IV.

INSTRUMENTATION – COMPONENTS

OPTICAL AND INFRARED INSTRUMENTS REQUIREMENTS FOR A VLT

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INTRODUCTION

I have been asked to remark on the instrumentation which, at least from the viewpoint of the 1980's, seems most important for early implementation on a VLT in the 1990's. To avoid simply making a long list of many possibilities, each of which has some advantage over its competitors, I will divide the discussion into three parts: a summary of the principal observational advances made possible by a VLT in the 15-20 meter class; a list of what is arguably the resulting basic set of needed instruments; and a brief consideration of the telescope design features, technology development programs, and political/financial efforts required to make those instruments a reality.

ADVANCES WITH A VLT

The interesting observational advances made possible with a VLT may conveniently be devided into two catagories: those for which very large - factors of ten and more - technical advances may be anticipated, and those for which one expects to cross some threshold with a VLT. Observational programs in the first class may be expected to open whole new fields of study, unappreciated at present, whereas those in the second may be planned now, to answer the questions of today.

Factors of ten and more

Two areas gain most from a VLT: spatial interferometry, because the increased baseline provided by the size of the telescope promises a substantial increase in the attainable spatial resolution (even over Space Telescope), and non-background limited spectroscopy, where the increased collecting area may be employed to full advantage.

It is difficult at the moment to predict the importance for a VLT of the different interferometric techniques. One may argue that the VLT-design should be driven by aperture synthesis requirements, because filled dish designs will yield gains in resolution of only a factor of a few over existing 4 and 5 meter telescopes. This point of view clearly has some merit, but useful high resolution mapping of sources more complex than a few clustered point sources will be possible only for rather bright objects, which in the optical means the discs of the brighter stars. These objects are known to vary on timescales of hours to

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days, raising the problem that any aperture synthesis scheme will need to fill its uv plane in a time on the order of an hour. Given the inherent difficulties of coupling simultaneously more than two separately mounted telescopes, it is very uncertain how well this requirement can be met, other than with a filled dish or MMT-type design. My feeling, therefore, is that optical aperture synthesis is neither mature enough as a technique, not has a convincing enough scientific potential, for it to drive the VLT design.

Filled, or nearly filled, dish interferometry using speckle techniques, on the other hand, clearly does show strong promise. Imaging spectroscopy at resolutions of better than 0.01 arcsec can be expected to contribute at least as much to understanding stellar mass loss physics as the opening up during the last decade of the middle UV via spacecraft. One may also anticipate major progress with such imagery in assessing the influence of rotation and magnetic fields on stellar evolution, and in studing the physics of convection in the stellar context. I think one has to consider the speckle technique now to be in the state that radio aperture synthesis was in the 1960's: it is known more or less what can be done with the technique, but an adequately strong effort has not yet been made to implement a high performance production instrument. I predict that the timescale for full development of the speckle technique for imaging and spectroscopy, even for the filled aperture case, may turn out to be comparable to that for construction of the VLT. And of course just as has been the case with other techniques as they develop unanticipated possibilities are likely to appear as its full potential is realized.

The situation for interferometry in the thermal IR is quite different. Here the atmosphere is much less of a problem, and heterodyning techniques may even be employed if desired. The case for an aperture synthesis instrument, therefore, seems very strong. We are thus in the position of needing different sorts of telescope for the two wavelength regimes. I do not think it would be wise to construct one VLT which tries to do both problems - the compromises required of each technique would just be too great. My impression is that optical regime scientific possibilities are on balance more important, and I will therefore concentrate where appropriate in the following on a VLT not optimized for aperture synthesis.

If questions of interferometry with a VLT are complex and not entirely agreed, the potential for non-background limited, high resolution spectroscopy is undisputed. In the optical, we can anticipate being able regularly to observe stars with resolutions high enough to resolve intrinsic line widths completely, and eliminate many of the problems of inadequate resolution and inadequate S/N which have plagued abundance and stellar atmosphere analyses to date. There will be enough light for spectropolarimetry to become a standard weapon in the obser-

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ver's arsenal, and for radial velocity precision to improve to the point where all kinds of previously unattempted analyses become possible.

Even greater relative advances may be expected in the near-IR if the detectors in this region remain detector noise limited. And if the promised availability of IR arrays is realized, we may look forward to mapping velocity and excitation fields in star forming complexes, and so determine the important physics of the intermediate stages of star formation, between the molecular cloud phase and the emergence of a visible, nuclear burning star. It is not inconceivable, in fact, that seeing compensation or interferometric techniques can profitably be exploited in this regard, and perhaps even show us where the angular momentum goes!

Thresholds

Any large step up in telescope capability also often brings with it the possibility of moving from marginal study of the few brightest members of a class to adequate investigation of much larger numbers of fainter members. In some cases there are good reasons to believe that crossing such a threshold may lead to very substantial progress in scientific understanding. I point here to two examples which seem to me of particular significance, sufficient in themselves, in fact, to justify the construction of a VLT.

The first of these concerns evolution in the Universe. We now have ample evidence that galaxy populations have changed in important ways since epochs corresponding to a redshift of roughly a half. This evidence first appeared in studies of radio galaxies and QSO's, but now has been extented to include high redshift clusters of normal galaxies (e.g. Butcher and Oemler 1984) and the high redshift field population (e.g. Shanks et al. 1984), and even, evidently, the histories of nearby dwarf galaxies as inferred from their main sequence luminosity functions (e.g. Stryker 1983; Mould and Aaronson 1983). Because distant galaxies remain extended objects at least to redshifts of order one, the study of their integrated properties, in particular their spectra, will be the province of a VLT rather than Space Telescope. Existing instruments on large telescopes have a very tough time obtaining decent spectra of any but the very brightest galaxies at $z>0.5$. Little improvement can be foreseen in the relevant instrumentation, so here is a clear threshold to be crossed with a VLT. Perhaps more than any other area, the study of galaxy evolution and its relation to the evolution of galaxy clustering cries out for a VLT.

The second important threshold I see is in the field of stellar evolution. Solar astronomers have recently shown us that the interior structures of normal stars are accessible to observation via stochastically exited, low amplitude global oscillations. Here at last is the chance to put some solid observational con-

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straints (beyond the overall properties of the Sun and consistency with cluster HR diagrams) on the theory of stellar structure and evolution. I may be overly cynical in this regard, but it seems to me that large areas of our understanding about stellar evolution could be quite wrong, and without additional observational input we would never know it. So I count this development as of fundamental importance to astronomy. If one supposes solar type oscillations (~1m/sec total power and 5 minute timescales), then a 4-m telescope collects enough photons to do this sort of seismology on stars to roughly second magnitude. A real cross-section of the stellar zoo doesn't become available, however, until a VLT is built, and stars to fifth magnitude are studied. Between now and completion of a 1990's VLT, we have just time to perfect the observational technique on existing facilities, and delineate where the most promising avenues of work will likely be with the large telescope.

As an aside, let me express the view that an observationally verified theory of stellar evolution could prove to be the most reliable of the cosmological chronometers. In the absence of a proven site for the r-process, and given the uncertainty about whether galaxies evolve as closed systems, the radioactive chronometers only tell us that the age of the elements is somewhere in the range 8 to 16 Gyr. And while we all hope ST will help determine H_o more accurately, the value found will in the end remain only a locally valid one, with extrapolation to high redshift relying on models for galaxy evolution. So it is at least possible now that stellar evolution theory can be proved and improved to the point that it can confidently set the timescale for cosmology.

Besides these two clear cases, there are of course many other potentially important thresholds to be crossed with a VLT. Just to scratch the surface, one might mention that the flux collecting power of a VLT will all of a sudden permit spectropolarimetry of large numbers of Seyfert nuclei and QSO's, which may lead to improved understanding of the broad line region. And high S/N, high resolution spectra of increased numbers of faint, high redshift QSO's may be expected to help in understanding the Lyα forest clouds.

"DAY ONE" INSTRUMENTS

Considerations such as those above lead one naturally to identify a set of key instruments for early implementation on a VLT. The list given below is a personal one, of course, and may not find universal support. At least it can provide a basis for discussion. It does try to make best advantage of what a VLT has to offer that is new, while assuming that any detailed technical uncertainties can be resolved during the years before the telescope is available. To keep the list small, I limit it to the three most interesting instruments each for bright

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time and dark time.

Bright of moon

a) Optical spectro-speckle camera. To exploit the potential for high spatial resolving power in the optical, one clearly wants an instrument capable of imaging the discs and outer atmospheres of bright stars in various spectral features: Hα, CaII, TiO, the continuum, etc. The goal here is to extend the very powerful analysis techniques developed by solar astronomers to other stars. The extent to which velocity fields and magnetic regions can be mapped on other stars is unclear at present, and will depend on the ultimate suitability of the telescope and its site, and on the solution of the rather formidable detector problems involved (i.e. efficient pulse counting with at least 1024x1024 resolution elements). Study of extragalactic sources should also be possible with such a device, but the inherent inefficiency of the technique makes it unlikely that the full resolution on such objects can often be achieved. It is clear that this instrument is a very formidable undertaking, and unless a concerted effort is made by ESO or other major observatories to produce an intermediate, but fully functional version for existing telescopes - to include both a satisfactory, scalable detector and on-line processor - it won't be possible to count on a useful VLT device at an early date. One reason why the speckle technique has not yielded more science to date is that it involves a system complexity substantially greater than most ground-based astronomers and observatories are used to. Exploitation of the technique in the future will therefore require attention not only to technical details, but also to the financial and managerial resources necessary to ensure success.

b) Oscillation spectrometer. Measurement of the cm/sec velocity oscillations relevant to stellar seismology will require a special purpose instrument optimized for the purpose. For efficiency and versatility, one should move away from the atomic resonance cells towards interferometers - Fabry-Pérots or FTS's, which can also be designed to make use of periods of poor seeing and non-photometric conditions.

c) IR imaging spectrometer. The step forward to be made with a VLT and 1-5μ array detectors used for imaging spectroscopy is so great that there is an excellent chance for real breakthroughs in our understanding of star formation to result. Because atmospheric phase errors diminish into the IR, every effort should be made to include adaptive optics seeing compensation in this instrument as well. I suspect a field-widened imaging FTS is the design of

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choice for this spectrometer.

I have not mentioned a general purpose high resolution spectrograph as a day-one instrument, because I personally do not like the thought of the gigantic, mosaicked-grating monster I have heard discussed in some quarters. Such an instrument is probably not worth the cost of its construction, especially since it might delay implementation of special purpose devices with more clear potential for making really new discoveries. My opinion is that one wants to go to interferometers for high spectral resolution on the VLT, and most likely a non-scanning FTS with a Reticon or CCD/CID as detector (a so-called holographic spectrometer). Such a spectrometer would even be quite useful for resolutions of 10^5 and greater on existing telescopes. Someone should build one and see how it works.

Dark of moon

a) Multi-object, faint galaxy spectrometer. To quantify the evolution of galaxies beyond z~0.5, one requires an optically very efficient spectrometer capable of observing many galaxies simultaneously at resolutions in the range 300-1000. Accurate sky subtraction for objects ≲1% of the sky will be needed, and will require extreme attention to detector stability and calibration, to stray light and unwanted reflections, and to uniformity of optical performance across the field of view. To be able to employ the smallest possible apertures for sky suppression, correction for atmospheric dispersion will be a necessity. The device can probably retain prism/grating technology.

b) Solid state array imager (CID). Several groups are now informally reporting limiting magnitudes for broad band CCD photometry on existing telescopes of near $R\sim26^m$ or $V\sim27^m$. The last two magnitudes are in all cases achieved by integrating out detector stability and calibration problems. Clearly if a VLT is to reach its corresponding potential of $V\gtrsim28^m$ - which could be close to the ultimate confusion limit - it will have to have imaging detectors superior to the CCD's in use today. The detector of choice could be the CID, which is definitely superior in photometric performance to the CCD, as well as being easier to manufacture and hence easier to obtain in custom formats. The higher noise of the CID may be reduced by repeated non-destructive readouts, but in any case is less of a problem with the increased sky flux from a VLT. To facilitate stellar work in other galaxies, this imager should if at all possible include a capability for seeing correction via a piezo-mirror or liquid crystal screen. A field of up to half an arcmin with improved seeing could be an enormous step for some photometric (and low reso-

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lution spectrographic) studies in crowded regions.

c) Intermediate dispersion spectrograph. The optical is blessed with an assortment of lines yielding information about gas in one of its most ubiquitous states in the cosmos (i.e. near 10^4K). If for no other reason, a general purpose intermediate resolution ($R \sim 10^3 - 3 \times 10^4$) spectrometer should be a standard instrument on any large optical telescope. For this sort of spectrometer, large wavelength coverage is paramount, so a design resembling existing grating spectrographs will probably result. Some spatial information, in the form of a long slit of, say, 3 arcmin in length, is also important. Finally, as mentioned previously, there is enough light with a VLT for spectropolarimetry to be a standard function of the spectrograph.

REQUIREMENTS

The instrumentation program for a VLT is likely to be of a rather different character from those for existing telescopes. The size and complexity of the instruments, and the increasingly sophisticated demands of the science, point to the need to consider carefully and well in advance what will be needed to realize the program on a reasonable timescale. Here I list some of the more obvious requirements, at least as seen from 1984.

As concerns the telescope itself, the discussion in the preceding sections leads one to several conclusions. Multi-object spectroscopy requires a field of view of at least ten arcmin, with the final field size probably being set by the needs of autoguider or perhaps IR seeing compensation machinery. And while interferometry will be of major interest with a VLT, aperture synthesis techniques should not drive the whole design of the telescope. The thermal IR will remain important scientifically, but the greatest gains are to be found in non-background limited applications. Hence neither should thermal IR requirements overly influence the basic telescope design. Similarly, one can say that for the near-IR, where detector noise dominates, for narrow band imagery and high resolution spectroscopy, where detector dark noise is often a limiting factor, and for very high S/N applications such as deep broad band imagery, where detector stability and signal dependent calibration problems appear, it is important to combine the light from all parts of the telescope <u>before</u> detection. Clearly, the absence of a combined focal position with reasonable field and stable, high quality images is a major flaw for any design. Finally, for a succesful program in interferometry, the site chosen for a VLT should not only have clear weather and excellent seeing, but also long speckle lifetimes. We hear reports of good seeing but fast speckles on Mauna Kea, which means that considerable dispersion does exist among other-

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wise good sites in suitability for interferometry.

On the instrumental side, continued developments in technology are especially needed in the areas of IRarrays, speckle detectors and on-line processors, CCD and CID detectors for the visible, adaptive optics for seeing compensation, and cm/sec stabilities with spectral interferometers. In each of these areas, VLT instruments will have needs which go beyond what is likely to be readily available commercially. Thus we can expect astronomy to move even further into the Big Science league, and we will also therefore have to develop additional political and managerial mechanisms to get the work done. I would not be surprised if a typical VLT instrument will need the same level of resources as a 2-m telescope does today. This means most probably that attention will have to be shifted away from the construction of local or national telescopes, such as have proliferated over the last decade, and towards apparatus for use on a VLT. It seems improbable, in any case, that organizations such as ESO or NOAO (Kitt Peak) will be able simultaneously to build a VLT and manage to develop the suite of instruments needed. A community-wide effort will be required.

Finally, I think it is particularly important not to let two classes of astronomy develop, ground-based and space-based. The difference in technologies will force two organizational structures to be maintained, but a balanced, complementary program will result only if governments and funding agencies perceive a single community which is more or less undivided in its views of what is important, and which cannot easily be set into destructive competition within its own ranks. At the same time we are observing with Space Telescope then, we should all be stressing the ever increasing need for a Very Large Telescope.

References

Butcher, H. and Oemler, A. 1984, Ap. J. in press.

Mould, J. and Aaronson, M. 1983, Ap. J., 273, 530.

Shanks, T., Stevenson, P.R.F., Fong, R., and MacGillivray, H.T. 1984, MNRAS, 206, 767.

Stryker, L.L. 1983, IAUSymp. No. 108, p. 79.

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