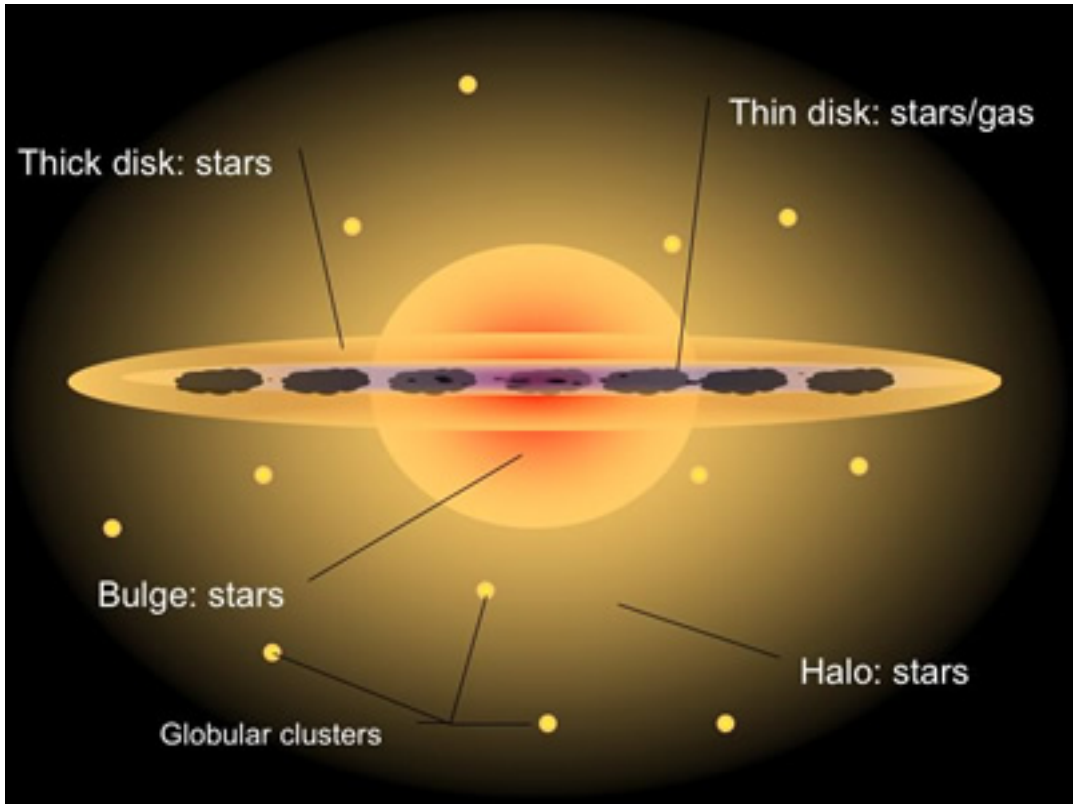
Rethinking the μ-merger Narrative

CARNEGIE SCIENCE | The Carnegie Observatories

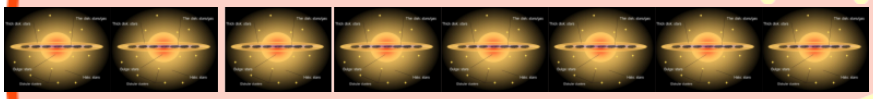
Rachael L. Beaton

Confession: I don't study galaxies.



If this is how you (Google) defines a galaxy.

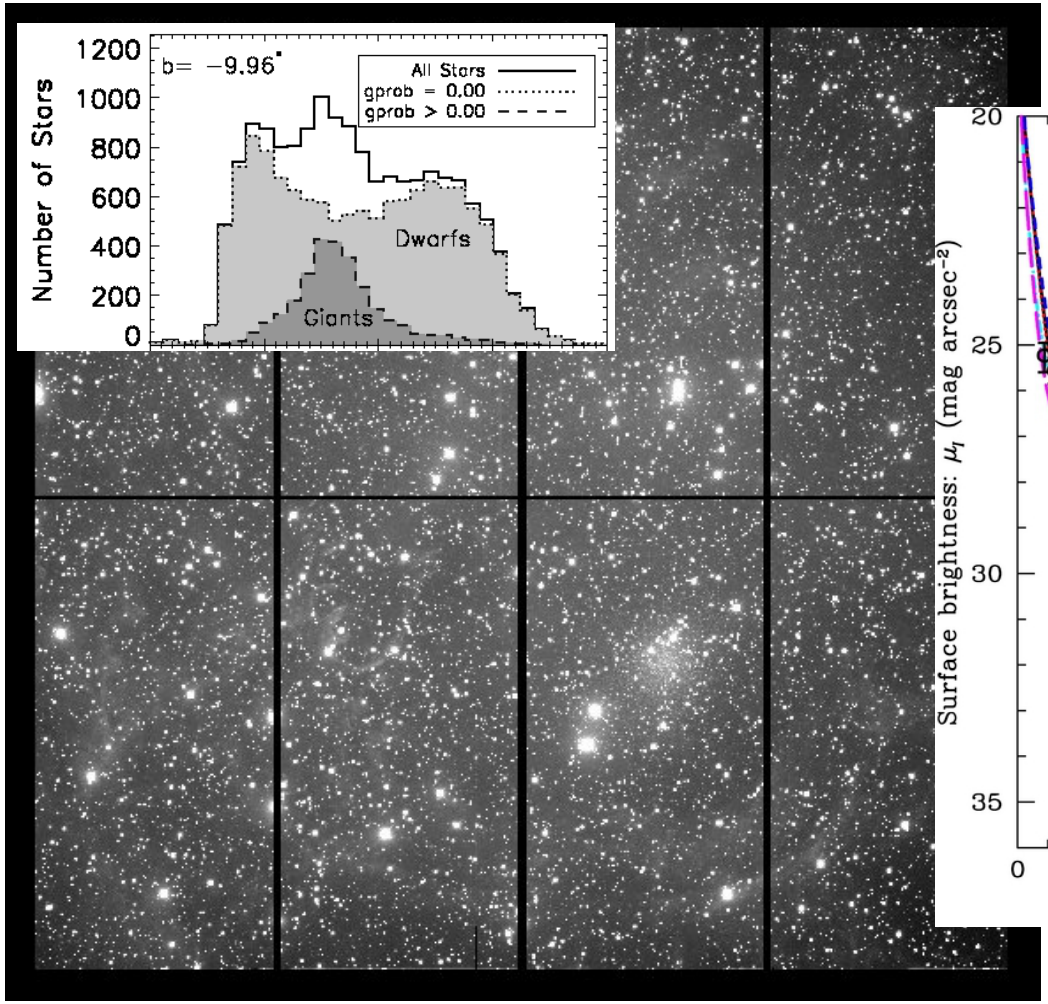
I study their haloes

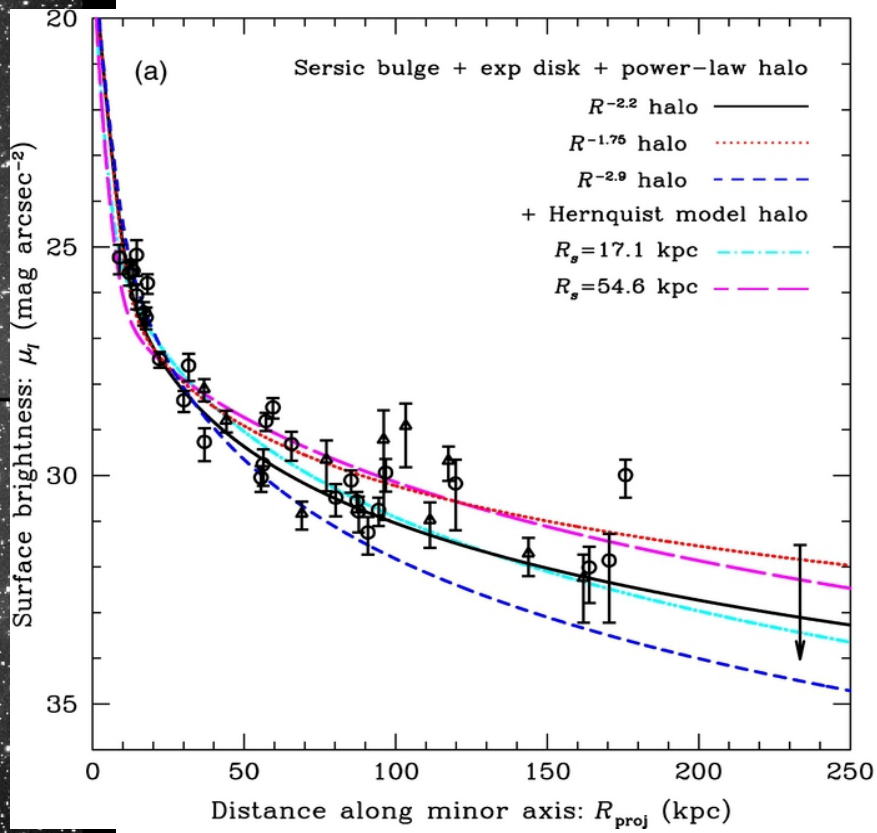


40 kpc

R_{virial} = 300 kpc
For a MW like Galaxy

And I count individual stars

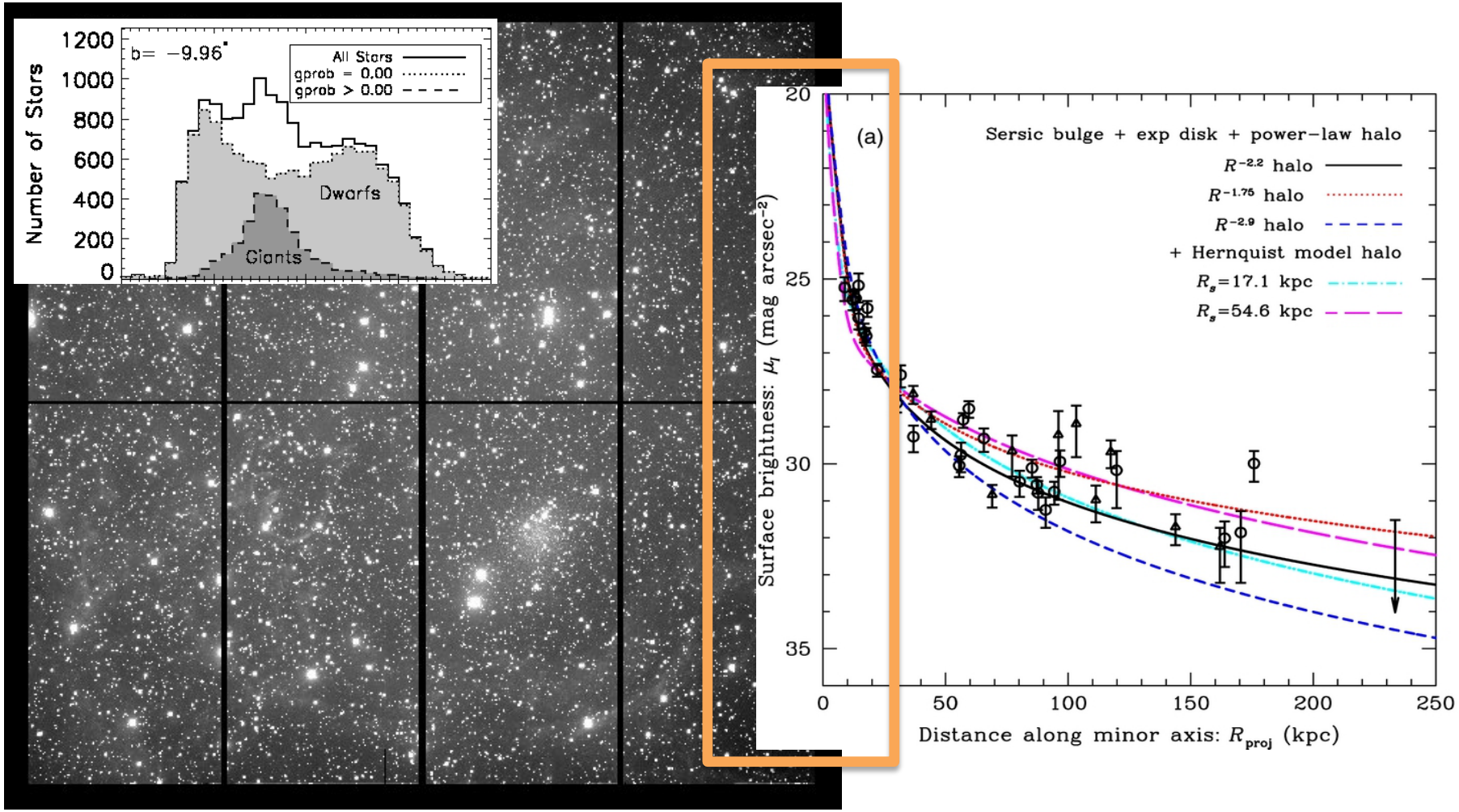




R~180 kpc in M31 Stellar Halo
Probably … two dozen M31 stars here.

Gilbert (incl RB)+ 2012
SPLASH Survey
Beaton 2014 Thesis

And I count individual stars



R~180 kpc in M31 Stellar Halo
Probably … two dozen M31 stars here.

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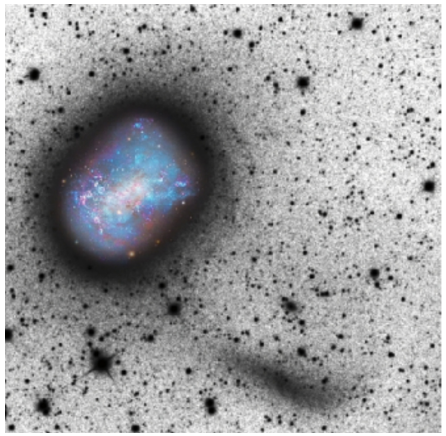
What is a μ-merger?

Major – [1:1; 1:3]

van der Marel+ (incl. RB) 2012a,b

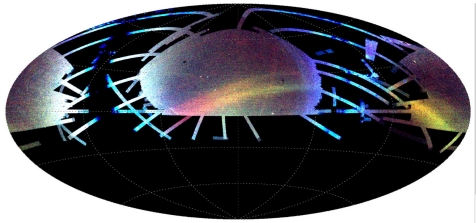
Intermediate – [1:3; 1:6]

Minor – [1:6; 1:10]



Martinez-Delgado+ 2012

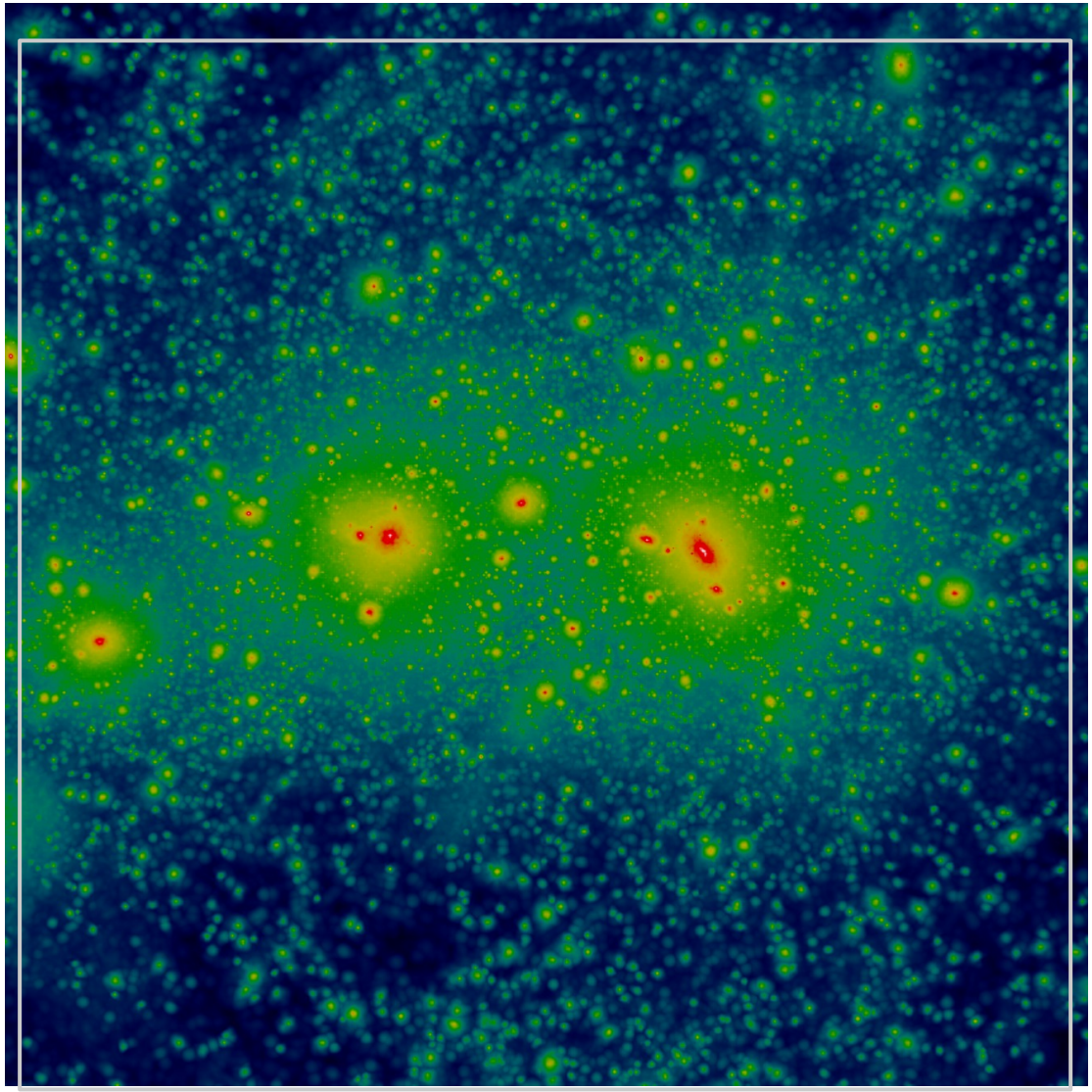
μ- [1:10; 1:inf]



SDSS Field of Streams

Just about everything we see in Local Group is in the micro-regime.

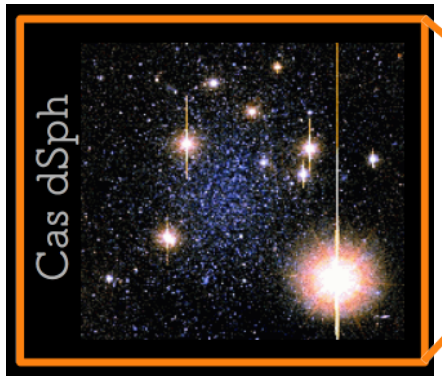
Put on your Dark Matter Glasses



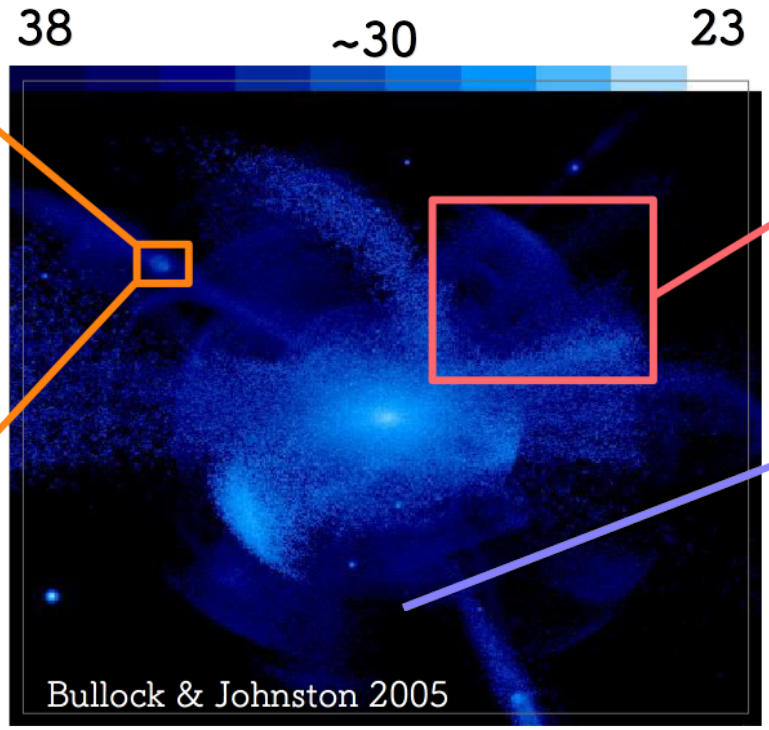
ELVIS:
A simulated Local Group
Garrison-Kimmel et al.

The Narrative

Satellite Galaxies =
"future" accretions



Surface Brightness mag arcsec^{-2}

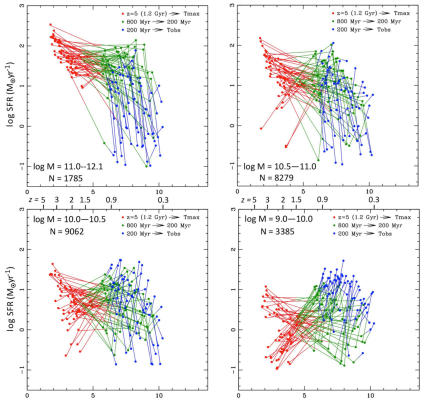


Tidal Streams =
"on-going" accretions

Smooth Halo =
"past" accretions

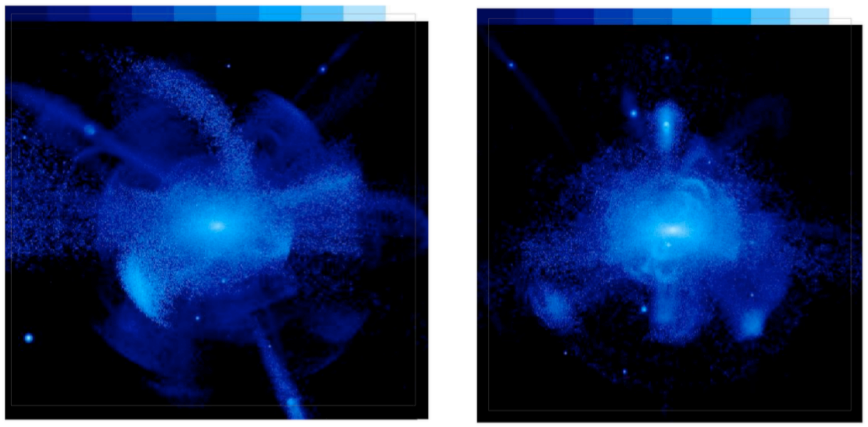
Due to long dynamical times, stellar haloes are fossil records
of the accretion history of the galaxy.
Most of what we see are old accretions.

Why do we care?



Galaxies are diverse.
The accretion histories are different.

Simulated Halos



Bullock & Johnson 2005

Observations

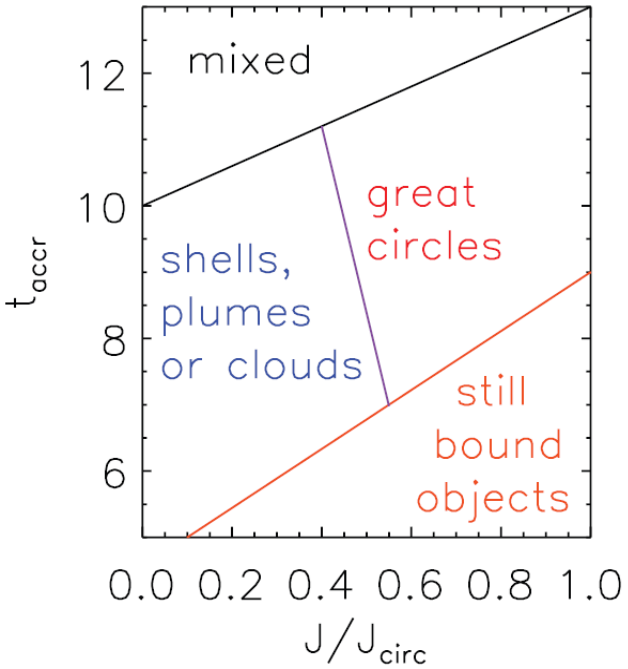
Martinez-Delgado+ 2010

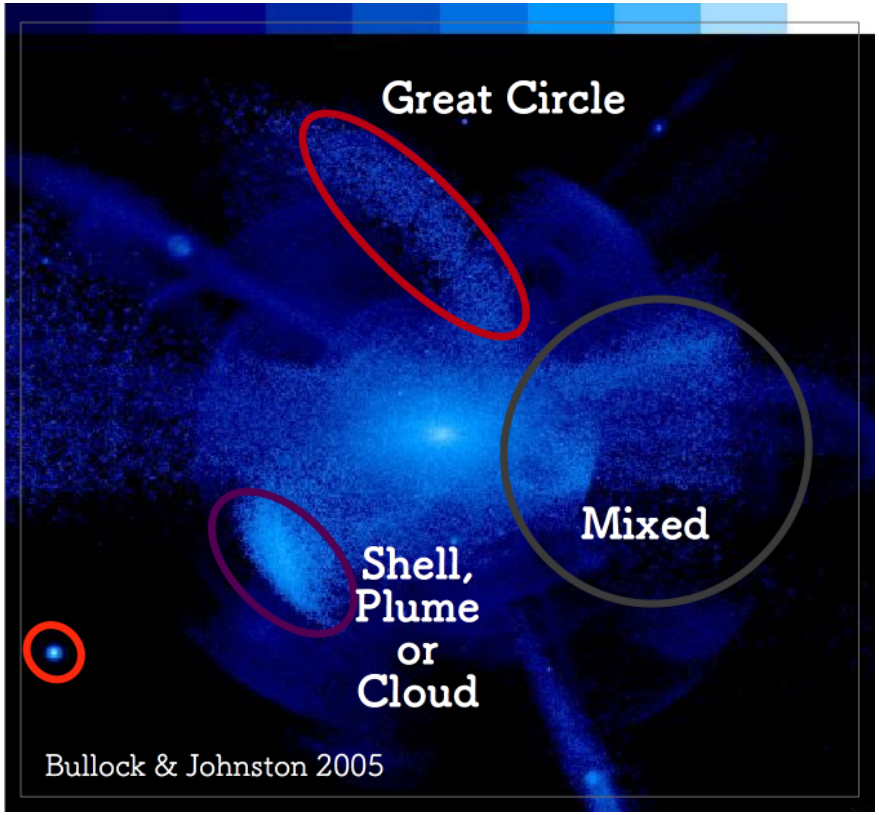
If we want to constrain the 'nurtured' aspect of the Galaxy disk(s)/bar(s)/bulge(s), we can't ignore this part of Galaxy formation & evolution.

Everything you want to know about Extra-Local Group Tidal Streams:
Carlin, RB, Martinez-Delgado & Gabany
ArXiv #1603.04656

More than Counting

Morphology ~
taccr + eccentricity of orbit



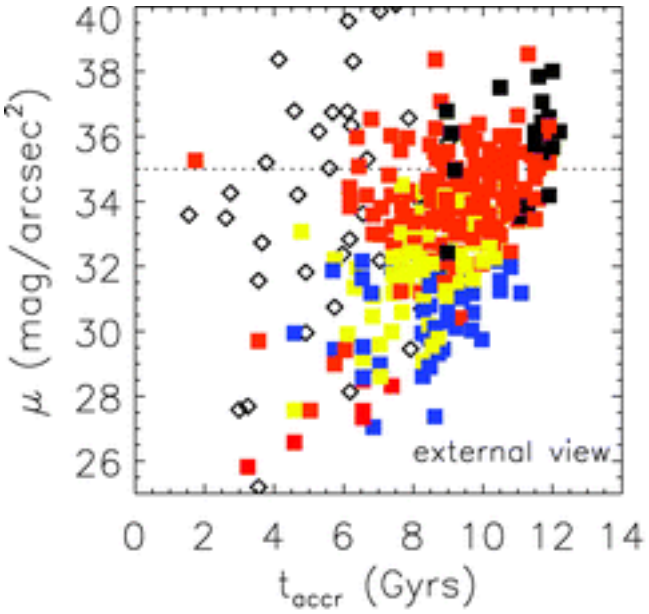


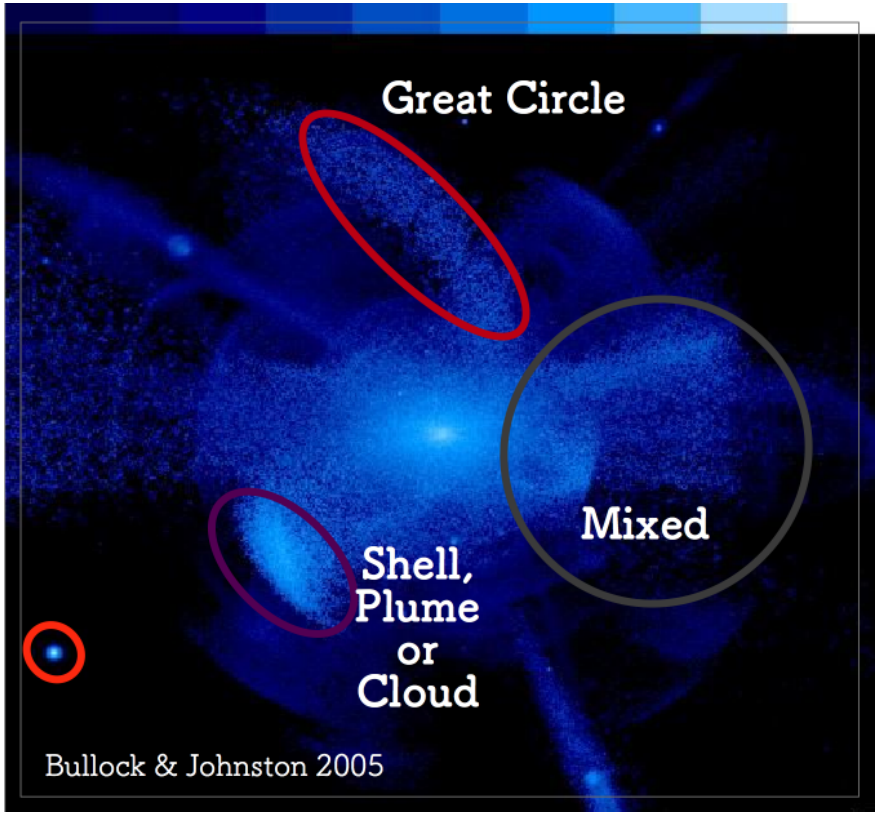
Panoramic imaging of halos gives us clues to how the sub-structure got there.

Johnston et al. 2008

More than Counting

.. but μ (SB) of debris does not track with L of host.

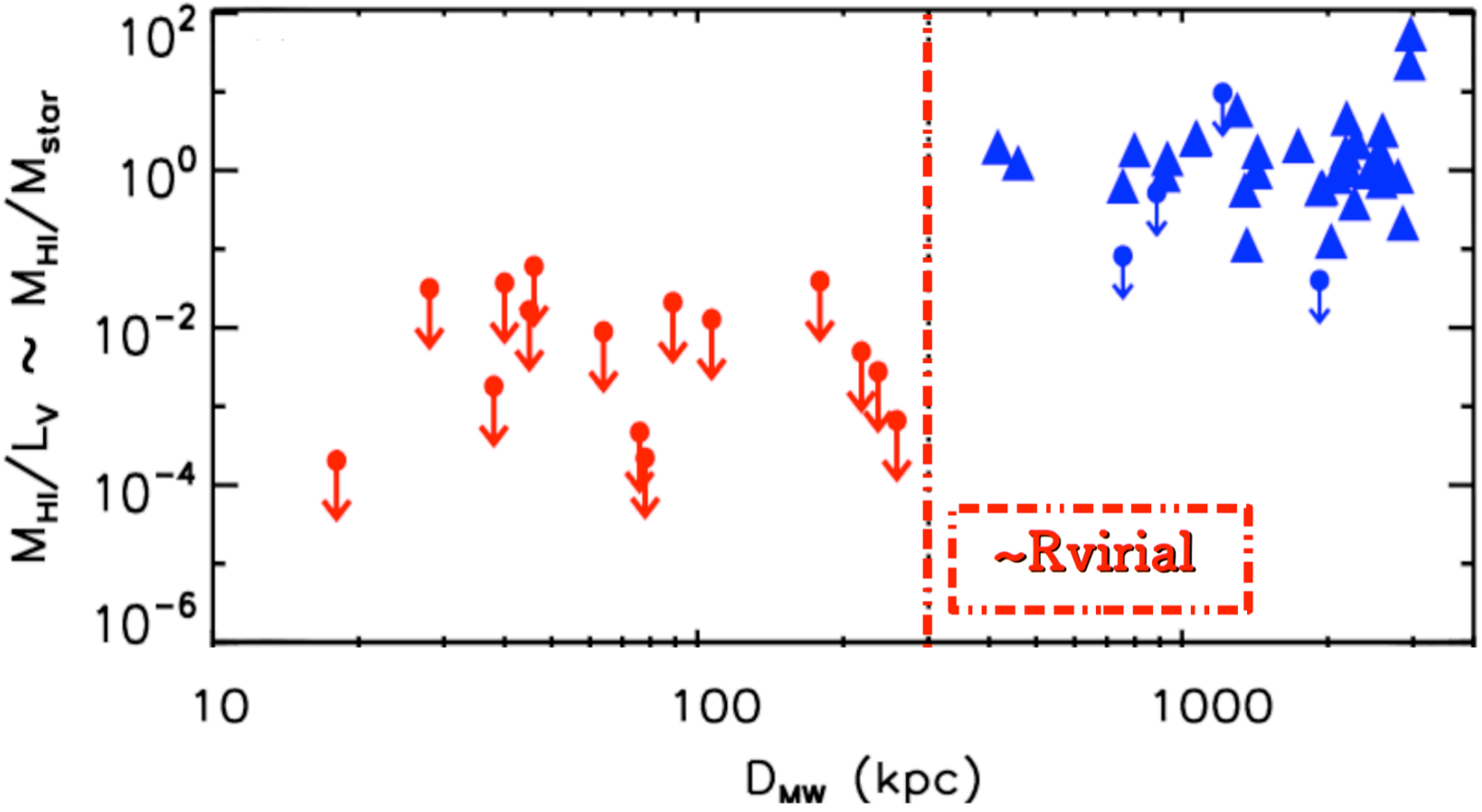




But we just can't know the timing – the one thing we need to connect μ-mergers to substructure in the disk(s)/bulge(s)/bar(s).

Johnston et al. 2008

The Local Group Dwarfs



Spekkens et al. 2014
Also: Grcevich & Putman 2009

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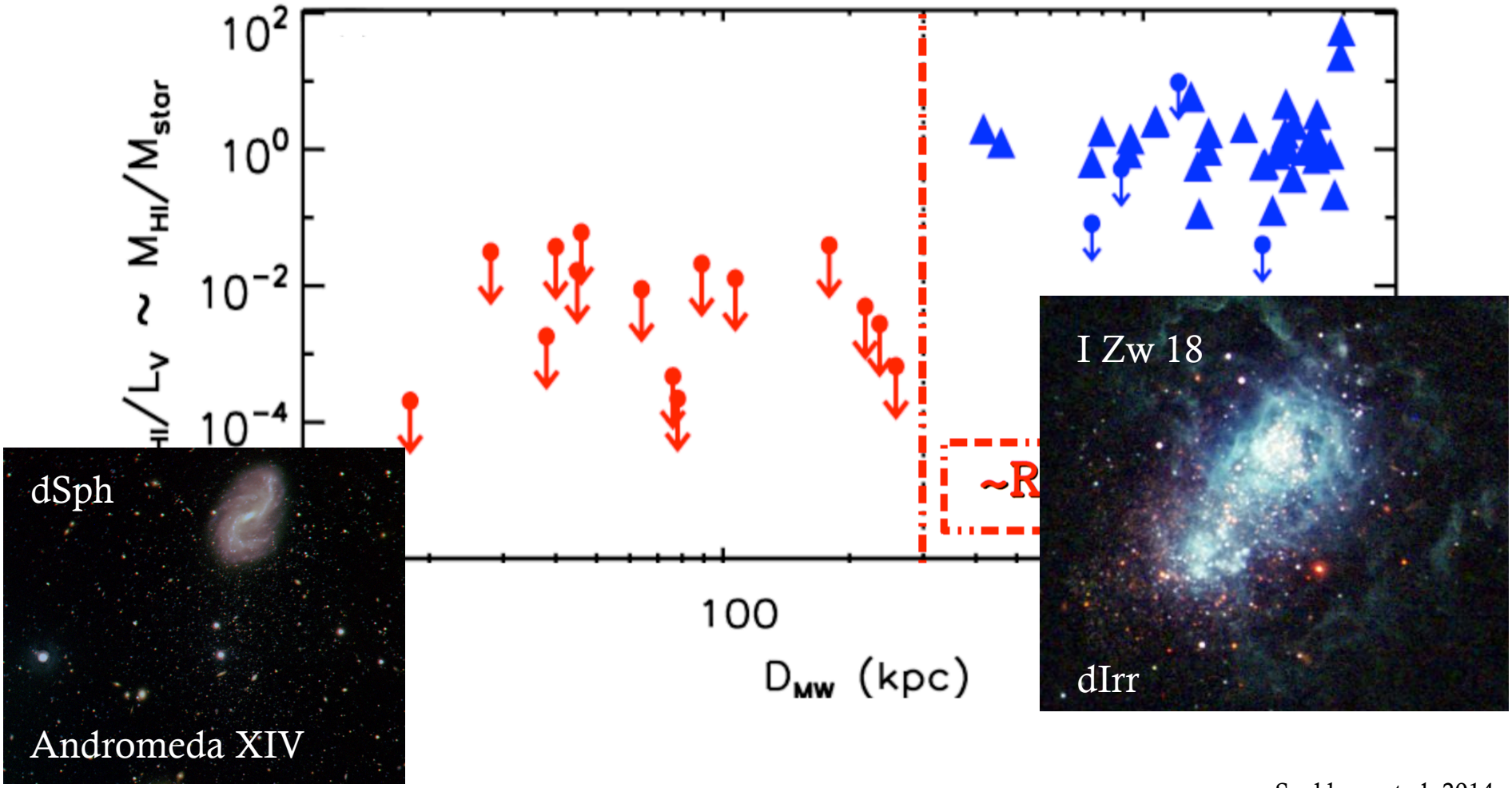

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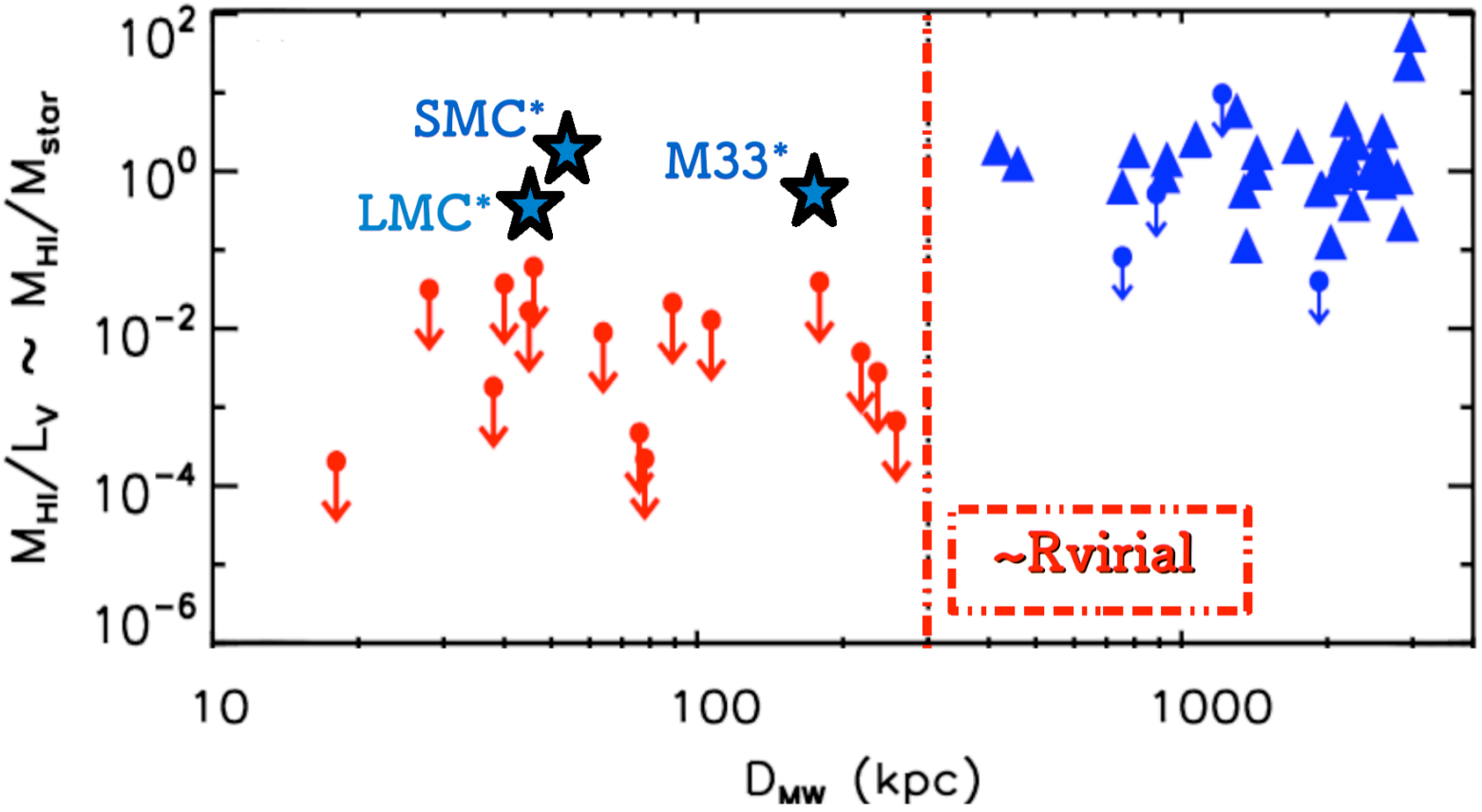
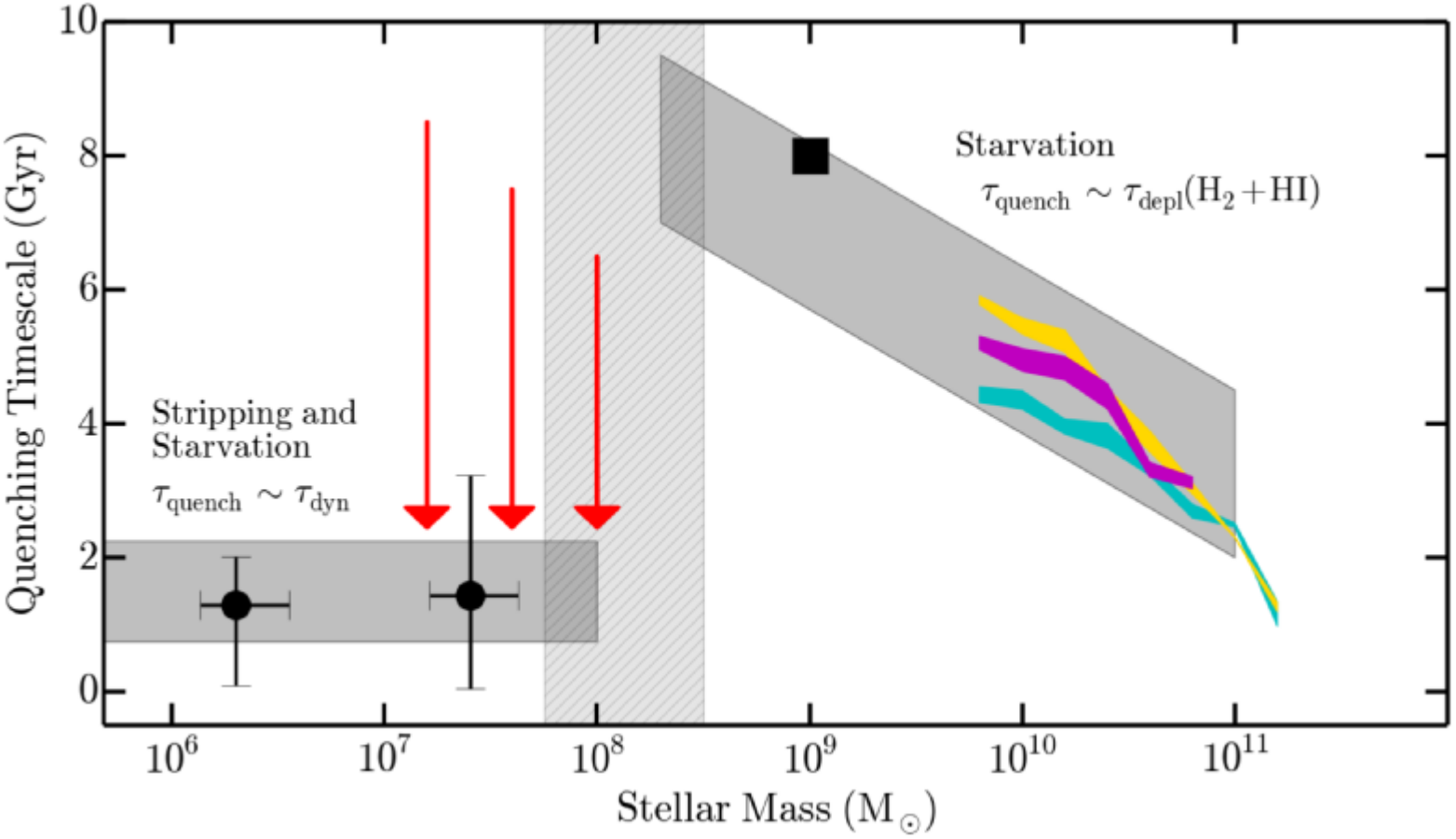
Limited to Local Group



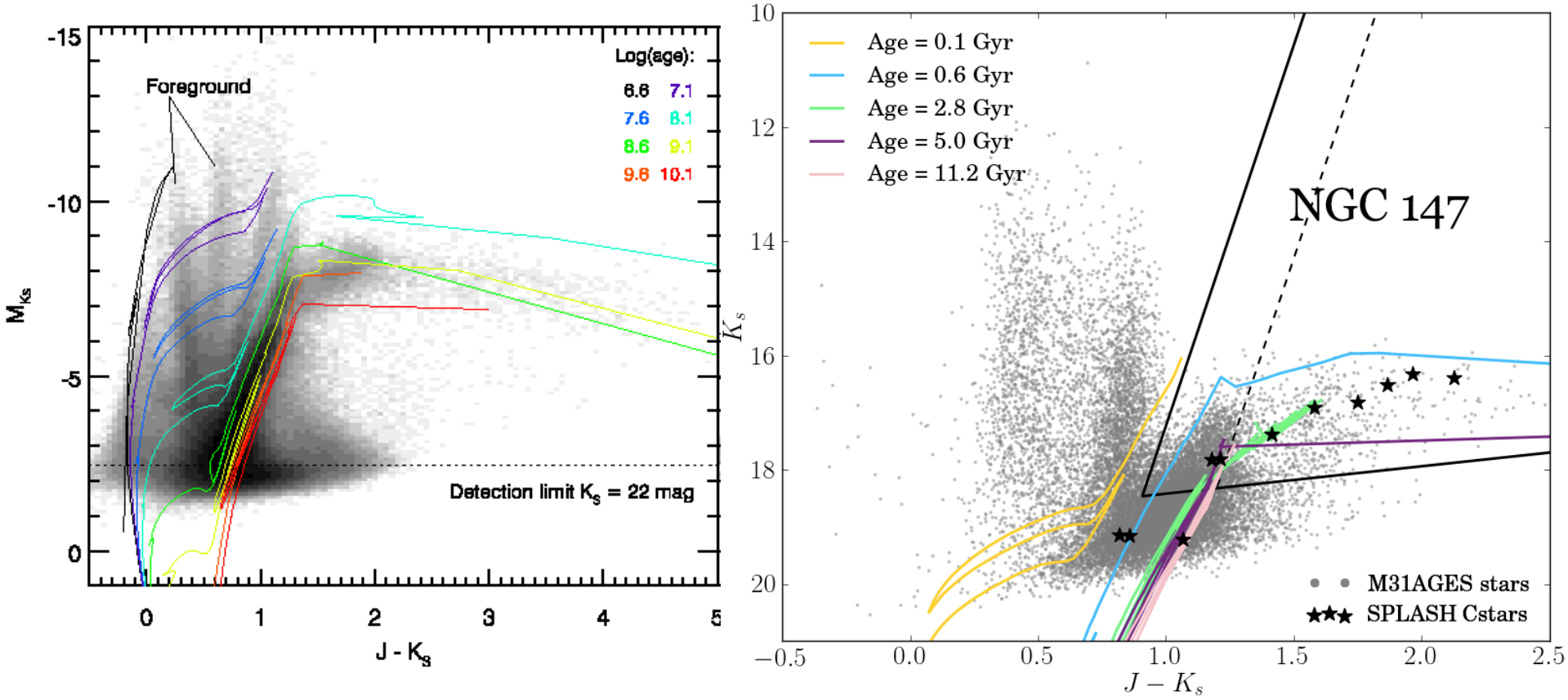
Spekkens et al. 2014
Also: Grcevich & Putman 2009
Approximate locations for LMC, SMC and M33.

Quenching is a Thing



Fillingham et al. 2015 Modeling with ELVIS suite
Colored sequences from Wetzel et al 2012;
see also Geha et al. 2012

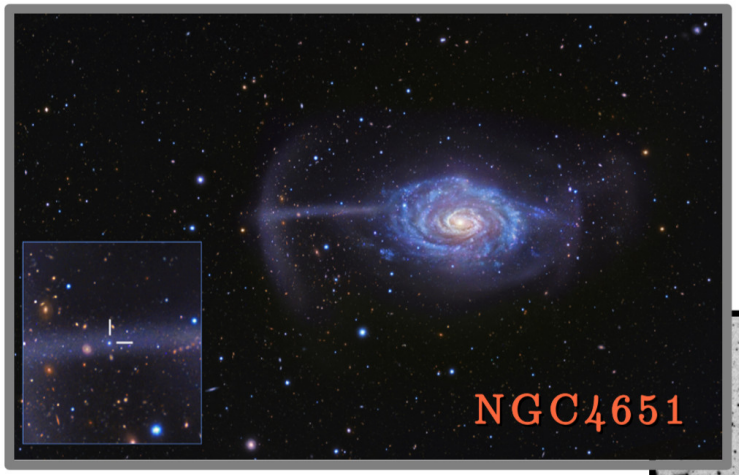
A path to t_{accr}

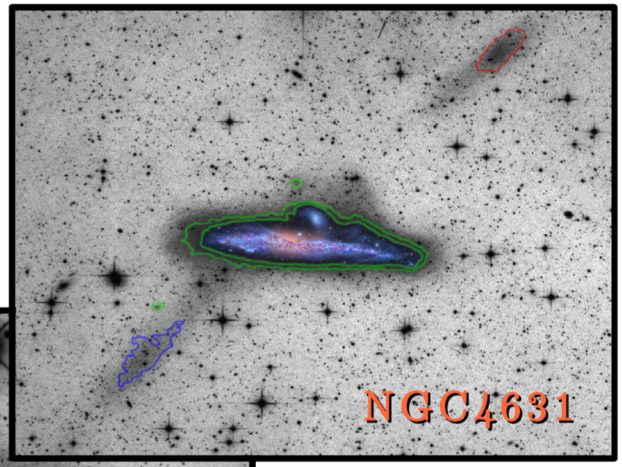


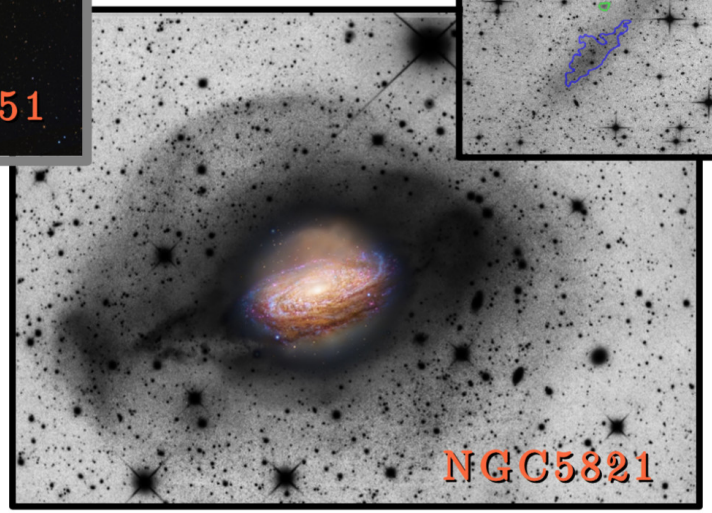
Intermediate age populations are the answer, but they are weird.

Hamren, Beaton, et al. (accepted)
Hamren, Beaton, et al. (in prep)
Beaton, Guhathakurta (in prep)

Impact of μ-mergers



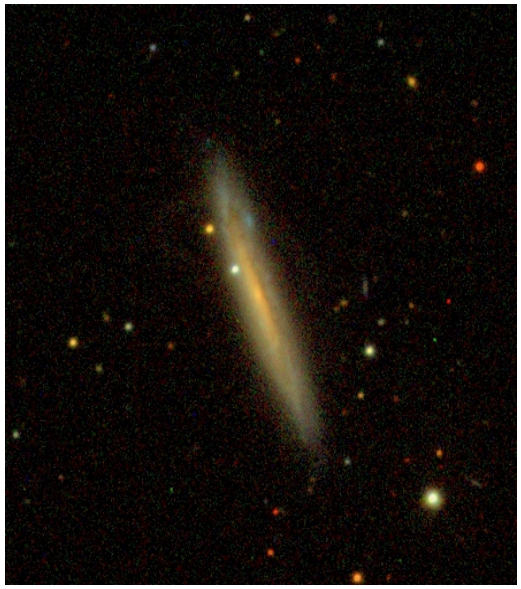




Its really a question of timescales. Larger samples give us a glimpse into events that occur quickly.

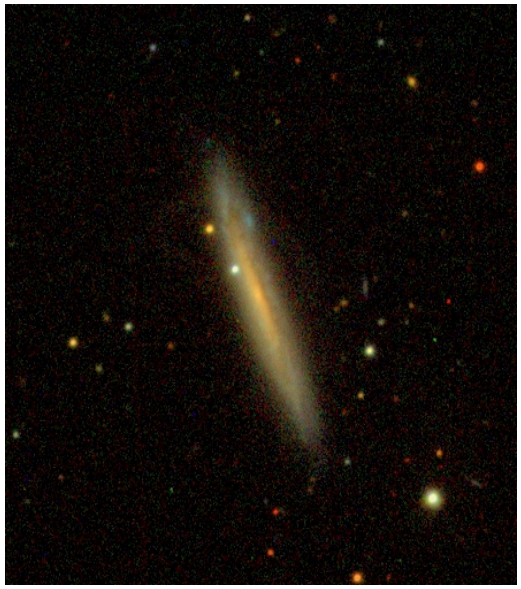
See Carlin, RB, Martinez-Delgado & Gabany ArXiv #1603.04656

Case Study: NGC5387



SDSS Discovery Image

Case Study: NGC5387



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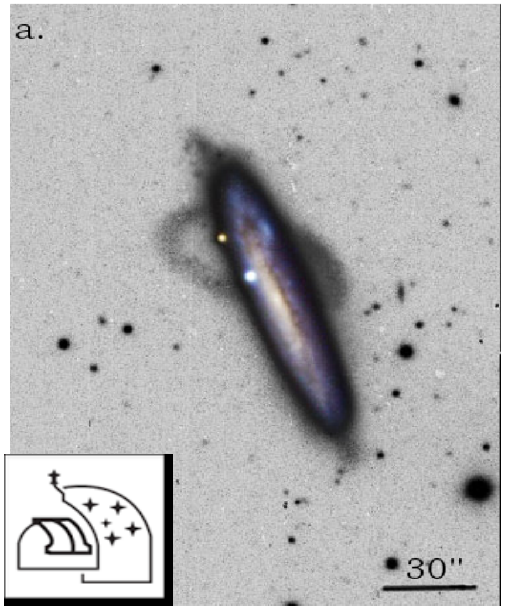
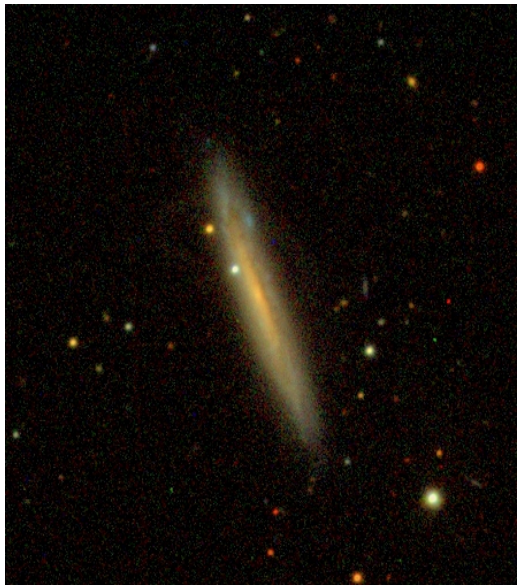


Greyscale: VATT R ~3 hours
Color: Blackbird Observatory
(amateur image)

Case Study: NGC5387



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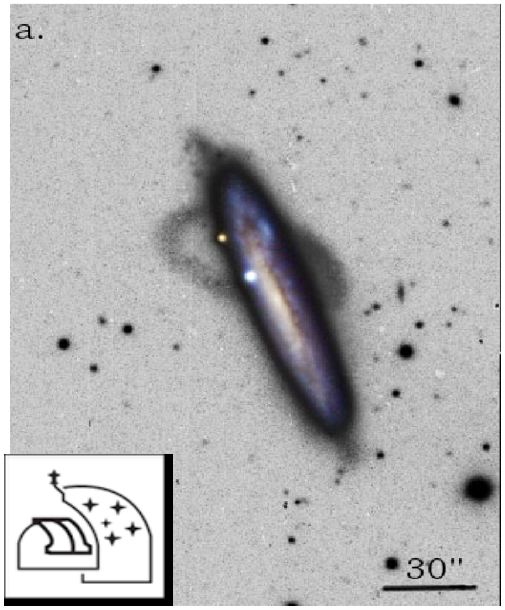

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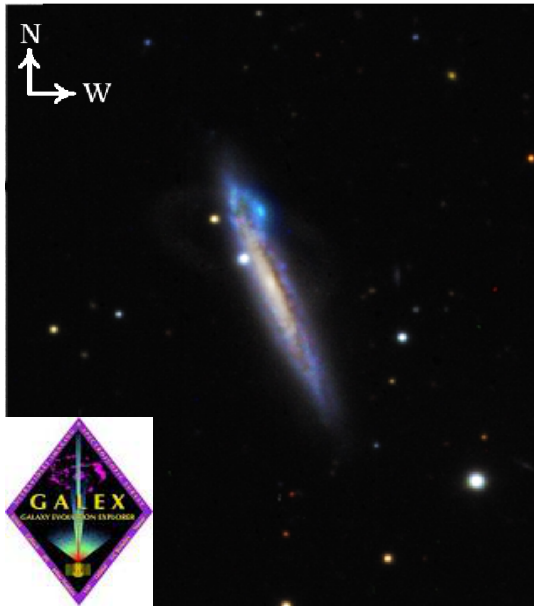
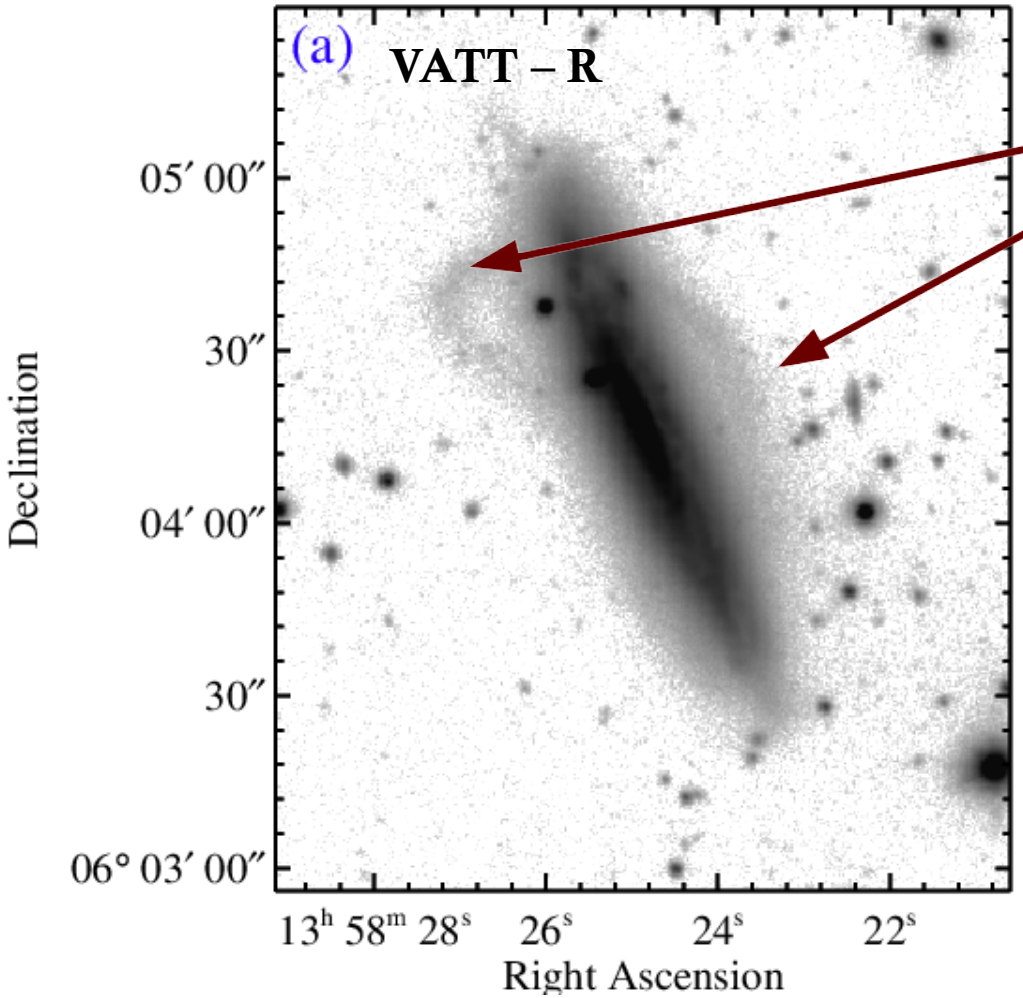


GALEX + BBO Optical

Morphology

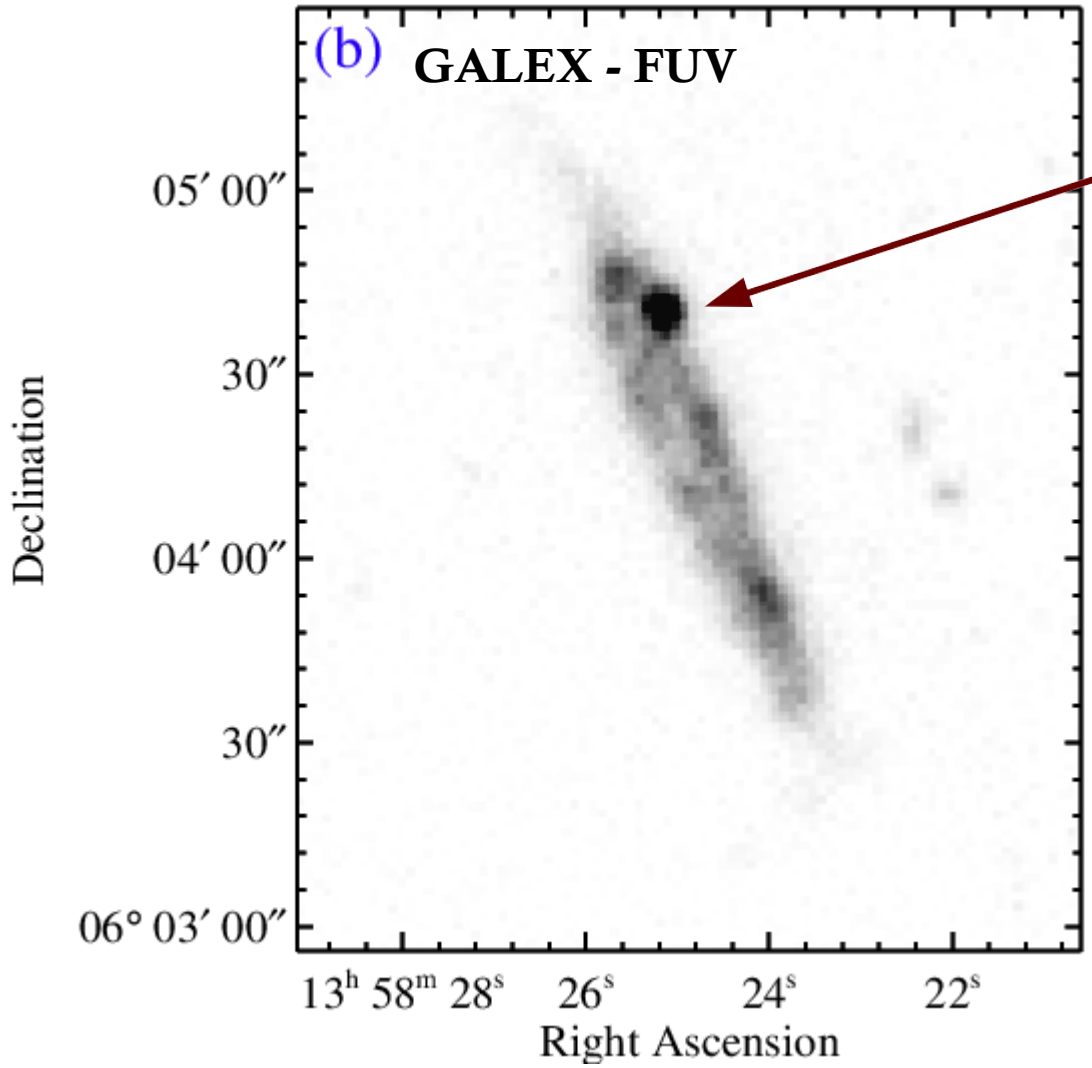


The Stream is:

- Red => Old Stars
- ~10^8 M-solar stars
  (1:50 mass ratio in stars)
- 200-500 Myr to create the stream
- Progenitor was ~10^{10} total mass
  (~1:10 mass ratio total mass)
- Plunges through disk ~10-12 kpc

Beaton et al. 2014

Disk-Stream Intersection

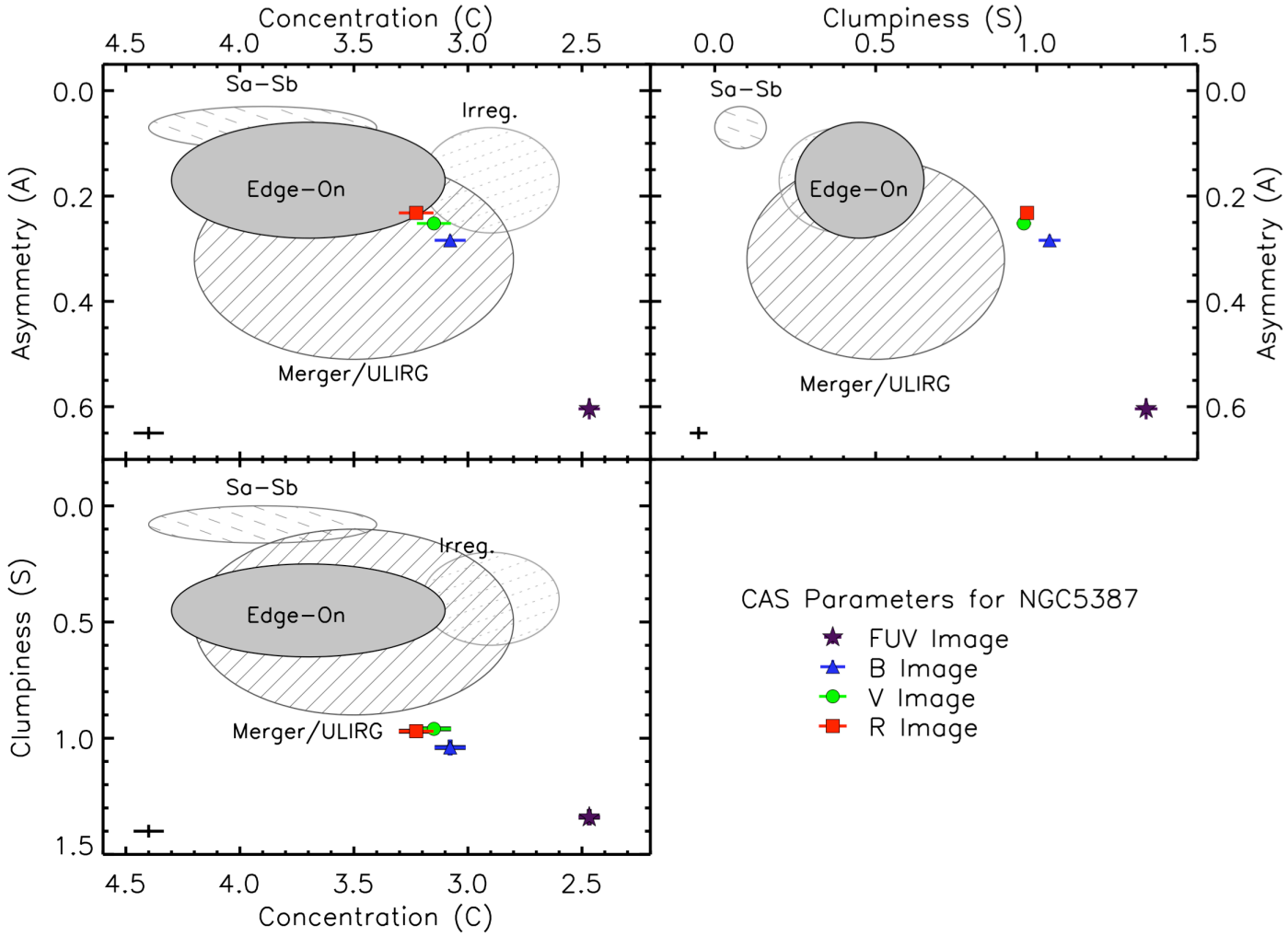


The blob is:

- Ultra-Blue at 10 Myr
- SF = ~2-3 Msolar/yr
- 40% of the total FUV flux is from this region
- ~1 kpc across

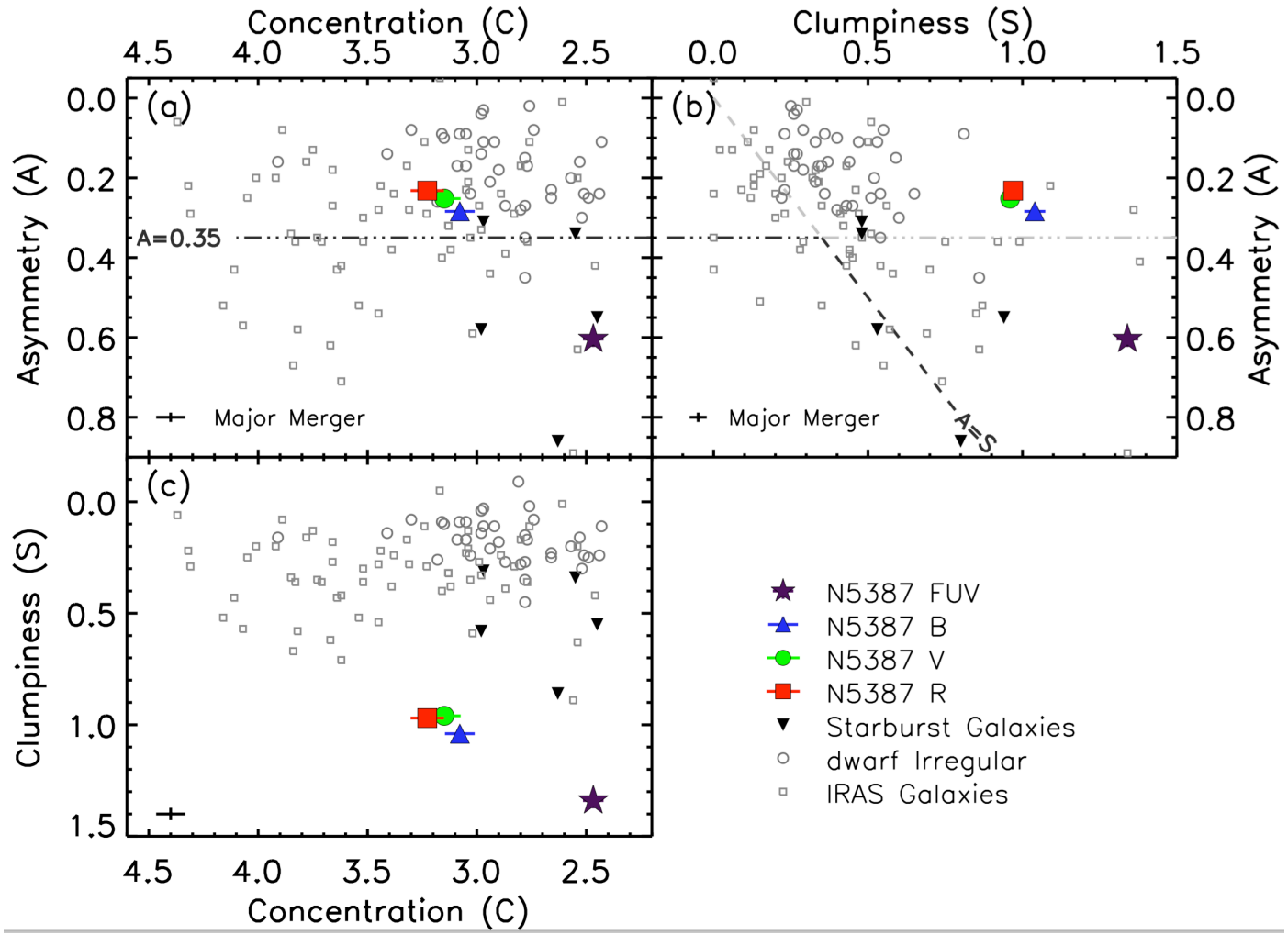
Beaton et al. 2014

CAS



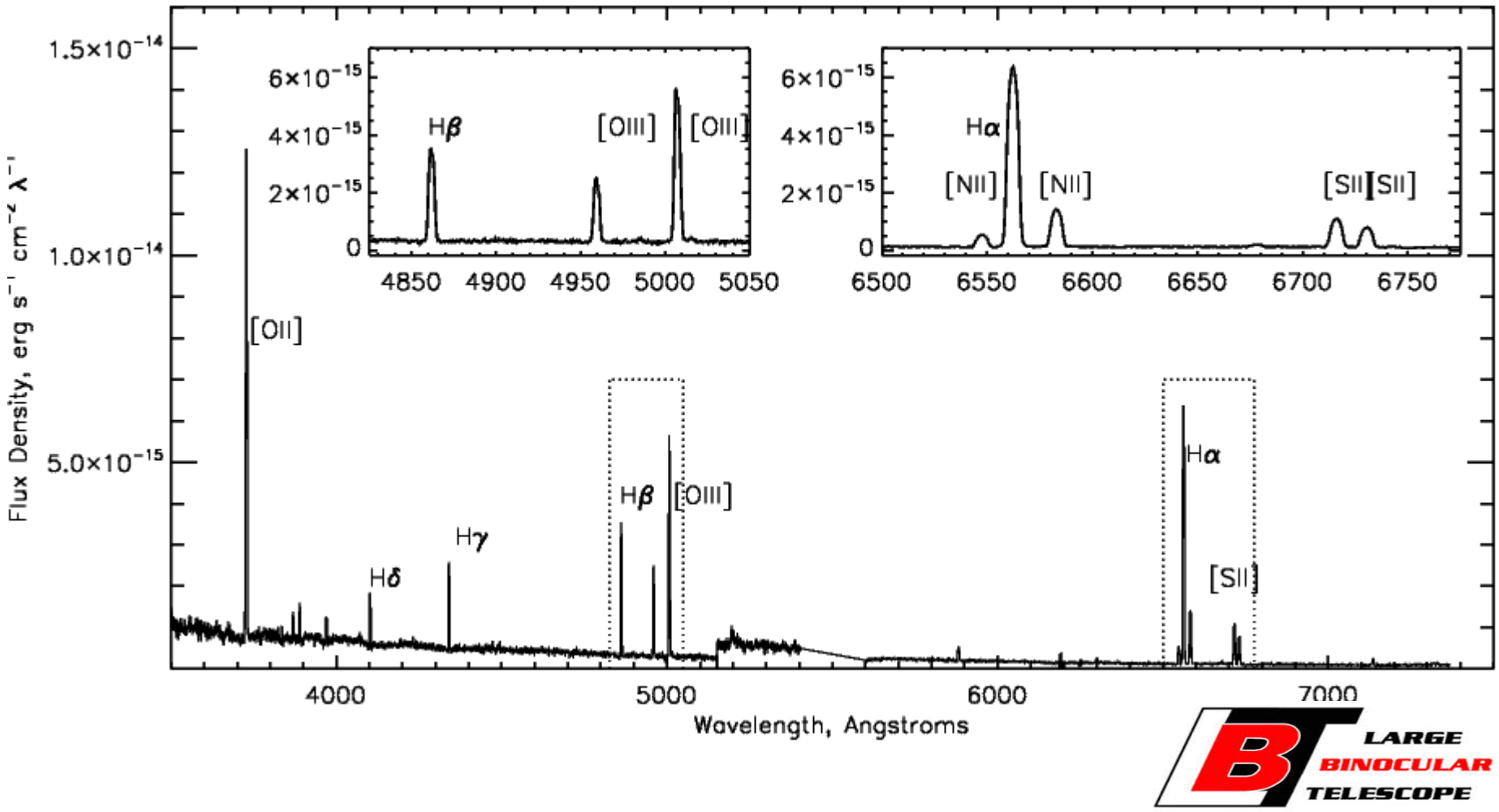
Conselice +
Beaton et al. submitted

CAS



Conselice +
Beaton et al. submitted

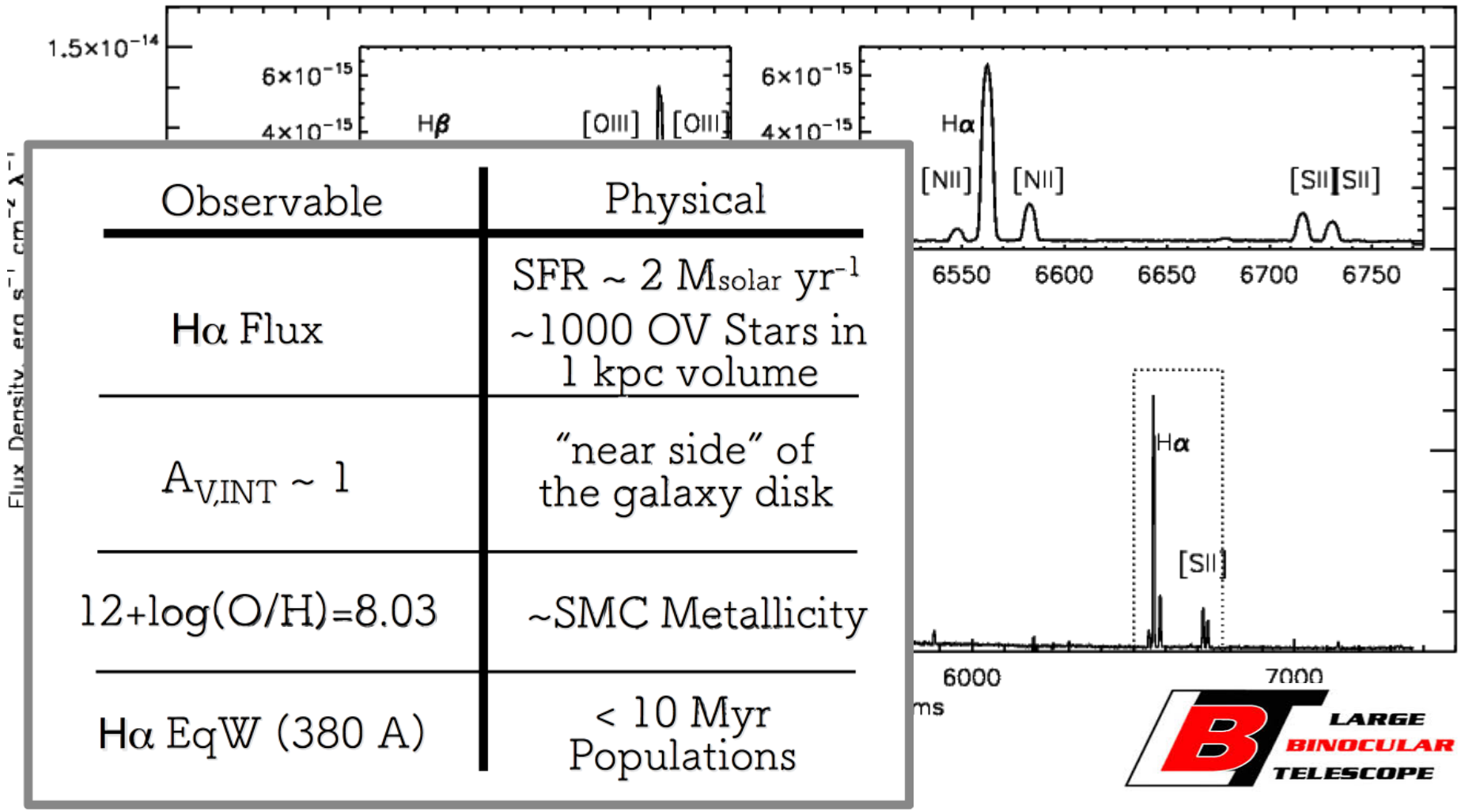
Spectroscopy



LARGE BINOCULAR TELESCOPE

Beaton et al. 2014

Spectroscopy

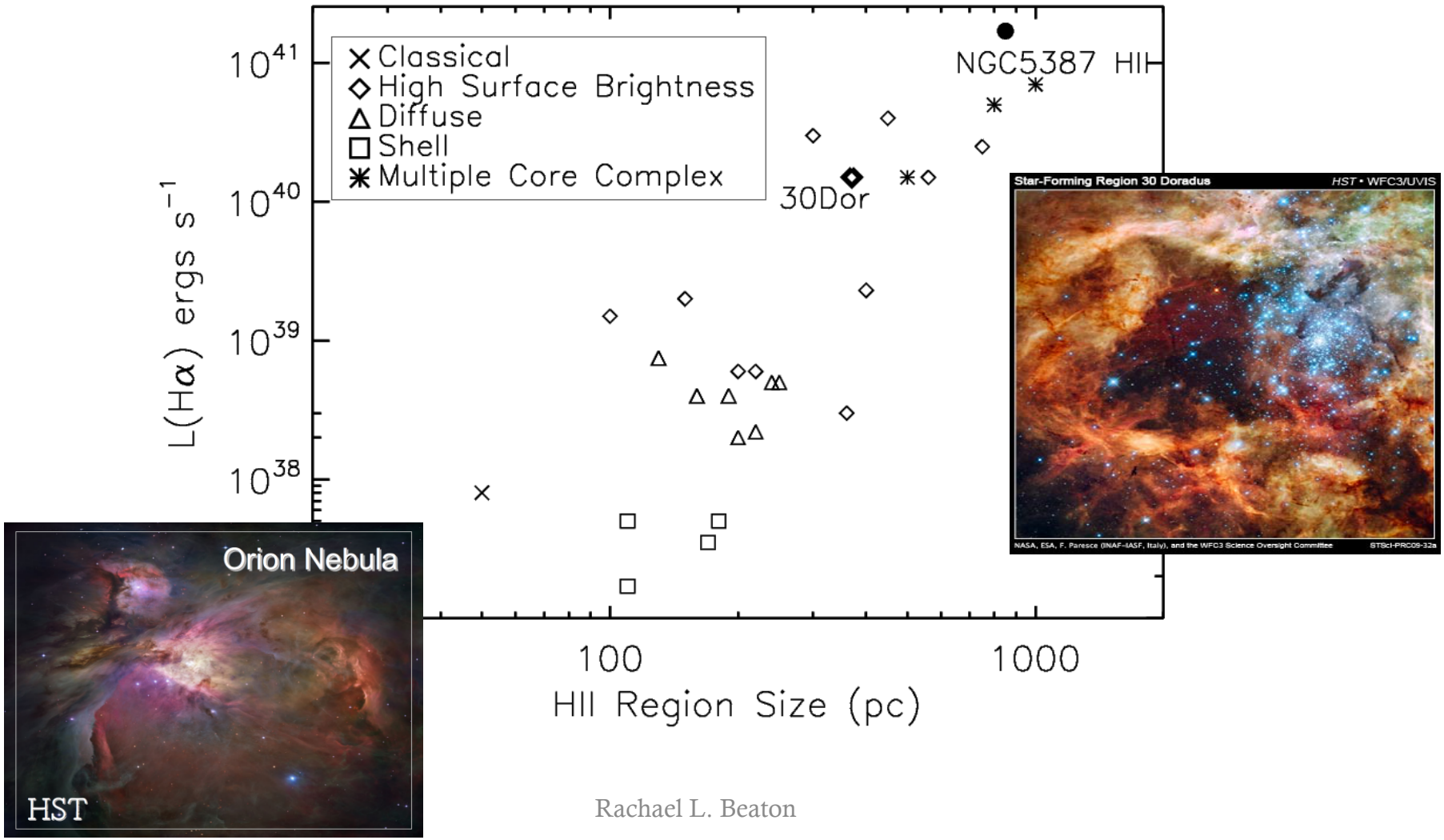


Observable	Physical
Hα Flux	SFR ~ 2 M_{solar} yr^{-1} ~1000 OV Stars in 1 kpc volume
$A_{V,INT}$ ~ 1	"near side" of the galaxy disk
12+log(O/H)=8.03	~SMC Metallicity
Hα EqW (380 A)	< 10 Myr Populations

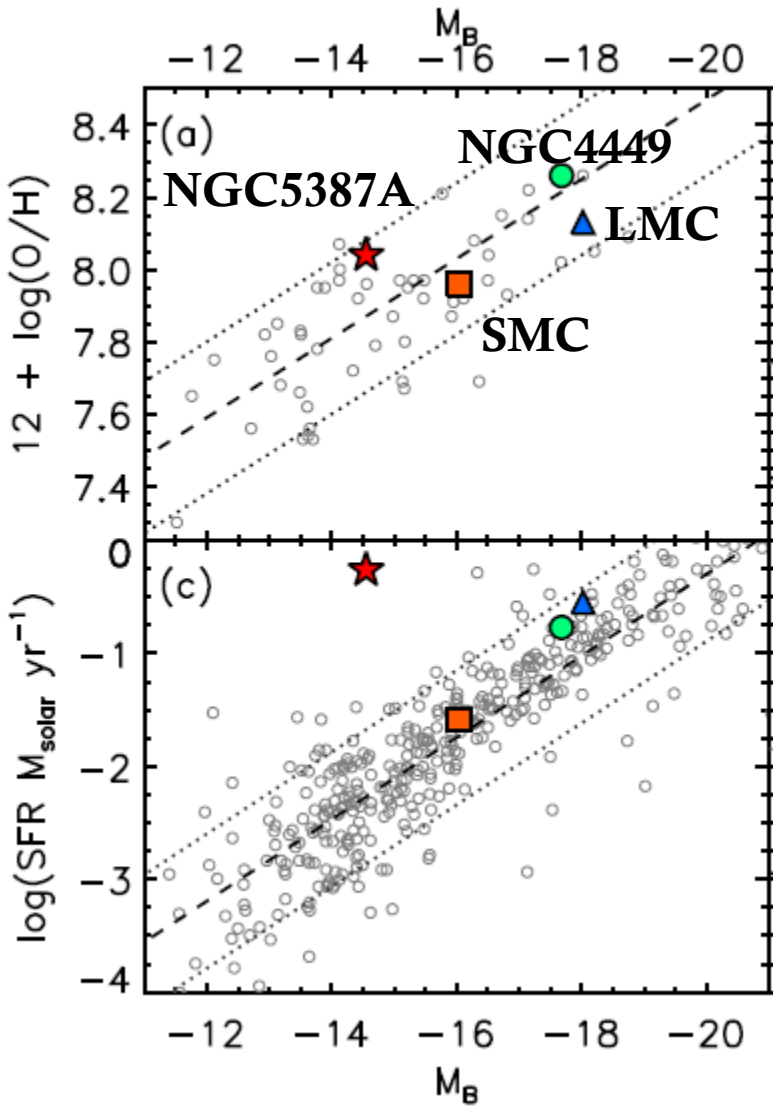
LARGE BINOCULAR TELESCOPE

Beaton et al. 2014

The SFR in Context

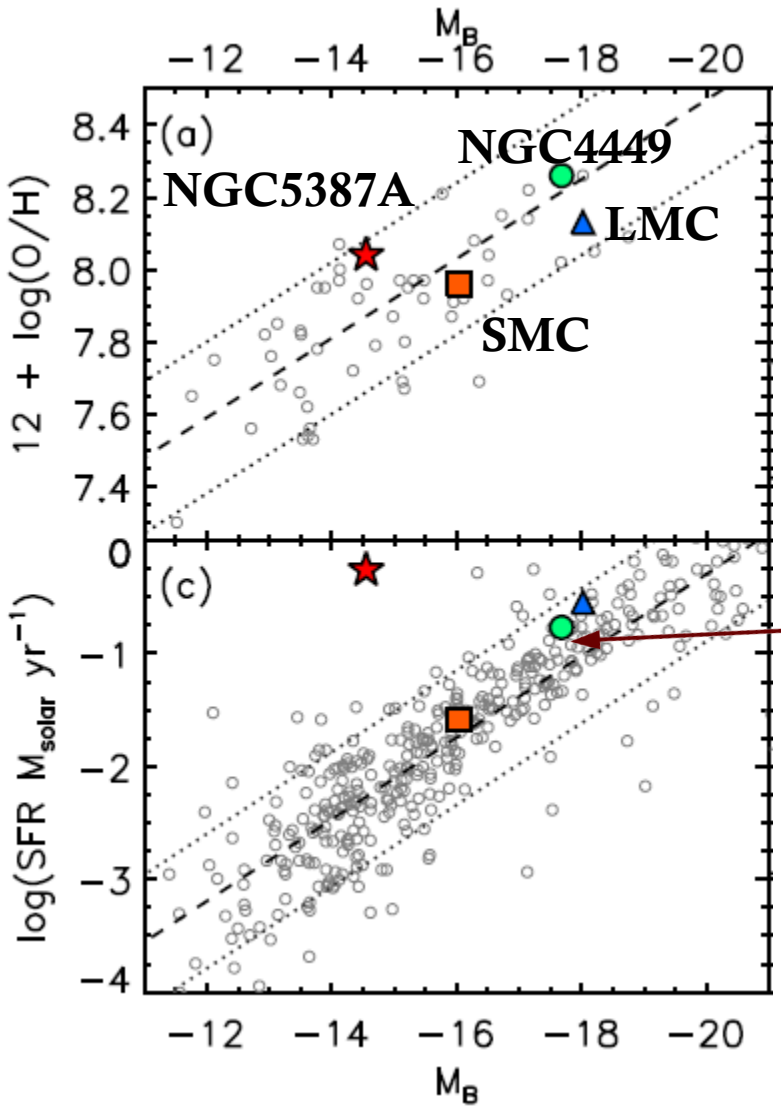


The SFR in Context

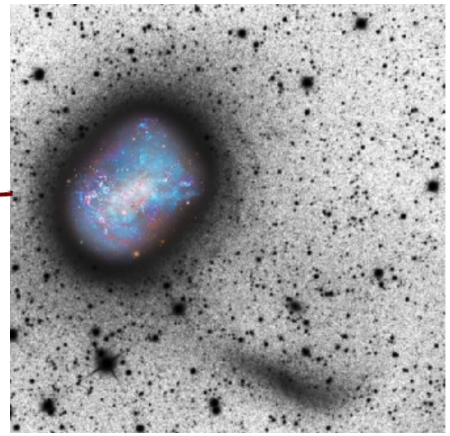


Beaton et al. submitted
Comparison data from the
Local Volume Legacy Survey

The SFR in Context

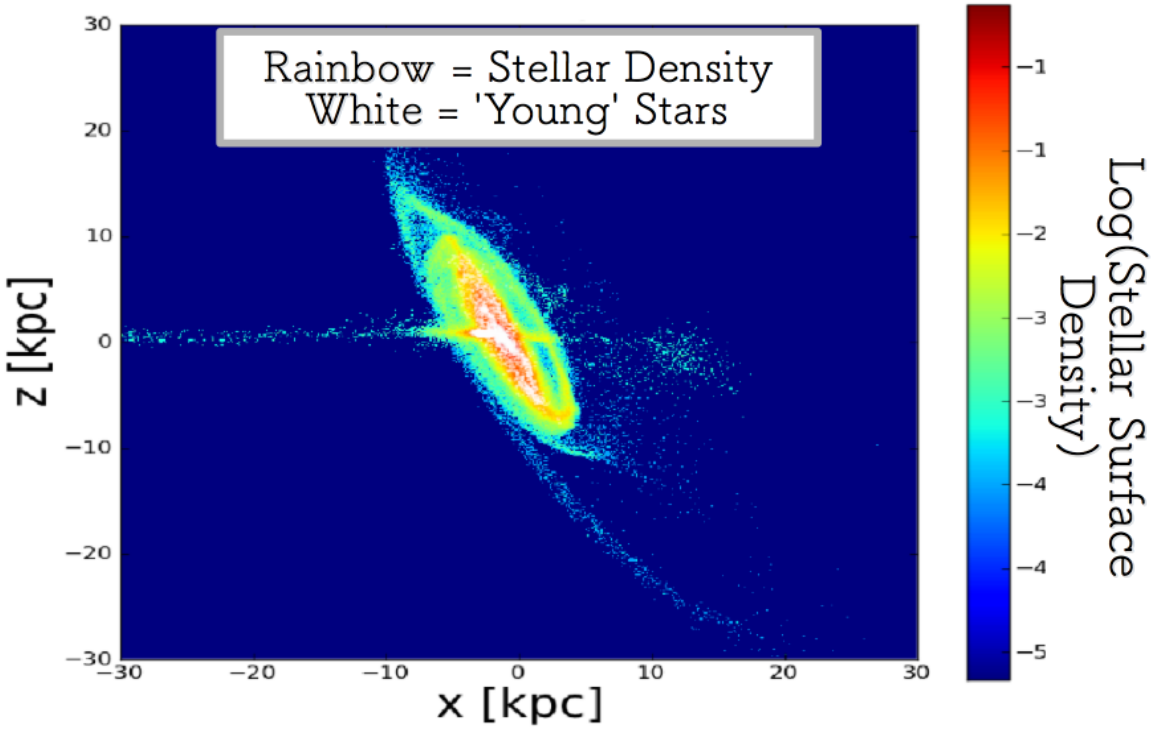


NGC4449



Beaton et al. submitted
Comparison data from the
Local Volume Legacy Survey

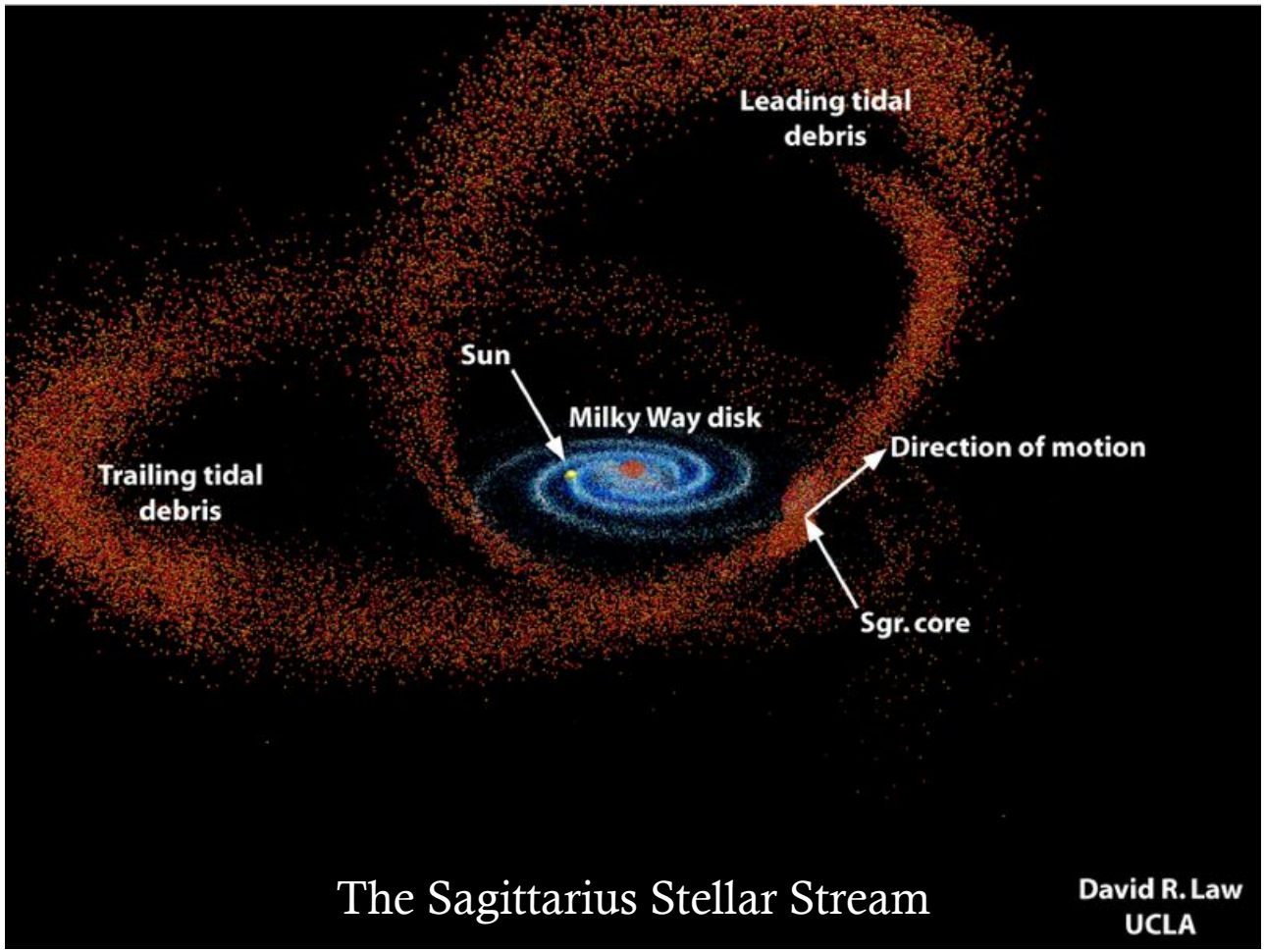
N-body + Arepo Model



Able to reproduce qualitatively all of our inferred properties with a single interaction.

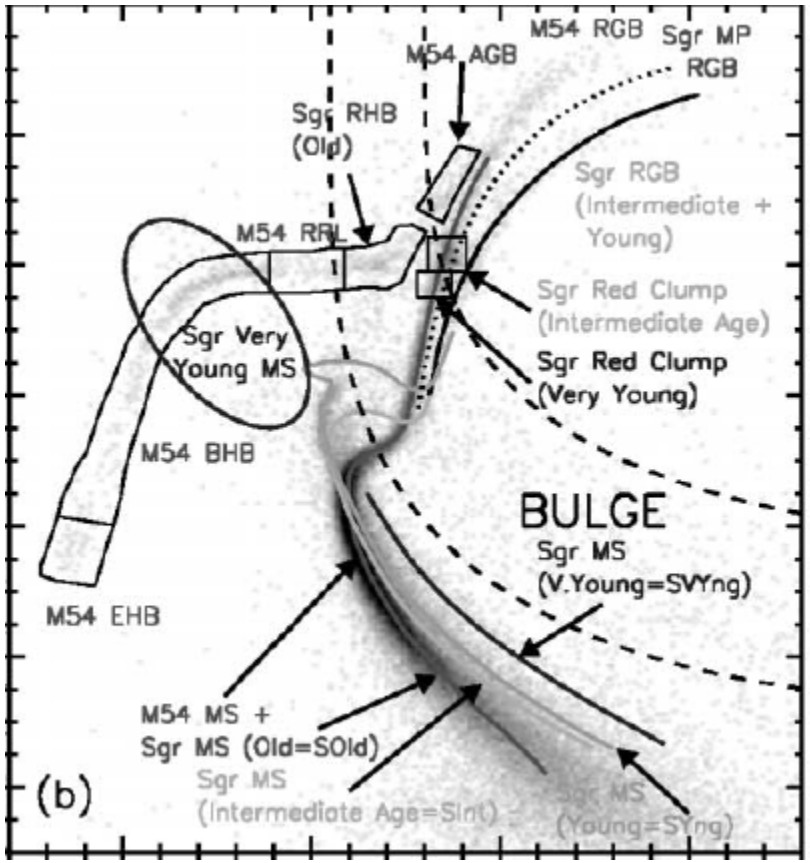
Beaton et al. Submitted
Modelling by E. D'Onghia

Is this believable?



Is this believable?

Sagittarius dSph has extended star formation history – despite multi-Gyr interaction and multiple disk passages at ~13 kpc.



Siegel et al. 2007
ACS Globular Cluster Treasury

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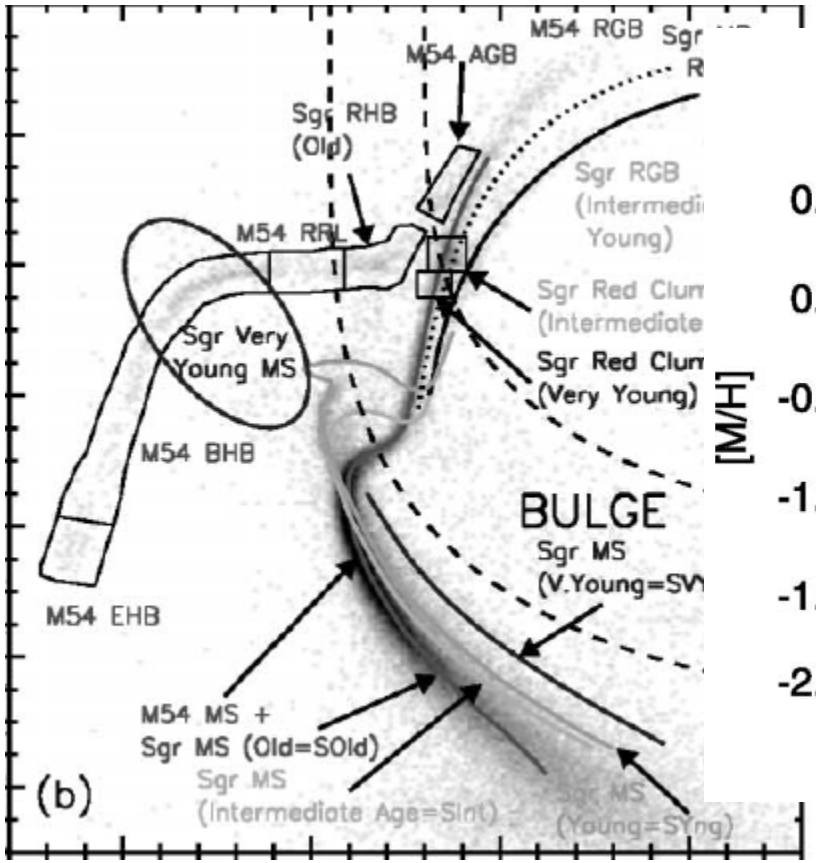
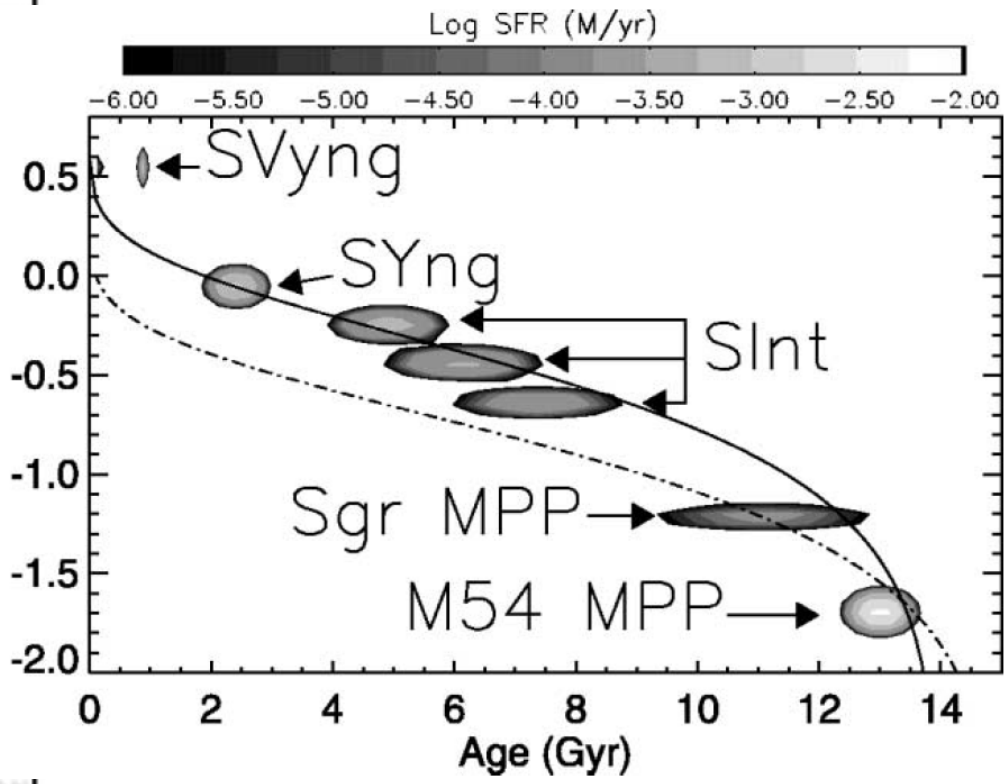
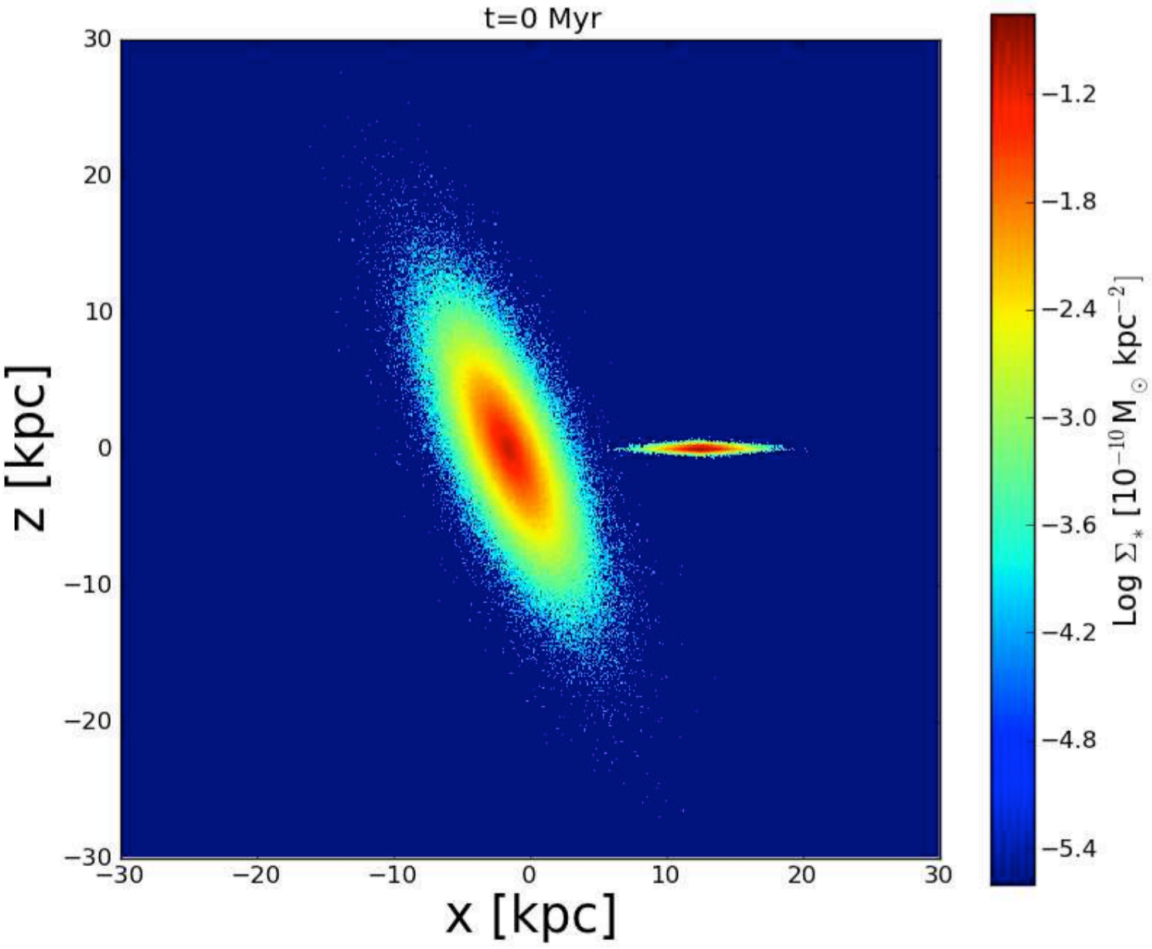


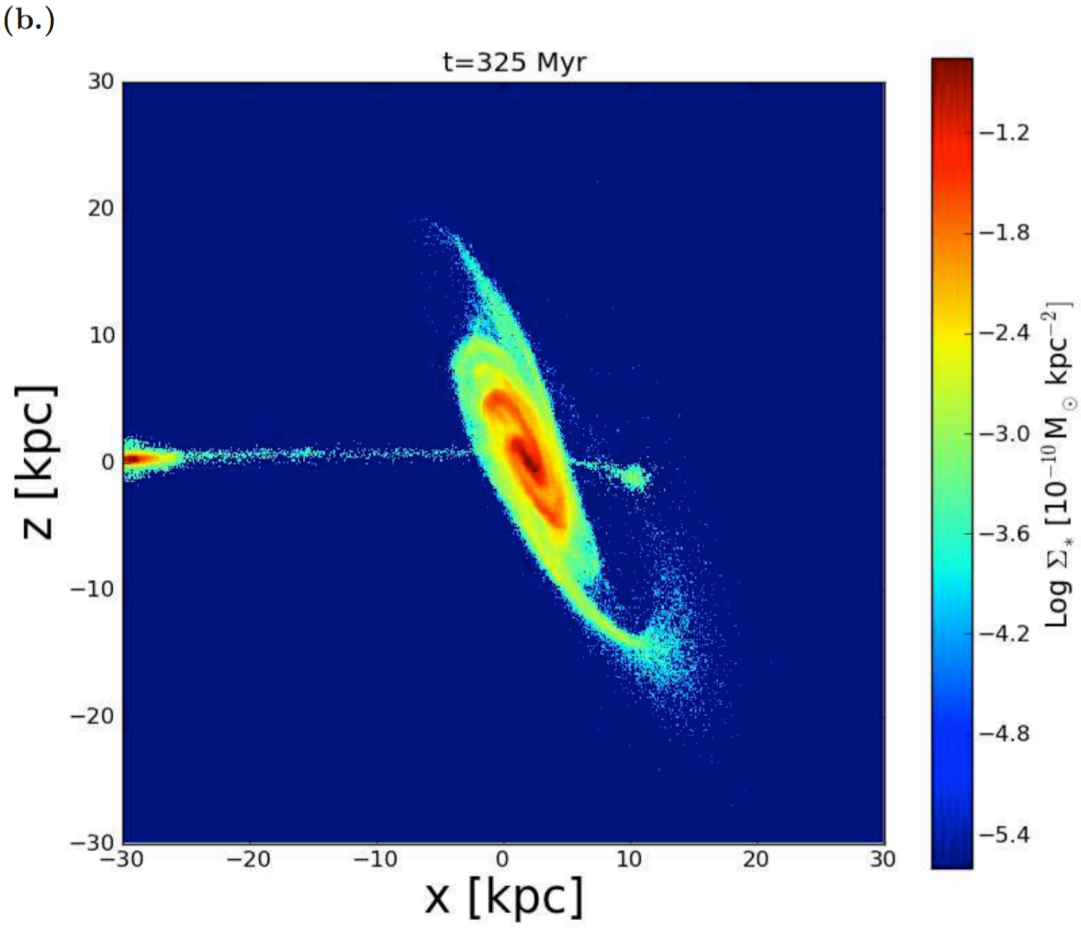


Siegel et al. 2007
ACS Globular Cluster Treasury

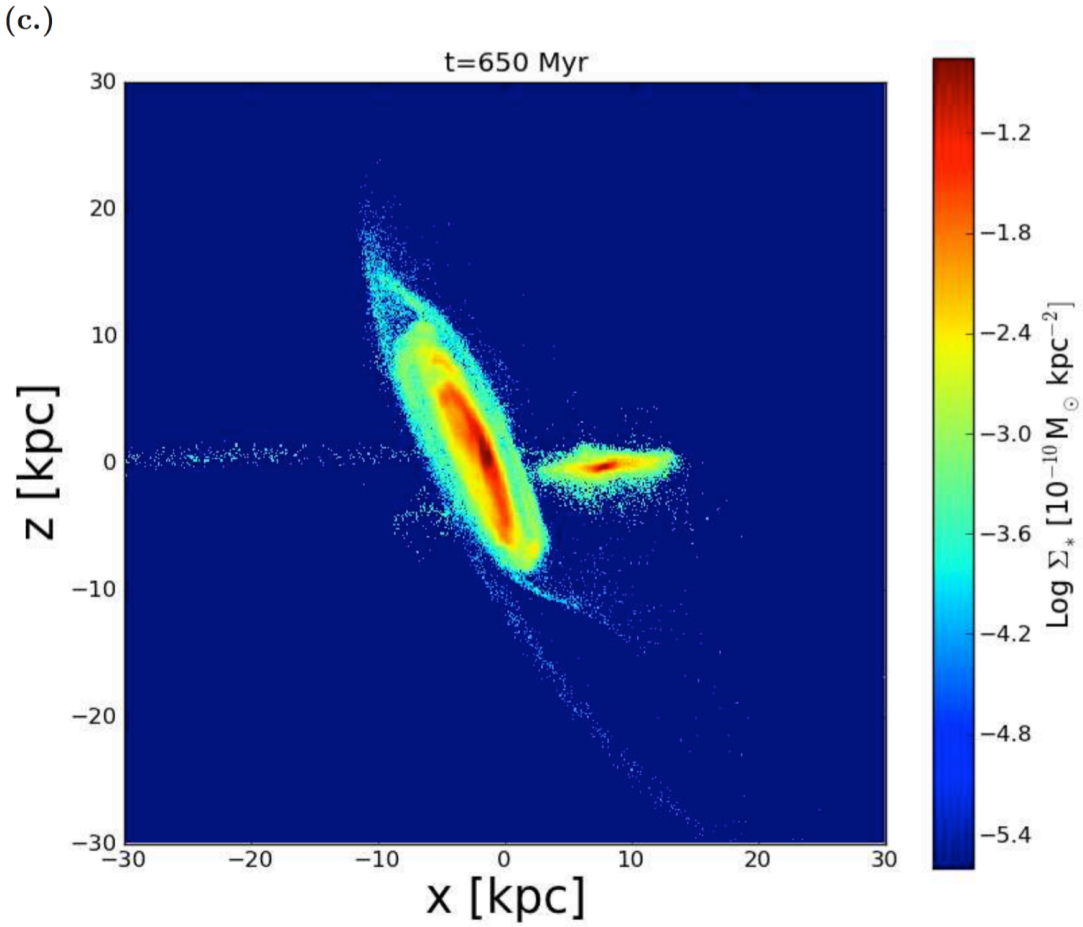
Flipbook


t=0 Myr
z [kpc]
x [kpc]
30
20
10
0
−10
−20
−30
−30
−20
−10
0
10
20
30
−1.2
−1.8
−2.4
−3.0
−3.6
−4.2
−4.8
−5.4
Log Σ* [10^−10 M⊙ kpc^−2]

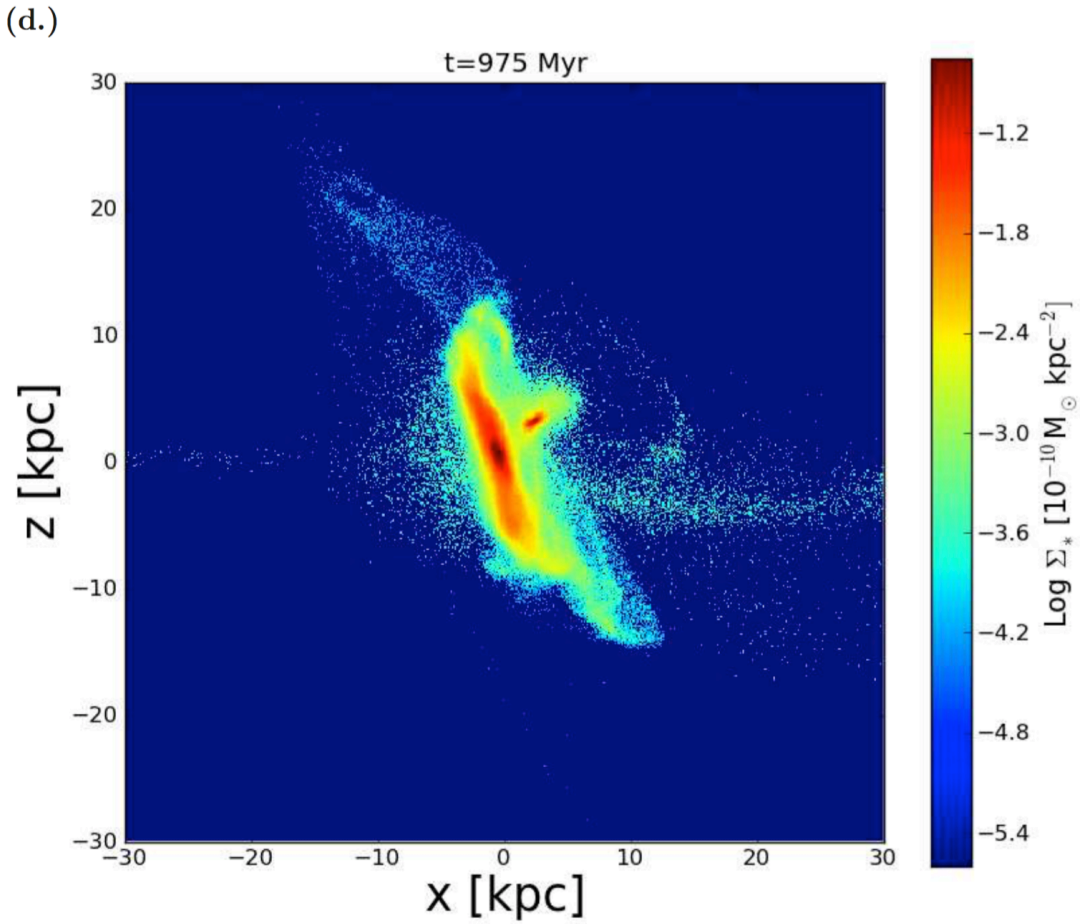
Flipbook


(b.)
t=325 Myr
z [kpc]
x [kpc]
30
20
10
0
−10
−20
−30
−30
−20
−10
0
10
20
30
−1.2
−1.8
−2.4
−3.0
−3.6
−4.2
−4.8
−5.4
Log Σ_* [10^{-10} $M_\odot$ kpc^{-2}]

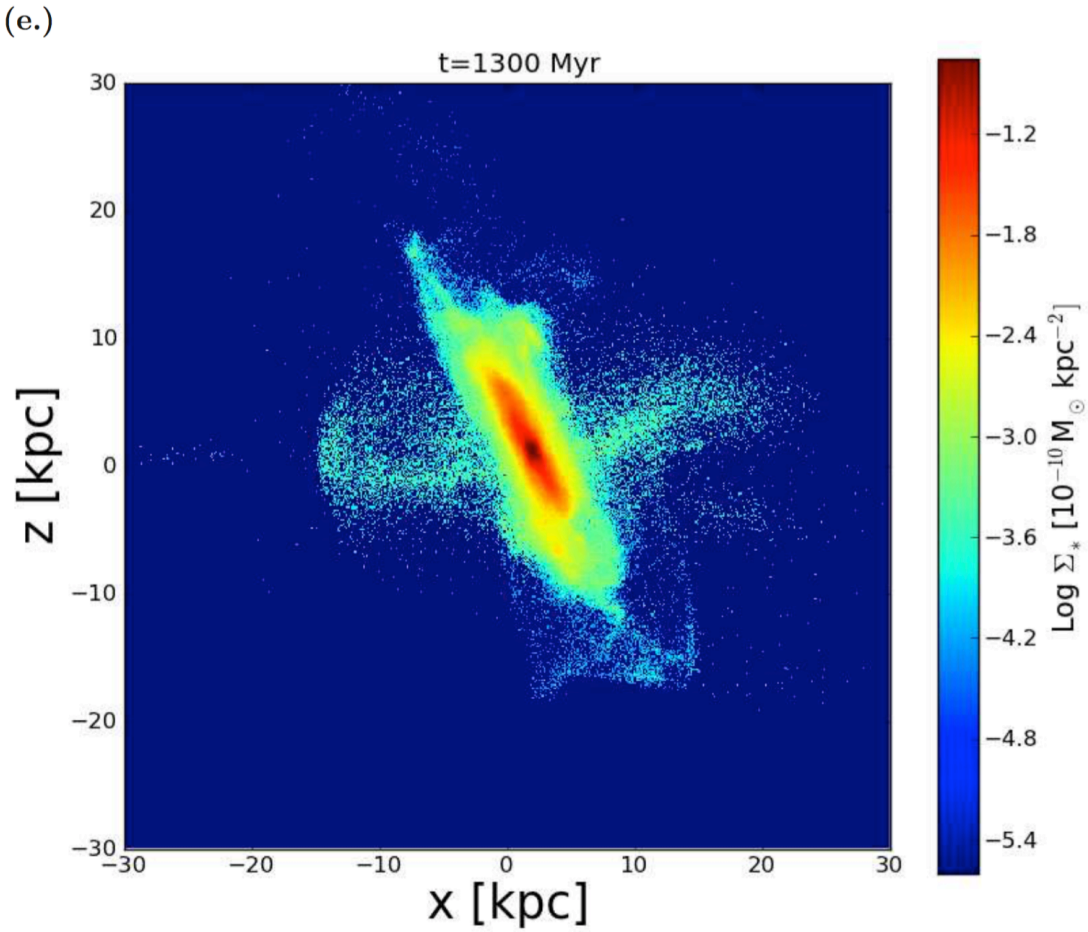
Flipbook


(c.)
t=650 Myr
z [kpc]
x [kpc]
30
20
10
0
−10
−20
−30
−30
−20
−10
0
10
20
30
−1.2
−1.8
−2.4
−3.0
−3.6
−4.2
−4.8
−5.4
Log Σ_* [10^{-10} $M_\odot$ kpc^{-2}]

Flipbook

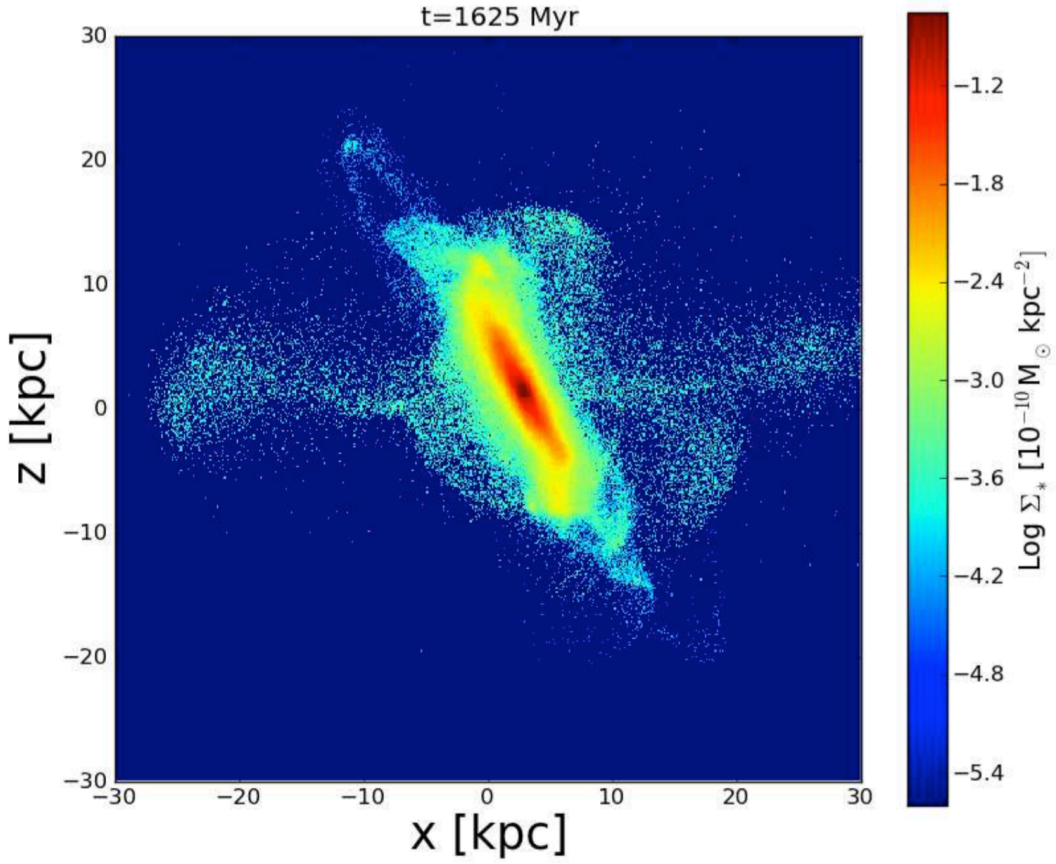

(d.)
t=975 Myr
z [kpc]
x [kpc]
30
20
10
0
−10
−20
−30
−30
−20
−10
0
10
20
30
−1.2
−1.8
−2.4
−3.0
−3.6
−4.2
−4.8
−5.4
Log Σ_* [10^{-10} $M_\odot$ kpc^{-2}]

Flipbook

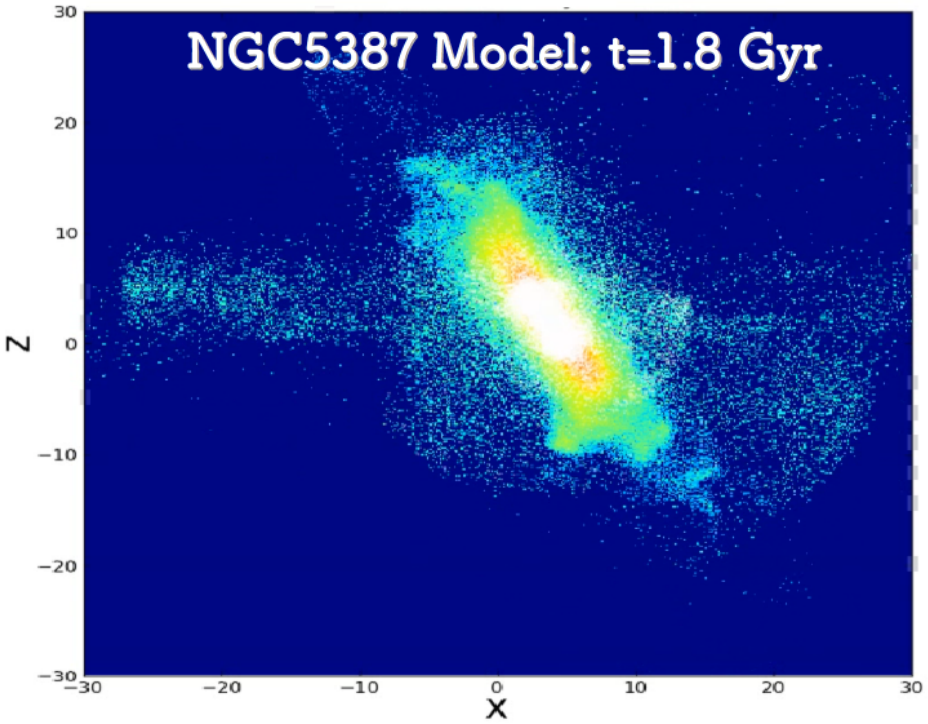

(e.)
t=1300 Myr
z [kpc]
x [kpc]
30
20
10
0
−10
−20
−30
−30
−20
−10
0
10
20
30
−1.2
−1.8
−2.4
−3.0
−3.6
−4.2
−4.8
−5.4
Log Σ_* [10^{-10} $M_\odot$ kpc^{-2}]

Flipbook

(f.)


t=1625 Myr
z [kpc]
x [kpc]
30
20
10
0
−10
−20
−30
−1.2
−1.8
−2.4
−3.0
−3.6
−4.2
−4.8
−5.4
Log Σ* [10^−10 M⊙ kpc^−2]

End Game for NGC5387

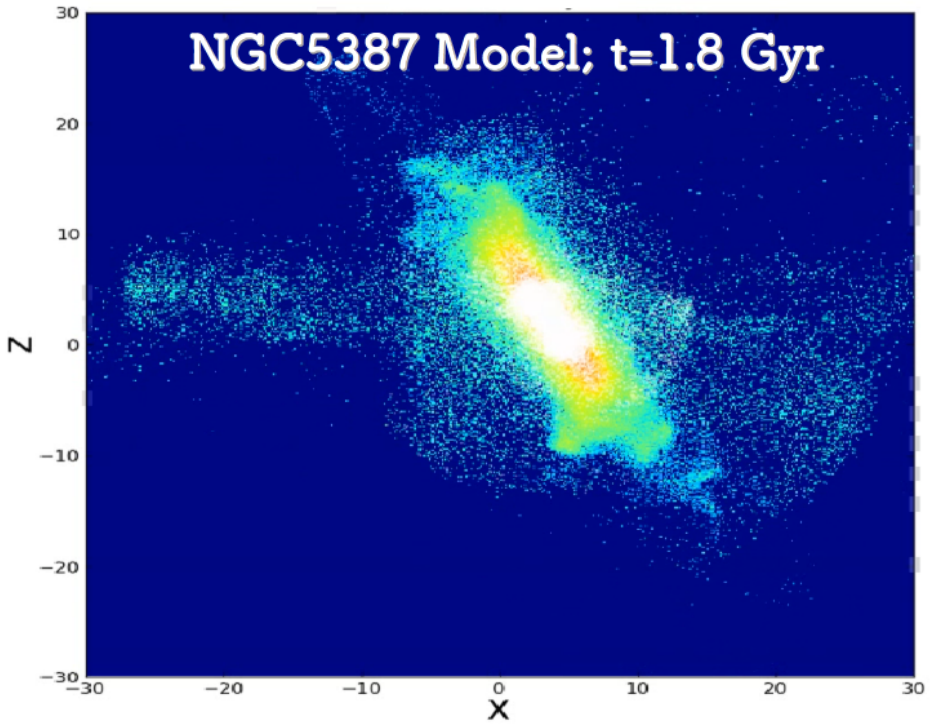


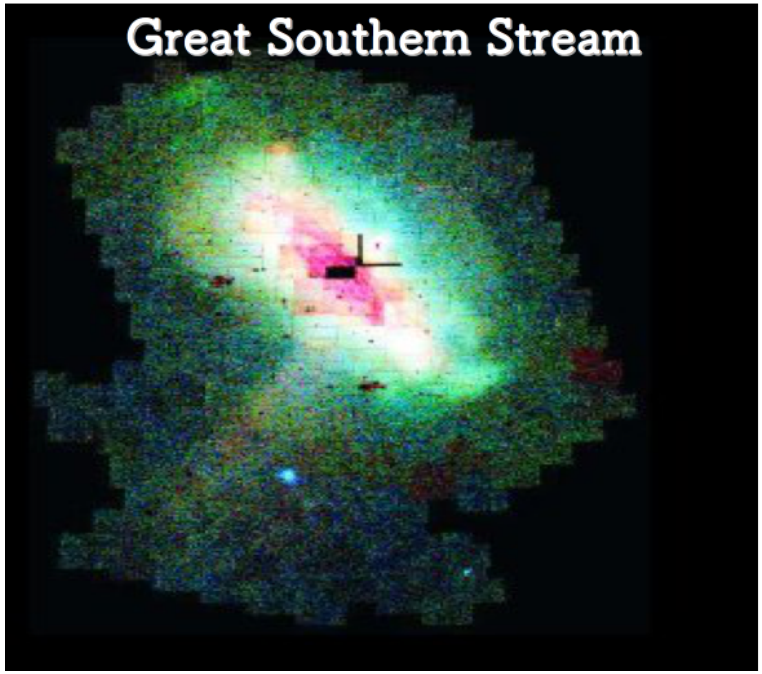
Forms stars in dwarf for another passage

“Quenching Time” ~ 1 Gyr

Dwarf is unbound by ~1.8 Gyr from falling in or ~1.5 Gyr from first signs of harassment

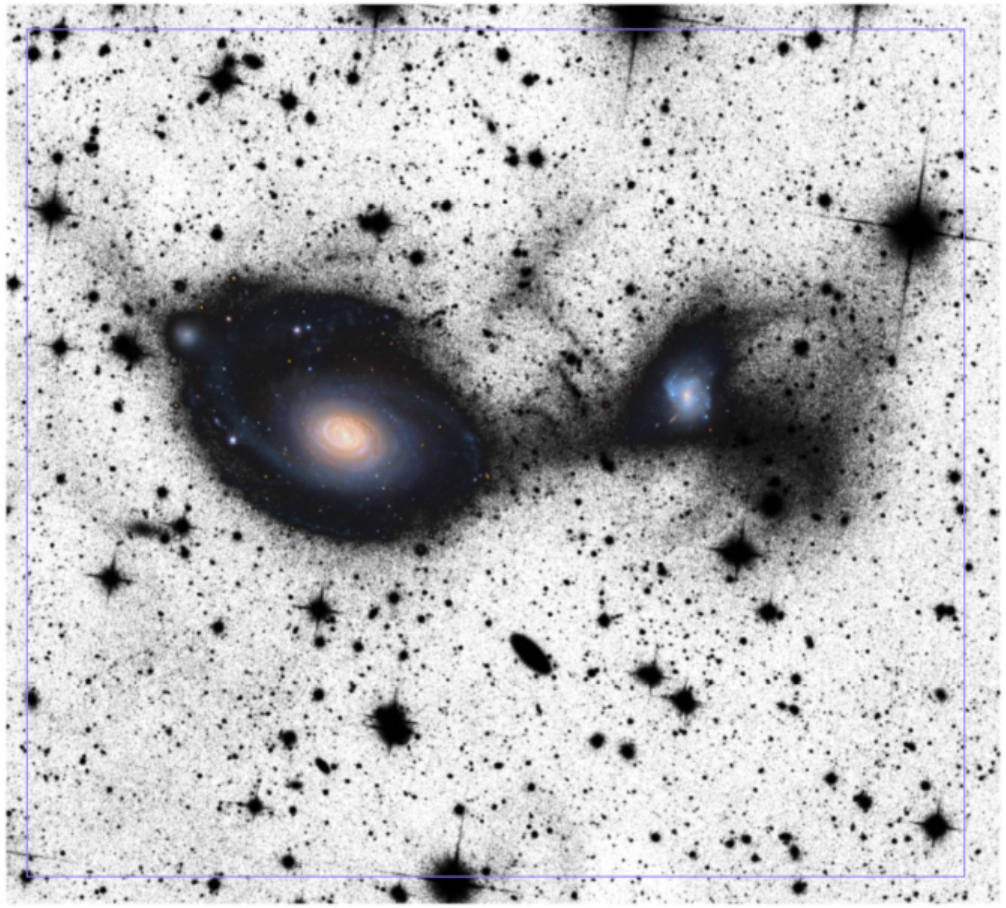
End Game for NGC5387

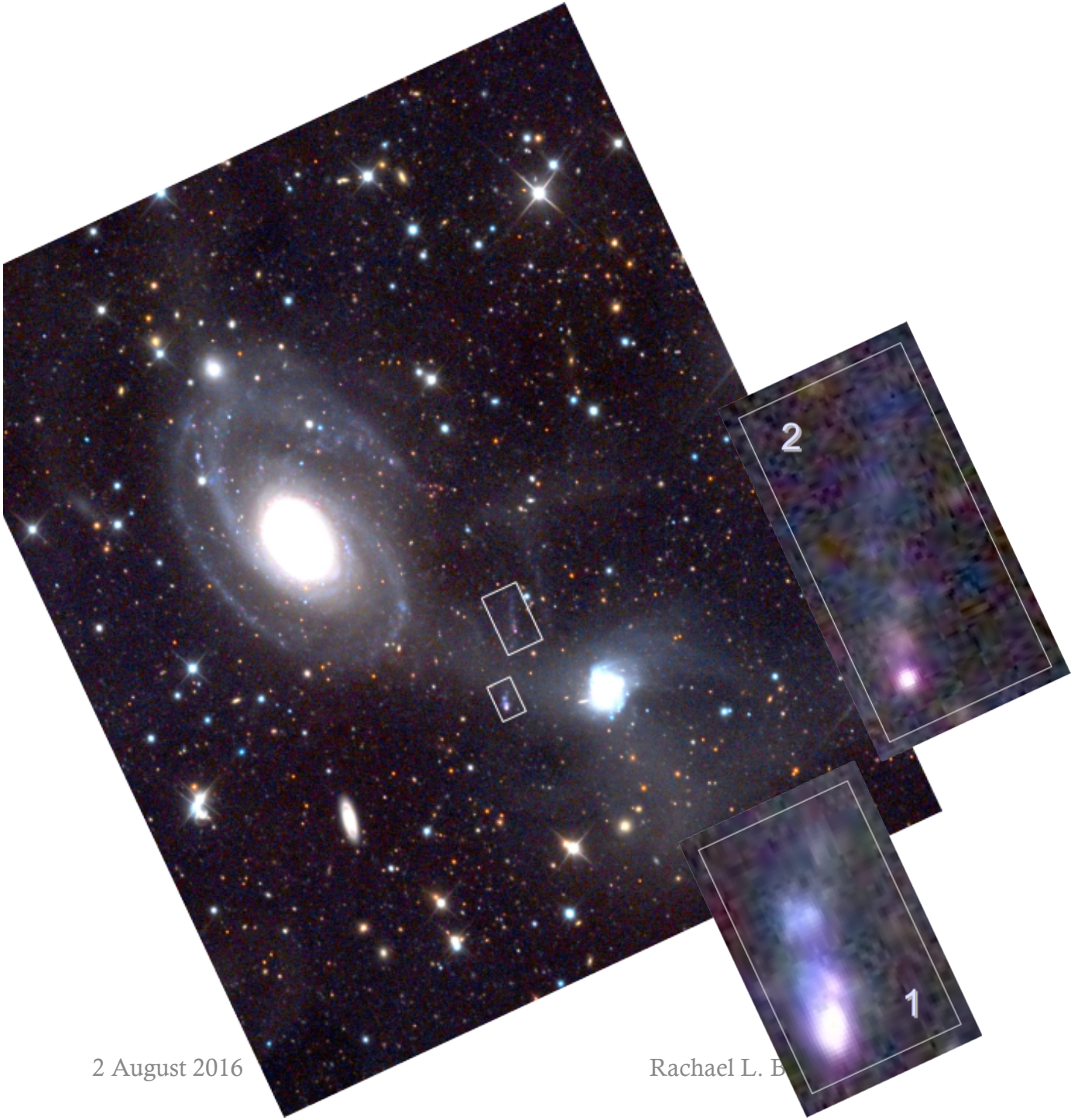


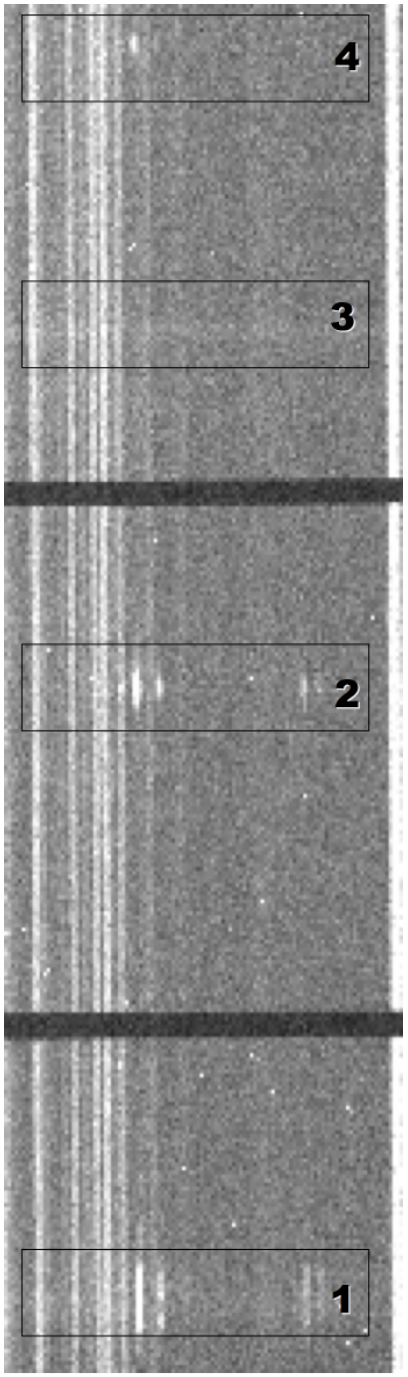


Ferguson et al. 2002
Fardal et al. 2008, 2010
Gilbert et al. 2009

Did I Cherry pick this example?







2D Spectrum

Summary

- There are more interactions in normal galaxies than meet the eye.
  These are not exotic interactions.
- Not every galaxy has a major or minor interaction (once its big enough), but all galaxies have μ-mergers.
- Fossils of accretion history are maintained in the stellar halo.
- Limited in the Local Group, but we can fill in missing pieces using extra-Local Group haloes.