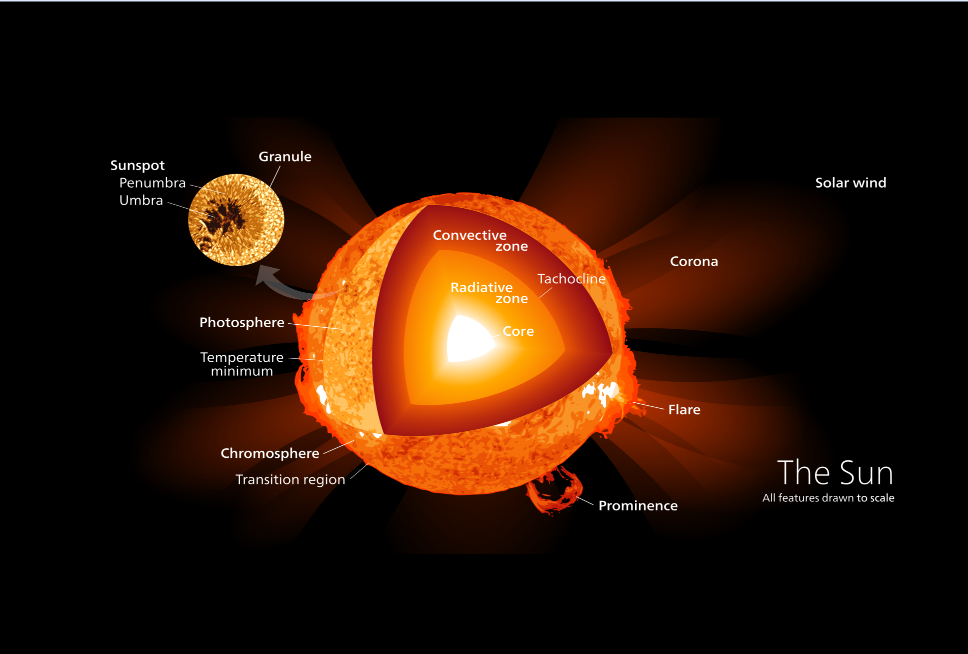
Magneto-acoustic waves in asymmetric solar waveguides

Progress in spatial magneto-seismology

Matthew Allcock
and
Robertus Erdélyi

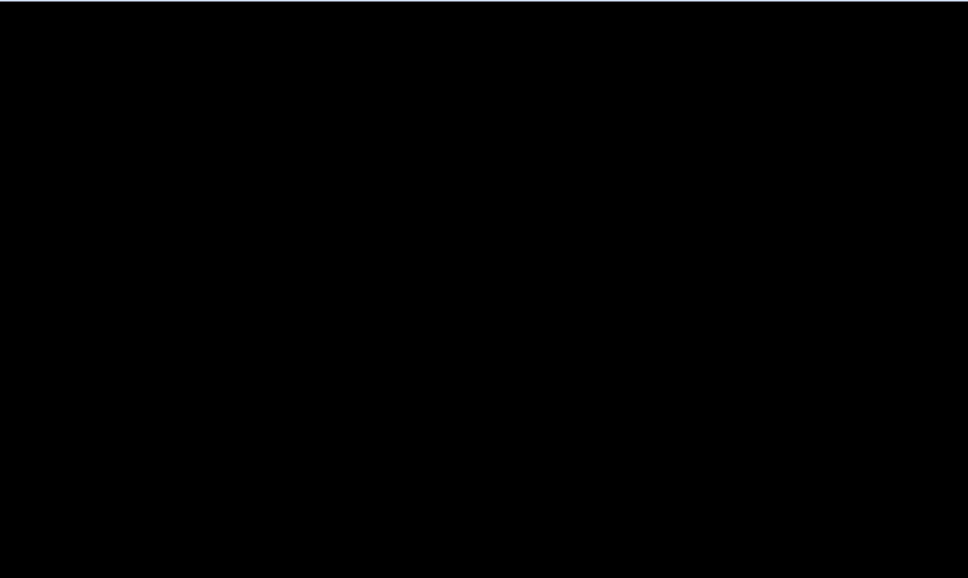
The University Of Sheffield.

The layers of an onion



Magnetohydrodynamic waves

Ubiquitous in the solar atmosphere

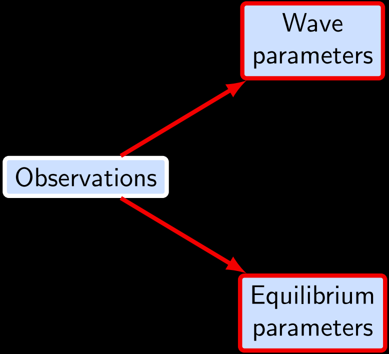


Credit: NASA, SDO

Observations

Magnetohydrodynamic waves

Diagnosing information about solar plasma



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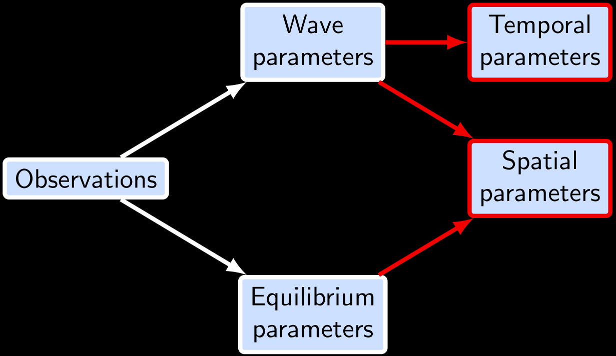

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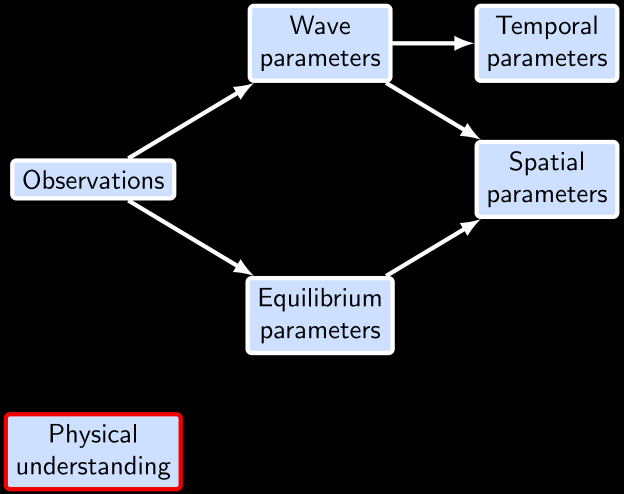

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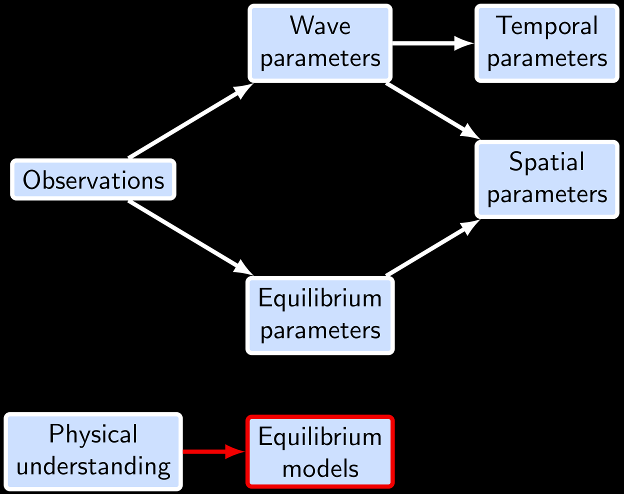

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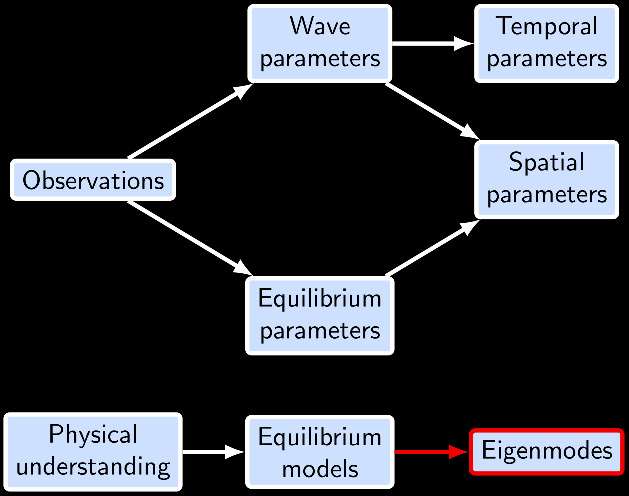

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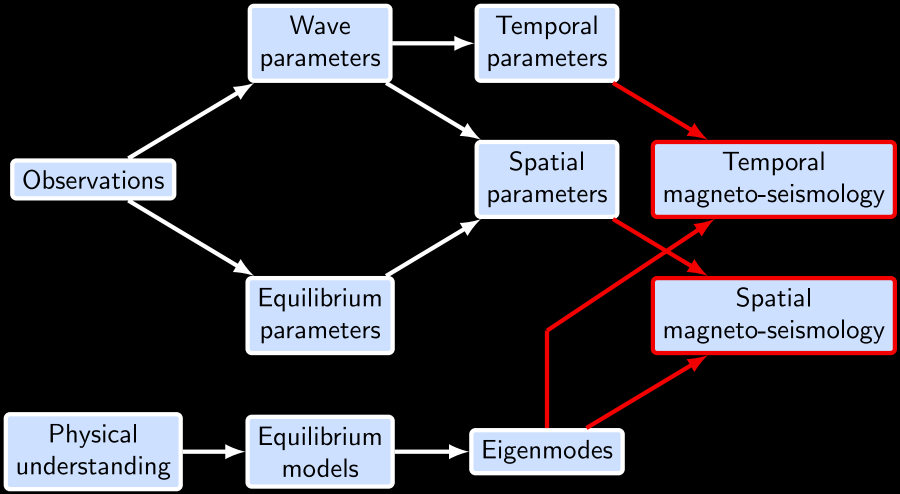

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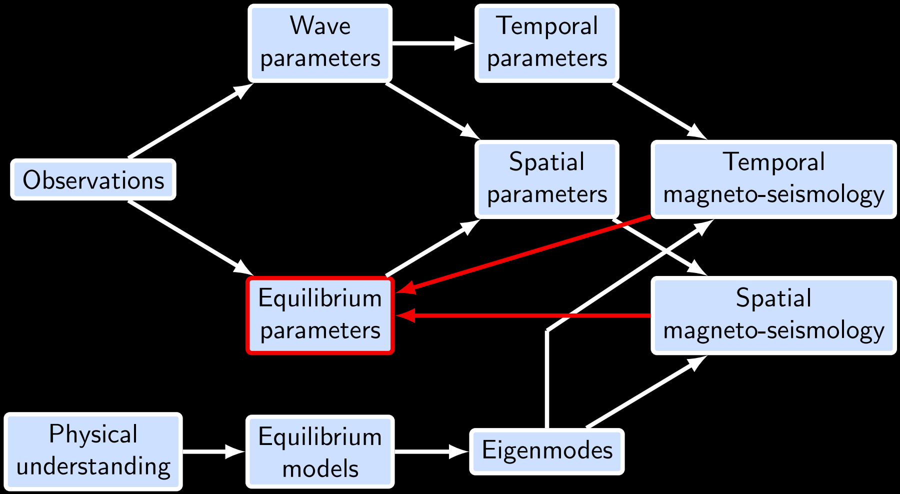

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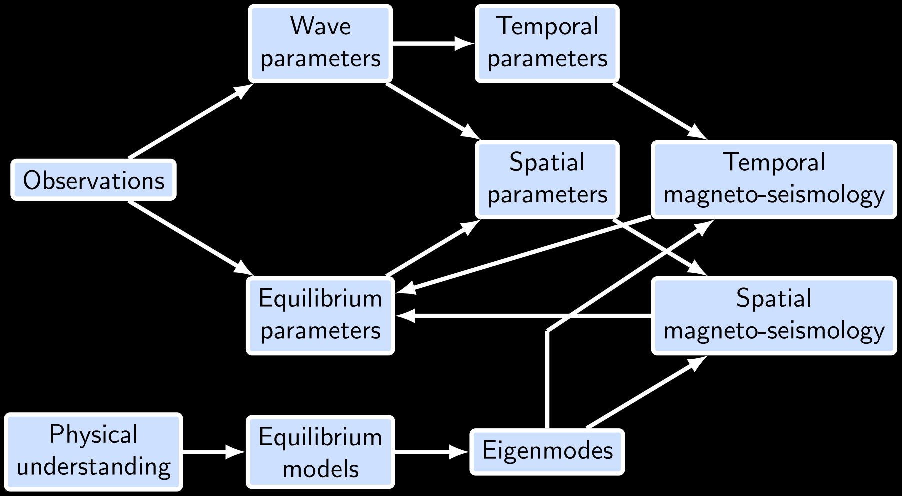

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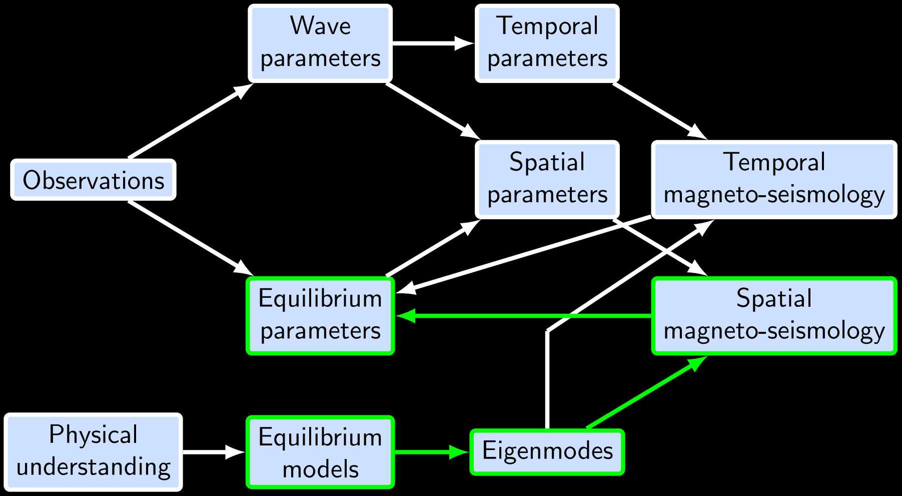
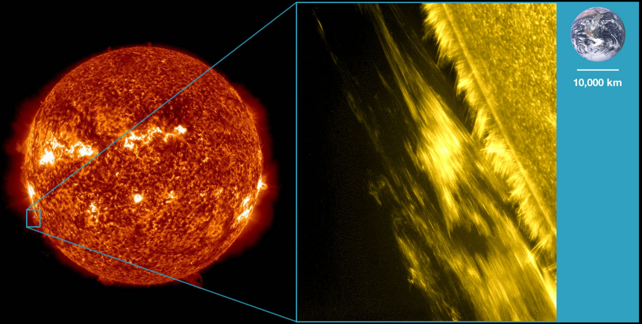


Slab structures on the Sun



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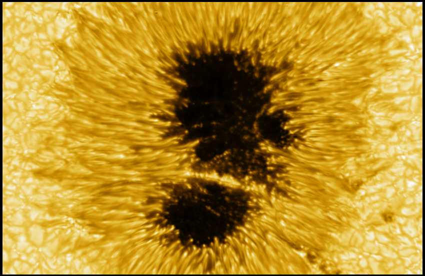
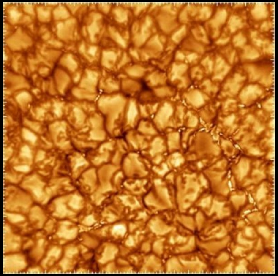
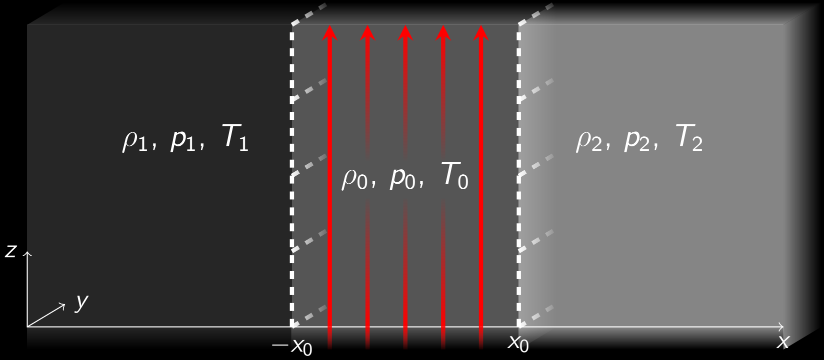


Max Planck Institute for Solar System Research



BBSO/NJIT

Equilibrium conditions



- Uniform magnetic field in the slab.
- Field-free plasma outside.
- Different density and pressure on each side.

Governing equations

Ideal MHD equations: Conservation of:

$$\rho \frac{\mathrm{D}\boldsymbol{v}}{\mathrm{D}t} = -\nabla p - \frac{1}{\mu}\boldsymbol{B} \times (\nabla \times \boldsymbol{B}), \qquad \text{momentum}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}) = 0, \qquad \text{mass}$$

$$\frac{\mathrm{D}}{\mathrm{D}t}\left(\frac{p}{\rho^{\gamma}}\right) = 0, \qquad \text{energy}$$

$$\frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times (\boldsymbol{v} \times \boldsymbol{B}), \qquad \text{magnetic flux}$$

$\boldsymbol{v}$ = plasma velocity, $\boldsymbol{B}$ = magnetic field strength,
ρ = density, p = pressure,
μ = magnetic permeability, γ = adiabatic index.

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Asymmetric slab modes

Dispersion relation:

$$\frac{\omega^4 {m_0}^2}{k^2 {v_A}^2 - \omega^2} + \frac{\rho_0}{\rho_1} m_1 \frac{\rho_0}{\rho_2} m_2 (k^2 {v_A}^2 - \omega^2)$$
$$- \frac{1}{2} m_0 \omega^2 \left(\frac{\rho_0}{\rho_1} m_1 + \frac{\rho_0}{\rho_2} m_2 \right) (\tanh m_0 x_0 + \coth m_0 x_0) = 0,$$

$${m_0}^2 = \frac{(k^2 {v_A}^2 - \omega^2)(k^2 c_0^2 - \omega^2)}{(c_0^2 + {v_A}^2)(k^2 {c_T}^2 - \omega^2)}, \qquad {m_{1,2}}^2 = k^2 - \frac{\omega^2}{{c_{1,2}}^2},$$

$${c_T}^2 = \frac{c_0^2 {v_A}^2}{c_0^2 + {v_A}^2}, \qquad v_A = \frac{B_0}{\sqrt{\mu \rho_0}},$$

See **Allcock** and Erdélyi, 2017.

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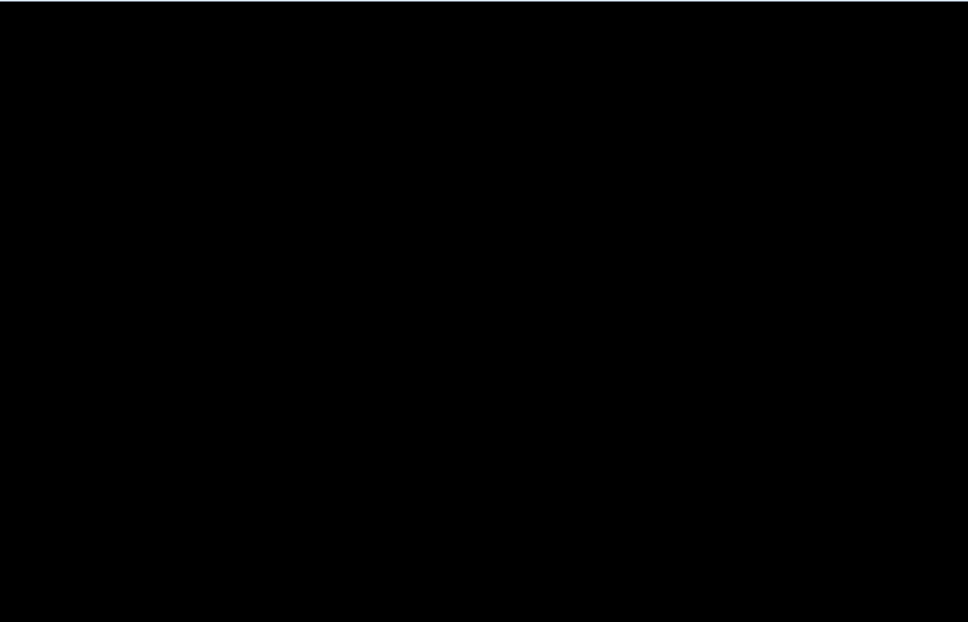
Slab eigenmodes

Symmetric kink surface mode



Slab eigenmodes

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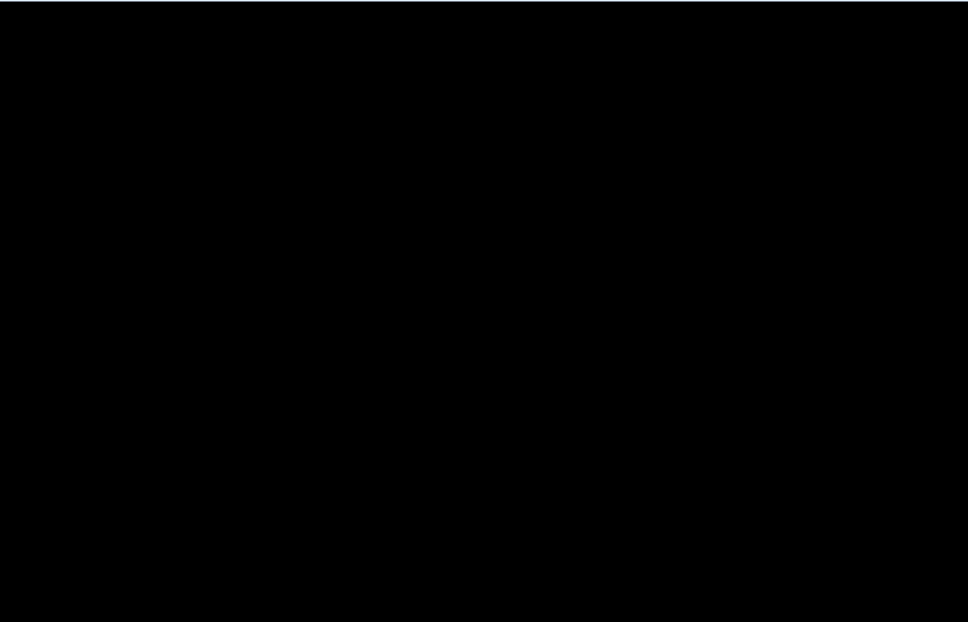
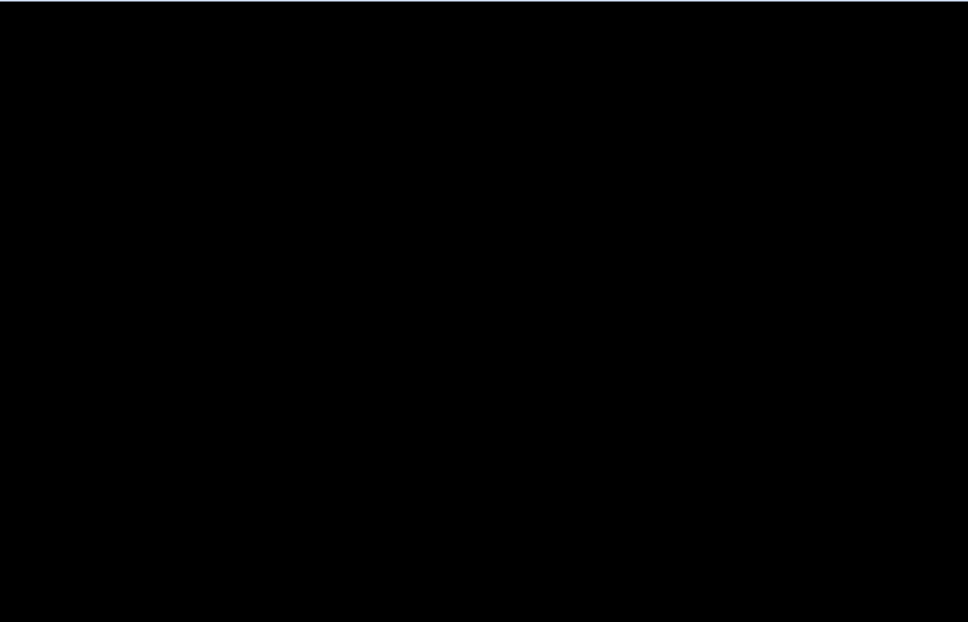
Slab eigenmodes

Symmetric sausage surface mode



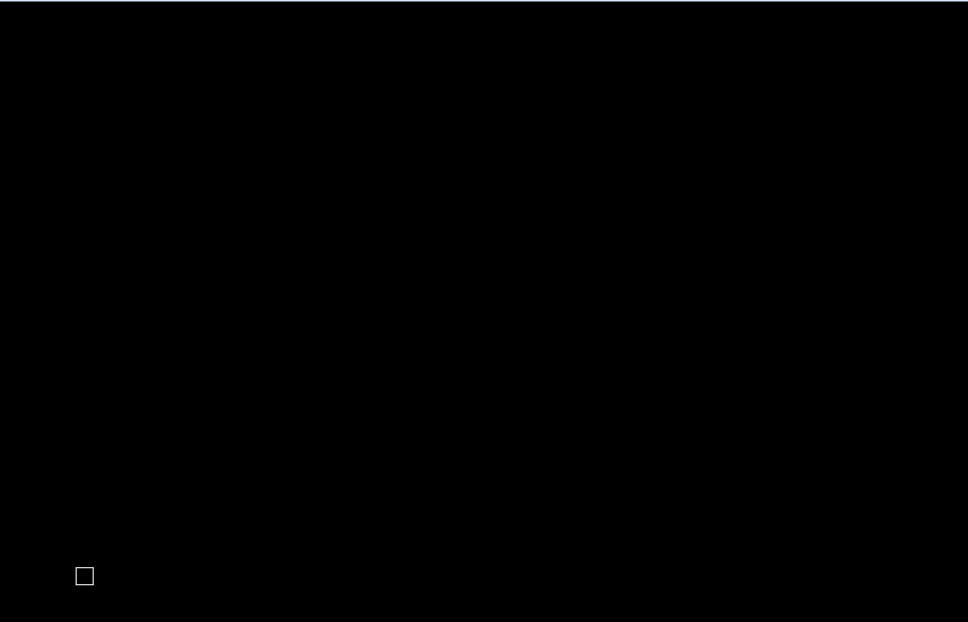
Slab eigenmodes

Asymmetric sausage surface mode

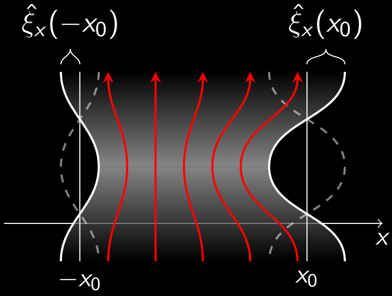


Slab eigenmodes

Body modes



Amplitude ratio

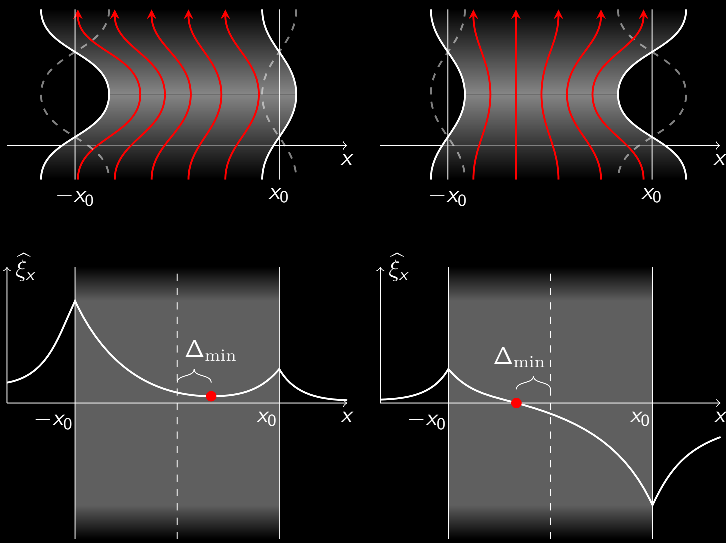


Amplitude ratio

$$R_A := \frac{\hat{\xi}_x(x_0)}{\hat{\xi}_x(-x_0)} \qquad \left(\begin{smallmatrix}\text{Top = quasi-kink}\\ \text{Bottom = quasi-sausage}\end{smallmatrix}\right)$$

$$= \binom{+}{-} \frac{\rho_1 m_2}{\rho_2 m_1} \frac{(k^2 {v_A}^2 - \omega^2) m_1 \frac{\rho_0}{\rho_1} - \omega^2 m_0 \binom{\tanh}{\coth} (m_0 x_0)}{(k^2 {v_A}^2 - \omega^2) m_2 \frac{\rho_0}{\rho_2} - \omega^2 m_0 \binom{\tanh}{\coth} (m_0 x_0)}$$

Minimum perturbation shift



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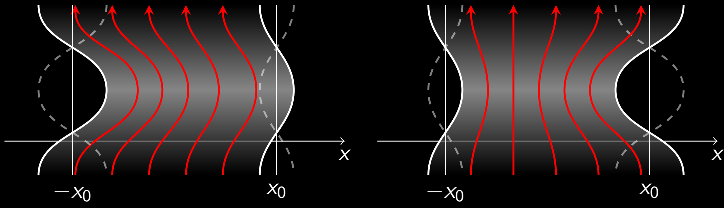


Quasi-kink:

$$\Delta_{\mathrm{min}} = \frac{1}{m_0} \tanh^{-1}(D)$$

Quasi-sausage:

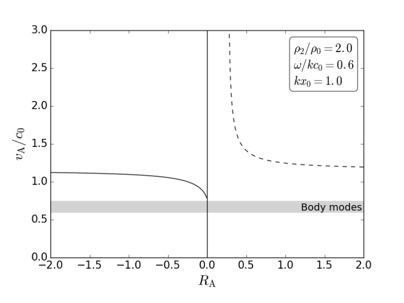
$$\Delta_{\mathrm{min}} = \frac{1}{m_0} \tanh^{-1}\left(\frac{1}{D}\right)$$

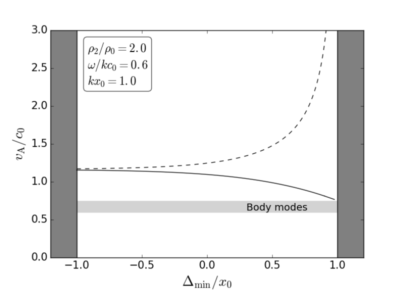
where $$D = \frac{(k^2 {v_A}^2 - \omega^2) m_2 \frac{\rho_0}{\rho_2} \tanh(m_0 x_0) - \omega^2 m_0}{(k^2 {v_A}^2 - \omega^2) m_2 \frac{\rho_0}{\rho_2} - \omega^2 m_0 \tanh(m_0 x_0)}$$

Solar magneto-seismology

Parameter inversion

- **Observe**: ω, k, x_0, T_i, and R_A or Δ_min.
- **Solve** to find: v_A and hence B_0.





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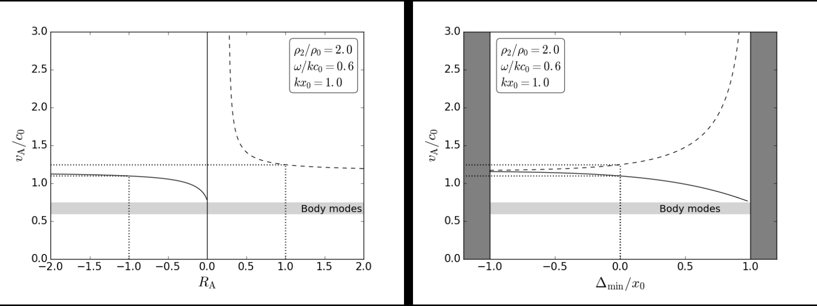
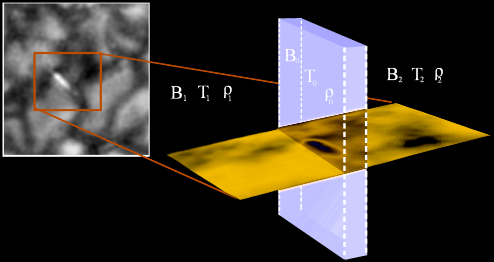


Future work

Diagnose magnetic field parameters using observations of MHD waves in magnetic structures in the solar atmosphere, for example:

- Elongated **magnetic bright points**,



Adaptation of Liu et al., 2017, by N. Zsámberger

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Diagnose magnetic field parameters using observations of MHD waves in magnetic structures in the solar atmosphere, for example:

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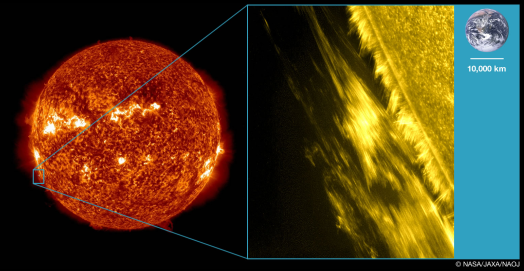
- **Prominences**,

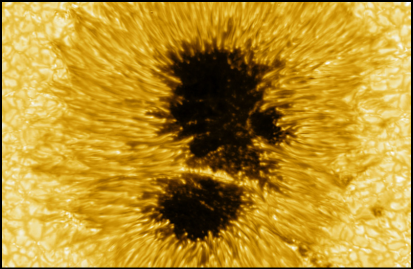


NASA

Future work

Diagnose magnetic field parameters using observations of MHD waves in magnetic structures in the solar atmosphere, for example:

- Elongated **magnetic bright points**,
- **Prominences**,
- Sunspot **light walls**.



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Research Centre