SUPER STAR CLUSTERS: High Resolution Observations

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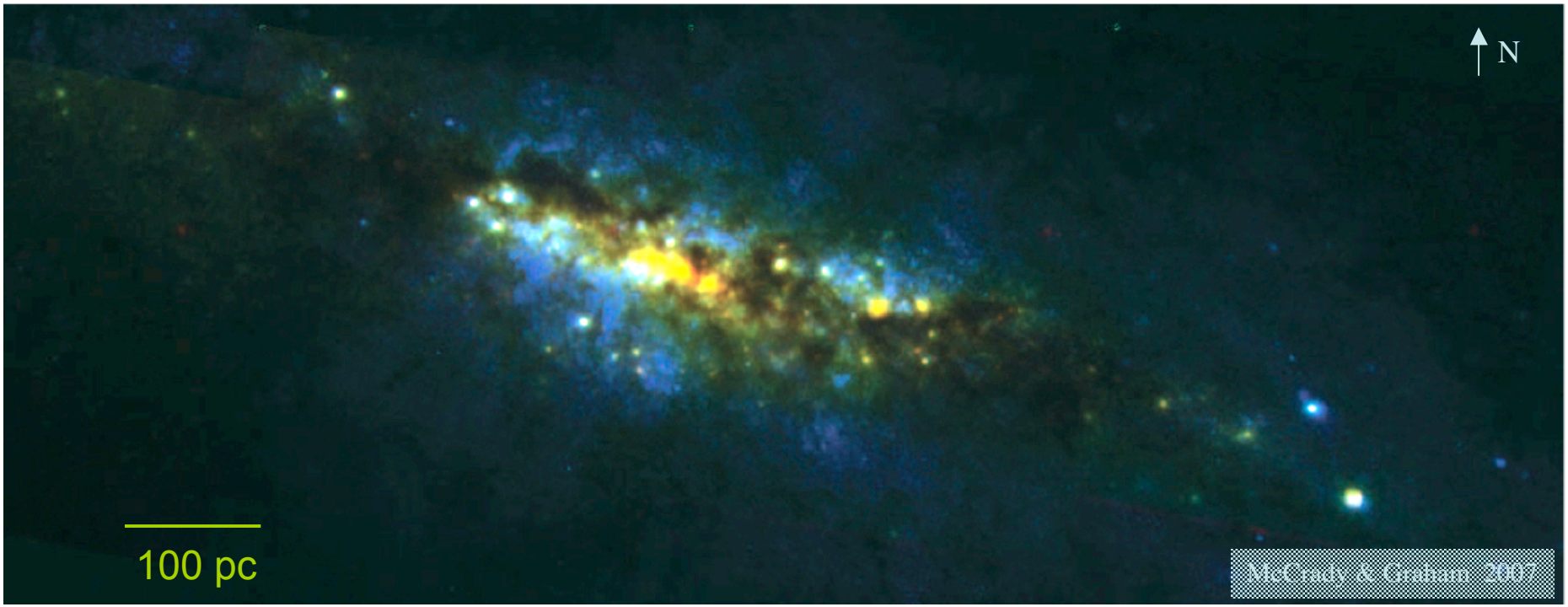
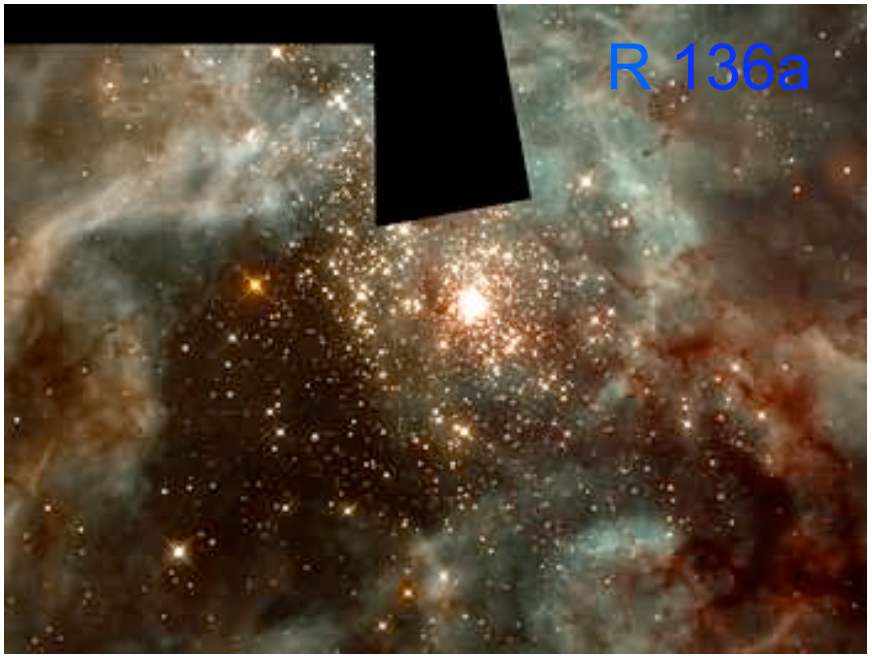
M82



- ACS F814W & NICMOS F160W/F222M images (25” × 65” or 0.4 × 1.1 kpc)
  - 10 Myr-old population of ≈ 20 SSCs in the central starburst
  - Strong reddening

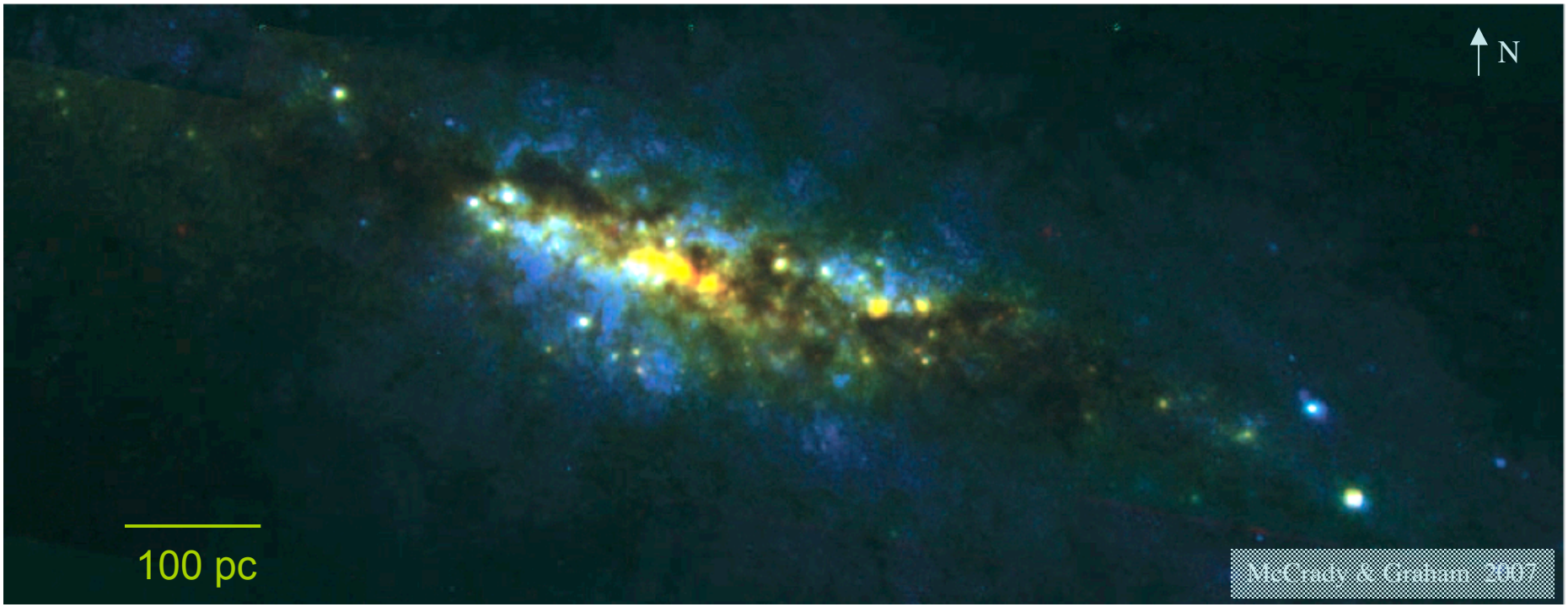
Local Massive Clusters



~ 50 O stars
~ 10^{51} Ly_c s^{-1}
~ 6 kpc, A_v ~ 4.5 mag
~ 0.3 - 1 Myr
(Brandl et al. 1999)

~ 120 O stars (2 x 10^4 $M_\odot$)
~ 4 x 10^{51} Ly_c s^{-1}
~ 50 kpc, A_v ~ 1.2 mag
~ 2 - 4 Myr
(Walborn et al. 2002)

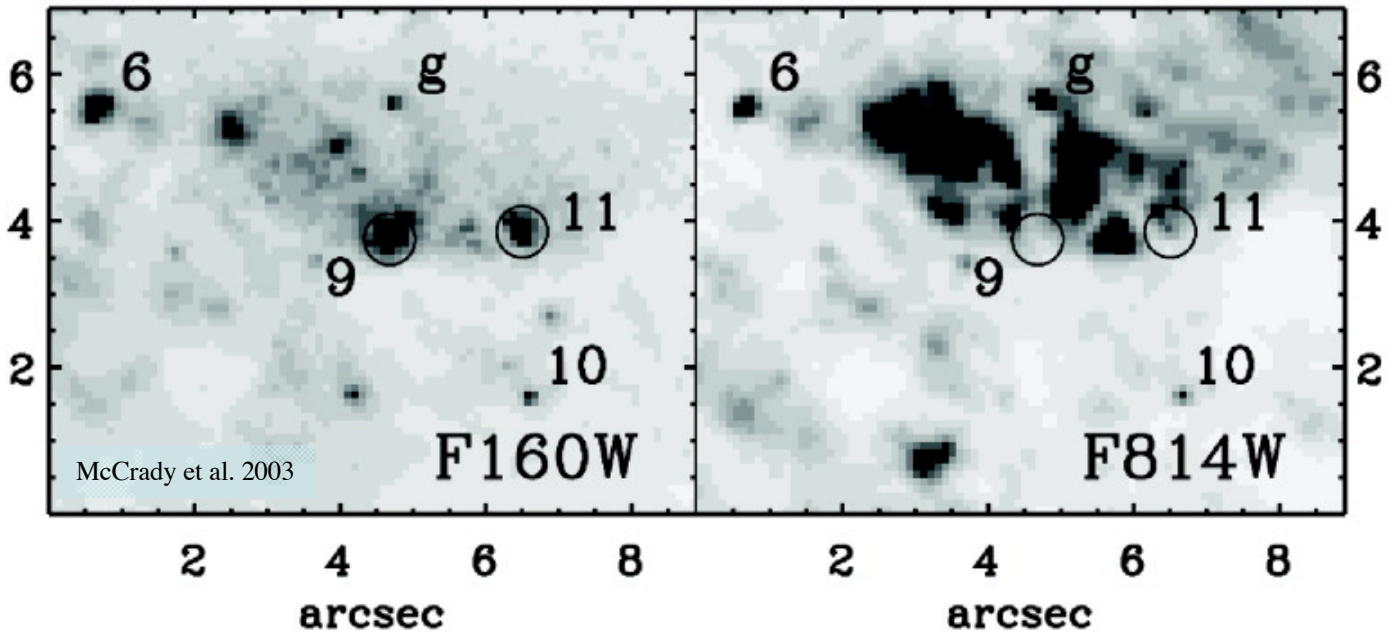
M82



~ 20,000 O stars
~ 9 x 10^{53} Ly_C s^{-1}
~ 3.6 Mpc, A_V ~1–10 mag
~ 10 - 50 Myr

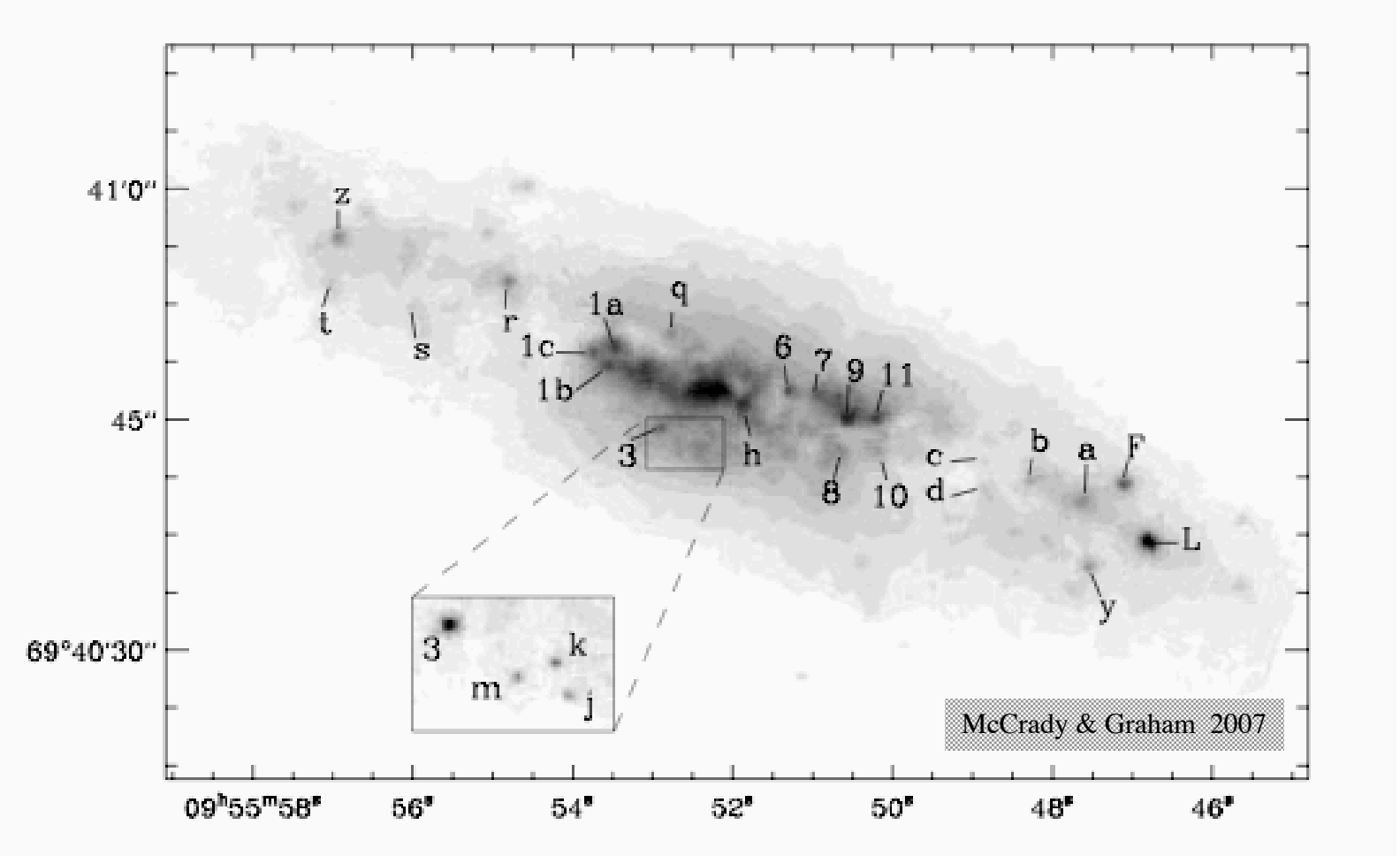
(Förster-Schreiber et al., 2003)

Near-IR is Essential



- NICMOS/WFPC2 images of the MGG-9 & 11 region in M82
  - Young clusters are only visible in the near IR because of heavy extinction
  - UV/optical cluster catalogs are contaminated by holes in extinction masquerading as sources

High Resolution M82 Cluster Survey



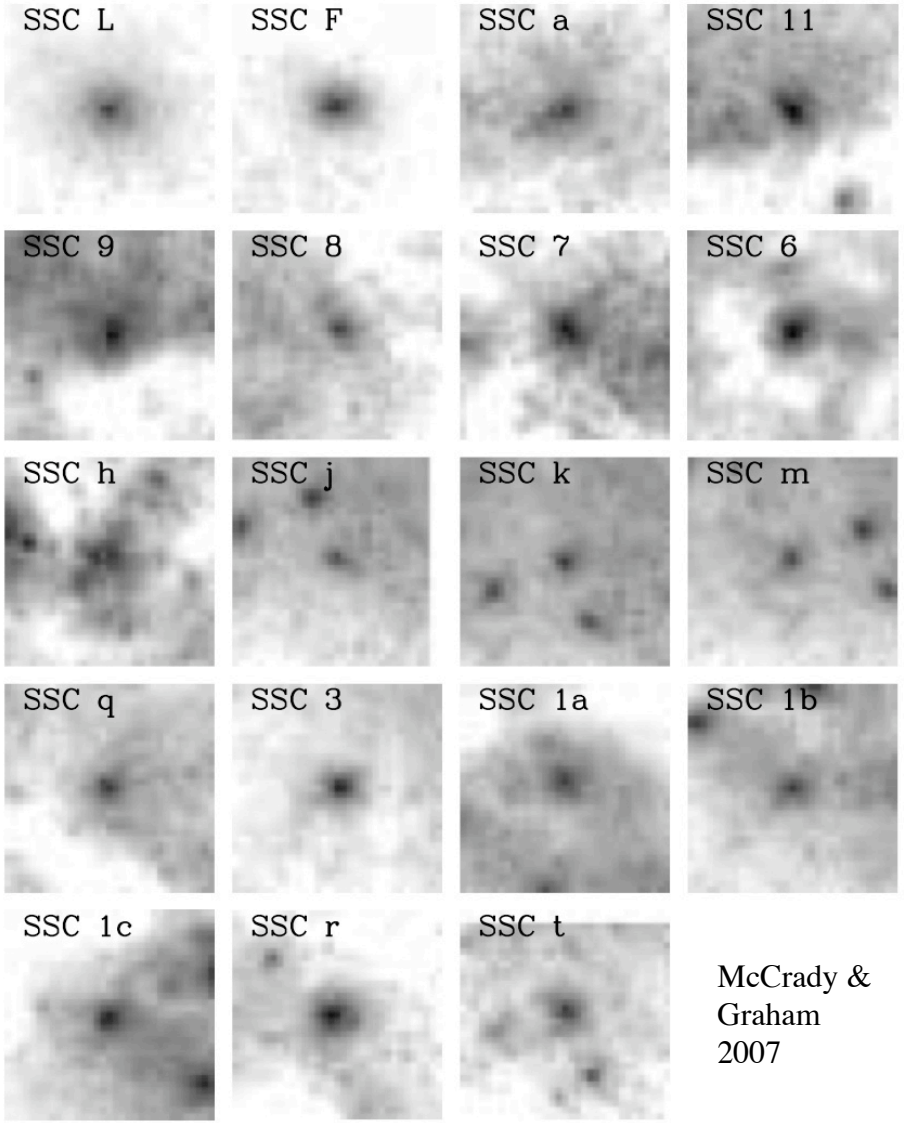
- HST/NICMOS + Keck2/NIRSPEC data for 19 clusters
  - Photometry & structural parameters (F160W)
  - *H*-band R = 23,000 echelle spectroscopy

High Resolution Observation

- Virial mass estimates

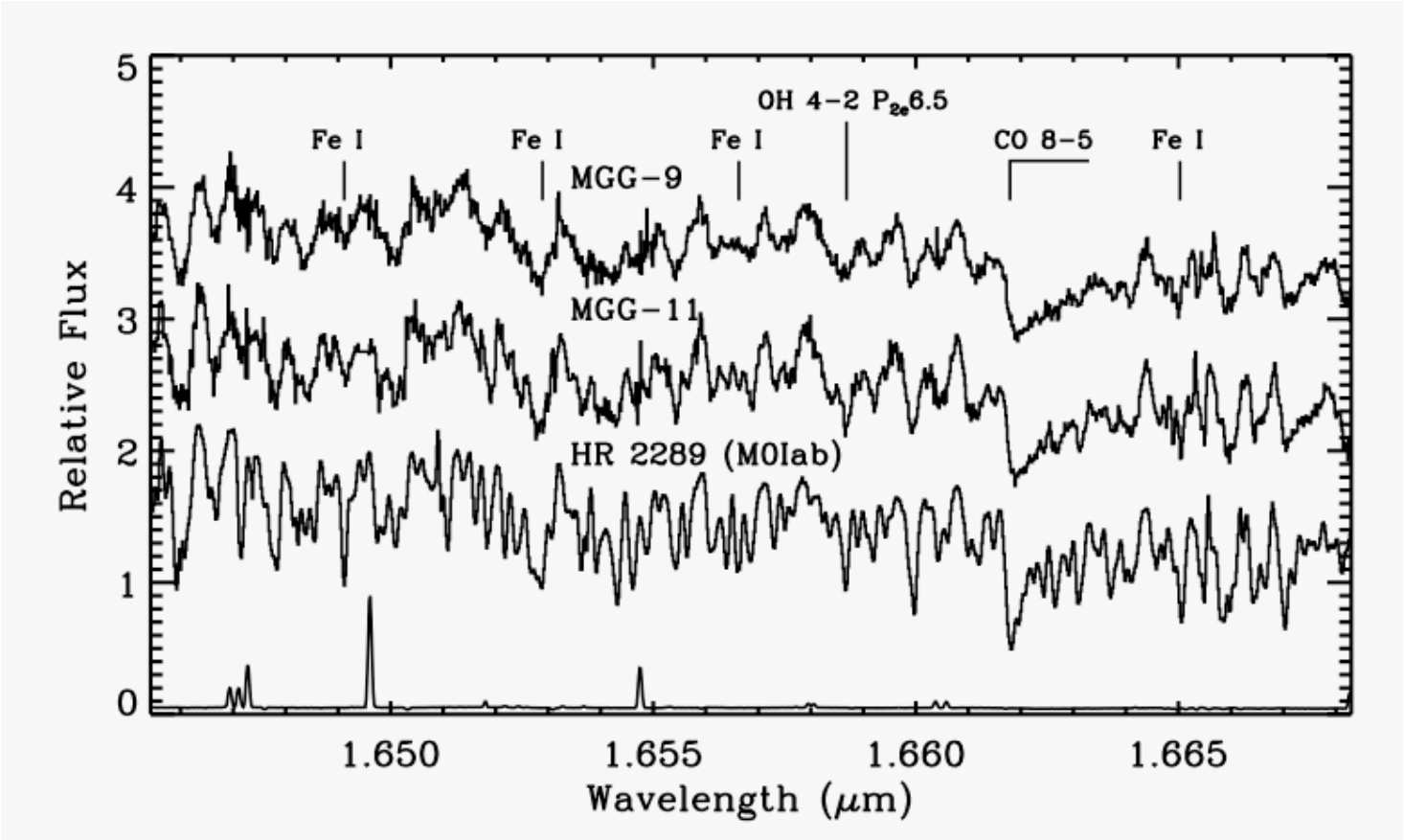
  $M \approx 9.8\, r_h \sigma^2 / G$

- HST/NICMOS measures size
  - King model fits
  - Errors typically ~ 10 mas (0.2 pc)
  - Principal systematic error associated with defining background



McCrady & Graham 2007

Echelle Spectroscopy of M82 SSCs

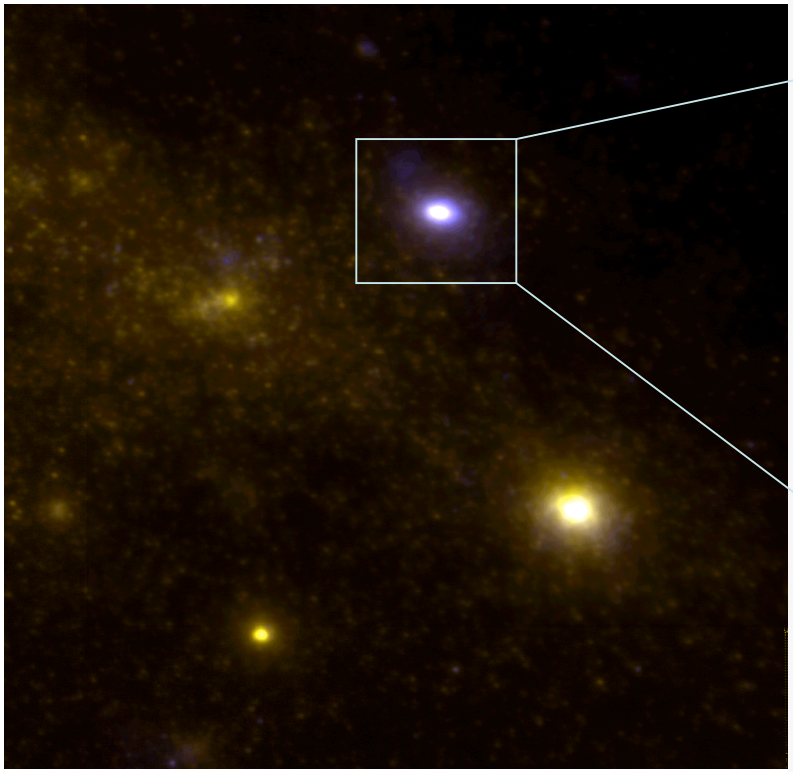


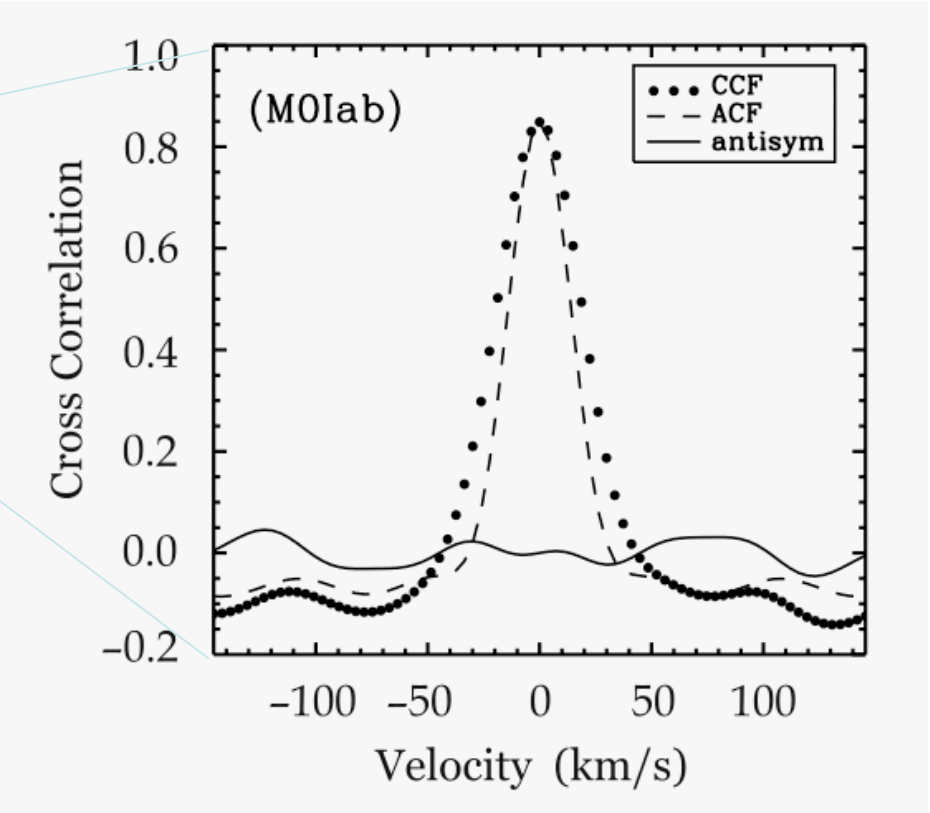
- Keck2/NIRSPEC measures the velocity dispersion
  - Cross-correlated with accurate supergiant templates
  - Typical uncertainty ~ 400 m/s

Velocity Dispersion Measurements

- Velocity dispersion is measured using the cross correlation
  - Accurate stellar template match required
    - Kirian & Graham (2007) supergiant library
  - Systematic errors from Fourier filtering must be quantified
    - Noise biases derived velocities
  - Symmetric & antisymmetric parts of cross-correlation must be inspected
    - Quantify noise & identify spatially unresolved kinematic components

M82-SCC F



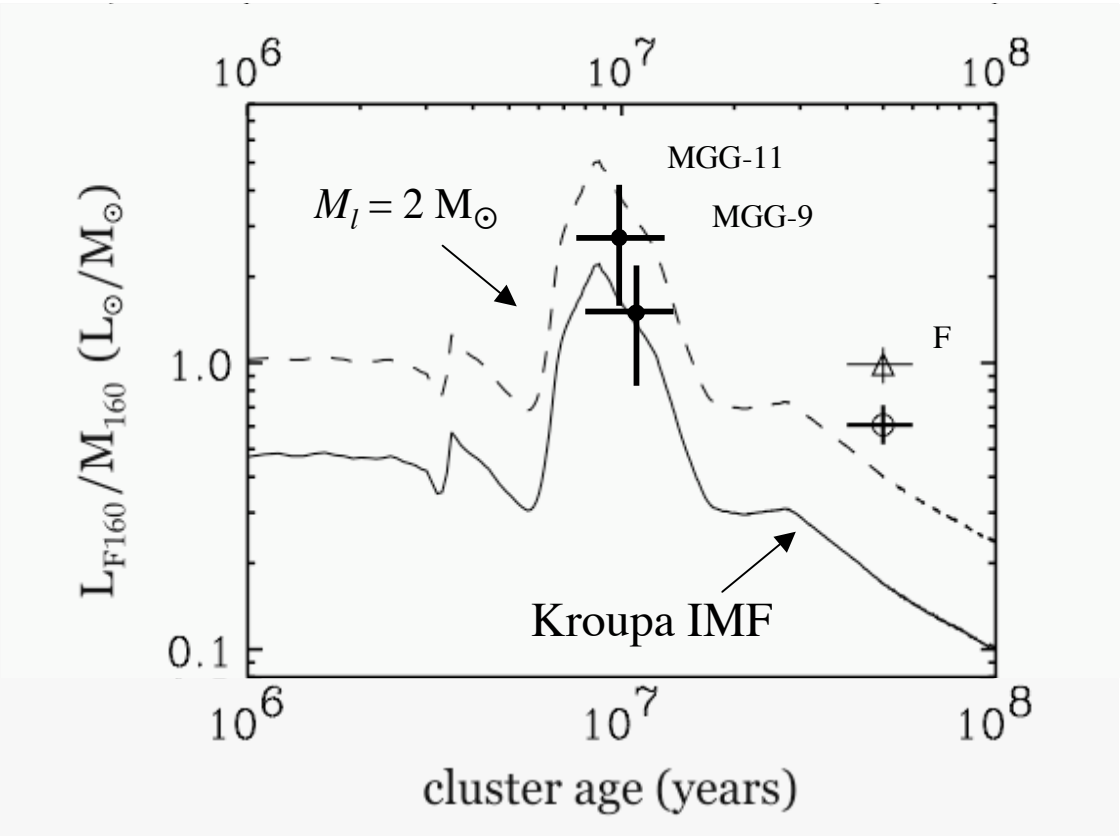


- Average cross correlation for seven echelle orders

$\sigma = 13.5 \pm 0.2$ km/s; $r_h{}^a = 112 \pm 2$ mas; $r_h{}^b = 63 \pm 1$ mas

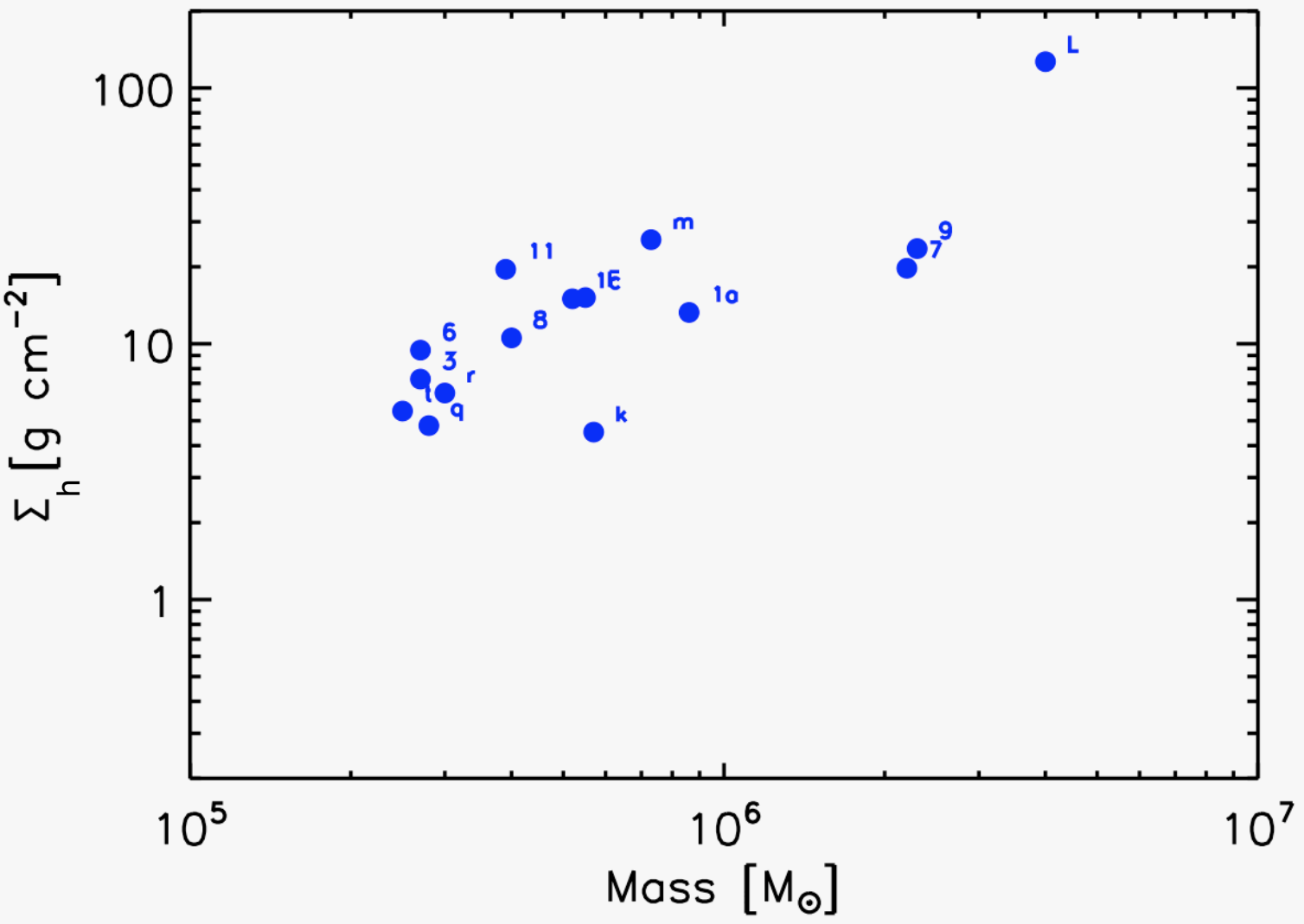
$M = 6.6 \pm 0.9 \times 10^5\ M_\odot$

Top Heavy IMF?



- F has the best evidence for a top-heavy IMF
- Virial mass is based on kinematics of red supergiants
  - Cluster F has evidence for mass segregation

Mass & Surface Density



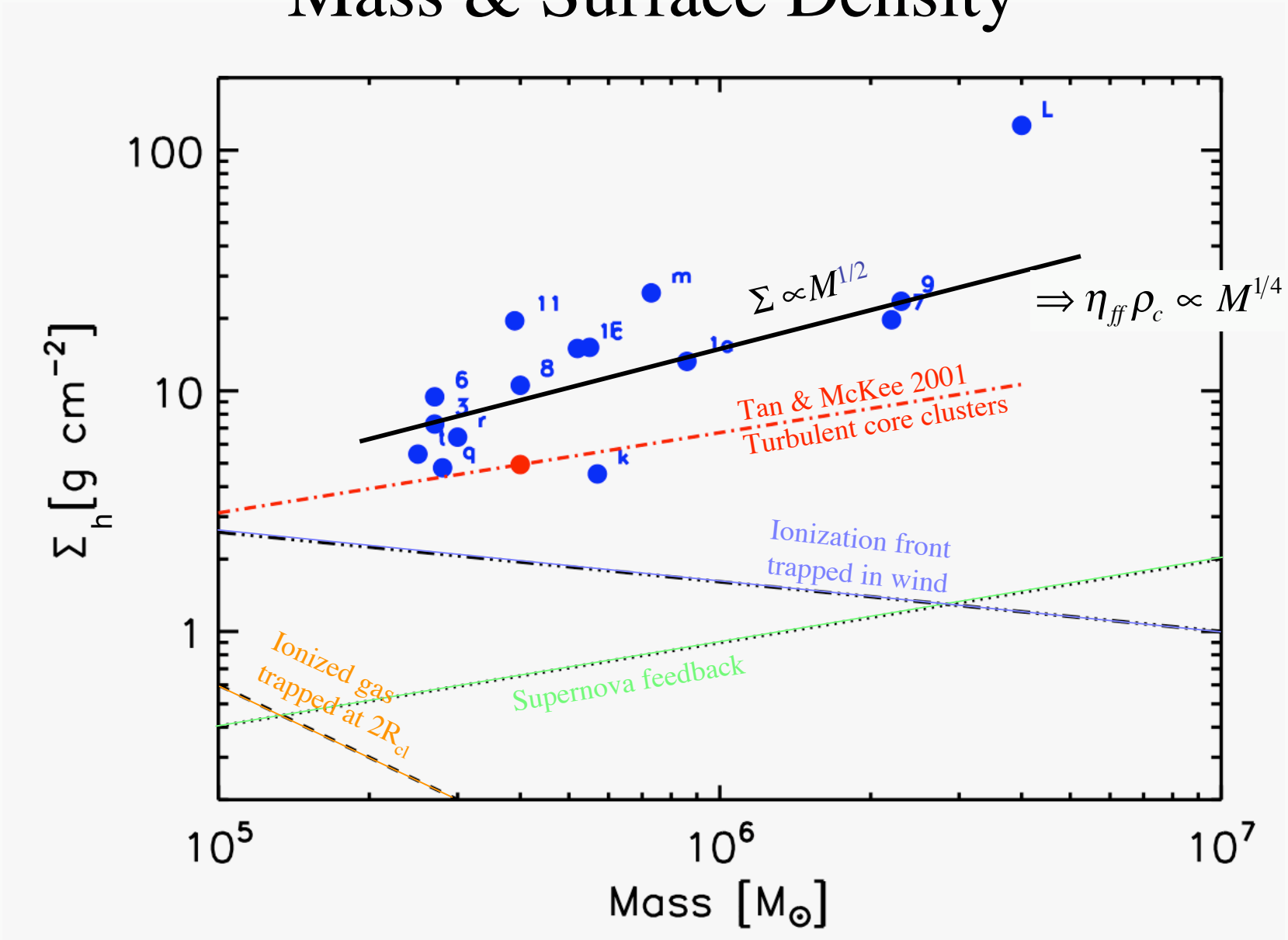
$1\ \mathrm{g\ cm^{-2}} = 4800\ M_\odot\ \mathrm{pc^{-2}} \equiv 214\ \mathrm{mag}$

Mass & Surface Density

Object	M ($M_\odot$)	$R_{1/2}$ (pc)	Σ (g cm^{-2})	$P/k = G\Sigma^2/k$ (K cm^{-3})
Hot cores	3800	0.5	1.0	4×10^8
ONC	4600	0.8	0.24	2×10^7
Arches Cluster	2×10^4	0.4	4	7×10^9
Globular Clusters	2×10^5	3.4	0.8	3×10^8
MGG-9	1.6×10^6	3.4	9.1	3.3×10^{10}
MGG-11	3.4×10^5	1.5	9.9	3.9×10^{10}

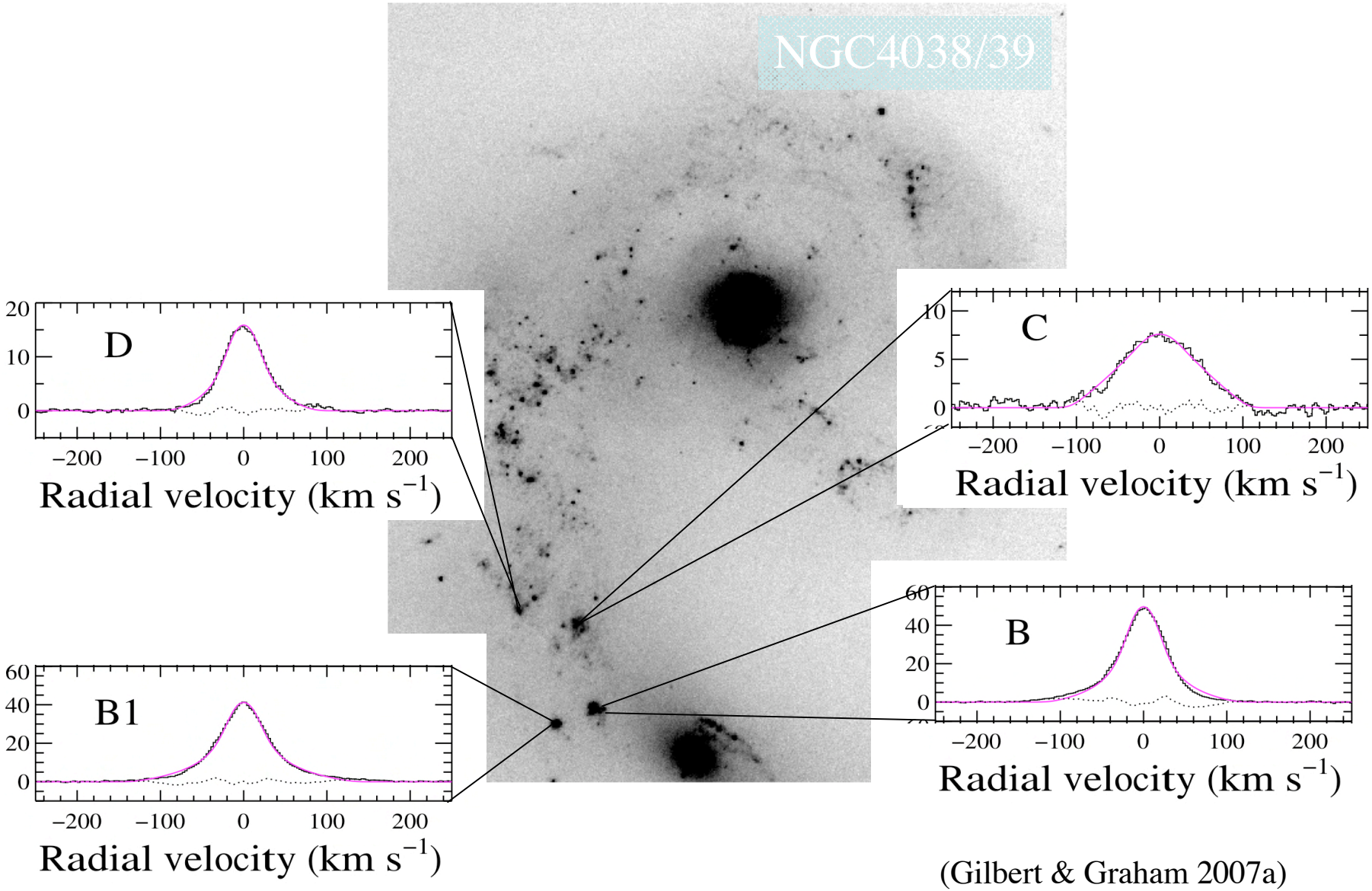
$$1 \text{ g cm}^{-2} = 4800\ M_\odot \text{ pc}^{-2} \equiv 214 \text{ mag}$$

Mass & Surface Density



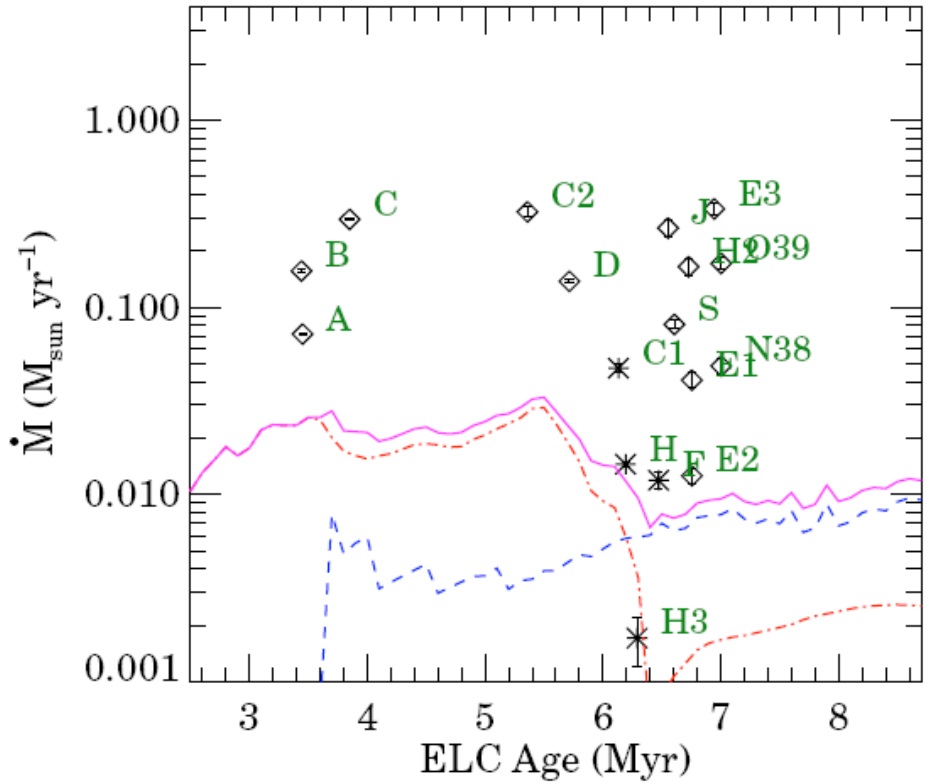
$1\ \mathrm{g\ cm^{-2}} = 4800\ M_\odot\ \mathrm{pc^{-2}} \equiv 214\ \mathrm{mag}$

Mass Loss from Young SSCs



(Gilbert & Graham 2007a)

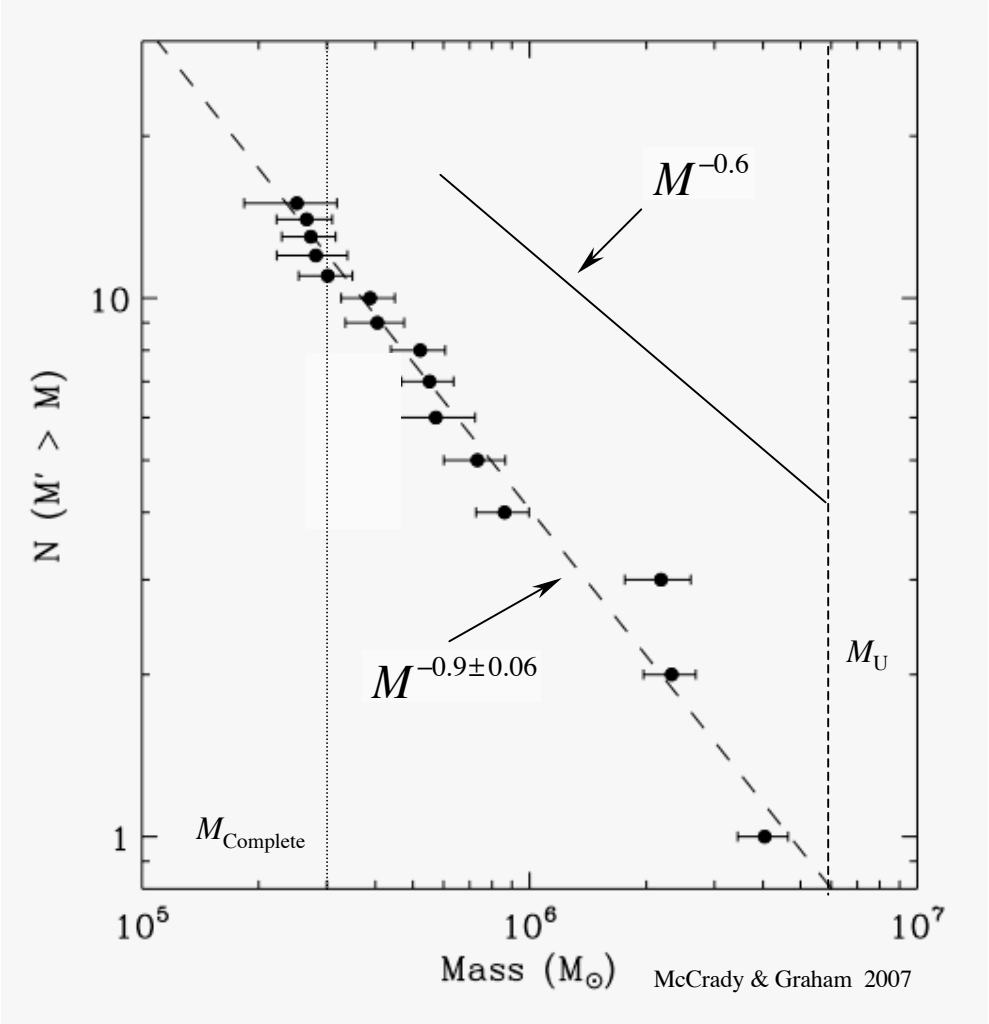
Mass Loss from Young SSCs



(Gilbert & Graham 2007a)

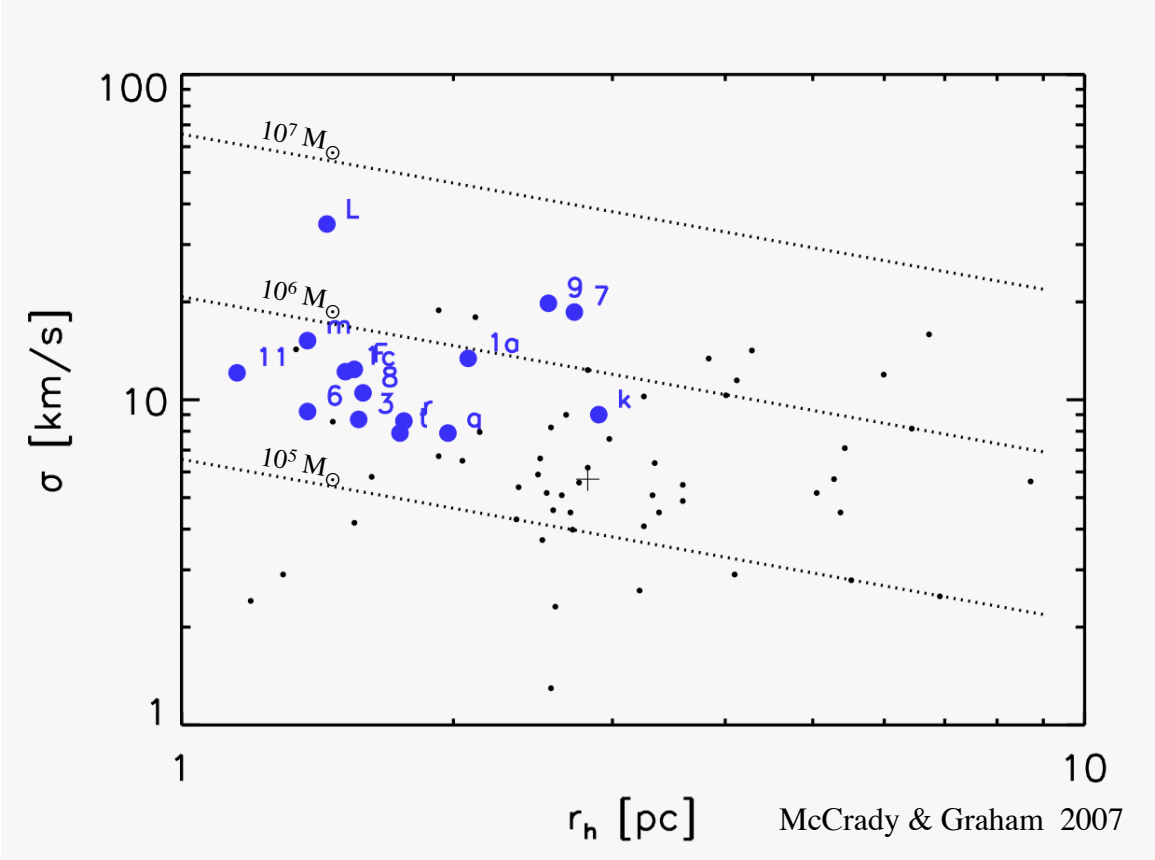
M82 SSC Mass Spectrum

- Complete for $M_{cl} > 3\times10^5$ $M_\odot$
  - $dN/d\ln(M_{cl}) \sim M_{cl}^{-0.91\pm0.06}$
- Each decade of M_{cl} has approximately the same total number of stars
  - Total M_{cl} of 1.4×10^7 $M_\odot$
- Comparable to clusters in the solar neighborhood & Galactic OB associations
  - Shallower in dIrr (Dowell, Buckalew & Tan 2007)
- An initial M^{-1} distribution is consistent with open & globular clusters populations
  - Low mass clusters preferentially destroyed (Elmegreen & Efremov 1997)



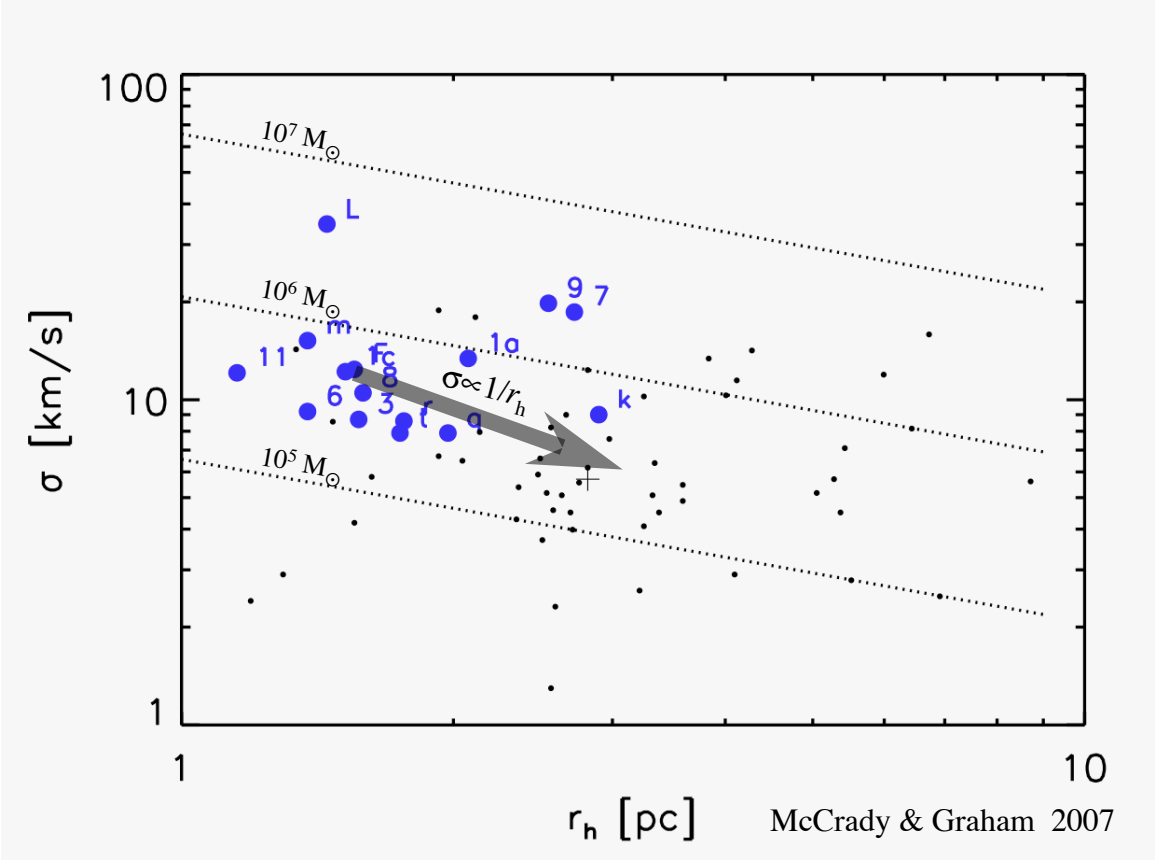
Proto-Globulars?

- Galactic globular cluster M82 SSCs are smaller (× 2) and have lower velocity dispersion (× 2)



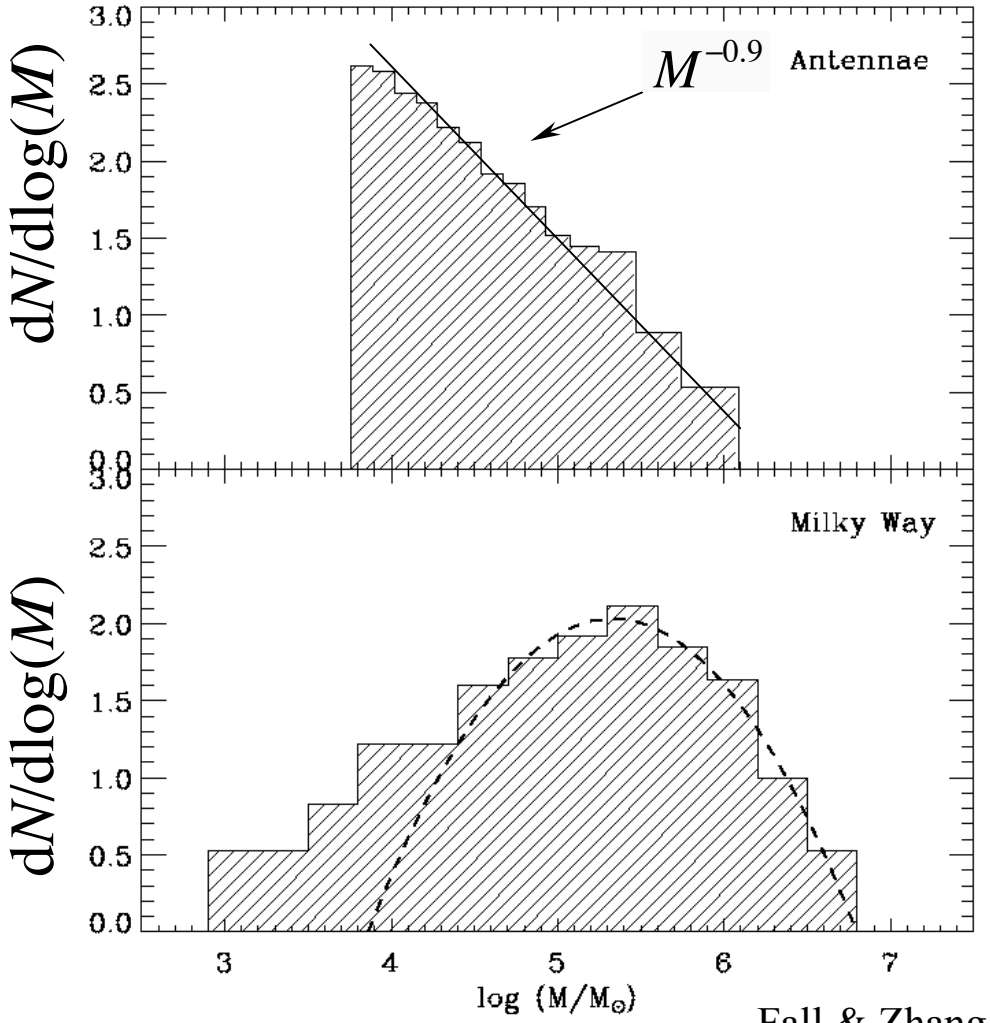
Population Evolution

- Comparison with Galactic globular clusters suggests they adiabatically ($\sigma \propto 1/r_h$) loose ~ 1/2 their mass
  - Only 15% of the mass is in stars M > 8M $_\odot$ for a normal IMF
  - Mass loss in addition to winds & SN is needed
    - Dynamical mass segregation & preferential ejection of low mass stars
    - Release of energy stored in binaries
    - Tidal & gravitational interactions



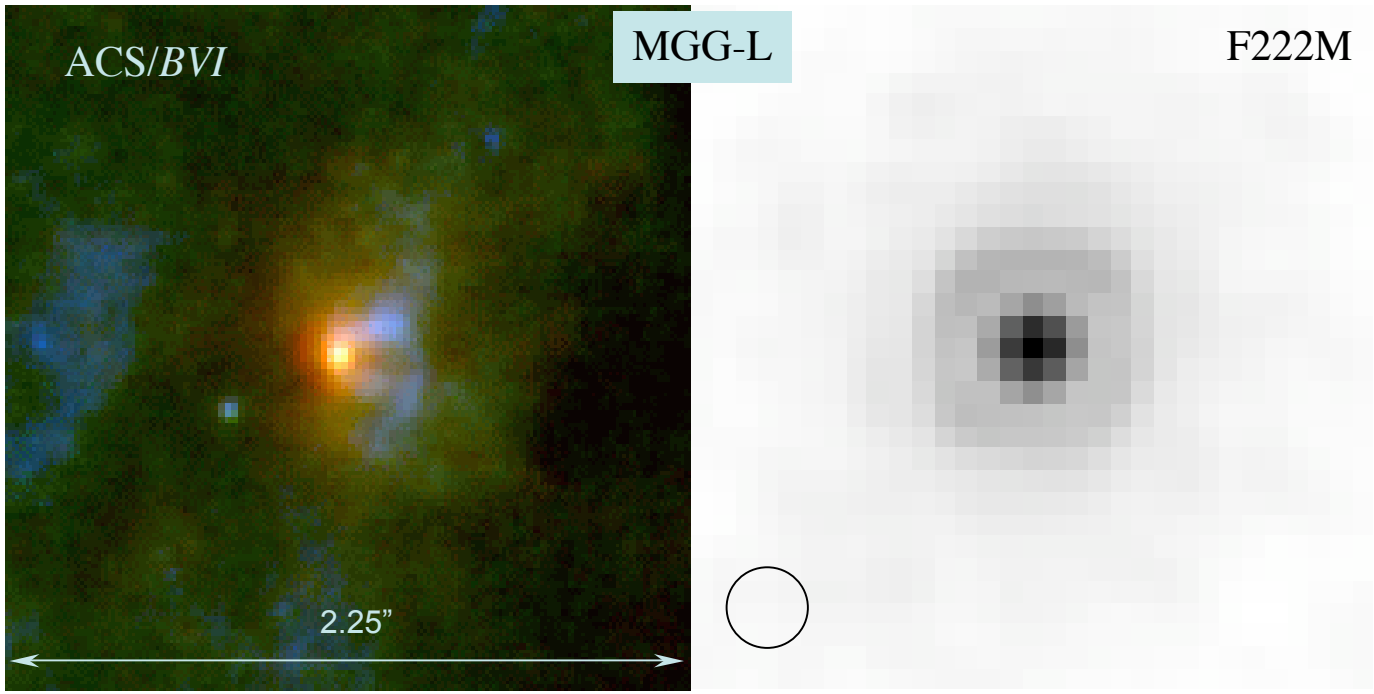
Antennae SSC Mass Spectrum

- The ~ M^{-1} mass function appears universal, e.g., in the Antennae Galaxies
- Mass functions of SSCs vs. GCs Virial and photometric methods agree
  - No evidence for systematic variation of IMF with cluster mass



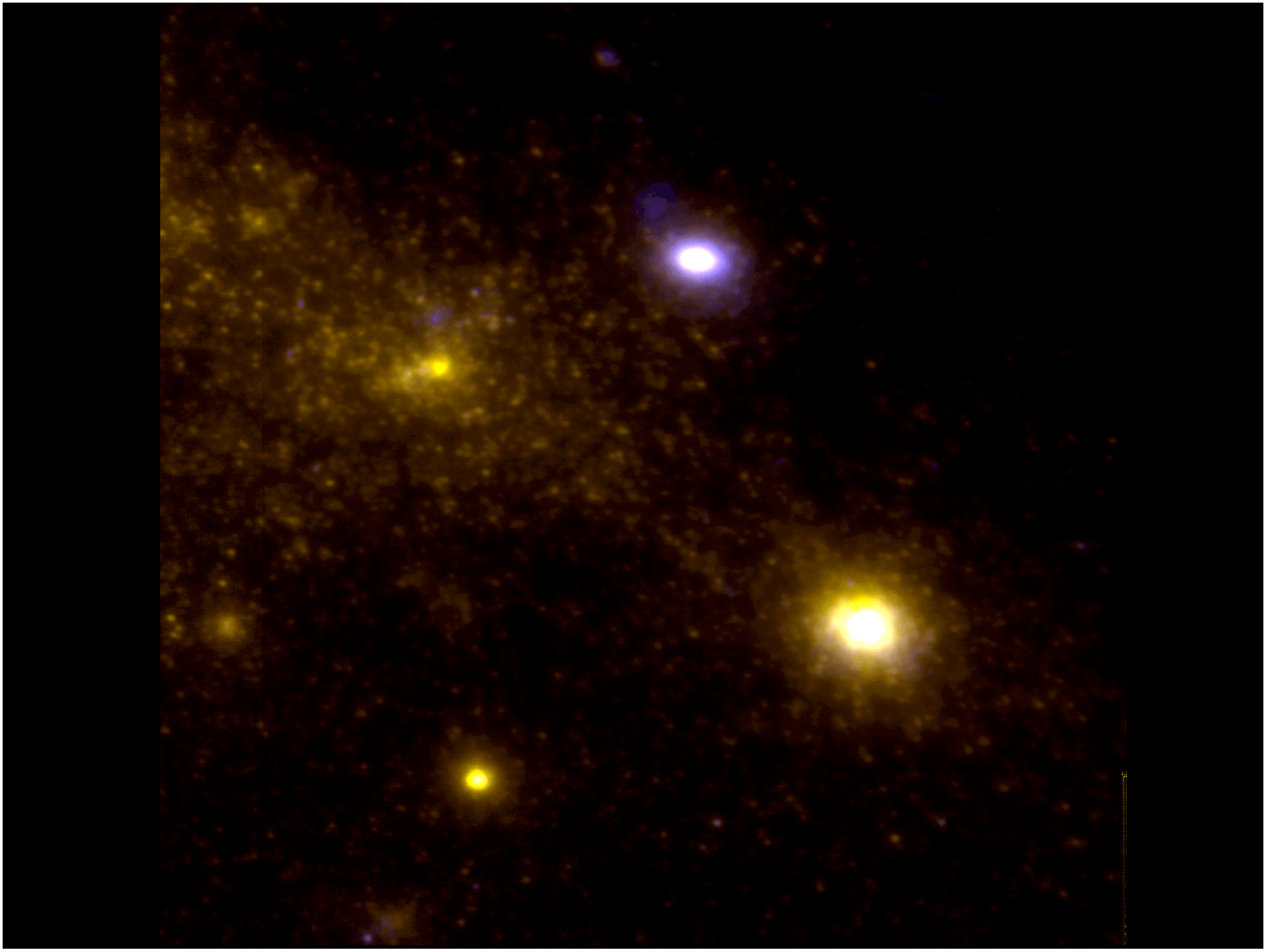
Fall & Zhang 2001

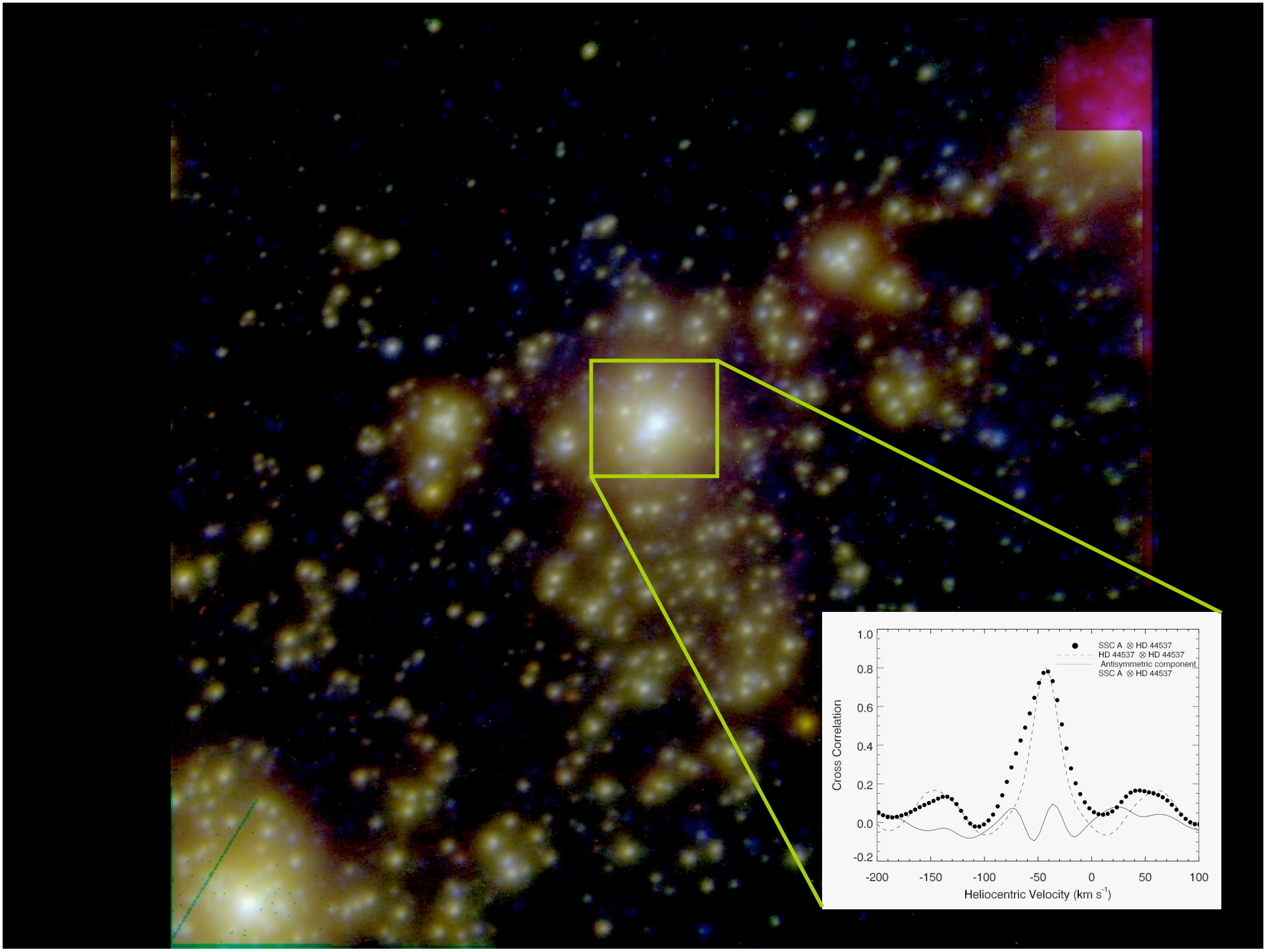
NICMOS is Resolution Challenged



- MGG-L is an older (≈ 50 Myr) SSC with modest foreground extinction that it can be studied at optical wavelengths


http://en.wikipedia.org/wiki/Image:Keck_laser_at_night.png




SSC A ⊗ HD 44537
HD 44537 ⊗ HD 44537
Antisymmetric component
SSC A ⊗ HD 44537
Cross Correlation
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-200
-150
-100
-50
0
50
100
Heliocentric Velocity (km s-1)

END