Star Formation in Nearby Galaxies:
Evolution in Your Neighborhood

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+ Many Others + ....

Legacy ExtraGalactic

LEGUS

Ultraviolet Survey

Star Formation Across Space and Time,
ESA-ESTEC, Noordwijk, The Netherlands, 11-14 Nov. 2014
Göran’s Introduction yesterday reminded me of something...
What about a 30 meter far-infrared (40-400 μm) telescope in space?

~1” at 150 μm
Angular Resolution - 1

M83 - GALEX

Thilker et al, 2005

GALEX resolution ~ 5”, similar to Herschel/70

How do I infer that these are stellar clusters, how many, their stellar population content? (degeneracies: dust, metallicity, age, etc.)
Angular Resolution - 2

M83 - HST/ACS

Thilker et al.

Resolution $\sim 0.1''$

I rest my case.
Angular Resolution - 2

M83 - HST/ACS

Thilker et al.

Resolution ~ 0.1"

I rest my case.

Truth in advertising: THIS is 1”
The LEGUS Team

Red for Senior Advisory Group
Blue for Science, Data Processing, EPO Leads

54 investigators (so far) at 30+ Institutions (US+EU):

Across Time...

We are currently in a position to describe to some accuracy the evolution of SFR and mass assembly across cosmic times...

Madau & Dickinson 2014, ARAA

Cosmic SFR

Mass Assembly
Across `Space’?

We can’t yet connect the two scales of `global’ galaxies and stars/star clusters:

- How do stars form? Always clustered? In a scale—free hierarchy? (Elmegreen et al. 2006)
- Do we have one or two modes of star formation (clustered and diffuse)? (Meurer et al. 1995, Crocker et al. 2014)
- How has the mode of SF evolved with time? ($10^9$ $M_\odot$ clump at $z\sim1$)
- On what timescale do stars disperse?
- What are the bound structures (star clusters) tracing? How do they evolve?
- How does SF power the ISM?
- Do we have a universal stellar IMF?
- How are `local’ SFRs affected?

The über-questions:
1. How does the Hubble sequence form?
2. How is SF linked to the gas supply (Kennicutt-Schmidt Law)?
3. What is the role of feedback in shaping galaxies and regulating SF?
The KS Law: One or Many?

\[ \Sigma_{SFR} \sim \Sigma_{gas} \]

\( \gamma_{gas} = 1.4 \)

Connected to physics

\[ \gamma_{\text{H}_2, \text{local, obs}} = 0.7, 1, 1.4, ... \]  

See, also, Blanc+2009, Shetty+2014

Cloud-counting C+2012
A common characteristic of local spirals: GALEX FUV-NUV color maps show that interarm regions have redder UV colors than arm regions. This cannot be an effect of differential attenuation.

Interarm regions in M101 do not contain stars younger than ~40 Myr (or more massive than ~10-15 M_☉) (Crocker et al. 2014, HST UV)

In starburst galaxies, the intercluster light only shows evidence for B stars (no O stars, like clusters). IC light = 80% of all UV light.

Dispersion of clusters (Tremonti et al. 2001, Chandar et al. 2005) or two modes of SF (Meurer et al. 1995)?
The Stellar IMF

Kroupa (2001) and Chabrier (2003) formulations are roughly equivalent to each other. For Kroupa:

\[ \chi(M) = \frac{dN}{dM} = A M^{-1.3} \quad 0.1 \leq M(M_\odot) \leq 0.5, \]
\[ = 0.5 A M^{-2.3} \quad 0.5 \leq M(M_\odot) \leq 120 \]

Variations in the IMF can crucially affect SFRs:
\[ SFR(\lambda) = C(IMF, SFH) \times L(\lambda) \]

Stochasticity in IMF sampling:
- In order to fully sample the Kroupa IMF, at least \( 2.7 \times 10^5 \) M\(_\odot\) in stellar mass need to be formed (4.2 \( \times 10^5 \) stars!).
IMF Variations in/between Galaxies?

SFR(λ) = C(IMF,SFH) x L(λ)

The effect can result if:
1. Small galaxies only form small clusters (Larsen 2006)
2. Small clusters only form low-mass stars (sorted IMF sampling, Weidner+2006)

Lee+2009
See, also, Hoversten +2008, Meurer+2009, Gunawardhana+2011

UGC8201, UV(GALEX)+Hα+24(Spitzer)
One of the most subtle ways to `vary' the IMF is to make the stellar population of a system (e.g., a star cluster) dependent on some parameter of the system itself (e.g., its mass). This is the principle of the IGIMF theory of Weidner et al. (Weidner & Kroupa 2005, Pflamm-Altenburg+2009, Weidner+2010).

In the IGIMF theory, the maximum stellar mass formed in a cluster is a (stochastic) function of the cluster mass. I.e., stars form from the `bottom up'.

Weidner, Kroupa & Bonnell 2010
The WKB10 IGIMF theory is degenerate with:
2. Loss of ionizing photons in low-mass galaxies (Hunter+2010, Pellegrini+2012)

Do NOT Assume...

… that all these issues are uncorrelated. For instance, cannot assume that there are two modes of SF without also assuming that the high-end of the IMF changes.

UV-red interarm SF regions = truncated IMF (or sorted-sampled IMF)
How to Make Progress...

(hint: need exquisite resolution on a statistically significant number of galaxies)

- Recent SFHs (< 100 Myr) as a function of location
  - Catalogs of UV stars (location, luminosity, etc)
  - HST 5-band photometry (Cycle 21 LEGUS)
- Cluster populations evolution, formation history
  - Catalogs of young clusters (ID, location, mass, age)
  - HST 5-band photometry (Cycle 21 LEGUS)
- Ionized gas, HII regions distributions
  - Hα images
  - HST (Cycle 22 Halpha-LEGUS)
- Ionized gas conditions, gas extinction maps
  - Spectral maps
  - Ground-based IFU, narrow-band imaging, long slit spectroscopy
The Project

- Cycle 21 HST Treasury Program (154 primary + 154 parallel Orbits)
- 50 galaxies, in the range 3.5-12 Mpc, in 126 pointings (63 primary); 100% complete as of Sept 2014.
- Primary: WFC3/NUV, U, B, V, I (5 bands) – leverage the HST Archive as much as possible
- Parallel: ACS/B, V, I

LEGUS footprint=magenta
LEGUS parallels=blue
Archival data=red
Full range of basic properties (morphology, sSFR, SFR, mass, interaction type, presence/absence of bars, etc.) found in the local Universe, < 12 Mpc.

Color-composites: NUV (blue), B (green), and I (red)
Star-Clusters: Age+Masses via BB Photometry

NGC5253
3.7 Mpc

5th band breaks degeneracy in SED fitting. UV more stable (~4X) than Hα for separating young, Qo-deficient from aging clusters, esp. at low cluster masses (da Silva+2014)
Test the High-End of the IMF

5 bands (UV-to-I) to derive ages, masses, extinctions of star clusters *at all masses*, with stochastically sampled models (LEGUS-like).

Additional information required: extinction-corrected ionizing photon flux: Hα (e.g., Halpha-LEGUS) + one other recombination line (e.g., ground)
Why Do We Need Hα?

Andrews+2013, 2014

(Also, C.+2010, Hermanowicz+2012)

$L(H\alpha)$ probes the ionizing photon rate (presence of massive stars) in unresolved, young star clusters.

A luminosity-independent extension of Corbelli et al. 2009
What the high $\text{H} \alpha / M_{\text{cl}}$ Look like...

M83 clusters: high $\text{H} \alpha$, with cluster mass $< 1500$ M$_\odot$

Andrews et al. 2014
Similar results hold for integrated galaxy photometry (Fumagalli et al. 2011)
Conclusions

1. The **spatial** (and not only temporal) **evolution of stellar populations** has major impact on our understanding of:
   1. Presence of multiple modes of SF
   2. Variations of the high-end of the IMF
   3. Calibration of local SFR(UV); (e.g., resolved KS Law)
   4. Dynamical evolution of galaxies
   5. Models of formation of massive stars (competitive accretion vs. core collapse)

2. To the extent that we have been able to test, variations of the **stellar IMF at the high end** are unlikely to occur in the star cluster populations of nearby galaxies. More tests will be necessary, to bring this result to a statistically significant level and to **capture the full range of galactic environments**.

3. And….
   1. We **NEED** a 30-meter far-infrared telescope in space.