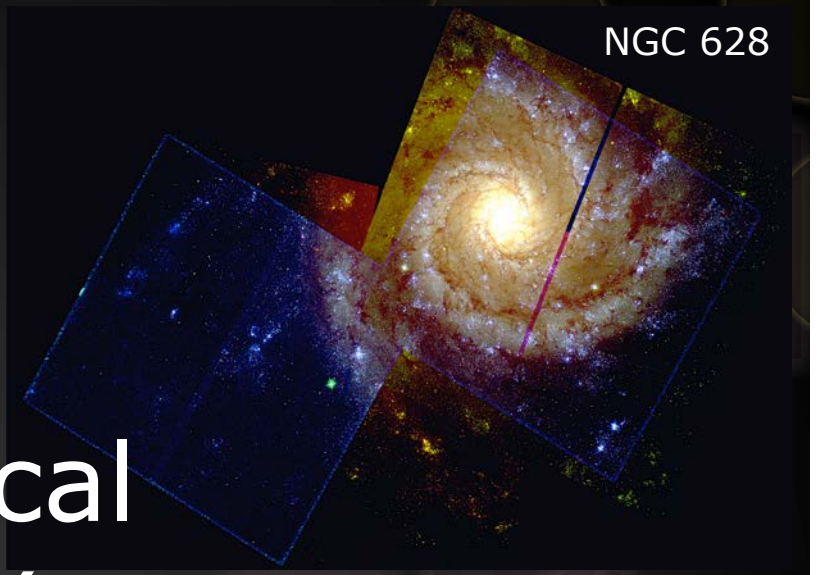


Defining Hierarchical Structures in the Young Stellar Clusters with LEGUS Galaxies

Katie Grasha

University of Massachusetts - Amherst

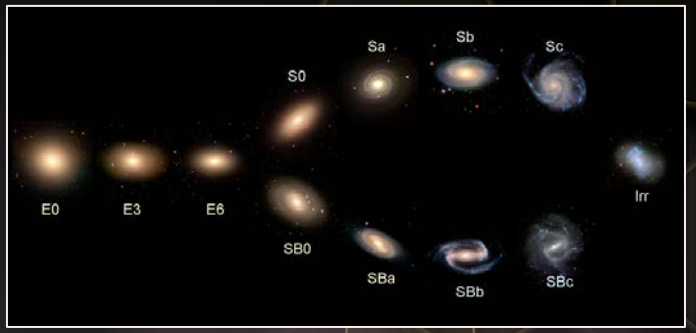
Dissertation Advisor: Daniela Calzetti

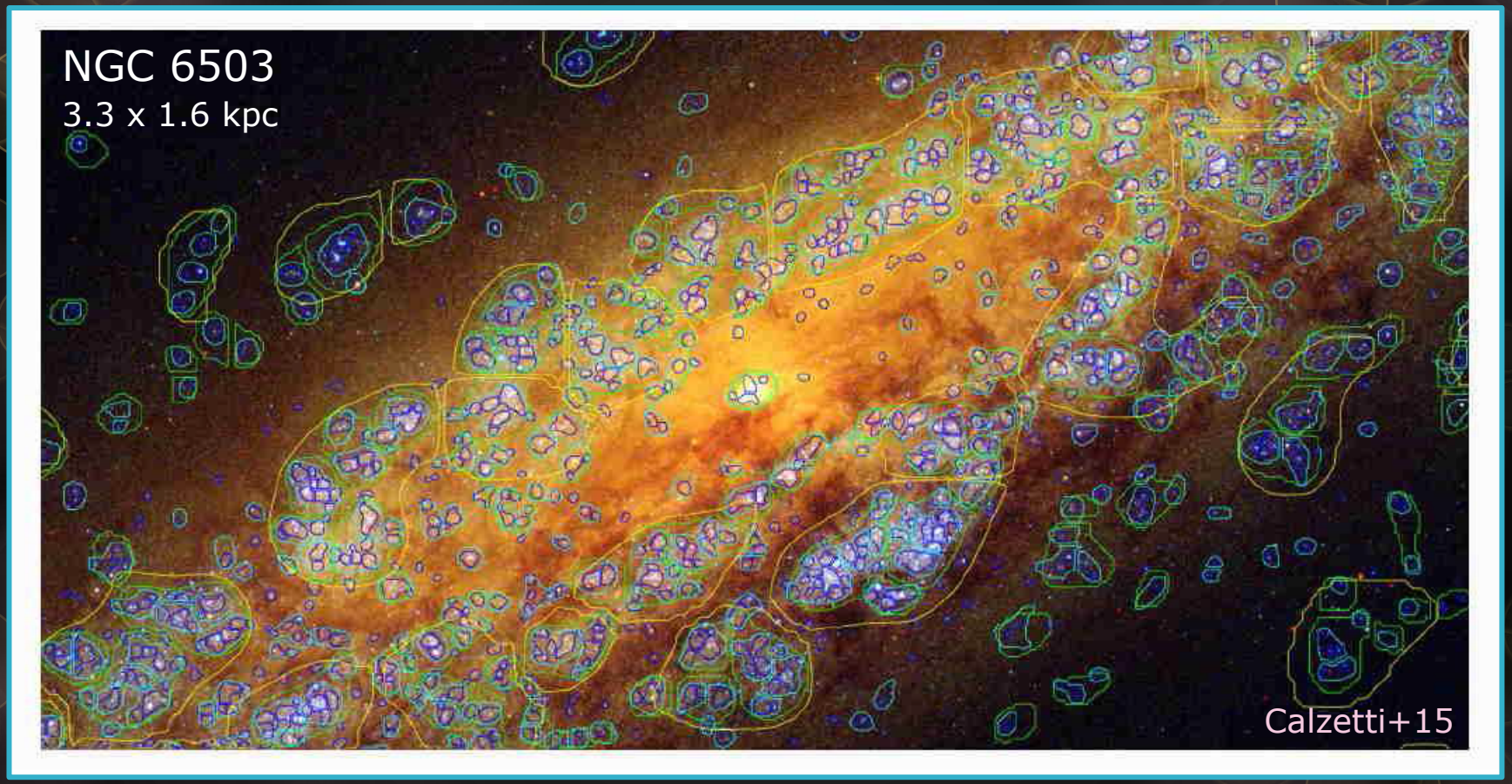
+ The LEGUS Team

Legacy ExtraGalactic LEGUS Ultraviolet Survey

Star formation is structured

Are stars and stellar clusters tracing the same type of hierarchy?





The BIG Picture

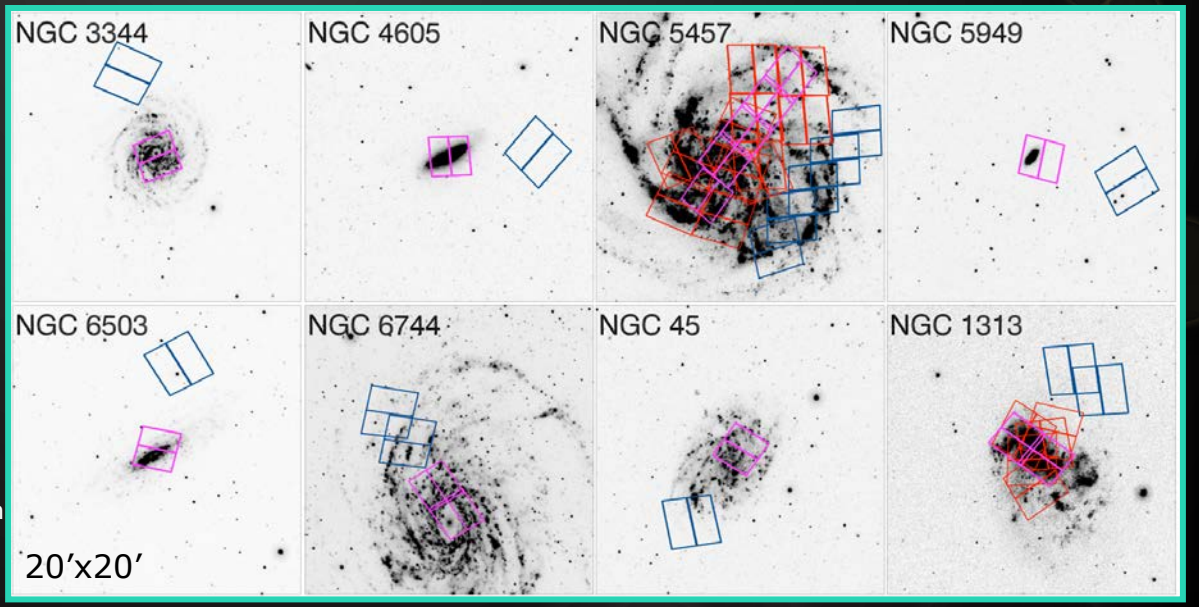
- The star formation efficiency is highest in the densest regions, promotes bound cluster formation
  - → Stars form in clustered structures
    - → Can we use observations of clustered structures to trace and better understand the processes involved in their formation

- If clusters are effective at tracing star formation…
  - We can use the clustering distribution to understand cluster formation efficiency in relation to SF efficiency

LEGUS: Legacy ExtraGalactic UV Survey (PI:Daniela Calzetti)

- Cycle 21 HST Treasury Program (154 Primary + 154 Parallel orbits)
  - Primary: WFC3/NUV,U,B,V,I
  - Parallel: ACS/B,V,I
- 50 local star-forming galaxies (4-12 Mpc)
- Resolution: 0.04 arcsec/pixel
- 55+ Investigators at 30+ Institutions (US+EU)

LEGUS footprint
LEGUS parallels
Archival data



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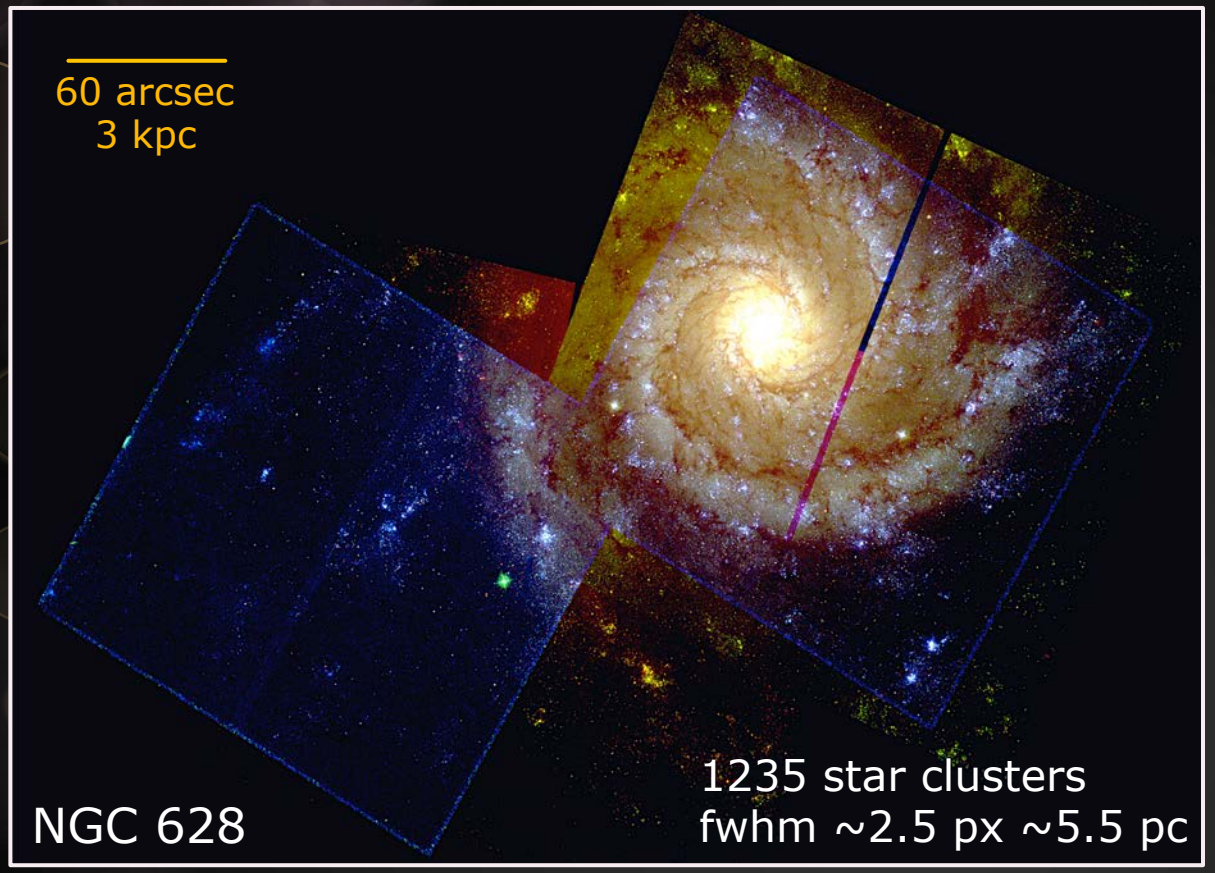
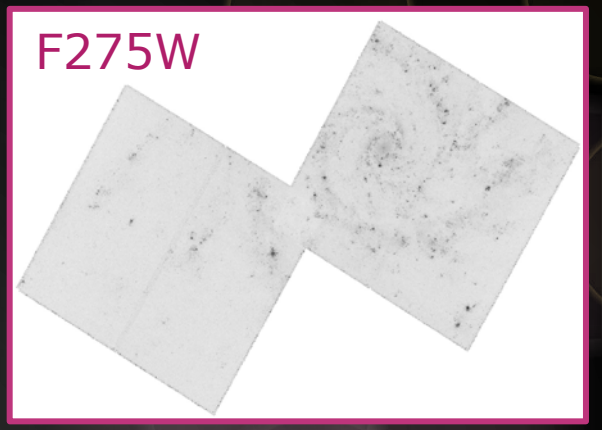
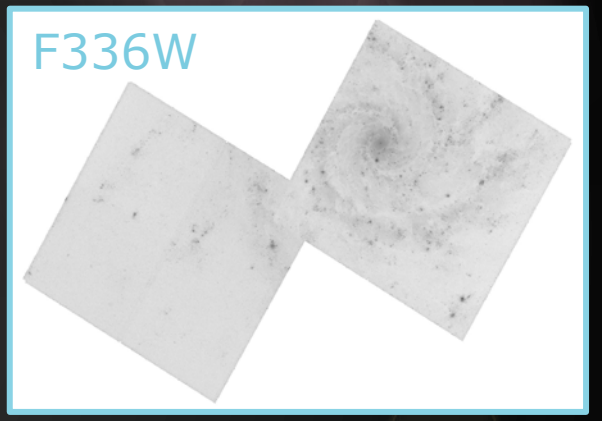

60 arcsec
3 kpc
NGC 628
1235 star clusters
fwhm ~2.5 px ~5.5 pc


F275W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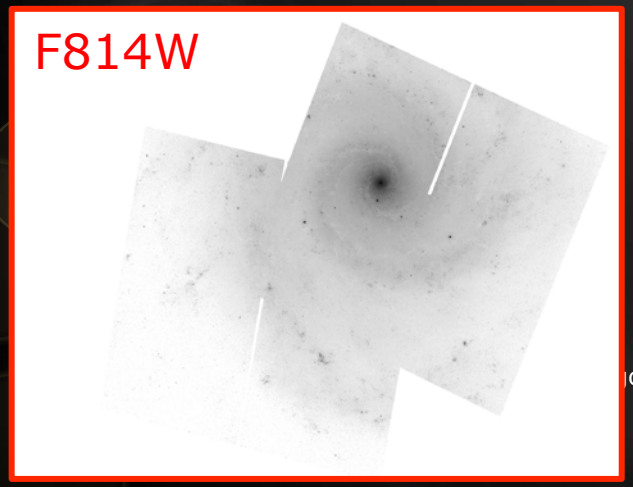
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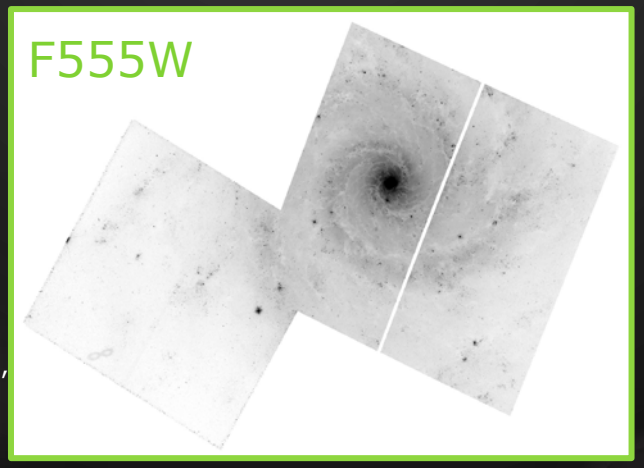
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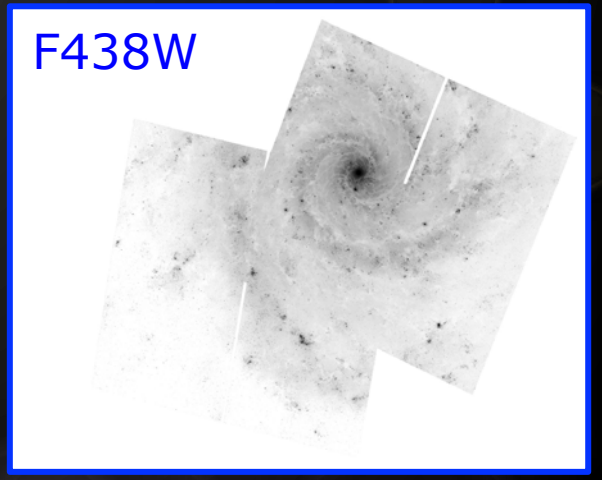
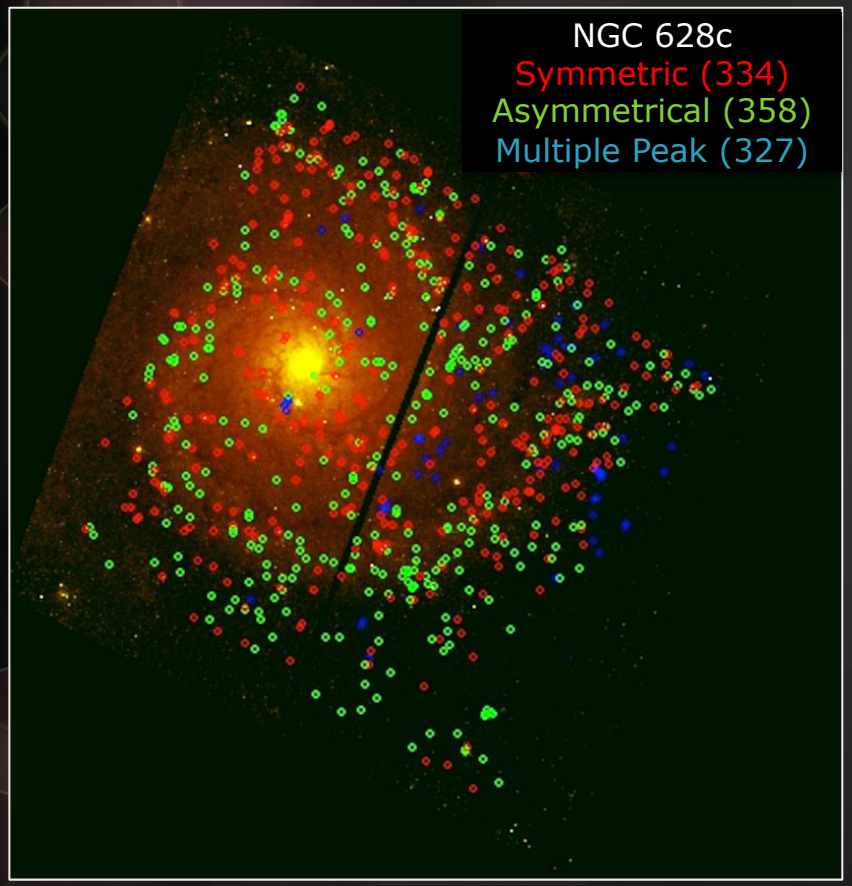
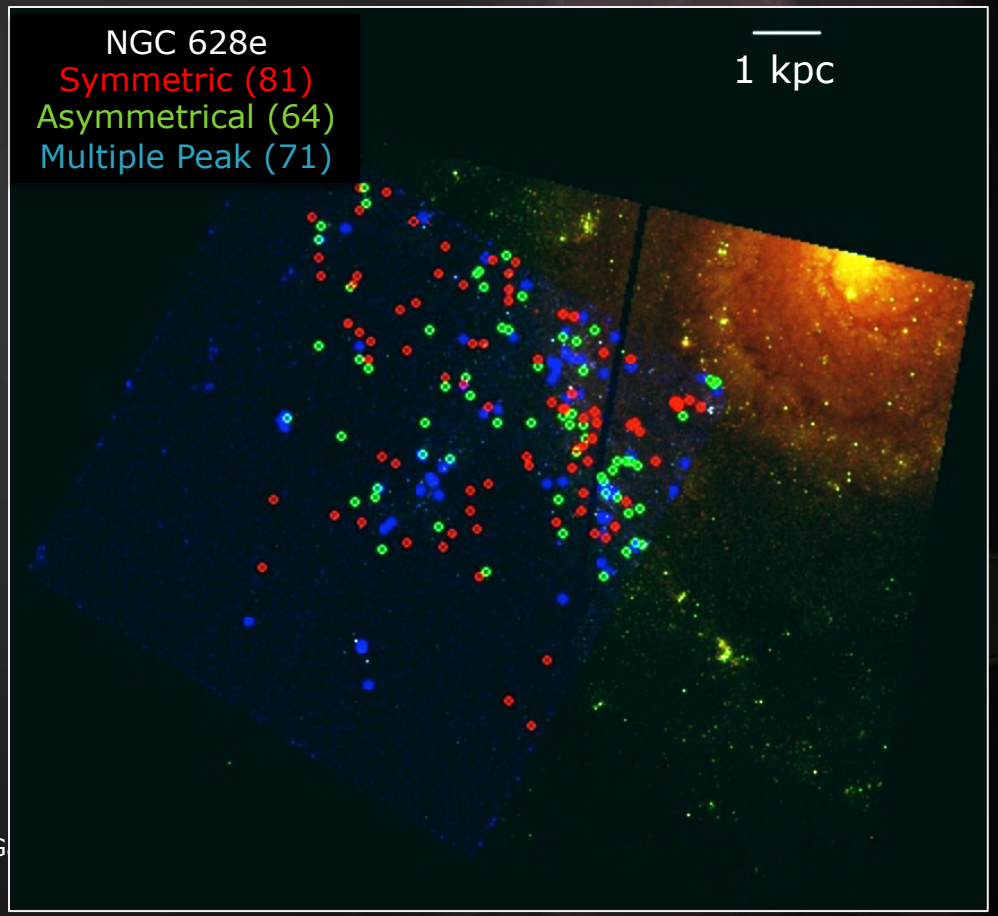

F438W

Hierarchical Structural Morphology: Global Clustering





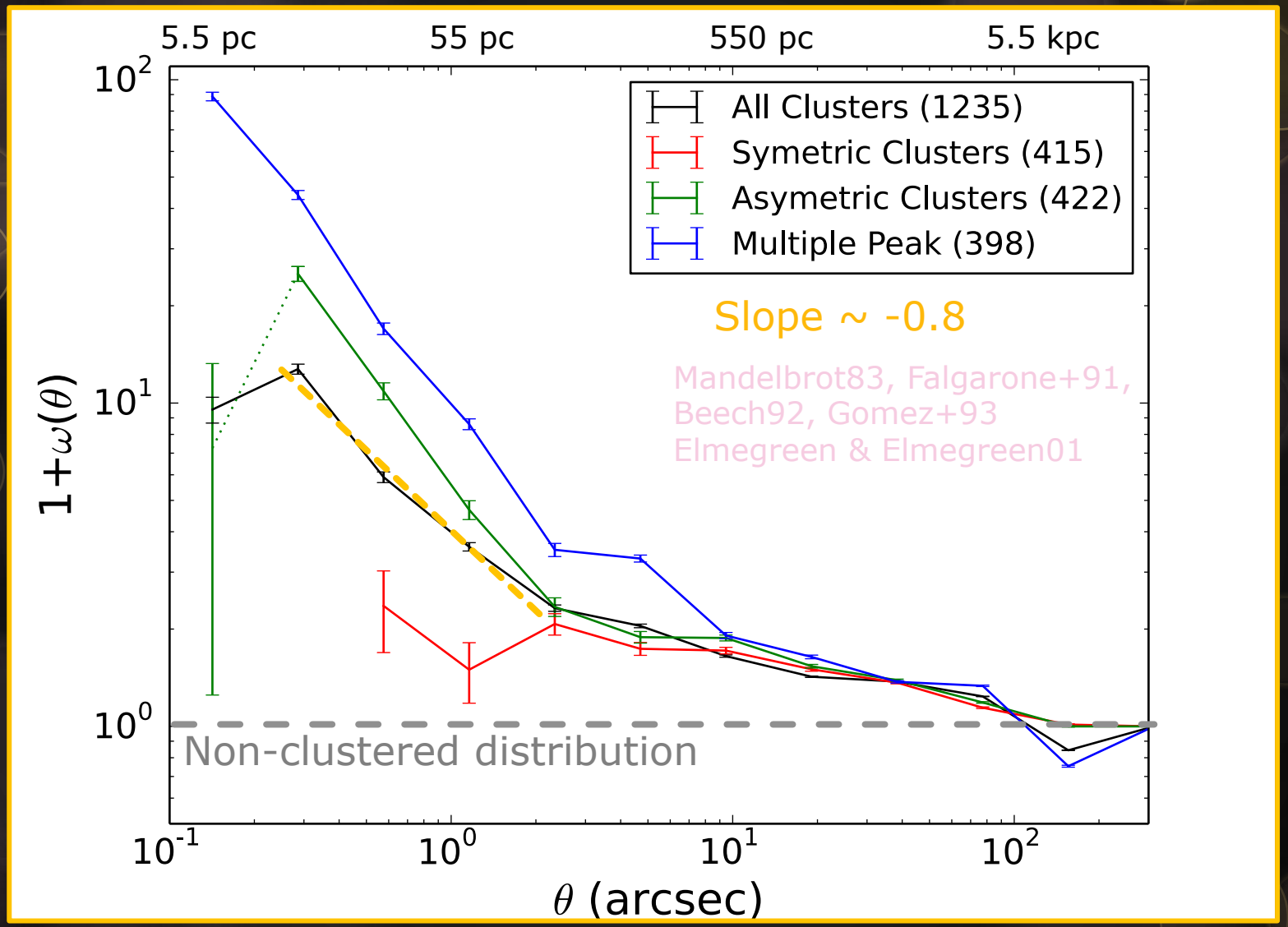
Two-Point Correlation Function

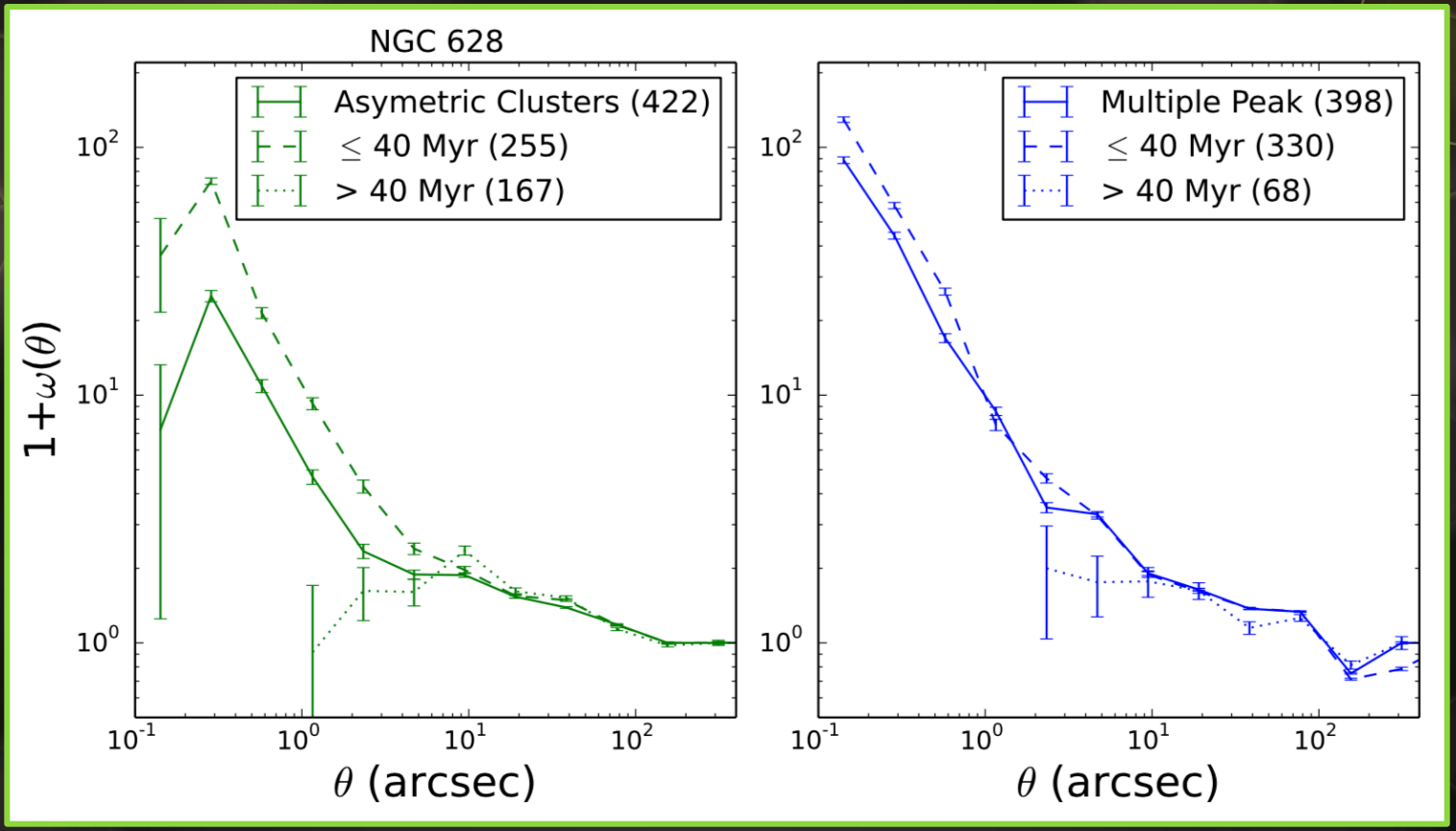
- $dP = \mathbf{n}[1+\xi(r)]\, dV$ Peebles80
  - A non-clustered random distribution will have ξ(r)=0 and a clustered distribution will have ξ(r)>0, peaking at small radii
- The Landy-Szalay estimator minimizes edge effects

$$\omega_{LS}(\theta) = \frac{DD(\theta) - 2DR(\theta) + RR(\theta)}{RR(\theta)}$$

- The random data (R) must have same geometry and masking conditions as the real data (D)

For hierarchical star formation, a decrease with ω(θ), fitted with a power-law, is expected





- What is the survival time of star clusters? Do the properties change as the cluster ages?
- Is there an age at which substructure has disappeared?

Age-Dependency in Clusterings

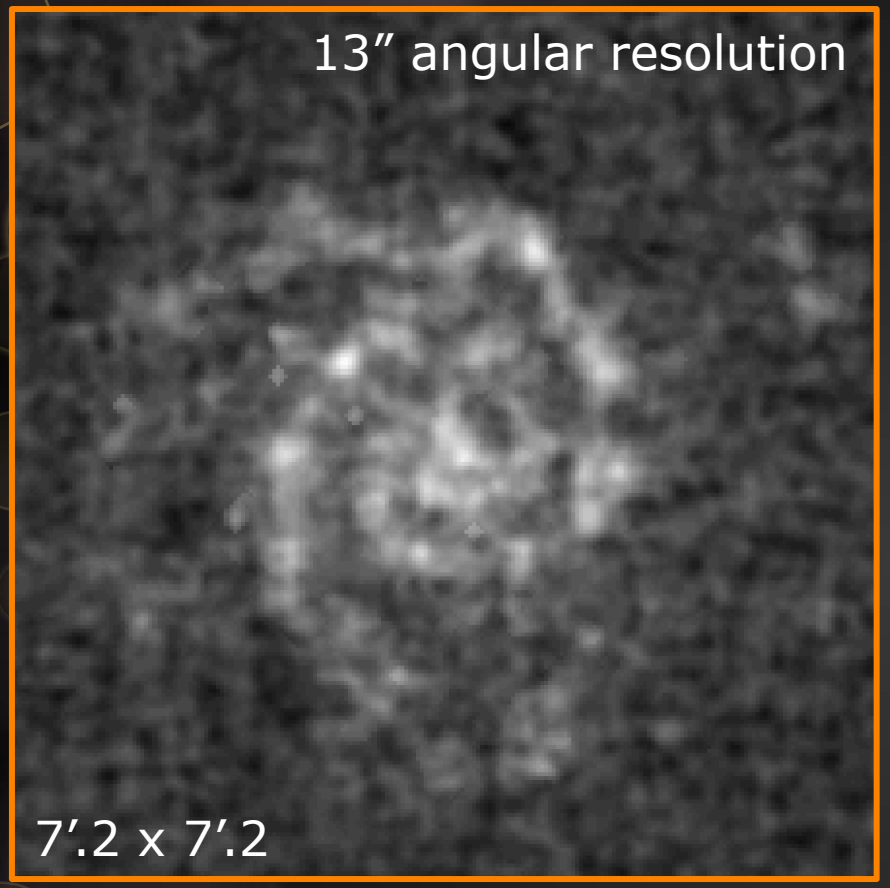
- There is an age-dependency on the clustering structure: depends on average life time & dissolution time
  - Leverage the SFHs to distinguish
- Dissolution: The timescale for clusters to abandon their clustered structure
  - Clustered structure slowly gets erased as the system evolves due to velocity dispersion
    - Smallest scales affected first
- Likely dependent on galactic environment

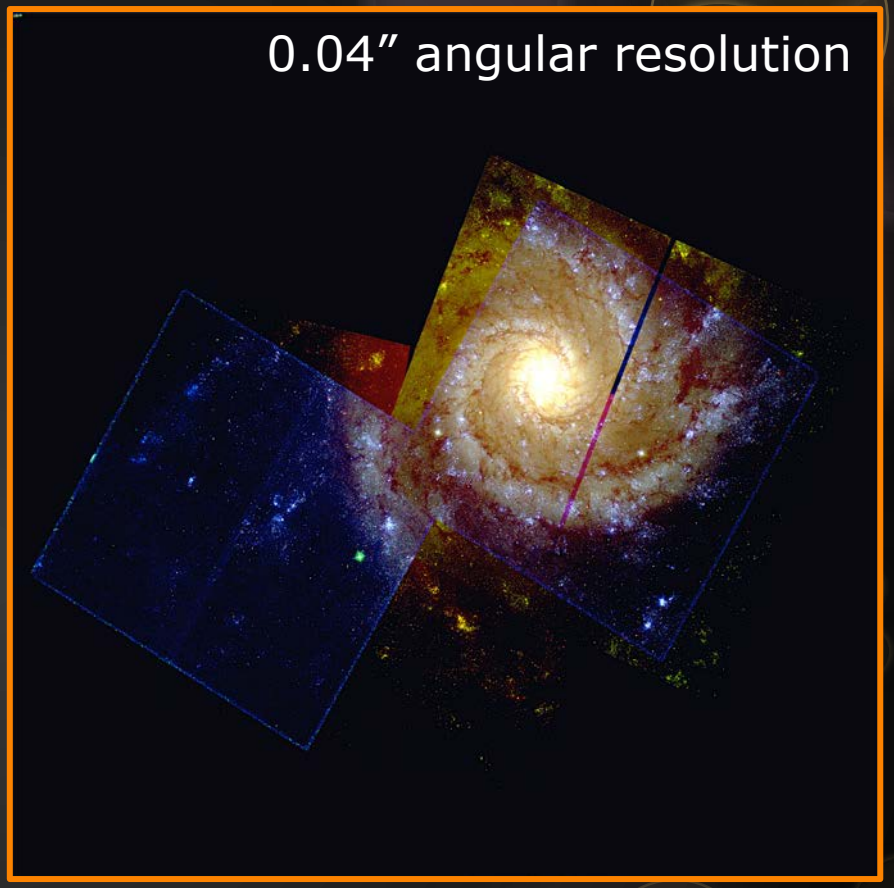
Connection to ALMA: GMC Properties and their Environments

- ALMA maps will trace the molecular gas to provide an accurate picture of the distribution and characteristics
  - Link between star clusters and their precursors (GMCs)?
  - What happens to the dense gas as clusters form/evolve?

- ALMA and LEGUS data will give us a unique opportunity to answer questions aimed at understanding the drivers of the characteristics of star-forming regions:
  1. What determines the properties (mass, density) of GMCs? Environmental dependencies: function of radius or location
  2. Do the properties of GMCs determine the characteristics of the star clusters that form from those clouds?

The ALMA connection





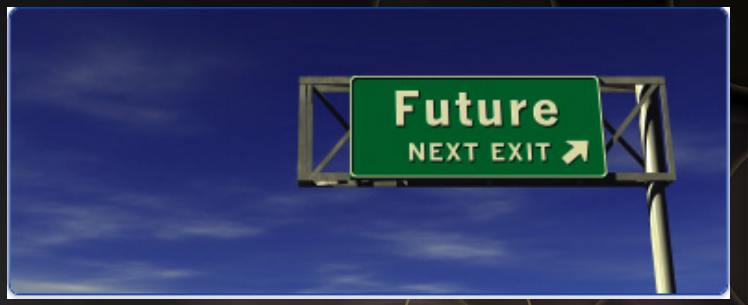
CO(J=2-1) 1.3 mm
IRAM 30 m
Leroy+09

In a Nutshell

- We know the star formation is hierarchical
  - LEGUS gives us a high-spatial resolution view of the products of the star formation process: star clusters and stellar populations

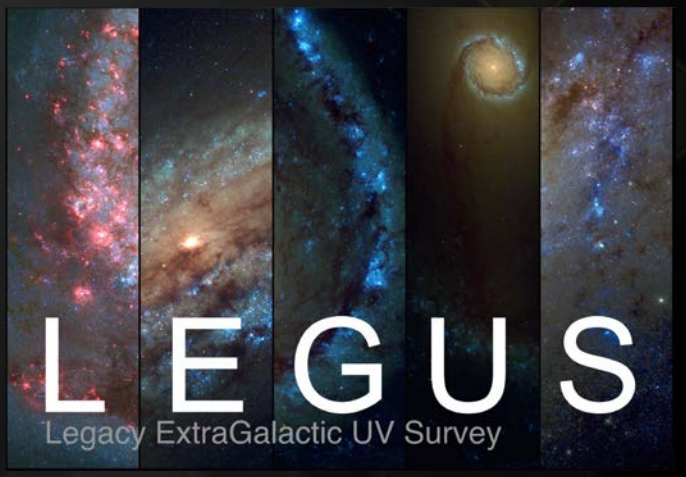
- With NGC 628, we examine clustering to investigate:
  - Clustering traces hierarchical star formation
    - Important to understand star formation and cluster formation efficiency
  - Timescale in which star clusters abandon their bound structures - how the hierarchy evolves with time
  - Spatial evolution of clustering - environmental dependence

In the Future



- What is next on our To Do List:
  - → Clustering analysis to all 50 LEGUS galaxies
    - Stacking galaxies for better statistics
  - → ALMA: shed light on the GMC-cluster connection
    - → Similarity between GMC properties and clusters as a function of environment?
    - → Is the hierarchy of GMCs reflected in the star clusters?

Thank you!



The Big Picture

- Star formation (SF) occurs in hierarchical patterns in both space and time
  - Galaxies → giant molecular clouds (GMCs) → star complexes → OB associations → star clusters → individual stars
    - Decreasing size and increasing density
  - Inside each scale and lifetime, smaller regions come and go in a hierarchy of time
    - Positions and ages are correlated with power law functions

Cluster Identification

- At LEGUS distances, half-light effective radii 1-10 pc
  - At 4 Mpc, r_{eff} = 1 pc has a $FWHM_{cluster}$ ~ 2.5 px, compared to $FWHM_{star}$ ~ 2.2 px

- Cluster identification two-step process:
  - (1) Automated: SExtractor to select slightly extended sources against a variable background (white light images)
    - CI = mag(1px) – mag(3px) > ~1.4 (CI_{star} ~ 1.05)
    - Aperture photometry on sources with detection in at least two contiguous filters with photometric error $\leq$ 0.3 mag
  - (2) Visual inspection to confirm cluster classification

Visual Cluster Identification

- Additional selection criteria:

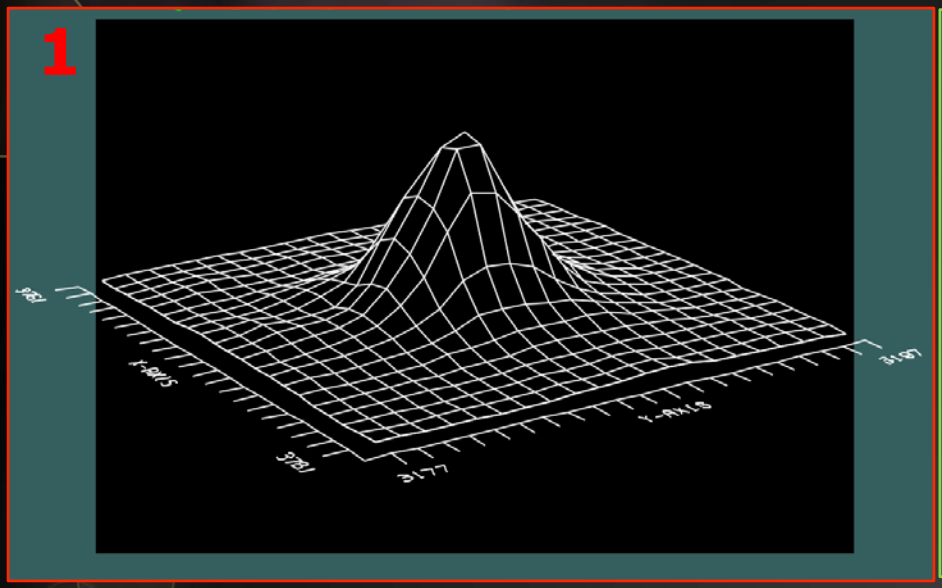
  CI = mag(1px) – mag(3px) > 1.4

  Detection in at least 4 filters

  Absolute V-band > -6 mag

- Classifications (done visually):
  - 0 Unclassified sources – did not meet the mag cut off
  - 1 Centrally concentrated clusters
  - 2 Elongated or asymmetrical
  - 3 Multiple peaked systems
  - 4 Stars, bad pixels, background galaxies

1



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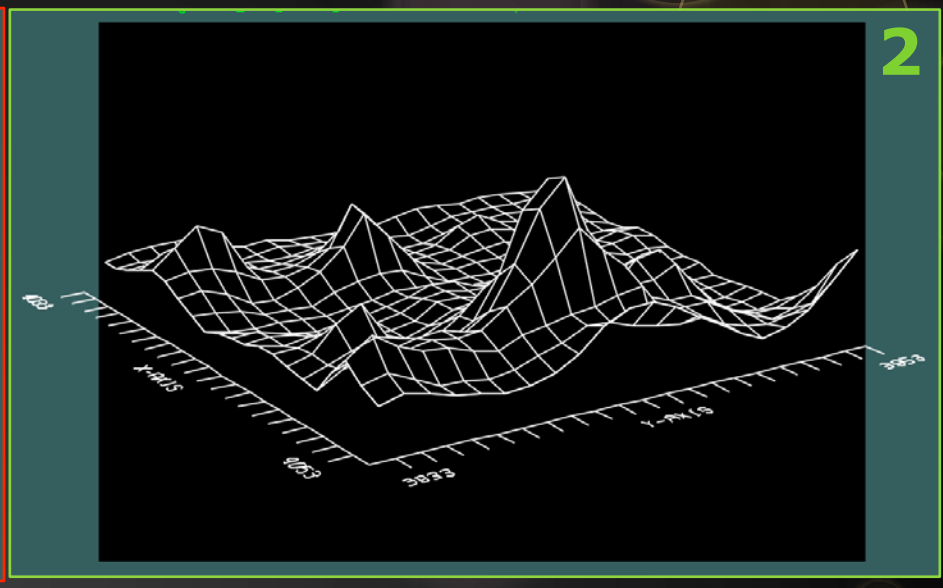

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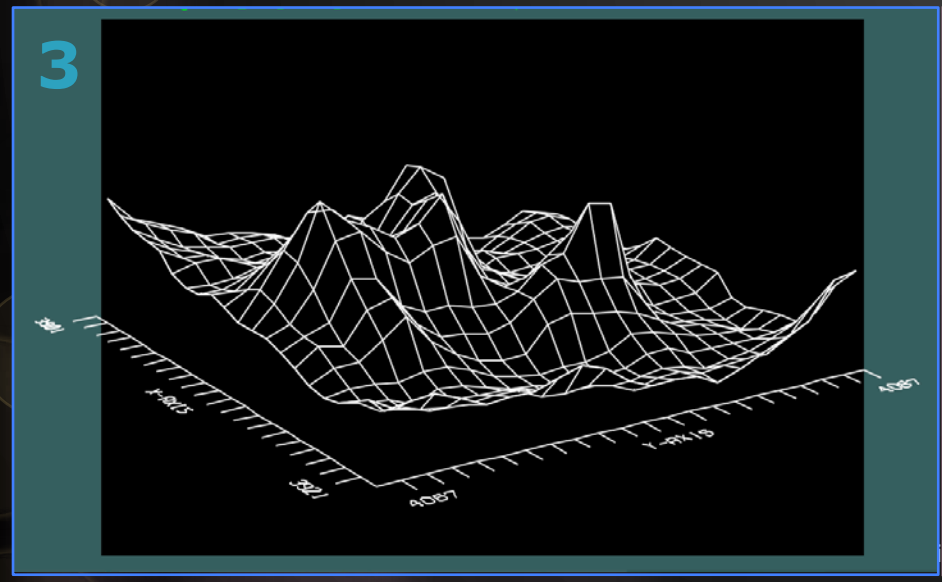
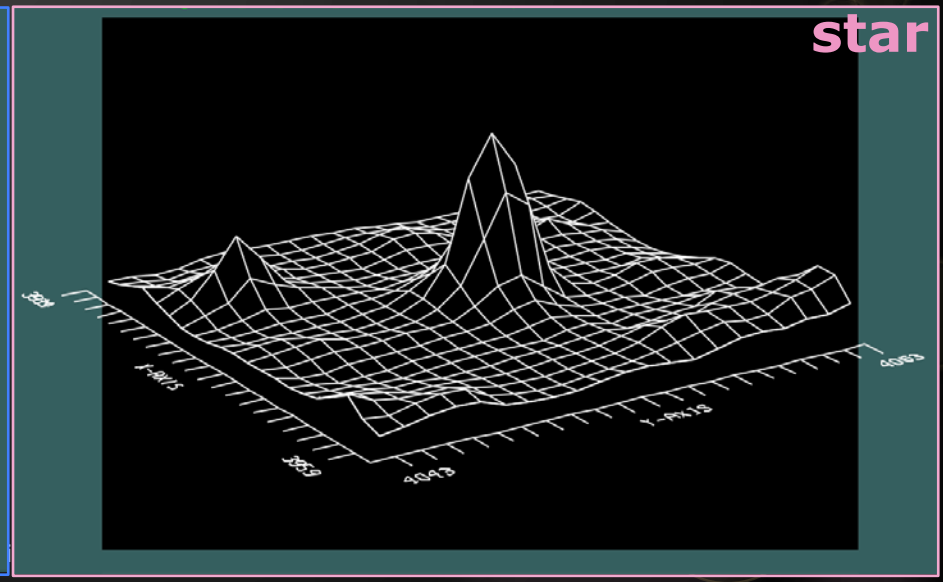


star



Two-Point Correlation Function

- For a hierarchical distribution: $1 + \omega(\theta) \propto \theta^{\alpha}$ Gomez+93
  - Slope gives clustering strength
- Total Number: $N \propto \theta^{\alpha} \times \theta^{2} = \theta^{\alpha+2}$
- Can relate the power-law slope α to the 2D fractal dimension: describes star formation and gas distribution
  $D2 = \alpha+2 = \sim 1.2\text{-}1.6$

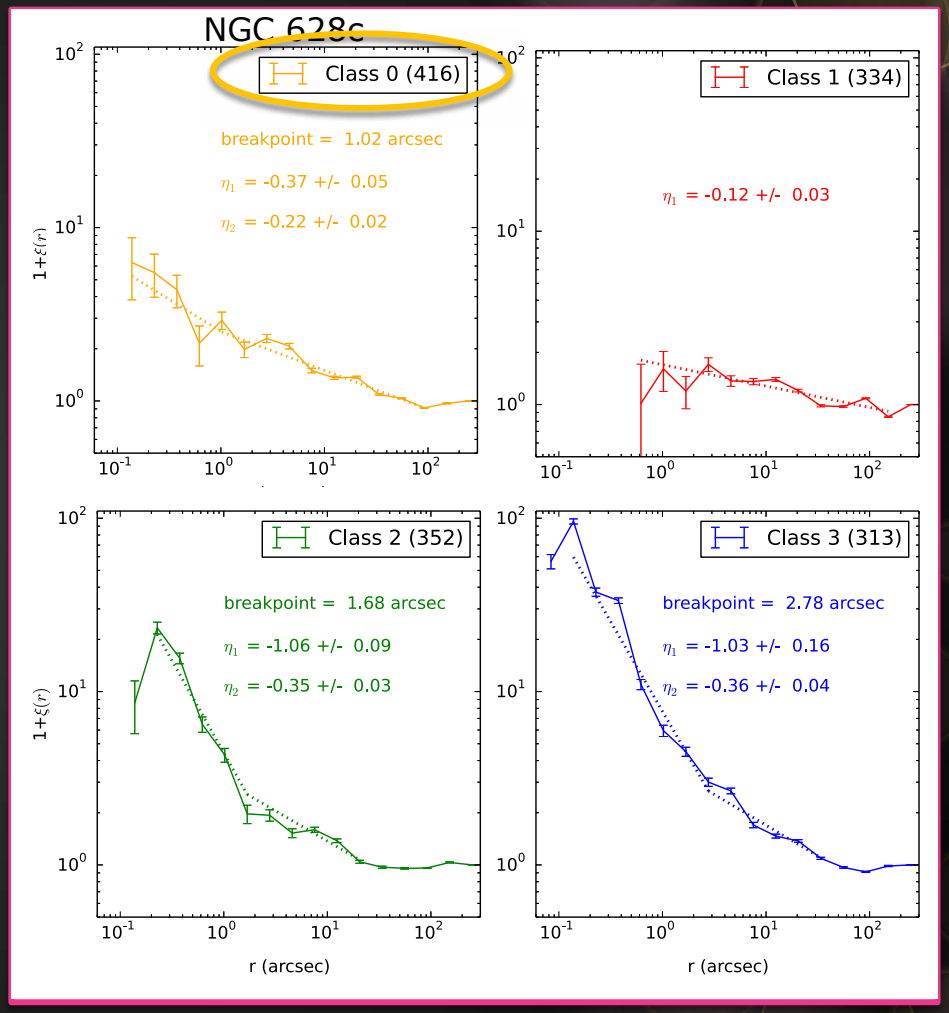
  ➔ $\alpha \sim -0.8$

Mandelbrot83, Beech92
Elmegreen & Elmegreen01

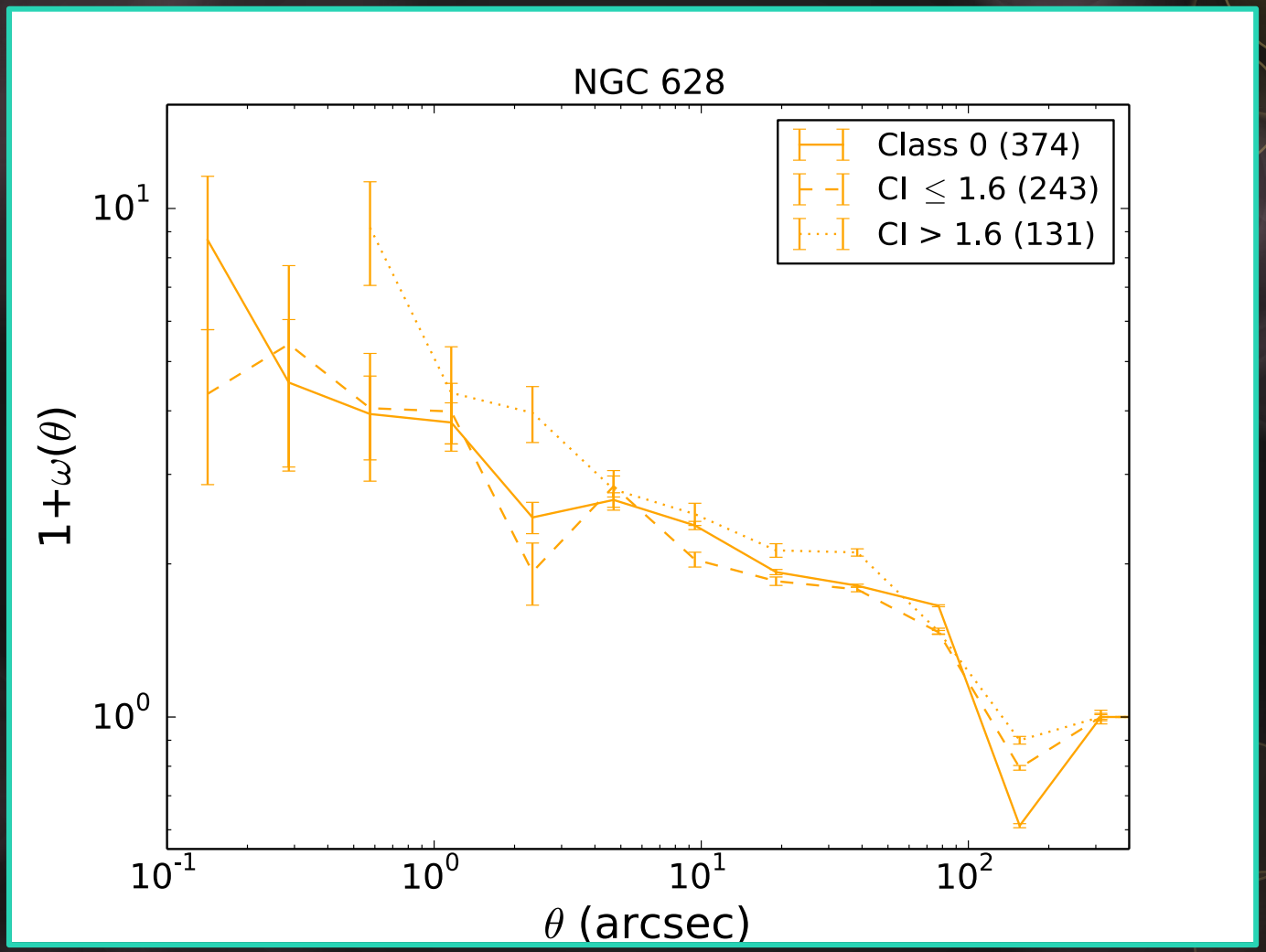
If the clustering distribution is hierarchical, expect $\alpha \sim -0.4 - -0.8$

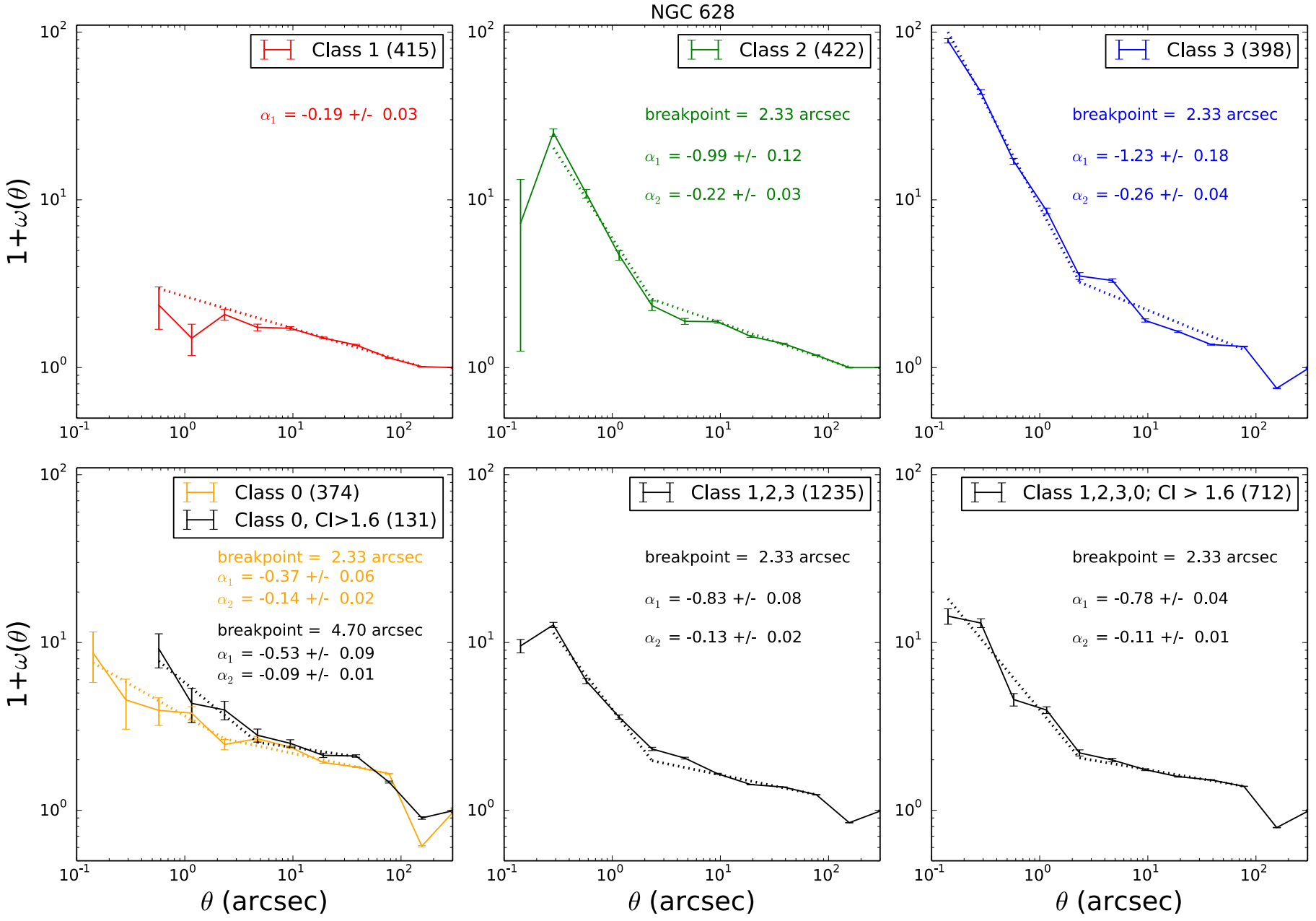
Contains everything! Can we identify the clusters without having to perform visual classification?

Do this with cuts in
- CI (youngest clusters have broadest CI)
- age (younger should be more clustered)



- Start with Class 0 and pull out genuine clusters: CI cut at 1.6 (broadest)




NGC 628
Class 1 (415)
α_1 = -0.19 +/- 0.03
Class 2 (422)
breakpoint = 2.33 arcsec
α_1 = -0.99 +/- 0.12
α_2 = -0.22 +/- 0.03
Class 3 (398)
breakpoint = 2.33 arcsec
α_1 = -1.23 +/- 0.18
α_2 = -0.26 +/- 0.04
Class 0 (374)
Class 0, CI>1.6 (131)
breakpoint = 2.33 arcsec
α_1 = -0.37 +/- 0.06
α_2 = -0.14 +/- 0.02
breakpoint = 4.70 arcsec
α_1 = -0.53 +/- 0.09
α_2 = -0.09 +/- 0.01
Class 1,2,3 (1235)
breakpoint = 2.33 arcsec
α_1 = -0.83 +/- 0.08
α_2 = -0.13 +/- 0.02
Class 1,2,3,0; CI > 1.6 (712)
breakpoint = 2.33 arcsec
α_1 = -0.78 +/- 0.04
α_2 = -0.11 +/- 0.01
$1+\omega(\theta)$
θ (arcsec)