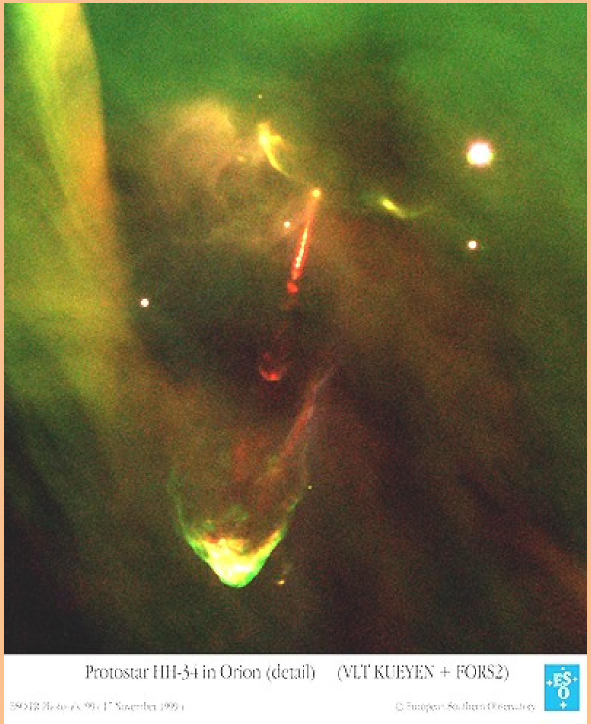
Exploring the feedback of asymmetric jets on the orbital motions



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(Universiy of Rome 2 ‘Tor Vergata’)

Projects DEXTEROUS & JEDI

Outline

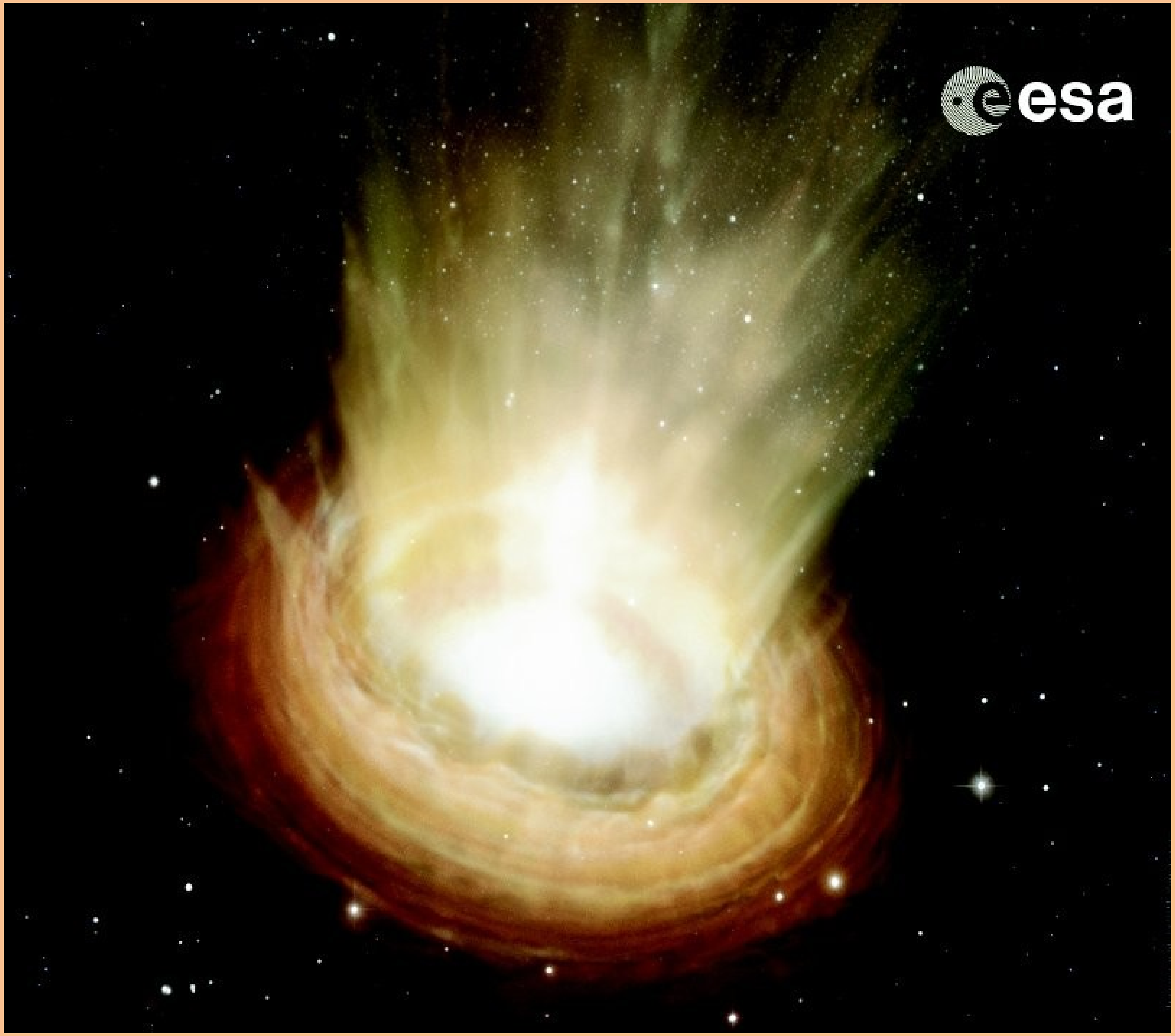
1. About asymmetric jets

2. Jet feedback :
Influence on the orbital motions

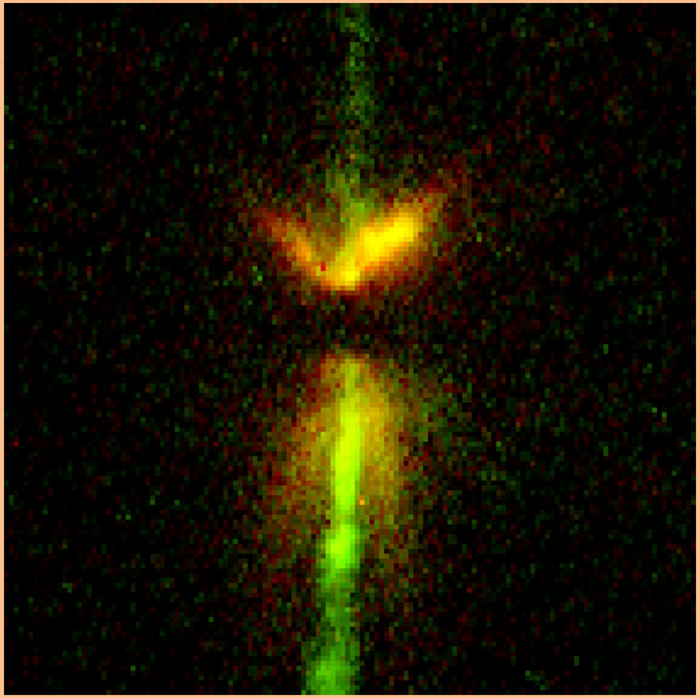
3. Exploring the parameter space

4. Applications and prospects

FACT : stellar jets ARE asymmetric

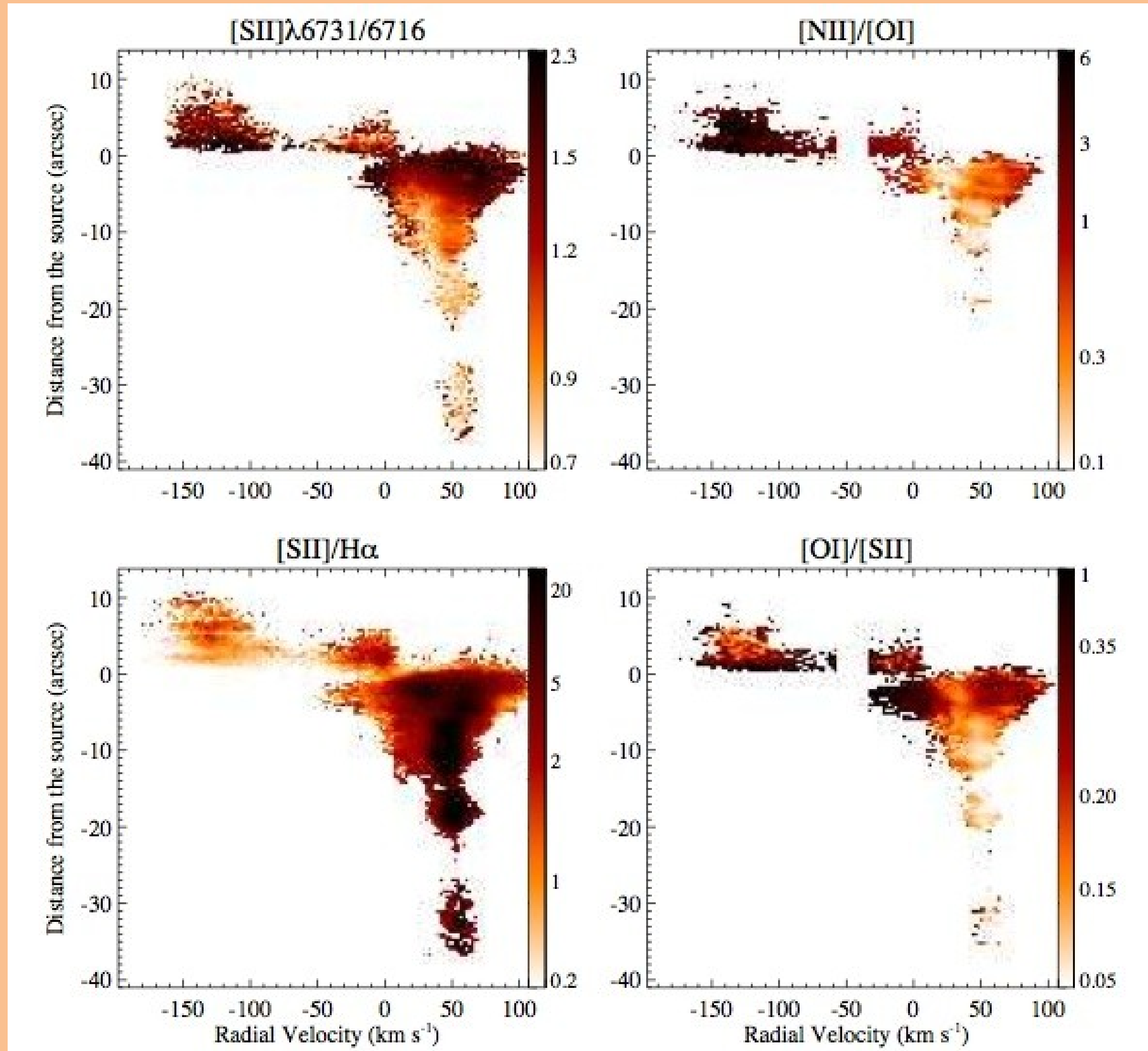


example 1 : the DG Tau B jet



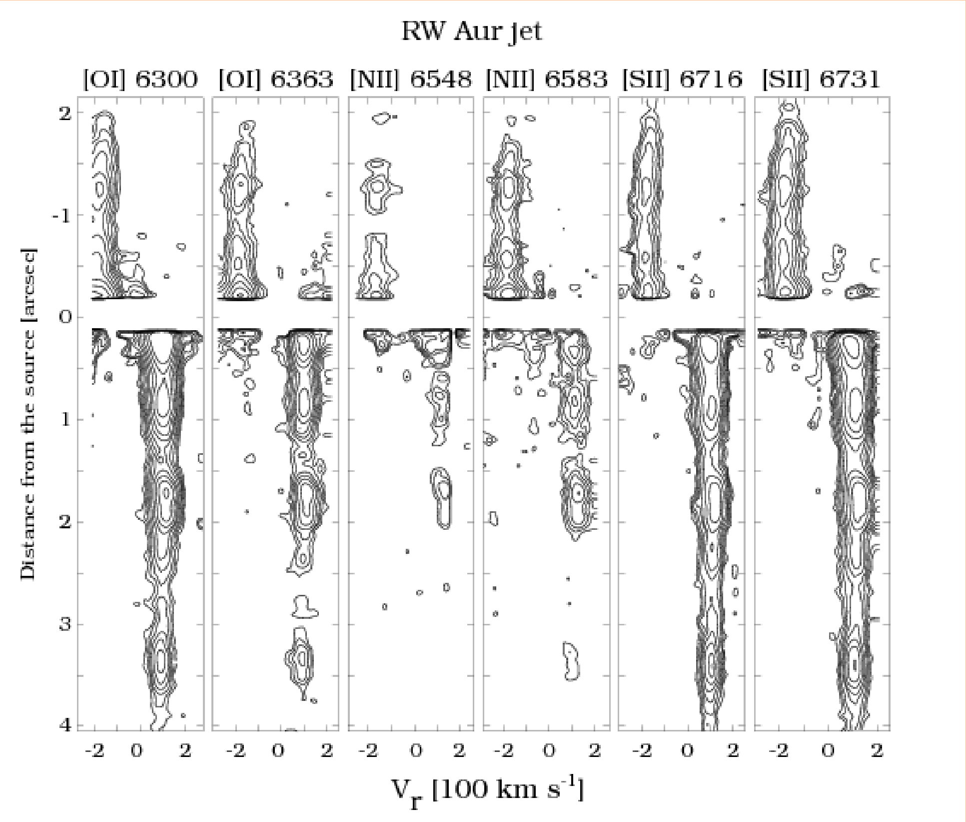
Burrows, NASA 1990

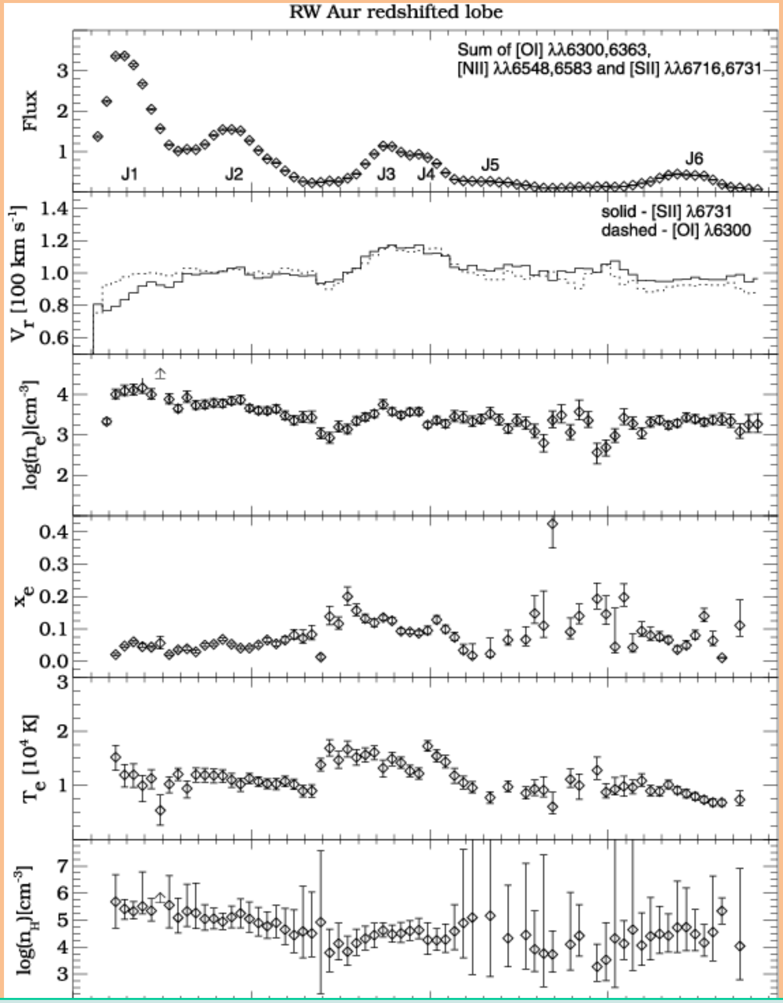
Asymmetry in brightness
AND
In physical conditions



Podio+ 2011

example 2 : the RW Aur jet





Melnikov+ 2009

ASYMMETRY IN BRIGHTNESS,
VELOCITY, DENSITY, IONISATION

Melnikov+ 2009

The ultimate outcomes of spectral diagnostics are :
- Mass outflow rates
- Momentum rates

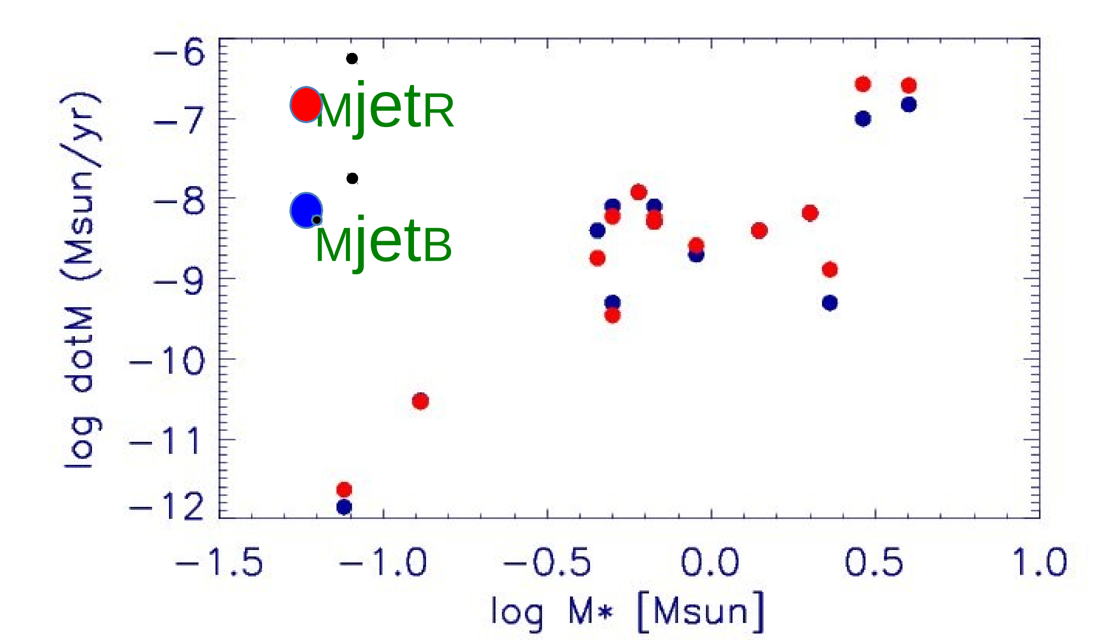
Observed properties of asymmetric jets

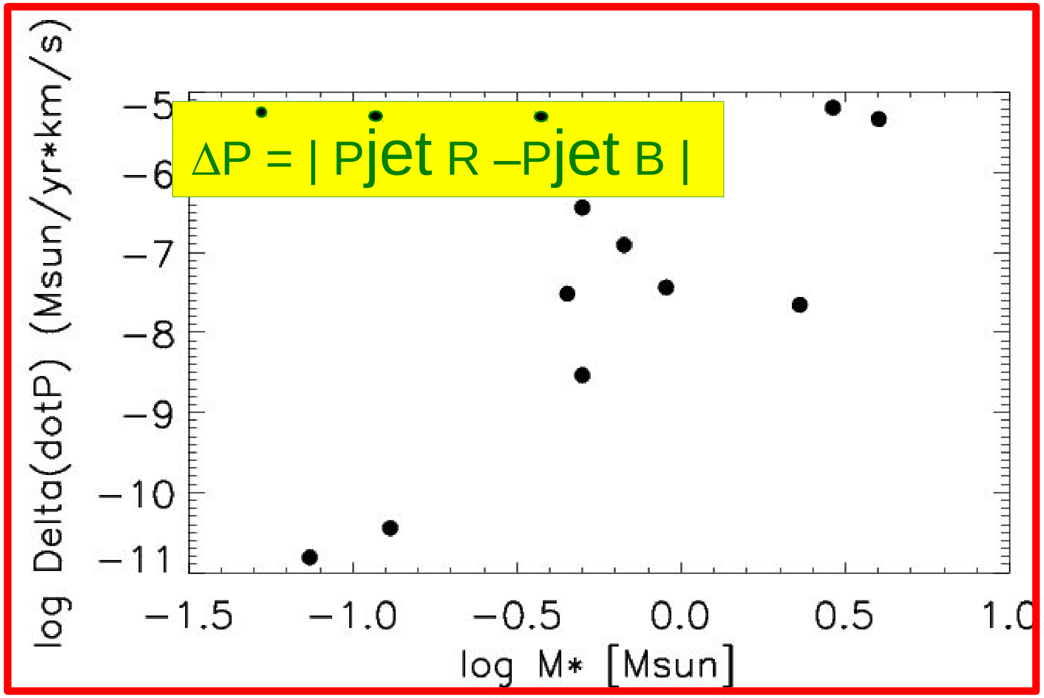
Similar B – R mass outflow rate

considering

velocity ratio B / R = 1.2 - 2.5

$$\dot{\boldsymbol{p}} = \dot{m}_{jet}\,\boldsymbol{v}$$





Jet asymmetry:

- same mass loss rate $\dot{M}_{jet} \sim n_H * V_{jet}$

- different momentum $\dot{P}_{jet} \sim \dot{M}_{jet} * V_{jet}$

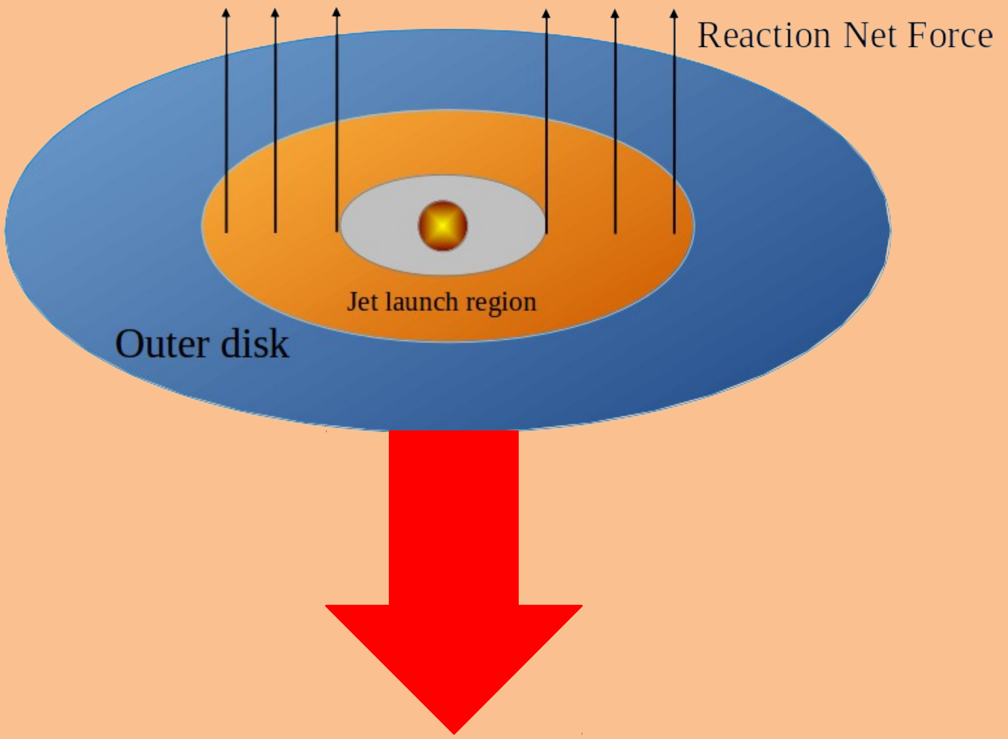
2. a possible jet feedback

Here it comes the FEEDBACK !!

How does the Δp force affect the system ?

By a NET REACTION FORCE

Question 1:
Global acceleration ?
just a fraction of km/s
after 1Myr
(typically measured:
v_sys ~ 10-30 km/s)

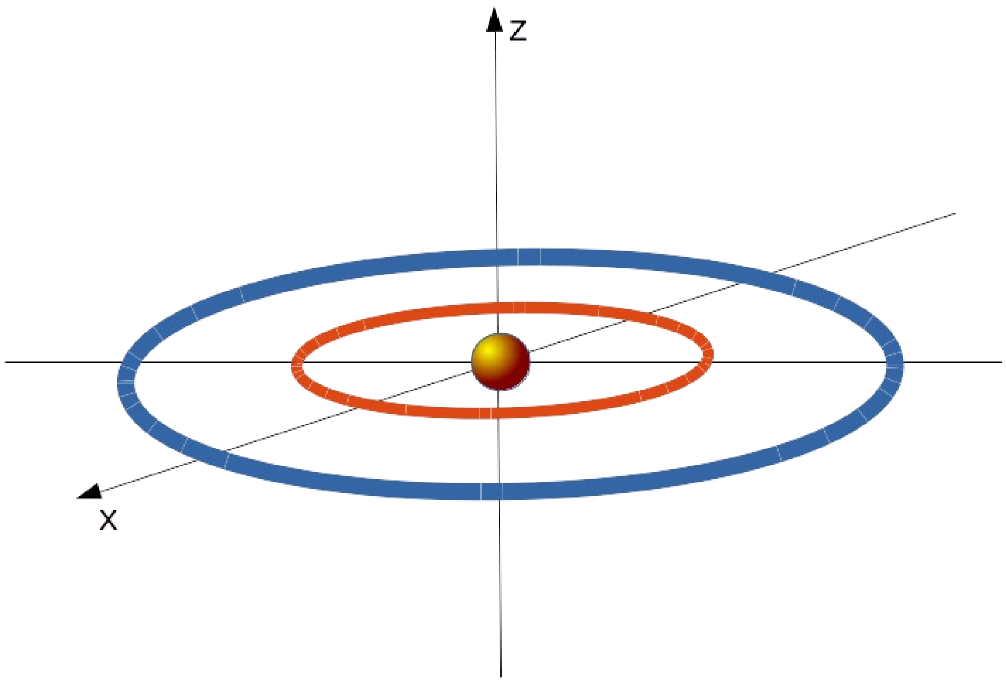


Question 2:
How are the motions
in the disk modified ?

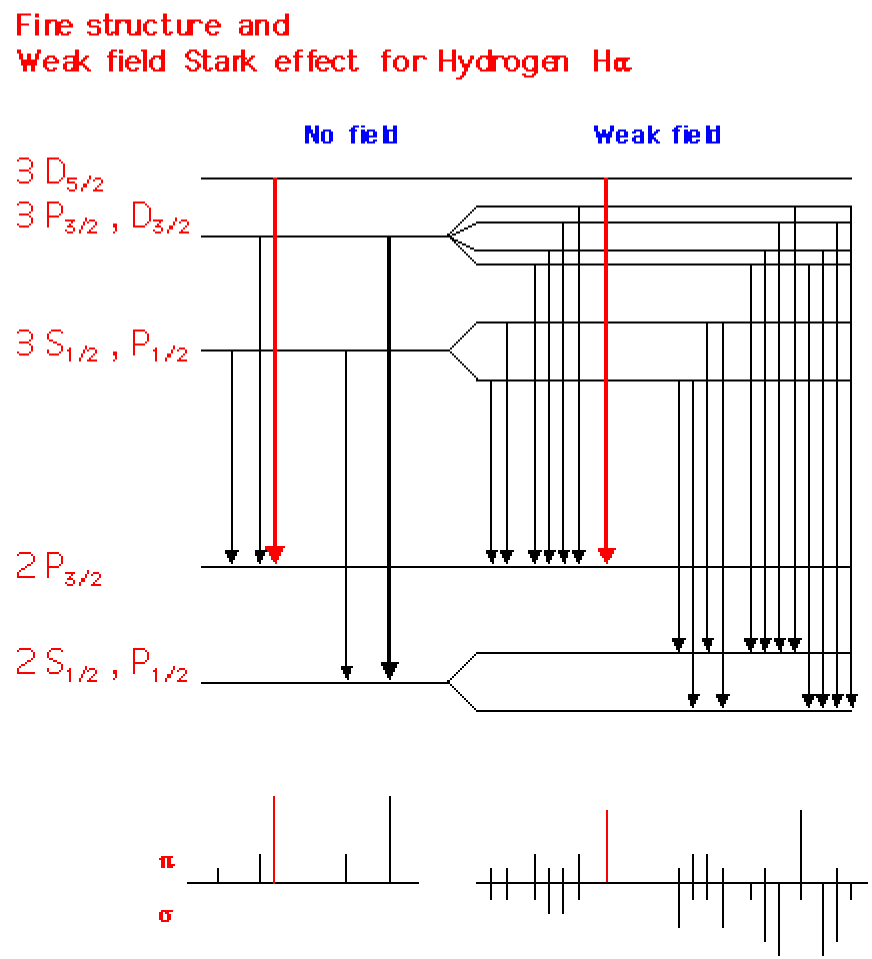
Method of investigation

apply CELESTIAL MECHANICS:

Consider the disk composed by annuli .
study their dynamics subject to gravity, rotation and an external force perpendicular to the disk plane



Same Concept of Stark effect



Hamiltonian: Energy of the System

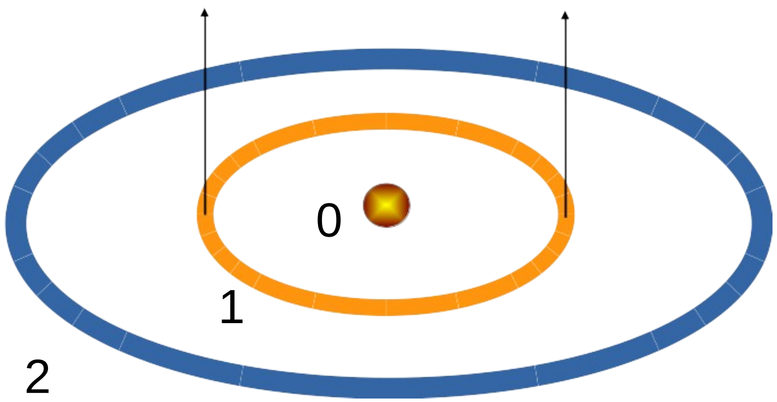
$$H(\tilde{\mathbf{u}}, \mathbf{u}) = T(\tilde{\mathbf{u}}) + U(\mathbf{u}),$$

$$T(\tilde{\mathbf{u}}) = \frac{1}{2}\frac{\tilde{\mathbf{u}}_0 \cdot \tilde{\mathbf{u}}_0}{m_0} + \frac{1}{2}\frac{\tilde{\mathbf{u}}_1 \cdot \tilde{\mathbf{u}}_1}{m_1} + \frac{1}{2}\frac{\tilde{\mathbf{u}}_2 \cdot \tilde{\mathbf{u}}_2}{m_2} \ ,$$

$$U(\mathbf{u}) = U_{01}(\mathbf{u}) + U_{02}(\mathbf{u}) + V_0(\mathbf{u}) + V_1(\mathbf{u}) + U_{12}(\mathbf{u}),$$

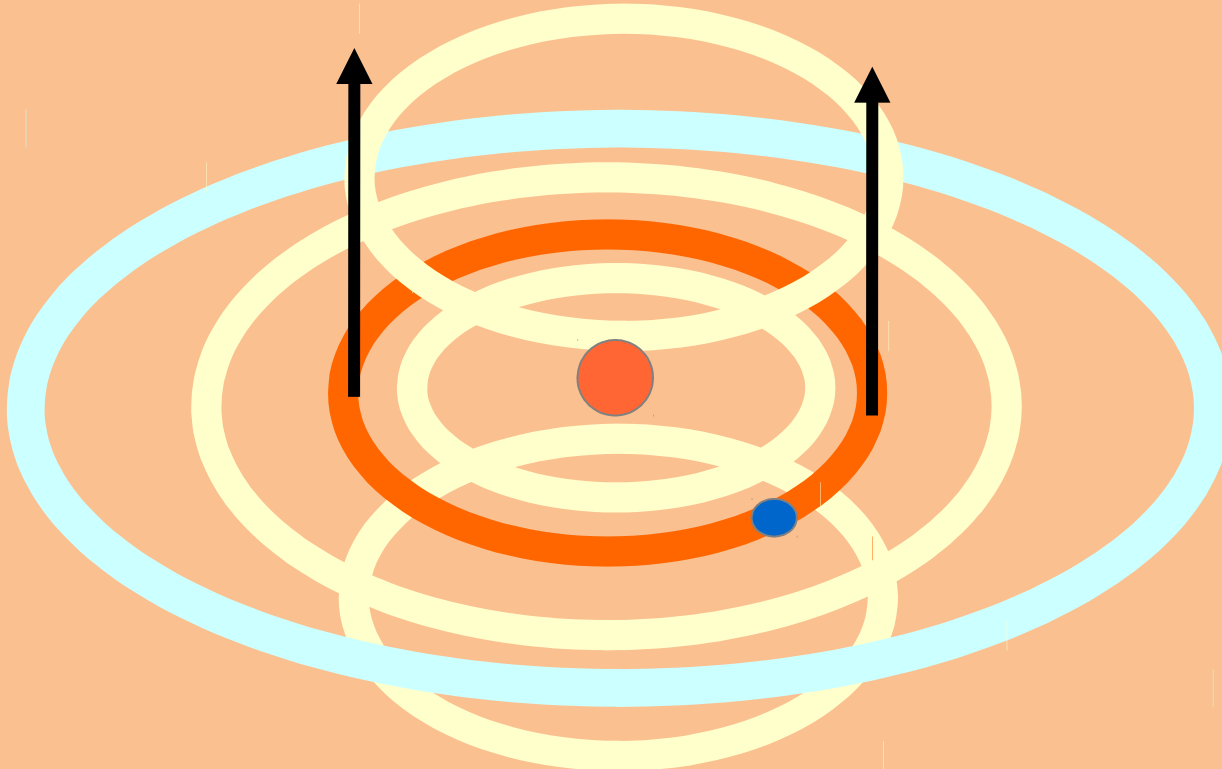
$$U_{01}(\mathbf{u}) = -\frac{G m_0 m_1}{\sqrt{R_1^2 + (u_{13} - u_{03})^2}} \ , \quad V_0(\mathbf{u}) = -m_0 a_0 u_{03} \ ,$$

$$U_{02}(\mathbf{u}) = -\frac{G m_0 m_2}{\sqrt{R_2^2 + (u_{23} - u_{03})^2}} \ , \quad V_1(\mathbf{u}) = -m_1 a_1 u_{13} \ .$$



"... model **with gravitationally interacting rings**."

$$U_{12}(\mathbf{u}) = -G m_1 m_2 \int_0^{2\pi} \frac{\mathrm{d}\psi}{\sqrt{R_1^2 + 2R_1 R_2 \cos\psi + R_2^2}},$$

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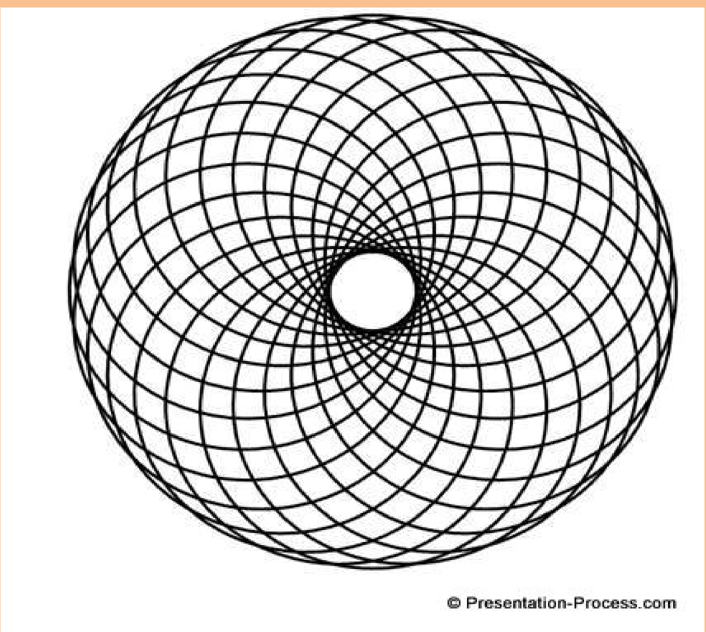
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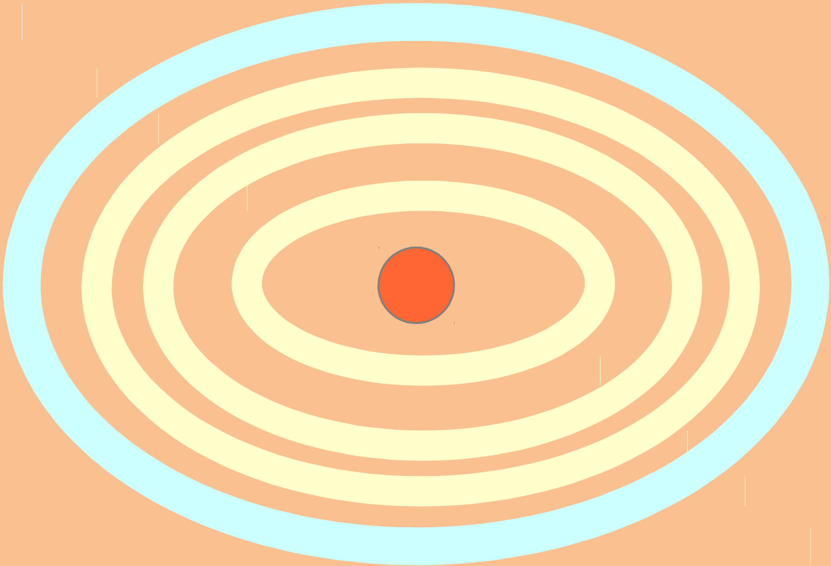
Same model with more rings

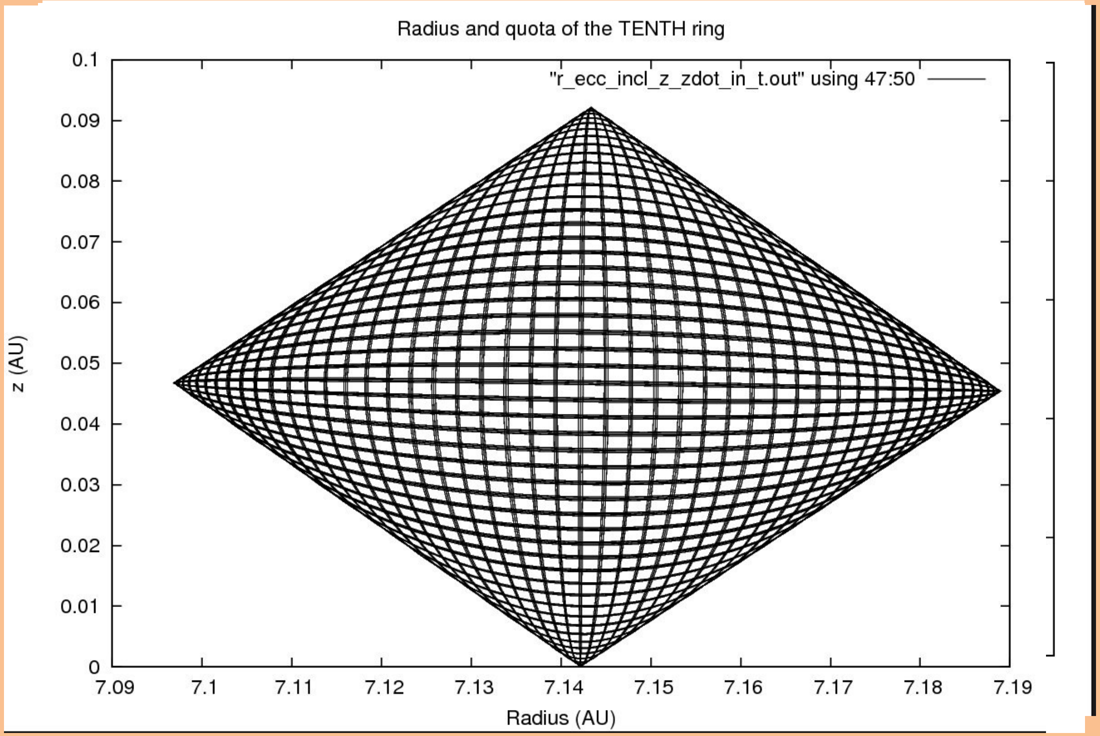
Since all the particles in a ring move the same way the rings remain rings But :

Pulsation of the rings in r and z

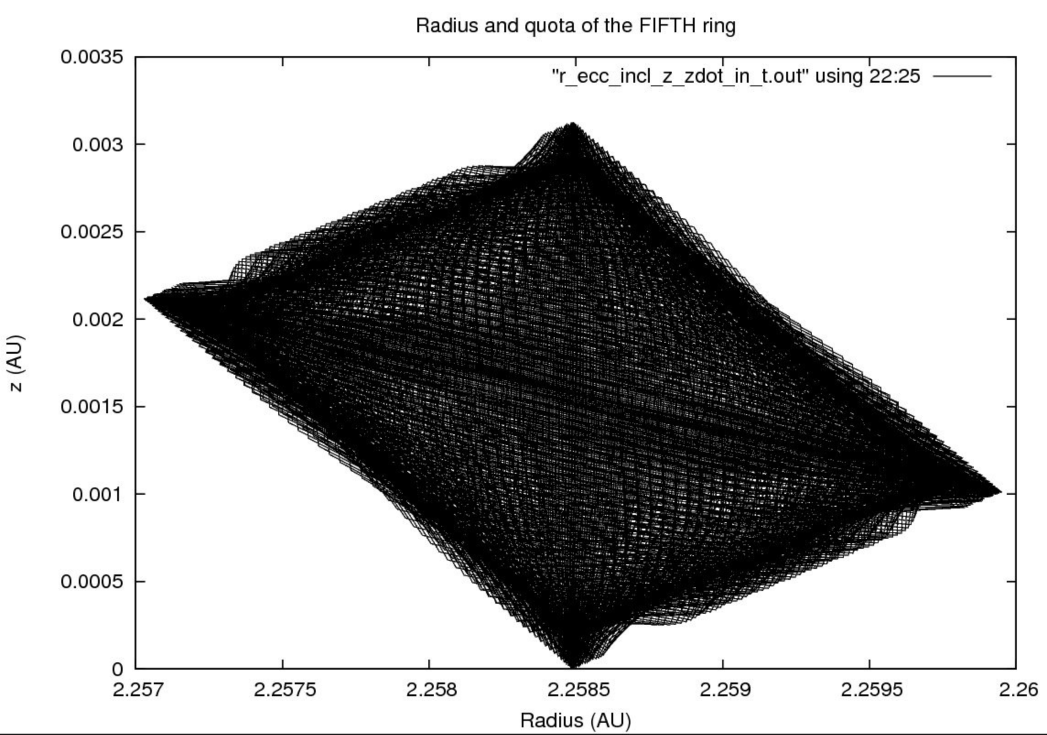
Each with its own frequency.

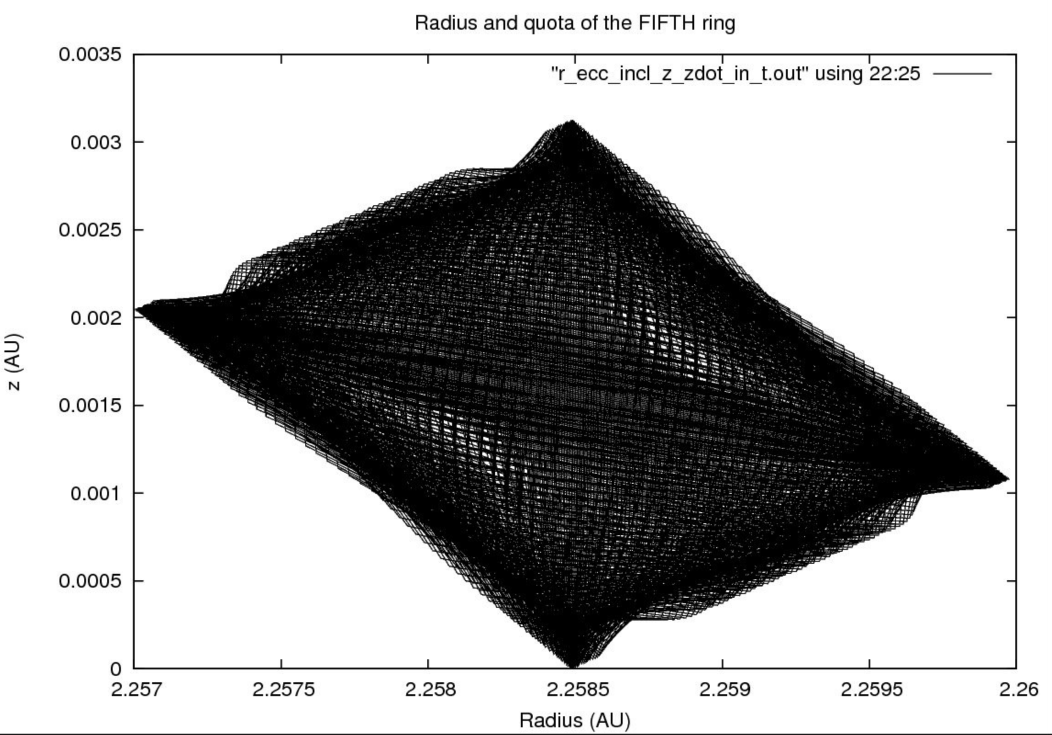
But with which motion ?   And on which scales ?





Ring-Ring Gravitational interaction





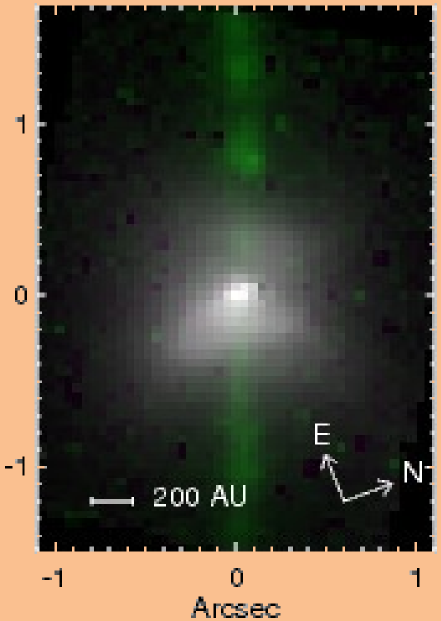
with **without**

SPOT THE DIFFERENCE :

Ring mutual Gravitational force negligible

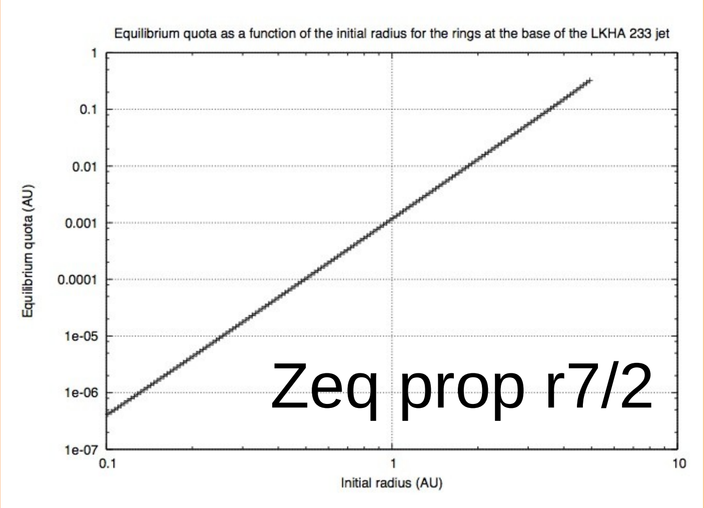
3. exploring the parameter space

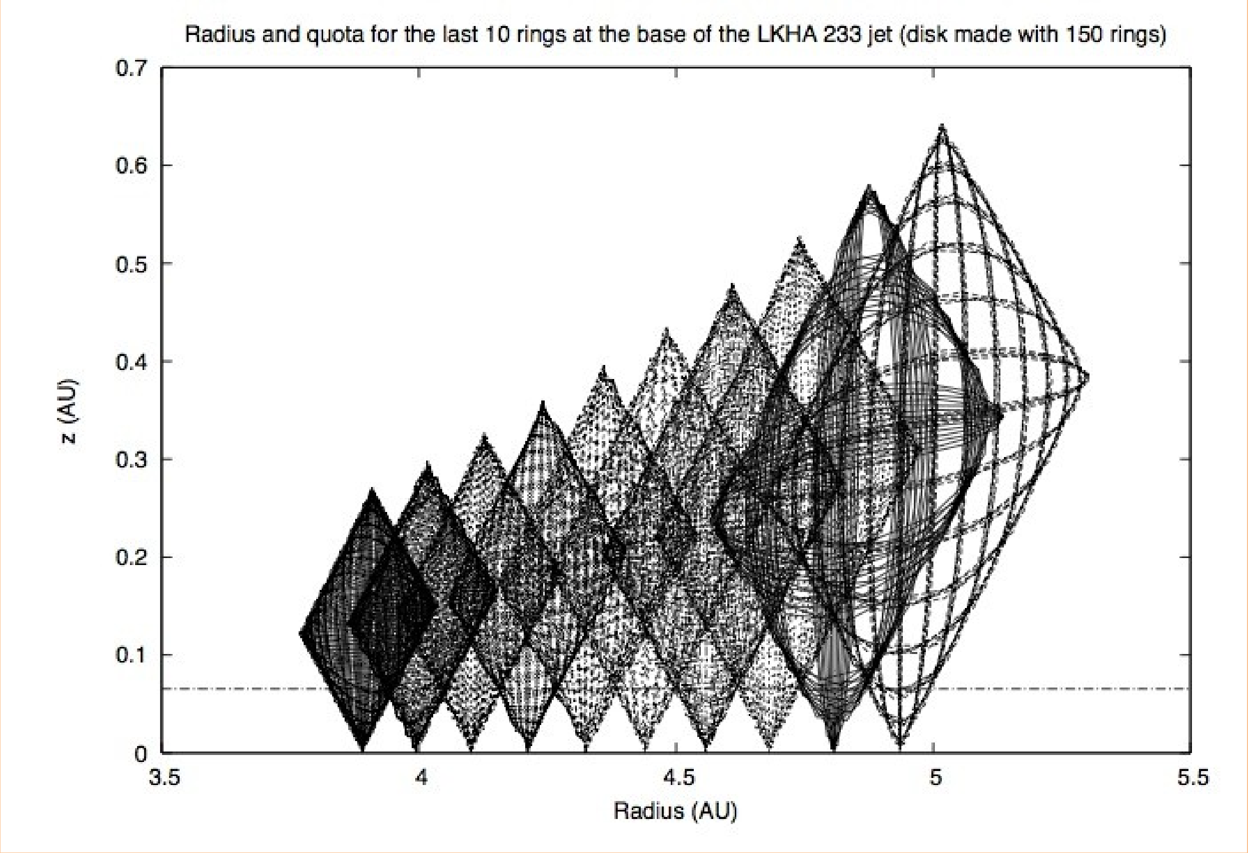
Herbig star, large disk, strong jet : LK Ha 233



Perrin+ 2007

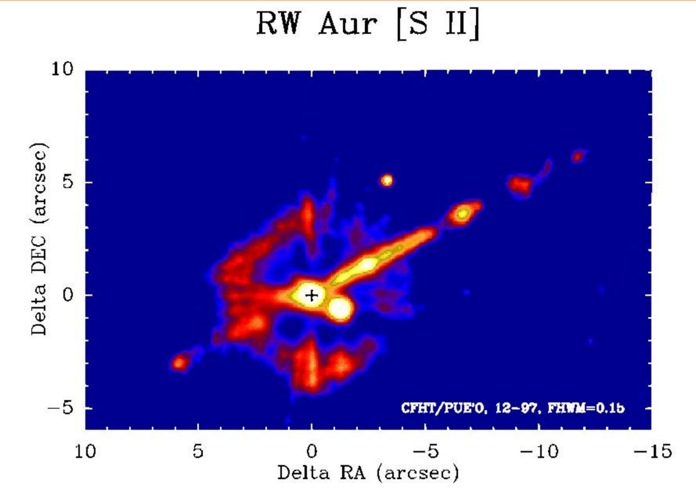
LKHa 233
Mstar = 2.9 Msun
Md = 0.030 Msun
Rd = 500 AU Rin = 0.01 AU
Dp = 3 E-5 Msun/yr km/s
t ~ 250 yr





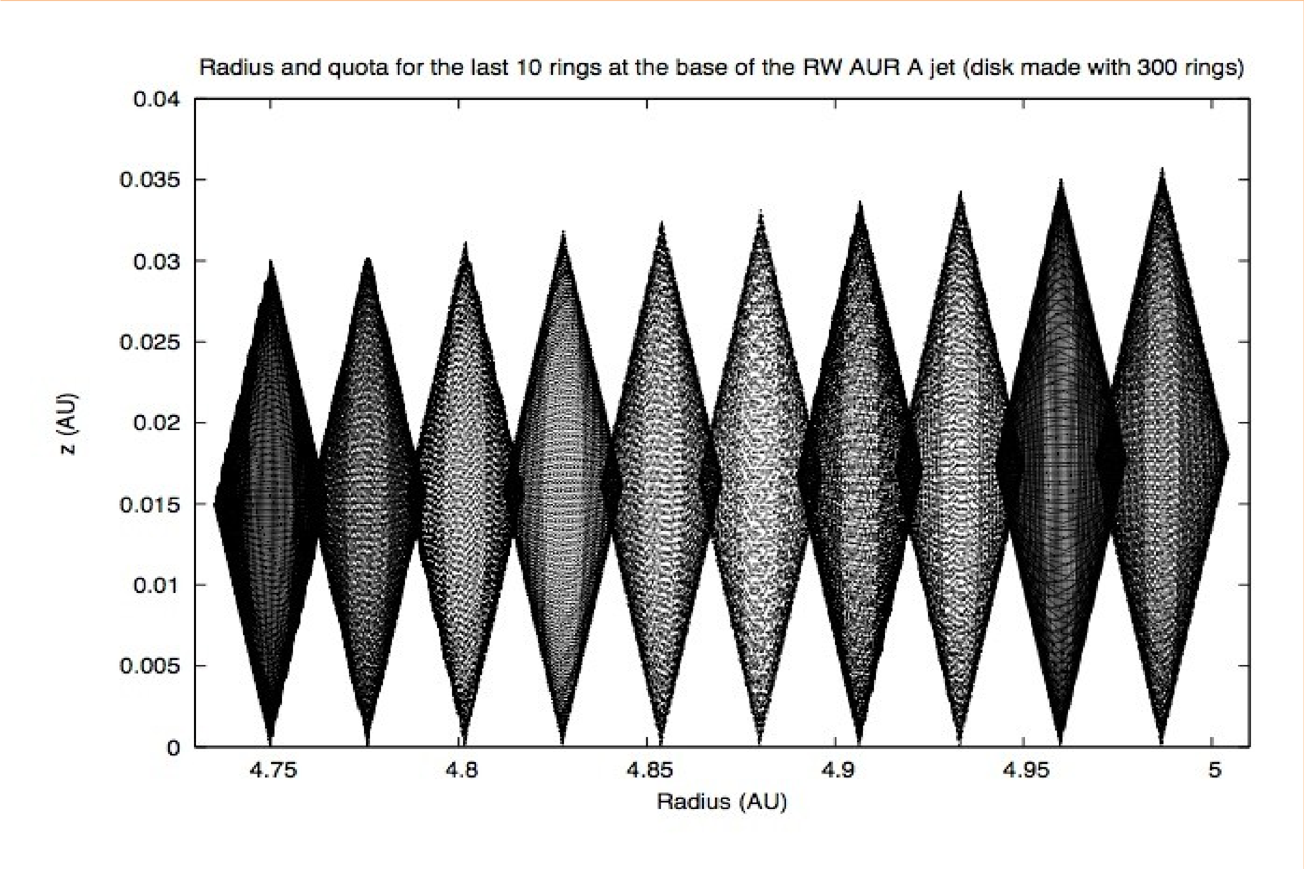
Bacciotti, Locatelli, Volpi, Paez, 2015 in prep

A T Tauri star with a light disk : RW AUR

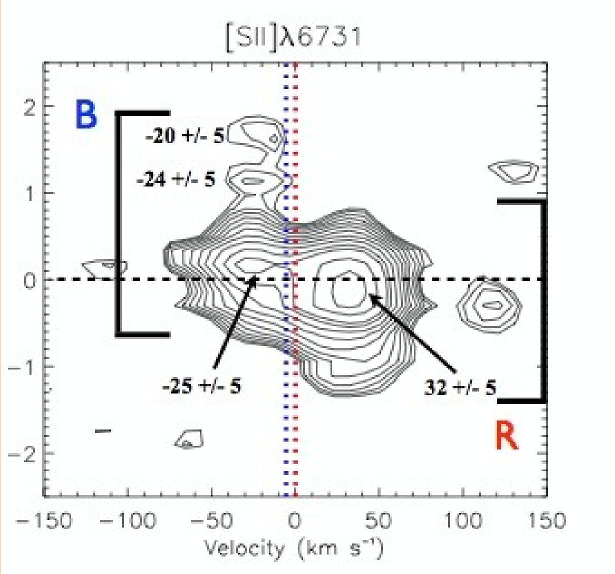


RW AUR
Mstar = 0.9 Msun
Md = 3 E-4 Msun
Rd = 50 AU Rin = 0.01 AU
Dp = 1.7 E-7 Msun/yr km/s
t ~ 1000 yr

CHF / U. Strasbourg

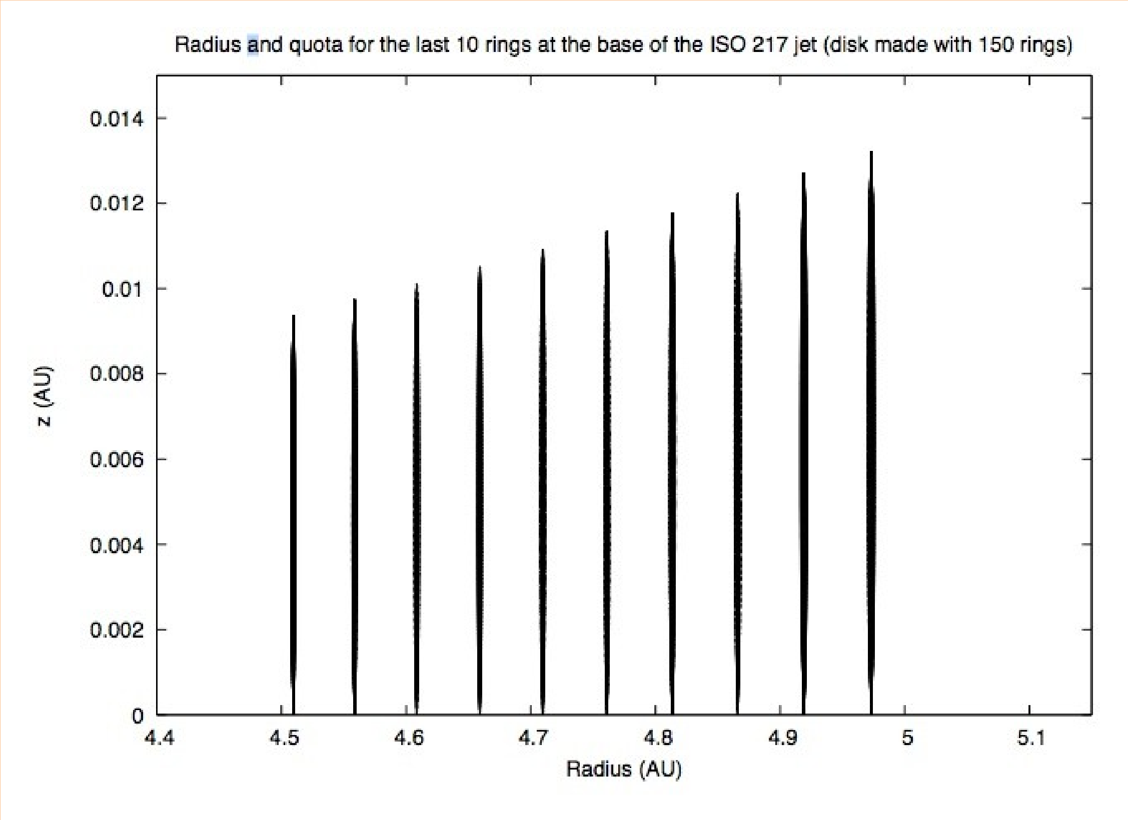


A brown dwarf with a weak jet : ISO-ChaI 217

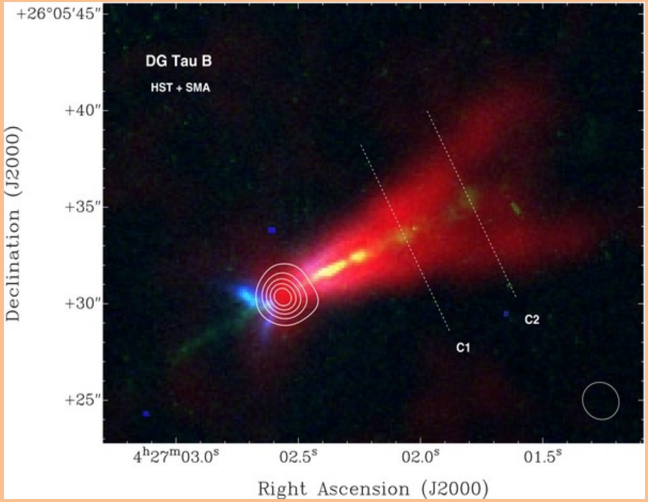


Whelan+ 2012

ISO 217
Mstar = 0.0764 Msun
Md = 4 E-6 Msun
Rd = 50 AU   Rin = 0.01 AU
Dp = 7.3 E-11 Msun/yr km/s
t ~ 1500 yr

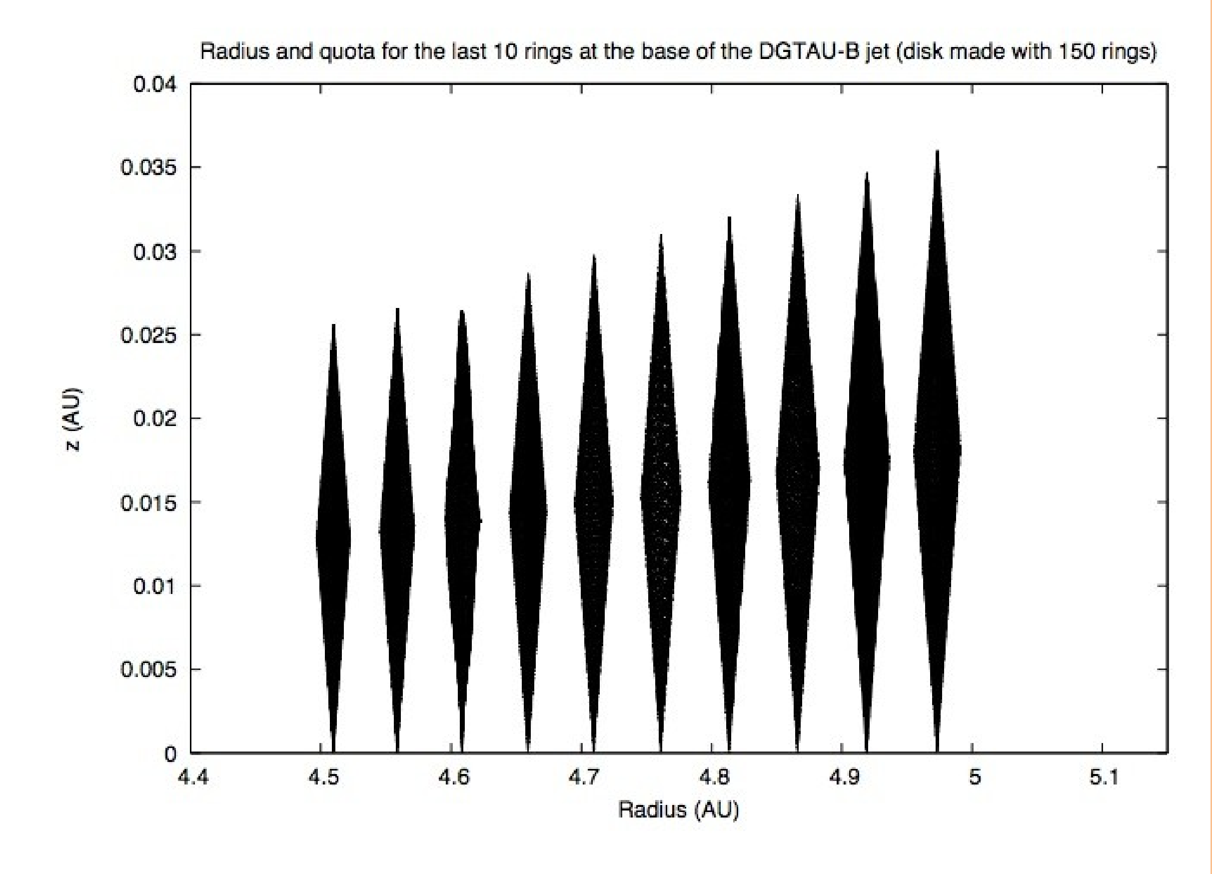


Class I sources :   DG Tau B

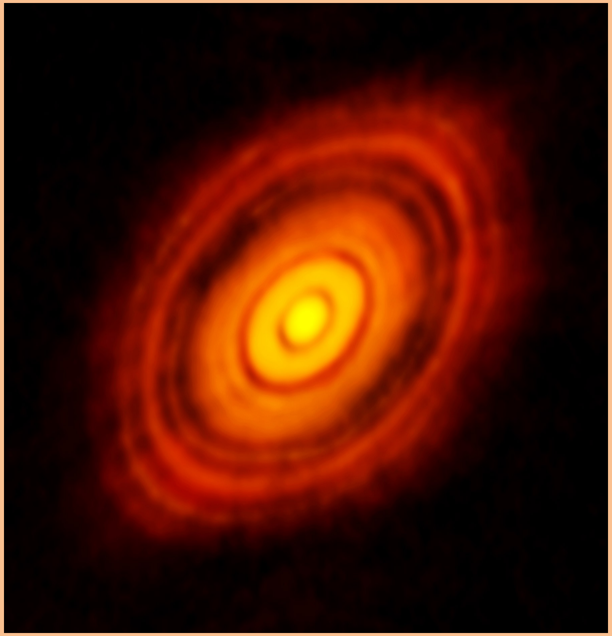


Zapata+ 2015

Dg Tau B
Mstar = 0.5 Msun
Md = 0.068 Msun
Rd = 275 AU   Rin = 0.01 AU
Dp = 1.7 E-6 Msun/yr km/s
t ~ 2000 yr

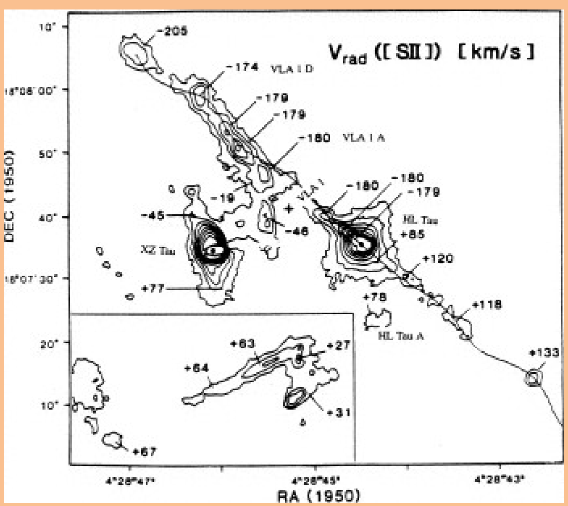


A class I source with massive disk :   HL Tau

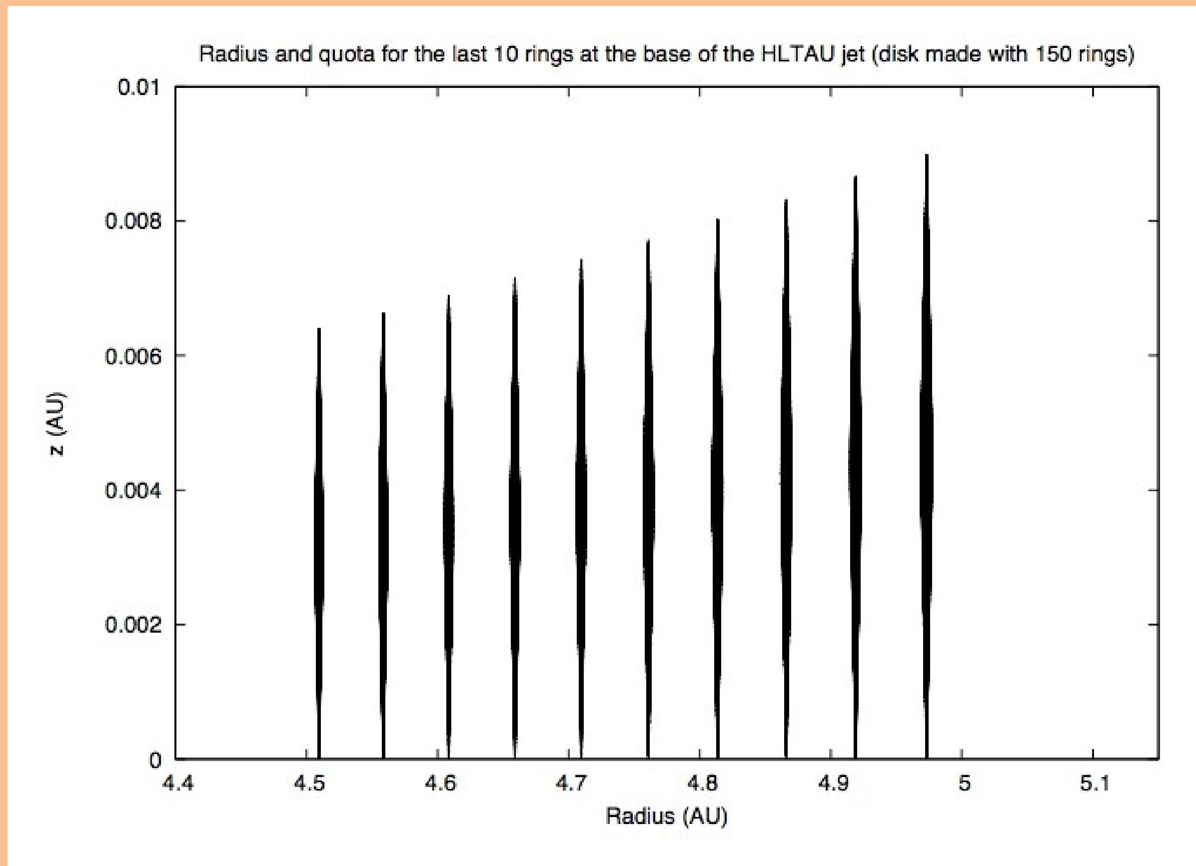


ALMA consortium

HL Tau
Mstar = 1.3 Msun
Md = 0.13 Msun
Rd = 275 AU   Rin = 0.01 AU
Dp = 5.3 E-6 Msun/yr km/s
t ~ 1500 yr



Close+ 1997



Summarising ....

The difference in linear momentum rate between the jet lobes makes Keplerian orbits shift in z and oscillate in (r,z) around the new equilibrium position

Oscillation amplitude is larger for

larger $\Delta\dot{p}$

larger distance from star

smaller MD

smaller Mstar

Oscillation amplitude is the same in z and r

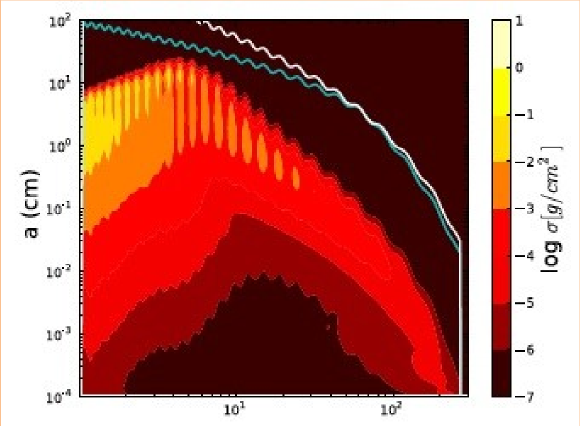
(for large enough r)

4. applications – prospects

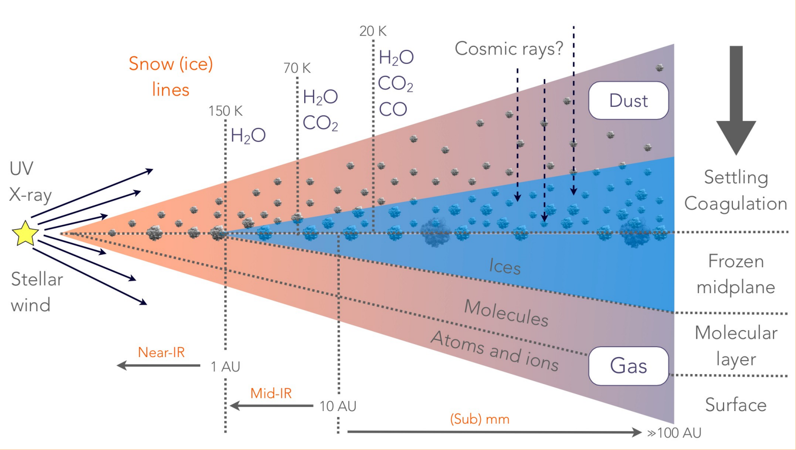
Some applications

Contribution to turbulent viscosity

Pressure bumps
for dust traps
and grain growth
(Pinilla+ 2012)



Vertical and radial
Mixing
for formation and detection
of complex molecules



Future studies

- Explore more sources and identify correlations

- Variable reaction force in r, t

- Disk structure with HAR observations (ALMA)

- Examine fully 3D with no axisymmetry Jet precession
   eccentricity

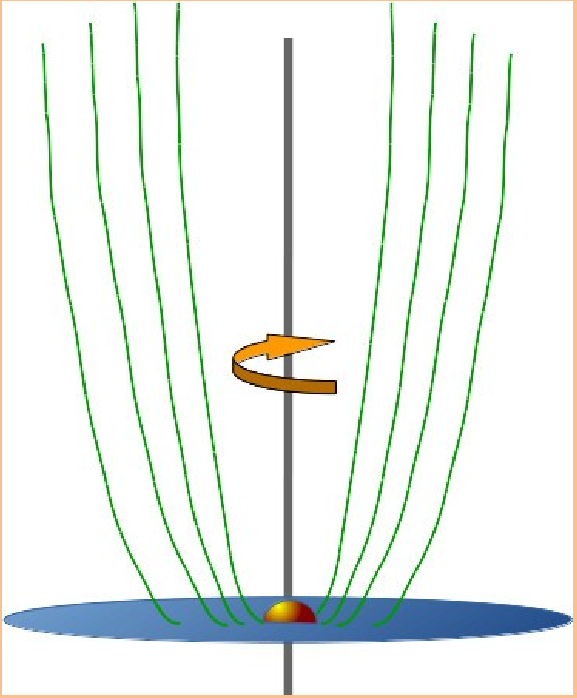
- Repeat investigation with HD code   - MHD code

- Examine different footpoint regions

HOW CAN WE CONSTRAIN THE SIZE OF THE JET FOOTPOINT REGION ????

Exploring the jet feedback: THE BIG UNKNOWN

SIZE OF THE JET FOOTPOINT REGION from jet rotation studies (Bacciotti + 2002, Anderson 2003, Coffey+ 2004, 2007, Ferreira+ 2006….)



Jet rotation the only viable measure ?
Observations are **still puzzling**
(Cabrit+ 2006, Codella+ 2007, Coffey+ 2012)
Other mechanisms can explain v-shift
(Cerqueira+2006, Soker 2005, Fendt 2011)

TEST jet rotation vs Disk rotation + B orientation

Granted time ALMA CYCLE 3 (PI Bacciotti)