ლექცია #3

ვარსკვლავური ოსცილაციები

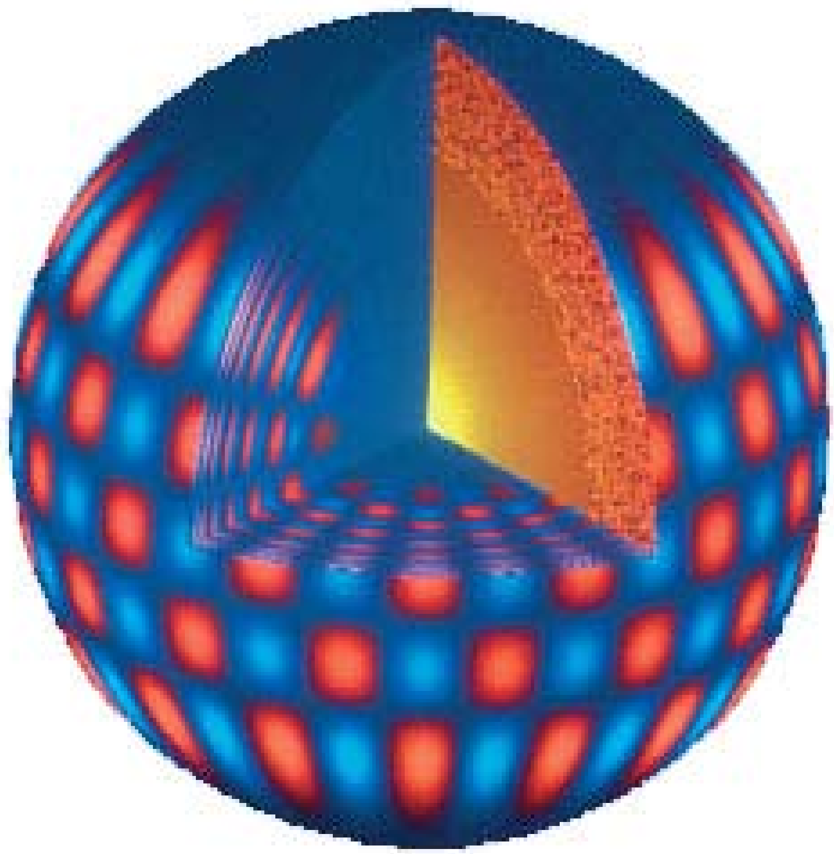
მზის ოსცილაციები

ჰელიოსეისმოლოგია

+ უწყვეტი ვიბრაციები;
+ გლობალური ვიბრაციები;

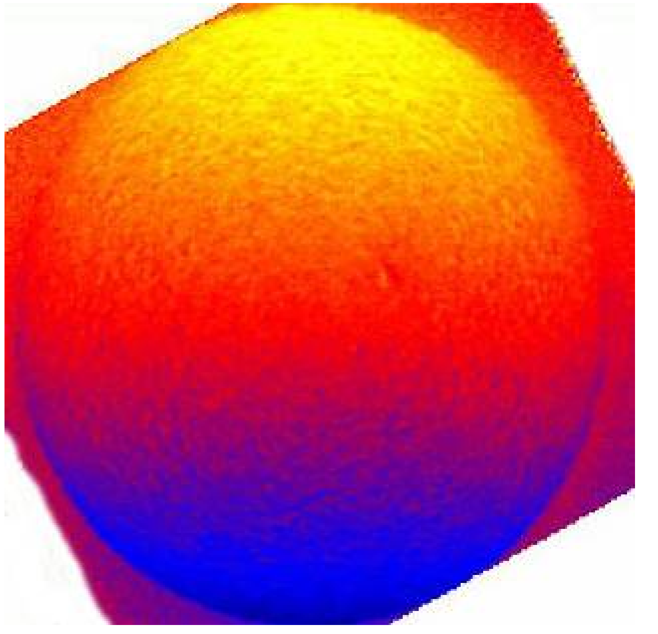
დედამიწა: სეისმოლოგია (--)

ასტეროსეისმოლოგია



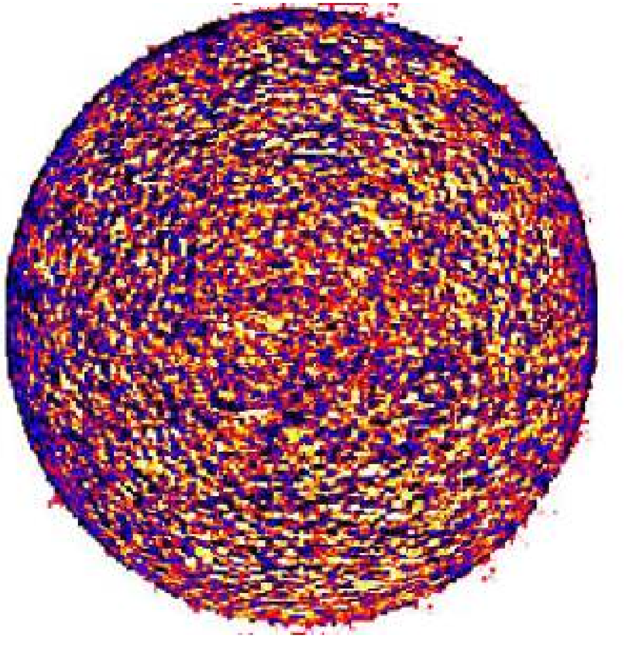
აკუსტკური ოსცილაციები;
ზედაპირული გრავიტაციული ტალღები;
მოცულობითი გრავიტაციული ტალღები;
...

მზის ოსცილაციები



აკუსტიკური მოდა (P მოდა)

პერიოდი:	5 წუთი
ამპლიტუდა ფოტოსფეროში:	10 კმ
ვერტიკალური სიჩქარე:	200 მ/წმ

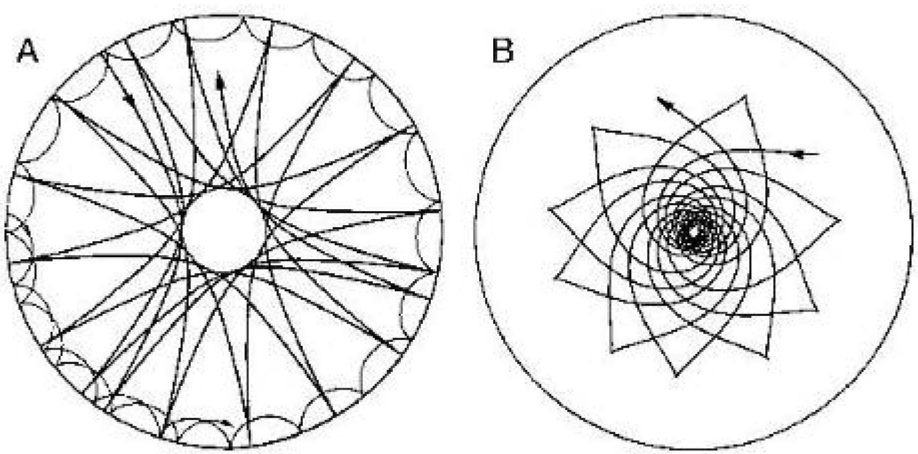


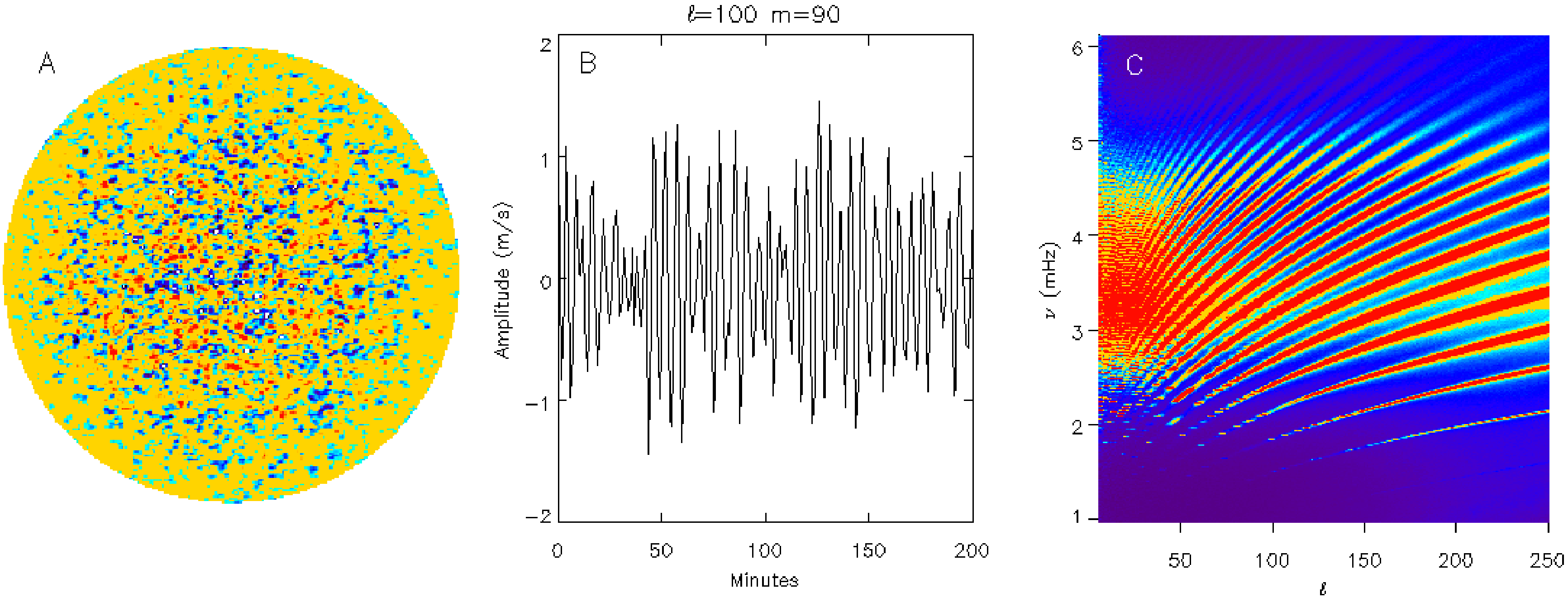
მოცულობითი გრავიტაციული მოდა (G მოდა): ?

ზედაპირული გრავიტაციული მოდა (F მოდა): ?

მზის ოსცილაციები

A - P მოდა;
B - G მოდა;

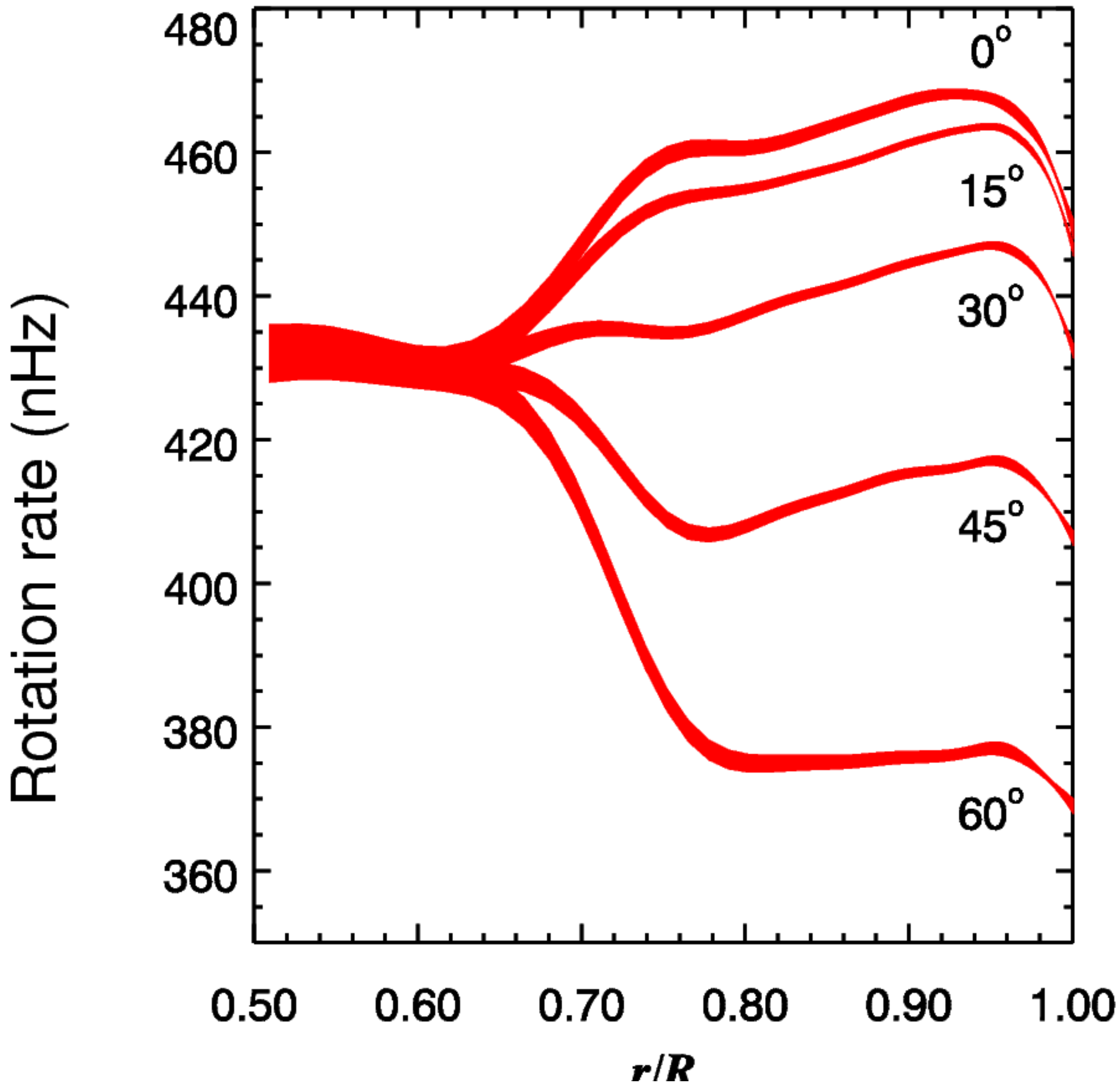




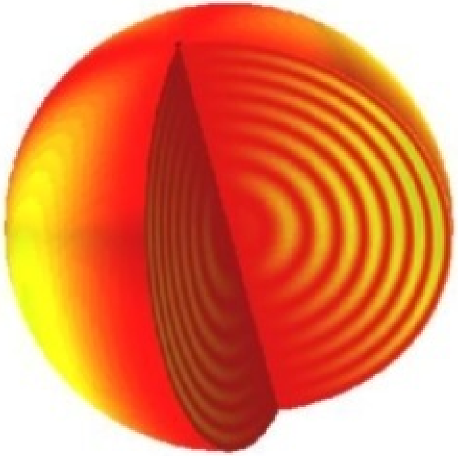
მზის ოსცილაციები

ზედაპირულ რხევებზე დაკვირვება
შებრუნებული ამოცანა:
მზის შიდა სტრუქტურის შესწავლა

მაგალითი:
მზის რადიალურად
დიფერენციული ბრუნვა



ასტეროსეისმოლოგია



Winget et al. ARAA2008

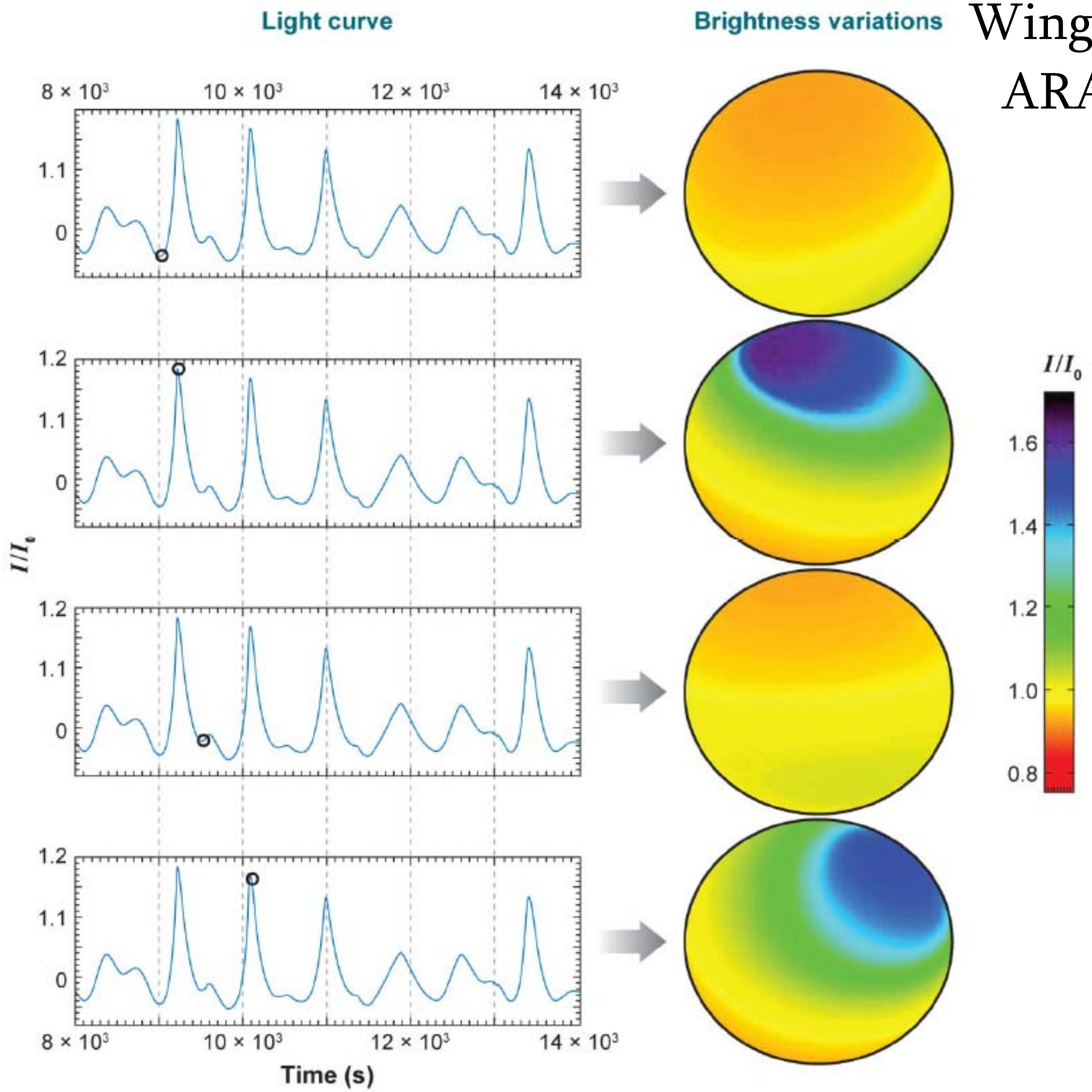


Figure 4 Surface brightness changes for the DBV GD 358, according to the non-linear convection/pulsation models of Montgomery (2007). The left side shows the position in the observed light (flux) corresponding to the surface brightness changes modelled on the right (intensity).

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \vec{V}) = 0 \quad ; \quad \frac{\partial \rho}{\partial t} + \rho(\nabla \vec{V}) + (\vec{V}\nabla)\rho = 0$$

$$1:)\ \frac{D}{Dt}\rho + \rho(\nabla\vec{V}) = 0 ; \quad \Big| \quad \frac{D}{Dt} \equiv \frac{\partial}{\partial t} + (\vec{V}\nabla)$$

$$2:)\ \frac{D}{Dt}\vec{V} = -\frac{1}{\rho}\nabla P + \nabla\Phi ; \qquad \vec{g} = (0, 0, g)$$

$$3:)\ \frac{D}{Dt}P = c_s^2 \frac{D}{Dt}\rho ;$$

$$P = \underline{P_0(z)} + P' \qquad V_0 = 0;$$

$$\rho = \underline{\rho_0(z)} + \rho'$$

$$-\frac{1}{\rho_0} \cdot \frac{\partial P_0(z)}{\partial z} = g$$

$$g \equiv const.$$

არაწრფივი

$$\frac{\partial \rho'}{\partial t} + \cancel{(\vec{V}_0 \nabla)\rho'} + (V' \nabla)\rho_0 + \boxed{(V' \nabla)\rho'}_{\to 0} + \cancel{(V_0 \nabla)\rho_0} +$$

$$+ \rho'\,\cancel{(\nabla V_0)} + \rho_0 \cancel{(\nabla V_0)} + \boxed{\rho'(\nabla V')}_{\to 0} + \rho_0 \cancel{(\nabla V_0)} = 0$$

$$\frac{\partial \rho'}{\partial t} + \left(V'_x \cancel{\frac{\partial}{\partial x}} + V'_y \cancel{\frac{\partial}{\partial y}} + V'_z \frac{\partial}{\partial z} \right) \rho_0 = 0$$

$$\frac{\partial \rho'}{\partial t} + \rho_0'(z)\, V'_z + \rho_0 (\nabla \vec{V}') = 0$$

$$\frac{\partial V_x'}{\partial t} = -\frac{1}{\rho_0}\frac{\partial P'}{\partial x}$$

$$\frac{\partial V_y'}{\partial t} = -\frac{1}{\rho_0}\frac{\partial P'}{\partial y}$$

$$\frac{\partial V_z'}{\partial t} = -\frac{1}{\rho_0}\frac{\partial P'}{\partial z} + \frac{\rho'}{\rho_0^2}\frac{\partial P_0(z)}{\partial z} = P_0'(z)$$

$$\vec{u} = \rho_0(z)\,\vec{V}$$

$$\frac{\partial \rho'}{\partial t} + \frac{\rho_0'(z)}{\rho_0(z)} u_z' = 0 \qquad + \nabla u_z'$$

$$\frac{\partial u_x'}{\partial t} + \frac{\partial p'}{\partial x} = 0$$

$$\frac{\partial u_y'}{\partial t} + \frac{\partial p'}{\partial y} = 0$$

$$\frac{\partial u_z'}{\partial t} + \frac{\partial p'}{\partial z} - \frac{p_0'(z)}{\rho_0(z)} \rho' = 0$$

$$\left(\frac{\partial p'}{\partial t} + \rho_0'(z) V_z' \right) = c_s^2 \left(\frac{\partial \rho'}{\partial t} + \rho_0'(z) V_z' \right)$$

$$\frac{\partial p'}{\partial t} + \rho_0'(z) V_z' - c_s^2 \nabla u' = 0$$

$$\frac{\partial p'}{\partial t} - c_s^2 \nabla u' + \frac{\rho_0'(z)}{\rho_0(z)} u_z' = 0$$

$$p(x,y,t) = \int \bar{P}(k_x,k_y,\omega)\, \exp(i\omega t - i k_x x - i k_y y)$$
$$\times\, dk_x dk_y d\omega$$

$$\frac{\partial p}{\partial x} \rightarrow \frac{\partial}{\partial x} y = -ik_x$$

$$\frac{\partial}{\partial \omega} \rightarrow i\omega\,, \qquad \frac{\partial}{\partial y} \rightarrow -ik_y$$

$$i\omega u_x' - ik_x p' = 0$$

$$i\omega u_y' - ik_y p' = 0$$

$$i\omega u_z' + \frac{\partial p'}{\partial z} - \frac{\rho_0'(z)}{\rho_0(z)} \rho' = 0$$

$$i\omega \rho' + k_x u_x' + k_y u_y' + \left(\frac{\partial}{\partial z} - \frac{\rho_0'(z)}{\rho_0(z)}\right) u_z' = 0$$

$$i\omega p' + c_s^2 k_x u_x' + c_s^2 k_y u_y' + \left(\frac{\partial}{\partial z} - \frac{\rho_0'(z)}{\rho_0(z)}\right) u_z' = 0$$

$$p_0(z) = p_0 \cdot \exp\left(-\frac{z}{H}\right)$$

$$z \ll H$$

$$\frac{p_0'(z)}{p_0(z)} = -\frac{1}{H}$$

$$\frac{\partial}{\partial z} \sim k_z$$

$$k_H = \frac{1}{H}$$

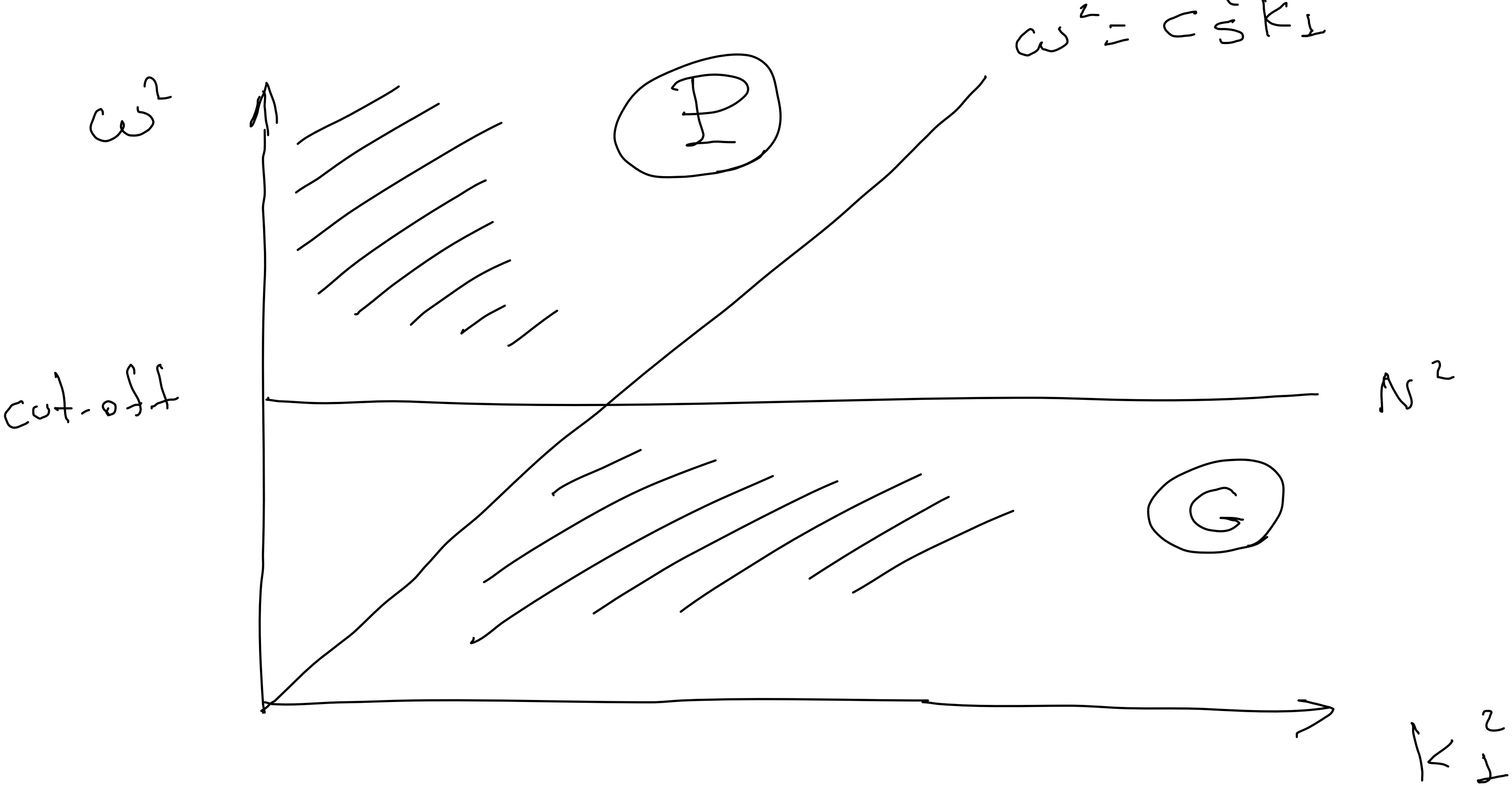
$$k_z \gg k_H$$

ლოკალური მიახლოება

$$N^2 \sim S_0'(z)$$

$$S_0(z) = p_0(z)\,\rho_0^{-\gamma}(z)$$

$$\left(\omega^2 - N^2\right)\left(\frac{c_s^2 k_\perp^2}{\omega^2} - 1\right) + k_z^2 = 0$$



$$(\omega^2 - N^2)\left(\frac{C_s^2 k_\perp^2}{\omega^2} - 1\right) + k_z^2 = 0$$

$$(\omega^2 - N^2)(C_s^2 k_\perp^2 - \omega^2) + \omega^2 k_z^2 = 0$$

$$-\omega^4 + C_s^2 k_\perp^2 \omega^2 - C_s^2 N^2 k_\perp^2 + \omega^2 N^2 + \omega^2 k_z^2 = 0$$

$$\boxed{\omega^4 - (C_s^2 k^2 + N^2)\,\omega^2 + N^2 C_s^2 k_\perp^2 = 0}$$

$$\omega^2 = \frac{1}{4}\left\{\frac{c_s^2 k^2 + N^2}{2}\right\}\left\{-1 \pm \sqrt{\left(c_s^2 k^2 + N^2\right)^2 - 4 c_s^2 N^2 k_\perp^2}\right\}$$

$$\omega^2 = + \frac{c_s^2 k^2 + N^2}{2}\left\{1 \mp \sqrt{1 - \frac{4 c_s^2 N^2 k_\perp^2}{\left(c_s^2 k^2 + N^2\right)^2}}\right\}$$

$$\omega^2 \approx \frac{c_s^2 k^2 + N^2}{2}\left\{1 \pm \left(1 - \frac{2 c_s^2 N^2 k_\perp^2}{\left(c_s^2 k^2 + N^2\right)^2}\right)\right\}$$

$$\omega_1^2 = \frac{c_s^2 N^2 k_\perp^2}{c_s^2 k^2 + N^2} \simeq N^2 \frac{k_\perp^2}{k^2} \qquad (\text{G-mode})$$

$$\omega_2^2 = \frac{c_s^2 k^2 + N^2}{2} \left(2 - \varepsilon \right) = c_s^2 k^2 \qquad (\text{P-mode})$$