The core of the galaxy NGC1068 as recorded recently by the Faint Object Spectrograph on the Hubble Space Telescope. The image clearly shows small clouds of ionized gas illuminated by the conical extrinsic emission from the galaxy's nucleus. (The extent of the cone, aligned with the radio axis, is indicated by the artificial computer-generated graphic.)

rate for steady spherically symmetric accretion) over a range of black hole masses. Another factor to include is the quasar's environment: rather surprisingly, no one at the workshop mentioned the possible role of galaxy mergers.

SOLID-STATE PHYSICS

Single-molecule probes

J. L. Skinner

UNDERSTANDING the nature of molecular dynamics in condensed phases has been a central theme in physics and chemistry for many years. On page 225 of this issue¹, Ambrose and Moerner report monitoring the fluorescence of single pentacene molecules in a molecular crystal of *p*-terphenyl. The fluorescence frequency of the pentacene molecule can jump by small amounts, the mean time between these jumps being 20–420 s. The authors interpret these frequency jumps as the result of changes in the local molecular environment of the pentacene molecule. Thus this experiment provides the first direct measurement of these local motions, and paves the way for detailed analyses of molecular dynamics in condensed phases.

The use of probe molecules that can be monitored spectroscopically is a time-honoured method for determining local structure and dynamics in condensed phases. One hopes, of course, that the probe molecule will not perturb the structure and dynamics of the host system to any significant extent. What one learns from the optical spectroscopy of dilute impurity probes in crystals and amorphous solids depends on the timescales involved. For times shorter than the

What are the biggest remaining puzzles? Very fast X-ray variability is a severe difficulty for any model. About a third of the Seyferts looked at by EXOSAT vary on a timescale of hours; five varied significantly in only 20 minutes. Some ultrafast radio variability also seems to be intrinsic to the sources. The origin of the jets remains a problem. Accretion disks are frequently suggested to be the means of extracting the gravitational energy to power quasars (and are also a means of providing some of the collimation for beaming), but they present serious observational and theoretical problems. One is the lack of hydrogen bound-free edges in the spectra in either emission or absorption²: such edges are seen in the accretion disks that surround cataclysmic variable stars but not quasars. Other problems include the relatively low polarization of quasars and the uniformity of apparent temperature of the ultraviolet spectrum in different objects and in individual objects as they vary. So although the unified theories have come a long way, we are still far from having a single grand unified theory of quasars. □

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this process over all impurities is known as spectral diffusion, which is thought to account for the discrepancy between photon-echo dephasing times and hole widths from hole-burning experiments for resorufin in organic glasses³ — the former experiments measure only short-time dynamics, whereas the hole widths also reflect a contribution from the longer-timescale spectral diffusion.

The direct observation of molecular dynamics from impurity spectroscopy⁴ relies on the detection of single molecules, which has recently been achieved through double-modulation absorption⁷ and fluorescence⁸ techniques. The key to the detection of single molecules in crystals involves both the spatial and the spectral isolation of the impurities, achieved by using very thin crystals and small laser spots and by tuning the laser frequency significantly away from the central maximum of the absorption lineshape. The fluorescence technique allows one to see the frequency jumps of individual probe molecules.

These can provide much more information than the average spectral changes measured in more traditional experiments, such as hole burning, that involve many impurities. Thus one could measure distributions of jump times and frequency changes and the correlations between them, or, for example, the frequency-frequency time-correlation function for a single molecule. The temperature dependence of these quantities should enable one to determine, by comparing with theoretical models, the specific molecular motions of the host that are responsible for the frequency jumps.

One possible limitation of the technique is that only those impurity molecules way out in the wings of the inhomogeneous distribution, which by definition means those molecules in atypical environments, can be spectrally isolated. One would, of course, like to develop a technique that could measure the environmental changes in real time near typical impurities. Nonetheless, the detailed data that are sure to follow from the present generation of experiments will provide grist for the mill for quite some time. □

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fluorescence lifetime of the impurity, small-amplitude thermal motions of the host molecules occur that are statistically the same for each impurity. These motions rapidly vary the resonance frequency of the impurity, and thus produce what is known as homogeneous line broadening of the absorption or fluorescence spectrum^{2,3}. On a timescale somewhat longer than the excited state lifetime, each impurity sees an average environment that is time independent and is different from the other impurities owing to disorder in the host crystal or glass. This produces inhomogeneous broadening. The actual absorption or fluorescence spectrum at low temperatures (1.5–10 K) is usually predominantly inhomogeneous. Nonetheless, various techniques — fluorescence line narrowing⁴, hole burning⁴, photon echo⁵ and statistical fine structure⁶ — have been developed that allow a determination of the homogeneous linewidth in these inhomogeneously broadened systems.

On a timescale substantially longer than the excited state lifetime, the time-averaged host environment of any particular impurity may change significantly, leading to a change in the absorption or fluorescence frequency. The average of

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