New Lessons from Panchromatic Observations of the SDSS Main Galaxy Sample

David Schiminovich
Columbia University
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

Salim et al. (2007)
GALEX
Galaxy Evolution Explorer
Surveying the Ultraviolet Universe
A Brief History

• 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
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

UV-Optical Color Magnitude Distribution: Converting to Physical Properties

- Observed Distribution
  - weight: $I/V_{\text{max}}$
  - Wyder et al. (2007), GALEX ApJS

- “Dust-corrected” Distribution
  - using Johnson et al. (2007) empirical corrections

- UV,cor$\rightarrow$SFR
  - $M_{r,\text{cor}}$$\rightarrow$$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)

Star-forming sequence

Residual star formation “Green Valley”

’SRed sequence’:
Upper limit to SFR/M*

SFR = 1 M☉ yr⁻¹

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

![Graph showing connections between SDSS and Spitzer IRS spectra, with UV, Optical, and IR regions and labeled spectral characteristics.](image-url)
Spitzer IRS spectra for SINGS sample (e.g. Smith et al 2007)
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-IR 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)
Derived MIR Physical Properties of SSGSS Sample
da Cunha (Ph.D. thesis, IAP; Charlot advisor)

\[ \frac{L_{\text{IR}}(\text{Diffuse ISM})}{L_{\text{IR}}(\text{Tot})} \quad \frac{L_{\text{IR}}(\text{PAH})}{L_{\text{IR}}(\text{Tot})} \quad \frac{L_{\text{IR}}(\text{Warm dust})}{L_{\text{IR}}(\text{Tot})} \]

\[ \frac{L_{\text{IR}}(\text{Cold dust})}{L_{\text{IR}}(\text{Tot})} \quad \frac{\text{Dust mass}}{M_*} \quad \frac{\text{Dust mass}}{(\text{SFR}/10^8 \text{ yr})} \]
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)
Nearly all (~90%) main sample galaxies detected in MIS (vs. ~50% in AIS).
Early type massive galaxies show residual star formation

SFR/\langle SFR\rangle \sim 0.01-0.10

GALEX + SDSS

Yi et al (2005)
Evolution off of the SF sequence

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
Evolution off of the SF sequence

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

"Green Valley" evolution

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

- 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: $f_{\text{gas}}>0.01$
- 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)

![Graph showing Log (M_H/M_☉) vs. Log M_☉ with markers for ALFALFA, GASS survey, and GASS test obs. with specific points labeled as GASS 3505, GASS 38748, and GASS 38462.]
Red (transition?)
galaxy with
‘residual’ star
formation &
moderate gas
fraction

GASS 38748
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

**GASS 3505**
- No emission lines
- NUV-r ~ 5.5
- $z=0.048$
- $\log M_{\text{HI}}/M_{\text{sol}} = 9.7$
- $\log M_*= 10.3$

[Images of SDSS, GALEX, and Arecibo HI spectra are shown.]

**SDSS Sp (g inset)**

**Arecibo HI**
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