CELT Instrumentation Working Group
Quarterly Report No. 1

Ian McLean (UCLA)
Keith Taylor (Caltech)

November, 2000

1. Introduction:

The CELT IWG has met on 4 occasions since the inception of the project and the next scheduled meeting is on November 30, 2000. The co-chairs (Mclean and Taylor) have also independently on several occasions. Jerry Nelson and Rich Dekany have attended several of the meetings.

The focus of discussions have ranged over a number of key concerns including:

- Arrival at a straw-man list of instruments which deserve more detailed study to bring out issues of viability, performance, new technology risk areas and, most critically, potential impact on telescope design; of course, detailed development of instrument designs should flow from a set of requirements based on the science case.
- Choice of accessible instrument foci. In particular, questions concerning desirability of Cassegrain and Prime foci in the context of wavelength range and AO configurations;
- Constraints on scale and curvature of focal planes at instrument foci. Will native image scales place practical constraints on fields of view ? Can instruments easily accommodate strong focal-plane curvature or severe non-telecentricity?
- The mechanical and optical implications of instrument rotation at Nasmyth or Cassegrain;
- Telescope secondary (or tertiary) obscuration;
- Consequences in telescope design implied by a demand for low emissivity IR observations;
- Staging of AO developments and the matching of these capabilities to instrument types. Do AO systems need to be cryogenic?
- What new instrument technologies does CELT imply and what are the implications for their development?

2. Straw-man instrumentation suite:

As reported in previous IWG Minutes, the following list of generic instruments was produced and discussed. The strategy employed was to consider what kind of AO facilities might be present as a function of time. This list of instruments was not generated by a set of science requirements, and is not necessarily a final list.

Seeing-limited instrumentation: (Day 1)

- VISMOS: (Day 1) A visual and near-IR, seeing-limited, multi-object spectrograph with the possibility of working out into the J-band;
- VIS HIRES: (Day 1) A high resolution, cross-dispersed echelle spectrograph, as modeled on Keck's HIRES with the possibility of a fiber or slicer feed;

Single-conjugate AO instrumentation: (Day 1 – assuming adaptive secondary)

- Mid-IR imager
- Mid-IR spectrograph fed by a large monolithic slicer/IFU

Multi-conjugate AO instrumentation: (Day 1.5)

- Near-IR imager with a 2 arcmin. FoV
- Near-IR deployable, cryogenic, IFU spectrograph

Extreme AO instrumentation: (Day 2)

- Visual very high dispersion spectrograph targeting R>>80,000
- Coronographic instrumentation

Polarimetric options in several of these instruments were also discussed.

3. Recent Activities:

1. McLean gave a powerpoint presentation on the work and plans of the IWG at the October meeting at UC Santa Cruz following the Keck Science meeting. Jerry Nelson received a copy of that presentation.

2. McLean and Taylor have met to work on the expansion of the Task List and to participate in the weekly CELT telecons together.

3. The initial focus of the IWG efforts was to raise issues that may affect telescope design e.g. the need for good thermal IR performance, f-ratios and available foci. The IWG also wants to emphasize the (potentially) very large dimensions and weights of CELT instruments, which has implications for their physical location.

4. Very little additional work on the straw-man designs themselves was warranted during the first quarter until there have been further joint meetings to understand the true science

case for CELT. The IWG hopes to coordinate such a meeting with the SWG in the near future. However, the preliminary designs already raise many technical concerns (see below).

5. One issue that is now being discussed by the IWG is the future availability of large format detectors. McLean is studying the InSb and BIB arrays and Taylor is researching the CCD and HgCdTe devices. Array controllers are another concern. Since array controllers are also of importance at Palomar, UCO and Keck, we hope to broaden this discussion to involve other interested parties.

6. The IWG is working to refine its list of Key Technology areas that might require an early investment of resources, perhaps even prior to completion of the study.

7. Our plans for the next 9 months are limited by available technical resources (engineering staff) and by the need for valid input on the science drivers. We will however:

- meet with the SWG and develop the true instrument requirements;
- investigate detectors and detector systems;
- prepare and refine the list of new technologies and identify study needs;
- continue to consider and review "telescope specific" concerns.

Further details of future tasks are given below.

4. Future tasks:

4.1 *Introduction*

It is becoming overwhelmingly clear that considerably more interaction between the Working Groups is required in order to resolve key issues across the project. These include, but are not limited to:

- Resolution of the mid-IR requirement (SWG – TWG)
- Questions concerning IR requirements for the AO systems (IWG – AOWG)
- Finer definition of the science requirements (SWG – IWG)

It is the IWG’s view that a mid-course correction is called for at this stage of the study to allow cross-fertilization and better communication between the groups. We would like to have a workshop in January 2001 in order to make progress on these interface issues and the Science Requirements.

Appended to this document is a Task List, which was produced for the CELT Steering Group in Sep’00.

4.2 *General comments*

To make timely and effective use of the unique capabilities that CELT will offer to observational astronomy, the CELT project will be forced to rely on innovative state-of-the-art instrumentation on its seeing-limited and AO-fed foci. The demands in optical, mechanical and cryogenic engineering implied by the massive scale of CELT itself means that a lack of early, in depth, consideration of CELT instrumentation could lead to an inefficient and compromised utilization of its giant aperture. The danger is that the use of *smart* instruments on 8-m class telescopes could challenge the deployment of *standard* instrument concepts on CELT.

Furthermore, the challenge of equipping a 30-m aperture telescope takes instruments well beyond the point where standard scaling laws apply. Even the factor of 2 leap in telescope diameter from Palomar to Keck would have been enough to create enormous problems were it not for the fact that commensurate (factors of ~2) improvements in site atmospheric conditions and dome seeing control had not been made simultaneously.

CELT, on the other hand, is being designed in an era where almost all that can conceivably be achieved, in terms of instrumental efficiency, to take advantage of the best "free-air" seeing, has already been achieved. Hence the factor of 3 increase in aperture from Keck to CELT really does mean a similar increase in size of seeing limited instruments. *Progress in this area requires significant investment in instrument research, development and prototyping, supplemented through extensive collaboration with industry.* Furthermore, the experience with adaptive optics on Palomar and Keck encourages us to envision a new generation of instruments crucial to the success of CELT.

4.3 *Review of 1st light instrumentation*

While a preliminary list of instruments has been generated, much work is required in:

- refining their functional specifications and performance requirements;
- folding this into the science requirements (as generated by the SWG);
- analyzing the difficulties and risks in developing such instrumentation;
- achieving a first-base design which can elucidate space, weight and service requirements;
- and studying optimal f-ratio and focal curvature constraints.

Furthermore, more work is required in identifying *alternative* or *additional* instrumentation, as spawned from the science requirements and also as inspired by new technological and conceptual developments. Our guiding principle should be the over-riding concern to maximize the scientific return of the first 10 years of CELT operation.

No matter how well the telescope performs, its inherent power to expand our view of the universe will be severely compromised by a lack of attention in this most vital area of instrument efficiency. This will require careful collaboration between astronomers, instrument scientists and engineers. Effective means of communication across these boundaries have to be developed in order to address the issue of optimally instrumenting CELT.

4.4 *Detector developments*

The CELT project brings clearly into focus the need to evolve a detector systems strategy That is capable of spanning the expected evolution of the detectors themselves over the CELT time-scale. Larger formats, quieter on-board amplifiers, lower dark counts and faster read electronics are all necessary requirements for a new generation of optical/IR detectors. Furthermore, novel readout protocols may be anticipated, driven by the demands of active and adaptive optics, and the particular challenges of observing in the near-IR. Naturally, new controllers to match this future generation of detectors will be required. In order to make best use of these devices our goal must always be to develop electronic systems that in no way limit the native performance of the detector, i.e. we need "array-limited" systems. It goes without saying that the current generation of controllers are inadequately specified for such demands; indeed, with the possible exception of ESO's FIERA controller, all existing systems are already significantly in deficit with respect to current detectors both in the optical and the near-IR.

Unfortunately, we cannot rely on the commercial sector to supply CELT's very specialized needs. While cottage industries have been maintained in the recent past to supply systems for some subset of the international astronomy market, their response to the constantly developing needs of science is highly limited. Much expensive in-house, but inevitably non-optimal, customization of the base product is experienced. One of the major goals of the IWG in this context is the development of a set of specifications for CELT detector systems. This is not a trivial task, especially if one is to explore the natural desire to consolidate detector systems across wavelength boundaries.

4.5 *New technologies*

Given the preliminary list of instrument options, and given the general recognition that a 3-fold growth in aperture will require a pro-active attack on new technology of relevance to both the AO-fed and seeing limited case, it is clear that some effort at this early stage needs to be spent on investigating new technologies and techniques judged to have potential benefit. A start on developing such a list has been made, although we have yet to identify those key technologies which would benefit from prototyping at this early stage.

In no particular order an incomplete list includes:

1. Theoretical and experimental studies of volume phase holographic (VPH) gratings;
2. Development of lenslet/fiber based IFUs - concentrating future efforts in the cryogenic IR;
3. Design and prototyping of slicer technologies for deployable IFUs both for optical and near-IR cryogenic applications;
4. AO fed IFUs in near-IR;
5. Investigation and prototyping of inch-worm technologies;
6. Designs for deployment of d-IFU;
7. The use of TIGER-style lenslet arrays for 3D imaging spectroscopy;
8. Refinement of coating technologies (Solgels; Rugate etc);
9. Design and prototyping of Lyot filters for wide-field tunable imaging;
10. Design and implementation of Tunable Echelle Imaging for Z,J,H-band OH-suppressed imaging;
11. Use of cooled FPs for an IR tunable filter imaging;
12. Development of charge-shuffling strategies for CCD observations;
13. Development of charge-shuffling analogues for the near-IR;
14. Evolution in software protocols directed at high quality, pipe-line processing of complex data sets;
15. Evolution of differential imaging and spectroscopy in a variety of forms.

The IWG needs to refine this list and start collecting information from other observatories and industry on the state-of-the-art and future trends.

Real money will need to be spent if sub-contracts to industry are deemed necessary, or if much more detailed optical designs are needed for the final report.

*****

Instrument Working Group Task List:

Terminology:

SR = Science Requirements
S = Science goals impact
T = Telescope design impact
AO = AO capability impact

1. General:

1.1 Identify the range of instruments that optimally satisfy the SRs for the first decade. This has, in part, been done in a preliminary fashion by the IWG, but that initial first-pass needs fleshing out in considerable detail. **[S]**

Notes:

- Await SR doc - when/who ?
- Action PIs for each nominal instrument config to generate base concept and fn. specs (PIs = 4 or 5 staff-months; Elapse time = 1.5 months)

1.2 For all listed instrument types, what are the requirements and constraints on input focal-plane (f-ratio; FoV; pre-AO image quality; AO mode) as a function of wavelength?

In addition, how do these constraints modify the *ideal* science goals? **[T ; S ; AO]**

Note:

- Await 1.1
- Iteration with SWG - no extra resources required

1.3 Given the full range of SRs, what range of instruments is envisaged through the first decade and what space/weight/cooling/power requirements does this imply? **[T ; S ; AO]**

Note:

- Await 1.2 (PI + ME = 10 weeks; Elapse time = 2 weeks)

1.4 What instrument scheduling and deployment modes are to be supported and what impact do such decisions have on telescope and instrument design? **[T ; S]**

Note:

- Await SR docs
- Discussion between SWG and IWG

1.5 What instrument user-support modes are envisaged and what impact do such decisions have on design and cost of instruments? **[S]**

Note:

- Await SR docs
- Discussion between SWG and IWG

1.6 For each instrument type and observation mode, what flux limit goals are set by the SRs and what is the likelihood of achieving these goals in practice ?
NB: Full system modeling (of source, atmosphere, telescope, AO-mode, instrument, detector) will be required. **[T ; S ; AO]**

Note:

- Await 1.2 (PI + Inst.Sc. = 4 months; Elapse time = 1 month)

1.7 Given the SRs, what 2D detector systems (wavelength span, pixel-size, format, speed, noise properties) are foreseen?
NB: This should include primary science detectors & high-speed AO wavefront detectors. **[S ; AO]**

Note:

- Await 1.2 (PI = 1 month ; Elapse time = 1 week)

1.8 What implications do detector characteristics have on electronics controller specifications? For example, is a whole new generation of detector controllers required? **[S ; AO]**

Note:
- CELT must act as a stimulus to generating a new generation of detector controller which, probably, unite the control of optical, IR and AO detectors
- Do we need to generate a coherent plan which satisfies the needs of CELT but which can be developed and proto-typed on Keck and Palomar?
- Await 1.7 (PI + EE = 3 months; Elapse time = 2 months)

1.9 What new technologies are required to be pioneered in CELT instrument development? For example, larger format CCDs, buttable IR arrays, VPH gratings, slicers/IFUs and MEMS devices; 3D detectors. **[S]**

Note:
- Await 1.6 (PI + Instr. Sc. = 2 months; Elapse time = 1 month)

1.10 What are the SRs for full Stokes parameters and how will polarization measurements be handled? **[S ; T ; AO]**

Note:
- Await 1.2 (PI + Inst. Sc. = 1 months; Elapse time = 2 weeks)

2. Telescope specific:

2.1 Given the range of instruments and scheduling requirements, is the available space at Nasmyth a constraint on telescope structure design? Is an elevation axis below the primary mirror an advantage? **[T]**

Note:
- Await 1.5 (PI + ME = 6 weeks; Elapse time = 2 weeks)

2.2 Does the range of instrument types and AO modes argue for interchangeable secondaries? **[T]**

How often could such a secondary mirror change occur and what are the science implications? **[S ; T]**

Note:

- Await 1.5 (PI = 2 weeks; Elapse time = 1 week)

2.3 Do we need other focii (Prime or Cassegrain)? **[T]**

2.4 How do we handle atmospheric dispersion correction, generically on the telescope or within each instrument? **[T]**

Note:

- Await 1.5 (PI = 2 weeks; Elapse time = 1 week)

2.5 What is the relative importance of low emissivity for the IR? What implications does this have on non-IR instruments and telescope/AO design? **[S ; T ; AO]**

Note:

- Await 1.5 (PI + Inst.Sc = 4 weeks; Elapse time = 1 week)

2.6 Will the next generation IR instruments require only LN2 cooling or will the telescope have to be plumbed for closed-cycle refrigerators? **[T]**

Note:

- Await 1.5 (PI + ME = 2 weeks; Elapse time = 1 week)

3. Instrument specific:

3.1 For all instruments -

- Instrument or field rotation **[T]**
- Flexure/stability constraints at various focii **[T]**
- Space/weight constraints **[T]**
- Detector systems
- Cryogenic/cooling requirements
- Auto-calibration and pipe-line data reduction systems

Note:

- Await 1.5 (PI +Inst.Sc. + ME = 3 months; Elapse time = 1 month)

3.2 Wide-field O and IR imagers (Seeing Limited (SL)) -

- FoV (contiguous or not) **[T]**
- Delivered image quality **[T]**
- Optimal sampling
- NB or tunable filter imaging
- Detector formats - detector technology development?
- Optics constraints (size ; f-ratio ; materials) **[T]**

Note:

- Await 1.2 (PI + Inst. Sc = 2 months; Elapse time = 1 month)

3.3 Wide-field O and IR MOS (Seeing Limited):

- Optimal slit-width * R products
- FoV (contiguous or not) **[T]**
- Slits, fibers or slicers
- Pick-off probes (IFU feeds)
- Optical constraints (size ; f-ratio ; materials) **[T]**

Note:

- Await 1.2 (PI + Inst. Sc = 2 months; Elapse time = 1 month)

3.4 VIS HIRES (SL or Single Conjugate AO?)

- Fiber/slicer feeds
- Length of fiber feeds **[T]**

Note:

- Await 1.2 (PI + Inst. Sc = 2 months; Elapse time = 1 month)

3.5 MIR Imager and Spectrograph (SCAO)

- Cryo-slicer design
- Detector formats - detector technology development?
- Forward cassegrain for lowest emissivity (~f/8)? **[T]**

Note:

- Await 1.2 (PI + Inst. Sc + ME = 3 months; Elapse time = 1 month)

3.6 Near-IR imager and IFU spectrograph (Multi-Conjugate AO) -

- Detector format and performance - detector technology development?
- PSF time and field variability **[AO ; T]**
- IFU technology (fibers or slicers)?

Note:

- Await 1.2 (PI + Inst. Sc + ME = 3 months; Elapse time = 1 month)

3.7 Extreme AO instrumentation -

- Coronographic OIR imager **[AO]**

Note:

- Await 1.2 (PI = 1 months; Elapse time = 1 month)

3.8 Non-specific instrumentation -

- Polarimeters **[S ; T]**

Note:

- Await 1.2 (PI = 1 months; Elapse time = 1 month)