Spectrum of a very hot object in hydrogen.

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The astonishing lack of observation of accreting neutron stars suggests that an "Impulsive Stimulated Raman Scattering" (ISRS) may be wrongly neglected. The ISRS is a coherent parametric effect which increases the entropy of a set of light beams refracted by a convenient medium, by frequency shifts. The theory of this effect, usually studied using femtosecond laser pulses, shows that it works with ordinary incoherent light, but that it becomes so weak that it cannot be observed in a laboratory, while astronomical paths may produce large frequency shifts.

In a very low density hydrogen cloud, a "pearl necklace" similar to SN1987A's is generated, while, at a higher density, the spectrum of a quasar is generated.

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I. INTRODUCTION

This is a paper of pure spectroscopy. It uses parametric light-matter interactions which, except refraction, are often not well known, although they allow amplifications, frequency multiplying, combining, shifting without any perturbation of the wave surfaces and any permanent excitation of the large amount of involved matter. The used effects are shortly described here, enough to follow the paper, the readers needing, for their full theories, to consult textbooks on laser spectroscopy or cited papers.

The conclusions of sections II and III are that the effects they describe are similar to astrophysical observation. To help the reader verify these conclusions, astrophysical notations and citations are put, in advance, in these sections.

In traditional optics, it is assumed that light beams refracted by the same medium do not interact; however many laser experiments show the contrary. In particular, the entropy of a set of femtosecond pulses laser beams may increase by a parametric effect named "Impulsive Stimulated Raman Scattering" (ISRS). "Parametric" means that the effect does not excite permanently the large amount of involved matter and implies the space-coherence, that is that the wave surfaces are not perturbed. The name ISRS reminds that the effect may be split into a set of connected frequency shifts of the involved beams [1–5], each frequency shift resulting from an interference of an exciting pulse with the Raman coherently scattered pulses it induces (just as refraction results from the interference of an exciting beam with the coherently scattered Rayleigh beam). In the approximation of constant tensors of polarisability, the relative frequency shifts do not depend on the frequencies. With ultrashort laser pulses, the frequency shifts are roughly proportional to the intensities of the pulses, but there is no intensity threshold, and the frequency shifts become independent on low intensities.

The ISRS works if the pulses of light are "ultrashort", a word which is meaningless without the time reference provided by G. L. Lamb [6] : *shorter than all relevant time constants.* This antiquated, but general definition of "ultrashort" is usually restricted to the shortest available laser pulses, but the optical theories use Lamb's condition, not the absolute frequencies, so that ordinary light is made of ultrashort pulses in a medium whose "relevant time constants" are larger than a few nanoseconds, the coherence time of ordinary light [7, 8].

The experiments and the theory of ISRS show that, in a gas, the relevant time constants are the collisional time, and the period of a Raman type resonance. Using femtosecond lasers, there is no problem to fulfil Lamb's conditions, using a gas in the usual physical states and the abundant Raman vibration-rotation resonances at frequencies of the infrared.

Using usual incoherent light, ISRS is renamed "Coherent Raman Effect on Incoherent Light" (CREIL). This new name specifies a different order of magnitude of time constants although the theory is unchanged, exactly as we differentiate light from radiowaves. Finding periods of Raman type resonances larger than some nanoseconds is not very difficult, but it happens in few populated states, except for atomic hydrogen in its first excited state (2S: 178 MHz, $2P_{1/2}$: 59 MHz, $2P_{3/2}$: 24 MHz). The required low pressure, a Raman resonance 10^6 times lower than in the infrared, while the effect is proportional to the square of the Raman frequency, the relatively difficult generation of this hydrogen show that a laboratory experiment would be very expansive. On the contrary, in space, the paths may be so long that the redshifts may be large. From Planck's law, the thermal background is made of cold beams so that it is blueshifted, that is heated, while light beams are generally hot and redshifted.

A practical rule to use the CREIL effect in astrophysics is: *Large, "anomalous" frequency shifts appear where light crosses 2S/2P atomic hydrogen.*

An example of very hot object is an "accretor" (accreting neutron star), introduced by the theory of neutron stars; it should be easily visible, but it is *never* observed

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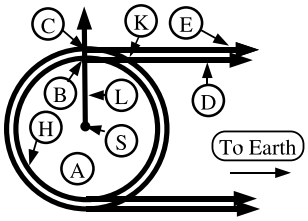

FIG. 1: Accretor in a low density cloud. See text.

[9, 10]. Is it possible that no neutron star meet a cloud of hydrogen to become an accretor? Else, a study of the spectrum of a very hot object merged in a cloud of hydrogen and traces of other gases appears necessary.

The surface temperature of the accretors is larger than 10^6 K, at least on hot spots where the accretion is large, therefore they radiate a lot of far UV radiations able to ionize or populate the high levels of atomic hydrogen and small amounts of other atoms. In function of the distance R to the centre of the star, Section 2 will study the case of an everywhere low density cloud, while section 3 will study the case of a cloud whose density may be large close to the neutron star.

Section 4 calls to mind the case of a source unable to heat hydrogen to dissociation.

II. ACCRETOR IN A LOW DENSITY CLOUD.

See figure 1.

If an extremely hot object S appears in a low density cloud of cold hydrogen, in a close A region, a strong absorption of the powerful radiation dissociates, ionizes, the gas; as long as the gas remains cold, electron-proton collisions generate atomic hydrogen, heating the gas; then hot hydrogen remains ionized, transparent.

Close to the star, other atoms are strongly ionised, so that the light elements lose all their electrons and do not absorb the light any more; we suppose that there is few heavier atoms able to absorb lines, generally reemitting the absorbed energy in the UV; thus the loss of UV energy is low, almost all radiated energy is transmitted. Therefore, assuming isotropy, the radius R_0 of a sphere of ionized gas increases.

Beyond R_0, at B, atomic hydrogen appears, a Lyman alpha absorption populates the 2P levels. The resulting strongly excited hydrogen is able to emit and amplify the Ly_α frequency; the amplification saturates the absorption of the radial ray L, and increases the intensity of spontaneously emitted beams, in particular in directions where the path of light in excited gas is large, for instance along a tangential ray D; it is a superradiance; as the Ly_α line is strong, at its frequency the thermal equilibrium tends to be reached, so that the luminances of rays L and D tend to the same value. The superradiance depopulates the 2P state, so that the absorption of ray L is strong and the spherical shell H in which energy is transferred is *a priori* relatively thin; in the direction of the earth, the superradiant beams make a cylinder. Shell H is seen as a circular line whose apparent surface is so larger than a small source S that, at the Ly_α frequency it is more visible than S which has the same order of magnitude of luminance.

Superradiances may appear at other frequencies; depopulation of the excited states by superradiances helps cooling the gas, so that the thickness of the transition zone between ionised and atomic hydrogen is not large.

The superradiance leaves some population in the 2P states, and the metastable 2S states are slightly populated by a decay from more excited states, so that a CREIL effect shifts the spectrum of the light emitted by the kernel; this shift renews the intensity at the Ly_α frequency (in C, for instance), so that the atoms are pumped by a wide band of UV until it does not remain light at frequencies higher than the Ly_α frequency: the shell of hydrogen excited mainly in the 2P states is thick.

Consider a superradiant pulse emitted along D; propagating in hydrogen containing 2P atoms, the emitted line is redshifted, so that a frequency of its high frequency foot comes to the Ly_α frequency, therefore is amplified in K, and so on. A wide band pulse of UV is emitted. It is in a *polychromatic* mode allowed by the mathematical theory of the modes: *a mode is a ray in the real vector space representing the solutions of a linear set of field equations*. Other lines may absorb simultaneously other wide bands and contribute to the superradiance.

In a given direction, the emissions are seen *a priori* as a circle. But the competition of the modes lets appear brighter spots corresponding to columns of light.

Crossing gas out of the shell containing 2P hydrogen, the UV columns may excite strongly atomic lines of other atoms which leave their energies in collinear monochromatic superradiances.

The redshifts produce transfers of energy to the thermal background which is strongly heated.

Supernova SN1987A shows a "pearl necklace" and infrared emissions whose interpretation appears difficult [11–13]. Although this necklace is less perfect than the figures showed by multimode lasers, the previous discussion may be a starting point of an interpretation; the anisotropy producing the elliptic shape of the necklace may result from an excitation of the gas by a double star or a moving star.

III. ACCRETOR IN A RELATIVELY DENSE CLOUD.

We suppose that the accretion leads to a density of atoms corresponding to several atmospheres at least in a shell thick of a few ten metres.

Describe the spectrum along a ray emitted by the kernel, increasing R and decreasing the redshift.

a) In the very hot, dense gas close to the kernel, the temperature is high enough to ionize the atoms several

times. Even if the proportion of atoms emitting far UV lines is not very large, the density of the gas and its high temperature produce a strong emission. The lines are not very wide in despite of a high temperature because the Doppler effect corresponds to the mean speed of the atoms, much lowered under their instantaneous speed by collisions (they have a "Galatry profile"); a strong superradiant process sharpens the emission lines.

The probability to obtain a necklace is low, because, in comparison with the case of a low pressure gas, the radius of the excited shells is much smaller, so that a tangential long path is not available to compensate that the intensity of the radial beams is much higher than the intensity of the spontaneous emissions.

b) By a decrease of the temperature at larger R, thermally excited hydrogen appears. Where the density of gas decreases enough to allow a CREIL, a permanent redshift appears, the widths of the emission lines become equal to the redshift, the lines are not any more visible.

c) A new increase of R, decrease of the temperature under 40 000 K, de-excites hydrogen, and there are two possibilities:

i) if in a region "A" the intensity at the Ly_α frequency is low, there is not much hydrogen in the 2P states, nearly no redshift, all lines are emitted or absorbed sharp.

ii) if in a region "S" this intensity is large, the lines get a width nearly equal to the redshift; emissions and absorptions are not easily detectable.

A single transition produces a spectral line each time the light beam crosses an "A" region, successive lines being separated while "S" regions are crossed.

Suppose that a ray leaves a region "S" to a region "A", an absorbed line of the nearly continuous spectrum getting the Ly_α frequency; all lines, in particular the Ly_β and Ly_γ are absorbed (case i). A decay from the levels excited by these absorptions produces some 2S/2P hydrogen, a small redshift, so that case ii restarts until the absorbed Ly_β and Ly_γ lines get the frequency of the Ly_α line by a relative frequency shift $(\nu_\beta - \nu_\alpha)/\nu_\alpha = 0.062 * 3$ or $(\nu_\gamma - \nu_\alpha)/\nu_\alpha = 0.062 * 4$. A Karlsson periodicity 0.062 appears [14–17].

The space is split into shells "A", separated by shells "S". Assuming a spherical symmetry (not several stars), the shells are spherical.

Case c splits into two sub-cases d and e:

d) Around 100 Pa, the lines of various atoms are "broad", saturated, having the shape of a hat or a trough, their flat top or bottom corresponding to an equilibrium between the temperature of the gas and the temperature of the light. However, if the kernel emits radio frequencies strongly, hydrogen is ionised, there is no atomic hydrogen, no redshift, emission then absorption superimpose [18, 19].

e) At lower pressures, the lines become sharper, hydrogen becomes preponderant. The multiplication of the existing lines creates a "Lyman forest". For a given Ly_α absorption, the ratio of 2P atoms over 1S atoms increases while a decrease of pressure decreases the collisional de-excitations. Thus, compared to the local thickness of "A" shells, the shells "S" become thinner and thinner while the pressure decreases; therefore, there is a large probability that the process stops in a region "A", so that the final redshifts are multiples of 0.062.

All CREIL frequency shifts blueshift the thermal radiation, so that the temperature of the thermal radiation of the neighbourhood of much redshifted, bright objects may be larger than 100 K.

It is a spectrum of quasar [20]. The micro-quasars are fast moving neutron stars having the radio and X characteristics of a quasar, but lying inside galaxies and almost invisible. If, leaving their galaxies, they meet a higher density of hydrogen, they become isolated quasars (leaving our galaxy) or quasars bound to other galaxies.

IV. A SOURCE IN COLD GAS.

Setting a similar theory of periodicities due to propagation of light in a molecular gas is much more difficult because the spectra of molecules are much more complicated than the spectrum of atomic hydrogen. Is it possible to replace in the theory the lines of atomic hydrogen by sets of molecular lines such that the interactions of all lines of a set produce similar effects, so that "a" and "s" shells similar to the "A" and "S" shells appear? In a first approximation, the rotational structures are regular, with a period $2B$, so that the combination rules let this period appear in the spectra.

Considering hydrogen does not seem sufficient to explain the Tifft-Napier periodicities of 37.6 km/s observed for the galaxies, corresponding to relative frequency shifts of 12.10^{-5} [21, 22]. This corresponds, for an UV absorption of the order of 10^5 cm^{-1}, to frequency shifts of 12 cm^{-1}. The rotational frequencies of hydrogen are too high, so that the problem cannot be solved simply. Heavier molecules may work better.

An other possible generation of "a" and "s" shells works with a molecule having a state split into hyperfine components producing a resonance around 100 MHz, and populated at the temperature of the gas. As the gas allows a CREIL effect, it is in a "s" region, and it may happen that a strong line (for instance Ly_α) emitted around the source is shifted to the frequency of a transition from this molecular state; the depopulation of the CREIL efficient level stops the frequency shift, the light enters an "a" region.

A solution of the astrophysical problem requires a better knowledge of the hyperfine structures of various molecules, in particular in the excited states.

V. CONCLUSION

We built models of pearl necklaces and spectra of quasars from standard spectroscopy and very simple as-

trophysical hypothesis, a hot object in a cloud of gas. We must be very careful proposing the CREIL model as an alternative to the standard theory:

i) Have we a numerical proof of an observation of a CREIL effect in astrophysics? We think yes: the Karlsson periodicity measured with a percent precision in the spectra of high redshift objects is equal to the value deduced from spectroscopy.

ii) Is the new theory able to explain observations better and simpler? The standard explanation of the pearl necklace of the supernova SN1987A requires a gravitational lensing, that is a very precise position of objects; it does not explain the pearls. In the standard explanation of the Lyman forest, a lot of far, thin clouds of hydrogen must be ionized. Their stability and ionization are not easily explained [23]. The explanation of the distortion of multiplets in quasar spectra requires a variation of the fine structure constant or an other strong change in physics [24], while the CREIL takes simply into account the dispersion of the tensor of polarizability of hydrogen.

iii) Explains it easily other observations? Yes. As a large redshift is mainly produced by a propagation of light in 2S, 2P atomic hydrogen, it is easy to find a correlation between the presence of these atoms and "anomalous" observations:

- Halton Arp observed a number of alignments of a galaxy with quasars, too large to be accidental [25]. Different redshifts of these objects result from different column densities of 2P hydrogen generated by the far UV radiated mainly by the quasars. A similar explanation works for many objects observed close to quasars named "Very Red Objects (VROs)" because their distance deduced from the standard theory seems to large [26–28].

- beyond 5-10 AU, the solar wind cools enough to generate excited atomic hydrogen. The counterpart of the redshift of the solar light by this hydrogen is a blueshift of the thermal or radio frequencies. This is observed by the blueshift ("anomalous acceleration") of the radio signals of Pioneer 10 and 11 probes, and by a bounding to the ecliptic of some low order terms of the development in spherical harmonics of the thermal background [29];

Some out of our arguments may be wrong, but it seems difficult to avoid systematically taking into account an elementary spectroscopic effect.

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