On converting the Blanco telescope to a general purpose survey facility.

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The Blanco

• The Victor M. Blanco 4-m telescope is the NOAO community’s wide-field survey platform in the southern hemisphere.

• The work done prior to and during the installation of DECam has made it a highly reliable, optically stable, and realistically state-of-the-art facility, keeping it maximally efficient and productive despite its 44 years of operation.

• With DECam, its productivity is the envy of other telescopes in its league.
Survey-scale spectroscopy on Blanco


• Of 11 concepts listed, 4 involve Blanco

• Nobody wants to retire DECam any time soon

• Can we build a spectrograph to use on Blanco interchangeably with DECam?

• Could such an instrument act as a stepping stone to 8m-scale spectroscopic facility as DECam did towards LSST?
A digression: what we would have to do to DECam (and may want to regardless)...

Converting Blanco/DECam

- While originally designed to make swapping the imager for another instrument feasible, DECam does not make this trivial.
- Some modifications will be necessary
  - These modifications may be desirable regardless of building any new instrument
- The cooling chain:
  - a large tank of LN₂ off the telescope,
  - a cryogenic pump,
  - a quantity of heavy, vacuum-jacketed piping,
  - running at 100 PSI
  - ... is not trivial to warm up, disconnect, reconnect, and cool down.
- Warmup and cooldown procedures take a minimum of 4 days
- Disconnecting (or reconnecting) the bulky cooling system and removing (or replacing) the imager would take this to well over a working week.
The cooling system – over-design

• Original design: high-capacity cooling system to make less stringent demands on the thermal efficiency of the dewar.
  • Parkinson’s law: built systems uses all that capacity.

• Approximately half the cooling capacity (~200W) is lost before the LN$_2$ gets to the dewar.

• Approximately half the cooling power available at the dewar (~100W) is lost to heat the focal plane array and close the temperature control loop on the CCDs.
  • The remaining 100W goes to keeping in-dewar electronics cold (~50W) and radiative losses to the FPA (~50W)
Compare to ZTF

• ZTF’s FPA is 6% larger than DECam’s
• Uses filed flatteners as thermally-floating radiation shields
• Uses two Polycold/PT-16 cryocoolers
  • Est. 48W cooling power at -155°C (PT-30 would give ~33W/head @ -125°C)
• Still has ~30% excess cooling power

Could we do this too? Require engineering study to explore:
• Narrower-band temperature control loop using direct cryocooling at the dewar
  • Could retain the “pretzel” for fast cooling.
• Better in-dewar insulation
  • Use a floating plate in front of CCDs?
• Redesign of in-dewar electronics.
A reason to redesign the cooling anyway

• The cooling system is by far the most troublesome component in the DECam system
• LN$_2$ pump in the off-telescope tank is unlubricated and runs continuously. It consumes its own bearings
• Specified 2 year MTBF was never achieved. We don’t trust them for more than 8 months and still have failures while observing.
• Pump replaced 9 times since deployment.
  • Each replacement costs ~6 nights observing, Blanco costs $17k/night = US$918,000
• We have also expended considerable resources attempting to control leaks from the vacuum-jackets

Using direct cryocooling of the dewar removes all of this and makes exchanging the imager with another instrument much more straightforward.
Back to spectrographs...
DESpec / MOHAWK

• An advanced concept design developed in 2012 (while DECam was being installed)
• DESpec: https://arxiv.org/abs/1209.2451
• MOHAWK: https://arxiv.org/abs/1207.7011
• Uses DECam corrector C1 through C4,
  • plus two additional lenses
  • with an ADC in the filter/shutter slots
• 4000 tilting spine positioners on a curved surface
• Covers 450 mm diameter field with a pitch of 6.75 mm, a reconfiguration time of ~15 s, and a placement precision of 7 μm at the focal plane
• Spectrographs copies of VIRUS design, or simple double-armed arrangement
• Estimated cost ~US$40M

• Since then, the landscape has evolved somewhat, a number of other projects have advanced and some systems expected to come online in the next few years. We can learn from these.
DESpec/MOHAWK

Figure 9. Complete Mohawk actuator array, with 4000 spines covering the 450mm diameter curved focal surface.

The patrol radius is limited by the OD of the carbon-fiber spine tube, the ID and length of the piezoceramic tube, and the diameter and length of the hole through the module base. However, these quantities are all constrained by the needs for functionality and rigidity. To maximize the patrol radius, the modules have 'crinkle cut' sides (Figure 10). This also allows individual modules to be removed from the instrument without disturbing the neighbouring modules.
<table>
<thead>
<tr>
<th>Instrument / Telescope</th>
<th>Telescope</th>
<th>Planned for ops</th>
<th>Positioner technology</th>
<th>ADC?</th>
<th>Max zenith distance deg</th>
<th>Fiber has break</th>
<th>#fibers</th>
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³ denotes that the FOV is variable.
Positioner technologies.

Considerations:
• Available space,
• Field of view, plate scale
• Pitch, patrol radius, placement precision, beam speed
• Heat dissipation
• Configuration time
• Number of moving parts
• Connectors

Current technologies:
• Robot & plate
• Starbugs
• Rotating posts
• Tilting spine (Echidna)
Positioner technologies

- Titling spines allow closest spacing (6-9mm) and smallest fiber head separation (~1mm)
- Starbugs allow fiber head separation down to 9mm, but are limited in focal plane density by navigation restrictions and the larger pitch of their supporting electronics & vacuum.
- Rotating posts range in pitch from 8 to 25 mm, and allow fiber proximities down to ~3 mm.
- Both tilting spines and Starbugs use piezoelectrics and so require the routing of relatively high voltages (100-200V) near the focal plane.
- Away from their centered position, tilting spines will no longer be telecentric as the fiber becomes increasingly inclined to the optical axis.
- Rotating posts incorporate the most moving parts, and might be expected to fail more frequently.
- In all cases care must be taken to avoid fiber collisions.
- The planned
  - tilting spines instruments have up to 4000 fibers,
  - rotating post instruments have up to 5000 fibers, and
  - robot&plate and Starbug instruments have up to 1000 independent actuators.
What actually exists?

• Robot & plate positioners have been developed and used many times. Their principle disadvantage seems to be their configuration time, and multiplexing has been limited to 1000 fibers.

• To date, Starbugs have only been used as prototypes and only two instruments using rotating post (LAMOST) and tilting spine (FMOS) technologies have actually been deployed; the rest are still in development. Both of these instruments have had their issues, and FMOS is now retired.
FMOS

• Configuration took 700sec
  • Fiber view camera could not see all the field in one shot and had to be scanned, taking 100sec each iteration, 7 iterations required to achieve necessary precision.

• Was mounted on Subaru such that the field would rotate against the fibers as observations progressed, limiting time on a single field to 30 minutes before a reconfiguration was required.

• Changing telescope focus with varying temperature also caused target displacements in the instrument’s focal plane.

• Lesson: proper interfacing with the telescope is a critical consideration

• Note: Subaru have moved to rotating posts for their next such instrument SuMIRe/PFS
LAMOST

• Positioning errors
  • As much as 8% of fibers end up to 7” from their intended position (3” fibers)

• Collisions
  • As many as 3-4% of fibers collide

• Positioner mortality?
  • Severity unknown

• They are working on a new, smaller positioner design allowing 25% greater fiber density.
Positioner technologies...
Robot & plate
(WEAVE)

Figure 3: (left) The general layout of the fibre positioner system. (right) Example of a fully configured field. The black circle marks the optical field of view.
Starbugs (TAIPAN)

Figure 1. Individual Starbug for TAIPAN (left) and TAIPAN connector plate (right).

Figure 4. Pictures of TAIPAN positioner showing primary support structure (left), section of bug-catcher (top-right), and view through the glass field plate of Starbugs with lit metrology fibres (bottom-right).
Rotating posts (DESI)

Figure 3.11: Left: Eccentric axis ("θ-φ") kinematics and coordinate systems. Whenever R2 is retracted within the dashed circle E, the positioner is guaranteed free rotation about θ without obstruction from its neighbors. Right: Patrol coverage regions for neighboring positioners. Regions labeled “1x” indicate coverage by a single positioner and “2x” by two positioners.

Figure 3.8: Prototype of the DESI 10.4 mm pitch fiber positioner.
Titling Spines (DESpec)

Figure 4.7: A single MOHAWK actuator. The piezoceramic tube is cemented and soldered to the module base, and has four electrodes in quadrants along its length. When supplied with a sawtooth waveform, the ball moves with sub-micron steps, allowing the spine tip to be positioned anywhere within the patrol radius. The actuator has just 7 parts in total, and only simple machining and assembly of off-the-shelf items is required.