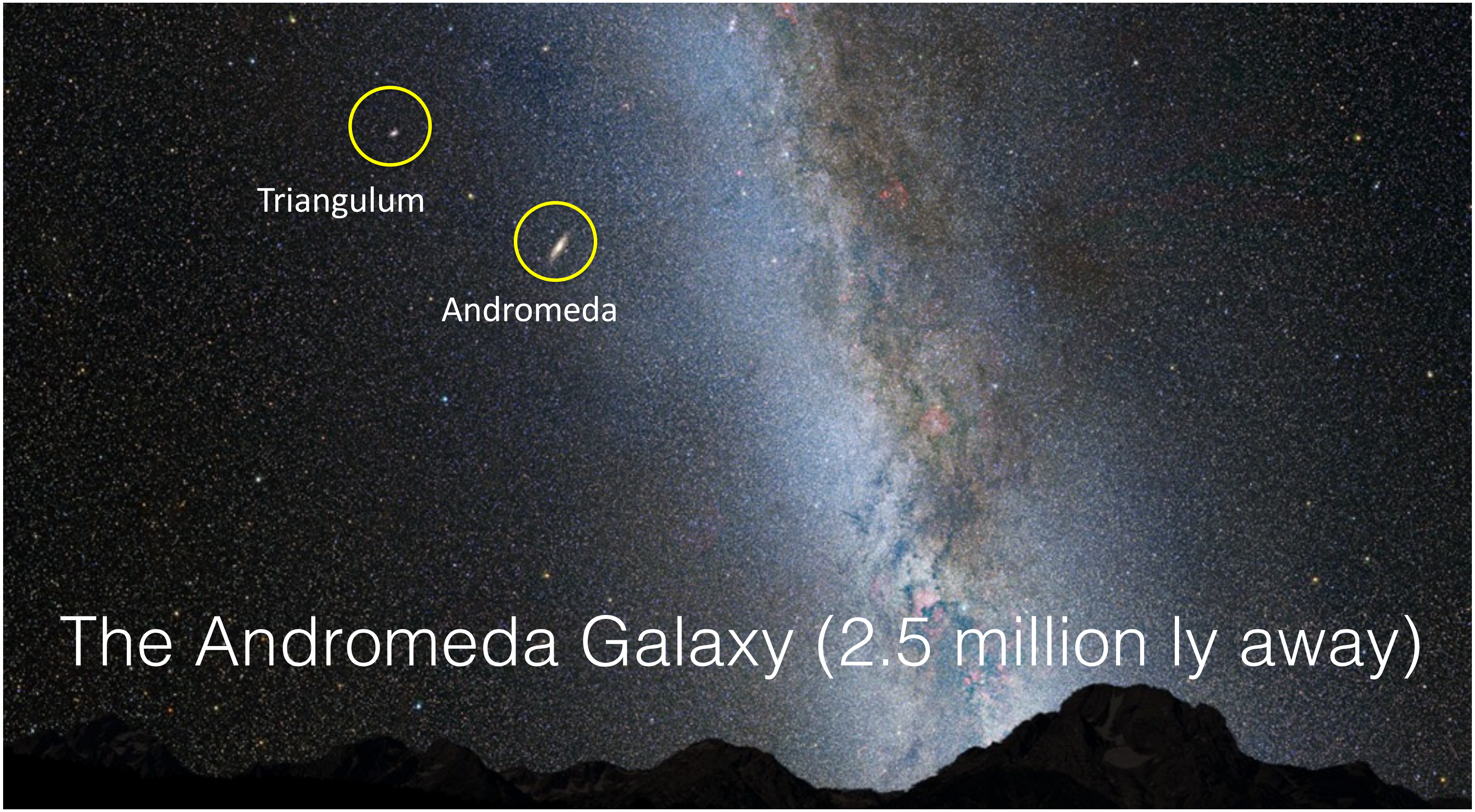
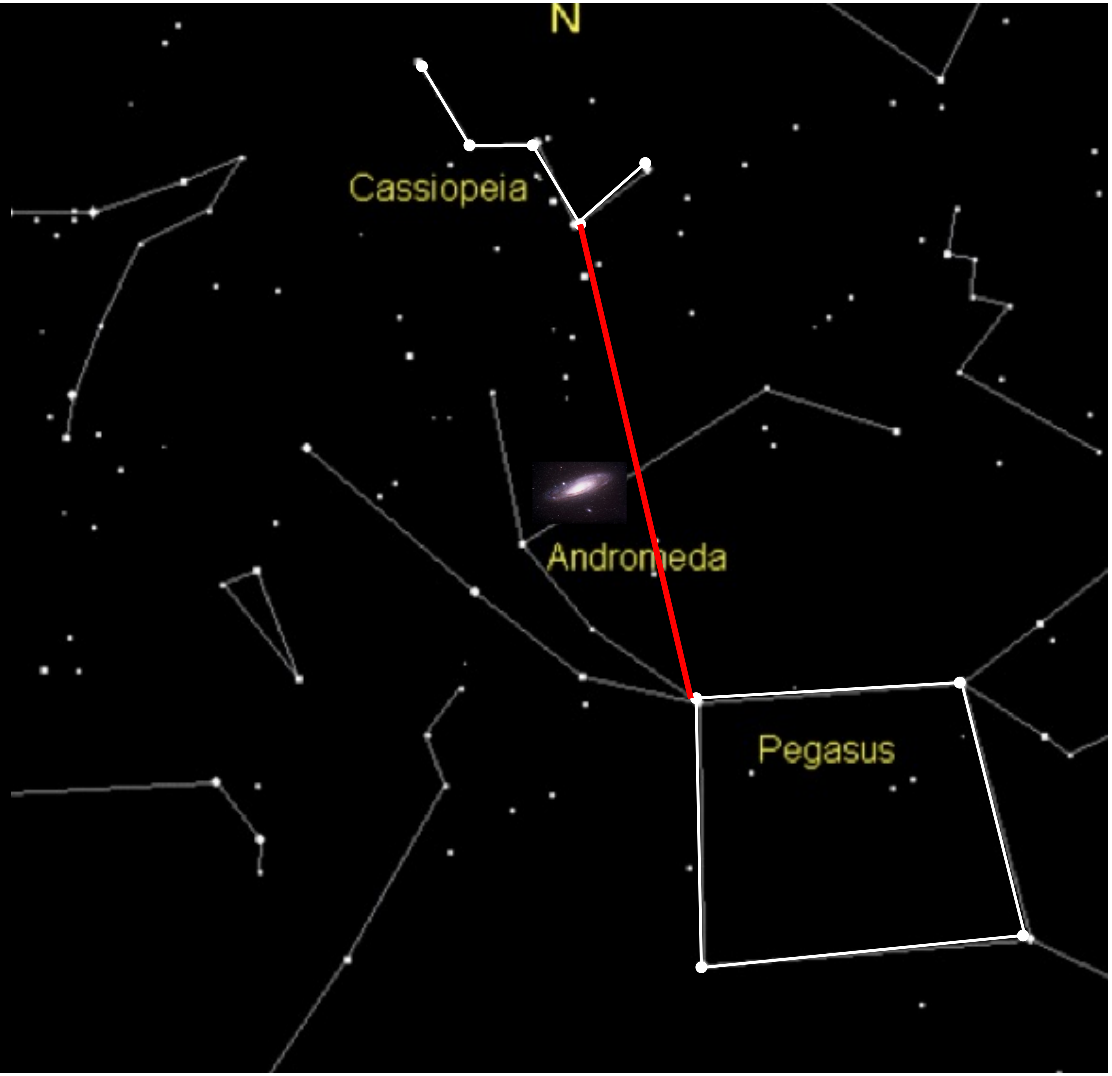
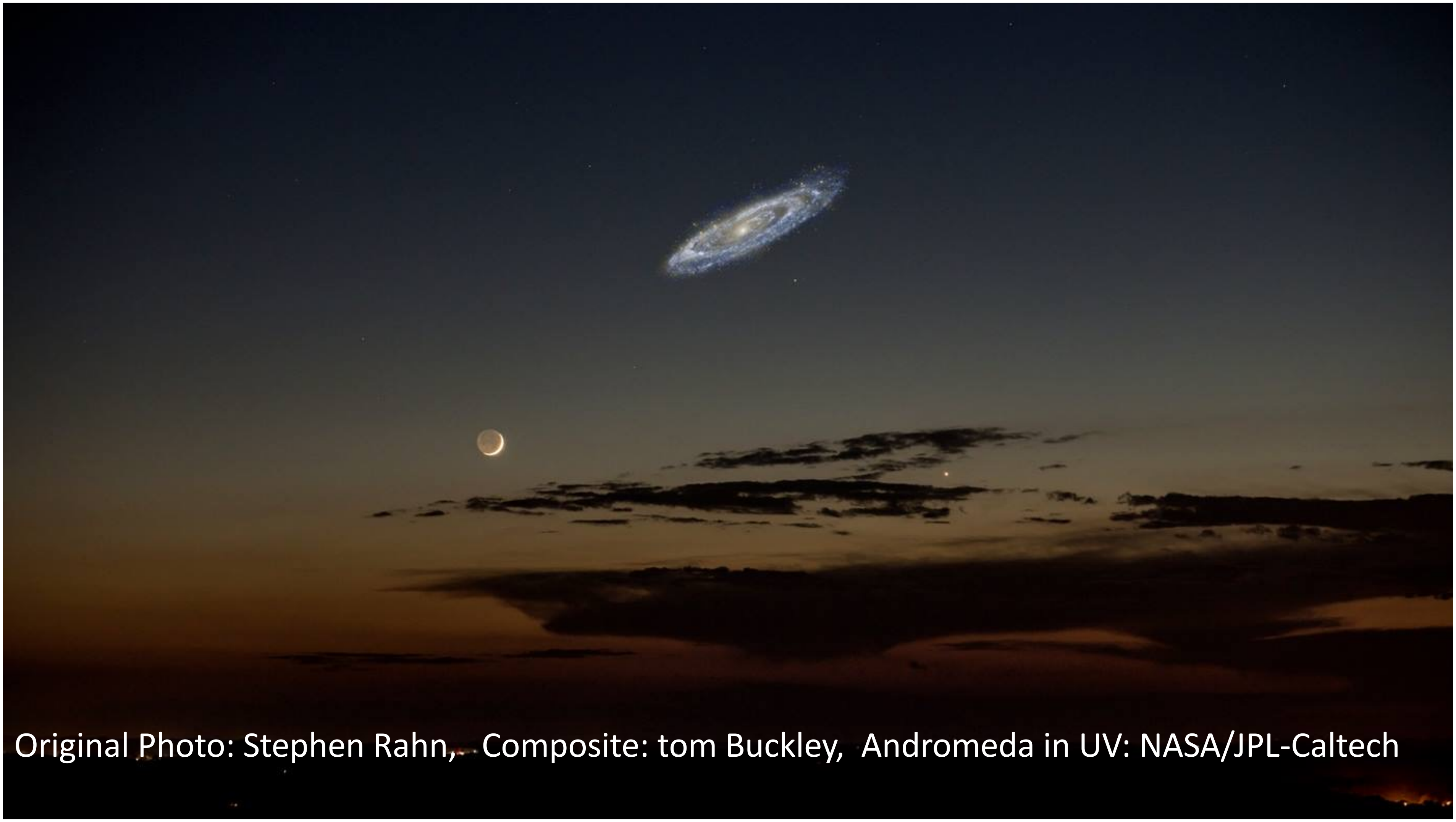
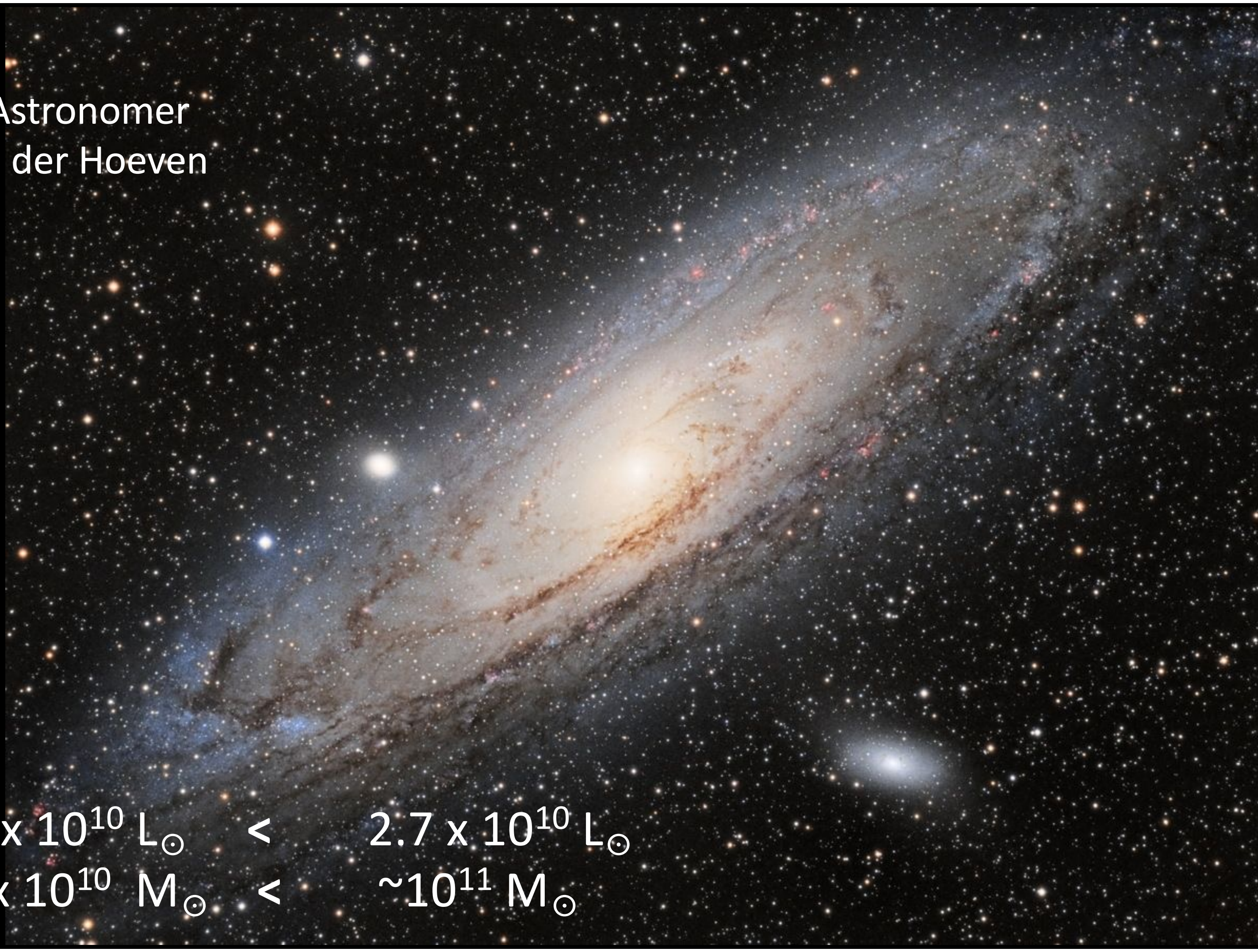

Triangulum
Andromeda
The Andromeda Galaxy (2.5 million ly away)

How do you find Andromeda on the night sky?




Original Photo: Stephen Rahn, Composite: tom Buckley, Andromeda in UV: NASA/JPL-Caltech

Optical
Amateur Astronomer
André van der Hoeven

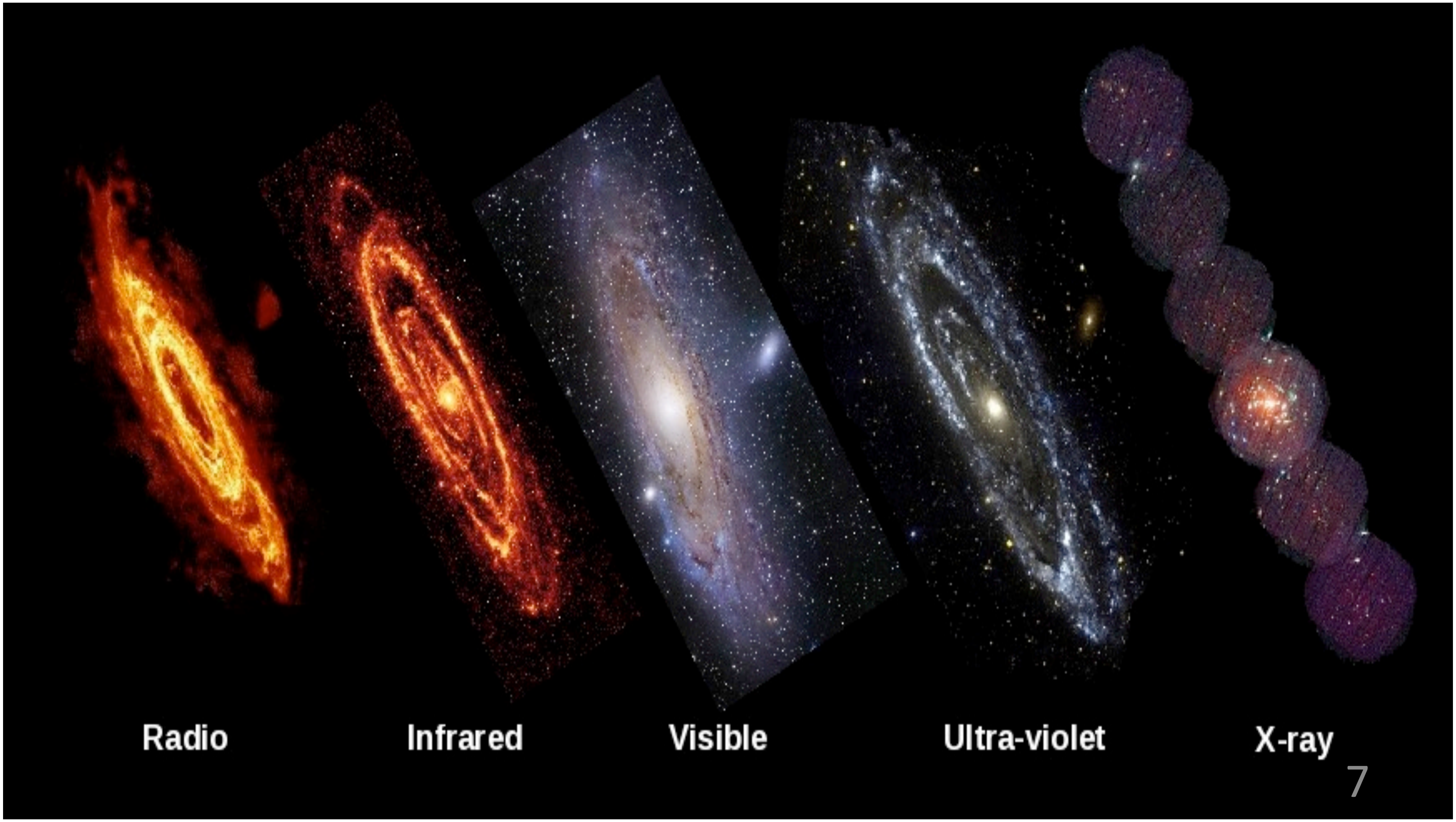


$Lv = 1.5\text{x } 10^{10}\ L_\odot \quad < \quad 2.7 \text{ x } 10^{10}\ L_\odot$

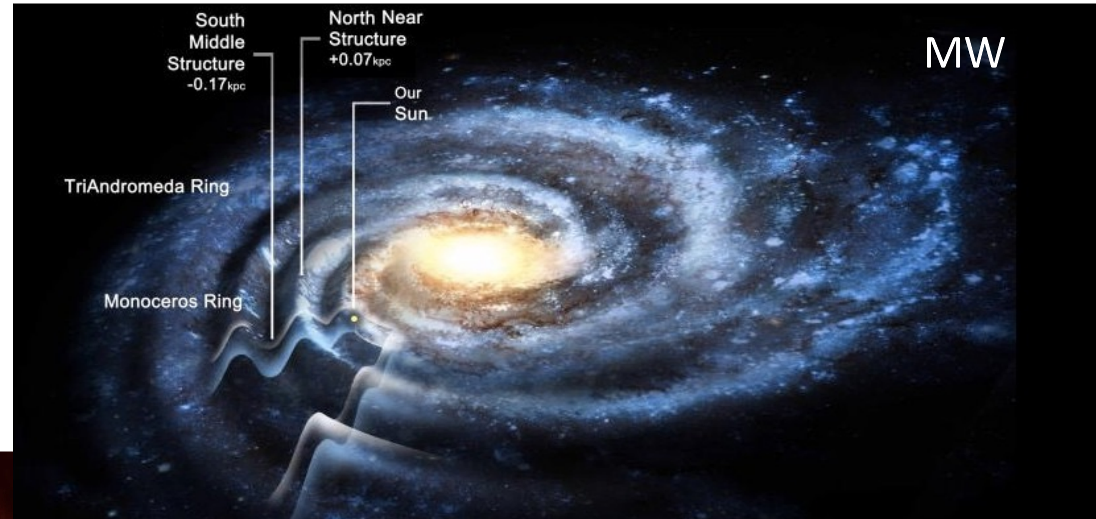
$M^* \sim 8 \text{ x } 10^{10}\ M_\odot \quad < \quad \sim 10^{11}\ M_\odot$


Infrared - Spitzer

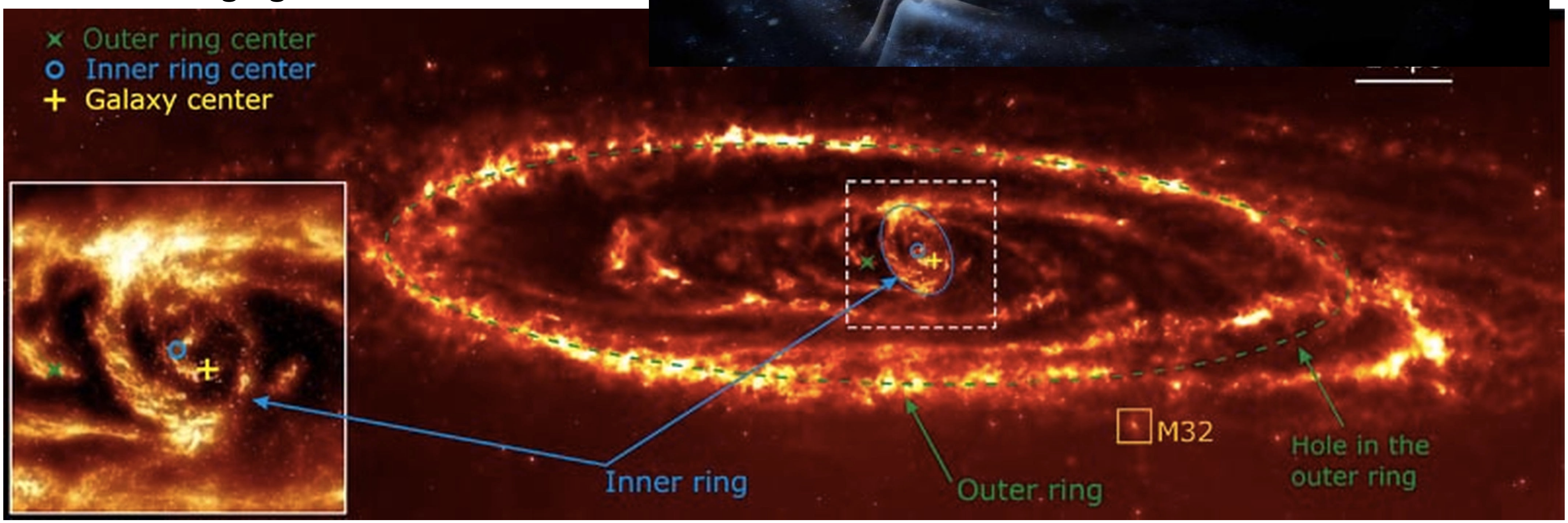

Ultraviolet - GALEX


Radio
Infrared
Visible
Ultra-violet
X-ray

MW vs M31: Spiral Arms/Rings/Ripples

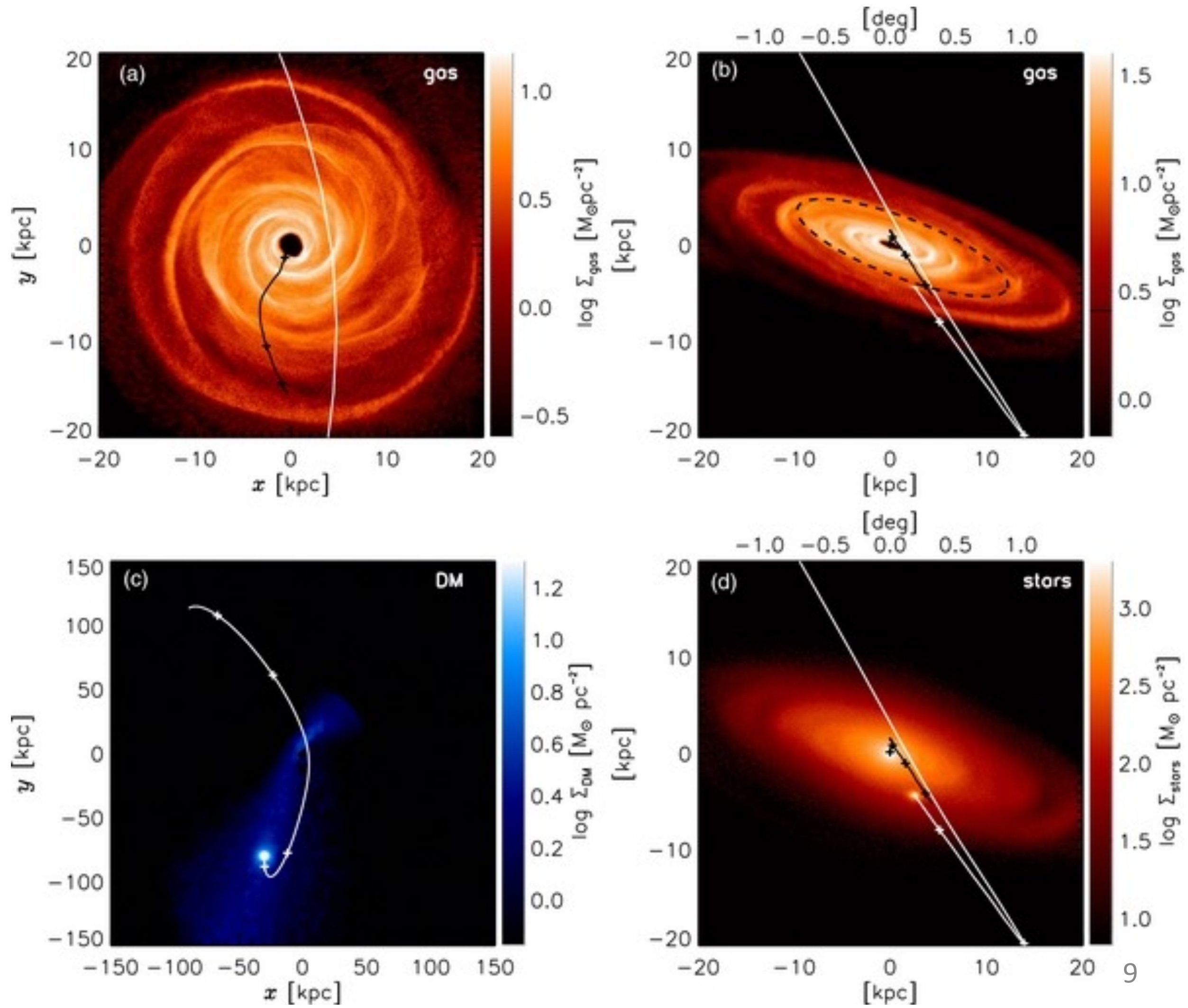


M31. IR imaging



https://www.youtube.com/watch?v=TBnd0hXGges&t=8s

Dierickx + 2014



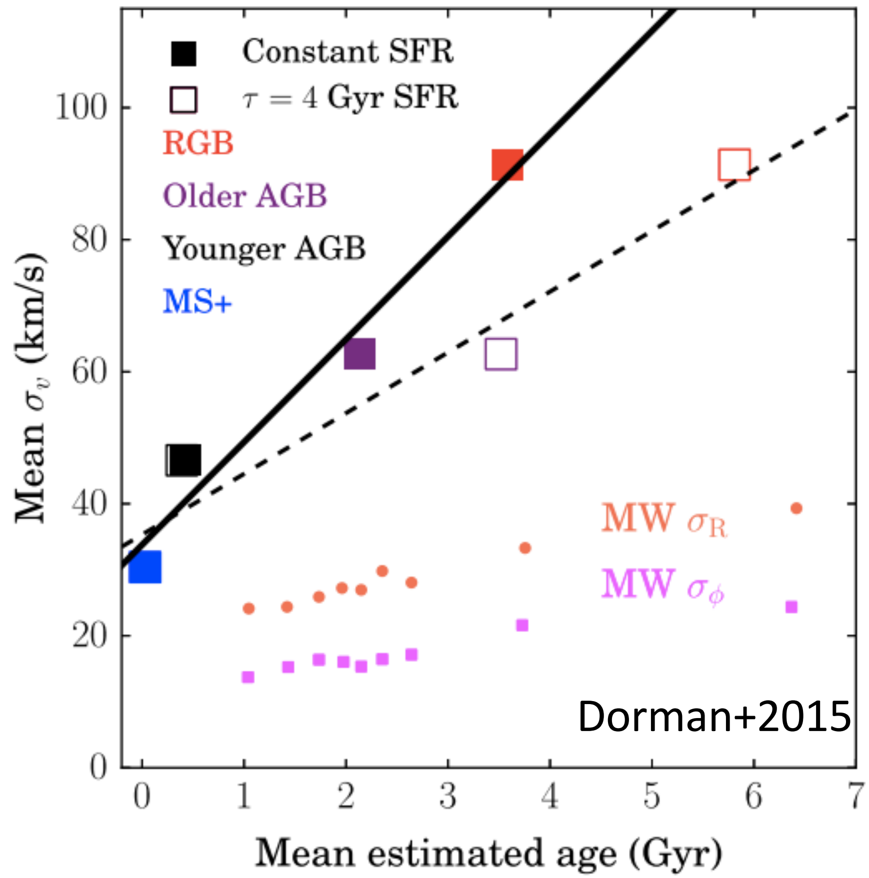
MW vs M31: Disk Velocity Dispersion

First time the age velocity dispersion relation has been measured in an external galaxy

Implies: M31 has had a violent recent past - this is more in line with LCDM expectations.

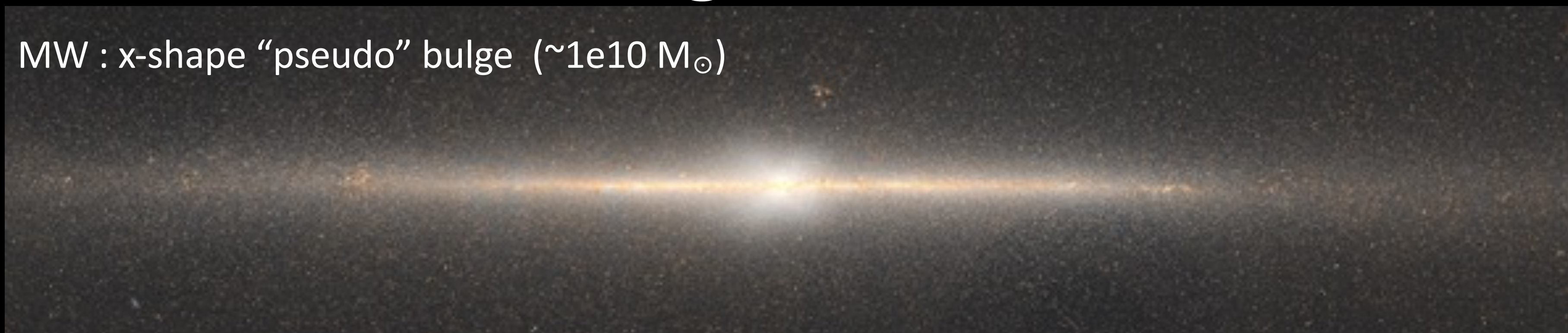
MW may be atypical in that it has a quiet history.

M31's RGB stars have $h_z = 770 \pm 80$ pc, which is far thicker than the Milky Way's thin disk, but comparable to its thick disk. The lack of a significant thin disk in M31 is unexpected, but consistent with its interaction history and high disk velocity dispersion.
Dalcanton+2023, AJ, 166

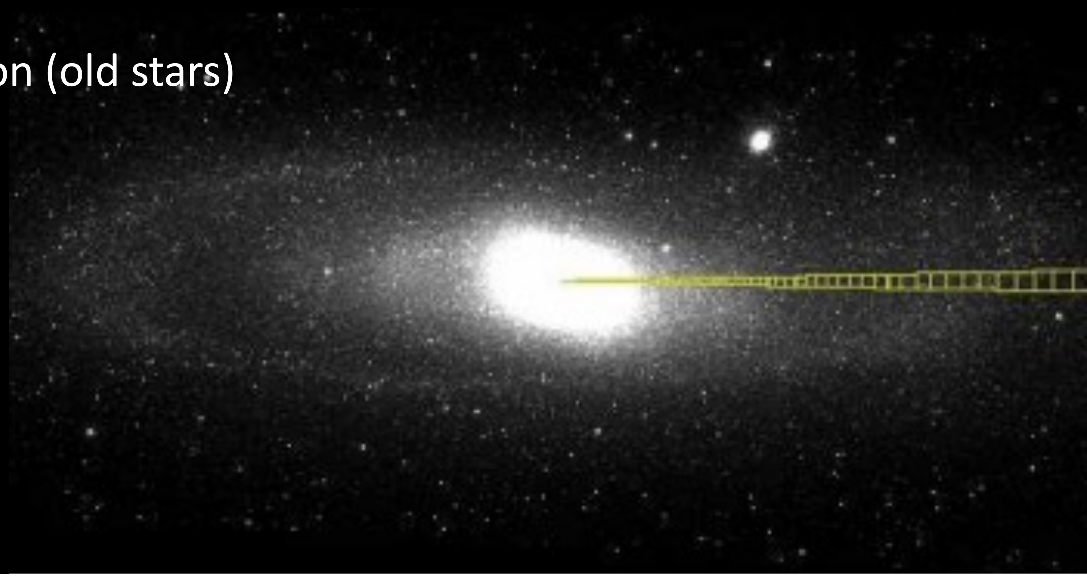


MW vs M31: Bulge

MW : x-shape “pseudo” bulge (~1e10 $M_\odot$)



M31 IRAC 3.6 micron (old stars)



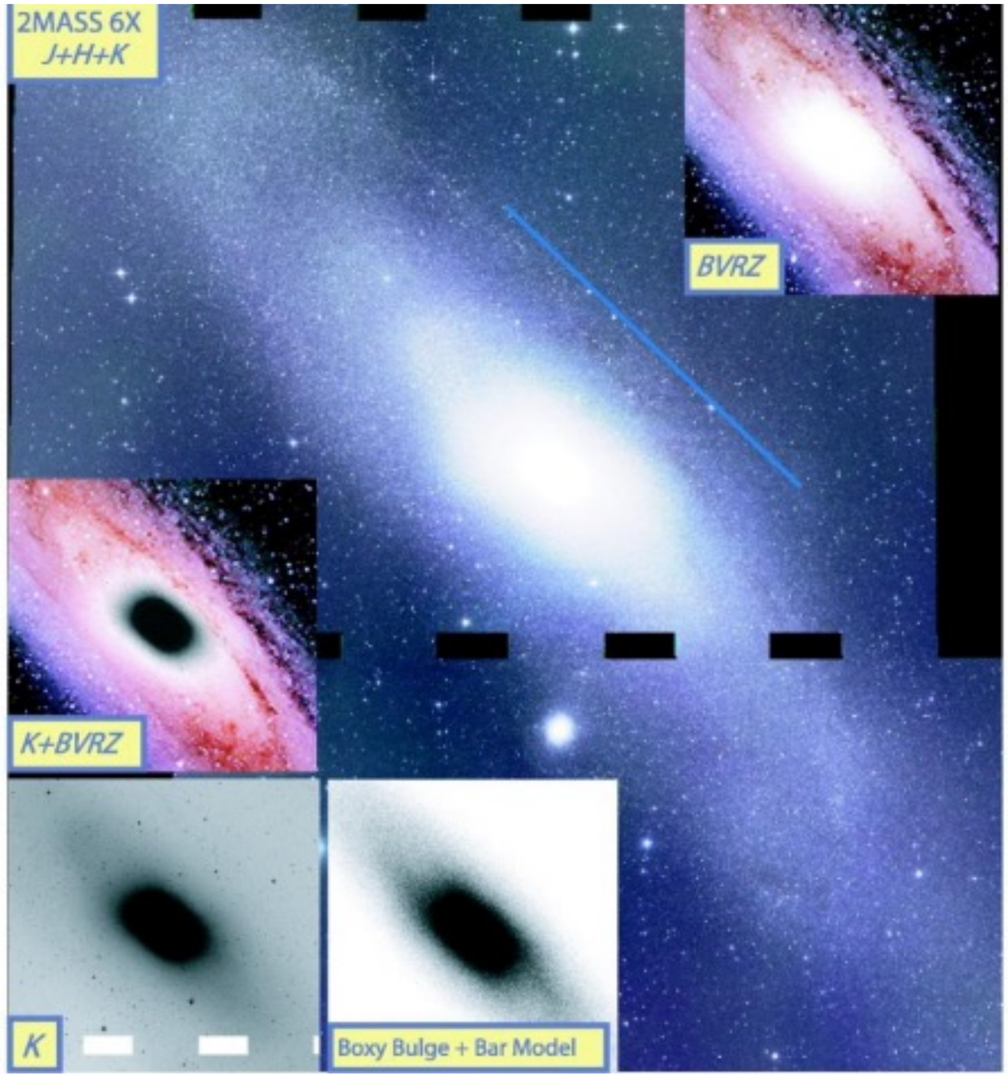
M31 Bulge

~2.5e10 $M_\odot$

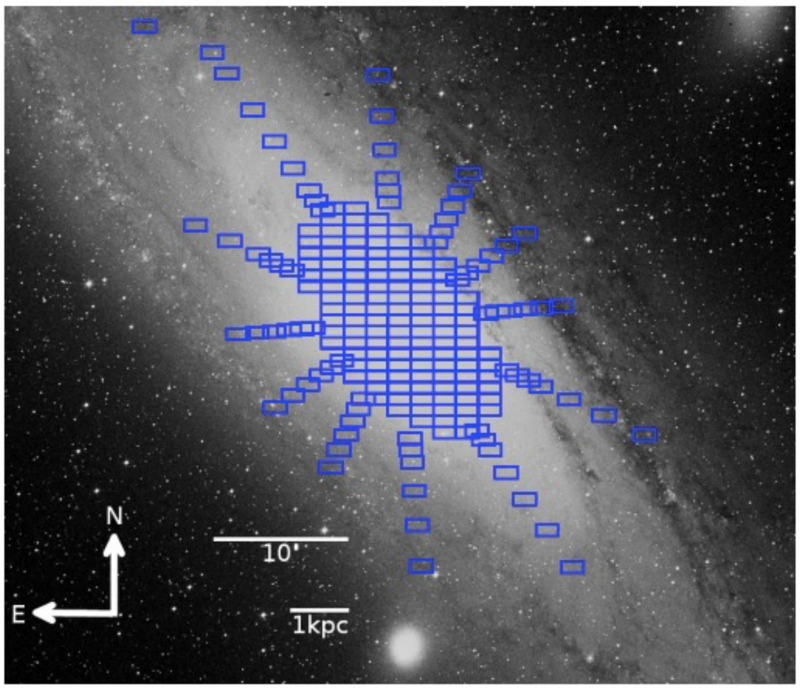
Massive and boxy

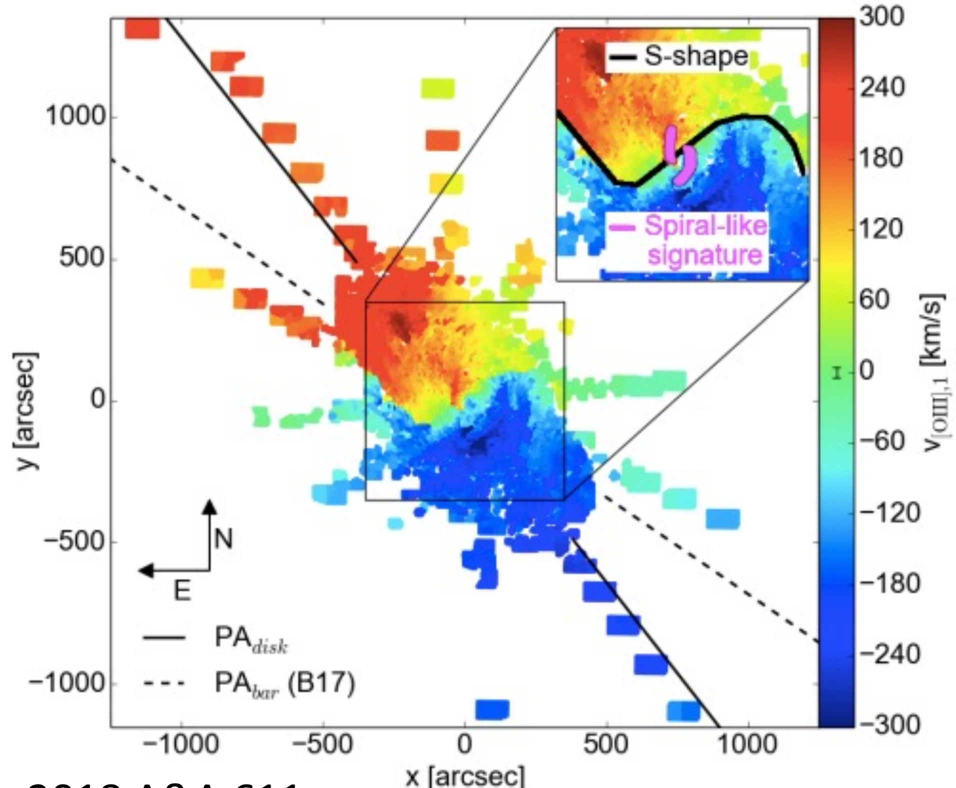
Classical + Pseudo Bulge?

Leahy + 2023 ApJS 265



M31: Bar

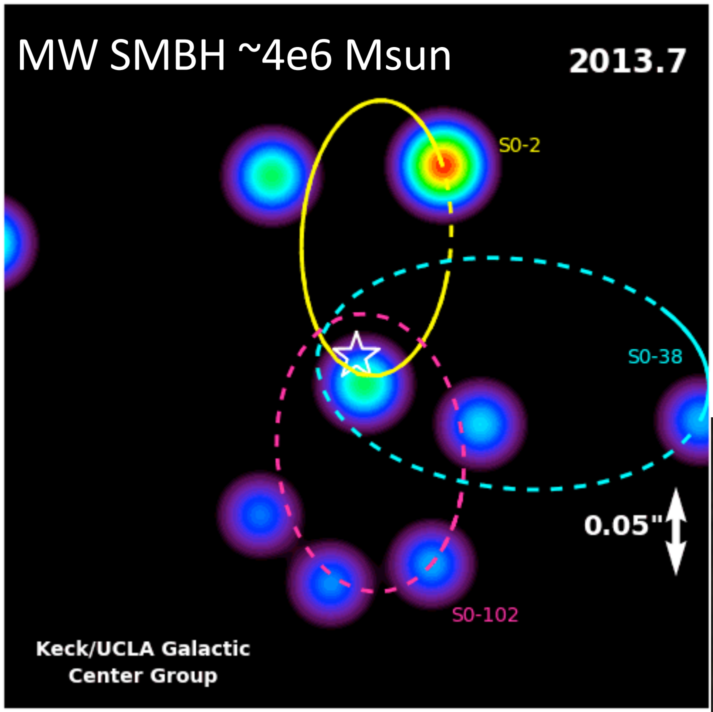


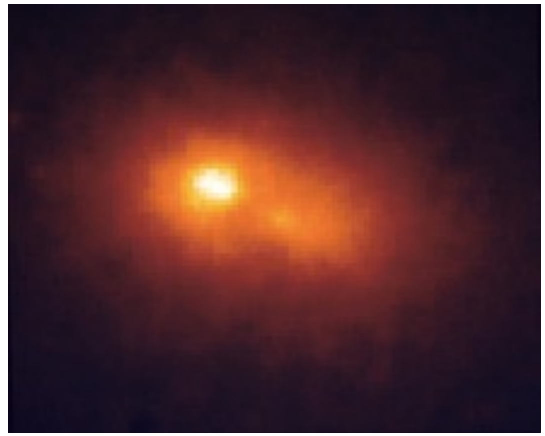


Opitsch+2018 A&A 611

IFU: OIII

MW vs M31: Black Hole/Nucleus





HST Imaging of M31 shows
2 complexes in the center.
One hosts a SMBH.
The other might be
Nuclear stellar cluster

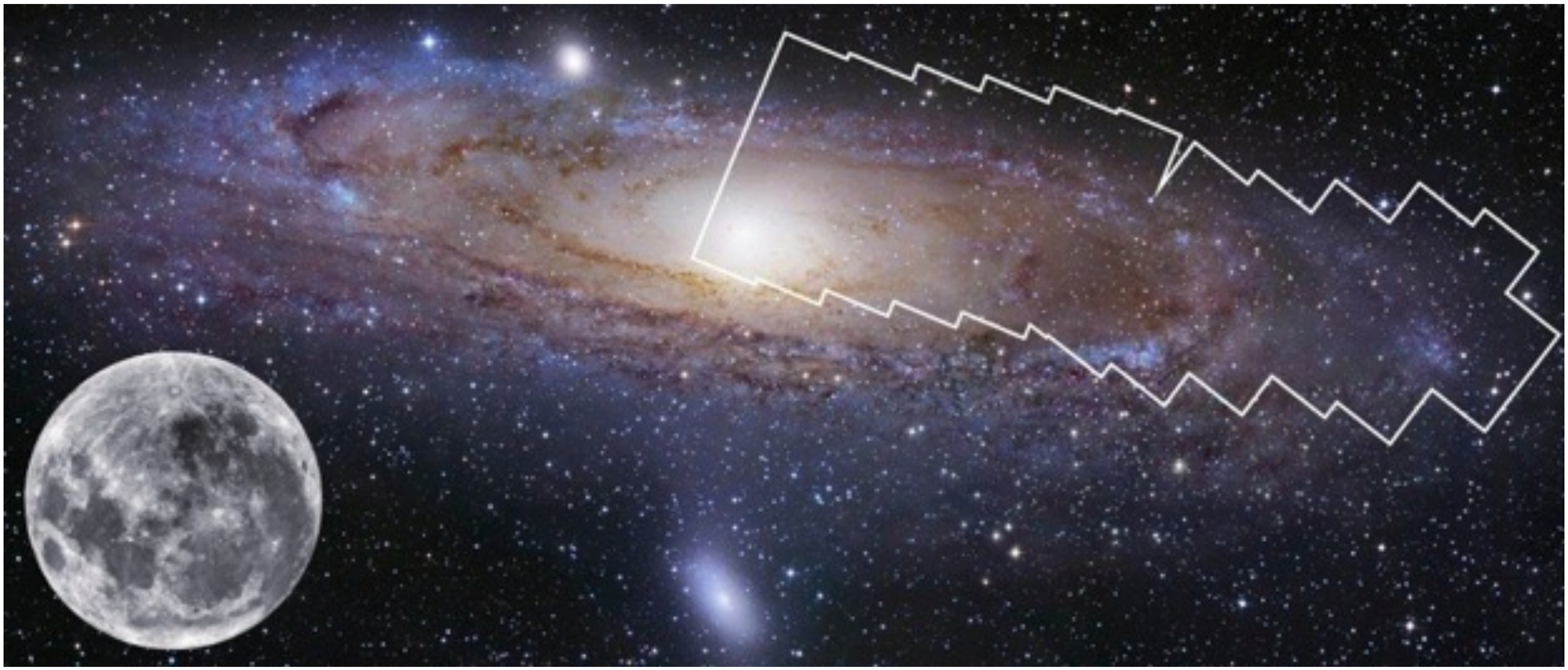
M31 SMBH
5–23 × 10^7 $M_\odot$

Bender+2005, ApJ, 631

https://www.youtube.com/watch?v=jojrHPITg-I

Lauer+2012, ApJ 745

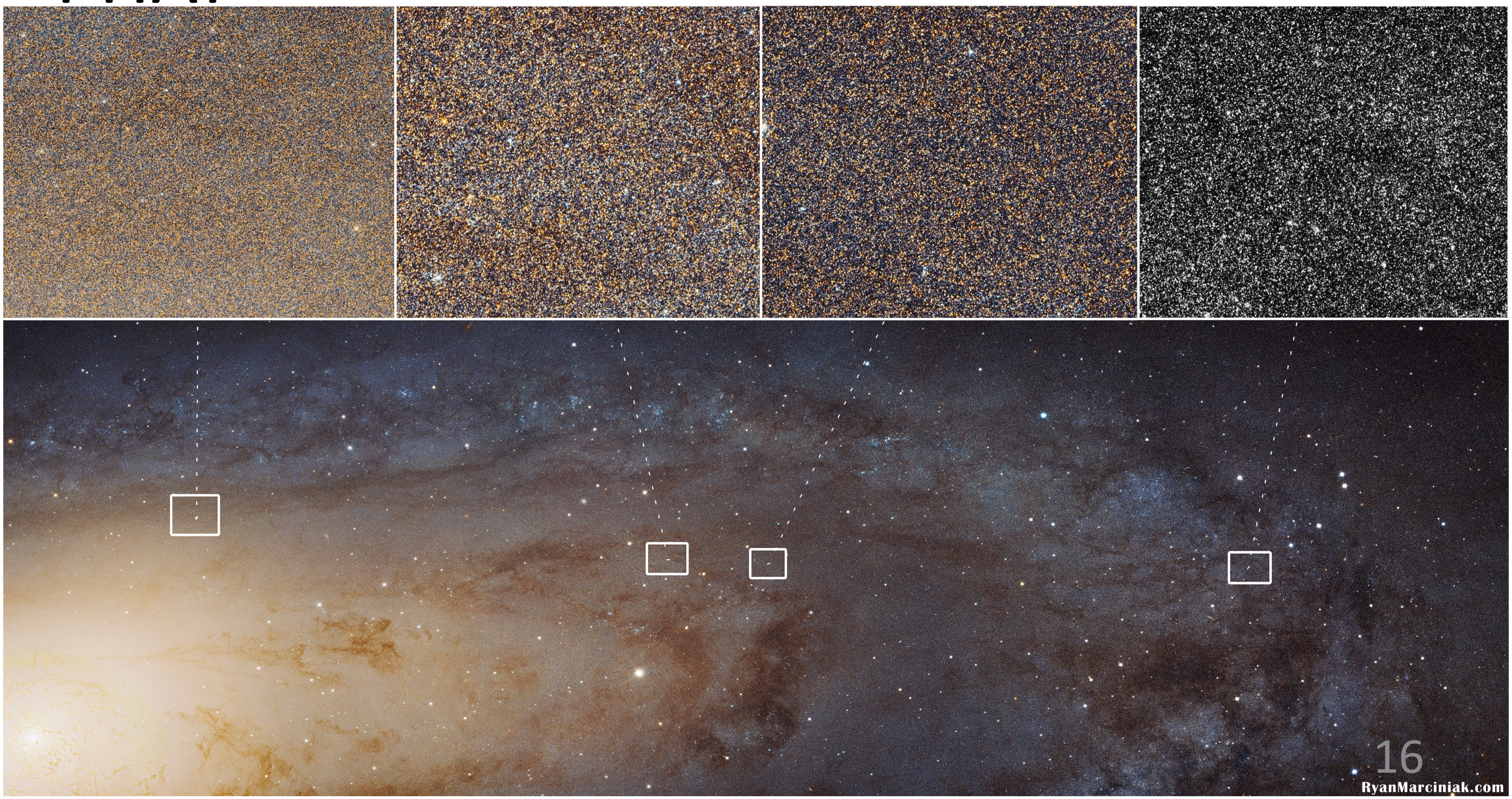
PHAT Dalcanton+2012 ; Williams + 2014



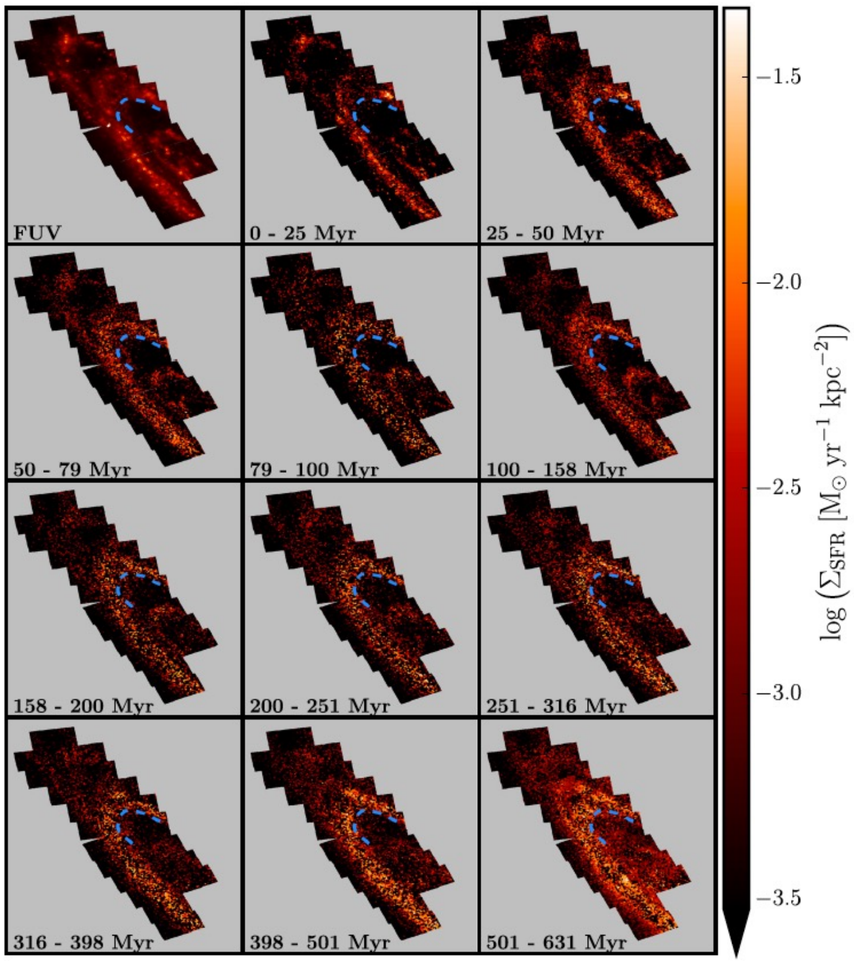
The Panchromatic Hubble Andromeda Treasury is a Hubble Space Telescope Multi-cycle program to map roughly a third of M31's star forming disk, using 6 filters covering from the ultraviolet through the near infrared. With HST's resolution and sensitivity, the disk of M31 is resolved into more than 100 million stars, enabling a wide range of scientific endeavors.

PHAT

https://hubblesite.org/contents/news-releases/2015/news-2015-02.html



MW vs M31: Star Formation Rate



MW SFR ~ 1 Msun/yr

M31 ~ Constant over past 500 Myr with mild upturn 50 Myr ago.

Over past 100 Myr, average SFR 0.28 +/- 0.03 Msun/yr in PHAT

Extrapolating to full disk = ~0.7 Msun/yr

Lewis+2015
PHAT survey

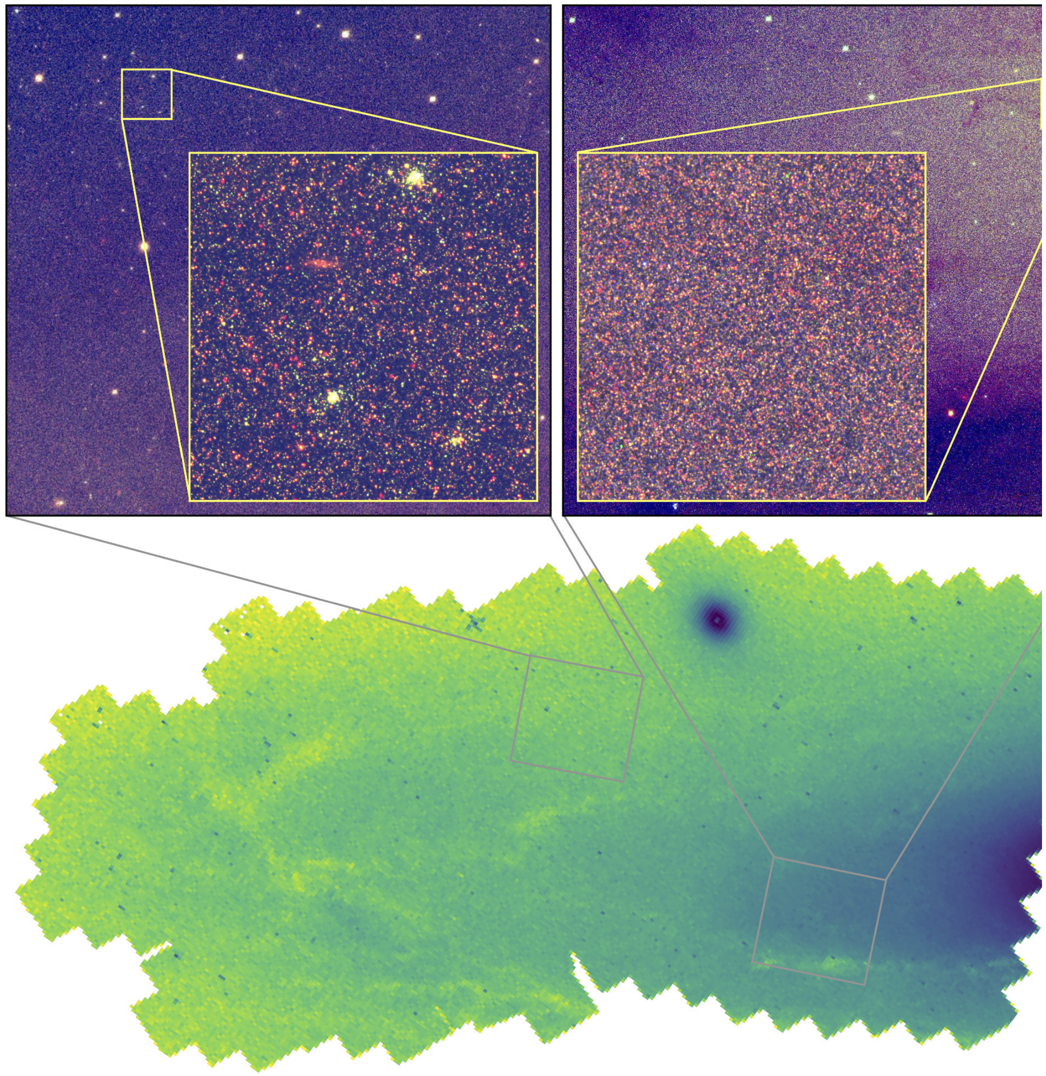
PHAST: The Panchromatic Hubble Andromeda Southern Treasury

Chen+2025, ApJ, 979, 35

(PHAST) is a large 195-orbit Hubble Space Telescope program imaging ~0.45 deg2 of the southern half of M31's star-forming disk at optical and near-ultraviolet (NUV) wavelengths,

The PHAST survey area extends the northern coverage of the Panchromatic Hubble Andromeda Treasury (PHAT) down to the southern half of M31, covering out to a radius of ~13 kpc along the southern major axis and in total ~two-thirds of M31's star-forming disk.

Photometry of > 90 million resolved stars



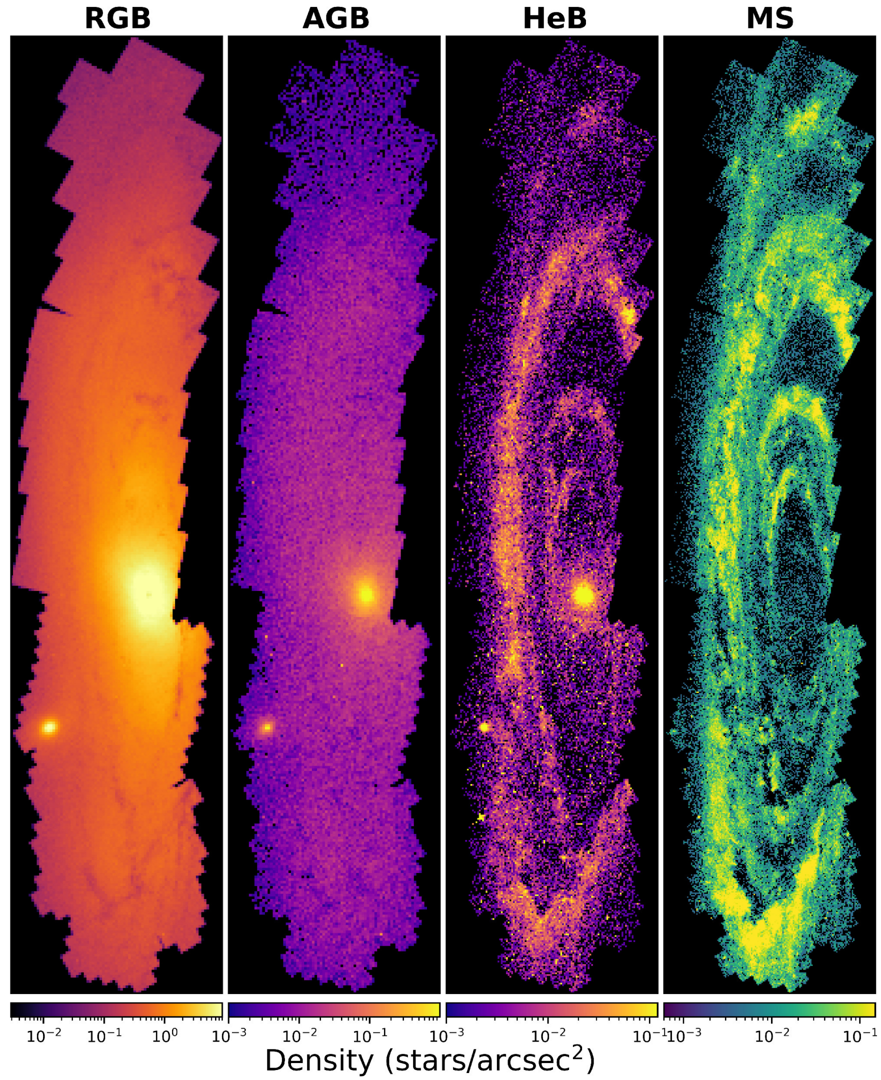
PHAST + PHAT

The combined PHAST + PHAT photometry catalog of
~0.2 billion stars
is the largest ever produced for equidistant sources and is available for public download.

Stellar density maps of M31 (PHAT and PHAST)

The MS probes ~3–200 Myr
the HeB probes ~30–500 Myr.
The AGB probes ~0.8–2 Gyr
the RGB probes ≳2 Gyr.

The two younger populations are more highly structured than the two older populations.



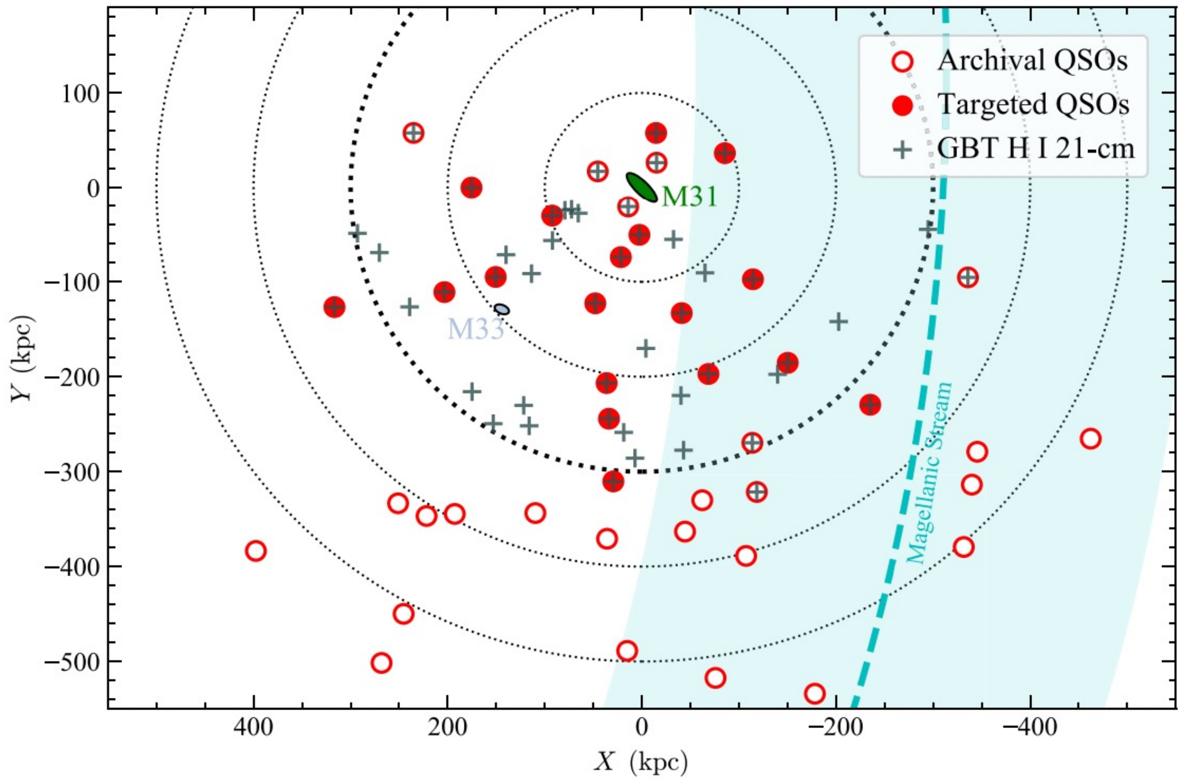
Chen+2025, ApJ, 979, 35

MW vs M31 : $\sim 10^4 - 10^{5.5}$ K CGM

Project AMIGA
Lehner+2020 ApJ 900

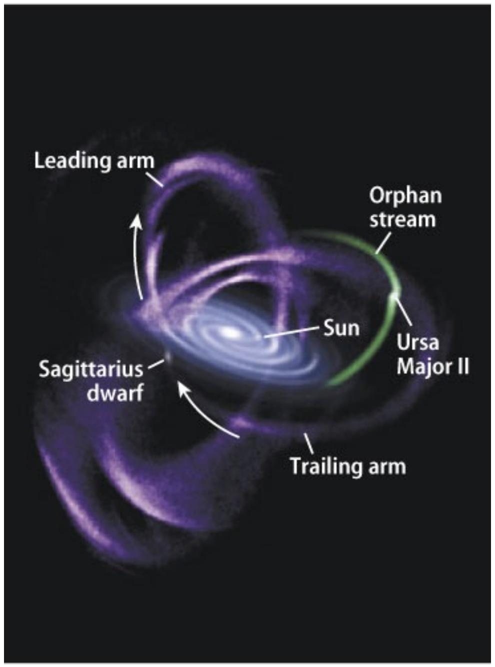
Baryon mass of the $\sim 10^4 - 10^{5.5}$ K CGM is:

> 4e10 $(Z/0.3\ Z_{sun})^{-1}$ Msun

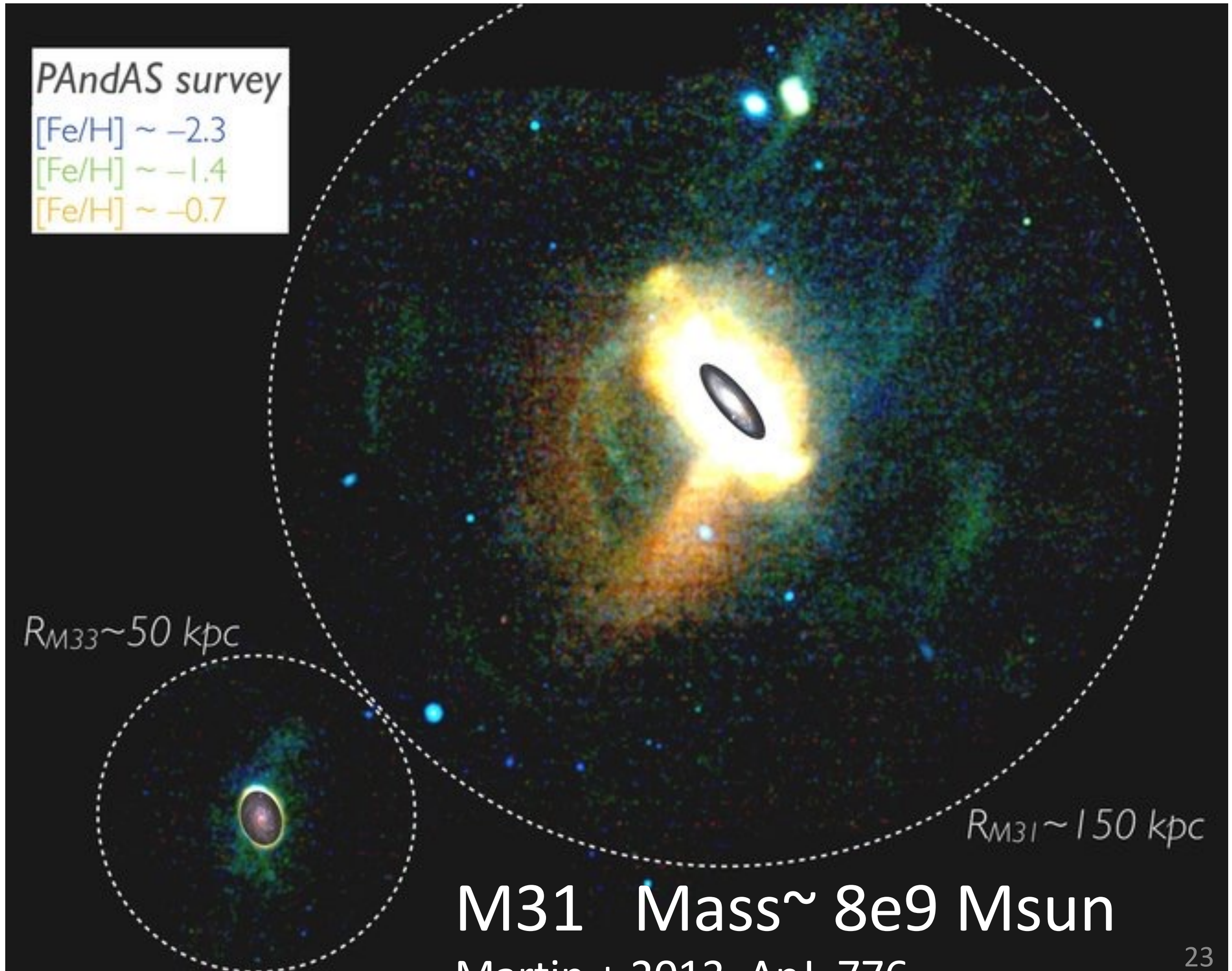


"It is likely that the Milky Way has a $\sim 10^4 - 10^{5.5}$ K CGM as extended as far as M31 and so their CGM (especially the warm–hot gas probed by O VI) are overlapping."

MW vs M31: Stellar Halo



MW: Mass ~ 1e9 Msun



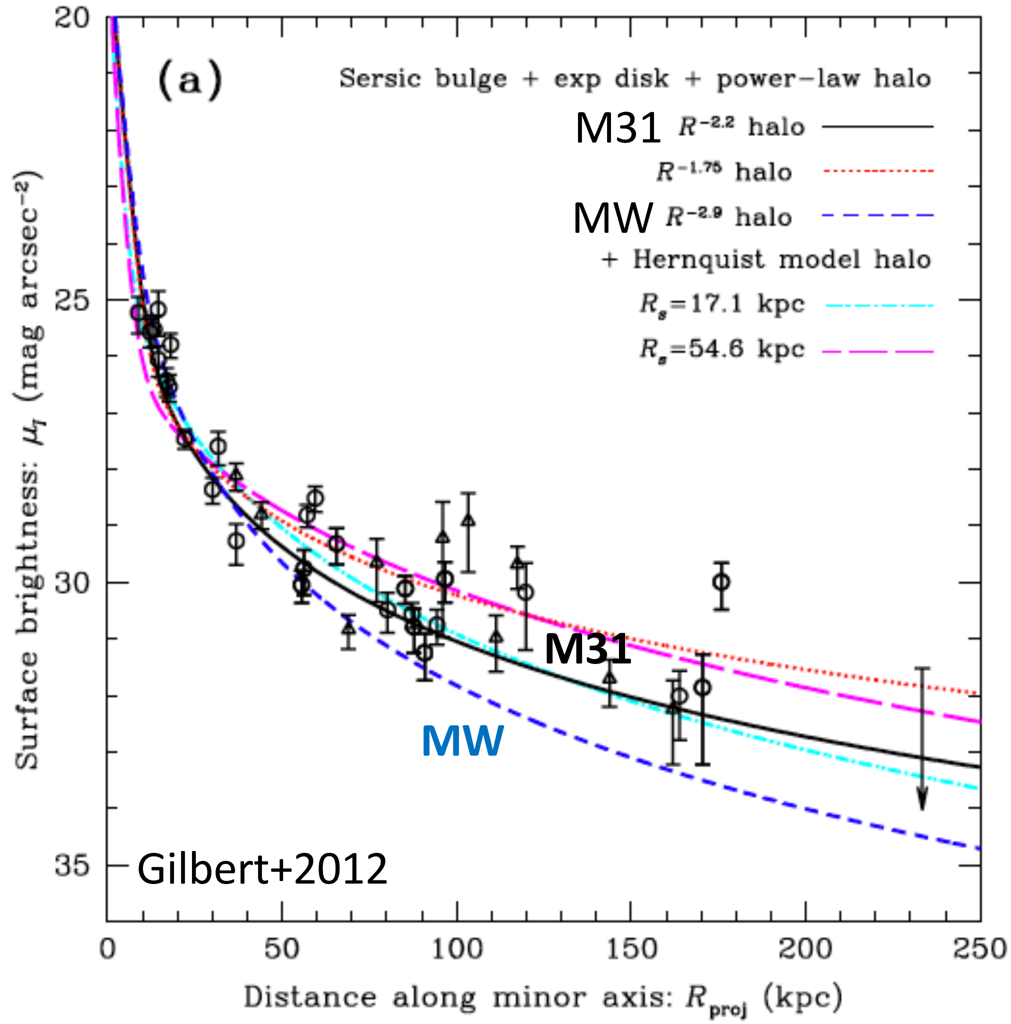
M31 Mass~ 8e9 Msun

Martin + 2013, ApJ, 776

Stellar Halo: Surface Brightness Profiles

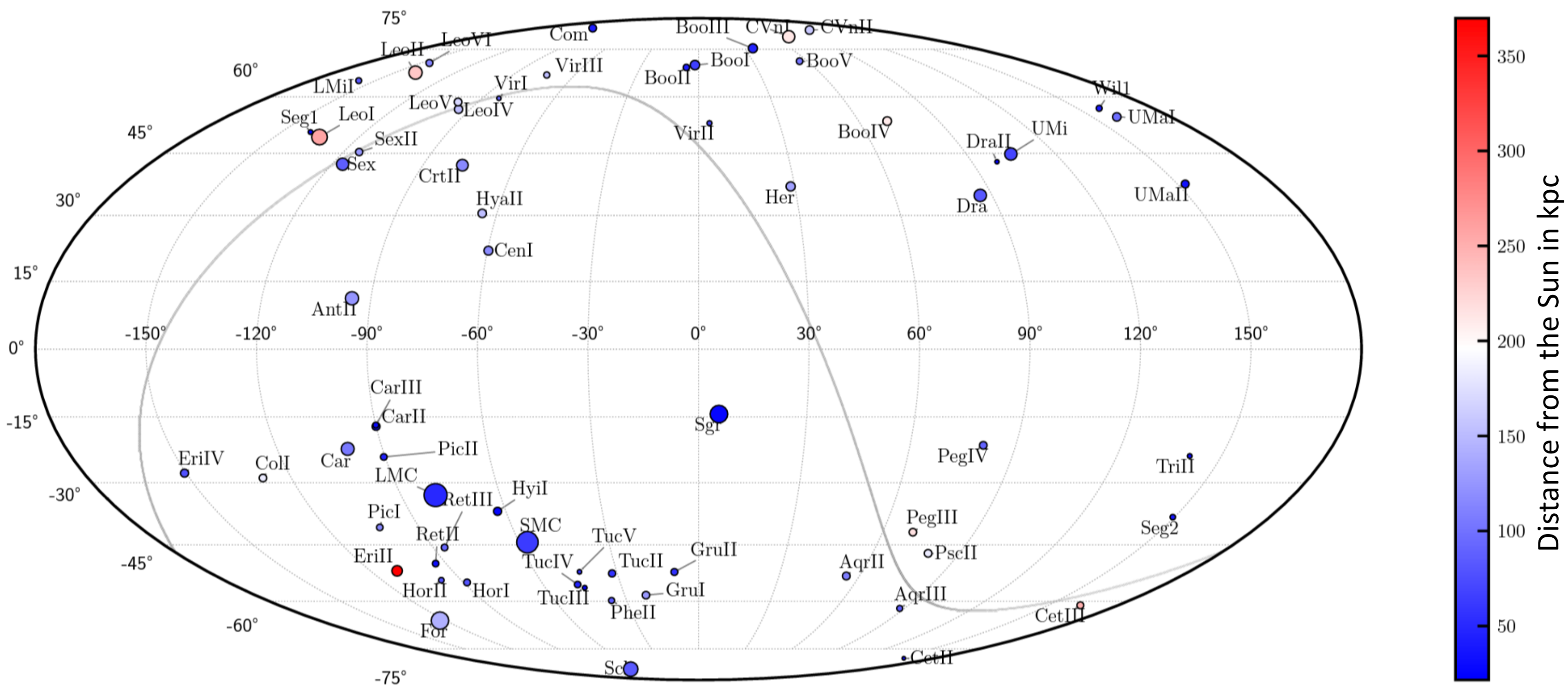
$I \propto r^{-\alpha}$

M31 profile is shallower (more extended) than the MW's stellar halo



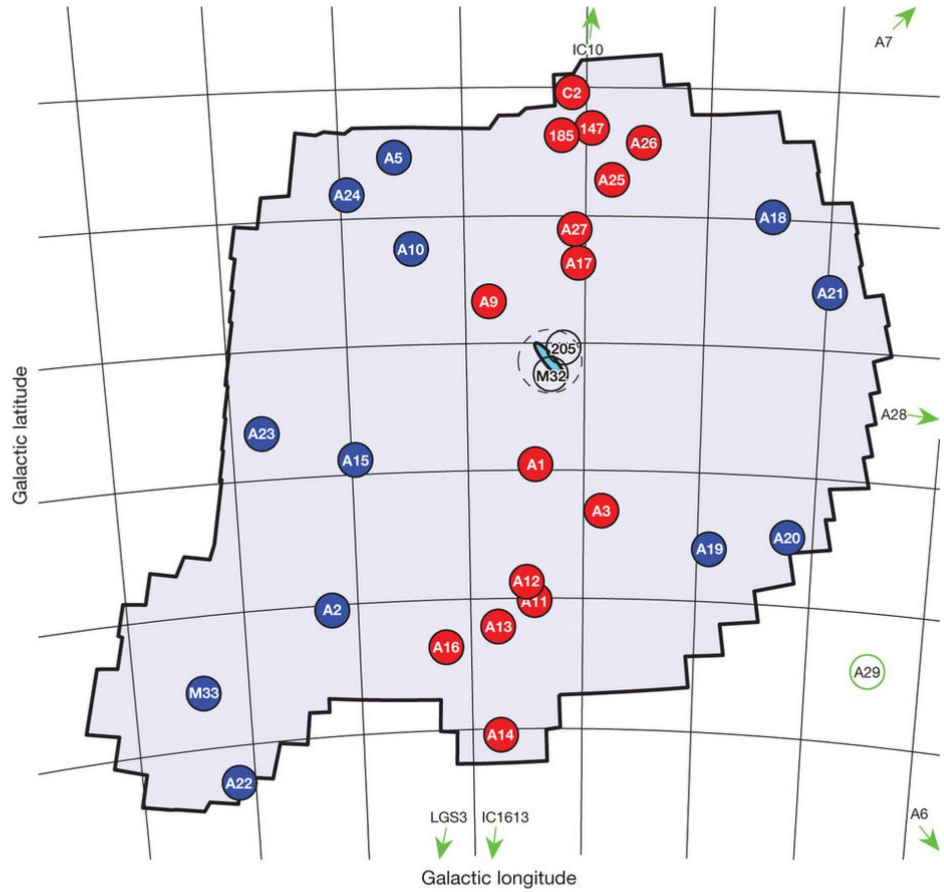
Number of MW Satellites in the Era of Gaia

- > 65 (not all confirmed) Pace 2024 arXiv 2411.07424



M31 Distribution of Satellites

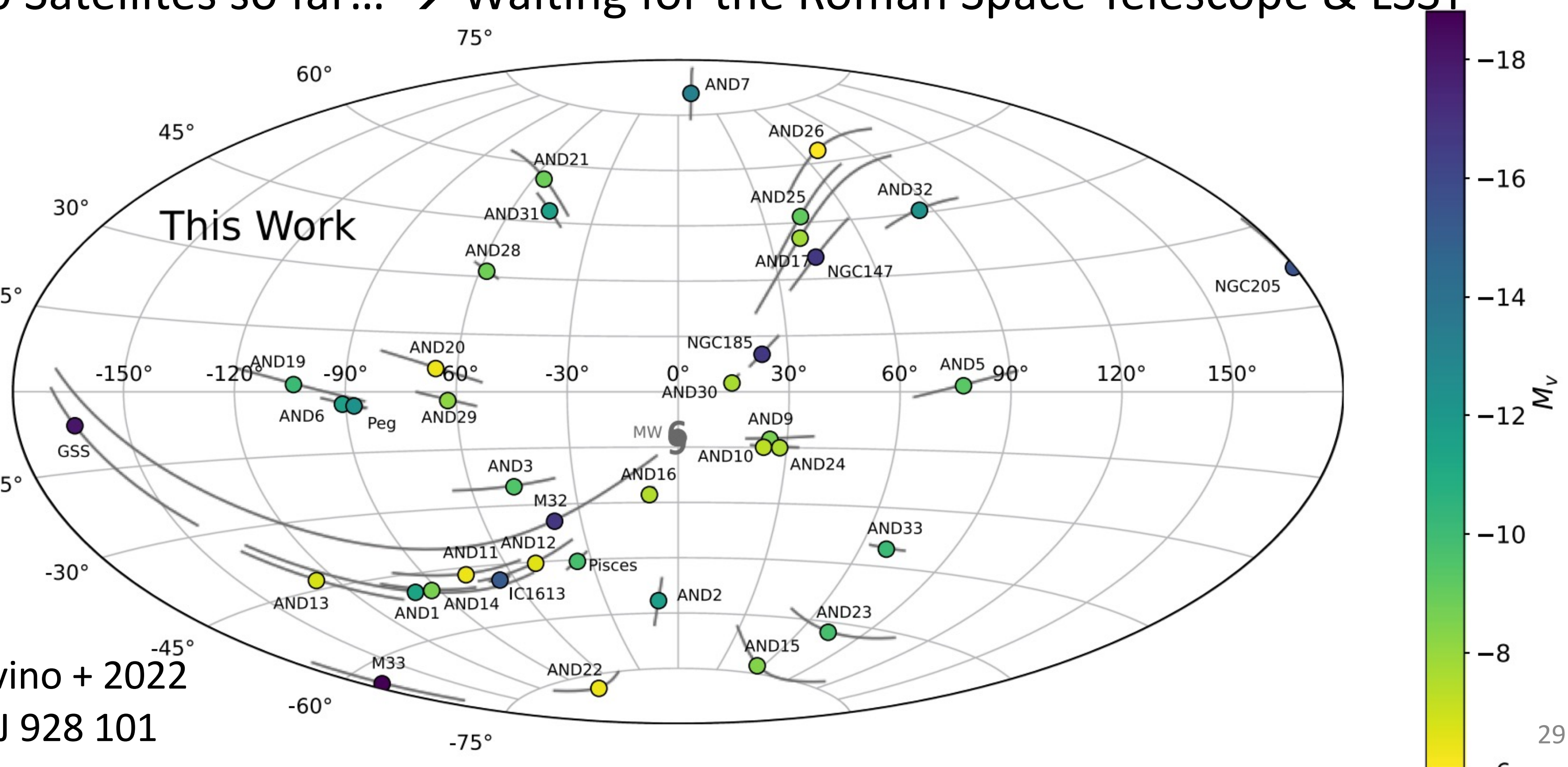
Pan-Andromeda Archaeological Survey (PAndAS)



Ibata + 2013
Nature, 493, 62

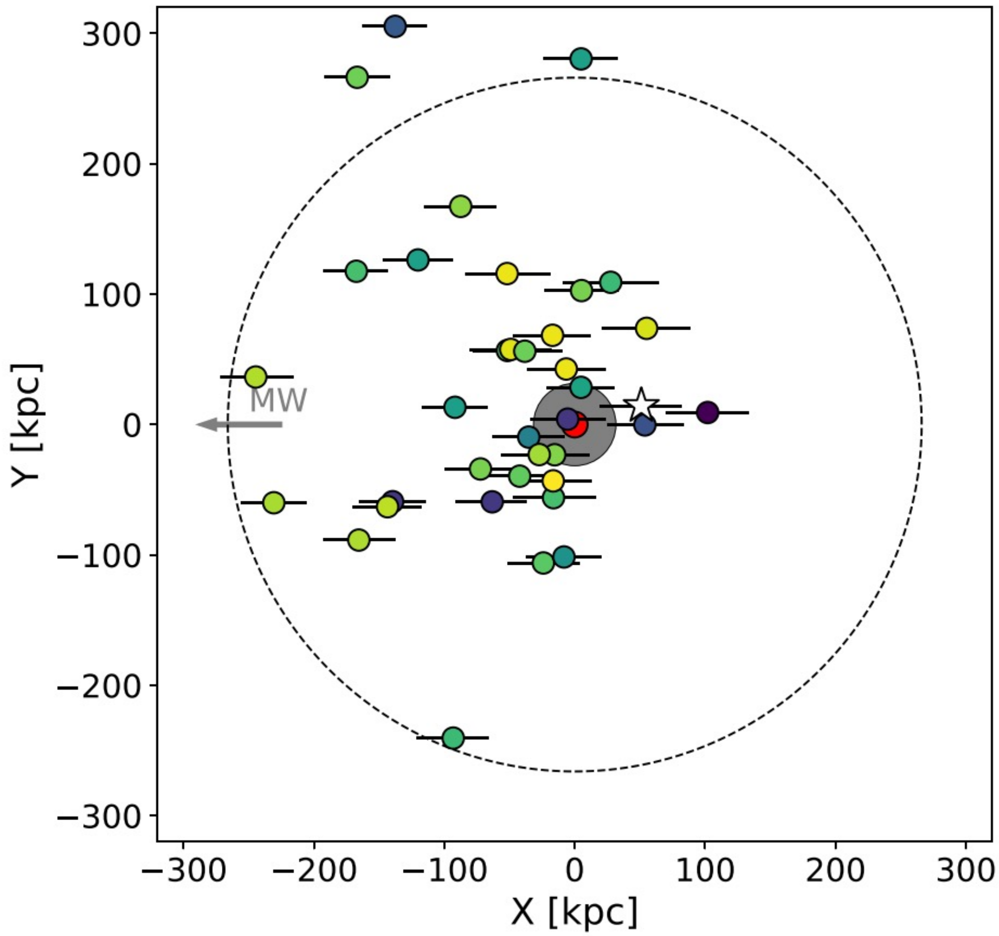
M31 Distribution of Satellites

~ 30 Satellites so far… → Waiting for the Roman Space Telescope & LSST



Savino + 2022
ApJ 928 101

Spatial Distribution of M31 Satellites



Savino + 2022
ApJ 928 101

Recall From Last Class:

Schechter Fxn (in terms of luminosity, L)

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

$\mathrm{n}_* = 8 \times 10^{-3} h^3 \ \mathrm{Mpc}^{-3}$ $L_* = 1.4 \times 10^{10} L_\odot$ $\alpha = -0.7$

Schechter Fxn (in terms of magnitude, M)

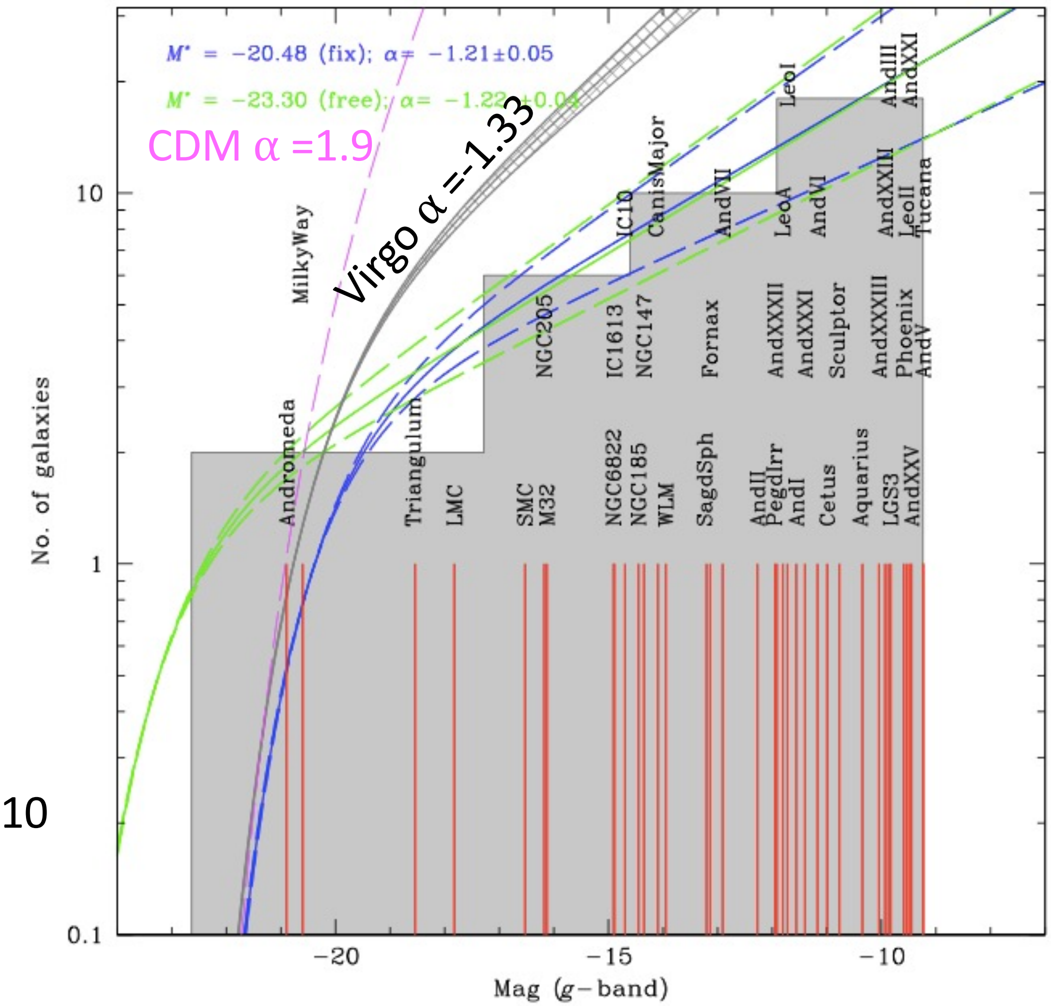
$$\Phi(M)dM = (0.4ln10)\phi_* 10^{0.4(M_*-M)(\alpha+1)} e^{-10^{0.4(M_*-M)}} dM$$

$\phi_* = 1.66 \pm 0.08 \times 10^{-2} h^3 \mathrm{Mpc}^{-3}$ $\alpha =$ -0.81 $\pm$ 0.04 $\mathrm{M}^* = \mathrm{M}_k^* =$ -23.19 $\pm$ 0.04 - 5log(h)

$h = H_0/(100 \ \mathrm{km/s/Mpc})$. Where $H_0 = 70.4 \ \mathrm{km/s/Mpc}$

Parameters from Smith+(2009 MNRAS 397, 868)
K band

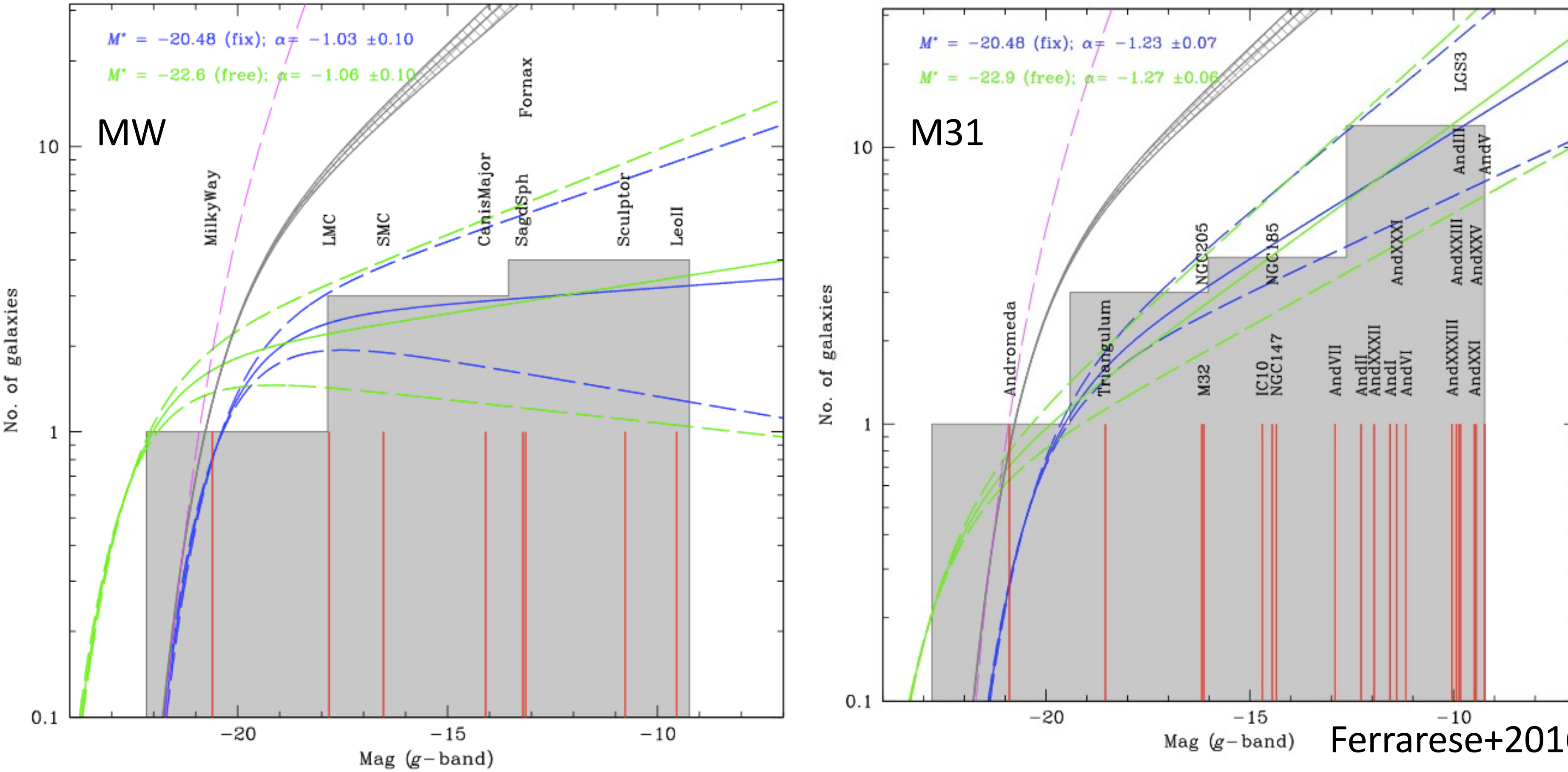
Luminosity Function of the Local Group



We're filling out the low mass end

Ferrarese+2016 ApJ, 824, 10

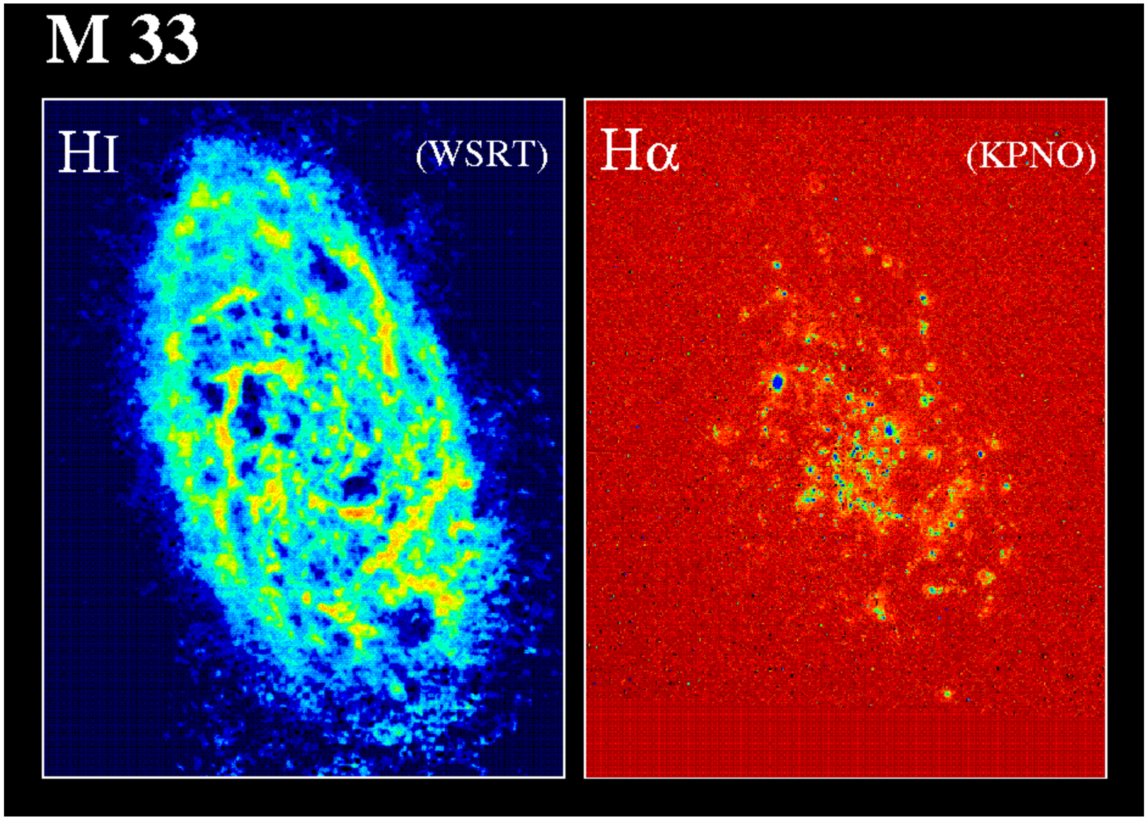
MW vs M31: Luminous Satellites Lum Fxn

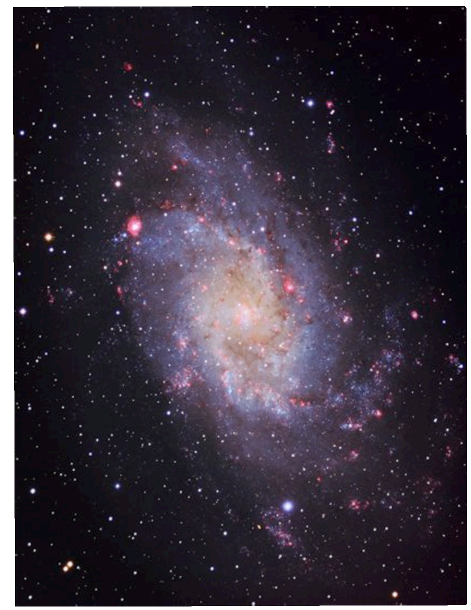


Ferrarese+2016

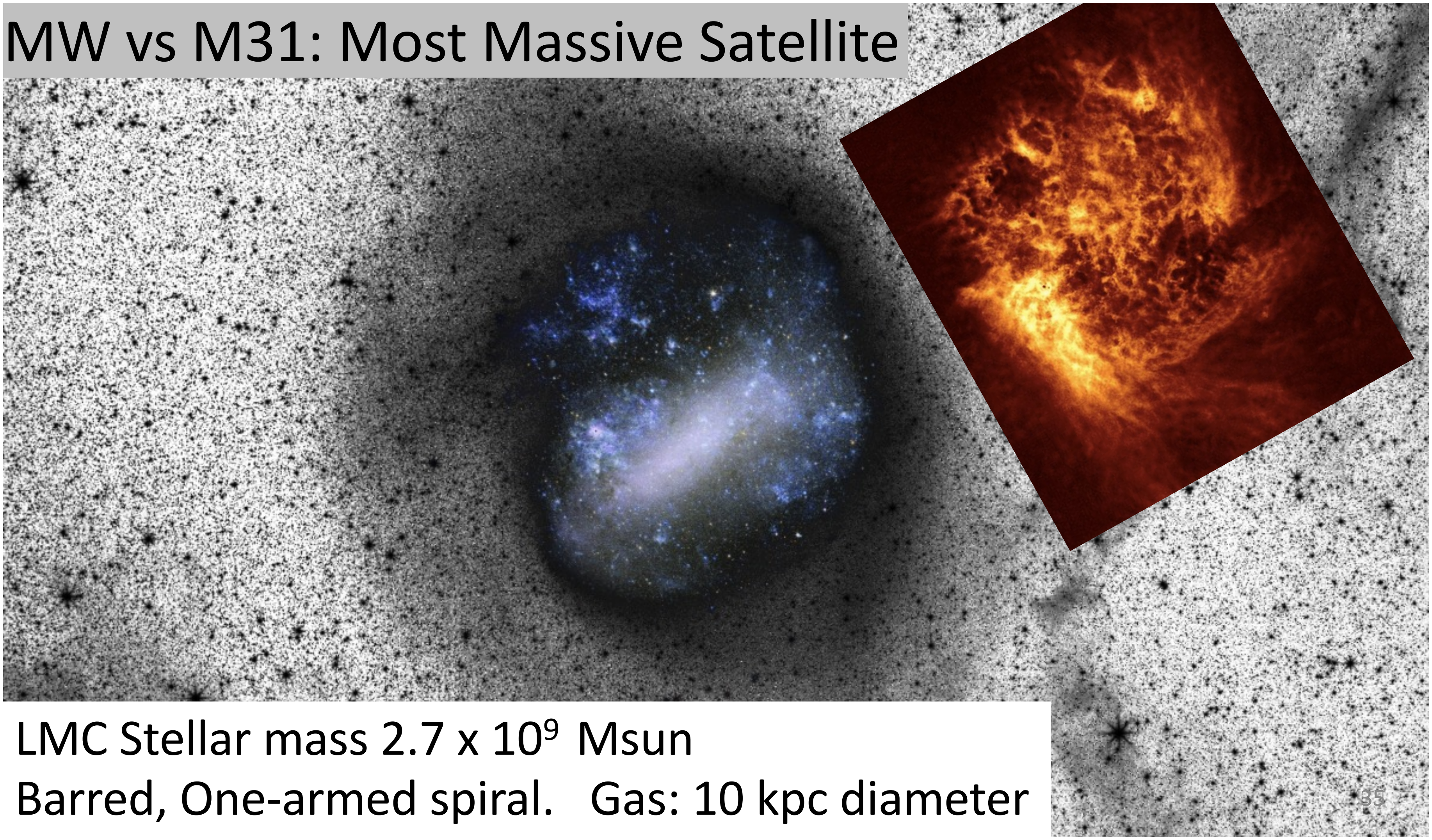
Higher number of luminous satellites and existence of 3 dEs around M31 favors it being a more massive system

MW vs M31: Most Massive Satellite

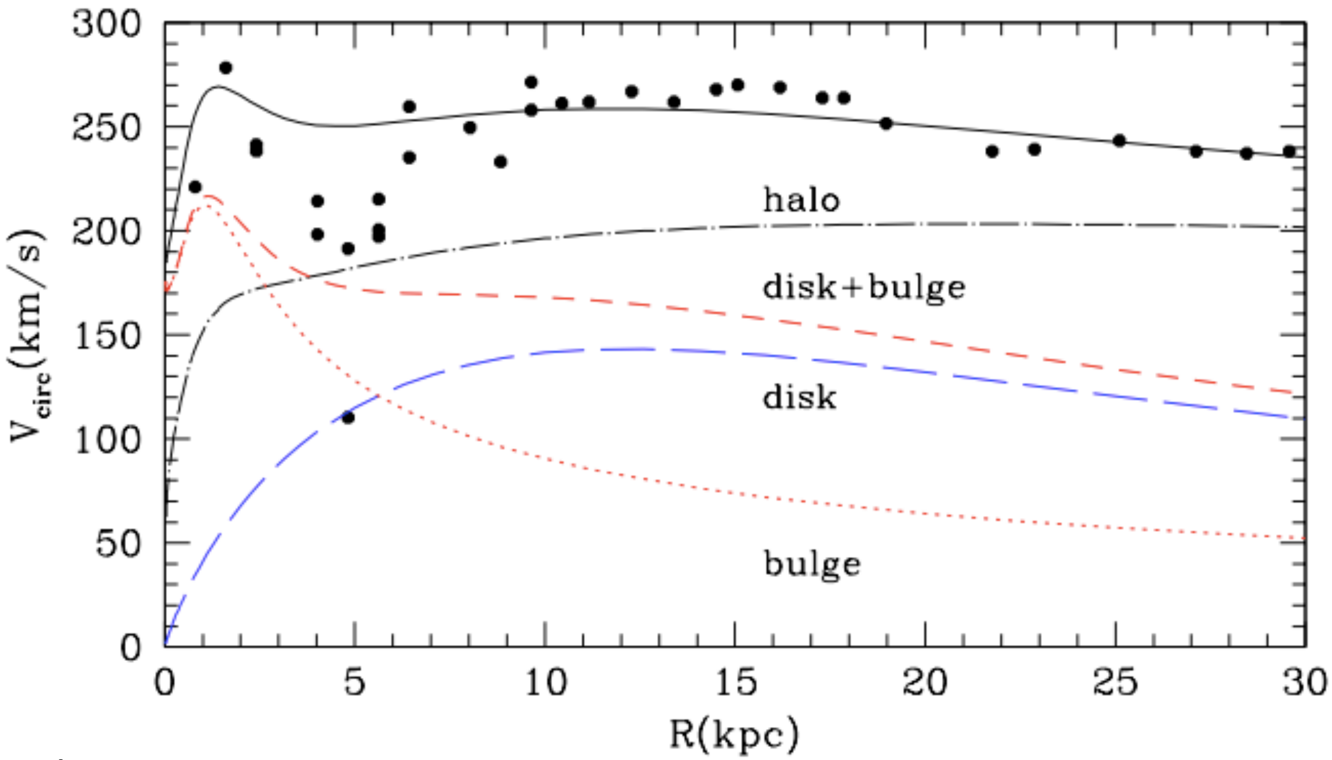




M33 Stellar mass ~ 3-5 x 10^9 Msun. Flocculent Spiral
Gas: 40 kpc diameter!


MW vs M31: Most Massive Satellite
LMC Stellar mass 2.7 x 10^9 Msun
Barred, One-armed spiral.   Gas: 10 kpc diameter

MW vs M31: Rotation Curve



Klypin+ 2002

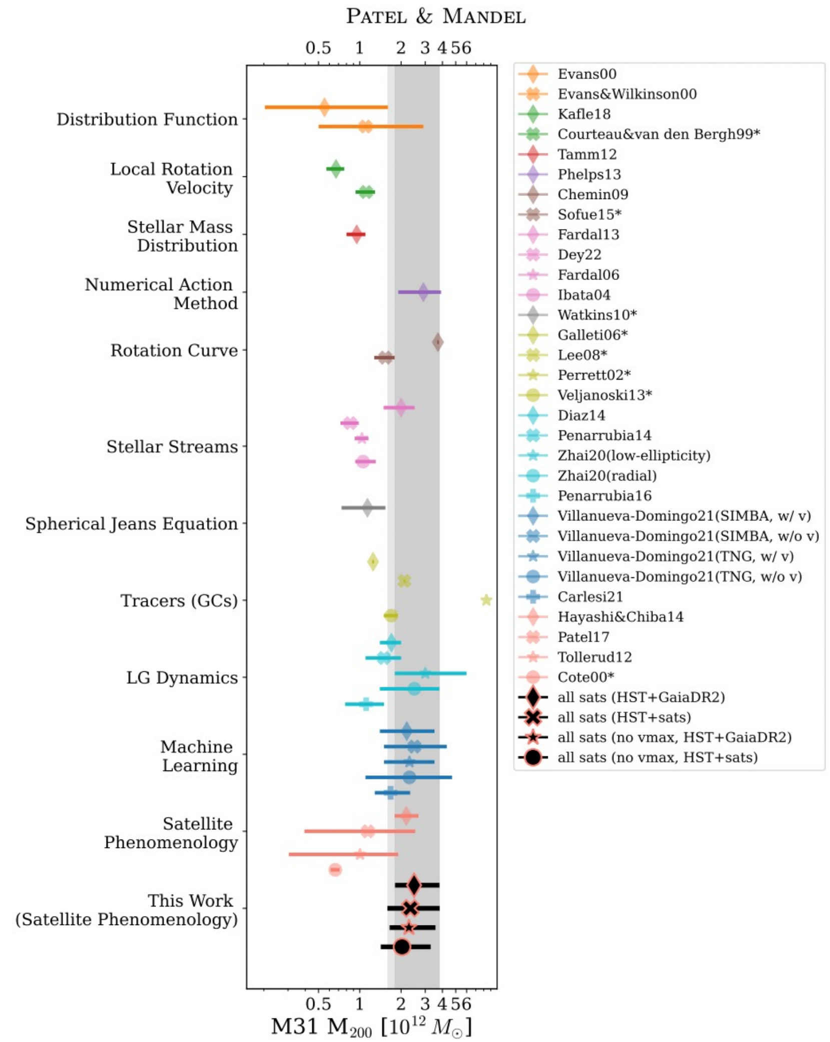
M31 VLSR (~8 kpc)
~ 250-270 km/s

MW VLSR (~8kpc)
~ 235-240 km/s

Patel & Mandel 2023 ApJ 948

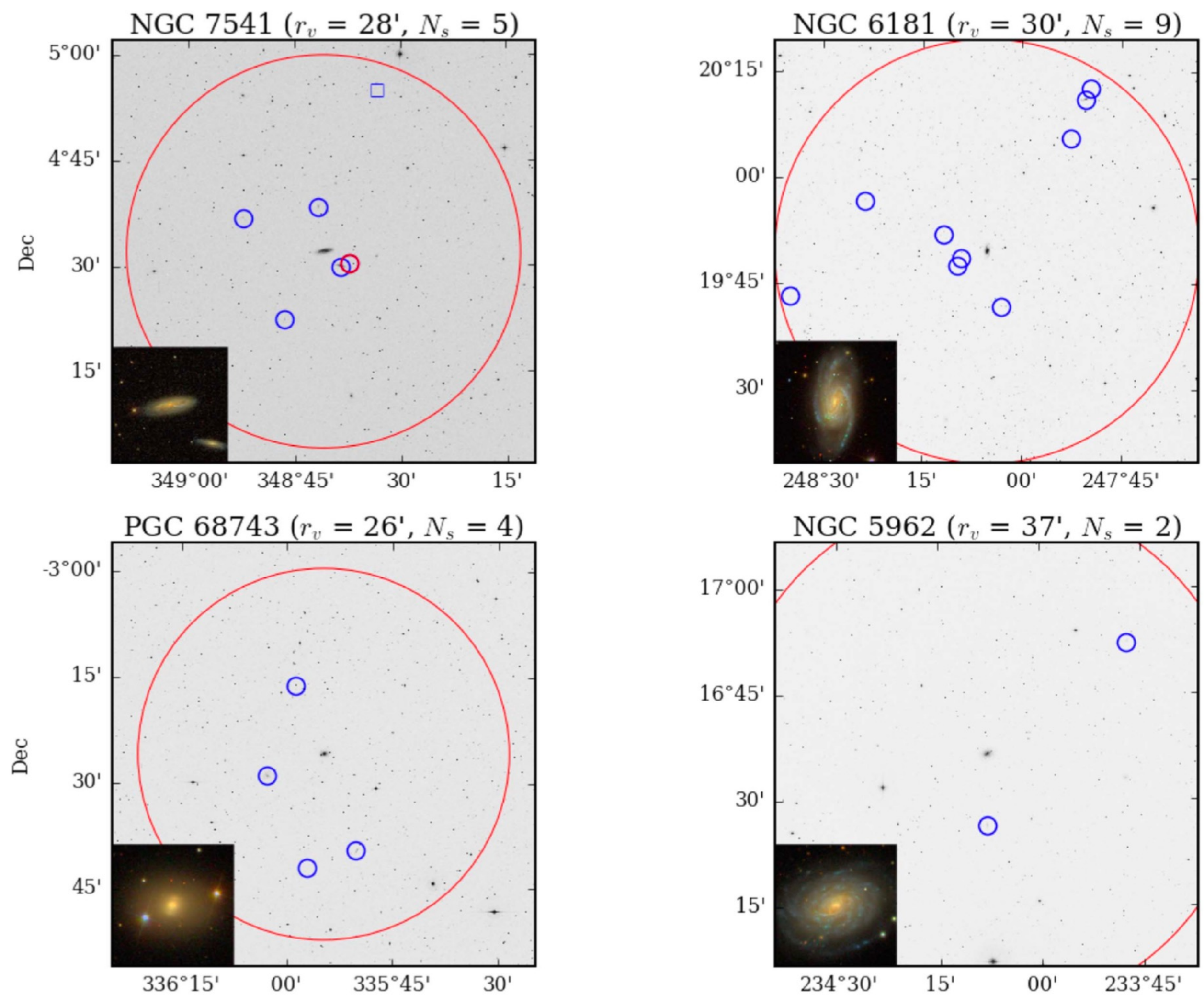
Range of Halo Mass Estimates for M31

Patel & Mandel ~ 3e12 Msun



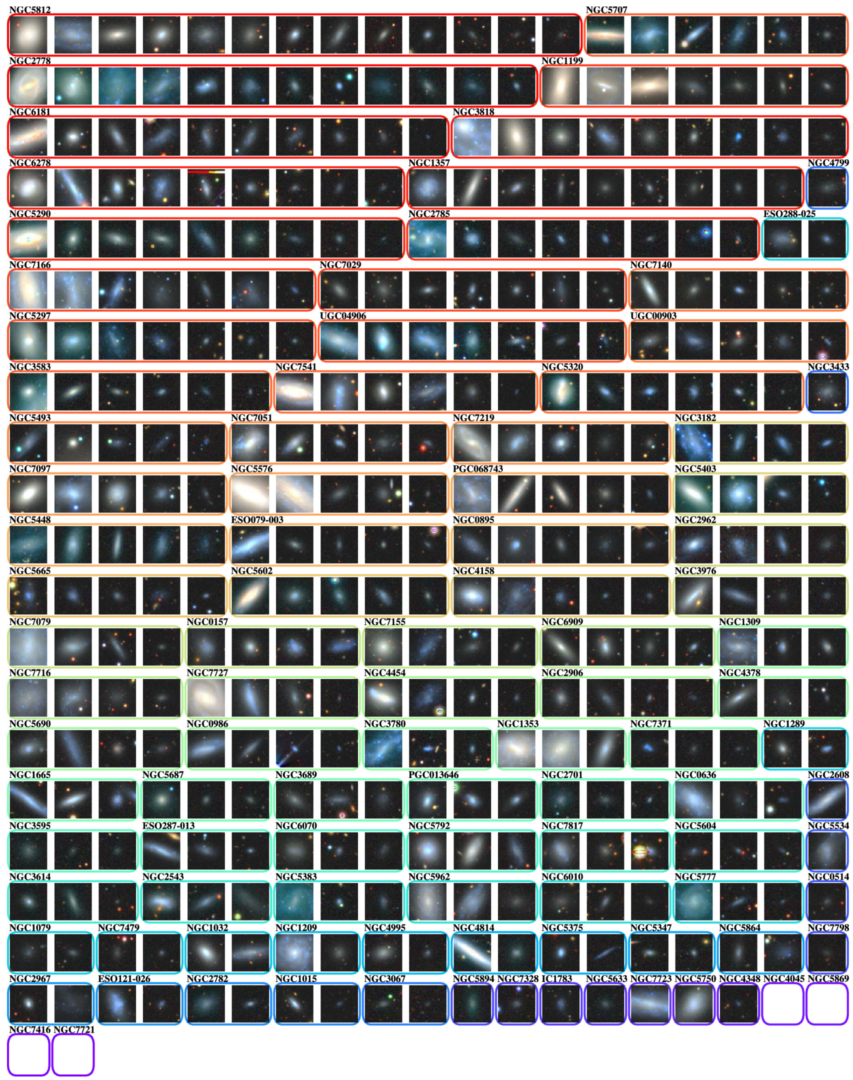
	MW	vs	M31
Stellar Mass/Luminosity	Lv = 1.5x 10^{10} $L_\odot$	<	2.7 x 10^{10} $L_\odot$
	M* ~ 8 x 10^{10} $M_\odot$	<	~10^{11} $M_\odot$
Bulge Properties	pseudo ~ 10^{10}	<	classical (ish) ~2.5e10 $M_\odot$
SMBH	~4 x 10^{6} $M_\odot$ (Ghez+2016)	<	5–23 × 10^{7} $M_\odot$ (Bender+2005, Lauer+2012)
CGM	4-6e10 Msun	~?	>4e10 Msun (Lehner+2020)
Stellar halo	1e9 Msun	<	8e9 Msun, more extended Gilbert+2012
Bar?	yes		yes
Satellites	Total: >~60	?	~30 (incomplete)
	~> 1e9: LMC		M33
	dE: 0	<	3 ; more bright satellites (LF)
SFR	~1 $M_\odot$/yr YSOs (Robitalle & Whitney2010)	~	1 $M_\odot$/yr Williams+2003
Disk Velocity Dispersion	< 40 km/s	<	30-100 km/s
Halo Mass (Mvir)	0.8-1.5 e12 $M_\odot$ (Shen 2022)	<	2.1-4.3e12 $M_\odot$ (Patel 2023)

SAGA Survey: Placing the MW and M31 in context



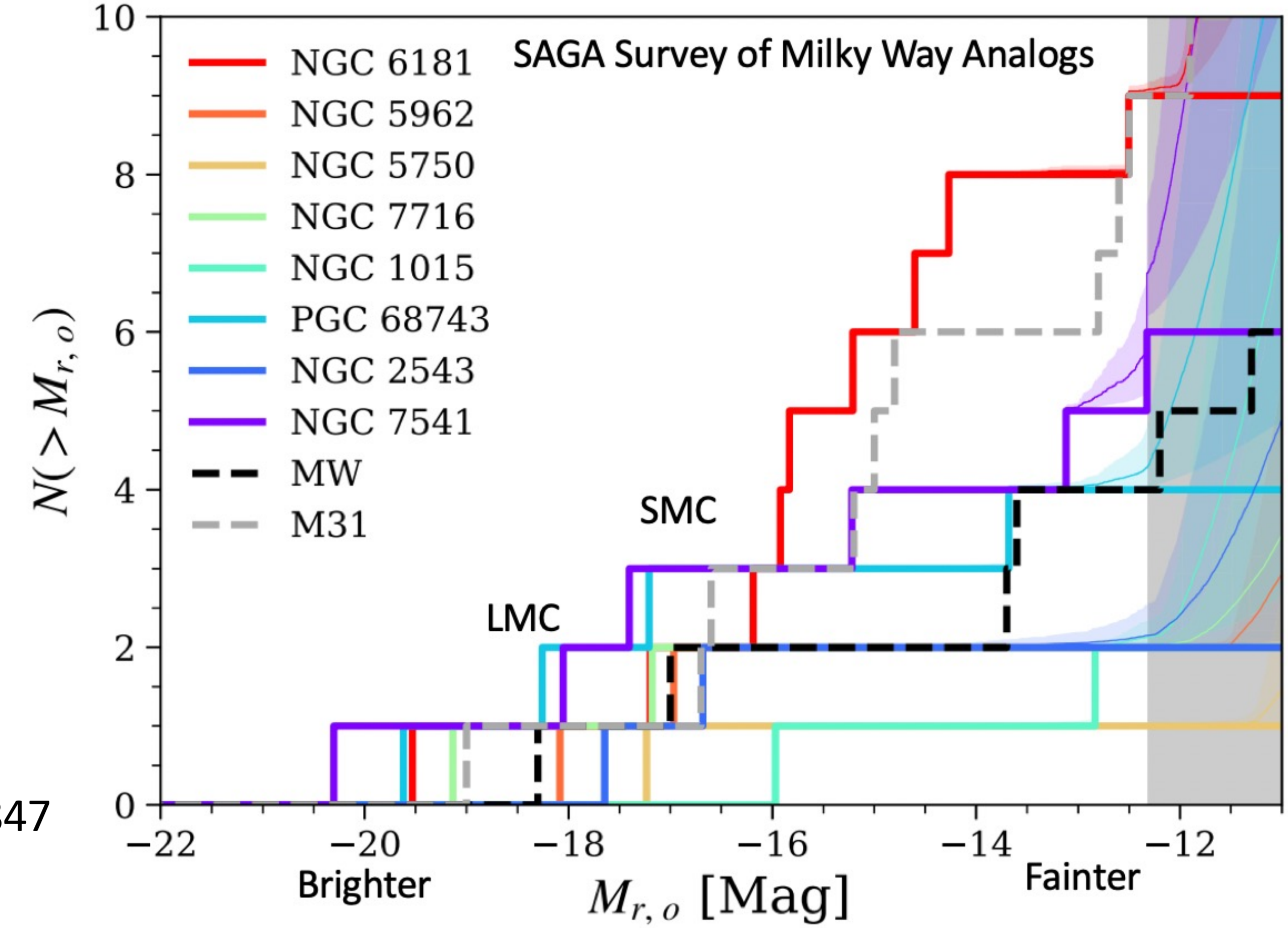
Geha+2017, ApJ , 847
SAGA Survey I

The SAGA Survey DR3 includes **378 satellites** identified across **101** MW-mass systems in the distance range of **25–40.75 Mpc**



SAGA Survey III
Yao-Yuan Mao et al 2024 *ApJ* **976**

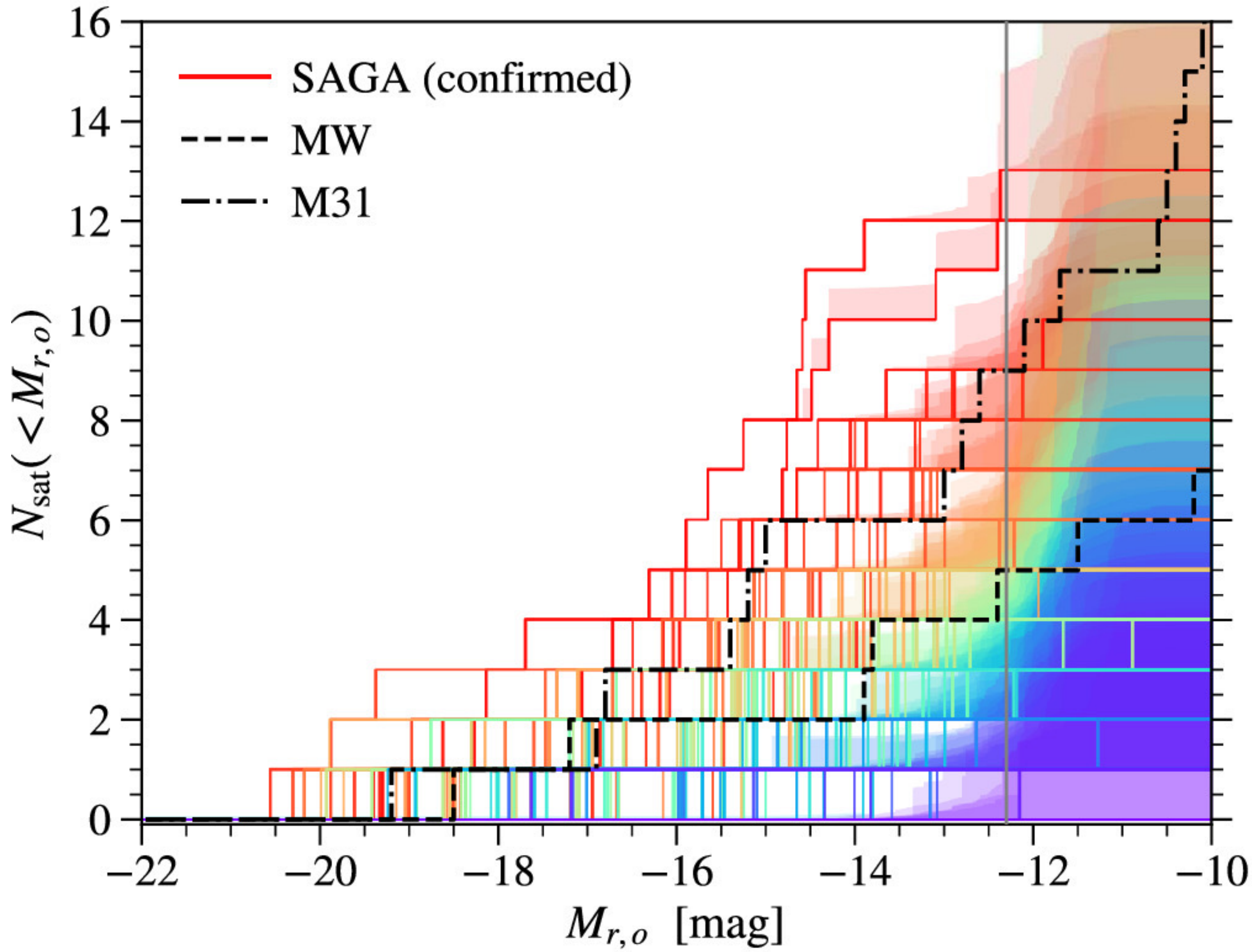
SAGA Survey: Luminosity Functions



Geha+2017, ApJ , 847
SAGA Survey I

“Perhaps the most remarkable aspect of the SAGA results is how this exhibit satellite systems around MW analogs solidifies the idea that our very own satellite system of the MW is just one “realization” from a diverse distribution.”

Mao+2021
ApJ 907
SAGA Survey II



SAGA Survey III Yao-Yuan Mao et al 2024 *ApJ* **976**