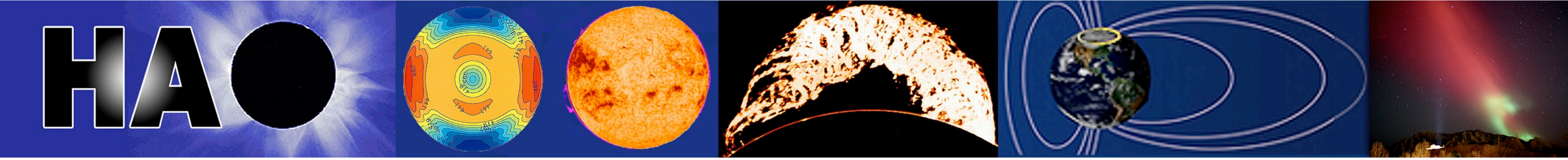

MHD Simulation of X-ray Coronal Jet Produced by Flux Emergence

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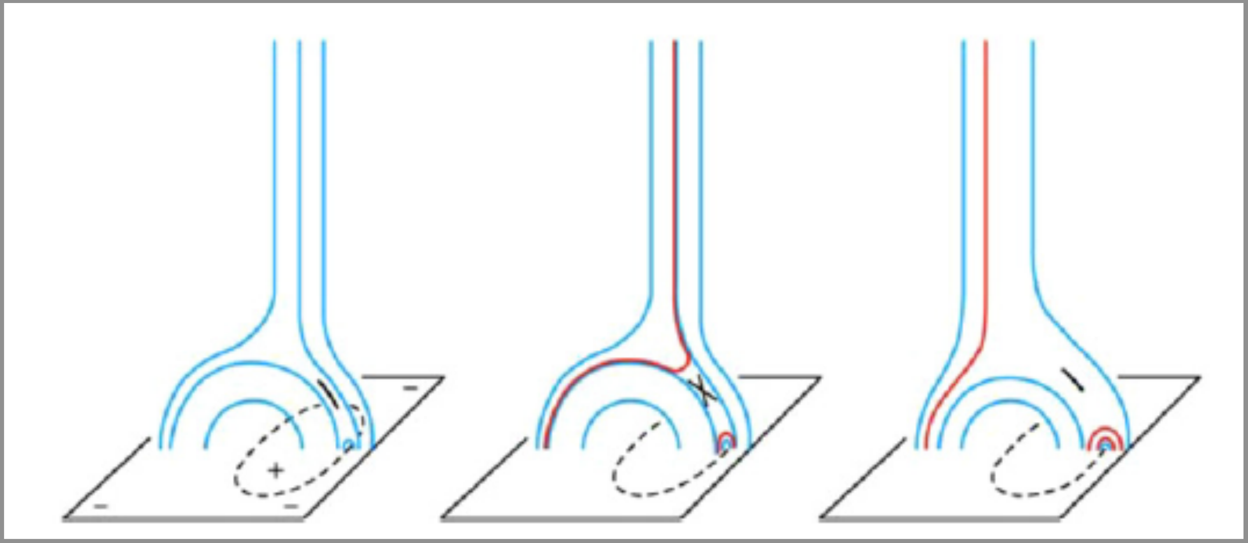
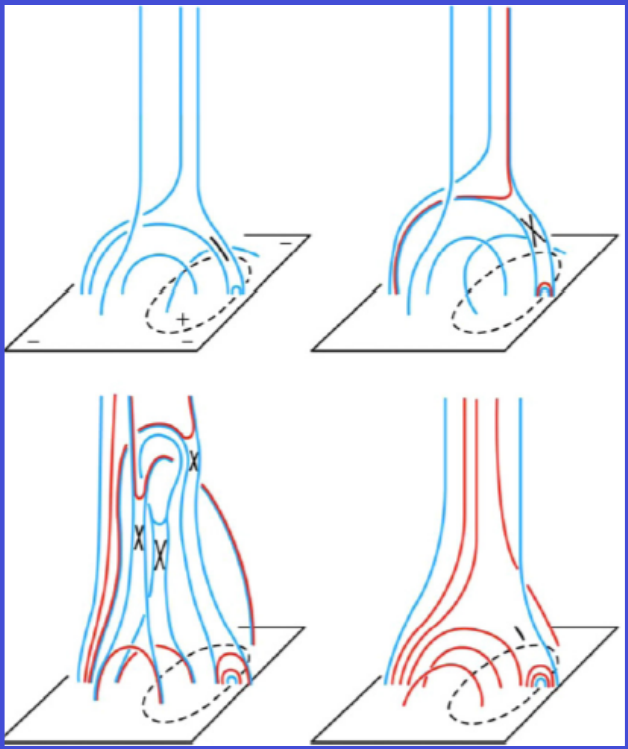
- Solar coronal jets are collimated, hot plasma ejecta ubiquitously seen in X-ray and EUV observations of coronal hole regions.
- Time scale ~ 10min, width ~ 8000km, height ~50,000 km, speed ~ 160km/s

Theory: “Standard” vs. “Blowout” jets

Standard jets: The interior of the arch remains quasi-static during the burst of reconnection.

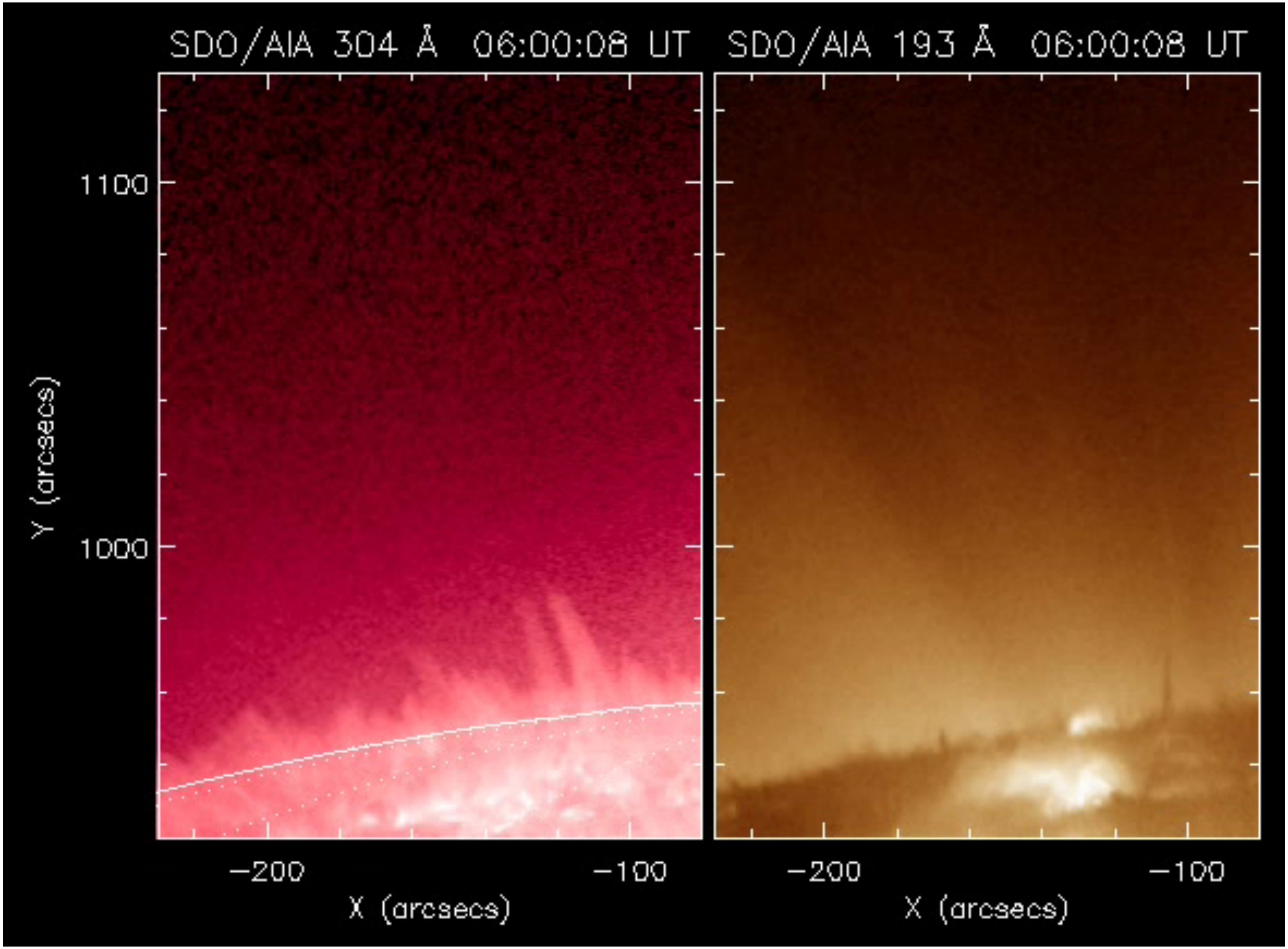




Blowout jets: core field is strongly sheared and twisted that it has enough free energy to drive an ejective eruption, a blowout of the arch, as in a CME eruption.

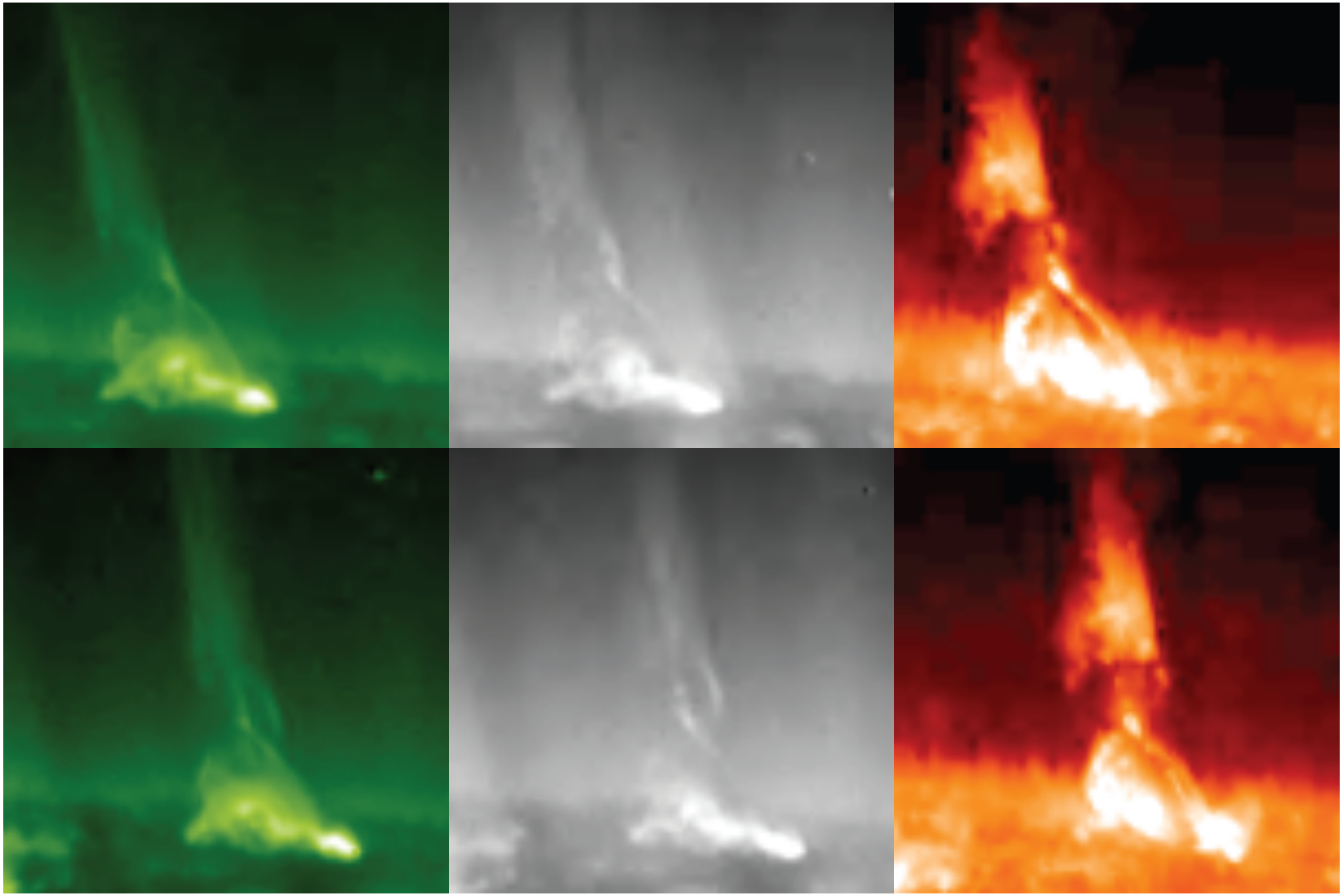
Moore et al, 2010, 2013

Observations of helical jets: twisted field in the eruption



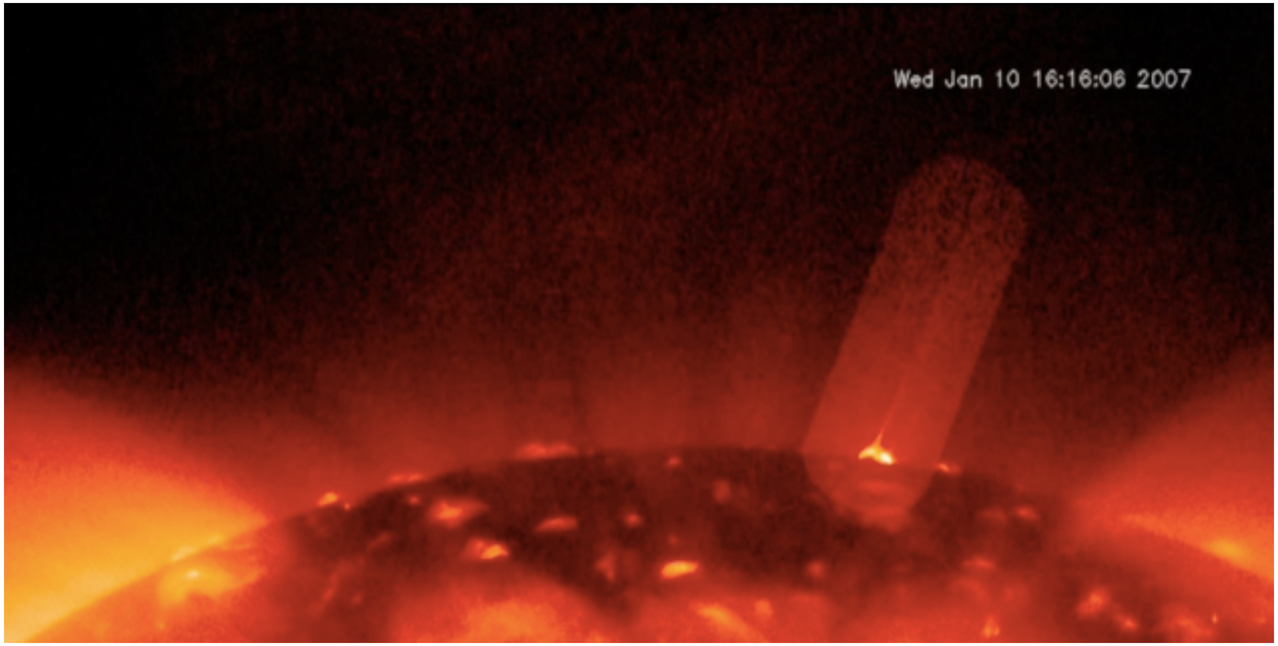
Shen et al., 2011

Observations of helical jets: twisted field in the eruption



Magnetohydrodynamics

- We solve MHD equations in a Cartesian domain to model the emergence of a buoyant twisted magnetic flux tube from the interior into an open coronal field.
- MHD describes the motion and magnetic field evolution of an charged fluid.
- Assumptions:
  - Fully ionized hydrogen gas with $\gamma=5/3$
  - Heating occurs from kinetic energy dissipation as well as reconnection of magnetic fields
  - We incorporate optically thin radiative cooling
  - Electron thermal conduction along the field



Simulation set up

Simulation domain:

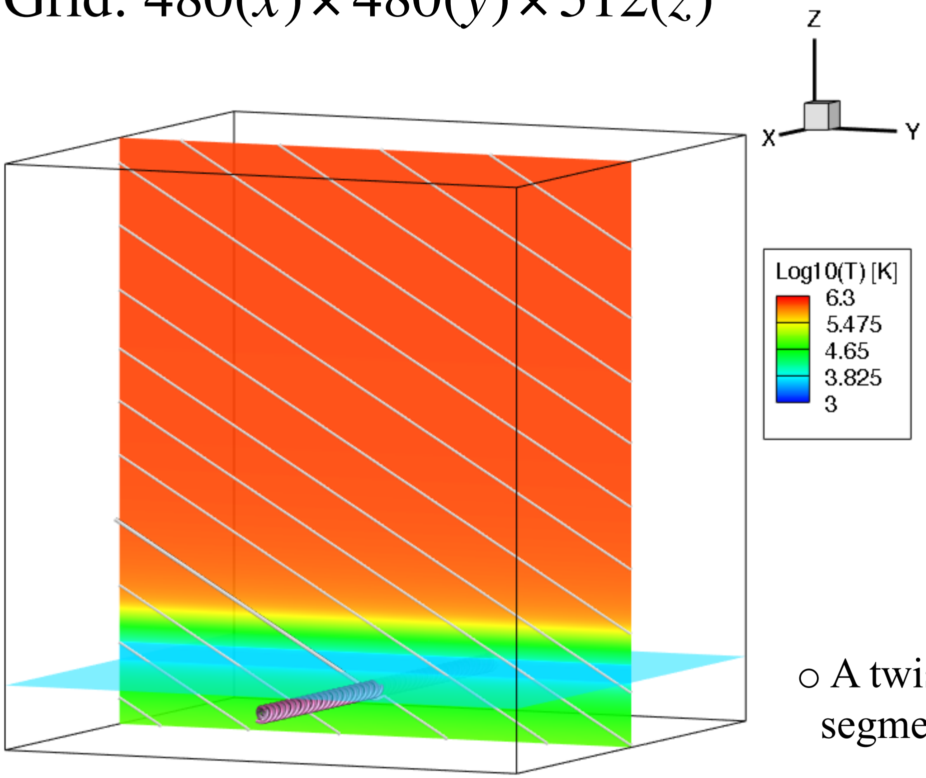
$x \in [-26.5\text{Mm}, 26.5\text{Mm}]$

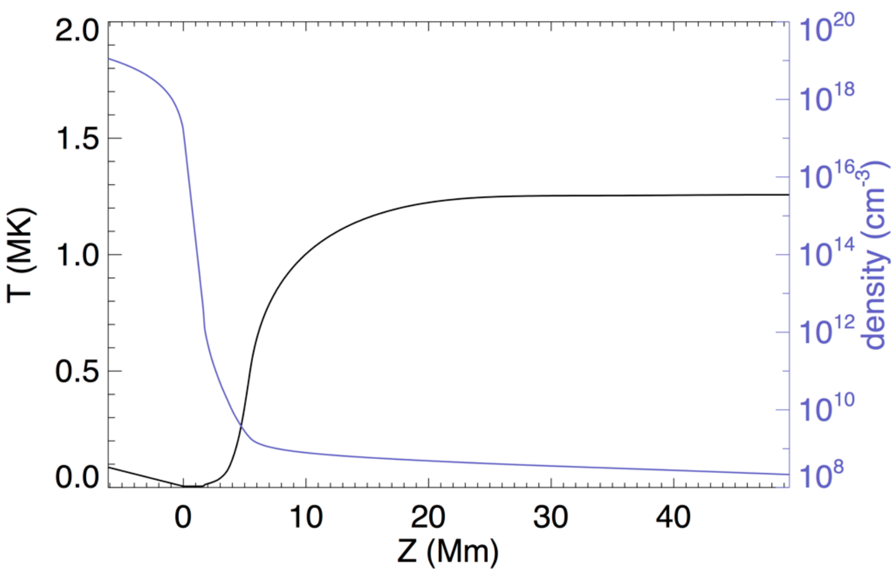
$y \in [-26.5\text{Mm}, 26.5\text{Mm}]$

$z \in [-6.1\text{Mm}, 49.8\text{Mm}]$

Grid: $480(x) \times 480(y) \times 512(z)$

- Initial state:
  - 1D hydrostatic equilibrium containing an adiabatically stratified interior layer, a nearly isothermal photosphere layer, transitioning to a high temperature corona layer, with a uniform slanted open magnetic field.
  - The transition region and corona are maintained by an empirical coronal heating function, with optically thin radiative cooling and field-aligned thermal conduction.

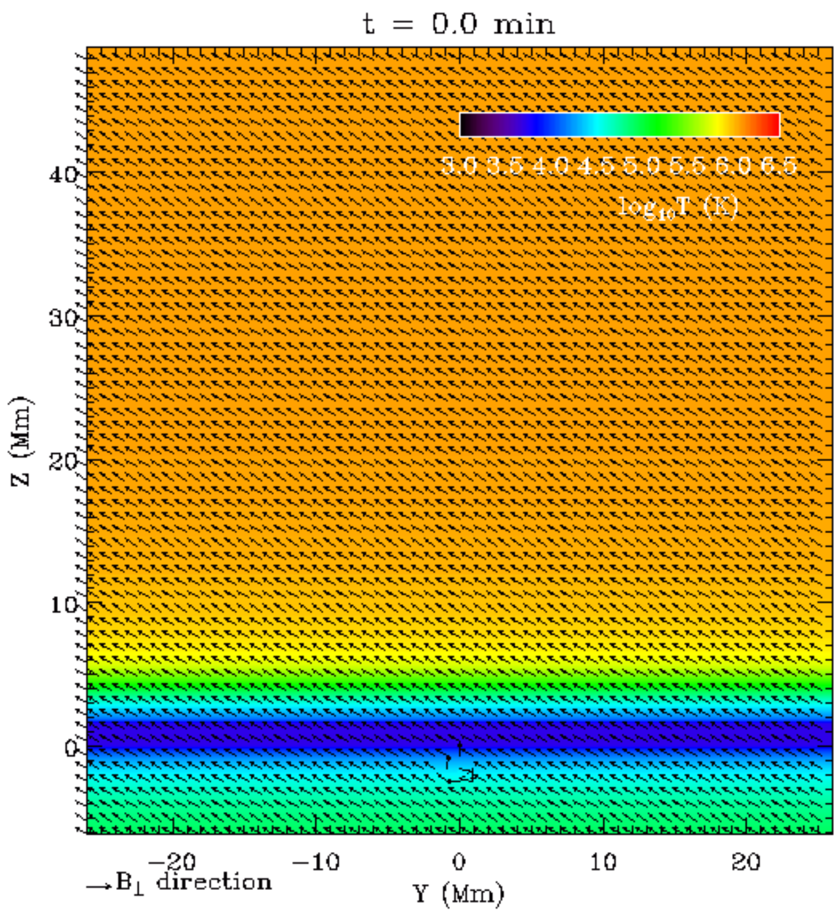




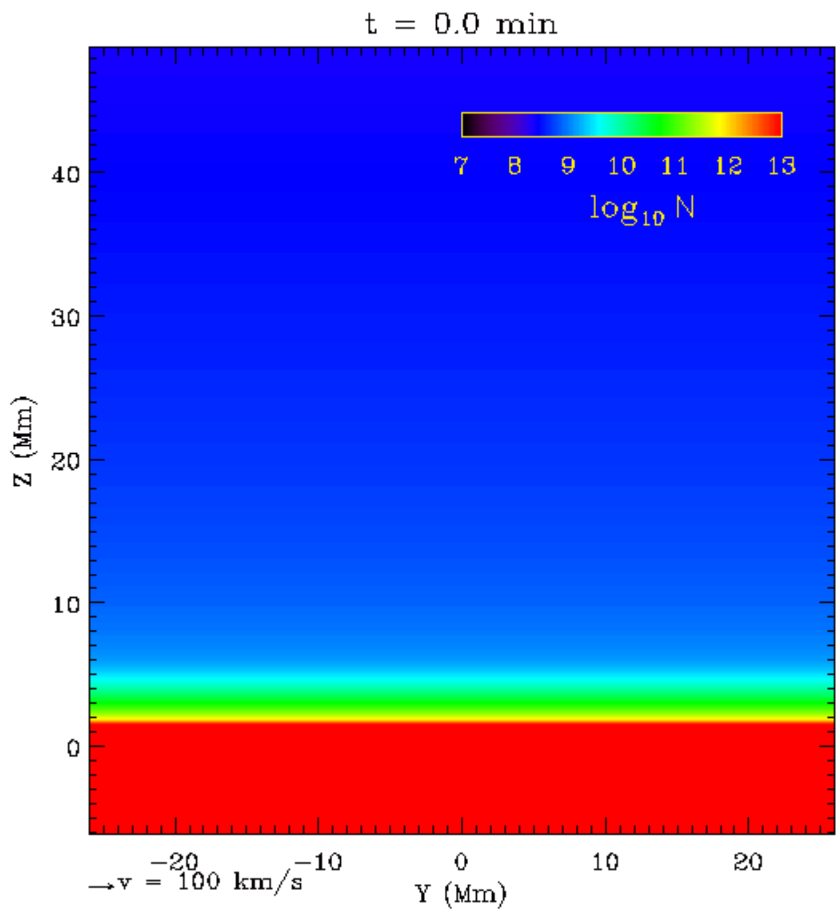
- A twisted horizontal flux tube, buoyant in the middle segment, is inserted just below the photosphere at z=-1.7Mm

Evolution in the central vertical cross section

B vector direction and temperature in the plane

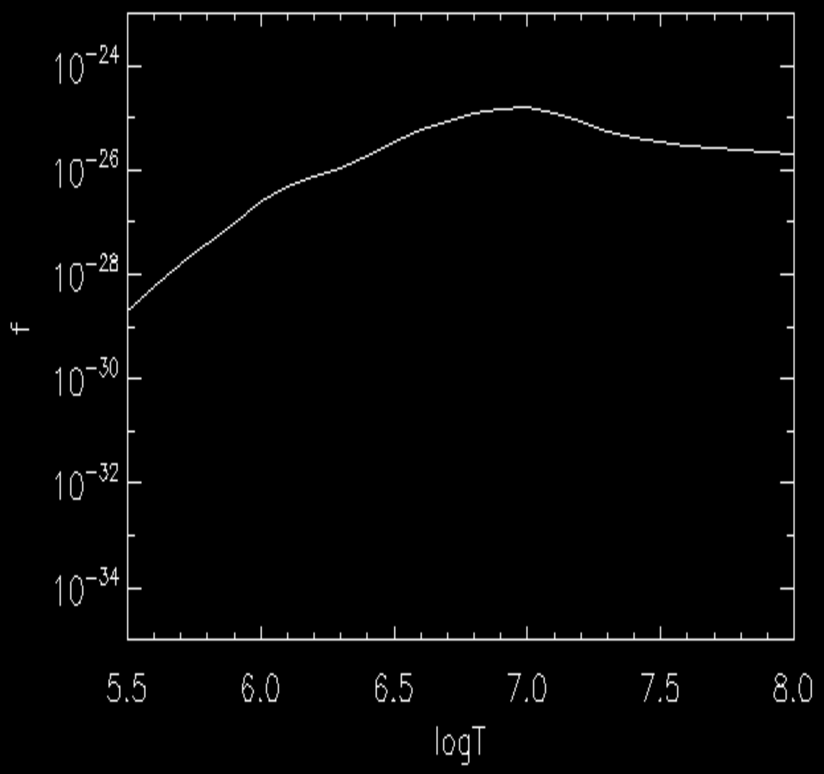


v vector and density in the plane

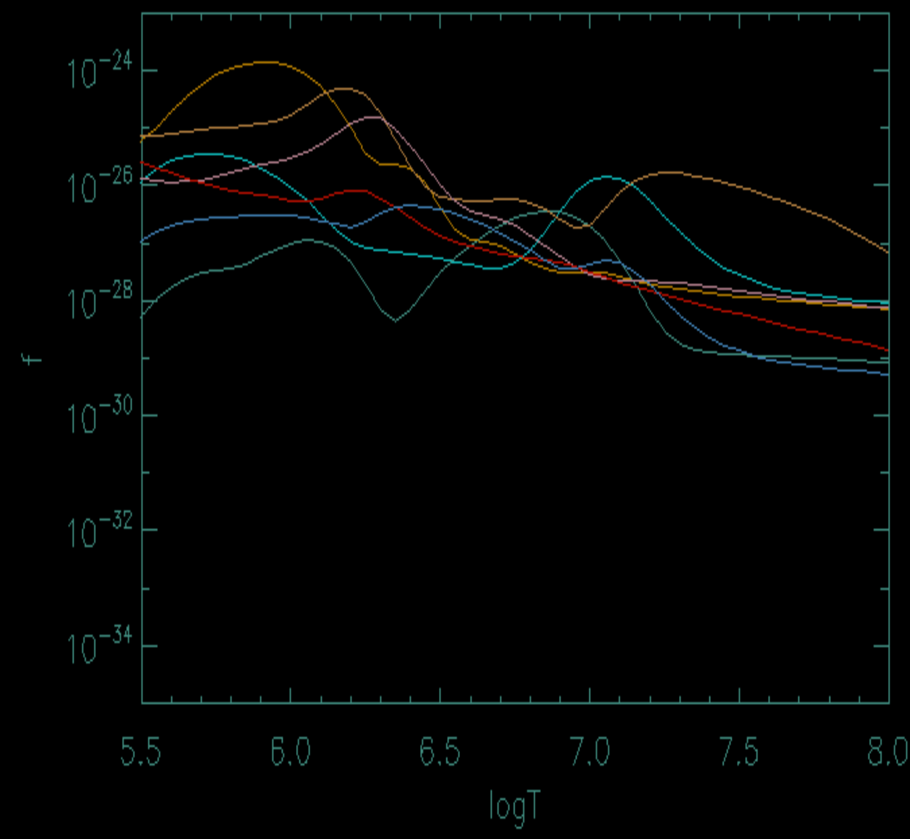


Compute the modeled EUV images by SDO/AIA and X-ray images by Hinode/XRT

$$I = \int n^2(x,y,z) f(T(x,y,z))\, dl$$

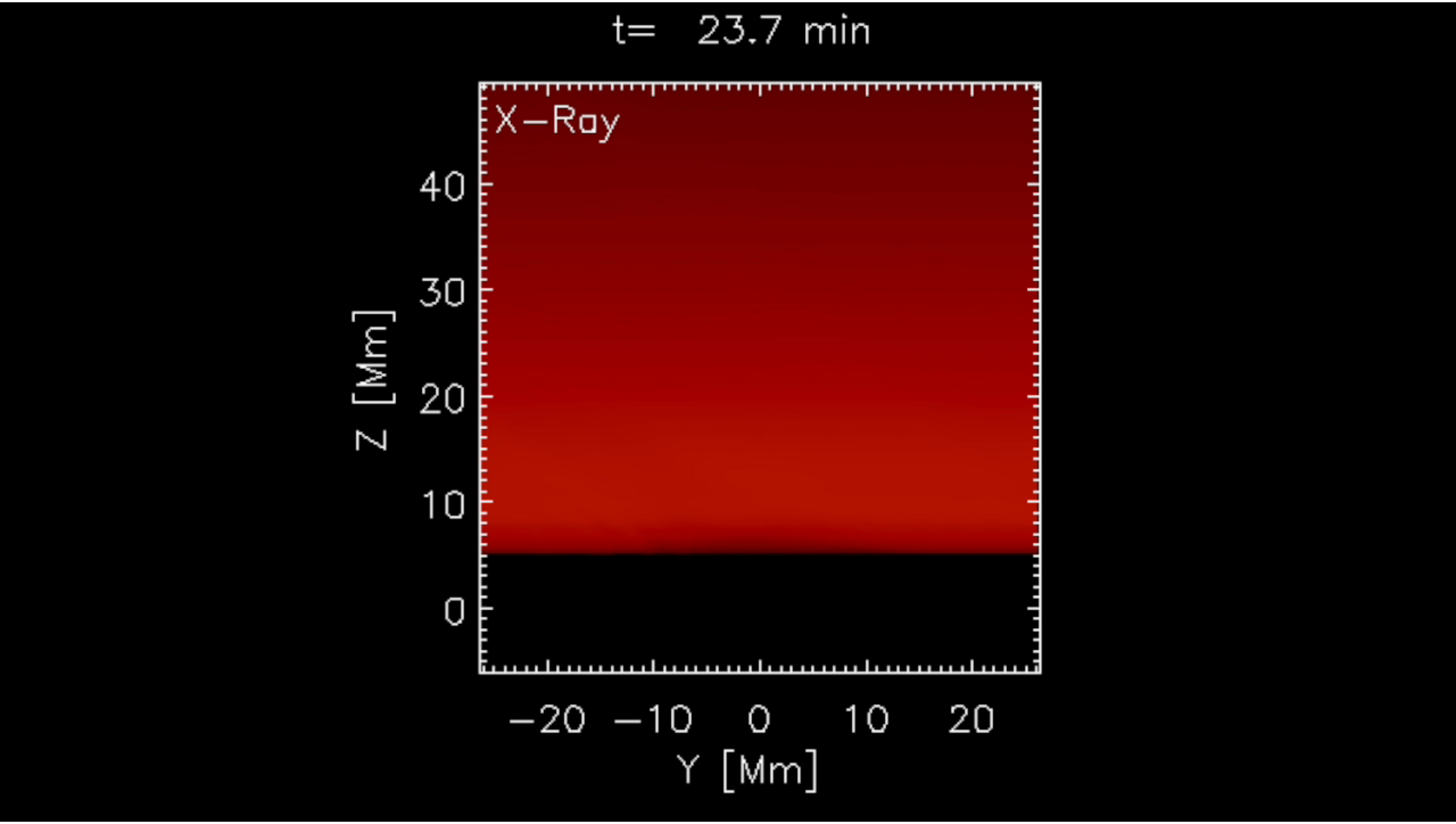


X-Ray Ti-poly

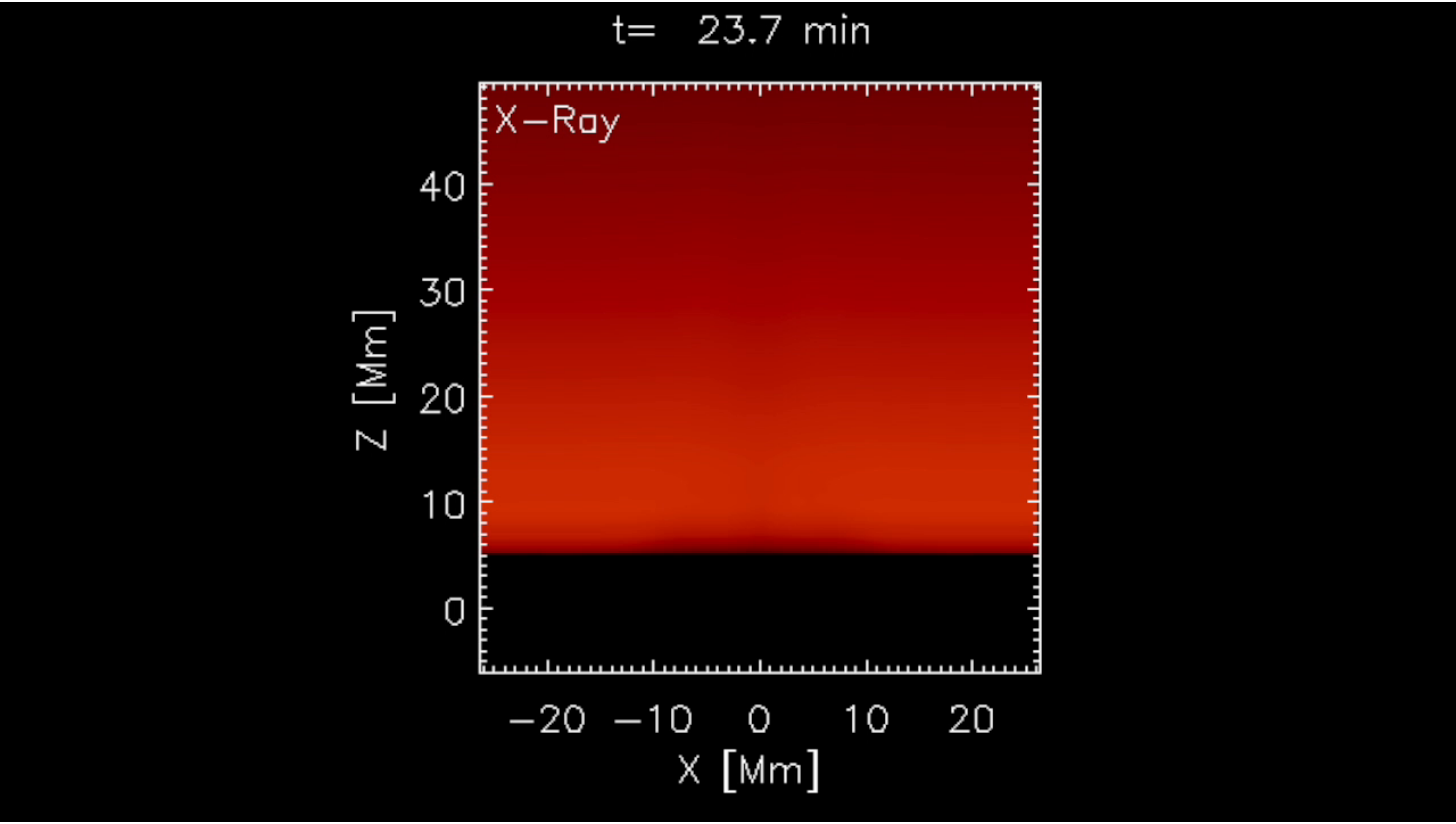


AIA EUV Channels

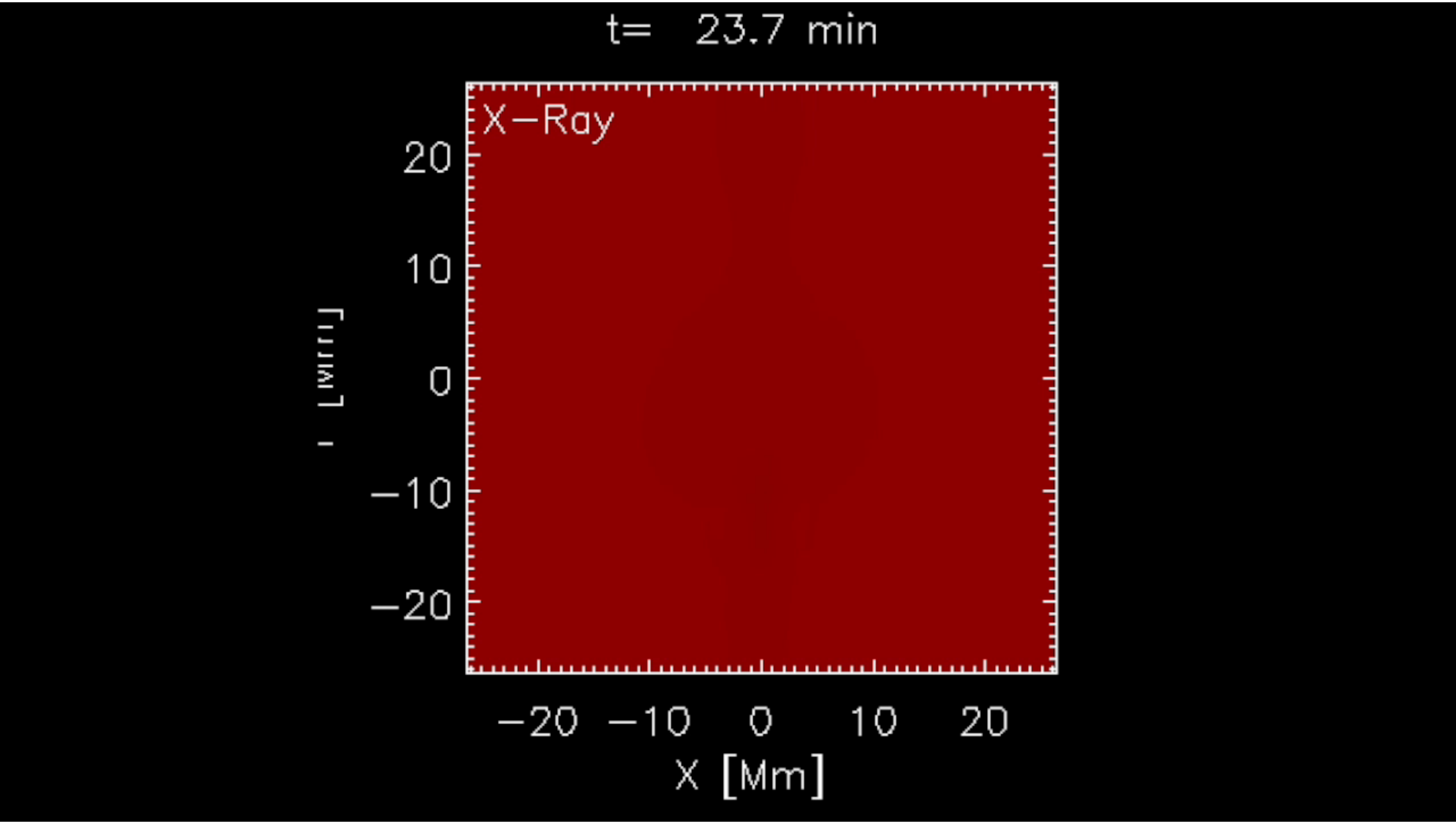
Simulation of X-ray Emissions



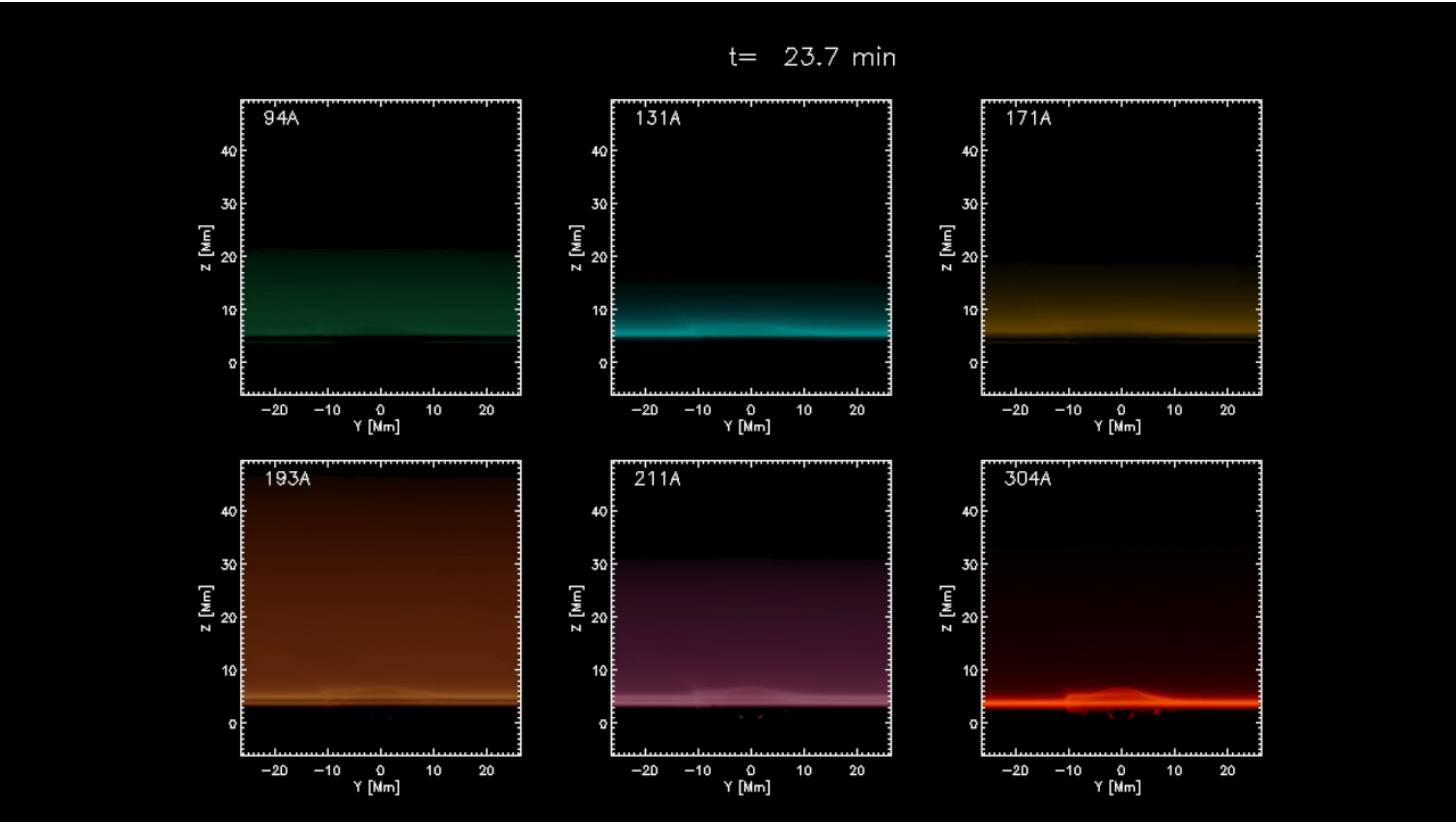
Simulation of X-ray Emissions



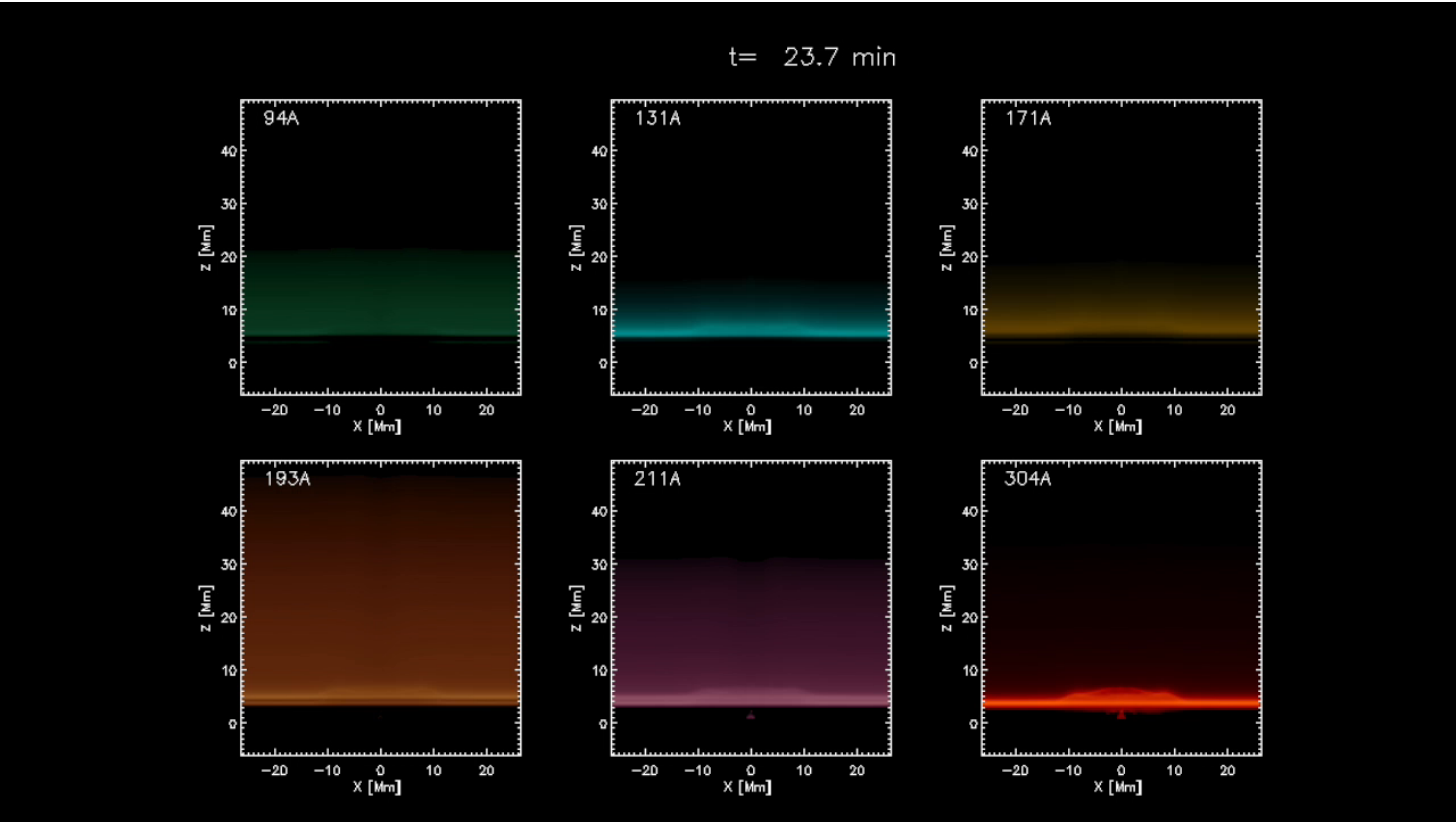
Another Perspective



Simulation of UV Emissions

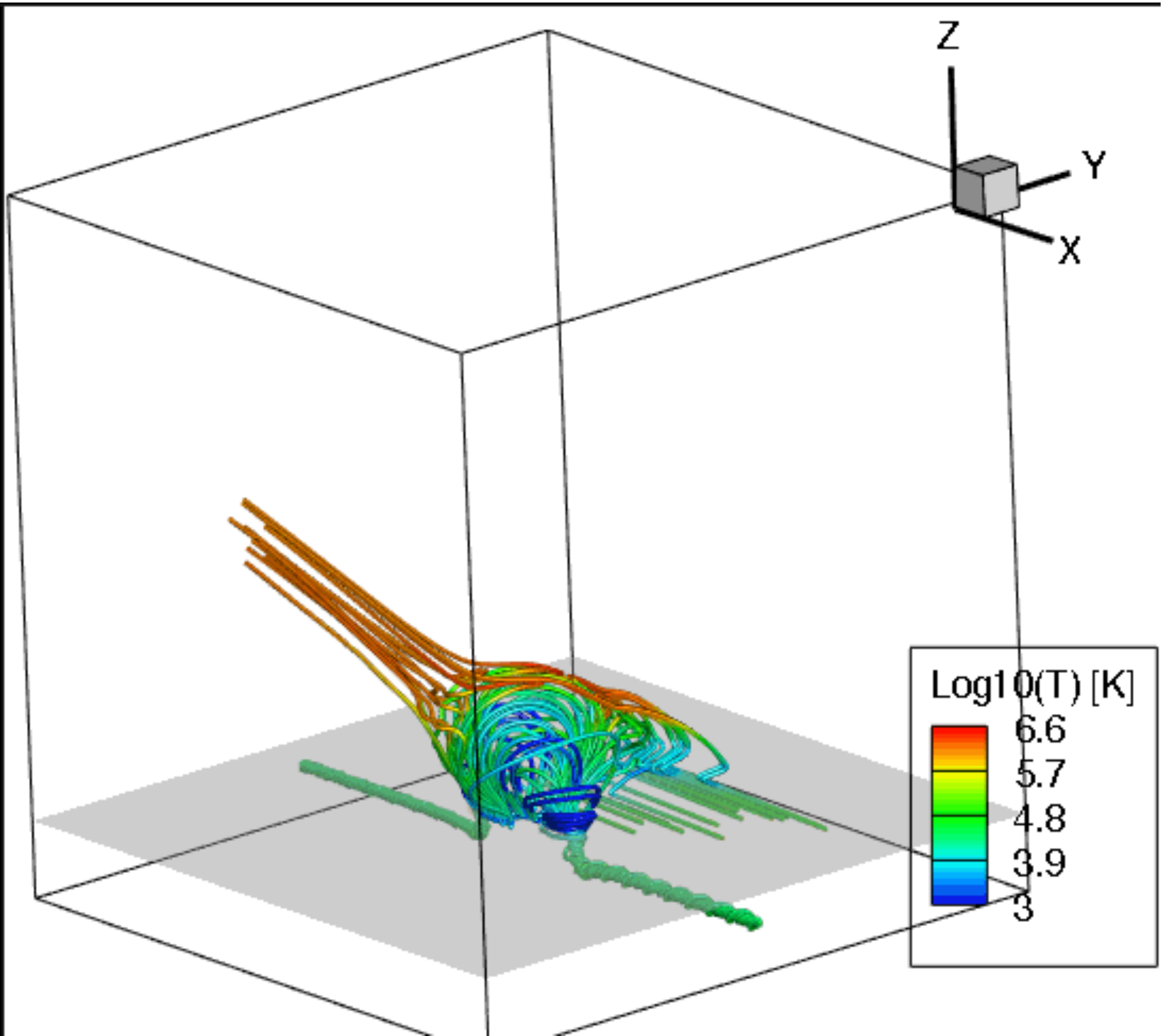


Simulation of UV Emissions

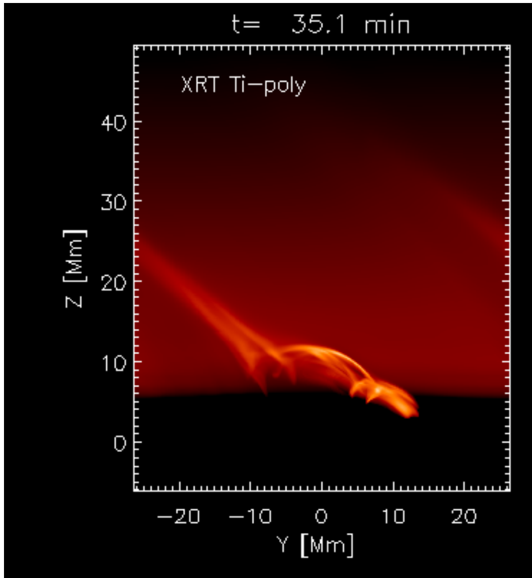


3D magnetic field structure at the "standard jet" phase

it = 89, t = 35.1 min

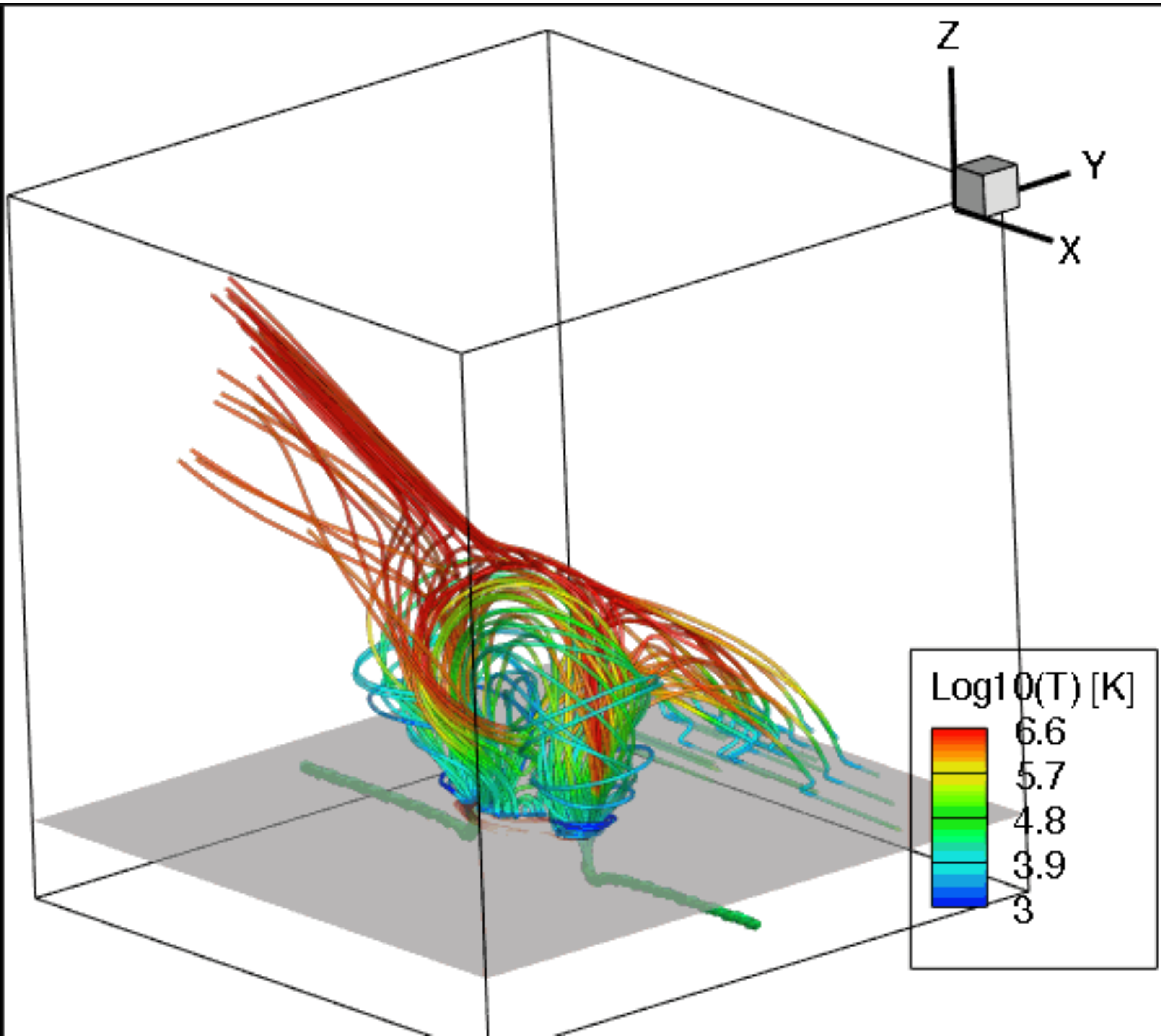


- The emerged field is stable and well-anchored
- Magnetic reconnection between the outer emerged field and the open field→ reconnected heated field lines produce the jet, the bright domes, and the bright close loops on the side (the bright point)

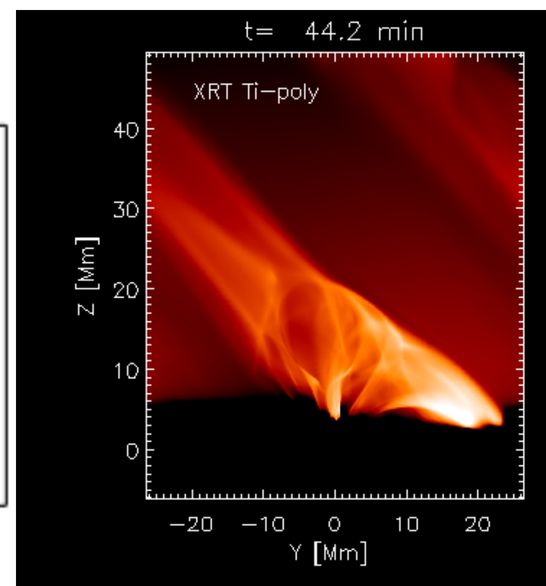


3D magnetic field structure at onset of blowout jet

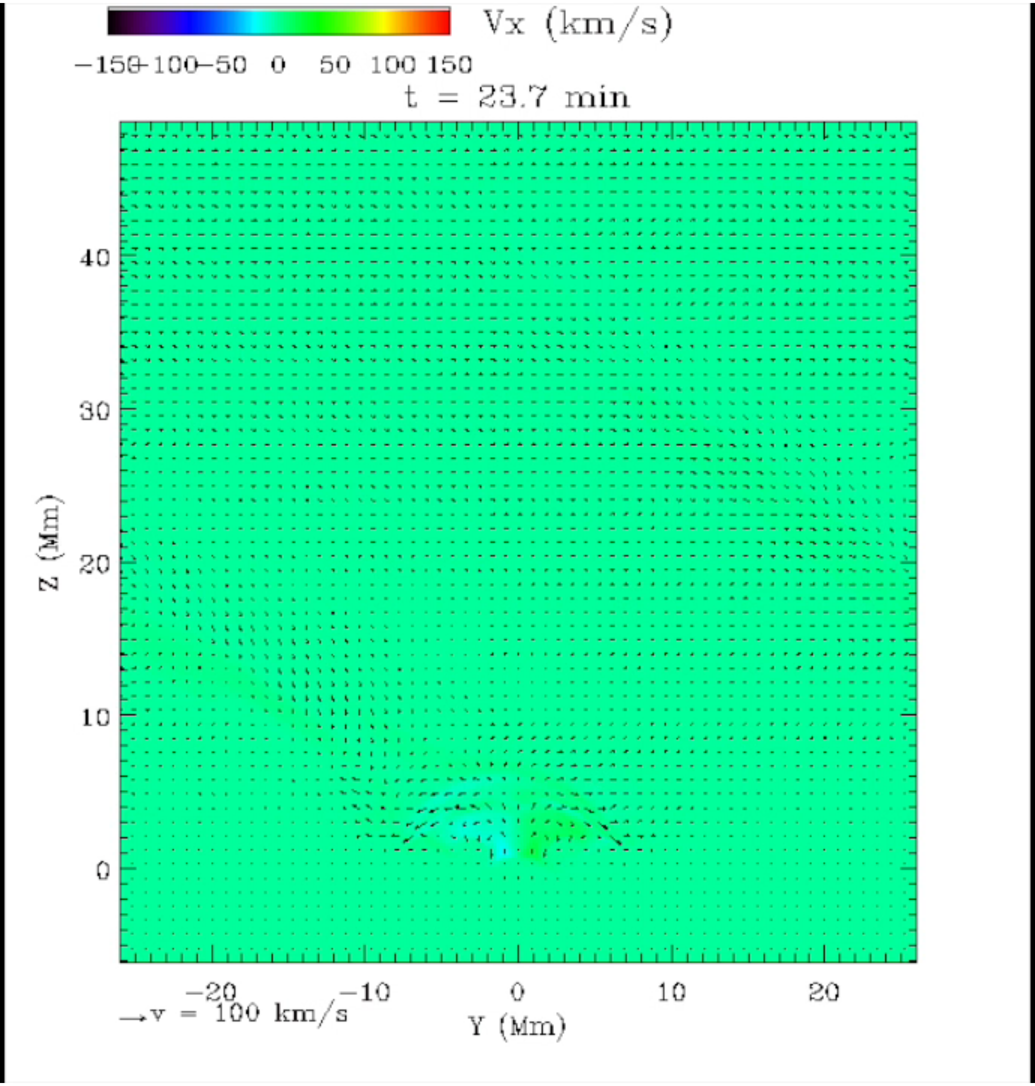
it = 112, t = 44.2 min



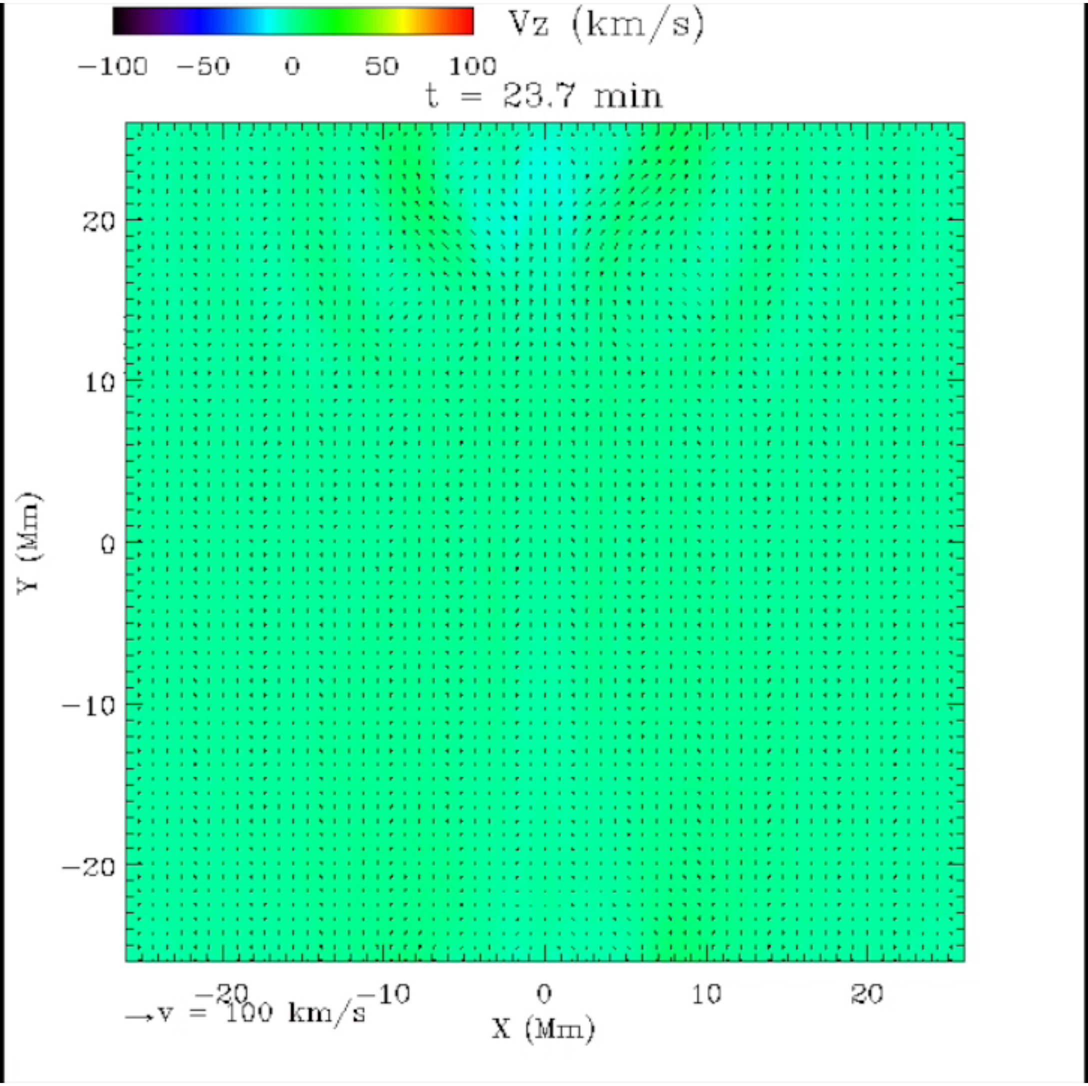
- The emerged flux rope begins to lift off pushing against the open field.
- Twisted core field of the flux rope reconnect with the open field, producing heated jet field lines and closed field lines rooted in the main legs of the rope, brightening of the jet base, in addition to the bright point on the side



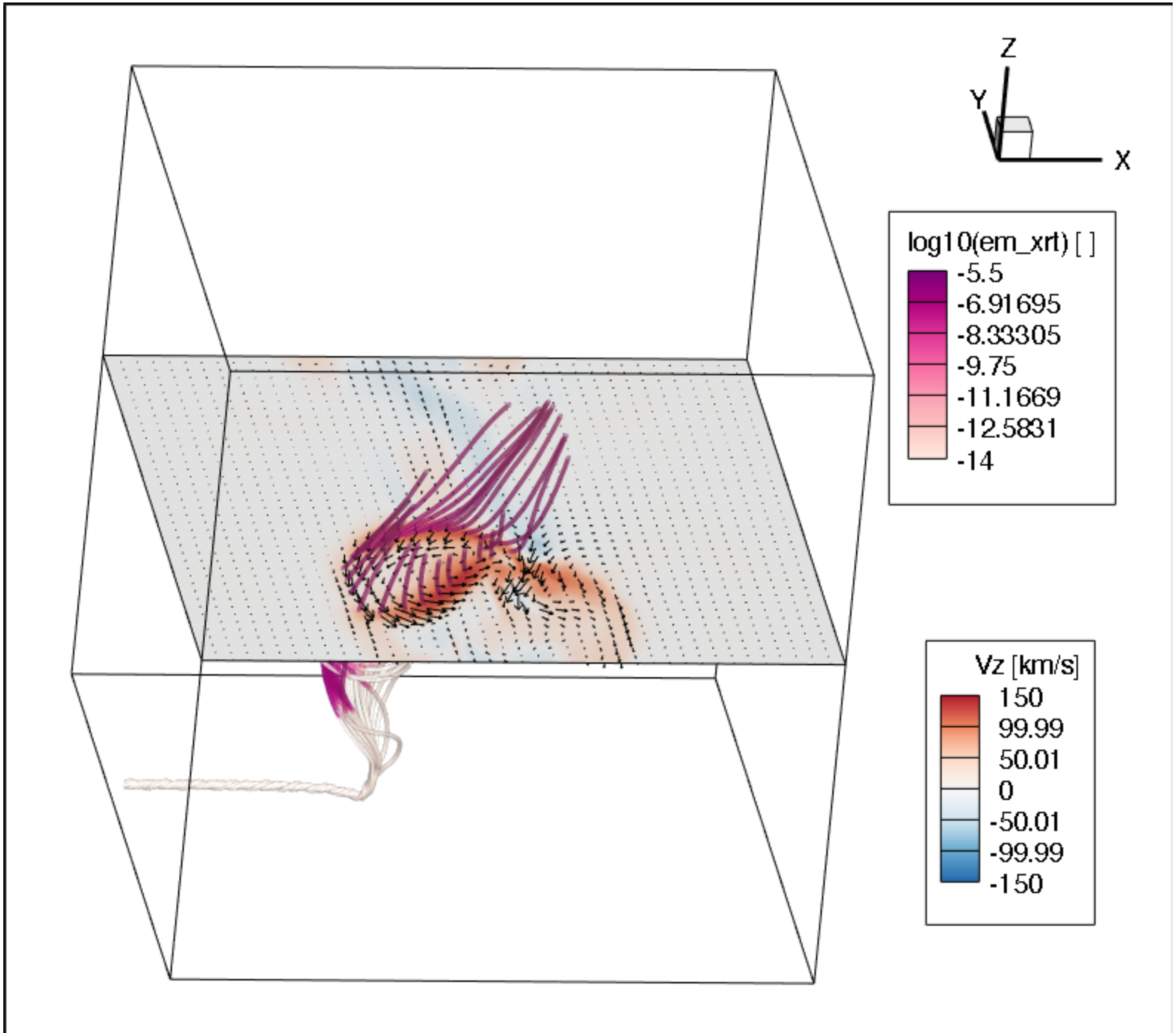
Velocity of the Jet



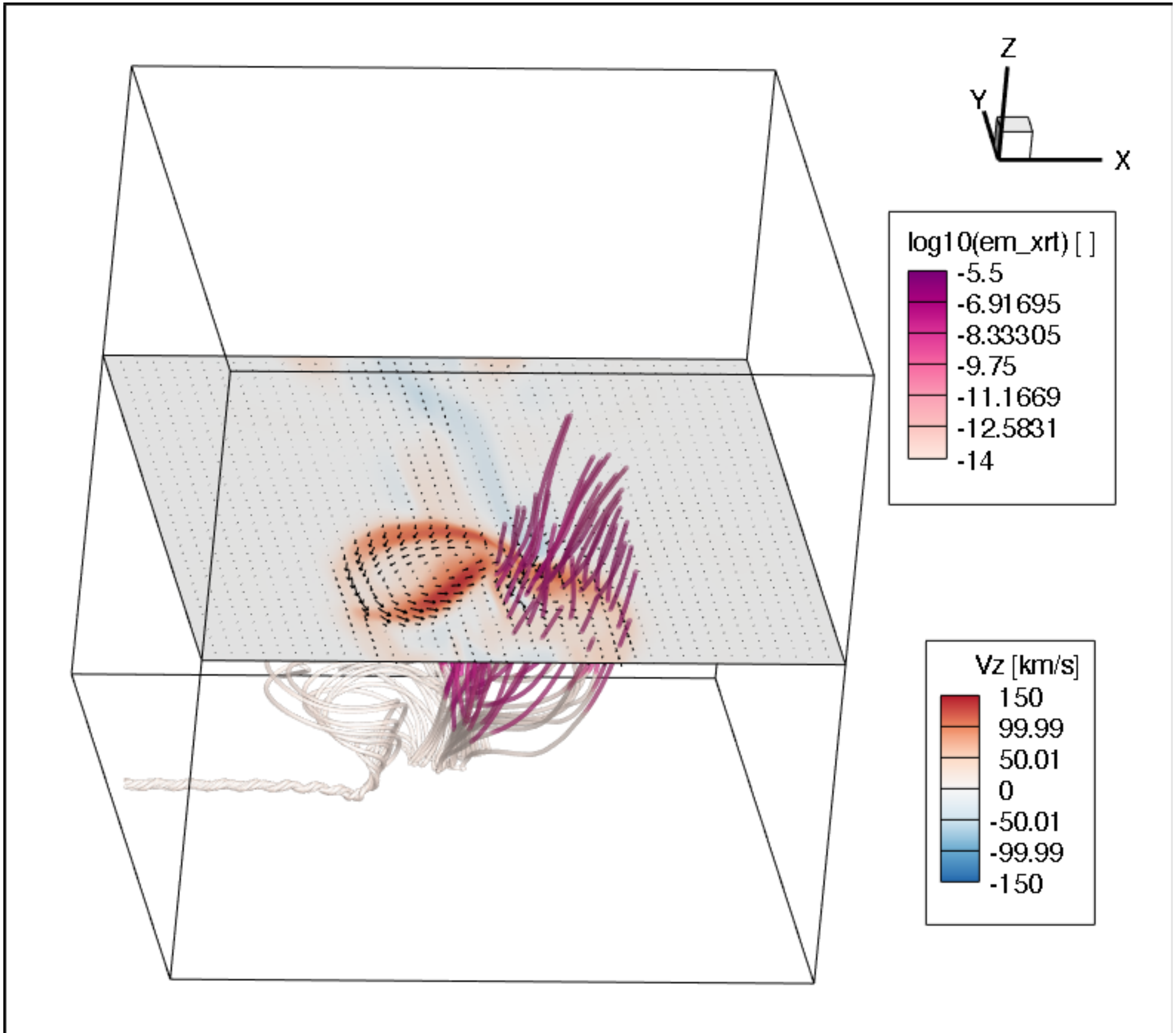
Velocity of the Jet



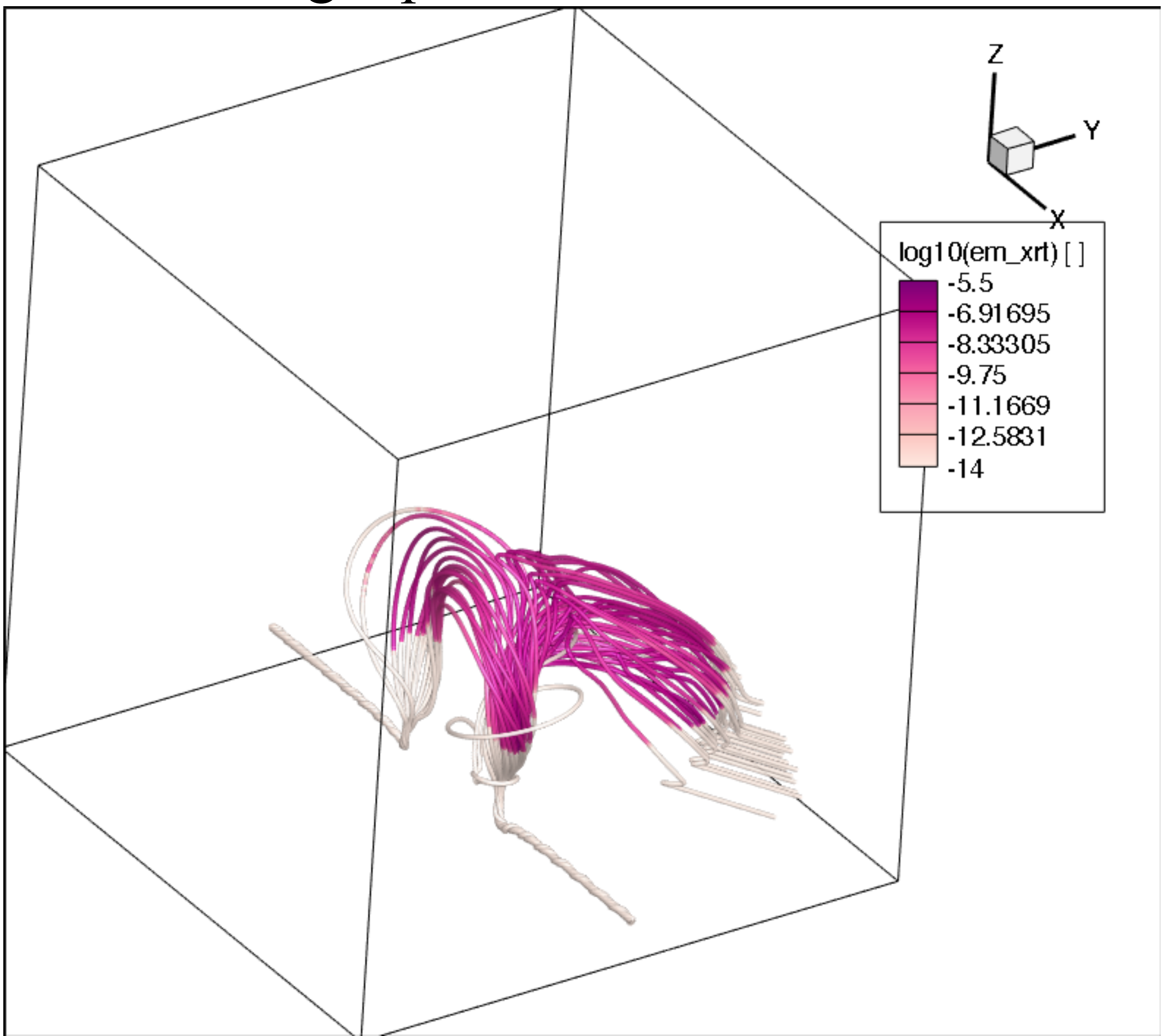
- Rotation of blowout jet due to unwinding of the helical magnetic field lines in the jet column



- Rotation of blowout jet due to unwinding of the helical magnetic field lines in the jet column



- The right leg of the flux rope becomes re-connected with the closed bright point field.



Summary and conclusions

We carry out an MHD simulation of the emergence of a twisted magnetic flux rope from the solar interior into a tilted open coronal magnetic field to study the development of X-ray coronal jets. From the simulation data we compute the modeled X-ray images for Hinode/XRT. We find:

- The observed transition of the "standard jet" to "blowout jet" morphology in X-ray emission can be reproduced by the simulation.
- The "standard jet" morphology is seen in the earlier phase when the emerged flux is still stably anchored, and magnetic reconnection between the outer emerged field and the open field produces the narrow jet, the bright dome, and the jet bright point on the side.
- The "blowout jet" morphology is produced when the emerged flux rope begins to erupt, and the twisted core field of the flux rope reconnect with the open field, leading to widening of the jet and brightening of the jet base.
- Two rotating jet columns develop, with the same sense of rotation. The rotation is driven by the unwinding of the twisted magnetic field in the open jet columns, connected mainly to one side of the flux rope.
- The ejection speed and the rotational speed in the jet columns are consistent with the observed values for blow-out jets.


Questions?

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