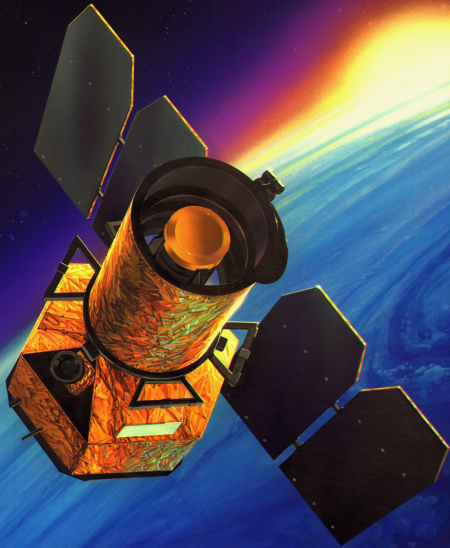


The Galaxy Evolution Explorer

Michael Rich, UCLA

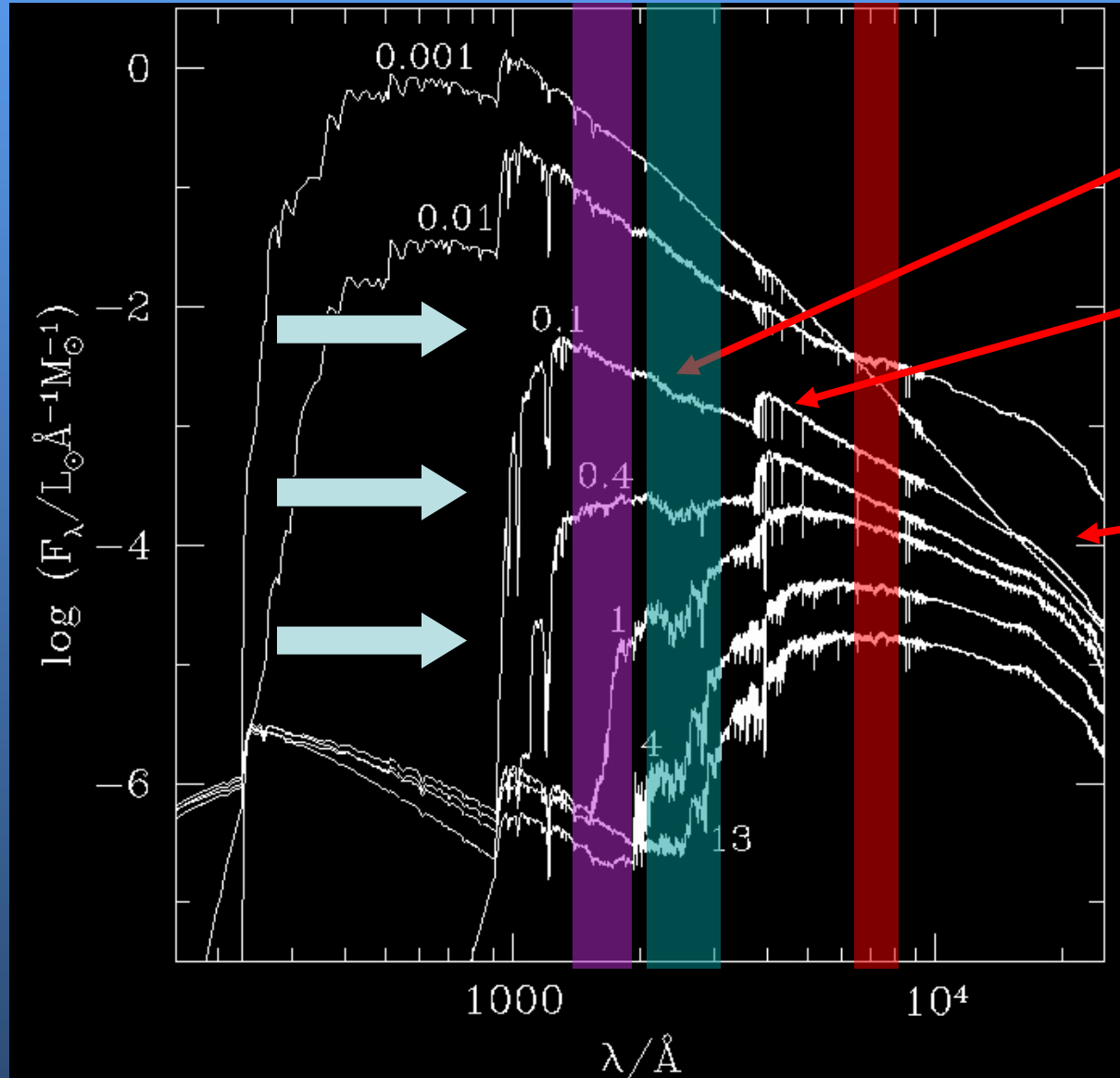
Samir Salim
Ryan Mallery



A decade long effort: From early proposals for UV imaging telescopes by C. Martin, and the FOCA balloon-borne telescope at LAS France.



UV continuum \sim SFR Simple Stellar Population



Age: 0.1-1 Gyr

B, A, F stars

Prominent
Balmer lines
and 3646 \AA
break

AGB stars
dominate IR

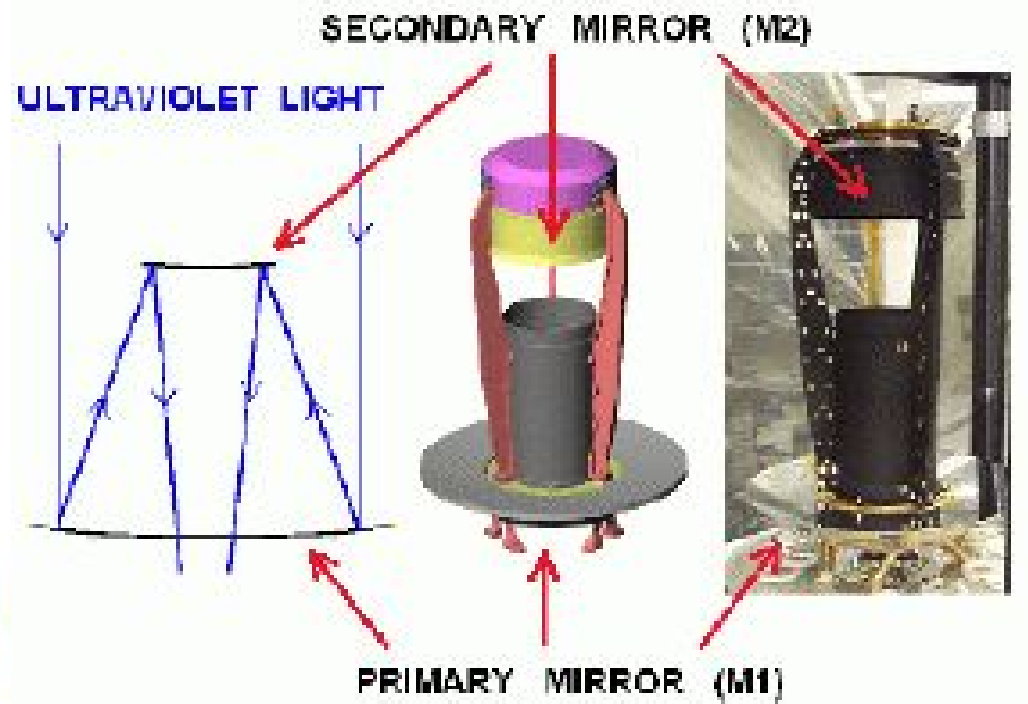
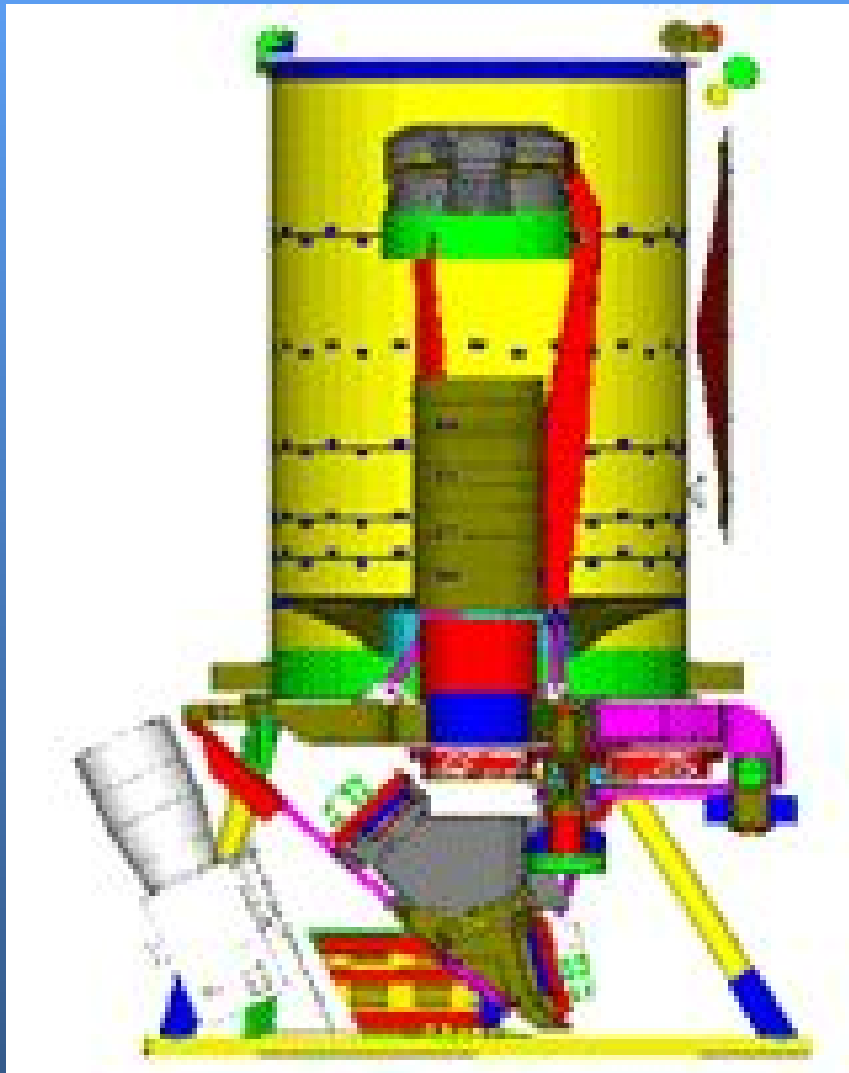
**Bruzual and
Charlot (2003)**

- 50 cm aperture
- 1.2 degrees FOV, circular
- CaF2 imaging window; transmission grism
- Dichroic beam splitter

- 65mm diameter MAMA detectors
- FUV channel: 1250-1800 A
- NUV channel: 1800-3000A
- 5 arcsec resolution

- All-sky survey for $b > 10$ deg AB=21
- Selected deep fields AB=24 to 26.5
- Spectroscopy fields

- 29 month mission + GO program **July 06**
Launch was April 28, 2003



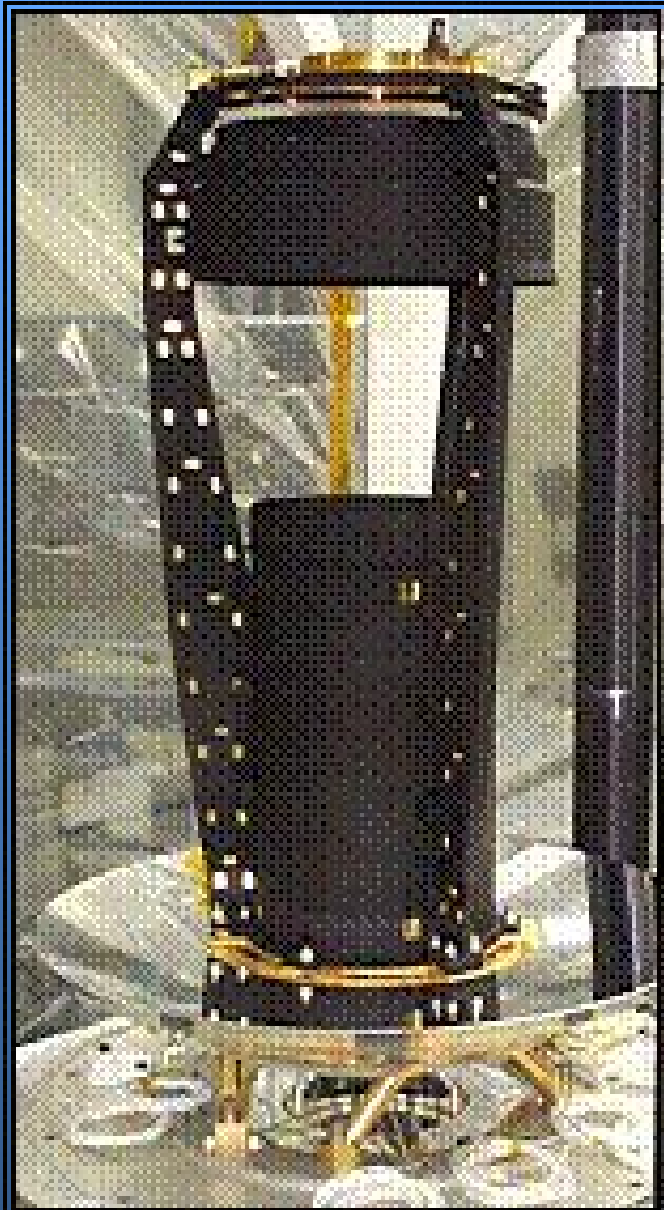


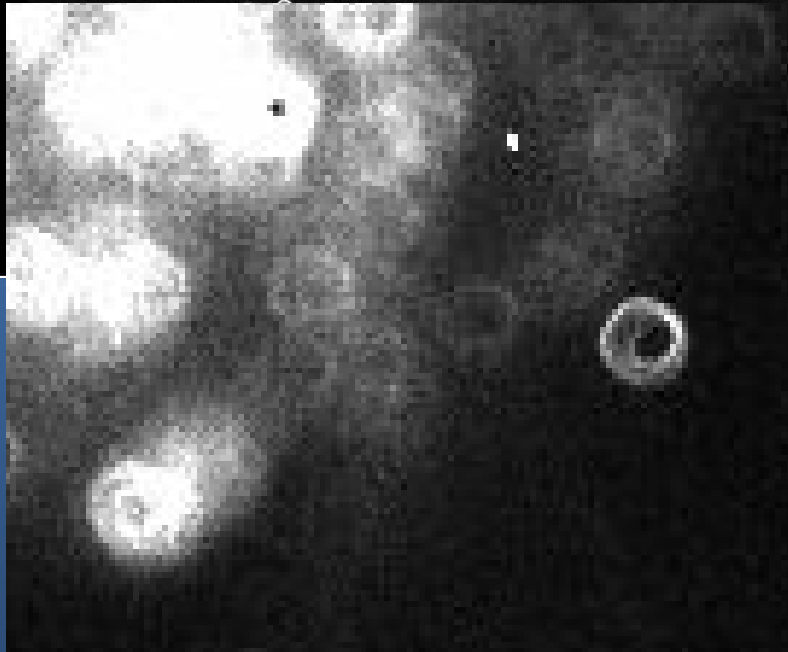
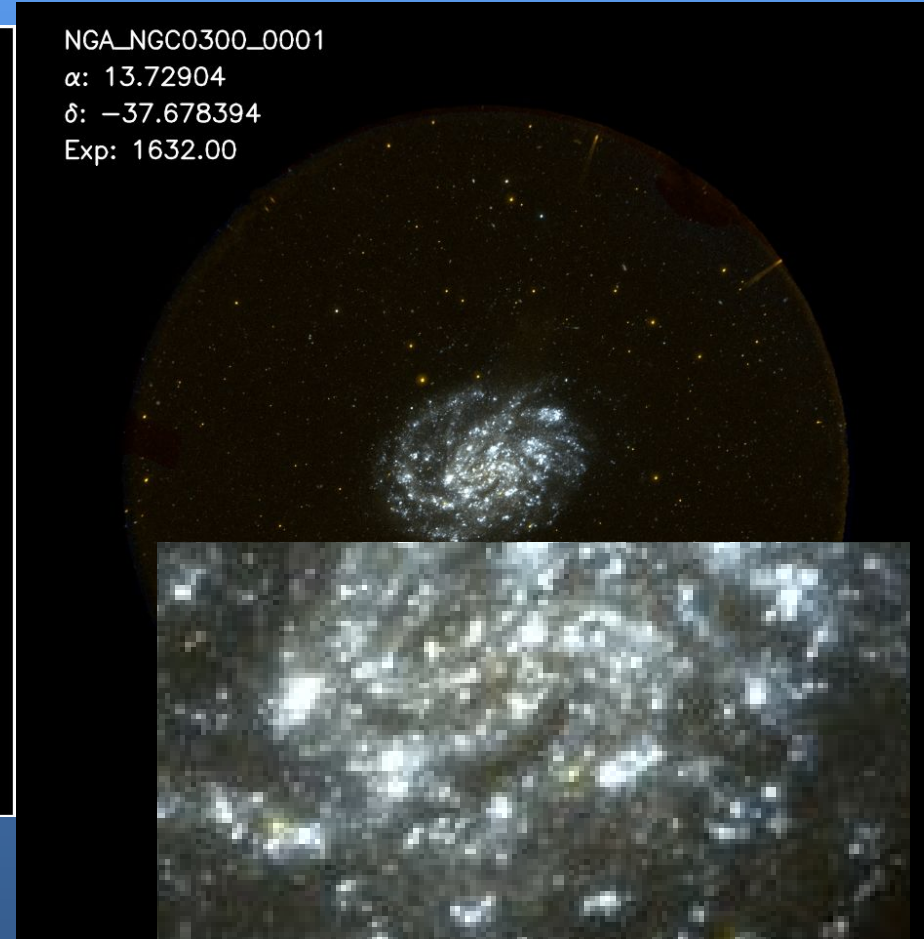
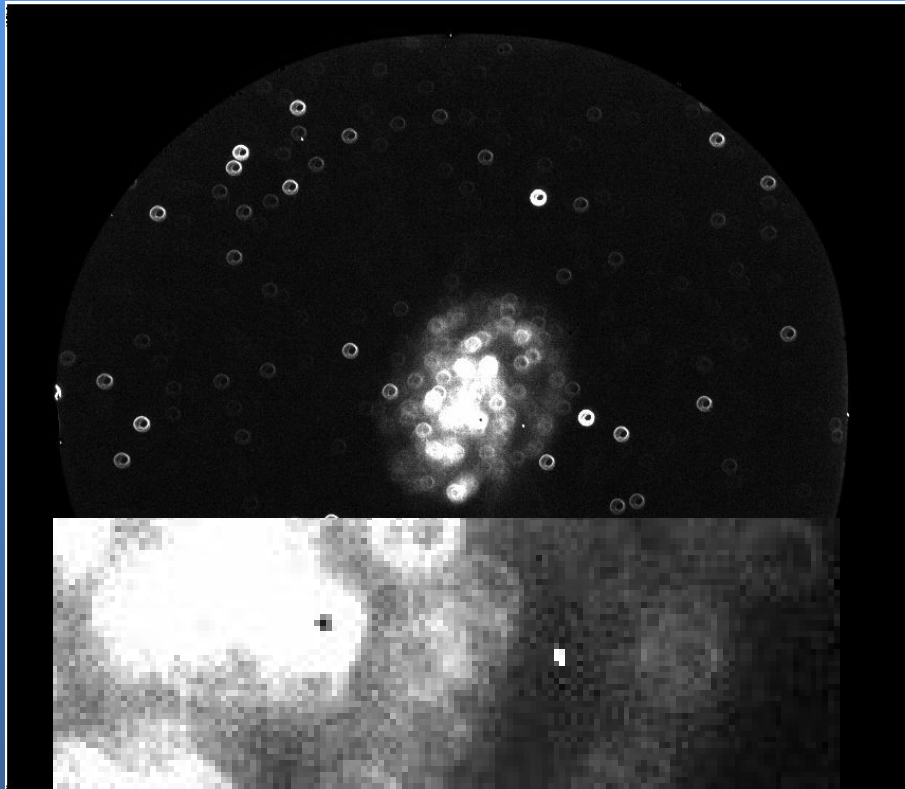
Figure 4 – GALEX
Telescope.



Greenwich Radio

Grism - LAS France

Photons to Images -arrival time retained

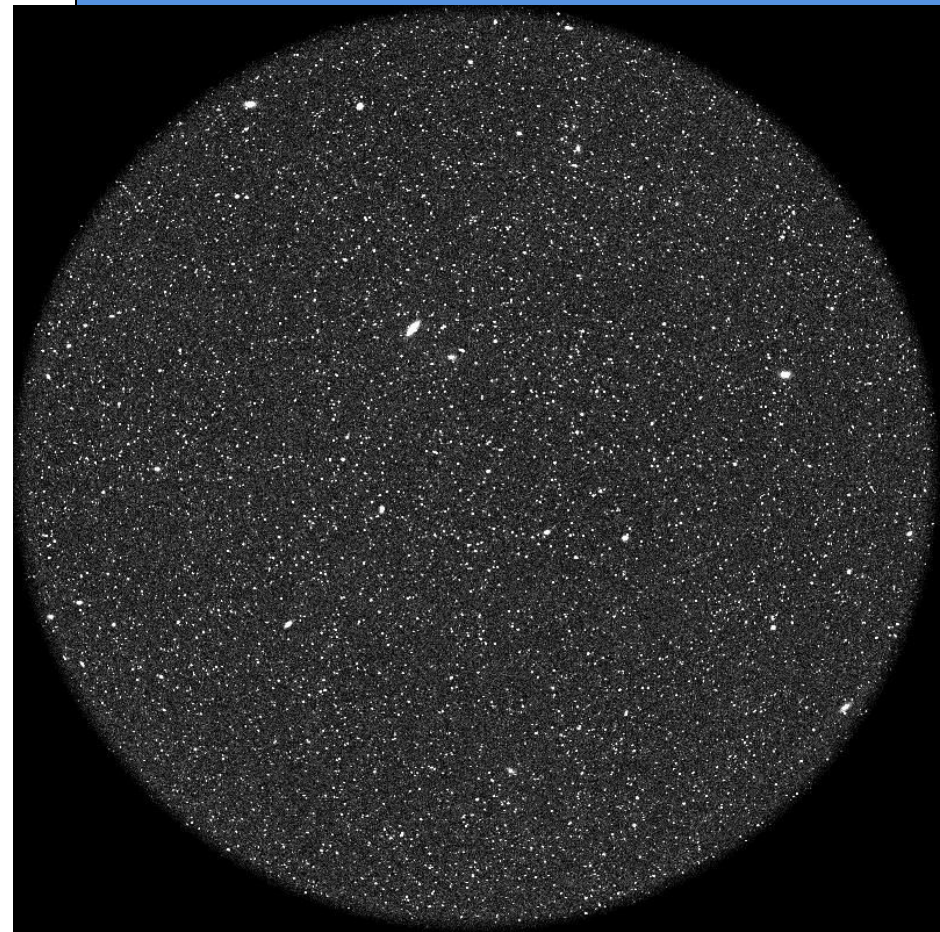


GALEX has a **wide-field of view** and uses a large-format photon-counting detector with low background, excellent sky background rejection and good multiplex capability

- Field of view
→ 1.2 degree diameter



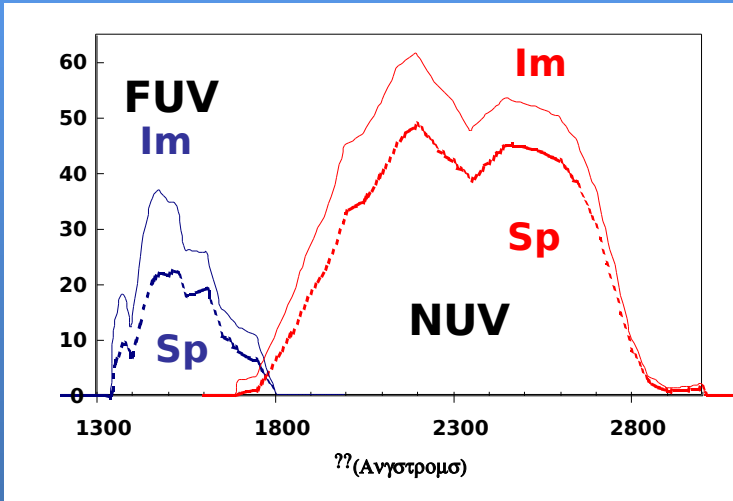
Moon shown for size comparison



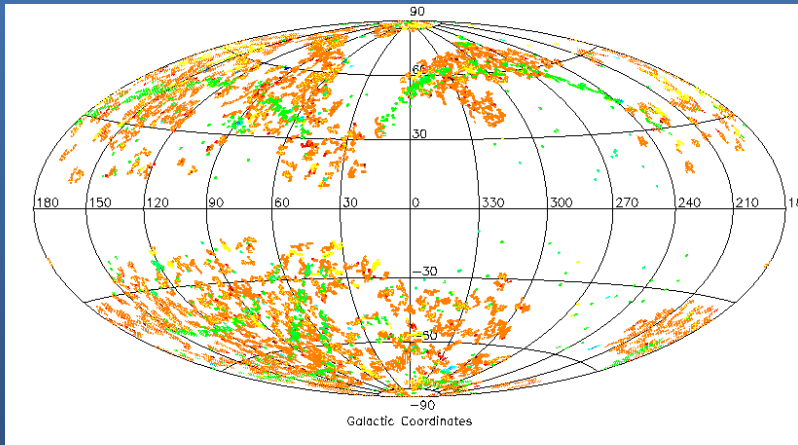
← 1.2 deg →

Performance Summary

2 Simultaneous Bands



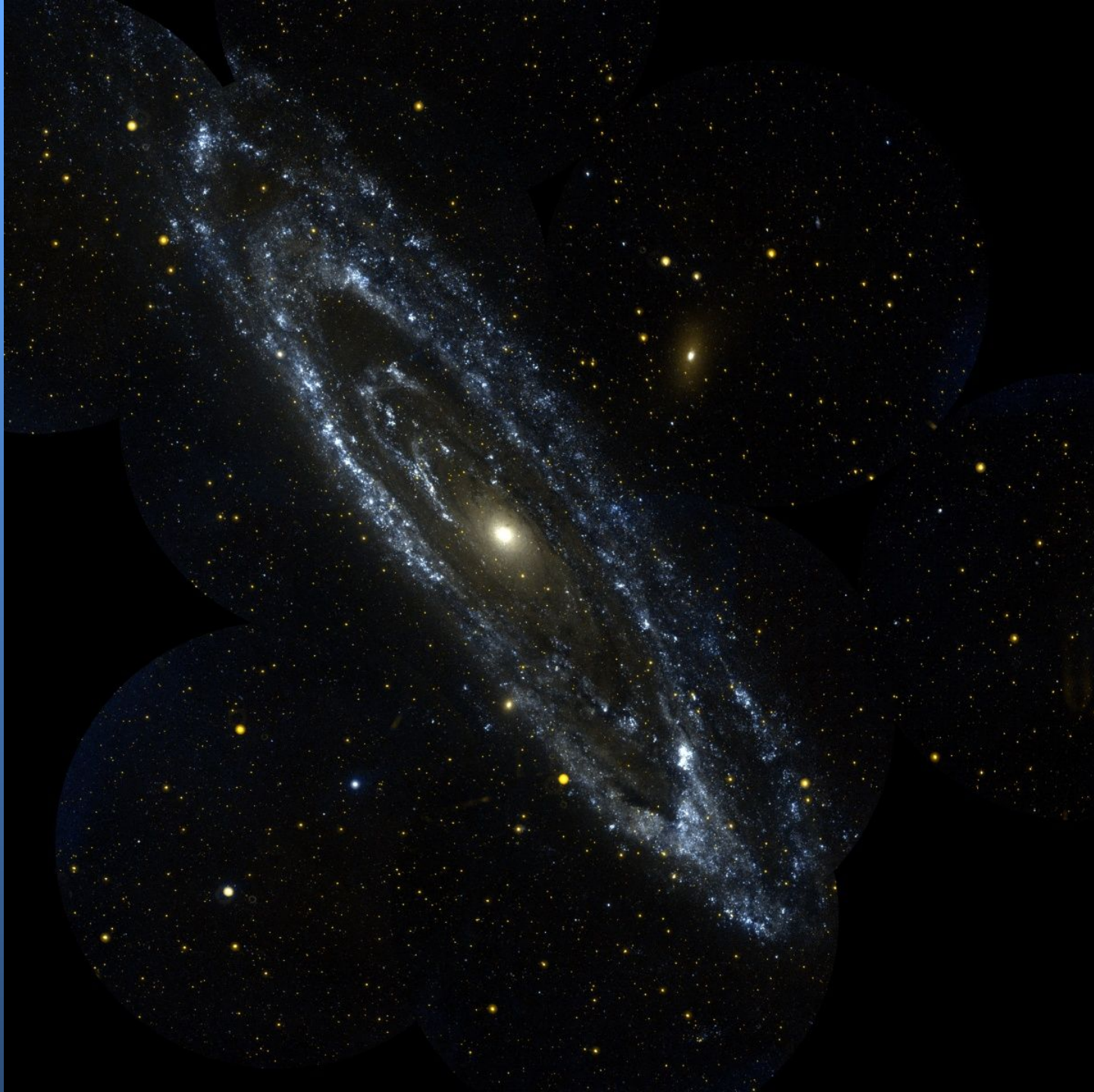
Survey Progress



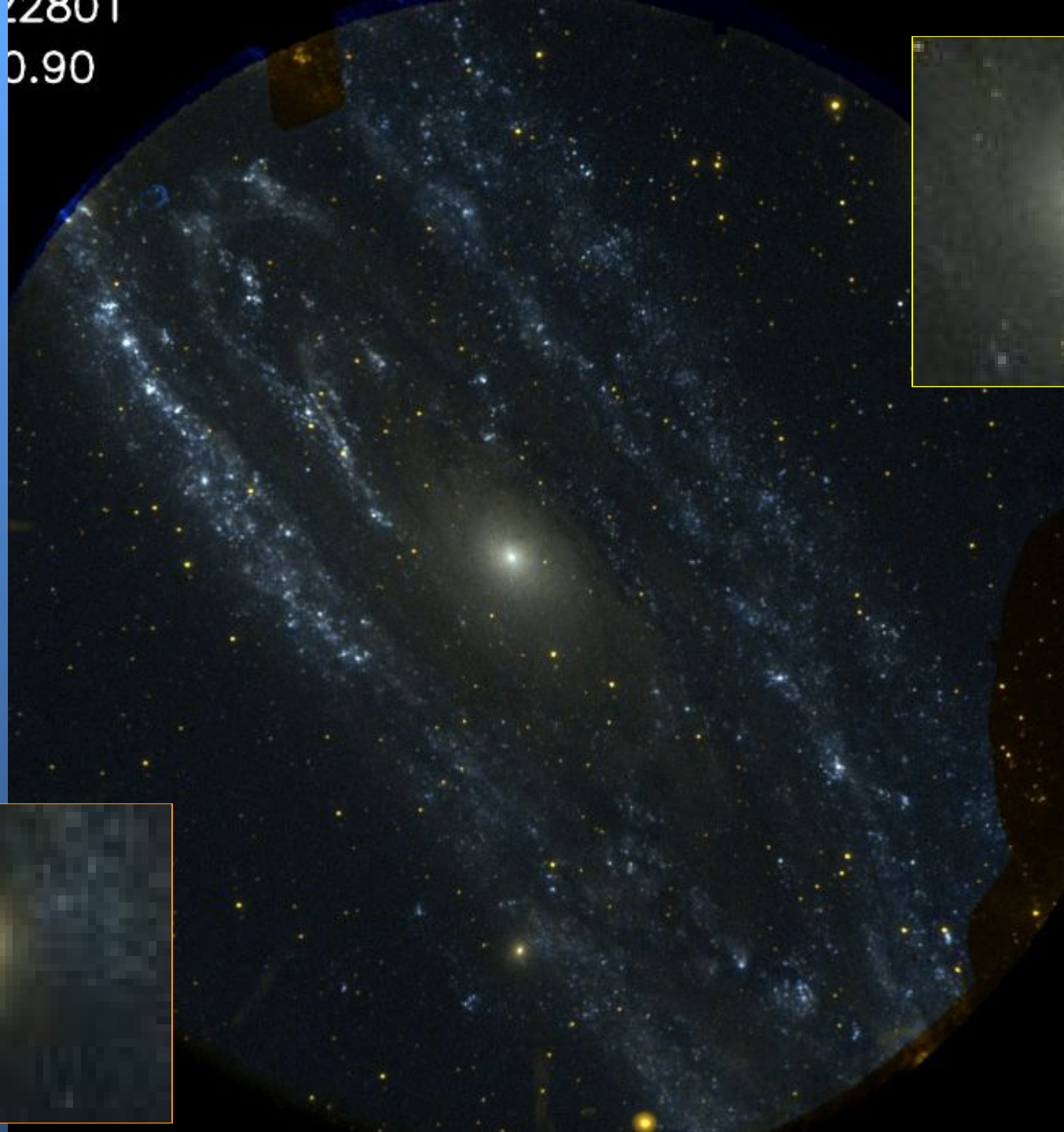
Effective Area	20-50 cm ² (0.5 mKeck)		
Angular resolution	5 arcsecs		
Spectral Resolution	100-250		
Field of View	1.2 degrees		
Bands	FUV 1350-1750 Angstroms NUV 1750-2800 Angstroms		
Sky Background	27-28.5 mag/arcsec ²		
Astrometry	1 arcsec		
Observations	Nighttime, 1 eclipse~1500 s		
Surveys	AIS	MIS	DIS
Exposure Time	100 s	1500 s	30 ks
Sensitivity [μ Jy]	20	1	0.1
Progress to date	25%	80%	50%
Area [deg ²]	20,000	1000	100
Mission Length	Baseline 38 months		

Kennicutt-Schmidt Law 2006





22801
0.90



M31 nucd

M32 nuc



α : 339.13591

δ : 34.194881

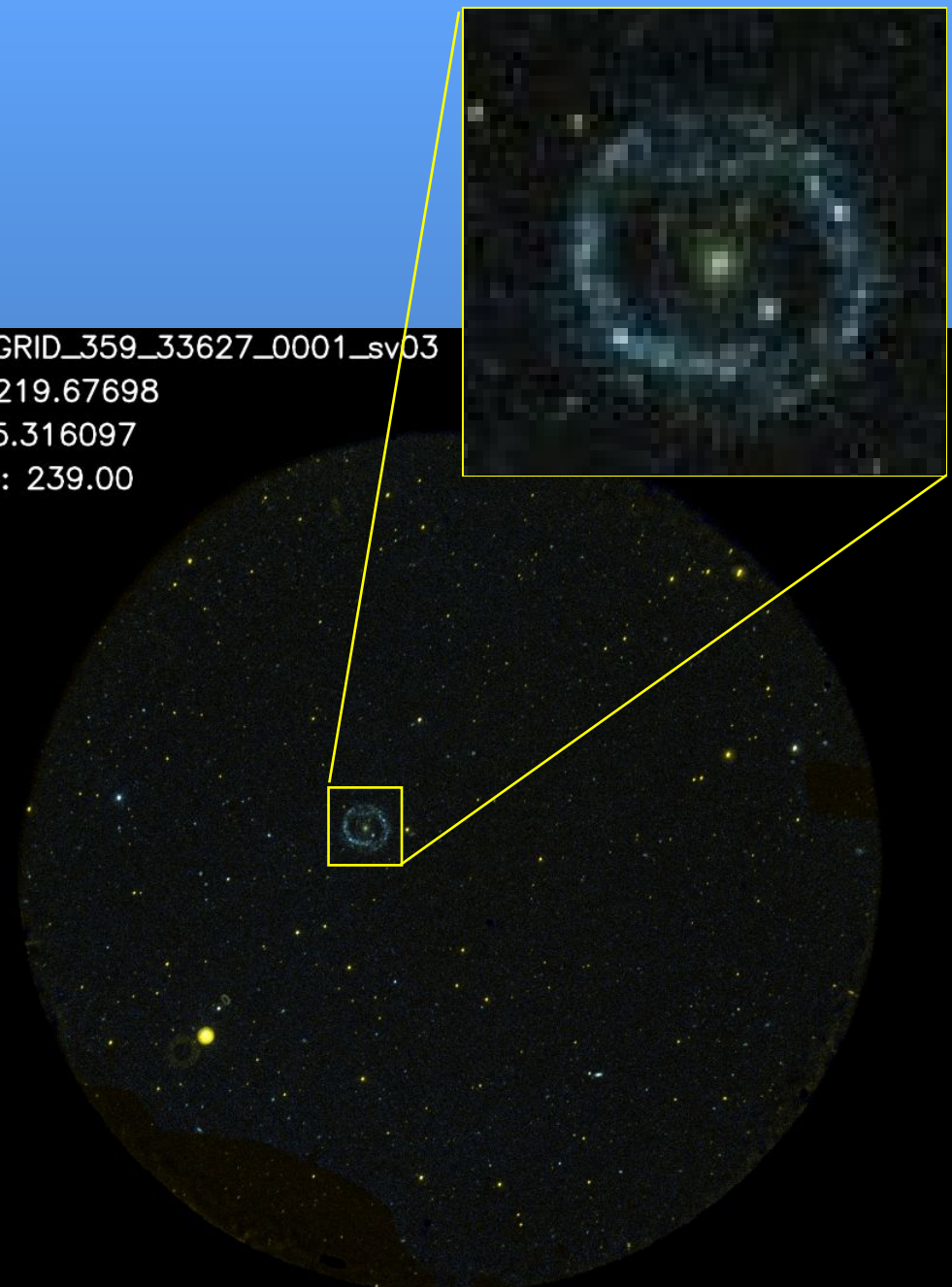
Exp: 1426.00



All-sky Imaging Survey (AIS)

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

AISGRID_359_33627_0001_sv03
 α : 219.67698
 δ : 5.316097
Exp: 239.00



Z=0.2 Kenn

Medium Imaging Survey (MIS)

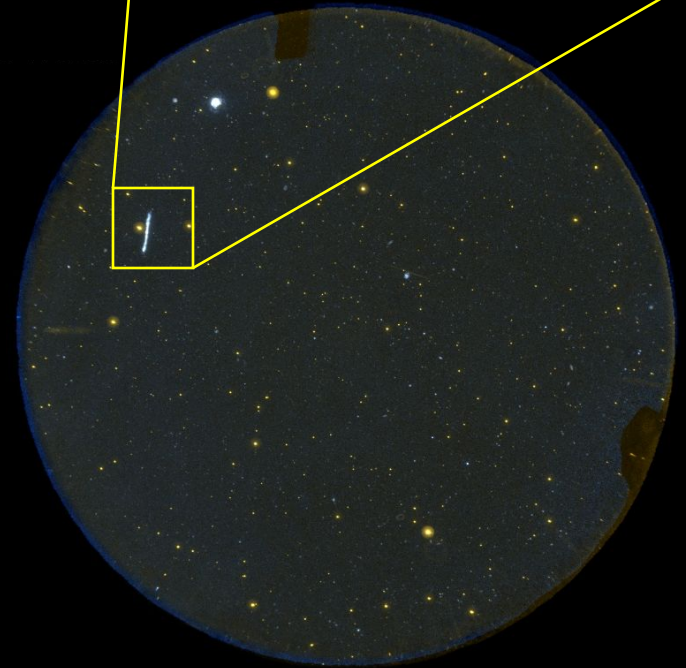
Magnitude	23
Area	1000 deg ²
Cosmic Vol	1 Gpc ³
Overlap	SDSS, 2dF
# Galaxies	3 Million

Z=0.5

Z=0.2

Kennicutt-Schmidt Law

2004-01-12



Nearby Galaxy Survey

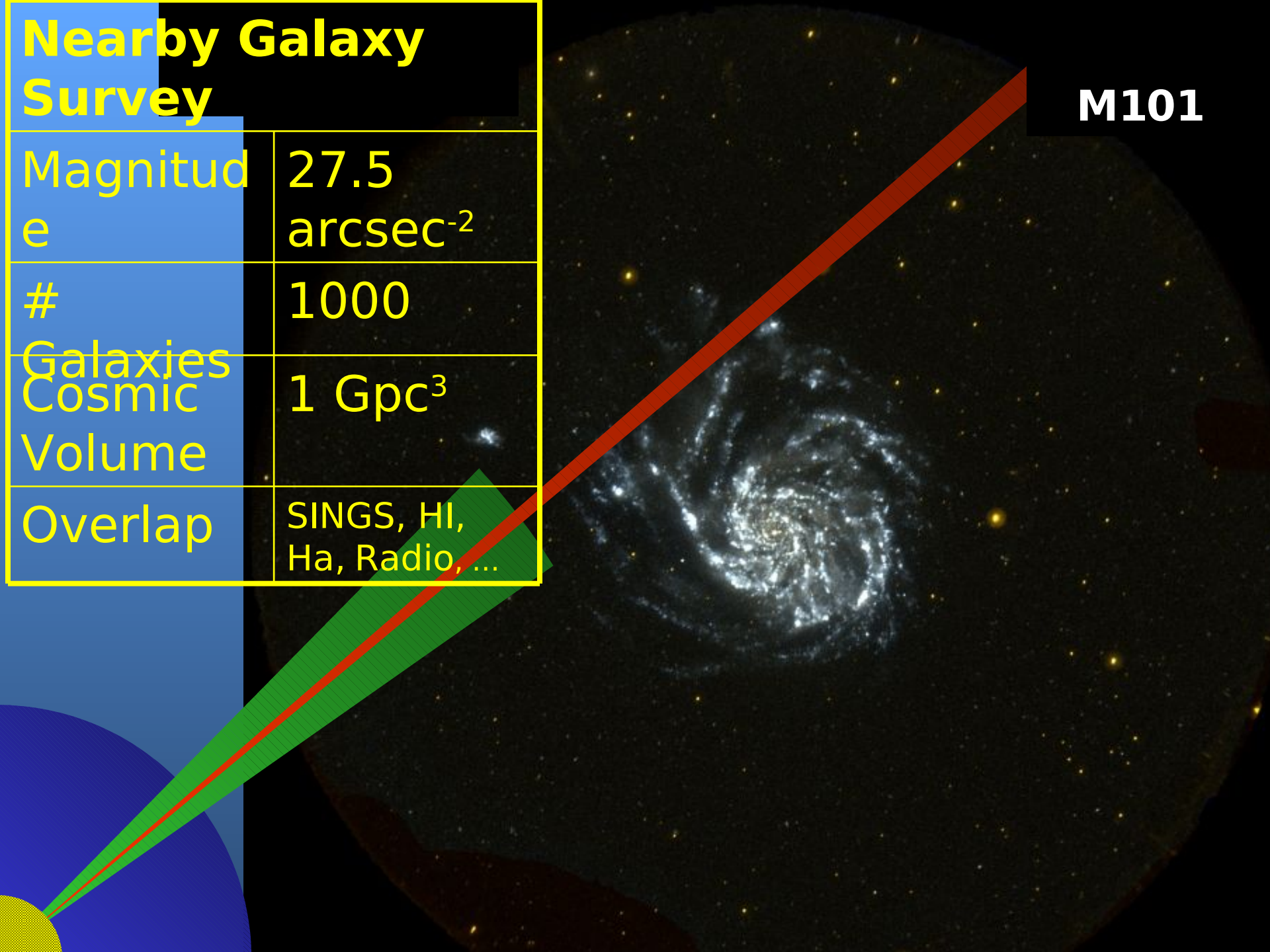
Magnitude
e 27.5
arcsec⁻²

1000

Galaxies
Cosmic
Volume 1 Gpc³

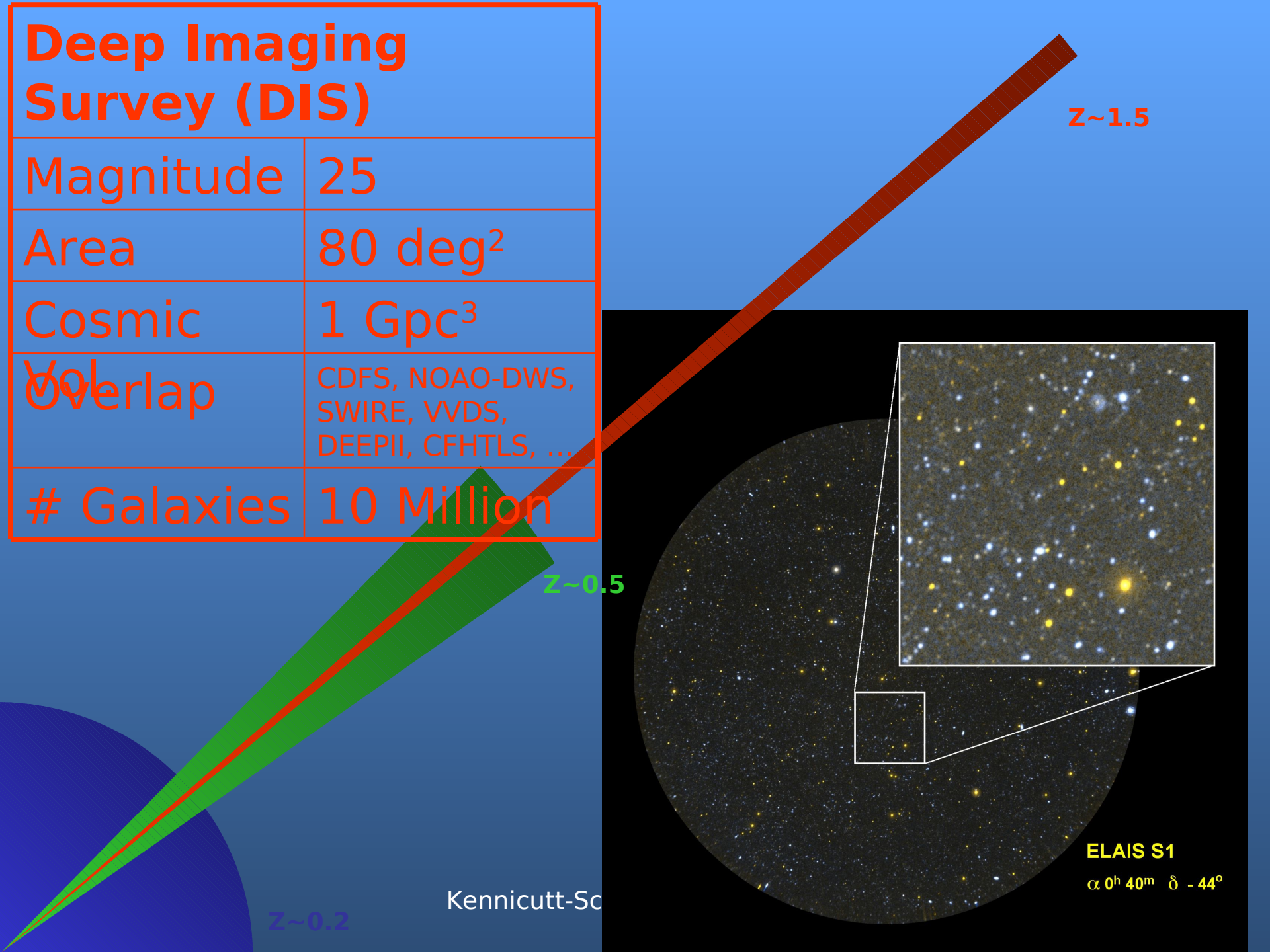
Overlap
SINGS, HI,
Ha, Radio, ...

M101



Deep Imaging Survey (DIS)

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



z~1.5

z~0.5

z~0.2

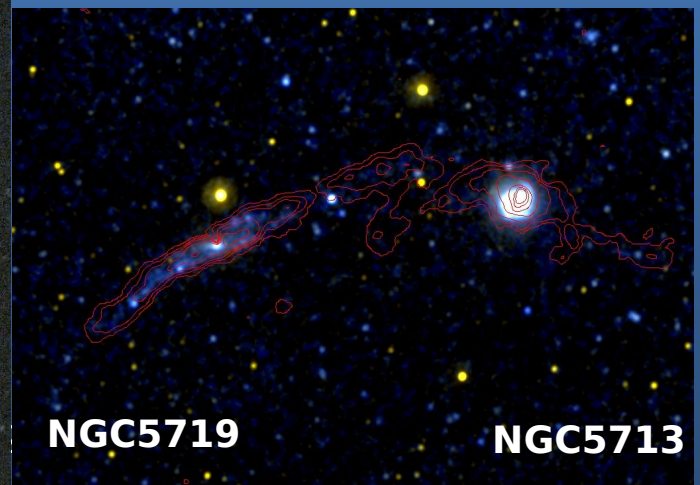
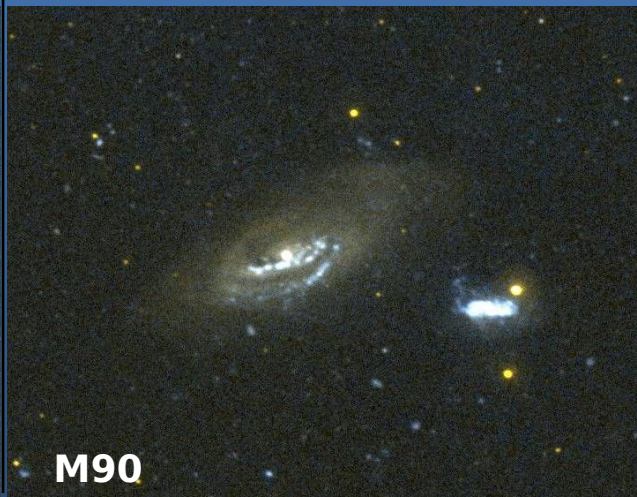
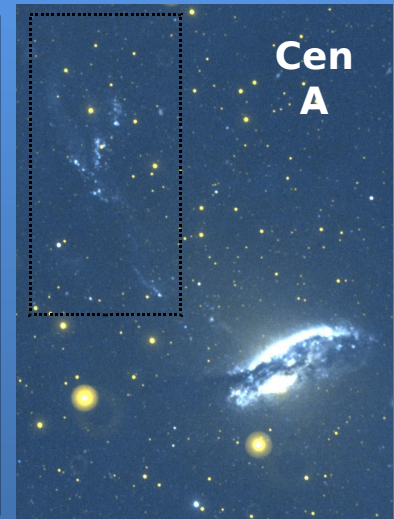
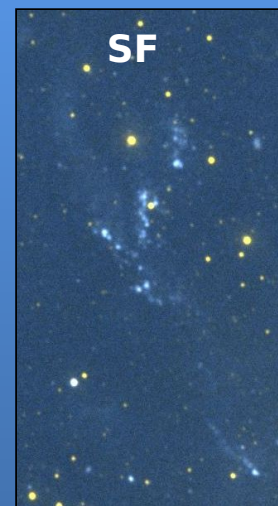
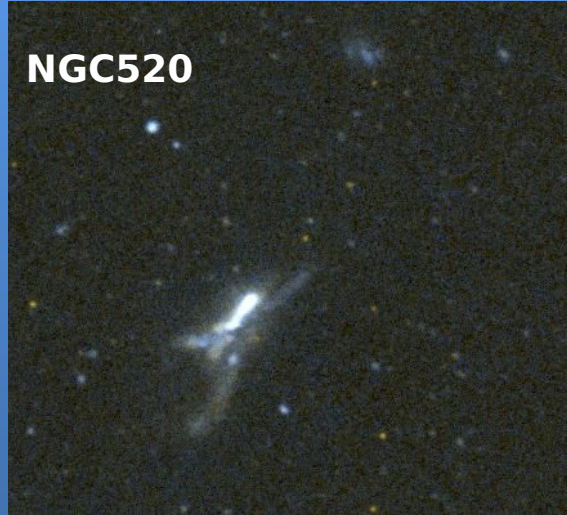
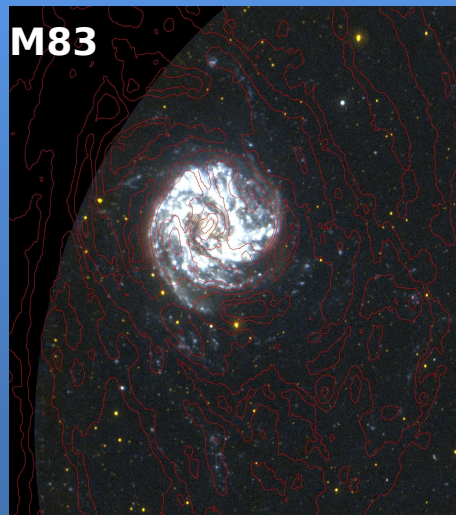
Kennicutt-Sc

ELAIS S1
 α 0^h 40^m δ -44^o

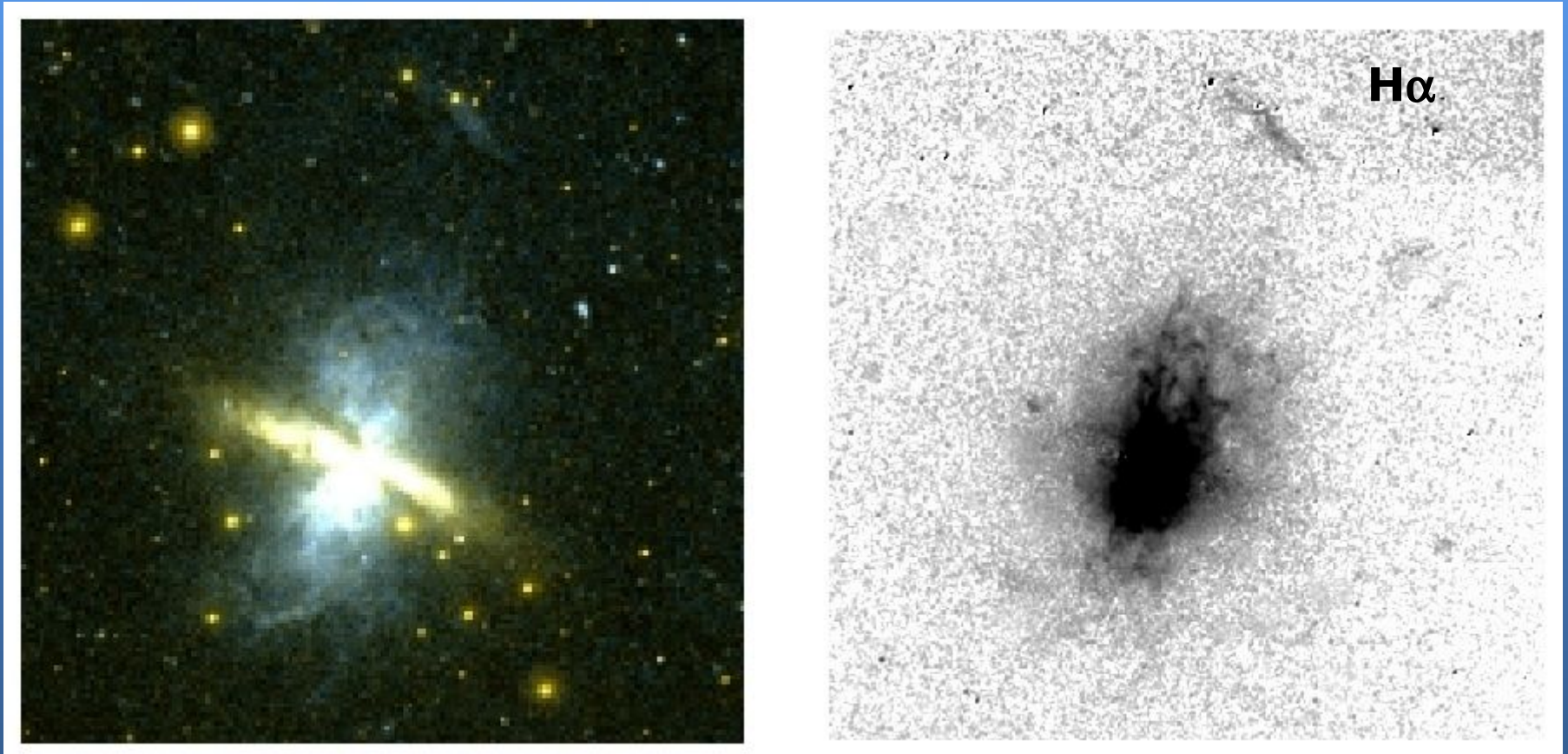
Science Highlights

- ApJ 619 Letters dedicated issue (20 January 2005)
- FUV-based estimate of local star formation rate (Wyder et al.)
- SDSS classification (Bianchi et al.)
- UV Luminous Galaxies (Lyman-break analogs)
- Physical parameters from SED fitting (Salim, Rich et al.)
- GALEX/VVDS UV luminosity evolution (Schiminovich et al.)
- Nearby Galaxies; SF in M31, antennae, mergers, etc. (Bianchi, Neff, Hibbard)
- UV rising flux (no dependence on Mg2), evolution, residual star formation in red galaxies (Rich, Yi, Lee)
- Extended disks in spirals (to > 50 kpc in FUV) Thilker et al.
- Star formation in Local U. (Martin et al.)

RestUV Traces Star Formation In Wide Range of Environments, Scales & Modalities

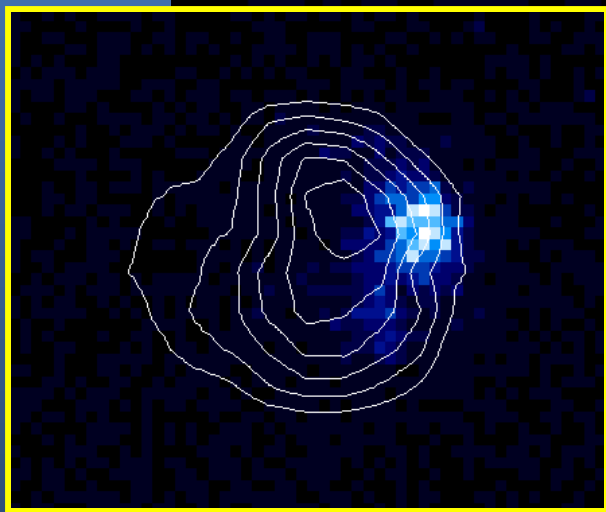
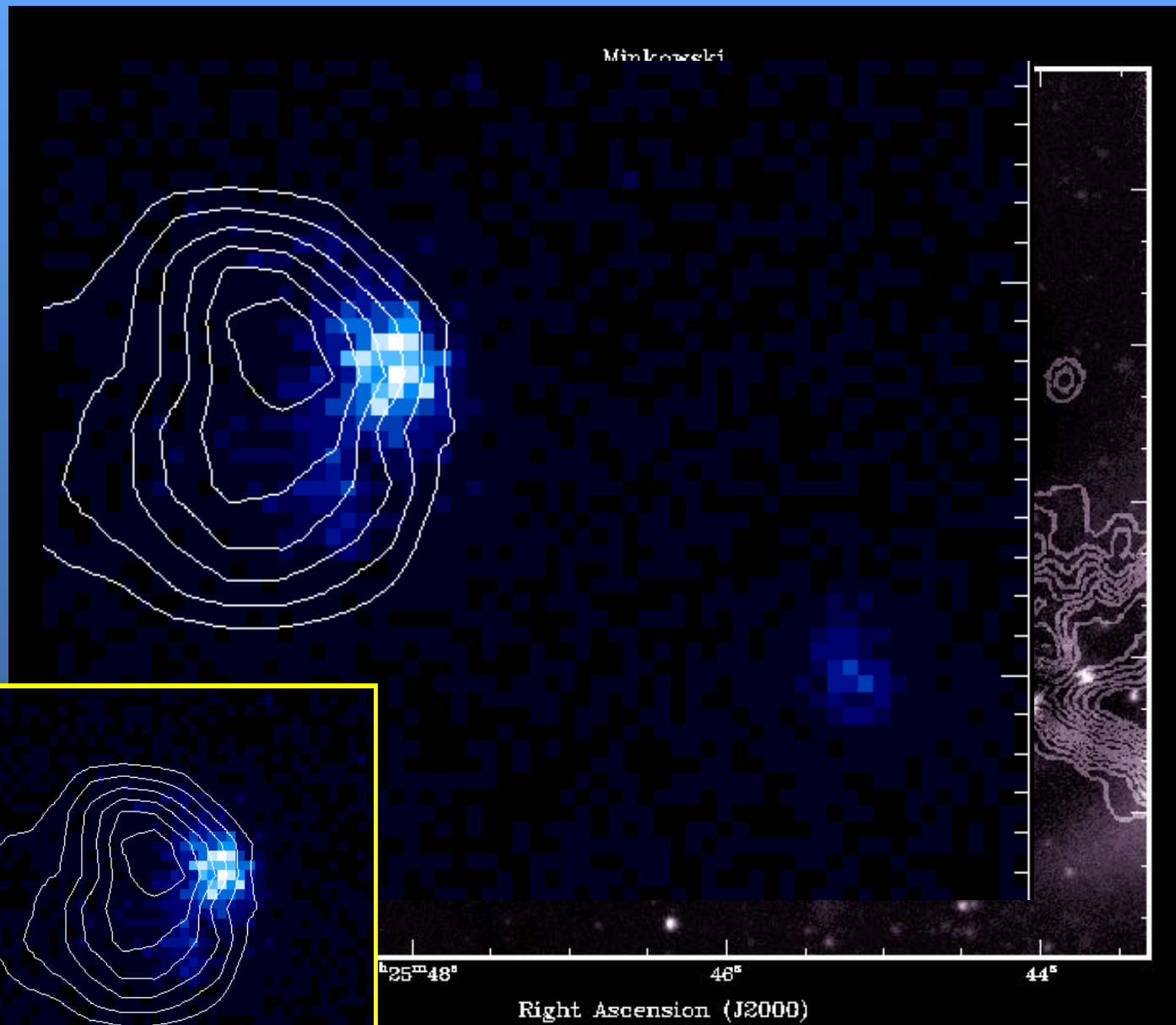


Local Analogs of high-z superwinds: M82



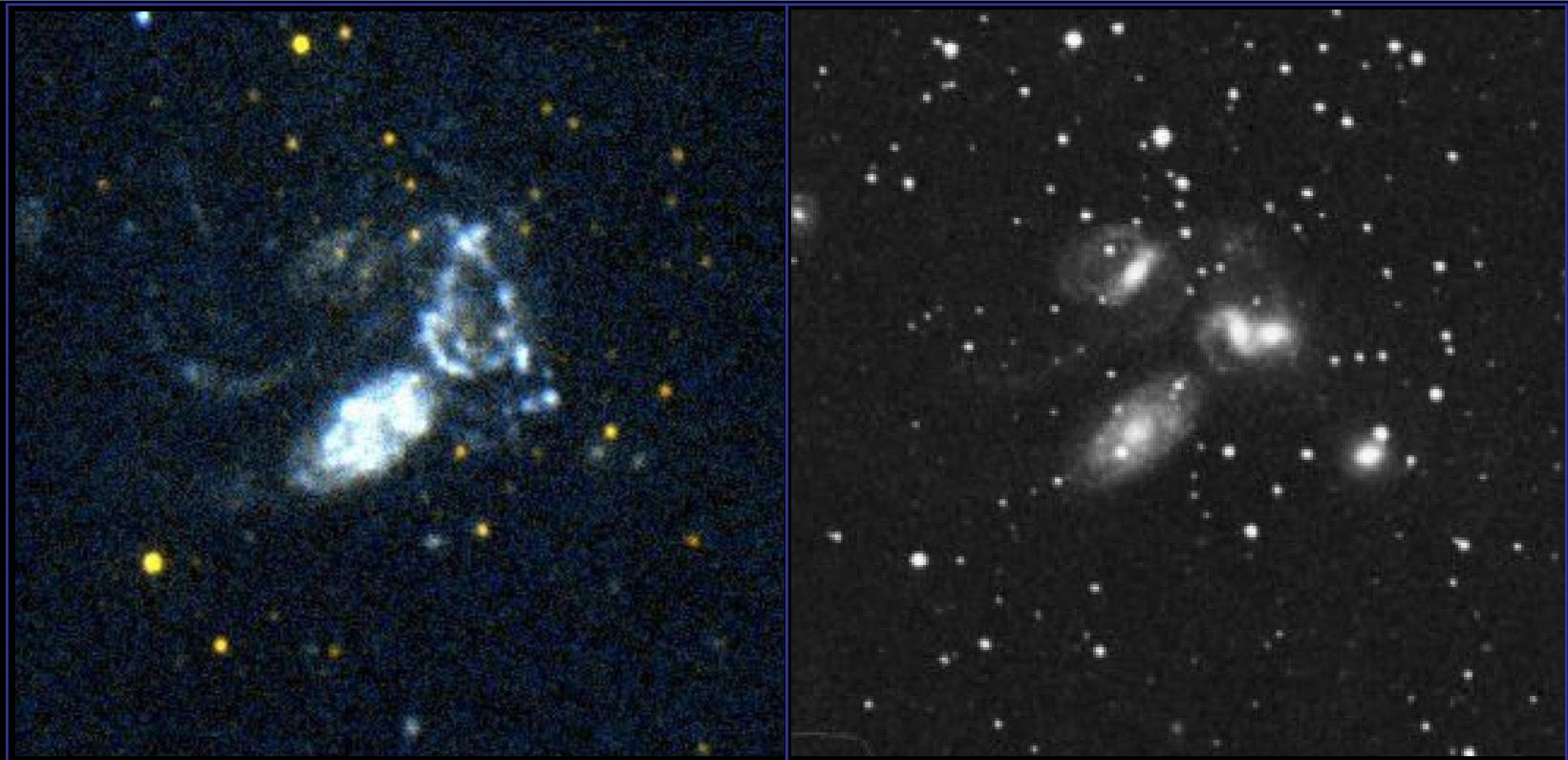
Hoopes, Heckman, Strickland et al (2005)

Minkowski's Object (Croft et al. 2006).



Kennicutt-Schmidt Law 2006

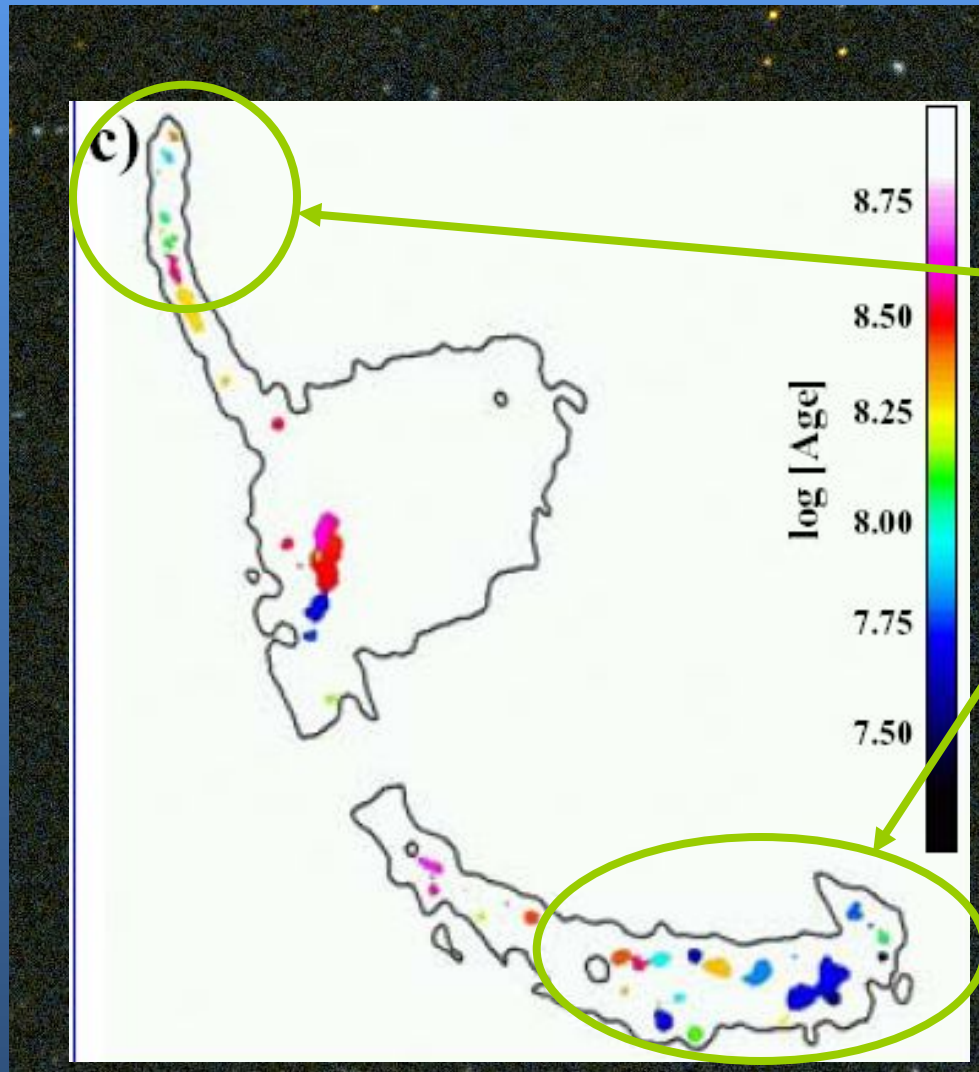
Rest UV Traces Star Formation in merging groups



**Ultraviolet
GALEX**

**Visible
DSS**

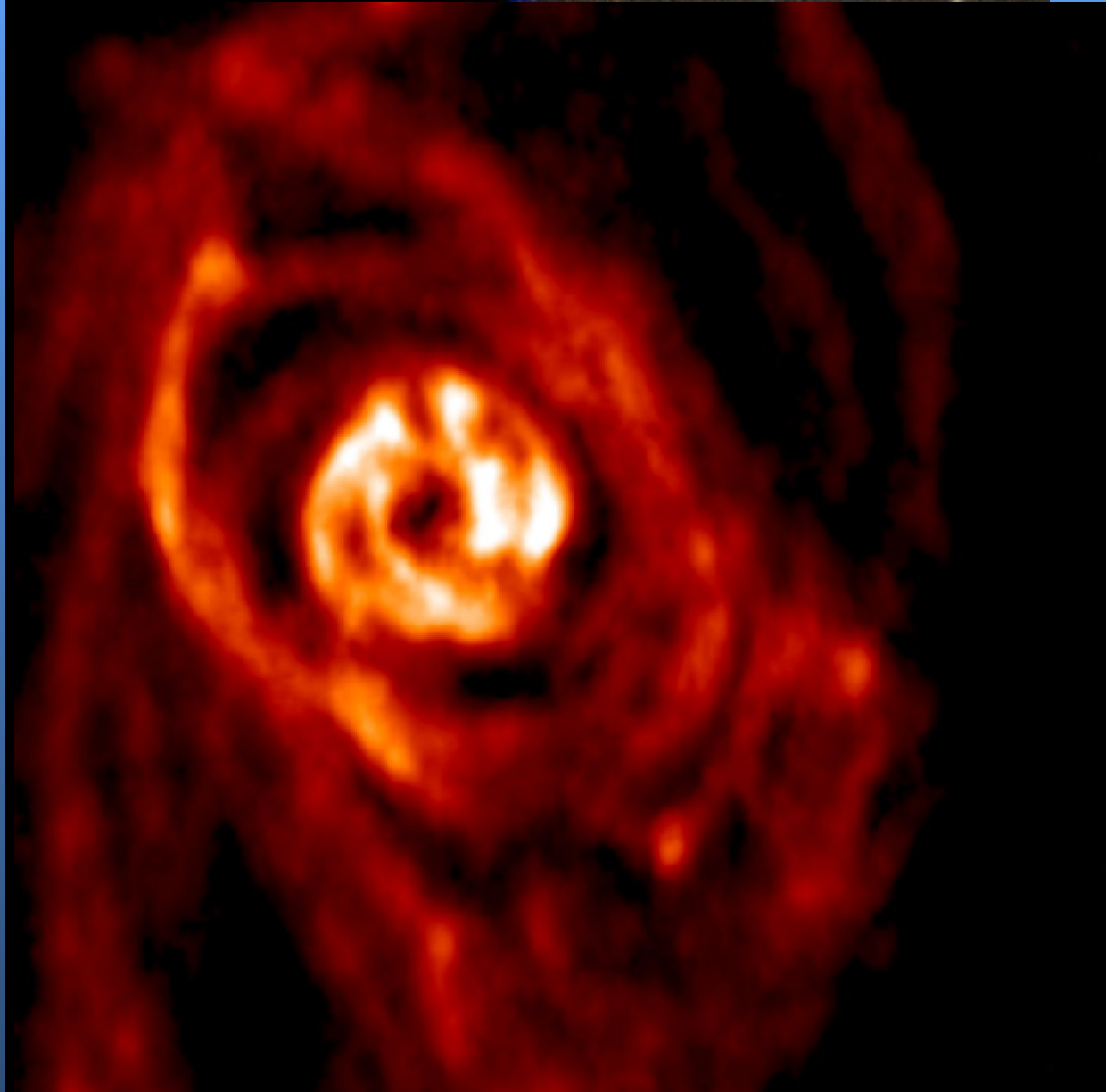
Rest UV Traces Starburst Age In Merging Galaxies



Regions younger than dynamical age 300 Myr

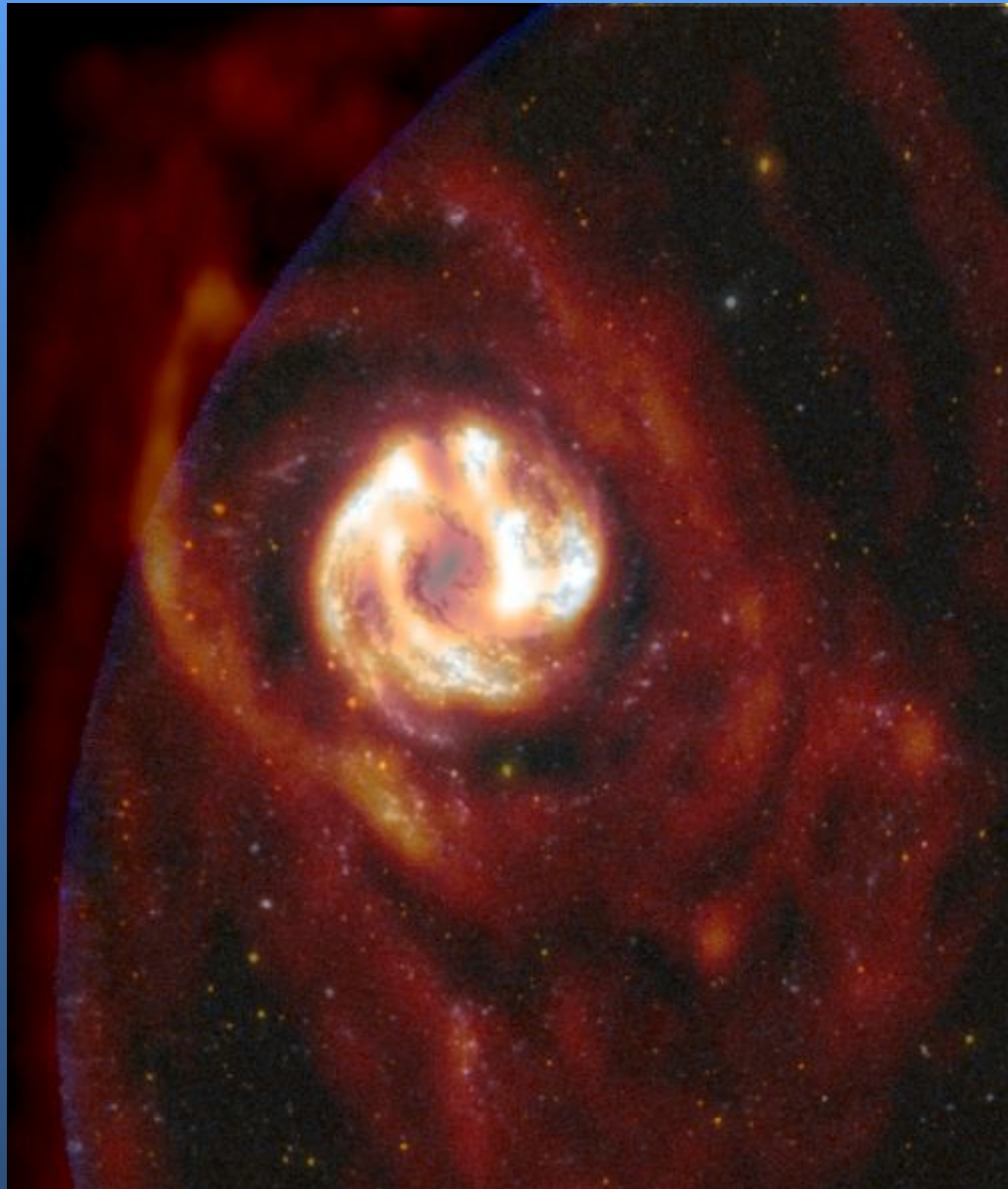
Rest UV Traces Star Formation
In Disks with Extended Star Formation

M83

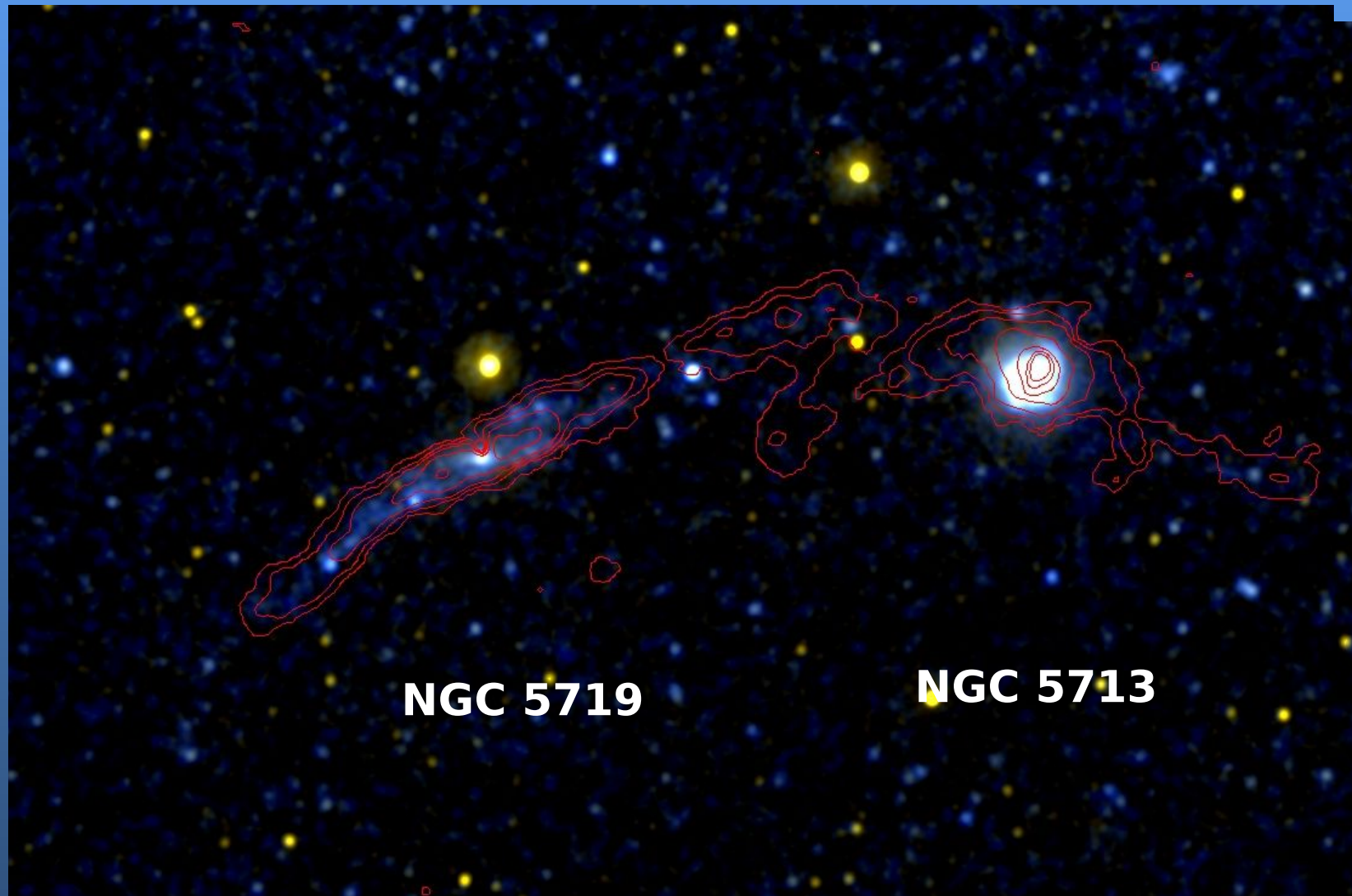


Rest UV Traces Star Formation
In Disks with Extended Star Formation

M83



Rest UV Traces Star Formation
In Tidal Tails formed by Interacting Disks

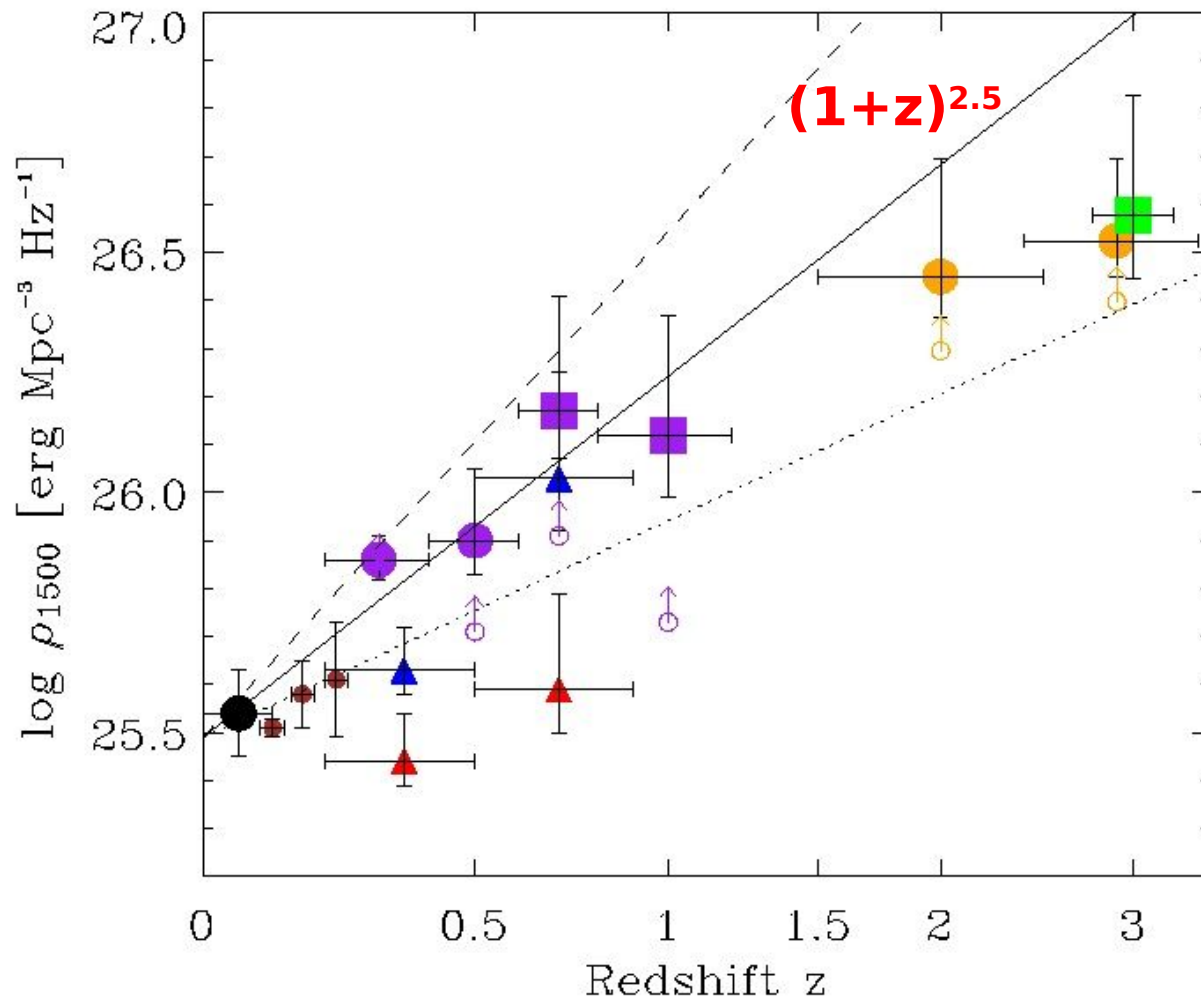


NGC 5719

NGC 5713

UV Luminosity Density Evolution

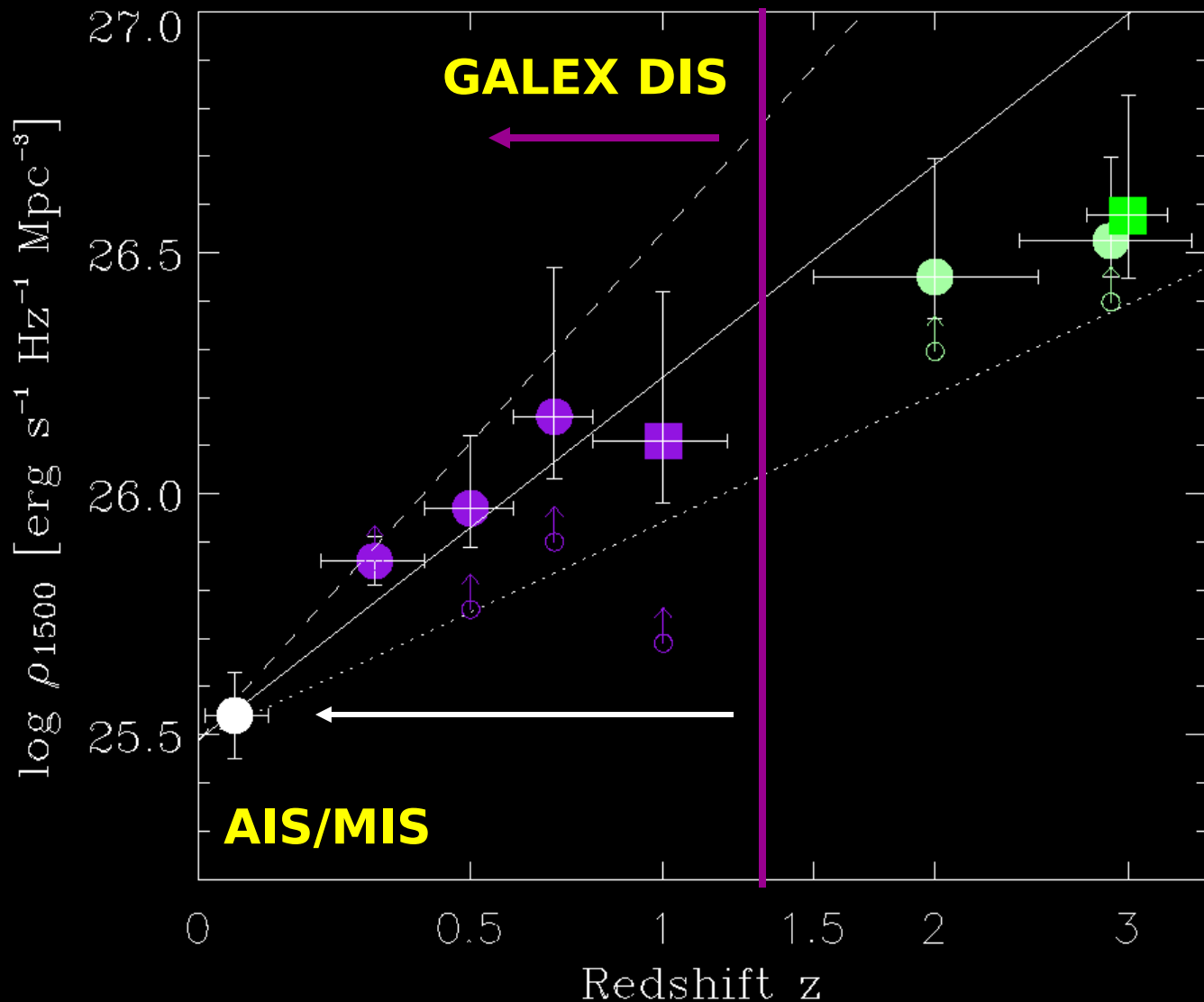
Schiminovich, Arnouts et al.



$(1+z)^{2.5}$ Luminosity Density Evolution to $z \sim 1$

Continued rise to $z \sim 3$

SFR Evolution from UV Luminosity Density w/ GALEX Deep Imaging z<1.5



Deep Imaging
Survey

10 sq. deg.
 $n_{\text{NUV}} < 25 \text{ AB}$

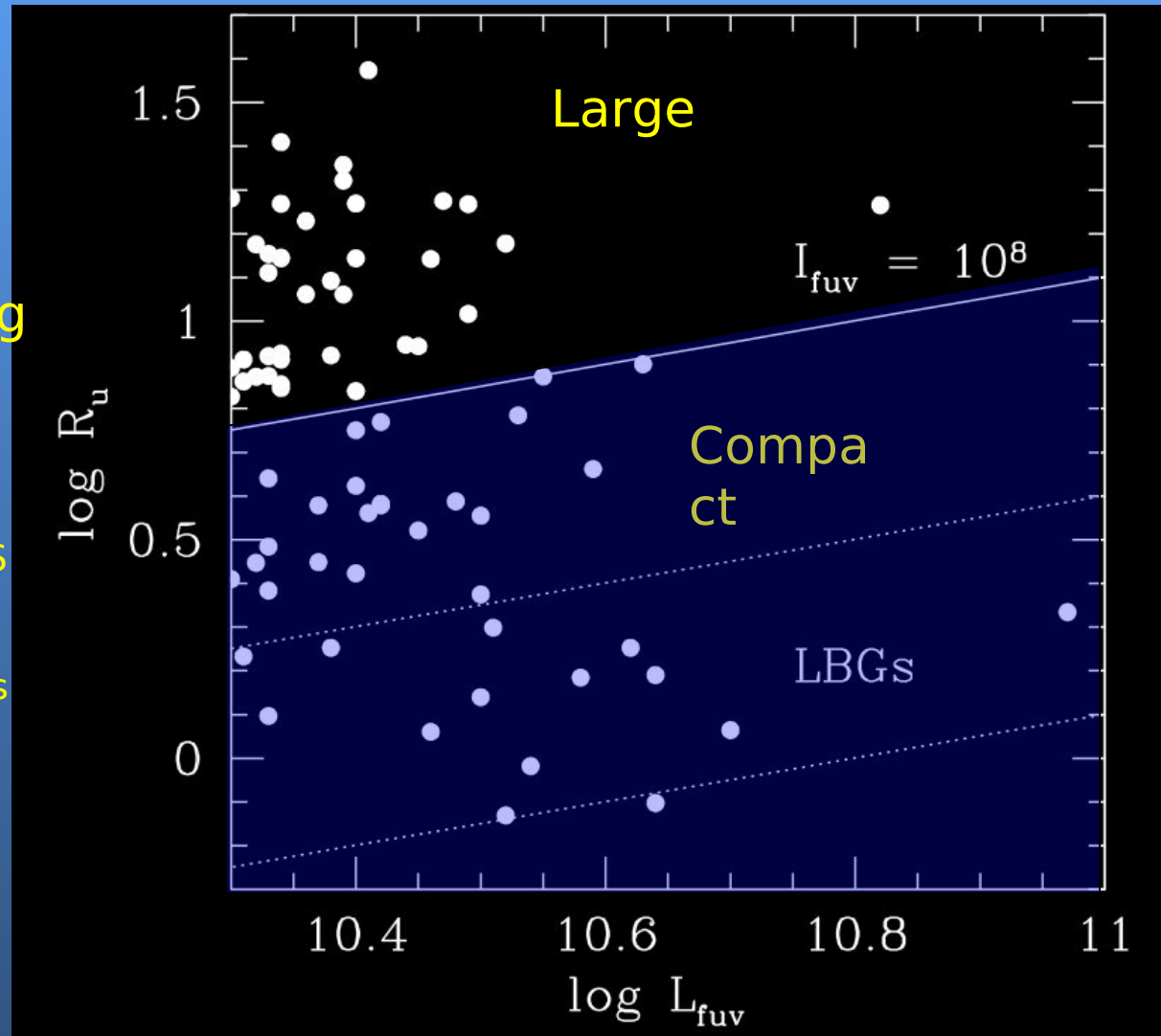
This plot:
0.5 sq. deg.
z completeness:
15%
 $m_{\text{NUV}} < 24.5 \text{ AB}$

Local Lyman Break /Luminous UV galaxies (Heckman et al. 2005; Hoopes et al. 2006)

$L_{\text{FUV, bol}} > 2 \times 10^{10} M_{\text{sol}}$
SFR 5-50 M_{sol}/yr

I_{FUV} determined using
SDSS u-band half-
light radius

GALEX AIS (FUV<20) and MIS
(FUV<23) + SDSS primary
spectroscopic sample ($r < 17.7$) + value added catalogs
(Charlot, Brinchmann,
Kauffmann, Tremonti,
Heckman, White, Seibert) +
7 band SED Classification
(Salim, Rich, Charlot et al)

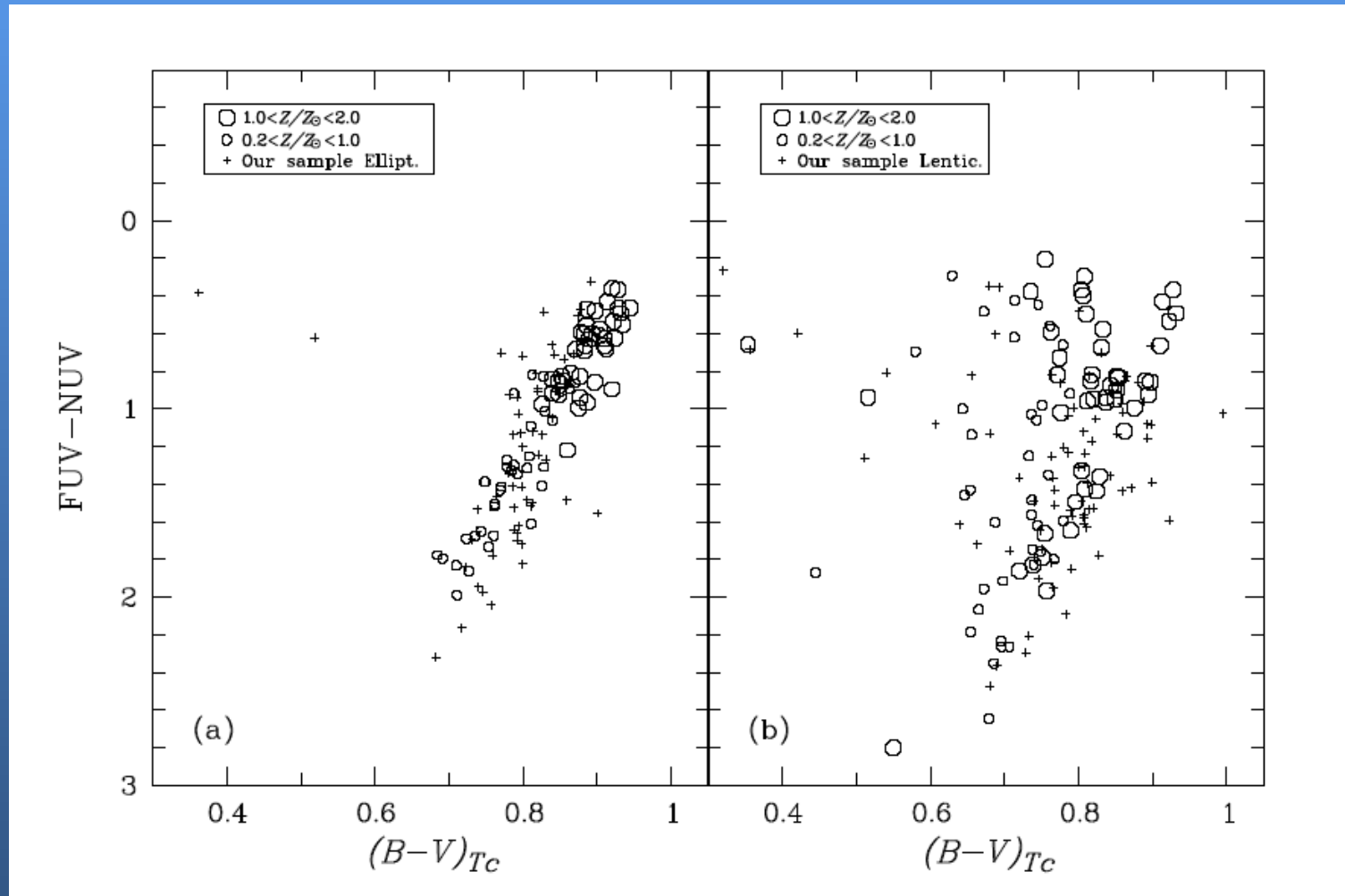


Kennicutt-Schmidt Law 2006

Property	LUGS(Large/ compact)	LBGs
Redshift	$z < 0.3$	$z > 2$
Vol. Density - Log ϕ_*	-5	-2.8
Luminosity Log(L/L_{sol})	10.3 - 10.5 10.3 - 10.7	10.3 - 11.3
R_{1/2 u} (kpc)	0.9 - 1.3 0.7 - 1.3 (0 -	0 - 0.5
Log SFR (A_{FUV})	2) 0.7 - 1.6 (0.5 -	0.5 - 2.5 (1 -
Log sSFR	-10.5²⁾ to -9.5 -9.8 to -8.6	-9 to -8
FUV - r	1.8 - 2.9 0.6 - 2.2	0.2 - 2.2
Emission line σ	60 - 130 km/s	Similar
12+log(O/H)	8.55 - 8.75 8.2 - 8.7	7.7- 8.8

Kennicutt-Schmidt Law 2006

Residual star formation in red galaxies (Rich et al. 05, Yi et al. 05, Donas et al. 06)



Scan of star formation papers

2005 ApJ Letters Special Issue ApJ 619

- UV Luminous galaxies at the current epoch (Heckman et al.)
- Star formation histories and Dust attenuation from GALEX Salim et al.
- 1500Å LF evolution, SFR from VVDS (Arnouts et al.; Schiminovich et al.)
- IRX-beta Seibert et al.
- SFR for local Universe Martin et al.
- M31/33 Thilker et al.
- Outer disk of M83 Thilker et al.
- Tidal Tails (Neff et al.); Antennae (Hibbard et al.)
- Stephans Quintet (Xu et al.)
- UV Rising Flux (Rick et al., Yi et al., Lee et al.)

Scan of star formation papers (contd)

- Nearby Galaxy Survey Gil de Paz et al. 2006 astro/ph 6440
- Bulges and Black holes Kauffmann et al. 2006, a/ph 9436
- Extended disks Boissier et al. 2006, astro-ph/ 9017

UV star formation detected in outer disks beyond H-alpha

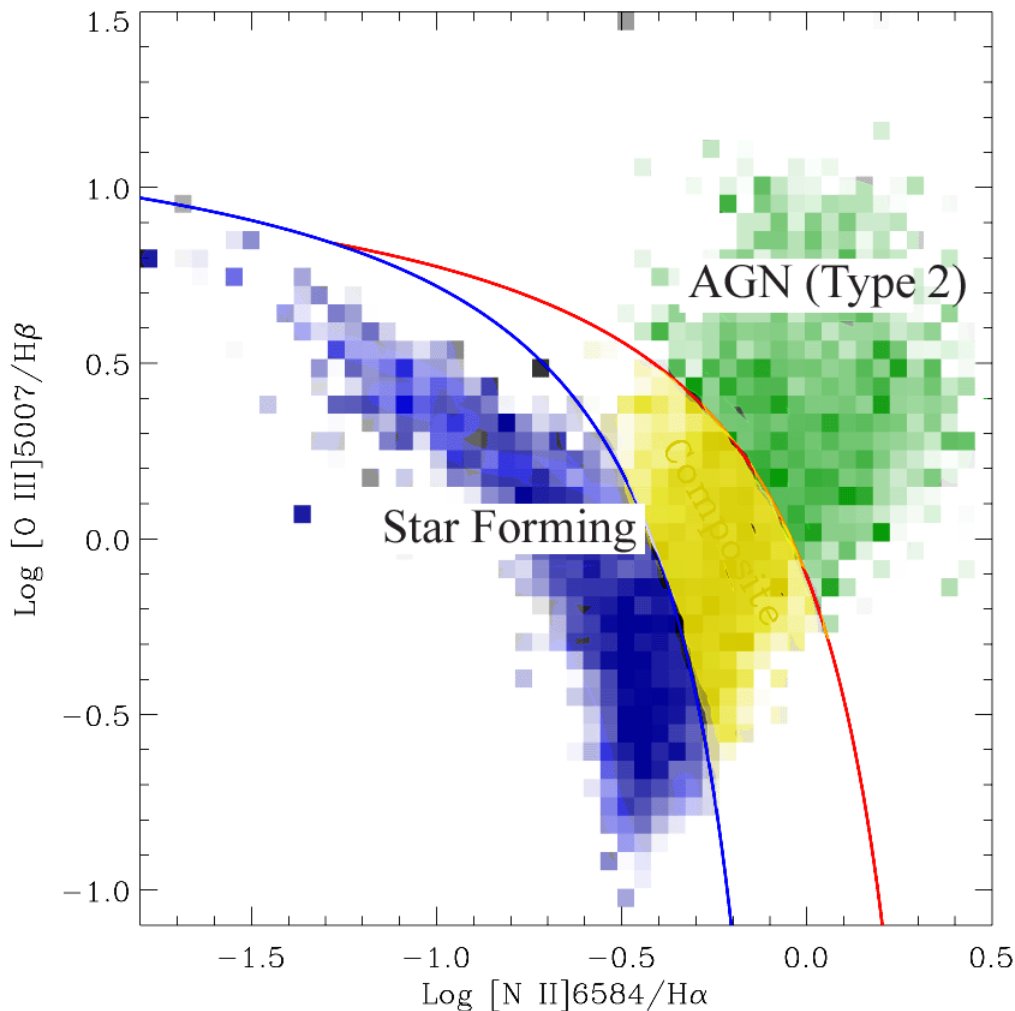
Boundary; low numbers of ionizing stars

Other papers in special issue include

Martin et al., Wyder et al. on blue/red sequence and transition galaxies

Kennicutt-Schmidt Law 2006.
Mallery, Kewley, Rich et al. on N/O ratios along blue

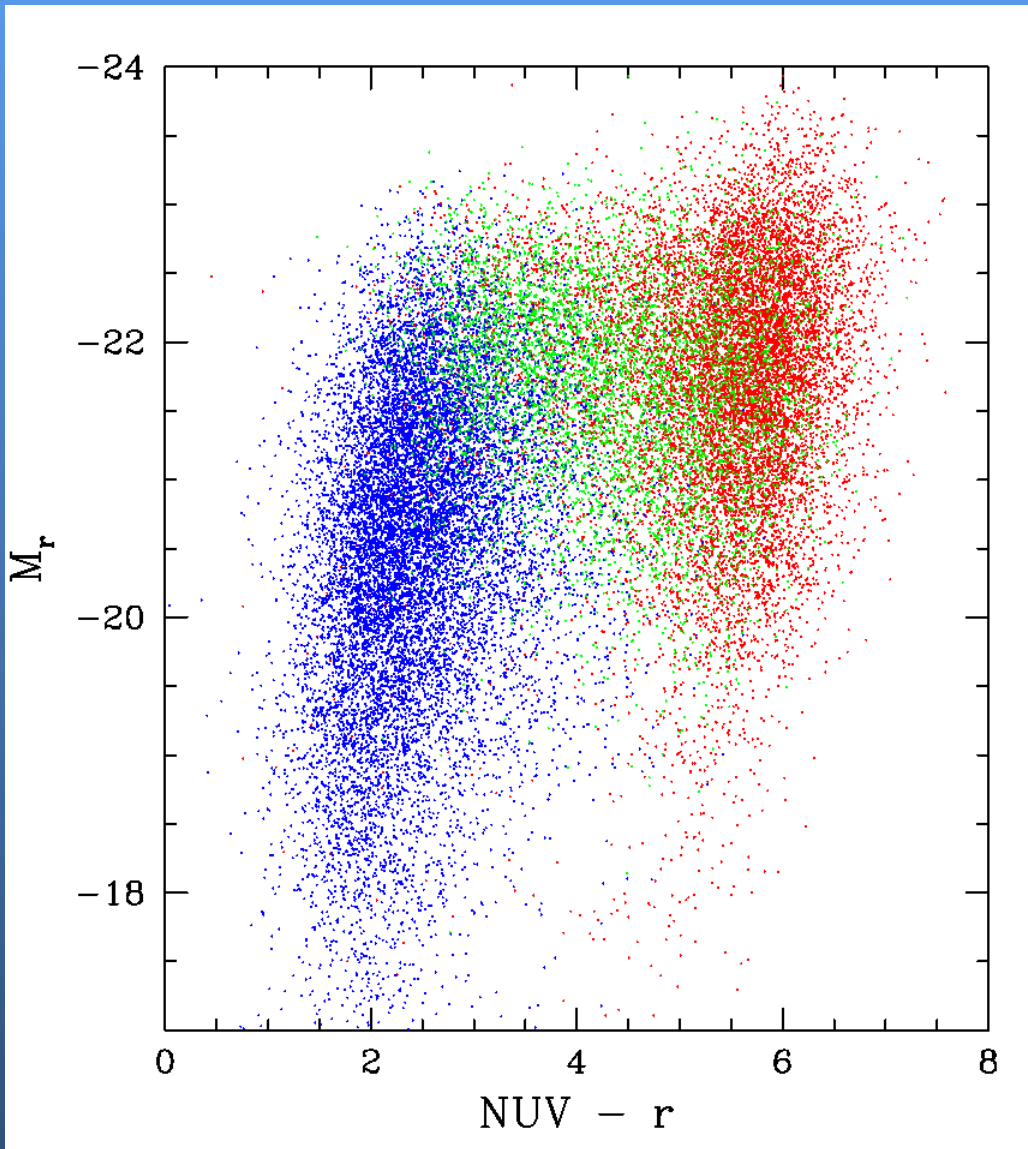
Emission line diagnostics



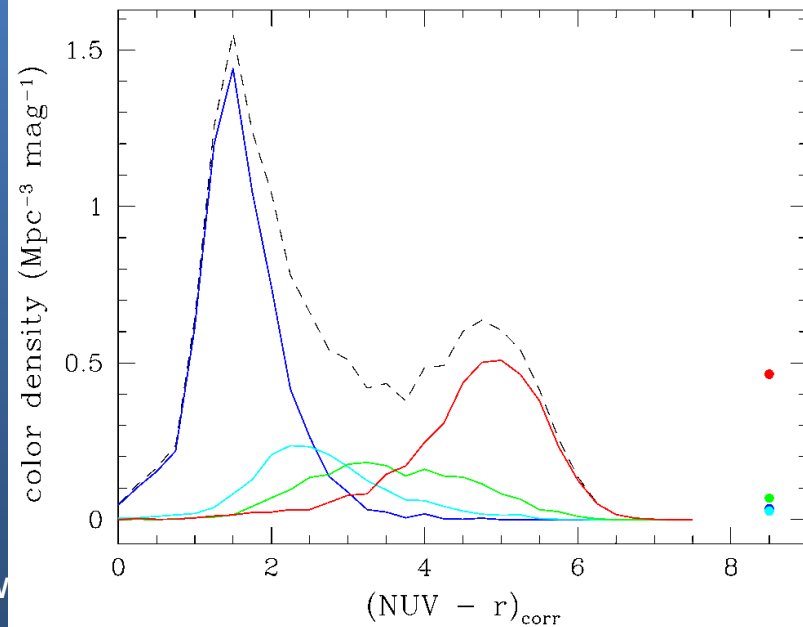
Kennicutt-Schmidt Law 20

- SDSS spectra
- Line ratios
⇒ nuclear classification
- SF galaxies
- Type 2 AGN
 - Obscured
 - Narrow line
 - Seyfert 2/LINERs
- No (detectable) emission lines

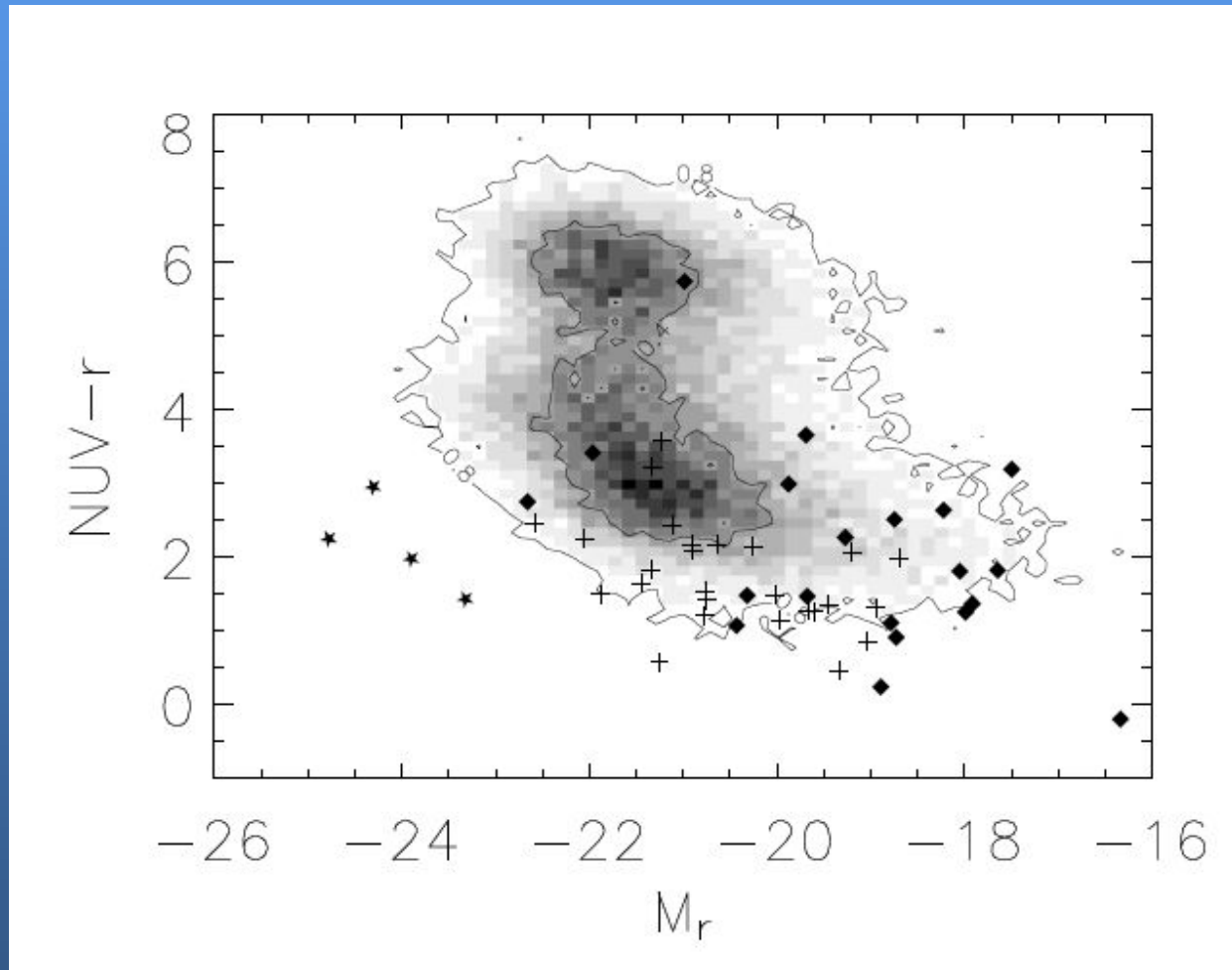
The “Green valley”

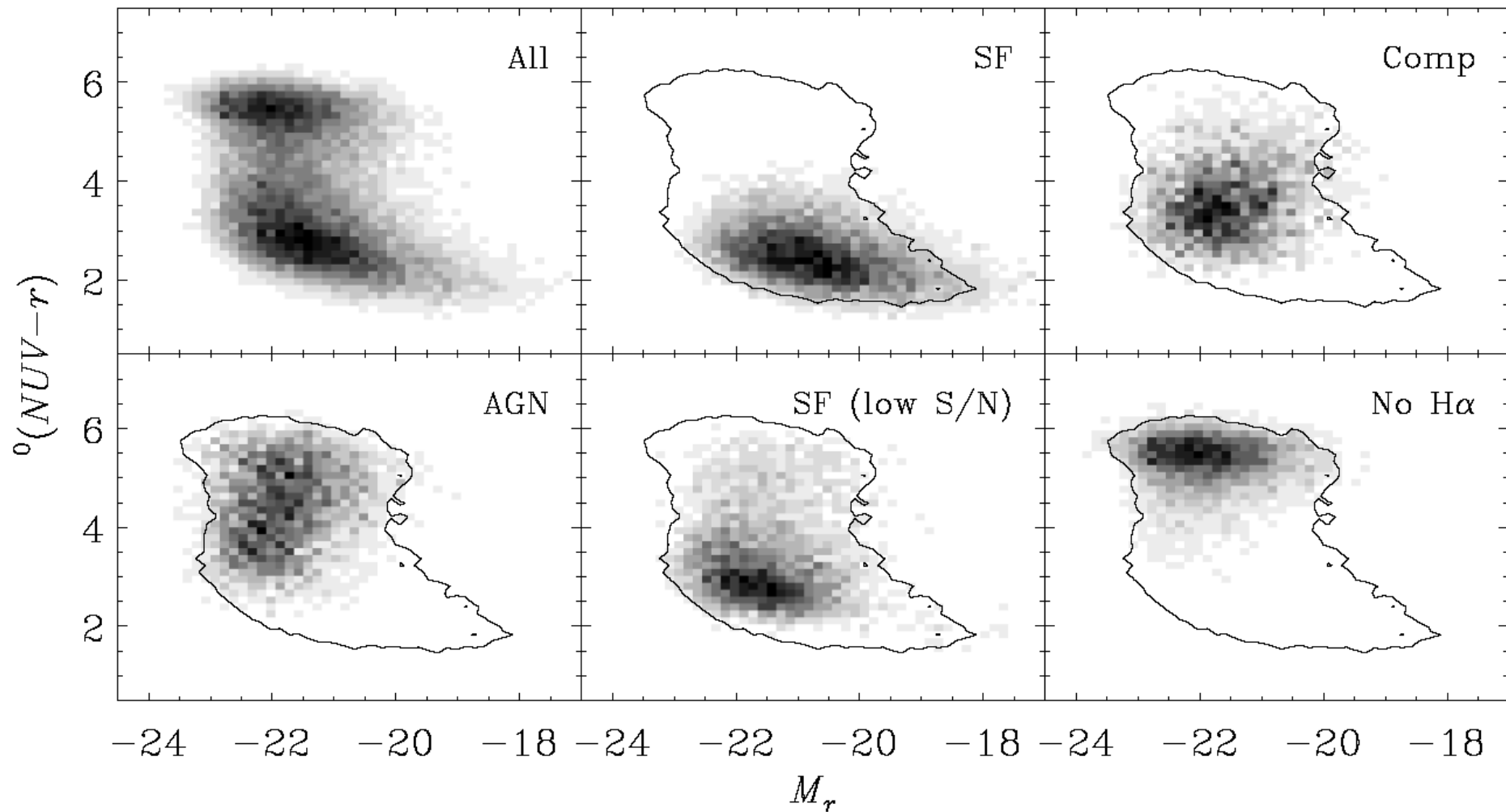


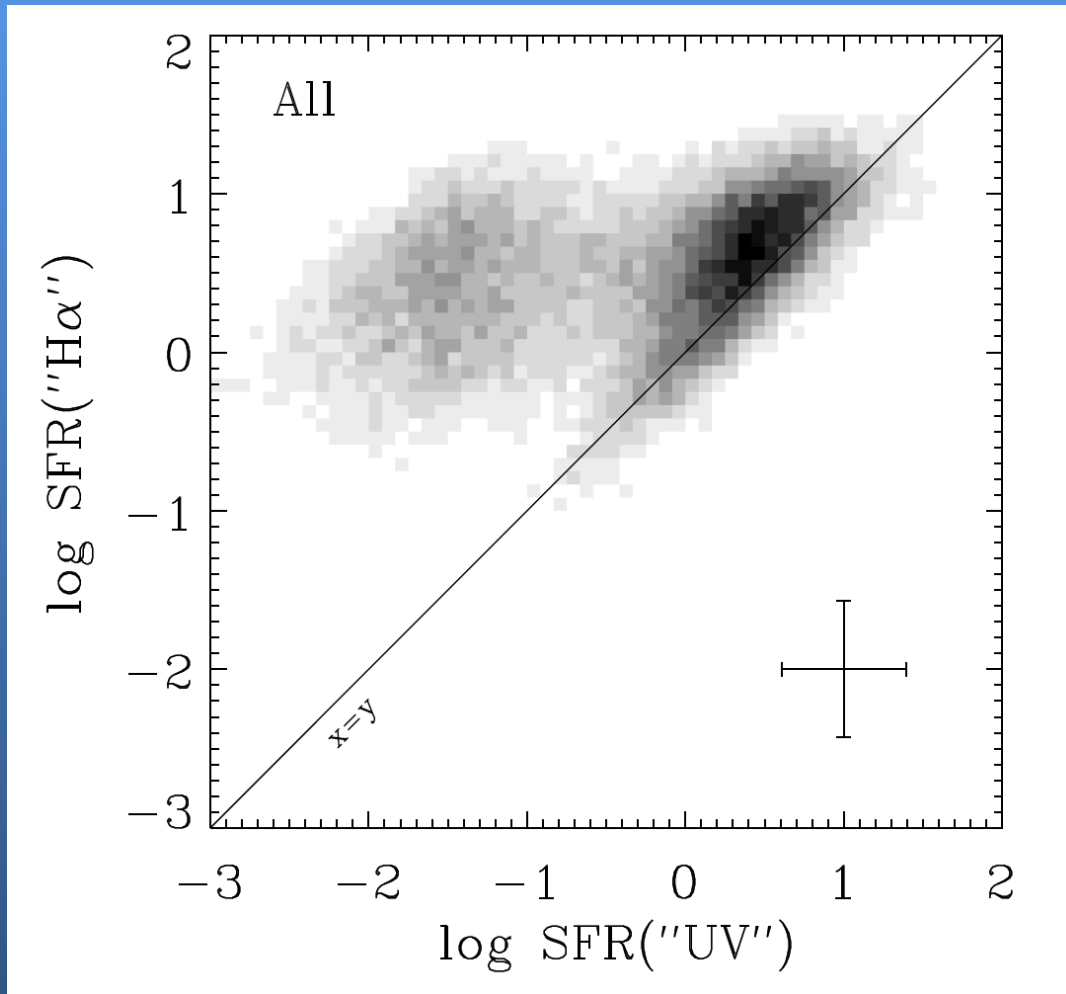
- Bimodality best seen in UV-to-optical
- Intermediate colors:
 - AGN
 - quiescent galaxies
 - reddened SF galaxies
- Steep LF (massive galaxies)



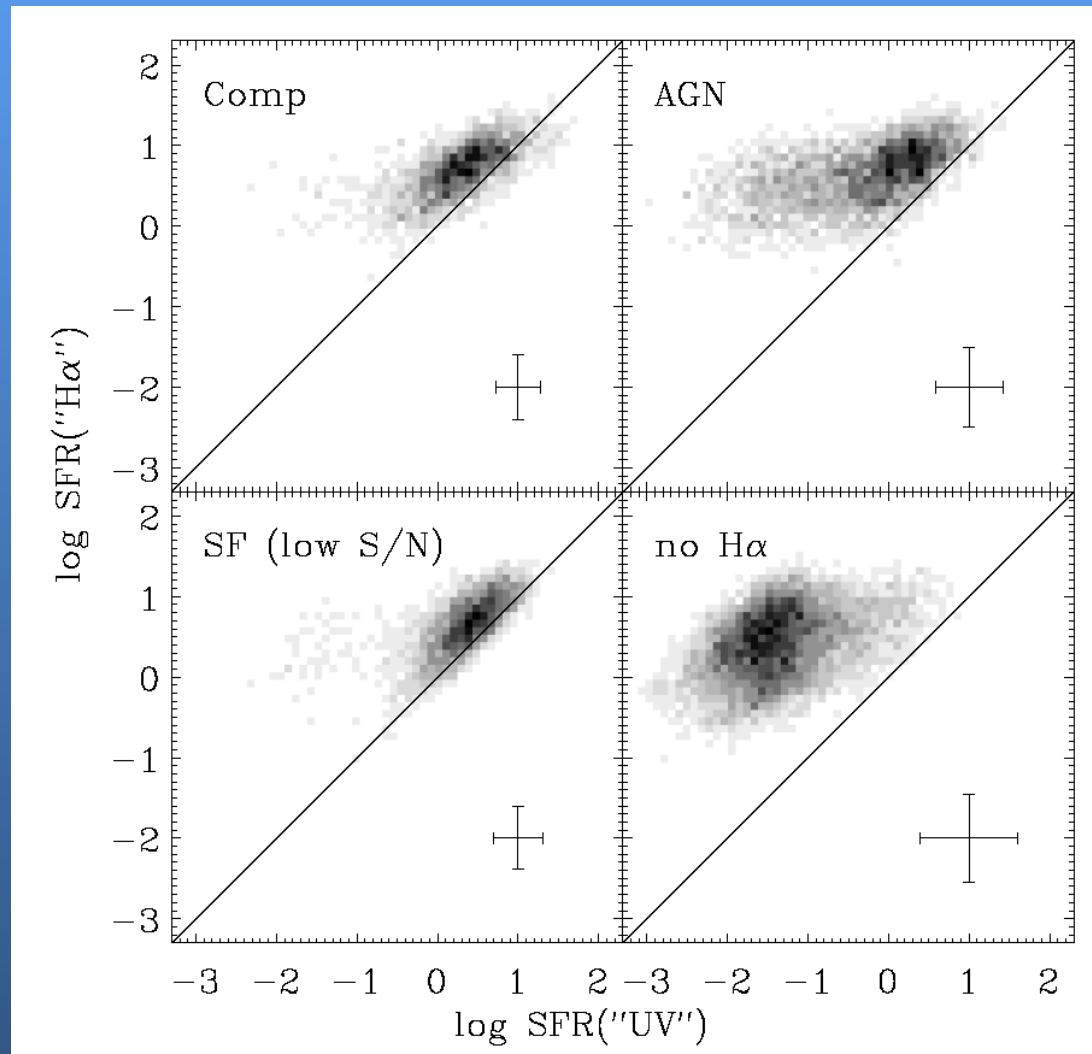
UV-selected pilot sample at Keck (Mallery, Rich et al.)



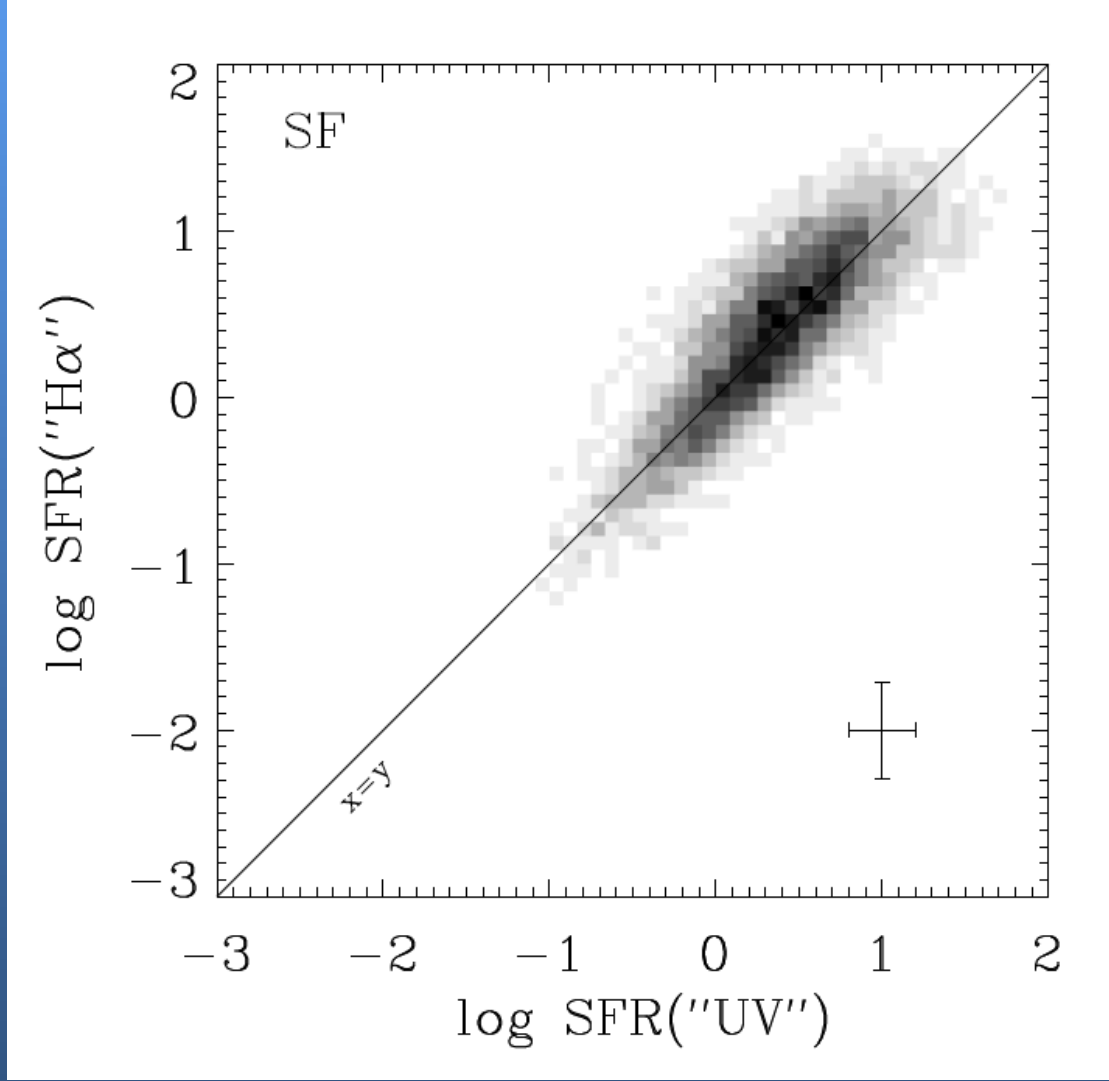




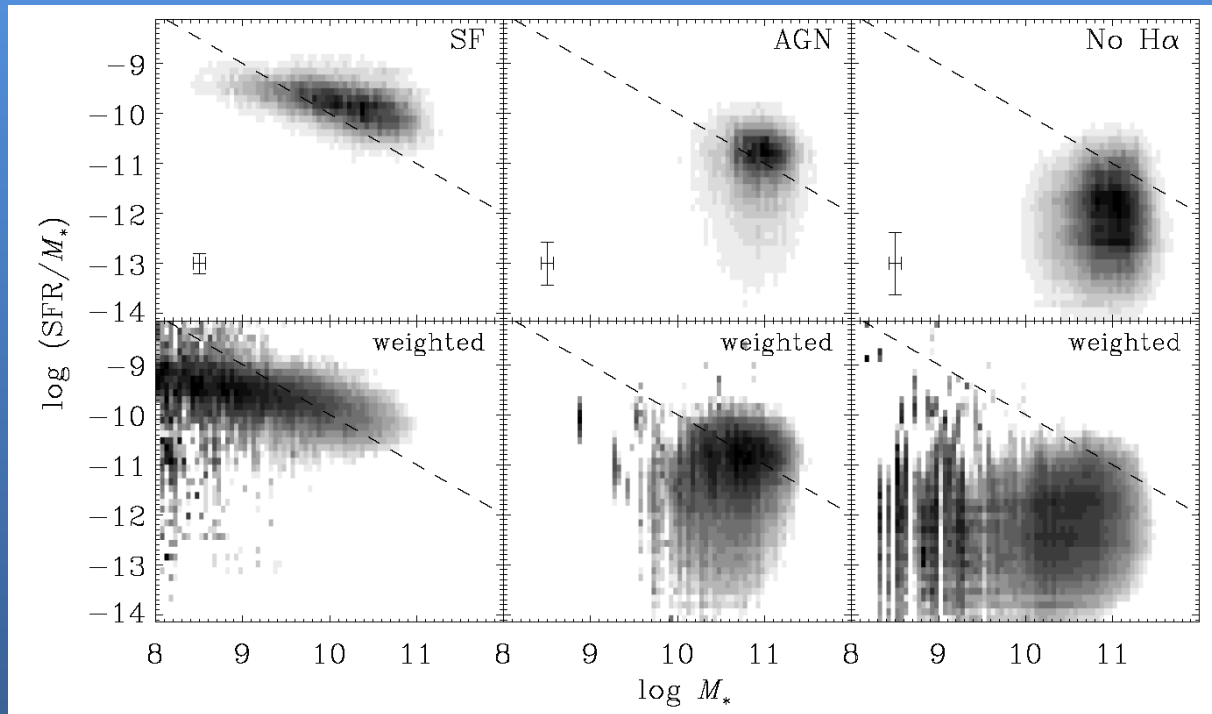
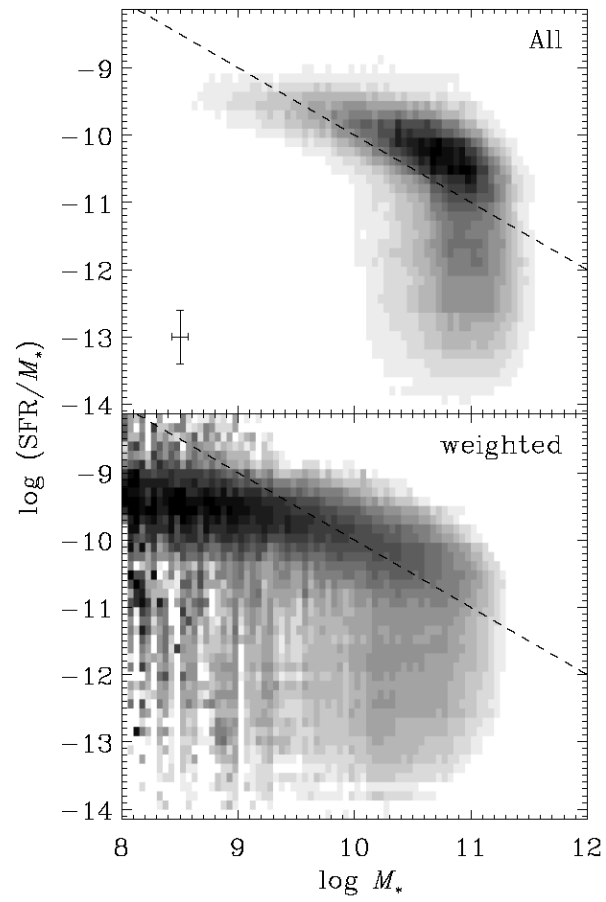
Kennicutt-Schmidt Law 2006



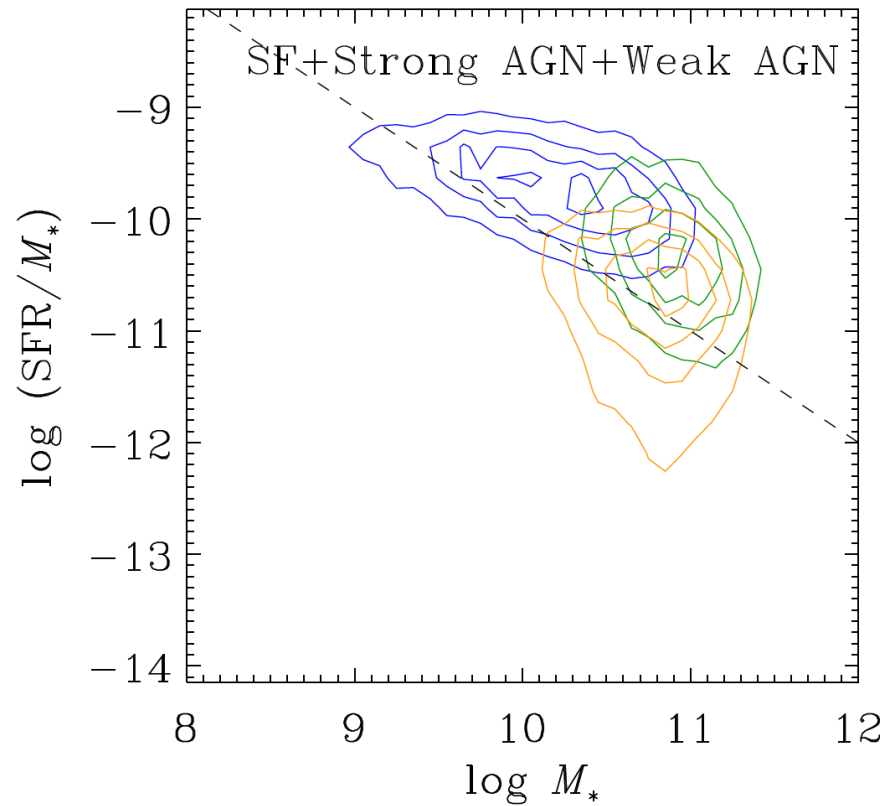
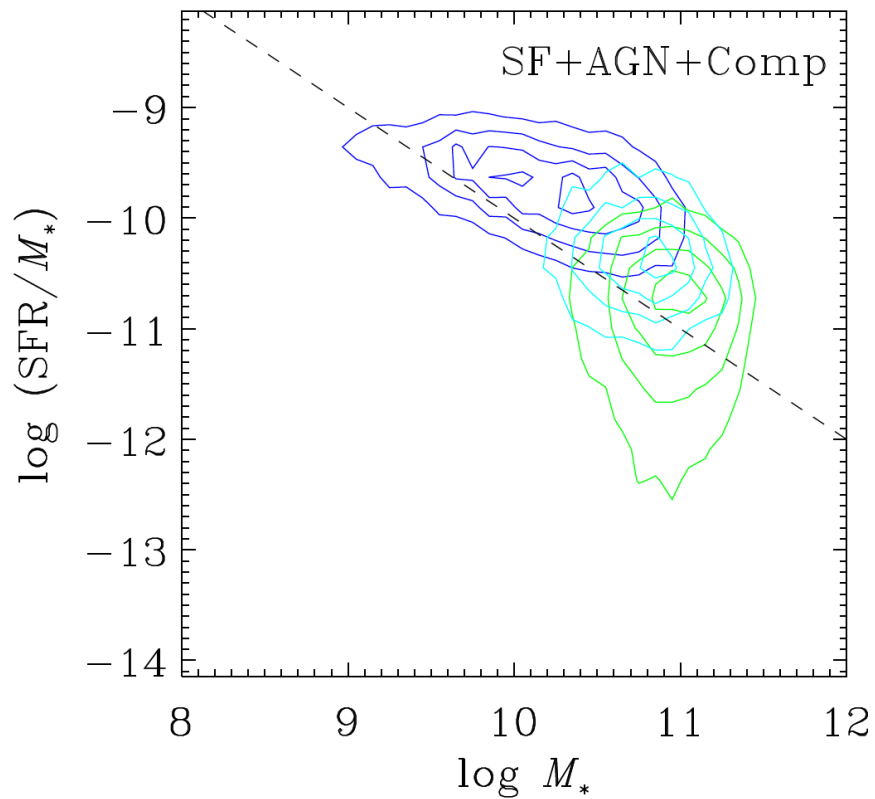
Kennicutt-Schmidt Law 2006



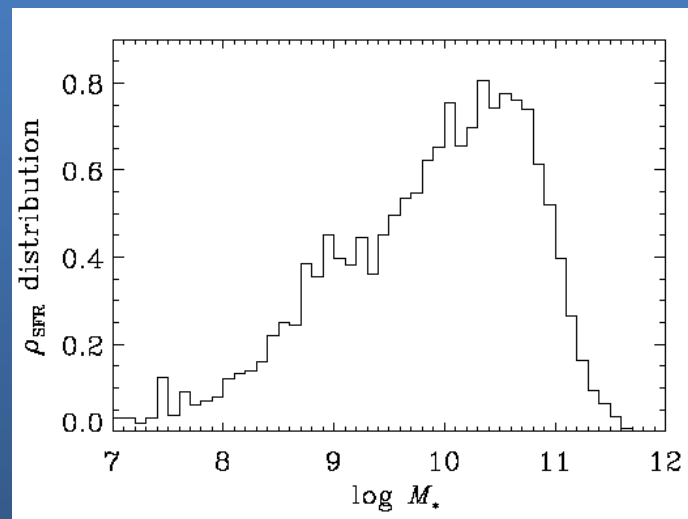
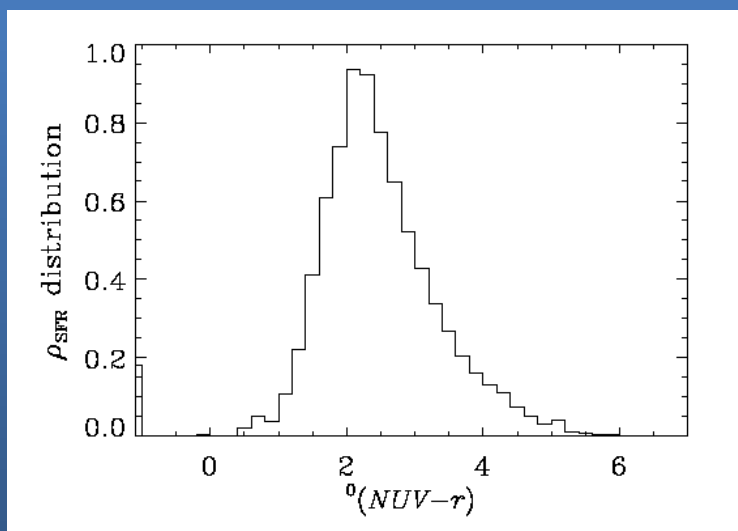
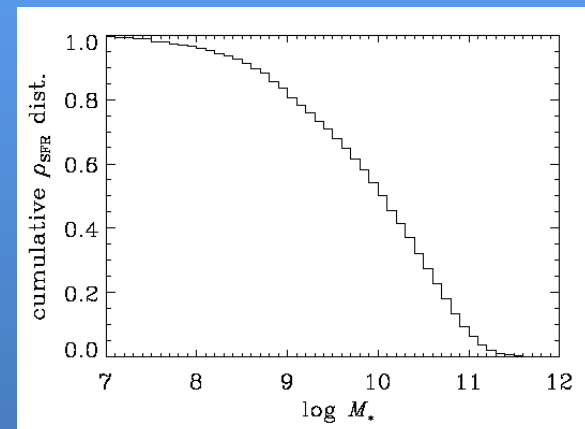
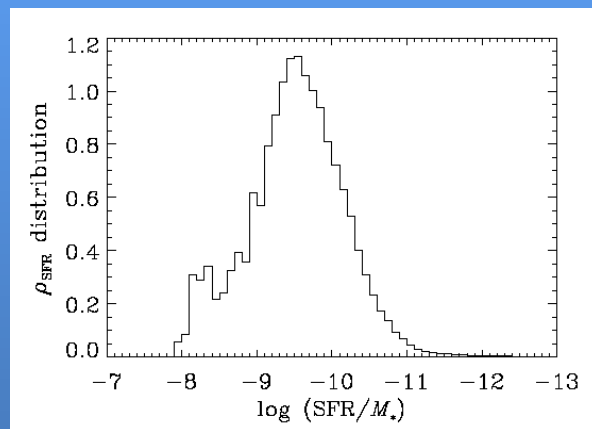
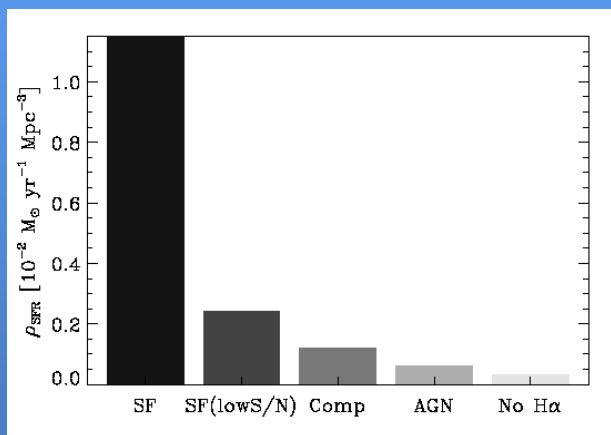
Kennicutt-Schmidt Law 2006



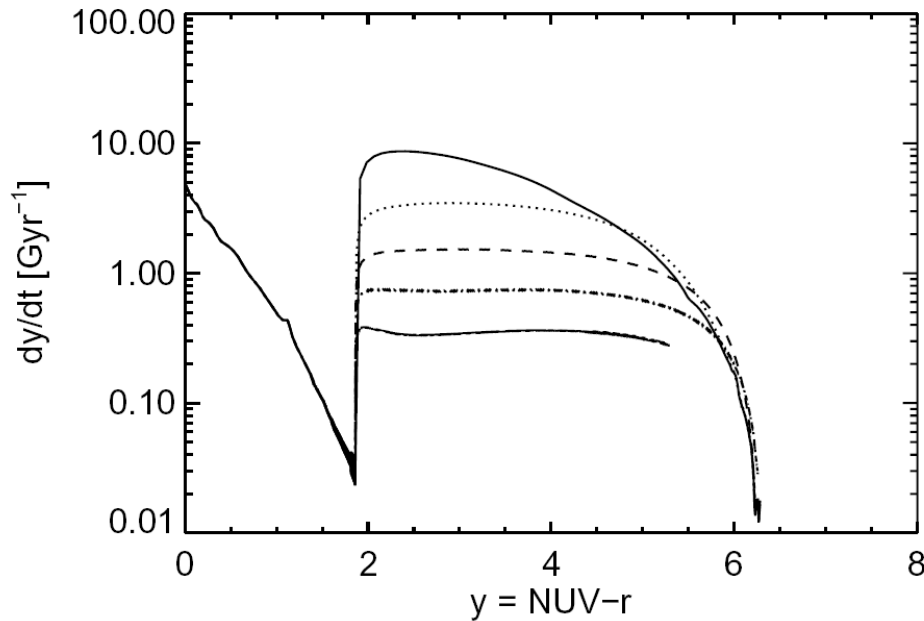
Kennicutt-Schmidt Law 2006



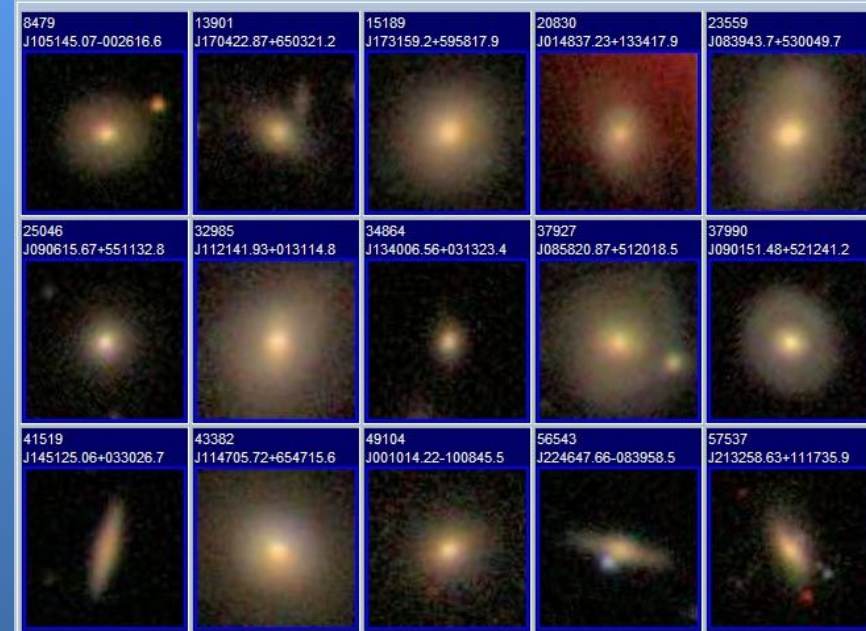
Star Formation Scan



AGN and transitional galaxies



Martin et al. 2006



- Quenched models
⇒ fast color evolution

- Morphology already spheroidal/lenticular
 - some structure
 - blue light

Kennicutt-Schmidt Law 2006

Summary

- GALEX is extraordinarily sensitive to star formation $0 < z < 1.5$
- SF detected in very low surface brightness regions (edges of disks, tidal tails)
- Disks do not have sharp boundaries; H-alpha boundary was due to small numbers of ionizing stars
- In the NUV-r vs M_r plot, galaxies divide into a striking blue and red sequence, with AGN filling a “green valley”
- AGN linked to star formation in massive galaxies
- Red galaxies have UV emission due to old stars and in some cases, low level star formation
- UV luminous galaxies $L_{uv} > 10^8 L_{sun}$ are found in the present epoch.
- Early indications are that GALEX detects some SF missed by Spitzer -- in low surface brightness & metal poor systems.