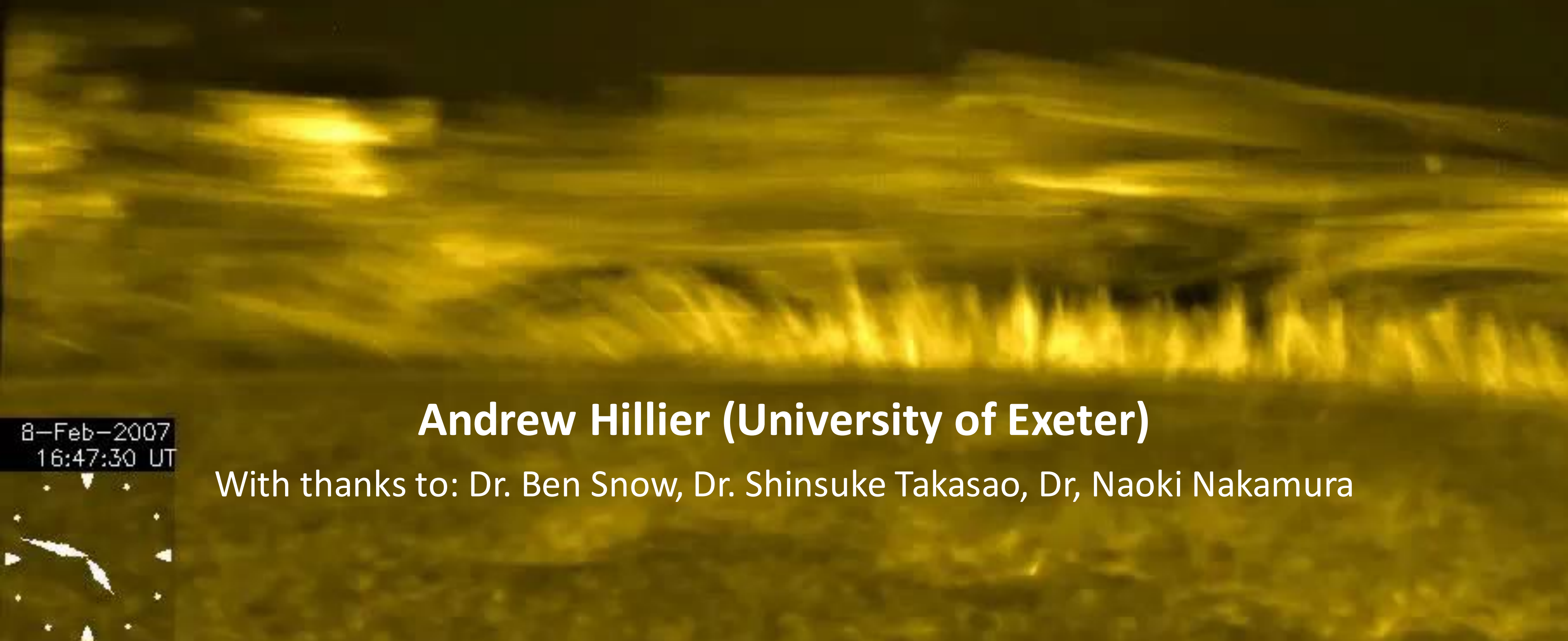
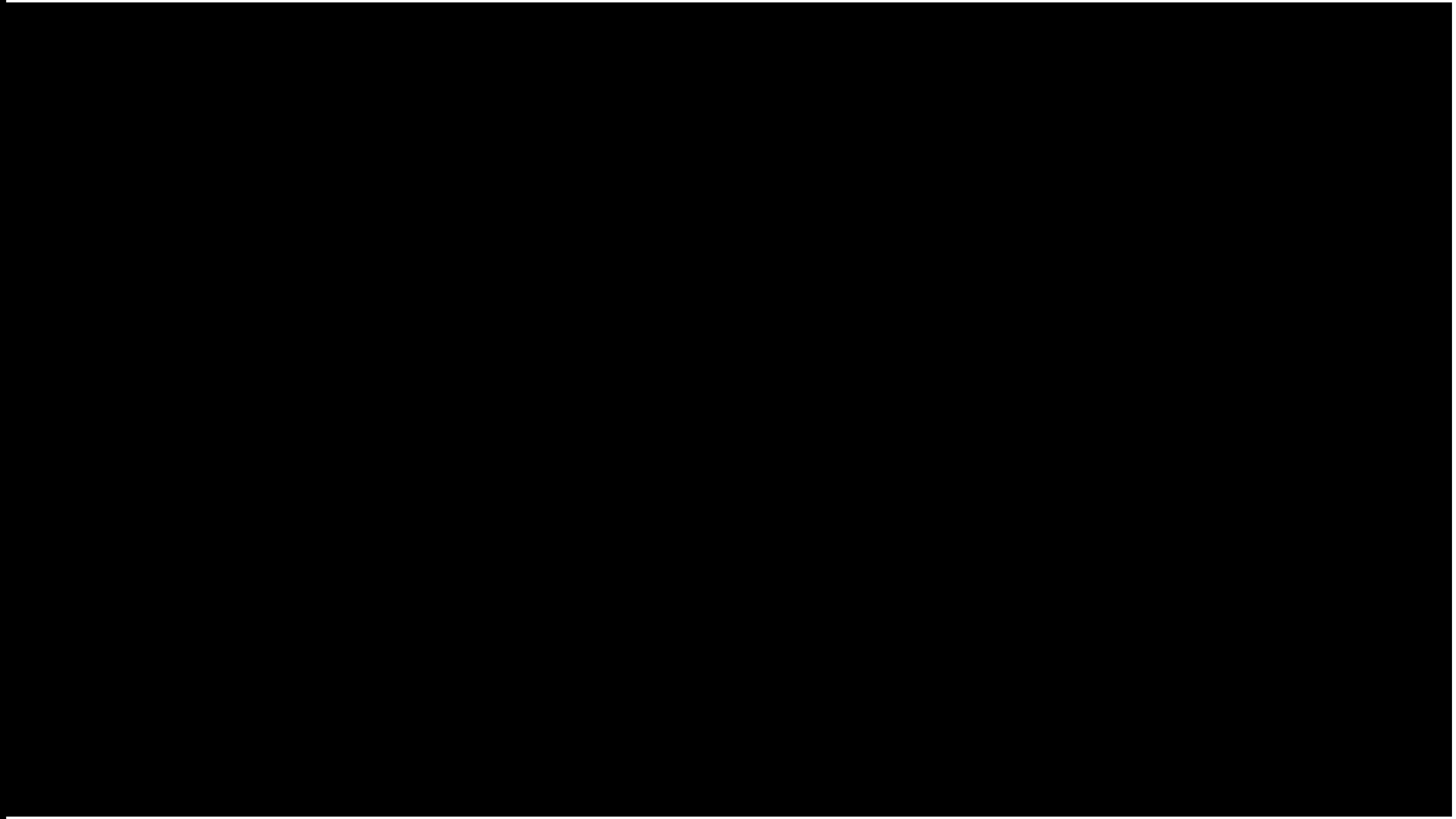
Shocks and Instabilities in the partially ionised plasma of the solar atmosphere

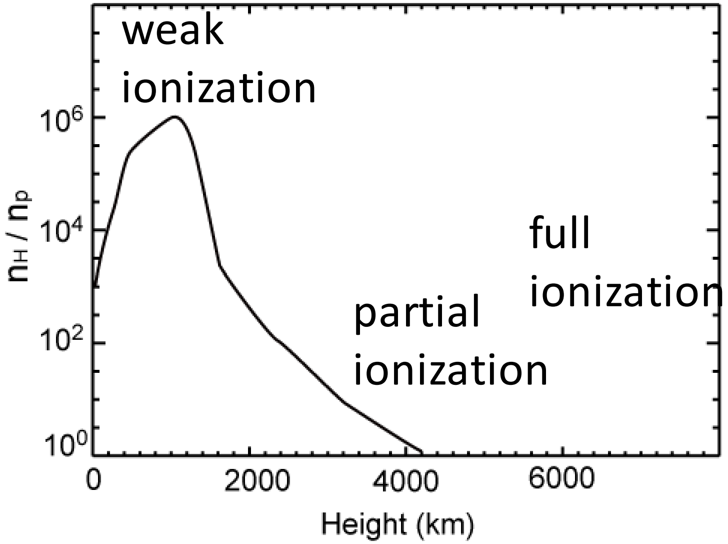


Andrew Hillier (University of Exeter)

With thanks to: Dr. Ben Snow, Dr. Shinsuke Takasao, Dr, Naoki Nakamura

The partially ionized solar atmosphere





Courtesy of H. Isobe

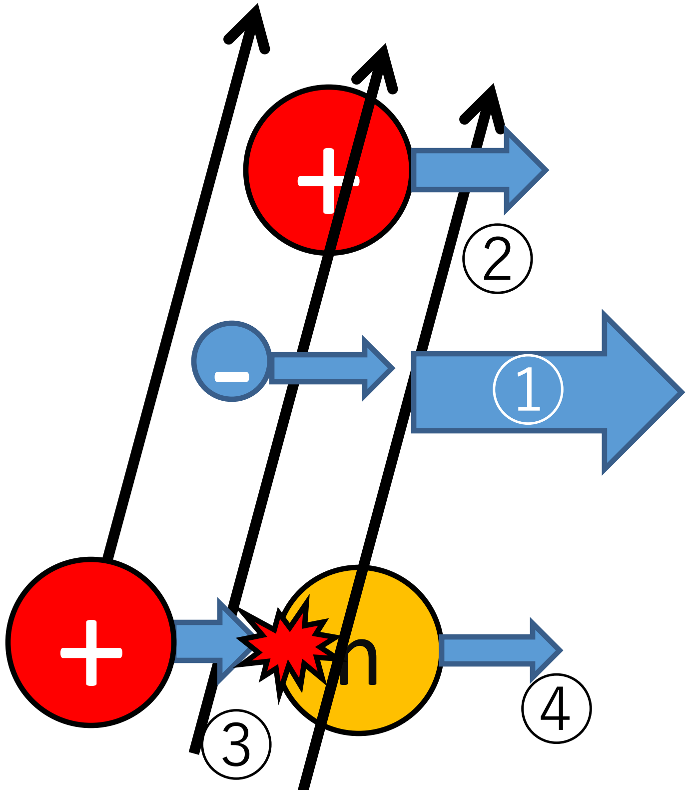
How are neutrals coupled to magnetic fields?

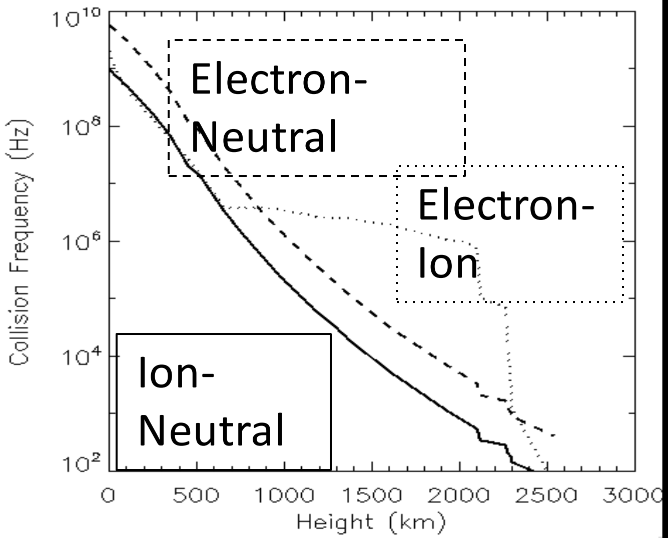
① Movement of magnetic field

② together with charged particles

③ Charged particles collide with neutrals

④ Neutrals move in the same direction as the charged particles



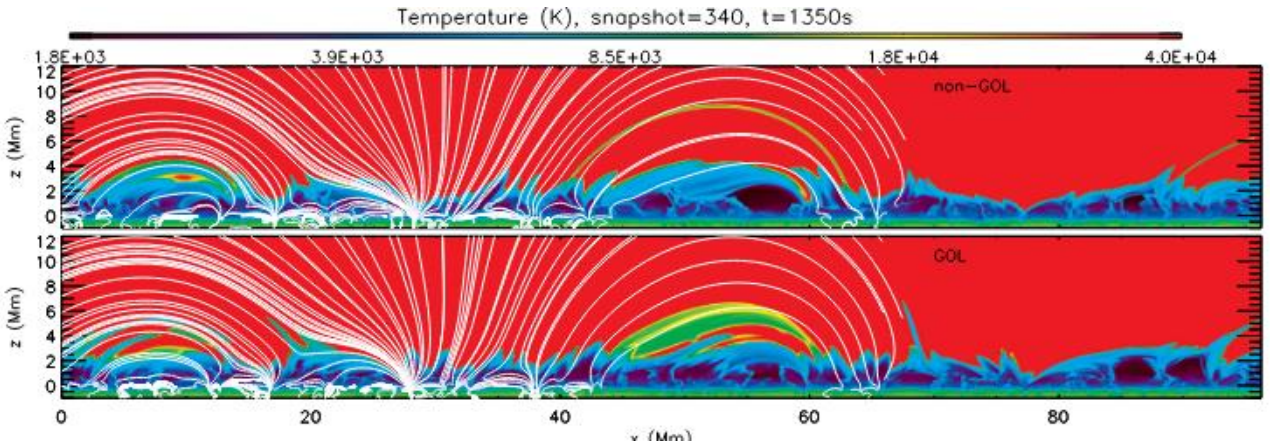


From H. Isobe

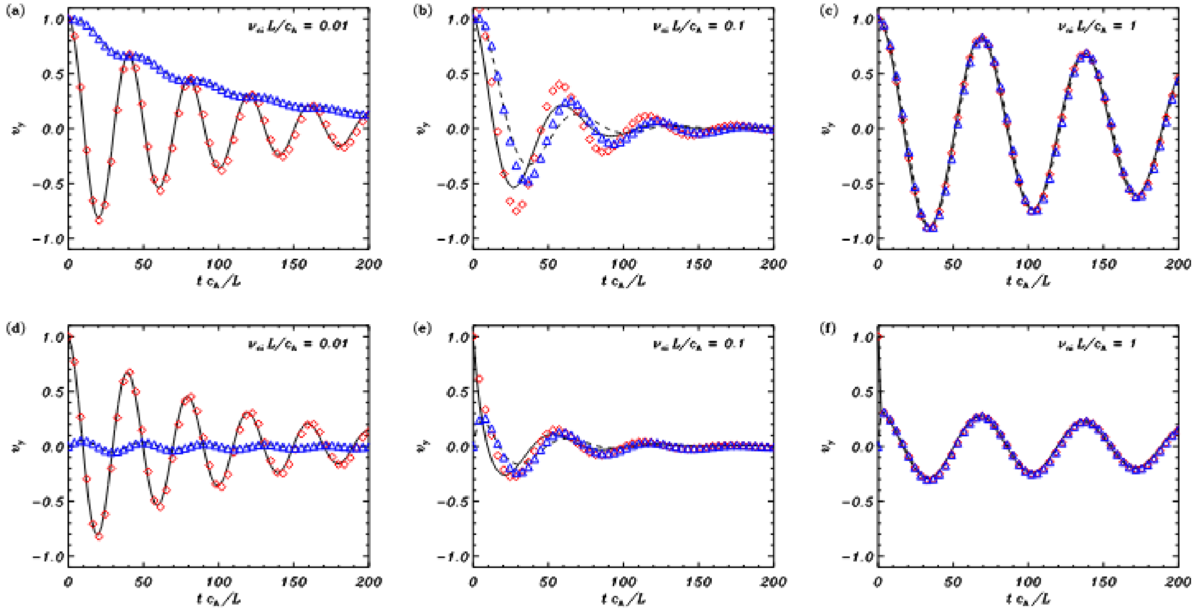
Perfect coupling	strong coupling	marginal coupling	weak coupling	no coupling
$\nu_{in/ni} = \infty$	$\nu_{in/ni} \gg \nu_{DYN}$	$\nu_{in/ni} \sim \nu_{DYN}$	$\nu_{in/ni} \ll \nu_{DYN}$	$\nu_{in/ni} = 0$

How partially ionised plasma becomes important?

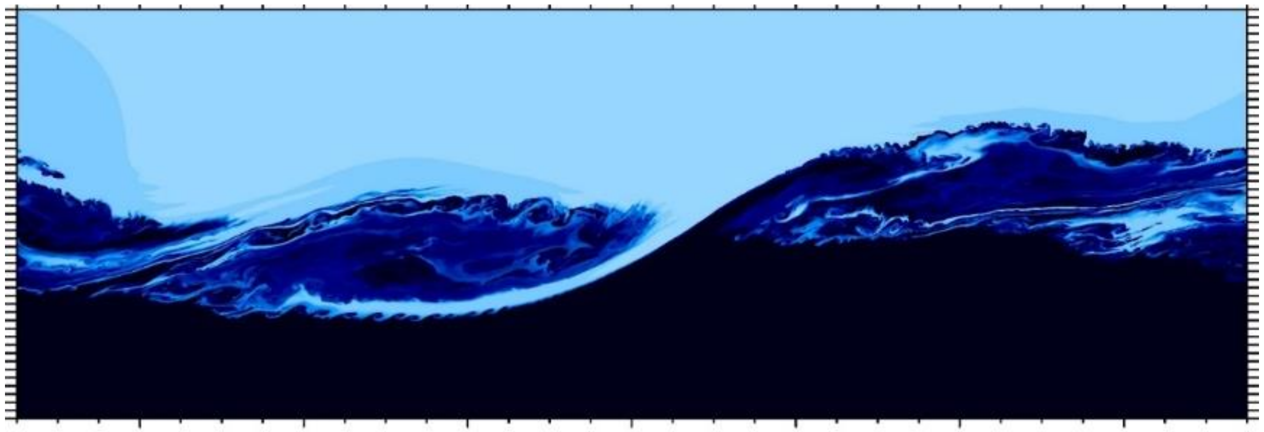
Heating e.g. Martinez-Sykora et al (2017, single fluid)



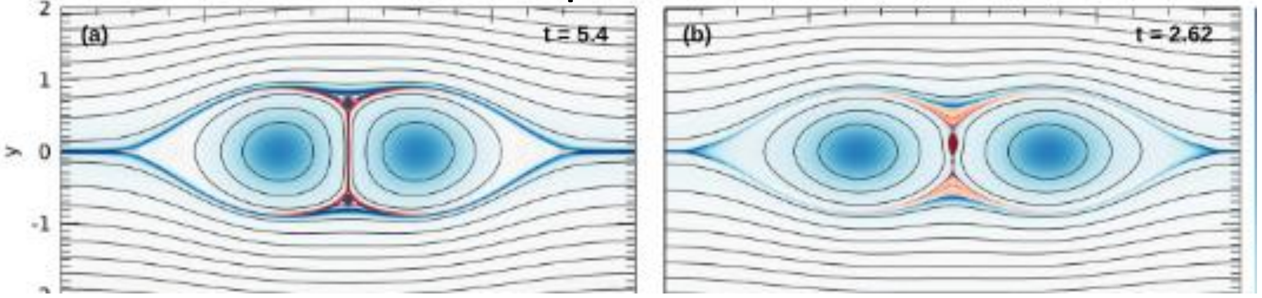
Wave damping e.g. Soler et al (2012, two fluid)



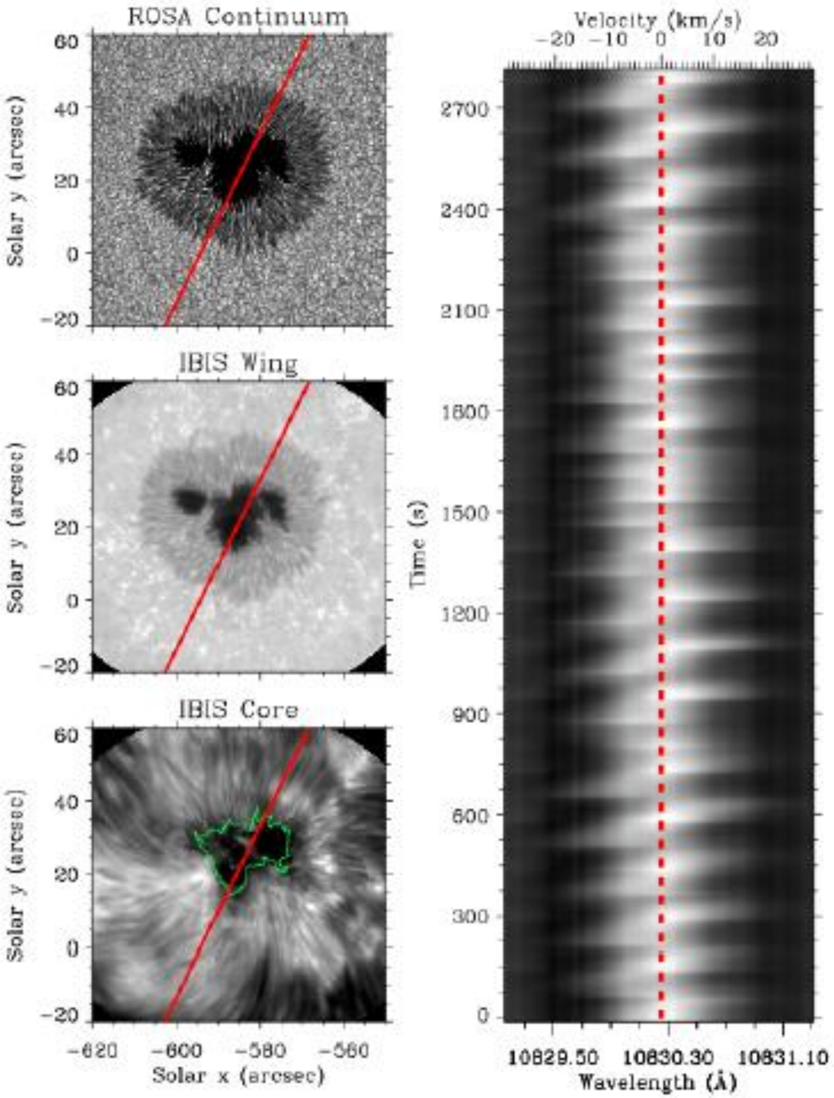
Cross-field transport e.g. Hillier (2019, two fluid)



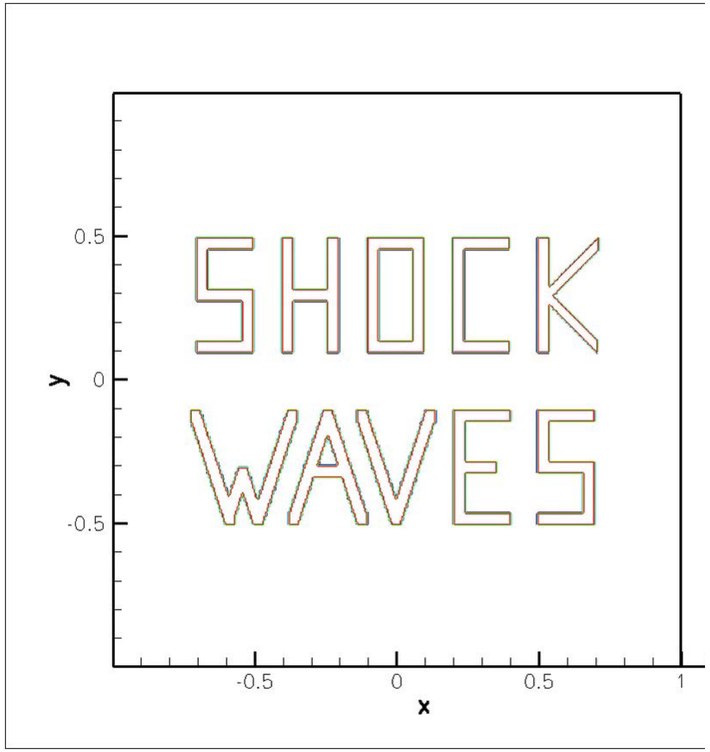
Change in dynamics Murtas et al (2021, two fluid) and poster 176



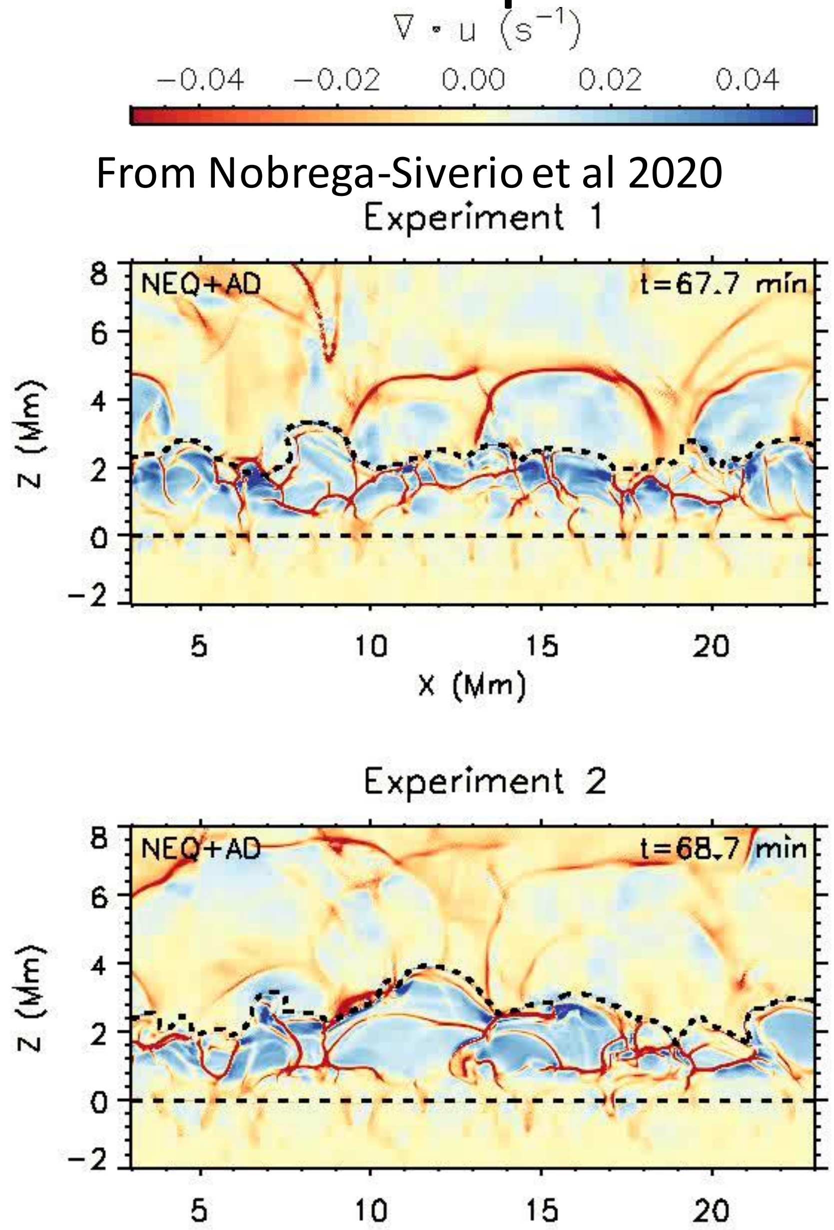
Shocks in the partially ionised solar atmosphere



From Houston et al (2018)

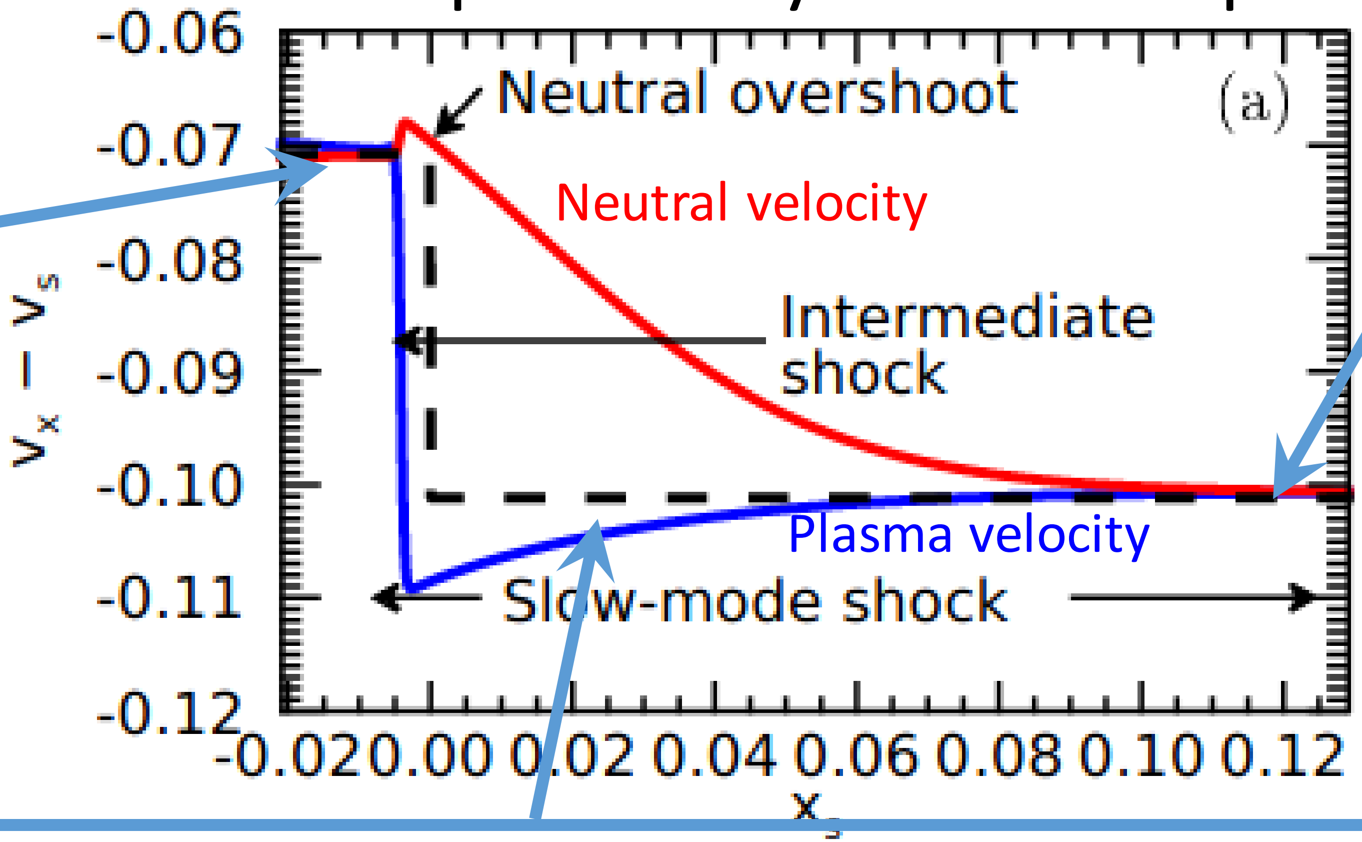


From Nobrega-Siverio et al 2020



A shock in a partially ionised plasma

Plasma and neutral gas recouple downstream of the shock



Plasma and neutral gas are coupled upstream of the shock

Snow and Hillier 2019

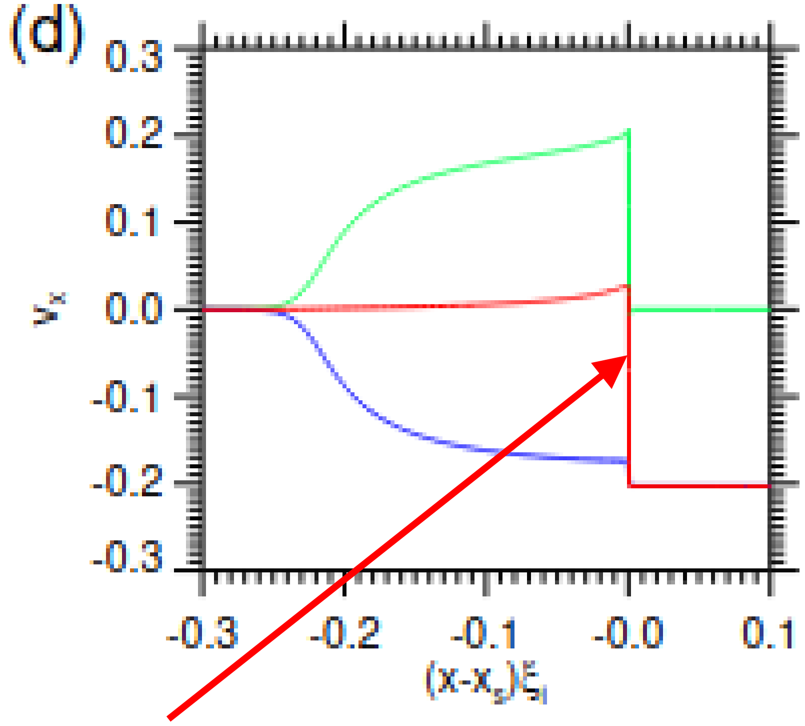
But in the shock, which has a finite width, the fluids decouple.

The width of the shock depends on a wide degree of parameters but could regularly be order of 1km in the chromosphere or even larger!

But looking at the shock jumps there is no difference between a PIP shock and an MHD shock (e.g. Snow and Hillier 2019)

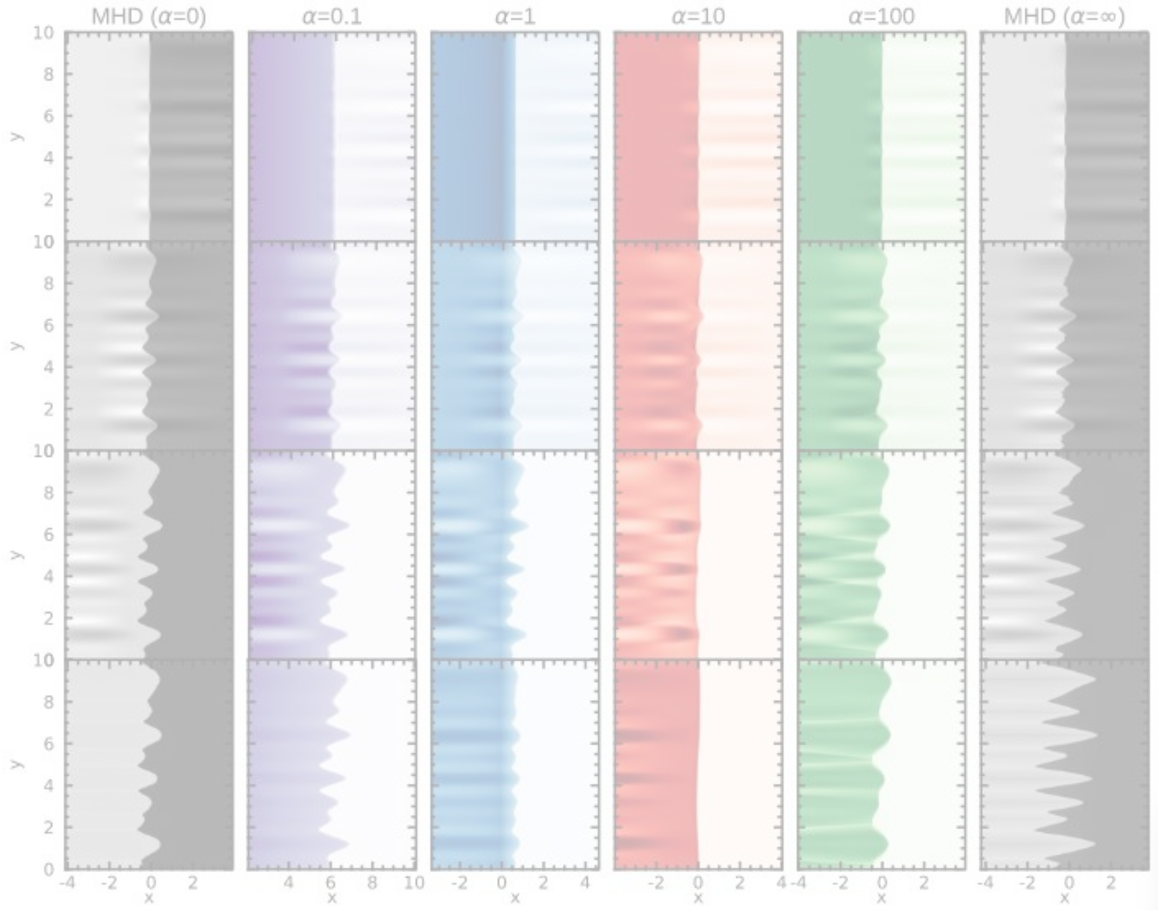
So where can PIP effects be important?

Shock substructure, including creating shocks within shocks (e.g. Hillier et al 2016, Snow and Hillier 2019) and large velocity drifts



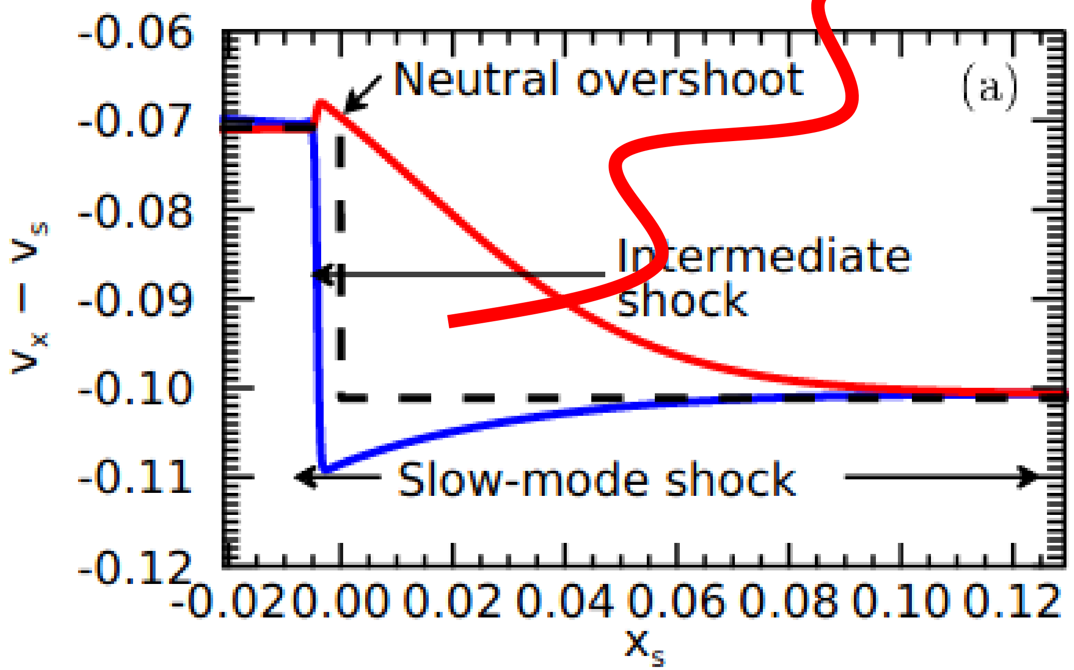
Neutral hydrodynamic shock

PIP effects change the stability properties of the shock front (Snow and Hillier 2021 and Poster 163)



Energy loss in the shock

In the finite width of the shock, the fluids are being heated and compressed. This gives the potential for energy losses inside the shock



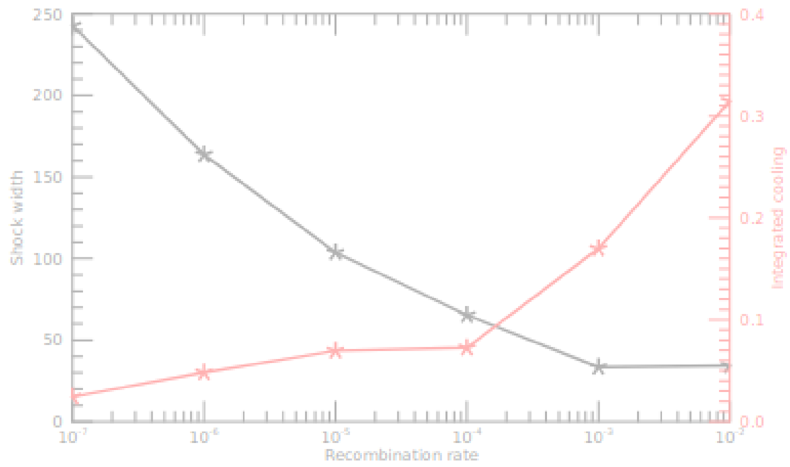
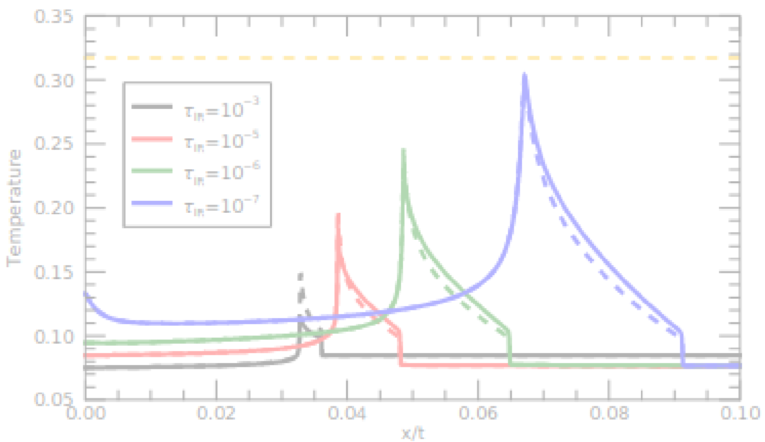


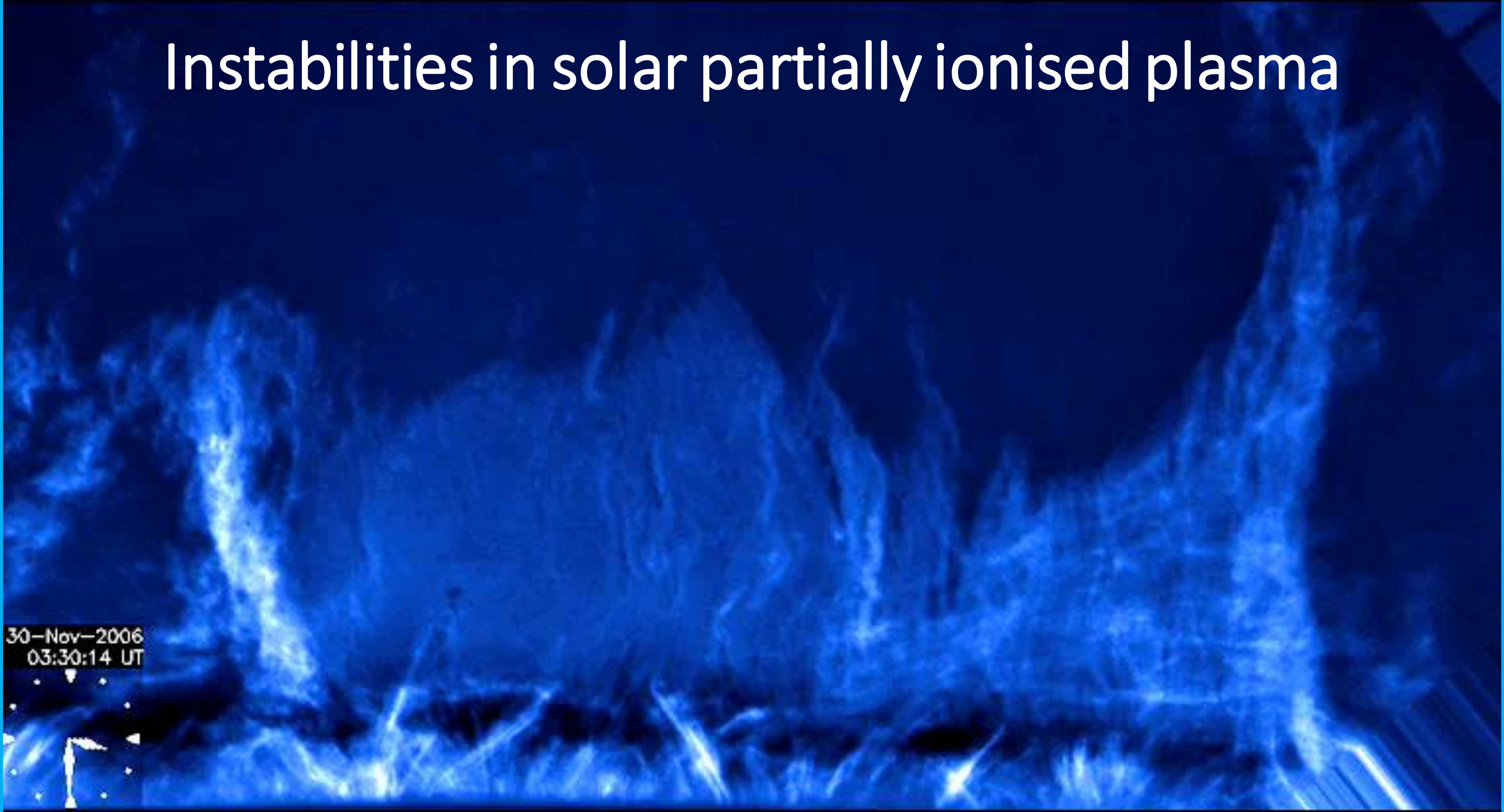
Fig. 10. Finite width of the shock (black line) as a function of the initial recombination rates. Integrated cooling for a parcel of fluid travelling through the shock (red line).



Mechanism important in molecular clouds (e.g. Draine & McKee 1993). Could this be important for shock heating of the chromosphere?

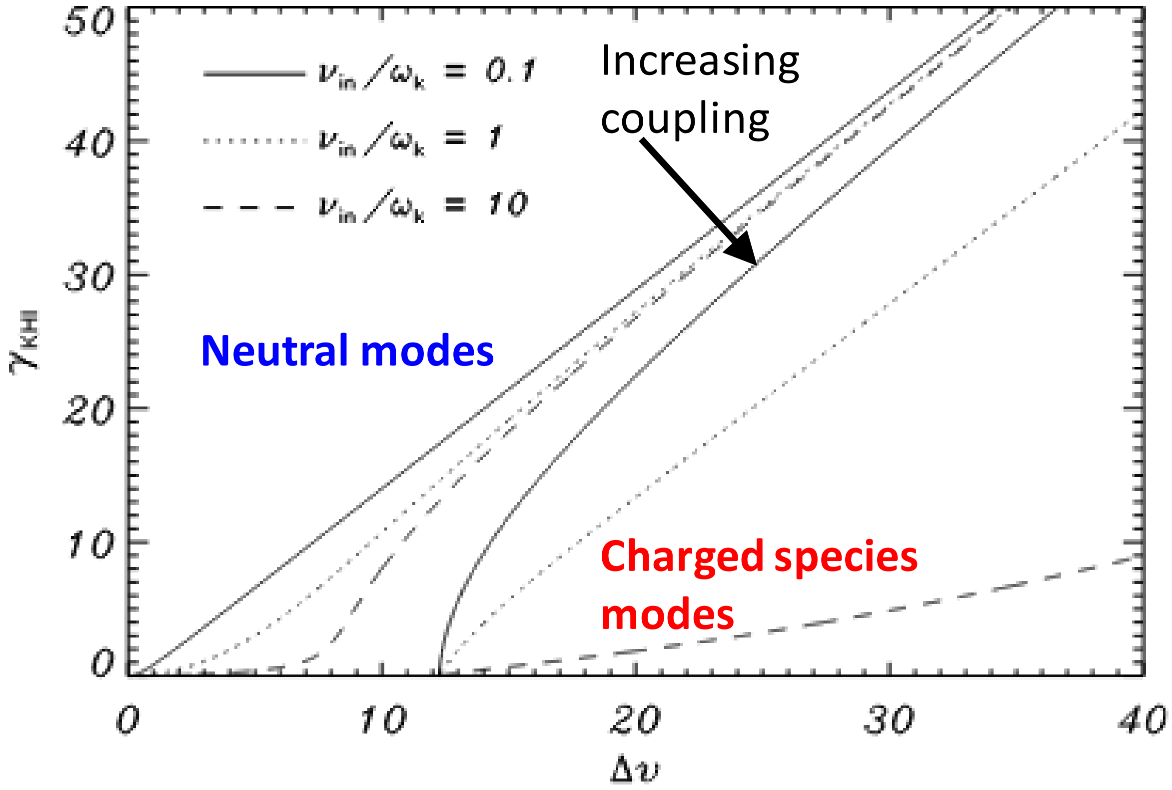
Snow and Hillier 2020b

Instabilities in solar partially ionised plasma



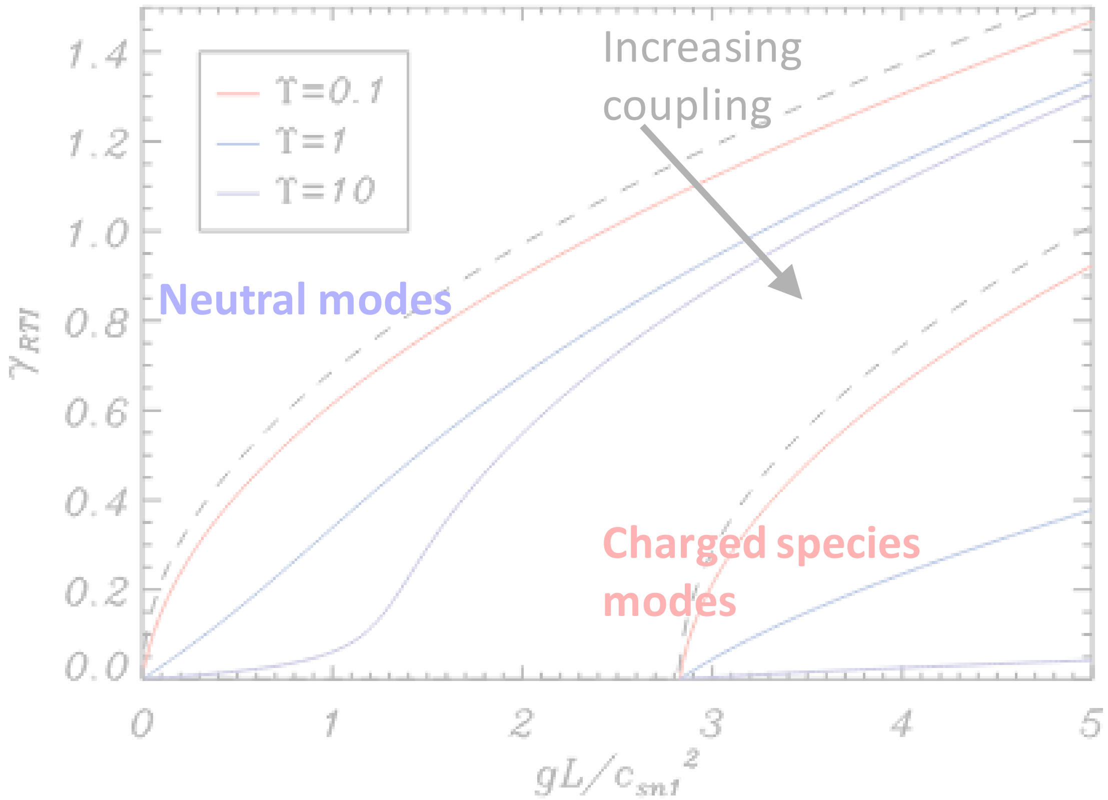
Linear instability in partially ionised plasma

KHi linear growth rate from Soler et al (2012)



In the Kelvin-Helmholtz instability, at low coupling, each fluid has its own instability mode, but as coupling increases, this collapses to a single joint instability mode

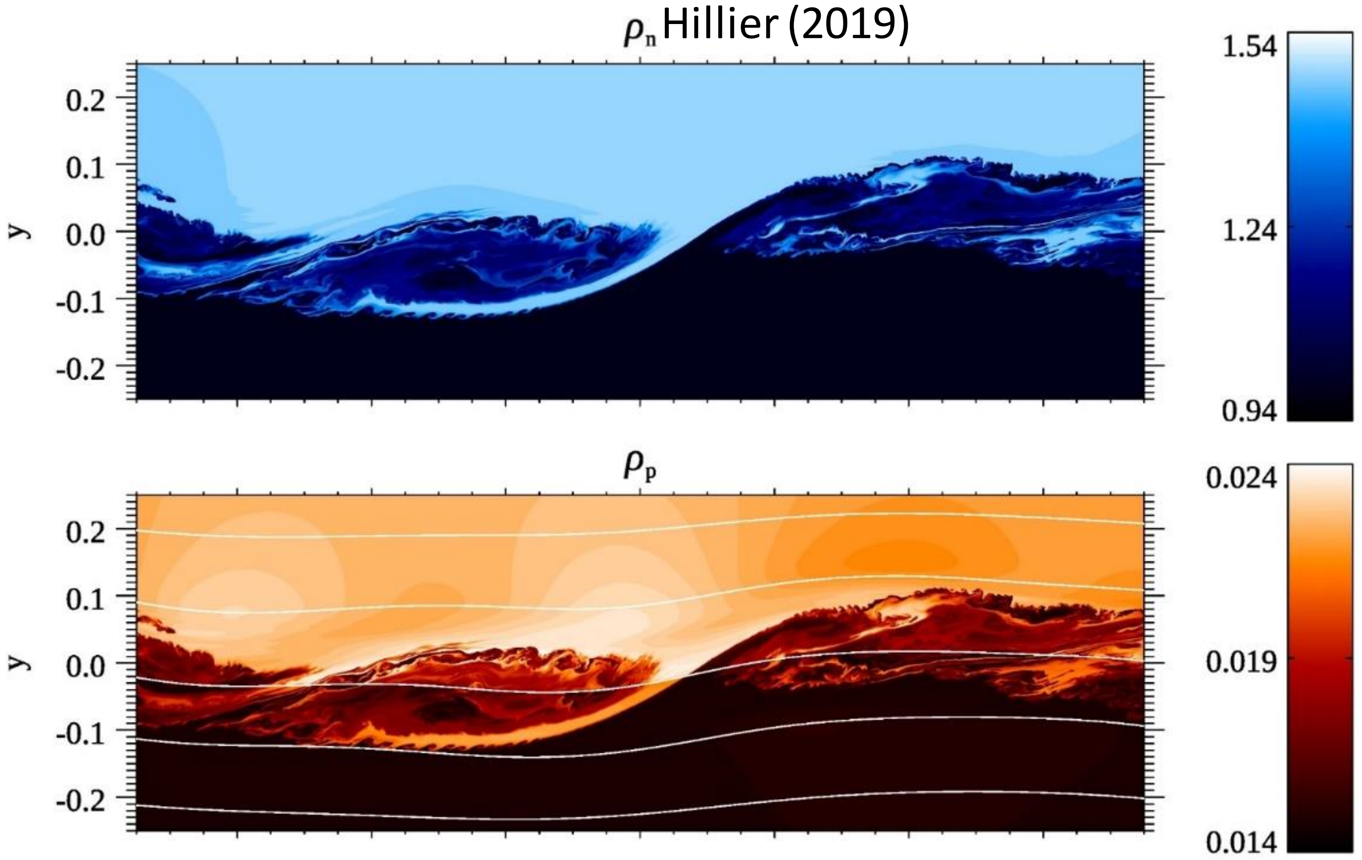
RTi linear growth rate from Diaz et al (2012)

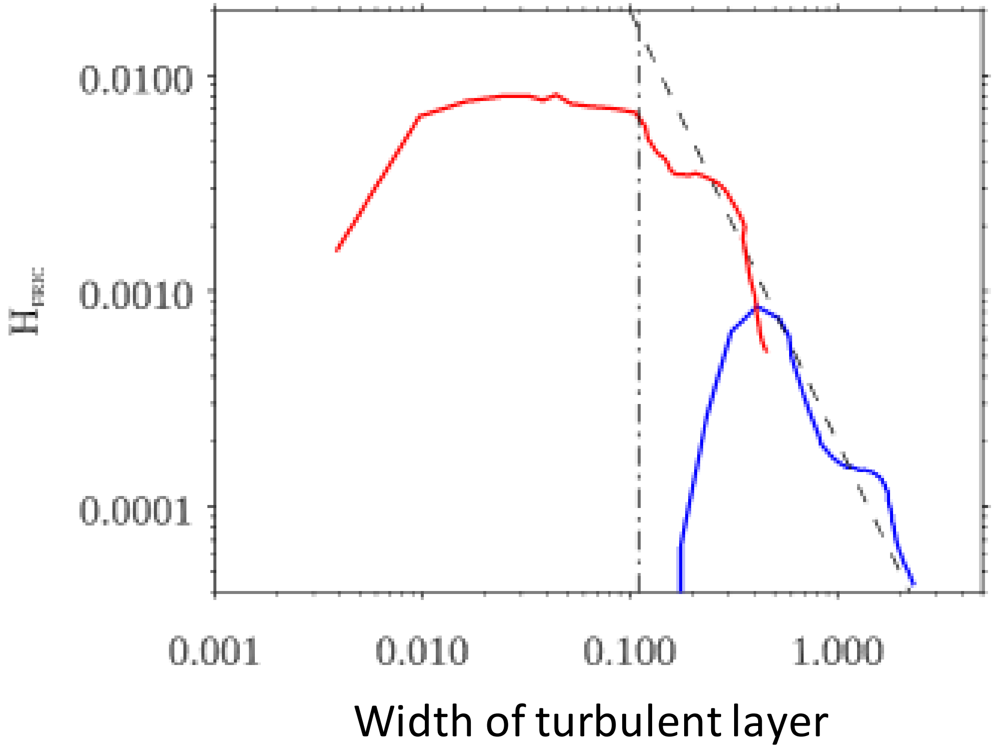


Similar behaviour is found for the Rayleigh-Taylor instability

See also Diaz et al (2014)

Philosophy of partially ionised plasma instabilities

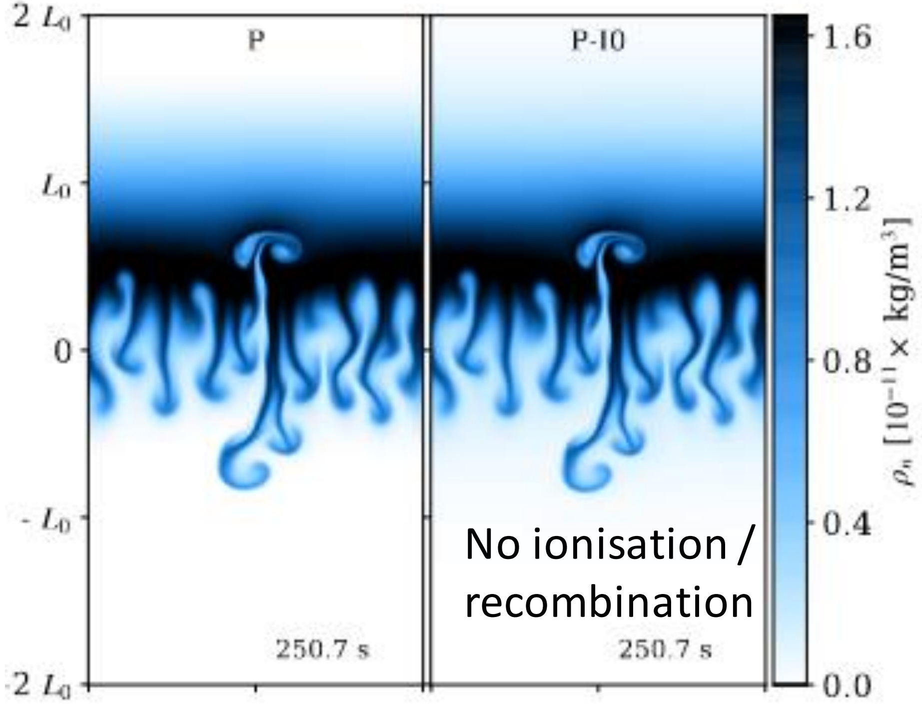




Looking at idealised simulations of the Kelvin-Helmholtz instability we see that two fluid simulations are some hybrid of HD and MHD.

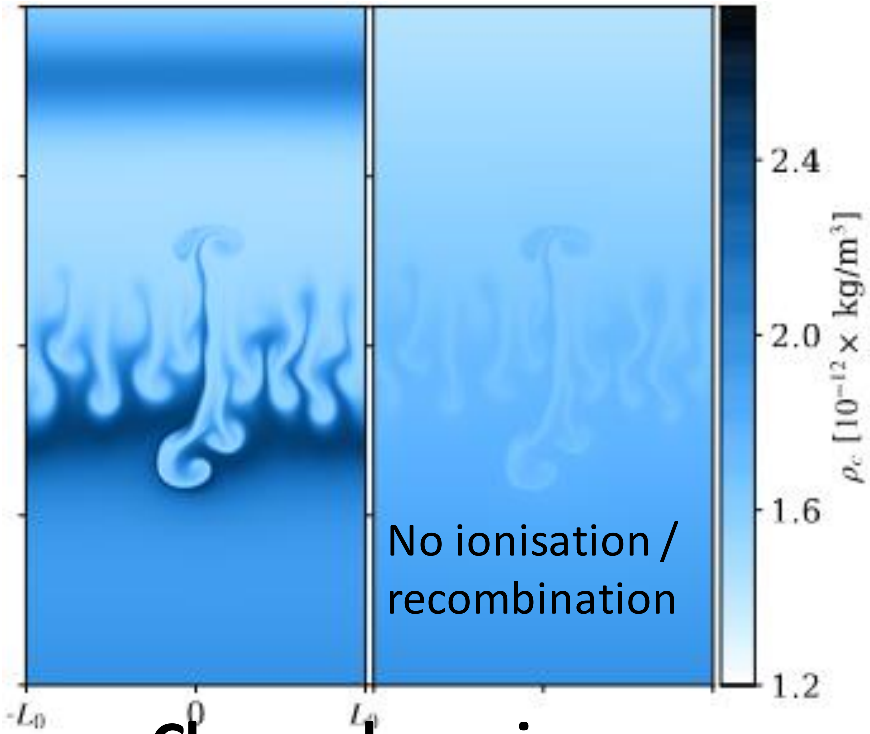
We found very **interesting effects in transport of mass and thermal energy across the field** by neutrals, **but** two-fluid **heating became less effective as the turbulent layer grew**.

Looking at RTi in prominence threads



Neutral species

Popescu Braileanu et al (2021b)

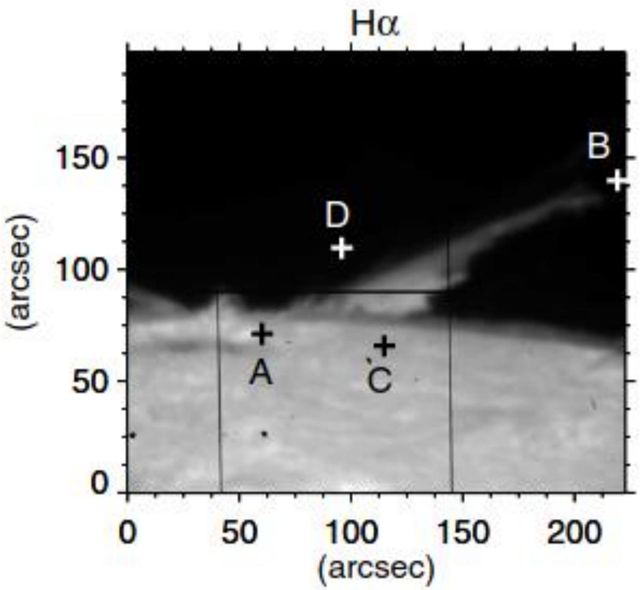


Charged species

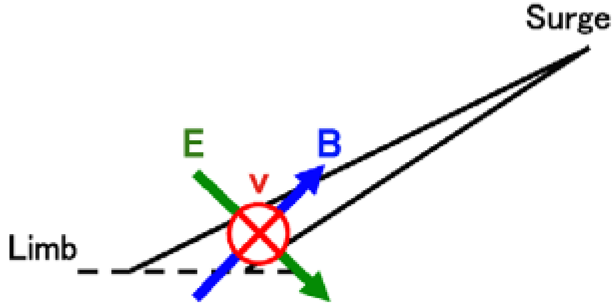
Two-fluid modelling of Rayleigh-Taylor plumes, reproduces a lot of the dynamics of MHD simulations, but importantly reveals that very **large velocity drifts** (>1km/s) are naturally formed as part of the dynamics.

See also Khomenko et al (2014), Popescu Braileanu et al (2021a) and poster 502

Where to from here? A Discussion



From Anan et al (2014)



We have seen that the importance of the role of partial ionisation comes through the timescales, with higher frequency dynamics resulting in less coupling between neutral and charged species.

We also find that even slow dynamics can have a high-frequency component, and that the velocity differences can be large (>1km/s). So where can observations come in?

I think the idea put forward by Anan et al (2014) gives the greatest hope to categorically observe velocity neutral velocity drifts. They proposed that the motional electric field felt by the neutrals will lead to polarization that can be measured. Hopefully EST sill be able to observe this.