X-ray Hybrid Radiation

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Motivations and goals

Top Goal:

- Development of soft x-ray sources in the water window spectral range ($284 - 543$ eV) based on x-ray Cherenkov radiation.

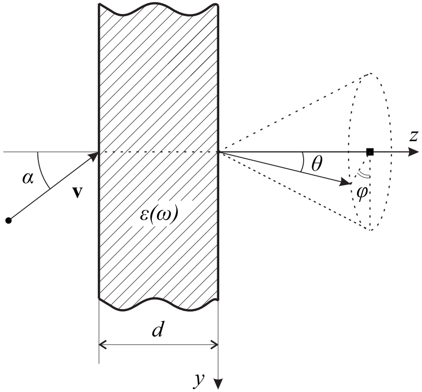
Subgoals:

1. angular distribution of x-ray hubrid radiation when relativistic charge crosses a finite-size sreen under an incedence angle;
2. spectral properties and determine monochromaticity;
3. investigation of polarization properties of hybrid radiation.

Report outline:

1. Radiation geometry and initial conditions for considered task;
2. Applied methods;
3. Results and discussions;
4. Conclusion.

Radiation geometry



the main points for calculation:

- charge passes through a screen under an incidence angle;
- a finite-size creen;
- a low energy charge (from a few MeV to 100 Mev);
- soft x-ray range.

Expression for spectral-angular distribution of polarization radiation

Spectral-angular distribution for considered radiation was obtained analitically[1]:

$$\frac{d^2W}{d\omega d\Omega} = \frac{e^2}{\pi^2 c}\beta^2\cos^2\alpha\left|\frac{\epsilon(\omega)-1}{\epsilon(\omega)}\right|^2 \frac{\cos^2\alpha}{\left[(1+\beta\sin\alpha\sin\theta\cos\phi)^2-\beta^2\cos^2\alpha\cos^2\theta\right]^2}$$

$$\times\left|\frac{1-\exp\left[-id\frac{\omega}{\beta c\cos\alpha}\left(1-\beta\cos\alpha\sqrt{\epsilon(\omega)-\sin^2\theta}+\beta\sin\alpha\sin\theta\cos\phi\right)\right]}{1-\beta\cos\alpha\sqrt{\epsilon(\omega)-\sin^2\theta}+\beta\sin\alpha\sin\theta\cos\phi}\right|^2$$

$$\times\left[\beta^4\cos^2\alpha\sin^2\alpha\sin^2\phi\left|\frac{\sqrt{\epsilon(\omega)}}{\cos\theta+\sqrt{\epsilon(\omega)-\sin^2\theta}}\right|^2\right.$$

$$\times\left(\sin^2\theta+\left|\sqrt{\epsilon\left(\omega\right)-\sin^2\theta}\right|^2\right)+\left|\frac{\epsilon(\omega)}{\epsilon(\omega)\cos\theta+\sqrt{\epsilon(\omega)-\sin^2\theta}}\right|^2$$

$$\times\left|\left(\beta^2\cos^2\alpha-1-\beta\sin\alpha\sin\theta\cos\phi\right)\sin\theta\right.$$

$$\left.\left.+\beta\cos\alpha\sqrt{\epsilon\left(\omega\right)-\sin^2\theta}\left(\sin\theta+\beta\sin\alpha\cos\phi\right)\right|^2\right]$$

[1] A.S. Konkov, Thesis, Tomsk Polytechnic University (2016).

Dielectric permittivity

The Henke model of dielectric permittivity was used:

$$\epsilon\left(\omega\right)=\left[1-\frac{1}{2Z}\left(\frac{\hbar\omega_p}{\hbar\omega}\right)^2 f\left(\omega\right)\right]^2,$$

where ω_p is the plasma frequency, Z is the atomic number and $f(\omega)=f_1\left(\omega\right)\pm i f_2\left(\omega\right)$ is the complex atomic scattering factor[2].

[2] B. L. Henke *et al.*, At. Data Nucl. Data Tables **27**, 1 (1982).

Stockes parameters for hybrid radiation

$\xi_1 = \dfrac{E_1^* E_1 - E_2 E_2^*}{E_1^* E_1 + E_2 E_2^*}$ describes the amount of linear horizontal or vertical polarization.

$\xi_2 = i\dfrac{E_1^* E_2 - E_1 E_2^*}{E_1^* E_1 + E_2 E_2^*}$ corresponds to the amount of linear $\pm 45^\circ$ polarization.

$\xi_3 = \dfrac{E_1^* E_2 + E_1 E_2^*}{E_1^* E_1 + E_2 E_2^*}$ helps to determine the amount of right or left circular polarization.

In the case of considered geometry of radiation

$E_1 = C(\beta^2 e_z \cos\alpha \sin\alpha - e_y[1 - \beta^2 \cos^2\alpha + \beta\epsilon(\omega)\, e_y \sin\alpha$
-$\beta\epsilon(\omega)\, e_z \cos\alpha]),$

$E_2 = C\left(e_x e_z[1 - \beta^2 \cos^2\alpha + \beta\epsilon(\omega)\, e_y \sin\alpha - \beta\epsilon(\omega)\, e_z \cos\alpha]\right.$
$\left.+\mathsf{e}_x e_y \beta^2 \cos^2\alpha \sin^2\alpha\right),$

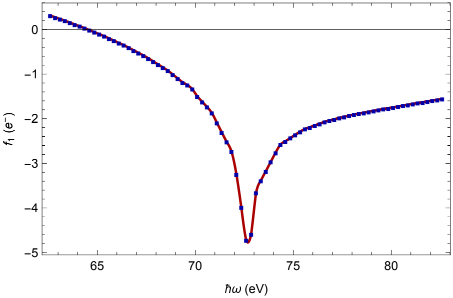
where $\mathbf{e} = \{\sin\theta \sin\phi, \sin\theta\cos\phi, \cos\phi\}$.

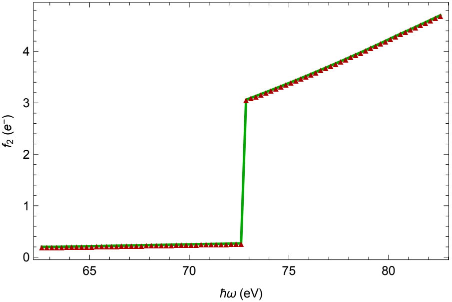
Calculation parameters for Al

$^{27}_{13}\text{Al}$

$\rho = 2.7\ \text{g/cm}^3$
$d = 8\ \mu m$
$\hbar\omega = 62.6 \div 82.6\ \text{eV}$

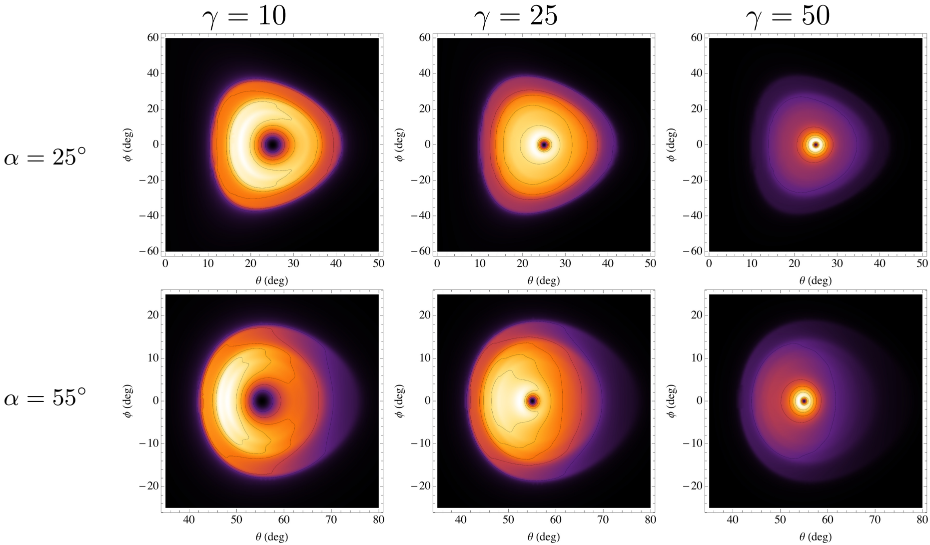
Scattering factors:



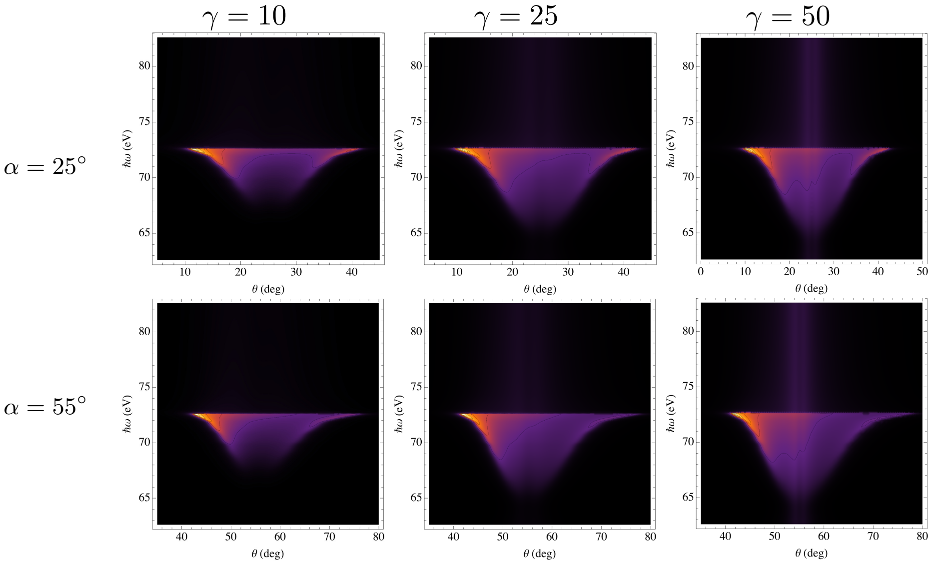


Dots are measurement data, the color curves are interpolation functions.

Angular distribution of hybrid radiation from Al screen

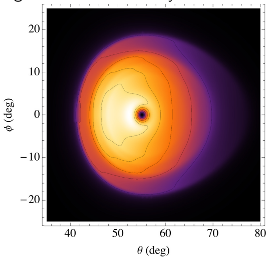


Spectrum of hybrid radiation from Al screen

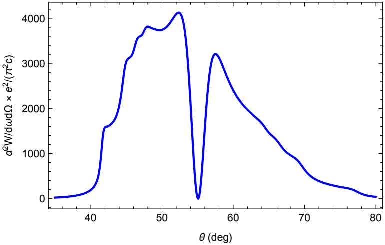


Al, $\gamma = 25$, $\alpha = 55$ deg

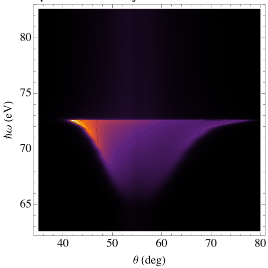
Angular distribution of hybrid radiation.



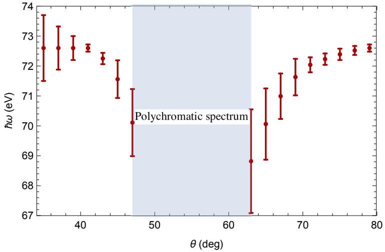
Angular distribution of hybbrid radiation for plane $\phi = 0$.



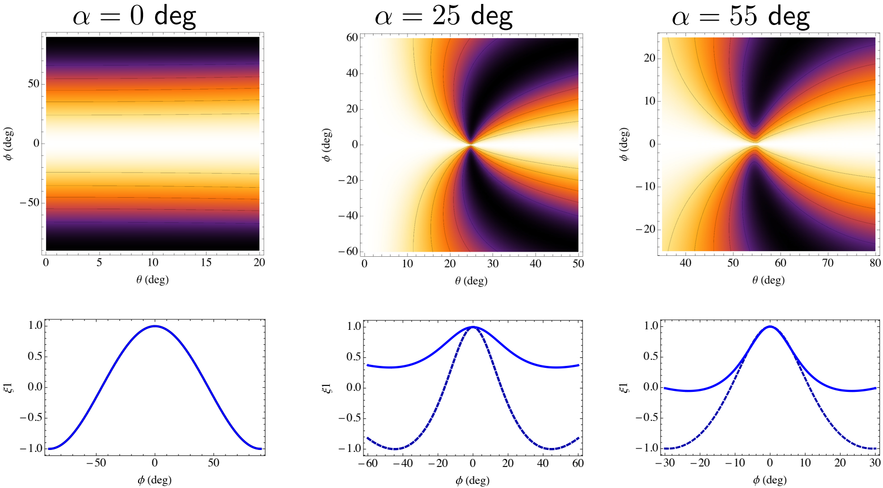
Spectrum of hybrid radiation.



Peak position and FWHM.

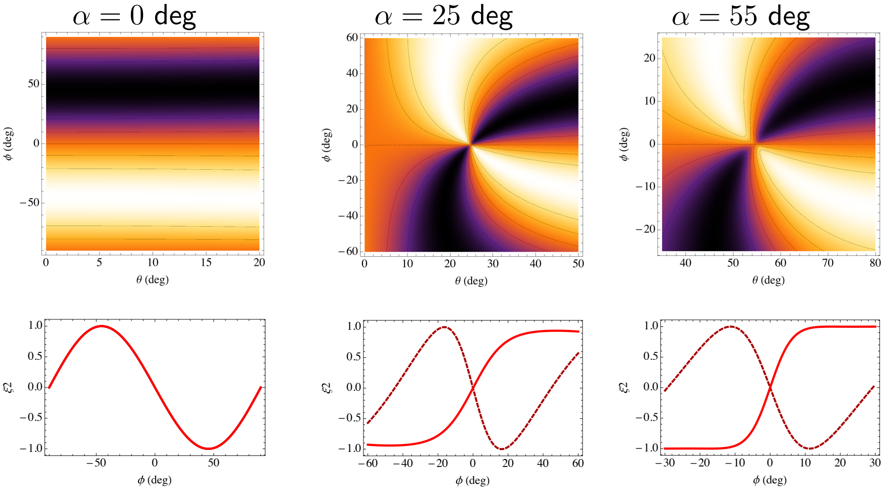


Polarization properties: ξ_1, Al, $\gamma = 25$, $\hbar\omega = 72.6$ eV



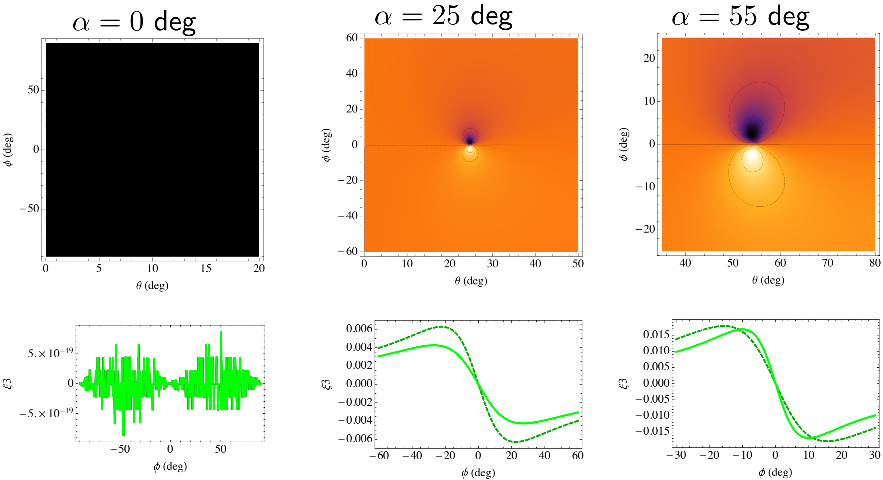
The blue and the dashed blue curves correspond, respectively, to observation angles $\theta_1 = \alpha - 10$ and $\theta_2 = \alpha + 10$ deg.

Polarization properties: ξ_2, Al, $\gamma = 25$, $\hbar\omega = 72.6$ eV



The red and the dashed red curves correspond, respectively, to observation angles $\theta_1 = \alpha - 10$ and $\theta_2 = \alpha + 10$ deg.

Polarization properties: ξ_3, Al, $\gamma = 25$, $\hbar\omega = 72.6$ eV



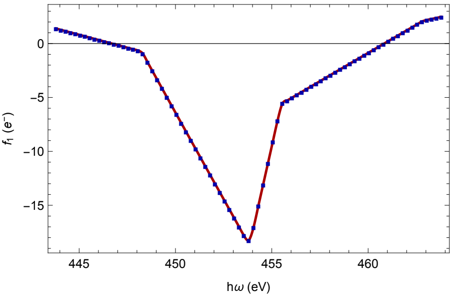
The greeb and the dashed green curves correspond, respectively, to observation angles $\theta_1 = \alpha - 10$ and $\theta_2 = \alpha + 10$ deg.

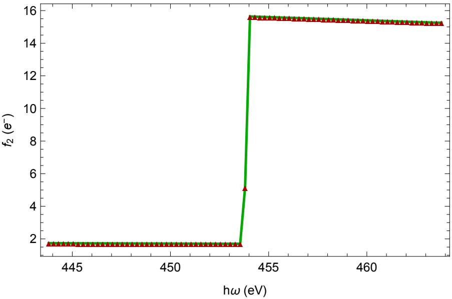
Calculation parameters for Ti

$^{48}_{22}\text{Ti}$

$$\rho = 4.54 \text{ g/cm}^3$$
$$d = 8\ \mu m$$
$$\hbar\omega = 443.8 \div 463.8 \text{ eV}$$

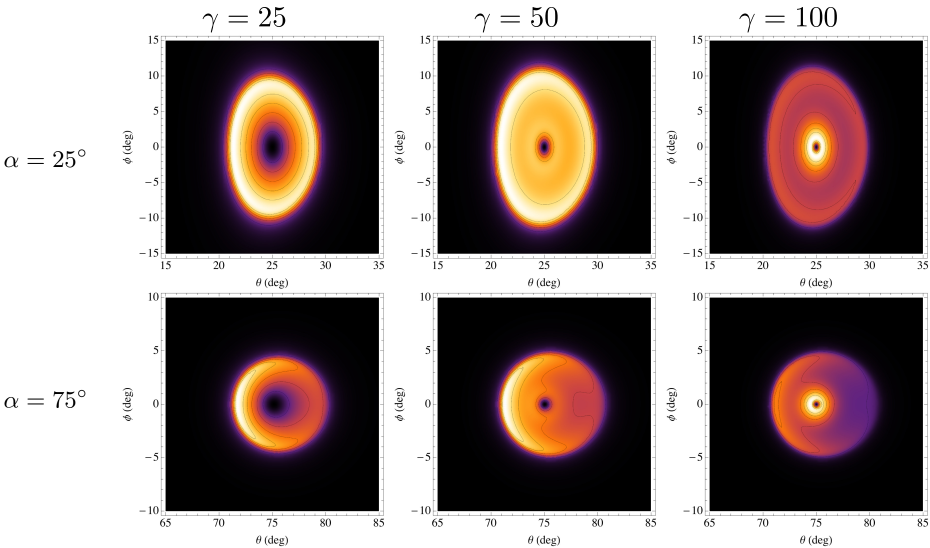
Scattering factors:



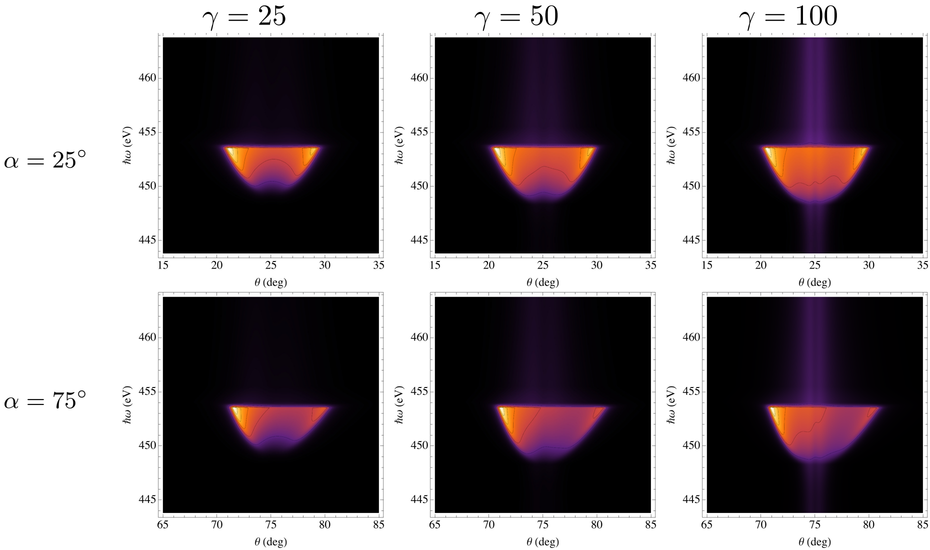


Dots are measurement data, the color curves are interpolation functions.

Angular distribution of hybrid radiation from Ti screen

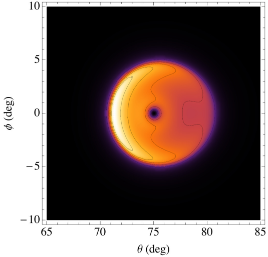


Spectrum of hybrid radiation from Ti screen

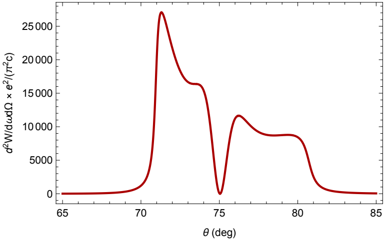


Ti, $\gamma = 50$, $\alpha = 75$ deg

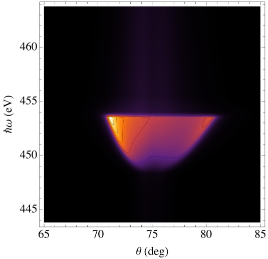
Angular distribution of hybrid radiation.



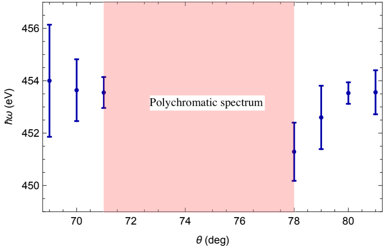
Spectral-angular distribution of hybbrid radiation for plane $\phi = 0$.



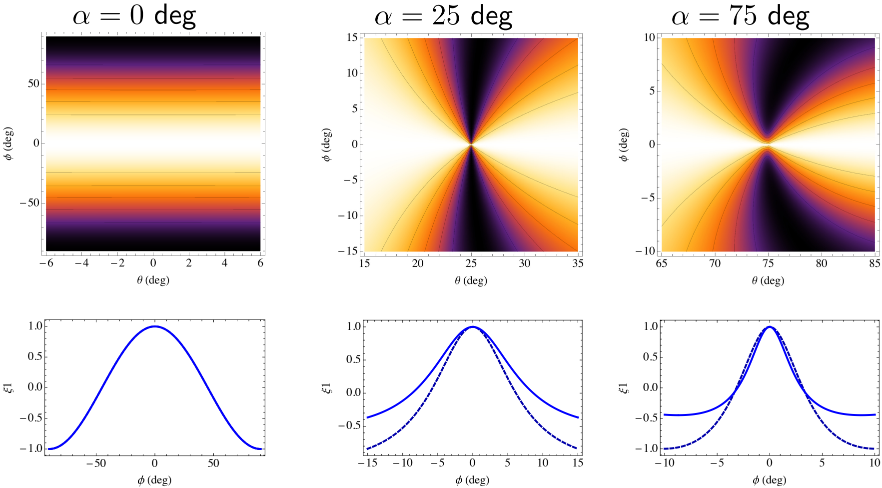
Spectrum of hybrid radiation.



Peak position and FWHM.

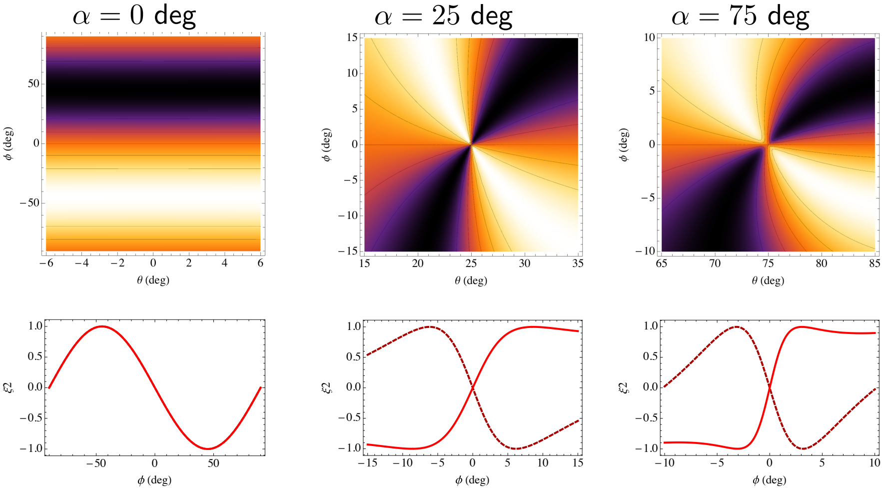


Polarization properties: ξ_1, Ti, $\gamma = 50$, $\hbar\omega = 453.8$ eV



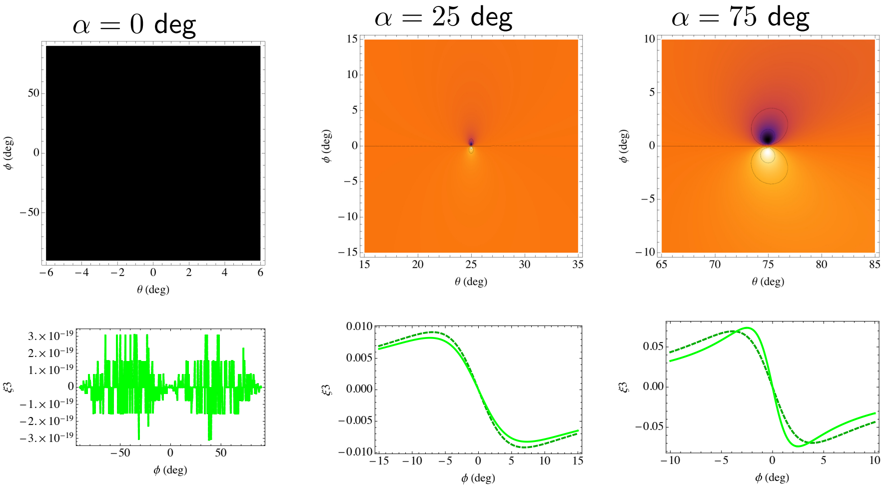
The blue and the dashed blue curves correspond, respectively, to observation angles $\theta_1 = \alpha - 3$ and $\theta_2 = \alpha + 3$ deg.

Polarization properties: ξ_2, Ti, $\gamma = 50$, $\hbar\omega = 453.8$ eV



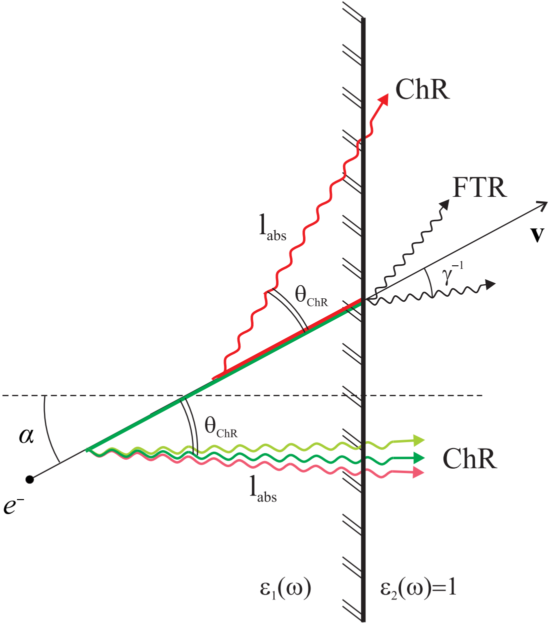
The red and the dashed red curves correspond, respectively, to observation angles $\theta_1 = \alpha - 3$ and $\theta_2 = \alpha + 3$ deg.

Polarization properties: ξ_3, Ti, $\gamma = 50$, $\hbar\omega = 453.8$ eV



The green and the dashed green curves correspond, respectively, to observation angles $\theta_1 = \alpha - 3$ and $\theta_2 = \alpha + 3$ deg.

Useful scheme



Conclusion future plans

Conclusions:

- hybrid radiation has assymmetry of angular distribbution;
- spectrum assymmetry occurs;
- radiation monochromaticity dependes on observation angle;
- hybrid radiation has circular polarization;

Future plans:

- we are going to investigate properties of hybrid radiation from layered structures;
- use interference effect to suppress influence of transition radiation on spectrum.

Thank you for attention!

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