INTERNATIONAL
SUMMER
INSTITUTE FOR
MODELING IN
ASTROPHYSICS

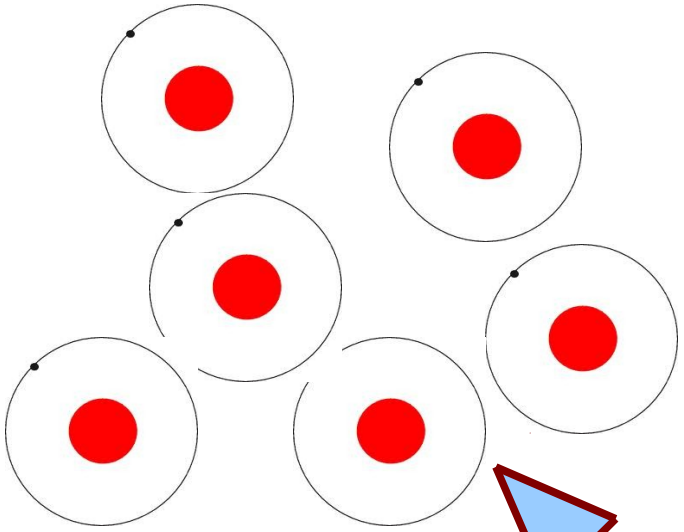
Multi-Phase Turbulent ISM: Theory Confronting Observations

ISIMA student: Guang-Xing Li
Supervisors: Patrick Hennebelle and Nicolas Peretto

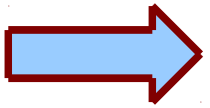
Outline

- Engineering- How do we make a star
- Observations

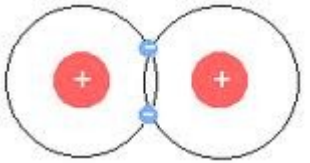

Magnitude: 9.75 (B-V: 0.95)
RA/DE (J2000): 11h58m31.1s/-16° 57'19.9"
RA/DE (of date): 11h59m7s/-17° 1'12"
Hour angle/DE: 7h51m2s/-17° 1'12"
Az/Alt: +274° 8'57"/-31°57'46"
Vega
How Can You Make A Star?
Vesta
S
Earth, Beijing, 53m
FOV 109°
32 FPS
2011-08-04 23:13:10

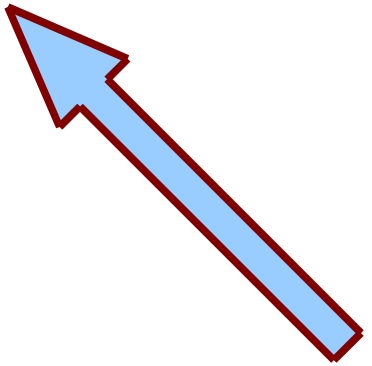


10^4 K

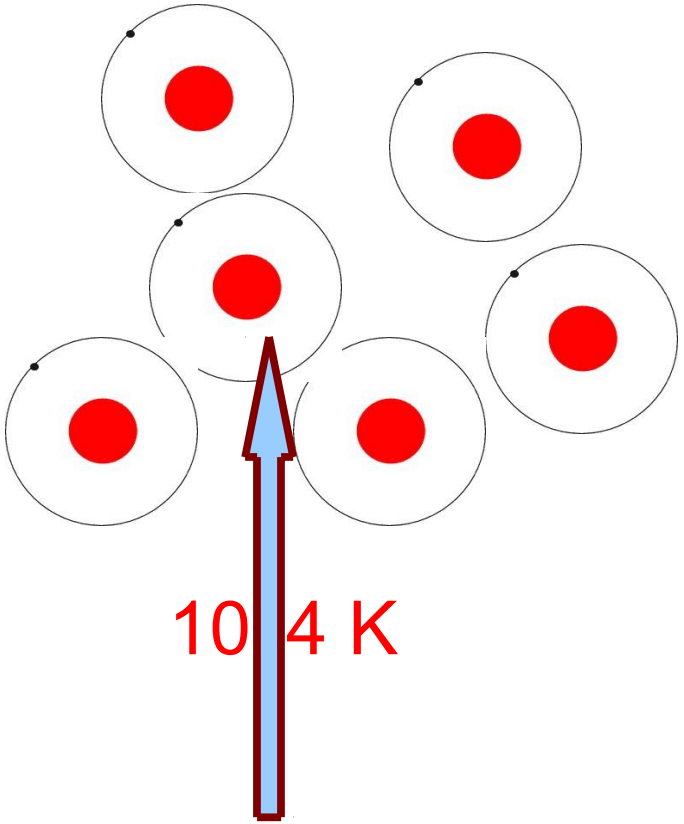


10K

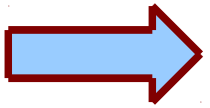




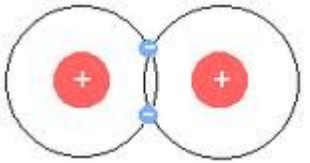
UV

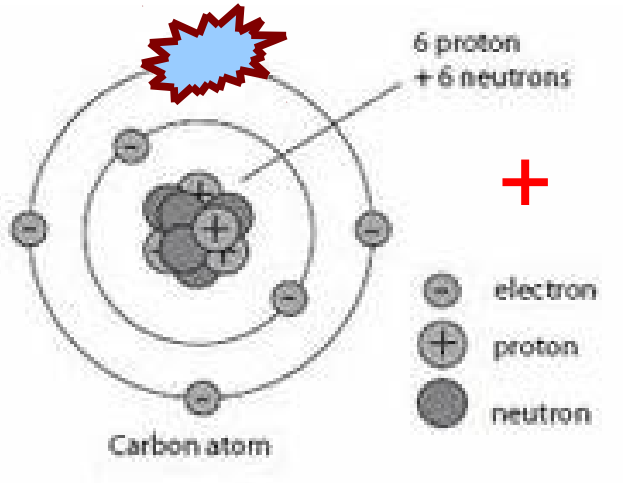


10 4 K

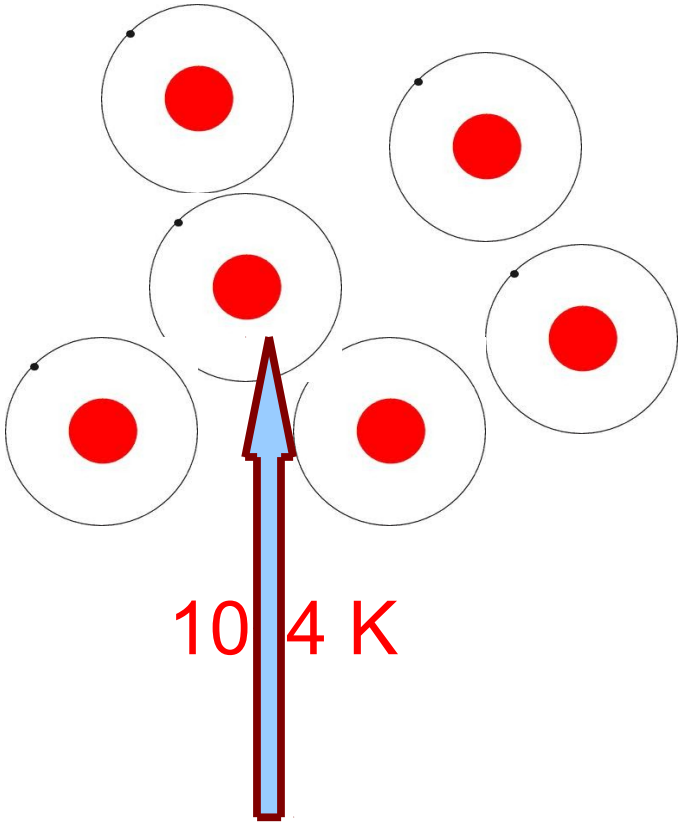


10K

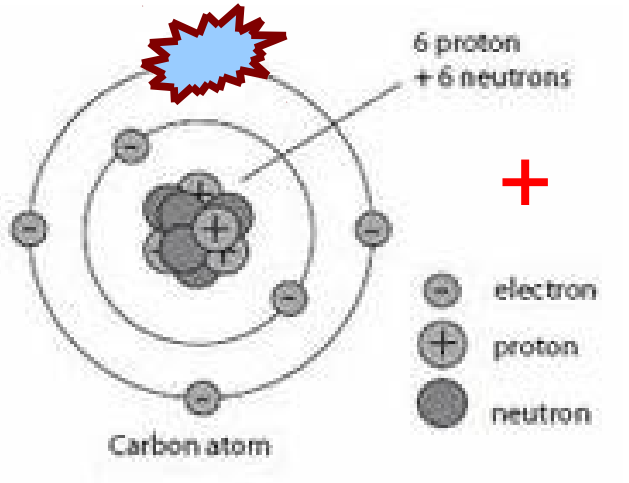




C+

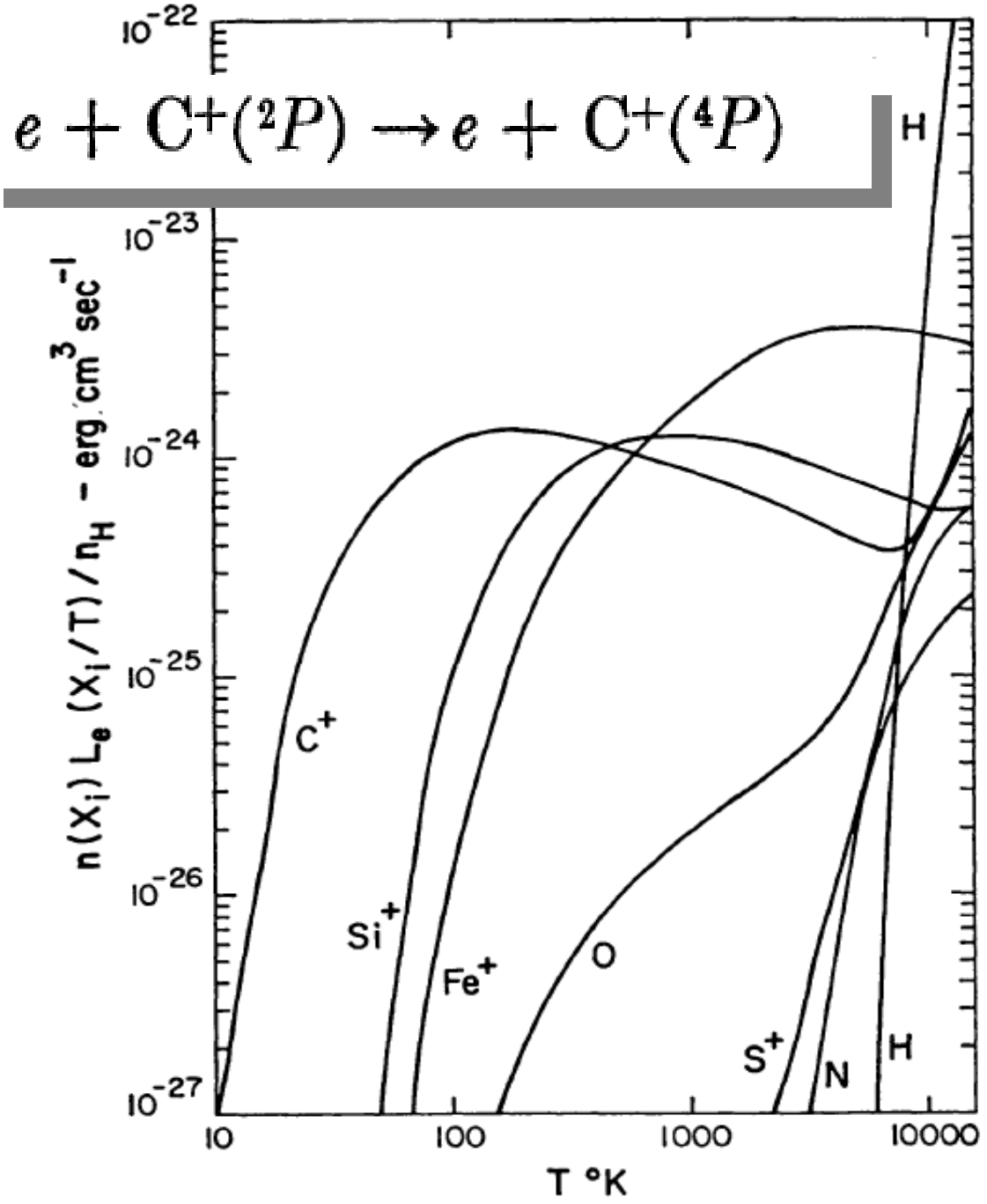


10 4 K



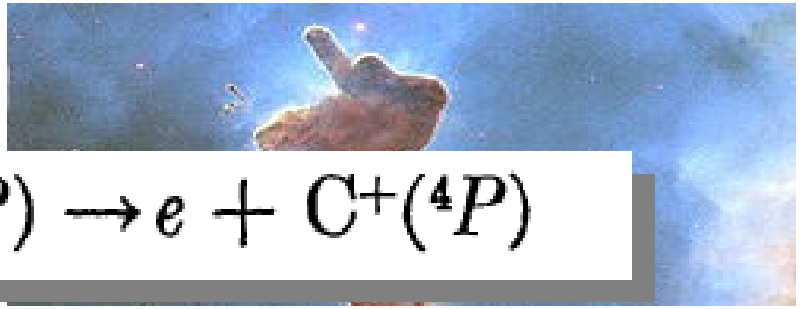
C+

$$e + C^{+}(^{2}P) \rightarrow e + C^{+}(^{4}P)$$

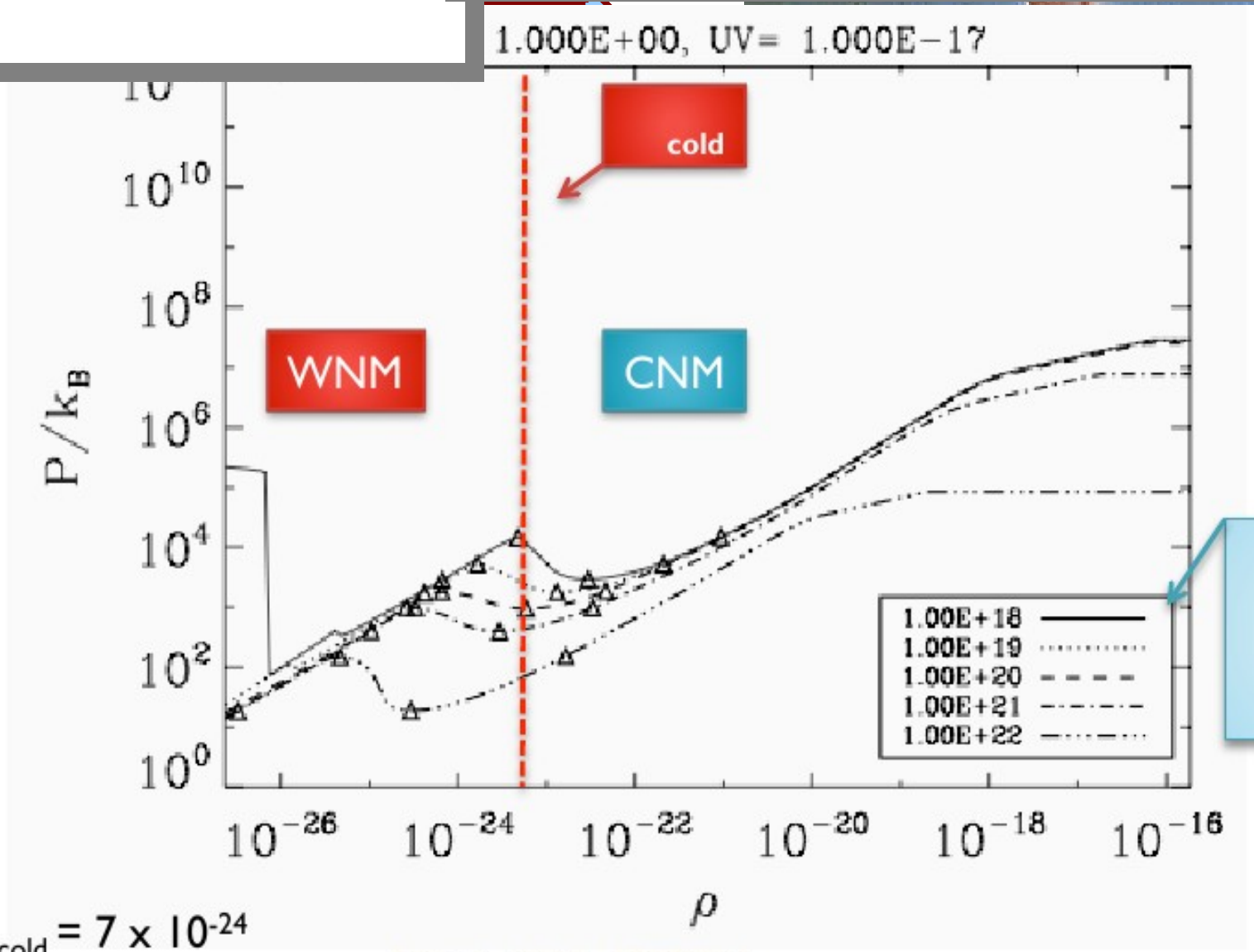


Dalgargo & McCray 1972

$$PV = NkT$$



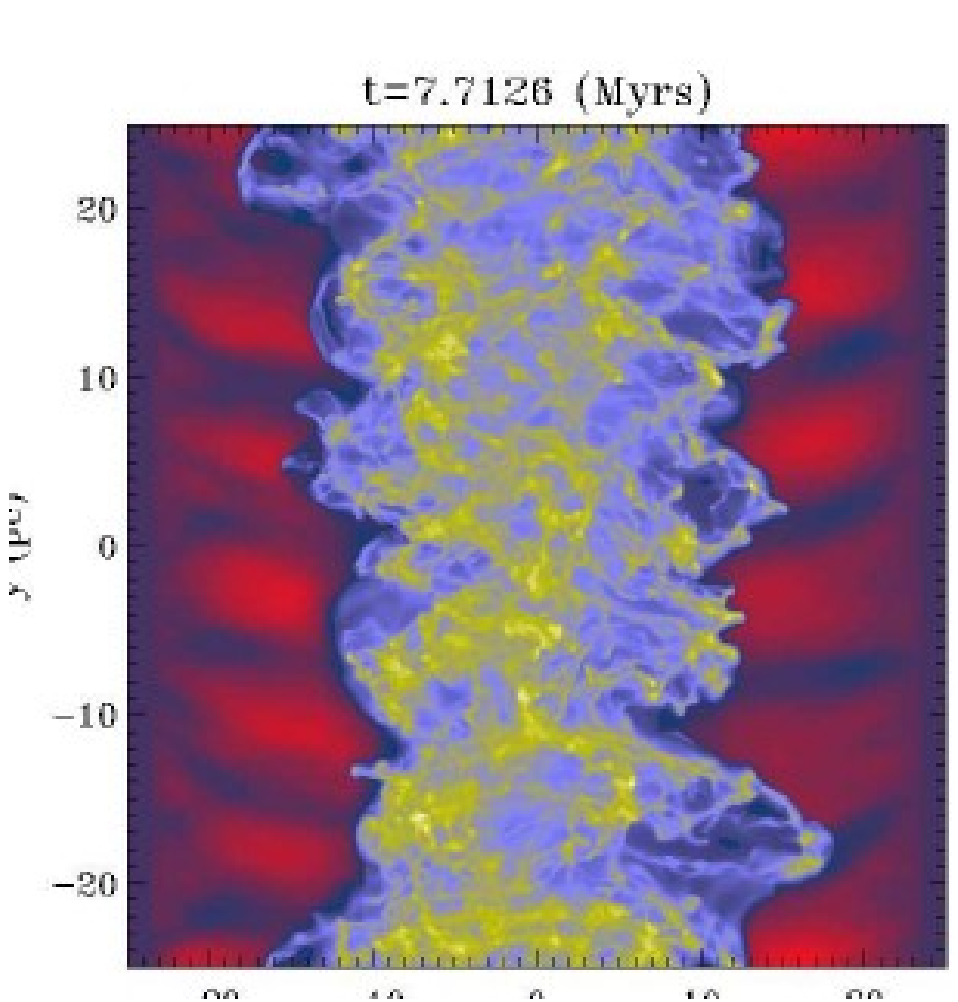
$$e + \mathrm{C}^+(^2P) \rightarrow e + \mathrm{C}^+(^4P)$$

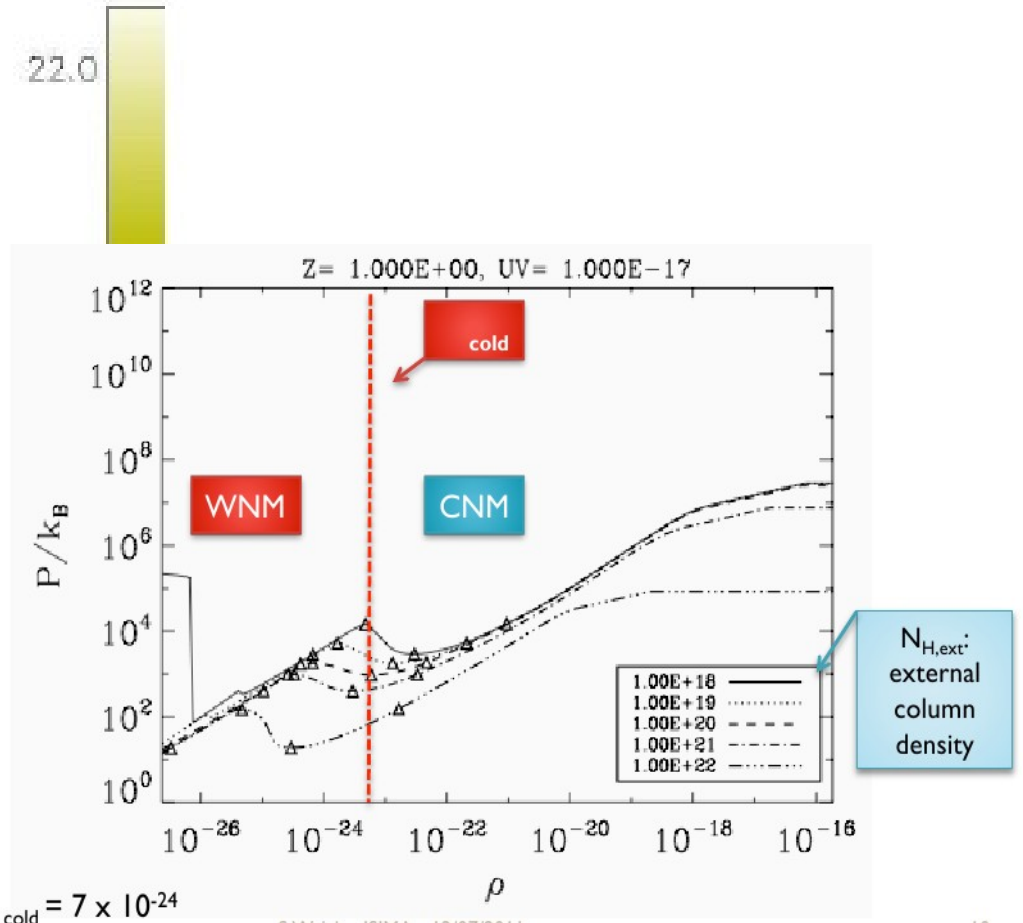


$N_{H,ext}$: external column density

$_{cold} = 7 \times 10^{-24}$

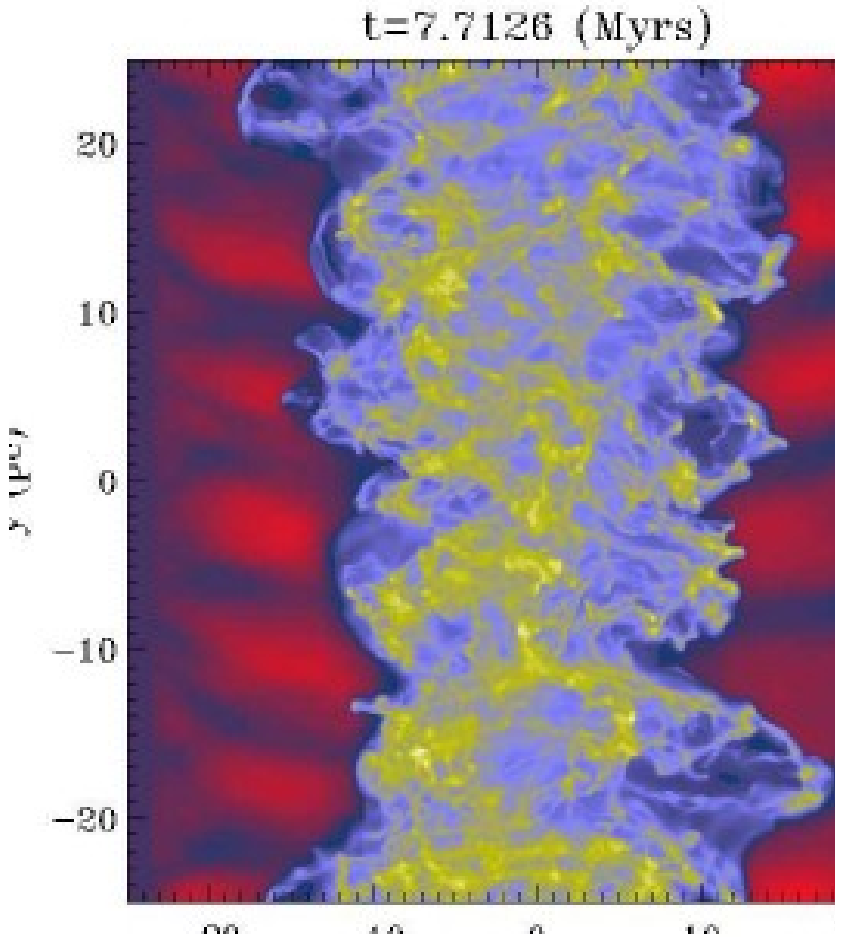
Converging Flow

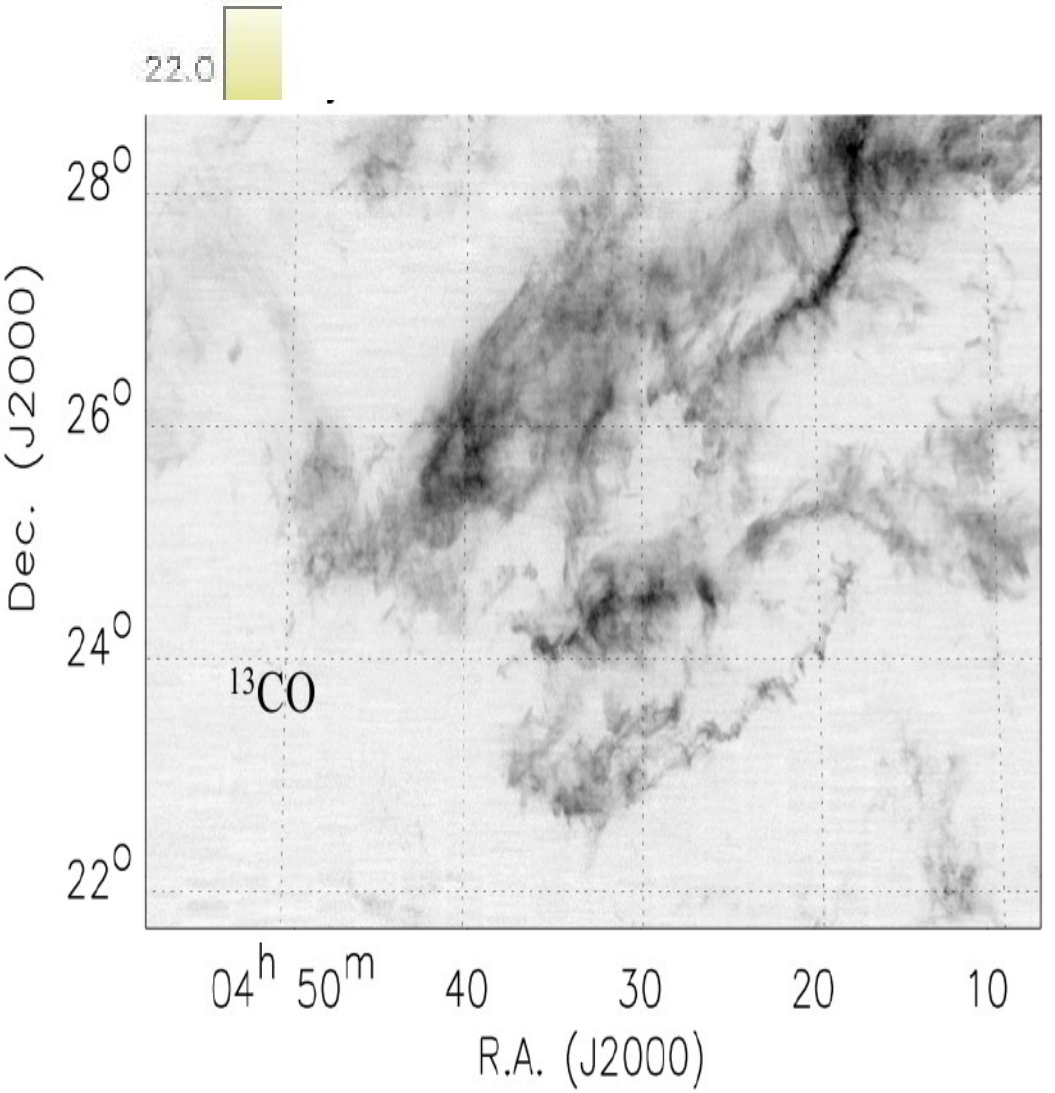




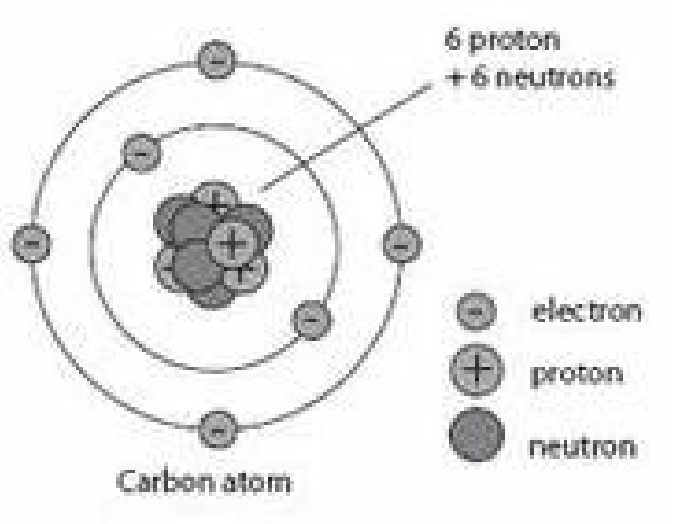
Hennebelle et al 2011

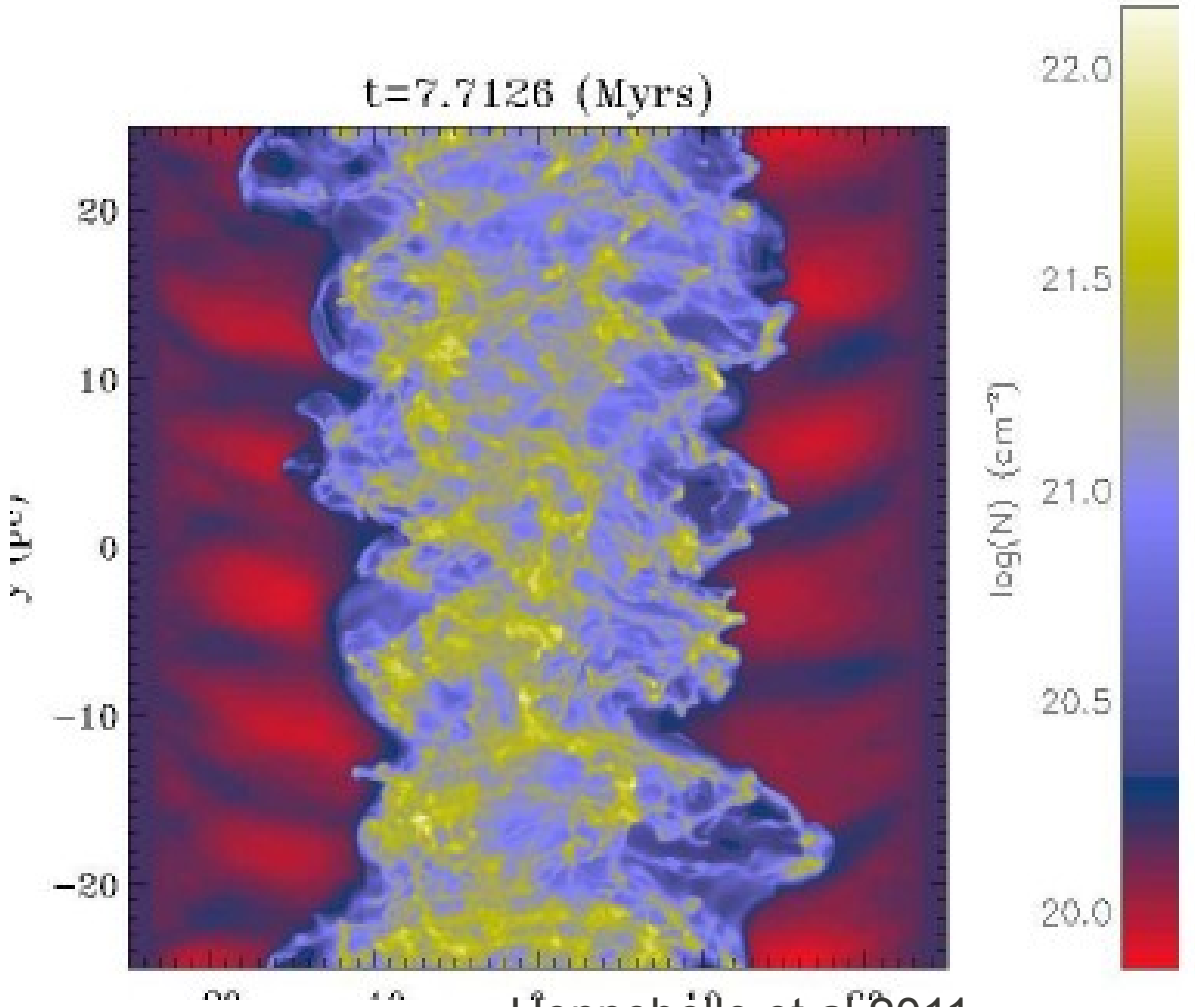
Converging Flow





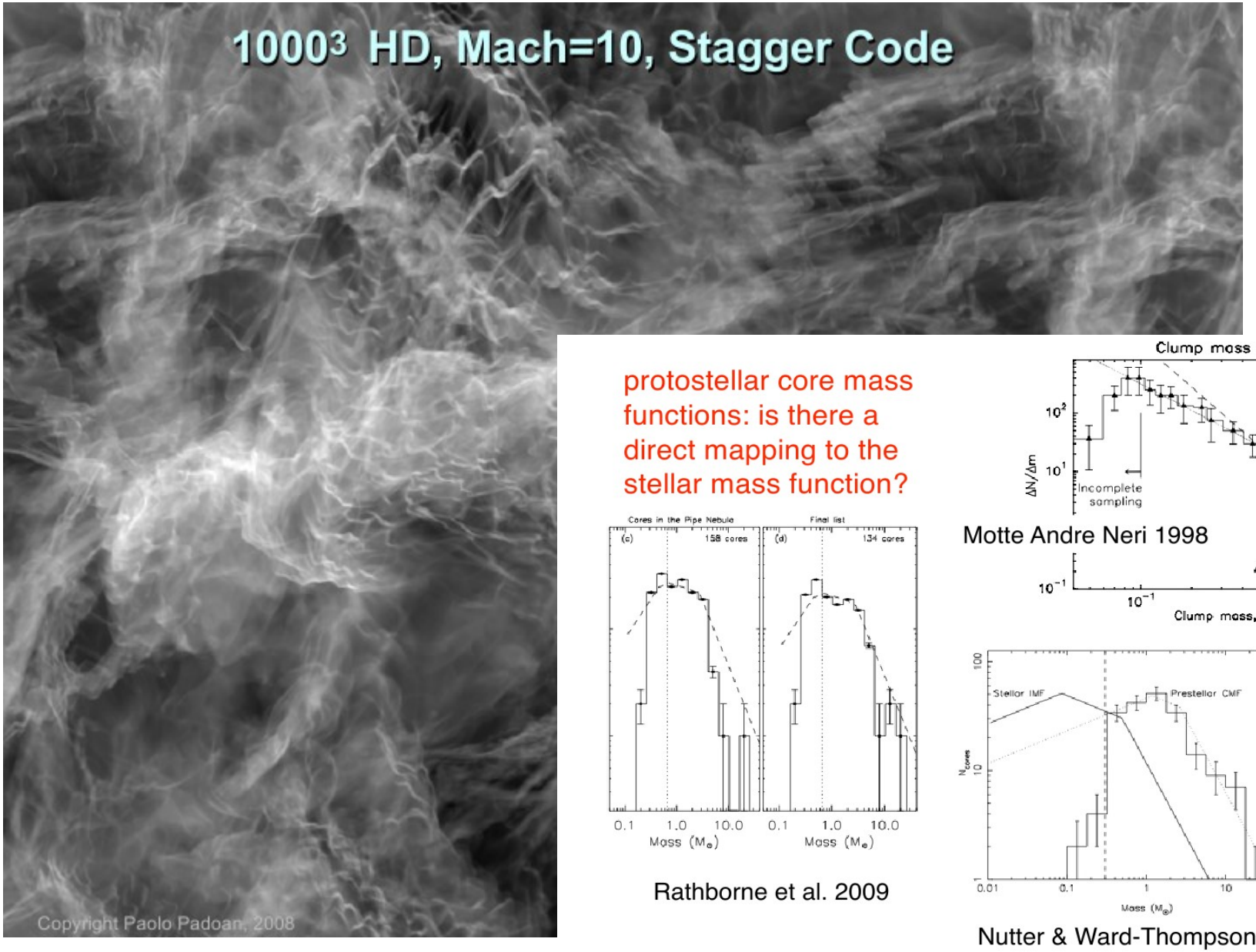
Summary 1





Hennebelle et al 2011

Turbulence



protostellar core mass functions: is there a direct mapping to the stellar mass function?

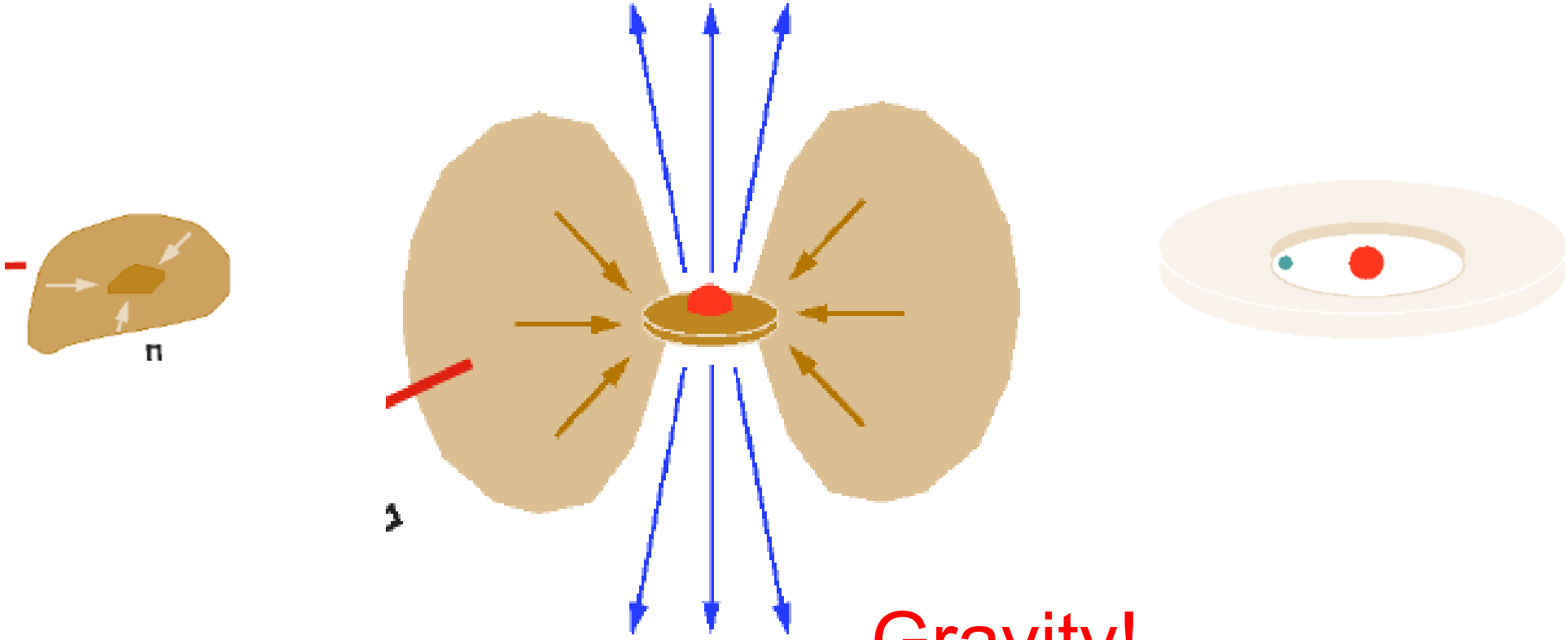
Rathborne et al. 2009

Motte Andre Neri 1998

Nutter & Ward-Thompson 2007

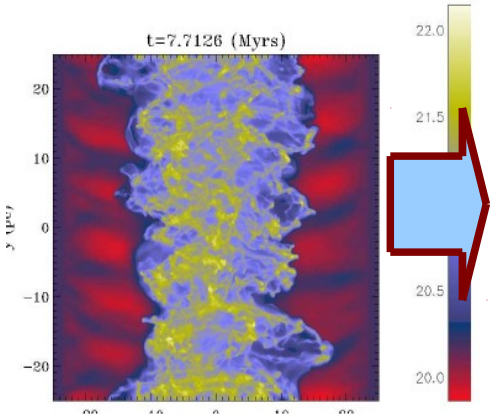
Padoan's PPT

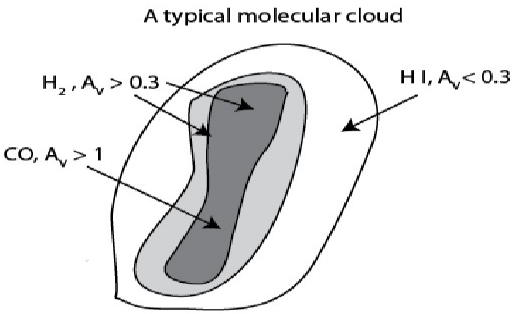
From Cores to Stars

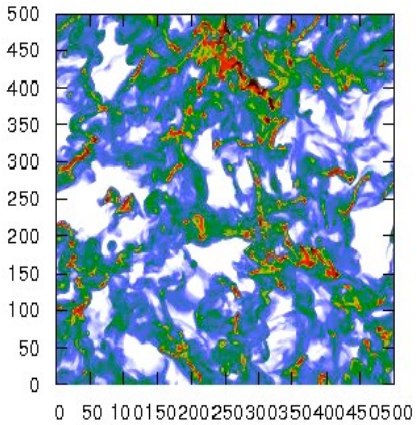


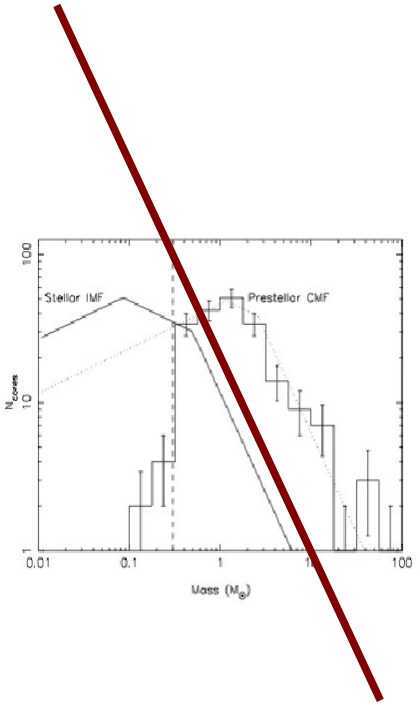
Gravity!

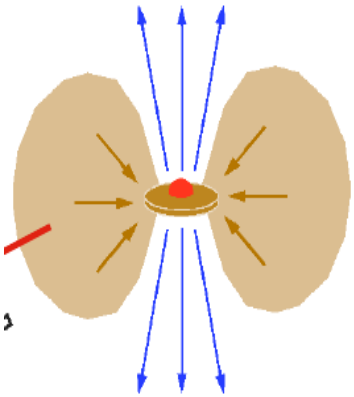
Star Formation Engineering





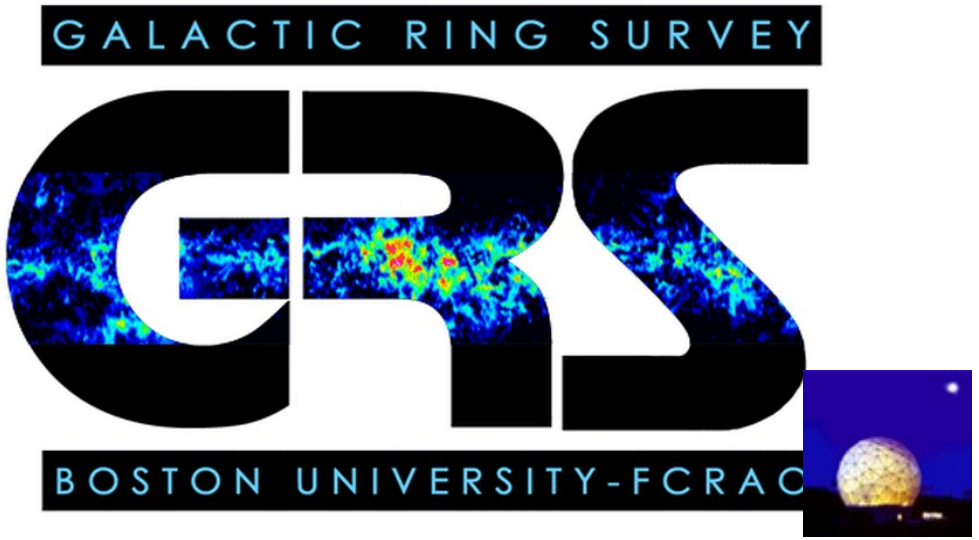






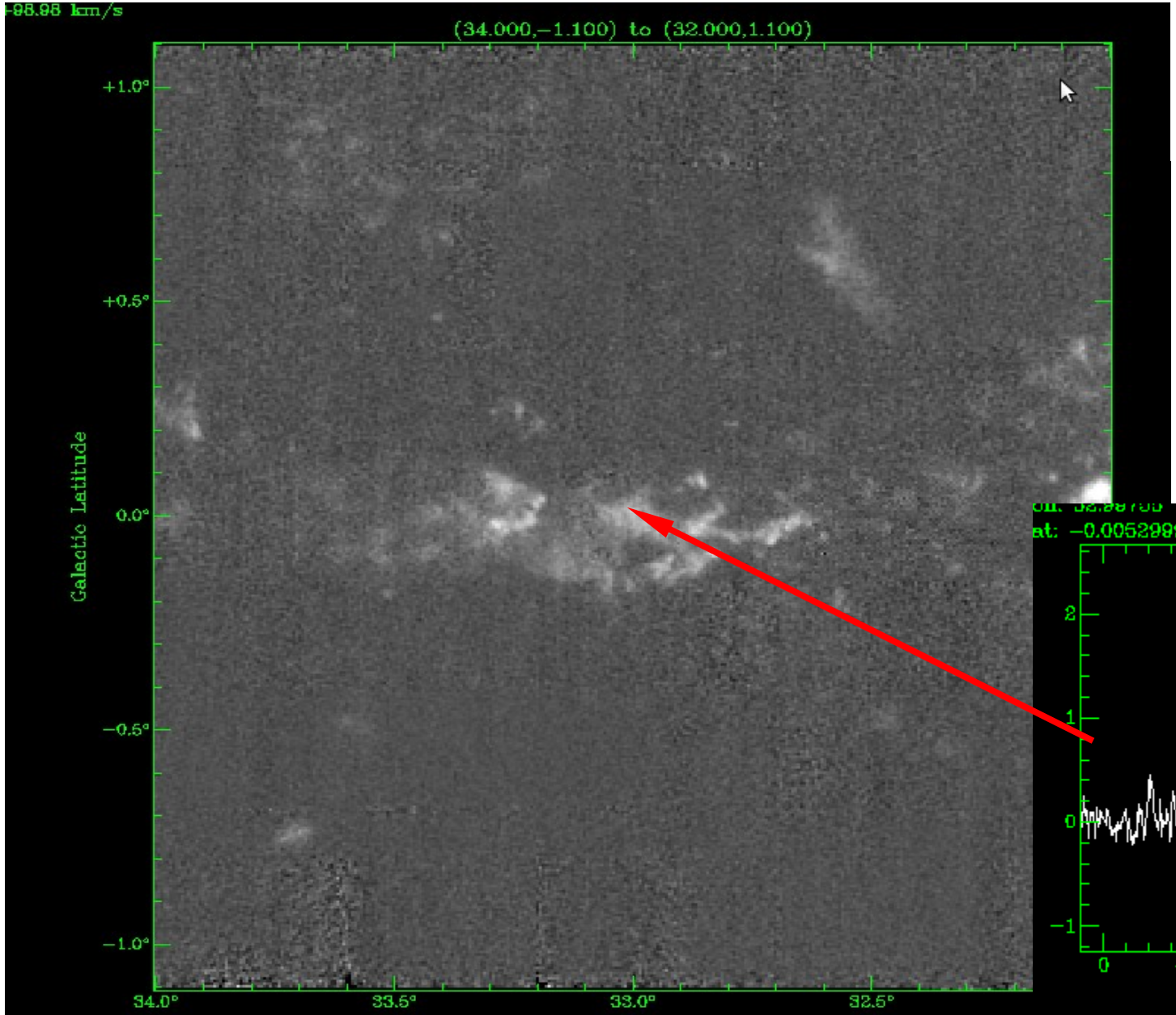
The Observations

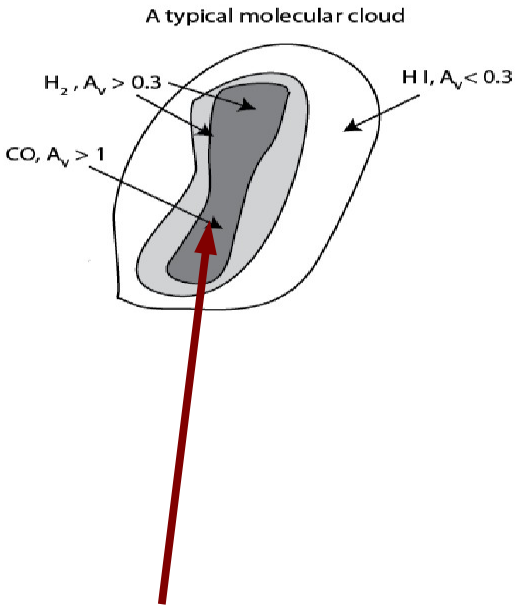
- CO data: GRS Galactic Ring Survey, 13CO(1-0)
  - Stil et al. 2006
  - 1 arcmin Resolution, (l from 18 deg to 52 deg)
- HI data: VLA Galactic Plane Survey
  - Jackson et al. 2006, (l from 18 deg to 67 deg)

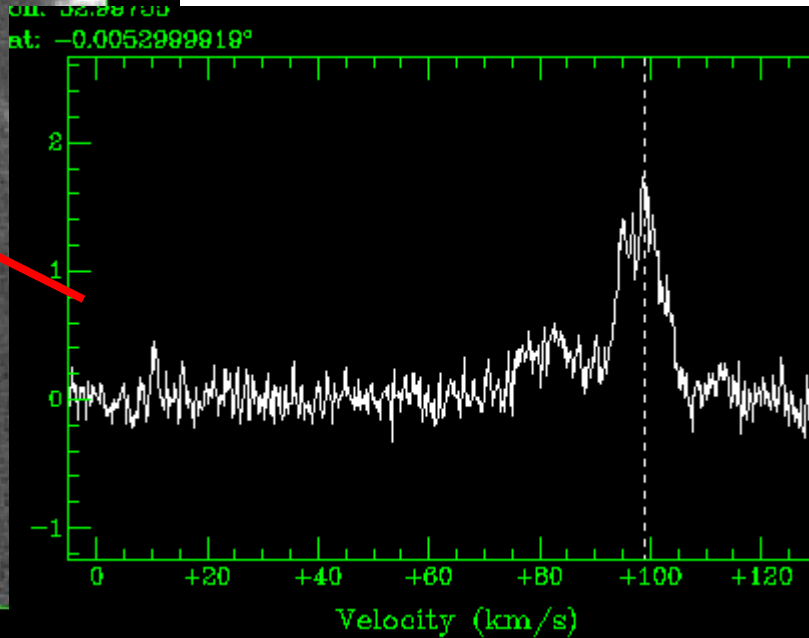


2 Degrees

CO

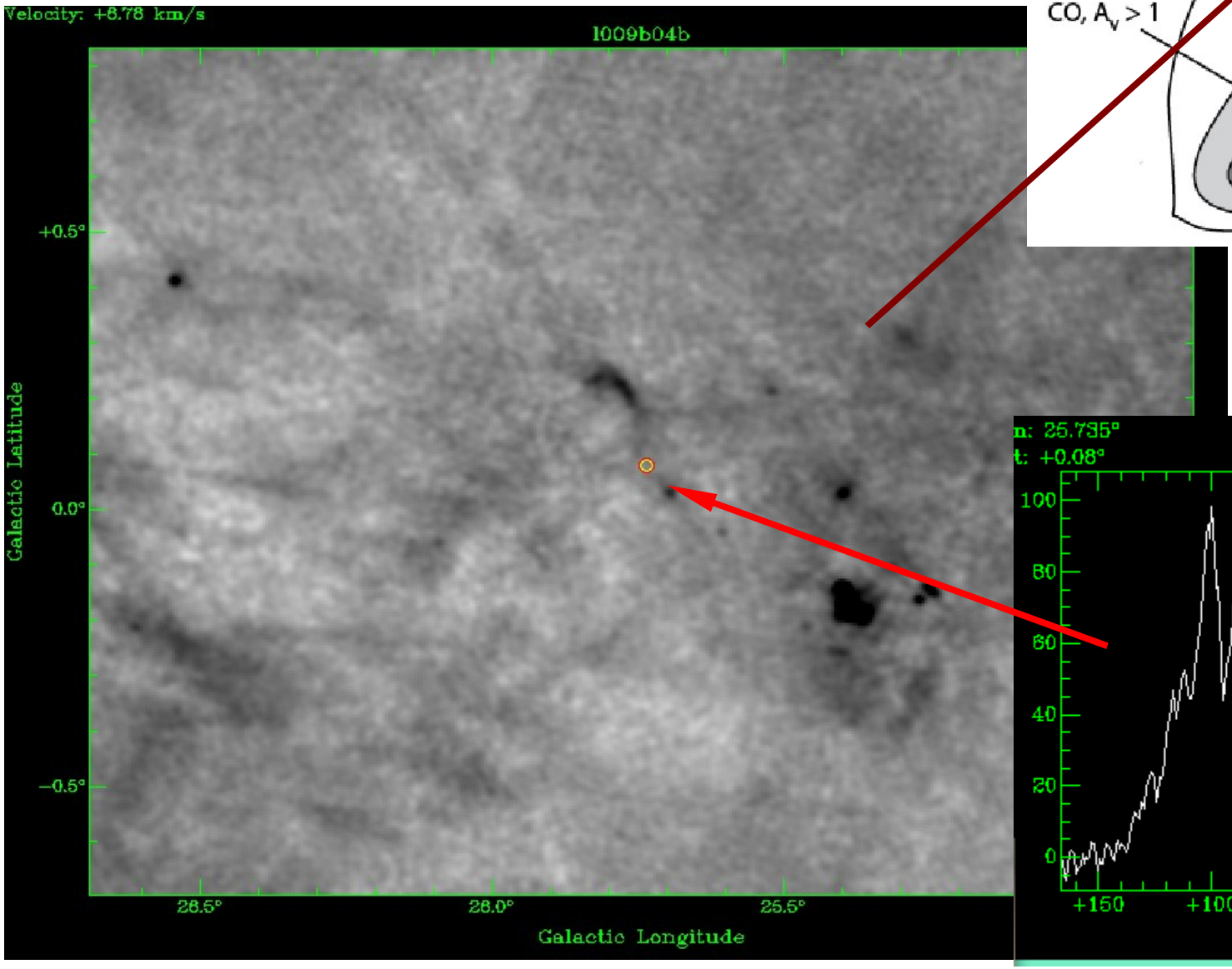

(34.000,−1.100) to (32.000,1.100)
+1.0°
+0.5°
0.0°
−0.5°
−1.0°
Galactic Latitude
34.0°
33.5°
33.0°
32.5°

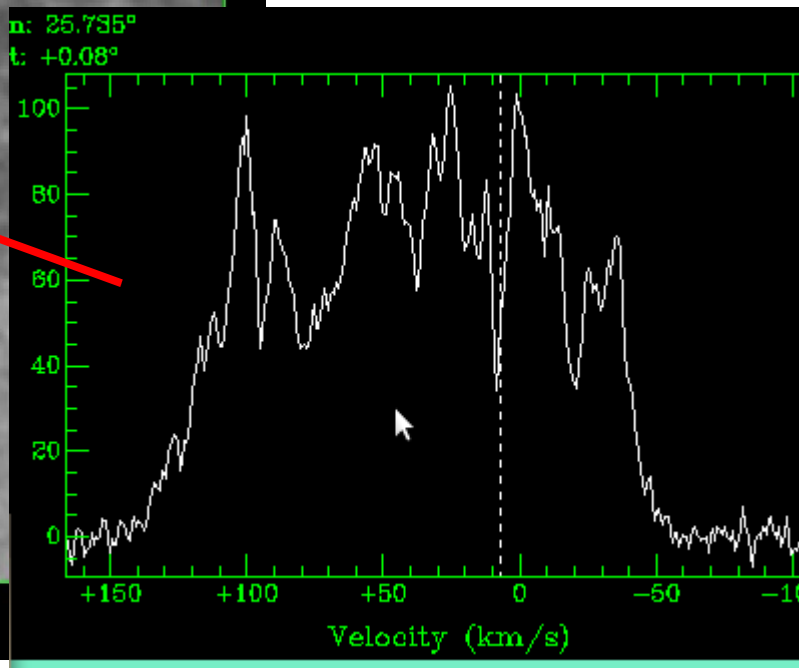

A typical molecular cloud
H2 , Av > 0.3
HI, Av < 0.3
CO, Av > 1

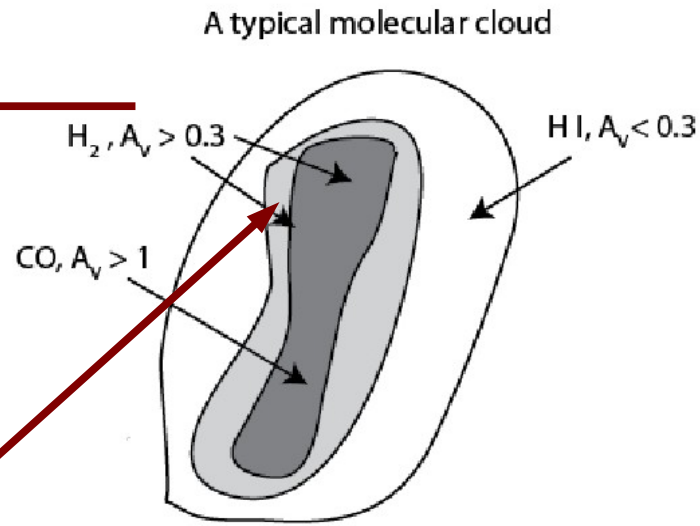

2
1
0
−1
0
+20
+40
+60
+80
+100
+120
Velocity (km/s)

2 Degrees

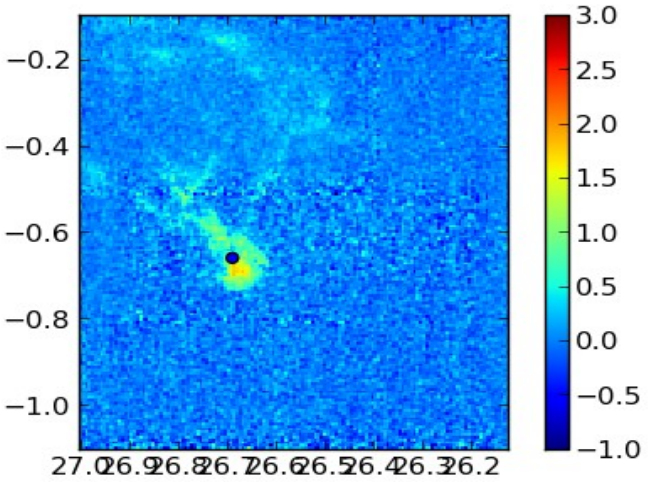
HI

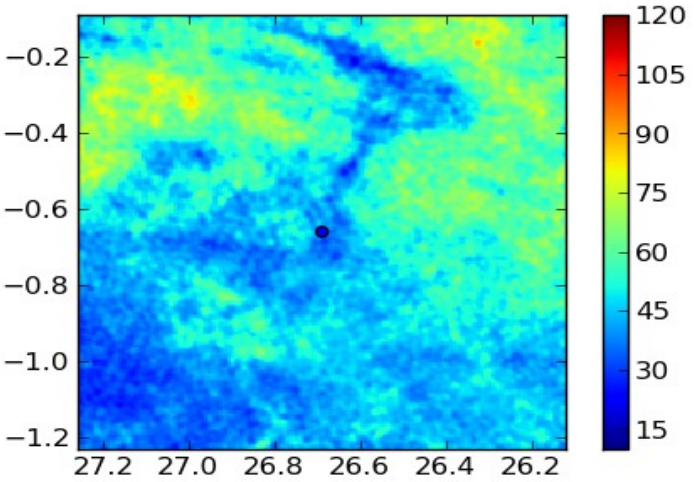

Velocity: +8.78 km/s
1009b04b
+0.5°
0.0°
−0.5°
Galactic Latitude
28.5°
28.0°
25.5°
Galactic Longitude

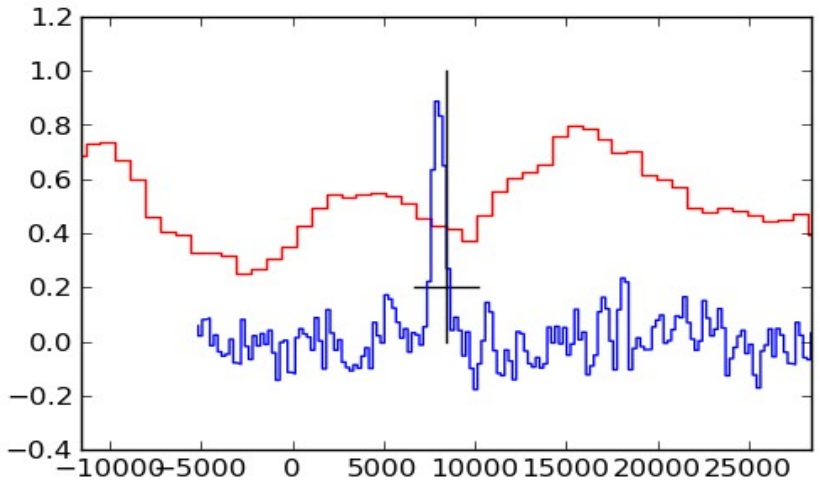

n: 25.735°
t: +0.08°
100
80
60
40
20
0
+150
+100
+50
0
−50
Velocity (km/s)

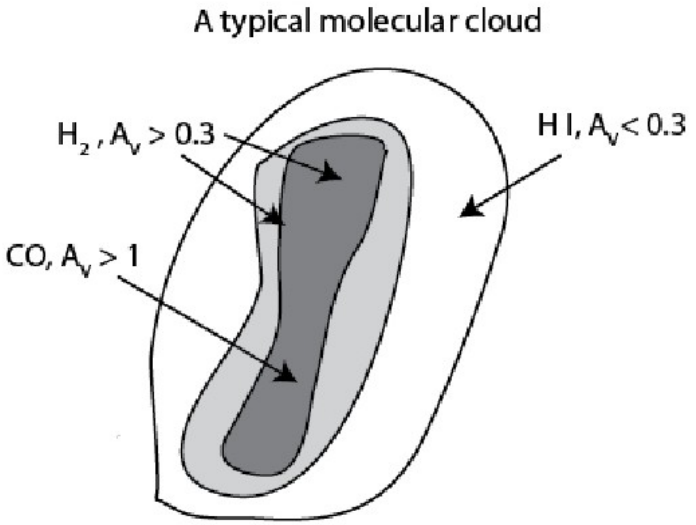

A typical molecular cloud
H2, Av > 0.3
HI, Av < 0.3
CO, Av > 1

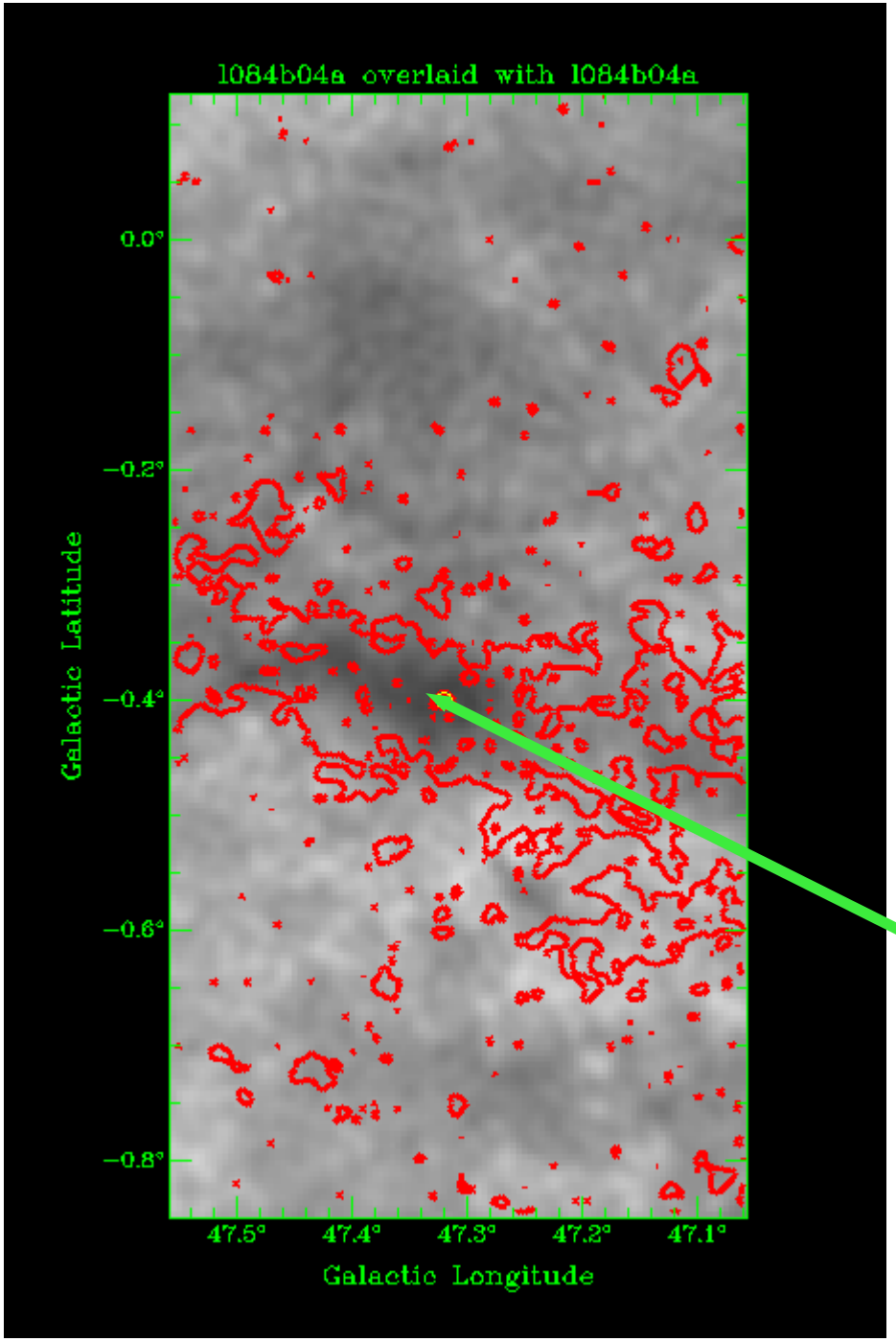
Finding The CO HI Association

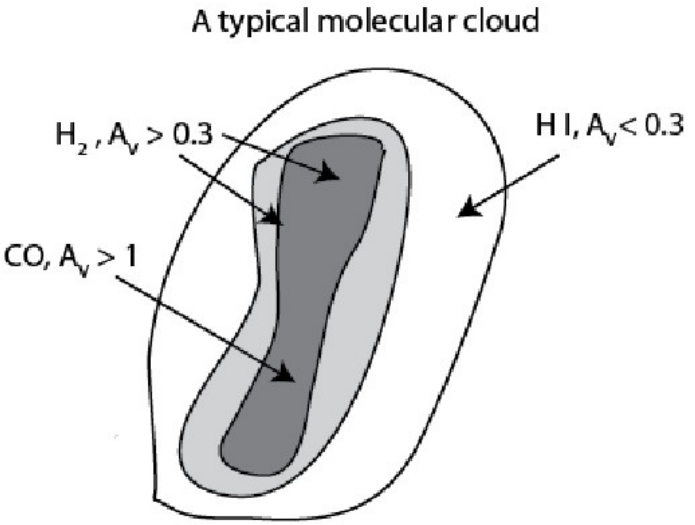


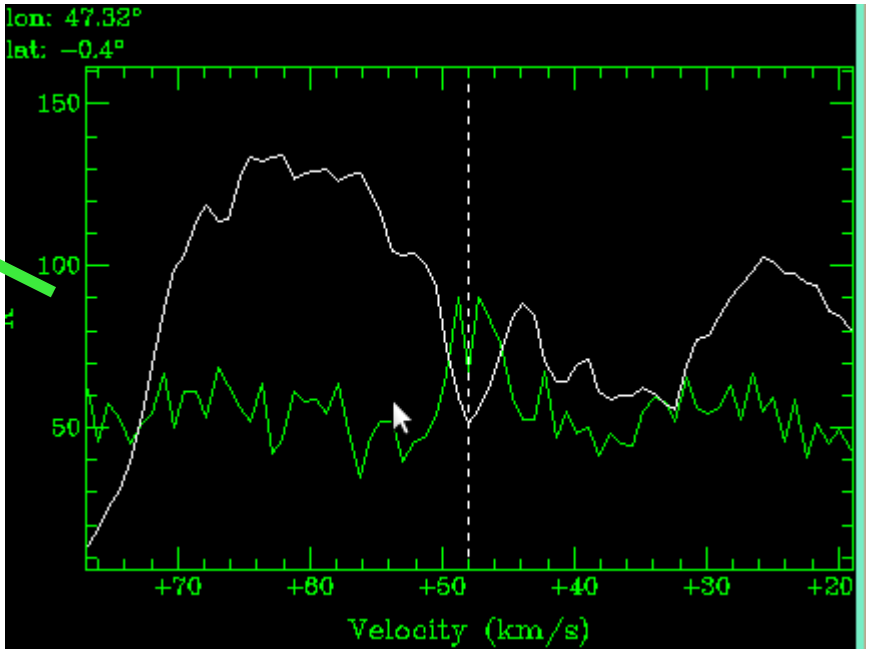


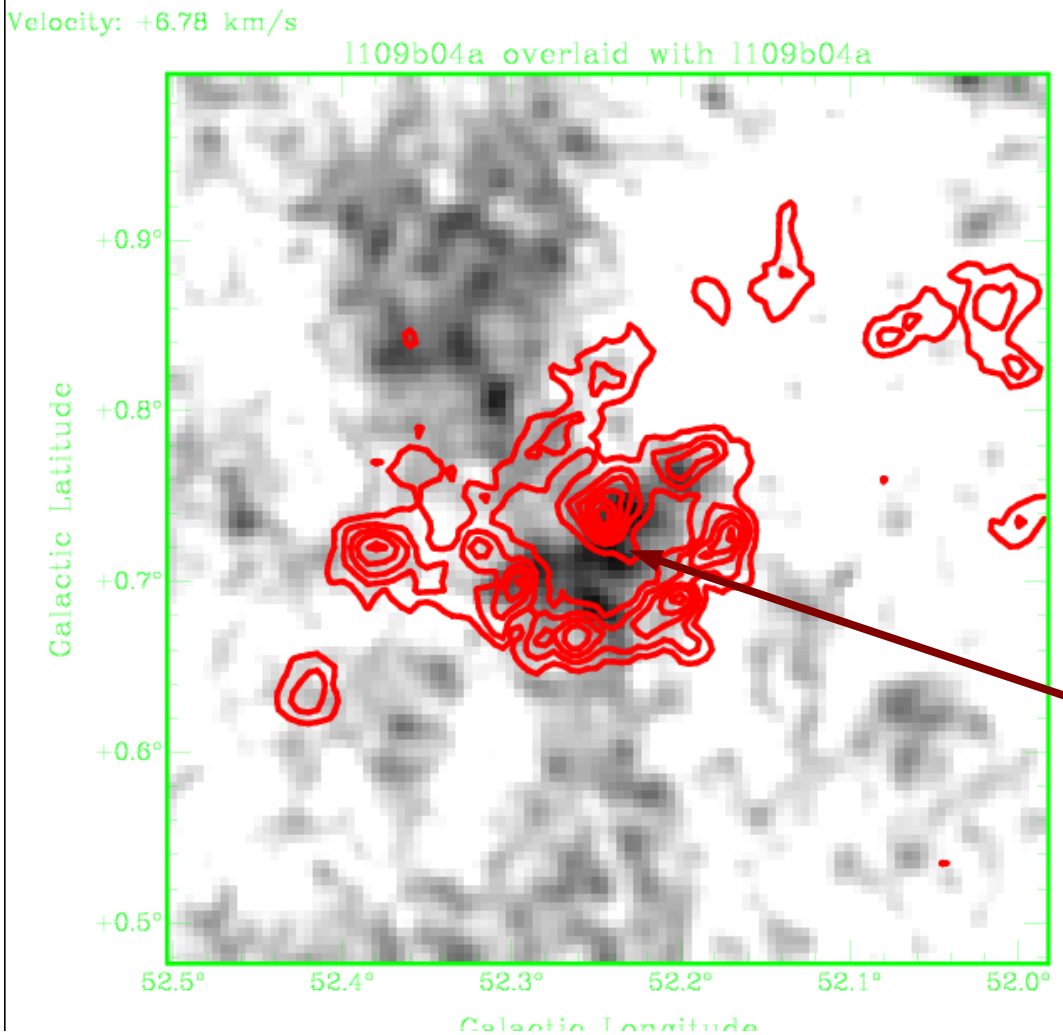


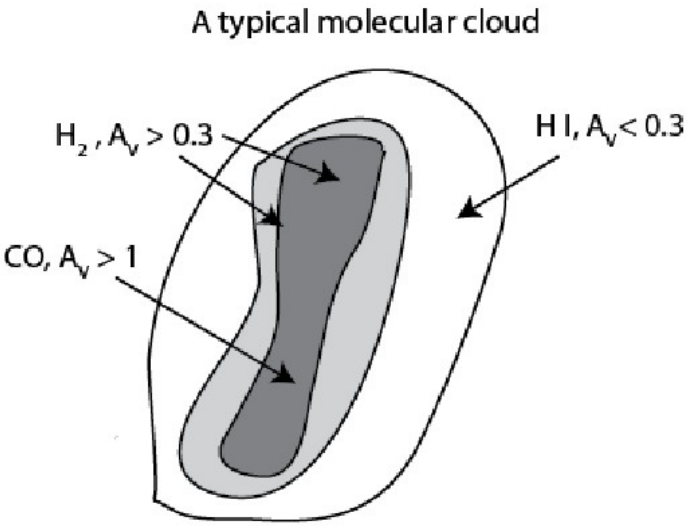



1084b04a overlaid with 1084b04a
0.0°
−0.2°
−0.4°
−0.6°
−0.8°
Galactic Latitude
47.5°
47.4°
47.3°
47.2°
47.1°
Galactic Longitude


A typical molecular cloud
H2 , AV > 0.3
HI, AV < 0.3
CO, AV > 1


lon: 47.32°
lat: −0.4°
150
100
50
+70
+60
+50
+40
+30
+20
Velocity (km/s)


Velocity: +6.78 km/s
l109b04a overlaid with l109b04a
+0.9°
+0.8°
+0.7°
+0.6°
+0.5°
Galactic Latitude
52.5°
52.4°
52.3°
52.2°
52.1°
52.0°
Galactic Longitude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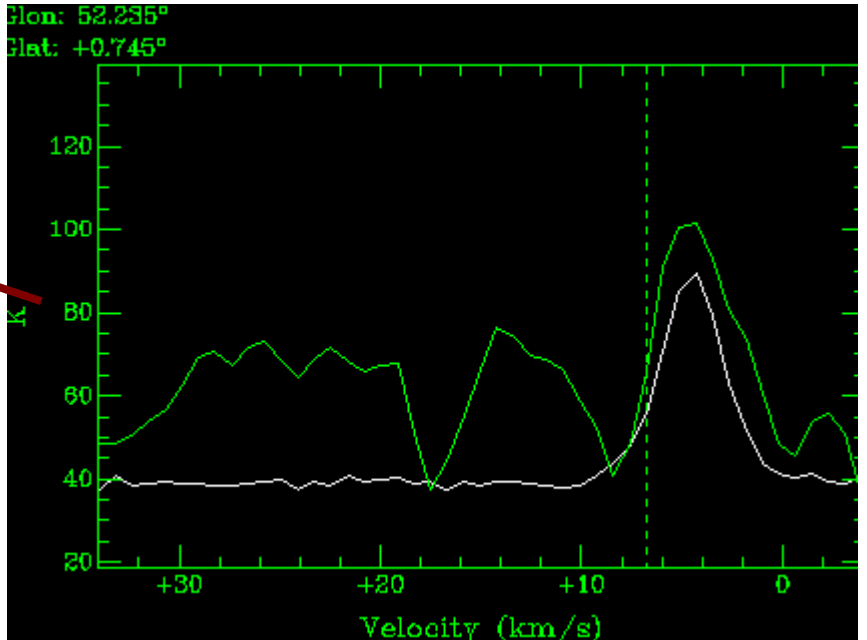
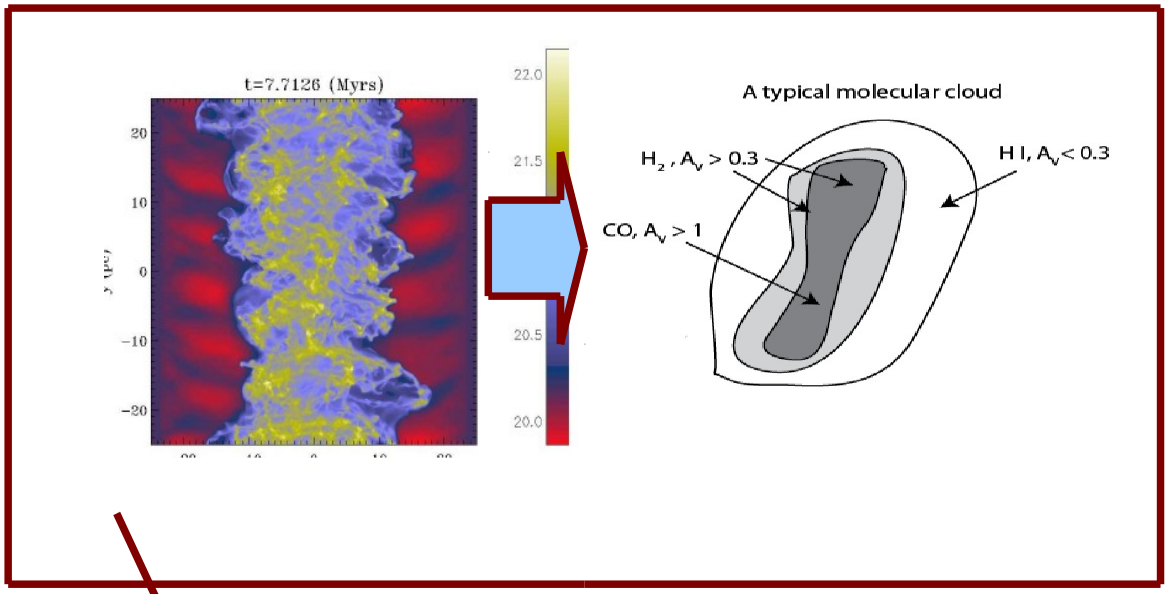
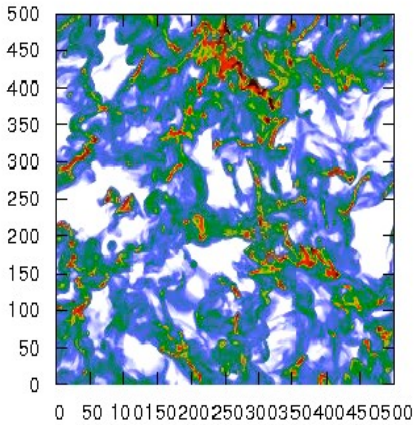
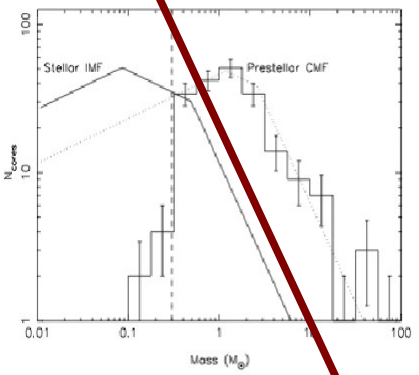
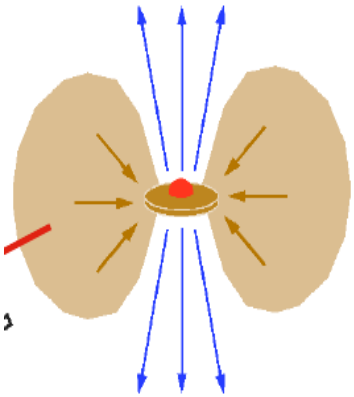

Glon: 52.235°
Glat: +0.745°
120
100
80
60
40
20
K
+30
+20
+10
0
Velocity (km/s)

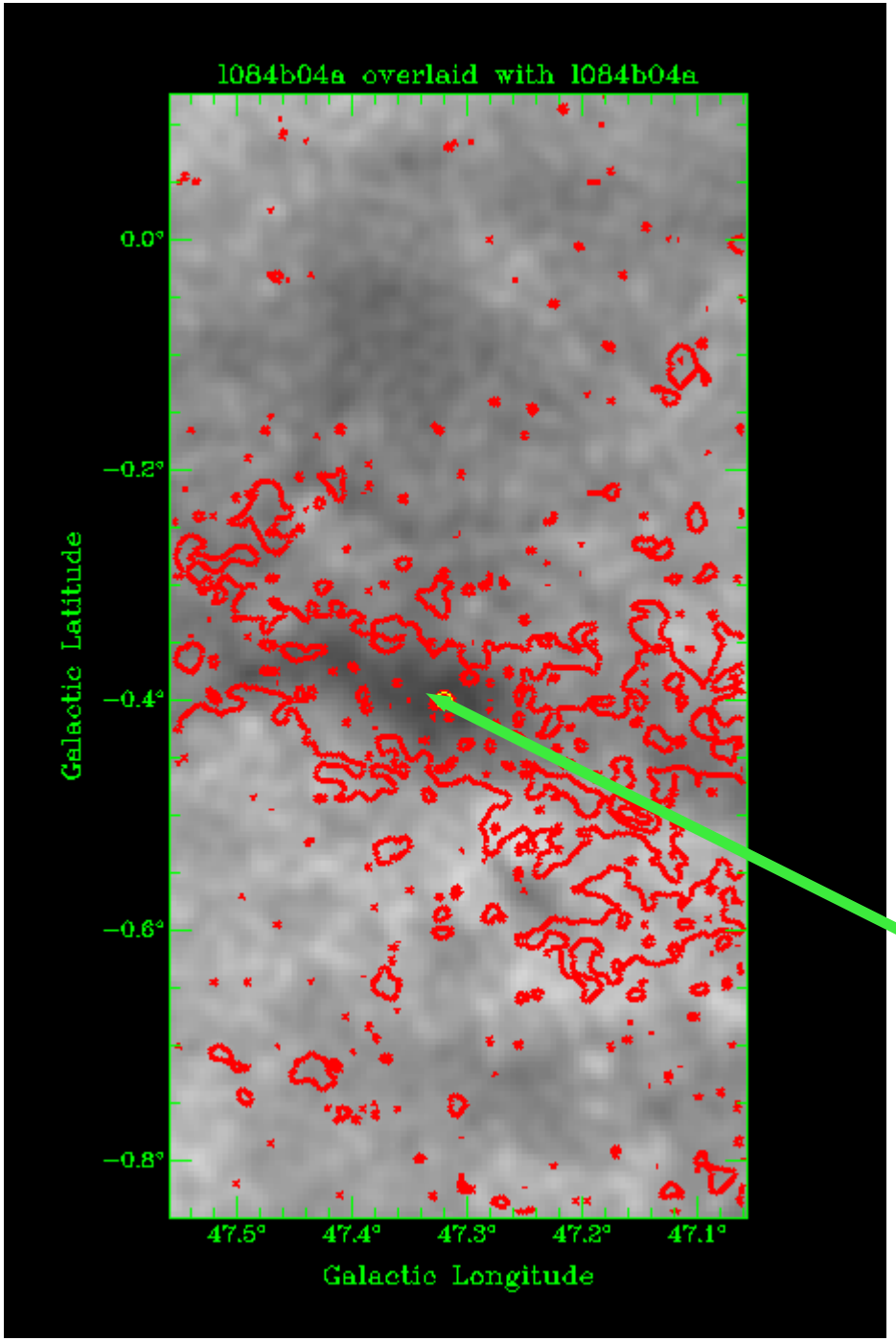
Star Formation Engineering







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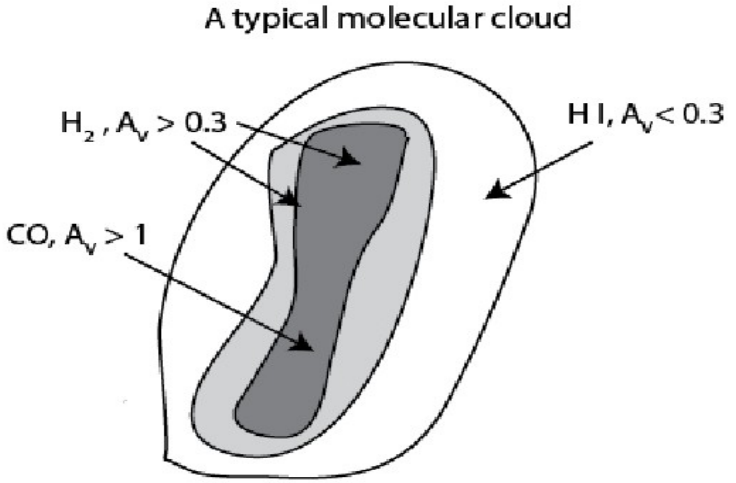
47.1°
Galactic Longitude


A typical molecular cloud
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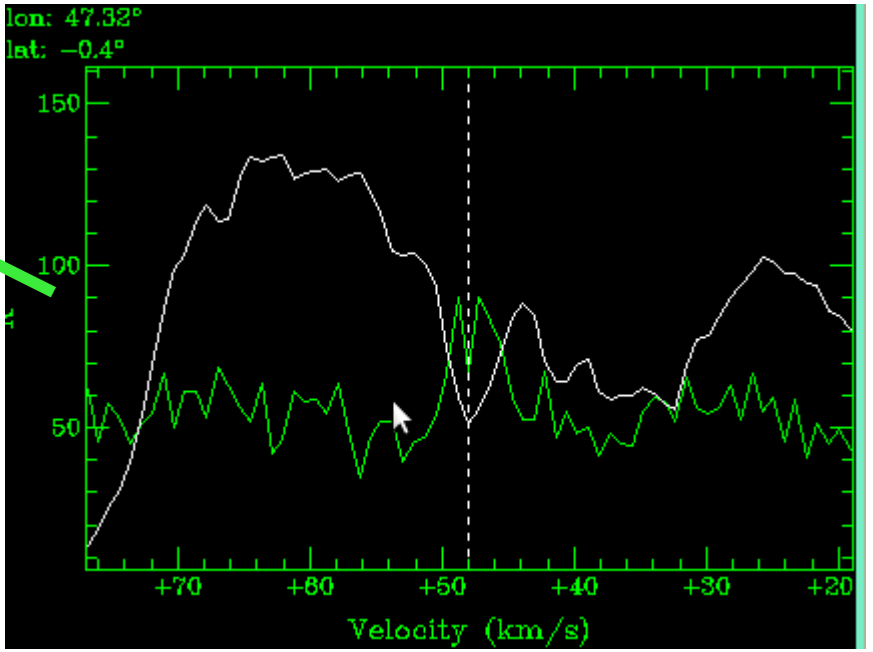
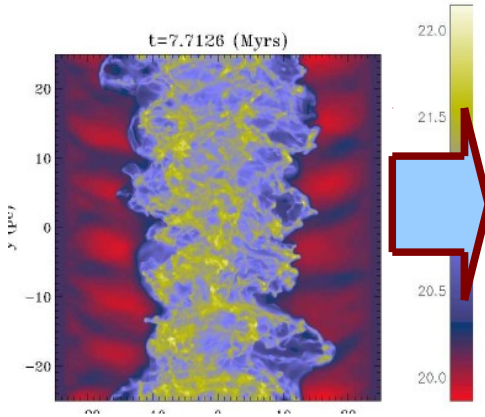
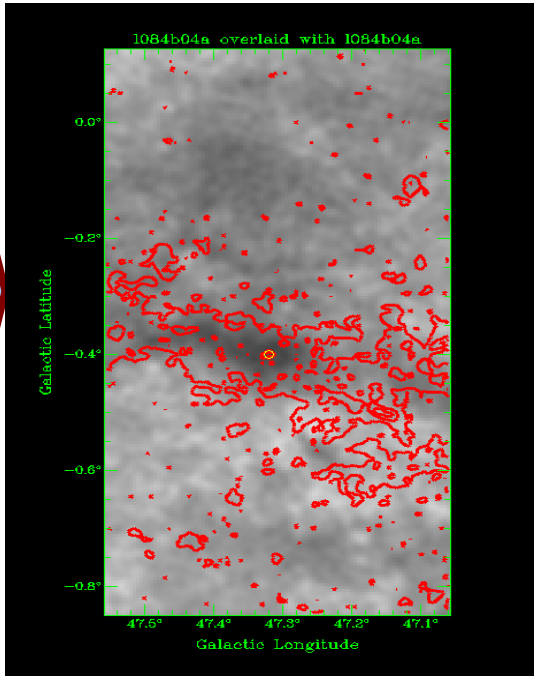
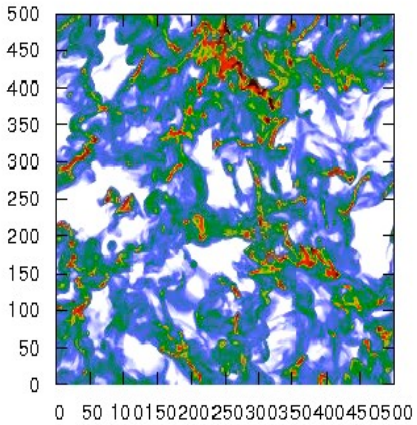
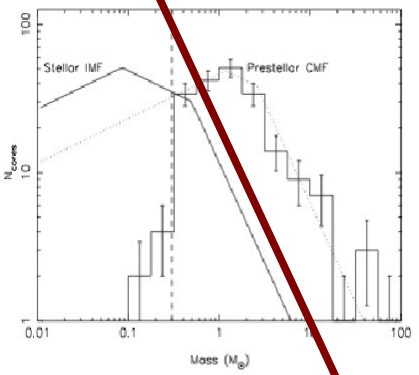

lon: 47.32°
lat: −0.4°
150
100
50
+70
+60
+50
+40
+30
+20
Velocity (km/s)

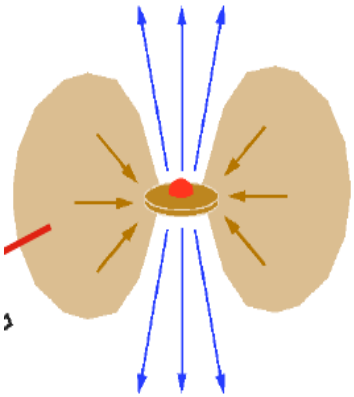
Star Formation Engineering



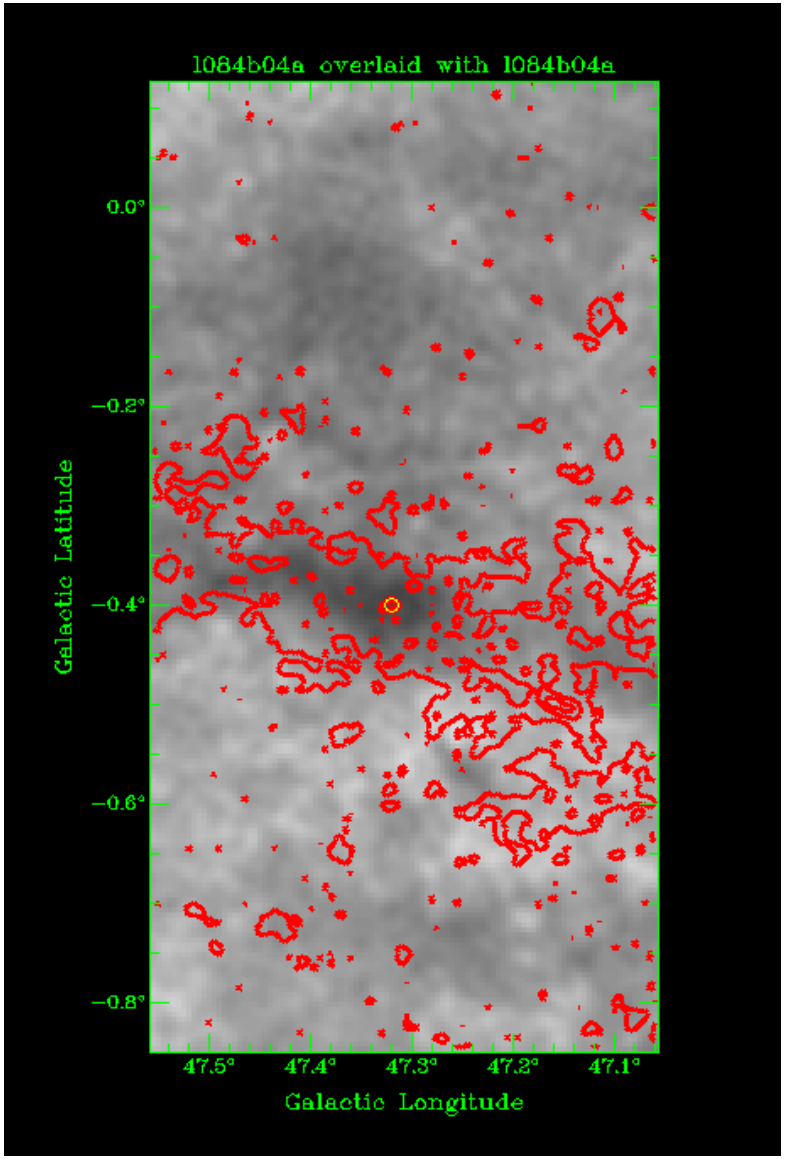




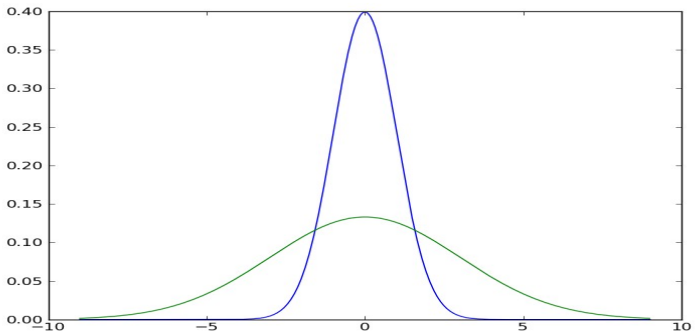


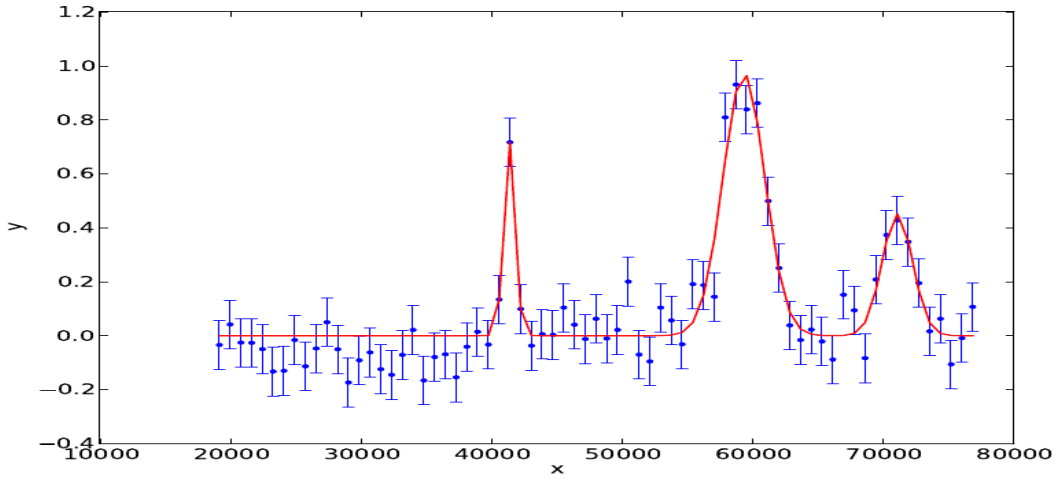


Do It Scientifically



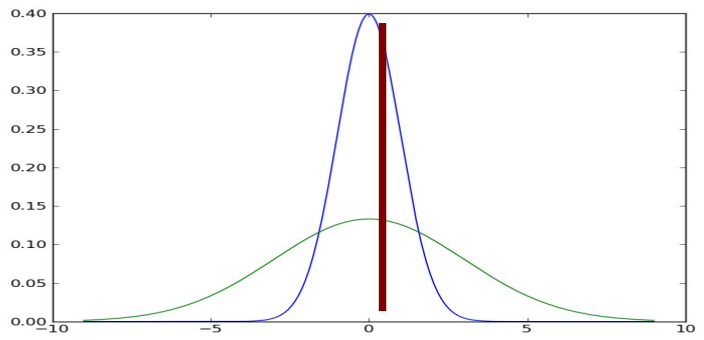
Abstraction



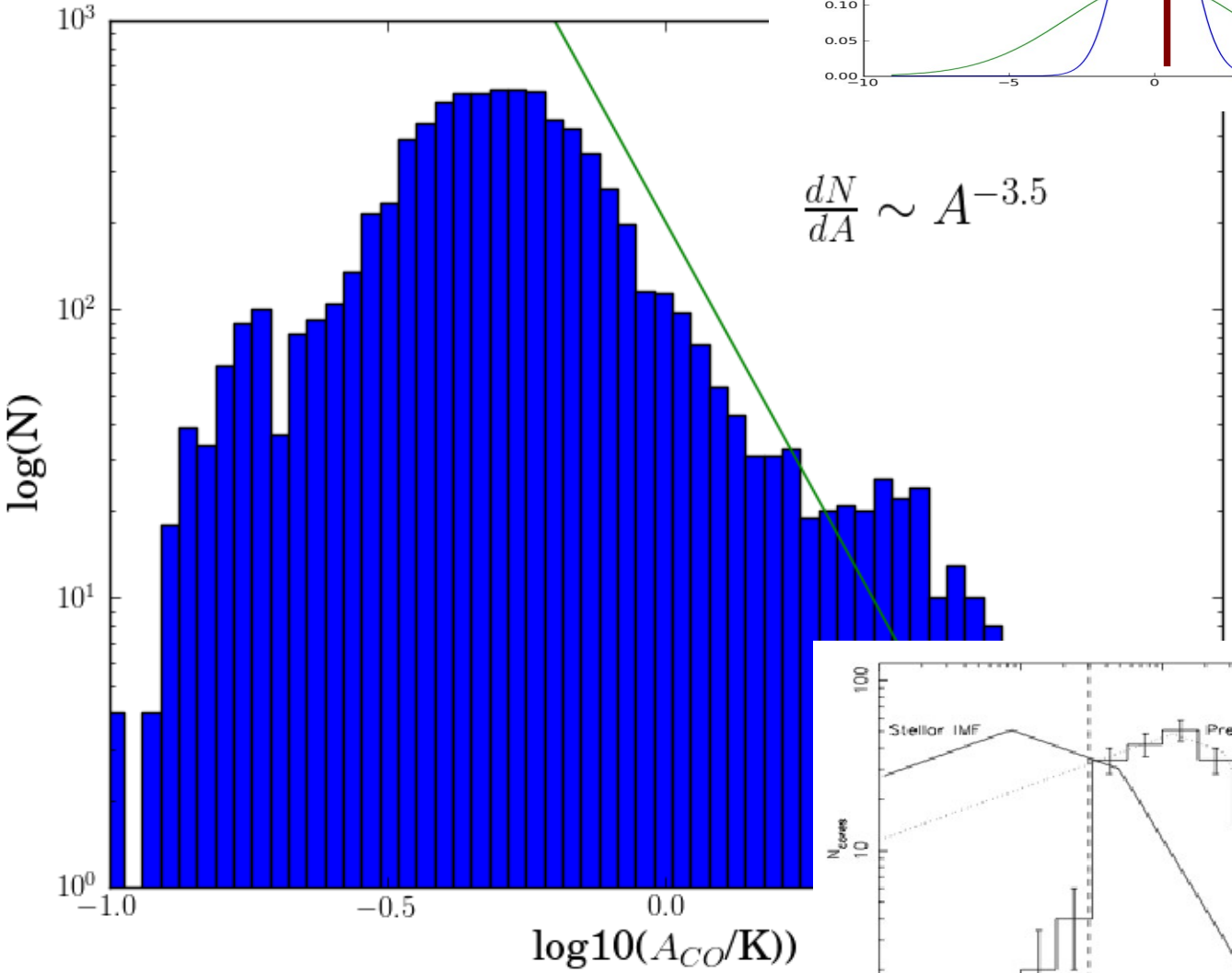


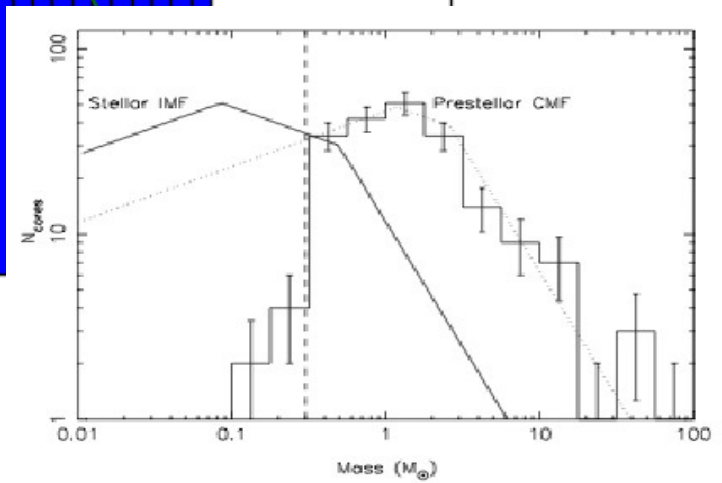
- (x,y, A, v, sigma)

CO line Amp

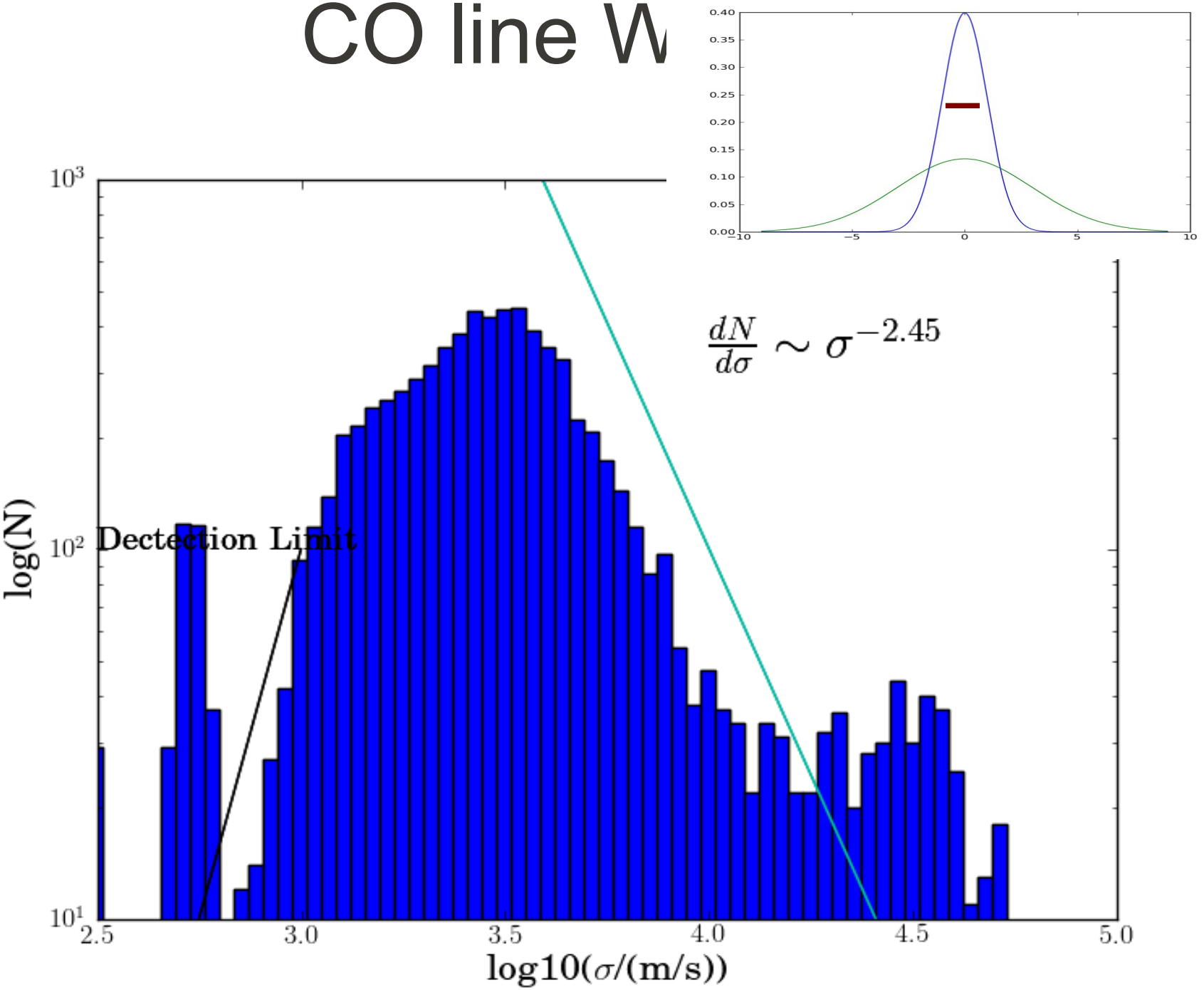


$$\frac{dN}{dA} \sim A^{-3.5}$$

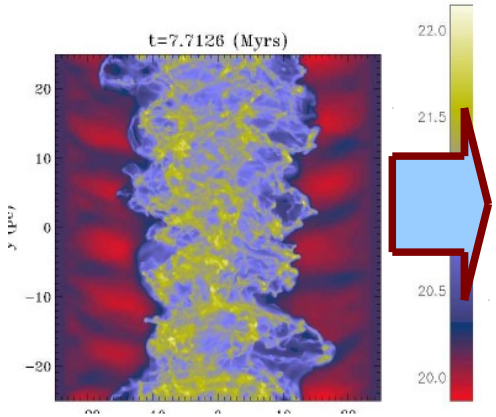


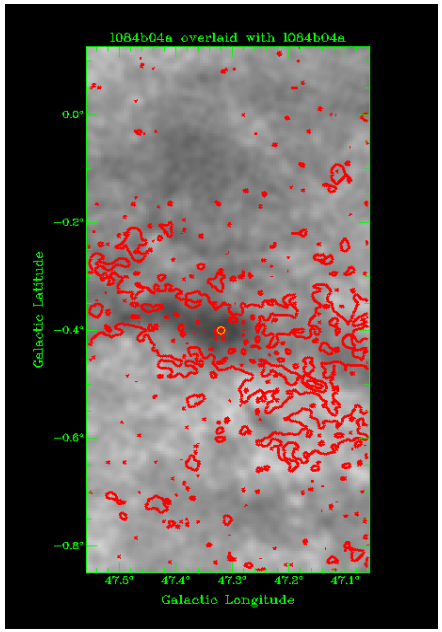


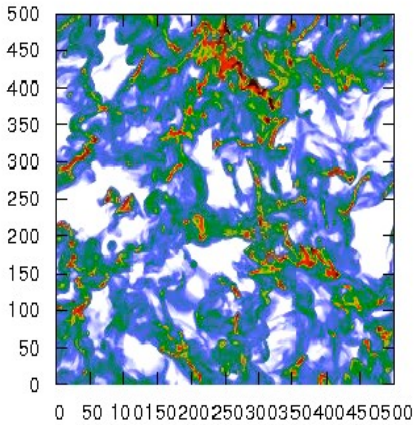
CO line W

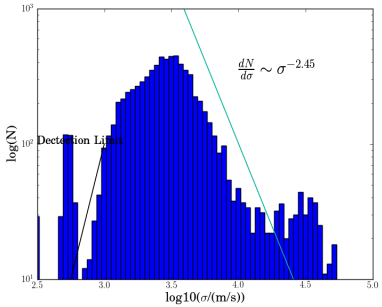

$\frac{dN}{d\sigma} \sim \sigma^{-2.45}$
Dectection Limit
log(N)
log10(σ/(m/s))
10^3
10^2
10^1
2.5
3.0
3.5
4.0
4.5
5.0

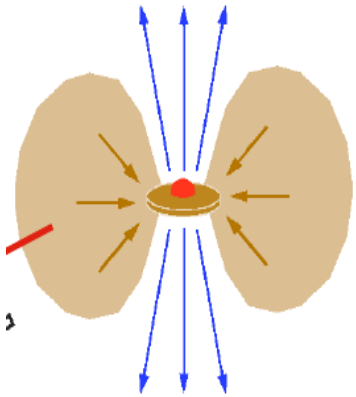
Star Formation Engineering



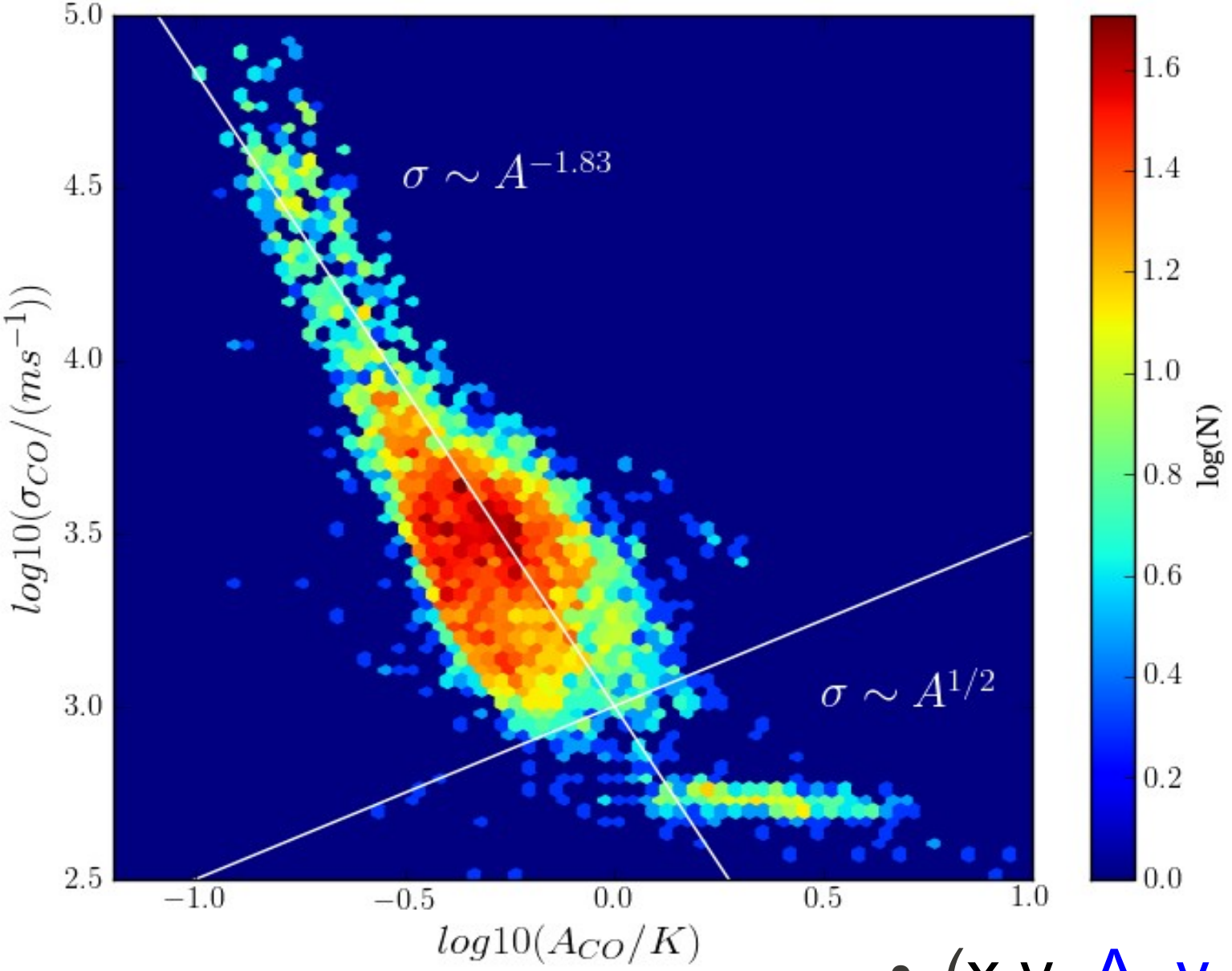








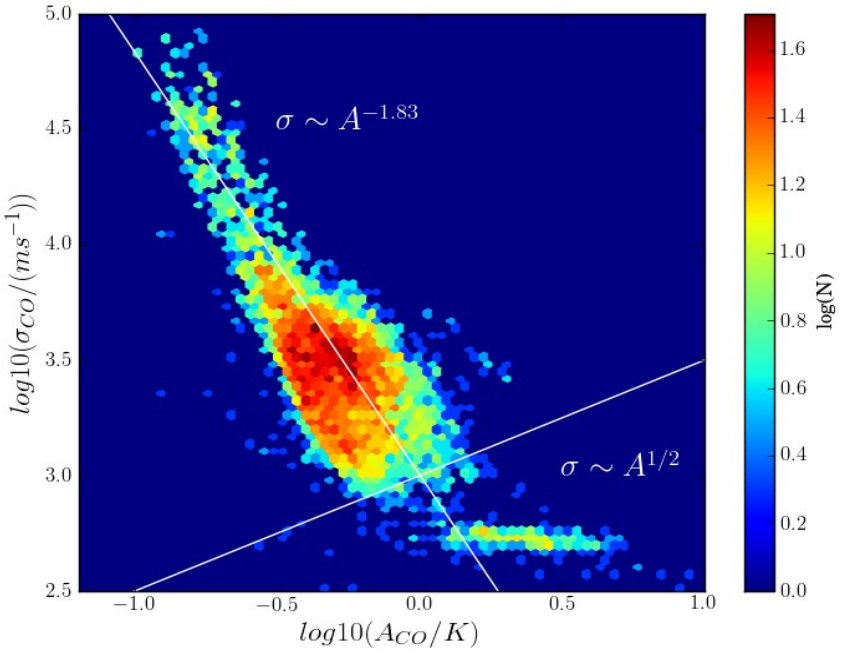
Line Intensity vs. Line Width



- (x,y, A, v, sigma)

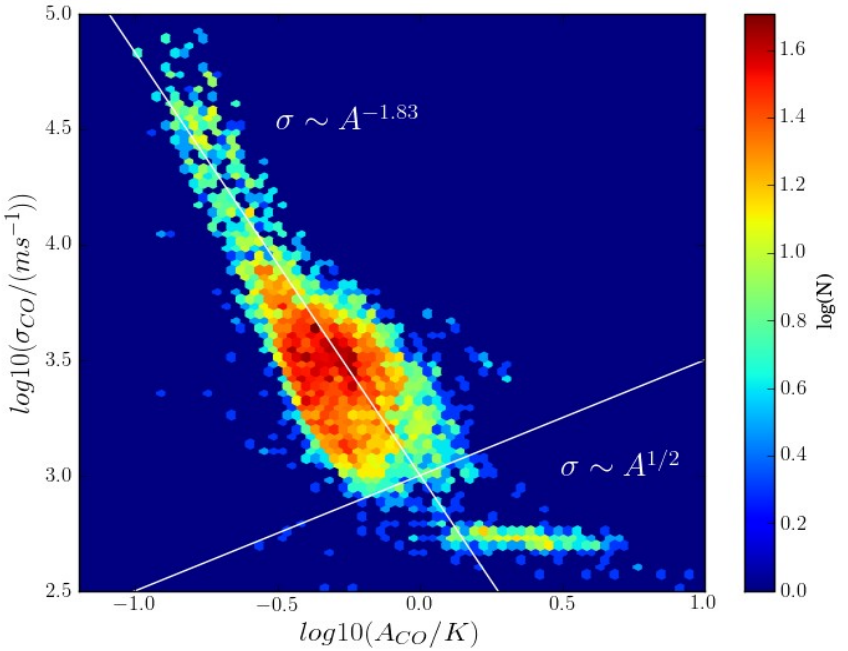
$$\sigma \sim A^{1/2}$$

- Larger Line Width at Higher Intensity?



$$\sigma \sim A^{1/2}$$

- Larger Line Width at Higher Intensity?
- Larger Velocity at Higher Column Density?



$$\sigma \sim A^{1/2}$$

- Larger Line Width at Higher Intensity?
- Larger Velocity at Higher Column Density?
- Self-Gravity!

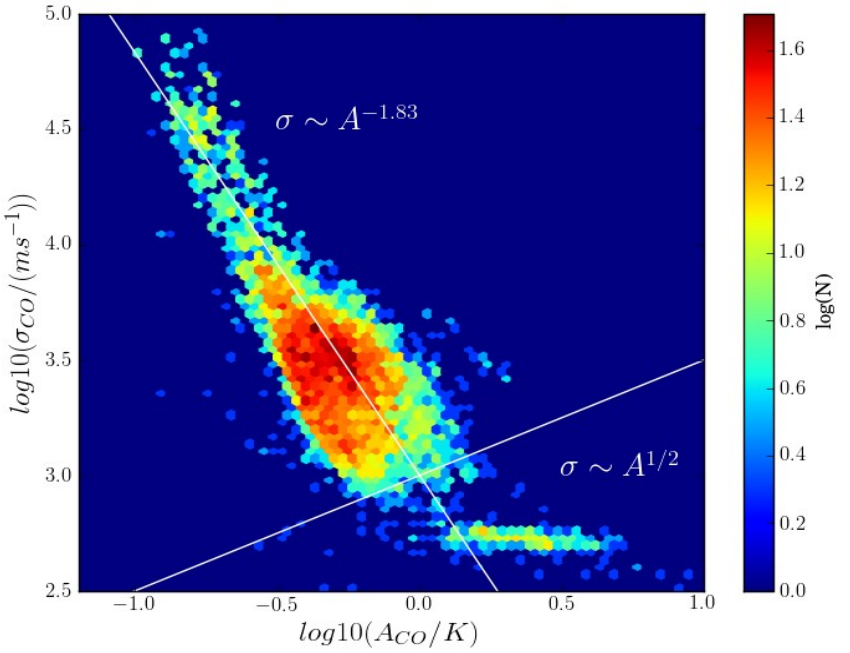
$$\rho_{core} \sim const$$

$$m_{core} \sim \rho_{core} l_{core}^3 \sim l^3$$

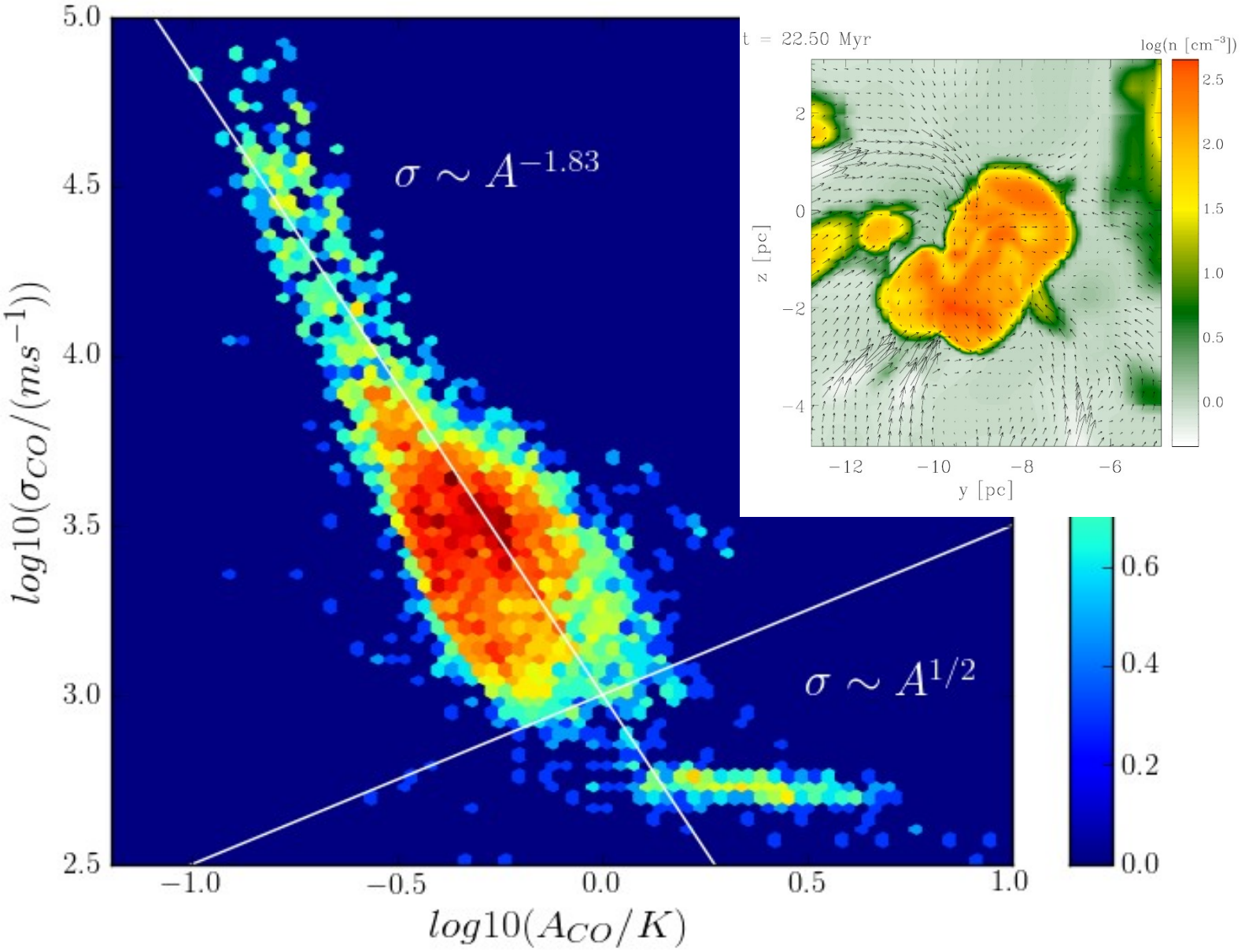
$$\sigma \sim \sqrt{\frac{GM}{r}} \sim l$$

$$A_{co} \sim \frac{m}{\sigma} \sim l^2$$

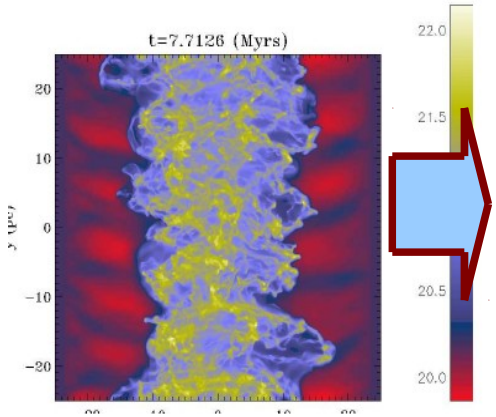
$$\sigma \sim A_{co}^{1/2}$$

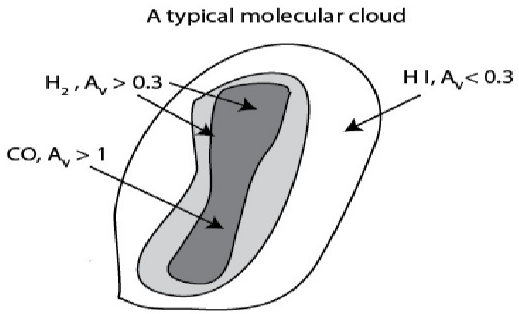


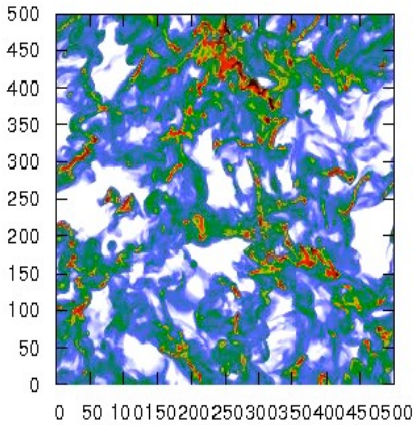
Line Intensity vs. Line Width

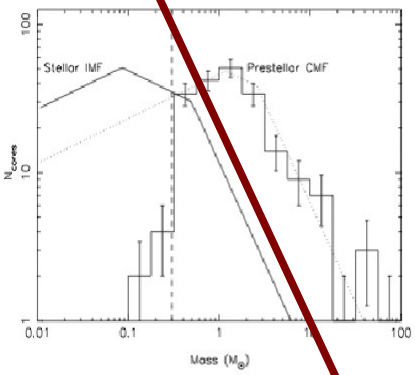


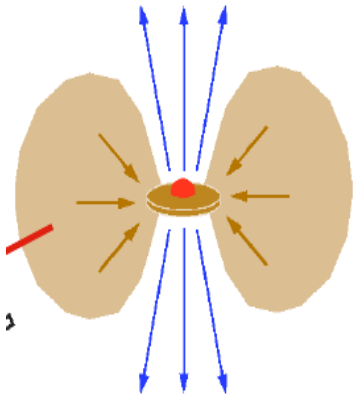
Summary


t=7.7126 (Myrs)
22.0
21.5
20.5
20.0

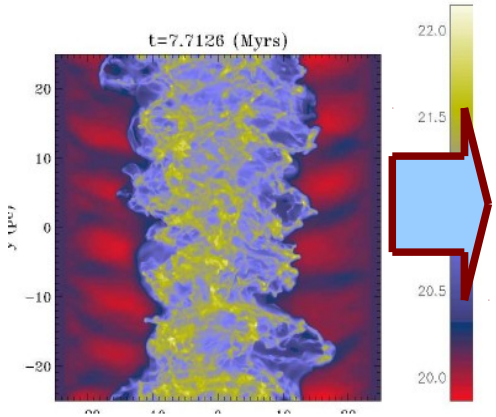

A typical molecular cloud
H I, $A_v < 0.3$
H_2, $A_v > 0.3$
CO, $A_v > 1$

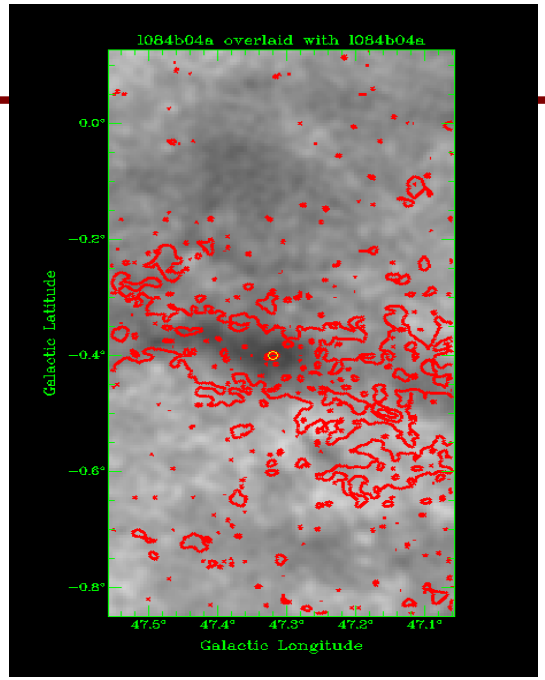

0 50 100150200250300350400450500

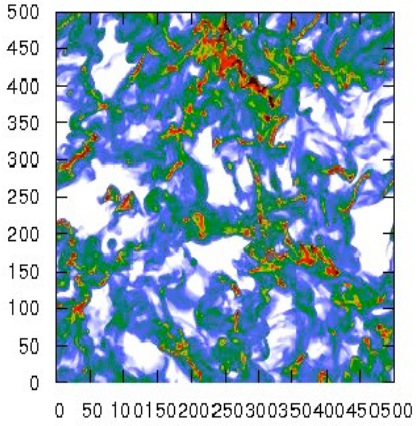

Stellar IMF
Prestellar CMF
Mass ($M_\odot$)

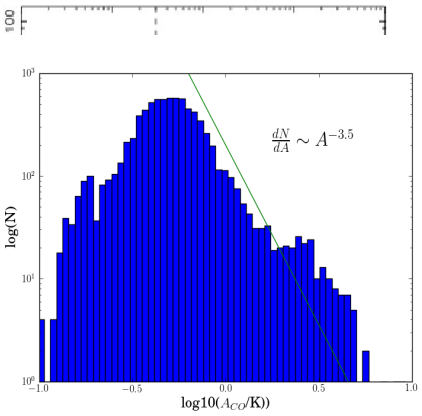


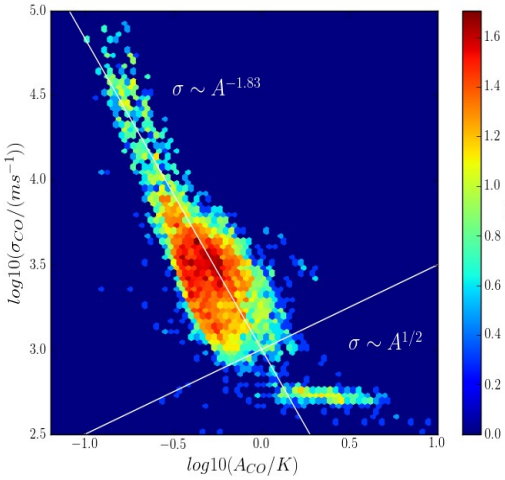
Summary


t=7.7126 (Myrs)
22.0
21.5
20.5
20.0


1084b04a overlaid with 1084b04a
Galactic Latitude
Galactic Longitude

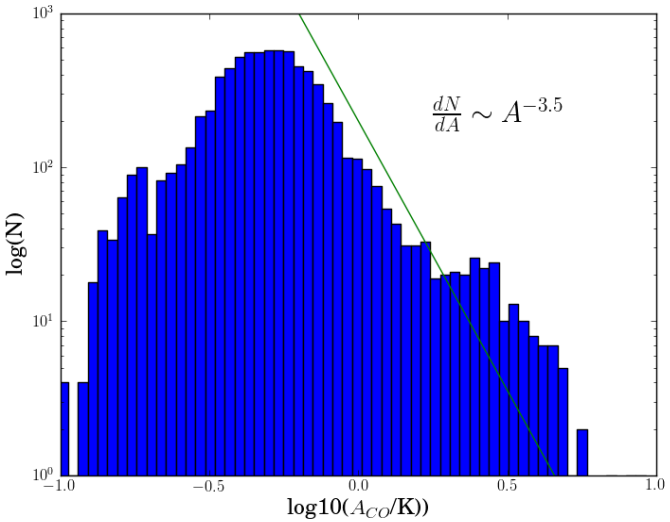


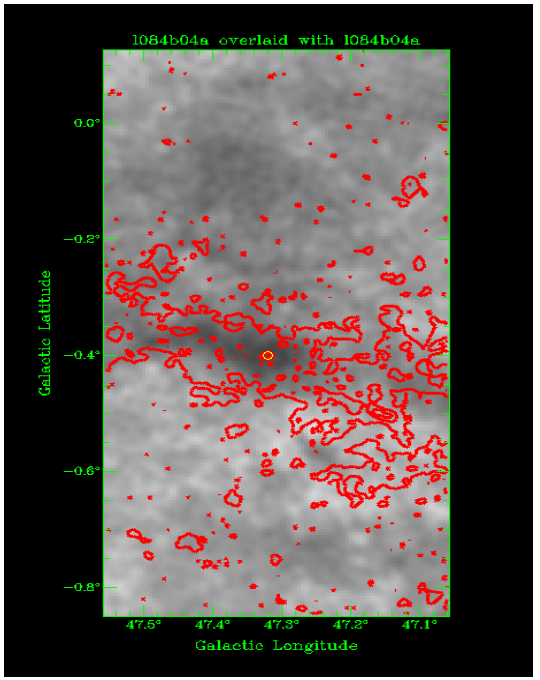

$\frac{dN}{dA} \sim A^{-3.5}$
log(N)
log10(A_{CO}/K)

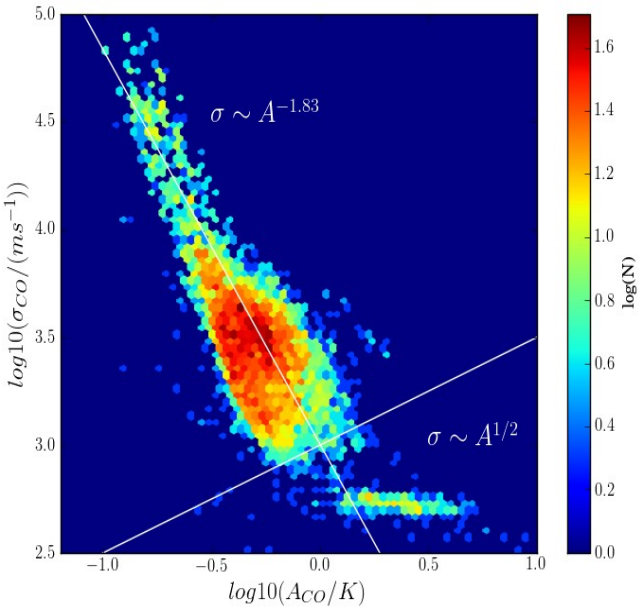

$\sigma \sim A^{-1.83}$
$\sigma \sim A^{1/2}$
$log10(\sigma_{CO}/(ms^{-1}))$
$log10(A_{CO}/K)$

Is the source typical?

- We have to look at more sources
  - –
-

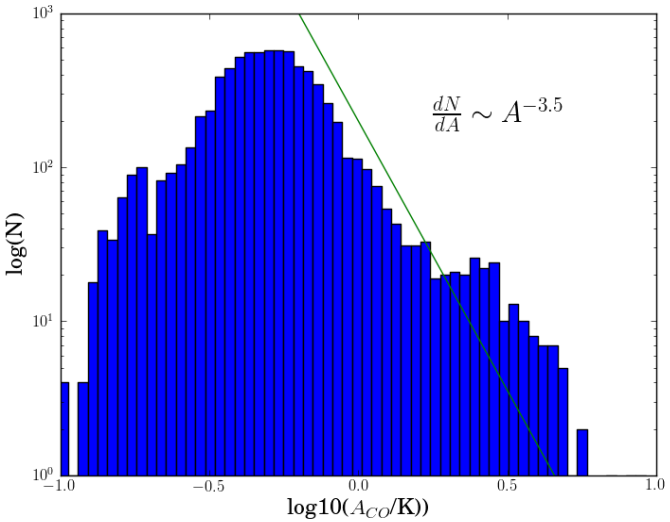


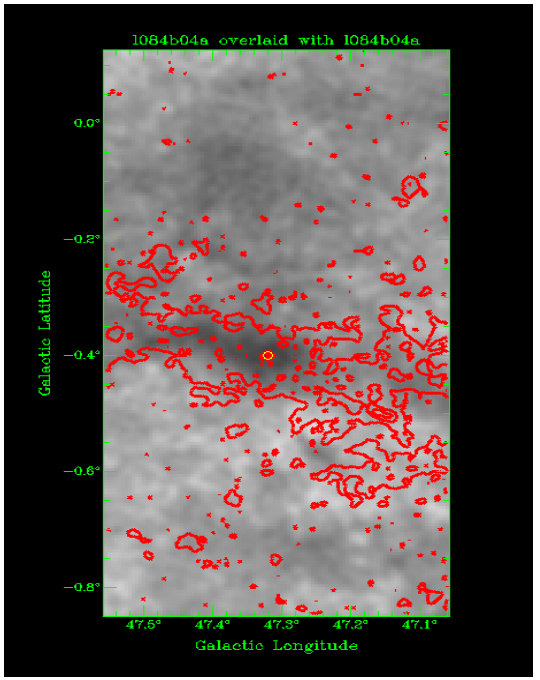


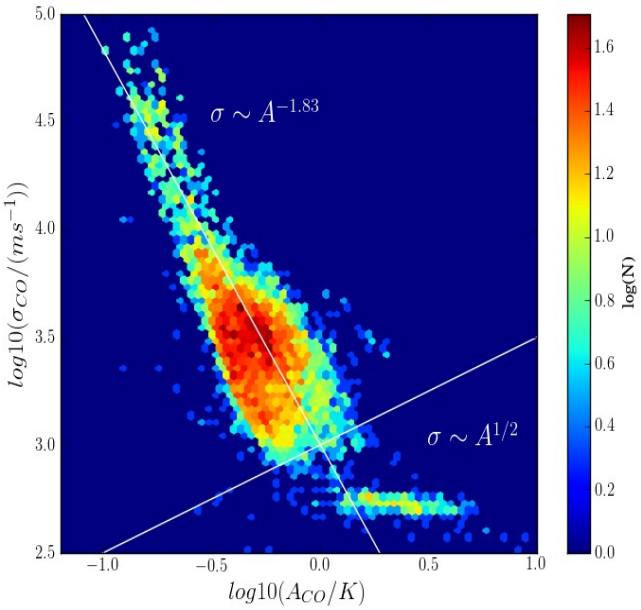


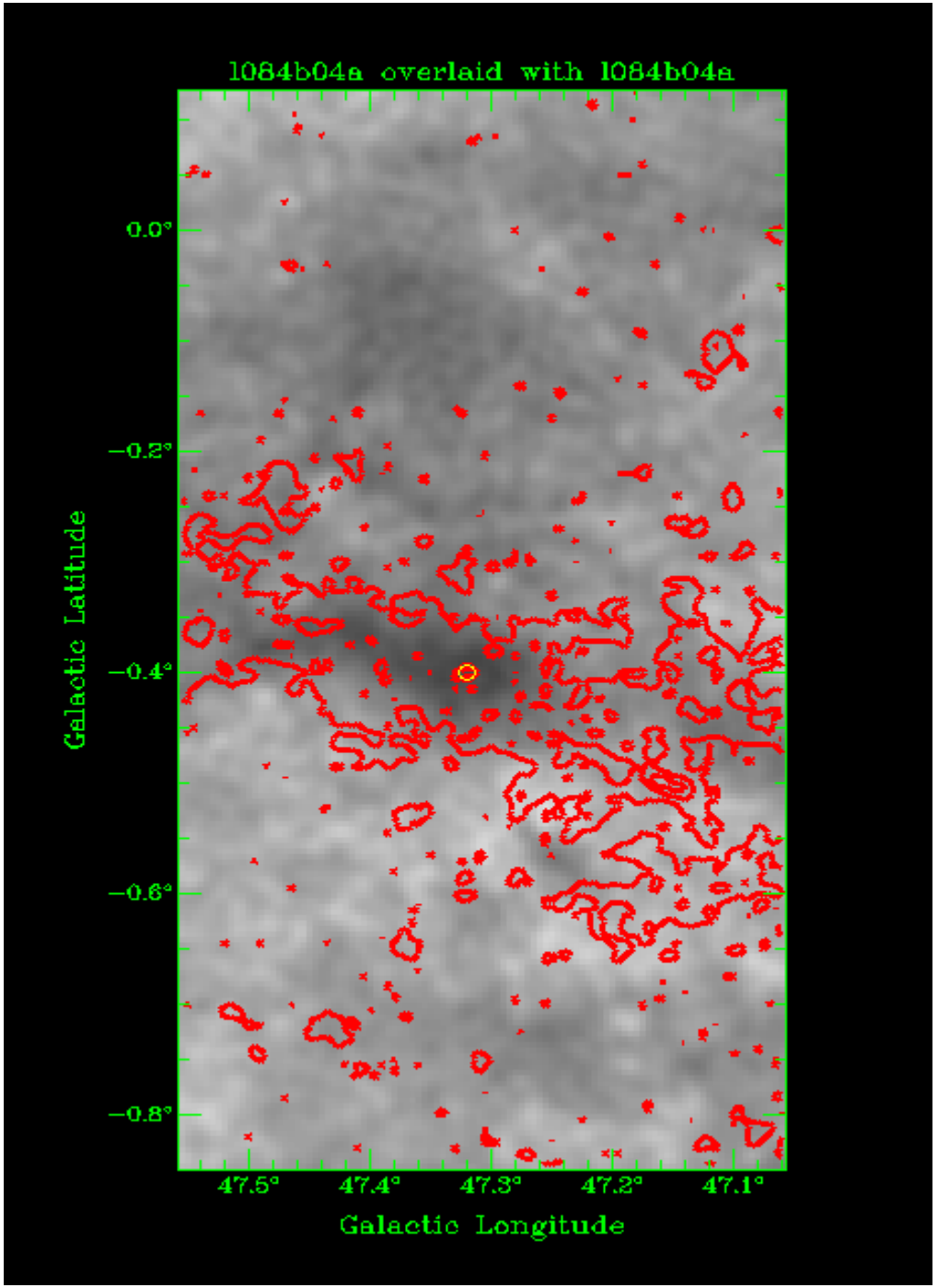
Is the source typical?

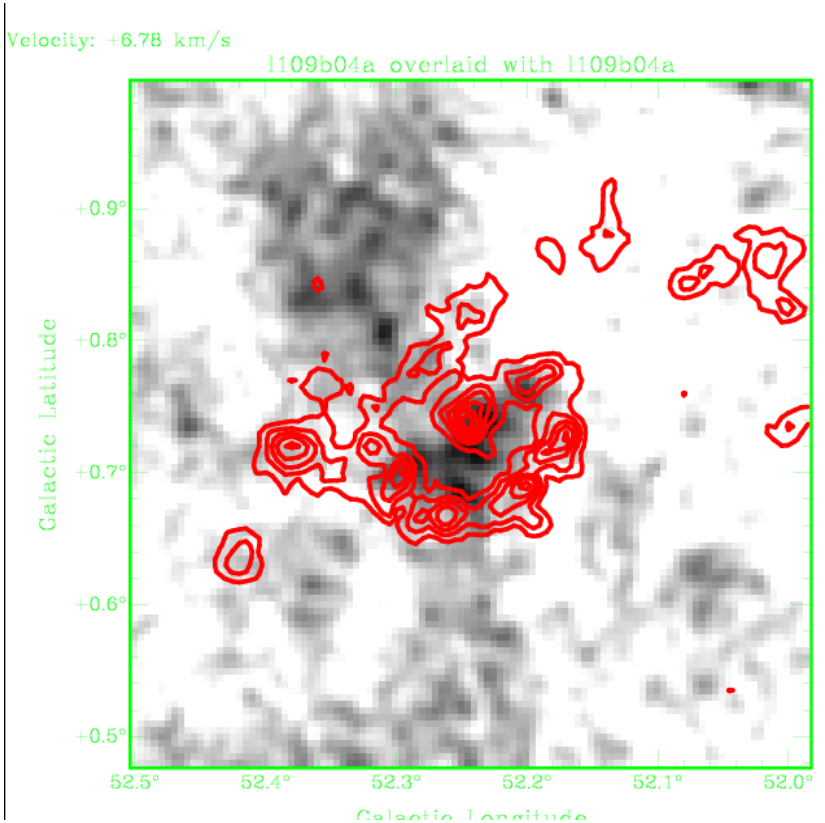
- We have to look at more sources
  - ZALAIYIGE? 再来一个？ One more?
- We have many more sources!

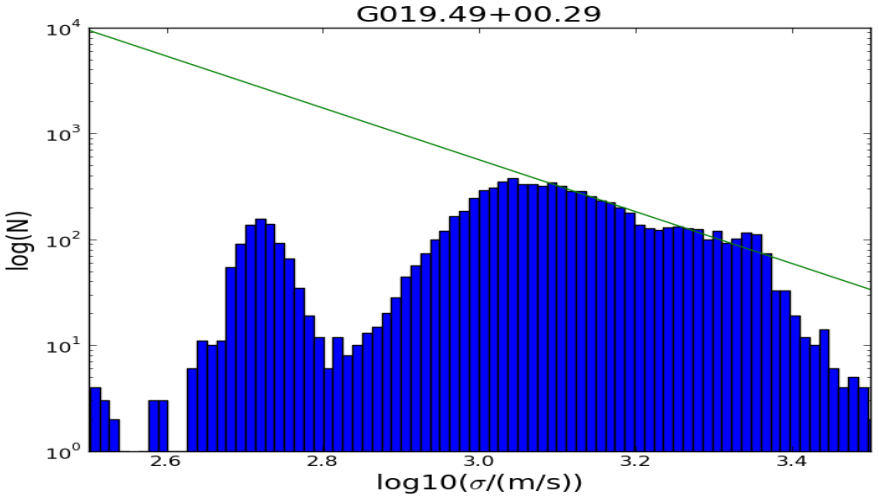


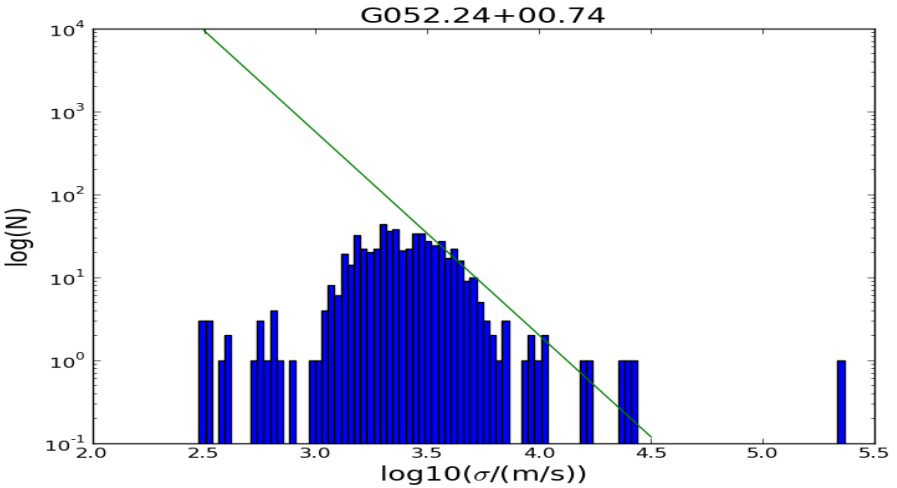


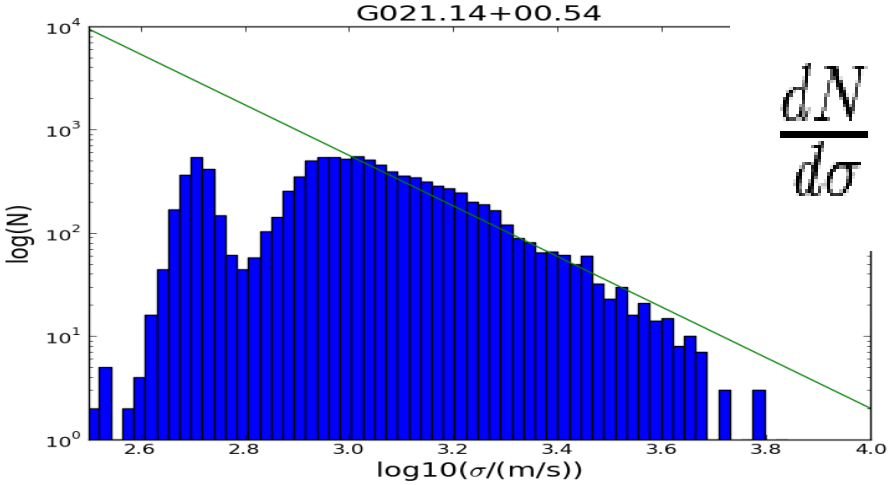



l084b04a overlaid with l084b04a
0.0°
−0.2°
−0.4°
−0.6°
−0.8°
Galactic Latitude
47.5°
47.4°
47.3°
47.2°
47.1°
Galactic Longitude

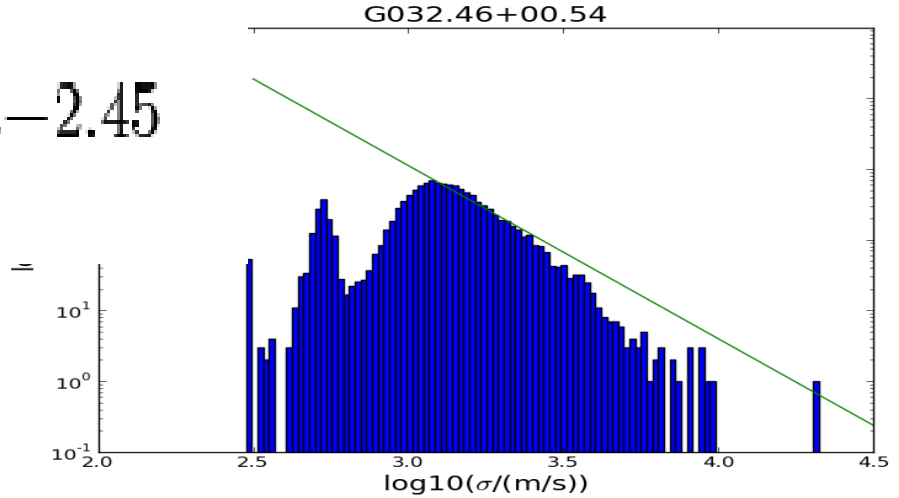

Velocity: +6.78 km/s
l109b04a overlaid with l109b04a
+0.9°
+0.8°
+0.7°
+0.6°
+0.5°
Galactic Latitude
52.5°
52.4°
52.3°
52.2°
52.1°
52.0°
Galactic Longitude

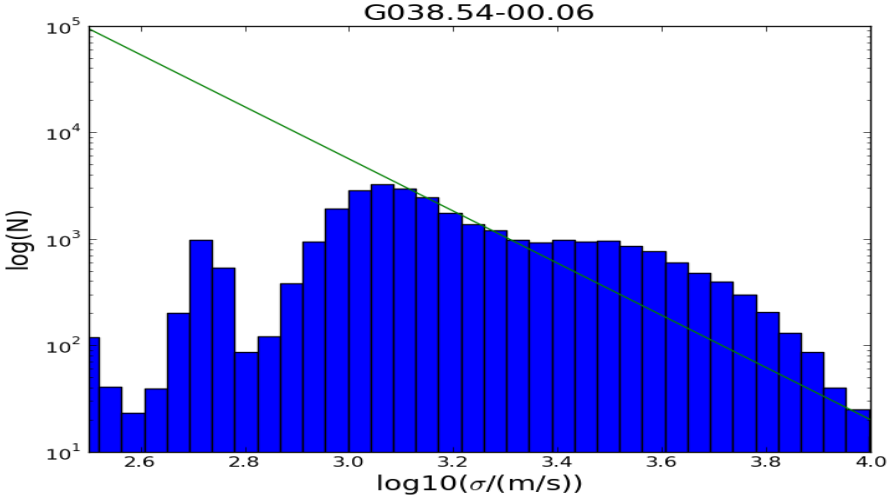


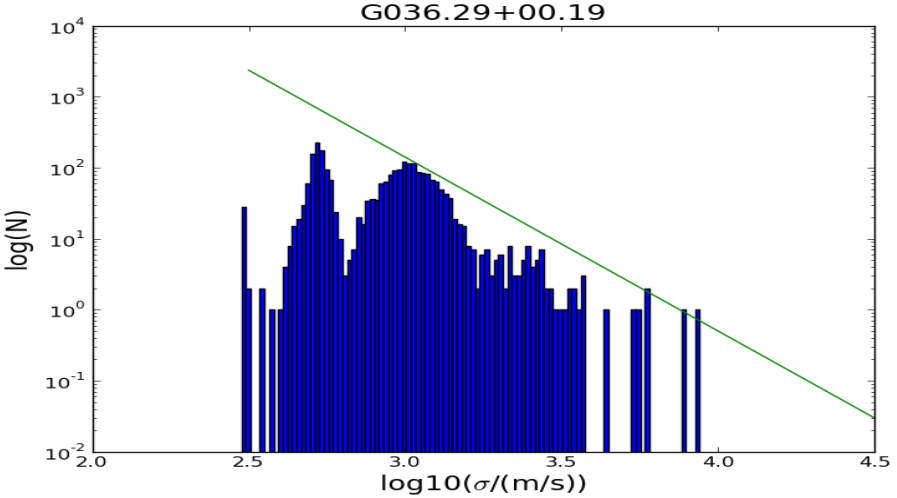




$$\frac{dN}{d\sigma} \sim \sigma^{-2.45}$$

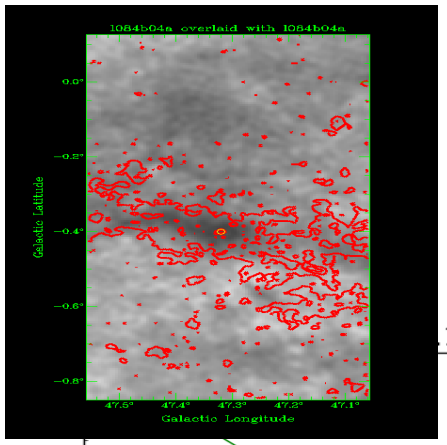


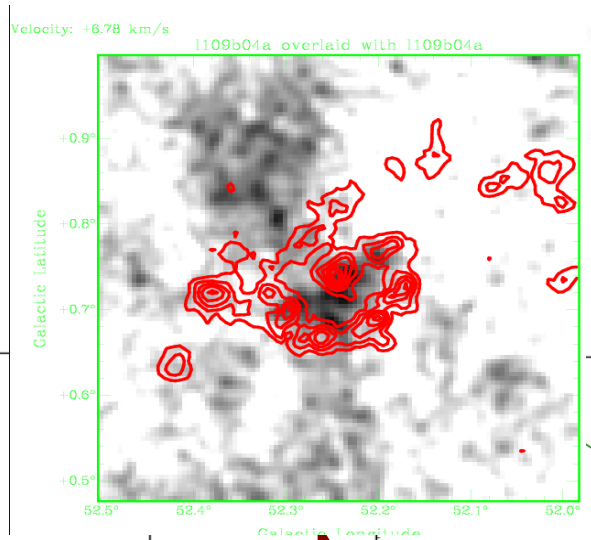


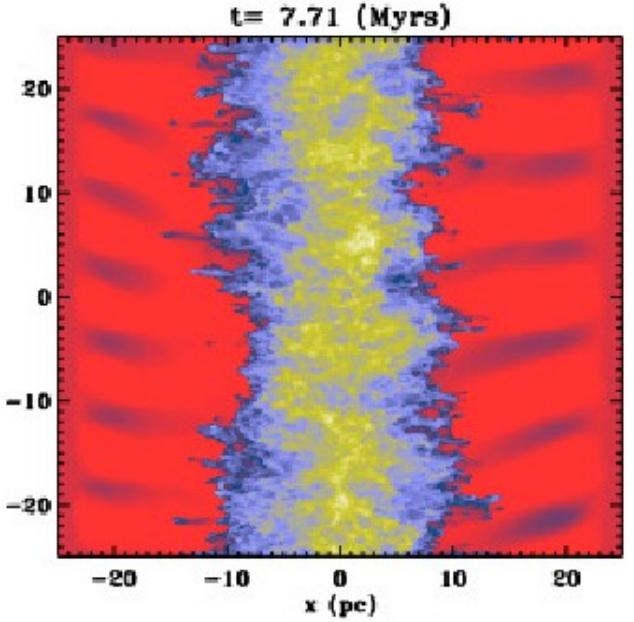


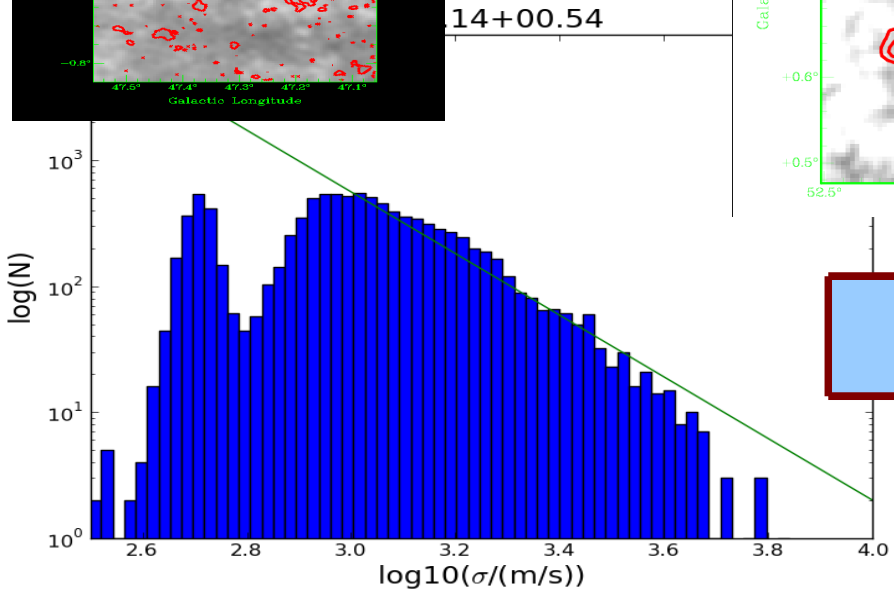
Turbulence Driven by Converging Flow?

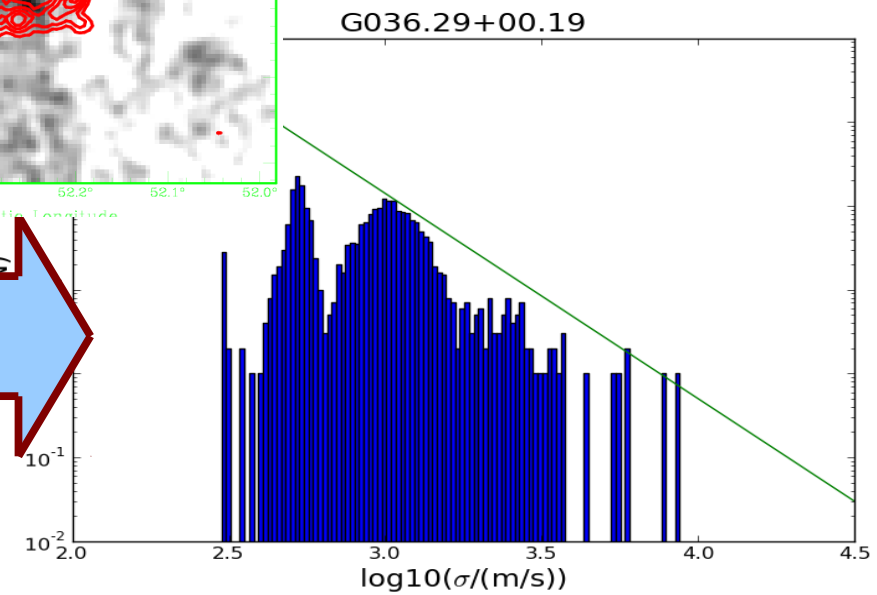
- Power-law Slope: Turbulence
- Cold HI gas: Converging Flow



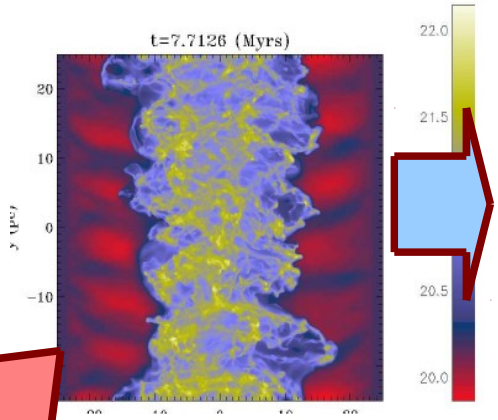


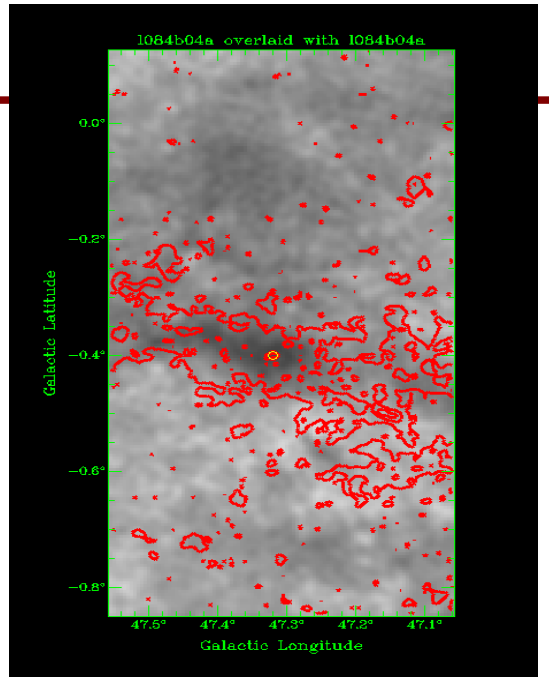


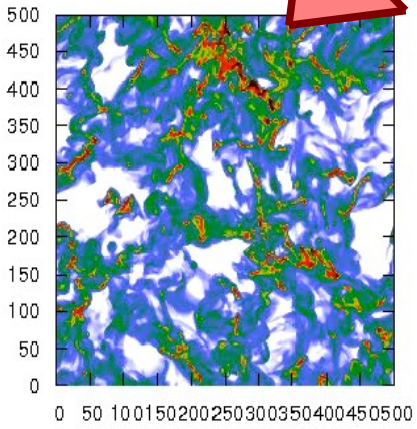


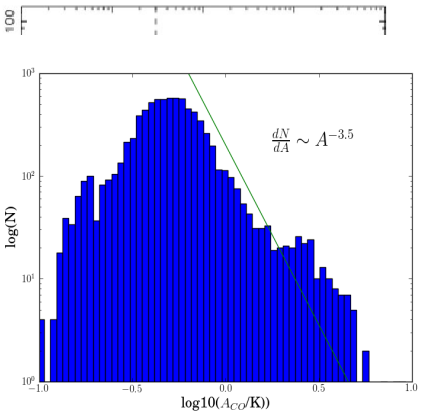


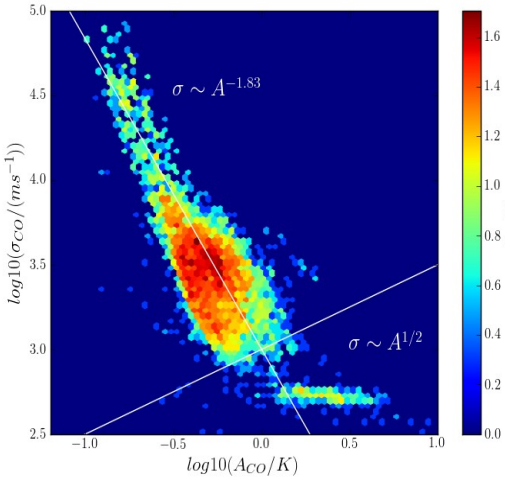
Summary


t=7.7126 (Myrs)
22.0
21.5
20.5
20.0


1084b04a overlaid with 1084b04a
Galactic Latitude
Galactic Longitude




$\frac{dN}{dA} \sim A^{-3.5}$
log(N)
log10(A_{CO}/K)


$\sigma \sim A^{-1.83}$
$\sigma \sim A^{1/2}$
$log10(\sigma_{CO}/(ms^{-1}))$
$log10(A_{CO}/K)$