GENERAL LOCAL LINEAR ANALYSIS OF RADIATING MAGNETIZED FLOWS

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THE PROBLEM:

- EXAMINE THE STABILITY AND MODE STRUCTURE FOR A FLOW THAT IS
  - STRATIFIED (UNDER GRAVITY)
  - RADIATING
  - MAGNETIZED (OR NOT)

ASSUMPTIONS

- THE FLOW IS OPTICALLY THICK

$$\tau \gtrsim 1$$

$$\vec{F} = \frac{-c}{3\kappa\rho}\vec{\nabla} E$$

$$\longrightarrow \boxed{\text{DIFFUSION APPROXIMATION}}$$

- THE FLOW IS HIGHLY CONDUCTING

$$\eta \to 0 \, , \; \sigma \to \infty$$

$$\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \times (\vec{v} \times \vec{B})$$

$$\longrightarrow \boxed{\text{FLUX FREEZING}}$$

ANALYSIS:

- LOCAL LINEAR THEORY

$$Q \rightarrow Q + \delta Q$$

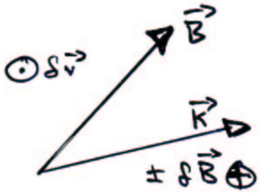
$$\delta Q = \delta Q \, e^{i[\vec{k}\cdot\vec{x} - \omega t]}$$

$$\vec{\nabla} \rightarrow i\vec{k} \, , \quad \partial_t \rightarrow -i\omega$$

- TURN GRAVITY AND RADIATION OFF

ALFVÈN WAVES $\Rightarrow$

$$\vec{\nabla}\cdot\delta\vec{v} = 0$$
$$\delta\vec{v} = \mp\delta\vec{B}$$
$$\omega_K = K \cdot v_A$$
$$\delta\rho = 0$$



MAGNETOSONIC WAVES

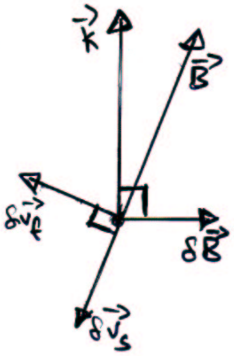
(e.g. $\frac{B^2}{8\pi} \gg P_{GAS}$)

FAST $\Rightarrow$

$$\nabla\cdot\delta v \neq 0$$
$$\omega_f \simeq k v_A$$

SLOW

$$\omega_s \simeq k \frac{\cdot v_A}{v_A} c_g$$
$$\delta\rho \simeq \rho \frac{k\cdot\delta v}{\omega}$$



- HOW DOES RADIATATIVE DIFFUSION ALTER THESE MODES?

RESULTS:

- ALL COMPRESSIBLE ($\nabla\cdot\delta v, \delta\rho \neq 0$) MODES ARE UNSTABLE

$\vec{B} = 0$: HYDRODYNAMIC "STRANGE" MODES (WOOD '76, SAIO ET AL. '84, GLATZEL '94)

- INSTABILITY IS PRESENT IN BOTH ONE AND TWO - TEMPERATURE LIMITS.

DRIVING $\Rightarrow$ $\vec{\nabla}\cdot\delta\vec{F}$ (RADIATIVE HEAT FLUX)

$$\vec{\nabla}\cdot\delta\vec{F} = \vec{\nabla}\cdot\left(\frac{c}{3\kappa\rho}\vec{\nabla}\,\delta E\right) + \vec{F}\cdot\vec{\nabla}\left(\frac{\delta\rho}{\rho} + \frac{\delta\kappa}{\kappa}\right)$$

DAMPING VIA RADIATIVE DIFFUSION

CANCELLED BY BUOYANCY FORCES

DRIVING

$$\frac{\delta\kappa}{\kappa} \sim \frac{\delta\rho}{\rho}\frac{\partial \ln\kappa}{\partial \ln\rho}$$

COMPRESSION DURING AN ACOUSTIC OSCILLATION MAKES THE PHOTONS "STICKIER" $\longrightarrow$ OVERSTABILITY.

$\vec{B} \neq 0$: FAST/SLOW MODE INSTABILITIES (ARONS '92, GAMMIE '98, BLAES & SOCRATES 2001, 2002)

- WORKS EVEN IF $\delta\kappa = 0$ (Thomson SCATTERING)

The KEY

$\delta\vec{v}$ → COMPONENT ALONG $\vec{k}$ (COMPRESSION)

$\delta\vec{v}$ → COMPONENT ALONG $\delta\vec{B}$ (TENSION)

∴ BUOYANCY CAN NOT COMPENSATE THE FORCE FROM $\boxed{F\cdot\nabla\frac{\delta\rho}{\rho}}$

- BOTH MODES ARE UNSTABLE. SLOW MODES ARE ALWAYS MORE UNSTABLE THAN FAST MODES.

* ALL THESE INSTABILITIES WORK OFF OF $-\vec{\nabla}\cdot\delta\vec{F} \sim \vec{F}\cdot\vec{\nabla}\left(\frac{\delta\rho}{\rho}+\frac{\delta\kappa}{\kappa}\right)$ IN HEAT EQ.

AND $-\vec{\nabla}\frac{\delta E}{3}$ IN MOMENTUM EQ.

* ALL THESE INSTABILITIES CAN EXIST IN FLOWS EVEN IF

$$\boxed{\frac{E}{3} = P_{RAD} < P_{GAS}}$$

AND/OR

$$\boxed{\frac{B^2}{8\pi} = P_{MAG} < P_{GAS}}$$

APPLICATIONS:

- ACCRETION DISKS (GLATZEL & MEHREN '96, GAMMIE '98, BEGELMAN 2001, BLAES & SOCRATES 2001, 2002)
  - RECONCILE WORK OF ALL THESE AUTHORS
  - SLOW MODE DOMINATES

    $\mathrm{Im}\,[\omega_s] \gg \Omega$ WHEN $P_{RAD} > P_{GAS}$.
- STELLAR ENVELOPES ($M \gtrsim 1 M_\odot$)
  - POSSIBLY SOLVE THE MYSTERY OF roAp STARS (5-15 min, p-MODES, ~1 mmag)
- NEUTRINO DIFFUSION IN INTENSE OBJECTS
  - PROTO-NEUTRON STAR ENVELOPES

    $N + N \rightarrow \nu + N$

    $L_\nu \simeq 3\% \, L_{EDD}$ IN NEUTRINOS.

    npe PLASMA.
  - COLLAPSAR ACCRETION DISKS

    $L_\nu \simeq L_{EDD}$ IN NEUTRINOS.

CONCLUSIONS:

- RADIATION HYDRO AND MHD (RHD & MHD) INSTABILITIES MAY CHANGE THE DYNAMICS AND THERMAL TRANSPORT OF VARIOUS ASTROPHYSICAL SYSTEMS
- FOR THE OBSERVER; IMPLICATIONS IN TERMS OF VARIABILITY (DYNAMICS) AND SECULAR EVOLUTION (THERMAL TRANSPORT) IN VARIOUS ASTROPHYSICAL SOURCES.