Jet launching from a circumplanetary disc embedded in an externally-ionised protosolar nebula

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We perform adaptive-mesh, global resistive-MHD computer simulations of a protoplanetary disc (PPD) section with an embedded giant planet. The disc model assumes self-consistent and dynamically evolving Ohmic resistivity and ambipolar diffusion (AD), which are determined by a balance between external ionisation from X-rays, CRs and FUV photons, and absorption of free charges by gas-phase elements and on dust grains. Before the insertion of the planet core, the resulting configuration consists of a magnetically inactive dead zone and turbulent surface layers in the case of Ohmic resistivity alone. When considering the combined effect of AD and Ohmic dissipation, the magneto-rotational instability is supressed and a magneto-centrifugal wind is launched from the PPD instead.

When the embedded planet core of initially 100 earth masses has opened a gap in the disc, we study the ionisation structure and turbulent state of this region. By determining accretion rates and analysing the flow structure in the vicinity of the planet, we aim to address the important question of what limits the growth of gas giant planets in the classic core-accretion picture. Unlike in earlier 2D studies, and confirming previous 3D hydrodynamic models, we identify that the bulk of the mass accretion onto the core happens from high latitudes. This implies that mass transport through the circum-planetary disc (CPD) is negligible. At late times during the simulation, we observe the self-consistent emergence of a magnetically collimated outflow from the CPD, which had been predicted theoretically by Fendt.

Subject :	:	oral
Topics	:	Astrophysics
Topics	:	Numerical simulations

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1-3 October, 2014
Accretion and Outflows throughout the scales:
from young stellar objects to AGNs

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gas giant interiors

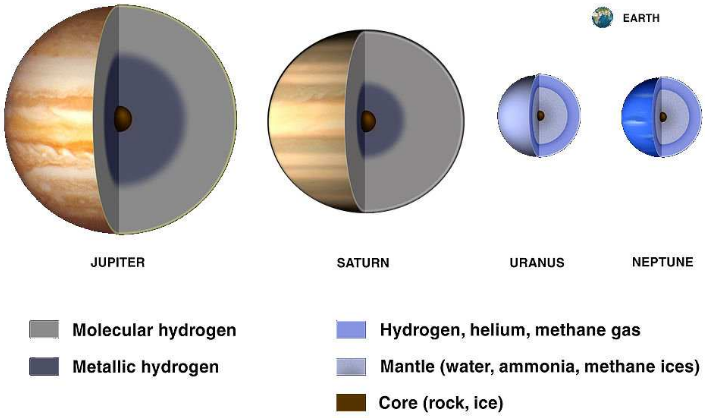
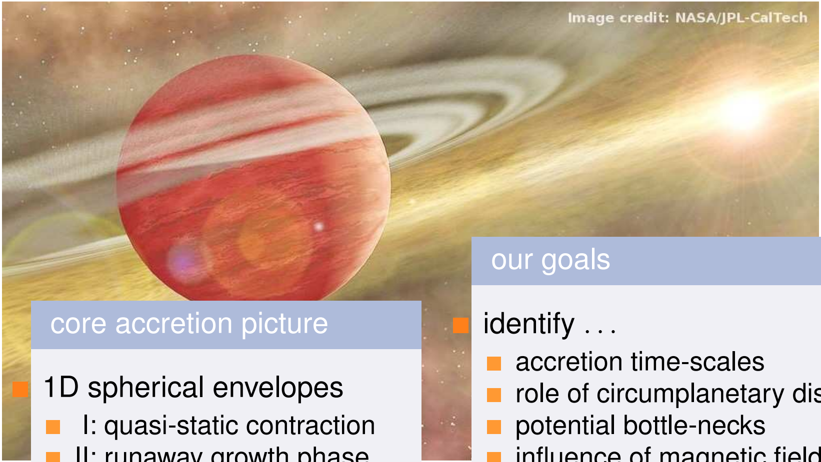


Image Credit: NASA, Lunar and Planetary Institute

motivation



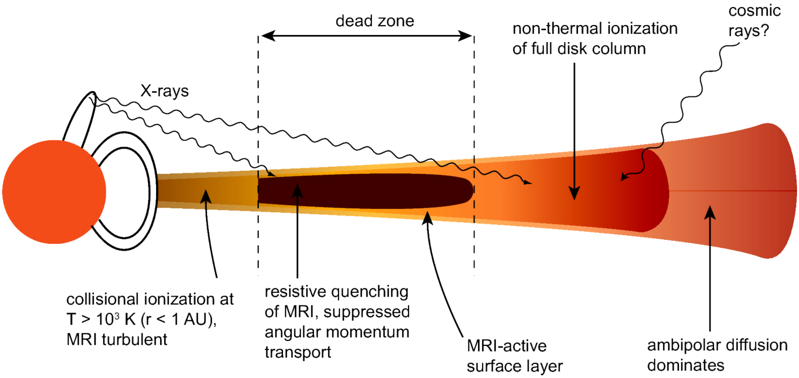
core accretion picture

- 1D spherical envelopes
  - I: quasi-static contraction
  - II: runaway growth phase

our goals

- identify . . .
  - accretion time-scales
  - role of circumplanetary disc
  - potential bottle-necks
  - influence of magnetic field

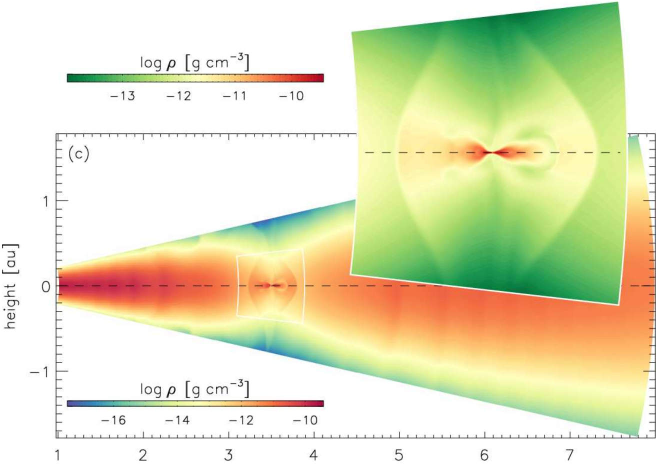
schematics of protostellar disc



play

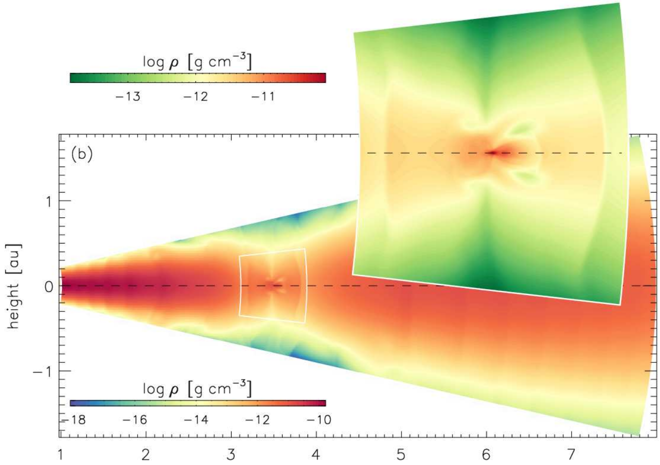
Armitage (2011)

embedded sub-disc



isothermal HD non-isoth. HD non-isoth. MHD

embedded sub-disc



isothermal HD **non-isoth. HD** non-isoth. MHD

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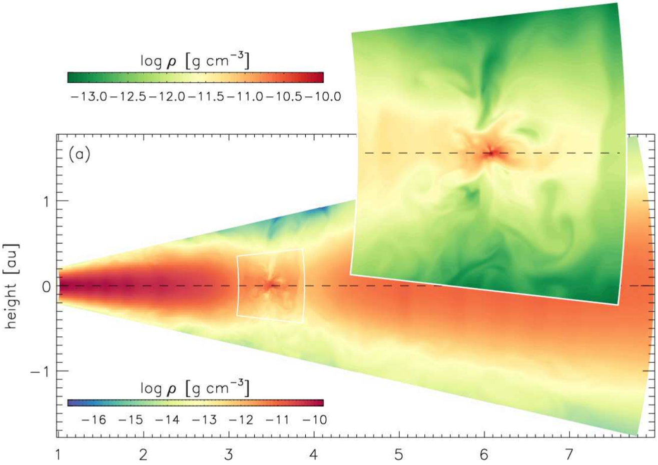
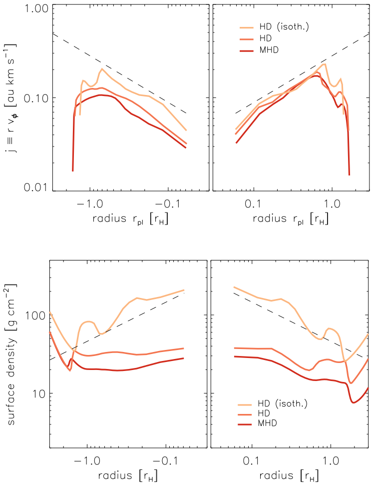


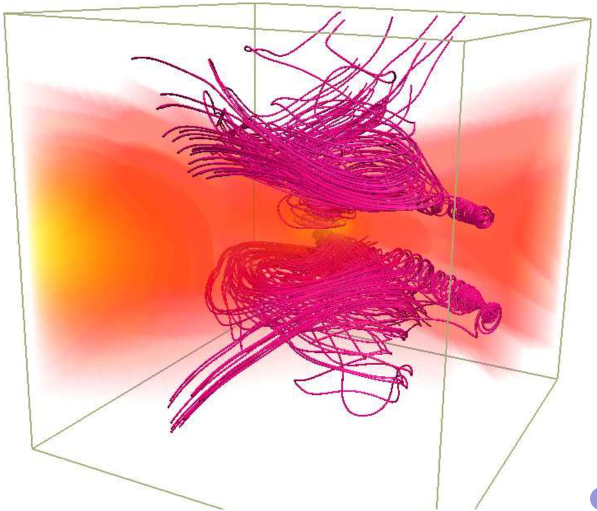
isothermal HD non-isoth. HD **non-isoth. MHD**

the circumplanetary disc



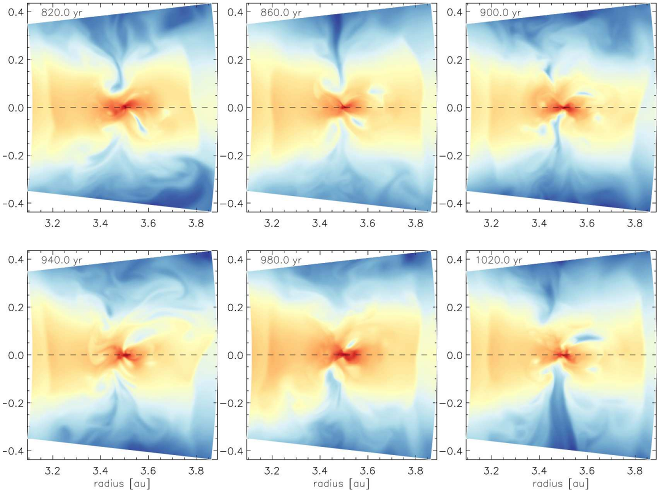
- Disc rotation profile
  - sub-keplerian rotation
  - inner disc hotter
    $\rightarrow$ pressure support
  - CPD extends to about half the Hill radius
- Disc surface density
  - non-isoth. case: flat surface density
  - isothermal case: steeper profile
    $m = 2$ spiral arms

accretion flow properties

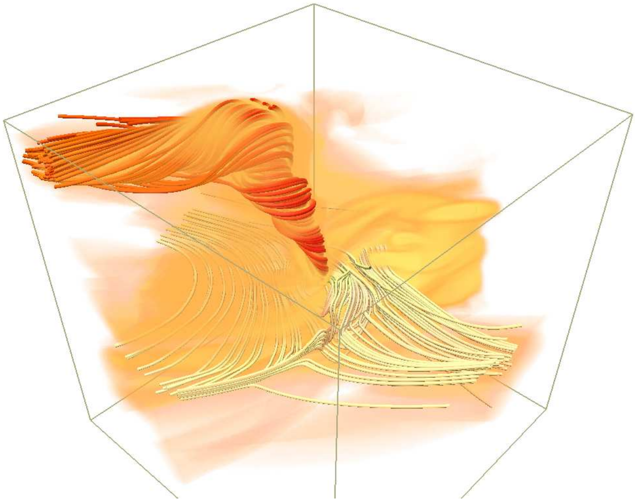


play

disc variability

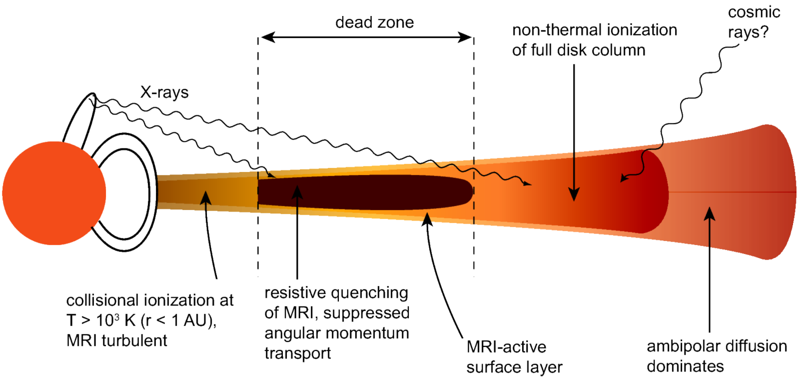


circum-jovian jet



- predicted theoretically by Quillen & Trilling (1998) and Fendt (2003)

revised schematics of protostellar disc



Armitage (2011) Armitage (2014)

- recent work by

Bai & Stone (2013), Bai (2013), Simon et al. (2013), Bai (2014a/b), Kunz & Lesur (2013), Lesur, Kunz & Fromang (2014), Gressel, Turner, Nelson & McNally (2015)

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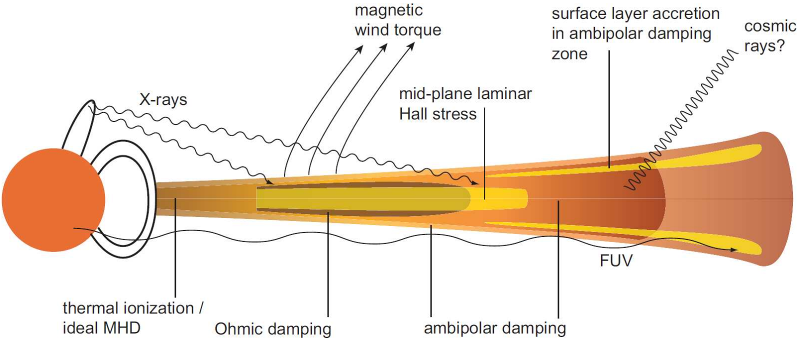

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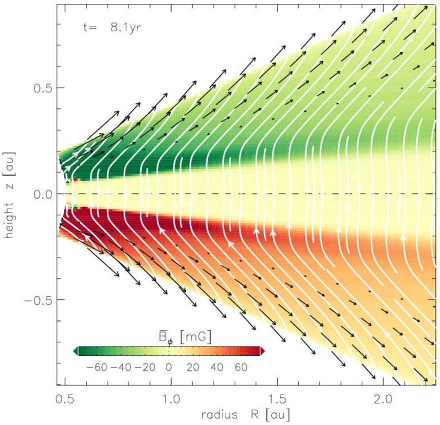
adding ambipolar diffusion



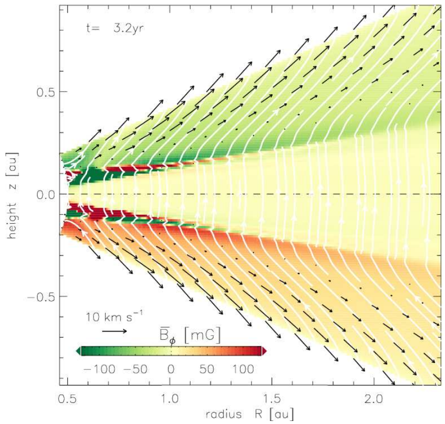
magneto-centrifugal wind from PPD with AD

Gressel, Nelson, Turner & McNally (2015) in prep.

- external ionisation
  via X-Rays, CRs, new: FUV layer
- Ohmic resistivity,
  new: ambipolar diffusion
- (no) magnetorotational instability (MRI)
  → (no) turbulent surface layers
- magneto-centrifugal (laminar) disc winds

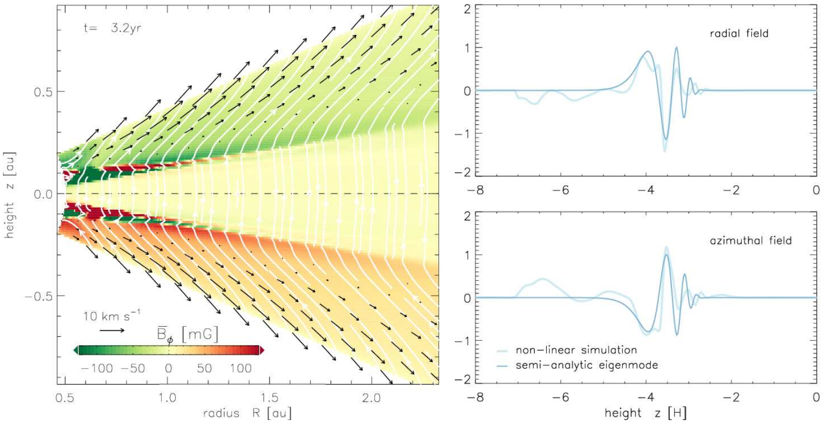
- effect of reduced gas column in the gap region
- ionisation state of the CPD
- effect on jet launching

laminar disc winds



- MMSN disc model, NVF with midplane $\beta_{\mathrm{p}\,0} = 10^5$, d/g mass ratio 10^{-3}, XR+CR+FUV

laminar disc winds



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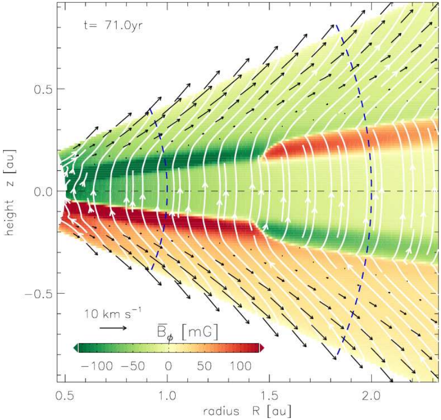

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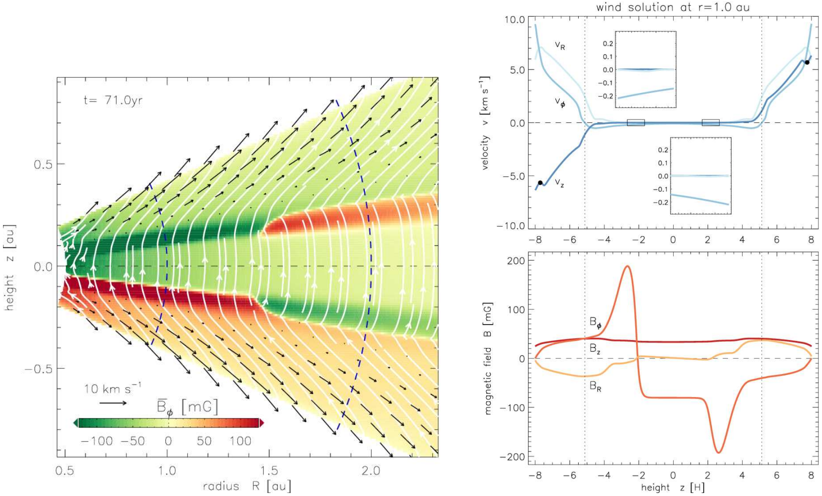

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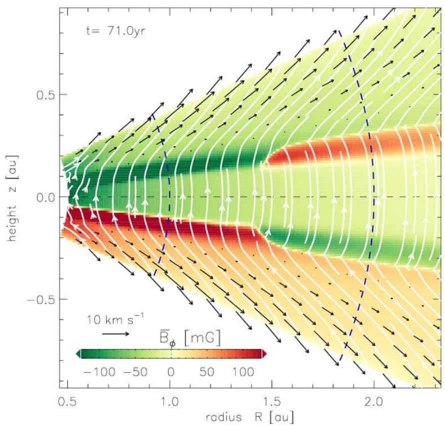
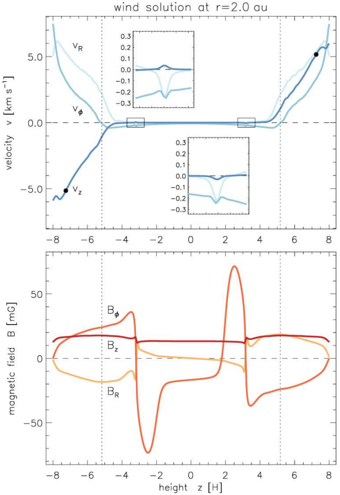
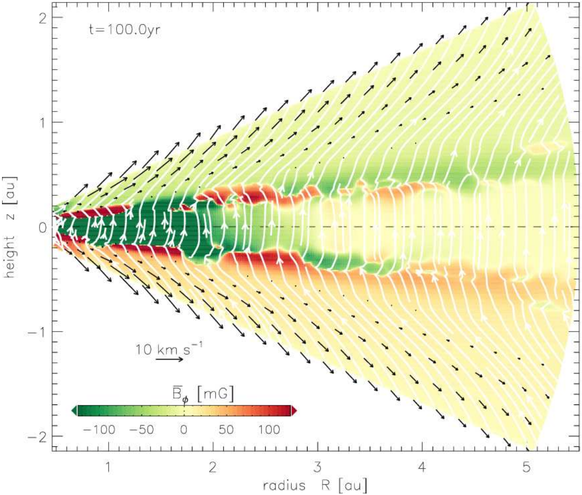




- MMSN disc model, NVF with midplane $\beta_{\mathrm{p}\,0} = 10^5$, d/g mass ratio 10^{-3}, XR+CR+FUV

reduced dust fraction



- MMSN disc model, midplane $\beta_{p\,0} = 10^5$, d/g mass ratio 10^{-4}, XR+CR+FUV

summary of results

- Core accretion
  - spin-out circumplanetary disc
  - mainly vertical inflow of low-metallicity gas
    $\rightarrow$ efficient cooling of contracting envelope (!?)
  - high accretion rate ($\sim 8 \times 10^{-3} M_\oplus \,\mathrm{yr}^{-1}$)
    Saturn $\rightarrow$ Jupiter in $\sim 30,000\,\mathrm{yr}$
- Launching of a "circumplanetary" jet
  - tornado-like flow drags down azimuthal field
  - swirling $\rightarrow$ helical field $\rightarrow$ magneto-centrifugal jet
  - disc outflow important for CPD evolution (!?)
- Including additional microphysics
  - magneto-centrifugal disc wind with AD
  - evolution of embedded sub-disc – work in progress