DESTRUCTION OF GMCs

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OUTLINE

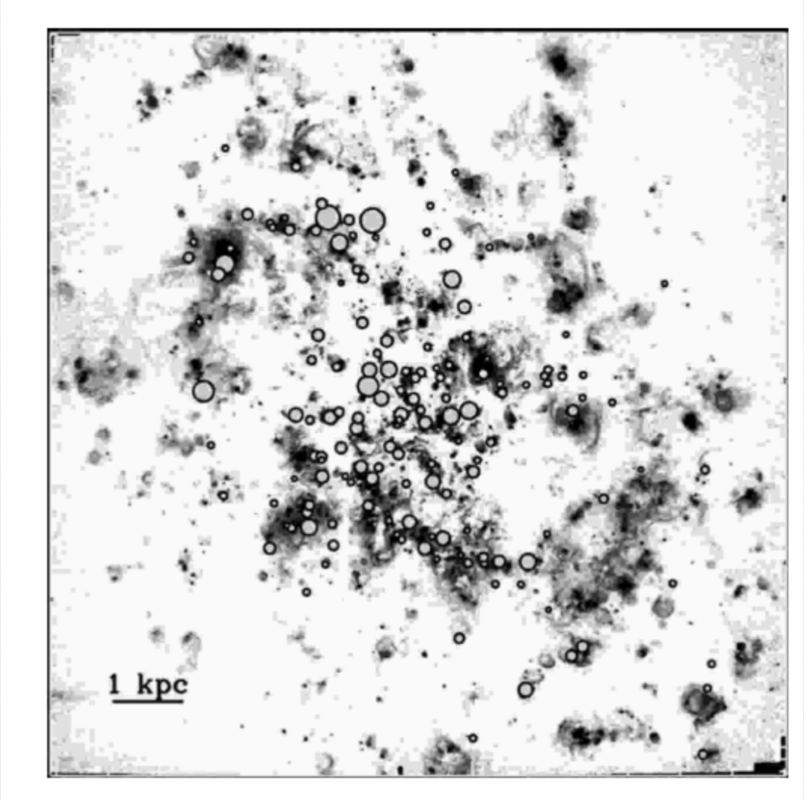
- Observations: dynamics and lifetimes
- Feedback mechanisms
    - Photoionization
    - Radiation
    - Winds
    - Supernova

OBSERVATIONS: HII REGIONS

Trapezium stars and
Champagne flow

H alpha + CO maps

Orion A:
Hubble (green/blue) + Spitzer (red/orange)

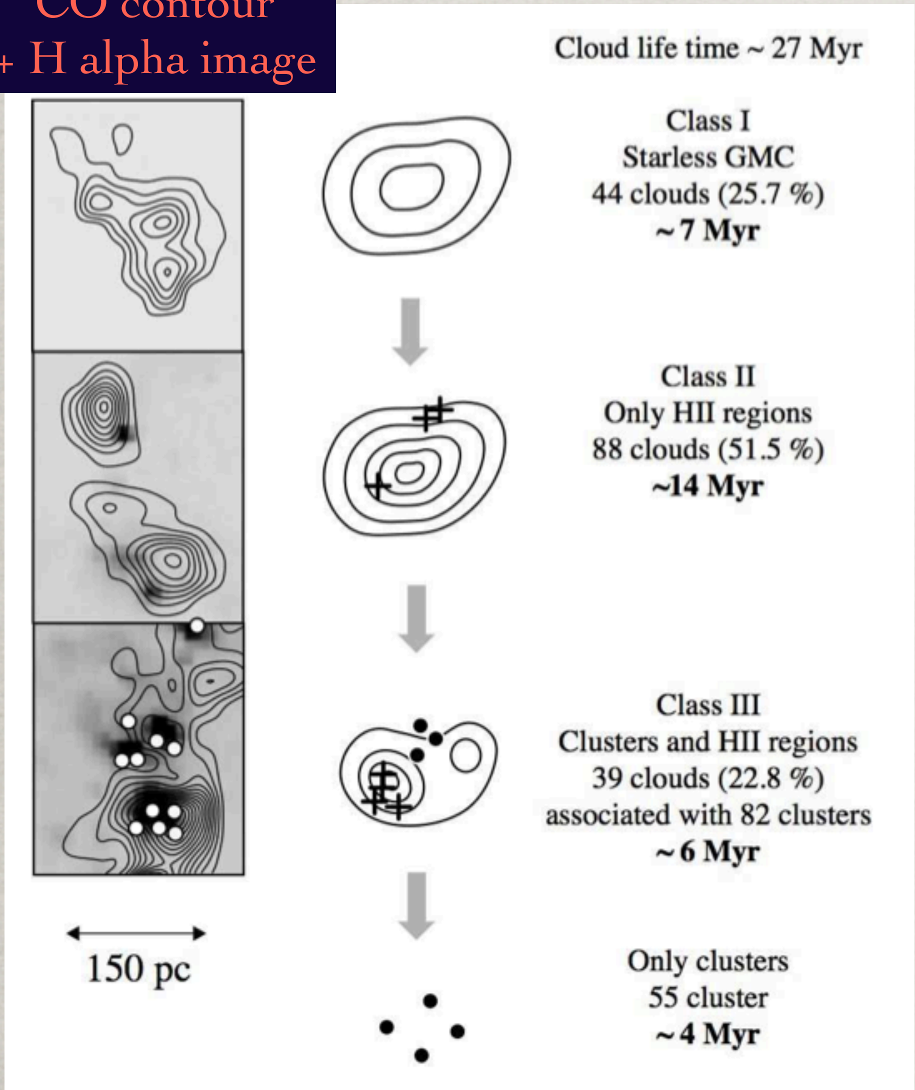


Locations of GMCs in M33

Blitz et al. 2006

OBSERVATIONS: CLOUD LIFETIMES

CO contour
+ H alpha image



- Example in LMC
  - compute frequency-> time in each phase (steady state)
  - absolute age given by young star cluster

...summing up:

cloud lifetime is ~27 Myr

Doing the same for nearby galaxies: LMC, SMC, M33, IC 10, M31 one concludes that lifetime is ~ 20-30 Myr

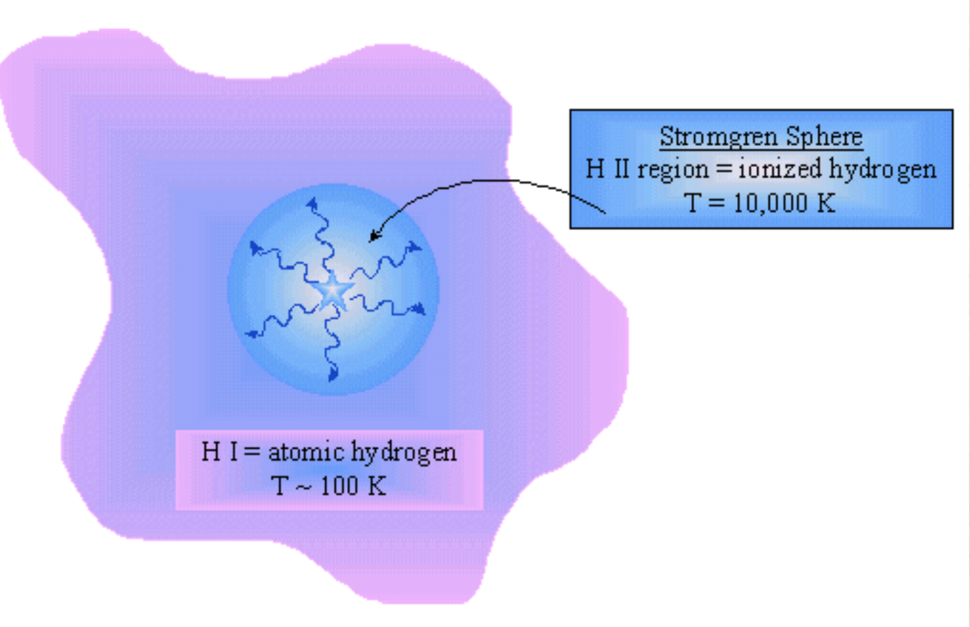
Blitz et al. 2006

FEEDBACK MECHANISMS

- Internal mechanisms:
    - Photoionization (HII gas pressure)
    - Radiation pressure
    - Winds
- Stage II: Supernova

$$\frac{dP_{shell}}{dt} = -F_{grav} + F_{H\ \mathrm{II}} + F_{rad} + F_{winds} + F_{SN}$$

HII REGION: IONIZATION



Strömgrem Sphere:

ionization = recombination

$$S = \frac{4\pi}{3} R_{St}^{3} \alpha_{B} n(HII) n(e)$$

$$R_{St} = 2.8 S_{49}^{1/3} n_{2}^{-2/3} \text{ pc}$$

S : emission rate of ionizing photons

α_B: recombination rate

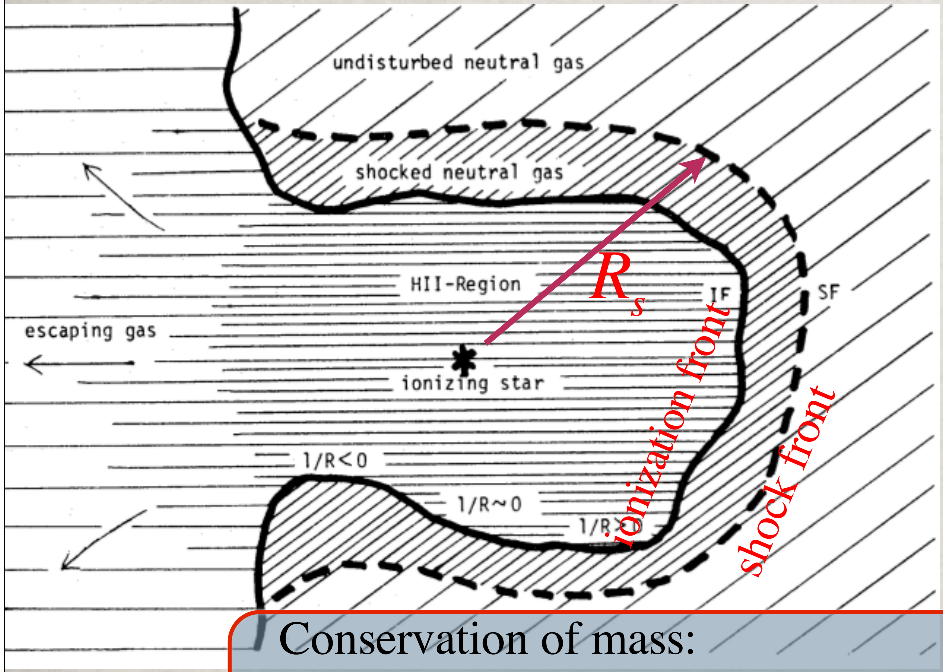
$$c_{II} \approx 10 T_{4}^{1/2} \text{km/s}$$

$$\tau_{ionization} = \frac{\# ions}{rate} \approx 10^{3} yr$$

Rosette Nebula (H alpha emission)

HII REGION: EXPANSION

- Order of magnitude by Whitworth 1979: gas pressure dominated



R_s : characteristic size HII region (R_{St})

Shock into cloud:

$$\rho_{II}c_{II}^2 \approx \rho_0 v_{shock}^2$$

$$\rightarrow v_{shock} = \frac{dR_s}{dt} \simeq \left(\frac{\rho_{II}c_{II}^2}{\rho_0}\right)^{1/2} \propto \left(\frac{S}{R_s^{\;3}}\right)^{1/4}\left(\frac{c_{II}^2}{\rho_0}\right)^{1/2}$$

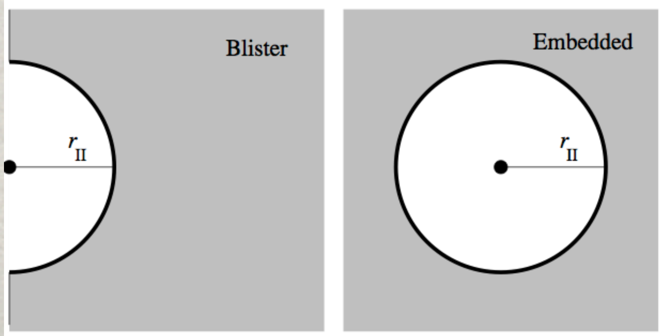
$$\Rightarrow R_s^{\;7/4} \propto t \rightarrow R_s = 8.7\left(\frac{S_{49}}{n_{H0,3}^2}t_6^4\right)^{1/7} \text{ pc}$$

Conservation of mass:

$\dot{M}_{lost} = \eta R_s^2(t)\rho_{II}(t)c_{II}$; η geometrical factor

$$\Delta M_{lost} \approx 2000\left(\frac{S_{49}^4}{n_{H0,3}}t_6^9\right)^{1/7} M_\odot$$

if $S_{49} \propto M_{GMC}$, $\Delta M_{lost}\big/M_{GMC} \propto M_{GMC}^{-3/7}$



HII: SIMULATIONS

- Let's start with a "simple" simulation: Isolated HII region (single star)
  - "MHD+radiative transfer+cooling/heating due to absorption of stellar radiation of gas/dust + advection of neutral/ionized gas"

Arthur et al. 2011

Hydro *MHD*

B0.5 star

at $1Myr$

$n_0 = 100cm^{-3}$

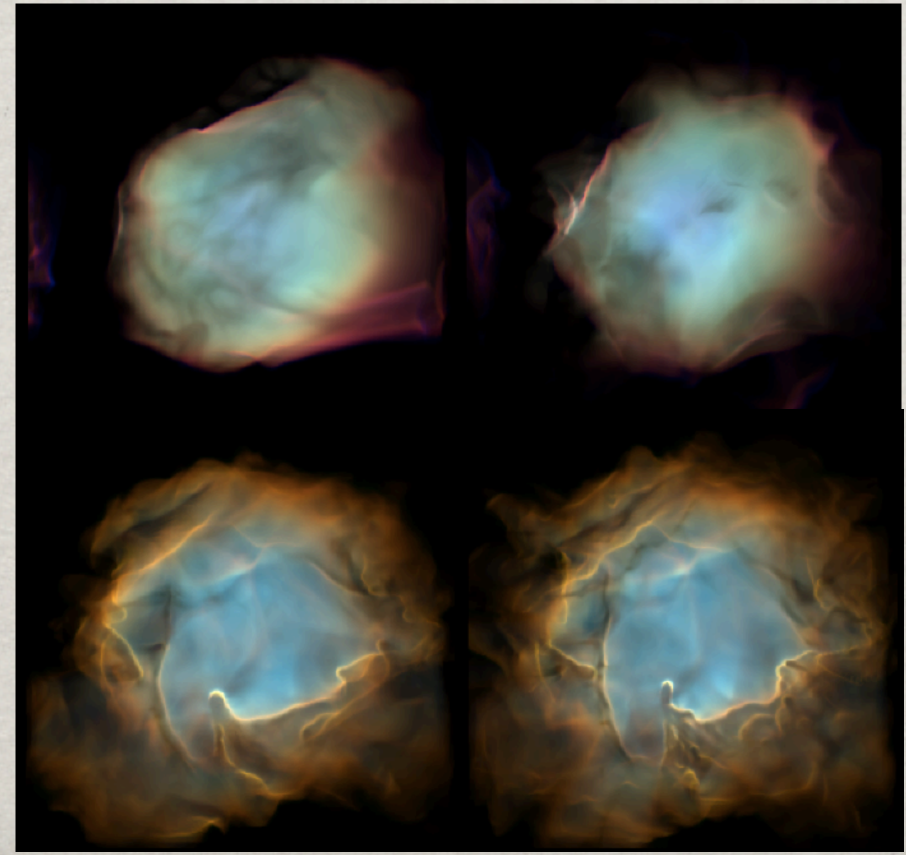
$T_0 = 11K$

$B_0 = 14.2\mu G$

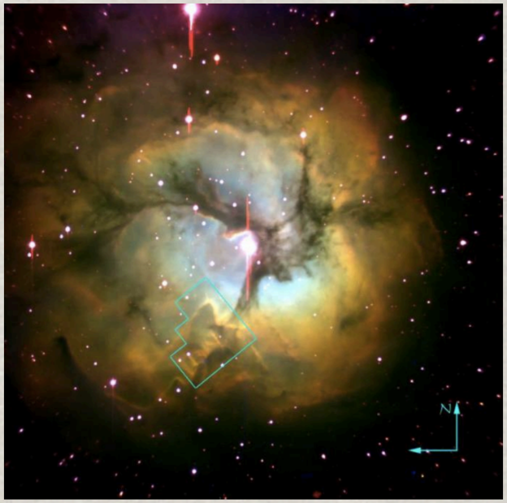
$Box\ 20\text{-}40pc^3$

O6 star

at $0.2Myr$



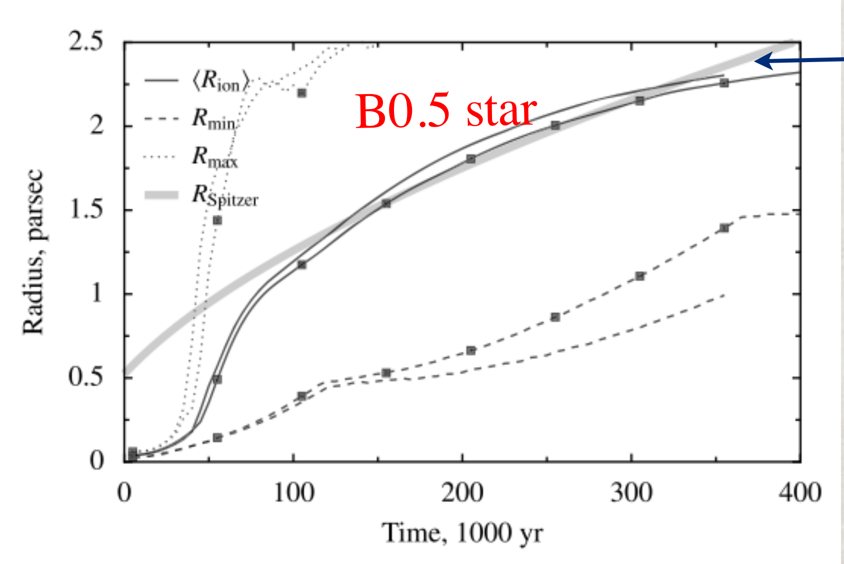
- Optical emission-line images in the light of [N II] 6584 Å (red), Hα 6563 Å (green) and O III 5007 Å (blue).



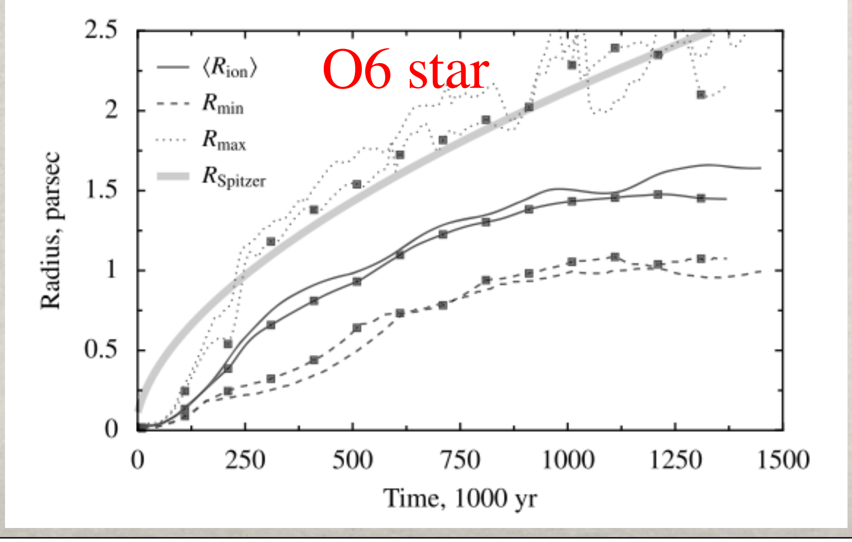
Trifid nebula: Red shows [S II] ll 6717+6731. Green shows Ha l 6563. Blue shows [O III] l 5007.

HII: SIMULATIONS

- Comparison with simple analytic theory



$$R_s(t) \equiv R_{Spitzer} = R_{St}\left(1+\frac{7c_{II}t}{4R_{St}}\right)^{4/7}$$



- Some general results:
  - maintained velocity dispersion ~7-9km/s
  - little dynamical effect of magnetic fields

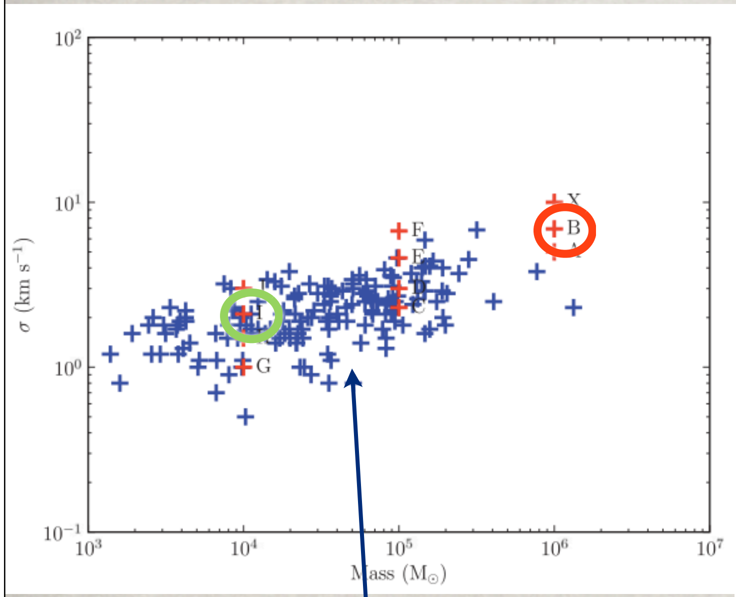
Arthur et al. 2011

HII REGION: CONCLUSION

- ... a single O/B star can disperse ~10^4 Mo in a few Myr, while lifetimes are tens of Myr.
  - Efficiency decreases with GMC mass
- Take home message: photoionization is efficient at removing the gas
- Indeed, Krumholz et al 2006 finds that for cloud models with only HII regions the in Local Group agree with observation: 20-30 Myr lifetimes
- But, what if escape velocity is larger than ~10 km/s?
  - e.g, cluster M82 has velocity dispersion of 10-30 km/s (lower limit) --> SFE is 100% or other mechanism removing gas

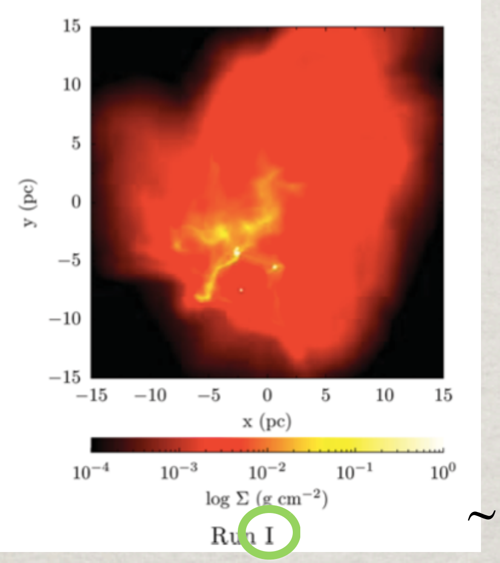
HII: SIMULATIONS

Dale et al. 2012

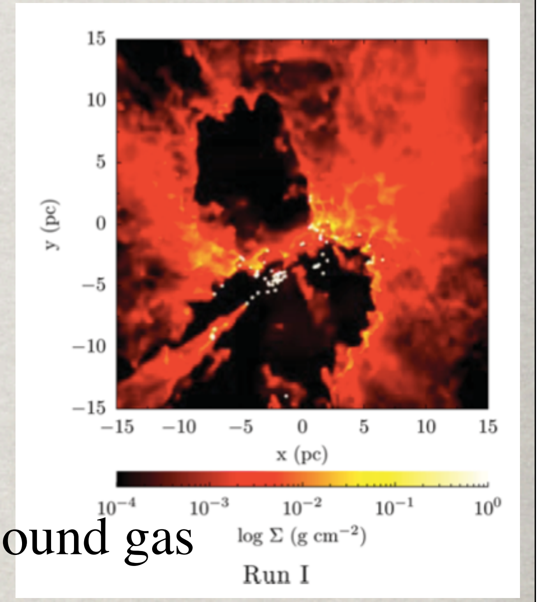


Sample of 158 GMCs

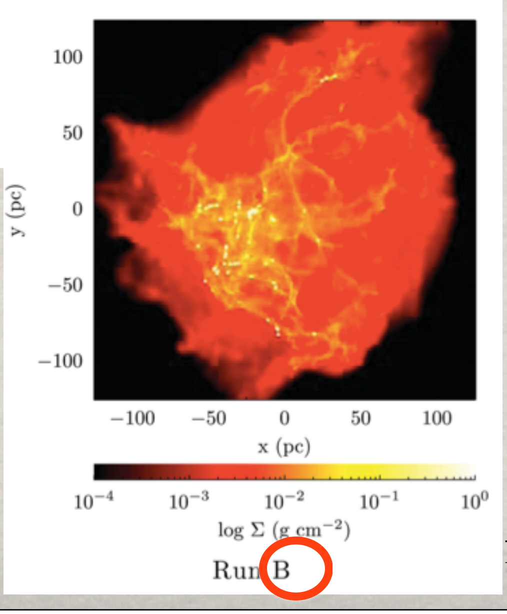
-Generally HII disrupt cloud (not massive/compact clouds)



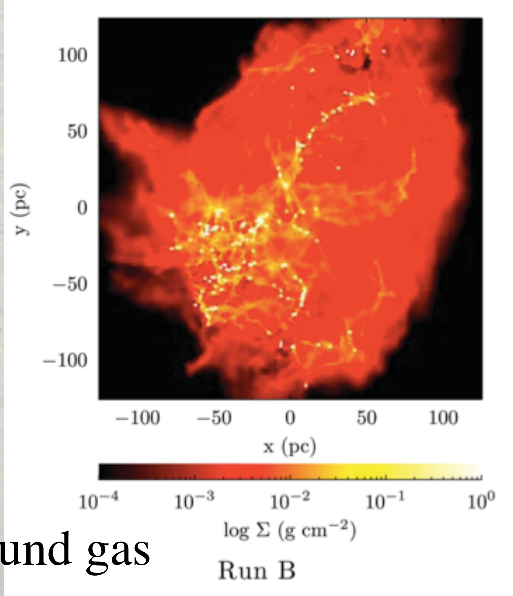
after 3*Myr*



~ 70 % of unbound gas



after 3*Myr*



few % of unbound gas

RADIATION-PRESSURE: BUDGET

- One possible way to remove the gas in massive GMCs is radiation pressure
  - Let's see if the numbers match: "budget"

Assume IMF: $\xi(m) = \frac{dn}{d\ln m}$

take quantity Q that stars of mass m

produce at rate $q(t,m)$, then:

$$\left\langle \frac{Q}{M} \right\rangle (t) = \int_m d\ln m\, \xi(m) \int_0^t dt'\, q(t',m)$$

$$\left\langle \frac{F_{rad}}{M} \right\rangle (t) = \frac{1+\tau_{IR}}{c} \left\langle \frac{L}{M} \right\rangle (t) = 23(1+\tau_{IR})\ \frac{km}{s \cdot Myr}$$

here is assumed that cloud is optically thick

to UV, τ_{IR} account FIR from dust

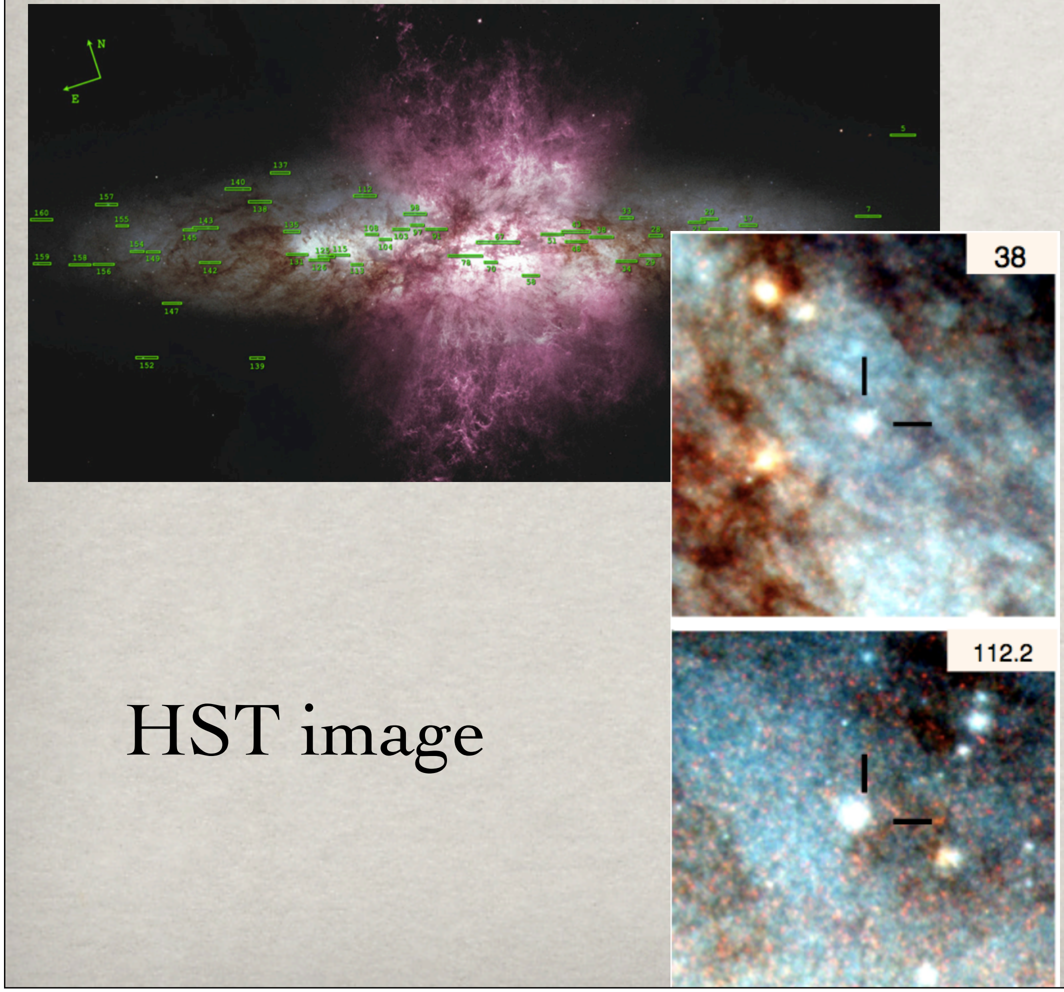
...for every gram of matter that goes into stars, they produce enough light over 1 Myr to accelerate another gram to ~23 km/s

For relatively high SFE or IR opacities this seems to work...

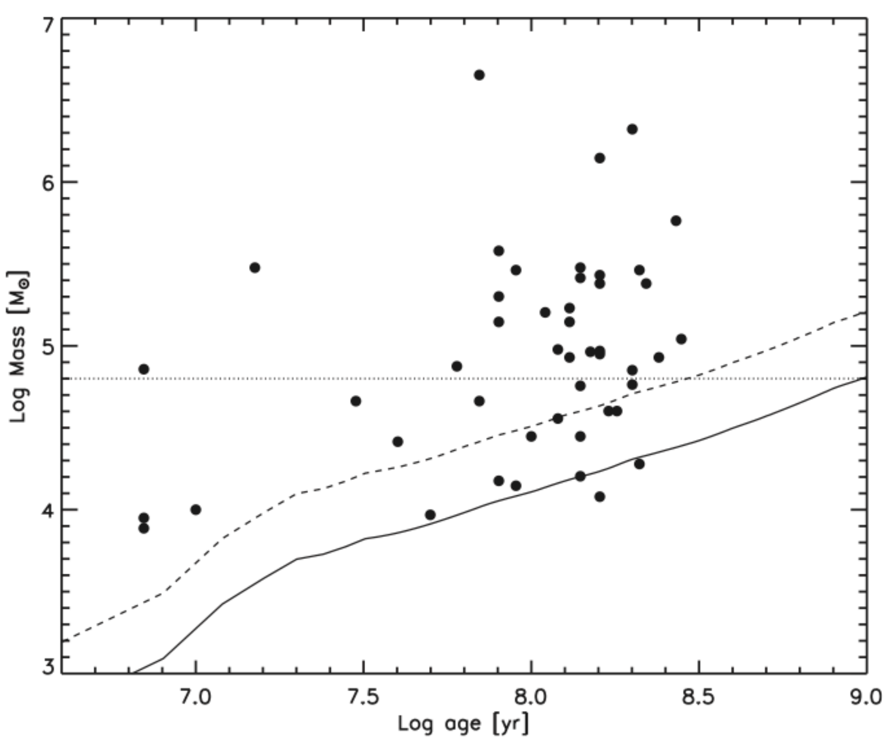
Notes from Krumholz

RADIATION-PRESSURE

- Let's consider one example: the starburst M82

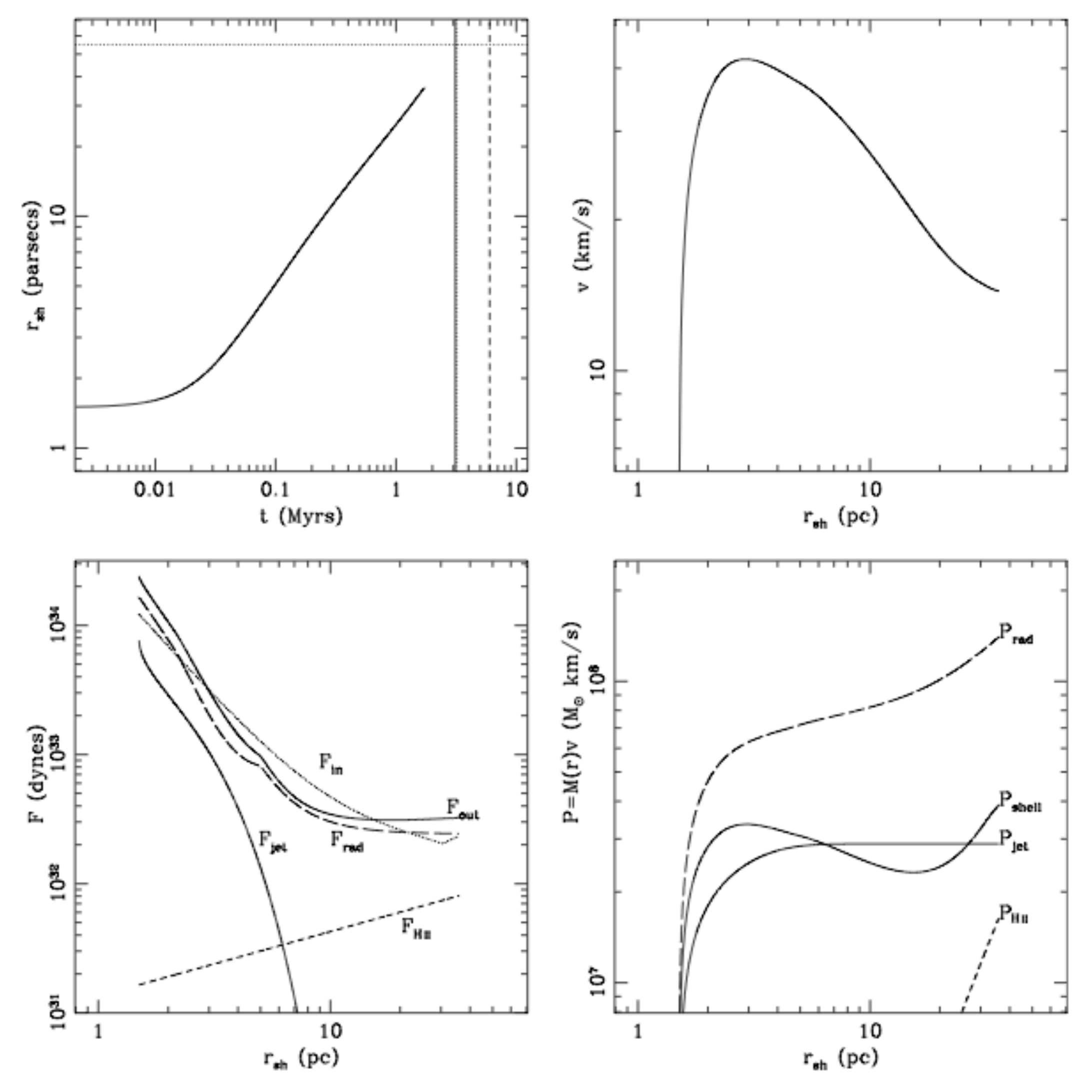


HST image



Konstantopoulos et al 2009

RADIATION-PRESSURE

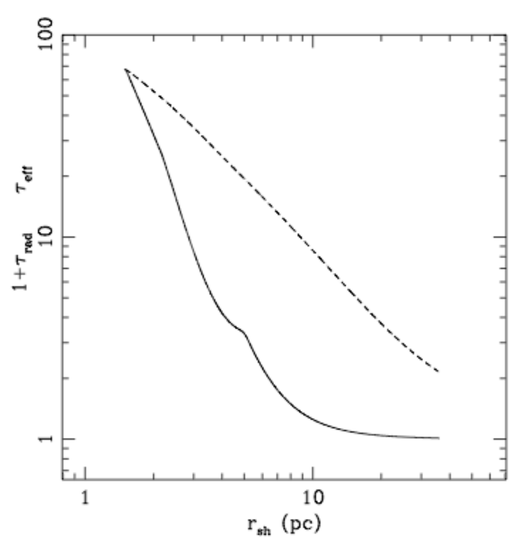


$$\frac{dP_{shell}}{dt} = -F_{grav} + F_{H\ \mathrm{II}} + F_{rad} + F_{winds} + F_{SN}$$

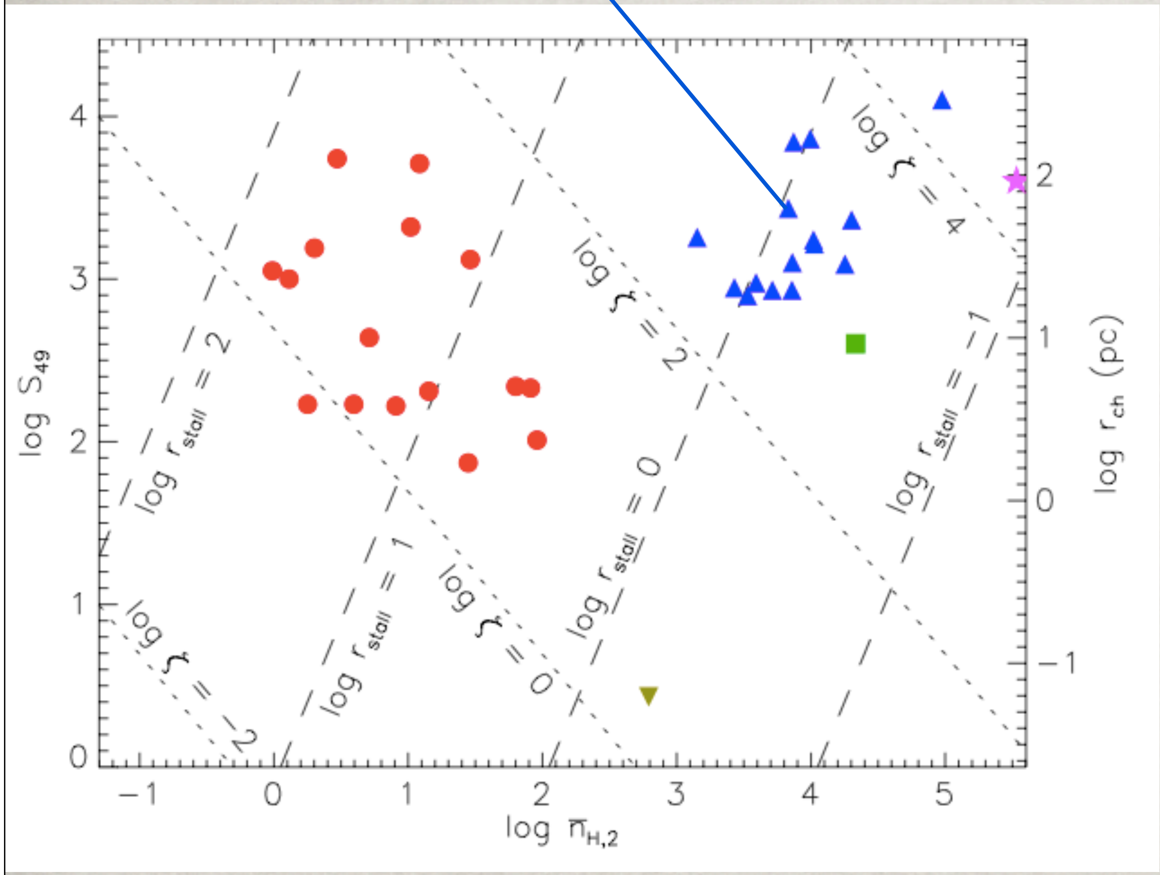
- 1D calculations for M82 by Murray et al 2010

$$\frac{F_{rad}}{F_{grav,shell}} \sim 1\left(\frac{\langle L/M\rangle}{1500\, L_\odot/M_\odot}\right)\left(\frac{\kappa_{FIR}}{30\, cm^2 g^{-1}}\right)\left(\frac{\varepsilon_{GMC}}{0.25}\right),$$

provided that $\Sigma_g > 0.5\, g cm^{-2}$ so that GMCs are optically thick to FIR



THE IMPORTANCE OF RADIATION PRESSURE



M82 clusters

- Again, radiation dominates in large GMCs

r_{ch} : radius at $P_{gas} = P_{rad}(r)$

$$\zeta \equiv \frac{r_{ch}}{R_{St}}$$

r_{stall} : expansion stalls

Krumholz & Matzner 2009

WINDS

- Not well-constrained (use model Starburst99)
- Momentum driven: $$\left\langle \frac{F_{wind}}{M} \right\rangle (t) \approx 7 \ \frac{km}{s \cdot Myr}$$
  - less than radiation...
- Energy driven: Winds from massive stars collide and form shock with T~10^7K--> could drive gas at ~100 times more kinetic energy than radiation, but
  - gas leaks out. Unless porosity is extremely small
    - unlikely: turbulence and low X-ray emission in bubbles

Krumholz & Matzner 2009

SUPERNOVA

A similar argument (but instantaneous) yields

$$\left\langle \frac{E_{SN}}{M} \right\rangle = \int_{m_{\min}=8M_\odot} d\ln m\,\xi(m) = 10^{51}\,\mathrm{erg/s}\,\left\langle \frac{N_{SN}}{M} \right\rangle,$$

where for a Chabrier IMF

$$\left\langle \frac{N_{SN}}{M} \right\rangle = \frac{0.01}{M_\odot}$$

The ejecta has roughly $\mathrm{v}_{shell} \approx v_{ej} \approx 10^4\, km/s$

$$\left\langle \frac{P_{SN}}{M} \right\rangle = \frac{2}{v_{shell}} \left\langle \frac{E_{SN}}{M} \right\rangle = 55\frac{1}{v_{shell}}km/s$$

...for every $M_\odot$ that goes into stars provides momentum to raise another $M_\odot$ to $55\,km/s$.

Note also that $v_{shell} \propto r^{-2}$...

SUPERNOVA

-Timescale problem

$t_{cross} \sim 10^5 yr$ for cluster of less than ~$10^6 M_\odot$

star cluster reaches SFE~1 in a few t_{cross}

BUT

$t_{SN} > 3Myr$

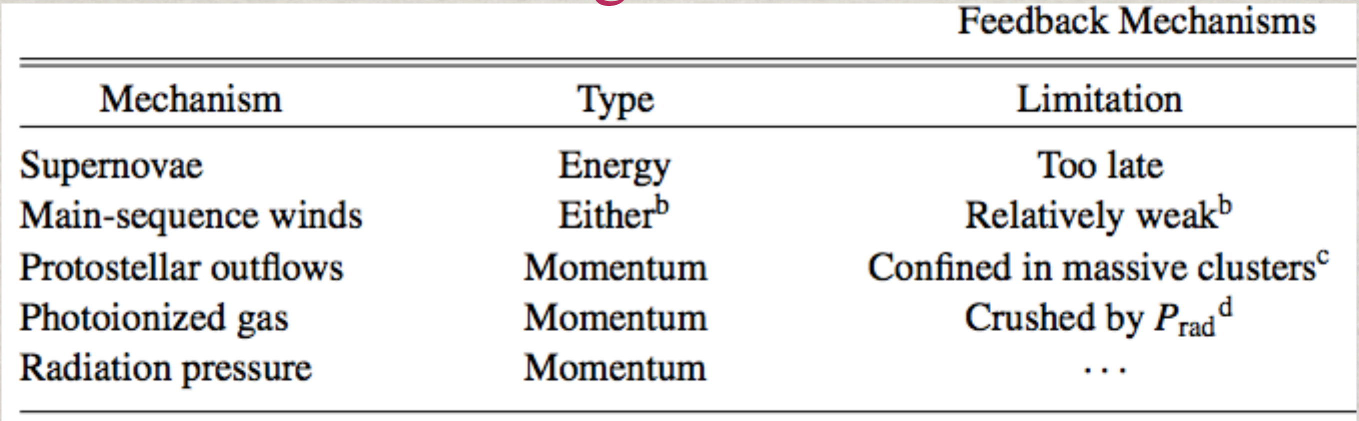
-This implies a limited role for the SN-->can be effective if other feedback mechanism quenches SF in ~10 crossing times

Krumholz & Matzner 2009

SUMMARY

- In general,
  - Observed GMCs lifetimes tend to agree with the evacuation times from HII expansions
  - For massive GMCs, HII can not expand and radiation can take over

High mass



Feedback Mechanisms

Mechanism	Type	Limitation
Supernovae	Energy	Too late
Main-sequence winds	Either^{b}	Relatively weak^{b}
Protostellar outflows	Momentum	Confined in massive clusters^{c}
Photoionized gas	Momentum	Crushed by $P_{\rm rad}{}^{d}$
Radiation pressure	Momentum	…

Table from: Fall, Krumholz & Matzner 2010

REFERENCES

- Arthur, S. J., Henney, W. J., Mellema, G., et al. 2011, MNRAS, 414, 1747
- Blitz L., Fukui Y., Kawamura A., Leroy A., Mizuno N., Rosolowsky E., 2007, in Reipurth B., Jewitt D., Keil K., eds. Protostars and Planets V. Univ. of Arizona Press, Arizona, p. 81
- Dale J. E., Bonnell I. A., Clarke C. J., Bate M. R., 2005, MNRAS, 358, 291
- Konstantopoulos I. S., Bastian N., Smith L. J., Westmoquette M. S., TranchoG., Gallagher J. S., III, 2009, ApJ, 701, 1015
- Krumholz, M. R., Matzner, C. D., & McKee, C. F. 2006, ApJ, 653, 361
- Krumholz, M. R., & Matzner, C. D. 2009, ApJ, 703, 1352
- Matzner, C. D. 2002, ApJ, 566, 302
- Murray, N., Quataert, E., & Thompson, T. A. 2010, ApJ, 709, 191
- Whitworth, A. 1979, MNRAS, 189, 59