VI INTERNATIONAL CONFERENCE

FRONTIERS OF NONLINEAR PHYSICS

PROGRAM

Nizhny Novgorod – St.-Petersburg, Russia
July 17 – 23, 2016

Tuesday, July 19
8:00 – 18:30

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10:00 – 10:30</td><td colspan="3">PLENARY SESSION 4
L. Zelenyi (IKI - Space Research Inst., Russia). Space decade (2016-2025): Russian plans for Lunar and Martian investigation
T. Piran (The Hebrew Univ., Israel). Emission process in gamma-ray bursts – A short review
M. Ghil (Ecole Normale Superieure, France and Univ. of California, USA). The wind-driven ocean circulation and global change</td></tr>
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I. Kostyukov and A. Sergeev (Inst. of Applied Physics RAS, Russia). Laser-matter interaction at extreme intensities
J. Rocca (Colorado State Univ., USA). Advances in compact soft X-ray lasers and bright X-ray generation from relativistic plasmas
L. Butov (Univ. of California San Diego, USA). Collective phenomena in quantum systems of indirect excitons</td></tr>
<tr><td>13:00</td><td colspan="3">Arrival at Goritsy</td></tr>
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<tr><td>14:00 – 16:00</td><td colspan="3">Bus tour to Kirillo-Belozersky Monastery</td></tr>
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5.6 Y. Shih (Univ. of Maryland, USA). Quantum noise and nonlocal interference (invited, 25 min.)
5.7 I. Novikova (College of William and Mary, USA). Analysis of the spatial mode decomposition of atom-generated squeezed vacuum (invited, 25 min.)
5.8 S. Shwartz (Bar-Ilan Univ., Israel). Ghost imaging and ghost diffraction in the X-ray regime (invited, 25 min.)
5.9 M. Erukhimova (Inst. of Applied Physics RAS, Russia). Squeezing of thermal fluctuations based on four-waves mixing (invited, 25 min.)
5.10 R. Shakhmuratov (Kazan Physical Technical Inst., RAS, Russia). Application of the low finesse frequency comb for high resolution spectroscopy (invited, 25 min.)</td><td>TS3: Nonlinear Problems in Astrophysics and Geophysics
3.7 Vl. Kocharovsky (Inst. of Applied Physics RAS, Russia). Variety of self-consistent magnetic field structures in a collisionless plasma: Exact solutions to a nonlinear many-particle relativistic problem (invited, 25 min.)
3.8 E. Churazov (IKI, MPA, Russia). Waves, turbulence and AGN feedback in galaxy clusters (invited, 25 min.)
3.9 G. Golitsyn (A.M. Obukhov Inst. of Atmospheric Physics RAS, Russia). Self-similarity of some integral characteristics of galaxies (invited, 25 min.)
3.10 G. Bisnovatyi-Kogan (Space Research Inst., Russia). Regular and chaotic dynamics of non-spherical bodies. Zeldovich's pancakes, and emission of very long gravitational waves (invited, 25 min.)</td><td>TS1: General Problems of Nonlinear Dynamics and Nonlinear Wave Phenomena
MS1.1: Mini-Symposium “Mathematics of Nonlinear Phenomena”
1.14 I. Barashenkov (Univ. of Cape Town, South Africa). Jamming anomaly in PT-symmetric optics and Bose-Einstein condensates (invited, 25 min.)
1.15 G. Tissoni (Inst. Non Lineaire de Nice, France). Spatio-temporal extreme events in a laser with a saturable absorber (invited, 25 min.)
1.16 Y. Joglekar (IUPUI, USA). PT-breaking transitions in dissipative, two-level, Floquet systems
1.17 S. Suchkov (Nonlinear Physics Centre, Australian National Univ., Australia). Frequency combs generation in high Q factor microscopic fiber resonators</td></tr>
<tr><td>18:00 – 18:30</td><td colspan="3">COFFEE BREAK</td></tr>
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Application of the low finesse frequency comb for high resolution spectroscopy

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High finesse frequency combs (HFC) with large ratio of the frequency spacing to the width of the spectral components have demonstrated remarkable results in many applications such as precision spectroscopy and metrology. In optical domain techniques using femtosecond-laser frequency combs allow to measure extremely narrow optical resonances with high resolution [1,2]. This is achieved by comparison of one of the spectral components of the calibrated frequency comb with the frequency of extremely stable laser, which is tuned in resonance with the narrow absorption line under investigation.

Special kind of gamma-ray frequency combs were generated much earlier by Doppler modulation of the radiation frequency, induced by mechanical vibration of the source or absorber [3-6]. They were observed in frequency domain and appear only if the source and absorber were used in a couple. Contrary to the optical combs, gamma-ray frequency combs do not produce sharp, short pulses in time domain, except the cases if some additional conditions are satisfied [7,8].

These special kind of gamma-ray frequency combs with high finesse $F >> 1$, where F is the ratio of the comb-tooth spacing to the tooth width, demonstrated that in many cases determination of small energy shifts between the source and absorber can be made more accurately in time domain by transient and high-frequency modulation techniques than by conventional methods in frequency domain [5,6,9]. In time-domain-spectroscopy technique the gamma-ray frequency comb is transmitted through a single line absorber whose resonant transition is studied. Out of resonance the phase modulation of the field, generating the frequency comb, does not produce the modulation of the field intensity at the exit of the absorber. If one of the comb components comes to resonance with the absorber, the intensity of the transmitted radiation acquires oscillations. Their pattern is very sensitive to the resonant detuning.

We have to emphasize that in gamma domain even standard spectroscopic measurements with such a popular Mössbauer isotopes as ^{57}Fe and ^{67}Zn have already demonstrated extremely high frequency resolution in measurements of gravitational red-shift [10,11]. This is because the quality factor Q, which is the ratio of the resonance frequency to the linewidth, is very high for these nuclei. For example, 14.4 keV transition in ^{57}Fe has $Q = 3 \cdot 10^{12}$ and 93.3 keV resonance in Zn demonstrates $Q = 1.8 \cdot 10^{15}$. Appropriate sources emitting resonant or very close to resonance γ-photons with high Q are available for both nuclei. They are ^{57}Co for ^{57}Fe and ^{67}Ga for ^{67}Zn.

Here we show that a low finesse comb (LFC) with $F << 1$ is more sensitive to the small resonant detuning between the fundamental of the radiation field and the absorber compared with the high finesse comb (HFC).

The basic idea of the modulation technique in gamma-domain is that the vibration of an absorber leads to a periodic modulation of the resonant nuclear transition frequency with respect to the frequency of the incident photons owing to the Doppler effect. This modulation induces Raman scattering of the incident radiation in the forward direction transforming quasi-monochromatic field into a frequency comb at the exit of the absorber [12] The relative amplitudes and phases of the produced spectral components are defined by the vibration amplitude d and frequency Ω, the detuning of the central frequency of the radiation source ω_S, the linewidth of the source Γ_S and absorber Γ_A, and the absorber optical depth T_A. To describe the transformation of the quasi-monochromatic radiation field into a frequency comb it is convenient to consider the interaction of the field with nuclei in the reference frame rigidly bounded to the piston-like vibrated absorber. There, nuclei 'see' the quasi-monochromatic source radiation with the main frequency ω_S as polychromatic radiation with a set of spectral lines $\omega_S \pm n\Omega$ (n = 0, 1, 2, ...) spaced apart at distances that are multiples of the oscillation frequency. The intensity of the nth sideband is given by the square of the Bessel function $J_n^2(a)$, here $a = 2\pi d/\lambda$ is the modulation index of the field phase $\varphi(t) = a \sin(\Omega t)$ and λ is the wavelength of the radiation.

If the modulation frequency Ω is much larger than Γ_S, the power spectrum of the radiation field, seen by absorber nuclei, demonstrates HFC ($F = \Omega/\Gamma_S >> 1$). It is observed in many Mössbauer experiments [3-6,9,12] by transmitting the radiation field through a single line absorber with resonant frequency ω_A. The carrier frequency of the source ω_S is changed by a constant velocity Doppler shift. Frequency-domain Mössbauer spectrum is measured by counting the number of photons, detected within a long time windows of the same duration for all resonant detunings, which are varied by changing the value of a constant velocity of the Mössbauer drive moving the source. Time windows are not synchronized with mechanical vibration and their duration T_W is much longer than the oscillation period $T_{OSC} = 2\pi/\Omega$.

If $F << 1$, the spectral components of the frequency comb, seen by the absorber nuclei, overlap resulting in the spectrum broadening of the radiation field. Therefore Mössbauer spectra for LFC show only the line broadening with increase of the modulation index a.

If time windows of the photon-count collection are synchronized with the phase oscillations and duration of the time-windows T_W is much shorter than the oscillation period T_{OSC}, then one can observe time dependence of the transmitted radiation. For HFC the number of counts $N(t)$, proportional to the radiation intensity $I(t)$, is described by equations [5,6,9]

$$N(t) = N_0 \sum_{n=0}^{\infty} D_n \cos[n\Omega(t - t_n)] , \quad (1)$$

where N_0 is the number of counts without absorber, D_n and $n\Omega t_n$ are the amplitude and phase of the nth harmonic. Here, nonresonant absorption is disregarded. Recoil processes in nuclear absorption and emission are not taken into account assuming that recoilless fraction (Debye-Waller factor) is f =1. These processes can be easily taken into account in experimental data analysis.

If the fundamental frequency ω_S of the comb coincides with the resonant frequency of the single line absorber ($\omega_S = \omega_A$), then the amplitudes of the odd harmonics are zero, $D_{2m+1} = 0$, where m is integer. They become nonzero for nonresonant excitation. For high finesse combs the ratio of the amplitudes of the first and second harmonics D_1/D_2 is linearly proportional to the resonant detuning $\Delta = \omega_A - \omega_S$ if the value of the modulation index a is not large and the resonant detuning does not exceed the linewidth $(\Gamma_A + \Gamma_S)/2$ [5,6]. This dependence helps to measure the value of small resonant detuning with high accuracy [9]. For HFC the optimal value of the modulation index providing the best signal to noise ratio is a = 1.08 when the amplitude of the first harmonic D_1 takes maximum. This is because for HFC D_1 is proportional to the product of the amplitude of zero and first components of the comb, i.e., to $J_0(a)J_1(a)$. High sensitivity of HFC to resonance of its central frequency with a single line absorber is explained by the interference of the spectral components of the comb, which are changed after passing though the absorber.

Here we show that LFC is much more sensitive to the resonance of the central component with the single line absorber. Such a sensitivity can be explained by the interference of many spectral components if they change after passing through the absorber. In contrast to HFC ($\Omega >> \Gamma_S$), LFC ($\Omega << \Gamma_S$) becomes sensitive to exact resonance if effective halfwidth of the comb $a\Omega$ is nearly equal to the width of the absorption line Γ_A. Since for LFC $a >> 1$, much more spectral components [$J_n(a)J_{n+1}(a)$ with n = 0, ±1, ..., ±a] participate in the interference compared with HFC and the spectral content of the intensity oscillations becomes more sensitive to the resonant detuning.

We demonstrate LFC sensitivity in the experiments with the radiation source, which is radioactive ^{57}Co incorporated into rhodium matrix. The source emits 14.4 keV photons with spectral width Γ_S = 1.13 MHz. The absorber is a 25-μm-thick stainless-steel foil whose optical depth is $T_A = \alpha l$ =5.18, where α is the resonant absorption coefficient and l is the absorber thickness. The stainless-steel foil is glued on the polyvinylidene fluoride piezo-transducer that transforms the sinusoidal signal from radio-frequency generator into uniform vibration of the foil. The frequency and the amplitude of the sinusoidal voltage were adjusted to have Ω = 200 kHz and a = 5.7, so that relation $a\Omega \approx \Gamma_A$ was satisfied. The source is attached to the holder of the Mössbauer transducer causing Doppler shift of the radiation field to tune the source in resonance or out of resonance with the single line absorber. The time measurements were performed by means of the time-amplitude converter (TAC) working in the start-stop mode. The start pulses for the converter were synchronized with radio-frequency generator and the stop pulses were from the signal of 14.4 keV gamma counter at the instant of photon detection time.

The experimental results demonstrated the oscillations of the radiation intensity in time. Their Fourier analysis for different resonant detunings Δ allowed to find the dependence of the ratio D_1/D_2 on Δ, which is shown in Fig. 1, left panel. This dependence is compared with that for HFC, generated by the vibration with high frequency Ω = 10 MHz and optimal value of the modulation index a = 1.08. We see that LFC is at least two times more sensitive to resonance than HFC since the slope of D_1/D_2 dependence is two times steeper. Right panel shows the Fourier content of the oscillations for LFC when $\Delta = 0.3\Gamma_0$. Noticeable contribution of the first and second harmonics is clearly seen.

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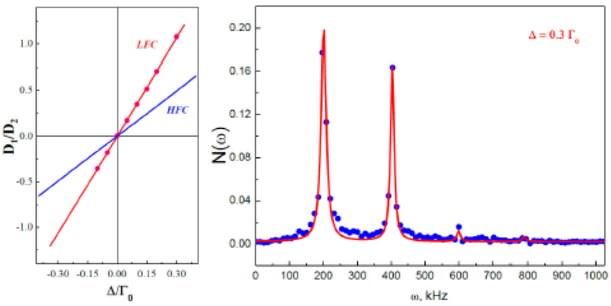

Fig. 1. Left panel: Comparison of the dependence of D_1/D_2 on Δ for LFC and HFC. Experimental data for LFC are shown by dots. Right panel: Fourier content of the intensity oscillations for $\Delta = 0.3\Gamma_0$. Dots correspond to the data, obtained from Fourier analysis of the experimentally observed intensity oscillations. Solid line is the analytical approximation.