Considerations for a new low-/moderate-resolution optical facility spectrograph at the VLT Coudé focus

Valentin D. Ivanov¹ and Jean-Louis Lizon¹

¹European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany; vivanov@eso.org

Abstract

Observing at the VLT Coudé focus can boost the collecting area by combining light from multiple VLT unit telescopes (UTs; albeit with some losses in the light train). An instrument at the Coudé enjoys significant operational flexibility advantage: it can be attached to any available UT and the “extra” instrument can help to match better the observing constraints with the current conditions. With modifications to the existing train it can even observe in parallel with ESPRESSO with different UTs.

Here we consider a general purpose VLT Coudé fiber-fed low-resolution facility spectrograph – provisionally named Cappuccino – suitable for rapid follow up and characterization of faint transients, for late-stage monitoring of transients and for rapid classification under poor conditions. With modifications the building cost can be reduced greatly if it is based – with modest changes – on existing hardware.

1 Motivation for an additional low/medium-res Coudé spectrograph at the VLT

The recent years saw a spiking interest in the time-domain astronomy. Sky monitoring and variability has long been a mainstay of astronomy, but now we see the community moving from a handful of dedicated variability surveys (e.g. EROS, MACHO, 2MASSX6 and OGLE) to a number of ambitious and efficient wide-field ground- and space-based facilities (e.g. VISTA, NGTS, WASP, WASP-S, MASCARA, Kepler/K2, TESS, etc.). Even more capable facilities are about to start operating in the near future (e.g. VCRO). Right now the Gaia mission yields on average 1350 alerts for transient events yearly. About 1/3 of them are brighter than R~18 mag. The expected yield of the Zwicky transient survey (47 sq. deg FoV camera, survey speed of over 3000 deg² per hour) is a million transients per night, and the team behind this project plans a robotized spectroscopic follow up of all objects with r<18.5 mag with the Palomar 5-m telescope. VCRO will sweep the field with over 10 million transients per year. The time scale of these events varies in a wide range: from minutes-hours for gamma ray bursts, to days-week for kilonovae and to many months for some types of supernovae.

The follow up and characterization of this large yield is an unprecedented challenge to astronomy. Various research teams and community working groups – e.g., [2] – have identified three types of necessary follow up facilities:

(1) efficient medium-resolution spectrographs like X-shooter and SoXS that cover the (nearly) entire optical/near-infrared range and in the infrared they can work between sky lines – aimed mainly, but not exclusively, at the extragalactic transients

(2) high multiplexity facilities that deliver thousands of spectra over degree-size fields in moderate/high-resolution 5000/30000 up to 1.3-1.7 µm in the red, similar to the incoming 4MOST – aimed at Milky Way transits that can be “injected” in other on-going surveys

(3) low/moderate-resolution R~1000-2000 wide wavelength coverage (400-1000/1300 nm) spectrographs, similar to the existing combinations
FORS2+SINFONI or EFOSC2+Sofi – to characterize faint transients, to follow up transients at late stages when they have grown faint, or to deliver preliminary classification of bright transients thereby saving time at other high-pressure instruments.

As noted above, ESO offers or will offer soon instruments in all these categories, but the third category deserves a special discussion. Despite numerous upgrades, SINFONI and EFOSC2 are ageing instruments that will be decommissioned eventually (albeit SINFONI will be replaced by ERIS). FORS2 is mounted on UT1 (unit telescope) that is typically over-subscribed by a factor of 4 or more, and over the last few years UT1 systematically comes as the first or the second most demanded among the four VLT units.

Expanding the options that the users have is possible by taking advantage of the already-operational Coudé facility and offering either (i) an additional focus for fiber-fed user instrument or by placing there (ii) a new fiber-fed low- or moderate-resolution facility spectrograph spanning the entire optical range from 360 to ~900 nm.

Such new instrument will have lower efficiency with respect to FORS2 or X-shooter because of the train and fiber losses, but will gain over SoXS and 4MOST because of the larger collecting area of the 8m class VLT telescope over 4m class NTT and VISTA (btw, 4MOST is also fiber-fed with respective losses).

A great cost optimization is achievable if the new instrument is based on some of the existing non-operational instruments, e.g. FORS1, EFOSC2, etc, upgraded with modern filter, grism and detector to improve the efficiency. Operationally, the instrument can be limited – at least initially – to a single mode which means no moving parts. This implies improved stability and maintainability, and more straightforward data reduction. Other modes can be implemented later, if the community requests them.

A fiber-fed Coudé spectrograph will potentially suffer from poor sky subtraction – like all single-fiber spectrographs, because there is no option to monitor the off-target sky simultaneously with obtaining the science spectrum. This may potentially lower the red end of the useful spectral range to 850-900 nm for faint targets, to exclude regions with strong sky emission lines.

The Coudé facility allows to feed the new instrument with light from multiple VLT units, gaining deeper limiting magnitude than with a single UT. Another advantage of the proposed instrument is the greater operational flexibility – the liberty to be used with any of the UTs. Finally, the new instrument will not compete with ESPRESSO, but it will complement it because of the incomparable resolutions.

2 Existing infrastructure – The VLT Coudé facility

The Coudé facility includes:

1. Combined Coudé Laboratory (CCL) – a rectangular room of approximately $10.7 \times 20$ m size, partially occupied by ESPRESSO [1]. Vibrations by the additional instrument should not disturb ESPRESSO (exhich is one of the many reasons why an additional Coudé instrument should not work in the infrared). Additional power and local area network connections may be needed.

2. Coudé Room – a circular room of roughly 8.5-m diameter centred on the azimuth axis of the telescope.

3. Coudé Bodega – located around the Coudé room, it was used as a warehouse.

4. Coudé Trains – a number of electric, optical and mechanical components, controlled by the telescope control software; they transfer the light of the UTs from their Nasmyth B foci to the CCL; Coudé A is reserved for VLTI and Coudé B – for ESPRESSO.

These components have existed, to one or another degree, since the construction of the VLT but they have been used only partially by the VLTI until ESPRESSO entered operations. A schematic drawing of the CCL with ESPRESSO is shown in Fig. 1 (reproduced form the ESPRESSO user manual [1]).

Cappuccino, the instrument considered here, could be located in the CCL next to ESPRESSO. Sharing the CCL with ESPRESSO sets limitations on heat production and vibrations, but the compact nature of Cappuccino, its lack of moving parts and of closed-
Figure 1: CCL, generic view. ESPRESSO is at the centre, the light trains from the individual UTs arrive to the CCL on the right (UT1, UT2, UT3 and UT4, respectively from top to right and to bottom). The compact size and the low weight of Cappuccino allow to place it on a rack above the ground, saving space and easing the access to it.

cycle coolers promise that these limitations will be easily met.

3 Cappuccino sub-systems

Cappuccino foreseen seen as a simple and manimalistic system – for easy building, operations, maintenance and for stability that in turn will make the data processing more straightforward. The basic components of this instrument are:

- Front end: optics receiving light from the Coudé train and feeding it into the spectrograph. Additional fiber pick ups are glued to the rotating table. In the simplest case it is just one pick up, allowing Cappuccino to use one UT at a time, in the more advanced case – four pick ups and a beam combiner, allowing it to use multiple UTs. Without further modifications Cappuccino can not work in parallel with ESPRESSO, but it is not impossible to image a design where the two instruments are fed simultaneously by different UTs. The front end performs target acquisition, alternates between on-sky observations and the calibration unit, and field/pupil stabilization during exposure. Similarly to ESPRESSO, it controls the atmospheric dispersion correctors (even though they are formally part of the Coudé train). The new instrument shares the toggling mechanism with ESPRESSO.

- Calibration unit: includes lamps for wavelength calibration and flat fielding, adjusting their intensity as necessary. It is located in the CCL and provides the light via optical fiber.

- Fiber link: connects the front end and the spectrograph.

- Spectrograph: includes a focal reducer. The slit is formed at the end of the fiber link. The dispersing element (prism, grism or grating) is mounted on a bench, reducing flexure and providing sufficient earthquake stability. The light of a single order is recorded onto the detector. Finally, there is a camera with respective input optics. The spectrograph is warm, except for the detector. The detector dewar is equipped with a pumping system and all the necessary vacuum and temperature sensors.

- Instrument electronics: controls instrument functions and telemetry, provides a link to the Instrument workstation. Part of it is inside the dewar with the detector.

If the design of the new spectrograph is based on an existing instrument, then the new systems (aside from any elements that might be upgraded to gain efficiency) are the focal reducer and the calibration unit that will feed it via a fiber – because all existing instruments that were considered here were directly fed and have f-ratio inconsistent with a fiber; their calibrations units typically are designed to shine the light on a screen.

4 Cappuccino efficiency

Estimated throughput breakdown (based on the ESPRESSO and FORS2 values, whenever possible):

- Coudé train: ≥80%
- Front end: ≥83%
- Fiber link: 70%
- Spectrograph optics: ∼70% at any wavelength (for approximately 10 optical elements with ∼2% loss per surface)
- Detector: 90% over most of the wavelength range

A conservative estimate of the total throughput is: 0.8*0.83*0.7*0.7*0.9 ∼ 30%. As expected, it is lower than for FORS2 with its average of 45% (grism 600I, 400-1000 nm range). 4MOST – another fiber-fed spectrograph – has an observing efficiency of 18% over 370–950 nm (resolution R ∼ 4000-7500).

5  Cappuccino hardware cost

These cost estimates are for the simplest design case – a single fiber pick up allowing Cappuccino to use one UT at a time, and single mode/grating (no moving parts). Data flow system is not included.

5.1 Case I: design based on FORS1 or EFOSC2

This option reuses an existing collimator and camera. Itemized costs:

(1) Fibre link and feed adaptation: design 0.3 FTE, procurement 40 K€
(2) Structure and enclosure for the optic and calibration unit: design 0.5 FTE, procurement 60 K€
(3) Grating (grism VPH and mount): design 0.2 FTE, procurement 40 K€
(4) Detector system:
   (4.1) Cryostat (Cryostat, NGC - new generation controller and detector; no new design required, everything exist already): test 1 FTE, procurement 55 K€ (cryostat and Cryo vacuum control and equipment), 60 K€ (NGC), 150 K€ (detector)
   (4.2) Electronic control (only for calibration source, and pick up system) 30 K€

Total: 2 FTE, 435 K€.

The additional costs over Case I are: for the design 0.5 FTE and procurement 300 K€.
Total: 2.5 FTE, 735 K€.

6  Summary and conclusions

Cappuccino, a new general-purpose optical facility instrument for the VLT Coudé focus is considered. Its main advantages are:

- capability to quickly deliver spectra of faint targets, especially ones that rapidly grow faint, e.g. various transients;
- significant improvement of the VLT operational flexibility, in effect adding an extra low-res spectrograph at each UT that can be used during poor observing conditions;
- extremely low cost.

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References

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