GALEX
(Galaxy Evolution Explorer)
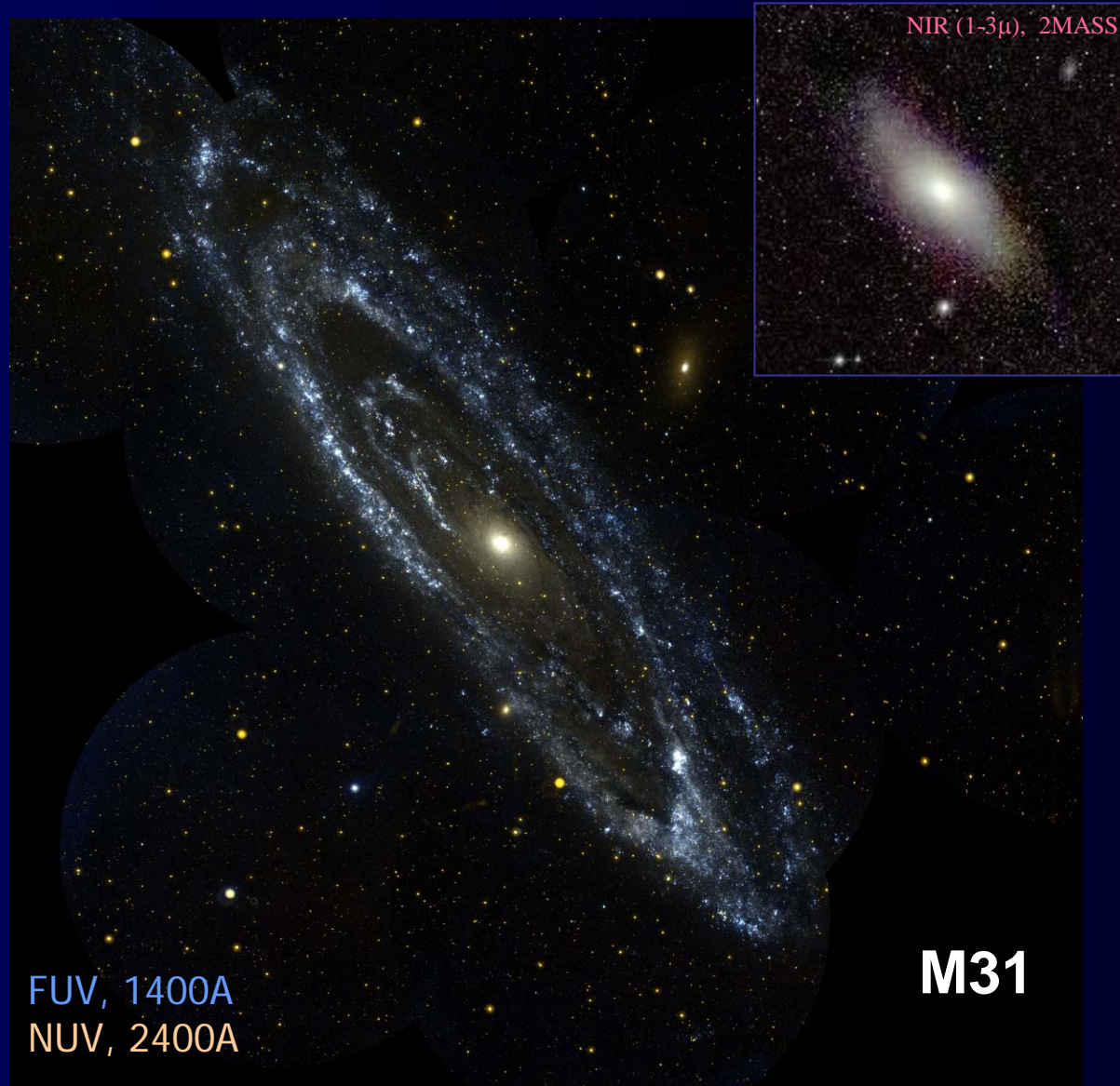
Susan G. Neff

GALEX Mission Scientist

NASA / Goddard Space Flight Center

GALEX PI: Chris Martin
Cal Tech

GALEX Science Team:
CalTech, JHU, Columbia,
Marseilles, UCLA, GSFC,
UCBerkeley

GALEX and ALFALFA

- Overview of GALEX mission / goals

- Some relevant early science results

- Quick look at ALFALFA Precursor

- Future?

NIR (1-3µ), 2MASS

FUV, 1400A
NUV, 2400A

M31

GALEX - Mission Overview

- Launch:
  - Launch: April 28, 2003, Pegasus XL

- Operations:
  - Orbit: 28 deg / 690 km
  - 2 X-band ground stations;
      2 ground links per day;
      4MBytes down per day
  - Night observations only
  - Prime Mission
      Originally 28 months, now 38 months
   1/3 time for GI's, starting 1 October 2004
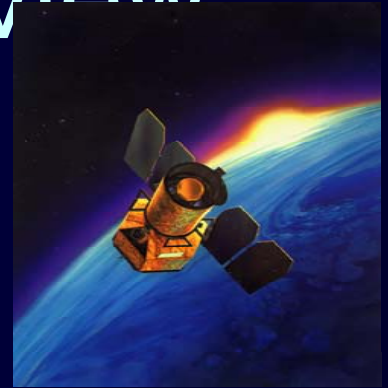
- Performance
  - Instrument working fine
  - Observing efficiency ~10% below predictions
   - Solar storms
    - Charging on detector windows

GALEX – Instrument Capabilities

- 50 cm telescope (0.25 μArecibo)
- Field of view 1.25 Degrees

- Two UV channels, simultaneously
  - FUV / NUV beamsplitter
  - 2 MCP photon-counting detectors
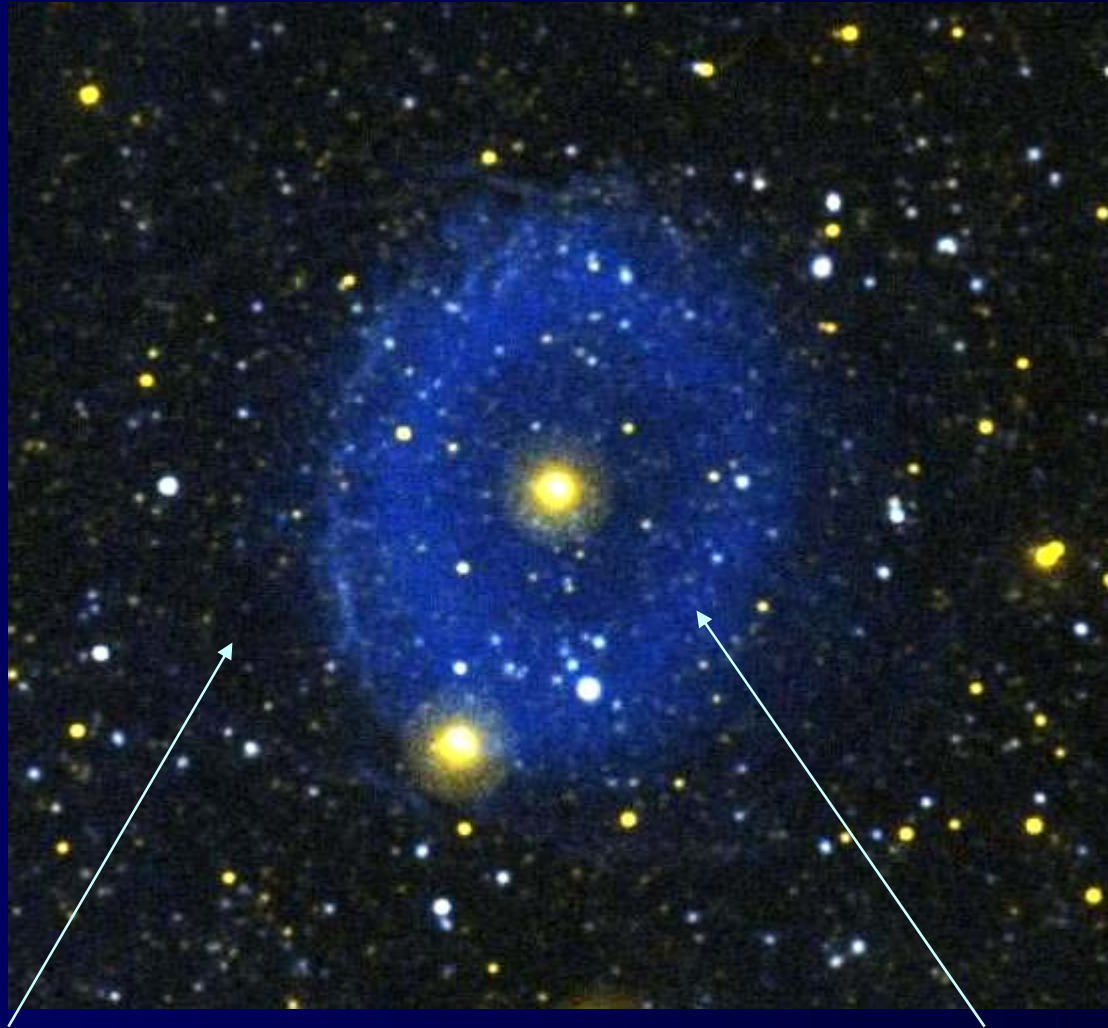   - 1350- 1700A FUV (CsI)
    - 1700-2800A NUV (CsTe
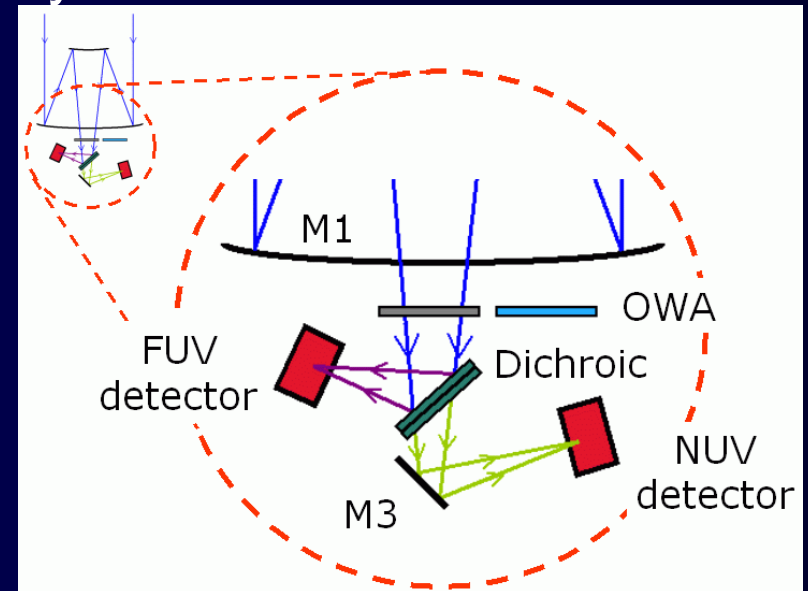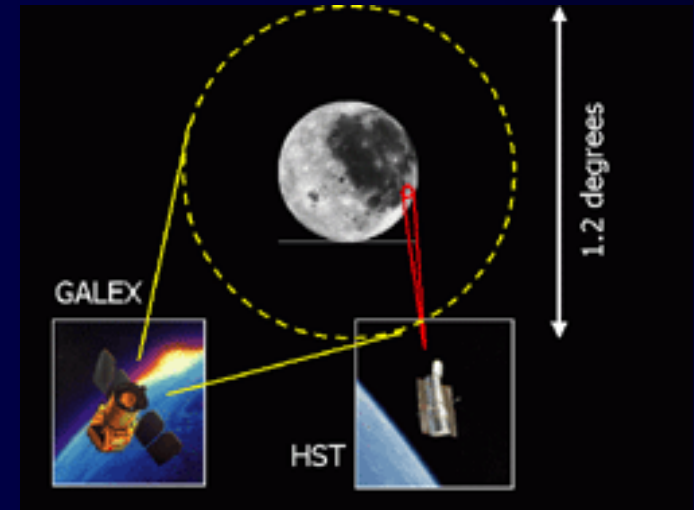
GALEX: Imaging *and* Spectroscopy

- Imaging:
  - Resolution ~ 4" FWHM
  - Sensitivity:
    - AIS   100sec m_{AB}~20.5
    - MIS / NGS   1.5ksec m_{AB} 23.5
    - DIS   30ksec m_{AB}~25.5
  - A_{eff} ~ 25cm^2 FUV, ~ 44cm^2 NUV

- Spectroscopy
  - FUV 2nd + 3rd order; NUV 1st + 2nd order
  - Typically do 6 grism positions and stack
  - Resolution ($\lambda/d\lambda$)
    - FUV   200-300
    - NUV   80-150
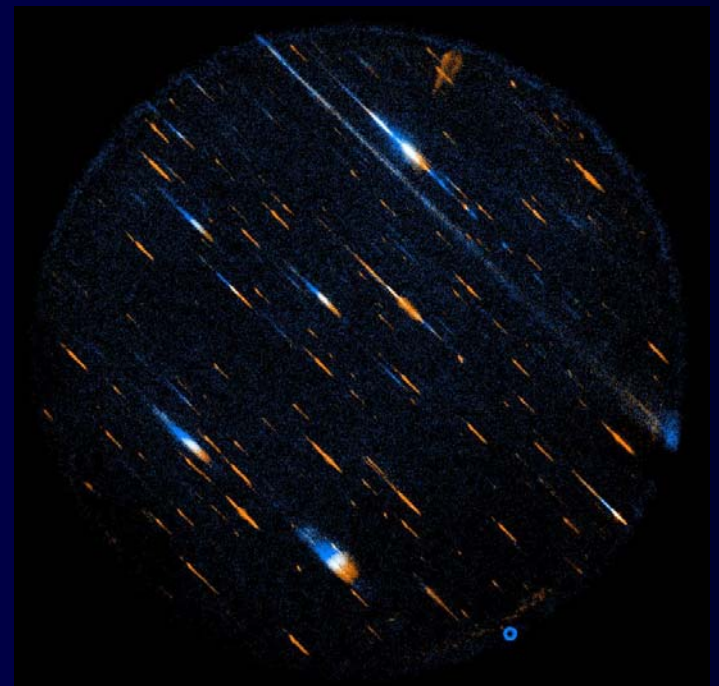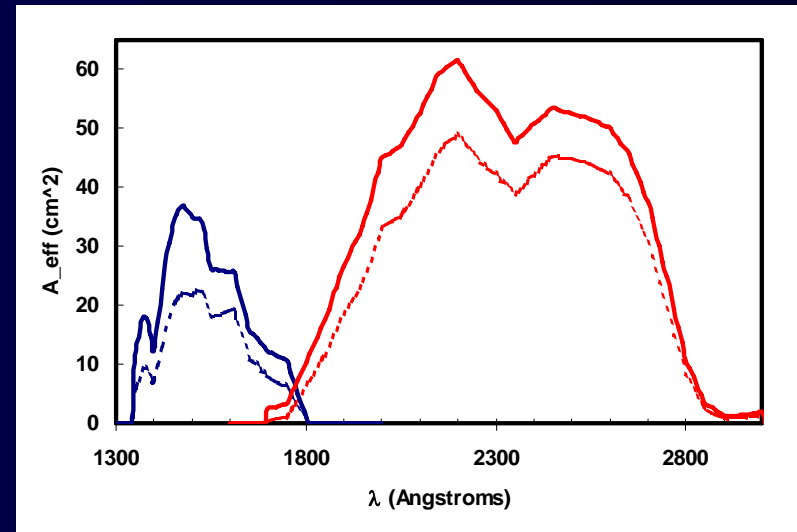
The Dark UV Sky

>1000 x fainter than Night Sky

>100 x fainter than Night Sky

FUV (1500A)
NUV (2300A)

SGN - ALFALFA mtg.
23 June 2005

Galaxy Evolution – Fundamental Questions

- How do galaxies change as they form and age?

- How does star formation change a galaxy?

- How does star formation change with cosmic time?

- How does star formation work in galaxies?

GALEX
Science
Goals

Science Goals → Mission Goals

- We Need:
  - very large sample of galaxies, covering
  - wide range of environments   and
  - large range of redshifts
  - with observations done consistently
    - in the same band (rest-UV)

      and
    - the same way

GALEX – Primary Mission Goals

- Use local galaxies to calibrate rest-UV emission to star formation

- Obtain large statistical samples of different types of star-forming environments

- Determine the history of star formation
  $0 < z < 2$, using rest-UV

All-sky Imaging Survey (AIS)

Magnitude	20
Mean Redshift	0.2
Area	>10,000 deg
Cosmic Vol.	1 Gpc^3
# Galaxies	10 Million

Z~0.2

AISGRID_359_33627_0001_sv03
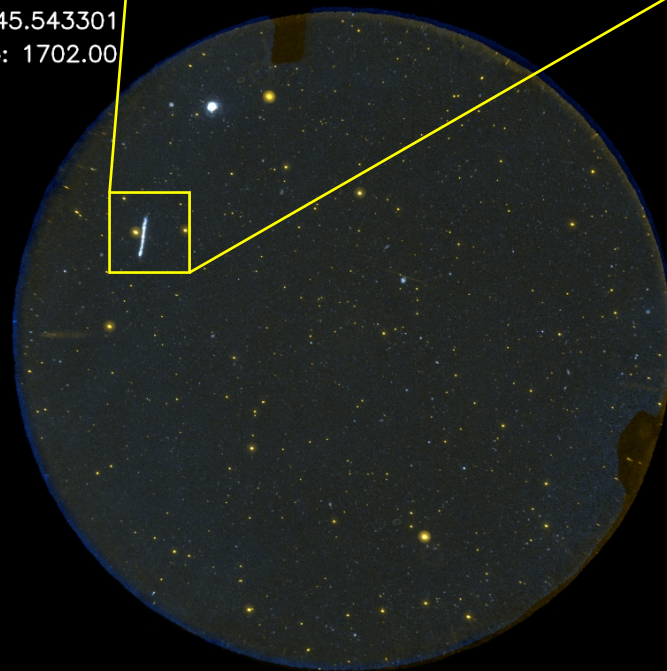α: 219.67698
δ: 5.316097
Exp: 239.00

FUV (1500A)
NUV (2300A)
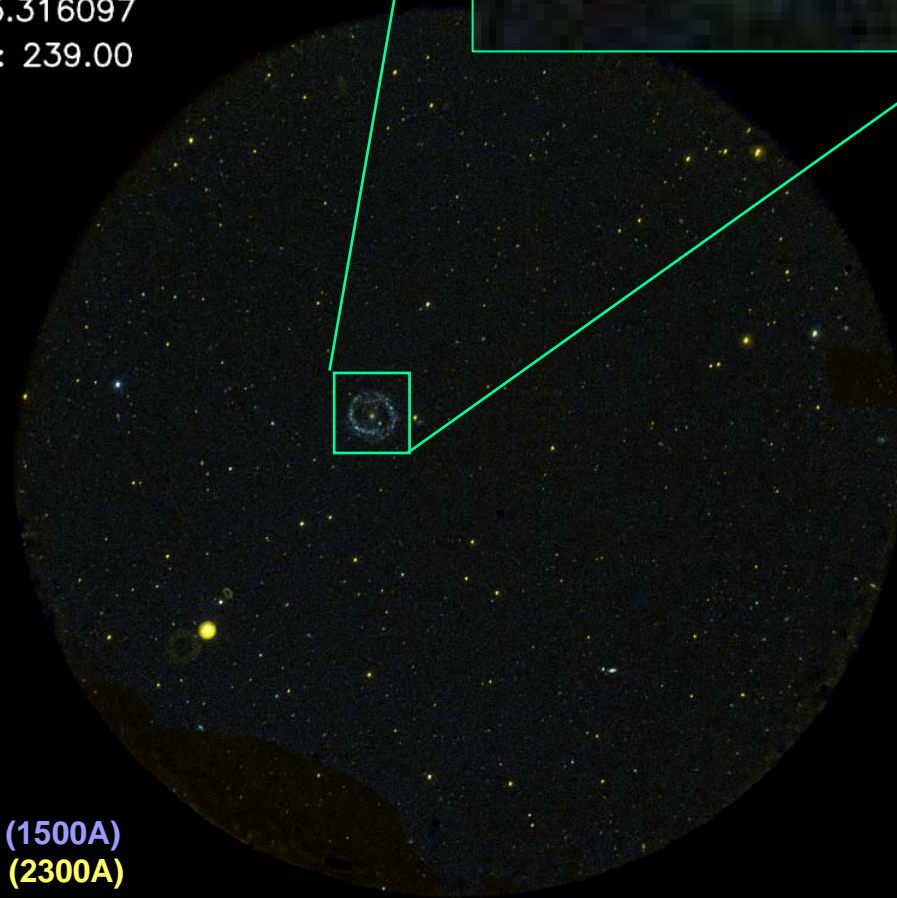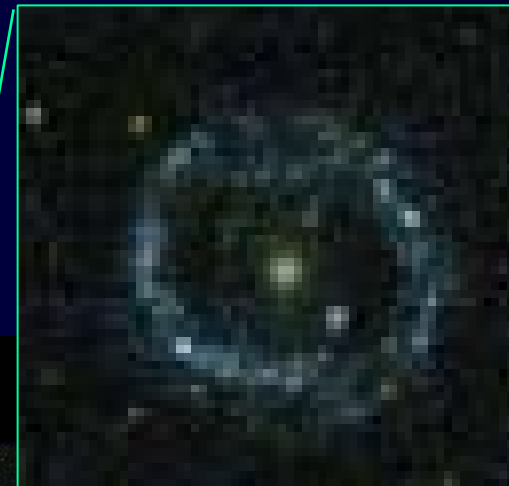
Medium Imaging Survey (MIS)	
Magnitude	23
Area	1000 deg^2
Cosmic Vol.	1 Gpc^3
Overlap	SDSS, 2dF
# Galaxies	3 Million

Z~0.5

Z~0.2

FUV (1500A)
NUV (2300A)
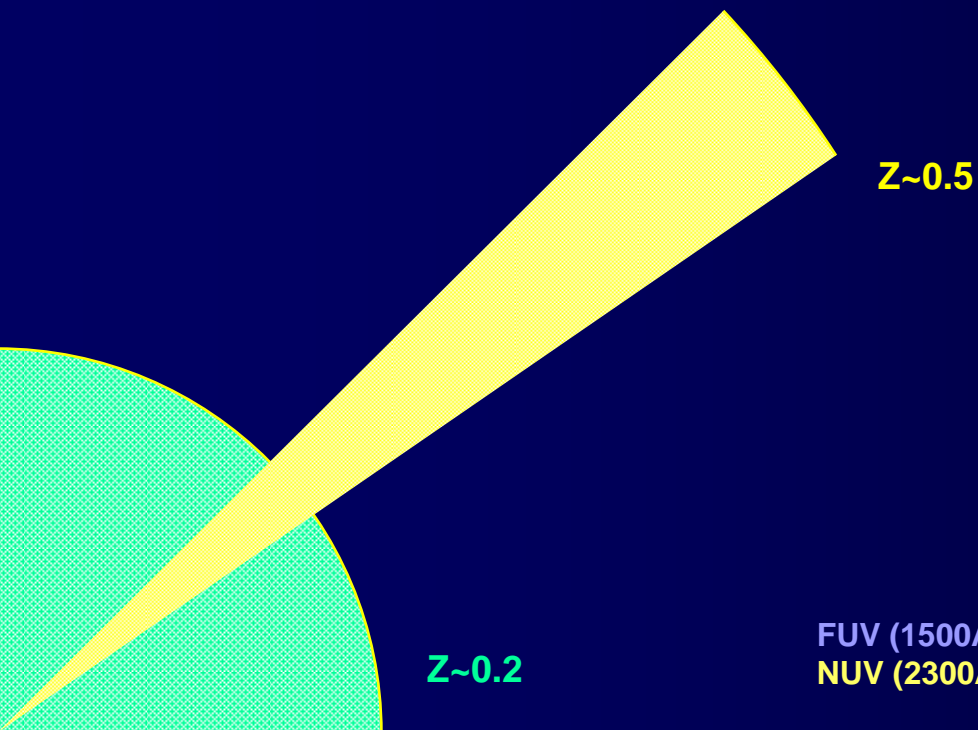
MISDR1_03721_04
α: 122.95921
δ: 45.543301
Exp: 1702.00
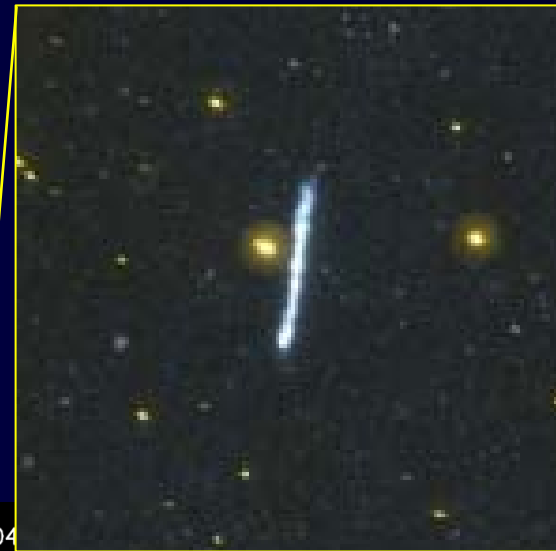
2004−01−12

Deep Imaging Survey (DIS)

Magnitude	25
Area	80 deg^2
Cosmic Vol.	1 Gpc^3
Overlap	CDFS, NOAO-DWS, SWIRE, VVDS, DEEPII, CFHTLS, …
# Galaxies	10 Million

Z~1.5

Z~0.5

Z~0.2

FUV (1500A)
NUV (2300A)

ELAIS S1
α 0^h 40^m δ - 44°
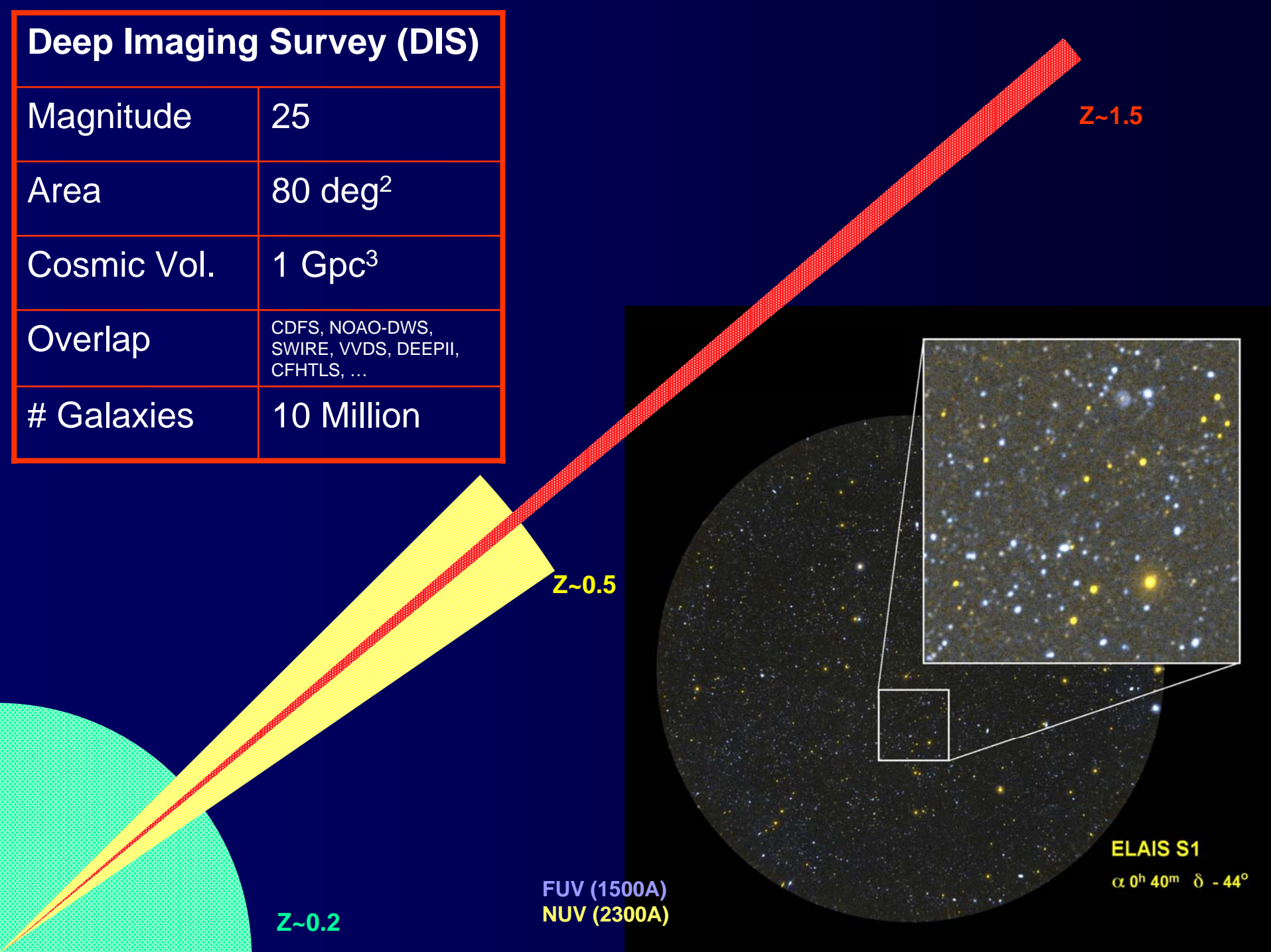
Nearby Galaxy Survey	
Magnitude	27.5 arcsec^{-2}
# Galaxies	200
Cosmic Volume	1 Gpc^3
Overlap	SINGS, HI, Ha, Radio, …
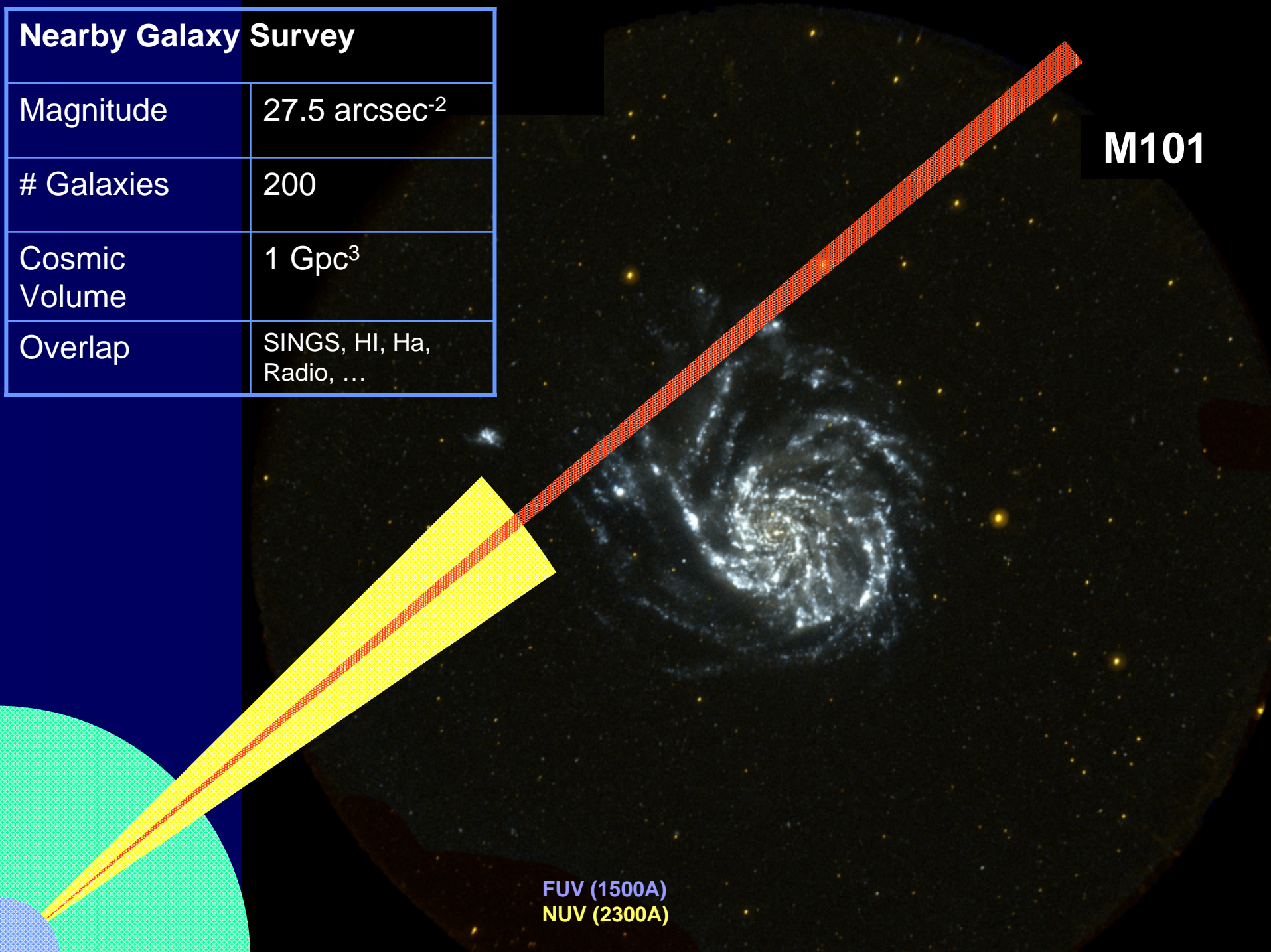
M101

FUV (1500A)
NUV (2300A)

GALEX – AIS Plan
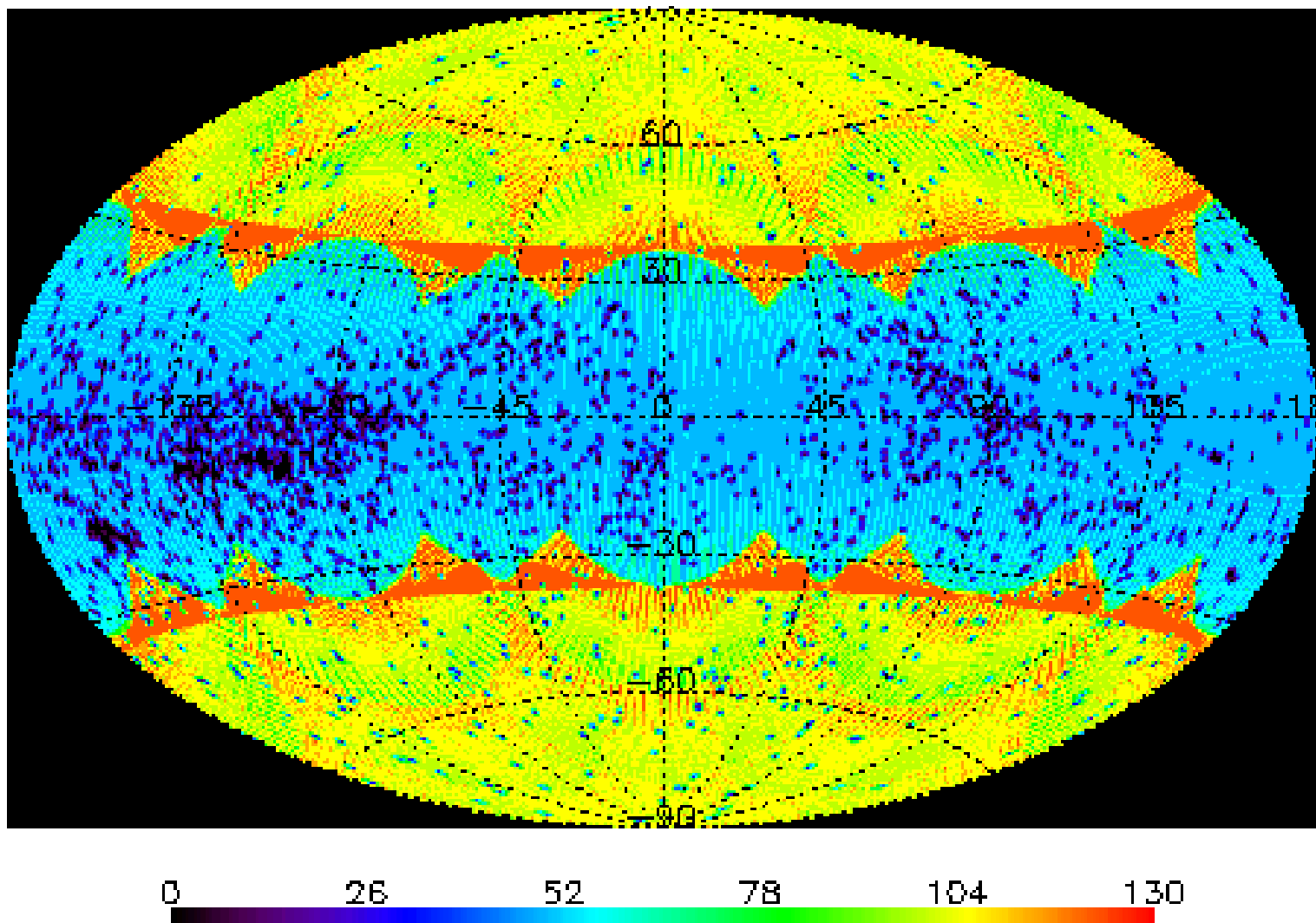
GALEX Survey Status - 18 June 2005

> 64sec (AIS)

> 260sec

> 1000sec (MIS / NGS

> 4ksec

> 18ksec

> 68ksec

GALEX Mission Status as of 050618T033802Z
Coverage depth (seconds)

Galactic Coordinates
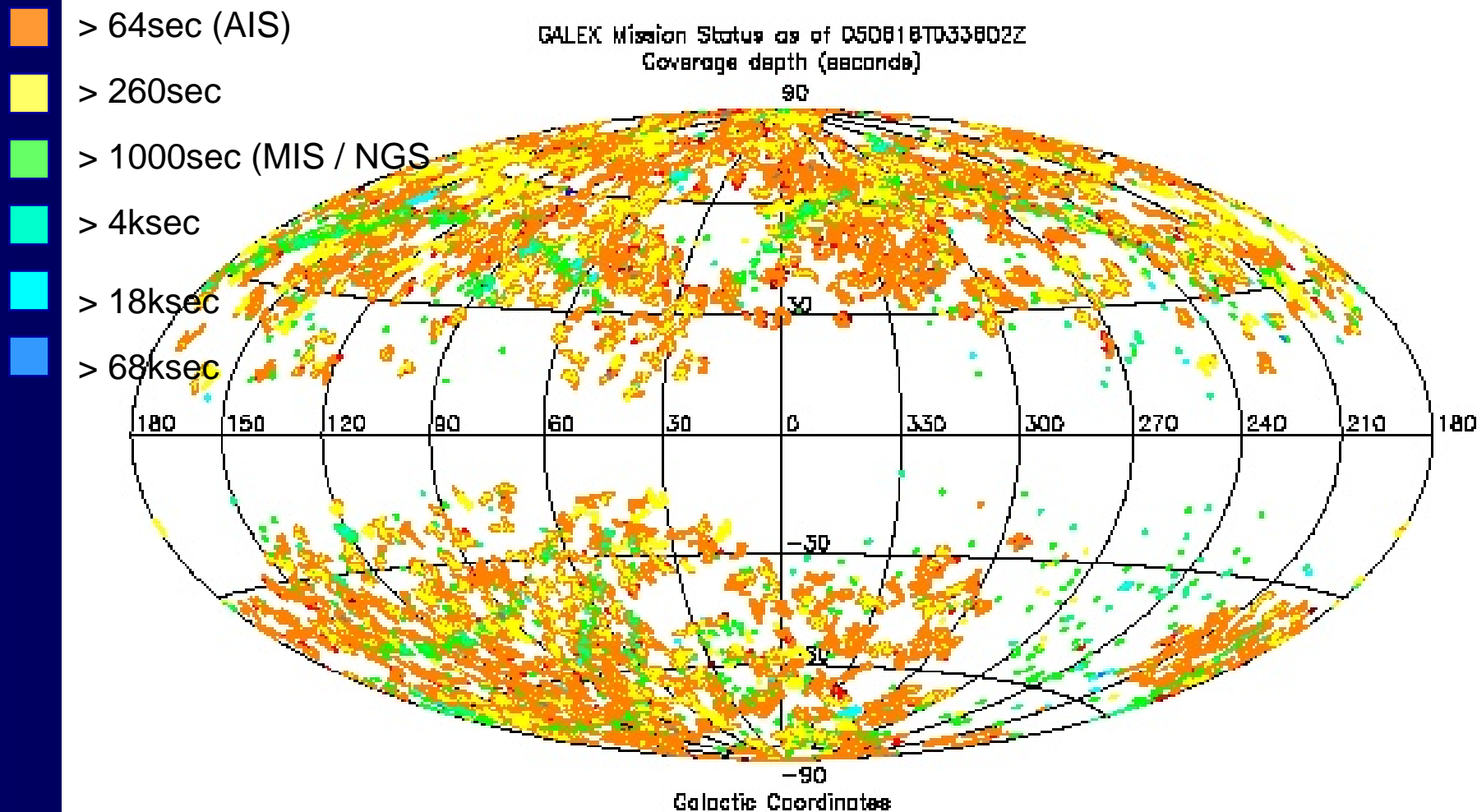
Star Formation in Tidal Tails

FUV **NUV**

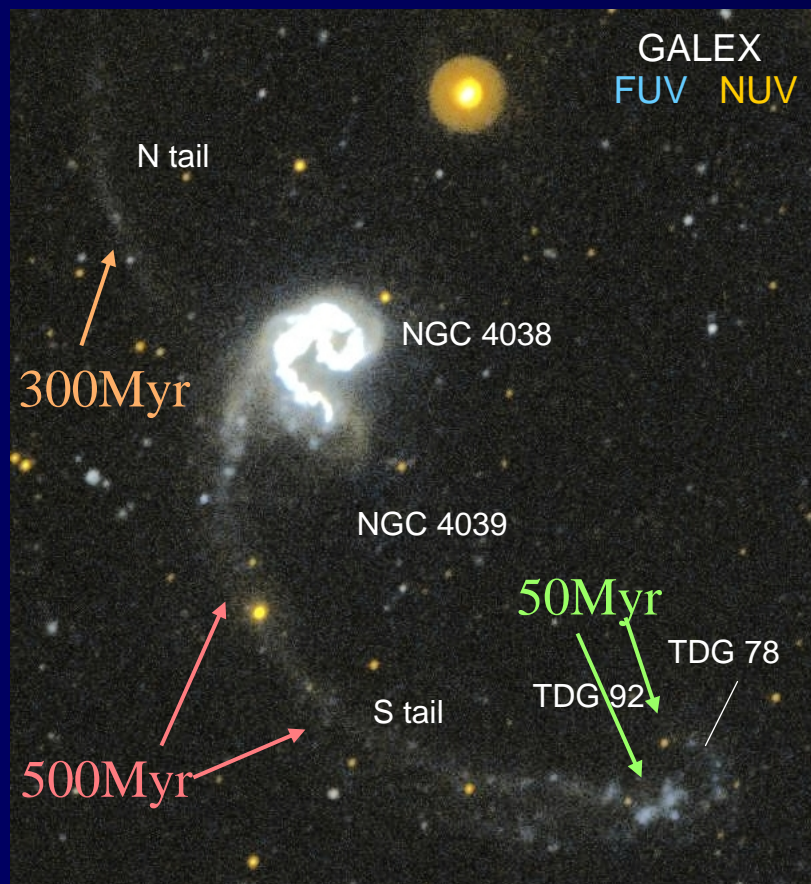FUV **R** **HI**

Earlier

Interaction Stage

Later

Neff et al. 2005
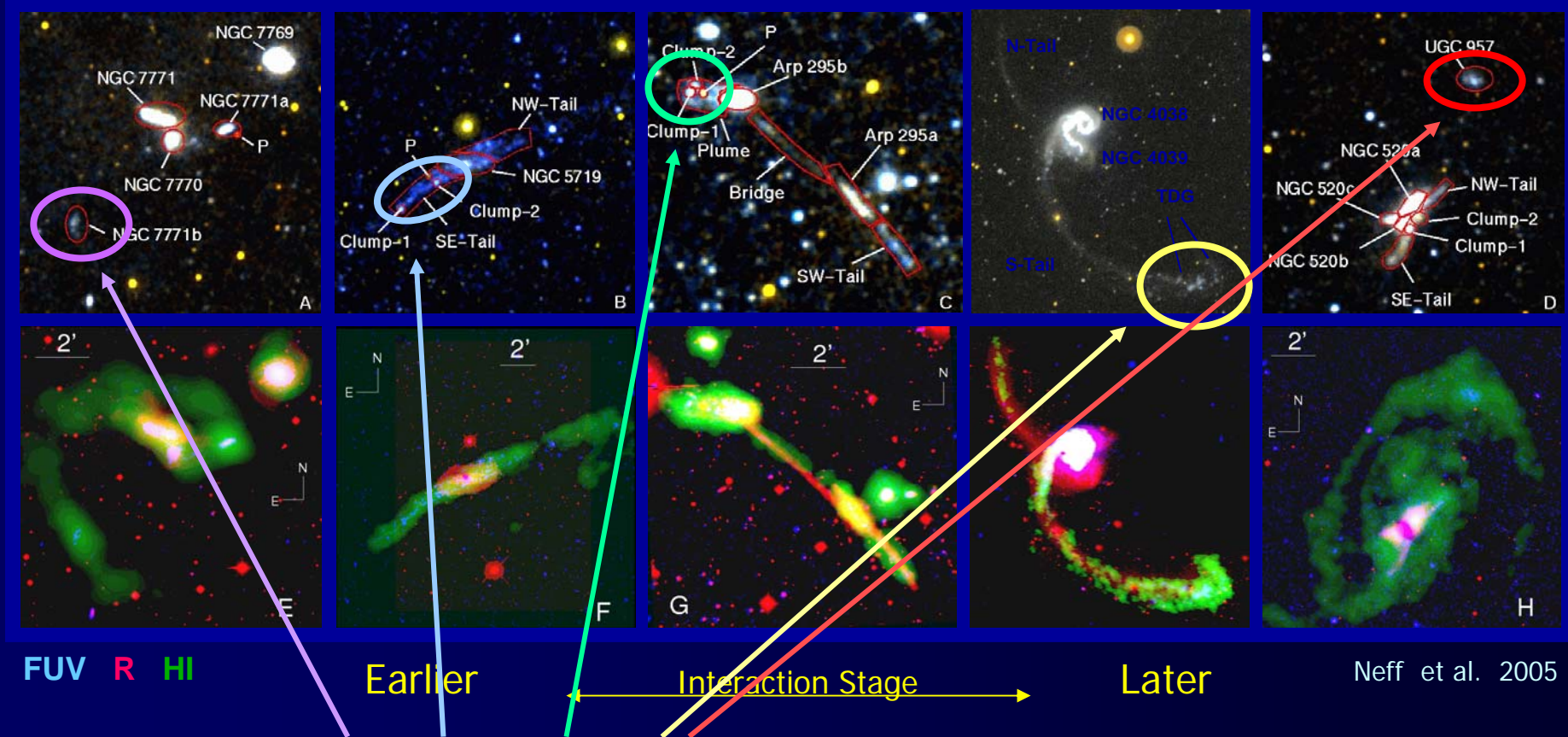
?Tidal Dwarf Galaxy formation - new galaxies forming in tails?

SF evolution seen *along* tails (youngest regions furthest out)
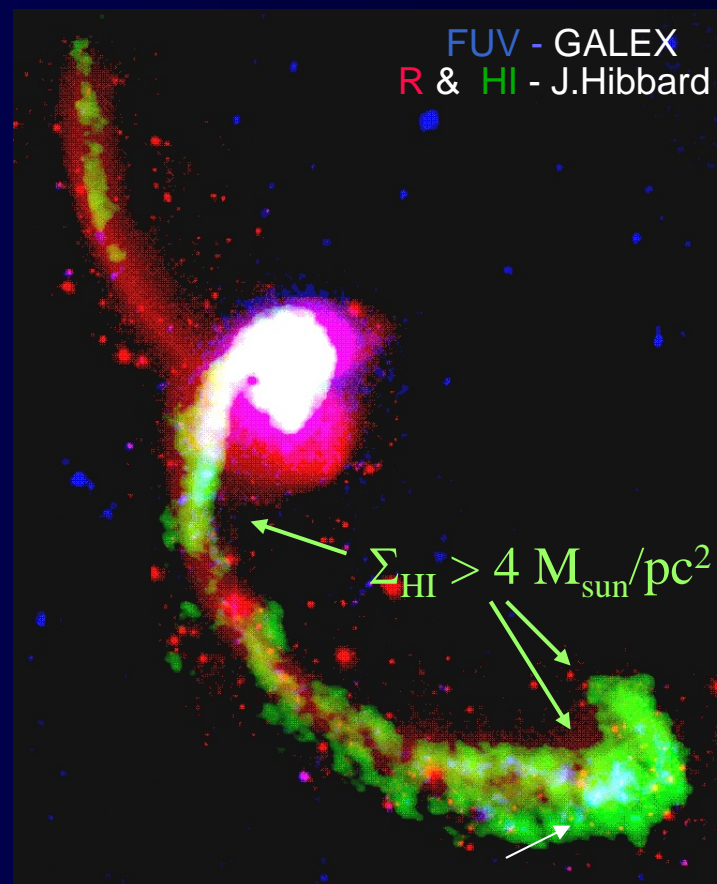
Star Formation in "the Antennae"

GALEX
FUV NUV

N tail

300Myr

NGC 4038

NGC 4039

50Myr

500Myr

S tail

TDG 92

TDG 78

FUV (1500A)
NUV (2300A)

FUV - GALEX
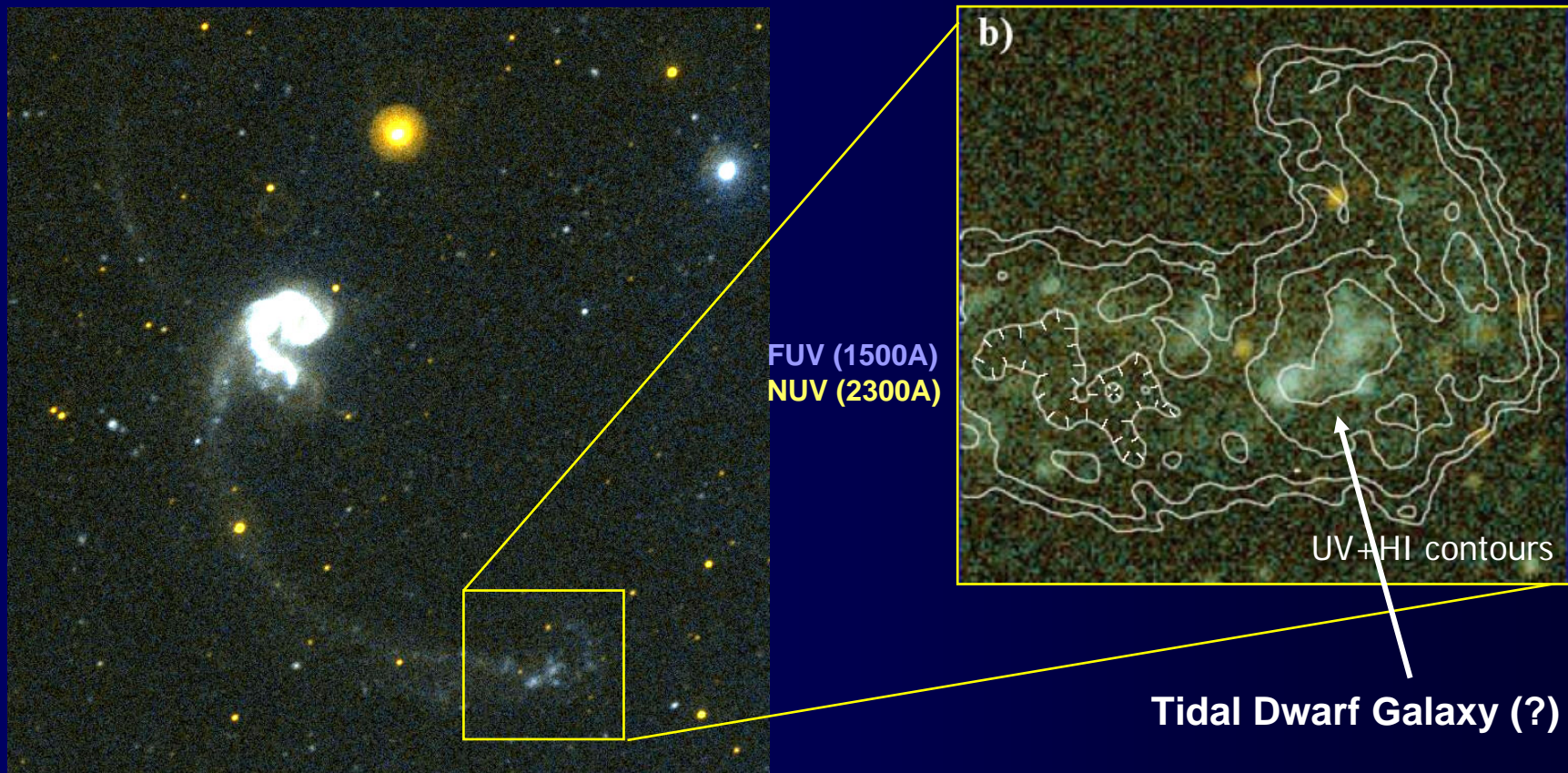R & HI - J.Hibbard

$\Sigma_{HI} > 4 \ M_{sun}/pc^2$

Youngest Stars - 50Myr

- Furthest out
- $\Sigma_{HI} > $ threshold ($\sim 2 M_{sun} / pc^2$)

Hibbard et al. 2005

Recent Star Formation in Tidal Tails of "Antennae"

FUV (1500A)
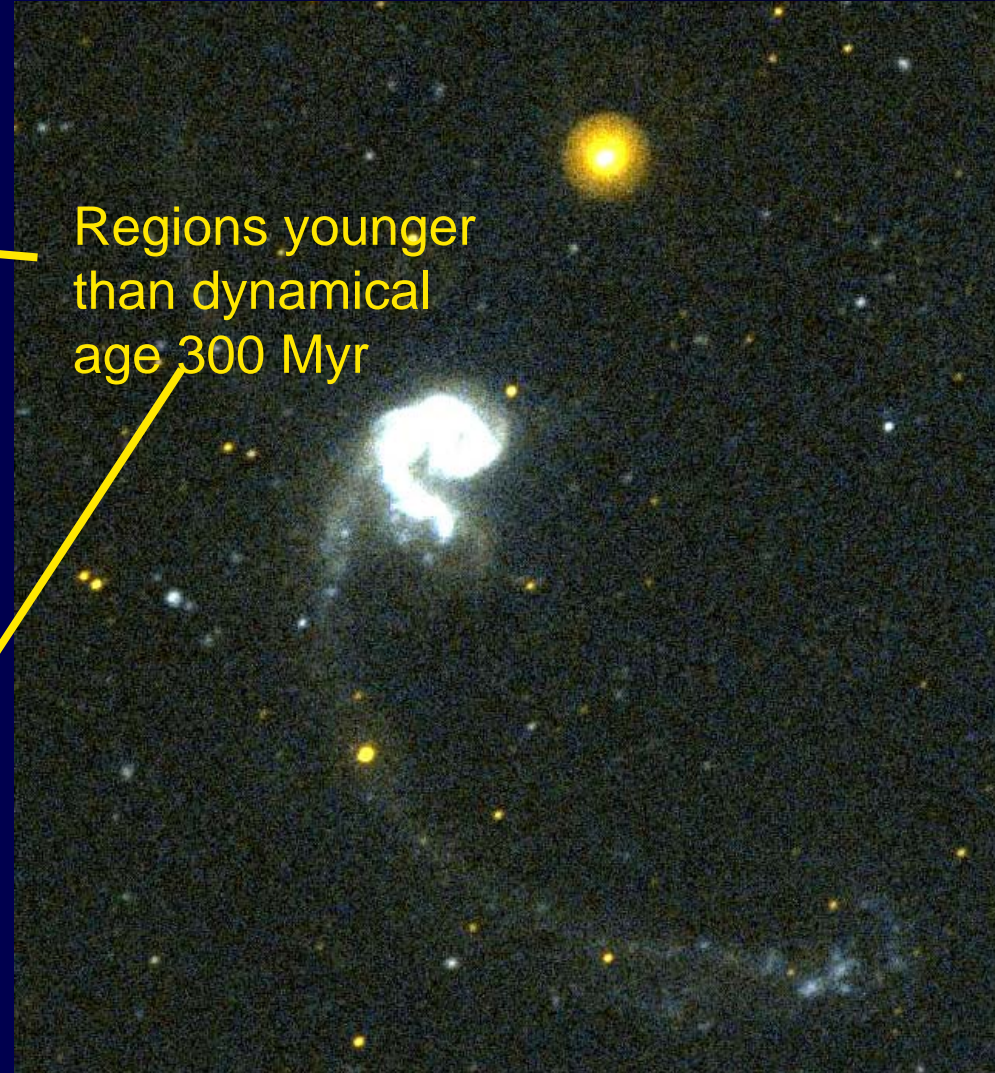NUV (2300A)

b)

UV+HI contours

Tidal Dwarf Galaxy (?)

Hibbard, et al. 2005

Starburst Aging Along Tidal Tails
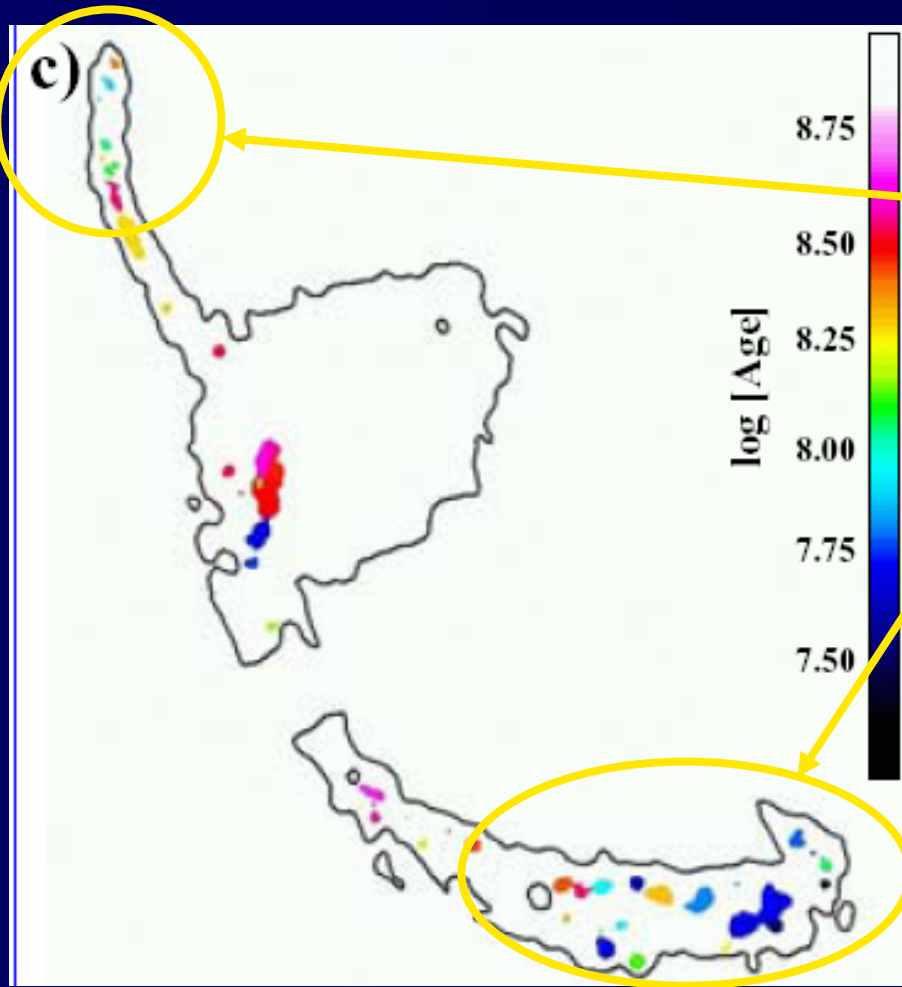
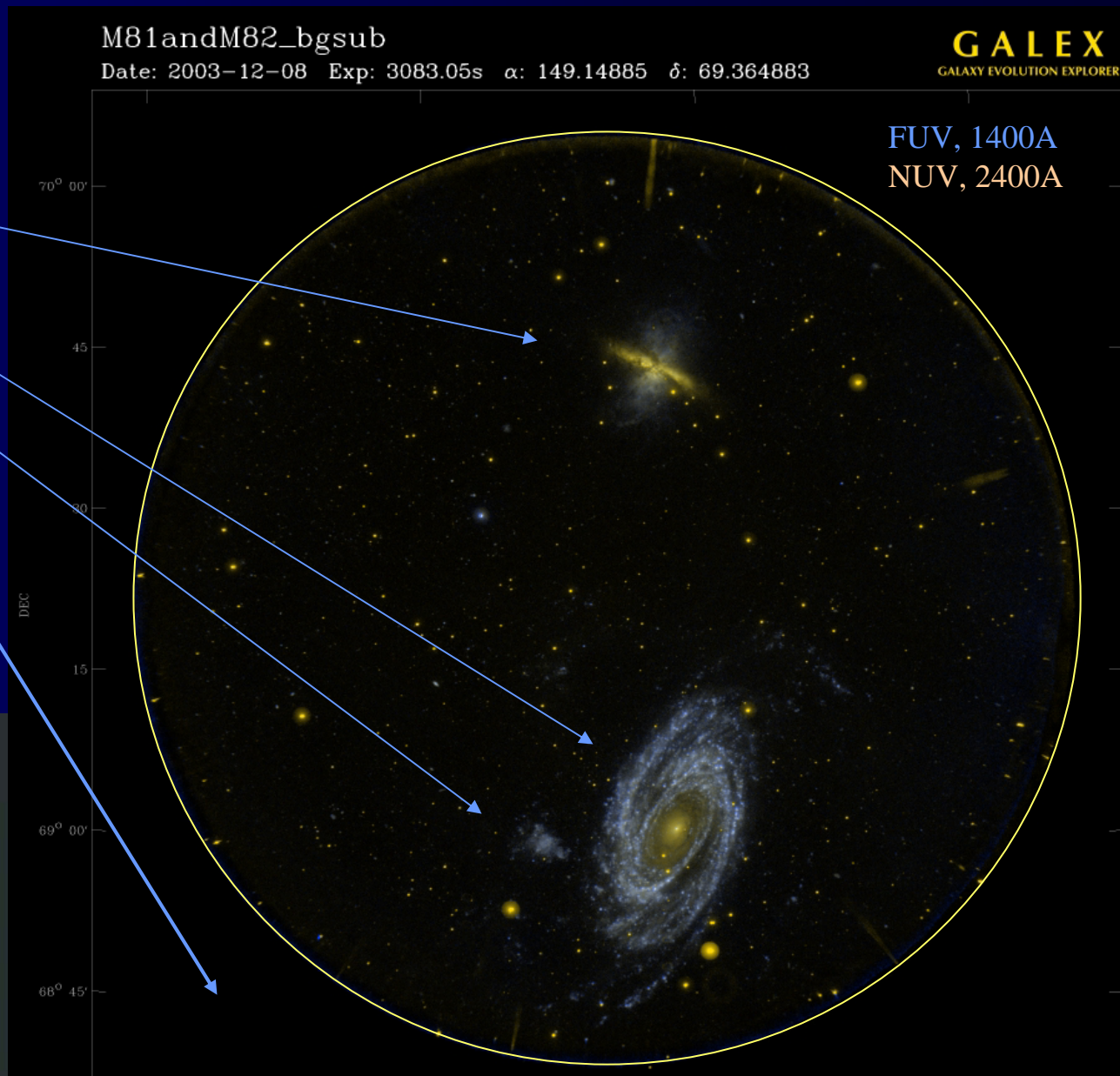Regions younger than dynamical age 300 Myr

log [Age]

8.75
8.50
8.25
8.00
7.75
7.50

Hibbard et al. 2005

GALEX : M81 Group
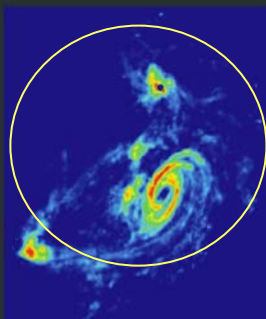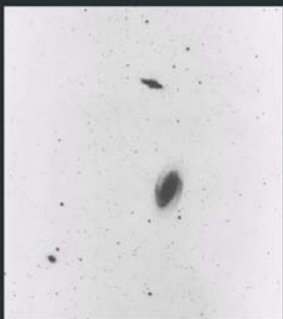
- Group includes
  - M82
  - M81
  - Ho IX
  - NGC 3077 (off field)
  - Extensive HI streamers
  - Several other dwarf galaxies

M81andM82_bgsub
Date: 2003-12-08 Exp: 3083.05s α: 149.14885 δ: 69.364883

GALEX
GALAXY EVOLUTION EXPLORER

FUV, 1400A
NUV, 2400A

TIDAL INTERACTIONS IN M81 GROUP
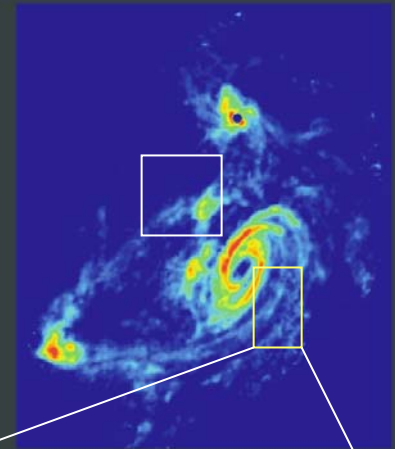
Stellar Light Distribution   21 cm HI Distribution

Dwarf Galaxies forming in Tidal Streams?

- UV emission detected at HI density enhancements *between* galaxies
- UV colors suggest 10-200Myr old stars (agrees with Makarova et al. - HST)
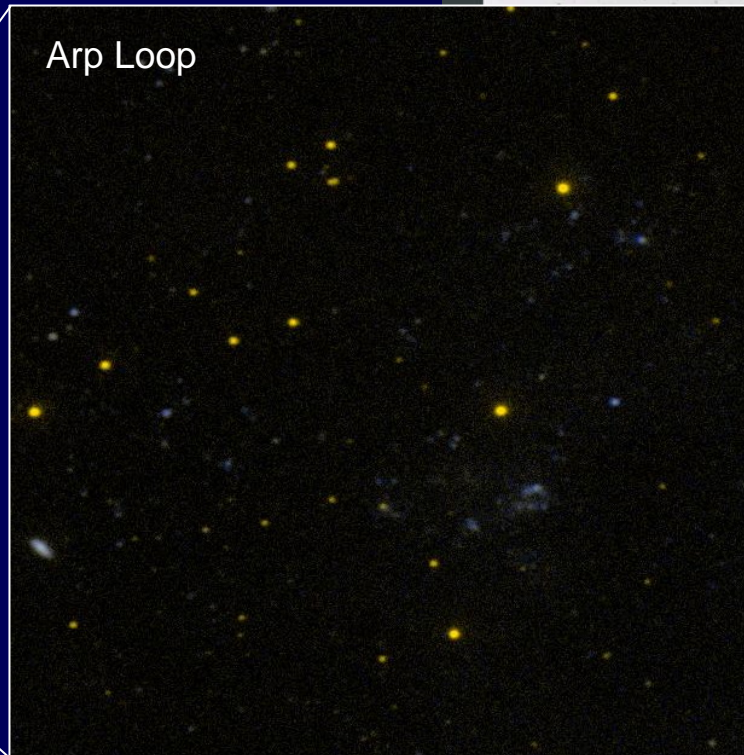- Galaxies forming?
  being disrupted?
  Outer spiral arms?

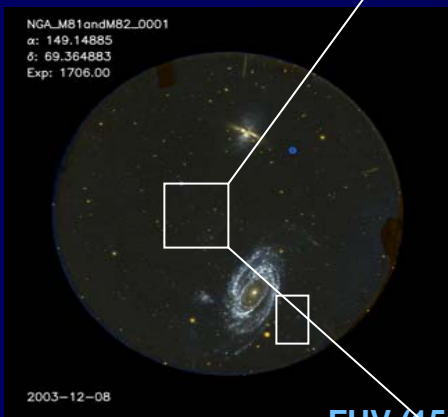**TIDAL INTERACTIONS IN M81 GROUP**

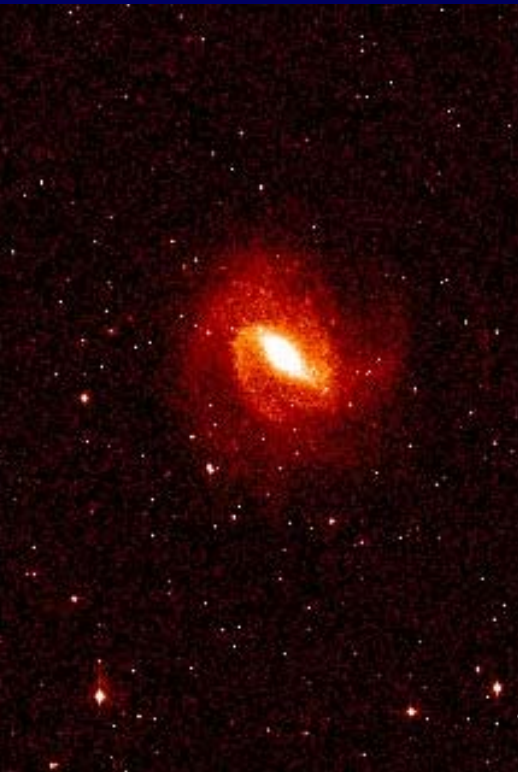Stellar Light Distribution   21 cm HI Distribution

Arp Loop

BK3N

NGA_M81andM82_0001
α: 149.14885
δ: 69.364883
Exp: 1706.00

2003-12-08

FUV (1500A)
NUV (2300A)

SGN - ALFALFA mtg.
23 June 2005

Star Formation in Extended Disks, (well beyond optical SF radius)

M83

Infrared
(2mass)

Visible
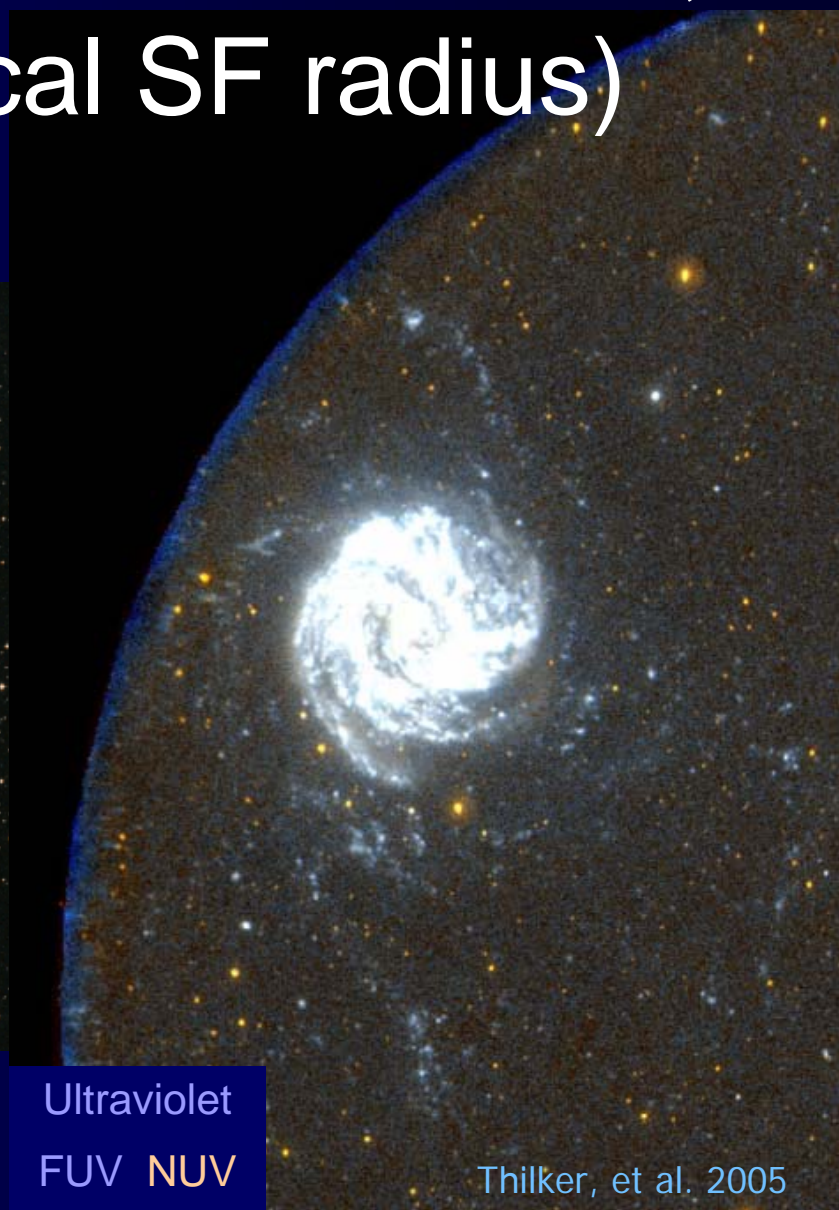
Ultraviolet

FUV NUV

(GALEX)

Thilker, et al. 2005

SGN - ALFALFA mtg.
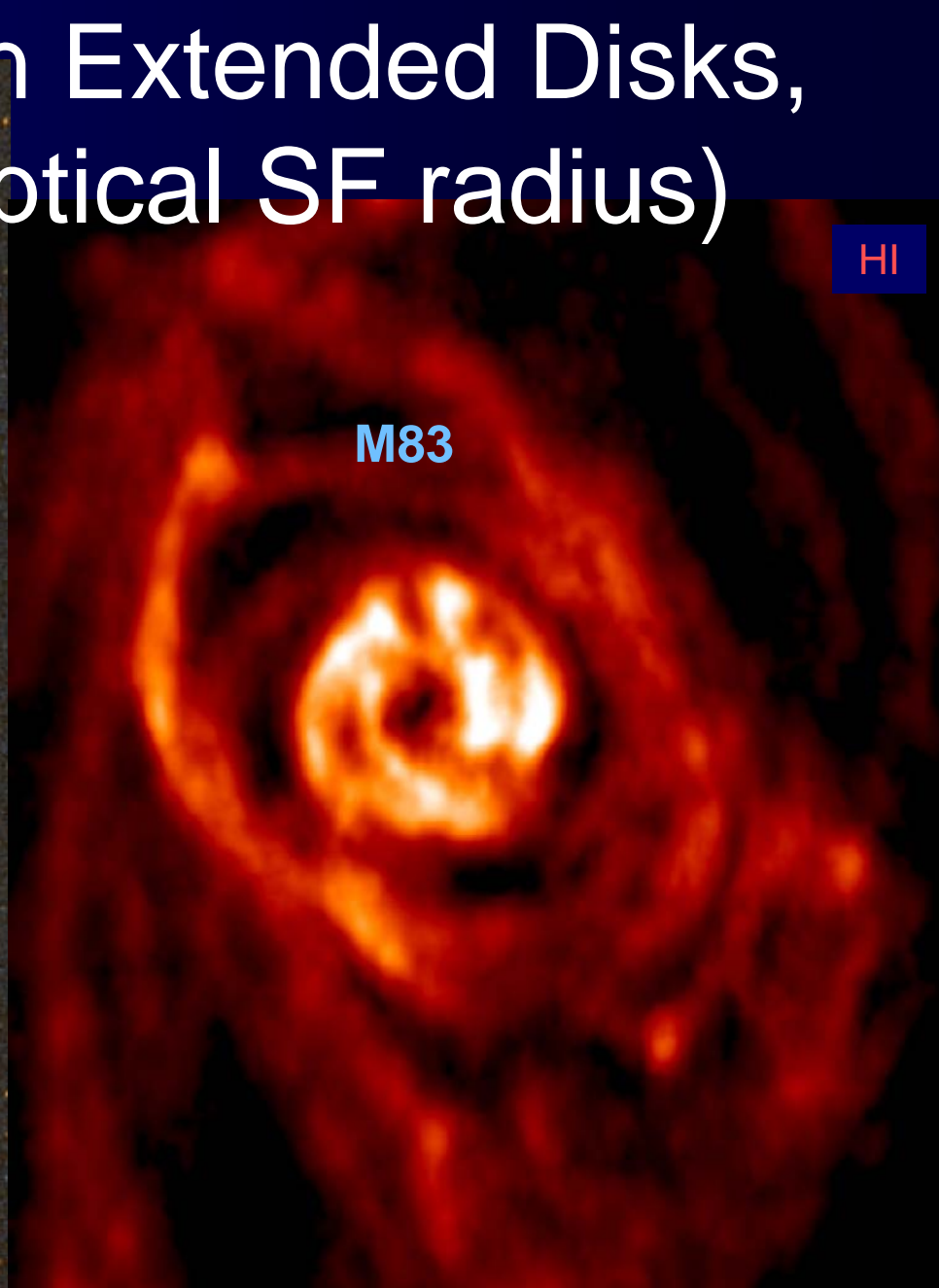23 June 2005

Star Formation in Extended Disks, (well beyond optical SF radius)

HI

Ultraviolet
FUV NUV

M83

Thilker, et al. 2005
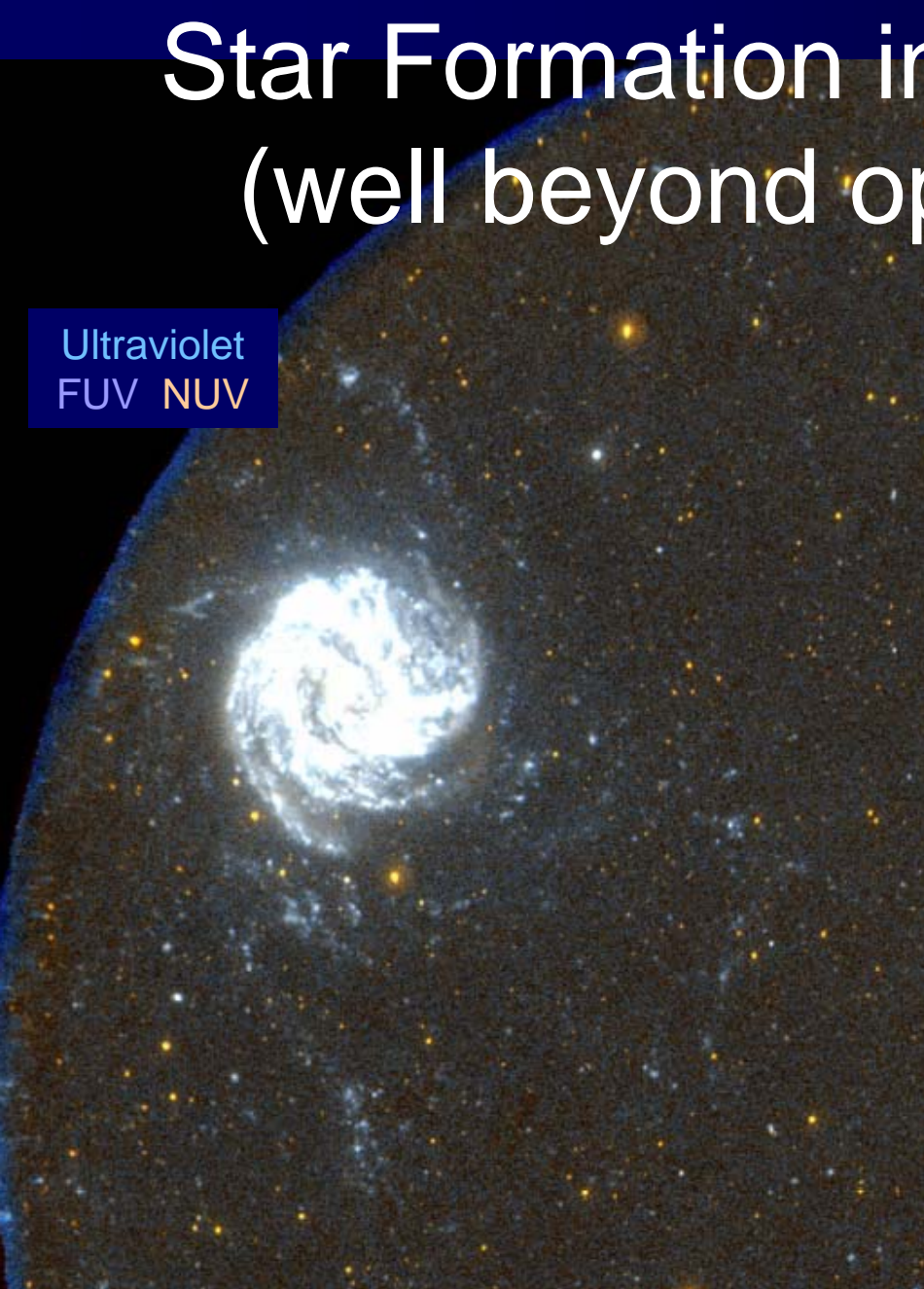
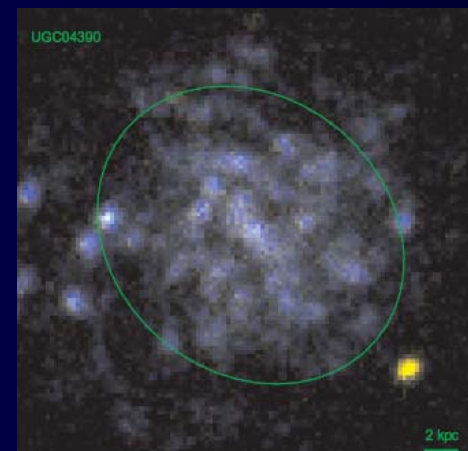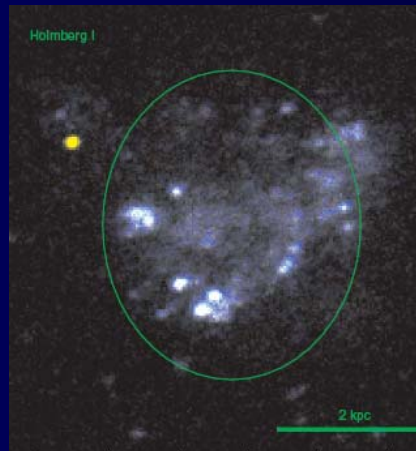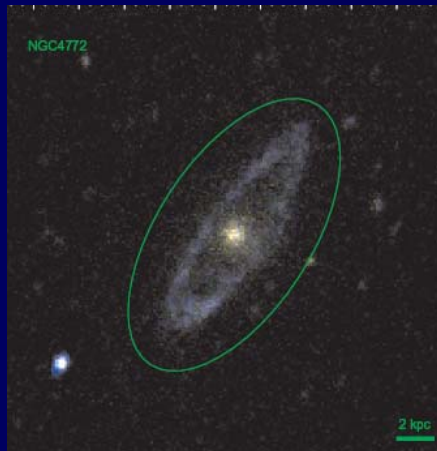# Star Formation Beyond the Hα threshold
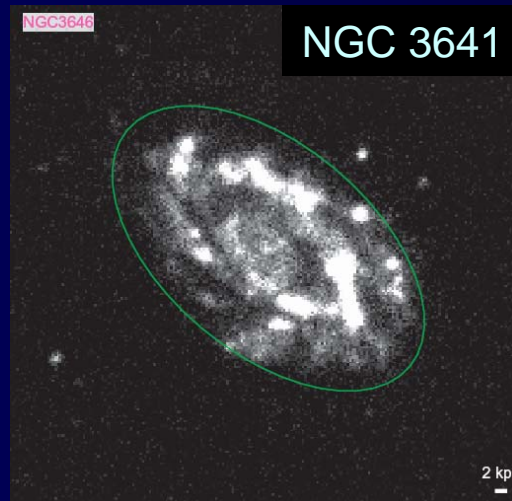

M83

Thilker, et al. 2005
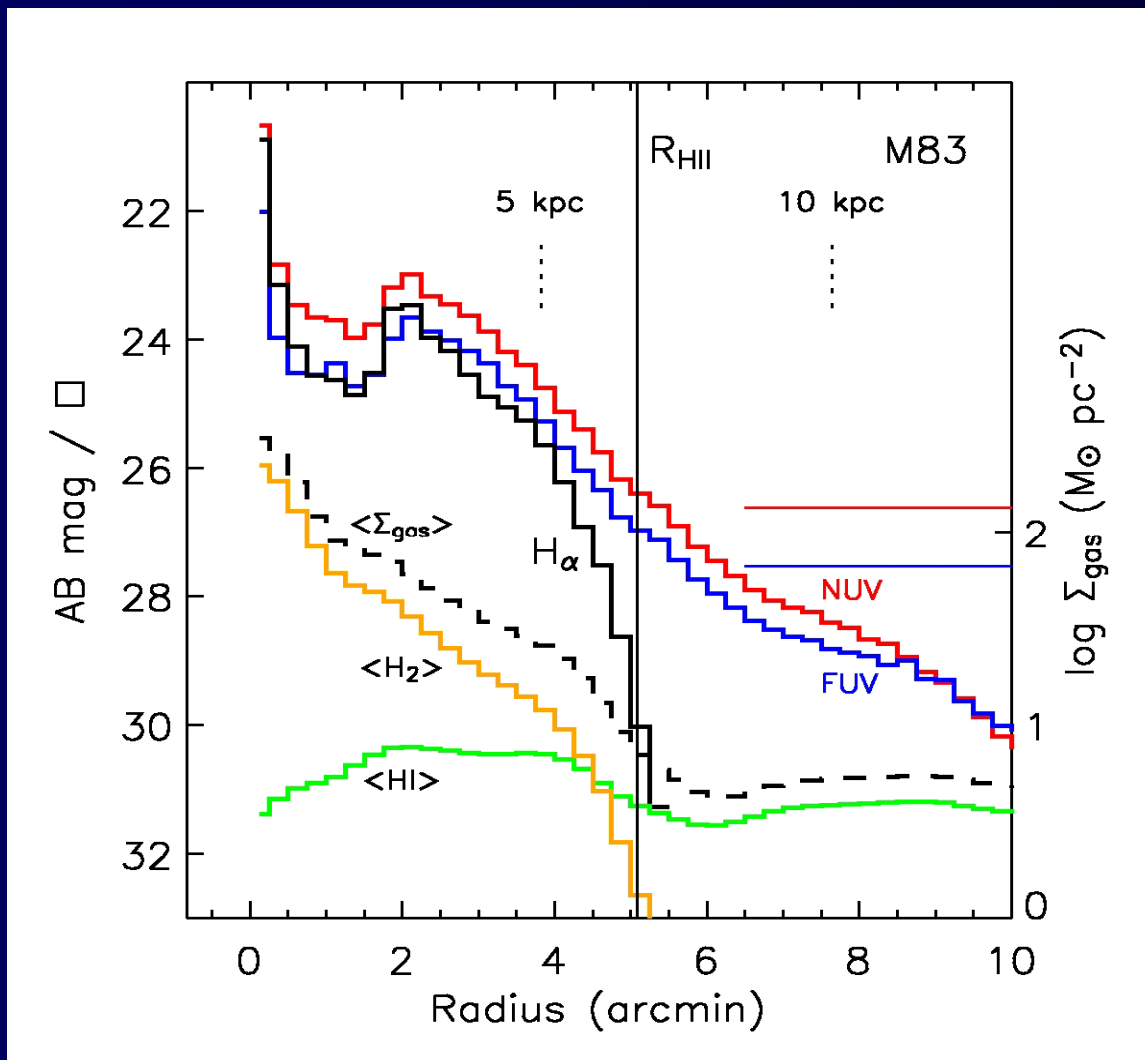
Low Surface Brightness Galaxies

FUV (1500A)
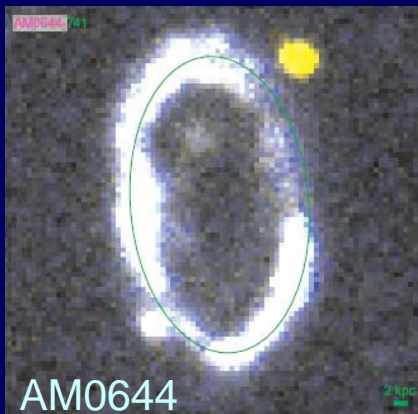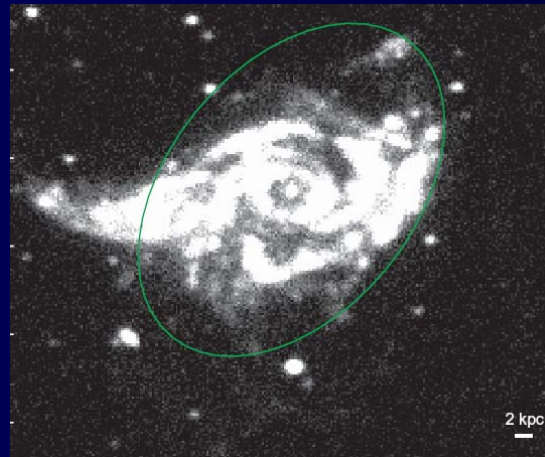**NUV (2300A)**
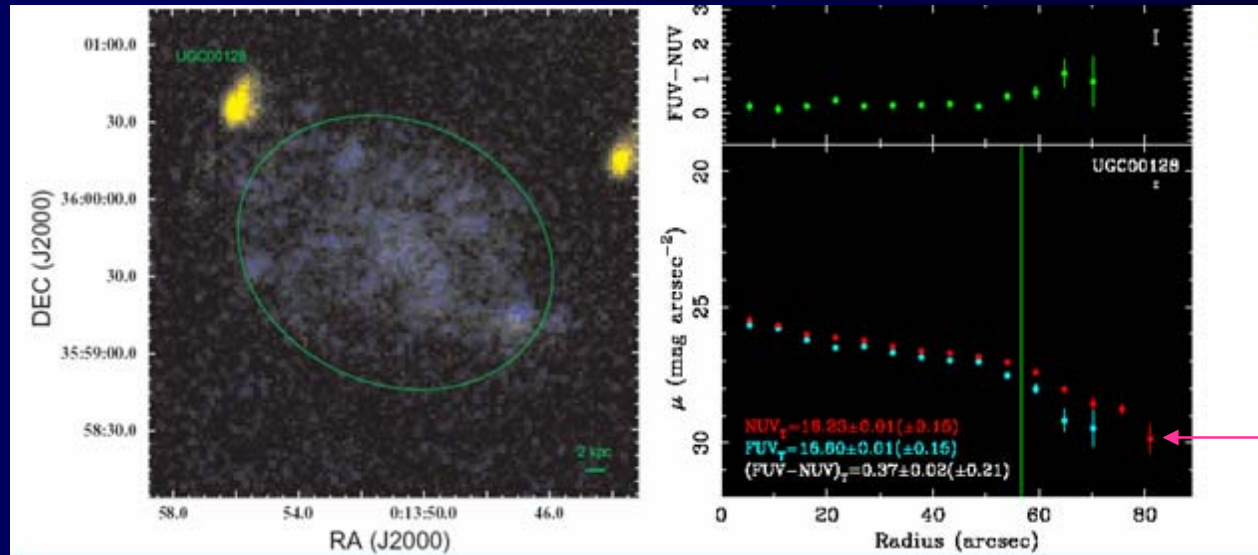
1000x Fainter than Visible sky

Gil del Paz, 2005

$\mu_{FUV} \sim 28\text{-}30 \quad \rightarrow \quad SFR/Area \sim 0.2\text{ - }1 \times 10^{-4}\ M_{SUN}\ /\ kpc^2 \quad (1\% \text{ of Milky Way})$

UV-Luminous Galaxies (ULG's, L > 10^{10} L$_{SUN}$)

Cartwheel

NGC 3641

NGC6069

AM0644

NGC 6052

FUV (1500A)
NUV (2300A)

Heckman et al. 2005

2 kpc

2 kpc

2 kpc
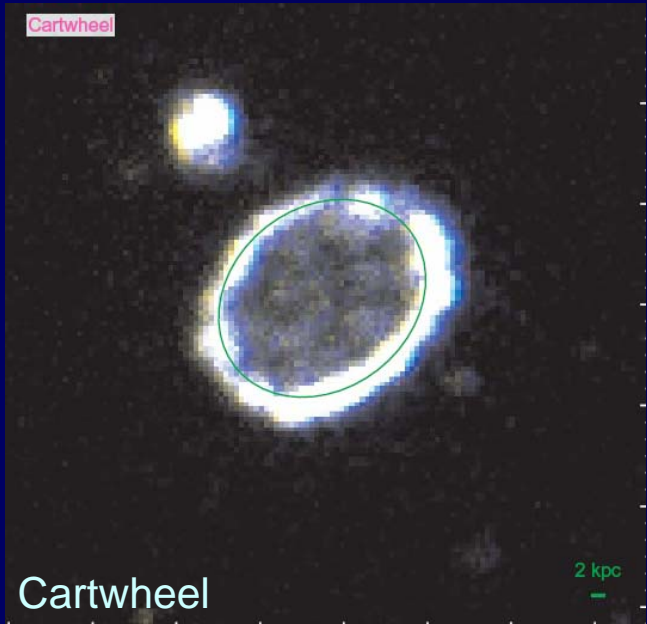
UV Luminous Galaxies ($L_{FUV} > 2 \times 10^{10} L_\odot$)

FUV (1500A)
NUV (2300A)

Small, High SFR/Area, "Young" - ~50%

Massive, "old", residual SF - ~40%

Heckman et al. 2005
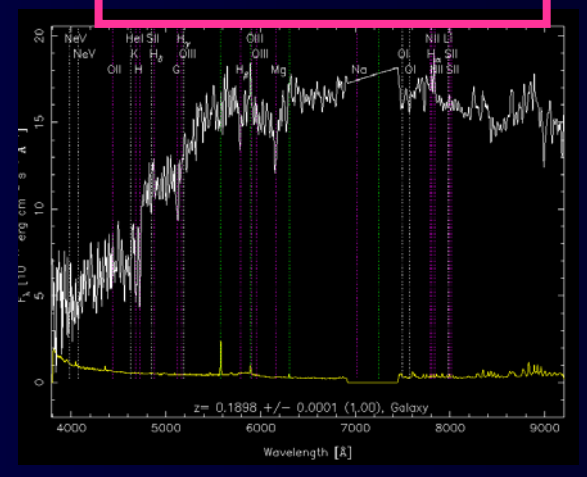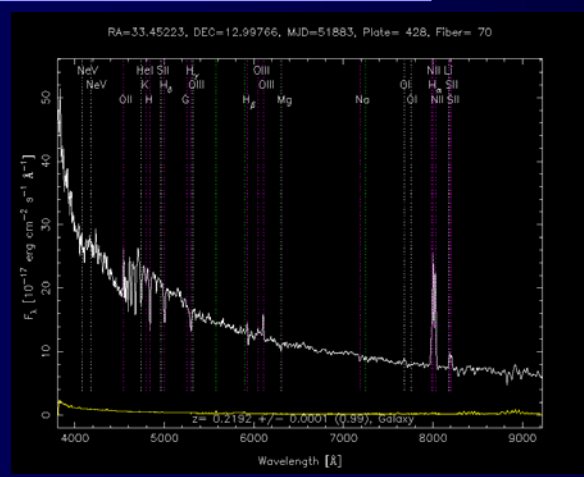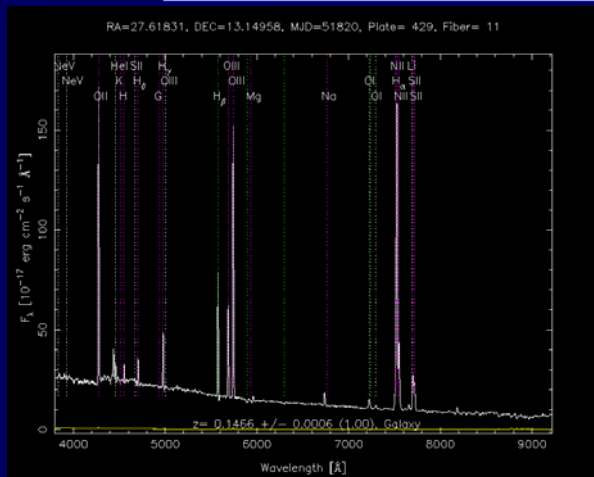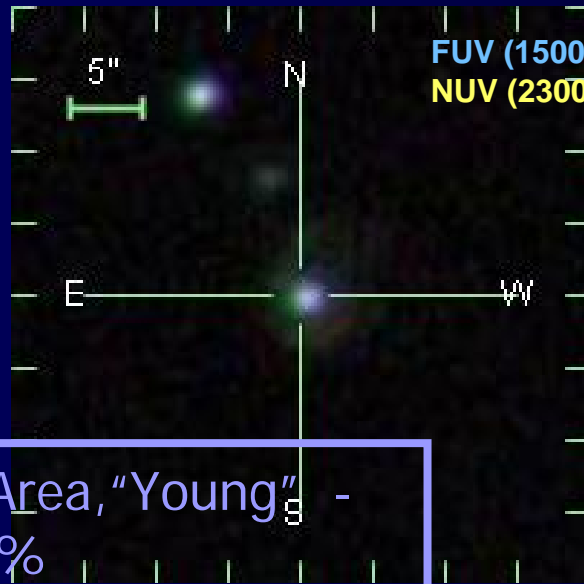
UVLG's - Physical Properties

■ Large (old) ULGs
■ Compact (young) ULGS
■ Lyman Break Galaxies (z > 2.2))

SGN - ALFALFA mtg.
23 June 2005

Heckman et al. 2004
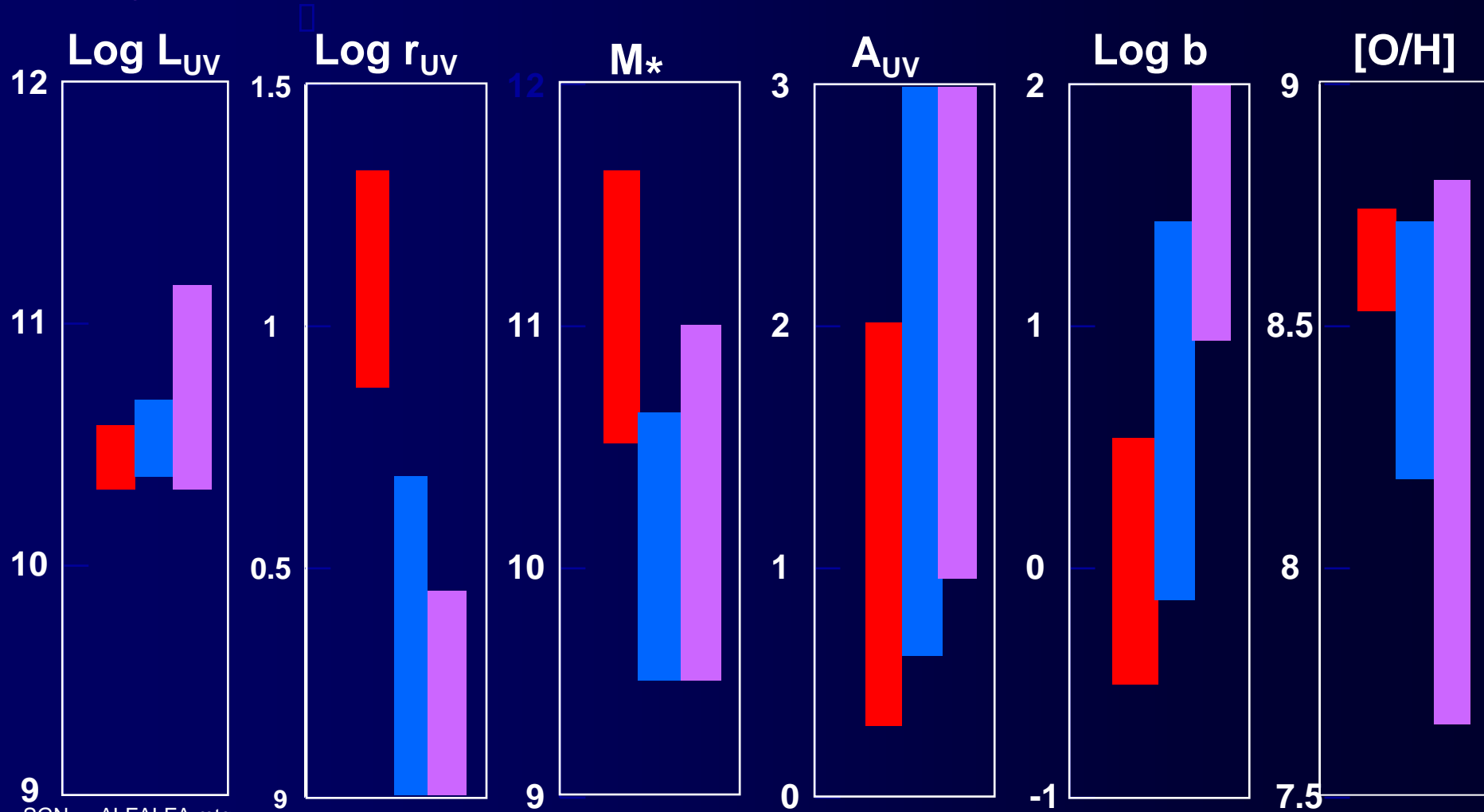
GALEX Data useful for ALFALFA

- AIS (All-sky survey)
  - 100 sec exposures, $m_A \sim 20$, $b > 20°$ .and. without UV-bright stars,
  - Rough UV colors, ages/masses of recent star formation (better if SDSS data available), probably don't detect extended structure
- MIS / NGS (Medium Imaging Survey / Nearby Galaxy Survey)
  - 1500 sec exposures, $m_{AB} \sim 23$, MIS overlaps SDSS Northern Galactic Cap
  - MIS $1000 deg^2$; NGS: 200 nearby galaxies
- Cycle 1 Legacy Programs
  - Volume-limited sample (D<10Mpc), PI Kennicut
  - Nearby HI selected sample, based on HIPAS, PI Meurer
  - 1500 sec exposures, data publicly available 3 months after GI teams receive it
- ?? Individual PI / GI programs (Virgo mosaic, Coma mosaic, …) ??
- ?? Cycle 3 ALFALFA Legacy Program ??
  - Proposals probably due April 2006; observations would begin October 2006
  - Comes with (some, scrimpy) funding!

- GALEX Data Releases
  - Data releases yearly (November-December), through MAST (at STScI)
  - GALEX Data Release 1 (GR1), includes 40NGS, 2000 AIS, 100 MIS, 10DIS fields
  - GI's have 6 months proprietary time (from when their data is available at MAST)
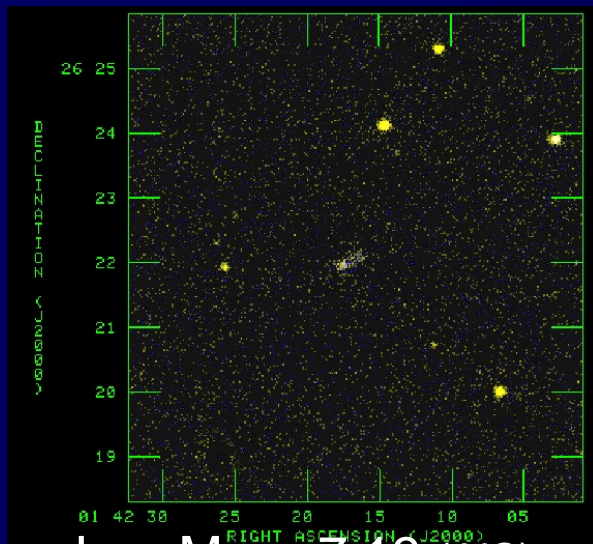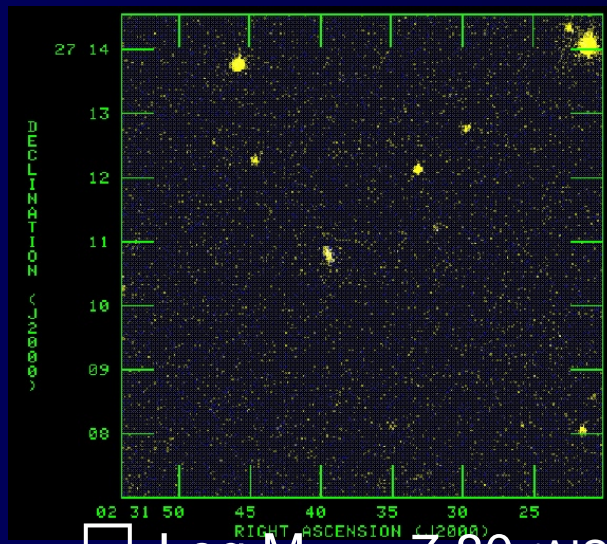
ALFALFA - precursor survey GALEX detections

Mass HI Log (M_{sun})		# detected Alfalfa-Pre	# GALEX observed	# GALEX detected*	D_{det} (Mpc)	D_{nodet} (Mpc)
< 8		8	3	3	7-22	-
8 - 8.5		3	2	2	10-24	-
8.5 - 9		14	7	4	(7) 23-53	71-78
9 - 9.5		40	11	10	(8) 58-75	135
9.5-10		65	17	15	51-206	
> 10		32	13	12	57-183	

*Mostly in AIS (~100 sec) observations!

GALEX detections: $M_{HI} < 10^{8.5} M_{sun}$

Log M_{HI} = 7.13 (AIS)

☐ Log M_{HI} = 7.80 (AIS)

Log M_{HI} = 7.85 (AIS)

☐ Log M_{HI} = 8.04 (AIS)

Log M_{HI} = 8.20 (MIS)

SGN - ALFALFA m...
23 June 2005

GALEX detections: $M_{HI} < 10^{8.5} M_{sun}$

Log M_{HI} = 7.13 (AIS)
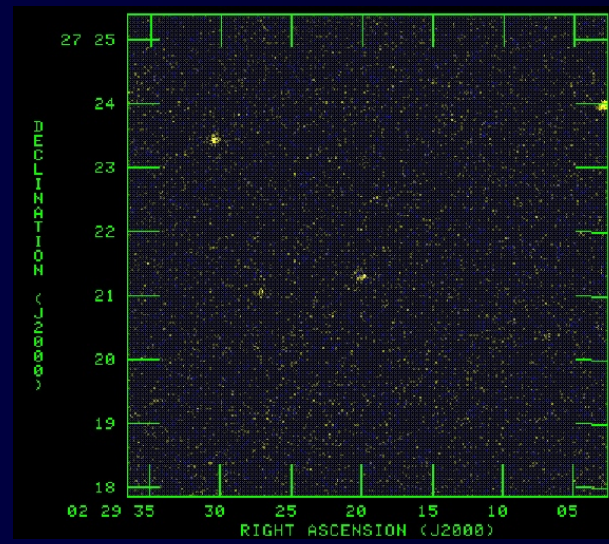
☐ Log M_{HI} = 7.46 (AIS)
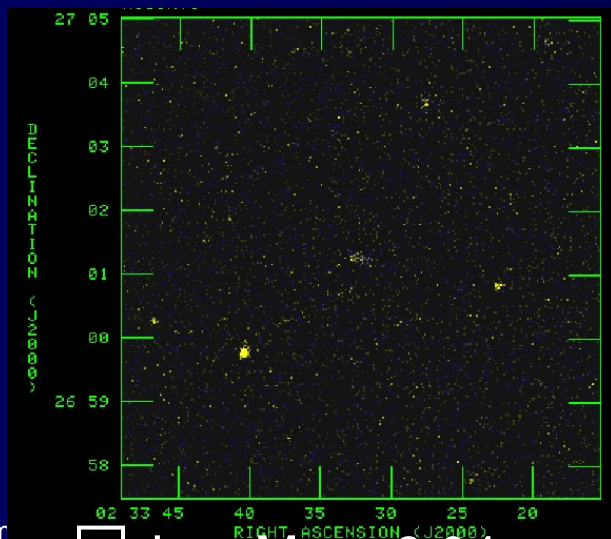
Log M_{HI} = 7.85 (AIS)
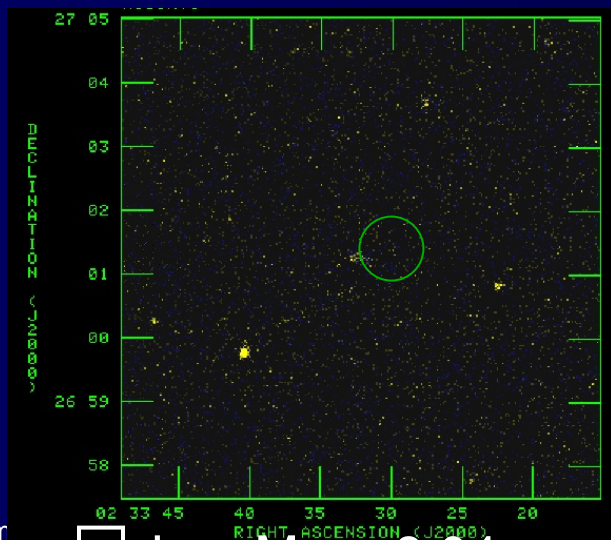
☐ Log M_{HI} = 8.04 (AIS)
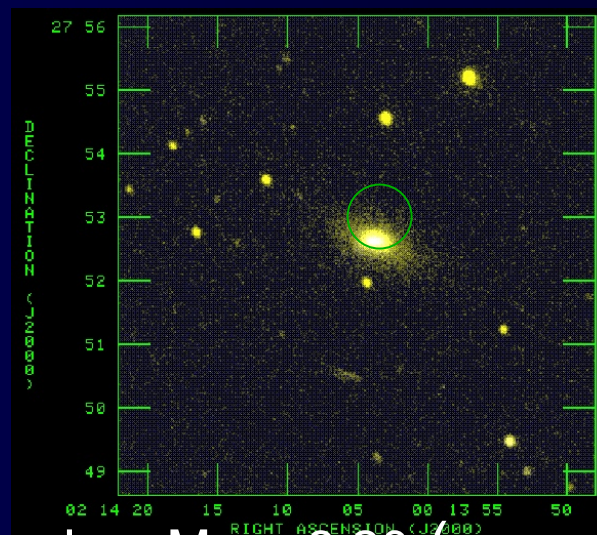
Log M_{HI} = 8.20 (MIS)

GALEX Data useful for ALFALFA

- AIS (All-sky survey)
  - 100 sec exposures, $m_A \sim 20$, $b > 20^o$ .and. without UV-bright stars,
  - Rough UV colors, ages/masses of recent star formation (better if SDSS data available), probably don't detect extended structure
- MIS / NGS (Medium Imaging Survey / Nearby Galaxy Survey)
  - 1500 sec exposures, $m_{AB} \sim 23$, MIS overlaps SDSS Northern Galactic Cap
  - MIS 1000deg^2; NGS: 200 nearby galaxies
- Cycle 1 Legacy Programs
  - Volume-limited sample (D<10Mpc), PI Kennicut
  - Nearby HI selected sample, based on HIPASS, PI Meurer
  - 1500 sec exposures, data publicly available 3 months after GI teams receive it
- ?? Individual PI / GI programs (Virgo mosaic, Coma mosaic, …) ??
- ?? Cycle 3 ALFALFA Legacy Program ??
  - Proposals probably due April 2006; observations would begin October 2006
  - Comes with (some, scrimpy) funding!

- GALEX Public Data Releases
  - Data releases yearly (November-December), through MAST (at STScI)
  - GALEX Data Release 1 (GR1), includes 40NGS, 2000 AIS, 100 MIS, 10DIS fields
  - GI's have 6 months proprietary time (from when their data is available at MAST)

GALEX Data Processing / Release

- Data pipeline
  - Receives data as photon lists (x, y, t on detector)
  - Constructs images from photon lists
  - Corrects for S/C attitude drifts / jumps; de-drizzles images
  - Removes detector hotspots; flatfields & calibrates data (background subtracts)
  - Runs SEXTRACTOR variant to find all unresolved or slightly resolved objects
  - (GRISM observations, extracts spectra for each point source in matching image)
  - Constructs catalogs of all object positions, fluxes, sizes, shapes, spectra, …
    - Similar to SDSS data sets and catalogues; based on SDSS architechture
  - QA: First automatic, then human
  - In some cases: multi-orbit observations of same field aligned and stacked, then other steps performed on stacked images