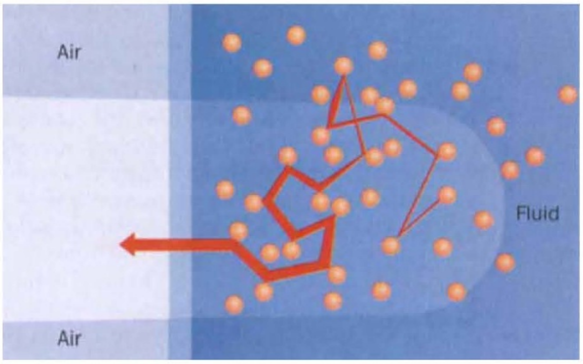

FIG. 2 Possible path for a photon emitted and amplified within a dye medium containing random scatterers. The lighter region indicates the volume strongly pumped by the laser.

nomena, and in particular, what are the conditions for producing compact super-radiant devices in strongly scattering systems? Let us consider the excitation and emission processes in the pure and colloidal dye solutions. The key length scales are given by the inverse of the product of a cross-section and density. The cross-sections for l, l_a (the pump absorption length) and l_{sr} are for scattering, absorption and stimulated emission, respectively, and the corresponding densities are of scatterers, of the excess of dye molecules in the ground over the excited state for the pumped transition, and of the corresponding excess of the excited state over the ground state of molecules in the emitting transition.

In the low-power limit in the pure dye solution, the pump intensity decays exponentially on a scale, l_a, determined by the ground-state population density. As the power increases, absorption is suppressed as the excited-state population increases. This pulls the system towards super-radiance because on the one hand the excited state population of the emitting state is enhanced and on the other the absorption is reduced, leading to an extended excitation region.

In strongly scattering colloidal systems, the penetration depth of radiation in the limit of low incident power is reduced to a depth of $L_a = (ll_a/3)^{1/2}$, where l_a is now the absorption length at a typical value of the spatially varying pump intensity. But as the pump power increases, l_a increases, leading to a far greater penetration depth. Just as in the pure dye solution, this enhances the power deposited in the sample and lengthens the typical path length of emitted photons in the gain region. In the absence of gain or loss for the emitted photons, the typical path length of an emitted photon from a depth L_a would be approximately equal to the absorption length l_a of the exciting photon. But much longer path lengths may be anticipated because photons experience gain along the path, so that the weight of such paths in the distribution of emitted light is increased. So any means of increasing the path length of photons in the region overlapping the exciting radiation, such as internal reflection by a large index mismatch at the sample boundary or resonances within scattering spheres containing dye molecules, may aid lasing action.

If we conservatively estimate the scattering cross-section to be the cross-sectional area of the particle, we find l is about 20 μm at the highest particle concentration studied. For the system discussed here, the low power value of l_a is about 100 μm and l_{sr} is about 400 μm. Thus in the absence of saturation we would not expect to observe laser action. But once the threshold for saturation is reached, the factors given above work together to stretch the typical path length of emission to a value beyond l_{sr}. The arguments given above require that l is smaller than l_a and L_a. In the opposite limit of weak scattering, the scatterers would destroy the coherence of the emission and suppress the super-radiance, as is indeed observed (Siddiq *et al.*, personal communication). Quite surprisingly, Lawandy *et al.* observe super-radiant emission induced by the presence of scatterers even in samples that are thinner than the scattering length. This may be the result of the trapping of a fraction of the scattered light by total internal reflection at the cuvette's internal surfaces. The phenomenon is reminiscent of the observation of super-radiance by R. L. Fork (*Phys. Rev.* **B19**, 3365–3398; 1979) in rare earth microcrystals.

In a related development, A. Yu. Zyuzin has predicted recently that the coherent backscattering from an amplifying slab of random scatterers should exhibit a narrow peak at a critical thickness at which the system is close to the super-radiant threshold (*Europhys. Lett.*, in the press). At this thickness the amplification of longer paths produces a uniform spatial profile of reflected light from point excitation instead of a narrow intensity distribution peaked about the point of incidence.

The observation of gain in random media opens up the possibility of developing compact super-radiant devices. Key experiments which would help establish the usefulness of such systems would be to measure the depth to which the pump radiation penetrates and the path length distribution of emitted light, which can be established using ultrashort optical pulses. □

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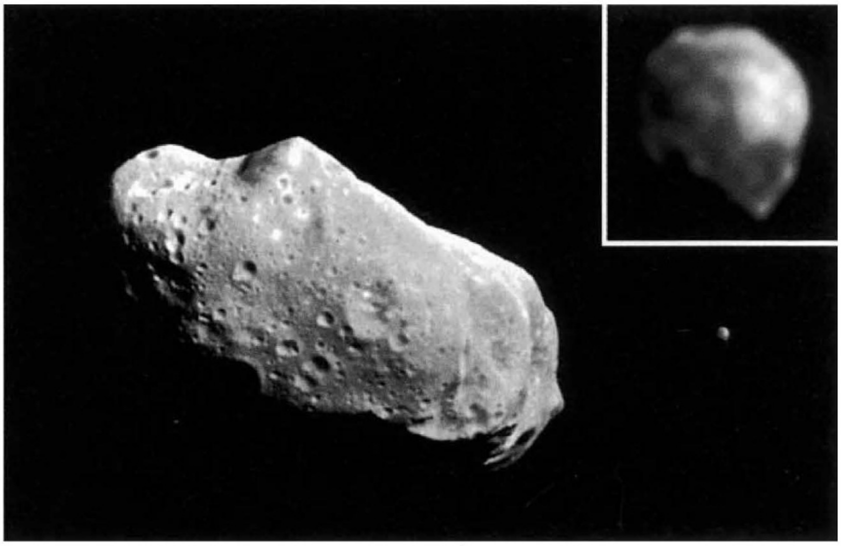
ASTEROIDS

New moon

A CHIP off the old block? Photographs and spectrographic maps returned by the Galileo spacecraft, and released by NASA last week, show a tiny moon accompanying the asteroid 243 Ida; this is the first confirmed natural satellite of any asteroid. Ida herself is about 56 kilometres long; and her far smaller companion (also shown enlarged) may be a fragment of the same large parent asteroid, or the relic of a more recent blow to Ida. Galileo recorded the images last August as it flew through the asteroid belt more than 500 million kilometres from the Earth. The moon, first spotted in a sample image strip in mid-February, should be revealed ever more clearly in the next few months as further images and spectra are returned. L. M.


NASA JPL