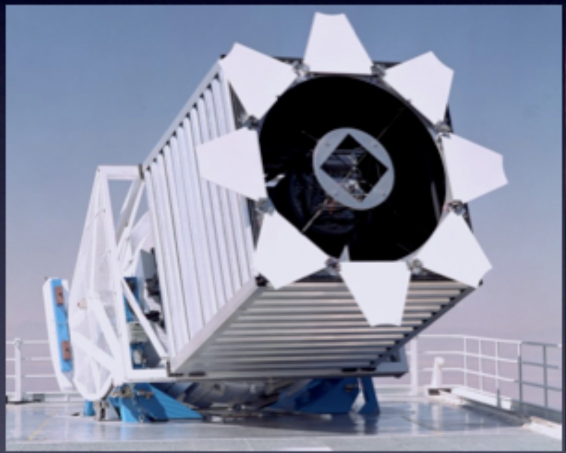
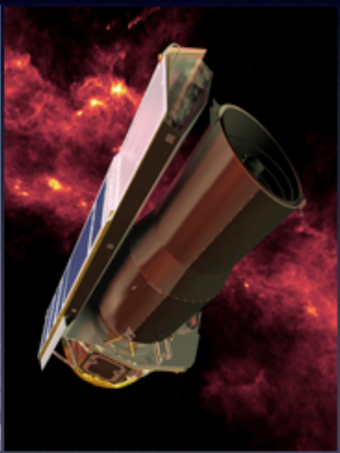
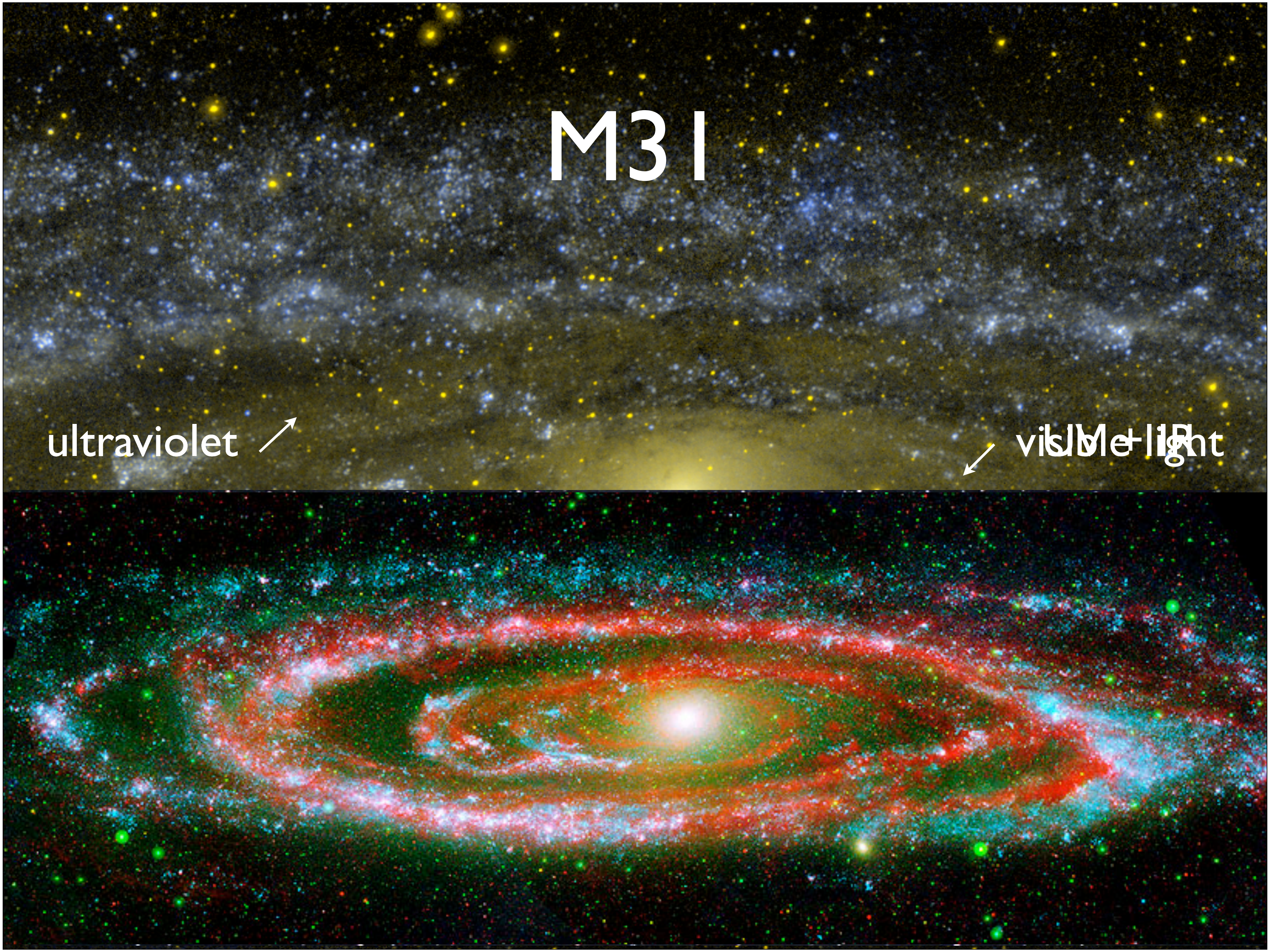
New Lessons from Panchromatic Observations of the SDSS Main Galaxy Sample



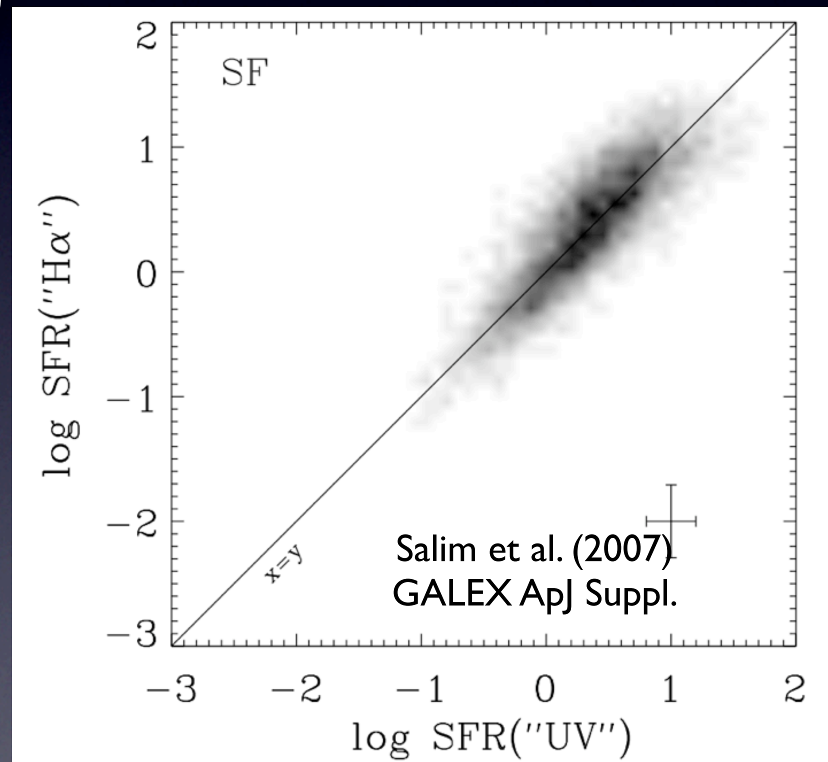


David Schiminovich
Columbia University


M31
ultraviolet
visible light
UV + IR

Panchromatic Observations
GALEX - SDSS - Spitzer - VLA/Arecibo

- Emphasis on probes of young stellar populations (e.g. star formation rates)
- Complications:
  - Dust attenuation
  - Old stellar populations
  - AGN
  - Metallicity
  - SF timescales
  - IMF variation
  - Geometry + Spectroscopy: aperture effects



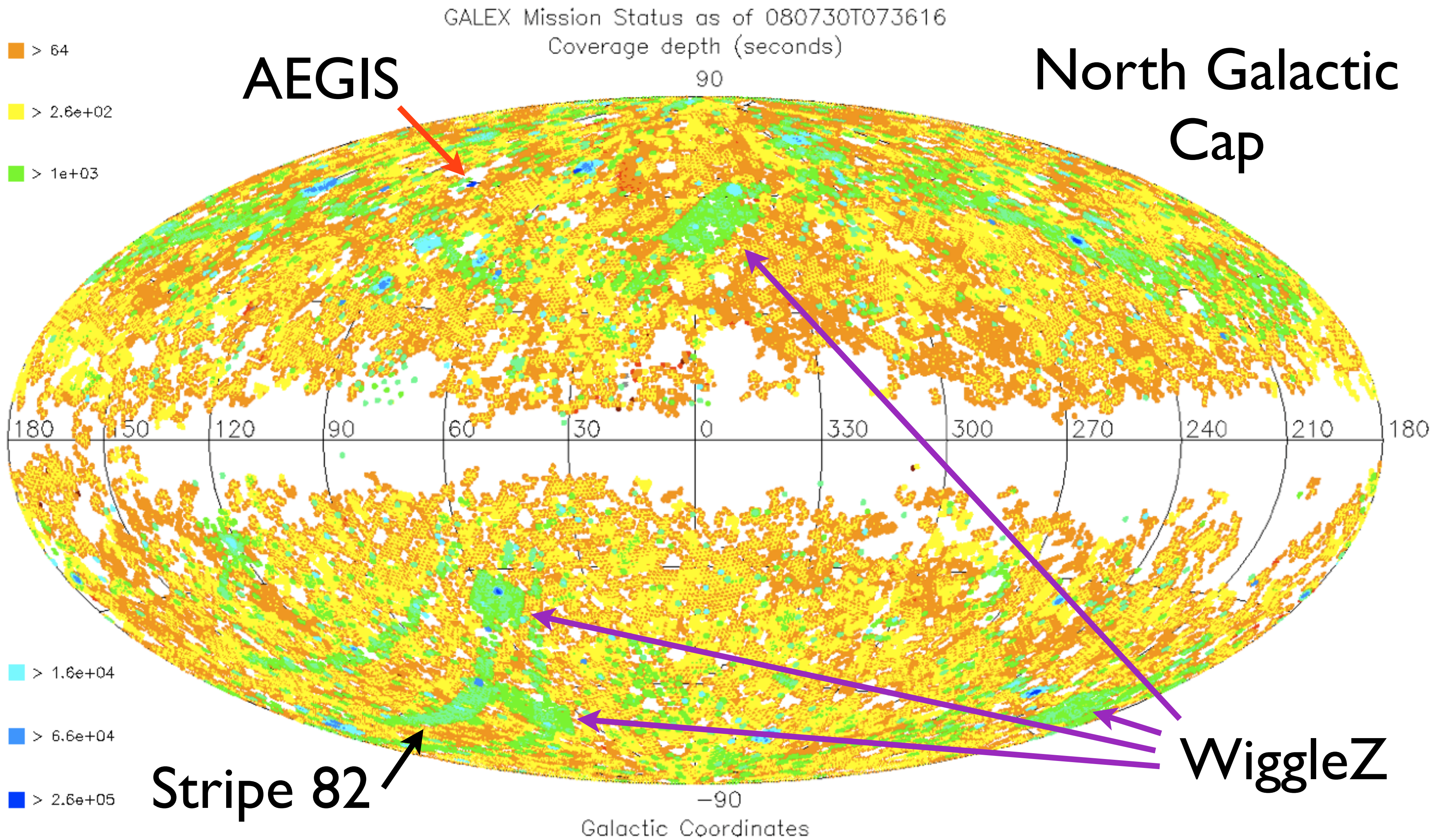

GALEX
Galaxy Evolution Explorer
Surveying the Ultraviolet Universe
NASA
JPL
Orbital
Columbia University
GSFC
UCLA

A Brief History

GALEX
Galaxy Evolution Explorer
Surveying the Ultraviolet Universe

- 1997: GALEX selected. Planned imaging surveys:
  - All-sky imaging survey (limiting $m_{UV} \sim 21$ AB)
  - Deep imaging survey (100 sq. deg; $m_{UV} \sim 25$ AB)
- 2000: Added GALEX Medium imaging survey
  - 1000 sq. deg in SDSS footprint ($m_{UV} \sim 23$ AB)
- 2003: Galex launched
- 2008: GR4 released, primary mission complete

GALEX Sky Coverage

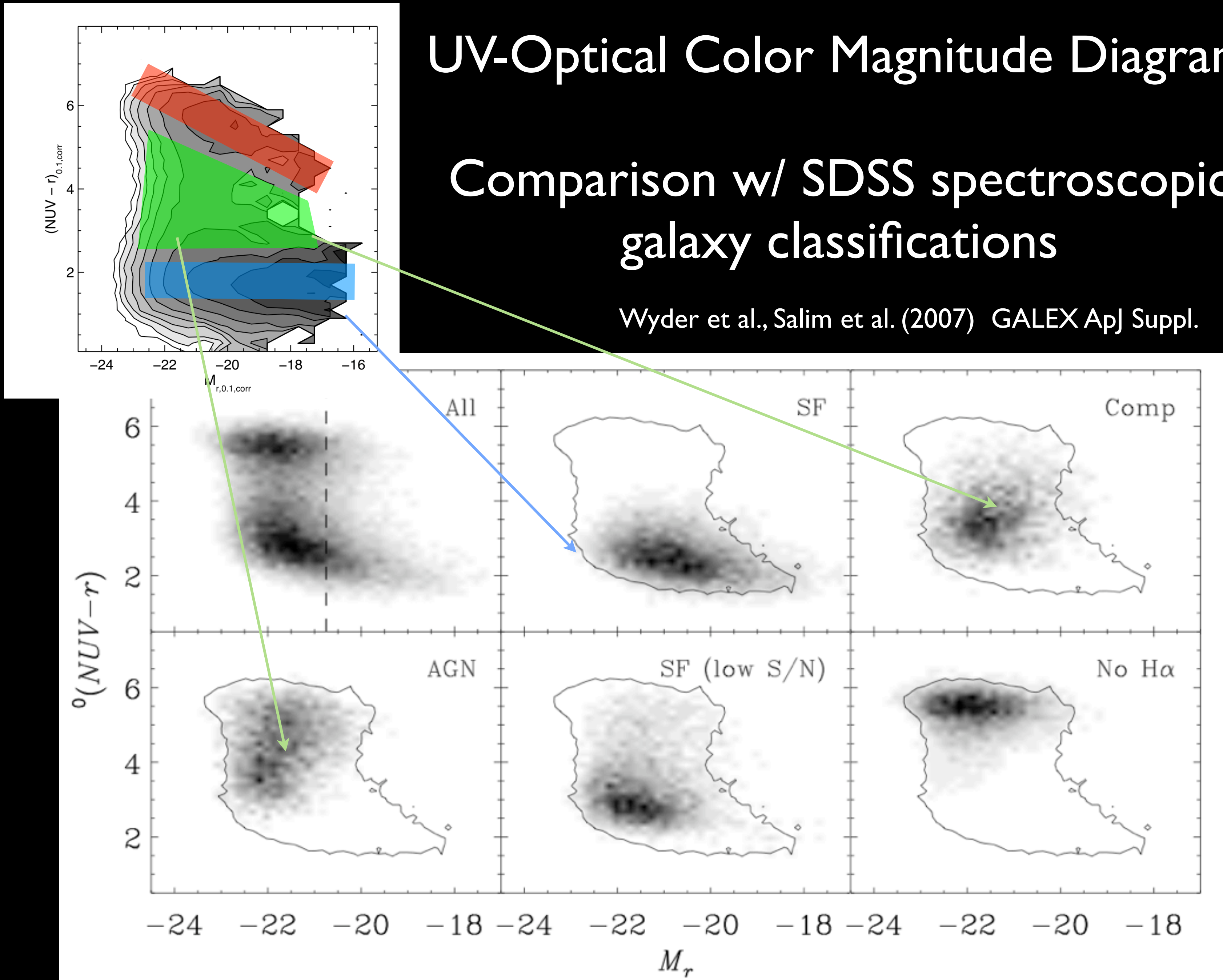


- To date ~50% of all GALEX publications use MIS data + SDSS. By far the most productive GALEX survey.

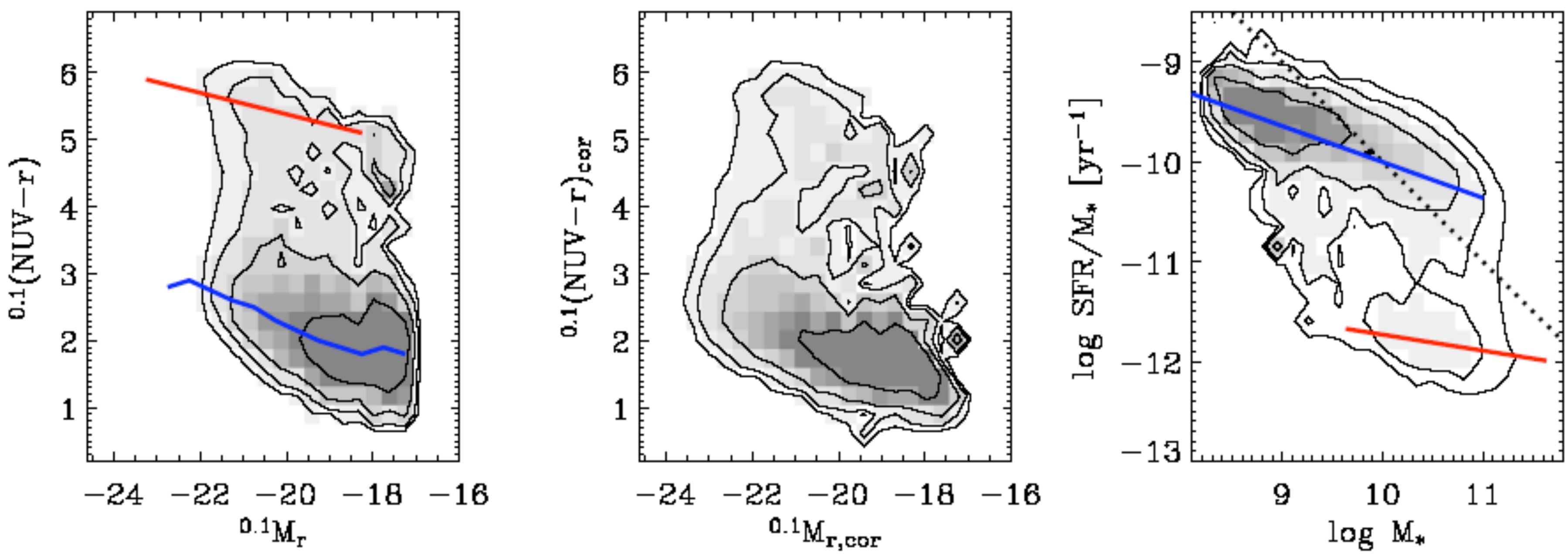
UV-Optical Color Magnitude Diagram

Comparison w/ SDSS spectroscopic galaxy classifications

Wyder et al., Salim et al. (2007) GALEX ApJ Suppl.



UV-Optical Color Magnitude Distribution: Converting to Physical Properties



Observed Distribution weight: $1/V_{max}$

Wyder et al. (2007) GALEX ApJS

"Dust-corrected" Distribution

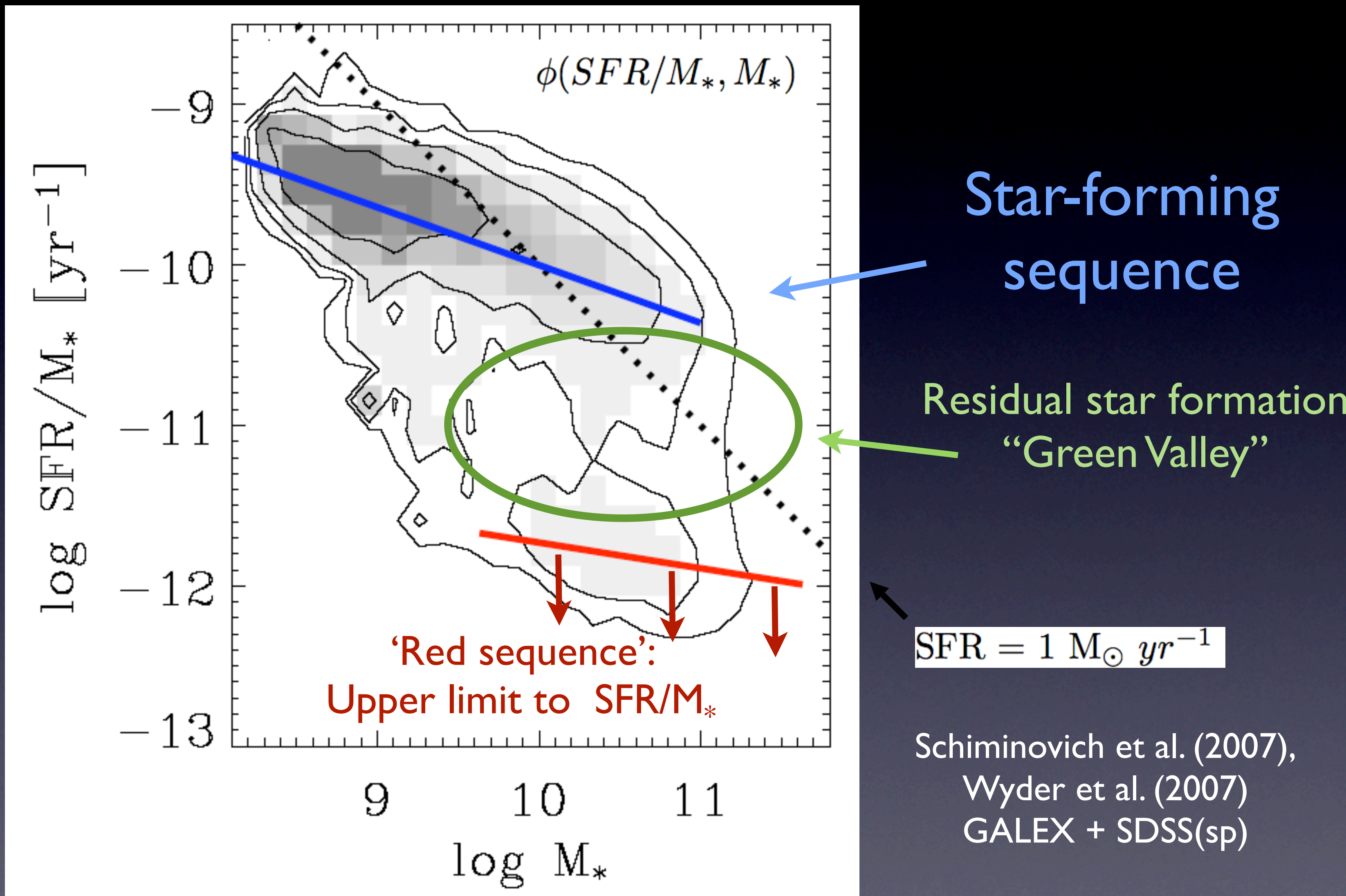
using Johnson et al. (2007) empirical corrections

UV,cor->SFR

$M_{r,cor}$-> M_*

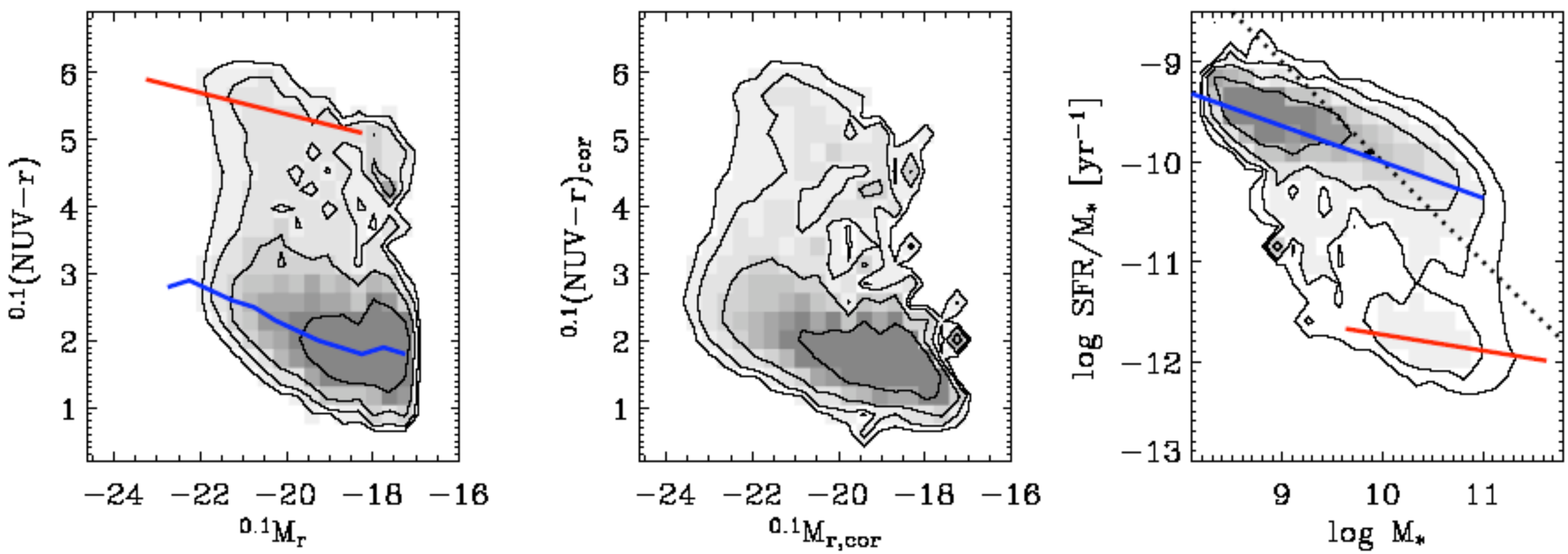
Schiminovich et al. (2007) GALEX ApJS

SFR/M$_*$ vs. M$_*$
Distribution of Galaxies at z~0.1



Schiminovich et al. (2007),
Wyder et al. (2007)
GALEX + SDSS(sp)

UV-Optical Color Magnitude Distribution: Converting to Physical Properties

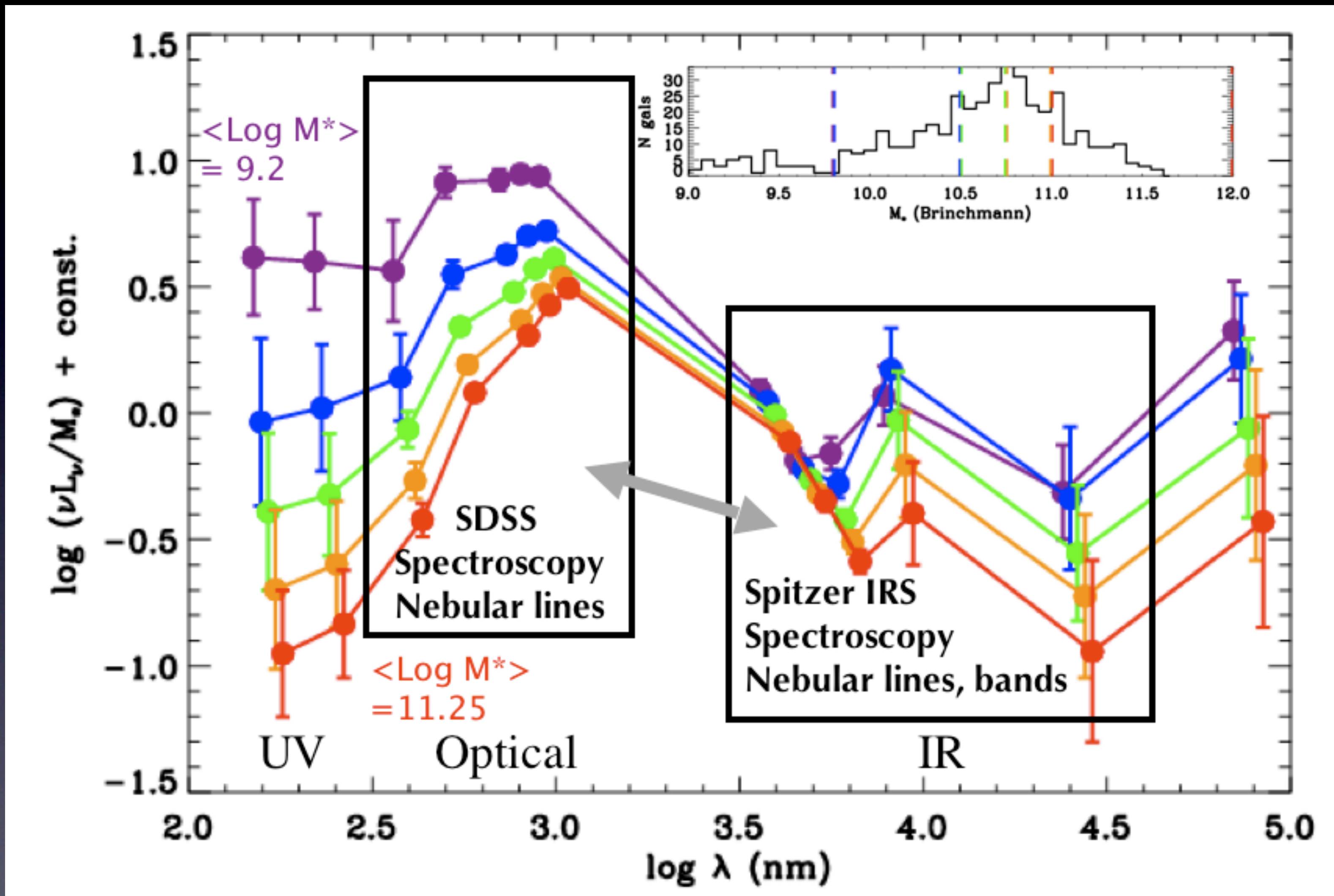


How accurate are our UV-optical derived SFRs? What information do we obtain from other less attenuated measures? (e.g. SFR, AGN, dust)

Existing Radio/IR surveys IRAS/FIRST

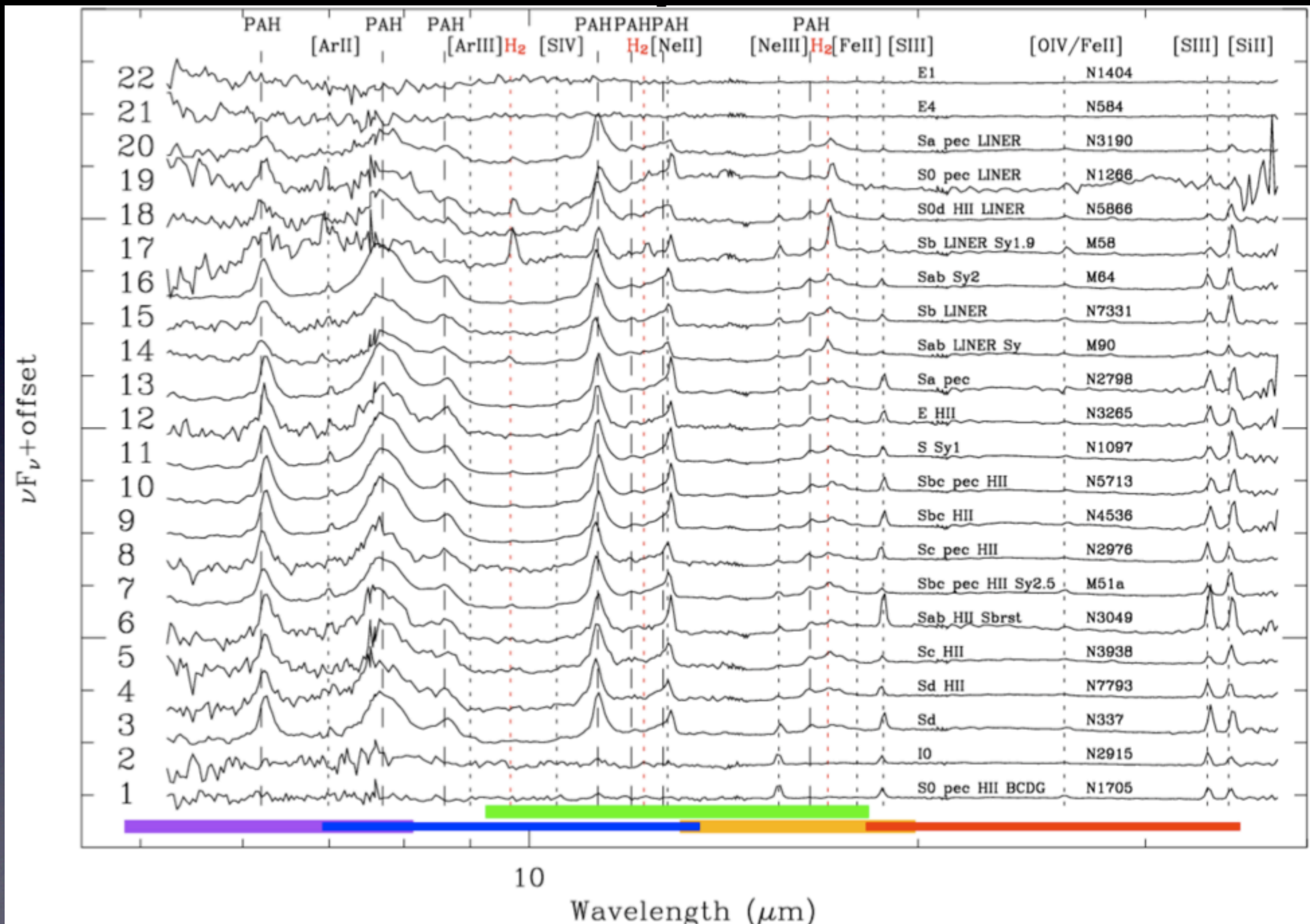
- Not deep enough to probe ‘typical’ star forming galaxy at z~0.1
- Deepest VLA surveys reach interesting limits over very small volumes
- Spitzer/SWIRE better match to SDSS
- WISE and EVLA a significant improvement
  - WISE should detect ~20% of SDSS spectroscopic sample (5 sigma).

SSGSS: Connecting SDSS and Spitzer IRS spectra



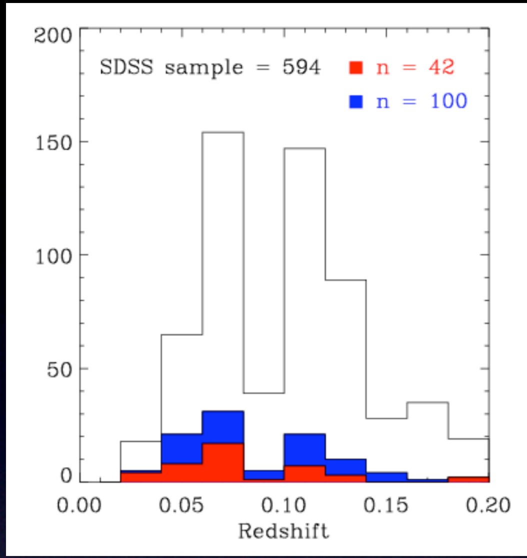
Spitzer IRS spectra for SINGS sample (e.g. Smith et al 2007)

NUV-R



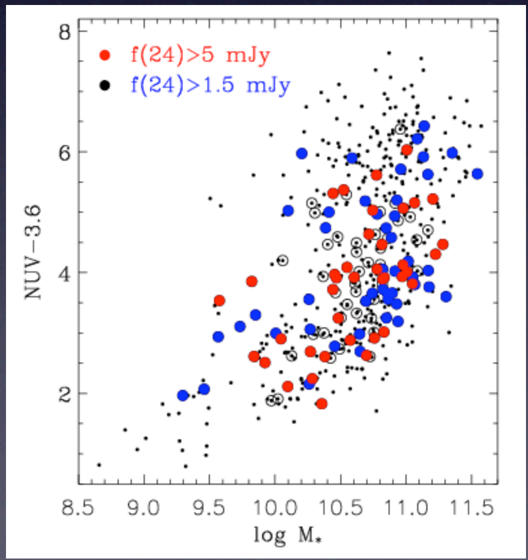
Spitzer-SDSS-GALEX Spectroscopic Survey

Mid-IR spectroscopy (~1 hr) of 100 galaxies selected from SDSS, with medium/deep GALEX photometry and Spitzer/SWIRE imaging



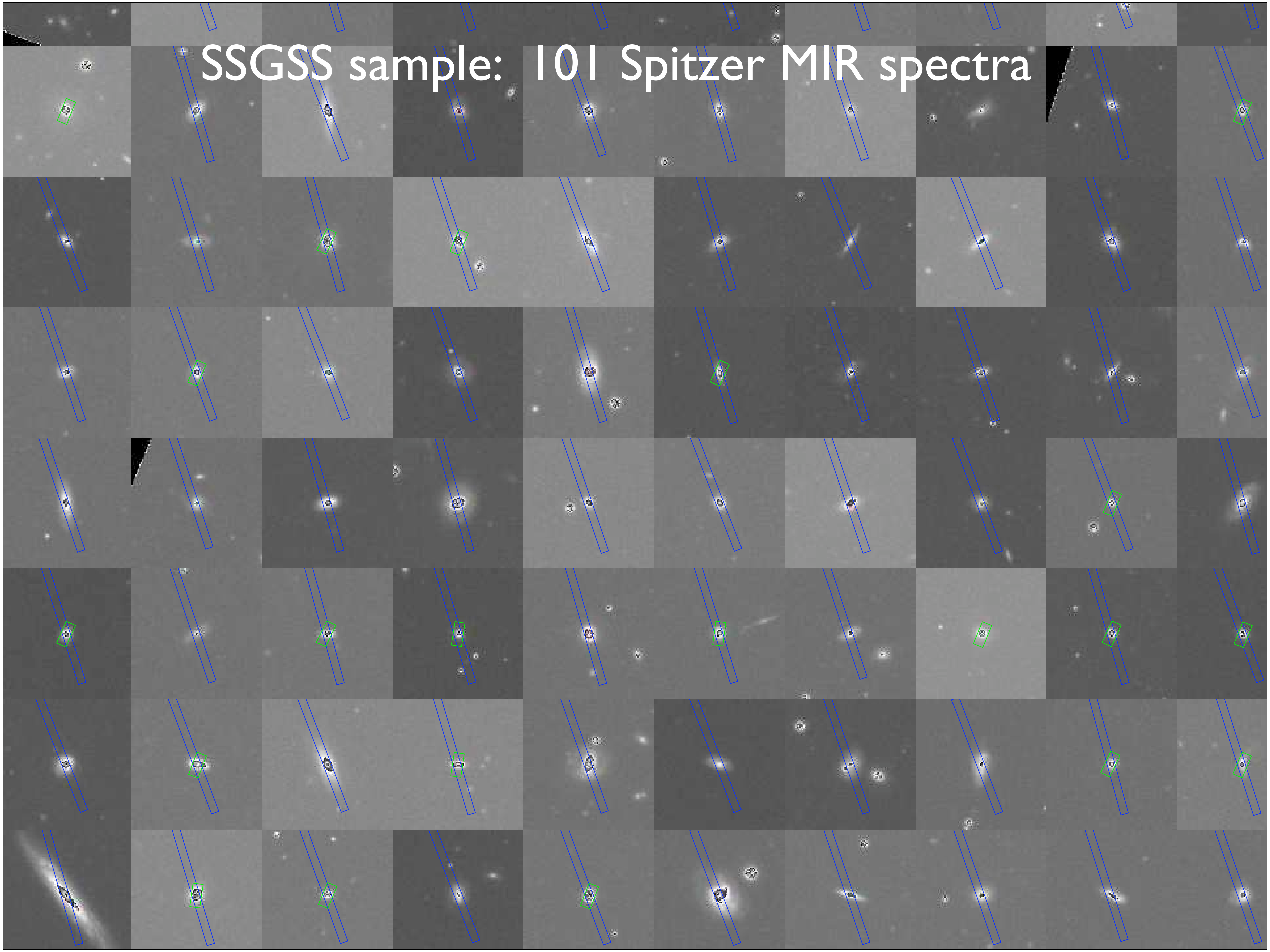
Reference sample:

- Normal vs. Extreme (e.g. ULIRG) galaxies
- Factor of 100 range in M* and SFR/M*
- Matched to SDSS fiber aperture

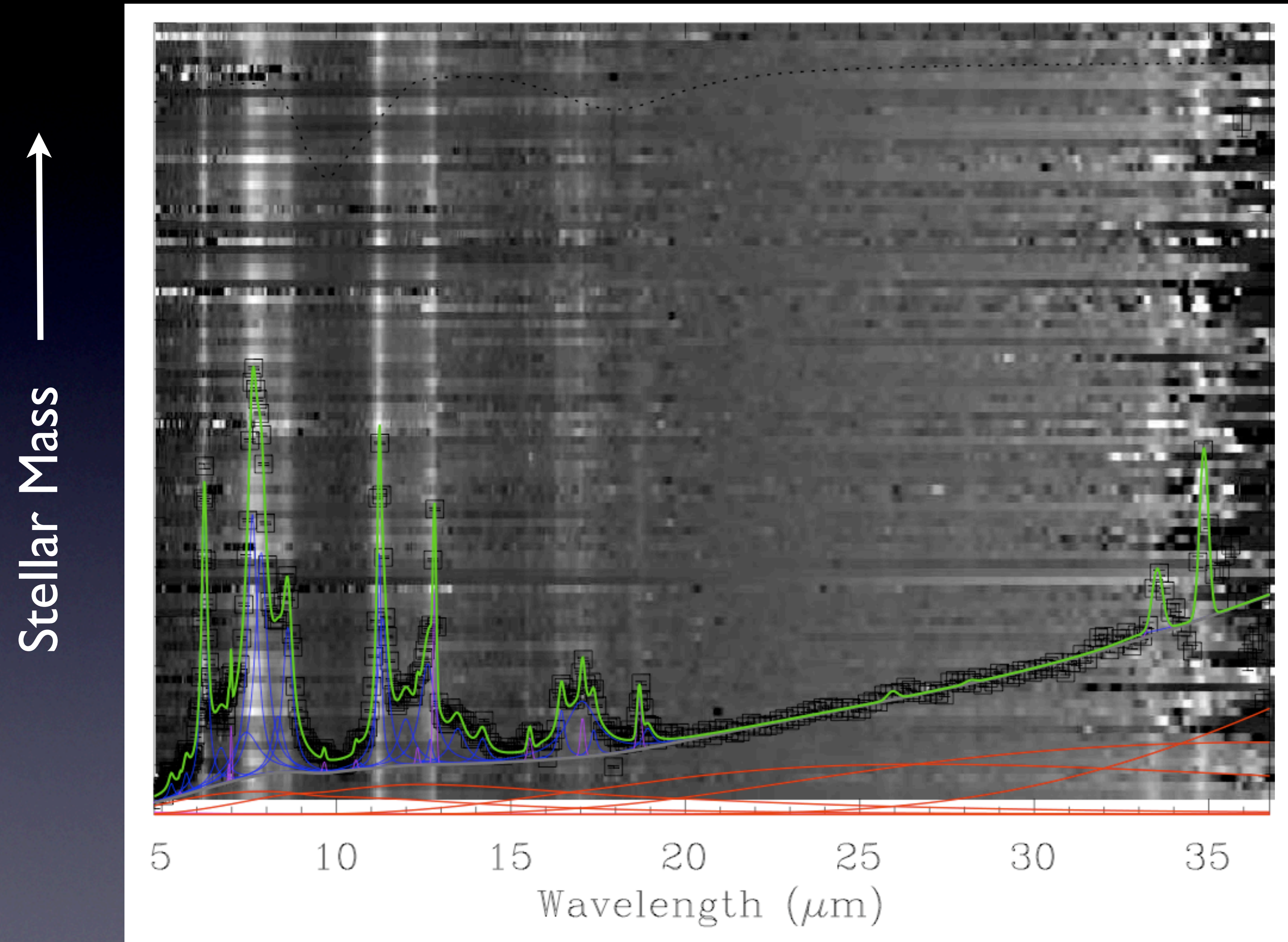


- Detailed comparison of optical and mid-iIR nebular diagnostics and molecular features
- Probe of physical conditions within obscured and unobscured star forming regions

Spitzer - Cycle 3 Legacy Program
Schiminovich, O'Dowd (Columbia), Johnson (Cambridge)
Charlot, da Cunha (IAP), Heckman (JHU)
Treyer (Caltech)


SSGSS sample: 101 Spitzer MIR spectra

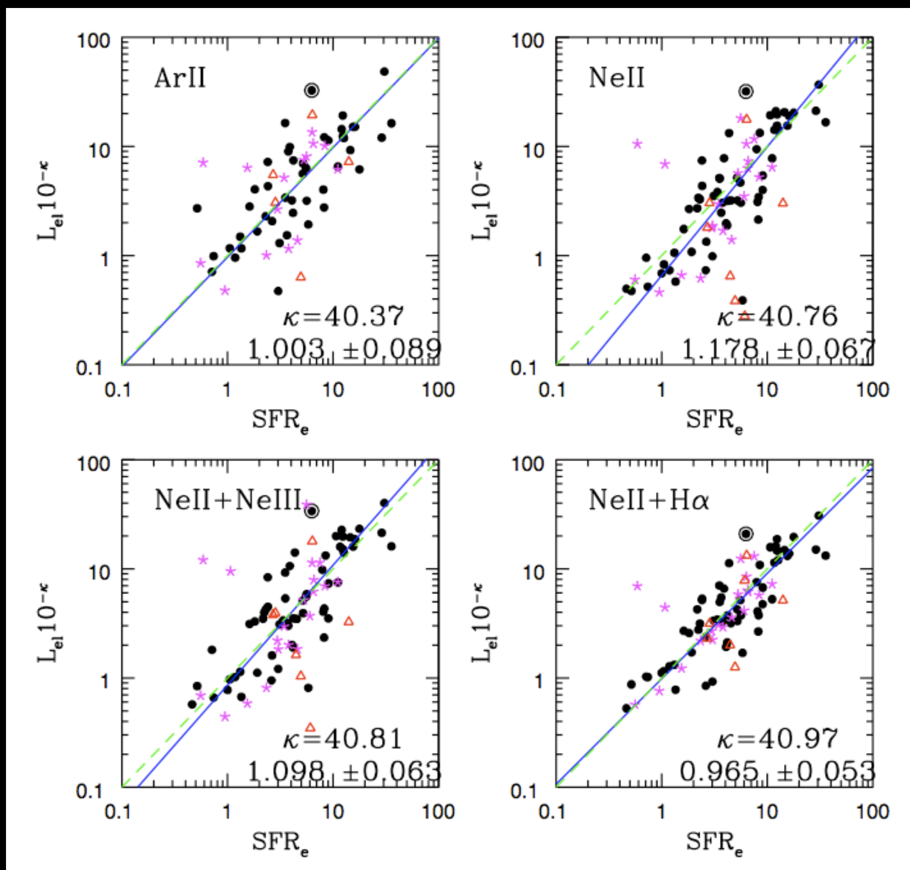
SSGSS sample: 101 Spitzer MIR spectra

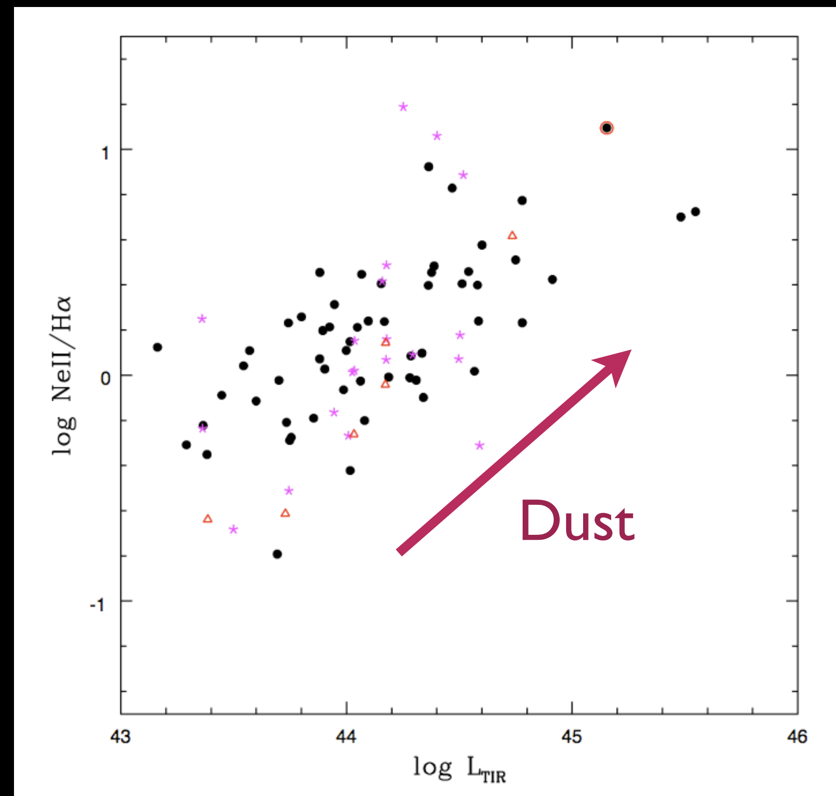


Overplot: Single spectrum and model fit

SSGSS Results:
MIR fine structure lines as SFR diagnostics

Treyer, et al. (in prep)

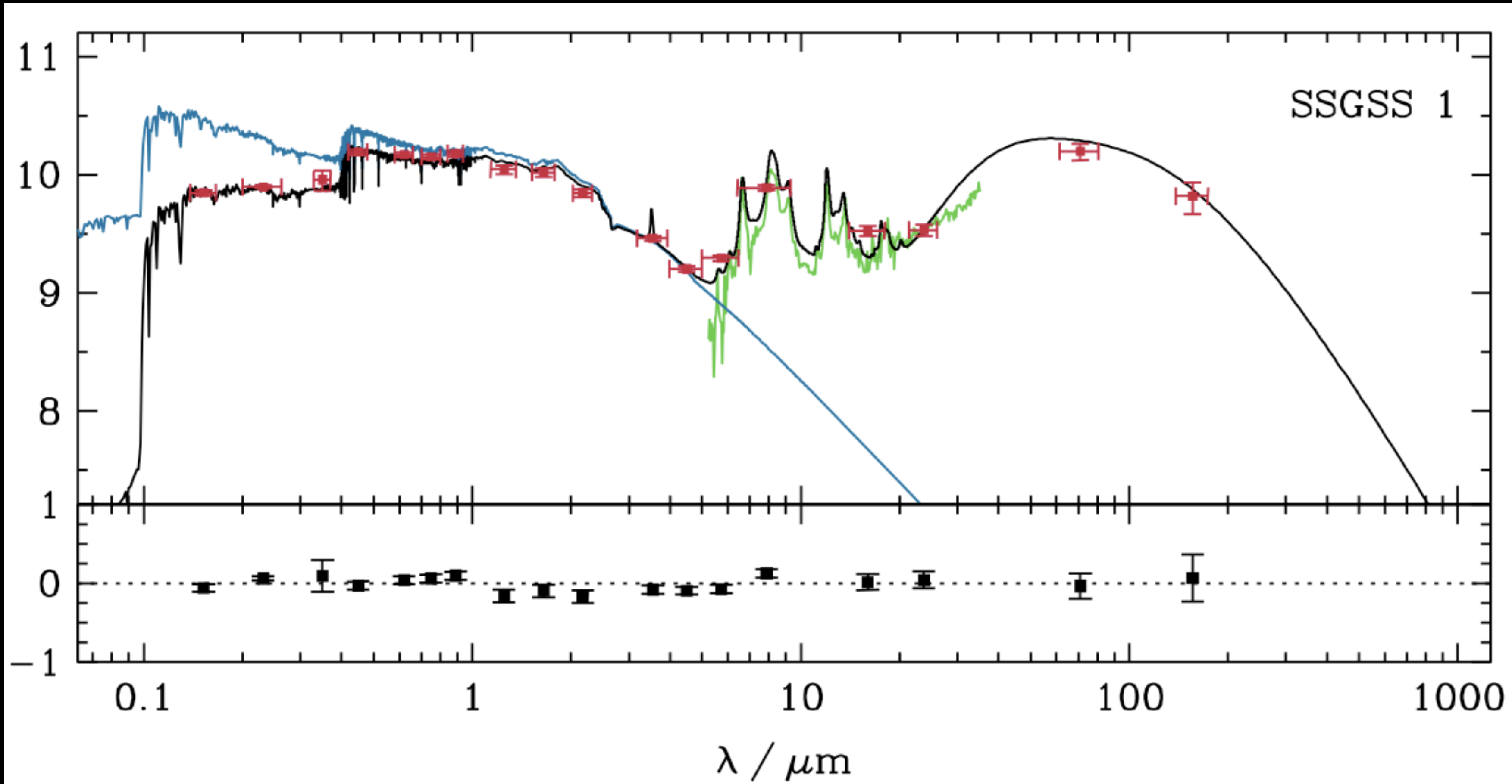




Comparison with optical emission-line-derived SFRs (Brinchmann et al 2004), UV-derived SFRs and total LIR luminosities

Derived MIR Physical Properties of SSGSS Sample

da Cunha (Ph.D. thesis, IAP; Charlot advisor)



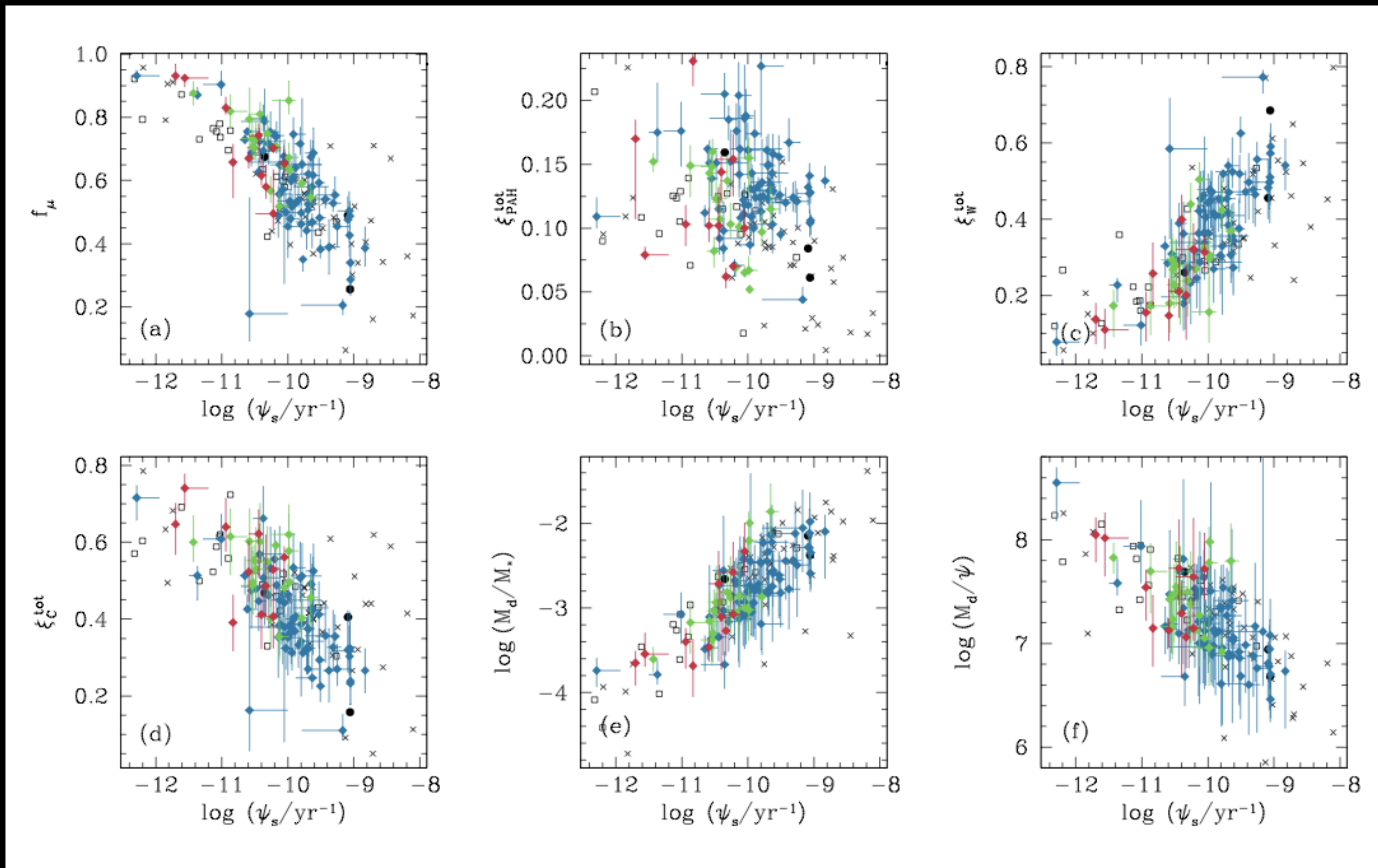
Based on simple UV-IR model incl. star formation history, birth clouds, dust and PAH (no emission line, AGN)

da Cunha, Charlot, Elbaz (2008, & Ph.D. thesis)

Derived MIR Physical Properties of SSGSS Sample

da Cunha (Ph.D. thesis, IAP; Charlot advisor)

L_{IR}(Diffuse ISM)/L_{IR}(Tot) L_{IR}(PAH)/L_{IR}(Tot) L_{IR}(Warm dust)/L_{IR}(Tot)



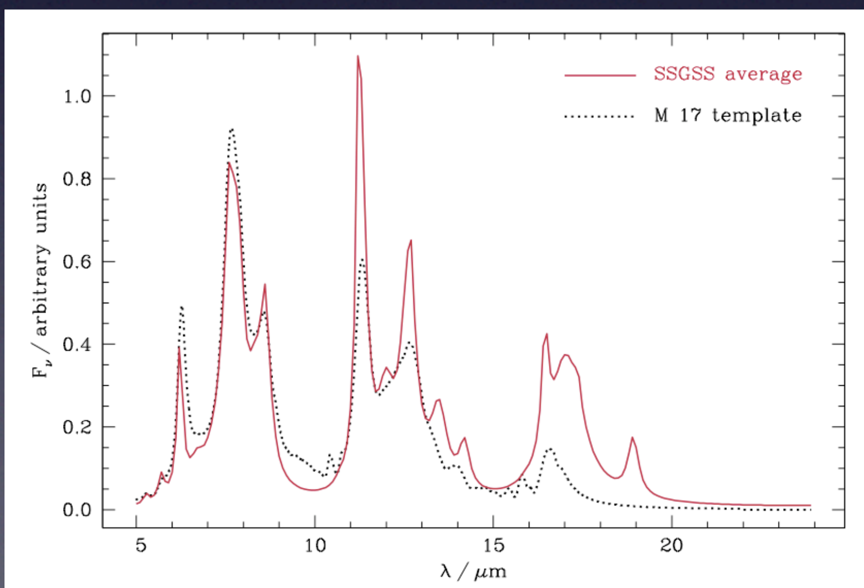
L_{IR}(Cold dust)/L_{IR}(Tot) Dust mass/M* Dust mass/(SFR/10^8 yr)

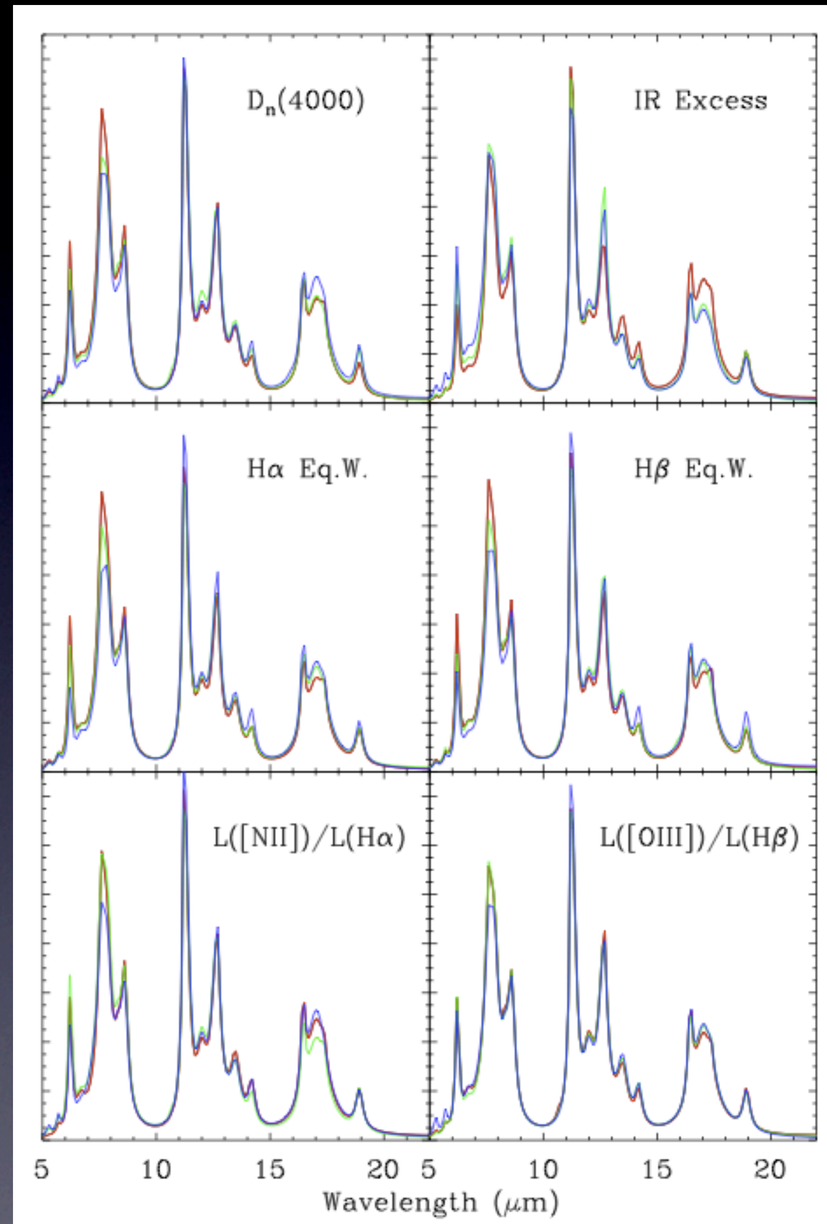
SSGSS Results:
PAH templates vs. measured optical, other properties:

O'Dowd, et al. (in prep)

In general, PAH features are remarkably similar across sample...

...but with interesting trends and scatter

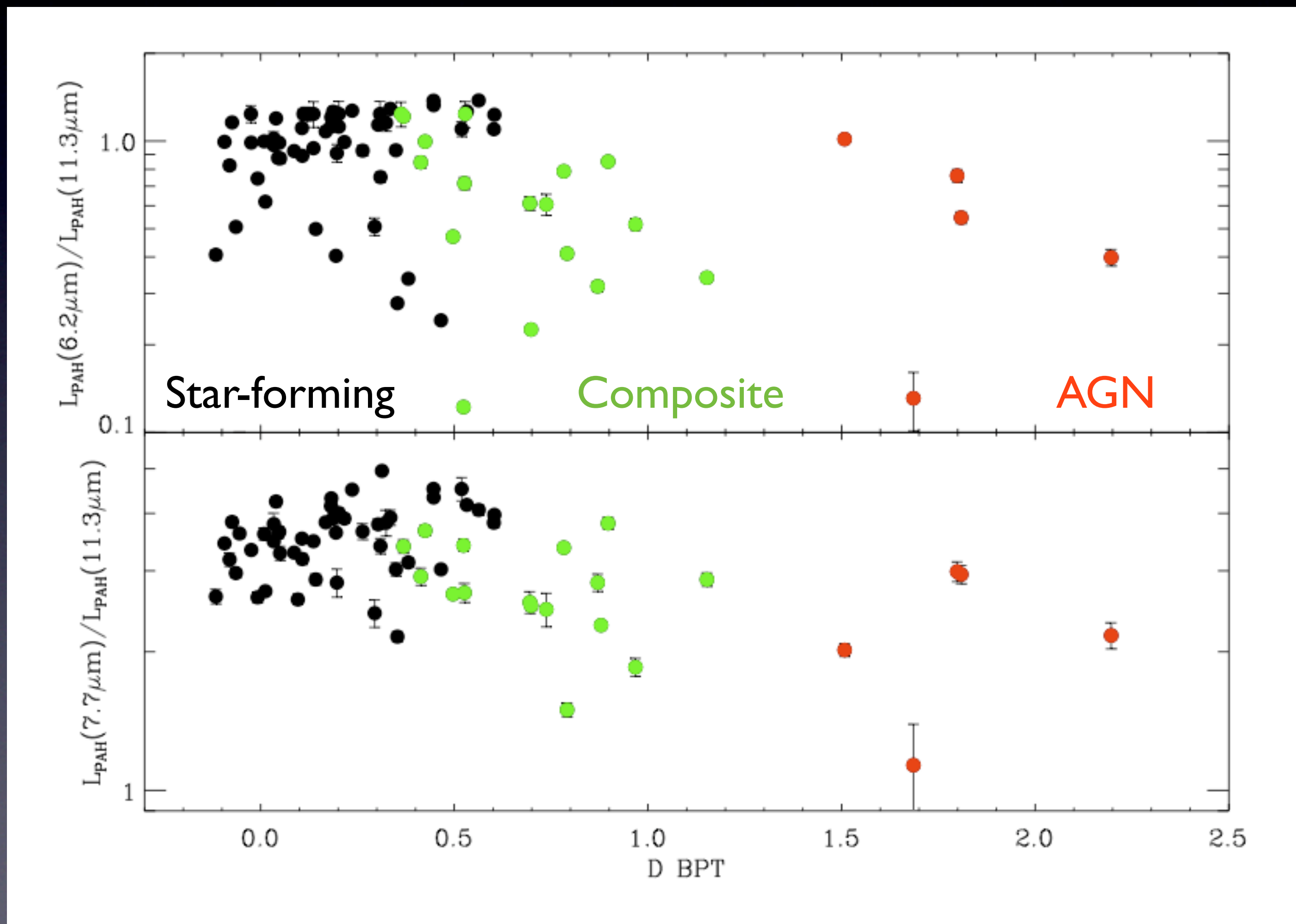




SSGSS Results: Combined Optical and MIR AGN diagnostics: PAH ratio vs. AGN 'strength' (D BPT)

Smaller PAH destroyed by AGN?

O'Dowd, et al. (in prep)

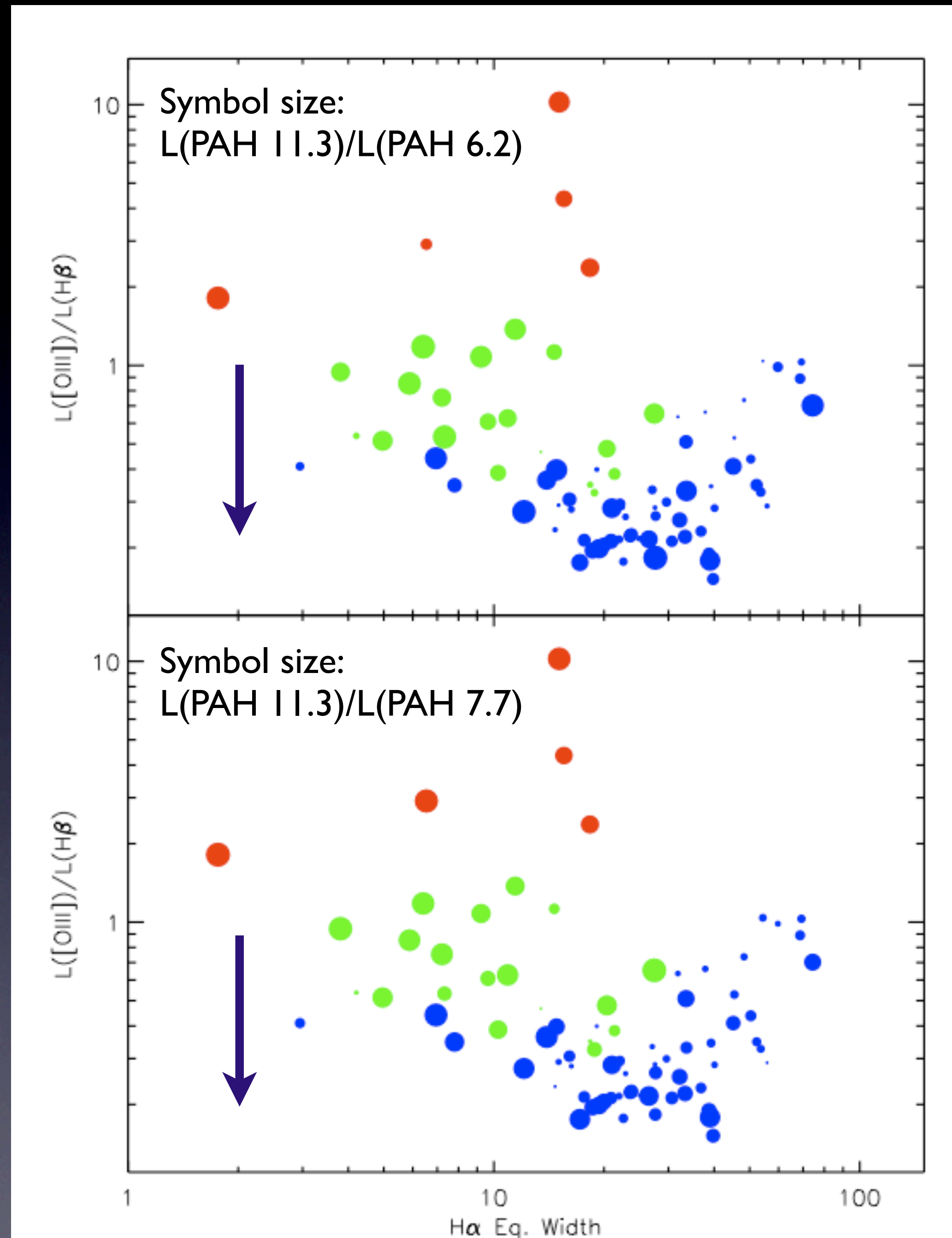


SSGSS Results: Combined Optical and MIR AGN diagnostics:

PAH ratio distribution
OIII/H_{beta} vs. H_{alpha}
Equivalent Width

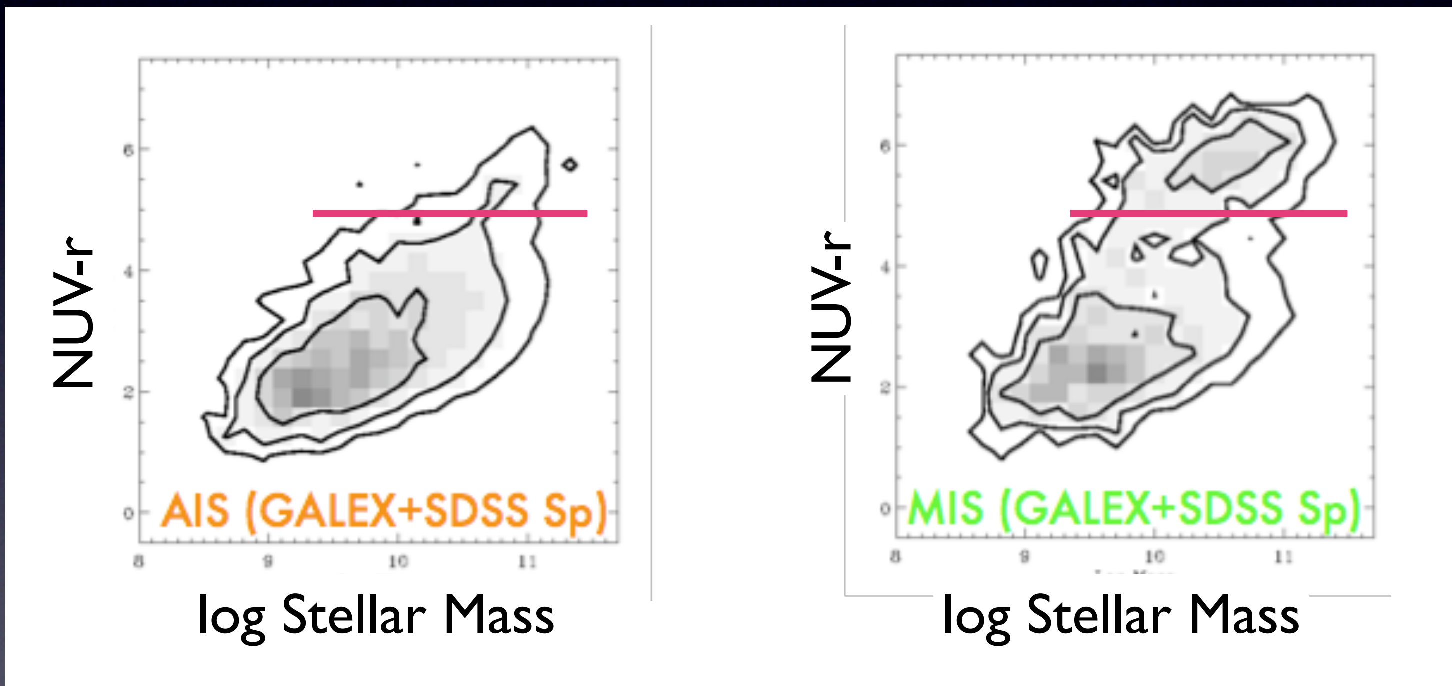
Little variation at constant H_{alpha} Equivalent width

O'Dowd, et al. (in prep)



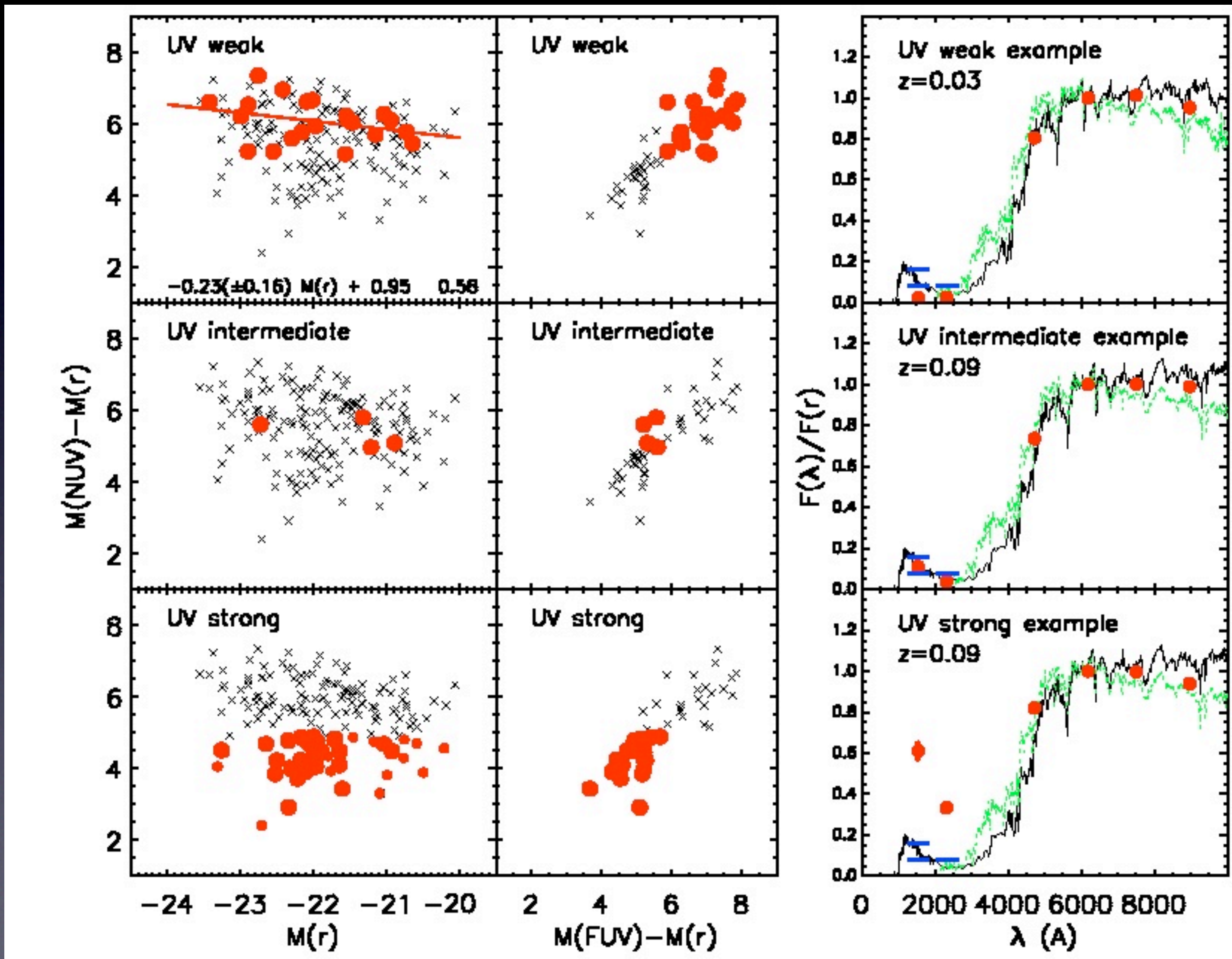
UV-Optical Color Magnitude Distribution: Galaxies in transition

The Importance of MIS depth



Nearly all (~90%) main sample galaxies detected in MIS (vs. ~50% in AIS).

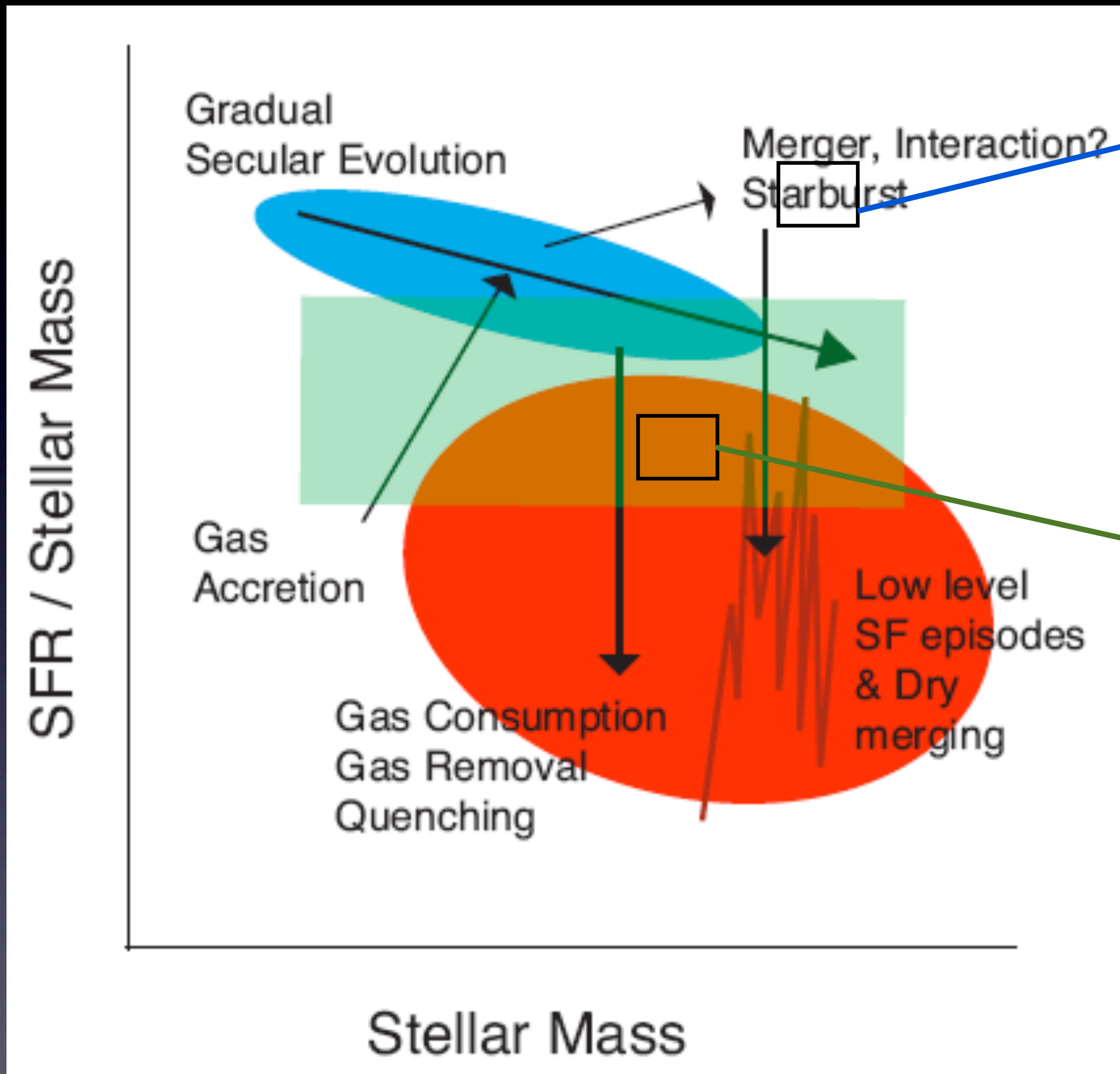
Early type massive galaxies show residual star formation



SFR/<SFR>~ 0.01-0.10

GALEX + SDSS
Yi et al (2005)

SFR/M$_*$ vs. M$_*$ Distribution: Galaxies in Transition



$$\dot{\phi}(SFR/M*, M_*)$$

$$\dot{\phi} = \frac{\phi(SFR/M_*, M_*)}{\tau_{burst}}$$

Evolution off of the SF sequence

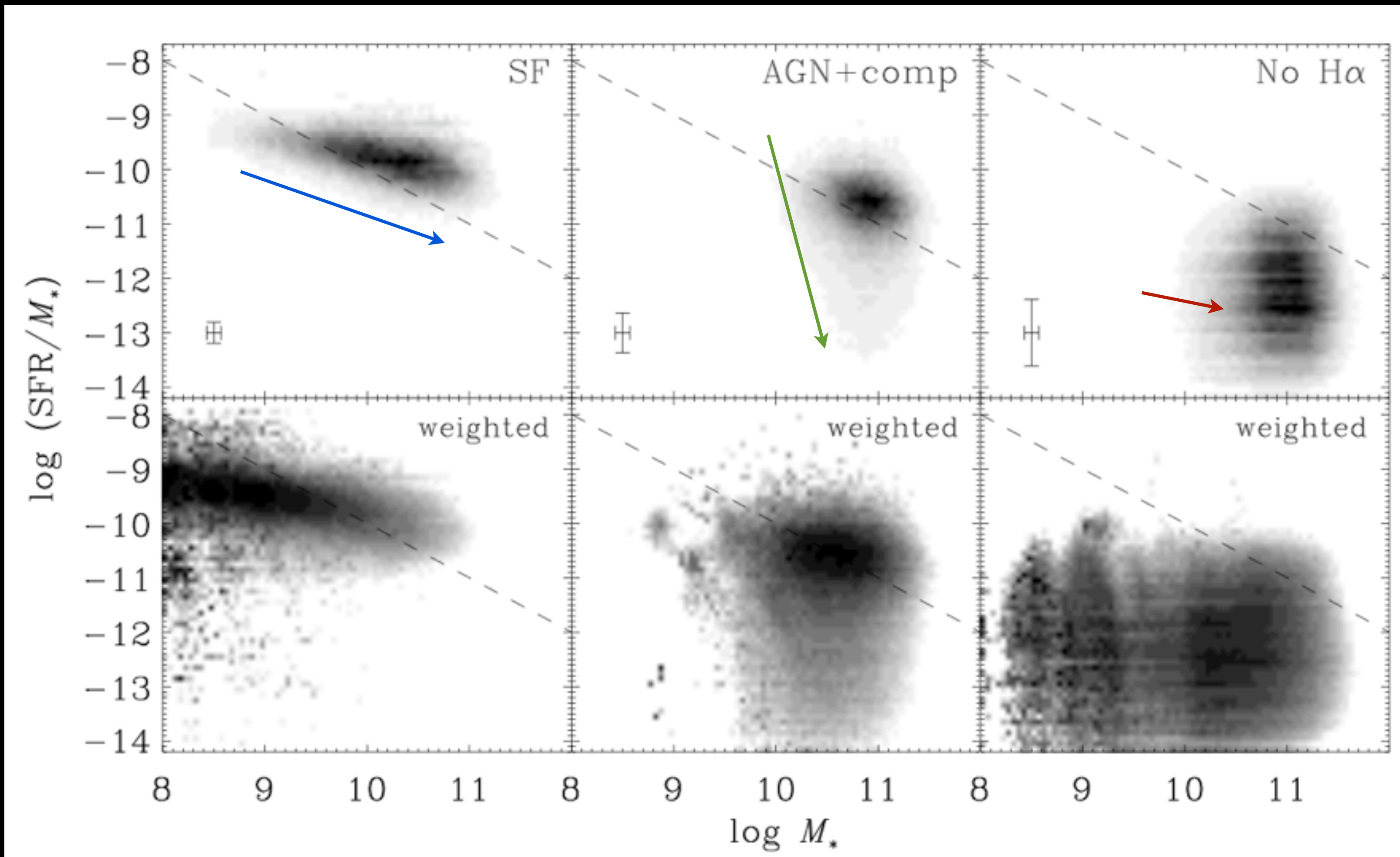
$$\dot{\phi} = \frac{\phi(SFR/M_*, M_*)}{\tau_{blue \rightarrow red}}$$

"Green Valley" evolution

Schiminovich et al. (2007)
Green Valley Evolution: Martin et al. (2007)

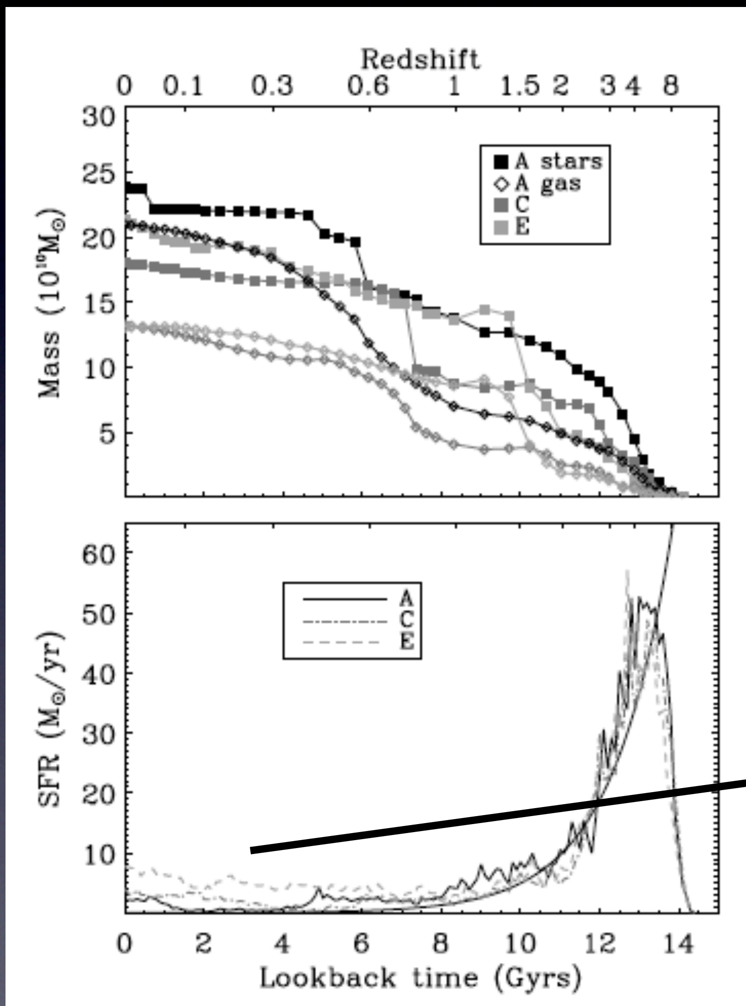
SFR/M_* vs. M_* Distribution: Galaxies in Transition

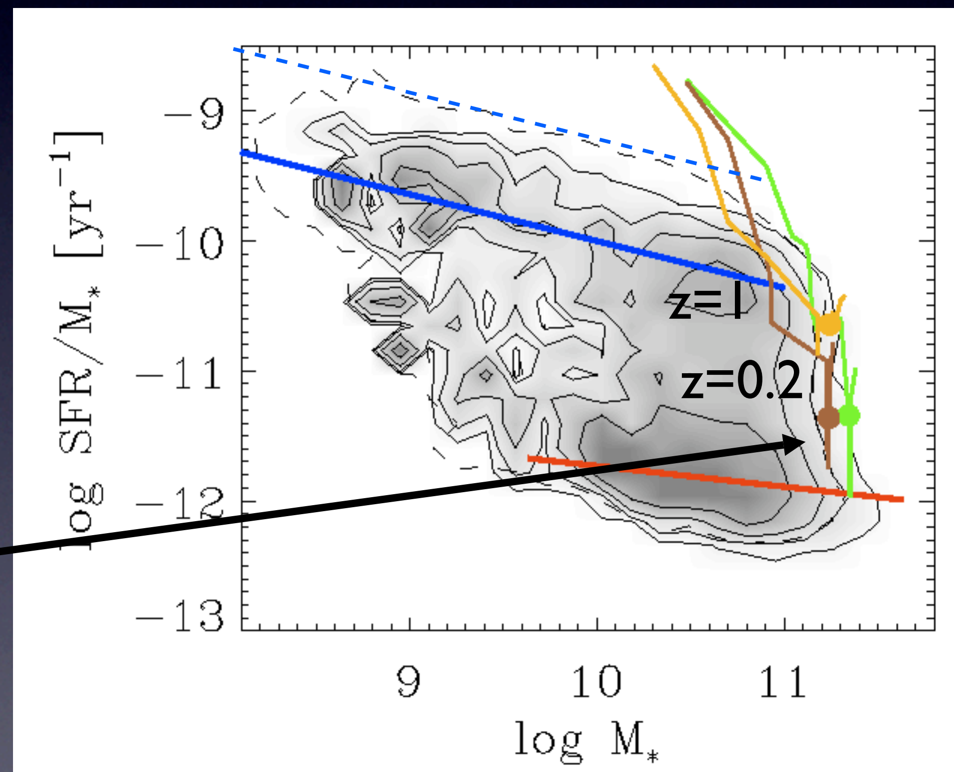
A role for AGN?



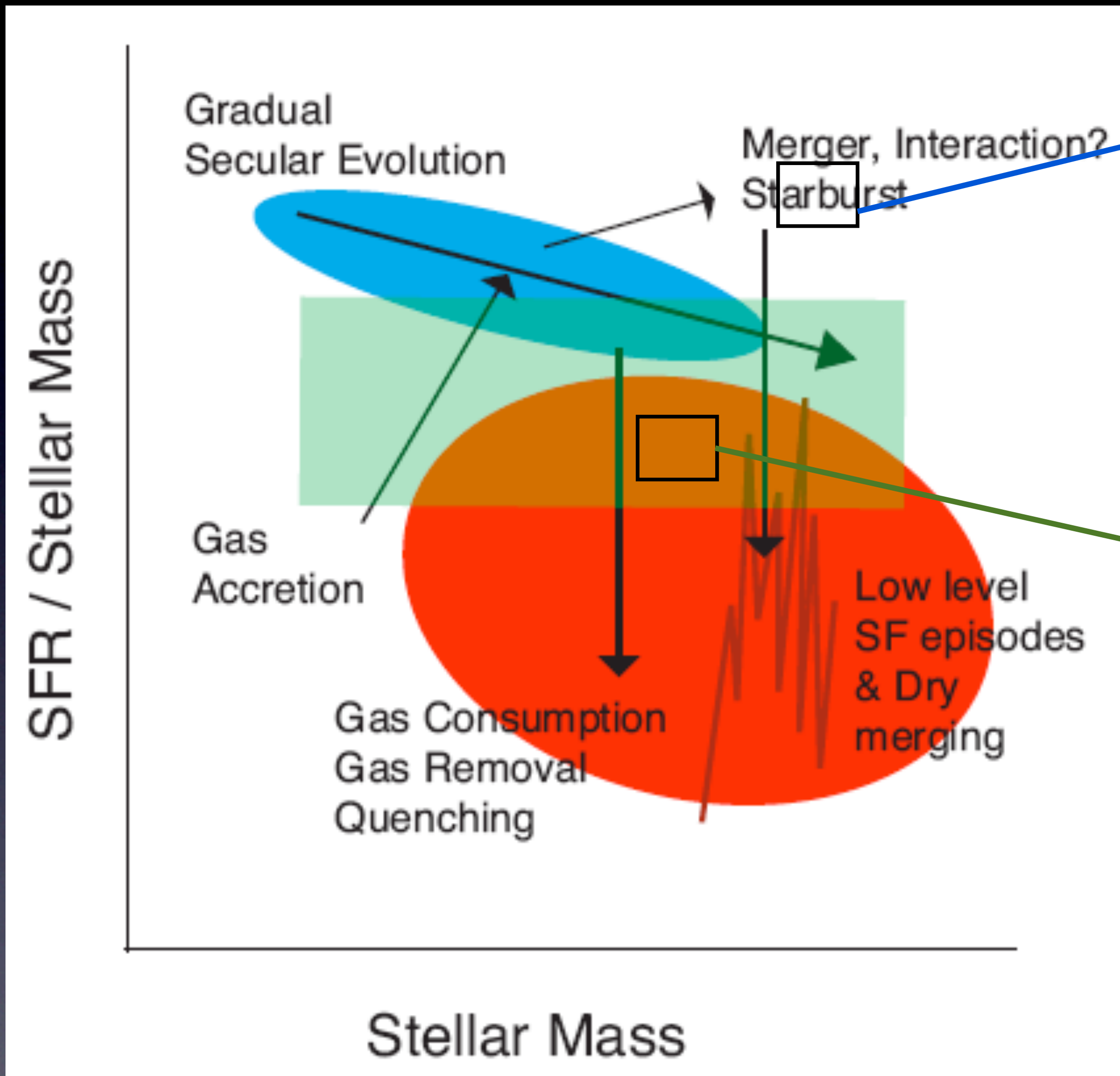
Evolution beyond the Star Forming Sequence: Comparison with Theory

"Formation of Early Type Galaxies from Cosmological Initial Conditions"
Naab, Johansson, Ostriker, Efstathiou (2007)
No Feedback, Single Major Merger





SFR/M$_*$ vs. M$_*$ Distribution: Galaxies in Transition



Schiminovich et al. (2007)
Green Valley Evolution: Martin et al. (2007)

$$\dot{\phi}(SFR/M*, M_*)$$

$$\dot{\phi} = \frac{\phi(SFR/M_*, M_*)}{\tau_{burst}}$$

Evolution off of the SF sequence

$$\dot{\phi} = \frac{\phi(SFR/M_*, M_*)}{\tau_{blue \rightarrow red}}$$

"Green Valley" evolution

Can information about the gas in transition galaxies provide some clues?

A deep, targeted, Arecibo HI survey of massive galaxies

Available samples of massive (log $M_{*}>10$) galaxies have generally been:

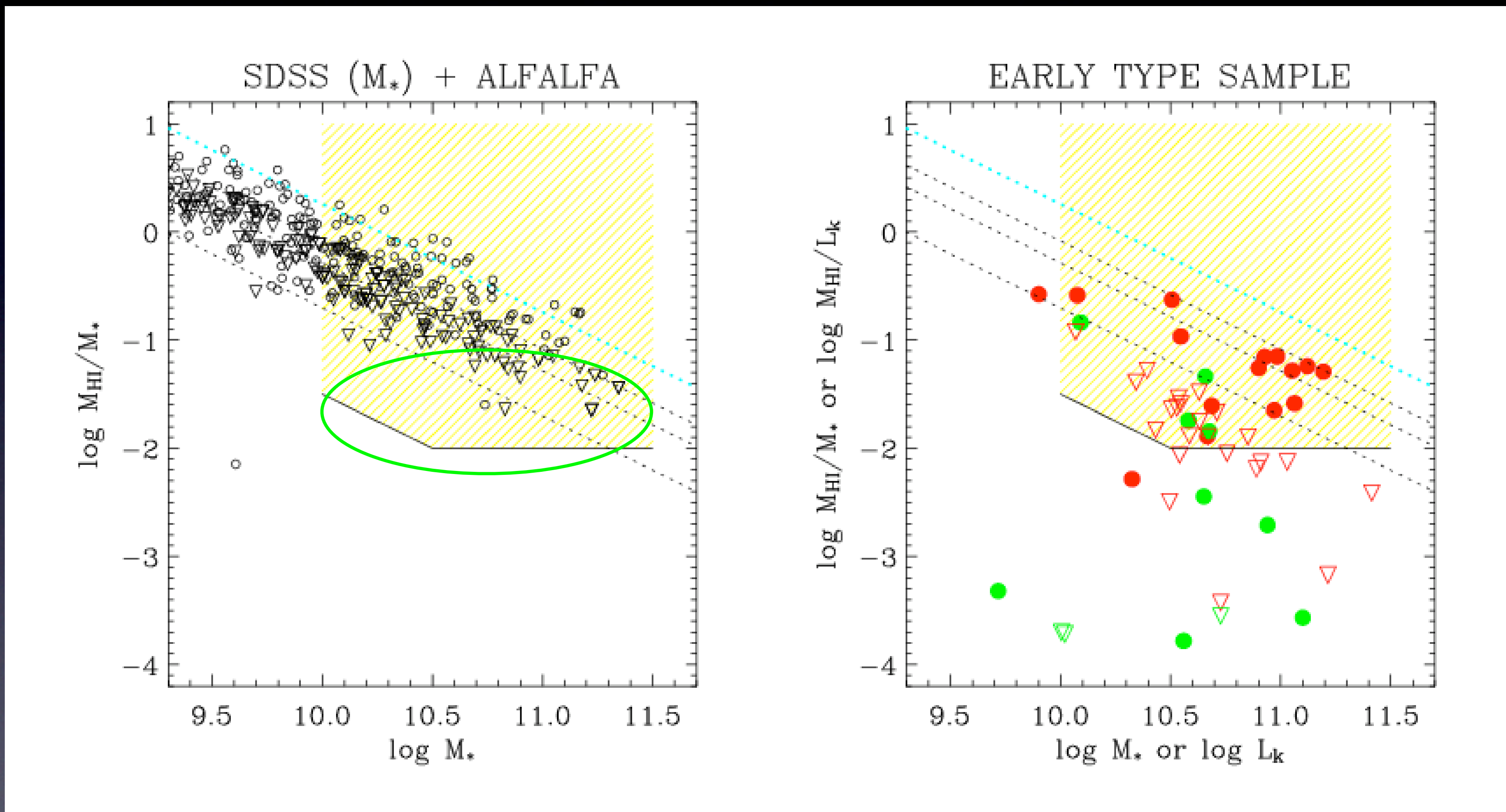
- Heterogeneously collected - Morphological selection, cluster environment, peculiar/unique samples
- HI-selected - inefficient, often with little available corollary data
- Small volumes/numbers - do not sample rich diversity of galaxies in this mass regime (SF and AGN properties, environments)

GASS (GALEX, Arecibo, SDSS Survey)

Schiminovich, Catinella, Kauffmann, Heckman, Haynes, Giovanelli, Blanton, et al.

- Targeted survey of ~1000 galaxies with log M_*>10, 0.025<z<0.05, selected from within SDSS (sp), GALEX and ALFALFA survey footprints.
- Galaxies observed down to constant gas mass fraction limit: f_{gas}>0.01
- Arecibo large program, initial observations began March 08. See Catinella et al. (2008) for details
- First statistically significant sample of massive transitional galaxies with homogeneously measured stellar masses, SFR and gas properties.
- Complementary to Arecibo blind, large area surveys

GASS investigates galaxy evolution at and above the "transition mass" (log M_*>10)

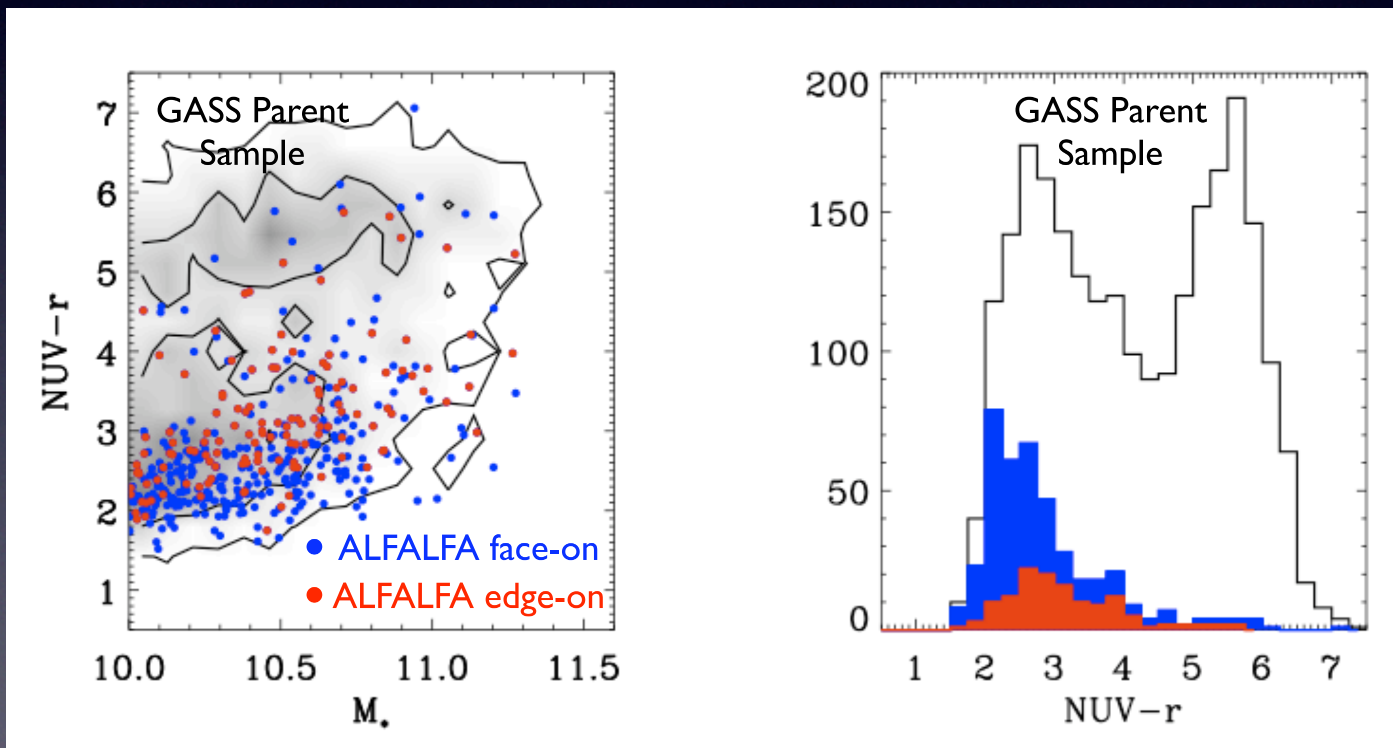


ALFALFA - mostly low M_* SF sequence galaxies from SDSS

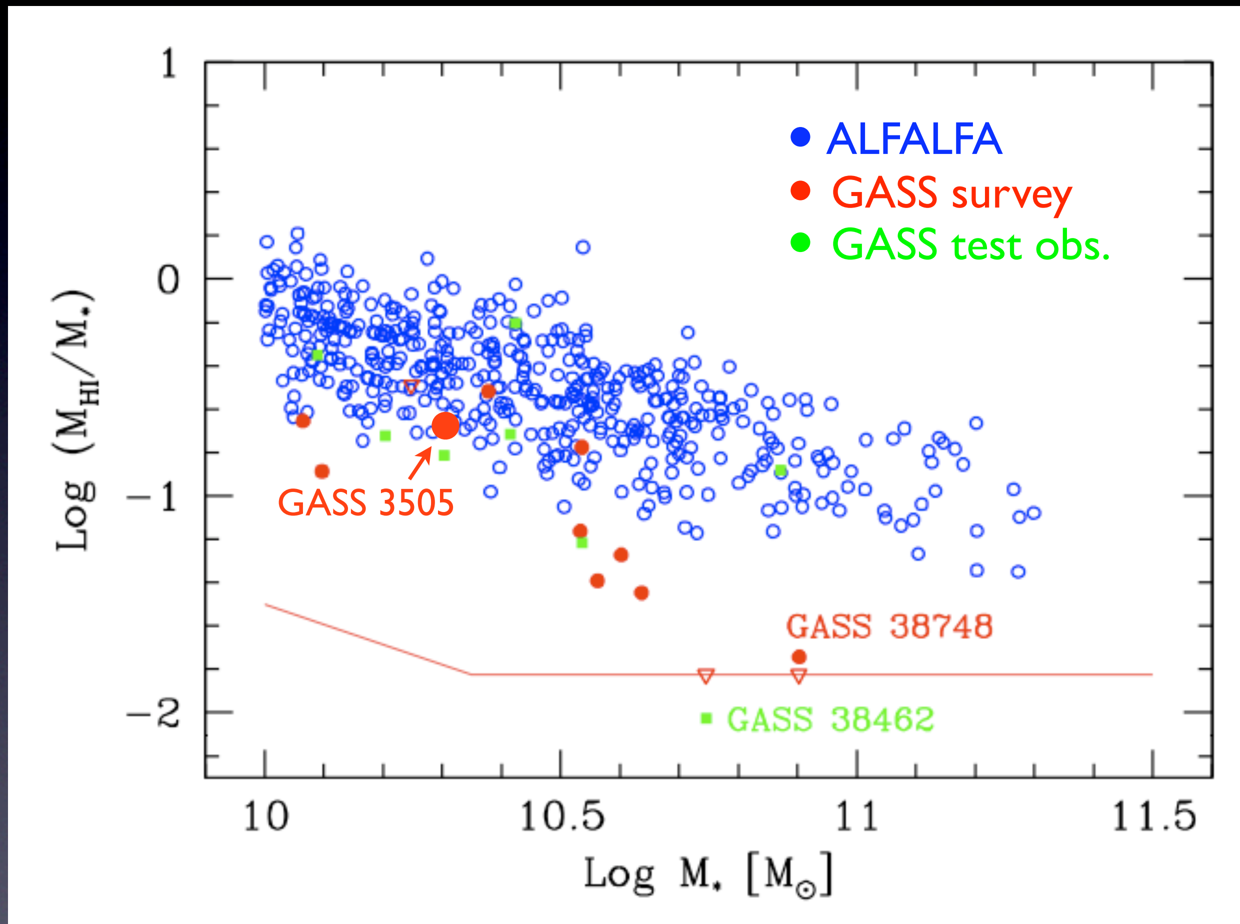
Green: Morganti et al. (2006)- Sauron
Red: Oosterloo et al. (2007) - HIPASS

GASS will measure the HI content of massive (log M_*>10) green valley & red sequence galaxies

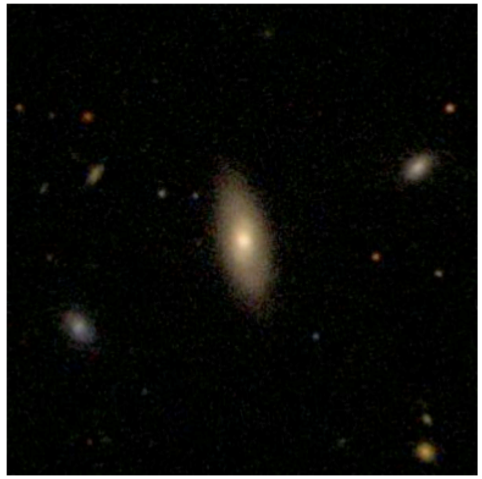
ALFALFA primarily detects massive galaxies on the star-forming sequence, including dusty star-forming galaxies

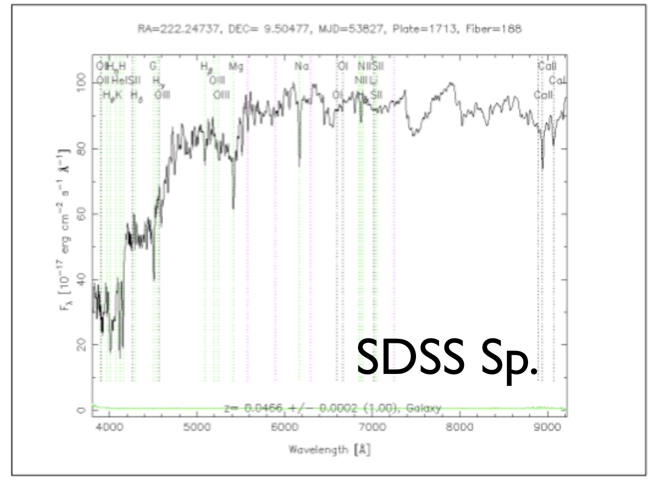


Preliminary results: GASS initial observations (3% of total sample)



Red (transition?) galaxy with 'residual' star formation & moderate gas fraction





<u>GASS 38748</u>

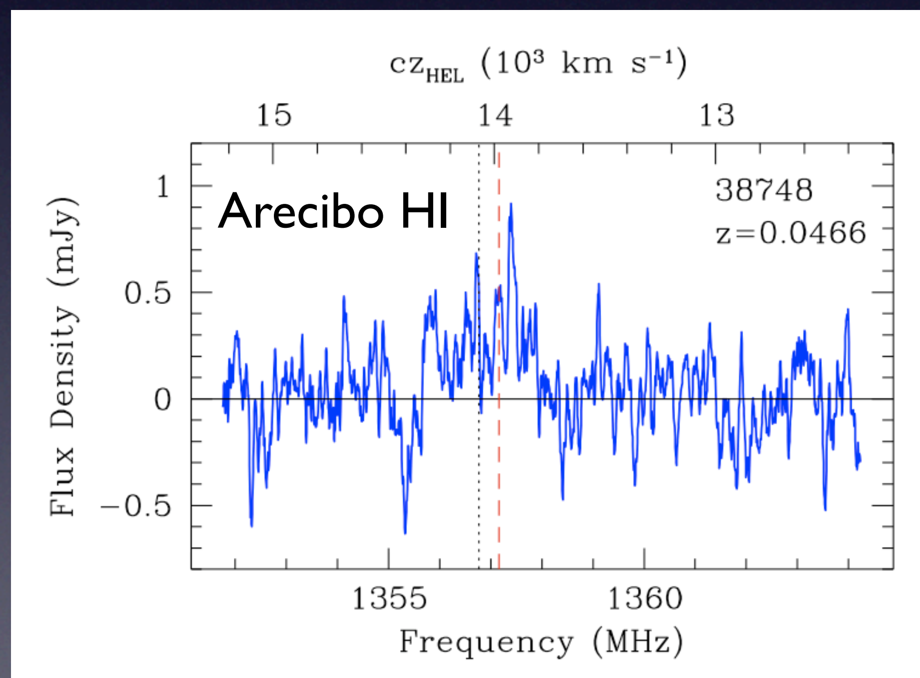
No emission lines

NUV-r ~ 5

z=0.047

log M_{HI}/M_{sol} = 9.23

log M_{*} = 10.9



Gas-rich red (transition?) galaxy w/ ‘residual’ SF

<u>GASS 3505</u>

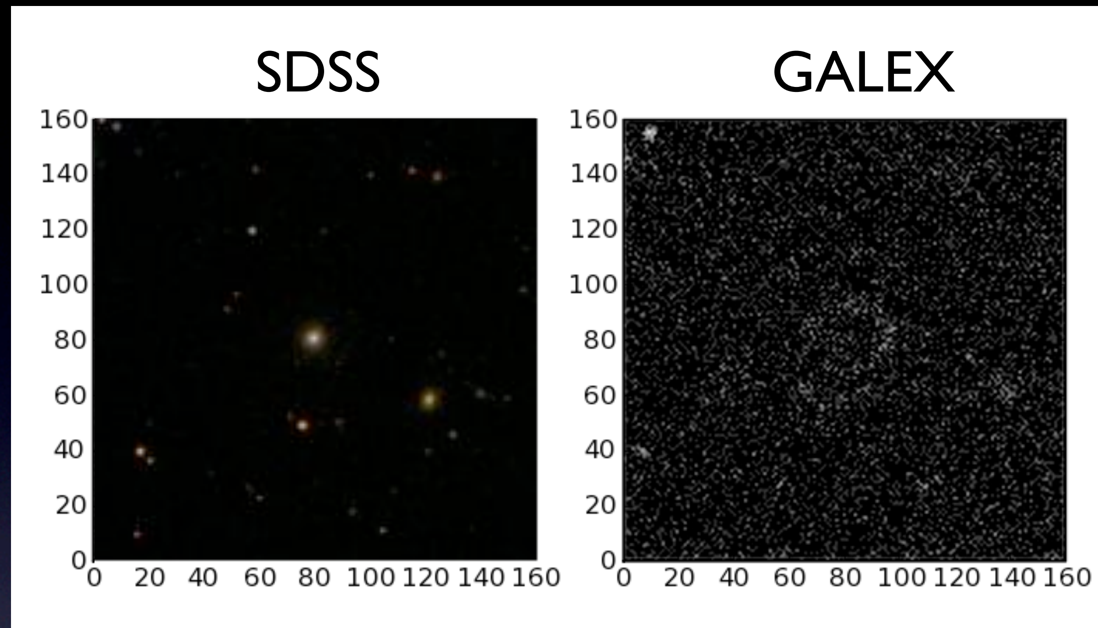
No emission lines

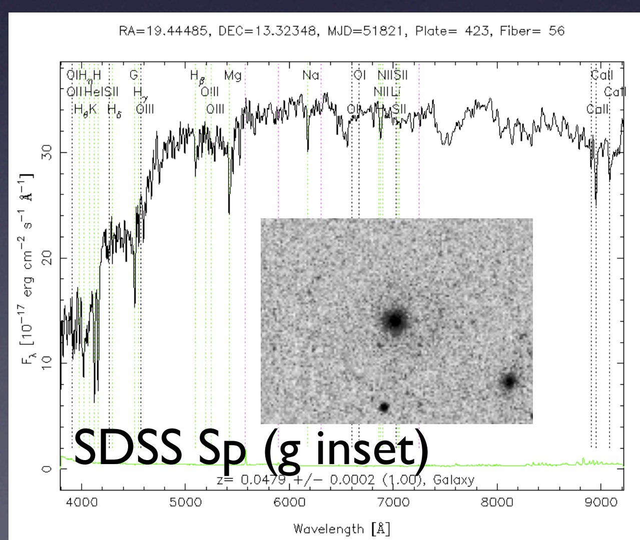
NUV-r ~ 5.5

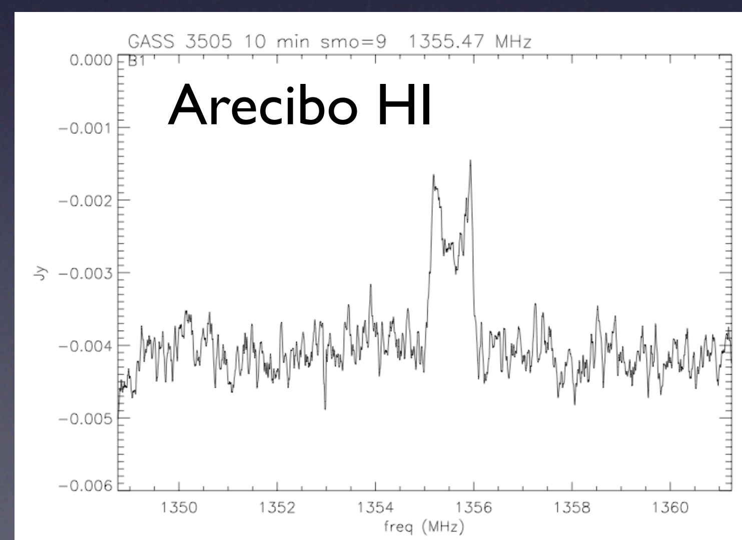
z=0.048

log M_{HI}/M_{sol} = 9.7

log M_* = 10.3







On-going/Future Observations

- S5: Spitzer SDSS Statistical Spectroscopy Survey:
  - IRS spectroscopy of 300 optically selected galaxies (H alpha; no IR selection)
  - Cycle 5 legacy program, more hi-res spectra. (50 observed so far)
- GASS Arecibo survey; VLA follow-up
- GALEX Extended mission
  - Highest priority to extend MIS survey to full SDSS footprint. (4-5 years required)
  - SDSS-III synergy. Luminous blue galaxies at z~0.6. Hi-z QSO selection