Jets from young stars:
From theory to synthetic observations

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NATIONAL OBSERVATORY OF ATHENS

ΕΘΝΙΚΟΝ & ΚΑΠΟΔΙΣΤΡΙΑΚΟΝ ΠΑΝΕΠΙΣΤΗΜΙΟΝ ΑΘΗΝΩΝ

NATIONAL & KAPODISTRIAN UNIVERSITY OF ATHENS

Collaborators

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- Trussoni (OATo)
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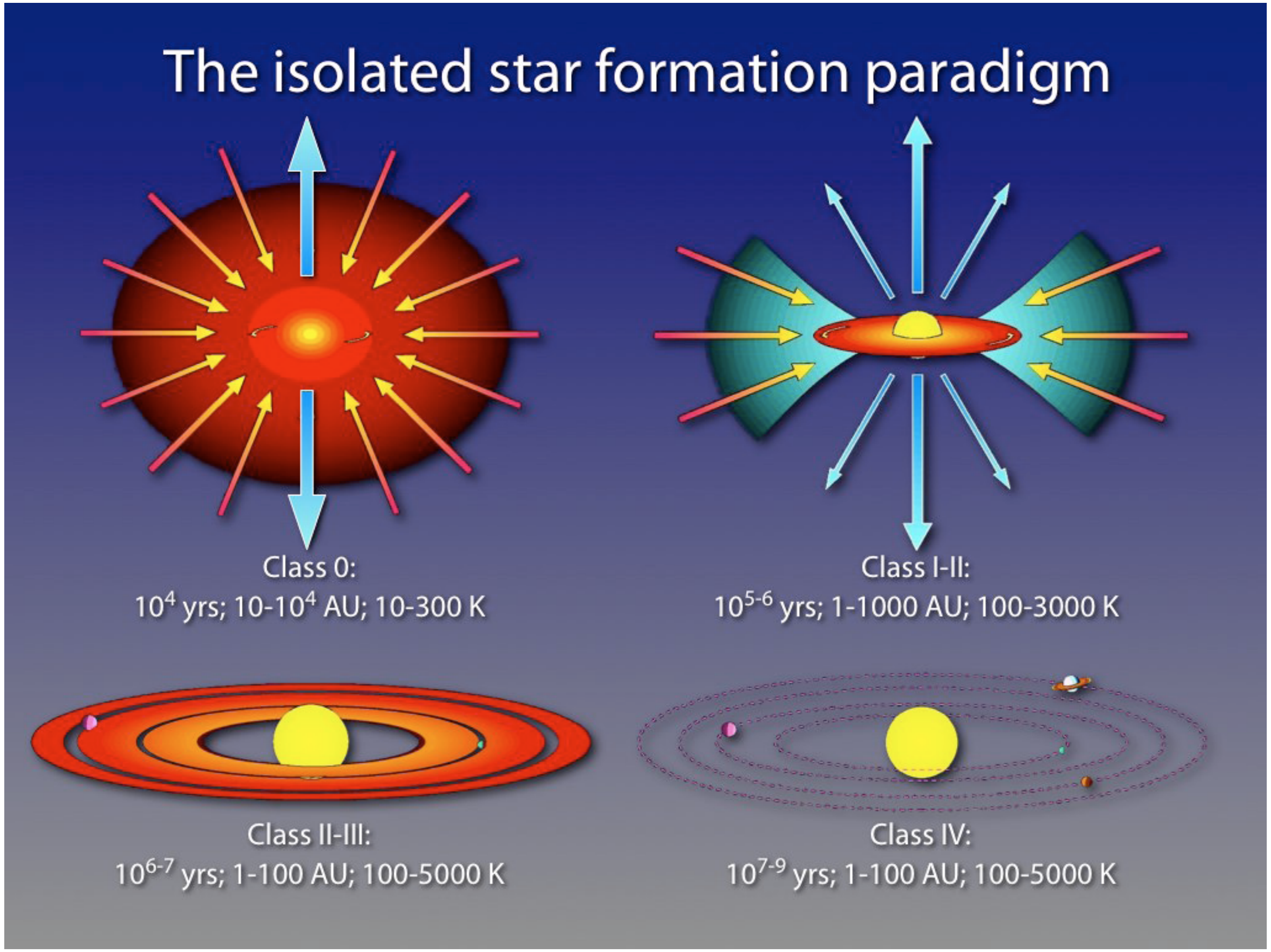
Germany
- Stute (Tuebingen)
- Gracia (Stuttgart)

UK
- Matt (Exeter)

The Fertile Interstellar Medium

Star Formation in other galaxies as well

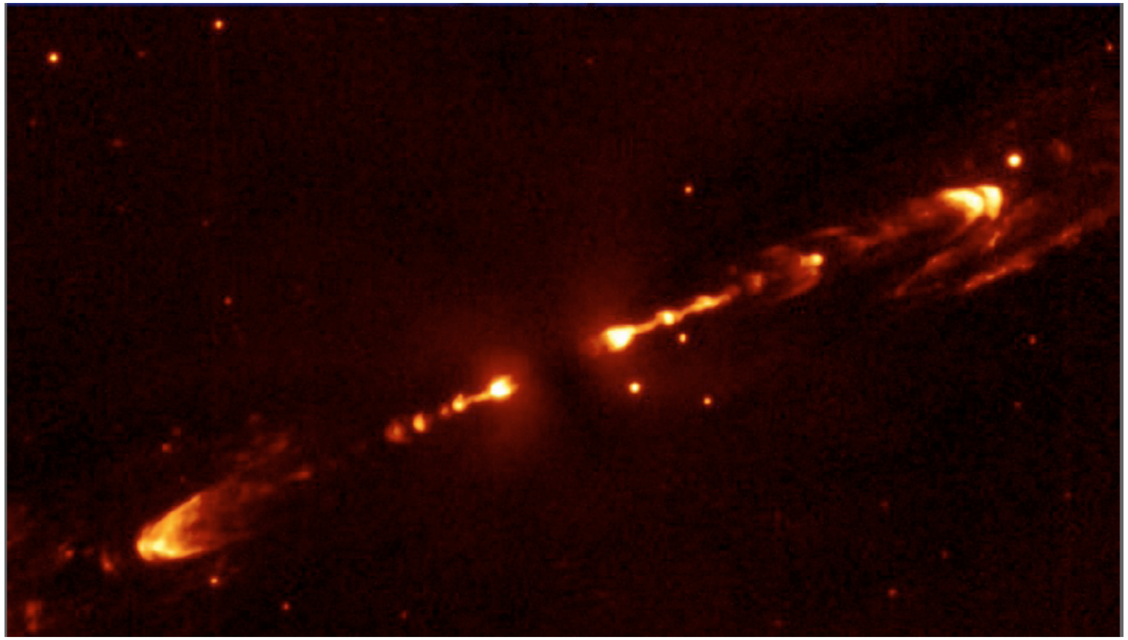
Star formation



McCaughrean

YSO jets

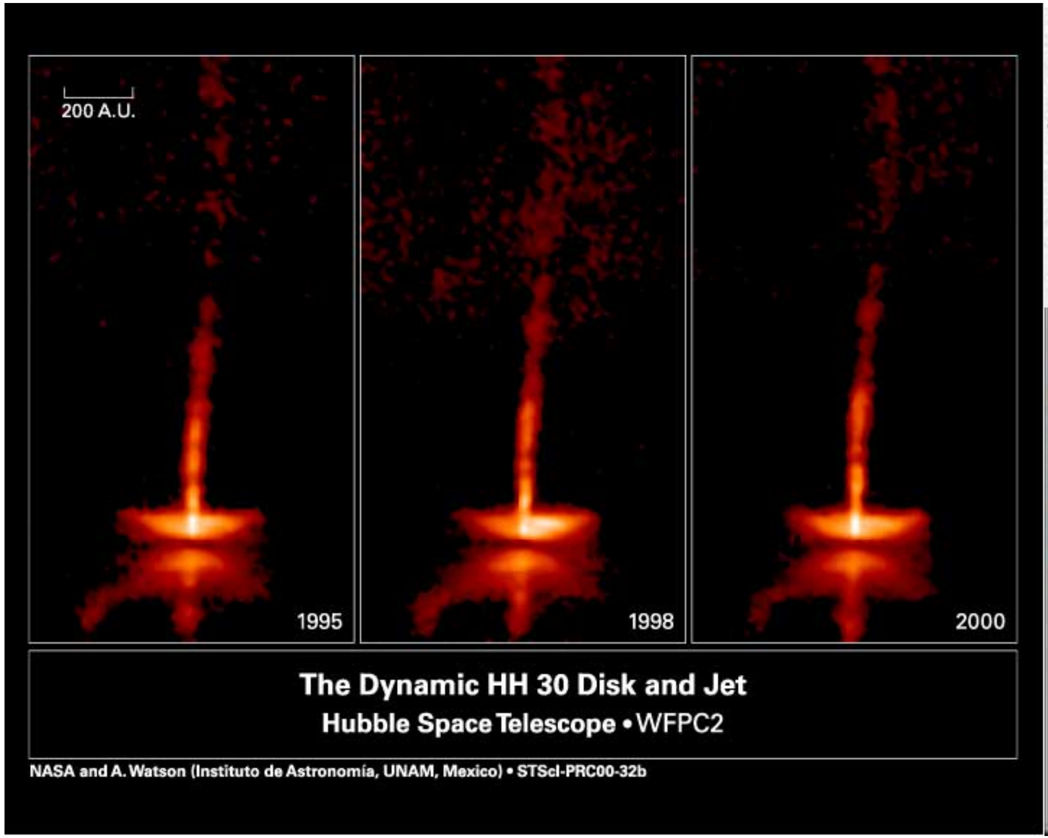
Protostellar jets are highly collimated mass outflows associated with star formation
(***Protostellar Jets in Context***, Tsinganos, Ray, Stute, 2009, Springer)

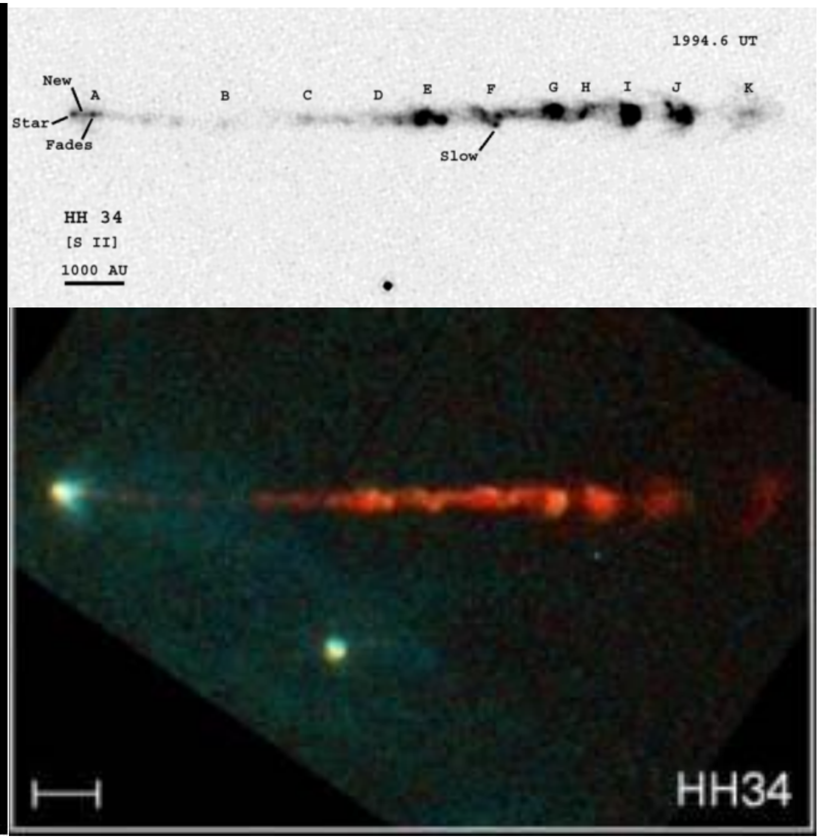


Maccaughrean+02

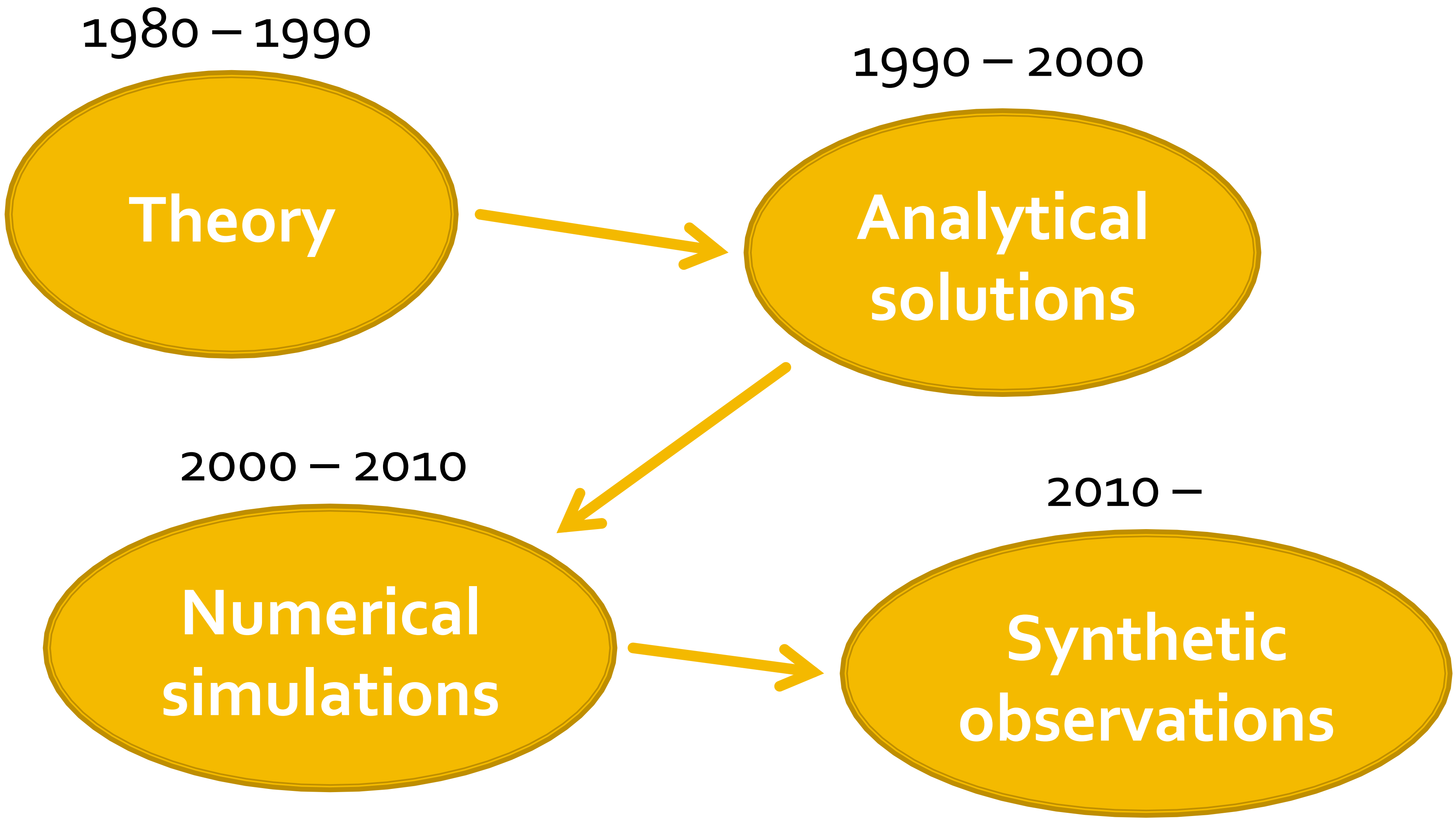
Some well known jets

Credit: STScI and NASA



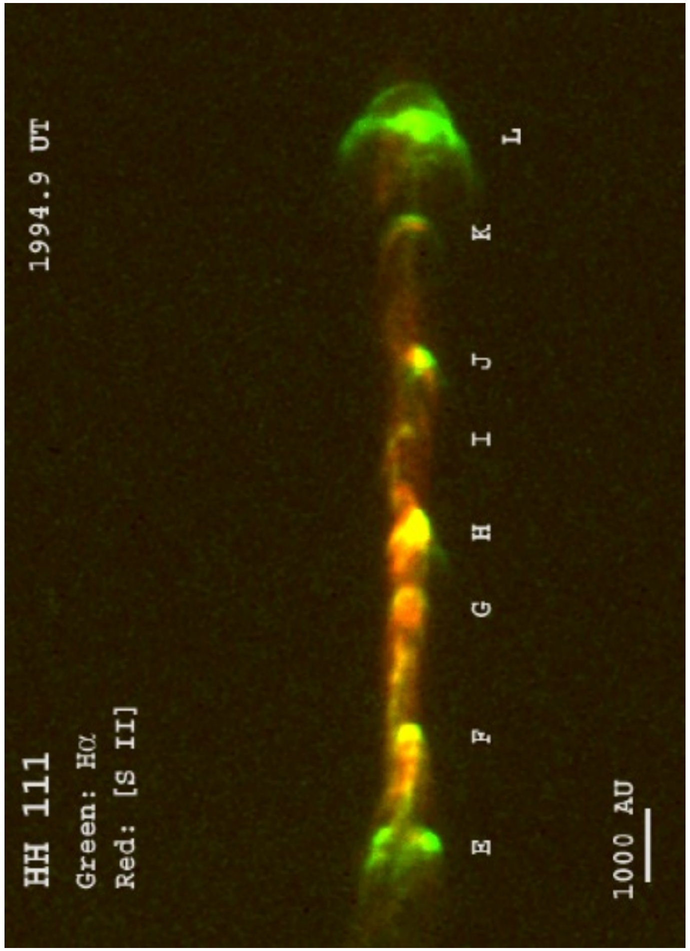


Historical treatment of jets



Observed features

- Velocities
  - ~ 100 – 500 km/s
- Temperatures
  - ~ 10 000 – 20 000 K
- Densities
  - ~ 10^5 particles/cm^3
- Jet widths
  - ~ 30 – 50 AU



Hartigan+95

Other observed features

- Velocity asymmetries between the blue and red shifted regions (e.g. ~50% for RW Aur)

  (Woitas+02; Coffey+04; Perrin+2007; Hartigan & Hillenbrand 09)

- Counter-rotation

  (Coffey+04; Cabrit + 06)

(Some) Questions

- Can we obtain the observed physical parameters?

- How are velocity asymmetries produced?

- Are counter-rotating jets possible?

The MHD equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = 0\,,$$

$$\frac{\partial \mathbf{V}}{\partial t} + (\mathbf{V} \cdot \nabla)\mathbf{V} + \frac{1}{\rho}\mathbf{B} \times (\nabla \times \mathbf{B}) + \frac{1}{\rho}\nabla P = -\nabla \Phi\,,$$

$$\frac{\partial P}{\partial t} + \mathbf{V} \cdot \nabla P + \Gamma P \nabla \cdot \mathbf{V} = \Lambda\,,$$

$$\frac{\partial \mathbf{B}}{\partial t} + \nabla \times (\mathbf{B} \times \mathbf{V}) = 0\,,$$

Optically thin radiation losses:
Evolution of 29 ions species

$$\frac{\partial(\rho X_{\kappa,i})}{\partial t} + \nabla \cdot (\rho X_{\kappa,i} \mathbf{v}) = \rho S_{\kappa,i}\,,$$

Two-component jets

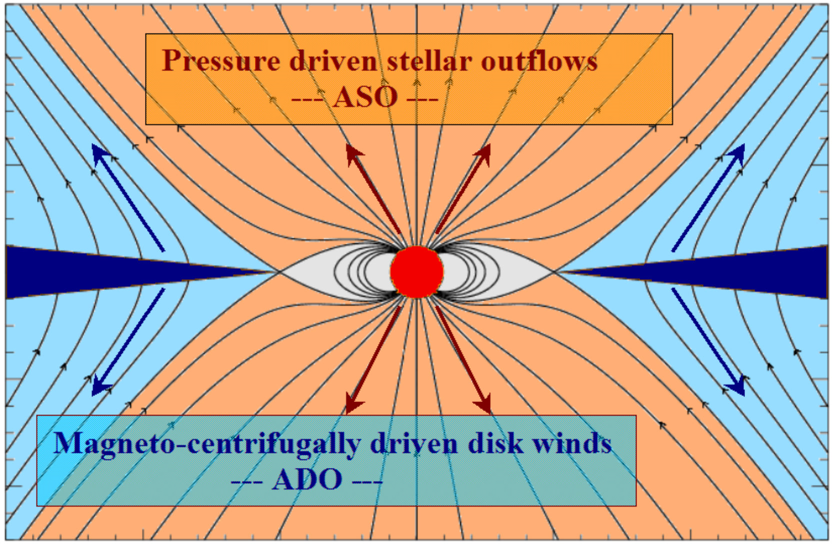
- Young Stellar Objects have 2 constituents:
  - Disk & Protostar
  - A disk wind is needed to provide the observed mass loss rates (Ferreira+06)
  - A stellar wind is expected to propagate in the inner region and spin down the star (Matt+Pudritz 08)

- Observations distinguish the two types of outlfows (Edwards+06; Kwan+07)

Two-component jets

- The disk wind
  - magneto-centrifugally driven
  - collimates the stellar outflow

- The stellar wind
  - pressure-driven
  - can spin down the star



Two-component jets

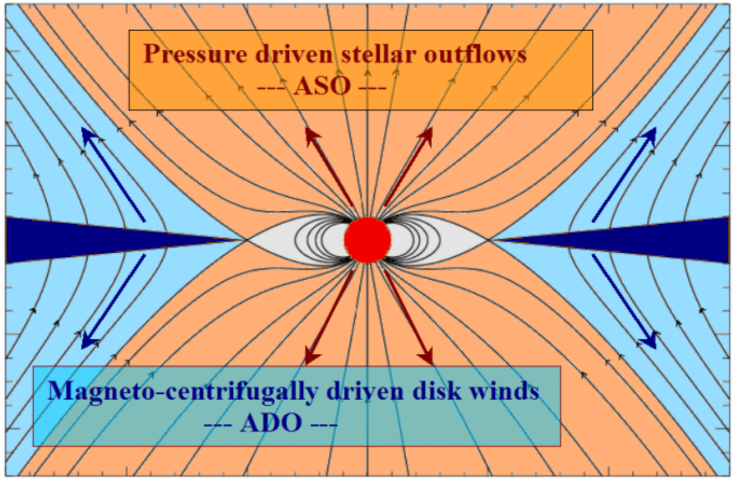
- We start from analytical solutions

- Combination

$$U = \left\{1 - \exp\left[-\left(\frac{A_2}{A_{\rm mix}}\right)^2\right]\right\} U_{\rm D} + \exp\left[-\left(\frac{A_2}{A_{\rm mix}}\right)^2\right] U_{\rm S}$$

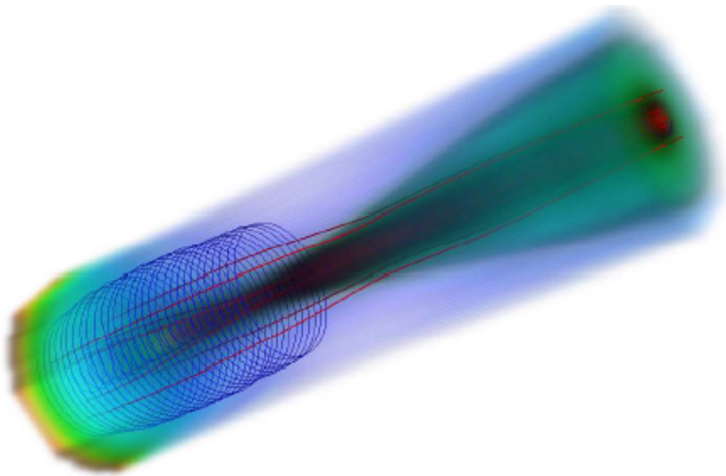
- Variability

$$f_{\rm S}(r,t) = 1 + p \sin\left(\frac{2\pi t}{T_{\rm var}}\right) \exp\left[-\left(\frac{r}{r_{\rm var}}\right)^2\right]$$

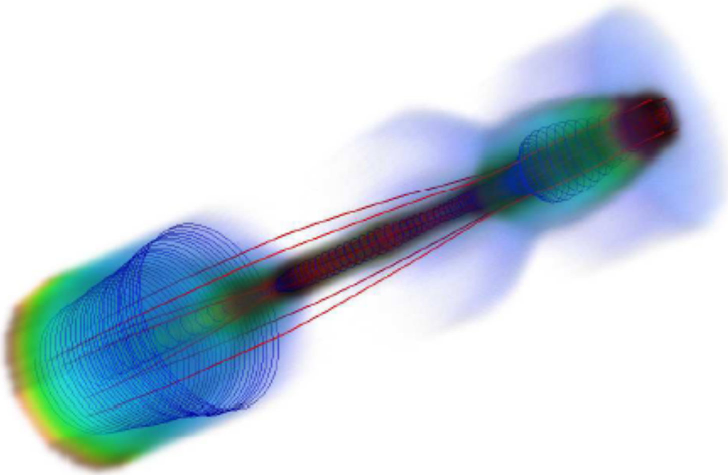


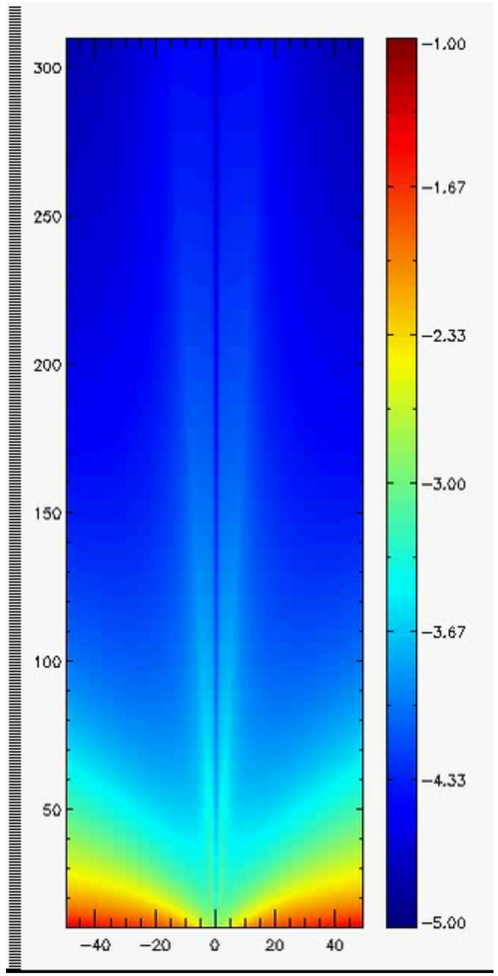
3D representation

- Initial conditions



- Snapshot during evolution



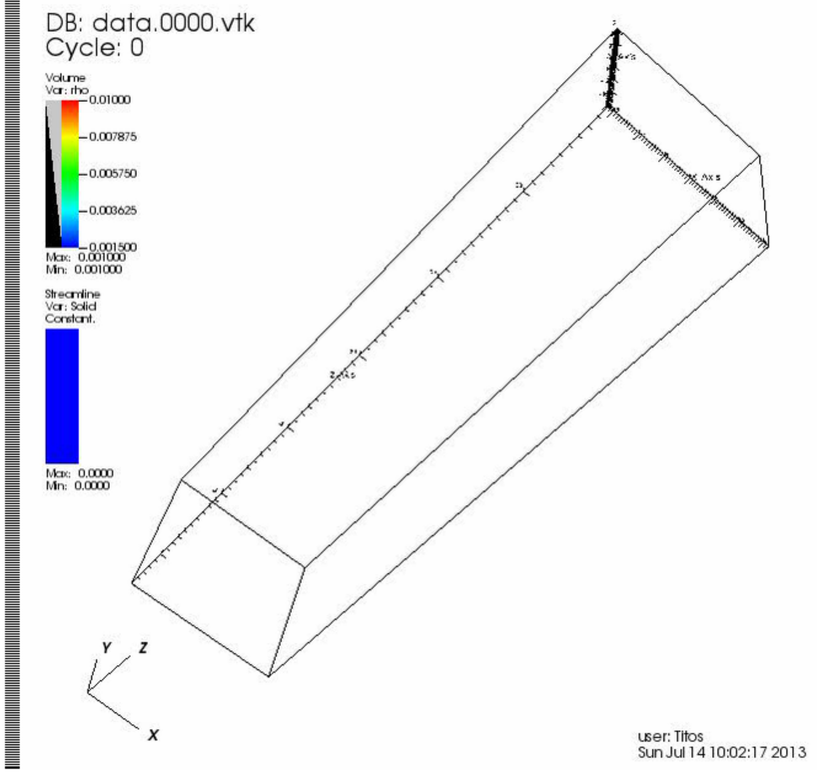


Tesileanu + submitted

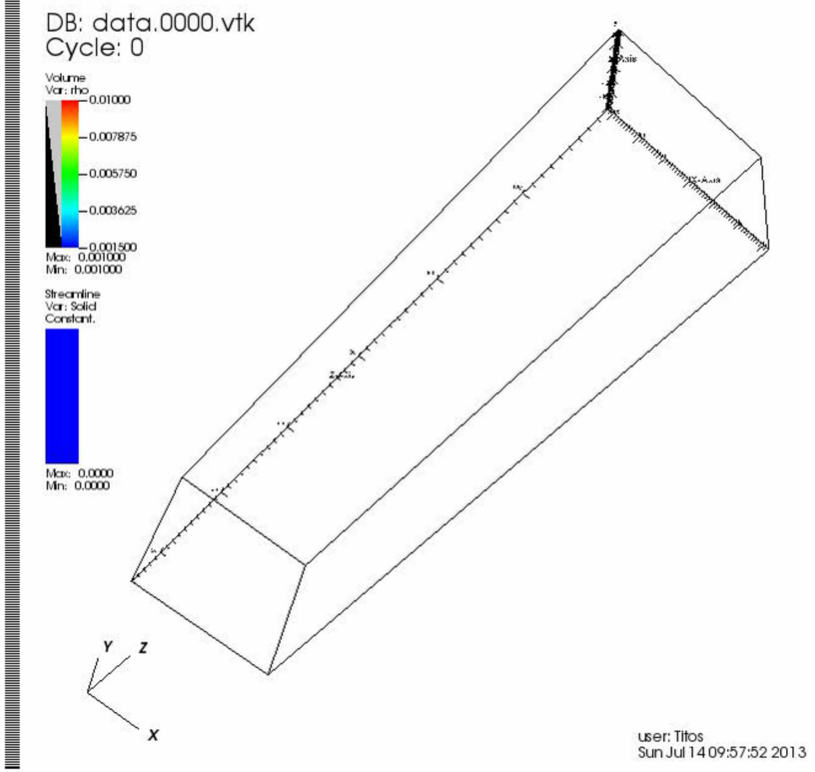
3D simulations

Tsinganos et al in prep

ENVIRONMENT



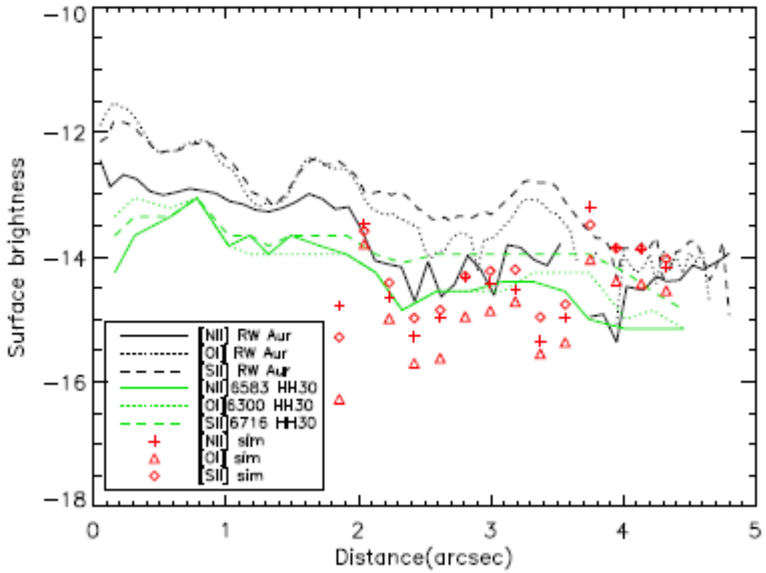
PRECESSION

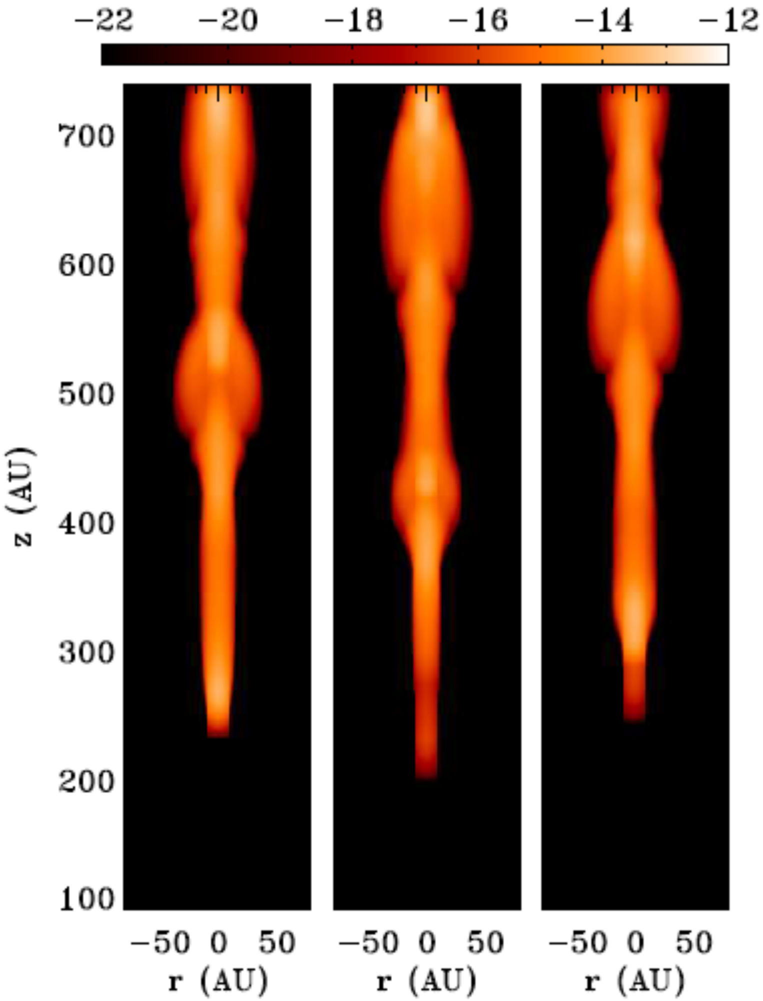


Surface brightness: Sims. vs Obs.

Below: Log maps of surface brightness of forbidden doublets [SII], [NII], and [OI] along two observed YSO jets (RW Aurigae & HH30) compared to MINEq simulation.

Right:Log map of surface brightness of forbidden doublet [SII] for 16.8, 19.2, 21.6 yrs

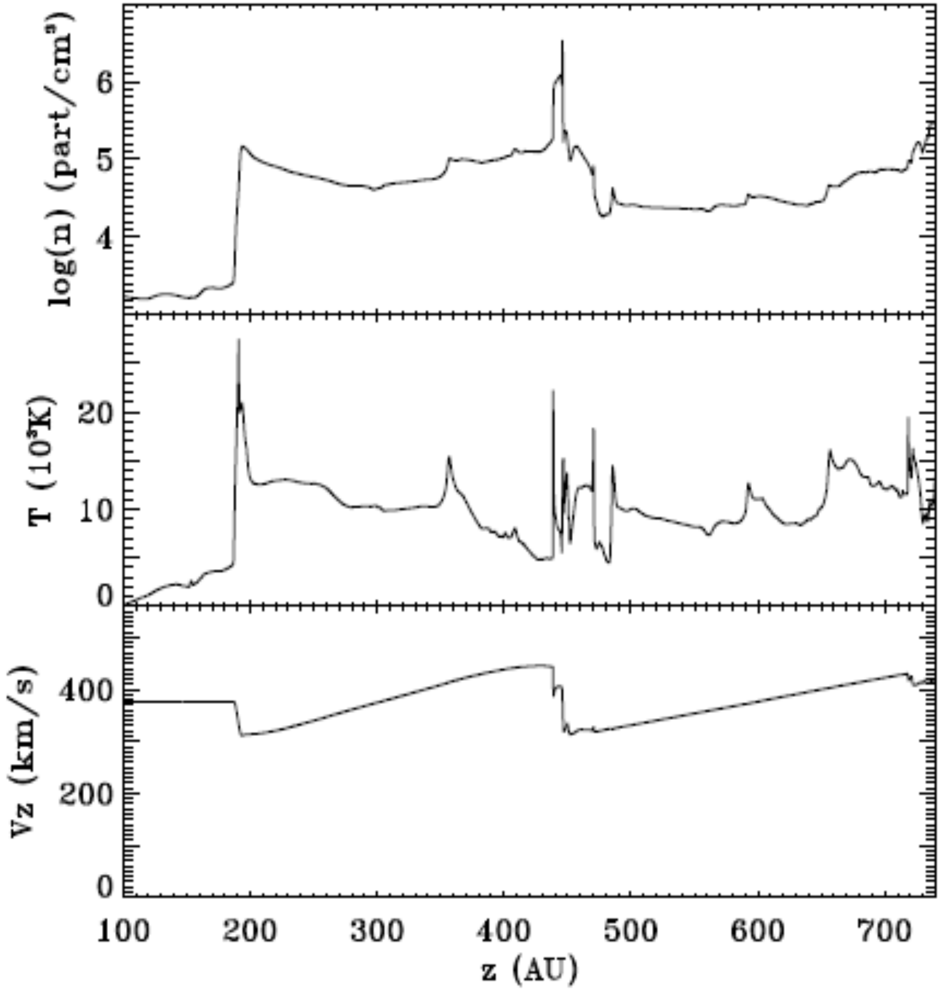




Tesileanu et al submitted

Quantities (n, T, Vz) along the jet

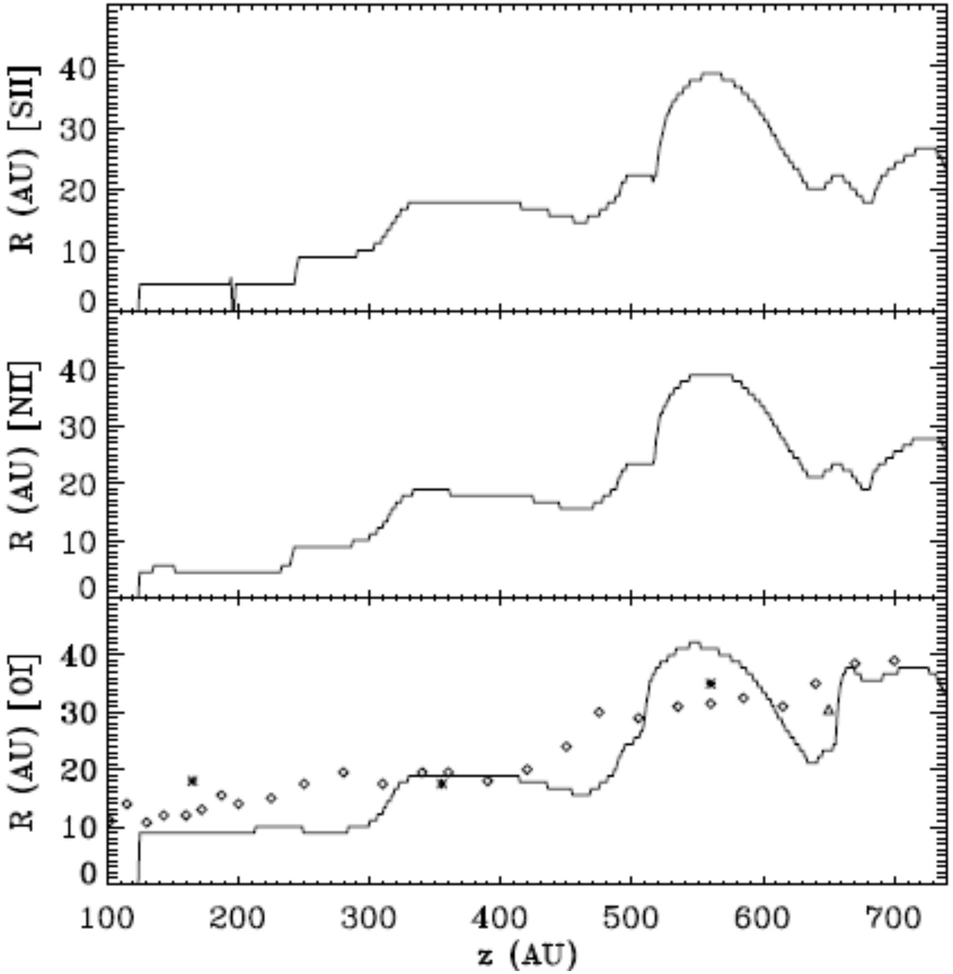
- Logarithmic density (top), temperature (middle) and velocity (bottom) profiles along the axis, for the model adopting MINEq. The instance corresponds to *t* = 12 yr.



Tesileanu et al submitted

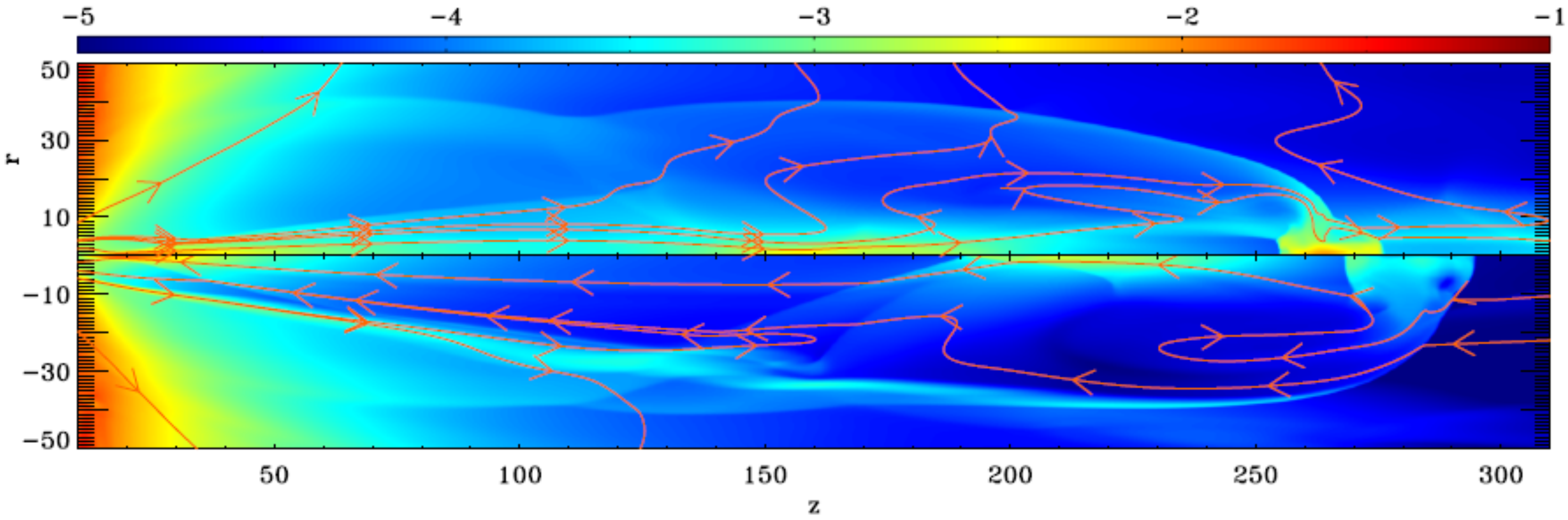
Jet radii

- The jet radius, *R*, as computed from each of the doublets O I, N II, and S II. The opening angle is a few degrees, i.e., ~ 2°



Tesileanu et al submitted

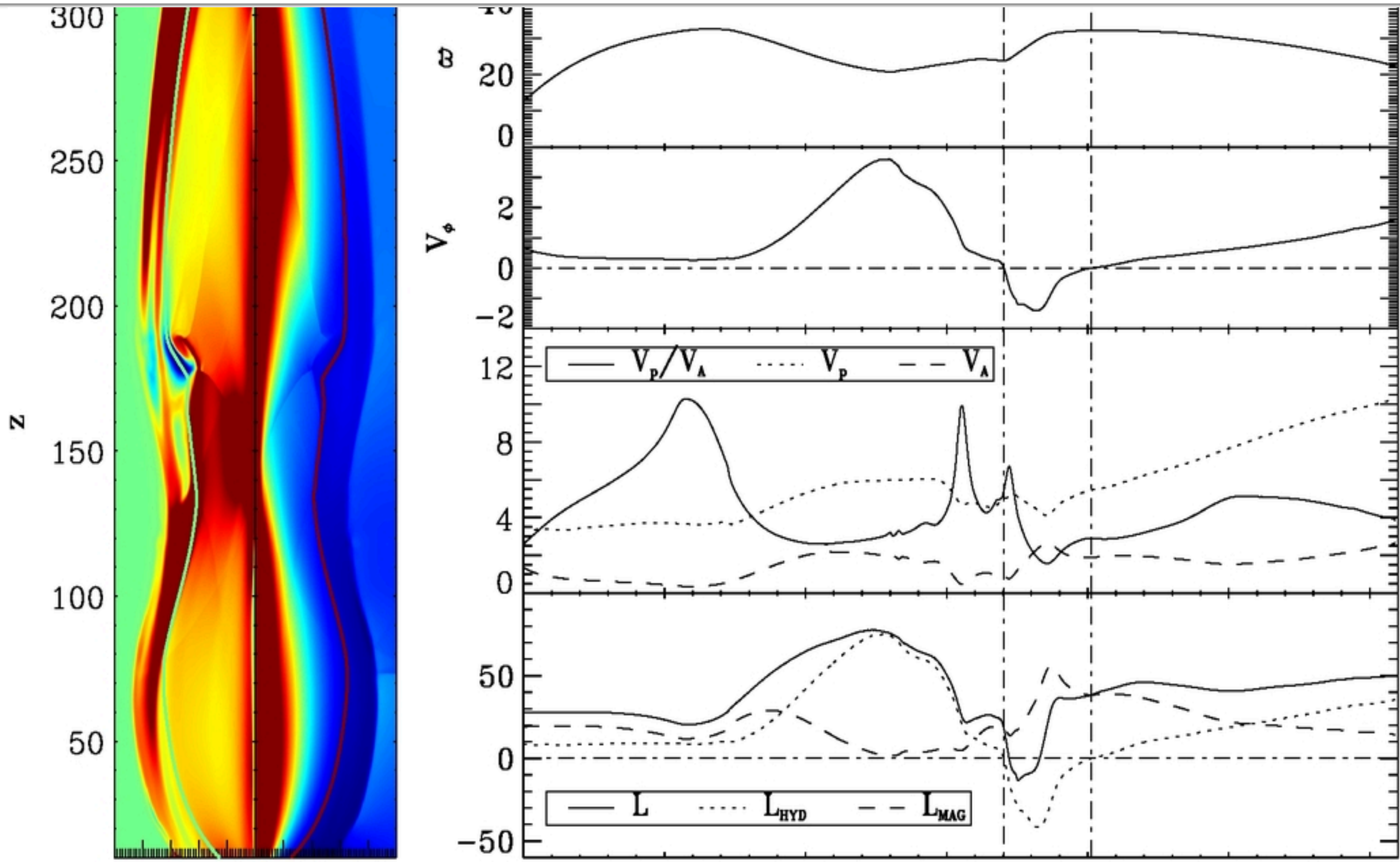
Velocity asymmetries



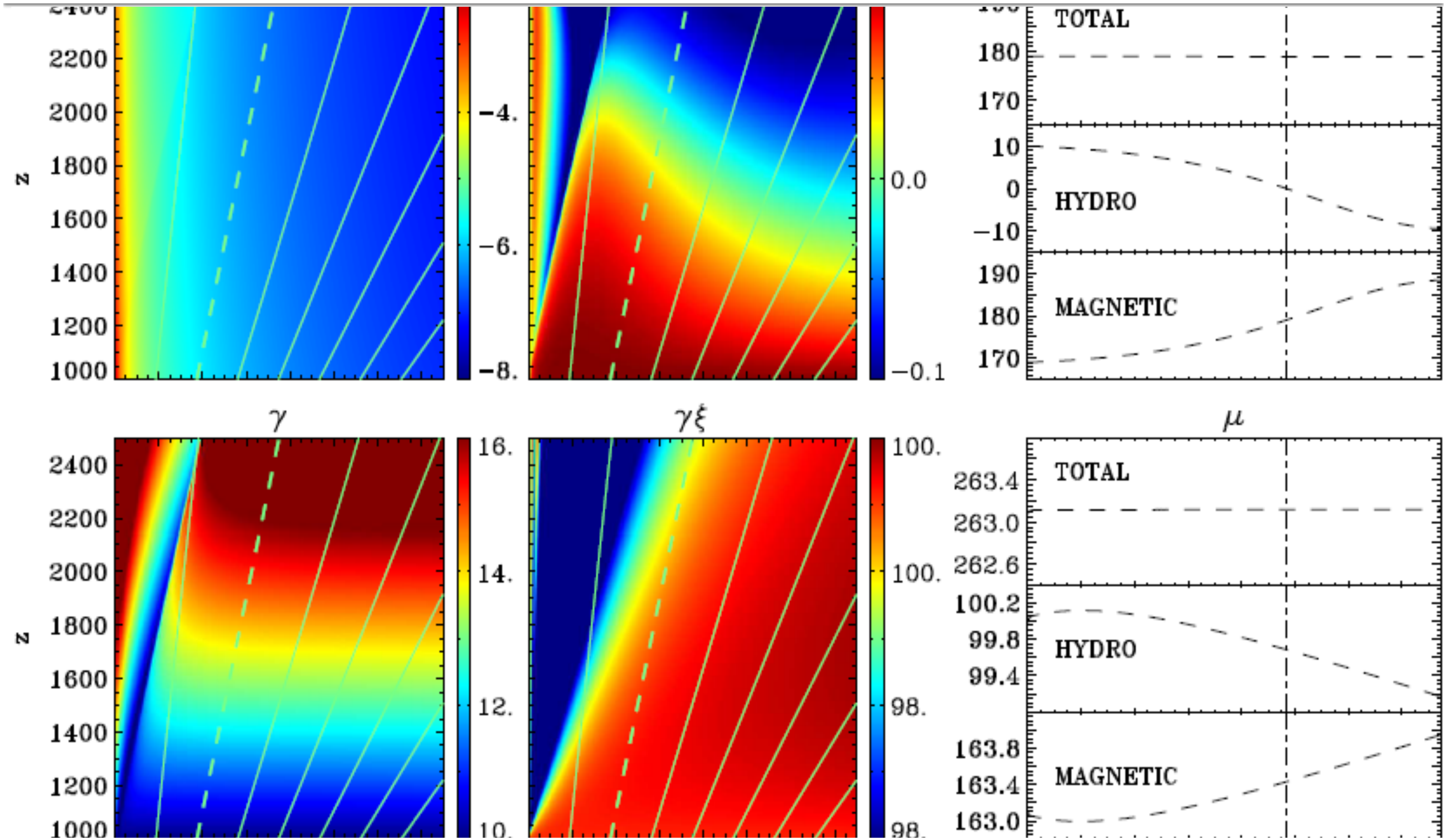
Logarithmic density and field lines for models Variable Resistive Parallel (VRP-top) and Variable Resistive Antiparallel (VRA-bottom). The two jets correspond to the two hemispheres of a YSO and are shown side by side for comparison. The shock front and matter condensations along the axis are found at different locations between the two cases. The stellar component of VRA displays a lower inner density as compared to VRP, whereas the inner part of its disk wind has higher values of ρ as matter accumulated along the current sheet is blown outwards from radial shocks.

Matsakos et al 2012, A&A, 545, 53

Counter-rotation – Non Rel



Counter-rotation – Relativistic



Conclusion

- Synthetic observations of two-component jets resemble closely real YSO jets


Thank you