Science & Technology Facilities Council
UK Astronomy Technology Centre

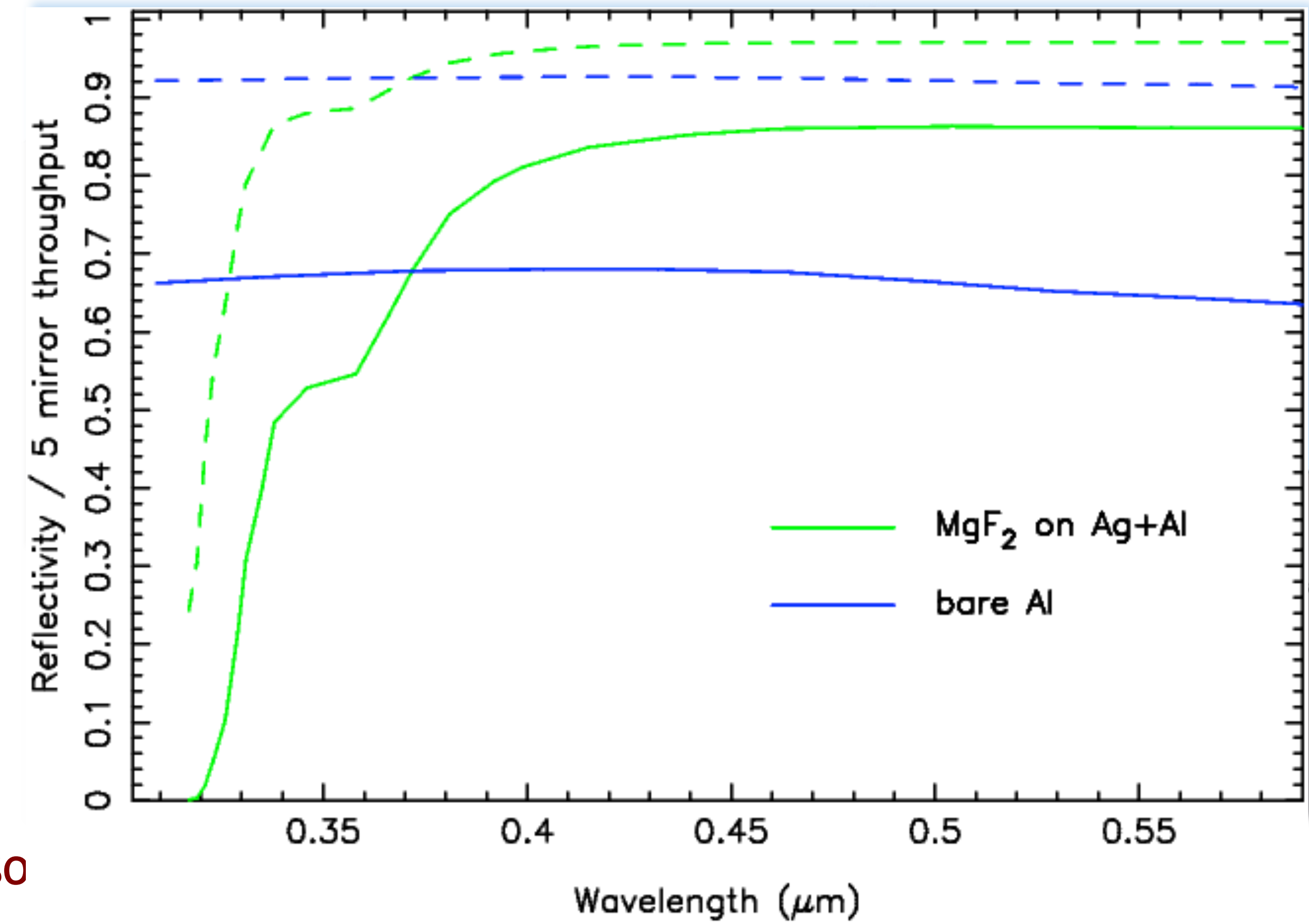
GCRF
Global Challenges Research Fund

Near-UV spectroscopy with the VLT

Chris Evans (UKATC)

Barbuy, Bawden de Arruda, Bianco, Bonifacio, Castilho, Christlieb, Cristiani, Dekker, Dias, Di Marcantonio, Ernandes, Henry, Melendez, Japelj, Morris, Parr-Burman, Puech, Quirrenbach, Smiljanic, Snodgrass, Wells, Zanutta

From ELT to VLT…



Credit: ESO

From ELT to VLT…

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

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

ESO

European Organisation
for Astronomical Research
in the Southern Hemisphere

Very Large Telescope

CUBES

Phase A study
Science Report

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

Issue: 1

Date: 31.08.2012

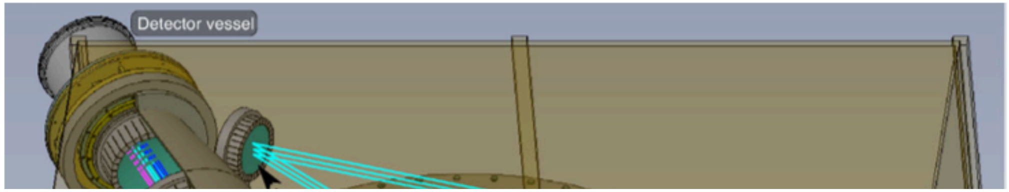
CUBES Phase A

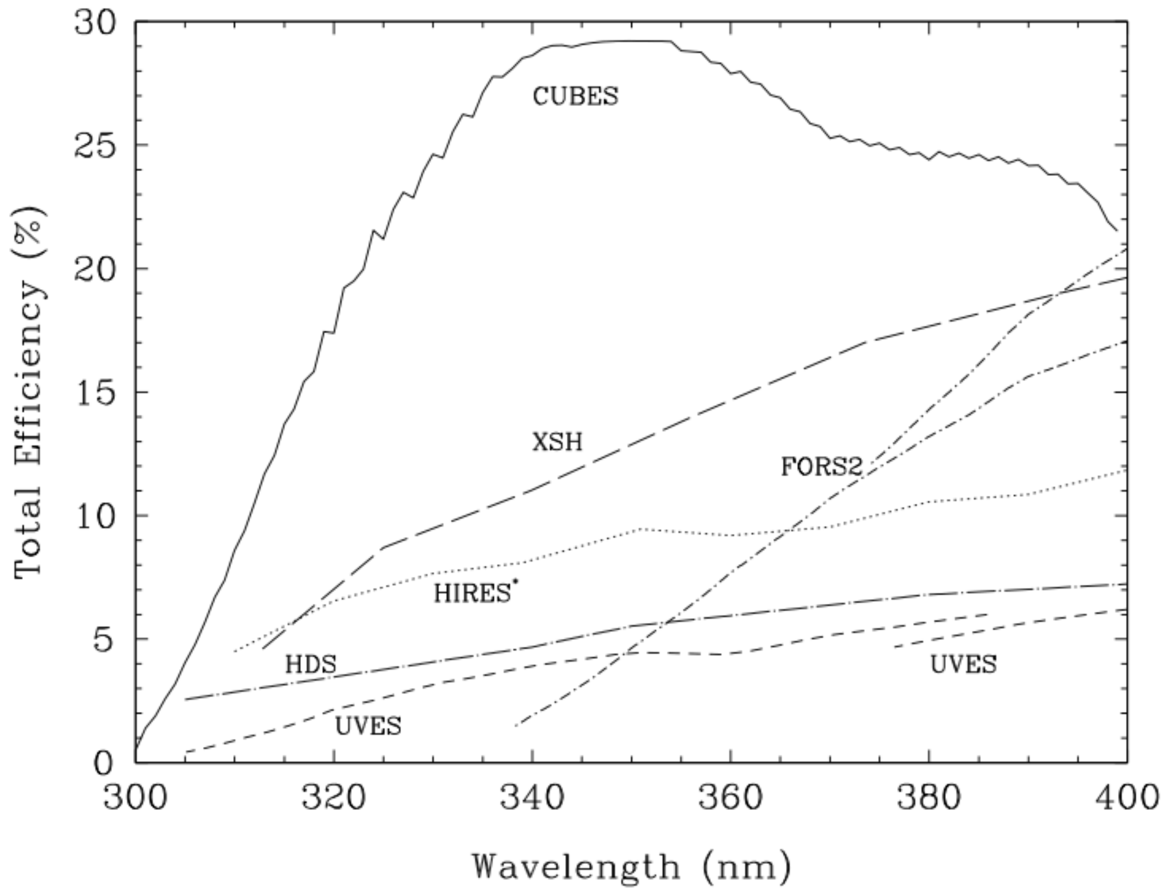
Table 4 Key CUBES parameters

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)





CUBES revisited

Global Challenges Research Fund

Revis

Cassegrain U-Band Efficient Spectrograph

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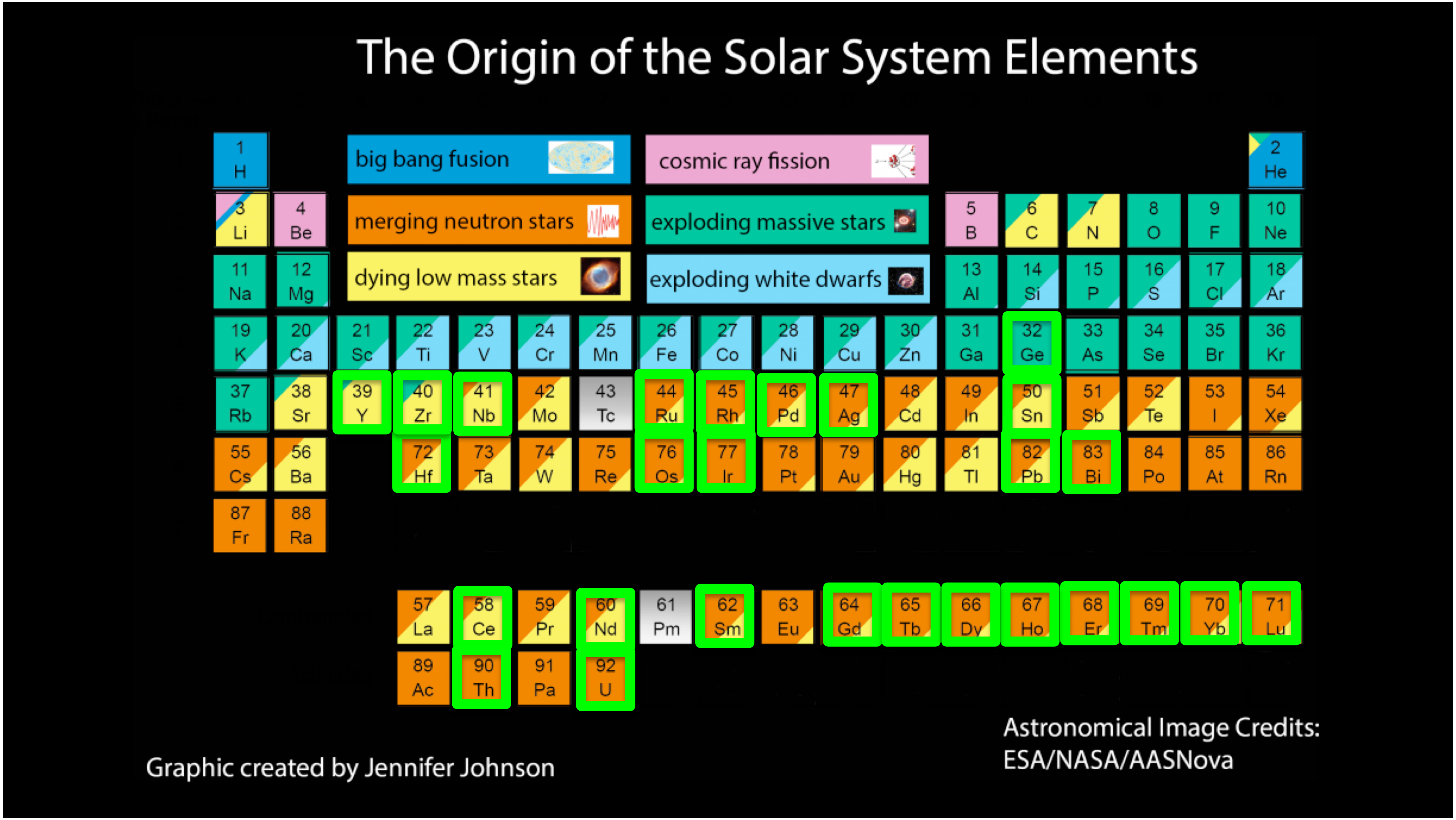
SPIE 2018 (arXiv:1806.11173)

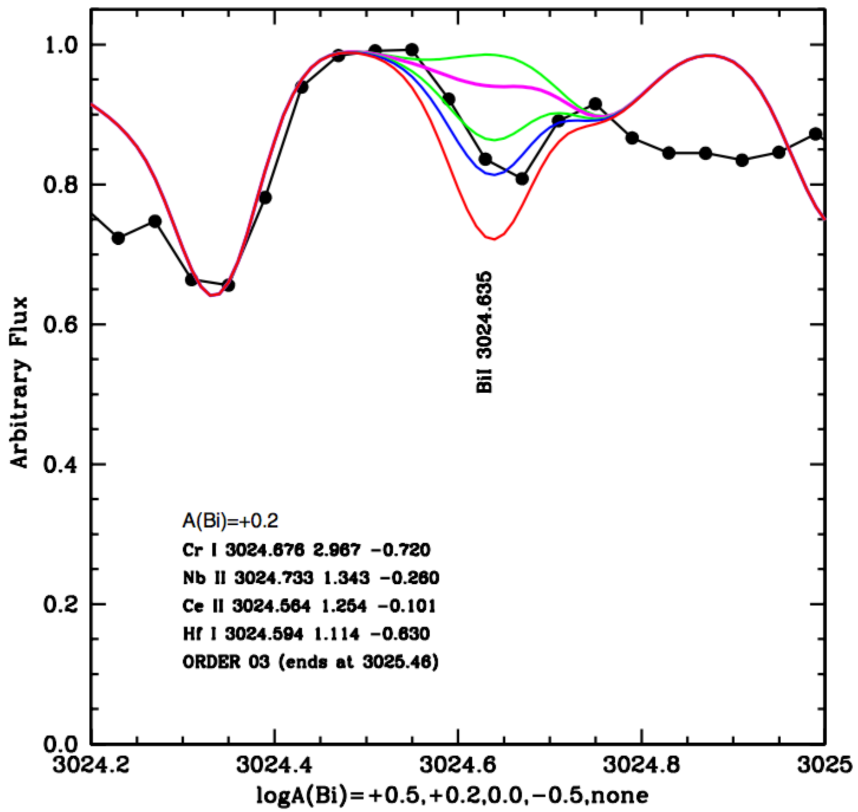
Instrument Requirements

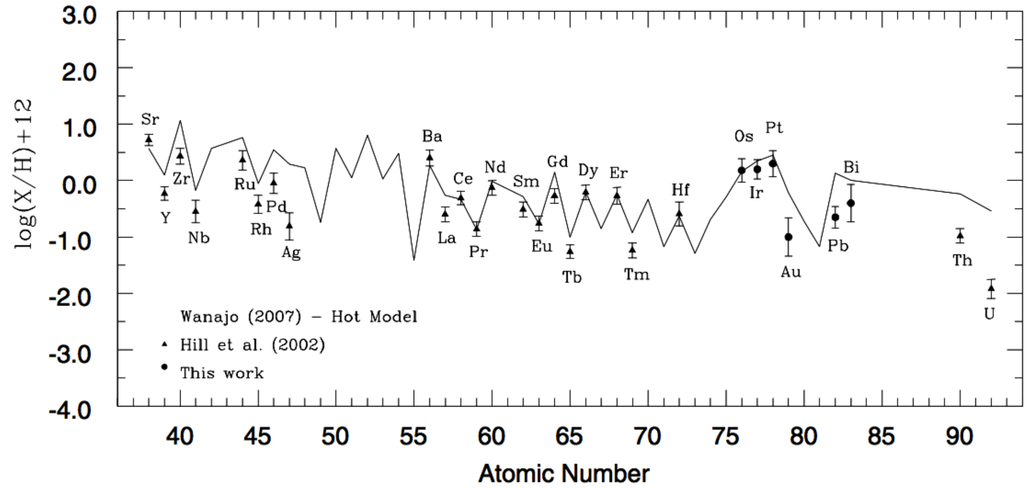
The two key requirements for the Phase A conceptual design were a spectral resolving power of $R \geq 20{,}000$ spanning 302-380 nm, with extension to 400 nm as a goal (ensuring good overlap with ESPRESSO). After revisiting the scientific case these are still valid, and will open-up unique discovery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

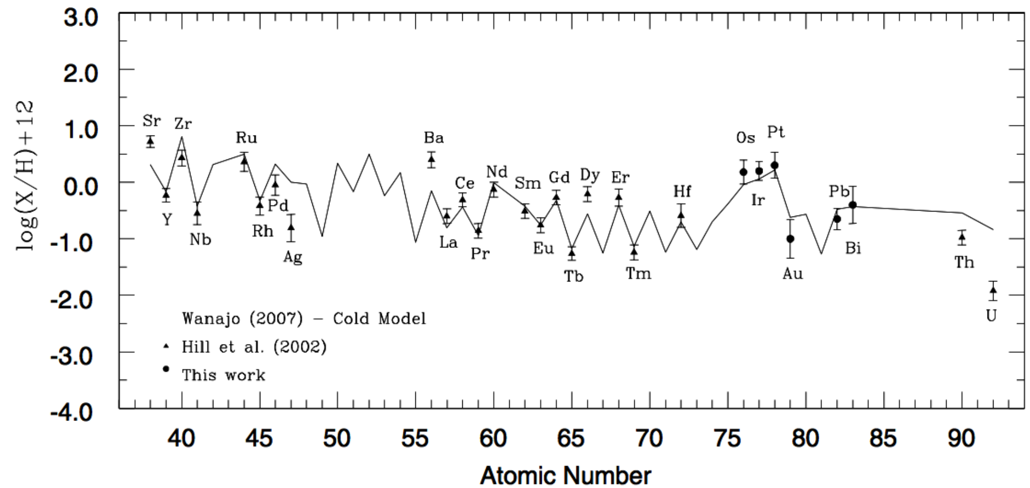

The Origin of the Solar System Elements
big bang fusion
cosmic ray fission
merging neutron stars
exploding massive stars
dying low mass stars
exploding white dwarfs
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
57 La
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
89 Ac
90 Th
91 Pa
92 U
Graphic created by Jennifer Johnson
Astronomical Image Credits:
ESA/NASA/AASNova

CUBES: Galactic science

Barbuy et al. (2012)



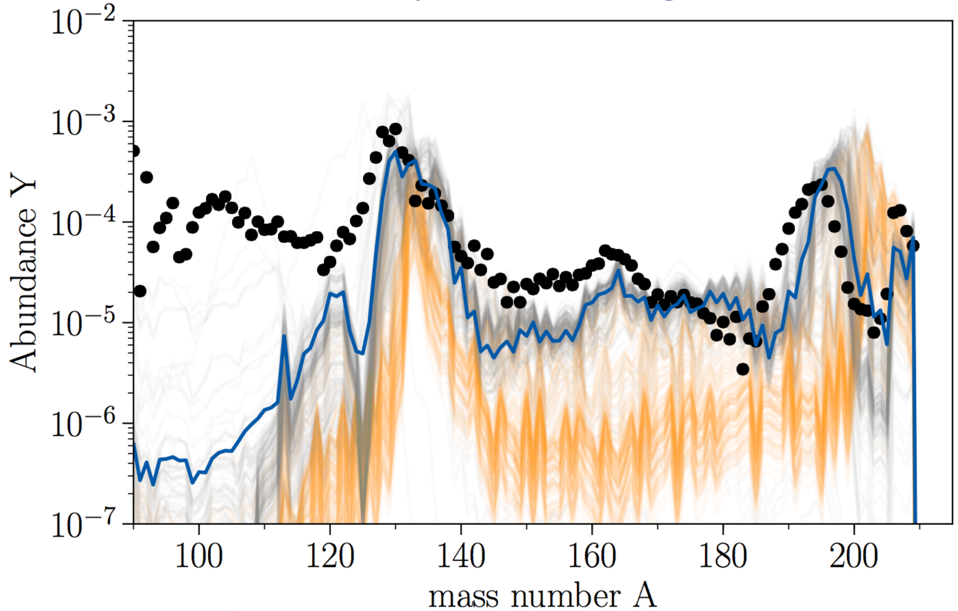




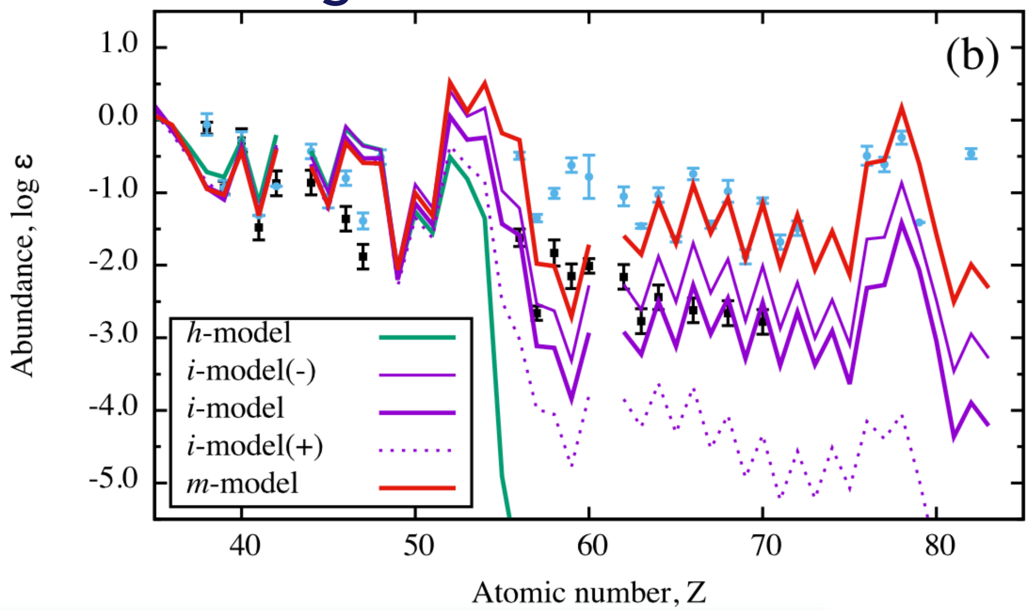
CUBES: Galactic science

Testing predictions of different channels for r-process nucleosynthesis

Binary NS mergers:

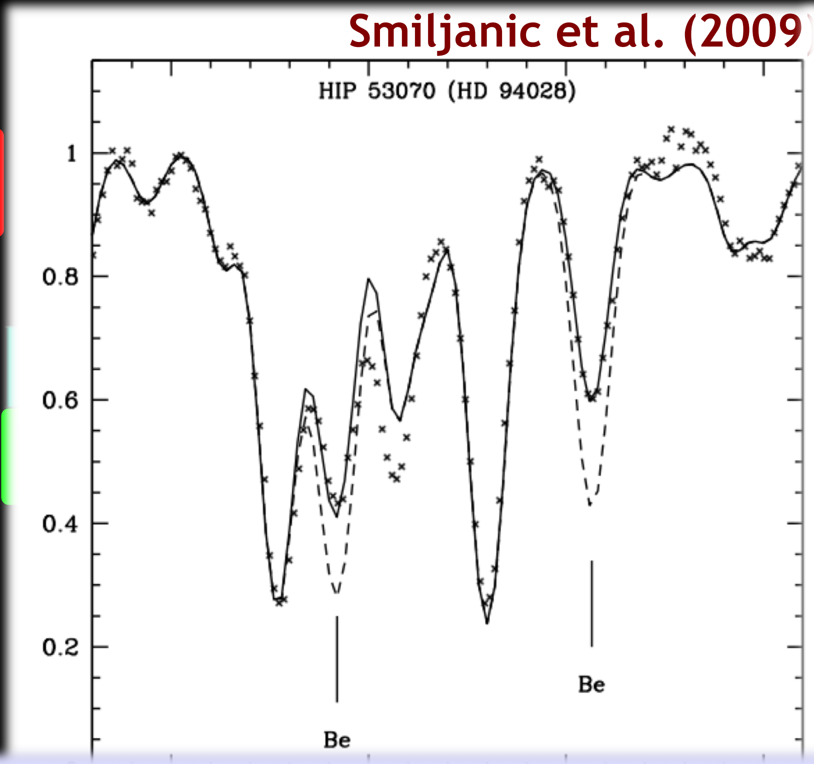


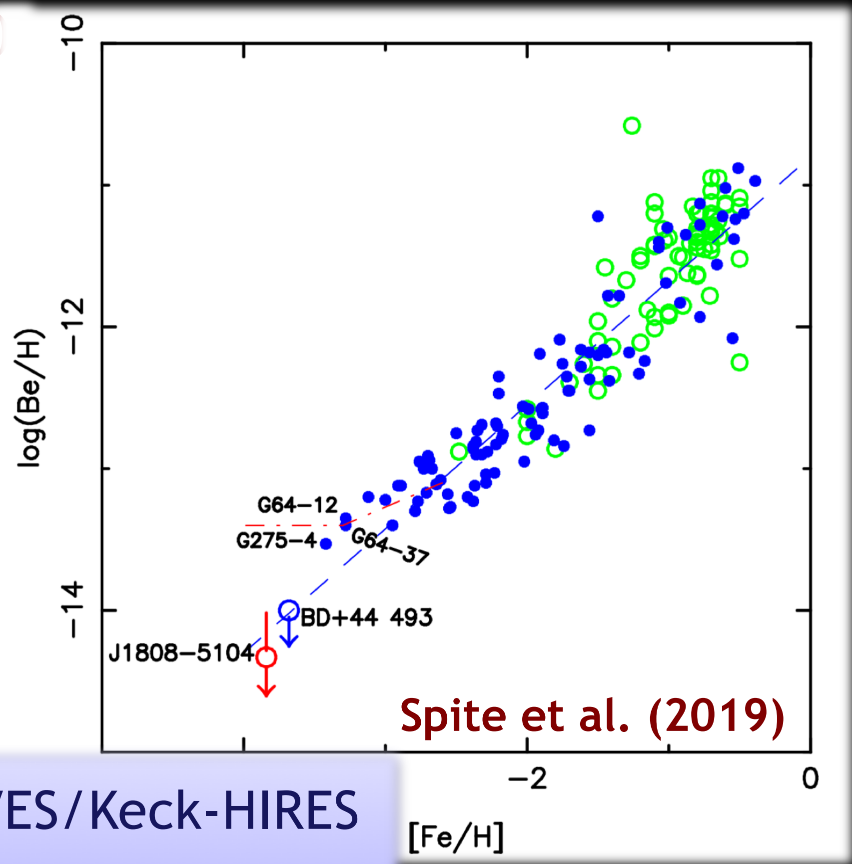
Magneto-rotational Sne:



<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

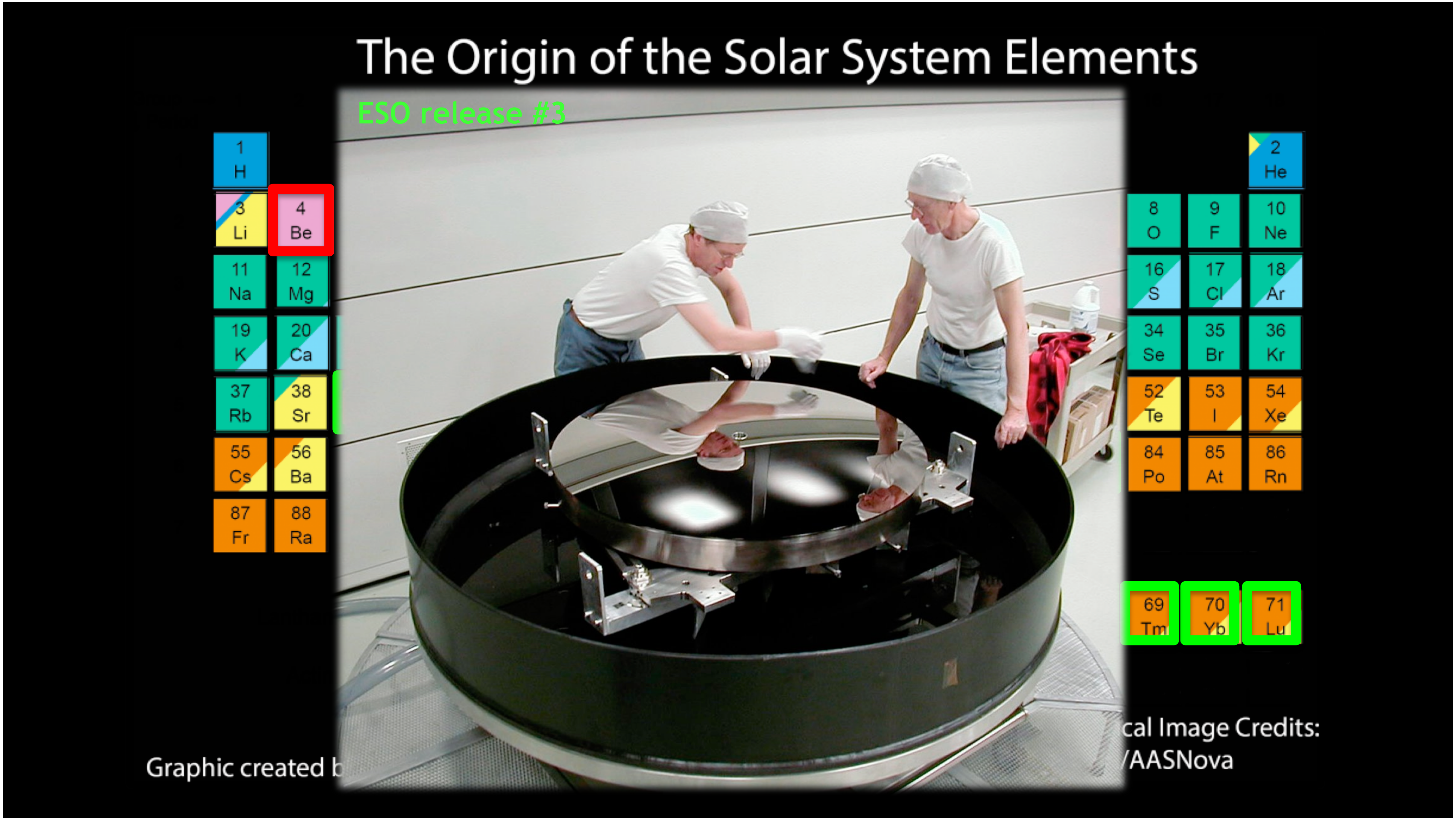
The Origin of the Solar System Elements





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

al Image Credits:
AASNova


The Origin of the Solar System Elements
ESO release #3
1 H
2 He
3 Li
4 Be
8 O
9 F
10 Ne
11 Na
12 Mg
16 S
17 Cl
18 Ar
19 K
20 Ca
34 Se
35 Br
36 Kr
37 Rb
38 Sr
52 Te
53 I
54 Xe
55 Cs
56 Ba
84 Po
85 At
86 Rn
87 Fr
88 Ra
69 Tm
70 Yb
71 Lu
Graphic created b
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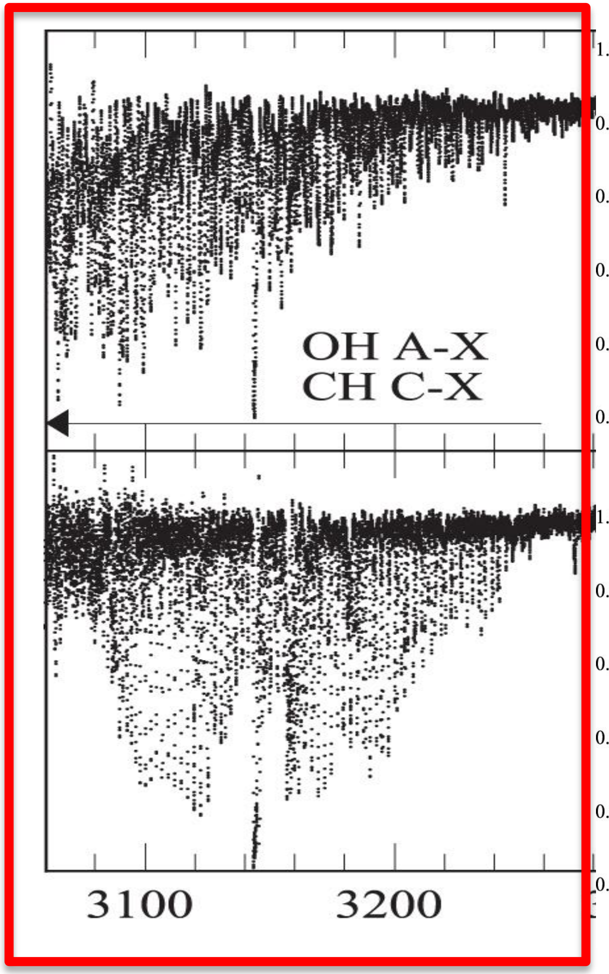
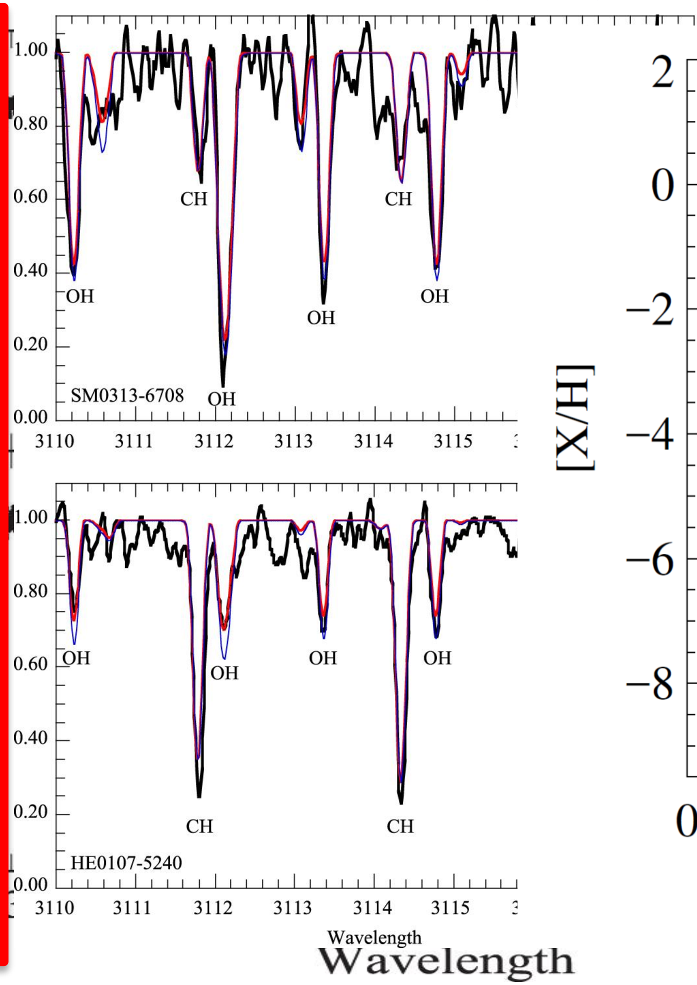
/AASNova

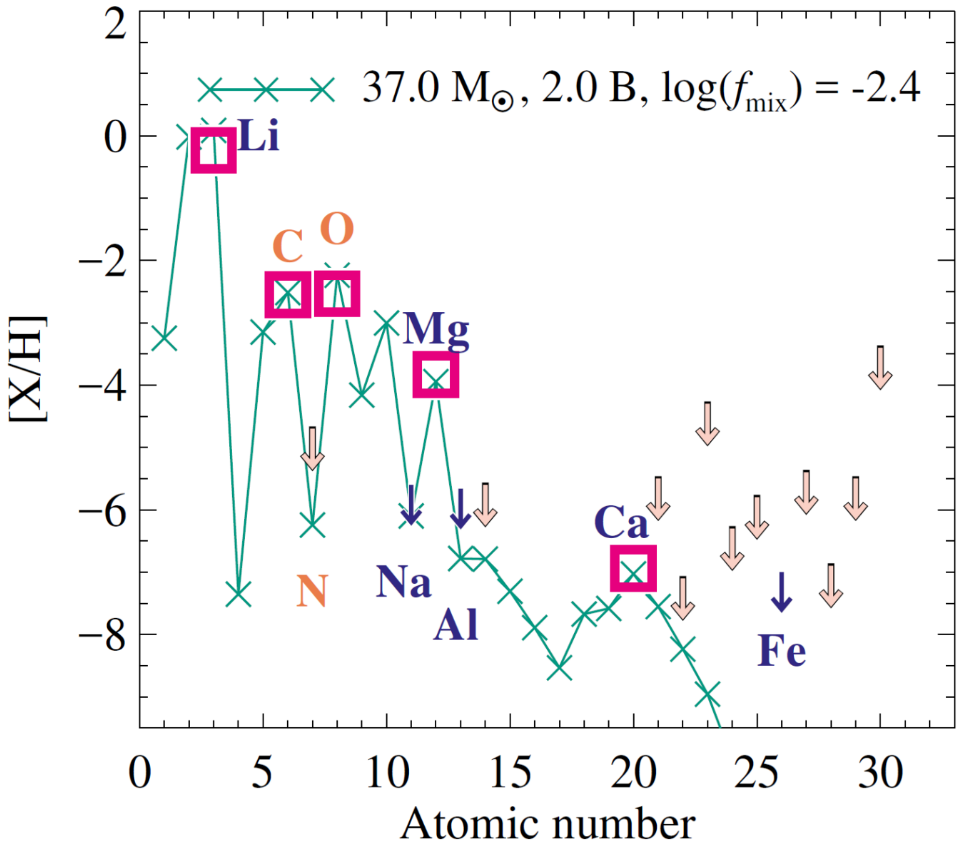
CUBES: Galactic science



Bessell et al. (2015)



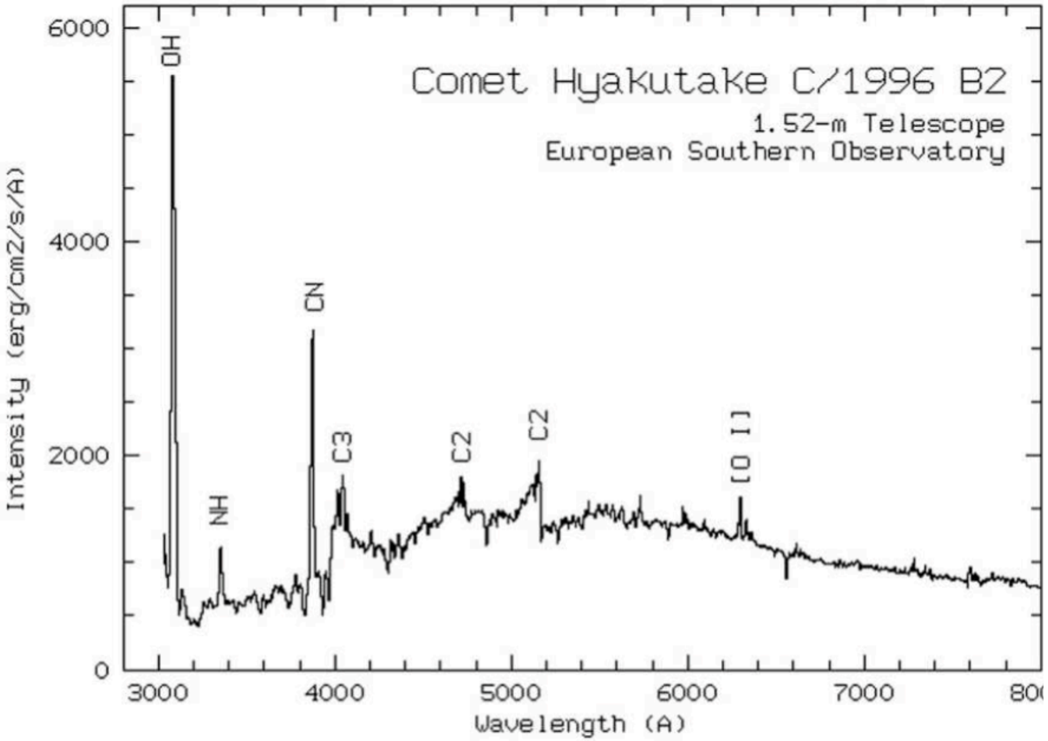
Nordlander et al. (2017)



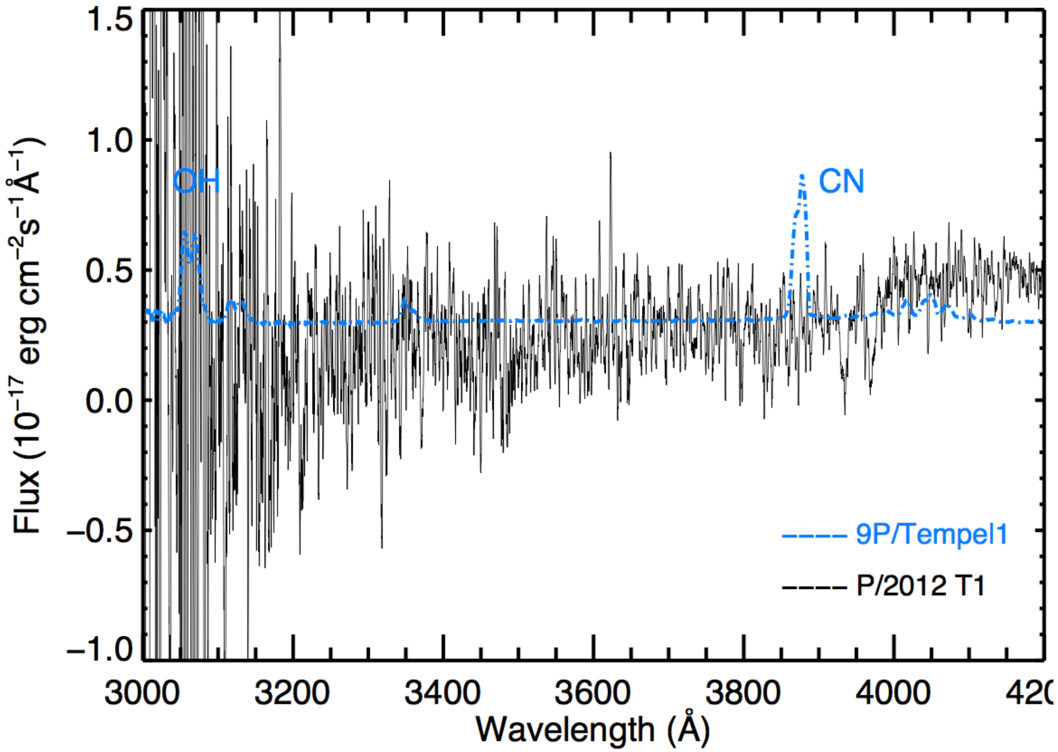
CUBES: Galactic science

See poster by Colin Snodgrass

Searching for water in the asteroid belt…

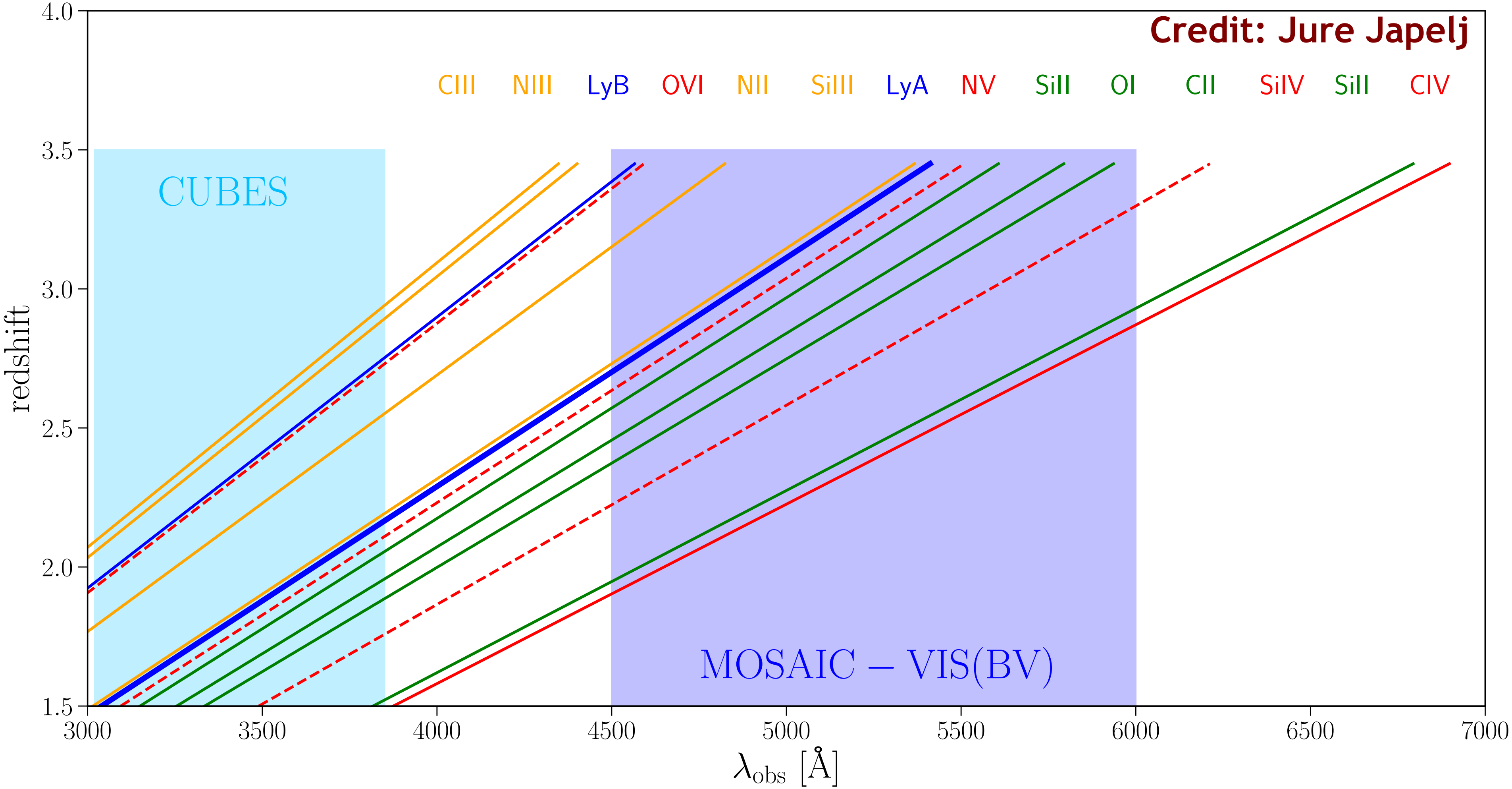


Credit: ESO



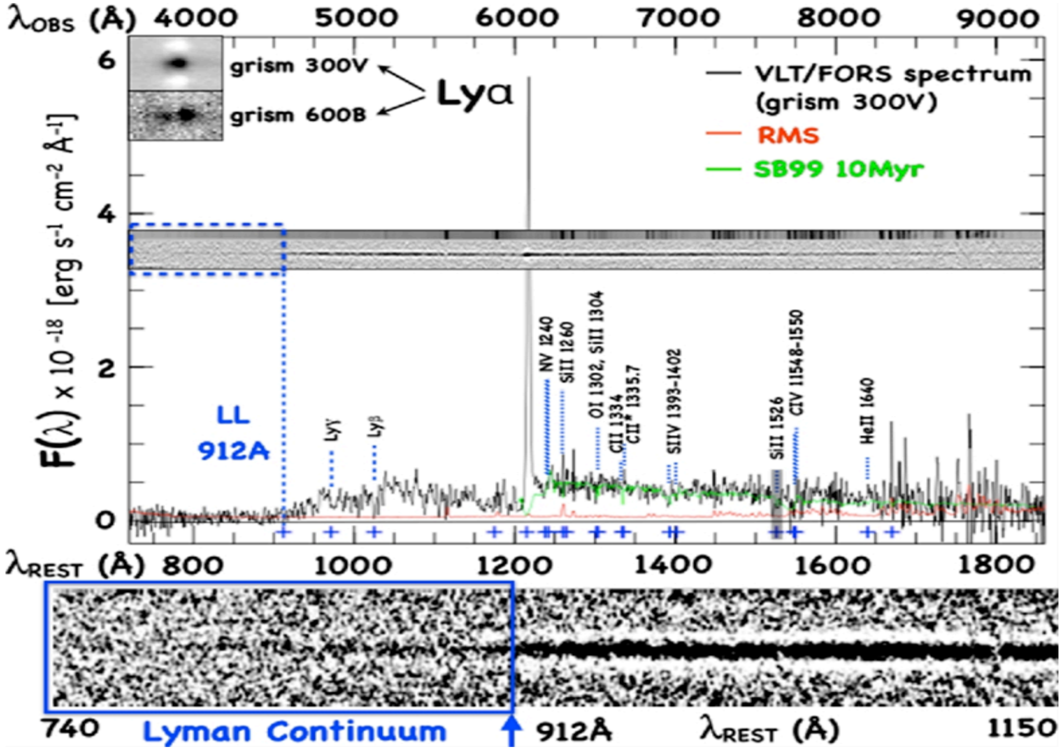
Snodgrass et al. (2017)

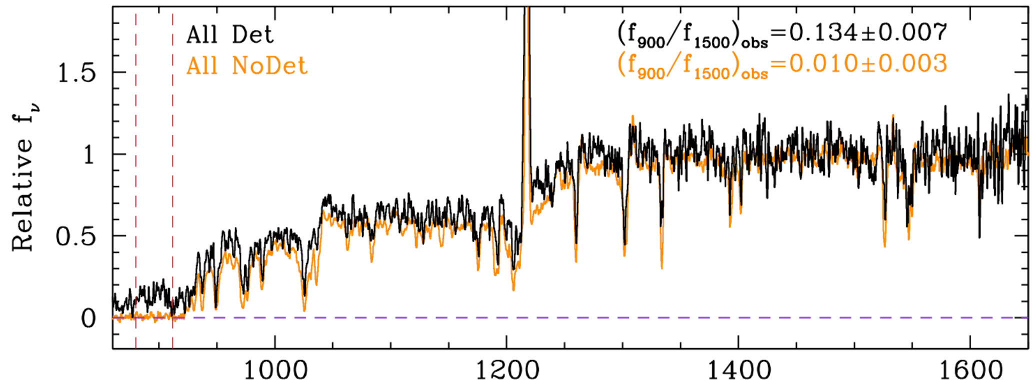
CUBES: Extra-galactic science



CUBES: Extra-galactic science

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



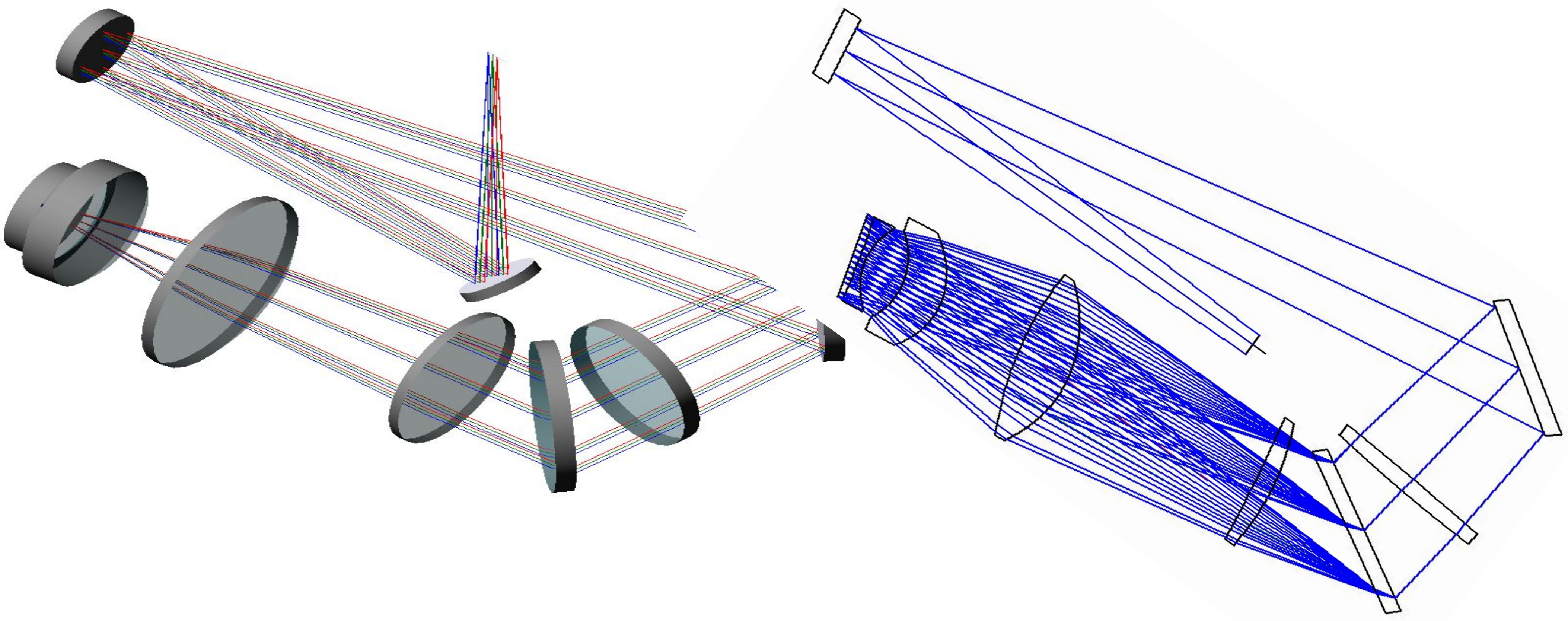


KLCS sample @ z~3 (Steidel et al. 2018)

Need greater near-UV sensitivity to probe *f*_esc

CUBES: Phase A optical concept

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



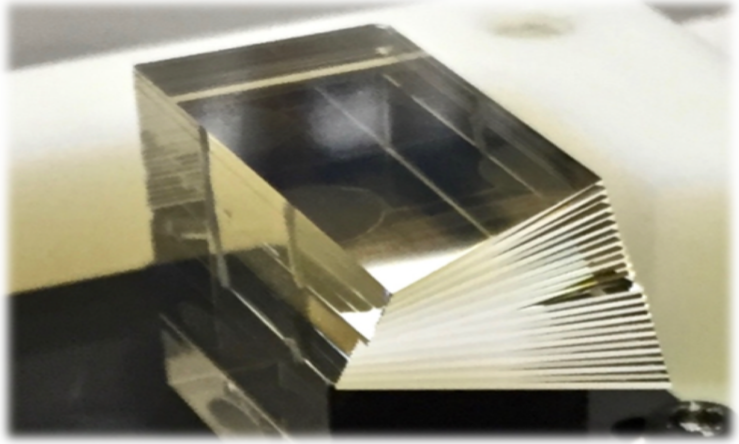
CUBES: Alternative optical concept

Philosophy: manufacturability (slices/lenses) and optical transmission

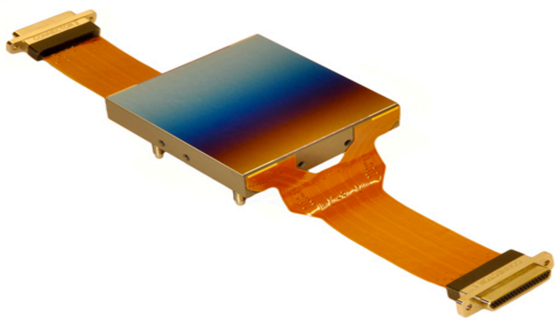
Image slicer:
- 6 slices x 0.25" on-sky
- Tot. width: 1.5" ➔ minimal slit losses

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

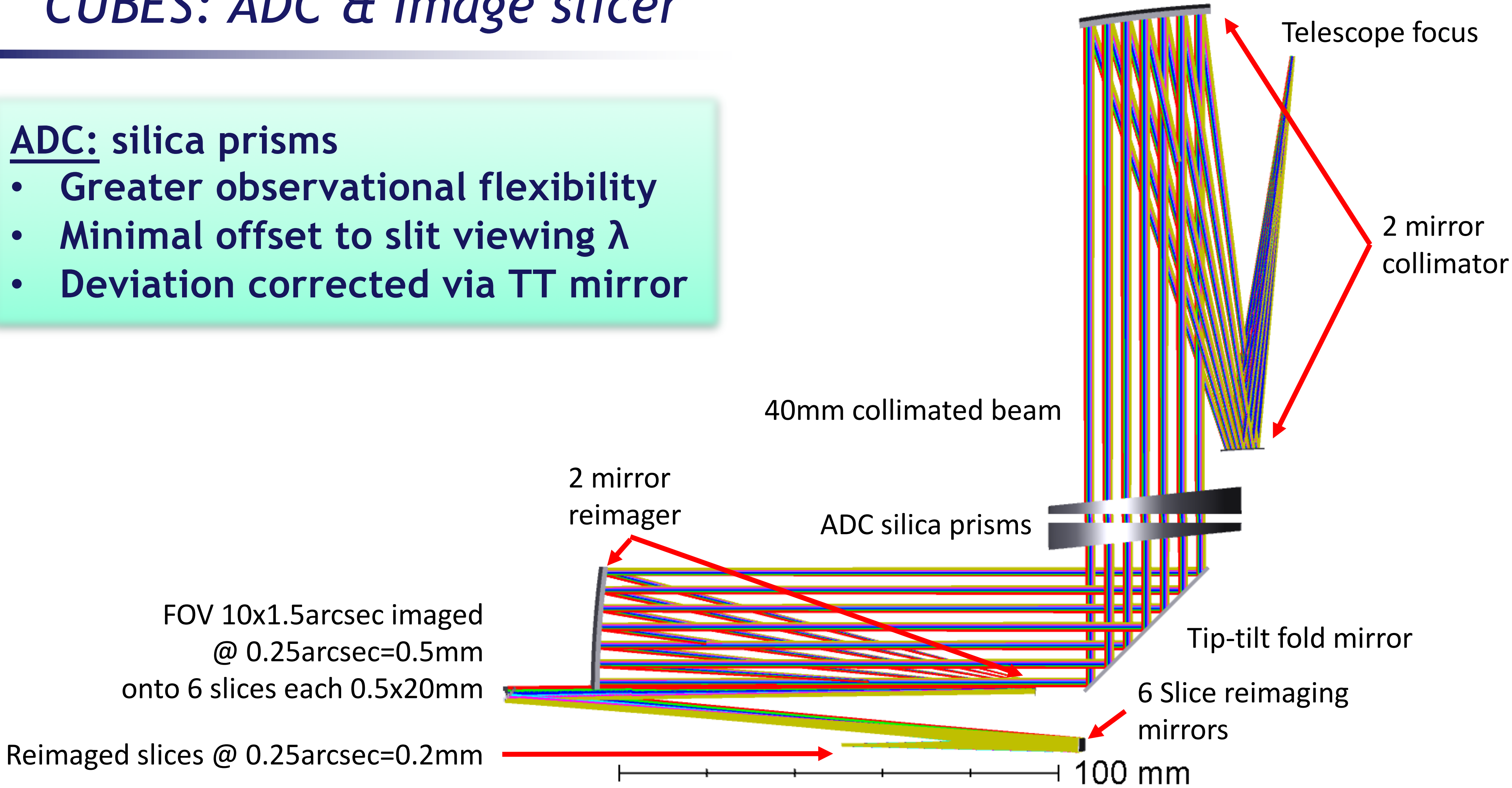


KCWI: Morrissey et al. (2018)



CUBES: ADC & Image slicer

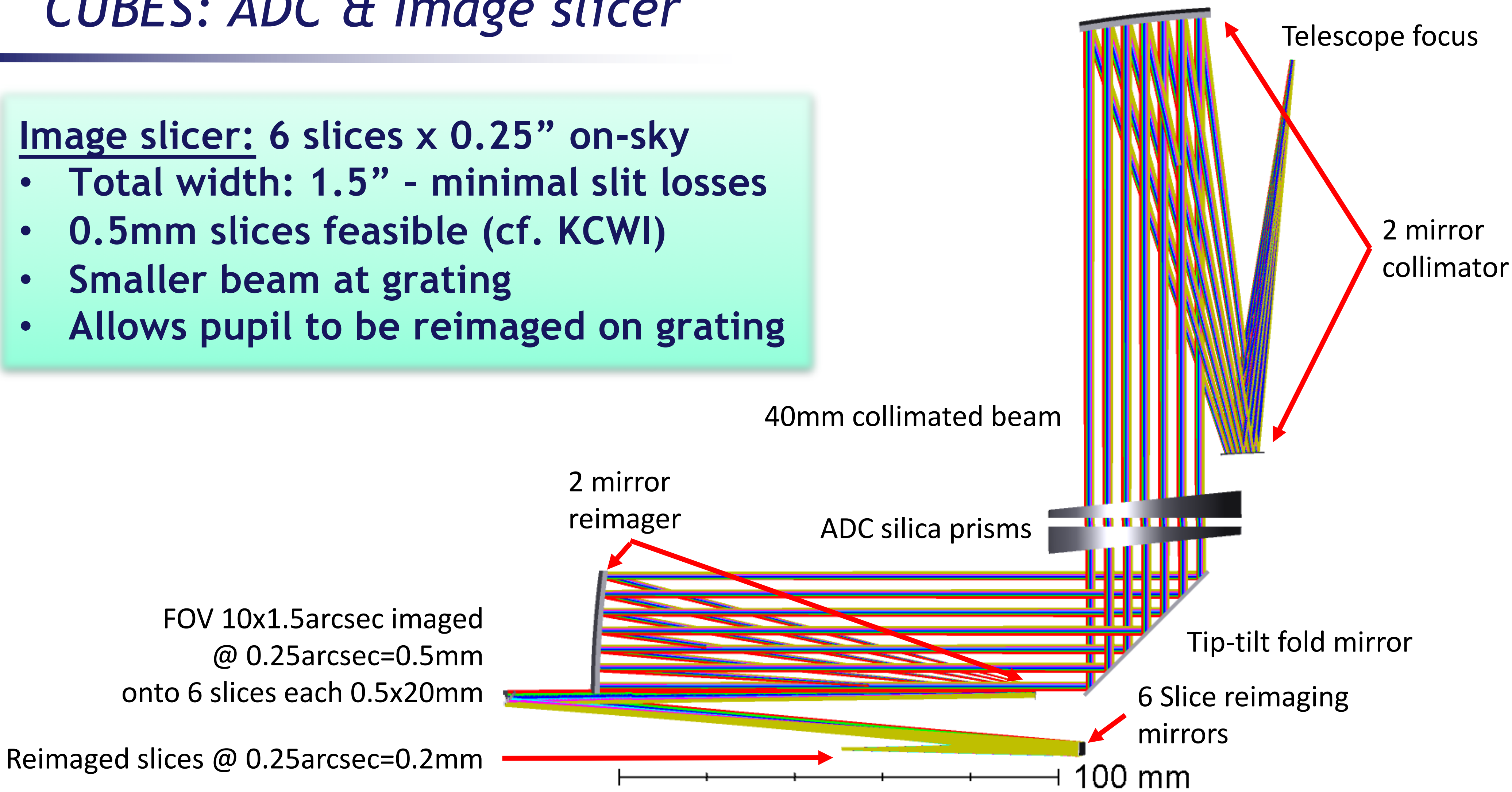
ADC: silica prisms
- Greater observational flexibility
- Minimal offset to slit viewing λ
- Deviation corrected via TT mirror



CUBES: ADC & Image slicer

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

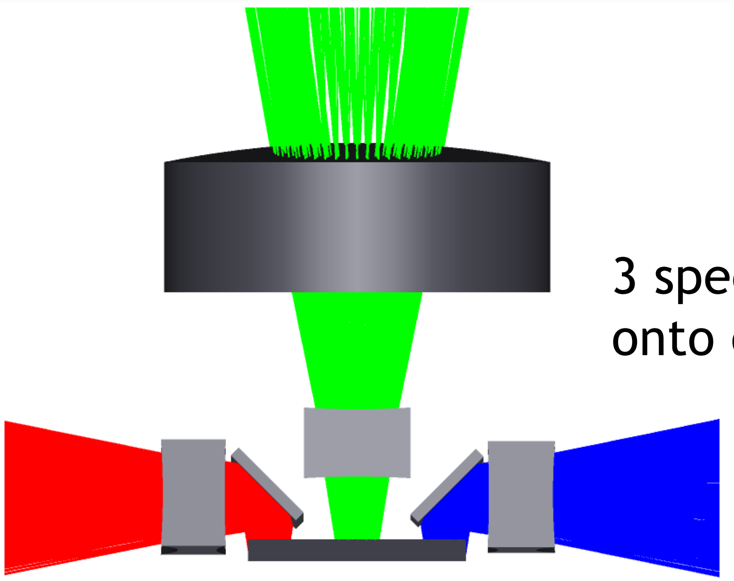
- **Total width: 1.5" - minimal slit losses**
- **0.5mm slices feasible (cf. KCWI)**
- **Smaller beam at grating**
- **Allows pupil to be reimaged on grating**



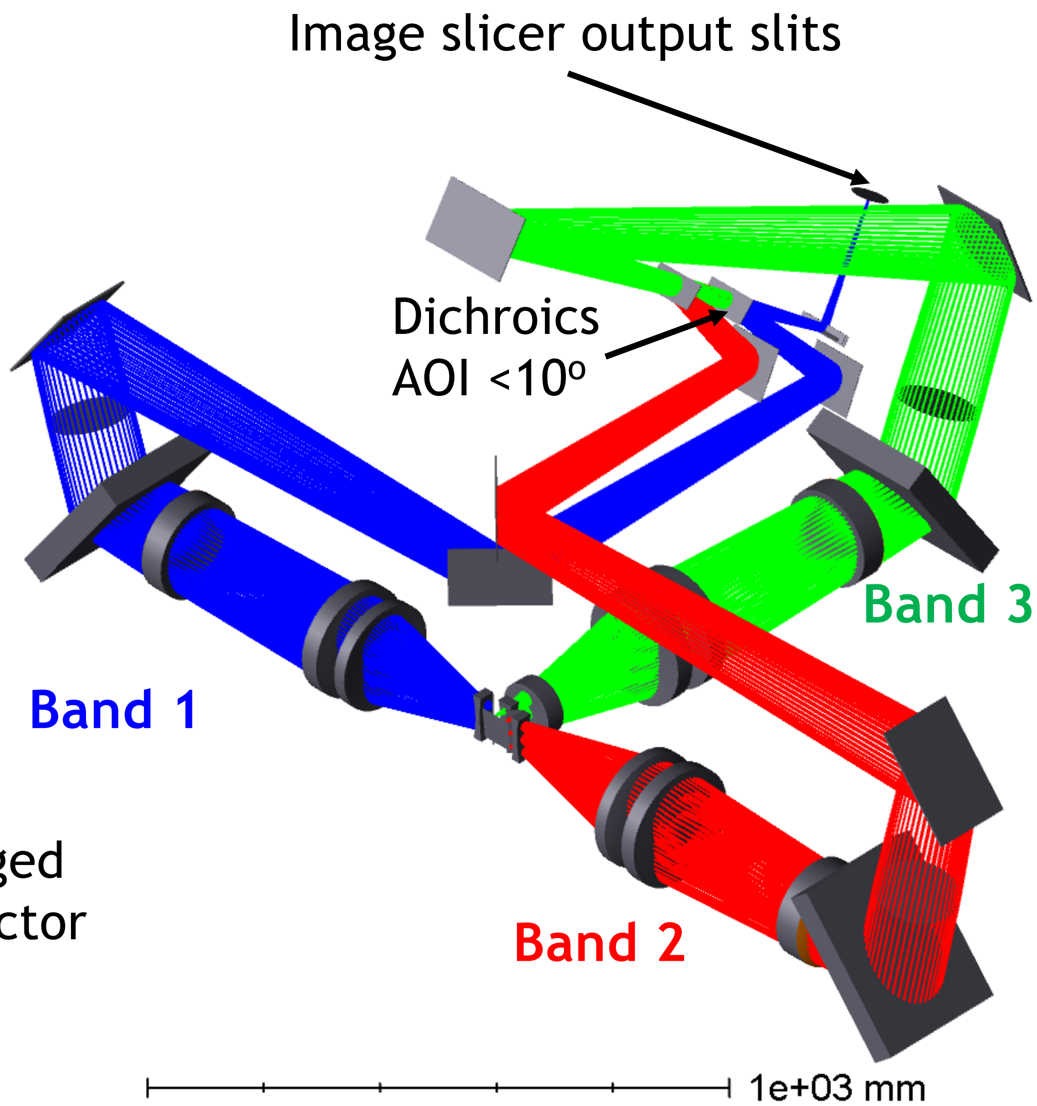
CUBES: Spectrometers

<u>Spectrograph:</u> 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 ≤ 0.6% (POG BBAR 280-450)

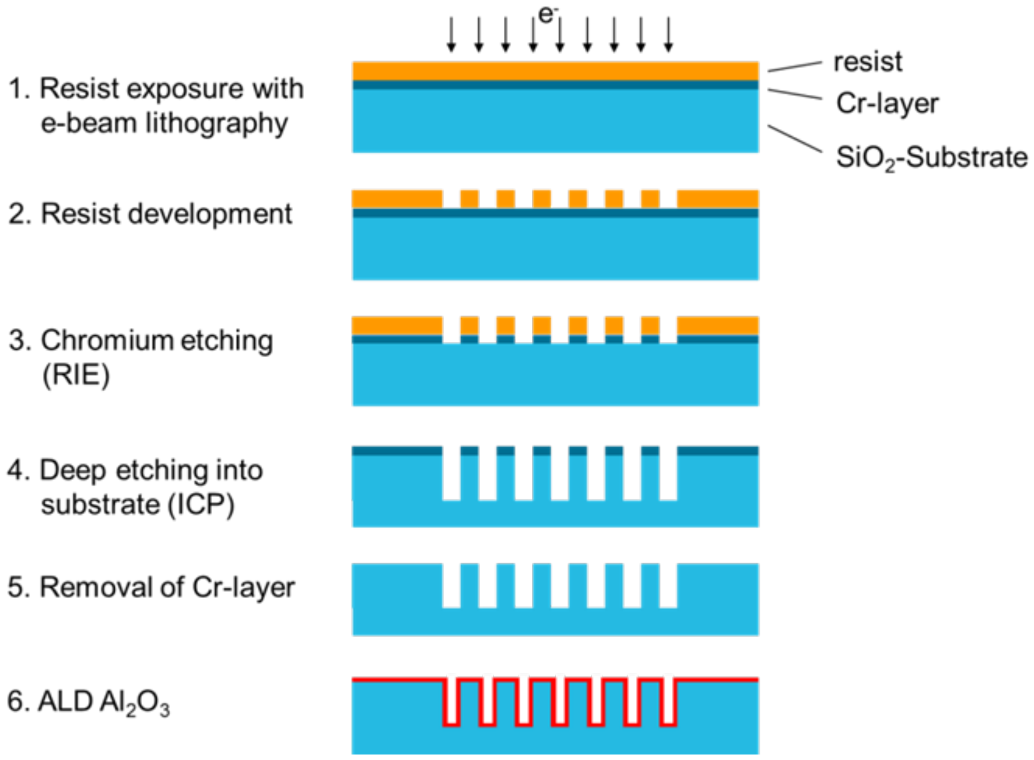
Mirror R ≥ 99% (Thorlabs standard coating)

Dichroics T ≥ 97%, R ≥ 97% (Based on measured dichroics)

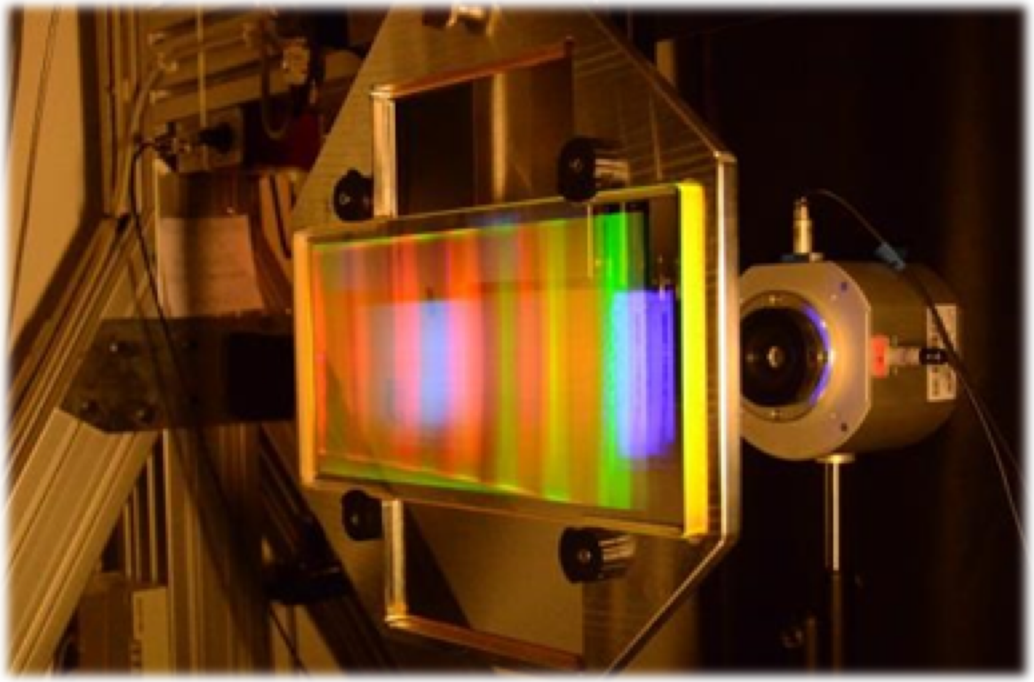
CUBES: Grating

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

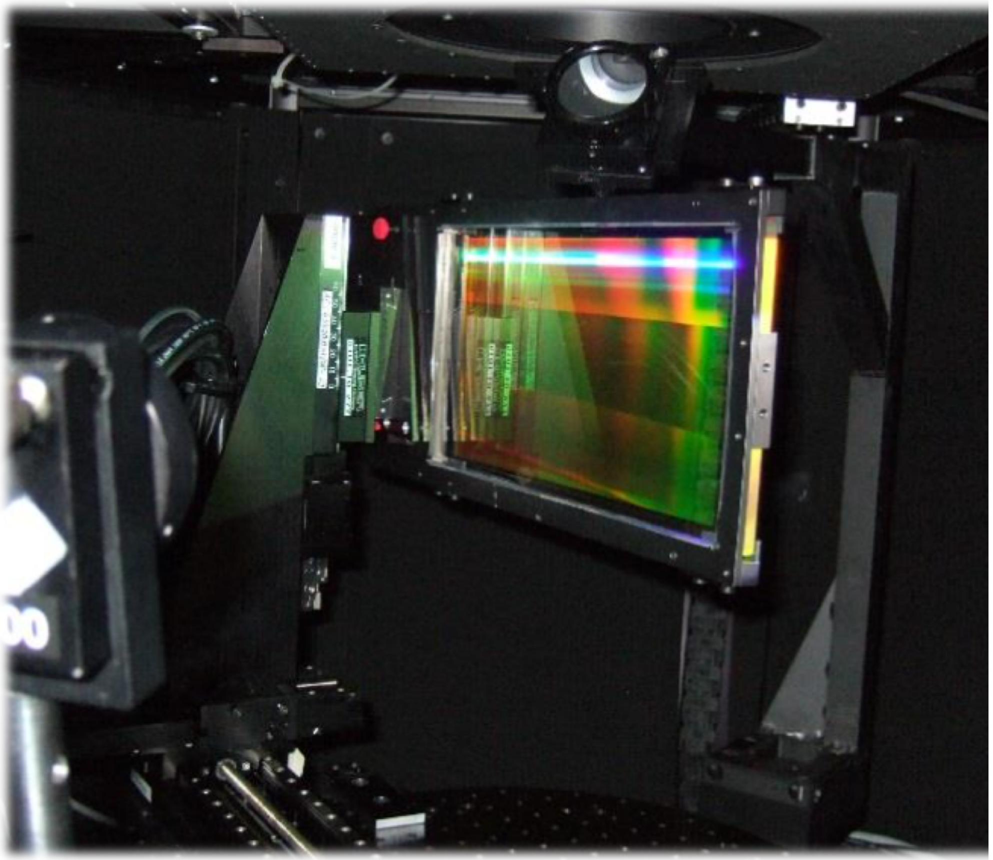
- Prototype manufactured by Fraunhofer IOF
- e-beam lithography & atomic layer deposition

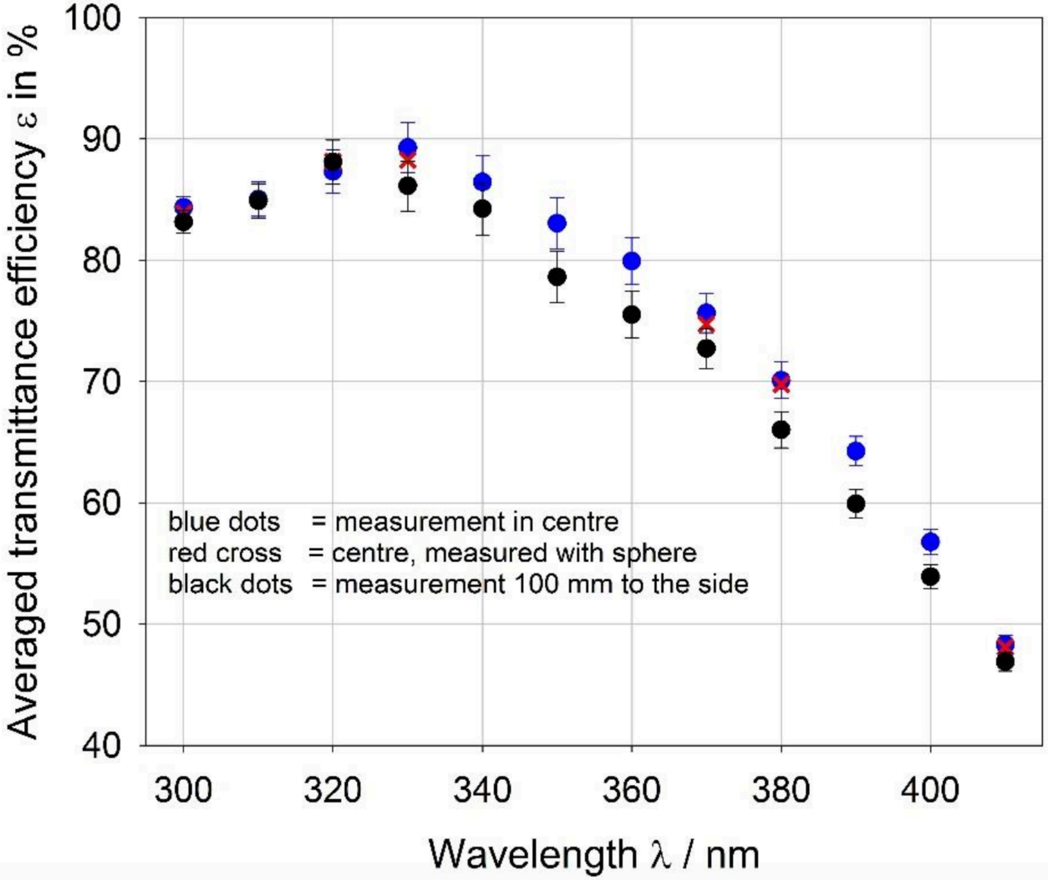


3448 lines/mm, 250 x 130 mm



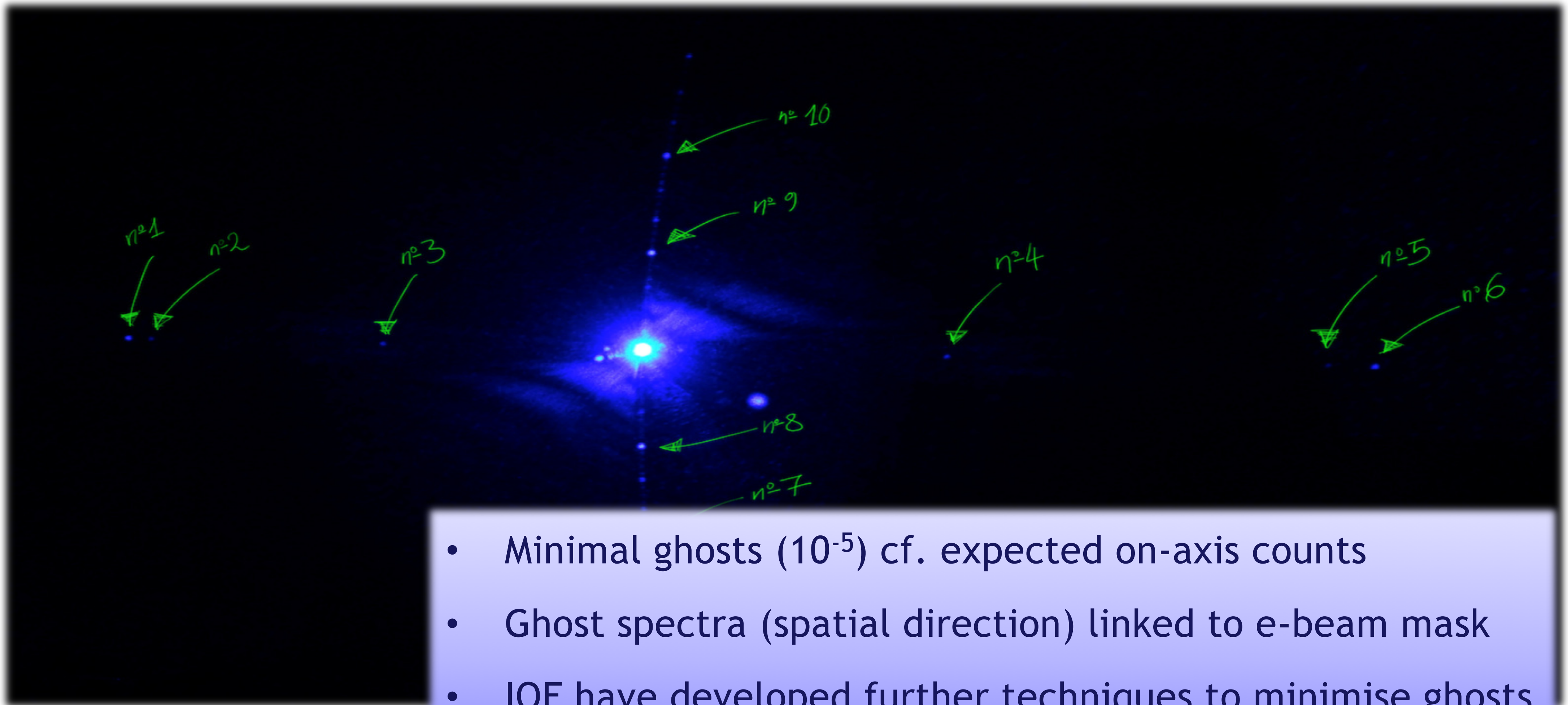
CUBES: Grating efficiency (PTB)





CUBES: Grating performance

From internal report by Alessio Zanutta & Andrea Bianco



- 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

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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