Galactic Accretion Histories beyond the Milky Way

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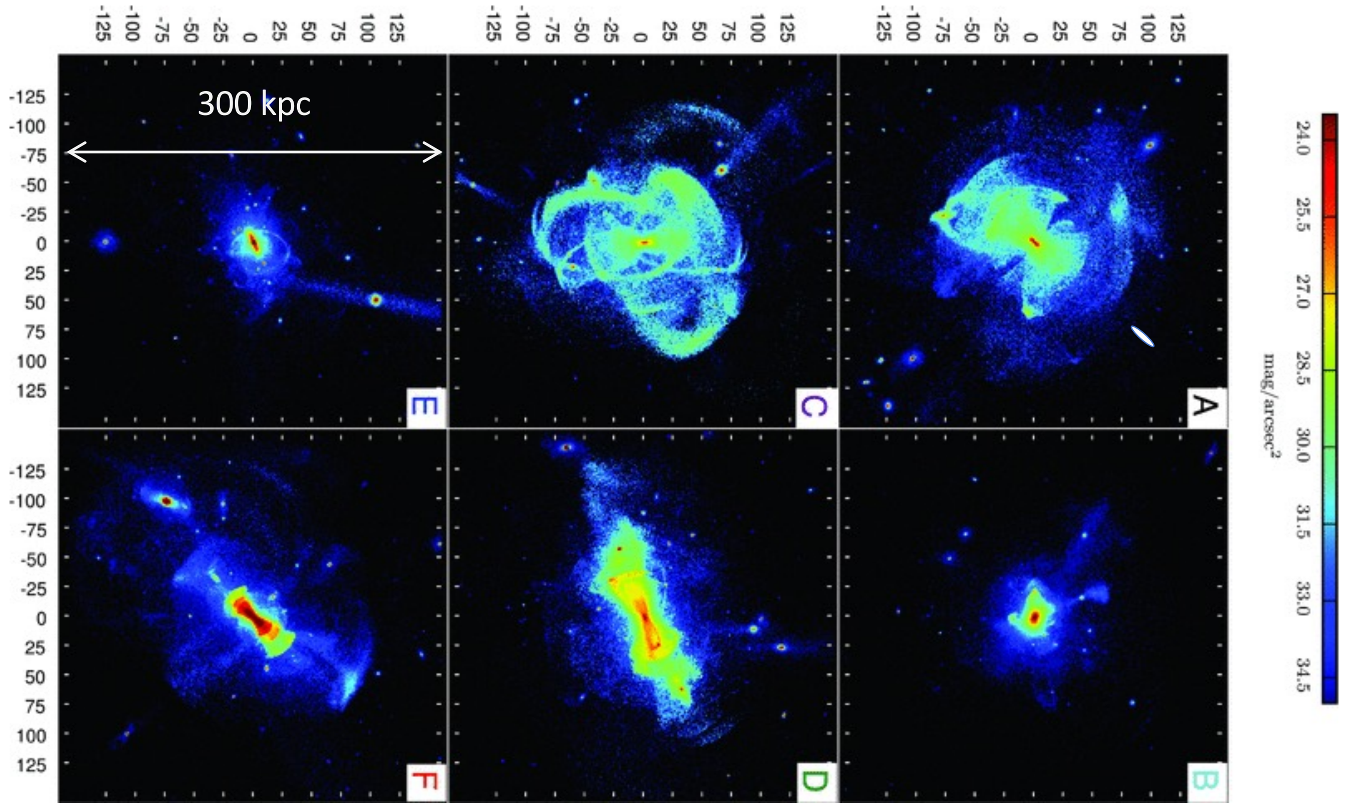
Galaxy Outskirts and Galactic Accretion Histories

Cooper et al. 2010,
Aquarius simulations



μ_V in mag/sq. arscec

μ_V~27 → 1% dark sky

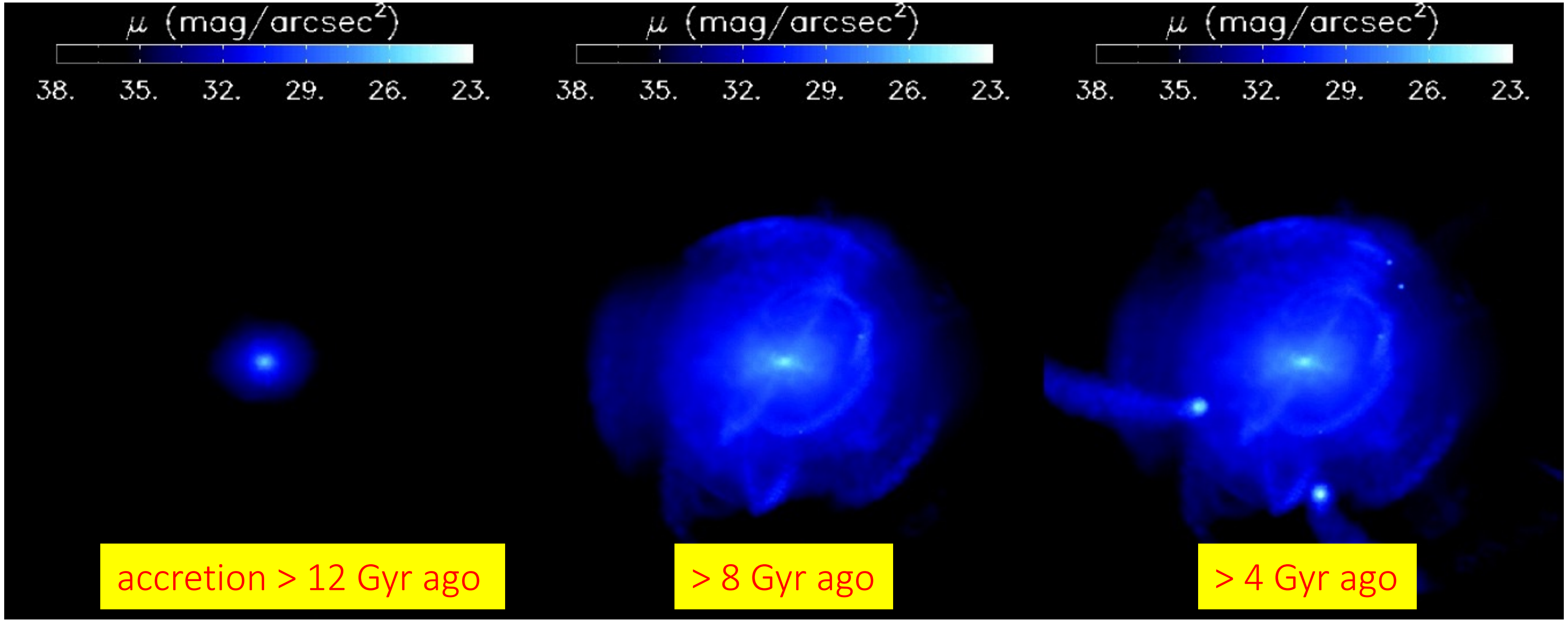
μ_V~29 → 0.1% dark sky

μ_V~32 → 0.01% dark sky

Expect lots of <u>low surface brightness</u> substructure in galaxy outskirts, the amount and morphology of which reflect the particular details of the host galaxy's accretion history).

Galaxy Outskirts and Galactic Accretion Histories

Bullock & Johnston 2005,
Johnston et al. 2008



Dynamical timescales long hence mixing takes place slowly – brightest features come from the most recent events. Observing the amount and types of substructure in galaxy outskirts can yield insight into what was accreted when etc.

Galaxy Outskirts and Galactic Accretion Histories

Summary of General Trends for Stellar Halo Interpretation

Observable Property	Interpretation	Implication
Fraction in substructure	Recent accretions	High fraction $\Rightarrow$ many recent events Low fraction $\Rightarrow$ few recent events
Scales in substructure	Luminosity function (and orbit type) of recent events	Large $\Rightarrow$ high-luminosity events Small $\Rightarrow$ low-luminosity events
Number of features	Number of recent events	Large $\Rightarrow$ many events Small $\Rightarrow$ few events
Morphology of substructure	Orbit distribution	Clouds/plumes/shells $\Rightarrow$ radial orbits Great circles $\Rightarrow$ circular orbit
[Fe/H]	Luminosity function	Metal-rich $\Rightarrow$ high-luminosity events Metal-poor $\Rightarrow$ low-luminosity events
[α/Fe]	Accretion epoch	α-rich $\Rightarrow$ early accretion epoch α-poor $\Rightarrow$ late accretion epoch

Caveat: Not all substructure is accreted!

Johnston et al. 2008; see also Hendel & Johnston 2015, Pillepich et al. 2014, Amorisco 2017 ++

Of course, Ken was onto all this a long time ago….!!

The Astrophysical Journal, 198:L93–L96, 1975 June 15

THE CORONA OF THE GIANT SPIRAL GALAXY NGC 253

K. C. Freeman, D. W. Carrick, and J. L. Craft
Mount Stromlo and Siding Spring Observatory, Research School of Physical Sciences, Australian National University
Received 1974 December 16; revised 1975 March 10

The Astronomical Journal, 124:3144–3156, 2002 December

A YOUNG BLUE TIDAL STREAM IN NGC 5128

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Received 2002 June 24; accepted 2002 August 20

The Astrophysical Journal, 629:239–249, 2005 August 10

NGC 300: AN EXTREMELY FAINT, OUTER STELLAR DISK OBSERVED TO 10 SCALE LENGTHS

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Received 2004 November 11; accepted 2005 March 22

The Astrophysical Journal, 697:361–372, 2009 May 20 doi:10.1088/0004-637X/697/1/361

THE ABUNDANCE GRADIENT IN THE EXTREMELY FAINT OUTER DISK OF NGC 300

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Received 2008 July 10; accepted 2009 March 5; published 2009 May 1

The Astrophysical Journal, 697:361–372, 2009 May 20 doi:10.1088/0004-637X/697/1/361
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[1] Astrophysics, Department of Physics, Keble Road, University of Oxford, Oxford OX1 3RH, UK; vlajic@astro.ox.ac.uk
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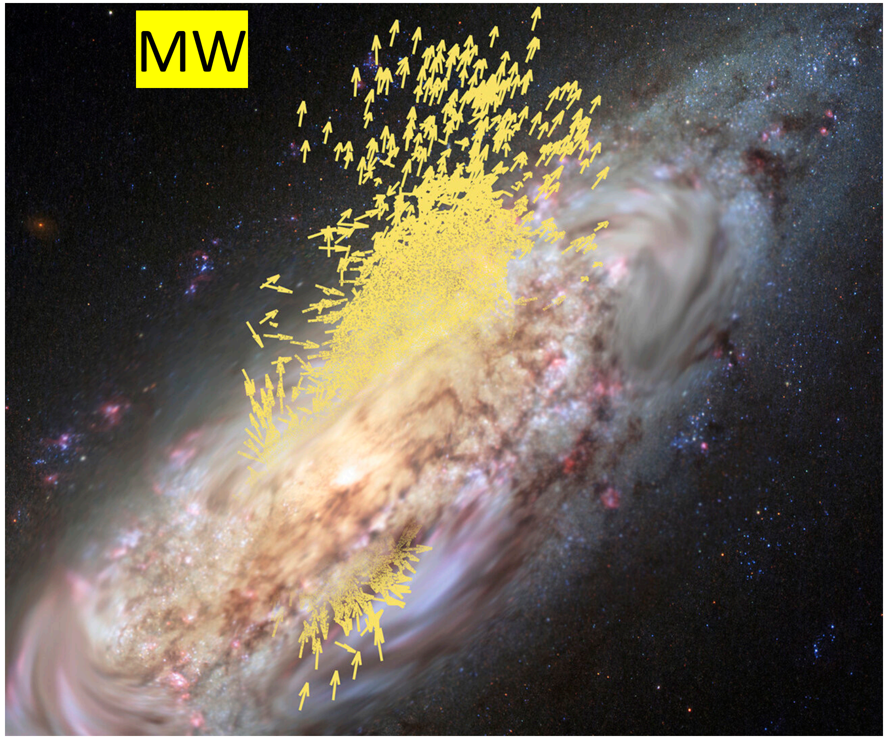
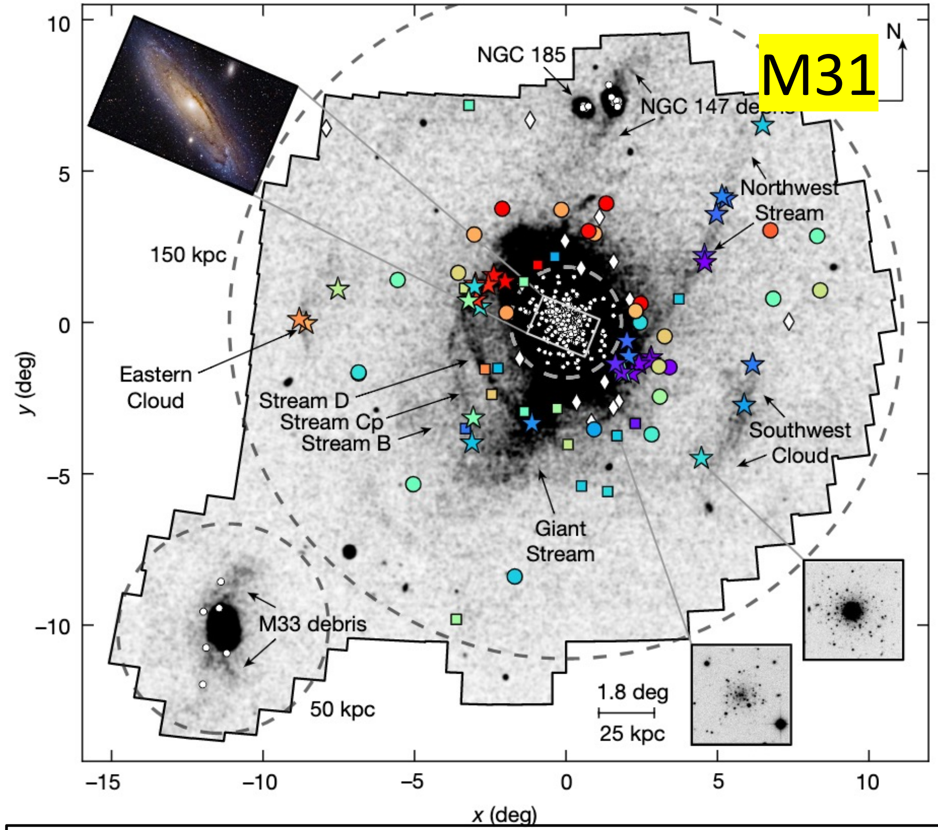
[3] Mount Stromlo Observatory, Private Bag, Woden, ACT 2611, Australia
Received 2008 July 10; accepted 2009 March 5; published 2009 May 1

What have we learned so far?

ESA PR



MW had a significant event ~10 Gyr ago when it merged with a similar-sized object and a rather quiet history ever since..



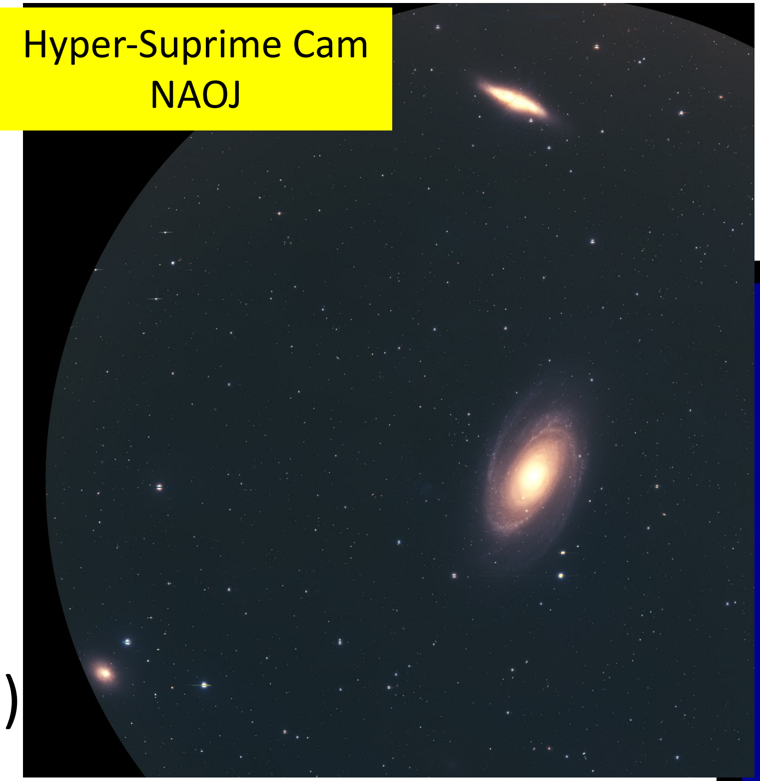
Mackey et al. Nature 2019

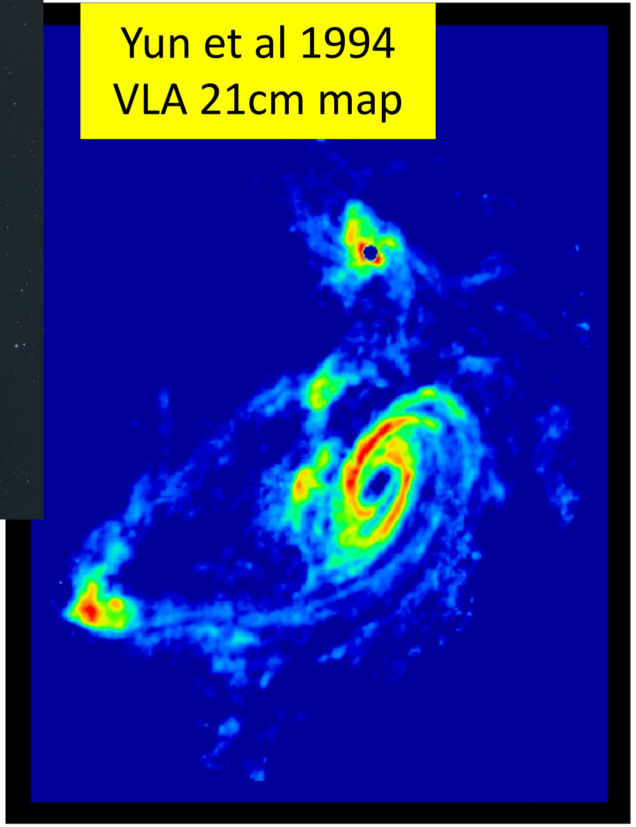
M31 had a significant event ~2-3 Gyr ago when it (likely) experienced 1:4-10 merger. May have had earlier events too.

Moving Outwards: The M81 Group at D=3.6 Mpc

M81/M82/NGC3077 dominate this nearby interacting group (40+ members, R_{vir}~230 kpc, M_{Group}~2-10 x 10^{12} $M_{\odot}$).

Remarkable HI filamentary structure connects all galaxies (~1.5×10^{10} $M_{\odot}$, roughly half in galaxies; (Chynoweth et al. 2008)





Early modelling suggested interaction ~200-300 Myr ago, which agrees with starburst ages in M82 and NGC3077.

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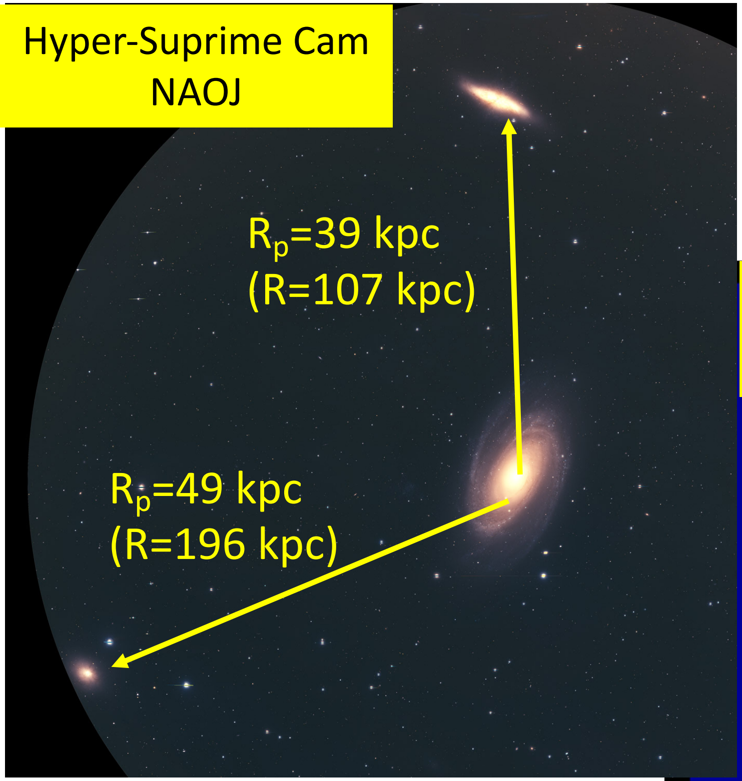

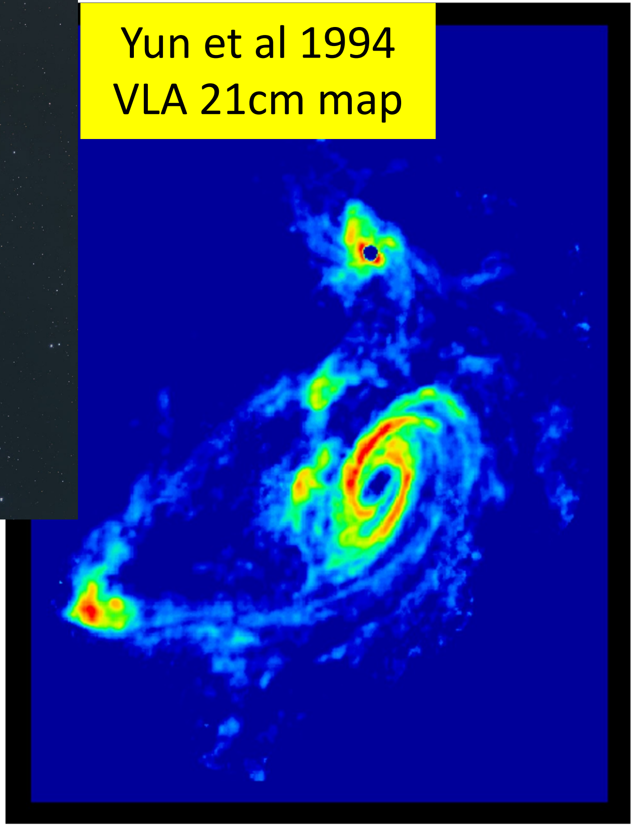

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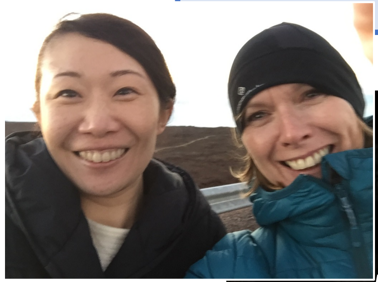
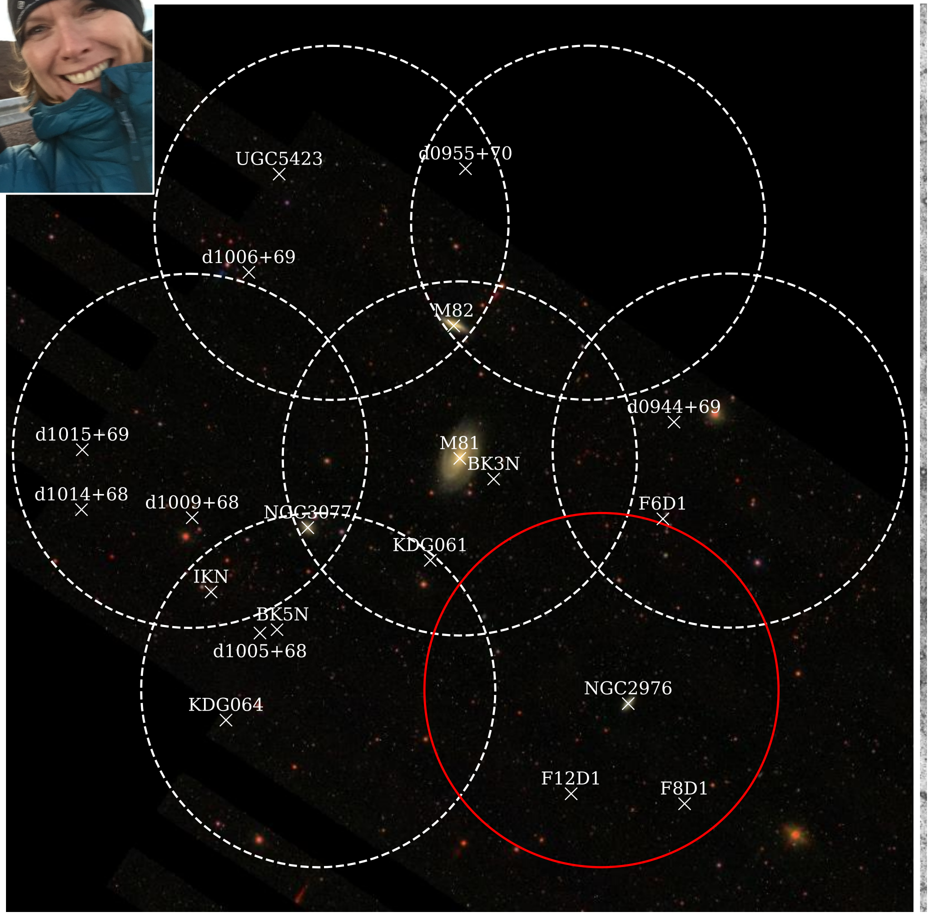
The Subaru HSC Survey of the M81 Group
PI Sakurako Okamoto





~4 degrees = 240 kpc

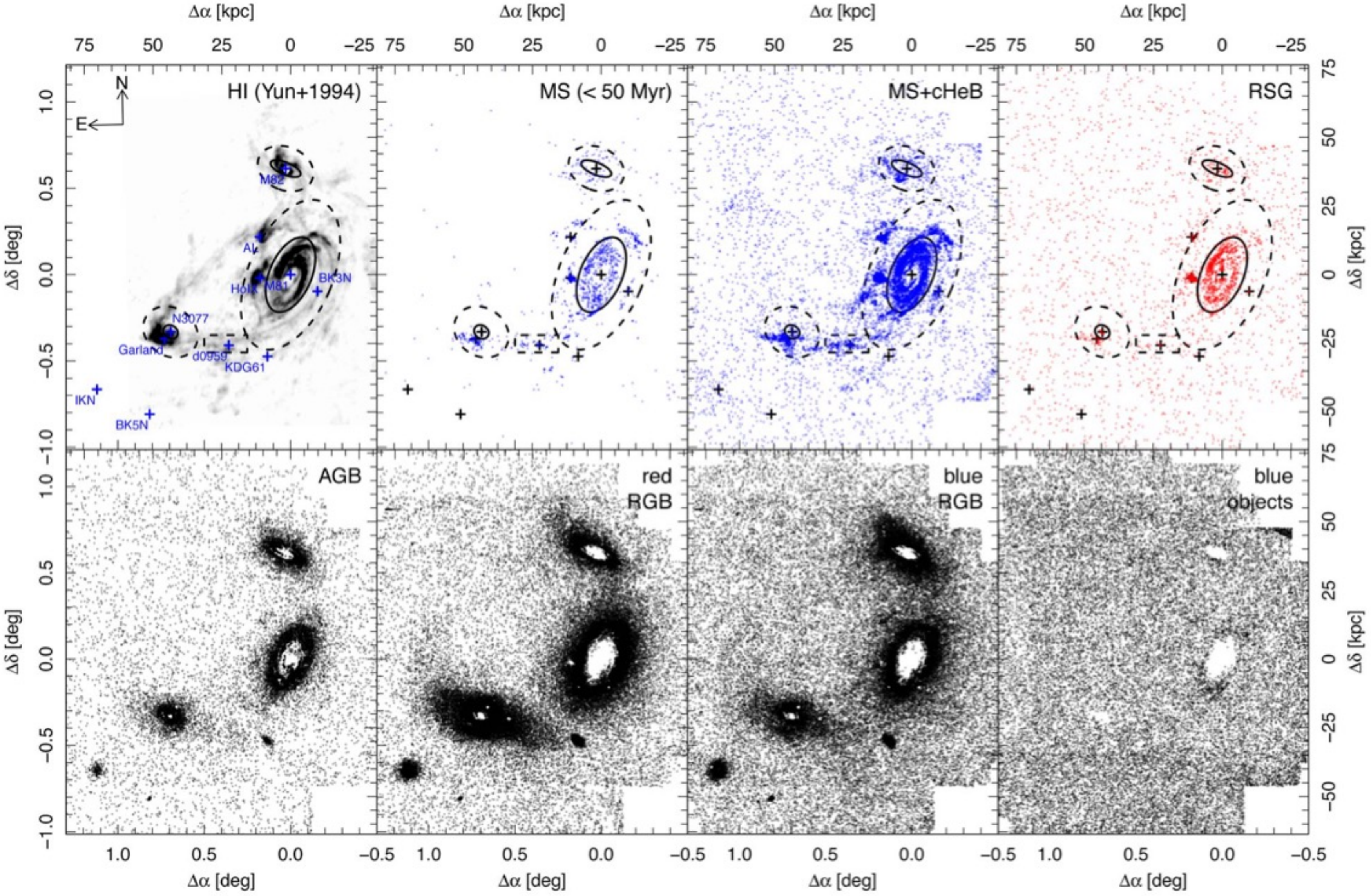
Survey of individual red giant branch (RGB) stars over ~12 sq. deg (7 HSC pointings) 2015-2019, reaching 120 kpc from M81.

Typically 4500s in g and 6300s in i per field, reaches >2 mag below TRGB in M81. IQ ~0.6 – 1.0” [g~27.5, i~27].

Covers 4 prominent galaxies (M81, M82, N3077, N2976) and > 40 dwarfs/dwarf candidates (including tidal dwarfs).

Mapping the M81 Group with Subaru/HSC

Okamoto, Arimoto, Ferguson et al 2015



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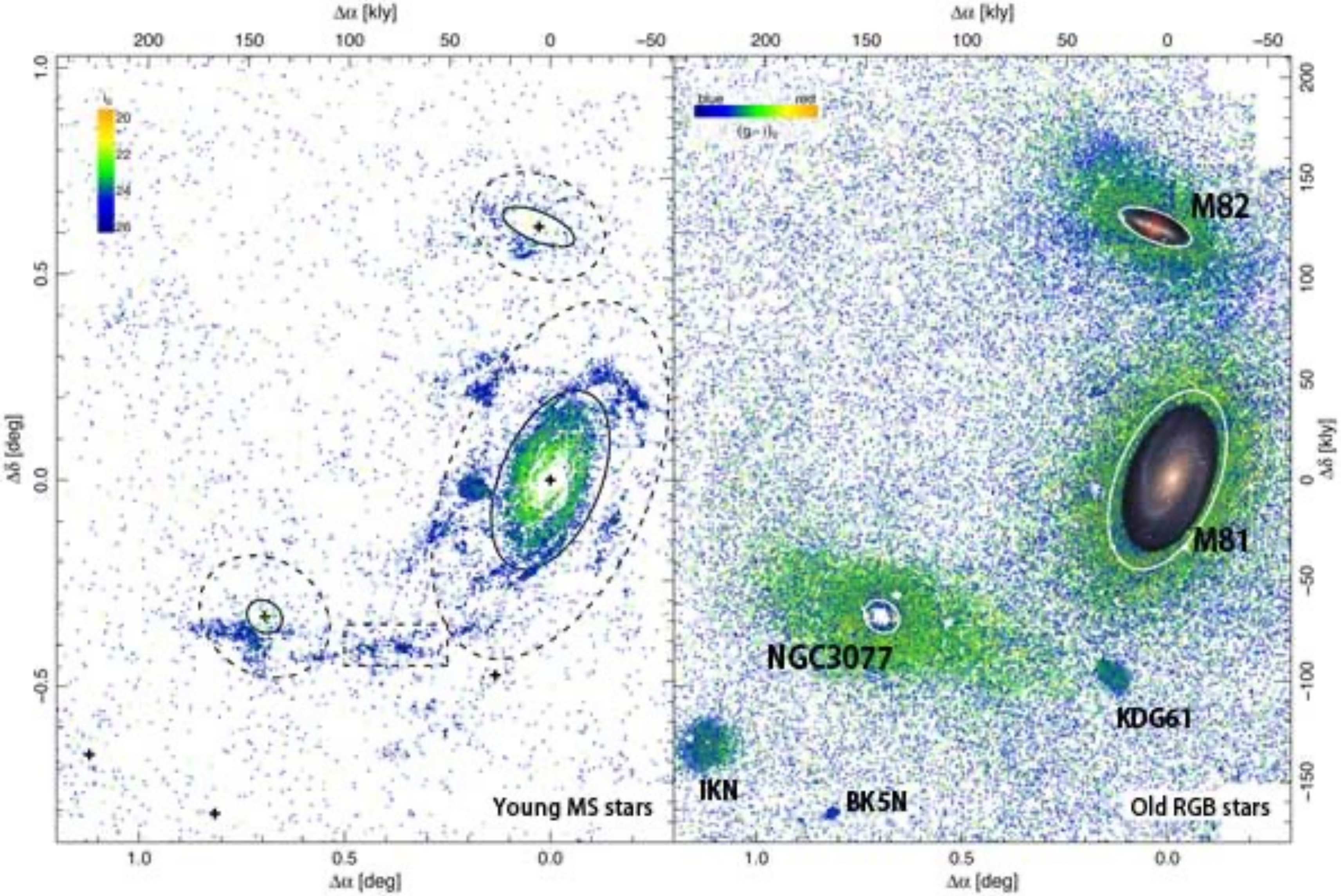
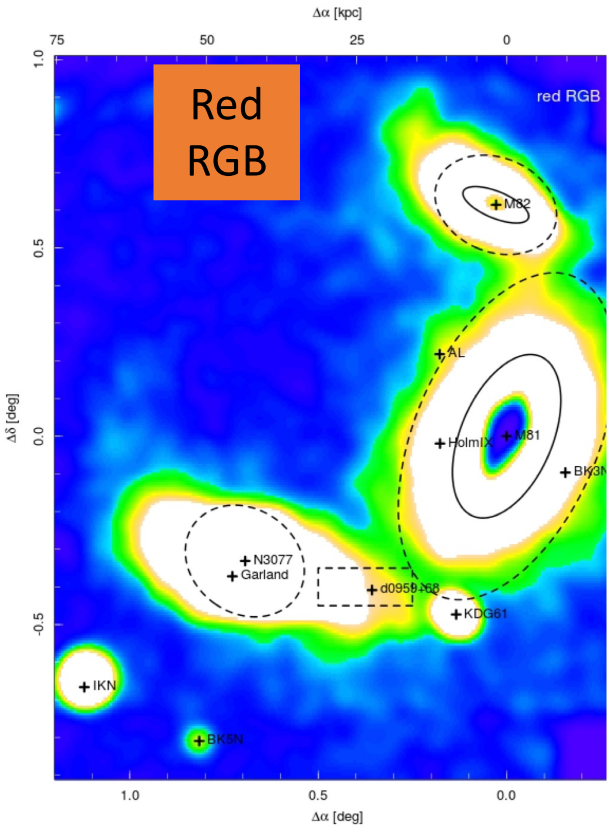
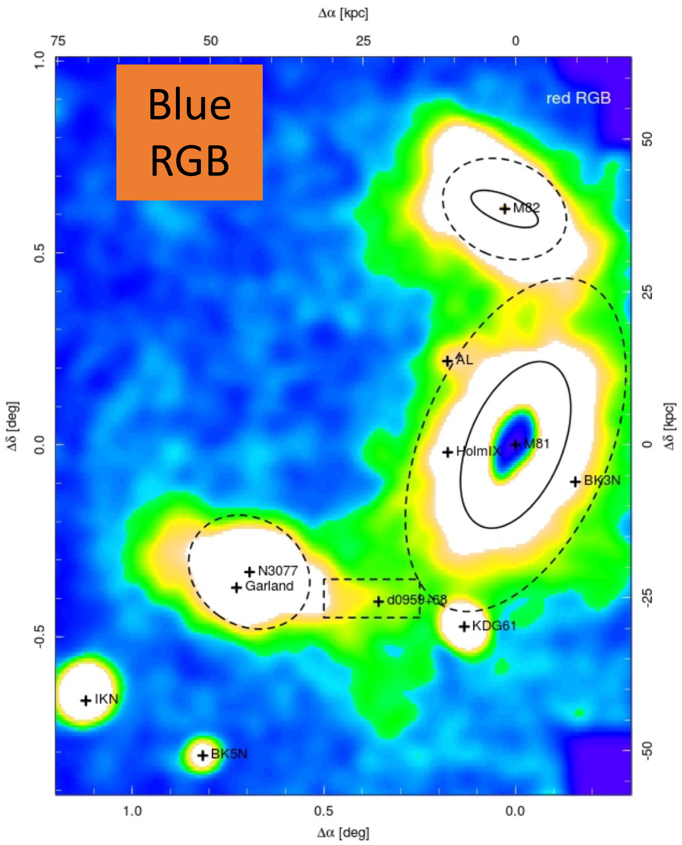


Mapping the M81 Group with Subaru/HSC

Okamoto, Arimoto, Ferguson et al 2015
See also Smercina et al. 2020

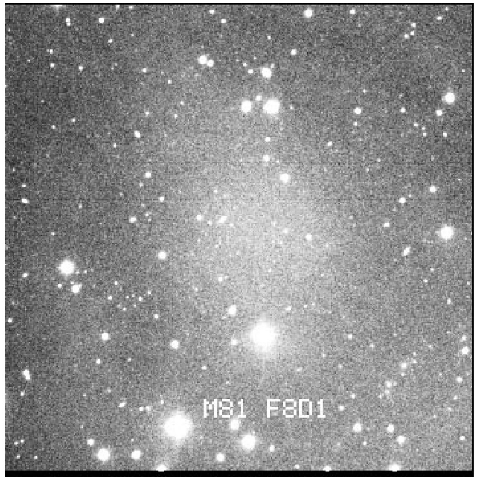


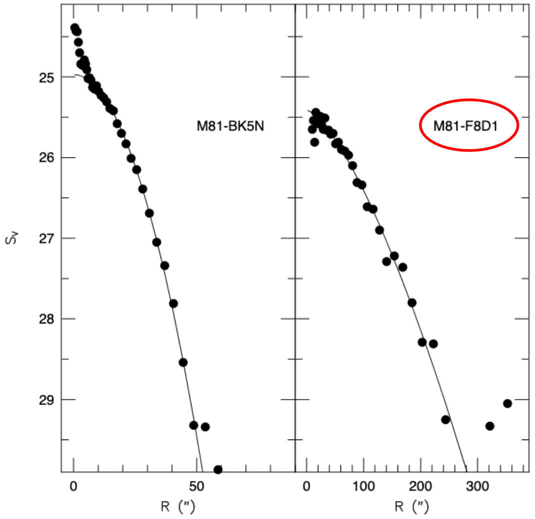


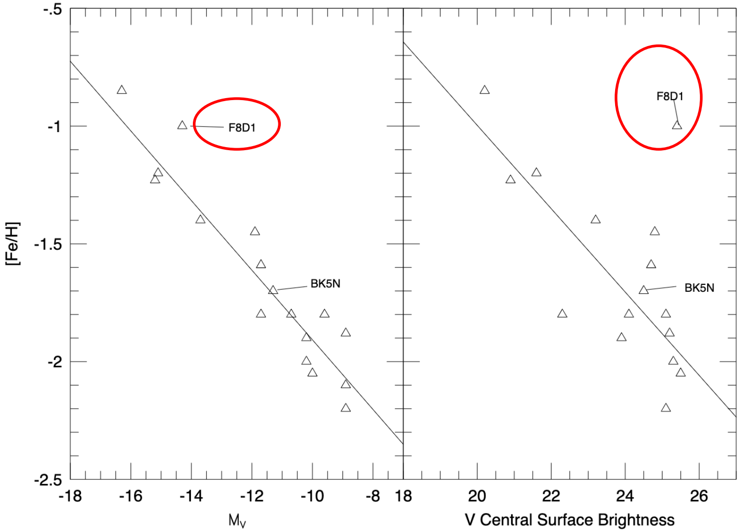
“Other than the optical filaments seen along the minor axis of M82, there is little hint of unusual activities in these galaxies in stellar light”, Yun et al. 1994 Nature !!!

New Views of the Peculiar Dwarf Galaxy F8D1

Caldwell et al. (1998)



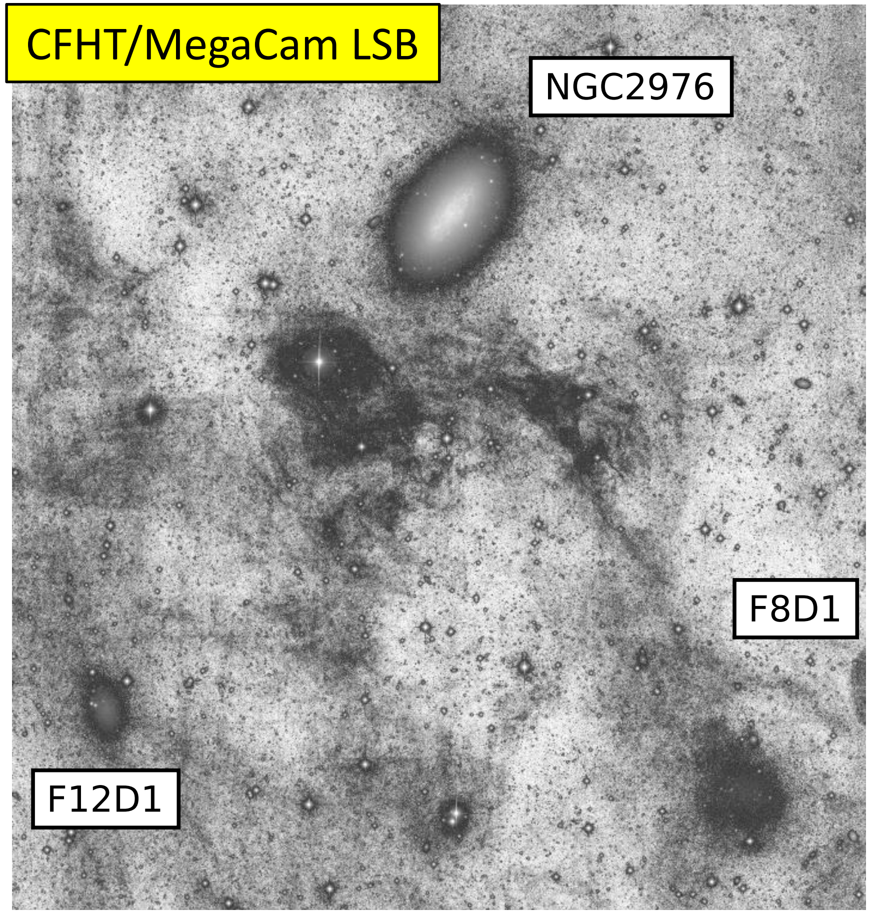




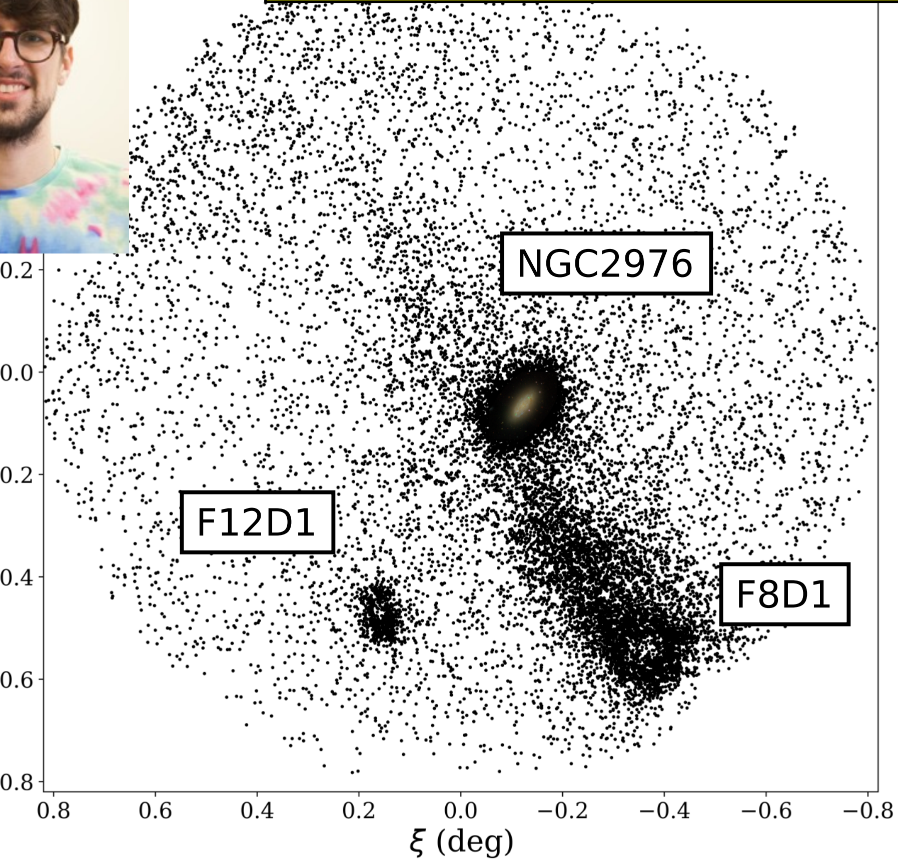
Discovered in a CCD survey by Caldwell et al (1998), who followed up with ground-based data and HST/WFPC2 and confirmed via tip of the RGB to lie at distance of M81 Group.

Very large (R_{eff}~2.5 kpc) and low surface brightness (μ_V~25.5 mag/□") for its luminosity (M_V~-14) → a bona fide "ultra-diffuse galaxy"

New Views of the Peculiar Dwarf Galaxy F8D1

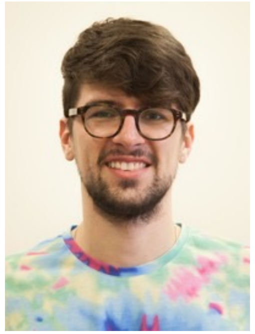


Zemaitis et al 2022, submitted

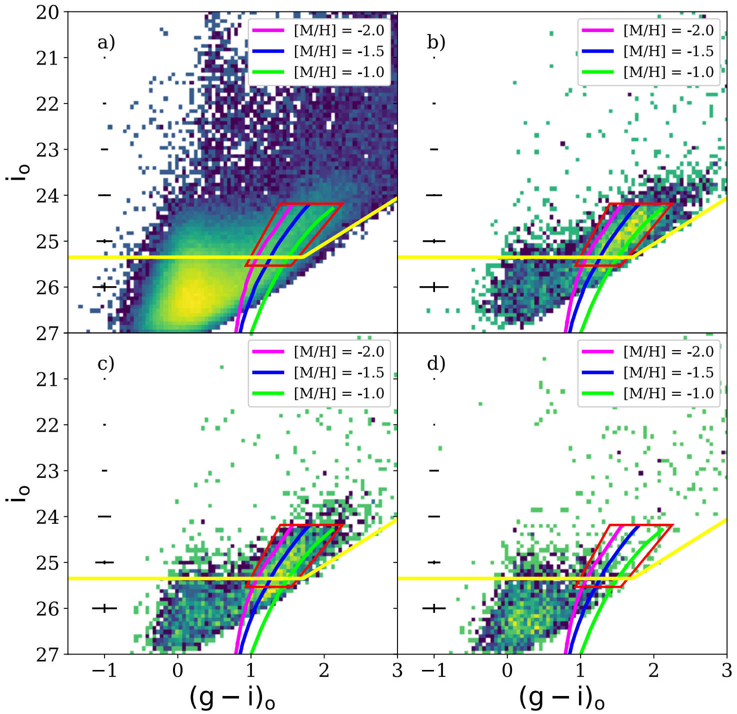


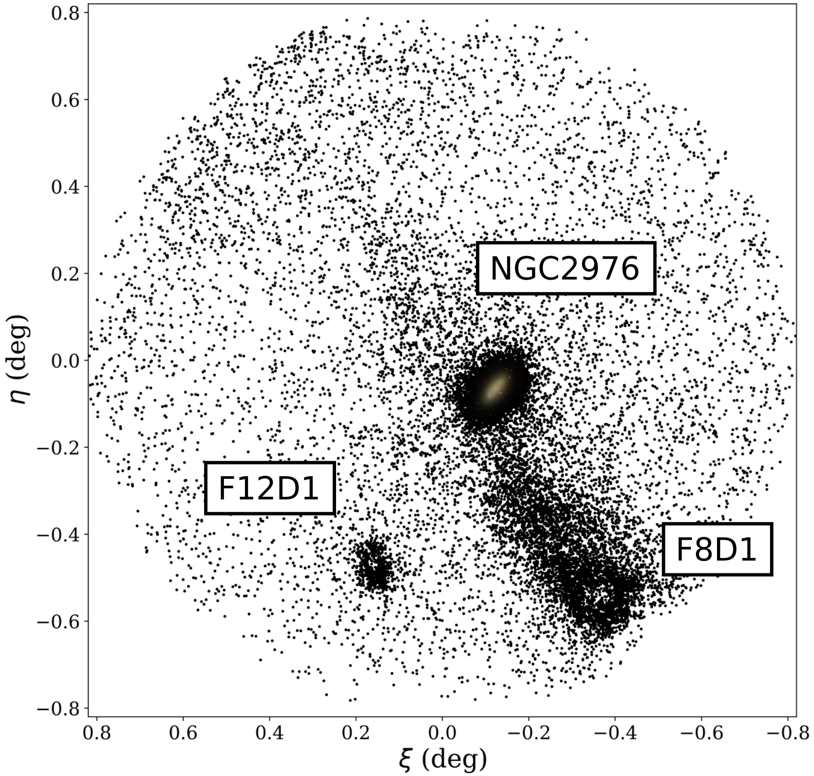
Huge (> 60 kpc long in projection) stellar stream discovered emanating from F8D1.
Seen on both sides of NGC2976 which lies 170 kpc in front.

New Views of the Peculiar Dwarf Galaxy F8D1



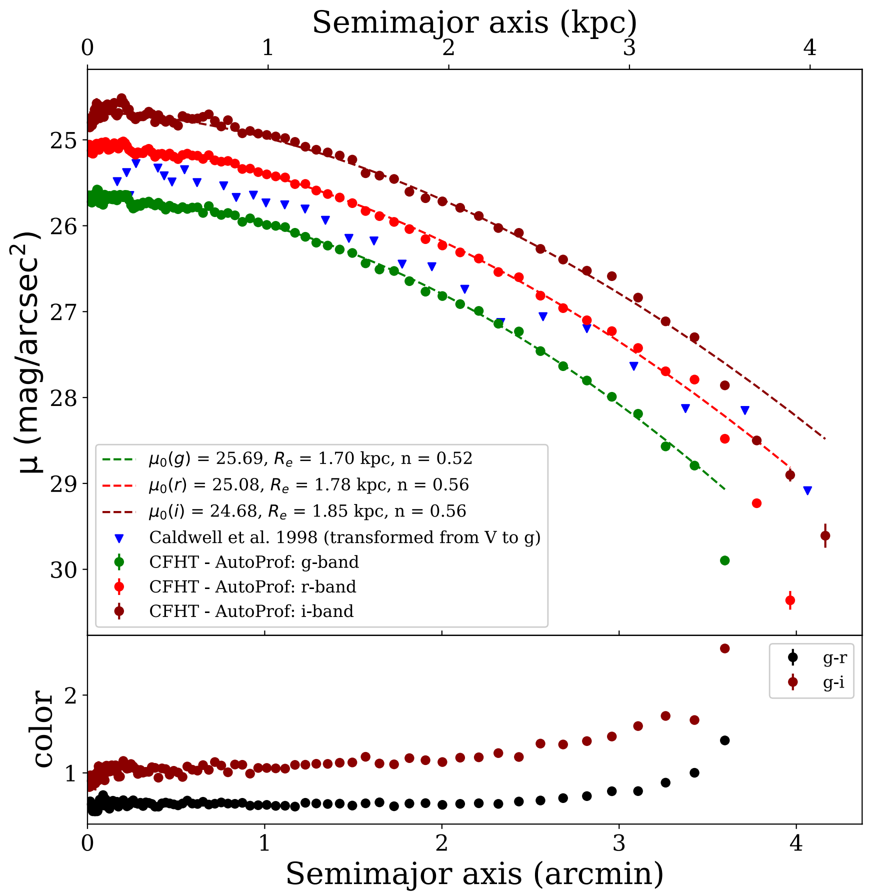
Zemaitis et al 2022, submitted

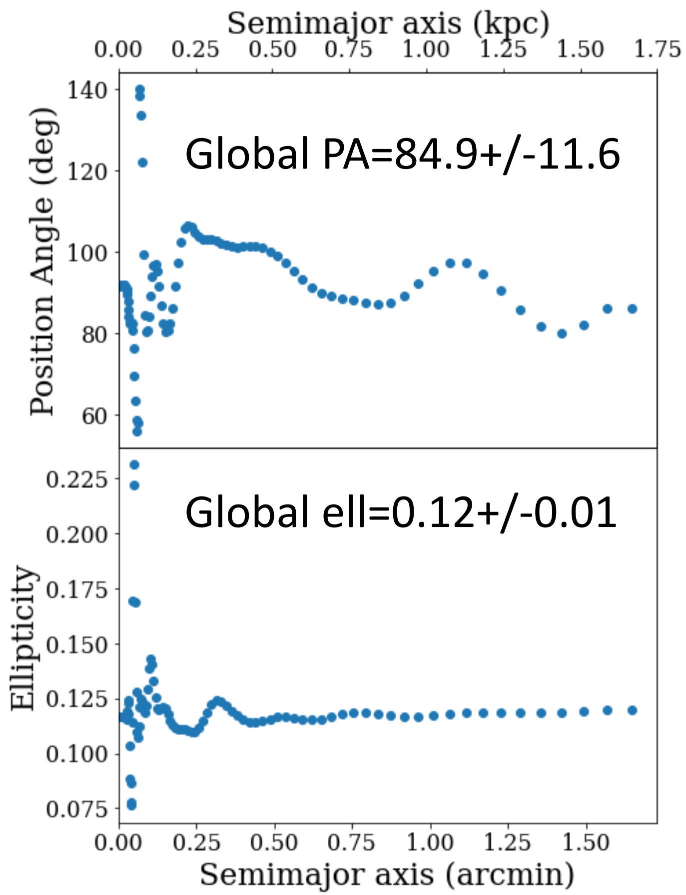




Luminosity in visible stream is 7.2 x 10^6 $L_{\odot}$, or M_g~-12. If a symmetric feature exists on the other side of the galaxy, we calculate the stream accounts for 30 – 36% of F8D1's present-day stellar luminosity.

New Views of the Peculiar Dwarf Galaxy F8D1





Zemaitis et al 2022, submitted

Structural measurements revisited using CFHT-LSB data. In spite the highly disrupted state, F8D1 looks regular in its inner regions – radial profile, colour gradient, ellipticity, PA.

Implications of F8D1's Highly-Disrupted State I. UDGs

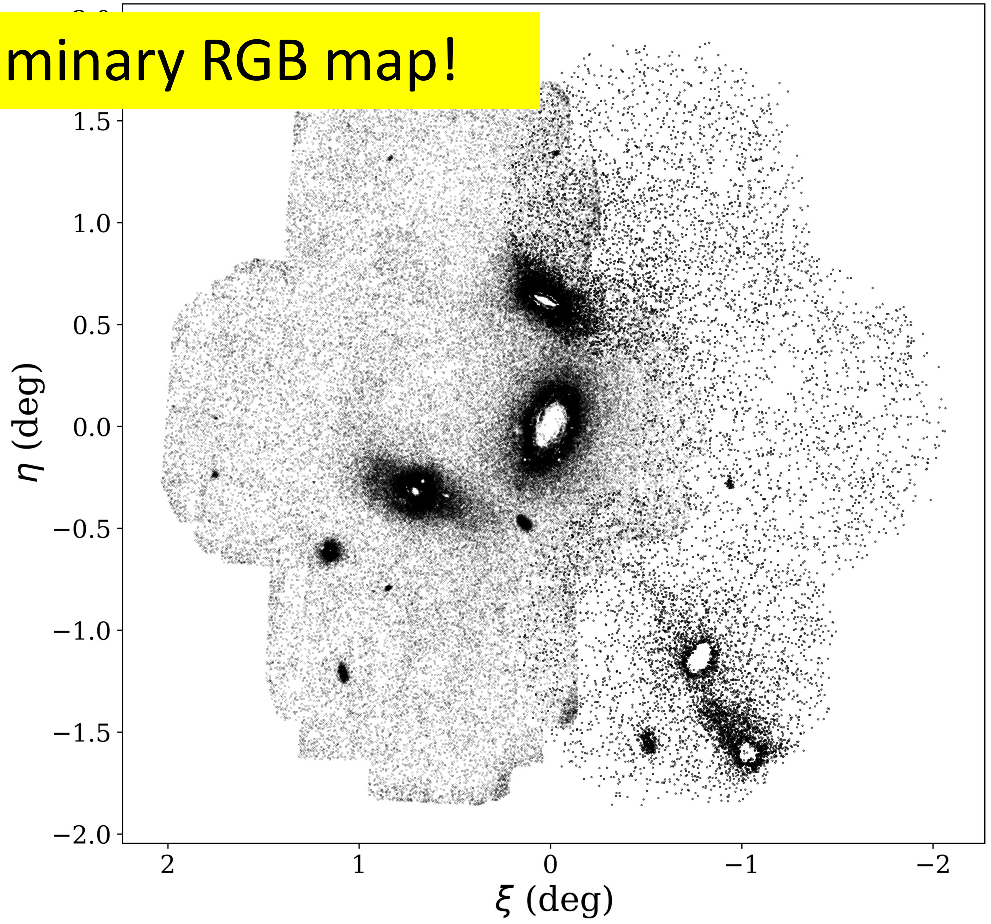
F8D1 is the nearest *bona fide* UDG and the only one that can be studied over wide areas with resolved stars. The stream has a $<\mu_V>$ ~32 mag/□", <u>far fainter than any integrated light studies of other UDGs.</u>

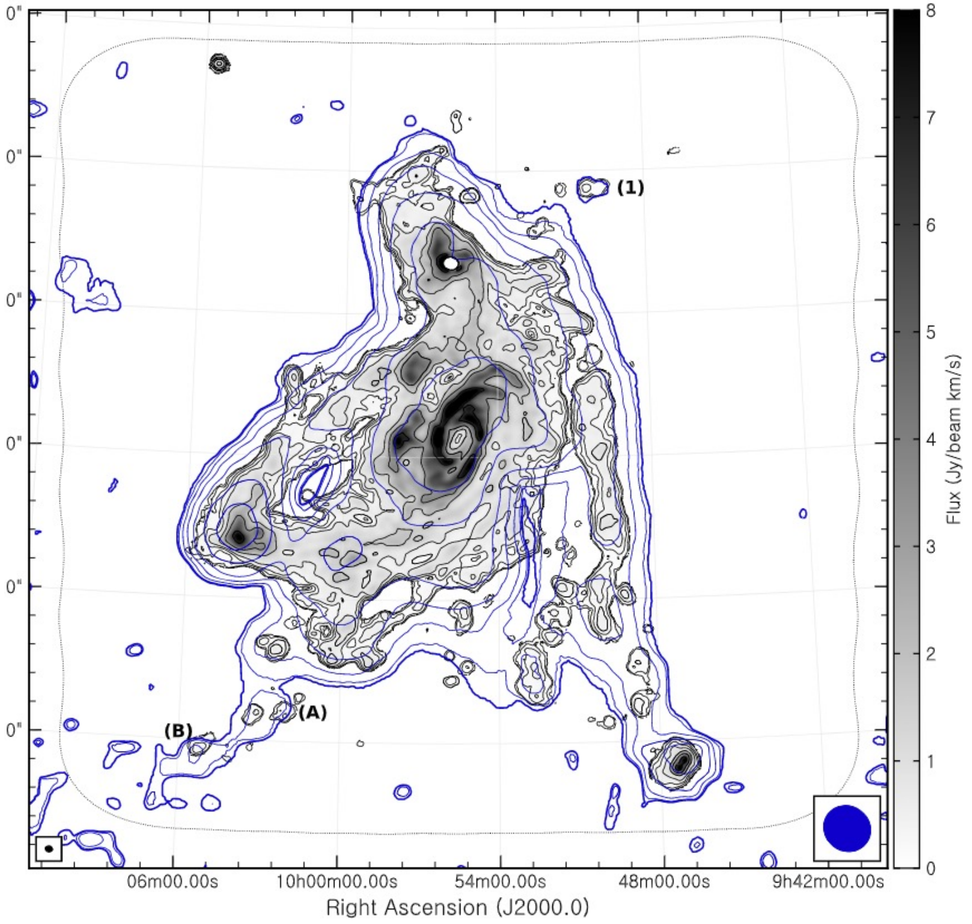
Could (some/many/all?) UDGs be explained as highly-stripped dwarfs? Many UDGs have been identified in cluster environments, which makes this idea at least plausible (Carleton et al. 2019). Others are at least near in projection to a massive host.

Some UDGs have gained fame through apparent dearth/lack of dark matter (e.g. van Dokkum 2018 + many others). A "dynamical" mass measurement for F8D1 would be very interesting as a comparison!

Implications of F8D1's Highly-Disrupted State II. Interaction History of the M81 Group

Preliminary RGB map!





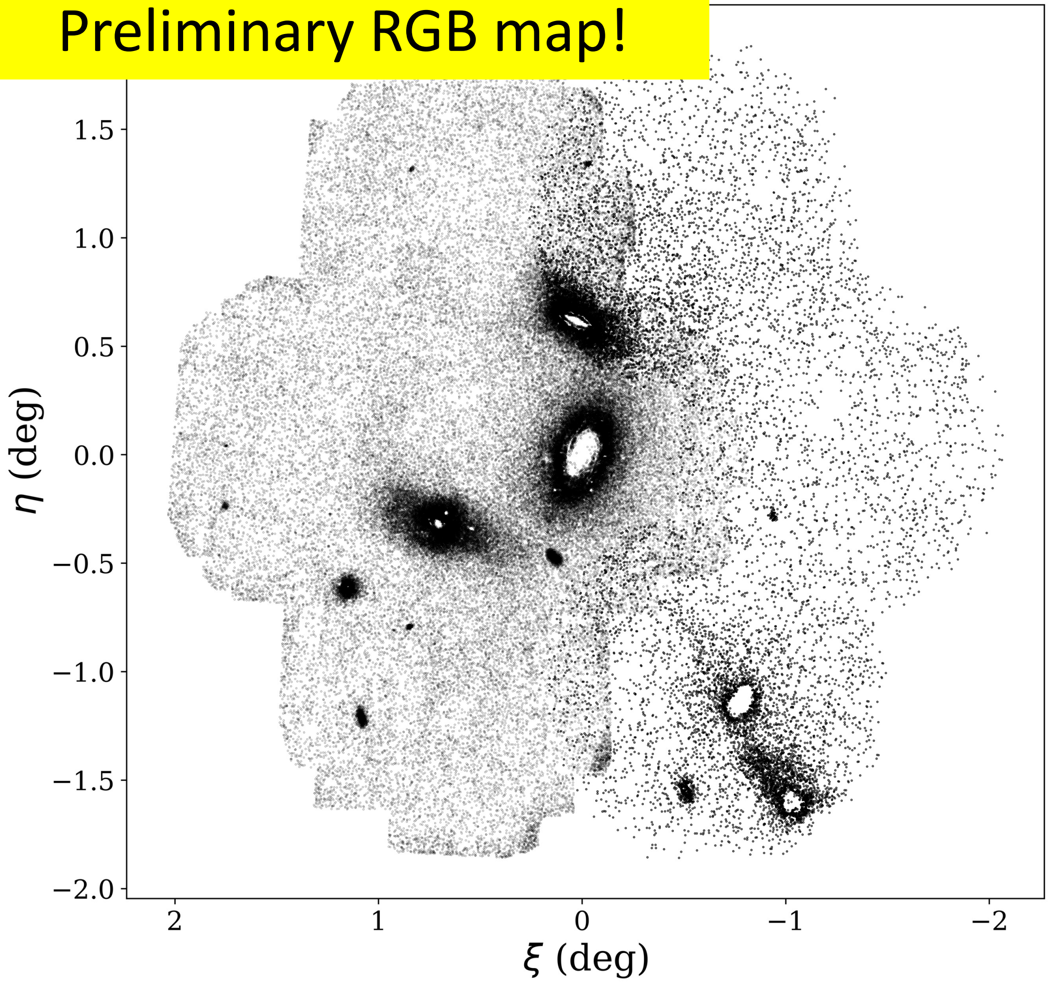
de Blok, Walter, Ferguson et al 2018

Chynoweth et al. 2008

Note HI tidal arm which points towards N2976 and F8D1; N2976 HI asymmetric.

Implications of F8D1's Highly-Disrupted State II. Interaction History of the M81 Group

Preliminary RGB map!



M81-F8D1 3D distance ~130 kpc
N2976-F8D1 3D distance ~175 kpc

Ratio of tidal forces:

$$\frac{F_{N2976}}{F_{M81}} \approx \left(\frac{M_{N2976}}{M_{M81}}\right)\left(\frac{130}{175}\right)^3$$

If N2976/M81 mass ratio ~ 0.1

$$\frac{F_{N2976}}{F_{M81}} \approx 0.04$$

→ M81 main perturber at present. F8D1 likely to have had at least one pericentric passage.

Implications of F8D1's Highly-Disrupted State II. Interaction History of the M81 Group

Long-standing puzzle why M81 Group even exists (e.g. Yun et al. 1994) → why have the three inner galaxies not merged yet?

Oehm et al. (2017) revisit this problem accounting for dynamical friction and rule out the current configuration of the system being long-lived. Argue that at least one or both of M82 and NGC 3077 were until recently unbound and that we are observing the M81 Group at a special time, with a merger set to take place within the next 1–2 Gyr. (or: these galaxies have little dark matter….)

It will be interesting to explore if future modelling efforts that include F8D1 change these conclusions. Also very urgent to measure a radial velocity for F8D1.

Establishing Galactic Accretion Histories: The (Near) Future

Our M81 HSC Survey work continues – full stellar halo modelling of all systems within footprint, search for new satellites. Map F8D1's stream on the other side. Some of this work is Rokas Zemaitis's PhD thesis (2023).

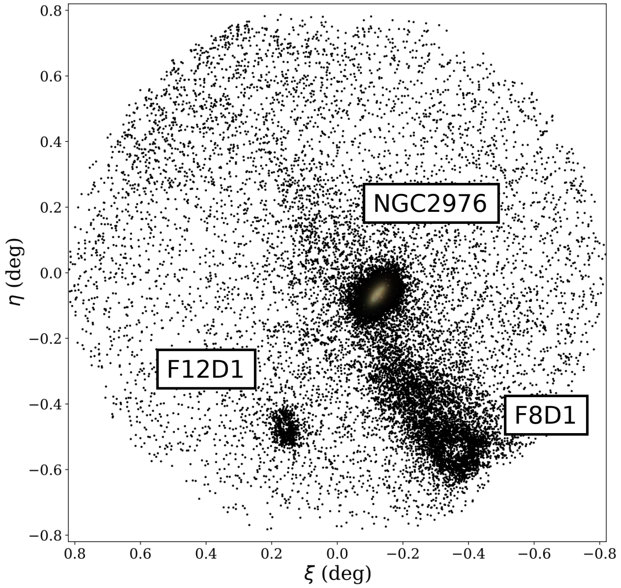
Recently completed deep u-band survey of the central 8 sq. deg of the M81 HSC footprint with CFHT/MegaCam. Will allow sensitive search for GCs down to 1.5 mag below GC LF peak out to ~130 kpc from M81, including in and around all satellites. Will provide a means to estimate dynamical masses.

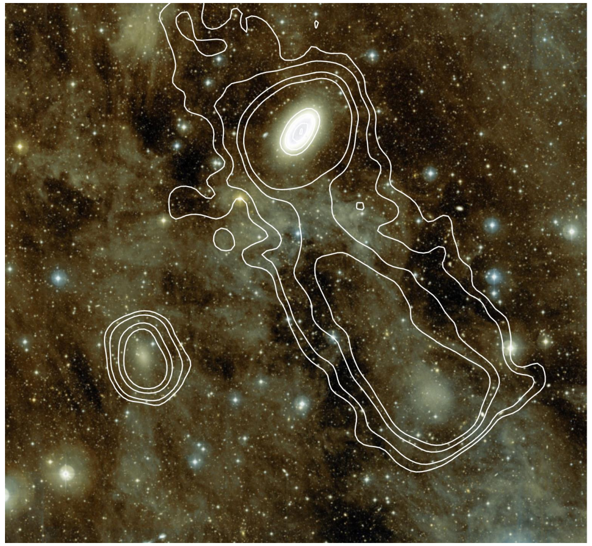
Ongoing Subaru Near-Field Cosmology Survey (PI Okamoto) – survey of 6 other Local Volume ($D < 6.5$ Mpc) galaxies with 1-4 Subaru/HSC pointings, reaching ~2 mags below the tip of the RGB (matching depth of M81 Group survey).

Summary

<u>Wide-field mapping of resolved stars in galaxy peripheries</u> is the gold standard for stellar halo analyses. The properties of these components reflect the history of mergers and accretions experienced by the host.

To understand whether the MW or M31 is more representative of disc population, these surveys must be pushed beyond the Local Group: challenging but now feasible.





Zemaitis et al 2022, submitted.

We have conducted an ambitious survey of the cirrus-affected M81 Group, covering ~10 sq. degrees with Subaru/HSC (first results: Okamoto et al. 2015, 2019). A new result is the <u>discovery of a giant (>60 kpc) low surface brightness (~32 mag sq. arcsec) tidal stream coming from F8D1</u>, a peculiar satellite of M81 and the closest bona fide ultra-diffuse galaxy.