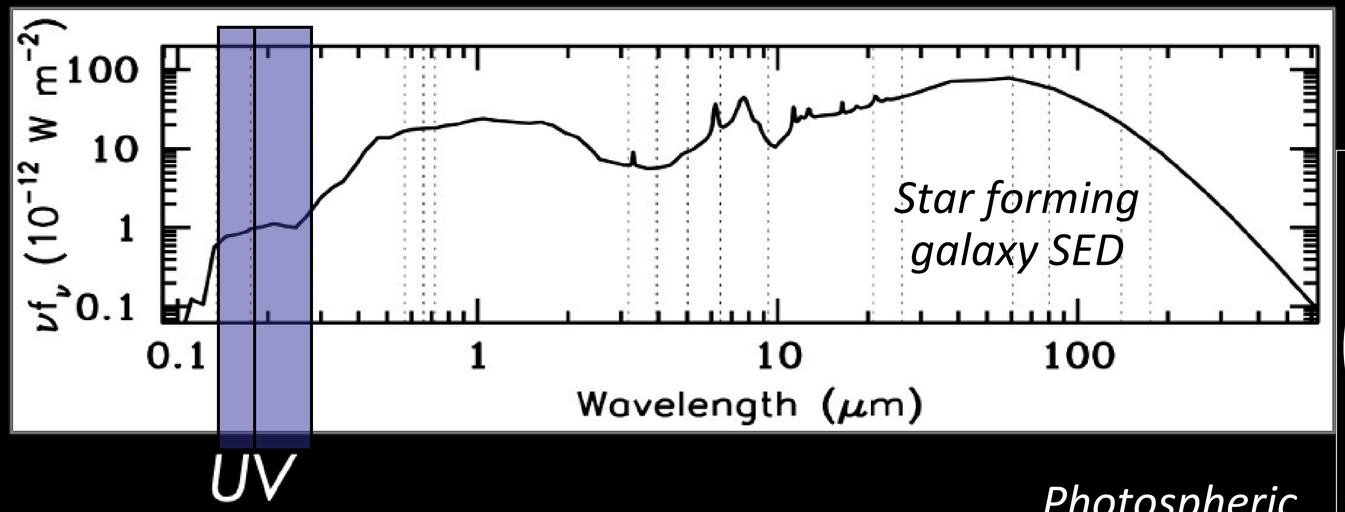
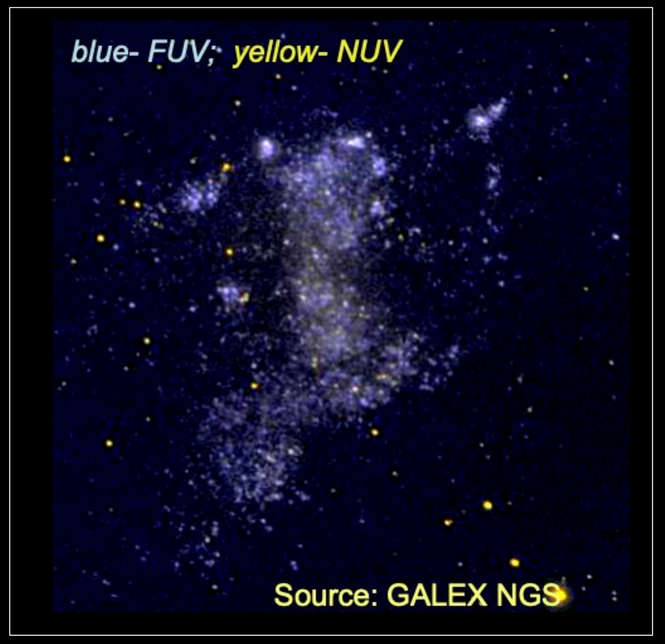
Star & Cluster Formation in Nearby Galaxies: The need for UV observations and HWO, the Next Generation Hubble Space Telescope

Janice C. Lee
COPAG@AAS
Jan 7 2024

UV observations are critical for the study of star formation

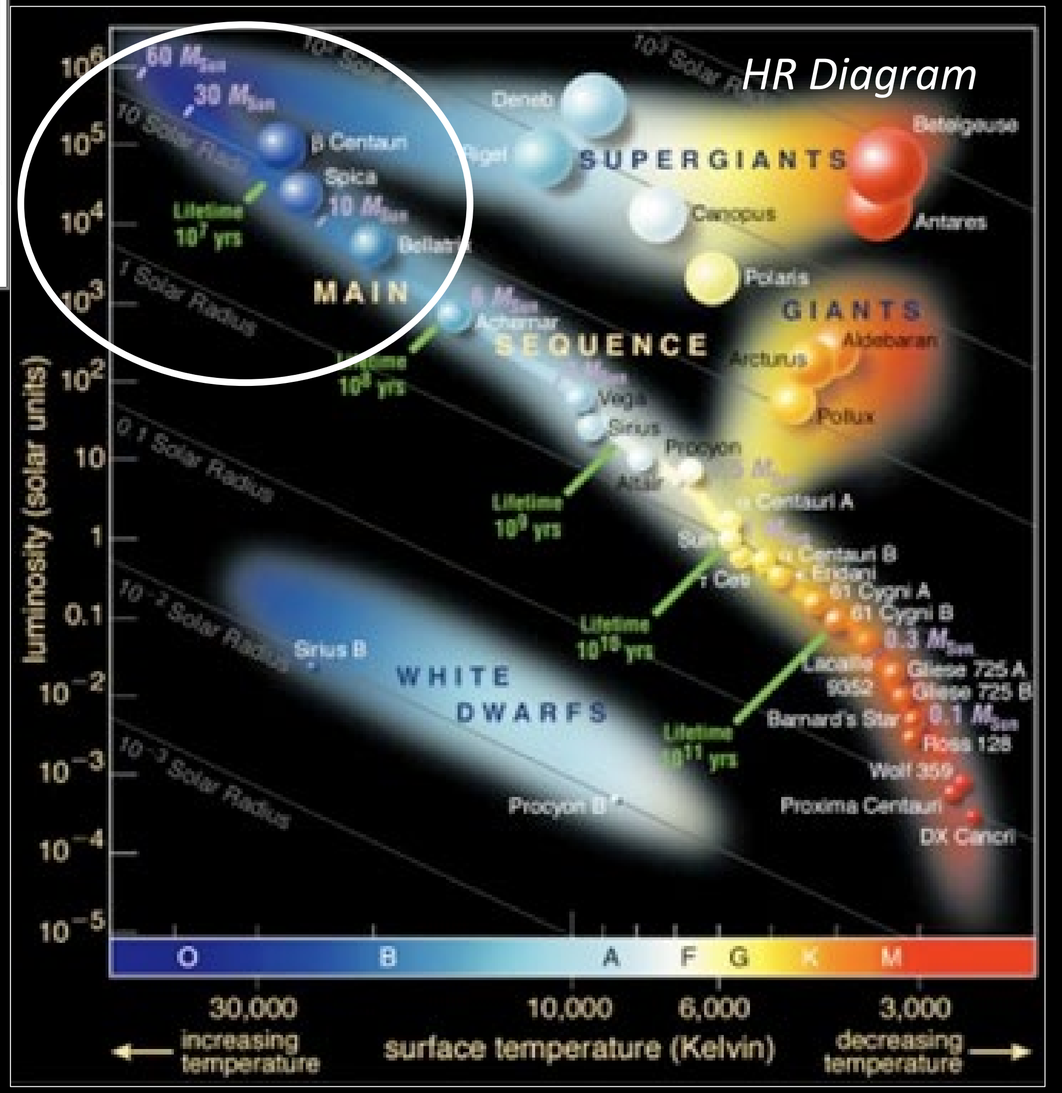


(esp for dwarf galaxies, Lee+09)



Photospheric emission from O & B stars

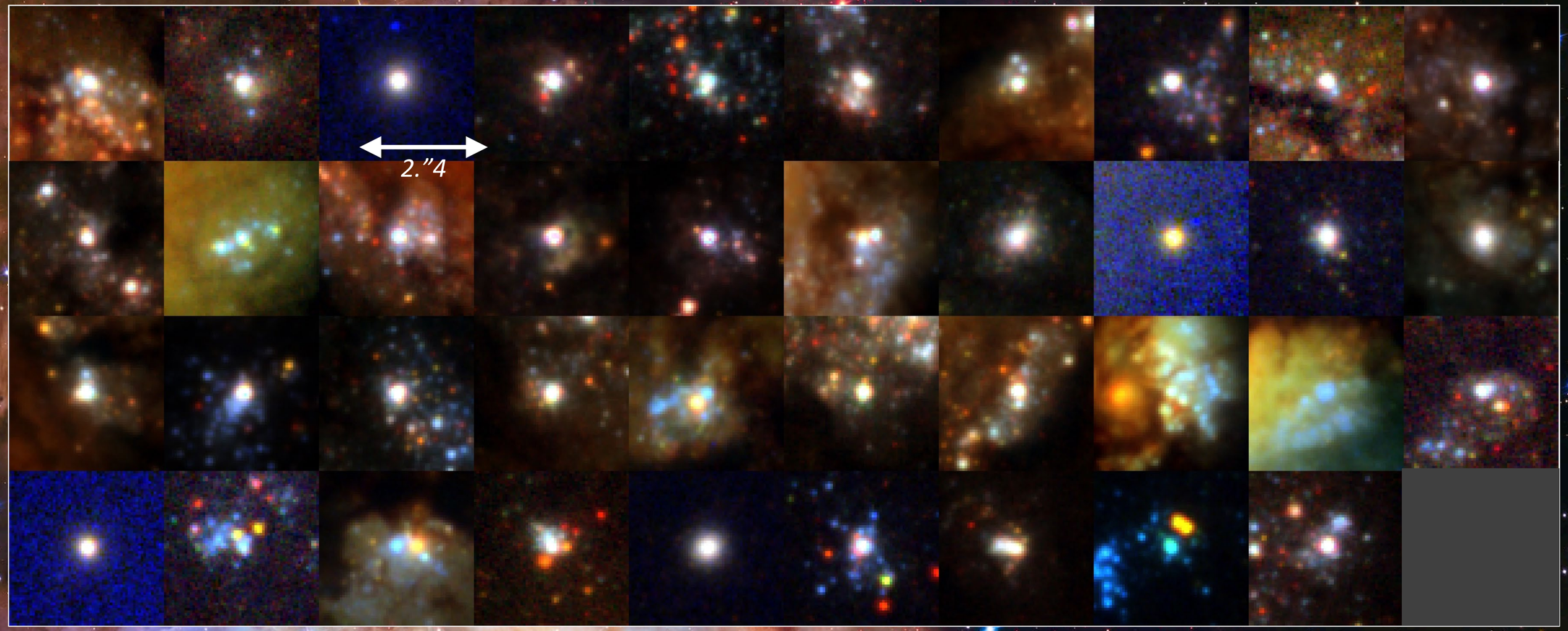
Principle SFR tracer (over last ~100 Myr)



High resolution UV-optical observations with Hubble are critical for the study of star clusters in nearby galaxies…


Hubble imaging of a MW star cluster 6000 pc away
Hubble 25th Anniversary Image - NASA, ESA, Hubble Heritage Team (STScI/AURA), A. Nota (ESA/STScI), Westerlund 2 Science Team

Hubble imaging of star clusters in PHANGS galaxies (5-23 Mpc)
(Physics at High Angular Resolution in Nearby GalaxieS)

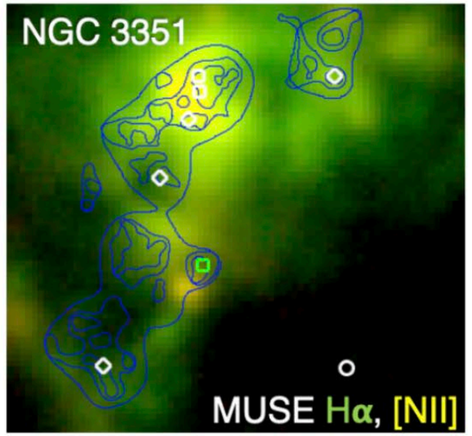


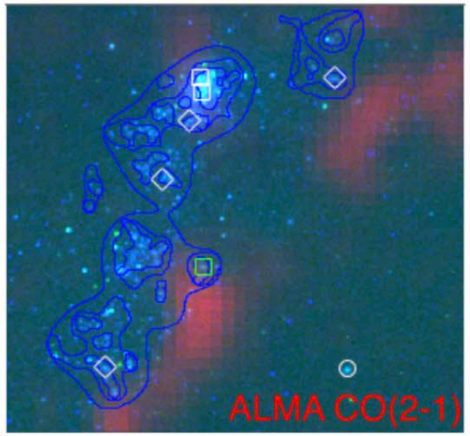
Brightest star cluster in each of the 38 PHANGS galaxies.
Postage stamps subtend 50-270 pc.
Maschmann, Lee, Thilker, Whitmore+ submitted
Are these preferentially formed in certain environments (e.g., Ali&Dobbs+23)?

Hubble census of star cluster and stellar associations

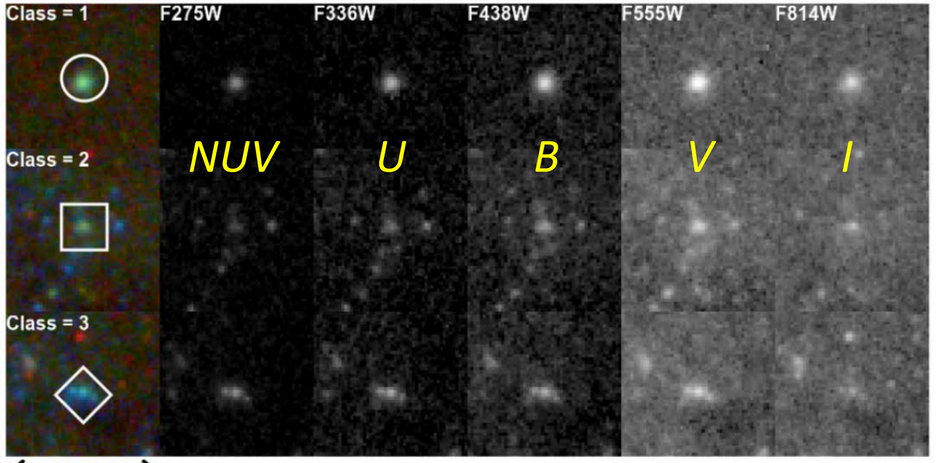
Star formation & evolution at the highest densities

Requires HST resolution (0.04”/pix → 1-5pc)

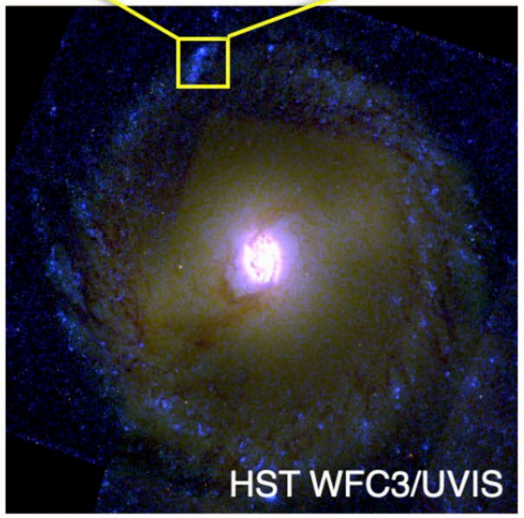


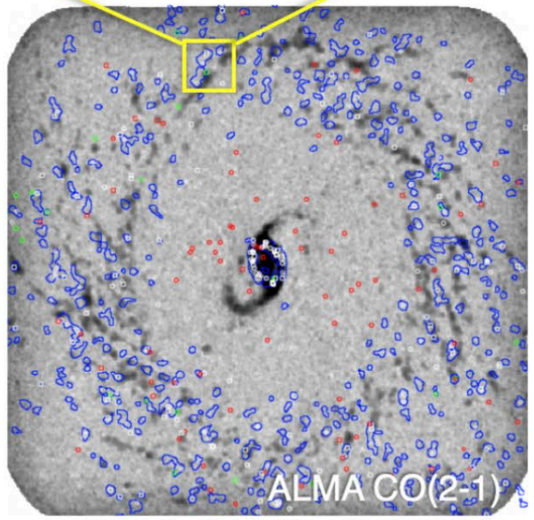


650 pc 650 pc

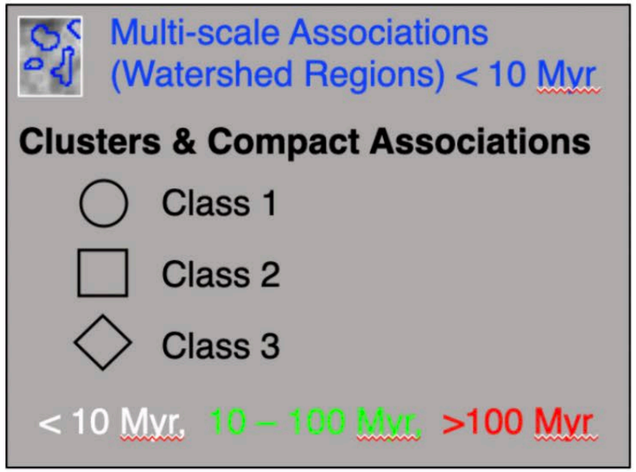


180 pc
50 pix

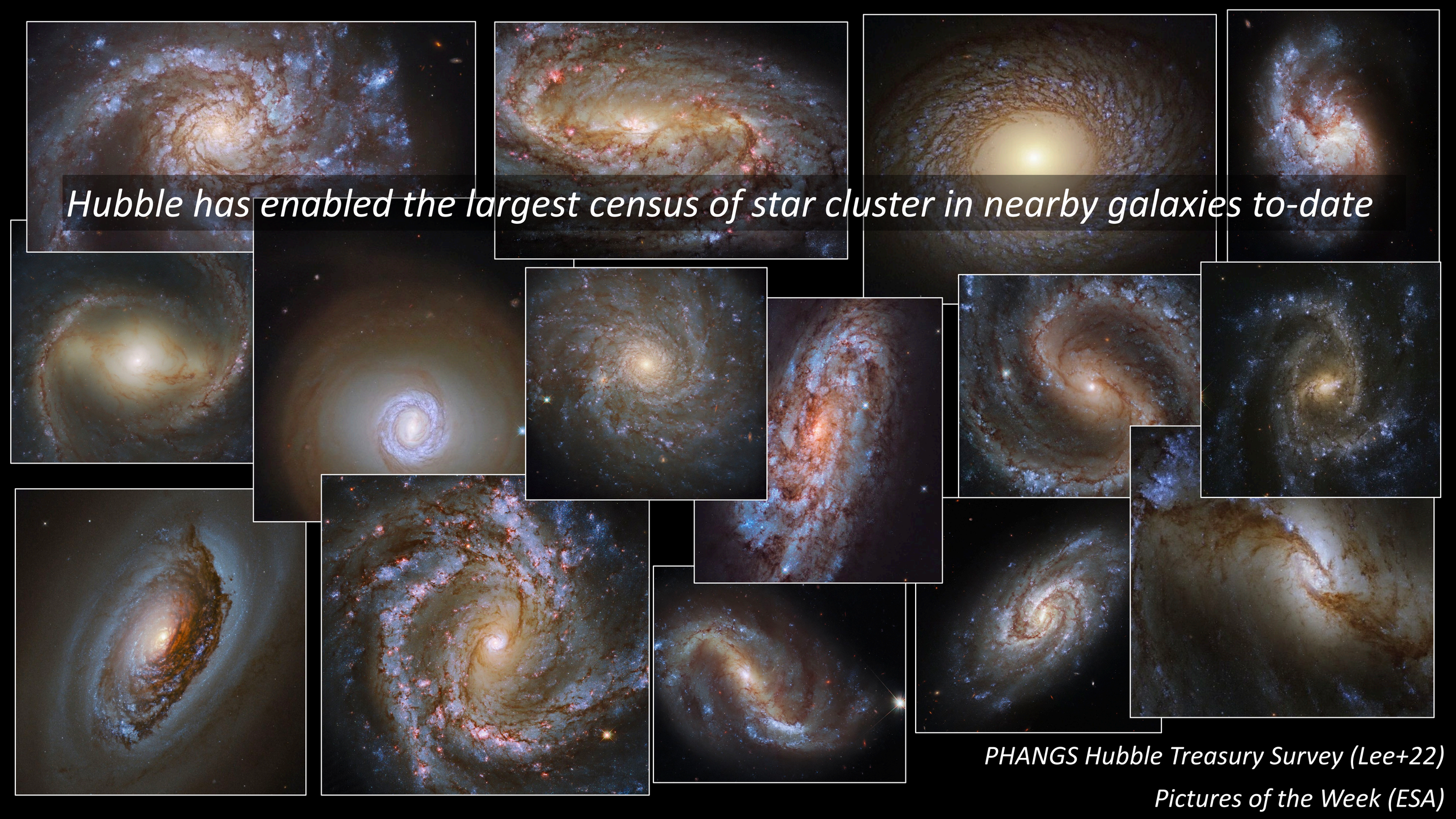




7.7 kpc 7.7 kpc



Lee+22



PHANGS Hubble Treasury Survey (Lee+22)

Pictures of the Week (ESA)

Hubble has enabled the largest census of star cluster in nearby galaxies to-date

PHANGS-HST catalogs for ∼100,000 star clusters and compact associations in 38 galaxies: I. Observed properties

Daniel Maschmann [1], Janice C. Lee [2,1,3], David A. Thilker [4], Bradley C. Whitmore [2], Sinan Deger [5,6], Médéric Boquien [7], Rupali Chandar [8], Daniel A. Dale [9], Aida Wofford [10,11], Stephen Hannon [12], Kirsten L. Larson [13], Adam K. Leroy [14], Eva Schinnerer [12], Erik Rosolowsky [15], Leonardo Úbeda [2], Ashley T. Barnes [16], Eric Emsellem [16,17], Kathryn Grasha [18,19,*], Brent Groves [20], Rémy Indebetouw [21,22], Hwihyun Kim [3], Ralf S. Klessen [23,24], Kathryn Kreckel [25], Rebecca C. Levy [1,†], Francesca Pinna [26,27,12], M. Jimena Rodríguez [1,28], Qiushi Tian [29], and Thomas G. Williams [30]

[1] *Steward Observatory, University of Arizona, Tucson, AZ 85721, USA*
[2] *Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA*
[3] *Gemini Observatory/NSF's NOIRLab, 950 N. Cherry Avenue, Tucson, AZ, 85719, USA*
[4] *Department of Physics and Astronomy, The Johns Hopkins University, Baltimore, MD 21218, USA*

Barbara A. MIKULSKI ARCHIVE FOR SPACE TELESCOPES

ApJ, submitted, 2023 Nov

Data release: end of January

phangs.stsci.edu

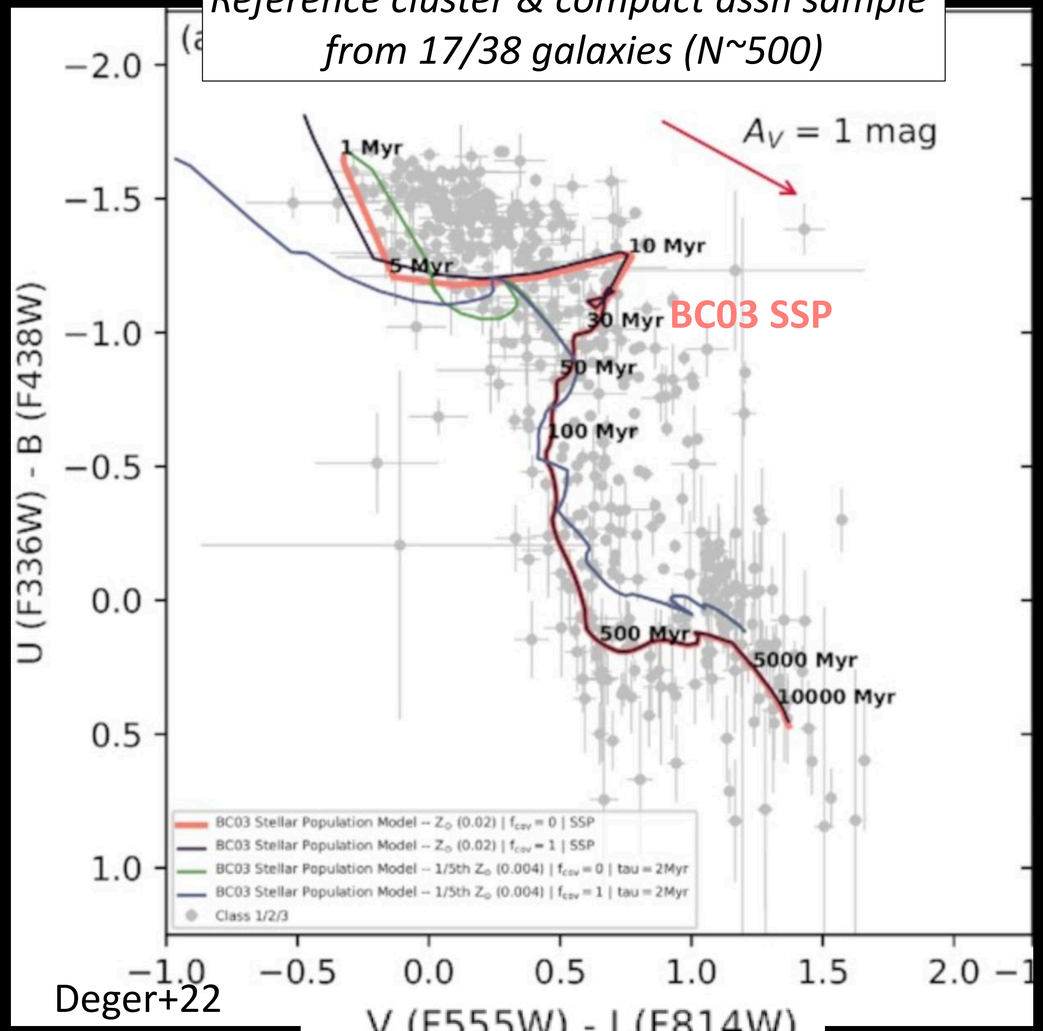
Hubble census of star cluster and stellar associations

Star formation & evolution at the highest densities

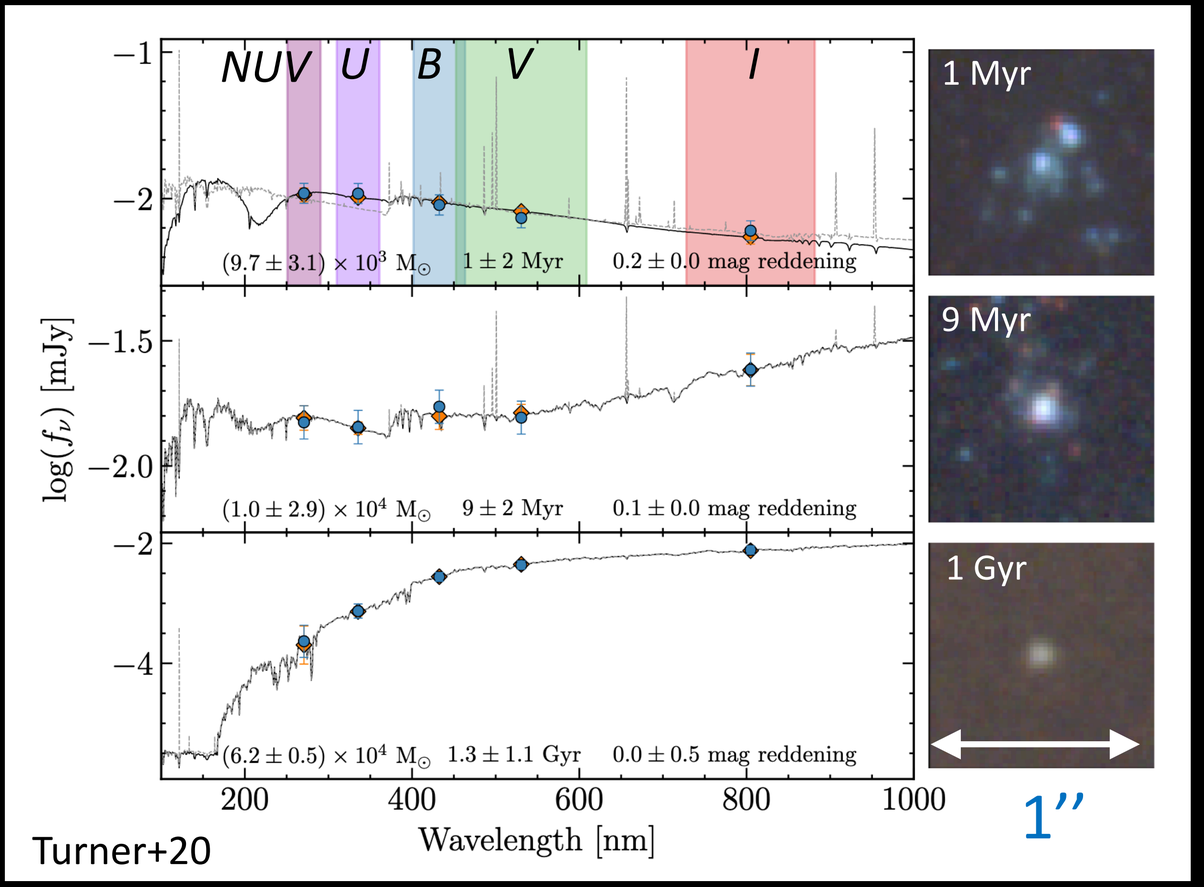
Cosmic chronometers (effectively SSP → time SF/ISM processes)

"Clusters as Clocks"

Reference cluster & compact assn sample from 17/38 galaxies (N~500)



Deger+22



Turner+20

Ages, M*, E(B-V) SED fits - CIGALE (Boquien+19; Thilker+ in prep)

Hubble census of star cluster and stellar associations

UBVI color-color diagram as a new diagnostic reference tool

Enabled by large sample, aggregated across local volume galaxies

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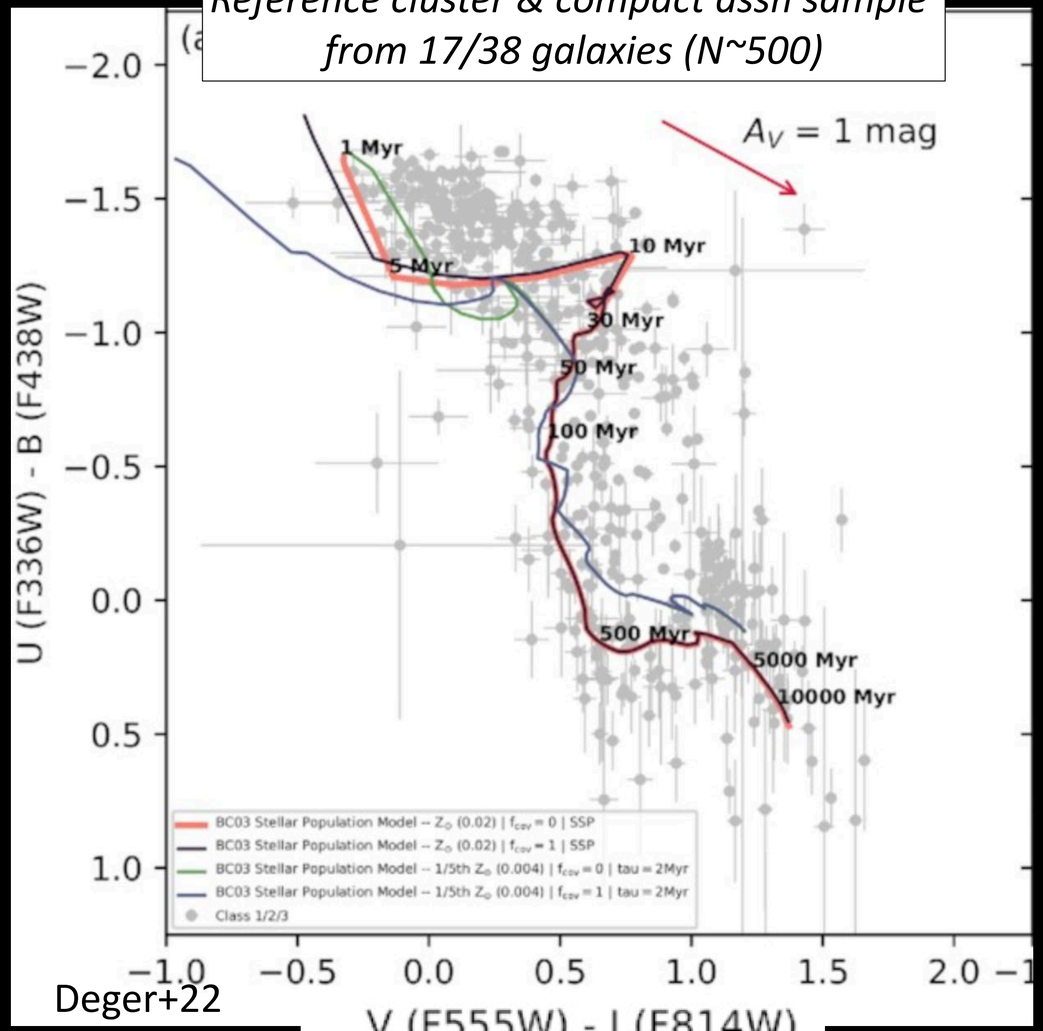
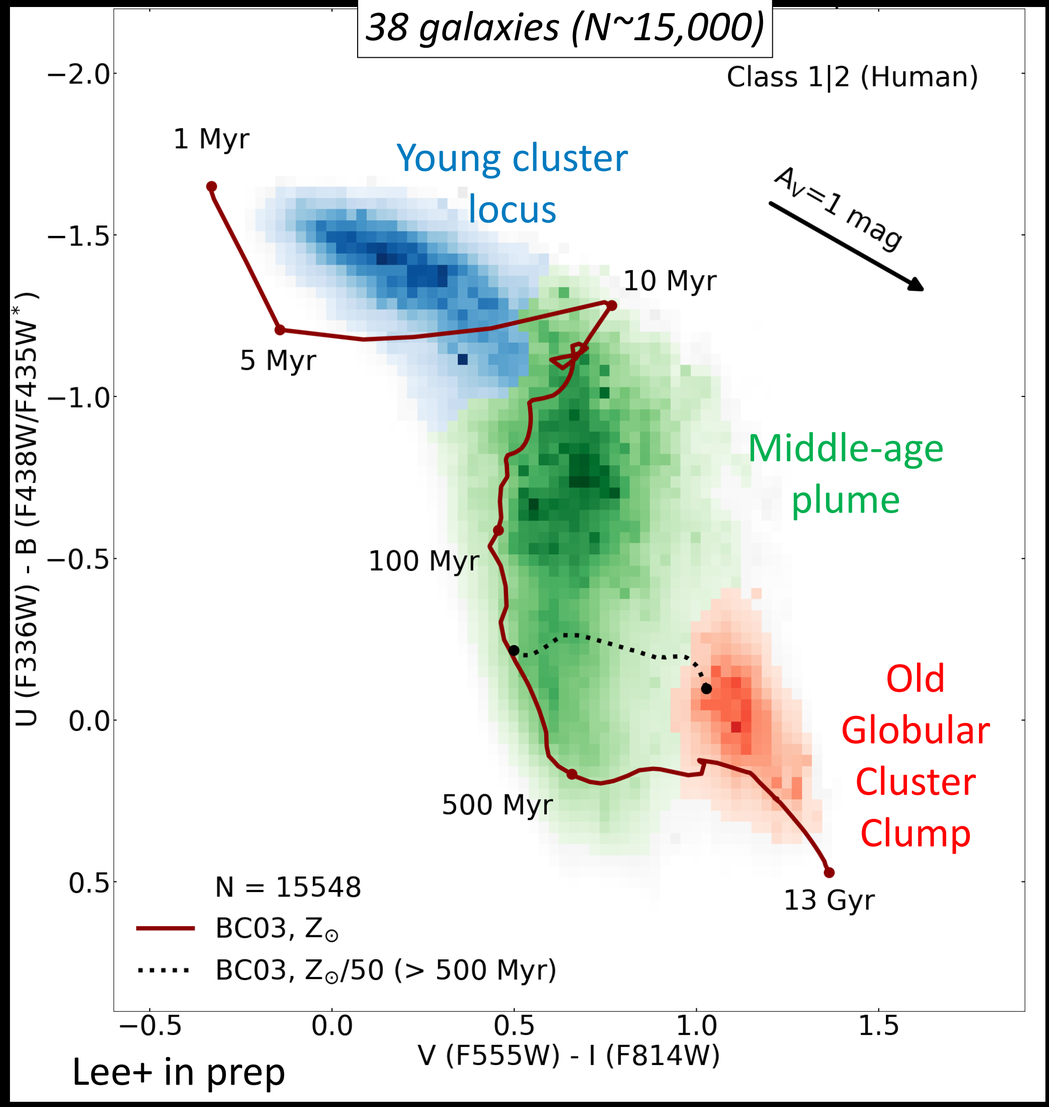


Deger+22

Bright cluster sample 38 galaxies (N~15,000)



Lee+ in prep

Hubble census of star cluster and stellar associations

UBVI color-color diagram as a new diagnostic reference tool

Enabled by large sample, aggregated across local volume galaxies

~15,000 Human classified clusters across 38 galaxies (C1+C2)

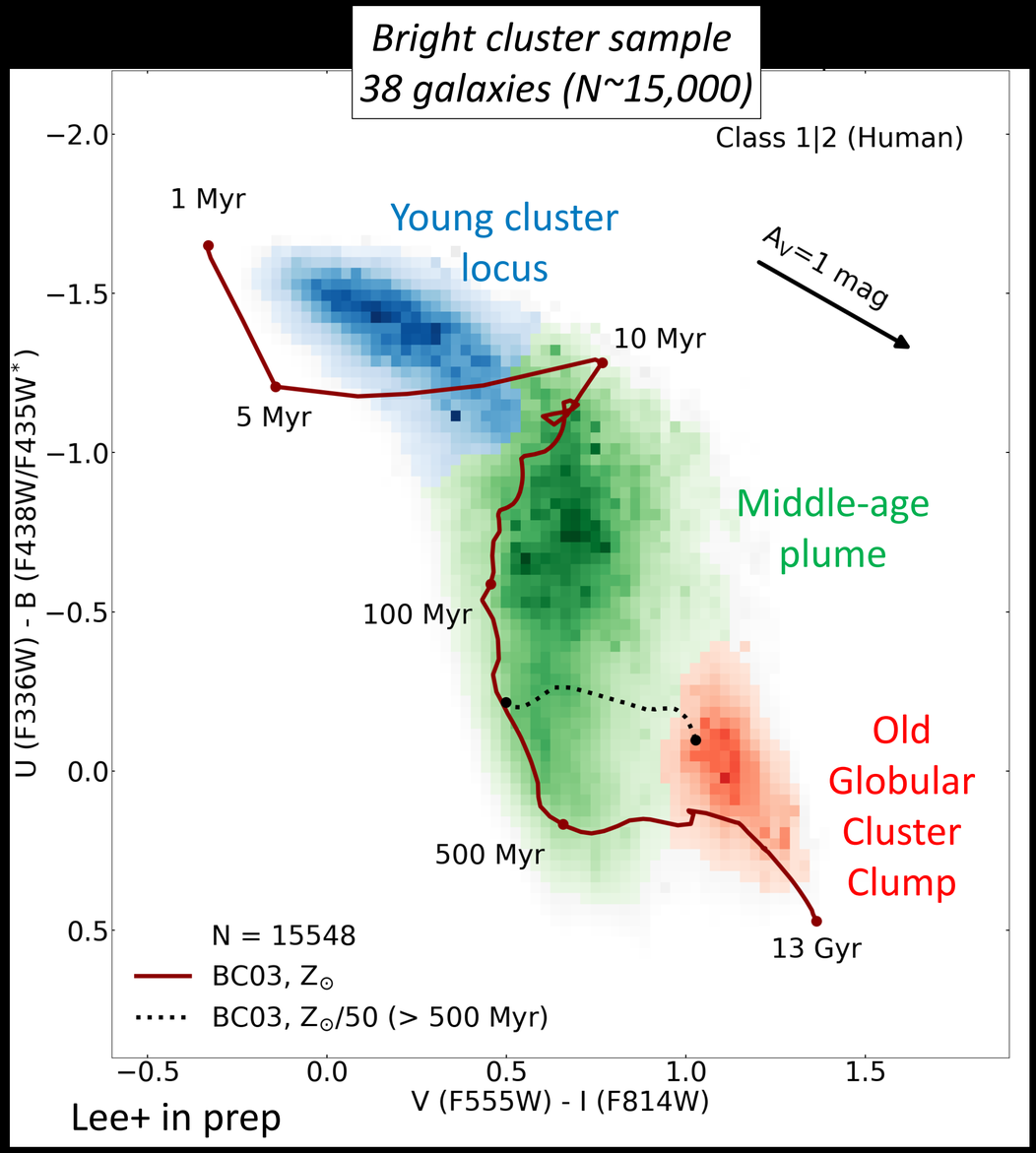
3 principal features observed

- young cluster locus (YCL)
- middle-aged plume (MAP)
- old globular cluster clump (OGC)

slope of the YCL consistent with reddening vector

MAP left edge show remarkable consistency with solar metallicity BC03 SSP

OGC separate into a distinct clump, consistent with their metal-poor nature



Hubble census of star cluster and stellar associations

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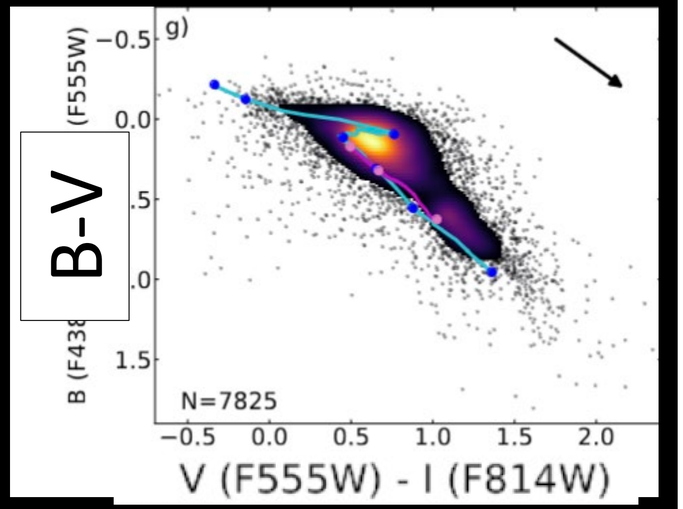
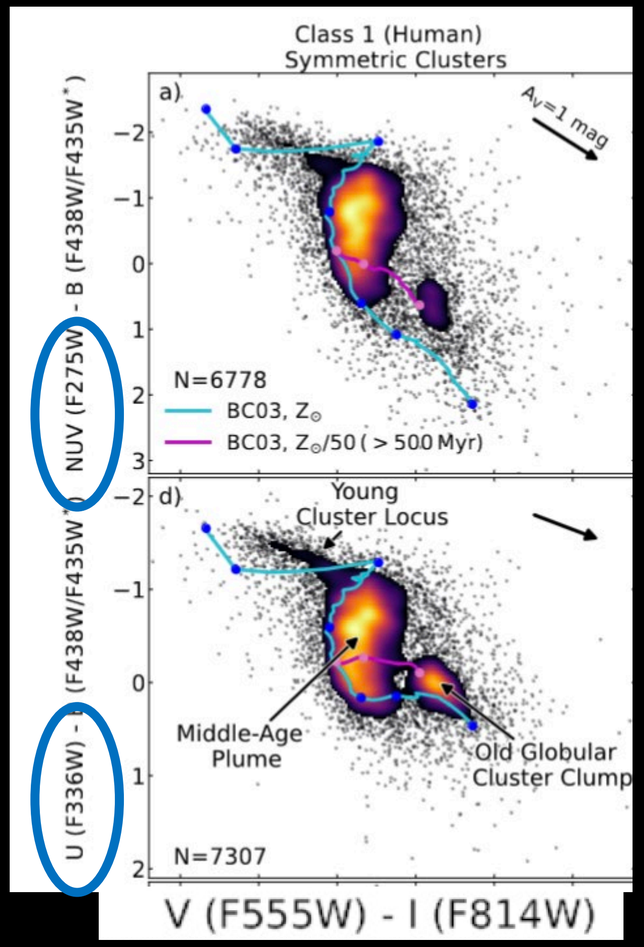
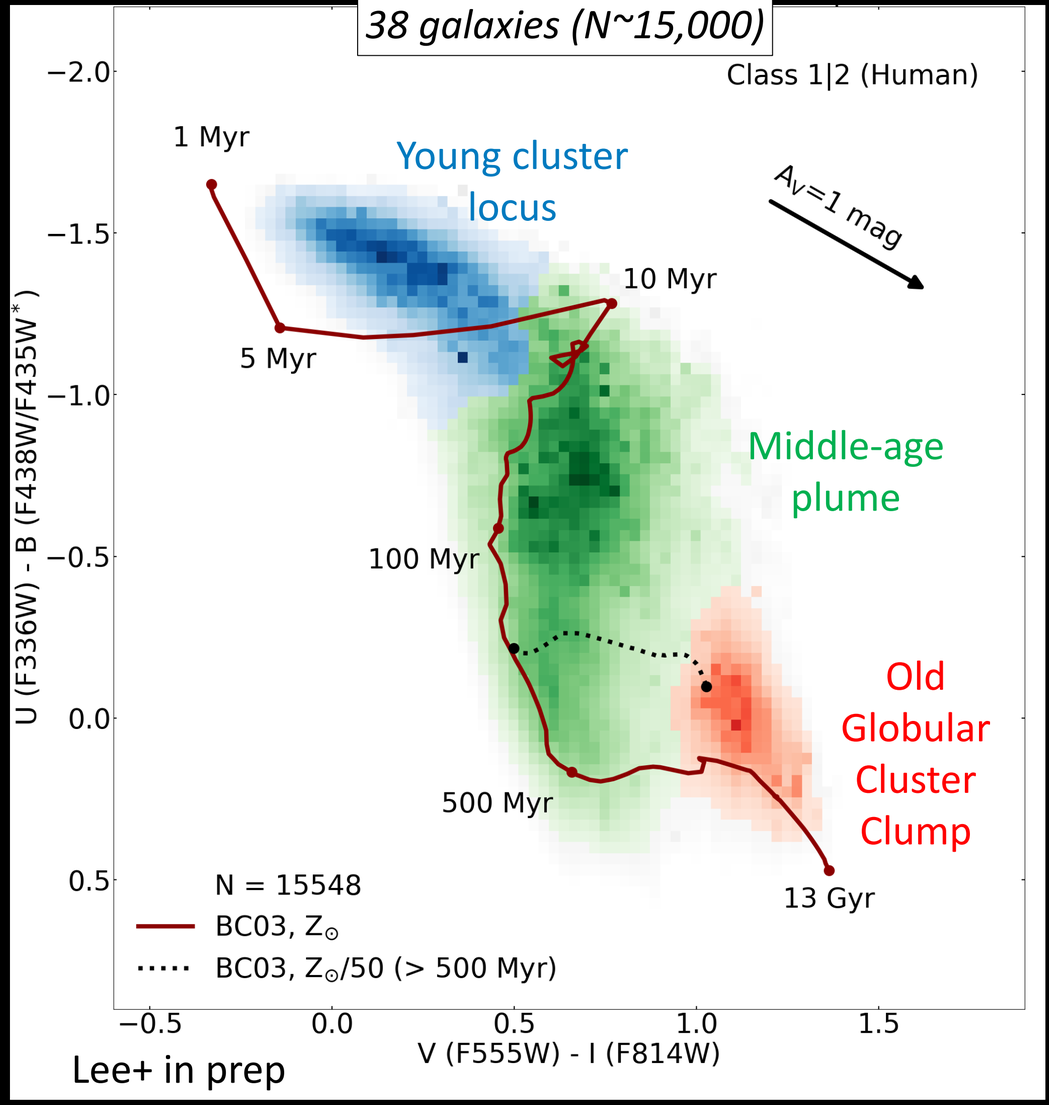


Requires U or NUV to break age-reddening-metallicity degeneracy



Bright cluster sample
38 galaxies (N~15,000)

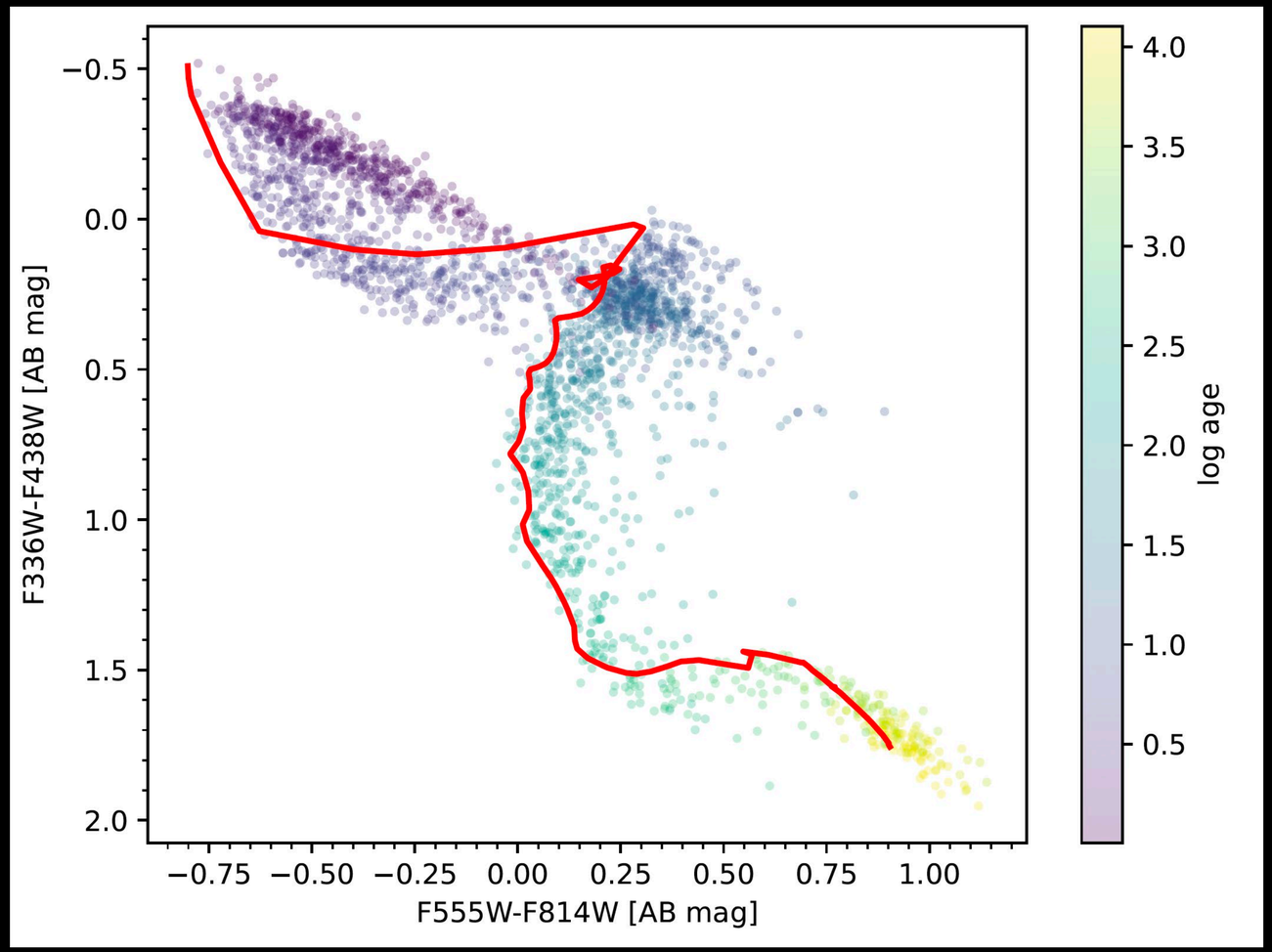


Hubble census of star cluster and stellar associations

UBVI color-color diagram as a new diagnostic reference tool

Enabled by large sample, aggregated across local volume galaxies

Test forward modeling by M. Boquien
Constrains cluster formation and destruction history



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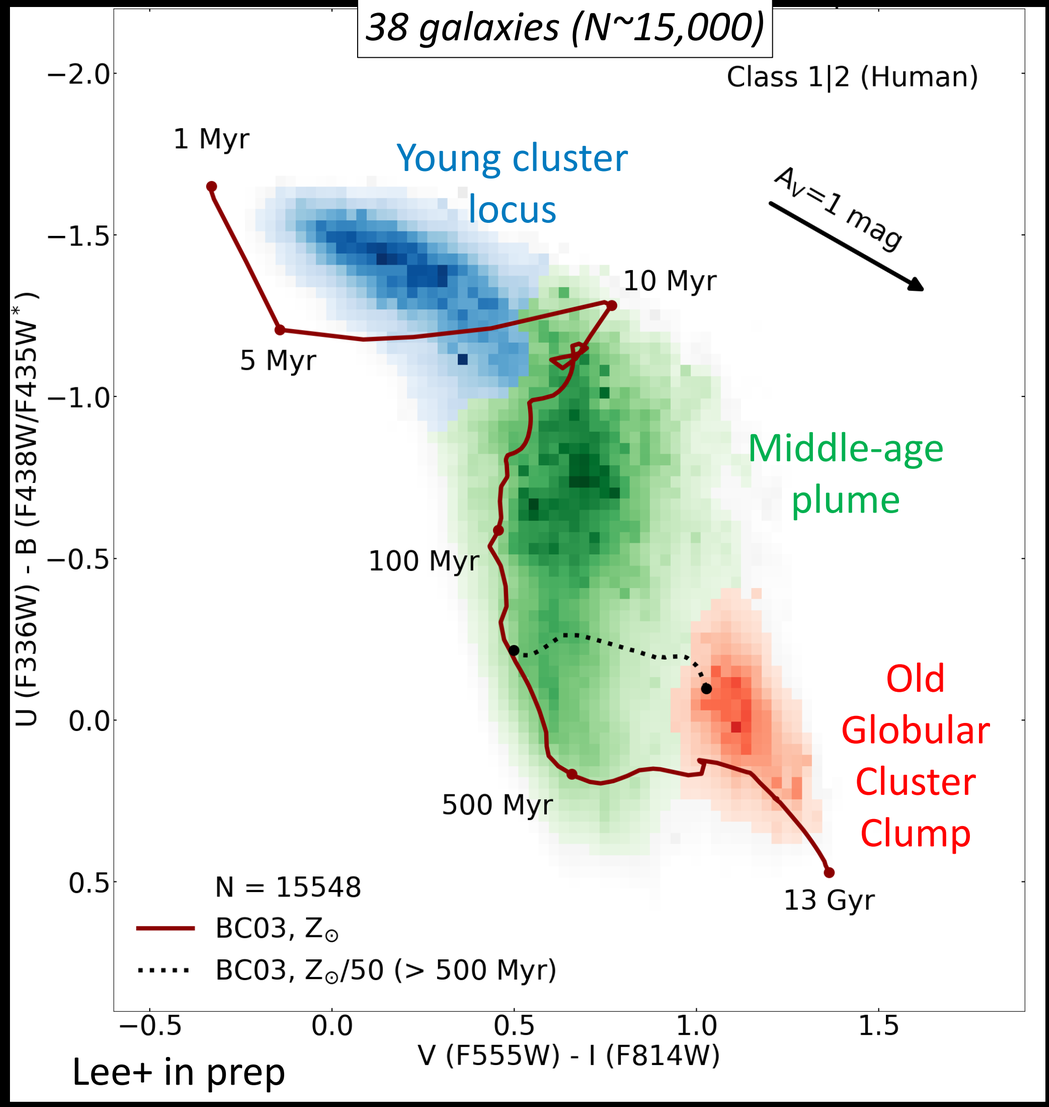
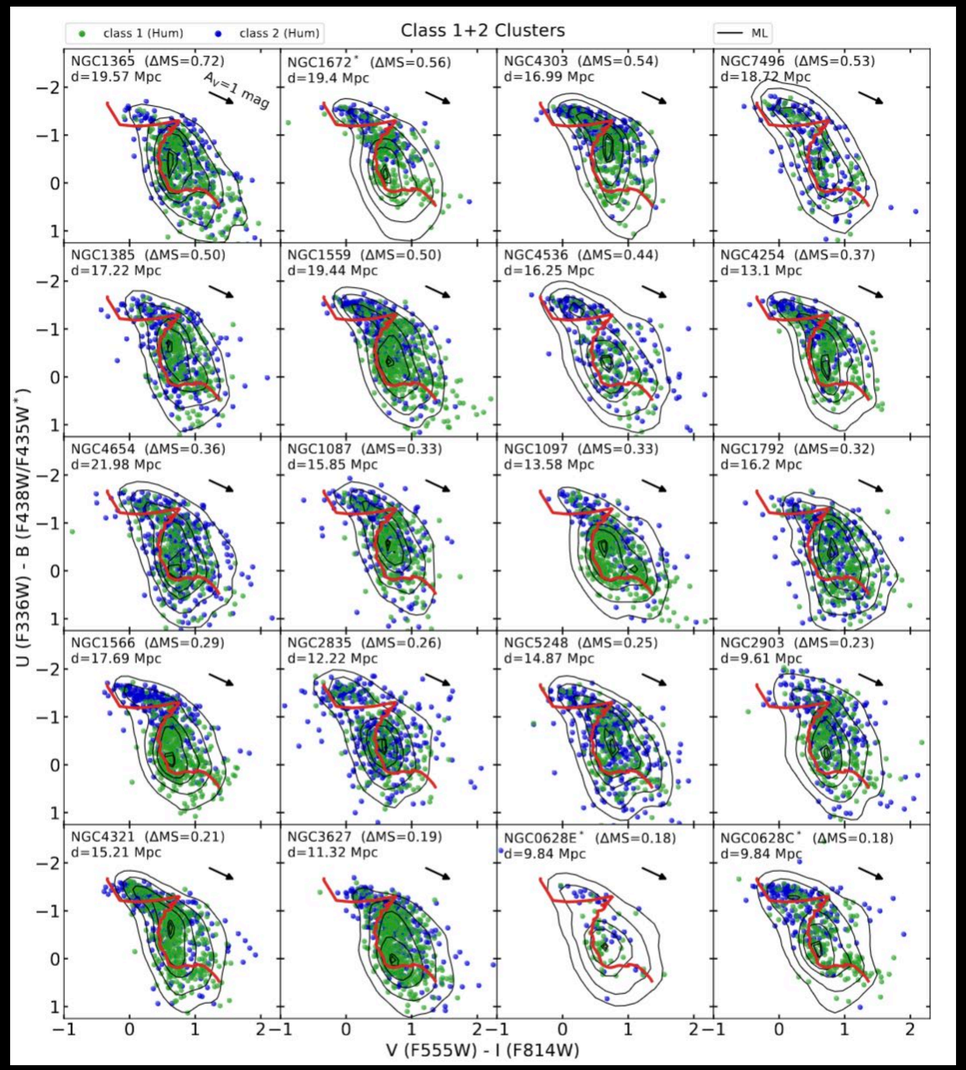


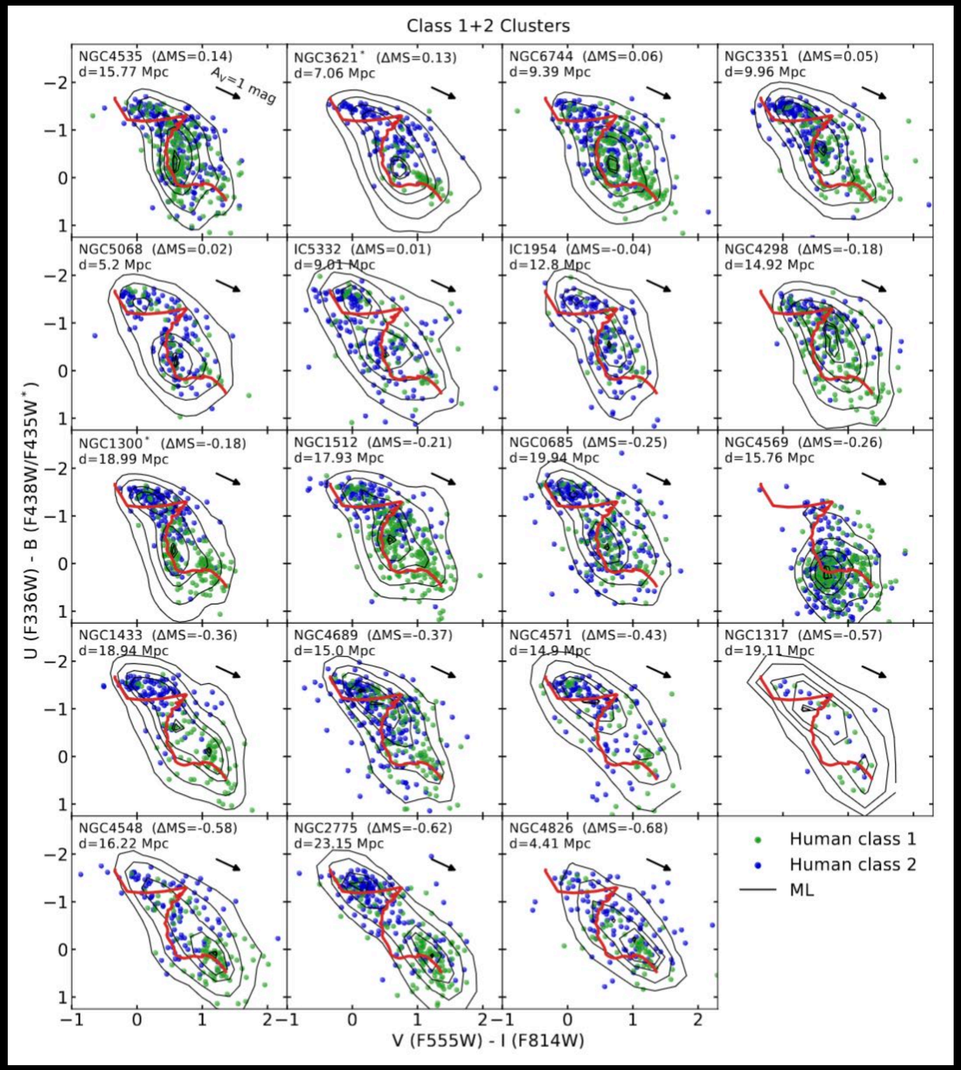
Lee+ in prep

Hubble census of star cluster and stellar associations

UBVI color-color diagram as a new diagnostic reference tool

UBVI color-color diagrams for individual galaxies



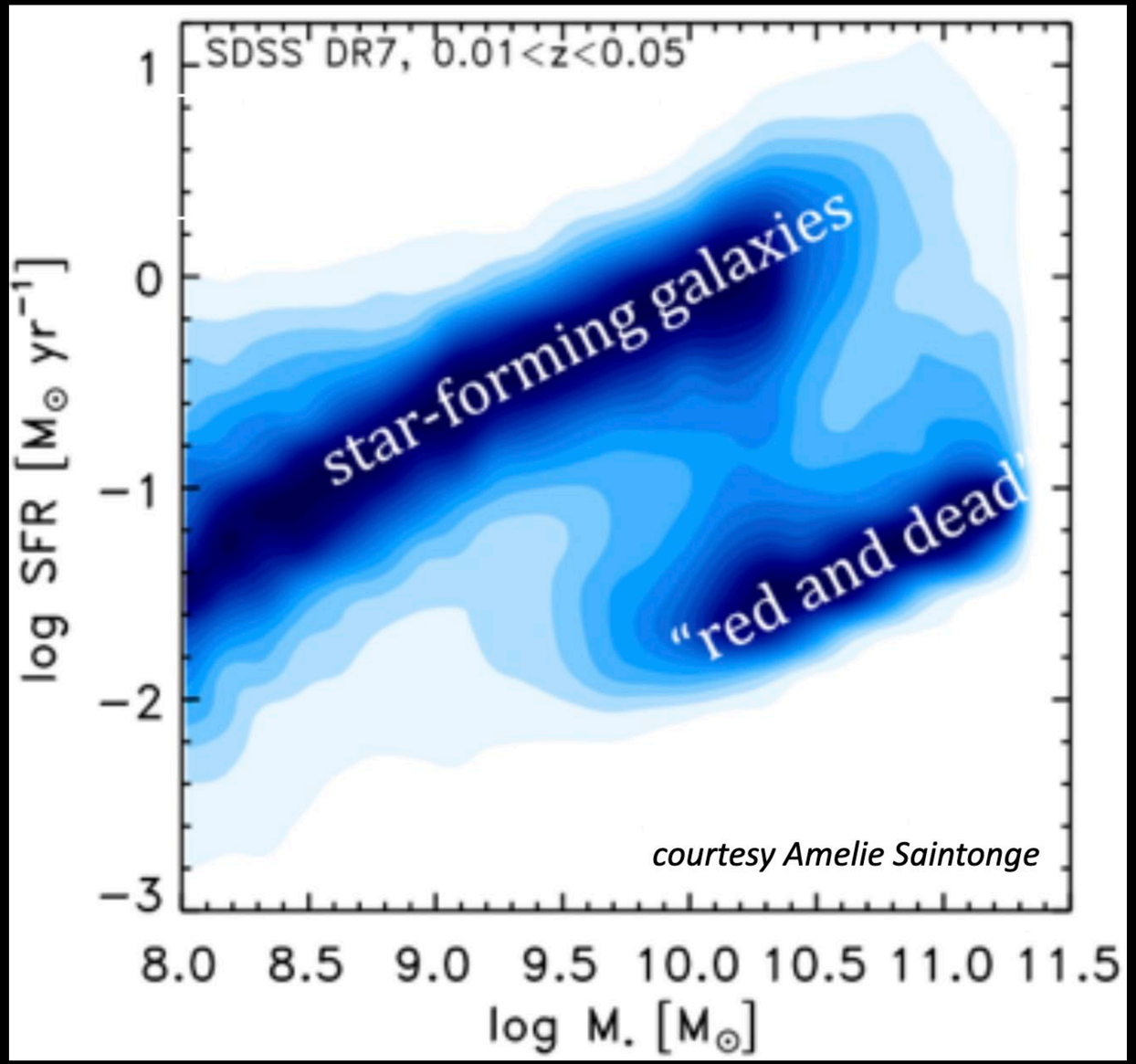


Hubble census of star cluster and stellar associations

UBVI color-color diagram as a new diagnostic reference tool

Bring together different techniques to explore dataset in a multi-scale context:

- characterization of galaxies (galaxy morphology and location relative to the galaxy main sequence)
- cluster populations (color-color diagrams and 2D spatial distributions)



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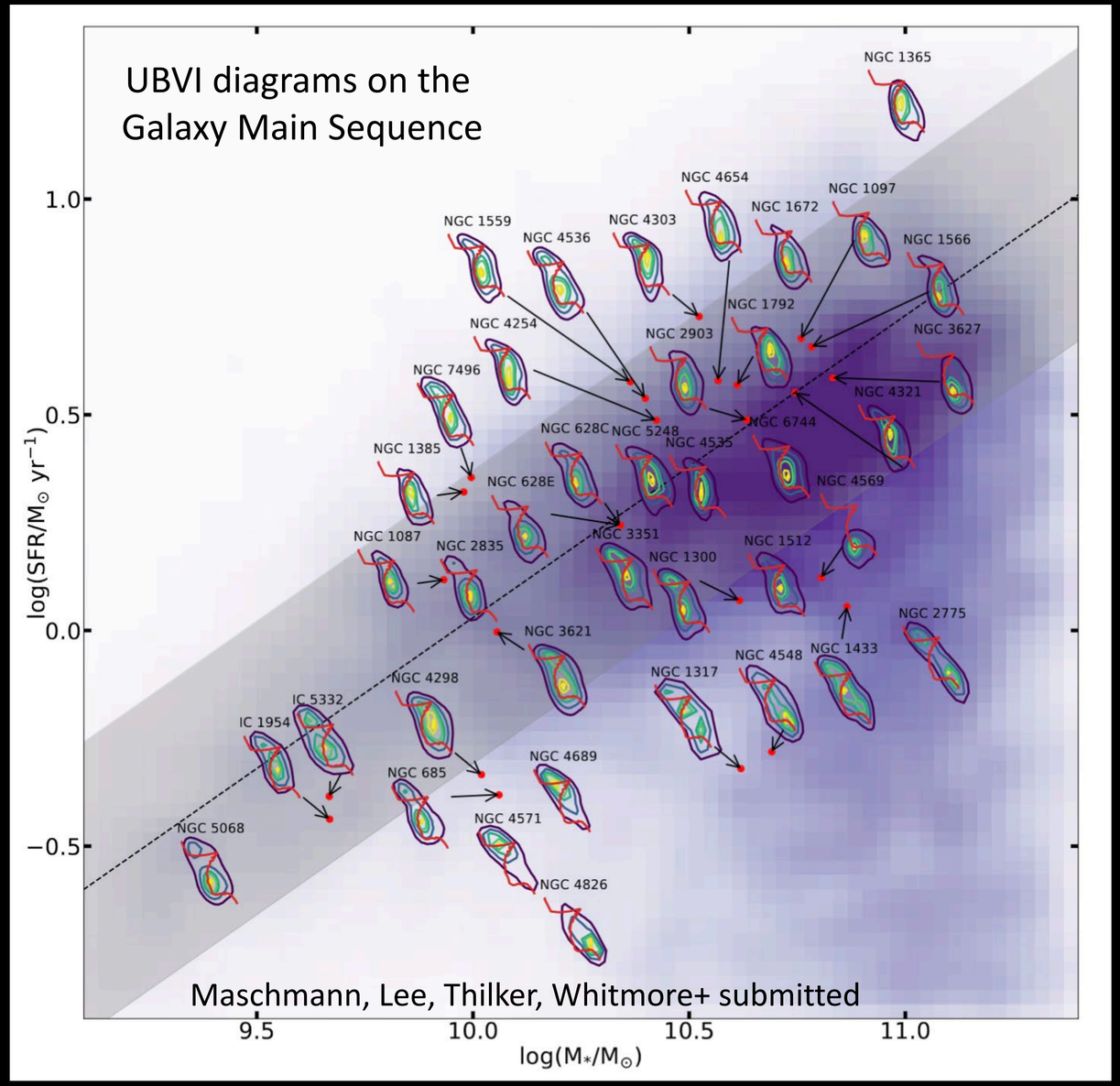
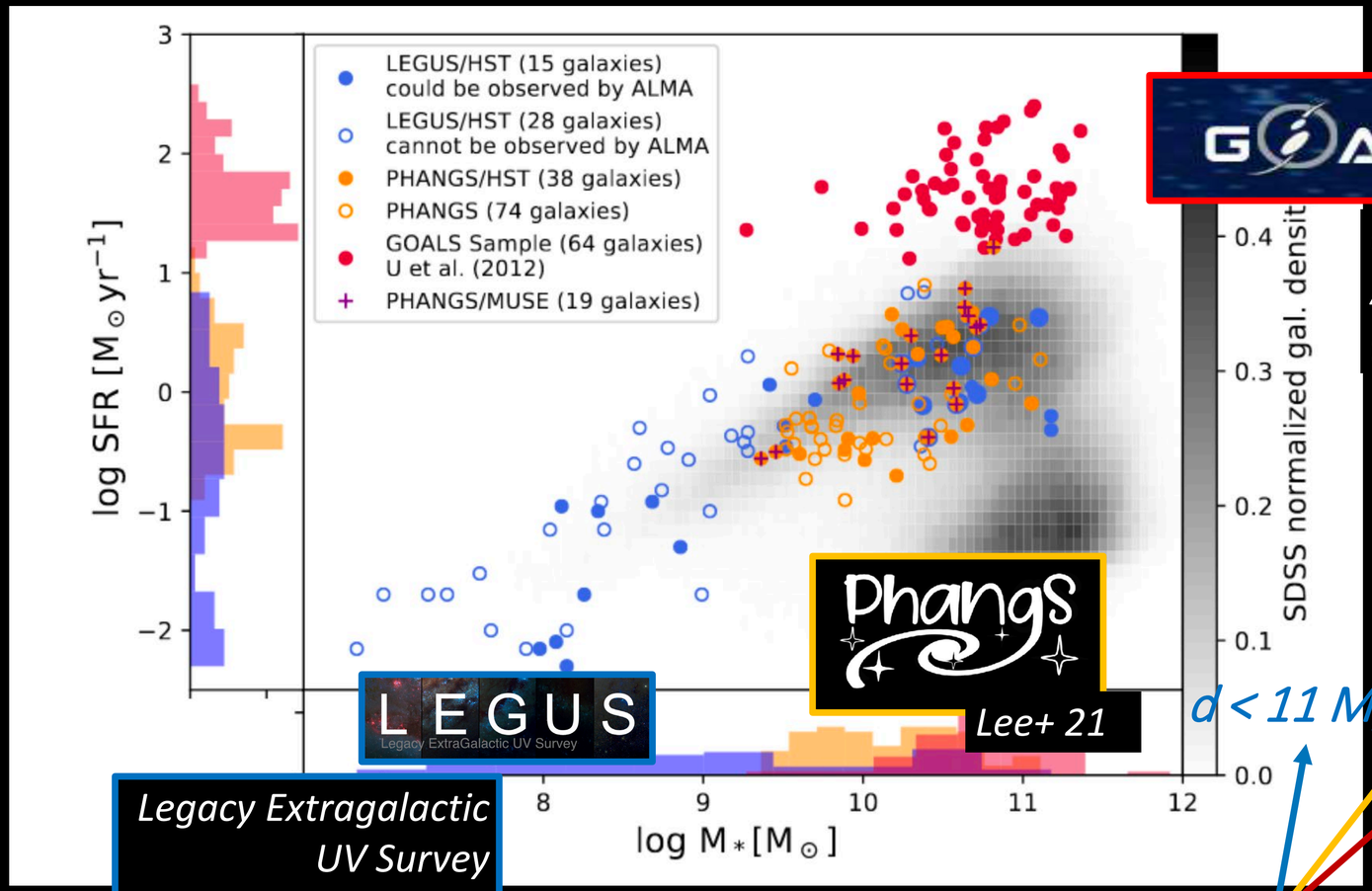
Isn’t a sample of ~100,000 star clusters enough?



Isn’t a sample of ~100,000 star clusters enough?

HWO needed to increase the volume available for star cluster studies to:

- capture galactic environments, rare in the present-day universe
- Increase the sample of massive young clusters >1e5 Msun (<1% of current census)



Legacy Extragalactic UV Survey (Calzetti, Lee+15)

GOALS

Great Observatories All-sky LIRG Survey (Armus+09)

50-100 Mpc

d < 25 Mpc

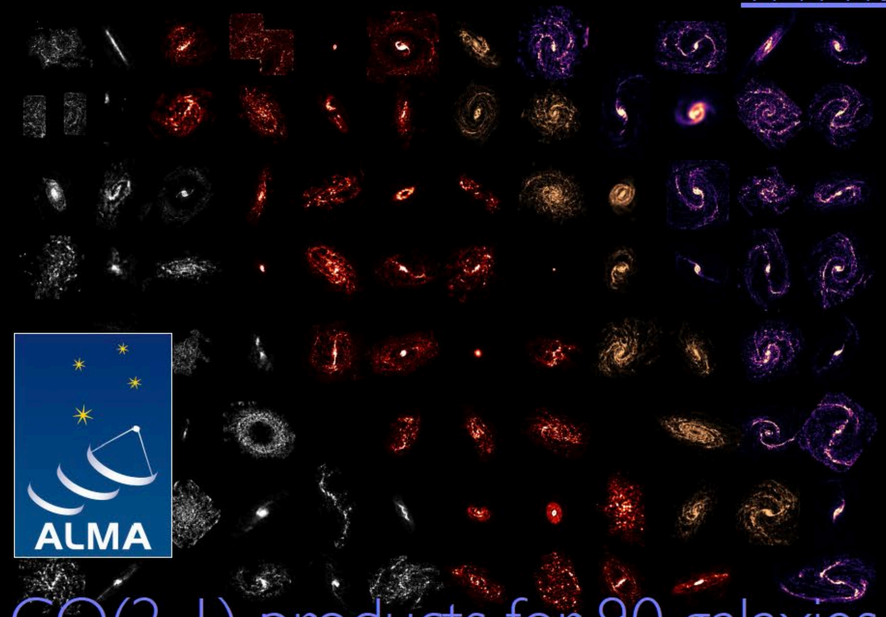
d < 11 Mpc

Ultimately, analysis of all programs together needed to fully understand impact of galactic environment on star formation

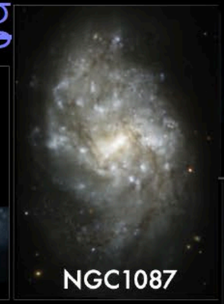
Phangs

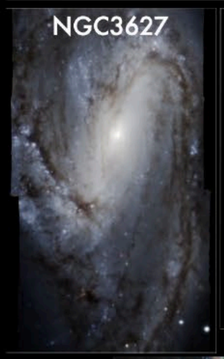
www.phangs.org

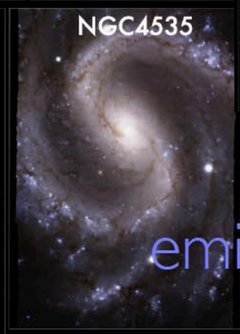
Public data products to support broader range of community science

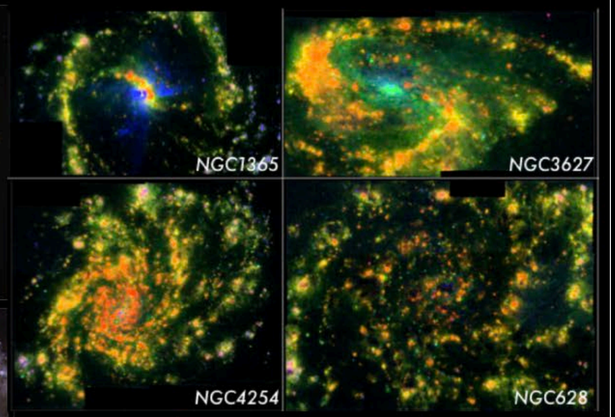


CO(2-1) products for 90 galaxies









muse multi unit spectroscopic explorer

emission line+stellar maps for19 galaxies

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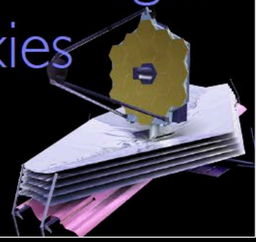
Linked from phangs.stsci.edu

NUV-UVBI imaging for 38 galaxies

near/mid-IR images for19 galaxies



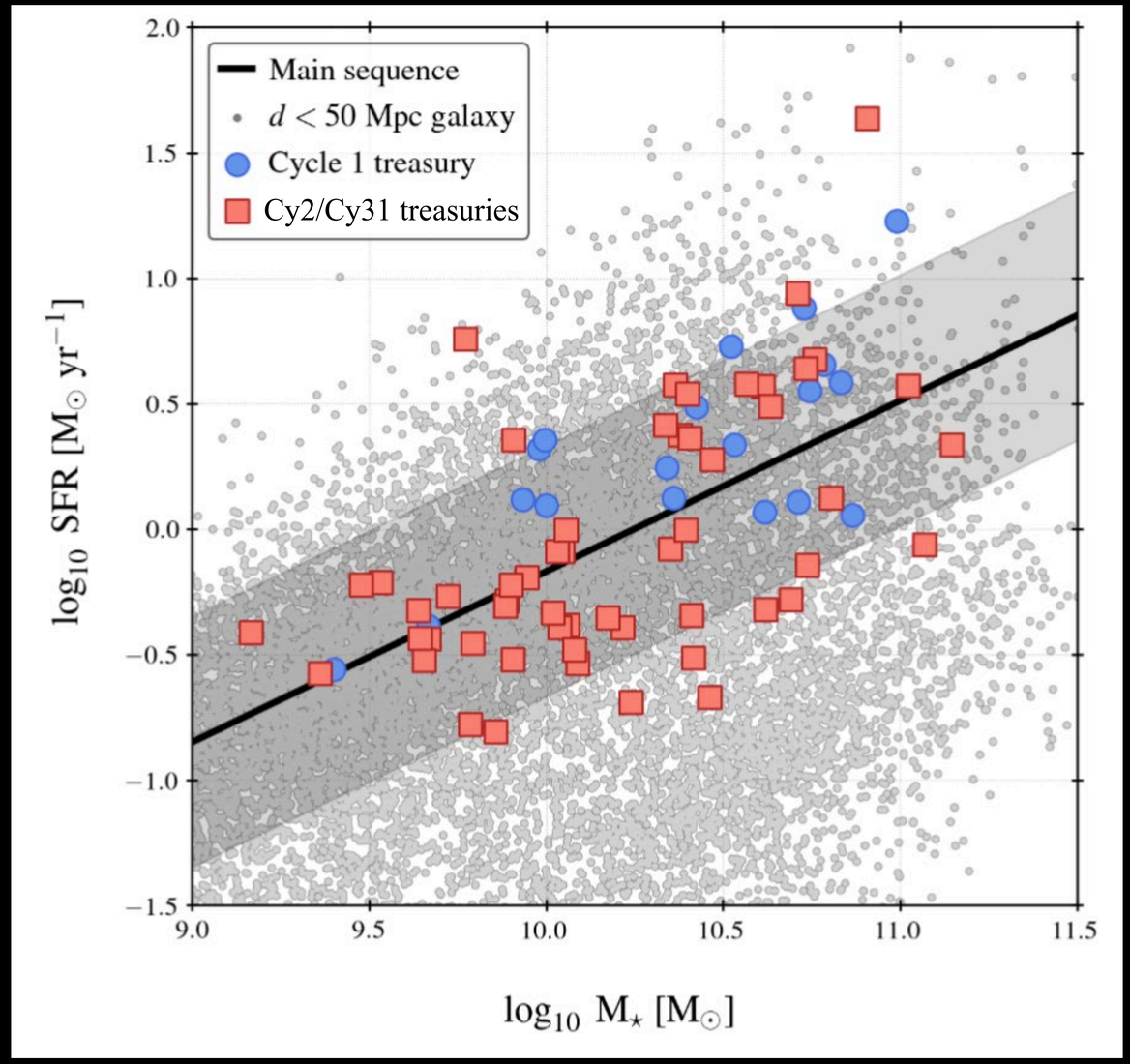
COMING IN 2023-24

NEW JWST/HST Treasury Surveys

- PHANGS-JWST Cy 2 (+ Paschen α)
co-PIs: Leroy, Kreckel, Lee, Rosolowsky, Sandstrom, Schinnerer

- PHANGS-HST Cy 31 (+ Hα)
co-PIs: Thilker, Lee

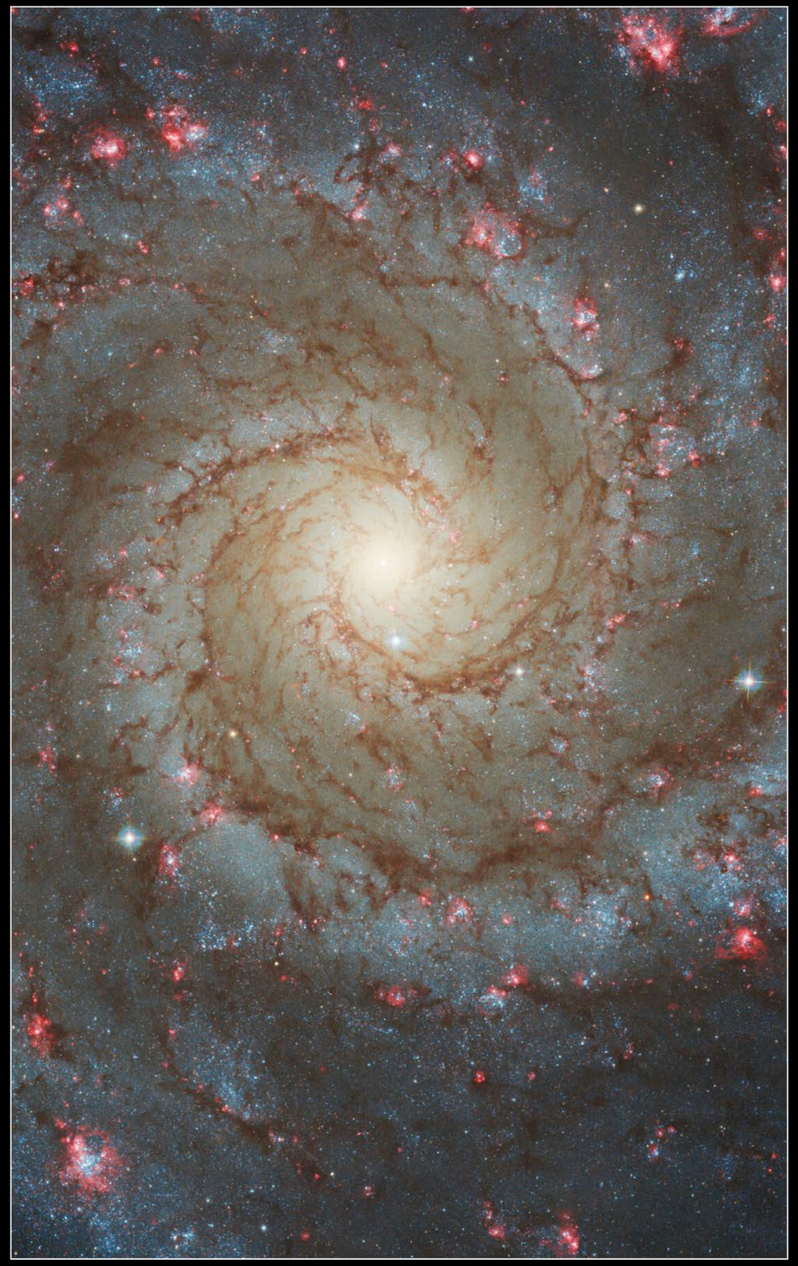
→ HST+JWST+ALMA for 74 spiral galaxies



- *span galaxy main sequence: log $M_\star[M_\odot]$ >9.75*
- *distances 4.4-23 Mpc*
- *ALMA observable: -75°<δ<20°*
- *not edge on (i<70°); avoid Galactic plane (|b|>15°)*
- *diversity of morphologies, dynamical features*

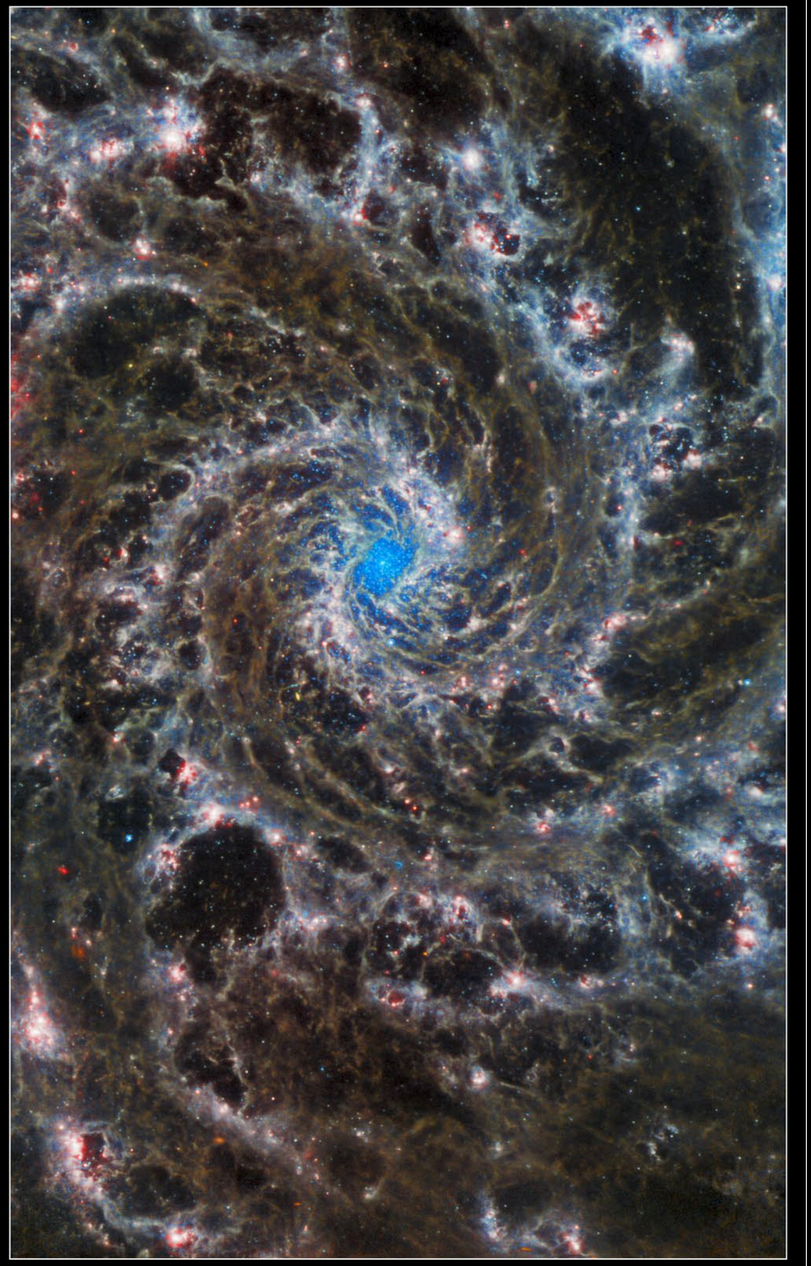
Summary

1. *The study of star formation in galaxies requires large observatories on ground and in space working together to capture the full SF cycle across a range of spatial scales.*
2. *PHANGS-HST provides the largest census of star clusters and associations to-date & enables new ways of studying stellar, cluster, galaxy formation & evolution.*
3. *The UBVI color-color diagram is a highly valuable, model-independent, observational diagnostic for star and cluster formation and evolution, and for the evolutionary status of galaxies.*
4. *The distribution of star clusters shows three principal features in the UBVI CCD: a young cluster locus (YCL), a middle age plume (MAP), and an old globular cluster clump (OGC)*
5. *Above the galaxy MS, cluster formation is promoted by bar-driven gas flows, often resulting in massive clusters in central ring structures, and at the bar ends.*
6. *Below the galaxy MS, peculiar UBVI CCDs reflect complex SFHs due to external environmental influences. Most galaxies lack strong MAP features. There is a strong correlation of the fraction of clusters in the MAP with ΔMS.*
7. *First results combining Hubble & JWST suggest that the youngest clusters (<2 Myr) may be underrepresented by a factor of 2 in Hubble-only censuses, and the embedded phase must be very short (< 2 Myr).*
8. *Multiple PHANGS studies suggest dust & gas clearing times are short (<2Myr), clearing begins before SNe at ~3 Myr → feedback from radiation pressure, stellar winds important (e.g., Hannon & Lee+19, 22; Chevance+22, Rodriguez & Lee+23,* Hassani+23, Kim+23, Whitmore+23).



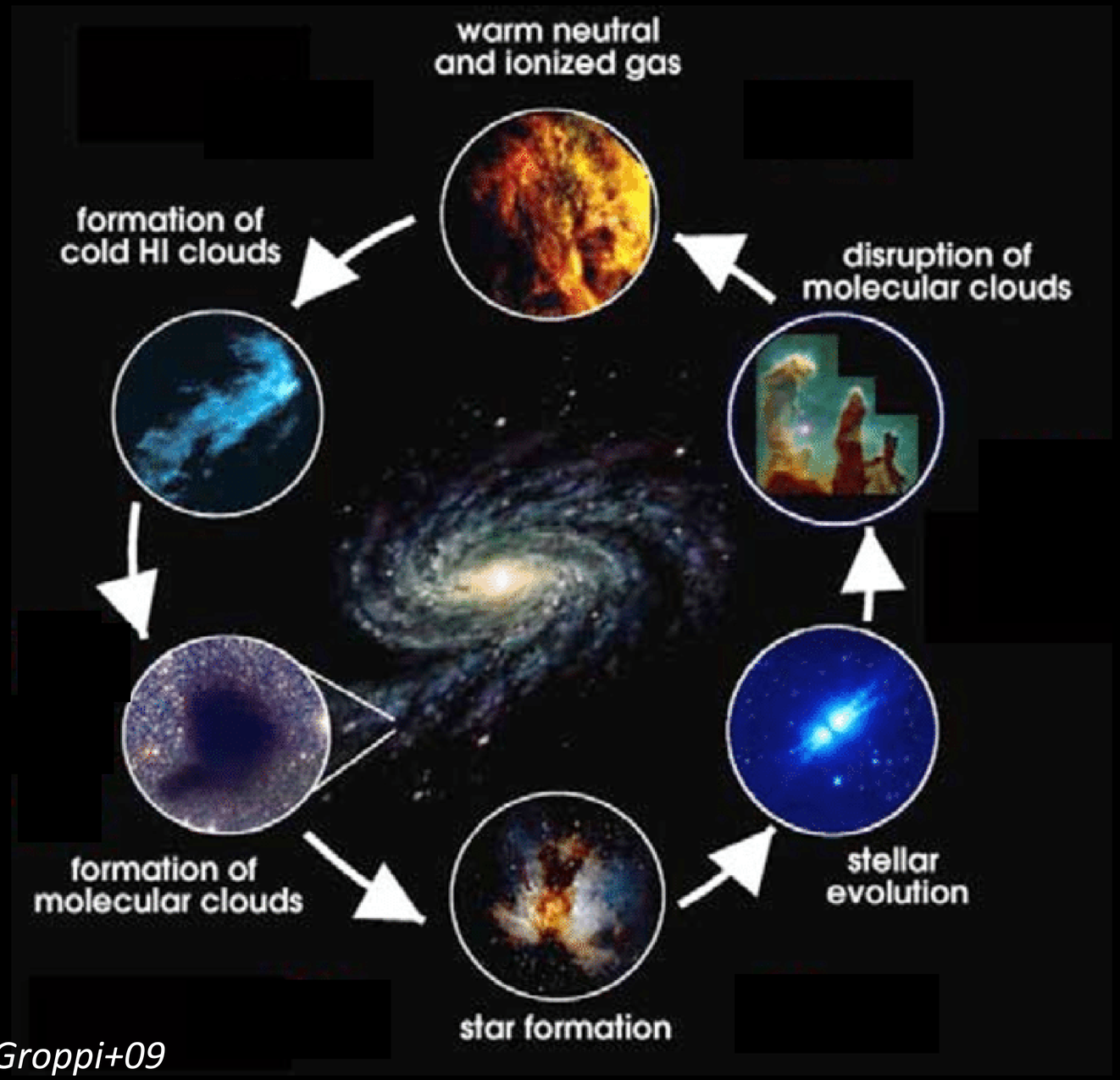
Hubble / Optical

Hubble & Webb



Webb / Infrared

NGC628: ESA/Webb, NASA & CSA, J. Lee and the PHANGS-JWST Team; ESA/Hubble & NASA, R. Chandar Acknowledgement: J. Schmidt



Groppi+09

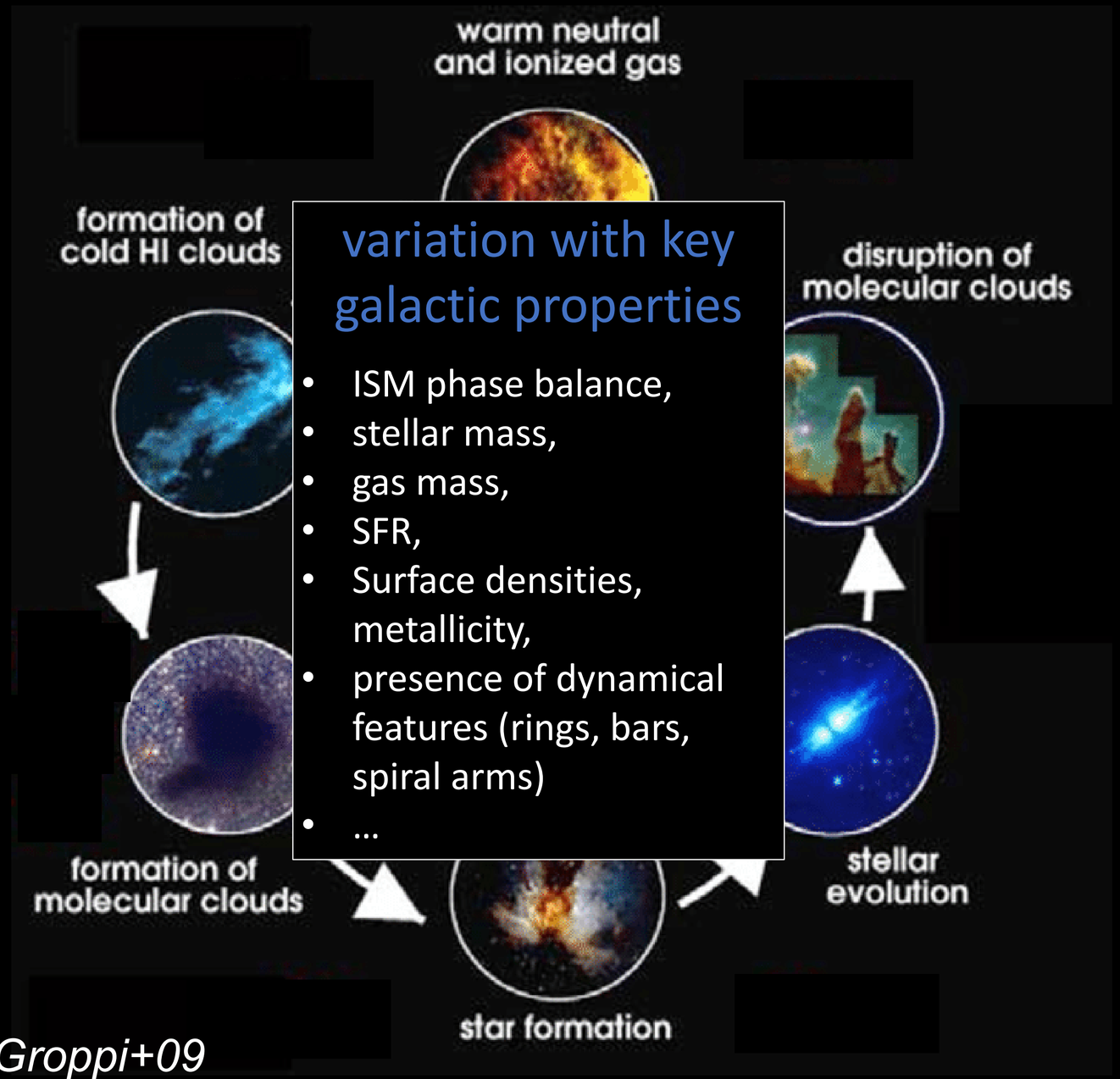
PHANGS-HST science goals: observational constraints on star formation

- Timescales: to onset of star formation in clouds, period of cloud inactivity, destruction of clouds, overall cloud lifetimes, removal of gas from young star clusters? *JWST: t(SF onset); correct t(inactive)*

- Relationship between mass functions of star clusters/associations related and clouds. Implied star/cluster formation efficiencies?

- How are star formation and gas organized into multi-scale structures? How do these spatial distributions evolve with time?

Previous work only in select galaxies (e.g., MCs, M51).



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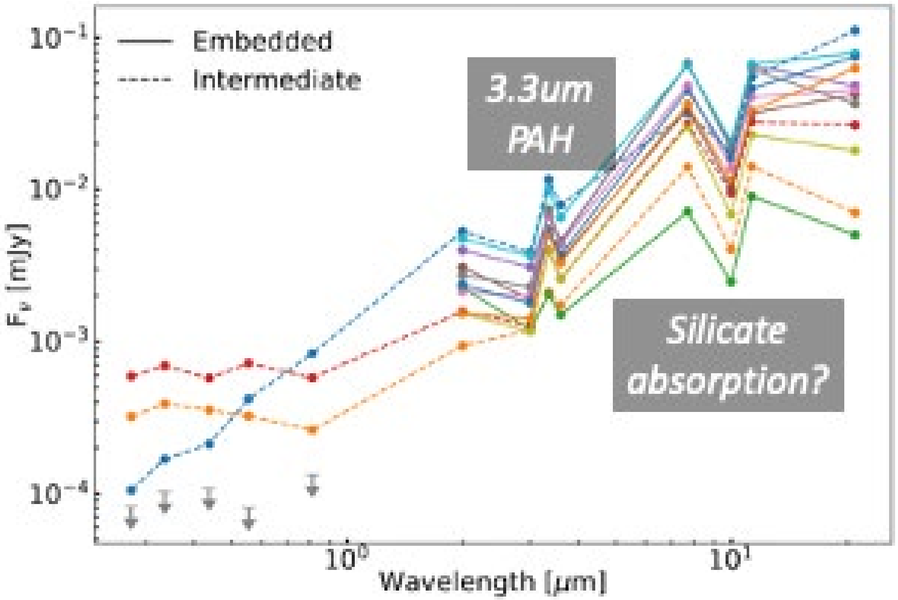
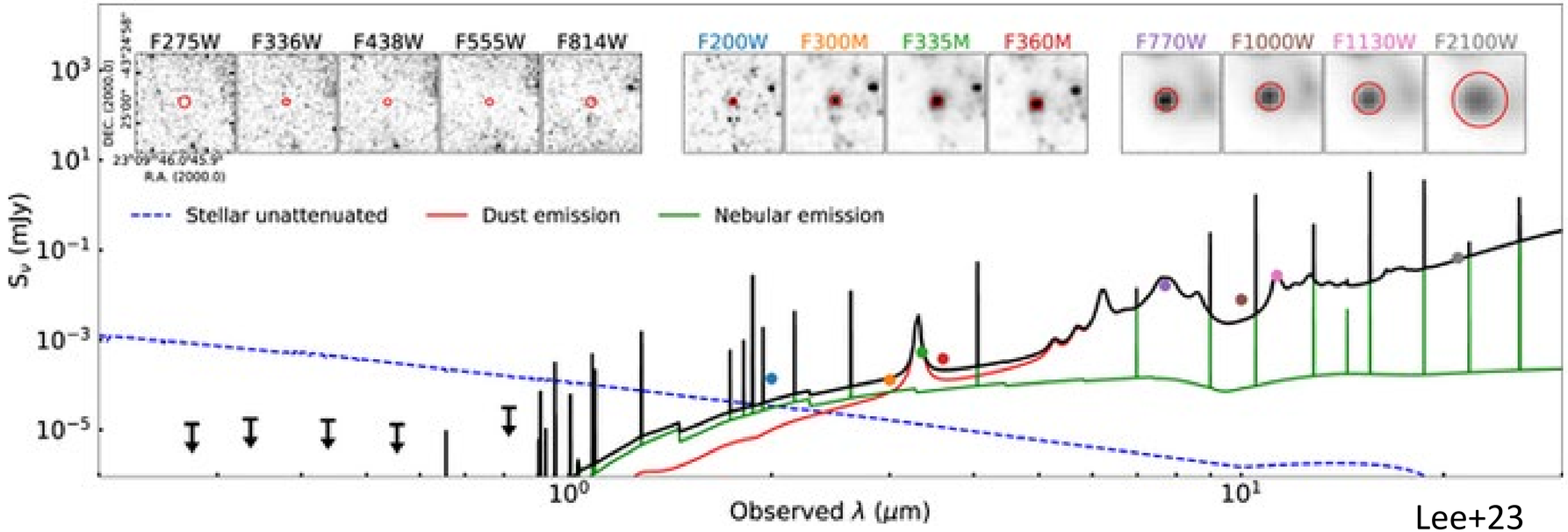
Challenges

SED modeling at cluster scale – how to constrain ages when there is no optical emission?

Resolution decrease from 2-21 micron



Rodriguez+23



Lee+23

PHANGS-JWST Initial Results (6 months after start of observations)

Why is mid-IR emission such a good tracer of bubble/shell/filament structure?

→ *can be calibrated as tracer of total gas column at all scales; destruction of PAHs in HII regions*

Leroy, Sandstrom,Thilker, Dale; Chastenet, Egorov

What processes are responsible?

→ *Stellar feedback; fragmentation from self-gravity regulated by turbulent pressure*

Watkins, Barnes, Meidt

What are characteristic timescales associated with SF, feedback, dust clearing?

→ *Embedded phase 2 Myr or shorter; pre SNe feedback is critical*

Rodríguez, Whitmore, J. Kim, Hassani

Papers also by Schinnerer; Hoyer; D. Liu; J. Kim; T. Williams

HST & JWST Stellar Populations Group

Janice Lee (STScI, PI)

Brad Whitmore (STScI)

David Thilker (JHU)

Rupali Chandar (U Toledo)

Daniel Dale (U Wyoming)

Remy Indebetouw (Uva/NRAO)

Aida Nava Wofford (U Ensenada)

Mederic Boquien (U Côte d'Azur)

Kirsten Larson (STScI)

Gagandeep Anand (STScI)

Postdocs, *Grads*, *Undergrad Interns*

M. Jimena Rodriguez (U AZ/STScI)

Daniel Maschmann (U AZ)

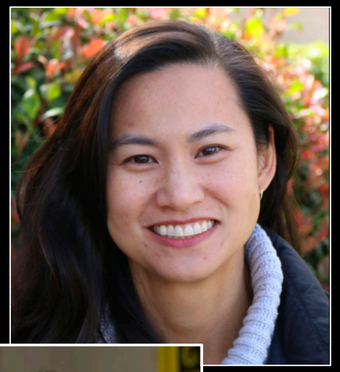
Matthew Floyd (U Toledo)

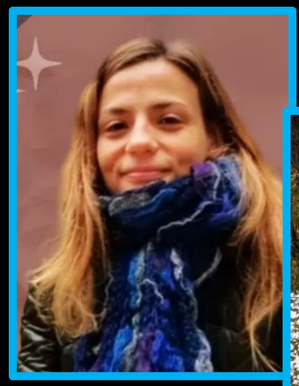
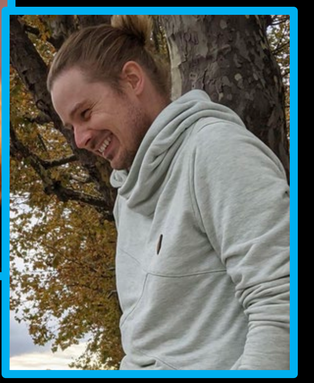
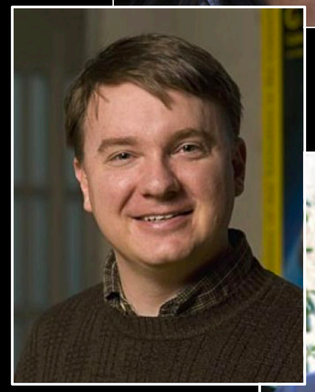
Kiana Henny (U Wyoming)

Stephen Hannon (MPIA)

Sinan Deger (Cambridge)

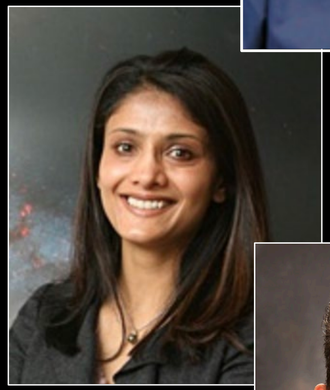
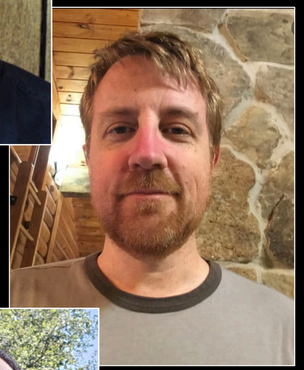
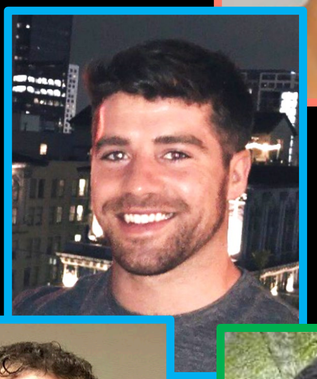
Qiushi Chris Tian (Wesleyan)









HST & JWST Stellar Populations Group

PHANGS-HST census of ~100,000 star clusters and compact assns (Maschmann, Lee, Thilker, Whitmore+ subm)

Technical pipeline efforts:

- *Survey and overview (Lee+22)*
- *Candidate detection & selection (Whitmore+21, Thilker+22)*
- *Photometry & aperture corrections (Deger+22)*
- *Machine learning cluster morphological classification (Wei+20, Whitmore+21, Hannon+23)*
- *SED fitting with CIGALE (Turner+21)*
- *TRGB distances (Anand+21)*