25th IAP conference 2009 July 6-10, Paris

Spectroscopy of a Strömgren system.

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Definition of the system: an extremely hot source is surrounded by a huge cloud of hydrogen.

Strömgren's results:

-The Strömgren sphere, made of protons and electrons is transparent.

-The Strömgren shell is a plasma similar to a laser plasma.

- The strong radiation of this plasma cools the gas strongly, absorbs the light, so that the shell is thin.

Correcting an error:

Strömgren and following authors study the propagation of photons by a Monte-Carlo method without pilot wave. Using this method, most physicists said: "Townes maser will not work". The correct method is the use of Einstein coefficient B, of induced, coherent emission (Einstein 1917):

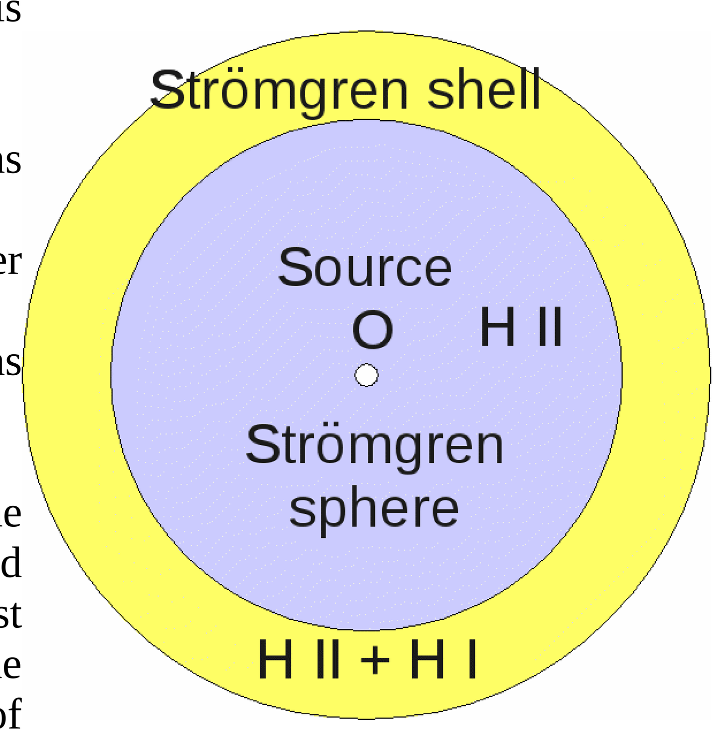

Fig 1: Strömgren sphere and shell.

Set L the *absolute spectral radiance* of a beam whose minimal average value corresponds to the energy hν/2 in a monochromatic mode (Planck 1911). Along a path dx, $dL/dx = BL(p_2-p_1)$ where p_2 and p_1 are the densities of atoms in the high and low states of the transition of frequency ν. If L corresponds roughly to hν/2, the emission is "spontaneous". If the radiance becomes much larger, it is a "superradiance", more energy is tranferred from the high state to the low state.

Consequence: The strongest superradiant beams depopulate the upper state of the transitions, killing the other beams (competition of the modes).

Which are the remaining beams?

Rays "A" and "B" cross the same infinitesimal amplifying shells, but the paths are longer for ray "B": Ray "B" is more amplified: the final radiance is an increasing function of distance d = r from O to the ray. For d small: n'>n.

As there is no amplification for ray "C", amplification has a maximum.

In astrophysics, it is often assumed that the Lyman line is reabsorbed "on the spot". This means that the light-matter interactions are large at resonance frequency. Thus, we assume here that the superradiances are large, so that there are few (*bright*) *superradiant beams*, for a value R of d that we consider as the radius of the Strömgren sphere.

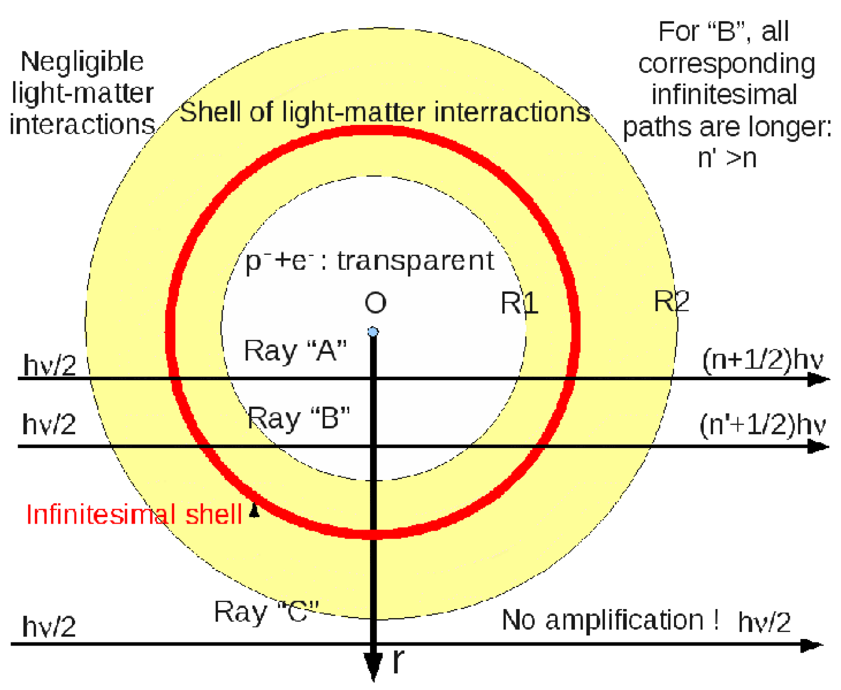

Fig 2: Amplification of the light beams.

Geometry of the superradiant beams.

Into a chosen direction, the superradiant beams are generators of a cylinder, the beams are seen on a circle. But the competition of the modes leaves only a few bright modes: the circle is dotted as the TEM(l,m) modes of a laser selected for a constant value of l.

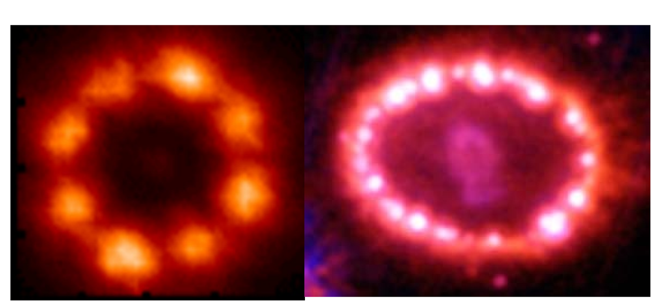

Fig 3: Modes of a laser and SNR1987A

Credit: NASA/ESA, P. Challis, R. Kirshner (Harvard-Smithsonian Center for Astrophysics) and B. Sugerman.

Correlations of superradiances at several frequencies.

Along its path, a superradiant beam depopulates the high state of the transition and populates its low state, so that the transitions *to* its high state and *from* its low state are favoured. Thus the superradiant beams tend to have the same paths, but diffraction moves outward the axis of the long wavelength beams.

States of the gas.

A non-negligible amount of neutral, excited atomic hydrogen H_I* appears where the temperature falls to around 5.10^4K.

Lyman alpha line is emitted spontaneously with an increasing intensity.

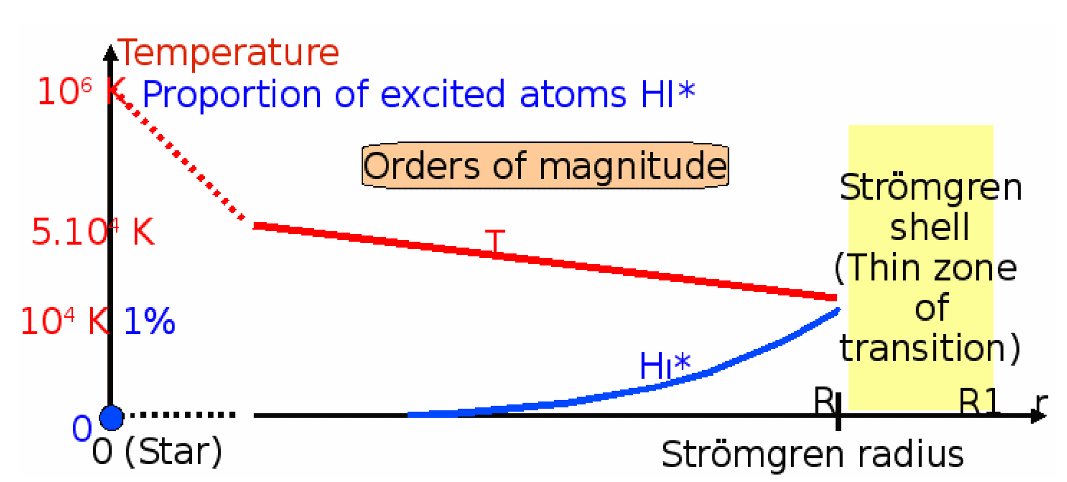

Fig 4: temperature and neutral atoms in the sphere for r~R.

Where the superadiance starts, at r=R, it depopulates strongly the excited levels, so that the density of H_I* falls.

The superradiance can induce a depopulation of the close states of the continuum, that is collisional states: the speed of de-ionization (H_{II} -> H_I) is limited by the need of collisions.

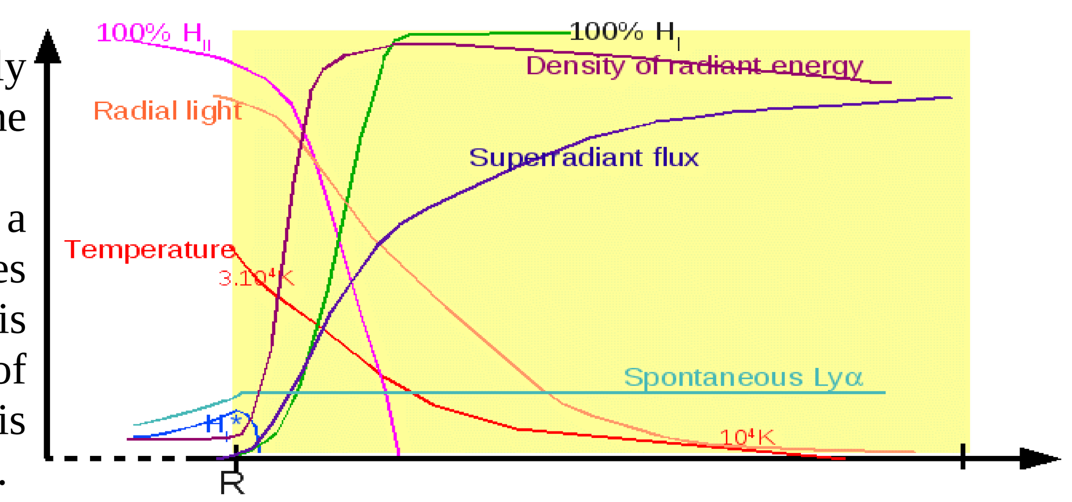

Fig 5: Evolution in the shell of H, light and temperature.

Multiphotonic interactions

If the radiances are low, a light-matter interaction requires exactly ΔE=hν (black lines).

A continuous spectrum is absorbed at frequencies large enough to reach the continuum (red line).

An atom may be excited by several lasers such that a simple combination of their frequencies is an eigenfrequency (purple arrows).

We may consider that the each laser pumps the atom between stationary or virtual states and that the corresponding transitions are packed into a single "multiphotonic interaction".

The intensity of the multiphotonic interaction decreases if the number of virtual states increases.

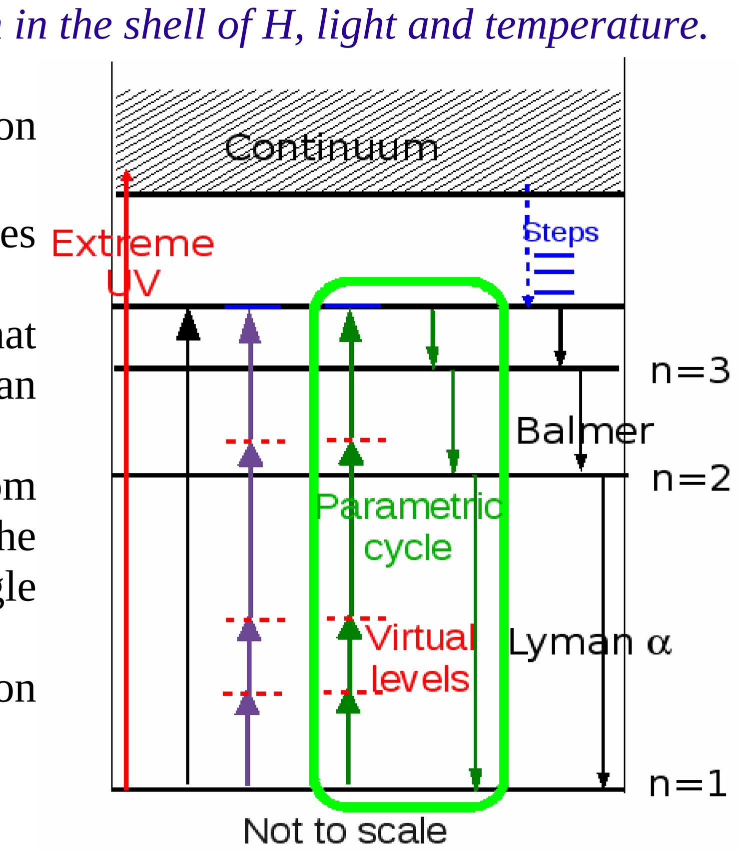

Fig. 6: Types of transition

Parametric interactions.

A parametric interaction is a *coherent* multiphotonic interaction in which the transitions make a cycle, so that the atoms play the role of a catalyst. The atoms do not need to perform real transitions, they are only "dressed" by the fields, their state being a non-stationary combination of stationary states in which the lowest state is usually preponderent. As real transitions are not needed, the parametric interactions are stronger than the corresponding quantized interactions. The parametric interactions are, in particular, used to combine, shift the frequencies of lasers in crystals.

Parametric induced scattering in the model (green arrows).

The extremely hot light rays emitted by the source add their frequencies so that the whole continuous spectrum is absorbed. The decay from an excited state is induced by the superradiant beams.

The interactions between the high radiance beams are very strong, so that the thermodynamic equilibrium is nearly reached at the involved fréquencies: The spectral temperatures of the radial beams at all frequencies tend to decrease to the temperatures of the superradiant beams; the total radiance of the source remains much larger than the total radiance of the scattered lines. However, *if the source is seen through a solid angle much smaller than the solid angle of observation of the dots, it becomes invisible.*

Coherent Raman Effect on Incoherent Light (CREIL).

The simplest parametric process is the interference of a beam with its coherent Rayleigh scattered beam, delayed by π/2: it is the refraction.

To obtain a similar result from a Raman scattered light, two conditions must be fulfilled:

i) Coherence. G. L. Lamb Jr. (1971) explained that the space-coherence of a light-matter interaction is reached if the coherence time of light (usually ~1ns for incoherent light) is "shorter than all relevant time constants", here the very long collisional time and the period of a quadrupolar resonance. The 1420 MHz spin recoupling resonance of hydrogen atoms is too high, but the frequencies 178 MHz in the $2S_{1/2}$ state, 59 MHz in $2P_{1/2}$ state, and 24 MHz in $2P_{3/2}$ are very convenient.

This coherence corresponds to an interference of the exciting and scattered beam whose result is a single frequency beam. It seems strange because the sum of two sine functions results in beats. But, if the range of the angles is short, and the initial phases zero, the beats do not appear, leaving a sine wave at an intermediate frequency. A simple addition of sine functions, with the approximations corresponding to Lamb's conditions, shows this result.

ii) No permanent excitation of the atoms. Several light beams must be involved. From the frequency and the spectral radiance, Planck's law associates a temperature to a light beam. To increase the entropy, the hottest beams must be cooled by a decrease of frequency, the other, including the thermal background, heated.

Application of CREIL to light spontaneously emitted in the sphere.

Study the spontaneous emission along a ray crossing the sphere (fig.2, ray "A" or "B"). Excited atoms H* appear for r slightly lower than R, and their density (fig. 4, 5), their emission increase fast versus r. Along their path in the region of the sphere containing H*, the rays receive, by CREIL effect, energy from the radial, hot beams, return energy to the thermal background. Suppose that the balance is a loss of energy: spectrum (Fig 7a) is obtained.

For r slightly larger than R, energy of the radial rays is transferred to the superradiant, tangential rays. This transfer decreases strongly the radial component of the speed of propagation of high temperature radiant energy, increases the density of hot energy, so that the spontaneously emitted light receives much more energy, shifting the spectrum to high frequencies (fig 7b). The relatively high density of H* decreases fast so that this shift occurs in a small region.

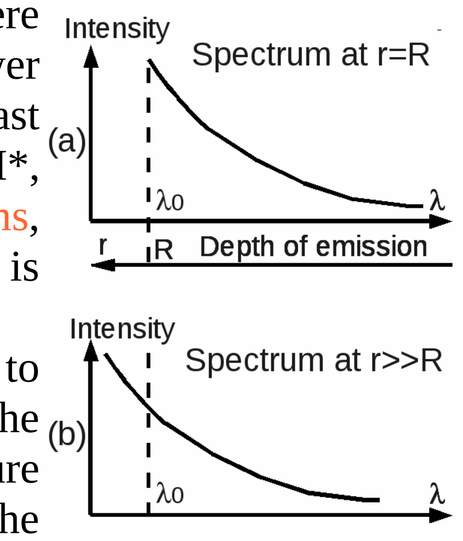

Fig.7: spectrum of a spontaneous line.

Changing the ray, for instance from "A" to "B" changes the paths in H*, so that the intensities and the frequency shifts of the spectrum vary as showed by the experimental spectrum of SNR 1987A (fig.8 top). In particular the sharp fall of intensity at wavelengths shorter than the resonance wavelength λ_0 becomes less visible.

Michael et al (2003) observe that their computation of the spectrum by the Monte-Carlo method is bad because the intensity decreases too fast from the off-figure maximum (fig 8 down).

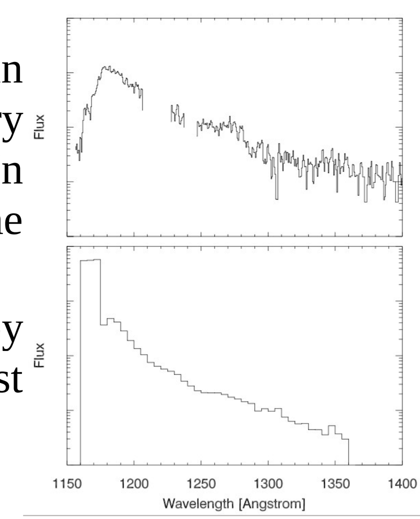

Fig. 8 Spectra of Ly α line (observed, calc.) from Michael et al.

Conclusion.

We used the correct law of propagation of light in a resonant medium, took into account that the high radiance light produces multiphotonic light-matter interactions, and took into account parametric frequency shifts. The observation of these effects in the labs requires convenient laser beams, providing the laws that we applied.

Supposing that SNR 1987A is a Strömgren system explains that:

- The star is invisible;
- The bright circle (probably distorted by inhomogeneities) is dotted, its spectrum is made of sharp lines; high frequency modes make it brighter at its inner rim;
- The surface inside the ring emits extremely broad lines.

Remark that **Michael et al. do not apply Hubble's law to the observed redshifts** because it leads to absurdly large distances. Their result is wrong because their Monte-Carlo computation introduces unjustified stochastic phases which destroy the coherence.

Using the CREIL, Hubble's law is explained by an hypothesis of a constant density of excited atomic hydrogen in the universe. But this hypothesis is wrong where very hot stars excite hydrogen clouds, where H_{II} cools, ...

Other examples of application of the parametric CREIL effect:

* Interpretation of the spectra of the quasars, in particular of the periodicities observed in the Lyman forests simply deduced from the spectrum of H. The sharp lines of these "accreting neutron stars" are emitted by Strömgren shells.

* Interpretation of the "anomalous redshifts" observed close to bright objects.

* Using the cooling of the solar wind beyond 5UA which generates neutral atoms, and transfers of energy from the solar light:

- Explanation of the "anomalous acceleration" of Pioneer 10 and 11 probes by a blueshift of the radio signals;
- Explanation of the binding of the first spatial harmonics of the CMB to the ecliptic, through the anisotropy of the solar wind.

* Explanation of the frequency shifts of the extreme UV lines of the Sun.

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