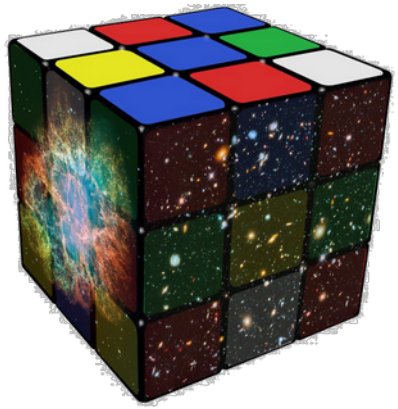

The Cassegrain U-Band Efficient Spectrograph (CUBES): status and opportunities

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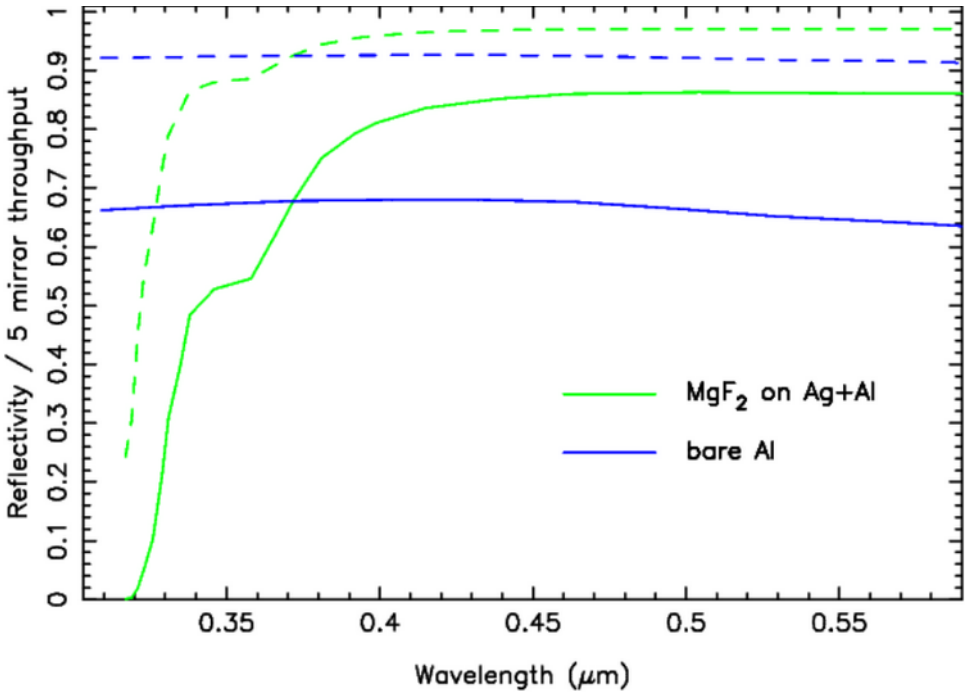
XLI Meeting of the Polish Astronomical Society, Toruń, 11-15.09.2023

What is CUBES?

- **Cassegrain U-Band Efficient Spectrograph** (Cristiani et al. 2022a,b; Zanutta et al. 2023)
- New spectrograph for the 8m VLT of ESO
- **Consortium:** Italy (leader; PI: S. Covino), Germany, UK, Brazil, Poland
- Ground near-UV **(300-400 nm)**
- Two resolutions (R~6000, R~23 000)
- Blue-optimised spectrograph @ VLT will be **competitive against the 39m ELT** (Pasquini 2014; Evans et al. 2016)

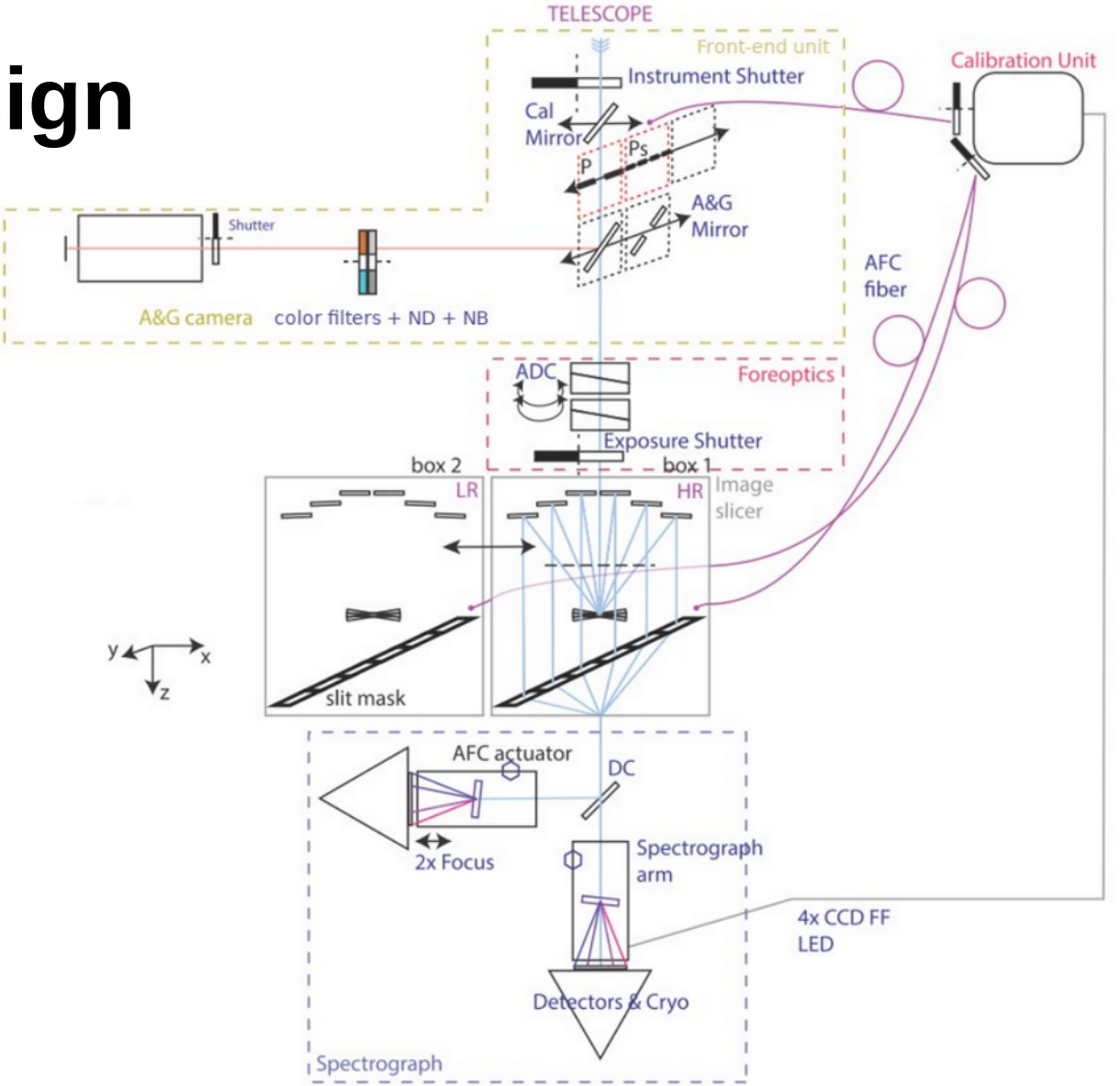


(Credit: ESO)

CUBES Design

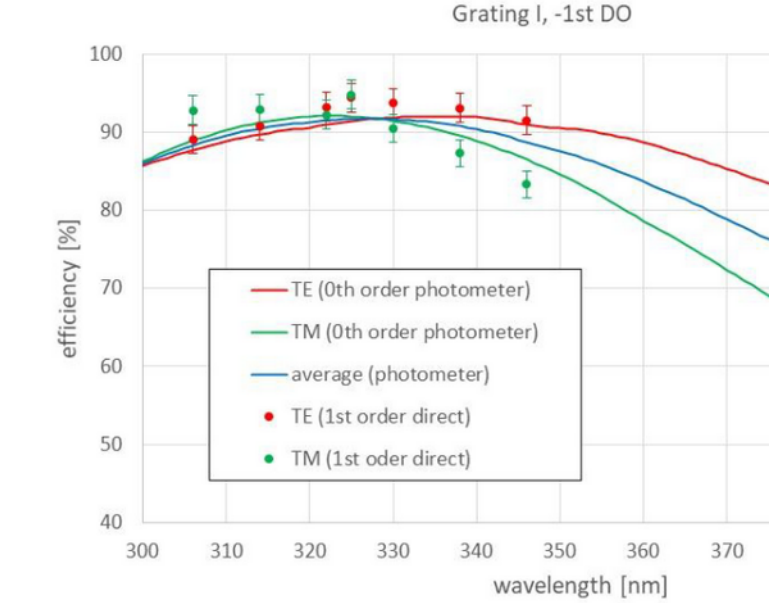
- High-efficiency (> 40 %)
- Two image slicers (Calcines et al. 2023)
- State-of-the-art first order transmission gratings (Zeitner et al. 2022, 2023)
- Two arms using a dichroic beam splitter (300-352nm; 346-405nm)
- Two large (9k x 9k) UV-optimized CCDs

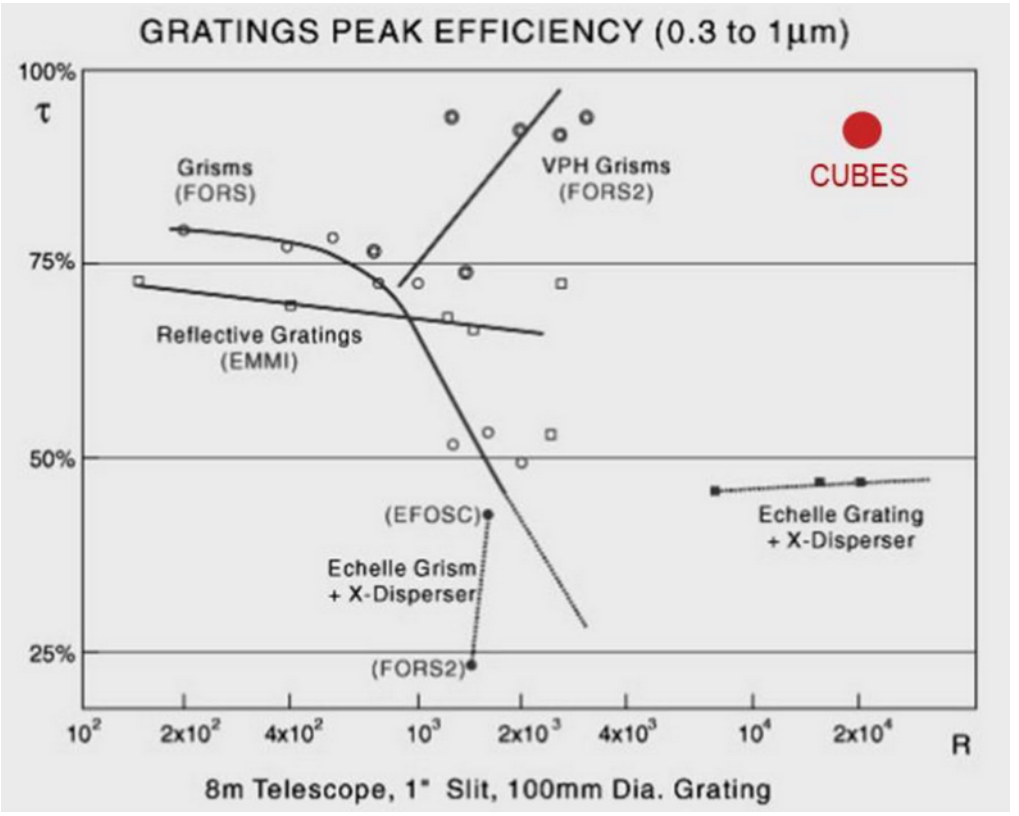
- **Option:** AFC – Active Flexure Compensation system (ThAr lamp used during science exposure to track changes in spectral and spatial directions)



Grating

- Fraunhofer Institute for Applied Optics and Precision Engineering (IOF), Jena, Germany
- On a fused-silica substrate using electron-beam lithography and atomic layer deposition (Zeitner et al. 2022, 2023)
- Prototype with 3600 lines/mm:





(Zeitner et al. 2023)

CUBES Science

- **See CUBES special edition in Experimental Astronomy (17 articles)**

- Summary in Evans et al. (2023): Solar system, Galactic, extragalactic and transient science
- Several topics with dedicated discussions and simulations

- Reach sources up to 3 mag fainter than currently possible at the near UV

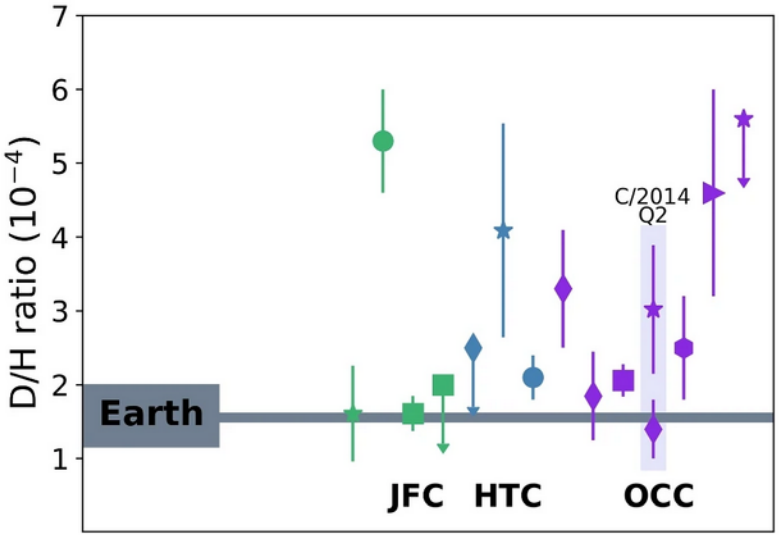
Table 1 Summary of high-level science cases developed during the CUBES Phase A study. Entries in the third column refer to the expanded articles presented elsewhere in this Special Issue (SI)

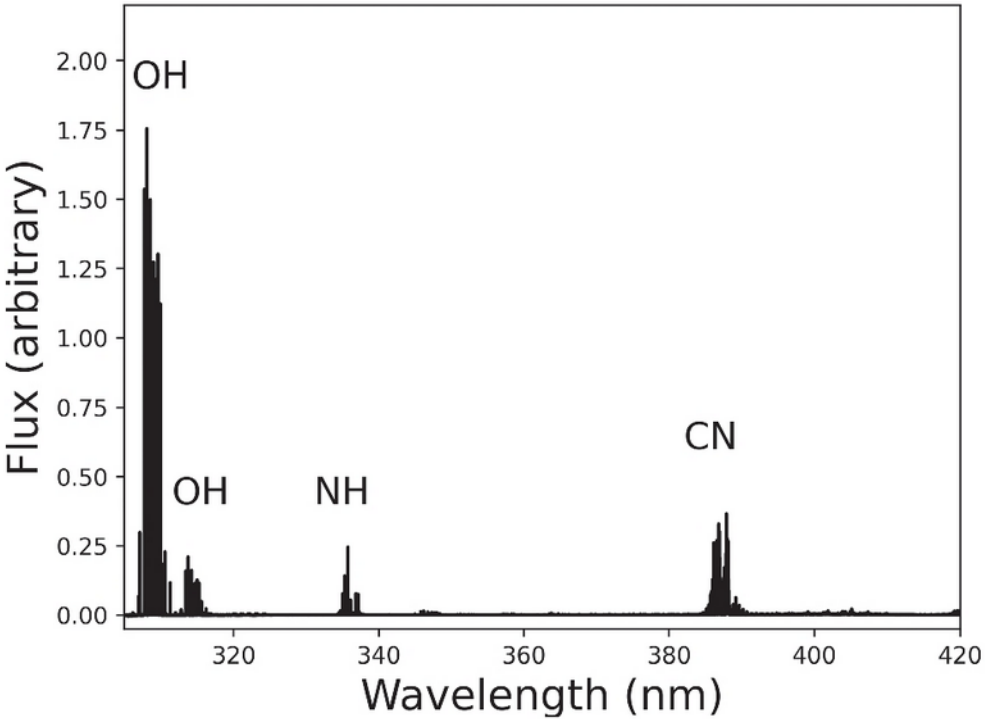
Field	Science case	SI Contrib.
Solar System	S1: Cometary Science	[3]
	S2: Icy Satellites	...
Galactic	G1: Accretion, winds & outflows in YSOs	[4]
	G2: Exo-planet composition	...
	G3: Stellar astrophysics & exoplanets	...
	G4: Beryllium in metal-poor stars and stellar clusters	[5, 6]
	G5: Lithium production in novae	...
	G6: Metal-poor stars & light elements	[7, 8]
	G7: Neutron-capture elements	[9]
	G8: Precise metallicities of metal-poor pulsators	...
	G9: Horizontal branch stars in Galactic GCs	...
	G10: Early-type companions in binary Cepheids	...
	G11: Extragalactic massive stars	[10]
Extragalactic	E1: Primordial deuterium abundance	...
	E2: Missing baryonic mass in the high-z CGM	[11]
	E3: Cold gas at high redshift	[12]
	E4: Reionisation	...
Transients	T1: GRBs	...
	T2: Kilonovae	...
	T3: Superluminous supernovae	...

(Evans et al. 2023)

Comets with CUBES

- Larger sample of (fainter) comets can be observed; not only close to the Sun
- Outgassing water: OH emission at 308 nm
- How much ice hidden in the asteroid belt?
- Deuterium to hydrogen (D/H) ratio

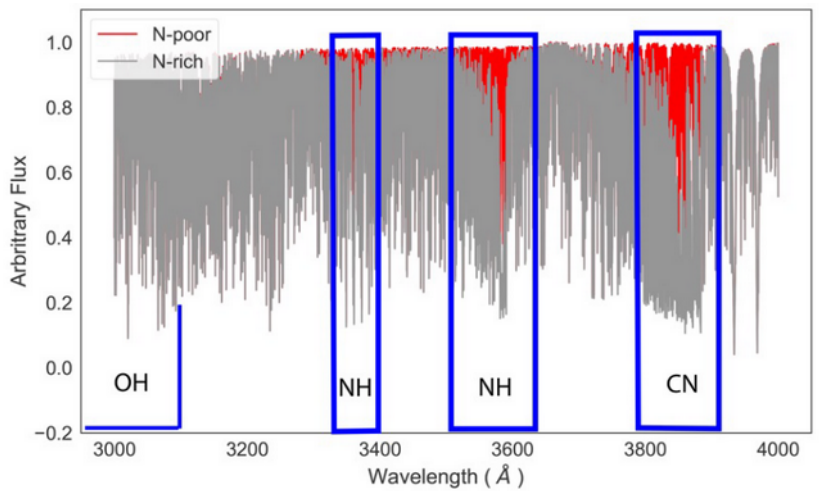




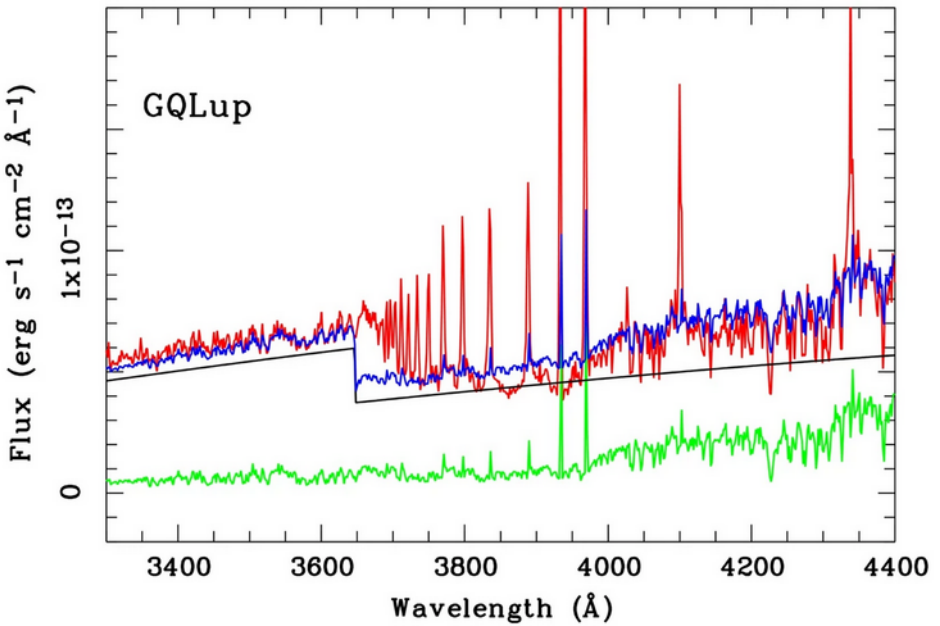
(Opitom et al. 2023)

Stars with CUBES

- Chemical abundances of light (Be, C, N, O; Smiljanic et al. 2023; Giribaldi & Smiljanic 2023) and heavy elements (r-process: Bi, U, …; Ernandes et al. 2023)
- Novae and Li nucleosynthesis (Izzo et al. 2023)
- Accretion and outflows in young stars (Alcalá et al. 2023)



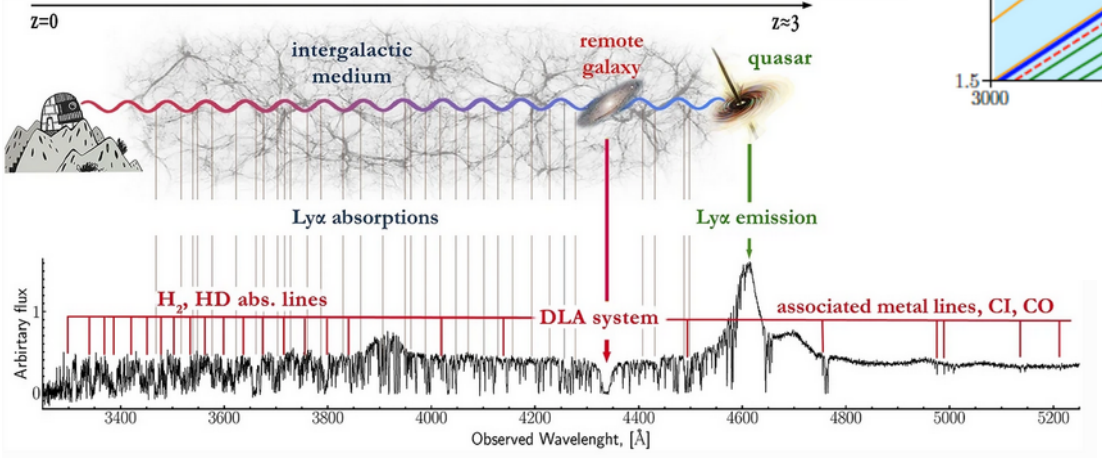
(Evans et al. 2023)

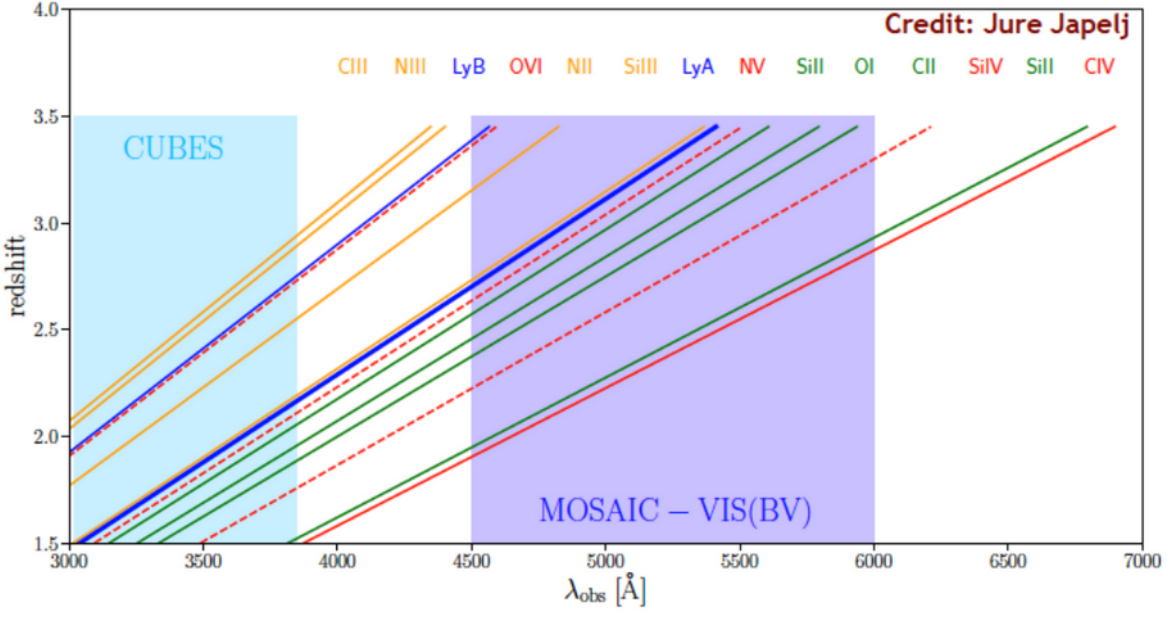


(Alcalá et al. 2023)

Extragalactic Science

- Emission lines in AGNs and QSOs
- Missing baryonic mass – quasars at z = 2-3 (D'Odorico 2023)
- UV-bright stellar populations in red galaxies (Ali & De Propris 2023)
- Molecular hydrogen at z > 2 (Balashev & Noterdaeme 2023):





(Kuntschner et al. 2012, adapted from Osborn et al. 1990)

Project status

- Phase A (*Conceptual Design*) in 2020-2021
- Phase B (*Preliminary Design*) in 2022
- Phase C (*Final Design*) started in 2023
  - Phase C ~ 18 months
  - **Long lead items review**
    - CCDs
    - Image slicers
    - Grating
- Phase D (Manufacturing, Assembly, Integration, Testing) ~ 36 months
- Phase E (Transport; Assembly, Integration and Verification) ~ 14 months

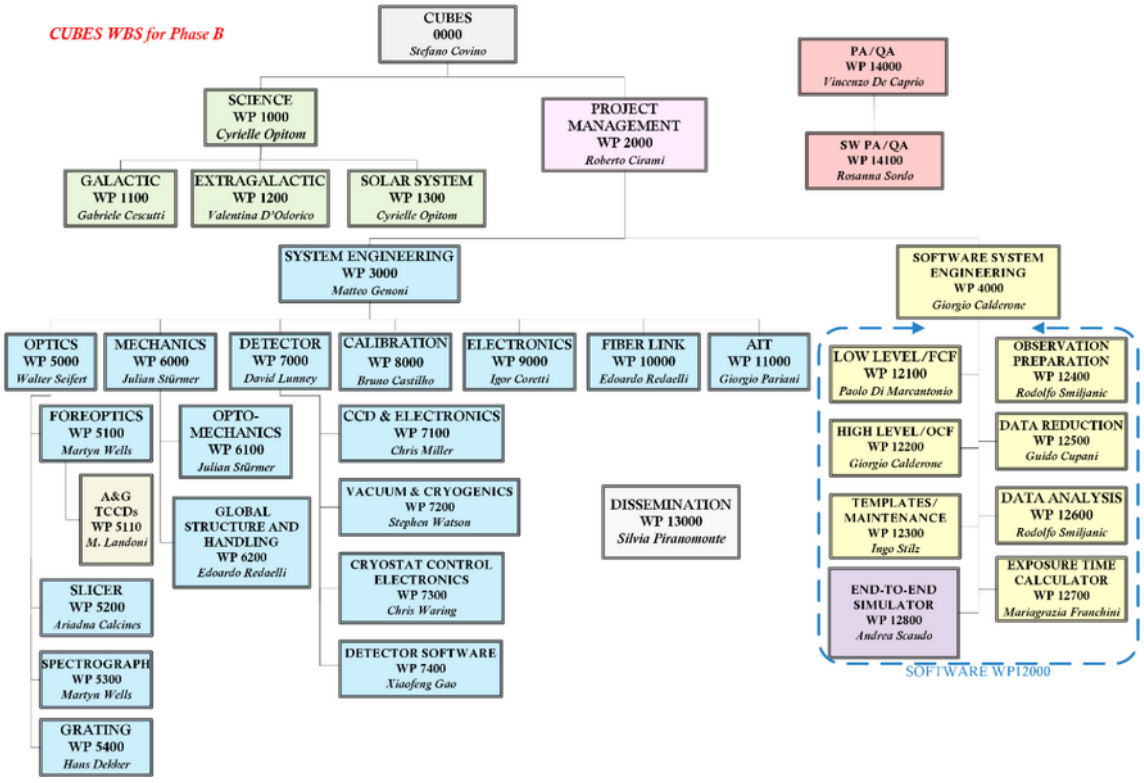
Key Milestones	Contractual Completion Date
KM.0 – Entry into force of the Consortium Agreement	T0
KM.1 – Kick-off Meeting	~~T0 + 1 month~~
KM.2 – Delivery of Prototype (grating)	~~T0 + 10 months~~
KM.3 – Preliminary Design Review (PDR)	~~T0 + 11 months~~
KM.4 – Long Lead Items Review	T0 + 17 months
KM.5 – Final Design Review (FDR)	T0 + 25 months
KM.P – Procured equipment delivered at the Consortium's premises and accepted by the Consortium	T0 + 40 months
KM.6 – Intermediate Milestone (Assembly Readiness Review)	T0 + 45 months
KM.7 – Test Readiness Review (TRR)	T0 + 57 months
KM.8 – Provisional Acceptance Europe (PAE)	T0 + 63 months
KM.9 – Intend to Accept and PTO of the Instrument	T0 + 65 months
KM.10 – Provisional Acceptance Chile (PAC)	T0 + 77 months

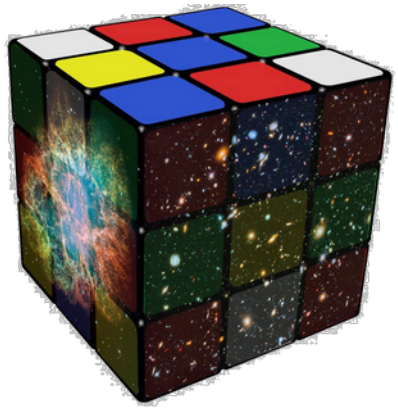
Polish participation

- Polish contribution at **5.7%** of staff effort and cost
- R. Smiljanic: co-PI at Executive Board

- Science contribution with simulations
- Leader in two Software WP (OPS and DAS) and participation in DRS
- Acquisition & Guiding Camera

- Participation in the 90 GTO nights to be awarded to the consortium (span 3-5 years)





- **CUBES: high-efficiency spectroscopy in the near-UV**
- **Expected at the VLT by 2027**

- Learn more:

https://cubes.inaf.it/

REFERENCES

- Alcalá et al. 2023, ExA, 55, 165
- Ali & De Propris, 2023, ExA, 55, 199
- Balashev & Noterdaeme, 2023, ExA, 55, 223
- Calcines et al. 2023, ExA, 55, 267
- Cristiani et al. 2022a, SPIE proceedings 121840A
- Cristiani et al. 2022b, The Messenger, 188, 36
- D'Odorico 2023, ExA, 55, 209
- Ernandes et al. 2023, ExA, 55, 149
- Evans et al. 2016, SPIE proceedings 99089J
- Evans et al. 2023, ExA, 55, 1
- Giribaldi & Smiljanic 2023, ExA, 55, 117
- Izzo et al. 2023, ExA, 55, 191
- Opitom et al. 2022, ExA, 55, 59
- Pasquini 2014, Ap&SS, 354, 121
- Smiljanic et al. 2023, ExA, 55, 95
- Zanutta et al. 2023, ExA, 55, 241
- Zeitner et al. 2022, SPIE proceedings, 121884Y
- Zeitner et al. 2023, ExA, 55, 281

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NARODOWE CENTRUM NAUKI