

# Propagation of Light in Low-Pressure Ionized and Atomic Hydrogen: Application to Astrophysics

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**Abstract**—Impulsive stimulated Raman scattering (ISRS) uses ultrashort laser pulses to shift light frequencies; the frequency shift depends on the power of the laser pulses because this power is very large. The relative frequency shifts of coherent Raman effect on incoherent light (CREIL) described in this paper are independent on the intensity of the ordinary incoherent light that it uses, and, in a first approximation, on the frequency of the light. Since CREIL does not blur images or alter the spectral pattern, CREIL effect may be confused with Doppler frequency shifts. ISRS and CREIL are parametric effects that do not excite matter; they transfer energy from “hot beams” to “cold beams.” These transfers correspond to spectral shifts; in CREIL thermal radiation is blue-shifted, that is heated. CREIL requires low-pressure gases acting as catalysts. These gases must have Raman transitions in the radio frequencies range: for example,  $H_2^+$  or excited atomic hydrogen in a magnetic field. The spectral lines resulting from a simultaneous absorption (or emission) and CREIL have a width at least equal to the frequency shift, so that the lines of a complex spectrum may be weakened and mixed, becoming nearly invisible. In interstellar space, molecular hydrogen is ionized, but since  $H_2^+$  is quickly destroyed by collisions it persists only at pressures low enough to provide CREIL; the redshift widens the weak absorption lines of  $H_2^+$  which becomes undetectable. It contributes to the “cosmological redshift” and amplification of the microwave 2.7 K background radiation. Using only well-established physics and normal astronomical objects, CREIL provides a plausible explanation for the enigmatic spectra of the quasars.

**Index Terms**—Plasma, quasars, redshifts.

## I. INTRODUCTION

THE WAVE patterns of an unknown surface may be deduced from wave patterns in close proximity by using a Huygens’ construction. In this construction, all points of a wave surface are considered as sources synchronous with the wave. The envelope of the “wavelets” radiated will, within a short time, create a new wave surface.

A similar construction is obtained replacing the sources of the Huygens’ construction by monoatomic or polyatomic molecules radiating waves which have the same frequencies and phases as the exciting waves. The difference between the Huygens’ reconstruction and the original wave form is a function of the finite number of sources that introduces discrepancies into the building of a new wave surface. Therefore, the coherent Huygens’ pattern is always perturbed, mixed with incremental amounts of incoherent scattering.

The most common example of coherent scattering is the refraction, whose imperfections produce the Rayleigh<sup>1</sup> incoherent scattering (blue of the sky). The amplitude of the coherently scattered wave is the sum of the amplitudes of the elementary scattered waves, while the incoherently scattered intensity is the sum of the intensities scattered by each molecule. Therefore, the coherently scattered intensity is  $N$  times larger than the incoherently scattered intensity, where  $N$  is the number of scattering molecules. Since  $N$  is usually large, Rayleigh coherent scattering is much more dominant than incoherent scattering.

For a long time, only Raman incoherent scattering was observed in the labs, so that the spectroscopists got into the habit introducing a stochastic phase correction factor into the off-diagonal elements of the density matrix used to study the scattering. The use of lasers has allowed observations of Raman coherent scattering, these studies usually involving diffraction of the scattered beam, but in this paper we are interested in Raman effects upon wide beams, for which diffraction is negligible.

A method for using Raman scattering to produce a coherent frequency shift without blurring the image or introducing new lines in the frequency shifted spectra was found in 1968 [1], [2]. This technique was developed in [3]–[6] and named “impulsive stimulated Raman scattering” (ISRS). Scientists using ISRS know that it has no intensity threshold, but it is so difficult to replace the ultrashort laser pulses by the pulses which make the usual incoherent light that no one developed “coherent Raman effect on time-incoherent light” (CREIL). The new name is justified by a qualitative difference due to the power of the laser pulses: ISRS is nonlinear, the frequency shifts depend on the intensity of the laser pulses; on the contrary, CREIL does not depend on the intensity of the natural light which is much lower than the intensity of the zero point field, except close to very bright stars.

The properties of CREIL may be deduced from the theory of ISRS, but it is better to develop the equations by comparing the basic properties with refraction. This is accomplished in Section II, reproducing and improving already published works [7]–[9].

Section III describes the propagation of light in an active gas such as excited molecular hydrogen, and explains why this gas cannot be detected even though the quantity of this gas is probably not negligible in the intergalactic space.

Section IV concerns of the propagation of light in atomic hydrogen and some of the conditions necessary to produce CREIL. These include excitation by Lyman absorption and the presence of a magnetic field.

<sup>1</sup>Here, the scattering of light is named “Rayleigh scattering” if it preserves the frequency, and “Raman scattering” if it changes it.

Hydrogen plasma was chosen because hydrogen is abundant in the Universe, and the long paths between the stars and us insure that the weak CREIL (due to the low pressure required to decrease the incoherences produced by the collisions) is integrated over a long enough path to create an observable redshift. Very simple hypotheses, most of which being not original, are outlined in Section V proposing an elementary interpretation of many of the spectral features of quasars.

## II. COHERENT RAMAN EFFECT ON INCOHERENT LIGHT (CREIL)

First, we shall examine a coherent light-matter interaction similar to refraction, which is an interaction that does not blur the images and the spectra. We will see that it shifts the frequencies, so that its effect may be confused with a Doppler shift.

### A. Condition for No Blur of the Images: Coherent Scattering

To obtain a strong scattering and avoid blurring the images, the scattered wave surfaces must be identical to the wave surfaces of the exciting light beam. The scattering must be coherent.

In Rayleigh coherent scattering, the frequencies and the indices of refraction are the same for the exciting and Rayleigh scattered waves; these waves interfere into a single wave. Can we find a similar behavior using Raman coherent scattering?

If the light is time-coherent, the excitation of a molecule starts with a collision; this is not a problem for a Rayleigh scattering because the difference of phase  $\phi$  between the exciting and scattered lights remains equal to  $\pi/2$ . However, in Raman scattering,  $|\phi|$  increases linearly from zero, so that when random molecular collisions interrupt the sequence, the light becomes incoherent, producing the effects normally observed in Raman scattering. To obtain a coherent scattering, it is necessary to avoid molecular collisions during the excitation phase, having, as unique starting point of excitation, the beginning of a light pulse: a time-incoherence of the exciting light and a low gas pressure are necessary. If time-incoherent light is represented by pulses of length  $T_{\text{coherence}}$ , and the collisional free time by  $T_{\text{collisional}}$

$$T_{\text{collisional}} \gg T_{\text{coherence}}. \quad (1)$$

The mean time  $T_{\text{collisional}}$  between two collisions in a gas made of identical spherical hard molecules is

$$T_{\text{collisional}} = \frac{1}{2Nd^2} \sqrt{\frac{m}{4\pi kT}} \quad (2)$$

where  $N$  is the number of molecules by unit of volume,  $d$  their diameter,  $m$  their mass, and  $T$  the temperature.

With most gases,  $T_{\text{collisional}}$  varies little with the molecule: for example, at 300 K, for He the product  $T_{\text{collisional}}N$  equals  $4 \cdot 10^{15}$  s, while for  $\text{CO}_2$  it equals  $1.86 \cdot 10^{15}$  s. In  $\text{CO}_2$ , with a density of the molecules  $N = 1.86 \cdot 10^{23}$ , at a pressure 700 Pa  $T_{\text{collisional}}$  is shorter than  $10^{-8}$  s. This is only a rough order of magnitude because the molecules are not hard particles, so that it is difficult to define a diameter  $d$  of molecule for which a collision dephases the scattered light.

### B. Condition for a Strong Light-Matter Interaction: Low Raman Frequency

In refraction, the exciting and scattered beams propagate at the same frequency, thus at the same speed, so that they interfere into a single beam. In contrast, in Raman scattering, since the exciting and scattered frequencies are different, the indices of refraction  $n_e$  and  $n_s$  for the exciting and scattered fields are also different. Thus, waves diffracted at a distance  $x$  on a ray of light have a phaseshift  $2\pi(n_e - n_s)x/\lambda$ . A phaseshift equal to  $\pi$  occurs for a distance  $x$  equal to the ‘‘length of coherence’’—the amplitudes scattered at this distance cancel by destructive interference, which limits the intensity of wide beam Raman coherent scattering.

However, what happens if the Rayleigh scattering produced by transitions inside undivided degenerate levels are split into Rayleigh and Raman scatterings by an external field which splits the levels? Examine low-energy Raman scatterings.

Consider first a single Raman Stokes transition.

In the classical theory of the Raman effect, the dipole induced by the incident field is coupled with the dipole which radiates the Raman wave; at the beginning of a light pulse, the dipoles are out of phase by  $\pi/2$ , so that the phases of the incident and scattered fields are the same. During the pulse, the phase changes because the dipoles have different frequencies.

The interferences patterns of two different frequencies is often observed, for instance, between the two beams of a Michelson interferometer: when one of the mirrors is moved, there is a Doppler shift in the frequency. It can be shown by elementary computation that, if this phaseshift is significantly less than  $\pi$ , the sum of the incident and scattered fields is a single field having an intermediate frequency.

The electric field in a pulse of light is the product of a sine function by a slow varying electric field  $E(t)$  giving the pulse shape; the sine function, for an exciting field of frequency  $\nu_e$ , may be written  $E(t) \cos(2\pi\nu_e t)$  and, for a field scattered at a frequency  $\nu_s$  by a thin layer of thickness  $\Delta x$  of gas, with the same polarization and the same phase at the beginning of the pulse ( $t = 0$ ):  $E(t)s\Delta x \cos(2\pi\nu_s t)$ , where the product  $s\Delta x$  is a small dimensionless coefficient;  $s\Delta x$  will be a first-order quantity; the sum of the two emerging fields is

$$D = E(t)(1 - s\Delta x) \cos(2\pi\nu_e t) + E(t)s\Delta x \cos(2\pi\nu_s t). \quad (3)$$

Writing the Raman frequency  $\nu_i = \nu_s - \nu_e$  to eliminate  $\nu_s$

$$\begin{aligned} D = & E(t)(1 - s\Delta x) \cos(2\pi\nu_e t) \\ & + E(t)s\Delta x (\cos(2\pi\nu_e t) \cos(2\pi\nu_i t) \\ & - \sin(2\pi\nu_e t) \sin(2\pi\nu_i t)). \end{aligned} \quad (4)$$

Writing the length of the pulse  $T_{\text{coherence}}$ , suppose

$$|\nu_i T_{\text{coherence}}| \ll 1 \quad (5)$$

that is the Raman period is much larger than the length of the pulses

$$T_{\text{Raman}} \gg T_{\text{coherence}}. \quad (6)$$

We may develop the trigonometric functions of  $2\pi\nu_i t$  into functions equivalent to them during the pulse

$$\begin{aligned} D &\approx E(t) \cos(2\pi\nu_e t) - 2E(t) s \Delta x \pi \nu_i t \sin(2\pi\nu_e t) \\ &\quad + 2E(t) s \Delta x (\pi \nu_i t)^2 \cos(2\pi\nu_e t) \\ &\quad + (4/3) E(t) s \Delta x (\pi \nu_i t)^3 \sin(2\pi\nu_e t). \end{aligned} \quad (7)$$

Set

$$\tan(\psi t) = 2s \Delta x \pi \nu_i t; \quad (-\pi/2 < \psi \leq \pi/2) \quad (8)$$

$\psi \approx 2s \Delta x \pi \nu_i$  is a first-order quantity.

$$\begin{aligned} D &\approx E(t) [\cos(2\pi\nu_e t) \cos(\psi t) \\ &\quad - \sin(2\pi\nu_e t) \sin(\psi t)] / \cos(\psi t) \\ &\quad + 2E(t) s \Delta x (\pi \nu_i t)^2 \cos(2\pi\nu_e t) \\ &\quad + (4/3) E(t) s \Delta x \pi (\nu_i t)^3 \sin(2\pi\nu_e t). \end{aligned} \quad (9)$$

In a first-order approximation

$$D \approx E(t) \cos((2\pi\nu_e + \psi)t). \quad (10)$$

The waves interfere into a single wave within the pulse. Thus, in place of the emergence of a new line shifted of  $\nu_i$ , the whole incident flux is slightly frequency shifted

$$\Delta\nu = \psi/2\pi = s \Delta x \nu_i. \quad (11)$$

### C. Computation of the ISRS and CREIL Redshifts

An exciting electromagnetic field induces for each Raman transition  $i$  a scattered field proportional to an element of the tensor of polarizability. Averaging this result for all orientations of the gaseous molecules, the scattered field is proportional to the trace  $\beta_i$  of the tensor of polarizability and has the same polarization than the exciting field; therefore, the electric field may be considered as a scalar.

The amplitude  $p_i$  of the dipole induced in an unit volume for a transition  $i$  is proportional to the incident electrical field and to the number  $N_i$  of molecules per unit of volume in the compatible state:  $p_i = N_i \beta_i E$ . The field scattered at the exciting frequency  $\nu_e$  produces the refraction through  $P$ ,  $N$ , and  $\alpha$  similar to  $p_i$ ,  $N_i$ , and  $\beta_i$ .

At the thermal equilibrium,  $N_i$  is deduced from a Boltzman factor  $B_i$ , so that the ratio of a Raman dipole, with respect to the refracting dipole, is

$$\frac{p_i}{P} = \frac{N_i \beta_i}{N \alpha} = \frac{B_i \beta_i}{\alpha}. \quad (12)$$

The ratios of scattered amplitudes are the same for a single molecule in any direction, or for a large set of identical molecules on an exciting wave surface in the initial direction of propagation<sup>2</sup>

$$\frac{s_i}{S} = \frac{p_i}{P} = \frac{B_i \beta_i}{\alpha}. \quad (13)$$

Recall the elementary theory of the refraction index  $n$  with our notations: Set  $E \cos(2\pi\nu t)$  the electric field of a wave of

frequency  $\nu$  as it reaches a thin sheet of gas whose thickness  $\Delta x$  is a first-order small quantity; the absorption through this sheet is neglected so that the output field is  $E \cos(2\pi\nu(t - \Delta x/c))$ ; the Rayleigh scattered field is delayed by  $\pi/2$ , the total output field is

$$\begin{aligned} E[\cos 2\pi\nu(t - \Delta x/c) + \Delta x S \sin 2\pi\nu(t - \Delta x/c)] \\ \approx E \cos[2\pi\nu(t - \Delta x/c) - \Delta x S]. \end{aligned} \quad (14)$$

The refraction index  $n$  is obtained by an identification of this field with  $E \cos 2\pi\nu(t - n\Delta x/c)$ , giving  $n - 1 = cS/(2\pi\nu)$ .

The dynamical dielectric constant  $\epsilon$  which equals  $1 + 4\pi N \alpha$  is nearly 1 in a dilute gas, so that its square root  $n$  equals  $1 + 2\pi N \alpha$ ; therefore

$$n - 1 = 2\pi N \alpha = cS/(2\pi\nu). \quad (15)$$

By (13) and (15)

$$\Delta x s_i = \Delta x S B_i \beta_i / \alpha = 4\pi^2 N B_i \beta_i \nu \Delta x / c. \quad (16)$$

From (11), we get the shift

$$\Delta\nu = \sum_i [\nu_i \Delta x s_i] = 4\pi^2 N \sum_i [B_i \beta_i \nu_i] \nu \Delta x / c. \quad (17)$$

In a first-order development,  $B_i$  is proportional to  $\nu_i$ , so that the contribution of transition  $i$  to the lineshift is proportional to  $\nu_i^2$ .

This formula shows that, neglecting the dispersion of the tensor of polarizability, the relative frequency shift  $\Delta\nu/\nu$  is constant. But it is very difficult to compute it numerically for the following reasons:

- 1) it requires the knowledge of a lot of tensors of polarizability;
- 2) it is very difficult to apply in (6).

Therefore, we are only able to find a rough order of magnitude of  $\Delta\nu/\nu$ . To do this, we replace the true molecule with a model molecule having a high excitation energy level and two low lying levels of energies  $E_1$  and  $E_2$ , close enough to allow a series development of the exponent in the Boltzman factor, so that the difference of the populations in the low states is

$$\begin{aligned} N_1 - N_2 &= N(B_1 - B_2) \\ &= N \left[ \exp\left(\frac{-E_1}{2kT}\right) - \exp\left(\frac{-E_2}{2kT}\right) \right] \\ &\approx N \frac{E_2 - E_1}{2kT} = N \frac{h\nu_i}{2kT}. \end{aligned} \quad (18)$$

$\beta_i$  requires a transfer of energy from the excited oscillator to the radiating one while  $\alpha$  does not, but this transfer is generally fast, so that generally  $\beta_i$  and  $\alpha$  have the same order of magnitude; therefore, we assume the rough approximation  $\alpha = 2\beta_1 = 2\beta_2$ . Equation (13) becomes  $s_i = B_i S/2 = -SE_i/(4kT)$  for  $i = 1$  or 2. From (11), then (15) the frequency shift is

$$\begin{aligned} \Delta\nu &= \Delta x (s_1 - s_2) \frac{E_1 - E_2}{h} \\ &= -\frac{\Delta x}{4hkT} (E_1 - E_2)^2 \frac{\pi\nu}{c} (n - 1) \\ &= \frac{\Delta x h \nu_i^2}{2kT} \frac{\pi\nu}{c} (n - 1). \end{aligned} \quad (19)$$

<sup>2</sup>The relation between the coefficients in the two configurations requires the addition of Huygens' wavelets by a simple but tedious integration called "the optical theorem."

In a numerical application:

For all gases  $n - 1$  is less than an order of magnitude under or over  $5 \cdot 10^{-4}$  in the normal conditions; at a pressure of 400 Pa which satisfies inequality (1),  $n - 1 = 5 \cdot 10^{-9}$ . To satisfy inequality (6), suppose  $\nu_i = 100$  MHz.  $\Delta\nu/(\nu\Delta x) = 4 \cdot 10^{-14} \text{ m}^{-1}$  at 300 K. For a length of pulse equal to  $\Delta t$ , Lord Rayleigh's criterion says that the frequency difference may be observed if it provides during  $\Delta t$  a difference in phase of  $2\pi$  between the original and frequency-shifted pulse. The light beam must cross a length of gas  $X$  such that  $2\pi\Delta\nu\Delta t = 2\pi$

$$\frac{\Delta\nu}{\nu\Delta x} X\nu\Delta t = 1 \quad \text{or} \quad X = \frac{\lambda}{c\Delta t(\Delta\nu/(\nu\Delta x))} \approx 20 \text{ km.} \quad (20)$$

Our computations of redshift may be optimistic, although Rayleigh's criterion is too strong for photoelectric measures. Therefore, it seems plausible to do an expansive experiment using a long multipath cell in a laboratory.

#### D. Properties of the ISRS and CREIL

CREIL and ISRS are really a single effect.

In ISRS, the laser energy is so high it overwhelms the collisions that usually de-excite molecules; in CREIL, collisional de-excitation is limited by the low pressure.

In both effects, a radiative de-excitation is necessary, which is provided by a second Raman coherent effect involving another exciting beam. Therefore, ISRS and CREIL are not two-photon Raman effects, which would excite the molecules, but four-photon effects, combinations of two simultaneous coherent Raman effects. As they do not excite the molecules, these effects are called "parametric"—the molecules play the role of a catalyst in allowing the transfer of energy from hot beams of light to cold ones, the temperatures being deduced from Planck's law.

The second Raman effect is provided by a second laser in ISRS, and by the thermal radiation in CREIL. In CREIL, this second effect is very strong because all frequencies are very low, so that there are strong resonances. Thus, the previous evaluation of  $\Delta\nu/\nu$  remains valuable.

The use of ultrashort, strong laser pulses makes ISRS easily observable: the collisions may be neglected in dense matter, the Raman active frequencies may be vibration-rotation molecular frequencies in the infrared. In CREIL, the low pressure decreases the probability of scattering; the low Raman frequencies correspond to hyperfine transitions which may be:

- 1) genuine hyperfine transitions involving nuclear spins;
- 2) transitions between levels split by a Stark or Zeeman effect;
- 3) transitions in heavy atoms and molecules.

In their low energy states, the light common gases do not have low level state transitions; however, such transitions are common in plasma.

### III. PROPAGATION OF LIGHT IN IONIZED HYDROGEN

Hydrogen may be ionized by UV radiation into  $\text{H}_2^+$ . This molecule has a complex spectrum due to its two nuclear spin and its electronic spin. Homonuclear, it has no permanent dipole, so that, in a first approximation, it does not absorb the light by

dipolar interactions. A lot of hyperfine structures have been observed in microwave band, which show the existence of Raman active transitions in the megahertz range [10]–[12]. Therefore, the molecule is active in CREIL; it is stable, but it reacts with almost all molecules, so that its persistence requires low pressure which satisfies inequality (1). Therefore, absorption and frequency shift are always simultaneous.

#### A. Visibility of Lines Absorbed During a Frequency Shift

The absorption of the gas, supposed homogenous, is generally represented by an absorption coefficient  $k(\nu)$  verifying

$$d\Phi(\nu, x)/\Phi(\nu, x) = k(\nu)dx \quad (21)$$

where  $\Phi(\nu, x)$  is the flux of energy of a spectral element of frequency  $\nu$  in a light beam propagating along an  $Ox$  axis.

The spectral element observed at a frequency  $\nu_X$  has scanned the spectrum from its initial frequency  $\nu_0$  to  $\nu_X$  while it propagated from  $x = 0$  to  $x = X$ . Its absorption is

$$\Delta\Phi = \int_0^X \Phi(\nu_x, x)k(\nu_x)dx. \quad (22)$$

The sharpest lines get a width larger than the redshift: they cannot be observed individually. As the absorption lines of  $\text{H}_2^+$  are numerous and weak, they cannot be seen: *Even though the  $\text{H}_2^+$  is not visible, it can redshift a beam of light.*

#### B. Detection of CREIL and of Its Red-Shifting Gas

Is it possible to detect that a redshift is produced by CREIL, and to find the nature of the redshifting gas?

A CREIL frequency shift may be written

$$d\nu = \frac{\rho\nu}{q}dx \quad (23)$$

where  $\rho$  is the density of the gas and  $q$  a parameter depending on the gas. Assume that the composition of the gas is constant; the equation is integrated from the frequencies  $\nu_{i0}$  of lines emitted or absorbed at  $x = 0$  to the frequencies  $\nu_{iX}$  observed at  $x = X$

$$\int_0^X \rho dx = \int_{\nu_{i0}}^{\nu_{iX}} q \frac{d\nu}{\nu} = \int_{\nu_{j0}}^{\nu_{jX}} q \frac{d\nu}{\nu} = \dots \quad (24)$$

To explicit that  $q$  depends slightly on  $\nu$ , set  $q = q_0 + r(\nu)$  where  $q_0$  is a constant, and the average of the small function  $r(\nu)$  is zero. From (24)

$$\begin{aligned} & q_0 \left[ \ln \left( \frac{\nu_{i0}}{\nu_{iX}} \right) - \ln \left( \frac{\nu_{j0}}{\nu_{jX}} \right) \right] \\ &= \int_{\nu_{i0}}^{\nu_{iX}} r(\nu) \frac{d\nu}{\nu} - \int_{\nu_{j0}}^{\nu_{jX}} r(\nu) \frac{d\nu}{\nu} \\ &= \int_{\nu_{i0}}^{\nu_{j0}} r(\nu) \frac{d\nu}{\nu} - \int_{\nu_{iX}}^{\nu_{jX}} r(\nu) \frac{d\nu}{\nu}. \end{aligned} \quad (25)$$

Assume that  $\nu_{i0} - \nu_{j0}$  is small;  $r(\nu)$  may be replaced by its mean value  $m(\nu_{i0}, \nu_{j0})$  between  $\nu_{i0}$  and  $\nu_{j0}$ , so that the equation becomes

$$\ln \left( \frac{\nu_{i0}}{\nu_{iX}} \right) - \ln \left( \frac{\nu_{j0}}{\nu_{jX}} \right)$$

$$= \frac{2(\nu_{j0} - \nu_{i0})m(\nu_{i0}, \nu_{j0})}{q_0(\nu_{i0} + \nu_{j0})} - \frac{2(\nu_{jX} - \nu_{iX})m(\nu_{iX}, \nu_{jX})}{q_0(\nu_{iX} + \nu_{jX})}. \quad (26)$$

Assuming that the frequency shift is purely Doppler, the first member of (26) is zero. Otherwise, the simplest explanation for ‘‘Doppler shifting’’ is CREIL. Observing a spectral line emitted by two stars, and assuming that the CREIL is due to the same gas, for a given line the last fraction in (26) has the same value, so that we obtain the variation of  $m(\nu_{i0}, \nu_{j0})/q_0(\nu_{i0} + \nu_{j0})$  as a function of the star, that is of  $\nu_{i0}$  or  $\nu_{j0}$ ; if the dispersion of CREIL due to this evaluation is precise enough, the redshifting gas may be characterized.

#### IV. PROPAGATION OF LIGHT IN ATOMIC HYDROGEN

In the excited states of H, the orbital quantum number  $\ell$  may be equal or larger than one, so that, in an electric or magnetic field, the energy which depends on the projection quantum number  $m$  may produce Raman transitions  $\Delta m = 2$  verifying inequality (6). We assume that hydrogen is dissociated by sufficient heating (10 000 K), and that a Lyman pumping excites the atoms. We also assume that the gas is nearly homogenous. In this scenario, a variable magnetic field induces a CREIL effect.

##### A. Lineshape for a Relatively High Pressure of Gas

When the Lyman interactions are strong, an equilibrium is reached between the temperature of the gas and the temperature of the light at the resonance frequencies. Therefore, in the absence of a CREIL effect, the intensity of the beam at the resonance frequency does not depend on the path in the gas. To find the intensity spectrum corresponding to a high magnetic field (and the associated CREIL effect), the magnetic field must be evaluated along the path for each of the following conditions.

- a) In a high magnetic field: The CREIL redshift rate is high, the temperature of the light at the resonance frequency remains constant.
- b) As the field strength decreases to zero, as CREIL redshift decreases, the temperature of the light approaches the temperature of the gas.
- c) While the field strength is zero, the temperature of the light reaches equilibrium with the temperature of the gas; a residual redshift widens the line.
- d) If the field strength intensifies, the CREIL rate increases.
- e) The field strength becomes constant.

Since d) and e) are opposite to b) and a), the line has the shape of a trough. It may appear as an emission line if the temperature of the gas is higher than the apparent temperature of the source, or else as an absorption line in a cool environment. Since an emission line indicates a very high temperature of the light in the Lyman frequencies, the emission is highly stimulated and may appear superradiant.

##### B. Lineshape for a Strong but not Saturated Absorption

A Zeeman splitting is usually proportional to a field  $H$ , so that the CREIL is proportional to the square of this field; assuming that the gas is nearly homogenous  $x$  is proportional to the mass

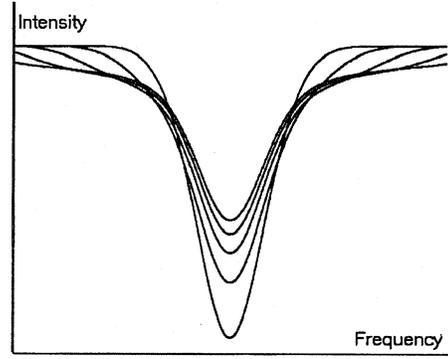


Fig. 1. Computed shape of absorption lines.

of gas passed by the light beam through a unit of surface. We may write

$$d\nu = AH^2(x)dx \quad (27)$$

where  $A$  depends on the physical state of the gas. Equation (27) may be integrated numerically to get  $\nu$  as a function of  $x$ , then (22) is integrated.

Set  $\nu_a$  the absolute frequency of a studied absorption line,  $x_n$  a value of  $x$  for which  $H = 0$  and  $X = x - x_n$ ; mark a spectral element of the light by its frequency  $f$  for  $X = 0$ . Suppose now that the absorption is low and that the linewidth is purely Doppler, so that without a field we would have the absorption at a frequency  $\nu$

$$d\Phi(\nu) = -\exp(-a(\nu - \nu_a))^2 dx. \quad (28)$$

Equation (27), written with a convenient coefficient  $b$  becomes, for  $X$  small

$$d\nu/dX = bX^2. \quad (29)$$

Integrating

$$\nu = bX^3/3 + f. \quad (30)$$

From (28) and (30), the variation of the intensity of the spectral element is

$$d\Phi(f) = -\exp(-a(bX^3/3 + f - \nu_a)^2) dX. \quad (31)$$

Fig. 1 shows lineshapes computed with  $a$  constant, a zero and four nonzero values of  $b$ ; the half intensity width is nearly constant while the absorption remains large outside of this region in the feet of the line: the line is damped. Taking into account only the fast changing intensities in the spectrum, that is neglecting the base of the lines, the pseudolines appear as sharp as a line stretched by the thermal Doppler effect.

##### C. Propagation With Low Pressure and Low Light Intensity

Assuming that the gas and the magnetic field are homogeneous and that the intensity of the absorption is constant, name ‘‘critical length’’  $L_c$  the length of path required to produce a redshift equal to the mean width  $\delta\nu$  of the lines whose absorption is necessary to get the redshift. At both ends of a path long of

$L_c$ , the intensity has a same value  $I_c$  so that our hypotheses are self-coherent.

Assume that the intensity is decreased, so that the redshift is decreased; after a path of the previously defined length  $L_c$ , the spectral elements which pump the gas are not fully renewed, so that the redshift is lowered. Iterating, the redshift disappears unless it exists atoms the redshifting power of which does not require a pumping; as this possible residual redshift has a low intensity, the absorption at *all* eigenfrequencies of all components of the gas are large. Therefore, a previous absorption may start an extinction of the redshift and the writing of many absorption lines.

On the contrary, assume that the intensity is equal to  $I_c$ ; a redshift is proportional to the surface number (number per unit of surface) of excited atoms, so that the surface number  $N_e$  of excited atoms along  $L_c$  is well defined. An increase of the intensity is an increase of  $I_c$  because the density of excited atoms increases, so that  $L_c$  decreases; assuming a linearity, the absorption of a line has a value deduced from  $N_e$ , which does not depend on the incident intensity. These absorptions move the base line of the spectrum, so that the contrasts of the weak lines already written in the spectrum are increased.

Consequently, a complicated interaction between spectra written at various redshifts appears: The ‘‘Lyman forest’’ may be a chaotic spectroscopic effect depending strongly on an initial setting of a spectrum, then on unpredictable slow variations of the properties of the halo.

## V. APPLICATIONS TO ASTROPHYSICS

The Universe is made up of mostly hydrogen; in the usual interpretation of the spectra of quasars, the intergalactic space contains areas of hot atomic hydrogen, but in our following interpretation this hot hydrogen is in the extended atmosphere of quasars. We therefore assume that the intergalactic space is cold and contains molecular hydrogen partly ionized by UV radiation from the stars.

### A. Cosmological Redshifts

Suppose that  $H_2^+$  has the same efficiency in CREIL as the gas considered in Section II-C. What density  $N$  would be required to provide the Hubble redshift without a Doppler, gravitational, or expansion contribution? For a moderate redshift, Hubble’s law is

$$\frac{\Delta\nu}{\nu L} = \frac{1}{L} \sqrt{\frac{c - LH_0}{c + LH_0}} - \frac{1}{L} \approx -\frac{H_0}{c}. \quad (32)$$

Using the value  $H_0/c = 10^{-26}$ , we obtain a pressure of  $10^{-14}$  Pa, that is  $N \approx 3 \cdot 10^6$  molecules per cubic meter. If the temperature of the gas is 3 K in place of 300 K, it remains  $N = 3 \cdot 10^4$  molecule  $m^{-3}$  that is 30 molecules per liter.

### B. Model of Quasars and Seyfert Galaxies

The Lyman forest of the quasars which demonstrates the existence of hot atomic hydrogen is not readily observed in low redshift quasars. However, some of the spectral traits are observed and this may indicate there is intrinsic redshift in these smaller

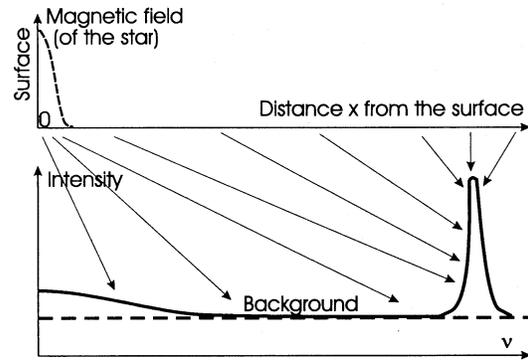


Fig. 2. High redshift emission lines of the quasars. The arrows show the correspondence between the distance to the star  $x$  and the frequency. In the absence of magnetic field (and therefore no CREIL), the emission along a long path concentrates at a frequency, producing a strong emission line.

quasars as well, indicating they may be much closer than expected. If this is true, these quasars may be very close [13], [14]. Consequently, their central engine does not radiate an enormous energy; it may be a small star (a neutron star?) heated by the fall of an accretion disk slowed by a relatively dense halo of atomic hydrogen. We propose that the density of the halo, its metallicity, and, with possible exceptions, its temperature decrease with the distance to the star. The slow change of properties of the gas is observed, but hard to explain for the clouds of the regular model [15].

Observing quasars, Webb *et al.* [16] measured that the relative frequency shift of lines absorbed by the same multiplet, thus absorbed by the same atoms are not equal. They wrote that it is due to a variation of the fine structure constant. A CREIL in gases between the quasars and us is a simpler explanation. As all frequencies are known, (26) gives a relation between  $m(\nu_i, \nu_j)/q_0$  and  $m(\nu_{io}, \nu_{jo})/q_0$ . Thus, as indicated in Section III-B, numerous, careful spectroscopic measures could measure the resonances of the CREIL, and possibly detect their origin which, in this case, is very likely atomic hydrogen.

### C. Correlation Between the Broad Lines and the Radio Quietness of the Quasars (and Seyfert Galaxies)

Many authors think that the quasars and Seyfert galaxies have an accretion disk; set  $\theta$  ( $0 \leq \theta \leq \pi/2$ ) the angle between the axis of the disk and the line of sight to the Earth. The physics of the disks is very complex [23]; the star and the disk can produce X rays whose absorption by the disk [17]–[19] is observed for  $\theta \approx \pi/2$ .

The radio emission of the quasars is generally attributed to the interaction of jets with magnetic fields; if this emission is produced by electric discharges in or at the surface of the disk, its intensity decreases with  $\theta$  down to nearly zero for  $\theta = \pi/2$  because these discharges are flat.

As the star is not a blackbody, the hot gases in the lower atmosphere radiate emission lines. Very close to the quasar, the magnetic field produces CREIL. Here, the effect is very strong producing a rapid redshift, but the spread emission line is nearly invisible (Fig. 2). Where the magnetic field disappears, the strong emission lines traditionally used to define the redshift of the quasar are written sharply into the spectrum.

If  $\theta \approx \pi/2$ , the light propagates close to the disk which produces a variable magnetic field [20], [21]. Here, the conditions exist described in Section IV-A, though are written into the spectrum, first in emission, then in absorption (Fig. 3). The presence of broad lines, as observed [22], is not compatible with detection of strong radio emissions even though all other spectral properties are similar [24].

In radio-loud conditions ( $\theta \ll \pi/2$ ), there is no magnetic field and no CREIL, the emission, then absorption which corresponds to the broad lines are confused as an excess of absorption near the emission lines used to define the redshift of the quasar [25], [26]. In this case, the propagation does not introduces a redshift, while it does in the other case; consequently the thermal radiation near the core is less amplified. This is why the “dust emission” is lower than in BAL quasars [27].

#### D. Damped Absorption Lines and the Lyman Forest

Many Lyman absorption lines are observed in the spectra of the quasars; in the standard model, these lines are absorbed by clouds of hydrogen in the interstellar medium. But it is difficult to explain the confinement of these clouds [14]. The Seyfert galaxies get their name from a proposed existence of many satellites. These satellites may be surrounded by magnetic fields, so that the line of sight crosses a variable magnetic field. As described in Section IV-B, damped lines are “written in” with a lower redshift than the broad lines (Fig. 4).

It seems difficult to have a density of satellites large enough to explain the large number of lines in the Lyman forest.<sup>3</sup> A linking of absorption patterns written when a shifted, already written line reaches a Lyman line (Section IV-C) may produce the quantification observed by Burbidge and Hewitt [29], [30], Bell and Comeau [31], [32]: a coincidence of the  $Ly_\alpha$  line with shifted  $Ly_\beta$  and  $Ly_\gamma$  lines corresponds to  $z = 0.185$  and  $z = 0.251$ , respectively, and these values are the products by 3 and 4 of the fundamental redshift 0.062 observed experimentally by these authors.

#### E. Dust

Where the CREIL effect is greatest, the absorption is weak, but the sum of the absorptions by all lines is not negligible; it may be confused with absorption by dust. The energy lost by the redshifts heats the thermal radiation, just like hot dust. This solves a paradox, that the bright, much redshifted objects appear dusty, while at the same time the dust is not burnt in the plasma, or rejected by the pressure of radiation [28], [33], [34].

### VI. CONCLUSION

It is the consensus among astrophysicists and cosmologists that all observed redshifts are the result of Doppler, expansion, or gravitational effects. Part of the justification is that CREIL has not been demonstrated in the laboratory, and to do so would require an expansive experiment. However, commonly used ISRS differs qualitatively from CREIL only by the nonlinearity caused by the power of the pulsed lasers used to produce this effect.

<sup>3</sup>However, the short decreases of intensity of the quasars may be due to occultations of the star by satellites.

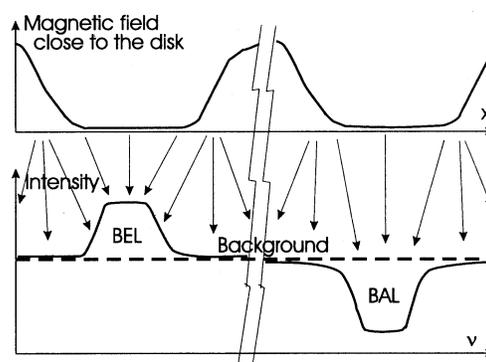


Fig. 3. Shapes of the broad lines. The emission or absorption reaches the equilibrium between the temperature of the gas and the temperature of the light at the resonance frequency.

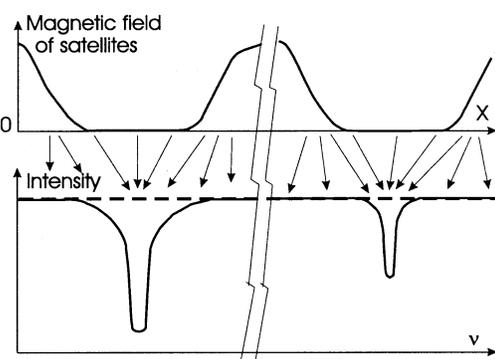


Fig. 4. Damped and forest lines. Fig. 1 provides better shapes.

The near vacuum of space and the high flux expands near quasars provides the right conditions for CREIL. CREIL provides a very simple explanation to many observations which defy expansion or gravitational solutions, even with the introduction of strange concepts such as dark matter.

This work is only an outline; both the physics and the astrophysics must be explored. For instance, the residual redshift in the Solar spectra, after correction of the local Doppler and gravitational effects, are proportional to paths in atomic, magnetized, and therefore CREIL active hydrogen.

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