The Ultraviolet Sky Surveys

filling the gap in our view of the universe

Luciana Bianchi, JHU

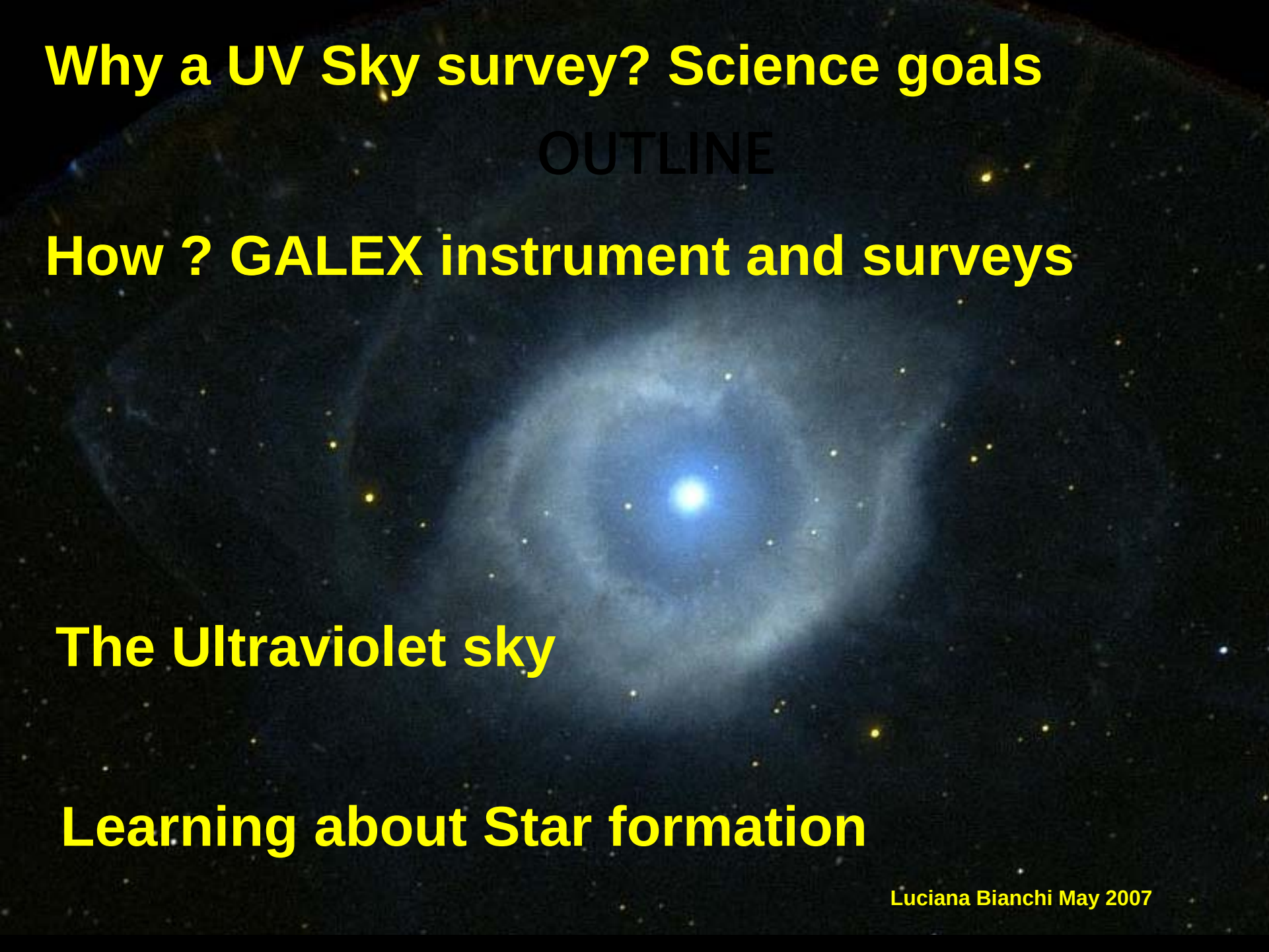
El Escorial, May 2007

PI C.Martin, Caltech

PARTNERS

- Johns Hopkins
- U.C Caltech
- JPL. Berkeley
- France
- South Korea
- Orbital Sciences Corp.

The Galaxy Evolution Explorer
(GALEX)



Why a UV Sky survey? Science goals

OUTLINE

How ? GALEX instrument and surveys

The Ultraviolet sky

Learning about Star formation

Luciana Bianchi May 2007

Why a UV sky survey?

Primary Science Goals :

1) How does the UV trace global SF ?

2) What is the SFR in galaxies, and how does it evolve over 0<z<2? History of SF over 0<z<2 , 80% of history of universe, when galaxies and gas evolve dramatically.

3) What are the physical drivers of SF in galaxies?

4) What is the nature of the UV universe?

Star Formation History

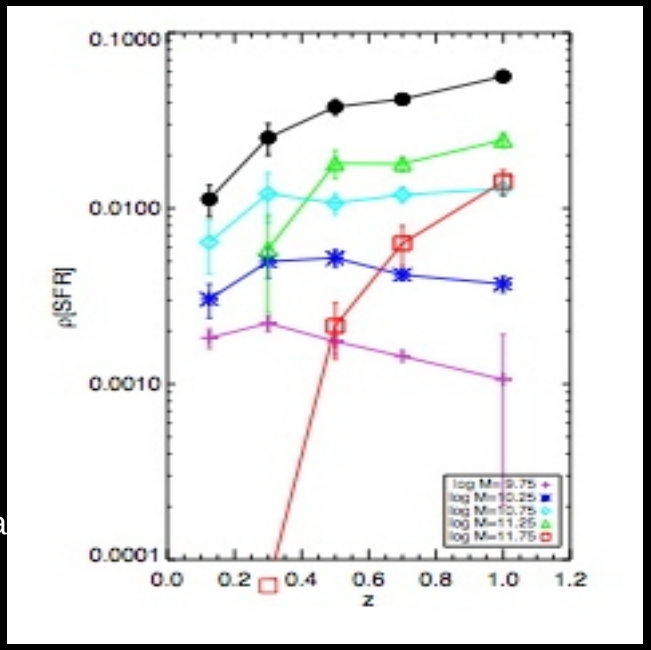


Fig.fm Martin et al. 2007 submitted UV-selected galaxies in ChandraDFS, COMBO-17, Spitzer IRAC and MIPS. Redshift 0-1.2

Segregate galaxies w/ a par. related to evol.timescale:Mass (lower mass galaxies have younger stellar age, sfr prop. gas densty)

DIS 50ksec, mag.lim(NUV) ~26, , COMBO m_r~24 , coomon area 0.19deg^2

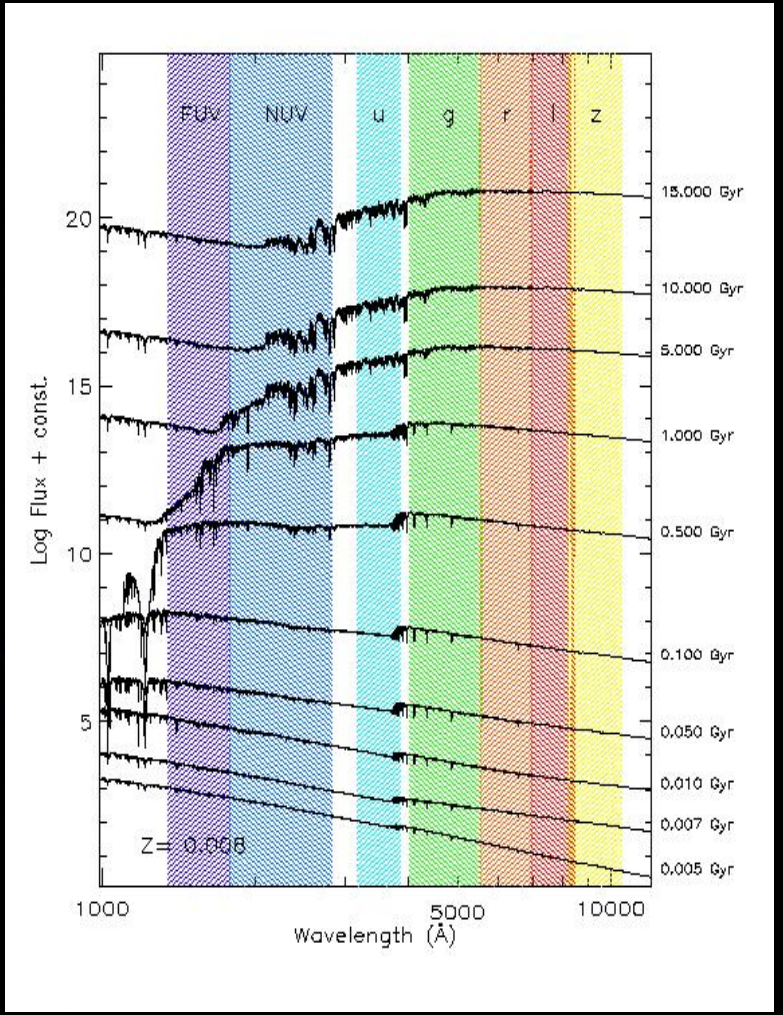
Specific SFR increases with redshift

At any given z, SSFR is flat un to a critical Mass (falls steeply at higher M)

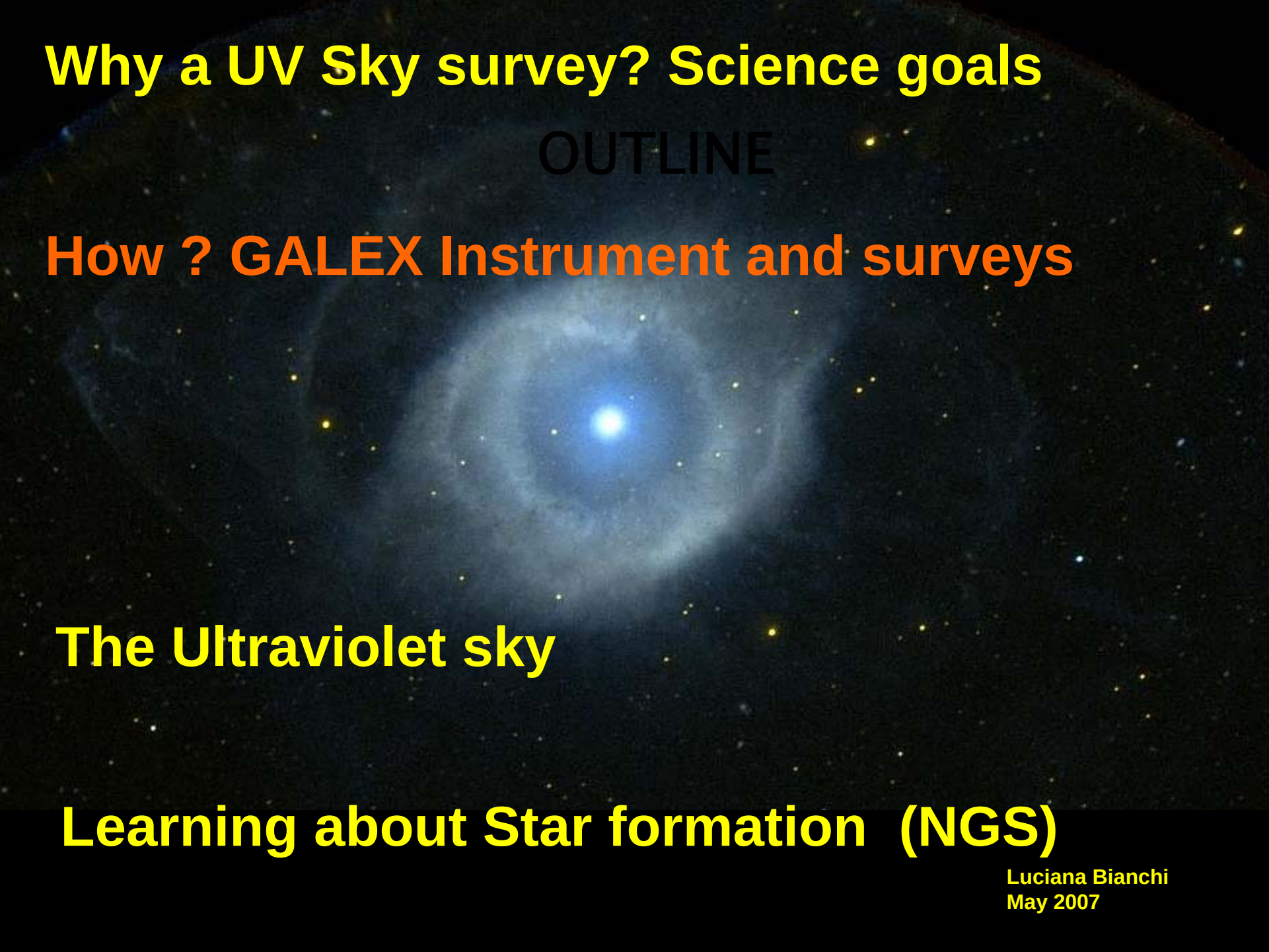
Evolution of dust and SFR interconnected

Rest UV Traces Star Formation

Over Large Range of Specific Star Formation



UV - GALEX provides red-shift (<2), extinction, UV luminosity: SFRH



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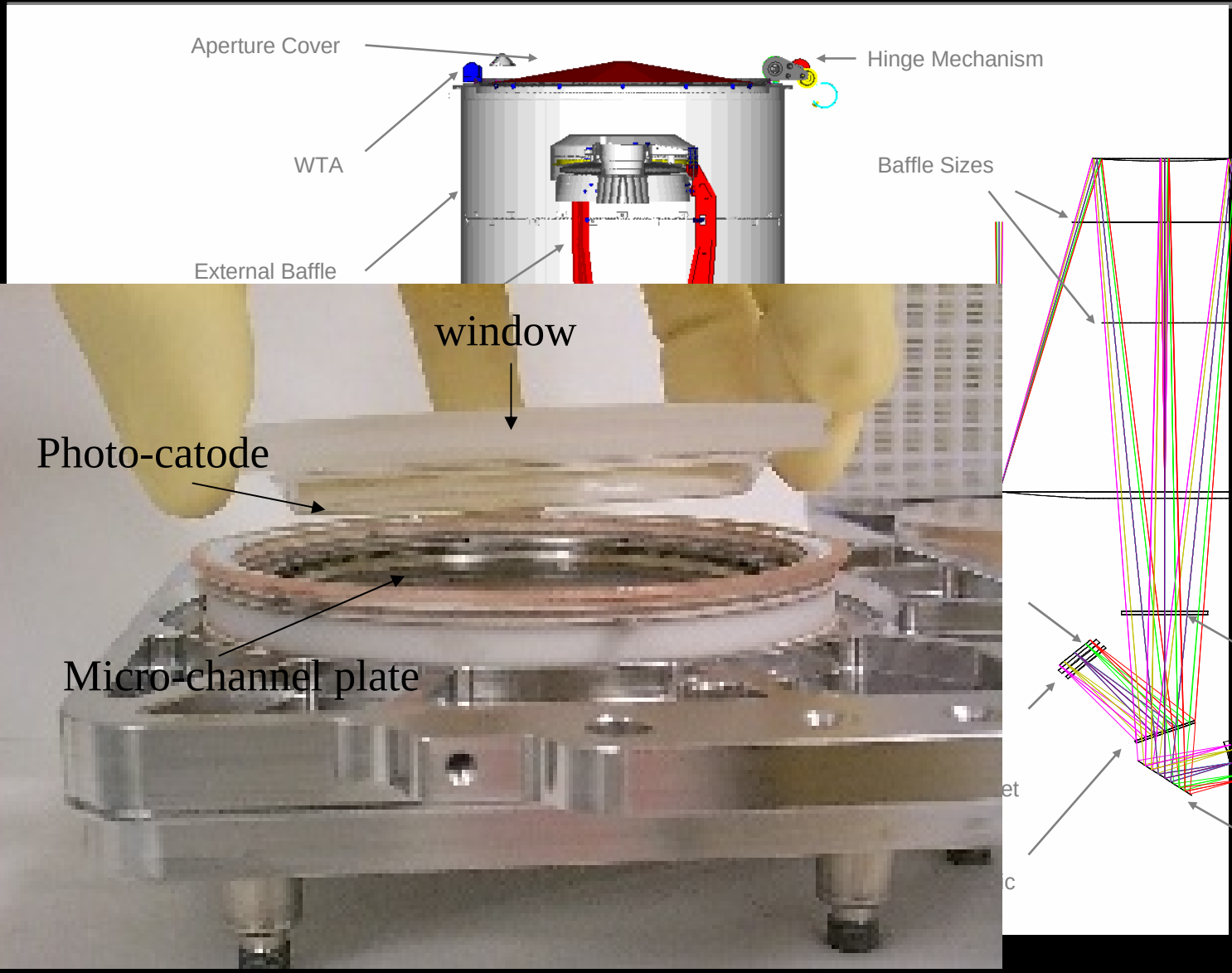
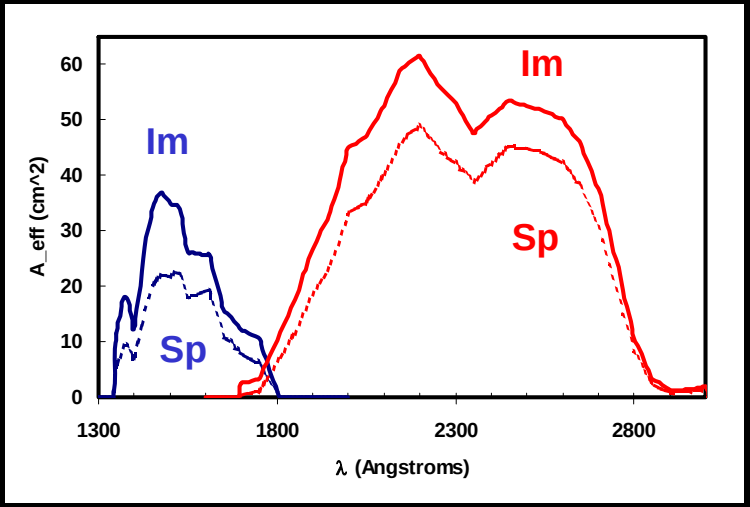
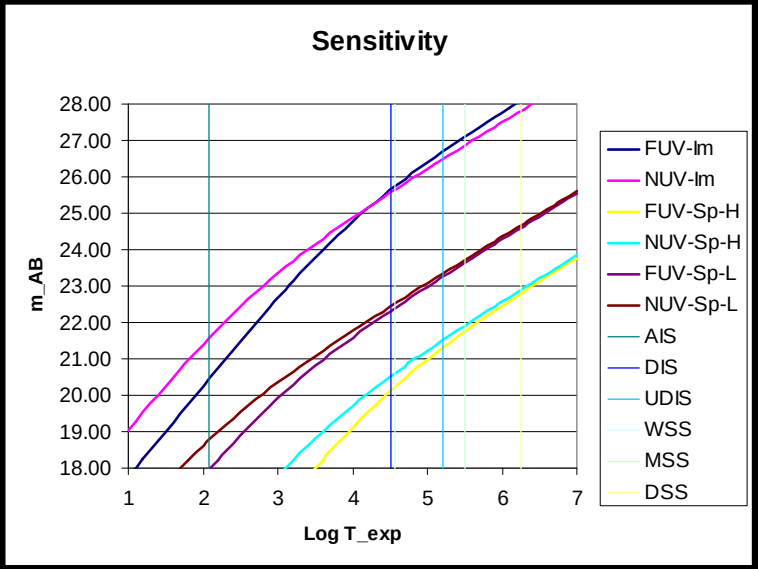
GALEX INSTRUMENT SYSTEM & OPTICAL VIEW



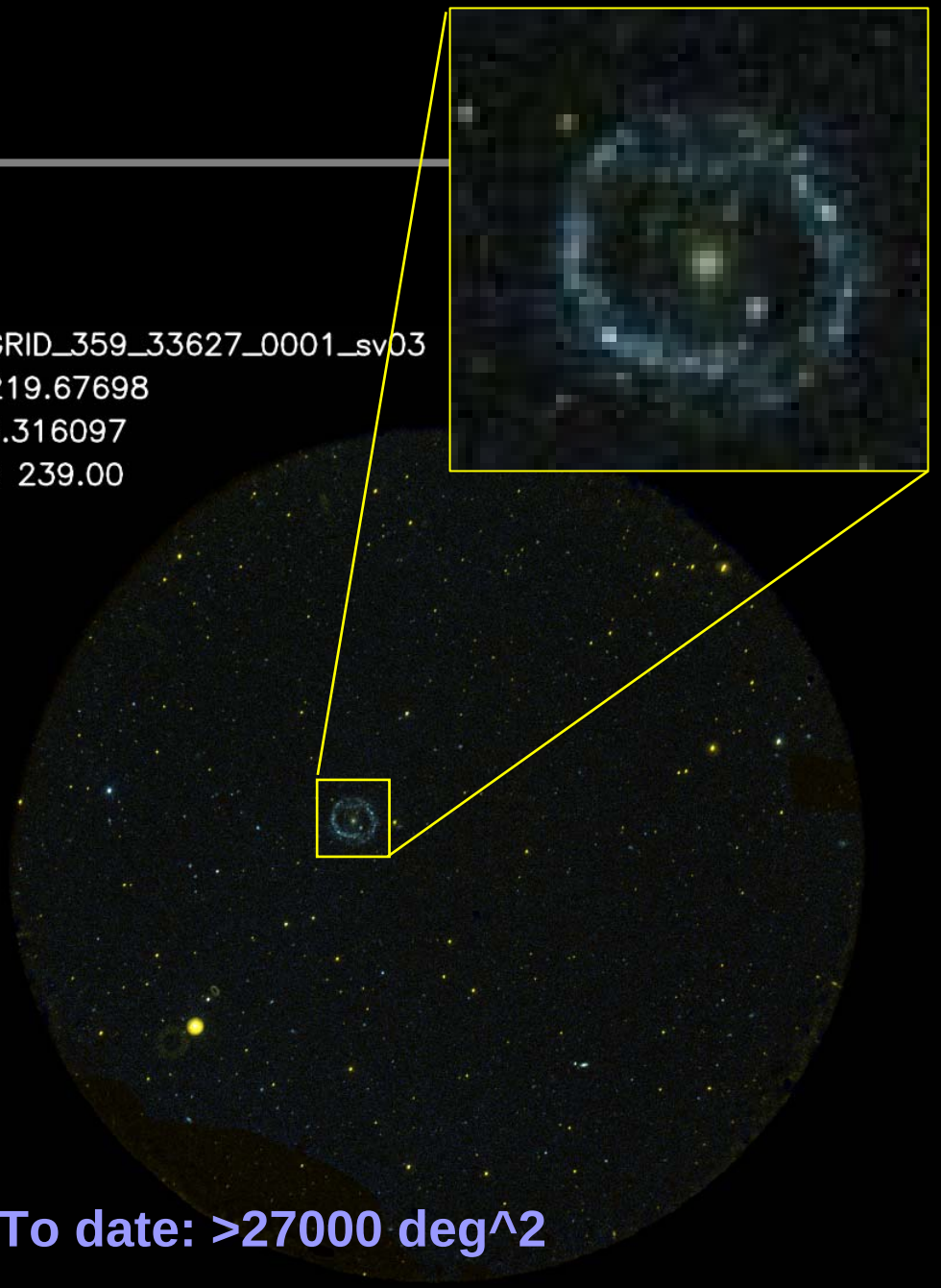
Performance Summary





Effective Area	20-50 cm^2 (0.5 mKeck)
Angular resolution	4.5-6” FWHM (FUV/NUV)
Spectral Resolution [grism mode]	100-250
Field of View	1.2 degrees
Bands [simultaneous]	FUV 1344-1786 A (1528) NUV 1771-2831 A(2271)
Sensitivity (AB mag)	100 s 20/20.8 [AIS] 1.5 ks 22.6/22.7 [MIS/NGS] 30 ks 24.8/24.4 [DIS]
Sky Background	2000/20000 cts/s (FUV/NUV)
Detector Bckg diffuse	0.7/1.8 cts/s
Detector bckg hot spots	78/193 cts/s (typical)
Observations	Nightime 1 eclipse=1000-2000 s
Mission Length	Limited by funding - no consumables

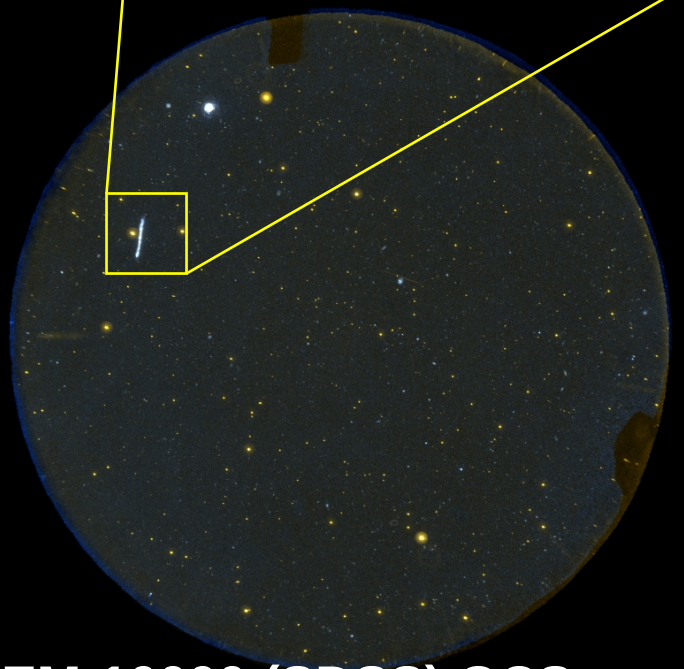
All-sky Imaging Survey (AIS)	
Magnitude Fλ	20/20.8FUV/NUV 4.7 / 2.2 10^{-16}
Mean Redshift	0.2
Area	>35,000 deg^2
Cosmic Vol.	1 Gpc^3
# Galaxies	10 Million



To date: >27000 deg^2

Z~0.2

Medium Imaging Survey (MIS)	
Magnitude	22.6 / 22.7
Fλ	4.3 / 2.0 10^{-17}
Area	>1000 deg^2
Cosmic Vol.	1 Gpc^3
Overlap	SDSS, 2dF
# Galaxies	>3 Million



Z~0.5

Z~0.2

To date: 1700 deg^2 EM:10000 (SDSS) GCS

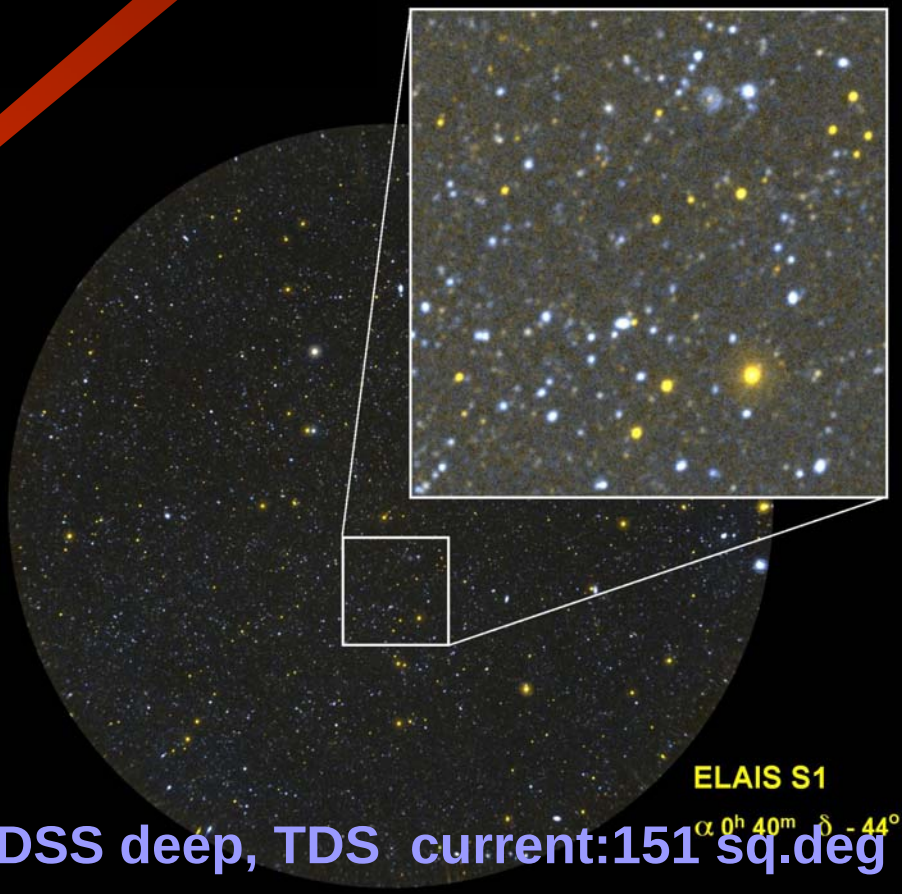
2004−01−12

Deep Imaging Survey (DIS)	
Magnitude AB	24.8 / 24.4
Fλ	5.7 / 2.710^{-18}
Area	>80 deg^2
Cosmic Vol.	1 Gpc^3
Overlap	CDFS, NOAO-DWS, SWIRE, VVDS, DEEPII, CFHTLS, …
# Galaxies	10 Million

Z~1.5

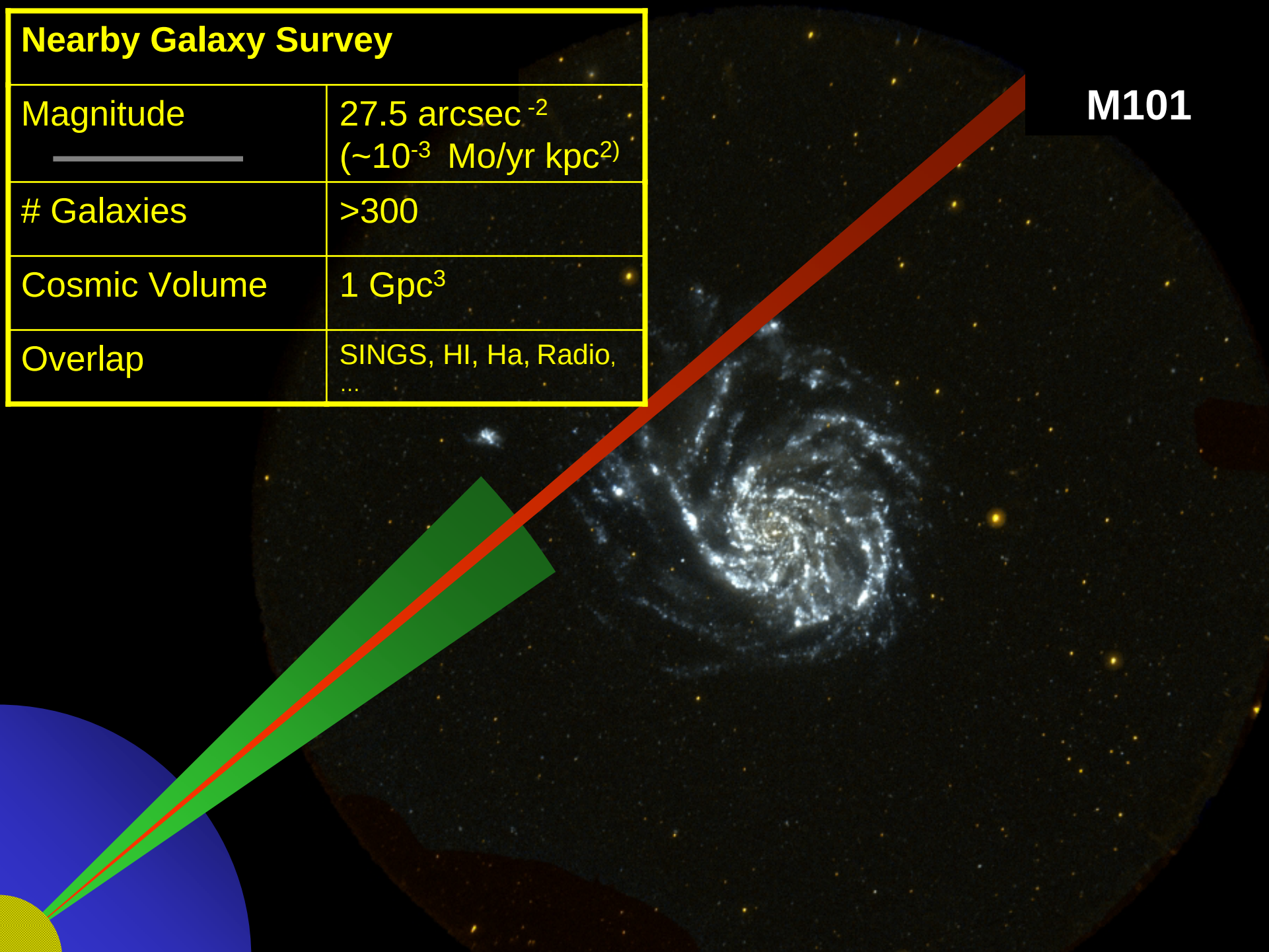
Z~0.5

Z~0.2

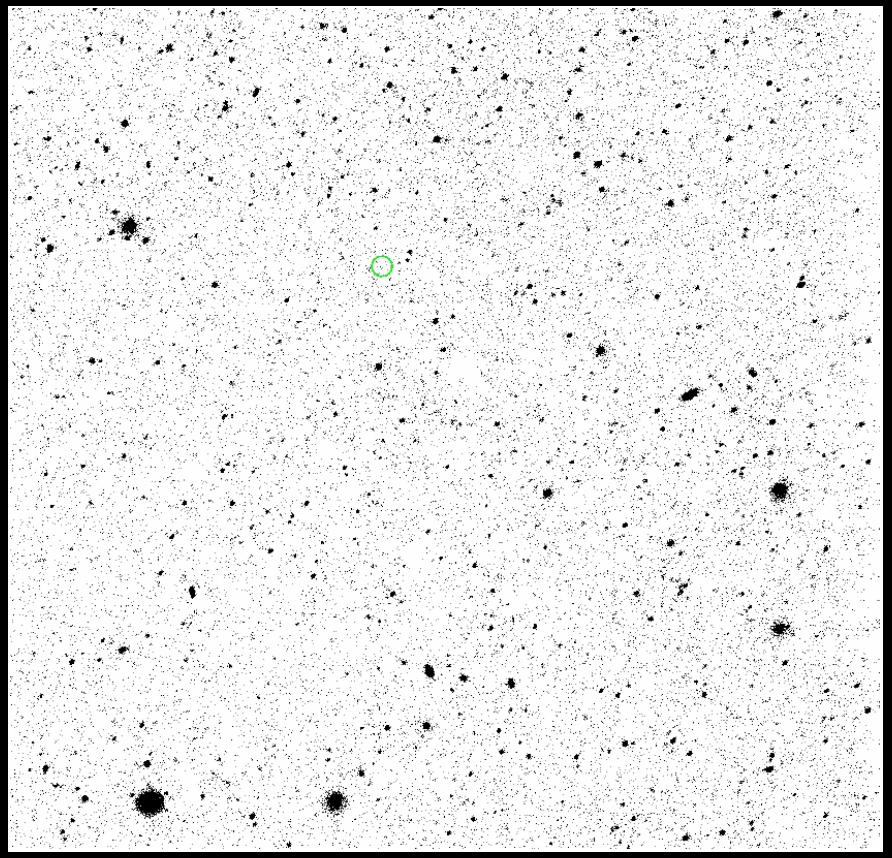


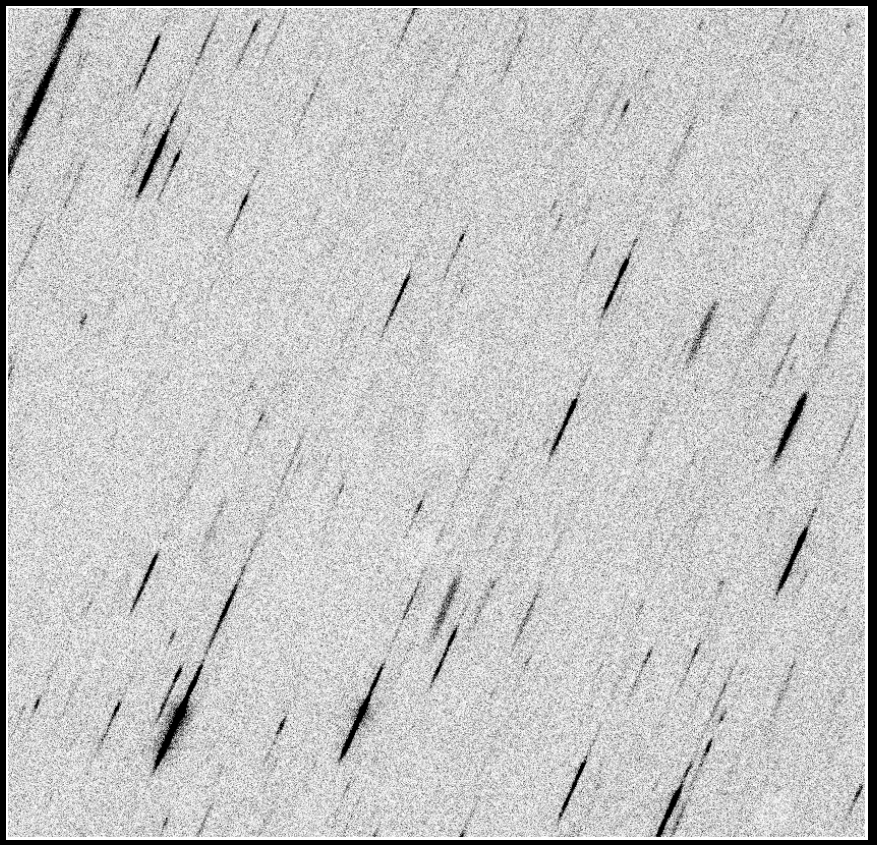
+ UDF, EM:SDSS deep, TDS current:151 sq.deg

Nearby Galaxy Survey	
Magnitude	27.5 arcsec $^{-2}$ (~10^{-3} Mo/yr kpc$^{2)}$
# Galaxies	>300
Cosmic Volume	1 Gpc^3
Overlap	SINGS, HI, Ha, Radio, ...



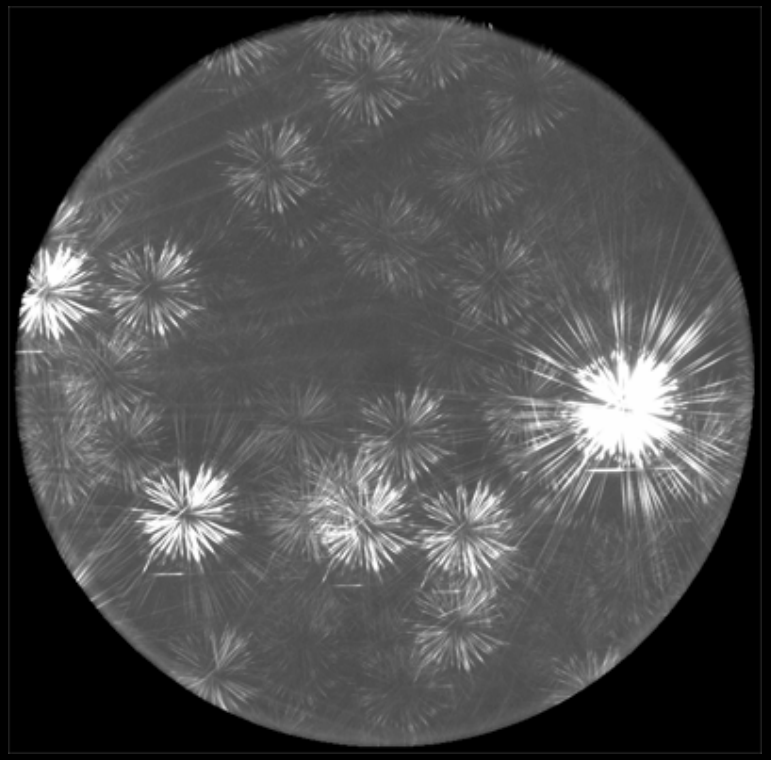
Grism – 1 orbit (NUV)

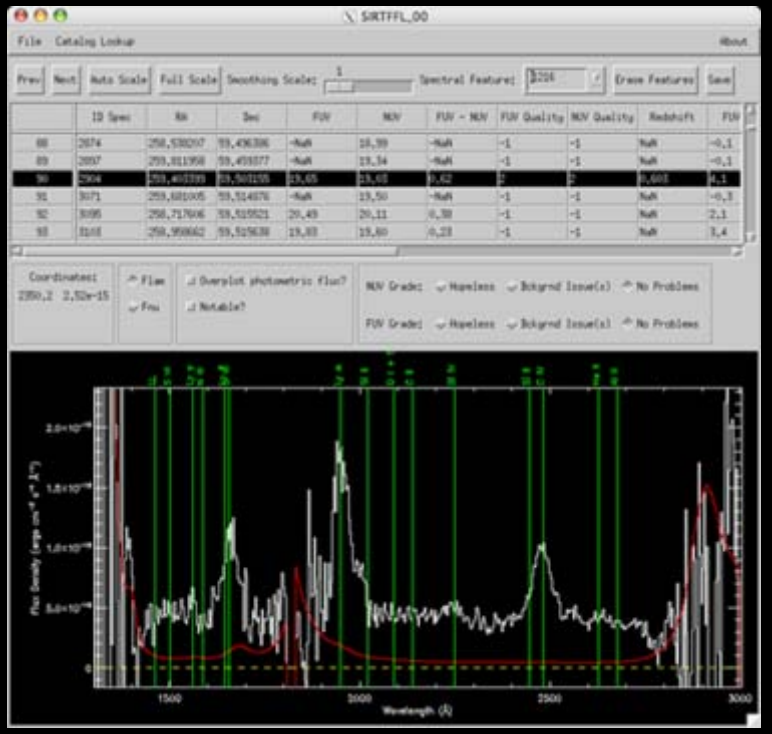




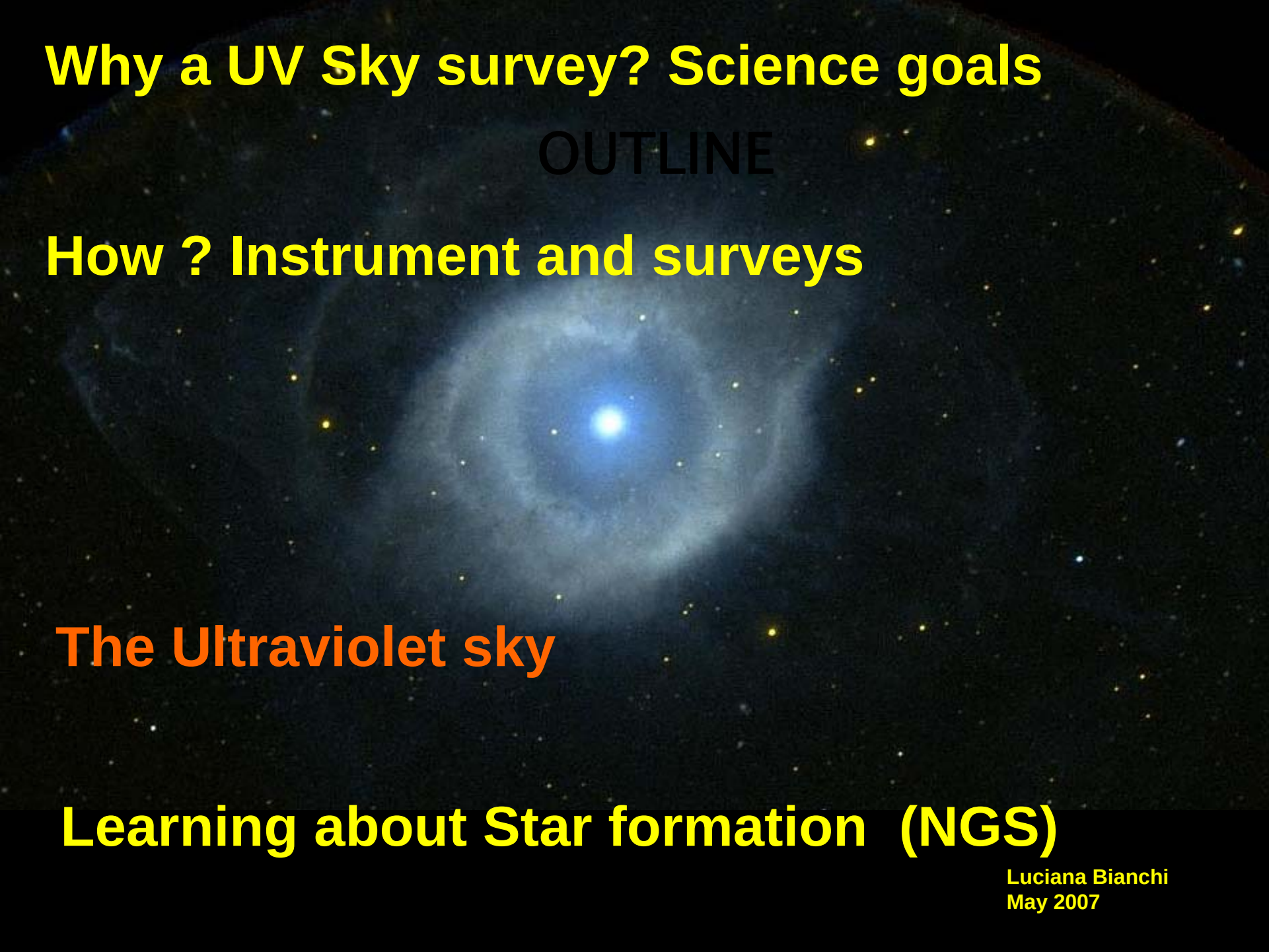
0.6 degree

Grism – 1 orbit (NUV)





Spectrum of a z=0.6 QSO



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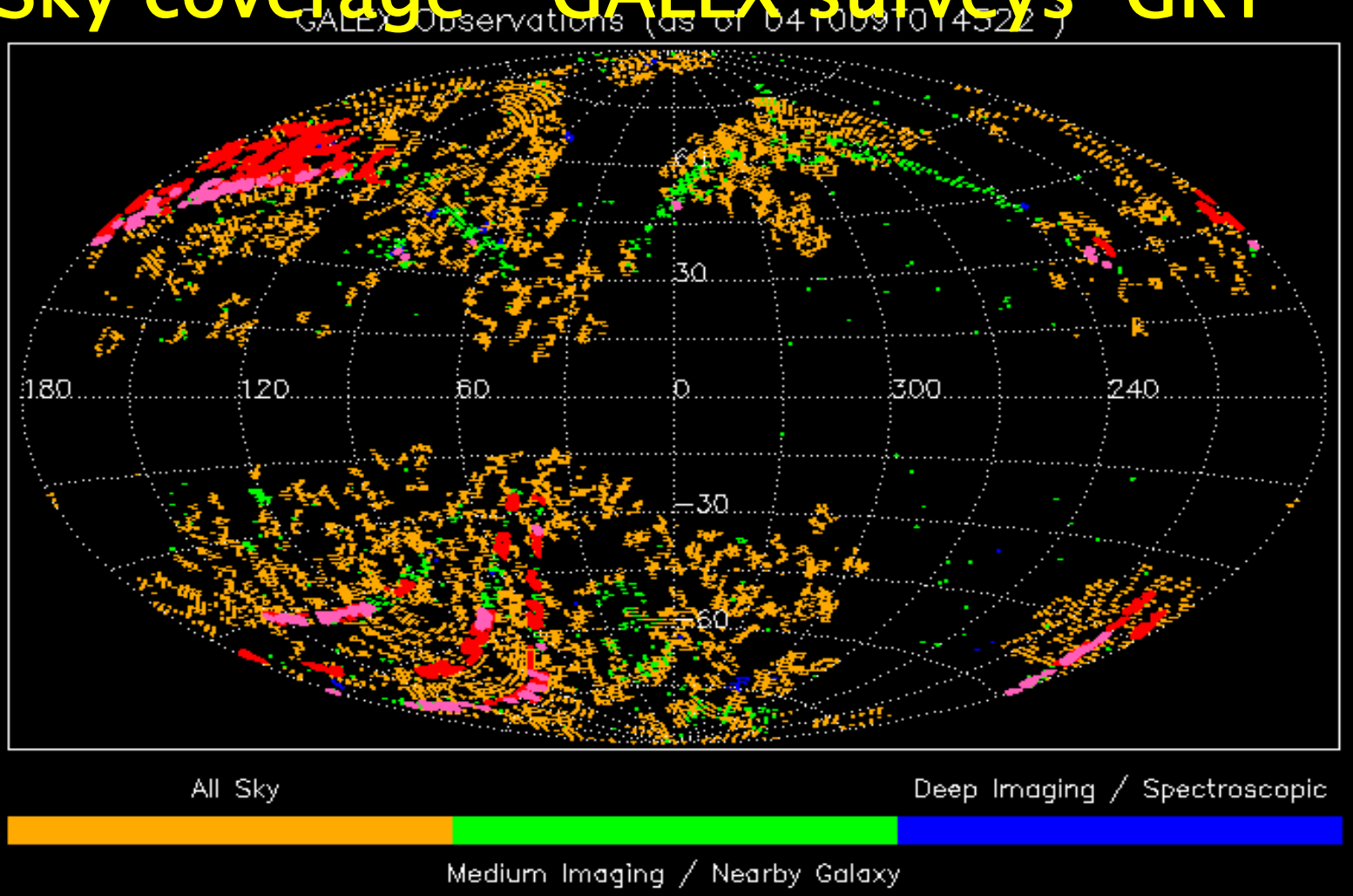
May 2007

Sky coverage – GALEX surveys GR1

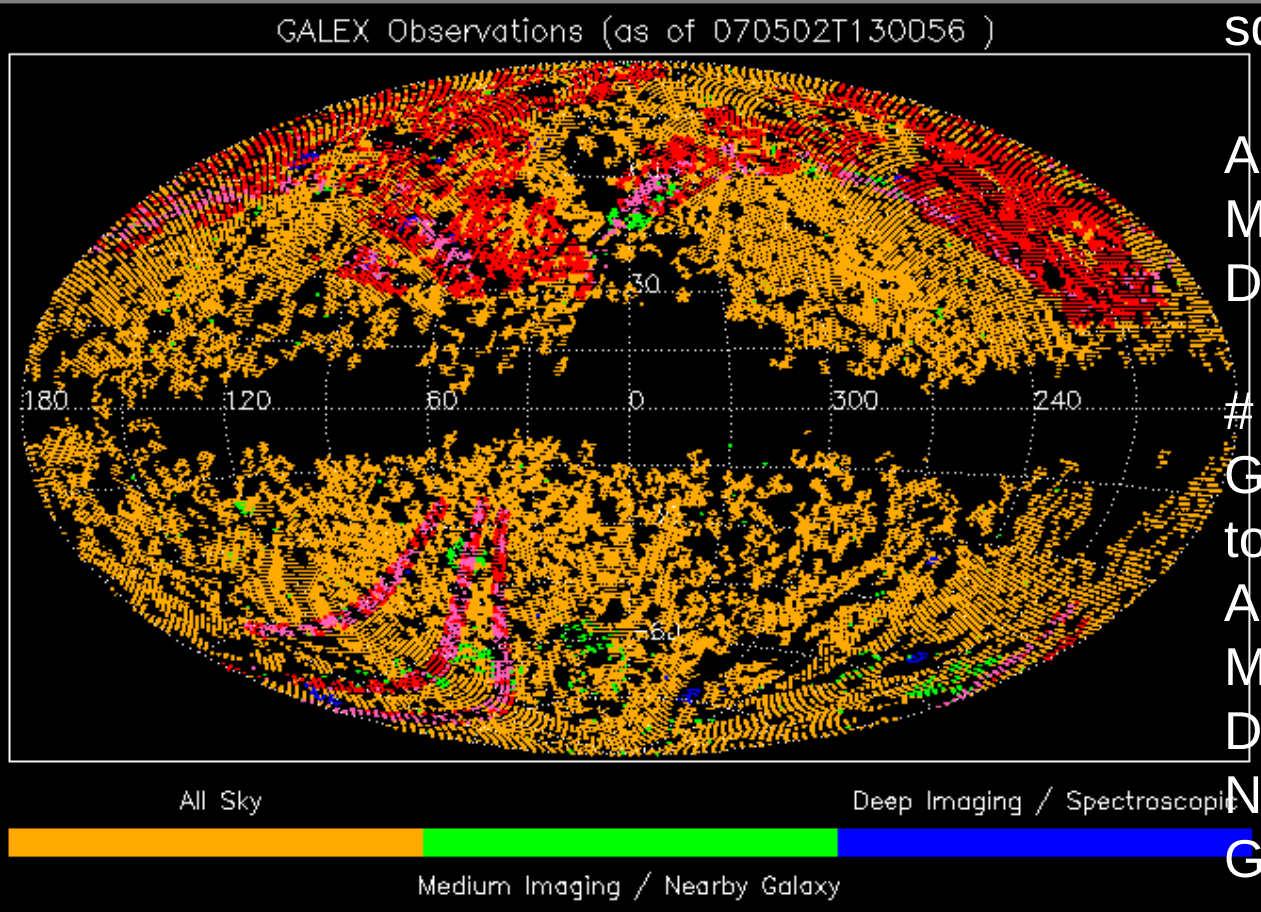


GALEX DR1 release: 20M sources (AIS, MIS, DIS)
2M matched with SDSS sources DR3
AIS: 1.2M matches sources, 363sq.deg., MIS: 0.9M, 83 sq.deg.
(Bianchi et al. 2007, APJS, in press)

Sky coverage – GALEX GR3

CURRENT
(May 2007)
fields:
AIS 27925
MIS 1673
DIS 151
NGS 307

GR3release
AIS 15721
MIS 1017
DIS 122
NGS 296
GI 288
Spectra 39



Objects/ sq. deg

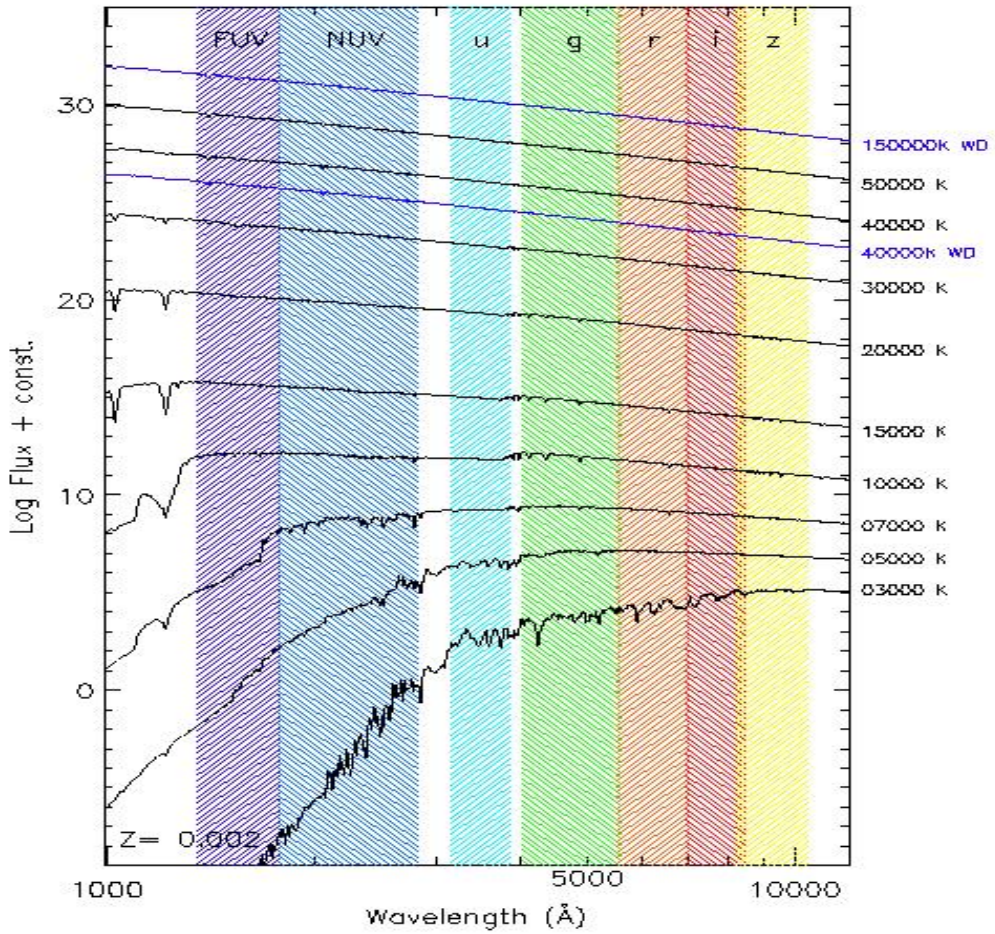
AIS ~5000
MIS ~13000
DIS ~30k

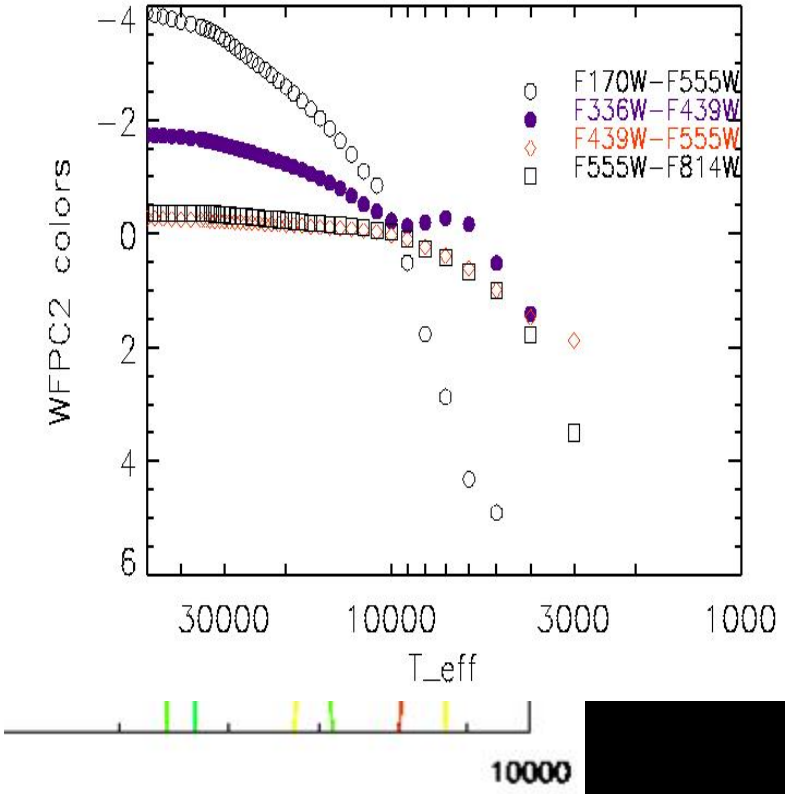
sources GR3release
total 110M
AIS 85M
MIS 13.5M
DIS 3M
NGS
GI 4M

GALEX GR3 Red = AIS and SDSS overlap, 3390 sq.deg (out of 12128)
SDSS DR6 Purple = MIS and SDSS 573sq.deg. (*) (out of 792)
(*) reducing field radius to 0.5deg

Origin of the UV light in galaxies

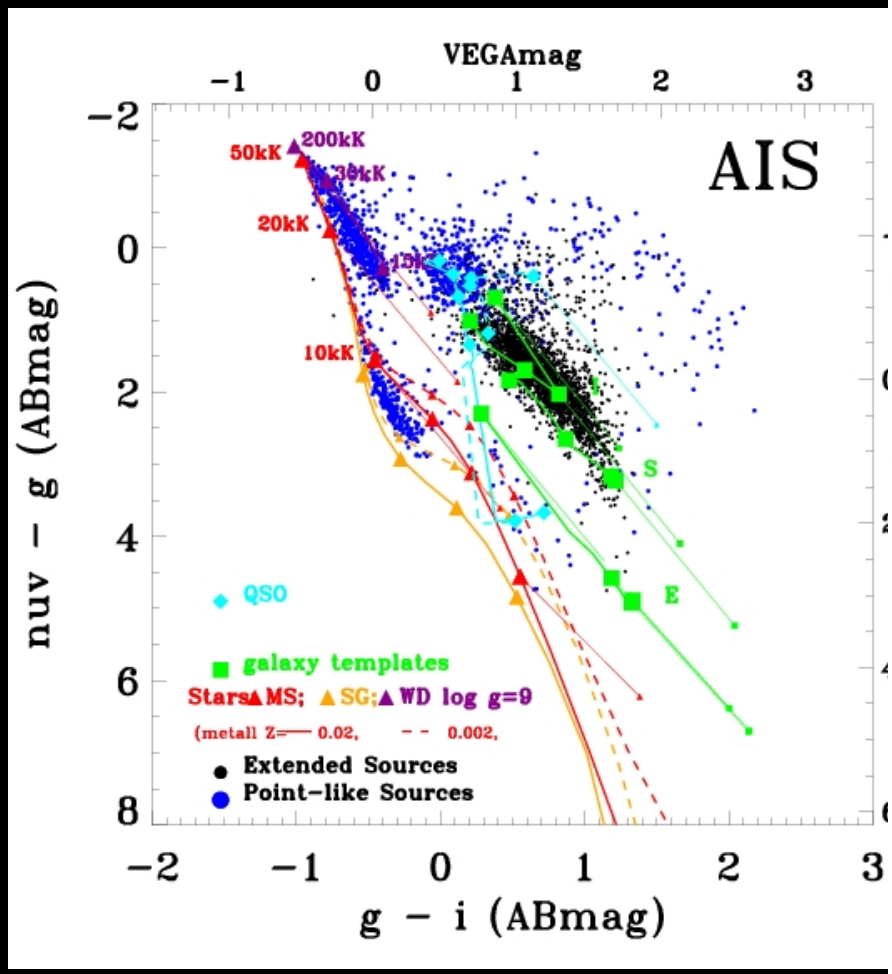
- ✓ Young, massive stars
- ✓ UV upturn: HB stars, either relatively-young metal rich stars or very-old metal-

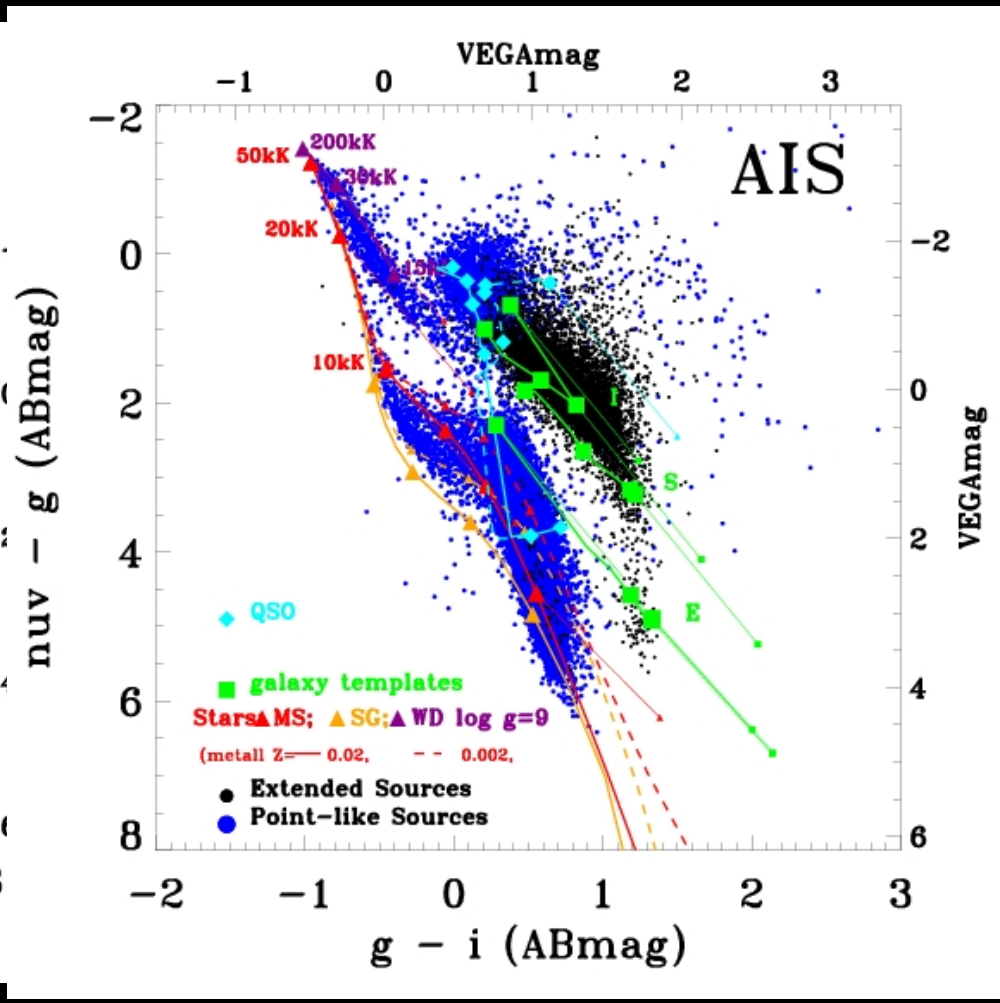


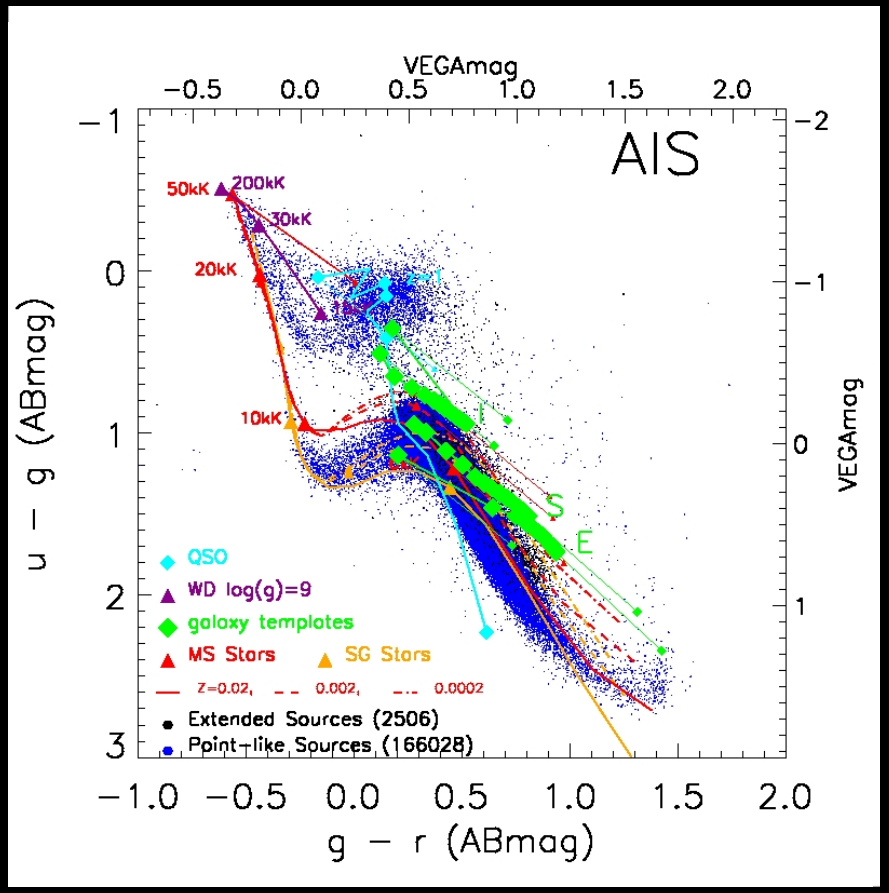


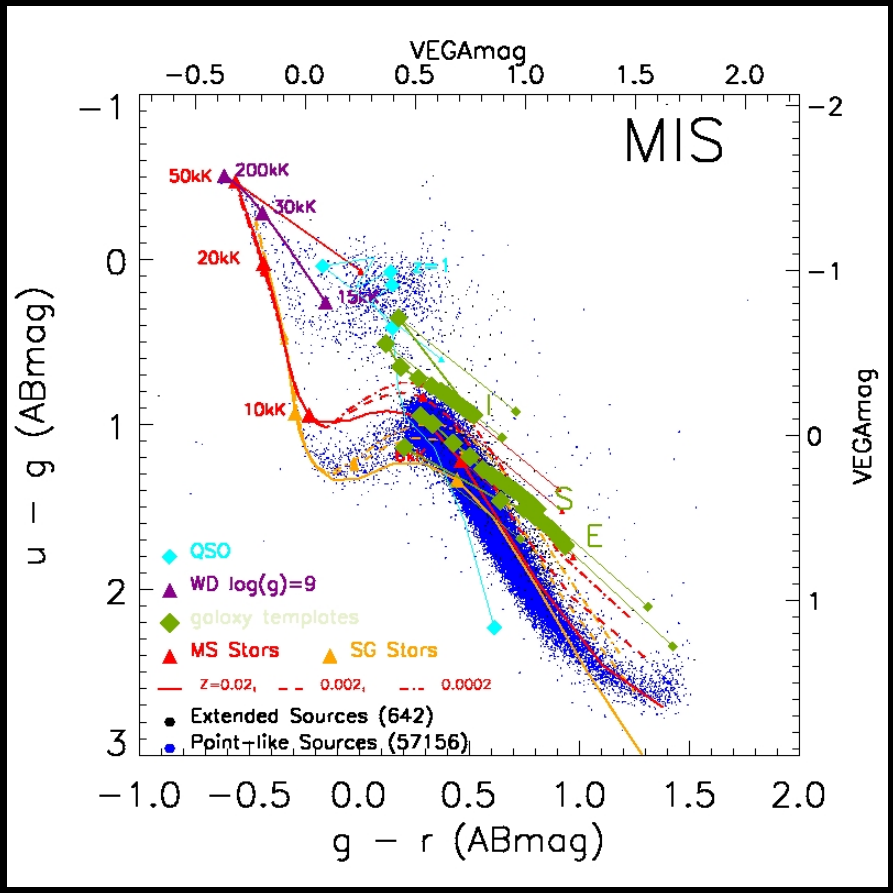
UV-g, g-i

Object classification from color-color diagrams

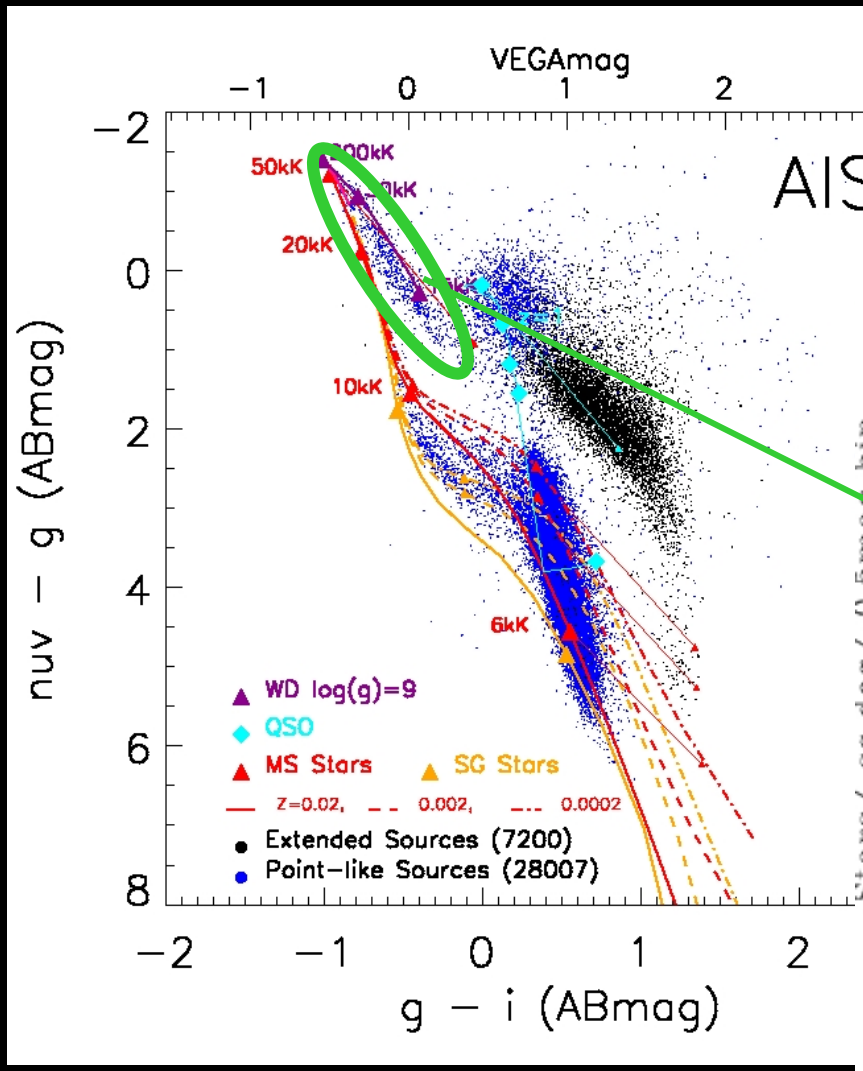





AIS
VEGAmag
−0.5 0.0 0.5 1.0 1.5 2.0
50kK
200kK
30kK
20kK
15kK
10kK
I
S
E
QSO
WD log(g)=9
galaxy templates
MS Stars
SG Stars
Z=0.02, 0.002, 0.0002
Extended Sources (2506)
Point−like Sources (166028)
u − g (ABmag)
g − r (ABmag)
VEGAmag
−1.0 −0.5 0.0 0.5 1.0 1.5 2.0

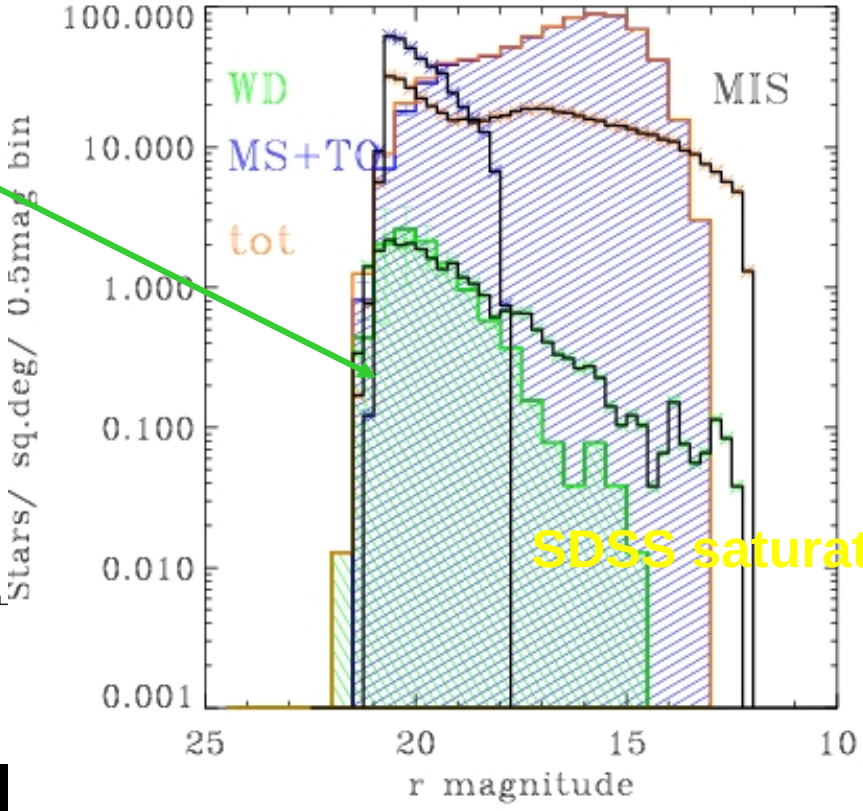

MIS
VEGAmag
−0.5 0.0 0.5 1.0 1.5 2.0
50kK
200kK
30kK
20kK
15kK
10kK
I
S
E
QSO
WD log(g)=9
galaxy templates
MS Stars
SG Stars
Z=0.02, 0.002, 0.0002
Extended Sources (642)
Point−like Sources (57156)
u − g (ABmag)
g − r (ABmag)
VEGAmag
−1.0 −0.5 0.0 0.5 1.0 1.5 2.0

Hot MW stars: WD, sd, binaries



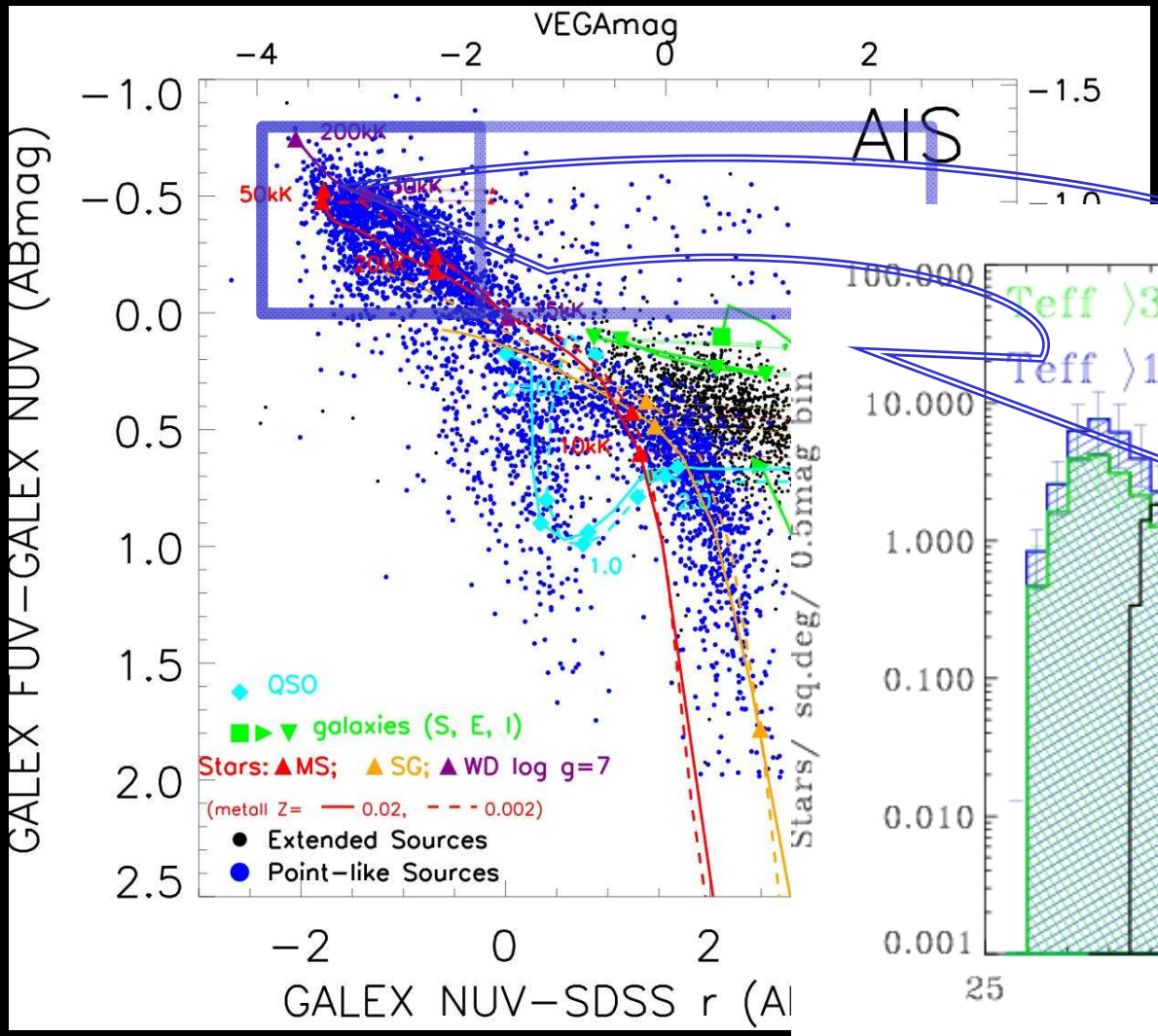
Search for hot stars

- Massive hot stars: snapshot of recent



Hot MW stars: WD, sd, binaries

Selection of hot stars from FUV-NUV only

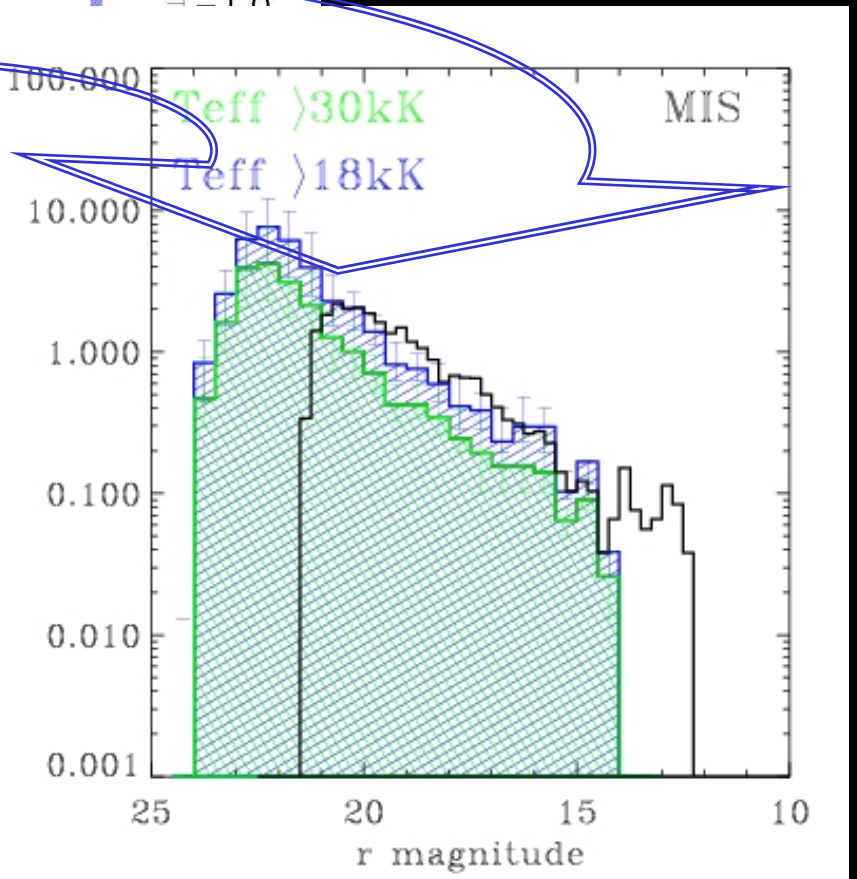


Known:

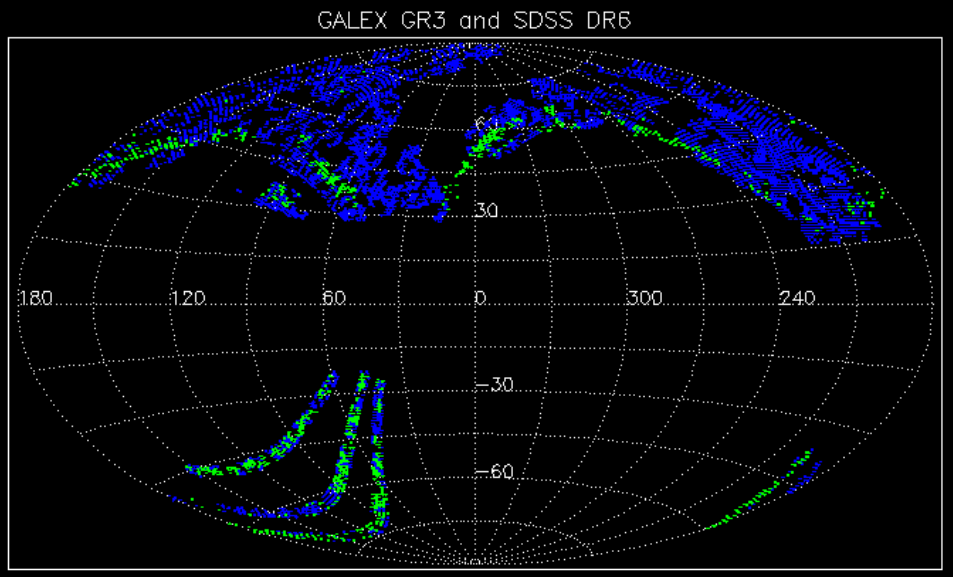
PN: 36(12) lat. >30(45)

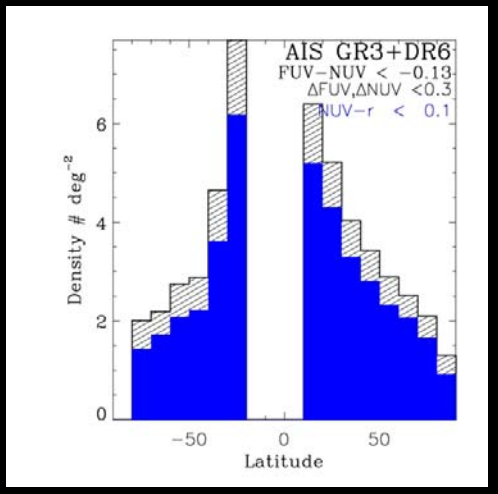
Kleinmann et al. 2004 2.2/sq.deg

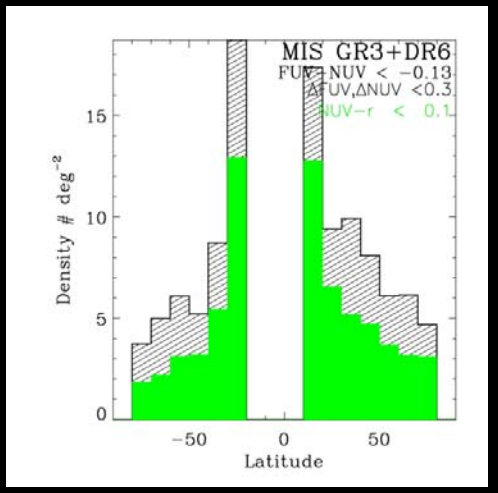
McCook & Sion 1553 (>45deg)



Hot wd, sd, binaries: MW structure







MIS green **AIS blue**

573deg² (of 792) **3390 (of 12128)**

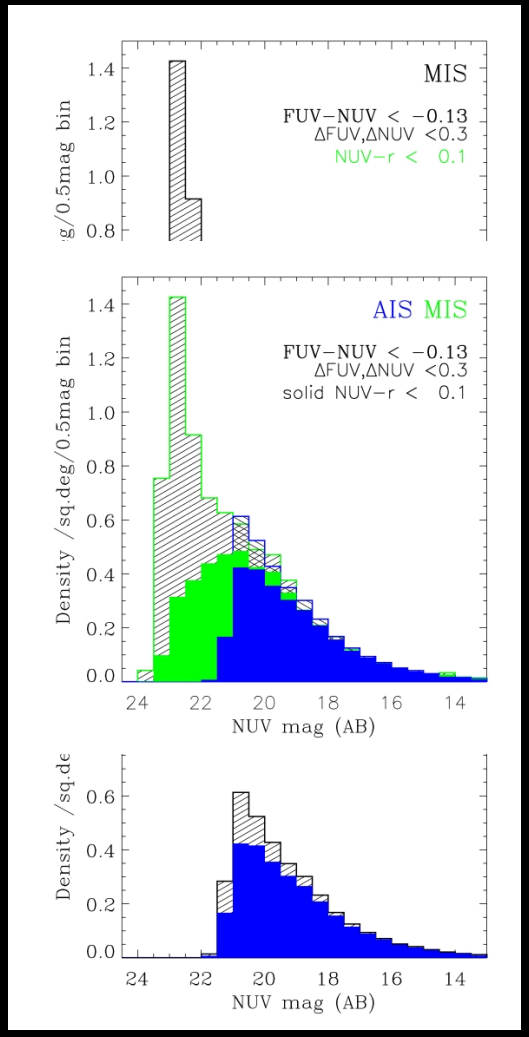
Stars hotter than ~20kK

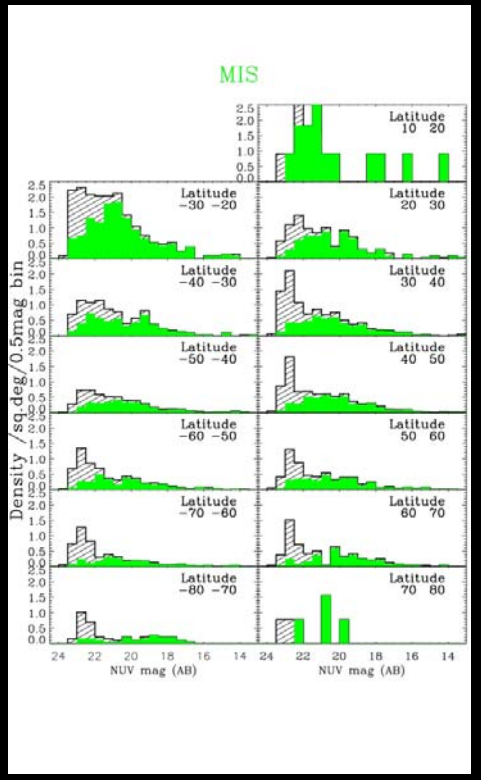
Imposing stringent err.cuts (10x cut)

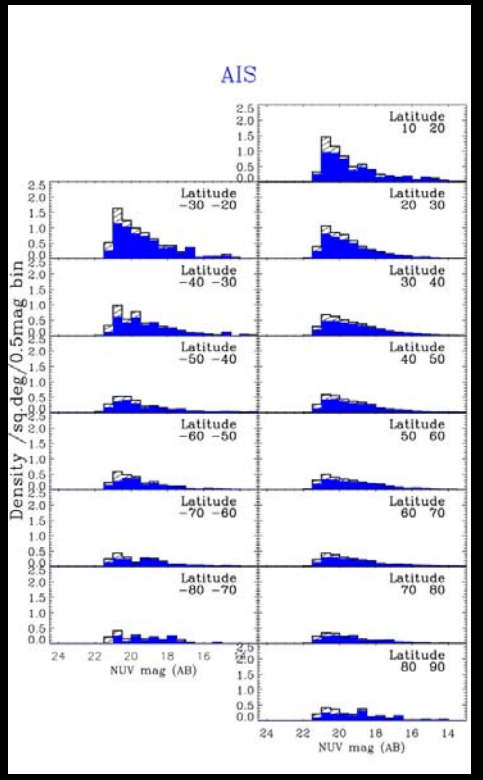
Extragal. objects increase at faint mag.s

	Lim ~23	~21
err cut 0.3	tot 4234	11448

Hot wd, sd, binaries: MW structure







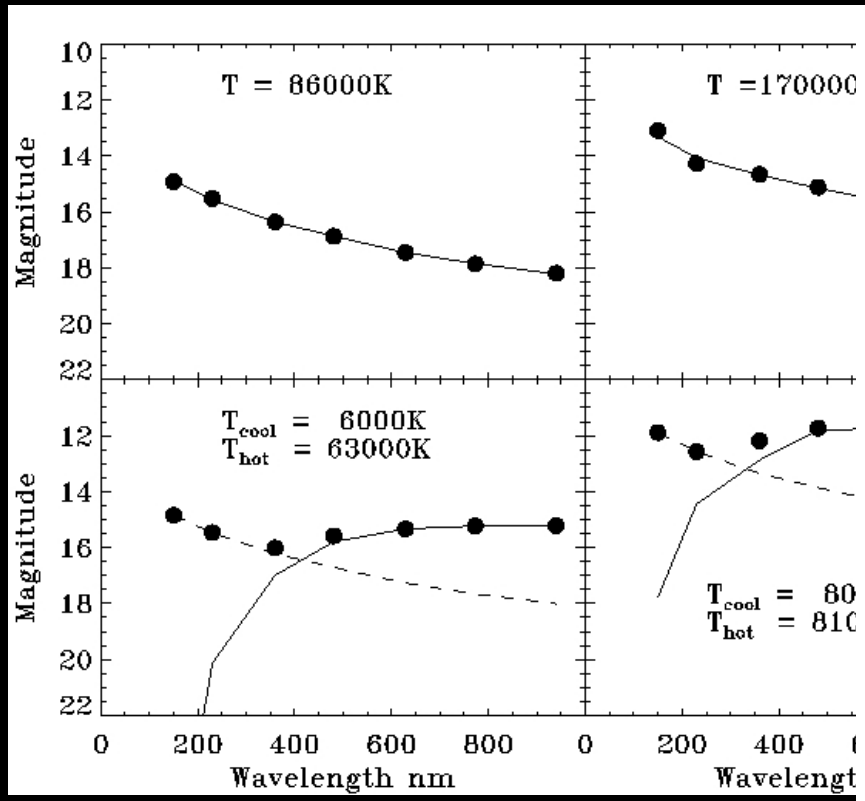
Stars hotter than ~20kK

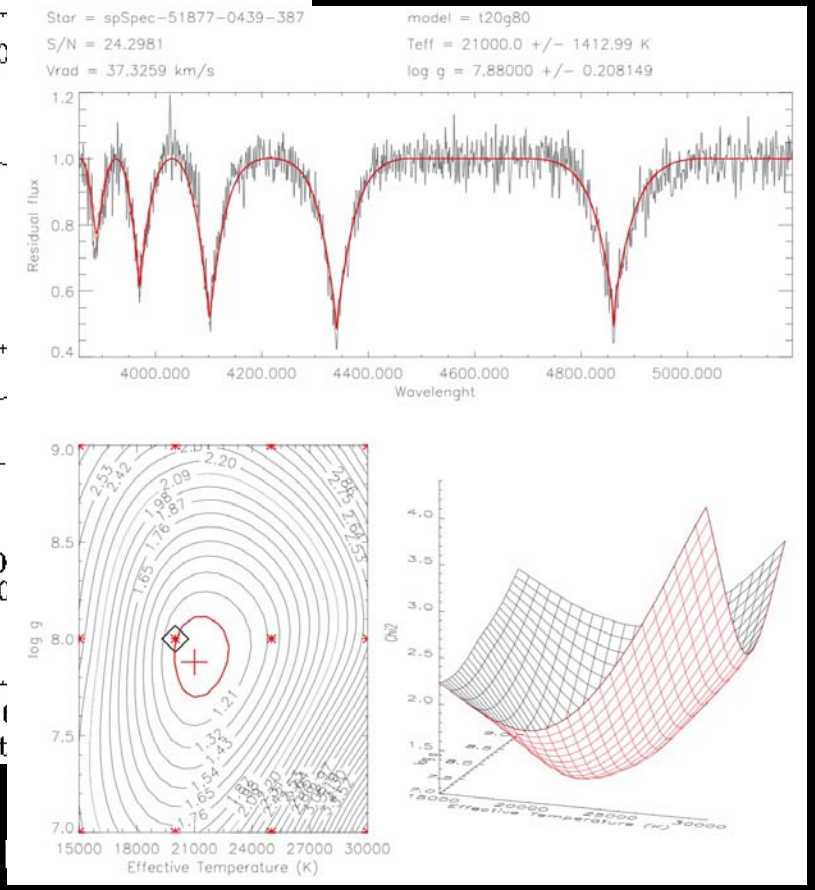
Variations >5x with Gal.lat. (uncorrected for ext.)

Imposing stringent err.cuts (10x cut)

Extragal. objects increase at faint mag.s

Objects classification : SED fit





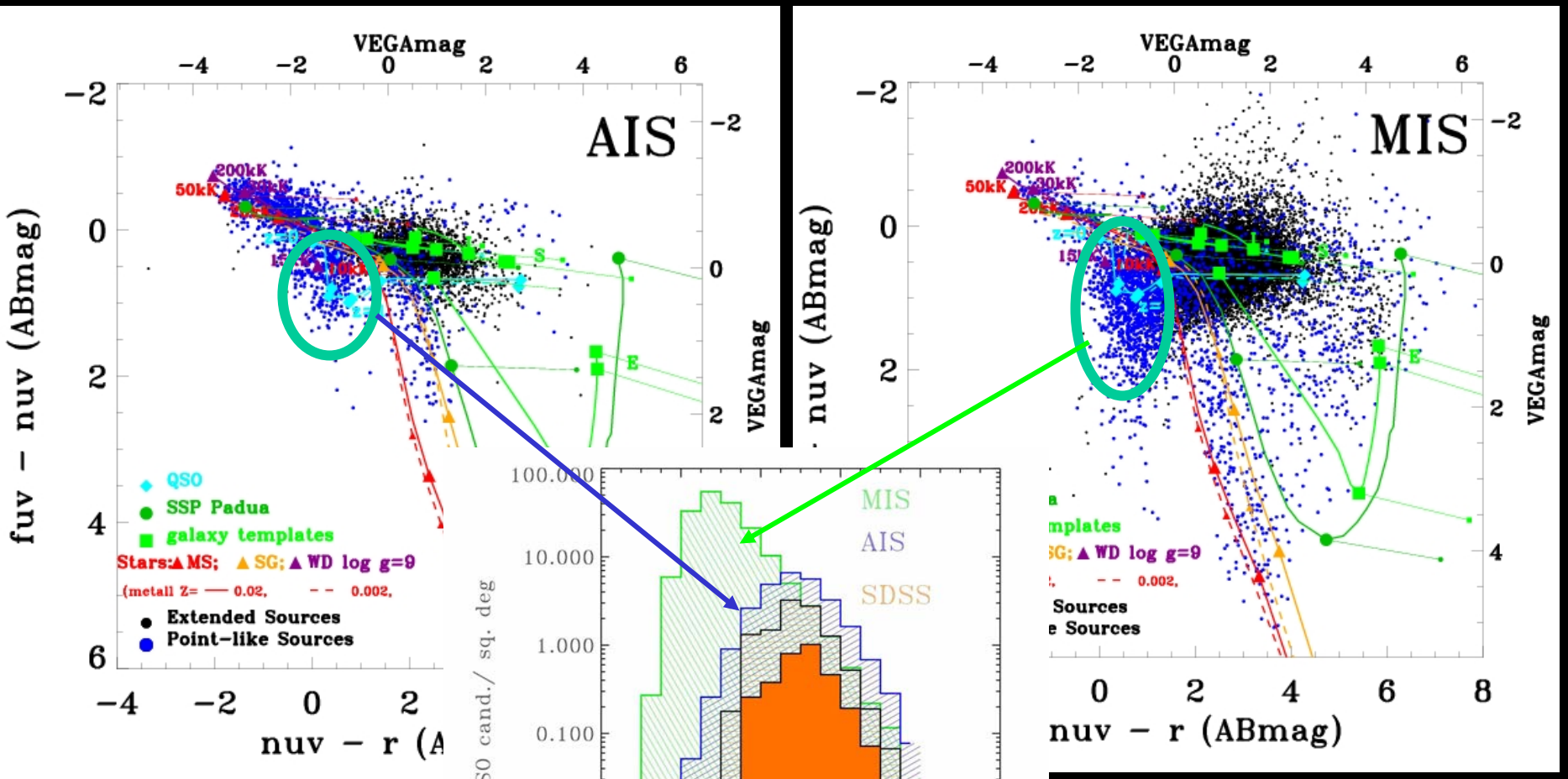
With: Boryana Efremova Vladimi

Spectr. fit: with G. Catanzaro and J. Herald

Next : kinematics

FUV-NUV , NUV-r

Low z QSO candidates



(COS targets)

Bianchi et al 2005 ApJL , 619,L27
Bianchi et al 2007, ApJS, in press

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Luciana Bianchi
El Escorial May2007

NGS Nearby Galaxies Survey

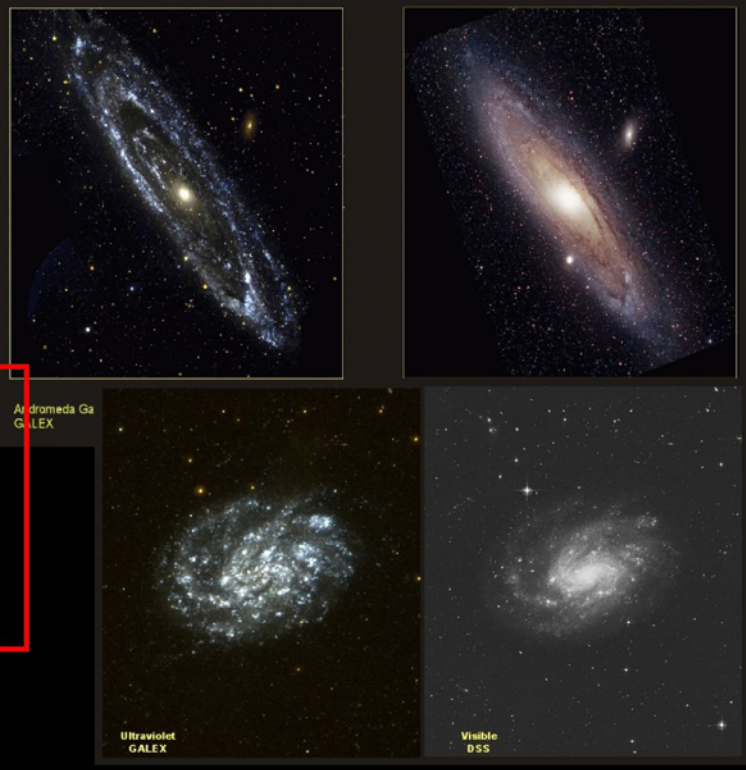
- Bianchi et al. 2004, 2005

Over 300 galaxies all types

- Representative sample for the local/present universe
- Includes SIRTF SINGS

- Benchmark for high z studies
  - Rest-frame UV morphology
  - Variation of UV extinction
  - 4-6x deeper than AIS

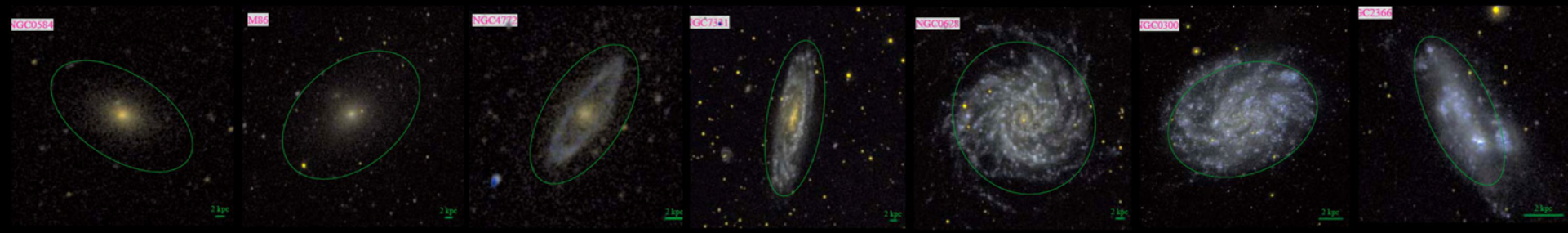
Bianchi, Madore, Thilker, Gil de Paz, many..



GALEX ATLAS of Nearby Galaxies (Gil de Paz et al.2007, APJS): Surface photometry, asymptotic magnitudes and colors for 1060 galaxies: 227 E/S0, 656 Spirals, 84 Irr, rest no type assigned. 581 galaxies observed in FIR (IRAS), 885 in B (RC3), 870 in K (2MASS)

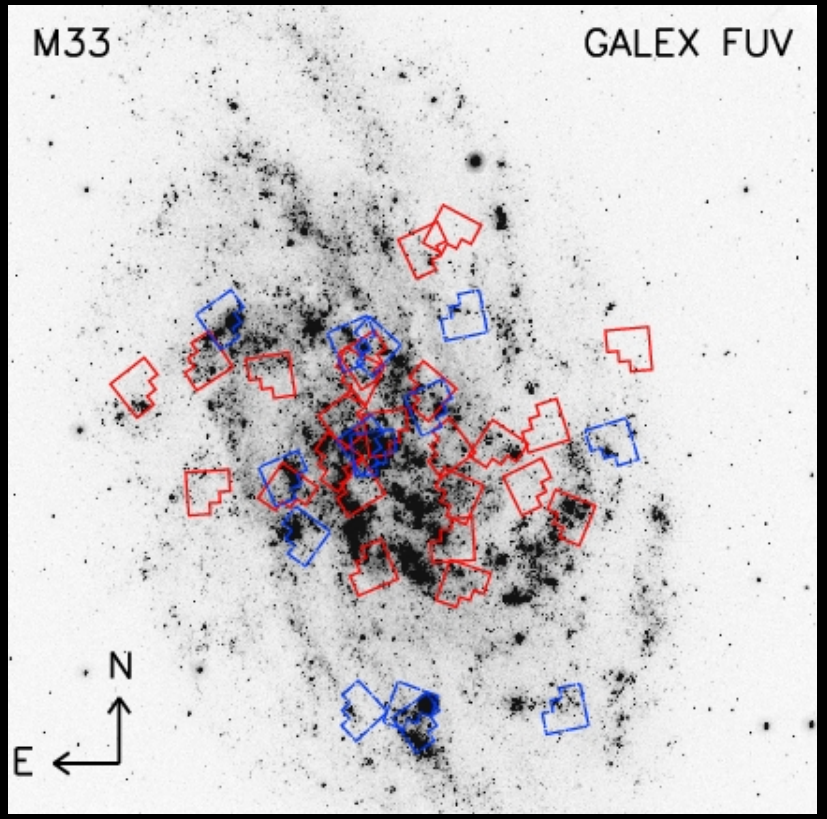
Hubble sequence:

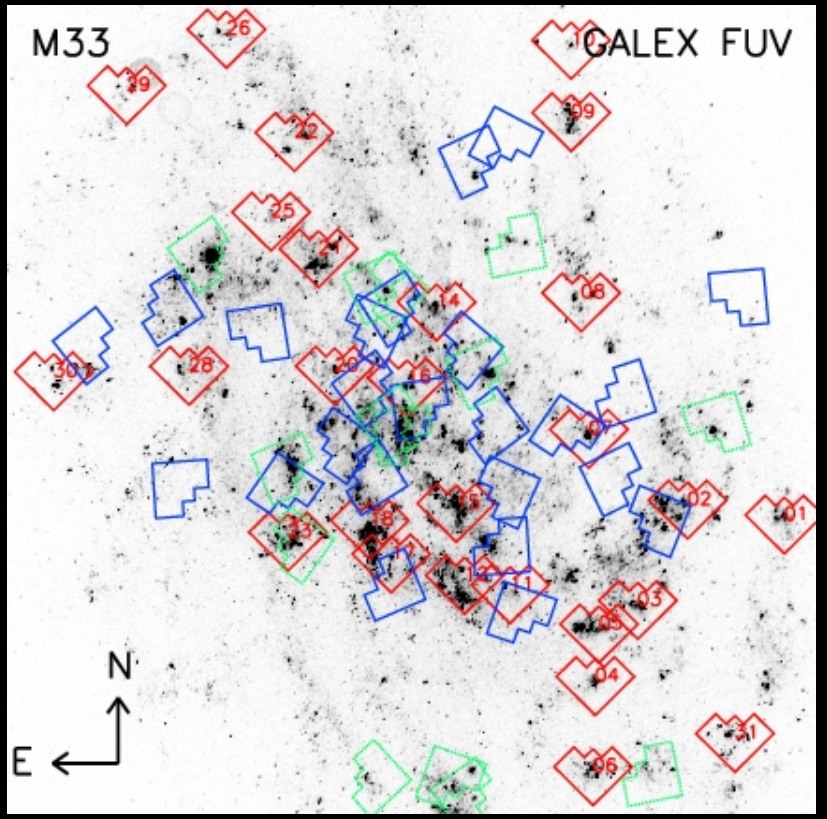
E4	S0	Sa	Sb	Sc	Sd	Im
NUV-K=4.8	NUV-K=4.2	NUV-K=3.9	NUV-K=2.8	NUV-K=0.9	NUV-K=0.4	NUV-K=-1



M33: Hα GALEX scale 6-18pc

M33: UV coverage with HST before GALEX





Learning about Star Formation from the Local Universe:

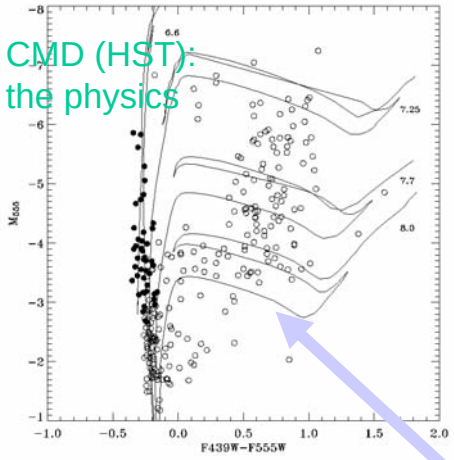
Nearby galaxies: different Hubble types and conditions (metallicities, interactions)
modalities of SF (IMF, SFR, spatial variations) ---> SF and evolution

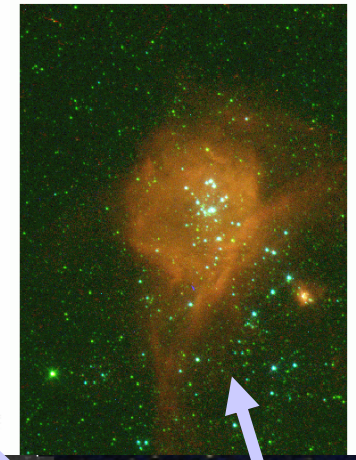
With: Boryana Efremova, PhD student

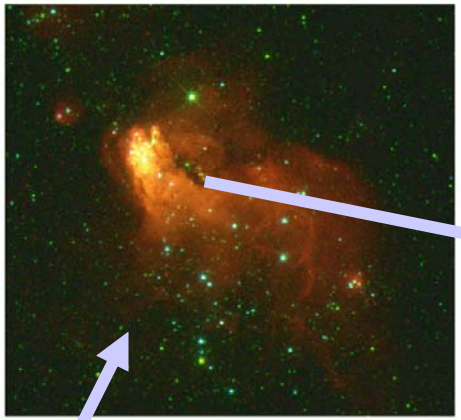
HST: high resolution :
the detailed view

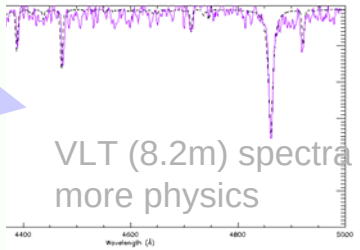
Bianchi et al. 2001
B. & Efremova 2006
Efremova & Bianchi **2007**

CMD (HST):
the physics



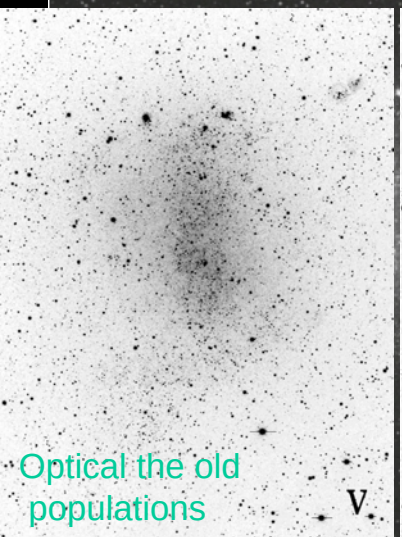






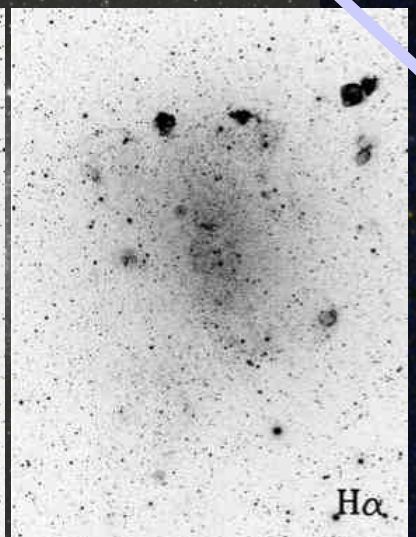
VLT (8.2m) spectra
more physics

NGC 6822: low metallicity LG galaxy



Optical the old
populations

V



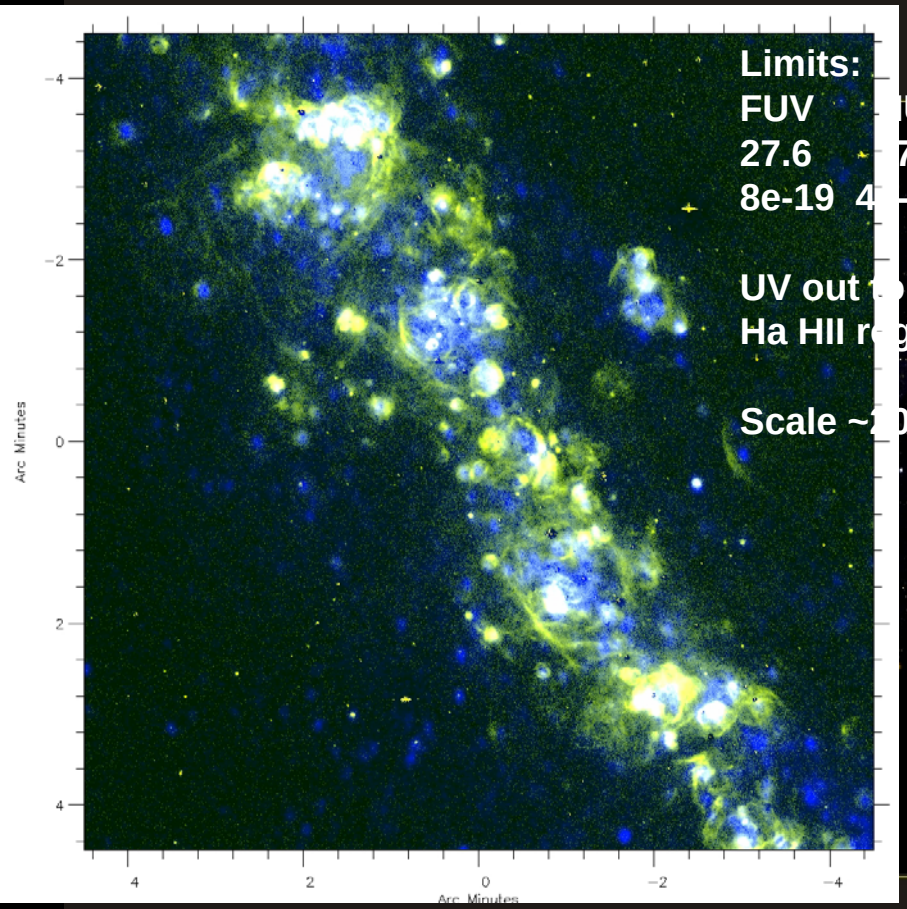
Hα

UV (GALEX) the
young and hot

IR (24m SPITZER)
the heated dust

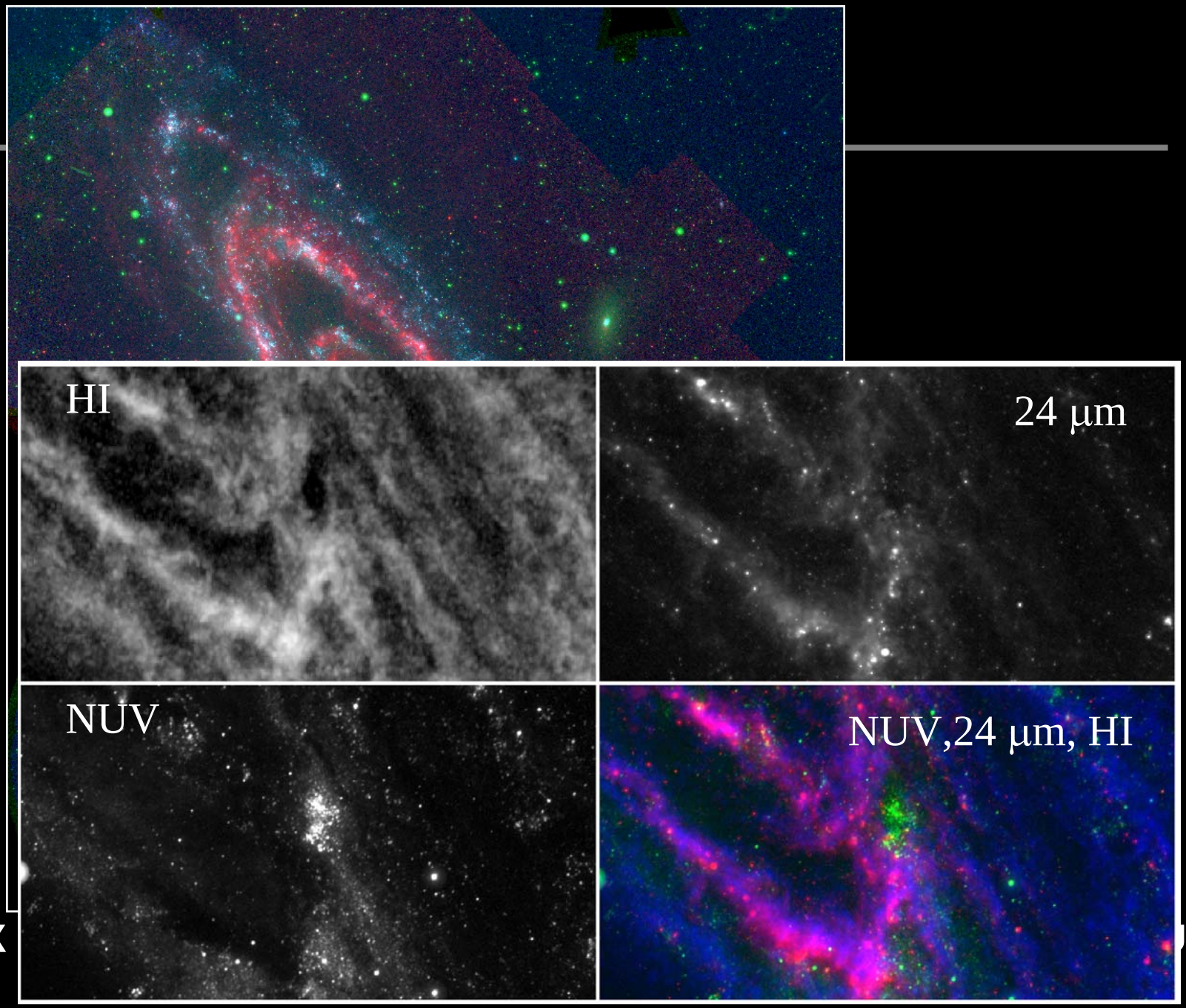
M31 UV vs. Optical

M31 >20 fields



Andromeda Galaxy
GALEX

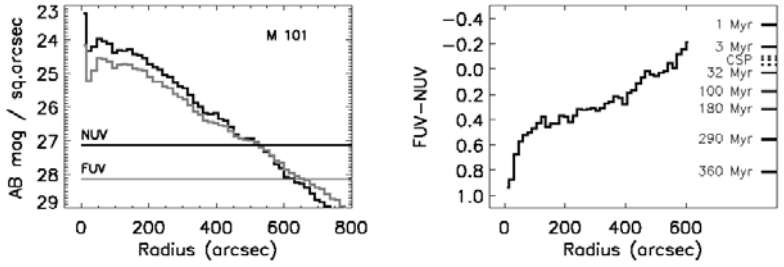
Andromeda Galaxy
Visible light image (John Gleason)

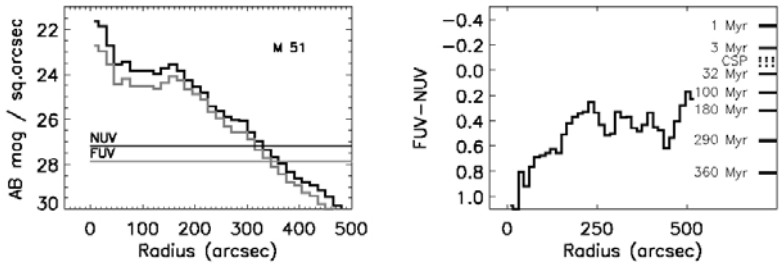


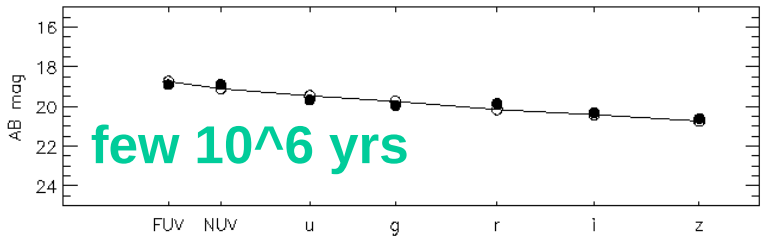
GALEX

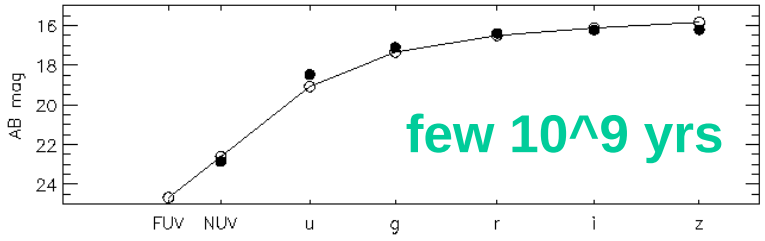
From Bianchi et al .2005 ApJL,619,L71

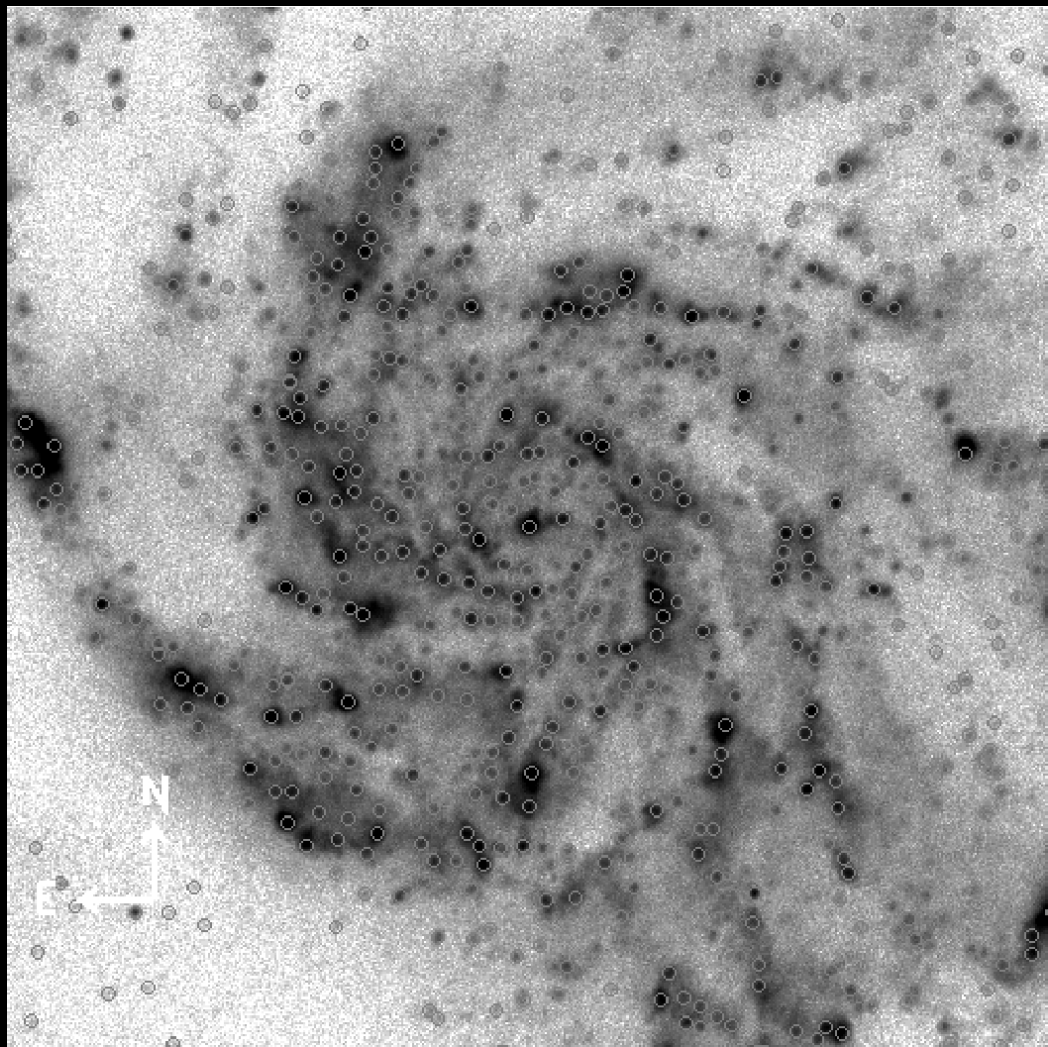
Age	1Myr	10Myr	100Myr	
FUV-r	-1.80	-0.30	1.11	(AB)
g-r	-0.48	0.06	-0.03	
u-g	-0.36	0.01	0.69	











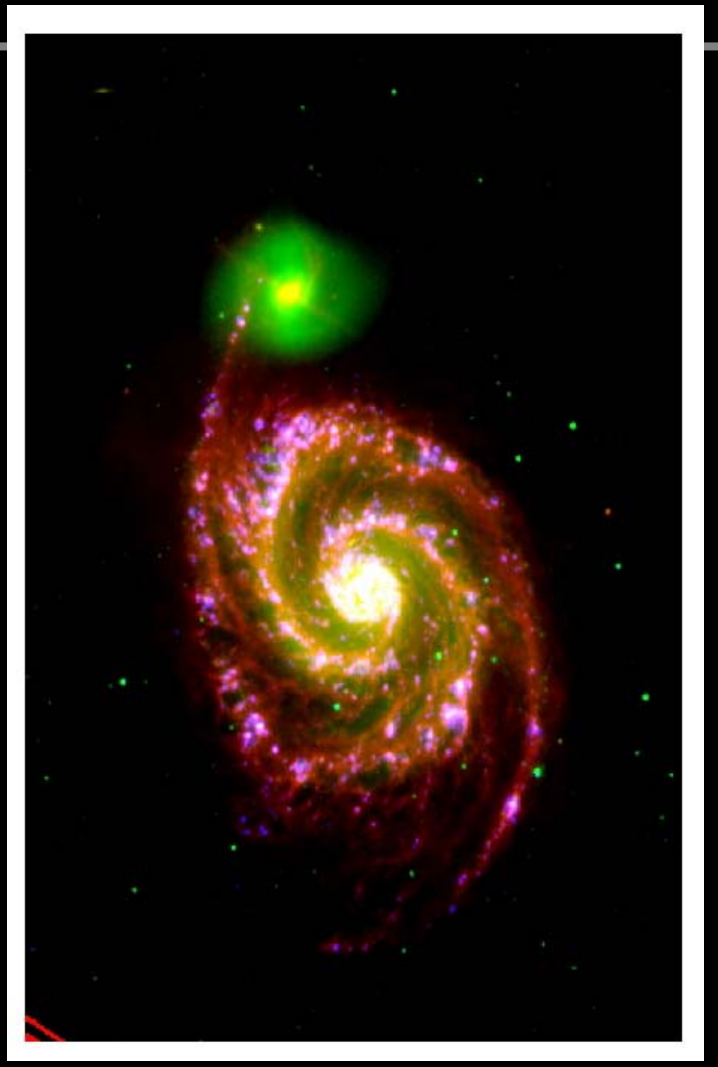
M51 – GALEX to Spitzer (Calzetti et al. 2005)

Used 8μm/24μm and 24μm/TIR
model relations of Dale & Helou 2002
to get TIR without depending on
(lower resolution) 70 or 160μm MIPS data.

Used 3.6um as "stellar cont."
To correct the 8um

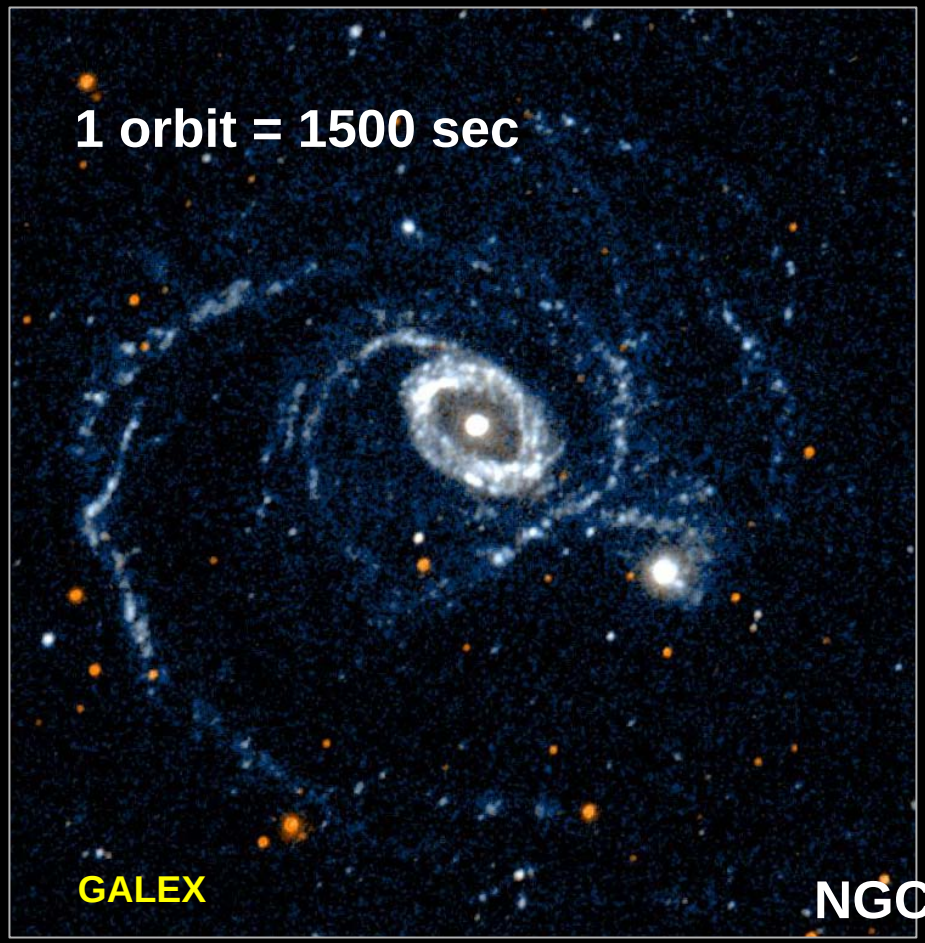
(R,G,B) = 8μm (dust), optical R, Hα
IRAC higher resolution
Down to ~ 500pc scale

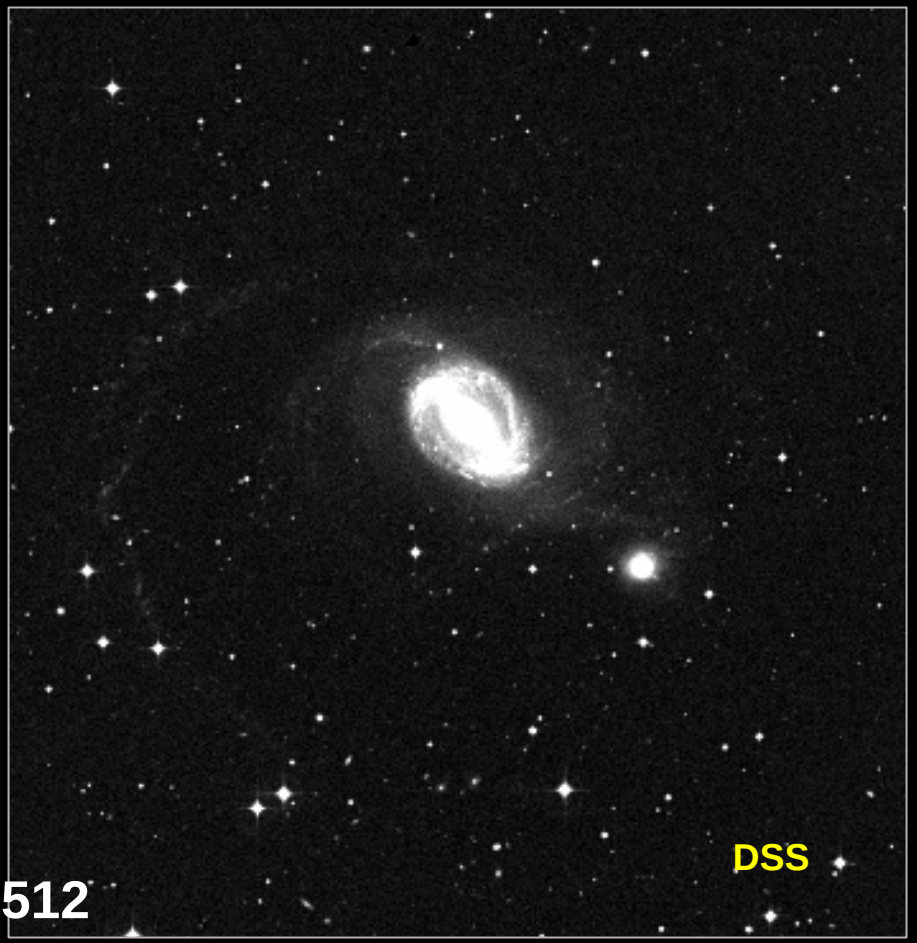
Results: 24um good SF tracer
Extinction= starburst-like only
for >1Msun/kpc2



Rest UV Traces Star Formation

In Disks w/ Strong Driving Dynamics

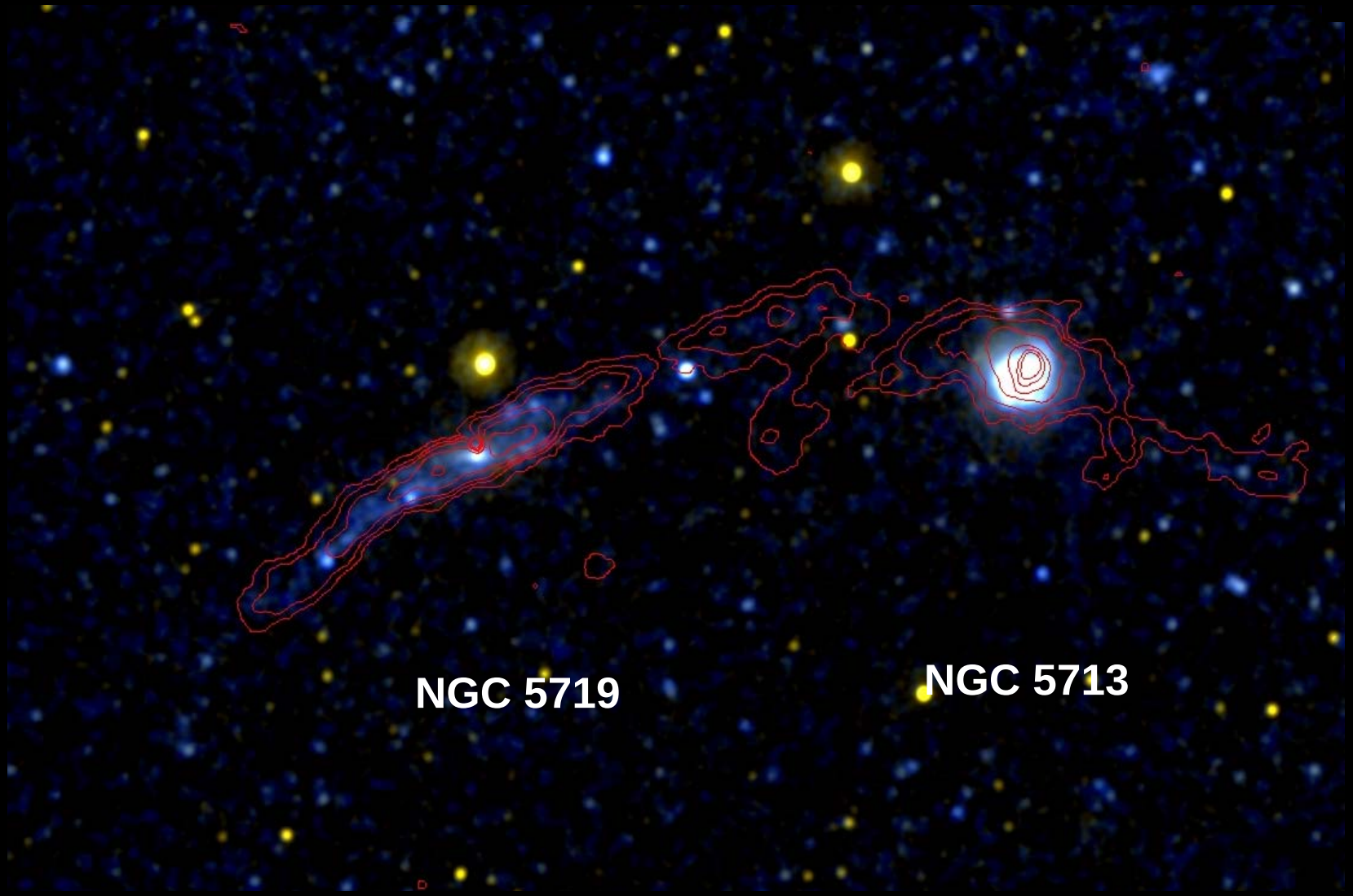


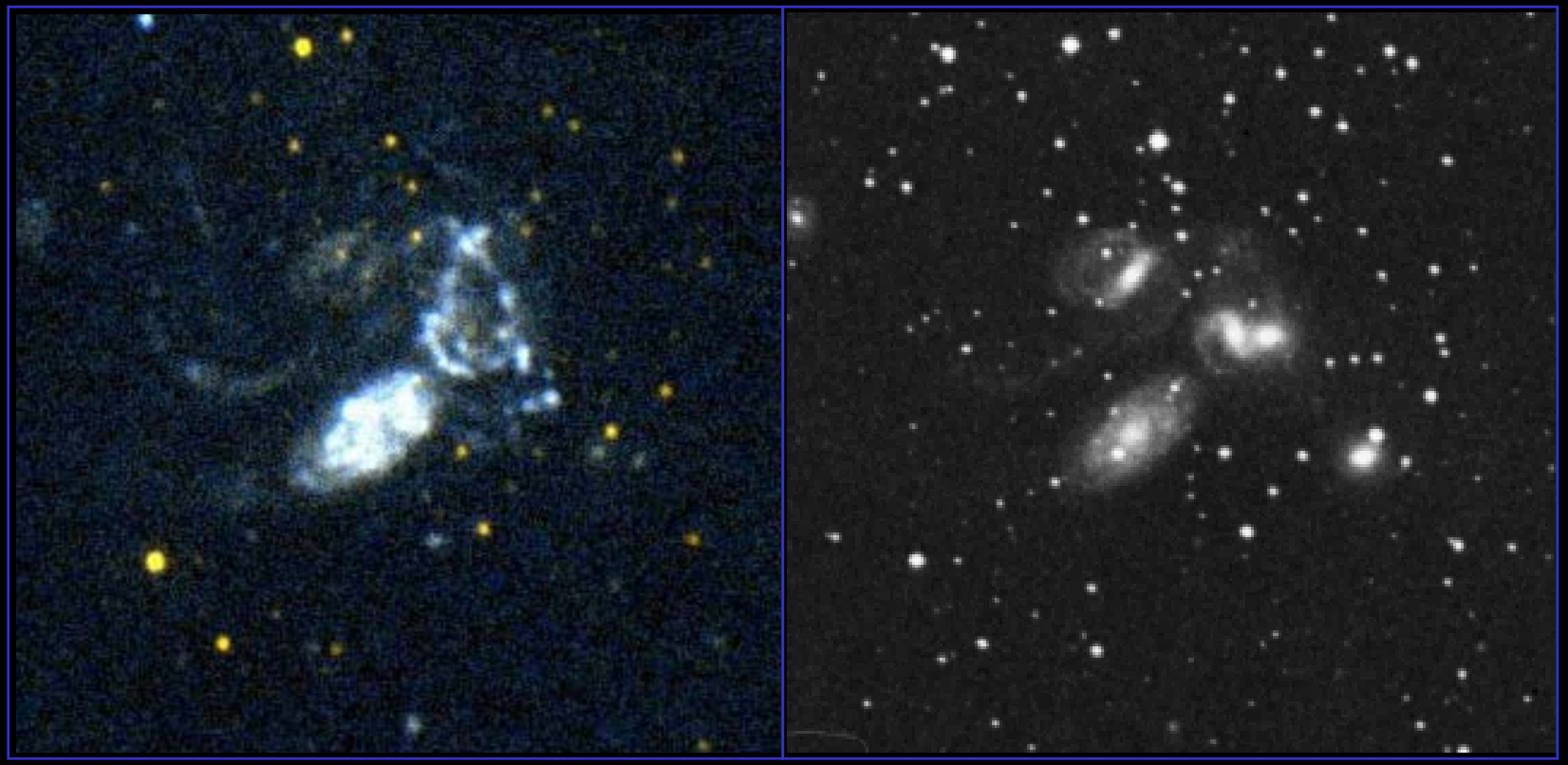


NGC1512

Rest UV Traces Star Formation

In Tidal Tails formed by Interacting Disks





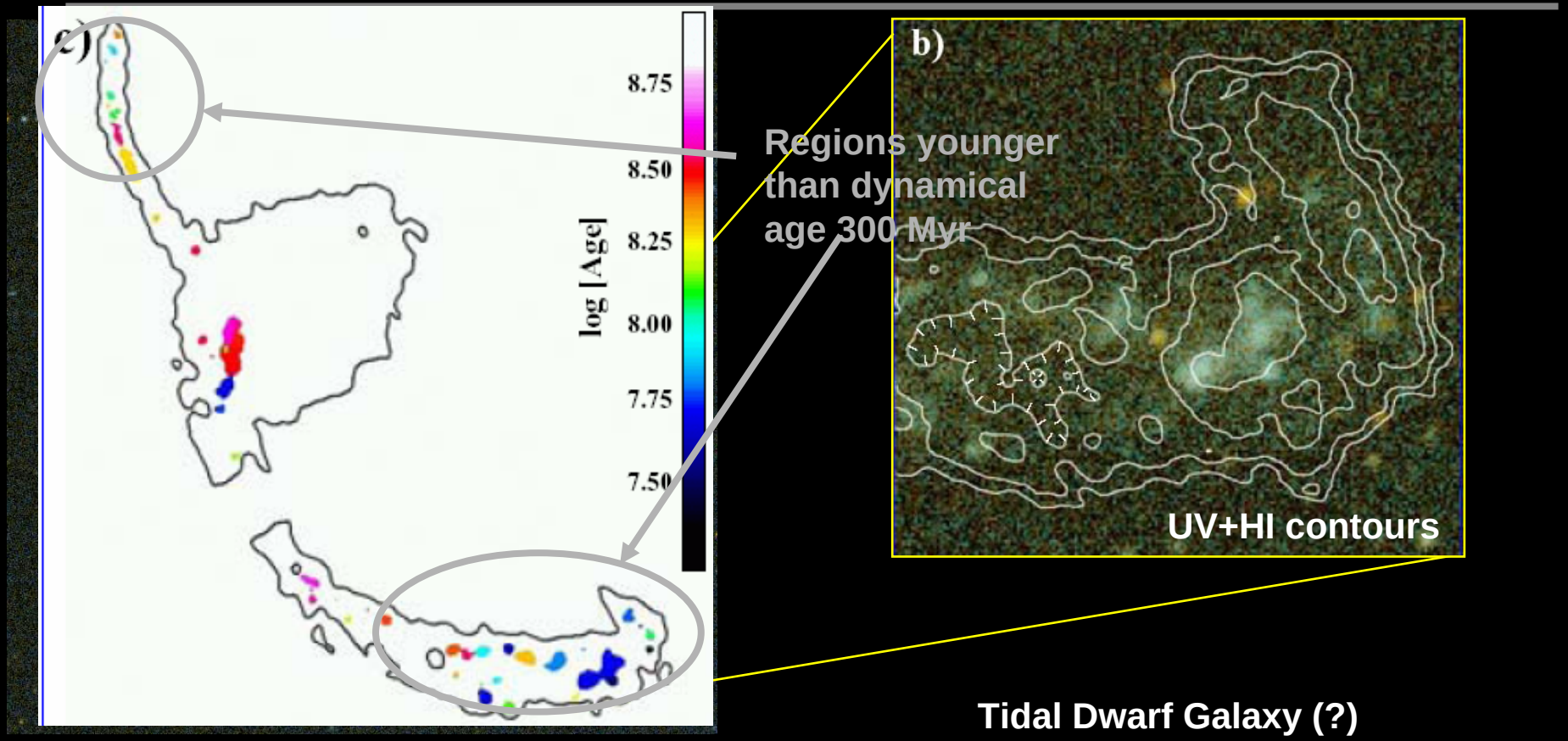
Ultraviolet
GALEX

Visible
DSS

Xu et al. 2005 ApJL : UV em. Extends beyond optical , 80kpc scale
UV coincides w/ Ha. HI coincides w/ disk of NGC7318b, not NGC7319 (diff.tidal features)
SF from UV about same age as dynamical time (~10^8 yrs)

Rest UV Traces Star Formation

In Merging Galaxies [Tidal Debris]

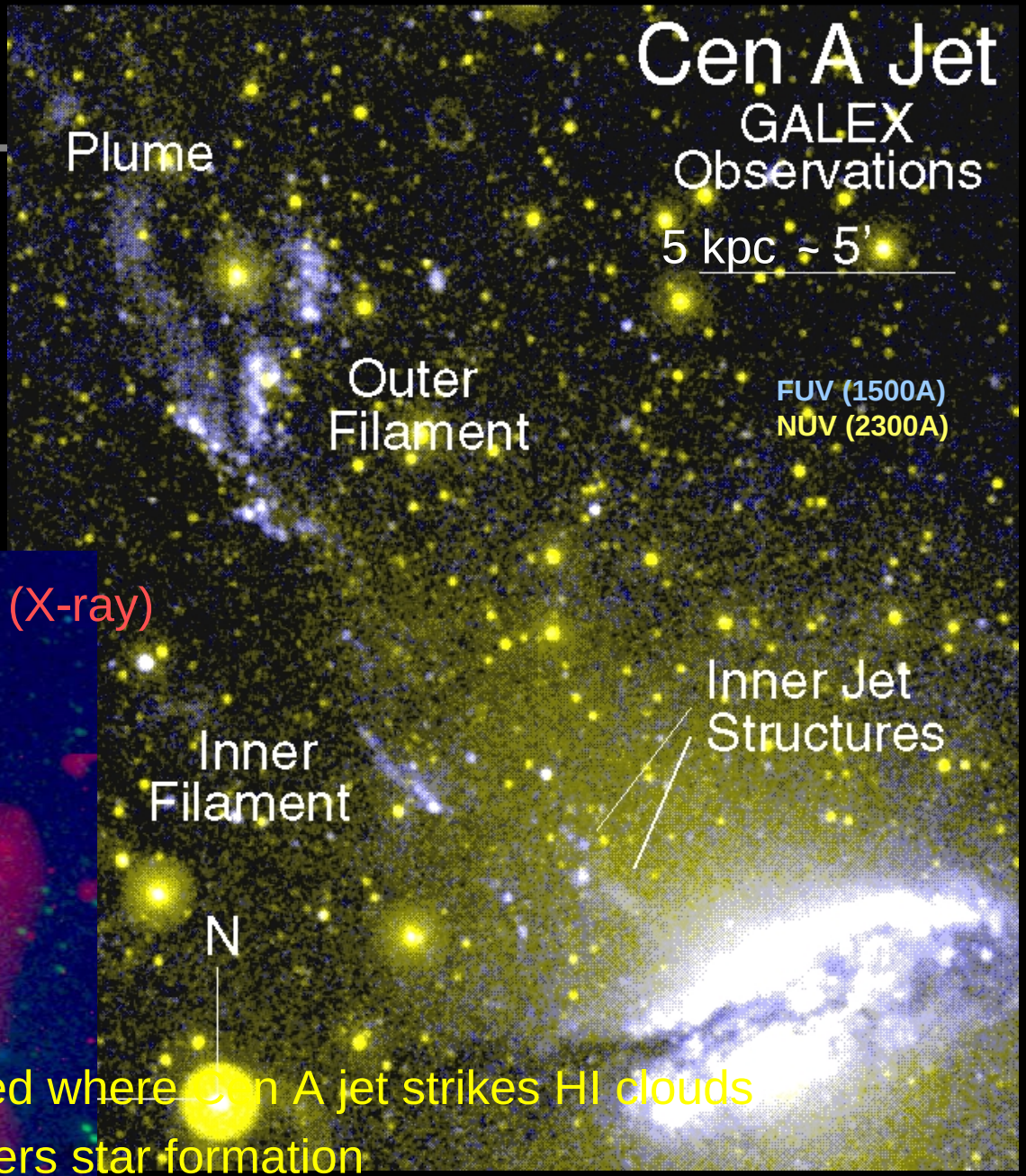


Hibbard, Bianchi et al. 2005, GALEX ApJL

Jet-Induced Star Formation in Centaurus A

Neff et al. in prep.

- New GALEX data:
  - Deep (~27 mag rms)
  - Wide field (1.2^{o})
- FUV emission (1500A) detected:

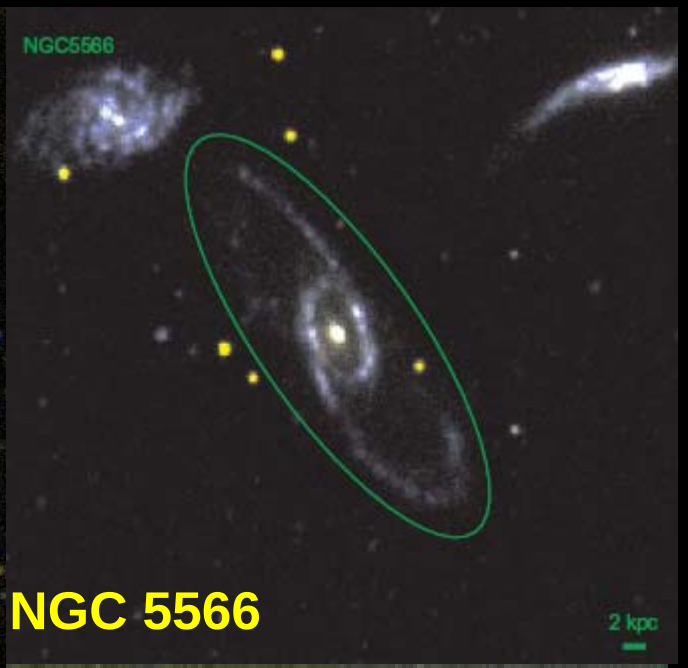


Star formation regions detected where Cen A jet strikes HI clouds

Jet compresses gas and triggers star formation

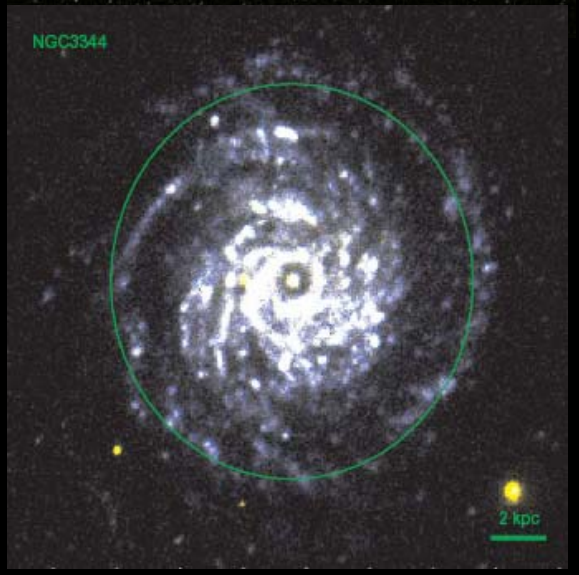
Rest UV Traces Star Formation

In Disks w/ Strong Driving Dynamics



Rest UV Traces Star Formation

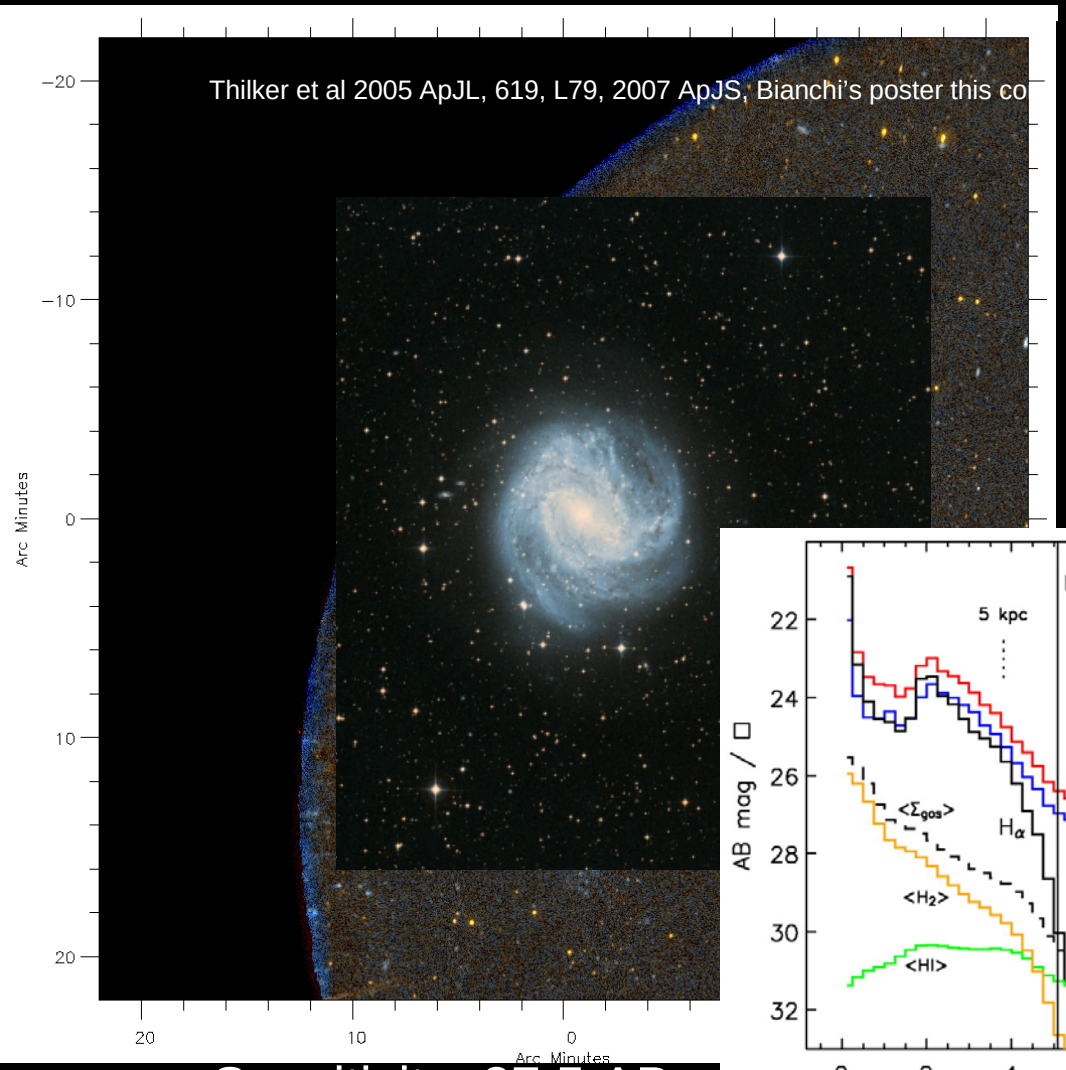
In Face-on Disks w/ Weak Driving Dynamics



Rest UV Traces Star Formation

in disks with Extended Star Formation

M83 : Extended UV disk – discovery



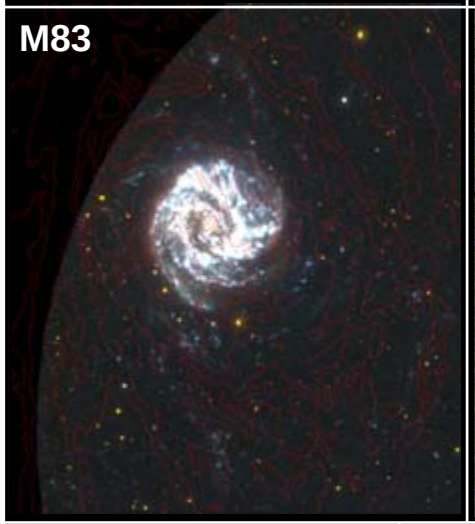
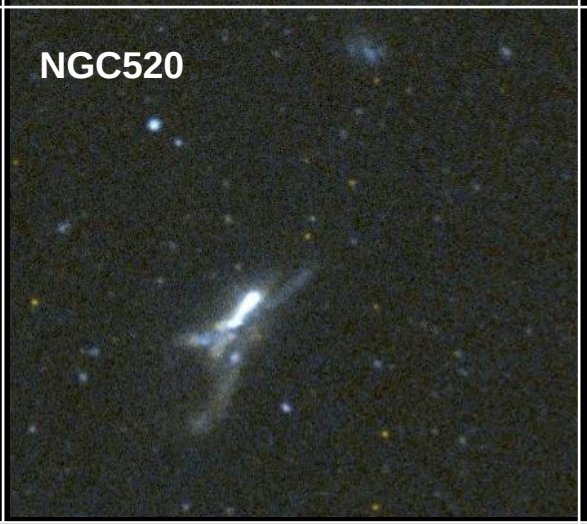
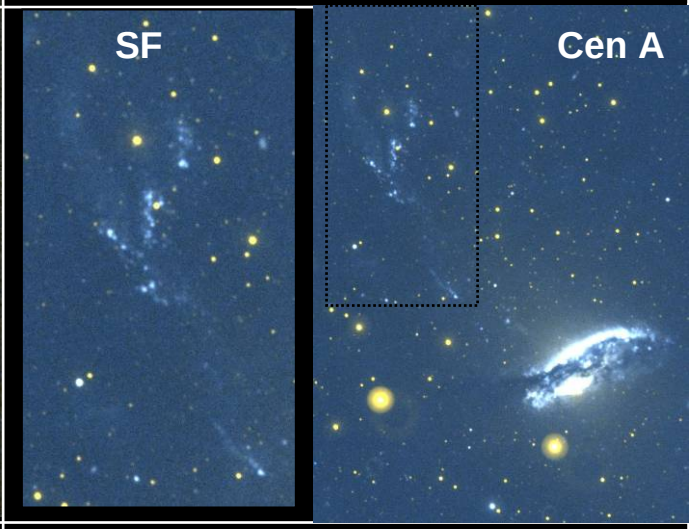
Outer disk UV-clumps follow HI distribution
Red contour: $N_{HI} \sim 2 \times 10^{20}$ cm^{-2} $S_{gas} = 0.4$ M$_o$ pc^{-2}
Toomre limit ~ yellow contour: $S_{gas} = 10$ M$_o$ pc^{-2}

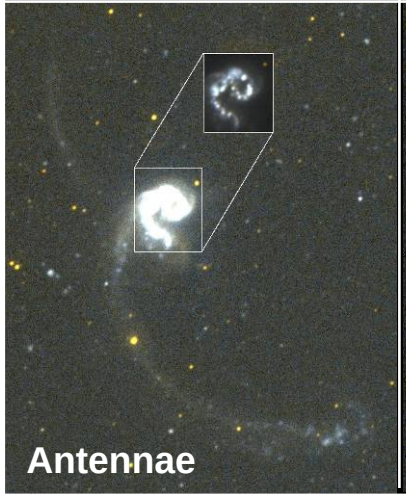
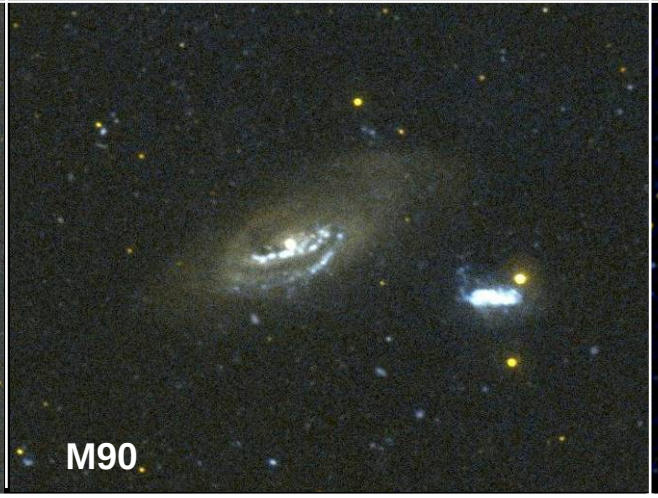
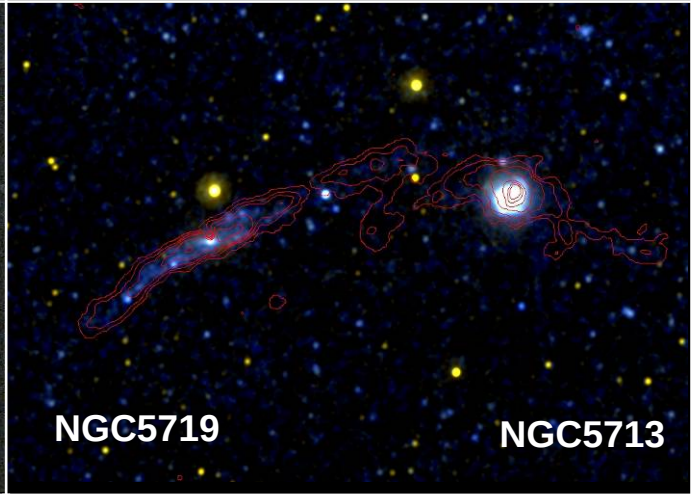
FUV, NUV, Hα median profiles
Hα-> edge , UV -> no edge
Gas profile shows extended "subcritical" disk
Few XUV disk sources have Hα (10-

Sensitivity: 27.5 ABm

Summary: Rest UV Traces Star Formation

In Wide Range of Environments, Scales & Modalities

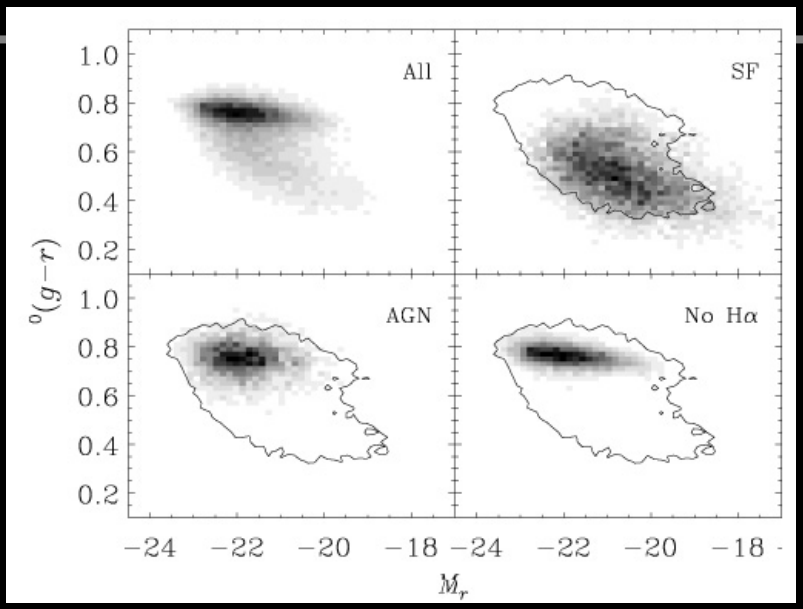
Growing Disk	Merger (Late)	Jet Induced Star Formation
		

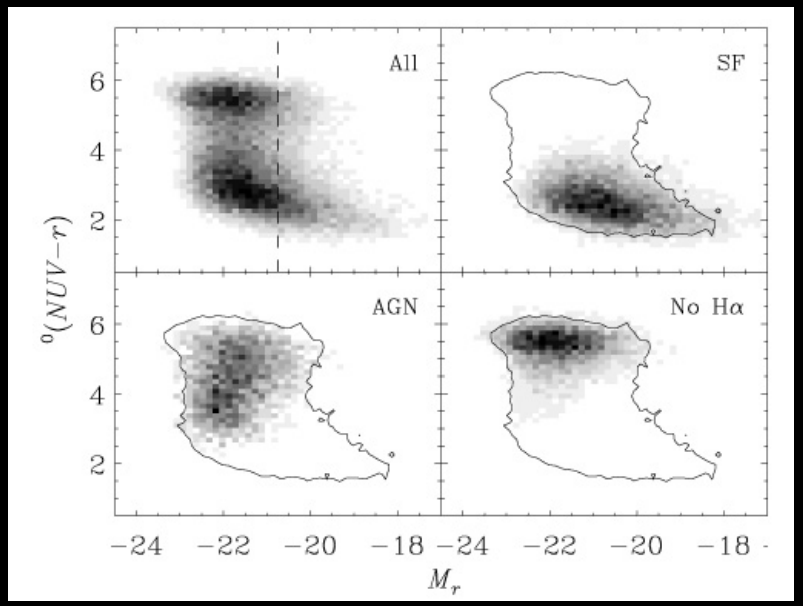
Merger (Mid)	Truncated Disk	Tidal tails, Galaxy Forms?
		

Optical vs. UV color-magnitude diagrams

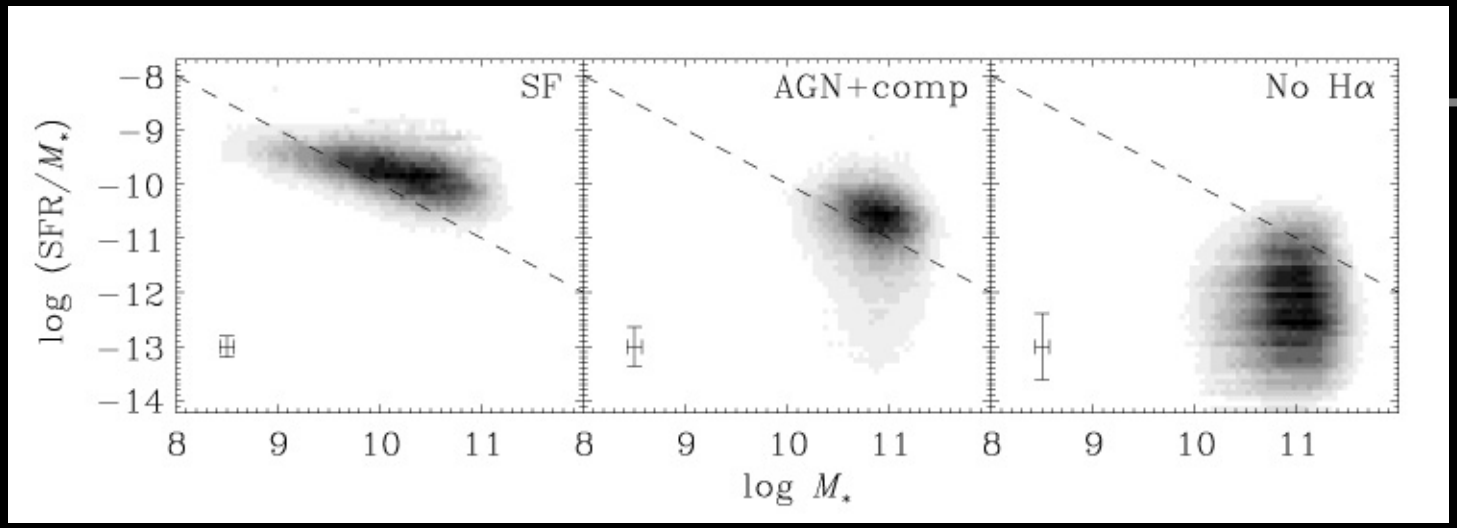
- Sample: 50000 galaxies with GALEX and SDSS photometry (+ SDSS spectra)
- Optical CMD (g-r color)
  - Star-forming (SF) galaxies blue
  - Early-type galaxies (No H alpha emission) – red sequence
  - Galaxies with AGN (LINERs, Seyfert 2s) also red
- UV to optical CMD (NUV-r color)
  - two well-separated sequences
  - SF – blue *sequence*
  - Early-types – red sequence
  - AGN – broad: red + region *in-between* (“green valley”)

(from Salim et al 2007)





Star formation rates and stellar mass (Samir Salim)



Salim et al. 2007

- - - - = $1M_{\odot}$/yr

- Specific SFRs and stellar masses from detailed SED fitting
- SF galaxies with no AGN:
  - *Narrow* sequence (mass determines SF)
- Galaxies with AGN:
  - Mostly *massive* (more massive than SF galaxies w/o AGN)
  - Many have ongoing SF, at various levels of activity
  - AGN and SF quenching connected
- Galaxies with no H alpha emission (mostly E/S0)
  - low or negligible SFRs
  - some have higher SFRs (in UV, but not in H alpha) - morphology: passive spirals (recent, but no ongoing SF)

The Dark UV Sky

Mystery Object

Thank you !

Collaborators:

Boryana Efremova

David Thilker

James Herald

M.Laget, M.Vitton

S.Heinis, …

G.Catanzaro

GALEX ST + SODA Team

Of interest:

GALEX C4 proposals deadline:

June 22 2007

http://galexgi.gsfc.nasa.gov

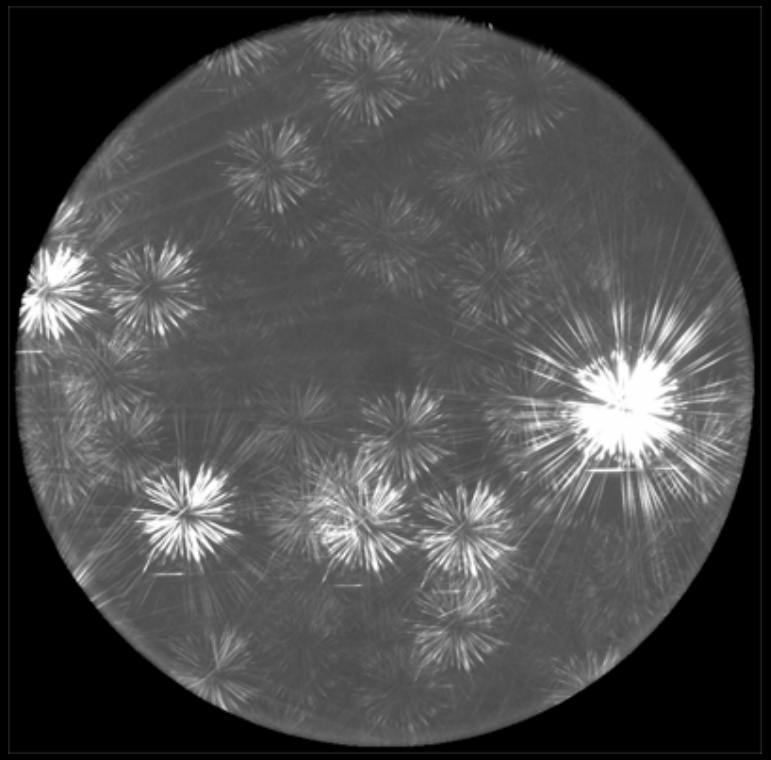
GR3 released!

>1000 x fainter than Night Sky

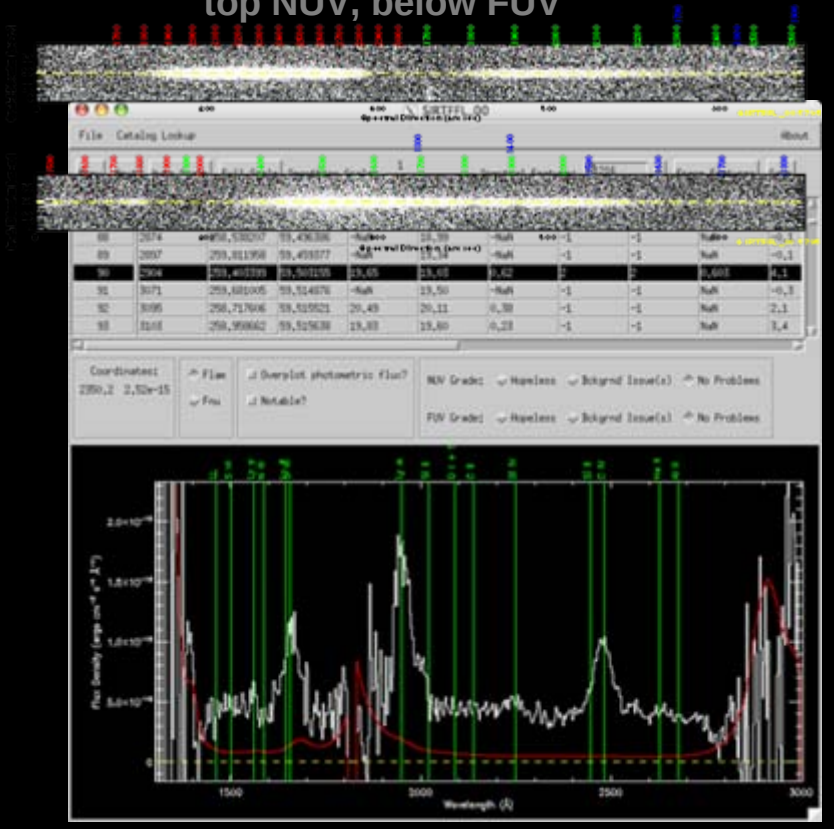
>100 x fainter than Night Sky

papers and more info at: http://dolomiti.pha.jhu.edu

Grism – 1 orbit (NUV)



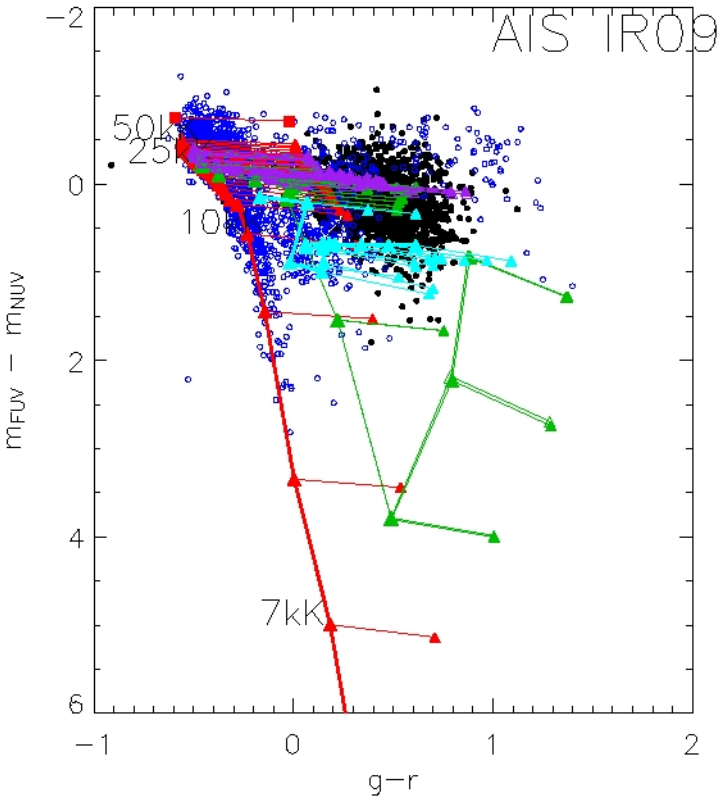
Wls of 1st 2nd 3rd order: red, blue, green
top NUV, below FUV

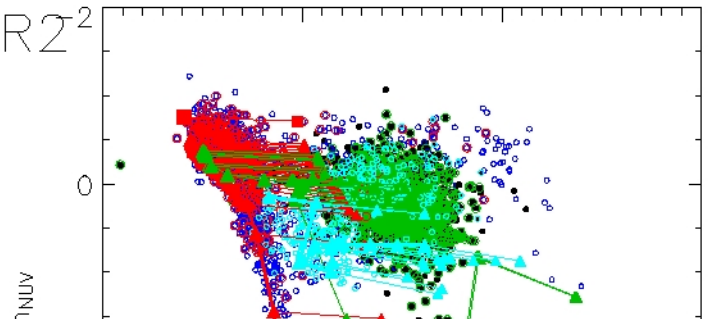


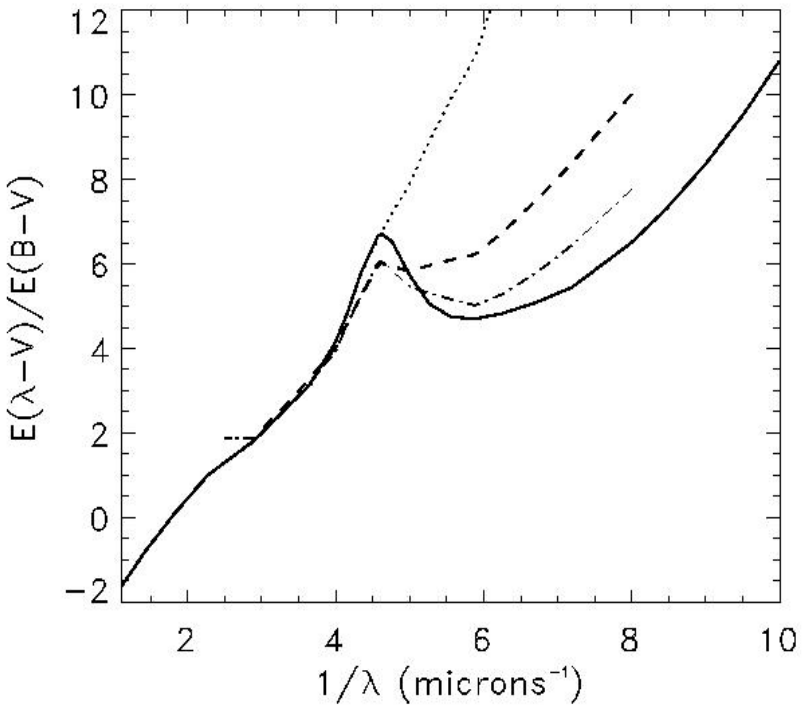
Spectrum of a z=0.6 QSO

FUV-NUV, g-r

Object classification from color-color diagrams

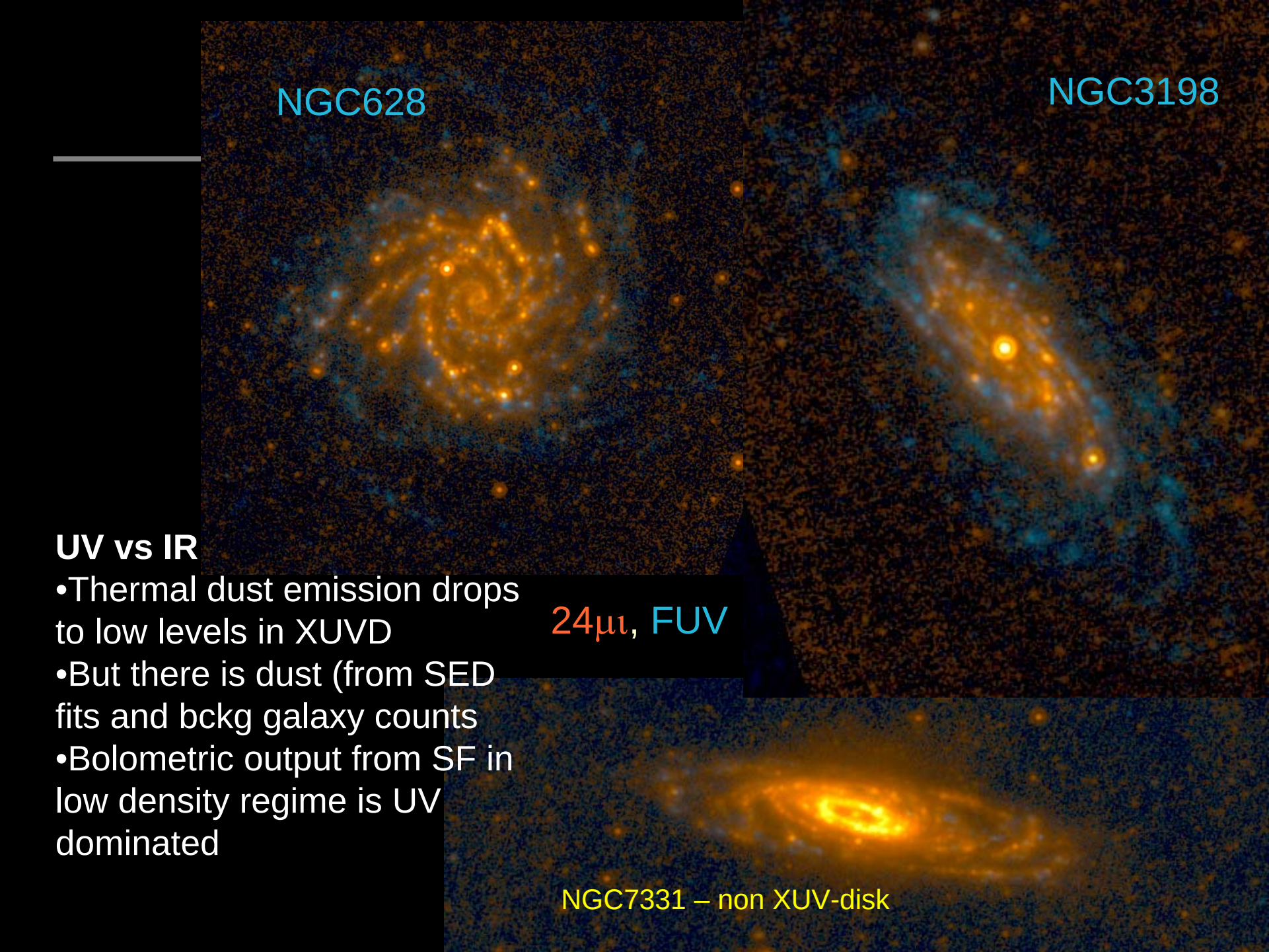






Error cuts: FUVerr=0.15, NUVer

Fm: Bianchi et al 2005 ApJL

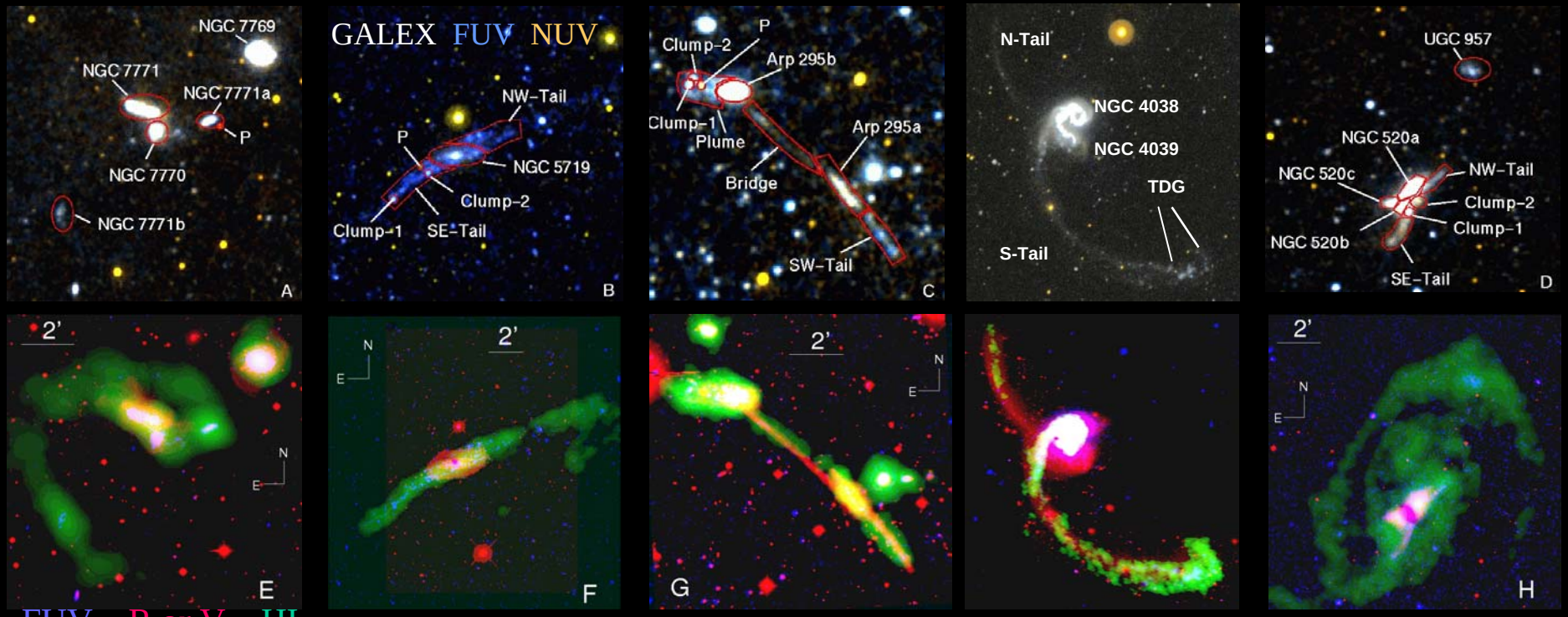


UV vs IR

- Thermal dust emission drops to low levels in XUVD
- But there is dust (from SED fits and bckg galaxy counts
- Bolometric output from SF in low density regime is UV dominated

Recent Star Formation in Tidal Tails: New GALEX results

S. G. Neff, et al.



FUV R or V HI

Earlier ⟷ Interaction Stage ⟷ Later

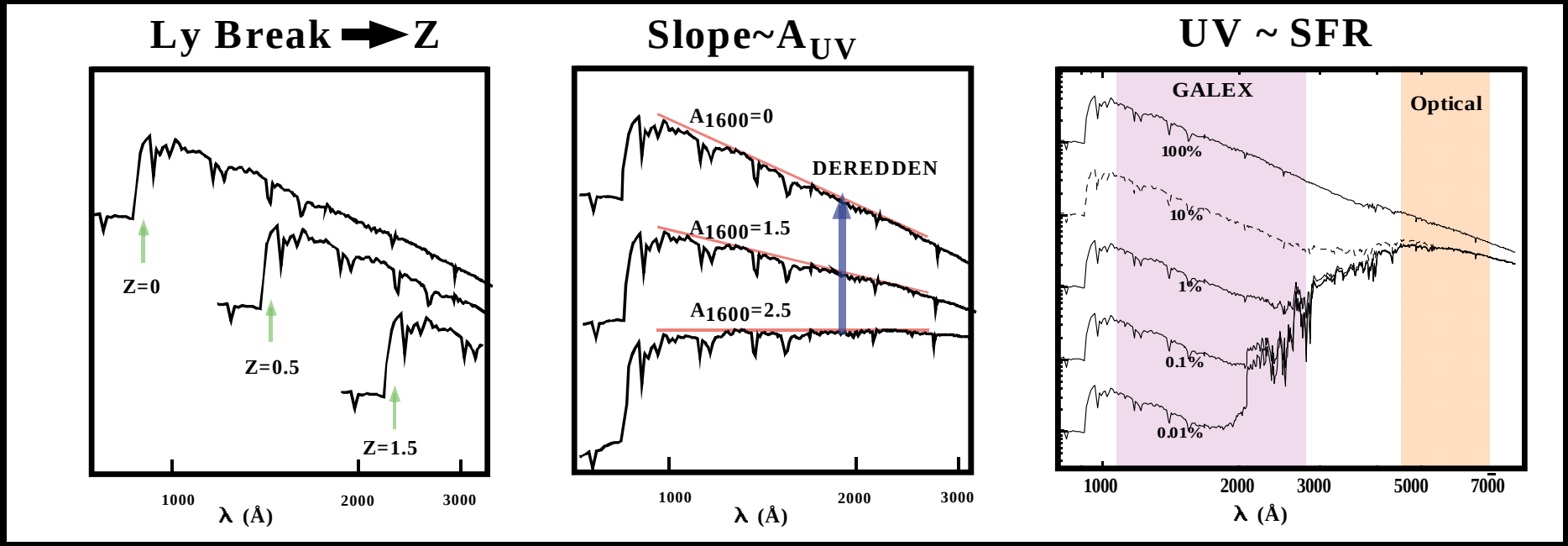
We detect FUV(1500A) and NUV(NUV) at distances >100kpc from disks

→ Threshold HI density required for SF (~$2M_{sun}/pc^2$)

→ SF evolution seen *along* tails: youngest regions furthest from galaxy

→ We may be detecting Tidal Dwarf Galaxy formation!

“GALEX Method”



GALEX method - spectroscopy:
GALEX provide a direct measurement of
-redshift (using metal lines and the Lyman break)
-extinction (using the UV slope)
- star formation rate (from UV Luminosity)

Classification of objects in the GALEX +SDSS surveys

Analysis: compare colors (GALEX far-UV, near-UV and SDSS u g r i z bands), to model colors

Restrict sample to mag. err. limits, eliminate artifacts etc.

Data:	**IR02+DR1**		**GALEX1.0+DR3**		**GR3+DR6**	
	Bianchi et al.2005		Bianchi et al 2007		in progress	
	AIS	**MIS**	**AIS**	**MIS**	**AIS**	**MIS**
Match area [sq.deg.]			**363**	**83**	**??**	**573**
# Fields			**622**	**120**		
Objects			**1.2M**	**.9M**		
# object/area	**>3300**	**10000**				
Fraction 3sigma FUV (NUV)	**0.14(0.90)**	**0.33(0.96)**				
Exp. Time (typical)	**100sec**	**1500sec**				
Lim. Mag (AB)	**20.5**	**22.7**				
Lim.Flux (FUV / NUV)	**1. / .5 10^{-16}**	**.7 / 3. 10^{-18}**				