



CUBES

Cassegrain U-Band Efficient Spectrograph Bringing a unique capability to ESO's VLT

Stefano Covino - Roberto Cirami (INAF)

on behalf of CUBES Consortium & Science Team



CUBES: The ultimate UV instrument for Paranal

High-res spectroscopy of the near-UV regime provides access to key lines of stellar spectra:

- a tremendous diversity of iron-peak and heavy elements
- lighter elements (notably Beryllium) and light-element molecules (CO, CN, OH)
- Balmer lines and Balmer jump (YSOs)

The near-UV range is also critical in extragalactic observations:

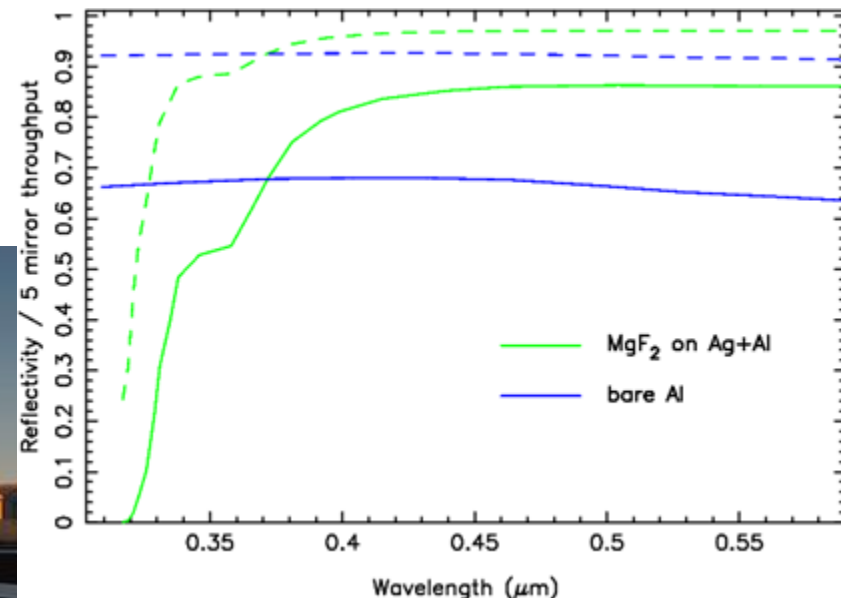
- circumgalactic medium (CGM) of distant galaxies
 - contributors to the cosmic UV background (galaxies/AGN)
 - H_2 and primordial Deuterium
- in a z regime of relatively transparent IGM



Unique discovery space (incl. cf. ELT)

Competitive for observations at $\lambda < 400$ nm
well into the 2030s (e.g. Evans et al. 2016)

ELT Performance

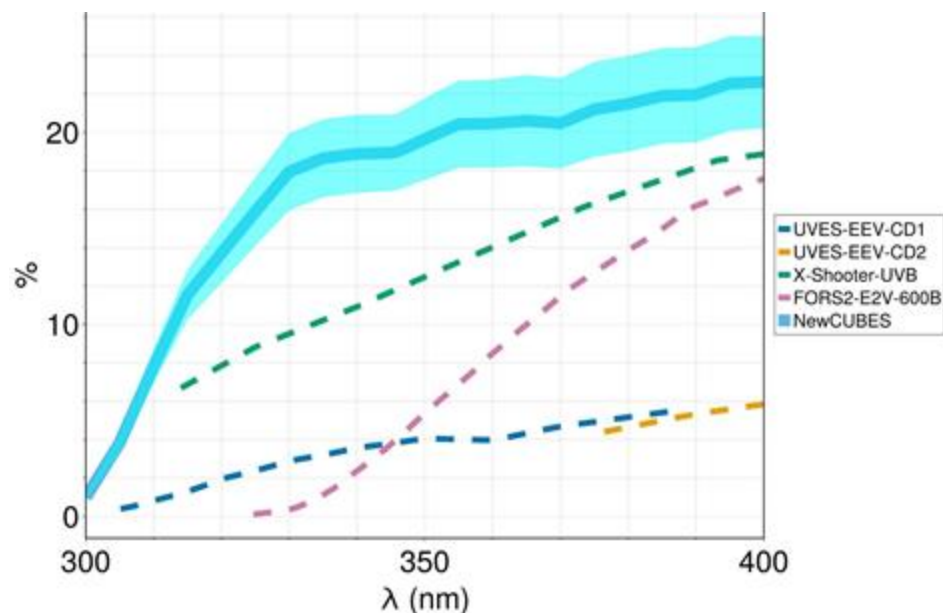


CUBES: The ultimate UV instrument for Paranal

- Spectral resolving power $R \sim 20,000$, with a second mode at $R \sim 7000$
- Range: 305-400 nm (goal 300-420 nm)
- Focus on efficiency: $> 40\%$ in the 305-360nm range (goal $> 45\%$)
- Broad science case



Including telescope and atmosphere



Motivations for the UV: Heavy elements



Needed resolution for our science goals

Stellar astrophysics in the near UV with VLT-CUBES

H. Ernandes^{1,2,3}, C. J. Evans², B. Barbuy¹, B. Castilho⁴, G. Cescutti⁵, N. Christlieb⁶, S. Cristiani⁵, G. Cupani⁵, P. Di Marcantonio⁵, M. Franchini⁵, C. Hansen⁷, A. Quirrenbach⁶, R. Smiljanic⁸

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²UK Astronomy Technology Centre, Royal Observatory, Blackford Hill, Edinburgh, EH9 3HJ, UK

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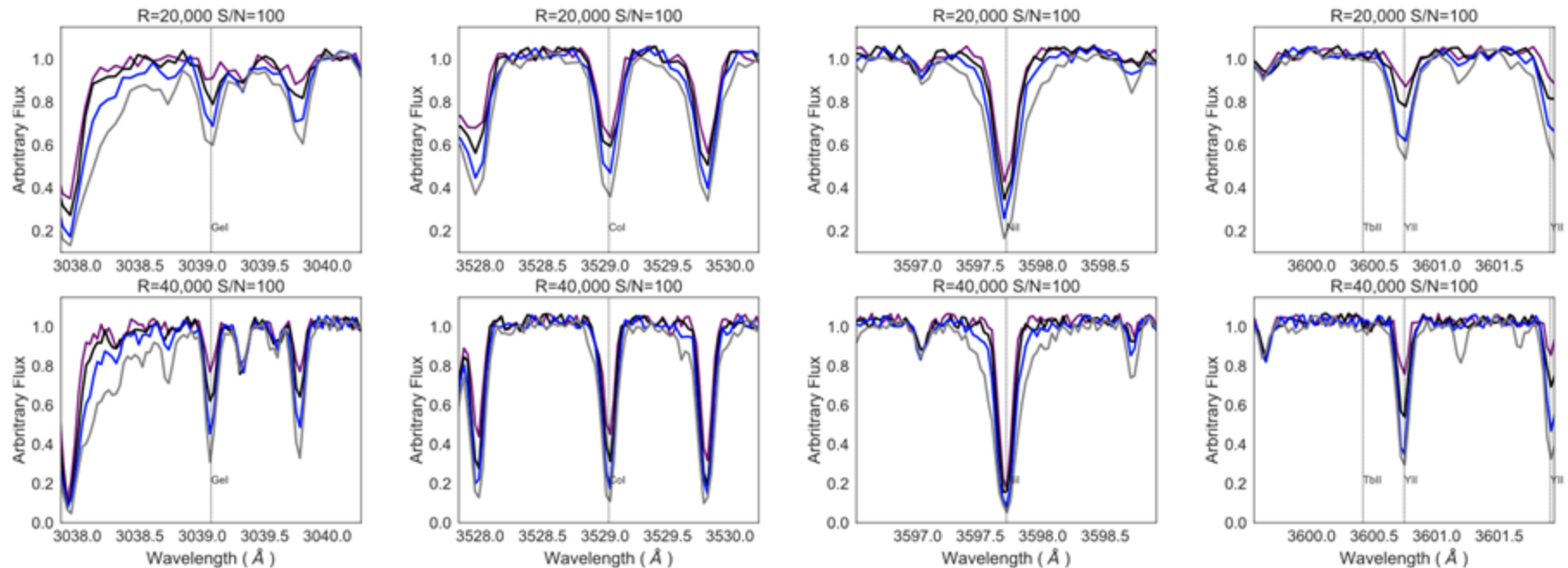
⁴Laboratório Nacional de Astrofísica/MCTIC, Rua Estados Unidos, 154 - 37504-364, Itajubá, MG, Brazil

⁵INAF - Osservatorio Astronomico di Trieste, via G. B. Tiepolo 11, 34131 Trieste, Italy

⁶Landessternwarte, Zentrum für Astronomie der Universität Heidelberg, Königstuhl 12, 69117, Heidelberg, Germany

⁷Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg Germany

⁸Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, Bartycka 18, 00-716, Warsaw, Poland



(a) Ge I $\lambda 3039.07$

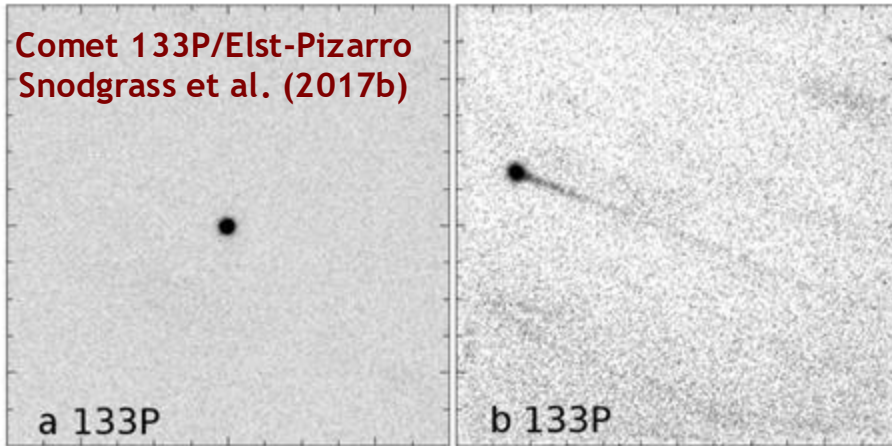
(b) Co I $\lambda 3529.03$

(c) Ni I $\lambda 3597.71$

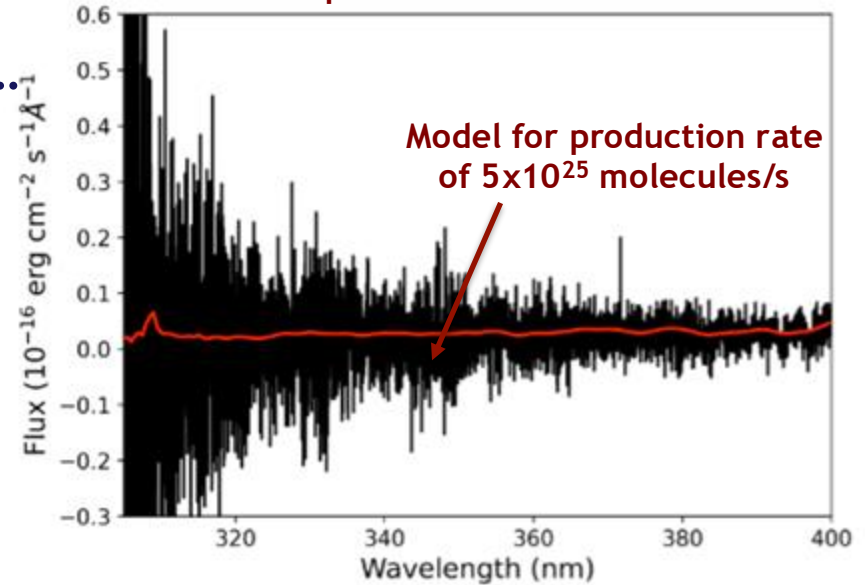
(d) Y II $\lambda 3600.74$

Cometary Science

Searching for water in the asteroid belt...

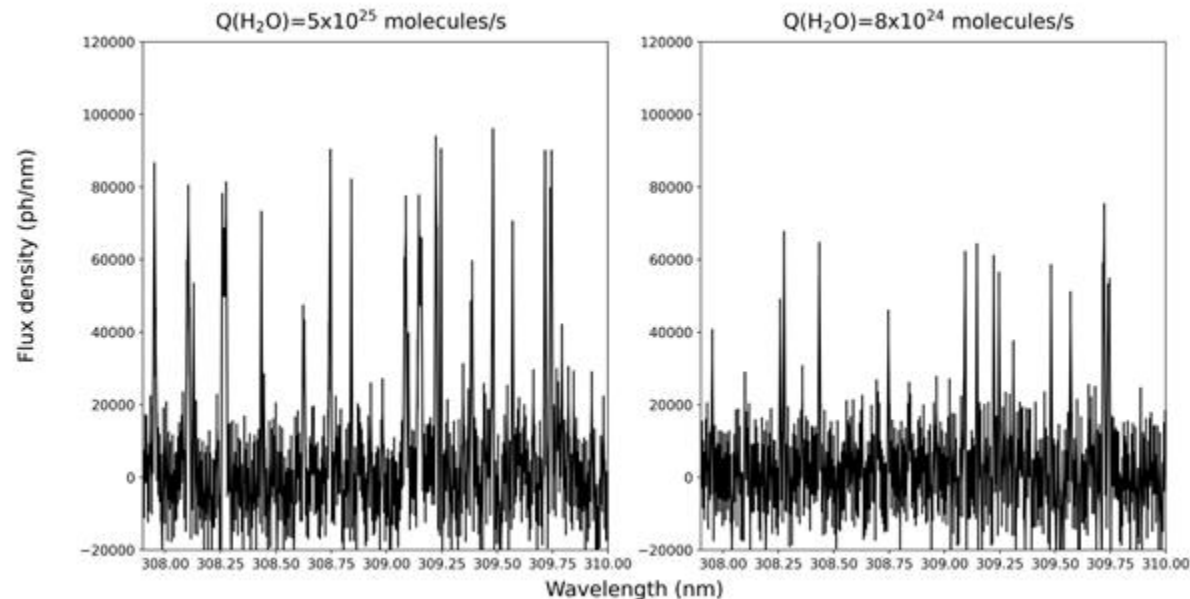


X-Shooter spectrum of Comet P/2012 T1



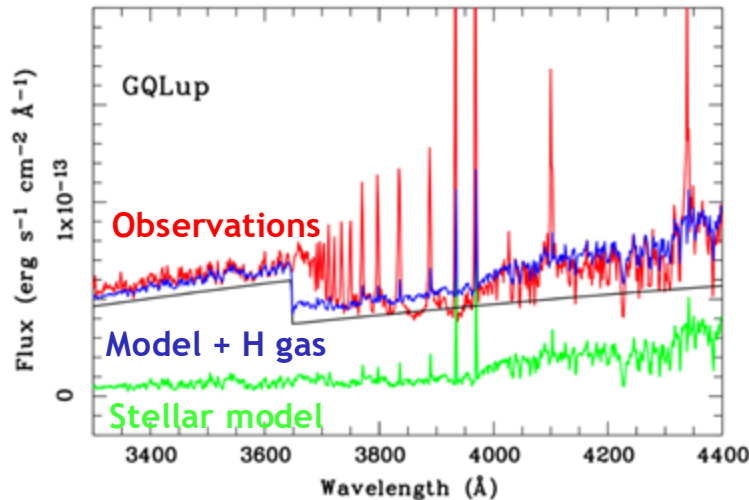
Simulations from Opitom et al.
(ExA Special Issue)

OH detections 10 times lower
($\sim 5 \times 10^{24}$ molecules/s) in 2hrs



Accretion/outflows in young stars

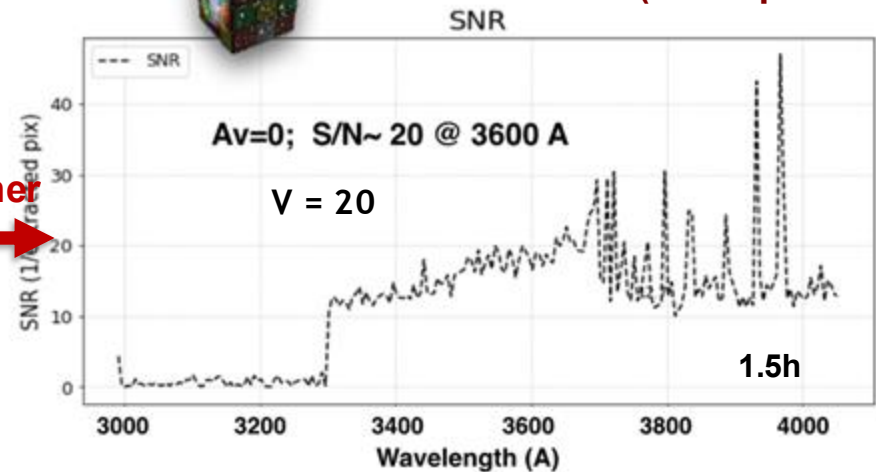
Near-UV is powerful for studies of YSOs (accretion, jets, winds etc)



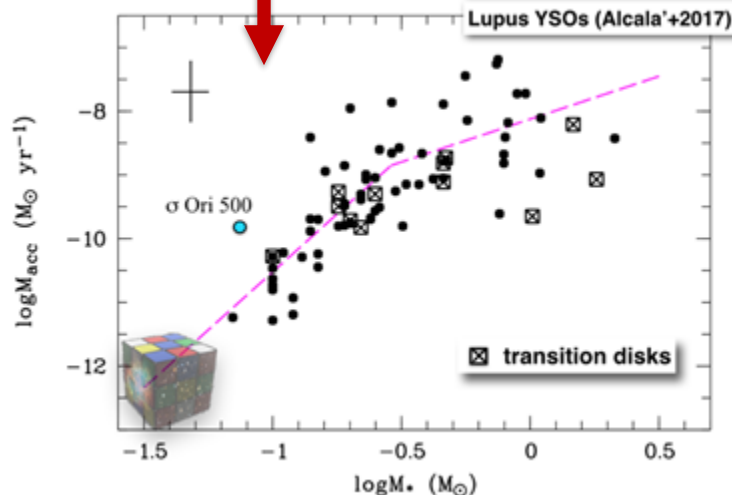
Further



From Alcalá et al. (ExA Special Issue)



Lower masses



Now kpc distances rather than just nearby star-forming regions

Low-res mode: sensitivity for faintest sources, so larger distances/extinction

Longer wavelength observations needed but objects also highly variable

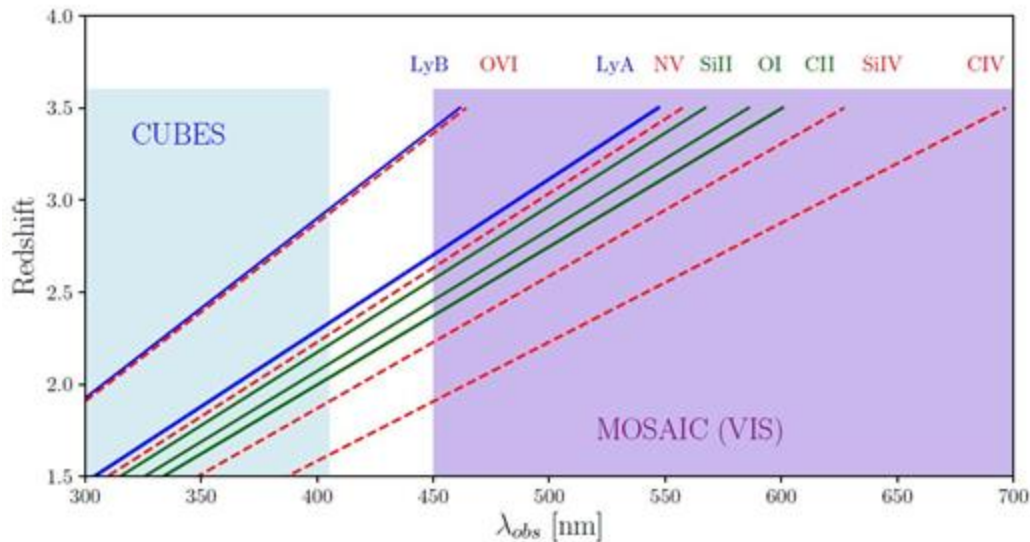


“simultaneous” UVES obs

Chasing baryons at cosmic noon

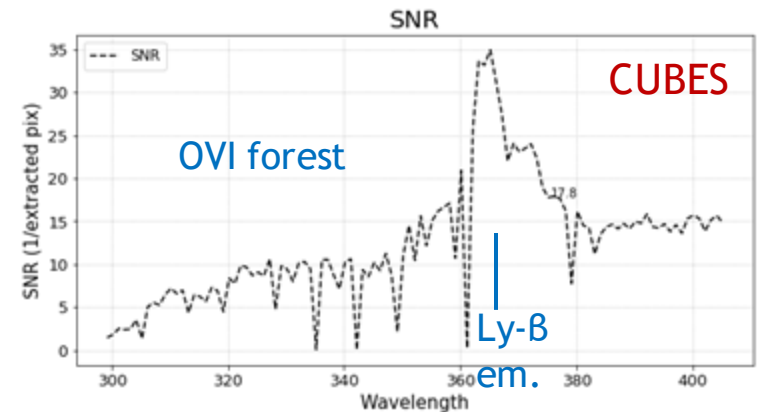
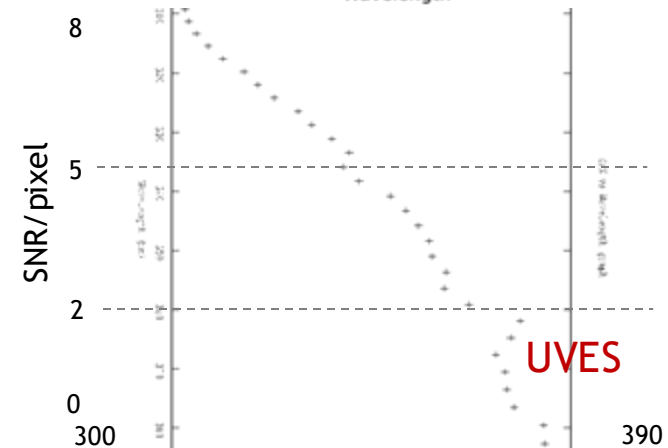


CUBES will enable the study and characterization of baryons in the inter-CGM at $z \sim 1.5-3.0$ with different tracers (mainly HI and OVI).



- Critical complementarity with ELT ANDES & MOSAIC
- Significant improvement of SNR/pix compared to UVES

D'Odorico (ExA Special Issue)



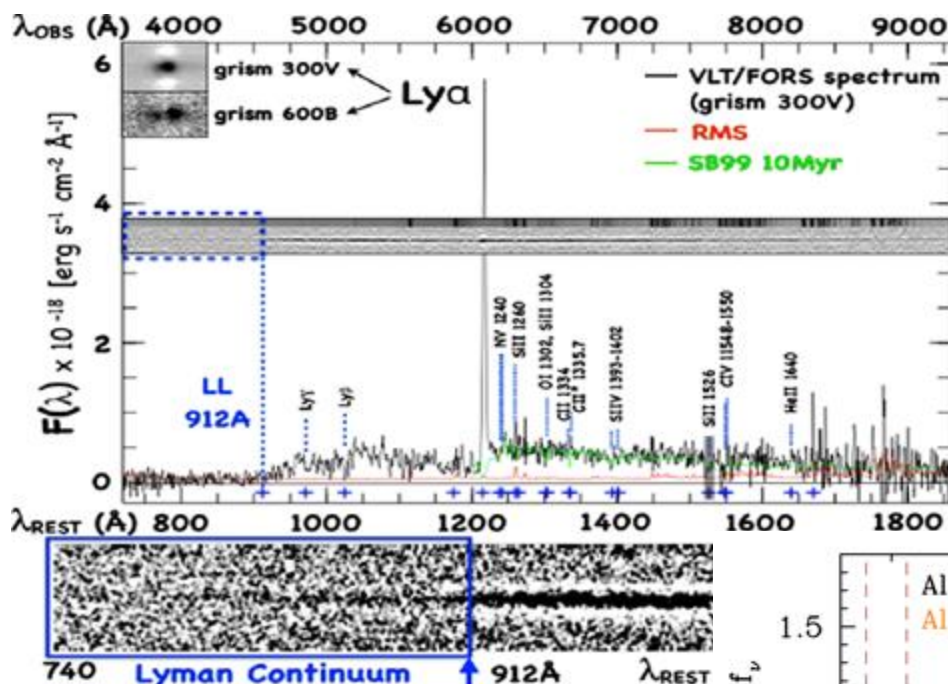
QSO at $z=2.5$ observed for 2x600s

Escape fraction from high- z galaxies



To quantify f_{esc} from galaxies (cf. QSOs) in context of cosmic UV background

LR-mode ensure we are background limited for faint high- z sources

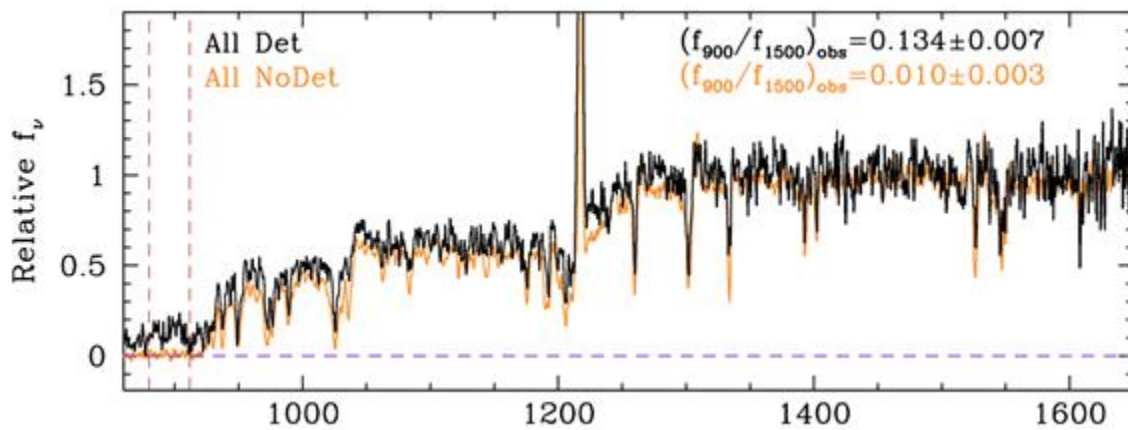


Need greater near-UV sensitivity to probe f_{esc} at peak SF epochs

Detailed simulations presented by Vanzella et al. (ExA Special Issue)

KLCS sample @ $z \sim 3$ (Steidel et al. 2018)

$z = 3.999$ (Vanzella et al. 2018)



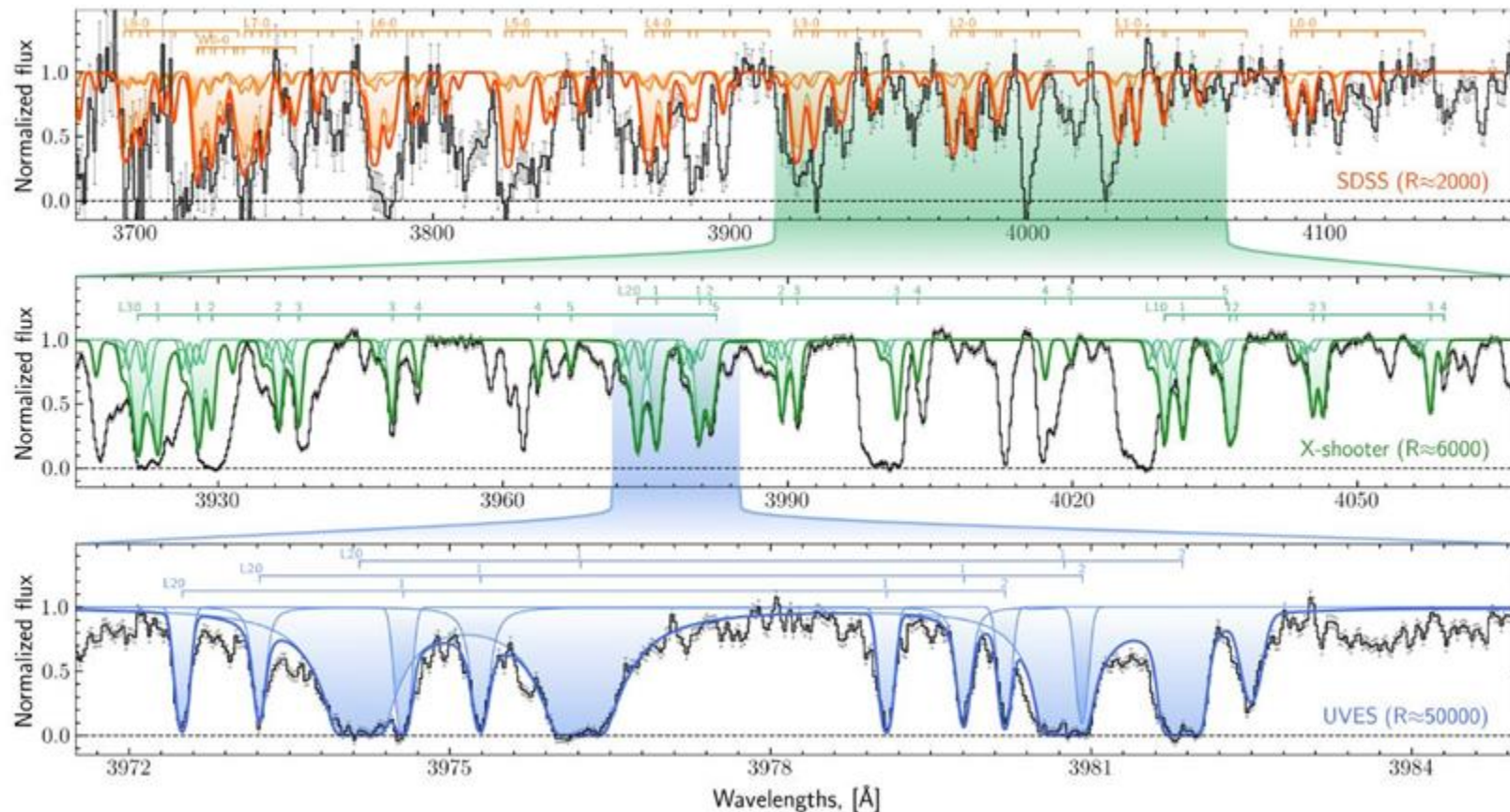
Molecular Hydrogen at high redshift



Balashev & Noterdaeme
ExA special issue

CUBES will expand on current sample via:

- Enabling observations of fainter quasars (of which there are more).
- Access quasars at $z = 1.9$ -3.1 (more than at higher z).
- Less blending of diagnostic lines at lower $z \rightarrow$ Cleaner measurements.

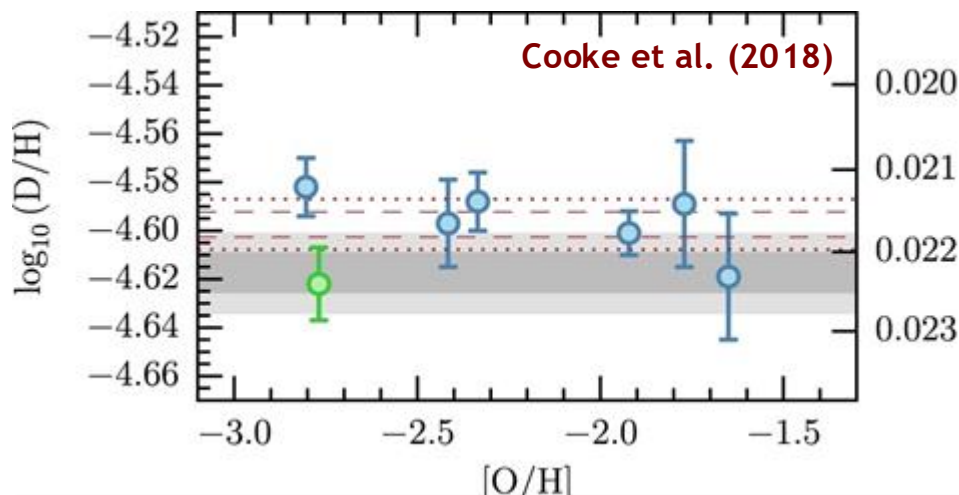


Primordial D/H ratio



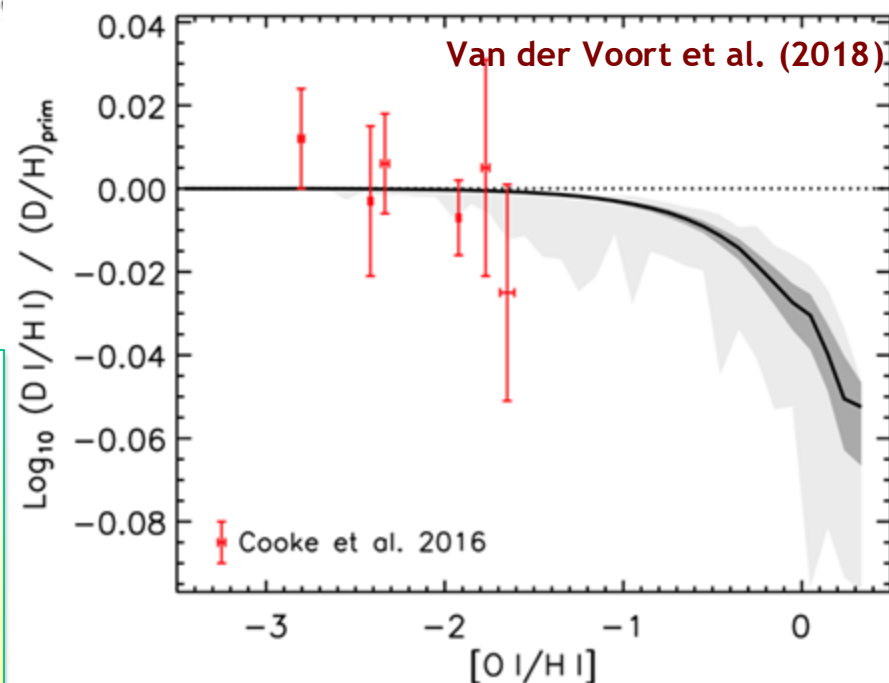
CUBES will expand on current sample via:

- Enabling observations of fainter quasars (of which there are more).
- Access quasars at $z = 2.5-2.8$ (more than at $z = 2.8-3.1$).
- Less blending of diagnostic lines at lower $z \rightarrow$ Cleaner measurements.



Enables:

- Identification of primordial D/H plateau.
- D/H to 0.3% provides 1% measure of N_{eff} (effective # of neutrino species; if $N_{\text{eff}} > 3$ then additional factors are missing in standard model).

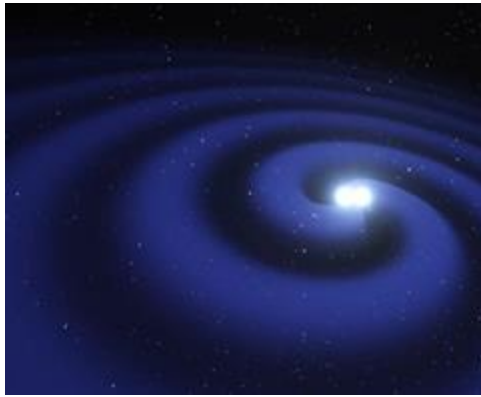
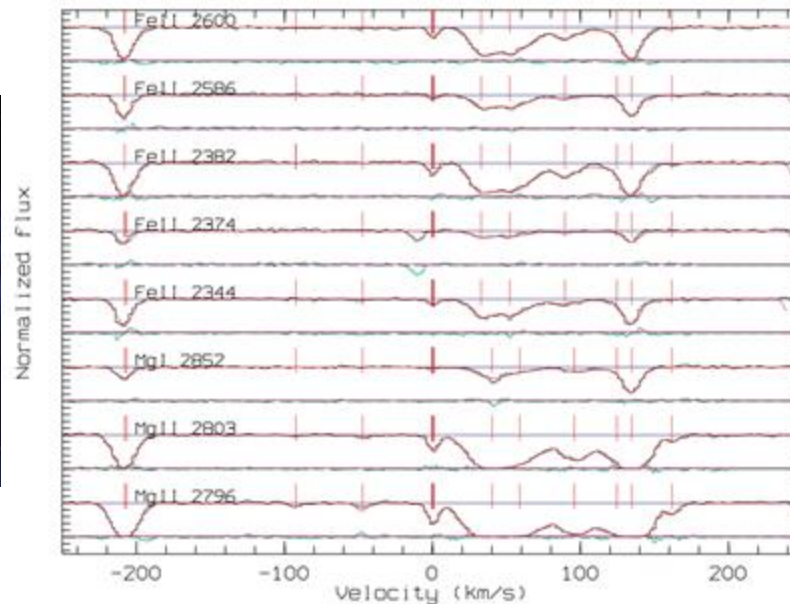


Transients



Transients (incl. kilonovae) a key motivation for fibre-link to UVES

Potentially excellent synergies with e.g. VRO/LSST



Absorption components in ISM to $z=0.94$ GRB (D'Elia et al. 2010)

Simultaneous CUBES+(UVES/X-shooter) observations critical for, e.g.:

- How GRB environment is influenced by the explosion
- Key diagnostic: FeII at $\lambda_{\text{rest}} \sim 240$ nm, so redshift range currently limited
- Helps separate interstellar features

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PS: Cyrielle Opitom

Solar System Science

Cyrielle Opitom

Galactic Science

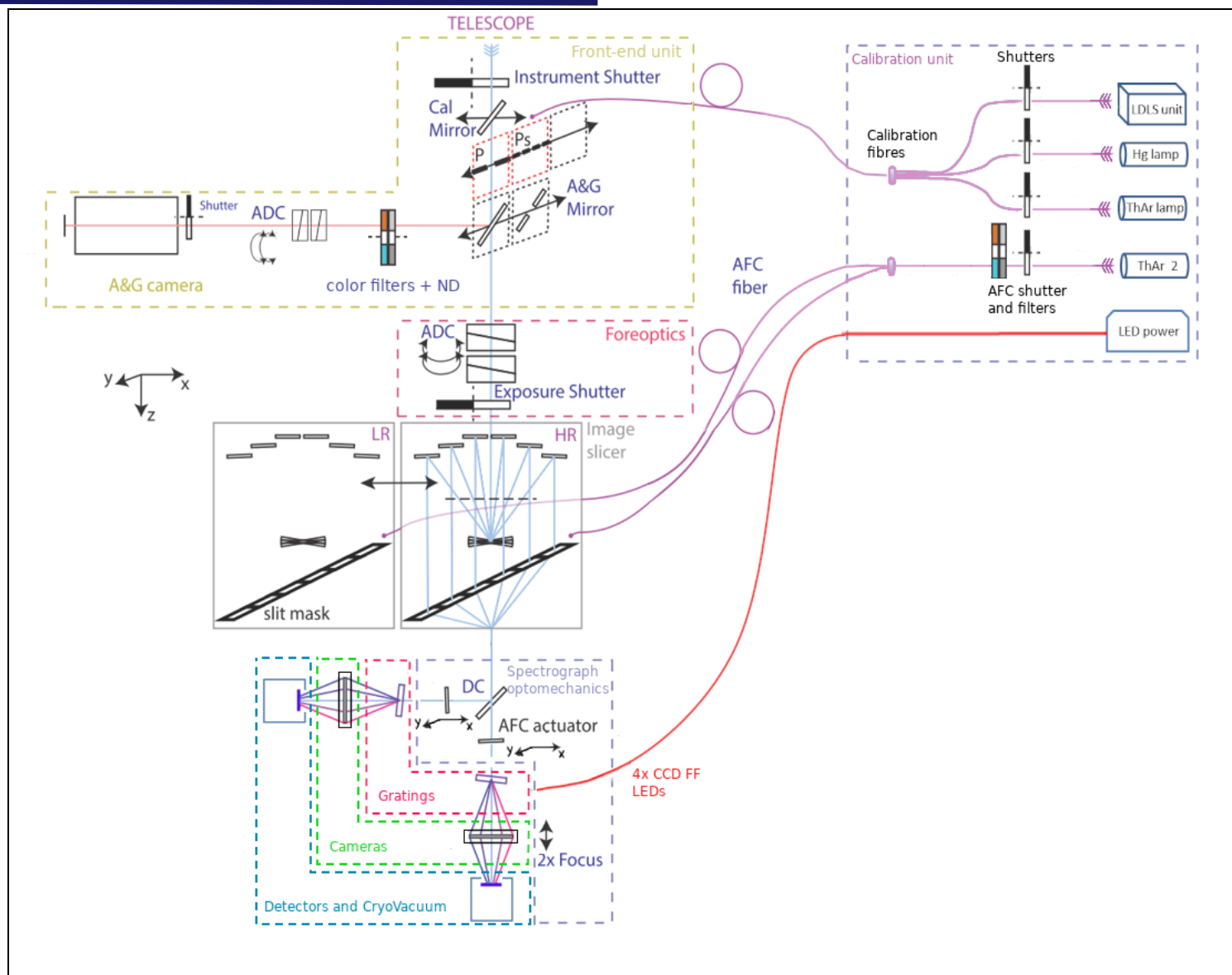
Gabriele Cescutti

Extragalactic Cases

Ryan Cooke



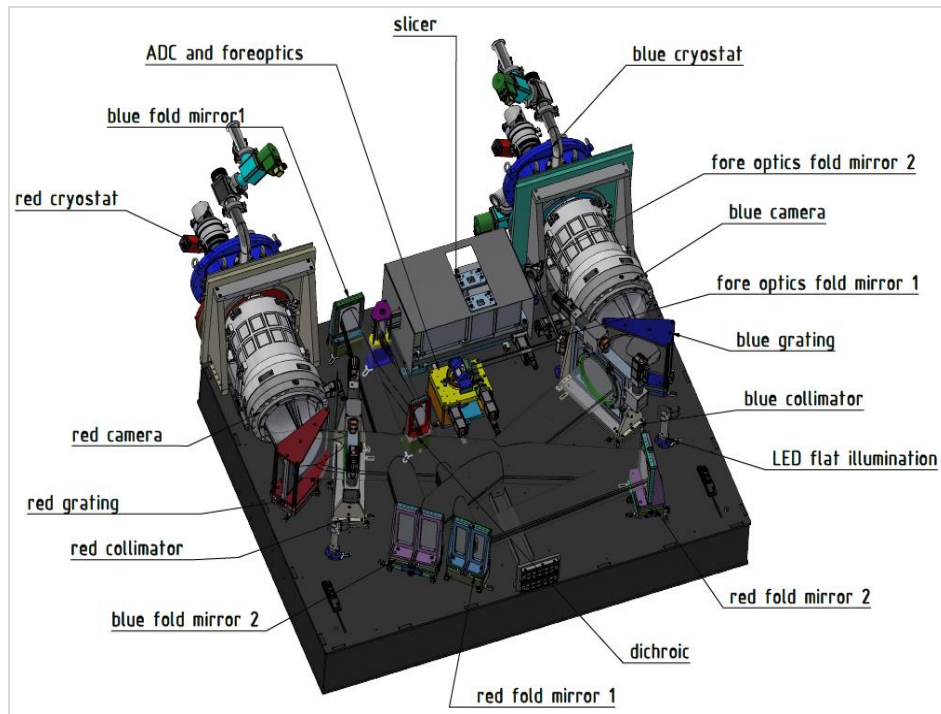
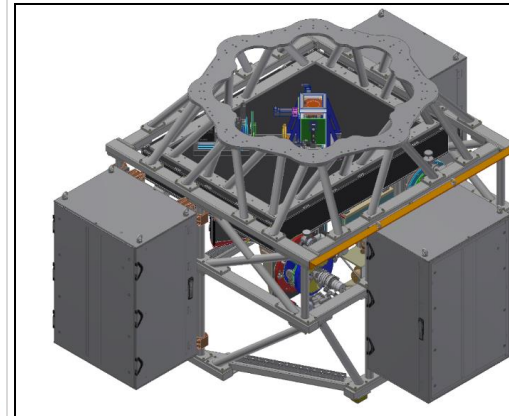
CUBES: System Architecture





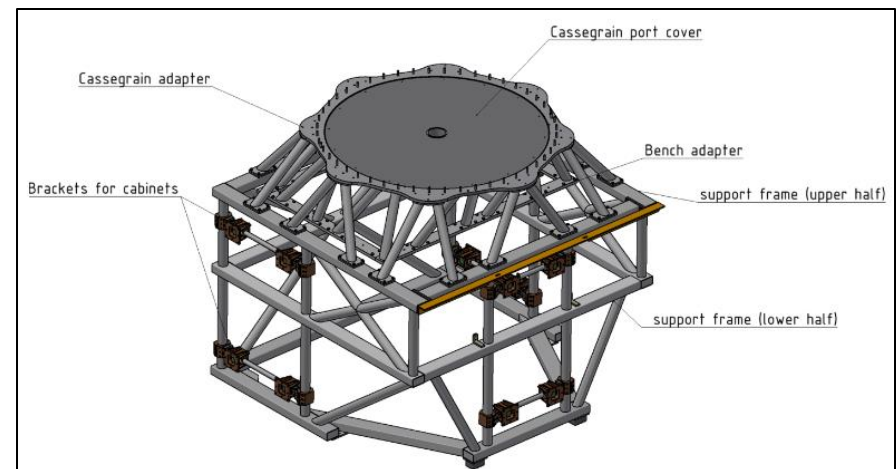
CUBES: Mechanical Design

All spectrograph optics are mounted on a single optical bench → CFRP bench with size $1.3 \times 1.7 \text{ m}^2$



Global Structure:

- External frame holding the 3 cabinets
- Bench adapter holding the Bench
- Cassegrain adapter single flange





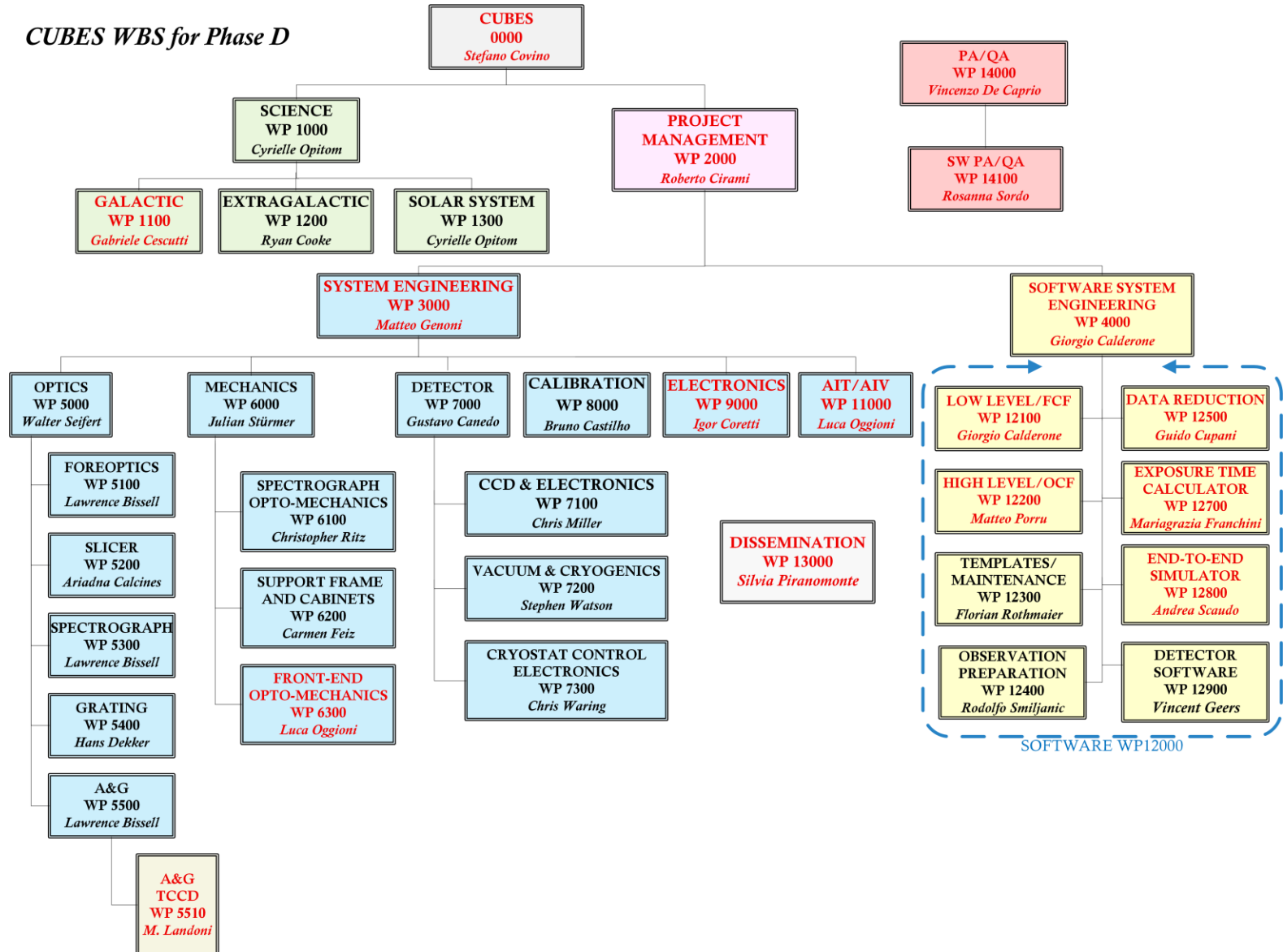
CUBES: The Consortium

- **Italy:** INAF - Istituto Nazionale di Astrofisica, (Consortium leader)
- **UK:** STFC-UKATC - UK Astronomy Technology Centre, (primary UK partner) and Durham University Centre for Advanced Instrumentation (secondary UK partner)
- **Germany:** LSW - Landessternwarte, Zentrum für Astronomie der Universität Heidelberg
- **Brazil:** IAG-USP - Instituto de Astronomia, Geofísica e Ciências Atmosféricas (primary Brazil partner) and LNA - Laboratório Nacional de Astrofísica (secondary Brazil partner)
- **Poland:** NCAC - Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences
- **Slovenia:** UL - Univerza v Ljubljani and UNG - Univerza v Novi Gorici



CUBES: WBS - The role of INAF

CUBES WBS for Phase D





CUBES: Project Schedule

Milestone / Activity	Date
Entry into force of the CA	15 Feb. 2022
Kick-off meeting	24 Mar. 2022
PDR	30 Nov.- 1 Dec. 2022
Detector LLI Review	6 Jul. 2023
Optics LLI Review	16 Nov. 2023
FDR	24-25 Oct. 2024
FDR close out meeting	27 May 2025
Spectrograph in Heidelberg	Aug. 2027 – Mar. 2028
AIT in Merate	Apr. 2028 – Jan. 2030
TRR	Oct. 2029
PAE	Apr. 2030
PAC	mid-2031

