first identified as a component, along with the proliferating-cell nuclear antigen (PCNA), of almost all CDK complexes in normal but not in transformed cells[4]. It was subsequently isolated in a number of ways: as CIP1, a protein that binds to CDK2 in the yeast two-hybrid system; as CAP20, a protein tightly bound to CDK2 in cell lysates; as SDI1, a protein encoded by an abundant messenger RNA in senescent cells that can inhibit cell proliferation; and as WAF1, a protein that is induced by wild-type but not mutant p53 (for review see ref. 5). That last finding immediately suggested that p21 is involved in inhibiting the cell cycle in response to DNA damage, and supporting data have been quick to arrive; p21 is induced in γ-irradiated cells that have wild-type p53, binds to the putative S-phase promoting kinase, cyclin E–CDK2, and so prevents cells from initiating DNA replication[6].

Waga *et al.*[1] illuminate another facet of the p21 response to DNA damage. They find that p21 will inhibit DNA replication when added into a SV40 T-antigen-dependent *in vitro* DNA replication extract, and moreover that p21 inhibits an *in vitro* DNA replication system made up of purified components. p21 seems to inhibit elongation rather than initiation events, and its inhibition can be relieved by adding excess PCNA (ironically, PCNA was once known as cyclin).

The sting in the tail is that the purified system does not contain any cyclin–CDK complexes. So p21 can inhibit the DNA-replication machinery directly, and Waga *et al.* present data to show that it does so by binding to PCNA. This provides a means by which DNA replication can be stopped in its tracks and damaged DNA repaired. Waga *et al.* point out that the DNA-repair machinery would have to be insensitive to p21 inhibition, which may pose a mechanistic problem because PCNA is required for DNA-excision repair *in vitro*, as well as DNA replication. Thus, if DNA is damaged before S phase p21 is able to prevent cells from starting DNA replication by inhibiting cyclin–CDK complexes, whereas if DNA is damaged during S phase p21 is able to halt the replication machinery by binding to PCNA (see figure).

These observations prompt a host of questions, not the least of which are how p21 is able to bind and inhibit such different proteins as the cyclin-dependent kinases and PCNA, and whether p21 is involved in DNA repair in G2 phase. It is entirely unclear how p21 inhibition is relieved after the DNA is repaired. Is p21 post-translationally inactivated, or do the levels of cyclin–CDK complexes and PCNA increase to exceed those of p21? A further possibility is that p21 is degraded in a similar fashion to the budding yeast CDK inhibitor, $p40^{SIC1}$. The SIC1 protein halts a yeast cell in a pre-S phase state by inhibiting the S-phase CDK[7], and inhibition is relieved by the ubiquitin-mediated degradation of $p40^{SIC1}$ (K. Nasmyth, personal communication). SIC1 has a possible counterpart in fission yeast, $p25^{rum1}$, which inhibits the fission yeast CDK (Cdc2) and also halts the cell in a pre-S phase state. The product of the *rum1* gene is required for the proper coordination of S phase and mitosis in the normal, non-perturbed cell cycle[8]. This puts mammalian p21 in a broader context.

Waga *et al.* suggest that because p21 is able to inhibit both cyclin–CDK complexes and PCNA, it may provide a link between the cell-cycle regulators and the DNA-replication machinery, along the lines of SIC1 and Rum1. But thus far p21 seems to be primarily involved in regulating DNA replication in response to adverse conditions such as DNA damage, so the mammalian homologues to Rum1 and SIC1 may have yet to be identified. Conversely, at present there is no evidence that either of the two yeast CDK inhibitors interacts with PCNA, so there may be other yeast inhibitors with roles more analogous to p21. Intriguingly, the *plutonium* gene in *Drosophila*, which encodes an inhibitor of DNA replication, is adjacent to the PCNA gene[9]. All in all, CDK inhibitors look set to reach critical mass in the very near future. □

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ASTRONOMY

Much ado about something

Douglas Richstone

DURING the three decades since quasars were discovered, a consistent picture of their energy source has been built up — that they are black holes fed by nearly axisymmetric influxes of material, and that the gravitational energy of the accreted mass powers the emitted radiation. Where, though, was the proof that such black holes exist? At a conference earlier this month, astronomers had the chance to hear in detail how highly publicized results from the Hubble Space Telescope (HST) measured up*.

Before the HST, there had been some evidence both for the geometrical configuration of the accretion disk in quasars and active galactic nuclei (AGNs), and for the presence of a small but massive object which might be a massive black hole in normal, quiescent galaxies that might once have been AGNs.

The Virgo elliptical galaxy M87 seemed an obvious target for observations, as it is one of our nearest active galaxies (it is admittedly rather a weak source, but qualifies as an active galaxy through its variable nuclear radio source and its well collimated jet). A lingering frustration over the past 15 years has been the inability to identify an axisymmetric structure or black hole in the galaxy, so when the superb angular resolution of the repaired Hubble Space Telescope allowed an apparent accretion disk to be resolved, the results made headline news around the world.

If axisymmetric, this object is nearly perpendicular to the observed radio jet and is about 65 light years across (see News, *Nature* **369**, 345; 1994). Spectra of the gas obtained with the Hubble indicate a central mass of about 3 billion solar masses provided it is in circular rotation, sufficient to have provided quasar luminosities by accretion in the past (H. Ford, Johns Hopkins Univ.; R. Harms, Computer Sciences Corporation).

Ford's report at the meeting met with general acceptance, although loopholes remain for the dedicated sceptics. A cluster of a billion neutron stars or white dwarfs smaller than the observed region of the disk would be small enough and dark enough to account for the observations and could survive against two-body relaxation, core collapse or stellar collisions for longer than the age of the Universe. No one, however, was willing to advocate such a model, at least in public, as its manufacture seems as daunting as a single massive black hole. There is general agreement that the identification of this rapidly rotating disk roughly perpendicular to the radio jet is a big step in the steadily solidifying picture of the quasar phenomenon as an accretion disk feeding a massive black hole.

Another key area where the HST is proving its use is the theory of evolution of massive stars. HST permits the study of individual ultraviolet bright knots in star-

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burst and interacting galaxies. Work on knots in two such galaxies, II Zw 40 and NGC 4861 (W. Vacca, Univ. California, Berkeley), identifies young star clusters with radii smaller than 300 light years. These dense young clusters, with masses as large as a million solar masses, may conceivably be young globular clusters. Spectroscopy reveals a large ratio of Wolf–Rayet stars to early O stars in these objects. This is a surprise: the most massive stars live for 3 to 5 million years on the main sequence as O stars, evolving off it to Wolf–Rayet stars for perhaps a tenth of that time.

The straightforward explanation for large numbers of the shorter-lived evolved species is that the timescale for star birth in these knots is short, but that the observation is well timed, so that we happen to catch the knots in this short-lived evolved state. If so, we should see the discovery of many more knots that are O-star rich as our statistical sample improves.

On the other hand, the ratio may be telling us something new and surprising about the evolution of massive stars. HST studies of the cluster R136 in the Large Magellanic Cloud provide some evidence in this direction. Once suspected of being a single supermassive star, this has been recognized for several years as a very dense cluster of young massive stars. It is now possible to exploit the HST's ultraviolet response and high resolution to obtain spectra from the individual stars in this dense cluster. A spectrum of one of them, the O3 star R136a5, yields an estimated mass-loss rate of 2×10^{-5} solar masses per year, about five times what was expected (S. Heap, NASA Goddard Space Flight Center). If continuous, this mass-loss rate is large enough to dominate the early evolution of the star, having even more effect than does thermonuclear burning.

Another clue that something is amiss in our understanding of the evolution of massive stars comes from Eta Carinae. Continuum images obtained with the refurbished HST confirm the bipolar nature of its outburst last century and reveal fragments of a disk that axially confined the explosion. Analysis of historical data had shown that the energy of the explosion about 100 years ago corresponds to the energy now observed in the flow, about 10^{49} erg. New data, especially spectroscopy from the HST, reveal the star itself for the first time (K. Davidson, Univ. Minnesota; D. Ebbets, Ball Aerospace). It is a roughly 100-solar-mass star at about 25,000 K and with a wind of about 3×10^{-4} solar masses per year. This type of star seems able to produce an outburst of supernova luminosity more than once.

Theoretical developments were highlighted in two special sessions on dynamics and on supercomputing in astronomy. The latest supercomputing efforts in hydrodynamic cosmology seem naturally to predict galaxy formation with a scale-dependent bias in a variety of models (J. Ostriker, Princeton Univ.), under reasonable but idealized treatments of small-scale physics. The bias appears as elevated contrast: dense regions have an enhanced ratio of galaxy density to dark matter density. This is worrying, as a choice of cosmological model is sometimes dictated by comparing simulations to the evolution of structure with redshift over modest look-back times. Questions remain, however, about the fidelity of simulations of large-scale structure, even in the most extensive simulations yet made (G. Lake, Univ. Washington).

In stellar structure, too, simulations of turbulence appropriate to understanding convective layers in stars fall well short of the required dynamic range, as the largest structures may be over 100,000 kilometres across and the dissipation of energy occurs on scales of 100 metres. Nonetheless, successes in understanding rotationally constrained turbulence through increasingly realistic simulations lend some hope of resolving certain issues, for example the disparity between the rotational pattern in a convective region expected from theory and 'observed' by helioseismology (J. Toomre, Joint Institute for Laboratory Astrophysics, Colorado). And the application of two-dimensional hydrodynamics deeper in more massive stars (W. D. Arnett, Univ. Arizona) shows that chemical inhomogeneities develop in the oxygen-burning shell before core collapse, strongly affecting the nickel yield during the supernova explosion. Like the HST, supercomputing seems to be on the verge of improving our understanding of stars and the Universe. □

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GEOLOGY

The new treasure seekers

Anthony E. Fallick

For the preparation of emerald: mix together in a small jar ½ drachma of copper green (verdigris), ½ drachma of Armenian blue (chrysocolla), ½ cup of the urine of an uncorrupted youth and ⅔ the fluid of a steer's gall. Put into this the stones, about 24 pieces weighing about ½ obolus each. Put the lid on the jar, seal the lid all around with clay, and heat for six hours over a gentle fire made of olive-wood...You will find that they have become emeralds.

TIMES have moved on since this recipe for gemstone enhancement appeared in the *Papyrus Graecus Holmiensis*[1], but emerald formation still holds some surprises. Work by Ottaway *et al.*[2] (page 552) and by Giuliani and his colleagues[3–5] shows that a new consensus seems to be emerging for the mode of formation of Colombian emeralds which implicates the interaction of basinal fluids with evaporites and organic-rich sedimentary horizons. Because this contrasts so forcefully with the conventional granite–greenstone model for pegmatite-associated emeralds and beryls, and removes the requirement for related igneous activity, it could well have profound consequences for exploration strategies.

According to J. R. Sauer[6], emeralds are the gemstone longest known to man (having been mined in Egypt about 5,000 years ago); they are much rarer than diamonds and, weight for weight, have a value thousands of times that of gold. Colombian emeralds are especially prized for the intensity of their colour, and this country has become the world's most important emerald producer, with registered exports worth 63 million US dollars in 1987 (ref. 3); stones from the inhospitable Muzo mine area set the standard against which others are compared. Herein lies an enigma, because the Colombian emeralds are found in sedimentary rocks and are not obviously associated with igneous activity, whereas emeralds elsewhere in the world are commonly found in coarse-grained dykes (pegmatites) intimately and genetically related to magmatic processes (see, for example, ref. 7).

Emerald is the chromium- (and vanadium-) rich variety of the mineral beryl, $Be_3Al_2Si_6O_{18}$. Because the Be^{4+} ion is too small to substitute in most silicate lattices, it is concentrated in residual fluids associated with crustally influenced acid magmas such as granites. If

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