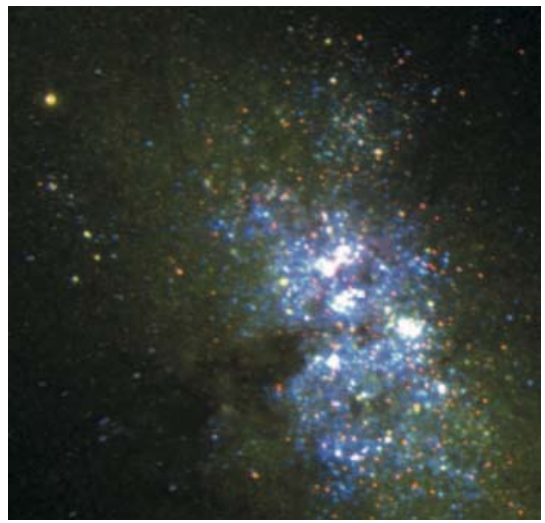
Compact Massive Young Star Clusters & Connections to Globular Star Clusters

J.S. Gallagher



With L. J. Smith, M. Westmoquette, N. Bastian, R. de Grijs, E. Wehner, R. O'Connell, I. Konstantopoulos, …

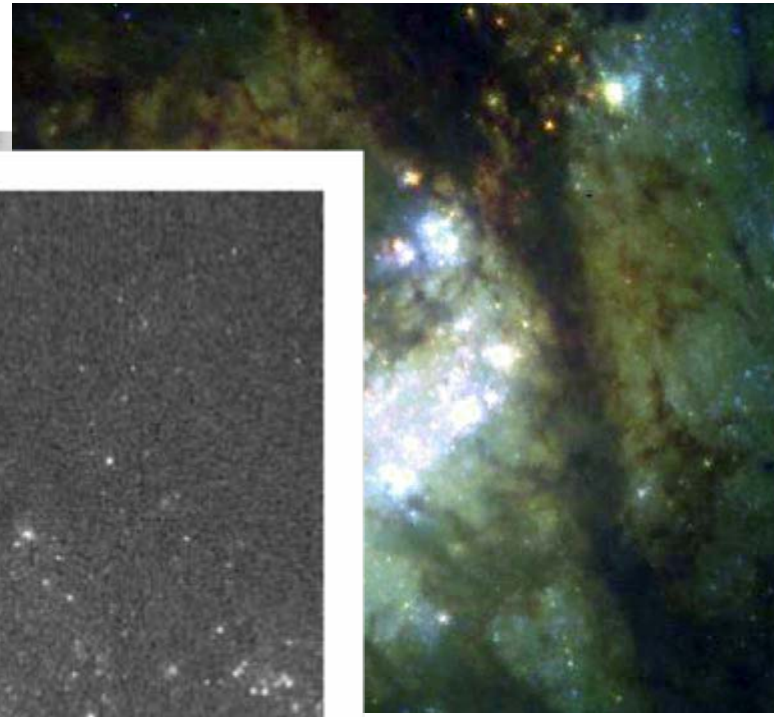
More than you probably wanted to know observational mini-review: **Focus on SSCs**

- **WHAT:** $M \geq 10^5\ M_\odot$ "super star clusters" structures, $R_H \approx$ 2-5 pc, τ<1 Gyr.
- **WHERE:** host galaxies and role of local conditions.
- **WHY:** Observe evolutionary & structural sequences of massive clusters.
- **WHEN:** range of formation conditions; relationships to open clusters and star formation conditions.

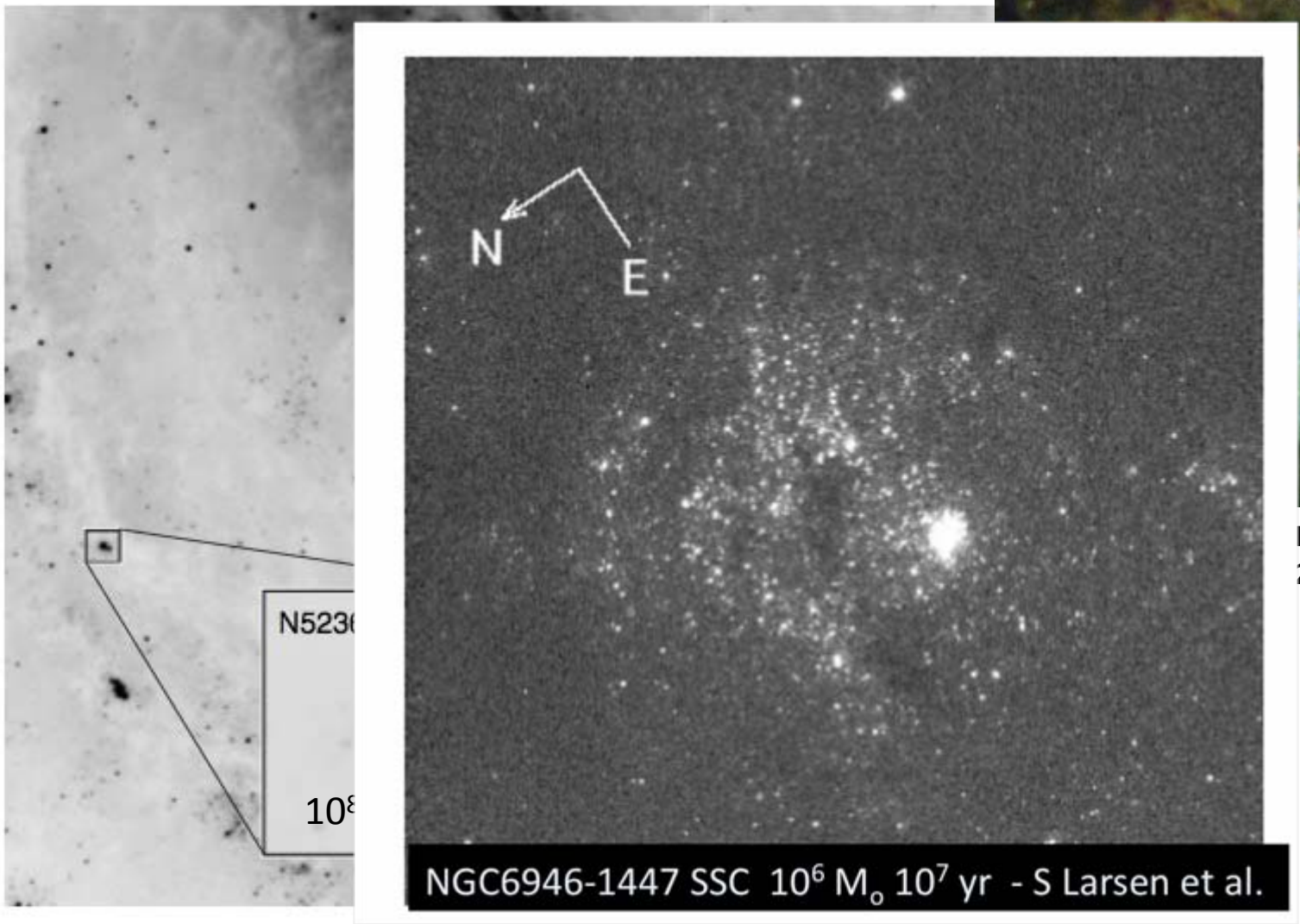
Where?

- High ISM density→ high SFR→ *galaxy centers STARBURSTS*
- High ISM density→ high dissipation factors
  - dynamic situations—shocks, etc.
    → *interacting systems, spiral disks, tidal debris, accretion flows?*
  - undisturbed cloud growth , quiescent mode
    → *dwarf galaxies; spiral disks?*

SSCs in spirals—inner & outer: M83



Harris et al.
2001, AJ

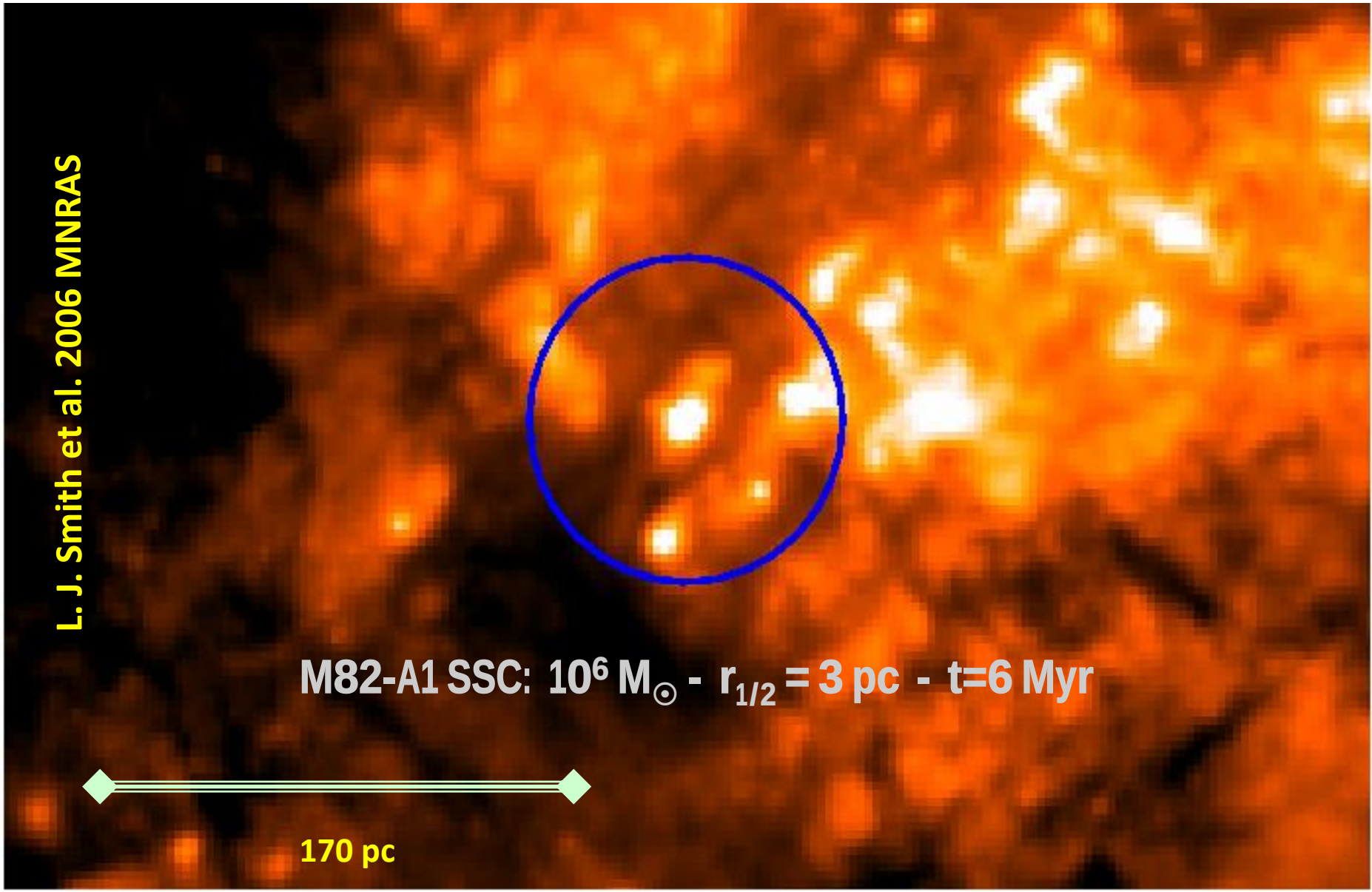


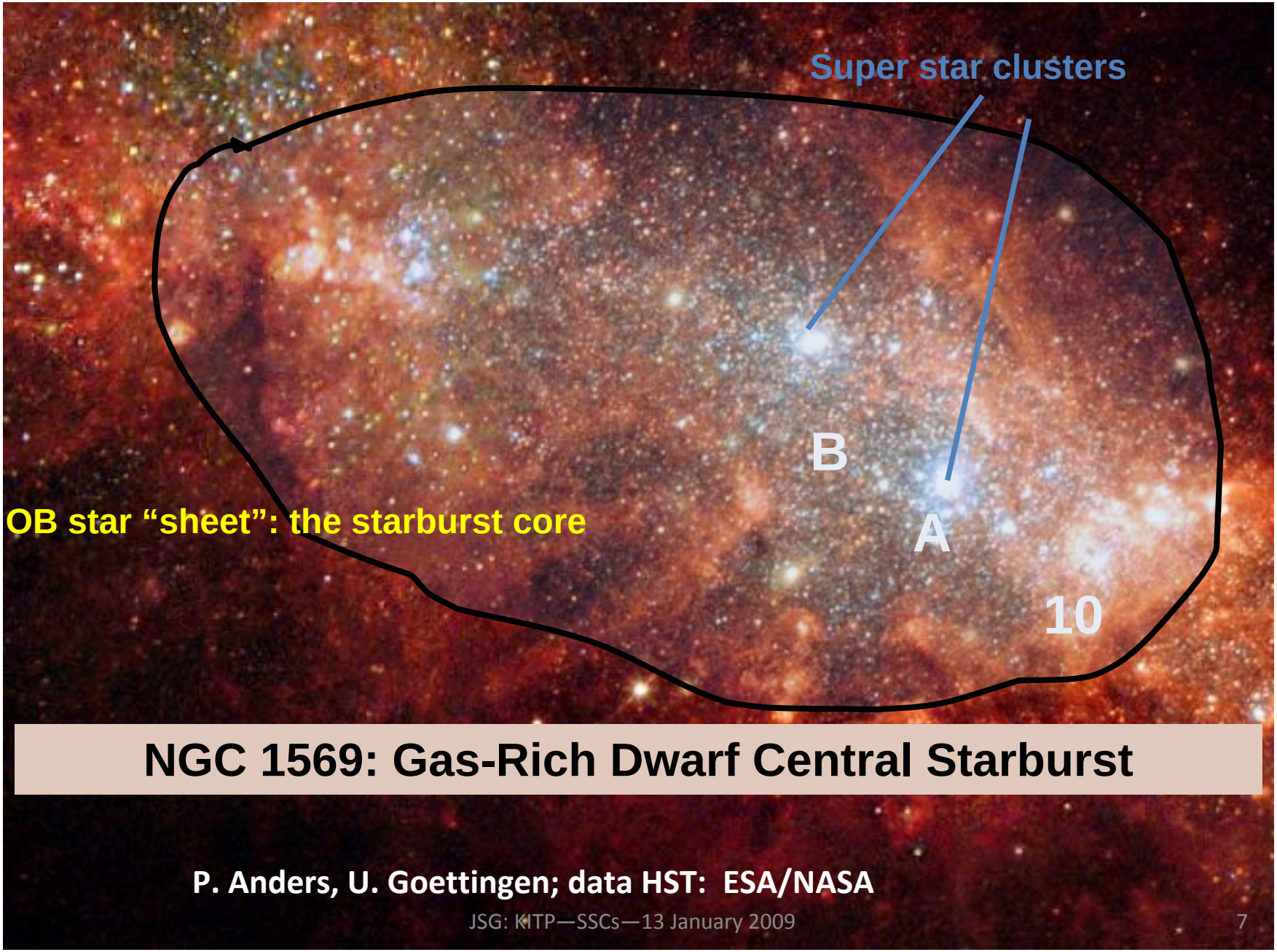
Larson & Richtler 2004, A&A

M82 Giant Starburst: Rich Populations of SSCs

M. Westmoquette from Hubble Heritage HST/ACS Data

M82-Clump A: YOUNG SSC STUDIED WITH HST/STIS



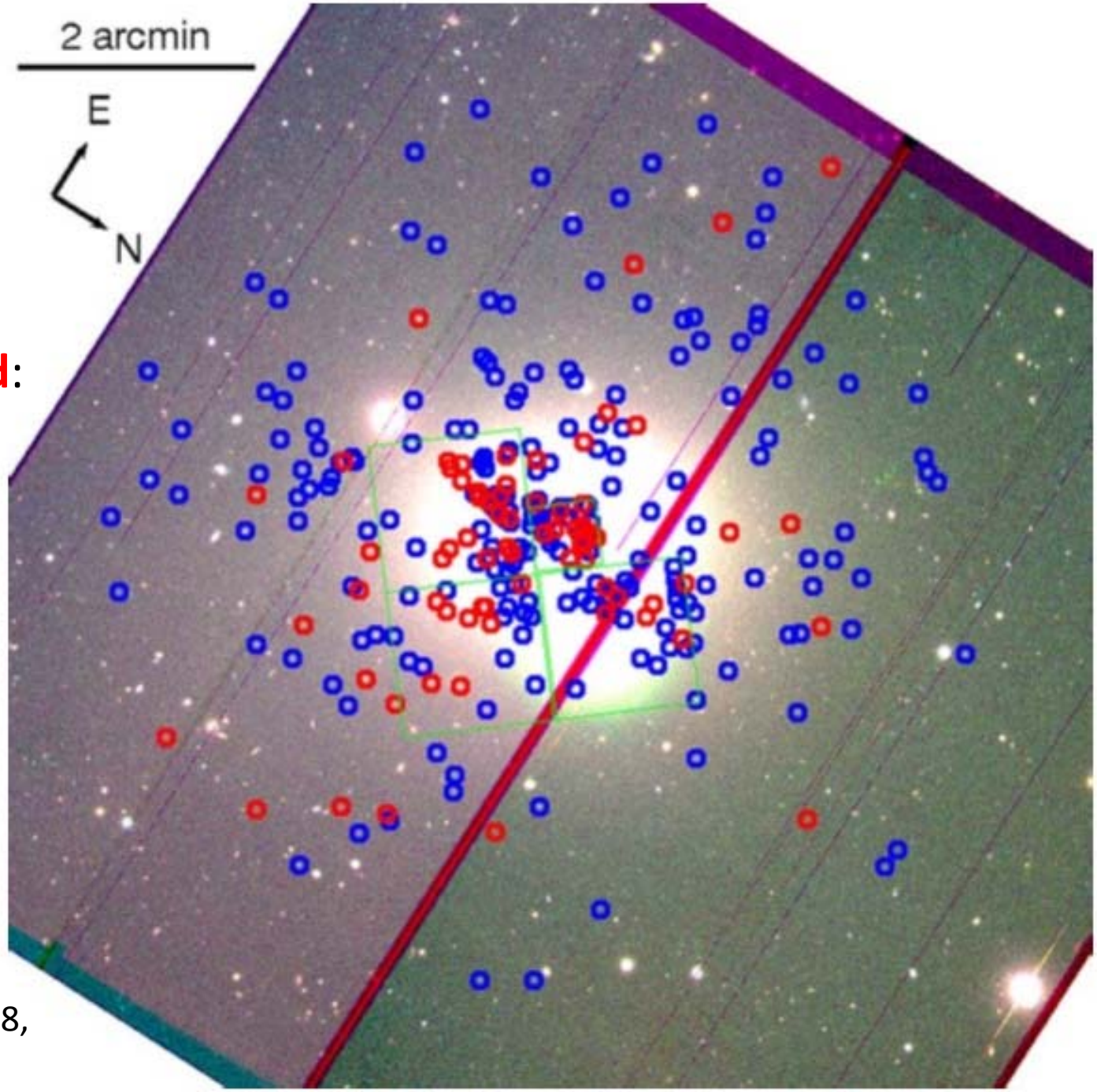


NGC 1569: Gas-Rich Dwarf Central Starburst

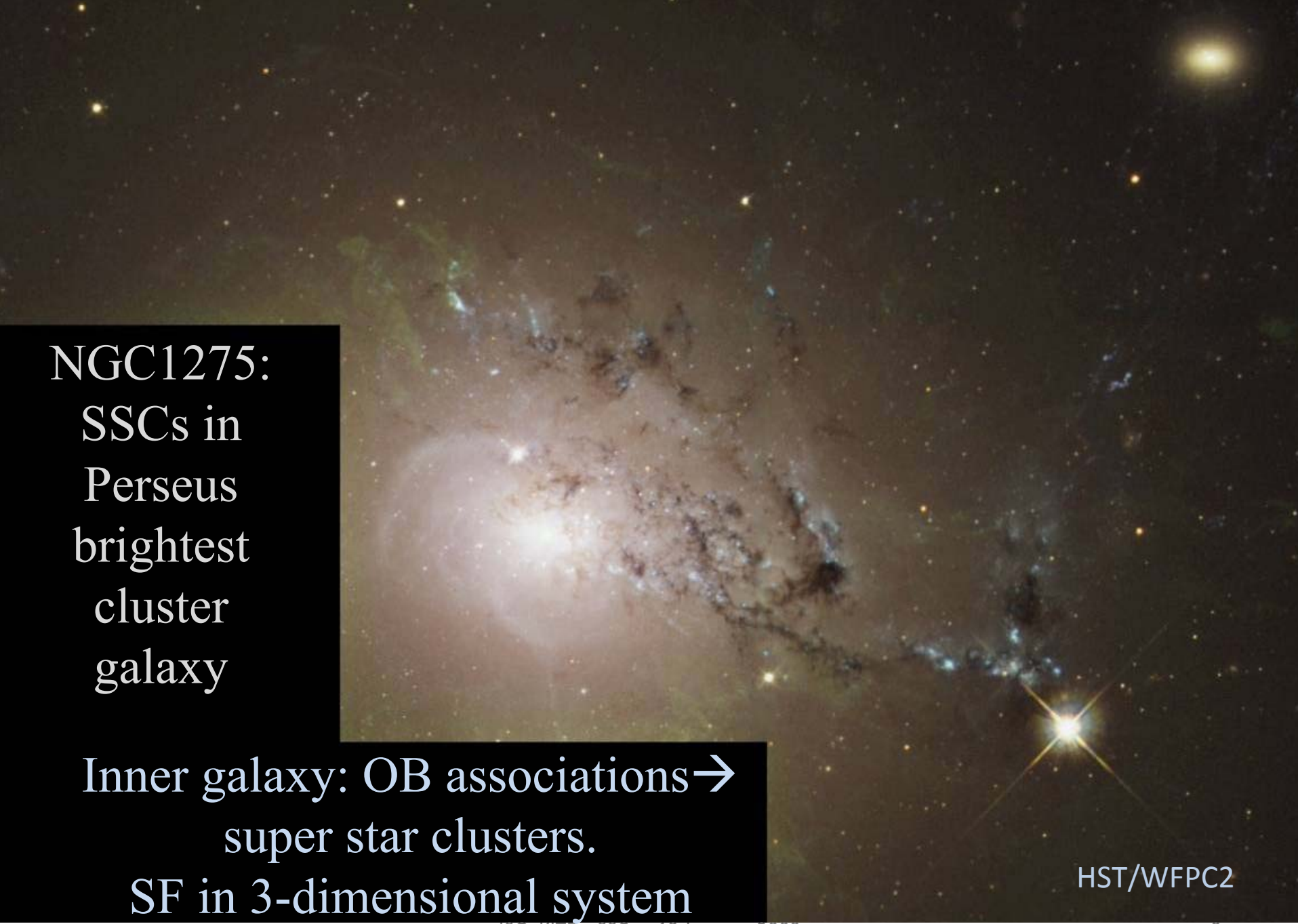
P. Anders, U. Goettingen; data HST: ESA/NASA

WIYN + WFPC2:
NGC821 E6 GCs
Radially extended:

SSCs:
Centrally Concentrated; Disky!

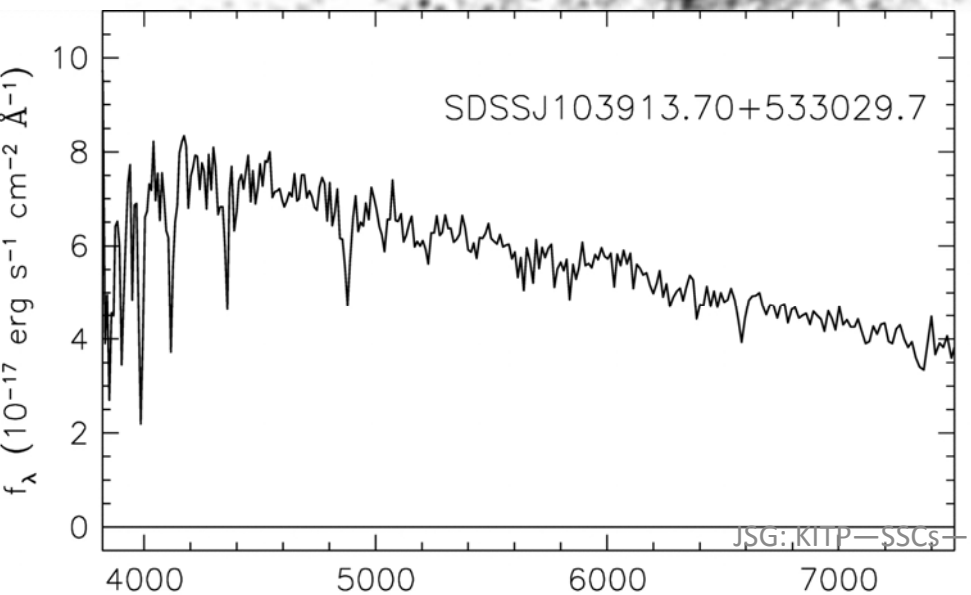


Spitler et al 2008, MNRAS. 385


NGC1275:
SSCs in
Perseus
brightest
cluster
galaxy
Inner galaxy: OB associations→
super star clusters.
SF in 3-dimensional system
HST/WFPC2

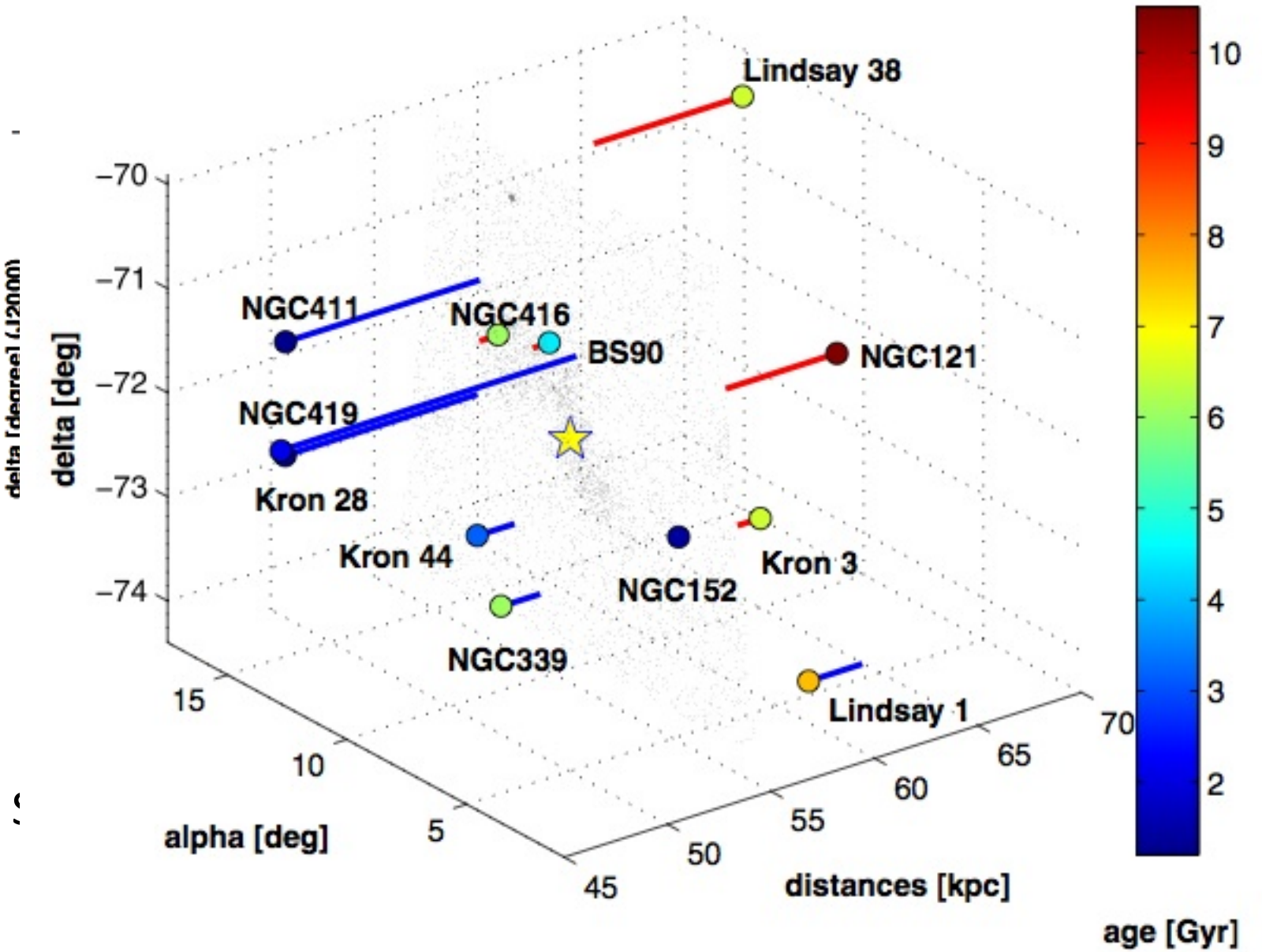
SSC D>17 kpc from NGC3310 starburst:
M_V= -11
≈10^6 Msun
Close to tidal debris but no HI.

Tidal debris GC formation mode?
Cluster ejection?



SDSS: Knapp et al.2006, AJ
Tidal debris: Wehner et al. 2006, MNRAS; 2005, ApJL

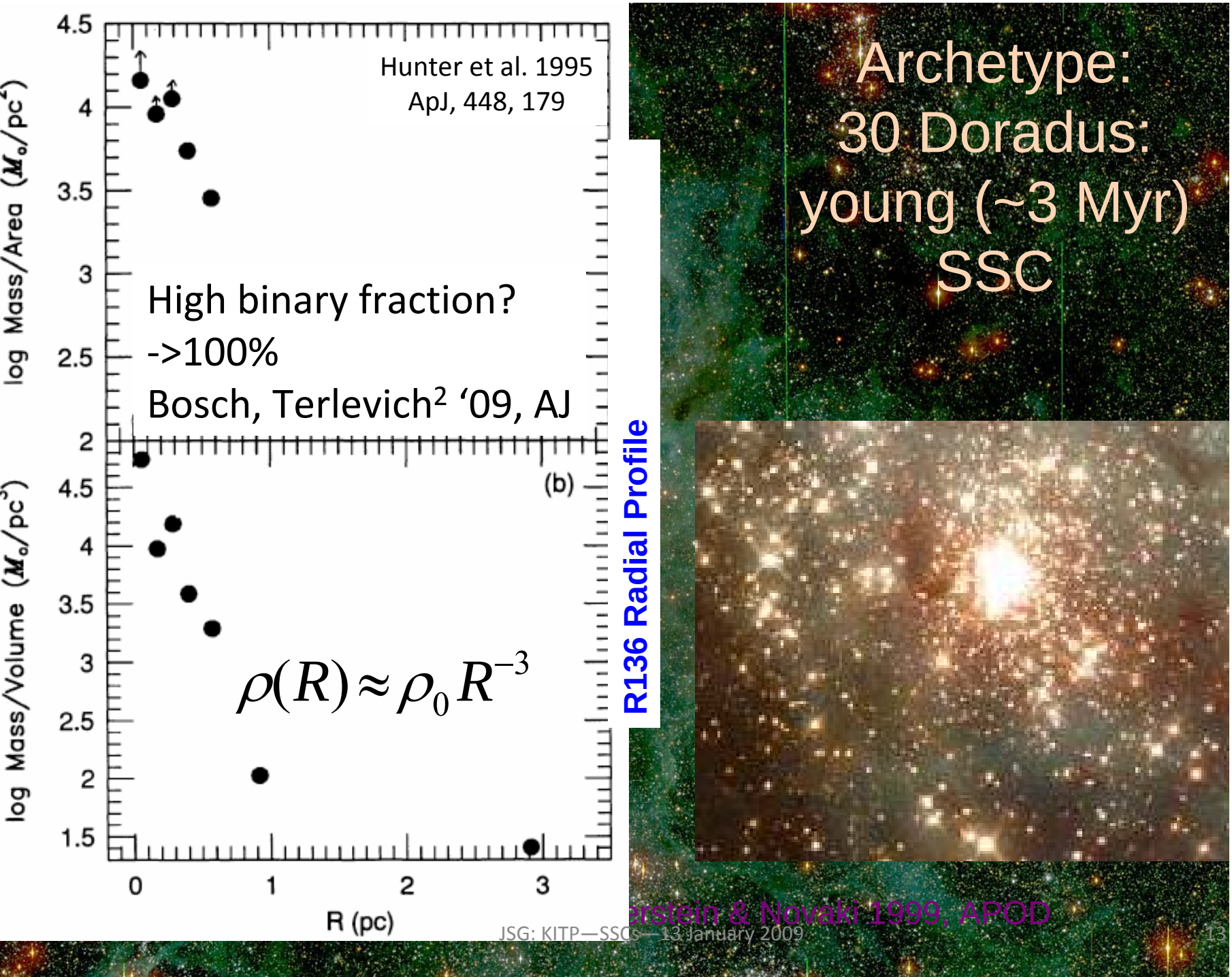
2008, AJ, 136

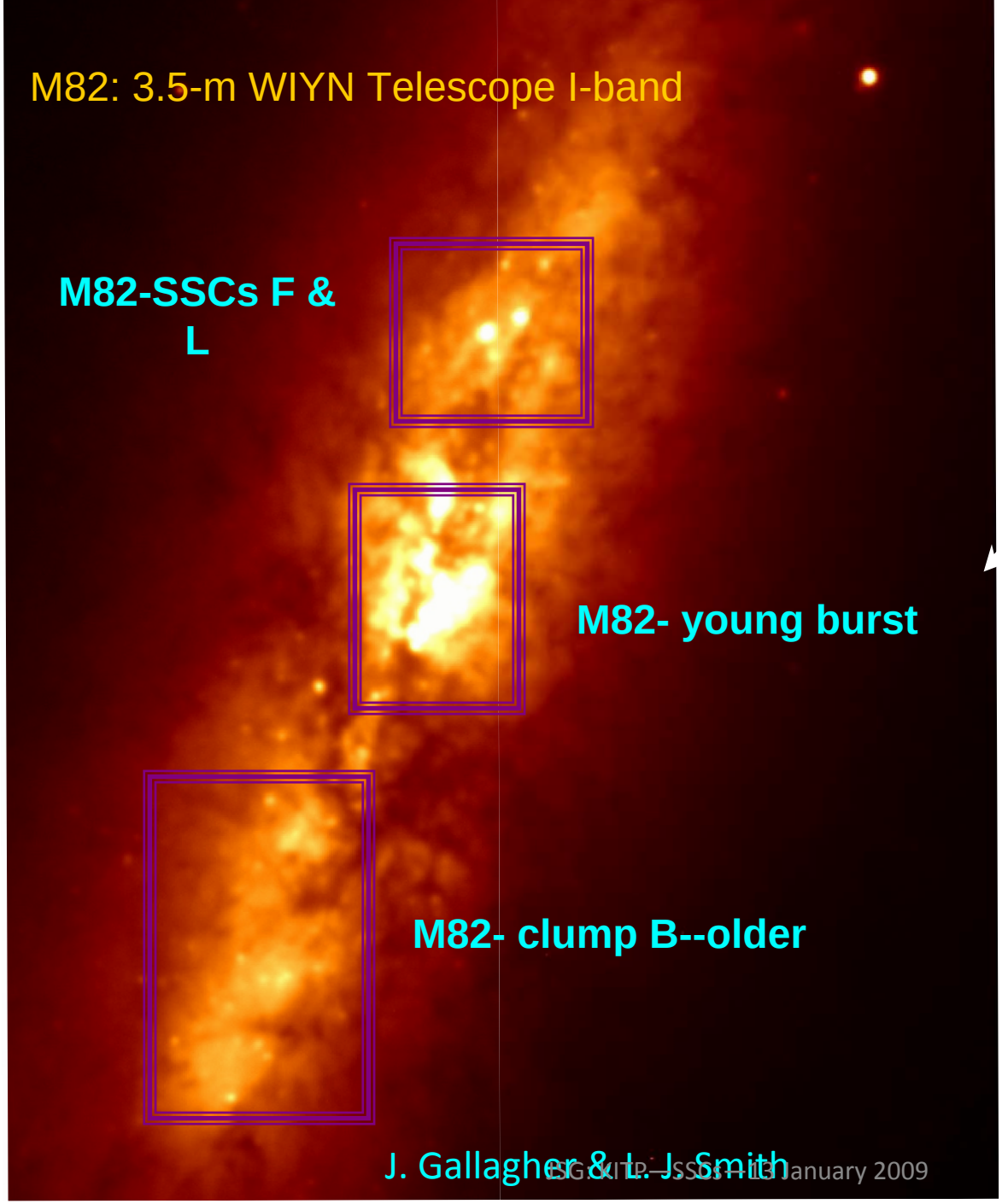

Lindsay 38
NGC411
NGC416
BS90
NGC121
NGC419
Kron 28
Kron 44
NGC152
Kron 3
NGC339
Lindsay 1
−70
−71
−72
−73
−74
delta [deg]
15
10
5
alpha [deg]
45
50
55
60
65
70
distances [kpc]
10
9
8
7
6
5
4
3
2
age [Gyr]

Why

Explore physical conditions as functions of time and environment. Age, mass, IMF, size…

Study conditions associated with massive compact cluster formation


Hunter et al. 1995
ApJ, 448, 179
High binary fraction?
->100%
Bosch, Terlevich² '09, AJ
$\rho(R) \approx \rho_0 R^{-3}$
log Mass/Area ($M_\odot$/pc²)
log Mass/Volume ($M_\odot$/pc³)
R (pc)
(b)
Archetype:
30 Doradus:
young (~3 Myr)
SSC
R136 Radial Profile
erstein & Novaki 1999, APOD



M82 view from the ground:

A VERY disturbed galaxy--

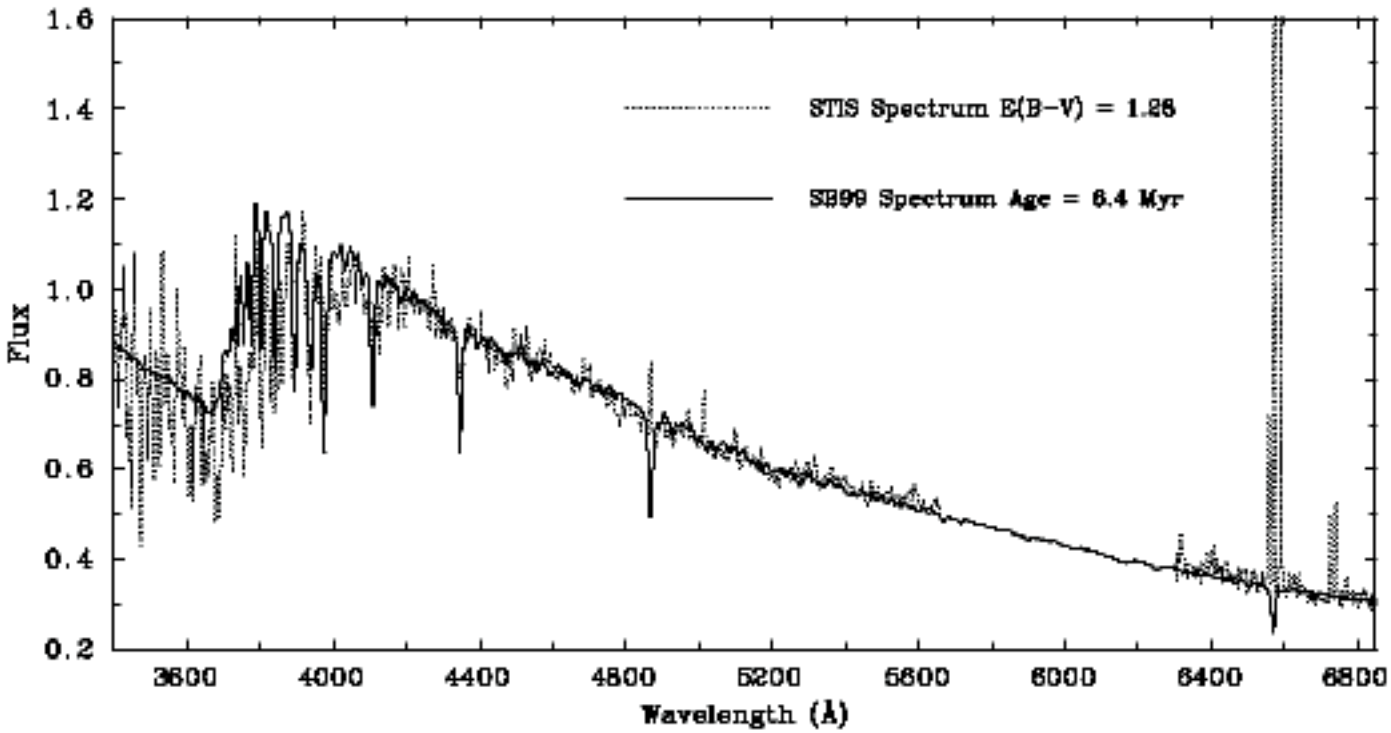
Bright starburst clumps: dust and SSC "stars"

D=3.6 Mpc

1 arcsec ≈19 pc

HST resolution for SSC structures: D(1/2)~0.3 arcsec

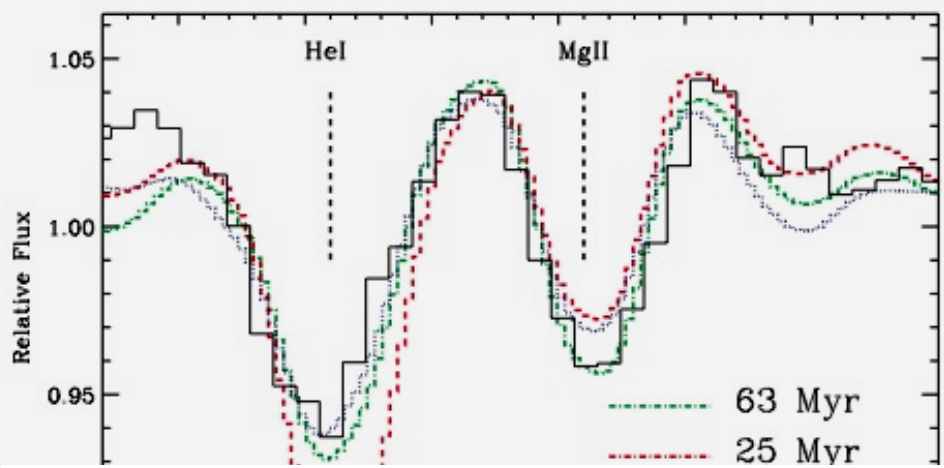
Ages: Keys to SSC structures & evolution



Spectroscopic ages from fits to optical synthetic spectra in M82—e.g. Gallagher & Smith 1999, MNRAS.

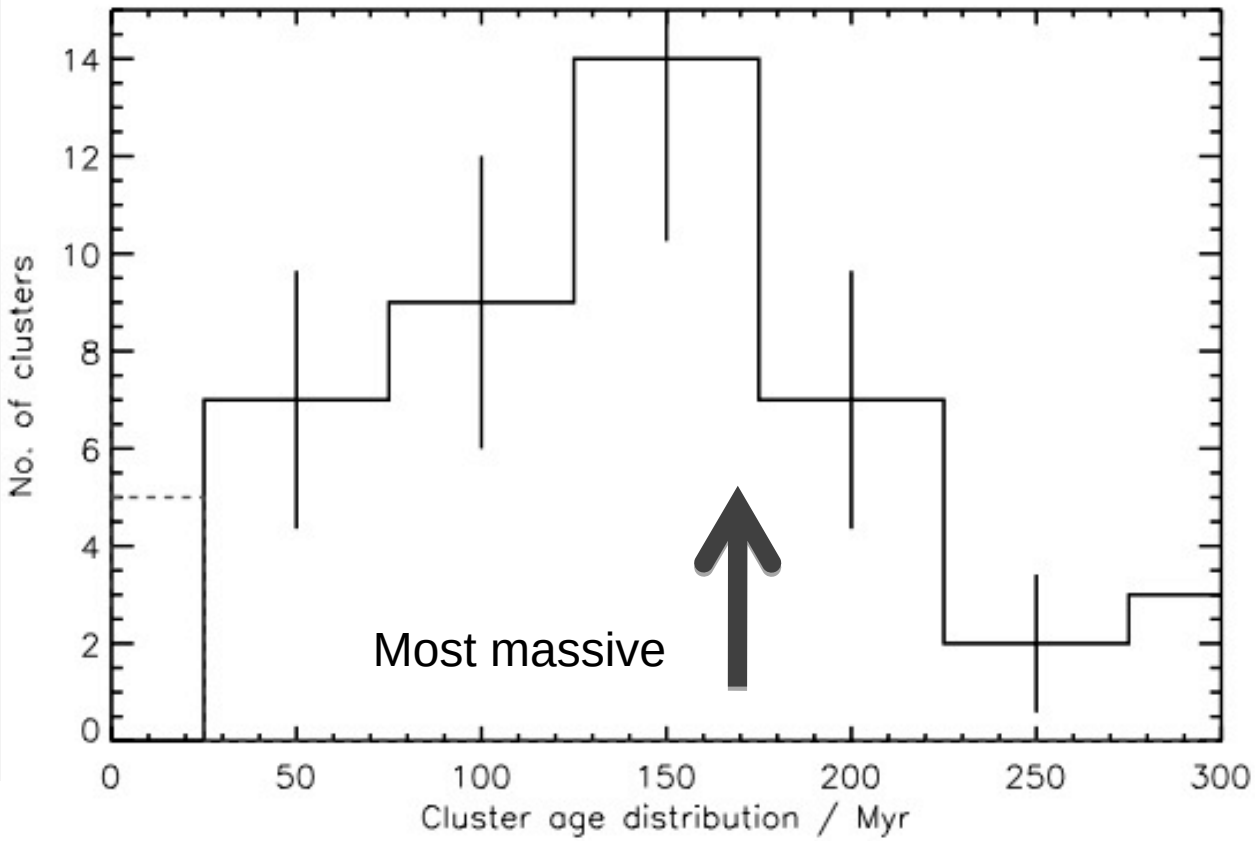
Here L. J. Smith et al 2006, MNRAS, 370, 513.

Fit STIS spectra to SB99 models gives age of 6-7 Myr for M82-A1 and $M \approx 10^6\ M_\odot$, $R_{1/2}$=3 pc. Half-light radius Dense cluster star forming mode very significant in M82.



Ages—critical for cluster lifetimes
Stellar integrated IMFs
Cluster mass functions
Optical data key for younger ages!

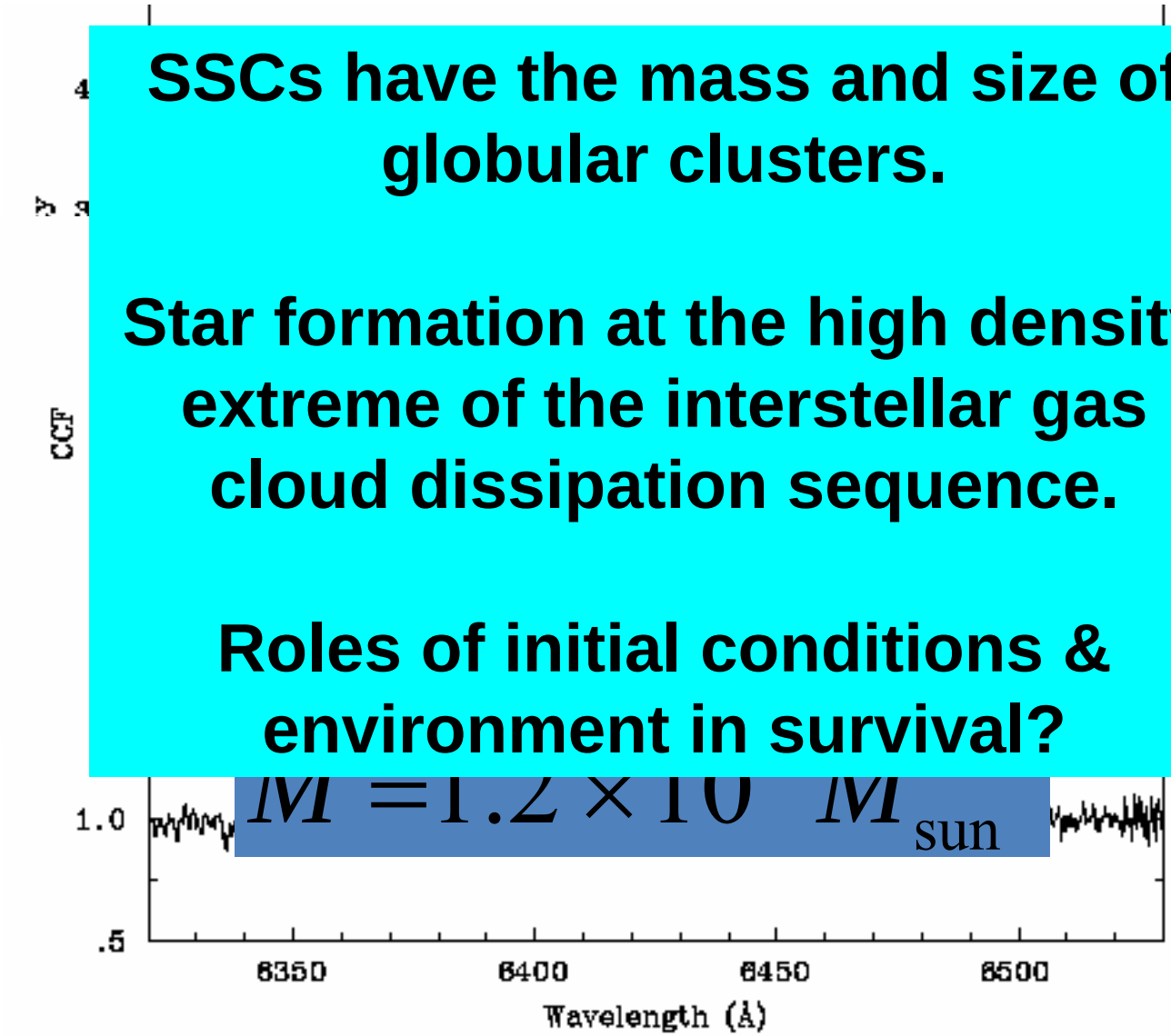
Konstatopoulos et al. M82 Gemini spectroscopic age studies building on Smith et al. 2007, ApJL, 667



M82 SSC formation R<3 kpc in disk extends over full >200 Myr M81 interaction event & significant fraction of clusters survive for >100 Myr.

M82-F: **WHT Echelle Spectra,** Stellar Velocity Dispersion **& Mass: A Doomed SSC?**

Smith & Gallagher 2001, MNRAS, 326, 1027



SSCs have the mass and size of globular clusters.

Star formation at the high density extreme of the interstellar gas cloud dissipation sequence.

Roles of initial conditions & environment in survival?

$M = 1.2 \times 10^{\quad} M_{\odot}$

To what degree
are SSCs normal extensions
of the star cluster
luminosity function
to higher masses versus
results of special
processes?

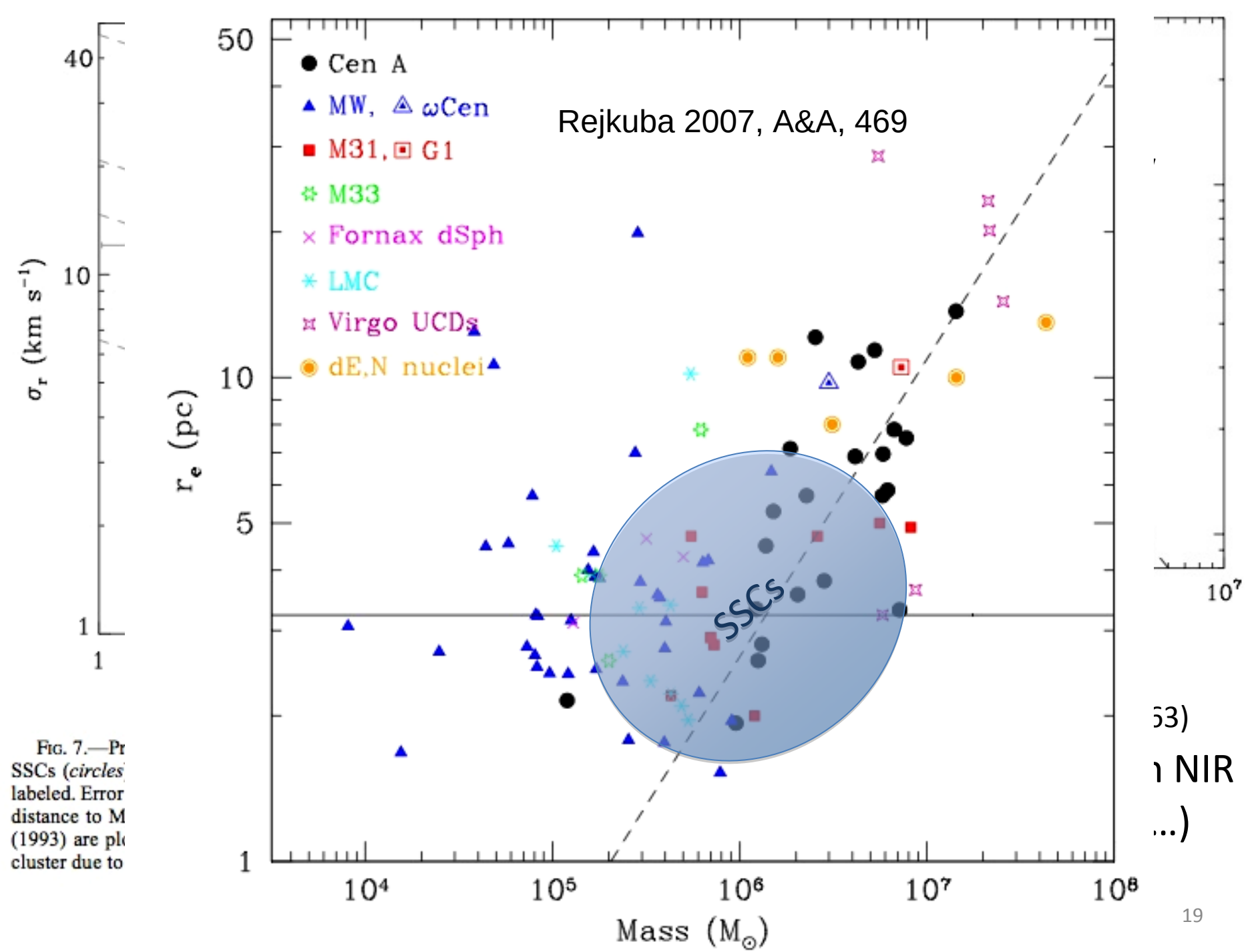


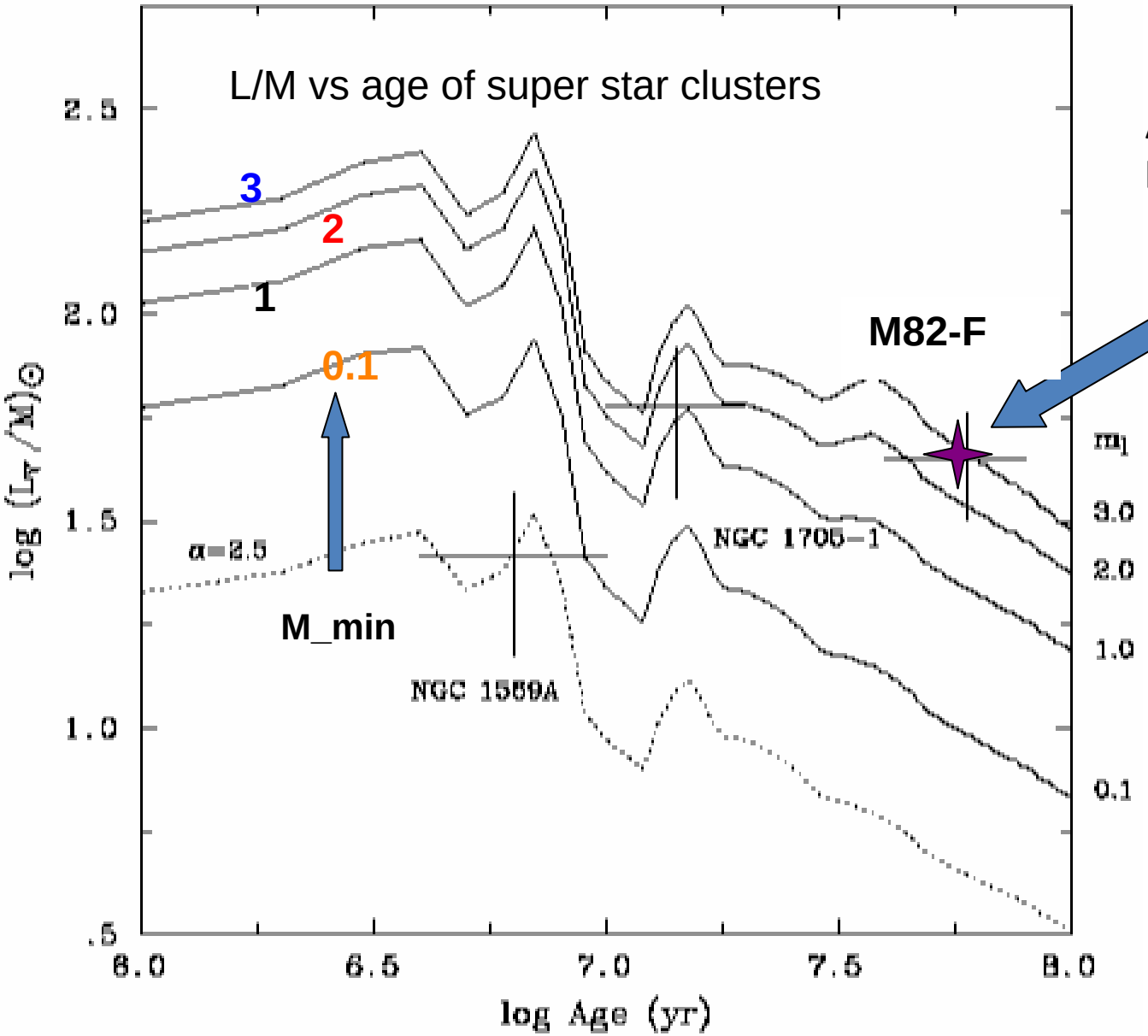
Fig. 7.—Pr
SSCs (*circles*
labeled. Error
distance to M
(1993) are pl
cluster due to

53)

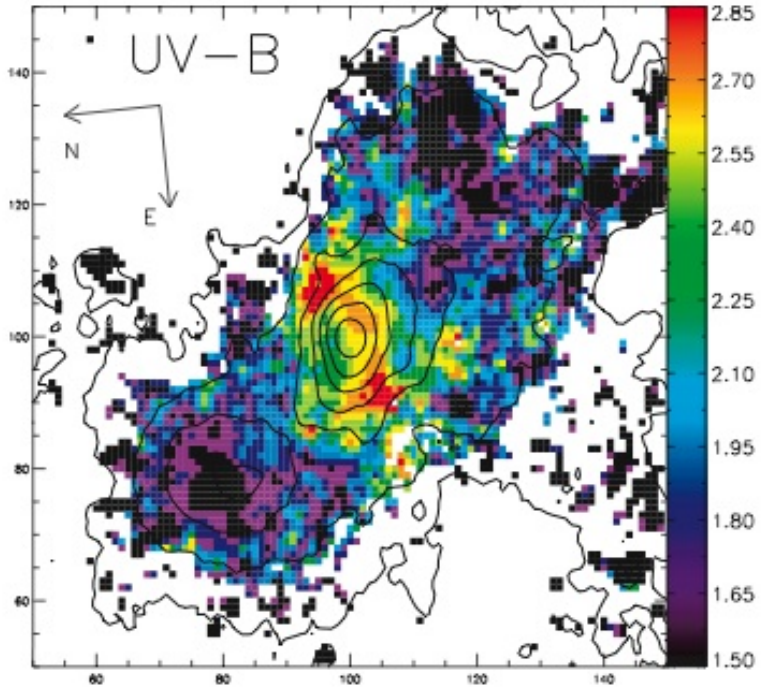
n NIR

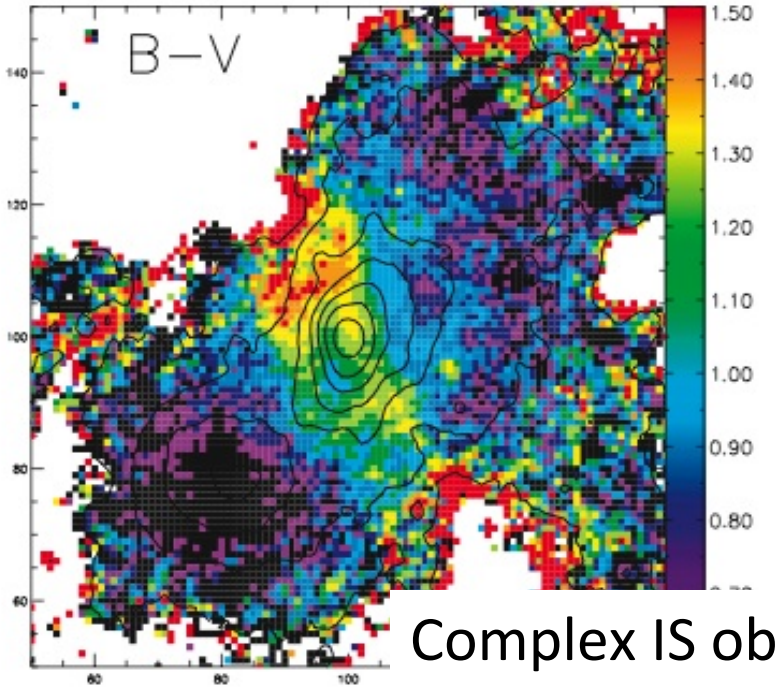
...)

Smith & Gallagher 2001, MNRAS, 326, 1027



Combination SSC Age + Mass → integrated stellar PDMF → IMF

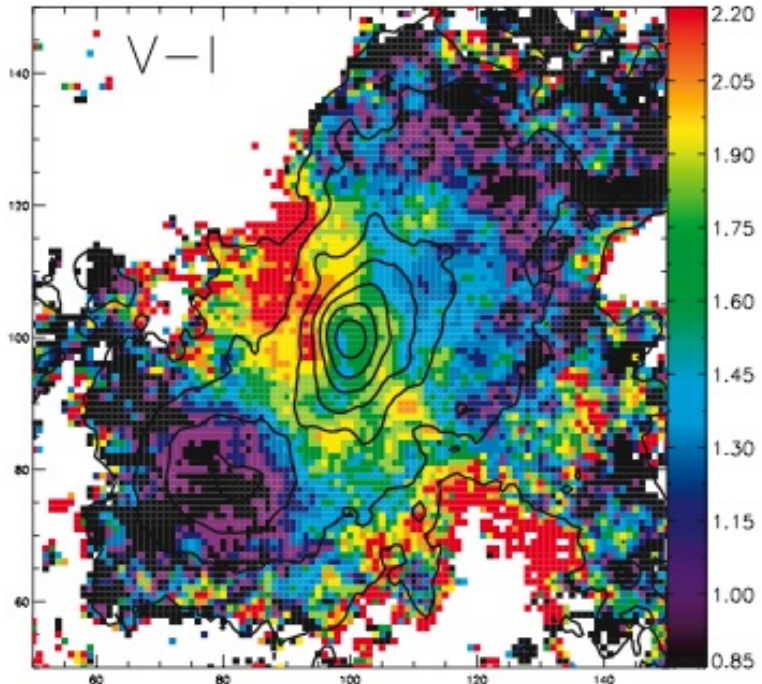


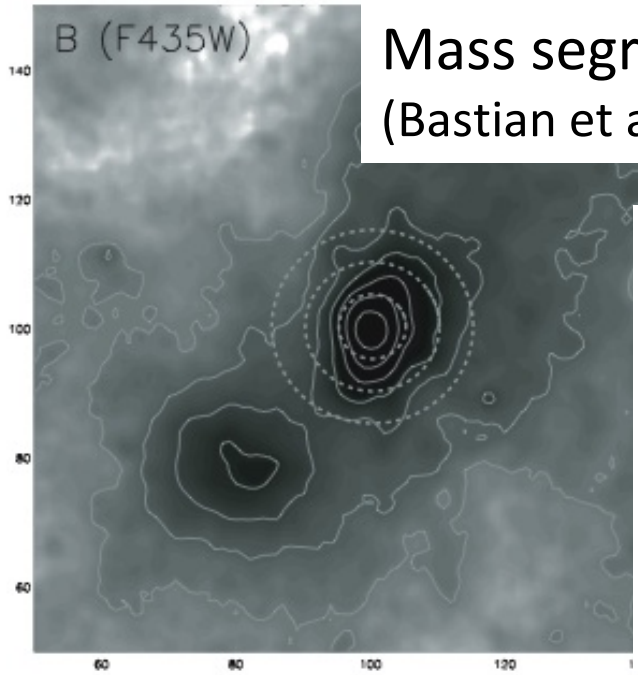


M82-F

HST-ACS

Trying to constrain source of PDMF issue.





Complex IS obscuration:
Affects brightness profiles
Mass segregation ????
(Bastian et al. 2007, MNRAS)

Internal AGB dust contamination?
Expected if AGB debris accumulates.
(Gallagher & Smith 2007, ASP Conf 378 Galaxies & AGB Stars)

When?

SSCs form when dense gas exists in massive concentrations

- High versus low pressure environments

Basic SSC Formation Requirements

$$n_{ISM} \cong 10^4 \left(\frac{M_{cl}}{10^5\, M_{\rm sun}}\right) \varepsilon_{SF}^{-1} \eta_{collapse}^{3}\, cm^{-3}$$

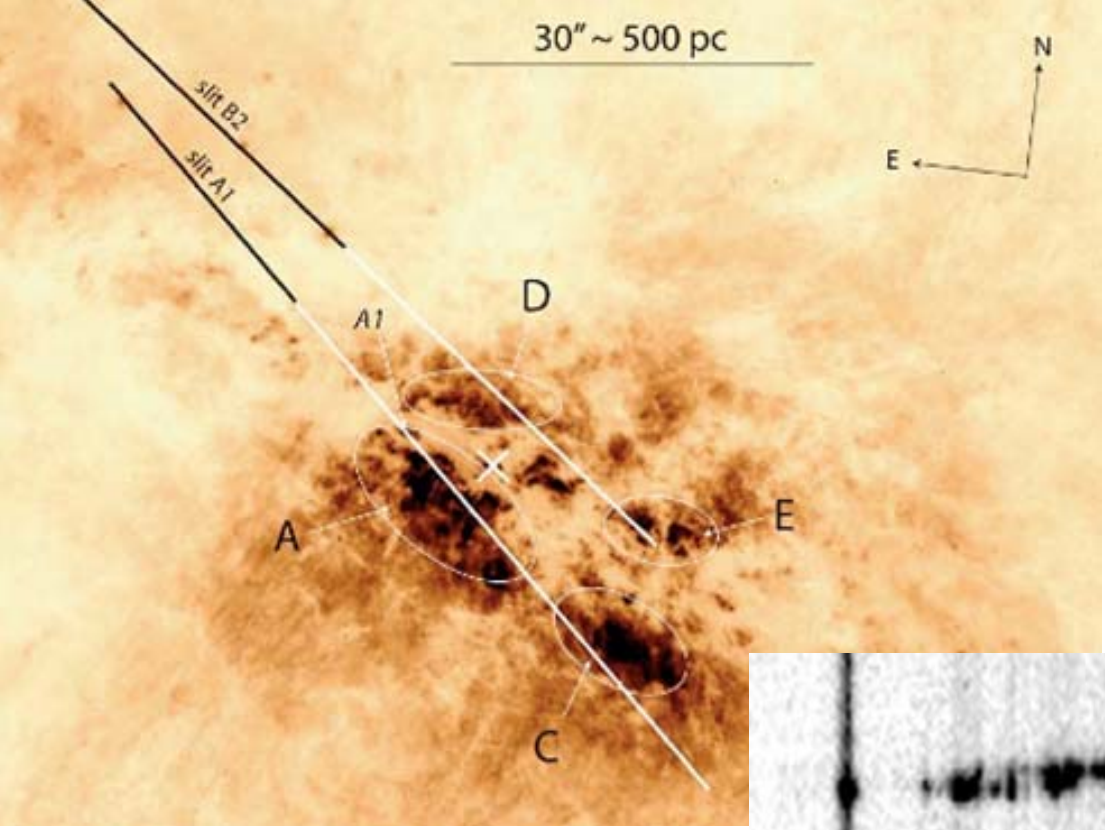
$$\varepsilon_{SF} \geq 0.3 \quad \text{(e.g. Parmentier \& Fritze 2009, ApJ)}$$

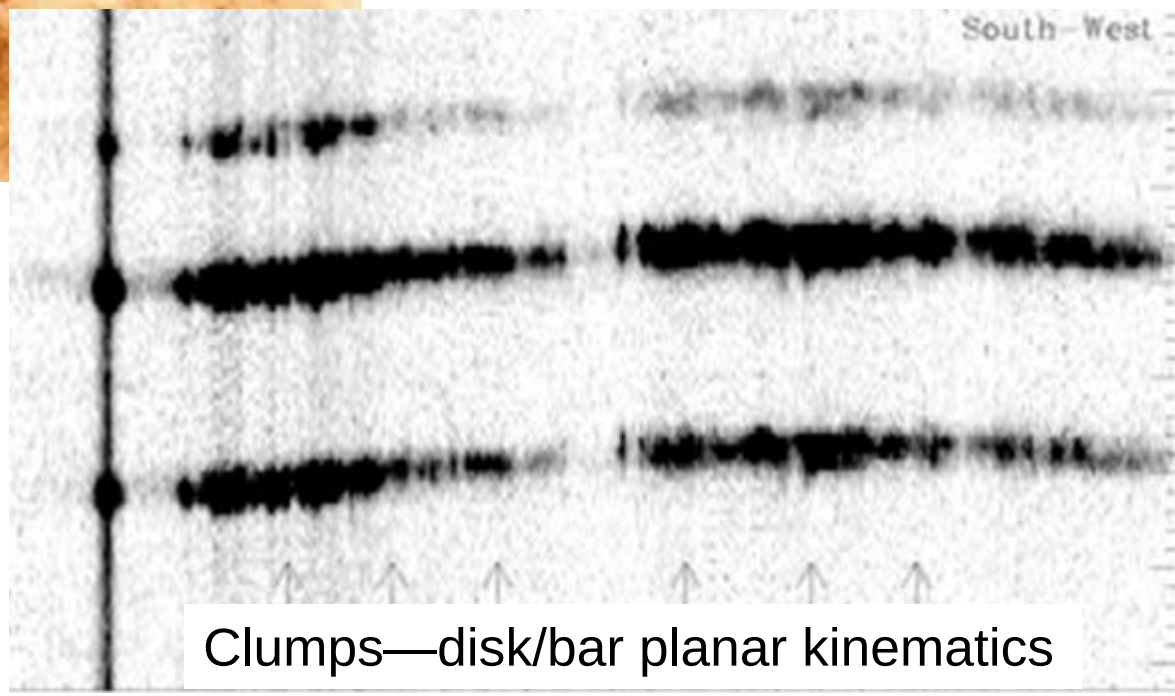
$$\eta_{collapse}(virial) \sim 8$$

SSCs require dense clouds for formation→
High mean ISM densities
or
large compression factors

M82 starburst clumps in detail with HST/STIS

(Westmoquette et al. 2007, ApJ, 671, 358)





Clumps—disk/bar planar kinematics

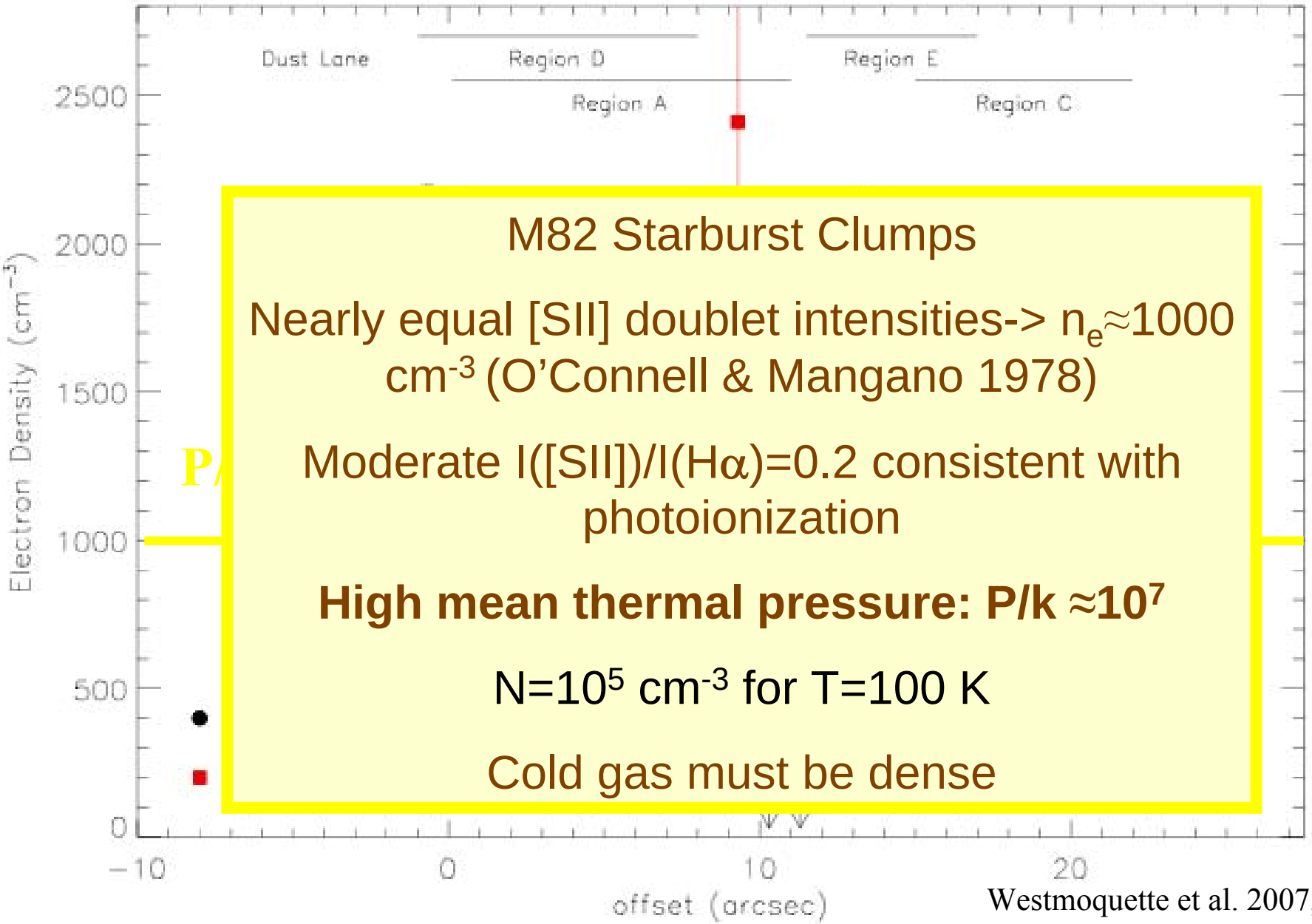
HST STIS Spectra

Emission line ratios, kinematics & profiles

High turbulent velocities

High n_e from [S II] line ratios.

High pressure ISM!



M82 Starburst Clumps

Nearly equal [SII] doublet intensities-> $n_e \approx 1000$ cm^{-3} (O'Connell & Mangano 1978)

Moderate I([SII])/I(Hα)=0.2 consistent with photoionization

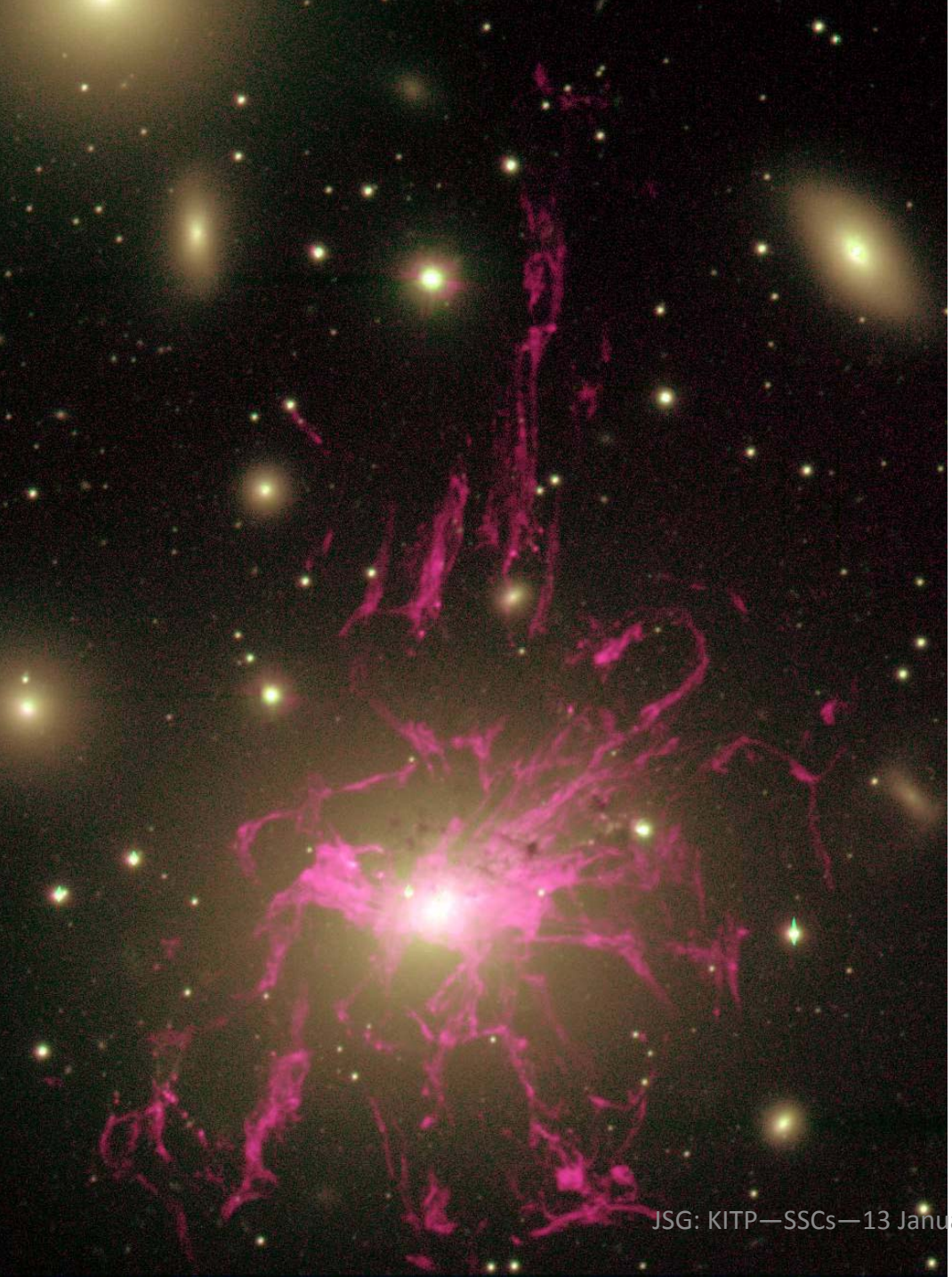
High mean thermal pressure: P/k ≈10^7

N=10^5 cm^{-3} for T=100 K

Cold gas must be dense

Westmoquette et al. 2007, MNRAS


M82 B REGION
COMPACT STAR CLUSTERS GALORE!
Disk spatial distribution & kinematics
BUT ALSO COMPACT DARK CLOUDS;
MOLECULAR DROPLET STARBURST
MODEL—CONNECTED TO M82 SSC
POPULATIONS?
M82-Hubble Heritage



SSCs Forming in Giant Spheroidal Distribution

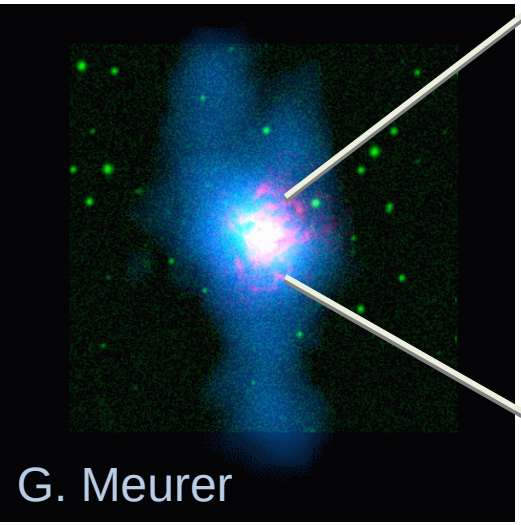
WIYN 3.5-m
NGC 1275
Hα+[NII] &
stellar continuum

Huge (10s kpc)
ionized filaments
with embedded SSCs

High pressure from
surrounding ICM

After Conselice et al. 2001, AJ, 122, 2281

***BUT* NGC1705: High pressure SSC in low pressure ISM**



Low mean ISM density SSC formation→ 2 modes?

HST

Concluding Thoughts

• SSCs structurally (size, σ_*, mass) resemble classical globular clusters.

• SSCs found in wide range of galaxy settings, most common in high SFR systems, most likely to have large mass clusters, most frequently rotating with disks/bars. Seen over range of Z reflecting host.

• SSCs themselves tend to cluster—interactions possible; probably overfill initial tidal radii. Isolation of most GCs compared to SSCs?

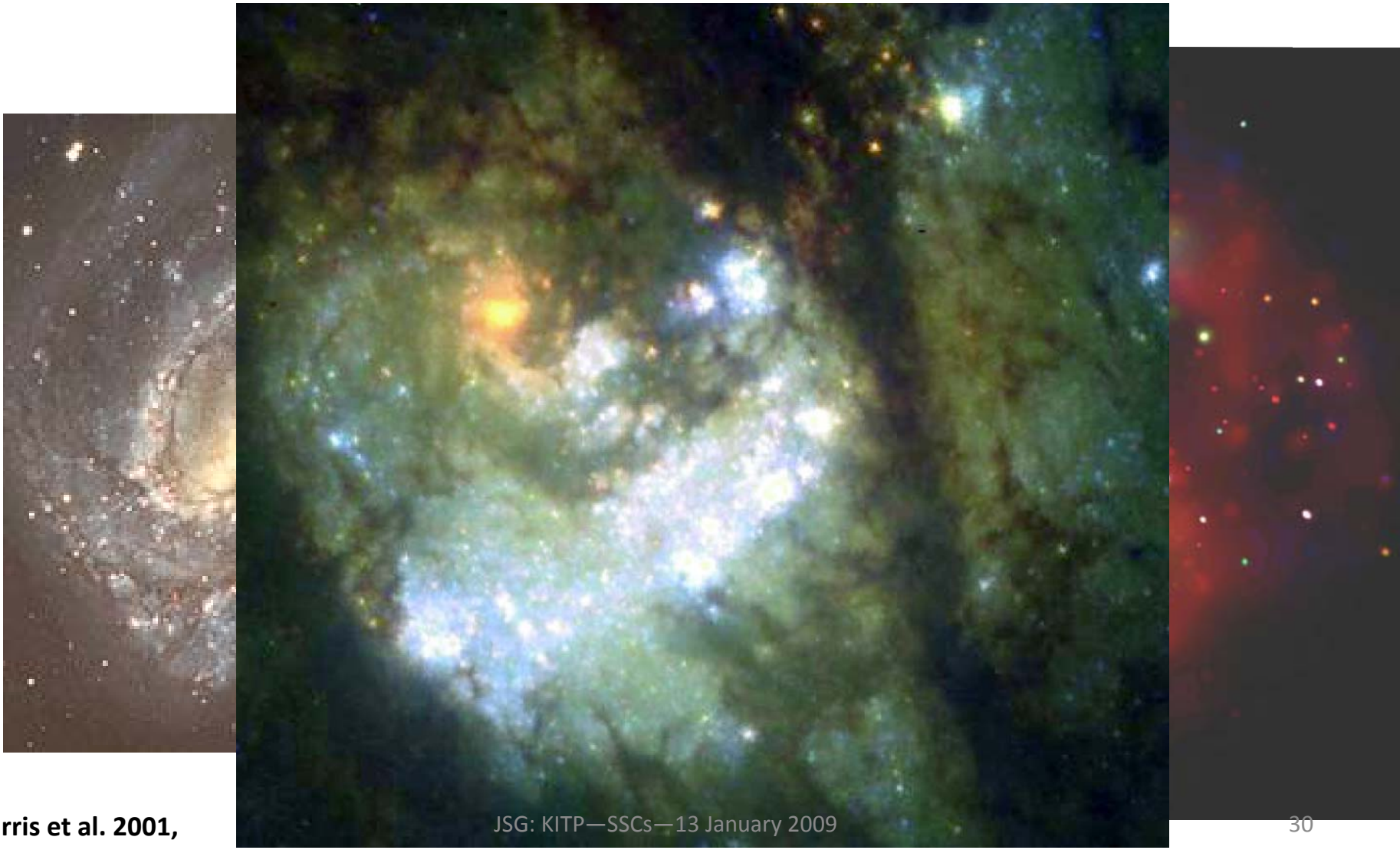
• Ages critical for physical interpretations; UV/optical data important.

• Most SSC PDMFs consistent with standard stellar IMF; M82-F??

• SSC formation implies high pressures—feedback in starbursts + ?

• SSCs mainly found in disks/inner galaxies; GCs widely distributed in radius—different formation paths, esp. for blue GCs? Interactions??

Nuclear disk starburst in M83



Harris et al. 2001, AJ

SBc Spiral NGC 2903 WFPC2: Nuclear Region Star Cluster Systems

D. Smith et al. 2004