Quantum of Quasars

Bringing quantum optics, astrophysics, photon-counting detectors and extremely large telescopes together.

http://www.quantumofquasars.org

Workshop 2009: Laboratoire d’Astrophysique de Grenoble (France), December 2-4.

Talk #4

Jacques Moret-Bailly

“Coherent spectroscopy in astrophysics”

Coherent spectroscopy in astrophysics.

Application to

The Strömgren model.

Jacques Moret-Bailly
JMO@laposte.net

QQ7-Grenoble, December 2-4, 2009.

Menzel (PASP 43 , 70 (1931)) rejected the use of many light-matter interactions, in particular space-coherent. Their recall is followed by an application to the model of Strömgren which seems explain the observations of the remnant of supernova 1987A.

Introduced light-matter interactions:

Rayleigh coherent scattering and Einstein theory of emission and absorption.

Multiphotonic interactions, stimulated scattering.

Raman coherent scattering of incoherent light (parametric interaction of several light beams).

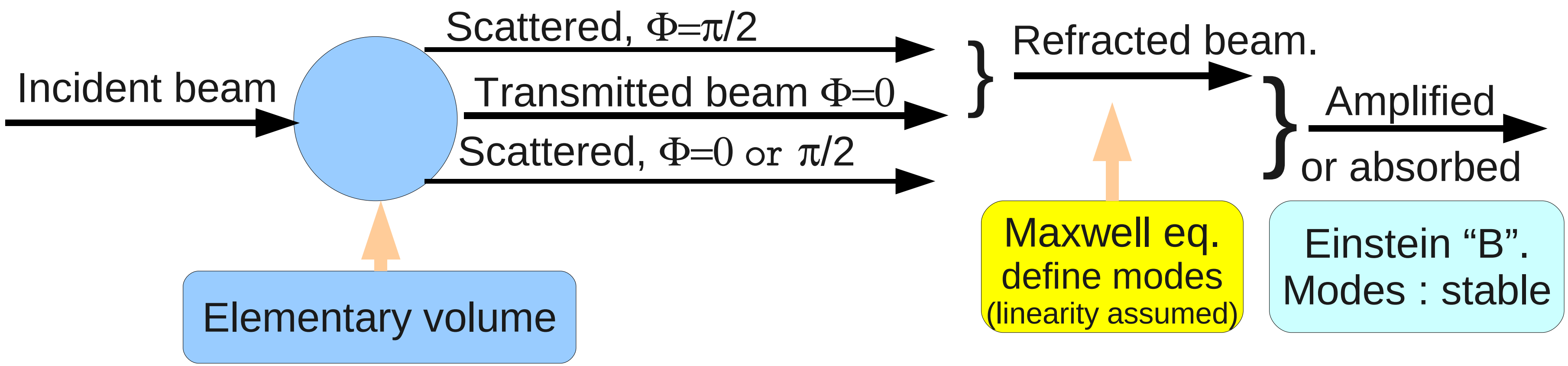
The astrophysicists often use a Monte-Carlo computation which ignores the phases of the pilot waves of the photons : No more waves, no interferences: absurd !

Can “A” and “B” Einstein coefficients be used to study the propagation of a mode of light in a large resonant media ?

1. Coherent Rayleigh interractions.

Aim: Define monomode beams in a resonant medium.

Rayleigh coherent scattering is (artificially) split according to phase shift Φ.



2. Spontaneous emission (Einstein coefficient “A”).

Atomic theory shows that matter cannot absorb completely an electromagnetic field; It remains a “residual” field (also qualified “zero point”, “stochastic”,...) evaluated by Planck.

“A” coefficient results from an amplification of the residual field.

Evolution of the spectral radiance of a light beam limited by diffraction (progressive mode).

Use absolute or relative radiance?

Planck, Verh. Deutsch. Phys. Ges.,**13**, 138 (1911)

Einstein (*Phys. Zeit.*, **18**, 121 (1917)) and Planck

Very cold far unknown medium

0

$h\nu^3/c^2$

Opaque amplifying medium (temperature T)

$$\frac{2h\nu^3}{c^2(\exp(h\nu/kT)-1)}$$

$$\frac{2h\nu^3}{c^2}\left(\frac{1}{2}+\frac{1}{\exp(h\nu/kT)-1}\right)$$

Very cold opaque, absorbing medium

0

$h\nu^3/c^2$

Relative radiance: difficult, many errors

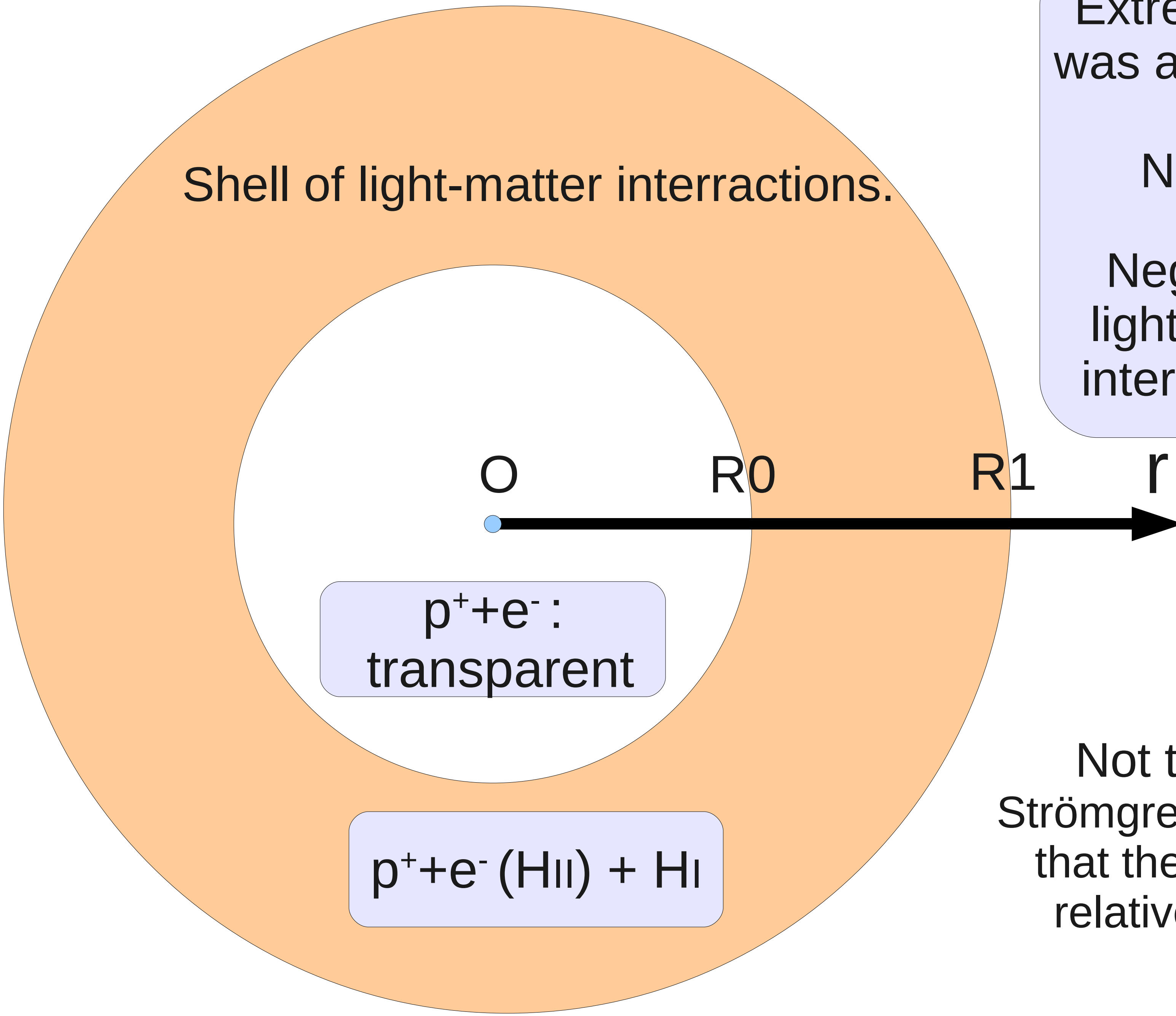
Absolute radiance: Simple, rigorous and reliable

Strömgren's model: Hypothesis:

- A star is extremely hot: $T>3.10^5$ K.

- It is surrounded by a low pressure, huge, static cloud of hydrogen, cold and vanishing at a long distance. Hydrogen if fully ionized (H_{II}) except in the low density region.

- Isotropy is assumed.

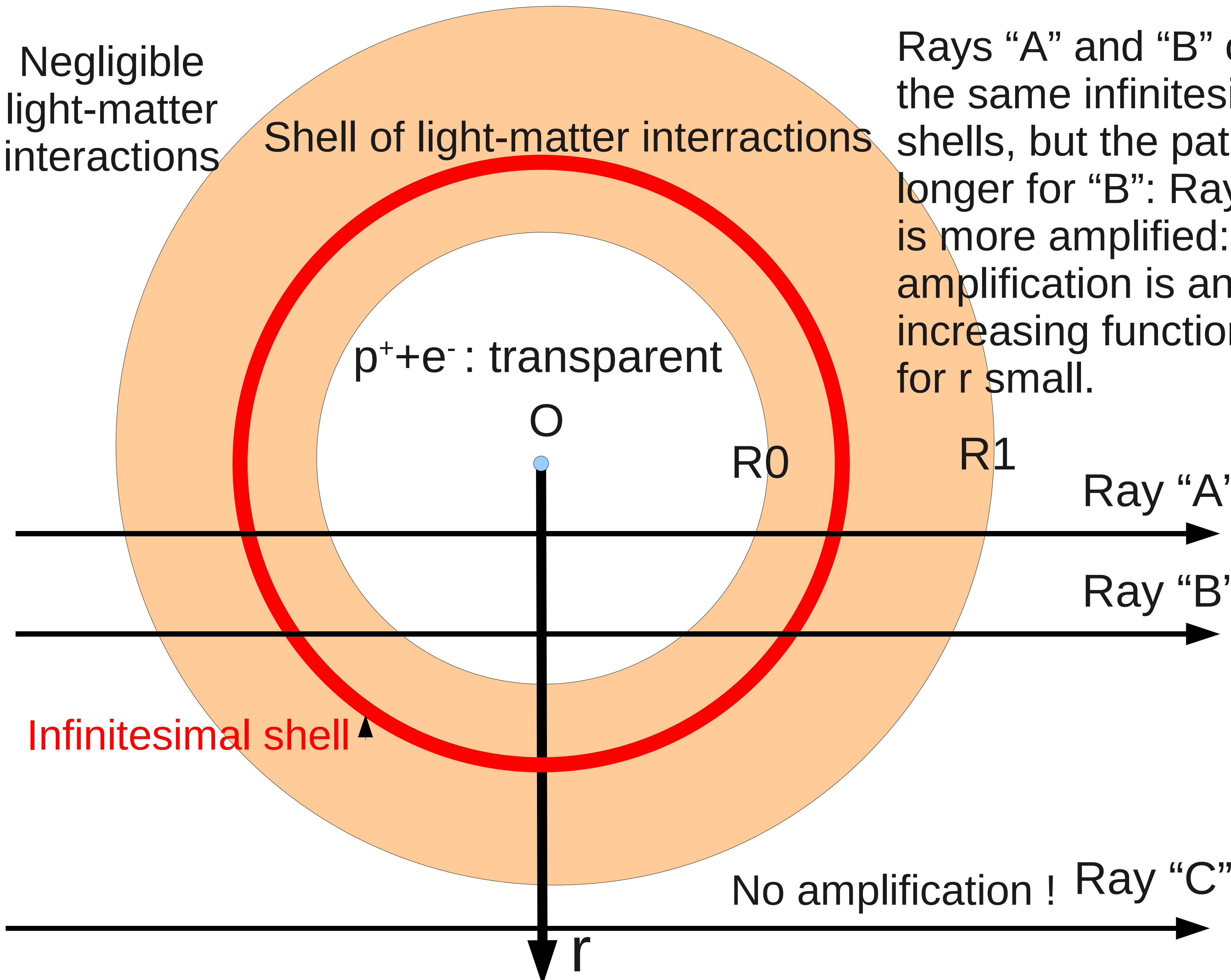


Extreme UV was absorbed.

No HII.

Negligible light-matter interactions.

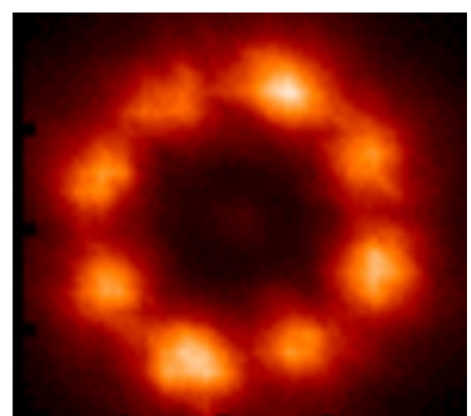
Not to scale :
Strömgren showed that the shell is relatively thin.



Rays “A” and “B” cross the same infinitesimal shells, but the paths are longer for “B”: Ray “B” is more amplified: the amplification is an increasing function of r for r small.

The function “amplification” has (at least) a maximum for r = R (R0<R<R1).
Assuming a large column density, the superradiance is as large as in a laser tube, so that the competition of the modes leaves only the strongest beams tangent to the “Strömgren sphere” of radius R.
Into a given direction, these beams are on a cylinder. They are seen as a ring.
By a competition of the modes, the ring is dotted, as daisy modes of a laser.

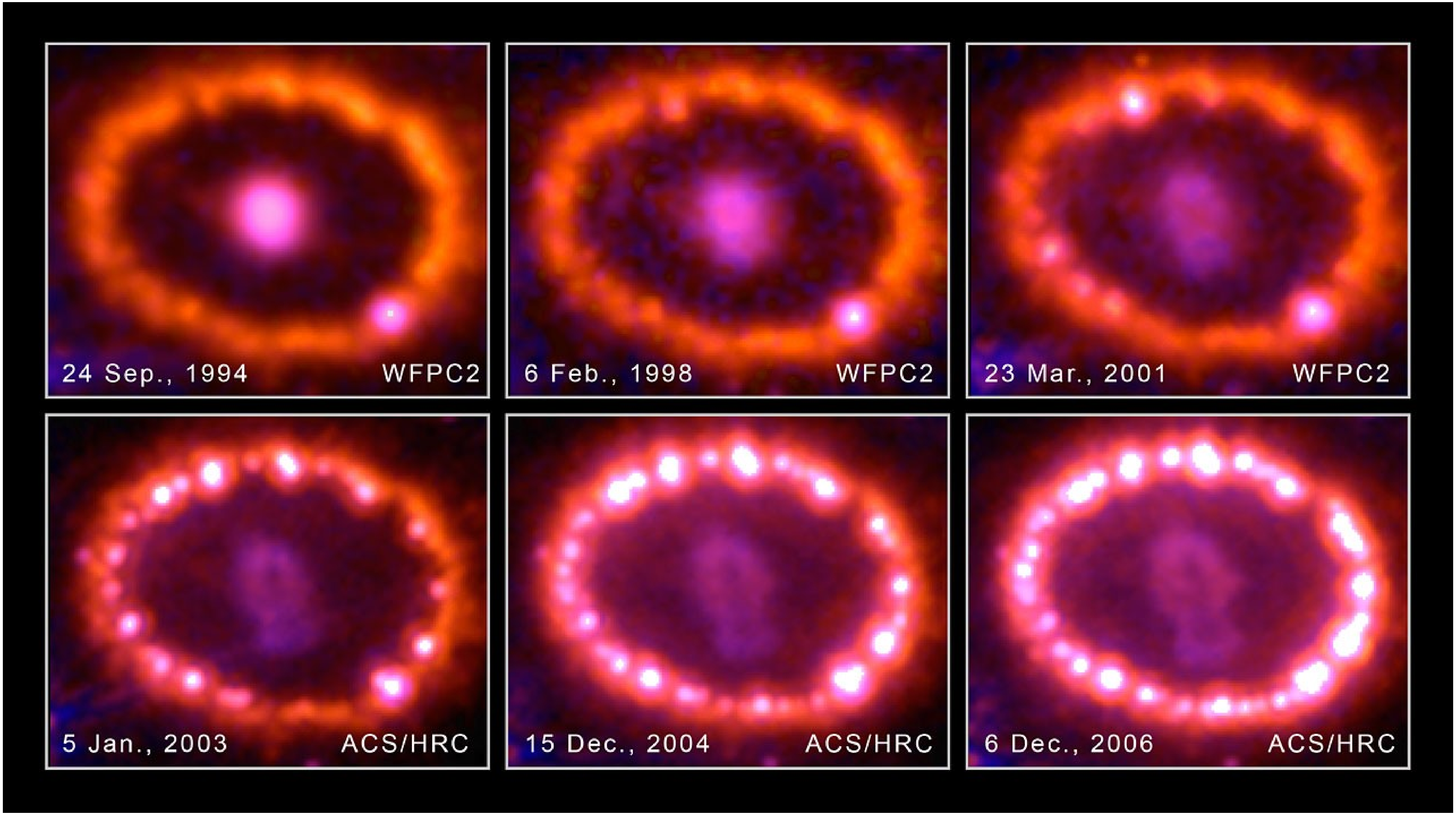
Laser modes:



Hubble observation of SNR1987A

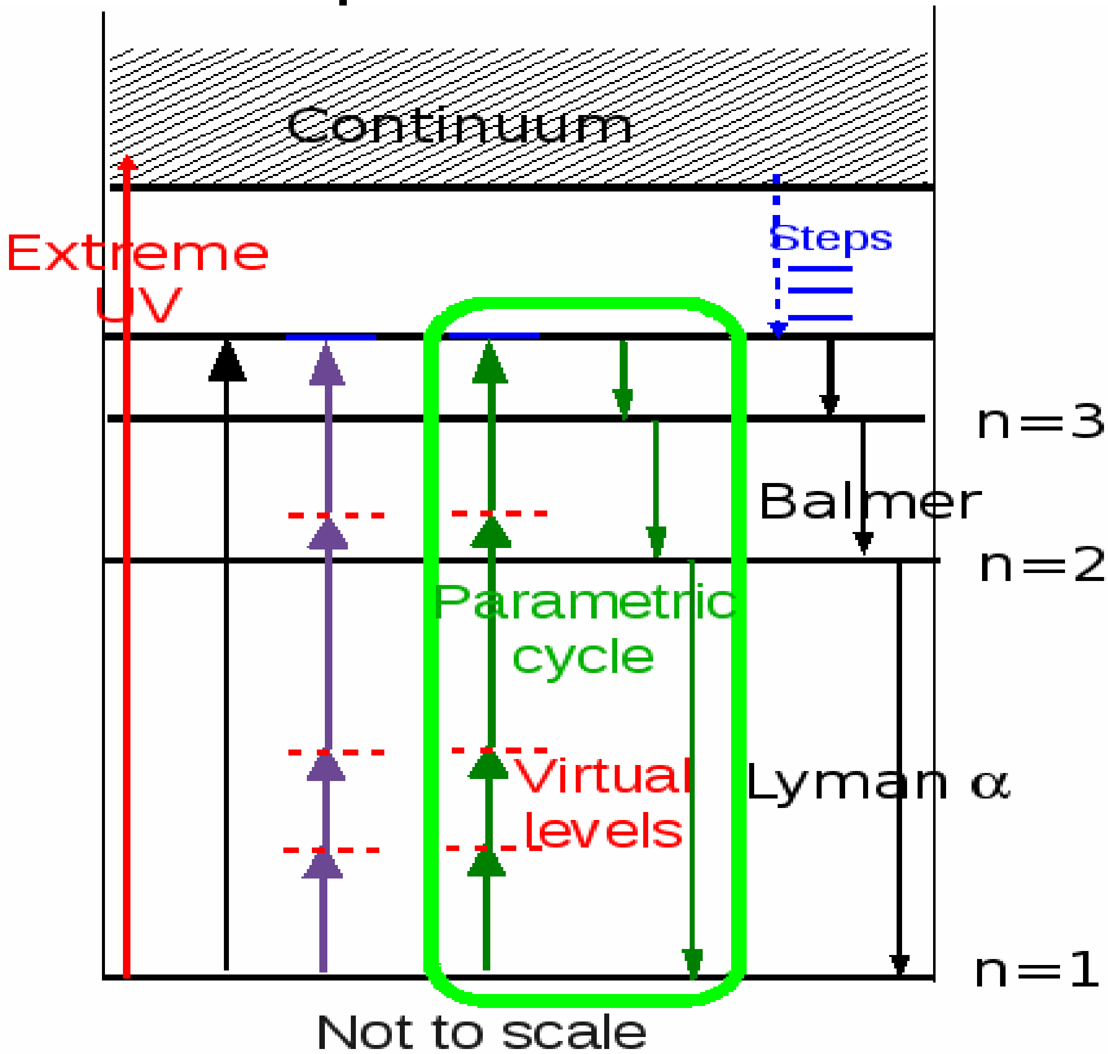
The star disappears while the superradiance increases.

Polychromatism increases the complexity.



In the shell :

As the radiance of the source is very large, the transitions of H (drawn in black, red, purple) may be multiphotonic and bound into parametric cycles.



The de-excitations are induced by the superradiant beams.
The whole parametric cycle is an induced multiphotonic scattering which transfers most energy of the radial continuuous spectrum to the line spectrum of the ring:
The star becomes invisible.

All atoms are involved,
the interaction is very strong

Propagation of light in excited hydrogen.

The parametric process of Rayleigh scattering which explains the refraction may be applied to Raman scattering provided that conditions of coherence set by G.L Lamb Jr.* be fulfilled: Use light pulses improperly named “ultrashort”: the length of these pulses must be “shorter than all relevant time constants”.

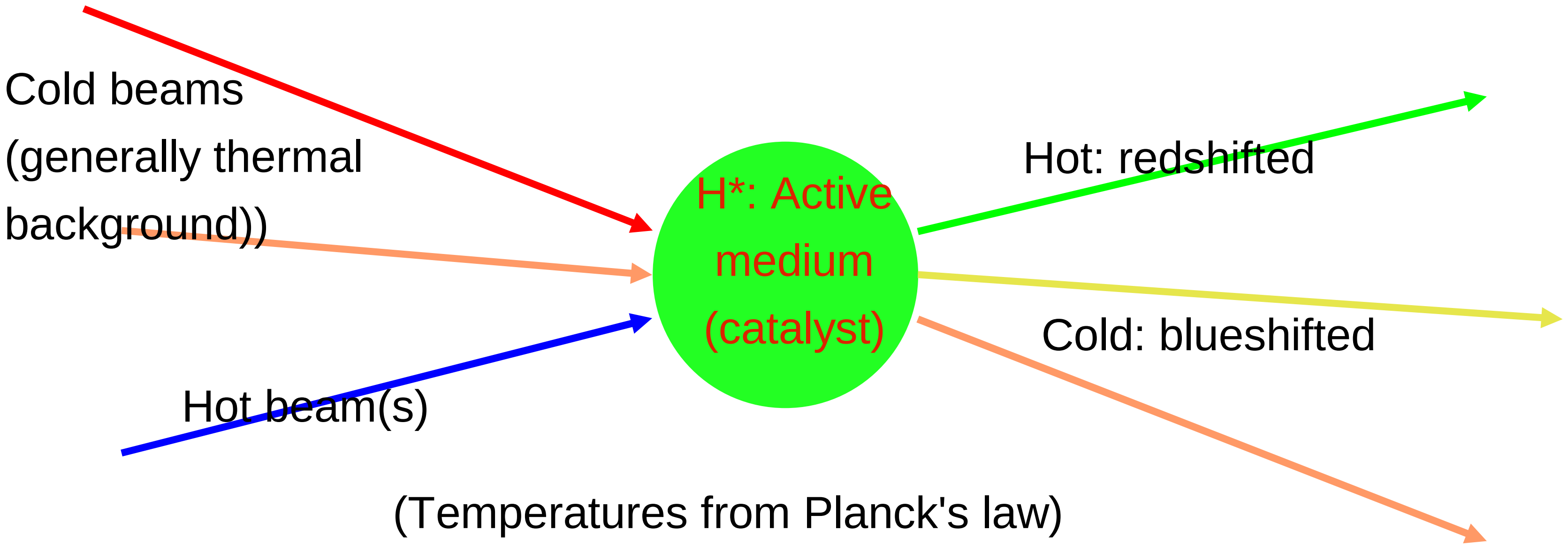
Accordingly :

With ordinary incoherent light made of nanosecond pulses:
- the pressure must be low (collisional time > 1ns).
- the Raman frequency must be lower than 1 GHz : frequencies 178 MHz in $2S_{1/2}$ state, 59 MHz in $2P_{1/2}$, and 24 MHz in $2P_{3/2}$

To be parametric, the interaction must not excite permanently the atoms: A zero energy balance for the atoms requires an interaction of atoms with at least two beams.
The hottest beams lose energy, their frequencies decrease.

* Rev. Mod. Phys. 43, 99 (1971)

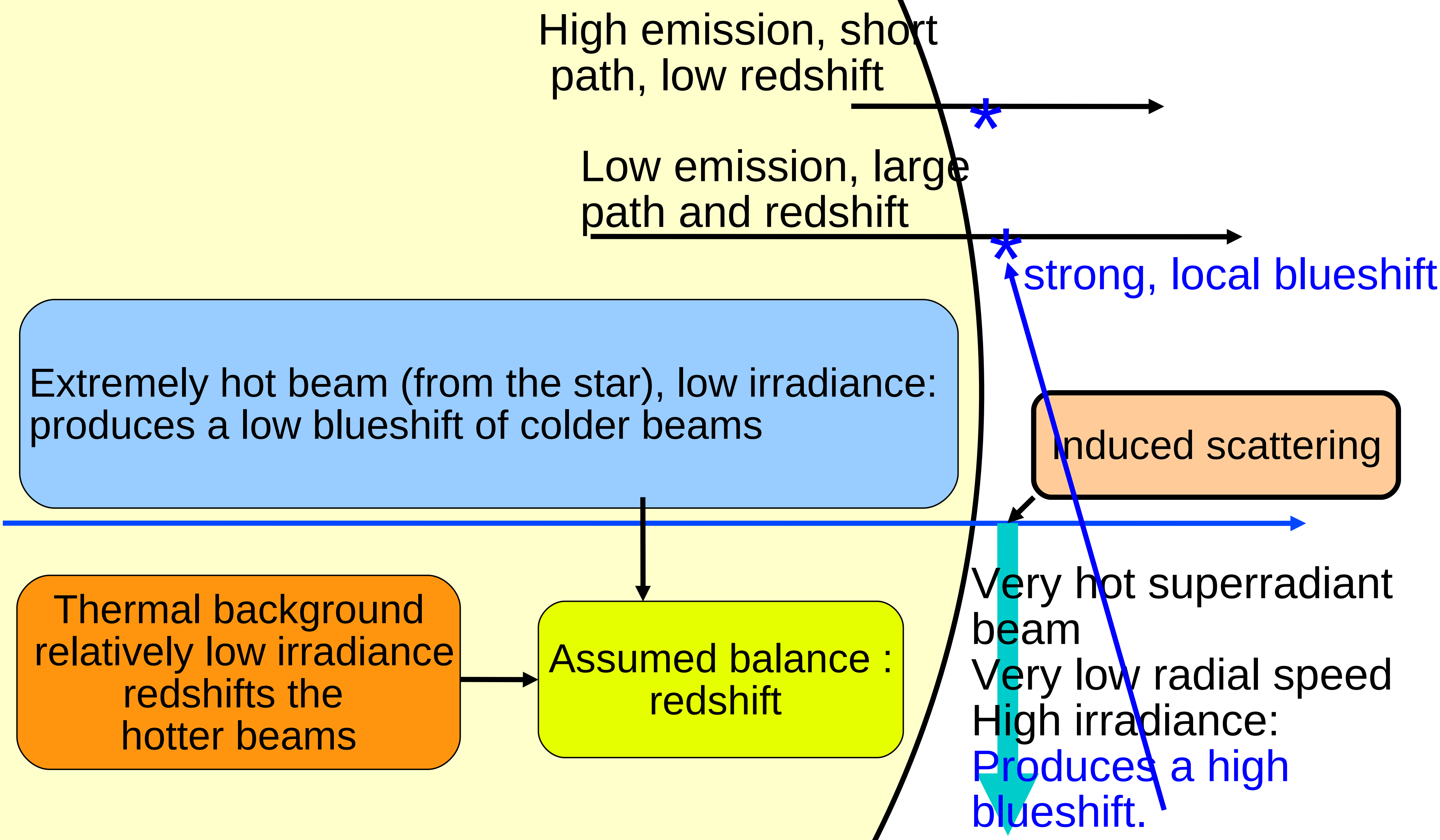
Coherent Raman Effect on Incoherent Light



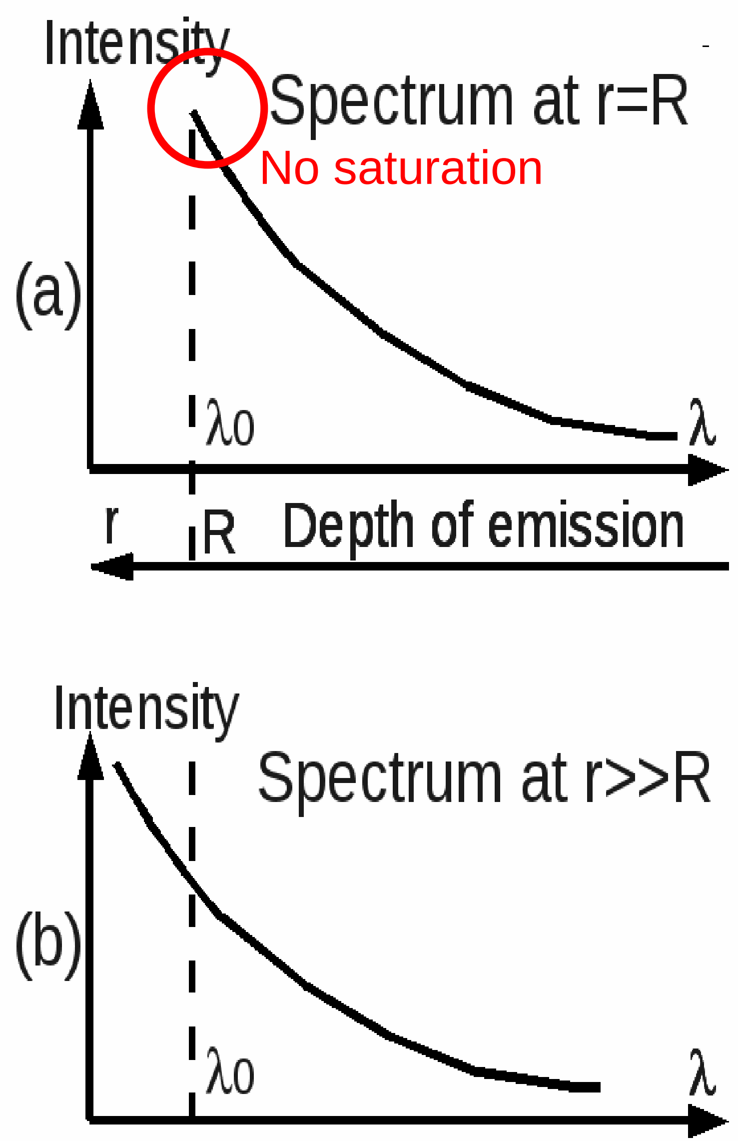
No blur of the images (the space-coherence preserves the wave surfaces)

Nearly constant relative frequency shift $\Delta\nu/\nu$

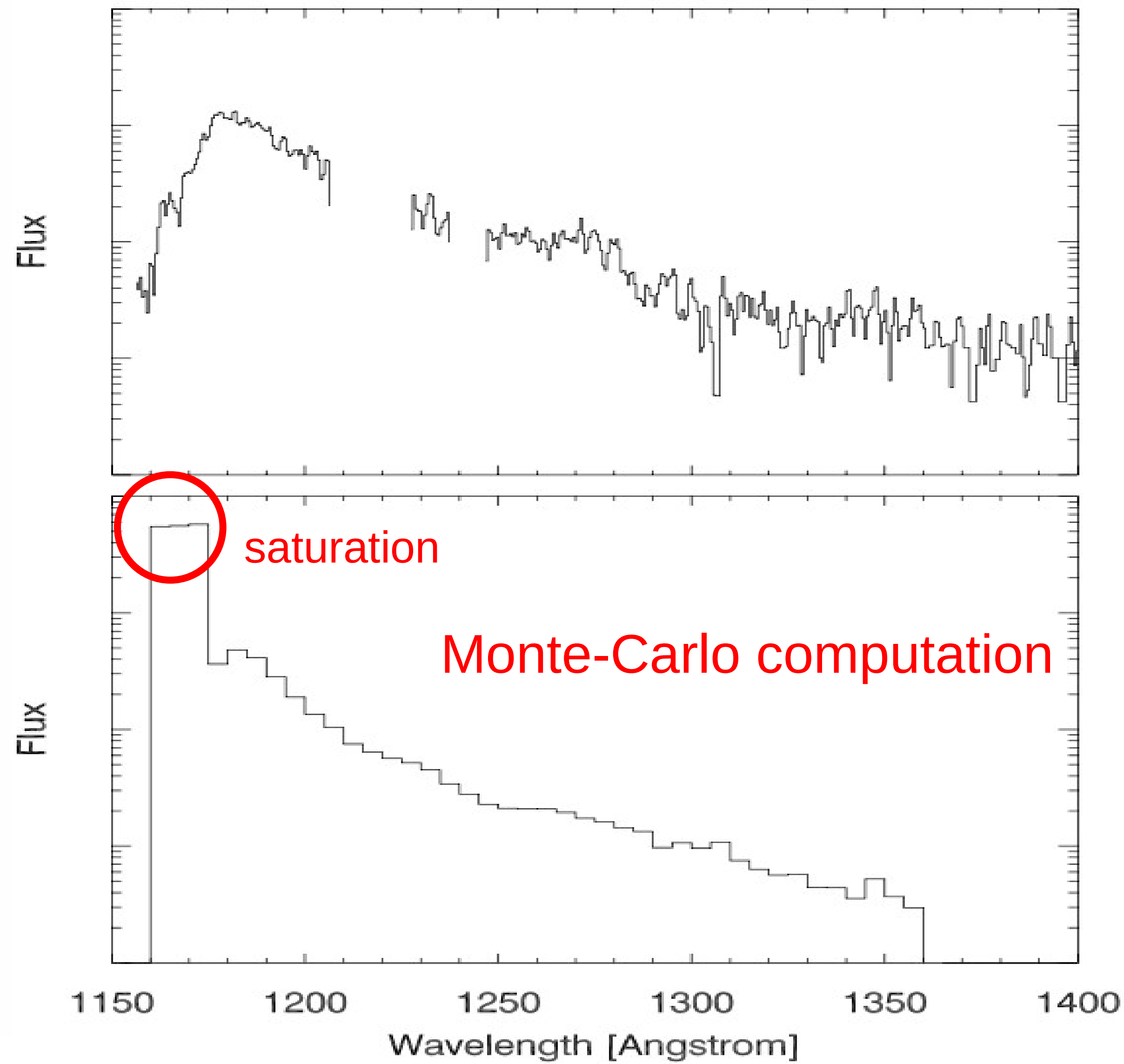
Light spontaneously emitted inside the sphere



Spontaneous spectra inside the ring.

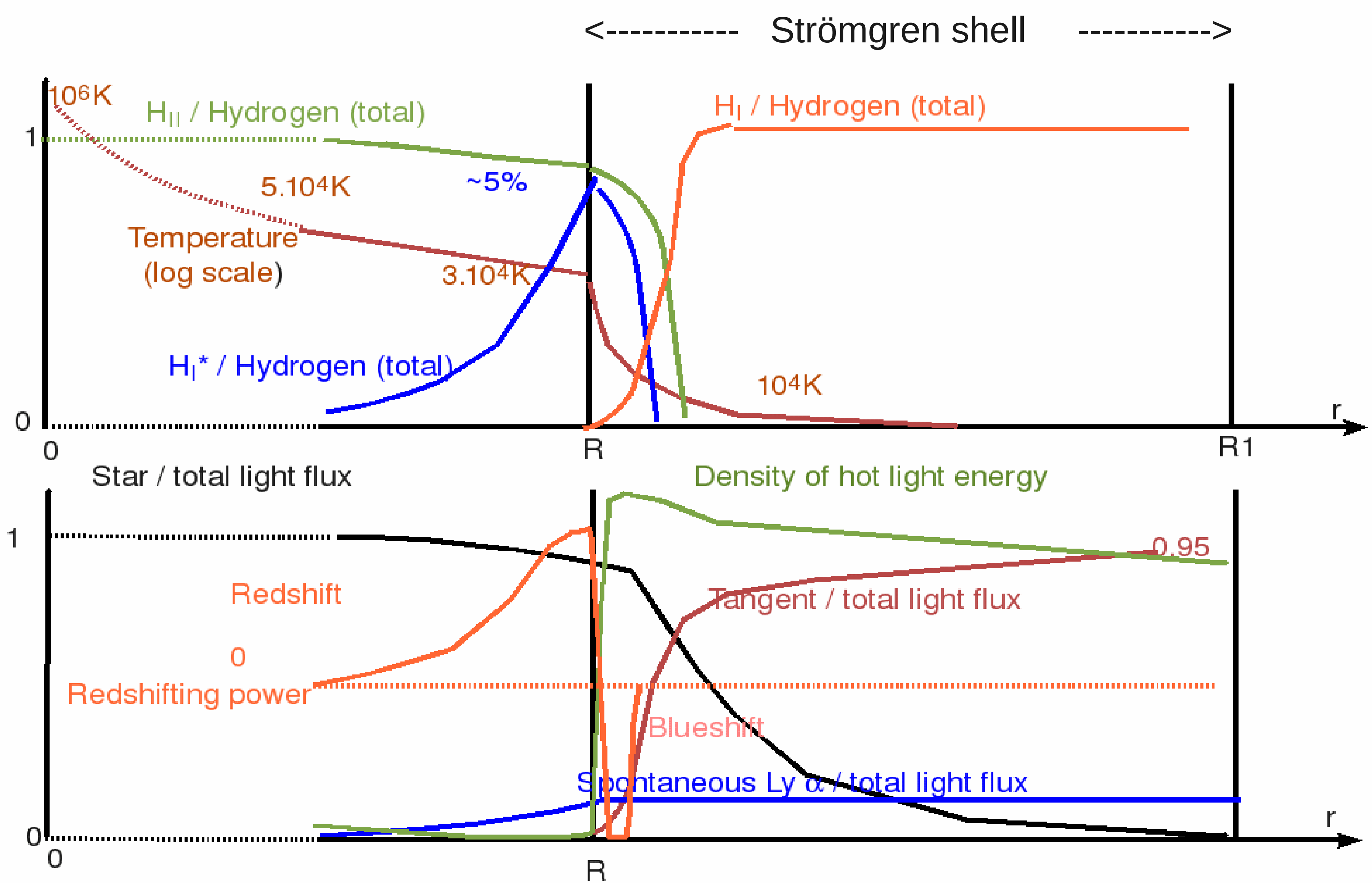


Present interpretation.



Spectrum and interpretation of Michael et al. Astrophys. J., **593**, 809 (2003).

Radial variations of hydrogen state, and light



Other applications

Circles and dotted circles whose origin is explained by an alignment of heavy objects may be created by Strömgren systems (Einstein cross for instance).

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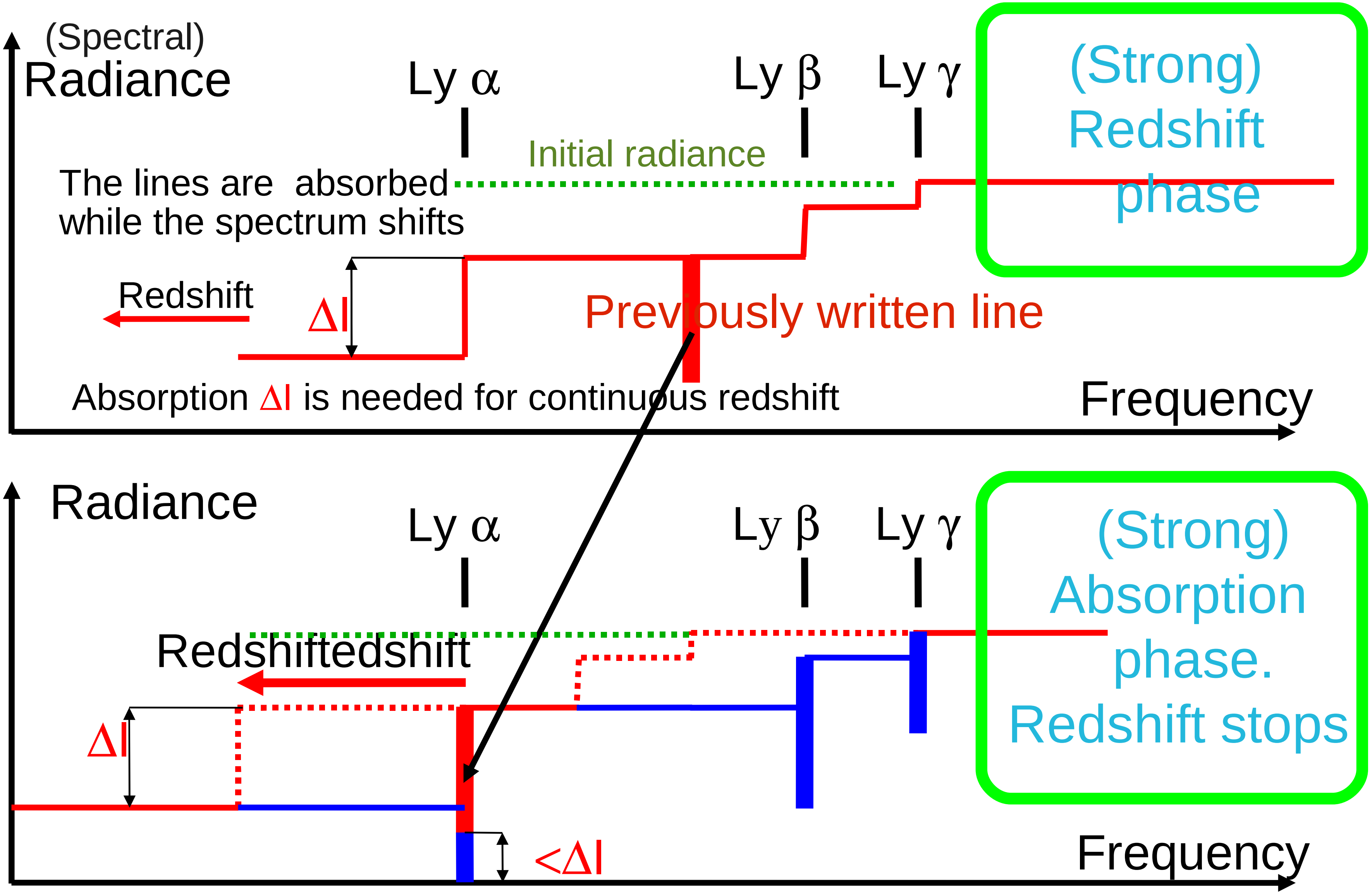
May be an explanation of Hubble's law: Assume a constant density of H*.

The holes in the maps of galaxies can correspond to small clouds of excited atomic hydrogen: Our maps may be popped!

More precise (quantitative) --->

Absorption of a Lyman forest.

Lyman alpha absorption creates 2P hydrogen atoms in 20 000K gas.
These atoms redshift light.



Redshift from the Ly β or γ to the Ly α:

$$Z = \frac{(\nu_\beta - \nu_\alpha)}{\nu_\alpha} = 0.062 * 3$$

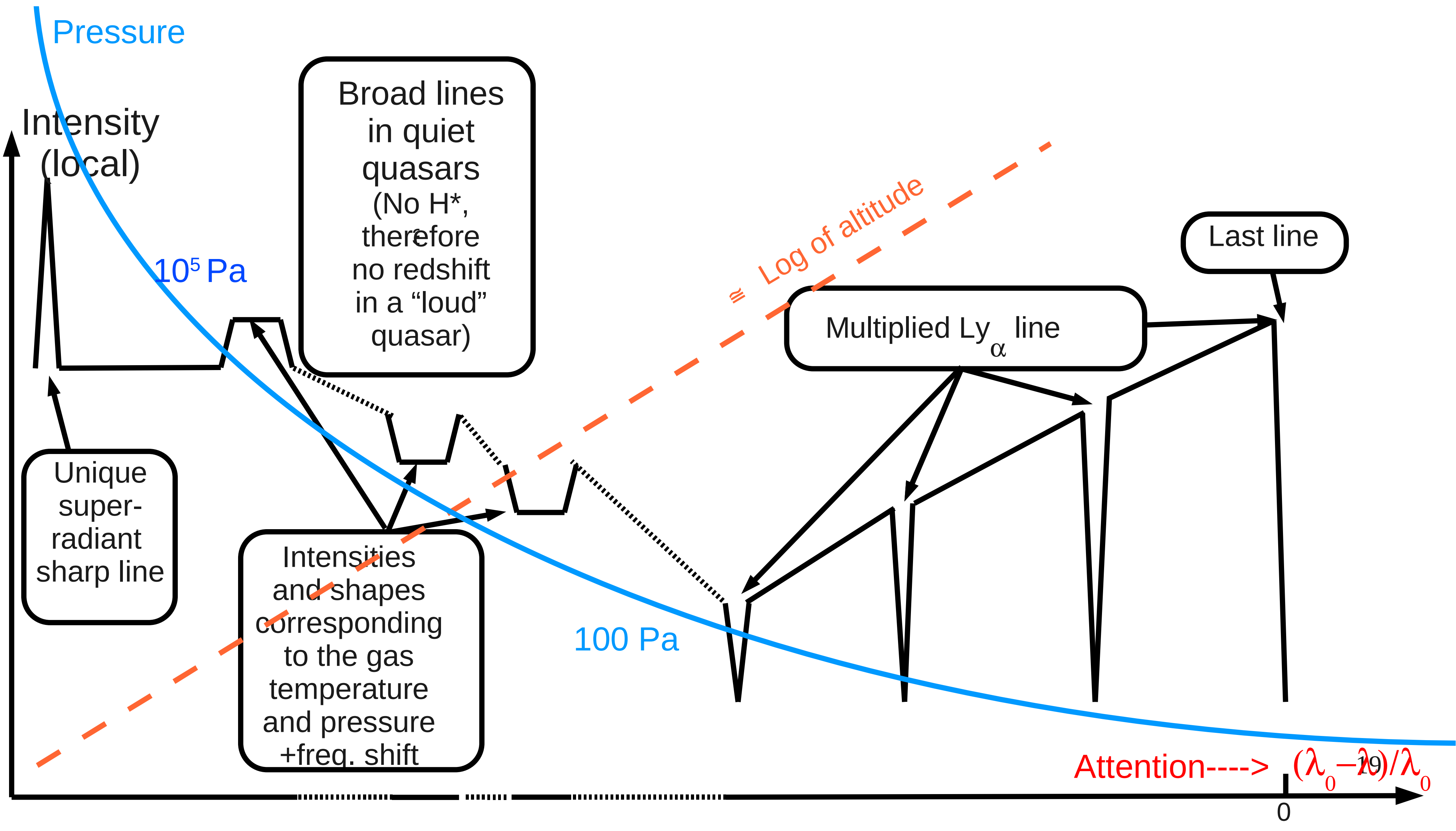
$$Z = \frac{(\nu_\gamma - \nu_\alpha)}{\nu_\alpha} = 0.062 * 4$$

↓

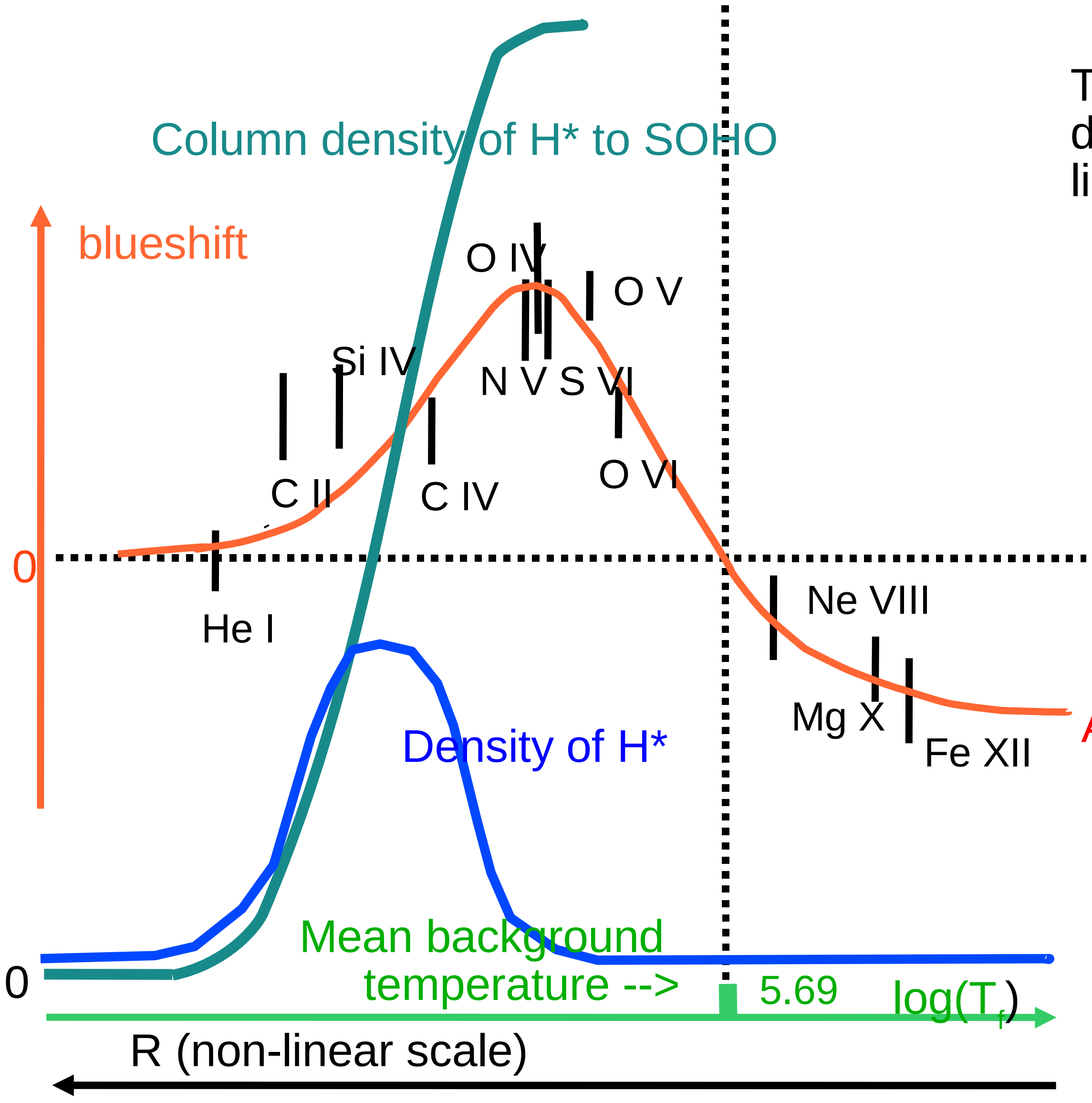
Fundamental parameter

observed in quasars and galaxies (Karlsson).

Redshifts and widths of quasar lines



Frequency shifts of UV-X line emissions of the Sun



The atoms cannot move in high density hydrogen, so that the lines are sharp and CREIL works.

From Peter & Judge
ApJ, 522, 1148 (1999)

Anomalous “accelerations” of Pioneer 10 and 11

Beyond 5 AU, the solar wind cools, excited hydrogen atoms appear.

The CREIL transfers energy from sunlight to radiowaves whose frequencies are increased.

Conclusion

Coherent spectroscopy works in astrophysics and is a powerful tool !

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