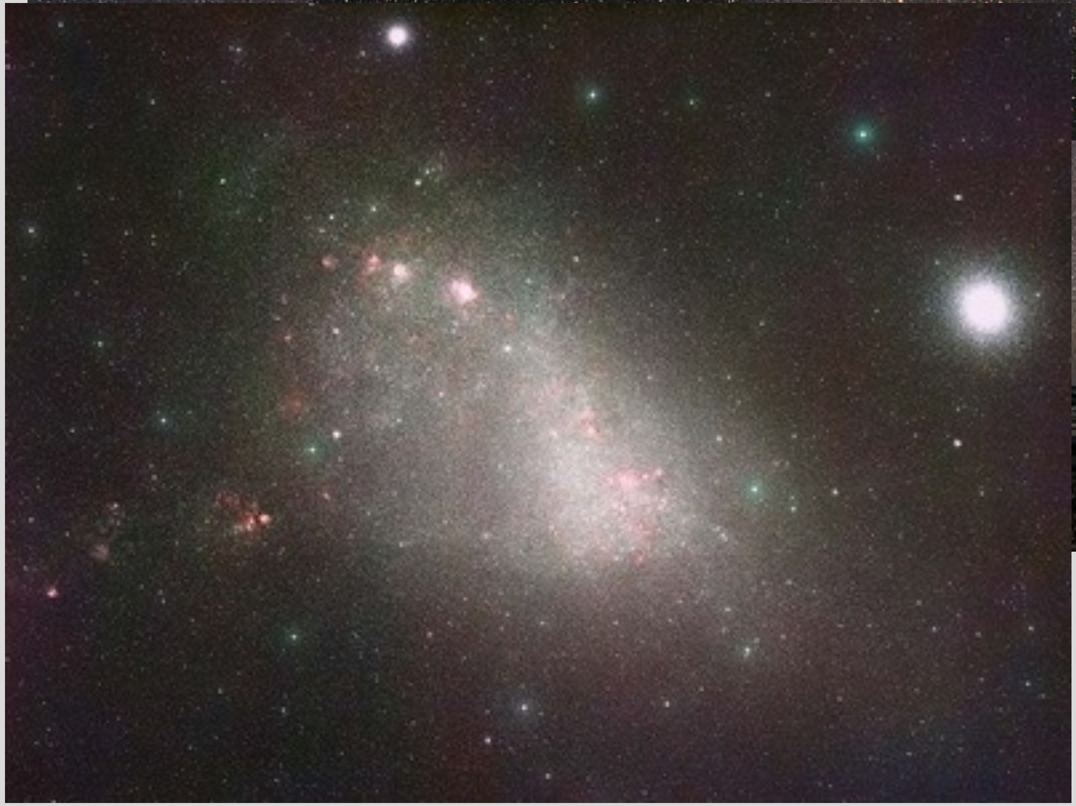
Classical Dwarfs: Local Group Galaxies

Magellenic Clouds: star-forming dwarf irregulars (dIrrs).

Brightest of MW companion galaxies.

Large Magellenic Cloud (LMC)
- D ≈ 50 kpc
- Size ≈ few kpc
- Luminosity ≈ $2 \times 10^9\ M_\odot$ (10% of MW)
- Mass ≈ $2 \times 10^{10}\ M_\odot$

Small Magellenic Cloud (SMC)
- D ≈ 60 kpc
- Size $\lesssim$ 1 kpc
- Luminosity ≈ $3.5 \times 10^8\ M_\odot$ (2% of MW)
- Mass ≈ $2 \times 10^9\ M_\odot$



Classical Dwarfs: Local Group Galaxies

Irregulars (Irr) / Dwarf Irregulars (dIrr):

Star forming, gas-rich. $M_{HI}/M_{tot} \gtrsim 10\%$

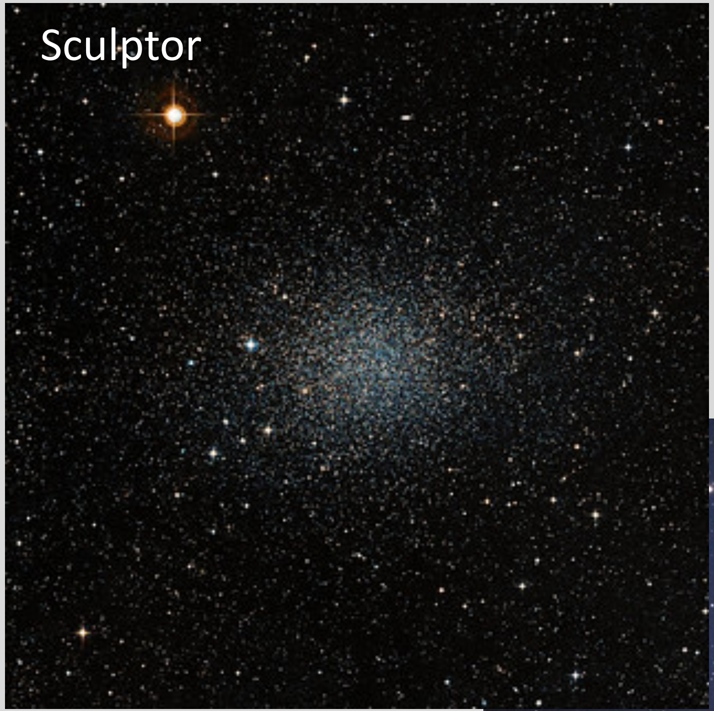
Rotating, but low circular velocity (low mass).

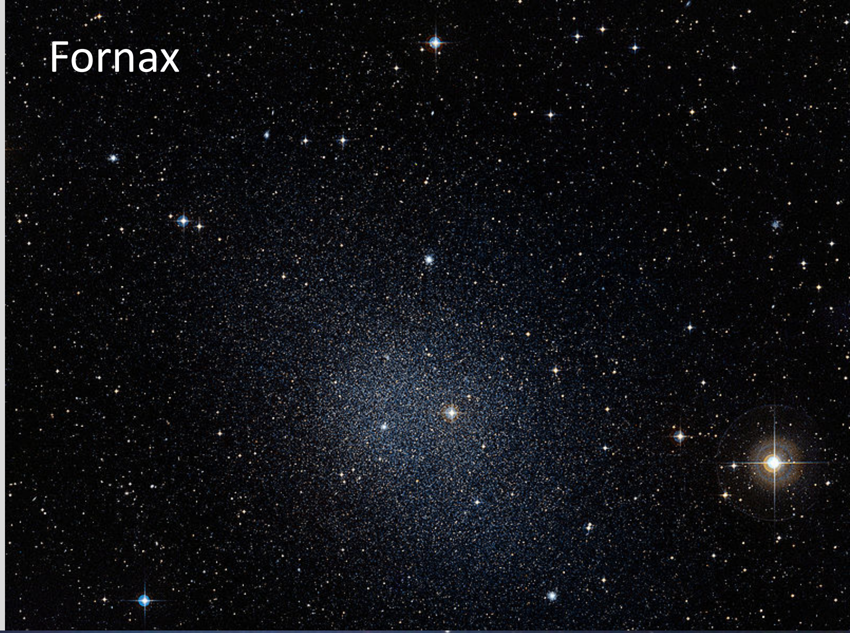
Classical Dwarfs: Local Group Galaxies

Dwarf Spheroidals (dSph)

Gas poor, low/no rotation, no ongoing star formation.

Very low surface brightness.



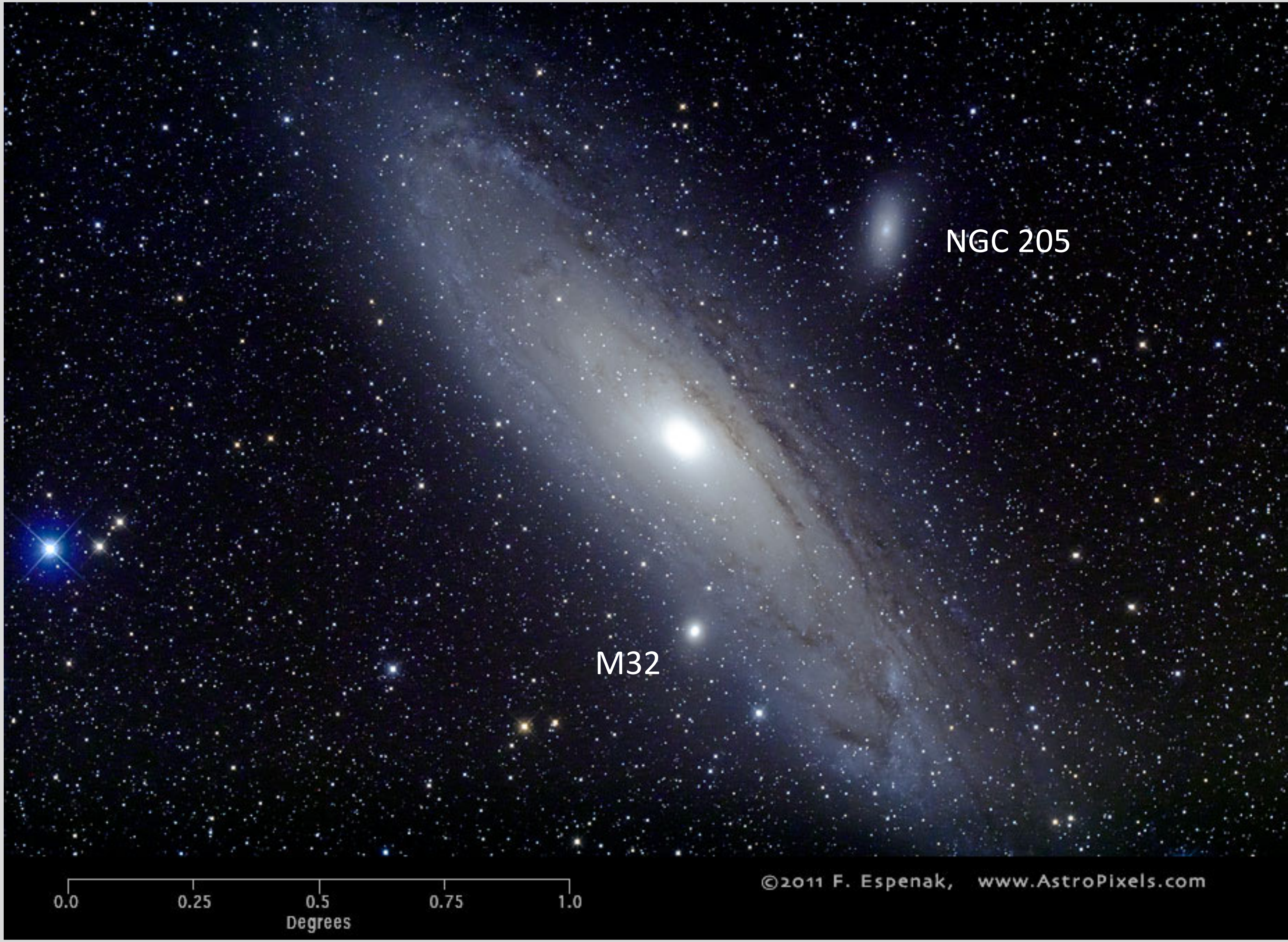


Classical Dwarfs: Local Group Galaxies

Dwarf Ellipticals (dE)

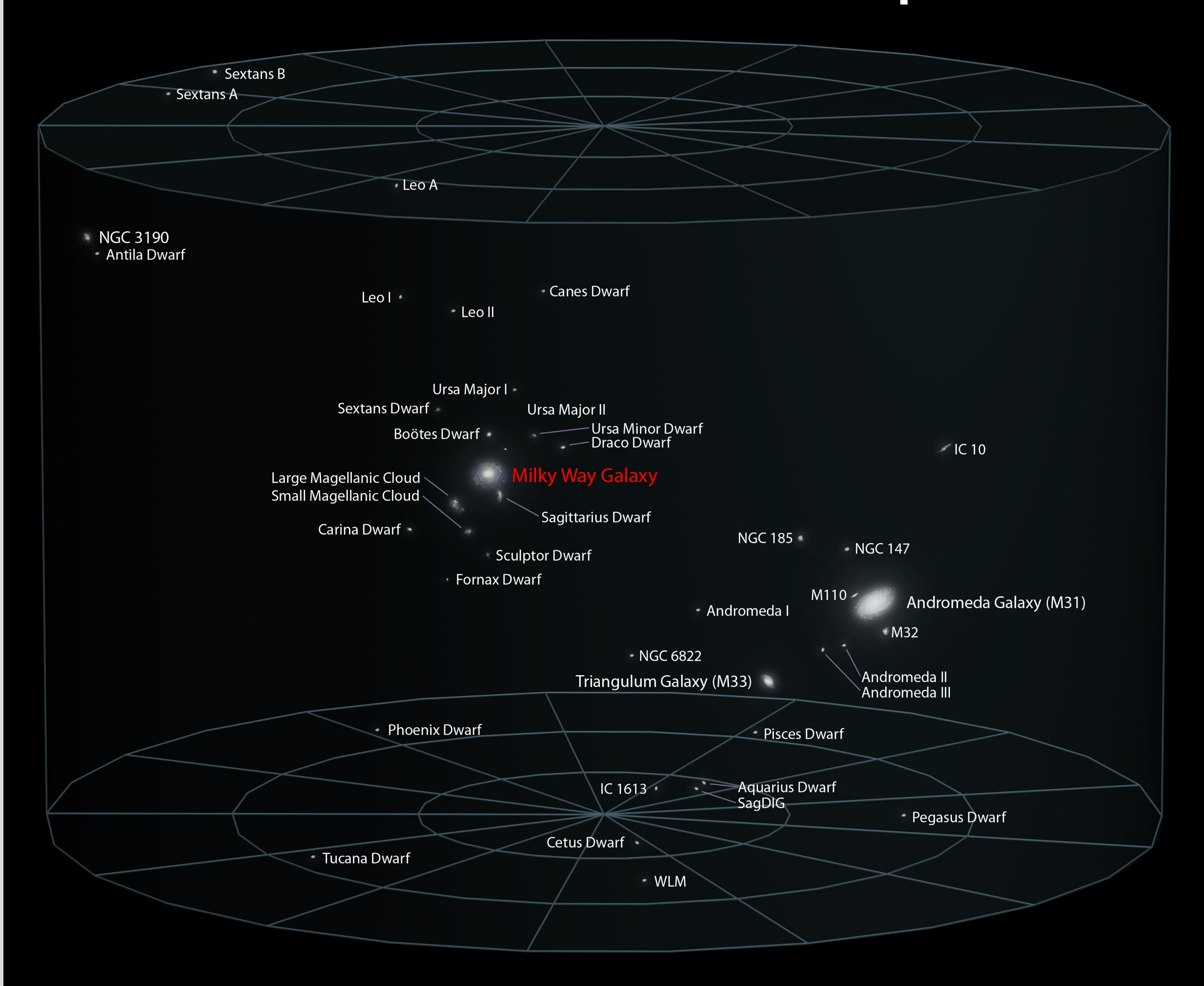
More luminous and higher in surface brightness than dSph.

But beware of nomenclature: some people call dSph galaxies dE's



Classical Dwarfs: Spatial Distributions

Cluster around bright galaxies (MW, And) but also found throughout the Local Group.



Classical Dwarfs: Spatial Distributions

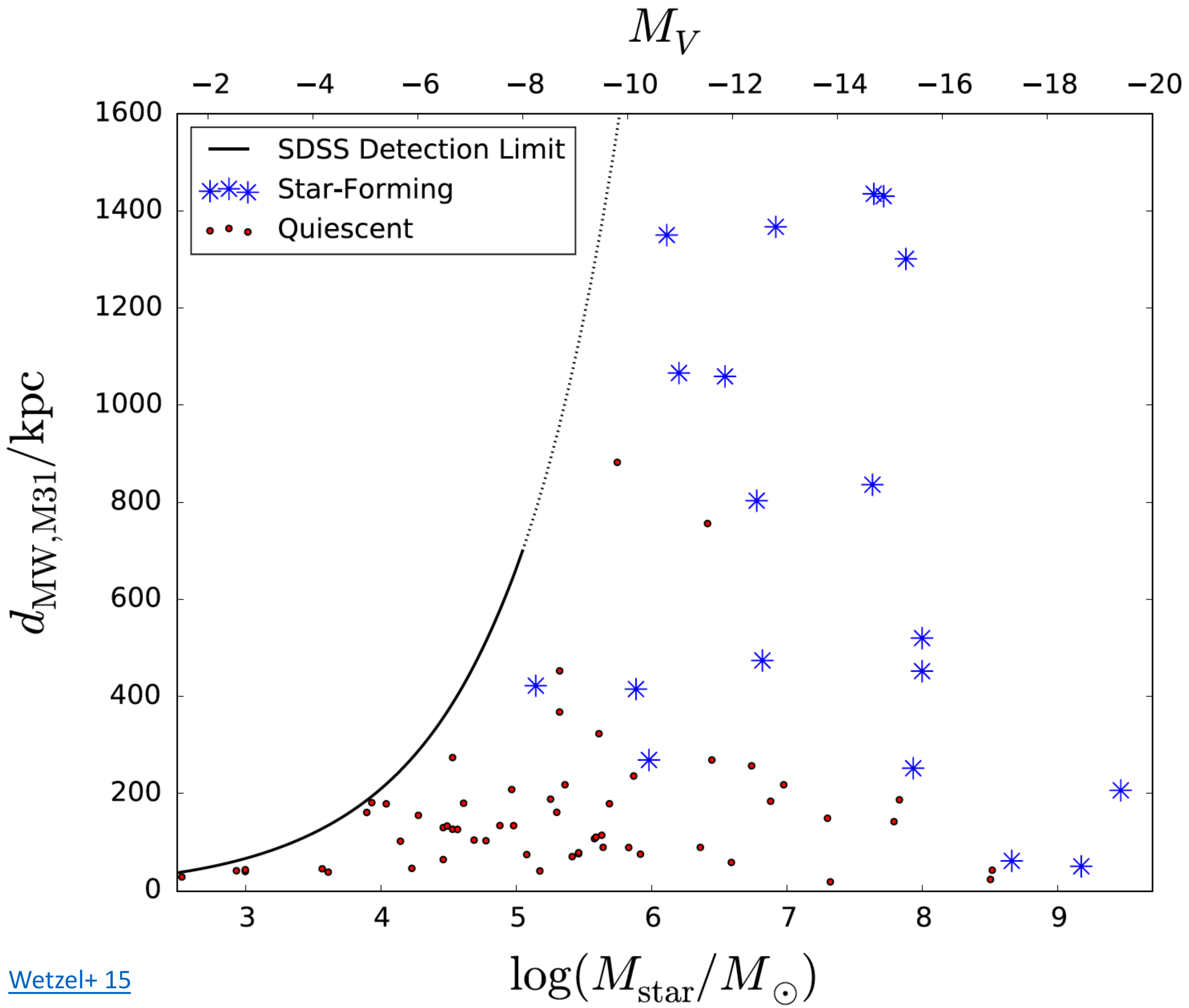
Star-forming Irr/dIrr tend to live further away from bright galaxies.

Quiescent dSph galaxies found closer to bright galaxies.

"quiescent" defined as gas-poor:

$M_{gas}/M_{star} < 0.1$

Distance from MW or M31



Wetzel+ 15

Possible signature of ram pressure stripping of gas from dwarf galaxies by a hot halo of gas around the Millky Way?

Classical Dwarfs: Structural Properties

Dwarf galaxies are structurally distinct from luminous galaxies.

Dwarfs are generally much lower in surface brightness.

dSph’s follow exponential profiles, not $r^{1/4}$ *(Sersic n=4)* profiles, but they are **not** rotating disks.

Fainter dwarfs are generally lower in surface brightness (unlike what regular E’s do....)

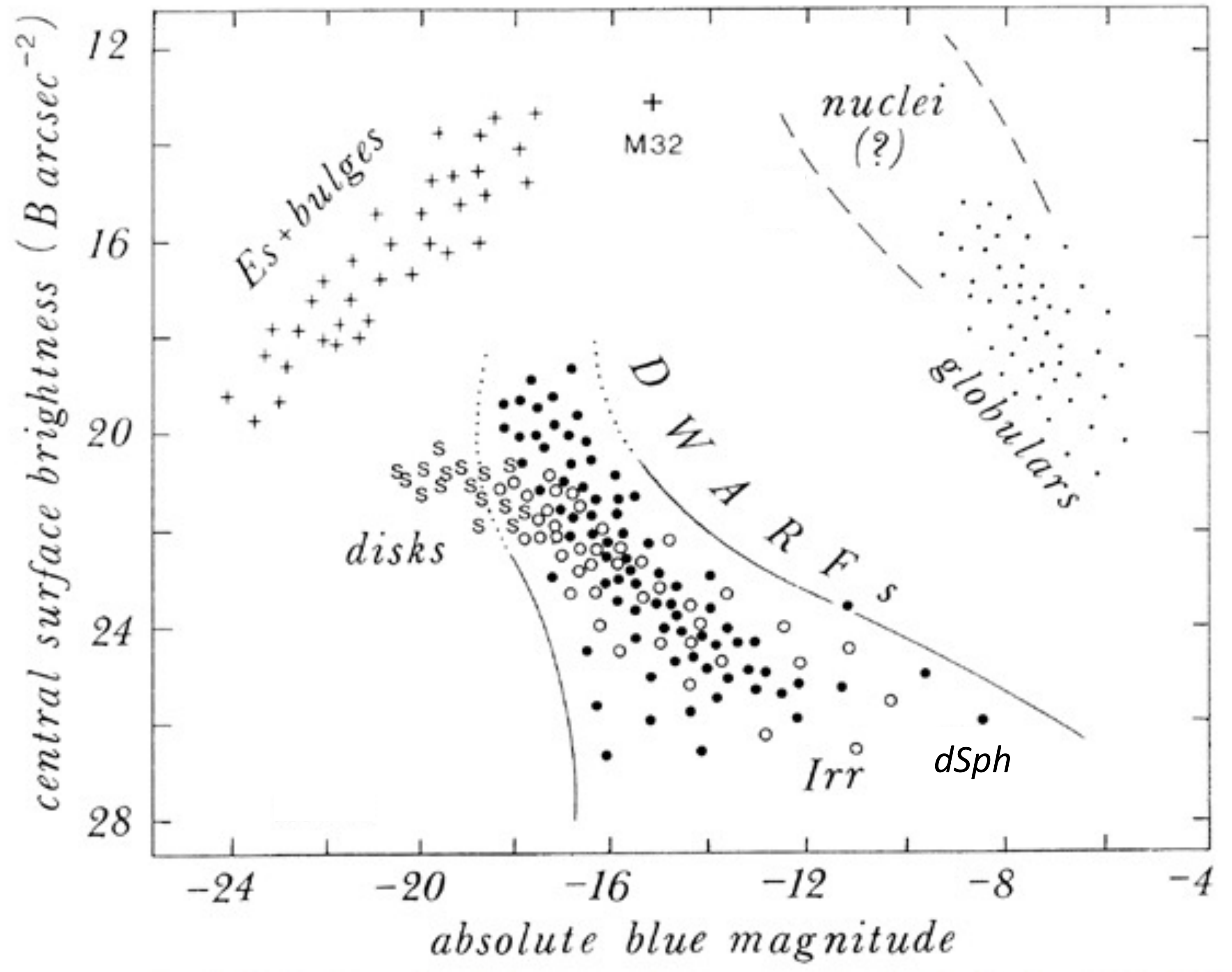
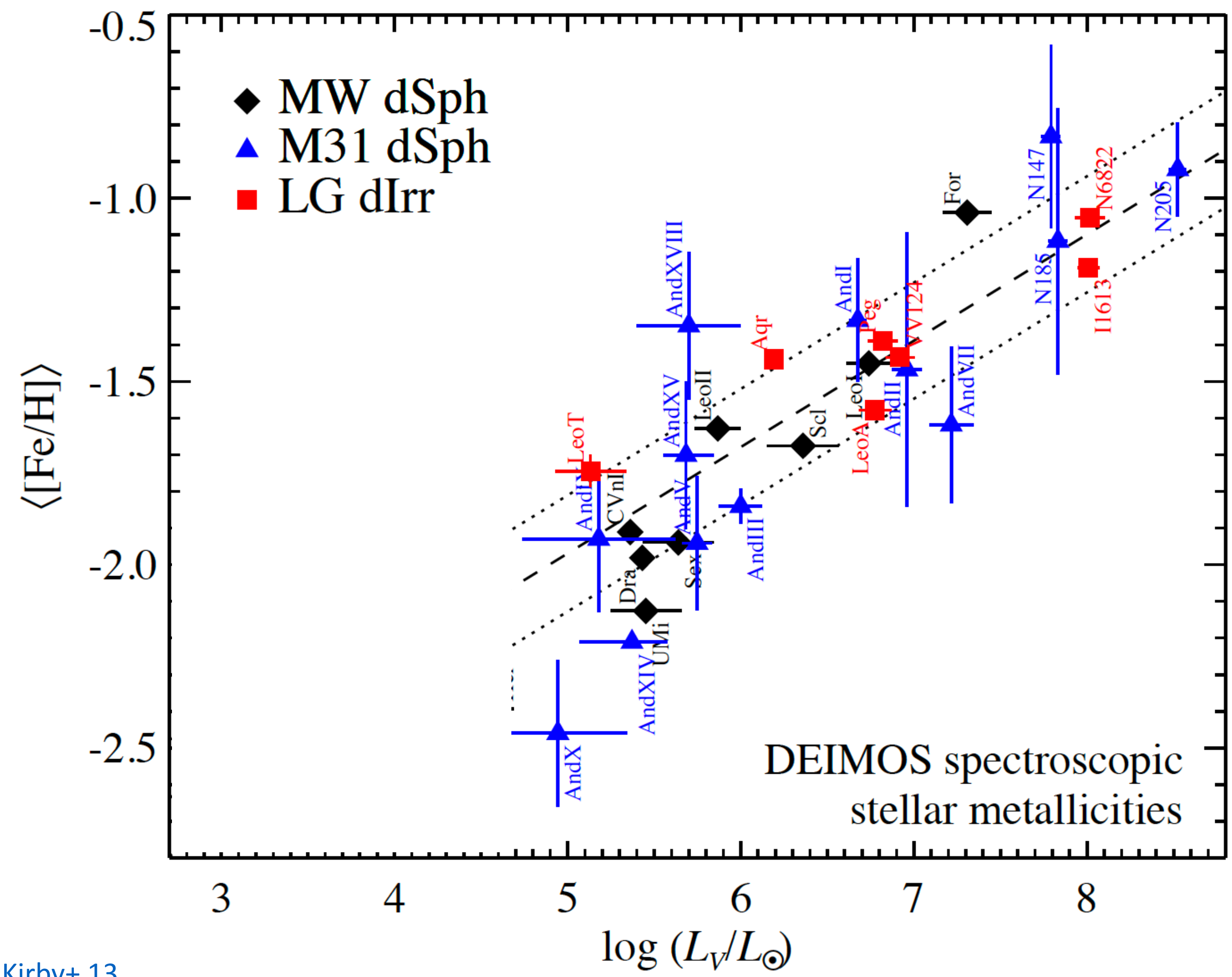


Fig 4.18 (B. Binggeli) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Classical Dwarfs: Stellar Populations

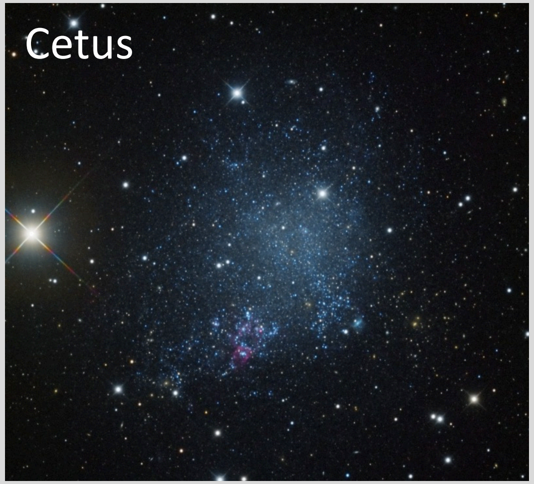
Continue the mass-metallicity (or luminosity-metallicity) relationship to even lower levels.



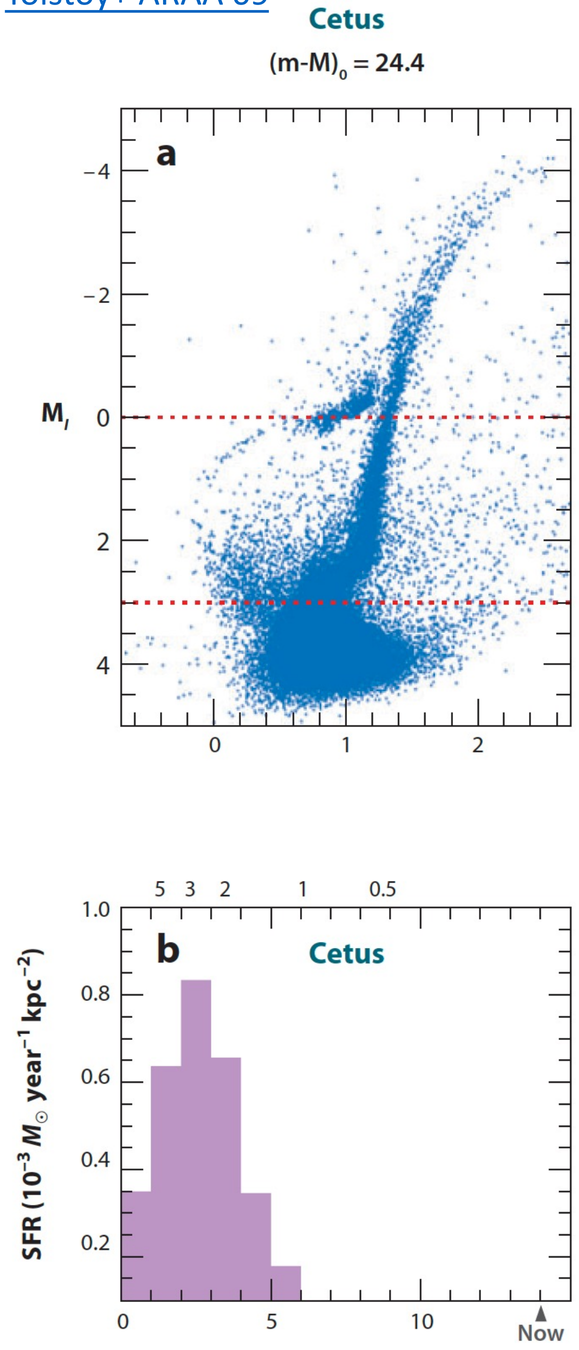
Kirby+ 13

Classical Dwarfs: Stellar Populations

Star formation histories show a wide variation.



[Tolstoy+ ARAA 09]



Classical Dwarfs: Stellar Populations

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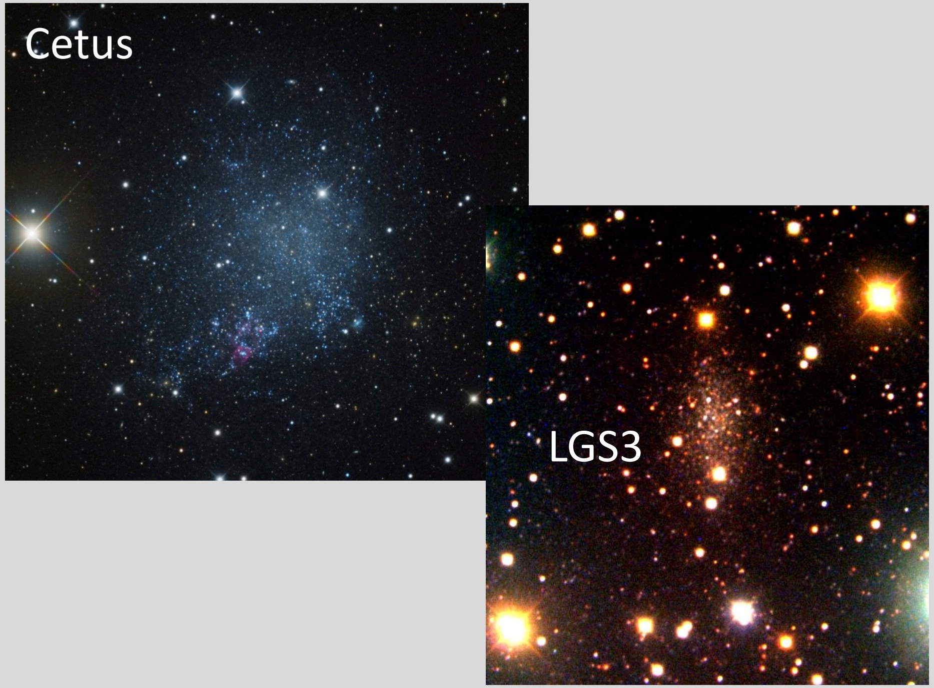
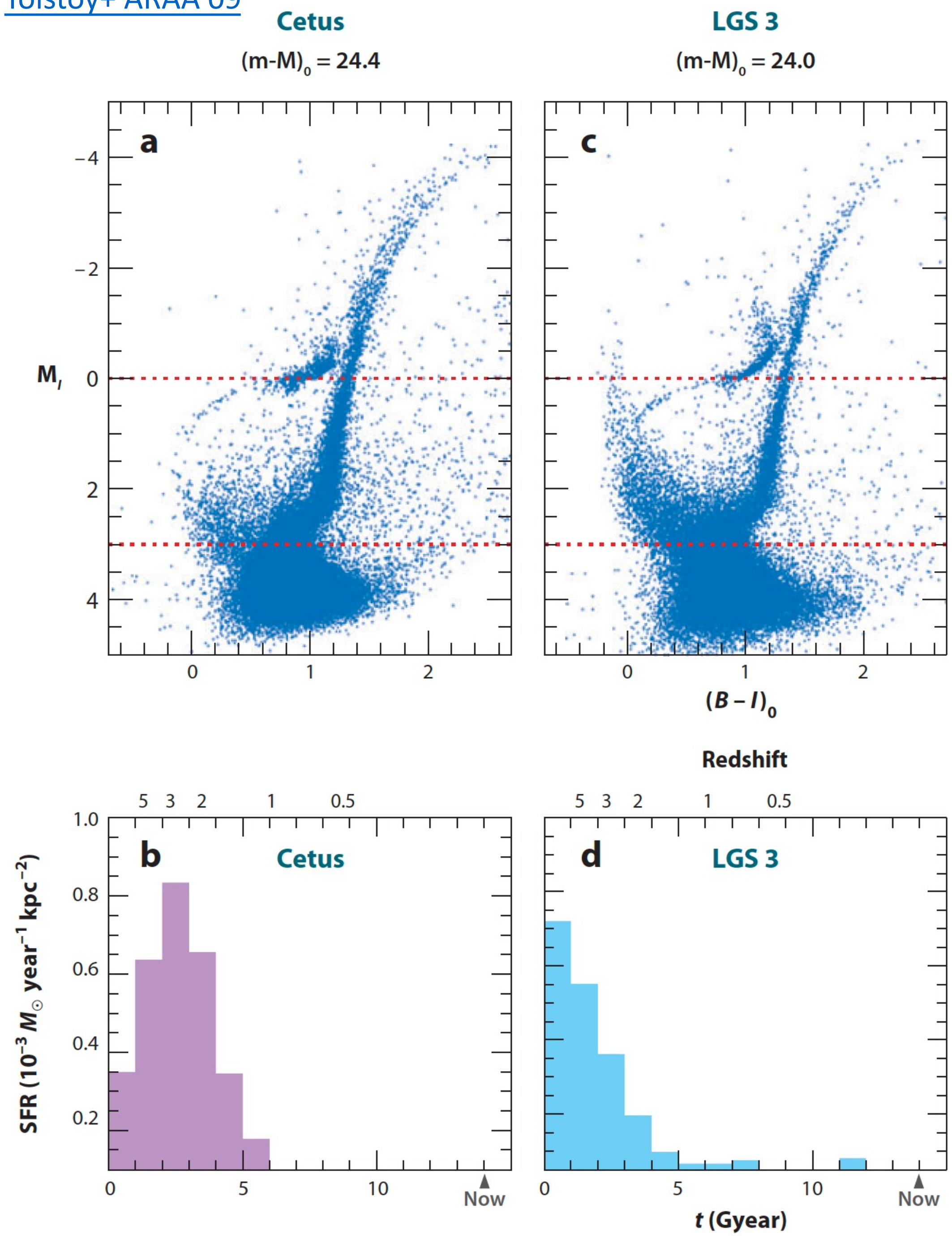
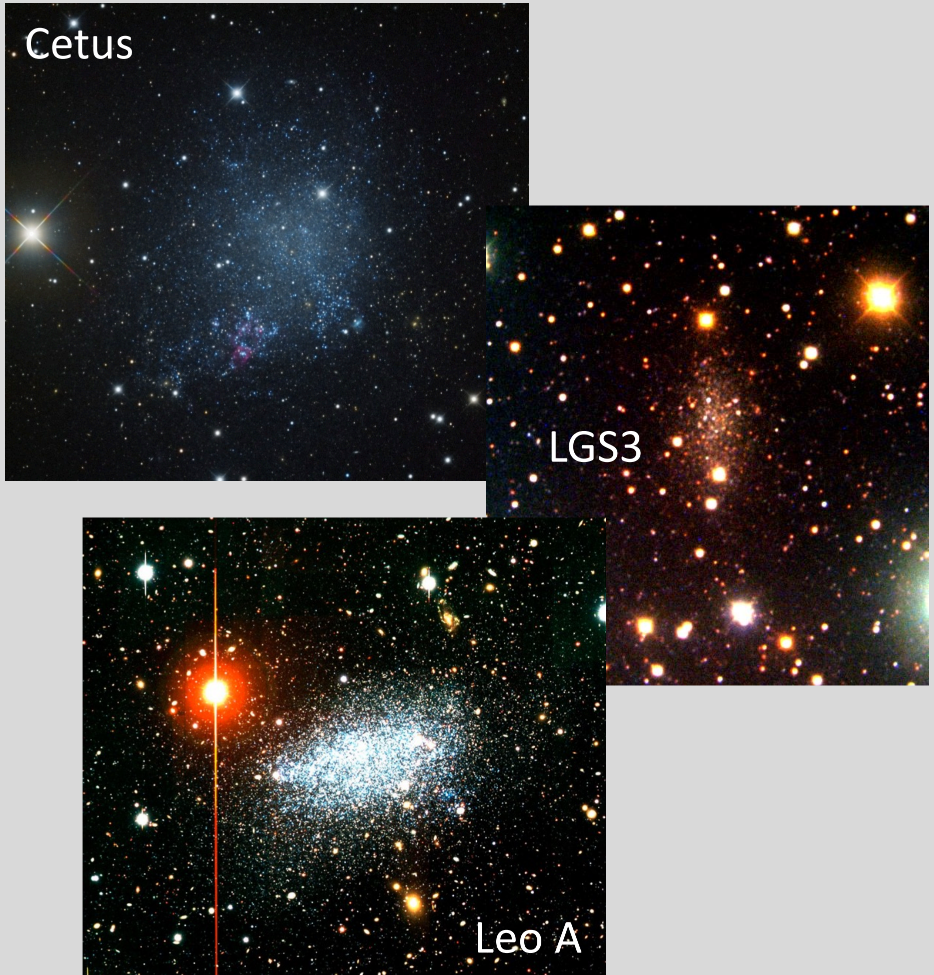


Tolstoy+ ARAA 09

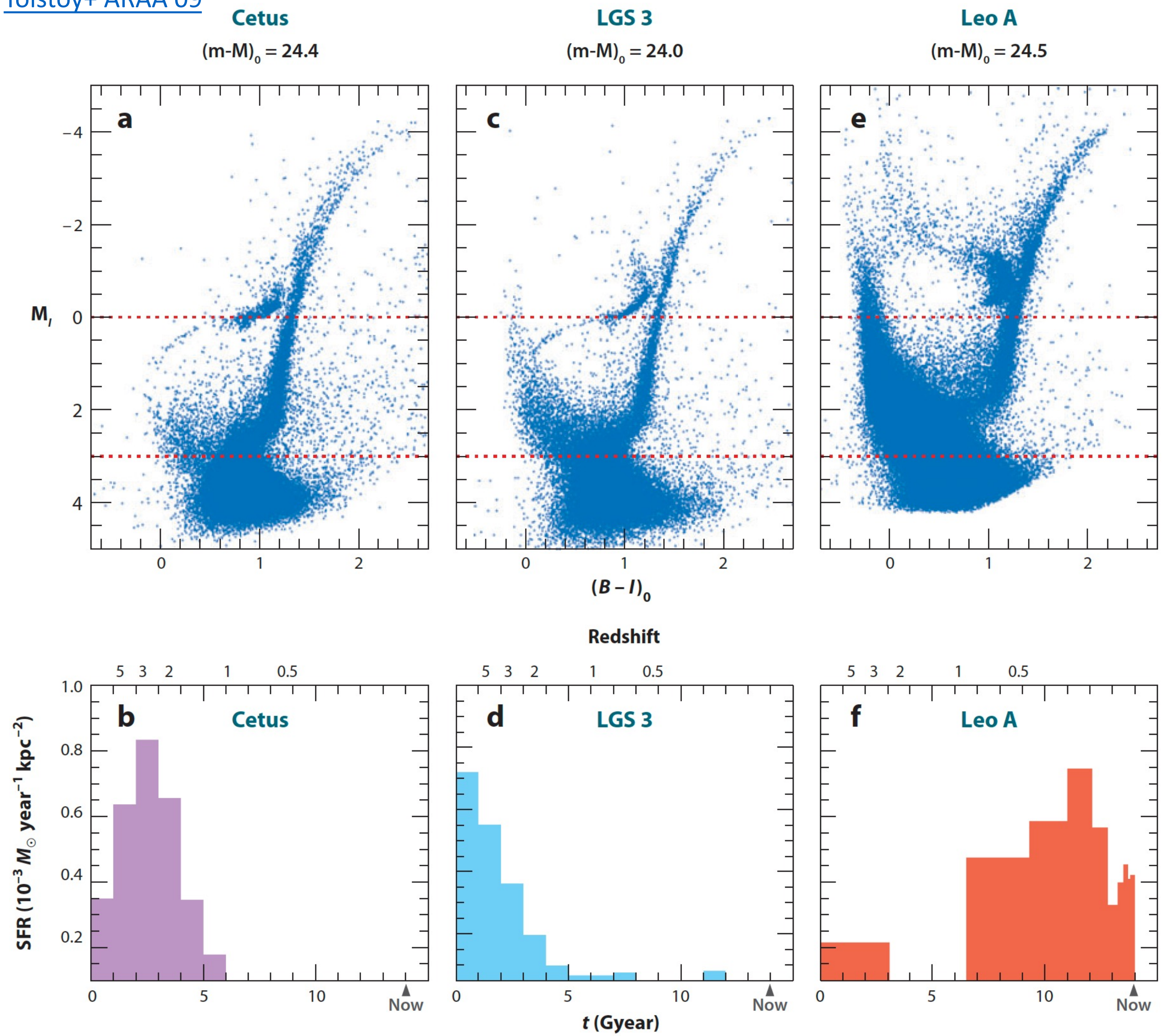


Classical Dwarfs: Stellar Populations

Star formation histories show a wide variation.



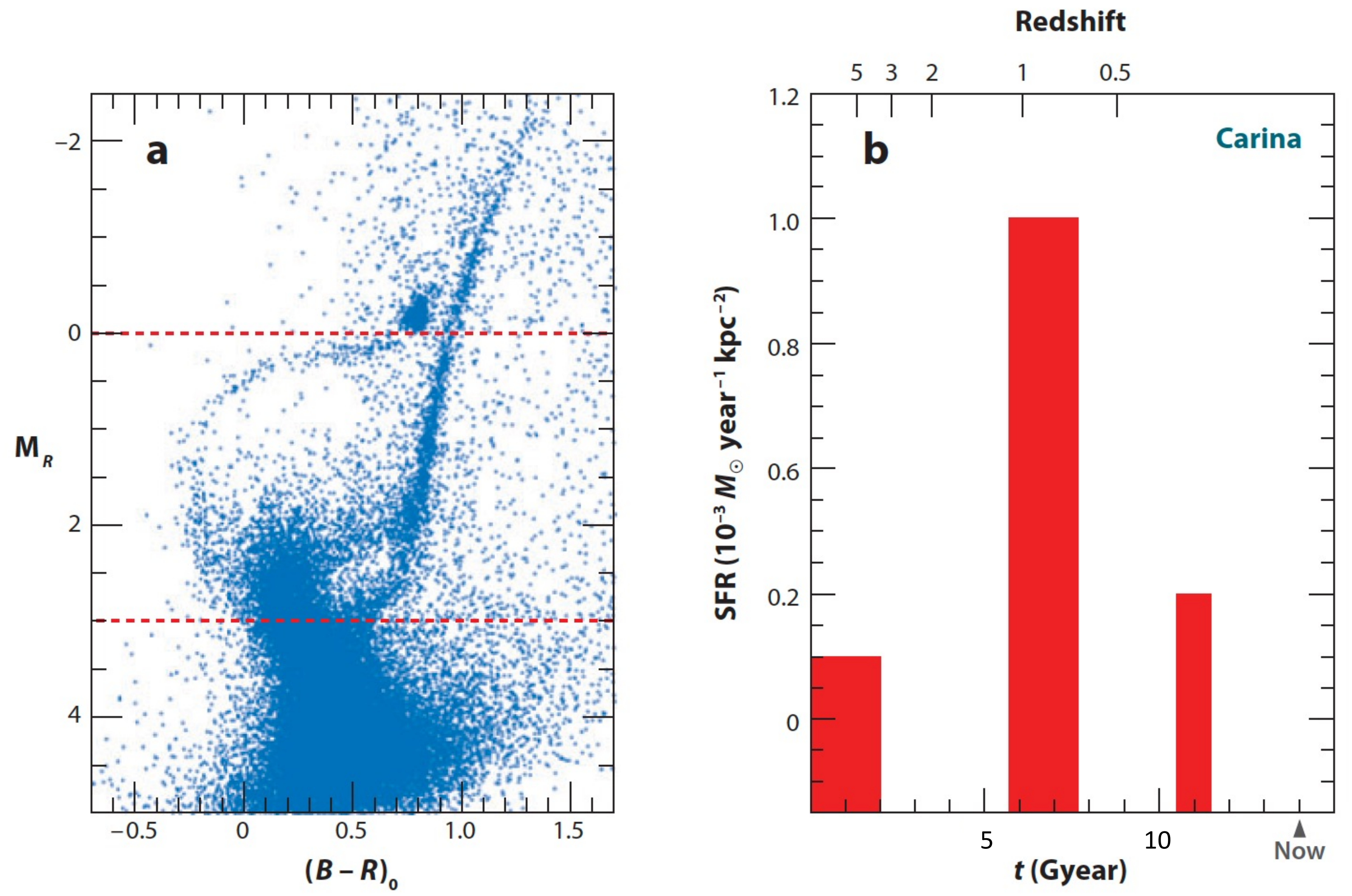
Tolstoy+ ARAA 09



Classical Dwarfs: Stellar Populations

Tolstoy+ ARAA 09

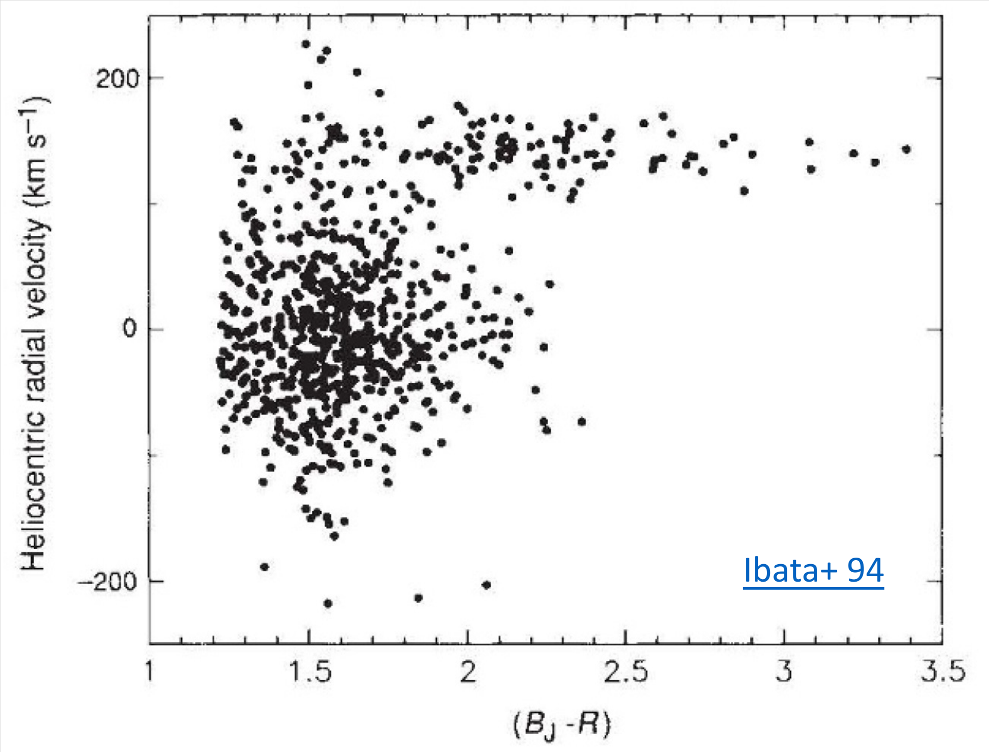
and look at Carina!

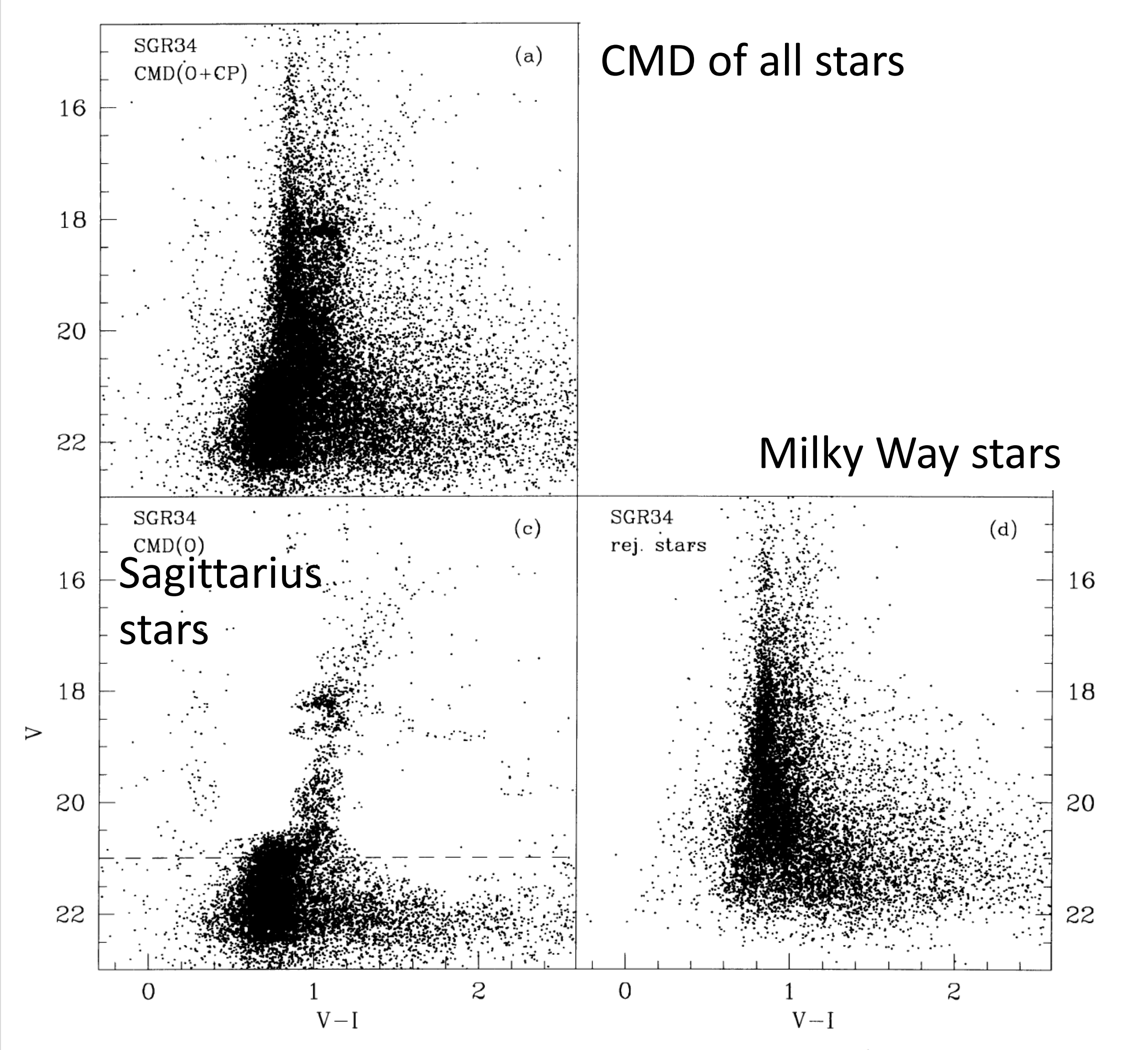


Multiple, discrete bursts of star formation....

The New Dwarfs: The discovery of Sagittarius

1994: Surveying stars in the MW bulge, Ibata+ 94 discover new satellite galaxy via kinematic sub-structure in properties of stars. Called the Sagittarius Dwarf. D ≈ 20 kpc, other side of MW.





Bellazzini+ 99

The New Dwarfs: The discovery of Sagittarius

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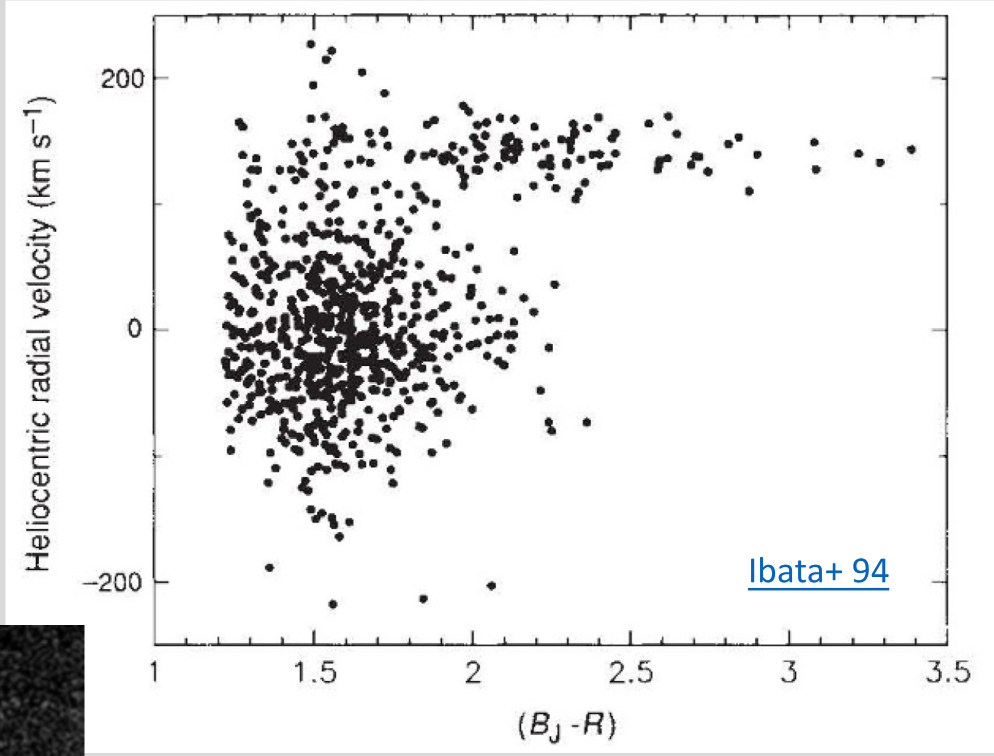
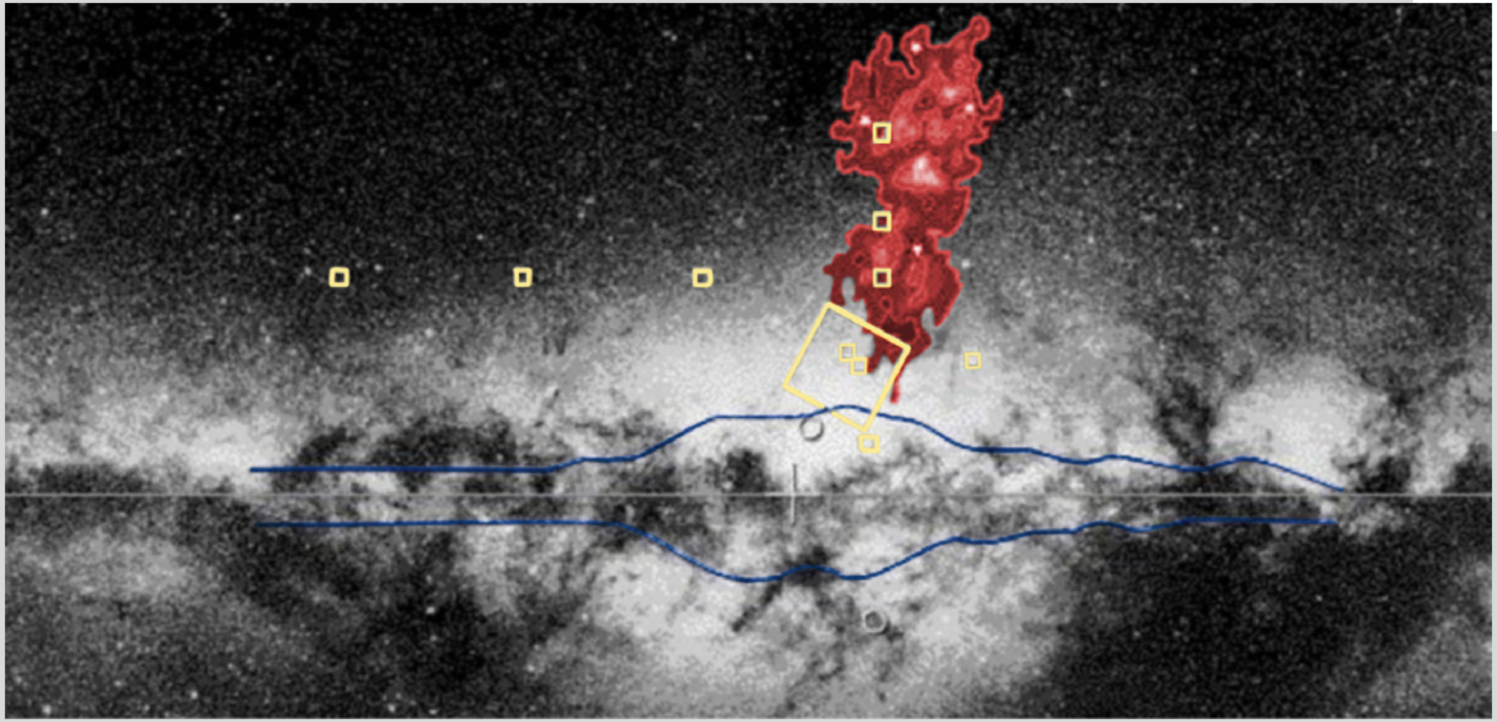


Knowing that something is there, you can look for overdensity in star counts at a given set of photometric properties (i.e. horizontal branch stars at a given distance). Trace out its shape.

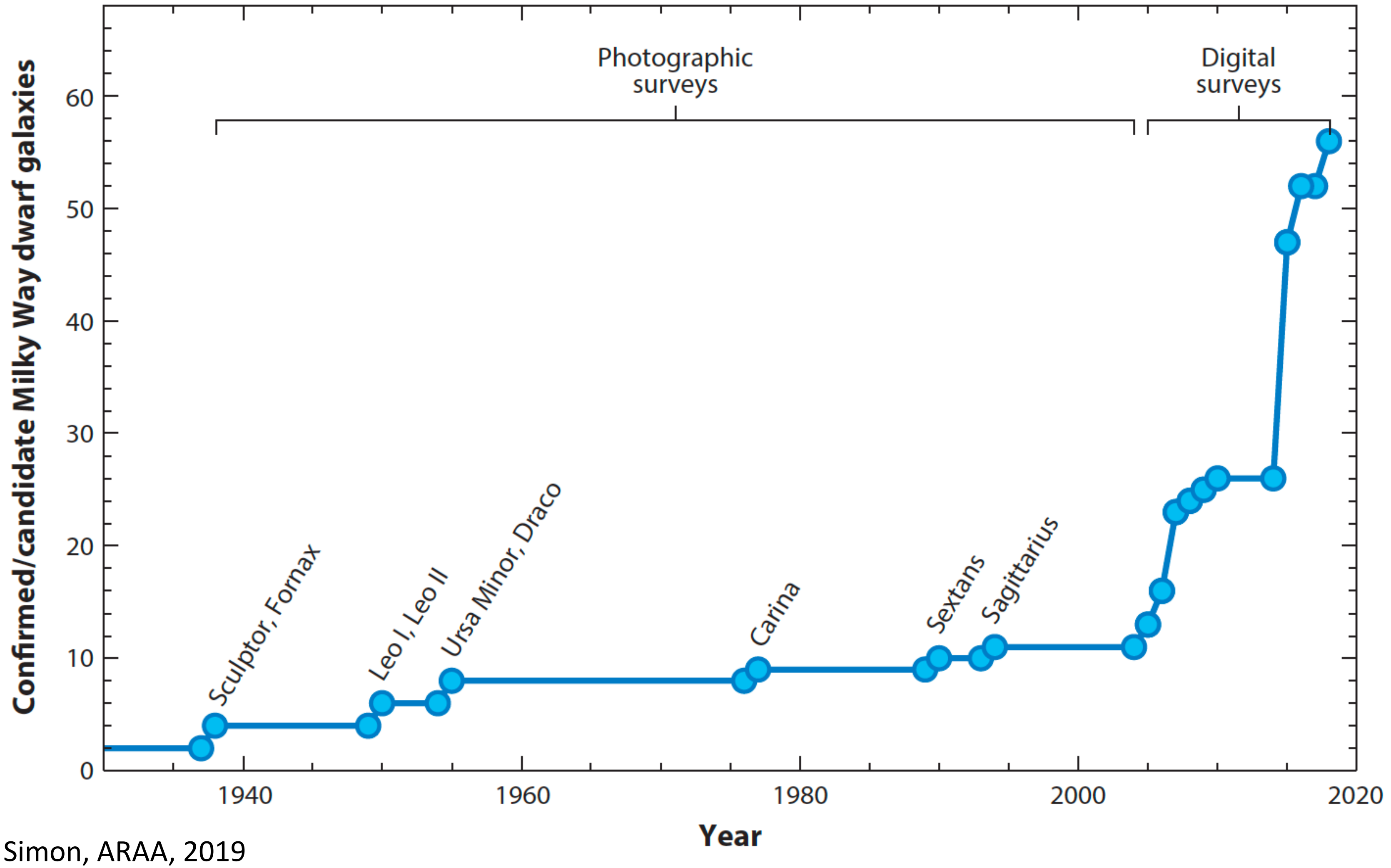


Elongated perpendicular to galactic plane, thought to be tidally disrupting on a polar orbit.

Sagittarius stars have since been traced across the sky – tidal streamers in the halo.

The New Dwarfs

Modern surveys are finding new (and very faint) Local Group dwarfs at a furious pace.



Simon, ARAA, 2019

The New Dwarfs

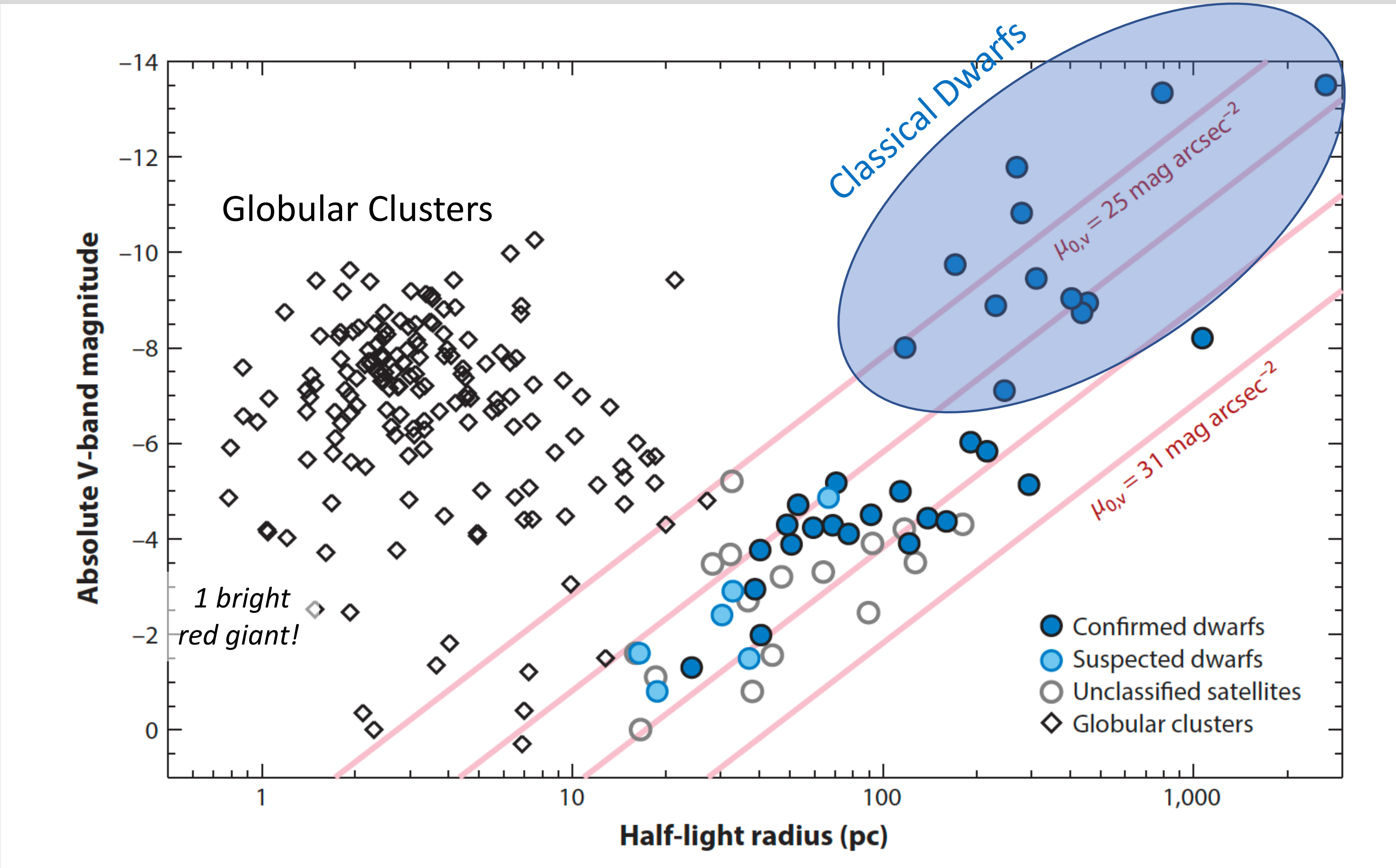
Simon, ARAA, 2019

Newly discovered dwarfs are very low in luminosity and surface brightness.

Luminosities often less than those of globular clusters!

Questions:

- what makes something a galaxy versus a star cluster?
- how well-defined is the luminosity of these extreme dwarfs?



The New Dwarfs

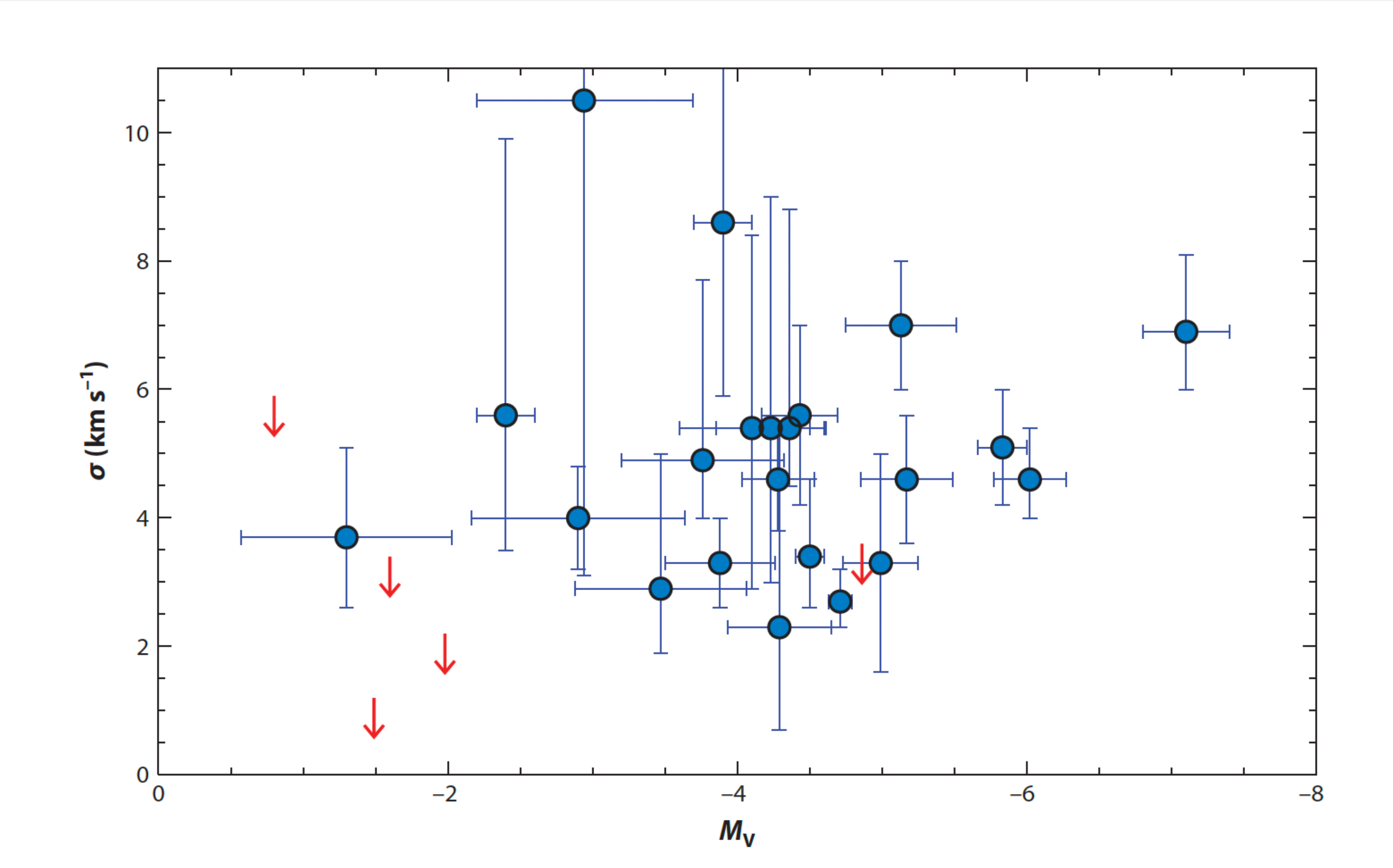
Simon, ARAA, 2019

Measure velocities of individual stars, calculate the velocity dispersion based on those stars.

(Why is this hard?)

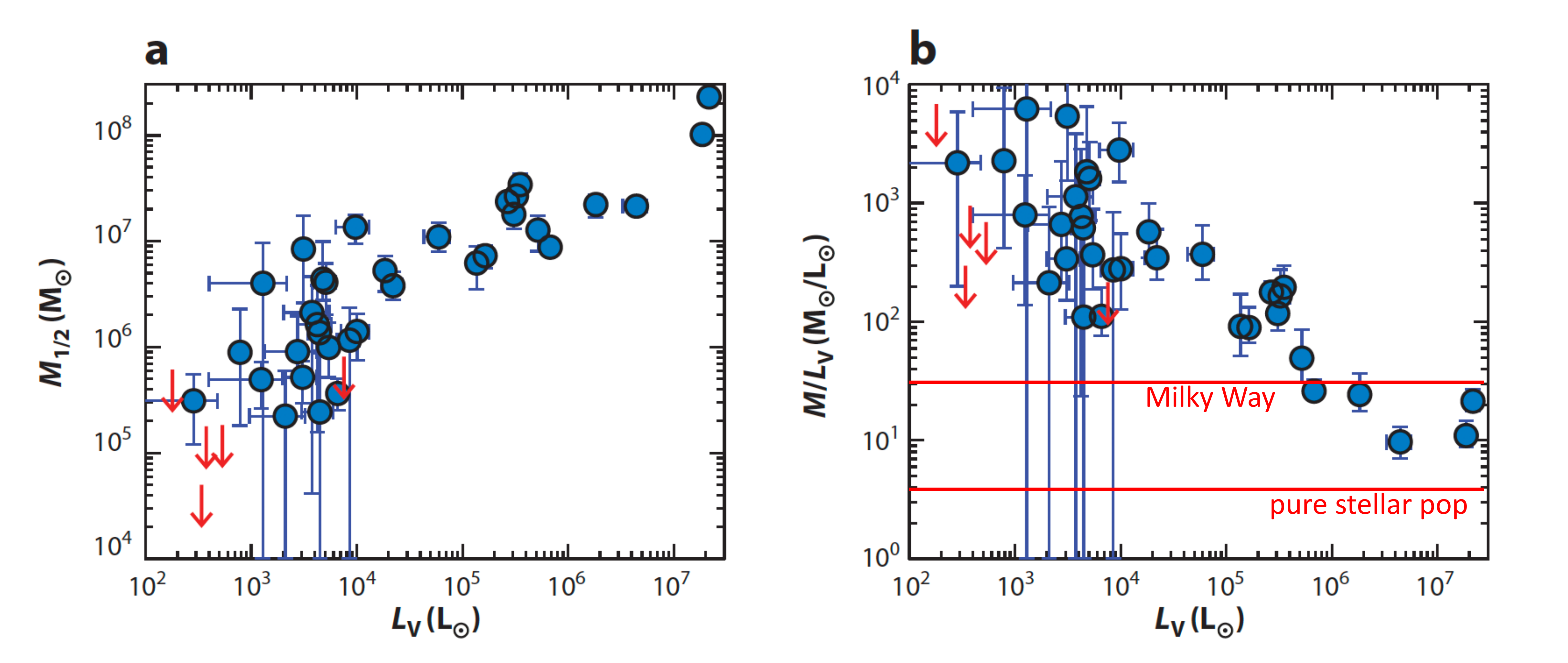
Can then estimate the mass within the half-mass radius from (Wolf+ 10)

$$M_{1/2} = 930 \left(\frac{\sigma}{km/s}\right)^2 \left(\frac{R_{1/2}}{pc}\right) M_\odot$$



The New Dwarfs

Simon, ARAA, 2019



These "ultra-faint dwarfs" have extraordinarily high mass-to-light ratios: ***dark matter dominated.***