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A Magnetic Ribbon Model for Star forming Filaments

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Today's Agenda

- Objective
- Background
- Filamentary Structure
- MHD Simulations
- Analytic Model
- Results

Objective:

We develop an **analytic model** to explain some of the recent observations by Herschel Space Observatory of constant width **(0.10 ± 0.03 pc)** in the filamentary structures in molecular clouds.

A MAGNETIC RIBBON MODEL FOR STAR-FORMING FILAMENTS

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ABSTRACT

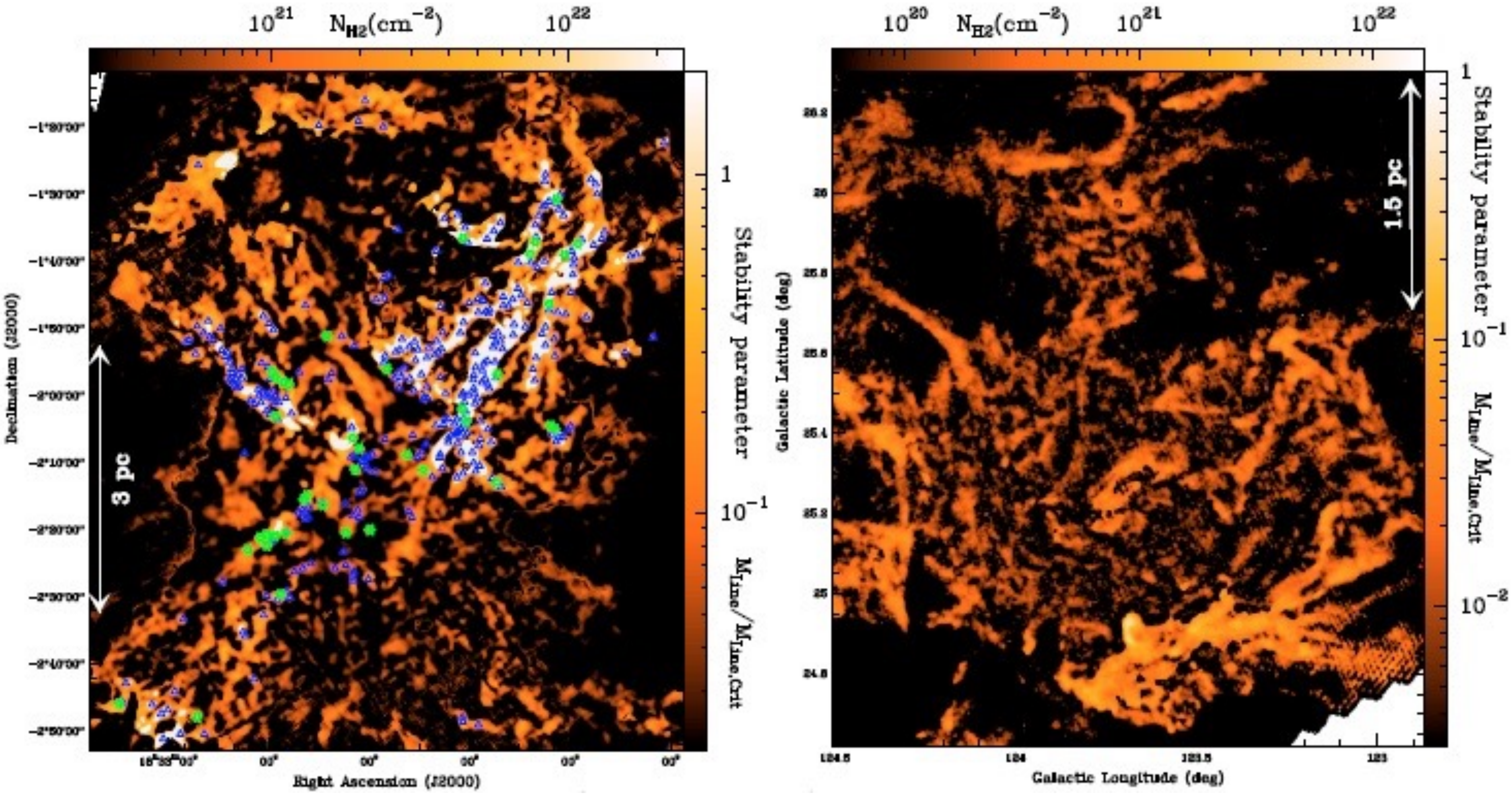
We develop a magnetic ribbon model for molecular cloud filaments. These result from turbulent compression in a molecular cloud in which the background magnetic field sets a preferred direction. We argue that this is a natural model for filaments and is based on the interplay between turbulence, strong magnetic fields, and gravitationally-driven ambipolar diffusion, rather than pure gravity and thermal pressure. An analytic model for the formation of magnetic ribbons that is based on numerical simulations is used to derive a lateral width of a magnetic ribbon. This differs from the thickness along the magnetic field direction, which is essentially the Jeans scale. We use our model to calculate a synthetic observed relation between apparent width in projection versus observed column density. The relationship is relatively flat, similar to observations, and unlike the simple expectation based on a Jeans length argument.

Keywords: ISM: clouds — magnetic fields — magnetohydrodynamics (MHD) — stars: formation —

Molecular Clouds

- These are one of the massive objects in the Galaxy with masses up to10^6 M_{solar} .
- Interstellar clouds where the density and the size permits the formation of molecules typically molecular hydrogen.
- The main constituent of Molecular Clouds are molecules, dust grains, ions and stars.
- These are the sites of the present day star formation.

Herschel Observations



André et al. 2010

Aquila (left) and Polaris (right) molecular clouds with class 0 sources (green) and prestellar cores (blue) overlaid. Enhanced contrast to emphasize filaments.

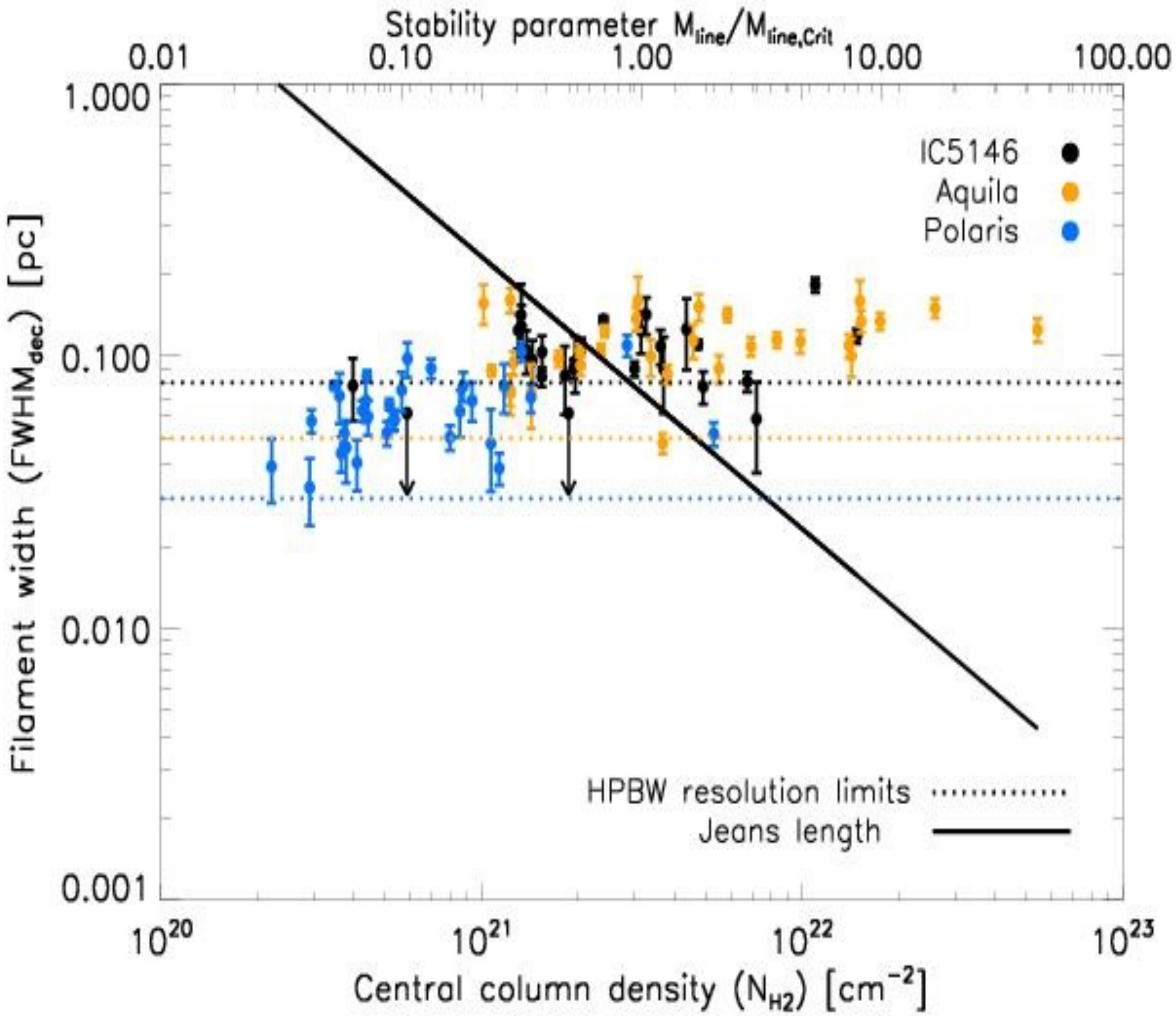
Filament Width

Western

Filament Width

• Filaments are characterized by a narrow distribution of widths with the median value of 0.10± 0.03 pc.

• The width is independent of the column density. This is in contradiction to the distribution of central Jeans length, which scales as
Σ^{-1}, where Σ is the surface density.



Arzoumanian et al 2011

MHD Model

MHD Equations

$$\frac{\partial \rho}{\partial t} + \vec{v}.\nabla \rho = -\rho \nabla.\vec{v},$$

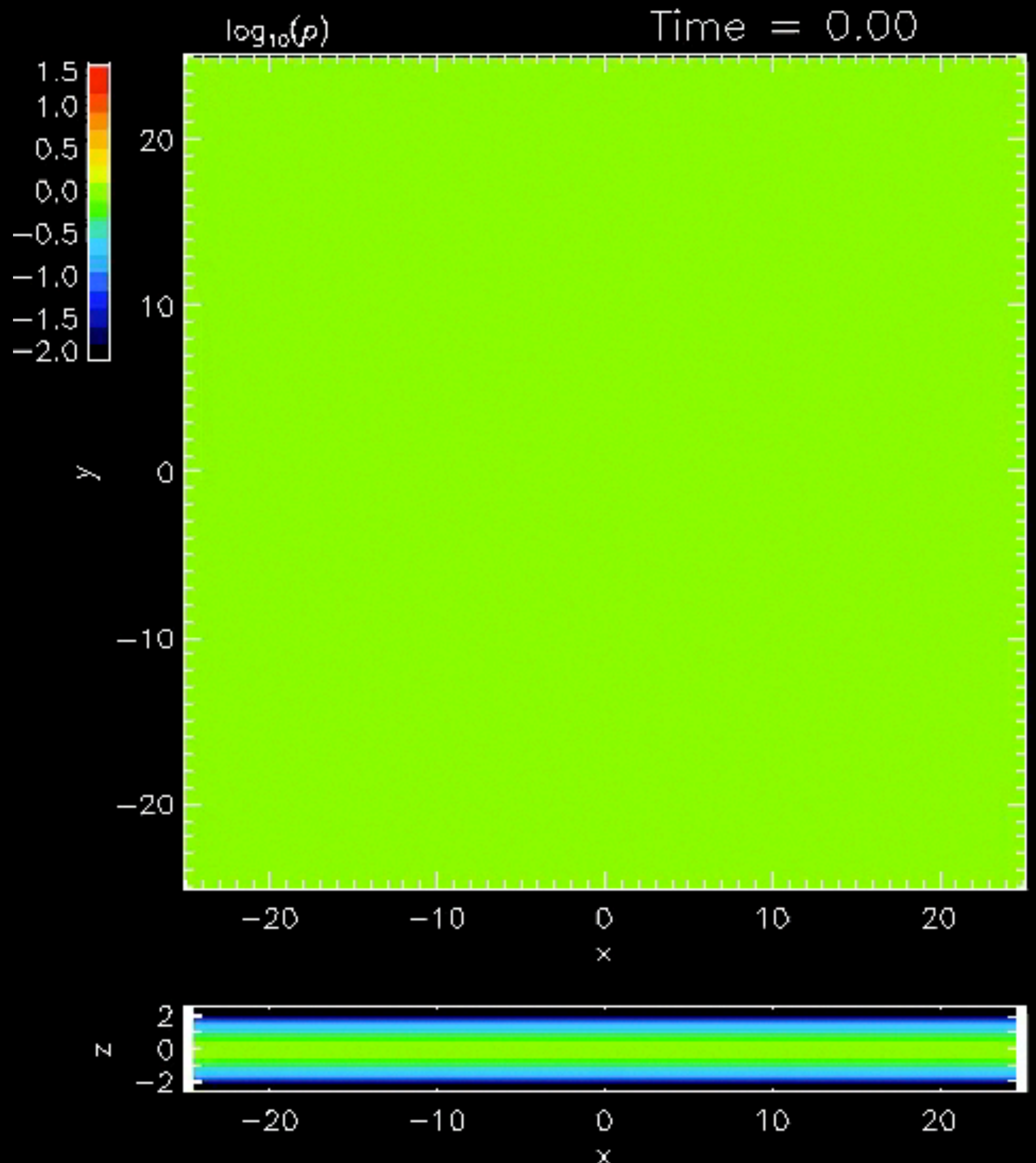
$$\frac{\partial \vec{v}}{\partial t} + (\vec{v}.\nabla)\vec{v} = -\frac{1}{\rho}\nabla P + \frac{1}{c\rho}\vec{j} \times \vec{B} - \nabla \psi,$$

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times \vec{v} \times \vec{B} + \nabla \times [\frac{\tau_{ni}}{c\rho}(\vec{j} \times \vec{B}) \times \vec{B}],$$

$$\vec{j} = \frac{c}{4\pi}\nabla \times \vec{B},$$

$$\nabla^2 \psi = 4\pi G \rho,$$

$$P = c_s^2 \rho.$$



log10(ρ)
Time = 0.00
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
20
10
0
−10
−20
y
−20
−10
0
10
20
x
2
0
−2
z
−20
−10
0
10
20
x

Analytic Model

Equate ribbon pressure to background magnetic and ram pressure in the x-y direction for a gas cloud stratified in the z direction.

$$H\frac{B^2}{8\pi} = H_0\left(\rho_0 v_{t0}^2 + \frac{B_0^2}{8\pi}\right)$$

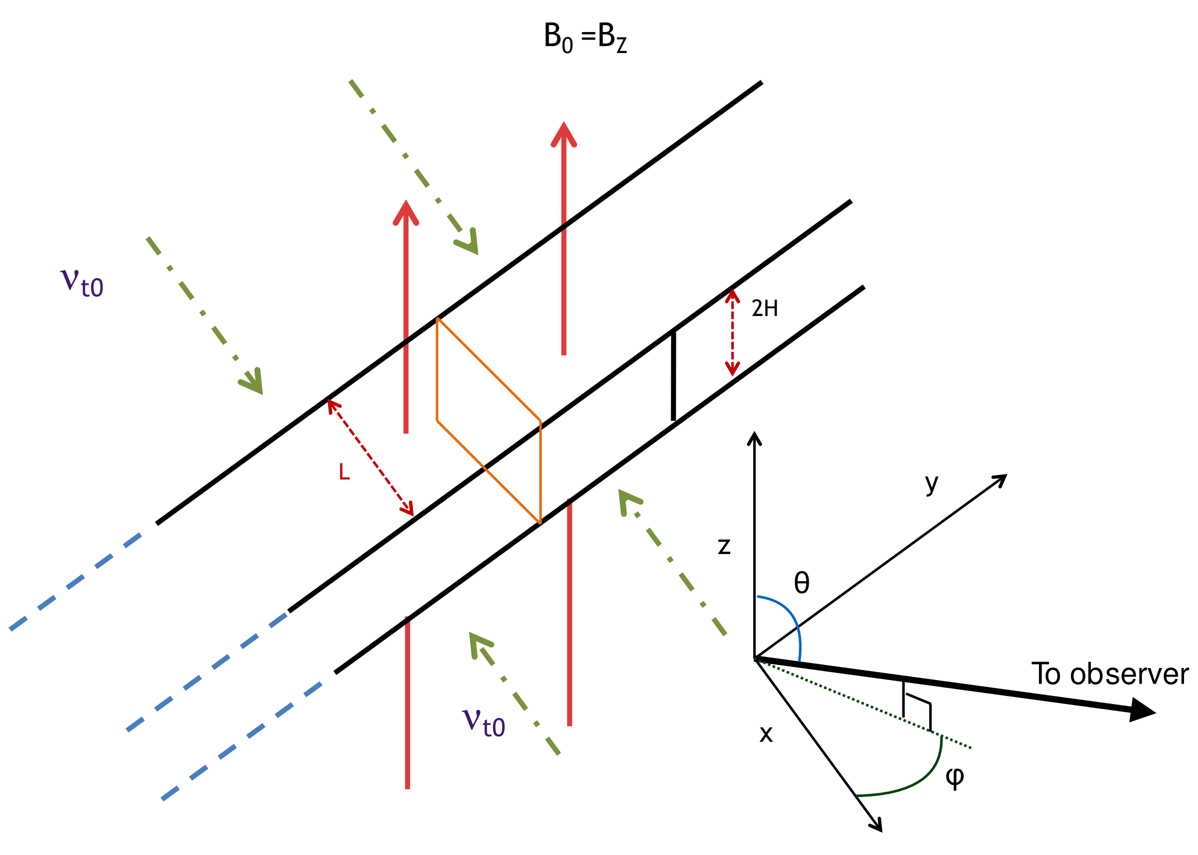
Oscillating quasi-equilibrium subcritical ribbon eventually collapses due to ambipolar diffusion.

ν_{t0} is the nonlinear flow speed

B_0 is the initial uniform magnetic field in z direction

ρ_0 is the initial density

$H_0 = c_{s0} / \sqrt{(2\pi G \rho_0)}$ is the initial thickness of the cloud in the z direction



Auddy et al 2016, ApJ

Analytic Model (Cont.)

Using flux freezing during compression,

$$\left(\frac{\rho}{\rho_0}\right)^{1/2} \sim \left(v_{t0}^2 + \frac{{B_0}^2}{8\pi\rho_0}\right)\left(\frac{B^2}{8\pi\rho}\right)^{-1}.$$

For mass per unit length conserved, i.e.
$\rho_0 L_0 H_0 = \rho L H$

$\nu^2_{A0} = B^2_0/(4\pi\rho_0)$ is the square of the Alfven speed of the cloud

The Ribbon width is:

$$L = L_0\left[2\left(\frac{v_{t0}}{v_{A0}}\right)^2 + 1\right]^{-1}.$$

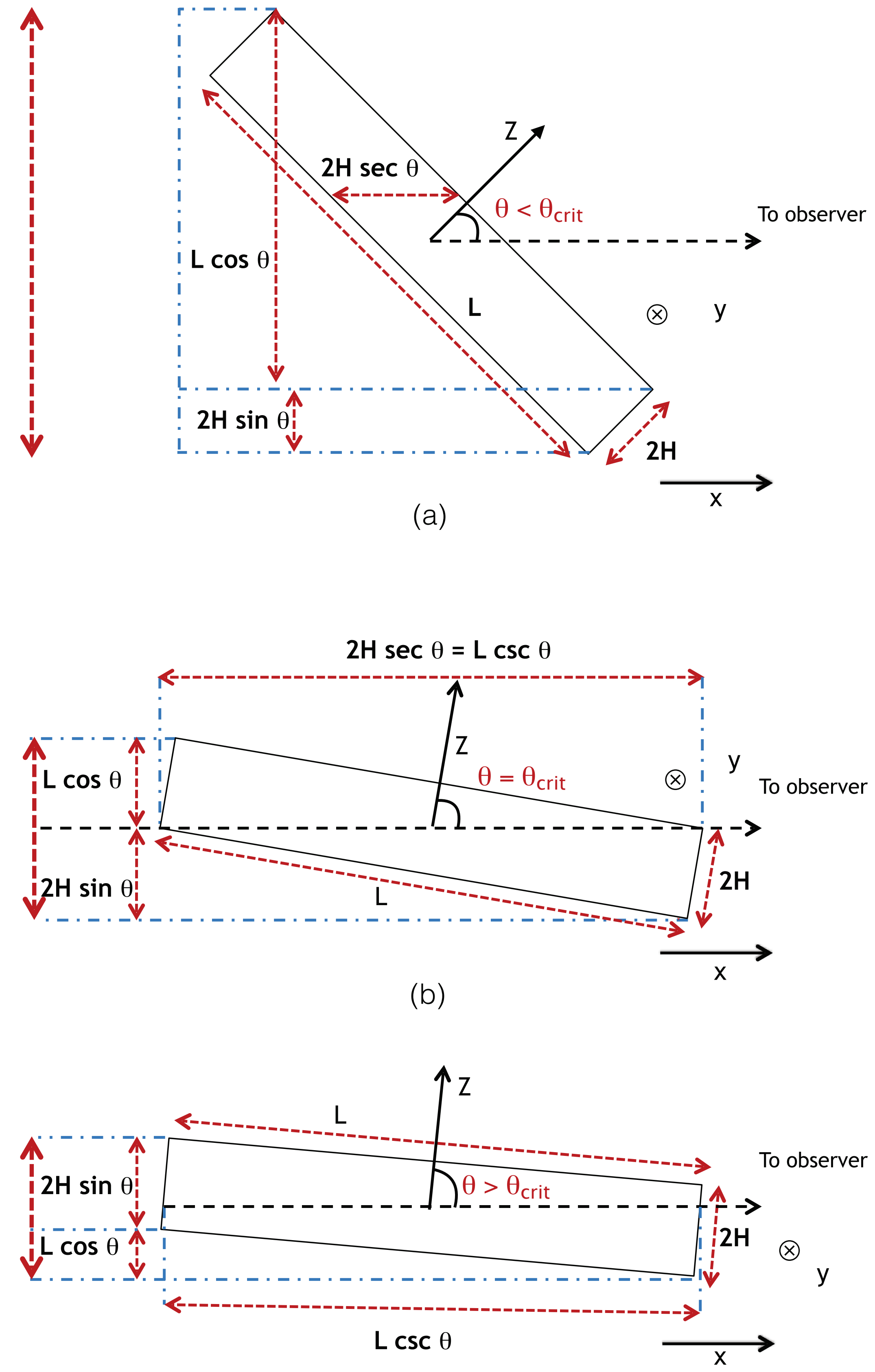
If the flow speed ν_{t0} is comparable to the Alfven Speed ν_{A0} then the ribbon width is $L \sim L_0/3$

Viewing Angle

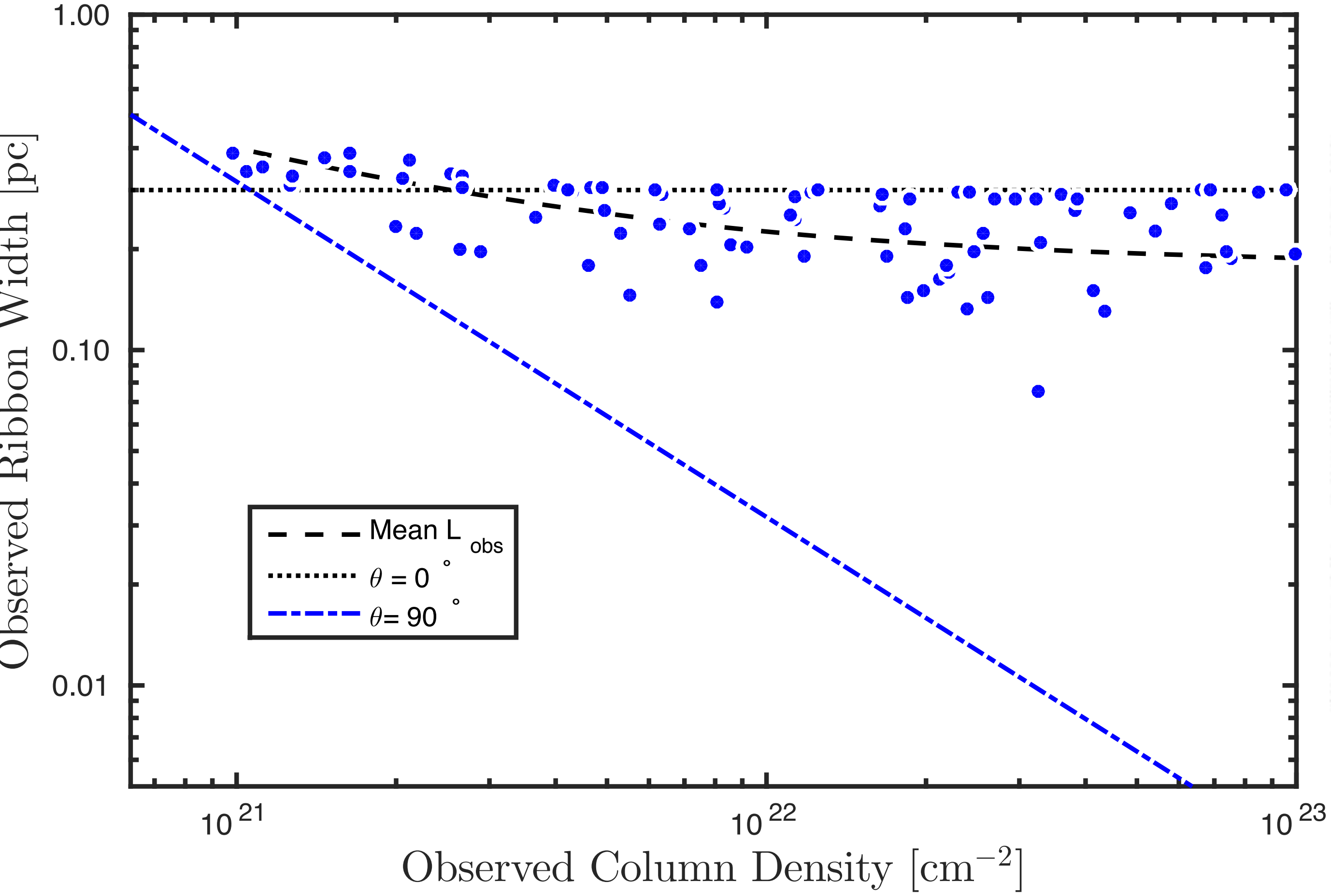
Depending on the viewing angle the observed width of the ribbons will vary.

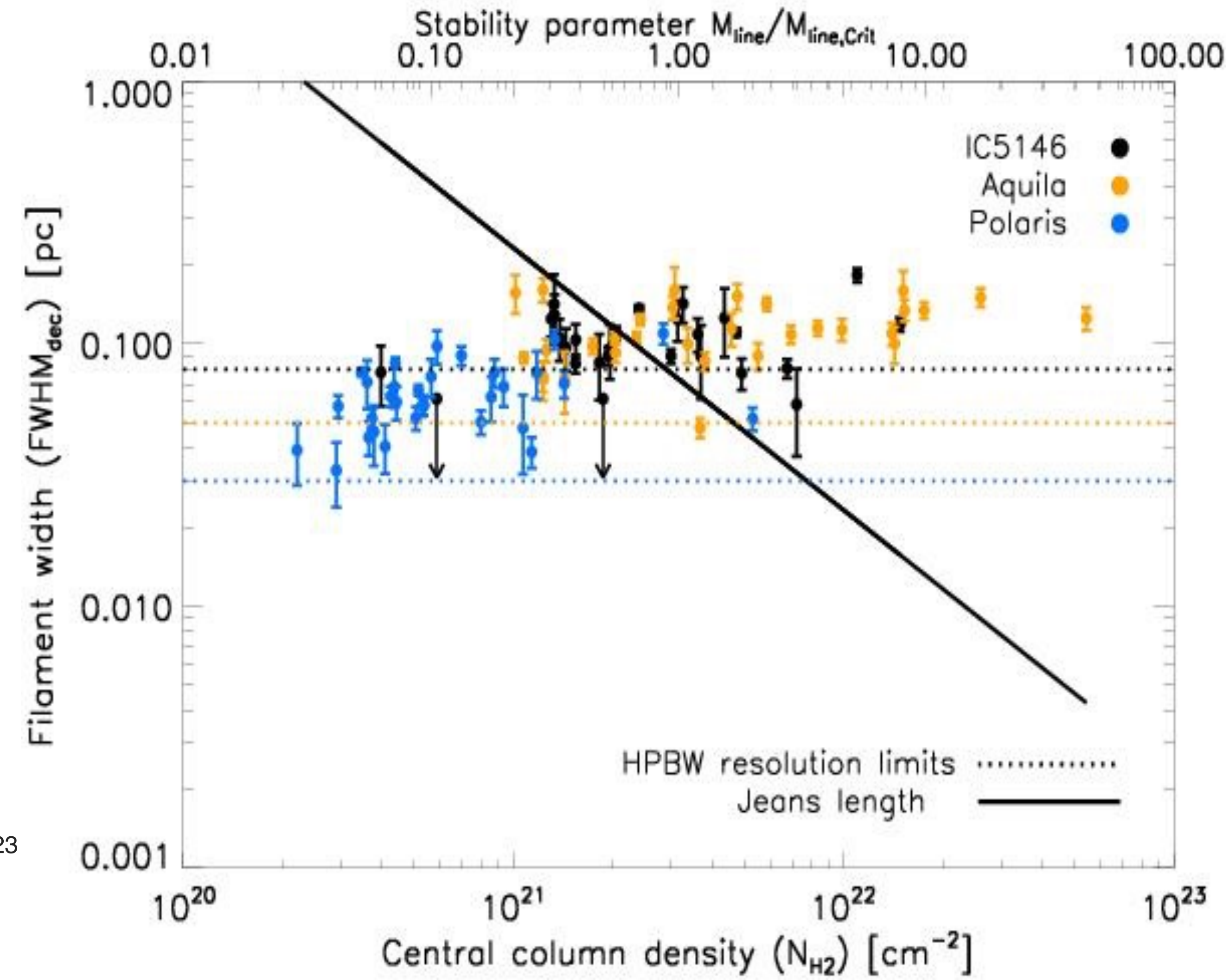
The column density will vary with different viewing angles.

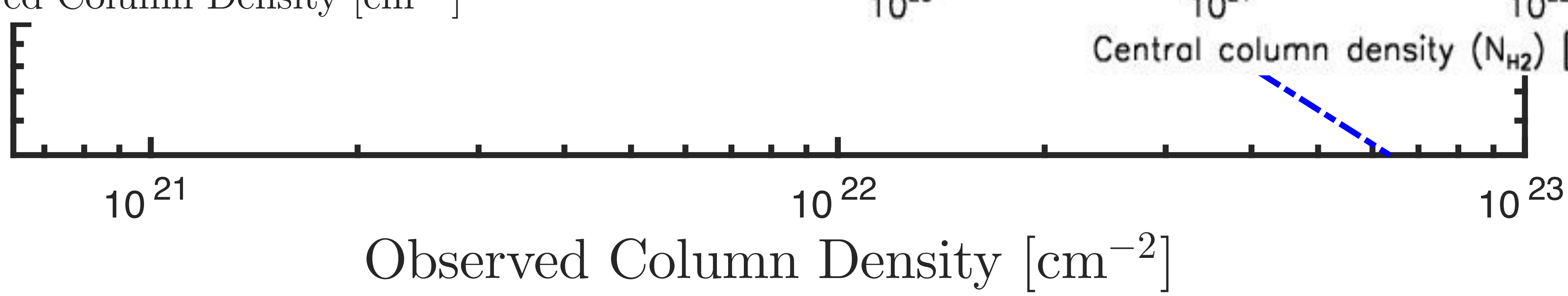
$$L_{obs} = L \cos \theta + 2H \sin \theta$$



Auddy et al 2016, ApJ







Auddy et al 2016, ApJ

Thanks

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