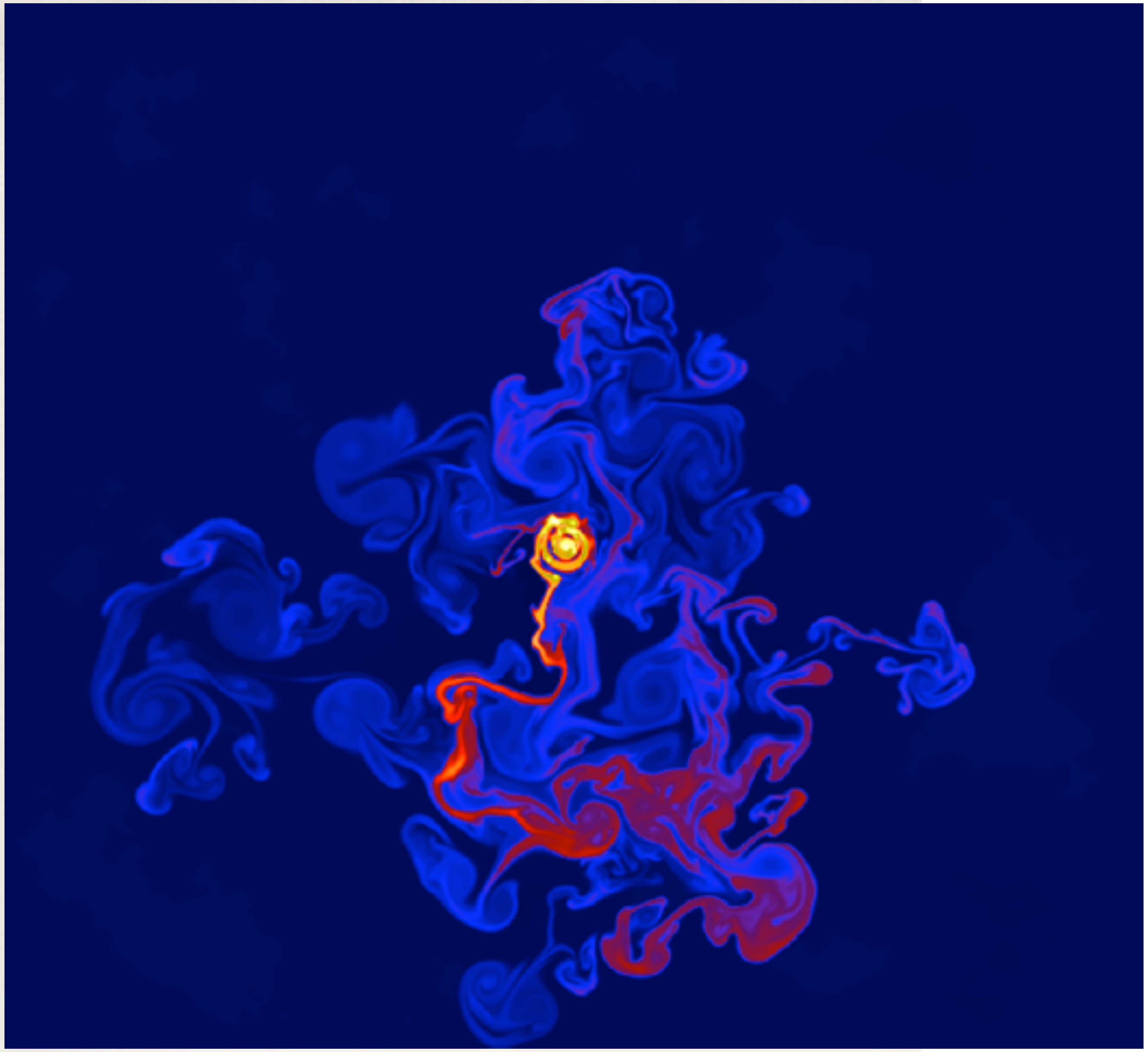

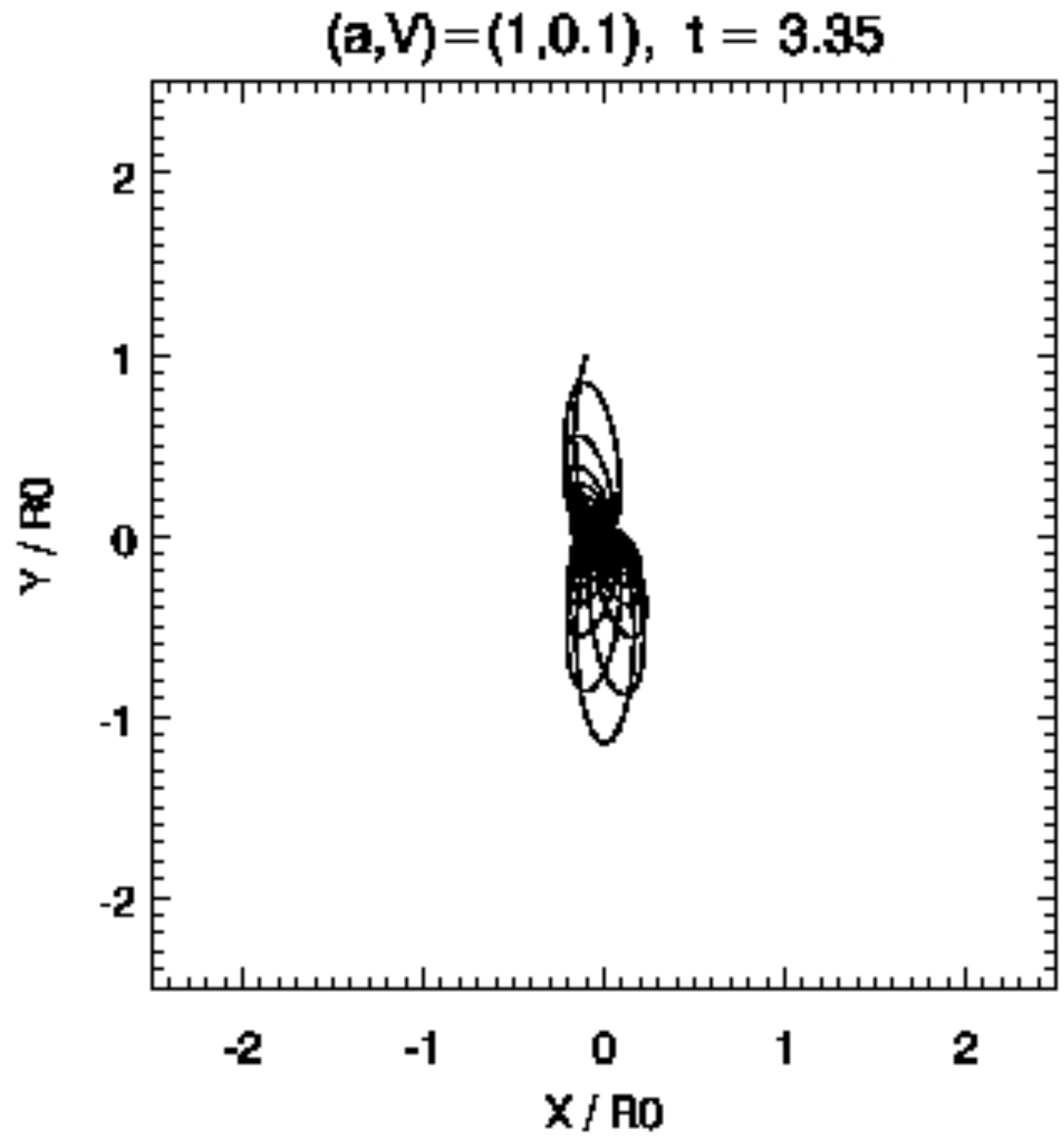

Dynamics of Clouds in the Broad Line Region

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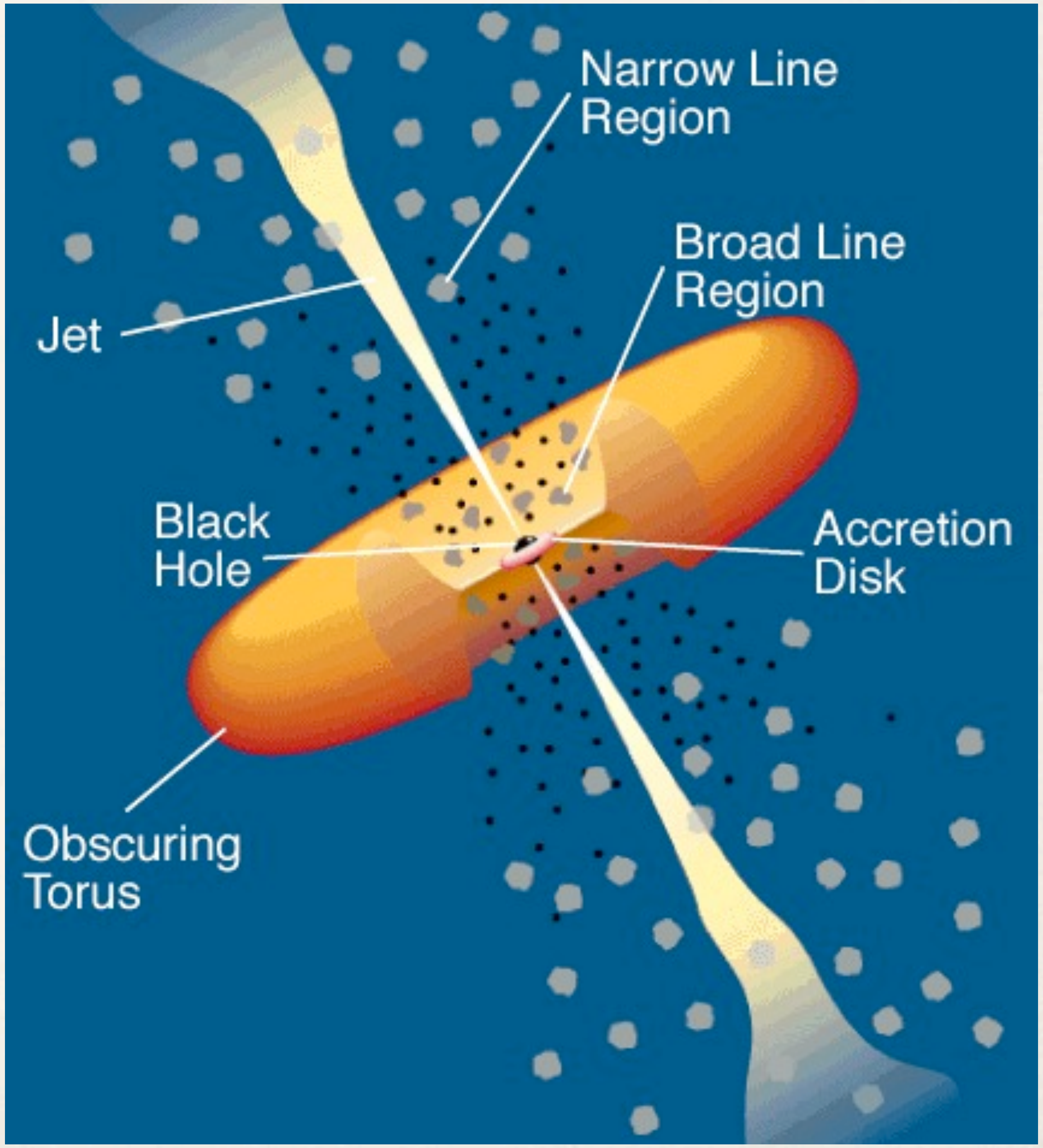
Milano, NLS1 Workshop, 4th April 2011

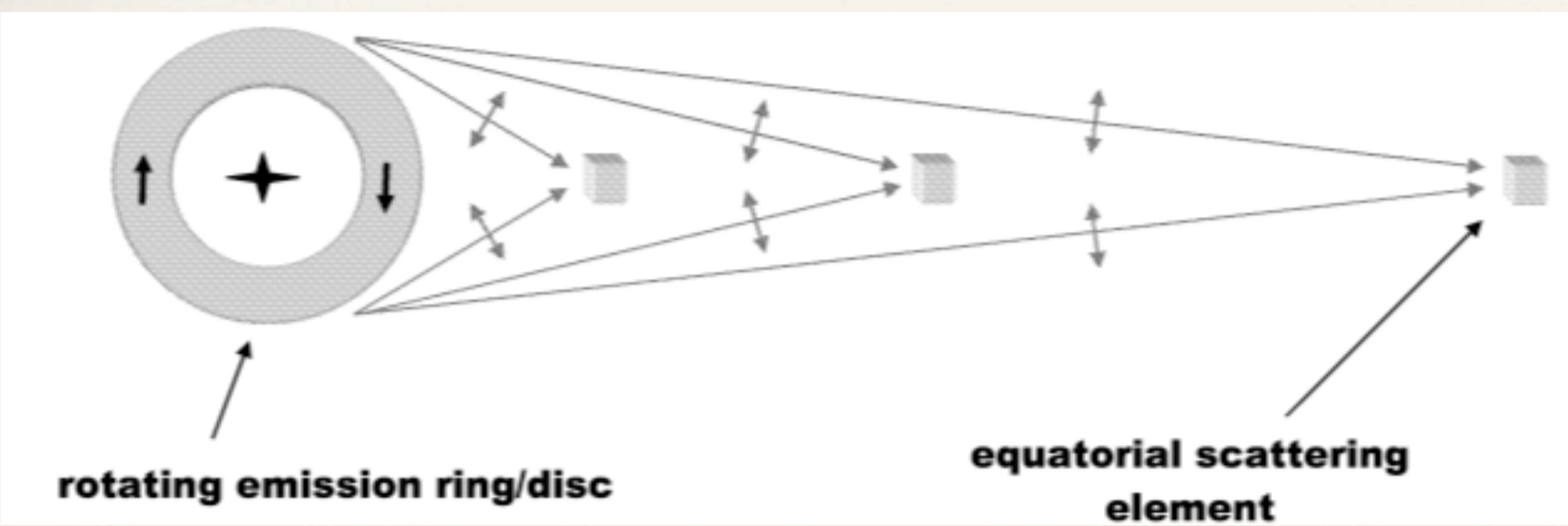
Overview

- Introduction: BLR=disk!, Clouds observed
- Featureless clouds: orbit stability
- Circular orbits: hydrodynamical stability



BLR: disk evidence

- line width statistics: $v/\sigma \approx 2\text{-}3$ (Osterbrock 1978)
- radio orientation (core/lobe, spectral index) ~ line width (Jarvis & Mc Lure 2006)
- spectropolarimetry: equatorial scatterer in type 1 objects resolves a Keplerian disk

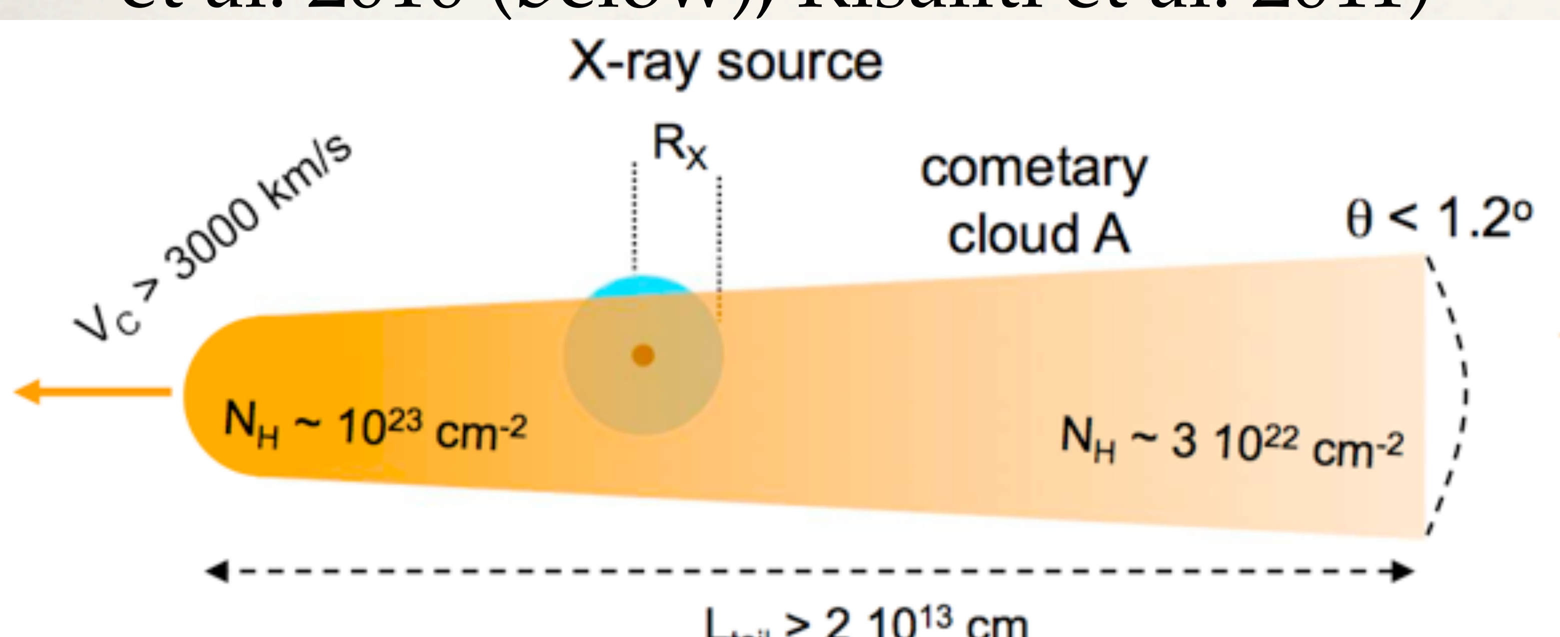


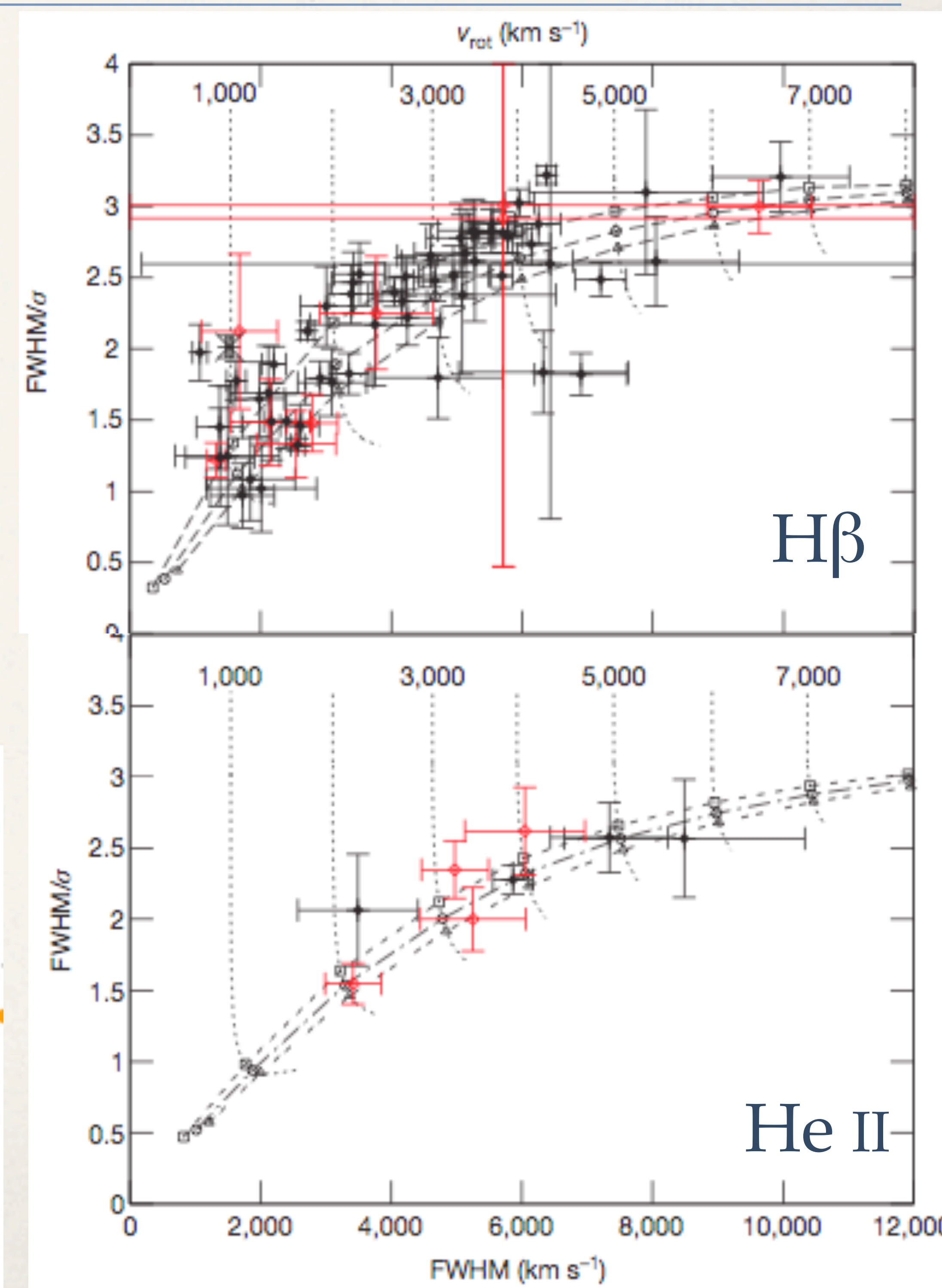
[Smith et al. 2005]

The BLR is a thick disk, mostly hot gas, with some very dense (10^{10} cm^{-3}) clouds.

BLR: disk & cloud evidence

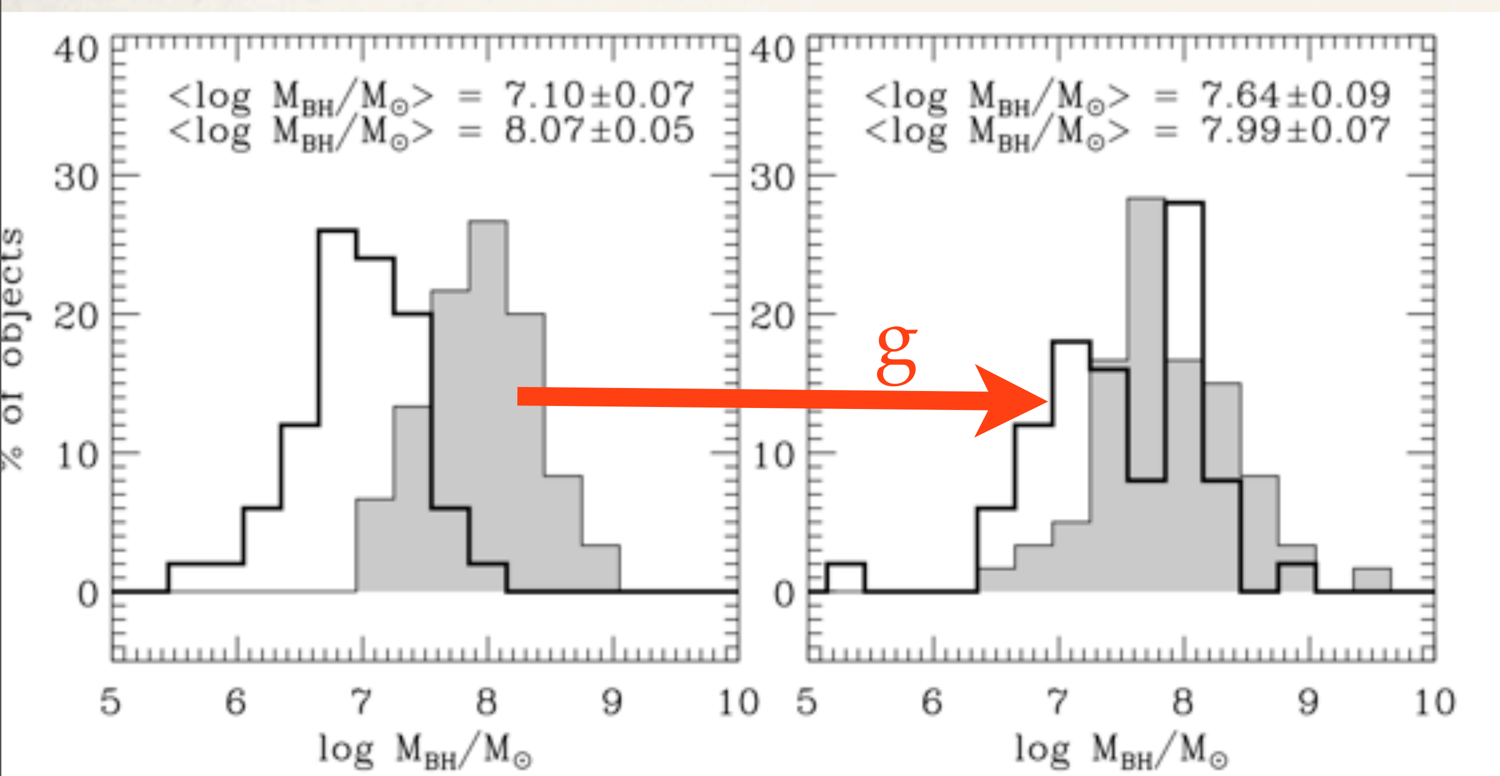
- Line shape ~ line width (Kollatschny & Zetzl 2011, right)
- ⇒ Rotation ∝ 1/turbulent velocity
- Hβ, He II, C IV: height ∝ 1/radius
- Cloud stability / shearing?
- X-ray obscuration: clouds (e.g. Maiolino et al. 2010 (below), Risaliti et al. 2011)





BLR dynamics: measure of black hole mass

Narrow line Seyfert 1:



$$M_{\rm BH} = f \frac{V^2 R}{G} + g\left(\frac{L_{5100}}{10^{44}\ \rm ergs^{-1}}\right) M_\odot$$

≈1 (f)

radiation pressure (g)

- NLS1: BH mass underestimated due to radiation pressure correction? (Marconi et al. 2008 (left), 2009)
- Requires reasonable cloud column density: N ≈ 1.1 x 10^{23} cm^{-2}

Orbit stability of clouds

Orbit stability analysis

Assumptions:

- opt. thick clds., force field:

$$F = \frac{GM_{\rm BH}m}{R^2}\left(\frac{3l}{2\sigma_{\rm T}N} + V^2 - 1\right)$$

- cloud reacts to pressure, $p \propto R^{-s}$
- perturbations:

$$N(R+\Delta R) = N(R)(1+\Delta R/R)^{-2s/3}$$

$$V(R+\Delta R) = V(R)(1+\Delta R/R)^{-1/2}$$

Results:

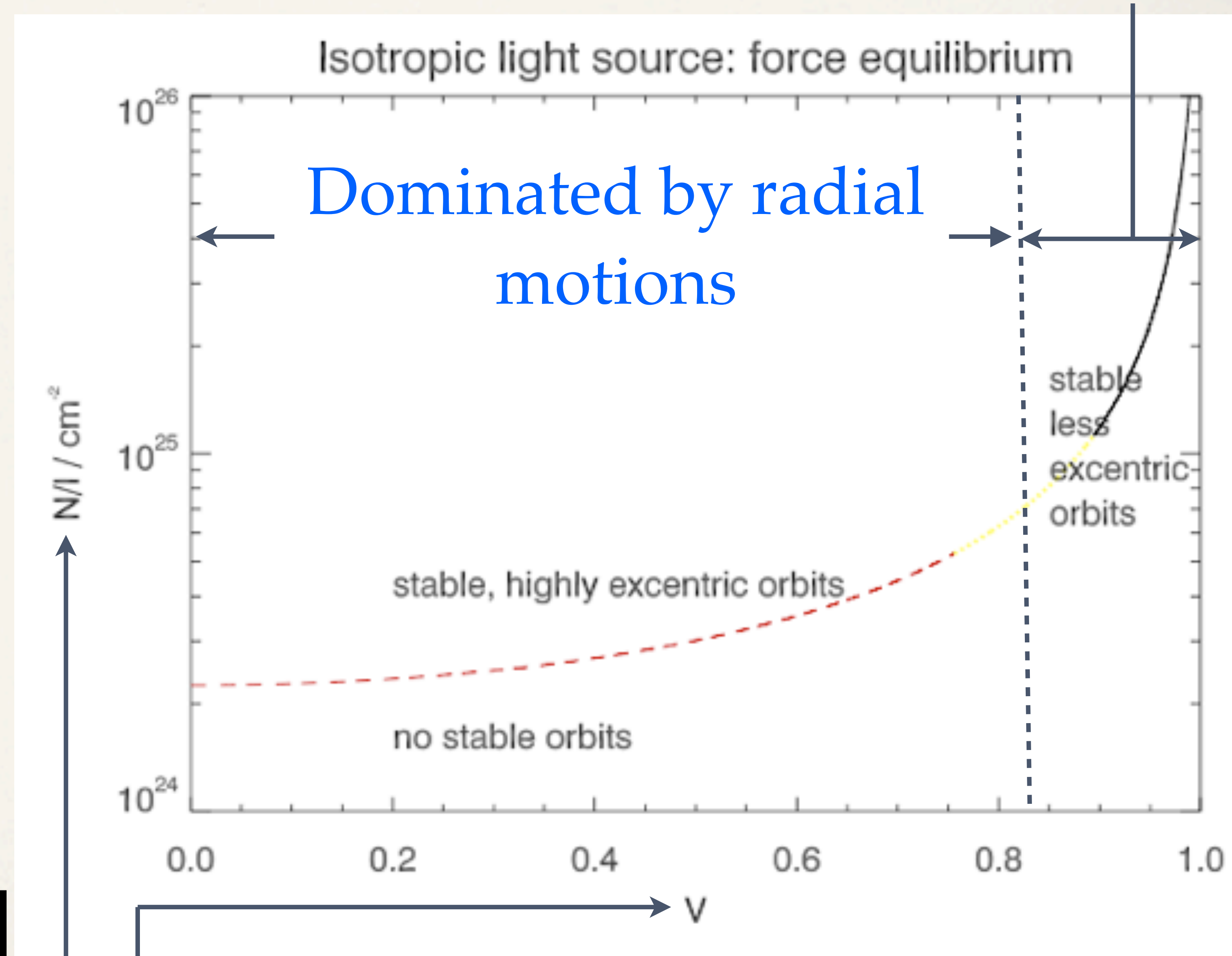
F=0, circ. orb.:

$$N = \frac{3l}{2\sigma_{\rm T}(1-V^2)}$$

Stability:

$$V^2 > V_c^2 = \frac{1}{1+\frac{3}{4s}}$$

Rotation dominated

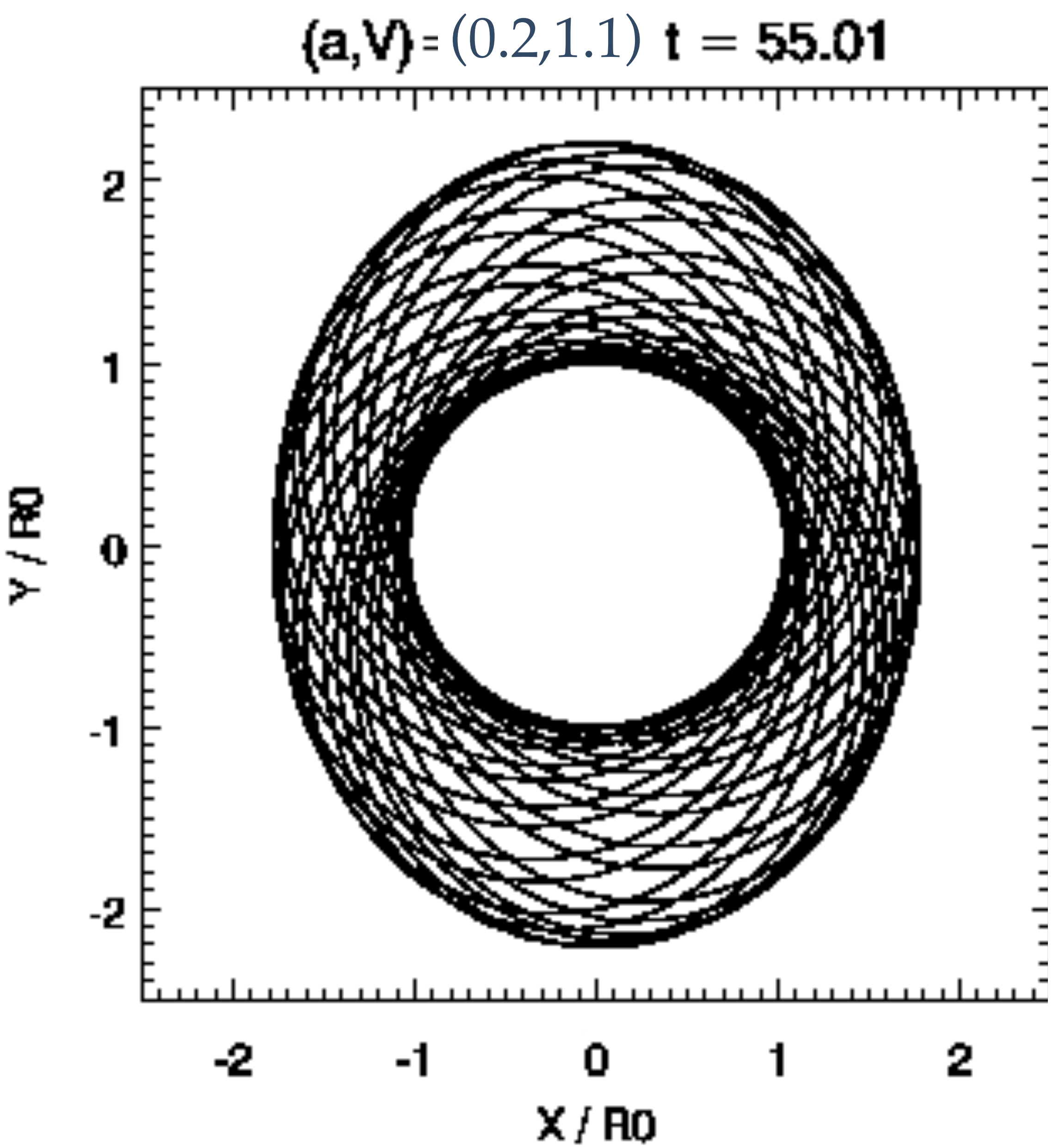


Velocity / Kepler velocity

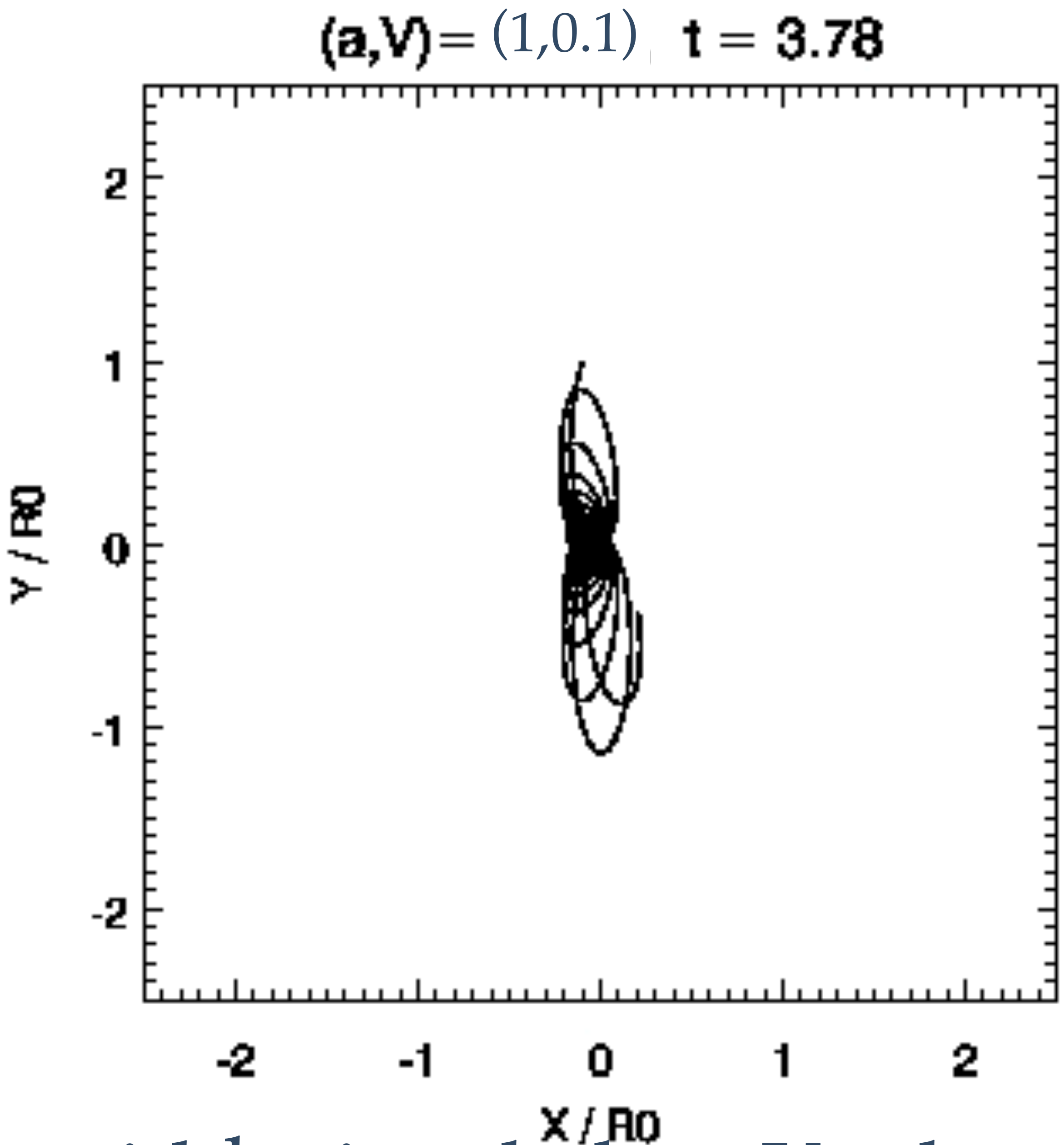
Column density / Eddington ratio

Example orbits (cos θ illumination)

High N, rot. support



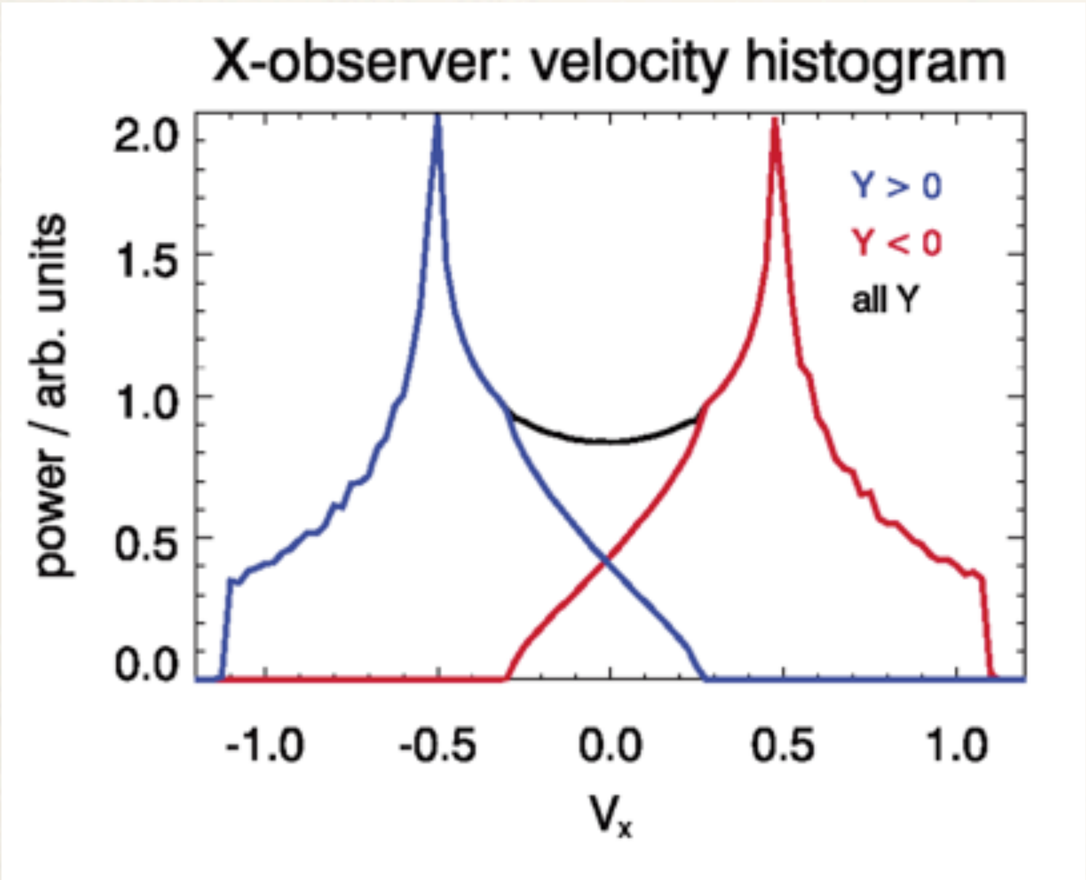
Low N, rad. support



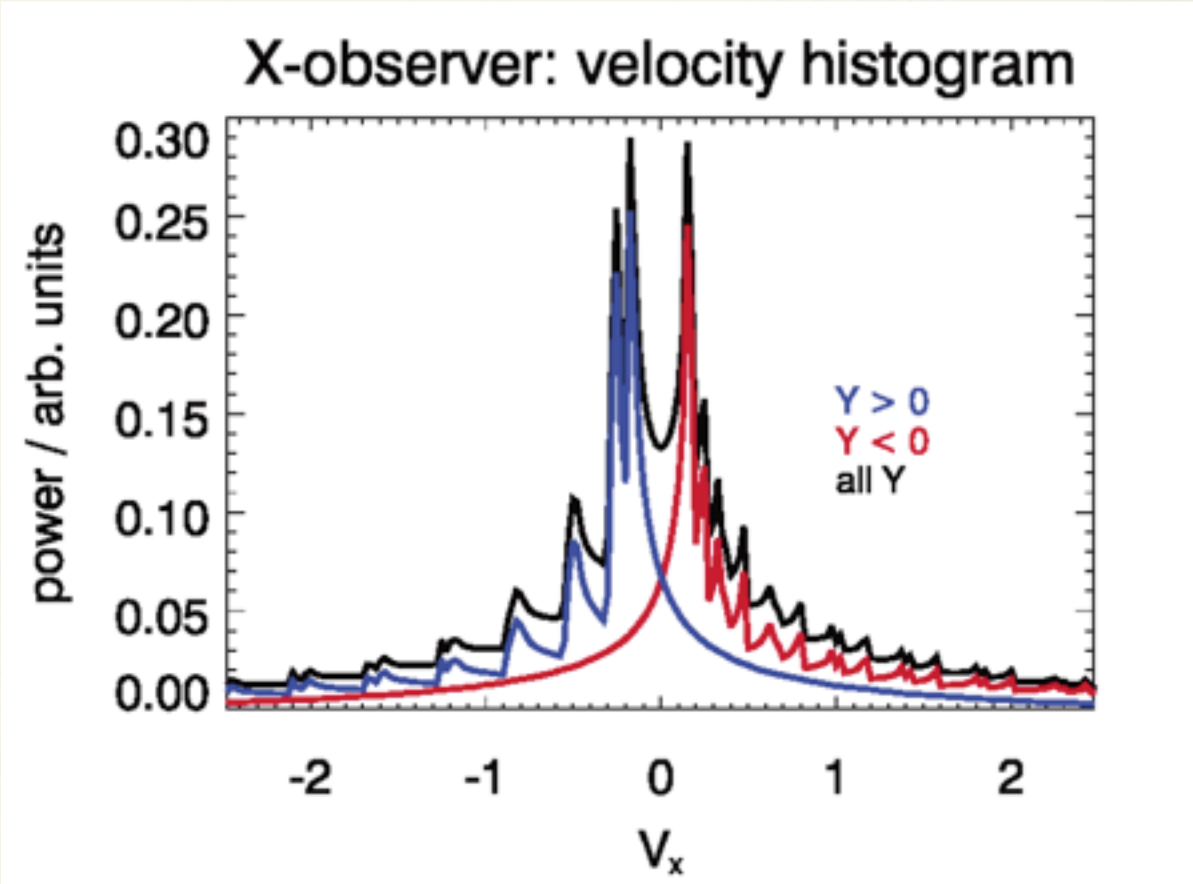
⇒ rad. support: would observe line width sign. below Kepler

Example orbits (cos θ illumination)

High N, rot. support



Low N, rad. support



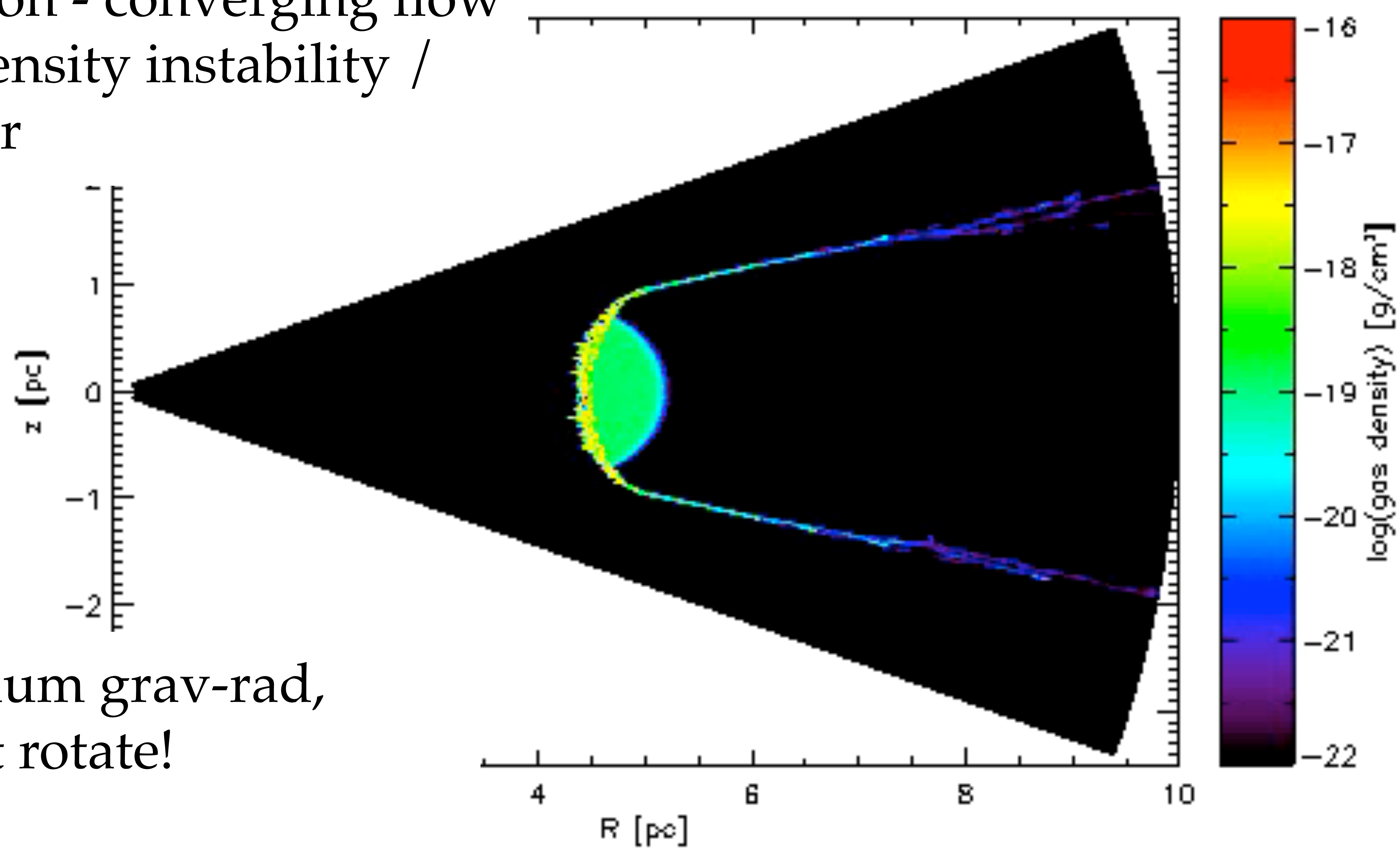
⇒ rad. support: would observe line width sign. below Kepler

Hydrodynamical stability

Pluto code
2.5D HD + 1D dust rad. transfer
no rotation (unstable position)

Hydrodynamic stability

- Compression - converging flow -column density instability / radial shear



- No equilibrium grav-rad, clouds must rotate!

- Radial shear elongates cloud

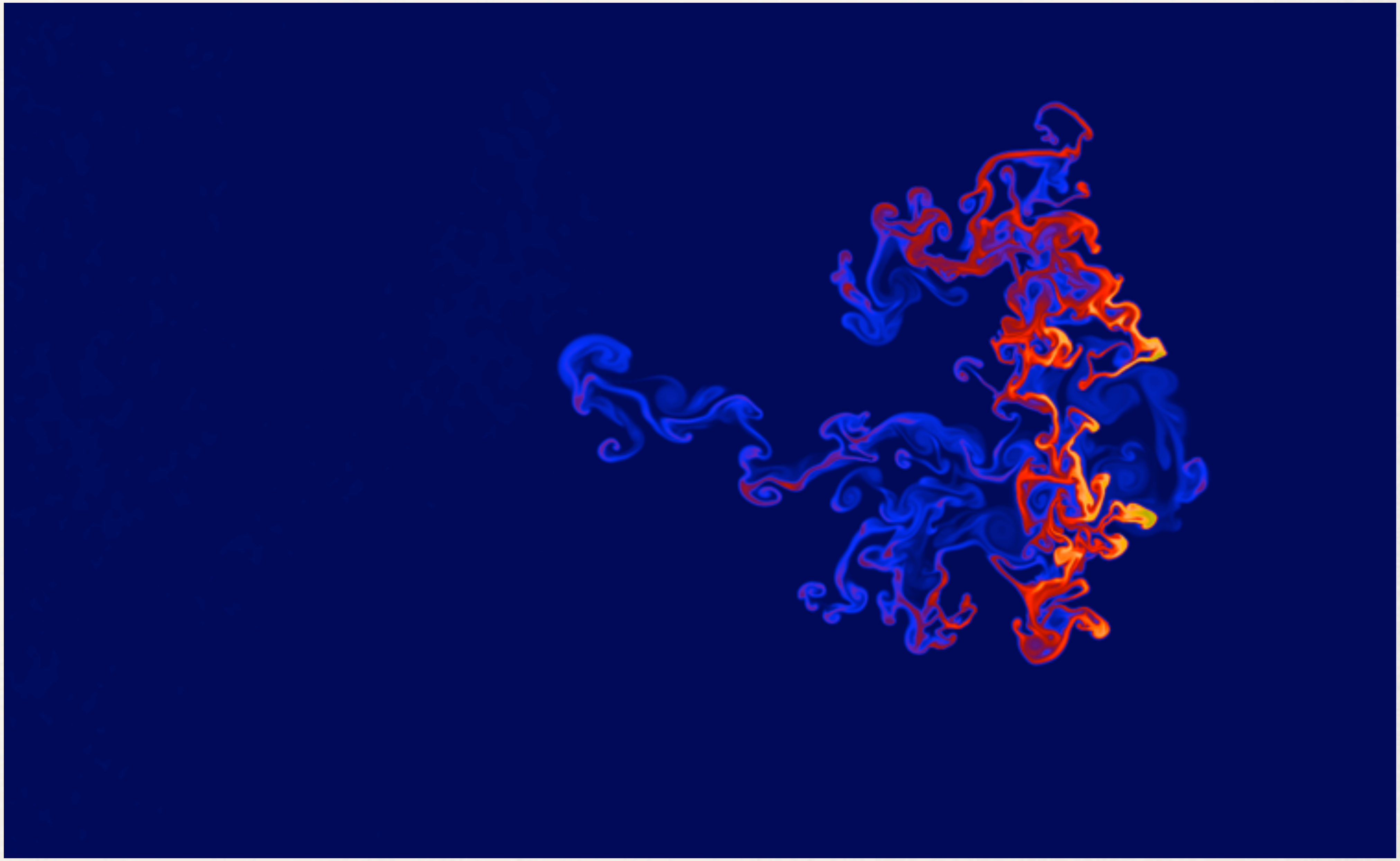
Schartmann, Krause & Burkert, MNRAS accepted

Magnetohydrodynamical stability

Nirvana code
2.5D MHD + 1D radiative transfer
hydrogen photoionisation + Thomson scattering
stable rotation
mag. press (cloud) = therm. press (halo) = rad. press.
$\Rightarrow B \approx 30$ G

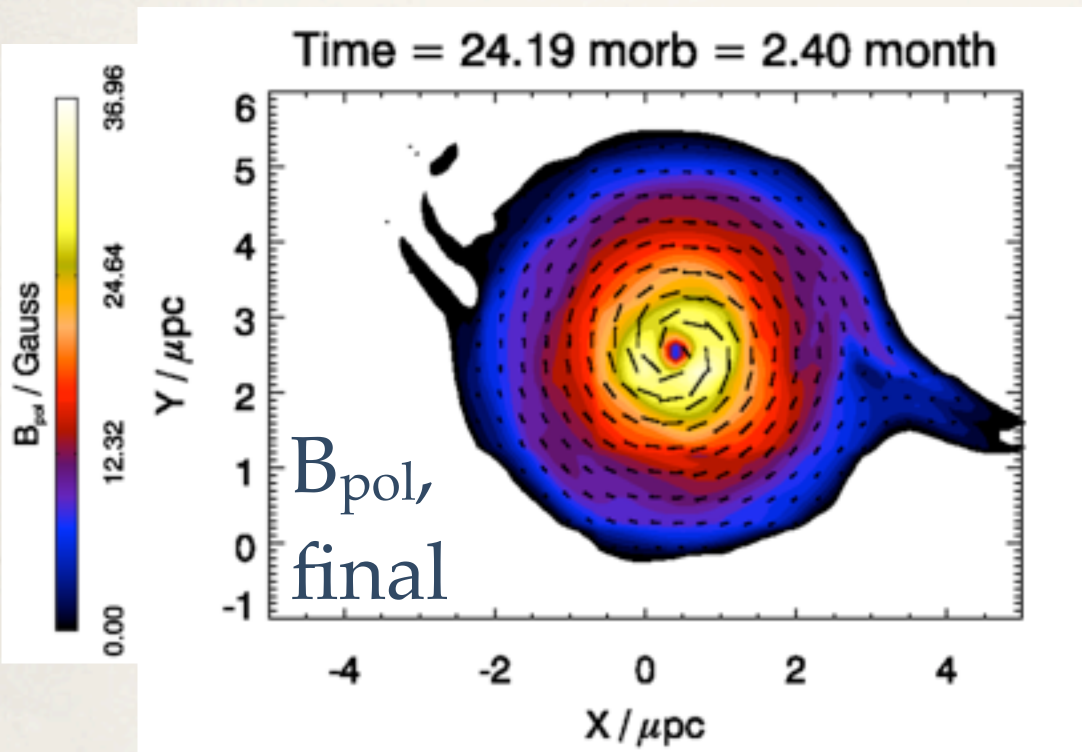
Azimuthal (perpend.) mag. field

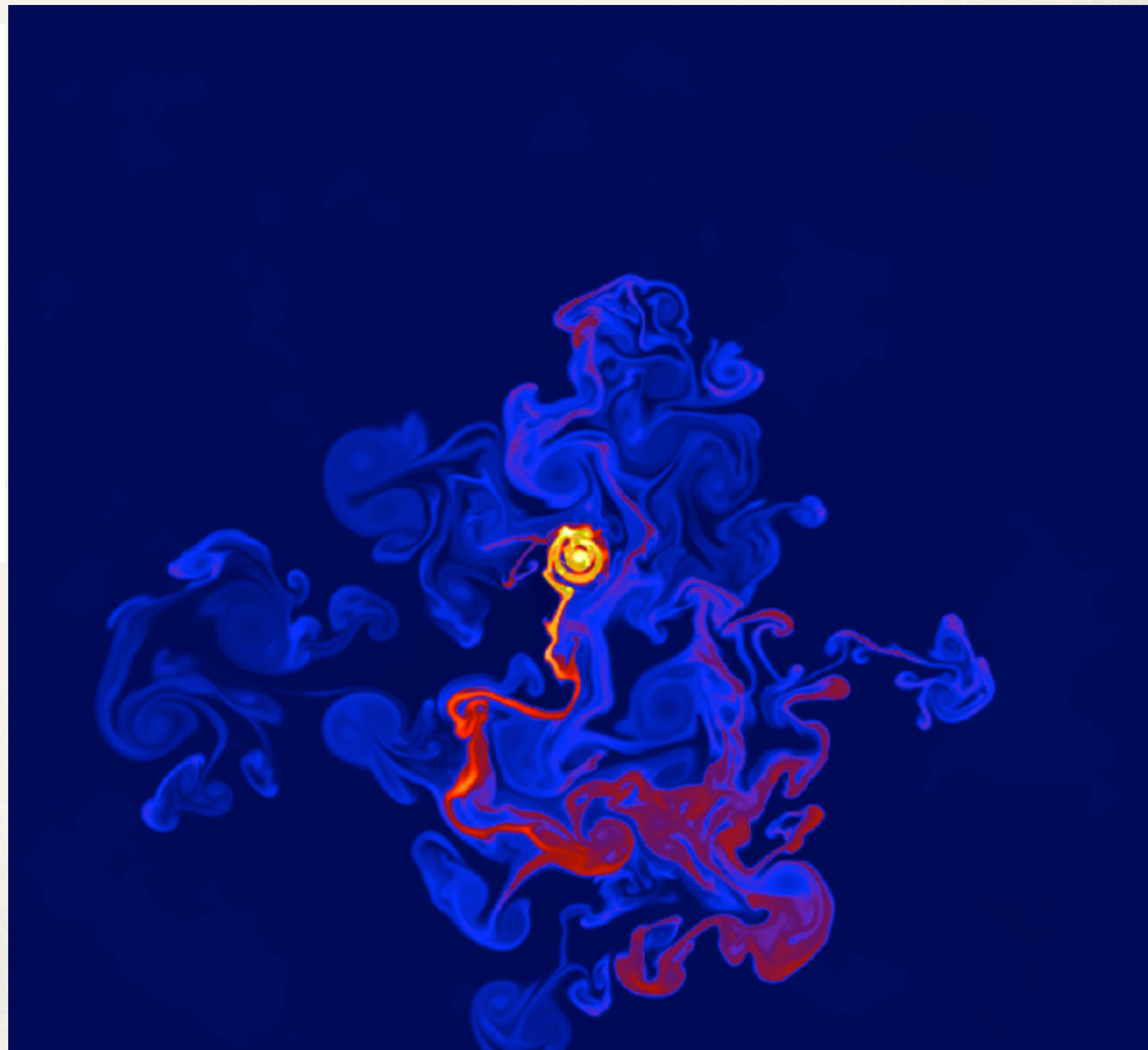
- Compression
- mag. pressure
- vertical expansion
- instabilities
- mixing (loss rot. support, months)
- infall



- turbulent filaments, ≈ 10-30% Alfven speed, azimuthally lag behind

Helical magnetic field





- Magnetic tension resists radiation pressure
- stable cloud core survives
- cloud core remains at equilibrium position

Conclusions

- Orbit analysis:
  - if clouds react to pressure:
  - no stable circular orbit for sign. radiatively sup. clouds: strong radial motions
  - em. dom. by slow outer part of orbit: may observe low velocities ⇒ NLS1 may be radiatively supported (Marconi et al 2008)
  - Rotation ∝ 1/turbulent velocity (Kollatschny & Zetzl)?
- Internal dynamics depends on magnetic field:
  - no: radial shear
  - azimuthal: cloud disperses and mixes
  - helical: stable cloud core
  - turbulent filaments: 10-30% Alfven speed
  - observed turb, 1000 km/s ⇒ B≈> 100G
  - Dispersing tail easily produced (Maiolino et al.)

Possible picture

- NLS1 have high Eddington ratio
- radiatively supported clouds on elliptical orbits
- Individual clouds stabilised by curved magnetic fields, reacting to pressure
- slowly dispersing with internal turbulence of small fraction of Alfven speed