Absorption of Gravitons by Hydrogen Atoms

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1. *Interaction of Gravitons with Hydrogen atoms*

2. *Graviton emission and absorption rates by Hydrogen*

3. *Selection rules for photons and gravitons*

4. *Thermal graviton radiation by Sun and stars*

5. *Ratio of photon luminosities*

G. Savvidy and P. Savvidis arXiv:2605.11278

Savvidy, G.: Schwinger's non-commutative coordinates for photons and gravitons. Duality between helicity and Dirac quantization conditions. J. Math. Phys. **66**(8),

Why Hydrogen Atoms ?

A typical galaxy contains a vast amount of hydrogen, which is the most abundant element.

Hydrogen in galaxies exists as a neutral atomic hydrogen HI, cold molecular hydrogen H_2 in dense clouds and as a highly ionised HII hydrogen near hot stars.

The neutral atomic hydrogen HI presents a significant amount of the cold diffused medium that is filling much of the galaxies. The interstellar medium (ISM) makes up roughly 5% galaxy's total mass, and about 70% of that gas is hydrogen, and most of the hydrogen atoms are in the ground state

and Hydrogen is exactly integrable quantum mechanical system

Detecting Gravitons is a great challenge !

$$\frac{L_g^{\odot}}{L_\gamma^{\odot}} = \frac{1.3 \times 10^{15}\,\frac{erg}{sec}}{3.8 \times 10^{33}\,\frac{erg}{sec}} \approx 10^{-19}$$

$$\frac{\mathcal{D}_g(1s \to 3d)}{\mathcal{D}_\gamma(1s \to 2p)} = \frac{1.6 \times 10^{-28}\,\frac{cm}{gram}}{1.27 \times 10^{20}\,\frac{cm}{gram}} \approx 10^{-43}$$

Interaction of Gravitons with Hydrogen atoms

Quadrupole gravitational radiation has the following form

$$\frac{d\bar{\mathcal{E}}}{dt} = \frac{G}{45c^5}\dddot{D}_{ij}\dddot{D}_{ij},$$

where the quadrupole momentum tensor is

$$D_{ij} = \int \rho(3x_i x_j - \delta_{ij}\vec{x}^2)dV$$

and ρ is the density of mass.

Interaction of Gravitons with Hydrogen atoms

Quadrupole transition rate $\mathcal{S}$ of an electron $m \to n$ is

$$(Transition\ Rate\ m \to n)_g = \frac{1}{\hbar\omega_{mn}} \frac{d\bar{\mathcal{E}}}{dt} = \frac{G}{45c^5\hbar\omega_{mn}}\ |\langle n|\dddot{D}_{ij}|m\rangle|^2,$$

the time dependence of the wave functions $e^{i\omega_{mn}t}$ for the $\mathcal{S}$ we will get

$$\mathcal{S}_g(m \to n) = \frac{2G\omega_{mn}^5}{45\hbar c^5}\ |\langle n|D_{ij}|m\rangle|^2,$$

where $\hbar\omega_{mn} = E^{(m)} - E^{(n)}$.

Matrix elements and selection rules

the corresponding matrix elements are defined as

$$\langle 3d_{l_z}|D_{ij}|1s\rangle = m\int R_{32}Y_{2,l_z}\ (3x_ix_i - \delta_{ij}r^2)R_{10}Y_{0,0}\ r^2dr\sin\theta d\theta d\phi = \mathcal{D}_{l_z}(ij),$$
$$l_z = 0, \pm 1, \pm 2 \qquad i,j = 1,2,3,$$

The matrix elements

$$\begin{aligned}\langle 1s|D_{ij}|1s\rangle &= 0,\\ \langle 2s|D_{ij}|1s\rangle &= 0\\ \langle 2p|D_{ij}|1s\rangle &= 0\end{aligned}$$

vanish, no radiation of gravitons from $n=1$ and $n=2$ states.

It is a consequence of the fact that a massless graviton has the helicity $h=2$

Spontaneous emission of Gravitons by Hydrogen atoms

the spontaneous transition rate $\mathcal{S}$:

Weinberg 1965

$$\mathcal{S}_g(3d \to 1s) = \frac{1}{36}\frac{Gm^2}{\hbar c}\left(\frac{e^2}{\hbar c}\right)^4\left(\frac{me^4}{2\hbar^3}\right).$$

The first term is the mass of the electron in units of the Planck mass $M_{Pl}^2 = c\hbar/G$,

the second term is the electromagnetic fine-structure constant $\alpha = e^2/\hbar c$,

and the last term is the Rydberg constant divided by Planck constant.

It is a beautiful unification of gravity, electrodynamics and quantum mechanics in one expression.

The numerical value of the spontaneous radiation rate of a graviton by a hydrogen atom is

$$\mathcal{S}_g(3d \to 1s) \approx 2.85 \times 10^{-39}\frac{1}{sec}.$$

Gravitons vs Photons

the life time of the $3d$ state due to the graviton radiation will be

$$\tau = \frac{1}{\mathcal{S}_g(3d \to 1s)} \approx \underline{3.51 \times 10^{38} sec.}$$

The spontaneous transition rate for the photon is

$$\mathcal{S}_\gamma(2p \to 1s) = \frac{2^9}{3^7}\left(\frac{e^2}{\hbar c}\right)^3 \left(\frac{me^4}{2\hbar^3}\right)$$

and the life time of the $2p$ state due to the photon radiation is

$$\tau = \frac{1}{\mathcal{S}_\gamma(2p \to 1s)} \approx \underline{5.3 \times 10^{-10} sec.}$$

Stimulated Absorption and Emission of Gravitons

The stimulated absorption of gravitons is

$$(Absorption\ rate\ of\ n \rightarrow m)_g = \mathcal{D}_g\ U_g(\omega)N(n),$$

where $\mathcal{D}_g$ is transition rate, $U_g(\omega)d\omega$ is the energy density of gravitational radiation and $N(n)$ is the number of atoms in the state n.

The radiation probability is a sum of spontaneous transitions $\mathcal{S}_g$ and stimulated emission of gravitons $\mathcal{I}$:

$$(Total\ radiation\ rate\ of\ m \rightarrow n)_g = \mathcal{S} + \mathcal{I}\ U_g(\omega)N(m).$$

The equation of the detailed balance at the equilibrium is

$$\mathcal{D}_g\ U_g(\omega)N(n) = \mathcal{S} + \mathcal{I}_g\ U_g(\omega)N(m).$$

Stimulated Absorption and Emission of Gravitons

it follows that the expression for absorption $\mathcal{D}_g$ and stimulated emission $\mathcal{I}_g$ rates in terms of the known spontaneous transition rate is:

$$\mathcal{D}_g = \frac{\pi^2 c^3}{\hbar\omega^3}\mathcal{S}_g, \qquad \mathcal{I}_g = \mathcal{D}_g.$$

thus and the expression for the absorption rate of gravitons

$$\mathcal{D}_g = \frac{2\pi^2}{45}\frac{G\omega_{mn}^2}{\hbar^2 c^2}\ |\langle n|D_{ij}|m\rangle|^2.$$

Absorption of Gravitons by Hydrogen atoms

we obtain the absorption rate of gravitons:

$$\mathcal{D}_g(1s \to 3d) = \frac{81}{512}\frac{G\pi^2}{c^2}.$$

and it is

$$\underline{\mathcal{D}_g(1s \to 3d) \approx 1.16 \times 10^{-28}} \ \frac{cm}{gram}$$

The absorption rate of photons is

$$\mathcal{D}_\gamma(1s \to 2p) = \frac{2^{17}}{3^{10}}\left(\frac{e^2}{\hbar c}\right)^{-1}\left(\frac{\pi^2\hbar}{m^2 c}\right),$$

and has the following value:

$$\underline{\mathcal{D}_\gamma(1s \to 2p) \approx 1.27 \times 10^{20}} \frac{cm}{gram},$$

Absorptions Ratio

$$\frac{\mathcal{D}_g(1s \to 3d)}{\mathcal{D}_\gamma(1s \to 2p)} = \frac{1.6 \times 10^{-28}\,\frac{cm}{gram}}{1.27 \times 10^{20}\,\frac{cm}{gram}} \approx 10^{-43}$$

Stimulated Absorption of Gravitons

The absorption rate of gravitons can be amplified

it is proportional to the number of hydrogen atoms N_{1s}

and to the spectral energy density $U_g(\omega)$ of the gravitational radiation:

$$(Rate\ 1s \to 3d)_g = \frac{81}{512}\frac{G\pi^2}{c^2}\ N_{1s}\ U_g(\omega_{31}).$$

Absorption of Gravitons by Hydrogen atoms

$$(Rate\ 1s \to 3d)_g = \frac{81}{512}\frac{G\pi^2}{c^2}\ N_{1s}\ U_g(\omega_{31}).$$

The number of hydrogen atoms N_{1s} in the $|1s\rangle$ state in a container of 10^6 grams of the hydrogen gas would contain $N_{1s} = 10^6 N_A$ atoms,

where the Avogadro number is $N_A = 6.0221 \times 10^{23}$,

and with a nonzero energy density of gravitons $U(\omega_{31})d\omega$ the absorption rate would be

$$(Rate\ 1s \to 3d)_g = \left(\frac{U_g(\omega_{31})}{gram/cm\ sec}\right)\left(\frac{mass\ of\ HI}{10^6\ gram}\right) \times 69.8 sec^{-1}.$$

How much is the value of $U_g(\omega_{31})$ in the Universe ?

How much is the number of neutral hydrogen HI in the Universe ?

Thermal graviton radiation by Sun and stars

Weinberg estimated the power of the thermal gravitational radiation generated by the Sun (or a typical star) through the scattering of electrons and protons $e^- \leftrightarrow e^-$ and $e^- \leftrightarrow p^+$ in a completely ionised hydrogen plasma at the core of the Sun.

$$U_g \approx \frac{dW_g}{\omega_c d\omega} = \frac{64 G m^2}{5c} \left(\frac{kT}{m_e c^2}\right)^2 n_e \left(\frac{\pi}{2}\right)^{1/2} \log(1/\theta_0)^{1+\sqrt{2}}.$$

$$\omega_c = 10^{15}\ \sec^{-1} < \omega_g < \omega_T = 10^{18}\ \sec^{-1},$$
$$1.88\ nm < \lambda_g < 1884\ nm.$$

$$L_g \approx 8 \times 10^{14} erg/sec,$$

Weinberg 1965

$$L_g \approx 1.3 \times 10^{15} erg/sec.$$

García-Cely, C., Ringwald, A.: Complete Gravitational-Wave Spectrum of the Sun. Phys. Rev. Lett. **135**(6), 061001 (2025) https://doi.org/10.1103/gtwg-pr41 arXiv:2407.18297 [hep-ph]

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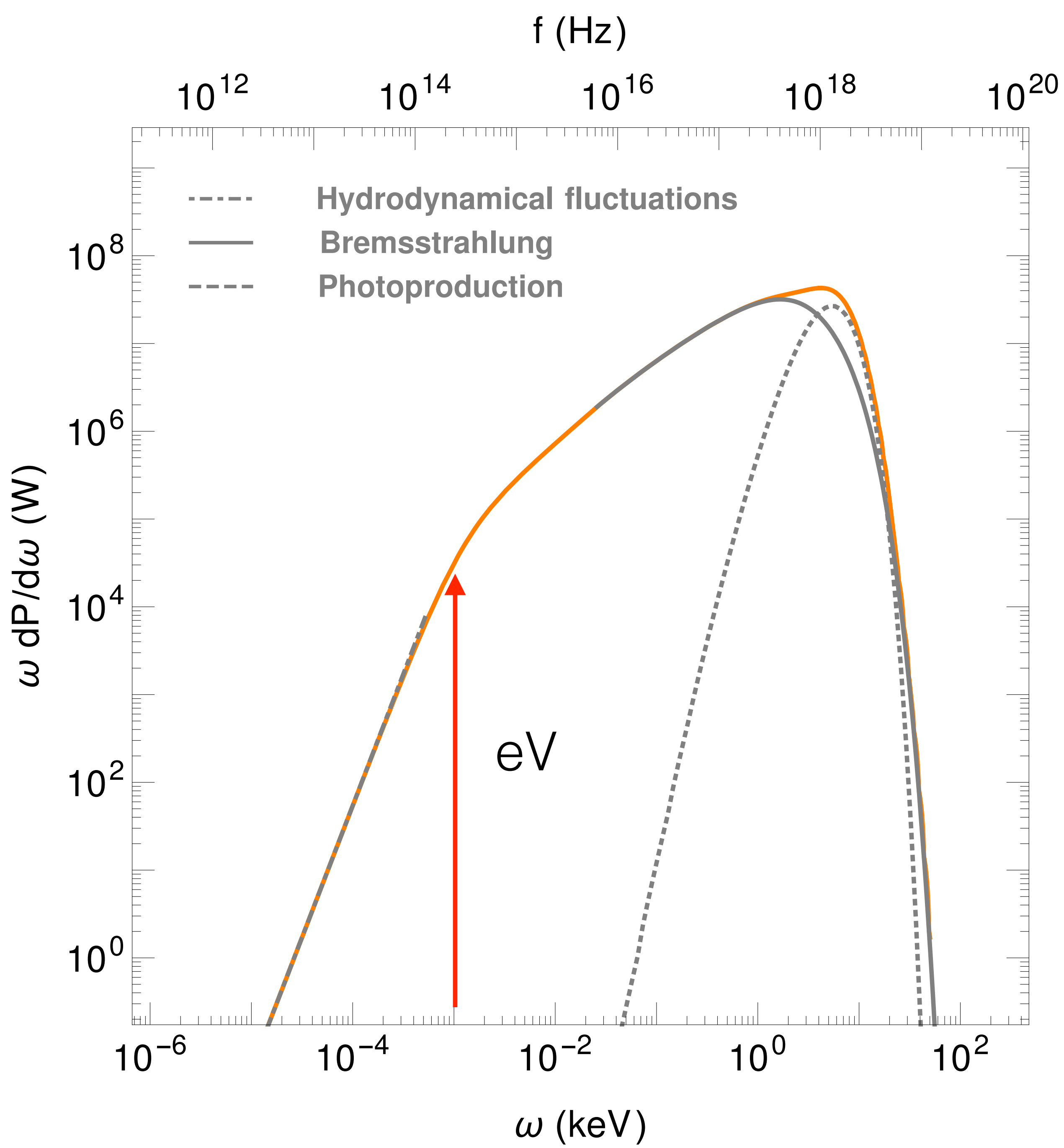


FIG. 1. GW power per unit logarithmic frequency, originating from the solar thermal plasma as a function of the frequency, $\omega = 2\pi f$.

Absorption of Gravitons on Earth

F.Dyson 2013

$$U = \frac{w_g}{\triangle\omega_{HI}} \approx 8.33 \times 10^{-40} \frac{g}{cm\ \ sec},$$

$$(Rate\ 1s \to 3d)_g = \Big(\frac{mass\ of\ \ HI}{10^6 gram}\Big) \times 5.82 \times 10^{-38} sec^{-1}.$$

It is a slow absorption rate, and the hydrogen detector that has the mass of the Earth would provide the counting rate of 3.5×10^{-16} per second, that is, dozens of gravitons per billions of years

Neutral hydrogen HI in Intergalactic space

The problem of measuring the graviton radiation was discussed in the literature by Dyson and other authors. These investigations are mostly concerned with a construction of sensitive ground-based detectors that would be able to capture gravitational waves and gravitons from the in-falling gravitational waves.

A typical galaxy contains a vast amount of hydrogen, which is the most abundant element. Hydrogen in galaxies exists as a neutral atomic hydrogen HI, cold molecular hydrogen H_2 in dense clouds and as a highly ionised HII hydrogen near hot stars.

Instead, we suggest measuring the the ratios $\mathcal{R}_\gamma$ of the photon luminosities from the vast amount of hydrogen atoms scattered in the interstellar and intergalactic space.

the ratio of the Ly_α, Ly_β and H_α luminosities

$$\mathcal{R}_\gamma = \frac{L^\gamma_{32} + L^\gamma_{21}}{L^\gamma_{31}}.$$

Absorption of Gravitons by Hydrogen atoms

How much is the value of $U_g(\omega_{31})$ in the Universe ?

How much is the number of neutral hydrogen HI in the Universe ?

Currently, the *observational* knowledge of the background energy density of gravitons in different regions of the Universe is limited, and here we will consider its value as an unknown quantity that should be determined by independent astrophysical observations.

Stochastic gravitational wave background detection using NANOGrav 15-year data set in the context of massive gravity.

Choi, C., Magallanes, J., Gurgenidze, M., Kahniashvili, T.: Stochastic gravitational wave background detection using NANOGrav 15-year data set in the context of massive gravity. PRD **110**(6), 063525 (2024) https://doi.org/10.1103/PhysRevD.110.063525 arXiv:2312.03932 [astro-ph.CO]

Stochastic gravitational wave backgrounds

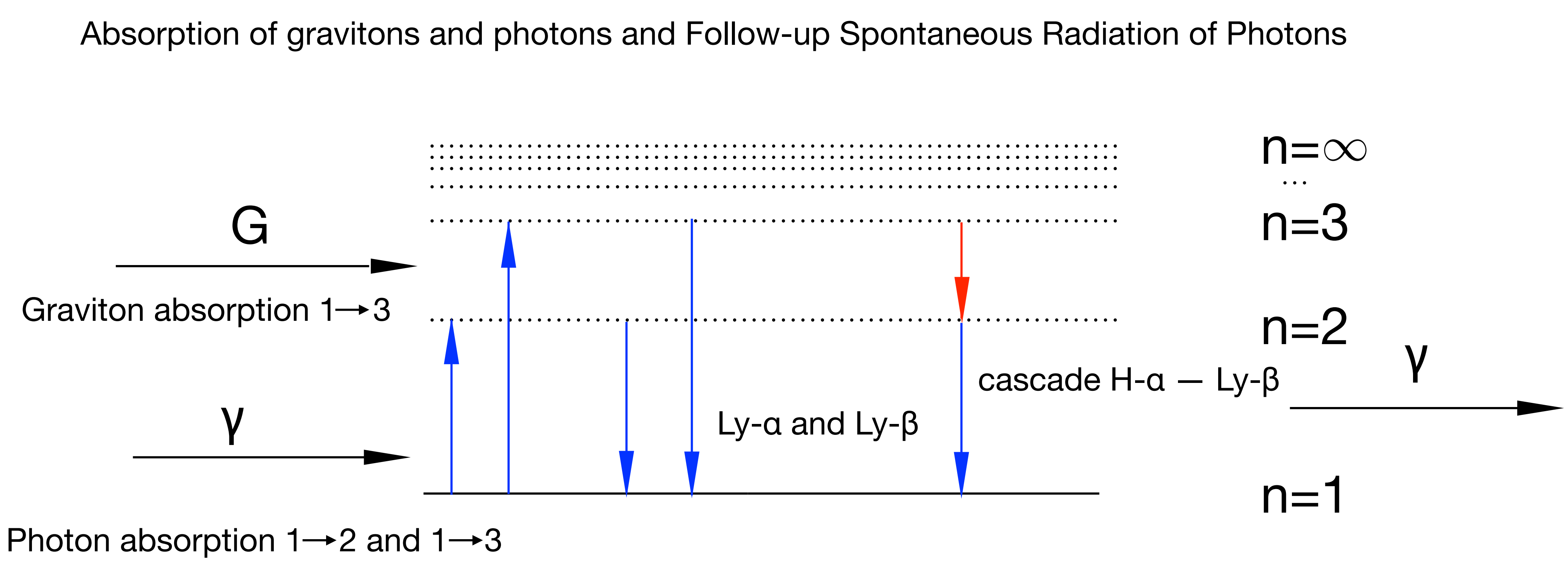
Christensen, N.: Stochastic gravitational wave backgrounds. Reports on Progress in Physics **82**(1), 016903 (2018) https://doi.org/10.1088/1361-6633/aae6b5

Gravitational Waves as a Big Bang Thermometer

Andreas Ringwald[1], Jan Schu¨tte-Engel[2,3,4] and Carlos Tamarit[5]

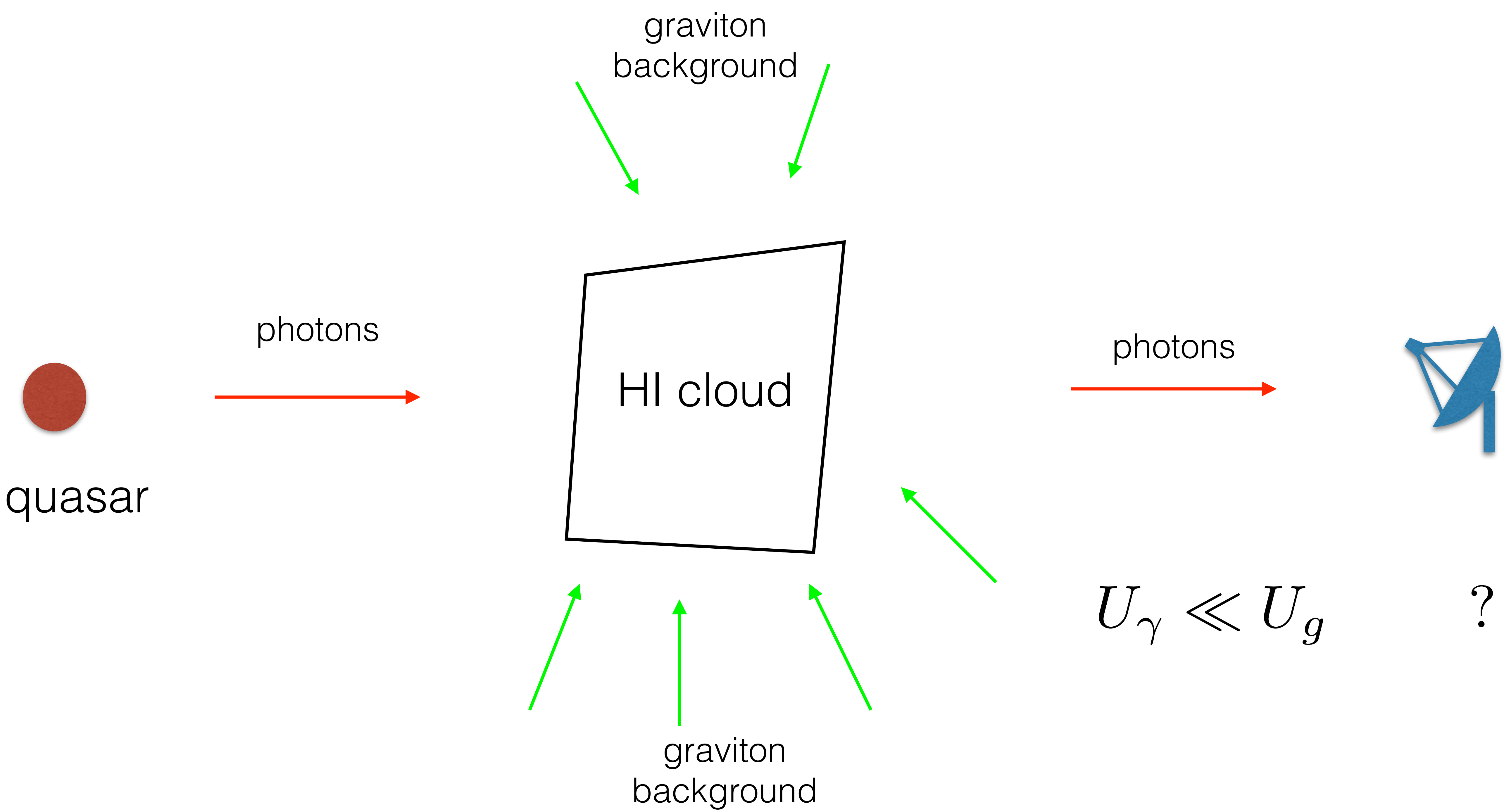
state- of-the-art prediction of Cosmic Gravitational Microwave Background

Selection rules for photons and gravitons



$$R_\gamma = \frac{\omega_{32} N_{3\gamma} \mathcal{S}_\gamma(3p \to 2s) + \omega_{21} N_{2\gamma} \mathcal{S}_\gamma(2p \to 1s)}{\omega_{31} N_{3\gamma} \mathcal{S}_\gamma(3p \to 1s)} = \frac{2^{13}}{5^8} + \frac{2^8}{3^4}\frac{N_{2\gamma}}{N_{3\gamma}}.$$

$$\delta R_g = \frac{\omega_{32} N_{3g} \mathcal{S}_\gamma(3d \to 2p) + \omega_{21} N_{2g} \mathcal{S}_\gamma(2p \to 1s)}{\omega_{31} N_{3\gamma} \mathcal{S}_\gamma(3p \to 1s)} = \frac{3\ 2^{16}}{5^9}\frac{N_{3g}}{N_{3\gamma}} + \frac{2^8}{3^4}\frac{N_{2g}}{N_{3\gamma}}.$$



The giant halos of pristine, primordial hydrogen gas that surrounded galaxies in the early universe at z = 5.5 - 13.4 were found by the James Webb Space Telescope.

Absorption of Gravitons by Hydrogen atoms

How much is the value of $U_g(\omega_{31})$ in the Universe ?

How much is the number of neutral hydrogen HI in the Universe ?

$$\Omega_{GW} \sim 10^{-9}, \qquad \rho_{GW} \sim 8.5 \times 10^{-39} \frac{gram}{cm^3}$$

$$\underline{U_g(\omega) = \frac{\rho_{GW} c^2}{\triangle\omega_{HI}} \sim 4.15 \times 10^{-34} \frac{gram}{cm\ sec}}$$

$$N_A = 6.0221 \times 10^{23}$$

$$M_{HI}(IGM) \sim 2 \times 10^{33} - 2 \times 10^{40} gram,$$

$$\underline{N_{1s} \sim 1.2 \times 10^{56} - 1.2 \times 10^{63}\ HI\ atoms}$$

$$(Rate\ 1s \to 3d)_g = \left(\frac{U_g(\omega_{31})}{gram/cm\ sec}\right)\left(\frac{mass\ of\ HI}{10^6\ gram}\right) \times 69.8 sec^{-1}.$$

$$\underline{(Rate\ 1s \to 3d)_g \sim 3.5 \times 10^{18} sec^{-1}\ -\ 3.5 \times 10^{31} sec^{-1}.}$$

Lorentz - Is hydrogen atom electromagnetically stable ?

dipole matrix elements $\langle 1s|d|1s\rangle = 0$ in 1s state vanish

Einstein - Is hydrogen atom gravitationally stable ?

quadrupole matrix elements $\langle 1s|D|1s\rangle = 0$ in 1s state vanish

Thank You !