Near-UV spectroscopy with the VLT

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From ELT to VLT...
CUBES: cassegrain U-band Brazil-ESO spectrograph

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ESO/NUVA/IAG Workshop on Challenges in UV Astronomy, ESO Garching, 7-11 October 2013

Scientific Rationale

ESO/NUVA/IAG Workshop on Challenges in UV Astronomy
ESO Garching, 7-11 October 2013
CUBES Phase A

Table 4  Key CUBES parameters

| Parameter               | Specification                                |
|-------------------------|----------------------------------------------|
| Slicer                  | No. slices ≥ 7                               |
|                         | slitlet widths ≤ 0.3"                       |
| Transmission grating    | ~3200 mm\(^{-1}\)                           |
|                         | 1st order                                    |
|                         | Ruled width ~260 mm                          |
|                         | Transmission > 80% @ 320 nm                  |
| Detector array          | 4 × 4 K × 2 K × 15 μm × 15 μm                |
|                         | 250 mm × 30 mm                               |
|                         | QE > 85% @ 320 nm                            |
|                         | Dark current < 0.001e-/pix/s                 |
|                         | RON < 2.5e-                                  |
| Wavelength range        | 302–390 nm (TBC)                            |
| Resolving power         | ≥20,000                                      |

Grating was key technical area needing further study/R&D

Barbuy et al. (2014)
Cassegrain U-Band Efficient Spectrograph

Instrument Requirements

The two key requirements for the Phase A conceptual design were a spectral resolving power of $R \geq 20,000$ spanning 302-380 nm, with extension to 400 nm as a goal (ensuring good overlap with ESPRESSO). After revisiting the scientific case these are still valid, and will open-up unique discovery space cf. the latest plans for Paranal and the future instrument suite of the ELT.
### The Origin of the Solar System Elements

| Element | Origin |
|---------|--------|
| H | big bang fusion |
| He | cosmic ray fission |
| Li | merging neutron stars |
| Be | exploding massive stars |
| Na | dying low mass stars |
| Mg | exploding white dwarfs |
| K | |
| Ca | |
| Sc | |
| Ti | |
| V | |
| Cr | |
| Mn | |
| Fe | |
| Co | |
| Ni | |
| Cu | |
| Zn | |
| Ga | |
| Ge | |
| As | |
| Se | |
| Br | |
| Kr | |
| Rb | |
| Sr | |
| Y | |
| Zr | |
| Nb | |
| Mo | |
| Tc | |
| Ru | |
| Rh | |
| Pd | |
| Ag | |
| Cd | |
| In | |
| Sn | |
| Sb | |
| Te | |
| I | |
| Xe | |
| Cs | |
| Ba | |
| Hf | |
| Ta | |
| W | |
| Re | |
| Os | |
| Ir | |
| Pt | |
| Au | |
| Hg | |
| Tl | |
| Pb | |
| Bi | |
| Po | |
| At | |
| Rn | |
| La | |
| Ce | |
| Pr | |
| Nd | |
| Pm | |
| Sm | |
| Eu | |
| Gd | |
| Tb | |
| Dy | |
| Ho | |
| Er | |
| Tm | |
| Yb | |
| Lu | |

Graphic created by Jennifer Johnson

Astronomical Image Credits: ESA/NASA/AASNova
**CUBES: Galactic science**

Barbuy et al. (2012)
CUBES: Galactic science

Testing predictions of different channels for r-process nucleosynthesis

Binary NS mergers:

Magneto-rotational Sne:

Near-UV essential: YII, ZrII, NbII, PdI, AgI, Ball, Lall, Cell, NdII, EuII, GdII, TblII, DyII, Holl, ErII, TmII, OsI, IrI, PbI, Bil, ThII, UII
• Be abundances: Limited to 10s of stars with UVES/Keck-HIRES
• Increased efficiency of ~3 magnitudes
  ➔ samples of 100s in ambitious large programme
The Origin of the Solar System Elements

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AASNova
CUBES: Galactic science

Searching for water in the asteroid belt...

Credit: ESO

Snodgrass et al. (2017)
CUBES: Extra-galactic science

CUBES: Extra-galactic science

Credit: Jure Japelj

CUBES

MOSAIC – VIS(BV)
**CUBES: Extra-galactic science**

Contribution of galaxies (cf. QSOs) to cosmic UV background

Need greater near-UV sensitivity to probe $f_{\text{esc}}$

KLCS sample @ z~3 (Steidel et al. 2018)
CUBES: Phase A optical concept

Updated Phase A concept (kindly provided by B. Delabre)
Philosophy: manufacturability (slices/lenses) and optical transmission

**Image slicer:**
- 6 slices x 0.25” on-sky
- Tot. width: 1.5” ➔ minimal slit losses

**ADC:**
- Greater observational flexibility
- Minimal offset to slit viewing λ

**Spectrograph:**
- 3 bands: 305-335, 328-361, 355-390 nm
- Can optimise each band
- One detector for all 3 bands

*KCWI: Morrissey et al. (2018)*
CUBES: ADC & Image slicer

ADC: silica prisms
- Greater observational flexibility
- Minimal offset to slit viewing \( \lambda \)
- Deviation corrected via TT mirror

FOV 10x1.5arcsec imaged @ 0.25arcsec=0.5mm onto 6 slices each 0.5x20mm
Reimaged slices @ 0.25arcsec=0.2mm

40mm collimated beam
2 mirror reimager
Telescope focus
2 mirror collimator
Tip-tilt fold mirror
6 Slice reimaging mirrors
100 mm
CUBES: ADC & Image slicer

**Image slicer:** 6 slices x 0.25” on-sky
- Total width: 1.5” - minimal slit losses
- 0.5mm slices feasible (cf. KCWI)
- Smaller beam at grating
- Allows pupil to be reimaged on grating

FOV 10x1.5 arcsec imaged
@ 0.25 arcsec=0.5mm
onto 6 slices each 0.5x20mm

Reimaged slices @ 0.25 arcsec=0.2mm
Spectrograph: 3 bands
- Separate collimator, gratings, cameras ➔ can optimise each band
- Spherical lenses (bar one conic)
- Bands have 6nm overlap, no gaps

3 spectra imaged onto one detector
### CUBES: Efficiency

|                           | Band 1 305-335 nm | Band 2 328-361 nm | Band 3 355-390 nm |
|---------------------------|-------------------|-------------------|-------------------|
| ADC (3MIR, 4AR)           | 0.95              | 0.95              | 0.95              |
| Slicer(4MIR)              | 0.98              | 0.98              | 0.98              |
| Dichroics                 | 0.94              | 0.91              | 0.94              |
| Camera (3MIR, 11AR)       | 0.89              | 0.91              | 0.90              |
| **Optics total**          | **0.78**          | **0.77**          | **0.79**          |
| Grating                   | 0.90              | 0.90              | 0.90              |
| CCD                       | 0.85              | 0.85              | 0.85              |
| **Instrument intrinsic DQE** | **0.59**          | **0.59**          | **0.60**          |
| Telescope                 | 0.72              | 0.72              | 0.72              |
| **Overall DQE**           | **0.43**          | **0.42**          | **0.43**          |

**Assumes:**
- **AR coatings**  \( R \leq 0.6\% \) (POG BBAR 280-450)
- **Mirror**  \( R \geq 99\% \) (Thorlabs standard coating)
- **Dichroics**  \( T \geq 97\% \),  \( R \geq 97\% \) (Based on measured dichroics)
CUBES: Grating

- Prototype manufactured by Fraunhofer IOF
- e-beam lithography & atomic layer deposition

See Burmeister et al. (2018) SPIE/10706-74

3448 lines/mm, 250 x 130 mm
CUBES: Grating efficiency (PTB)
Minimal ghosts \(10^{-5}\) cf. expected on-axis counts

Ghost spectra (spatial direction) linked to e-beam mask

IOF have developed further techniques to minimise ghosts
CUBES: Next steps

- Consortium: depth in relevant expertise

WP1: Management
WP2: Pre-optics
WP3: Spectrograph
WP4: Detector system
WP5: Science (incl. DRS)
WP6: EICS
WP7: AIT/Handling

Order-of-mag estimates:
- Effort: 30-35 FTE
- Costs: ~€2M
- 4-year schedule
CUBES: Take-home points

- Broad range of cases that demand near-UV spectra
- Modest instrument development (effort/hw)
- Prototype grating has excellent performance
- Opportunity to build on Brazil’s past investment
- Exploits a powerful strength of the VLT in the ELT era