Making physics more fundamental

Bologna's Palazzo Re Enzo was the historic setting for this year's CERN/European Southern Observatory (ESO) Symposium on Astronomy, Cosmology and Fundamental Physics.

The stellar death throes of supernovae have been seen and admired since time immemorial. However last year's (1987A, May 1987 issue, page 1) was the first to come under the combined scrutiny of space-borne radiation detectors and underground neutrino monitors as well as terrestrial optical telescopes and even gravity wave antennae. The remarkable results underline the power of modern physics to explain and interrelate processes in the furthest reaches of the cosmos and the deep interior of nuclear particles.

In recent years this common ground between 'Big Bang' cosmology and particle physics has been regularly trodden and retrodden in the light of fresh new insights and new experimental results, and thinking has steadily converged. In 1983, the first Symposium on Astronomy, Cosmology and Fundamental Physics, organized by CERN and the European Southern Observatory (ESO), was full of optimism, with new ideas ('inflation') to explain how the relatively small variations in the structure of the Universe could have arisen through the quantum structure of the initial cataclysm.

In 1986, the second Symposium paused for reflection in the light of new results from satellite-borne experiments, showing new evidence for large-scale asymmetries in the universal distribution of galaxies, tying in with a curious directional effect in the microwave background radiation (the fossil relic of the Big Bang).

The third Symposium, held in Bologna in May to coincide with the celebrations of the university's 900th anniversary, hinted at a further new threshold in understanding. Fundamental theorists, looking at physics on the widest scale, need theories encompassing all the forces of Nature.

Although the confirmation of the 'electroweak' unification of electromagnetism with the weak nuclear force by experiments at CERN in 1983 was a major step forward, fundamental theorists also need to bring in the strong nuclear force – inter-quark attractions – into the picture, not to mention the classic enigma of gravity, the dominating factor in the large-scale structure of the Universe.

After many years of ups and downs, with fundamental theorists often more concerned with detailed mathematics than with reality, Dimitri Nanopoulos of Madison (Wisconsin) came to Bologna with 'stunning' developments to report.

Universal theories first have to synthesize electroweak and quark effects, not conceptually difficult as the electroweak picture has shown the way, but an awesome dimensional gap has somehow to be bridged. To sugar this bitter pill and to open the door to gravity, theorists turned to new ideas. 'Superstrings' use one-dimensional strings rather than infinitesimal points as the pawns of the game. The other unorthodox step involves abandoning the 'classical' view of particles as either 'fermions' – carrying half units of spin angular momentum and obeying the famous Pauli Exclusion Principle – and 'bosons' – integer spins with no quantum occupancy restrictions. In supersymmetry, each fermion is allocated a boson partner and vice versa. Doubling the number of particles in this way opens new mathematical avenues, and although no supersymmetric particle partners have been seen so far, this flexibility gives physics scope too.

Hitherto devoid of predictive

Dimitri Nanopoulos – 'stunning' new results.

power, this superstring approach has been dogged by problems of too many dimensions, requiring all sorts of 'compactification' dodges to somehow map ultra-dimensional worlds onto the modest four dimensions that we know. However new approaches to invariance and consistency have shown how to build four-dimensional superstring pictures, and using an alternative method of embedding the unification of electroweak and quark forces, real results seem to follow.

Nanopoulos startled his Bologna audience with theorists' predictions of the mass of the unseen sixth ('top') quark in the range 70-90 GeV (in line with experiments so far), while the 'heavy' tau- and muon-type neutrinos are attributed with masses of a few electron-volts, and the light electron-type version could weigh as little as 10^{-8} electronvolts, small to be detected directly but still full of cosmological import.

Ten years ago, before the electroweak unification had even been confirmed, bold theorists were toying with the unification of the electroweak and quark sectors, predicting that the proton would be unstable. At some 10^{32} years, this lifetime dwarfed even the estimated age of the Universe (conventionally measured in Giga – 10^9 – years), but no problem to accommodate with so many protons available.

In three continents, new underground experiments were built or existing ones modified to provide the intense shielding from random cosmic rays to search for nucleon (proton) decay. However no convincing evidence for proton decay has been seen in many years of patient search, and the proton has been given a new lease of life.

The new formulation of unified theory now predicts a proton lifetime of some 10^{35} years, holding out new hope for the next generation of bigger underground detectors. With no positive evidence to report, Nucleon Decay (ND) searches had reconfigured as Neutrino Detectors, and the neutrino sighting from last year's supernova was cynically heralded as one of the greatest success of the old theory of electroweak/quark force unification. With the unstable proton now back on the theoretical map, and with big new underground detectors being prepared or proposed, the ND label could revert to nucleons.

However these stimulating new ideas are still highly speculative and could yet evaporate as quickly as their predecessors. The front line of established physics is still the 'Standard Model' – a loose combination of the electroweak picture with the field theory of inter-quark forces (quantum chromodynamics – QCD). Roberto Peccei of DESY reviewed the latest experimental results, where evidence for just three types of neutrinos continues to accumulate, and where insights from experiments at the CERN proton-antiproton collider firmly put the mass of the top quark at above 70 GeV.

Impressive, according to Peccei, is the way detailed (radiative) electroweak effects can now hone results, showing excellent agreement between the electroweak parameters measured in fixed target and colliding beam experiments. Consistency arguments based on these calculations show the top quark to be lighter than about 200 GeV, providing a useful upper limit.

Although the sixth quark remains aloof, there is 'excellent indirect evidence', Peccei assured. The subtle asymmetries seen in electron-positron annihilation show that the fifth ('beauty' or 'bottom' – b) quark must have a partner.

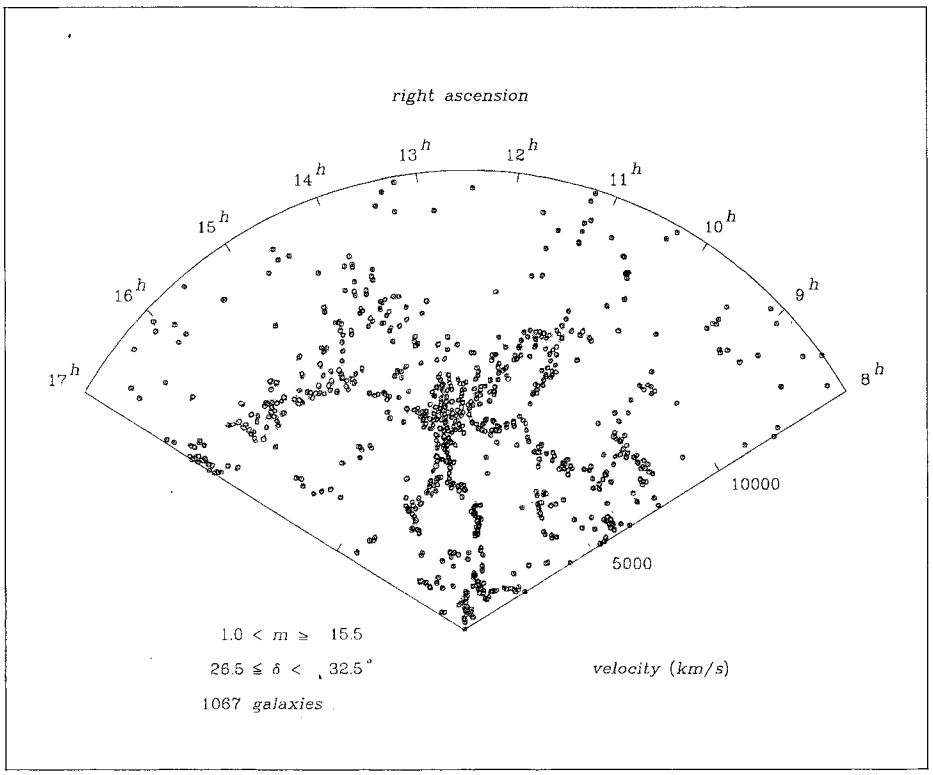
Peccei explored the (Cabibbo-Kobayashi-Maskawa) matrix relating quark and weak nuclear interaction parameters (see page 7), showing how some parameters are in good shape, others less certain.

Supernova

After the initial formation (primordial nucleosynthesis) of light elements in the Big Bang, heavier material is believed to have been cooked in the fiery interior of supernova explosions. A special session at the Bologna symposium was given over to the 1987A supernova, now well over a year old. Former ESO Director L. Woltjer showed how the progressive dimming of the supernova reflects the

Close analysis of slices of the sky shows how clusters of galaxies seem to lie in 'sheets' and 'filaments'.

(Margaret Geller)



radioactive processes at work in the core, with nickel, then cobalt being produced. About 6-7 per cent of a solar mass of iron looks to be the outcome, and when multiplied by the estimated number of such supernovas to have occurred in the history of the Universe, ties in well with the natural abundance of iron, the most stable nucleus, providing a startling bridge between nuclear physics and cosmology.

Complementing the optical tracking of the supernova were results from neutrino (M. Koshiba) and X-ray (Y. Tanaka, J. Trumper) sightings. The neutrino results provide a good test of basic neutrino parameters, while a marked two-fold X-ray spectrum (hard and soft components) needs explanation.

Wolfgang Hillebrandt of Garching showed how theoretical understanding of the 1987A supernova is assisted as this time the progenitor star of the explosion is known, although the picture is still far from complete ('weather forecasts are always difficult').

Another intriguing supernova effect is the report by the Rome group operating a 2300 kilogram gravity wave detector of correlations between impulses recorded in their apparatus (and in the Maryland, US, instrument) and neutrino signals from the detector in the Mont Blanc tunnel.

Astrophysics

In contrast with Peccei's rich harvest of particle physics data, Alan Dressler of California's Mount Wilson Observatory added the latest chapter in the painfully slow determination of basic cosmological parameters. In the late 1920s, Edwin Hubble opened a new era in cosmology with his discovery that stars recede at a rate proportional to their distance.

The proportionality (the Hubble constant) has moved over the years as observational astronomy has improved, but with star brightness and distances difficult to quantify, stubbornly refuses to be fixed. However when local variations are added to the main Hubble flow, Dressler showed how the picture looks tidier, with less scatter between different observations.

With an expanding Universe, one question is whether it can continue to expand, or whether there is enough gravitational interattraction between matter for it one day to reach some critical limit and become 'flat'. While there is lots of prejudice supporting this idea, 'there is lots of evidence against it,' remarked Dressler.

Margaret Geller showed remarkable large-scale structure in the distribution of luminous matter. Looking at slices of the sky ('red-shift surveys'), the clusters and 'superclusters' of visible galaxies seem to lie in 'filaments' or 'sheets', with intervening voids, themselves expanding at thousands of kilometres per second. Analysis of neighbouring slices shows clearly that these structures are real, and not just some statistical accident. Explaining such marked effects by gravity alone is not straightforward, leaving loopholes for additional 'explosive' forces.

Bruce Partridge of Haverford College took a hard look at the microwave background radiation, the thermal vestige of the Big Bang. Dipole asymmetries in the observed pattern of radiation point to local motion, with no comparable quadrupole effect to suggest directional matter expansion as the culprit.

Wandel & Goltermann

Electronic Measurement Technology

Have you got an ISDN data analyzer that can cope with all your service, test and development needs?

The new DA-20 is different. New style design, new features. Ready for ISDN, compact and versatile. The DA-20 is a go-anywhere unit for R&D, service, maintenance. For analysis, simulation, emulation, statistical evaluation and much more. Some other features: ★ data store handles online recording at up to 72 kbps FDX. ★ easy to use with autoconfigure, postprocessing and device setups ★ remote controllable ★ big LC display ★ state programming. If you are interested in learning more about the DA-20, just send off the coupon for detailed information.

Wandel & Goltermann (Schweiz) AG, Postf. 254, 3000 Bern 25
Tel. 031-42 66 44, tlx. 912 350 wgch, Fax 031-42 61 33

☐ Please send DA-20 color brochure
☐ Please arrange for a sales engineer to call.

Name .....

Company .....

Street .....

Town .....

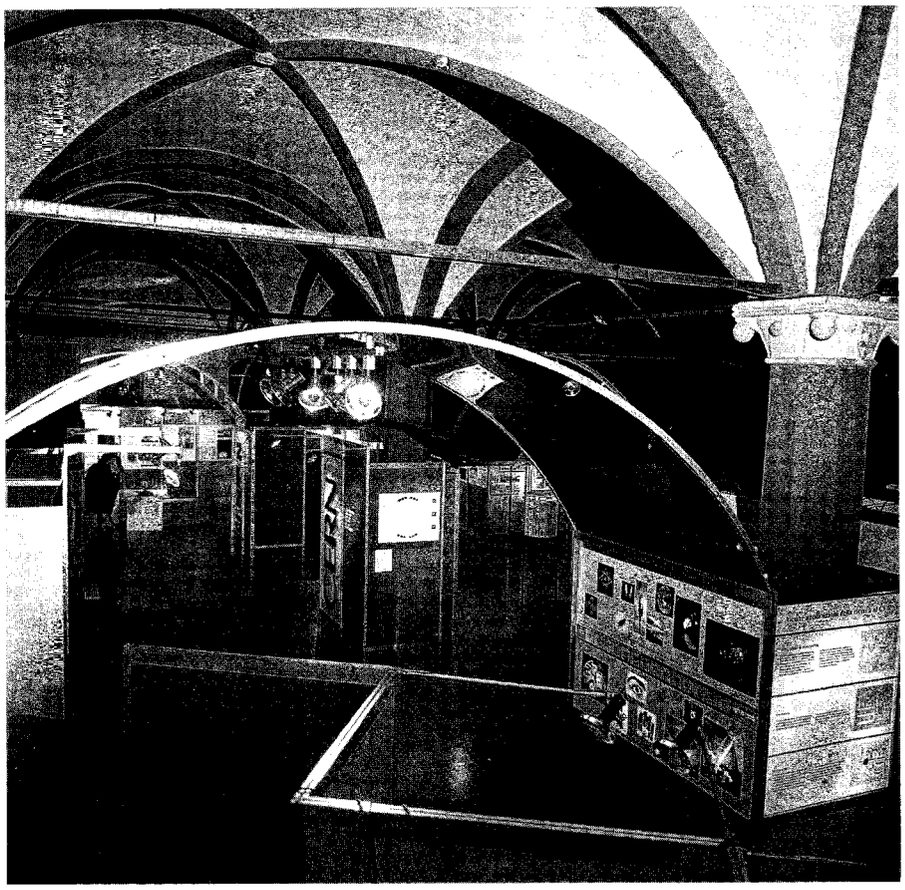
Telephone no. ..... E 7423 K

The remaining signal is uniform to less than one part in a thousand over a wide range of wavelengths, but Alexei Starobinsky of Moscow's Landau Institute preferred to wait for measurements from new Soviet space studies probing down to one part per million. In his talk, Starobinsky pointed out the range of 'inflation' theories now on the market.

Recent rocket-borne studies looking at sub-millimetre wavelengths see a marked effect, which could be a distortion in the microwave radiation itself or the onset of a new signal from rapidly receding intergalactic dust, nothing directly to do with the Big Bang.

Nostalgia came from Fred Hoyle, once an advocate of the 'Steady State' picture of the Universe, now abandoned in favour of the Big Bang idea. Had this never happened, he pointed out that the new information gathered in the meantime might have made it more difficult to revoke the Steady State idea!.

The CERN portion of the public exhibition held in parallel with the Symposium.



More light on dark matter

More than half a century ago, analysis of stellar motion and the visible distribution of galactic matter first showed a basic incompatibility – more matter is required than meets the eye. The concept of invisible 'dark matter' was born. More support came from Big Bang calculations of nuclear synthesis.

New ideas (April issue, page 25) have provided a new scenario which lessened the need for 90 per cent of the Universe to be invisible,

Former CERN Director-General Leon Van Hove received an honorary doctorate from the 900-year old Bologna University at a ceremony marking the end of the ESO/CERN Symposium. Former ESO Director L. Woltjer was also honoured.

Participants at the ESO/CERN Symposium pose in front of the CERN bubble chamber mosaic, part of the exhibition organized in parallel with the meeting.

but at Bologna Paris astrophysicist Hubert Reeves pointed out incompatibilities with the observed levels of lithium-7.

Cambridge astronomer D. Lynden-Bell was 'sceptical' of measured light element levels. He also underlined differences in the matter distributions measured optically and through the IRAS infra-red astronomy satellite. While the optical results need dark matter support, the infra-red data taken at face value might not. Rather than using this as evidence against dark matter, Lynden-Bell pointed out the inherent difficulties ('underclustering') in infra-red source counting.

Chicago astrophysicist Michael Turner surveyed the candidate list for the missing 90 per cent of the Universe. 'Even if you buy the idea of all baryons, where do you put them?' he challenged. Neutrinos figured high on Turner's list, an alternative not viewed as too exotic by symposium summarizer Leon Van Hove of CERN.

New hope for revealing matter in the outlying regions of the Universe came from B. Fort of ESO, showing how rich clusters of galaxies can act as natural 'gravitational telescopes' to amplify and image the faint light from more distant objects. After initial investigations, further careful analysis has picked out extremely faint contributions due to additional star-forming galaxies far beyond the usual range of vision.

For particle physics, Fermilab Director Leon Lederman sketched the range of experiments in progress or in preparation at his Laboratory, while Enrico Bellotti outlined the physics studies being readied at the new Italian Gran Sasso underground Laboratory.

The cosmic scope of particle physics ideas was indicated by Abdus Salam in his introduction, chaired by Bruno Pontecorvo, and underlined by summarizer Leon Van Hove, who also drew attention to other recent particle physics and astrophysics results, such as the new data from CERN on the distribution of intrinsic angular momentum (spin) deep inside the proton (June issue, page 9), and the information learned from satellite monitoring of Halley's Comet in 1986.

With the same laws of physics holding good over some fifty powers of ten of distance, and with new breakthroughs in understanding on the horizon, the frontiers of physics seem to be converging.

Report by Gordon Fraser

SERPUKHOV Experiments for UNK

With half the 21 kilometre tunnel for the UNK accelerator at Serpukhov, near Moscow, now excavated and with completion expected some time early in 1990, attention is now turning to the experiments to exploit this latest addition to the front rank of the world particle physics scene.

While work on UNK has been underway for some time, construction was given a boost last year by a top-level Moscow decision (January/February issue, page 3). With Soviet accomplishments in other areas of technology so impressive, such a move should considerably benefit high energy physics.

The 400 GeV UNK booster ring (maximum energy 600 GeV) of conventional magnets could be ready as early as 1990, with the 3 TeV beams from the superconducting ring following 3 years later. The addition of a second ring will provide 3 TeV colliding proton beams (6 TeV collisions) in the middle 1990s.

An international meeting at Protvino last year highlighted the physics opportunities that the new machine would offer (May issue, page 1).

Some initial UNK experiments have now been approved, although in some cases further details remain to be fixed, while the green light for further experiments could follow later this year. Already playing a significant role in experiments at other world centres (in particular the Delphi and L3 experiments at CERN's LEP electron-positron collider have Soviet contributions), Soviet scientists are keen to have international collaboration at UNK.