SPANet meeting - São Paulo - Oct. 2019

Development of new spectrographs for ESO

VLT-CUBES & ELT-MOSAIC

Chris Evans
Head of Science, UKATC, Edinburgh

Science and Technology Facilities Council

GCRF
Global Challenges Research Fund

UKATC

- UK's national lab for astronomical instrumentation
- Co-located with U. Edinburgh's Institute for Astronomy (IfA)
- Incl. Higg's Centre for Innovation (in partnership with UoE)
- Incl. Royal Observatory Visitor Centre
  - Part of UKATC-led National Laboratories Public Engagement programme

STFC

- UKATC is part of the Science & Technology Facilities Council…
- …which is part of UK Research & Innovation (UKRI)
- Staff: ~2000, across 6 sites


Credit: STFC

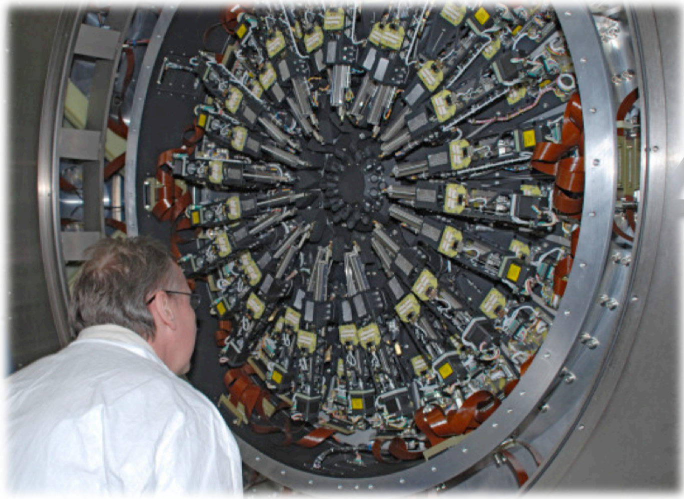

Credit: STFC


Credit: STFC

STFC

In UK astronomy, STFC funds:

Facilities

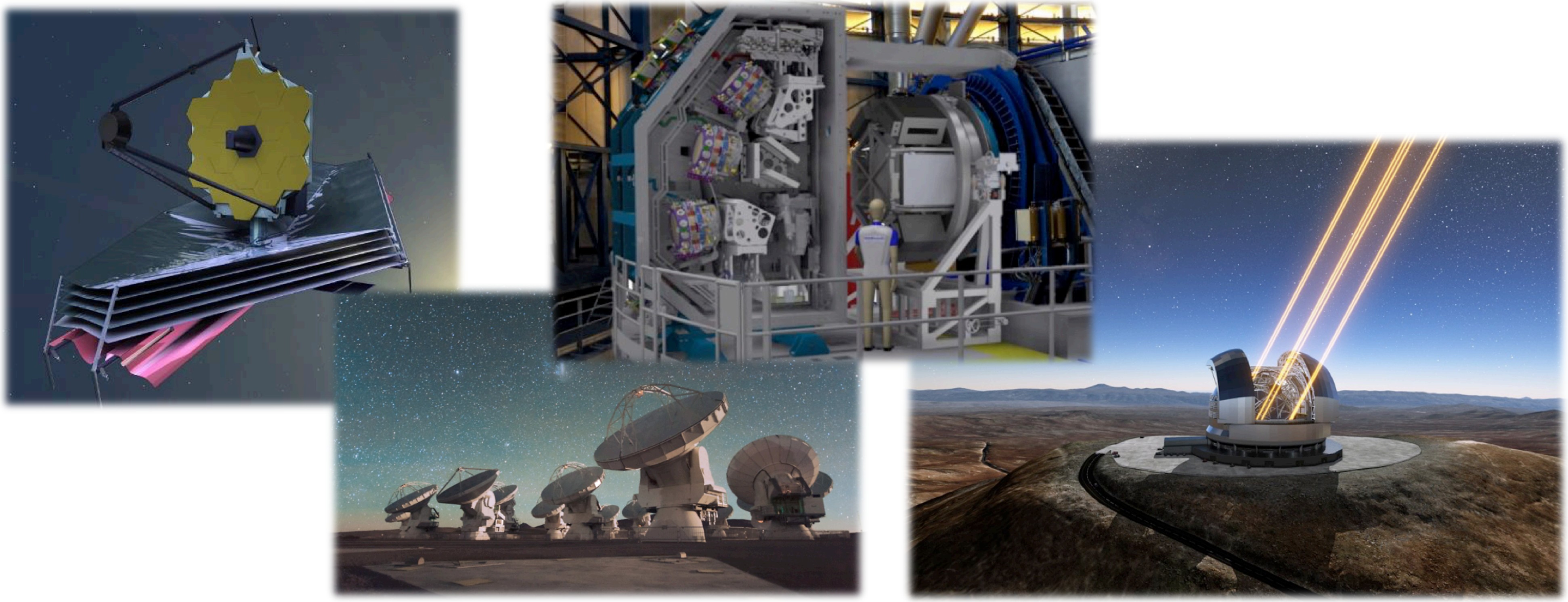


R&D

Exploitation

UKATC

- ~85 staff, with skills/expertise across all aspects of astronomy
  - Science, management, system eng., optics, mechanical, electrical, detectors, software
- 70-80% of programme is astronomy:
  - Leading roles in facility-class instruments
  - Partner roles developing key sub-systems
  - Smaller R&D projects



UKATC

- ~85 staff, with skills/expertise across all aspects of astronomy
  - Science, management, system eng., optics, mechanical, electrical, detectors, software
- 20-30% of non-astronomy projects:
  - Earth Observation, Diamond Light Source, healthcare
  - Use connections & skills to support commercial companies

UK-Brazil collaboration

Two UK-Br grants:

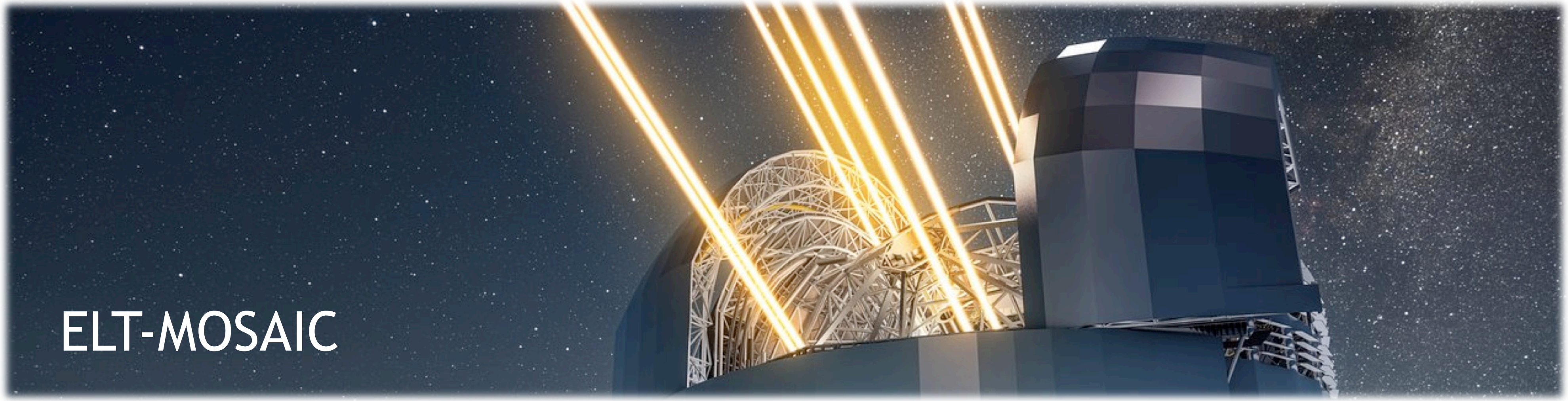
- Newton Fund (STFC/FAPESP)
  - Two workshops (USP, LNA),
  - 7 visits of Brazilian early-stage researchers to UK (1 u/g, 3 PhD, 3 postdoc)
- GCRF (STFC)
  - Collaboration to progress CUBES concept for ESO
  - 11 visits from Brazil to UK (4 staff, 7 PhD)

USP, 2015

Edinburgh, 2018

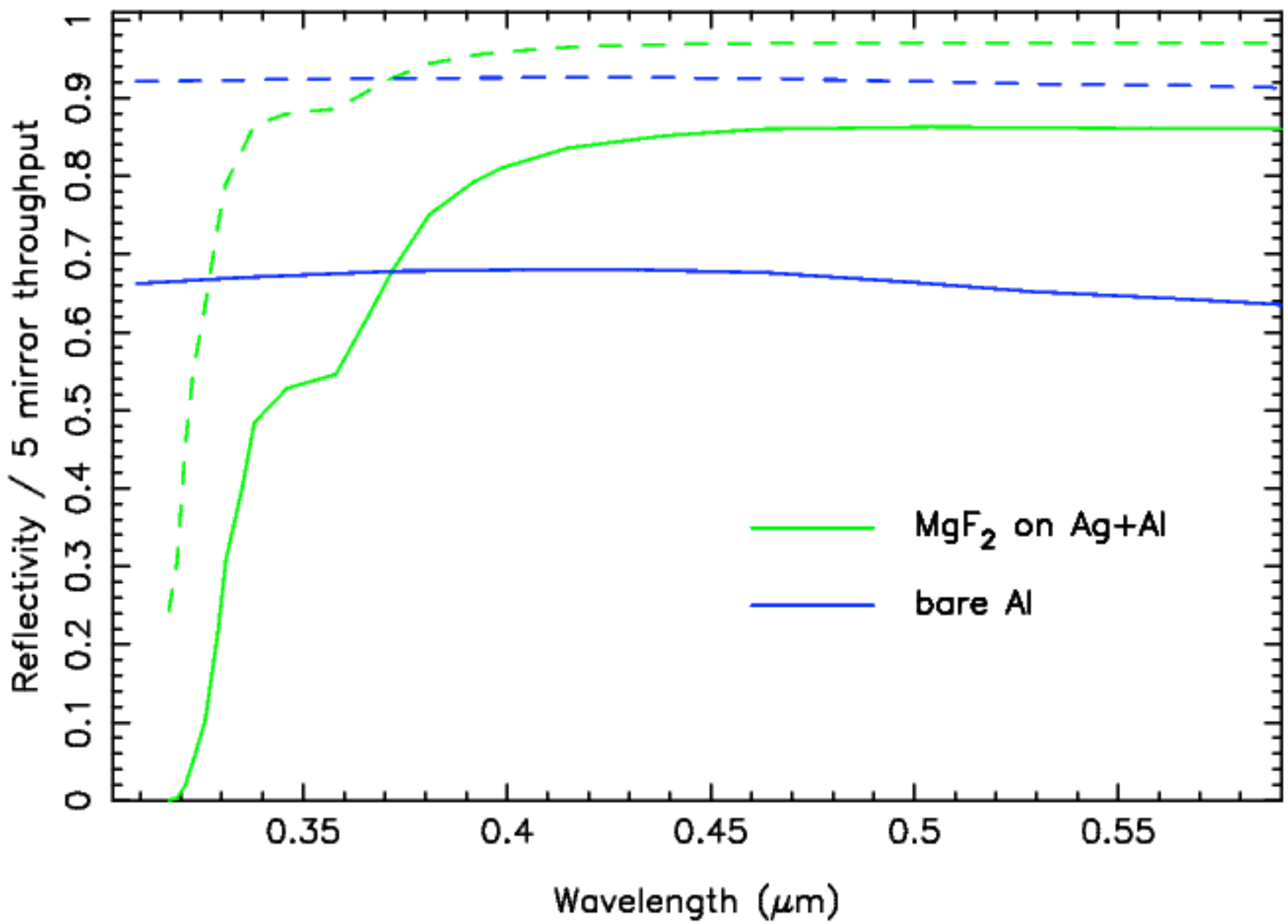
UK-Brazil collaboration

Two UK-Br projects:



CUBES: Context

ELT performance



Credit: ESO, from: https://www.eso.org/sci/facilities/eelt/science/drm/tech_data/telescope/

CUBES: Phase A

ESO

European Organisation for Astronomical Research in the Southern Hemisphere

www.eso.org

Astrophys Space Sci
DOI 10.1007/s10509-014-2039-z

ORIGINAL ARTICLE

CUBES: cassegrain U-band Brazil-ESO spectrograph

B. Barbuy · V. Bawden Macanhan · P. Bristow · B. Castilho · H. Dekker · B. Delabre · M. Diaz · C. Gneiding · F. Kerber · H. Kuntschner · G. La Mura · W. Maciel · J. Meléndez · L. Pasquini · C.B. Pereira · P. Petitjean · R. Reiss · C. Siqueira-Mello · R. Smiljanic · J. Vernet

Very Large Telescope

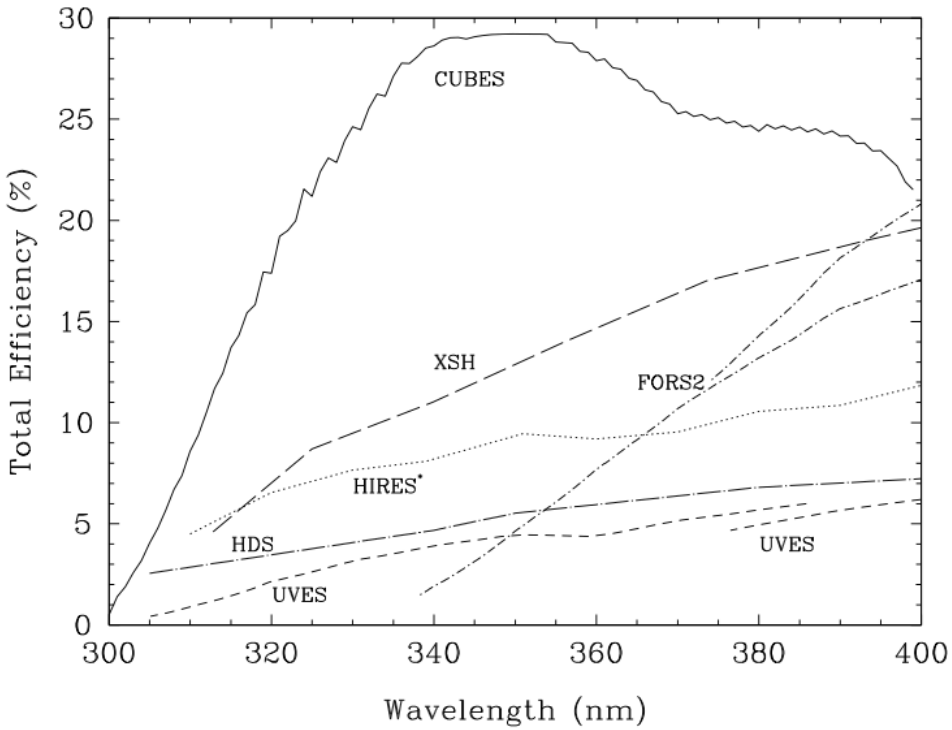
CUBES

Phase A study
Science Report

Doc. No.: VLT-TRE-ESO-13800-5679

Issue: 1

Date: 31.08.2012



Revisiting CUBES

SPIE 2018 (arXiv:1806.11173)

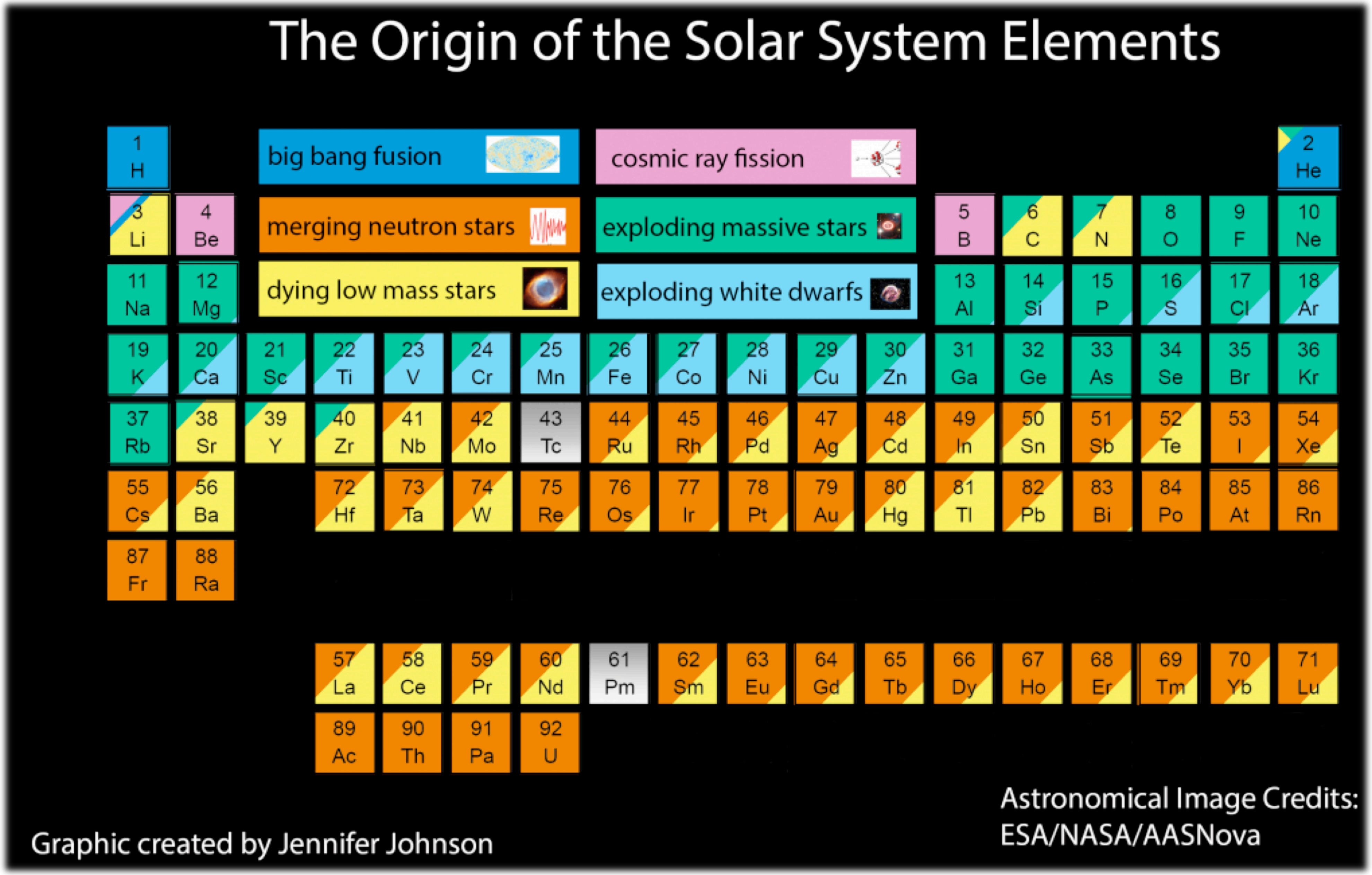
Revisiting the science case for near-UV spectroscopy with the VLT

C. J. Evans[1], B. Barbuy[2], B. Castilho[3], R. Smiljanic[4], J. Melendez[2], J. Japelj[5], S. Cristiani[6], C. Snodgrass[7], P. Bonifacio[8], M. Puech[8], A. Quirrenbach[9]

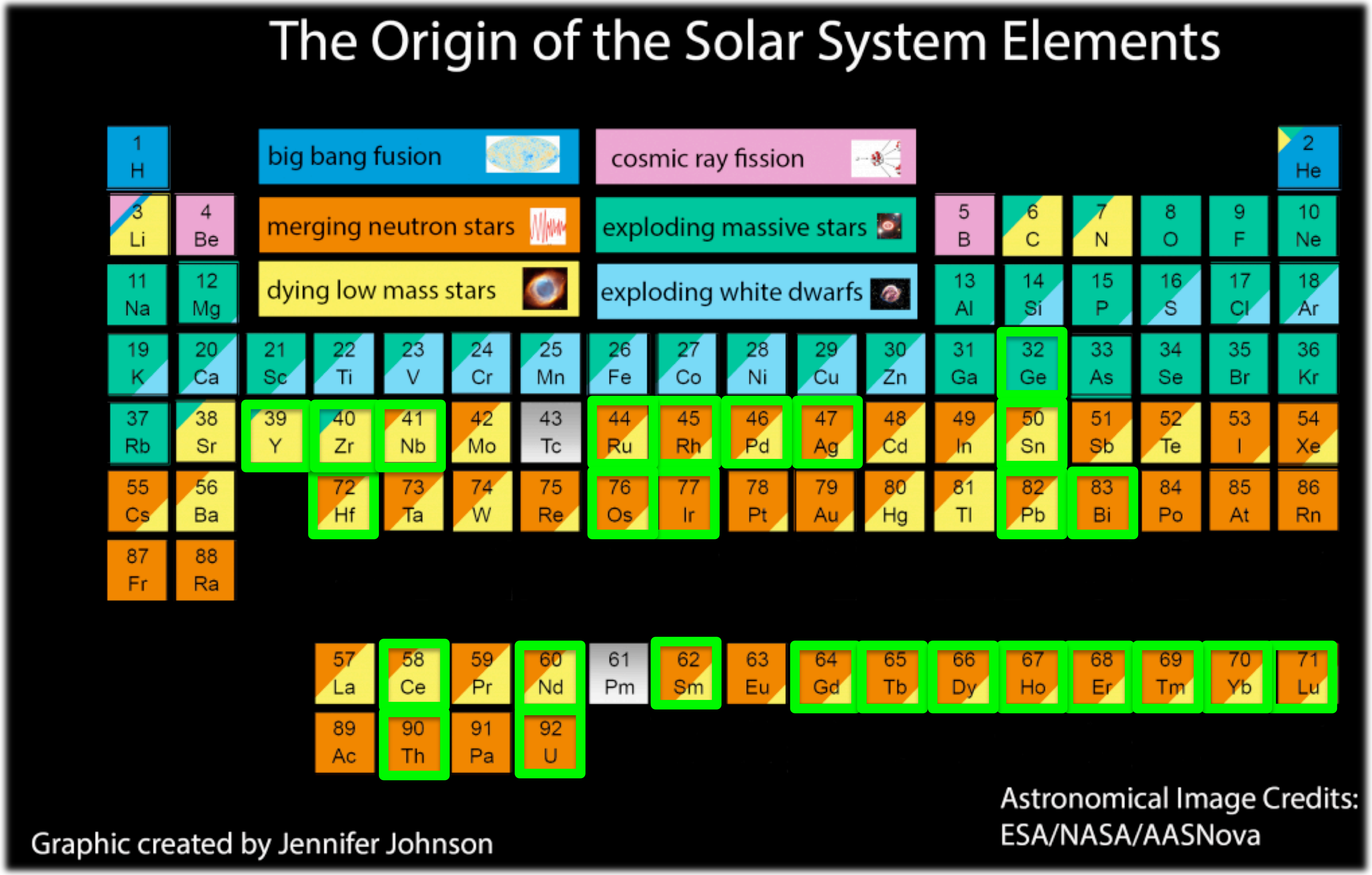
[1] UK Astronomy Technology Centre, Royal Observatory, Blackford Hill, Edinburgh, EH9 3HJ, UK
[2] Universidade de São Paulo, IAG, Rua do Matão 1226, Cidade Universitária, São Paulo, 05508-900, Brazil
[3] Laboratório Nacional de Astrofísica/MCTIC, Rua Estados Unidos, 154 - 37504-364, Itajubá, MG, Brazil
[4] Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, Bartycka 18, 00-716, Warsaw, Poland
[5] Astronomical Institute Anton Pannekoek, University of Amsterdam, Science Park 904, 1098 XH, Amsterdam, the Netherlands
[6] INAF - Osservatorio Astronomico di Trieste, via G. B. Tiepolo 11, 34131 Trieste, Italy
[7] School of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, UK
[8] GEPI, Observatoire de Paris, PSL University, CNRS, 5 Place Jules Janssen, 92190 Meudon, France

- Instrument concept: still unique and valid
- Science case: even stronger (e.g. link to nucleosynthesis in GW sources)
- Key design requirements unchanged:
  - Wavelength range: 302-380nm
  - *R* ~20,000
  - Design philosophy: Maximise efficiency

CUBES: Galactic Science

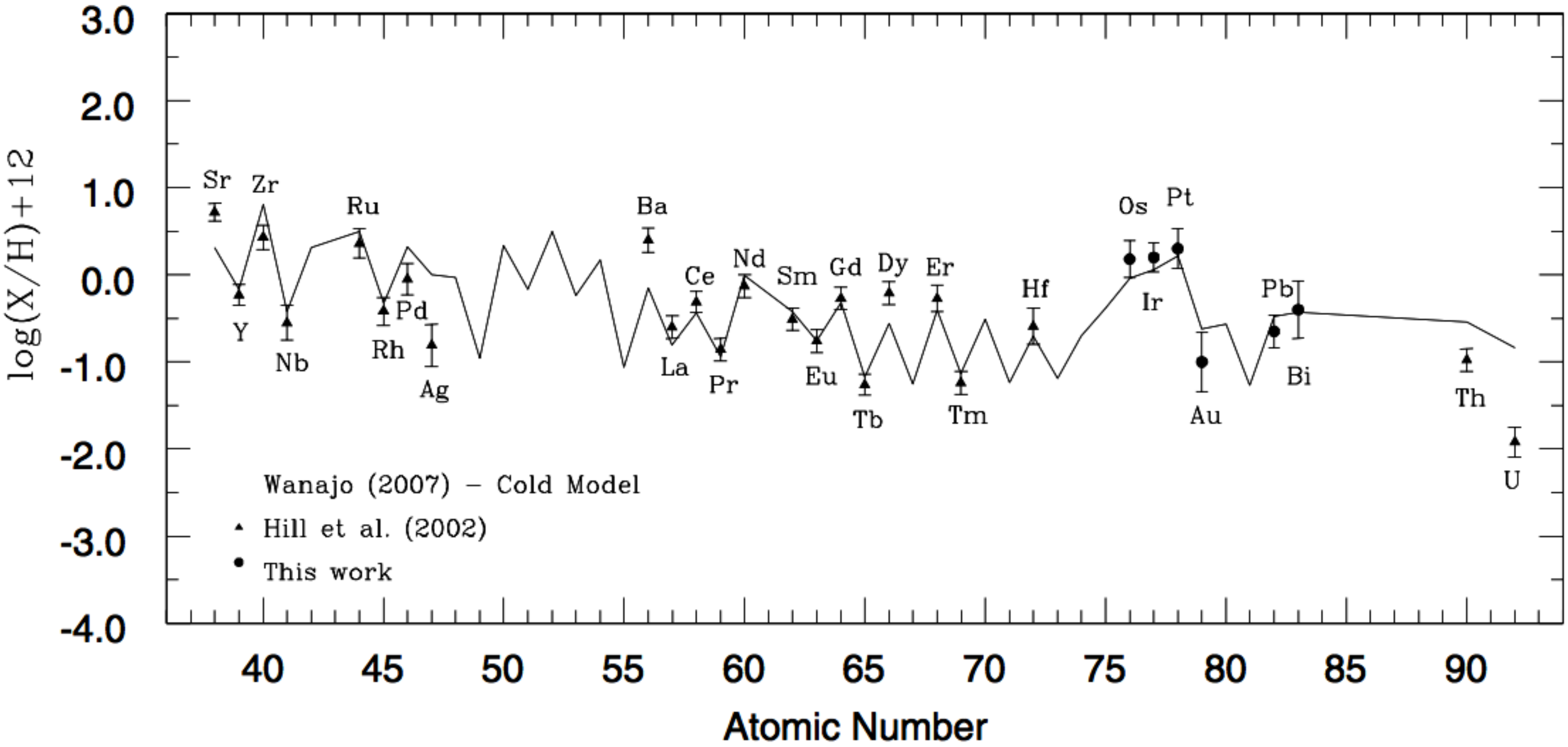


CUBES: Galactic Science



CUBES: Galactic Science

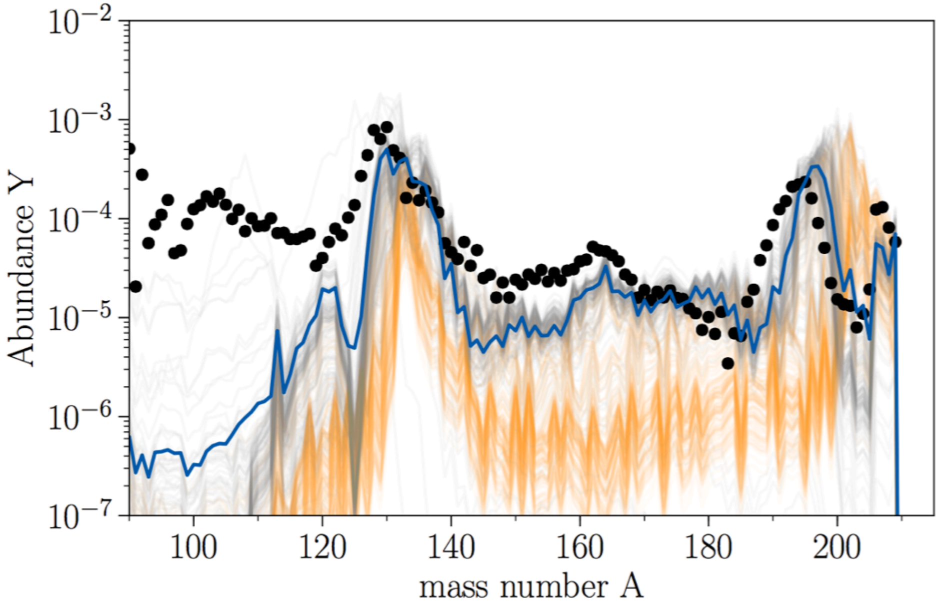
Barbuy et al. (2012)



CUBES: Galactic Science

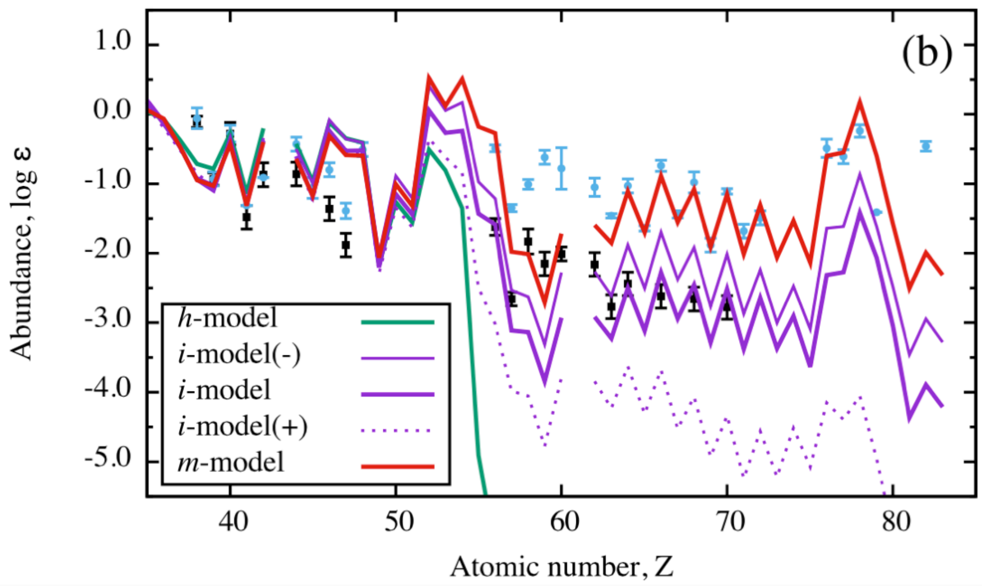
Testing predictions of different channels for r-process nucleosynthesis

Binary NS mergers:



Bovard et al. (2017)

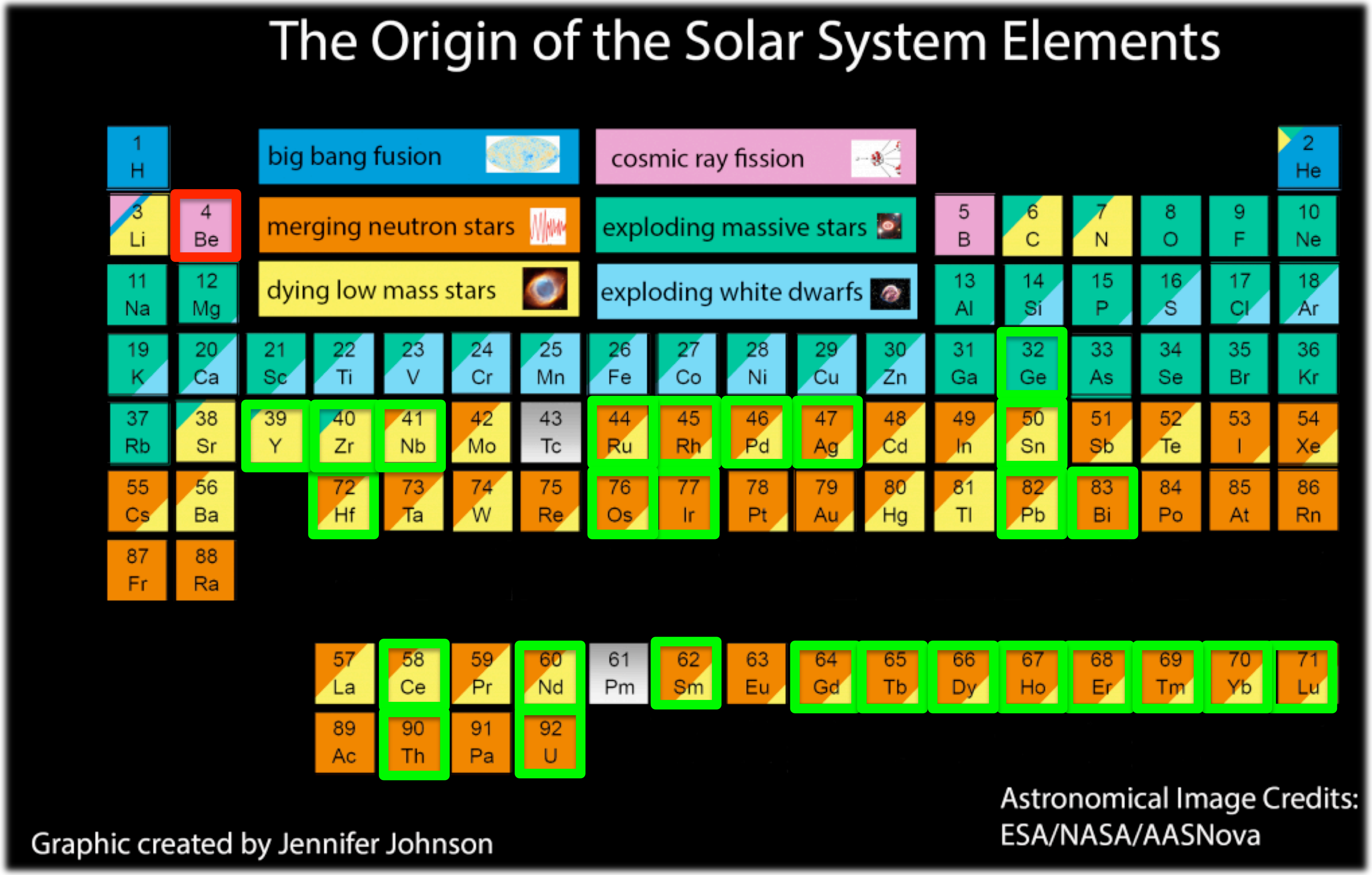
Magneto-rotational SNe:



Nishimura et al. (2017)

<u>**Near-UV essential:**</u> YII, ZrII, NbII, PdI, AgI, BaII, LaII, CeII, NdII, EuII, GdII, TbII, DyII, HoII, ErII, TmII, OsI, IrI, PbI, BiI, ThII, UII

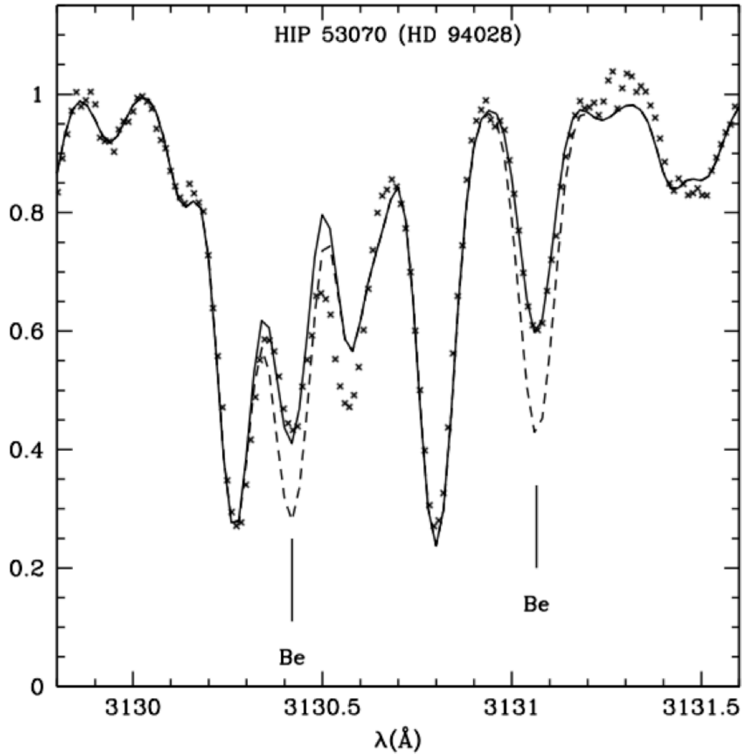
CUBES: Galactic Science



CUBES: Galactic Science

^{9}Be produced via cosmic-ray spallation in ISM in early Galaxy

Smiljanic et al. (2009)

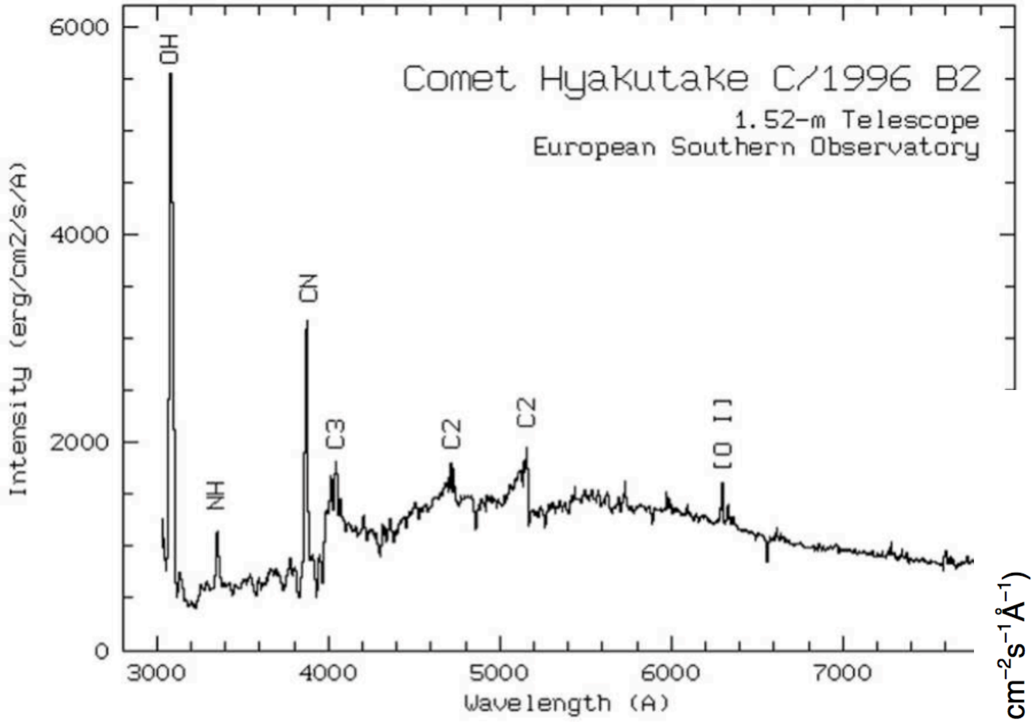


ESO release #3

- Be abundances: Limited to 10s of stars with VLT-UVES/Keck-HIRES
- Increased efficiency of ~3 magnitudes
  ➔ samples of 100s in ambitious large programme

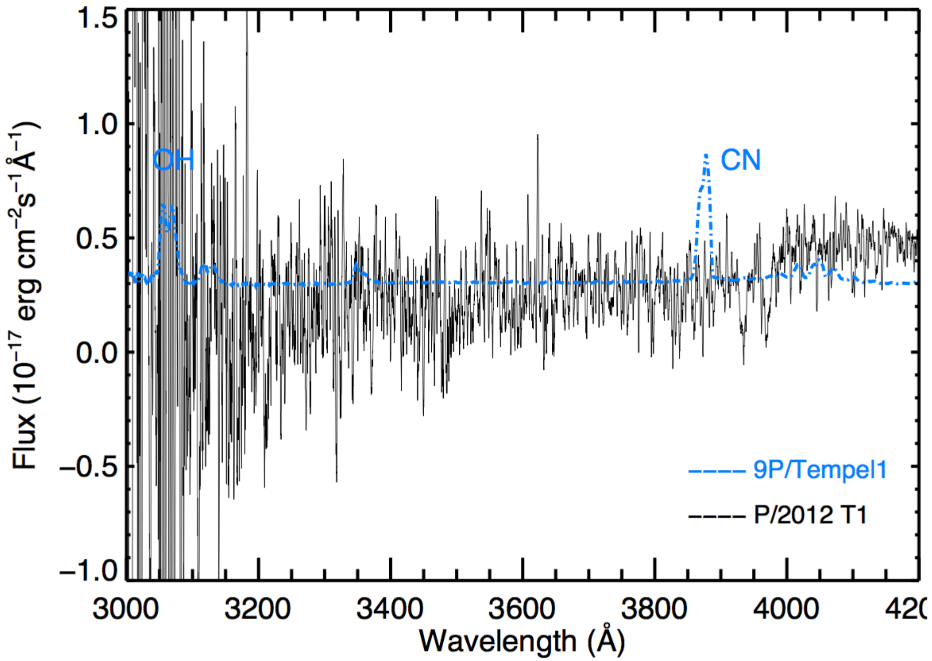
CUBES: Wider Science

- Searching for water in the asteroid belt



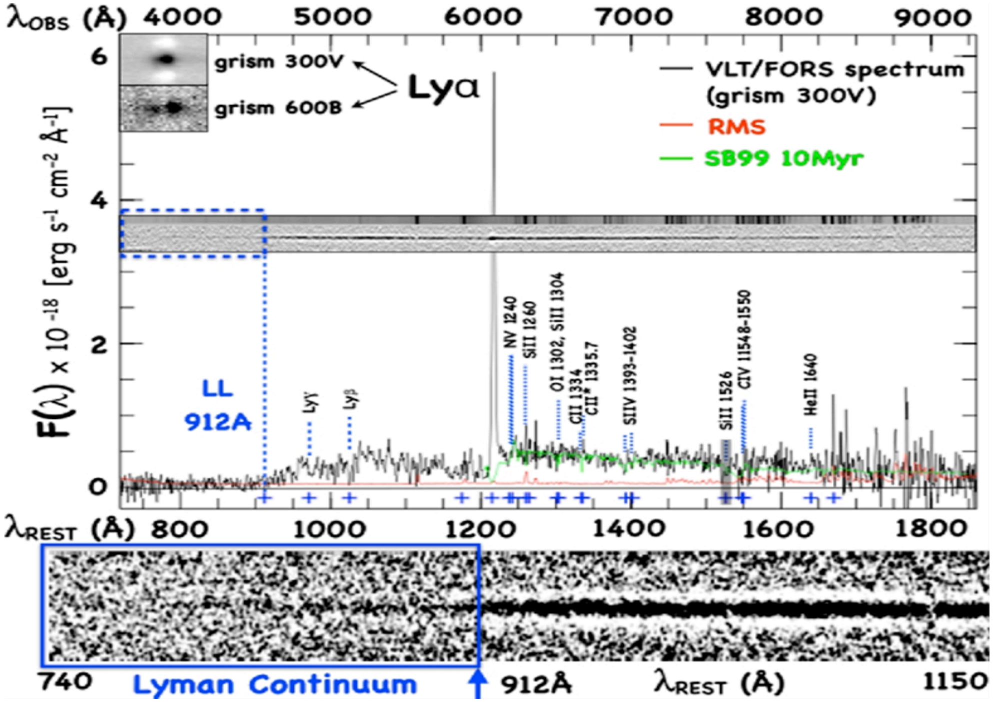
Credit: ESO

Snodgrass et al. (2017)



CUBES: Wider Science

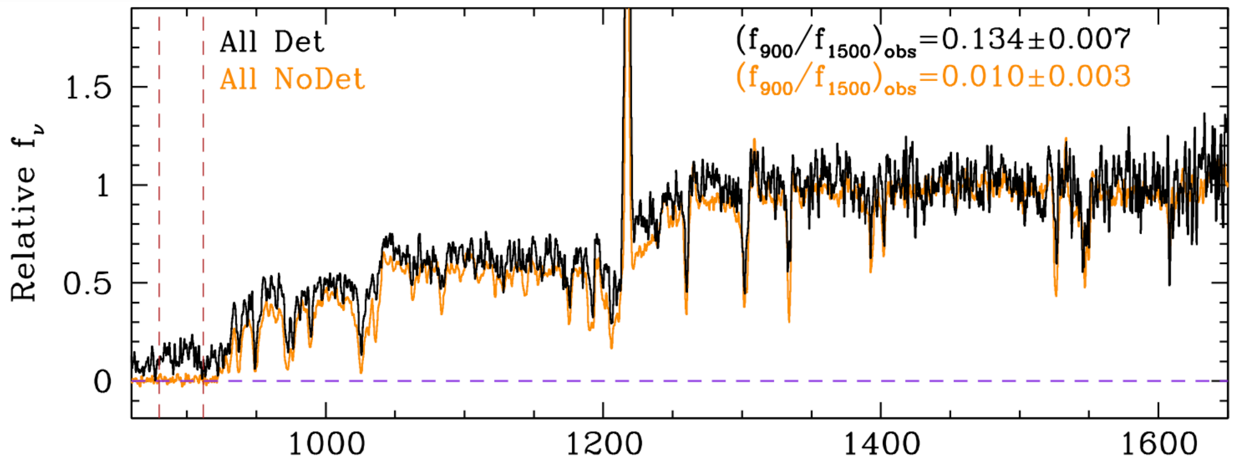
- Contribution of galaxies (cf. QSOs to cosmic UV background)



z = 3.999 (Vanzella et al. 2018)

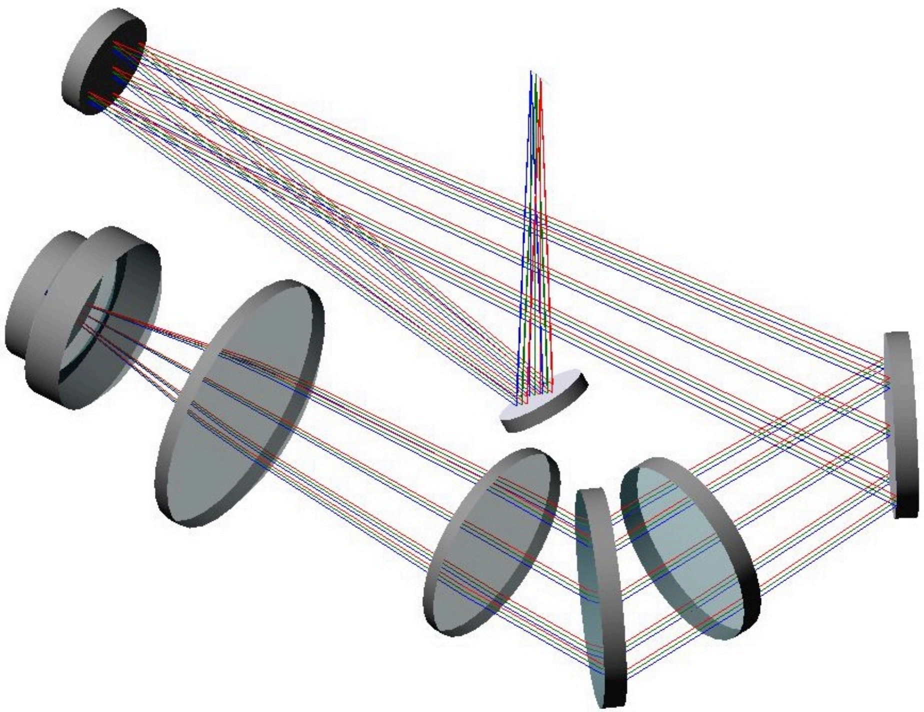
Need greater near-UV sensitivity to probe f_{esc} at peak SF epochs

KLCS sample @ z~3 (Steidel et al. 2018)



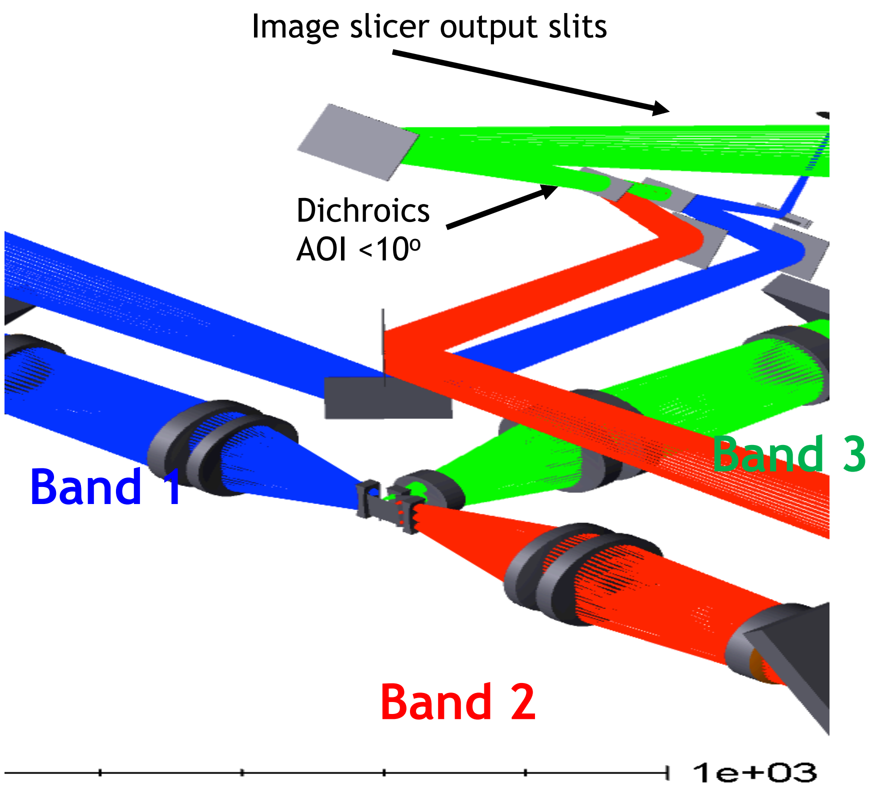
CUBES: Optical concepts

Updated Phase A concept
(kindly provided by B. Delabre)



1 grating, 3 detectors

New concept
(M. Wells, UKATC)



3 gratings, 1 detector

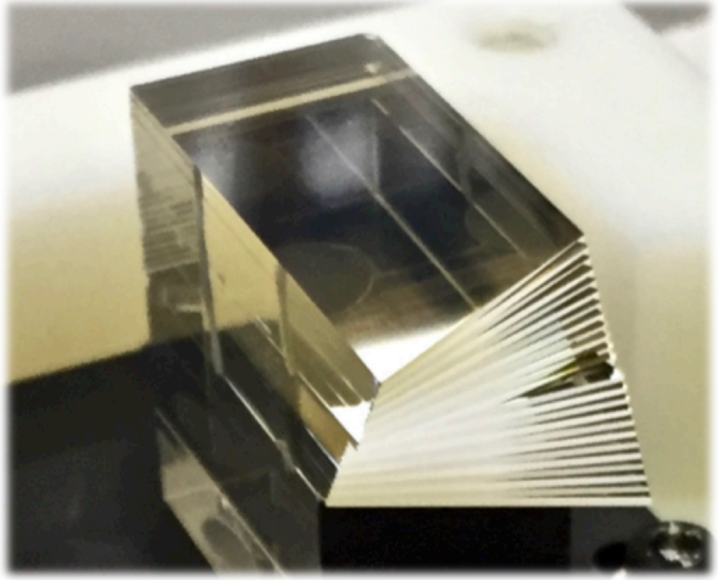
CUBES: Optical concepts

Philosophy: manufacturability (slices/lenses) and optical transmission

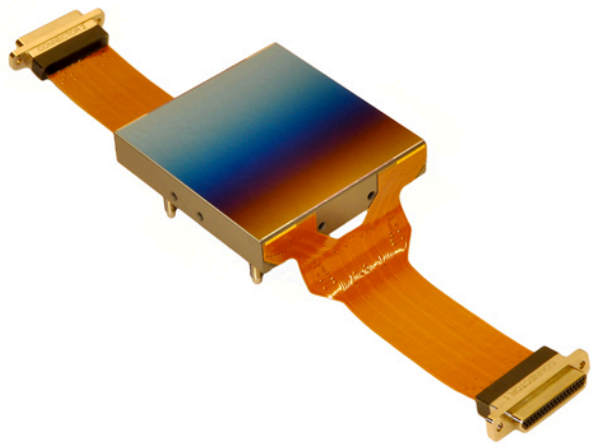
Image slicer:
- 6 slices x 0.25” on-sky
- Total width: 1.5” ➔ minimal slit losses

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

Spectrograph:
- 3 bands: 305-335, 328-361, 355-390 nm
- Can optimise each band (collimator, gratings, cameras)
- One detector for all 3 bands



KCWI: Morrissey et al. (2018)



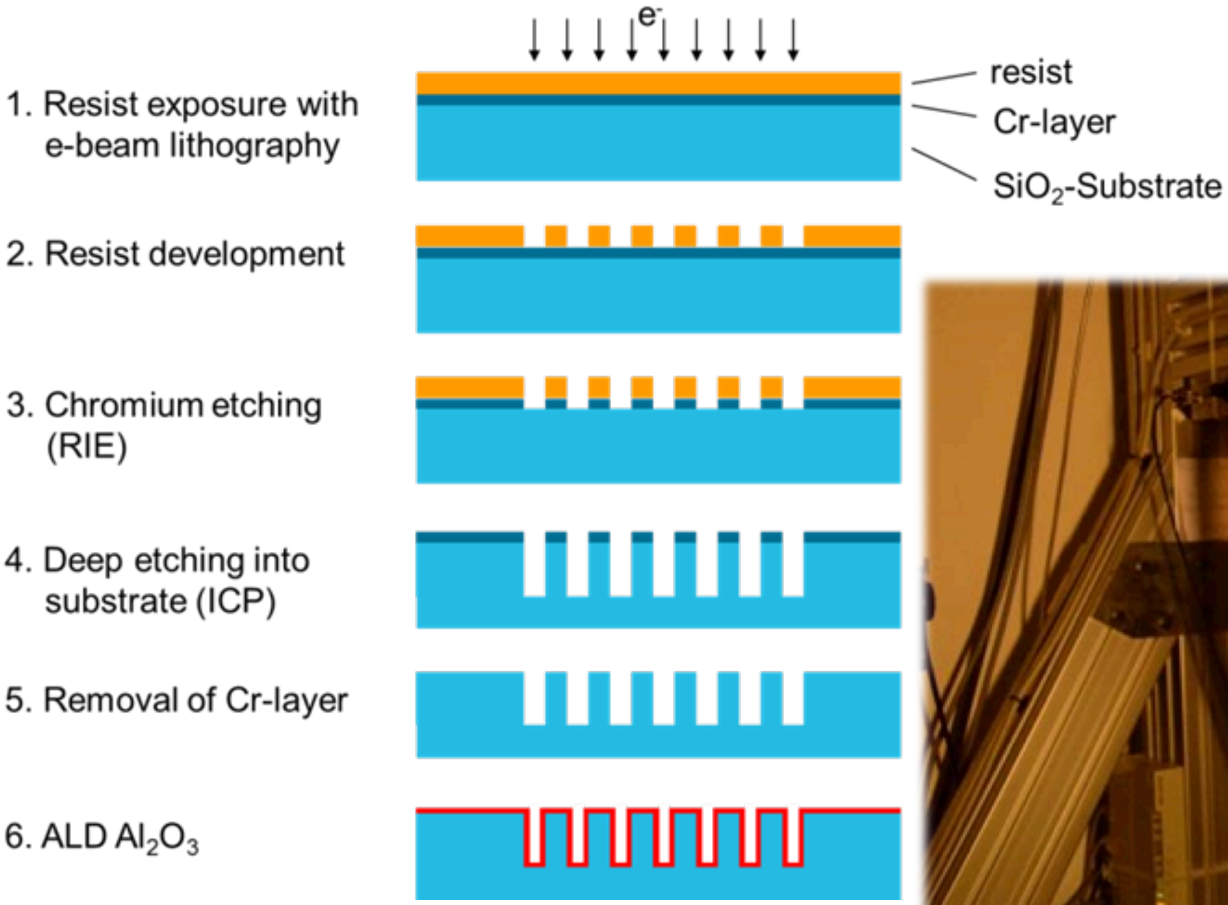
CUBES: Efficiency

	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**

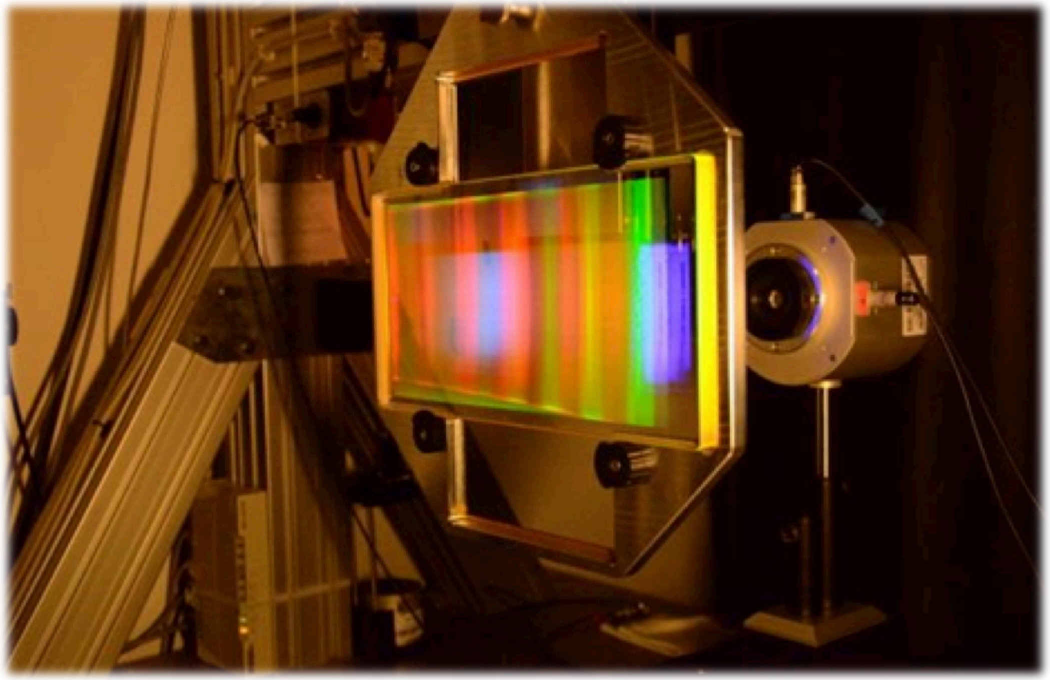
CUBES: Grating

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

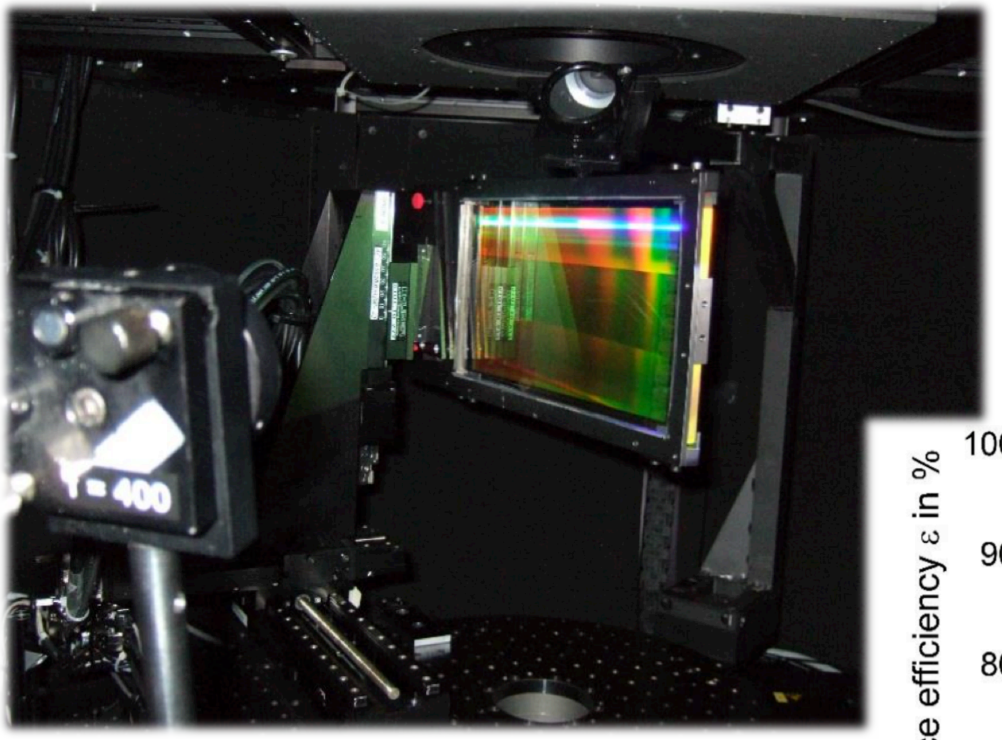
- Prototype manufactured by Fraunhofer IOF
- e-beam lithography & atomic layer deposition



3448 lines/mm, 250 x 130 mm



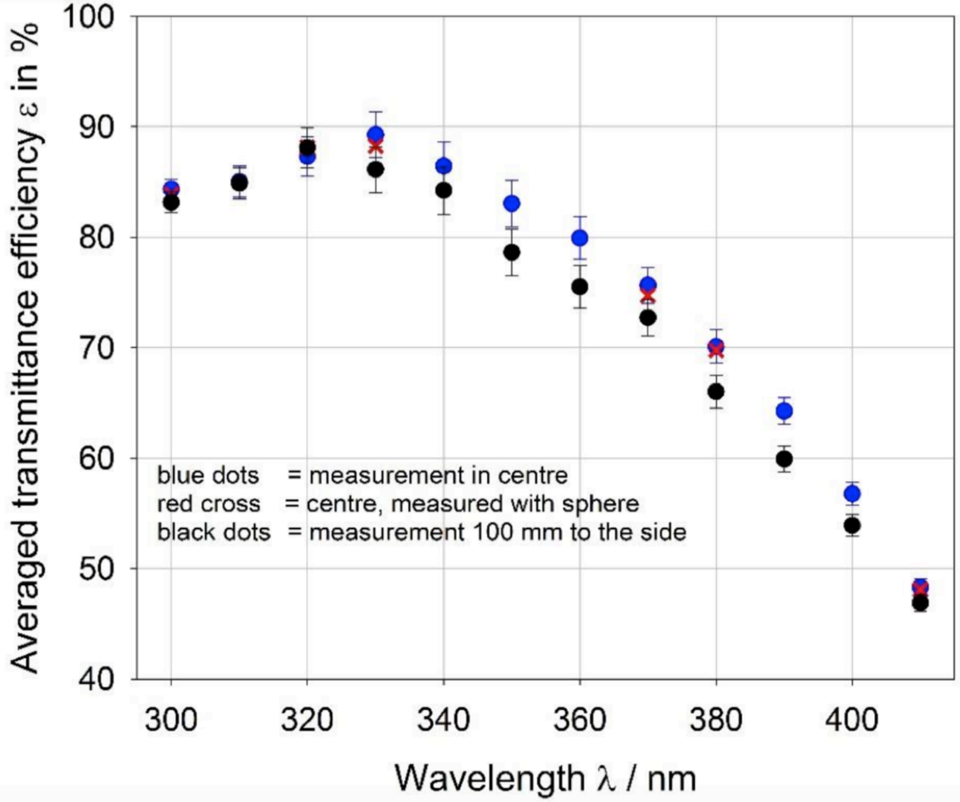
CUBES: Grating efficiency



Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

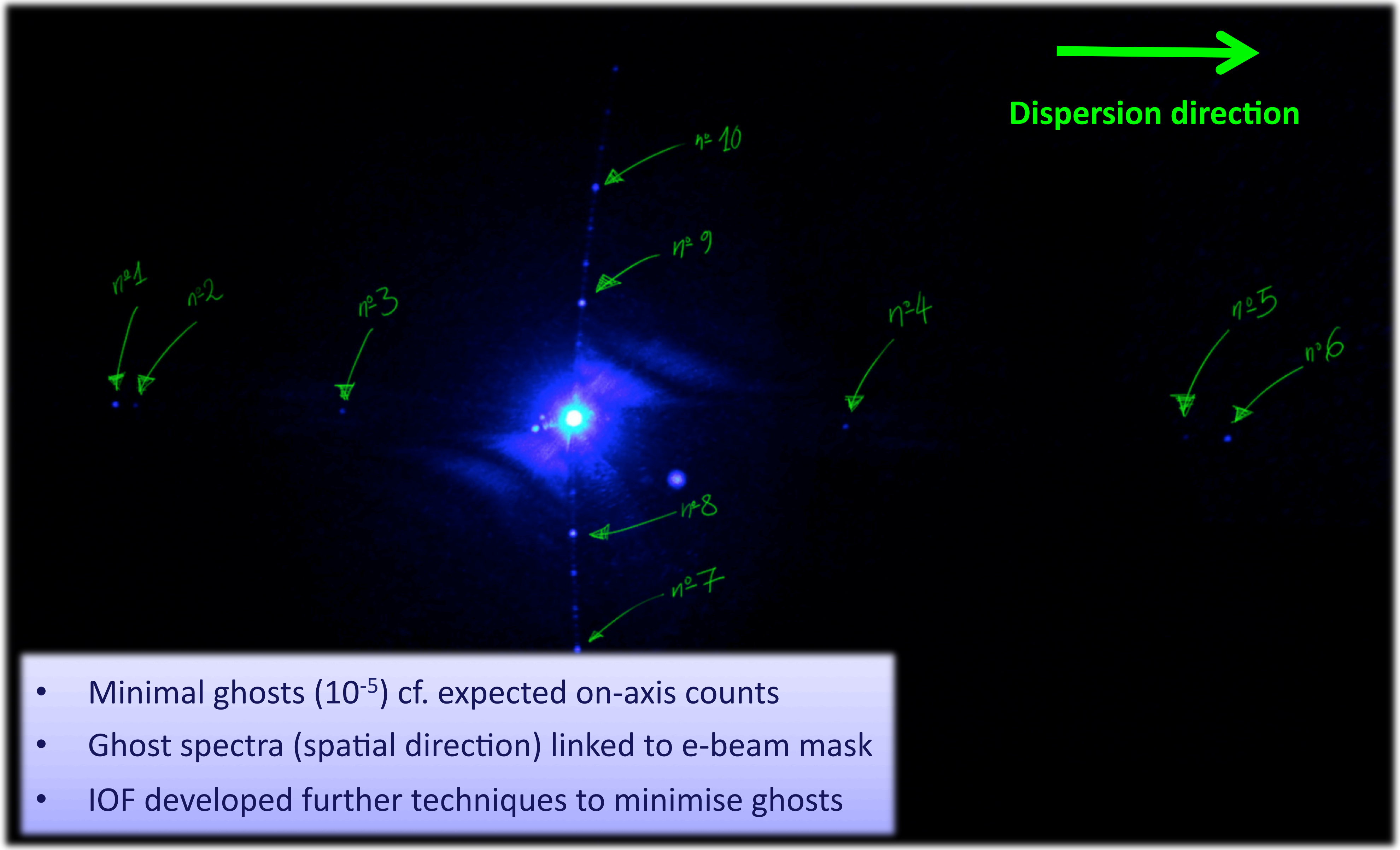
Bericht
Report

Determination of the transmittance efficiency of an optical grating in the wavelength range of 300 nm to 410 nm



CUBES: Grating performance

From internal report by: Alessio Zanutta & Andrea Bianco (Milan)



- Minimal ghosts (10^{-5}) cf. expected on-axis counts
- Ghost spectra (spatial direction) linked to e-beam mask
- IOF developed further techniques to minimise ghosts

CUBES: Next steps

- Expecting RfI from ESO in coming weeks
- New consortium forming
- RfI response in New Year, then 'δ Phase A' in 2020

Potential work-packages:

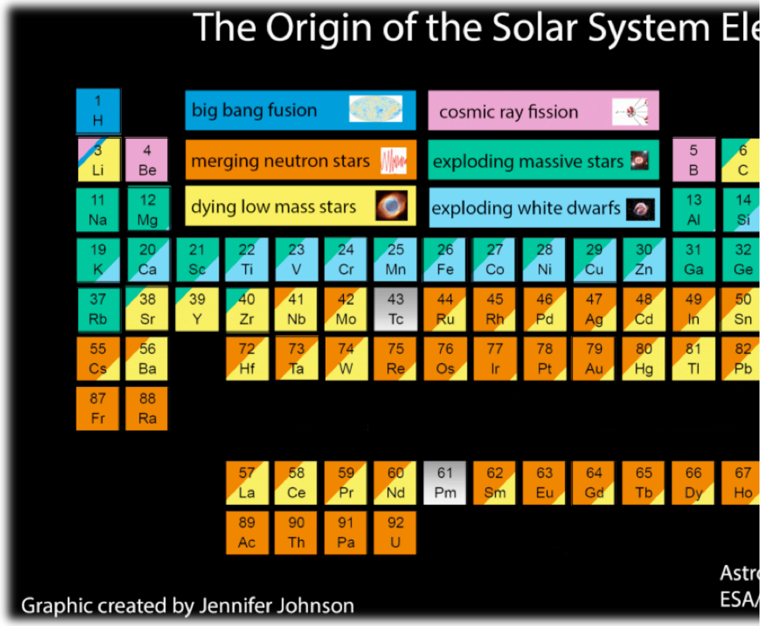
- WP1: Management
- WP2: Pre-optics
- WP3: Spectrograph
- WP4: Detector system
- WP5: Science (incl. DRS)
- WP6: EICS
- WP7: AIT/Handling

Order-of-mag estimates:

- Effort: 30-35 FTE
- Costs: ~€2.5M
- 4-year schedule

CUBES: Next steps

- Ongoing science trade studies (with Ernandes, USP)
- Species available at R = 20,000 vs. 40,000?



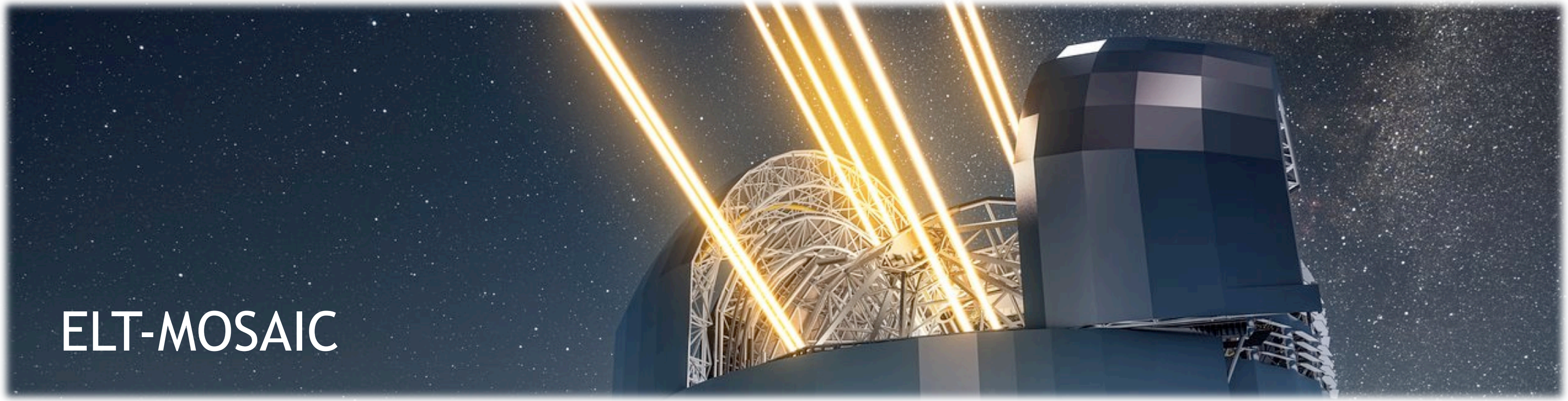
	DWARF							
	20K				40K			
[FE/H]	-3	-2	-1	0	-3	-2	-1	0
BeII 3130.42	G		b		G		B	
BeII 3131.07	G		g		G		G	
#								
ScII 3576.34	g		G		G		G	
ScII 3590.47	g		G		G		G	
#								
TiI 3998.64	G		G		G		G	
TiII 3321.70	G		G		G		G	
TiII 3343.76	G		G		G		G	
TiII 3491.05	G		G		G		G	
#								
VII 3951.96	B		G		G		G	
#								
CrI 3578.68	G		G		G		G	
#								
MnII 3441.99	G		G		G		G	
MnII 3460.32	G		G		G		G	
MnII 3482.90	G		G		G		G	
MnII 3488.68	G		G		G		G	
MnII 3495.83	B		G		B		G	
MnII 3497.53	G		G		G		G	
#								
CoI 3412.34	G		G		G		G	
CoI 3412.63	G		G		G		G	
CoI 3449.16	G		G		G		G	
CoI 3529.03	G		G		G		G	
CoI 3842.05	G		G		G		G	
CoI 3845.47	G		G		G		G	
#								
NiI 3437.28	G		B		G		G	
NiI 3483.77	G		G		G		G	
NiI 3500.85	G		G		G		G	
NiI 3597.71	G		G		G		G	
NiI 3807.14	G		G		G		G	

UK-Brazil collaboration

GCRF Global Challenges Research Fund

Newton Fund

Two UK-Br projects:



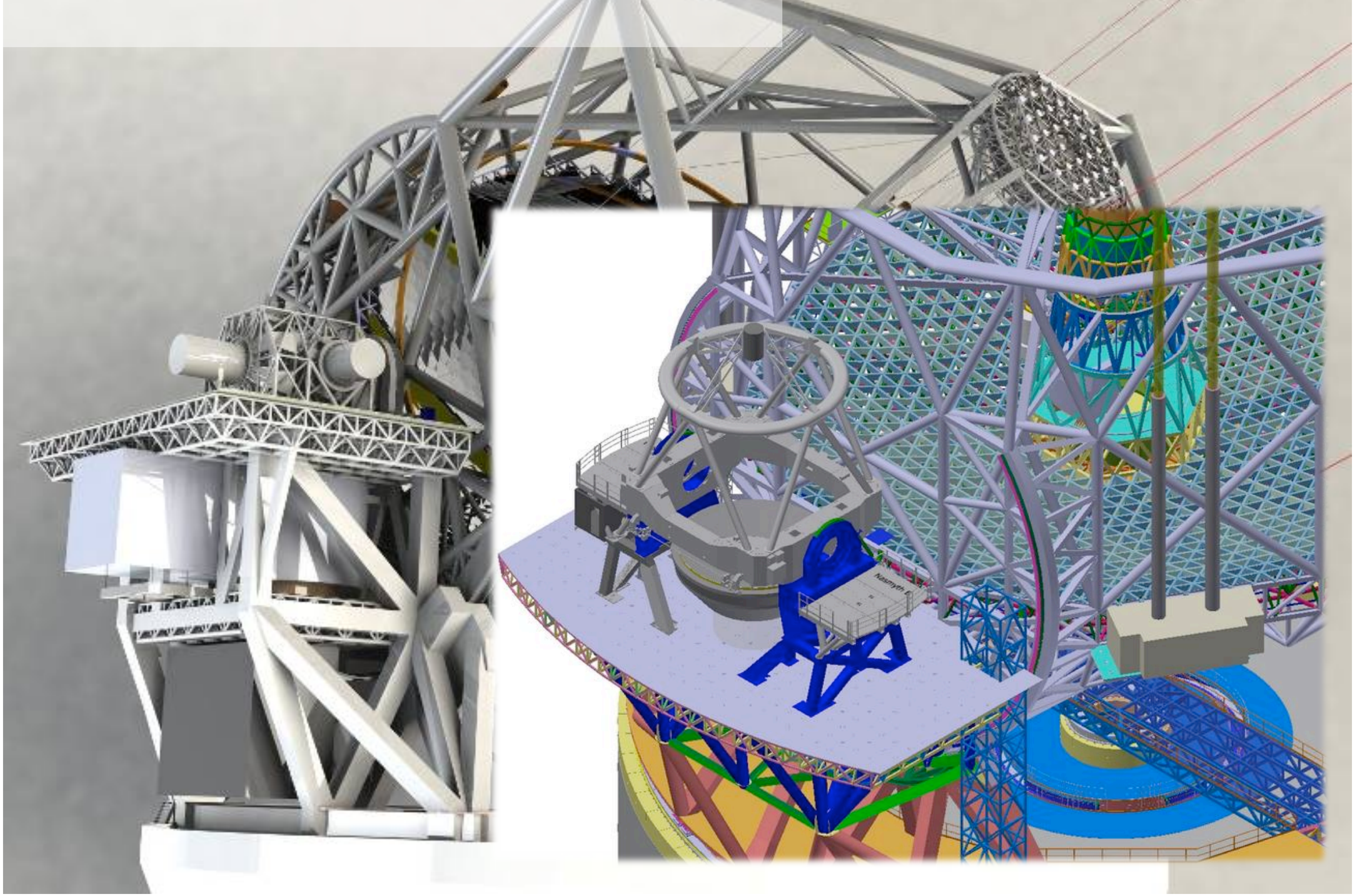
ELT: Extremely Large Telescope

ELT: Extremely Large Telescope

European Southern Observatory

ELT: Instrumentation

ELT: Instrumentation



ELT: Instrument Roadmap

Ramsay et al. (SPIE, 2018)

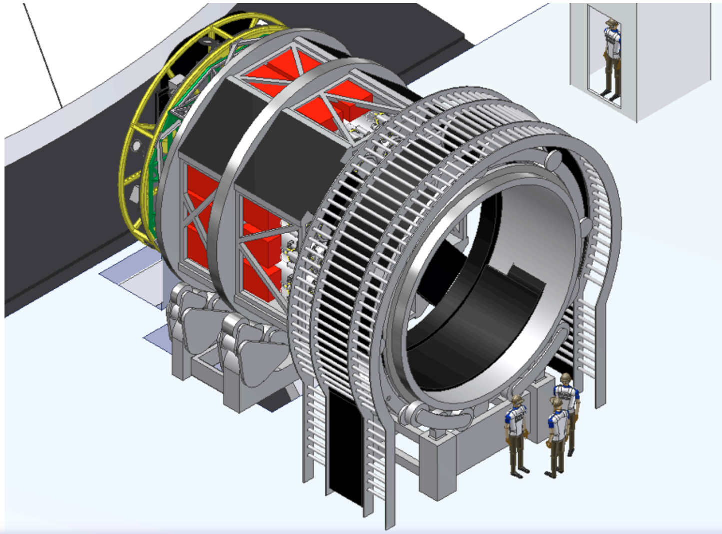
Year	ELT-IFU HARMON I+LTAO	ELT-CAM MAORY +MICADO	ELT-MIR METIS	ELT-MOS MOSAIC	ELT- HIRES HIRES	ELT-6	ELT-PCS
2014	Decide science requirements, AO architecture.		VISIR start on-sky	Develop science requirements for MOS/HIRES			Start ETD
2015				Cal for Proposals			
2016				Start Phase A			
2017						Call for proposal s	
2018				Phase A reviews Finalise agreements			
2019				Start Construction Phase			
2020							
2021							
2022							
2023							
2024							
2025	Instrument on-sky commissioning						

(grey)	Pre-studies: (delta) phase A work/ESO-funded Enabling Technology Development (ETD)
(yellow)	Decision point
(green)	Development Technical Specifications, Statement of Work, Agreement, Instrument Start.

- Instruments in construction phase:
  - HARMONI (UK)
  - MICADO (DE)
  - METIS (NL)
  - MAORY (IT)
- Next instruments:
  - MOSAIC (FR)
  - HIRES (IT)
- Future plans…
  - PCS (lead TBD)
  - ‘ELT 6’, new ideas etc.

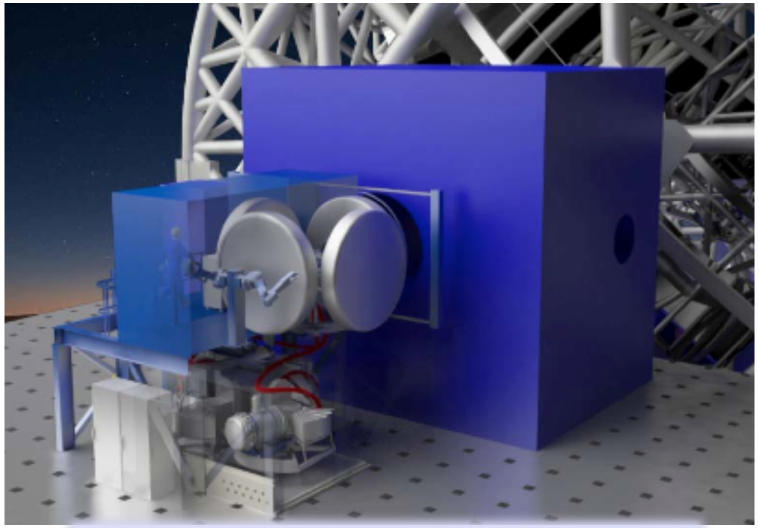
The road to MOSAIC

EAGLE



Multi-IFU, AO-corrected, near-IR

EVE



Multi-fibre/IFU, opt/IR

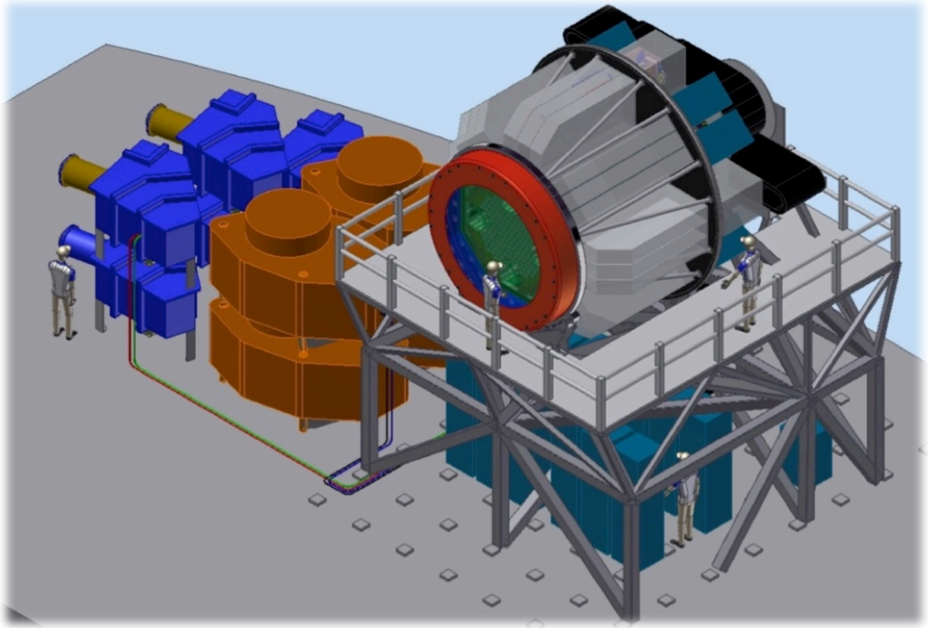
MOSAIC

Multi-Object Spectroscopy with the European ELT:
Scientific synergies between EAGLE & EVE

C. J. Evans[1], B. Barbuy[2], P. Bonifacio[3], F. Chemla[3], J.-G. Cuby[4], G. B. Dalton[5,6], B. Davies[7], K. Disseau[3], K. Dohlen[4], H. Flores[3], E. Gendron[8], I. Guinouard[3], F. Hammer[3], P. Hastings[1], D. Horville[3], P. Jagourel[3], L. Kaper[9], P. Laporte[3], D. Lee[1], S. L. Morris[10], T. Morris[10], R. Myers[10], R. Navarro[11], P. Parr-Burman[1], P. Petitjean[12], M. Puech[3], E. Rollinde[12], G. Rousset[8], H. Schnetler[1], N. Welikala[13], M. Wells[1], Y. Yang[3,14]

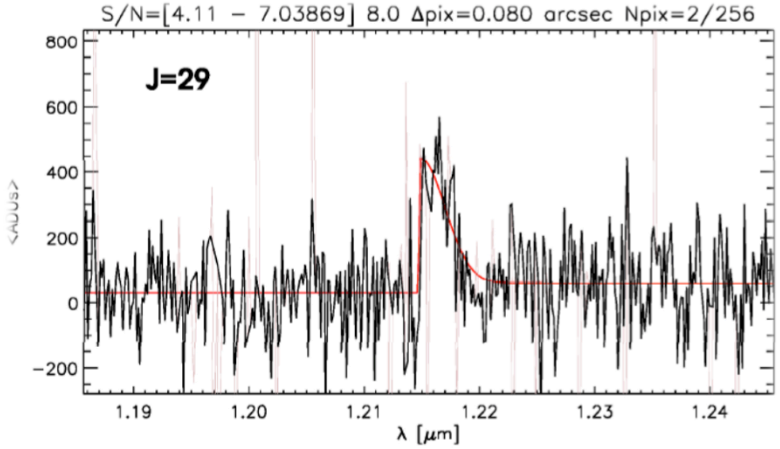
MOSAIC: The ELT MOS

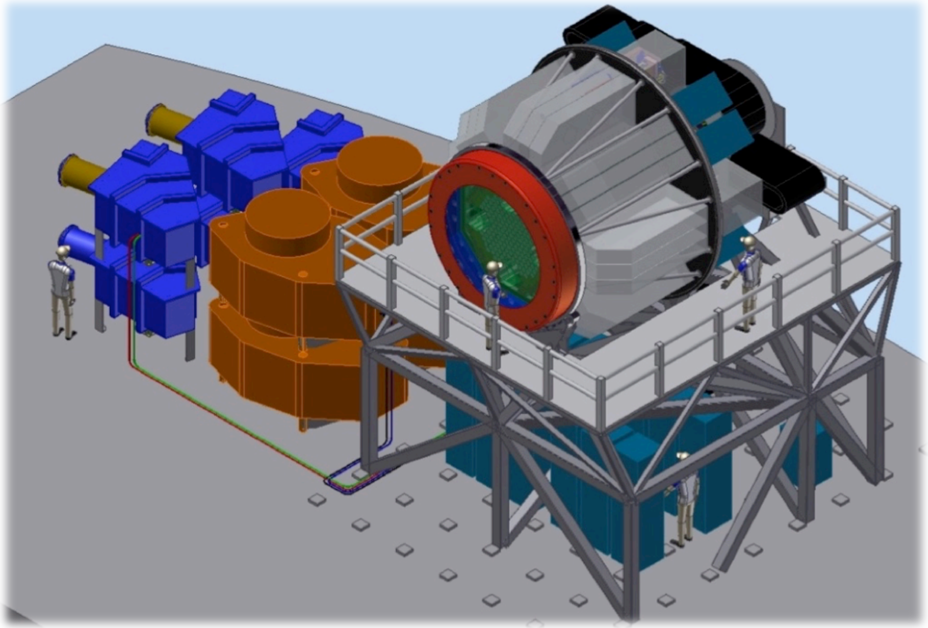
- PI: F. Hammer (Paris)
- Multi-mode, visible/near-IR MOS
- Phase A study completed (03/18)
- Iterating with ESO on specs for Phase B
- Start of Phase B expected in early 2021

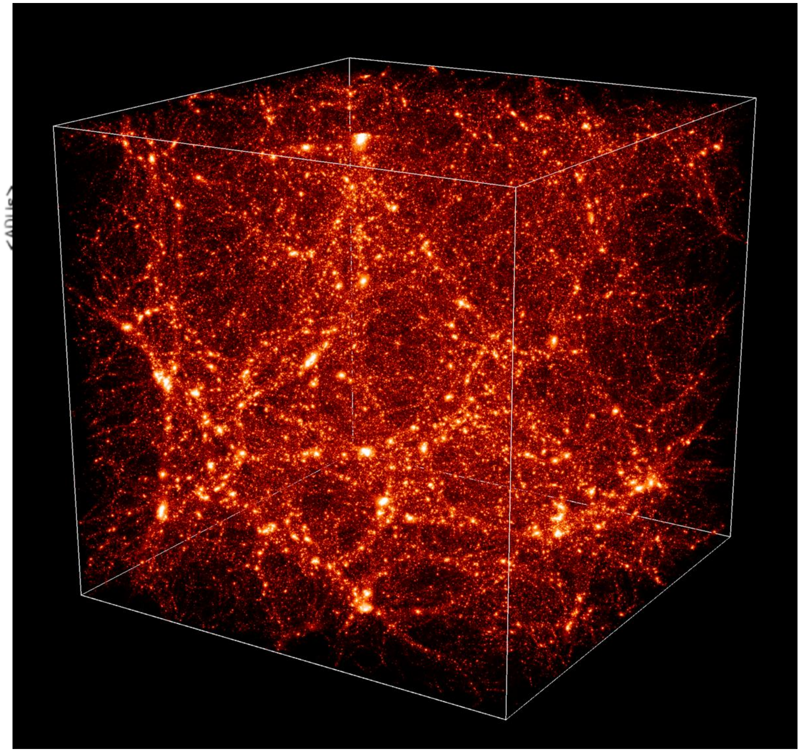


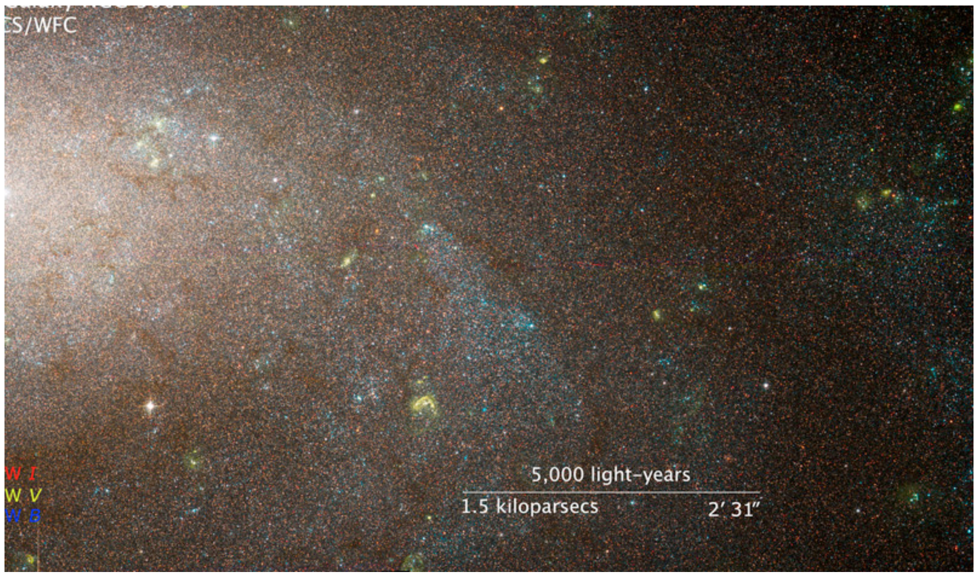
- Science topics (Proj. Scientists: Puech, Sanchez-Janssen, Evans):
  - First-light galaxies
  - Evolution of large-scale structures
  - Mass assembly of galaxies (& AGN) through time
  - Resolved stellar populations

MOSAIC: The ELT MOS



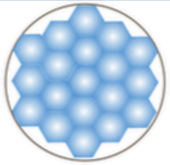






MOSAIC: The ELT MOS

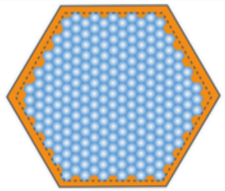
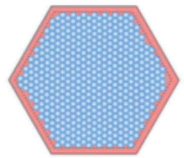
High-multiplex mode:

	Visible	Near IR
	 *	
Number of apertures	200	100 (+100 on sky)
Patrol area	52.1 $arcmin^2$	47.3 $arcmin^2$
Operating bandwidth	0.45 - 0.9 µm	0.8 - 1.8 µm
Diameter of the aperture on sky	840 mas	500 mas
Spectral resolution	5000 & 15,000	5000 & 20,000
AO performance	GLAO (~seeing limited)	GLAO

Final numbers/sizes under review

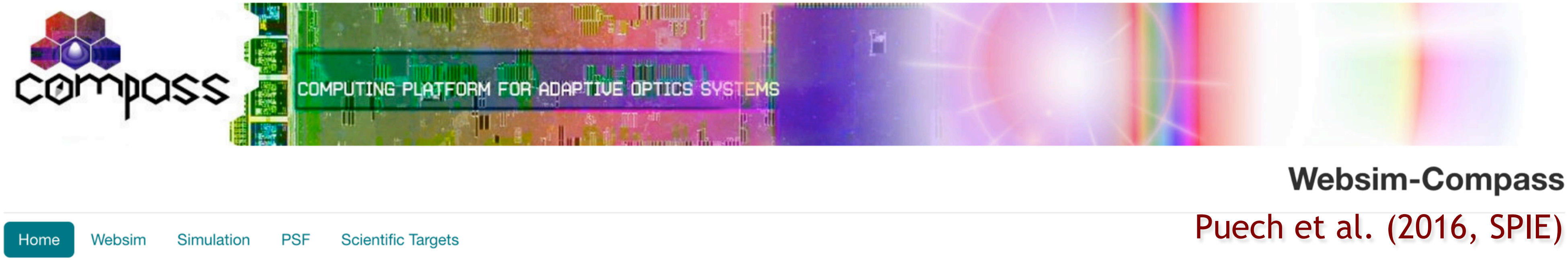
MOSAIC: The ELT MOS

IFU mode:

	Visible	Near IR
		
Number of apertures	10	10
Patrol area	44.2 arcmin^2	44.2 arcmin^2
Operating bandwidth	0.45 - 0.9 μm	0.8 - 1.8 μm
Outer diameter of on-sky subfield	2.31 arcsec (hexagonal)	1.9 arcsec (hexagonal)
Sampling	138 mas	80 mas
Spectral resolution	5000 & 15000	5000 & 20,000
AO performance	GLAO (~seeing limited)	MOAO: 25% EE in 150 mas

Final numbers/sizes under review
(visible IFUs not in current baseline)

MOSAIC: Performance



Puech et al. (2016, SPIE)

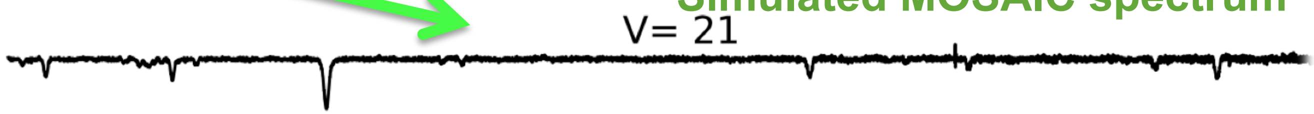
Advanced simulations with 'WEBSIM' (developed by Paris Obs.)

INPUTS:

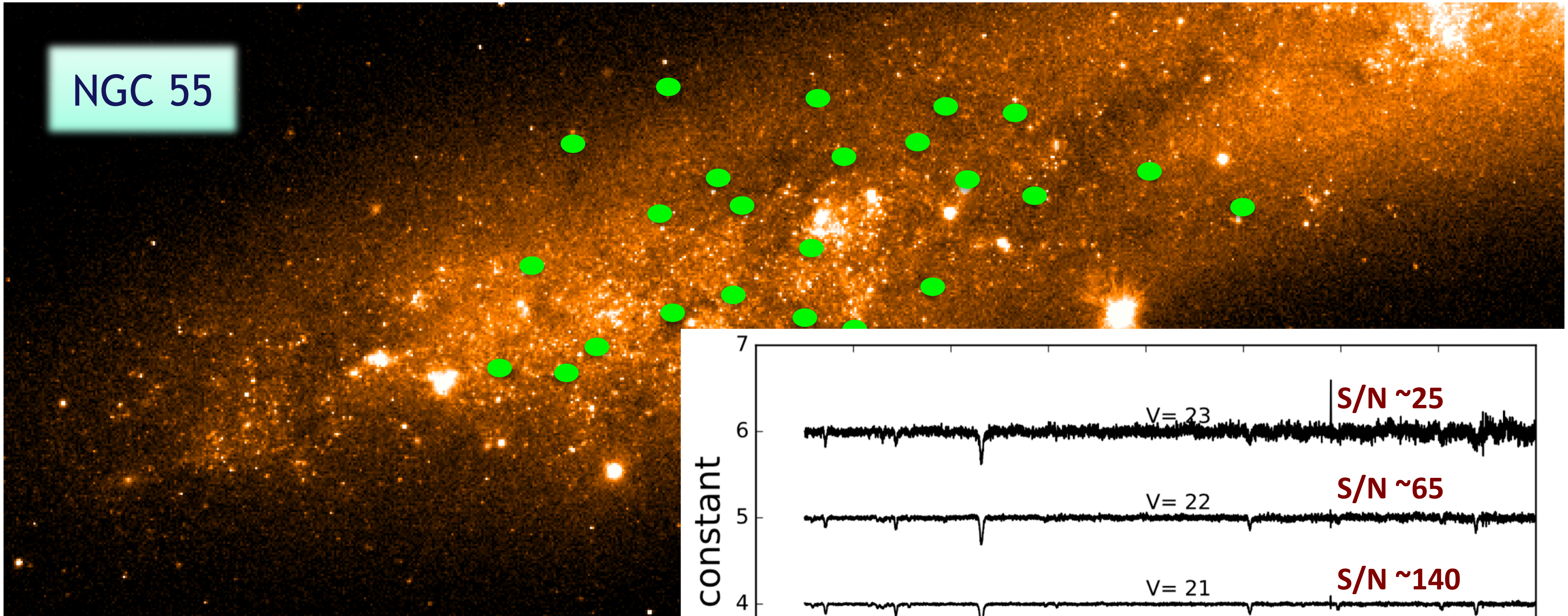
- **Template spectrum**
- **PSF from AO system**
- **End-to-end efficiency**
- **Spectral configuration**

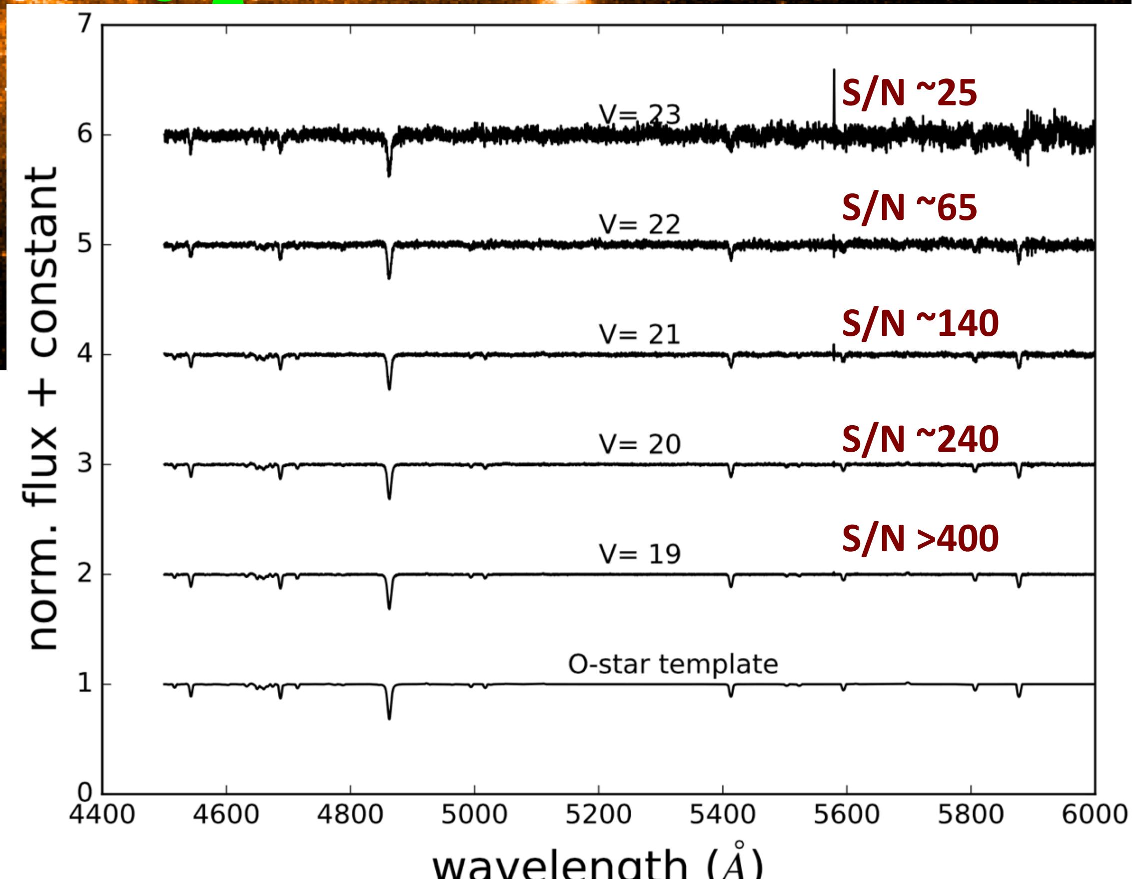
& light-gathering power of 39m!

Simulated MOSAIC spectrum



MOSAIC: Performance





Before I conclude...

Thank you!

Summary

VLT-CUBES:

- Exciting scientific opportunity, incl. builds on Brazil's past investment
- Exploits unique strength of VLT in the ELT era

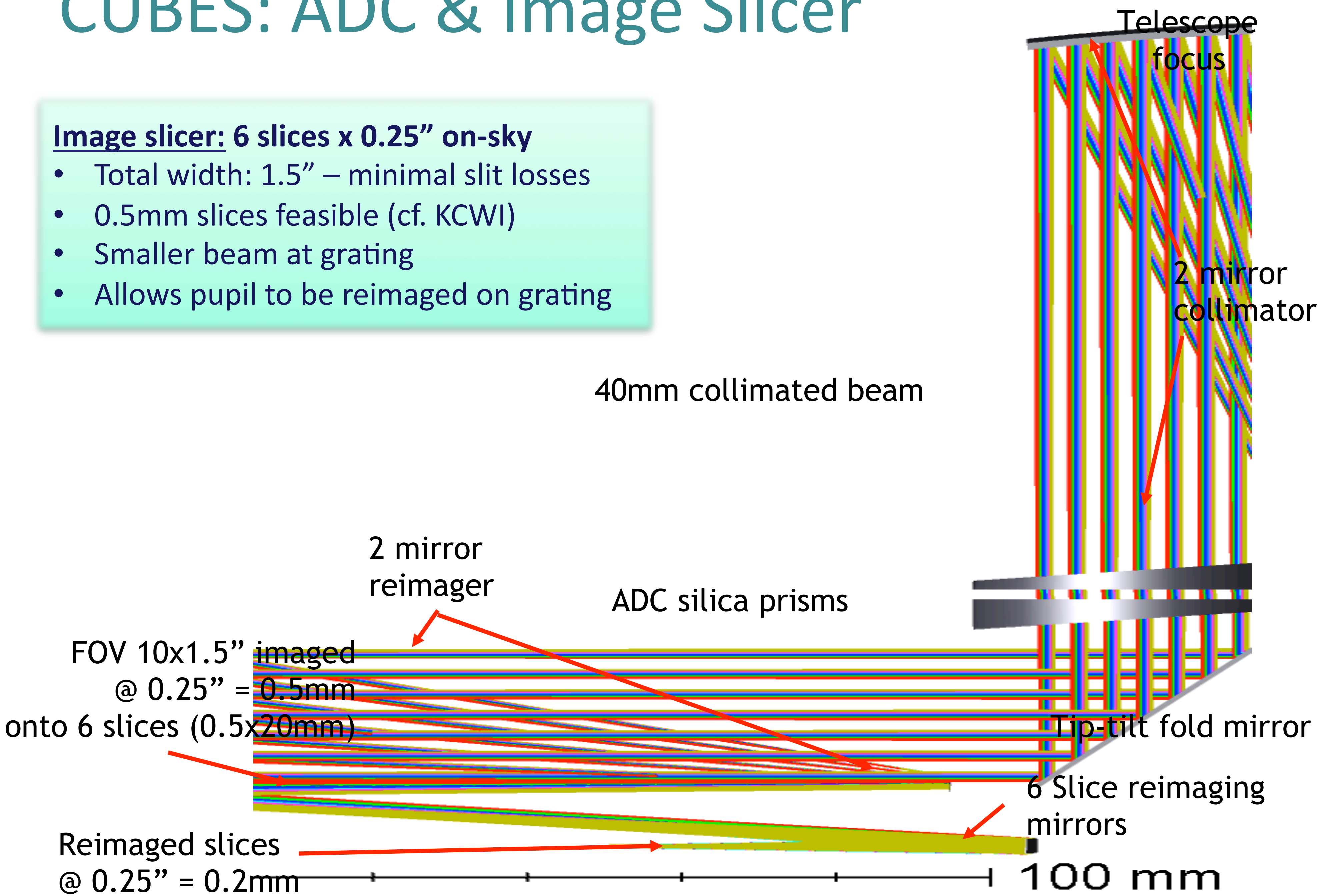
ELT-MOSAIC:

- Advanced planning for visible/near-IR multi-object spectrograph on the world's 'Biggest Eye on the Sky'

CUBES: ADC & Image Slicer

<u>Image slicer:</u> 6 slices x 0.25” on-sky

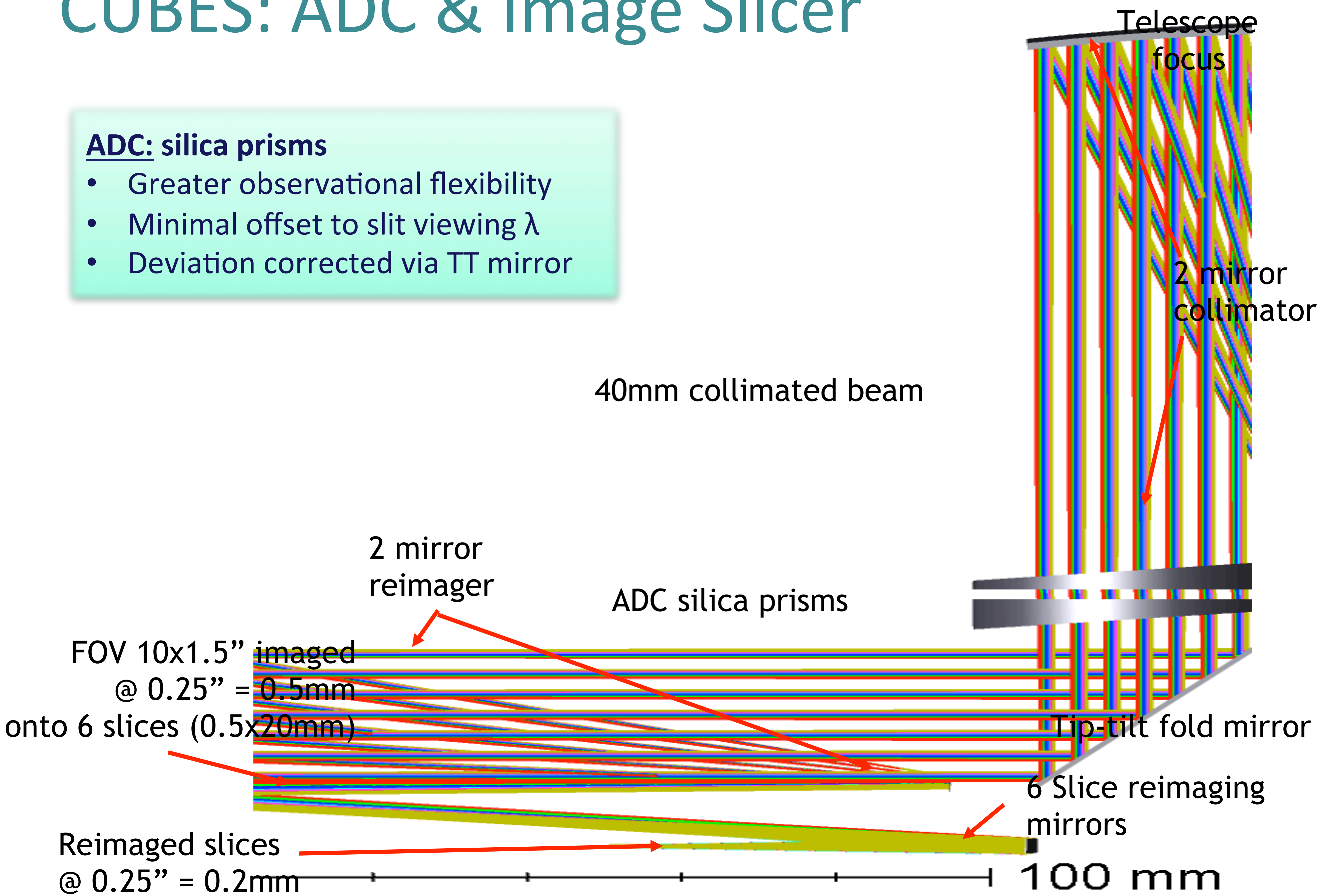
- Total width: 1.5” – minimal slit losses
- 0.5mm slices feasible (cf. KCWI)
- Smaller beam at grating
- Allows pupil to be reimaged on grating



CUBES: ADC & Image Slicer

ADC: silica prisms

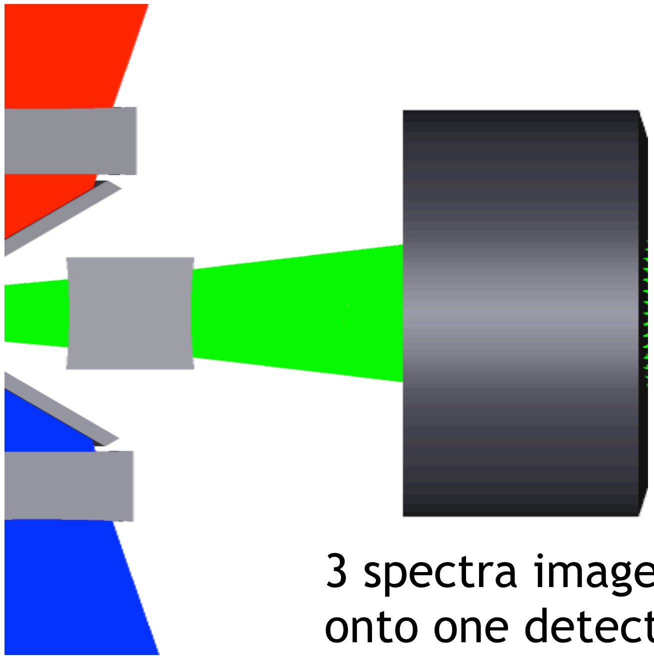
- Greater observational flexibility
- Minimal offset to slit viewing λ
- Deviation corrected via TT mirror



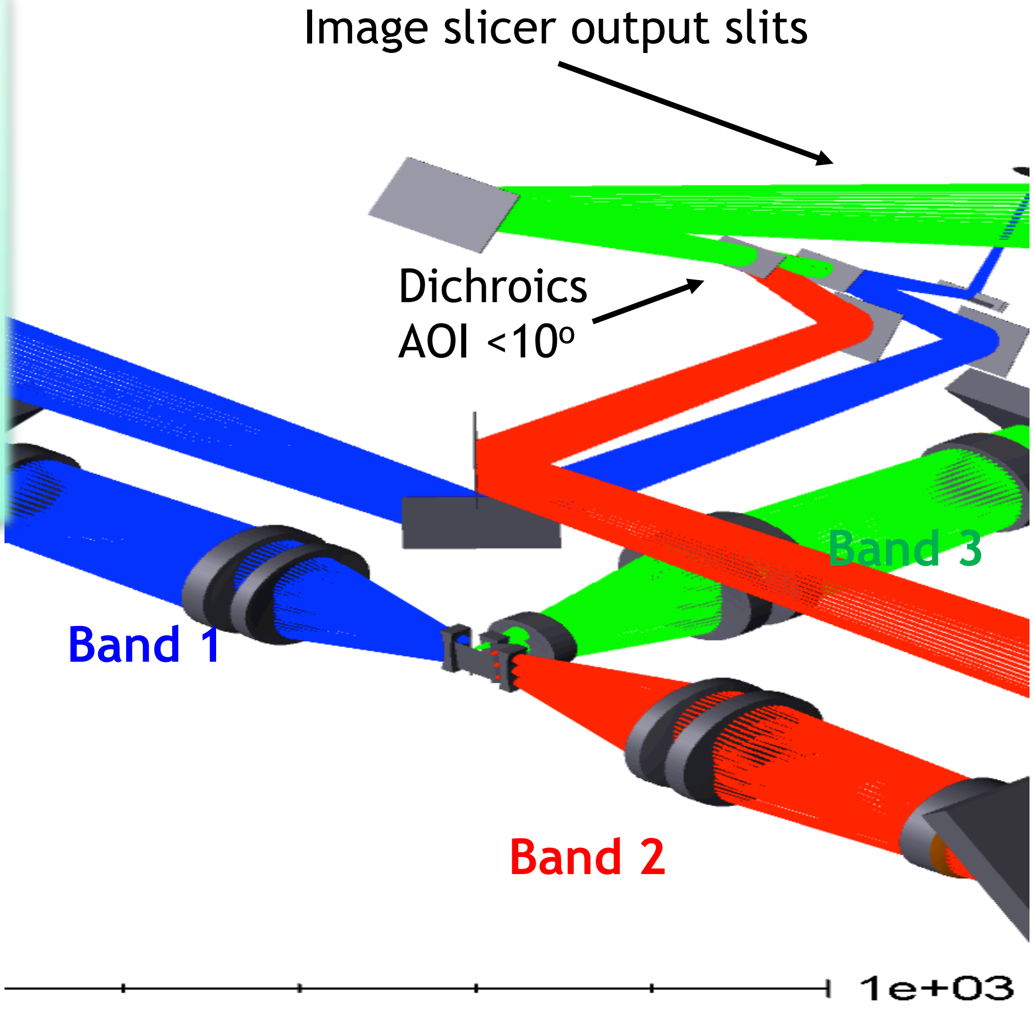
CUBES: Spectrometers

Spectrograph: 3 bands

- Separate collimator, gratings, cameras
  ➔ can optimise each band
- Camera lenses are spherical except for 1^{st} surface (modest conic)
- One detector for all 3 bands
- Bands have 6nm overlap, no gaps



3 spectra imaged onto one detector



CUBES: Galactic Science

^{9}Be produced via cosmic-ray spallation in ISM in early Galaxy

- ***Direct process:*** accelerated p/He^{2+} colliding with CNO in ISM

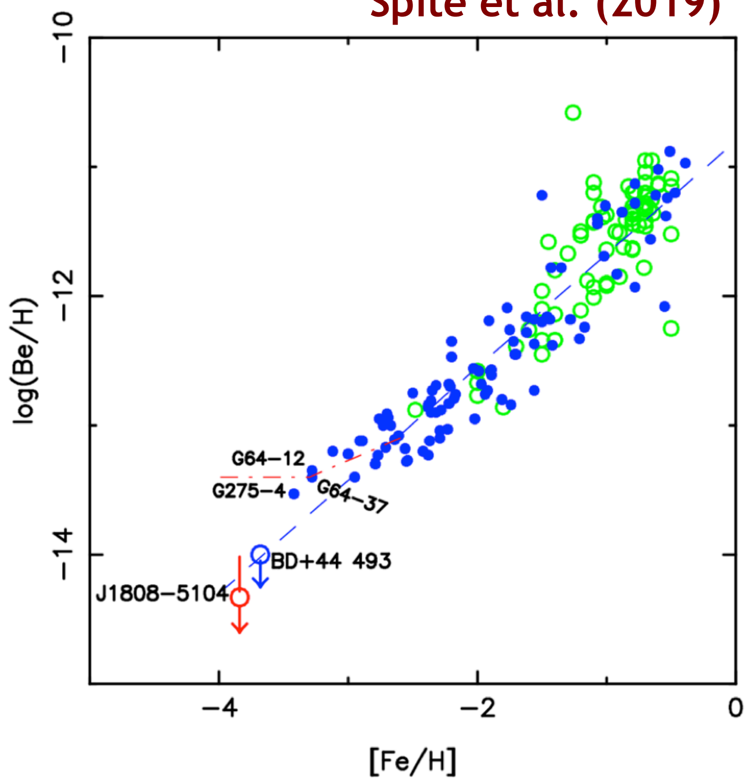
➔ scales with Z = secondary element

- ***Inverse process:*** accelerated CNO collides with p/He^{2+} in ISM

➔ primary element

If primary, Be potential chronometer of early star formation

Spite et al. (2019)



- Be abundances: Limited to 10s of stars with VLT-UVES/Keck-HIRES
- Increased efficiency of ~3 magnitudes
  ➔ samples of 100s in ambitious large programme

Rest-frame UV lines at high-z

Missing baryonic mass in the high-redshift CGM