Issues for ELT Instrumentation

ELT Science Case Workshop
Florence, Nov 2004

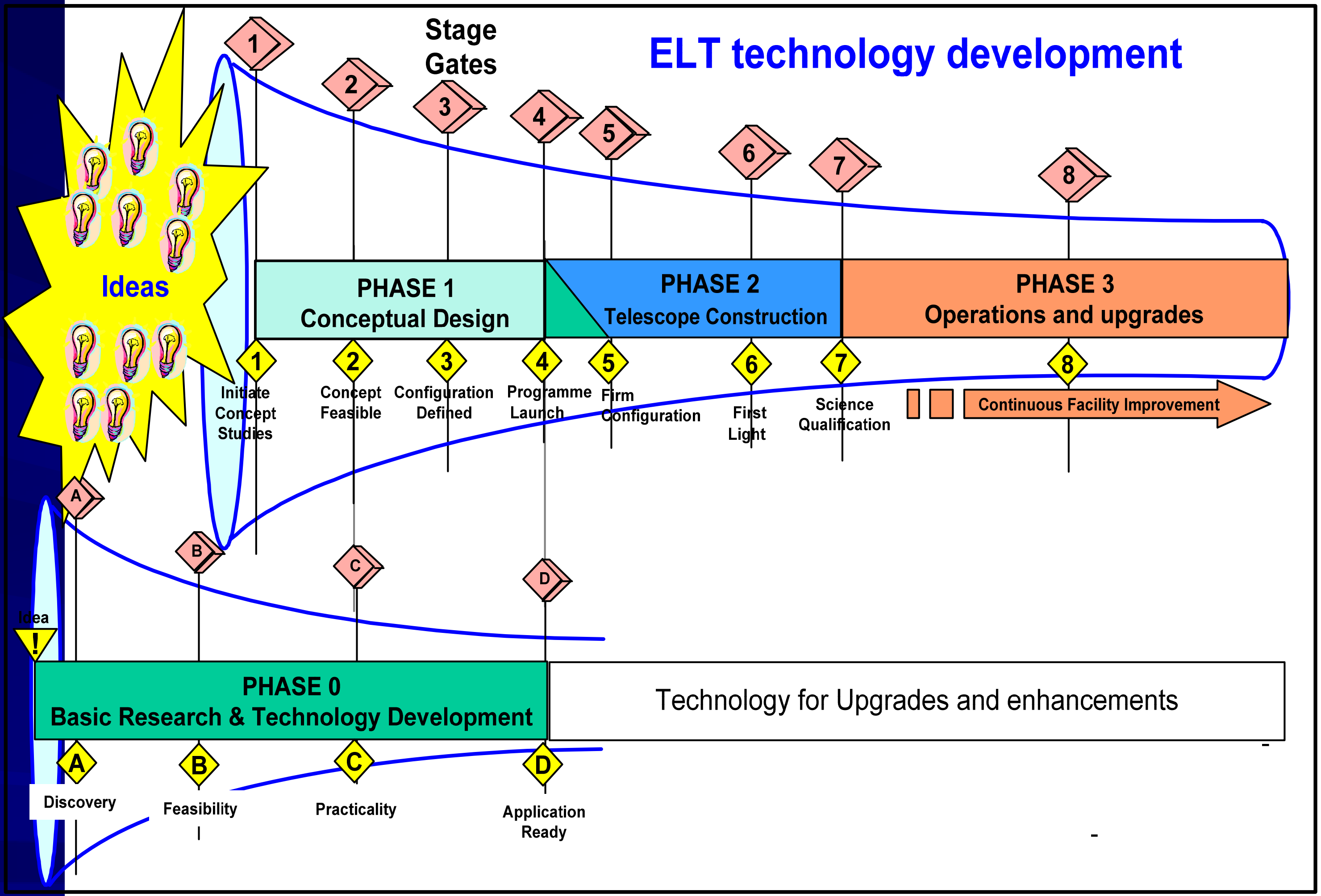
Colin Cunningham
UK Astronomy Technology Centre

Why is it important to study instrumentation?

- Mike Merrifield : 'We need a future proof design for telescope'
- We must avoid being painted into a corner!
- But most telescopes end up doing just that – and get heavily modified to meet much different aims as technology advances, eg UKIRT

Need for Instrumentation studies

- Science Case drives instrument suite and specifications – but it also works the other way!
- These Instruments specs put requirements on the Telescope design
- And determine a technology development timeline to build such instruments
- We must ensure new parameter space is exploited – and the unique capabilities offered by an ELT are used – or can be during its lifetime



ELT technology development
Stage Gates
Ideas
PHASE 1
Conceptual Design
PHASE 2
Telescope Construction
PHASE 3
Operations and upgrades
Initiate Concept Studies
Concept Feasible
Configuration Defined
Programme Launch
Firm Configuration
First Light
Science Qualification
Continuous Facility Improvement
Idea
PHASE 0
Basic Research & Technology Development
Technology for Upgrades and enhancements
Discovery
Feasibility
Practicality
Application Ready

Categories of science we could do with an ELT (Tim Hawarden's classification)

1. **Previously-known widely-spaced objects: << 1 arcmin^{-2}: one per telescope pointing**
2. **Previously-known moderately-spaced objects: >1 arcmin^{-2}: ~10 per pointing**
3. **Previously-known closely spaced objects: >>10 arcmin^{-2}: 100s per pointing**
4. **As-yet-undiscovered medium-to-closely spaced objects: ~1 to >>100 per pointing**
5. **Objects arranged in very extended structures: >> 2 arcmin**

Instrument types in ELT design study which exploit these categories

1. **Previously-known widely-spaced objects:**

- Spectroscopy of very high redshift (z = 6 – 20) “first generation” objects such as GRB afterglows, Population III Supernovae (SNe) and QSOs
- Spectroscopy of galaxies in the re-ionisation era (Lyman-Break Galaxy analogues)
- Imaging and spectroscopy of asteroids and comets
- Imaging and spectroscopy of the outer planets and moons of the major planets
- The search for planets around nearby stars

Total pixels (2k-sq arrays)	Sub-fields	Instrument Types	AO type needed	Telescope design issues
I: $\sim 4\times10^6$ (1) S: $\sim 6\times10^7$	~ 1	Single-beam Imagers and spectrometers	Small-FOV (few arcsec)	None (hi-R Spectr. stability?)

Instrument types in ELT design study which exploit these categories

2. **Previously-known moderately-spaced objects:**

- Studies of stellar populations in nearby galaxies to reveal details of systems which have merged to form the present-day galaxy
- Photometric (spectroscopic) monitoring of distant supernovae at about 6 (3) per MCAO field

Instrument: KMOS clone

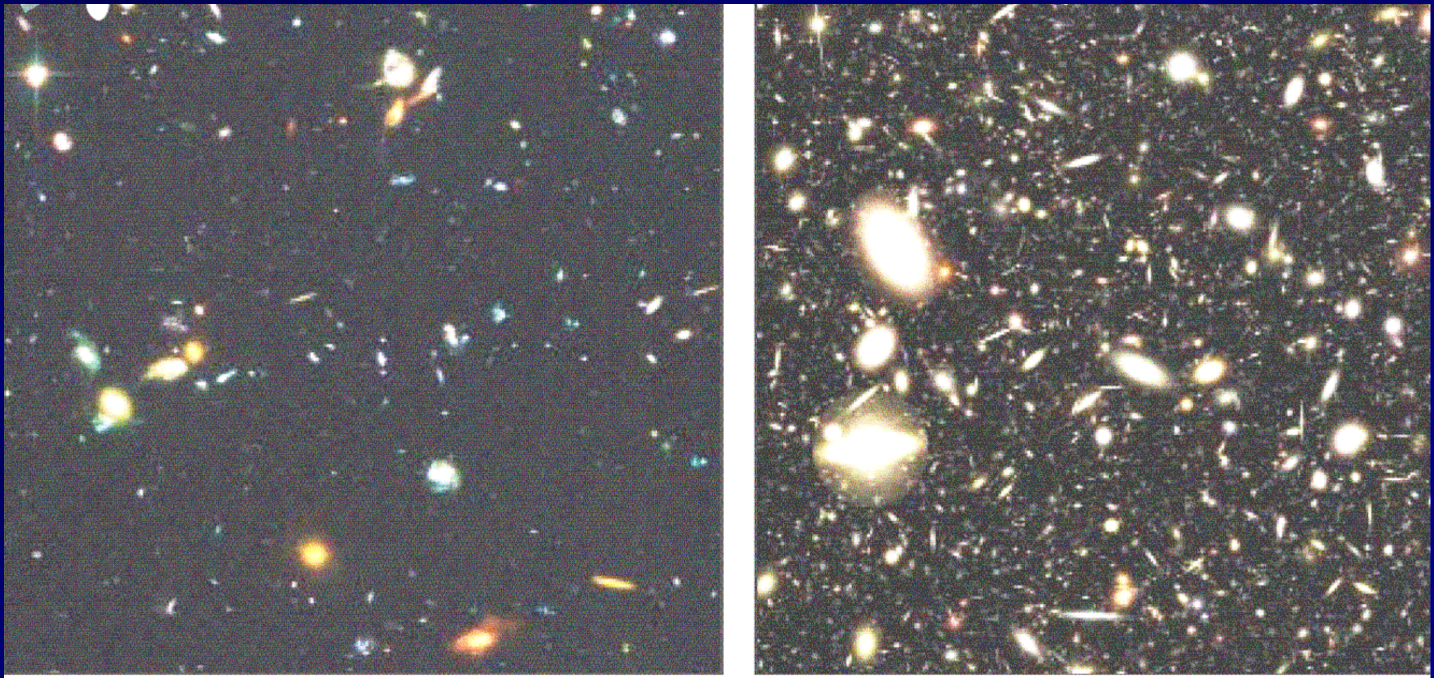
Total pixels (2k-sq arrays)	Sub-fields	Instrument Types	AO type needed	Telescope design issues
I: ~10^8 (>10) S: ~10^8 (>10)	~10 -20	~20-beam (K)MOS or (K)MOI	MCAO (2' x 2')	Instrument stability, 2'x2' DL FOV

Instrument types in ELT design study which exploit these categories

3. Previously-known closely spaced objects:

- High-resolution imaging and, especially, spectroscopy of objects revealed by HST and JWST. The Hubble Ultra-Deep Field contains about 900 galaxies per square arcminute, down to R ~29
- Spatially resolved spectroscopic observations of galaxies at high and very high redshifts to confirm their natures, kinematics and composition and to track their changes with redshift

Hubble UDF & JWST UDF



Hubble Ultra-Deep Field
(300,000s exposures in B & V,
800,000s in I & z)

Myungshin Im's simulation of a JWST
Ultra-Deep Field (36,000s
exposures in each of I, J,& K)

Figure 1.
Hubble Ultra-Deep Field and simulated JWST Deep Field

Instrument types in ELT design study which exploit these categories

3. Previously-known closely spaced objects:

- **High-resolution imaging and, especially, spectroscopy of objects revealed by HST and JWST. The Hubble Ultra-Deep Field contains about 900 galaxies per square arcminute, down to R ~29**
- **Spatially resolved spectroscopic observations of galaxies at high and very high redshifts to confirm their natures, kinematics and composition and to track their changes with redshift**

Instruments: functionally equivalent to many KMOS-clones: MOMSI with 100 > 100s pick-offs

Total pixels (2k-sq arrays)	**Sub-fields**	**Instrument Types**	**AO type needed**	**Telescope design issues**
I: ~10^9 (>100) S: >10^9 (>200?)	100 – 500?	Multiple (>10) (K)MOSs or (K)MOIs	MCAO	Instrument volume, mass, power, stability

Instrument types in ELT design study which exploit these categories

4. **As-yet-undiscovered medium-to-closely spaced objects:**

- Identification of high-redshift SNe for photometric and spectroscopic monitoring
- Identification of the products of first-generation objects such as GRB glows, Pop III SNE and QSOs for spectroscopy

Instrument: 2x2 arcmin diffraction limited imaging

2-4000 IR arrays…. Or rely on serendipity in other observations?

Total pixels (2k-sq arrays)	Sub-fields	Instrument Types	AO type needed	Telescope design issues
Up to 10^{10} (up to 1000?)	1 (& "tiling")	Very large mosaic array imager	MCAO	None?

Instrument types in ELT design study which exploit these categories

5. **Objects arranged in very extended structures:**

- Study of the roles, properties and evolution of dark-matter haloes and baryonic matter during galaxy formation at early epochs
- the 3-D evolution of Large-Scale Structure

Instruments: wide-field (~10 arcmin) mode of operation, providing GLAO and "button AO"

Total pixels (2k-sq arrays)	Sub-fields	Instrument Types	AO type needed	Telescope design issues
I: $\sim 4\times10^{7}$(~10) S: $\sim 4\times10^{6}$ (1)	I: 1 S: >1000 (fibres?)	Wide-field imager; fibre-type MOS (cryo-fibres?)	None, or GLAO	~10' FOV, very large instruments

Example instrument suite

In ELT design study:

- 'Point designs'
  - MOMSI: Multi-Object Multi-field Spectrometer and Imager
  - WFSPEC: Wide-Field seeing limited (or ground-layer corrected) SPECtrometer
  - MIDIR
- Concept studies
  - GRB Catcher
  - HISPEC
  - Planetfinder
  - HiTRI: high time resolution
  - FALCON: multi-object AO
  - SCUBA3: submm imager

Reminder:

- This is a representative suite – which will be used to
  - Understand the telescope requirements
  - And help define what technology developed is needed, and when it must be ready
- It is NOT what we will build in the end…

Big questions for you

- Does this suite fulfill your needs?
  - – If not it will not be used to ask the right questions
- What do we need for imaging? How do we find faint unknown objects?
- Does it exploit the ELT parameter space, particularly for discovering new phenomena, not predicted today?

Big questions for engineers and technologists

- Can we build such instruments for a reasonable cost?
- Is the necessary technology available now?
- If not, can we develop to a sufficient readiness level in time to adopt in real instruments?
- Don't forget that the instrument programme could have a long life of upgrades and new instruments
- Trade offs of FOV, pick of fields, pixel size, array size, spectral resolution

Big questions for telescope designers

Can the ELT design we choose meet the needs of these ambitious instruments?

- Stable PSFs
- Scattered light
- Stable acquisition
- Alignment stability
- Do the instrument stability requirements push for gravity stable platforms?
- Mass, space, thermal budgets
- Emissivity
- Optical properties of telescope focal plane
  - F ratio
  - Curvature
  - Telecentricity

Big questions for Adaptive Optics designers

- How stable will MCAO be?
- Field stability – plate scale constant?
- What proportion of operating time will the system be near diffraction limited?
- What is the best use of the ELT when the AO cannot function?

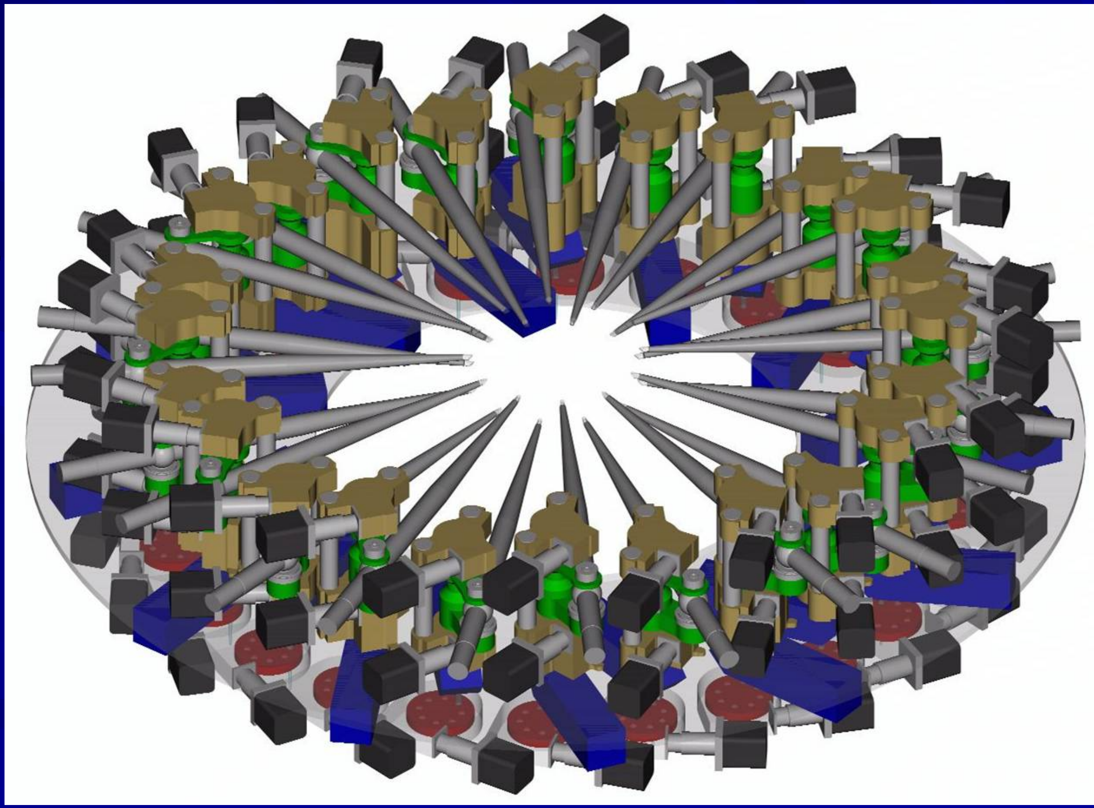
Next steps

- FP6 design study will use 'point designs' and instrument concept studies to push against science requirements and telescope spec, capabilities and budgets
- ESO OWL instrument concept studies
- Smart Focal Planes project will use these designs to define technology requirements:
  – Pick-off robots, Beam Steering Mirrors, Image slicers, Slit mechanisms, fibres
- Key Technology Network: Studies also required for novel spectrometers, coronographs, detectors, integrated AO

Example: Multi object spectroscopy in IR

KMOS:

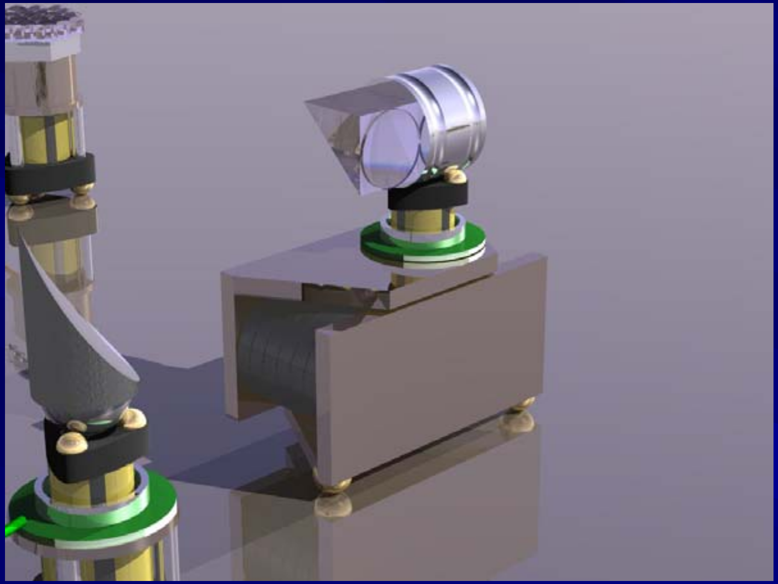
- VLT 2nd generation
- 24 pick off arms
- Each Feeding IFUs
- Feeding 3 spectrometers
- Challenging!



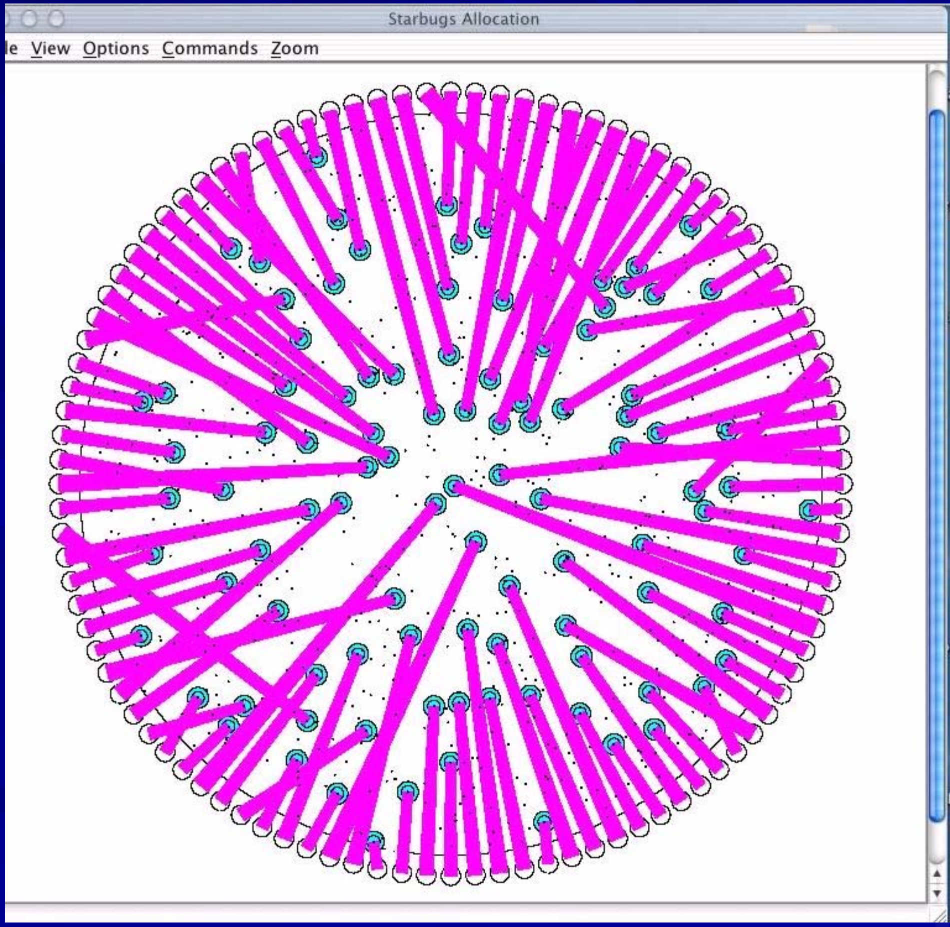
ELT Example: MOMSI

- Working Specification:
  - 50 > 1000 patrol fields of 100 mas within 2’ field
  - Near diffraction limited
  - Will evolve as practicality and telescope compatibility is explored
- First cut instrument requirements done
- First steps: Smart Focal Plane workshop in Marseille, October
  - LAM, ATC, AAO, Durham
- Only understood constraints on telescope and instrument technology needs following intensive 3 day workshop
- Feedback process essential!

Starbug pickoffs: 100 x 100mas in 2' field



- •100 Starbug pick-offs – AAO idea
- •Each feeds a beam-steering mirror
- •Which then feeds an image slicing IFU and a simple spectrometer with a 2kx2k IR array
- •Modular design for batch industrial manufacture



Telescope Issues highlighted by MOMSI

- Volume and Mass
- Differential Refraction – up to 19 mas movement over 1’ field with 60 deg Zenith Distance
  - 2D moves for Starbugs?
- ADC - 100m telescope at optical wavelengths atmospheric dispersion reaches 500 times the diameter of the diffraction spot
- Image de-rotation
- Field flattening – 3D moves!
- Preservation of focal length
- Telecentric input
  - > problem with F/6 beam

Technology Issues for MOMSI

- Imaging – separate instrument with 10 x 1” pick offs?
- Detectors – only 2k x 2k, but 100 of them!
- Image slicers – 40 slices, ~0.3mm thick
- ‘Industrial’ batch production of image slicers and spectrometer modules
- Stability and position measurement of pick-offs
- Reliability of mechanisms

If you want to be scared by the problems of ELT instruments…

Instruments for a European Extremely Large Telescope:

The challenges of designing instruments for 30-100m telescopes.

Adrian Russell, Guy Monnet, Andreas Quirrenbach, Roland Bacon, Michael Redfern, Torben Andersen, Arne Ardeberg, Eli Atad-Ettedgui & Timothy G. Hawarden

Glasgow SPIE

Conclusions

- Instruments turn a telescope into a research facility – obvious statement
- Studies will focus science case on practical capabilities of instruments – what we can really do
- Many scientific goals push the instrument FOV, spatial and spectral resolution in mutually incompatible directions - Some combinations will not be feasible with reasonable budgets
- Key questions for each science goal are source density and how close to the diffraction limit we need to be
- We should not underestimate the task of such instruments– as Tom Herbst said!