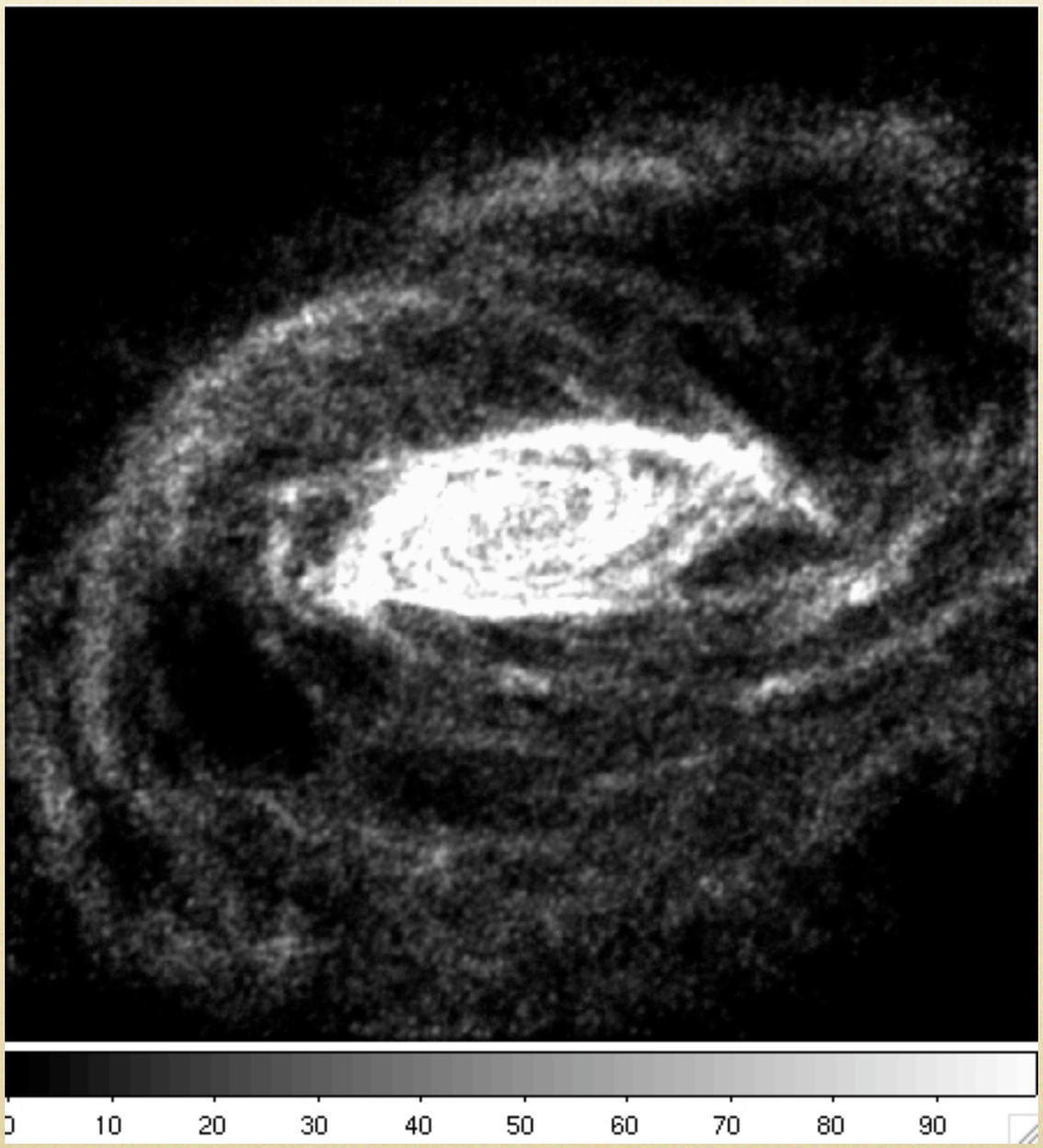
A new perspective on the fate of extended HI in spiral galaxies

David Thilker (JHU) et al.

Spineto, Italia -- June 2007

Quiescent outer HI disk, or not?

NGC 5055
(M63)



HI (VLA),
THINGS
F. Walter

Quiescent outer HI disk, or not?

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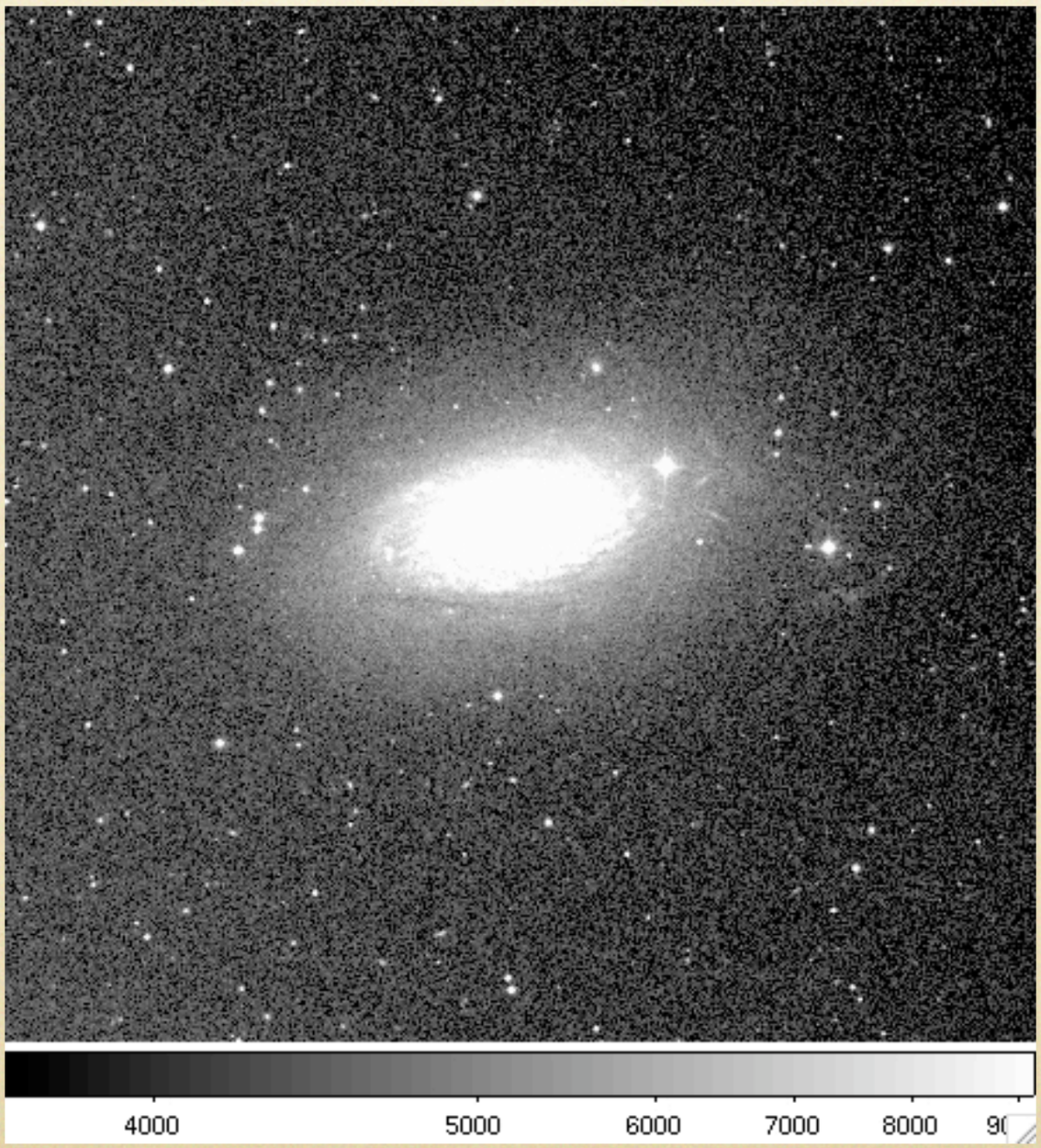
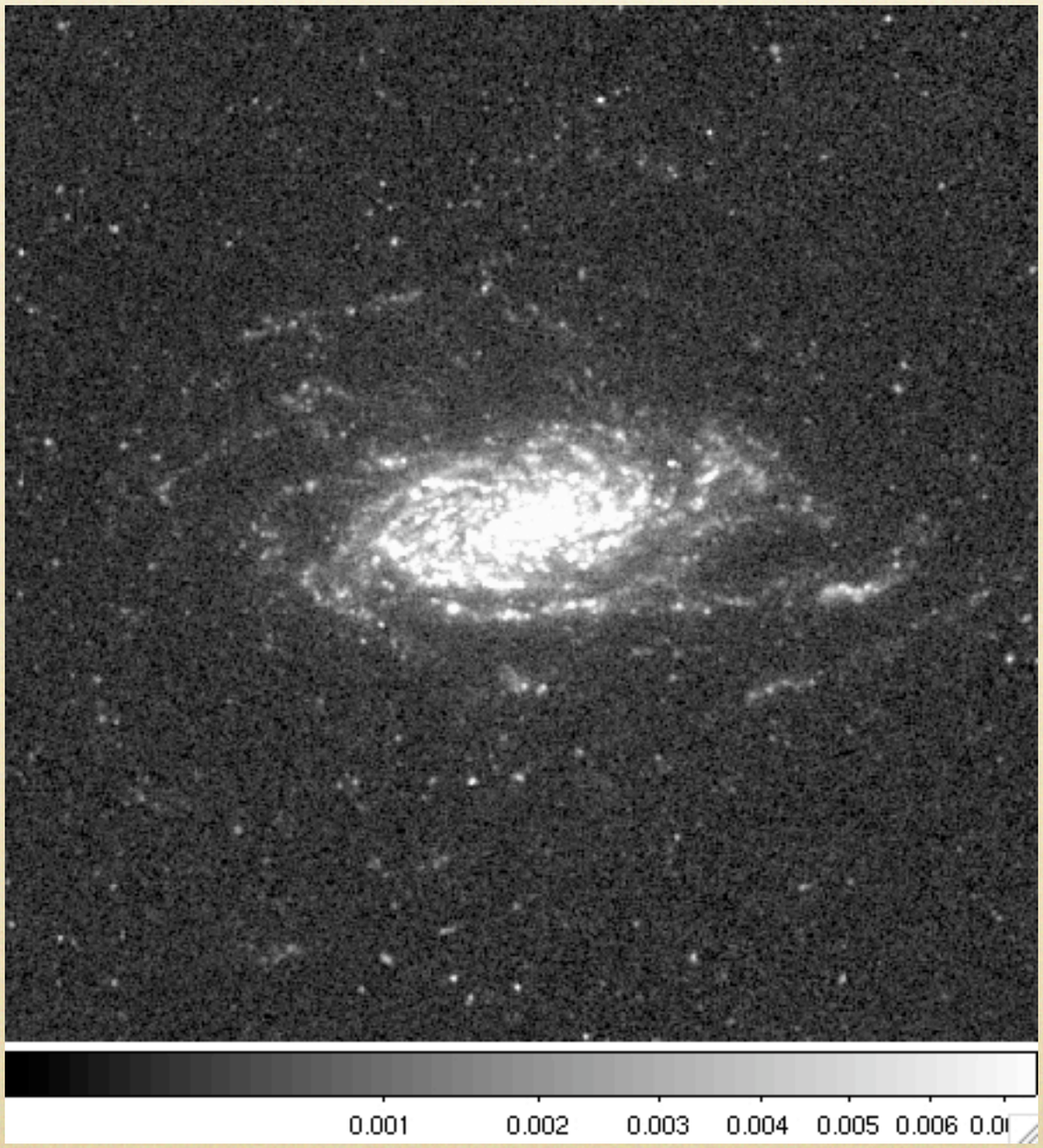


DSS2
“red”

~~Quiescent~~ outer HI disk, or not?

NGC 5055
(M63)

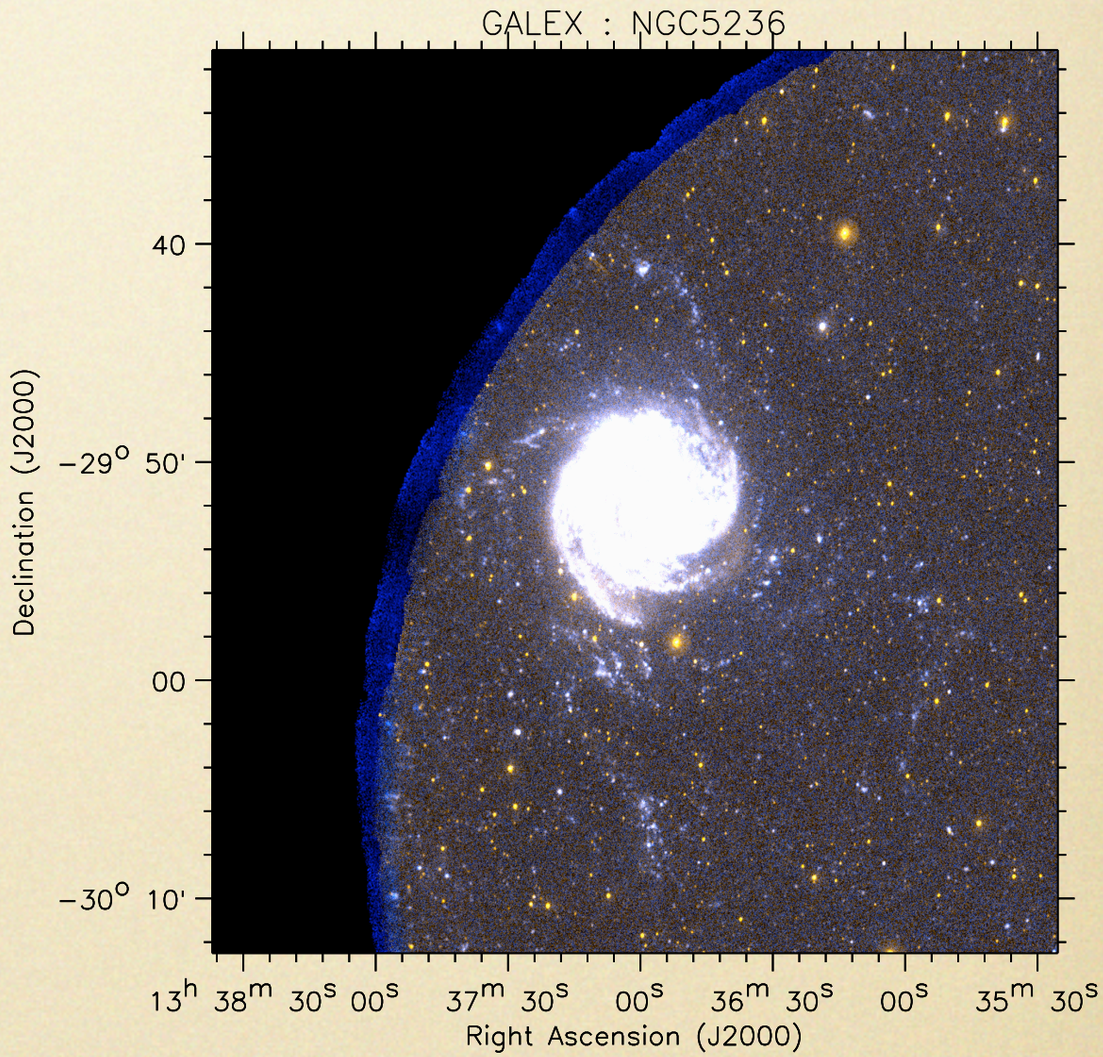


GALEX
FUV

The prototype: M83

Outer disk gas is undergoing conversion to an extended stellar component via secondary SF mechanisms.

UV isn't dust-scattered or from hot evolved stars, but loose OB groupings.



Thilker et al. (2005)

NGC 4625 also...

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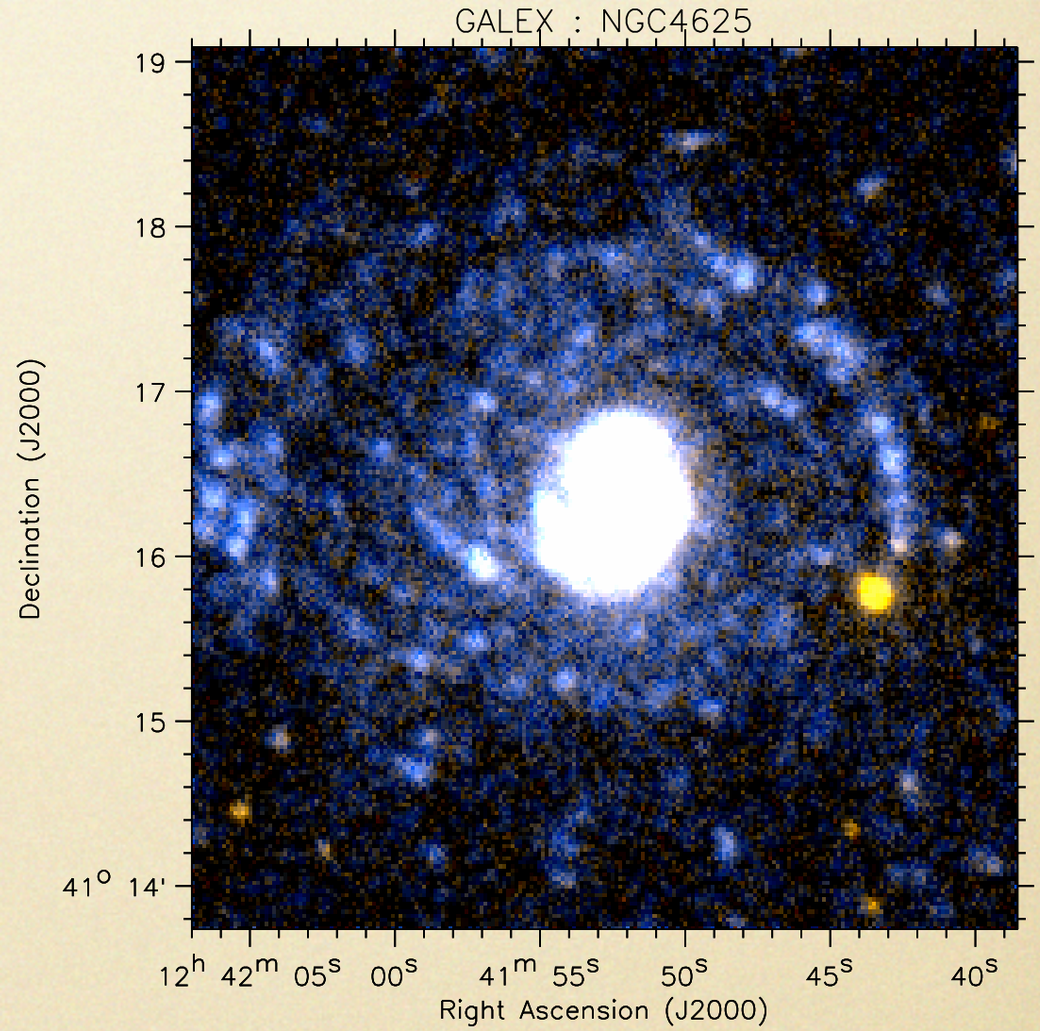


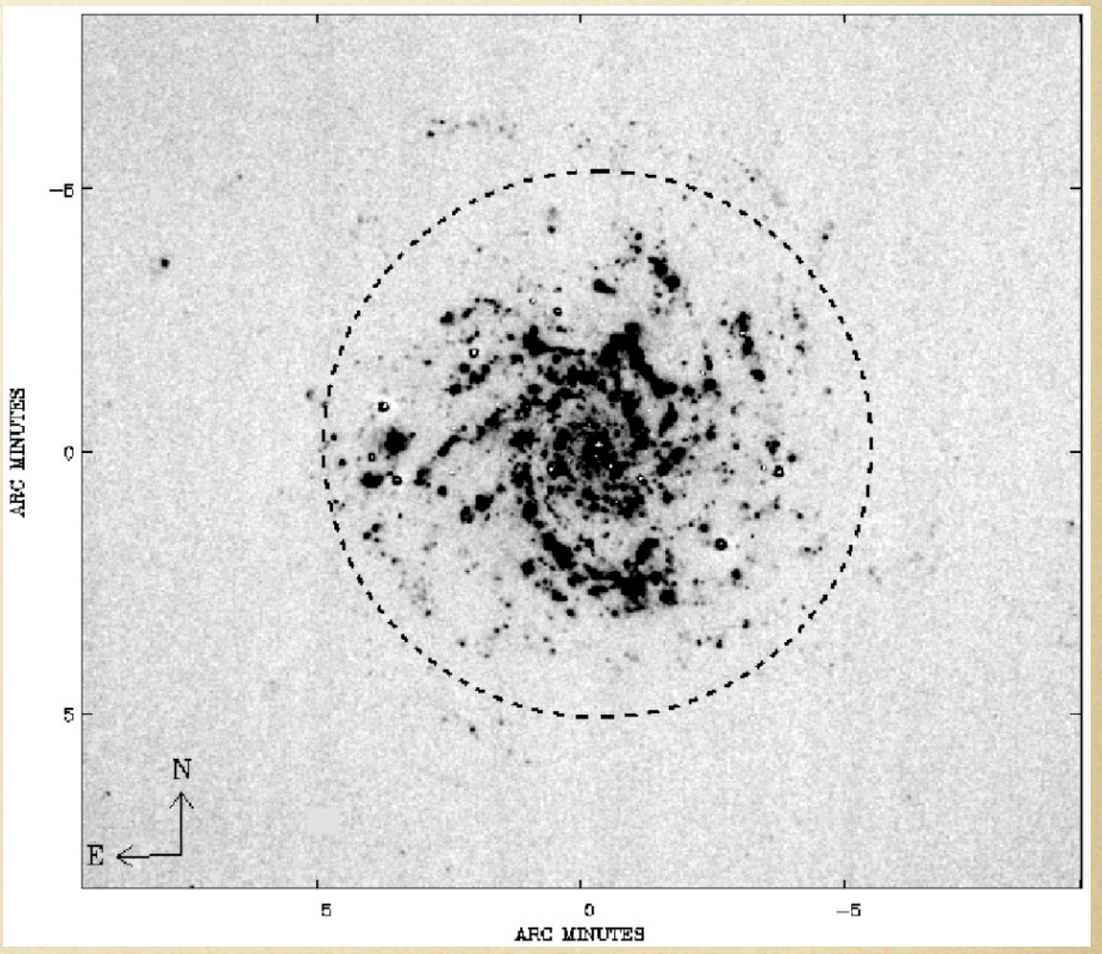
Gil de Paz et al. (2005)

Continuing disk galaxy formation

- Extended UV-disk (XUV-disk) galaxies

  - Outer disk SF detected previously in only a handful of objects via Hα imaging (e.g. Ferguson et al. 1998).

  - GALEX => seemingly commonplace!!



XUV-disk relevance to "HI Survival"

- SF in low-surface brightness, low-N(HI), low-metallicity environments
- Local inside-out galaxy formation -- perhaps analogous to high z disk assembly?
- Indicative of gas feeding modes
- Gas consumption and enrichment of outer disk => implications re. QSO abs. lines

What's an XUV-disk?

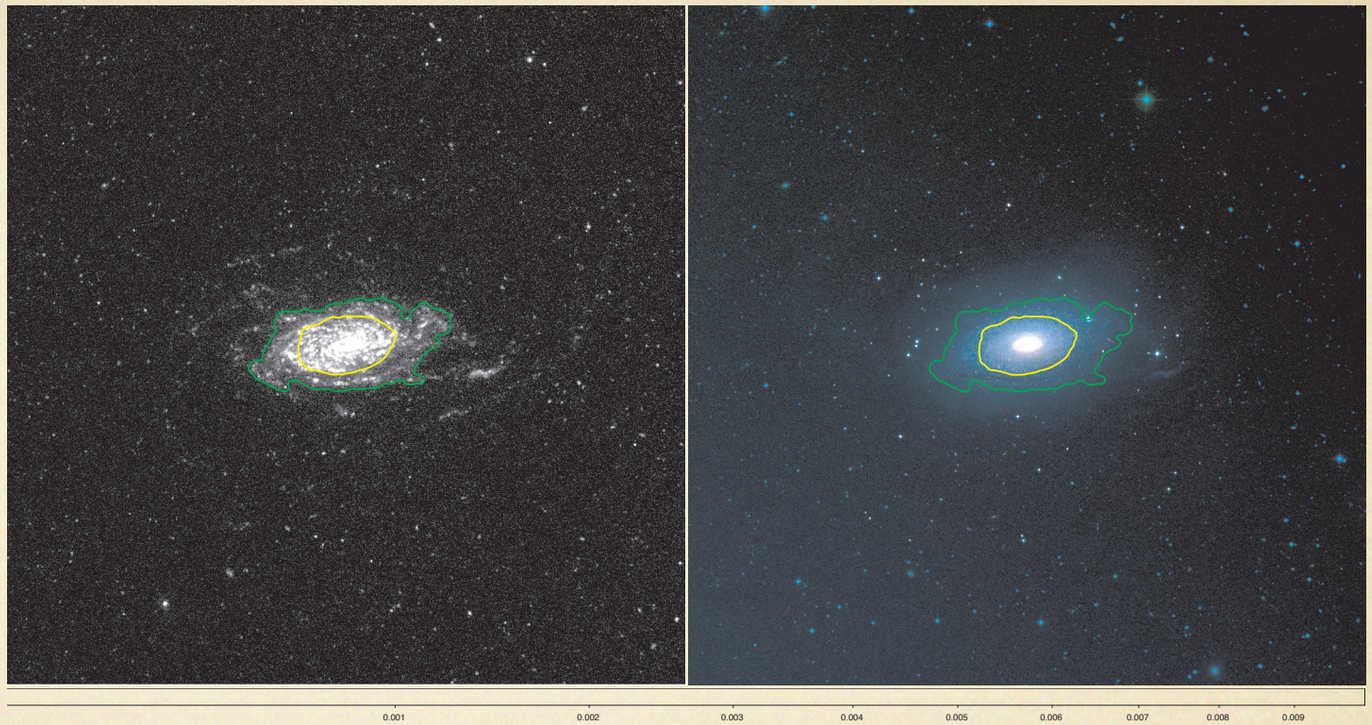
- We inspected a sample of 189 S0-Sdm galaxies in the **GALEX Atlas** with $D < 40$ Mpc, $i < 80°$, angular size $> 90''$, and $A(V) < 0.5$ mag

- Two independent definitions catch all cases:

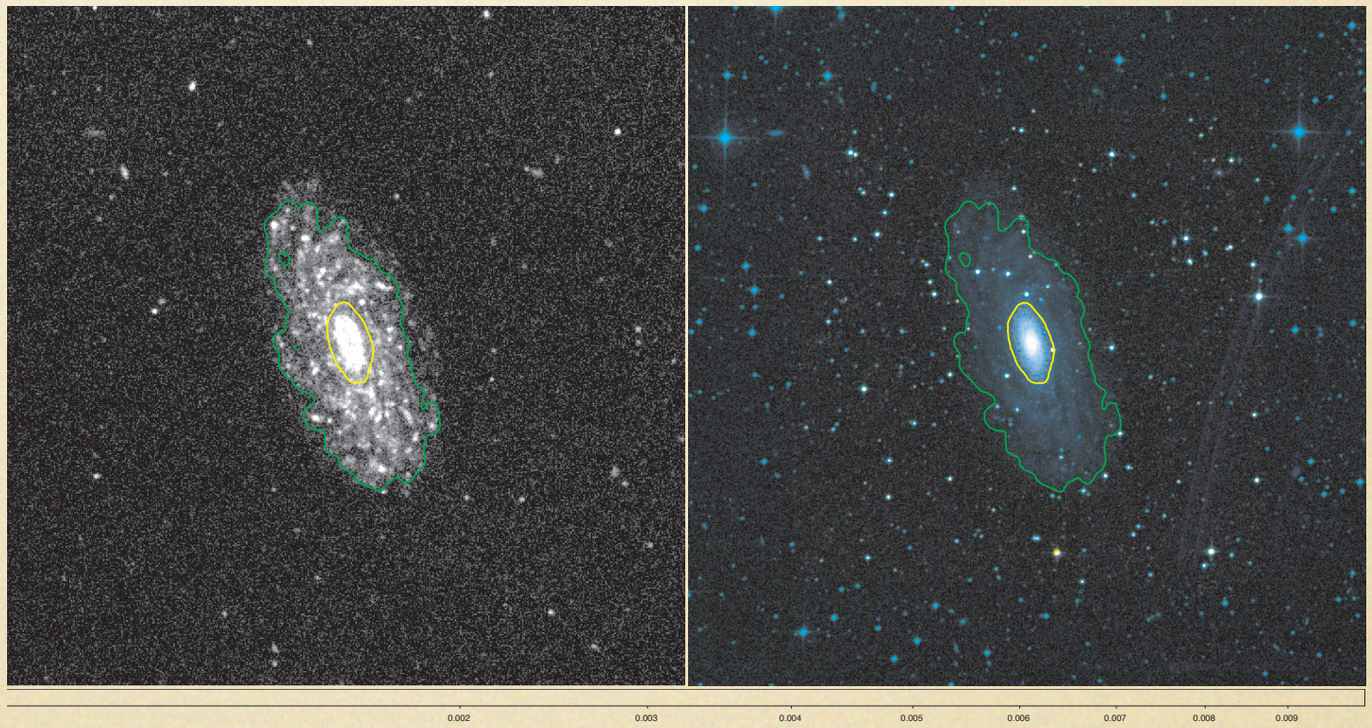
  - *Type 1* XUV-disks have structured, UV-bright emission complexes beyond the "anticipated" location of the SF threshold.

  - *Type 2* XUV-disks have blue UV-NIR within an exceptionally large, outer, optically-LSB zone.

- *Type 1*



- *Type 2*



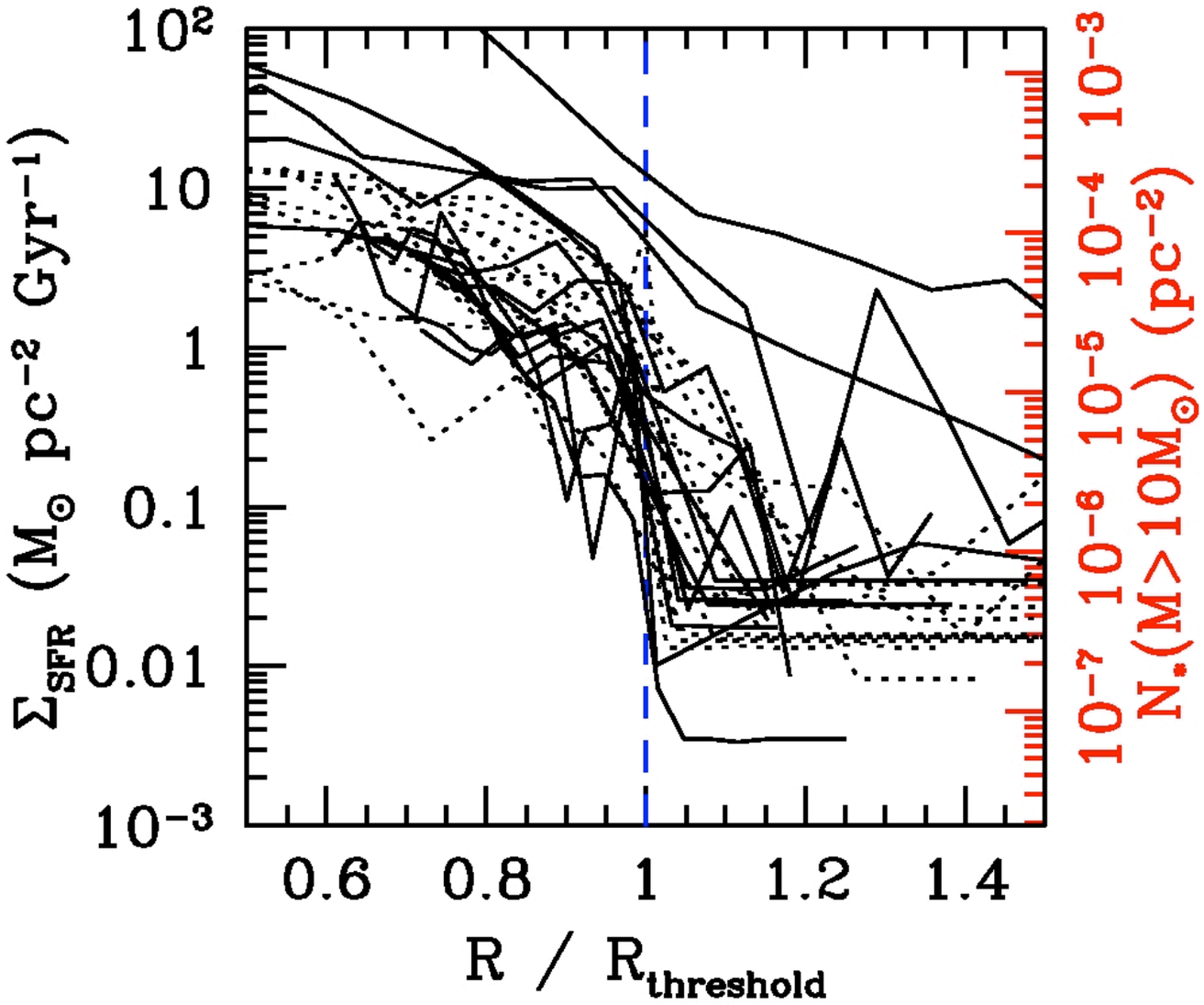
- *Mixed-type* XUV-disks meet both criteria

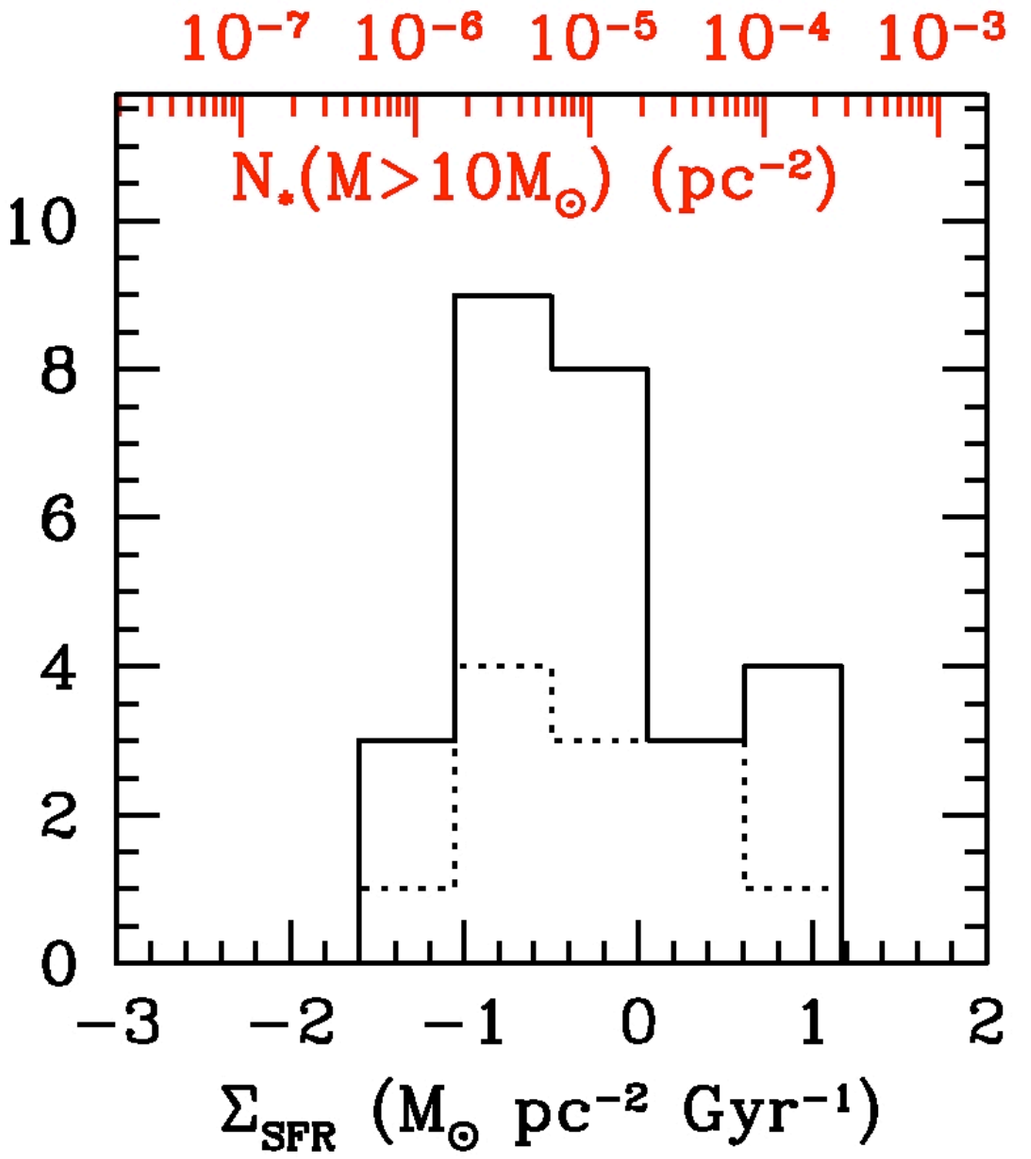
(Thilker et al. 2007a, submitted)

Type 1: Where to expect a SF threshold?

- **Boissier et al. (2007)** found that near the apparent Hα threshold radius, the GALEX UV Σ_{SFR} is generally ~3x10^{-4} M$_\odot$ yr^{-1} kpc^{-2} for the galaxies of **Martin & Kennicutt (2001)**

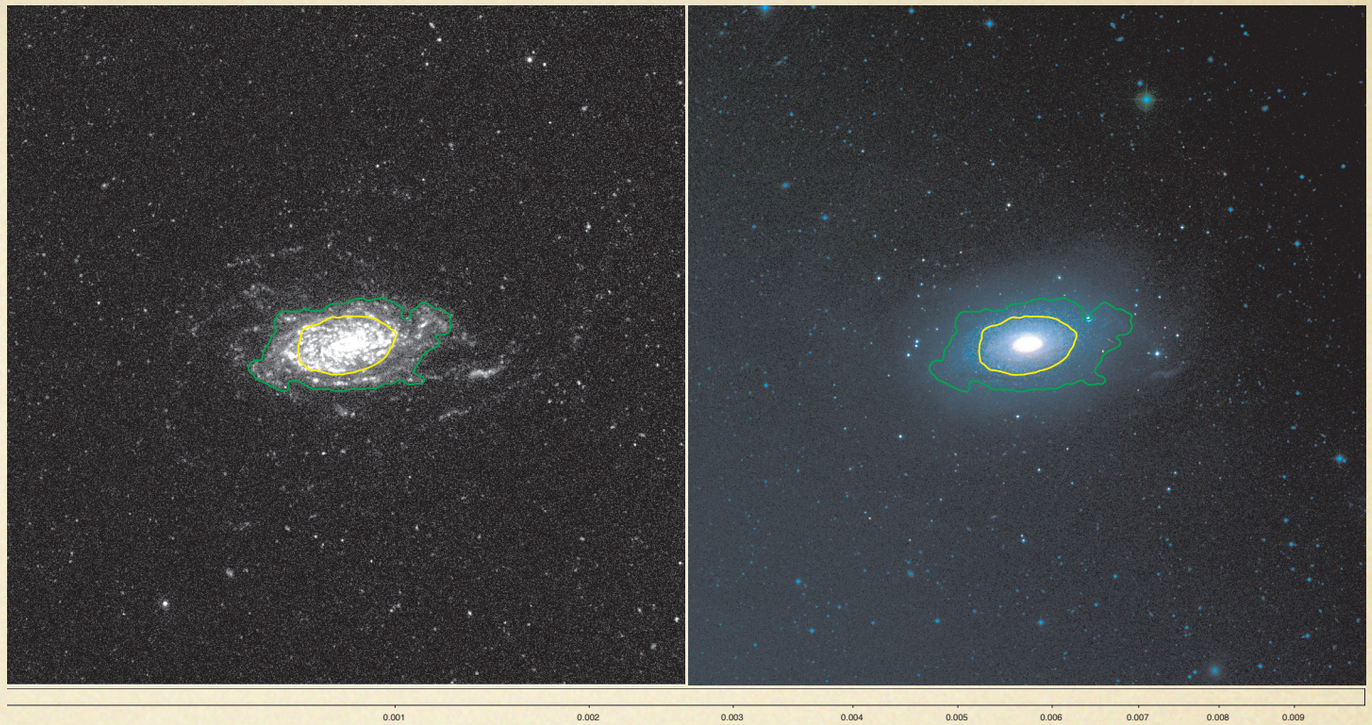
- Spatially resolved Schmidt Law analysis (**Thilker et al. 2007b**) shows that for the critical N(HI) derived by **Schaye (2004)** allowing the CNM phase, we expect similar Σ_{SFR} levels



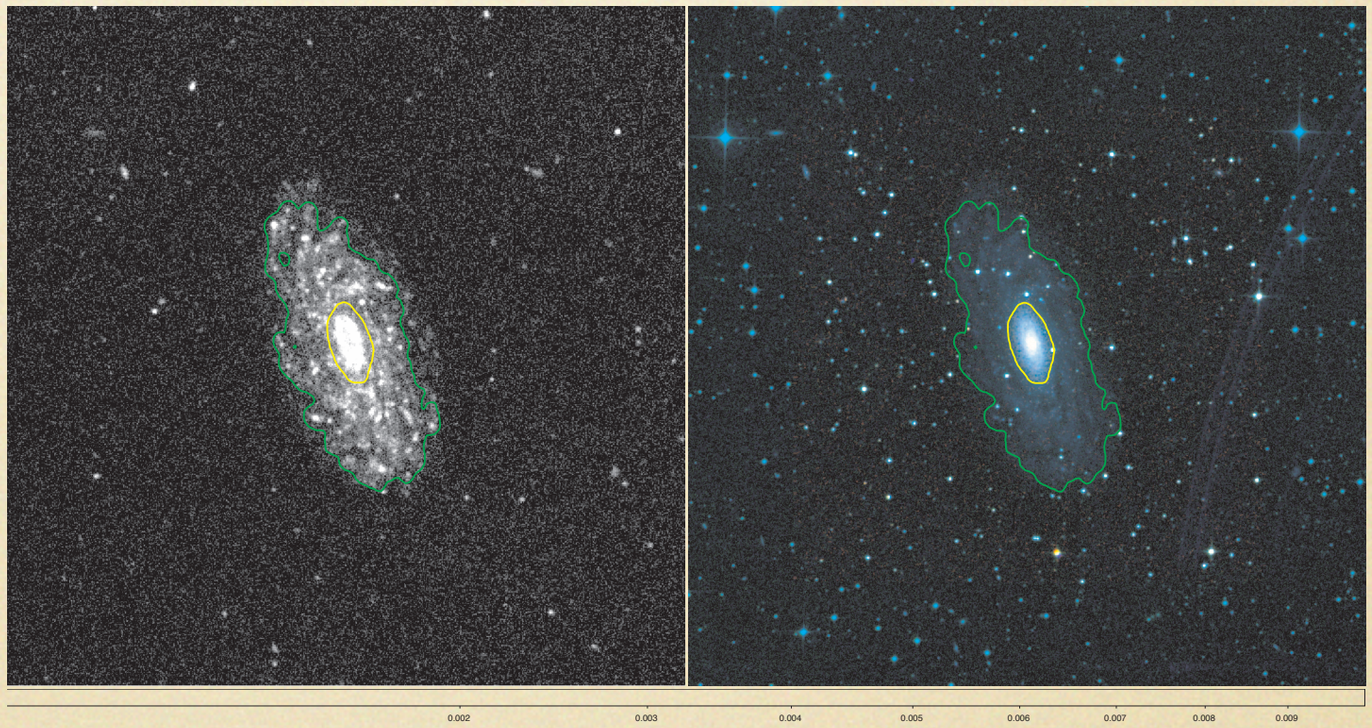


Boissier et al. (2007)

- *Type 1*



- *Type 2*



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(Thilker et al. 2007a, submitted)

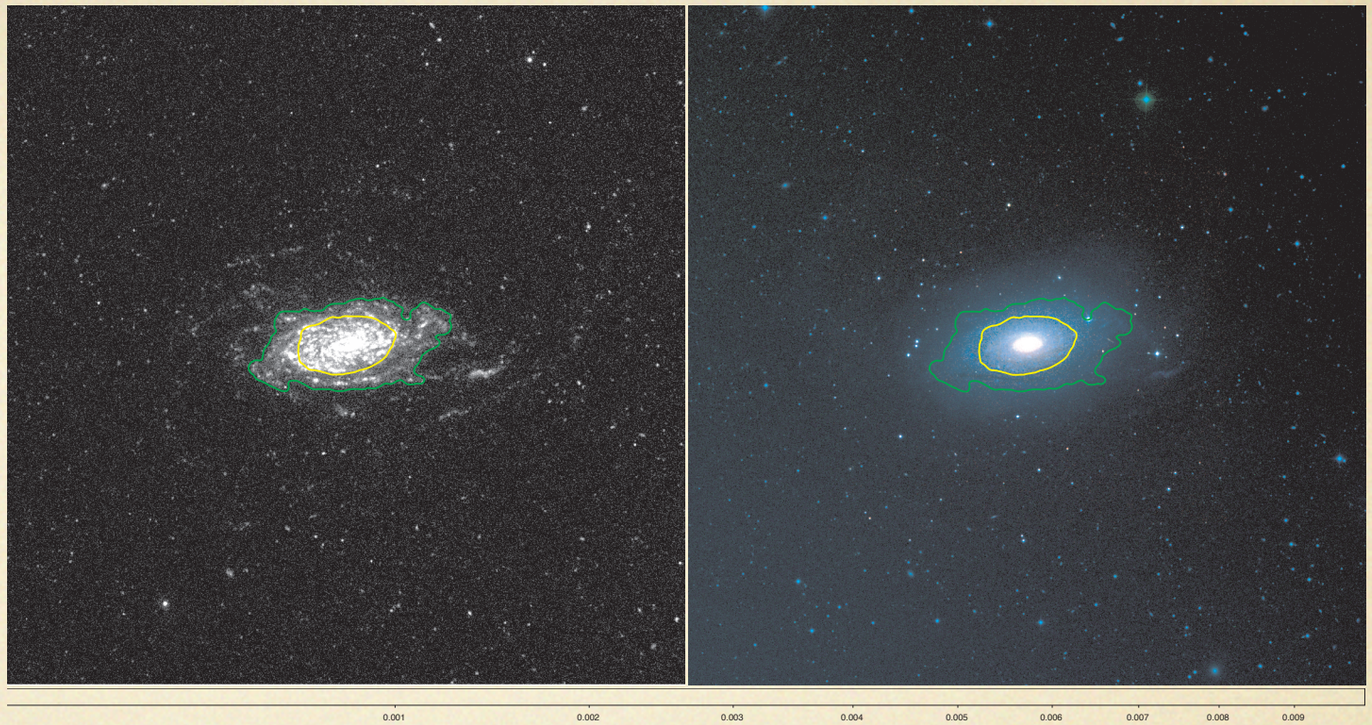
Type 2: Defining an outer "LSB zone"

- K_{80} contour encloses 80% of the K-band galaxy emission, generally excludes only faint features

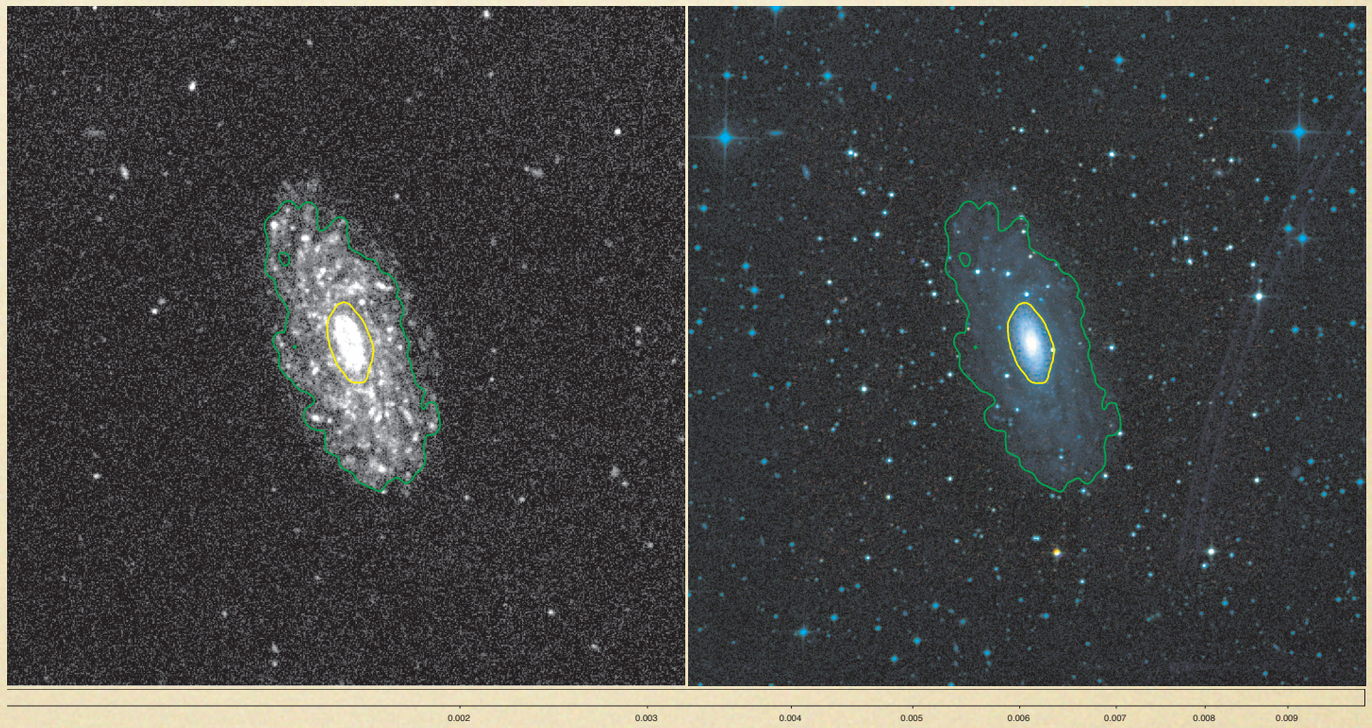
- **LSB zone** defined to lie *between* K_{80} contour and GALEX "threshold" contour

  - This would ideally include outer (Type 1) clump complexes, but hard to do in practice

- *Type 1*



- *Type 2*



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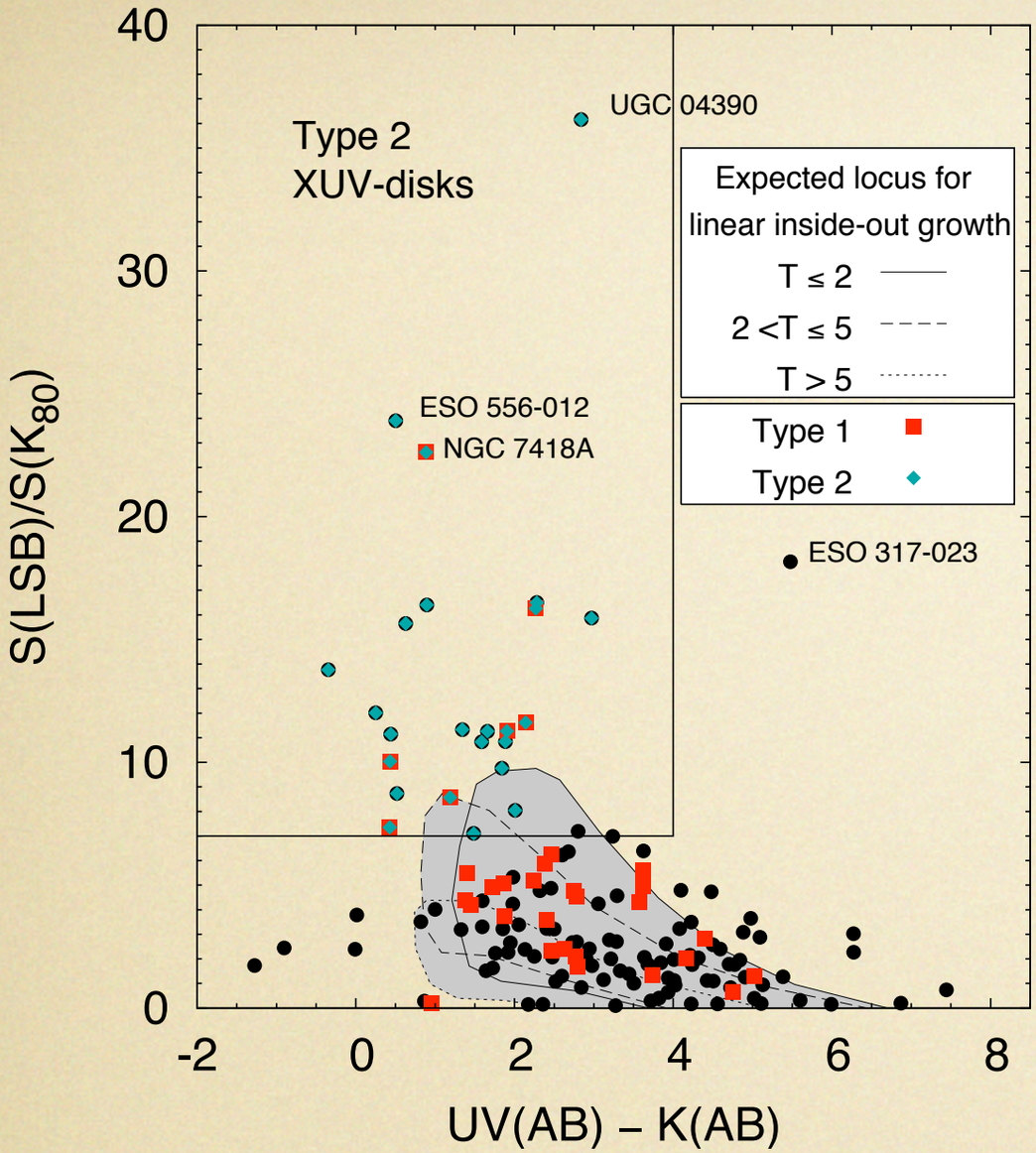
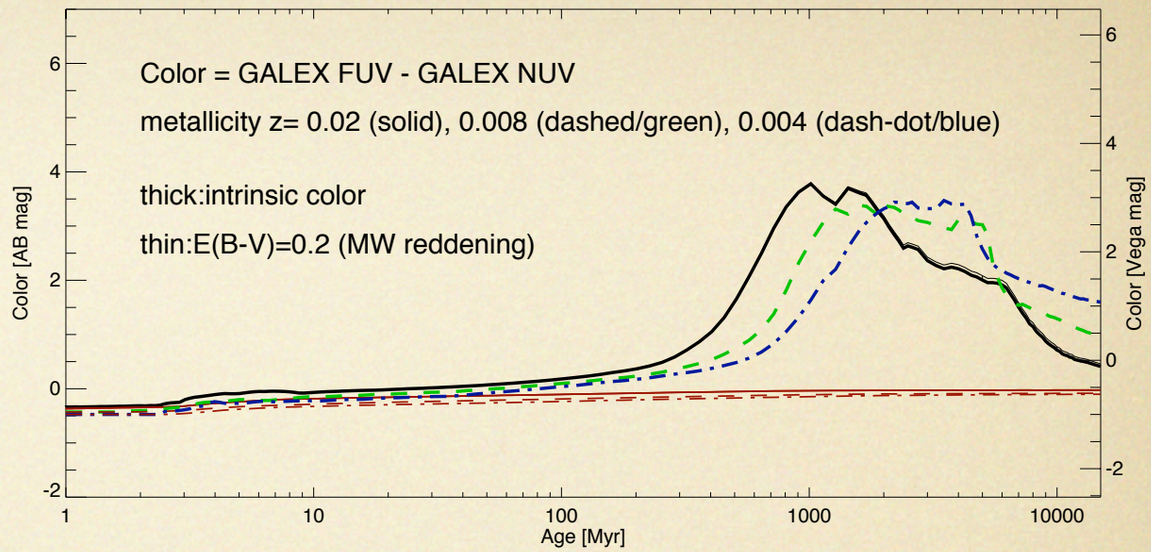
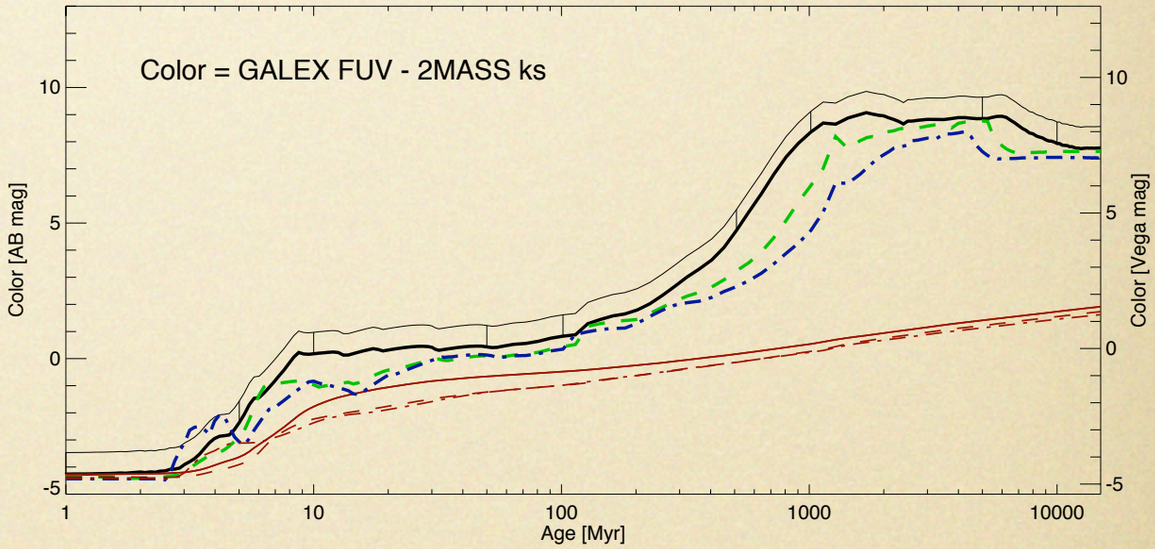

Type 2
XUV-disks
UGC 04390
ESO 556-012
NGC 7418A
ESO 317-023
Expected locus for
linear inside-out growth
T ≤ 2
2 <T ≤ 5
T > 5
Type 1
Type 2
S(LSB)/S(K80)
UV(AB) – K(AB)
40
30
20
10
0
-2
0
2
4
6
8


Color = GALEX FUV - GALEX NUV
metallicity z= 0.02 (solid), 0.008 (dashed/green), 0.004 (dash-dot/blue)
thick:intrinsic color
thin:E(B-V)=0.2 (MW reddening)
Color [AB mag]
Color [Vega mag]
Age [Myr]
1
10
100
1000
10000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Color [Vega mag]
Age [Myr]
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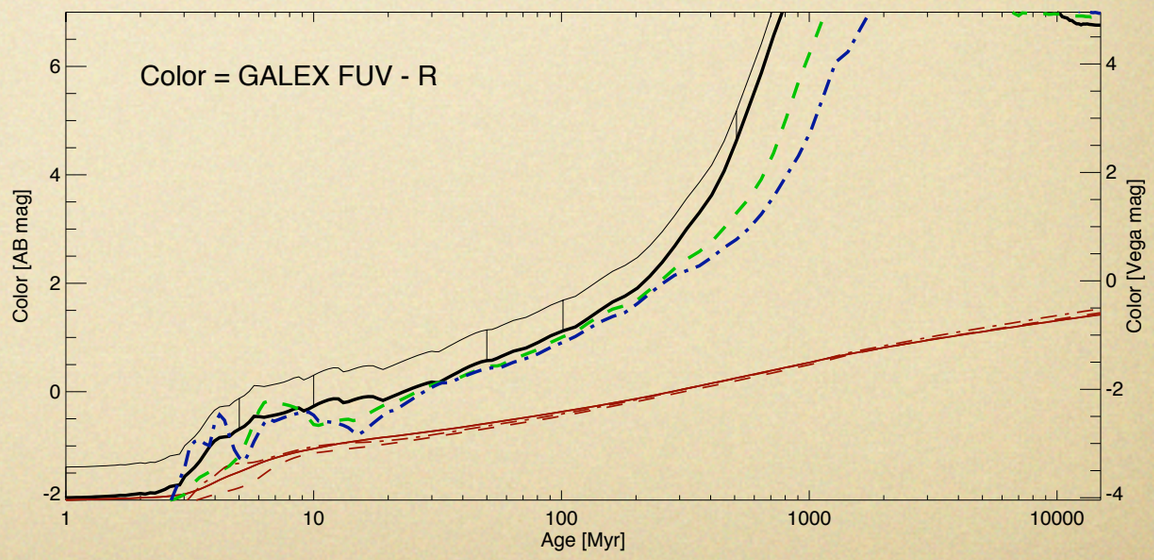
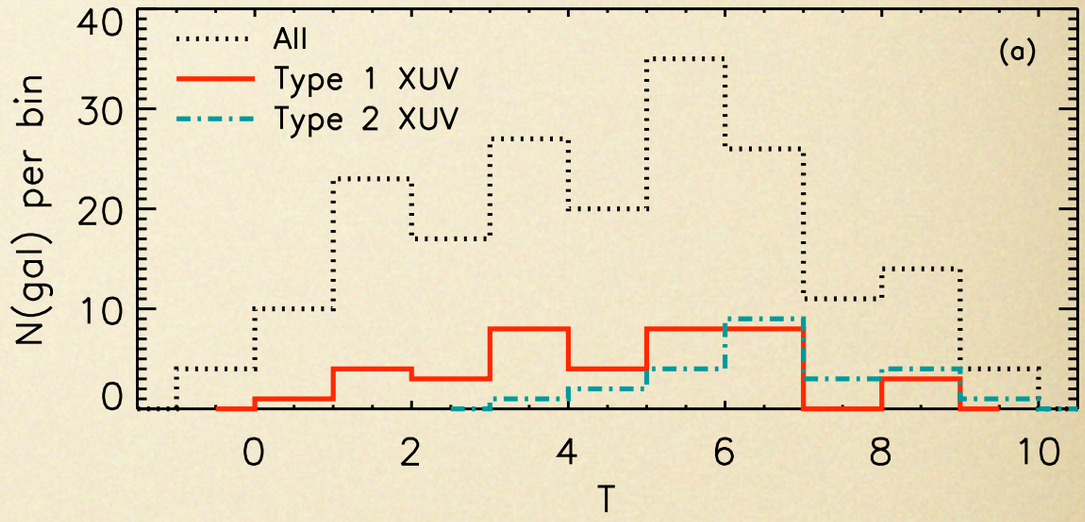
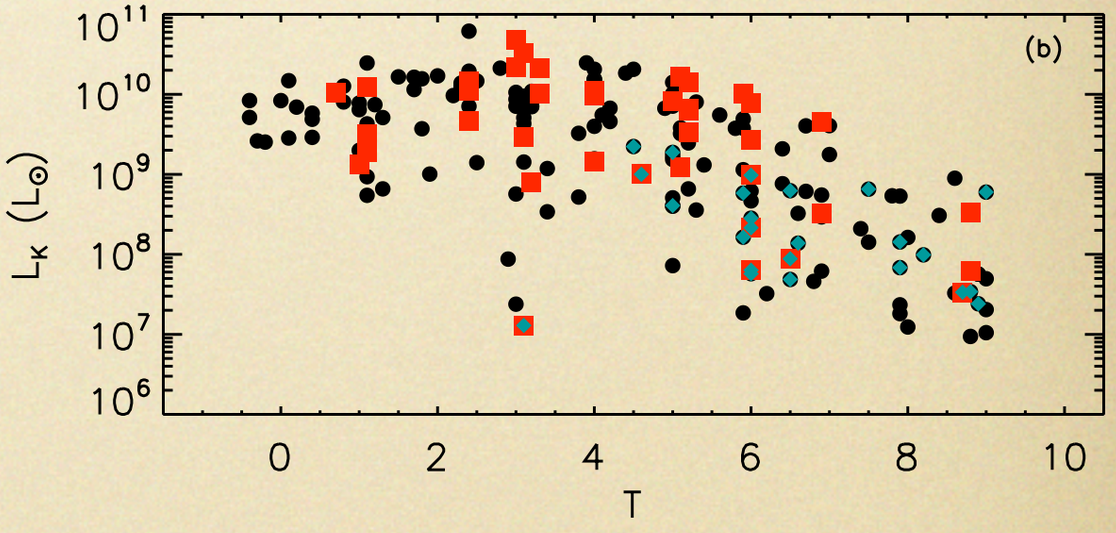
10
100
1000
10000

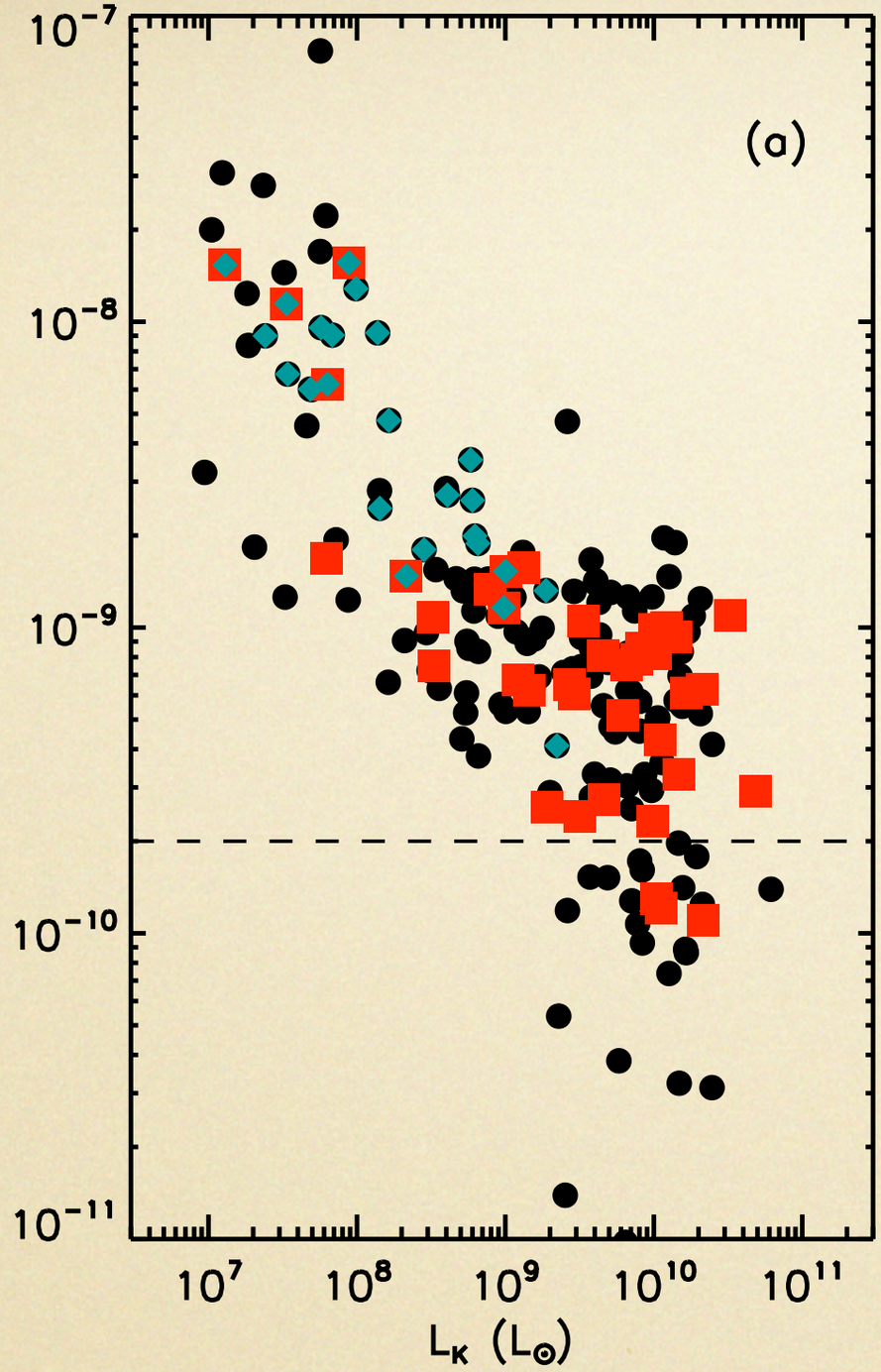

Color = GALEX FUV - R
Color [AB mag]
Color [Vega mag]
Age [Myr]
1
10
100
1000
10000

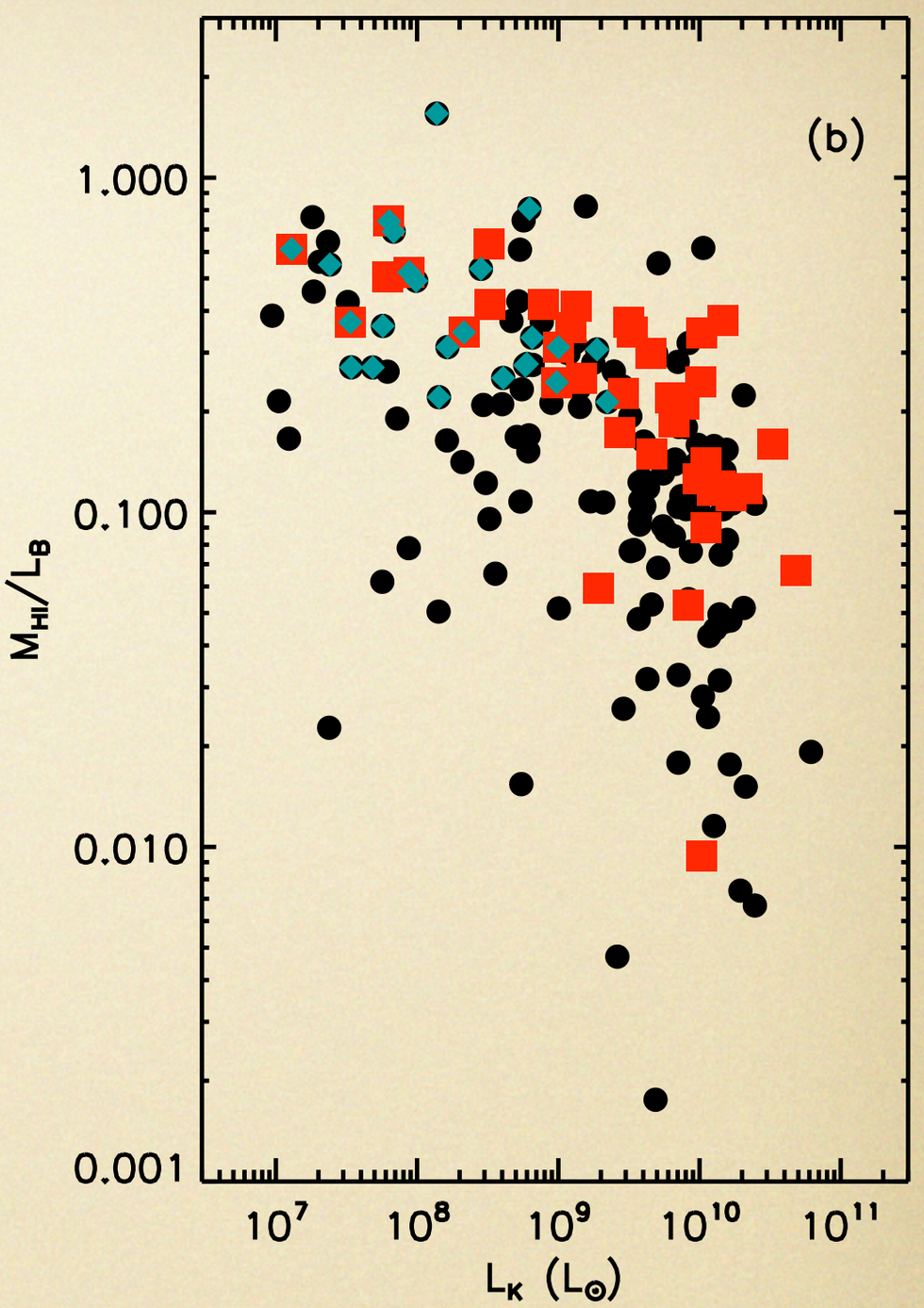
Characteristics of the XUV-disk population

- Type 1: ~20%, no preferred T
  - Environment/perturbation matters most?
- Type 2: ~10%, T>5 usually
  - Galaxy-wide burst only for low mass objects?



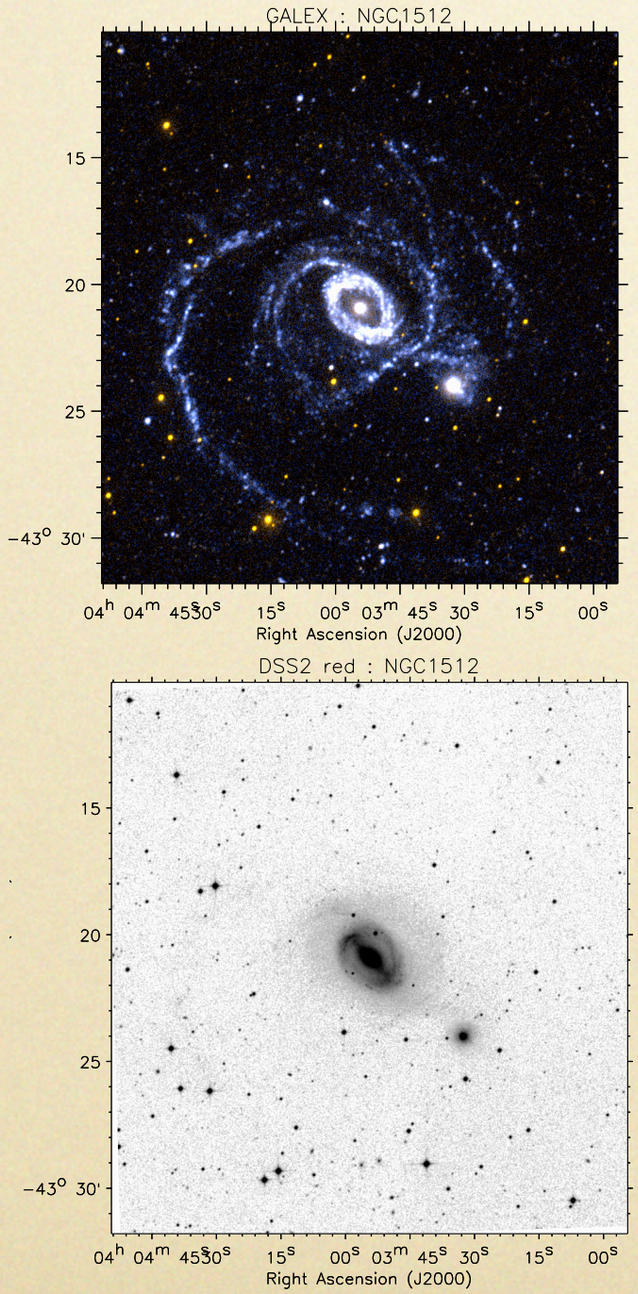


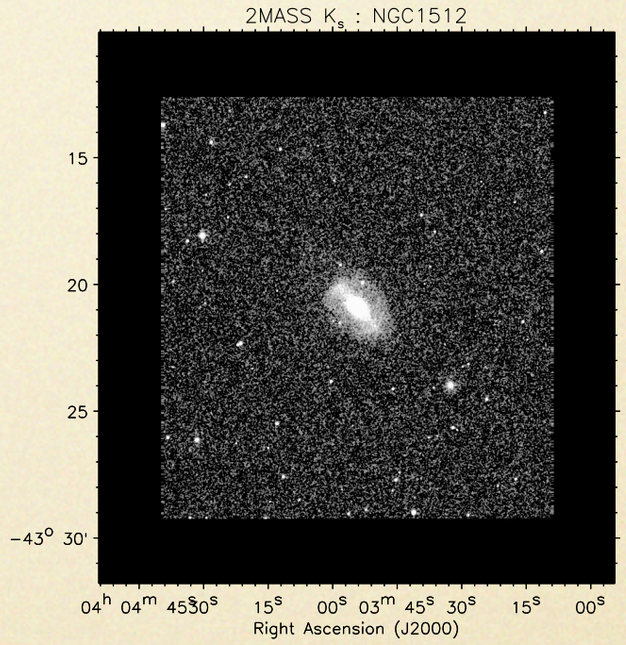




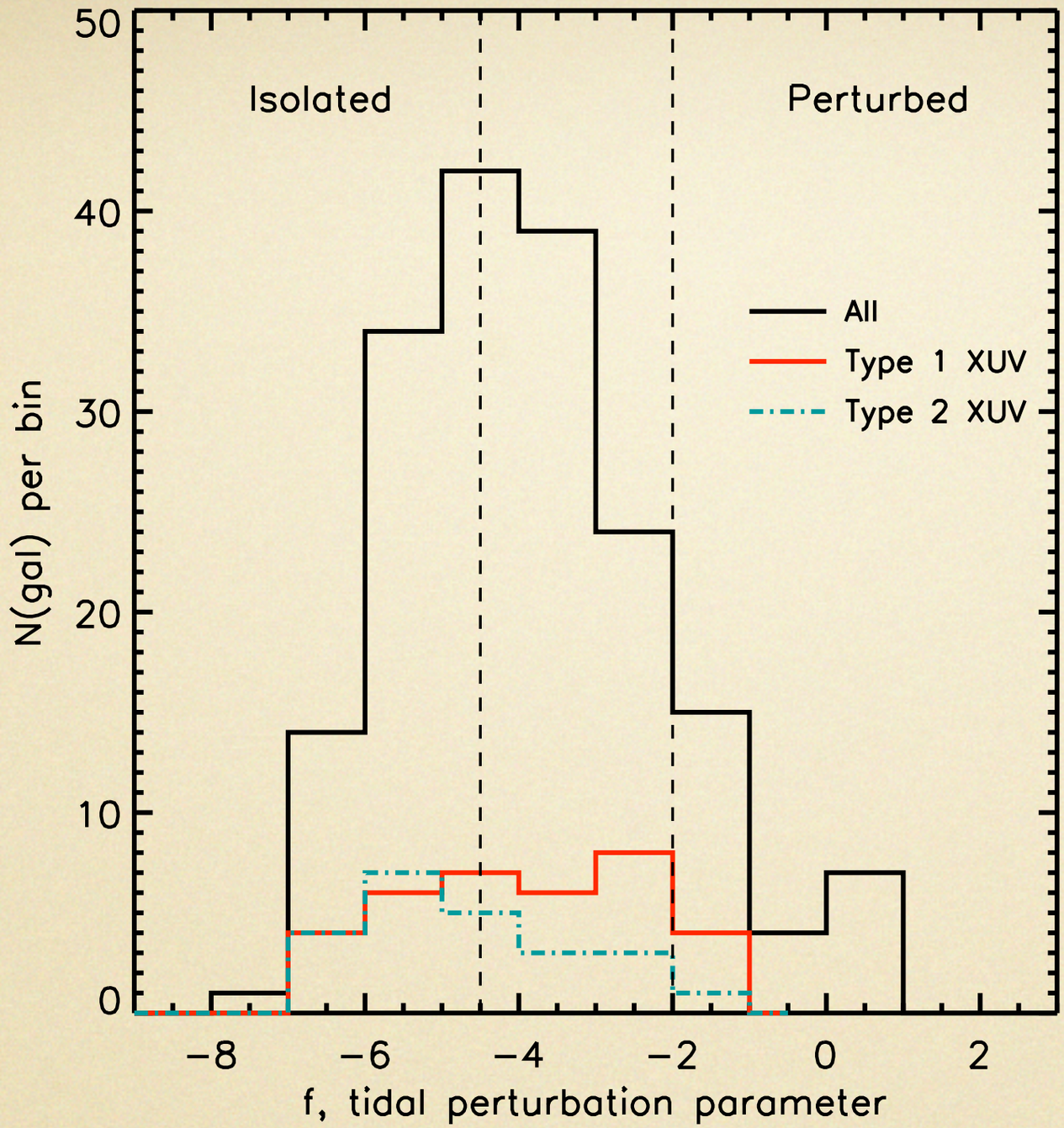
- Very high *sSFR* for Type 2, $t_{form} < 1$ Gyr
- XUV-disks are ~2x more gas-rich on average

NGC 1512/10





Role of interaction?



Type 1 XUV-disks are more perturbed than the overall sample, but not often trainwrecks.

Type 2 galaxies are comparatively isolated.

Other evidence for interaction?

- Subtle signatures of environmental perturbation:
  - Asymmetry (visible or UV) or pec. morph.
  - Anomalous HI (filaments, HVCs, extraplanar gas)
- Such evidence in ~75% Type 1, ~50% of Type 2
  - But what about non-XUV's?

SF at low...

Σ_{gas}

abundance

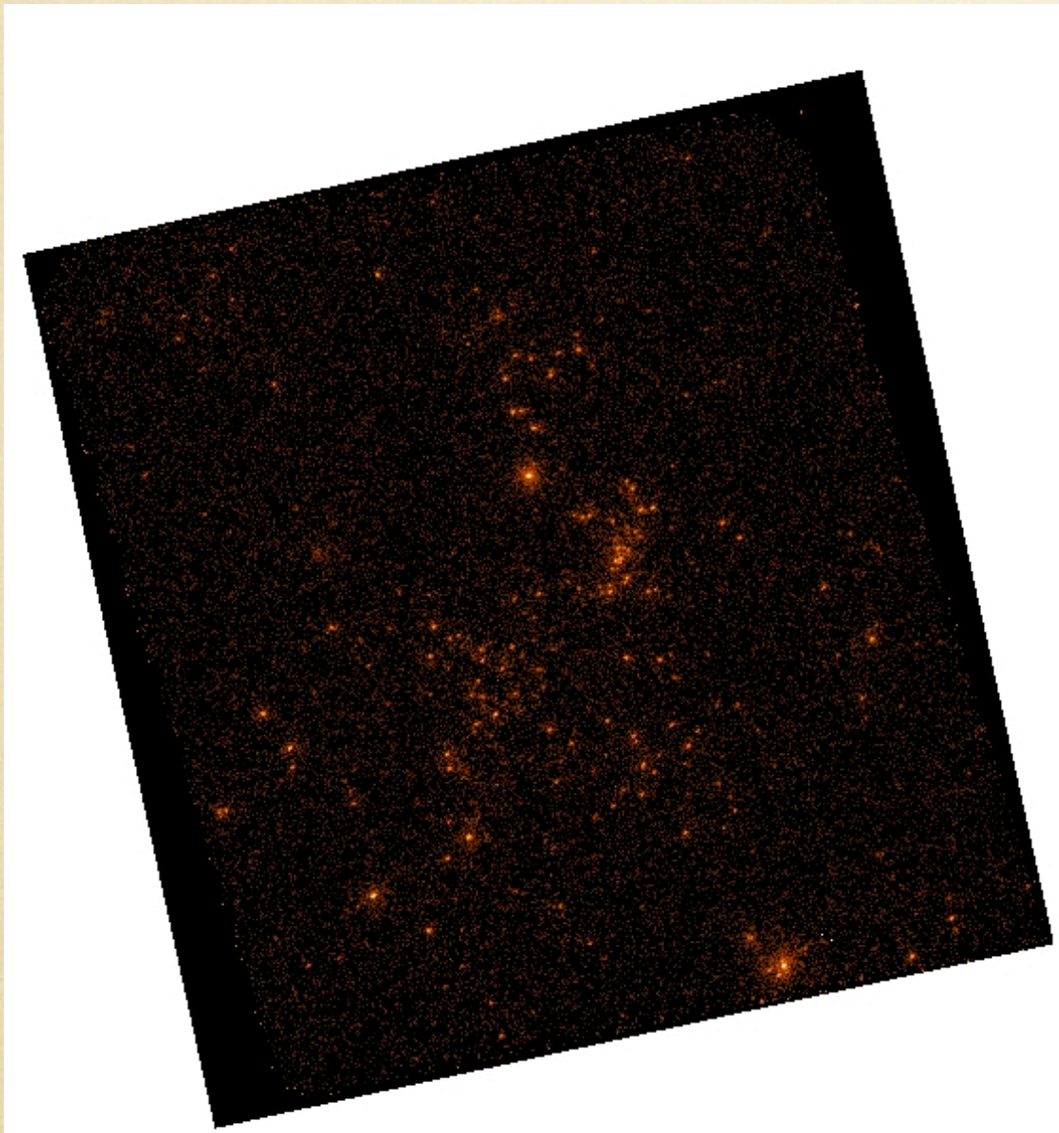
surface brightness or Σ_{stars}

- Similar to prevailing conditions in early universe? (Not Pop III, but still illustrative)
- Probabilistic, not deterministic process
- Stochastic effects: IMF and SFR tracers

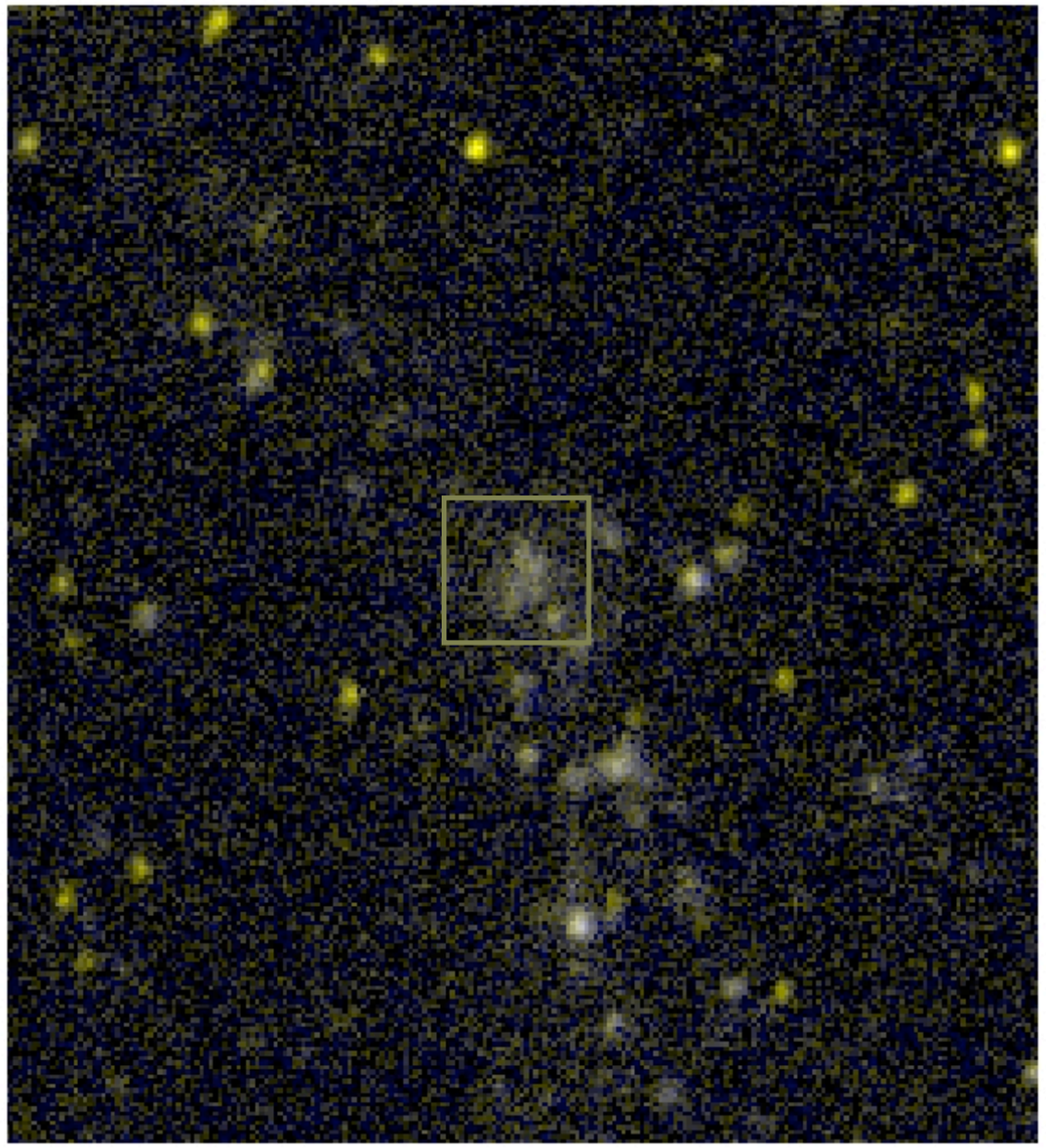
- Hα SFR tracer only suitable for log SFR > -3
  - otherwise incomplete!
- Hα/UV dropout probably due to stochastic incompleteness, low density HII, high-porosity, IMF sampling/change?
- Secondary pathways of initial cloud collapse such as spiral shocks, turbulence compression are important in outer disk (**Elmegreen & Hunter 2006**)
- Rather than use discrete SF threshold, one should construct a multivariate PDF

HST followup on M83

Thilker et al. 2007c, in prep.



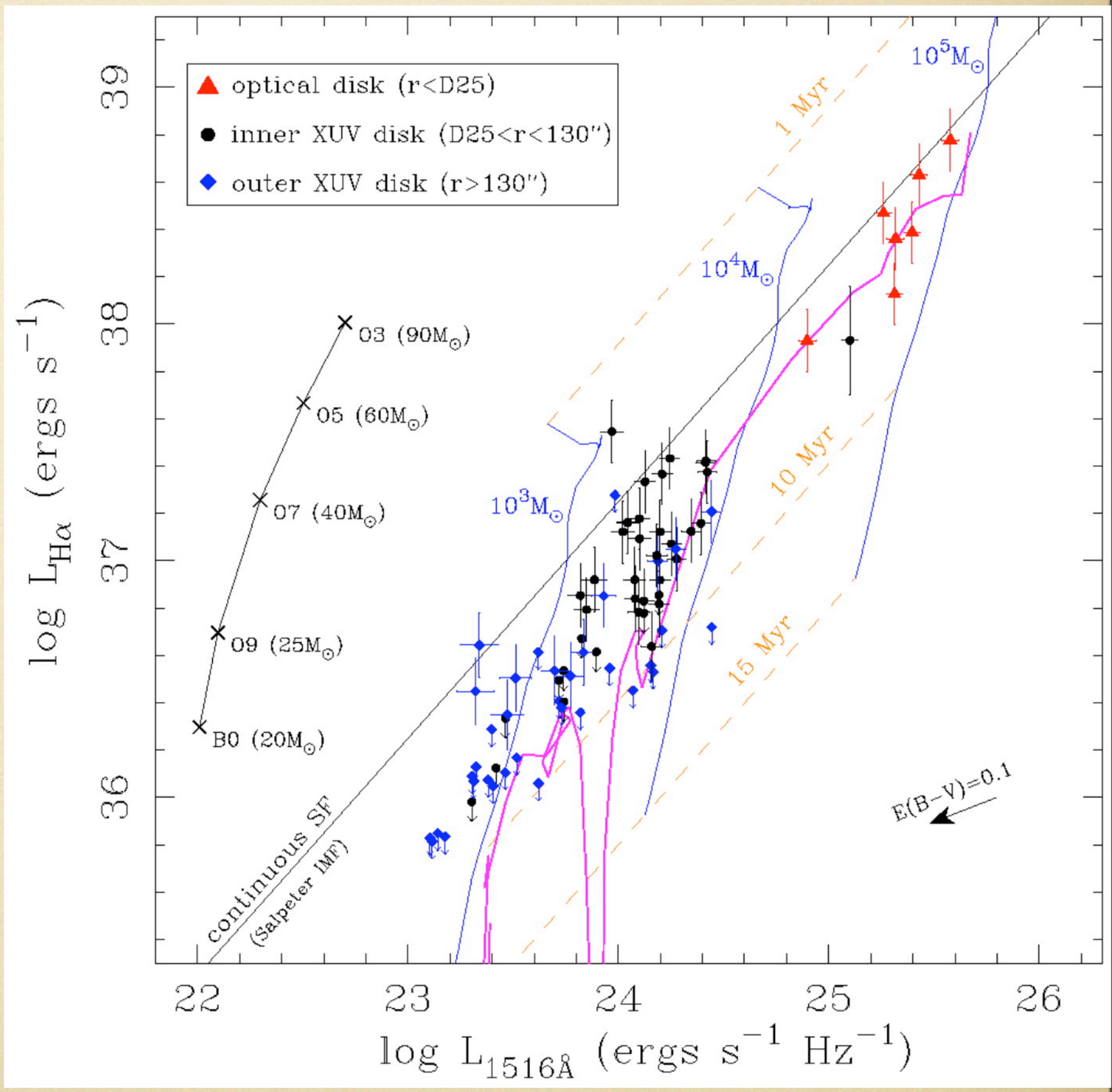
ACS/SBC (F150LP)



GALEX FUV, NUV

XUV-disk sources

- L(Hα) is consistent with ionization by a single massive star in some cases
  - IMF sampling
  - Upper limits in outer XUV-disk
- Total stellar mass per cluster tends to decrease with radius.

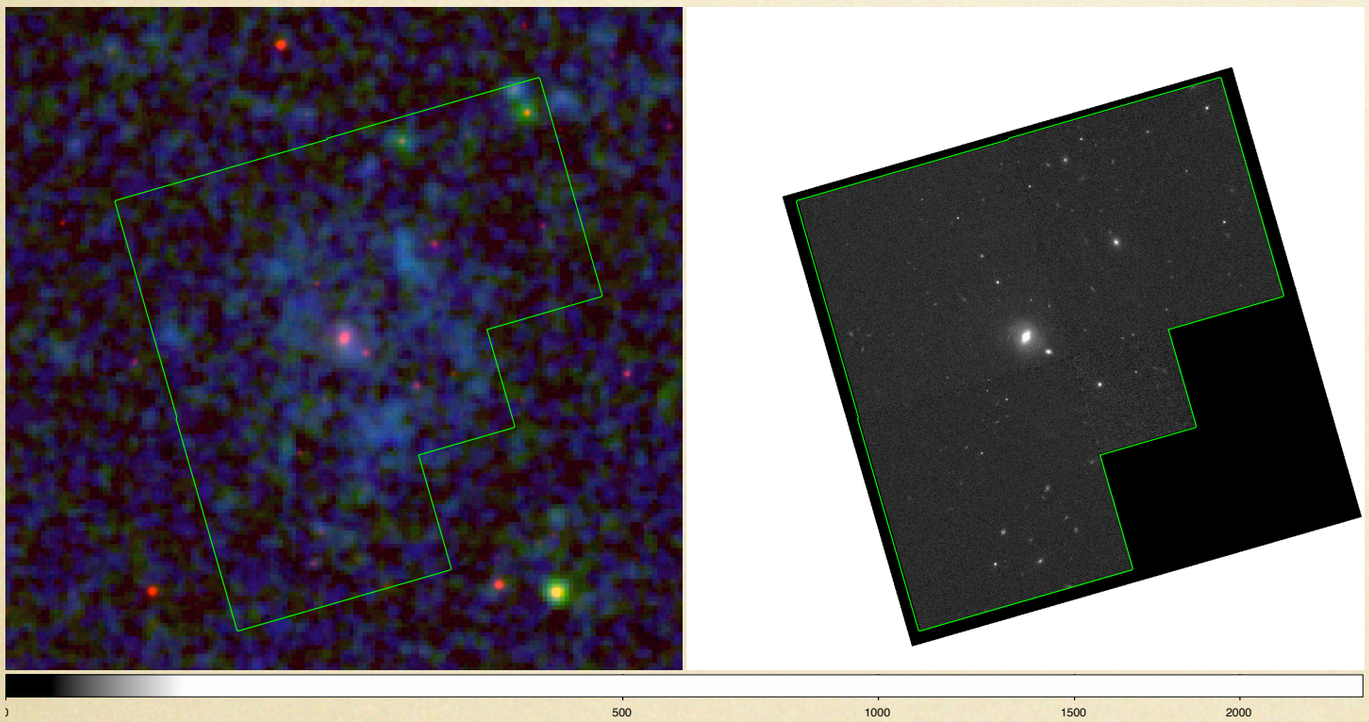


SF at low...

Σ_{gas}

abundance

surface brightness or Σ_{stars}



Malin 1
(GALEX, HST)

- Implications for LSB galaxies
  - Massive LSBs are likely extreme XUV-disks
  - LSB dwarfs (Hα SFRs -- underestimates?)

Inside-out disk formation

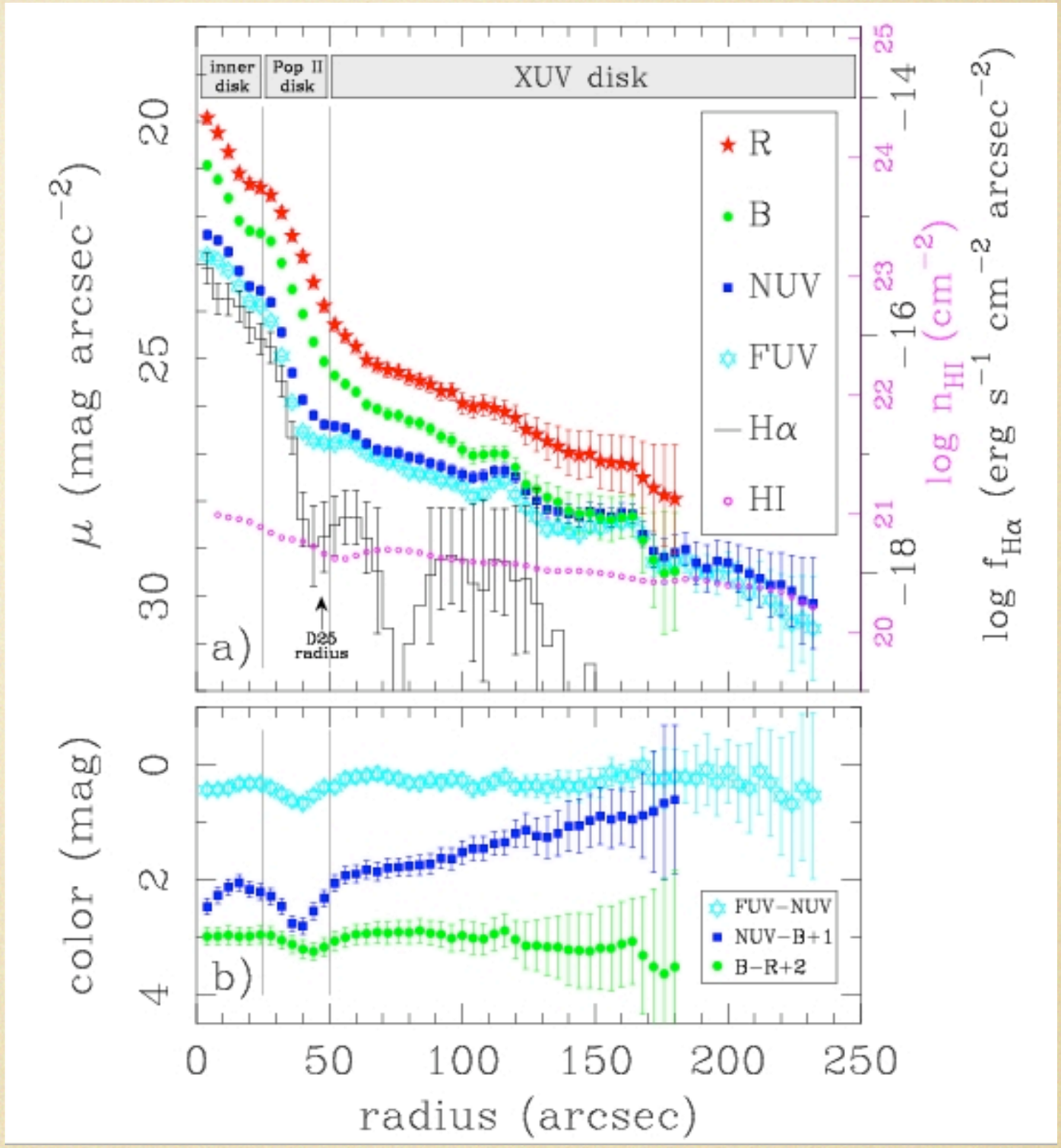
- XUV-disks mesh well with the concept of inside-out disk formation
  - Type 1 => residual assembly following the primary epoch of disk building at higher z?
  - Type 2 => galaxies experiencing non-linear inside-out formation, due to enhanced gas accretion?
- Do all spirals undergo an XUV phase??

UV vs. optical appearance

- Optical surface brightness profiles for spirals are increasingly complex at low levels
  - Only 10% pure exponential (Pohlen et al.)
- Our survey shows XUV relation to opt. profiles remains unclear
  - “Anti-truncated” disks (Erwin et al. 2005, Pohlen & Trujillo 2006) without XUV SF
  - Down-bending broken exp. with XUV SF

UV-opt. profiles in NGC 4625

- (NUV-B) gets progressively bluer in XUV disk outside D_{25}
- Population change [SFH] continues within XUV disk
- Hα deficit, but not as pronounced...



Gil de Paz et al. (2005)

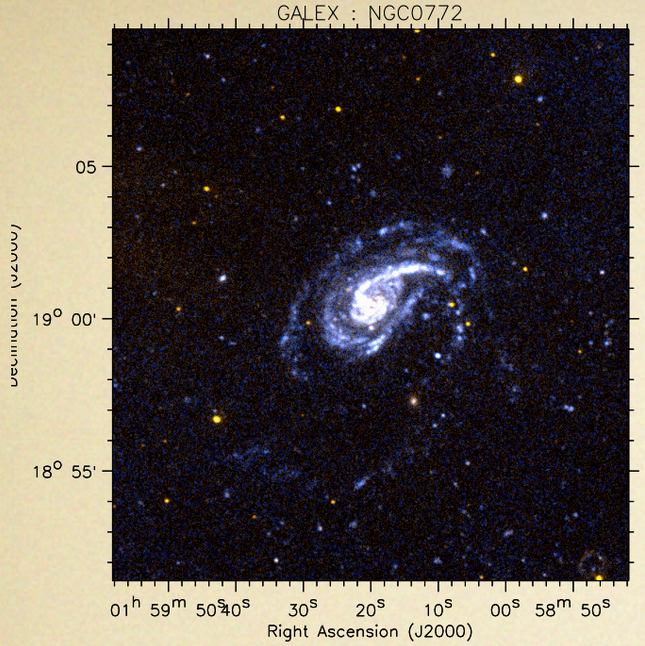
Modes of gas feeding

- Galaxy interaction/mergers (NGC 1512, M81)
- Hot and Cold IGM accretion (e.g. Keres et al.)
    - Type 2 XUV-disks have low mass, similar to that for which cold accretion is dominant.
- Recycled gas from inner disk fountain?

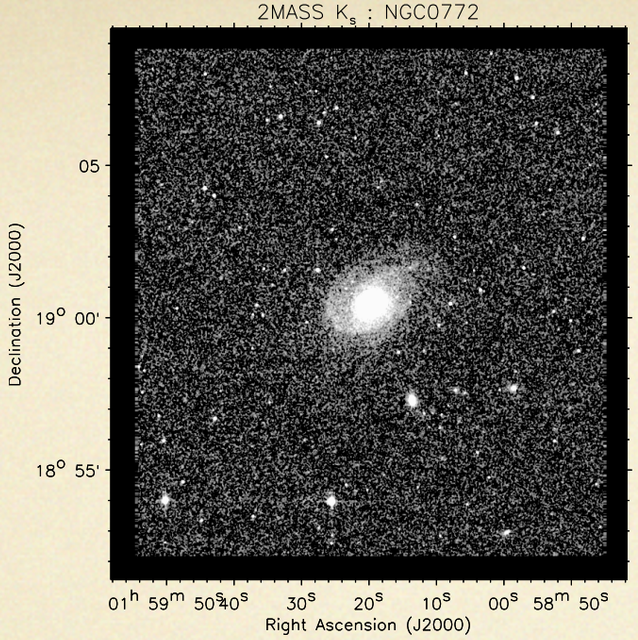
Gas consumption and metal enrichment

- Little to say on this yet... except:
  - Outer HI is being converted to stars *in-situ*
  - Massive SF implies “post accretion” enrichment, influences QSO abs. interpretation.
    - 1/10th solar abundance in some XUV-disk environments (M83, NGC 4625)
    - More multi-slit spectra being obtained.

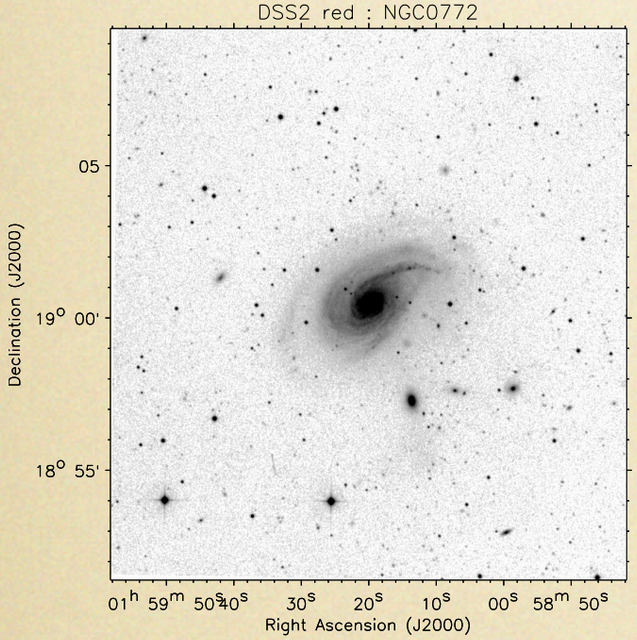
GALEX : NGC0772



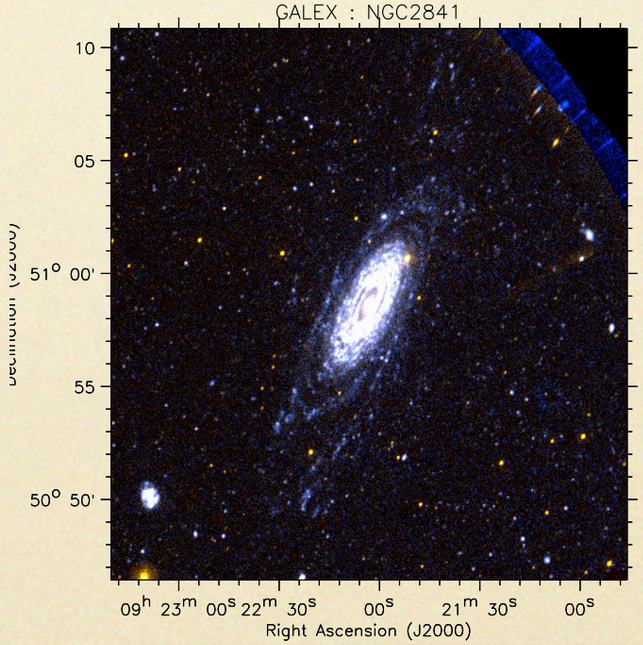
2MASS K_s : NGC0772



DSS2 red : NGC0772



GALEX : NGC2841



2MASS K_s : NGC2841