scopes: they should be diffraction limited, also in the UV.

The real breakthrough will come when assembly and maintenance can be done in space (on the moon?). HST has made very clear the limitations of pre-assembly and control from the ground.

For individual telescopes, active optics is essential and also the simplest and cheapest solution. HST, I think, proves this clearly. Since there is no atmosphere, *no* adaptive optics is required: it is meaningless. But the harsh thermal environment makes active optics even more necessary than on earth. It also becomes easier in the absence of the disturbing effect of local air: In space, the NTT could go immediately to the diffraction limit even in the UV and be maintained there with simple technology.

Assuming the existence of bigger diffraction-limited telescopes in space after the year 2000, they should be unbeatable for direct imaging of deep, faint objects until a complete solution of adaptive optics is available. Even then, the complete absence of atmospheric turbulence and absorption are bound to give the edge on space observation for direct imaging. However, cost-effectiveness will still mean many observations will be better performed by ground-based telescopes. Space is also the natural environment for interferometry whose success on earth is closely linked to, and dependent on, the advances in adaptive optics.

Wide-field telescope projects in space have been mentioned at this conference and will certainly be carried out. The quality requirements will be far higher than those of any existing ground-based Schmidt telescopes.

Ideas and technologies that will remain a phantasy for high quality ground-based telescopes may be investigated and become a reality in space, e.g. plastic film reflectors with a fixed (dc) or slowly varying active corrector for small fields. Maybe "longer" telescopes may come back since "length" in a weightless environment is of less consequence. The technical possibilities are far wider than for ground-based telescopes.

3. Optical Design Developments

Optical design solutions for telescopes are effectively worked out: it is most unlikely that new design solutions will emerge. Developments will come rather from advanced technologies to realize known designs with higher precision.

X- and Gamma-Ray Astronomy Beyond the Year 2000

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Astronomy should progress in a balanced way. This simple statement needs no proof beyond the simple reflection, for example, on the importance for cosmology of the joint radio, optical and X-ray studies of extragalactic sources. Thus, in view of the impressive progress now being planned for the turn of the century at all wavelengths, both from the ground and from space, it is logical to think also of the goals of high-energy astronomy, in X- and gamma-rays.

Celestial objects happily carry on emitting their energy at the wavelength they please, but astronomers have to worry about how to do astronomy with photons that are widely different in their interaction/detection processes. For example, there is a basic difference between X- and gamma-ray photons: while X-ray photons can be focussed by a sufficiently smooth surface, gamma rays cannot because their wavelength is small compared to the interatomic distances in solids. Thus, X-ray astronomy can, and must, rely on focussing telescopes (of ever increasing throughput and angular resolution) and clever focal plane detectors for doing both imaging and spectroscopy of the X-ray sky. This has been the winning recipe introduced by the Einstein Observatory, currently used in the ROSAT mission, and also adopted by the "great observatories" in X-ray astronomy of the end of this century: NASA'S AXAF and ESA's XMM.

To speculate realistically on the future of X-ray astronomy beyond such great observatories, means to think of what more can be done using the same technique. Firstly, the optics. Of course, high throughput, essential for high sensitivity, means light-weight material, with all the technological complications involved. Very high (i.e. sub-arcsec) angular resolution will also be mandatory for matching the source positioning at other wavelengths. Such high resolution should be maintained over a wide enough field of view, in itself a big challenge, only now being seriously tackled; but not yet solved. Finally, the focal plane detectors should afford an excellent spatial resolution, so as to correctly oversample the telescope's PSF, but, most importantly, should also have a very high spectral resolution, since accurate spectroscopy will remain a key issue in the X-ray astronomy of the future.

It is difficult, at the moment, to imagine an X-ray observatory with the above characteristics without thinking of a "bigger and better" combination of AXAF and XMM: high-throughput (tens of thousands of cm^2), optics with high resolution (sub-arcsec) over square degrees FOV, suitable imaging detectors, and spectroscopy with resolving power in the several hundreds. However, it is also difficult to imagine how such a mission could be designed and realized in the current framework of research from space, given the financial and practical constraints within which national and international Space Agencies have to move. No concrete sign for the birth of an idea of such a mission exists at present.

A possibly even more realistic approach would be to specialize missions by splitting the science objectives. For example, a pilot mission centred on high-resolution, wide-FOV imaging, dedicated mostly to extragalactic work, is currently being studied in the context of an Italy-U.S. collaboration, with manageable dimensions and reasonable budget. Complementarily, a mission dedicated to high-resolution spectroscopy of selected sources could capitalize on the wealth of imaging results presumably available in X-ray astronomy by the end of the century.

For gamma-rays, on the other hand, the situation is quite different. Because of the severe limitations posed by the physics of the detection process as well as by the intrinsically poor astronomical signal-to-noise situation, gamma-ray astronomy is only now leaving the exploratory phase, with the imminent launch of GRO, the first gamma-ray Great Observatory. On the eve of such a

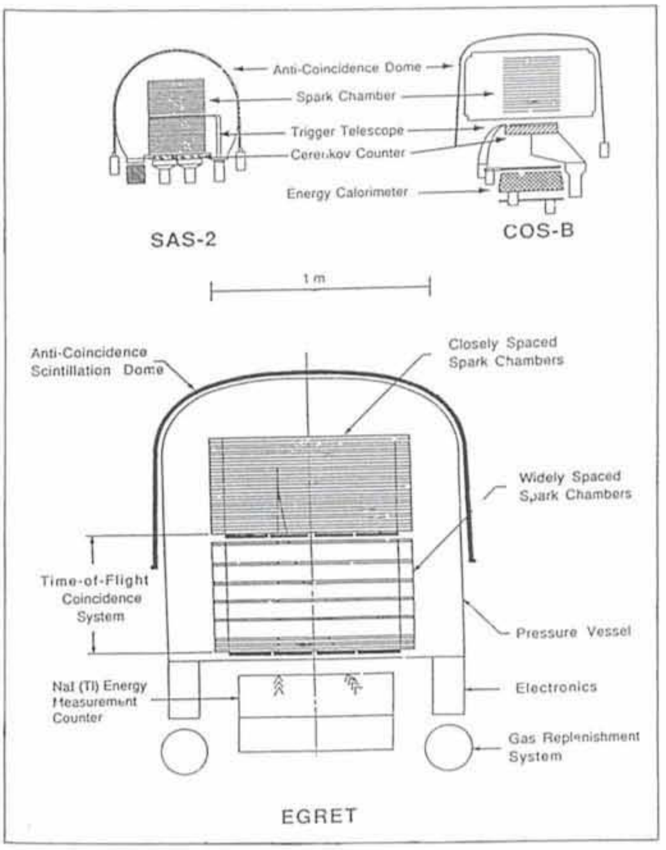

Figure 1: *Schematic drawing, to scale, of the three main gamma-ray astronomy space chamber experiments: SAS-2 (1972–1973), COS-B (1975–1982), EGRET (1991– . . .).*

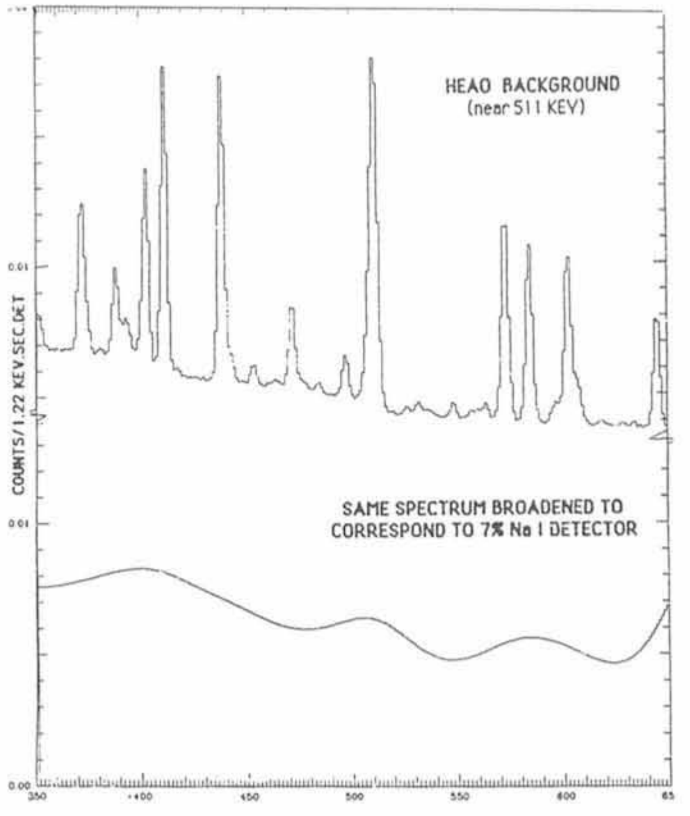

Figure 2: *The effect of high spectral resolution: Upper curve: true background spectrum as seen with the HEAO-3 Germanium detector, with $\Delta E/E \sim 1/500$. – Lower curve: the same spectrum folded through the ~ 7% resolution of a "standard" Na I detector.*

launch, it is of course difficult to say precisely what GRO, with its complement of instruments, will be able to achieve. It is probably easier to speculate on what it will not, because it cannot, achieve.

Here again, as usual in astronomy, it is a matter of sensitivity, background rejection, angular resolution and spectral resolution. For gamma-rays, sensitivity can only be achieved by brute force, i.e. by increasing the exposed square centimetres. In this GRO does quite well, at least within the practical limits of what can be flown on a space mission. For the high-energy experiment (EGRET, sensitive above few tens of MeV), based on the classical spark chamber technology, a straight comparison can be made with the earlier SAS-2 and COS-B missions, showing an increase in the exposed surface of more than a factor of ten (see Fig. 1). Background rejection is also achieved very well on GRO, with different techniques according to the type of instrument and energy range.

However, it is in the field of angular and spectral resolution that the majority of post-GRO efforts will have to be done. The only way realistically applicable for increasing angular resolution in gamma-ray astronomy is the use of the coded mask technique. Conceptually, this is an extension of the pinhole camera, i.e. of an infinitely-small-aperture collimator centred on the source to be observed. A coded mask is a collimator consisting of roughly half open spaces and half absorber elements arranged in a quasi random, repetitive pattern. A source in the sky will cast the shadow of the absorbing mask onto a detection plane, located at an appropriate distance and capable of sufficient positional resolution. By applying suitable image unfolding techniques, one can then reconstruct the real source distribution, with, of course, the limitations imposed by the instrumental and sky backgrounds. Within the payload of a near future gamma-ray astronomy space mission, a coded mask with cm-size elements could be placed at several metres from the detection plane, for which the technology is already in hand which yields positional accuracies of a few millimetres. The resulting angular resolution or, better, the instrument's source location capability can easily reach the arcminute level or better, depending on signal-to-noise and source statistics.

An ideal new-generation gamma-ray astronomy telescope should not only be able to improve dramatically (by a factor of about 100) the source positioning via the coded mask imaging, but should also have good spectroscopic capabilities. This is especially disirable in the few MeV range, where nuclear lines promise a new tremendous potential for astrophysics, still virtually untapped.

Very good energy resolution can already be obtained with solid-state (Germanium) cooled spectrometers, reaching a resolving power of nearly 1000 at about 1 MeV. The improvement over existing, classic scintillator spectrometers, for example Na I crystals, is spectacular: Figure 2 shows the effect of Germanium-type resolution on a real spectrum in the nuclear line region. Current technology is beginning to allow the construction of Ge spectrometers in a mosaic of separate elements of dimensions of few centimetres, or less. It is thus conceivable to use such a mosaic as the detection plane for a coded mask telescope, thus coupling high angular and spectral resolution. Indeed, a mission based on the design outlined above, and with the adequate sensitivity, is currently being assessed by the European Space Agency under the name of INTEGRAL, the INTErnational Gamma-RAy Laboratory. Its timing appears good, coming as it does, just after the GRO will have exploited a maximum in the classical way of doing gamma-ray astronomy.