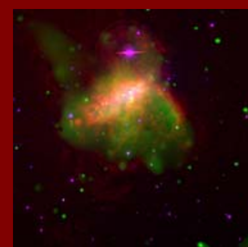
MULTI-WAVELENGTH DIAGNOSTICS OF STARBIRTH IN STARBURSTS



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MOTIVATION

- Populous clusters ($N_* > 10^3$) may account for more than 30% of star formation in galaxies (C. J. Lada & E. A. Lada 2003, ARAA, 41, 57).

- These rich clusters produce energetic starburst activity.

- How does this activity influence present and future star formation?

BASIC TRUISMS

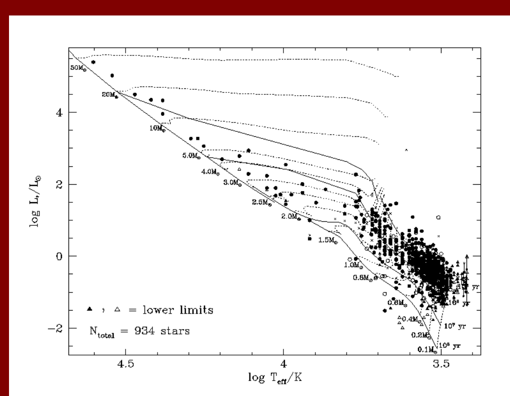
- Star formation takes time ($10^6 – 10^8$ yrs).
- Populating a rich cluster is also a protracted affair ($10^6 – 10^7$ yrs).
- Serious “stuff” can happen during these formative stages.

NGC 3603 (E. K. Grebel and Y.-H. Chu)

FORMATIVE TIMESCALES

- Strong mass dependence during protostellar stage.

  $T_{ps} \sim 30\ \text{Myr}\ \{M_*/M_{Sun}\}^{-2}$



Orion Cluster (Hillenbrand 1997, AJ, 113, 1733)

FORMATIVE TIMESCALES

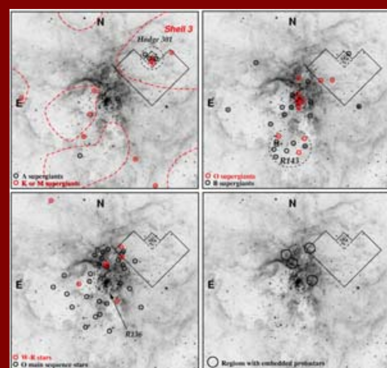
- Initial core collapse in starbursting system is not coeval.

  $t_{cluster} \sim 1\ \mathrm{Myr}\ \{D_{cluster}/10pc\}\ \{10\ \mathrm{km\ s^{-1}}/v_{sonic}\}$

  => t(Orion)~1 Myr   => t(30 Dor)~10 Myr   => t(NGC 1569)~100 Myr

10-20 Myr   3-10 Myr

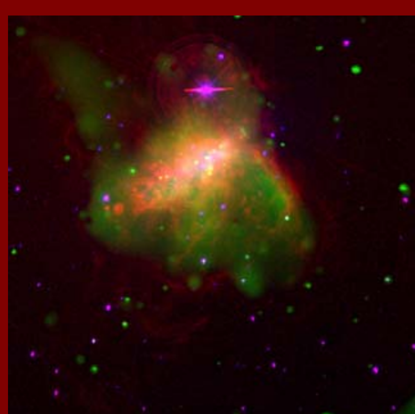
2-5 Myr   < 1 Myr



30 Doradus (E. K. Grebel and Y.-H. Chu 2000, AJ, 119, 787)

Extenuating Circumstances

- Ionizing radiation (O3 - O9) $\{t = t_{cluster} + [1\text{-}5]\mathrm{Myr}\}$
- Energetic winds (WR, SG, LBV) $\{t = t_{cluster} + [3\text{-}10]\mathrm{Myr}\}$.
- Supernova explosions (Type II) $\{t = t_{cluster} + [10\text{-}50]\mathrm{Myr}\}$.



Starbursting dwarf galaxy NGC 1569 in H-alpha (red), stars (purple), and X-rays (green) (C. Martin et al. 2002, ApJ, 574, 663.)

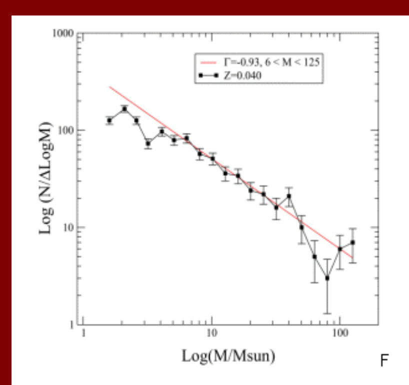
Intense UV Irradiation from Hot Stars

- Photo-evaporates ("ablates") nebular and protostellar environment.
  => Orion's cometary *proplyds* (D ~ 1000 AU ~ 0.005 pc).
  => M16's *pillars* (D ~ 1 pc) with evaporating gaseous globules (*EGGs*).
  => Similar signs of *UV weathering* in NGC 3603, Carina, 30 Dor, NGC 346.

"We conclude that the masses of stars in the cluster environment in M16 are generally determined not by the onset of stellar winds, as in more isolated regions of star formation, but rather by disruption of the star forming environment by the nearby O stars." (from J. J. Hester et al. 1996, AJ, 111, 2349).

Evidence for Variation in Stellar Populations

- Populous clusters near the *Galactic center* show flatter IMF slopes.
  (D. F. Figer et al. 2002, ApJ, 581, 258; Stolte et al. 2002, A&A, 394, 459)

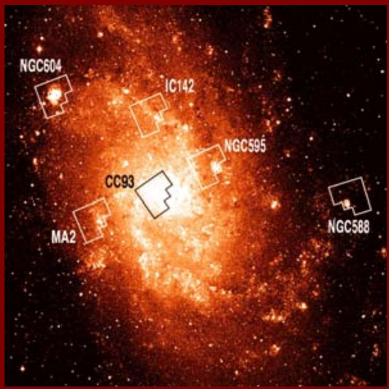


Arches Cluster (HST/NICMOS)   IMF (Gemini/Hokupa'a)

More Evidence for Variation in Stellar Populations

- Giant HII regions in M33 show large range of metallicities and luminosities.

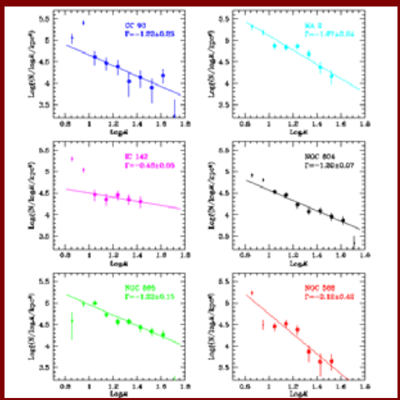
  => HST can reveal the corresponding stellar IMFs (D ~ 0.4 pc).

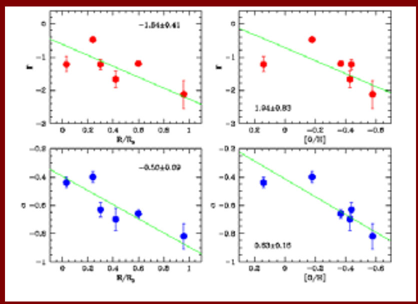


More Evidence for Variation in Stellar Populations

- Giant HII regions in M33 show flatter IMF slopes near galaxy's center.
  => Greater numbers of most massive stars at higher metallicity.

  (M. G. Lee et al. 2002, in *Extragalactic Star Clusters, IAU Symp. 207*)





Can *photo-evaporation* modify stellar IMFs? Can *metallicity* mediate this process?

Scenario:

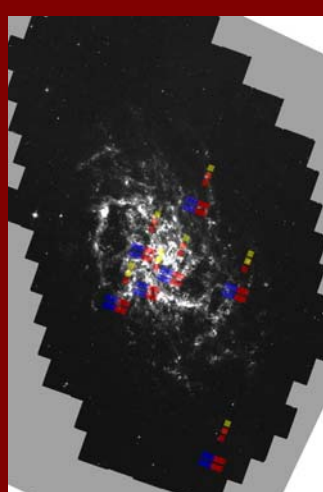
Dust in high-metallicity HII regions shields proto-stellar cores from UV photo-ablation by hot stars.

=> greater numbers of high-mass stars in high-z IMFs.

Prediction:

Variation of nebular structure and content wrt metallicity.

Infrared imaging and spectroscopy reveals ionized, molecular and dust components



M33 – 8 micron mosaic

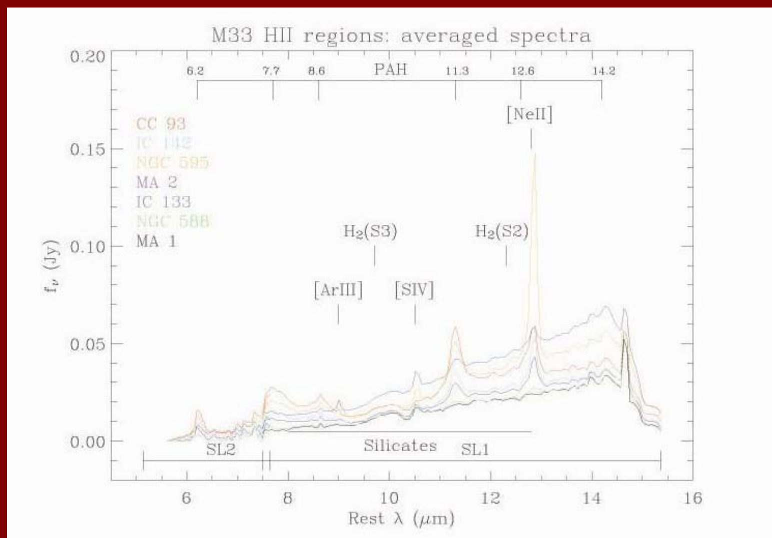
Imaging:

Full mosaics of M33 have been made at 8 microns (Spitzer/IRAC)
[R. D. Gehrz et al. – in progress]
and at 24, 70, and 160 microns (Spitzer/MIPS)
[J. L. Hinz et al. 2004, ApJ, 154, 259]

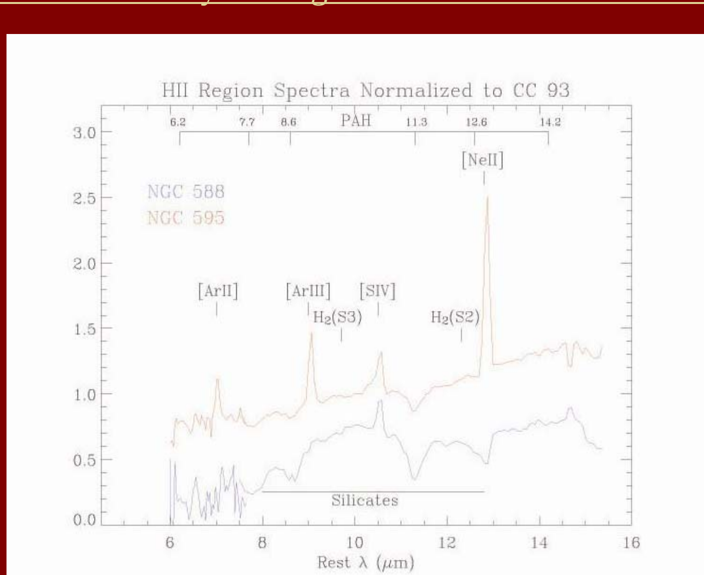
Spectroscopy:

Spectral maps of 8 HII regions in M33 have been made (Spitzer/IRS)
[W. H. Waller et al. – in progress]
[B. R. Brandl et al. – in progress]

Spitzer/IRS Spectra of M33 HII regions exhibit variations in ionized, molecular, and dust components.



Spectral ratios reveal depleted small grains and PAHs in lower-metallicity HII regions NGC 595 and NGC 588.



Stellar-Nebular Feedback in Galaxian Starbursts:

Key Challenges and Emerging Prospects

1. *Verifying/refuting variations in the stellar IMF of starbursting systems –*

=> UV/Opt/NIR stellar photometry and spectroscopy in the Milky Way and other Local Group galaxies (Groundbased active optics, Spitzer, SOFIA, JWST).

=> Chandra, XMM-Newton, etc. X-ray studies of hot windy stars and stellar remnants.

Stellar-Nebular Feedback in Galaxian Starbursts:

Key Challenges and Emerging Prospects

2. *Untangling effects of age, scale, and metallicity on starburst nebulae* --

=> Spitzer/GLIMPSE studies of *nebular structures* in the Milky Way.

=> SOFIA follow-up of selected regions in MW.

=> JWST MIR studies of same in LG galaxies.

=> Chandra, etc. X-Ray studies of *diffuse emission*.

=> Theoretical modeling of aging starbursts!

Irradiation of Clumpy Nebulae:

(F. Varosi and E. Dwek 1997, in *The Ultraviolet Universe…*)