Newsletter

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Stimulated Raman Scattering in Quasar Plasmas

Vinod Krishan

The inelastic scattering of electromagnetic radiation by matter is known as Raman scattering. The matter may be in any of the four states, a solid, a liquid, a gas or a plasma. The incident electromagnetic radiation may be monochromatic or a continuum or a combination of the two. The scattered radiation consists of three components: radiation at the incident frequency and two new lines at shifted frequencies, the amount of shift being a characteristic of the scattering medium. Thus Raman scattering turned out to be a diagnostic tool for studying the structures of molecules and later of crystals. With the realization of lasers, entirely new vistas opened up in the use of Raman effect. A new generation of accelerators, known as Beat Wave Accelerators have been conceived. These are based on Raman Forward Scattering where two coherent electromagnetic waves beat to give a Langmuir wave which can accelerate electrons to extremely high energies in a very short time. Novel sources of coherent radiation, the free electron lasers, operate on the principle of Raman backscattering. Here a virtual electromagnetic wave in the form of a spatially periodic magnetic field gets scattered by a Langmuir wave. The frequency of the scattered radiation is $\sim\gamma^2$ times the frequency of the virtual electromagnetic wave where γ is the Lorentz factor of electrons.

The possible role of Raman scattering in astrophysical situations has not been adequately explored. Perhaps Kastler (1949) took the first step in this direction. He suggested the use of Raman effect for the detection of H_2 molecules in the outer edges of Jupiter. The idea is to use the H and K absorption lines of sunlight as the incident radiation and look carefully for the Raman lines in the spectrum of Jupiter. Raman lines are in the optical part of the electromagnetic spectrum and therefore can be easily observed.

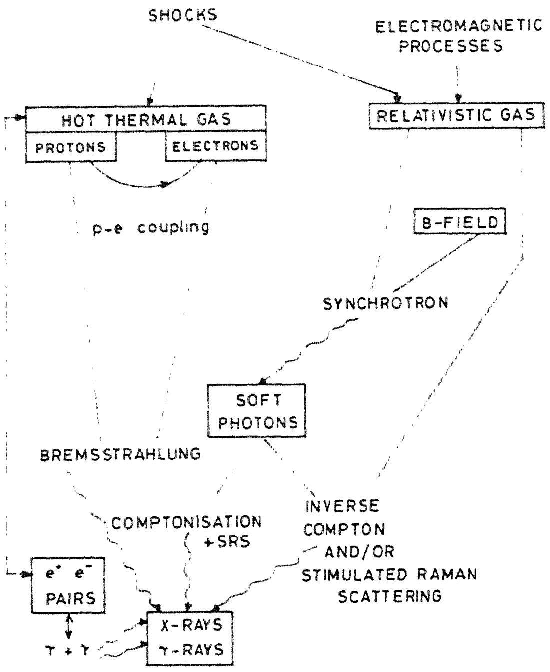
More recently, Radhakrishnan *et al.* (1975) suggested stimulated Raman scattering as an explanation for the exceptionally wide spectrum of H_2O sources since Doppler shifts turn out to be insufficient.

Miska & Miska (1987) consider the scattering of a highly magnetized electron. Compton scattering leaves the electron's Landau level unchanged. If, on the other hand, the scattered electron is raised to a higher Landau level, the process is named as Raman scattering. Conditions for such processes may exist in hard x-ray sources and γ-ray burst sources.

Astrophysical plasmas is another area where stimulated Raman scattering (SRS) is being investigated presently. SRS in plasmas is the scattering of a strong electromagnetic wave off an electron plasma wave. The scattered radiation carries information on the density, temperature and magnetic field of the plasma. It is a nonlinear process and operates when the incident radiation is of very high intensity. Quasars are known to be the most luminous objects in the sky and so are likely to provide the right conditions for the action of SRS. Stimulated Raman scattering in Plasmas is included in the general category of parametric instabilities where an incident electromagnetic wave, depending upon its intensity and frequency, couples with two natural modes of a plasma, both of which grow at the expense of the incident wave. Out of the two modes, if one is an electron plasma wave and the other an electromagnetic wave, the process is called SRS. The following problems have been addressed using stimulated Raman scattering:

1. Heating of the intercloud plasma of quasars

The broad emission-line region of quasars consists of high-density ($n \sim 10^{10}$–10^{11} cm^{-3}) and low-temperature ($T \sim 10^4$–10^5 K) clouds confined by a low density ($n \sim 10^4$ cm^{-3}) and high temperature ($T \sim 10^8$ K) intercloud medium. The intercloud medium is heated to such temperatures by Compton scattering of the high-frequency nonthermal radiation of the quasars. If Compton heating is the only mechanism, then the clouds can be in pressure equilibrium with the intercloud medium over a small range of pressures in the neighbourhood of $nT \sim 10^{12}$–10^{14} K cm^{-3}. The need of additional heating processes is manifold. First, the range of equilibrium pressures needs to be extended. Second, the intercloud medium exerts a drag force on the moving clouds and the drag-limited speed is found to be too small for $T \sim 10^8$ K to account for the observed line widths. Third, a higher intercloud temperature can lead to a simpler motion of the clouds as is indicated by the uniformity and simplicity of the line profiles observed in quasars and Seyferts. It has been shown that the conditions for SRS are satisfied; the scattering rate for SRS is found to be larger by several orders of magnitude as compared to Compton scattering, and the intercloud medium can attain much higher temperature via SRS of the nonthermal radio continuum of quasars (Krishan 1988a).



Physical processes in compact regions of quasars.

2. Spectral modification in synchrotron self-absorbed sources

The discrepancies between the observed flat spectra of the compact extragalactic radio sources and the predictions of the homogeneous synchrotron models are usually explained by invoking multiple components inhomogeneity and/or specialized electron energy distributions. We proposed SRS as another source of spectral modification. It is found that the plasma in the accretion disc surrounding a supermassive black hole provides the right conditions for SRS of the radio radiation. Incident radiation with flux density $F_0 \propto \omega_0^{5/2}$ undergoes Raman scattering in radiation-pressure supported tori and emerges with a scattered flux density $F_s \propto \omega^{1.22-4/\beta}$ where $\beta \geqslant 3$. It is therefore distinctly possible that the radio emission typically observed with a spectral index ~ 0.3 has a large component due to Raman scattering (Krishan 1988b).

3. Polarization modification of quasar radio-radiation

The BLLs show such strong linear polarization in radio and optical region that it seems natural to assign it to the intrinsic radiation source. The fact that OVVs and NGC 1275 show similar polarization characteristics suggests that BLLs, QSOs and Seyferts all have a similar source of energy. If so, then the lack of polarization in QSOs and Seyferts could be due to depolarization effects. Large changes in the rotation angle of an electric vector are produced through SRS. Since it is a nonlinear process, the change in rotation angle depends upon the luminosity of incident radiation in addition to its dependence on plasma parameters. The new features like (i) the possibility of equal amount of rotation of electric vector at very different frequencies, (ii) a large change in the rotation angle for a very small change in plasma density, and (iii) extremely short temporal changes, would help explain many observations for which the existing mechanisms prove inadequate. Because of the very strong dependence of rotation angle on plasma paramters, the depolarization is a natural outcome (Krishan 1988c).

4. Generation of the active galactic nuclei continuum

Stimulated Raman scattering (SRS) processes offer an attractive and efficient method for producing both essentially the entire nonthermal continuum as well as fast electrons in active galactic nuclei (AGN). In this picture, electrons are accelerated by Langmuir waves which are generated by Raman forward scattering (RFS); these electrons then rapidly radiate their energy by means of Raman back-scattering (RBS) off the spatially periodic magnetic fields. Such periodic fields can be produced by magnetic modulational instabilities of the Langmuir field. The emission is envisaged to arise from an expanding region, with the highest frequency radiation originating from the smallest volumes at the core of the AGN. Time variability is dominated by density fluctuations in these magnetohydrodynamic flows (Krishan & Wiita 1986, and references therein).

Conditions for stimulated Raman scattering appear to be satisfied for radio-radiation in the environment of quasars. "Can SRS explain the superluminal motion in compact radio sources"? is the question; a positive answer to which will add two more S's to SRS (Stimulated Raman Scattered Superluminal Sources), and SRS to figure 11 of Rees (1985) as reproduced here.

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Some Characteristics of the Central Pulsar in SN 1987a

Harish C. Bhatt & Bhaskar Datta

The experimental detection of neutrinos from supernova SN 1987a by the IMB group (Bionta *et al.* 1987) and the Kamiokande II group (Hirata *et al.* 1987) is generally accepted to be indicative of the formation of a neutron star. The subsequent detection of gamma-ray lines from SN 1987a characteristic of ^{56}Co decay (and the exponential decay of the supernova light curve with a time scale similar to the ^{56}Co decay half-life after about 120 days since the explosion) suggest that the energy source is the ^{56}Co radioactive decay (Matz *et al.* 1988). On the other hand, the peculiar behaviour of the SN 1987a light curve during the first few months may be due to the central pulsar as the energy source (Ostriker 1987). If this is indeed the case, then the energy transferred by the pulsar to the surrounding nebula will cause the supernova light curve to level off at certain asymptotic value after the radioactive contribution has declined sufficiently. This transition will depend on the relative magnitudes of the pulsar luminosity and the radioactive energy. The observed luminosity therefore is an upper limit to the luminosity of the central pulsar. Even after about 400 days since the explosion, the supernova light curve has not shown any sign of levelling off. This implies that the luminosity of the central pulsar must be low, and that the pulsar must not be rotating very rapidly. We derive a quantitative lower limit on the period of rotation of the central pulsar in SN 1987a using the available observational information.

For an observed bolometric luminosity L_0 of SN 1987a, we can write

$$L_{\rm PSR} \leqslant L_0, \qquad (1)$$

where $L_{\rm PSR}$ is the luminosity of the central pulsar. Following Ostriker & Gunn (1971)

$$L_{\rm PSR} = L_i/(1+2t/\tau_i)^2, \qquad (2)$$

$$L_i = \frac{2B^2 R^6 \Omega_i^6}{3c^3}, \qquad (3)$$

$$\tau_i = \frac{3c^3 I}{2B^2 R^6 \Omega_i^6}. \qquad (4)$$

Here B is the surface dipole magnetic field and R, I and Ω_i are radius, moment of inertia and initial angular speed of the pulsar. For time $t \lesssim 1$ year, the factor $2t/\tau_i \ll 1$ for typical values of pulsar parameters. Therefore,

$$L_{\rm PSR} = L_i \leqslant L_0. \qquad (5)$$

So, the (initial) rotation period (P_i) will satisfy.

$$P_i \geqslant 2\pi \left(\frac{3}{2} c^3 L_0\right)^{-1/4} B^{1/2} R^{3/2}. \qquad (6)$$

On day 134 after the explosion, the visual magnitude of SN 1987a was $V = 4.4$, and the bolometric luminosity $L_0 = 10^{41.5}$ erg s^{-1} (Catchpole *et al.* 1987). Therefore

$$P_i \geqslant 5.75 \times 10^{-3} B_{12.5}^{1/2} L_{41.5}^{-1/4} x^{3/2} \,{\rm s}, \qquad (7)$$

where x is R in units of 10 km, $B_{12.5}$ is the surface magnetic field strength in units of $10^{12.5}$ Gauss and $L_{41.5}$ is the luminosity in units of $10^{41.5}$ erg s^{-1}. The visual brightness has been declining continuously since then. By 1988 April 22, it declined to $V = 7.4$. In the absence of any published report on the distribution of the total spectral energy of the supernova, we assume here that the bolometric luminosity has also fallen by 3 magnitudes from day 134 to day 424. Since P falls as $L^{-1/4}$, we can write, corresponding roughly to the present day,

$$P_i \gtrsim 11.47\, x^{3/2}\ \mathrm{ms}, \tag{8}$$

where we have taken the canonical value of $B(\simeq 10^{12.5}$ Gauss) Equation (8) sets a general lower limit on the rotation period.

The total binding energy (W) of the remnant neutron star in SN 1987a can be estimated using the IMB and Kamiokande II data and choosing a specific cooling model of the star and a distance estimate.

Kahana, Cooperstein & Baron (1987) estimate that

$$W = (2.0 \pm 0.5) \times 10^{53}\ \mathrm{erg}, \tag{9a}$$

while Sato & Suzuki (1987) give

$$W = \begin{cases} (1.7\text{–}3.4) \times 10^{53}\ \mathrm{erg} \\ (1.2\text{–}5.3) \times 10^{53}\ \mathrm{erg} \end{cases} \tag{9b}$$

For a given equation of state of neutron star matter, the parameters W, R, I and mass M can be calculated as a function of central density by integrating the equations of stellar structure. We have considered a representative set of equation-of-state models, namely those due to (a) Pandharipande (1971), (b) Bethe & Johnson model V (1974), (c) Walecka (1974), (d) Canuto, Datta & Kalman (1978), (e) Friedman & Pandharipande (1981) and (f) Kutschera & Pethick (1986), and plotted W versus R. Corresponding to the range of W, Equations (9a) and (9b), we find that x lies in the range (1.0–1.5). Equation (8) then implies that the lower limit on P_i is in the range (11.47–21.08) ms. If the SN luminosity declines further in the coming months, the lower limit on the pulsar period will correspondingly increase. Therefore, the limits derived here are firm lower limits.

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from the director

In the first Antarctic Workshop held in New Delhi recently some ideas about unique astronomical experiments which could be undertaken in the frozen continent were voiced. The fact that the geographical location of the station being low down in the southern hemisphere, the exotic southern objects will be in very convenient positions, was not enough to justify their observations from Antarctic locations. It is absolutely essential that only those experiments need be considered which cannot be done anywhere else.

Among several new ideas presented a few such experiments could be identified. The unique feature of "ozone hole" over antarctica can be utilised for ultraviolet observations from ground, which at present can be performed only from space platforms. A ground-based telescope with ultraviolet detectors may be tried to assess the duration and extent of ultraviolet seepage through the antarctic atmosphere.

A second idea voiced was the possibility of excellent astronomical seeing over the frozen expanse of the continent. A deeper knowledge about the temperature structure of boundary layers will be needed in the first instance; this also can be gauged from observations through the same telescope.

Possibilities of detecting long-period stellar oscillations through continuous observations spanning long winter nights were also suggested. Still another idea was to attempt detection of gamma-ray sources through Cerenkov flashes in the atmosphere; the antarctic skies appear to present some unique advantages in these experiments.

The antarctic expedition has opened up new avenues in observational astronomy, which the younger generation will surely explore with enthusiasm.

J. C. Bhattacharyya

Photography Laboratory of Vainu Bappu Telescope

The 2.3-m Vainu Bappu Telescope has facilities for direct photography at its prime focus. The usable field has a diameter of 40 arcmin. The supporting facilities available are (1) an air-conditioned, dust-free, dark room; and (2) facilities for hypersensitization of photographic plates.

The dark room is situated on the first floor of the VBT building, and surrounds the north pier of the telescope. A double-door entrance to the dark room, and a 5-micron dust filter in the air-conditioning duct, help in maintaining the room dust free.

The speed of photographic emulsions can be increased by subjecting them to different kinds of treatment (known as hypersensitization) prior to use. Experiments have shown that oxygen and water molecules trapped in the emulsion reduce the speed. The easiest way of removing these molecules is to store the emulsions in vacuum for several hours. The outgassing processes remove the molecules. Baking the plates in dry nitrogen atmosphere at about 70 C improves the gain further.

For the purpose of hypersensitization of photographic plates, VBT dark room is being equipped with an oven with a stainless steel cylindrical chamber of 25 cm diameter and 30 cm length, to hold the plates to be hypersensitized. The chamber can be evacuated to 10^{-4} torr with the help of a combination of rotary and diffusion pumps. Later, dry nitrogen may be introduced into the chambers and the plates baked at required temperature for required duration.

The above set-up can also be used to evacuate liquid-nitrogen-cooled devars containing infrared or CCD detectors.

K. K. Scaria & N. K. Rao

The Crab Nebula photographed by K. K. Scaria and M. J. Rosario with 2.3-m Vainu Bappu Telescope through a Wratten 25 red filter on 098-02 emulsion; exposure time: 20 minutes

of human elements

Relatively difficult

. . . a student from Washington, D.C., wrote to him [Albert Einstein] on 3 January 1943 mentioning among other things that she was a little below average in mathematics and had to work at it harder than most of her friends.

Replying in English from Princeton on 7 January 1943, Einstein wrote in part as follows:

> Do not worry about your difficulties in mathematics; I can assure you that mine are still greater.

Albert Einstein
The human side
H. Dukas & B. Hoffmann
Princeton University Press 1979, P. 8.

out of context

In his next-to-last chapter . . . .

Sky & Telescope (1988) **75**, p. 43.

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VLT, an extraordinary astronomers' dream.

The messanger, No. 50, Dec. 1987

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It is definitely a challenge to reproduce the rich variety of pulse shapes observed in a natural manner.

IAU Symp. 95: *Pulsars*, D. Reidel, 1980, p. 158

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. . . WL data give the distribution

ASSSASSSSSSSAASSSSSSSSSSSAAAAAASS

in an obvious notation.

Astrophys. J. (1988) **327**, L77.

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