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

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Starburst Clusters as Astrophysical Laboratories

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)
- Optical HST observation provide similar resolution over a large field of view 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

NGC 3603 Young Cluster
1 pc
1 Myr
(Stolte et al. 2004)

Westerlund 1
3-5 Myr
(Brandner et al. 2008)

Arches
2 Myr
(Stolte et al. 2005)

Quintuplet
3-6 Myr
(Figer et al. 1999)

RSGC1
(UKIDSS JHK)
7-12 Myr
(Davies et al. 2007)

Compact cores ($r_c = 0.2$ pc) are only observed in the two youngest clusters

$\Rightarrow$ 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 ionizing radiation and fast stellar winds 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), ...
- 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 ($N_c \sim 10^{51} \text{s}^{-1}$, 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)
Blue Supergiant Sher 25 with Nitrogen enhanced ring + bipolar outflow (reminiscent of SN 1987A)

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

Pillars & ionized “blobs” (Proplyds?)

Ha+\([\text{NII]}\) colour composite

NGC 3603
Hubble Space Telescope • WFPC2

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)
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

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!)

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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

=> cluster members are ∼1 Myr old
plus additional underlying ∼ 4 Myr old population of HII region

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

(Rochau et al. 2010)
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\(_{\text{Sun}}\) agrees well with total stellar mass (10000 to 16000 M\(_{\text{Sun}}\), 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 ($\approx 50000 \, M_{\odot}$)

=> 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

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