Drift of HF components in PSR 0531+21 radiation as confirmation of the idea of nonlinear reflection from the surface of neutron star

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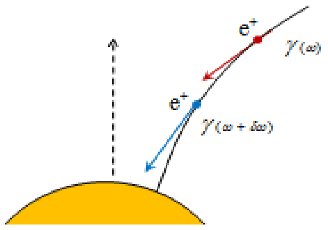
Saint Petersburg, Russia

S.Trofymenko and author (arXiv 2016 & this conference):

The radiation of a pulsar in the Crab nebula contains a signal reflected from the surface of the neutron star in the form of shifted IP.

That signal is associated with radiation of the returning positrons in an **inclined** magnetic field



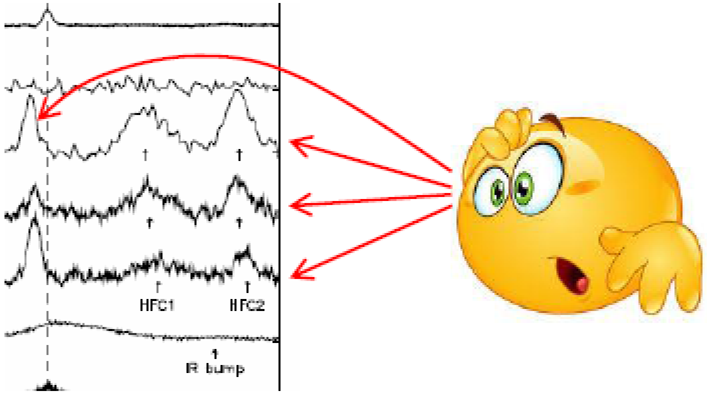
LTP (2016) & **This report:**

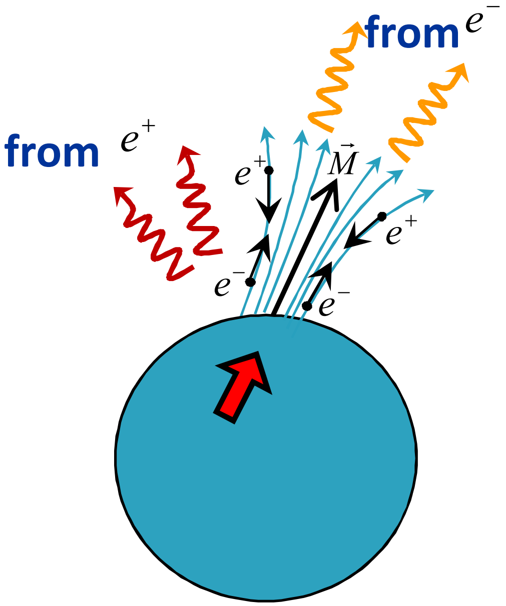
It is possible that in this case also a stimulated scattering from the star surface is observed in the form of HF components.

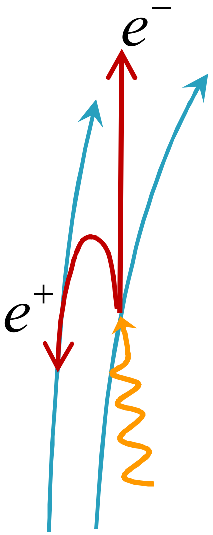
The frequency Drift of the HFC’s is discussed

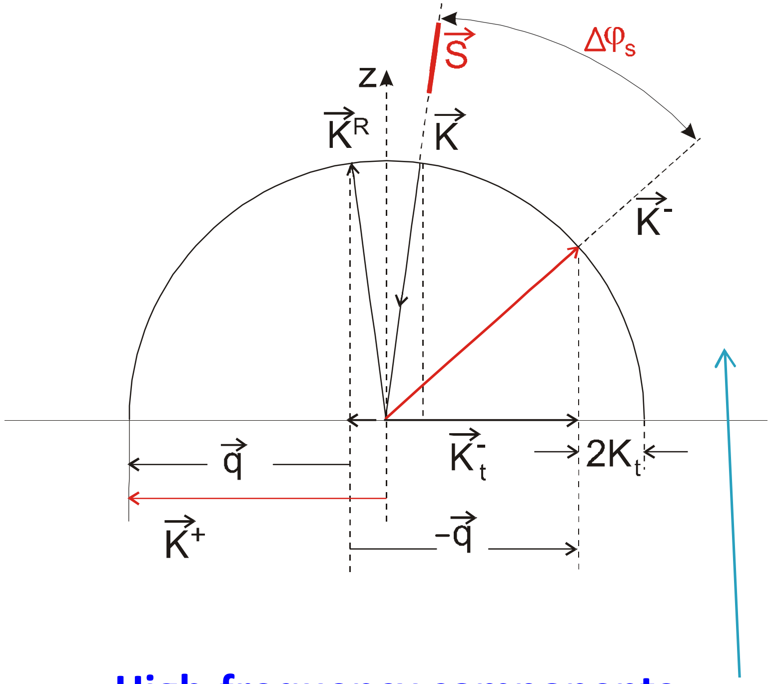
Shift of the interpulse as a result of mirror reflection from the pulsar surface of the radiation by relativistic positrons flying to a star from the magnetosphere

S.Trofymenko and author (arXiv 2016 & this conference)









Inclination angel of S find from the shift of IP

There is an alternative model of HF components not linked with reflection and IP shift (S.A.Petrova, RPhys and RAstr, 1, 27 (2010)

High-frequency components as a result of stimulated scattering on surface waves of the radiation of returning relativistic positrons. LTP (2016)

Stimulated Scattering

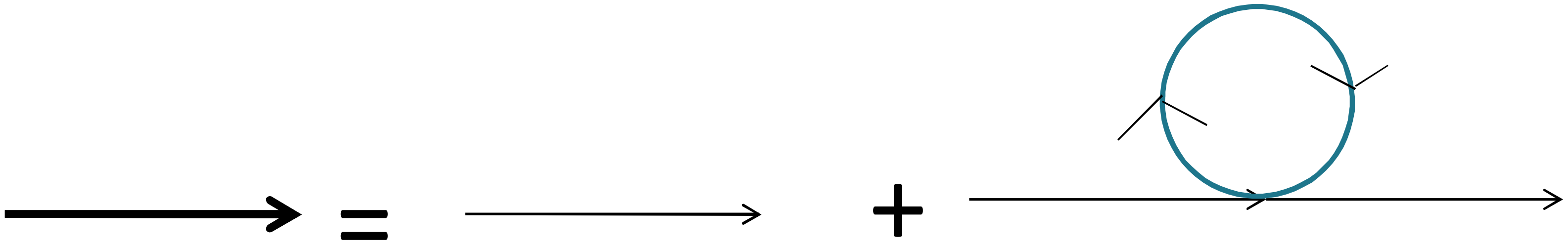
Stimulated scattering (SS) is an effect as common as a nonlinear frequency shift. In contrast to the frequency shift, at SS the coefficient at a squared module of the amplitude of strong incident wave contains an imaginary part, which is responsible for the arising instability.

Each type of stimulated scattering corresponds to its spontaneous analogue. What concerns scattering on surface waves, there has to be the stimulated scattering on them (SS on SW).

All kinds of SS had been observed in special experiments using powerful sources of radiation (lasers). SS on SW, unlike the rest of SS, has not been observed in its pure form, although it indirectly manifested itself in the appearance of the surface structures.

In nature, any type of SS of the natural origin is still nowhere to be registered.

Analogy of SS to the nonlinear frequency shift



$$\Omega(q) = \pm\,\Omega_0(q) - 2iq^2\,\frac{\eta^I + \eta^{II}}{\rho^I + \rho^{II}} \mp \frac{iq^2 P\varepsilon^I \left|E_0^i\right|^2}{16\pi(\rho^I + \rho^{II})\Omega_0(q)}.$$

As example of SW may serve the gravitational-capillary wave

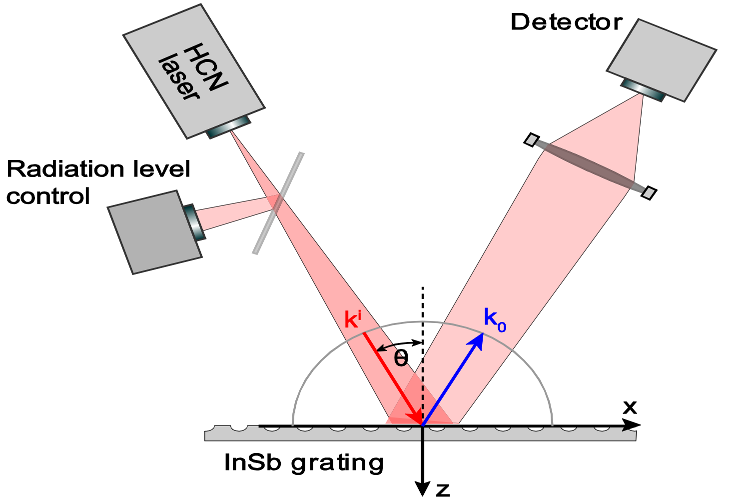
SS arises when the Decrement ↓ becomes less than the ↑ Increment

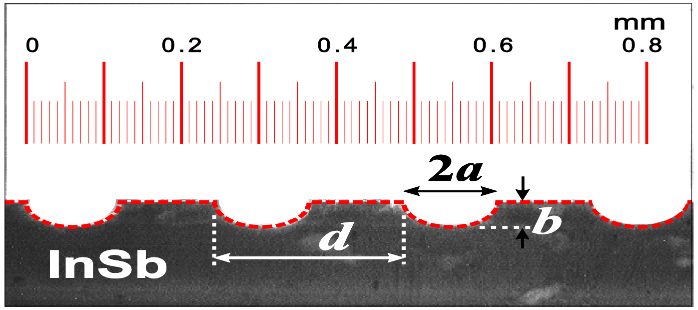
$$\Omega^2(q) = gq + \cancel{\frac{\alpha}{\rho}q^3}$$

$$\Omega(q) = \sqrt{gq} << \omega = ck$$

For the cm-wave region the main is the gravitational term

Illustration of Wood’s anomaly : Diffraction of a laser beam on a lattice



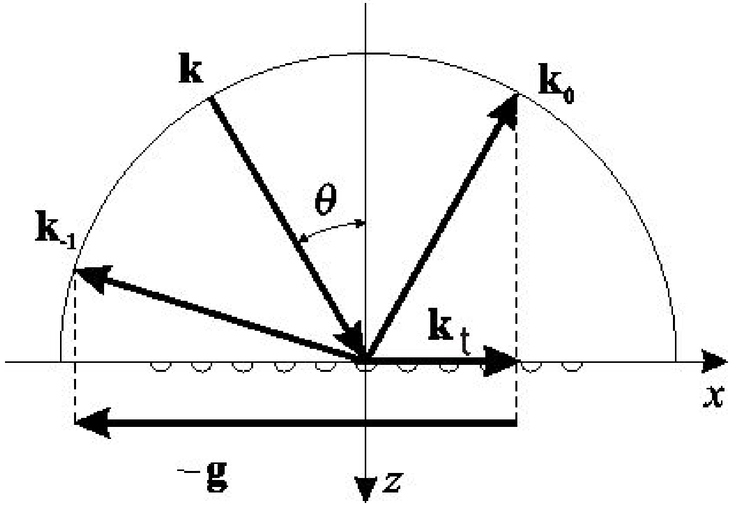


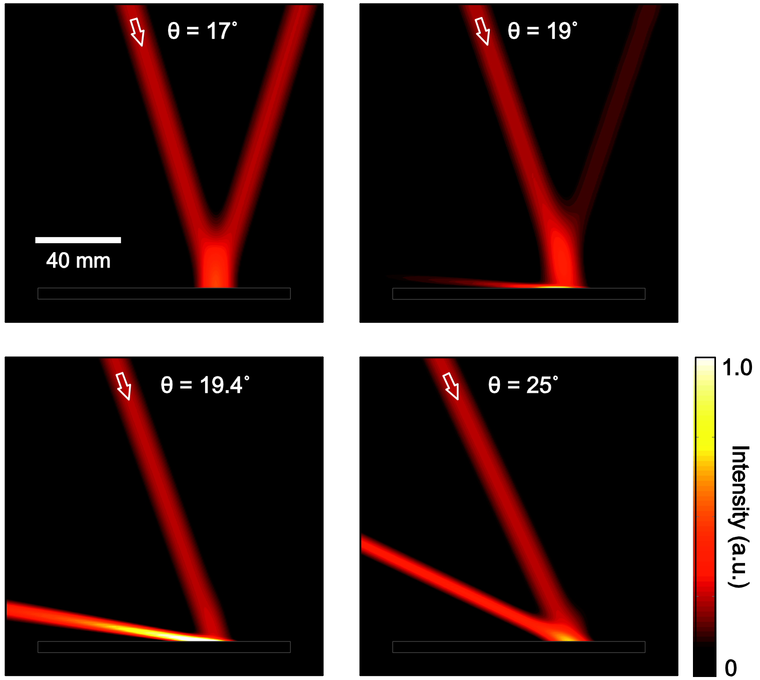
$$\sin\theta_R = \frac{\lambda}{d} - 1 \qquad \lambda = 366.7\, mkm \qquad d = 254\, mkm$$

$$\theta_R = 18{,}978 \text{ град.}$$

By **M. Tymchenko, V. K. Gavrikov, I. S. Spevak, et al,**
Applied Physics Letters **106,** 261602 (**2015**)

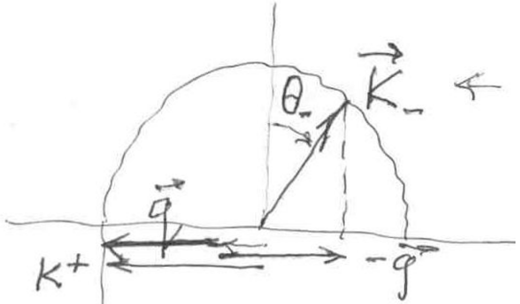
Geometry of diffraction





Excited surface waves and Wood's anomalies

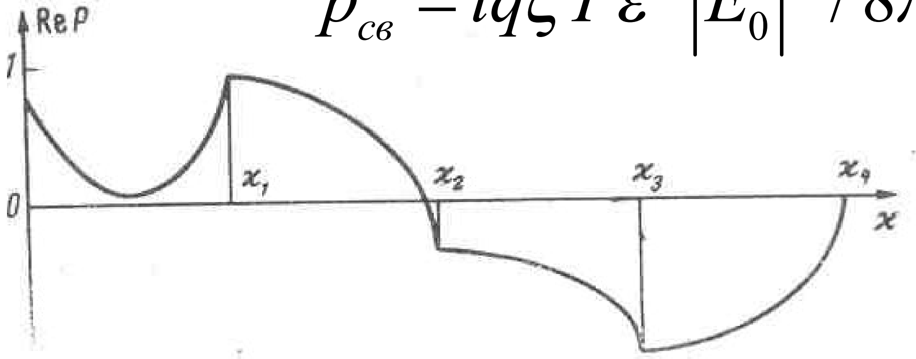
Gavrikov, Kats & Kontorovich
Soviet Doklady, 1969; JETP, 1971



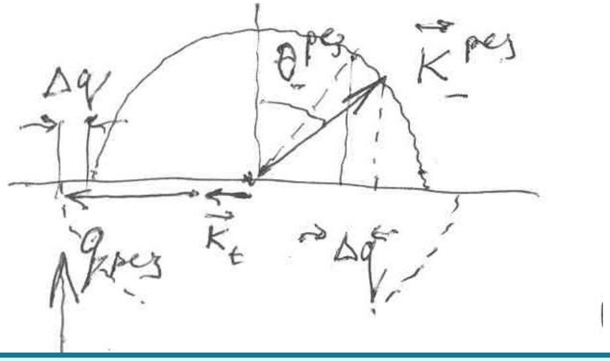
This (Wood's) wave has k_z=0

For Wood's wave maximum Is expected of ReP

$$p_{св} = iq\zeta P\varepsilon^{I}\left|E_0^i\right|^2/8\pi$$



The Light Pressure **P** as function of wave number q/k, where **q** belongs to SW and **k** to EM wave. Maxima correspond to generation of grazing waves



We may expect also the Resonance with surface EM H-wave

Kats & Maslov, JETP, 1972

$$P = \frac{(\varepsilon-1)}{4q}\left\{T_s^2\cos^2\varphi\cdot\left(C_{1y}^{T}-C_{-1y}^{T*}\right)+\right.$$
$$+\varepsilon^{I}T_p^2\sin^2\varphi\left[Z_x\left(B_{1x}^{T}-B_{-1x}^{T*}\right)+\varepsilon Z_z\left(B_{1x}^{T}-B_{-1x}^{T*}\right)+2q_x(\varepsilon-1)Z_xZ_z\right]-$$
$$\left.-\sqrt{\varepsilon^{I}}\frac{T_sT_p}{2}\left[B_{1y}^{T}-B_{-1y}^{T*}+Z_x\left(C_{1x}^{T}-C_{-1x}^{T*}\right)+\varepsilon Z_z\left(C_{1z}^{T}-C_{-1z}^{T*}\right)+2q(\varepsilon-1)Z_z\right]\sin 2\varphi\right\}$$

T=E/Ei , H/Hi are the Fresnel coefficients, Z=E/H are wave impedances , phi – is the angle with i-plane

$$\Omega(q) = \pm\Omega_0(q) - 2iq^2\frac{\eta^{I}+\eta^{II}}{\rho^{I}+\rho^{II}} \mp \frac{iq^2P\varepsilon^{I}\left|E_0^i\right|^2}{16\pi\left(\rho^{I}+\rho^{II}\right)\Omega_0(q)}.$$

Mandel'stam-Raman electromagnetic fields

$$\varepsilon = \varepsilon^{II} / \varepsilon^{I} >> 1$$

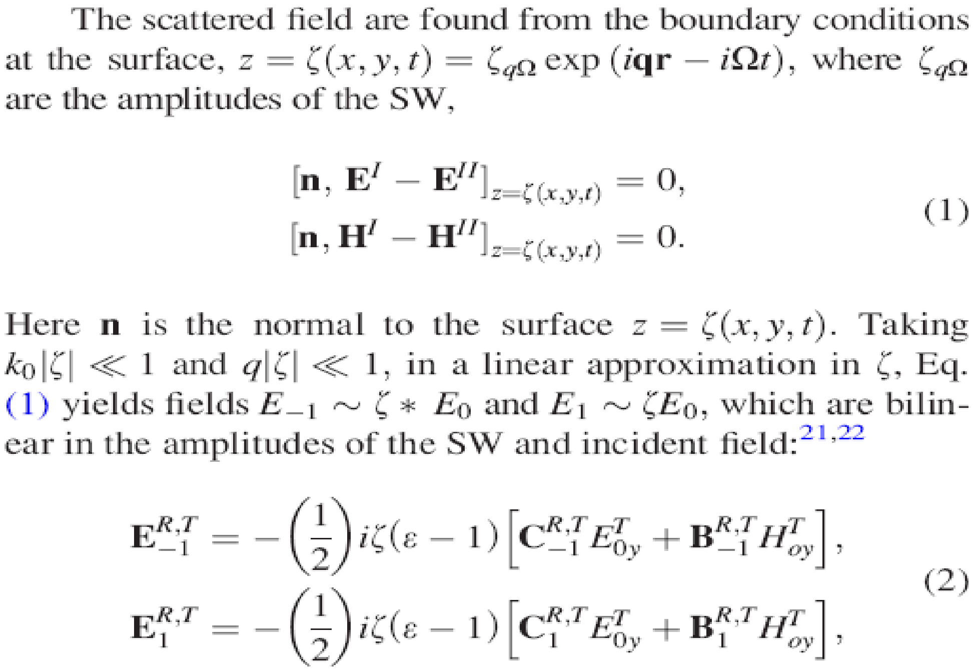
$$a_{-1} = (k^{T}_{-1z} - \varepsilon k^{R}_{-1z})^{-1}, \quad d_{-1} = a_{-1} c / \omega\varepsilon$$

The Wood's anomaly and estimates for the scattered fields

$$E_{\pm} \approx (k\varsigma) E_{0y} \qquad \text{kz} \neq 0 \qquad (1)$$

$$E_{\pm} \approx \sqrt{\varepsilon} \cdot (k\varsigma) E_{0y} \qquad \text{Kz} = 0 \qquad (2)$$

We will be interested in the case of large moduli of ε. In the coefficients for combinational fields, this factor enters in the numerator: (ε -1) and in the denominator (the coefficients "a”) in the form of multipliers at k_z. Therefore, for ε>>1, they cancel each other and do not affect the evaluation of the combinational fields, unless k_z is small. For the grazing components (k_z = 0), the amplitudes increase significantly..



The scattered field are found from the boundary conditions at the surface, $z = \zeta(x, y, t) = \zeta_{q\Omega} \exp(i\mathbf{qr} - i\Omega t)$, where $\zeta_{q\Omega}$ are the amplitudes of the SW,

$$\begin{aligned} [\mathbf{n}, \mathbf{E}^{I} - \mathbf{E}^{II}]_{z=\zeta(x,y,t)} &= 0, \\ [\mathbf{n}, \mathbf{H}^{I} - \mathbf{H}^{II}]_{z=\zeta(x,y,t)} &= 0. \end{aligned} \qquad (1)$$

Here $\mathbf{n}$ is the normal to the surface $z = \zeta(x, y, t)$. Taking $k_0|\zeta| \ll 1$ and $q|\zeta| \ll 1$, in a linear approximation in ζ, Eq. (1) yields fields $E_{-1} \sim \zeta * E_0$ and $E_1 \sim \zeta E_0$, which are bilinear in the amplitudes of the SW and incident field:[21,22]

$$\begin{aligned} \mathbf{E}^{R,T}_{-1} &= -\left(\frac{1}{2}\right) i\zeta(\varepsilon - 1)\left[\mathbf{C}^{R,T}_{-1} E^{T}_{0y} + \mathbf{B}^{R,T}_{-1} H^{T}_{oy}\right], \\ \mathbf{E}^{R,T}_{1} &= -\left(\frac{1}{2}\right) i\zeta(\varepsilon - 1)\left[\mathbf{C}^{R,T}_{1} E^{T}_{0y} + \mathbf{B}^{R,T}_{1} H^{T}_{oy}\right], \end{aligned} \qquad (2)$$

$$C^{R,T}_{-1x} = -a_{-1} k_{-1x} k_{-1y}, \quad C^{R,T}_{-1y} = a_{-1}(k^{2}_{-1x} - k^{R}_{-1z} k^{T}_{-1z}),$$

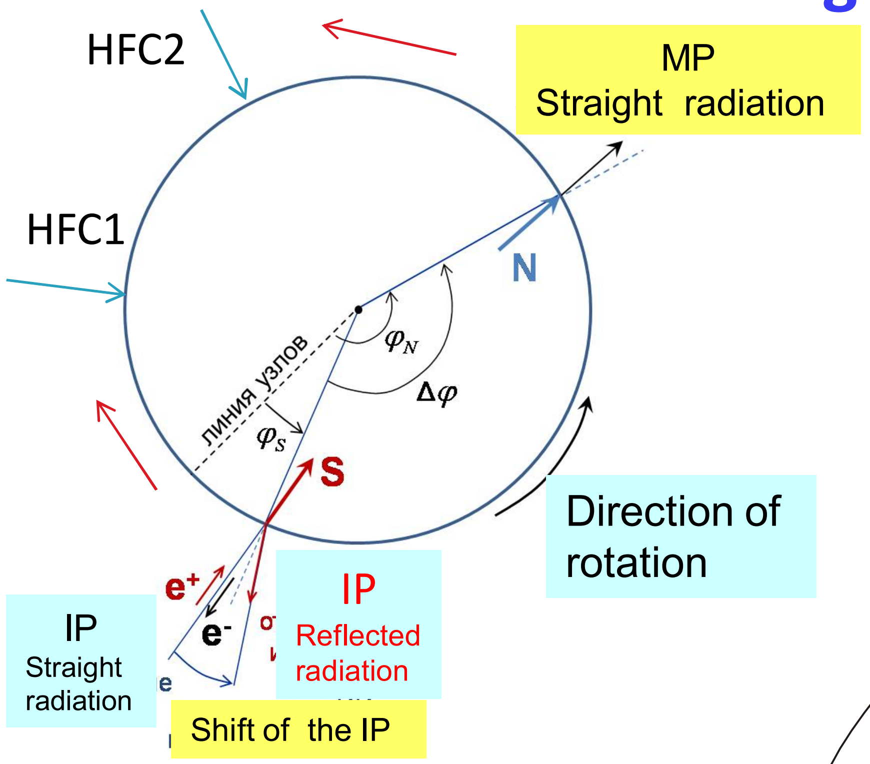
$$C^{R,T}_{-1z} = a_{-1} k_{-1y} k^{T,R}_{-1z},$$

$$B^{R}_{-1x} = d_{-1}\left[\varepsilon k_{0x} k_{-1x} k^{R}_{-1z} - k^{T}_{0z}(k^{R}_{-1z} k^{T}_{-1z} - k^{2}_{-1y})\right],$$

$$B^{R}_{-1y} = d_{-1} k_{-1y}(\varepsilon k_{0x} k^{R}_{-1z} - k_{-1x} k^{T}_{-1z}),$$

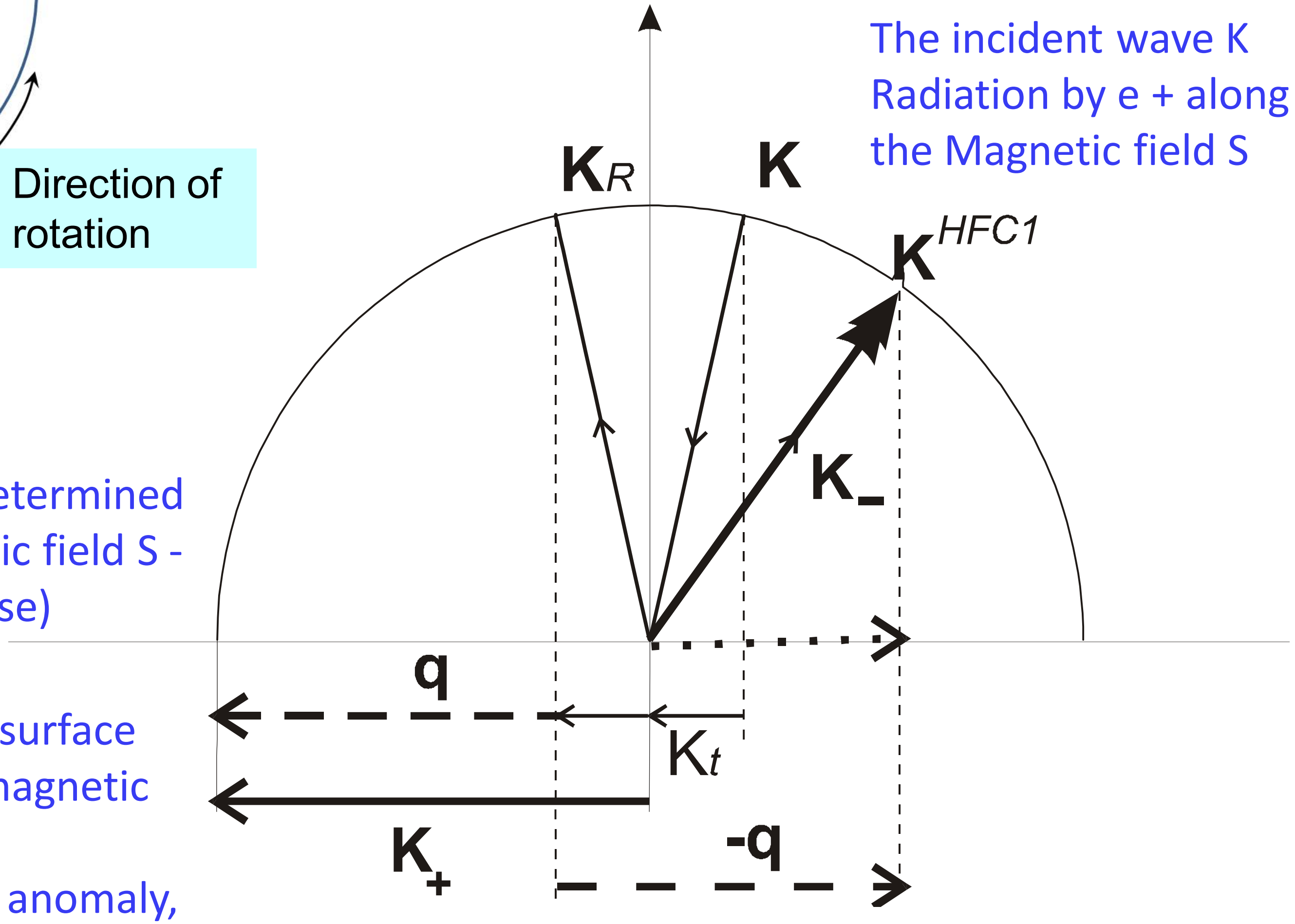
$$B^{R}_{-1z} = d_{-1}\left[\varepsilon k_{0x}(k^{2}_{-1x} + k^{2}_{-1y}) - k_{-1x} k^{T}_{0z} k^{T}_{-1z}\right],$$

The stimulated scattering scheme at the S pole of a pulsar



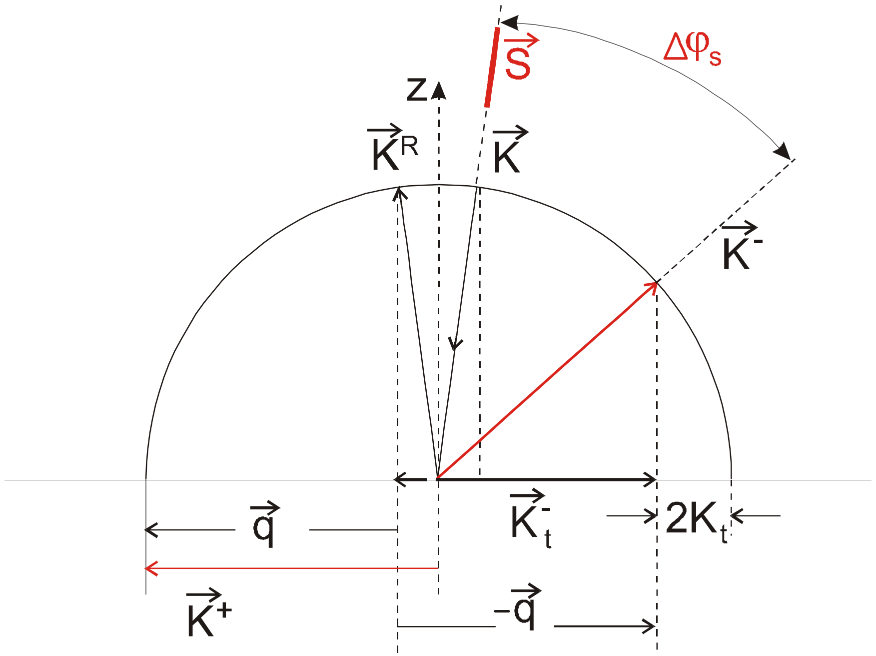
Amplified with Wood's anomaly Stokes wave K_ generates high-frequency Moffett-Hankins' component ----------- HFC1

The incident wave K
Radiation by e + along
the Magnetic field S

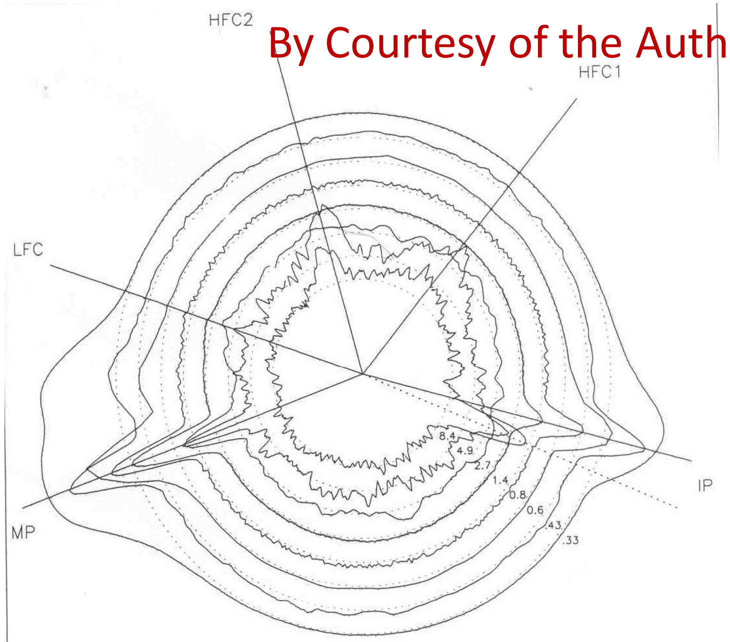


The angle of incidence is determined by the Slope of the magnetic field S - (By the shift of the interpulse)

q is the wave vector of the surface wave, anti-Stokes electro-magnetic surface wave K +
corresponds to the Wood's anomaly,
the angle of incidence is the Rayleigh's angle.



The scheme of the appearance of Combinational Raman Spectra of the first order at the pole S at Stimulated Scattering of radiation by returning Positrons

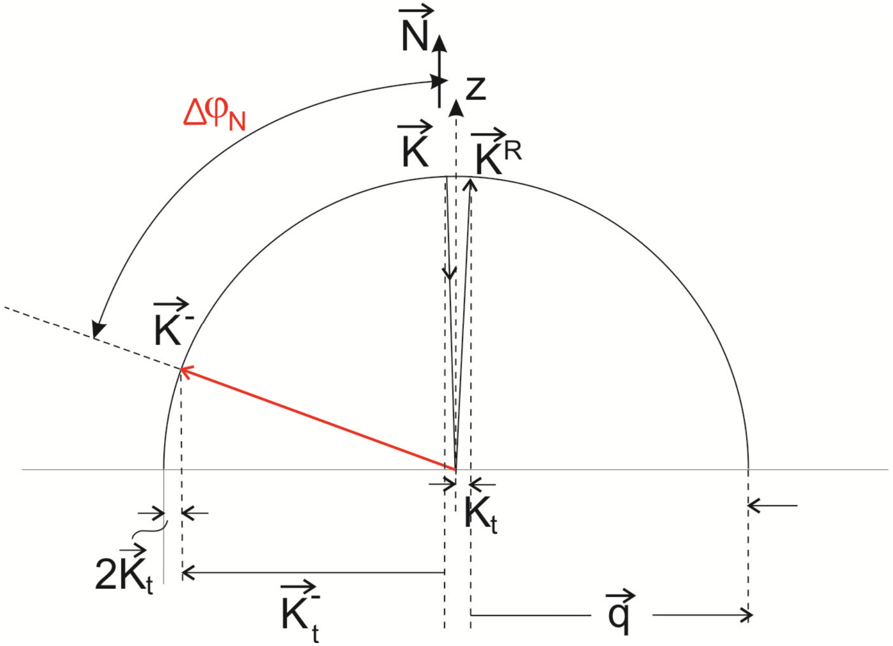


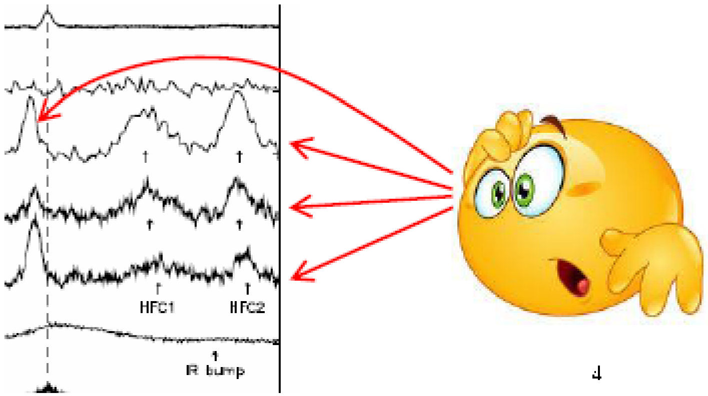
By Courtesy of the Authors

D. Moffett, T. Hankins // ApJ, 1996

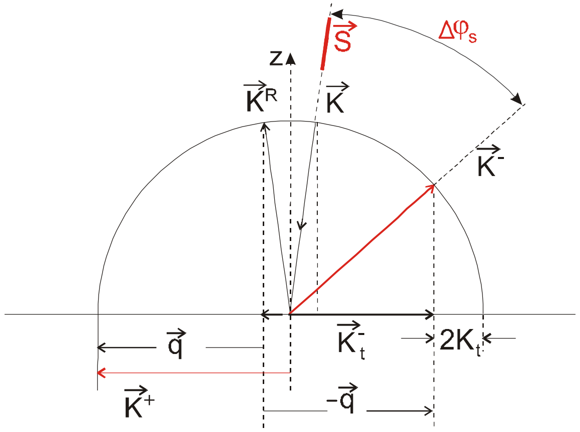
V.M.Kontorovich
LTP, **42**, № 8, 854-862 (2016)

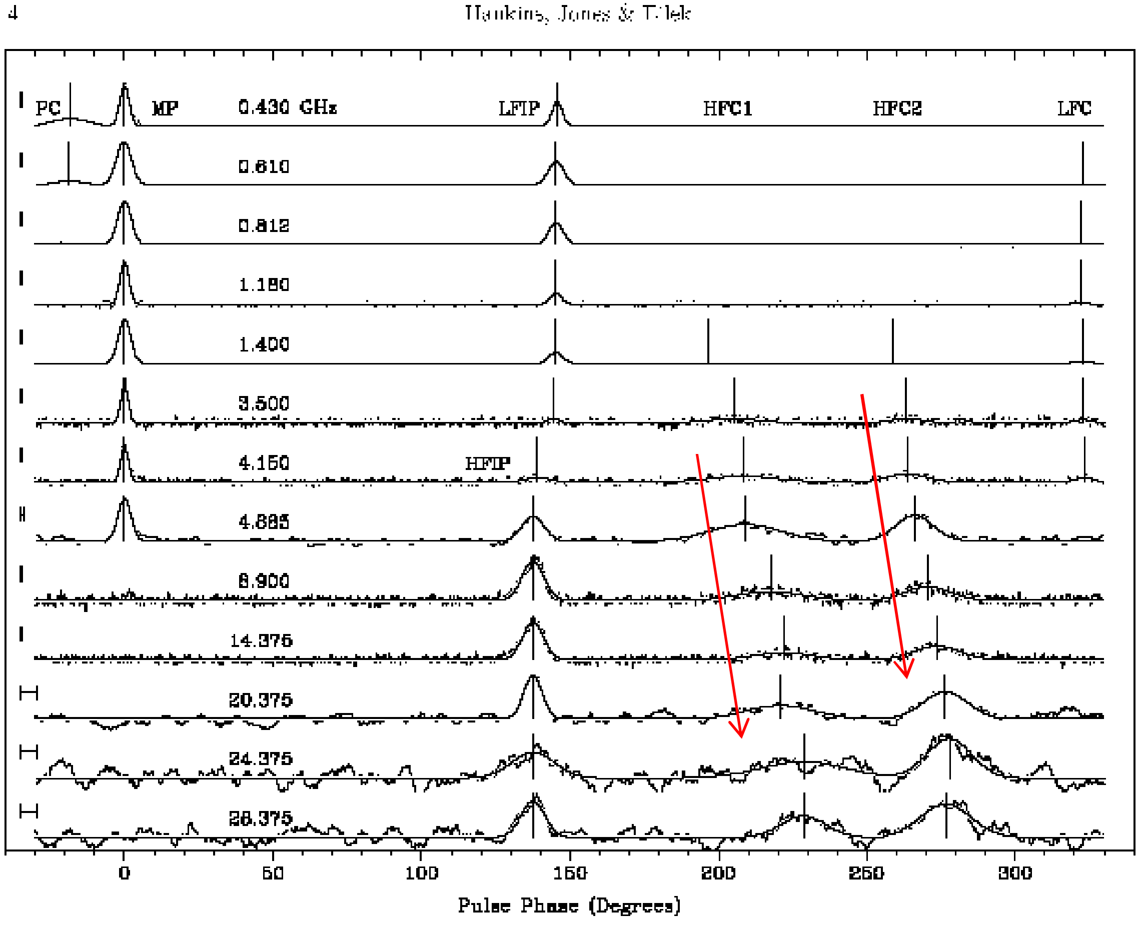
The scheme for appearance of the first-order Raman spectra at the pole N.
The direction of the phase shift here is inverse compared to the pole S.





Drift of the HF component in the Stimulated Scattering model





International Conference -
"Physics of Neutron Stars
- 2017. 50 years after"
Saint Petersburg, Russia

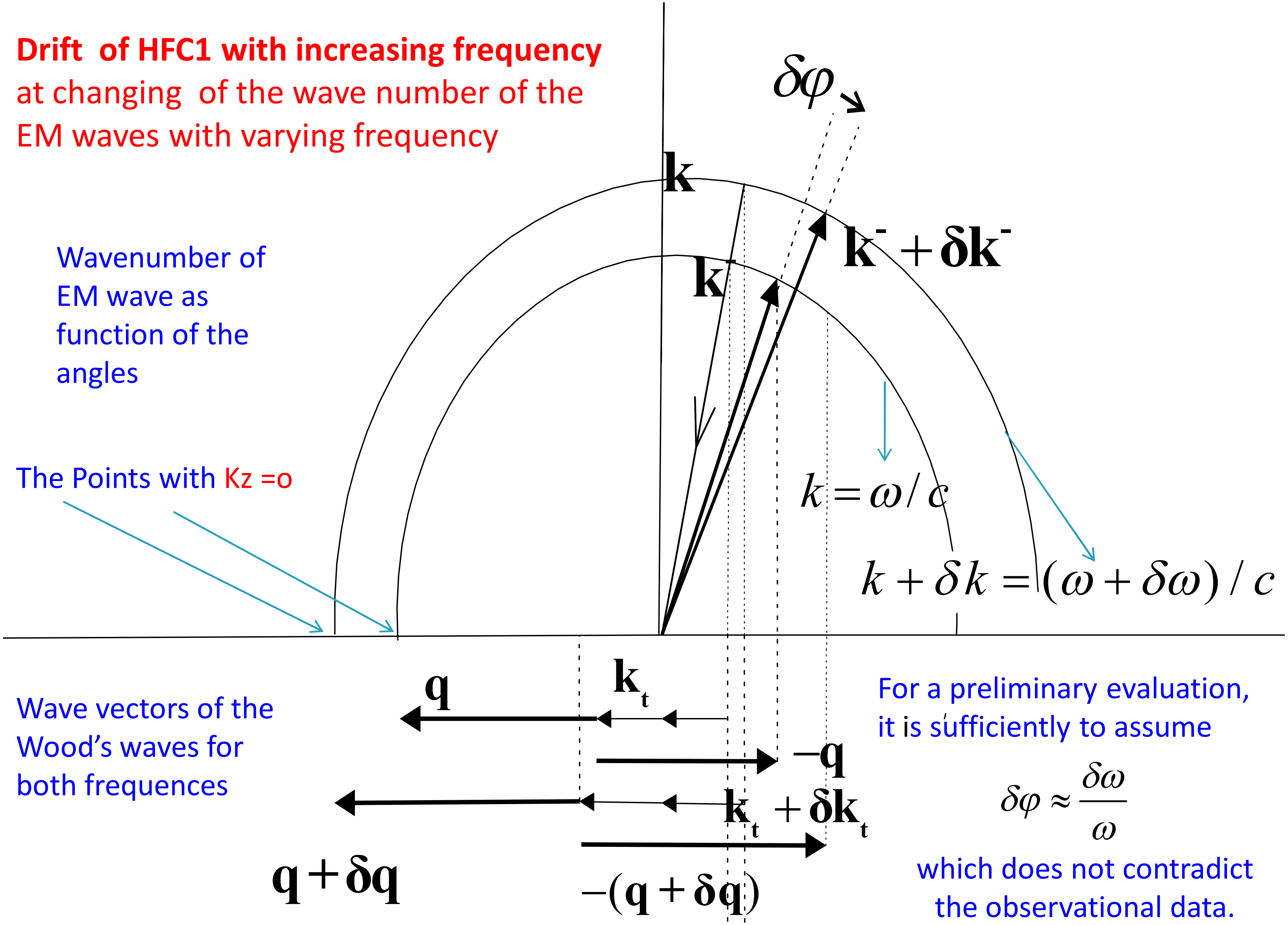
Hankins, Jones & Eilek, arXiv:1502.00677

By Courtesy of the Authors

The frequency drift of the components

is very important in choosing the right theoretical model. Particularly, the coincidence of its directions for both components is an argument in favor of the birefringence of the scattered wave in anisotropic magnetized pulsar plasma. Returned motion of positrons, arising at penetration of accelerating electric field of the gap in the pair plasma, was considered in literature in connection with heating of the surface by the reverse current. The difference of magnetic field from dipole one, leading in particular to its slope, also was discussed with regard to its toroidal component as well. However, the low-frequency radiation of backflow positrons and reflected radiation from the surface of the pulsar were not considered anywhere until our works.

Drift of HFC1 with increasing frequency at changing of the wave number of the EM waves with varying frequency



Wavenumber of EM wave as function of the angles

The Points with Kz =o

Wave vectors of the Wood's waves for both frequences

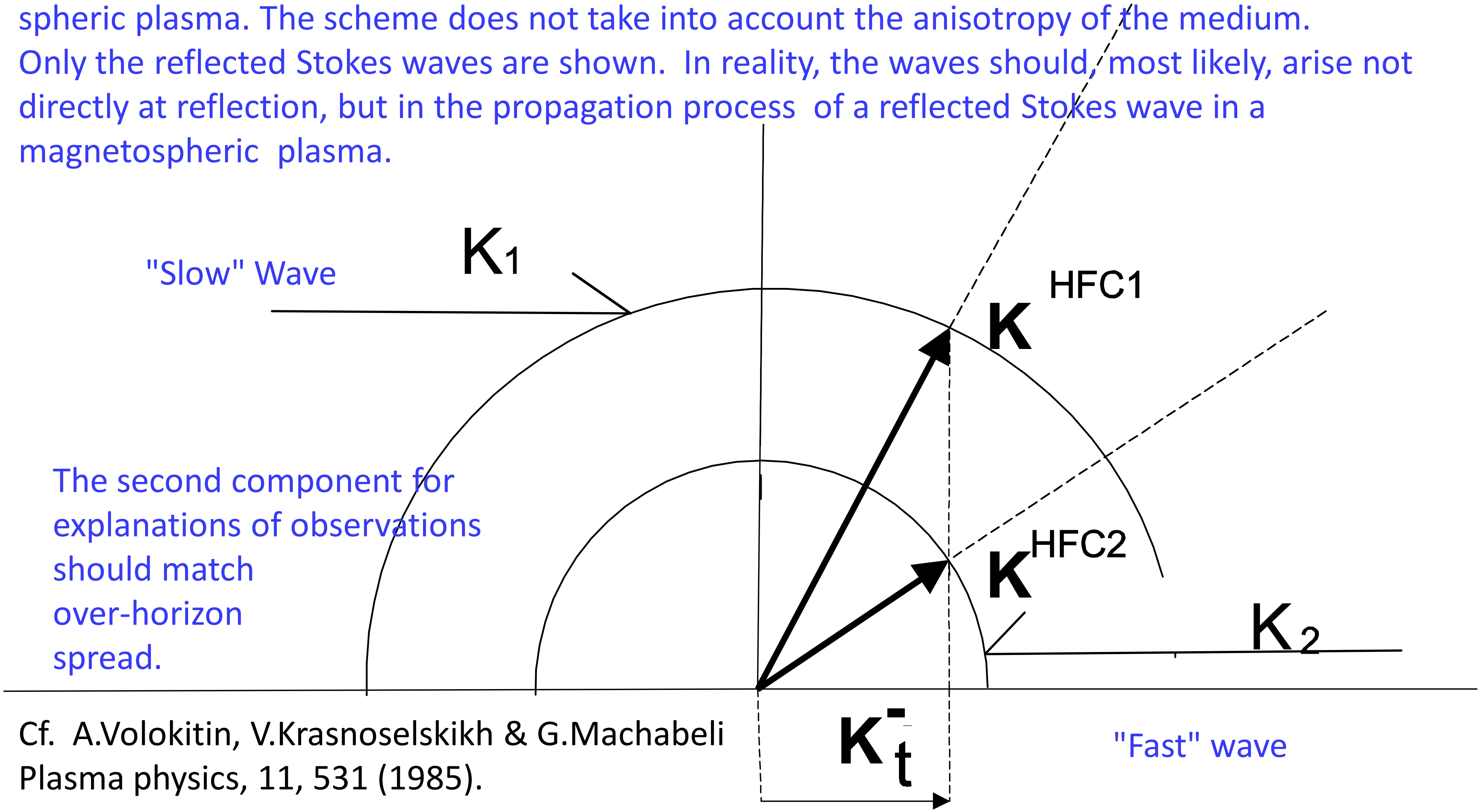
For a preliminary evaluation, it is sufficiently to assume

$$\delta\varphi \approx \frac{\delta\omega}{\omega}$$

which does not contradict the observational data.

Possible scheme of occurrence of two HF components due to birefringence in reflection

Two components can arise due to slow and fast waves, which are present in the magnetospheric plasma. The scheme does not take into account the anisotropy of the medium. Only the reflected Stokes waves are shown. In reality, the waves should, most likely, arise not directly at reflection, but in the propagation process of a reflected Stokes wave in a magnetospheric plasma.



The second component for explanations of observations should match over-horizon spread.

Cf. A.Volokitin, V.Krasnoselskikh & G.Machabeli Plasma physics, 11, 531 (1985).

RESUME

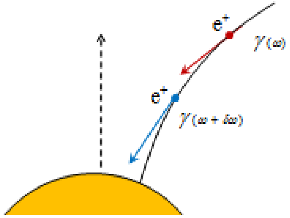
A new mechanism of radiation emission in the polar gap of a pulsar is proposed in [3]. It is the curvature radiation which is emitted by positrons moving towards the surface of the neutron star along magnetic field lines and **reflects** from the surface. Such radiation interferes with transition radiation emitted from the neutron star when positrons hit the surface. It is shown that the proposed mechanism may be applicable for explanation of the mystery of the inter pulse shift in the Crab pulsar at high frequencies discovered by Moffett and Hankins twenty years ago.

(See the Previous report of Trofimenko and author)

The radiation of high-frequency components of the pulsar in the Crab Nebula can be considered also as a manifestation of instability in the **nonlinear reflection** from the neutron star surface [4]. The discussed instability is a **stimulated scattering** (SS) by surface waves, predicted more than forty years ago and still nowhere and by no one have observed.

Drift of HFC’s has a natural explanation in the frame of SS model.

Thank you for attention!



1. **D. Moffett & T. Hankins**, ApJ. **468,** 779 (1996); astro/ph 9604163.
2. **T. Hankins, G. Jones & J. Eilek**, Ap J. **802**, 130 (2015); arXiv:1502.00677v1 [astro-ph.HE]
3. **V. M. Kontorovich & S.V.Trofymenko,** 'Half-bare' positron in the inner gap of a pulsar and shift of interpulse position. **ArXiv**: 1606.02966.
4. **V. M. Kontorovich**, Nonlinear reflection from the surface of neutron stars and features of radio emission from the pulsar in the Crab nebula Low Temperature Physics **42**, 2 (2016); **arXiv**: 1701.02304.
5. **J. Eilek & T. Hankins,** Radio emission physics in the Crab pulsar. Journal of Plasma Physics 82, article ID 635820302 (2016), arXiv:1604.02472
6. **D.P.Barsukov, O.A.Goglachidze & A.I.Tsygan**, Influence of small-scale magnetic field on the reverse positron current in the inner gaps of radio pulsars. АЖ, **93,** 569 (2016)