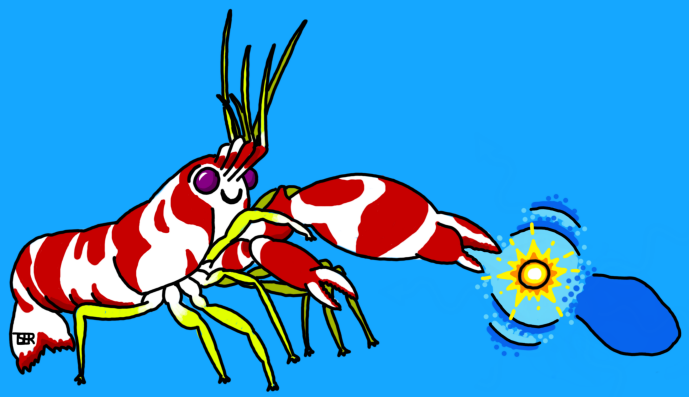
The Mechanism of Shrimpoluminescence

Tyler C. Sterling



Snapping shrimp

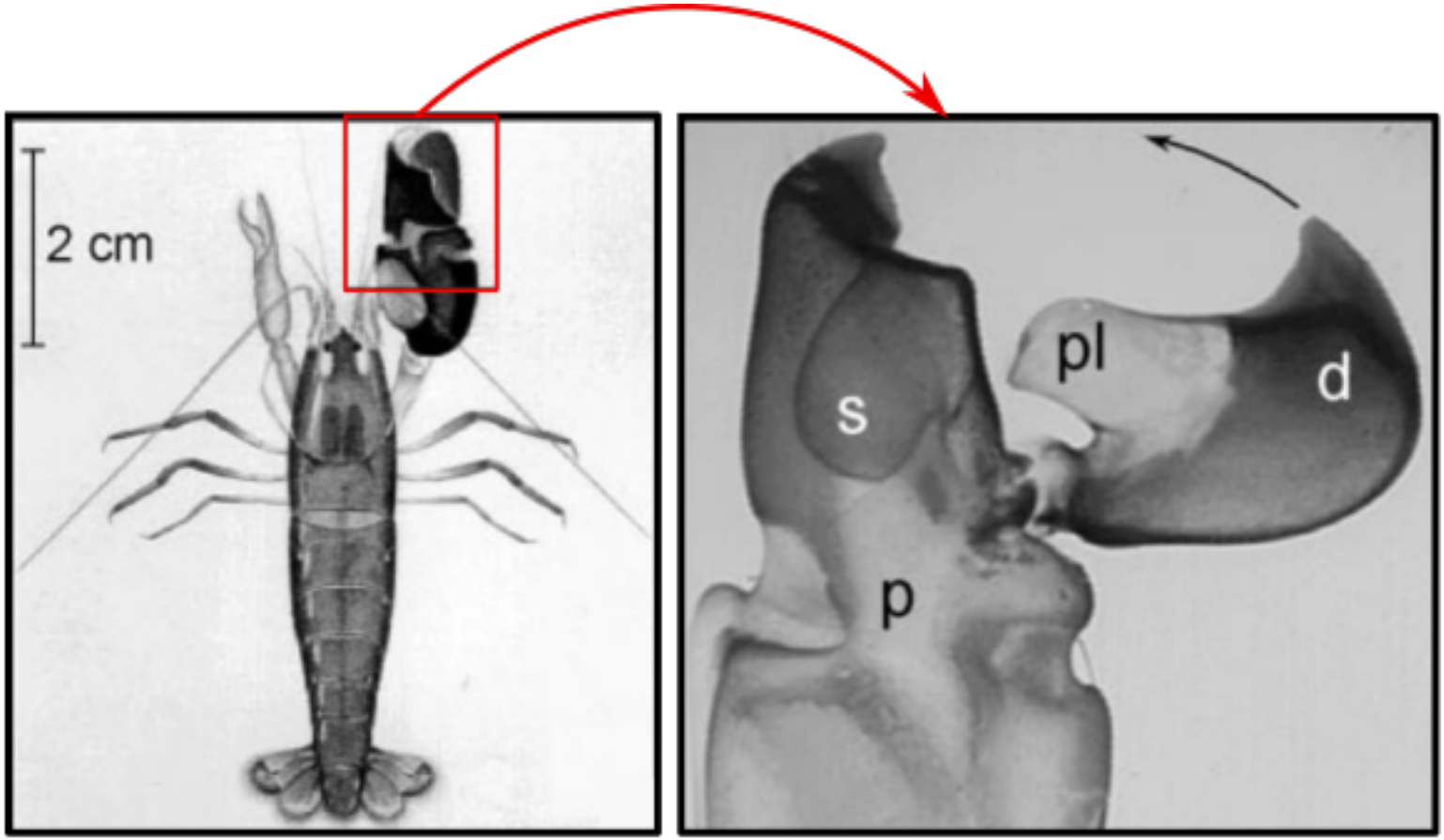


Figure: Adapted from Versluis et al. 2000

How do they snap?

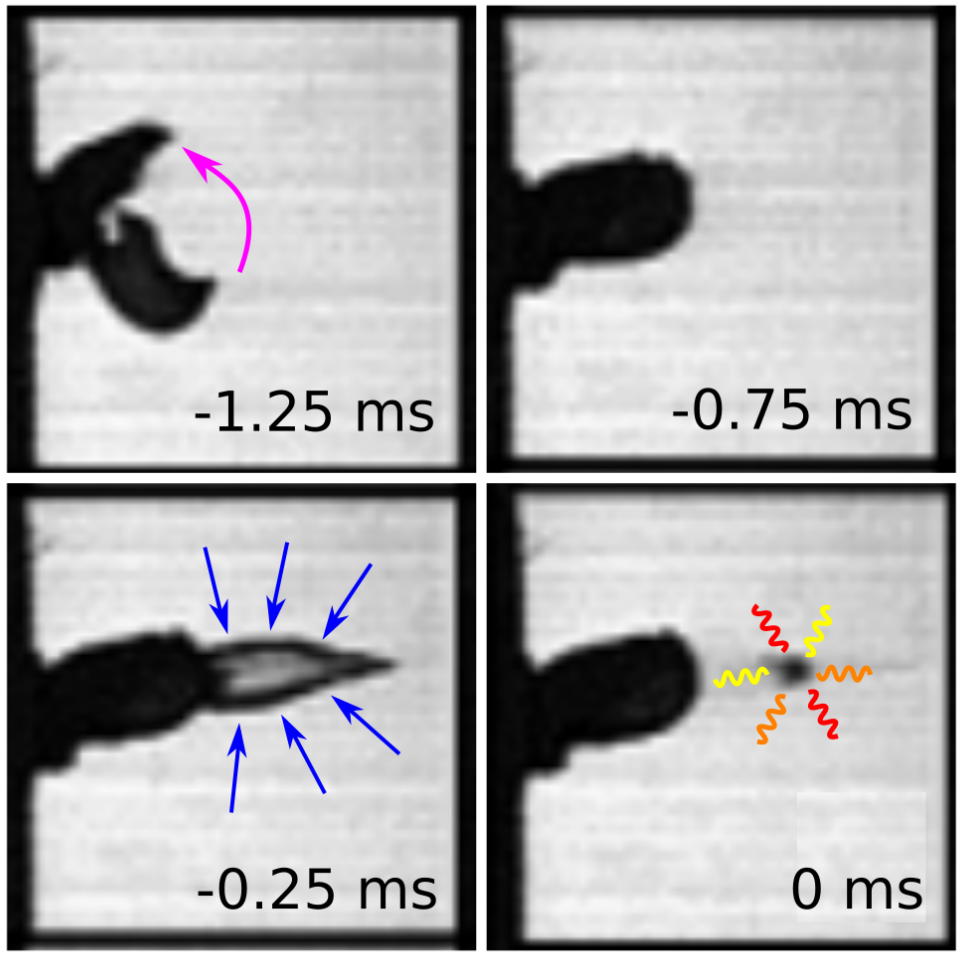


Figure: Adapted from Versluis et al. 2000

Sonoluminescence

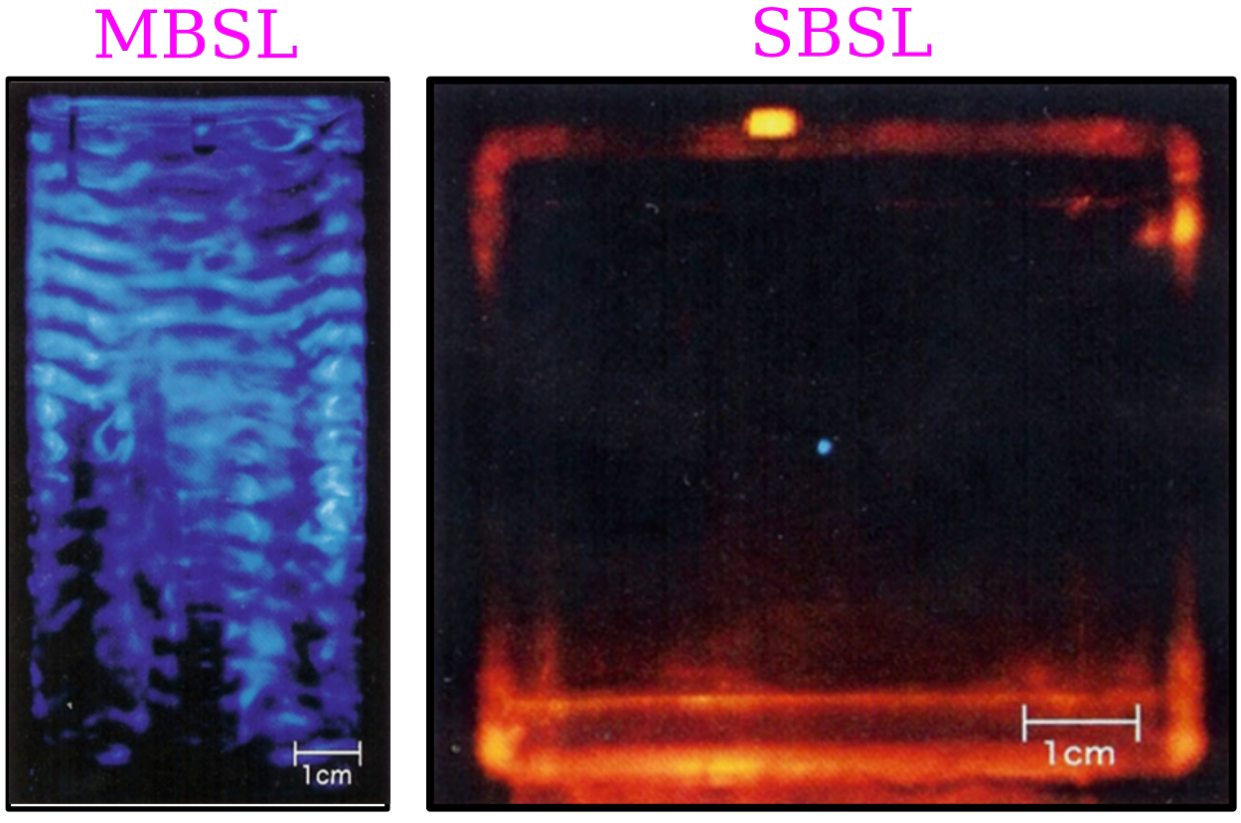


Figure: Adapted from Yasui 2018

Multi-bubble sonoluminescence (MBSL)

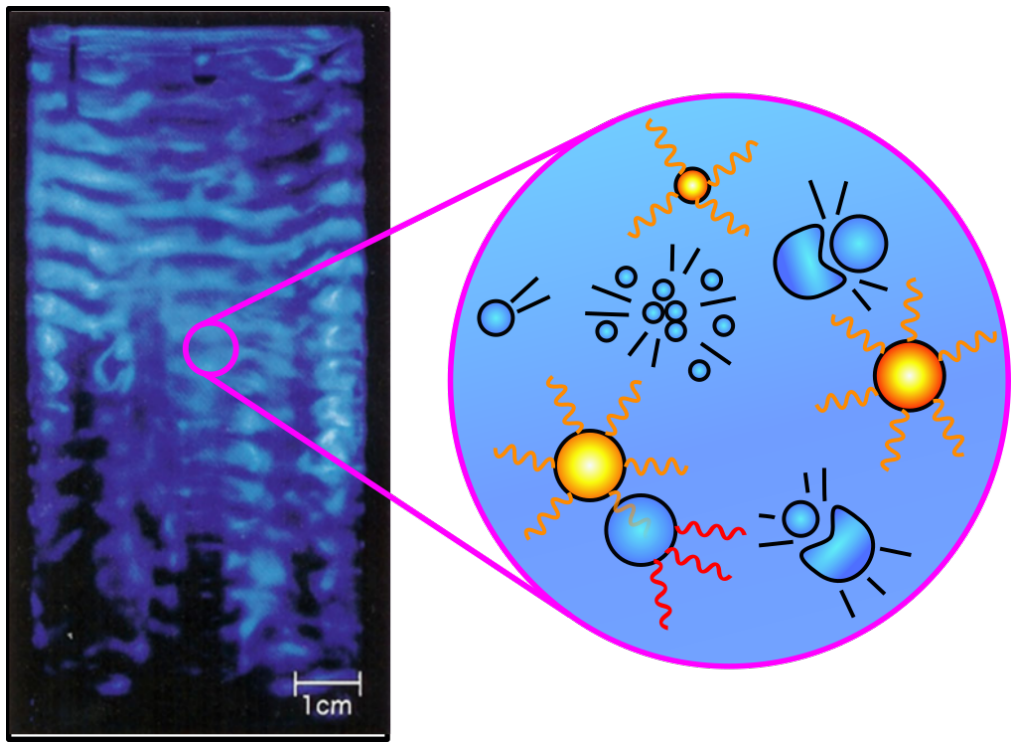
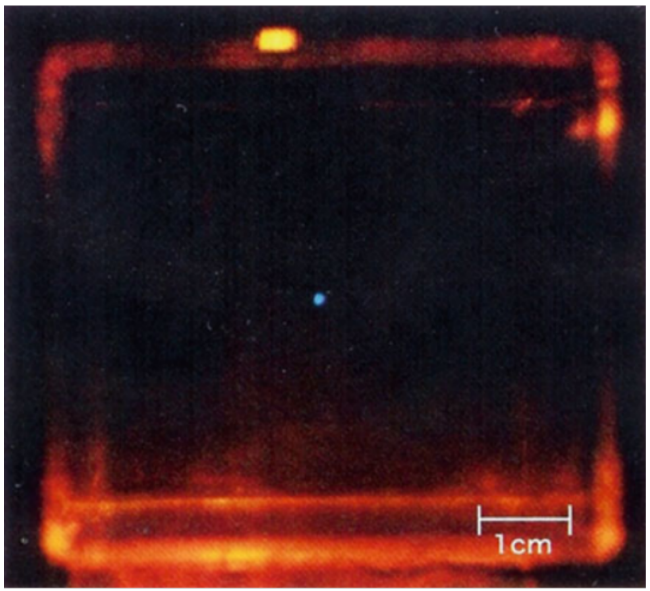


Figure: Adapted from Yasui 2018

Single-bubble sonoluminescence (SBSL)



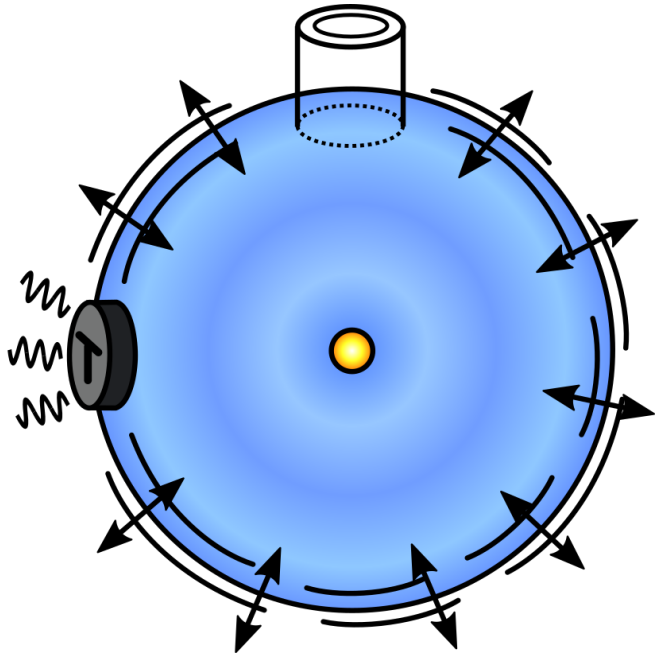


Figure: Adapted from Yasui 2018

"the hydrogen atom of sonoluminescence" [1]

[1] Brenner, Hilgenfeldt, and Lohse 2002.

Stable SBSL

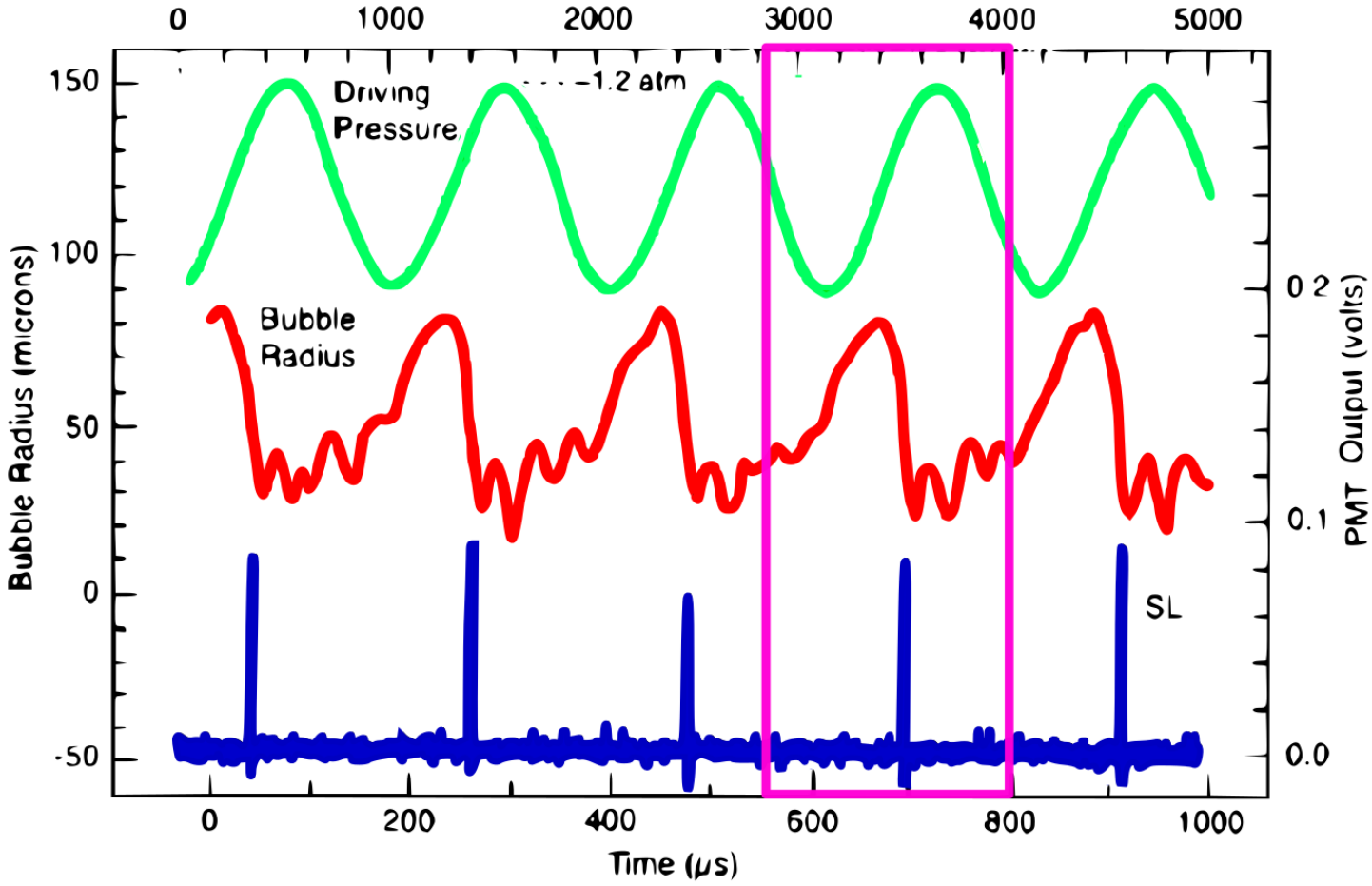
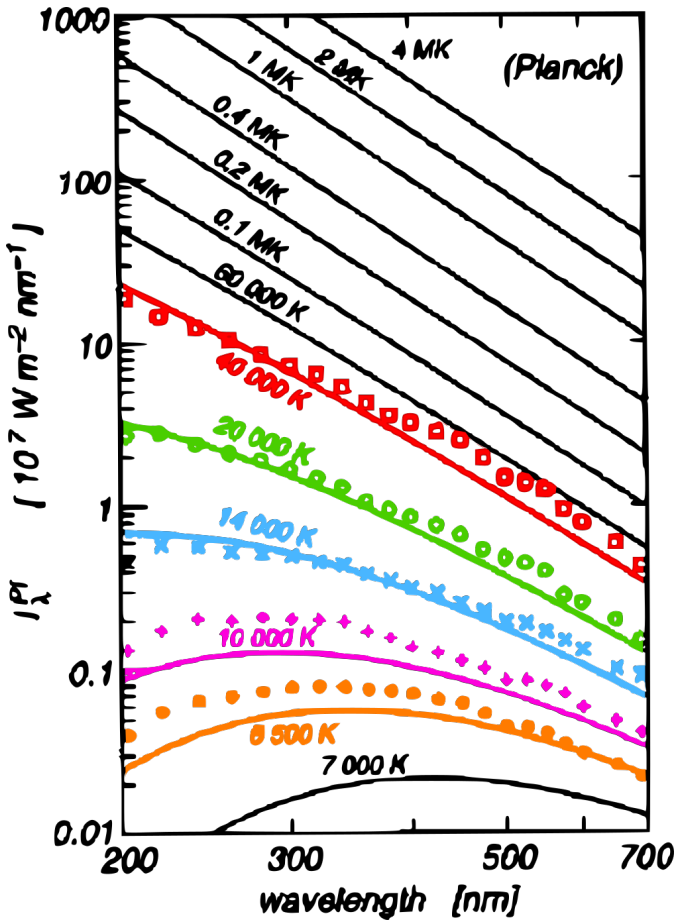


Figure: Adapted from Brenner, Hilgenfeldt, and Lohse 2002

The light spectrum

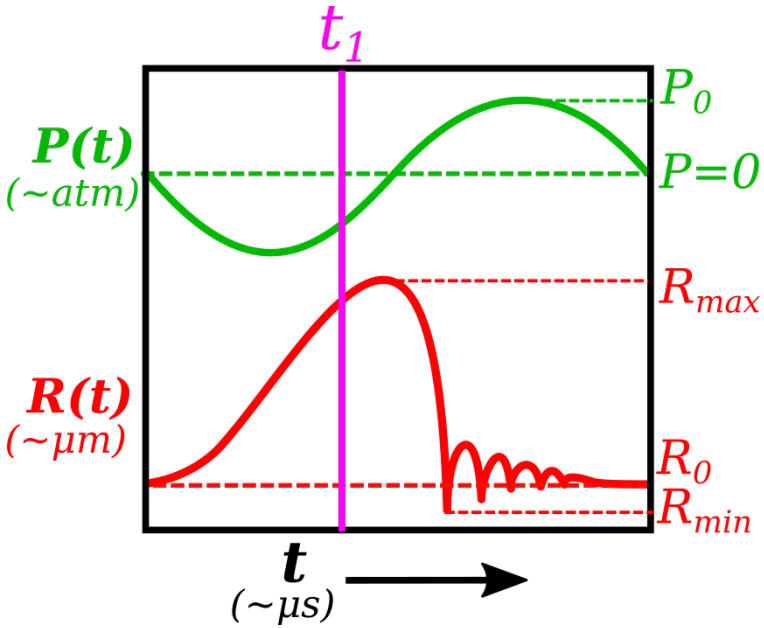
$$\frac{P_{Theory}}{P_{Exp.}} \sim 10^2$$

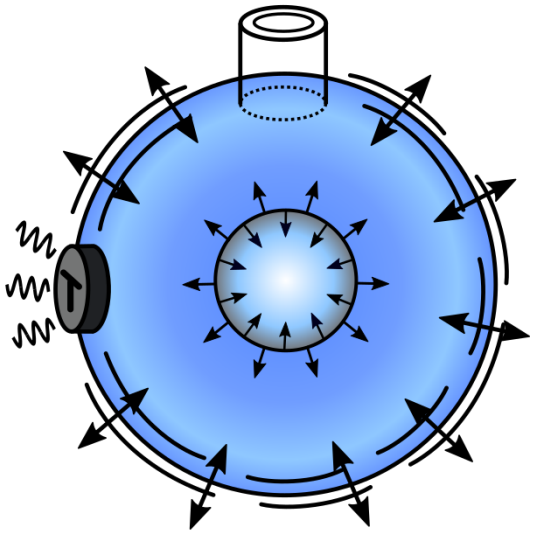


"...featureless spectra of unknown origin" [2]

[2] Suslick and Flannigan 2008

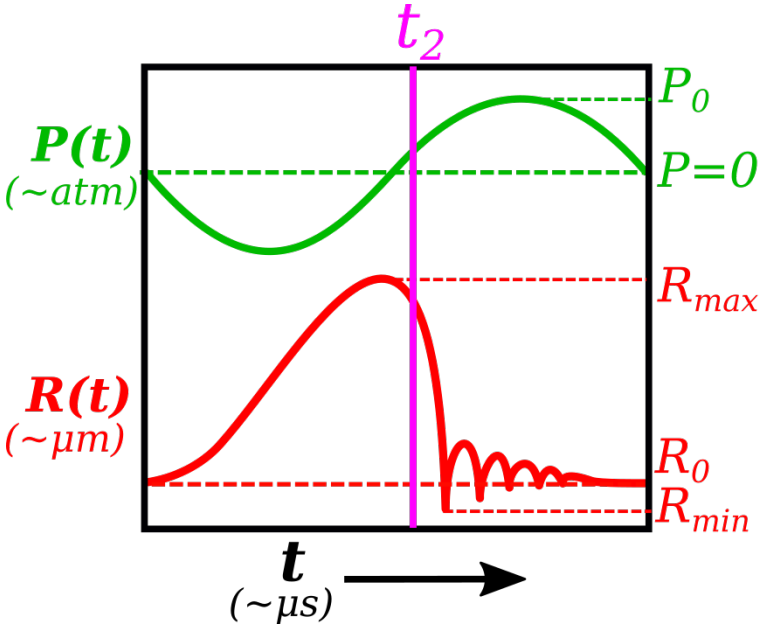
Bubble dynamics: expansion

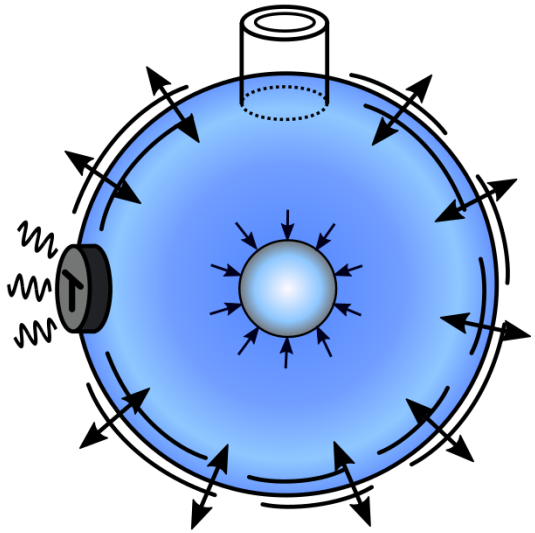




$$\underbrace{\rho(R\ddot{R} + \frac{3}{2}\dot{R}^2)}_{\text{“kinetic energy”}} = \underbrace{p_g(t) - P_a \sin(\omega t) - \frac{2\sigma}{R} + \cdots}_{\text{“work”}}$$

Bubble dynamics: cavitation



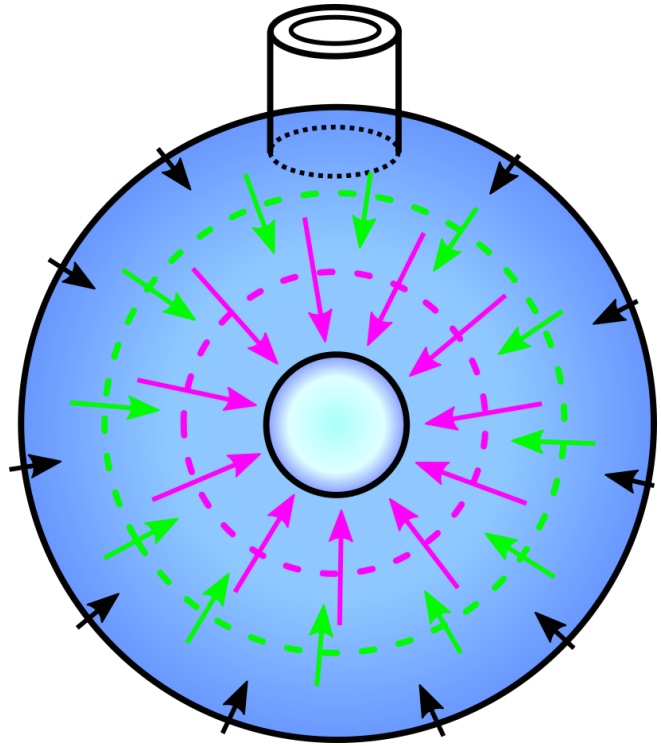


$$\dot{R} \sim \left(1 - \frac{t}{\tau}\right)^{-3/5}$$

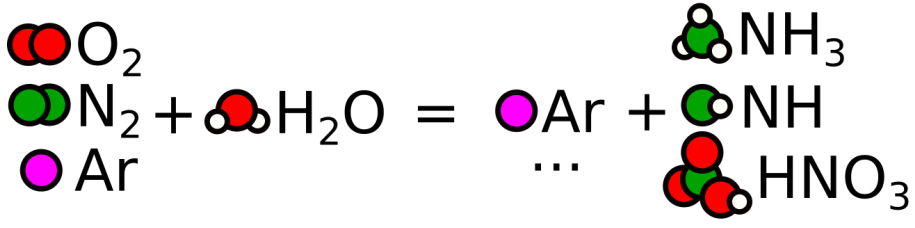
Interlude: cavitation

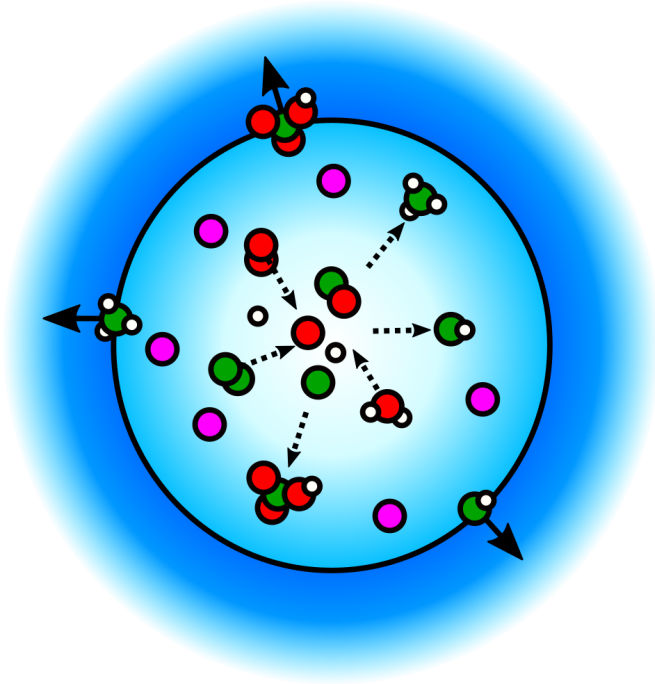
$$\rho_0 4\pi R_1^2 \cdot u(R_1) \equiv \rho_0 4\pi R_2^2 \cdot u(R_2)$$

$$u(R_1) = u(R_2) \left(\frac{R_2}{R_1} \right)^2$$

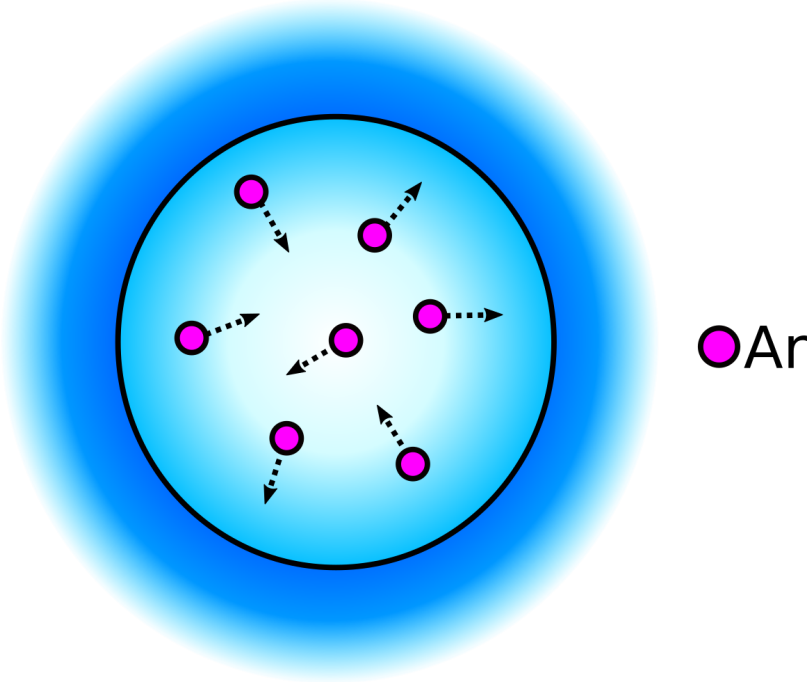


Argon rectification





The bubble's interior



$$p_g(t) = \underbrace{\left(p_0 + \frac{2\sigma}{R_0}\right)}_{P_i} \underbrace{\left[\frac{{R_0}^3 - h^3}{R^3(t) - h^3}\right]^{\gamma}}_{V_i/V(t)}$$

The bubble's interior

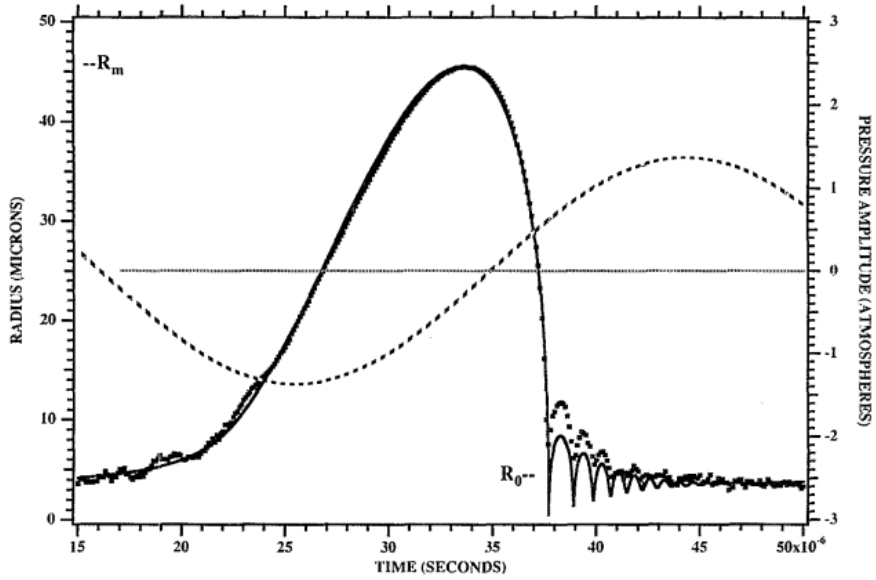
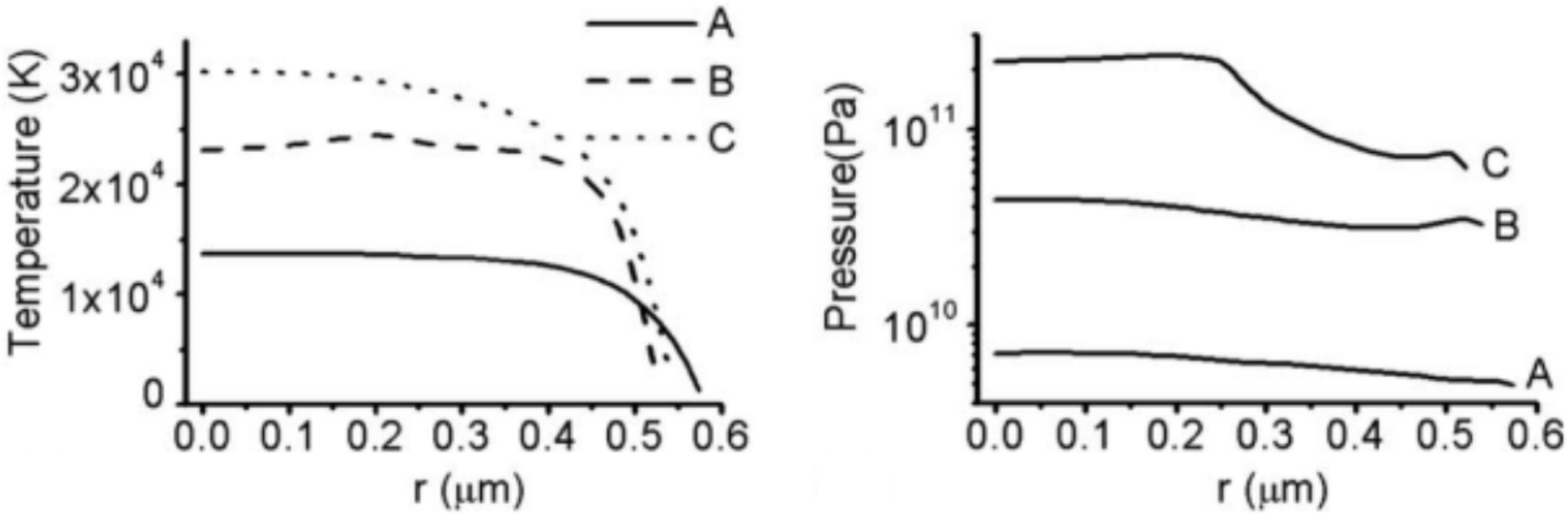


Figure: $R_0 = 4.5$ μm and $T_{max} = 8,500$ K. From Löfstedt, Barber, and Putterman 1993

$$T(t) = T_0 \left(\frac{R_0^3 - h^3}{R^3(t) - h^3} \right)^{\gamma - 1}$$

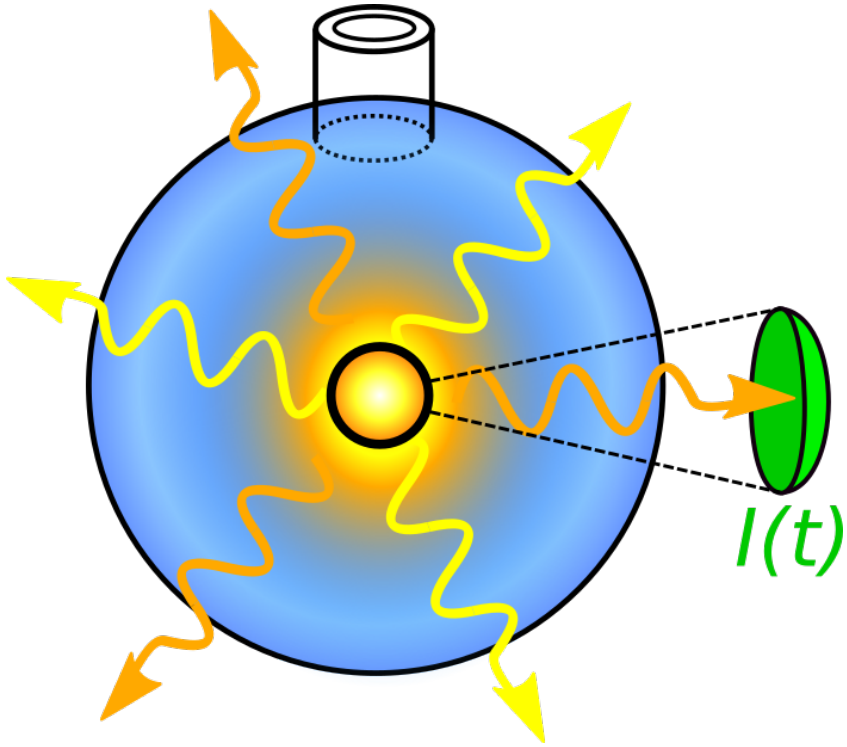
The bubble's interior: redux



(A) 1.22 atm, 20 C° (B) 1.32 atm, 20 C° (C) 1.32 atm, 0 C°

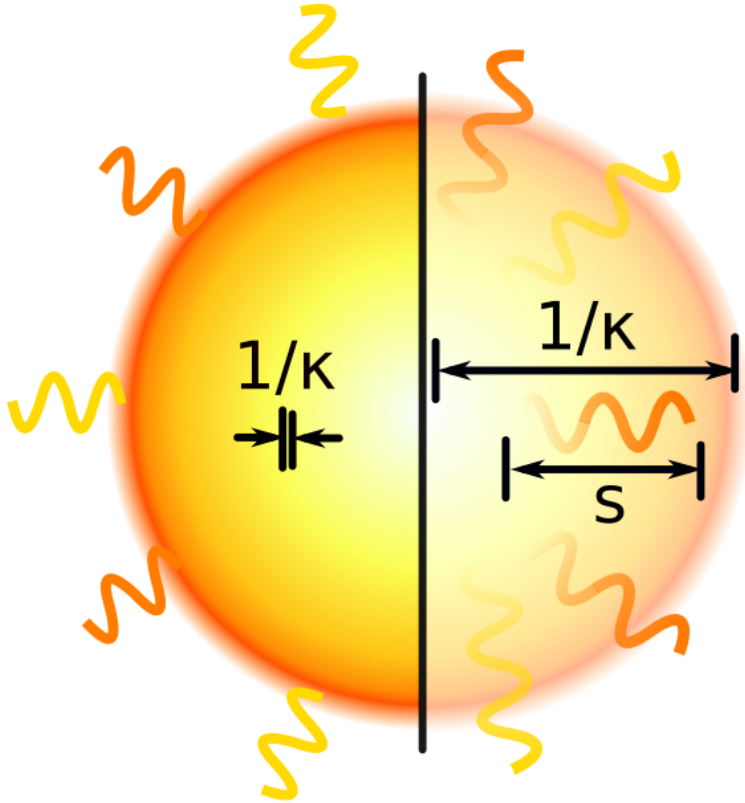
Figure: From An and Li 2009

Sonoluminescence



$$I(T(t),\lambda) = \underbrace{I_B(T(t),\lambda)}_{\text{Black-body spectrum}} \; [1 - \exp(-\underbrace{\kappa[T(t),\lambda]\cdot s}_{\text{optical "thickness"}})]$$

Where does the light come from?

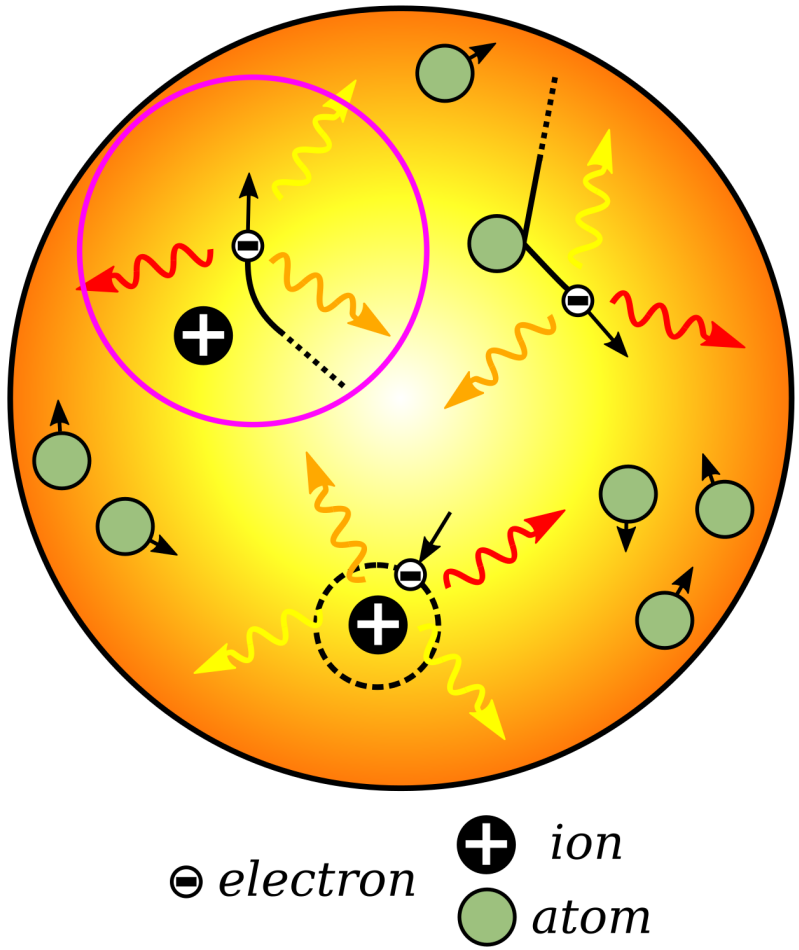


$$\kappa s \gg 1$$

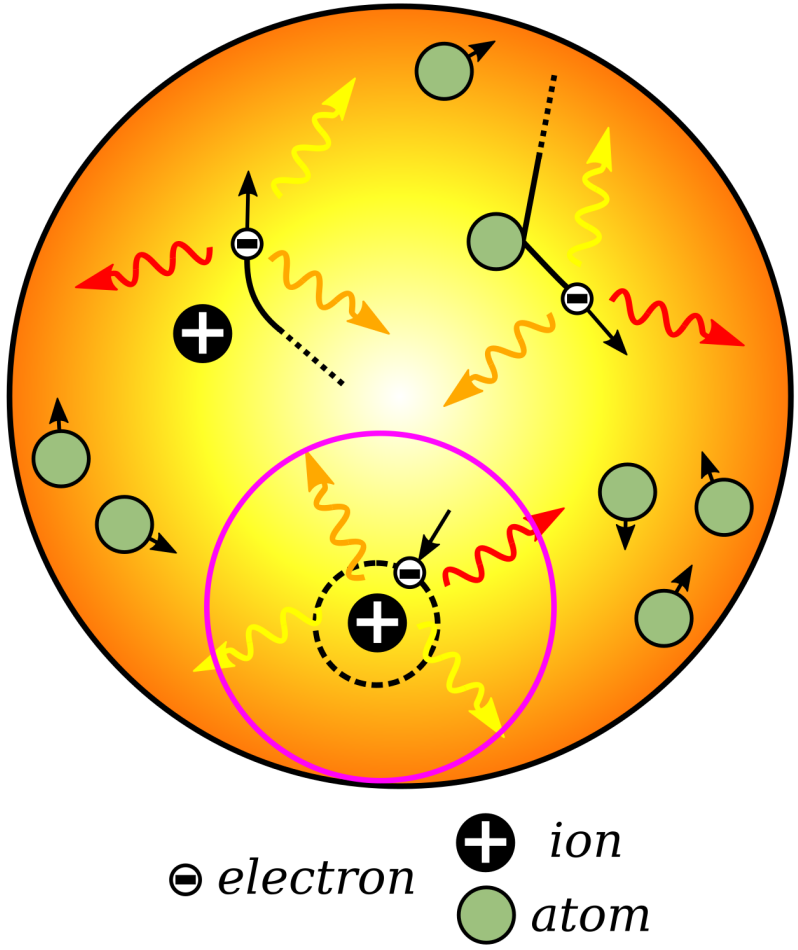
$$I(T,\lambda) \approx I_B(T,\lambda)$$

$$\boxed{\begin{array}{c} \kappa s \ll 1 \\ I(T,\lambda) \approx I_B(T,\lambda) \cdot \kappa s \end{array}}$$

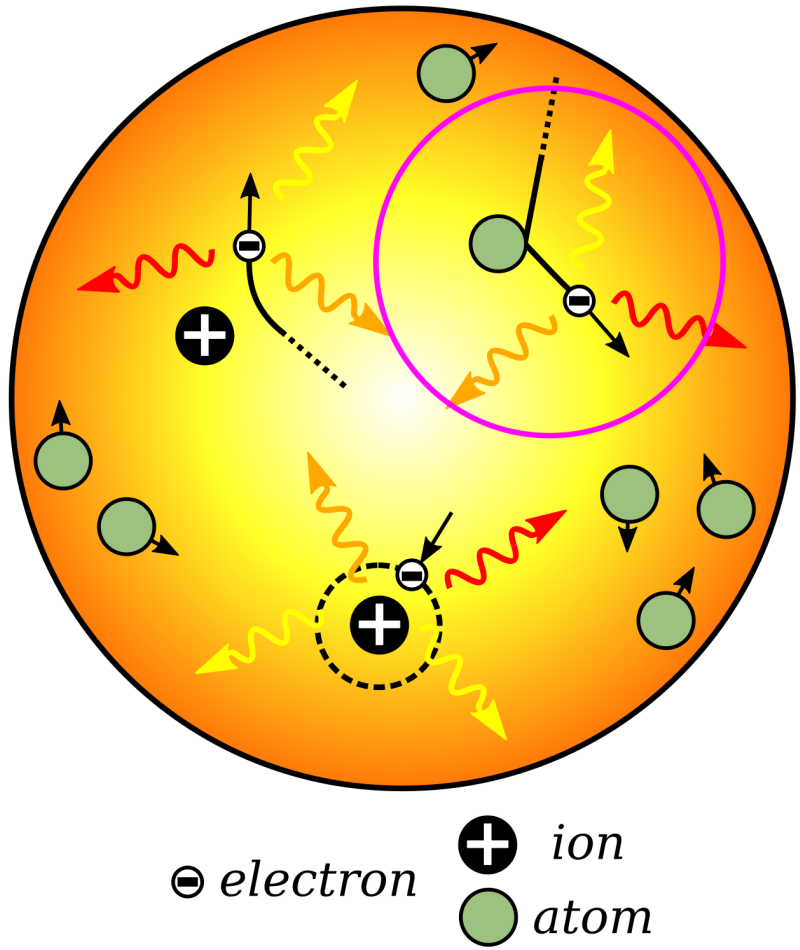
Electron-ion bremsstrahlung



Electron-ion recombination



Electron-atom bremsstrahlung



SBSL in H_2SO_4

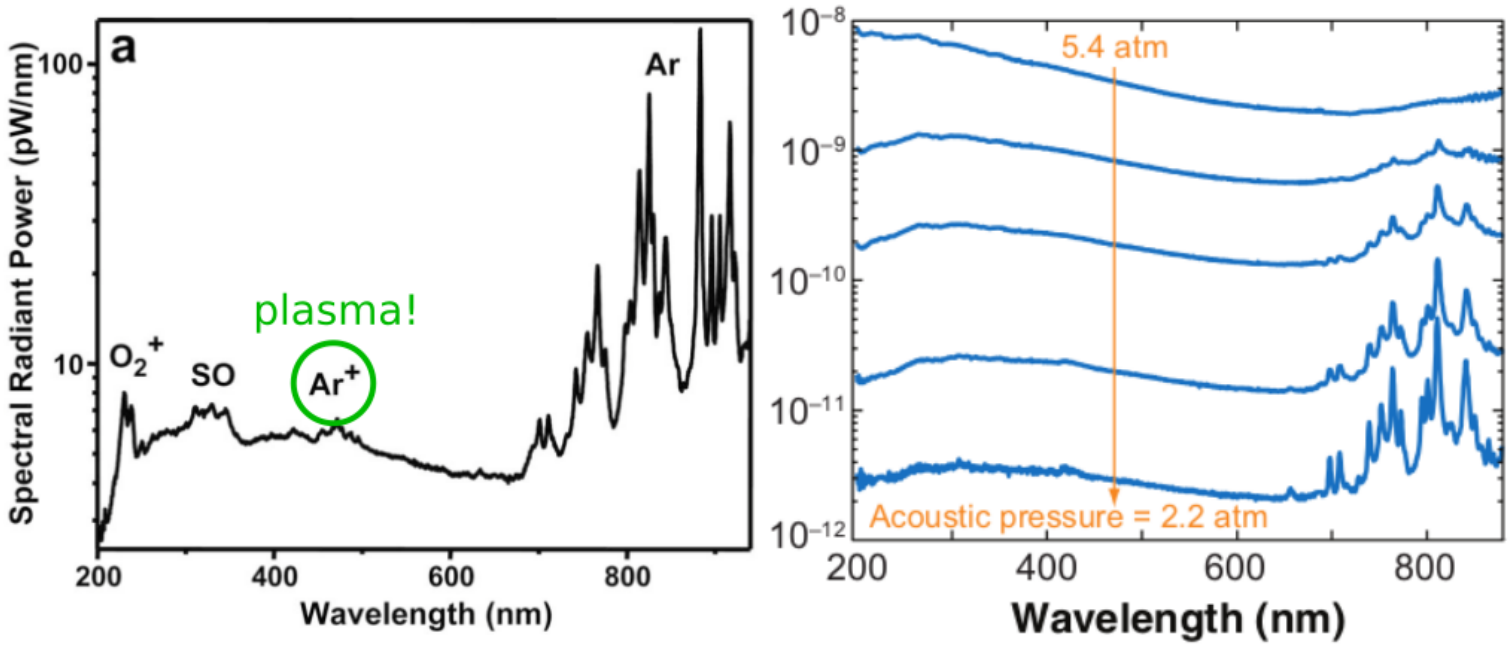


Figure: From Suslick and Flannigan 2008 and Flannigan and Suslick 2005

Theoretical results

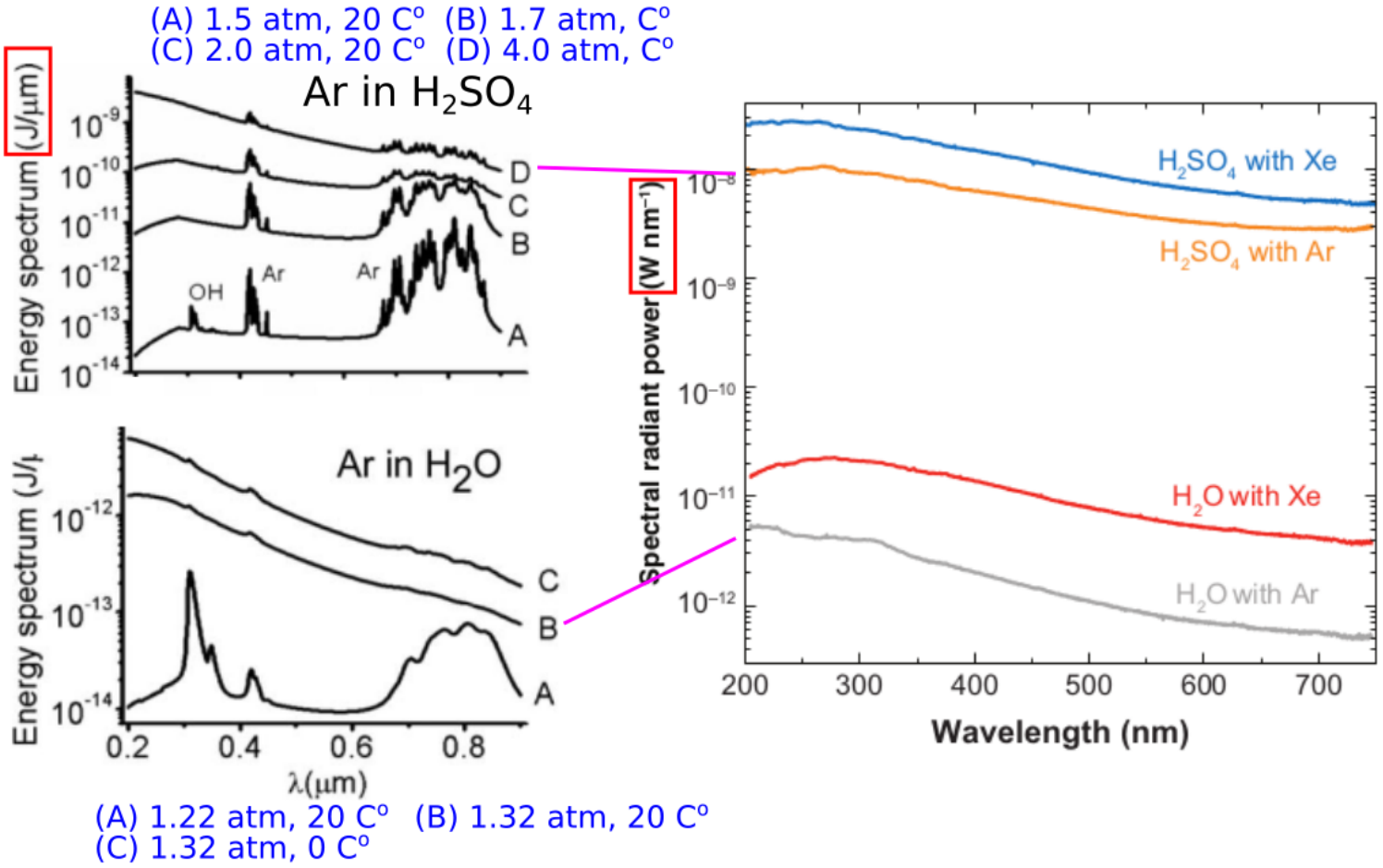


Figure: From An and Li 2009 and Suslick and Flannigan 2008

Theoretical results

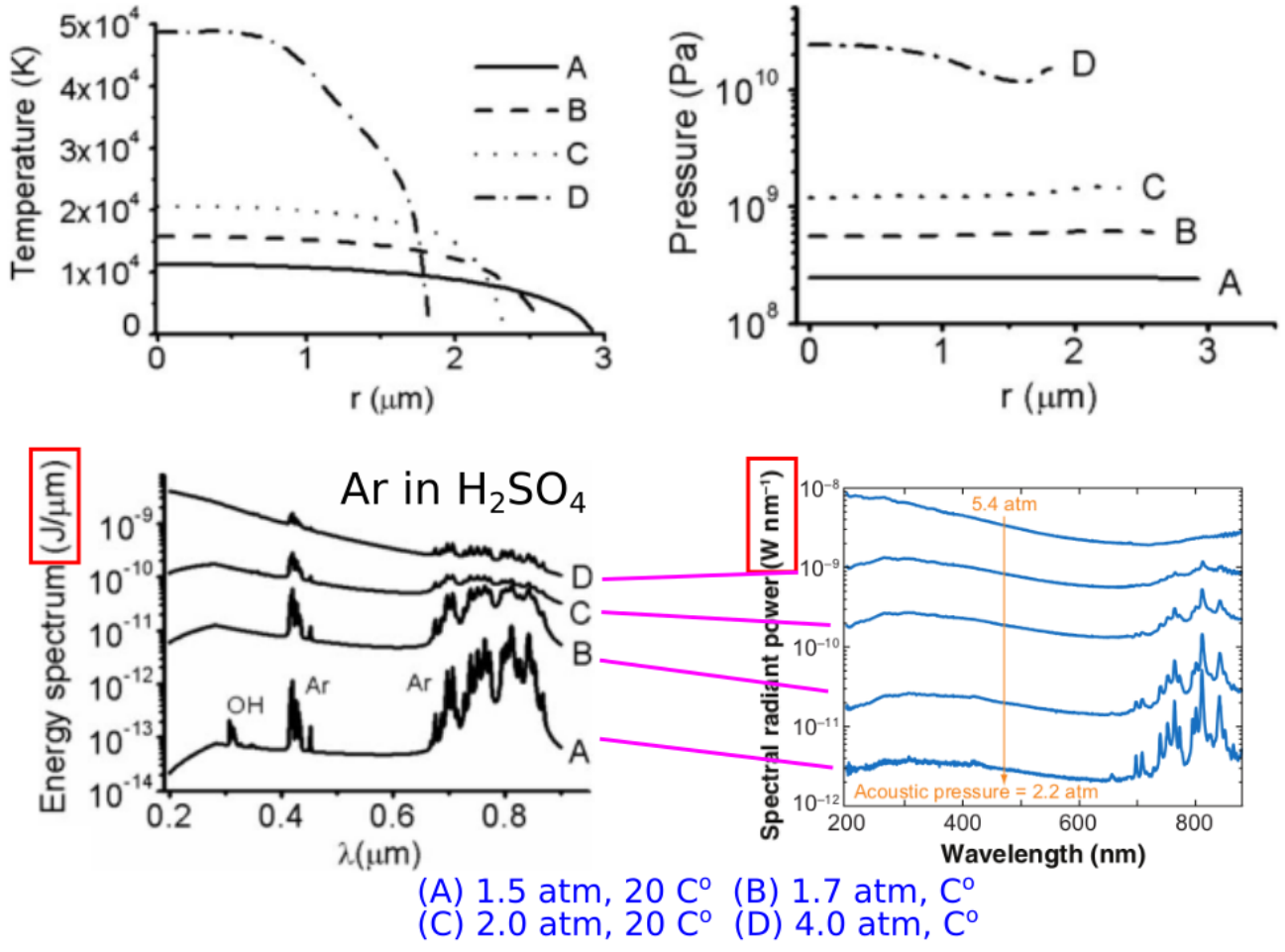


Figure: From An and Li 2009 and Suslick and Flannigan 2008

Shrimpoluminescence revisited

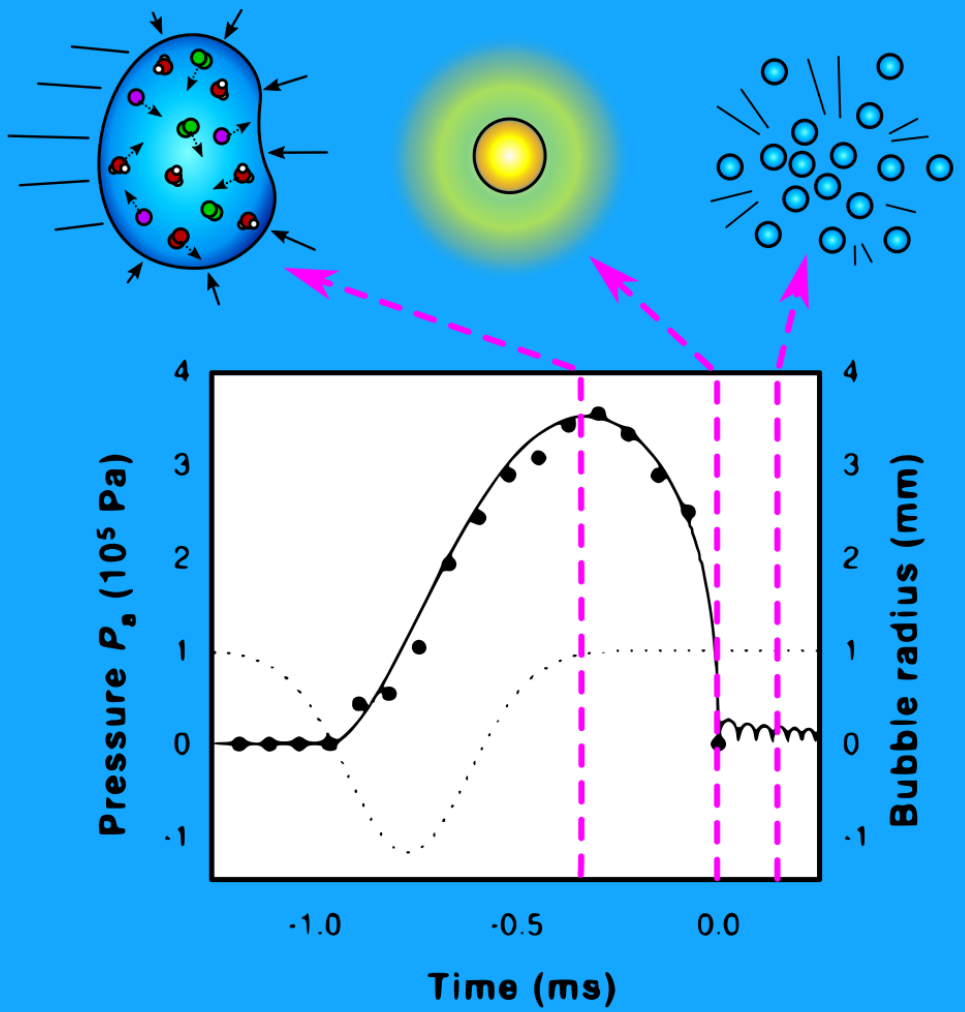


Figure: Adapted from Versluis et al. 2000

Summary

- Snapping shrimp produce cavitating bubbles
- The gas in the bubble becomes hot enough to ionize
- Electron-ion bremsstrahlung, electron-ion recombination, and electron-atom bremsstrahlung produce light

Questions?