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Simulation of a Transient Raman Amplifier

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In a series of recent experiments at the Naval Research Laboratory, Reintjes and co-workers[1-3] have studied Raman amplification in H_2. A number of different studies have been carried out to investigate beam cleanup and beam combining and to study Stokes amplification. In these studies, both diffractive and temporal effects can play an important role.

In order to support the experimental effort and to explore the basic physical phenomena, we have developed a code RAM2D1 (Raman Amplification in 2 Dimensions, Version 1) and an associated diagnostic code PRAM1. This code solves the basic equations

$$\frac{\partial E_L}{\partial z} - \frac{i}{2k_L}\frac{\partial^2 E_L}{\partial y^2} = -i\kappa_2 \frac{k_L}{k_S} Q E_S, \tag{1a}$$

$$\frac{\partial E_S}{\partial z} - \frac{i}{2k_S}\frac{\partial^2 E_S}{\partial y^2} = -i\kappa_2 Q^* E_L, \tag{1b}$$

$$\frac{\partial Q}{\partial t} + \Gamma Q = -i\kappa_1 E_S^* E_L, \tag{1c}$$

where E_L and E_S are the complex pump and Stokes amplitudes, k_L and k_S are the pump and Stokes wavenumbers, Q is the material excitation, Γ is the collisional attenuation, and

κ_1 and κ_2 are the gain parameters. The quantity z represents distance along the Raman cell, t represents time with a z-dependent origin, and y represents the transverse dimension. The experimental configuration is not spherically symmetric due to the presence of multiple beams, and it was deemed impractical to keep more than one transverse dimension. The boundary conditions are that $E_L(z,t)$ and $E_S(z,t)$ are fixed for all time at $z = 0$ while $Q(z,t) = 0$ at $t = -\infty$ for all z. Mathematically, Eqs. (1a) and (1b) are propagation equations while Eq. (1c) is a constraint equation.

We use a semi-spectral, midstep Euler approach to solve Eq. (1). For equations like Eq. (1) which are "smoothing," *i.e.*, do not develop shocks or discontinuities, and have infinite or periodic transverse boundaries, strong indications exist that this approach is usually more efficient than a finite difference or a finite element approach.[4] The semi-spectral approach has the related advantage that the linear propagation is solved exactly (to within computer roundoff) so that this method is particularly advantageous in the limit of weak nonlinearity. This limit is of great importance in optics generally and certainly holds in our simulations.

A number of other considerations played an important role in our choice of algorithms. These included making efficient use of vectorization in the CRAY-XMP24 and not exceeding its memory limits.

Equation (1) has previously been examined in two special limits. The first[1] is the stationary limit in which $\partial Q/\partial t$ can be ignored so that

$$Q = -i\kappa_1 \frac{E_S^* E_L}{\Gamma}. \tag{2}$$

The second is the transient limit[2,5] where diffractive effects can be ignored. We have constructed RAM2D1 so that it runs efficiently in either of these two limits using simple switches.

This code has been used to date to carry out a number of different studies, including:

1) A thorough investigation of the transient 1-D evolution, including wave evolution in the highly depleted regime. Comparison with experiments clearly indicates the limitations of the 1-D model.
2) Studies of the conditions under which soliton-like structures can form.

3) Studies of side beam replication.
4) 2-D studies of gain profiles. Shown in Fig. 1 is typical output of the code in the low-gain limit over a propagation distance of 40 cm.

Discussion of these phenomena is included in our talk.

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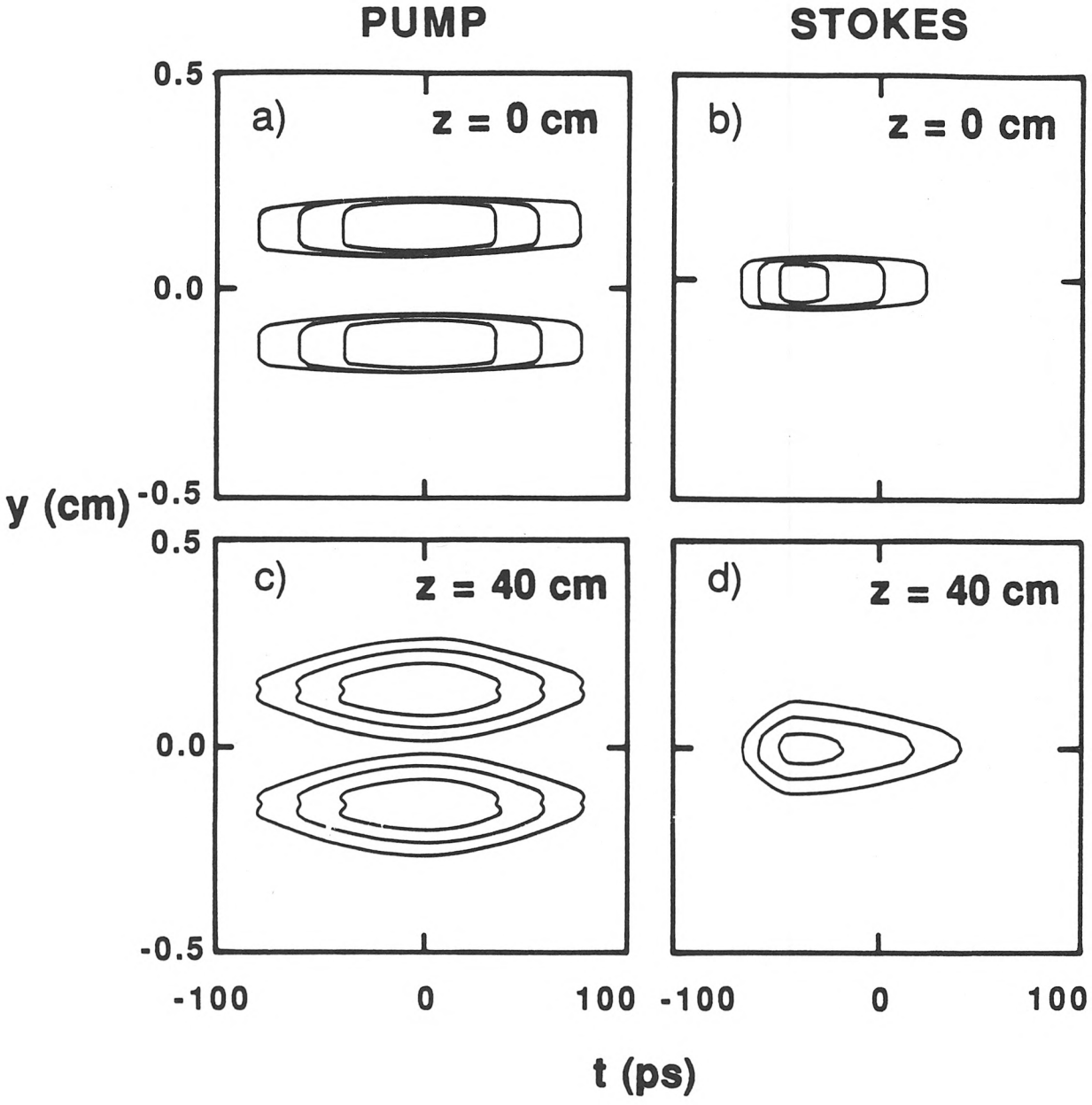

FIGURE 1. Contour plots of 2-D Raman amplification. The pump beams cross at $z = 20$ cm. The initial Stokes beam is offset and temporally asymmetric. Total gain is 2.