Westerlund 1 and its Galactic Siblings

(Observation confronts theory)

Westerlund 1 equivalent in the Antennae?

Wolfgang Brandner, Andrea Stolte, et al.

Starburst (SB) cluster - loose definiton:

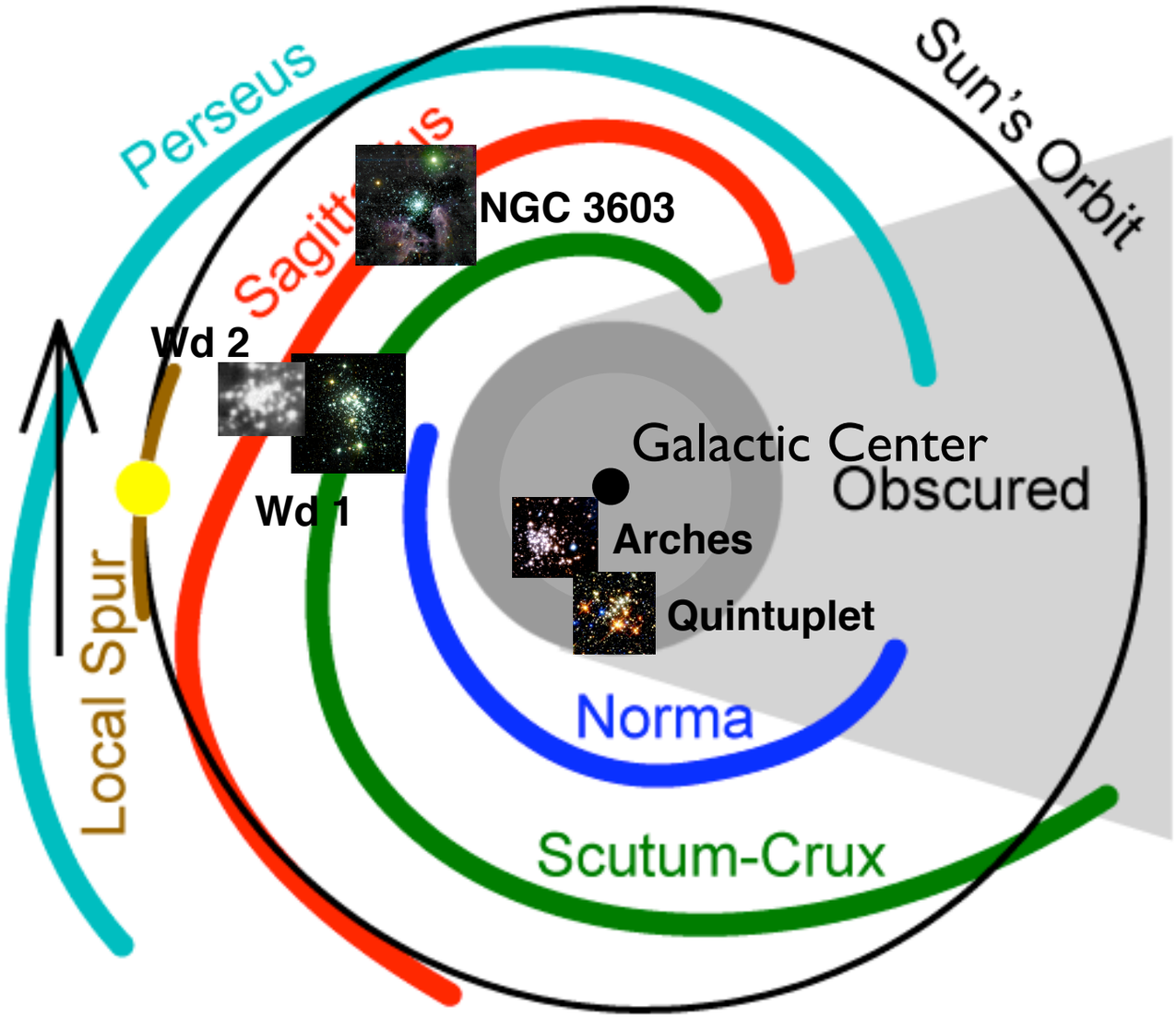
- > several 10,000 stars
- >10,000 Mo in stellar mass
- house massive stars with initial masses ~120M_o (O2V)

Observation confronts theory

3 “challenges”

- Your favorite PMS tracks - right or wrong?
- Do SB clusters tell us how proto-globular clusters form?
- What is the contribution of starburst clusters to the young field population in the disk and the Galactic Center nuclear region?

Where are they located and how many are there?



≥3 spiral arm SB cluster:

- NGC 3603: d = 6.0 kpc (A_v = 4.5 mag)
- Westerlund 1: d = 3.5 kpc (A_v = 10 to 13 mag)
- Westerlund 2: d = 2 to 5 kpc

Two “nuclear cluster”:

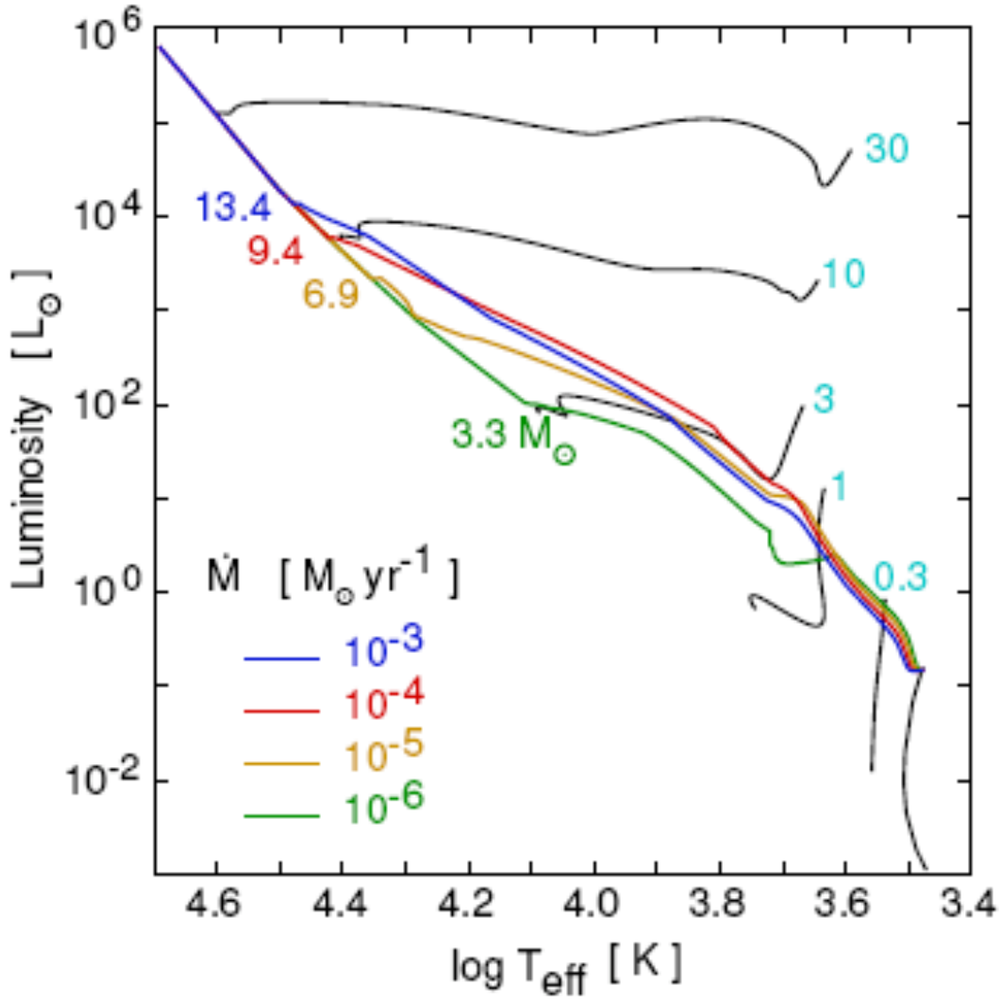
- Arches & Quintuplet: d = 8.0 kpc (A_v = 24 mag)

Advantages of studying local (spatially resolved) starburst clusters

- Large number of stars (good statistics for determination of mass function and dynamical properties)
- Photo-evaporation of remnant circumstellar material around low-mass stars by UV photons from O-stars:
  - little differential extinction and IR excess (bad news if you are looking for disks & planets)
  - non-accreting pre-main sequence tracks can be used

Accreting and non-accreting pre-main sequence tracks

How is ongoing accretion affecting pre-main sequence evolution?



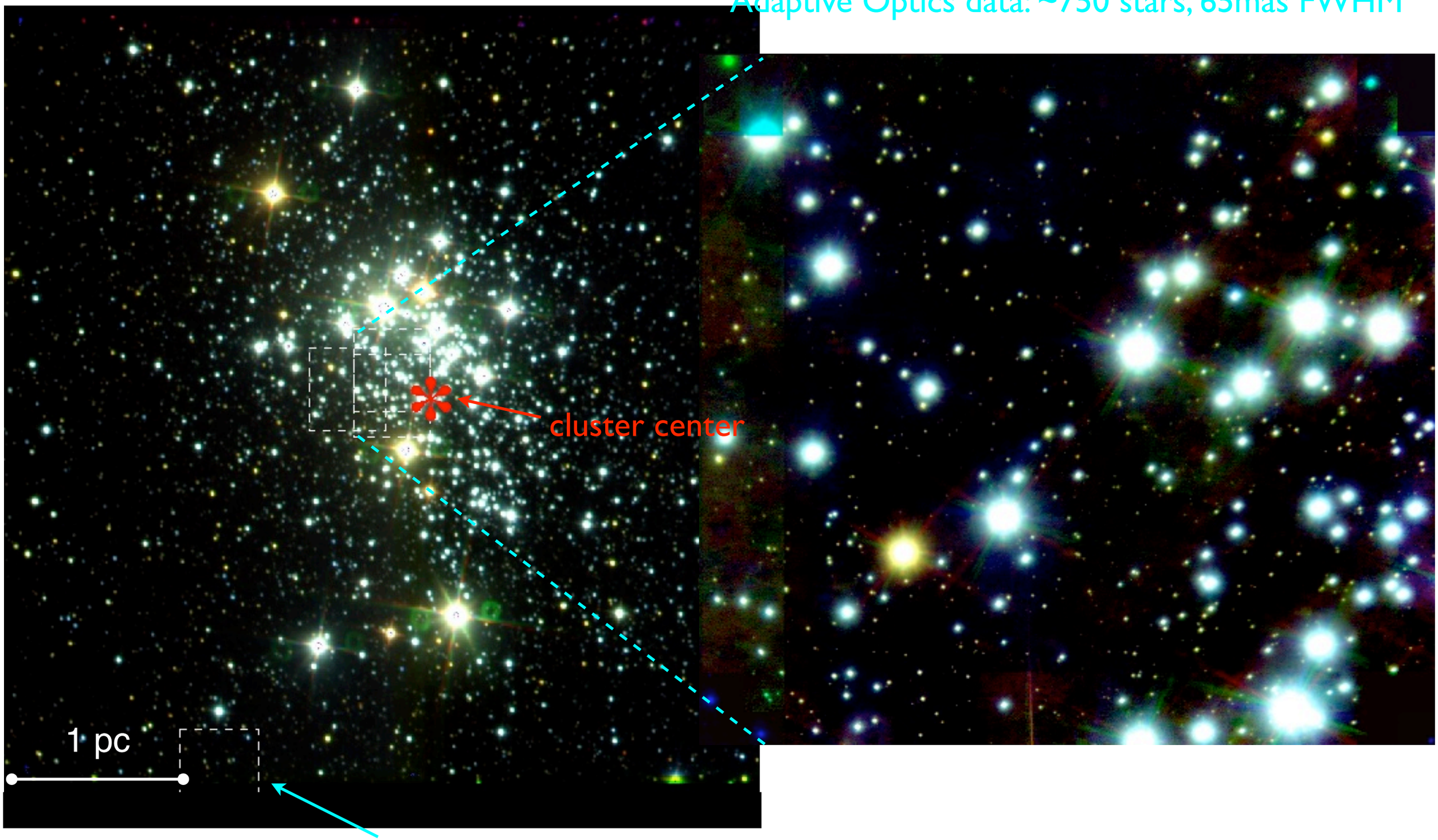
Zinnecker & Yorke 2007, ARAA

Proto-stars follow “black” tracks only if accretion is entirely shut-off early-on!

Westerlund 1 NIR studies

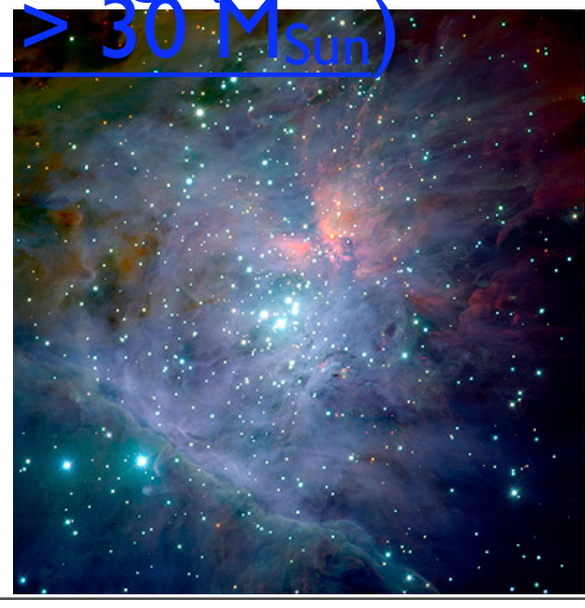
Seeing-limited and Adaptive Optics data: location of fields

Adaptive Optics data: ~750 stars, 65mas FWHM

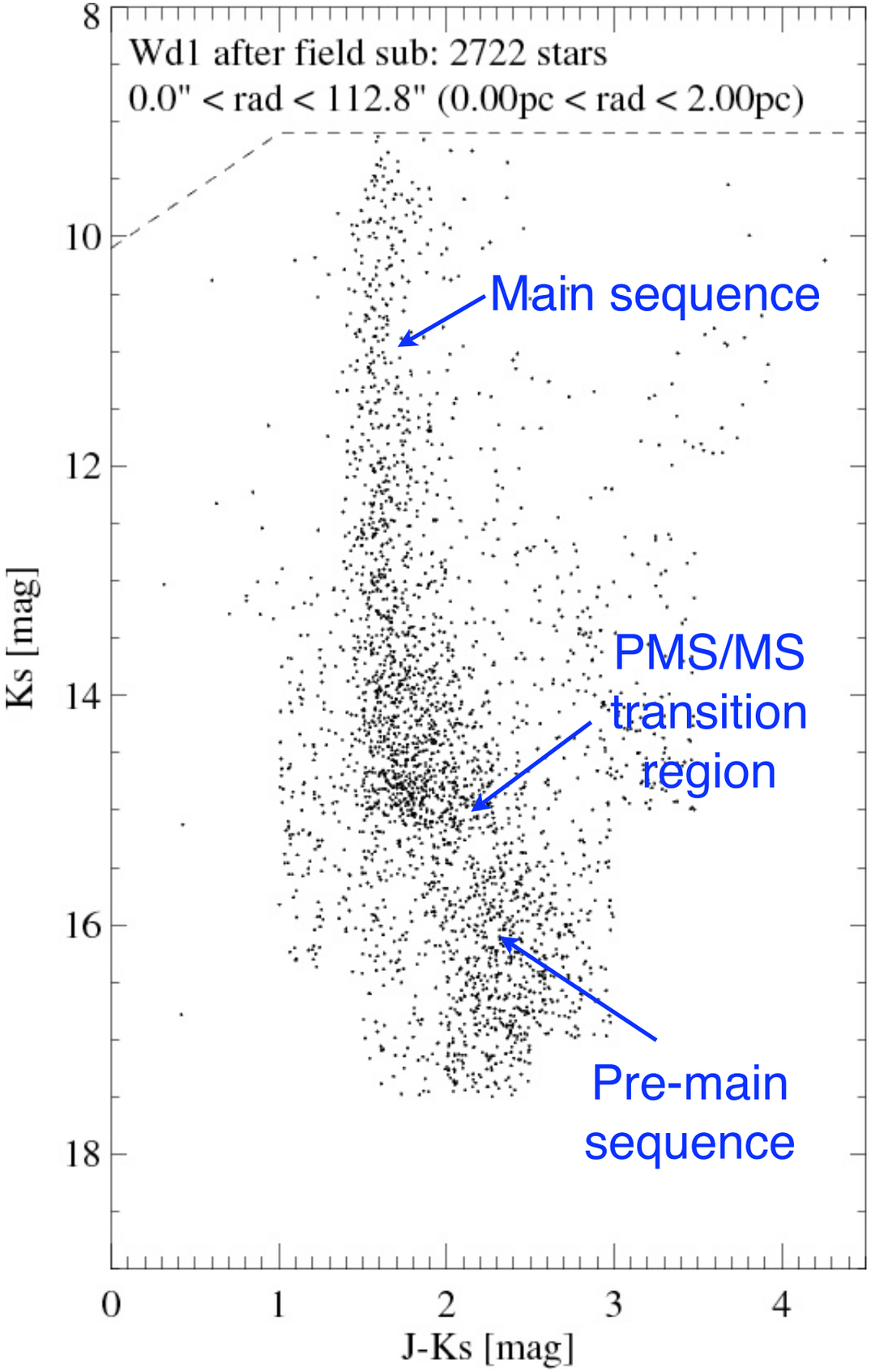


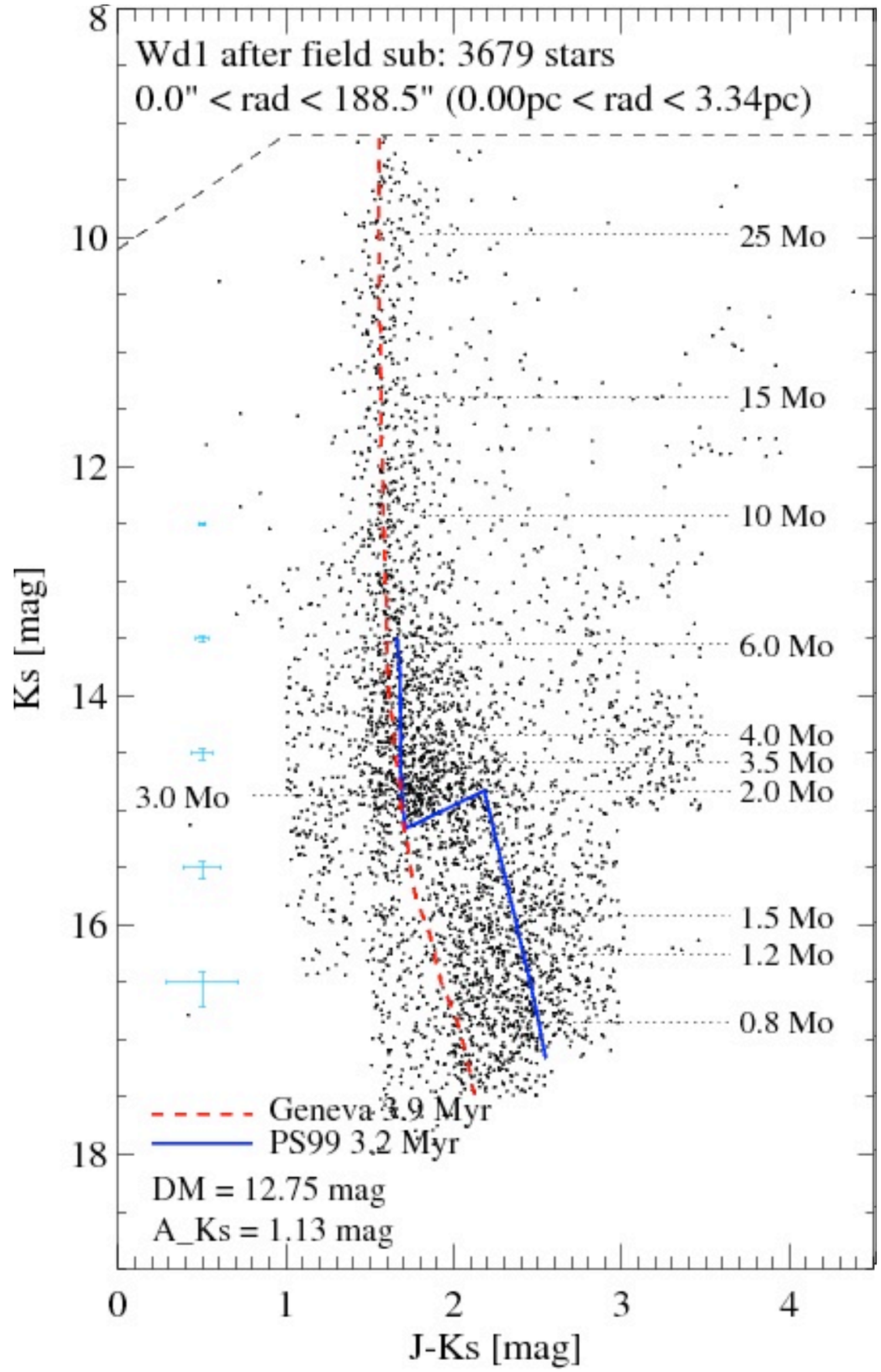
previous studies focused on the evolved high-mass stars:

- Wd 1 has 24 W-R stars (Crowther et al. 2006), >40 supergiants and hypergiants have been identified by spectroscopy (Clark et al. 2005)
- Wd 1 has produced an estimated >50 supernovae over the past ~1 Myr, i.e. 1 SN every 20,000 yr (Muno et al. 2006; Brandner et al. 2007)
- Dynamical mass ~60,000 M_{Sun}, half-light radius ~1 pc (Mengel & Tacconi-Garman 2007)
- Studies of stars with masses ≤ 30 M_{Sun} are still missing (for comparison, the Orion Nebula Cluster has 1 star > 30 M_{Sun})



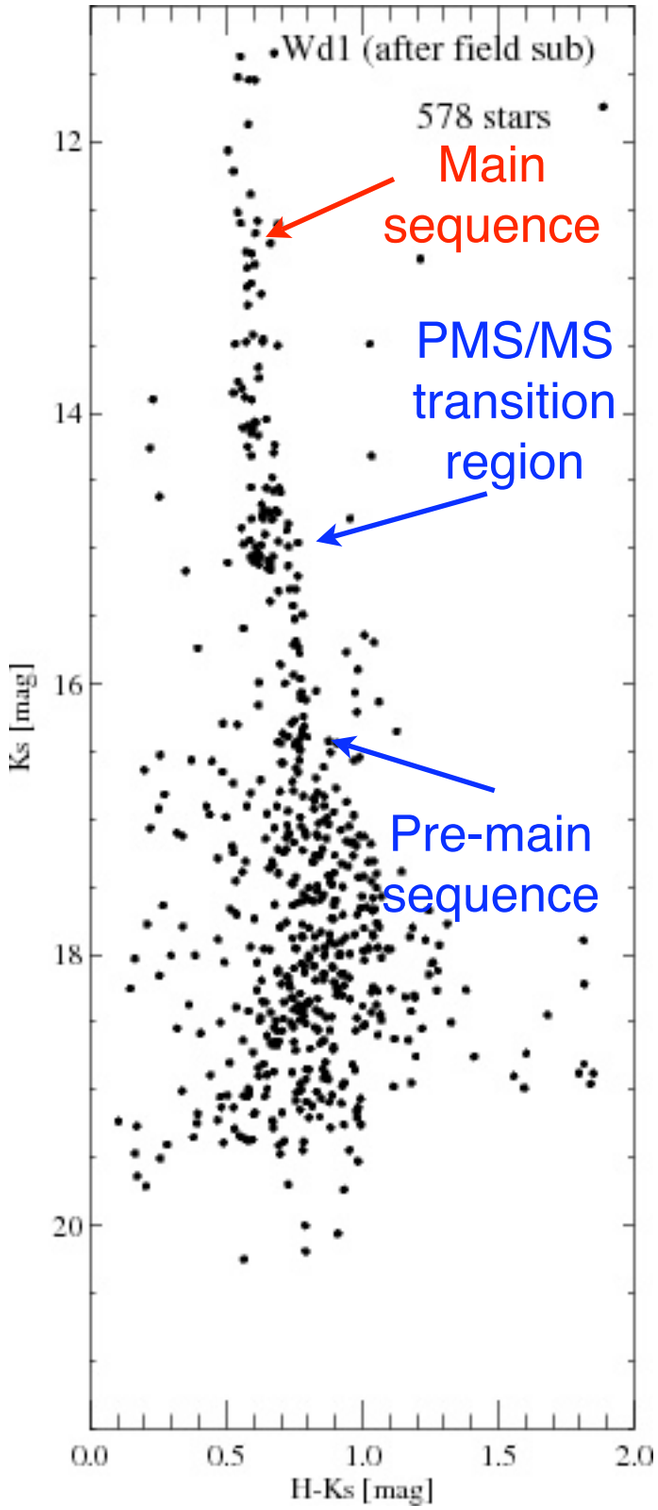
Seeing-limited data: HRD + isochrone fit

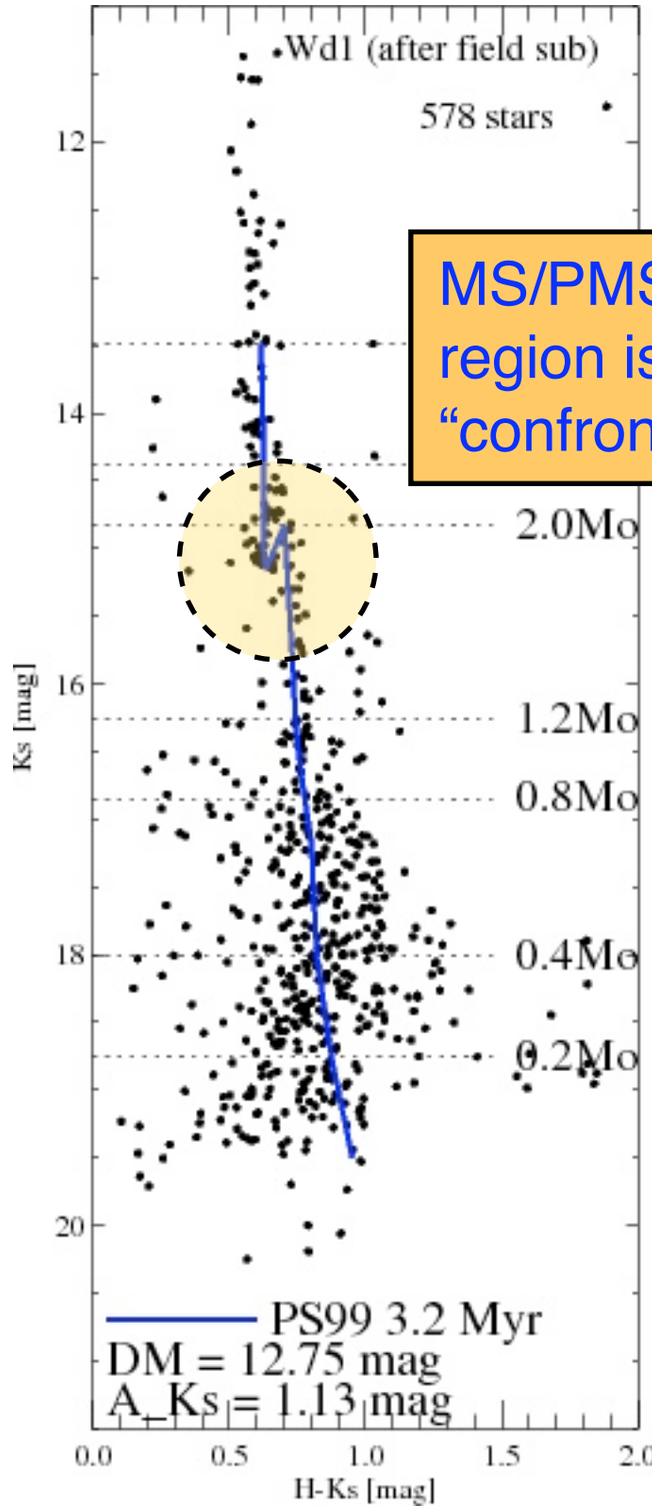




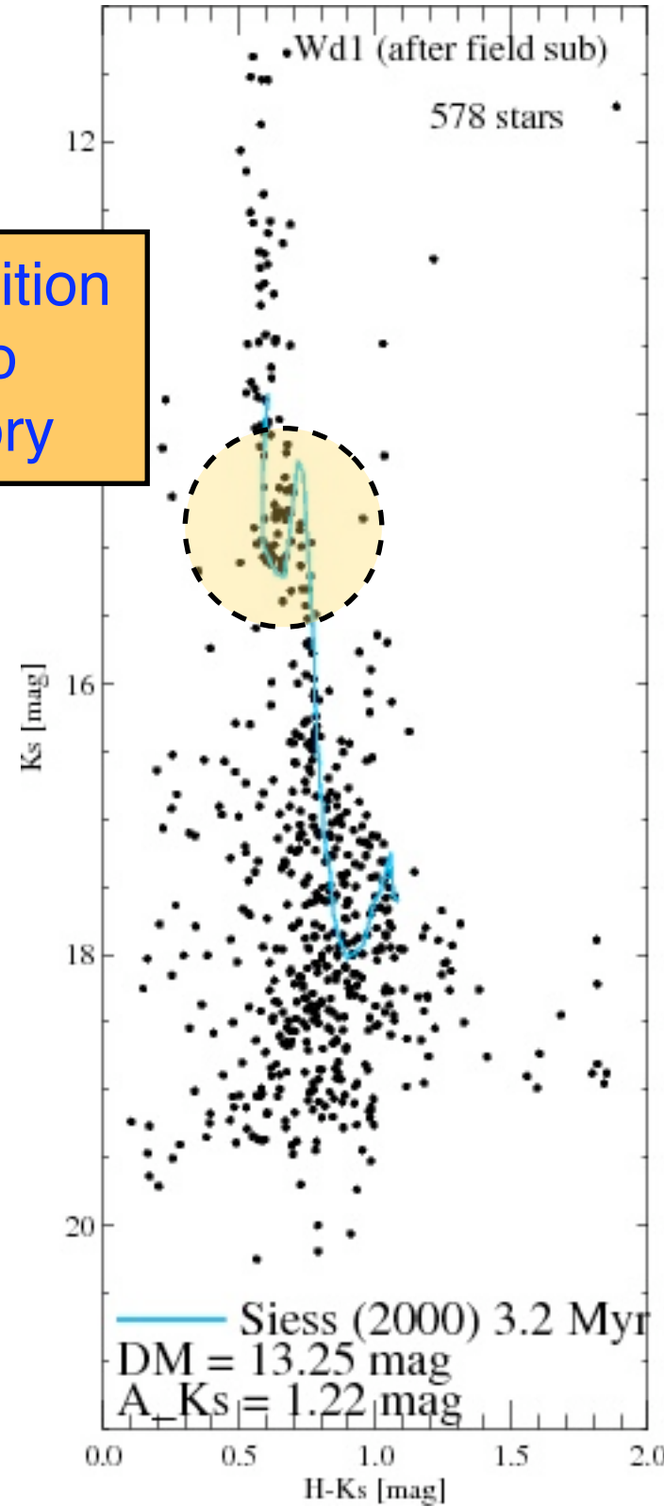
=> extinction, age, distance & individual masses for ~2500 stars

Adaptive Optics data: Pre-main sequence evolutionary tracks
Palla & Stahler models (1999) & Siess et al. (2000)





MS/PMS transition region is key to "confront" theory

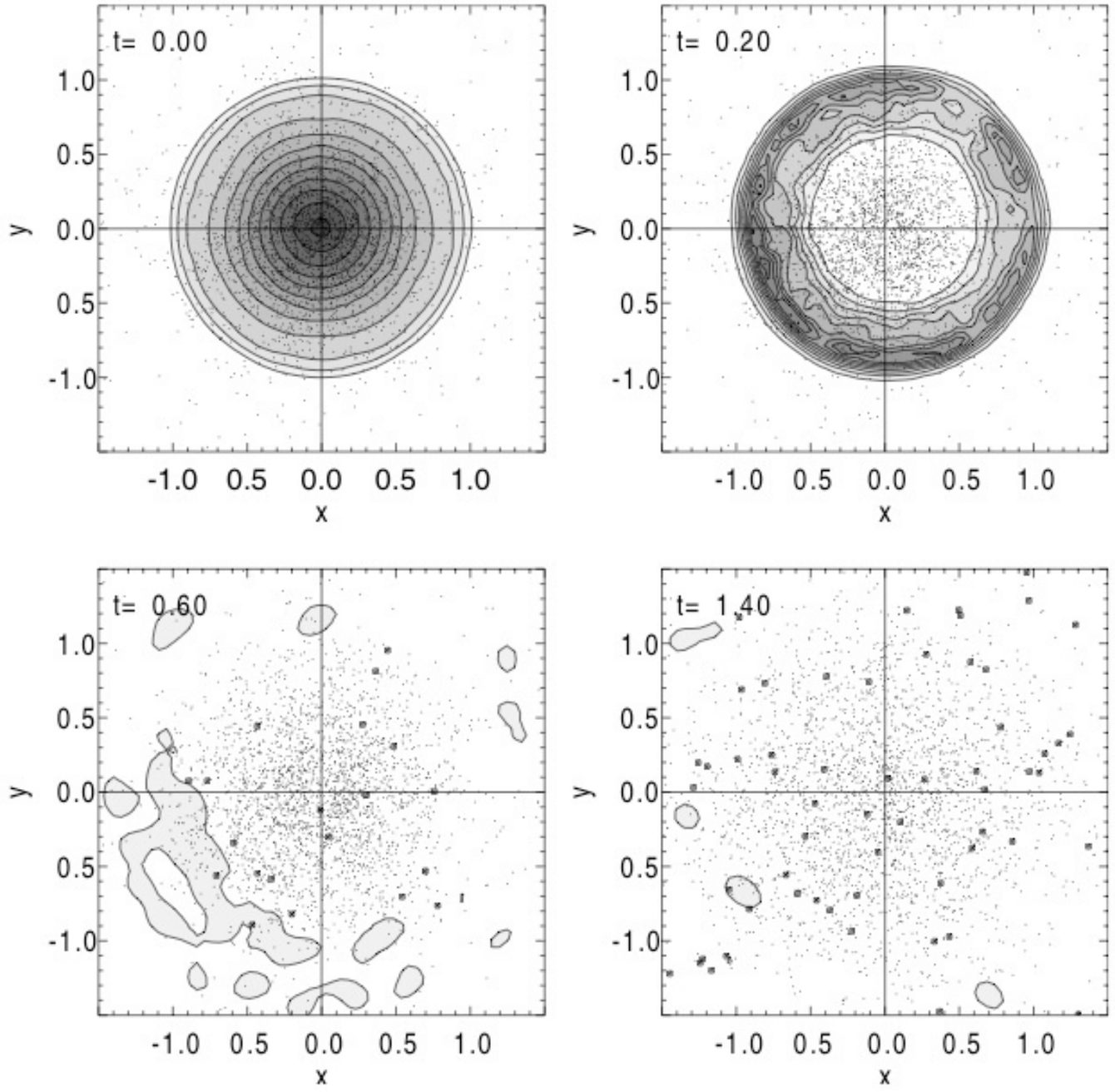


PS99: same A_{Ks} as from Geneva tracks (but "coarse" mass sampling!)

Siess: higher A_{Ks}, worse fit to PMS/MS transition region (same for NGC 3603)

How long to Starburst Clusters survive?
Do they evolve into globular clusters?

- formation out of giant molecular cloud
- once the most massive stars form, they rapidly ionize and disperse the remaining gas
- Star Formation Efficiencies >33% required for the stellar cluster to remain bound

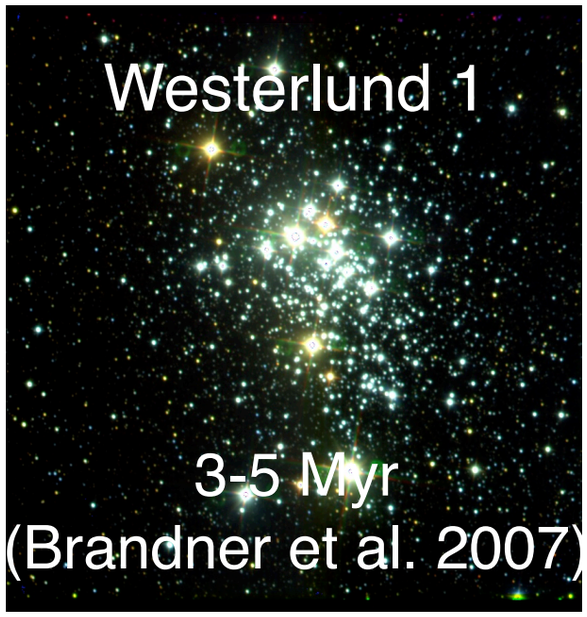


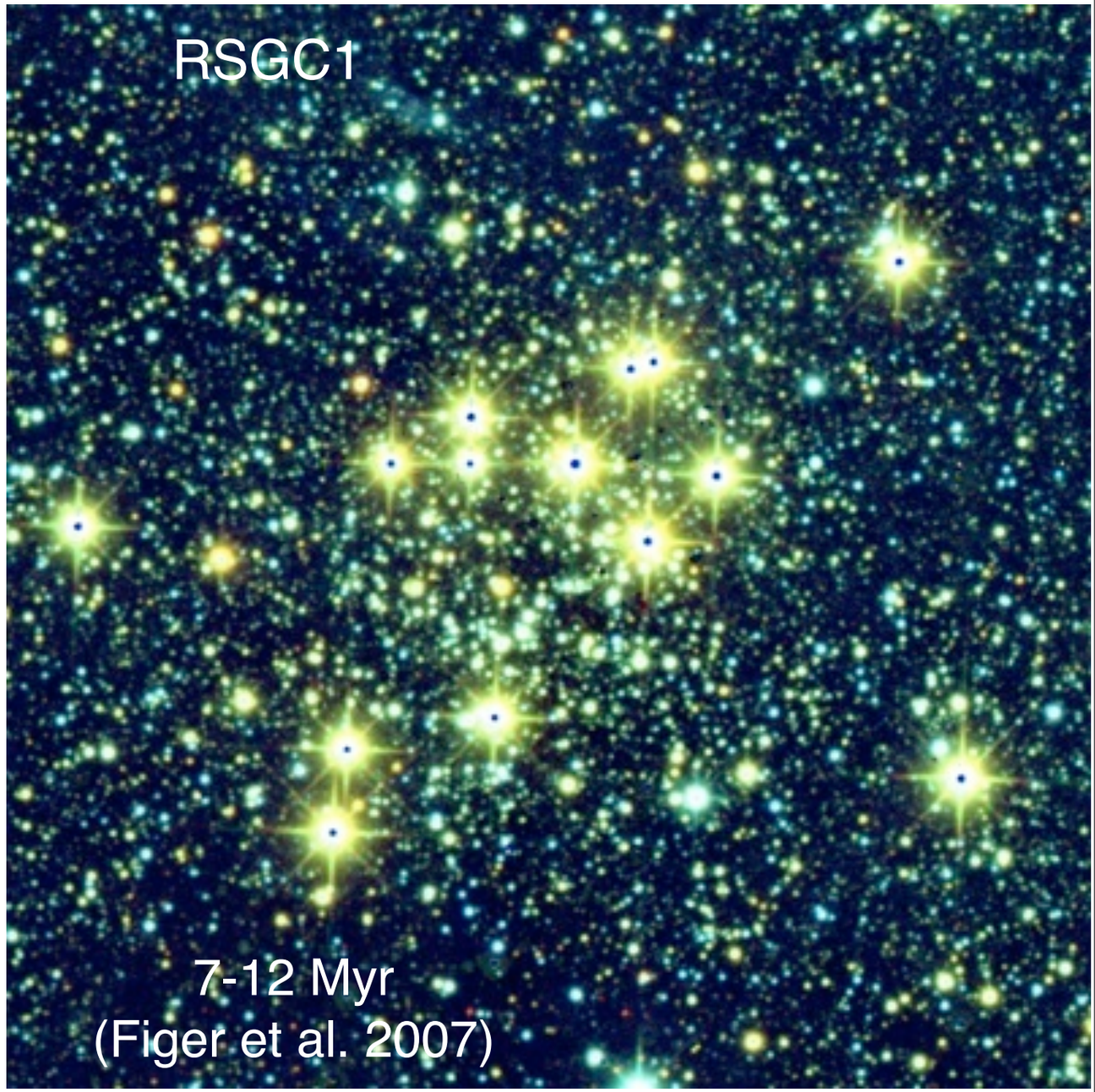
Geyer & Burkert (2001)

Let's confront this with observations...

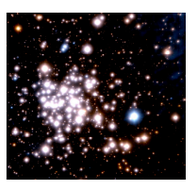
Near-infrared obs, plotted to the same physical scale

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?

-> see e.g. Baumgardt & Kroupa (2007)

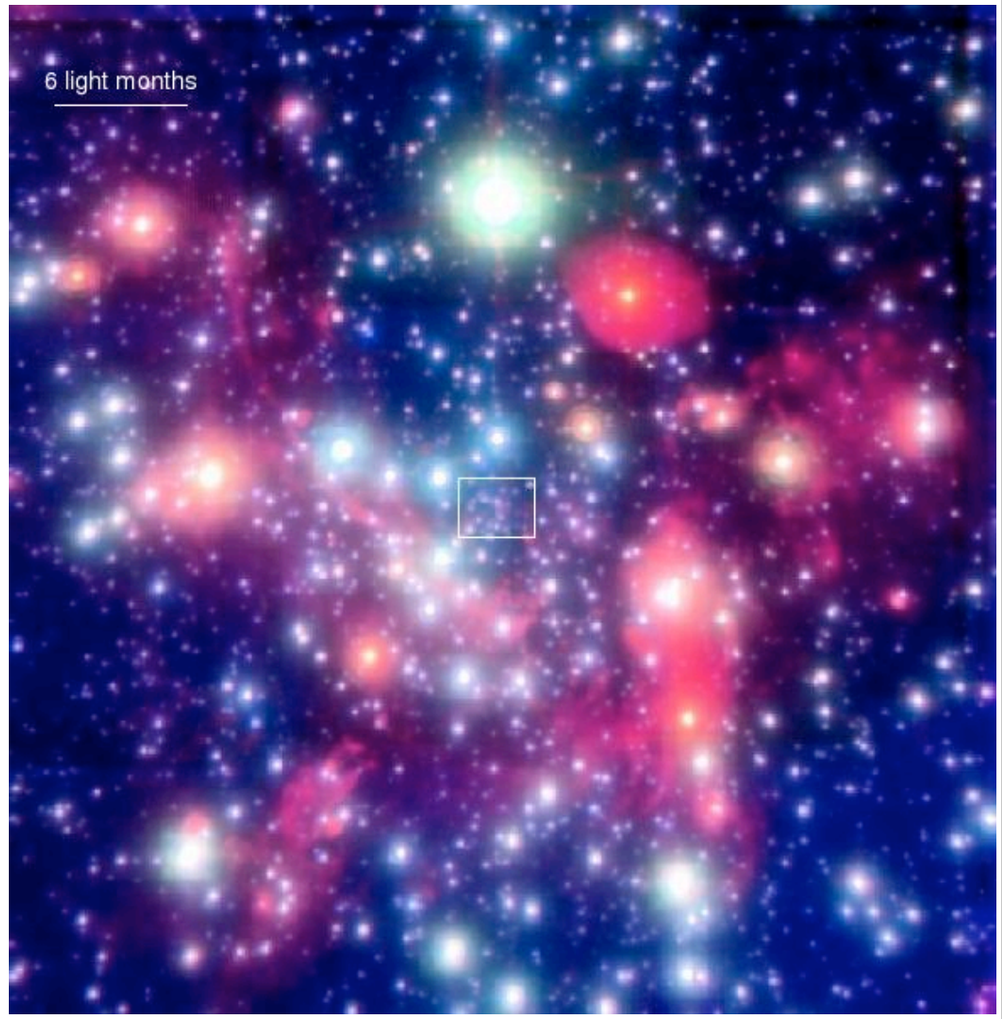
Long-term survival of starburst clusters?

- Due to gas expulsion and stellar mass loss (winds, SN, ...) starburst clusters are far from virial equilibrium
- The small sample of Milkyway starburst clusters suggests that they might disperse rapidly and contribute to the low- to intermediate-mass field population
- Thus at least the <100,000 Mo starburst clusters in the Milkyway cannot be considered as proto-globular clusters

- ... unless they contain more mass than meets the eye
- do (starburst) clusters house intermediate mass blackholes in their centers?

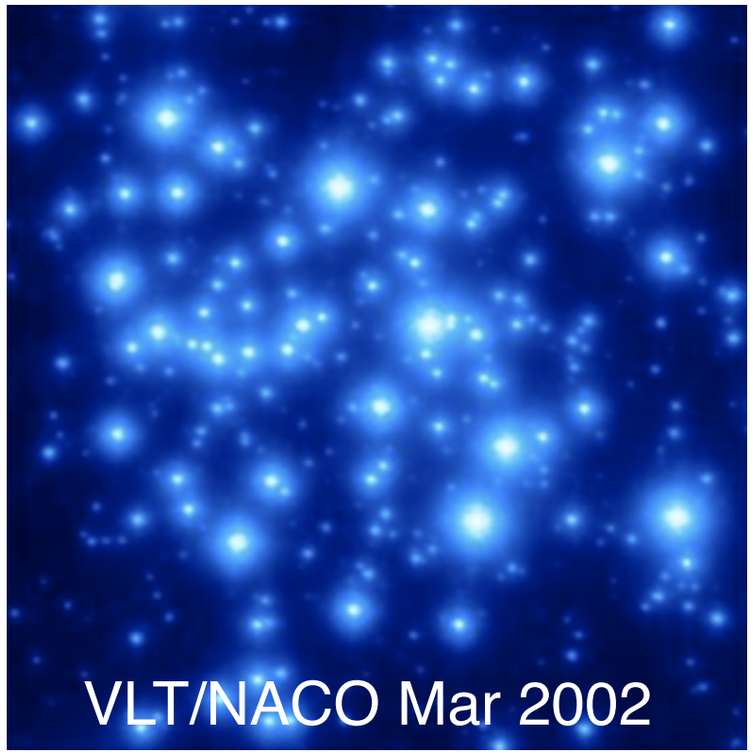
Starburst clusters in the Galactic Center region

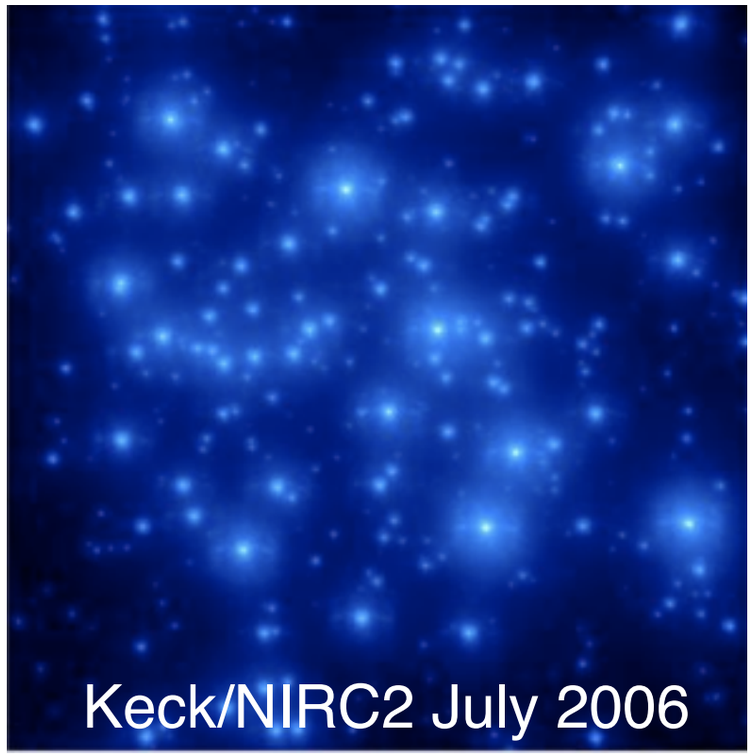
- There is a population of young, high-mass stars close to the GC blackhole
- Models suggest that massive (10^6 $M_\odot$) young clusters could migrate inwards from 10s of parsec to the inner few pc (e.g. Gerhard 2001)



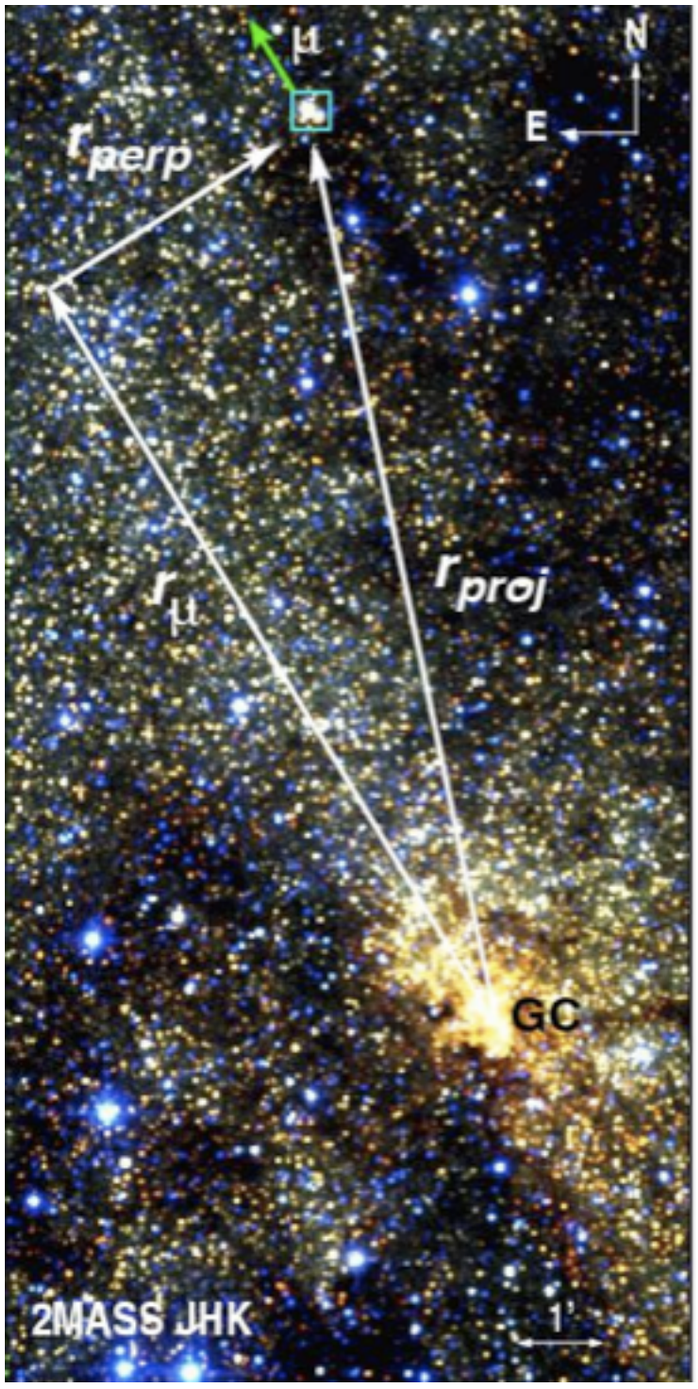
Do starburst clusters in the Galactic Center region feed the nuclear central cluster around the supermassive blackhole, or is there in-situ starformation?

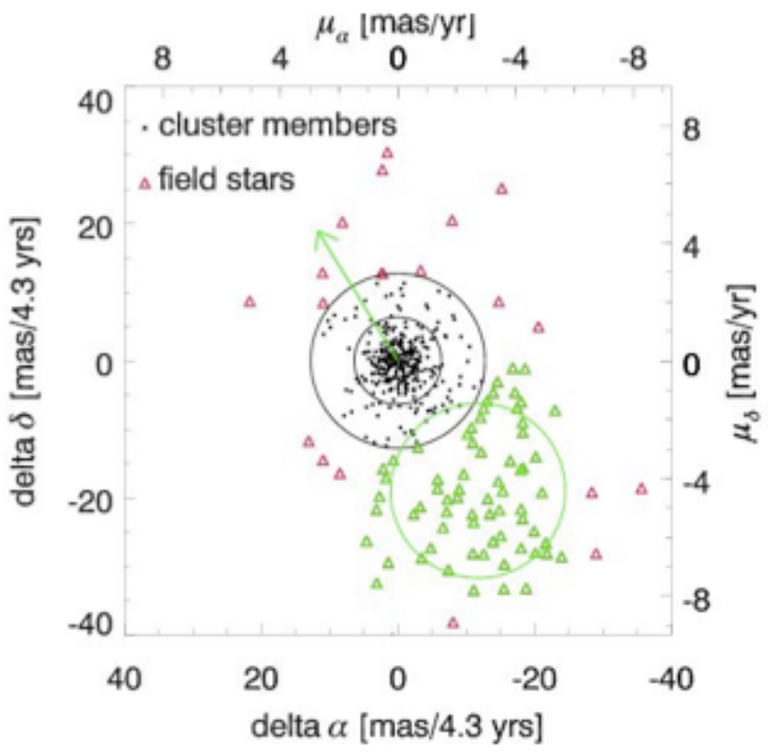
Comparison of 2 epochs of adaptive optics K-band data





Stolte et al. 2007 see astro-ph/0706.4133





Arches has a proper motion of ~5.6 mas/yr or 212 km/s, i.e. its 3d space motion is way too fast for a circular orbit with r = 25 pc

Clusters like Arches and Quintuplet cannot explain the young, massive stars in close orbit around the supermassive blackhole in the GC

=> In-situ star formation in a rather hostile environment: strong magnetic field, strong radiation field, tidal shear, ...

Summary:
Observations of Milky Way starburst clusters offer quite a few challenges to theory :

- PMS tracks
- (globular) cluster formation
- star formation in extreme environments
- ...