THERMAL FILAMENTATION AND RAMAN AMPLIFICATION OF SHORT WAVELENGTHS

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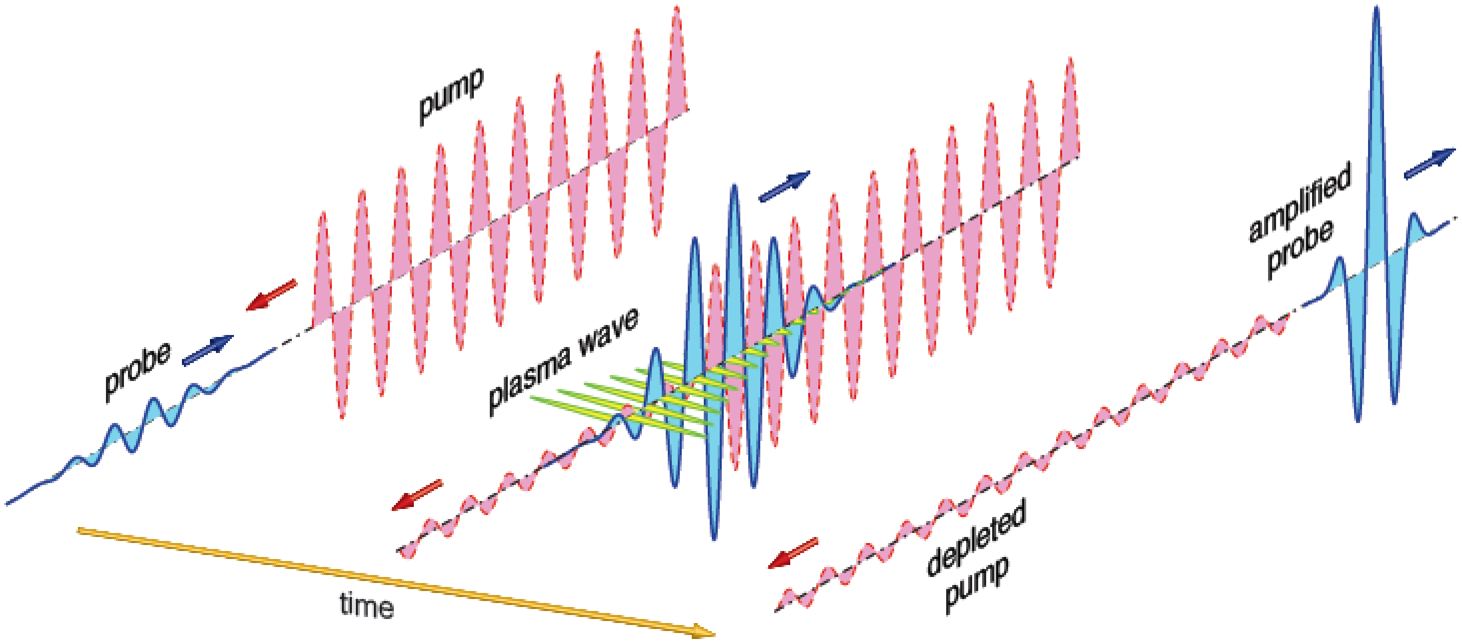
Overview

- Raman Amplification at short wavelengths
- Filamentation instability:

Ponderomotive vs Thermal

- Bandwidth issues
- Conclusions

How it works



•A long laser pulse (pump) in plasma will spontaneously scatter off Langmuir waves: Raman scattering

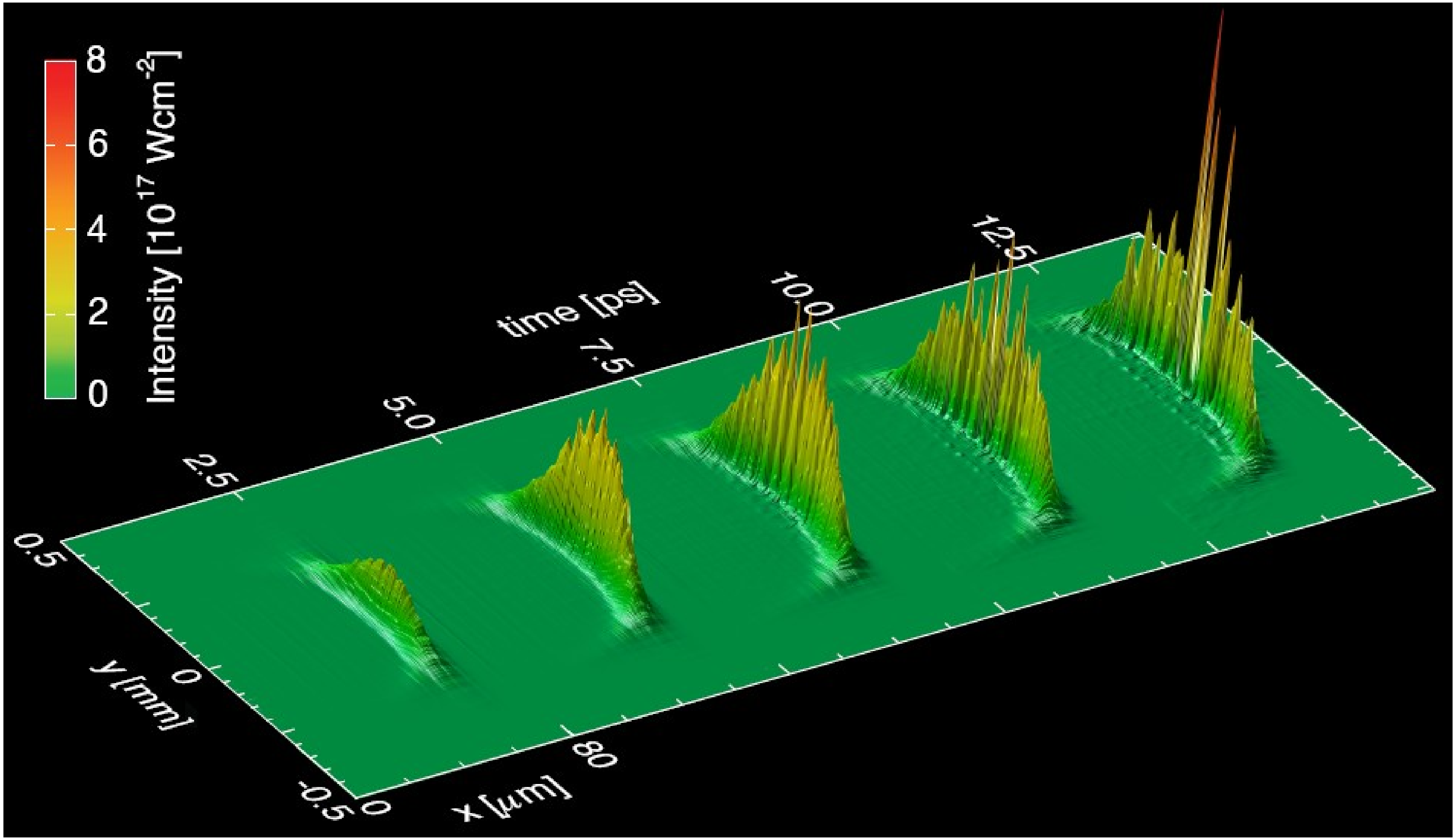
Stimulate this scattering by sending in a short, counter propagating pulse at the frequency of the scattered light (probe pulse)

Because scattering happens mainly at the location of the probe, most of the energy of the long pump will go into the short probe: efficient pulse compression

Raman Amplification

	Visible	X-ray
Wave length	800 nm	10 nm
Pump duration	25 ps	300 fs
Interaction length	4 mm	50 µm
Spot diameter	600 µm	7.5 µm
Pump intensity	10^{15} W/cm^2	10^{19} W/cm^2
Pump power	10 TW	10 TW
Pump energy	250 J	3 J
Plasma density	$5\text{x}10^{18}$ cm^{-3}	$3\text{x}10^{22}$ cm^{-3}
Probe intensity	10^{18} W/cm^2	10^{21} W/cm^2
Probe duration	25 fs	300 as
Facility	Vulcan at CLF	FLASH/LCLS

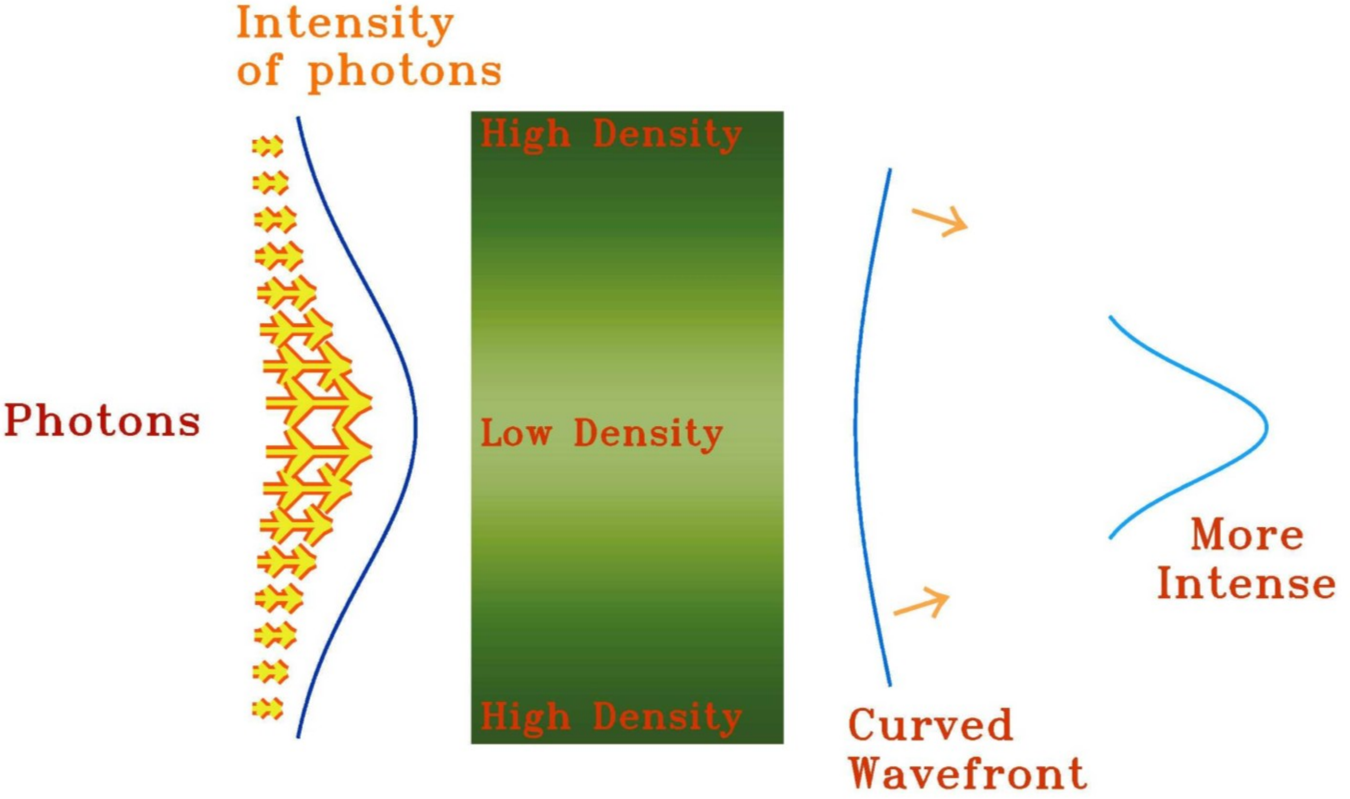
A bad result



For a $2*10^{15}$ W/cm^2 pump and $\omega_0/\omega_p = 10$, the probe is still amplified, but also destroyed by filamentation

Trines et al Nature Physics 2010

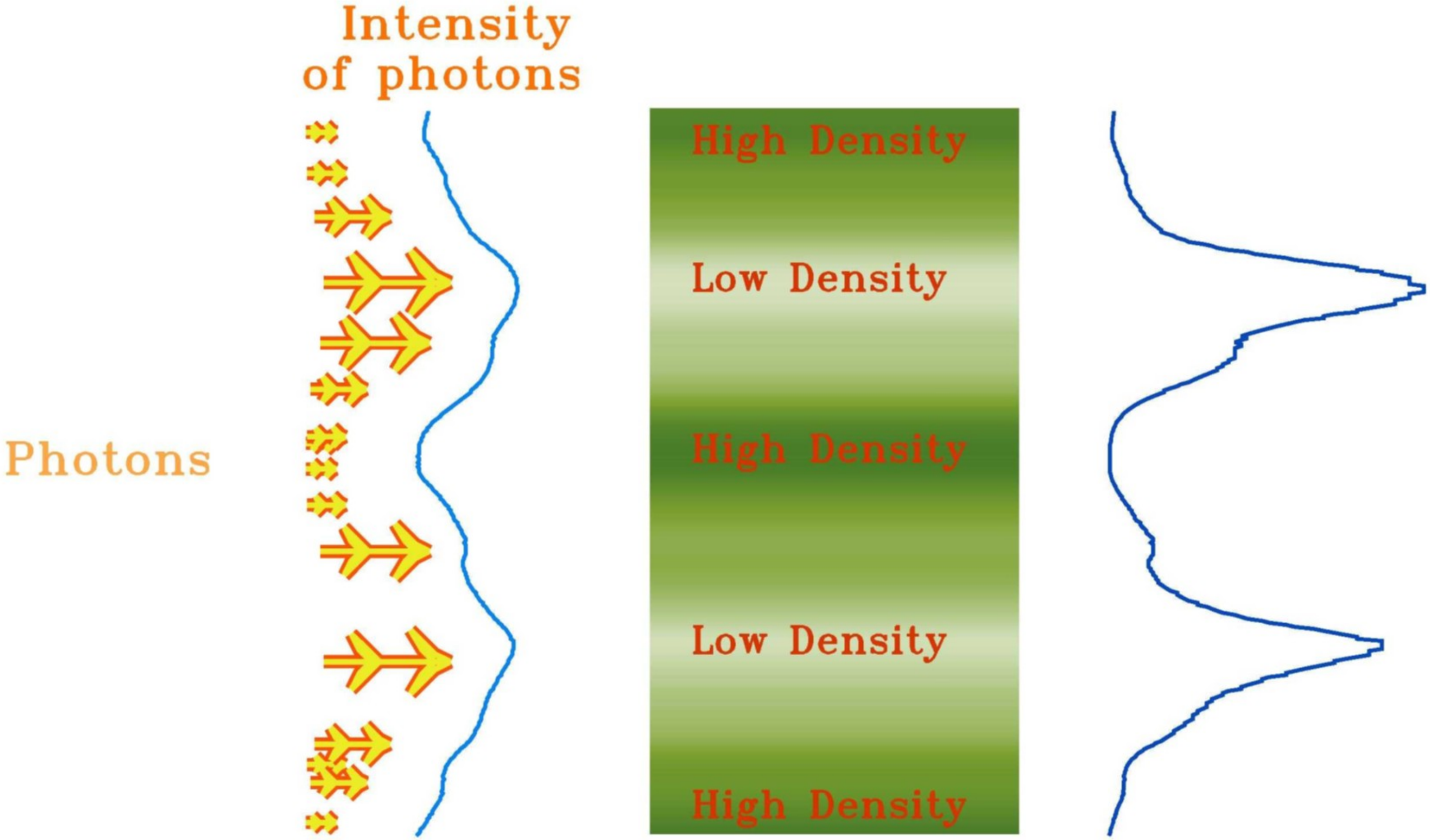
Self-Focusing



Physical mechanism for self-focusing driven by the ponderomotive force, relativistic mass increase or thermal effects.

$$\underline{F}_{pond} \propto -\underline{\nabla} I$$

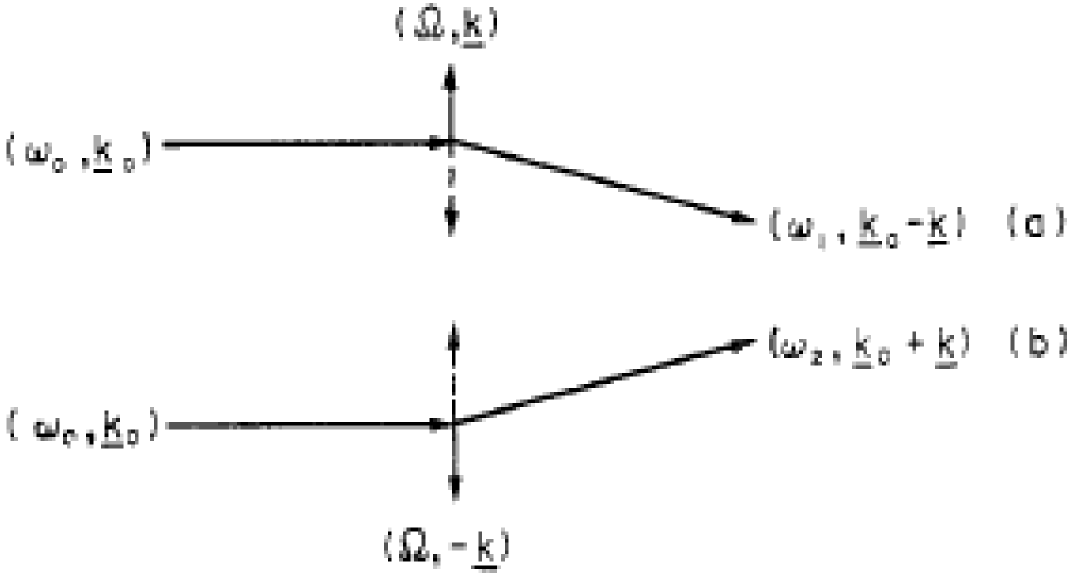
Filamentation



Filamentation Instability

Filamentation – Four wave process.

An initial plane wave scatters from density perturbation into a stokes and anti-Stokes wave.



$$c^2\nabla^2\mathbf{E} - \partial^2\mathbf{E}/\partial t^2 - \omega_{pe}^2\mathbf{E} = i4\pi e\omega\delta n\mathbf{v} + 4\pi n_0 e v_e \mathbf{v}$$

$$\delta n = in_0 e\langle(\mathbf{v}\times\mathbf{B})_y\rangle/k_y k_B T_e - n_0\delta T_e/T_e$$

Ponderomotive vs Thermal Filmentation

Ponderomotive filamentation $\propto I\lambda^2$

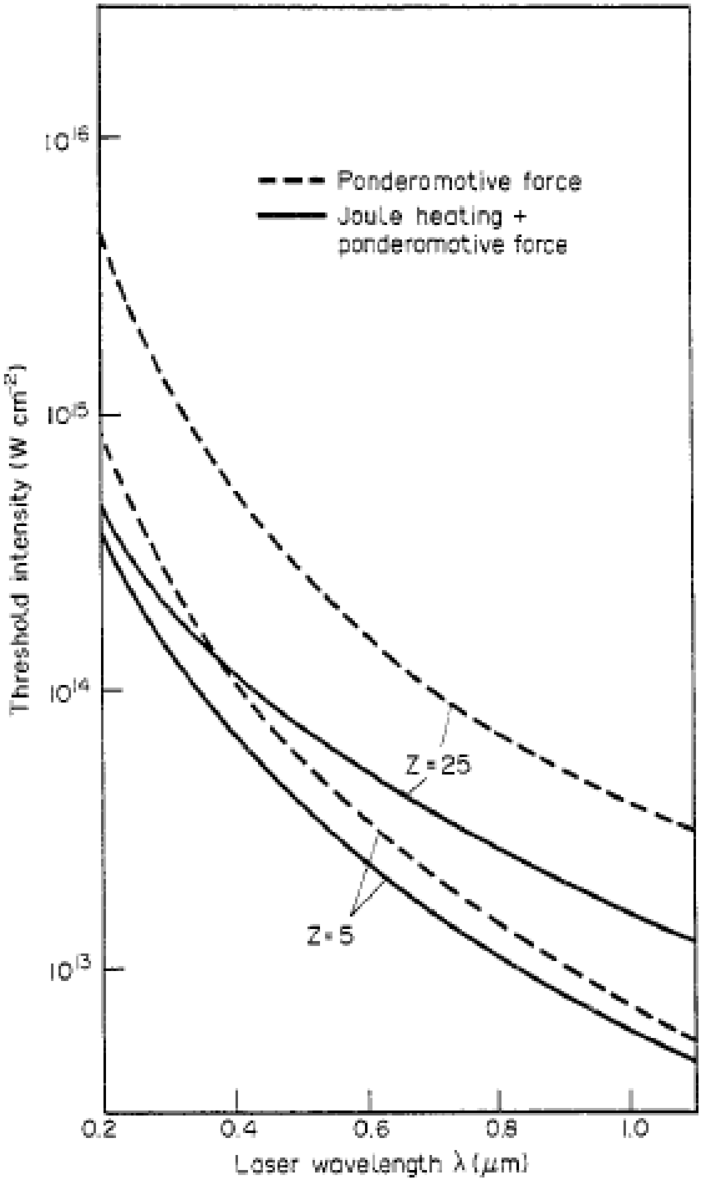
Thermal filamentation $\lambda_{\text{mfp}} < L$ filament width

Threshhold;

$$\left(\frac{v_0}{v_{Te}}\right)^2_{\text{Threshold}} = \frac{8\omega_0^2}{\omega_{pe}^2}\left(\left[(0.065/k_0^2\lambda_{\text{mfp}}^2)^2 + (\gamma_T/\omega_0)^2\right]^{1/2} - 0.065/k_0^2\lambda_{\text{mfp}}^2\right).$$

Where v_0 is the electron quiver velocity in the laser field.

Threshold Intensity for thermal and ponderomotive filamentation



Thermally driven and ponderomotive filamentation need to be investigated

The threshold intensity is higher for short wavelengths.

At x-ray wavelengths threshold intensity may not be reached.

Broadband Stimulated Raman Scattering

- Plasma wave SRS

$$\left(\partial_t^2 + \frac{1}{\gamma_0}\right)\tilde{n} = \frac{1}{\gamma_0^2}\nabla_{\mathbf{r}}^2\left(\langle \mathrm{Re}\left[\mathrm{a}_p \cdot \tilde{\mathrm{a}}\right]\rangle\right)$$

where

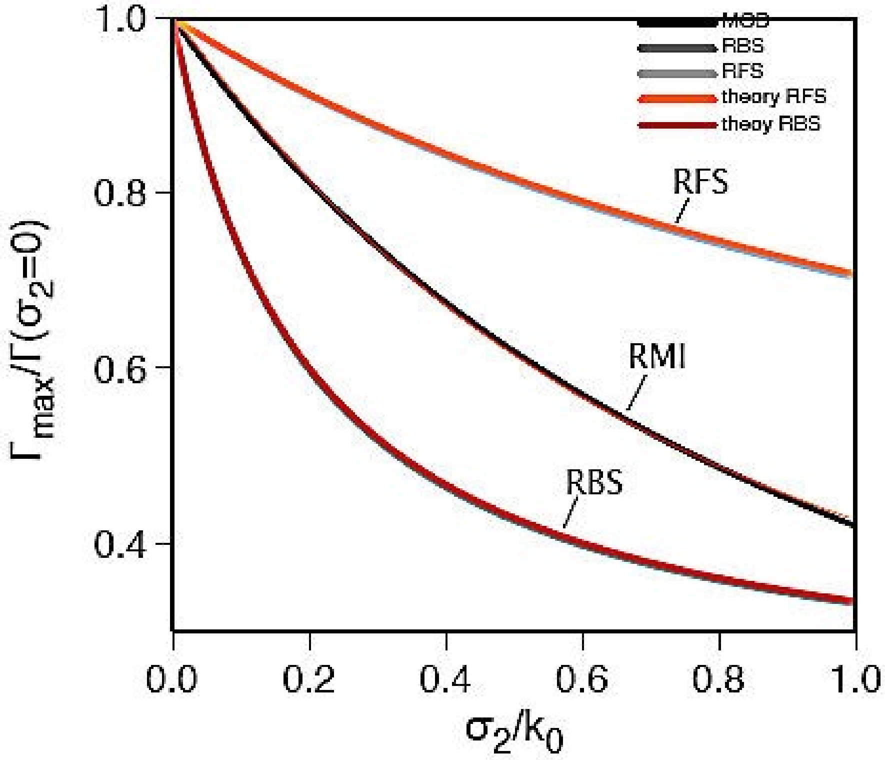
$$\gamma_0 = \sqrt{1 + \langle \mathrm{a}_p \cdot \mathrm{a}_p^* \rangle} = \sqrt{1 + a_0^2}$$

- Dispersion relationship follows:-

$$1 = \frac{1}{2\gamma_0^3}\left(\frac{\mathrm{k}_L^2}{\omega_L^2 - \frac{1}{\gamma_0}} - 1\right)\int \rho_0\left(\mathrm{k}\right)\left(\frac{1}{D^+} + \frac{1}{D^-}\right)\mathrm{dk}$$

Santos et al. PRL 2010.

Bandwidth Results For Raman forward and backward scattering



Maximum growth rate as a function of the photon distribution width.

Raman Backscatter growth rate much more controlled by bandwidth.

Raman forward scatter a four wave process like filamentation is less affected by bandwidth.

Conclusions

- At short wavelengths the filamentation instability is dominated by Joule heating.
- Raman backscatter and hence Raman amplification affected by finite bandwidth effects. One other reason for not using beams with spatially induced incoherence.
- Raman amplification at short wavelengths may be seriously affected by thermal filamentation.

Stimulated Raman scattering Growth rates

- Maximum growth rate for RFS

$$\Gamma_{\mathrm{RFS}} = \frac{a_0}{2\sqrt{2}\gamma_0^2\sqrt{(k_0-\sigma_1)(k_0+\sigma_2)}}$$

in the limit of $\sigma_{1,2} \rightarrow 0$ gives the standard result.

- Maximum growth rate for SRS

$$\Gamma_{\mathrm{RBS}} = \frac{\pi a_0^2}{8\gamma_0^{5/2}} \frac{k_0+\sigma_2}{\sigma_1+\sigma_2} \frac{1}{1+\frac{a_0^2}{8\gamma_0^{5/2}}\frac{k_0+\sigma_2}{(\sigma_1+\sigma_2)^2}}$$

- RBS

$$\mathrm{Im}(\Gamma) = \Gamma_{\mathrm{SCB}} \approx \frac{3\,2^{4/3} a_0^{8/3} (k_0+\sigma_2)^{8/3}}{\gamma_0^4(\sigma_1+\sigma_2)^3}$$