Gravitational acceleration in molecular clouds

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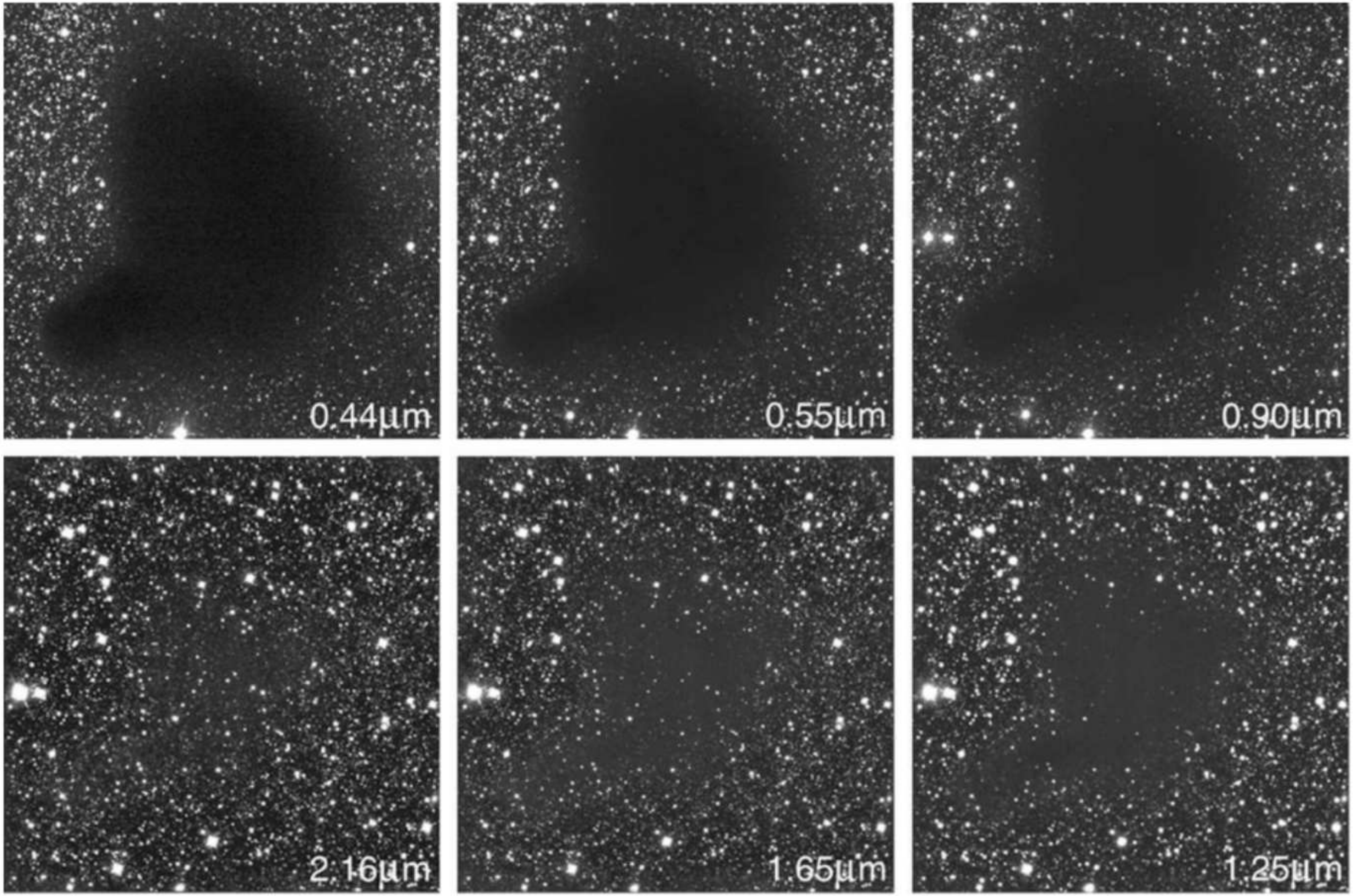
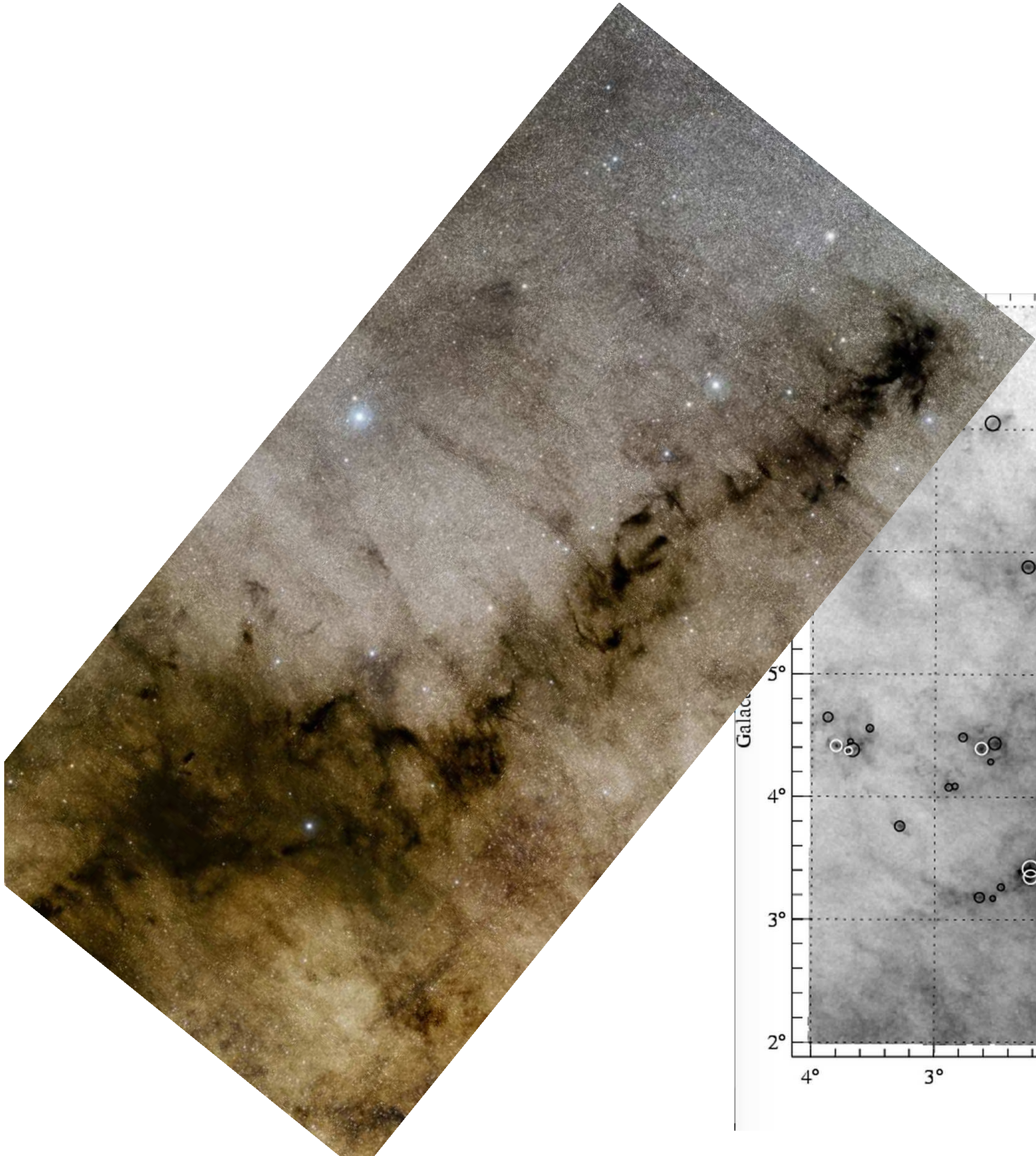
Tom Megeath (Toledo), Friedrich Wyrowski (MPIfR Bonn)

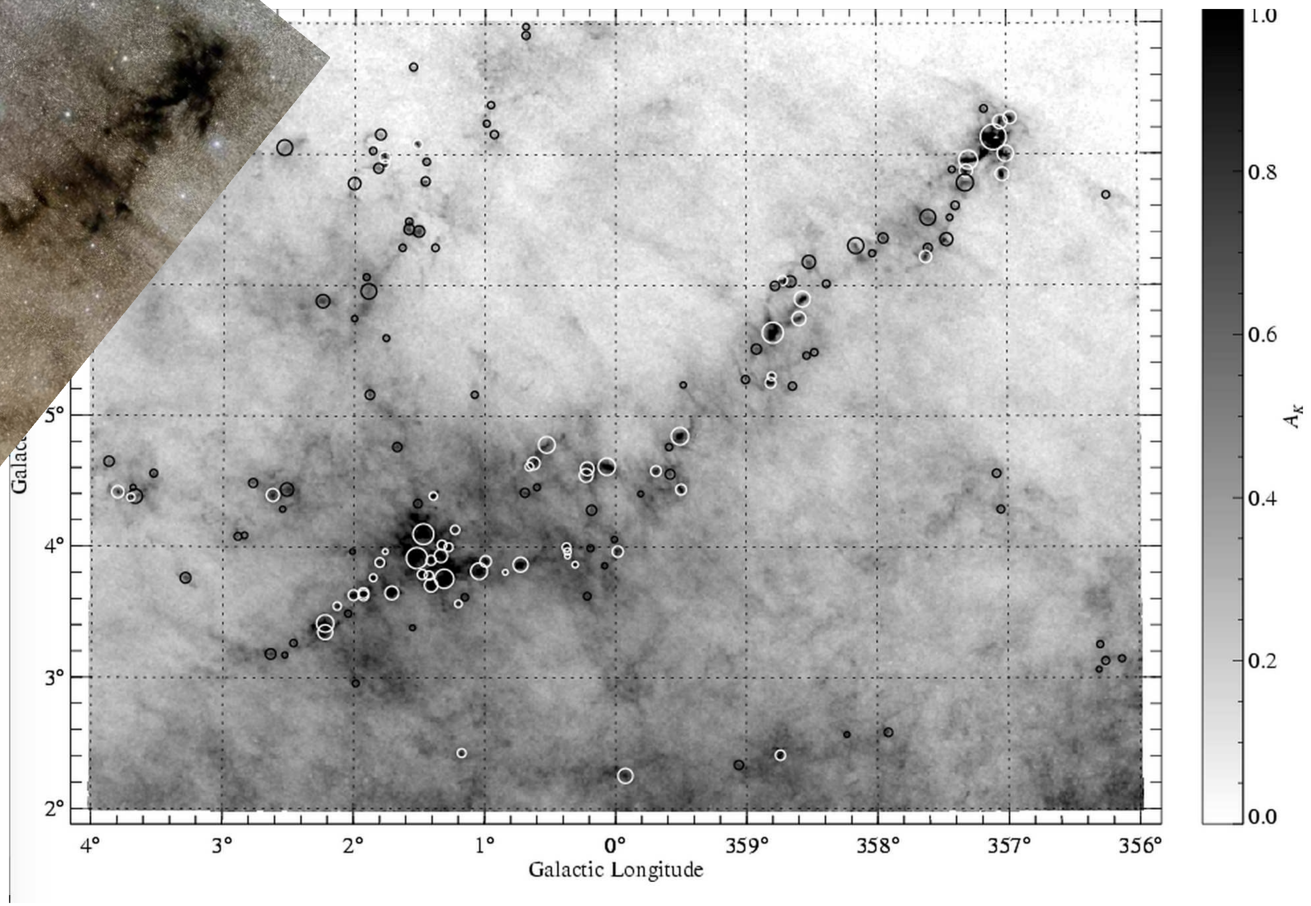


Cambresy, Lada, Alves, …

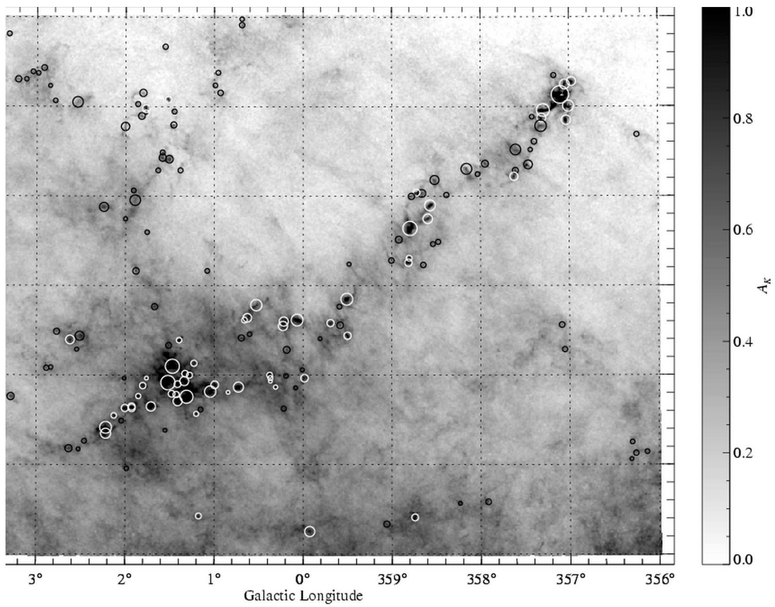
Observing molecular cloud

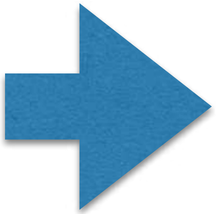
do we understand them?





The Pizza experiment





Simplification

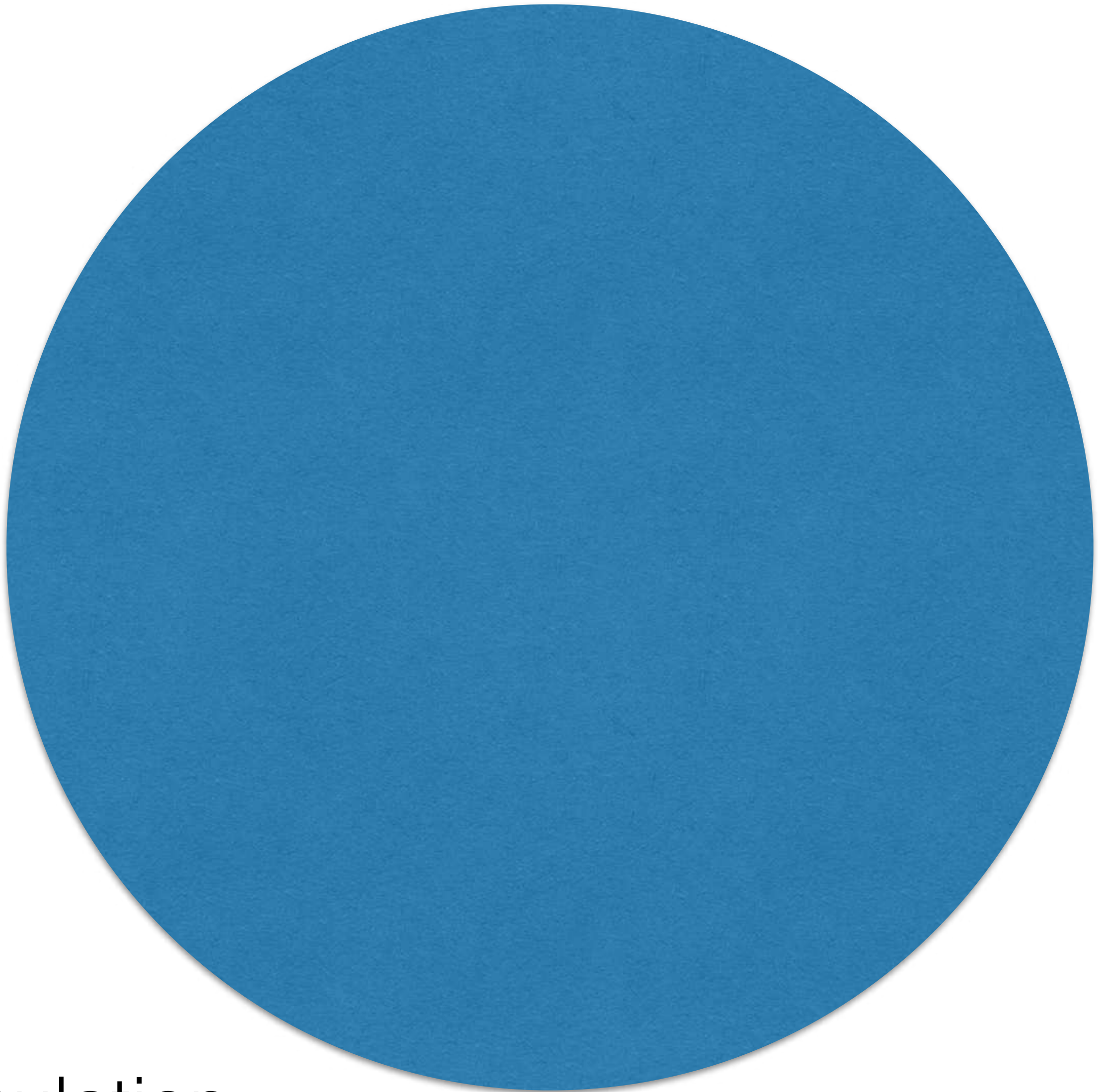
Neglect turbulence and magnetic field

The Pizza experiment

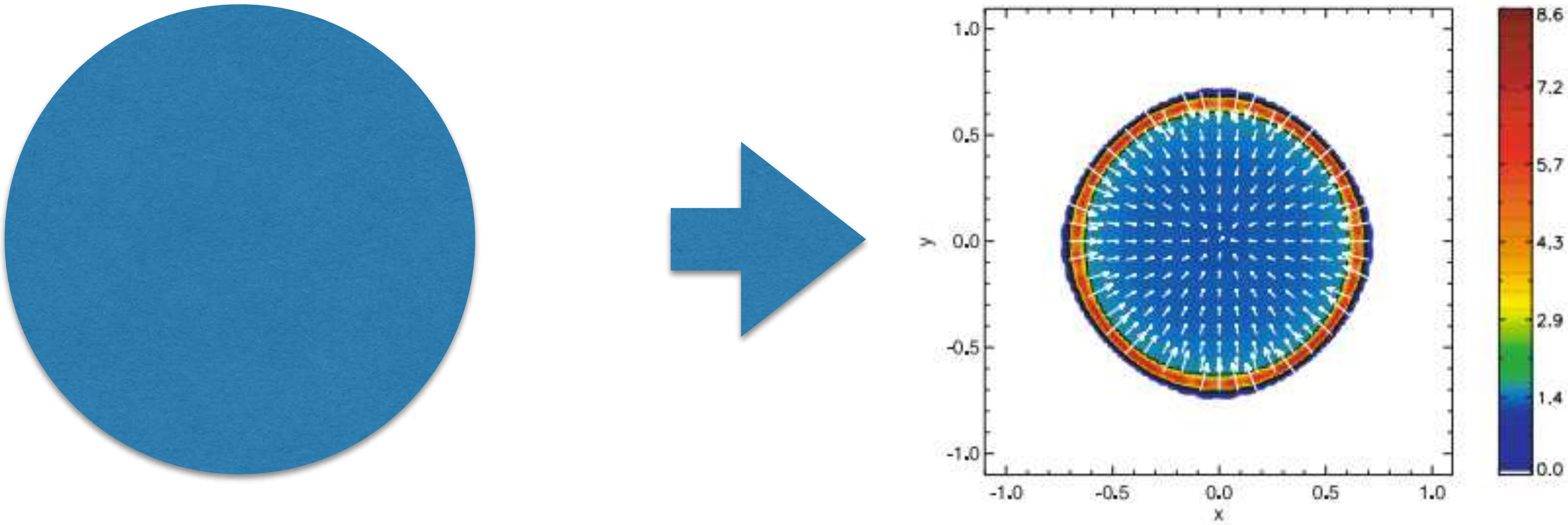
?

$$\nabla^2 \Phi = -4\pi G \rho$$

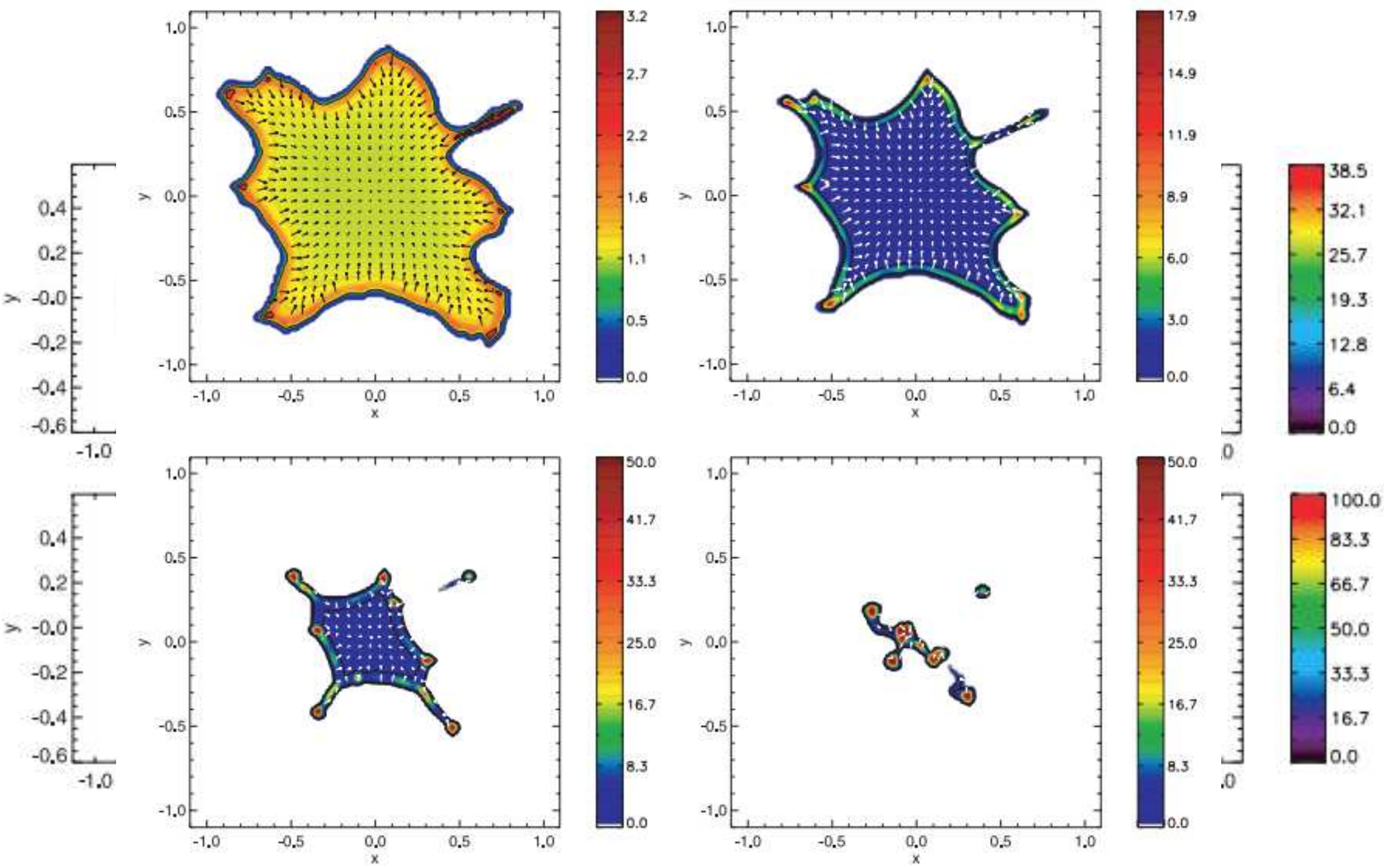
Collapse of a pizza



iso-thermal simulation


1.0
0.5
0.0
-0.5
-1.0
y
-1.0
-0.5
0.0
0.5
1.0
x
8.6
7.2
5.7
4.3
2.9
1.4
0.0

More examples



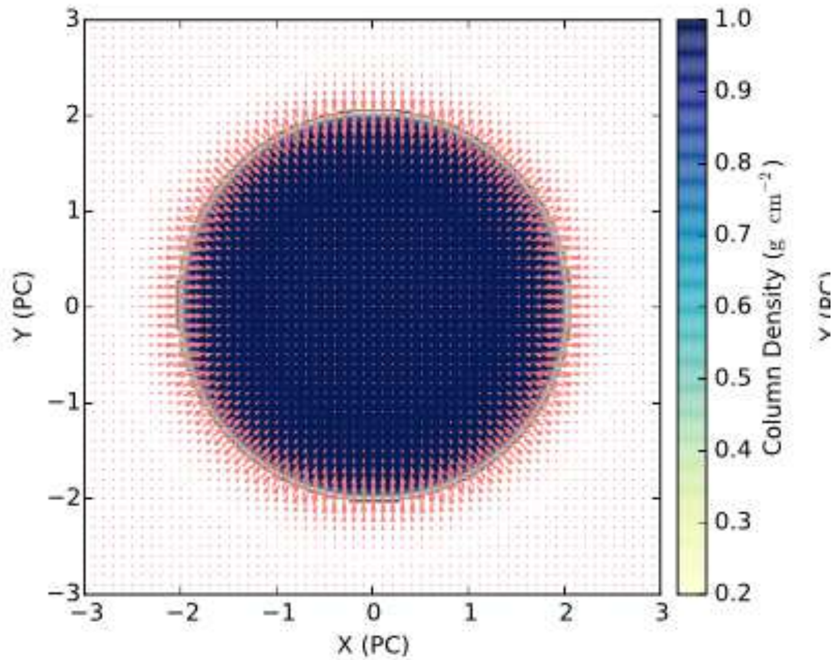
Burkert & Hartman 2004

Understanding Edge Effects

ρ

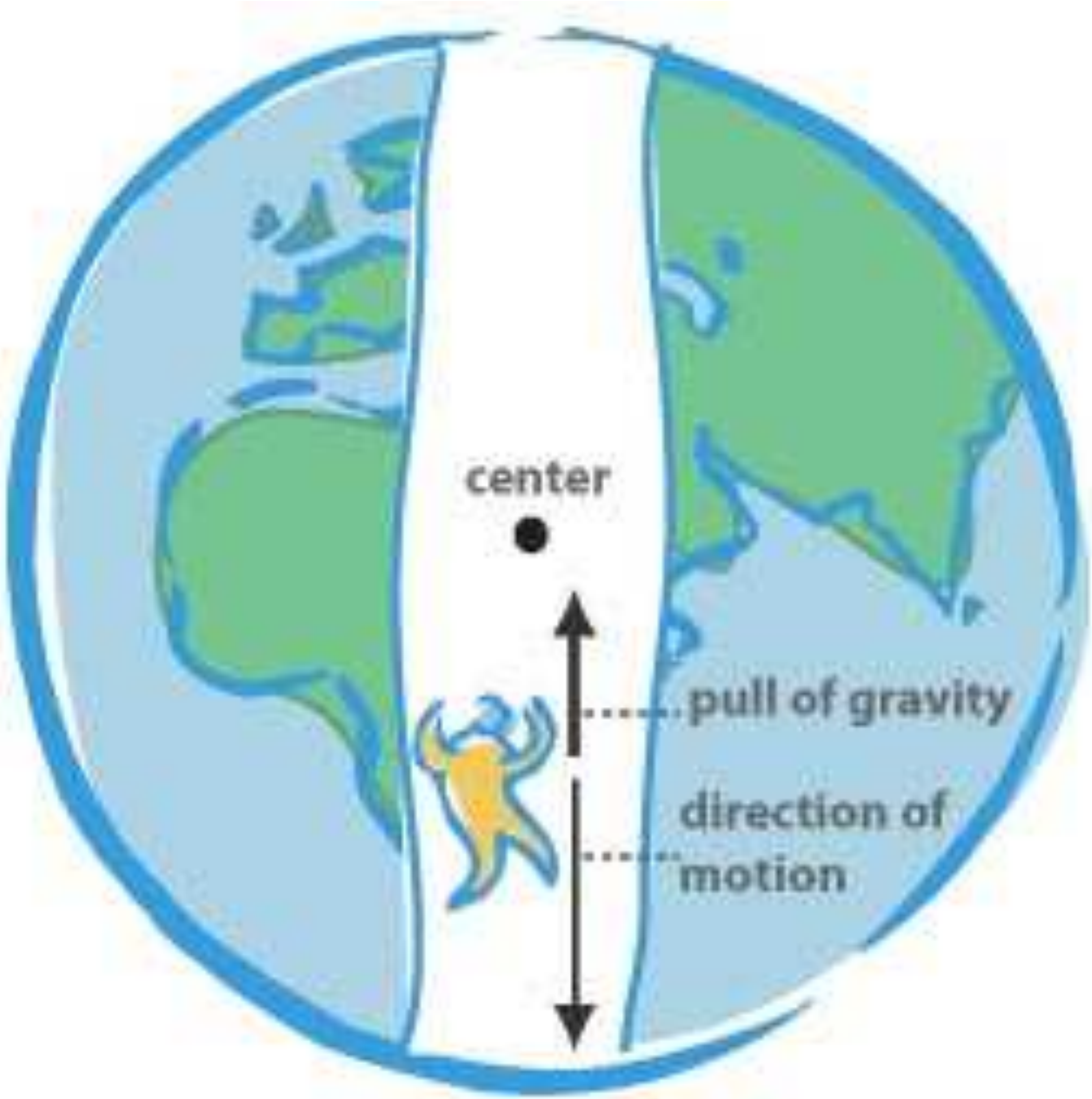
ϕ

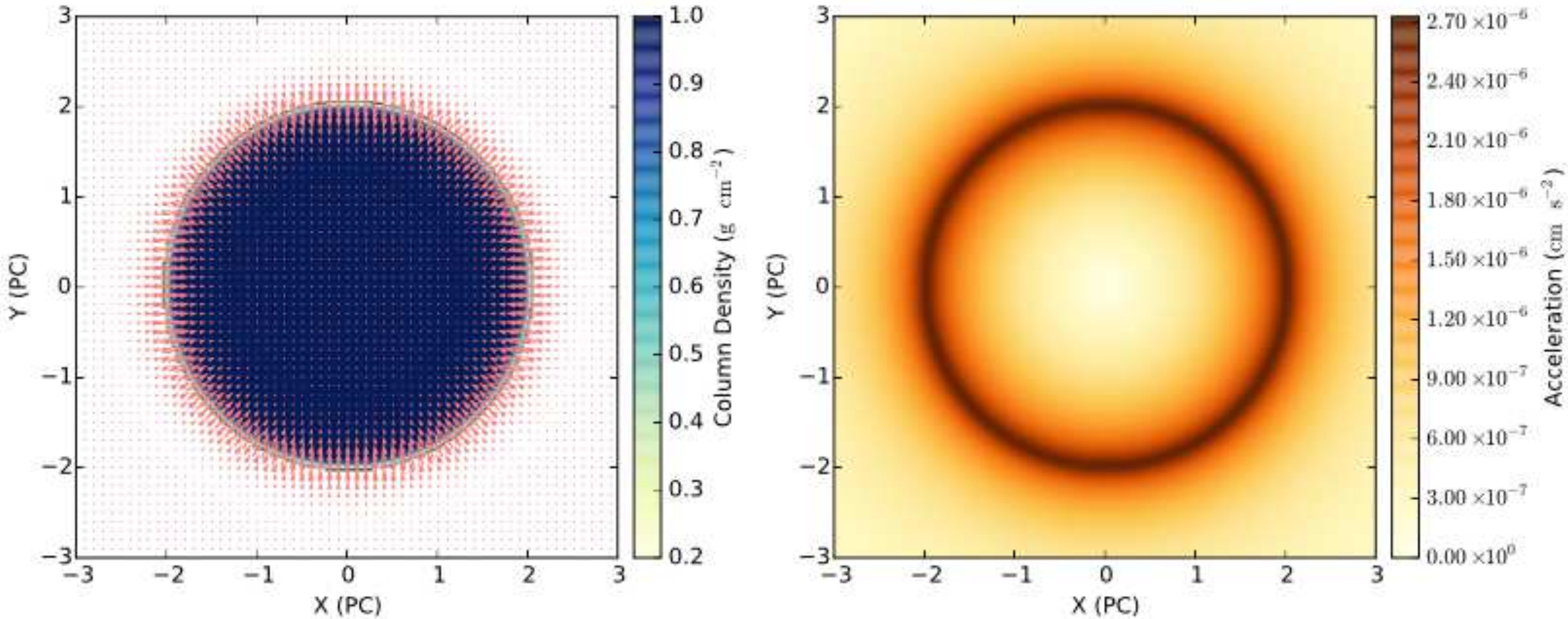
$$\vec{a} = \nabla \phi$$



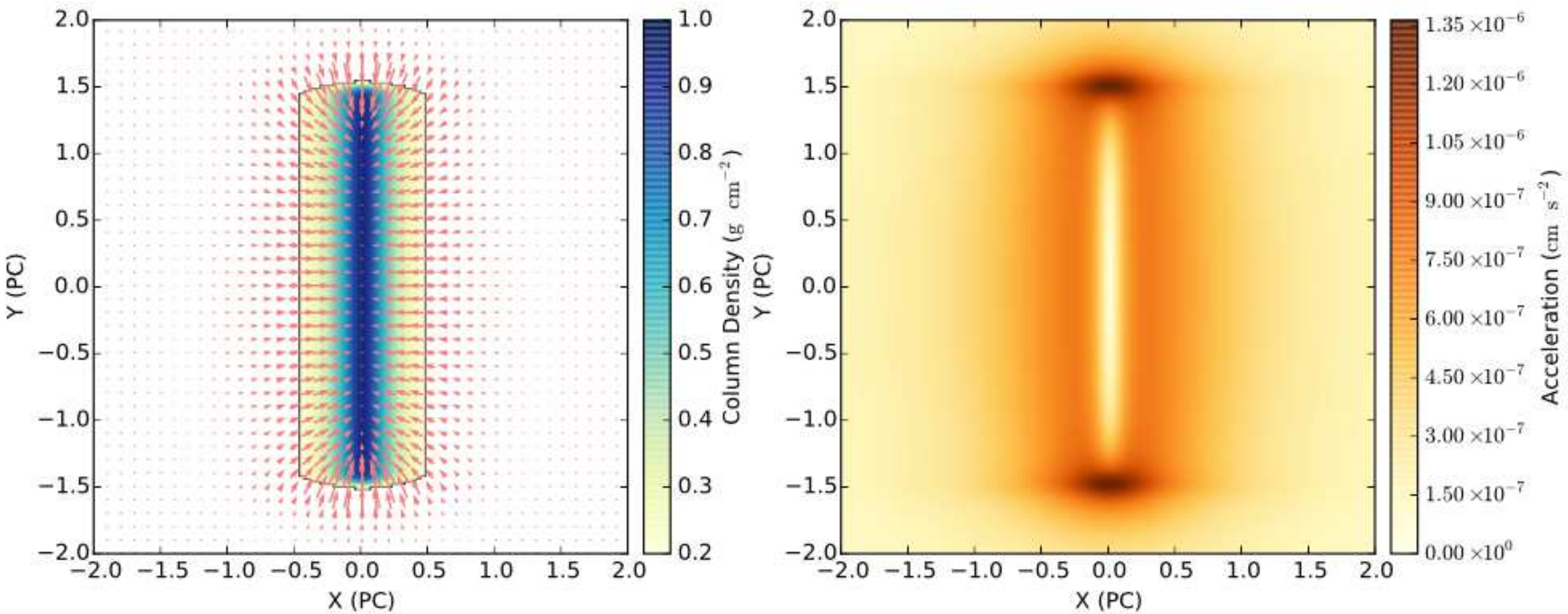
Matter -> Gravity

Not always true!!





Y (PC)
X (PC)
Column Density (g cm^{-2})
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Acceleration (cm s^{-2})
2.70×10^{-6}
2.40×10^{-6}
2.10×10^{-6}
1.80×10^{-6}
1.50×10^{-6}
1.20×10^{-6}
9.00×10^{-7}
6.00×10^{-7}
3.00×10^{-7}
0.00×10^{0}



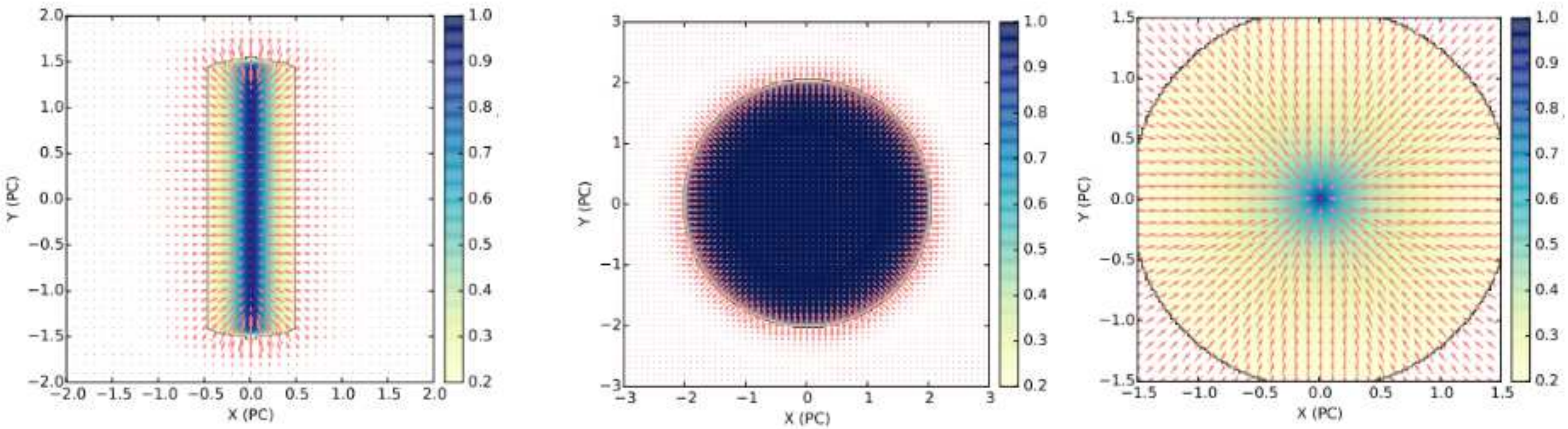
Y (PC)
X (PC)
Column Density (g cm^{-2})
Acceleration (cm s^{-2})
1.35 ×10^{-6}
1.20 ×10^{-6}
1.05 ×10^{-6}
9.00 ×10^{-7}
7.50 ×10^{-7}
6.00 ×10^{-7}
4.50 ×10^{-7}
3.00 ×10^{-7}
1.50 ×10^{-7}
0.00 ×10^{0}

Gravity is complicated …

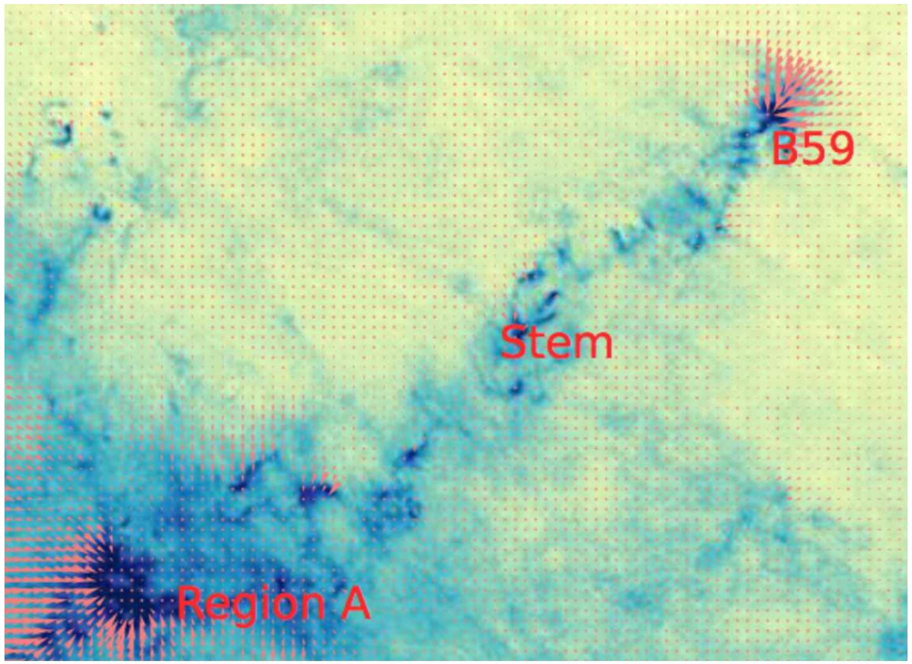
Gravitational focusing

Edge collapse

Accretion to the center



Acceleration mapping method



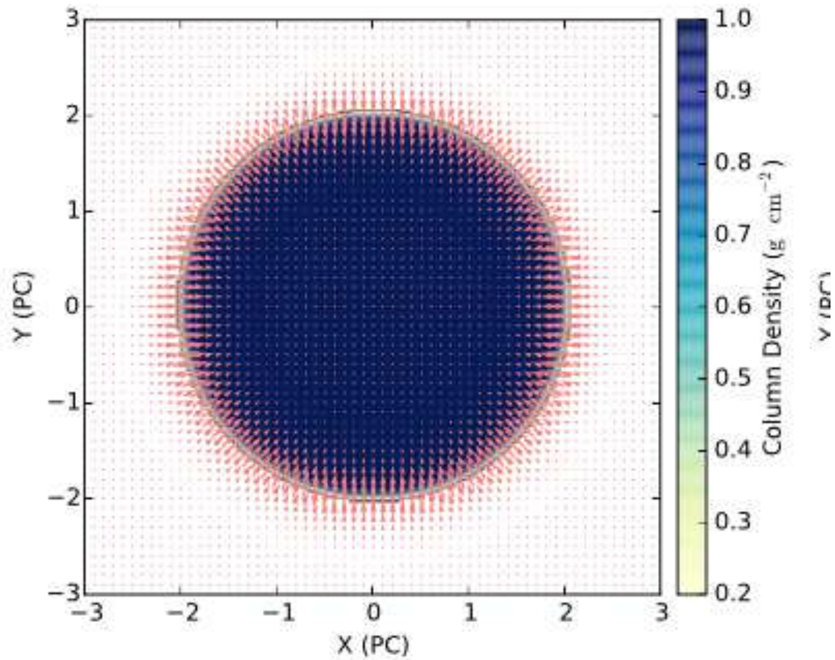
The edge mechanism

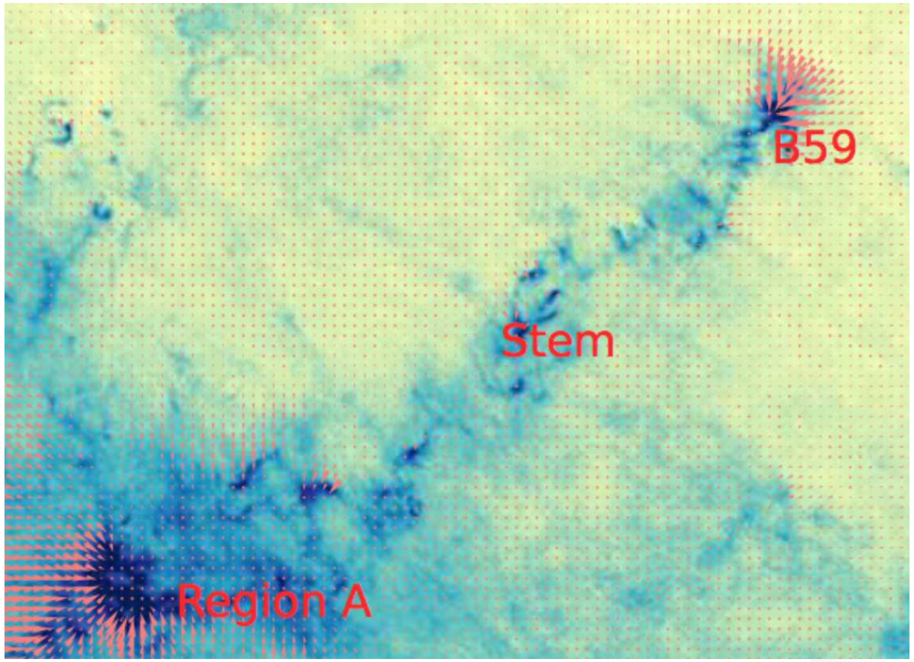
ρ

Observations!

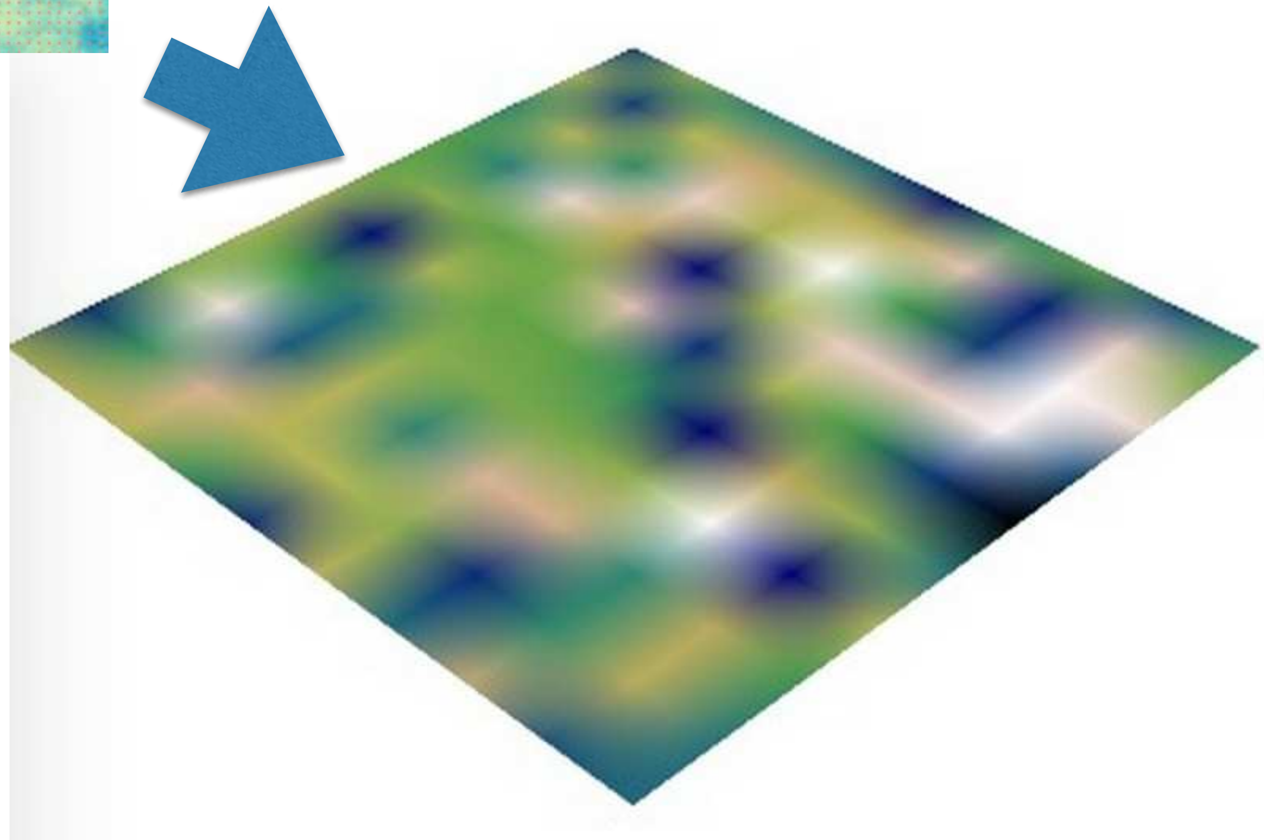
ϕ

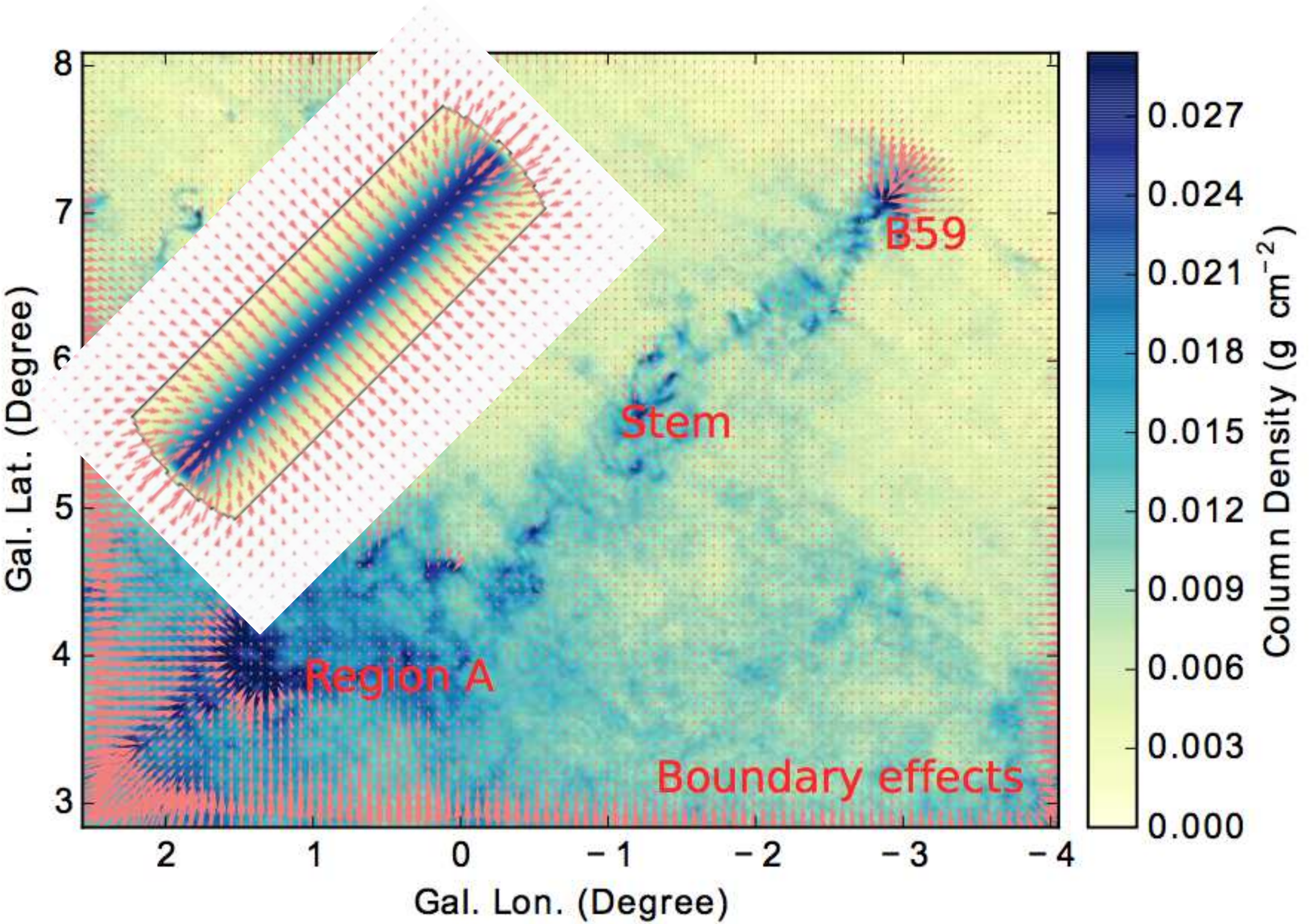
$$\vec{a} = \nabla \phi$$



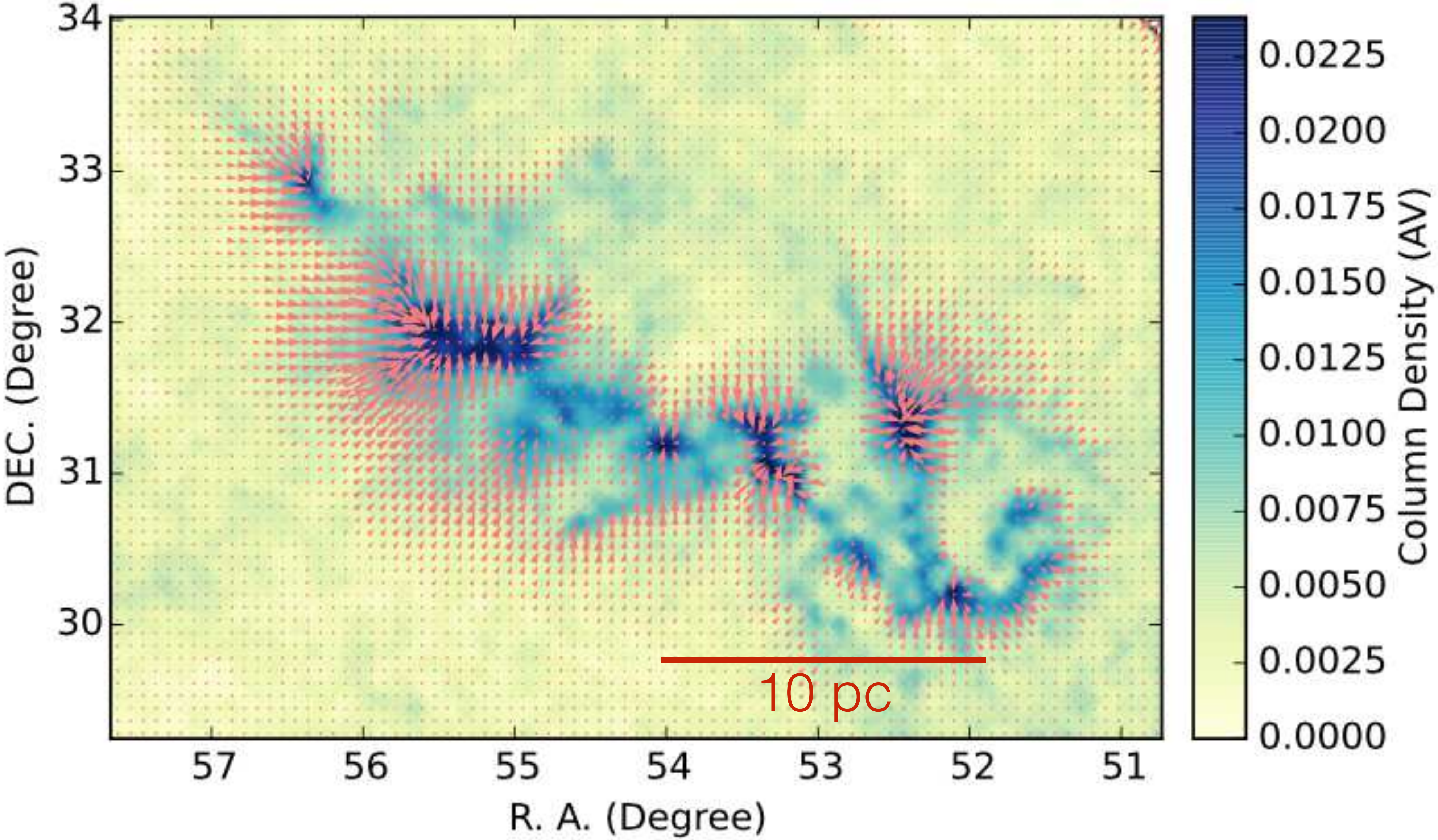


Assuming the gas staying on a 2D plate

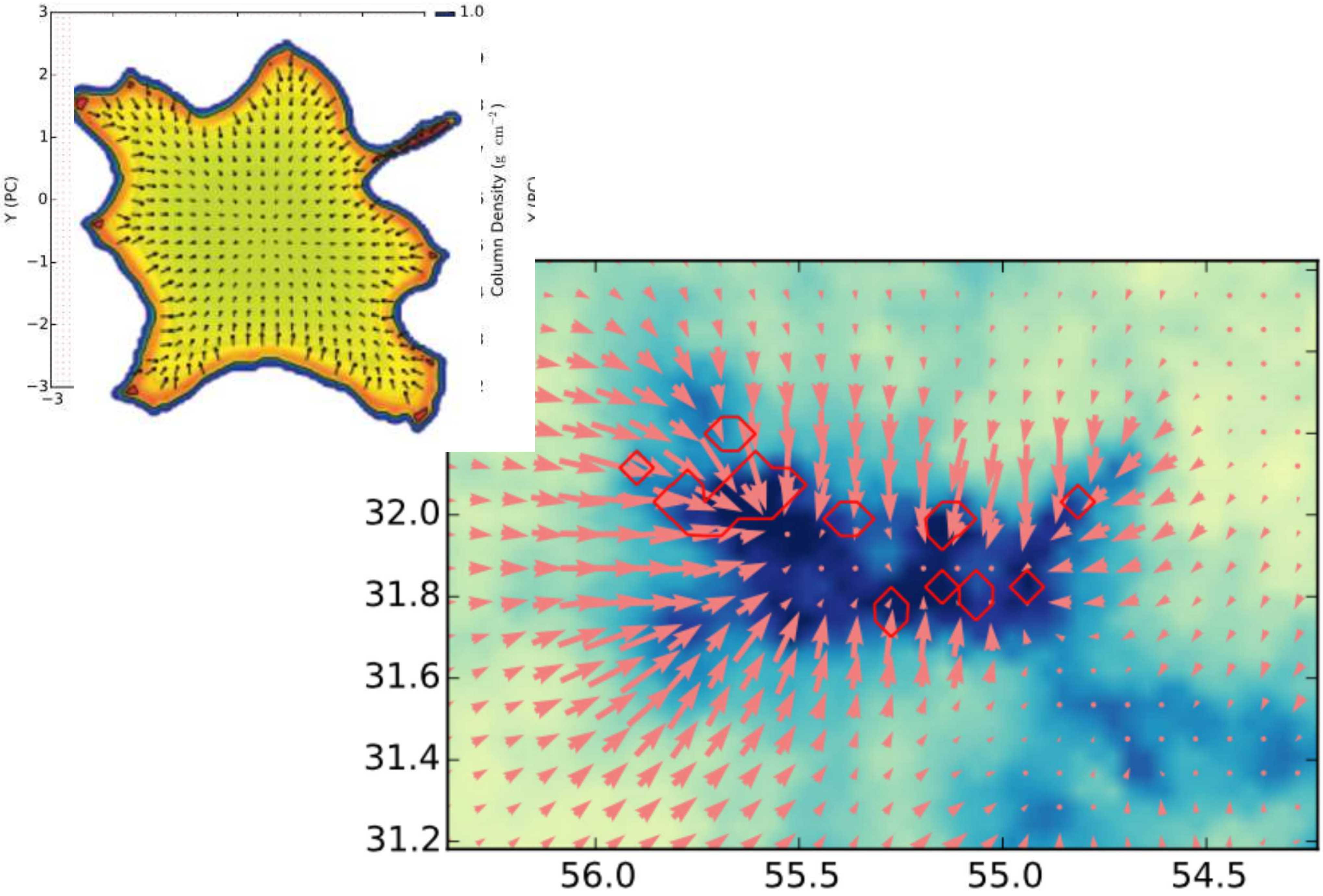




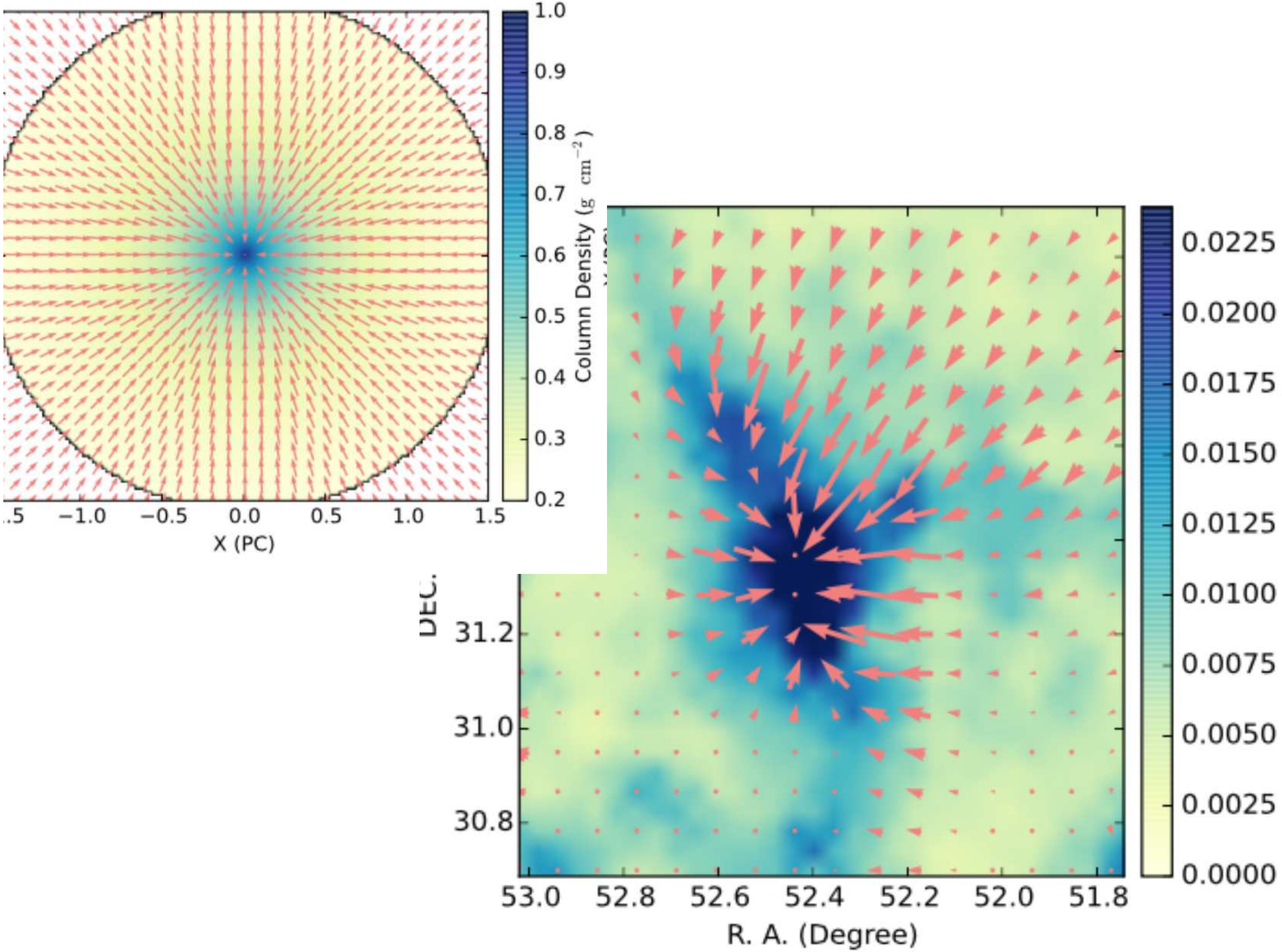
8
7
6
5
4
3
2
1
0
− 1
− 2
− 3
− 4
Gal. Lat. (Degree)
Gal. Lon. (Degree)
B59
Stem
Region A
Boundary effects
0.027
0.024
0.021
0.018
0.015
0.012
0.009
0.006
0.003
0.000
Column Density (g cm^{-2})



34
33
32
31
30
DEC. (Degree)
57
56
55
54
53
52
51
R. A. (Degree)
10 pc
0.0225
0.0200
0.0175
0.0150
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000
Column Density (AV)

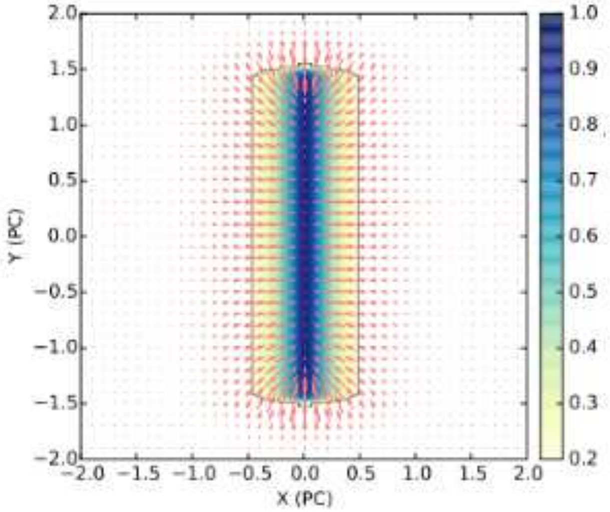


Y (PC)
3
2
1
0
−1
−2
−3
−3
1.0
Column Density (g cm^{-2})
32.0
31.8
31.6
31.4
31.2
56.0
55.5
55.0
54.5

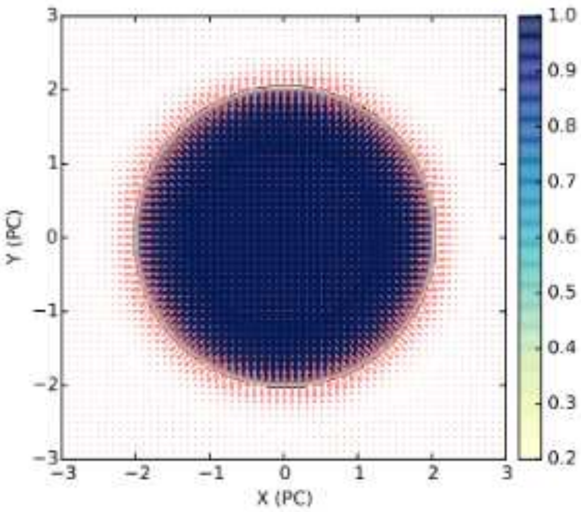


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Column Density (g cm^{-2})
.5 −1.0 −0.5 0.0 0.5 1.0 1.5
X (PC)
0.0225
0.0200
0.0175
0.0150
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000
DEC.
31.2
31.0
30.8
53.0 52.8 52.6 52.4 52.2 52.0 51.8
R. A. (Degree)

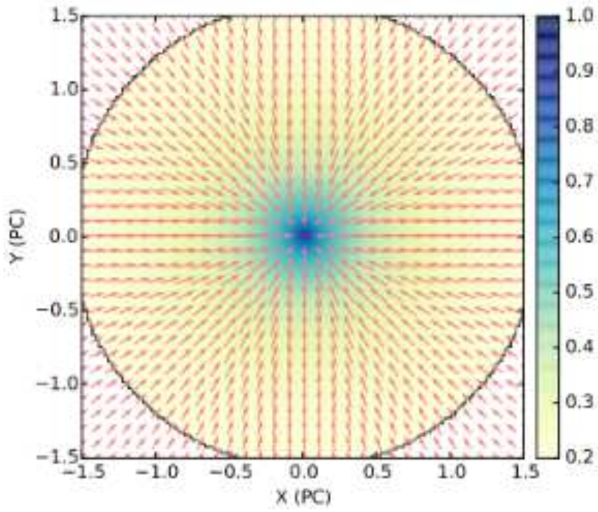
Gravitational focusing

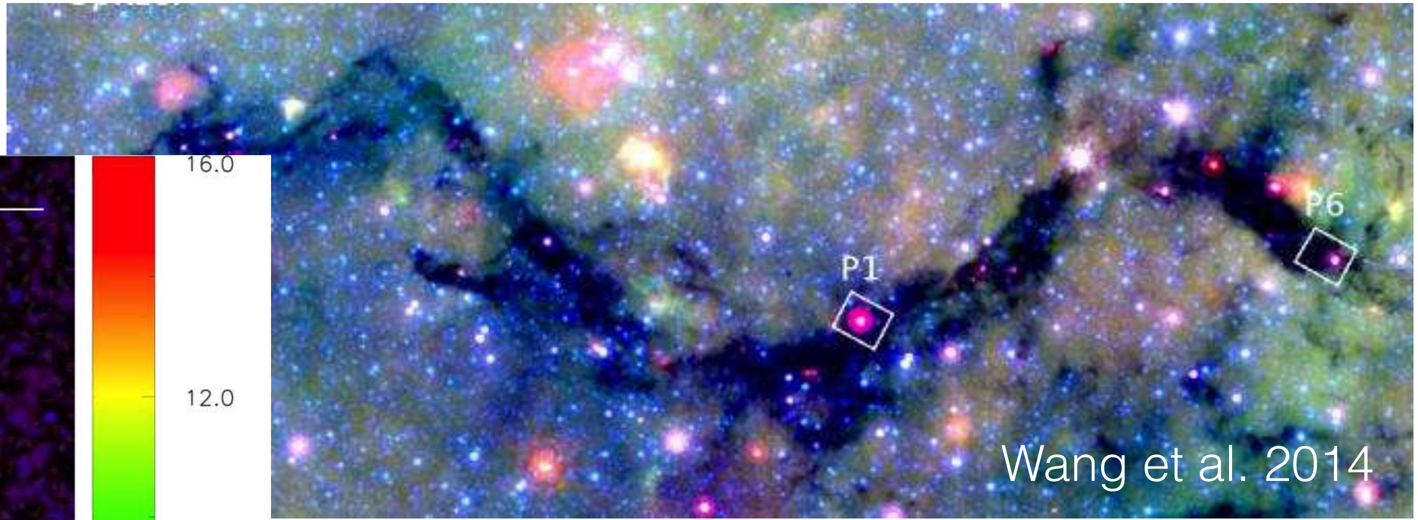


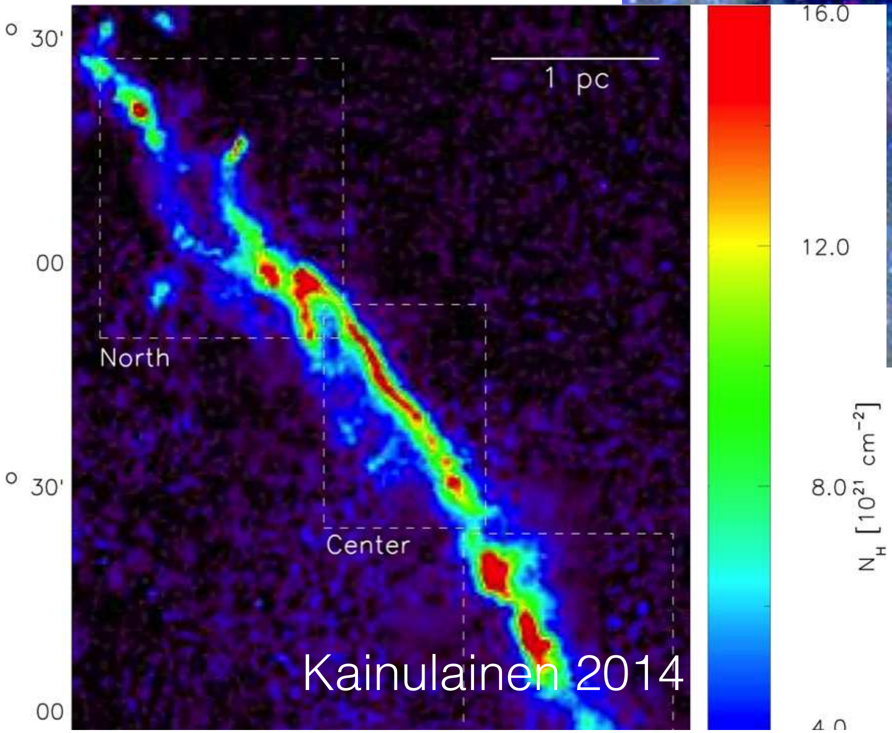
Edge collapse



Accretion to the center





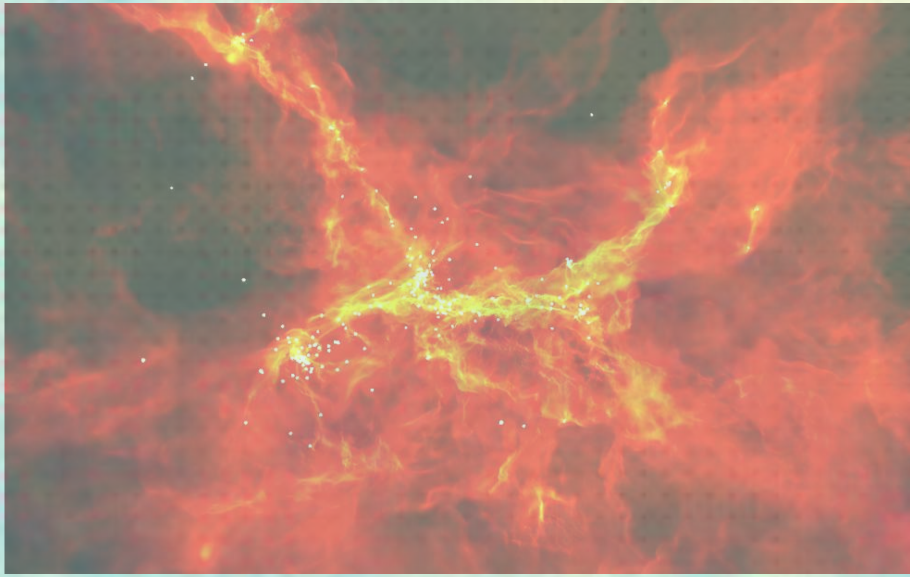


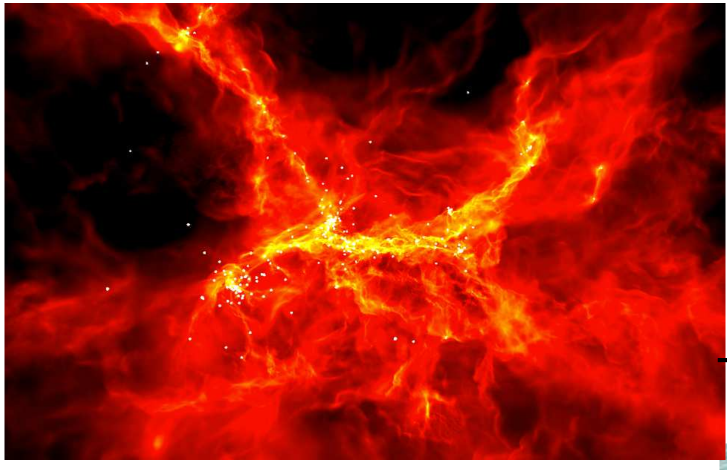
Structures are created by Compression, shear…

Conclusions

- Gravity is a long-range force. Self-gravity is not enough
- Edge effects expected — compression, shear create structures
- Acceleration is the key
- Gravity is not the full story, need to understand turbulence and B field

$$\alpha_{\rm vir} \sim \frac{\sigma_{\rm v}^2 r}{Gm}$$

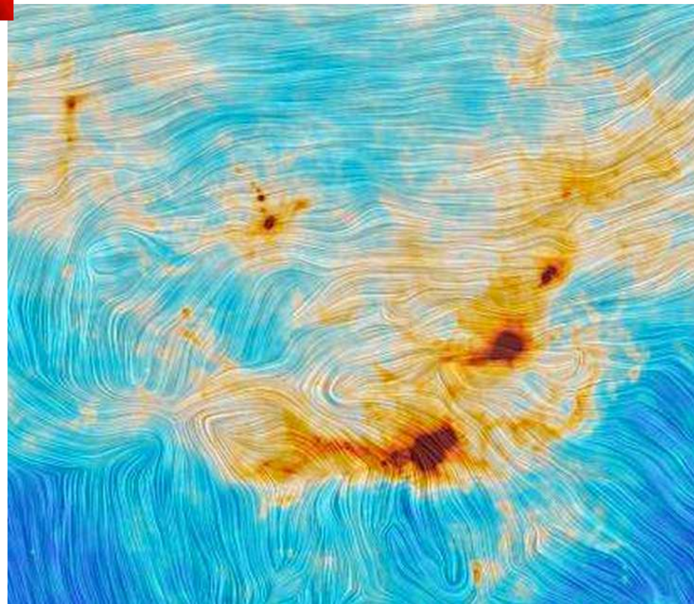




Turbulence

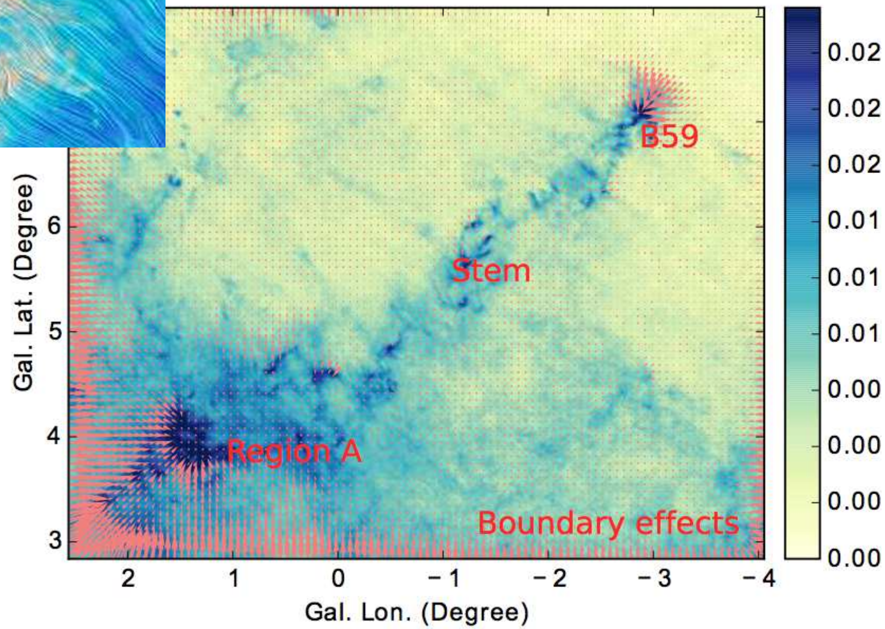
Simulation from Bate

Turbulence + B Field



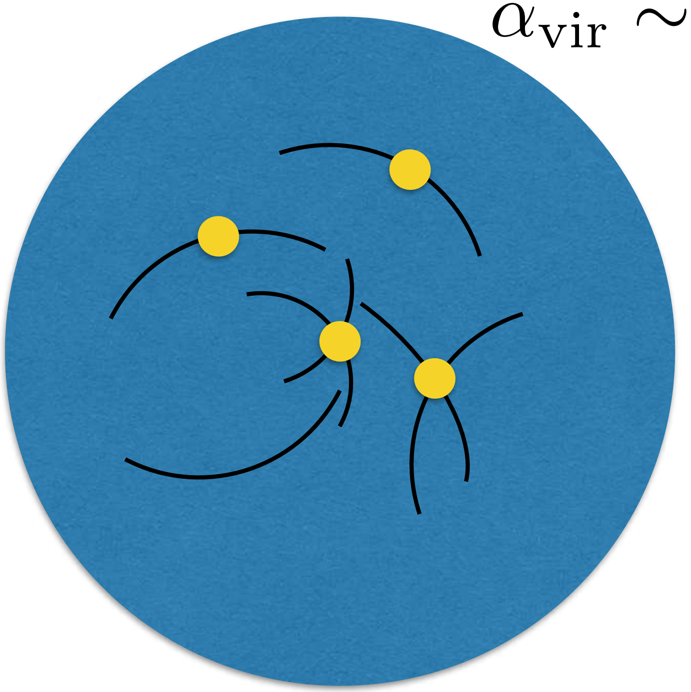
Planck Magnetic Field

Gravity

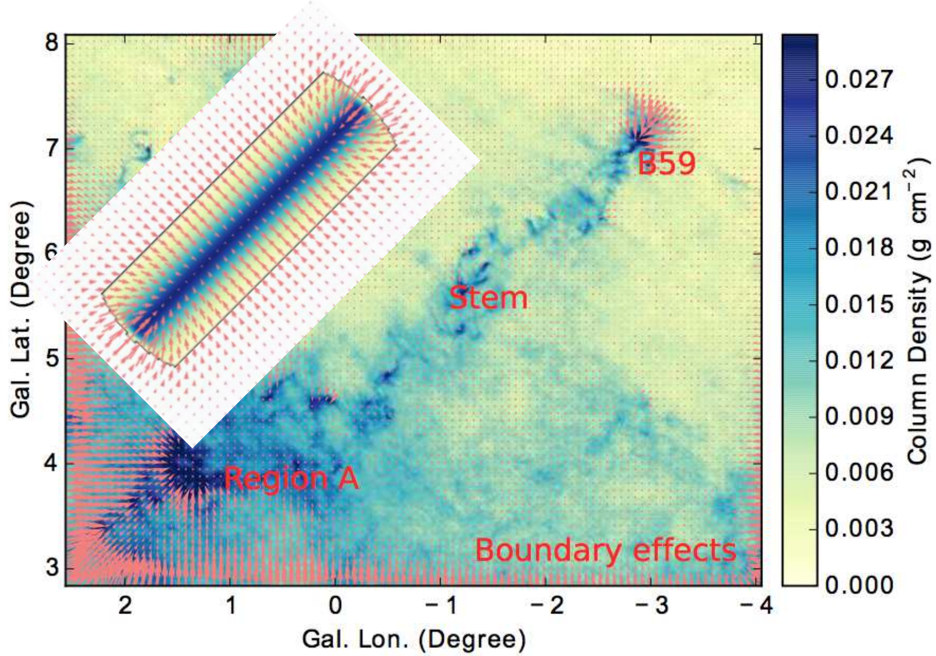


Star formation in general

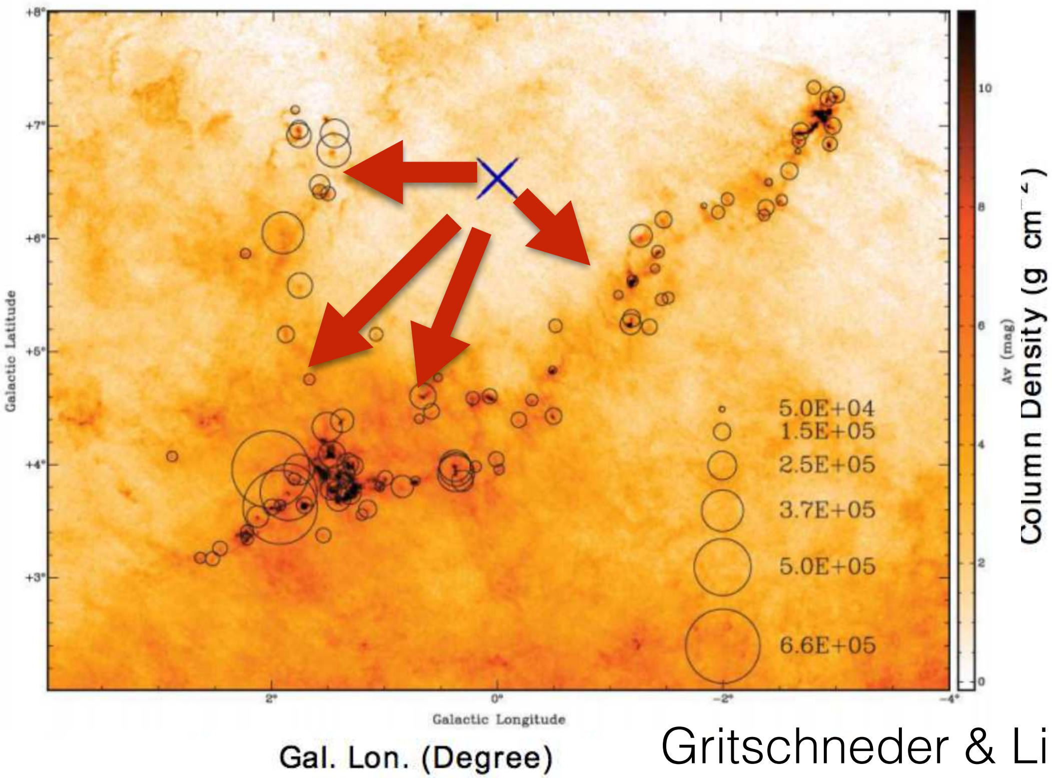
$$\alpha_{\rm vir} \sim \frac{Gm}{\sigma_{\rm v}^2 r}$$



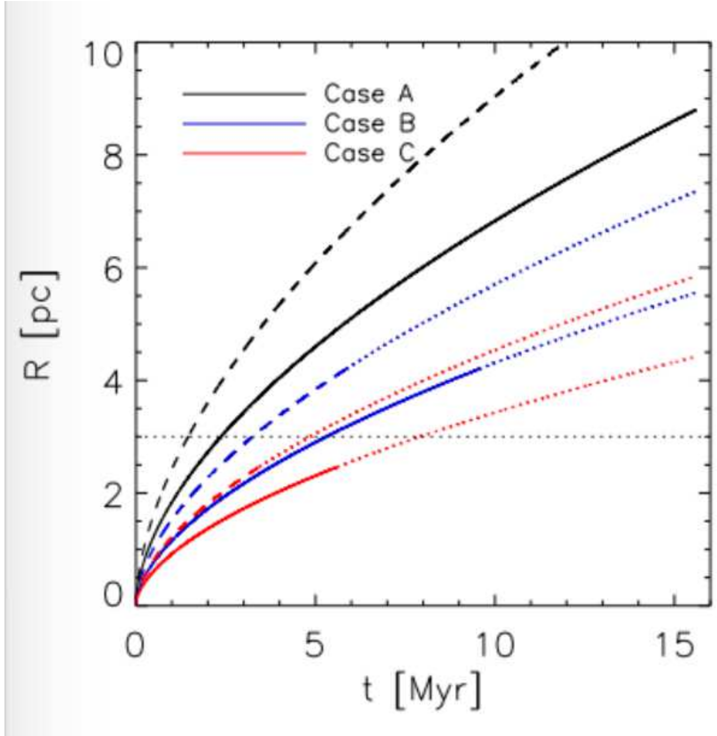
Turbulence: Large L
Gravity: Small L



Gravity is important
at various scales

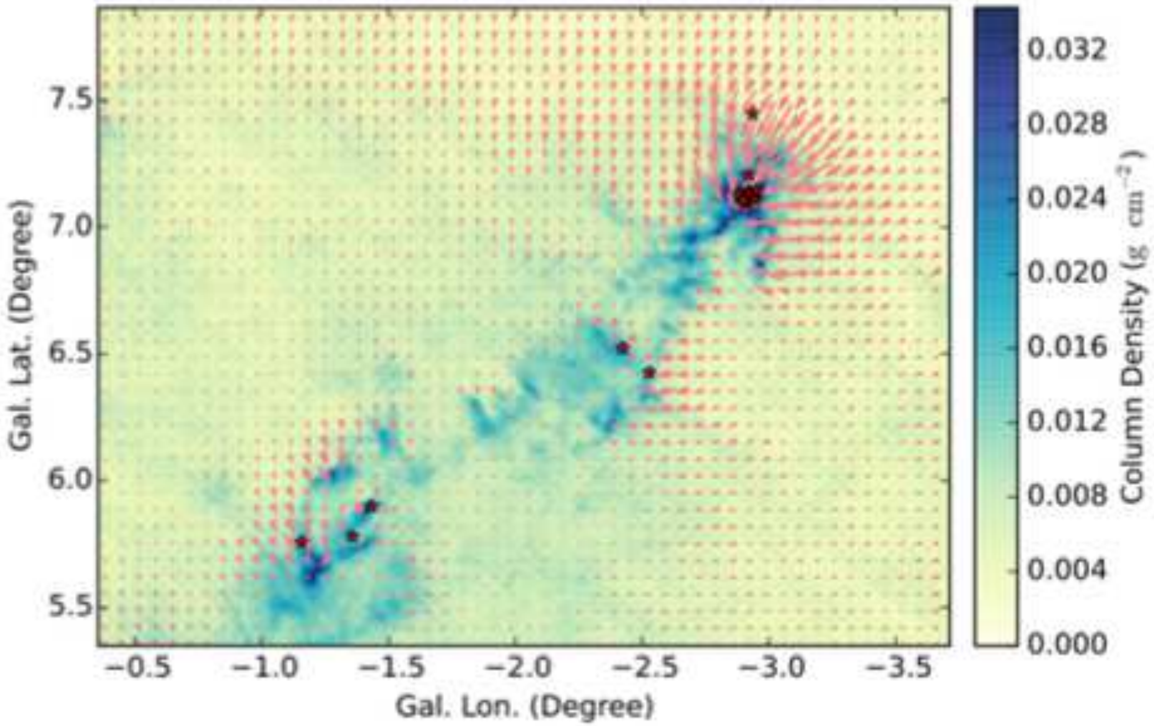


Gritschneder & Lin 2012



Filamentary structures can be produced by bubble expansions

Application to observations



Acceleration map of the *Pipe nebula*. Vectors represent accelerations. The red stars stand for protostars.

A simple estimate of the timescale (using $L = 1/2\; a\; t^2$)

$$t \sim \sqrt{\frac{L}{a}}\,. \tag{2}$$

If $L \sim 1$ pc and $a \sim 3 \times 10^{-8}$, a typical timescale is $t \sim 10^6$ yr.
→ Comparable to the free-fall timescale, much shorter than typical cloud lifetimes.
→ A possible mechanism to form dense gas.