
Results from the
EDGES Survey
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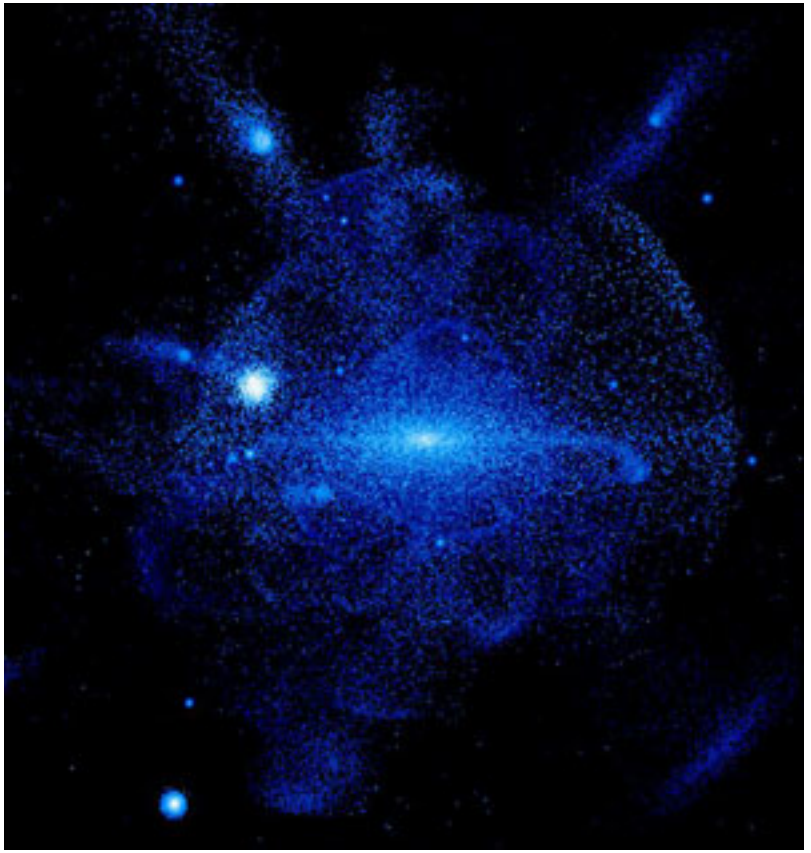
Indiana University

# Background: Galaxy Formation in a Cosmological Context

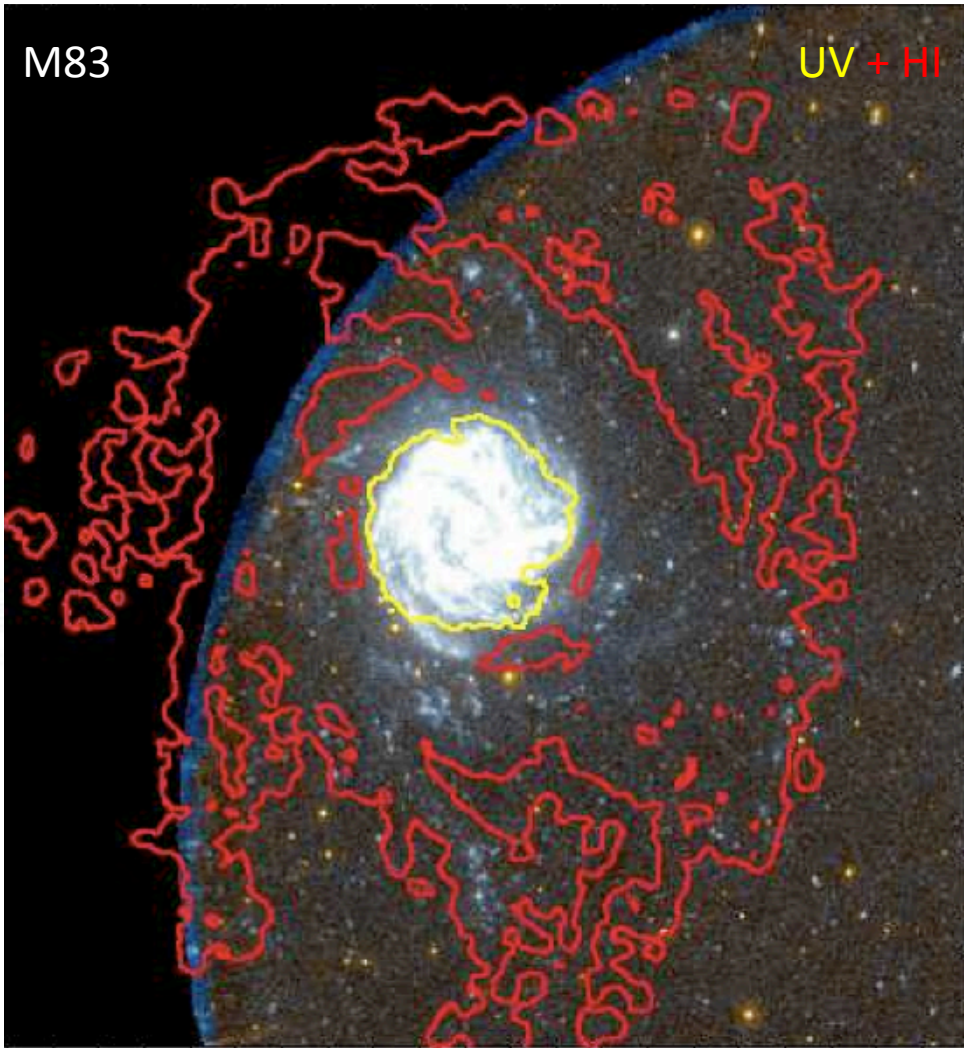
- Faint stellar streams and tidal debris are expected around most galaxies as a result of hierarchical galaxy formation scenarios.



J. Bullock & K. Johnston 2005

# Faint Stellar Populations: Old and Young


Martínez-Delgado et al. 2008, ApJ, 689, 184




Thilker et al. 2005, ApJ, 619, L79

# Why Near-Infrared Observations?
## M/L is Less Sensitive to Stellar Population



T=30,000 K

T=10,000 K

T=5,000 K

T=3,000 K

IRAC
Ch1

Dust, T=100 K

Intensity (arbitrary units)

$10^{14}$ $10^{13}$ $10^{12}$ $10^{11}$ $10^{10}$ $10^{9}$ $10^{8}$ $10^{7}$ $10^{6}$ $10^{5}$ $10^{4}$

0.1 1 10 100

Wavelength ($\mu$m)

# EDGES: Extended Disk Galaxy Exploration Science Survey

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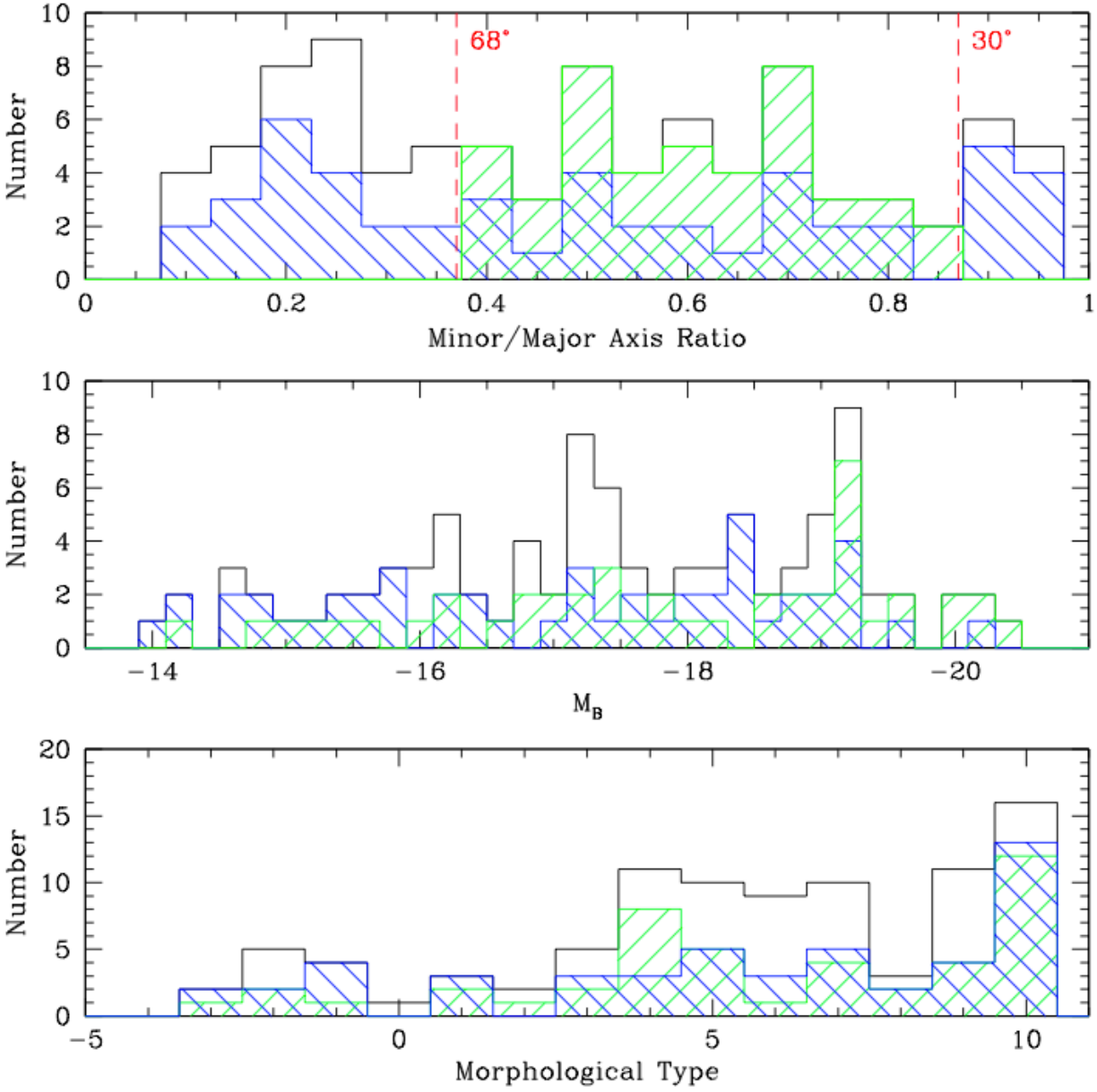
- *Spitzer* 3.6μm survey of 92 galaxies, spanning a wide range of morphology, luminosity, and environment.
- We are sensitive to stellar mass surface densities of few × 0.01 $M_{\odot}/pc^2$, independent of star formation history.
- Our wide FOV observations allow us to trace substructures out to 5× $R_{25}$.
- When the analysis is complete, we will create a census with the first quantitative measurements of low surface brightness features identified around nearby galaxies.

# EDGES Sample

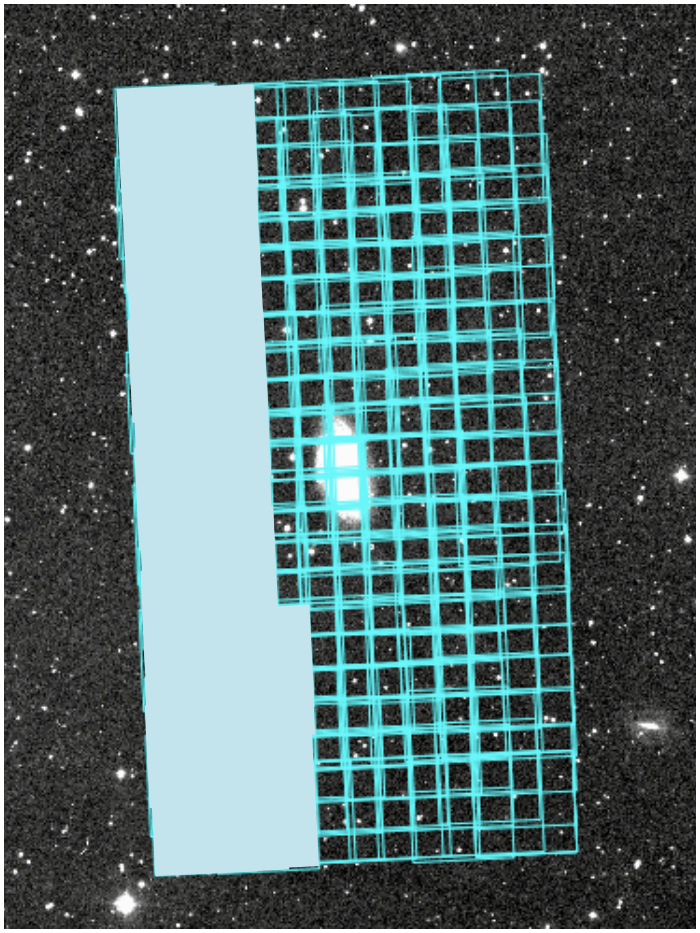



- *Black: full EDGES sample*
- *Blue: GALEX sub-sample*
- *Green: kinematic sub-sample*

# EDGES Survey Design

- **Deep:** 1800 s/pixel
- **Wide:** at least 5× $R_{25}$
- **IR:** Relatively insensitive to stellar population and dust extinction

- Concerns: sky background stability and point source masking
- Two precursor studies in Cycle 6:
  - M83
  - Dwarf Galaxies with Extended HI Distributions

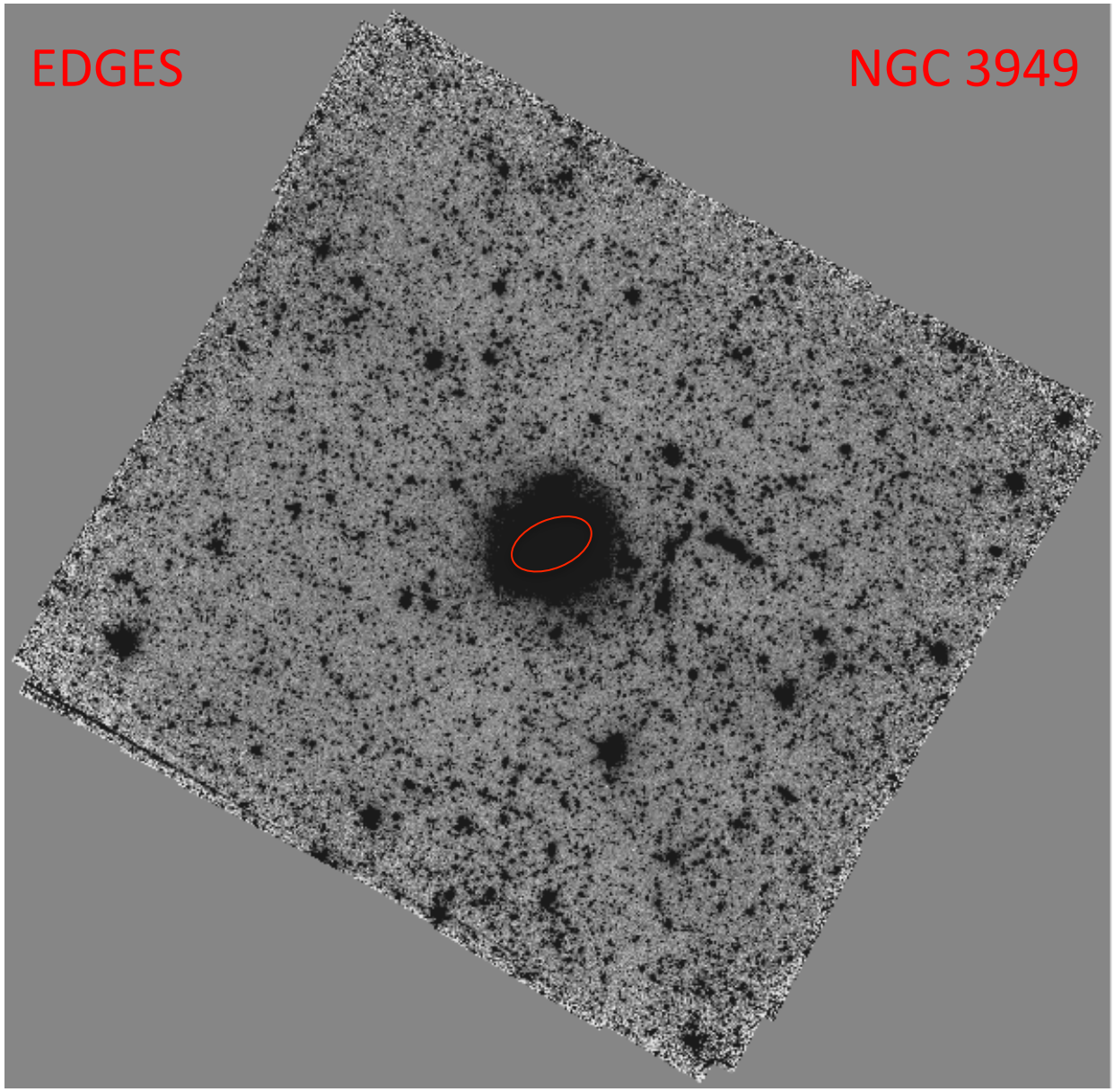


NGC3953: 40’ × 21.7’
a x b : 6.9’ × 3.5’

# Comparison to Other *Spitzer* Surveys

- For example: SINGS, LVL, S$^4$G:
  - Shallow: 240 s/pixel
  - Small: at least 1× $R_{25}$ (usually)
  - IR: Relatively insensitive to stellar population and dust extinction
- Consider NGC 3949, observed by Swaters et al. in Cycle 3 and reprocessed by S$^4$G

# Comparison to Other *Spitzer* Surveys

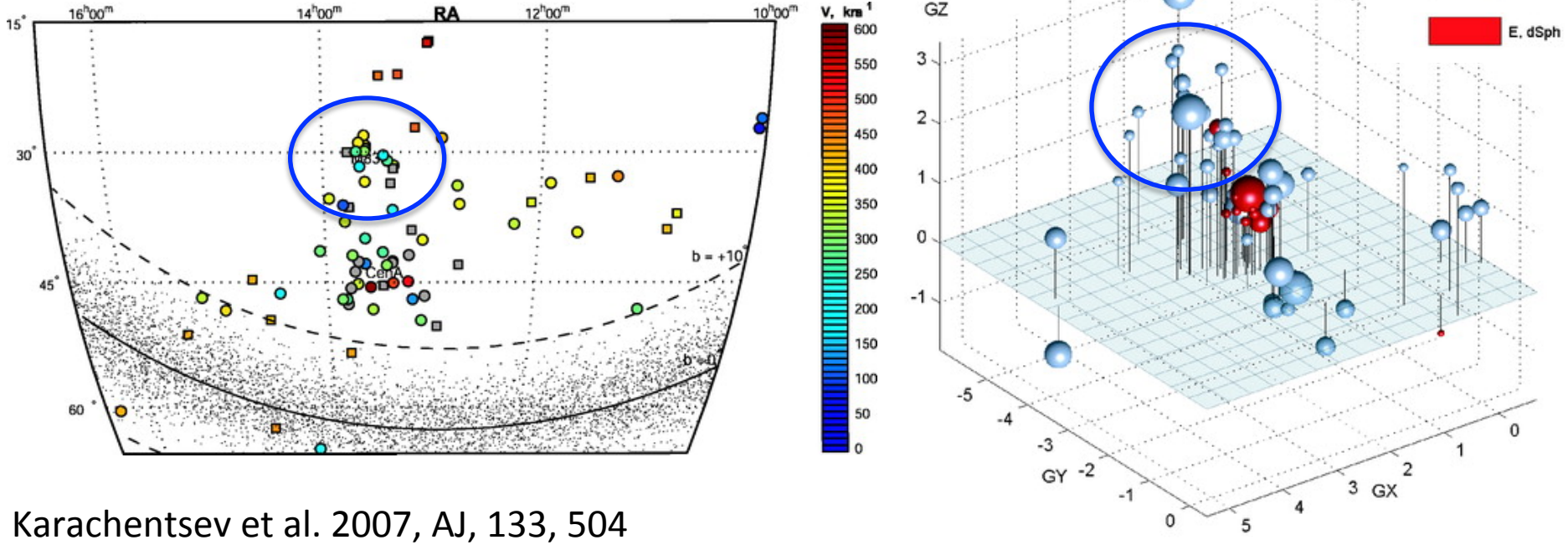


# M83: Young and Old Stellar Streams

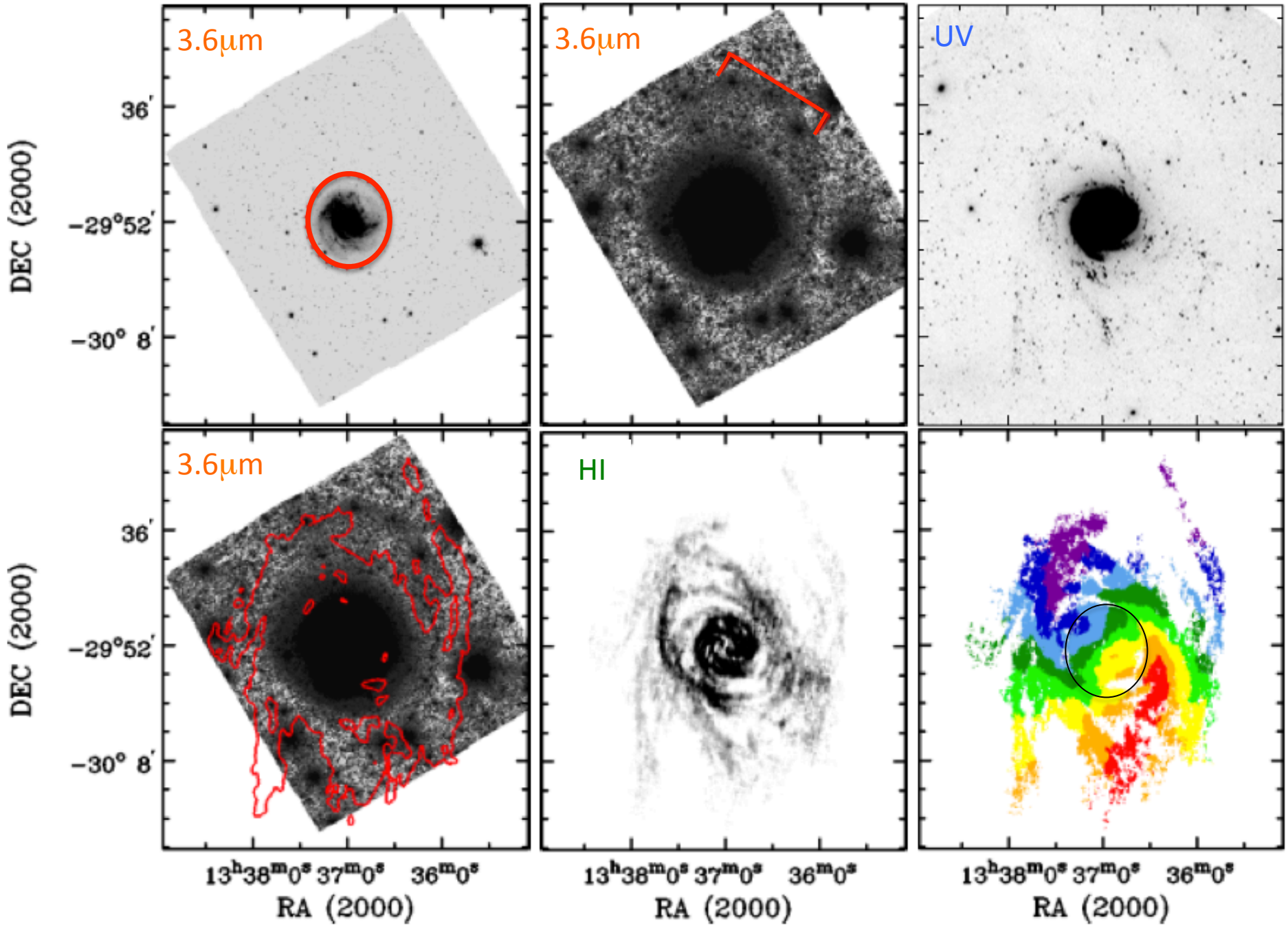
- M83 has long been known to have an extended HI distribution, with a strong warp in the inner disk and arms extending to $3\times R_{25}$ (Rogstad et al. 1976)
- UV imaging with GALEX revealed an extended star forming disk (Thilker et al. 2005)
- Deep optical imaging revealed an extended stellar stream (Malin & Hadley 1997)
  - Part of this stream was identified as KK98-208 (Karachentseva & Karachentsev 1998)

# M83: A Complex Environment

- The M83 group is located at a mean distance of 4.79 Mpc; the neighboring Cen A group is located at a mean distance of 3.76 Mpc

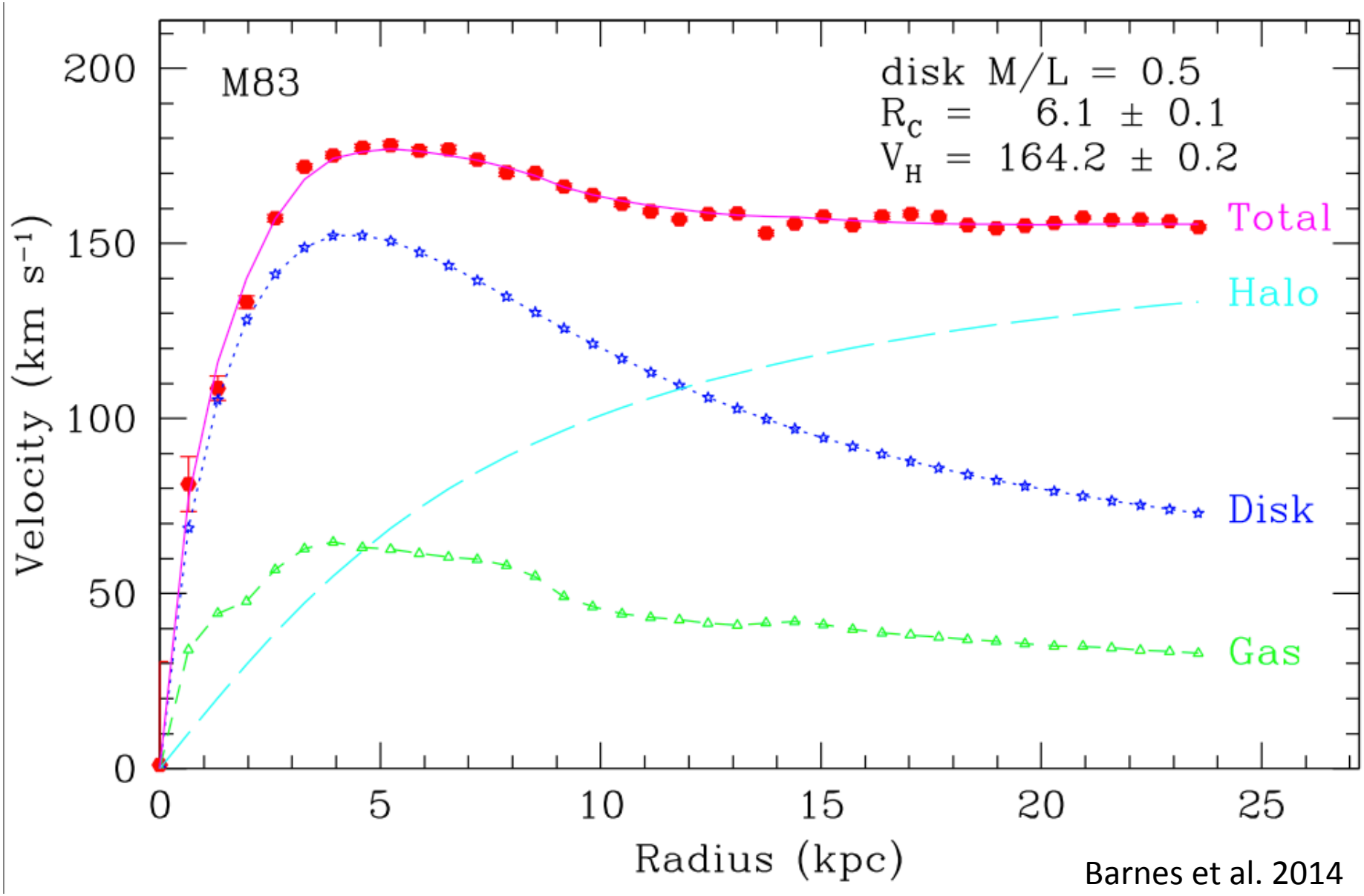



Karachentsev et al. 2007, AJ, 133, 504



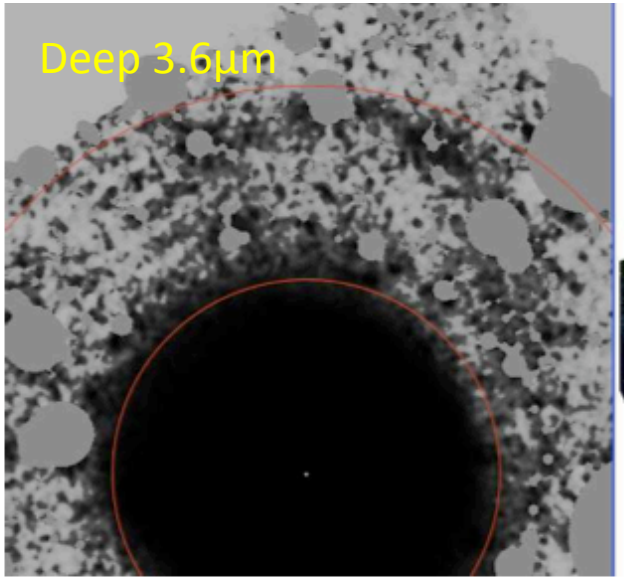

Barnes et al. 2014

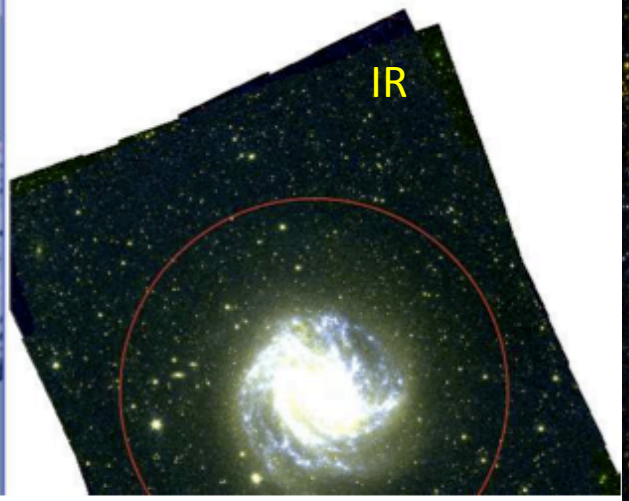
# Mass-to-light Ratios

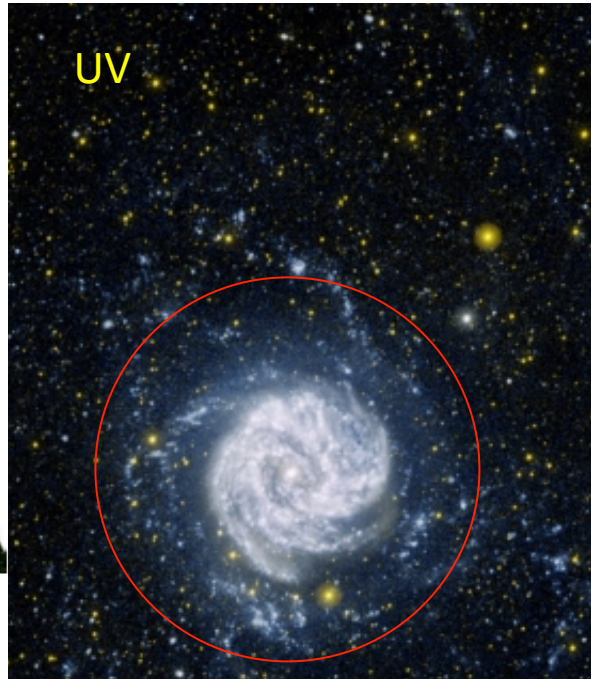


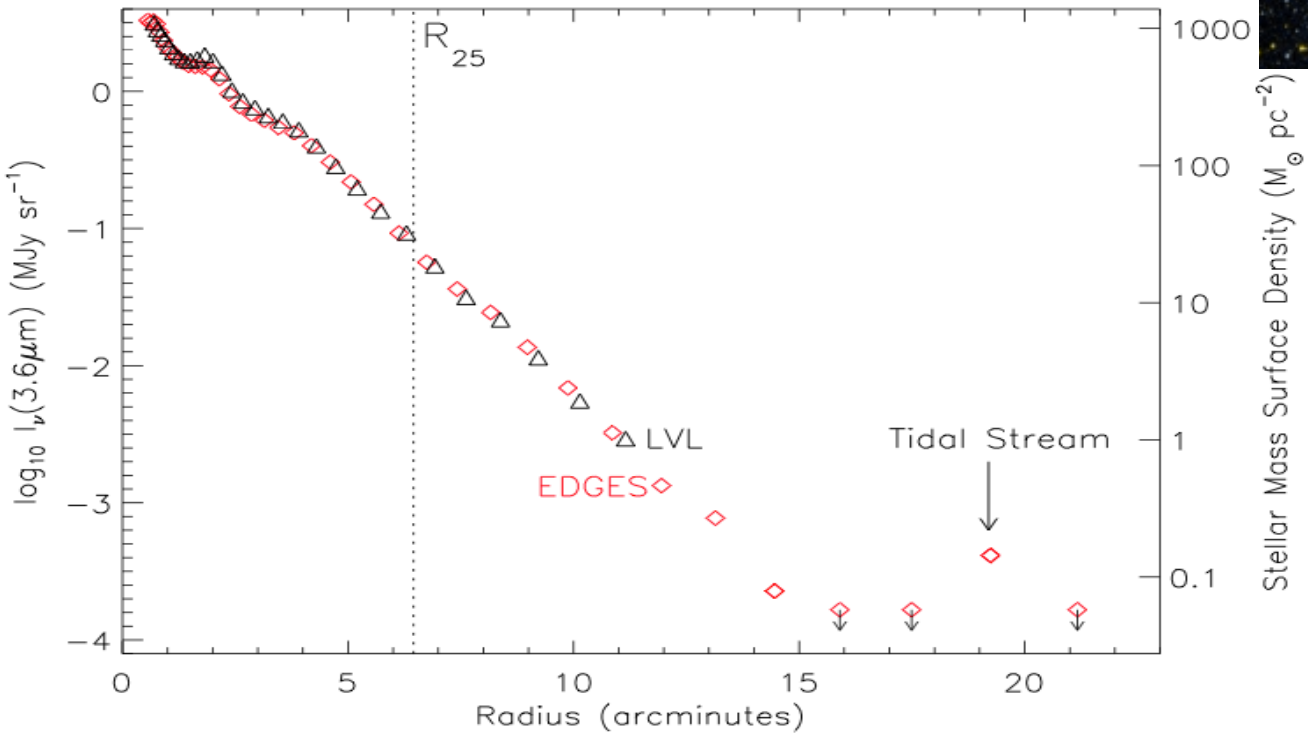

Barnes et al. 2014

# M83



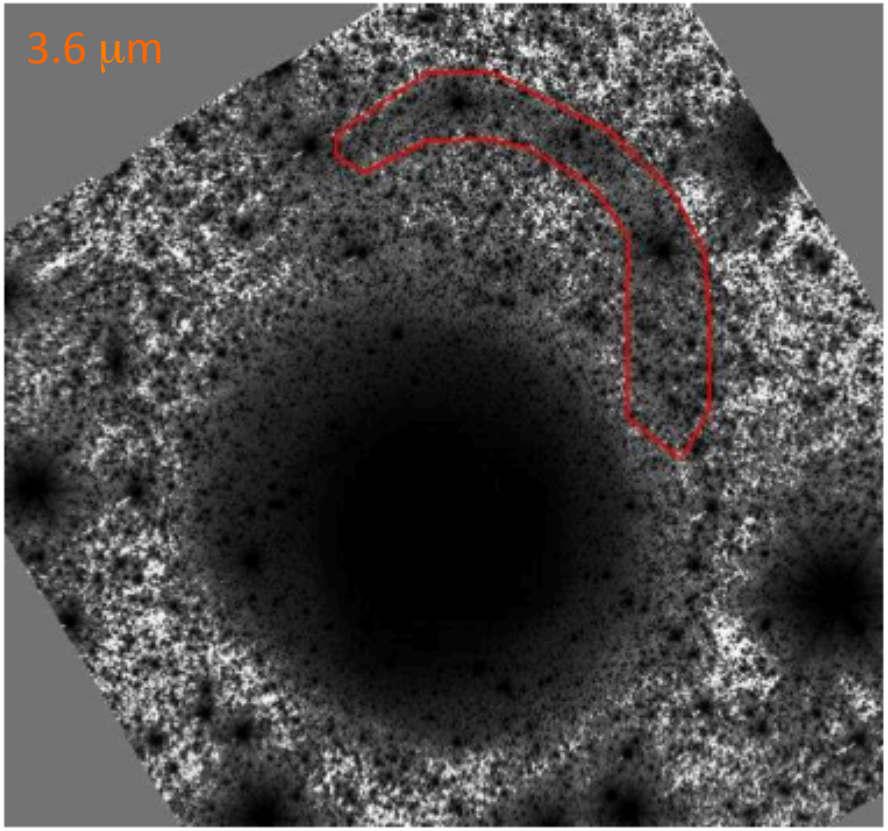



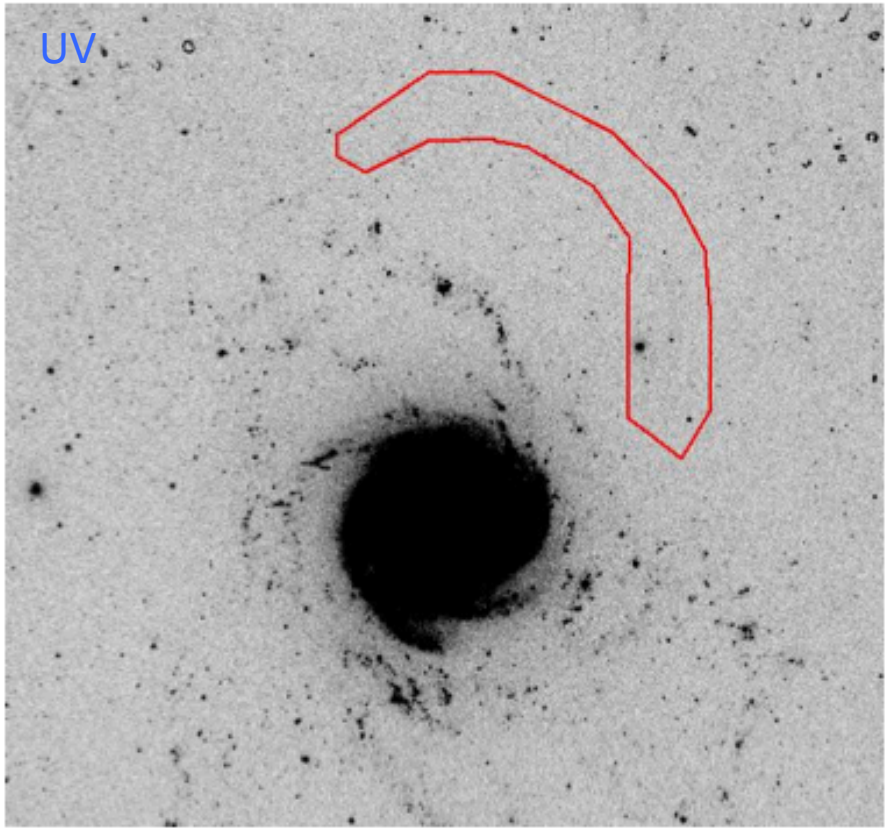




Barnes et al. 2014

# Stellar Stream in M83

- No current star formation activity associated with the stellar stream

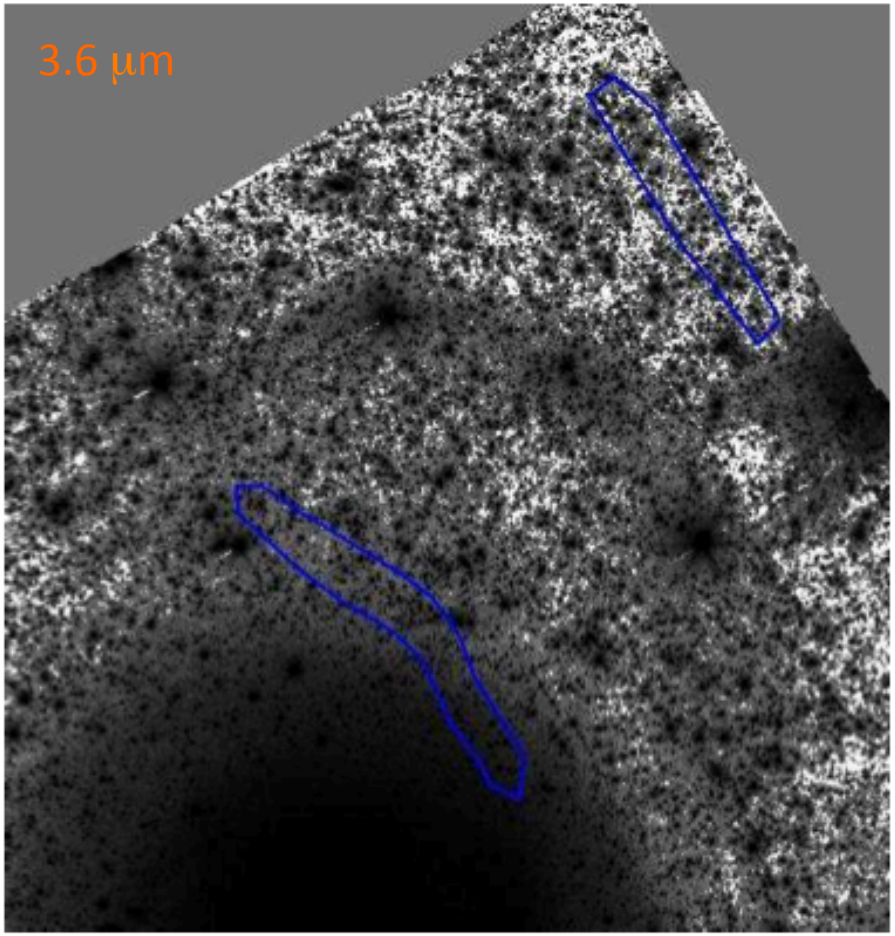


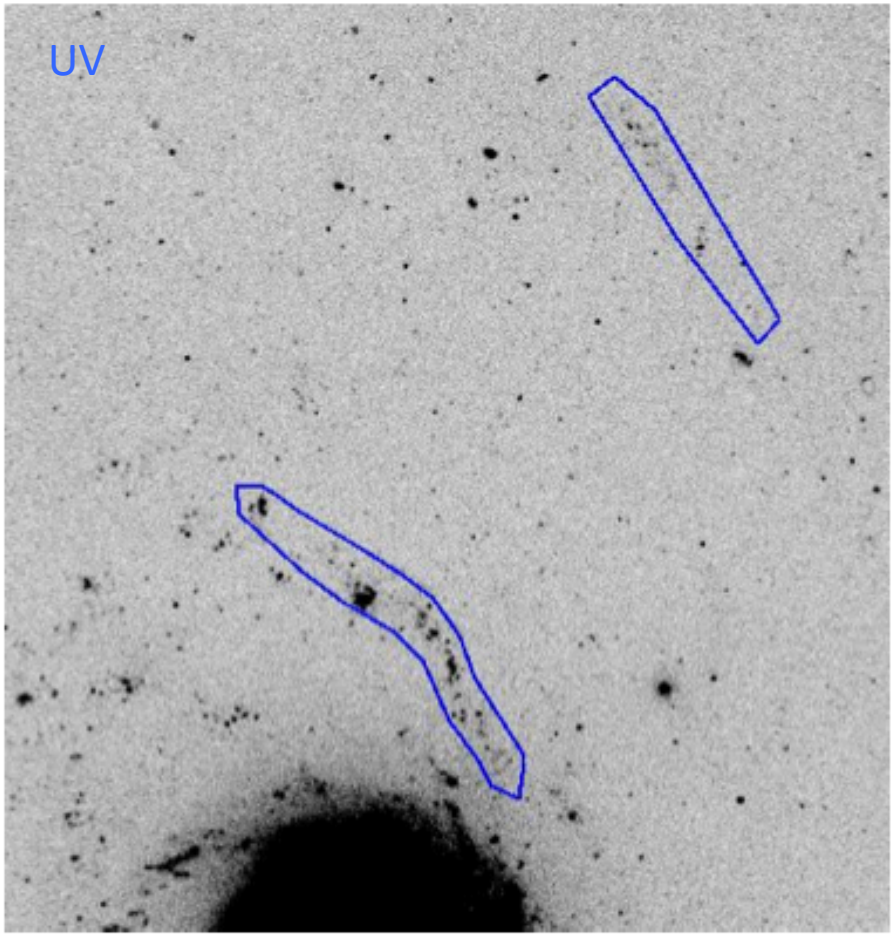




Barnes et al. 2014

# Stellar Stream in M83

- Outer FUV arm is extremely young

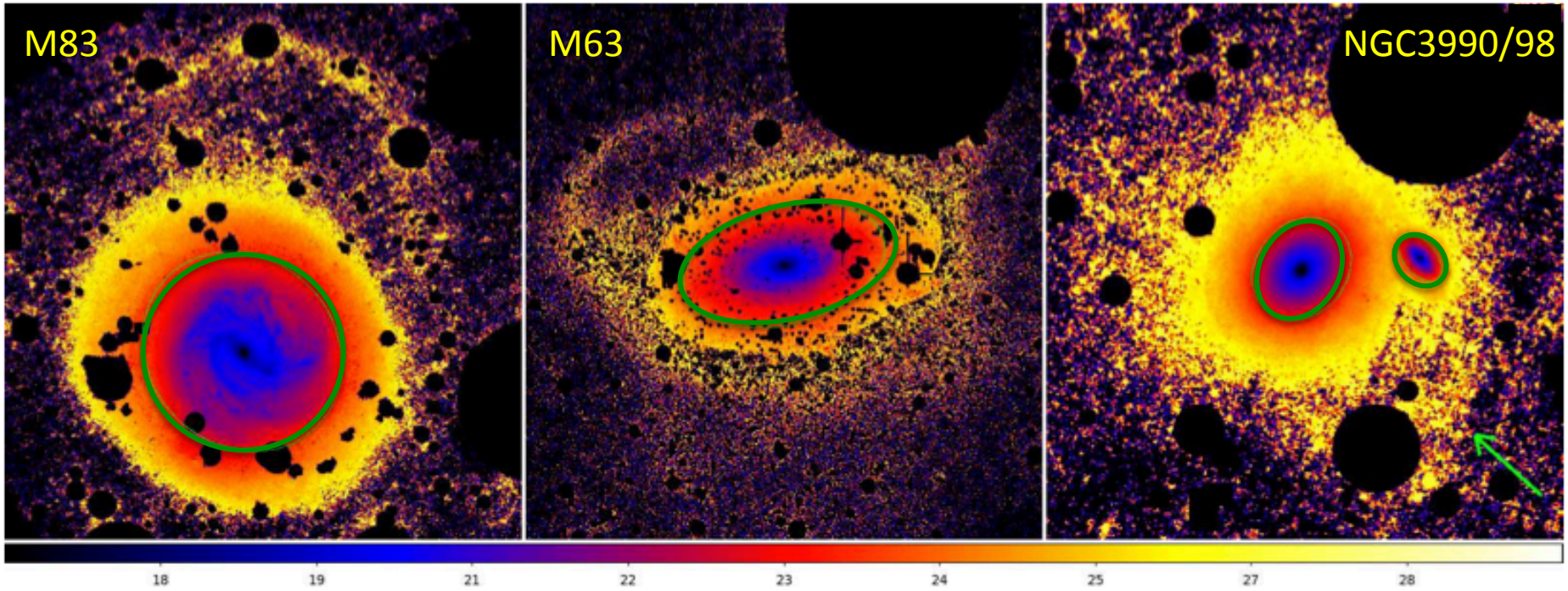



Barnes et al. 2014

# EDGES Results

- Full EDGES survey includes 92 normal galaxies
- We detect extended stellar distributions and stellar streams in many of these fields



# M63

UV+optical+IR

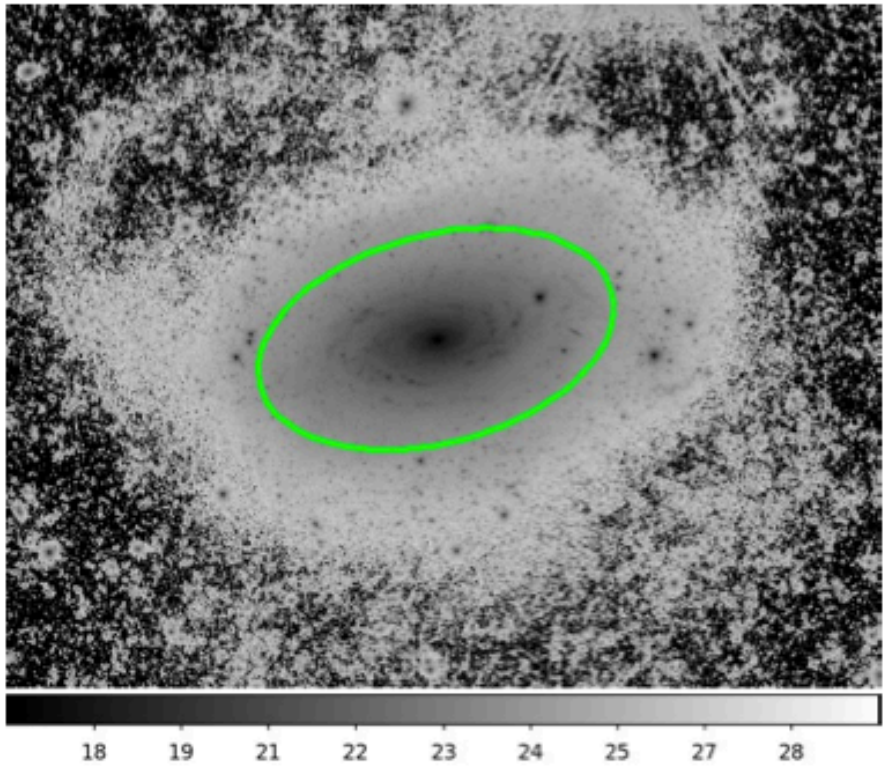
1528 Å, B, R, 3.6 μm

Radio

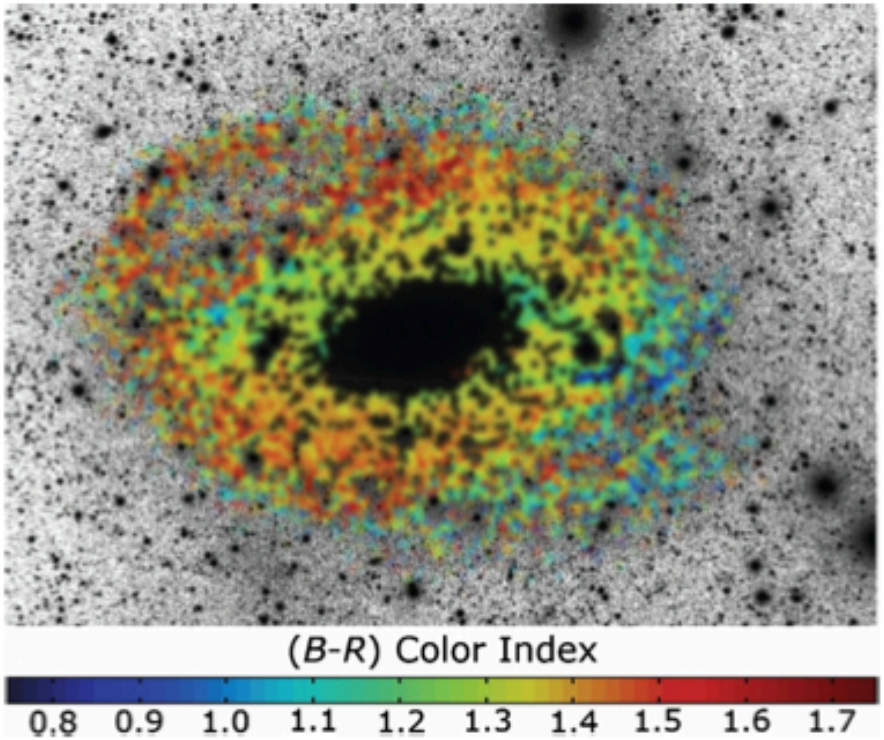
HI, B, R


# The stellar streams associated with M63 have complex stellar populations

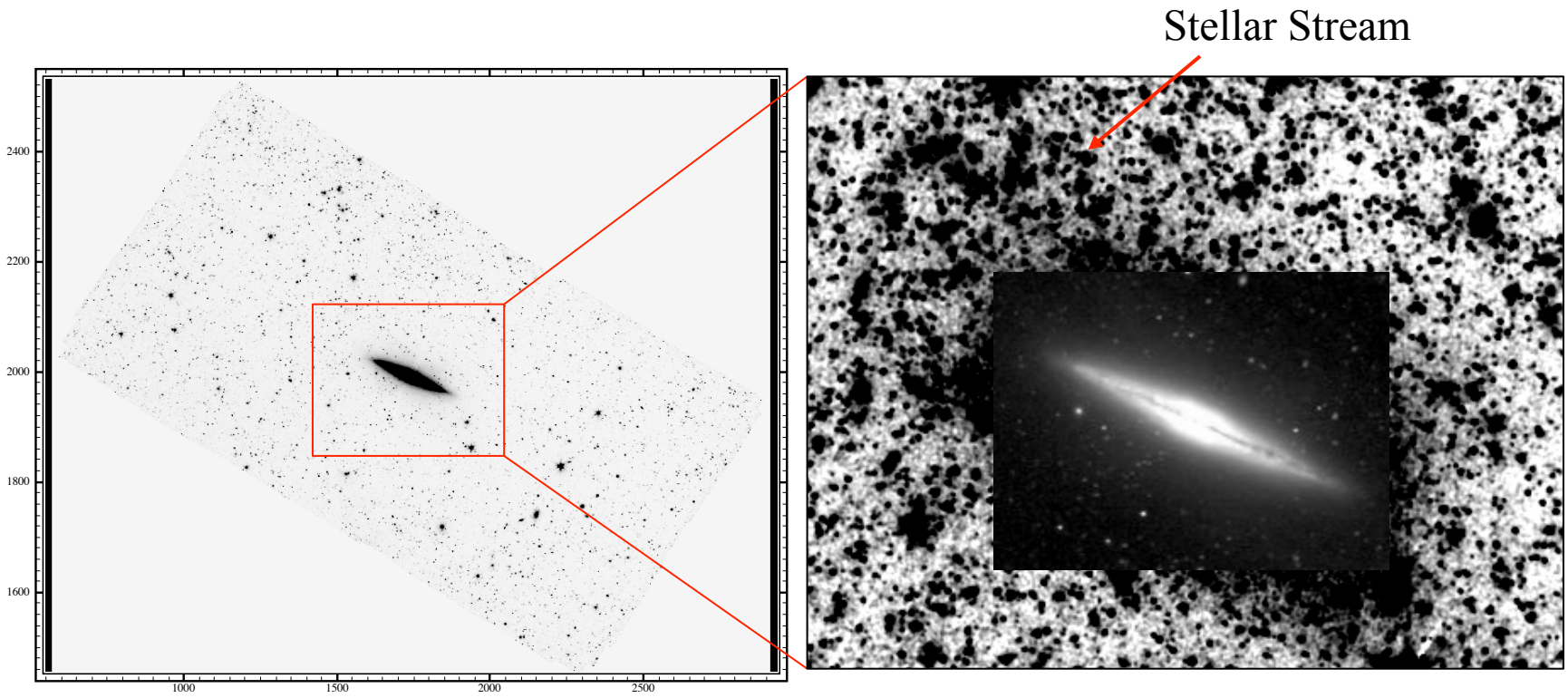
M63 at 3.6μm, EDGES




M63 in B-R, Chonis et al. 2011



# EDGES Results: NGC 4013

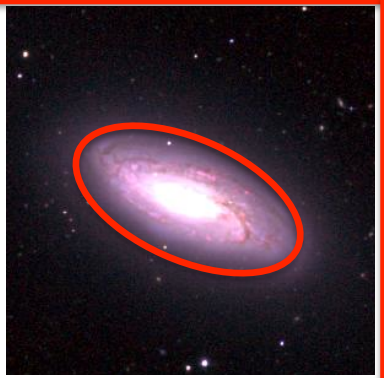


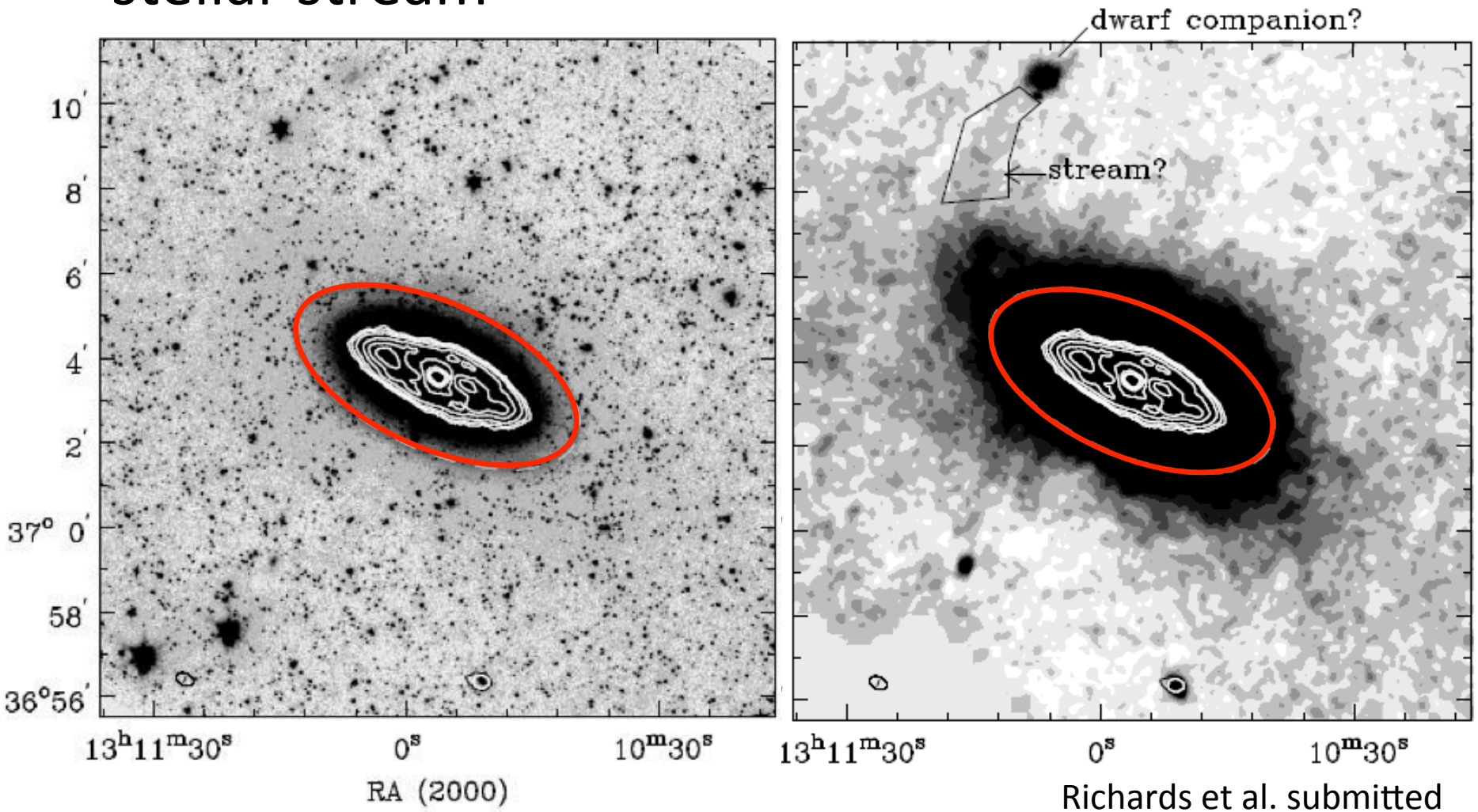

This stellar stream was previously identified by Martínez-Delgado et al. (2009) based on ground-based optical imaging. Note the over-density of point sources, which may be globular clusters associated with the stellar stream.

Staudaher et al. in prep

# EDGES Results: NGC 5005

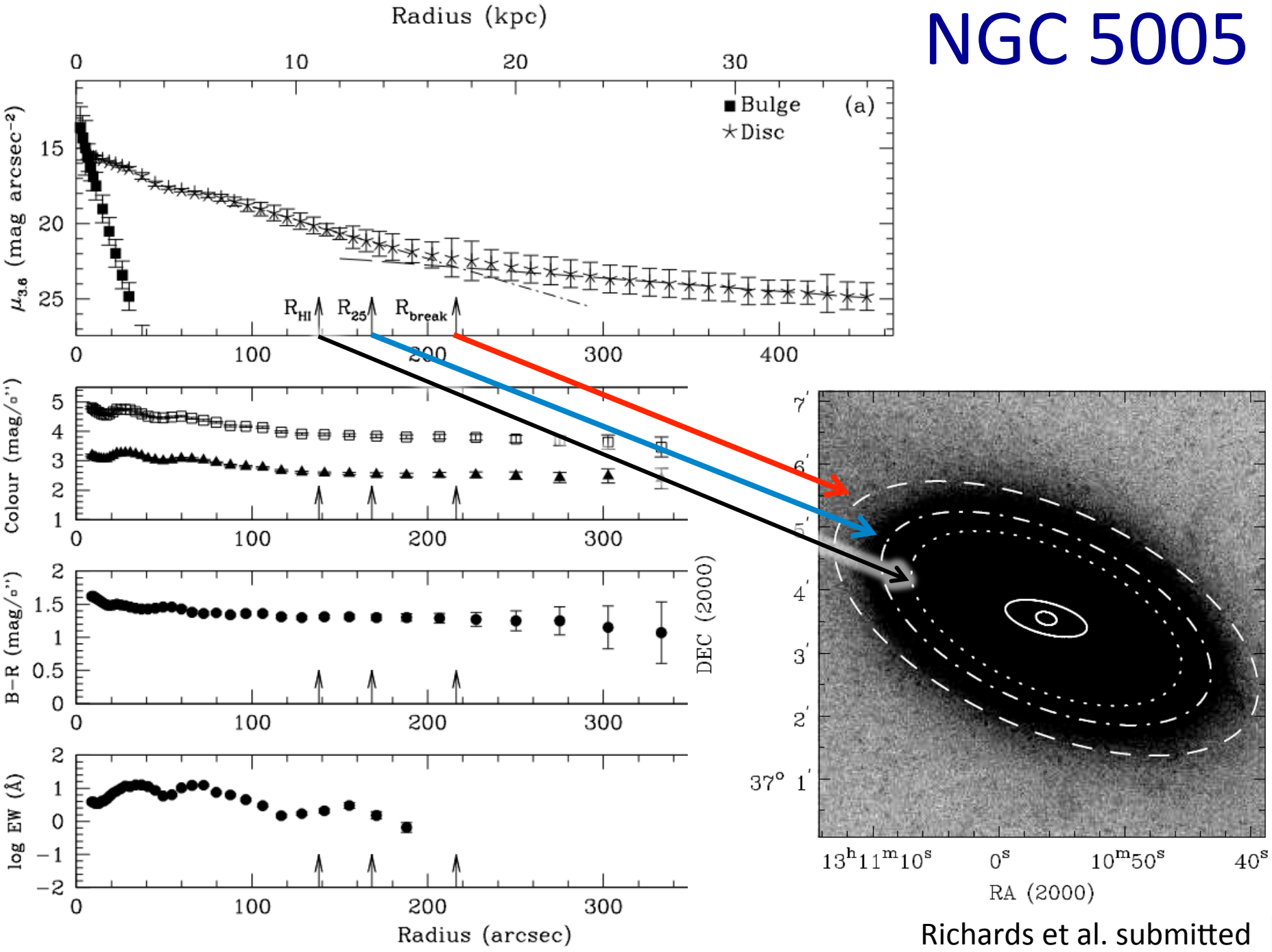
- Extended stellar distribution and stellar stream






Richards et al. submitted

# NGC 5005



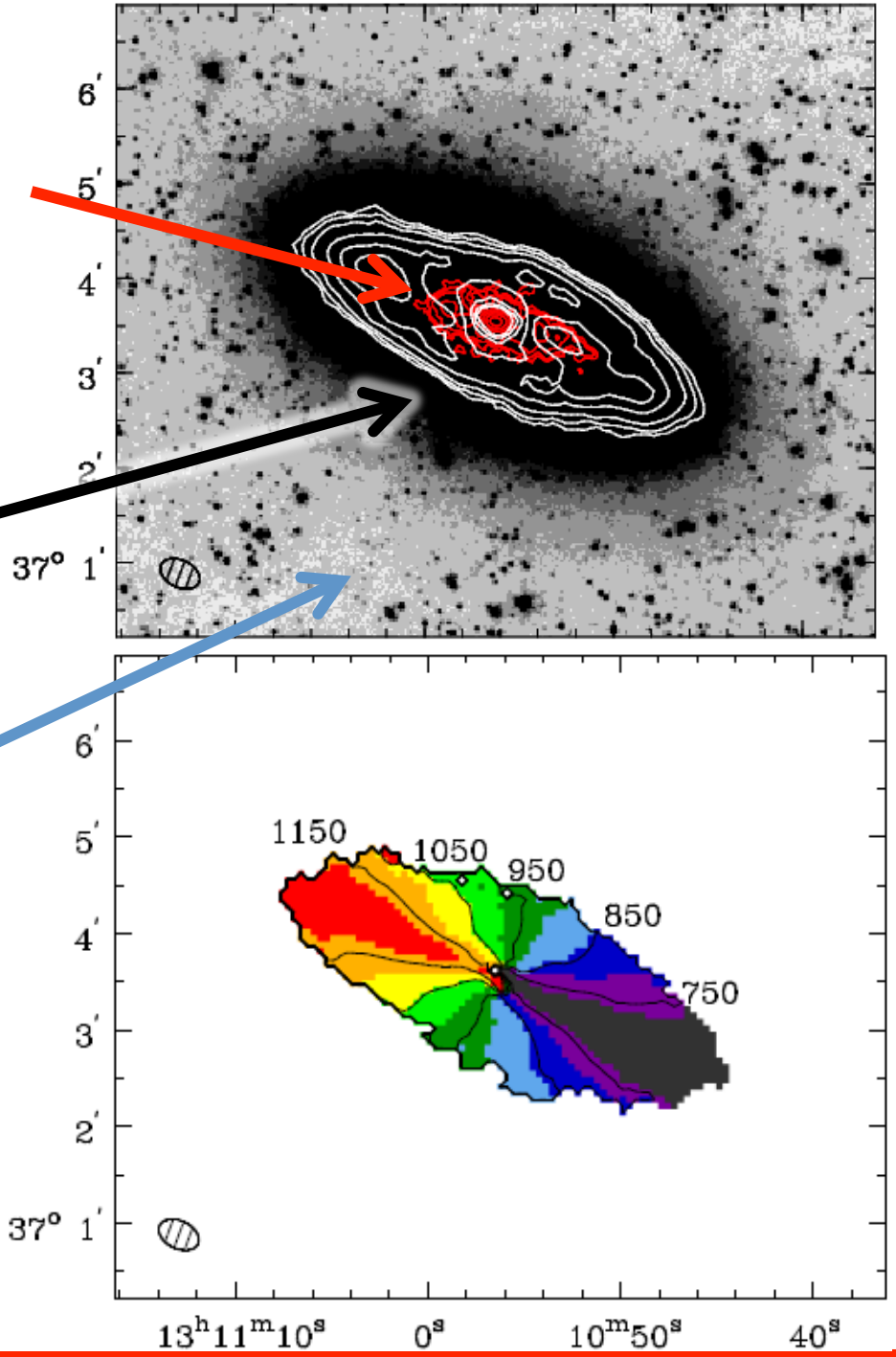

Richards et al. submitted

# NGC 5005

**CO**
**(BIMA SONG; Helfer et al. 2003)**

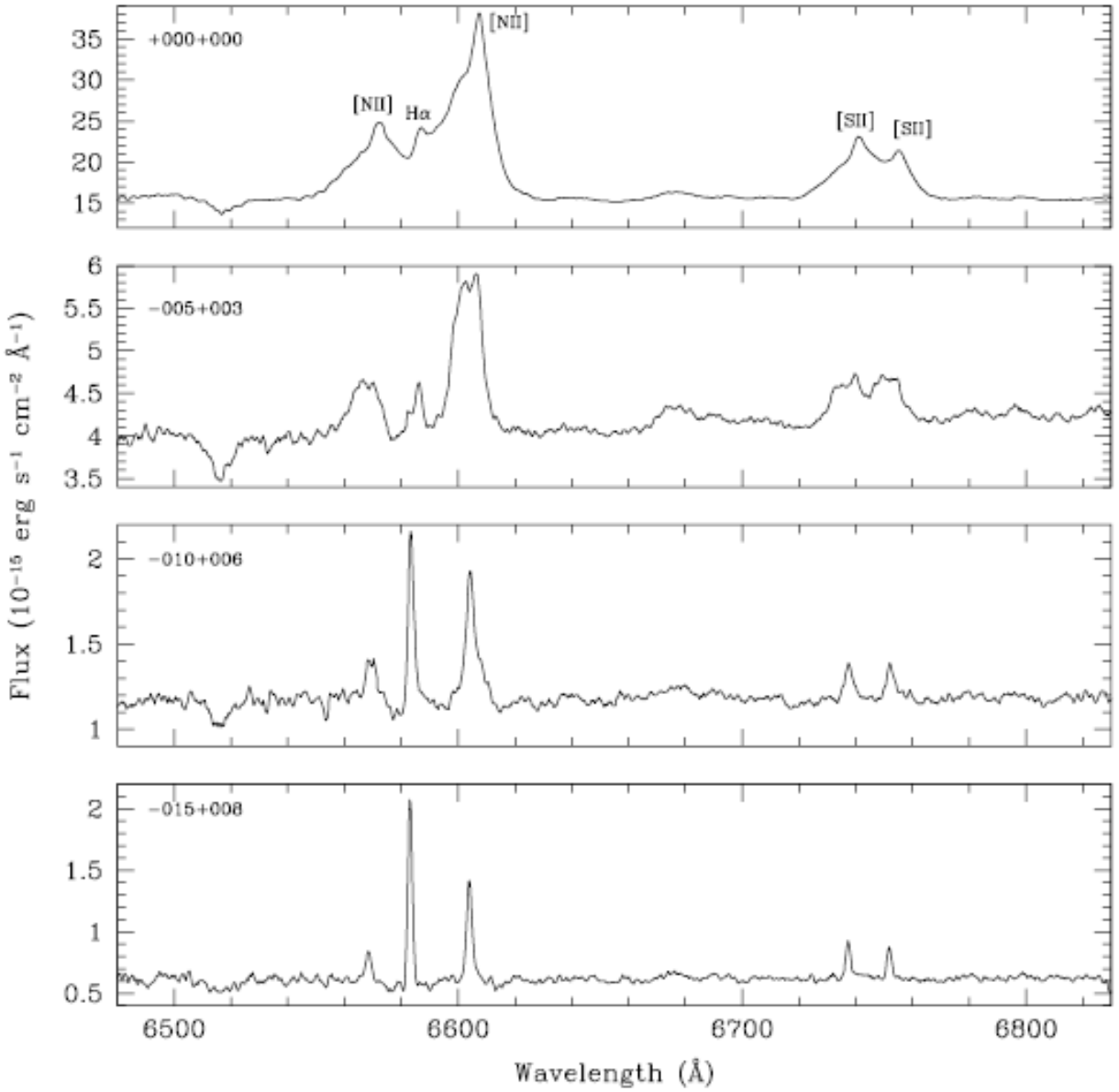
**HI**
**(VLA 21cm)**
**1st contour =**
**$10^{20}$ atoms $cm^{-2}$**

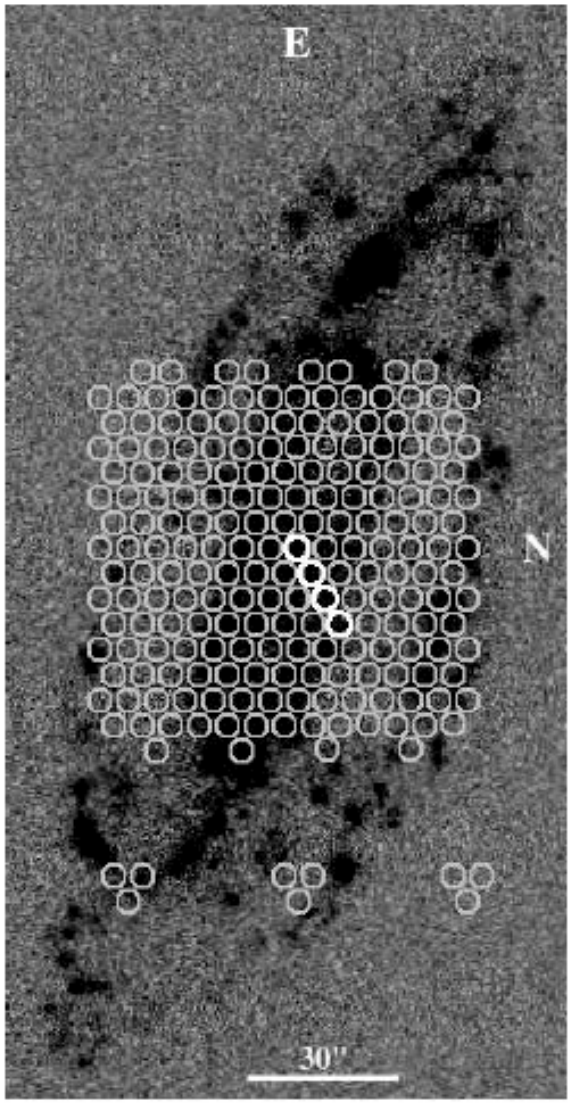
**extended stellar disk**
**(*Spitzer* 3.6μm)**




Richards et al. submitted

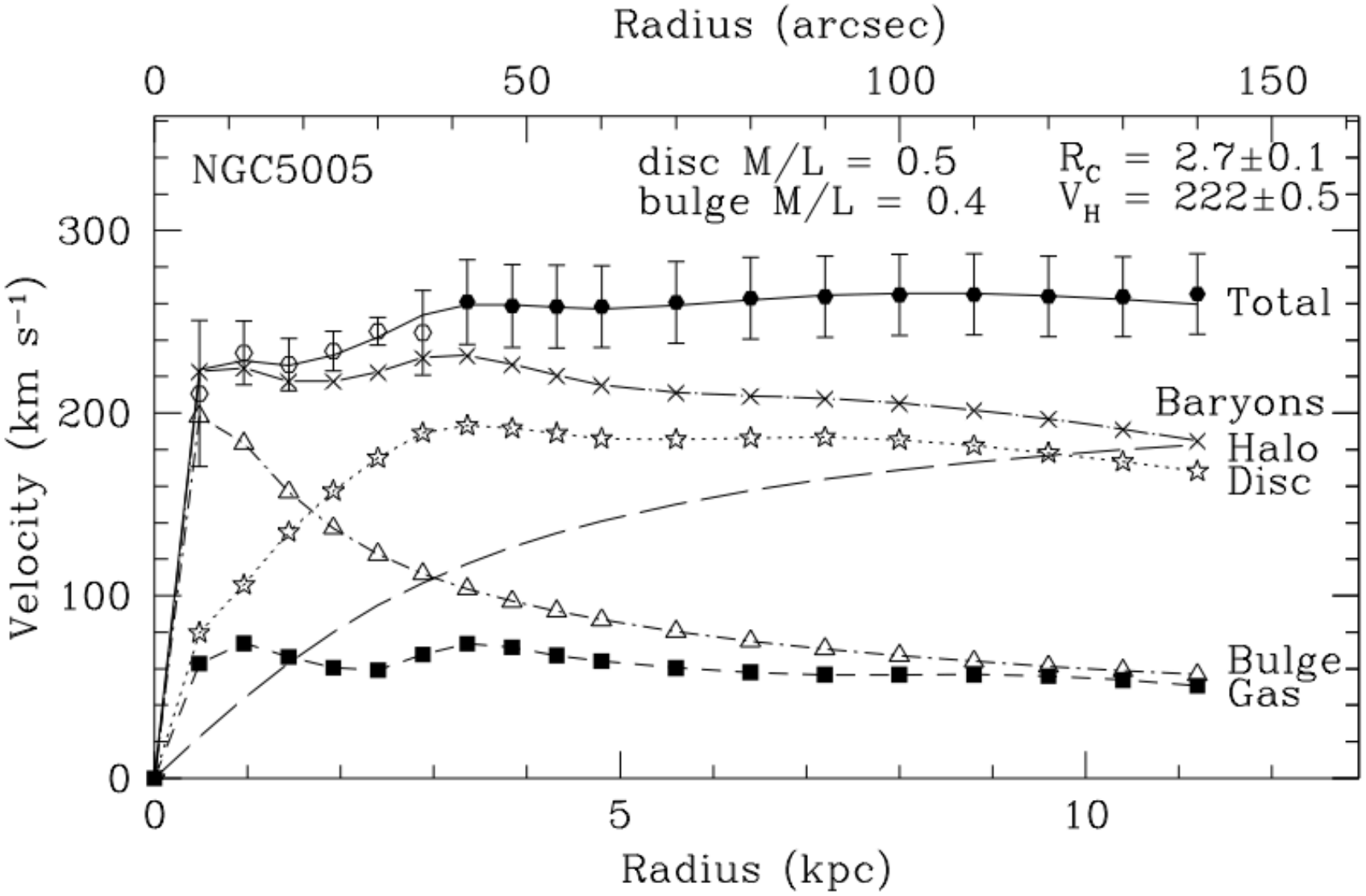
# NGC 5005: Sparsepak Observations




Richards et al. submitted

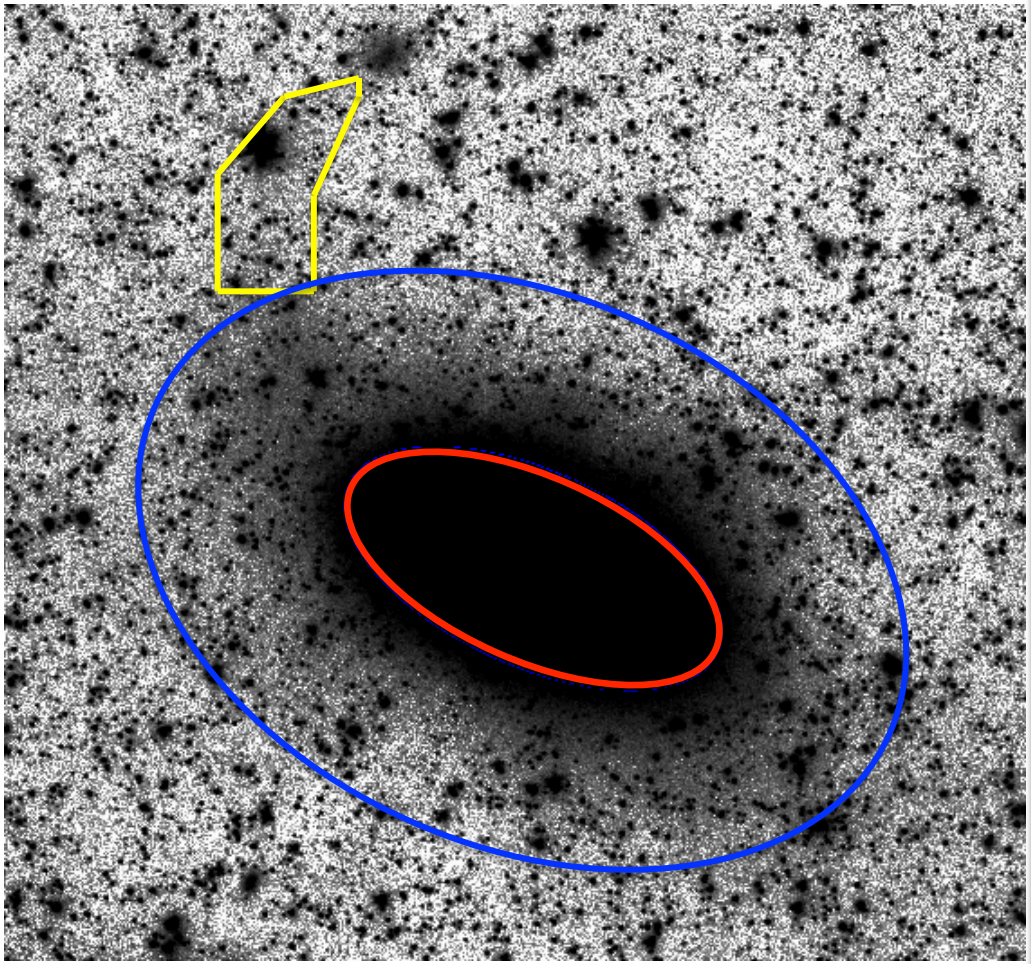
# NGC 5005: Rotation Curve Decomposition




Richards et al. submitted

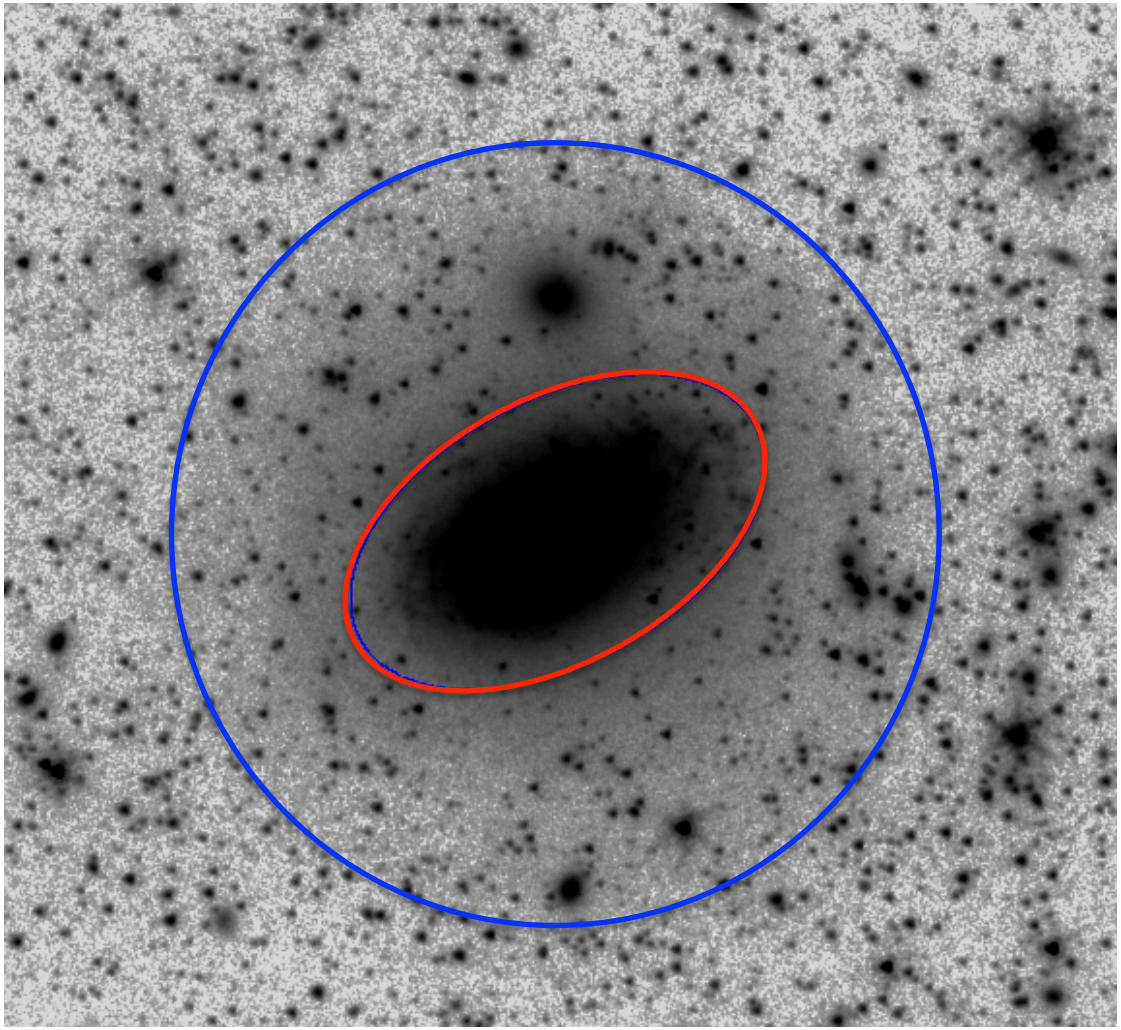
# NGC 5005: Stellar Stream

- Stellar stream corresponds to $M \sim 1.8 \times 10^7 M_\odot$
- Extended structure corresponds to 3% of total light



Richards et al. submitted

# EDGES Results: NGC 3949

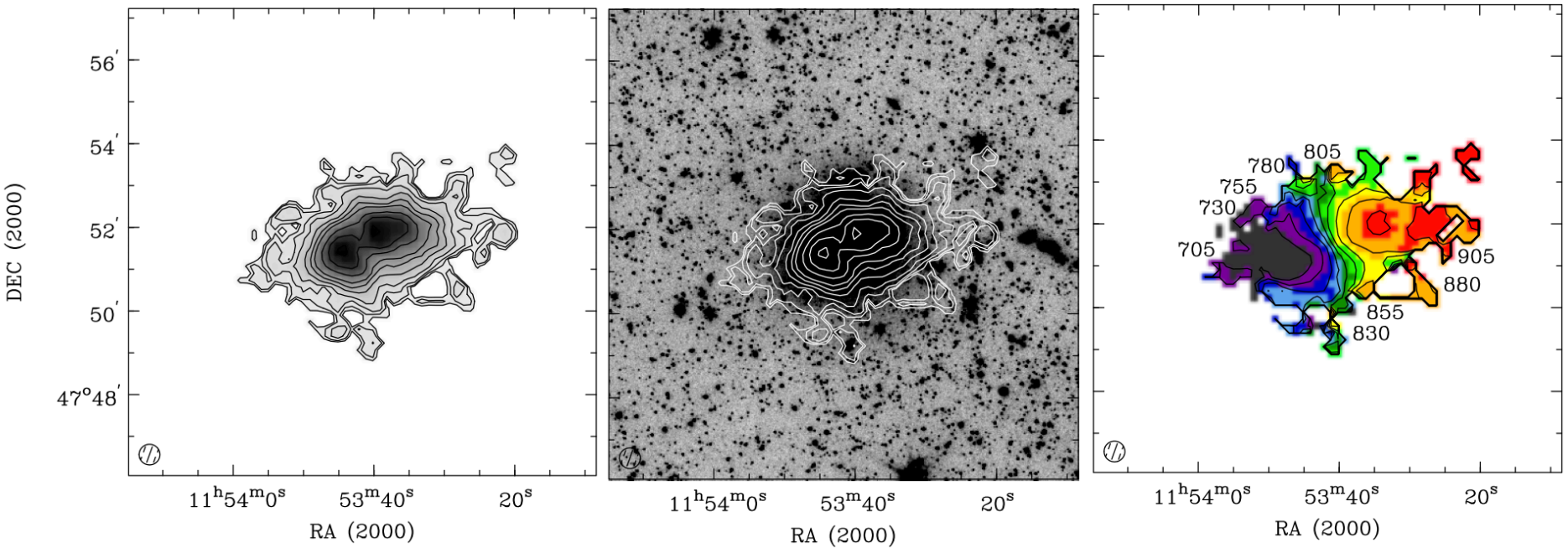


Extended structure in NGC 3949 has a change in morphology relative to the high surface brightness disk. Is this a result of a warp, or a stellar halo?

Barnes et al. in prep

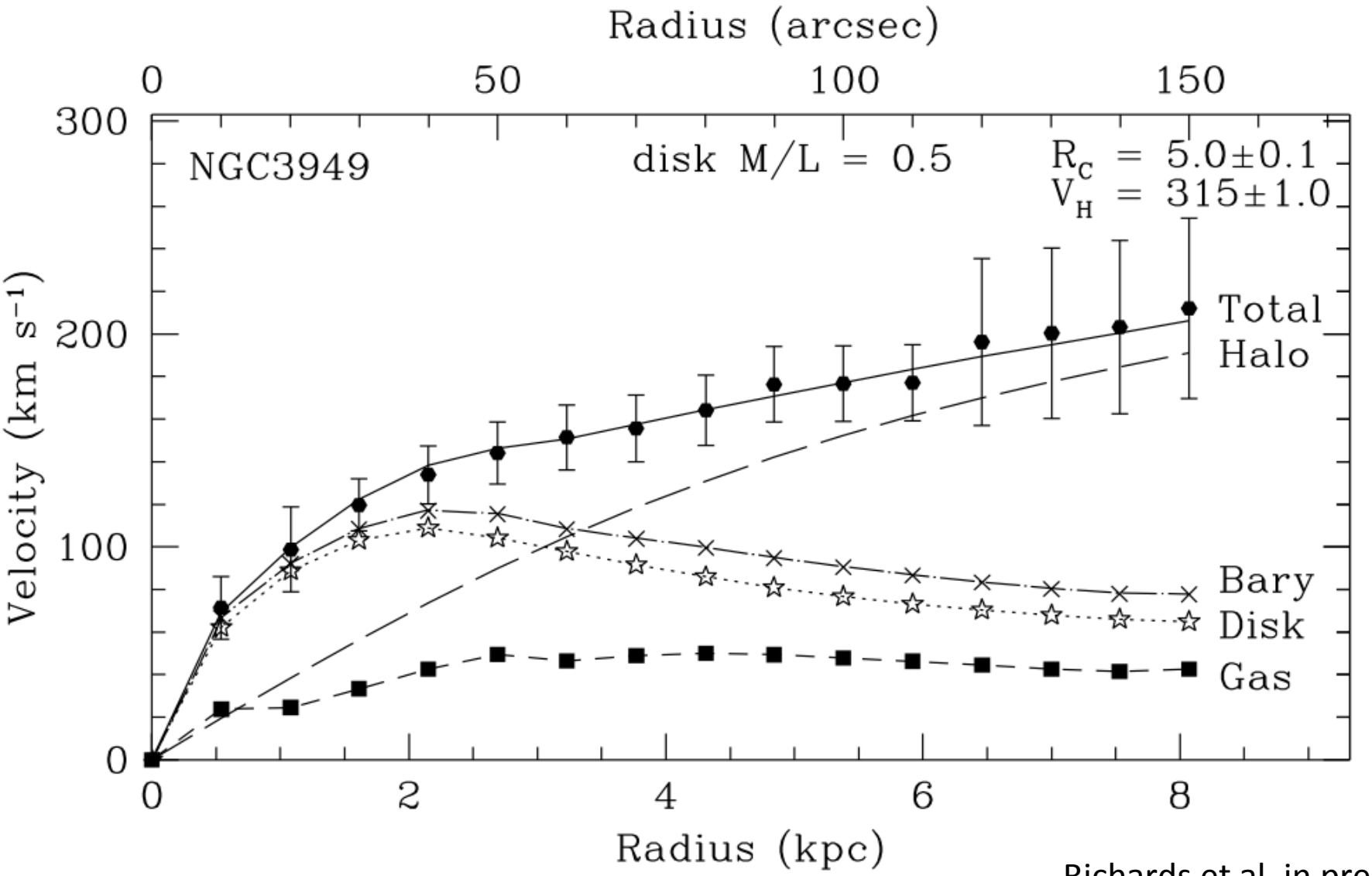
# NGC 3949: Neutral Gas Disk

- Neutral hydrogen distribution follows the high surface brightness component, but shows evidence of a kinematic warp at large radii.



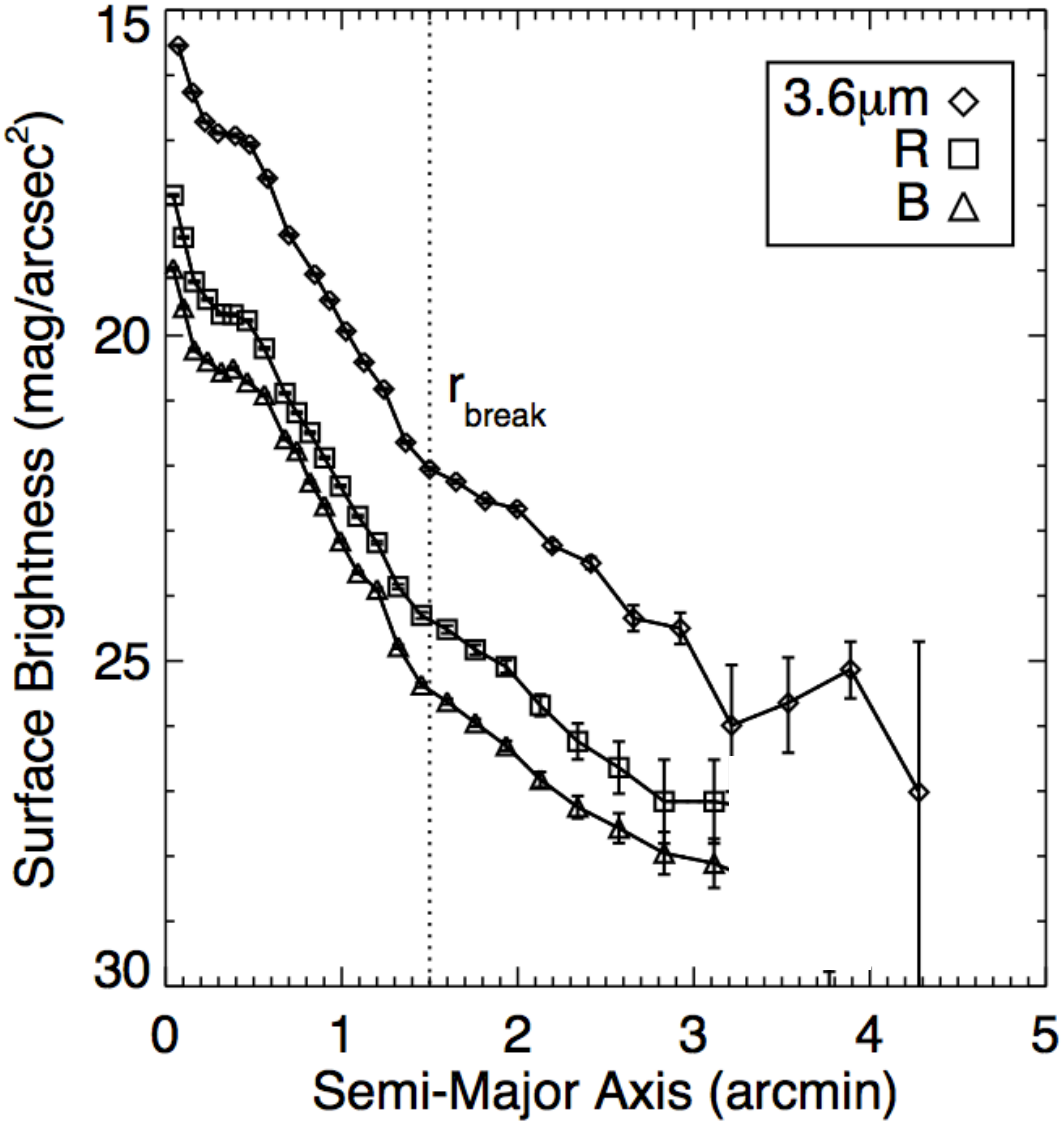

Richards et al. in prep

# NGC 3949: Rotation Curve




Richards et al. in prep

# NGC 3949: Surface Brightness Profile

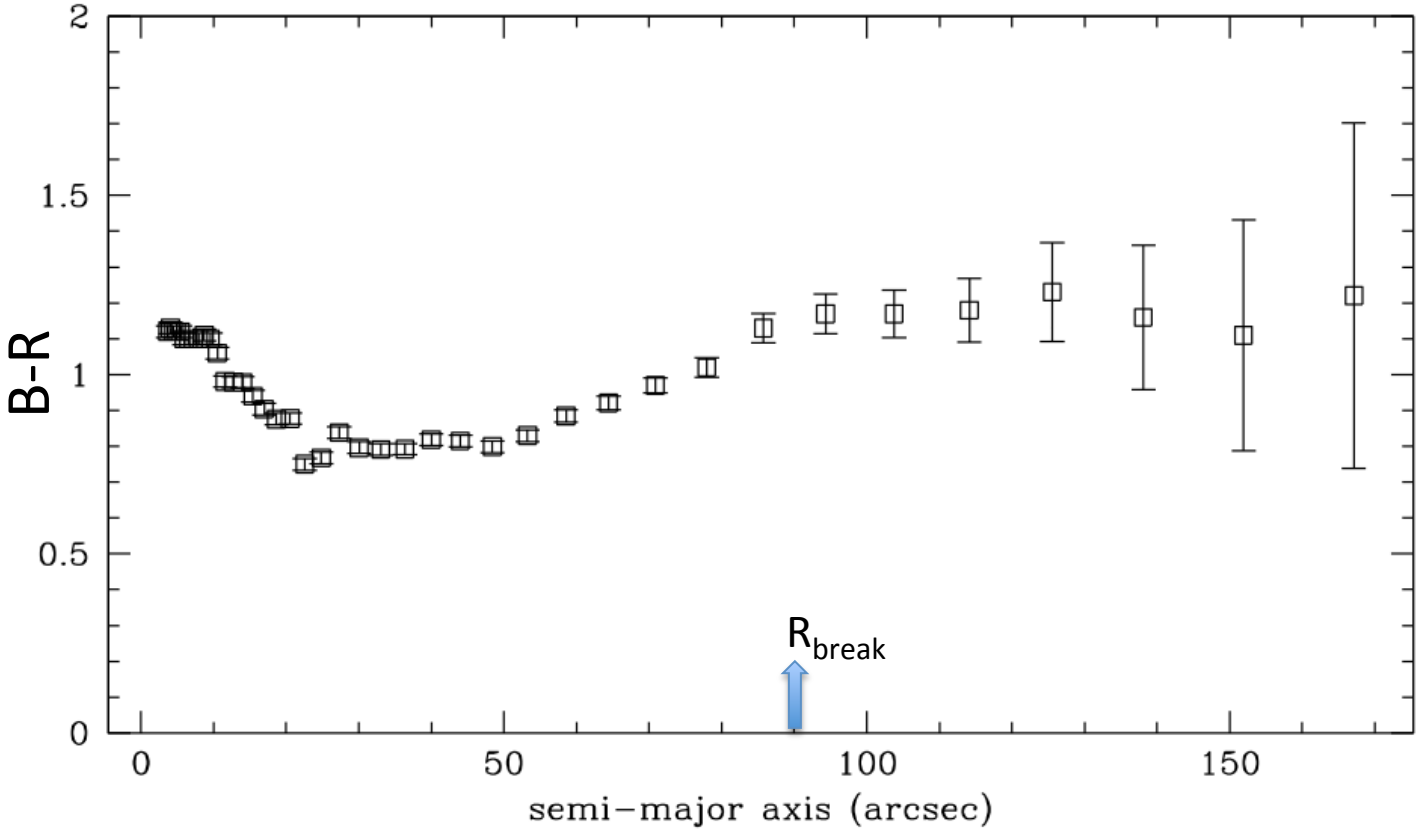



Extended structure corresponds to 10% of the total light

Barnes et al. in prep

# NGC 3949: Color Gradients

- Significant color gradient detected:
  inner regions are blue, outer region is red.




A similar functional form for B-R surface colors are also detected in a few other galaxies in the EDGES sample (Dale et al. in prep)

Barnes et al. in prep

# (Preliminary) EDGES Results

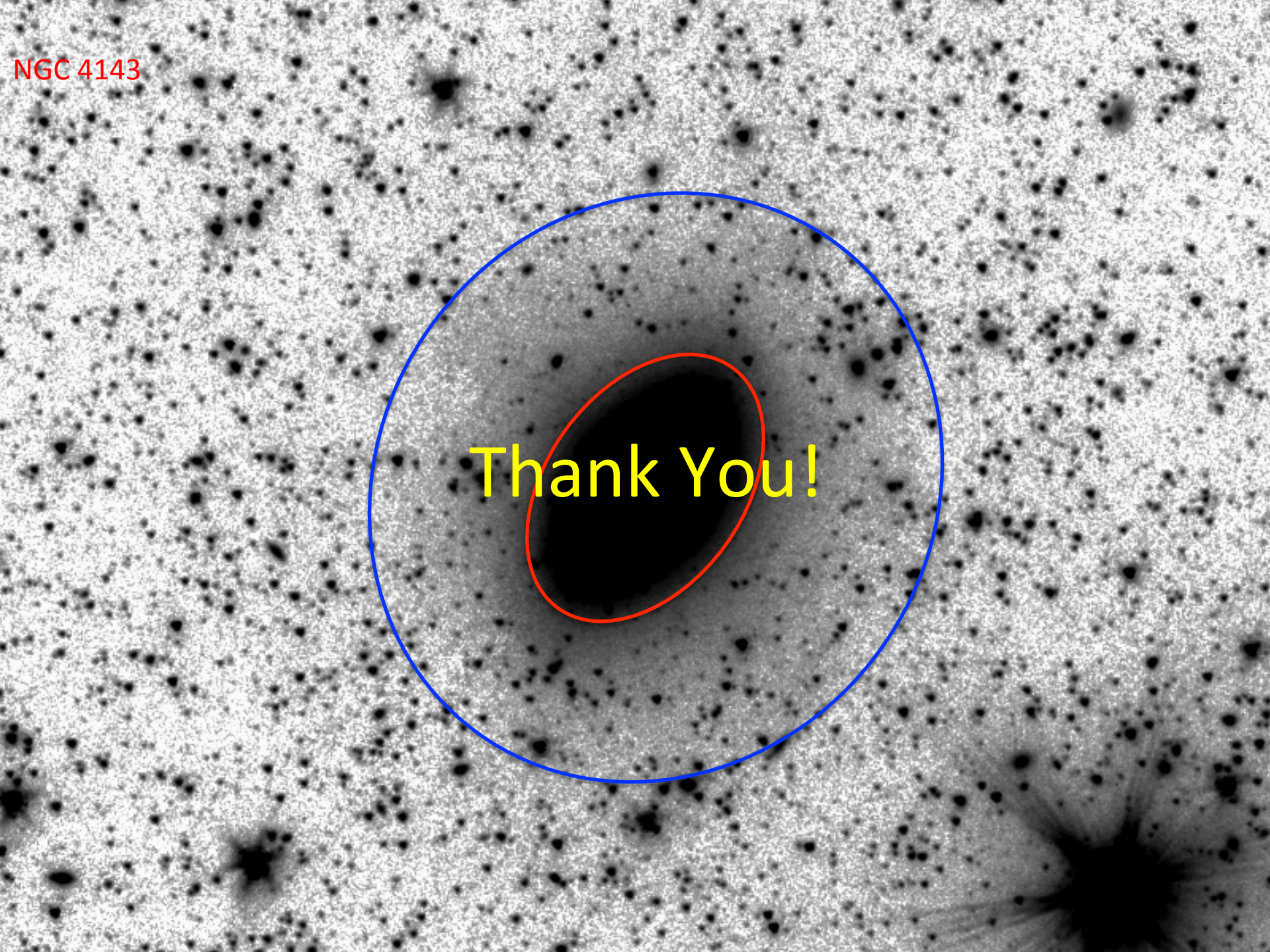
- As expected, stream-like structures are more common in groups and interacting systems
- Extended structures that are also high surface brightness are almost always associated with luminous galaxies (there are a few exceptions)
- Extended stellar distributions may be diffuse disks or stellar halos

# Conclusions

- We detect extended stellar distributions associated with many galaxies, including stellar streams and diffuse light
- When the analysis is complete, we will measure the mass associated with these streams and compare with hierarchical galaxy simulations

# Future Directions

- Dynamical analysis of kinematic sub-sample to determine dark matter fraction and correlations between dark matter and structural properties
- Stellar populations of GALEX sub-sample to examine mass-normalized star formation activity
- Comparison of the neutral gas distribution with that of the diffuse stellar component to investigate stability of the gaseous disk and growth of the stellar disk


NGC 4143
Thank You!