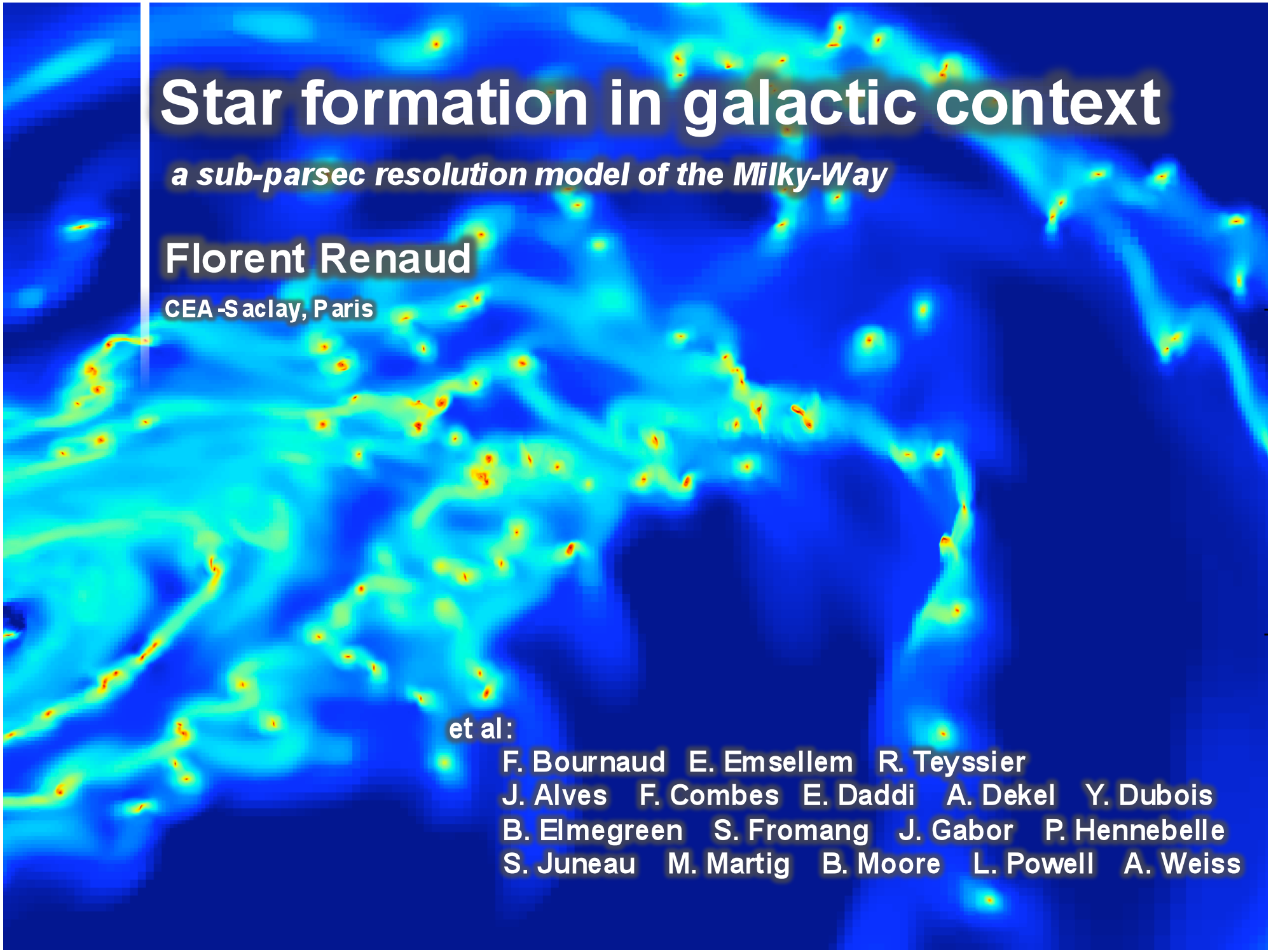


# Star formation in galactic context

*a sub-parsec resolution model of the Milky-Way*


Florent Renaud

CEA-Saclay, Paris

et al:

F. Bournaud E. Emsellem R. Teyssier
J. Alves F. Combes E. Daddi A. Dekel Y. Dubois
B. Elmegreen S. Fromang J. Gabor P. Hennebelle
S. Juneau M. Martig B. Moore L. Powell A. Weiss

# Star formation in a nutshell

GMC

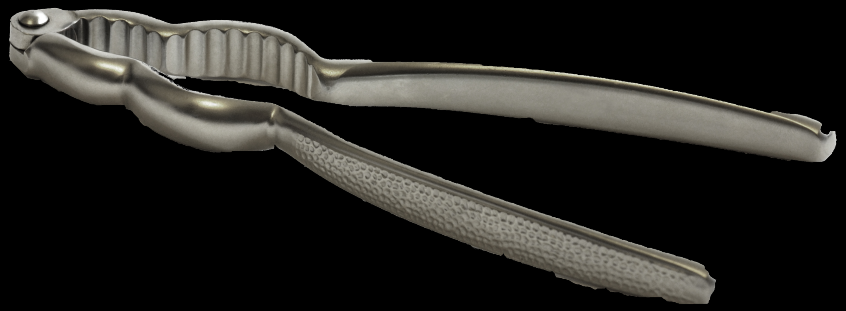
Filaments

Cores

Proto-stars

Embedded star cluster

Gas-free star cluster



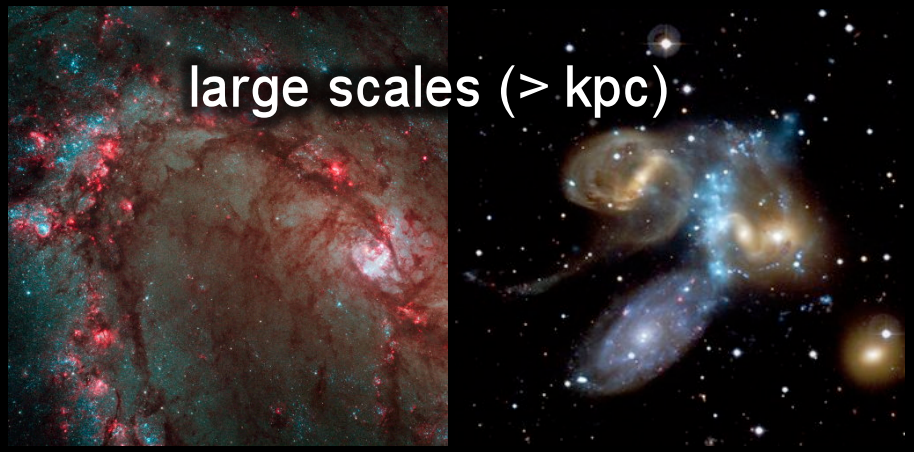
# Enters the nutcracker

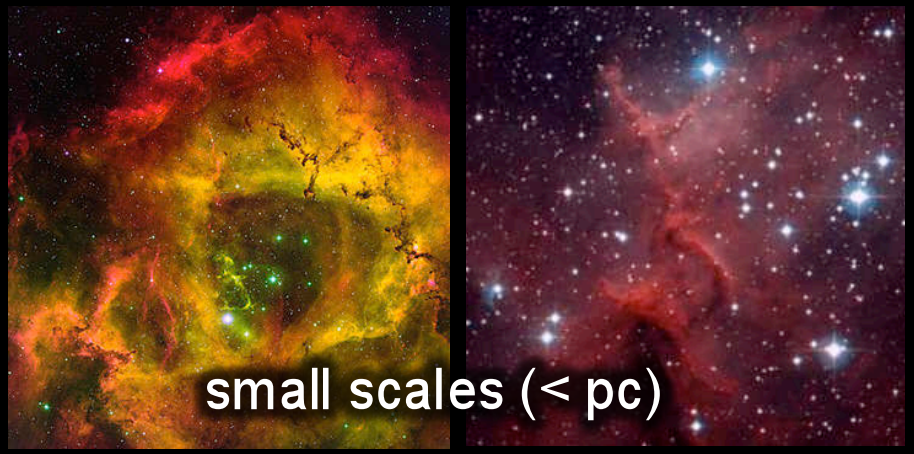
tides

shear

density waves

2D turbulence



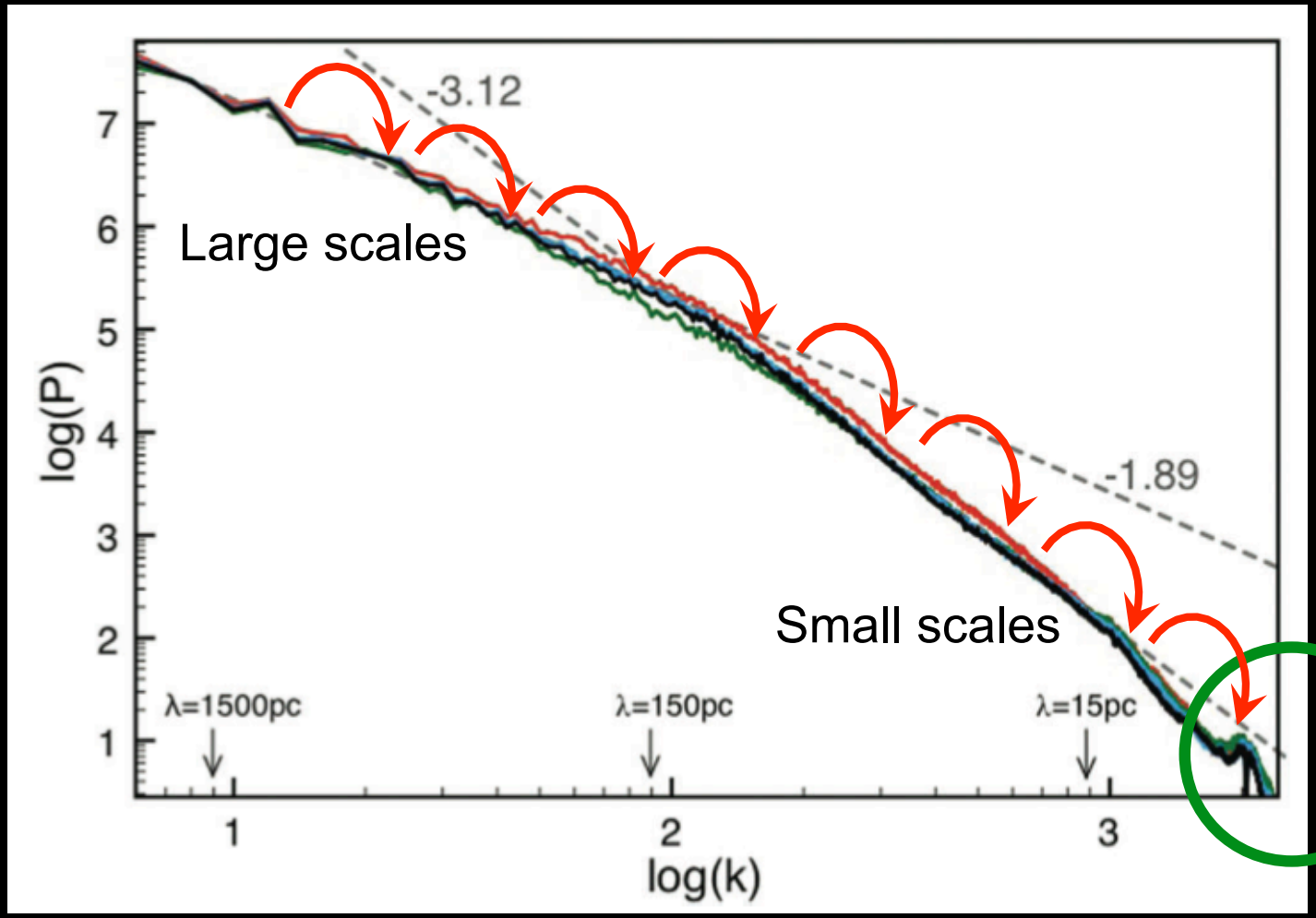




fragmentation

heating (feedback)

3D turbulence (Kolmogorov)

# Turbulence cascade




Bournaud et al. 2010

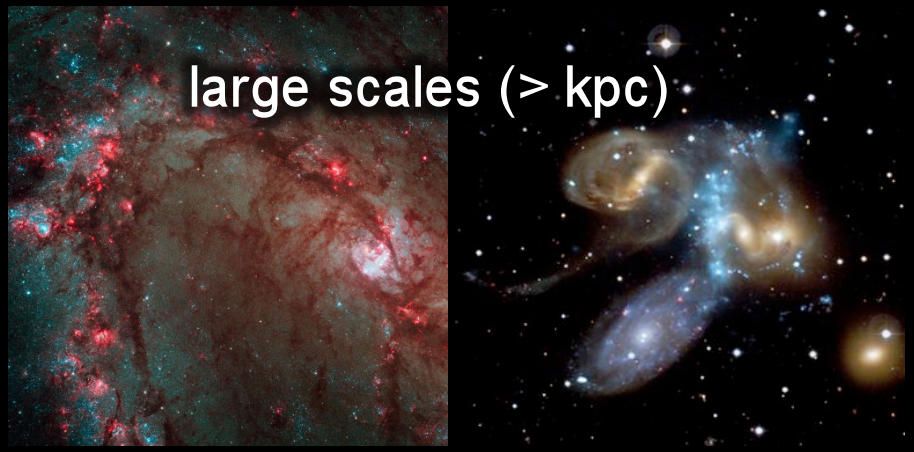
# Enters the nutcracker

tides

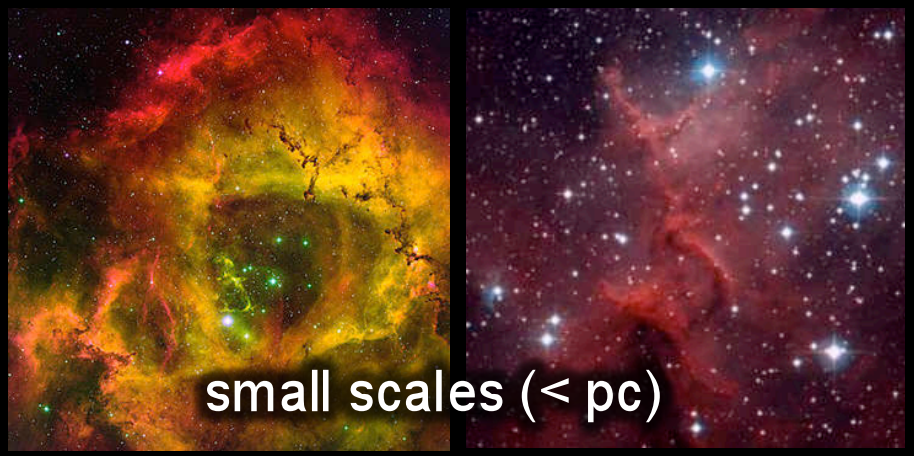
shear

density waves

2D turbulence




scale coupling



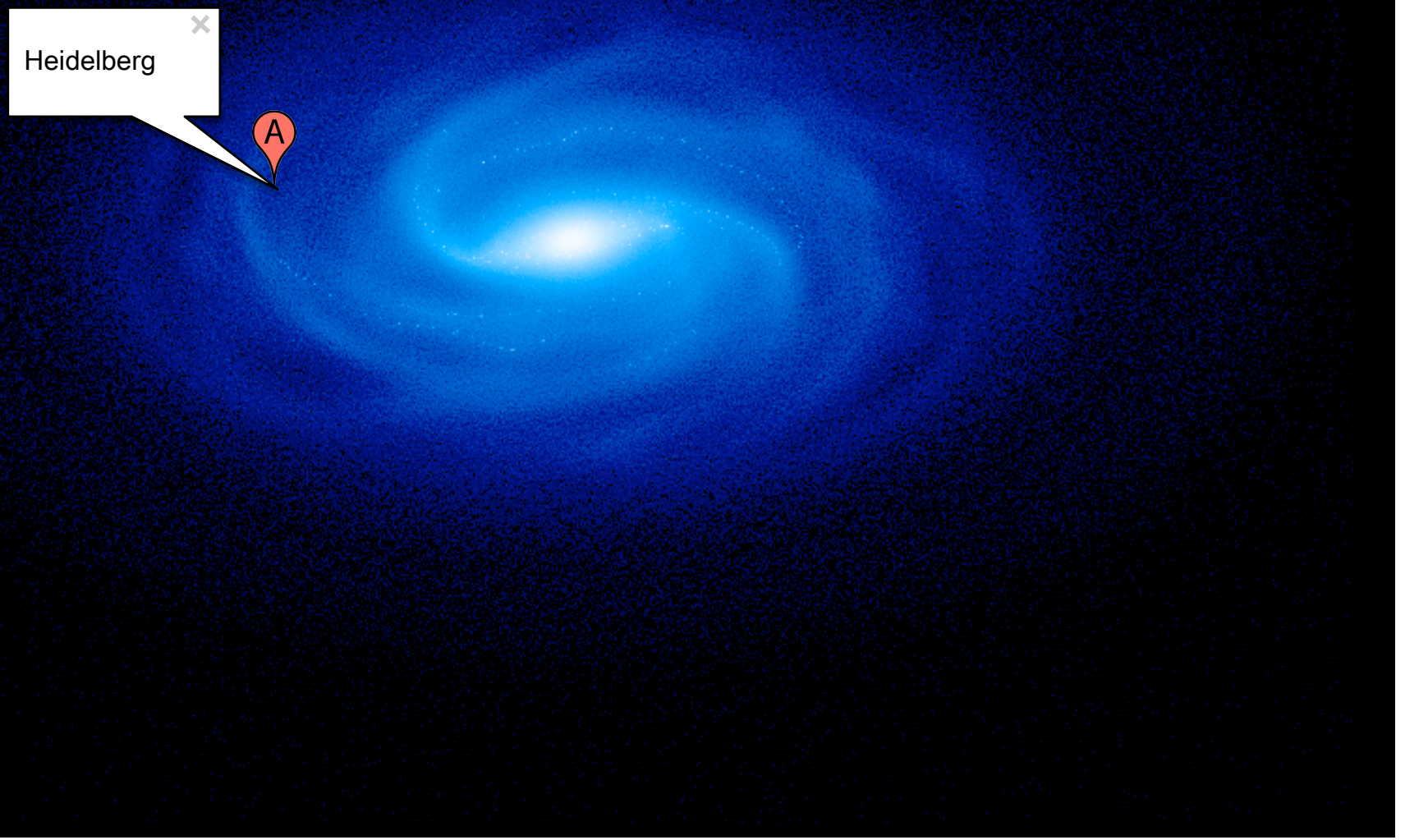

fragmentation

heating (feedback)

3D turbulence (Kolmogorov)

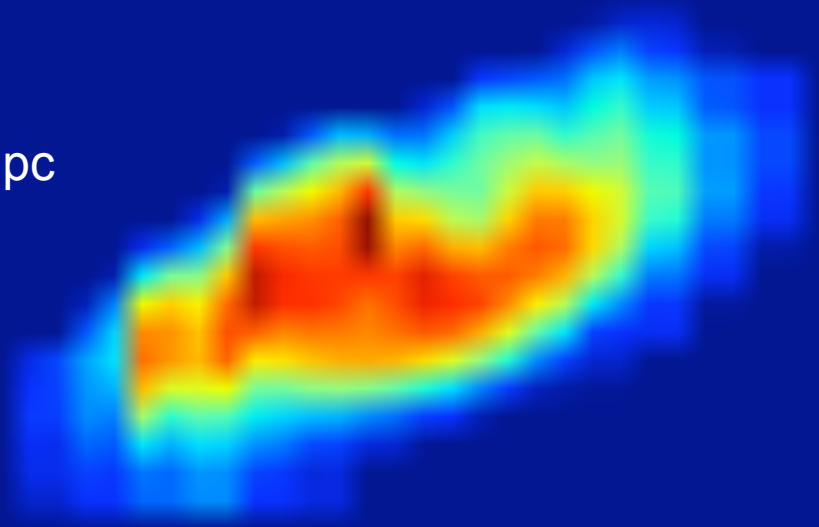
# THE GOAL

Need to resolve SF cores (< pc) in a galactic context (100 kpc)



0.5 pc

~ 0.1 pc * 1 pc

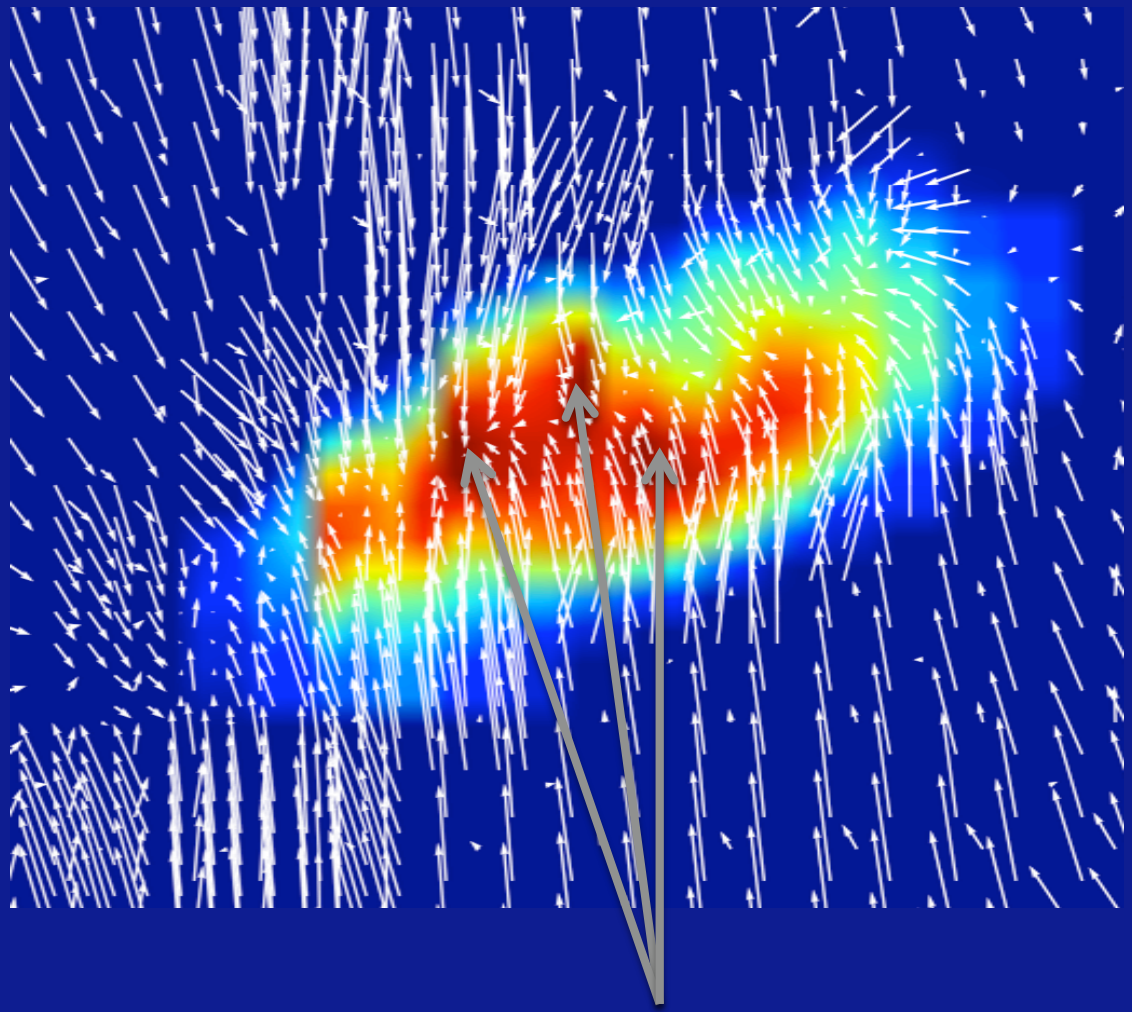


$$q = \frac{\sigma^2}{2G\mu}$$

Jeans unstable

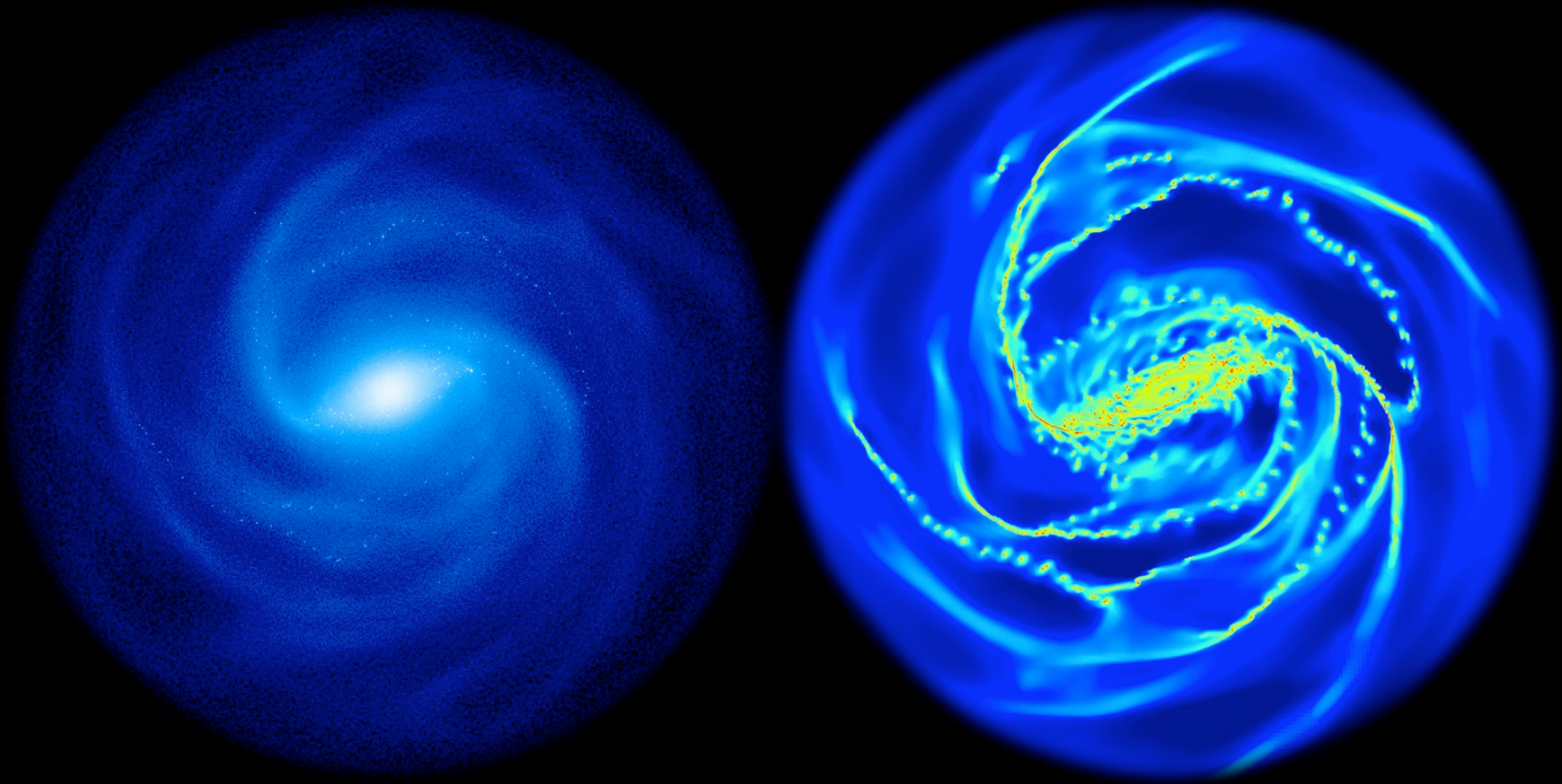
Chandrasekhar & Fermi 1953

0.5 pc



accreting (protostellar?) cores

# Milky-Way Simulation



0.05 pc 14 K 0.5 km/s 30 $M_{\odot}$

turbulence cascade described down to sonic scale (0.1 - 0.05 pc)

Larson 1981

# Initial Conditions

pyMGE

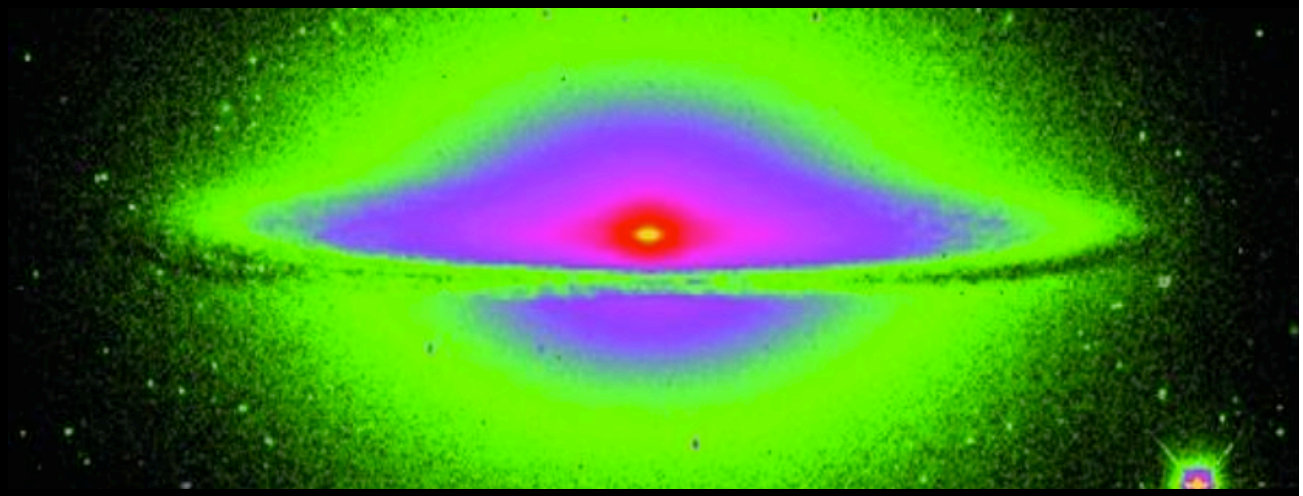
Emsellem et al. 1994
Emsellem & Renaud (in prep.)

python Multiple Gaussian Expansion

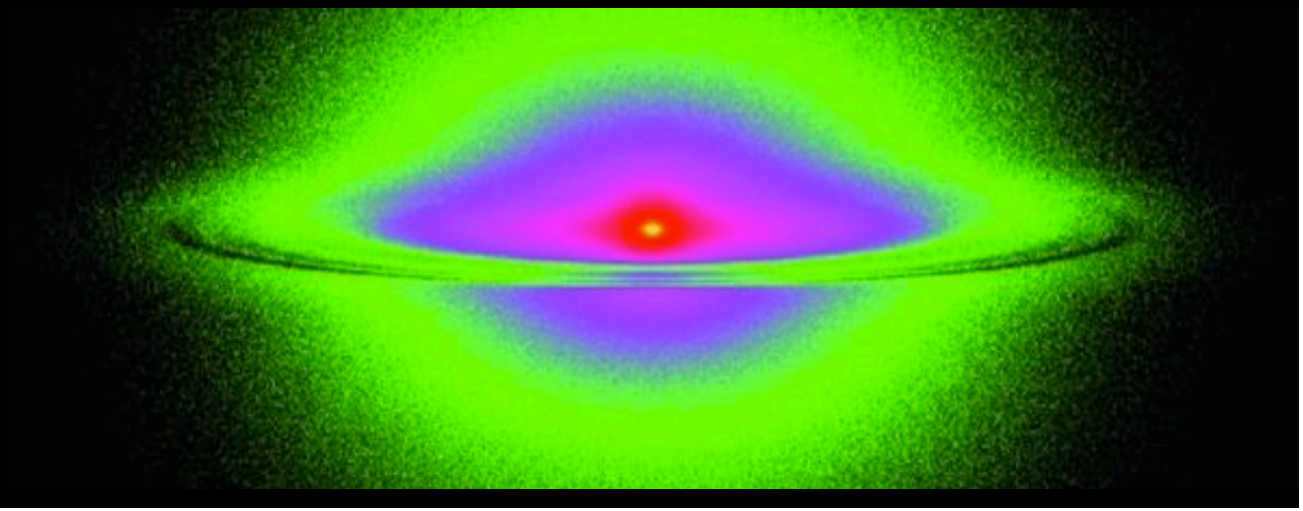
Sombrero galaxy

V-band observation

Baes et al. 2011



pyMGE model

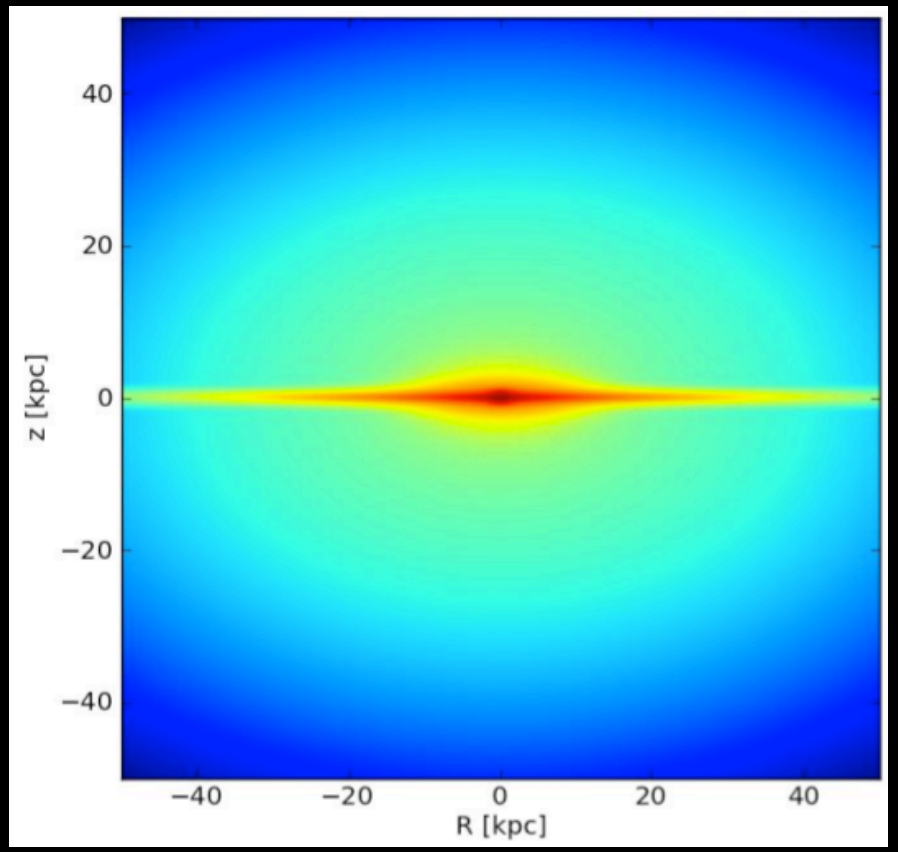


# Initial Conditions

Besancon model Robin et al. 2003

- Dark matter halo
- Spheroid
- Bulge
- Thick and thin disks
- Black hole

60M particles



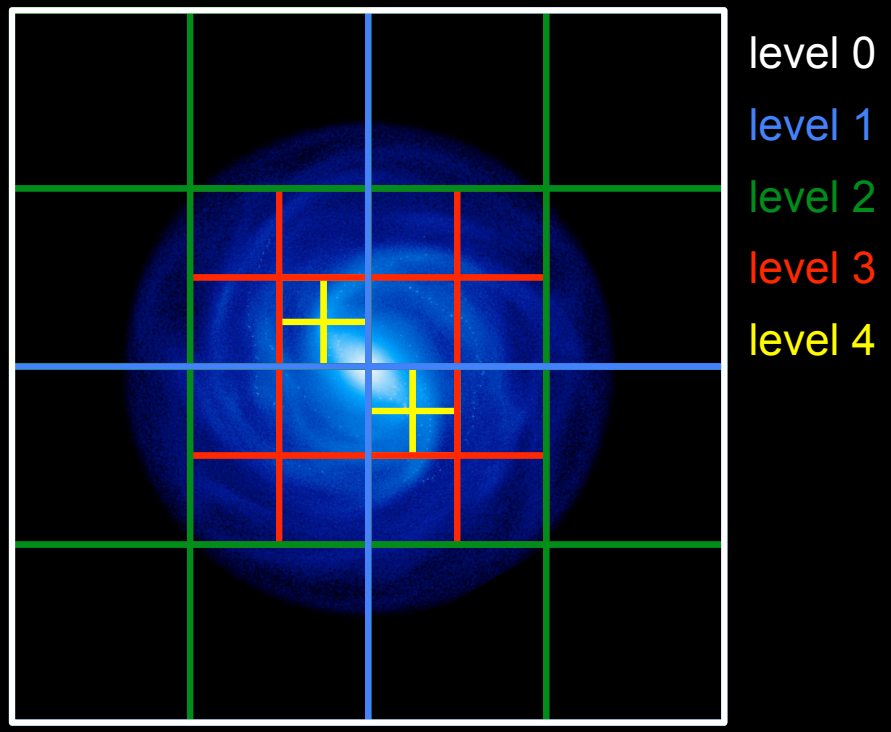

Gas disk: analytical setup on grid (100 kpc * 100 kpc * 100 kpc)

No satellites, no cold flows, no B-field

# Software: Ramses

RAMSES Teyssier 2002

*Résolution Adaptative sur Mailles,*
*Sans Efforts Surhumains*




Adaptive Mesh Refinement

Refinment on density and Jeans length

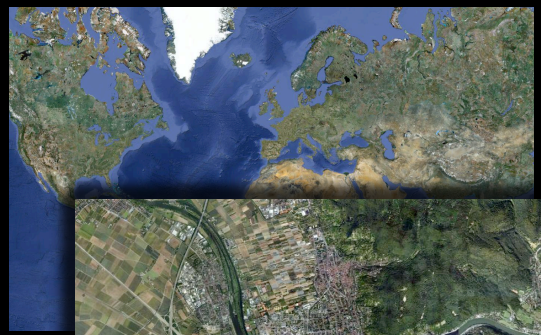
Truelove et al. 1997

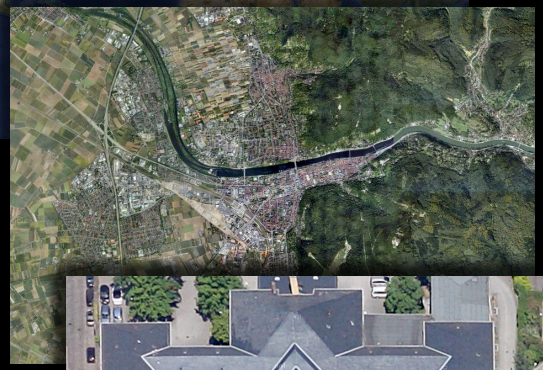
# • YOU USE AMR EVERYDAY!

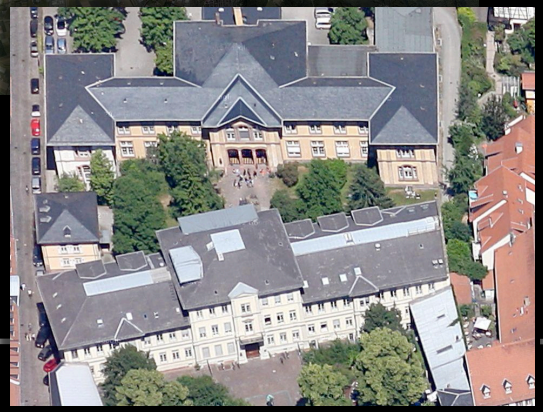
...AND EVEN ON YOUR IPHONE

Google

Milky Way







*Level 0*

← Earth  galaxy →

*Level 12*

← town  molecular clouds →

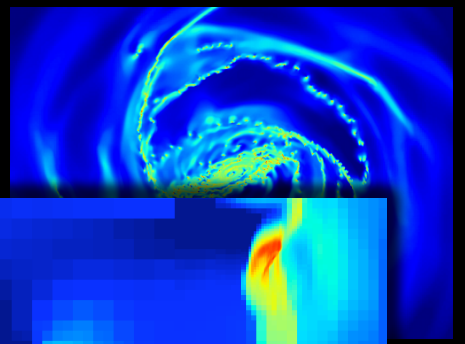
*Level 18*

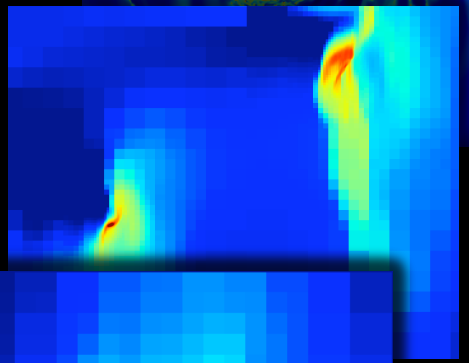
← building  filaments →

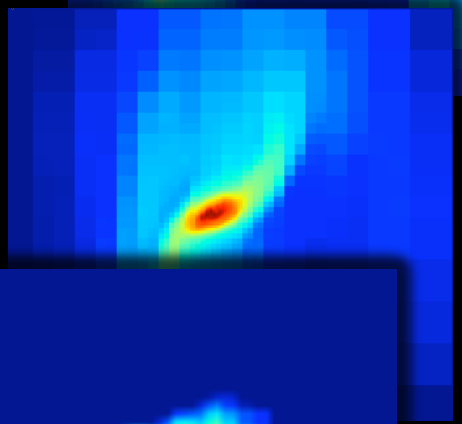
GoogleMaps limit

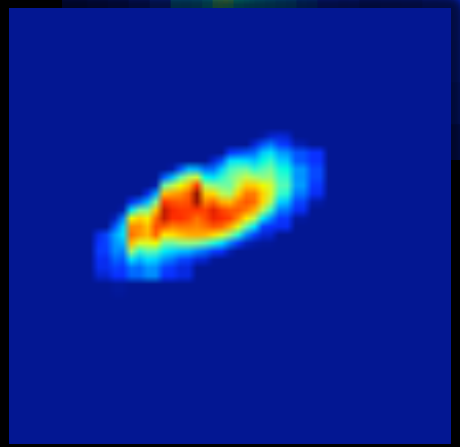
*Level 21*

cores →

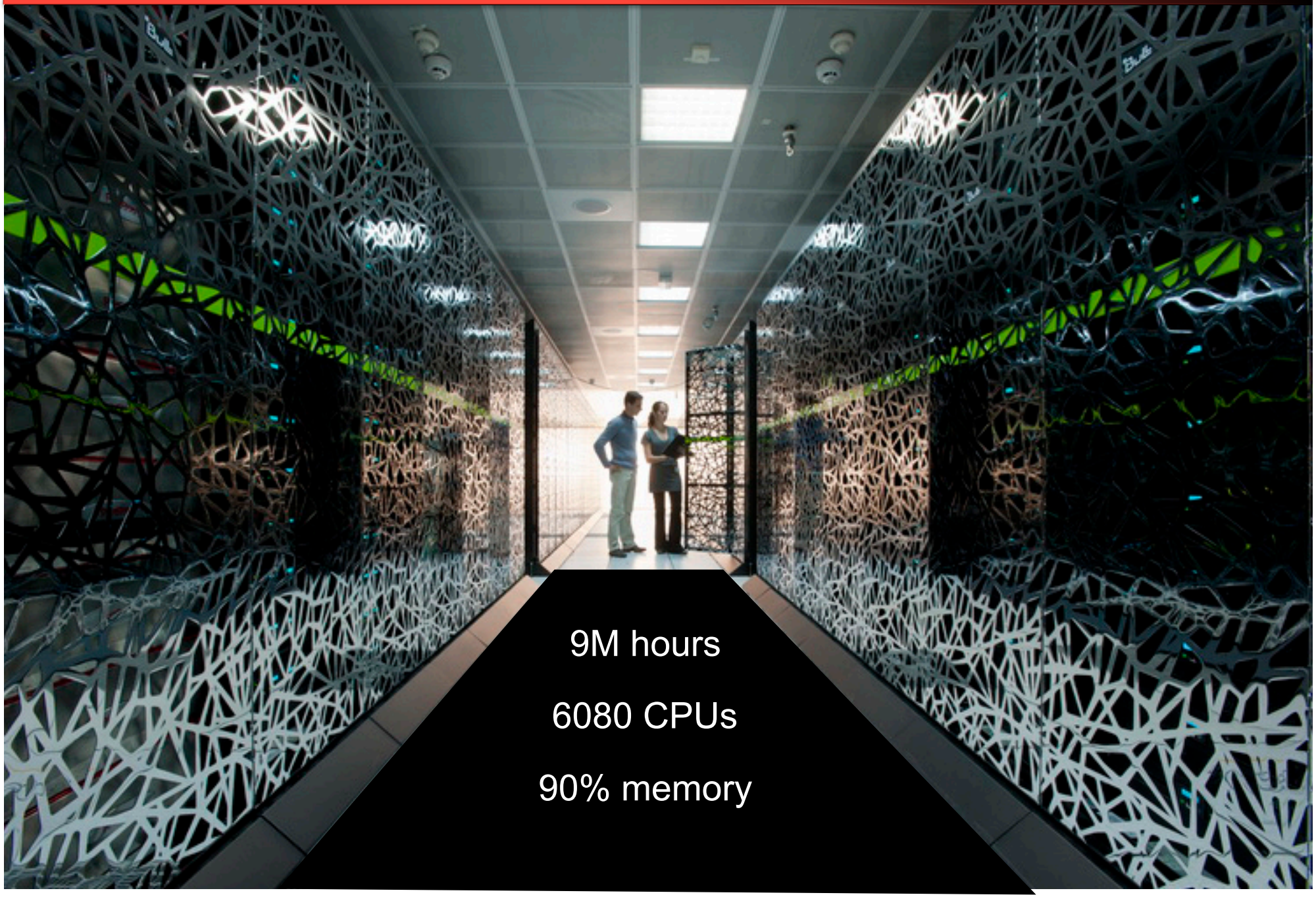








# Hardware: Curie



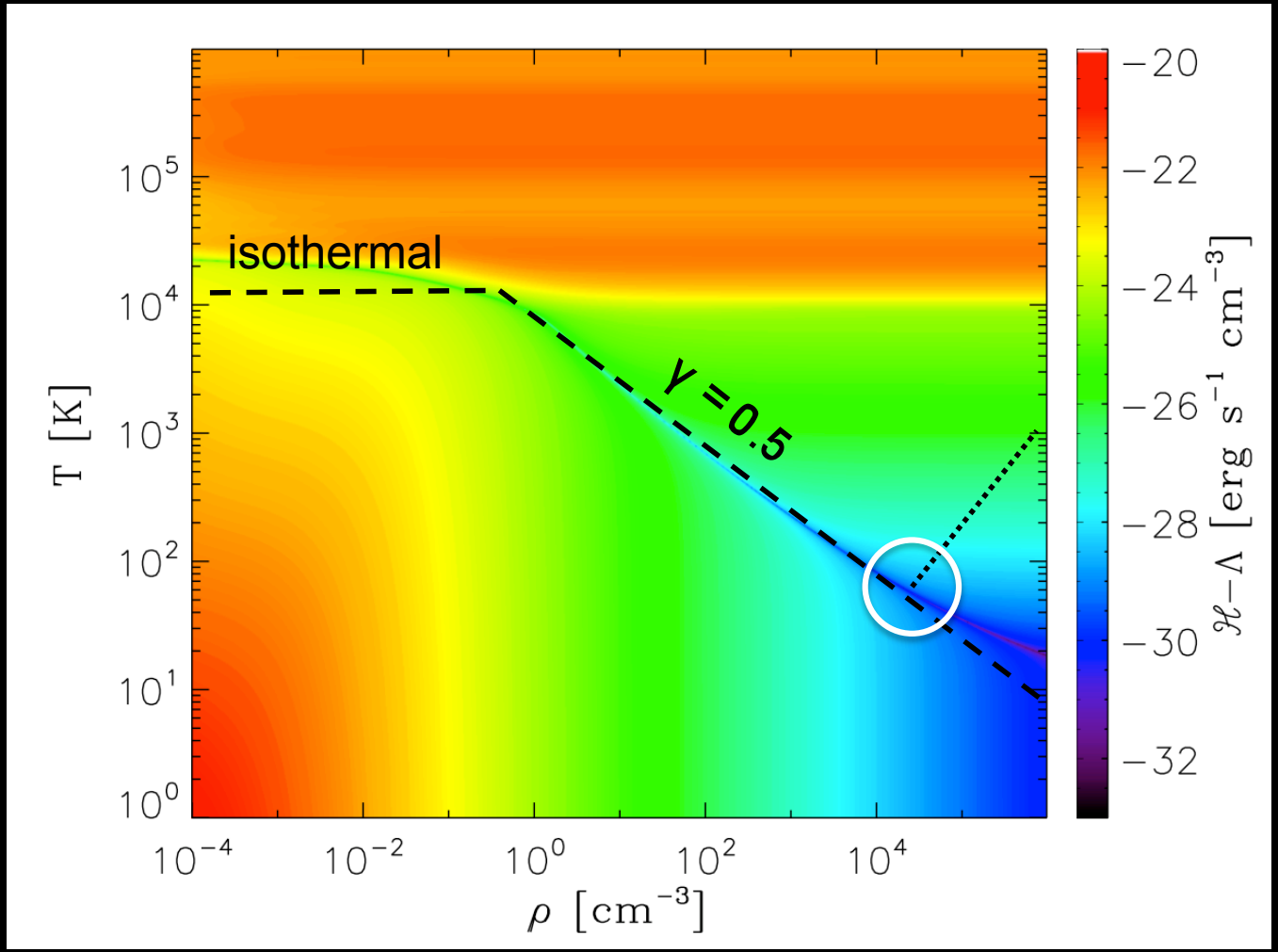
# Science inside: EoS

Piecewise polytropic EoS

Bournaud et al. 2010

+ pressure floor

Robertson & Kravtsov 2008




down to 14 K

# Science inside: Star formation

Density threshold: 1000 $cm^{-3}$

SF law

Schmidt 1959

$$\rho_{\mathrm{SFR}} = \epsilon \frac{\rho}{t_{\mathrm{ff}}} \propto \epsilon \rho^{1.5}$$

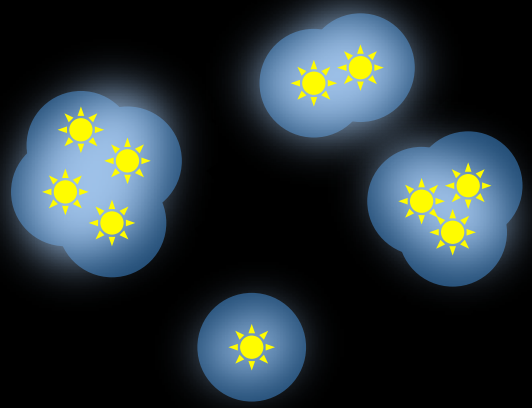
Poisson distribution of mean

Katz 1992

$$\frac{\rho_{\mathrm{SFR}}}{M_\star} \mathrm{d}t$$

$$\epsilon = 0.03$$
$$M_\star = 160 M_\odot$$

# Science inside: Stellar feedback



Creation of HII photo-ionized bubbles
(thermal pressure)

Momentum driven feedback
(radiative pressure)

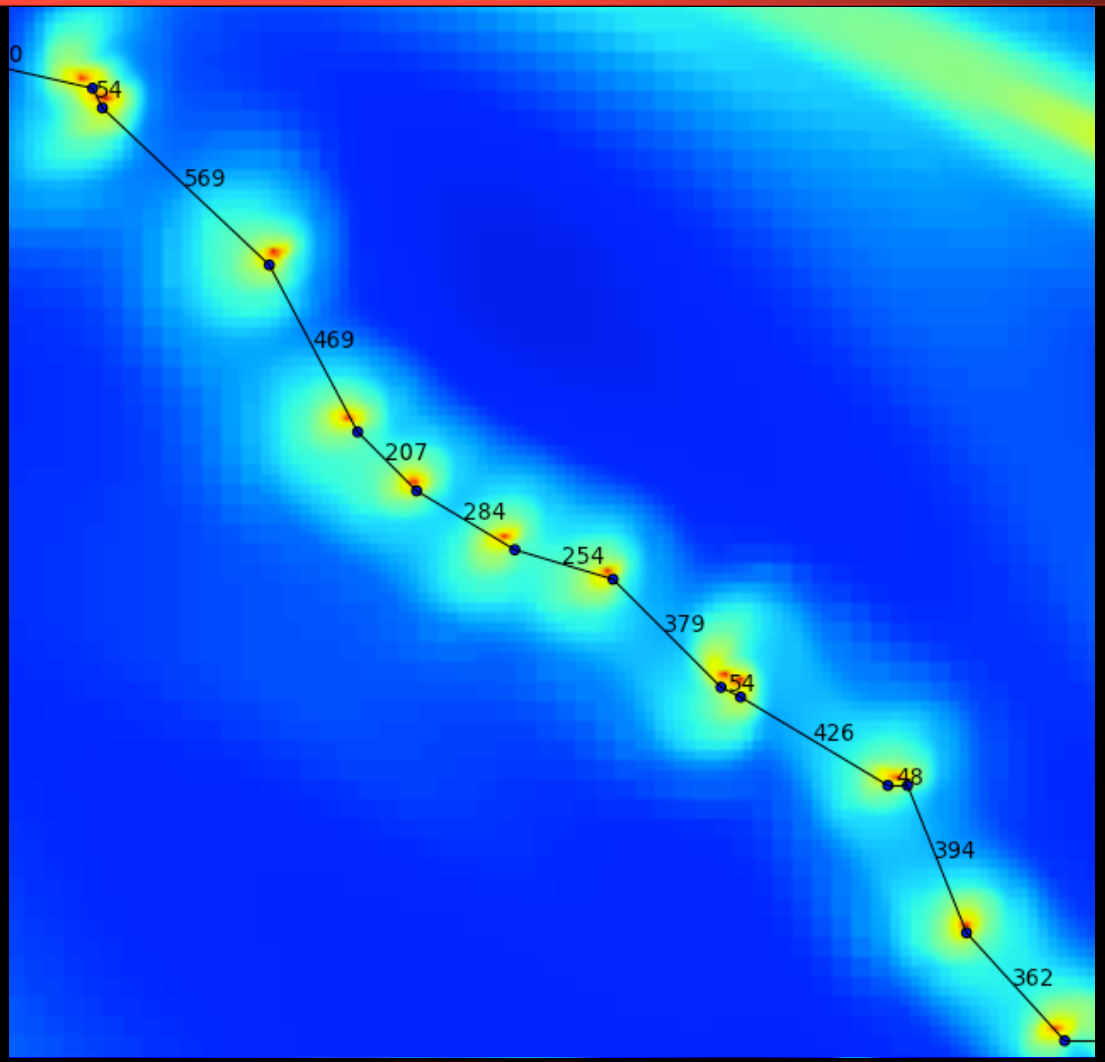
Renaud & Bournaud (in prep)

SN explosions

Dubois & Teyssier 2008

*Predictive* feedback
(no free parameters)

# Beads on a String

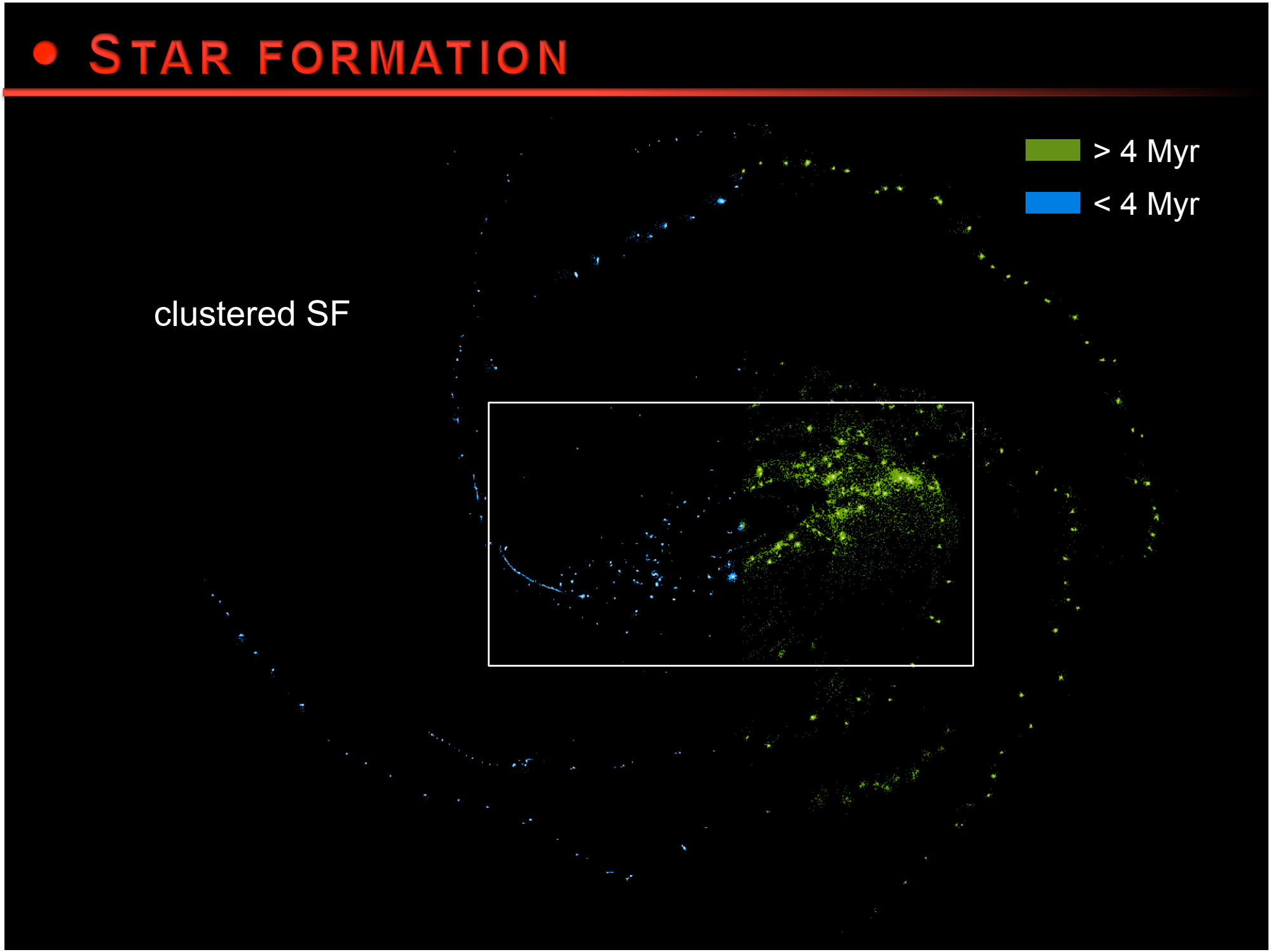



Separations correlate with FWHM

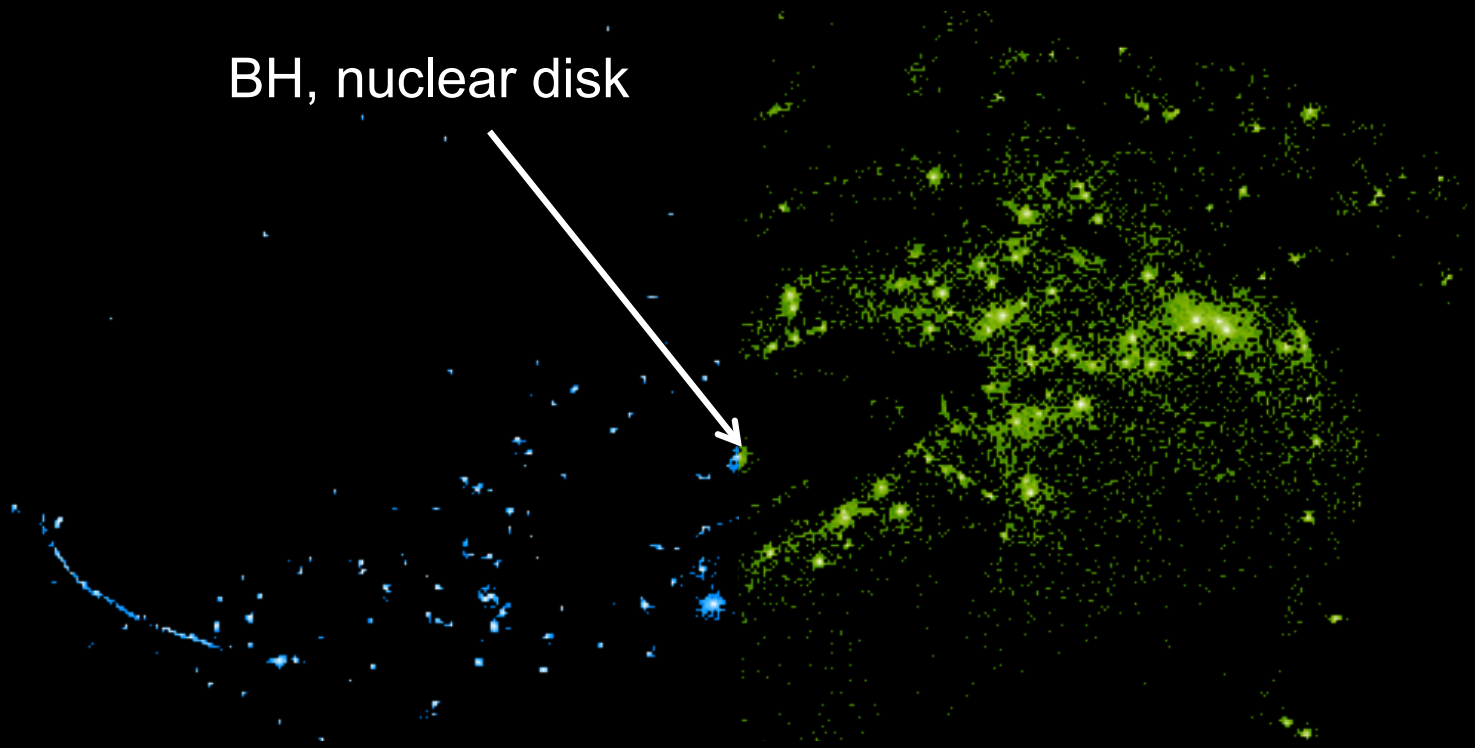
Fischera & Martin 2012

(see the talk by B. Elmegreen)

# STAR FORMATION



# (No) SF in the Bar

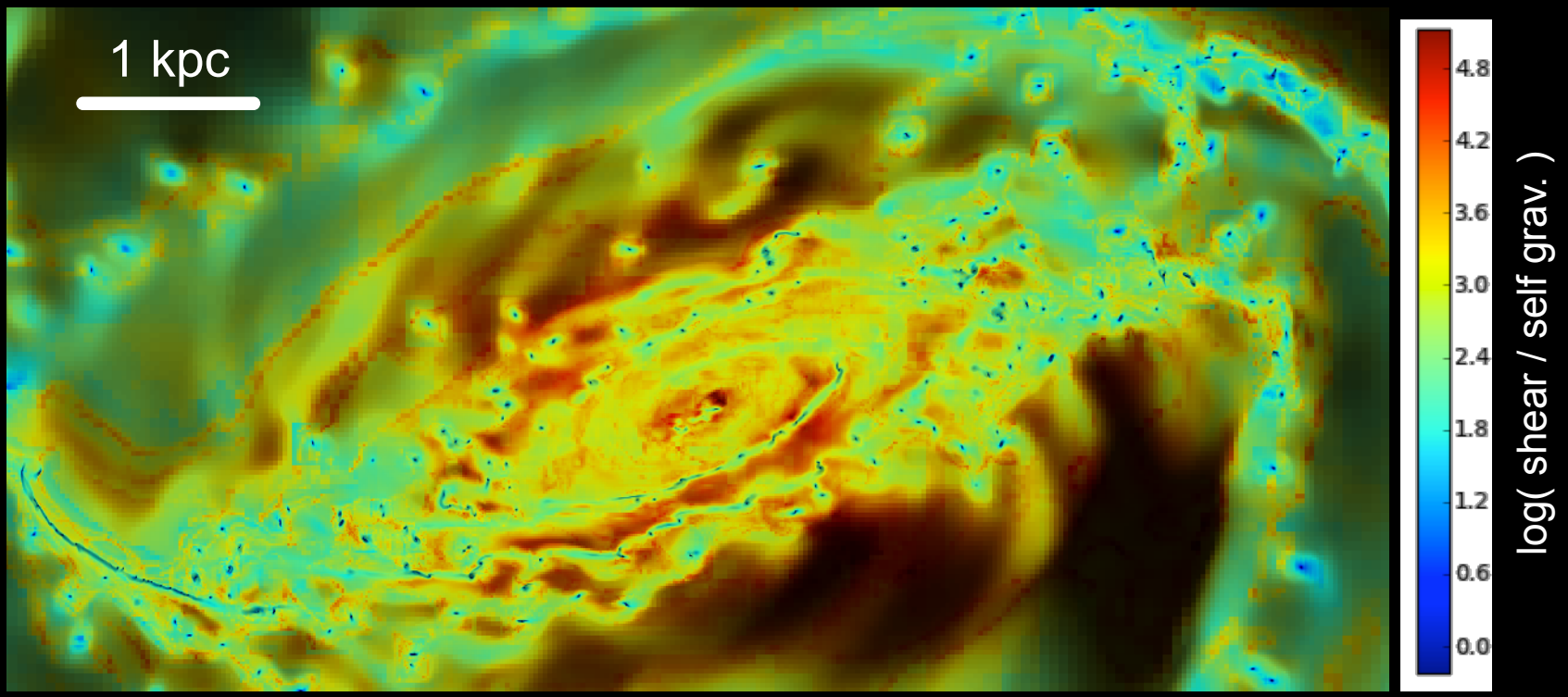



No SF *inside* the bar

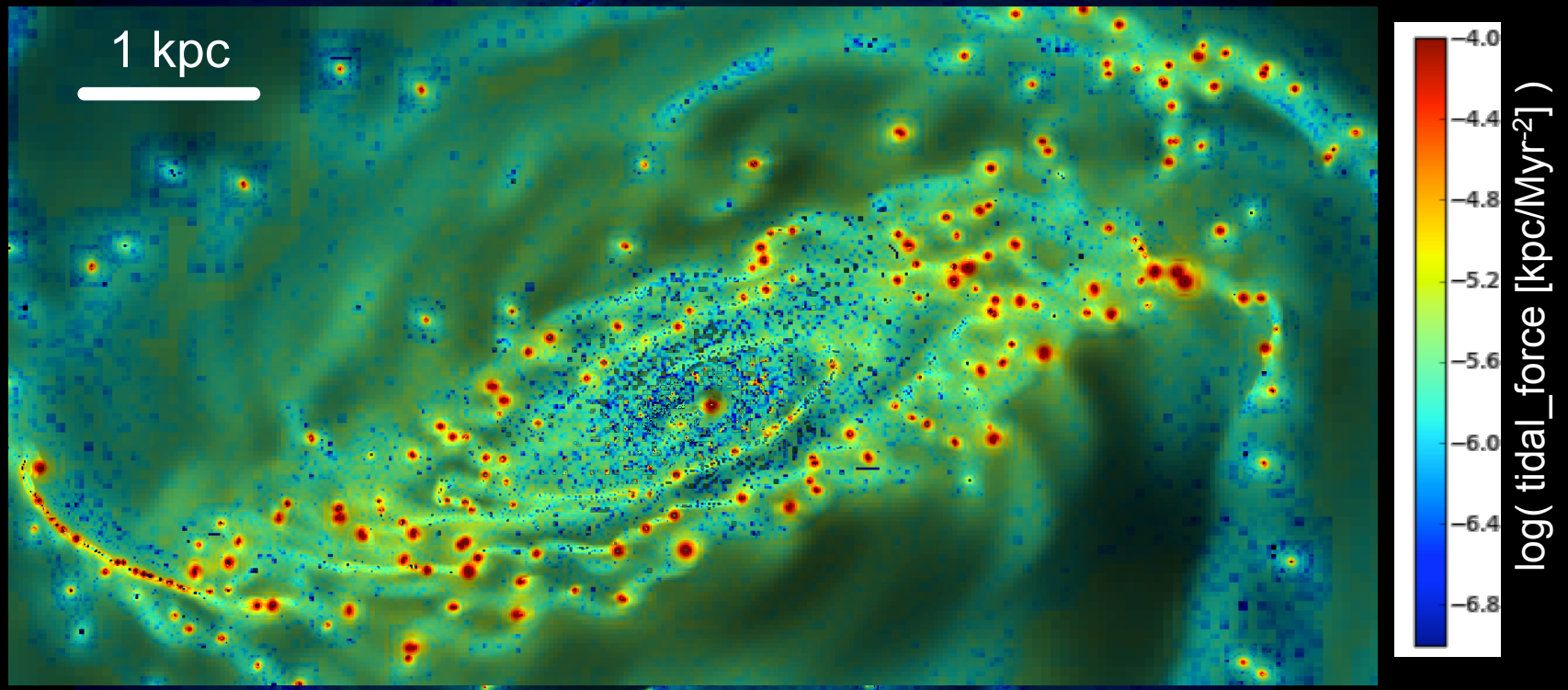
Comparable to observations

(see the talks by S. Longmore and H. Beuther)

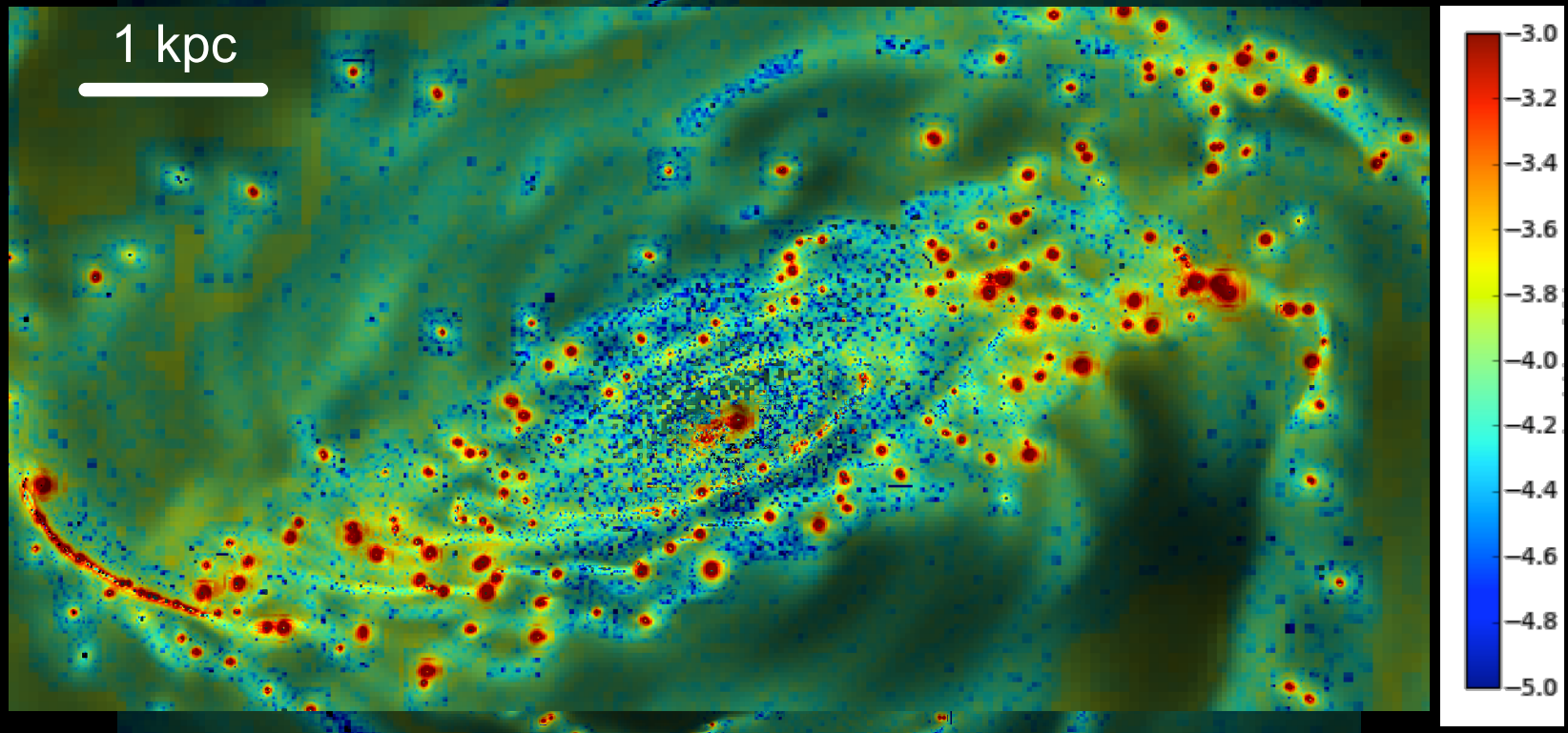
# Because of Shear?



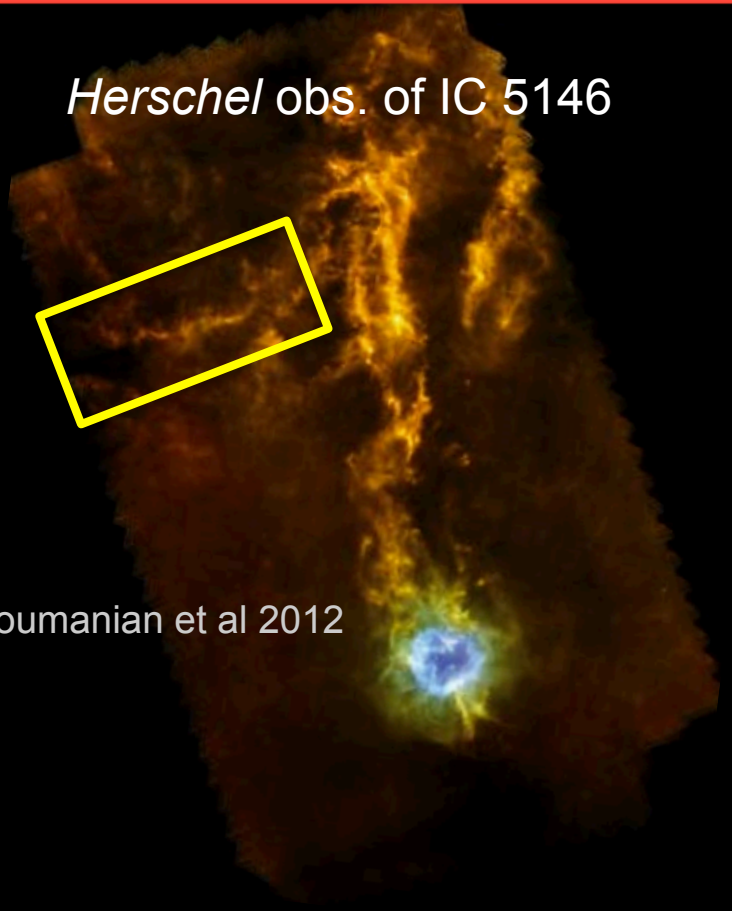
# • And what about Tides?

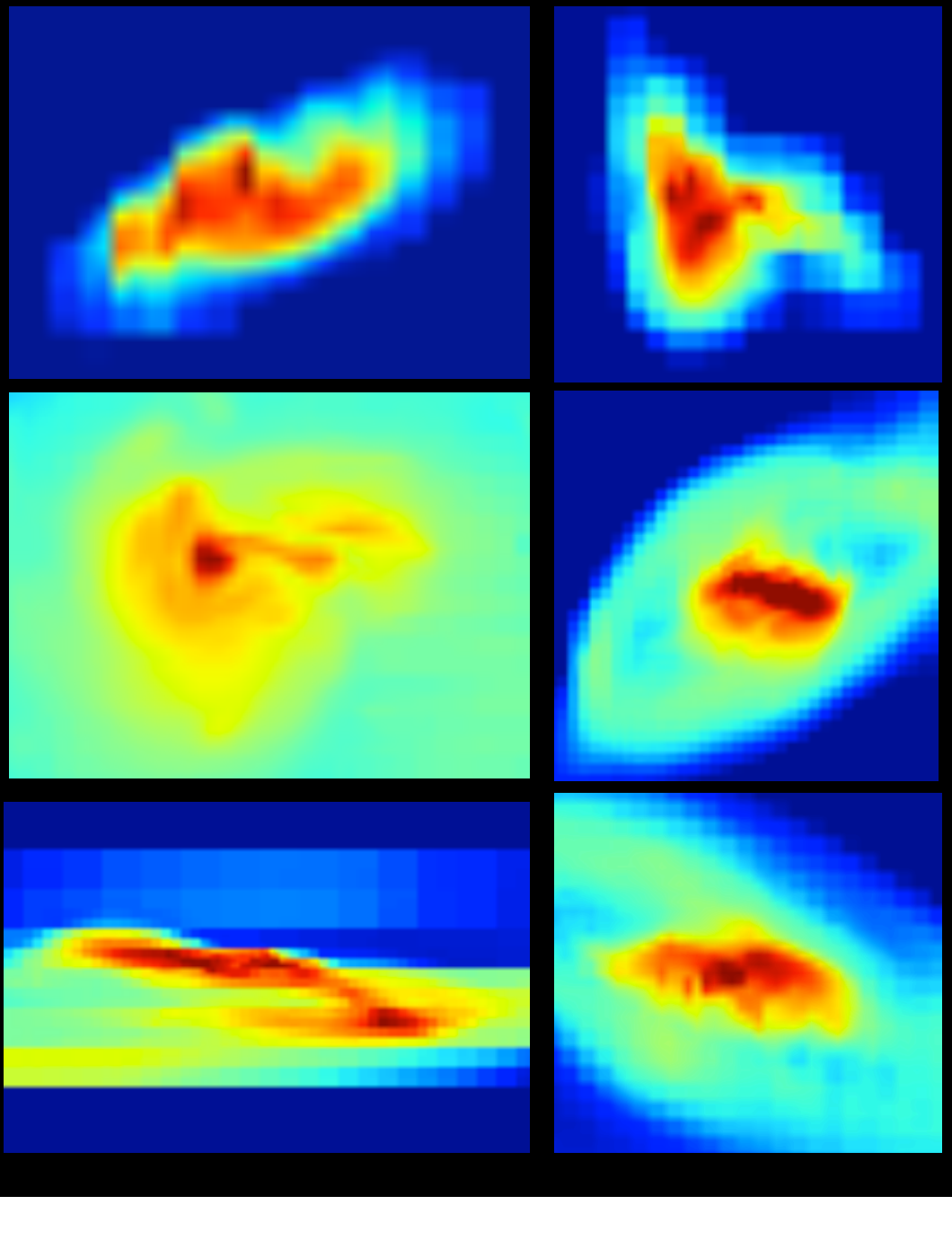


# • And what about Tides?



# Interstellar Filaments



Is magnetic field needed? No!

Padoan et al 2001
Balsara et al 2001

Fragmentation → SF cores

# Conclusions

Simulation of the MW at subparsec resolution

Turbulent cascade fully described (down to sonic scale)

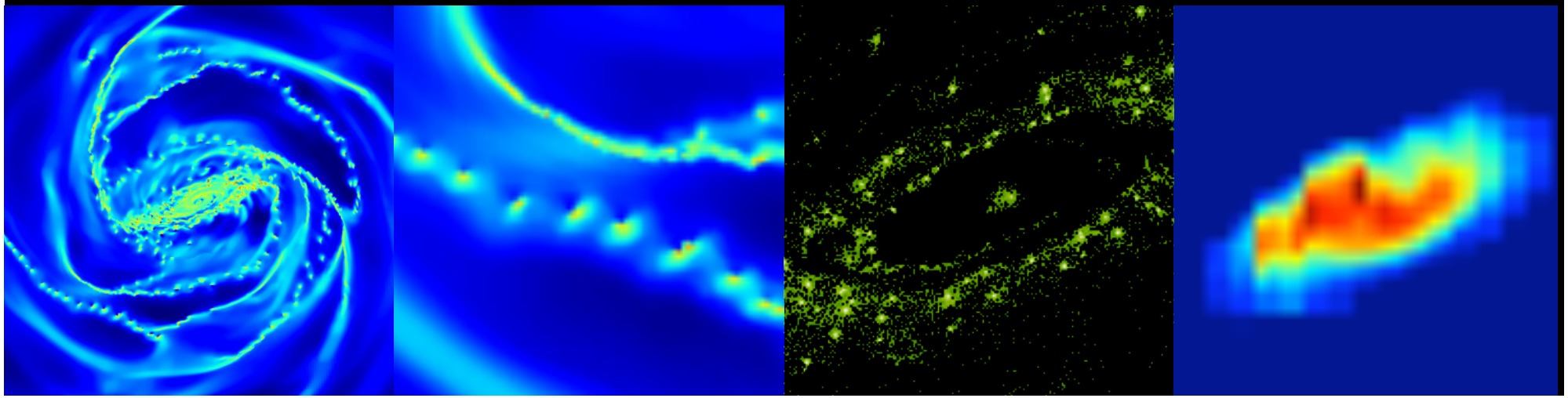
Beads on a string, clustered star formation

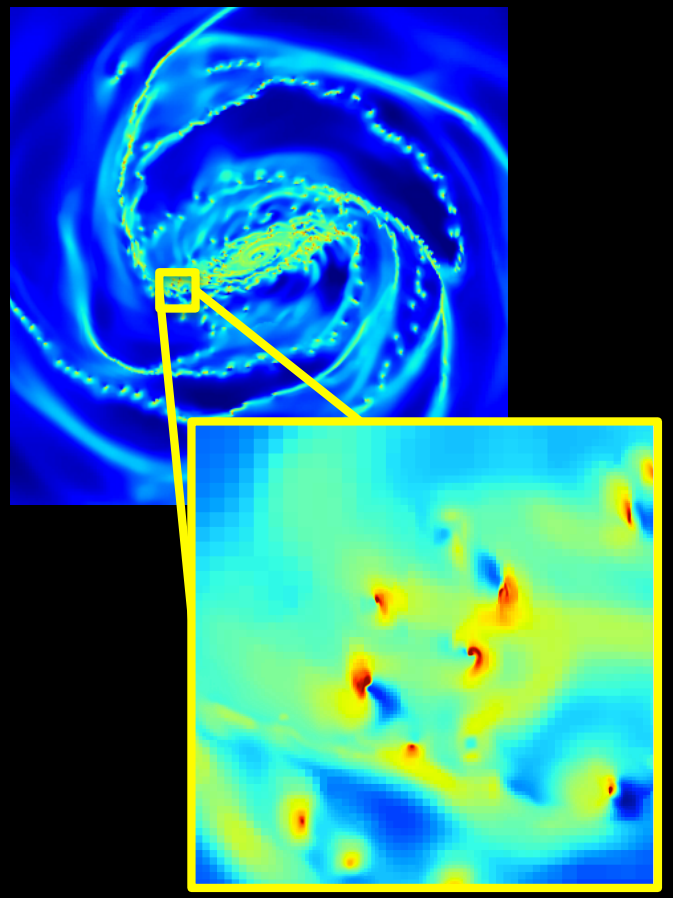
No star formation inside the bar

*because of shear*

Interstellar filaments formed

*with no magnetic field*





*Fly over the (molecular) clouds*

http://irfu.cea.fr/Pisp/florent.renaud