Cluster Formation & Bound Stellar Fractions in M31
via PHAT and the Andromeda Project

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We use high resolution Hubble Space Telescope imaging to identify a stellar cluster sample in the nearby Andromeda galaxy. We obtain mass estimates for clusters and the surrounding field populations from color-magnitude diagram fitting of the resolved star populations and calculate the fraction of 10-100 Myr old stars that are members of bound clusters. From these bound mass fractions, we infer the fraction of mass born in long-lived clusters and explore the environmental dependency of this factor.

PHAT Survey

The Panchromatic Hubble Andromeda Treasury (PHAT; PI: Dalcanton) has surveyed 1/3 of M31 disk, obtaining 6-band imaging using ACS & WFC3, spanning in NUV (F275W) to NIR (F160W). Resulting catalogs include photometry for 117 million stars (Williams+14).
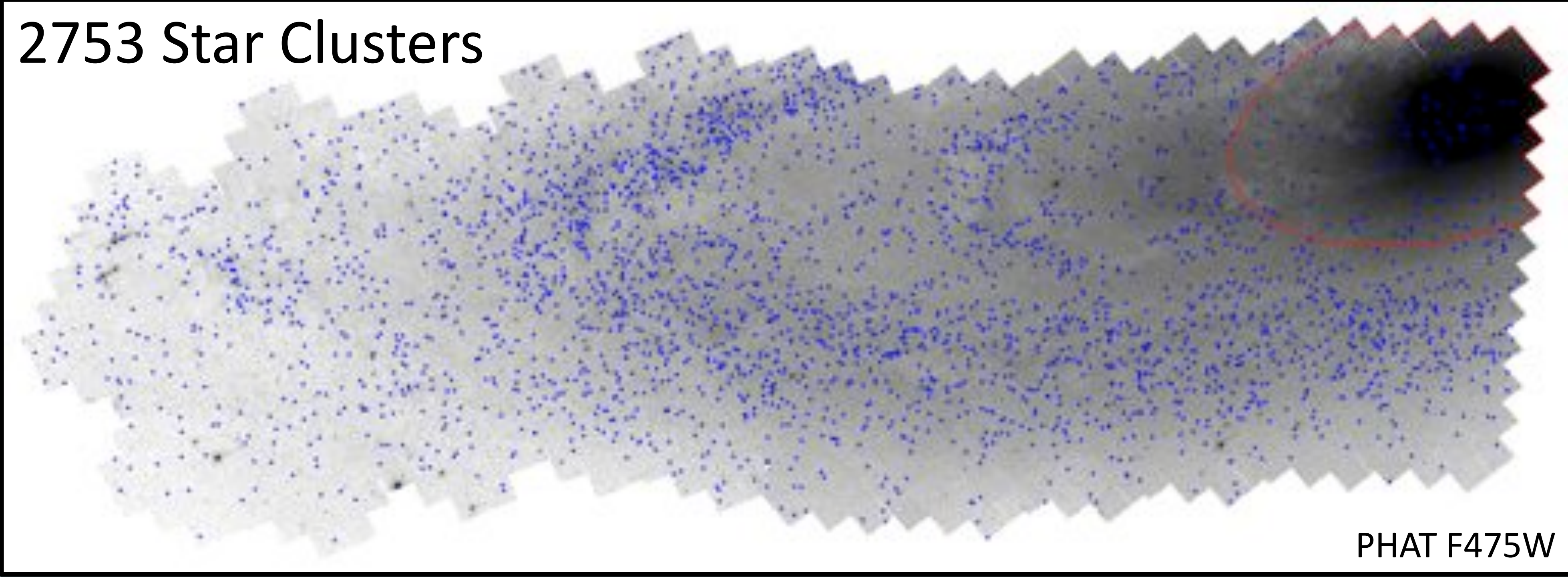
Andromeda Project Cluster Catalog

Cluster identification was accomplished using classifications from citizen scientists through the Andromeda Project (AP) website, build and hosted by the Zooniverse.
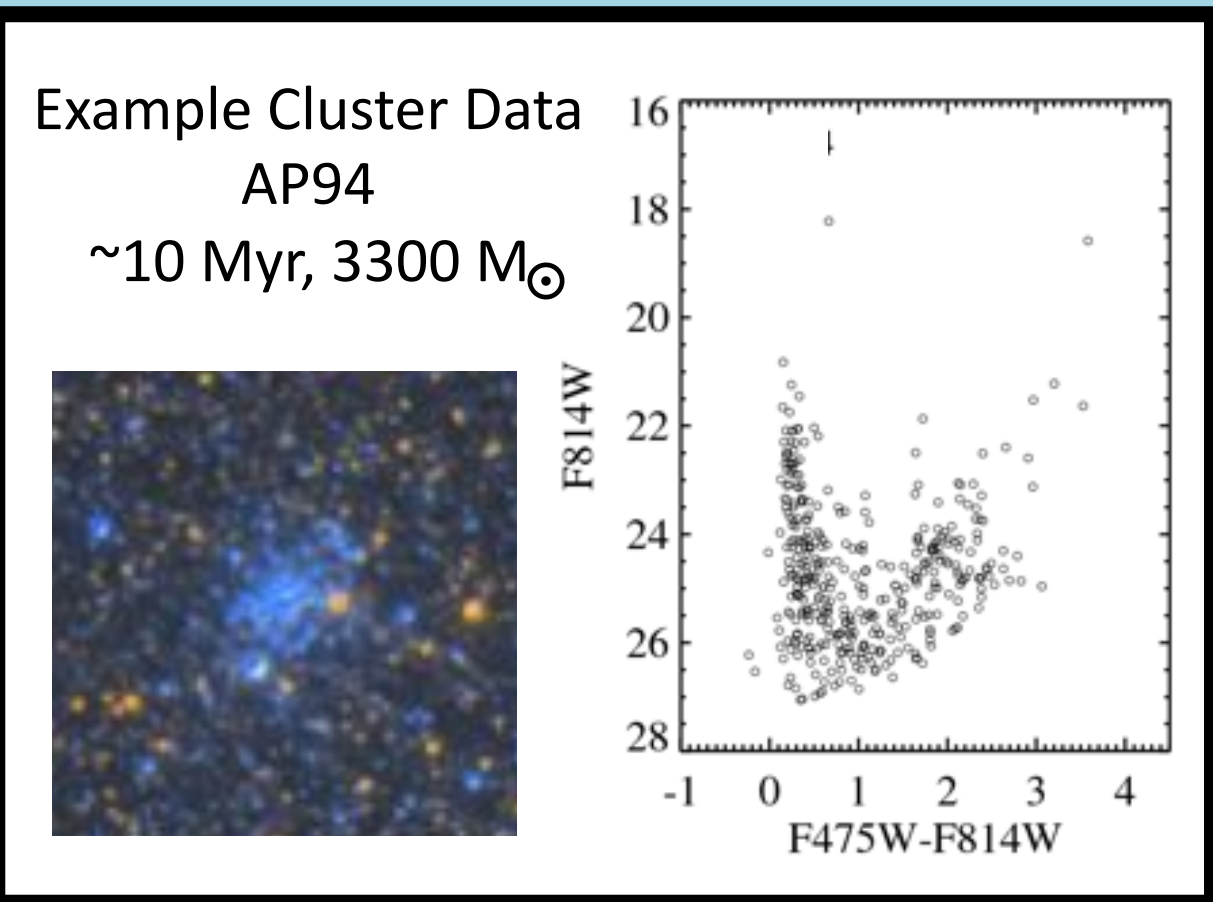
Cluster Catalog: Johnson et al. 2014 (submitted)

By The Numbers:
25 days of data collection   >30,000 volunteers
1.82 million image classifications   ~2 years of human attention

andromedaproject.org

2753 Star Clusters

PHAT F475W

Example Cluster Data
AP94
~10 Myr, 3300 $M_\odot$

Catalog Completeness Analysis:

We injected **3100 synthetic clusters** into images to robustly determine the catalog's completeness characteristics as a function of cluster properties (age, mass, R_{eff}, etc).

We find that we are **mass-limited** for clusters <100 Myr old, with a 50% completeness of ~500 $M_\odot$.

Γ: Clustered Fraction of Star Formation

$$\Gamma = \frac{M_{clusters}}{M_{total}}$$

Previous observational studies (Larsen & Richter 01, Goddard+10, Silva-Villa & Larsen 11, Adamo+11, Cook+12, Silva-Villa+13) have shown evidence for a relation between **star formation rate density** and Γ. Most of this work has occurred on galaxy-wide scales. We improve upon this previous work by measuring Γ at sub-galactic scales using a cluster catalog that includes <10^3 $M_\odot$ clusters.

Assumptions for our work here:
- We make a correction for undetected cluster mass (<500 $M_\odot$), assuming a mass function with -2 index from 10-2x10^5 $M_\odot$.
- Cluster dissolution over 10-100 Myr time period is negligible – see Morgan Fouesneau's talk for discussion of cluster dissolution.
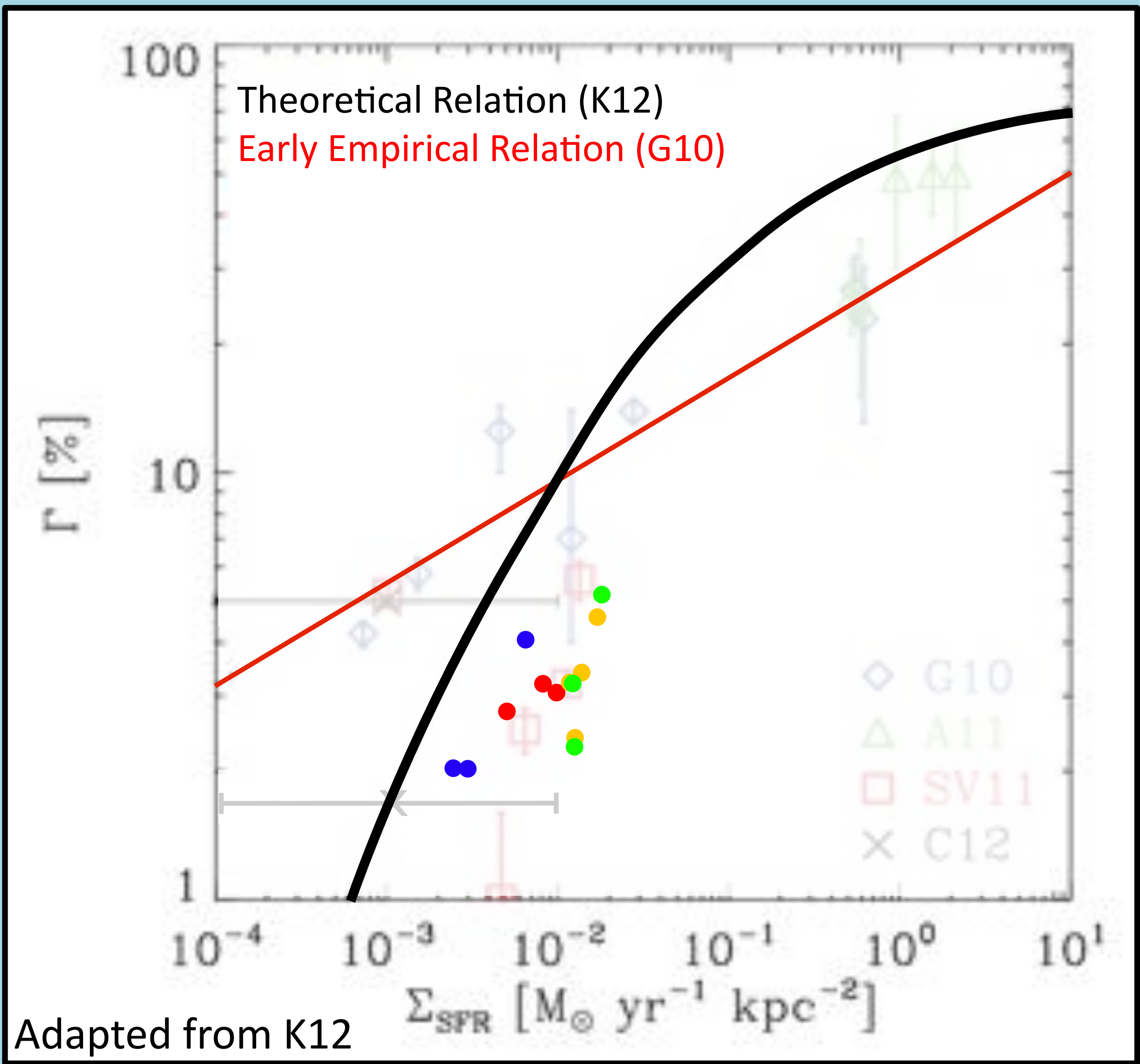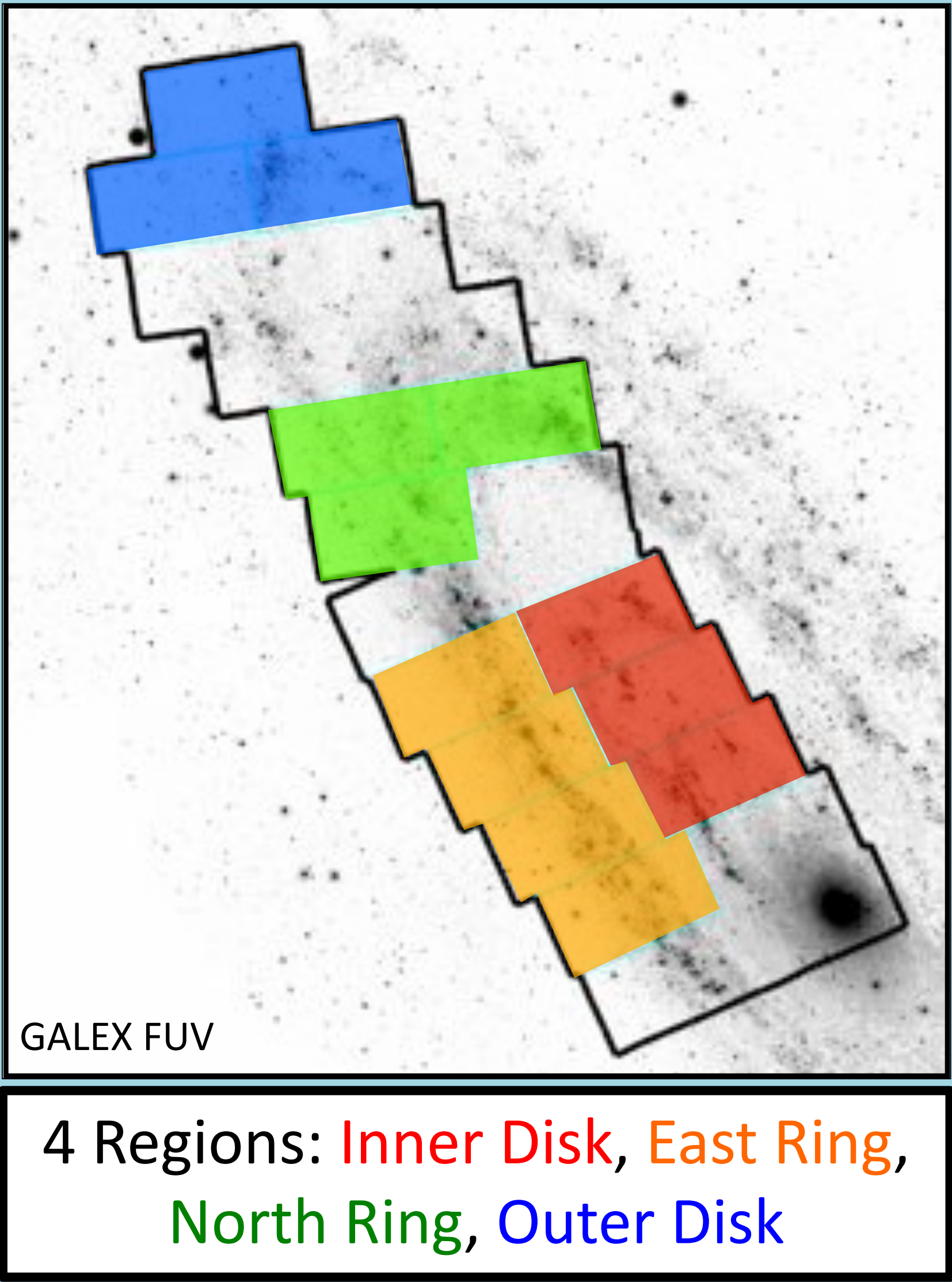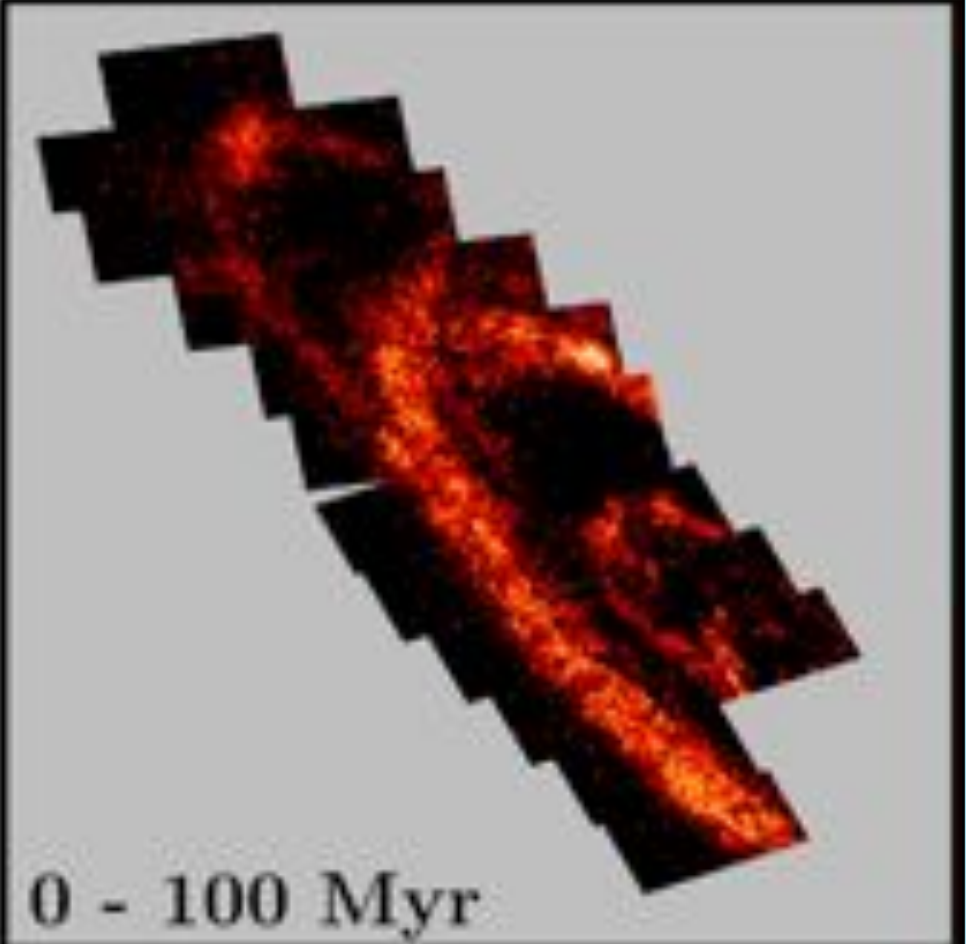
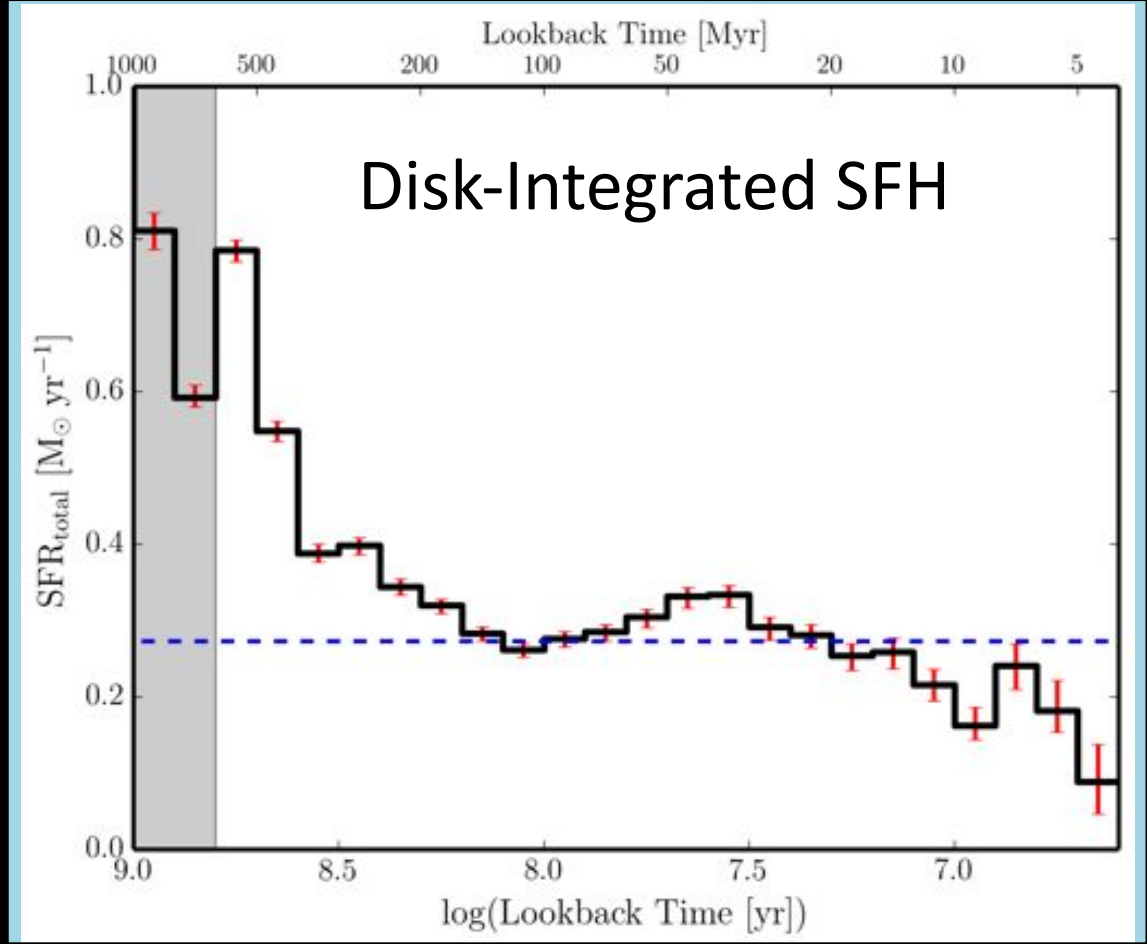## $M_{clusters}$: Cluster Parameter Fitting

Cluster ages & masses determined through CMD fitting (Beerman et al., in prep).

339 young (10-100 Myr) clusters analyzed here.

Current Sample
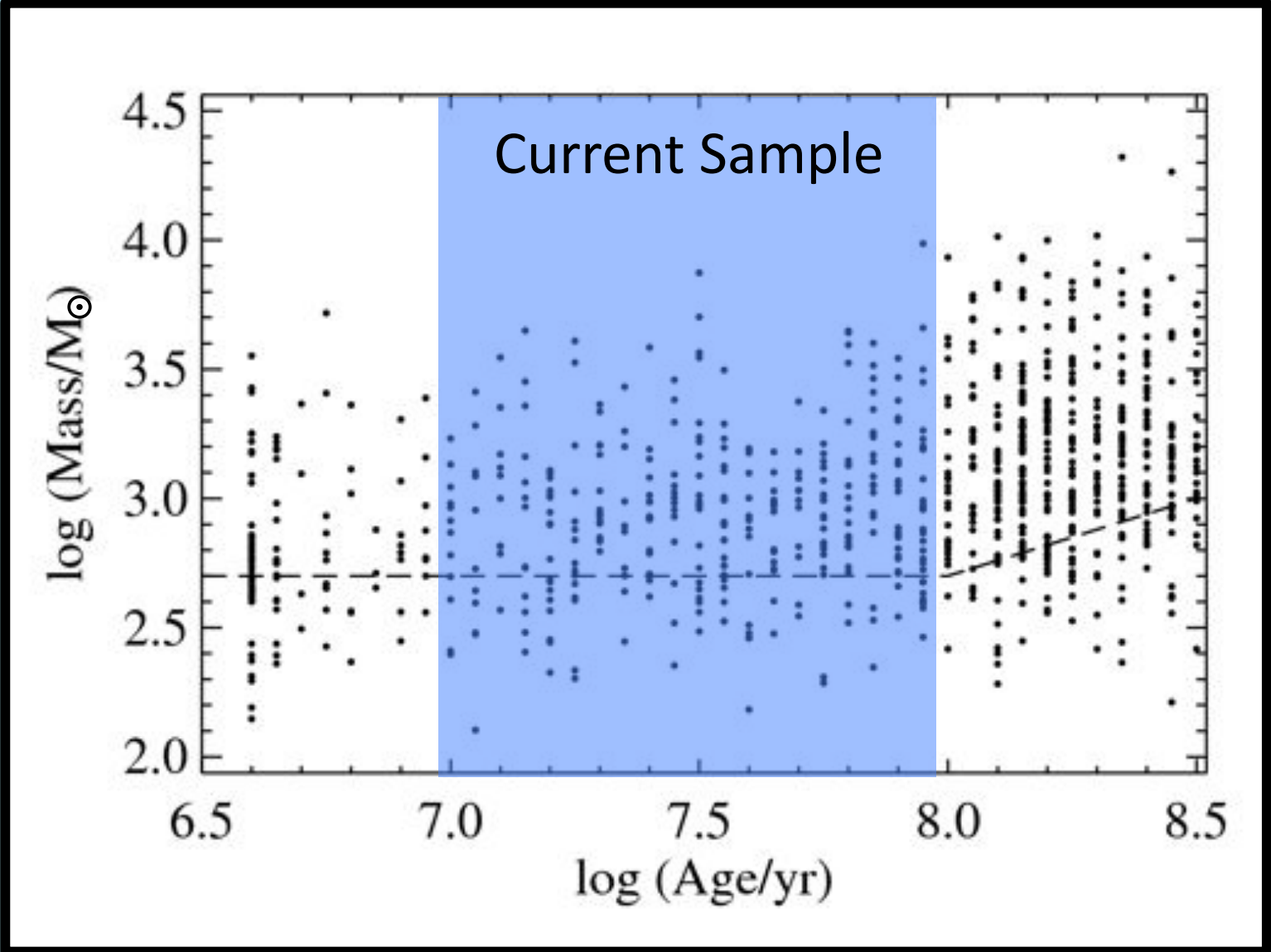
M_{total}: Star Formation Histories

Results from Alexia Lewis et al. (in prep)
Derived using MATCH (Dolphin 2002) CMD fitting software
Spatial Resolution: 100 x 100 pc
Time Resolution: ~0.1 dex over last ~600 Myr

We bin results up into "bricks" (2.7 x 1.5 kpc).

Disk-Integrated SFH

0 - 100 Myr

GALEX FUV

4 Regions: Inner Disk, East Ring, North Ring, Outer Disk

Theoretical Relation (K12)
Early Empirical Relation (G10)

Adapted from K12

Preliminary Results

- We compute Γ within a 10-100 Myr time bin for 13 kpc-scale "brick" regions – we color code the results according to galaxy environment.

- We find that **2-5%** of stars reside in bound clusters.

- In contrast to earlier measurements at low ΣSFR, as captured by relation by Goddard+10 (G10), we find a turnover in Γ as a function of ΣSFR. This behavior is consistent with model predictions by Kruijssen 12 (K12) as well as other observational measurements.

- Future work will test the predictions of Kruijssen 2012 in detail through locally-derived input parameters, as opposed to the single characteristic curve shown here.

Implications

We find Γ values that are in qualitative agreement with the cluster formation model of Kruijssen 12, where cluster formation occurs as a result of locally increased star formation rate efficiencies.

The correlation between Γ and ΣSFR suggests a connection between galaxy-scale properties and local-scale star formation.

Future Work

- Complete a disk-wide calculation of Γ.

- Analyze Γ results as a function of gas properties within the disk.

- Extend the range of environments through targeted analysis of specific regions within M31.