Gravity or Turbulence? Dynamics, Fragmentation and Cloud Structure

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Bondi-Hoyle accretion?

Yes. Modified by the global potential well, but still BH accretion

See poster 5

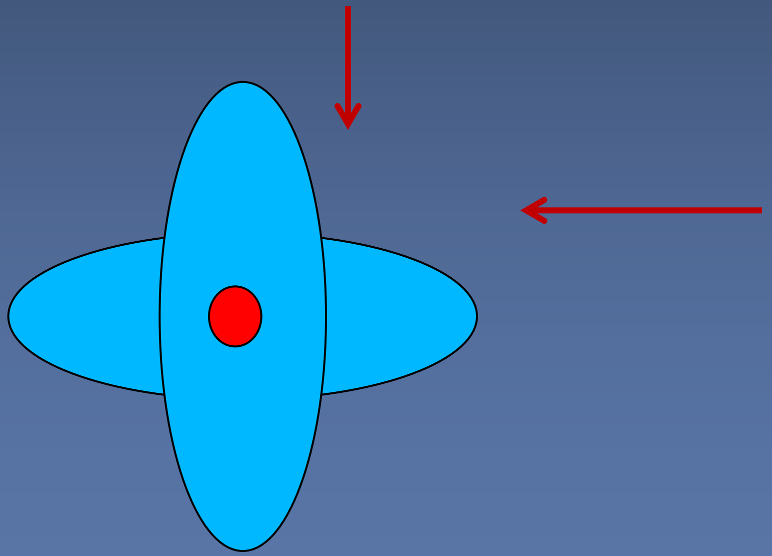
(BP, Hartmann, Pérez-Goytia & Kuznetsova, MNRAS submitted)

En términos generales, si

$$\dot{M} = \alpha(t) M^n$$

entonces

$$\xi(M) \propto \frac{d \log M_0}{d \log M} \propto M^{-(n-1)}, \qquad n > 1$$



Wilson, Jefferson & Penzias (1970)

- Supersonic linewidths

L44 R. W. WILSON, K. B. JEFFERTS, AND A. A. PENZIAS

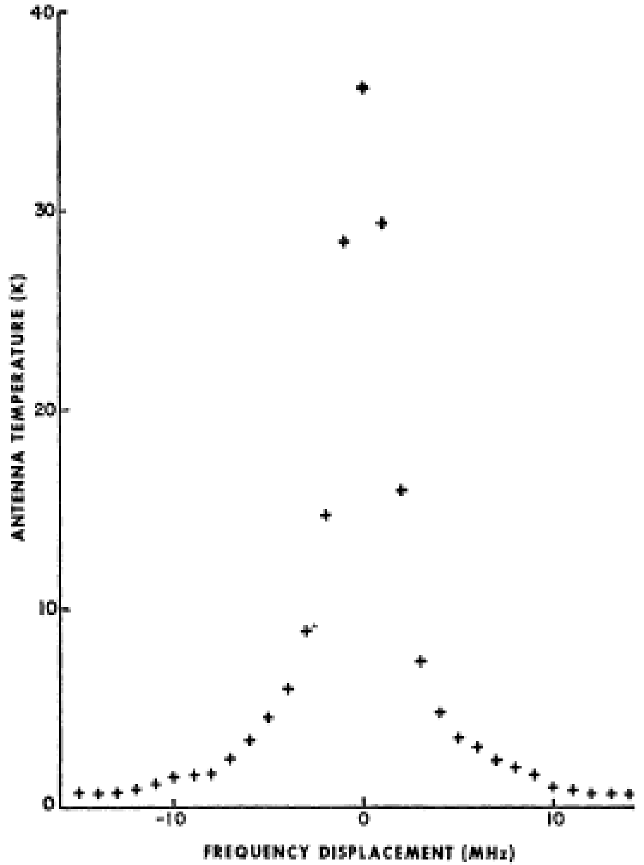


FIG. 1

Goldreich & Kwan(1974)

- MCs are in state of collapse

THE ASTROPHYSICAL JOURNAL, 189: 441–453, 1974 May 1

MOLECULAR CLOUDS

PETER GOLDREICH AND JOHN KWAN
California Institute of Technology, Pasadena
Received 1973 August 23

ABSTRACT

It is proposed that molecular clouds are in a state of gravitational collapse. The coupled equations of statistical equilibrium and radiative transfer from diatomic molecules in a collapsing cloud are solved for arbitrary optical depths in the rotational lines. It is shown that most of the observed CS and SiO lines and the stronger CO lines are optically thick. In this limit the emitted intensities are independent of the molecular dipole moments.

The rate at which energy is radiated in the CO lines is found to exceed the rate at which work is done by the adiabatic compression of the collapsing gas. This result implies the existence of an energy source which maintains the temperature of the gas against the cooling due to radiative energy losses. It is suggested that collisions between gas molecules and warm dust grains transfer energy to the gas. The dust grains are heated by radiation from H II regions and protostars in the center of the molecular cloud. This picture is supported by the detection of copious far infrared fluxes from many molecular clouds. The rate of energy transfer from the dust to the gas is calculated to be sufficient to maintain the gas at temperatures deduced from observations of CO lines if $N_{H_2} > 10^4\ cm^{-3}$.

Subject headings: molecules, interstellar — nebulae

Zuckerman & Evans(1974)

- Global collapse implies large SFRs

THE ASTROPHYSICAL JOURNAL 192:L149–L152, 1974 September 15

MODELS OF MASSIVE MOLECULAR CLOUDS

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Received 1974 May 10; revised 1974 July 5

ABSTRACT

Observations of carbon monoxide lines from massive molecular clouds, such as those near Orion A and Sgr B2, have recently been interpreted in terms of large-scale motions, generally collapse or expansion, that imply rapid evolution of these clouds. We suggest an alternative explanation: the clouds are not dominated by large-scale systematic motions and the CO profiles are determined primarily by local motions. Therefore, it is generally not possible to see through these clouds in optically thick lines of molecules such as CO and HCN. Some consequences and tests of this model are briefly discussed.
Subject headings: interstellar matter — line profiles — molecules, interstellar

I. INTRODUCTION

Observations of ^{12}CO and ^{13}CO lines in the direction of galactic H II regions have led to a new interpretation of the structure and internal motions of molecular clouds (Liszt 1973; Liszt *et al.* 1974; Goldreich and Kwan 1974). These authors suggest that CO line profiles are most readily understood in terms of simple, large-scale radial velocity structure, generally a symmetrical collapse or expansion of the entire cloud. In particular, Goldreich and Kwan (1974) have argued

formed in the cooler, outer edges of the cloud where the velocities with respect to the center are large. According to the RM model, the line profiles can best be understood as radial motions of the entire cloud, either collapse or expansion, about the center of mass. In addition to the arguments based on CO profiles, theoretical arguments in favor of collapsing clouds have been advanced, usually focusing on the large masses and the probable rapid damping of any supersonic turbulence which might prevent collapse (Goldreich

From then, clouds are considered turbulent. Several evidences:

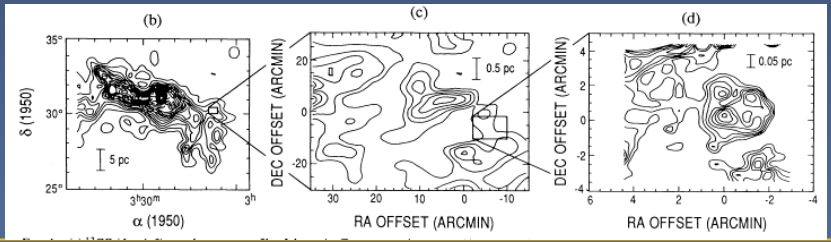
- Large Reynolds numbers

$$\mathcal{R} \equiv \frac{ul}{\nu}$$

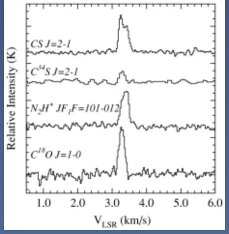
$$\mathcal{R} \sim 3 \times 10^7 \left(\frac{u}{\mathrm{km\ s^{-1}}}\right)\left(\frac{l}{\mathrm{pc}}\right)\left(\frac{n}{10^3 \mathrm{cm^{-3}}}\right)$$

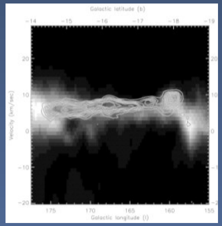
- Large density
- fluctuations

Fractal apparence of MCs (Scalo 1990; Falgarone et al. 1991)

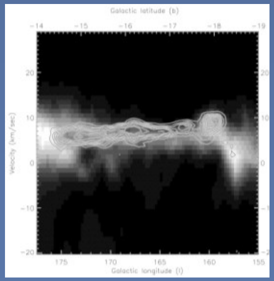


- Large velocity fluctuations

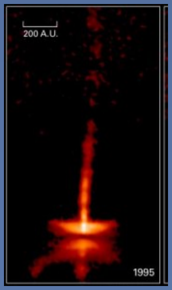


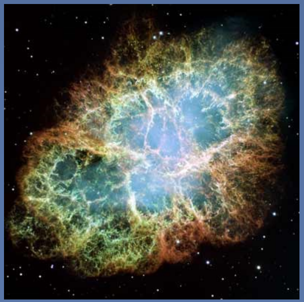


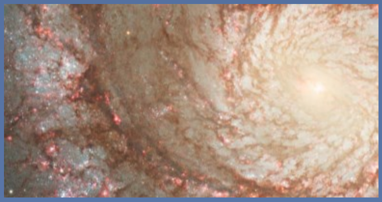
- Nonthermal linewidths



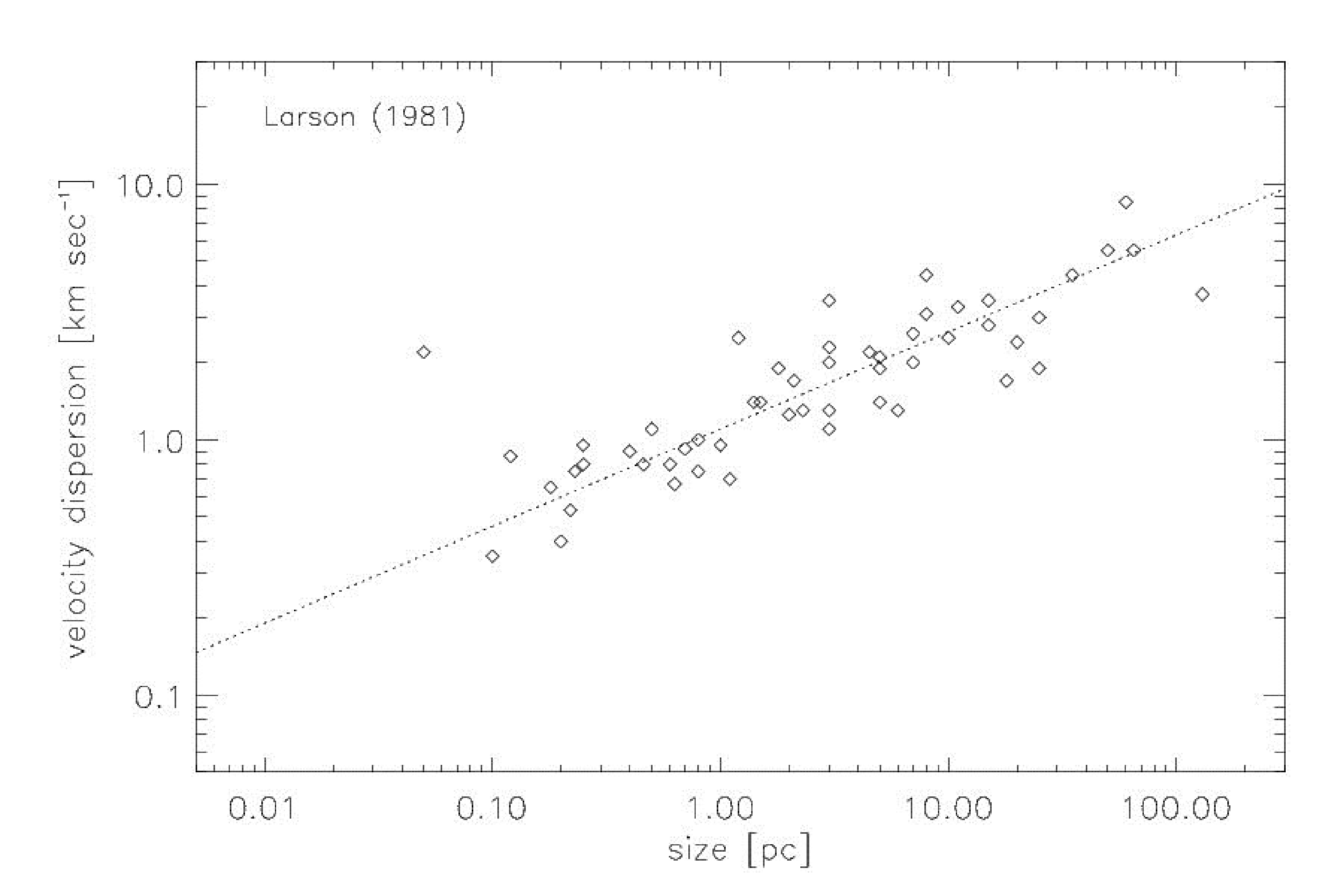
- Energy injection at all scales



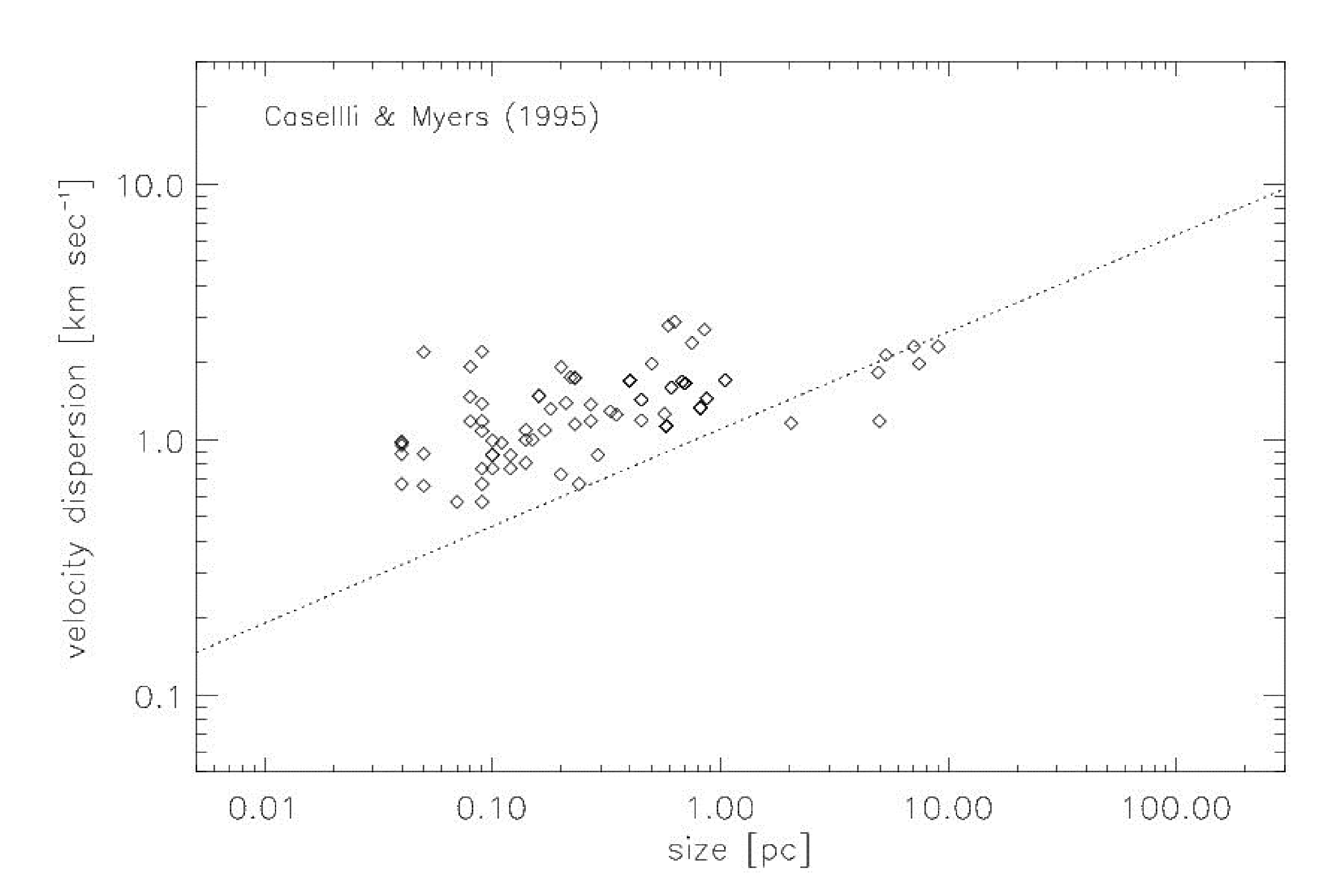




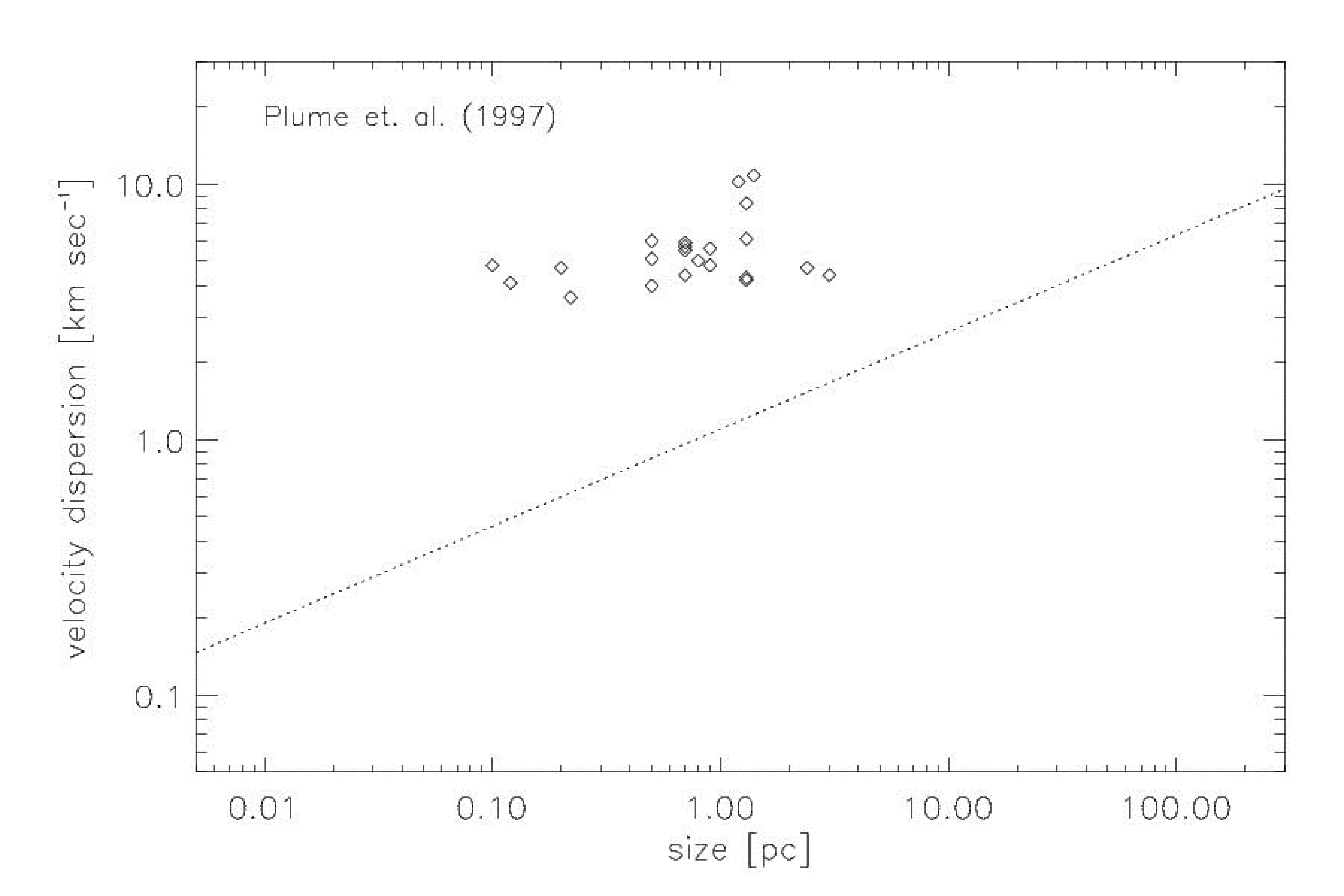
Larson (1981)


Larson (1981)
10.0
1.0
0.1
velocity dispersion [km sec^{-1}]
0.01
0.10
1.00
10.00
100.00
size [pc]

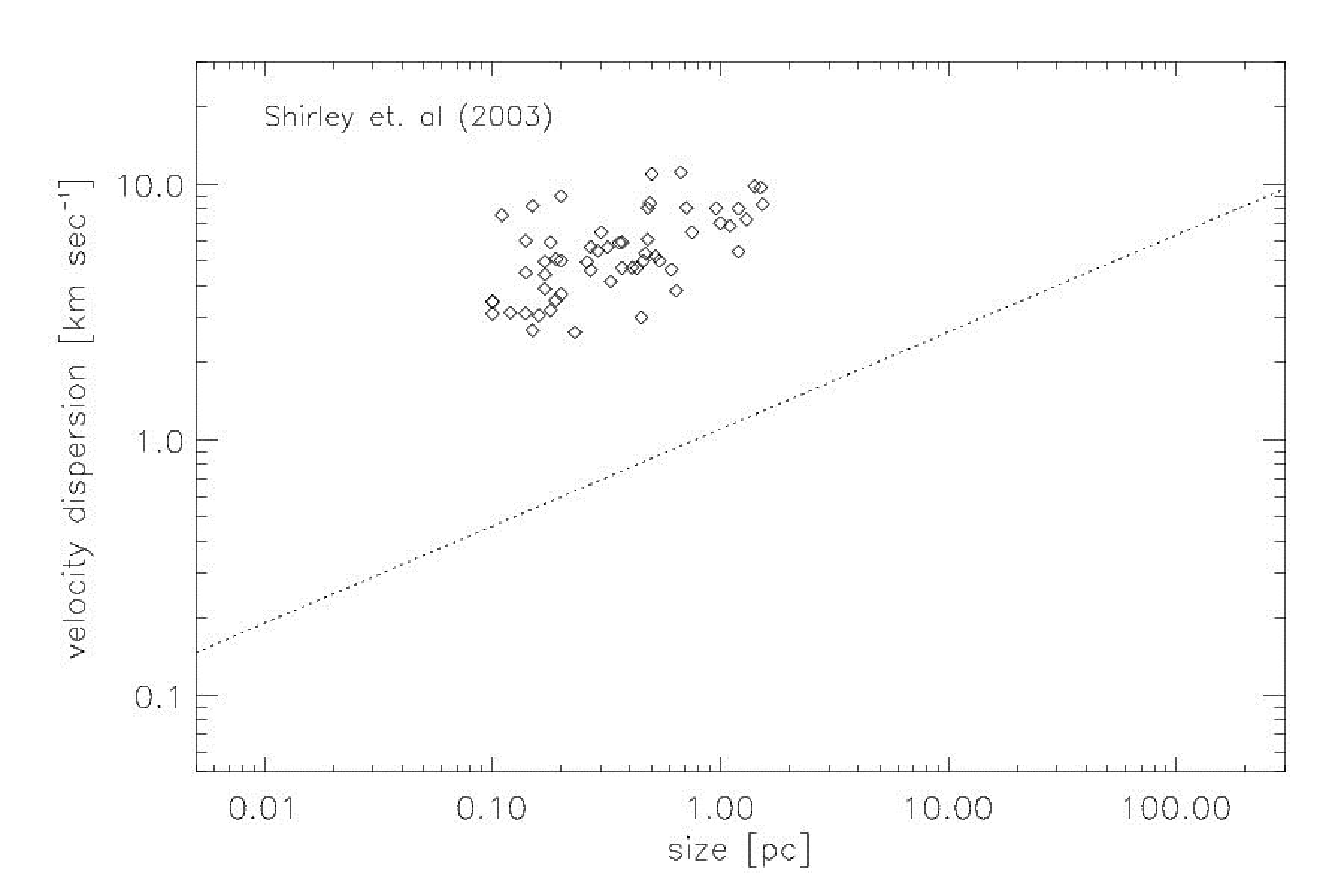
Caselli & Myers (1995)



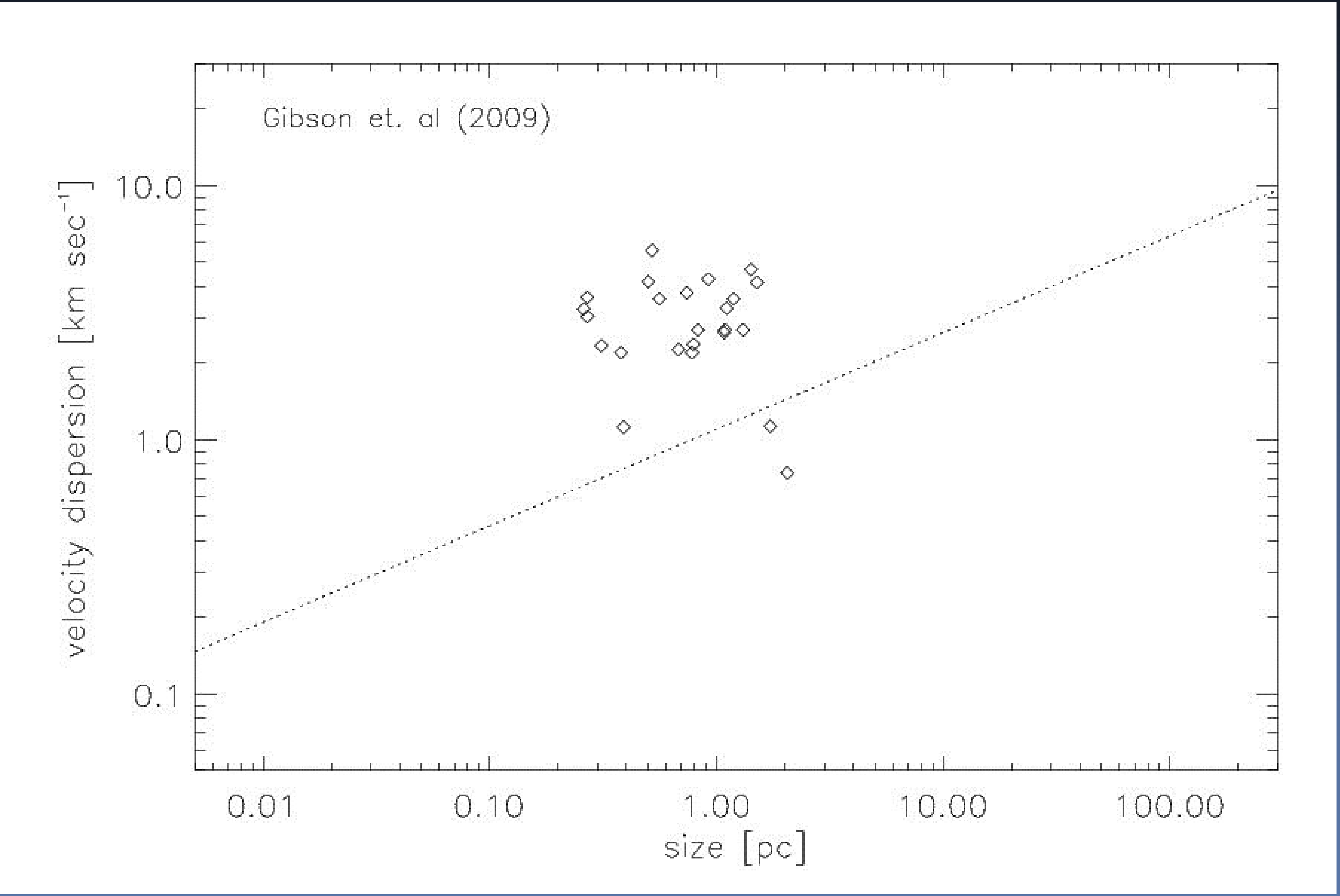
Plume et. al (1997)



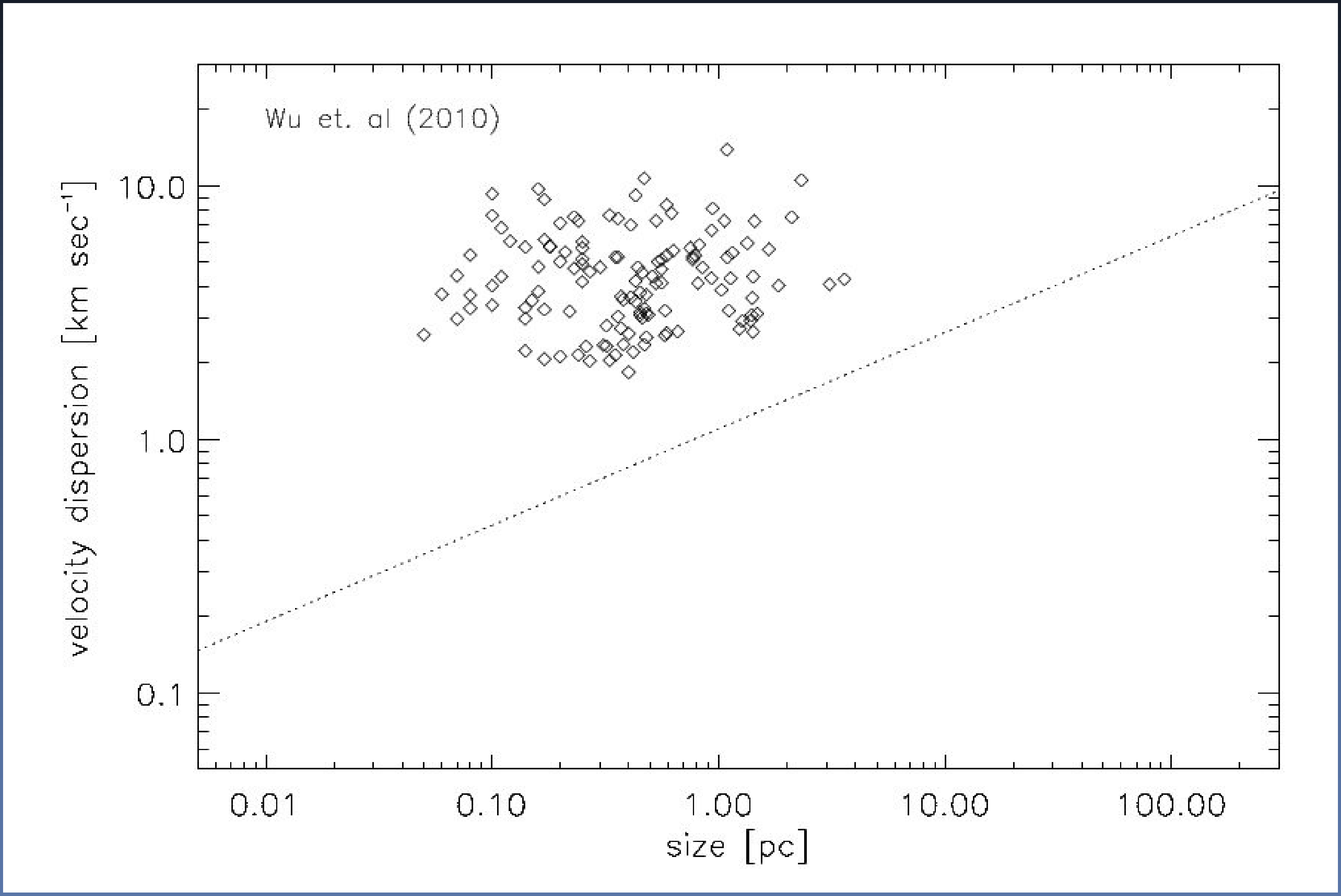
Shirley et al. (2003)



Gibson et al. (2009)

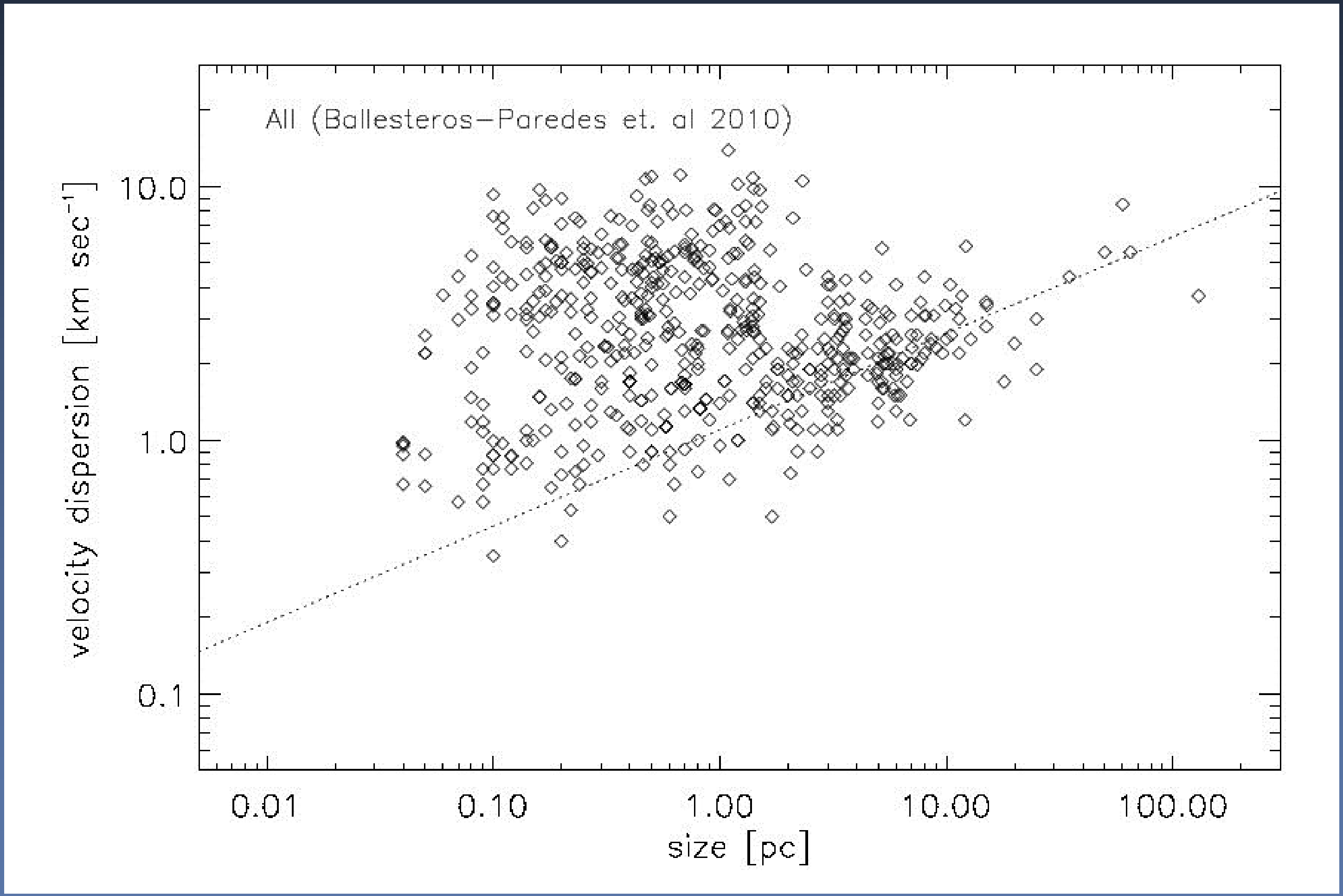


Wu et al. (2009)



Wu et. al (2010)
velocity dispersion [km sec^{-1}]
10.0
1.0
0.1
0.01
0.10
1.00
10.00
100.00
size [pc]

All together
(Ballesteros-Paredes et al. 2011)



Is there actually a δv–r relation,

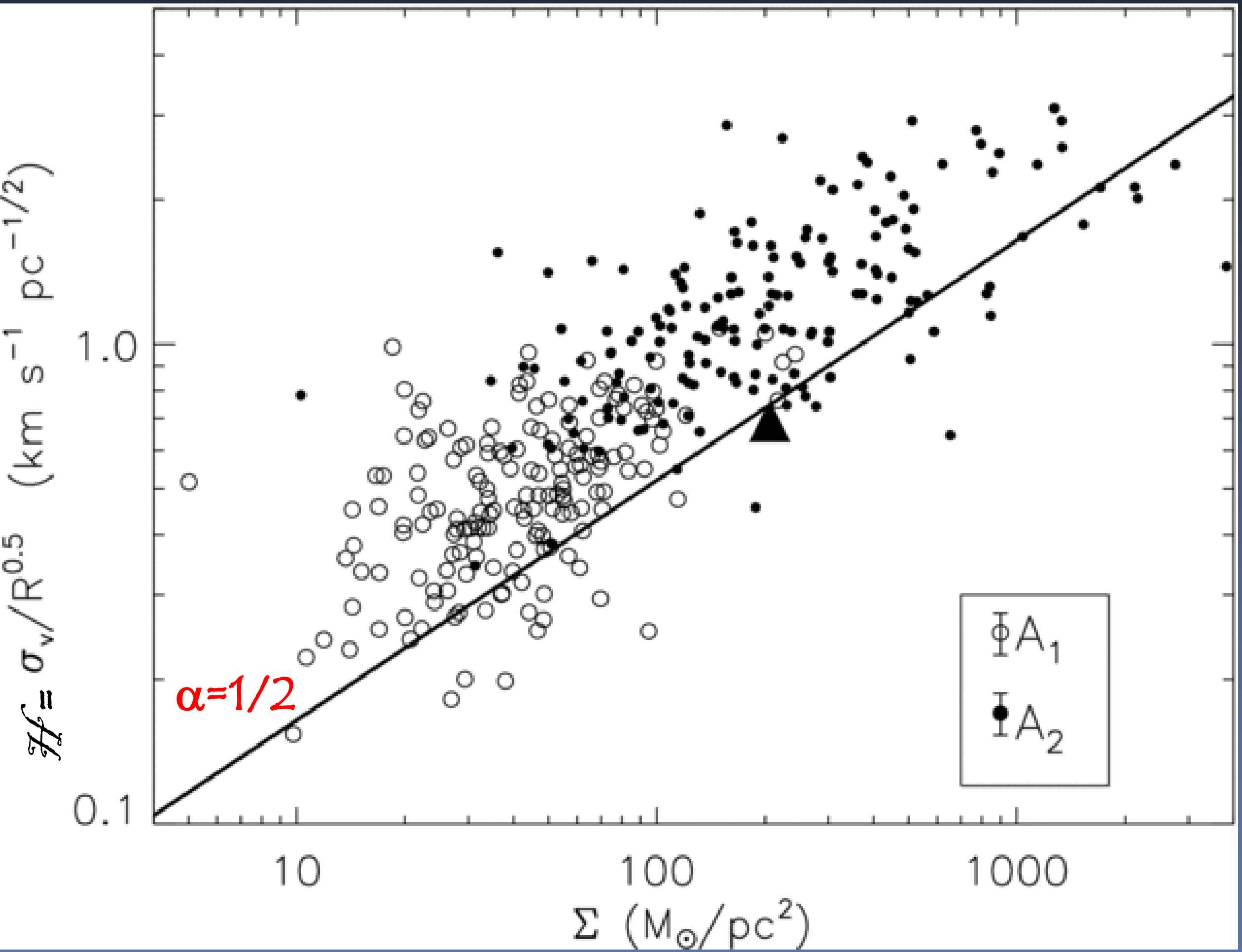
or not???

Is there actually a δv–r relation, or not?

$$\delta v = \mathcal{H} r^{1/2}$$

$$\mathcal{H} = \frac{\delta v}{r^{1/2}}$$

Heyer et al. (2009)



$$\mathcal{H} \propto \Sigma^{1/2}$$

How to understand Heyer's results

Cloud formation:

Clouds are formed by large-scale compressions at large scales in the ISM

(Ballesteros-Paredes, Vázquez-Semadeni & Scalo 1999;

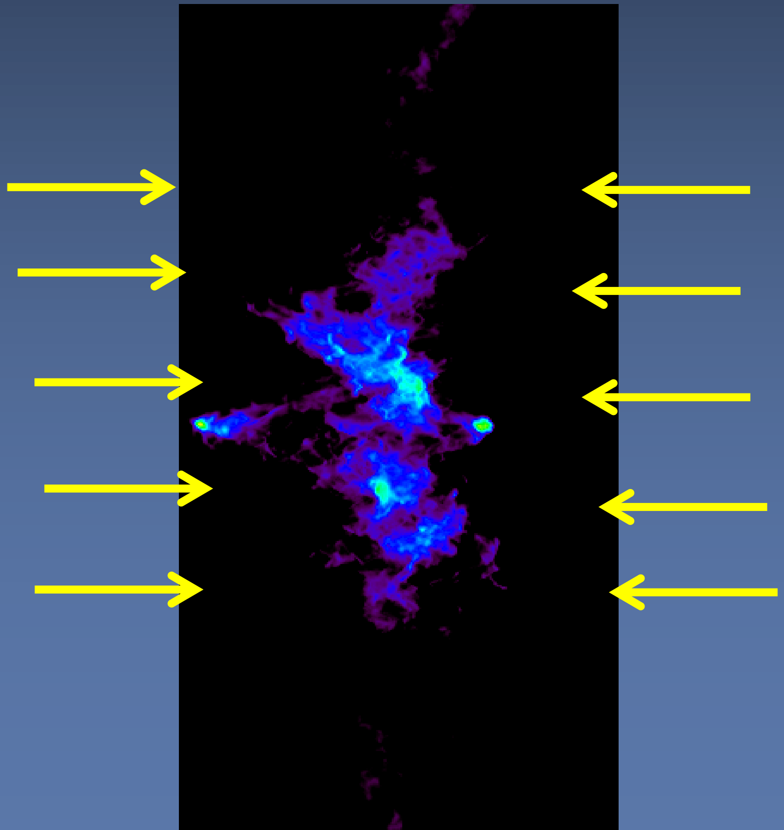
Ballesteros-Paredes, Hartmann & Vázquez-Semadeni 1999;

Hartmann, Ballesteros-Paerdes & Bergin 2001)

How to understand Heyer's results

Cloud formation:

If the diffuse ISM is thermally bistable, compressed gas cools down rapidly (Hennebelle & Pérault 1999)



How to understand Heyer's results

Then global collapse proceeds

Burkert & Hartmann 2004;

Vázquez-Semadeni et. al 2007

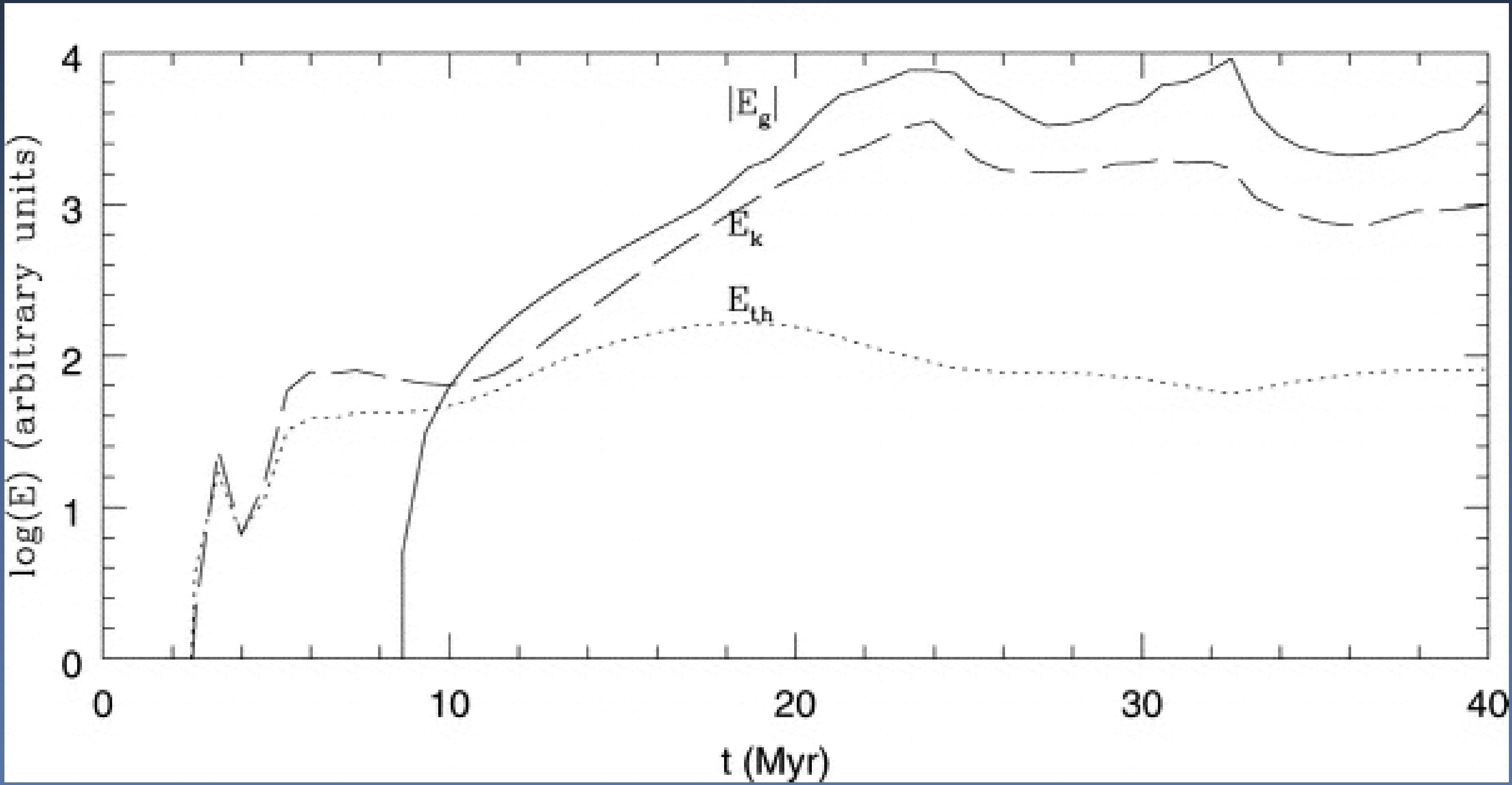
Heitsch & Hartmann 2008

Heitsch, Ballesteros-Paredes & Hartmann 2009

Vázquez-Semadeni et. al 2010)

Key ingredient:

Virial-like relation for collapsing gas (VS etal 2007)



If clouds are in global collapse

$$E_K = E_g$$

$$\frac{1}{2}\delta v^2 = \frac{GM}{R}$$

Si $\Sigma = M/R^2$,

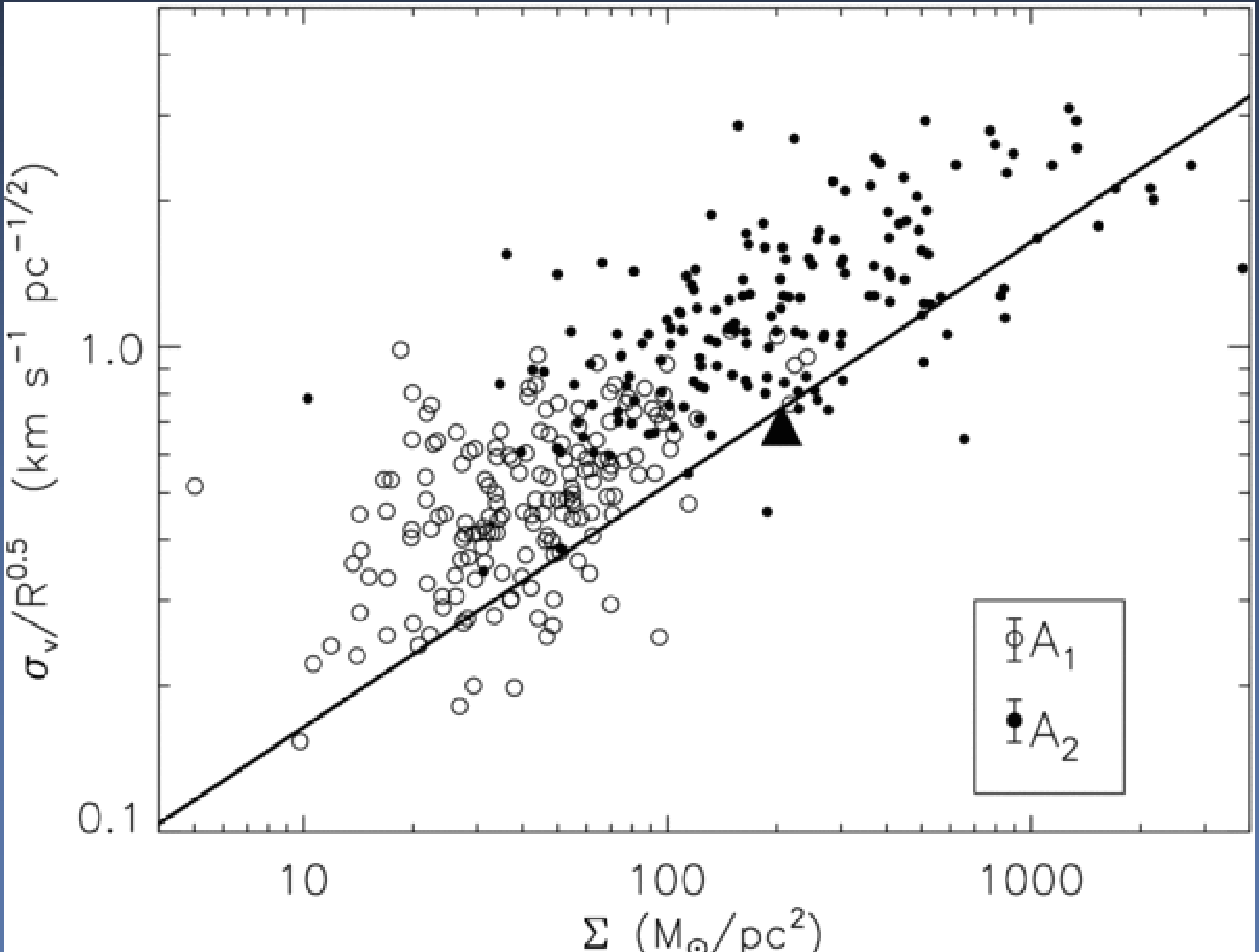
$$\delta v = \sqrt{2G\Sigma R}$$

o equivalentemente

$$\mathcal{H} \equiv \frac{\delta v}{R^{1/2}} = \sqrt{2G\Sigma}$$

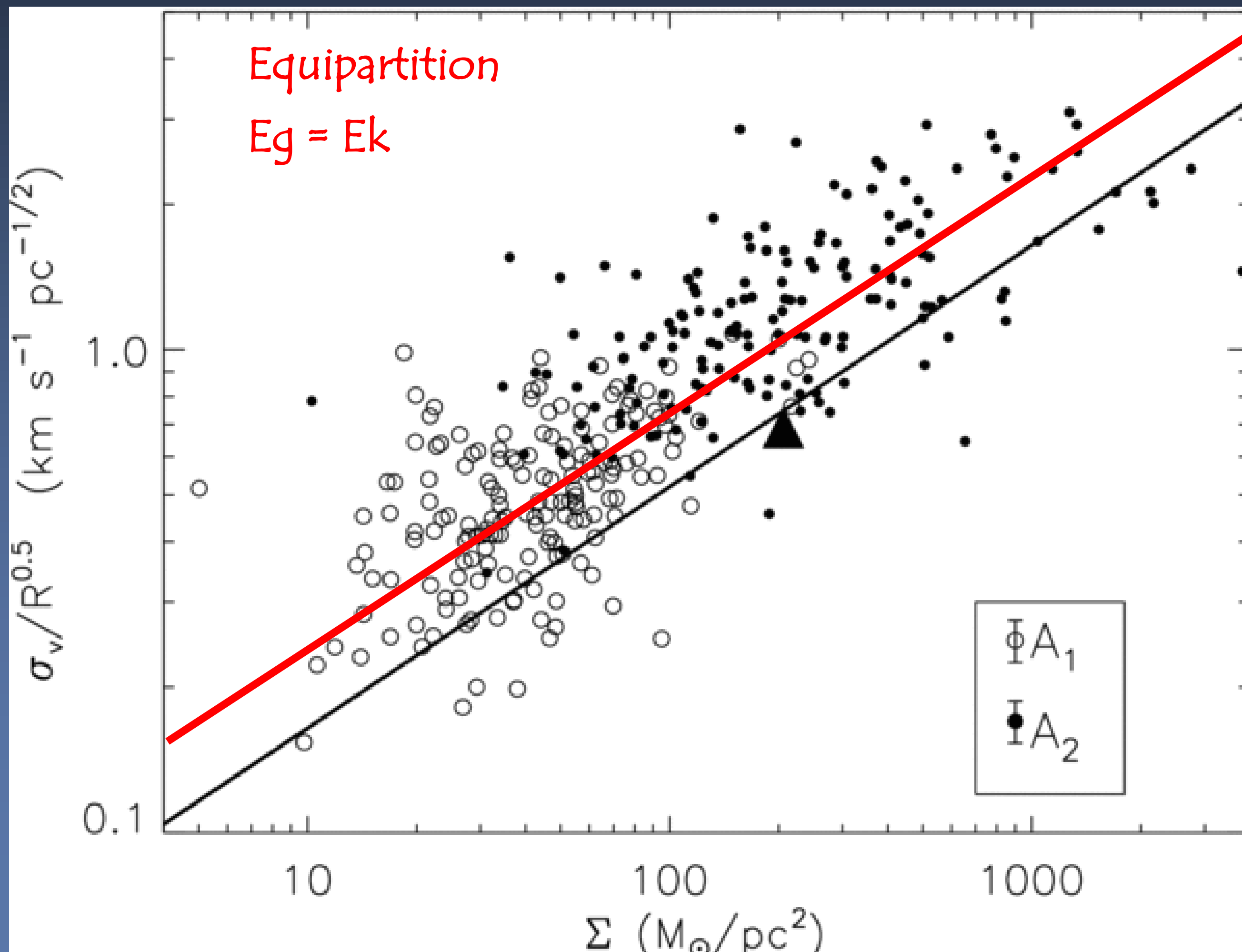
If clouds are in global collapse

$$\mathcal{H} \equiv \frac{\delta v}{R^{1/2}} = \sqrt{2G\Sigma}$$

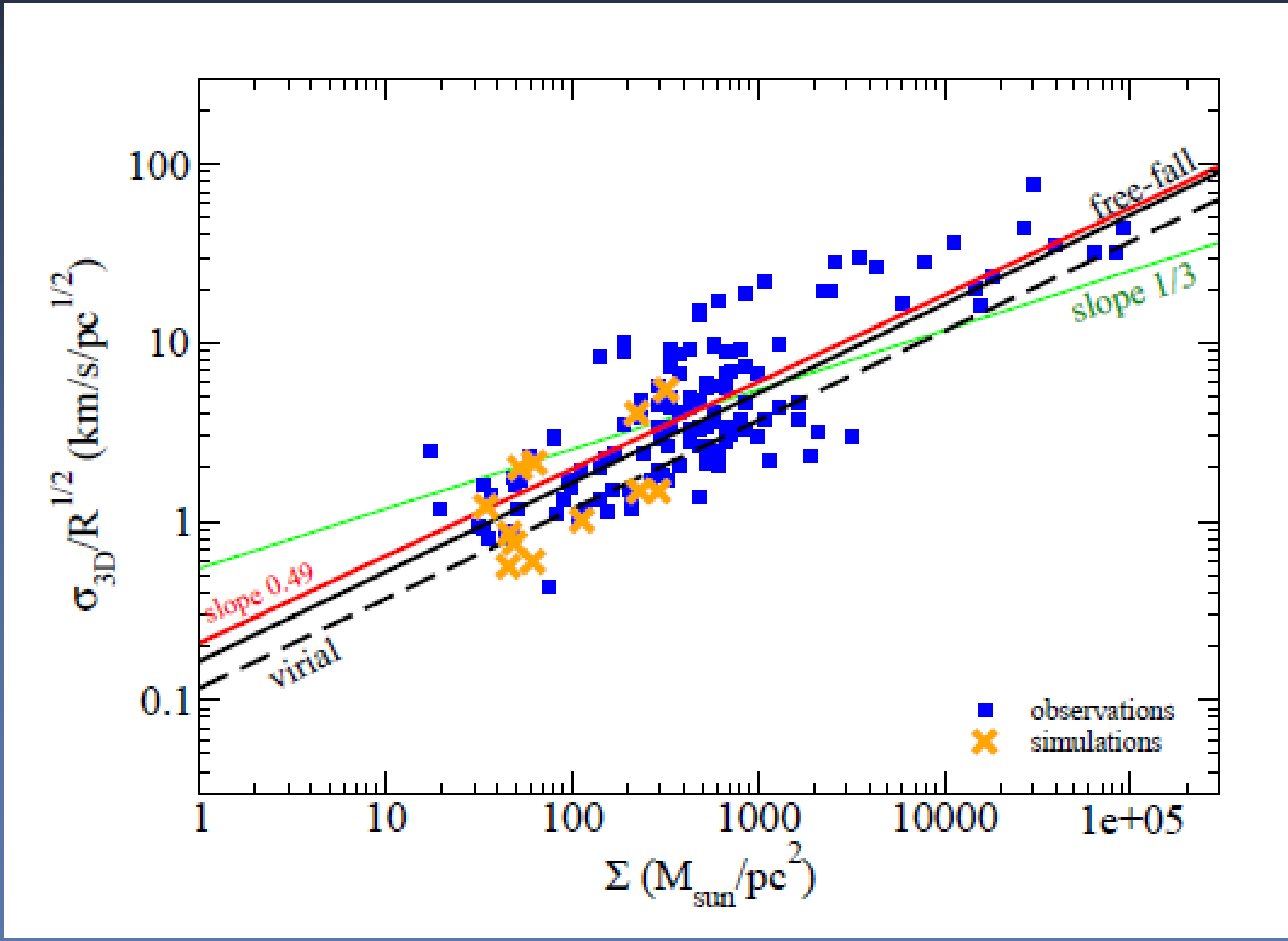


Si las nubes están en estado de colapso global,

$$\mathcal{H} \equiv \frac{\delta v}{R^{1/2}} = \sqrt{2G\Sigma}$$

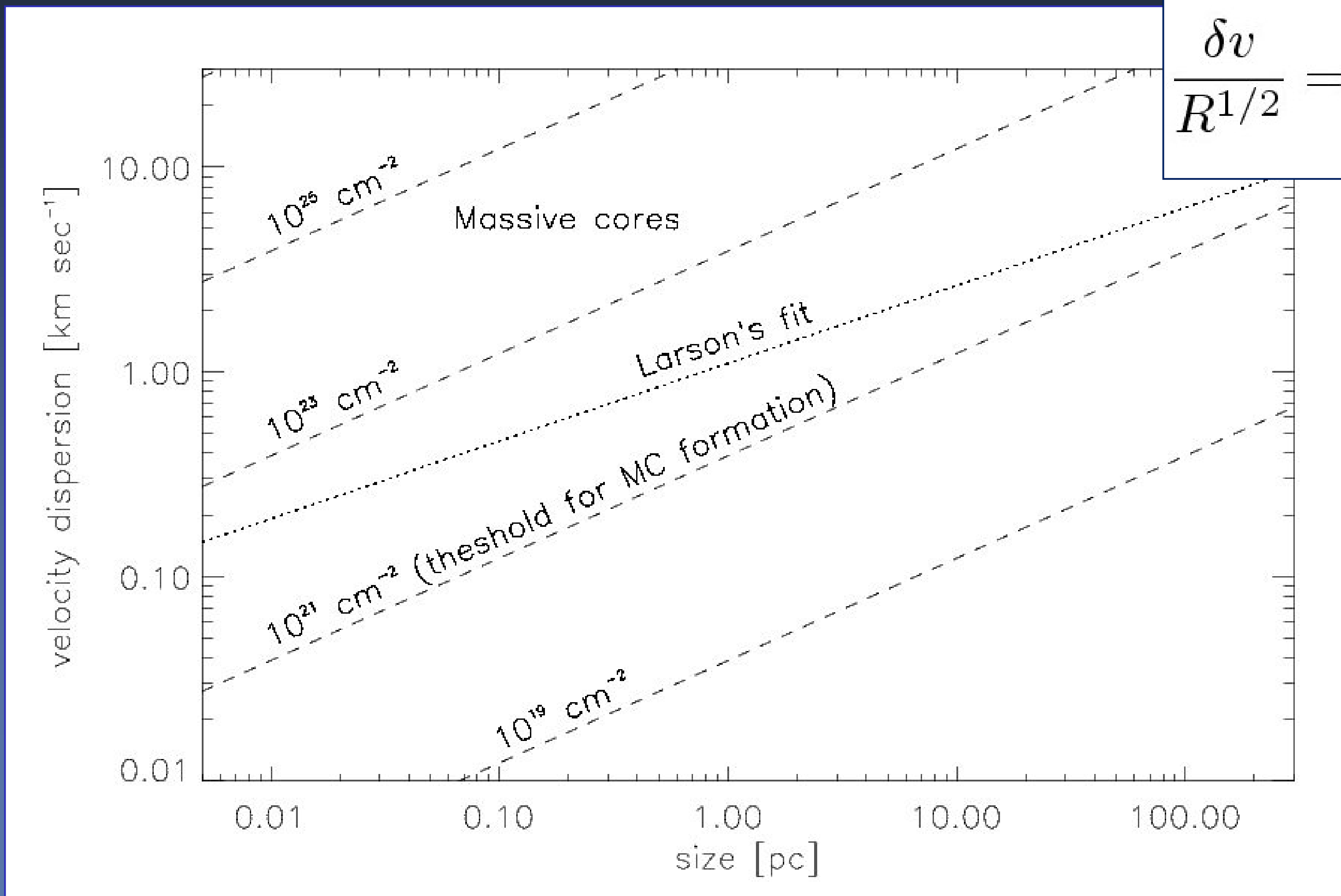


Palau + (2015) data: cores without stellar feedback

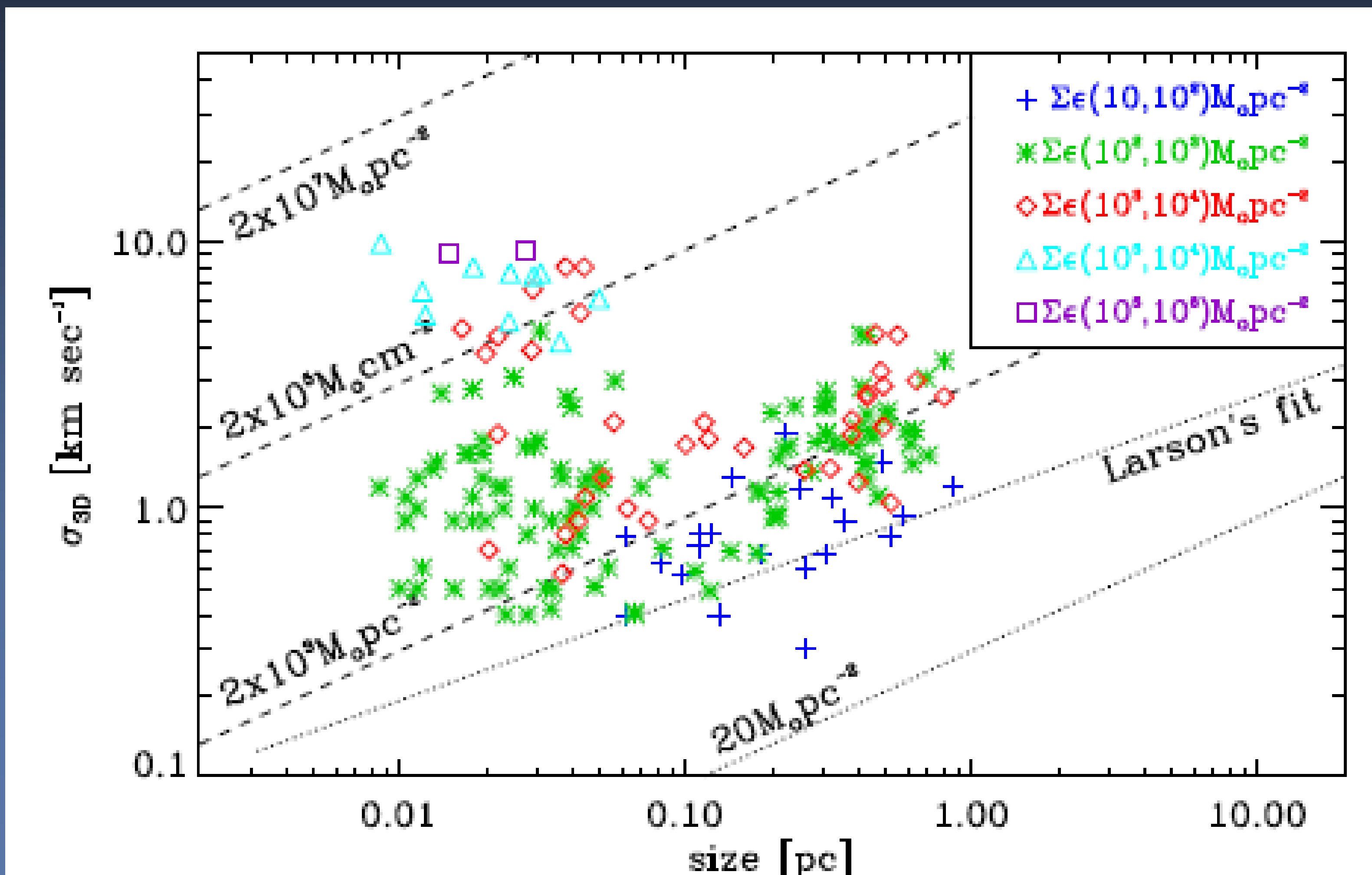


Why Larson(81) got a nice dv-r relation? (Ballesteros-Paredes + 2011)

$$\frac{\delta v}{R^{1/2}} = \sqrt{2G\Sigma}$$



Why Larson(81) obtained a nice dv-r relation? (Palau+15a)



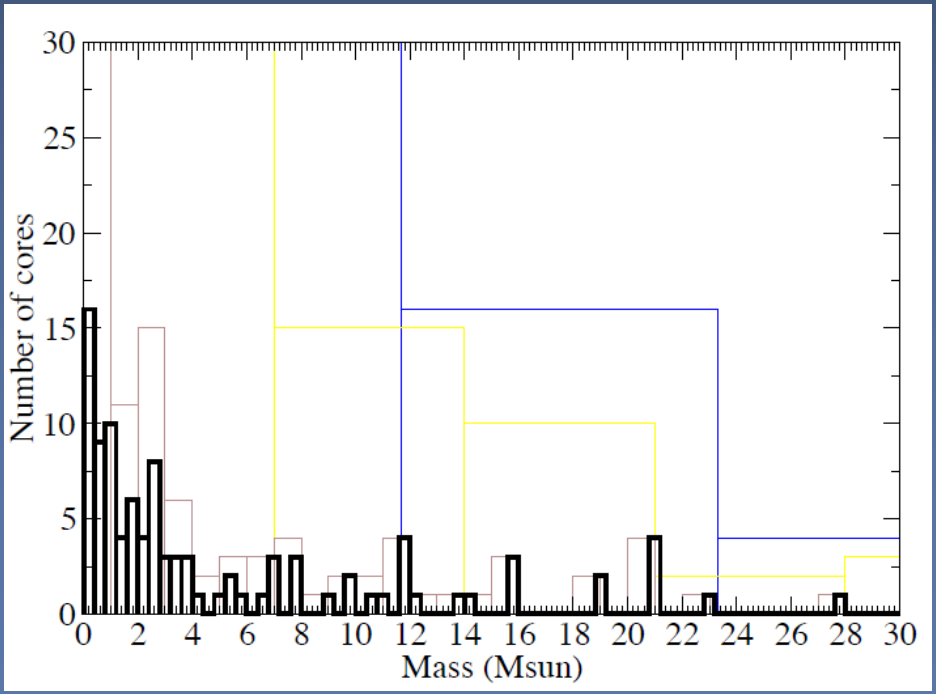
Fragmentation (Palau + 2015b)

What produces fragmentation in MCs?

Turbulence?

Magnetic fields?

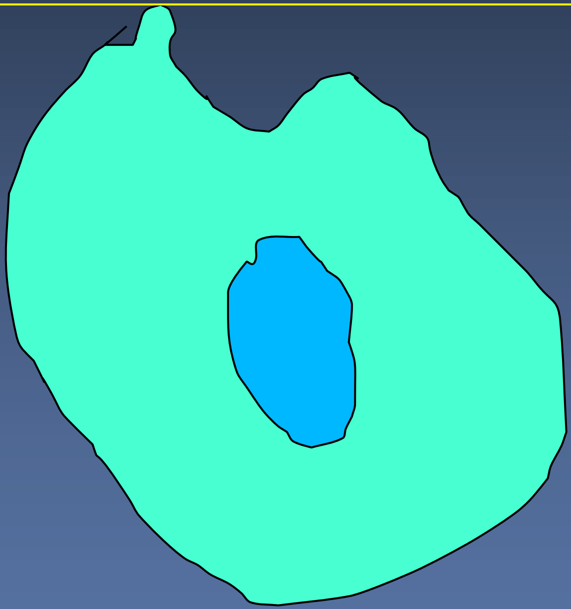
Gravity?



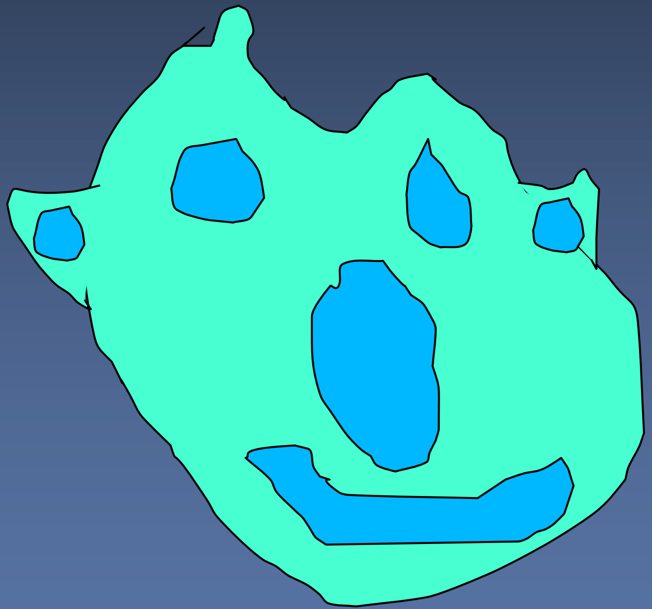
Fragmentación

- Palau et. al (2015b):

Fragmentation level: # millimetric sources, N_{mm}



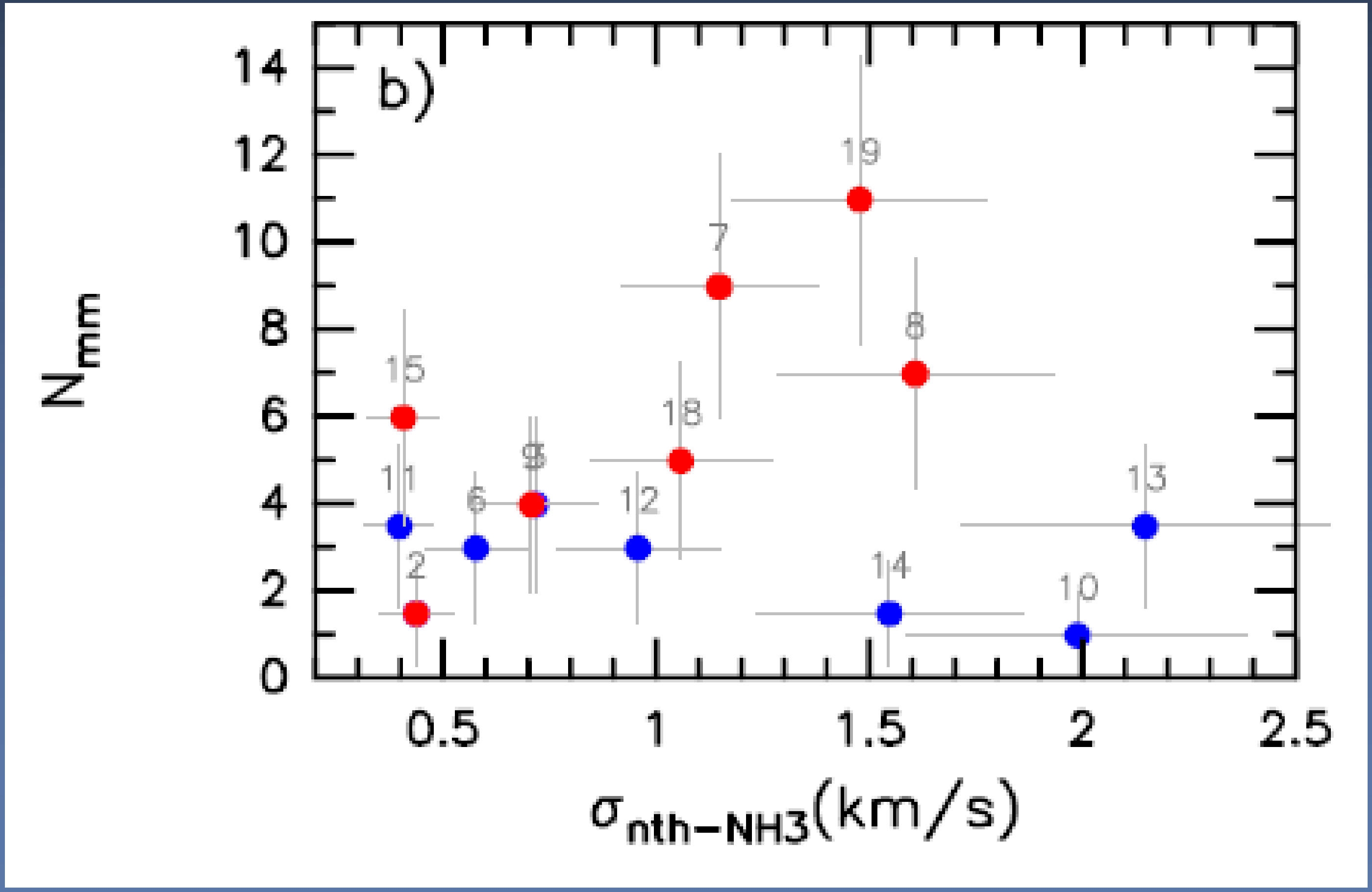
- Cloud not very fragmented



- Happily fragmented cloud

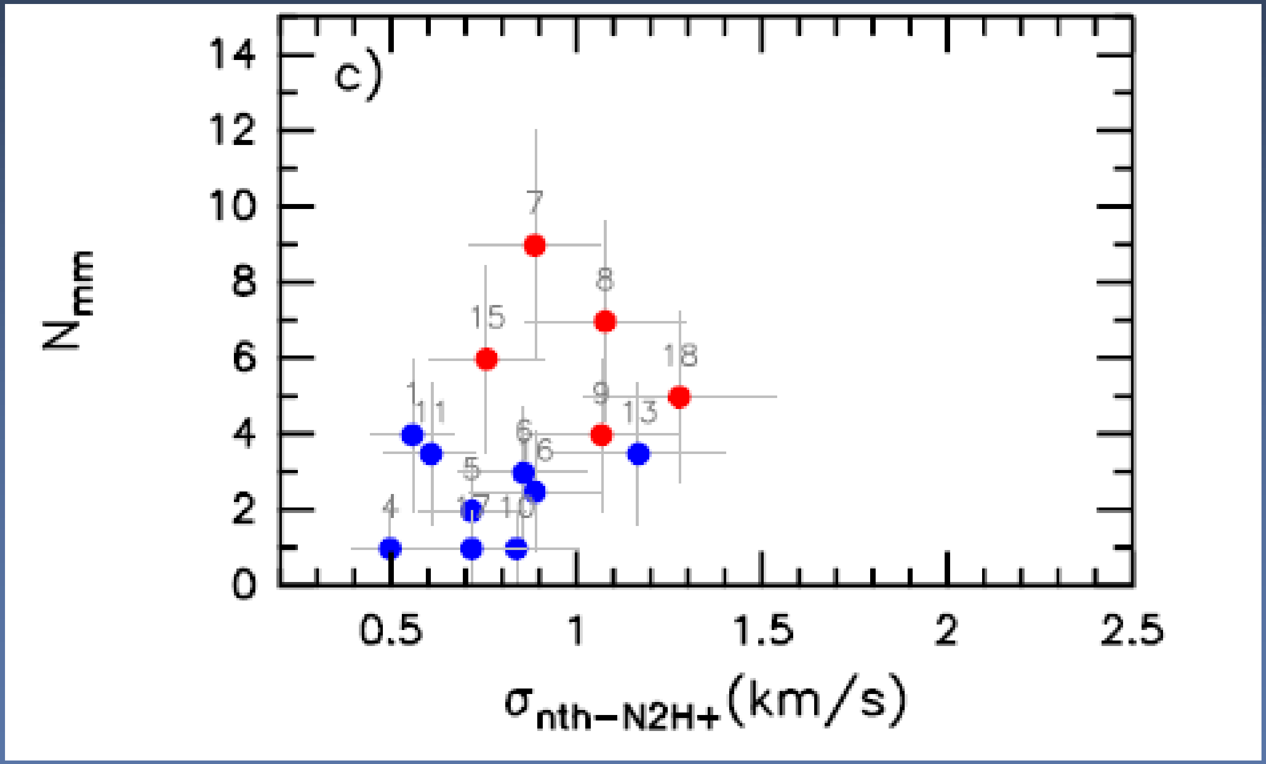
Fragmentación

- Palau et. al (2015b):
- Fragmentation does not correlates with non-thermal linewidth (ammonia)



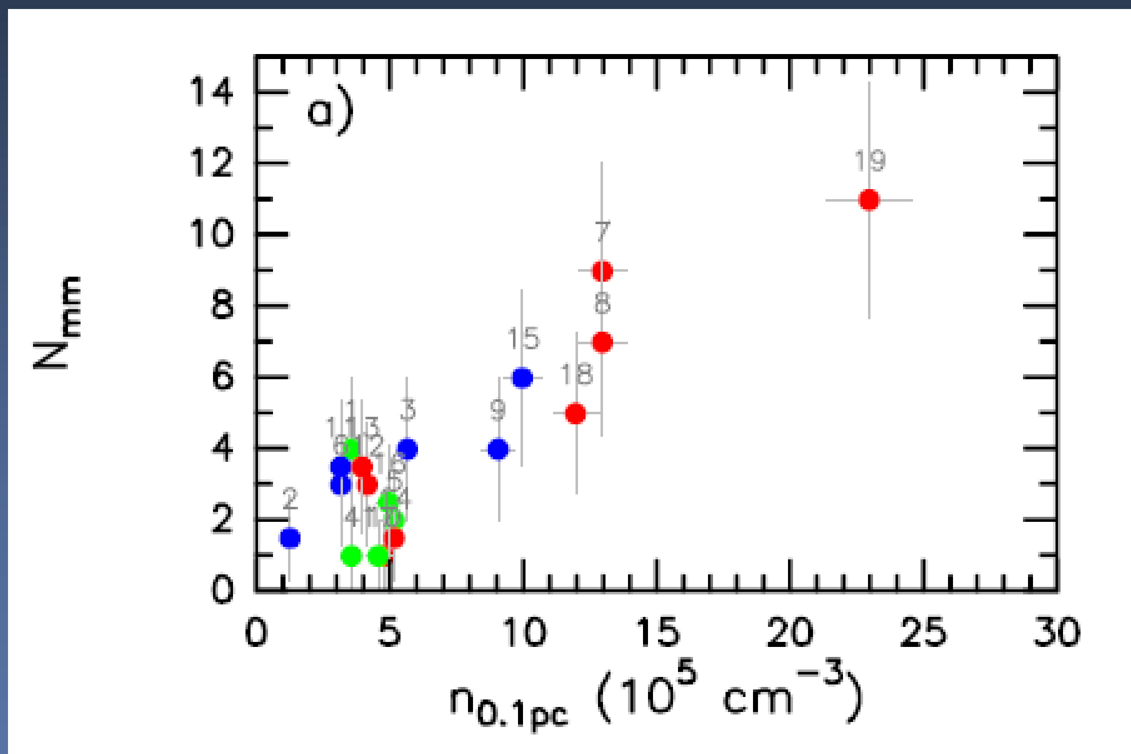
Fragmentación

- Palau et. al (2015b):
- Fragmentation does not correlate with non-thermal linewidth (N2H+)



Fragmentación

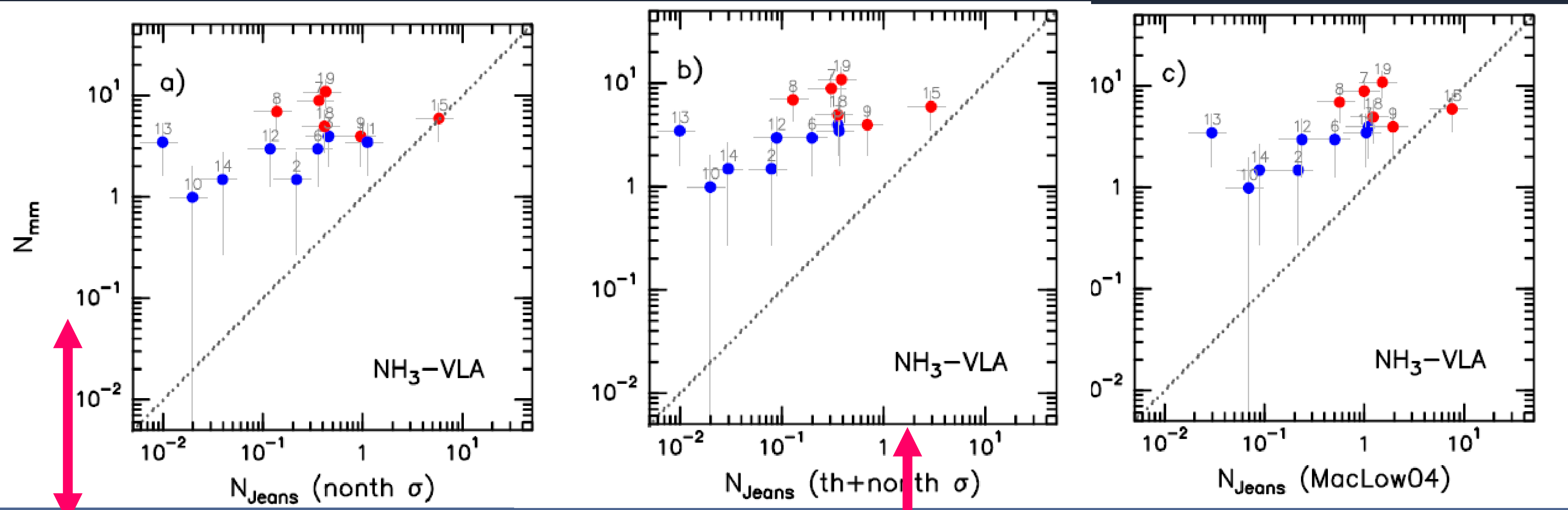
- Palau et. al (2015b):
- Fragmentation does correlate with density



$$M_J \simeq (2\ \mathrm{M}_\odot)\left(\frac{c_s}{0.2\ \mathrm{km\ s^{-1}}}\right)^3\left(\frac{n}{10^3\ \mathrm{cm^{-3}}}\right)^{-1/2}.$$

Fragmentación

- Palau et. al (2015b): Njeans = M/Mjeans



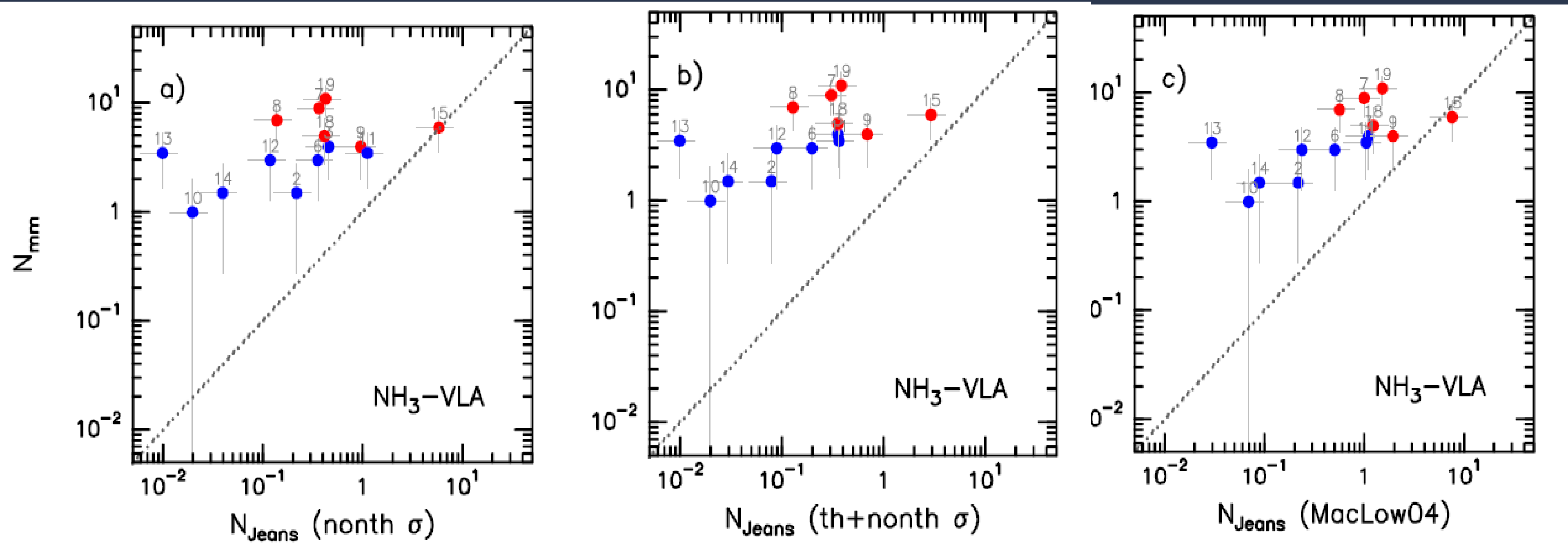
$$\left[\frac{M_{\rm Jeans}^{\rm nth}}{M_\odot}\right] = 1.578 \left[\frac{\sigma_{\rm nth}}{0.188\,{\rm km\,s^{-1}}}\right]^3 \left[\frac{n}{10^5\,{\rm cm^{-3}}}\right]^{-1/2}.$$

$$\left[\frac{M_{\rm Jeans}^{\rm tot}}{M_\odot}\right] = 1.578 \left[\frac{\sigma_{\rm tot}}{0.188\,{\rm km\,s^{-1}}}\right]^3 \left[\frac{n}{10^5\,{\rm cm^{-3}}}\right]^{-1/2},$$

$$\left[\frac{M_{\rm Jeans}^{\rm conv.flows}}{M_\odot}\right] = 1.578 \left[\frac{\sigma_{\rm nth}}{0.188\,{\rm km\,s^{-1}}}\right]^3 \left[\frac{n\,\mathcal{M}^2}{10^5\,{\rm cm^{-3}}}\right]^{-1/2}.$$

Fragmentación

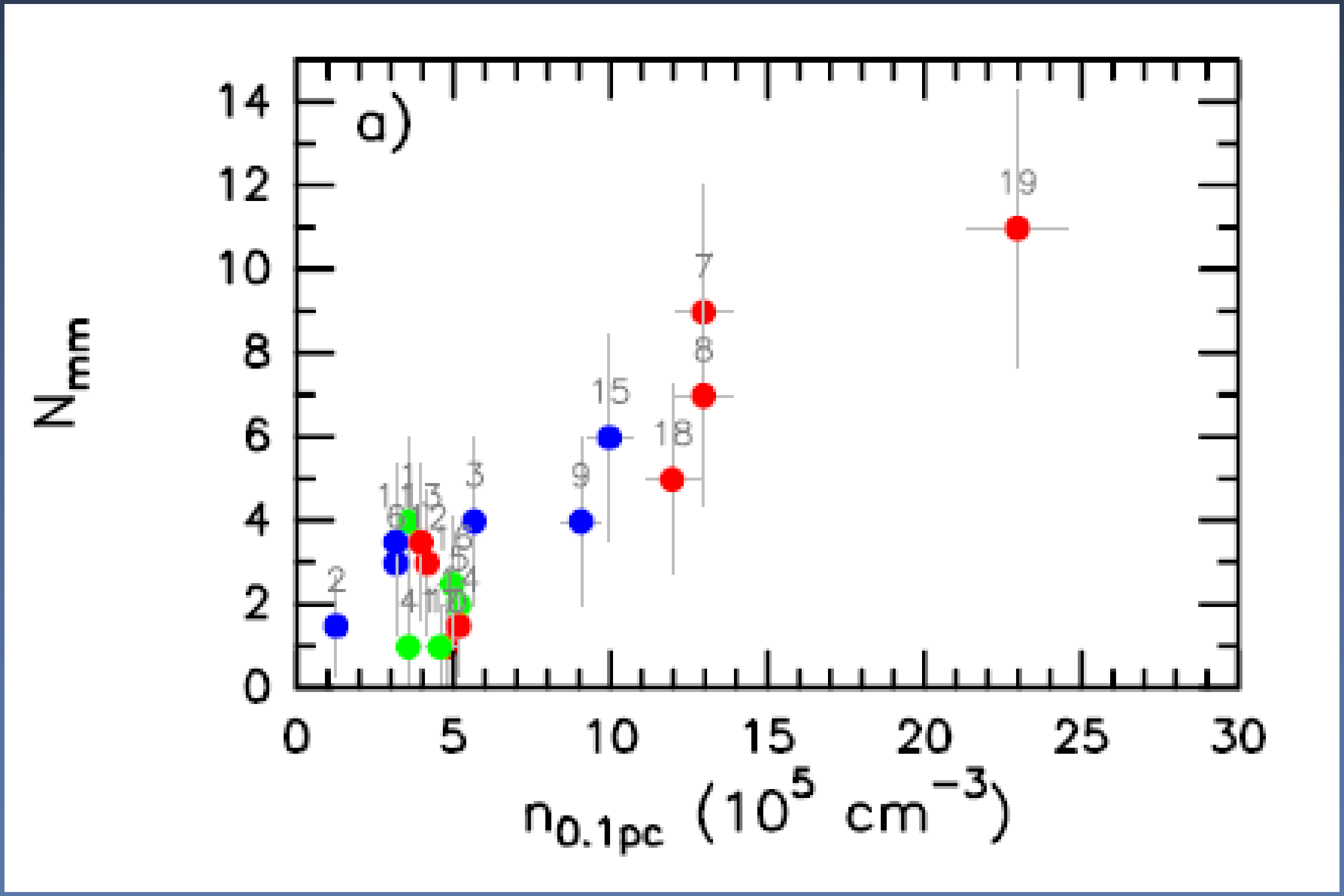
- Palau et. al (2015b): Njeans = M/Mjeans



In many cases (blue points + some red), Njeans < 1: there should not be fragmentation at all!!

Fragmentación

- Palau et. al (2015b):
- Fragmentation has a gravitational origin, not turbulent



Models of MCs in global colapse predict:

- Linewidths of MCs (Heitsch+09).
- Core-to core velocity dispersions (Heitsch +09)
- Stellar population ages (Hartmann+12)
- Non-existence of a dv-r relation (Ballesteros-Paredes+11a)
- Explains the $dv/r^{1/2}$ vs. Σ relation (Ballesteros-Paredes+11a)
- Explains the shapes of the Npdf's (Ballesteros-Paredes+11b)
- Non-existence of a n-r relation (Ballesteros-Paredes+12)

Conclusions

- Molecular clouds seem to be formed by large scale compressions, cool down rapidly because of the thermal instability, and proceed to collapse.
- They appear to be in Virial equilibrium because collapse involves gravity, and its motions are of the same order of magnitude.
- Fragmentation and velocity dispersions are produced by gravity. No need of turbulence or magnetic fields.
- The model reproduces several observational features

Fin… ally

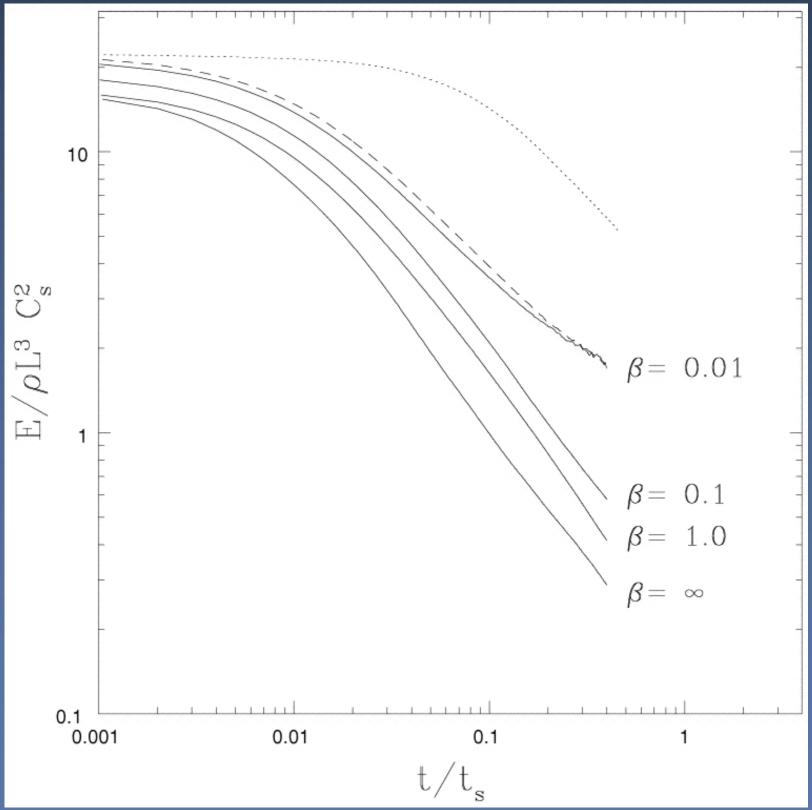
Eficiencia de formación estelar

- El problema de la posible alta eficiencia de formación estelar parece a salvo si las nubes están soportadas.

  - Pero surgen nuevos problemas:

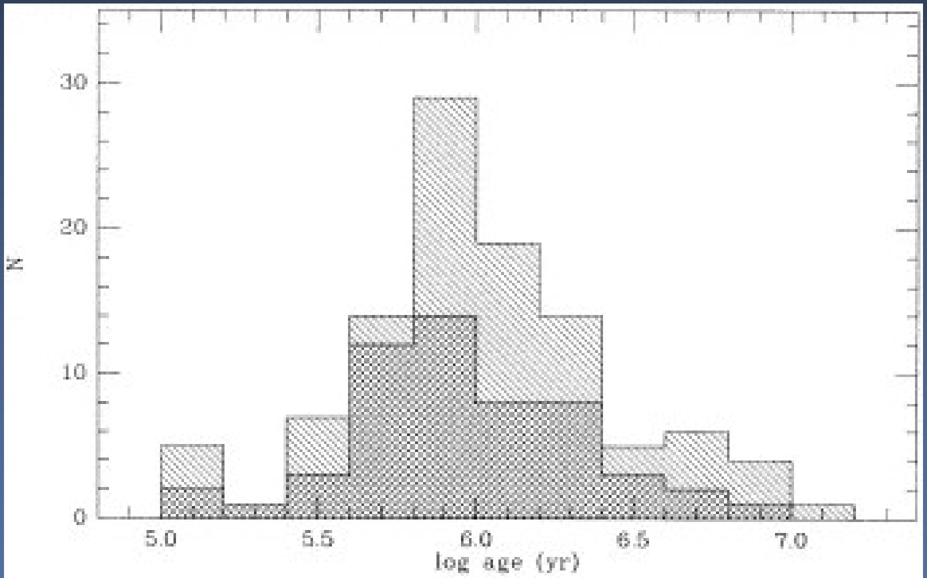
Eficiencia de formación estelar

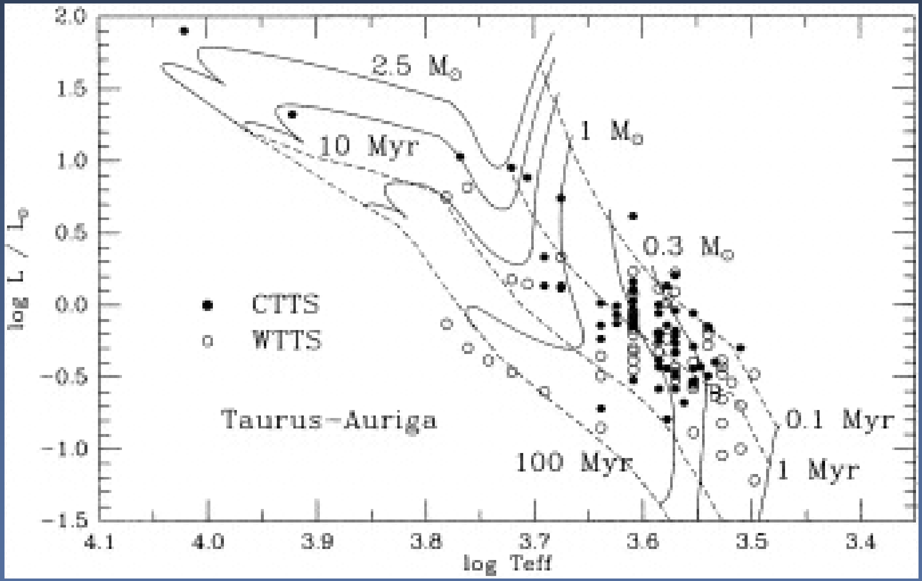
- 1. La turbulencia, incluso magnética, se disipa rápidamente (Goldreich & Kwan 1974; Mac Low et al. 1998; Ostriker et al. 1998; Padoan & Nordlund 1998)



Eficiencia de formación estelar

- 2. ¿por qué las nubes tienen solamente estrellas jóvenes de 2-3 Myr?





Eficiencia de formación estelar

- El problema de la posible alta eficiencia de formación estelar parece a salvo si las nubes están soportadas.
- Pareciera entonces que hemos cambiado el problema de la eficiencia por el problema de la turbulencia + el problema de las edades de las estrellas...

Eficiencia de formación estelar

- ¿qué mantiene baja la eficiencia de formación estelar?

  - 1. feedback estelar:

estrellas masivas: vientos y radiación.

Estrellas de baja masa: chorros

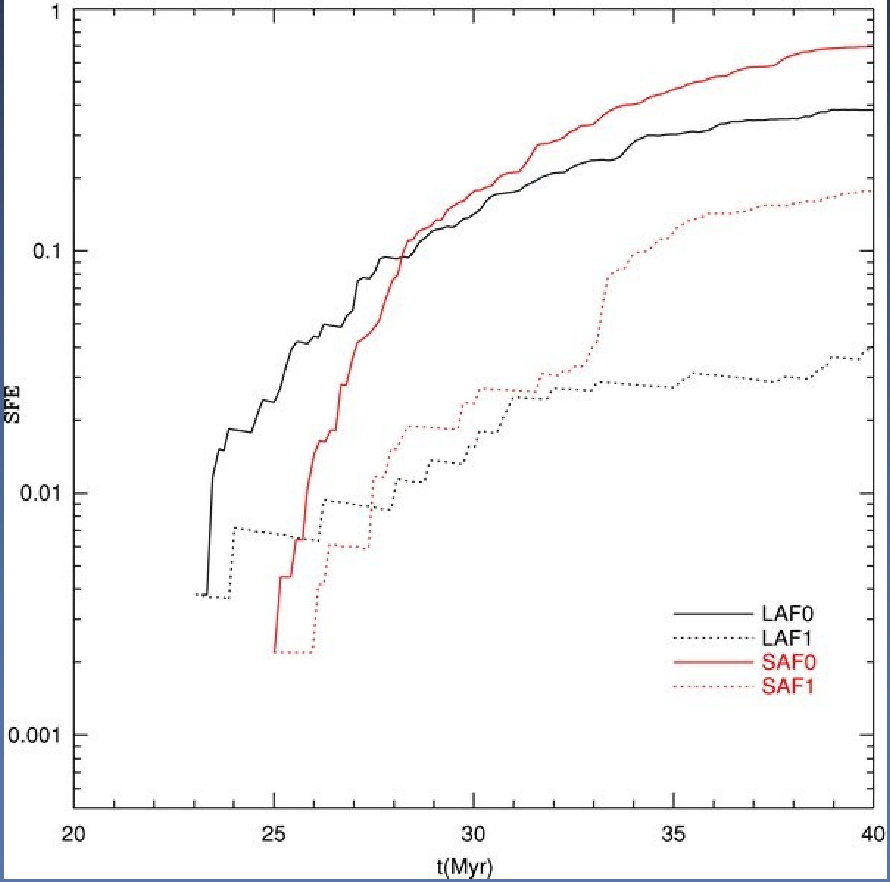
Eficiencia de formación estelar

- ¿qué mantiene baja la eficiencia de formación estelar?
  - 2 ¿definición incorrecta de la eficiencia?

Las nubes acretan hasta que se les acaba la masa.

Eficiencia de formación estelar

- ¿qué mantiene baja la eficiencia de formación estelar?
  - 2 ¿definición incorrecta de la eficiencia?



Ahora sí,

(Por)

Fin