STELLAR FEEDBACK

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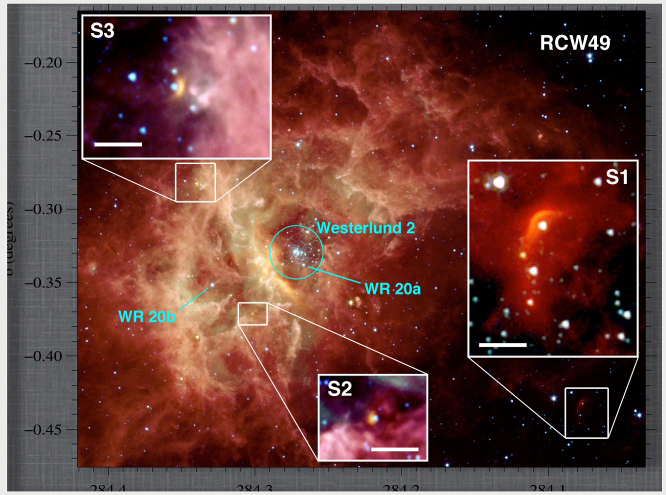


STELLAR FEEDBACK

- Given a surface or volume density, star formation is slow, 0.02 of M_{H2} per dynamical time
- Star formation happens in GMCs, but is inefficient (0.02 in local galaxies)
- turbulent velocities increase with increasing surface density
- I will argue that the last two (at least) are a result of stellar feedback, in the form of radiation pressure
- Predict that GMC efficiency increases with surface density

PRELIMINARIES

- most stars form in clusters (and most of these in massive clusters) in GMCs; model as a ~1-5pc cluster in the center of the GMC (can relax this)
- See GMCs in nearby starbursts---assume they exist in ULIRGs as well
- Assume Muench et al. or Chabrier IMF

1 D MODELS

- Include radiation pressure, HII gas pressure, protostellar jets, shocked stellar winds, and CR pressure (in ULIRGs---they don't affect dynamics in Milky Way)
- Account for cloud/shell self-gravity, cluster-shell gravity, turbulent pressure from overlying ISM

SCALINGS

The shell self-gravity is

$$F_{\rm shell} = -\frac{GM_{\rm sh}^2}{2r^2} \sim M_g^2 r^{-2}$$

The HII gas pressure:

$$n_{\rm HII} = \sqrt{\frac{3Q}{\alpha_{\rm rec} 4\pi r^3}} \sim L^{1/2} r^{-3/2}$$

For massive clusters, $Q \sim L$, so

$$F_{\rm HII} = 4\pi r^2 P_{\rm HII} \sim L^{1/2} r^{1/2} \sim M_*^{1/2} r^{1/2}$$

The radiation force is given by

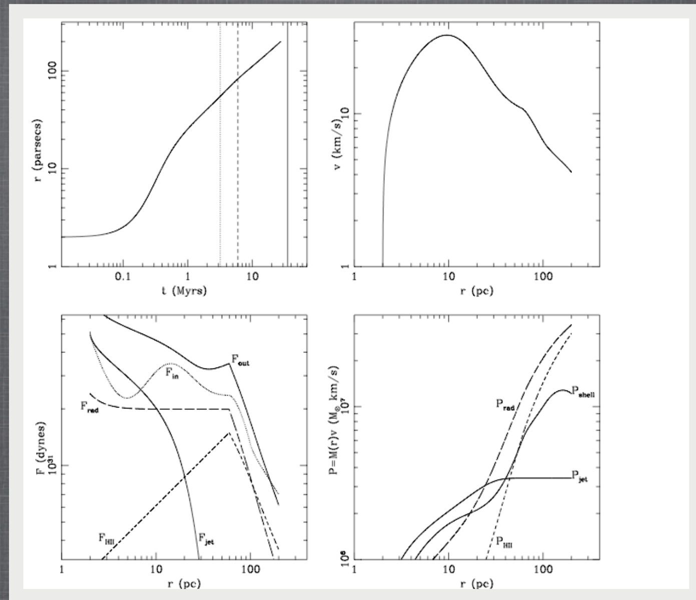
$$F_{\rm rad} = (1+\tau_{\rm rad})\frac{L}{c} \sim M_* M_g r^{-2}$$

or

$$F_{\rm rad} = \frac{L}{c} \sim M_*$$

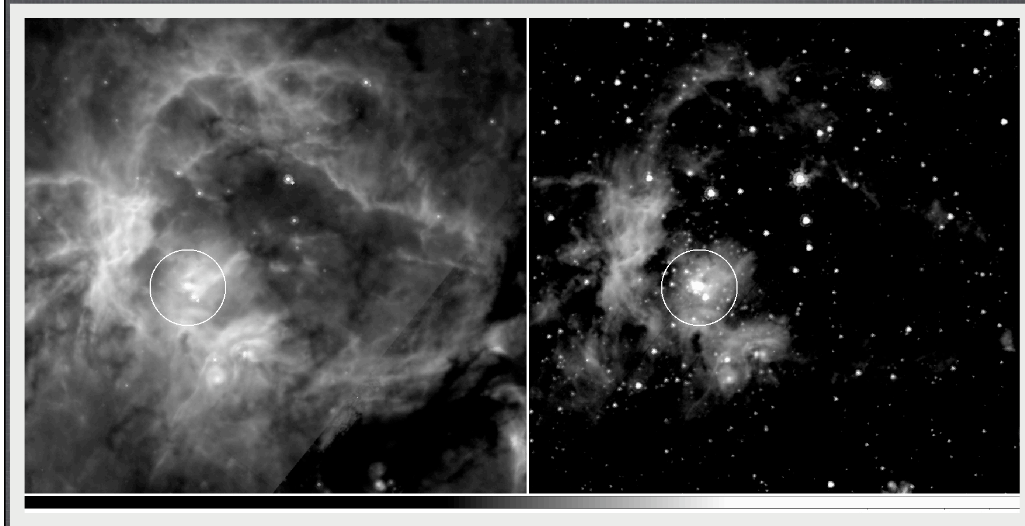
Hot gas and CR forces scale as, at best

$$F_{hot} \sim L \sim M_*$$



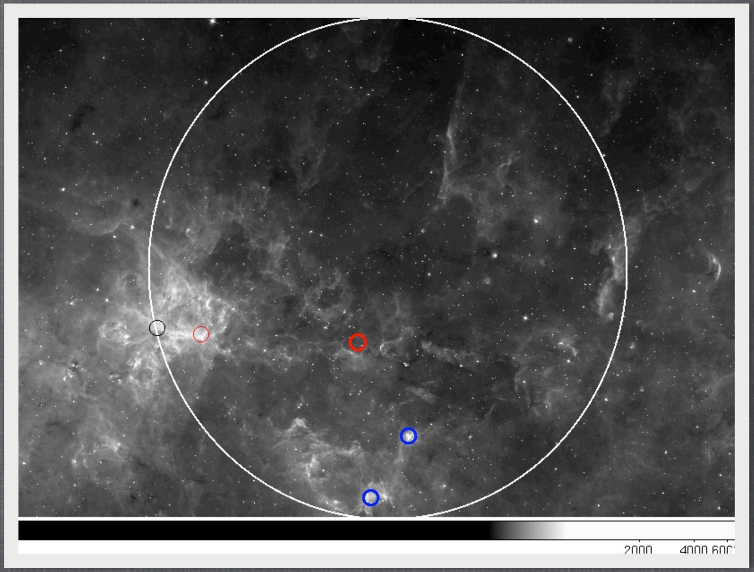
MILKY WAY MASSIVE CLUSTER, E.G., G298.4-0.3

$M_* = 4x10^4\ M_{sun}$ $M_{GMC} = 3x10^6\ M_{sun}$ $R_{GMC} = 100pc$; radiation pressure dominated



G30.48-0.03 W43

bubble mean radius = 4pc, WMAP source radius = 160pc



G336.4+0.08

bubble mean radius = 77pc, WMAP source radius = 300pc (but it confuses two sources)

G291.6 (NGC 3603) MSX IMAGE

bubble mean radius = 100pc, WMAP source radius = 130pc

Table 4

Galactic Massive Clusters (Greater Than 10^4 $M_\odot$)

Cluster	Lon (deg)	Lat (deg)	Distance (kpc)	Age (Myr)	Mass (10^3 $M_\odot$)	References
RSGC2	26.2	0.0	$5.8^{+1.9}_{-0.8}$	17 ± 3	40 ± 10	Davies et al. (2007)
Westerlund1	339.5	−0.4	3.6 ± 0.2	3.6 ± 0.7	36 ± 22	Brandner et al. (2008)
RSGC1	25.3	−0.2	6.6 ± 0.9	12.0 ± 2.0	30 ± 10	Davies et al. (2008)
RSGC3	29.2	−0.2	6 ± 1	18.0 ± 2.0	30 ± 10	Clark et al. (2009)
Arches	0.1	0.0	7.62 ± 0.32[a]	2.5 ± 0.5	∼20	Figer (2008); Figer et al. (1999b)
Quintuplet	0.2	−0.1	7.62 ± 0.32[a]	4 ± 1	∼20	Figer (2008); Figer et al. (1999b)
GC central	0.0	0.0	7.62 ± 0.32[a]	6.0 ± 2.0	∼20[b]	Martins et al. (2007); Figer (2008)
					1000 ± 500	Schoedel et al. (2009)
NGC 3603	291.6	−0.5	6.0 ± 0.8	<2.5	13 ± 3	Harayama et al. (2008)
Trumpler14	287.4	−0.6	∼2.8	3.25 ± 2.75	10 ± 1	Ascenso et al. (2007b)
Cyg OB2	80.2	0.8	∼1.5	∼2.5	∼10[c]	Negueruela et al. (2008)
W49A	43.2	0.0	11.4 ± 1.2	1.2 ± 1.2	∼10	Homeier & Alves (2005)
Westerlund2	284.3	−0.3	∼2.8	2.0 ± 0.3	>7[d]	Ascenso et al. (2007a)

Notes. For each cluster, names and Galactic coordinates are followed by distances, ages, masses, and references.

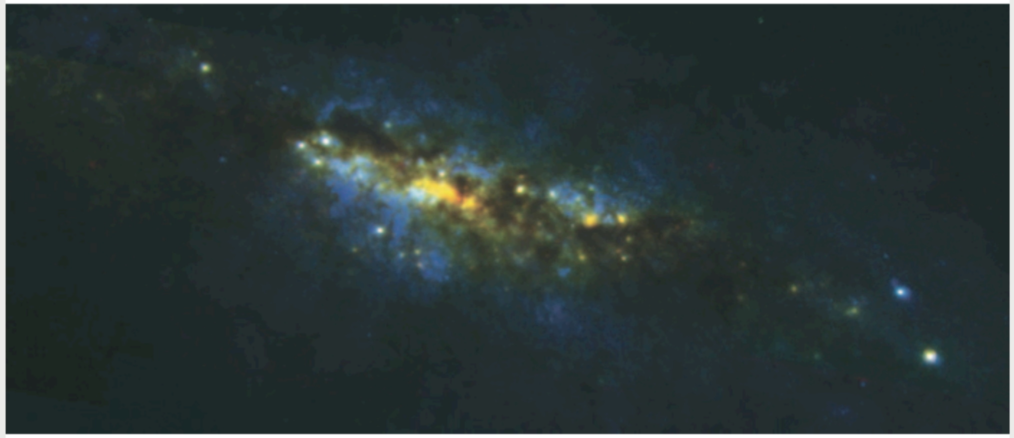
[a] Distance to the Galactic center as given by Eisenhauer et al. (2005).

[b] This mass estimate is for the young population.

[c] A mass of 10,000 $M_\odot$ is estimated using a number of 50 stars more massive than 20 $M_\odot$ (Negueruela et al. 2008), and a Salpeter IMF down to 0.8 $M_\odot$.

[d] The cluster mass is likely a lower limit because it was estimated assuming a distance of 2.8 kpc; recently Nazé et al. (2008) and Rauw et al. (2007) reported a distance of 8.0 ± 1.4 kpc.

MILKY WAY CLUSTERS



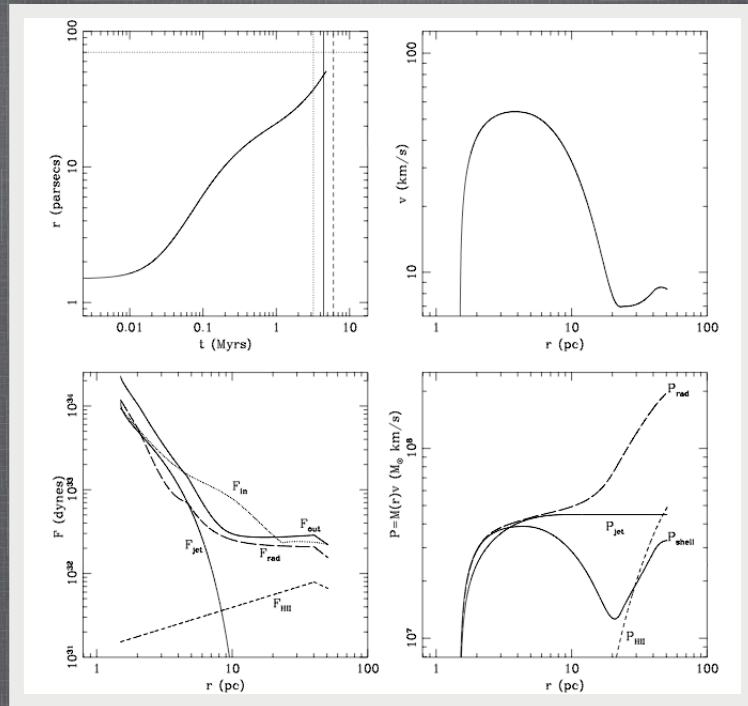
1.—Color mosaic of *HST* ACS WFC and NICMOS images of the nuclear region in M82. ACS F814W, NICMOS F160W, and NICMOS F222M
l to blue, green, and red, respectively. The image is ~25″ × 65″ (0.4 × 1.1 kpc) with north up and east to the left. About two dozen super star clusters a
f which are spatially coincident with and reddened by the band of variable extinction running from upper left to lower right in the image.

M82

McCrady & Graham (2007)

M81

- GMC masses similar to MW, $3x10^6$ M_{sun}
- Star cluster masses $\sim 7x10^5$ M_{sun}



r (parsecs)
t (Myrs)
v (km/s)
r (pc)
F (dynes)
F_in
F_out
F_jet
F_rad
F_HII
P=M(r)v (M⊙ km/s)
P_rad
P_jet
P_shell
P_HII

M82

M82

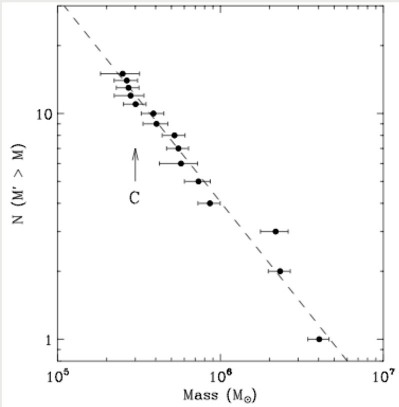


Fig. 8.—Cumulative mass function for the M82 SSCs. The dashed line indicates a power-law fit, where $N(M' > M) \propto M^{\gamma+1}$. The best fit has a slope of $\gamma = -1.91 \pm 0.06$. The estimated completeness point for cluster mass is marked "C" (see text). The fitted power law does not reflect any correction for completeness.

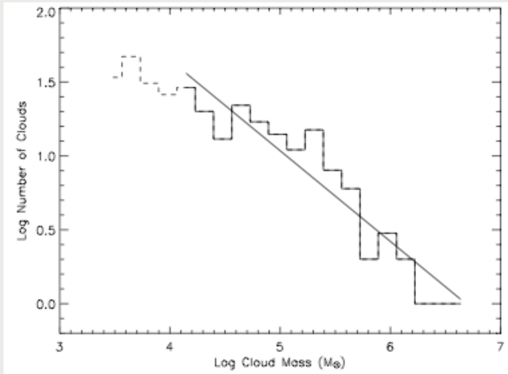


Fig. 3.—Mass spectrum of molecular clouds in the nucleus of M82. The cloud masses were estimated from the CO brightness and are binned at $\Delta \log M =$ 0.165 to produce 20 bins across the mass range from 3.4 to 6.7 $\log M_\odot$. The heavy solid line shows a fit to the M82 data. The data from the dashed portion of the histogram, with cloud masses $<10^4\, M_\odot$, were not included in the fit. Here $dN/d \log M \propto -0.5 \pm 0.04$.

M82

- Less massive clusters fail to disrupt GMC---R_{GMC} much smaller than in MW (at same mass)
- Need ~25% of GMC mass in star cluster to disrupt

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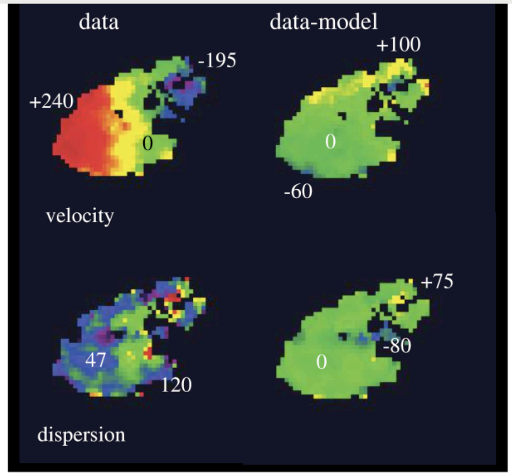
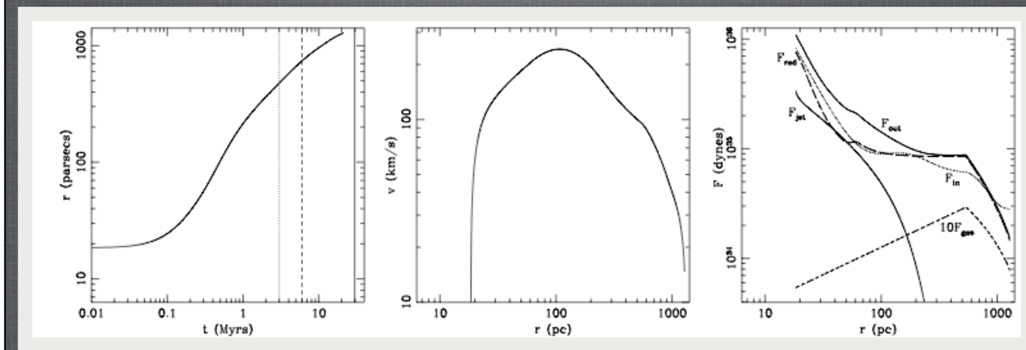
Clump Galaxy



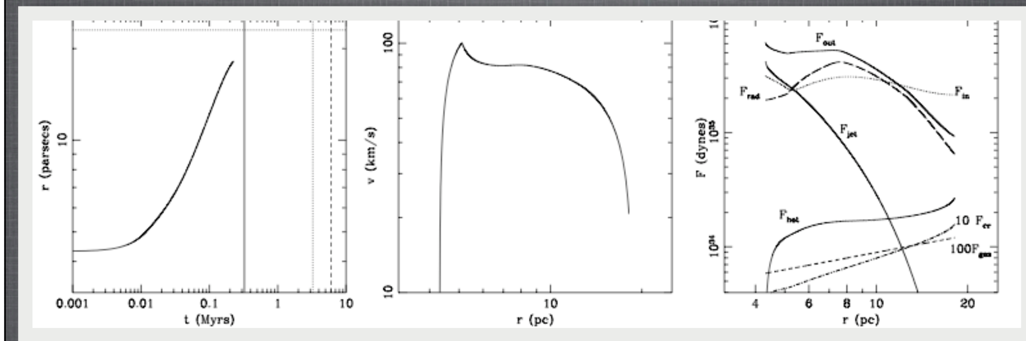
$M_* = 2.7x10^8\ M_{sun},\ \ M_{GMC} = 10^9\ M_{sun},\ \ R_{GMC} = 925pc$



ARP 220

- ULIRG, compact starburst (100pc disk)
- surface density 7g/cm^2 (3300 M_{sun}/pc^2)

$M_* = 1.4x10^7\ M_{sun},\ \ M_{GMC} = 4x10^7\ M_{sun},\ \ R_{GMC} = 5pc$



STELLAR FEEDBACK

- Gravity ~ M^2, so $F_{rad} \sim \tau L \sim M^2$ looks promising
- Simple 1-D model does show disruption
- Motivated by this, a search for large bubbles in MW, with positive results
- turbulent velocities increase with increasing surface density, since more massive clusters form
- Predict that GMC efficiency increases with surface density