VISTA: science specifications, and challenges.

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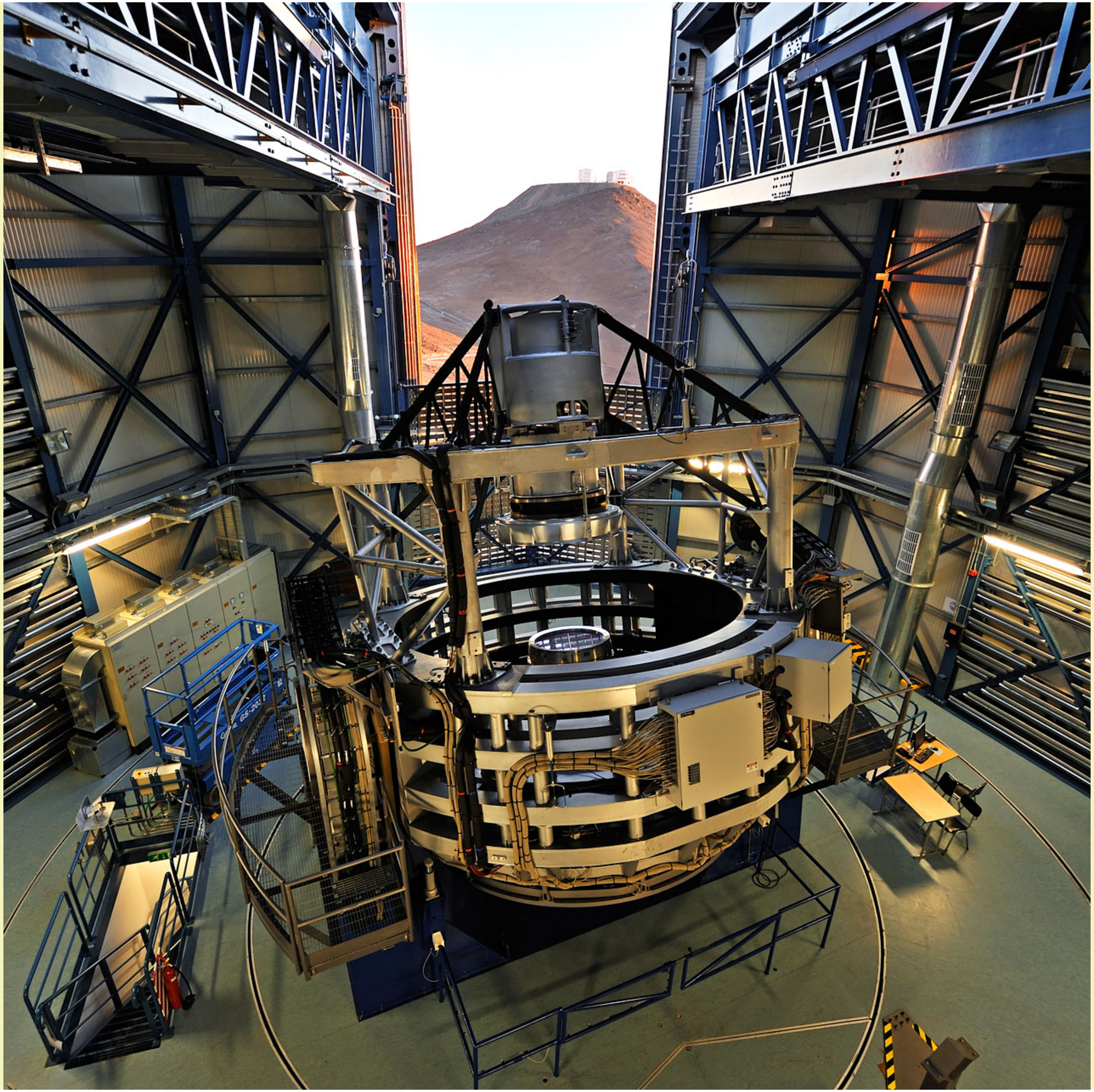
VISTA science drivers (Phase A):

- Givens: Southern hemisphere, Paranal (Sloan, CFHTLS, WFCAM, Suprime all in North); and ~ 4-m (existing mirror blank).
- Capability for both Near-IR and Visible cameras.
- Top priority: maximise "survey speed" ~ FoV x Throughput x Efficiency.
- Near-IR camera took priority in optimisation decisions.
- Seeing limited (no adaptive optics)
- IR Camera: concept 36 Mpix, J,H,Ks.
  - Stop at 2.3 micron: clearly the right decision given Spitzer and later WISE.
  - Ks required, not necessarily K. Still all-cryogenic instrument.
- Vis. Camera: 400 Mpix, B through Z.
  - Field corrector, active optics and guiding sensors included in VIRCAM.
  - "Deferred", due to cost, and VST under construction. 2005 proposal to revive as DarkCam; but STFC chose a minority share in DECam, delivering very similar specifications. Probably the right decision in order to maximise speed on IR surveys.
  - The lateness of VST has caused some problems… But VST, DECam and others now ramping up.

ESO Paranal Observatory, Chile

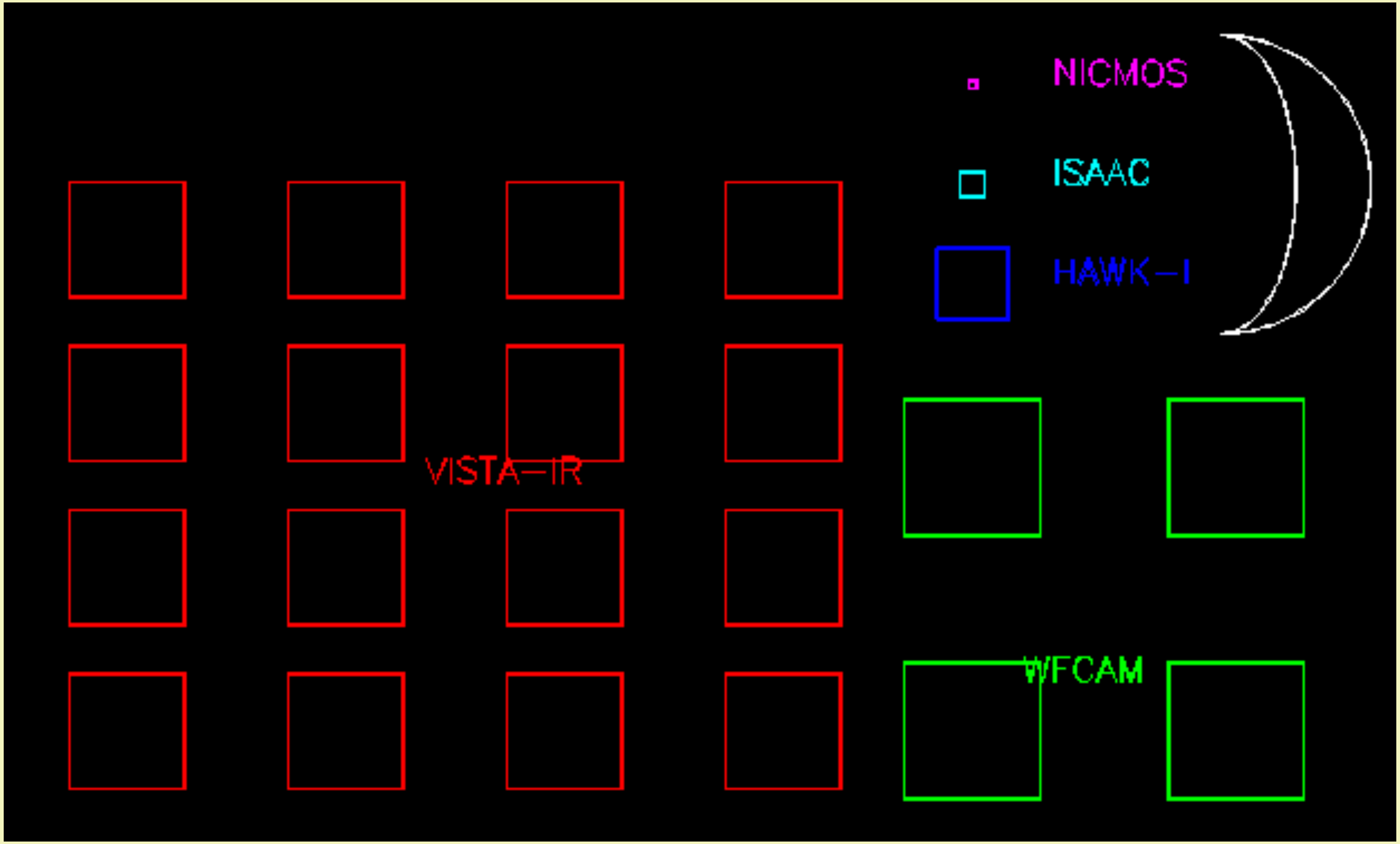


Phase A: two key goals

1. Capability to upgrade to 16 arrays in near-IR camera.
   - Delivers "major advance" over 4-detector WFCAM and others.
   - Protect against "price crash" in near-IR arrays, leading to other competing systems with ~ 9-12 detectors. (Has not actually happened: IR arrays are nearly as expensive today as 2002).
2. Capability to switch between IR and Vis instruments in ~ 1 hour.

- Goal (1) was delivered only by the f/1 telescope design, and was a significant (but not dominant) factor in selecting f/1 .
- Goal (2) was delivered by the initial concept of f/2.5 flipping top-end; this was judged impractical from engineering perspective. An f/1 with 2-Nasmyth solution might have delivered this, but makes M2+M3 painfully large: downsides outweigh benefits, goal discarded.
- As we know, the 16-detector system was realised as part of the ESO negotiations – a major success !

IR camera field sizes:



Other major science specifications:

- Goal to enable Y-band operation.
  - Fortunately, the Raytheon detectors work well at Y (and Z) bands.
  - Y-band especially has been very important for substantial fraction of science.
  - Getting Z-band was a "lucky accident" since the LOWFS CCDs had to work at Z, requiring tolerable image quality and throughput at Z.
- Minimising overheads.
  - Required parallel LOWFS operations – significant design impact, see later.
  - Fast readout detectors. Spec 1 sec, achieved; but actually 2 sec since detectors require non-parallel reset+read. Impact fairly minor but non-trivial.
  - Fast jitter movements. (Mostly successful but slightly slowed by unavoidable lags in ESO software).
- Preserve capability for visible instrument.
  - Long-term, space will overtake ground for deep NIR surveys: **much** lower sky foreground. The 2001 PRIME proposal died; SNAP became JDEM became WFIRST, not yet funded. Euclid is approved, but 2020+.
  - Keeping capability for another instrument has substantial future-proofing. The visible camera is overtaken by others, but the 4MOST spectrograph offers unique and compelling science into the 2020's.

The f/1 telescope : pluses and minuses

- The f/1 is selected to give an f/3.25 Cassegrain, while keeping M2 size not too large (actual 1.24m) . This has many pluses, and two minuses…

+ Very compact telescope structure

+ moderate mass and inertia

+ high stiffness, nimble jittering, low windshake

+ small dome

+ reduced costs.

+ Accommodates large and heavy Cass instrument(s).

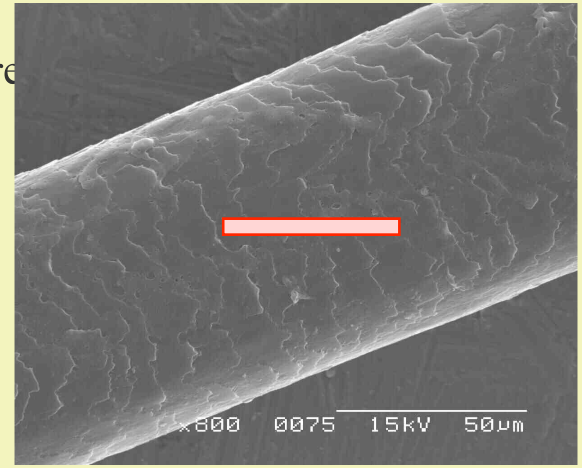
- f/1 mirror is highly aspheric, and very hard to figure : a known issue, but turned out even harder than expected. Cause of lateness (+2.5 yrs w.r.t. estimate).

- f/1 system is very fussy about alignment: see below.

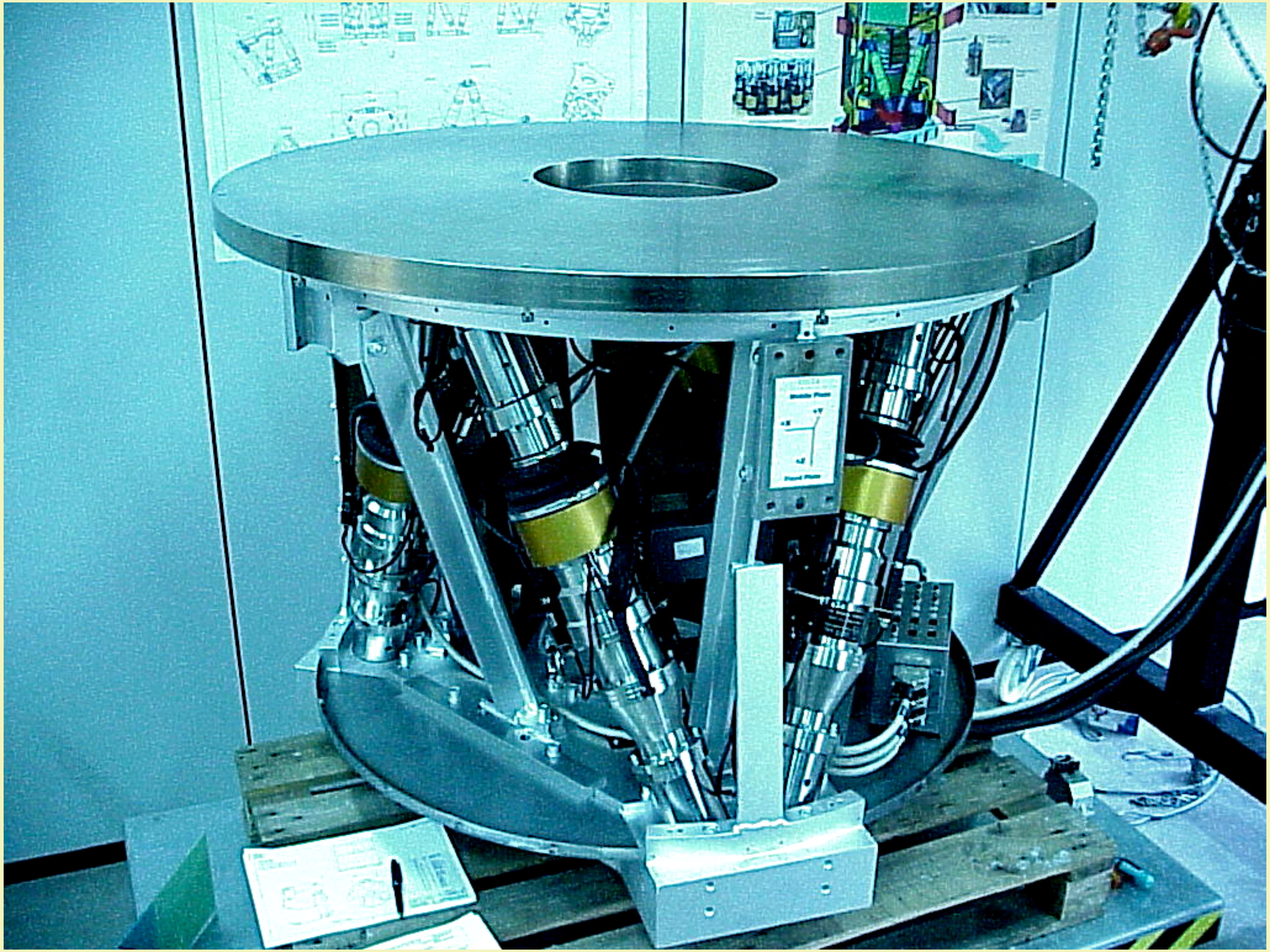
Primary mirror – first coating, Apr 2008.

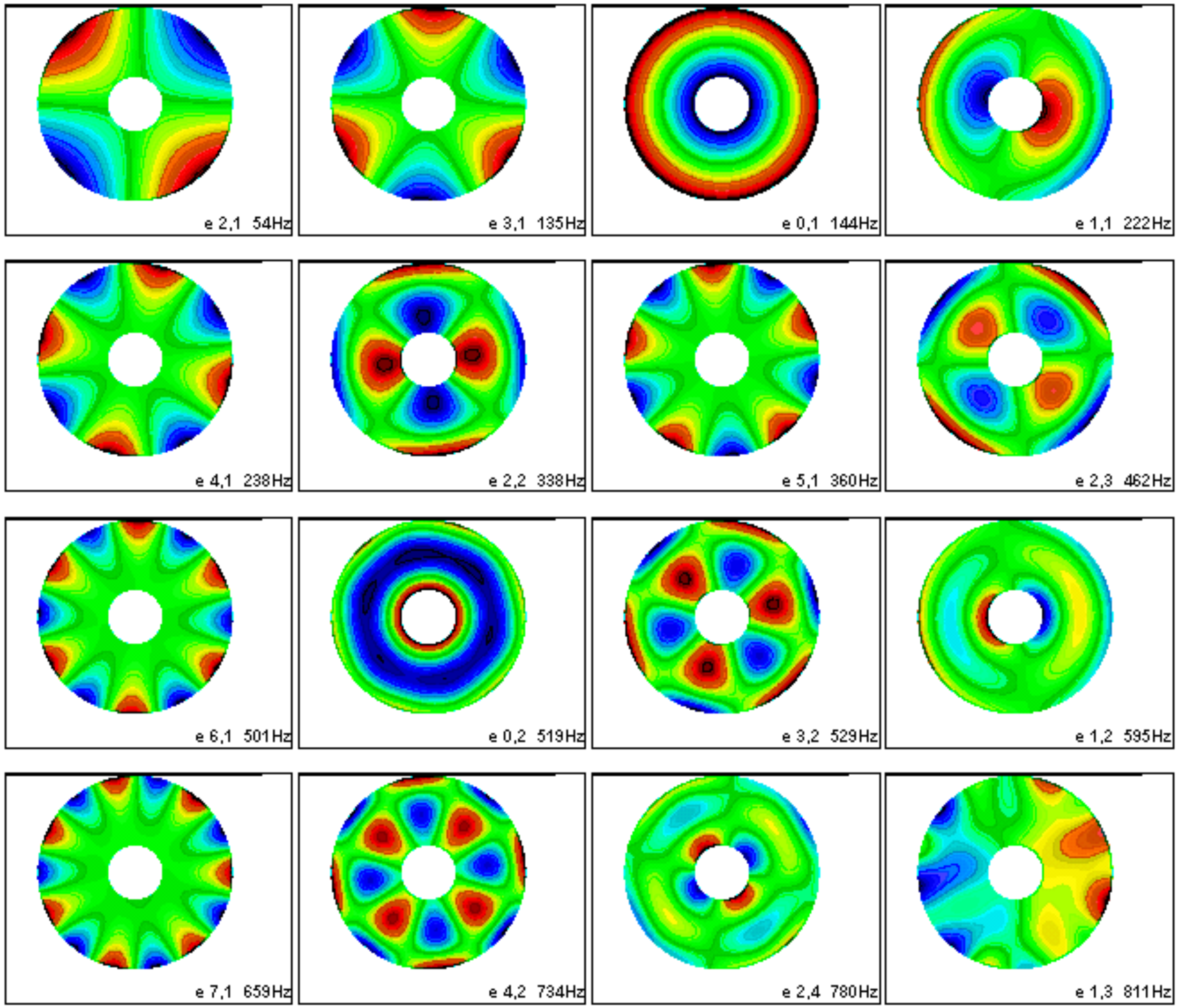
The Active Optics Challenge :

- The f/1 wide field VISTA is probably the hardest-to-align telescope ever built.
  - f/1 implies very tight tolerances on focus and decenter of M2.
  - Wide field implies "every alignment matters": M2 decenter and tilt, and camera tilt, and camera decenter w.r.t. M1 .
  - Compact and rigid telescope helps, but you still need to measure enough parameters to align everything: two diametrically opposite low-order wavefront sensors.
- Another challenge: the wavefront sensors have to be inside the VIRCAM cryostat.
  - The "VLT-like" solution would be two patrolling Shack-Hartmanns. This is scary, since a failure of the cryo patrol mechanism would wipe out 8+ nights of observing.
  - Solution is to go with fixed curvature sensors, viewing enough sky area for ~ 99% probability of a usable star.



Secondary mirror focus+collimation hexapod (NTE)

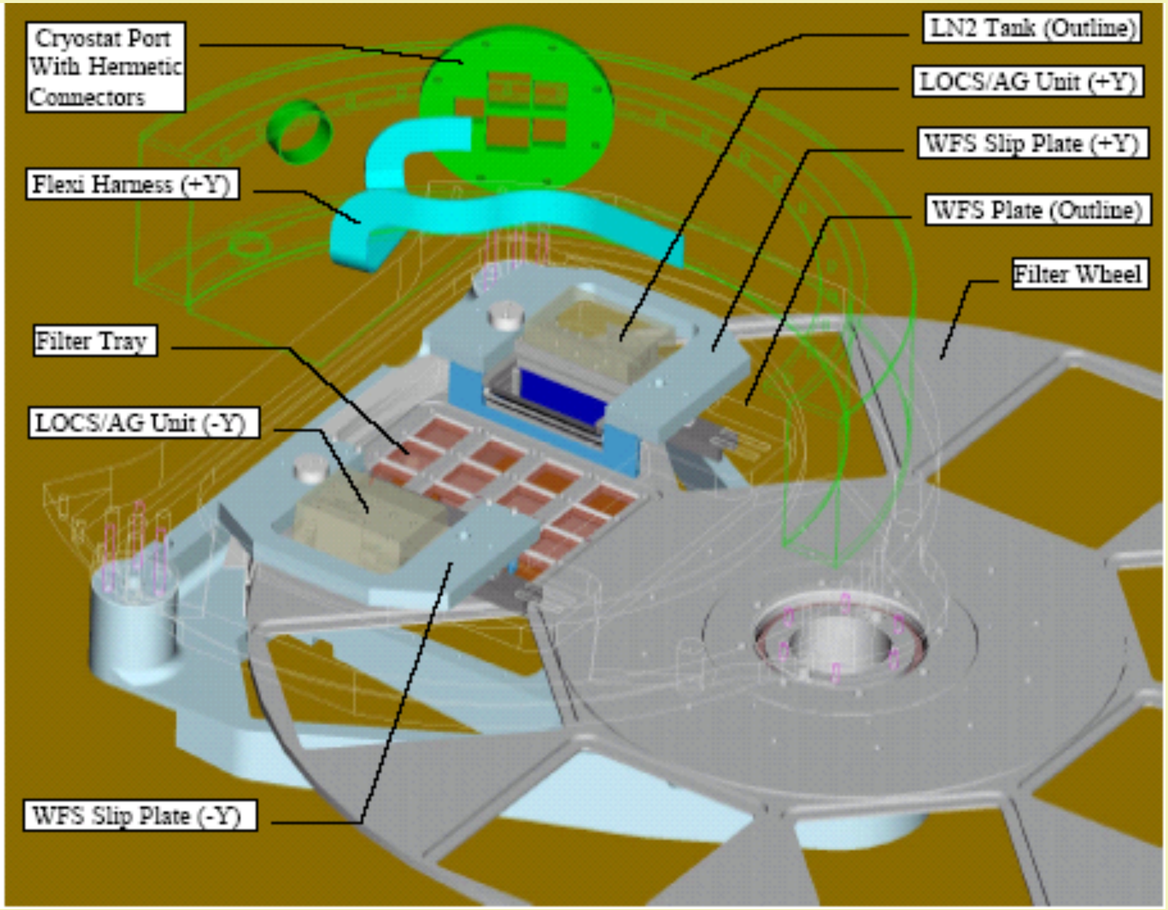



e 2,1 54Hz
e 3,1 135Hz
e 0,1 144Hz
e 1,1 222Hz
e 4,1 238Hz
e 2,2 338Hz
e 5,1 360Hz
e 2,3 462Hz
e 6,1 501Hz
e 0,2 519Hz
e 3,2 529Hz
e 1,2 595Hz
e 7,1 659Hz
e 4,2 734Hz
e 2,4 780Hz
e 1,3 811Hz

The WFS solution :

- Solution (1): curvature sensors viewing large area of sky, so a usable star is present 99% of the time. No moving parts !
  - But high-orders require bright star and infeasibly large area.
- Solution (2) : M2 alignment has to be frequent, but M1 figure update does not. Therefore, split the low-order and high-order WFS functions:
  - Two LOWFSs run in parallel with science every ~ 1 minute, for M2 alignment (only measure focus, coma, astigmatism).
  - HOWFS is a non-parallel sensor (interrupt science, re-point at bright star): measures ~ 17 M1 figure modes. Build lookup tables vs Altitude, and apply once-nightly tweaks for M1 figure optimisation.
- This works well ! Over 200,000 LOWFS corrections executed, the vast majority successful. The HOWFS successfully corrects the M2 trefoil problem.
- But was a major effort to implement: many man-years of design, software development, algorithm simulating and debugging. The software challenge was significantly under-costed at the outset.

LOWFS units: view from above.



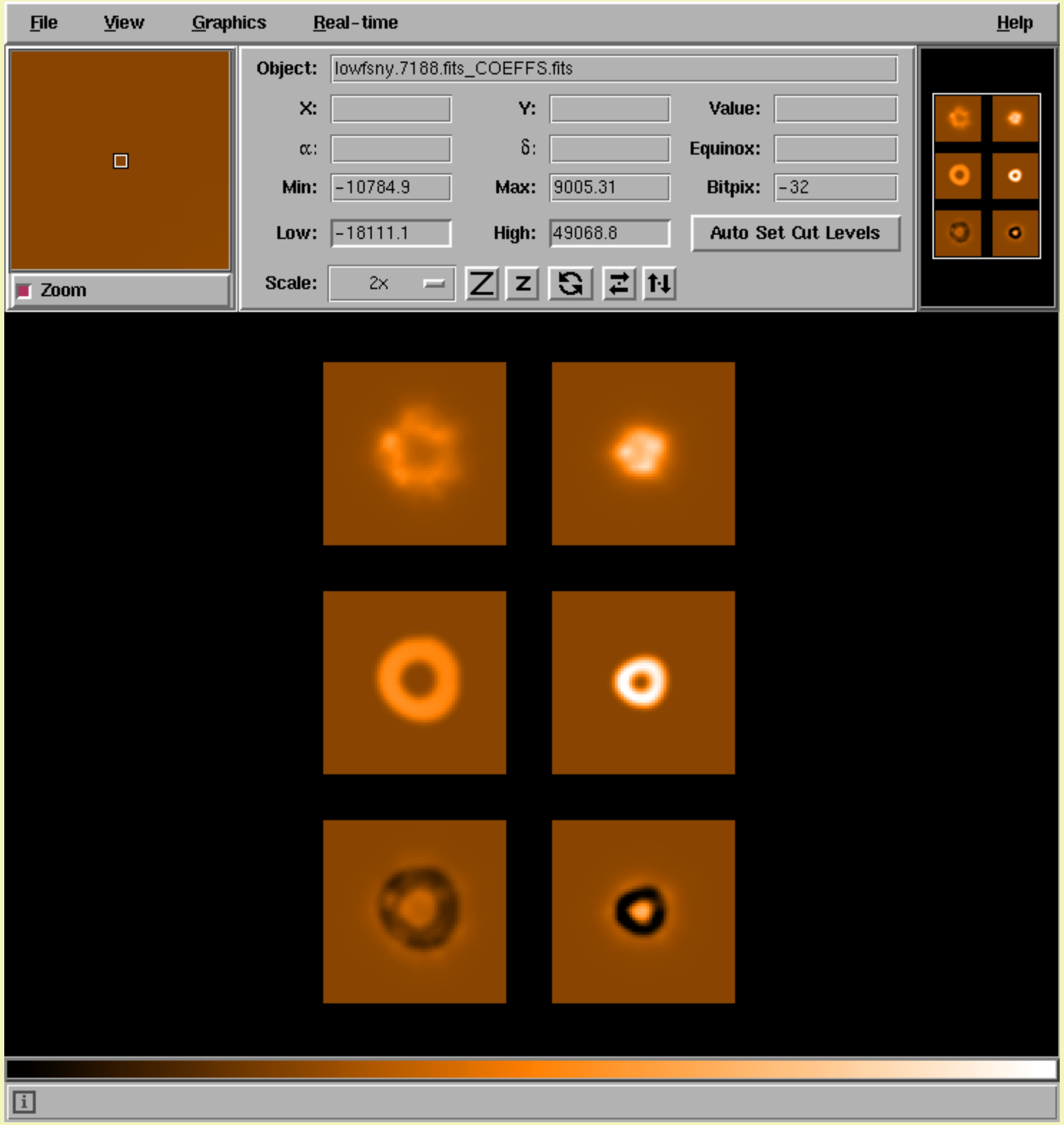
On-sky LOWFS

Image:

Actual:

Model:

Difference:



HOWFS beamsplitter

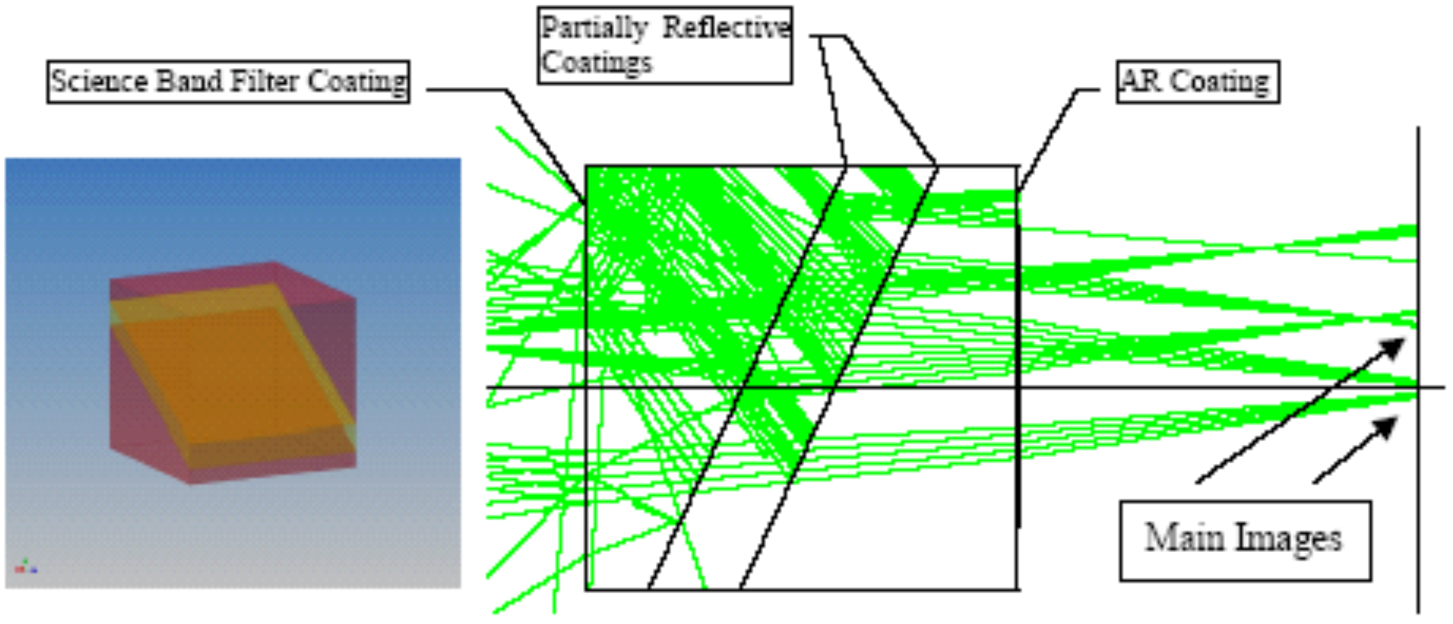
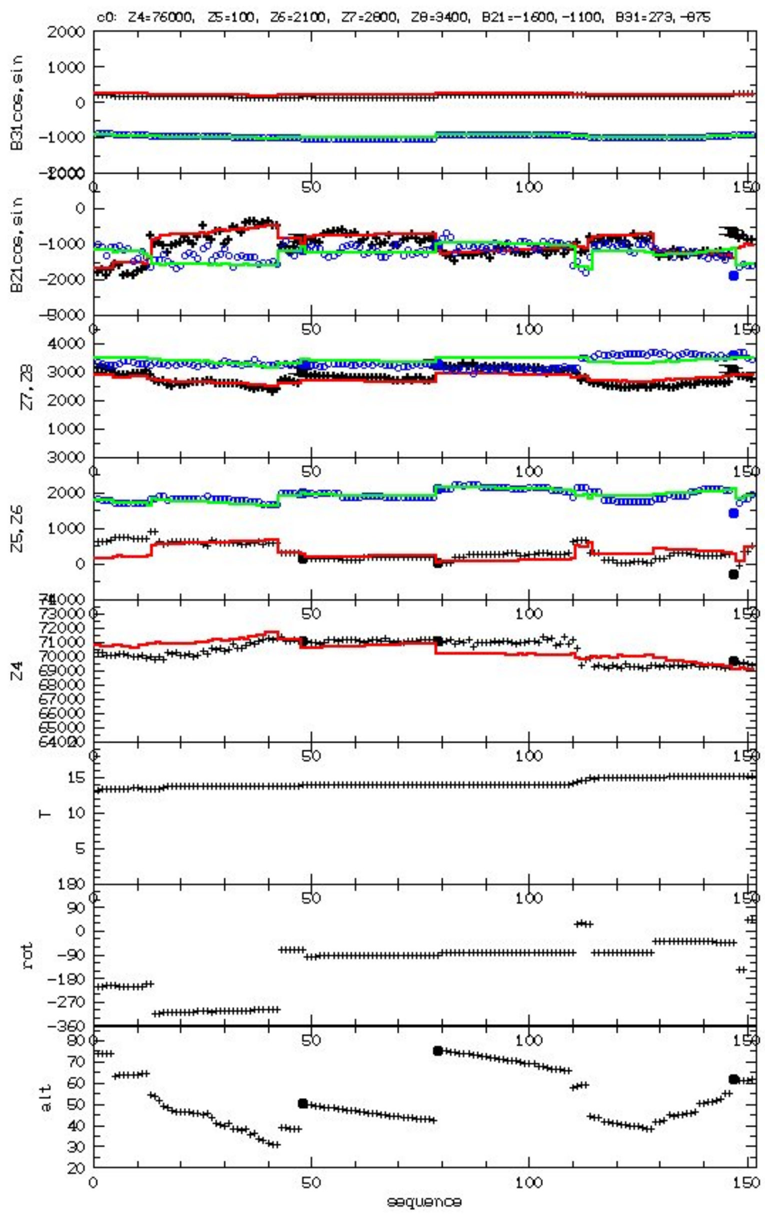


Figure 7.1: HOCS Optical Element and Ray Trace

Thickness ~ 16mm (cf science filter 10mm),
straight-through image is 2mm pre-focus.
Double-reflected image zigzags, 2mm post-focus.

LOWFS measurements: actual(points) vs lookup table (line)



The Cold-baffle Challenge :

- The cold-baffle camera solution is very simple and elegant .
  - Few optical elements, high throughput.
  - Excellent image quality on paper: decent margin for real-world imperfections.
  - All Infrasil window + lenses: robust and homogeneous material.

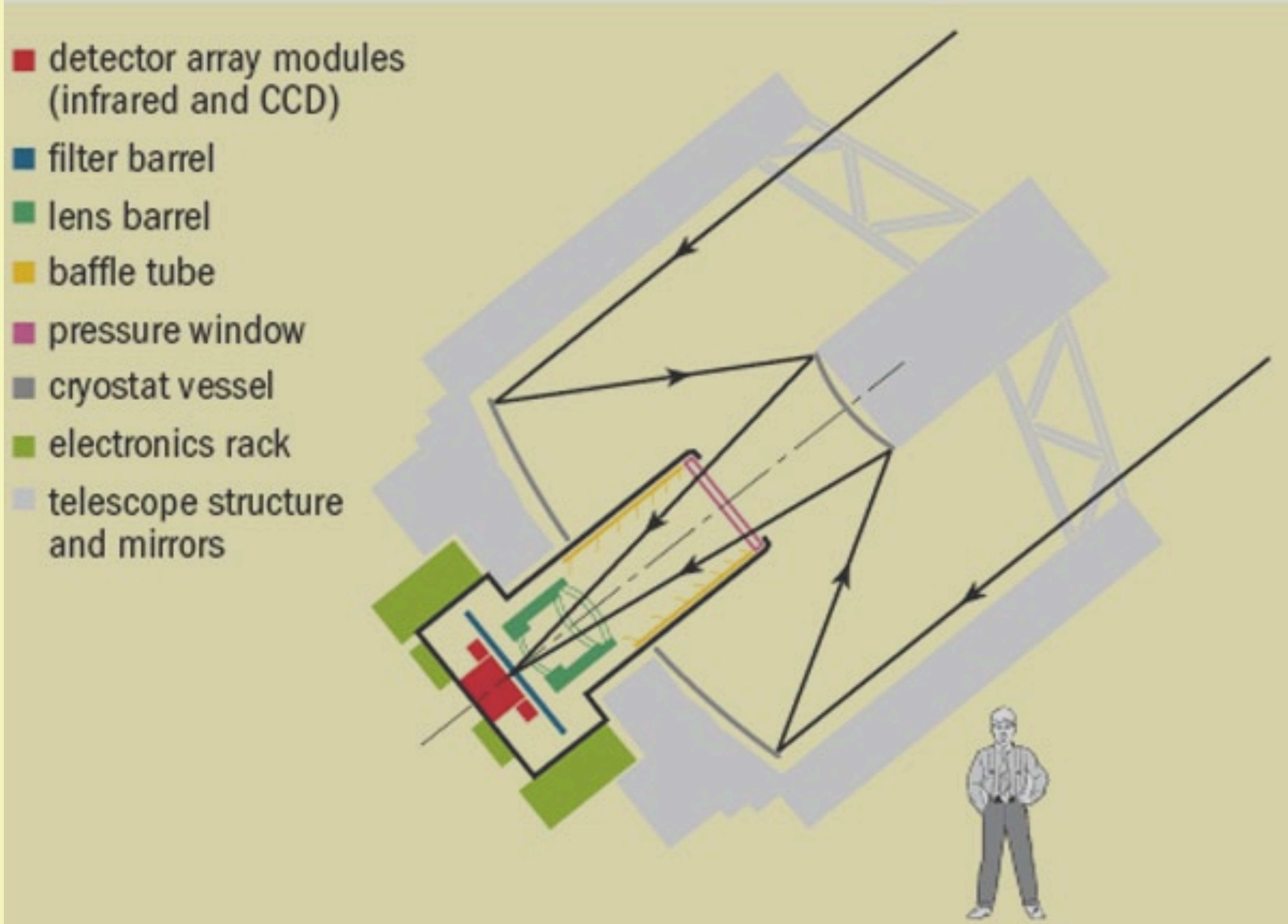
- But there are two substantial challenges:

1. The very large window was time-consuming, and hard to keep warm enough.
   - Series of ellipsoidal reflectors on the cold-baffle: reflect heat back to window.
   - Dichroic coating on ellipsoids: absorbs science bands, reflects thermal IR. Several options were studied before finally getting to an acceptable solution.
   - Main baffle tube is thick and massive for good conductance.

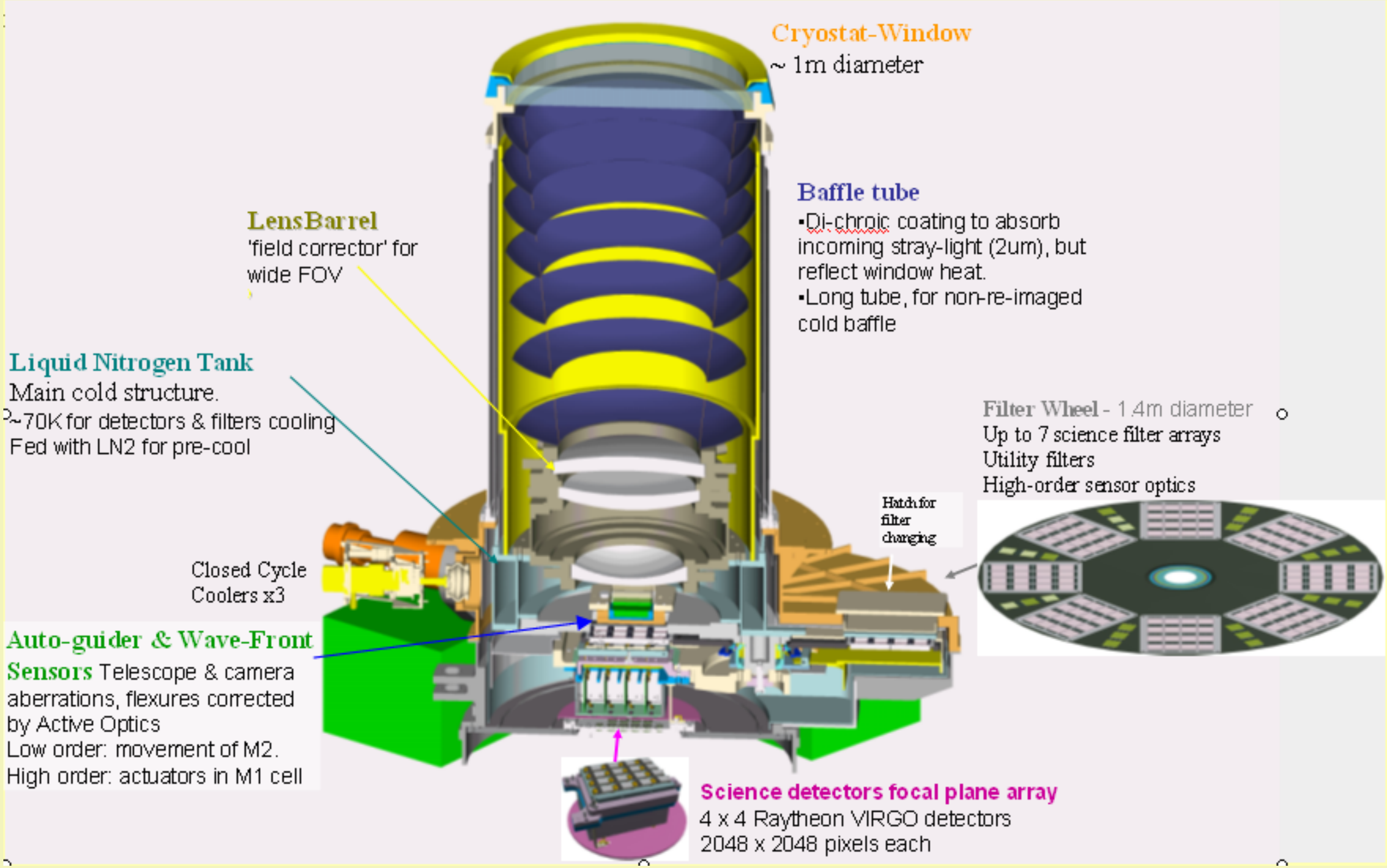
2. Stray light is a concern: careful design attention needed to block off-axis scattered light.
   - Narcissus baffle around M2: nested spheres to keep diameter down.
   - Oversize lenses: deep pockets eliminate scatter off lens edges.
   - Grooved walls on lens barrel block single-scatter paths to detector.
   - Special shaping on filter trays, sides of WFS, etc, block scatter.

- It all works ! Ks performance is very competitive with conventional cold-stop system; and Y,J,H throughput is better.

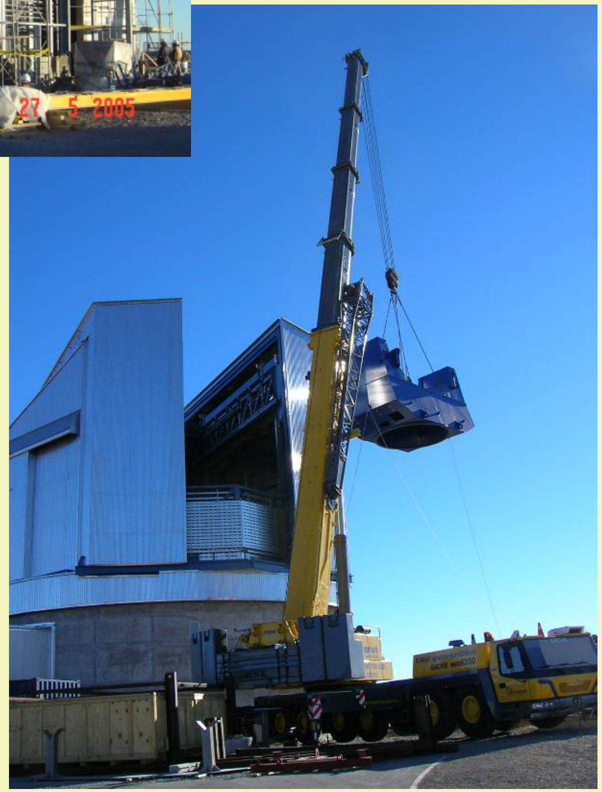
VISTA + IR Camera schematic



IR Camera cross-section



Construction 2005 – 06.



The camera image quality challenge

- VISTA telescope and camera form a matched system: camera lenses (almost) cancel the off-axis aberrations of the telescope. No intermediate focus -> hard to test the camera standalone.

- A "CIQ test source" (0.5m 2-mirror "telescope") was designed and built, to inject a beam aberrated similar to the telescope, at either near-axis or edge-of-field position.

- Validating the test source was tough – aberrations large, and sensitive to spacings in the test source. This took several months of effort, and never quite reached optimal accuracy.
- However, it did rule out any "serious blunder" in the Camera optics, before shipping to Chile.

The commissioning challenge

- Commissioning was a lot harder and longer than anticipated: plan said 7 months from M1 arrival, reality 18 months - what happened ?
- Good news: no major design flaws. All key subsystems were capable of performing as predicted (most of the time).
- Huge team effort into TechSpec, CoDR, PDR, FDR documentation packs and review meetings for every subsystem was worthwhile.

The commissioning challenge (2)

- Bad news:
  - Large number of minor niggle-type faults: dodgy electrics, wobbly PSUs, dodgy fibres, glycol/overheating electronics problems. (Mundane stuff tends to get neglected in testing).
  - Number of open Trac tickets maxed at > 100 in Dec 2008. Eventually 276 closed tickets.
  - Shortage of manpower: few techs “running to stand still” , key staff leaving for new projects, + Martin Fisher illness.
  - Relations with ESO staff good, but complicated by the penalty-clause stuff.
  - Software was a lot harder than anticipated – WFS, random freezes, inter-system comms problems etc.
  - Several “medium-size” problems:
    - M2 trefoil – fixed on M1, but ate time understanding knock-ons.
    - Filter wheel - loose maintenance bolt.
    - M2 hexapod oscillations- very hard to get diagnostics out of the black box.
    - M1 required lateral shift by 1.6mm, out of (actual) adjustment range – removed to rework definer mounts.
    - Incomplete spares – takes ages to get parts from Europe .

Commissioning lessons

- Hofstadter's Law: it always takes longer than you think, even allowing for Hofstadter's Law.
- Stuff will tend to go wrong when the key expert is unavailable.
- The "infrastructure" items e.g. wiring, fibres, PSUs, glycol, compressors, etc, are viewed as boring, and tend to get under-tested.
- Diagnostic info is crucial – can take much longer to pinpoint a fault than fix it.
- A subsystem that works 90% of the time is more painful than 0% of the time.
- Audible alarms important: far too many screens to notice printed error messages.
- All worked out well in the end, but could have been smoother.

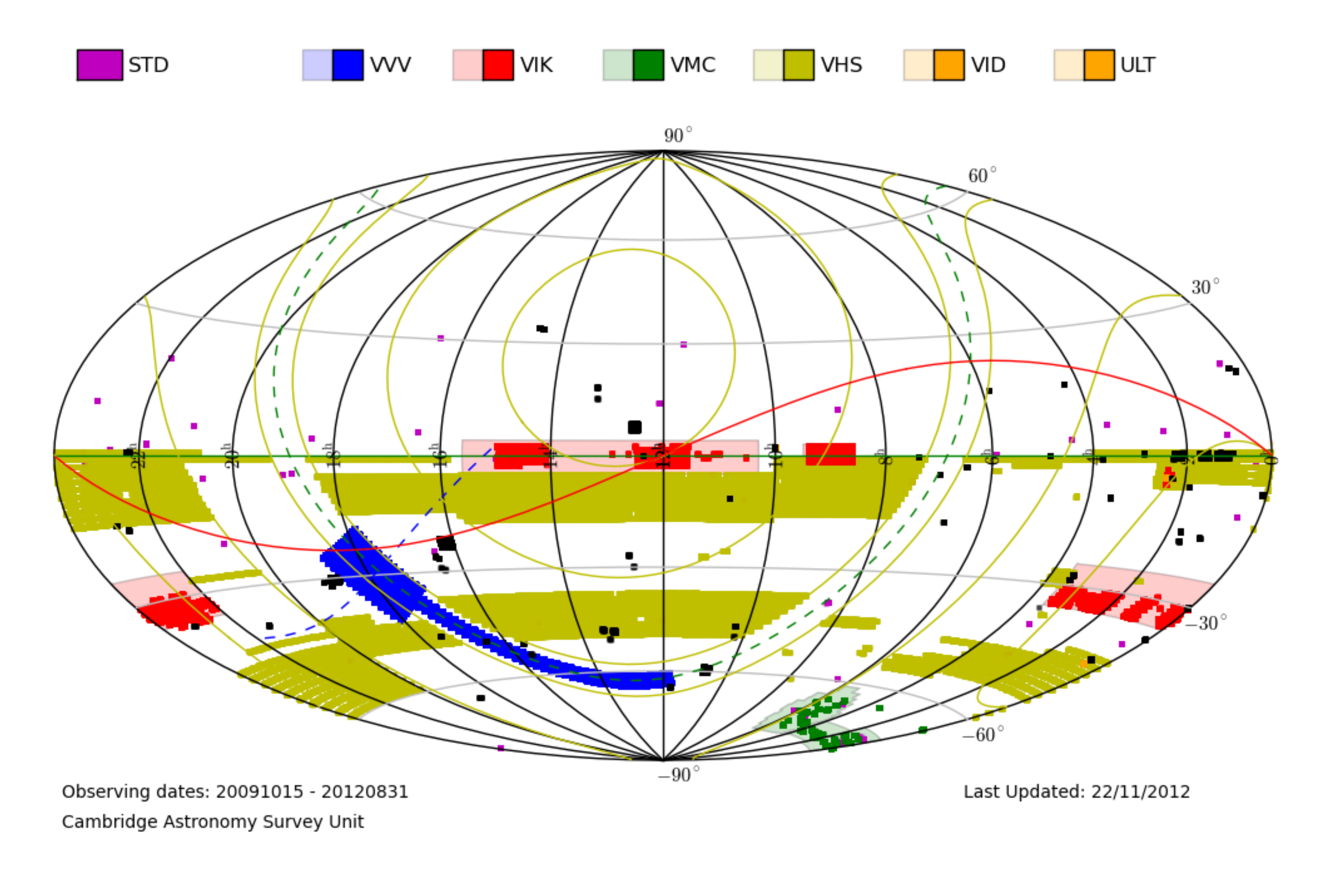
The final alignment challenge.

- Aligning M2 to M1 in 5 axes was a well-understood problem, and the LOWFSs do this, as modelled.
- System was designed to give very rigid linkage between M1 and Camera – this is a "set right and forget" alignment.
- **Both** M1 and Camera have to be correctly aligned to Cass axis... The camera rotates but M1 does not, so you cannot compensate one with the other.
- It was still complicated to get this right… there were 3 sources of focal gradient …
- M1 misalignment gets compensated by M2, but leaves you with a focus gradient fixed to the Telescope: the WFSs rotate w.r.t. this, difference between WFSs is sinusoidal in rotator angle.
- Camera misalignment co-rotates with WFSs… can't see it. Needed focus blinks on the science detectors.
- More complications: focus varied with position of star on WFS chip (software error). Trefoil on M2 also causes complicated knock-on effects.
- Several iterations to disentangle all of this. Finally, M1 was adjusted laterally, and Mk-2 wedged shim made between Camera and Cass … alignment has stayed good since.

Performance summary vs predictions :

- **Throughput:** well above requirements, due to high QE of Raytheon detectors. Throughput close to theoretical predictions, i.e. no significant unexplained light loss – good. Hope to go back to silver coatings after the enhancement package.
- **Image quality:** best conditions deliver < 0.6 arcsec actual FWHM. Basically on-spec. Major effort on IQ budgets appears to have been worthwhile.
- **Stability:** astrometry is very good (distortion present but stable). Photometric stability good, except for detector-16 bad area.
- **Stray light:** "known" filter ghosts. No other significant problems.
- **Overheads:** somewhat worse than expected (overhead 2 sec per DIT; jitter moves take ~ 10 sec, due to hexapod and software delays). Impact is modest for 4 surveys, significant for VVV, VHS.
- **Reliability:** steadily improving, not quite optimal yet.
  - Main sources: software glitches, hexapod glitches (mostly fixed), various wobbly electronics.

Sky coverage (Nov 2012)



Summary

- VISTA was a challenging project to deliver, but overall performance is as good as specified and predicted. Thanks to all involved at UKATC (plus RAL, Durham).
- Six major public surveys running in parallel, until ~ 2017; early data releases already out, many interesting science results starting to appear.
- CASU & WFAU processing effort is critical – data volume is way above capabilities of average users.

- Very likely to remain as world's best wide-field near-IR imager until Euclid in ~ 2020+.
- Future 4MOST spectrograph in Phase-A design, aiming for 2019 – see tomorrow.