WORKSHOP SUMMARY: PART III

--with apologies in advance to all the people who contributed to the success of the workshop but are not mentioned.

Chris McKee

12/07/07

High Mass Star Formation and Clusters

[Churchwell, Hanson, Henning, MeGeath, Shepherd, van der Tak]

Observations show that stars ~< 20 Msun (up to B stars) are formed by process similar to low-mass star formation

Circumstellar disks observed around such stars

More massive stars (O stars) more difficult to observe because more distant, in regions of greater extinction, and confused by hypercompact HII regions.

Time scale for formation ~ 10^5 yr

As yet, no evidence for circumstellar (as opposed to cluster-scale) disks

High-mass and clusters--2

Analysis of Spitzer data for star-forming regions within 1 kpc (MeGeath):

- Embedded clusters are not isolated, well-defined objects

- Even GMCs with young massive stars contain many low-mass stars in relative isolation

- Mean protostellar luminosity higher in crowded regions

- Embedded clusters form in a few Myr; associations can take over 10 Myr to form

Formation of Stars at High Redshift

[Bouwens, Elmegreen, Genzel, Labbe, Noeske, Steidel]

Starburst galaxies of today were normal galaxies at $z \sim 1\text{-}2$

LIRGs = Luminous Infrared Galaxies (10^{11} - 10^{12} L_{sun}) are starbursts now but were common then.

Bursts not common: SFR(z, M) constant to within factor 2 for 2/3 of optically selected galaxies

Maximum SFR $\sim 0.1\, f_g\, v^3/G \sim 0.1\, M\, f_g\, /\, t_{ff}$ (Elmegreen)

High SFR at high z because gas was in galaxies with higher v

Star-forming clumps were much more massive ($10^{8.5}$ M_{sun} vs $10^{5.5}$ M_{sun})

Elmegreen infers similar Jeans mass: $T^2/P^{1/2}$ ~ to local SF regions

High-z star formation--2

Most gas in high-z galaxies within a few kpc of center--smaller than today since formed from gas at higher density (Mo et al)

Feedback important: even fairly massive galaxies eject substantial metal-enriched gas into IGM

Maintaining Turbulence in GMCs

[Blackman, Clark, Frank, Hartmann, Hennebelle, Inutsuka, Krumholz, Li, Nakamura, Ostriker, Vazquez-Semadeni]

Current paradigm for star formation is that turbulence supports gas on large scales and generates gravitationally unstable cores on small scales that become stars (turbulent fragmentation). Has strong observational support.

A number of speakers (eg, Blackman, Clark, Hartmann, Vazquez-Semadeni) questioned this, and argued for the dominance of gravitational infall

Hennebelle and Inutsuka suggested that clumps in GMCs could be confined by warm (~ 10^4 K) HI heated by damping of HM waves

Maintaining Turbulence -2

A problem with the paradigm: How is the turbulence maintained? It is observed to be ubiquitous, but it decays in ~ 0.6 dynamical times

* Formation pumping

GMCs form by a magneto-gravitational instability on scales~10^{6-7} M_{sun} that will generate turbulence

(Classical Parker instability ineffective-- Kim & Ostriker)

Turbulence also generated by spiral density wave shocks

Explains turbulence only in first stage of GMC life.

* External forcing (SNRs, galactic MRI): ineffective due to impedance mismatch

Maintaining turbulence--3

*Stellar feedback

Protostellar outflows adequate for regions of active star formation like NGC 1333, but not for GMCs

HII regions appear adequate to maintain turbulence in GMCs (Matzner; Krumholz, Matzner, & McKee)

- GMCs undergo several oscillations before being destroyed
- Virial parameter self-regulated with SFR prescription of Padoan & Nordlund

Maintaining turbulence--4

Driven vs. decaying turbulence: Fundamental divide in simulation community since codes are currently unable to adequately represent stellar feedback or cover a sufficient range of scales

*Driven turbulence: maintain a fixed level of turbulence consistent with observation by ad hoc injection of energy (“science fiction”)

*Decaying turbulence: allow turbulence to decay; avoids ad hoc injection, but maintains observed level of turbulence for only short time interval and becomes very unrealistic for $t < 0$. Fails to include cascade of energy from larger scales.

This distinction underlies debate on validity of competitive accretion as a model for star formation: competitive accretion works only for decaying turbulence such that turbulent virial parameter becomes small

The Core Mass Function and the IMF

[Andre, Bate, Beuther, Blitz, Krumholz]

A number of observations suggest that the mass function of molecular cores determines the initial mass function of stars

Observational questions:

--One of the best cases (the Pipe Nebula--Alves et al) has almost no star formation

--The characteristic core mass increases with distance => not well determined yet. However, Enoch averaged data from 3 clouds and found a good match between the CMF and IMF with a scaling factor $\varepsilon_{core} = m_*/M_{core} \sim 0.25$.

--If the core lifetime depends on core mass, then the shape of the IMF will differ from that of the CMF

Theoretical problem: Cores can fragment gravitationally, destroying correspondence

Thermal feedback and the IMF--a recent development

Heating by accreting low-mass protostars increases the Jeans mass and suppresses gravitational fragmentation, thereby preserving the CMF-IMF correspondence

High-mass stars (Krumholz 06, Krumholz, Klein & McKee 07)

Low-mass stars (Bate & Whitehouse, in prep)

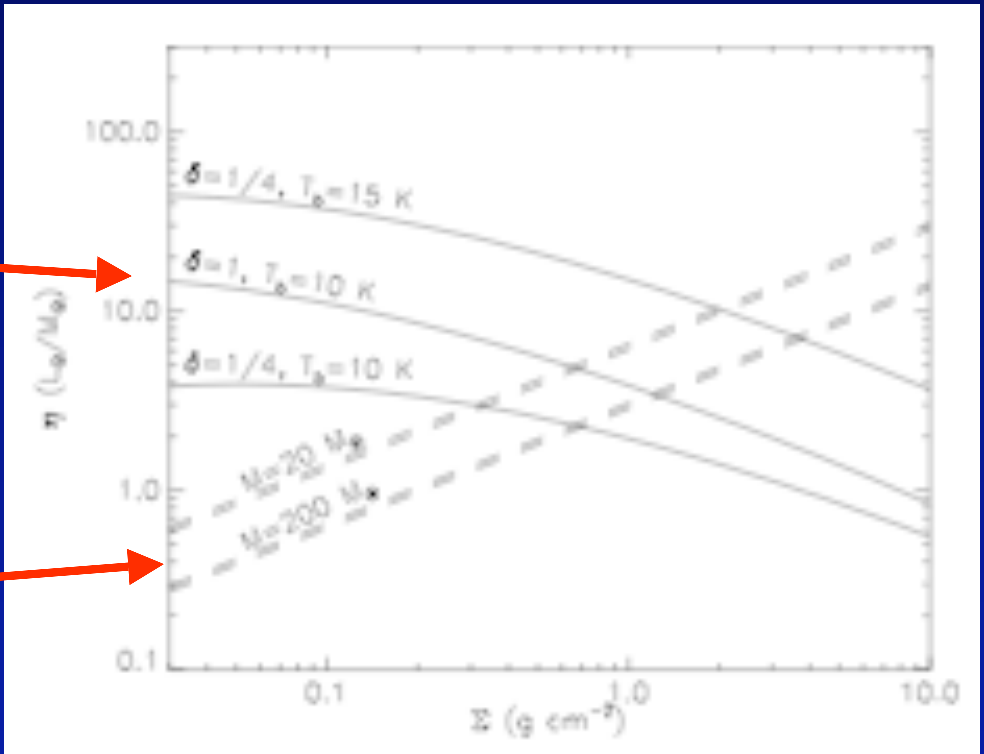
Thermal feedback--2

Thermal feedback determines the condition for massive SF, $\Sigma \sim 1$ g cm^{-2}

(Krumholz & McKee 08)

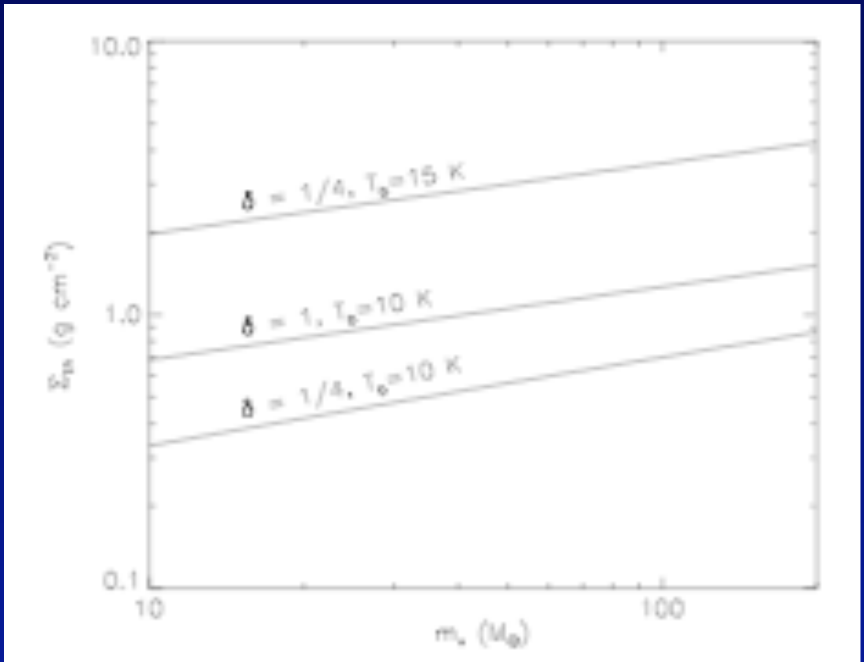
Light-to-mass ratio η needed to heat entire core above background temperature

Light-to-mass ratio produced by low-mass stars forming in core at a rate of a few % per free-fall time



Thermal feedback--3

Minimum surface density required for supression of fragmentation as function of stellar mass: Σ ~ 1 g cm^{-2}



Qualitatively consistent with MeGeath result that more luminous stars form in more crowded (=> higher Σ) regions

Can account for GALEX finding of UV emission but no H-alpha emission in the outer parts of disk galaxies: surface density Σ too low for high-mass star formation there

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