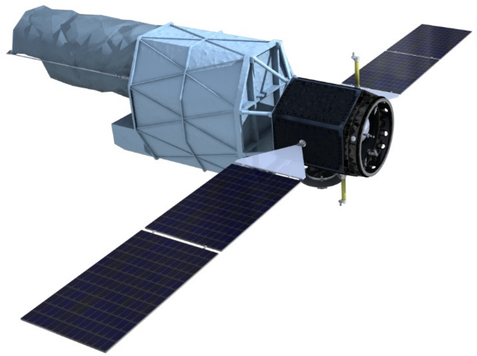
Star Formation in Dwarf Galaxies

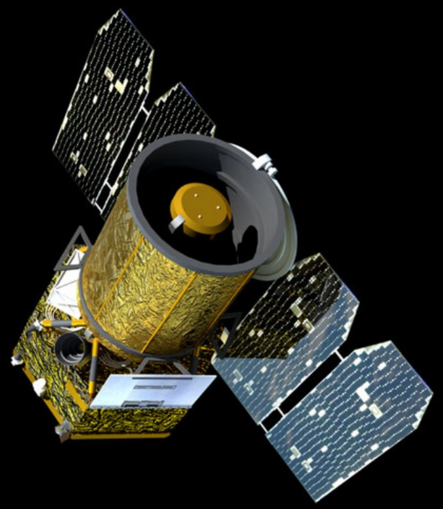
Lessons for UVEX Exploration of the Low Mass Galaxy Frontier from GALEX



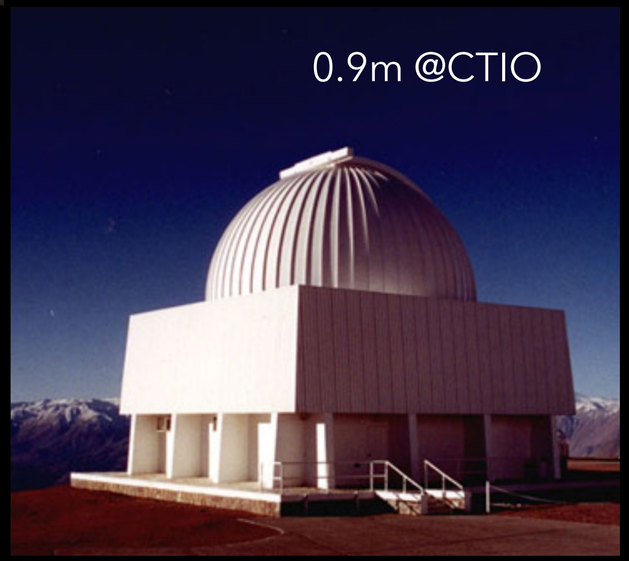
Janice C. Lee
Gemini Observatory/NOIRLab
UVEX Community Meeting
March 14 2023

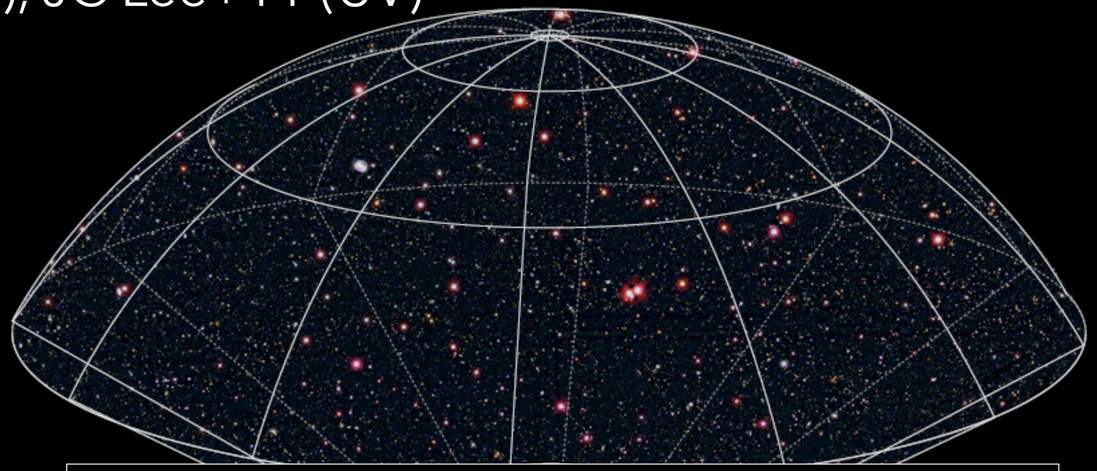
11 Mpc Halpha Ultraviolet Galaxy Survey

Kennicutt+08 (Halpha), JC Lee+11 (UV)



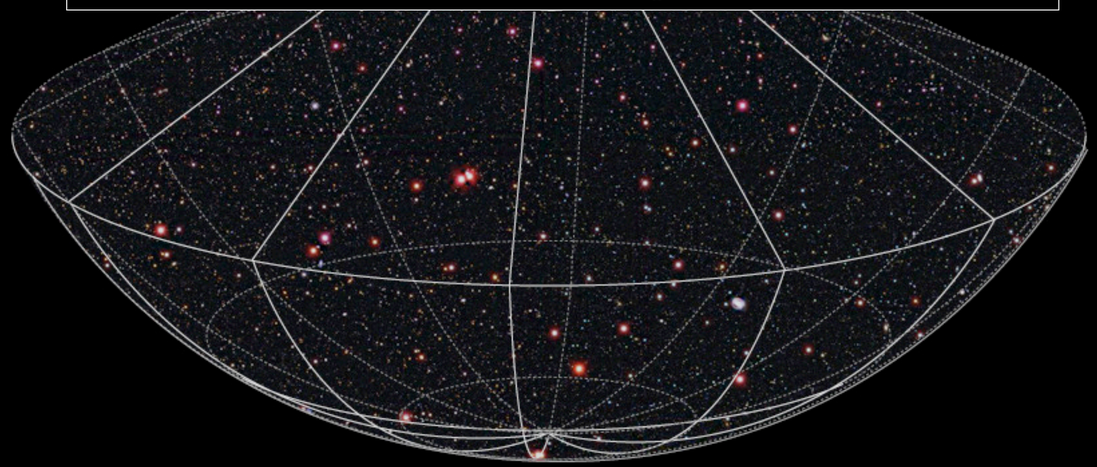
GALEX (Martin+05)





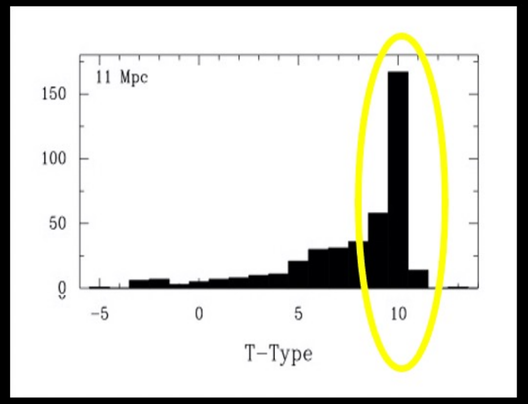
~400 late-type galaxies within 11 Mpc

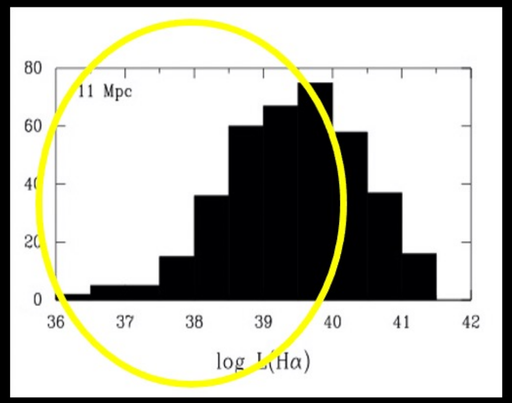
~260 galaxies in complete sample
|b|> 20 deg, B<15, T>0
+
~170 additional galaxies

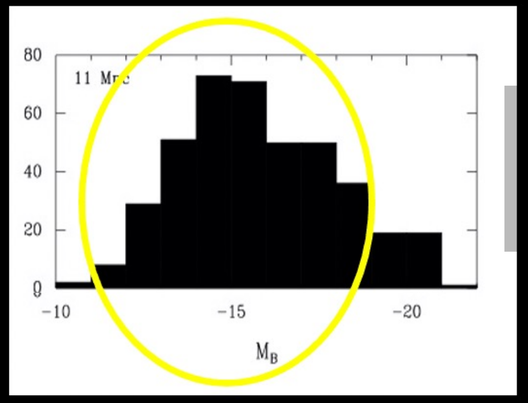


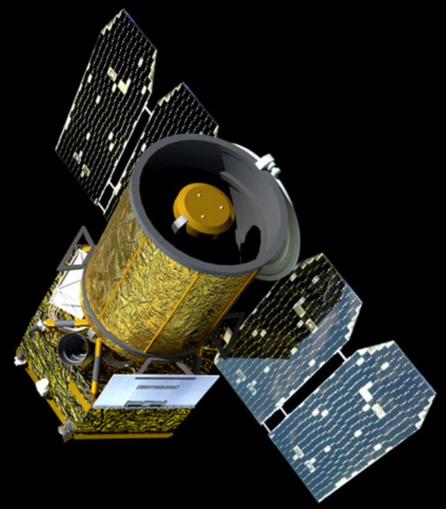
11 Mpc Halpha Ultraviolet Galaxy Survey

Kennicutt+08 (Halpha), JC Lee+11 (UV)









GALEX (Martin+05)

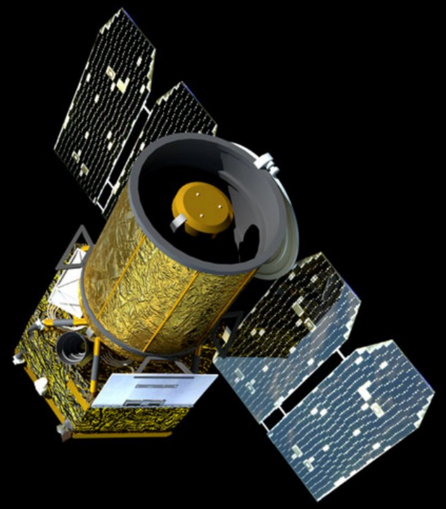
>80% of sample less luminous, lower SFR than LMC

Meet the Neighbors

The Spitzer Local Volume Legacy Survey

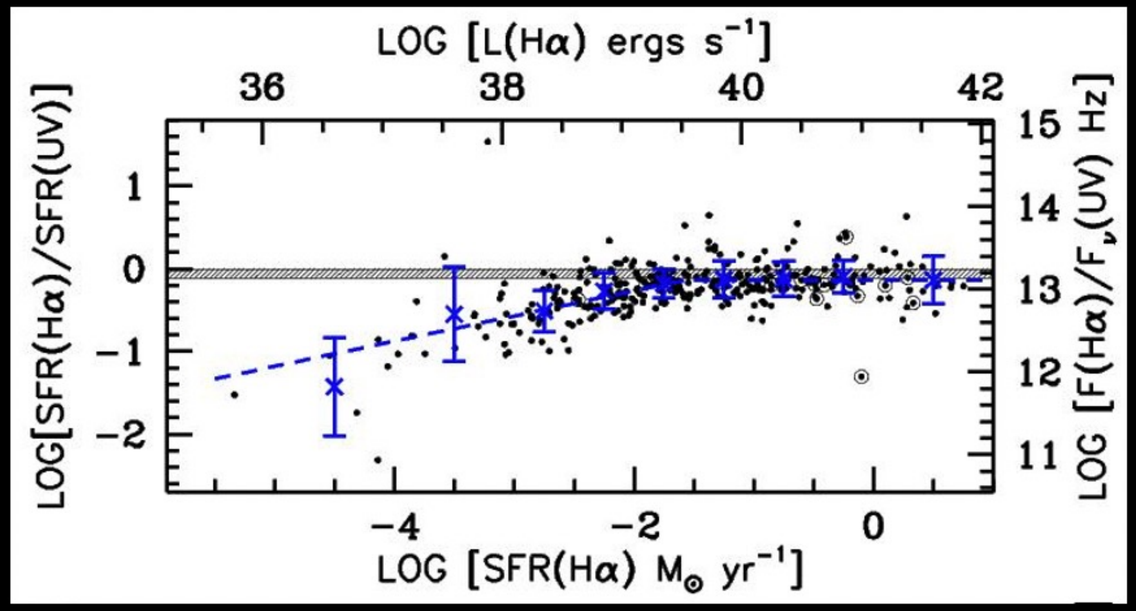
~400 late-type galaxies within 11 Mpc

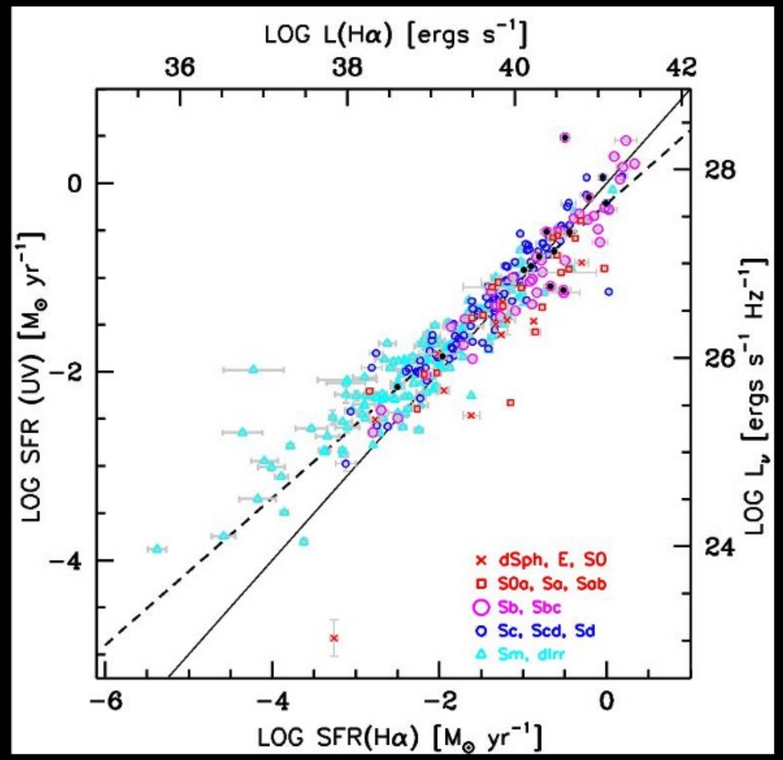
~260 galaxies in complete sample
|b|> 20 deg, B<15, T>0
+
~170 additional galaxies



GALEX (Martin+05)

Lesson 1: Hα does not faithfully trace SFR in the low density regime (SFRs<0.01 Msun/yr)



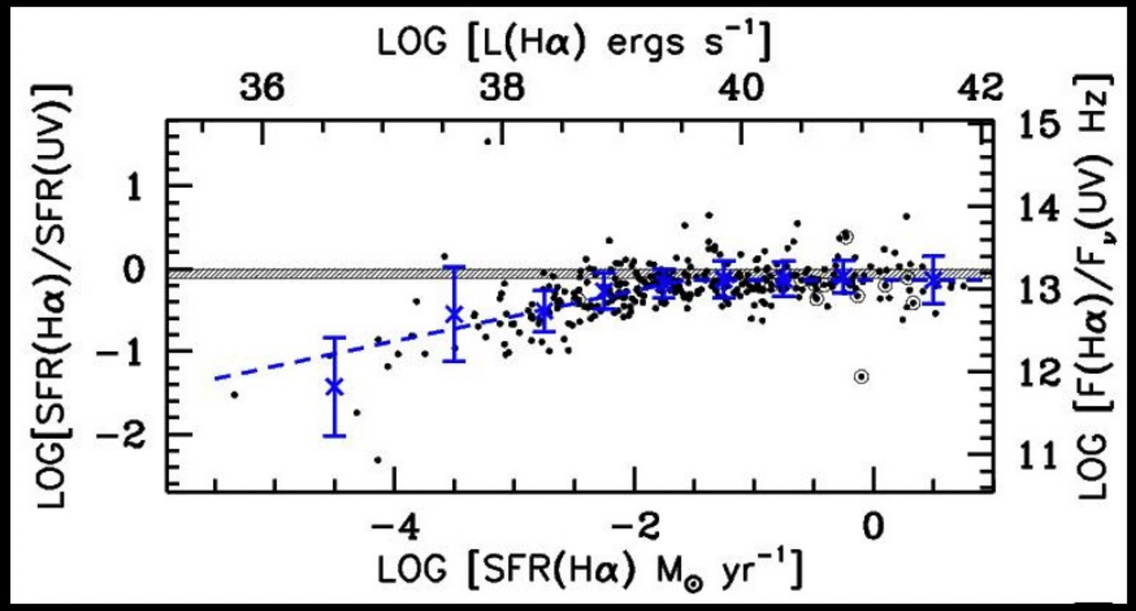


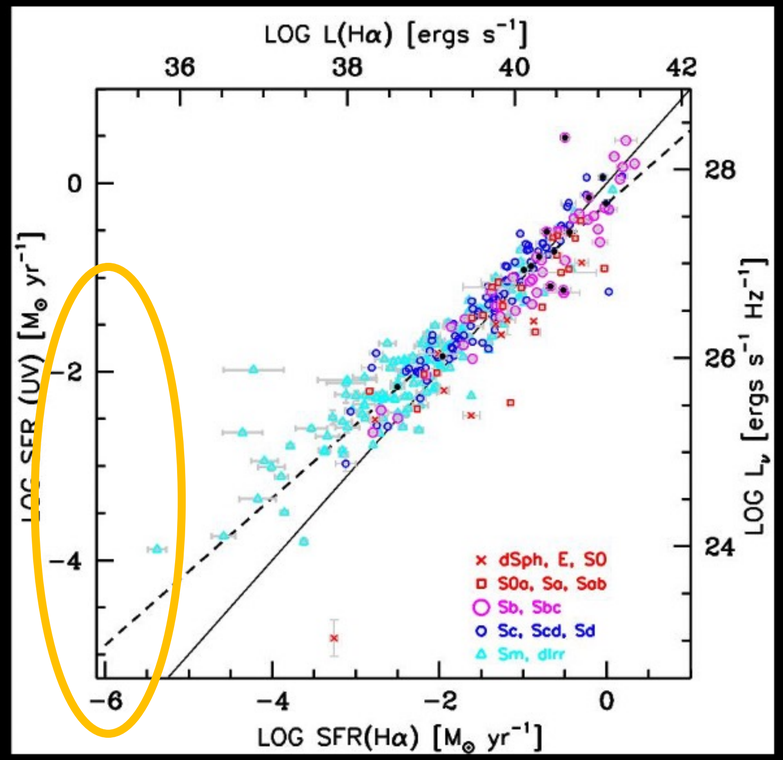
JC Lee+ 09b

L(Hα)/L(FUV) systematically declines for dwarf galaxies

Population synthesis assumptions underlying L(Hα)/L(FUV) or SFR/L=C

- universal IMF (Salpeter, Kroupa)
- fully populated IMF (M_{up}=100)
- stellar evolution tracks and model atmospheres ($Z=Z\odot$)
- continuous star formation over *teq*
- case B recombination (for Hα); no leakage of ionizing photons
- L represents intrinstic, dust corrected values





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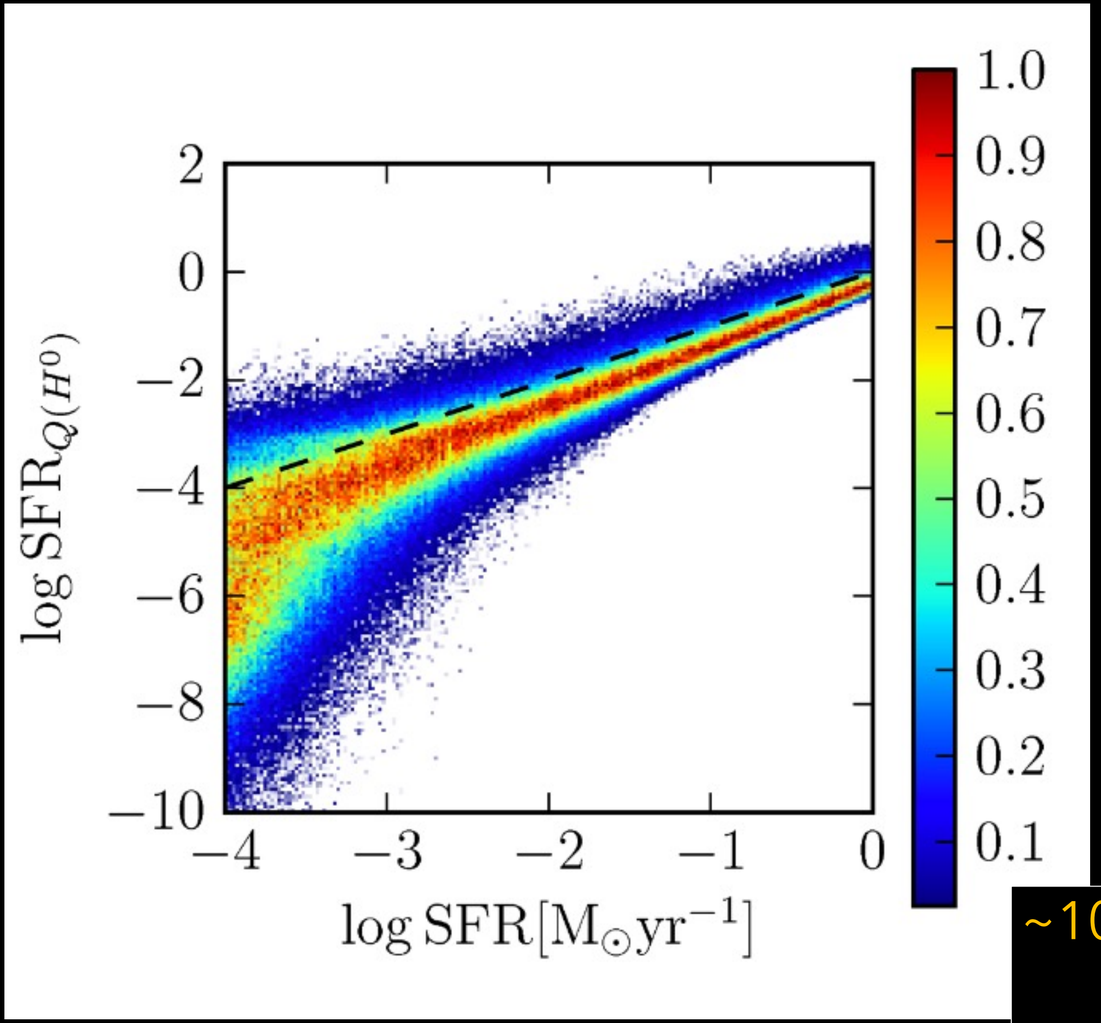
~10 O stars in ~5000 Msun SSP
→ SFR ~10^{-3} Msun/yr

SLUG – Stochastically Lighting Up Galaxies – II. Quantifying the effects of stochasticity on star formation rate indicators

Robert L. da Silva,[1⋆] Michele Fumagalli[2,3⋆] and Mark R. Krumholz[1⋆]

[1]*Department of Astronomy and Astrophysics, University of California, 1156 High Street, Santa Cruz, CA 95064, USA*
[2]*Institute for Computational Cosmology, Department of Physics, Durham University, South Road, Durham, DH1 3LE, UK*
[3]*Carnegie Observatories, 813 Santa Barbara Street, Pasadena, CA 91101, USA*



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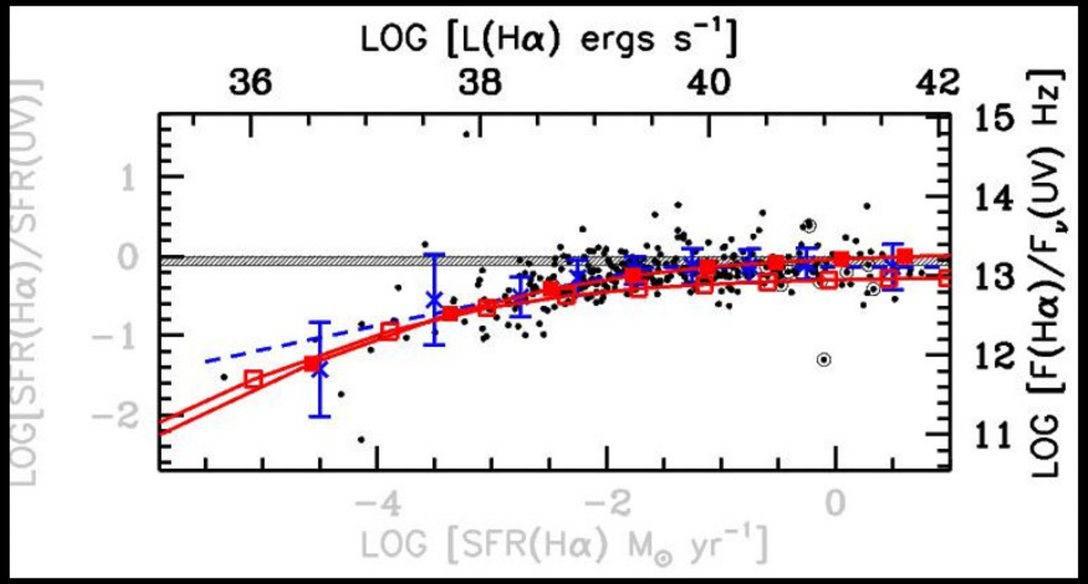
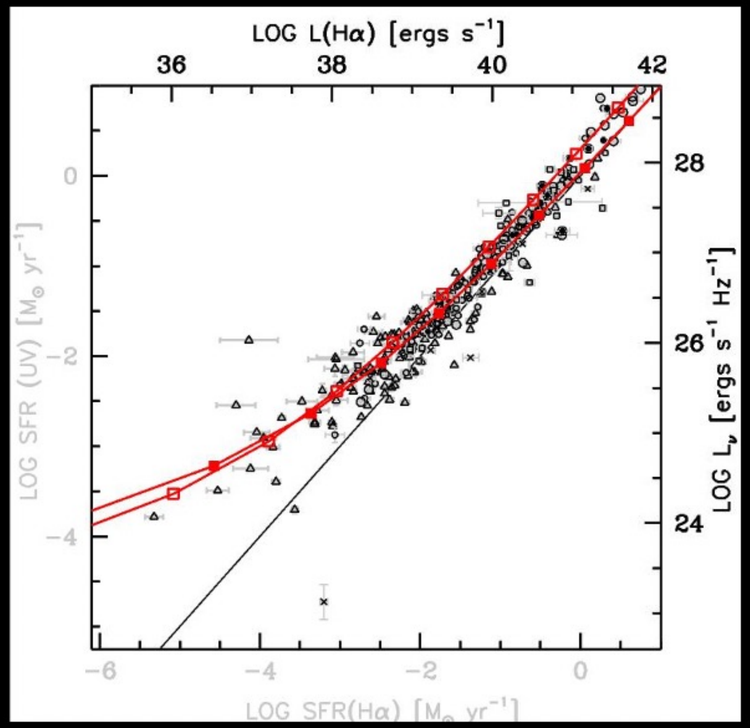
da Silva+ 14

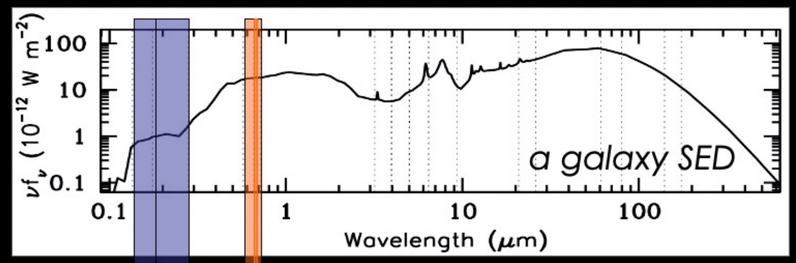




JC Lee+ 09b

L(Hα)/L(FUV) systematically declines below SFR~0.01 Msun/yr

- FUV more robust to stochasticity
- Hα underestimates SFR

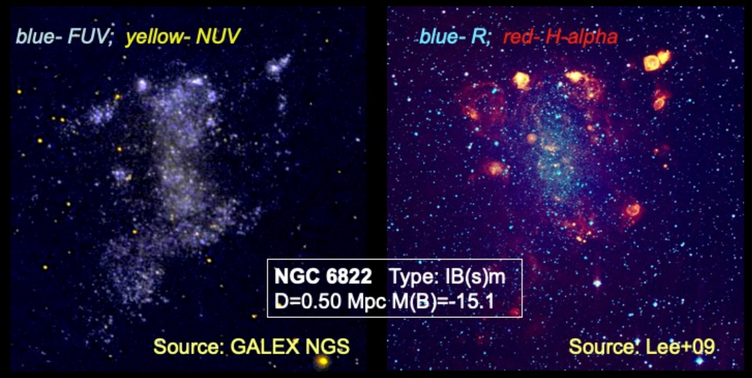


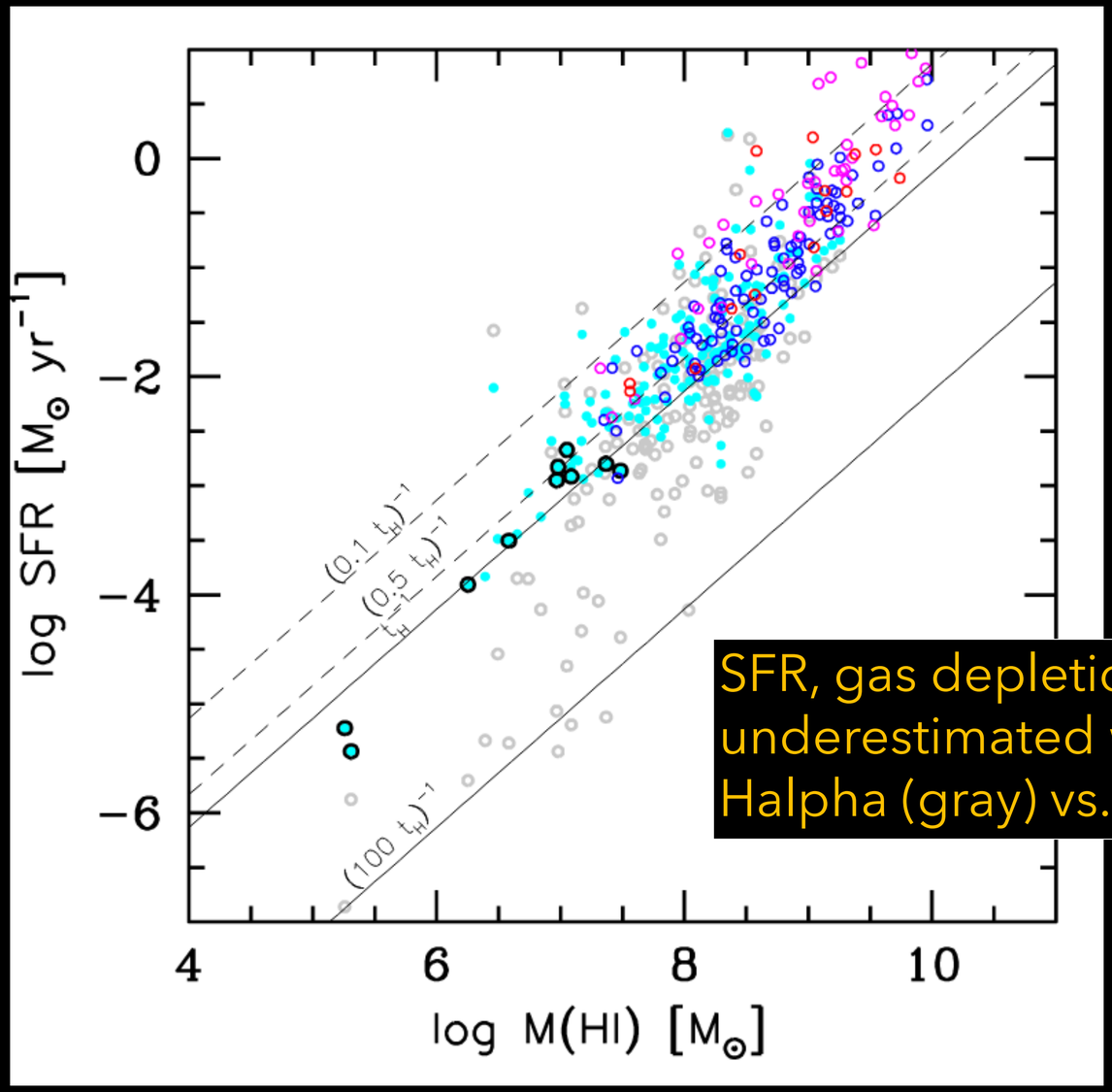
FUV

Hα & R

Photospheric emission from O & B stars; traces SF over last ~100 Myr

Recombination emission of gas ionized by O stars; traces SF over last ~5 Myr

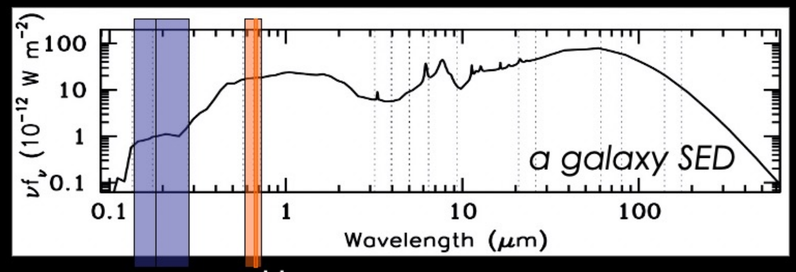




SFR, gas depletion times underestimated with Halpha (gray) vs. FUV (color)

L(Hα)/L(FUV) systematically declines below SFR~0.01 Msun/yr

- FUV more robust to stochasticity
- Hα underestimates SFR



FUV

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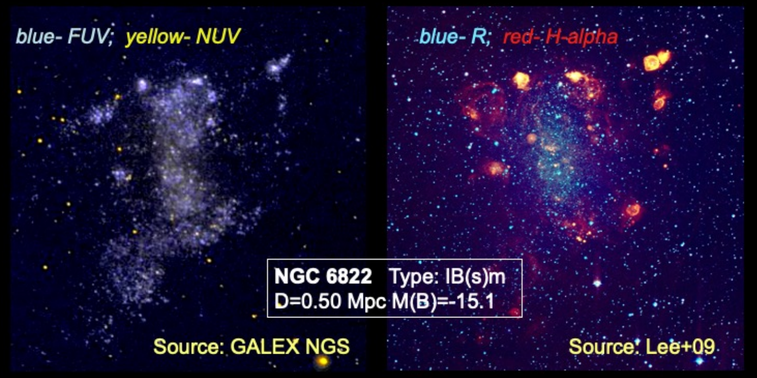
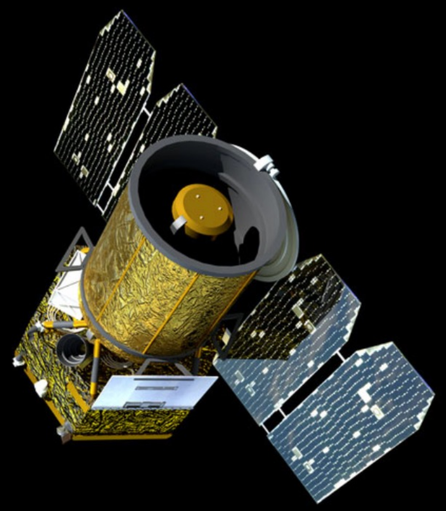


JC Lee+ 11

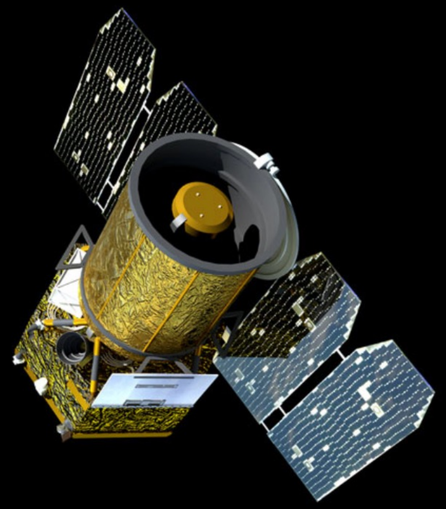


GALEX (Martin+05)

Lesson 1: Hα does not faithfully trace SFR in the low density regime

→

FUV is essential for measuring SFRs<0.01 Msun/yr



GALEX (Martin+05)

Lesson 2:
Different tools required to model the observed properties of systems where the upper IMF is not fully sampled (dwarf galaxies, extended UV/outer disks, star clusters)

A cascade of problems when SF does not fully sample IMF

Stellar IMF stochastically sampled above ~20 Msun for SFRs < 0.01 Msun/yr

Modeling of physical properties related to massive stars non-deterministic, e.g.,

- SFR over Myr timescales
- Ages of YSCs
- Escape fraction of ionizing photons
- α-element yields

But standard population synthesis models predict SEDs by scaling/summing properties of 10^5 -10^6 Msun SSP

Require tools to perform synthesis star by star, provide PDFs for physical properties.

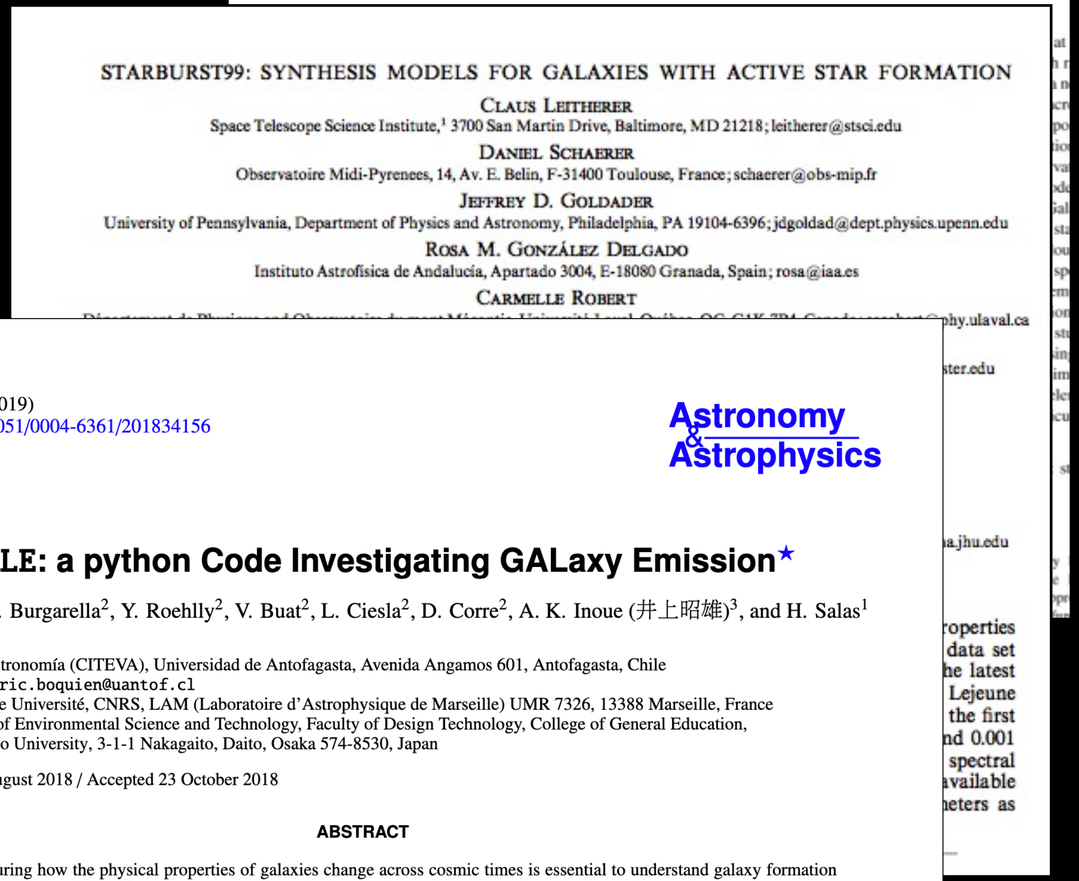
Mon. Not. R. Astron. Soc. **344,** 1000–1028 (2003)

Stellar population synthesis at the resolution of 2003

G. Bruzual[1]★ and S. Charlot[2,3]★

[1]*Centro de Investigaciones de Astronomía, AP 264, Mérida 5101-A, Venezuela*
[2]*Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Strasse 1, 85748 Garching, Germany*
[3]*Institut d'Astrophysique de Paris, CNRS, 98 bis Boulevard Arago, 75014 Paris, France*

Accepted 2003 June 10. Received 2003 June 10; in original form 2002 December 17



STARBURST99: SYNTHESIS MODELS FOR GALAXIES WITH ACTIVE STAR FORMATION

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Space Telescope Science Institute,[1] 3700 San Martin Drive, Baltimore, MD 21218; leitherer@stsci.edu
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CARMELLE ROBERT

A&A 622, A103 (2019)
https://doi.org/10.1051/0004-6361/201834156

Astronomy & Astrophysics

CIGALE: a python Code Investigating GALaxy Emission★

M. Boquien[1], D. Burgarella[2], Y. Roehlly[2], V. Buat[2], L. Ciesla[2], D. Corre[2], A. K. Inoue (井上昭雄)[3], and H. Salas[1]

[1] Centro de Astronomía (CITEVA), Universidad de Antofagasta, Avenida Angamos 601, Antofagasta, Chile
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Received 28 August 2018 / Accepted 23 October 2018

ABSTRACT

Context. Measuring how the physical properties of galaxies change across cosmic times is essential to understand galaxy formation and evolution. With the advent of numerous ground-based and space-borne instruments launched over the past few decades we now have exquisite multi-wavelength observations of galaxies from the far-ultraviolet (FUV) to the radio domain. To tap into this mine of

A cascade of problems when SF does not fully sample IMF

Stellar IMF stochastically sampled above ~20 Msun for SFRs < 0.01 Msun/yr

Modeling of physical properties related to massive stars non-deterministic, e.g.,

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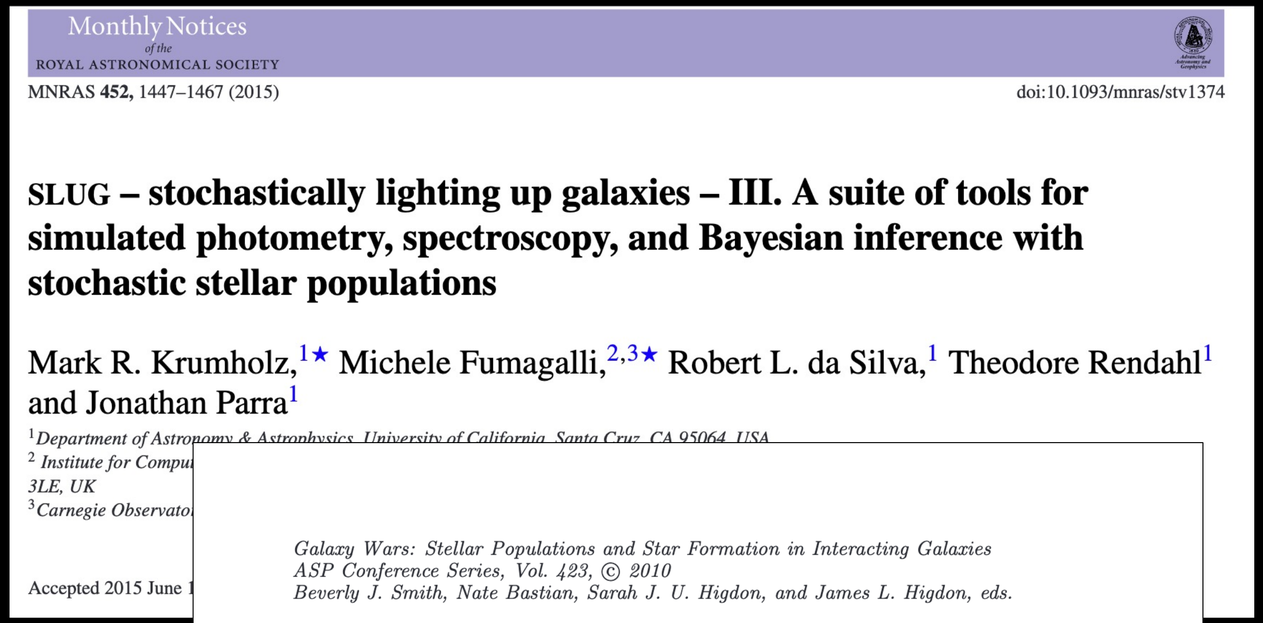
Require tools to perform synthesis star by star, provide PDFs for physical properties.



Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **452,** 1447–1467 (2015) doi:10.1093/mnras/stv1374

SLUG – stochastically lighting up galaxies – III. A suite of tools for simulated photometry, spectroscopy, and Bayesian inference with stochastic stellar populations

Mark R. Krumholz,[1]★ Michele Fumagalli,[2,3]★ Robert L. da Silva,[1] Theodore Rendahl[1] and Jonathan Parra[1]

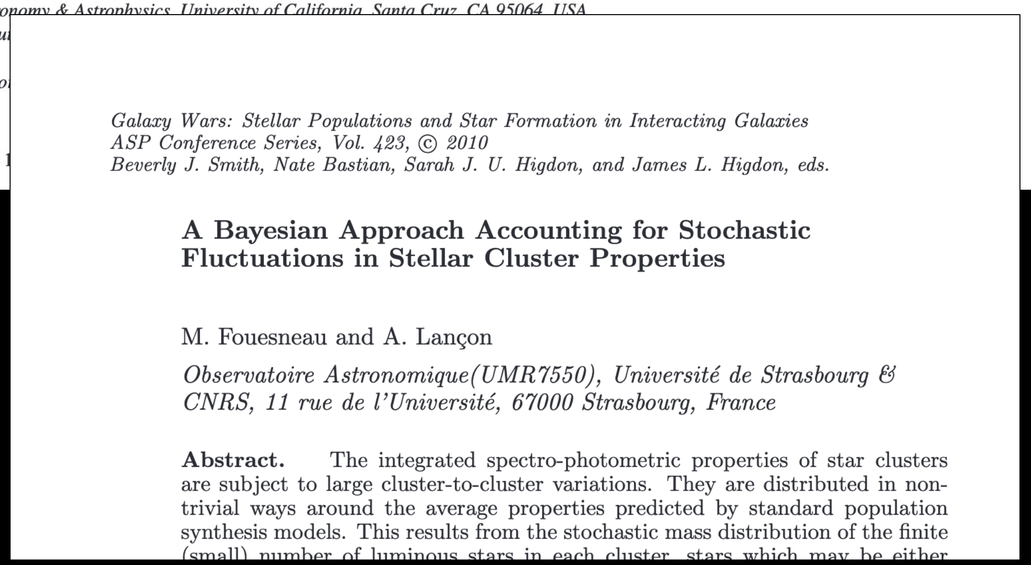
[1]*Department of Astronomy & Astrophysics, University of California, Santa Cruz, CA 95064, USA*

[2] *Institute for Compu*

3LE, UK

[3]*Carnegie Observato*

Accepted 2015 June 1



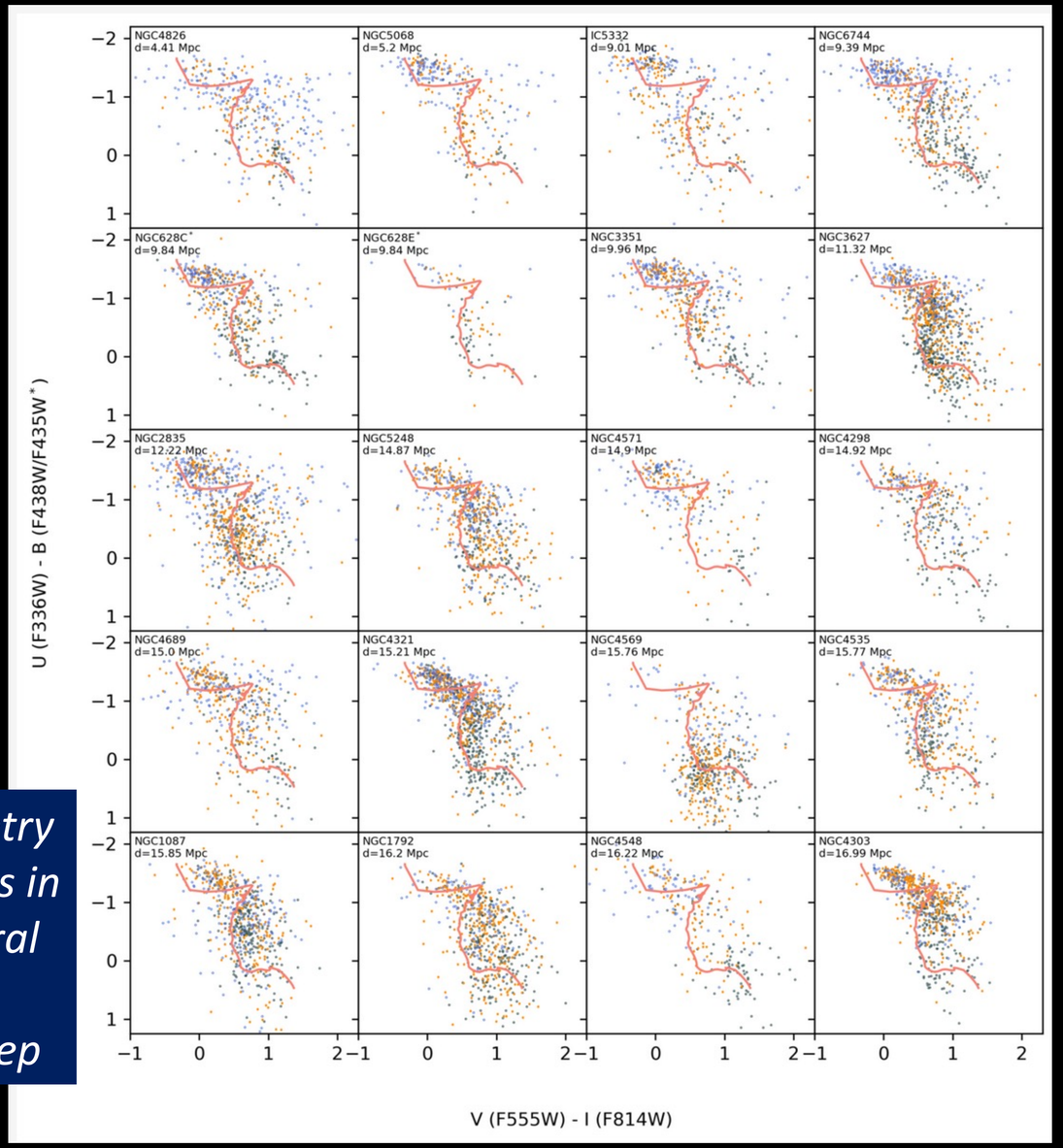
Galaxy Wars: Stellar Populations and Star Formation in Interacting Galaxies
ASP Conference Series, Vol. 423, © 2010
Beverly J. Smith, Nate Bastian, Sarah J. U. Higdon, and James L. Higdon, eds.

A Bayesian Approach Accounting for Stochastic Fluctuations in Stellar Cluster Properties

M. Fouesneau and A. Lançon

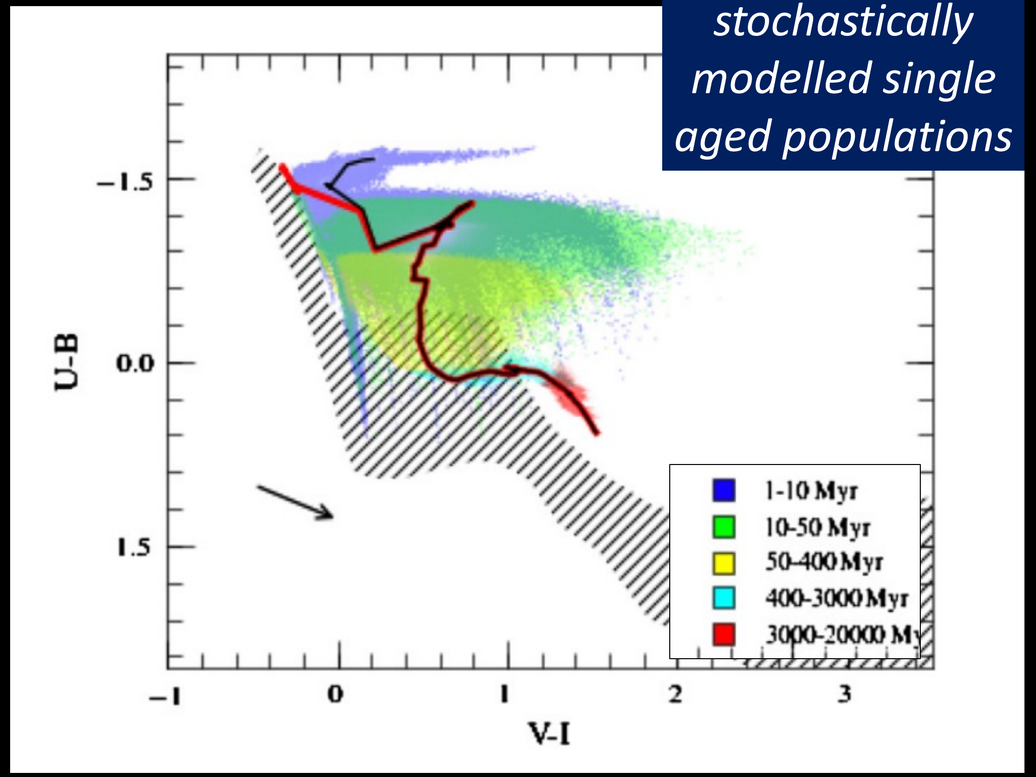
Observatoire Astronomique(UMR7550), Université de Strasbourg & CNRS, 11 rue de l'Université, 67000 Strasbourg, France

Abstract. The integrated spectro-photometric properties of star clusters are subject to large cluster-to-cluster variations. They are distributed in non-trivial ways around the average properties predicted by standard population synthesis models. This results from the stochastic mass distribution of the finite (small) number of luminous stars in each cluster, stars which may be either



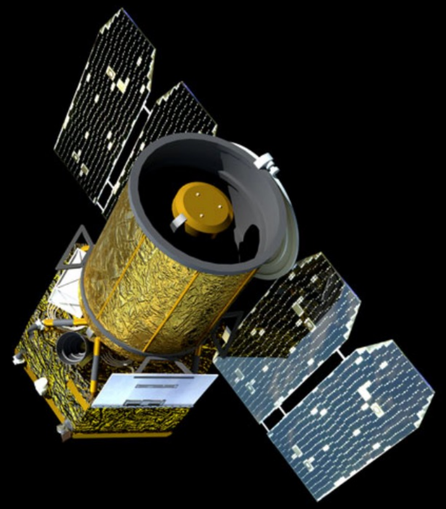
HST photometry of star clusters in PHANGS spiral galaxies
JC Lee+ in prep

Colors of stochastically modelled single aged populations



Fouesneau+12

Require tools to perform synthesis star by star, provide PDFs for physical properties.



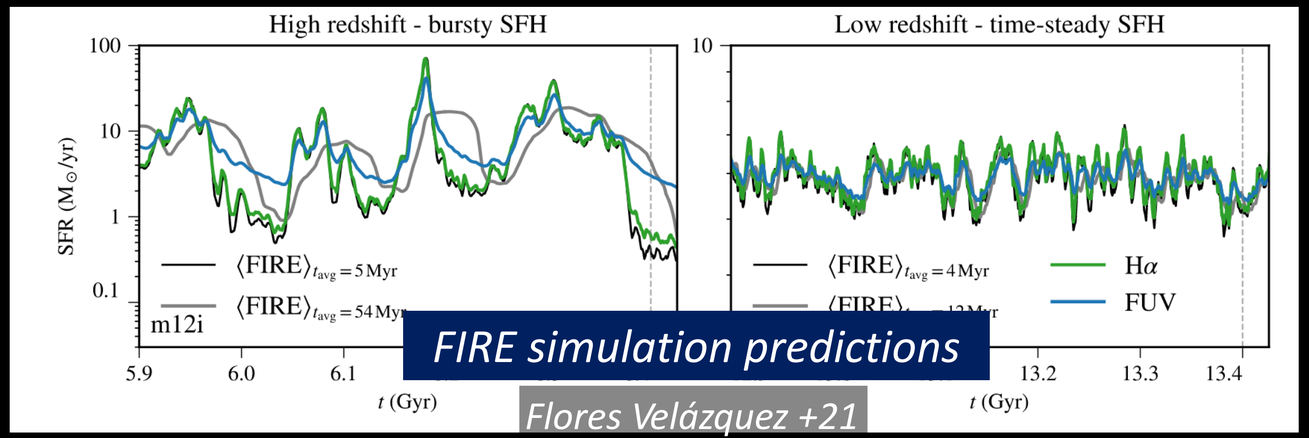
GALEX (Martin+05)

Lesson 3:

Hα/FUV as a burst indicator not as straightforward as initially imagined.

Hα/FUV as a burst indicator

Constraints on “burstiness” (amplitudes, frequencies, durations) key test of galaxy simulations, feedback, esp in dwarfs, high-z



FIRE simulation predictions

Flores Velázquez +21

Hα/FUV as a burst indicator

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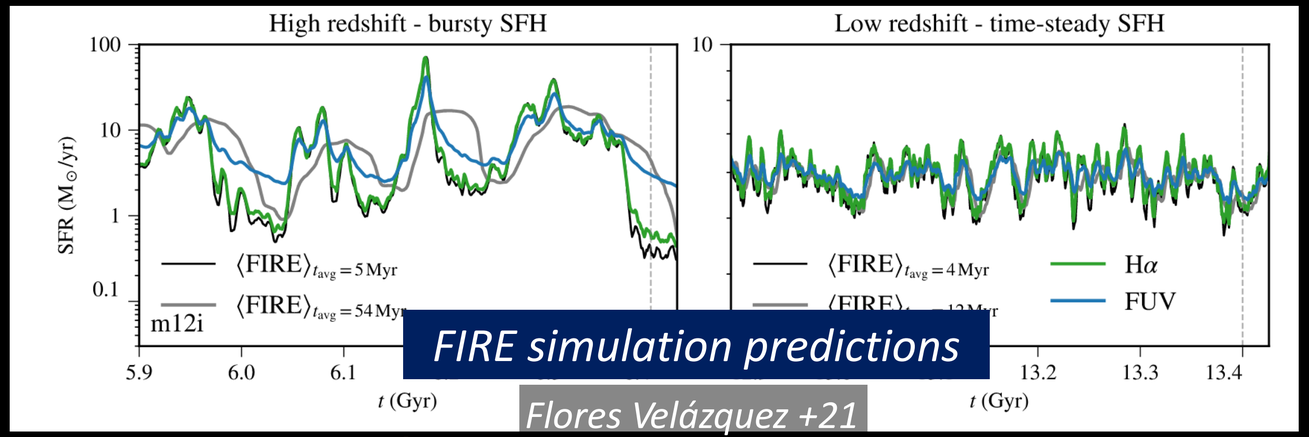
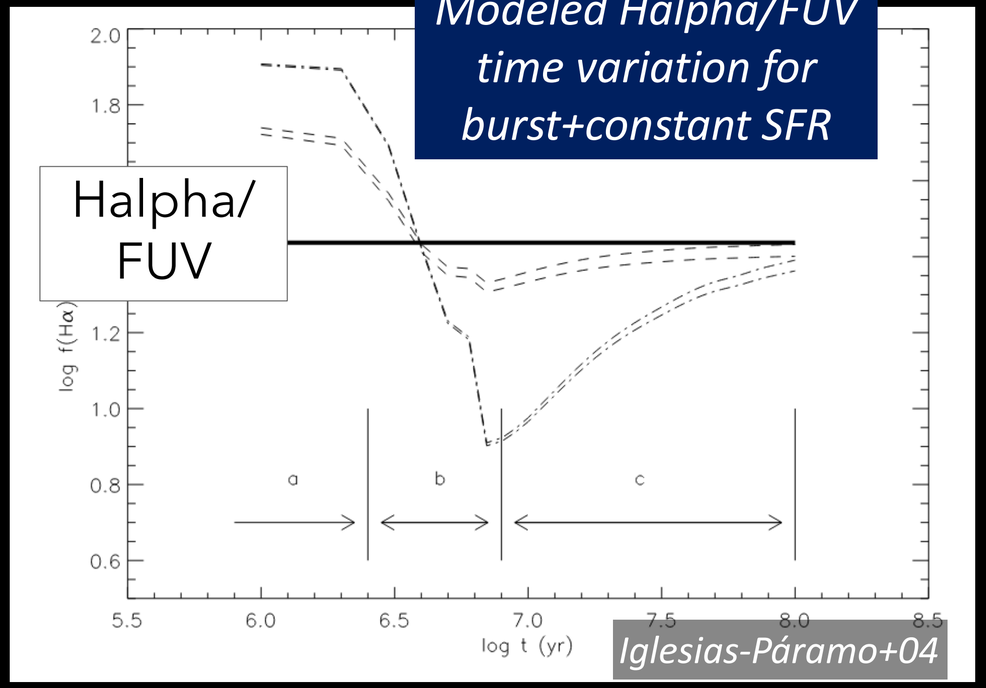


FIRE simulation predictions

Flores Velázquez +21

Modeled Halpha/FUV time variation for burst+constant SFR



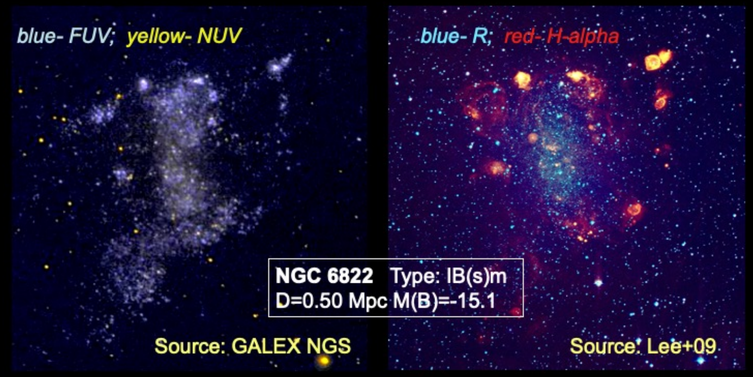
Iglesias-Páramo+04

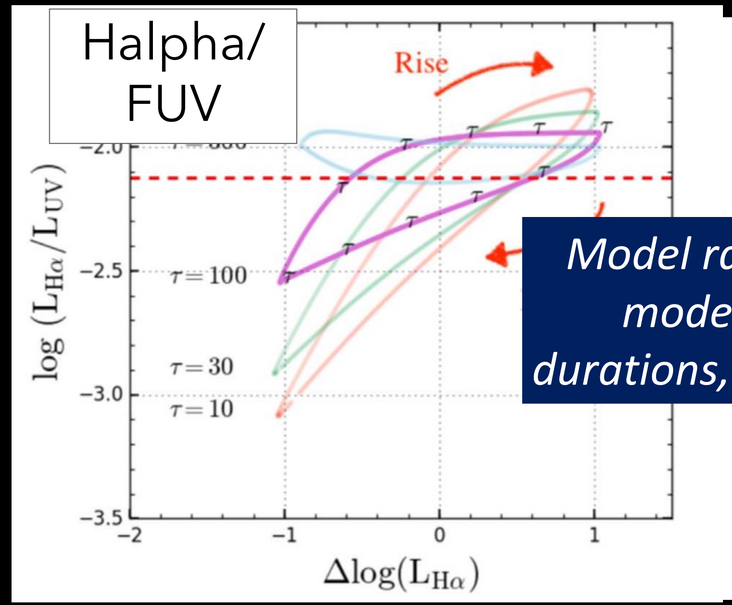
FUV

Photospheric emission from O & B stars; traces SF over last ~100 Myr

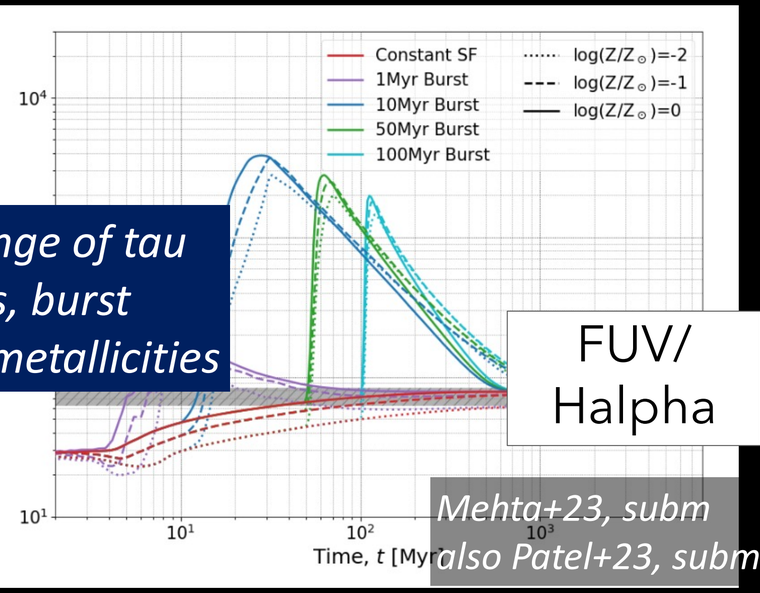
Hα & R

Recombination emission of gas ionized by O stars; traces SF over last ~5 Myr





Model range of tau models, burst durations, metallicities



FUV/ Halpha

Mehta+23, subm

also Patel+23, subm

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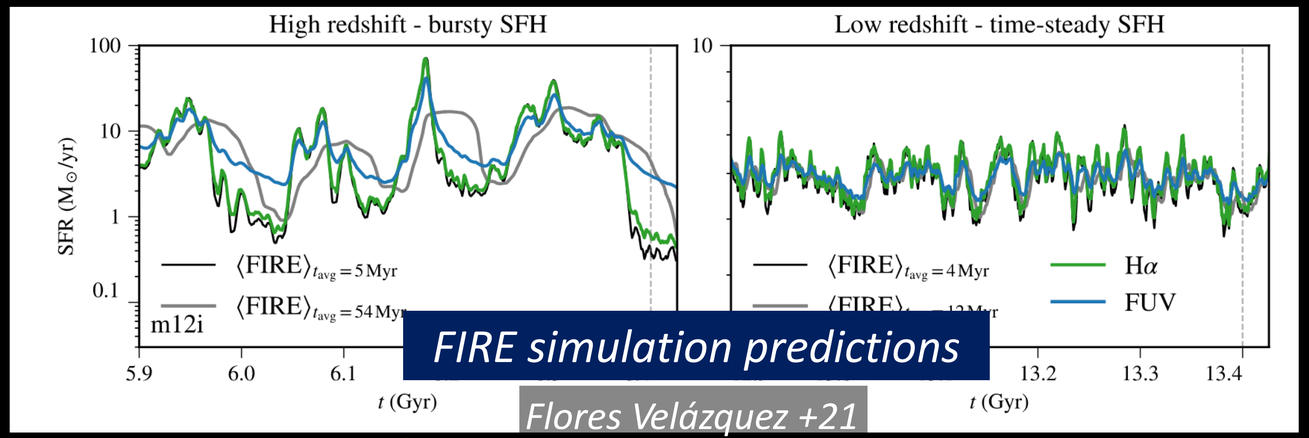

FIRE simulation predictions

Flores Velázquez +21

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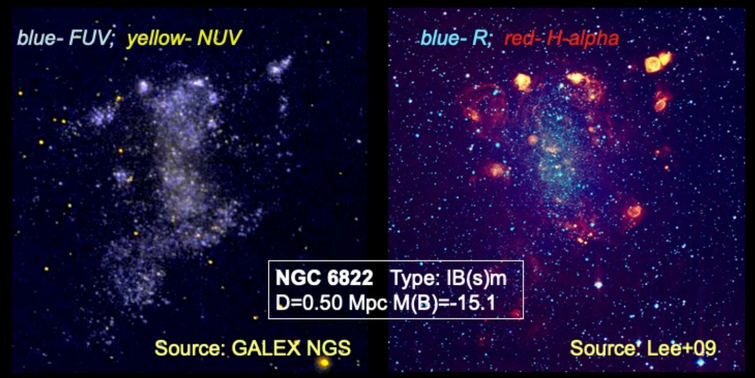
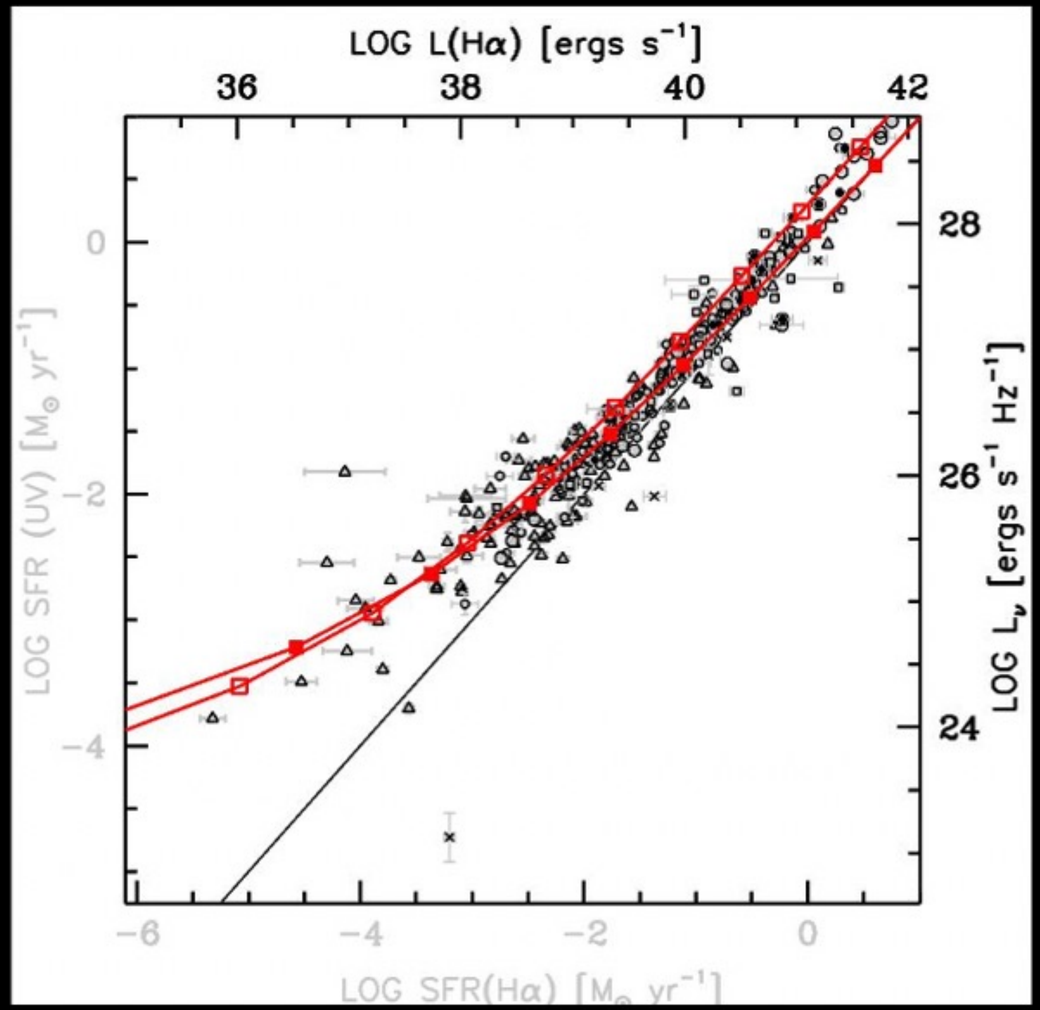


Original science driver for 11 Mpc Hα UV Galaxy Survey



JC Lee+ 09b

Hα/FUV as a burst indicator

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A Closer Look at Bursty Star Formation with $L_{H\alpha}$ and L_{UV} Distributions

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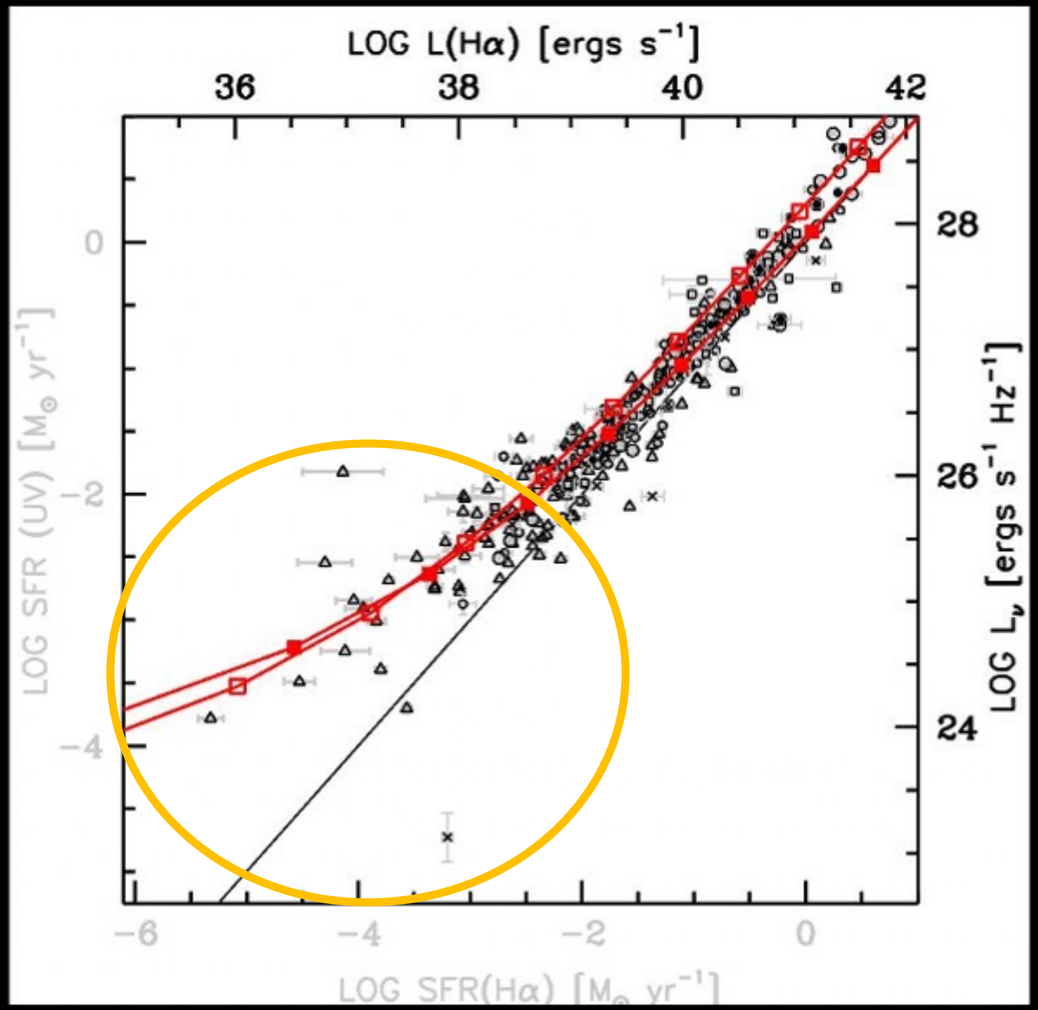
Abstract

Modeling of Lee+09b,11 data:
"galaxies below 10 $^{7.5}$ Msun undergo large (maximum amplitudes of ~100) and rapid (τ<30 Myr) bursts, while galaxies above $10^{8.5}$ Msun experience smaller (maximum amplitudes ~10), slower (τ ~300 Myr) bursts"

Key words: galaxies: dwarf – galaxies: evolution – galaxies: formation – galaxies: star formation

- Such large bursts not seen from dwarf galaxy CMDs (e.g., McQuinn+10)
- Inconsistent with Hα EW distirbution and optical color distirbutions
- Forward modeling with stochastic population synthesis models needed, perhaps much larger samples

Original science driver for
11 Mpc Hα UV Galaxy Survey



JC Lee+ 09b

Hα/FUV as a burst indicator

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No Evidence of a Correlation between Hα-to-UV Ratio and Burstiness for Typical Star-forming Galaxies at $z \sim 2$

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EW of FUV stellar features (C IV, Si IV) may more reliably trace SF bursts than Halpha/FUV (stacked MOSDEF z~2 LRIS spectra) → test locally

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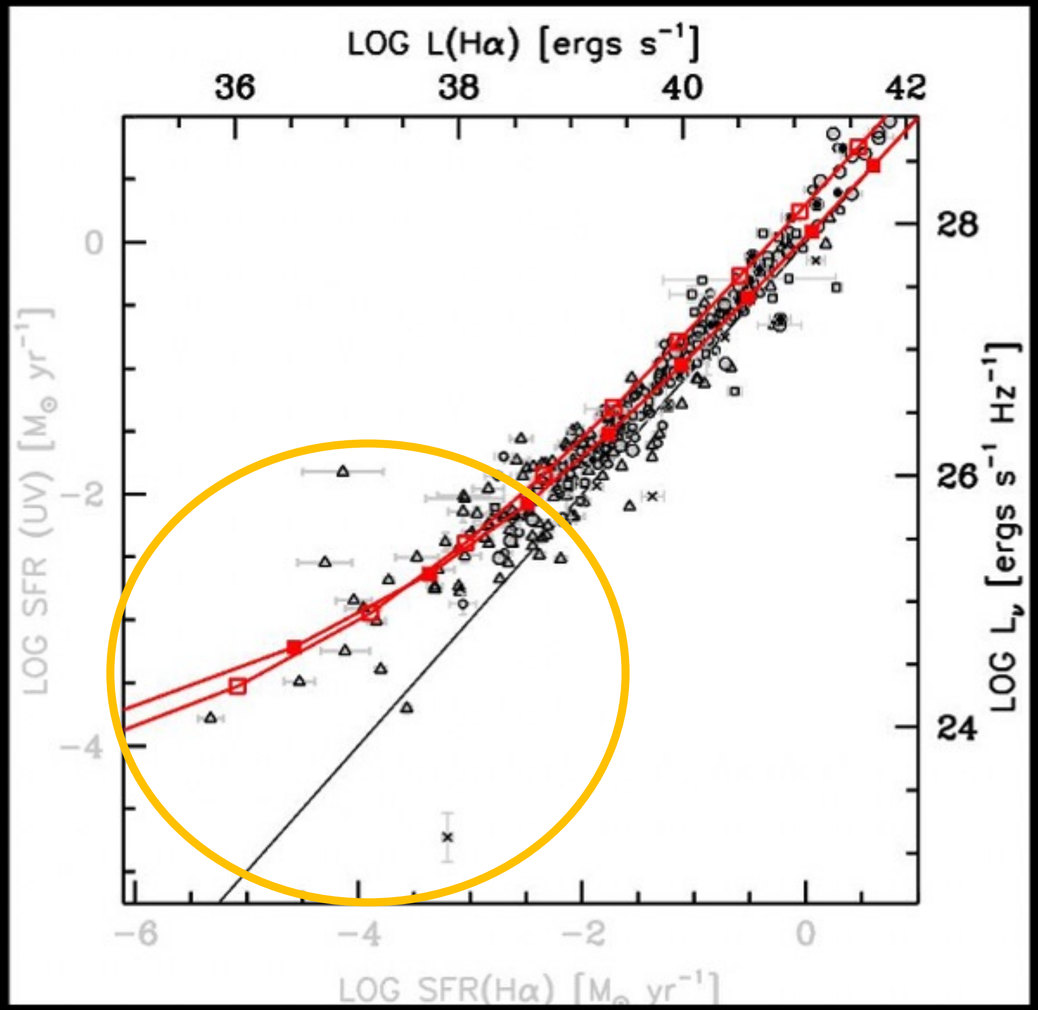

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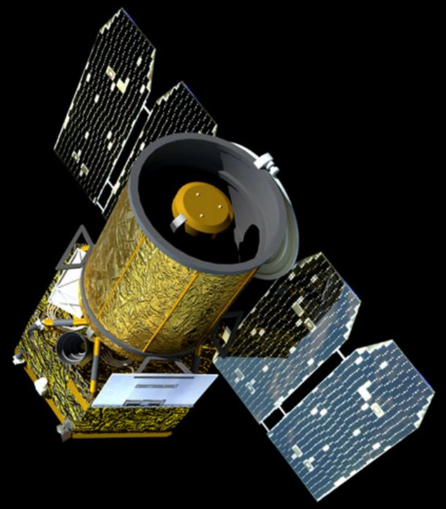
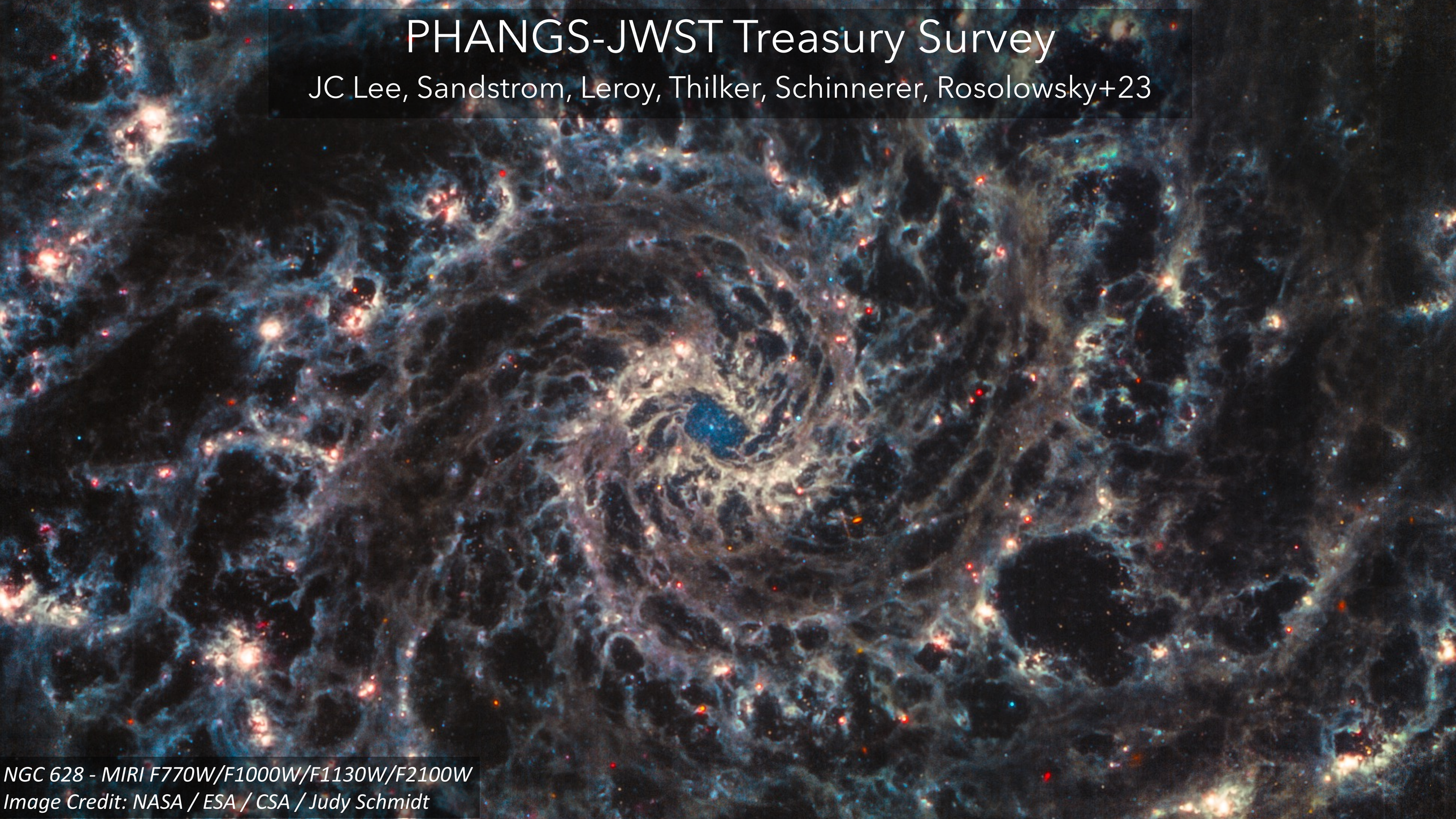


GALEX (Martin+05)

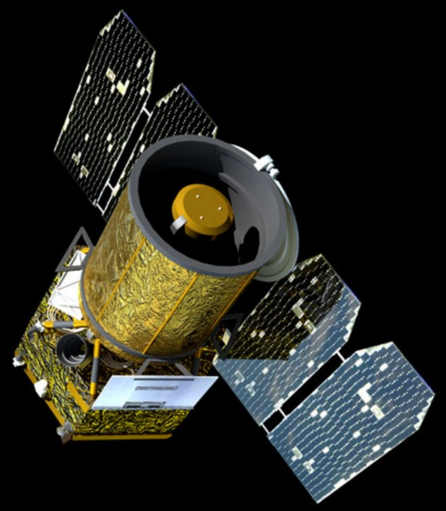
Lesson 4:
It is easier to study spiral galaxies...

PHANGS-JWST Treasury Survey

JC Lee, Sandstrom, Leroy, Thilker, Schinnerer, Rosolowsky+23



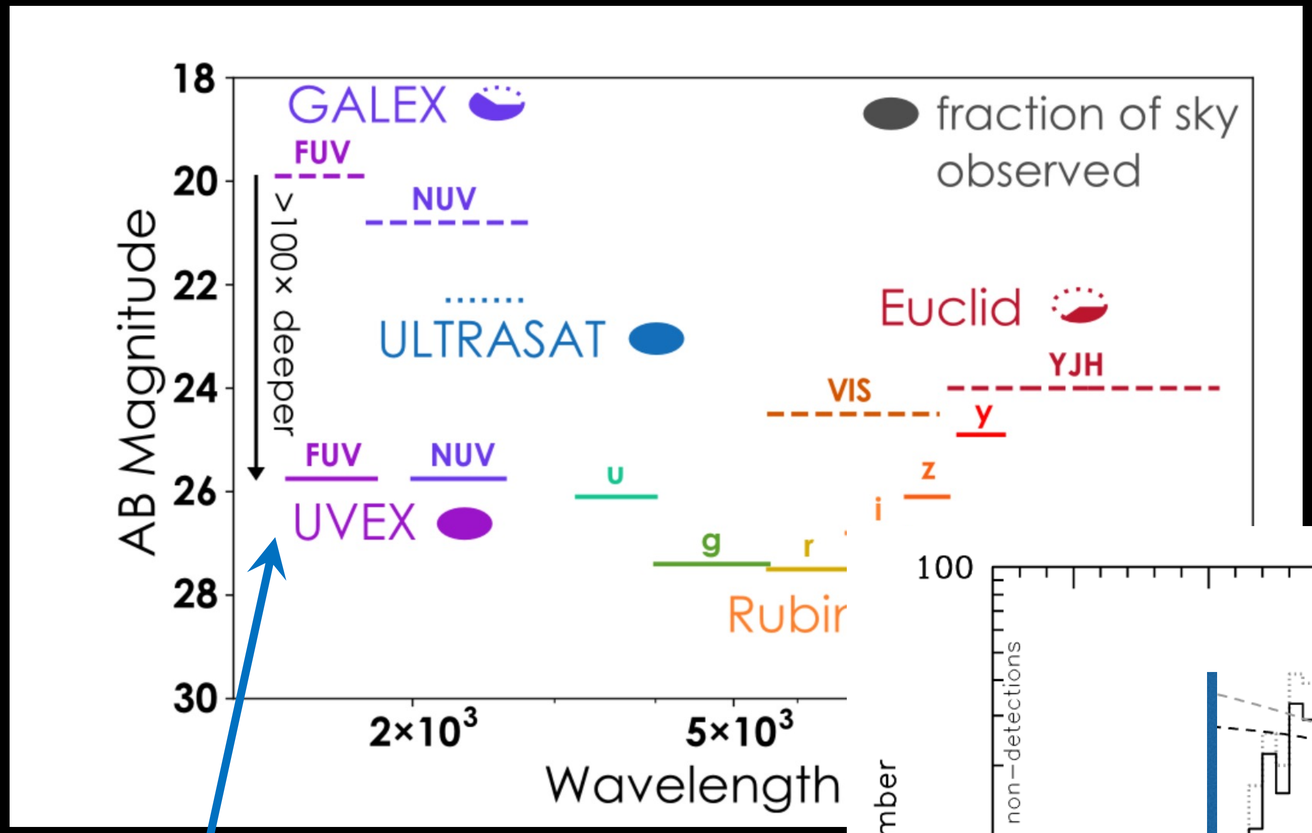
NGC 628 - MIRI F770W/F1000W/F1130W/F2100W
Image Credit: NASA / ESA / CSA / Judy Schmidt



GALEX (Martin+05)

Lesson 4:
It is easier to study spiral galaxies...

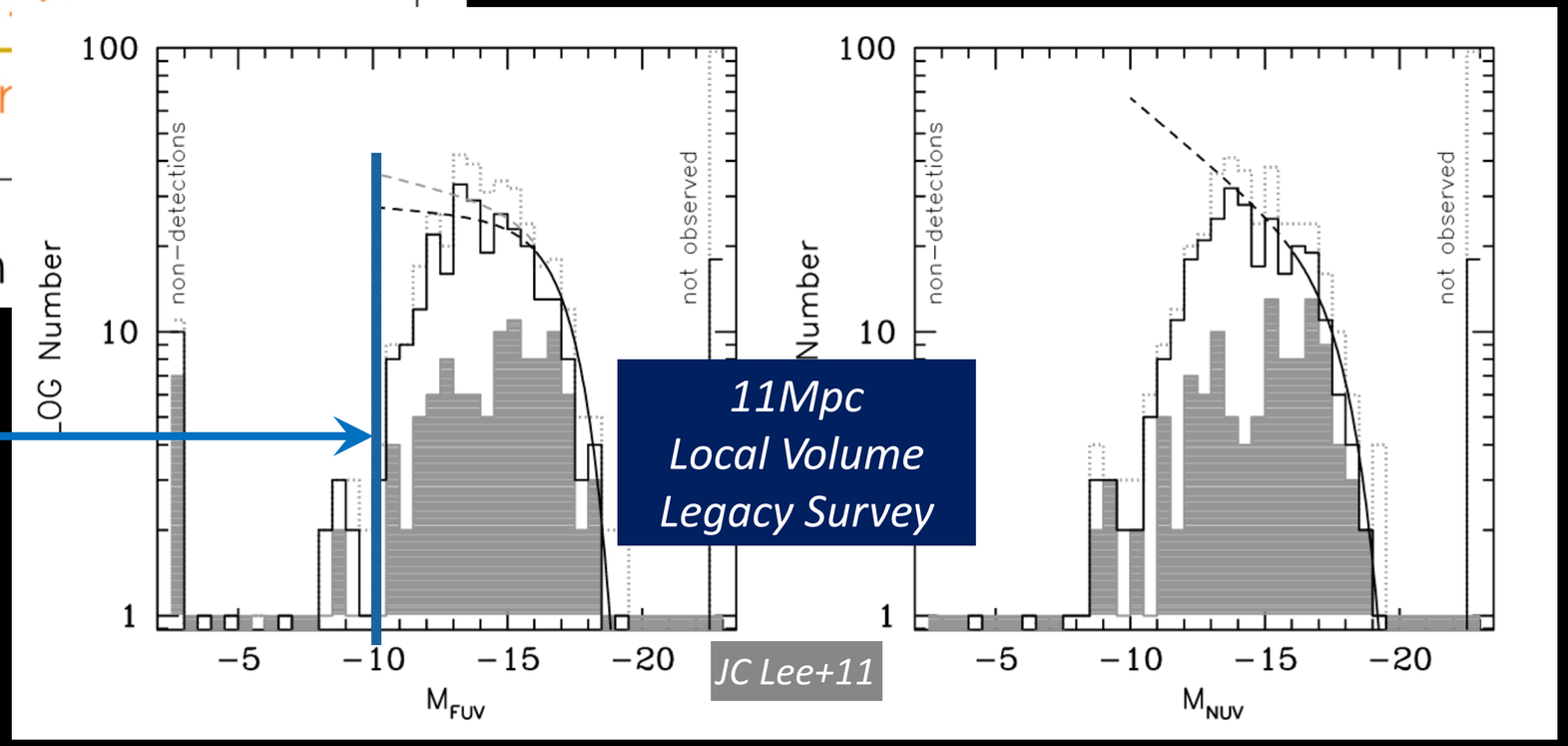
→
Forward modeling of Hα, FUV, optical SED of tens of thousands of UVEX dwarf galaxies with stochastic population synthesis models to constrain burstiness (SFH), stochasticity, maybe constrain variations in upper IMF at low metallicity?



UVEX will provide the very large samples of dwarf galaxies within 100 Mpc needed for proper PDF modeling of observed properties in the stochastic regime

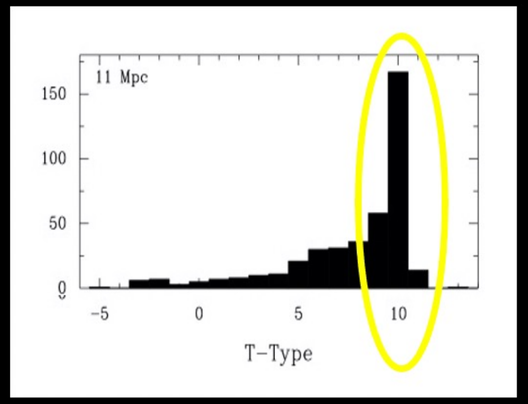
M(FUV) = -10 →
SFR ~10^{-3} – 10^{-4} Msun/yr

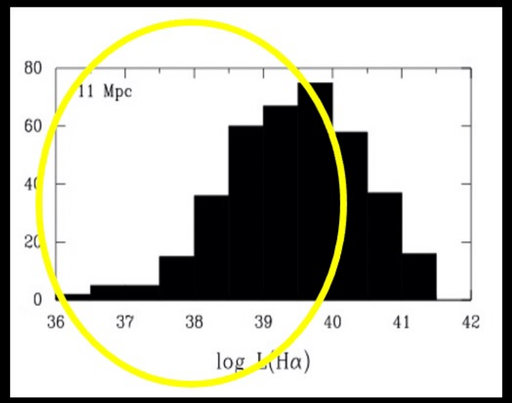
M(FUV)=25 →
M(FUV) = -10 @ 100 Mpc!

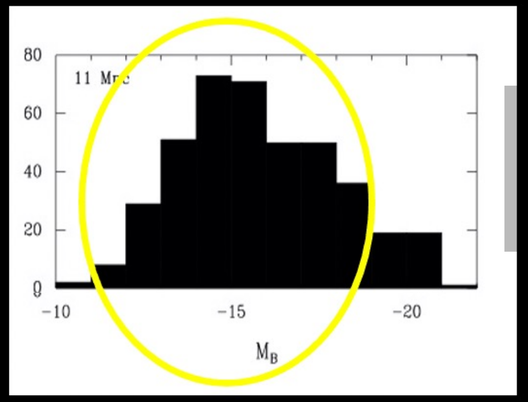


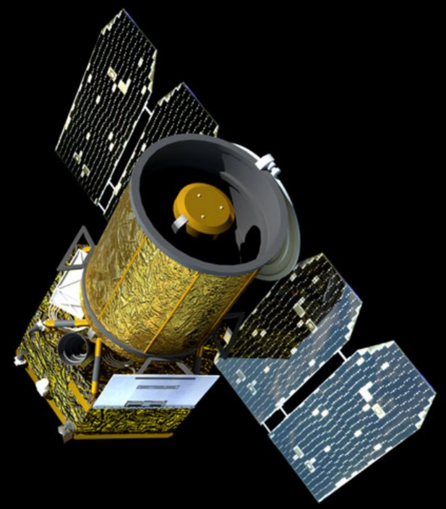
11 Mpc Halpha Ultraviolet Galaxy Survey

Kennicutt+08 (Halpha), JC Lee+11 (UV)









GALEX (Martin+05)

80% of sample less luminous, lower SFR than ~LMC

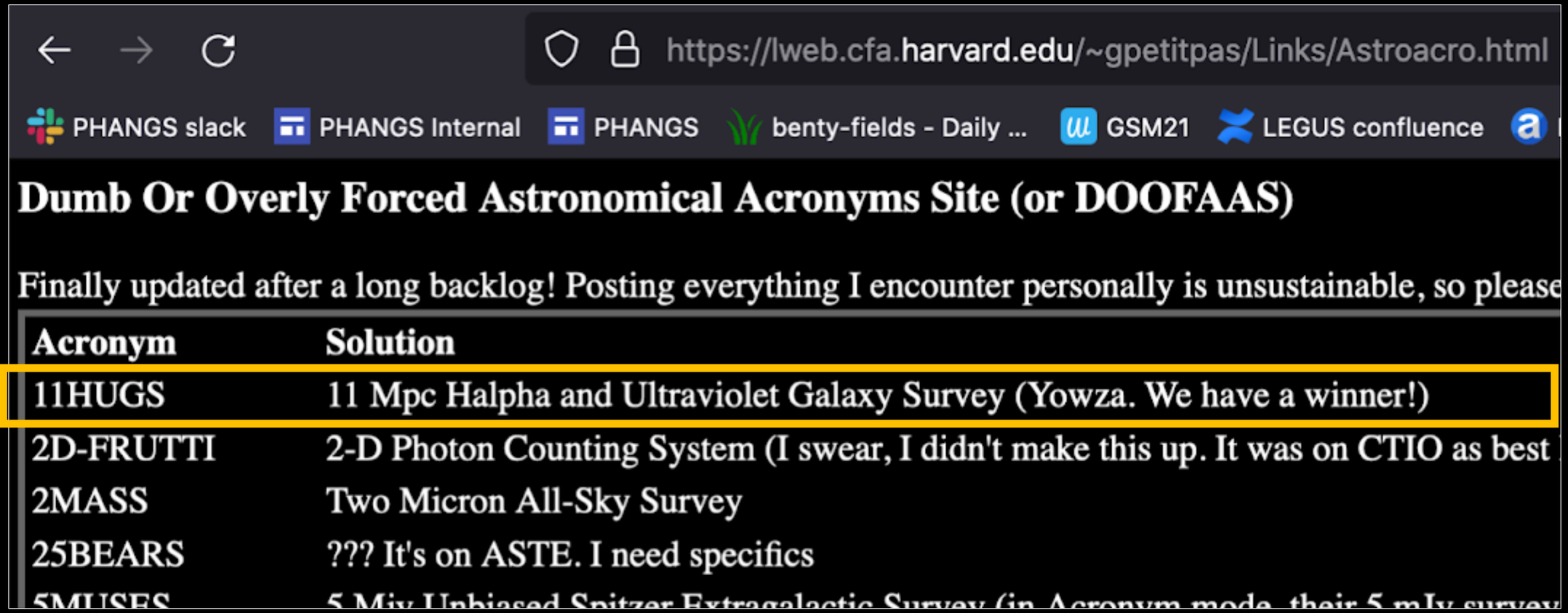
Meet the Neighbors
The Spitzer Local Volume Legacy Survey

~400 star forming galaxies within 11 Mpc

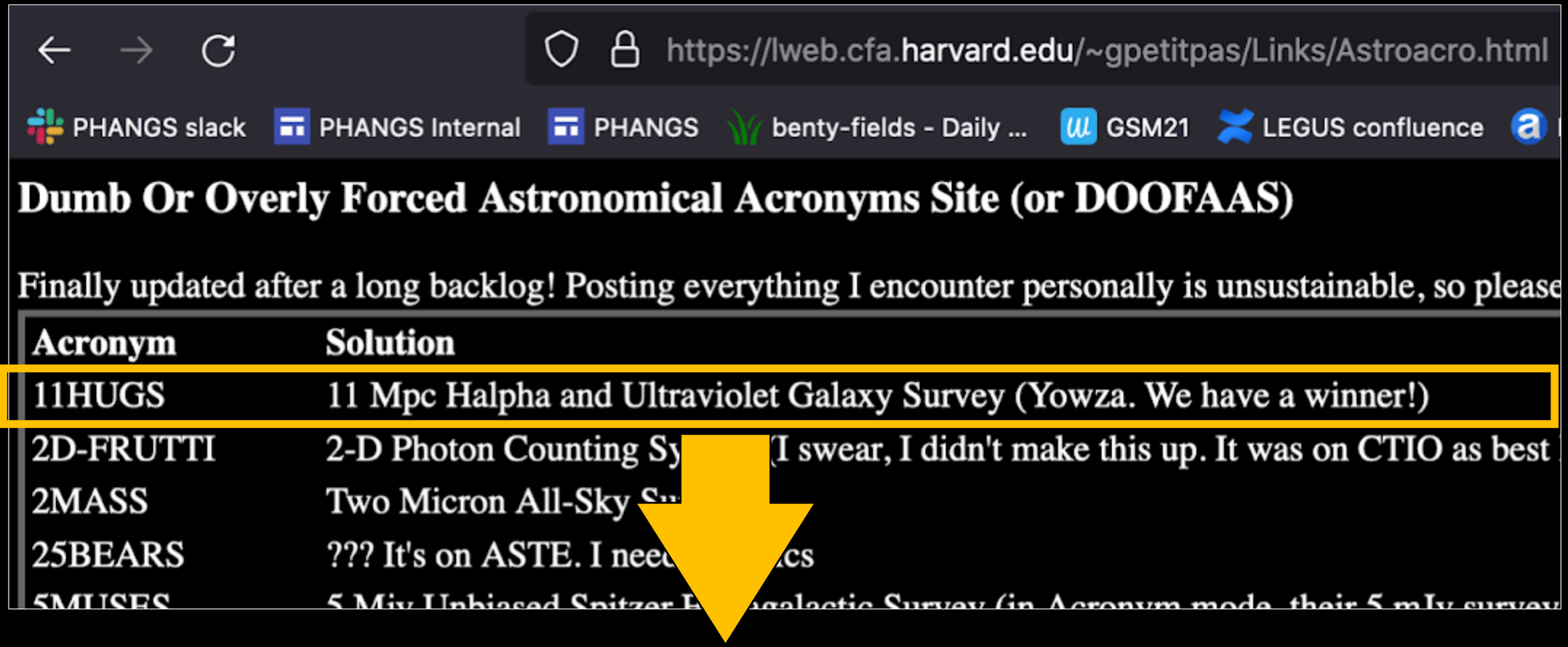
~260 galaxies in complete sample
|b|> 20 deg, B<15, T>0
+
~170 additional galaxies

11 Mpc Halpha Ultraviolet Galaxy Survey
“11HUGS”

11 Mpc Halpha Ultraviolet Galaxy Survey



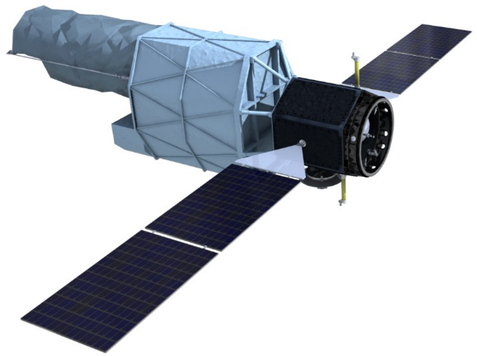
"I have this thing where I get older but just never wiser" T. Swift



1000 HUGS with UVEX starting 2028

Lessons for UVEX Exploration of the Low Mass Galaxy Frontier from GALEX

- FUV essential for measuring SFRs<0.01 Msun/yr; Hα unreliable
- Standard population sythesis, SFR recipes not appropriate for deriving properties of systems where the upper IMF is not fully sampled (dwarf galaxies, extended UV/outer disks, star clusters)
- Hα/FUV as burst indicator, other parameters must be modeled using stochastic population synthesis
- Forward modeling of FUV, Hα, optical SEDs of large samples of dwarf galaxies can potential provide constraints on burstiness and IMF



1000 HUGS with UVEX starting 2028