Dicke's Superradiance in Astrophysics – Maser Flares and FRBs

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Abstract

We apply Dicke's theory of superradiance (1954) to explain maser flares in the interstellar medium for the 6.7-GHz methanol, 1612-MHz OH, and 22-GHz water spectral lines. We also extend our superradiance model to FRBs and our analyses suggest that FRBs could originate from regions in many ways similar to those known to harbor masers or megamasers. The evidence of superradiance in these sources suggests the existence of entangled quantum mechanical states, involving a very large number of molecules, over distances of up to a few kilometer for maser flares and 1000 AU for FRBs [1].

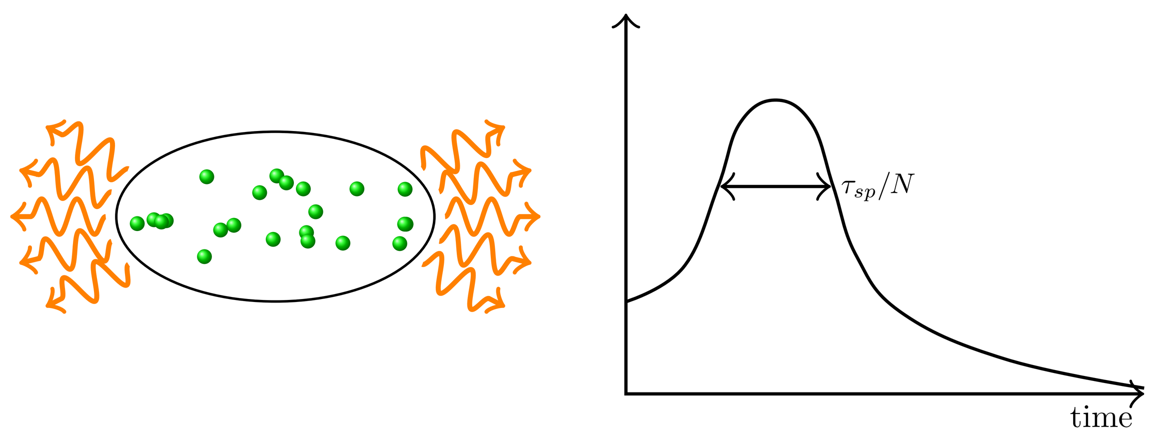
Superradiance (SR)

SR is a quantum mechanical and coherent behaviour between molecules (or atoms) leading to quantum entanglement. It is characterized by:

- Short decay timescales ($T_R \ll \tau_{sp}$, τ_{sp} the spontaneous emission time scale)

$$T_R = \tau_{sp}\frac{8\pi}{3nL\lambda^2}$$

  with (nL) : inverted column density
- Very directional radiation beam
- Burst-like phenomenon ($I_{SR} = N I_{nc} \propto N^2$ where N : number of inverted atoms, and I_{nc} : non-coherent intensity)

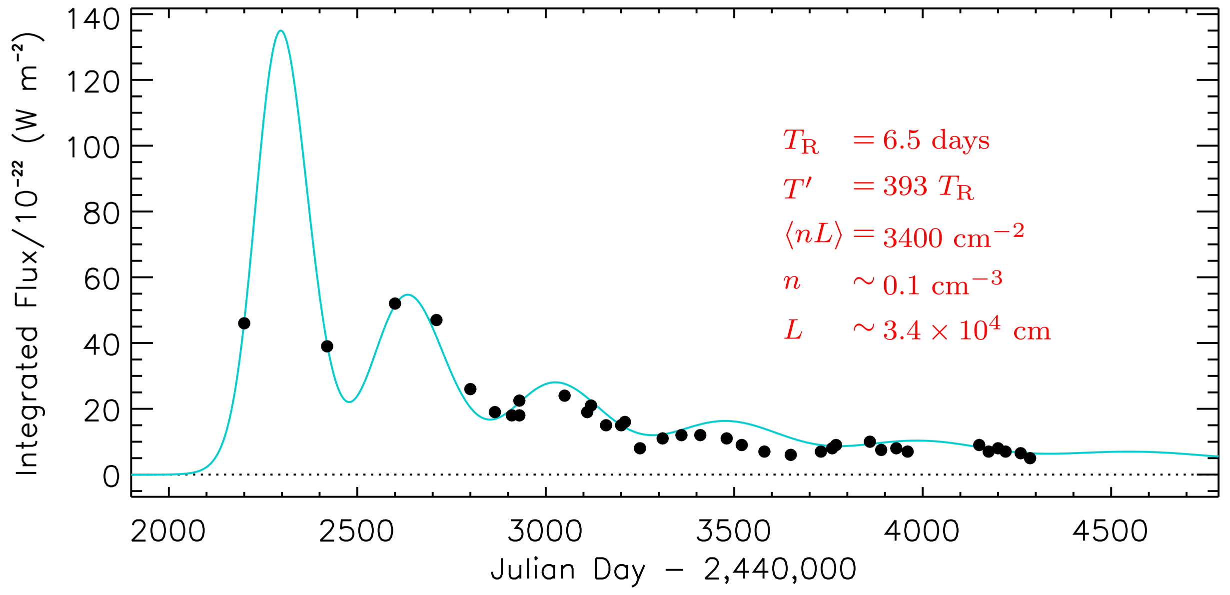


$\mathbf{I \propto N^2}$

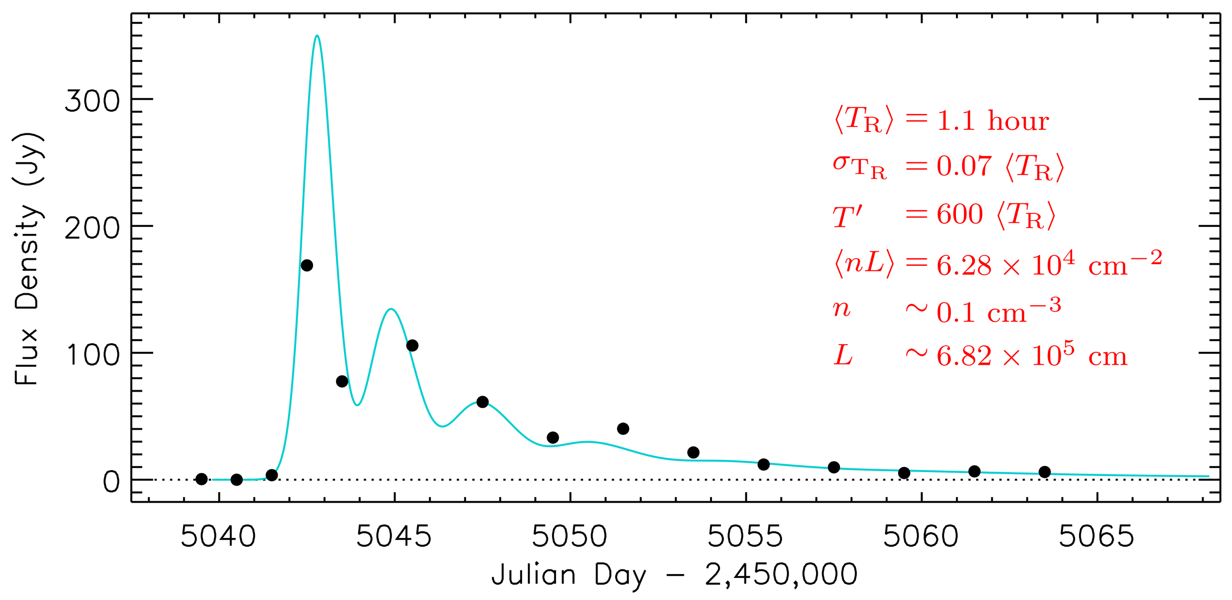
Requirements for SR:

- Population inversion
- Velocity coherence
- Dephasing effects (e.g., collisions) must occur on a time scale $T' \gg T_R$

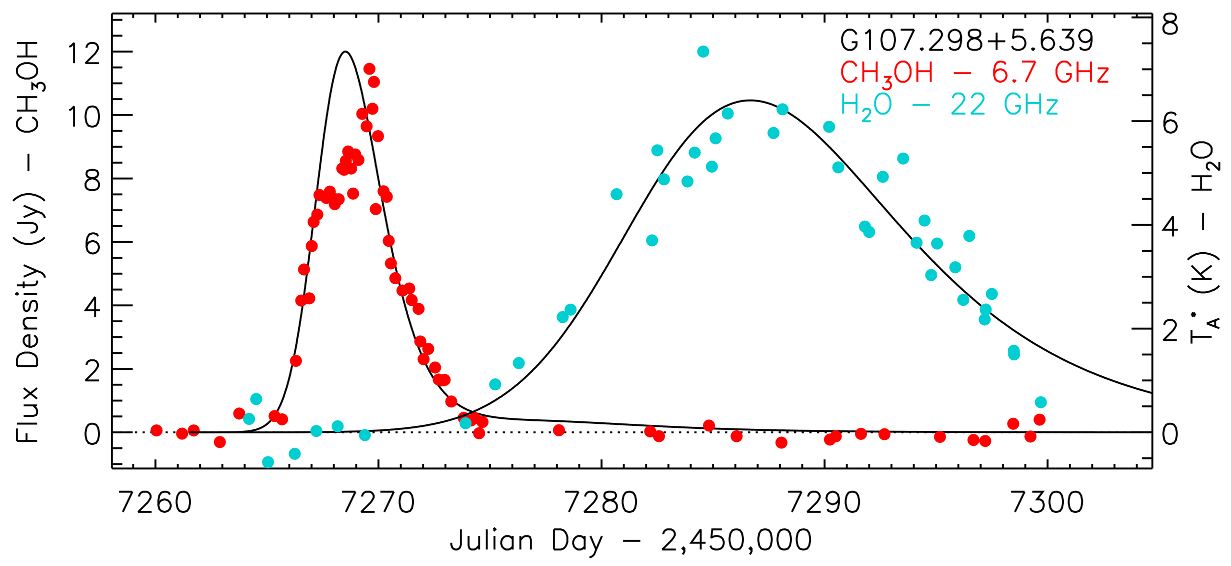
Superradiance in the ISM



OH 1612 MHz maser flaring episode of U Orionis (1974 to 1979)- A superradiance intensity model (solid blue curve) produced using 1000 samples is superposed on data (black dots). The SR model yields $\langle nL\rangle = 3400$ cm^{-2}, which for $n \sim 0.1$ cm^{-3} results in SR samples of $L \sim 3.4 \times 10^4$ cm [2].

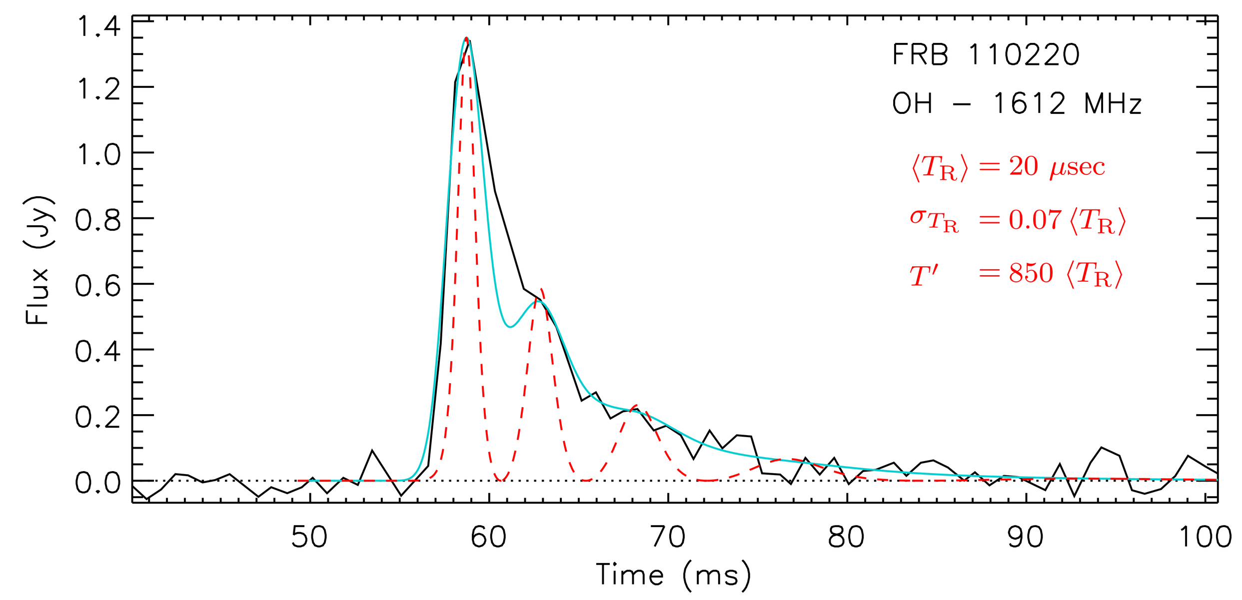


Methanol 6.7-GHz burst in G33.64-0.21-A superradiance intensity model averaged over 1000 samples (solid blue curve) superposed on data (black dots) obtained in July and August 2009. The SR model yields $\langle nL\rangle = 6.28 \times 10^4$ cm^{-2}, which for $n \sim 0.1$ cm^{-3} implies SR samples of $L \sim 6.28 \times 10^5$ cm [3].

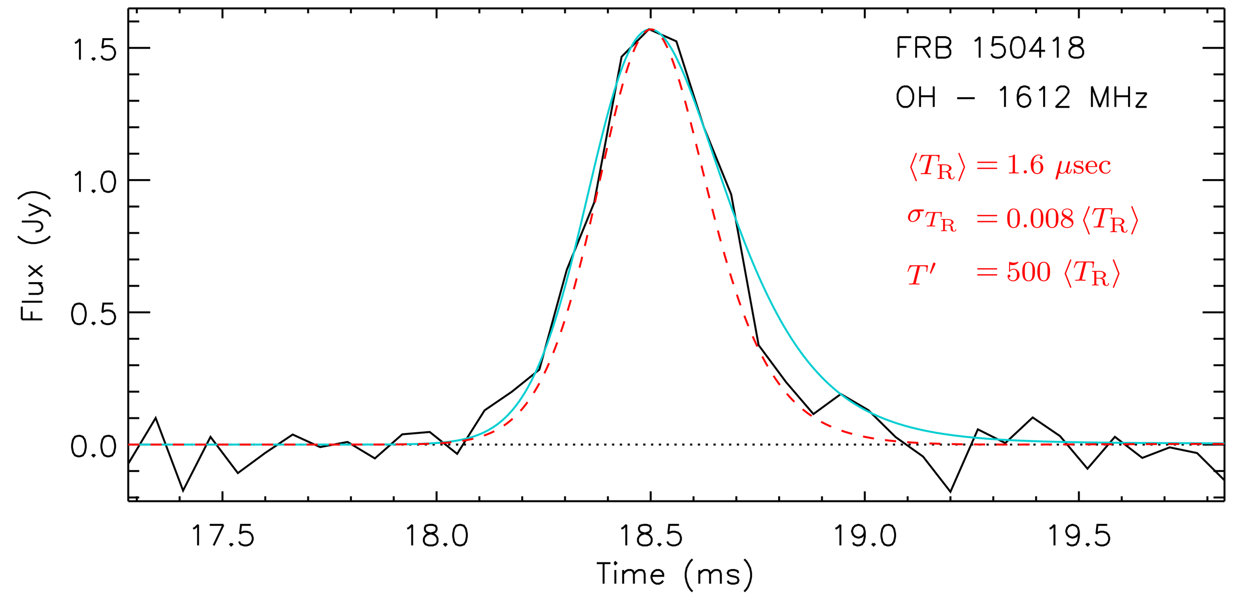


Methanol 6.7-GHz and water 22-GHz flaring event in G107.298+5.639 - The SR intensity (solid black) curve is produced using $\langle T_R\rangle_{CH_3OH} = 2.1$ hr, $\sigma_{T_R,CH_3OH} = 0.07\,\langle T_R\rangle_{CH_3OH}$ and $T'_{CH_3OH} = 90\,\langle T_R\rangle_{CH_3OH}$ for Methanol and $\langle T_R\rangle_{H_2O} = 7.7$ hr, $\sigma_{T_R,H_2O} = 0.04\,\langle T_R\rangle_{H_2O}$, $T'_{H_2O} = 70\,\langle T_R\rangle_{H_2O}$ for water. This yields Methanol and water SR samples of, respectively, $\langle nL\rangle_{CH_3OH} \sim 3.5 \times 10^4$cm^{-2} and $\langle nL\rangle_{H_2O} \sim 8.4 \times 10^4$cm^{-2} [3].

Superradiance and FRBs



SR model for FRB 110220. The black and cyan solid curves trace, respectively, the data and the resulting fits, while the broken red curve is for a single SR sample. The mean inverted column density resulting from the fit is $\langle nL\rangle = 9.5 \times 10^{13}$ cm^{-2}, which for $\langle n\rangle = 0.1$ cm^{-3} yields $\langle L\rangle = 9.5 \times 10^{14}$ cm [1].



SR model for FRB 150418. Same as for FRB 110220. The fit parameters give a mean inverted column density $\langle nL\rangle = 1.2 \times 10^{15}$ cm^{-2}, which for $\langle n\rangle = 0.1$ cm^{-3} yields $\langle L\rangle = 1.2 \times 10^{16}$ cm. The broken red curve is for a single SR sample [1].

Results

- Several realizations of cylindrical SR samples are combined to produce the final SR pulse, which were fitted to the maser flares data and dedispersed FRB data.
- Our analyses imply a typical SR sample size on the order of 100 AU to 1000 AU could be responsible for FRBs, which is a reasonable size for regions harboring inverted molecular populations.
- A staggeringly large number of SR samples could radiate simultaneously and easily match the detected flux associated with FRB signals or maser flares.
- SR systems are seemingly capable of reproducing the observed time scales, as well as intensity levels and profiles of some maser flares and FRBs through the emission of coherent radiation [1].
- The evidence of SR in the ISM suggests the existence of entangled quantum mechanical states, involving a very large number of molecules, over distances of up to a few kilometer for maser flares and 1000 AU for FRBs [1, 3].

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References

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