MOHAWK

A 4000 fiber positioner for DESpec
Will Saunders, Greg Smith, Jamie Gilbert, AAO
KICP Dark Energy workshop, 31st May 2012
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FMOS instrument for Subaru needed 400 fibres in 150mm diameter focal plane - so needed a completely new and very compact design.

- Echidna uses 'spines' – carbon-fibre tubes, with a piezo-electric stick-slip actuator to position fibres.
- **7.2mm pitch** between fibres
- Short repositioning times*

*conditions apply*
ECHIDNA features

- Very close minimum target separation, < 1mm
- Patrol radius ~ pitch, so multiple coverage
- Spine tilt introduces focal errors (up to ±86 μm), and telecentricity errors, (up to 2.75°)
  ⇒ 5-10 % throughput and/or etendue loss

Spines reposition in parallel, several iterations per fibre, few seconds per iteration, <10 μm final positioning error.
Echidna in operation
WFMOS concept design

- 2005 proposal for 4500 fibre positioner for Gemini or Subaru, primarily to study dark energy.
- Curved focal plane, 500mm diameter, 7-8mm pitch.
- Fully prototyped at AAO
- Lost out to COBRA!
WFMOS-A concept design

- 2008 proposal to put cut-down WFMOS on AAT
- 1600 spines over 450mm FOV
- Simplified design – 7 parts per actuator, mostly off-the-shelf
- Prototype module built
- Costed at A$2.4M!
MOHAWK Design Drivers

- 4000 fibres over 450mm focal plane $\Rightarrow$ 6.75mm pitch
- Telescope speed F/2.95 - use standard multimode fibres
- Telecentricity and defocus losses $\Rightarrow$ use long spines
- Plate scale 57$\mu$m/" + 1.8" apertures $\Rightarrow$ ~100$\mu$m core fibers
- Telecentric input $\Rightarrow$ curved focal plane, 8m ROC
- DECam barrel > 1 meter diameter - lots of room
- Fiber yield and target completeness $\Rightarrow$ large patrol radius
- Must be low cost, low risk, simple, modular.
Proposed MOHAWK positioner

- 4000 spines, 450mm Focal Plane diameter, 6.75mm pitch.
- Curved modules, each with two rows of spines, fit together like staves of a barrel to form spherical surface.
- All spines identical (except for guide star and metrology spines)
- All modules identical (except for number of spines used)
- 160mm minimum spine length
  ⇒ maximum defocus \( \pm 36 \mu m \) (5\( \mu m \) rms spot radius)
  ⇒ maximum telecentricity error 2.4° (vs 10° beam half-width)
- Now prototyping longer spines to further reduce these errors.
1 MOHAWK spine

- Magnet and cup (pole piece)
- Counterweight
- Bearing ball
- Piezoceramic tube
- Carbon fibre tube
- Fibre ferrule
- Fibre

**Spine length** = 195mm

**Ferrule protrudes** 5mm past end of carbon fibre tube

**Spine tip to ball distance** = 162mm

Tungsten counterweight may be used if size becomes issue
The yellow lines indicate home positions.

The first and last spines are pointing to the right as far as possible.

The central 3 spines are pointing as far left as possible.

The patrol radius is equal to the pitch.

Each position on the Focal Plane is covered by at least 3 spines.
128 MOHAWK spines
4000 MOHAWK spines
MOHAWK on the Blanco
MOHAWK in reality
Proposed MOHAWK control

- 34-layer PCBs for each half-module
- Half-modules driven in quadrants.
- PCBs curved as needed (in one dimension) to take up relevant ROC,
- May drive first in X then Y, halves control electronics! But all spines driven simultaneously.
- Expect 5-6 iterations for repositioning, first iteration takes ~5s but others much faster. Should be easy to reposition during readout.
Proposed MOHAWK metrology

- Fibers must be back-illuminated, from within the spectrographs. Not easy to avoid light leakage to detector.
- Back-illumination can be 'flashed' to reduce CCD contamination during readout.
- Will image Focal Plane with an SBIG-type telescope and 4Kx4K+ camera, mounted in Cassegrain chimney.
- 1/20 pixel centroiding gives 6µm precision, good enough.
- Each module contains 'fiducial' spines, identical to others but fixed, to define positioner metrology.
Proposed MOHAWK design: Fibers

- Use Polymicro FBP fibre – cheap, available, excellent FRD and transparency (few % over 30m for 600-1000nm).

- Fiber cable must surely be connectorised (for instrument changes). Standard telco connectors are good (when gelled) \( \Rightarrow \) need 125\(\mu\)m cladding.

- Standard preforms are 1:1.2 or 1:1.4 core/cladding ratio. So want 89/125\(\mu\)m or 104/125\(\mu\)m core/cladding ratios.

\( \Rightarrow \) 1.56" or 1.83" apertures on sky. Trade-off between light collection versus spectral resolution and spectrograph numbers.
AAO provides whole data taking package, based on our 2dF, 6dF, AAOmega, Echidna, Ozpos, HERMES experience. Now routine to modify package for different instruments and telescopes. Package includes:

- Observing planning software
- Configuring software
- Interface between instrument and telescope (instrument usually drives telescope)
- Data reduction pipeline
Configuring software includes guide stars, target priorities, checking for validity over range of Hour Angles, etc.

Now based on simulated annealing, can't do better!
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• PCA (Principal Component Analysis) sky subtraction now routine \(\Rightarrow\) Poisson-limited sky subtraction with dedicated sky-fibres.
Yield (% fibers on targets) and completeness (% of targets observed) both increase with patrol radius.

If patrol radius = 0.6 x pitch, yield x completeness ~ 0.45

If patrol radius = pitch, yield x completeness ~ 0.7, when $N_{\text{targets}} \sim N_{\text{fibres}}$

Gain diminishing for greater patrol radii
All fiber systems introduce FRD. FRD means accepting collimator losses, or increasing collimator speed (⇒ fewer spectral resolution elements, and fewer spectra per spectrograph).

FRD acts like a convolution of the input beam with an \(~f/10-f/15\) beam.

Spine tilt is just the same, like a convolution with beam of (up to) \(f/12\).

Can estimate resulting collimator loss analytically. For \(f/2.9\) telescope beam and \(f/2.75\) collimator, get few % losses from each effect.
MOHAWK throughput losses

Principal throughput losses:

- Additional aperture losses caused by spine defocus: 0-2%
- Fiber input faces not AR-coated: 4%
- Collimator losses as described in last slide: 5%
- Connectors: 3%

Total losses: 12-14%
MOHAWK positioner cost

- WFMOS positioner costed at A$8.5M for 4500 spines
- WFMOS-A design greatly simplified, positioner costed at A$2.4M in-house cost for 1600 spines
- MOHAWK will be cheaper than WFMOS, and cheaper per fiber than WFMOS-A. **Estimated cost A$7M.**
- **Includes positioning and data reduction software**