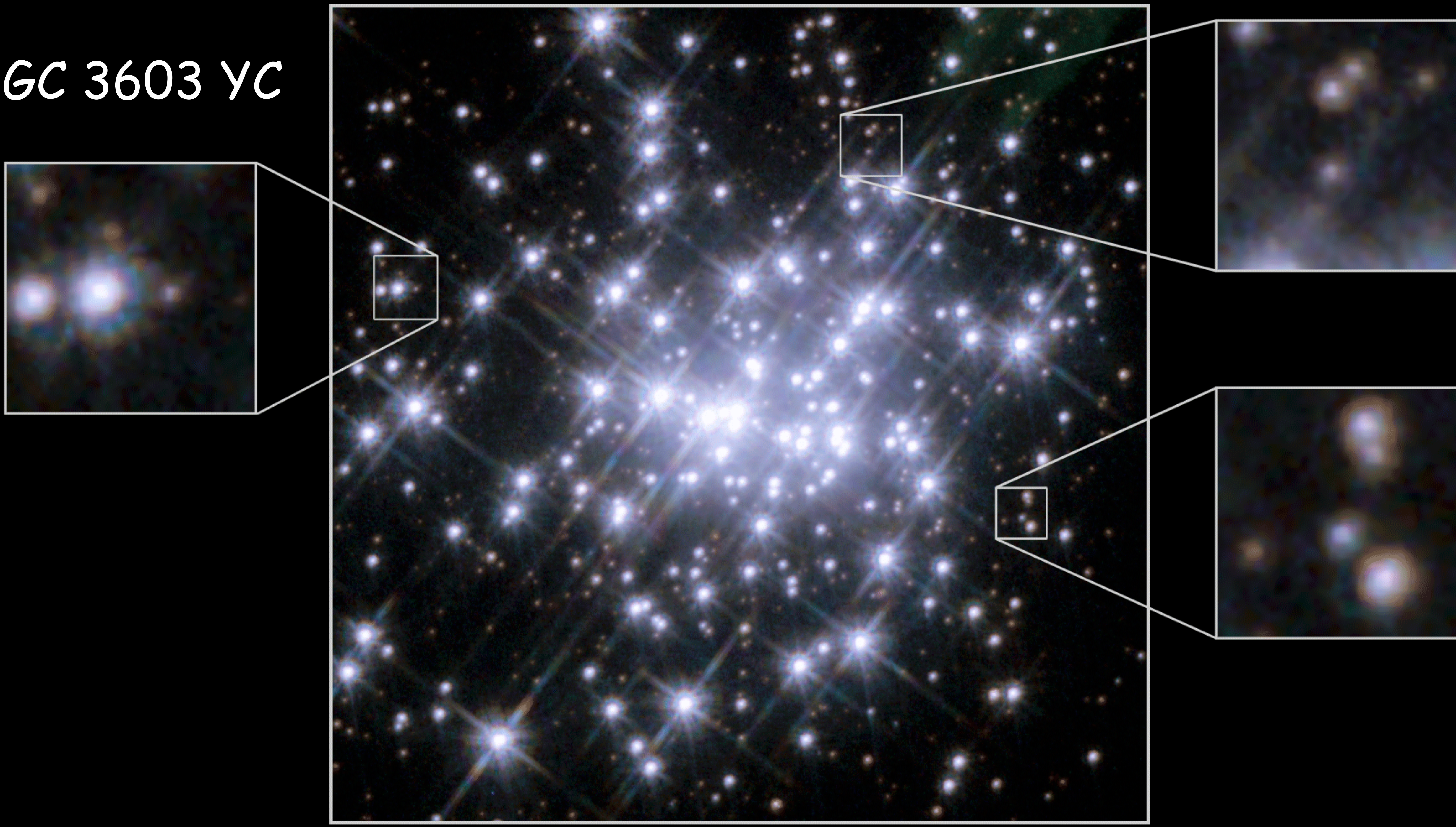
Dynamics of the Galactic starburst cluster in NGC 3603 from µas astromety with HST/WFPC2

NGC 3603 YC



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Scientific questions addressed by high-angular resolution & multi-epoch studies of starburst clusters:

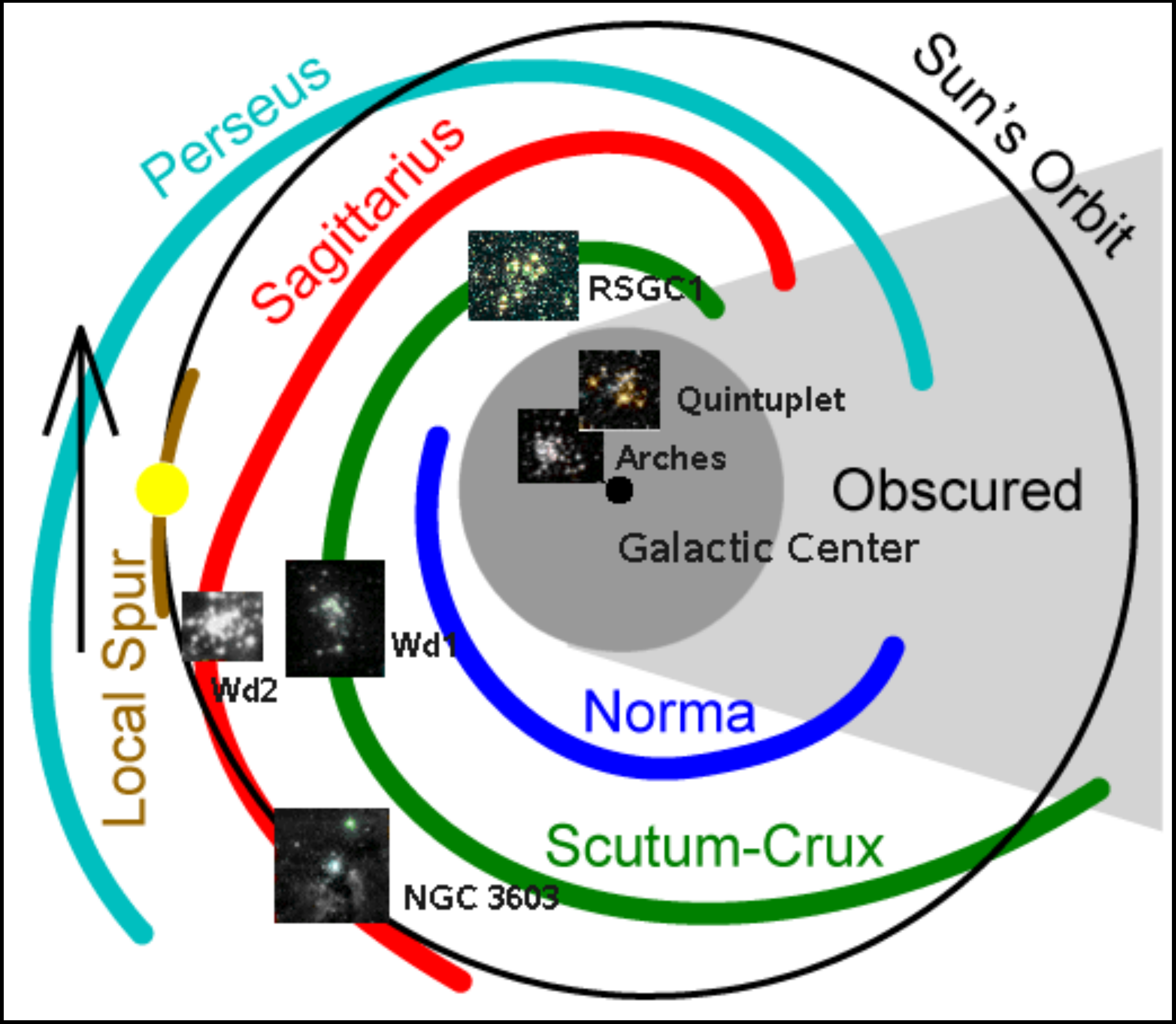
* Are starburst clusters proto-globular (“bound”) clusters?
* How do starburst clusters form and (dynamically) evolve?
* Do low-mass stars (and brown dwarfs) form in starburst environments (presence of a mass function cut-off?)
* Testing and calibrating stellar evolutionary models
* Masses of the most massive stars
* ...

HST vs. ground-based adaptive optics

- measurement accuracy is crowding limited => high angular resolution required
- single-guide star and LGS AO can provide ~65mas to 80 mas resolution within the isoplanatic patch (~10”) in K-band, but is limited by spatially & temporal varying PSF (MCAO angular resolution is in general inferior)
- <u>optical</u> HST observation provide similar resolution over a <u>large field of view</u> with well determined PSF

HST for wide-field studies of clusters accessible in the optical <=>
AO for “pencil beam” studies of embedded clusters and for probing very low masses

Galactic zoo of starburst clusters



A dynamical evolutionary sequence?

Starburst clusters plotted to the same physical scale

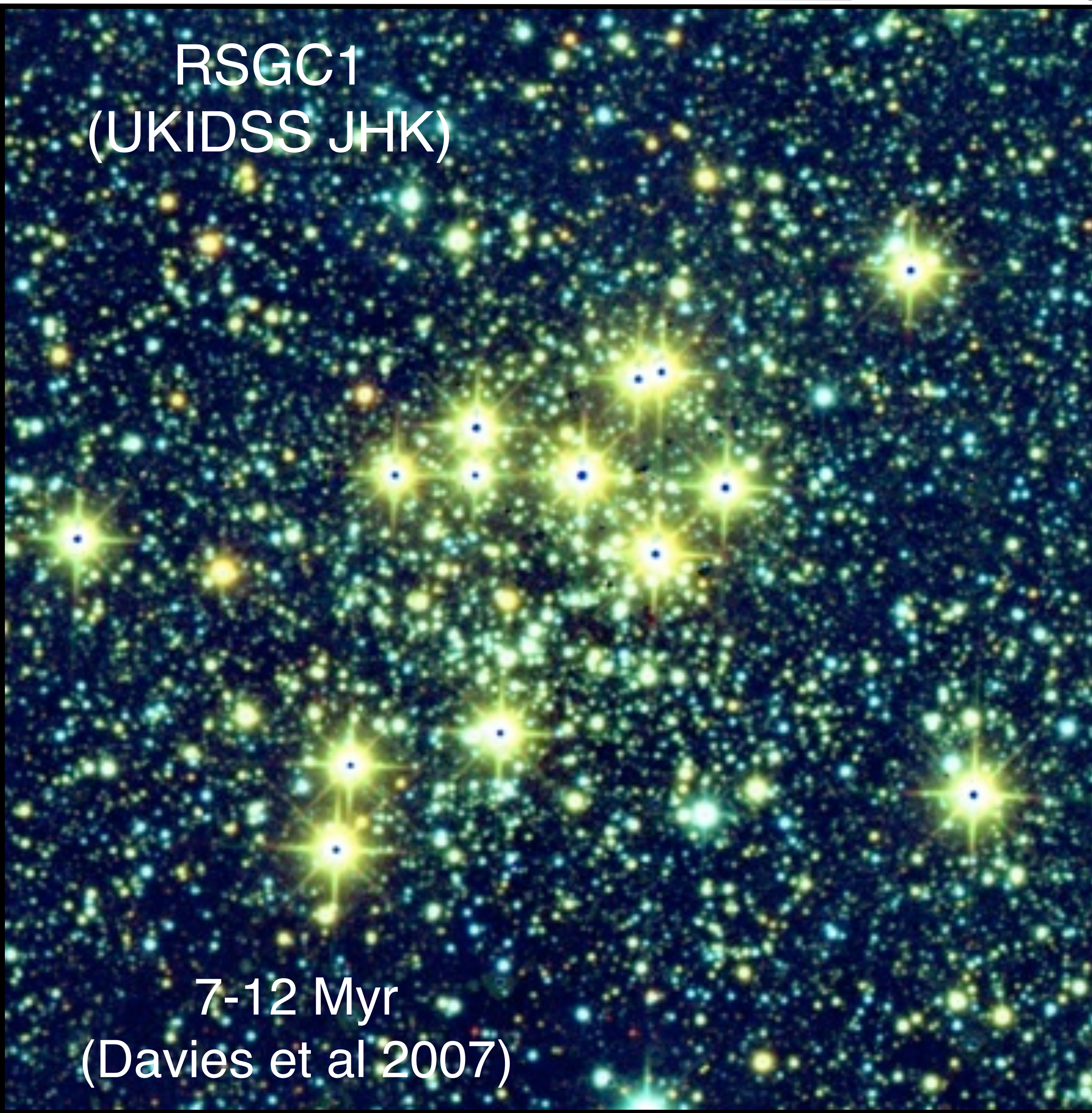
1 pc

Arches

2 Myr
(Stolte et al. 2005)

Quintuplet

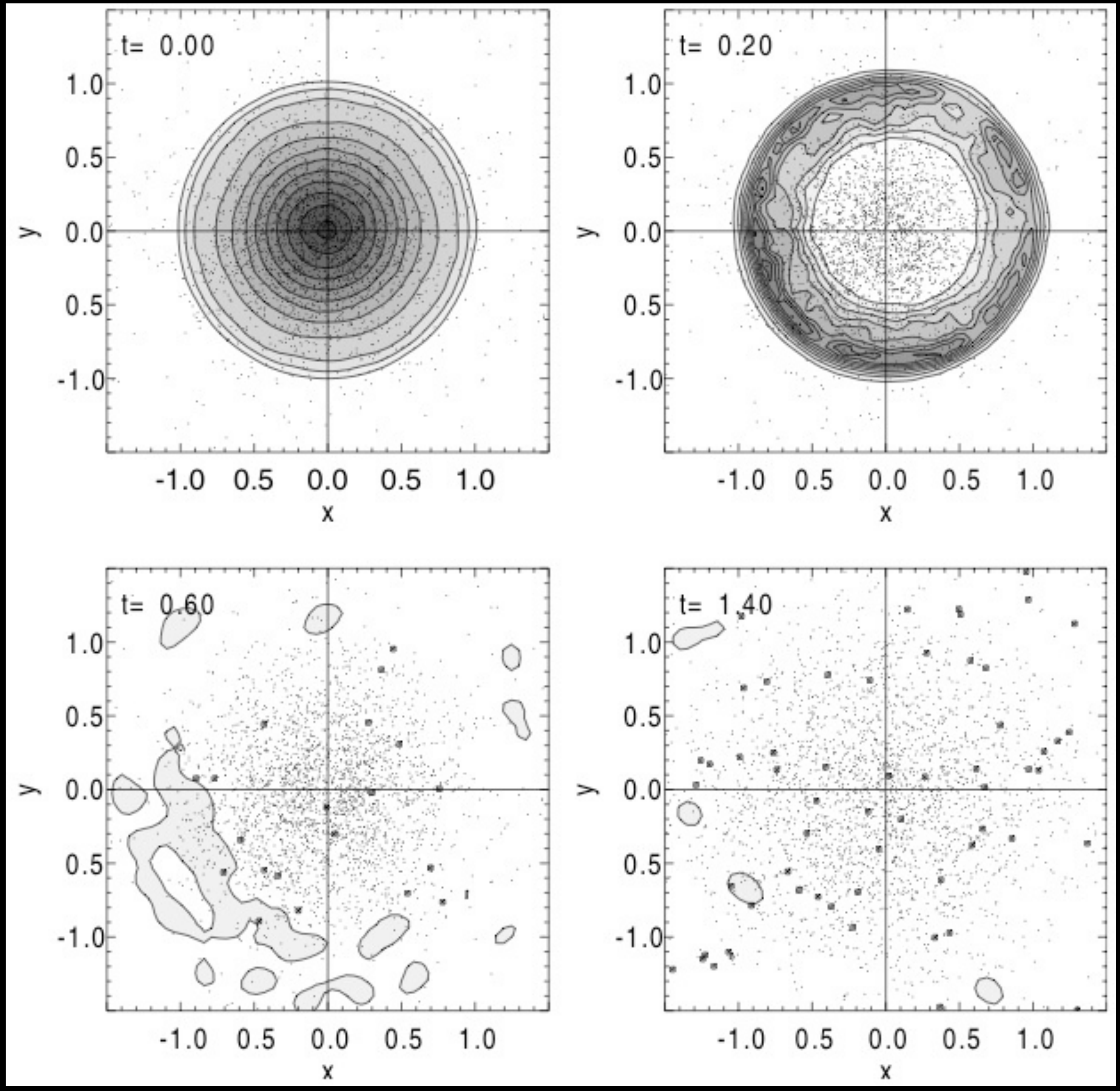
3-6 Myr
(Figer et al. 1999)



Compact cores (r_c = 0.2pc) are only observed in the two youngest clusters
<=> evidence for dynamical evolution accelerated by gas expulsion?

How does gas expulsion work?

- star cluster formation out of giant molecular cloud
- once the most massive stars form, their <u>ionizing radiation</u> and <u>fast stellar winds</u> rapidly disperse the remaining gas
- Star Formation Efficiencies >33% required for the stellar cluster to remain bound



Geyer & Burkert (2001)

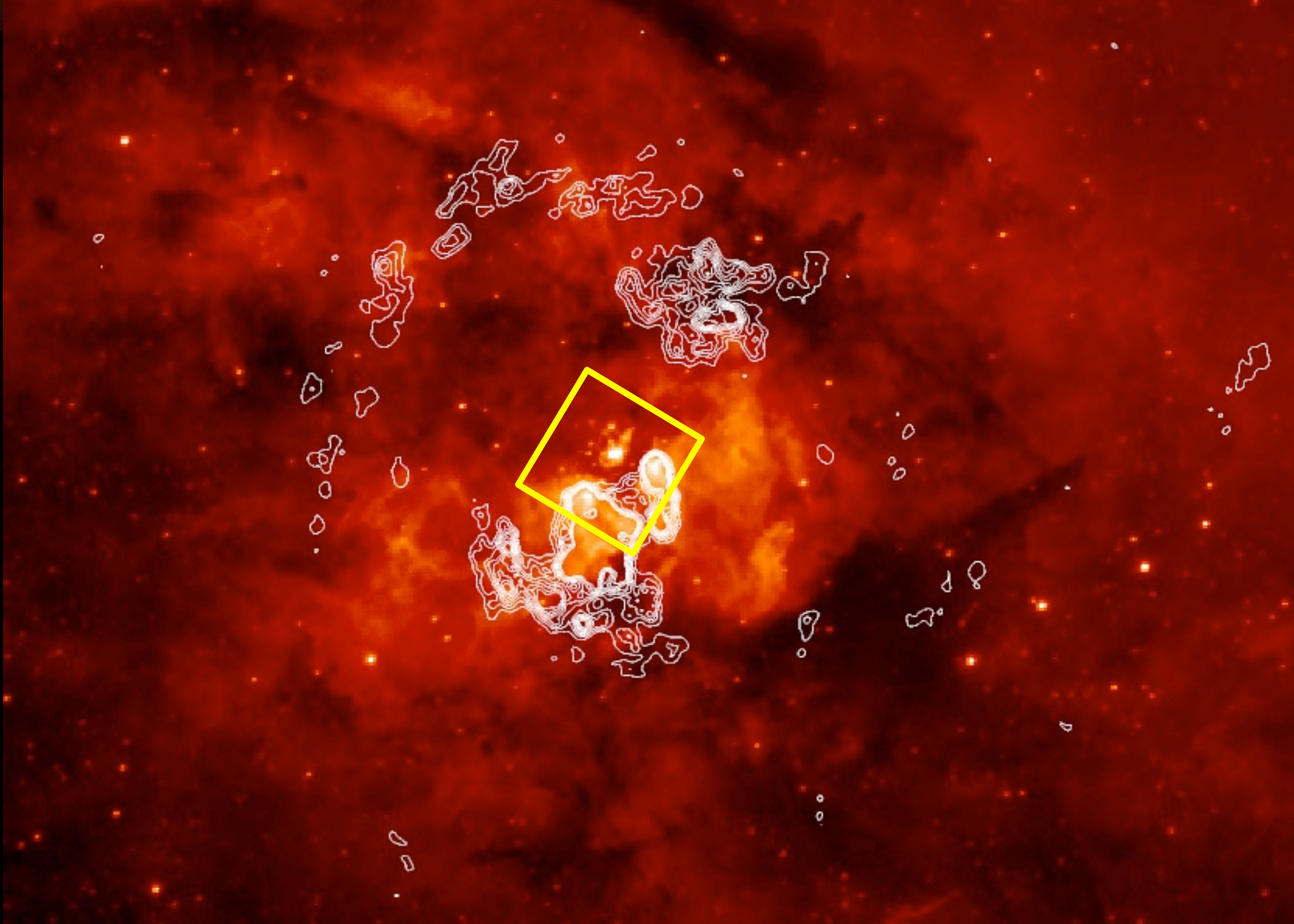
Simulations: rapid gas expulsion strongly affects dynamical evolution of cluster

HST observations of NGC 3603

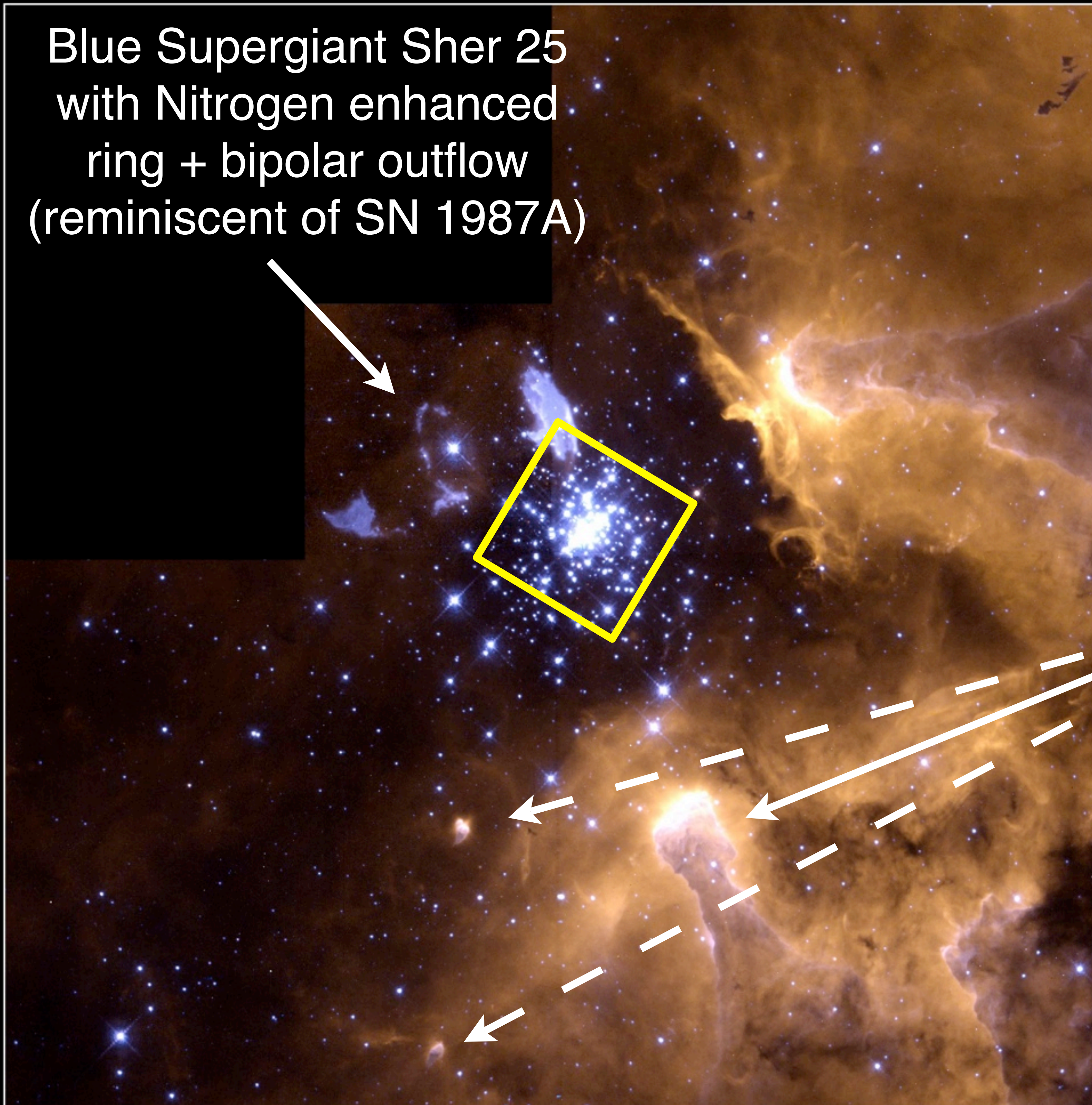
- since 1991 NGC 3603 has had numerous HST visits
- currently ~3900 data sets on NGC 3603 in the HST archive: FOC, FOS, FGS, WF/PC, WFPC2, STIS, ACS, WFC3 (incl. ~3000 technical data sets from the NICMOS focus monitoring campaigns)
- Results reported in papers by Moffat et al. (1994), Drissen et al. (1995), Brandner et al. (1997), Crowther & Dessart (1998), Brandner et al. (2000), Sung & Bessel (2004), Stolte et al. (2004), Moffat et al. (2004), Melena et al. (2008), Rochau et al. (2010), Beccari et al. (2010), ... =>see also poster by Beccari et al. on WFC3 obs.
- WFPC2 broad-band imaging data span epoch difference of 10 yr (1997 to 2007)

=> Focus our analysis on PC2 frames (PSF sampling!)

NGC 3603 is among the most luminous HII regions in the Milky Way
(N_c ~10^{51} s^{-1}, Kennicutt 1984)



Ha/Curtis Schmidt 30′ x 30′ (50 pc x 50 pc) view of NGC 3603
+ ATCA 3.4cm H contours (de Pree et al. 1999)



NGC 3603
Hubble Space Telescope • WFPC2

PRC99-20 • STScI OPO
Wolfgang Brandner (JPL/IPAC), Eva K. Grebel (University of Washington), You-Hua Chu (University of Illinois, Urbana-Champaign) and NASA

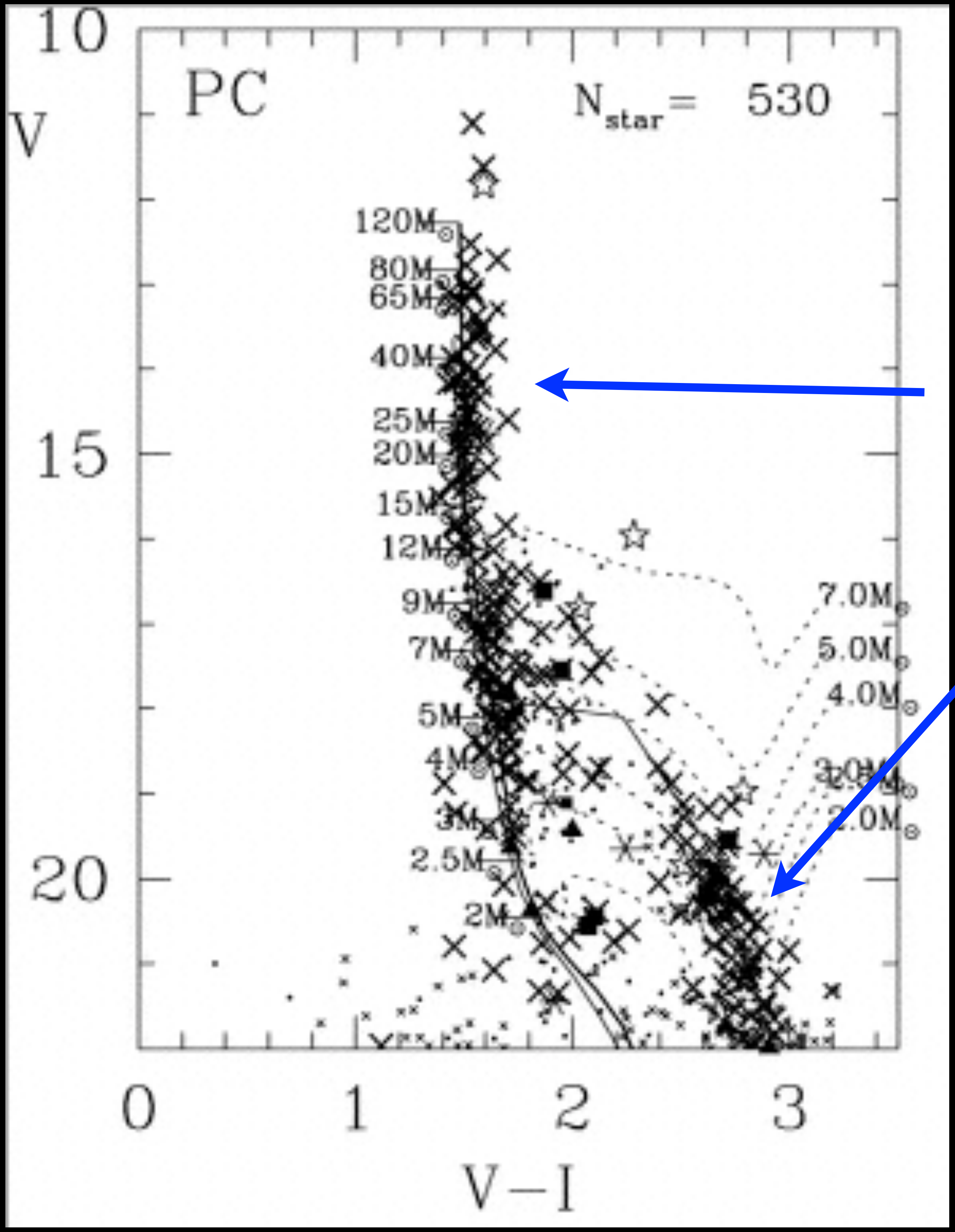
The HII region is powered by a young cluster of massive, hot stars

Pillars & ionized "blobs" (Proplyds?)

Ha+[NII] colour composite

(Brandner et al. 1997, 2000)

Colour-magnitude diagram of the cluster



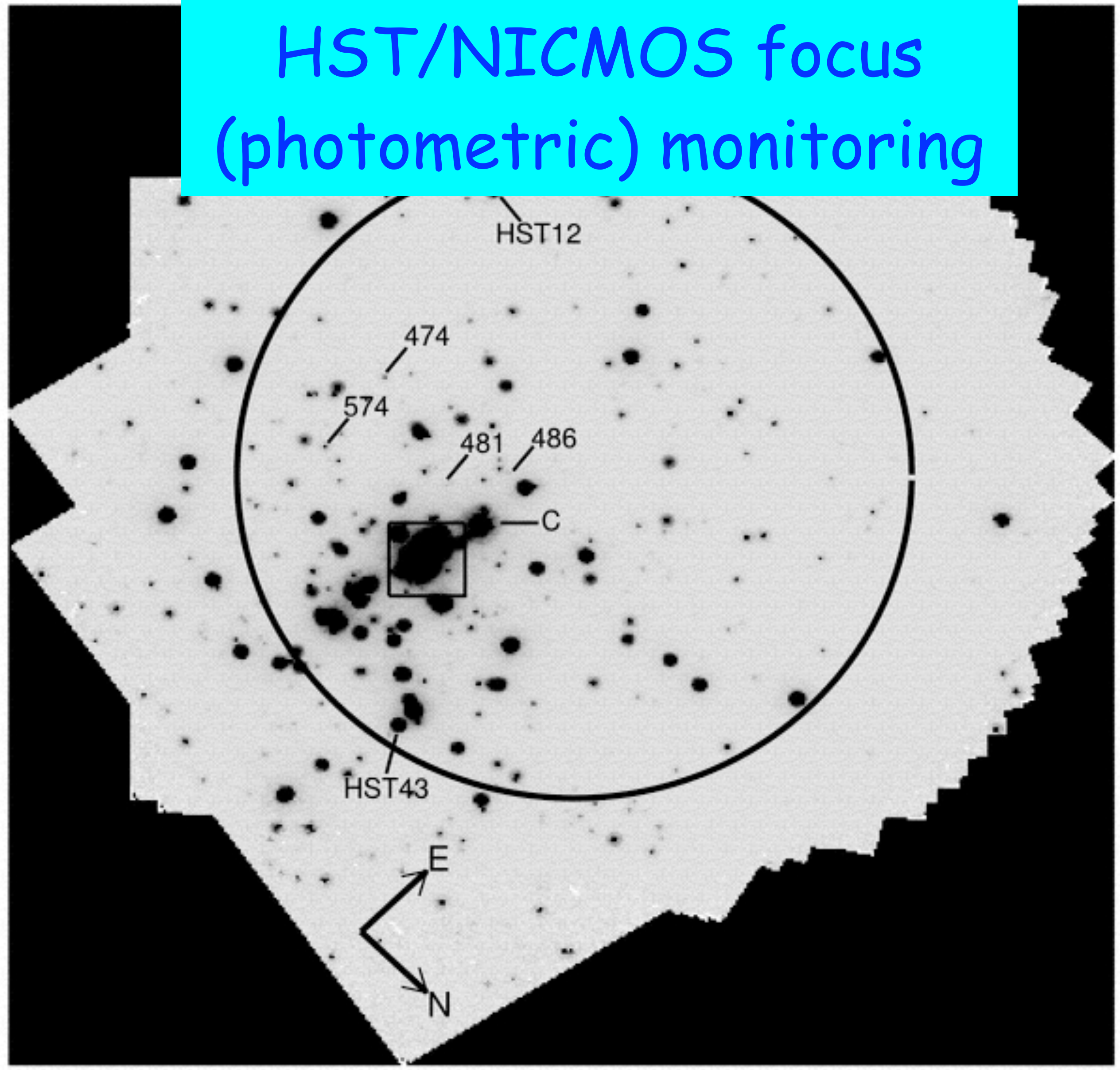
WFPC2 observations

main sequence
(~3.5Mo to 120 Mo!)

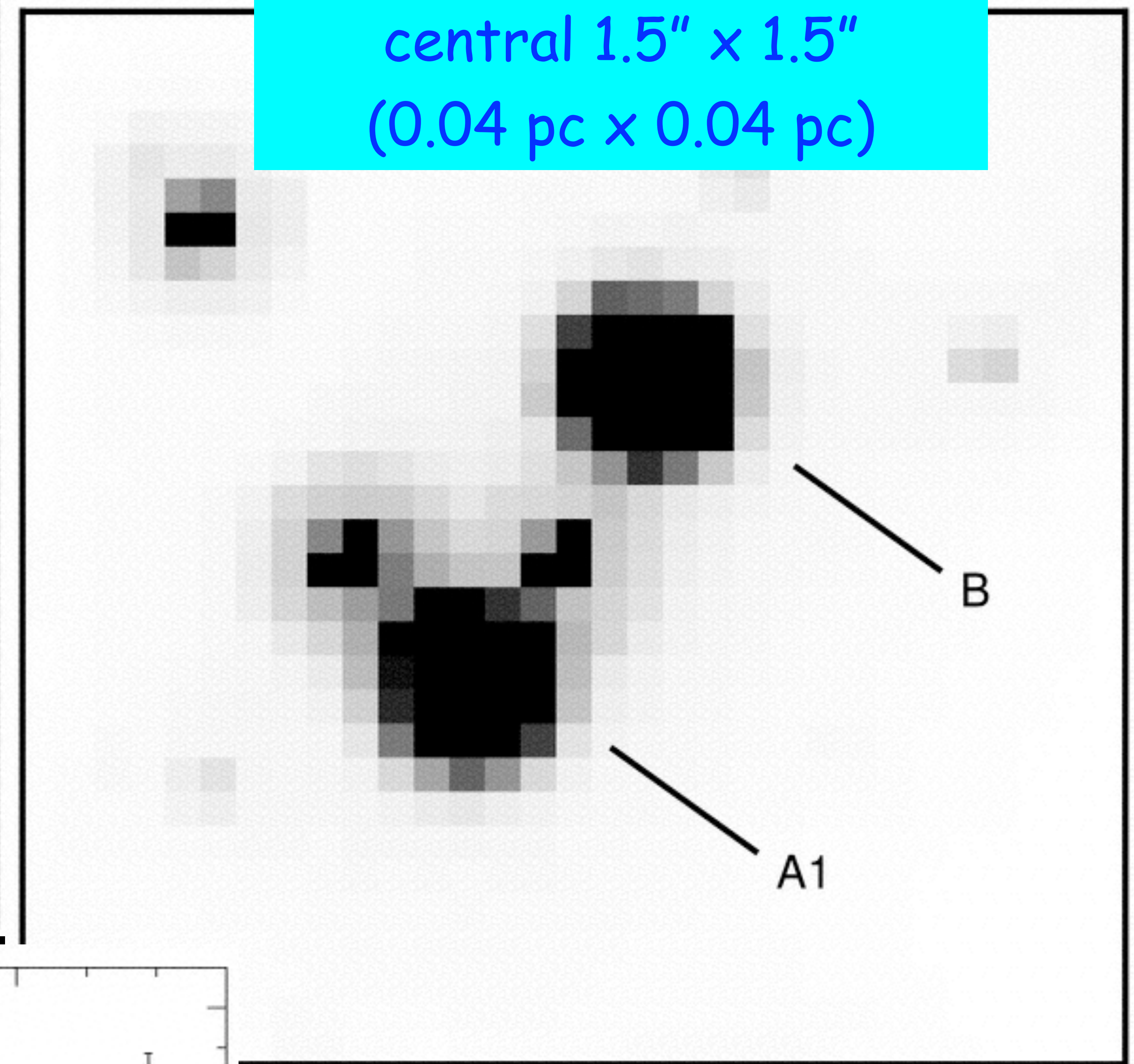
pre-main
sequence

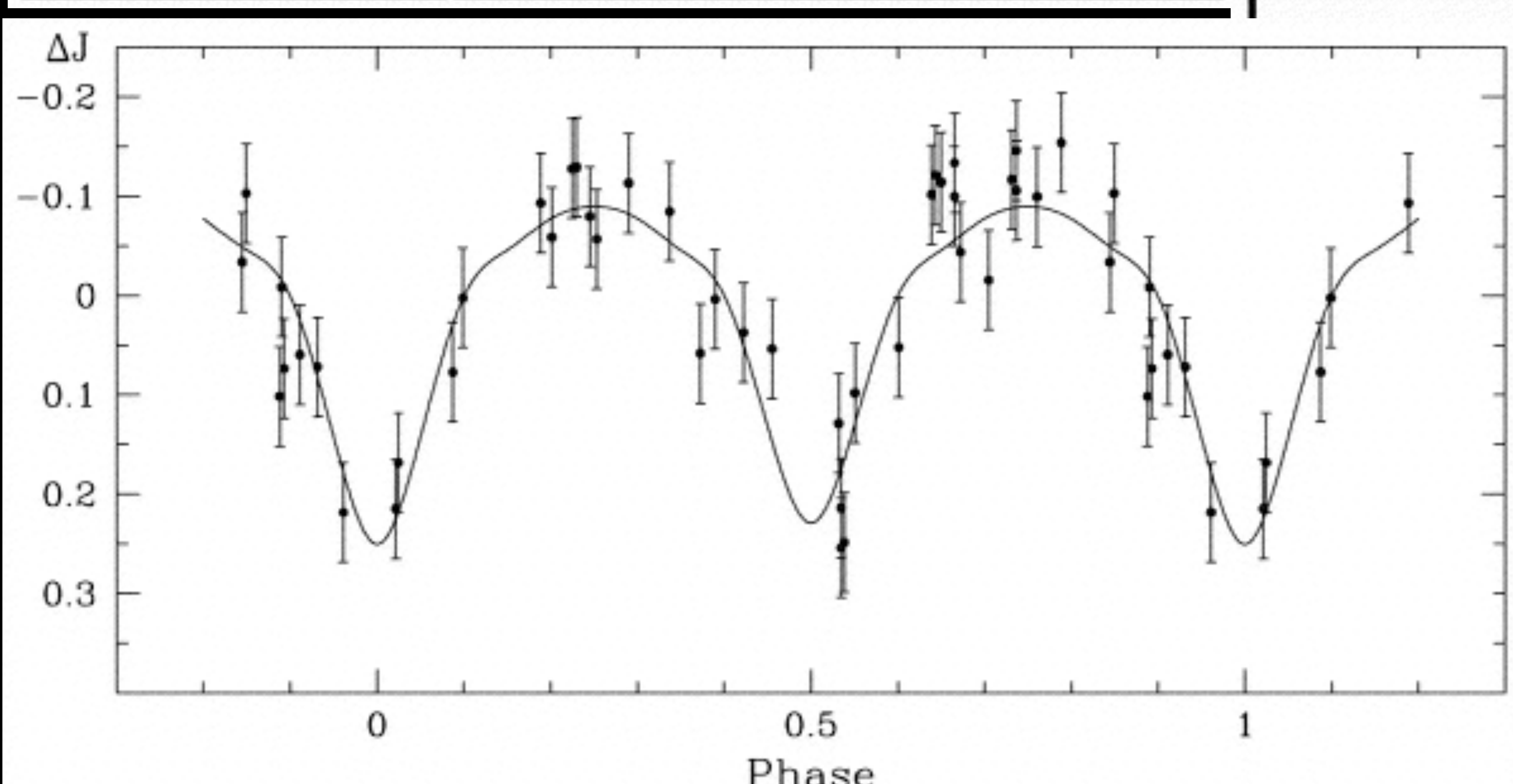
distance ~6 to 7 kpc
age ~ 1 Myr
(Sung & Bessel 2004)

HST/NICMOS focus (photometric) monitoring



central 1.5″ x 1.5″ (0.04 pc x 0.04 pc)





NGC 3603 A1 (O2V) is an eclipsing binary with component masses of 120 Mo and 80 Mo (Moffat et al. 2004)

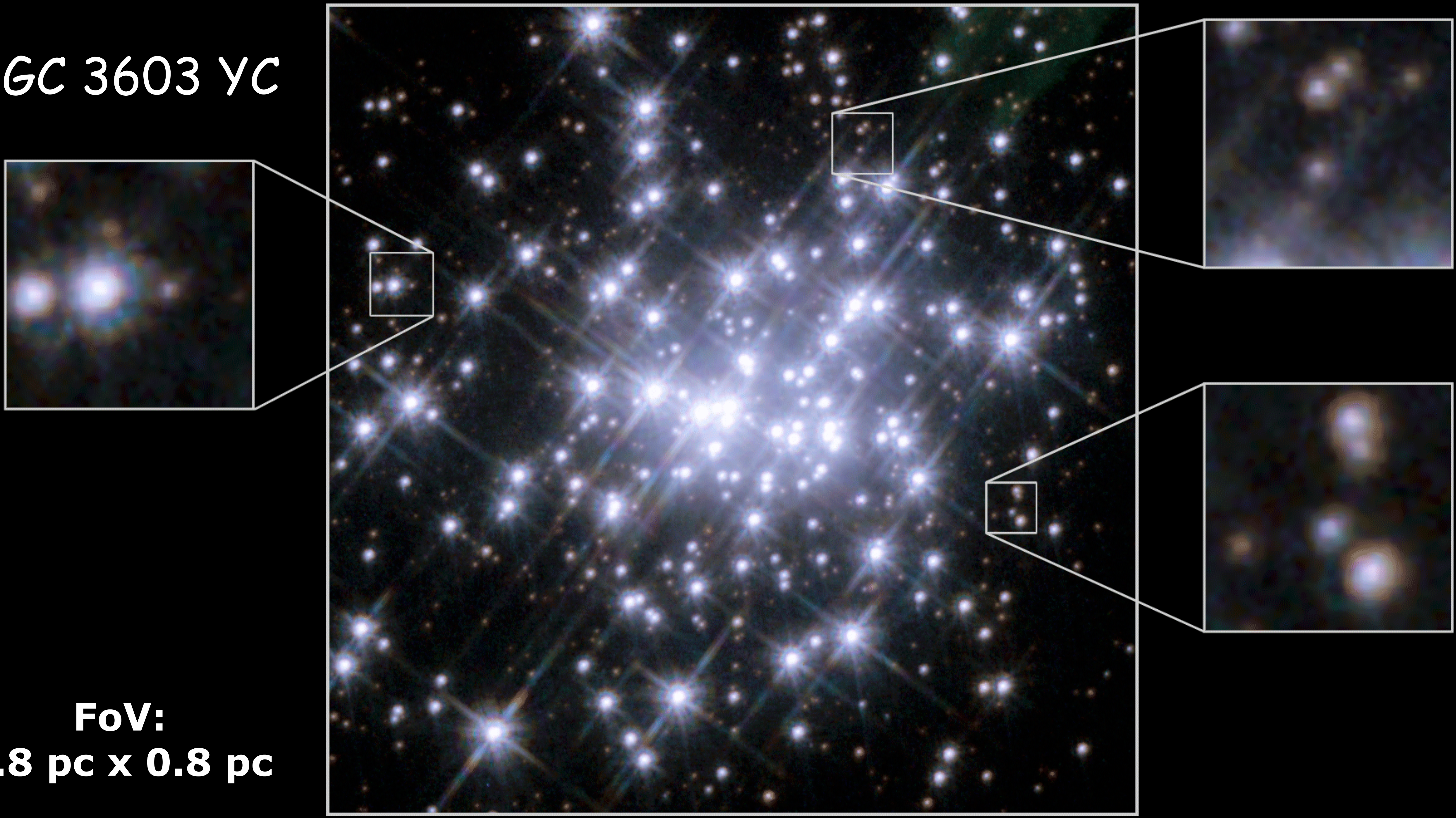
Astrometric analysis of NGC 3603 data

- based on pioneering work by J. Anderson & I. King (47 Tuc, Omega Cen, ...)
- individual stellar centroids can be determined and matched across epochs to better than 1/20 of a PC2 pixel (~ 2 mas)
- WFPC2 broad-band imaging data span epoch difference of 10 yr (1997 to 2007)

=> Focus our analysis on PC2 frames (PSF sampling!)

Astrometric analysis of NGC 3603 data

NGC 3603 YC

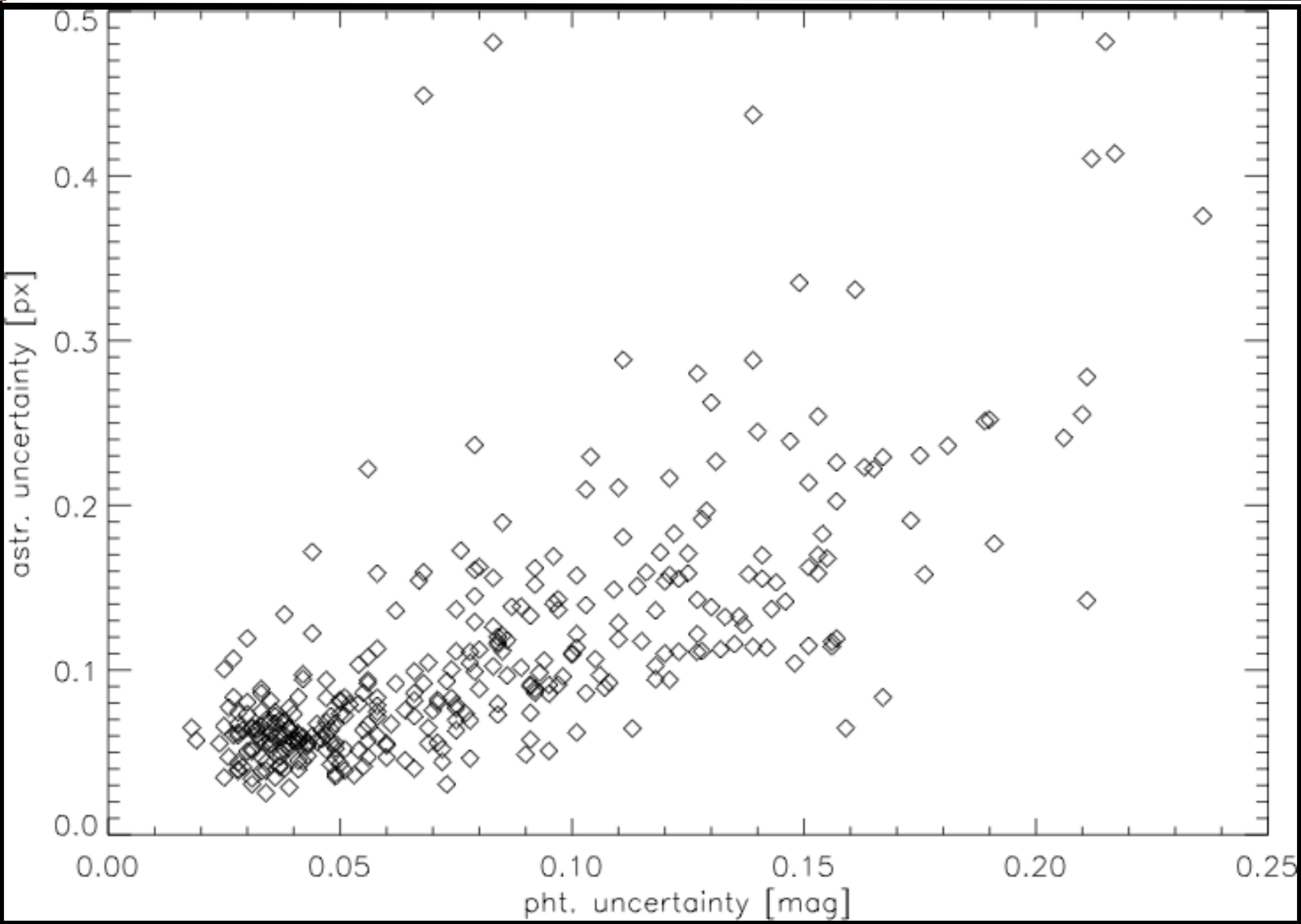


FoV:
0.8 pc x 0.8 pc

Hubble catches stars on the move (June 2010)

(thanks to ST-ECF for help with the ESA PR!)

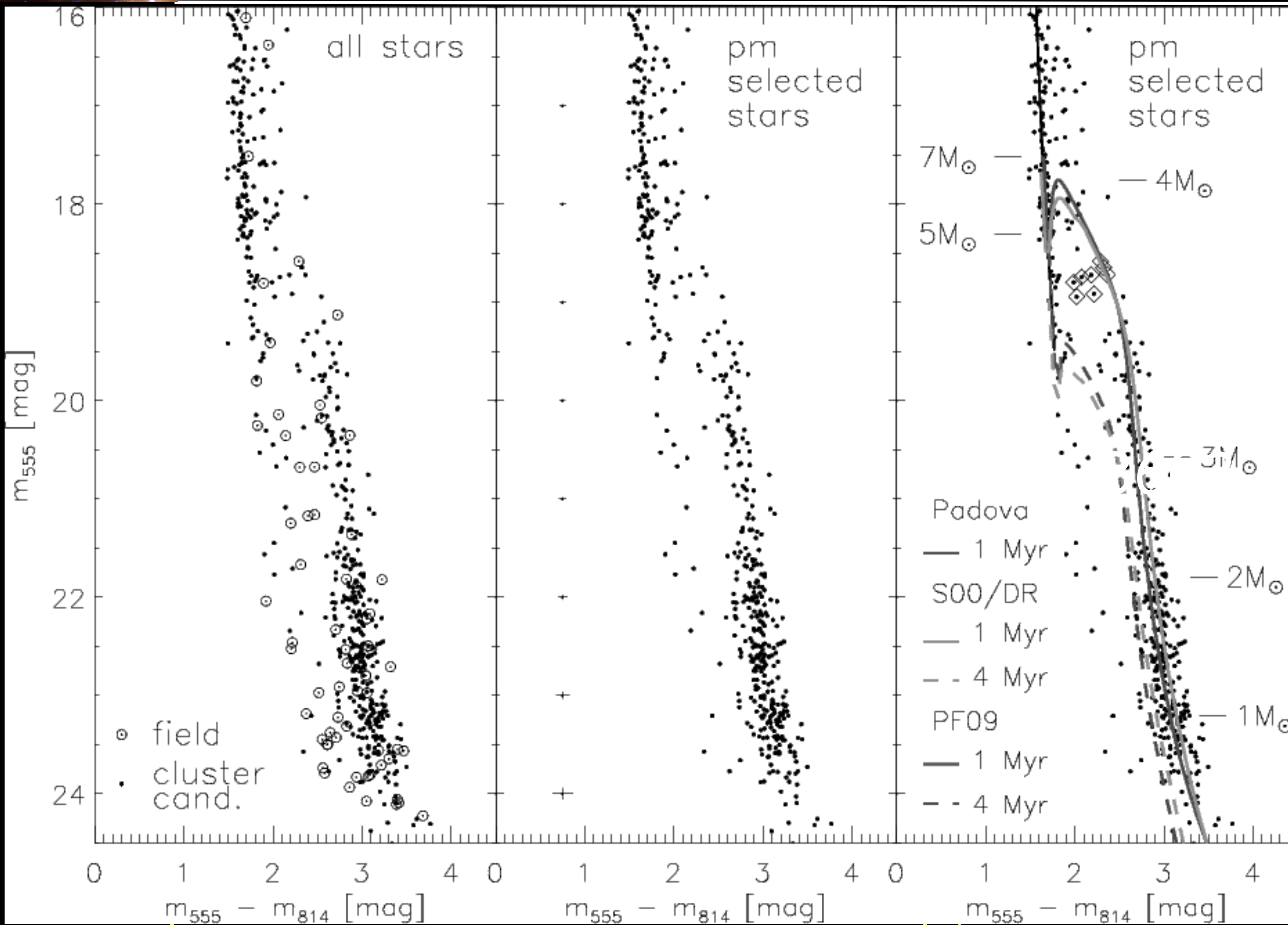
Crowding errors in NGC 3603



Astrometric and photometric errors are correlated

=> astrometric errors enable us to clean-up CMD

CMD of NGC 3603 young cluster



Isochrones:

- Palla & Stahler 1999
- Siess/Da Rio 2010
- Degl'Innocenti et al. 2008

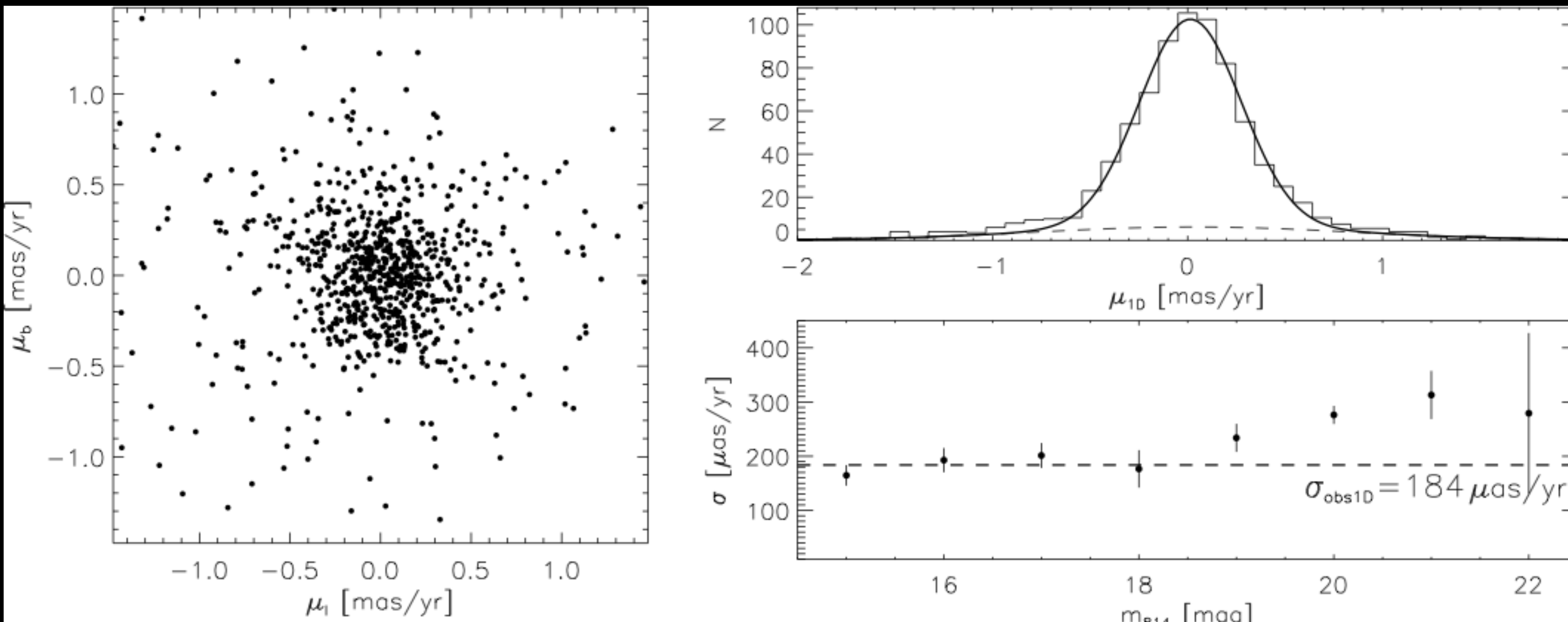
=> cluster members are ~1 Myr old

(Rochau et al. 2010)

plus additional underlying ~ 4 Myr old population of HII region

Astrometric results

Astrometry yields “true” 2D velocity dispersion (Rochau et al. 2010)



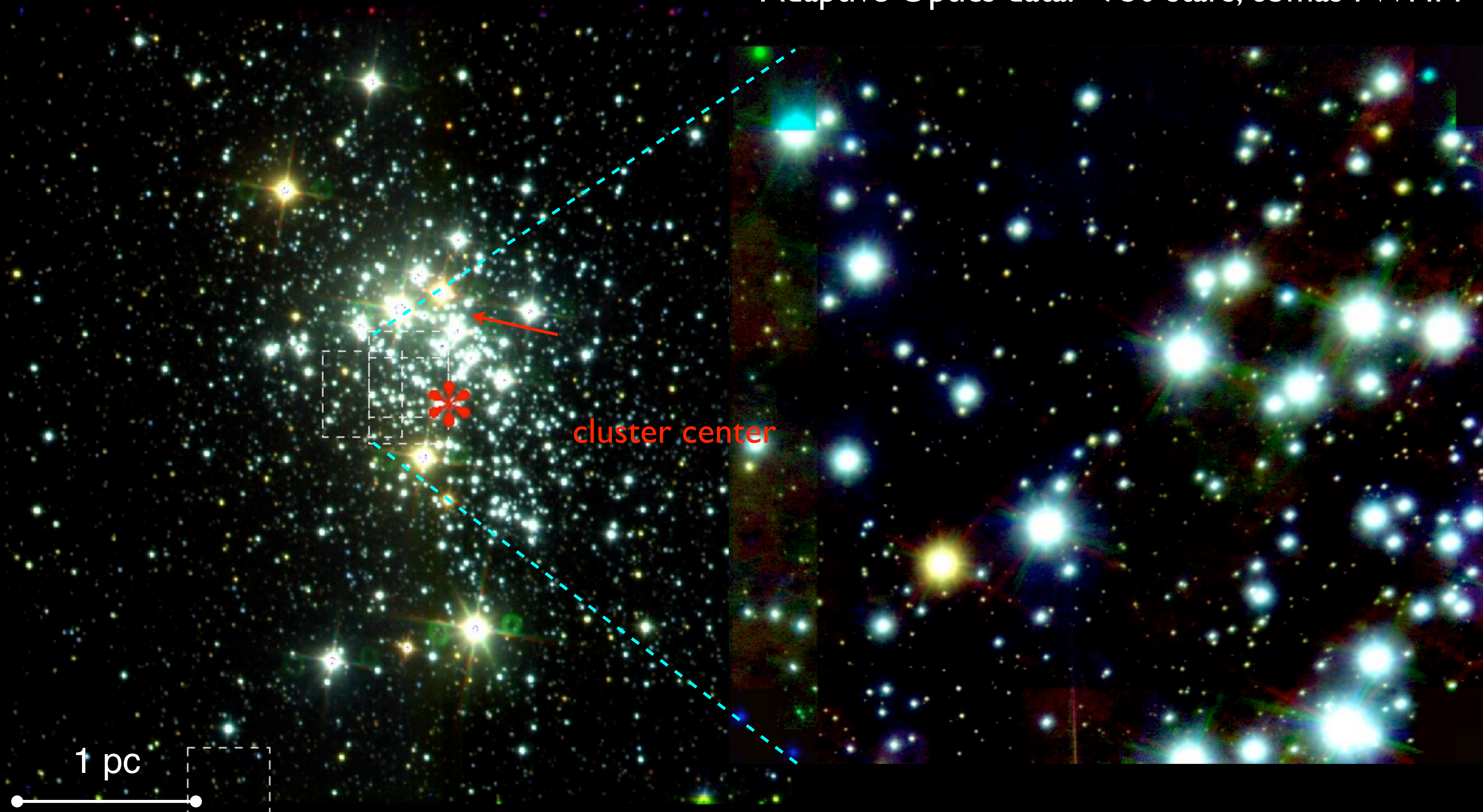
proper motions yield an internal 1D velocity dispersion of 4.5 km/s
=> virial mass of 18000 M_{Sun} agrees well with total stellar mass (10000 to 16000 M_{Sun}, Stolte et al. 2006, Harayama et al. 2008)

Internal velocity dispersion indicates that NGC 3603 YC is close to virial equilibrium
=> cluster should remain compact & bound for an extended period of time

Outlook: studies of other Galactic starburst clusters

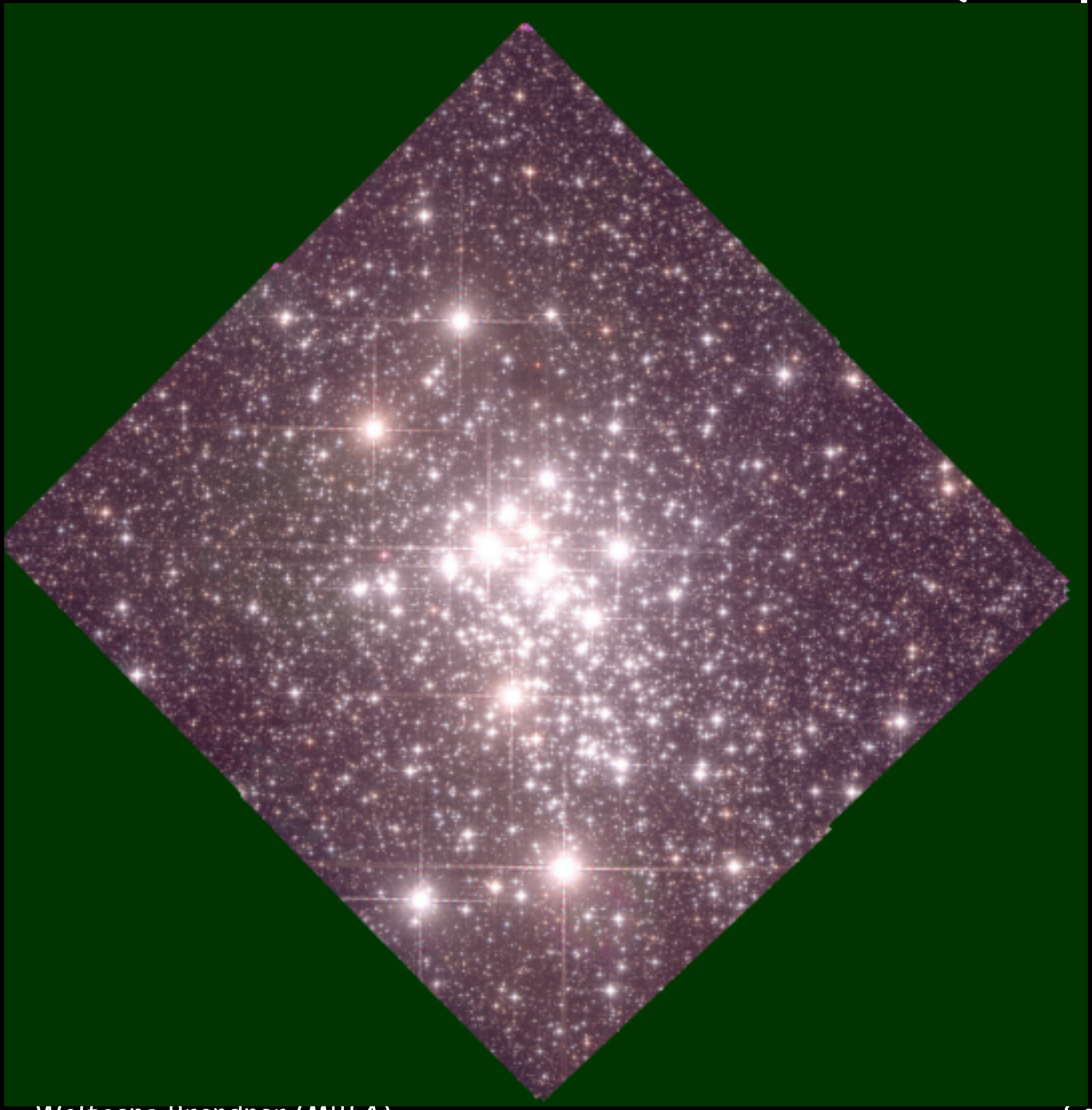
Westerlund 1: ground based NIR: seeing limited vs. AO

Adaptive Optics data: ~750 stars, 65mas FWHM



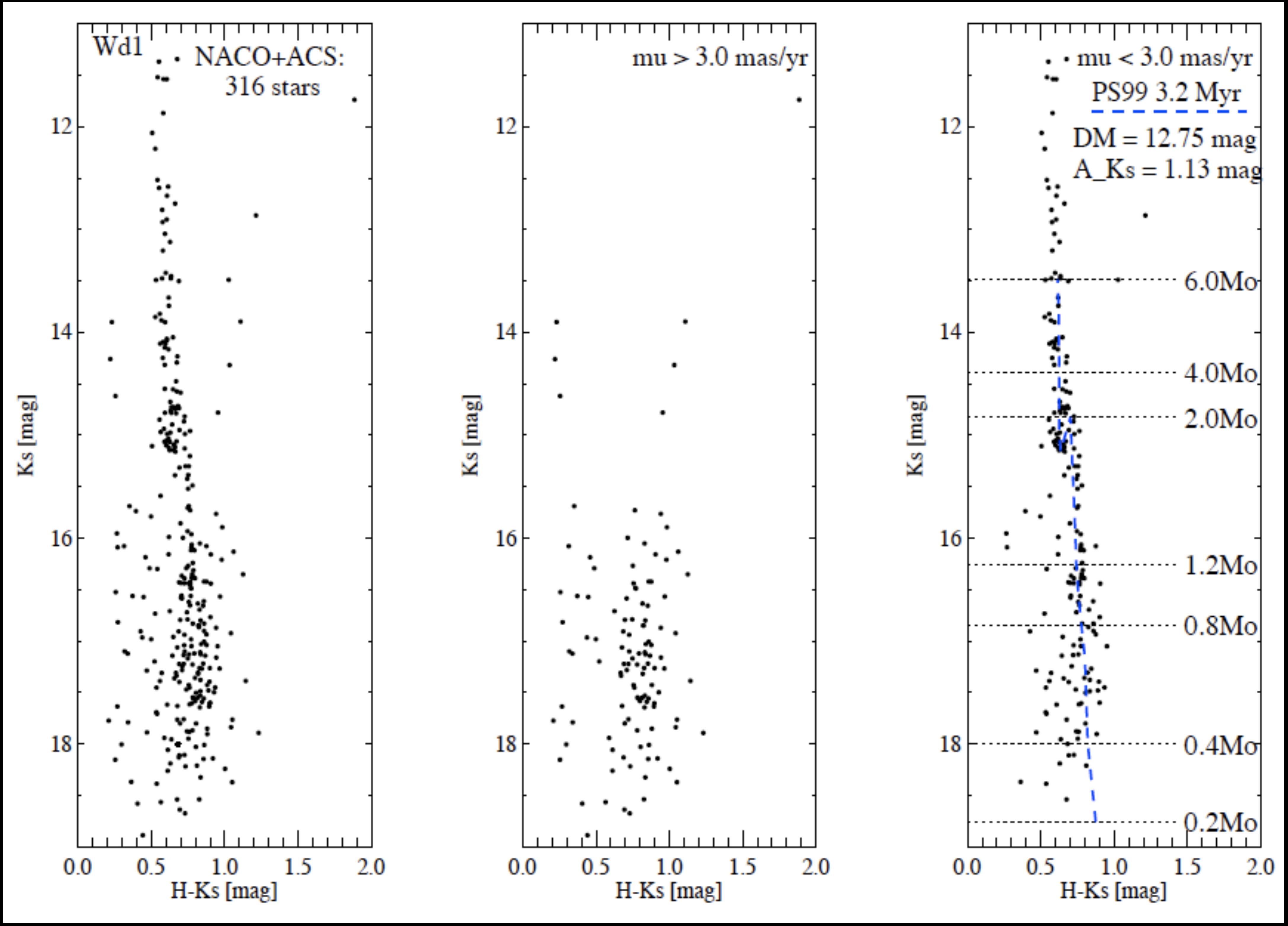
Outlook: studies of other Galactic starburst clusters

Westerlund 1: HST/ACS&WFC3IR (wide field); two epochs of VLT/NACO NIR observations (deep, low-mass content)



WFC3/IR data from Aug 2010 (PI M. Andersen)

Westerlund 1: astrometric identification of cluster members



Dynamical (virial) and phot. mass estimates are in agreement (≈50000 M_{Sun})

=> cluster should remain bound for an extended period of time

(Kudryavtseva et al., in prep.)

Summary

* Multi-epoch high-angular resolution observation yield proper motions and internal kinematics of Galactic starburst clusters

* NGC 3603 YC and Westerlund 1 are close to virial equilibrium => good prospects for long-term survival

* No deviation from a Kroupa IMF down to our completeness limits

Thanks to SOC/LOC for organizing this great conference at such a wonderful place, and many thanks to all ST-EFC members for their long-term support of (European) HST programmes and science!!!