Modelling the Effect of Spatially Varying Flow on the Oscillations of Fine-Scale Magnetic Structures in the Solar Orbiter and DKIST Era

Samuel Skirvin[1], Viktor Fedun[1] & Gary Verth[2]

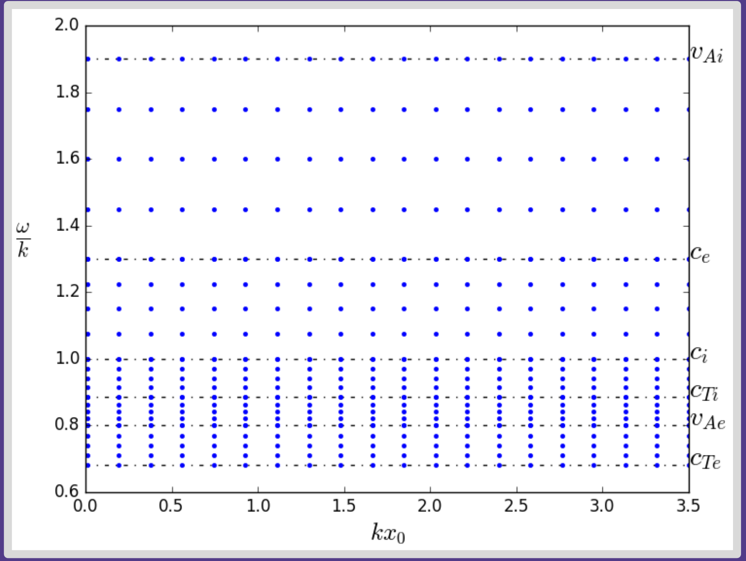
[1] Plasma Dynamics Group, Department of Automatic Control & Systems Engineering, University of Sheffield, Sheffield, S1 3JD, United Kingdom

[2] Plasma Dynamics Group, School of Mathematics and Statistics, University of Sheffield, Sheffield, S3 7RH, United Kingdom

Key Findings:

1. A numerical technique is presented based on the shooting method which solves for eigenvalues in **any** symmetrically **non-uniform** plasma equilibrium.
2. This technique **successfully reproduces** previously obtained analytical results for uniform equilibria in both Cartesian and Cylindrical geometries.
3. A number of specific **non-uniform** cases are investigated including inhomogeneous background **density** and background **flow**.
4. The observed **spatial structure** of eigenfunctions is changed due to the background inhomogeneity – with **slow body modes** being the most affected, which may have **implications for observers** analysing high spatial resolution data.

DKIST will provide much greater understanding of features observed in the solar atmosphere and the MHD waves propagating within.



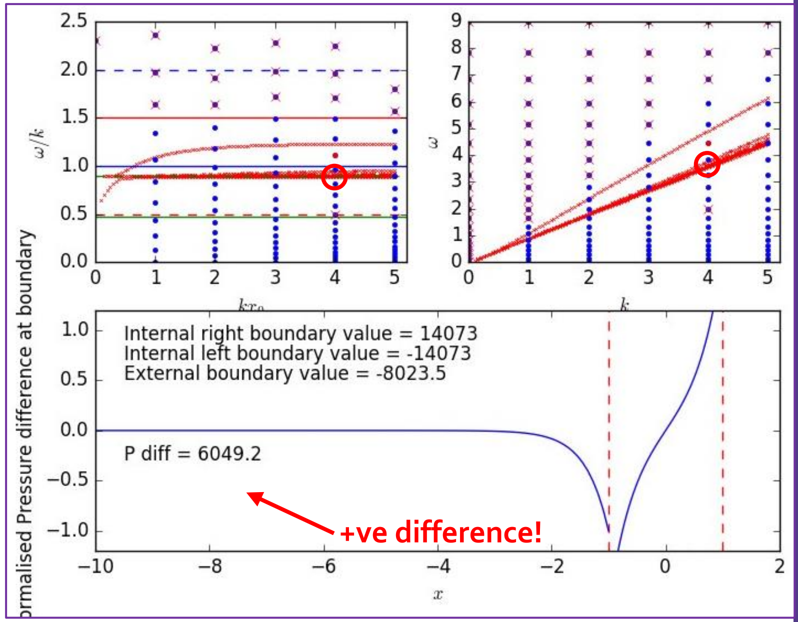
Step 1:
Breakdown initial domain by **seed samples** on dispersion diagram – considering **real** frequencies and wavenumbers.

Step 2:
Iterate through seed points calculating $\widehat{P}_T$ **and** $\widehat{v}_x$ ($\widehat{\xi}_r$) for each ω,k pair.

Require $\widehat{P}_T$, $\widehat{v}_x$, $\widehat{v}_x{}'$ **<< 1 far away** from boundary – use shooting method to solve ODE.

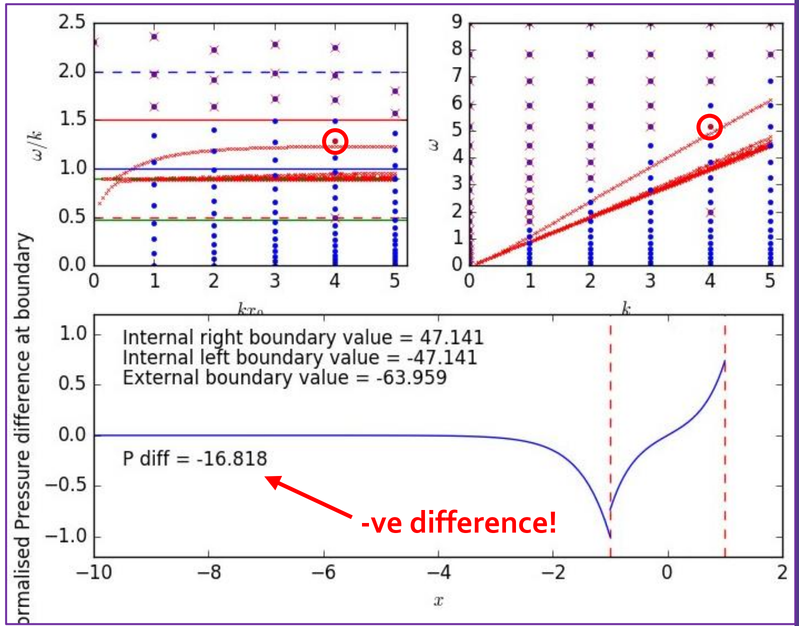
NUMERICAL METHOD

1



ZOOM IN TO SEE SAMPLE DOTS (RED)

2



Step 3:
Locate point where **difference** between internal boundary value and external boundary value **changes sign**.

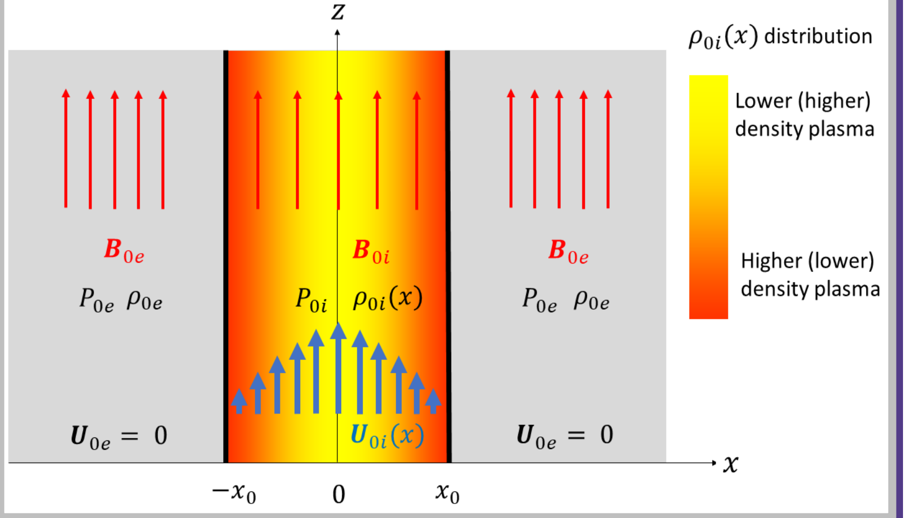
In plots this happens as we pass a red cross which shows known analytical solution to dispersion relation

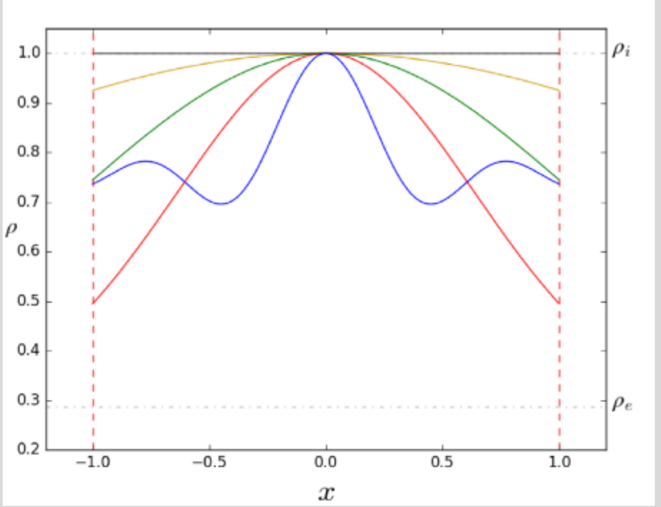
Step 4:
Go back to previous sample, **narrowing step size** and repeat process **until difference** at boundary becomes **very small**.

Step 5:
Store values for ω,k and move onto next main sample **repeating** same process.

NON-UNIFORM MAGNETIC SLAB

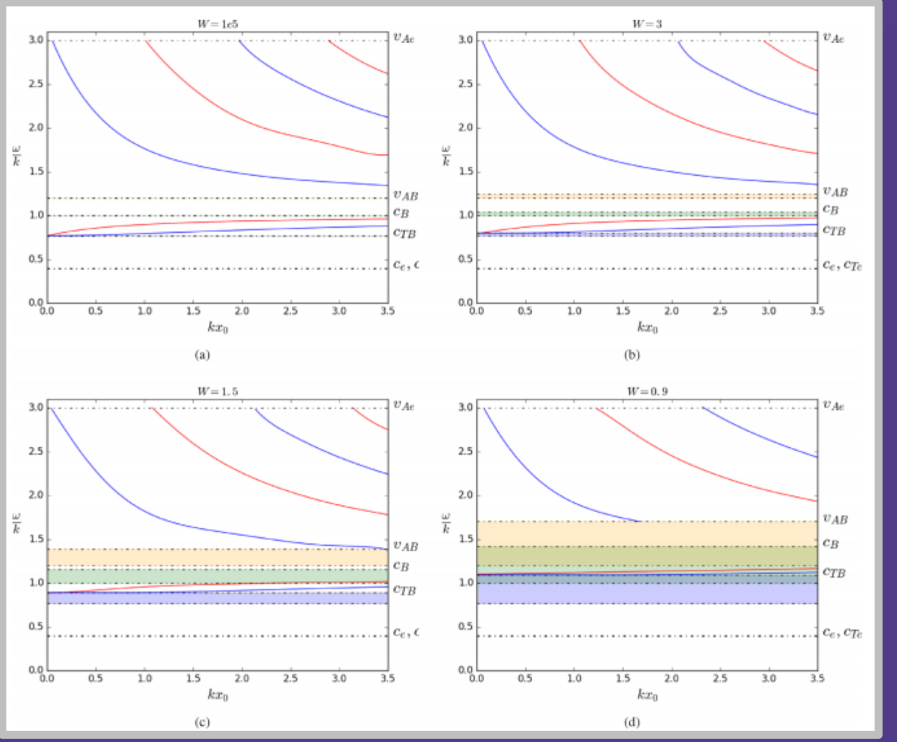
Non-uniform magnetic slab – let's consider a **Gaussian** profile in background **density**.



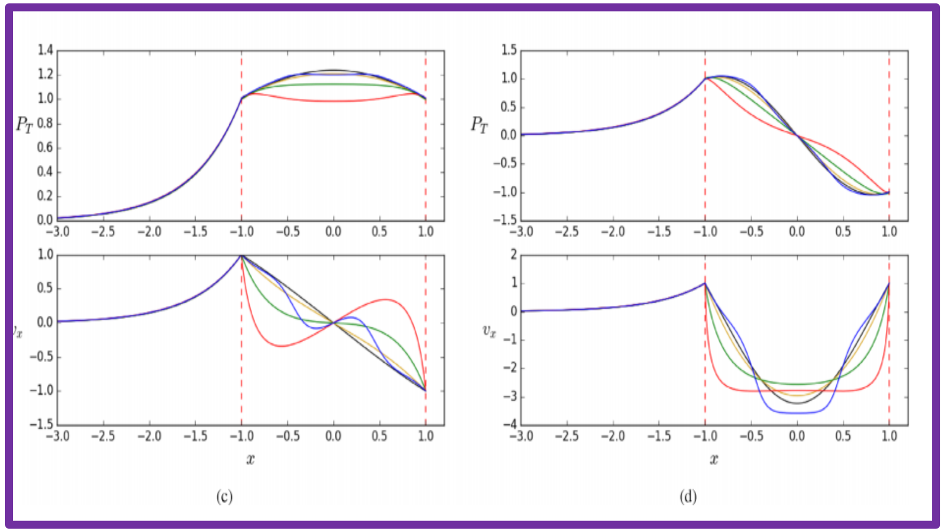


(Above): Gaussian profiles in density shown by **different** standard deviations (**widths**). **Uniform** slab shown by **black** profile. **Increasing inhomogeneity** shown by **yellow**, **green** and **red** curves.

(Below): **Dispersion diagrams** for each case of Gaussian density.



(Below): Eigenfunctions for **slow body** sausage and kink modes for each case of Gaussian density with consistent colour scheme. **Additional nodes** appear for **larger inhomogeneity**. May be **misinterpreted** as **different wave modes** or overtones by observers.



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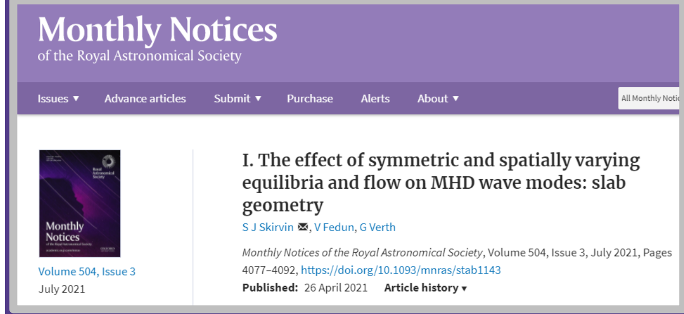
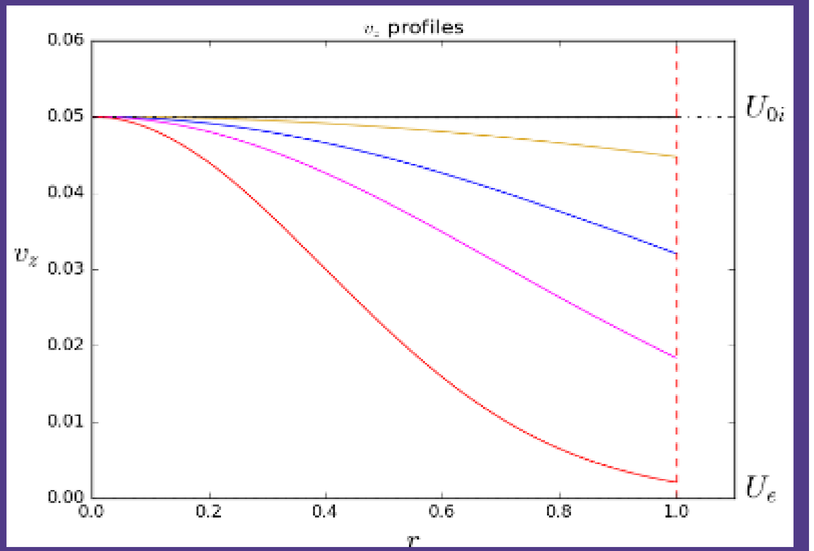


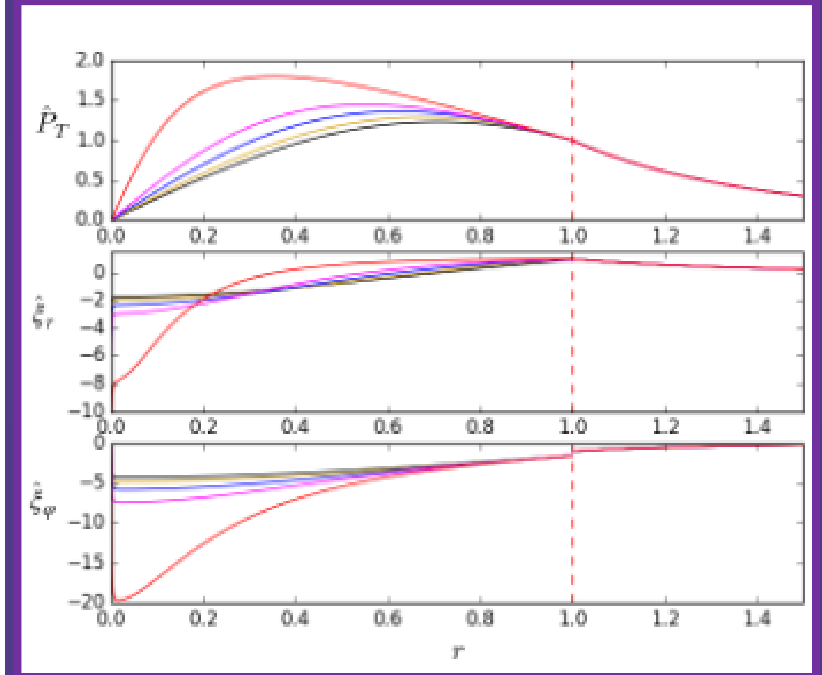
NON-UNIFORM MAGNETIC CYLINDER



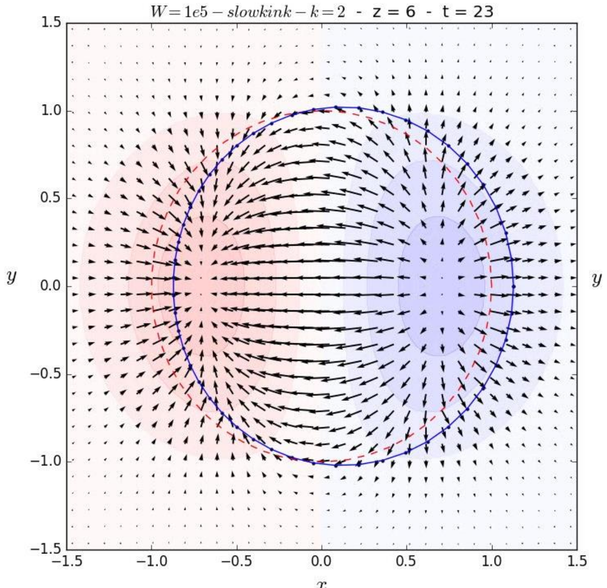
As **inhomogeneity** of background flow is **increased**, resulting **velocity field** becomes more **rotational** – suggesting **vorticity** is present.

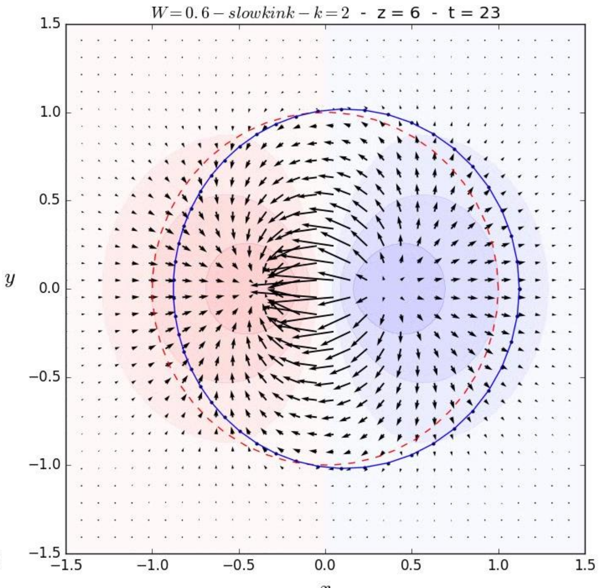
Non-uniform magnetic **cylinder** – let's consider a Gaussian profile in background **plasma flow / density**. [Skirvin et al. 2021(b) **in prep**]

(Right): **Eigenfunctions** including ξ_φ for slow body kink mode for Gaussian **background flow**. Similar to non-uniform Gaussian density in magnetic slab, the **spatial structure** is **changed** because of the **non-uniform equilibrium**.



For **velocity** we analyse specific **slow body kink** mode with $ka = 2$.





(**Left**): Comparisons of **velocity field** for cylinder with **uniform** flow and plasma flow modelled as **Gaussian**. For non-uniform background – wave propagation **increases vorticity**.

(**Right**): Snapshot of **velocity field** for equilibrium **non-uniform density**. Boundary of surface becomes **distorted**.