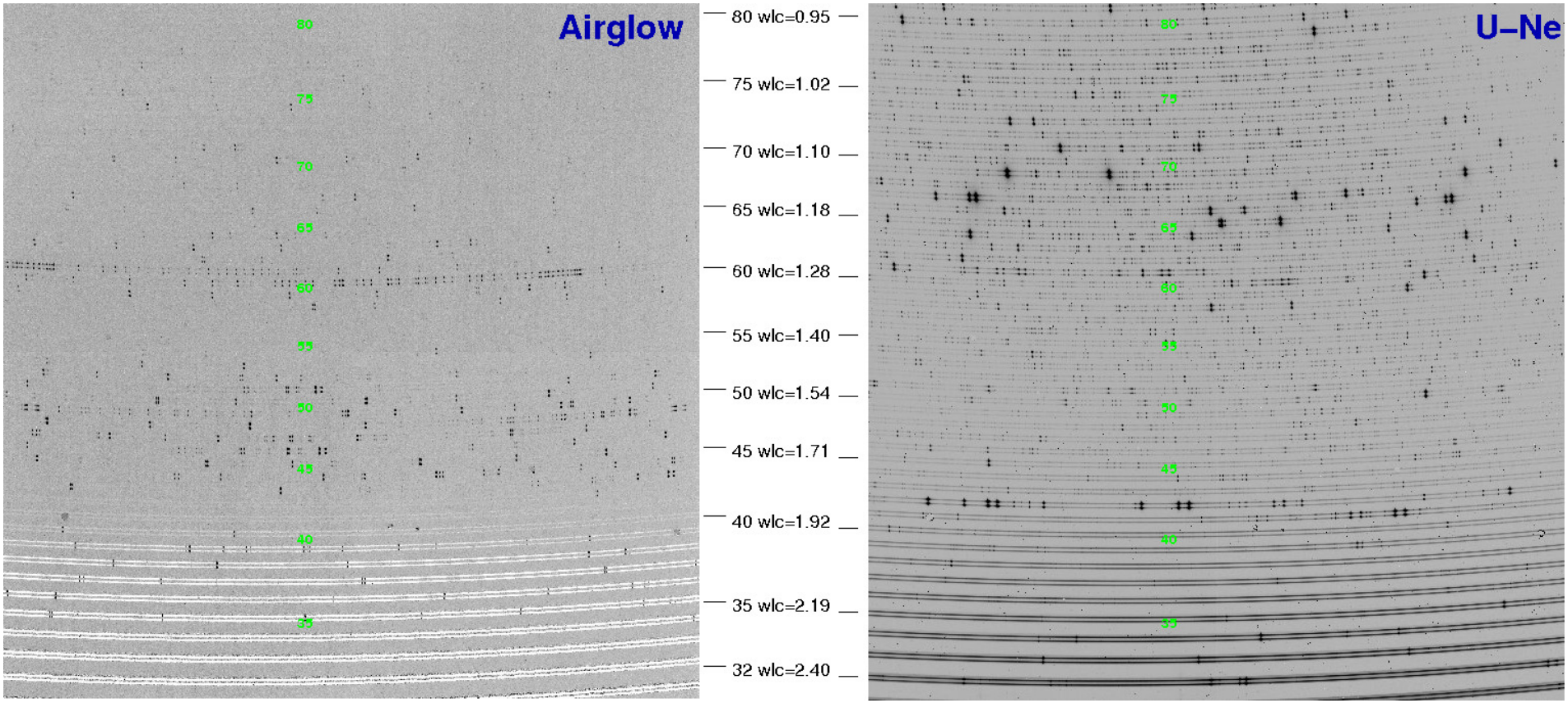
High resolution spectroscopy in astronomy

- "High" means $\Delta\lambda/\lambda \sim 10^{-5}$ i.e. a resolving power of ~3 km/s or ~3 GHz or ~0.01 nm
- Broad wavelength coverage in one exposure (…funny spectral format..)

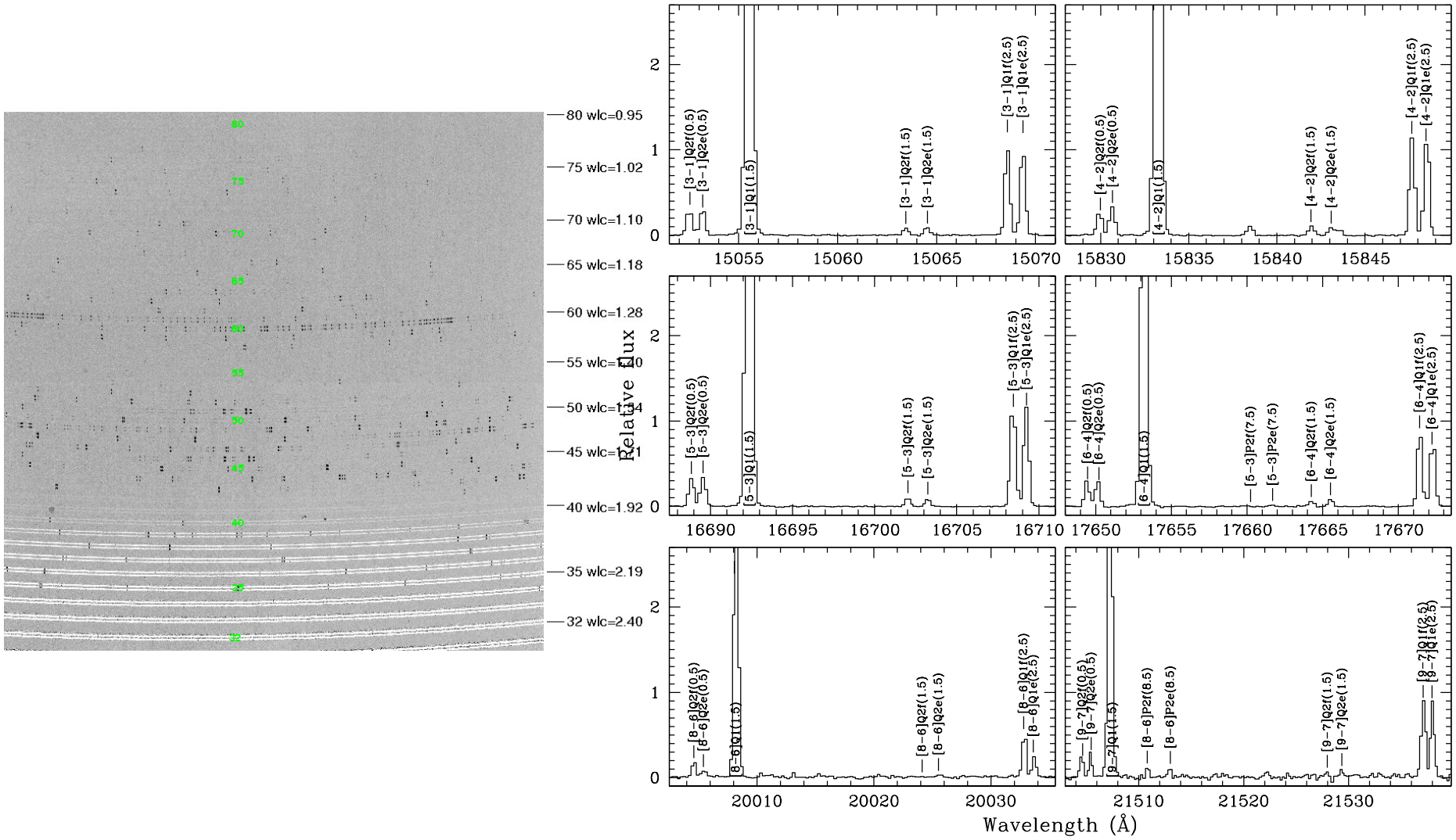
Typical/classical science cases

- Physics and chemics of star photospheres
- Physics and chemics of interstellar medium
- Kinematics (Doppler's shift)
- etc. etc.

HR spectral format: …like a book…



Airglow spectrum: OH, O_2 & physics of the mesosphere

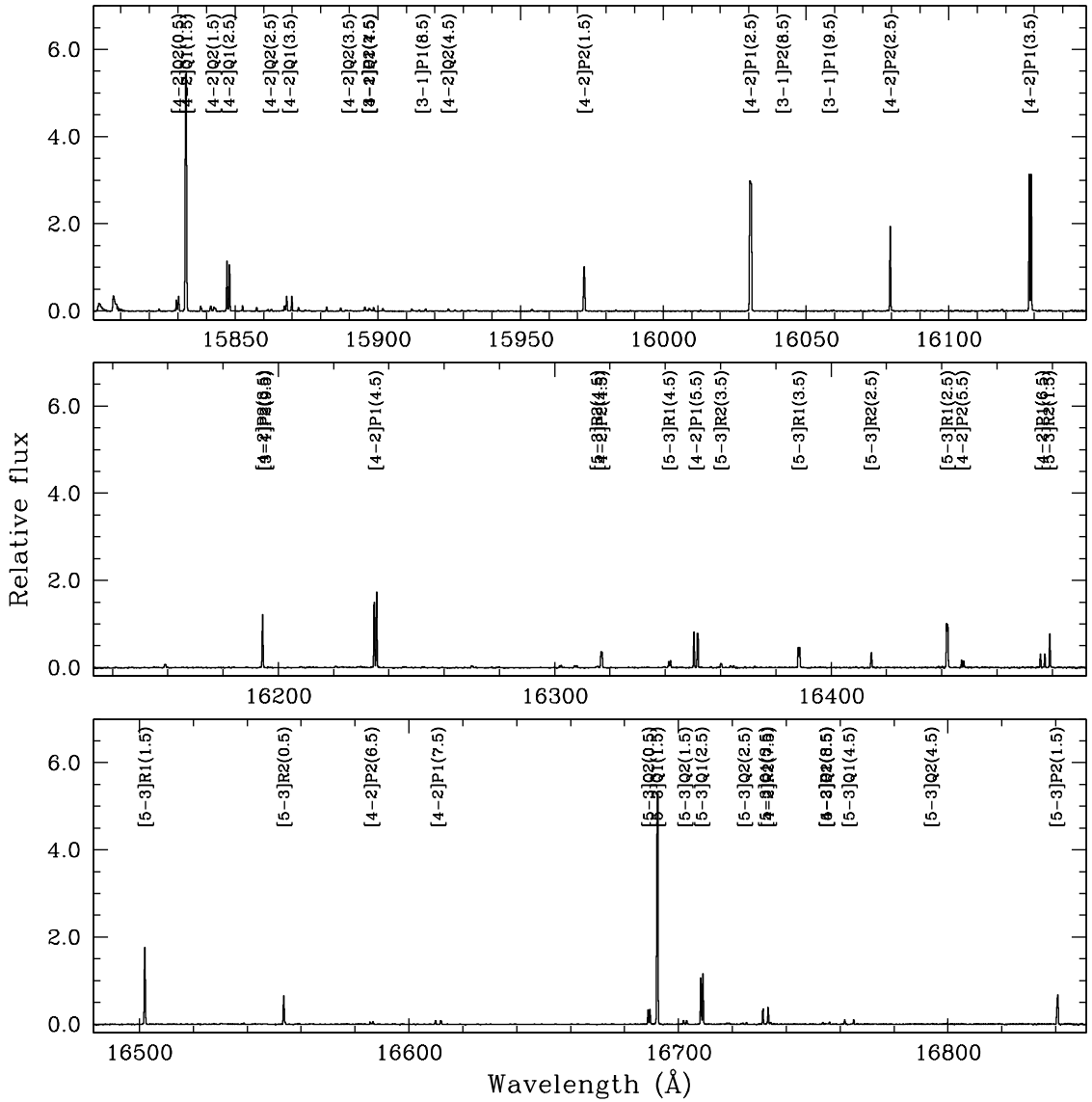


Cancelling the airglow spectrum: the dream of all astronomers

>99% of the emission in <1% of the spectral band.

A “super-notch” filter can improve by orders of magnitude the sensitivities of broad-band imaging and LR spectroscopy

May be we could develop this filter together…..



Pushing HR spectroscopy to its limits

Detection of extra-solar planets via Doppler's shift of the star around which the planet is orbiting.

Doppler signatures to detect in a solar type star

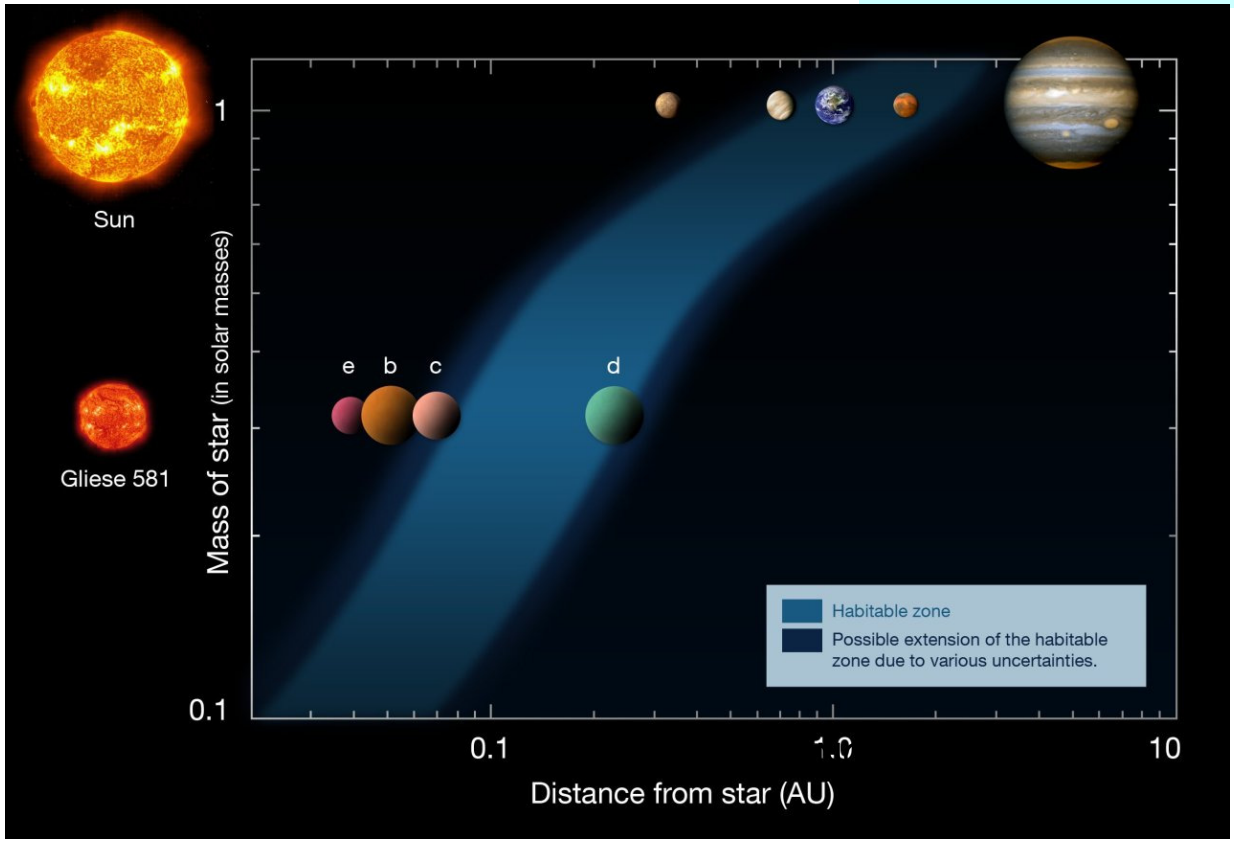
- Giant planet: few m/s (10^{-3} of resolution)
- Habitable Earth-like planet: few cm/s (10^{-4} of resolution)

→ Need very high s/n ratio and perfect control of the systematic errors which may affect the measurements

Ambitious science cases: habitable exo-Earths detected by Doppler-shift

$$v_{rad} \simeq 0.09 \left(\frac{M_*}{M_\odot}\right)^{-5/4} \left(\frac{M_{planet}}{M_{Earth}}\right) \quad \mathrm{m/s}$$

Easier on lowest mass stars

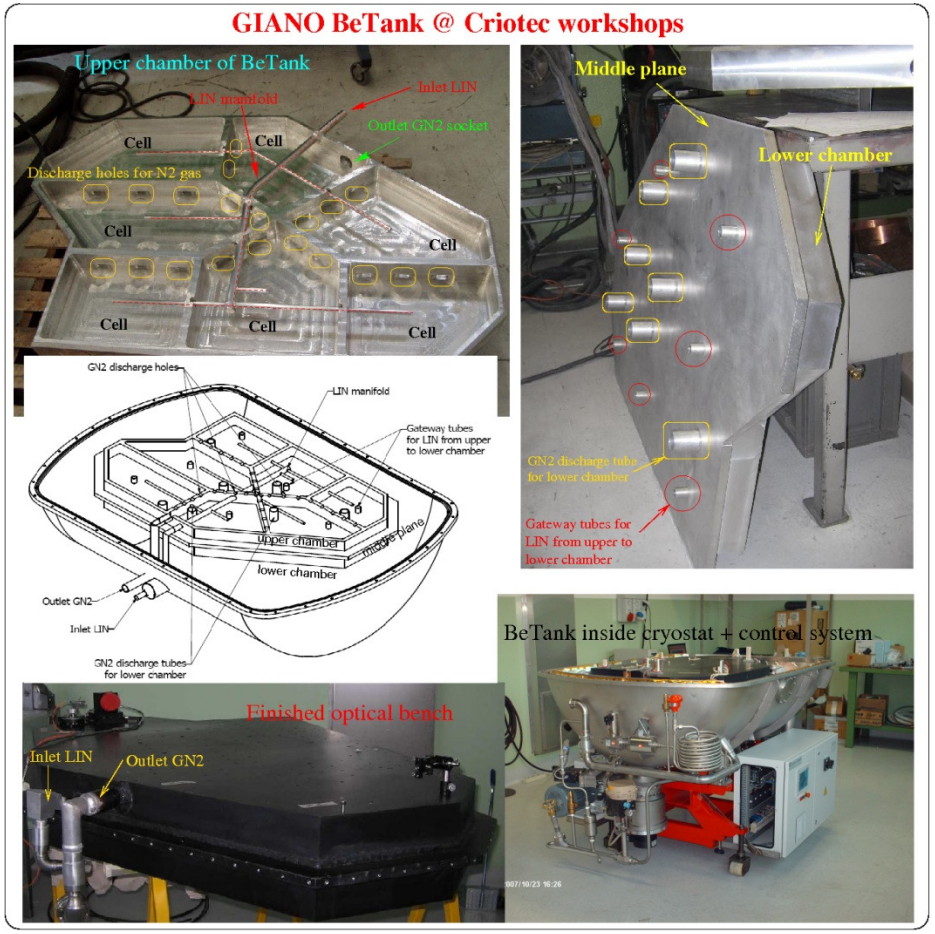


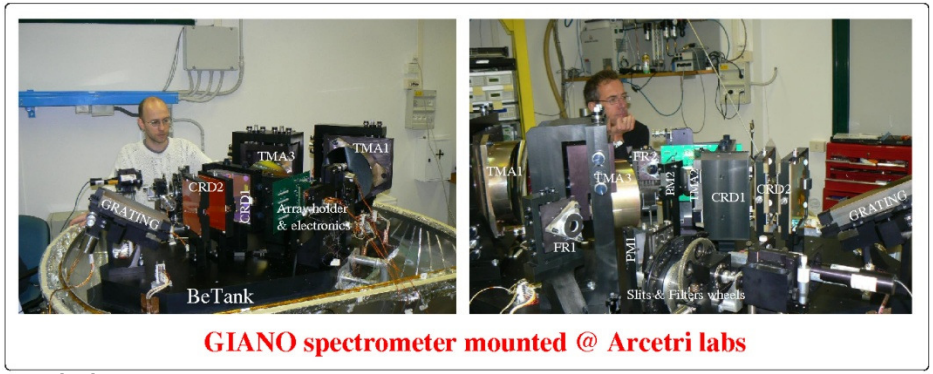
- **High resolution (R=50,000) near-IR (0.95-2.50 micron) spectrograph**

- **Selected by the INAF science council following a formal call for new instruments for the TNG**

- **Mostly developed in Arcetri**

Cryo-opto-mechanics



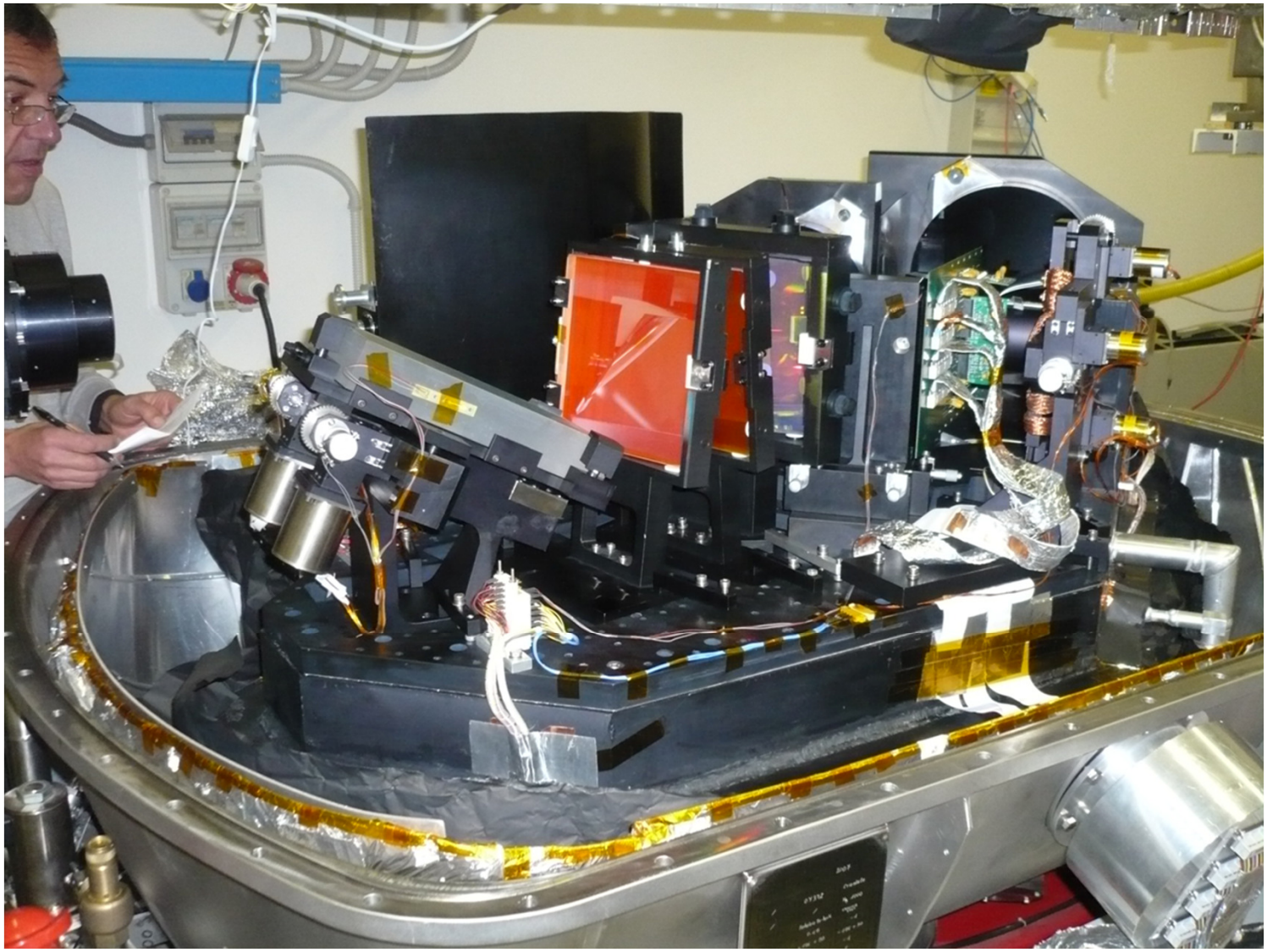


Precision optics

GIANO

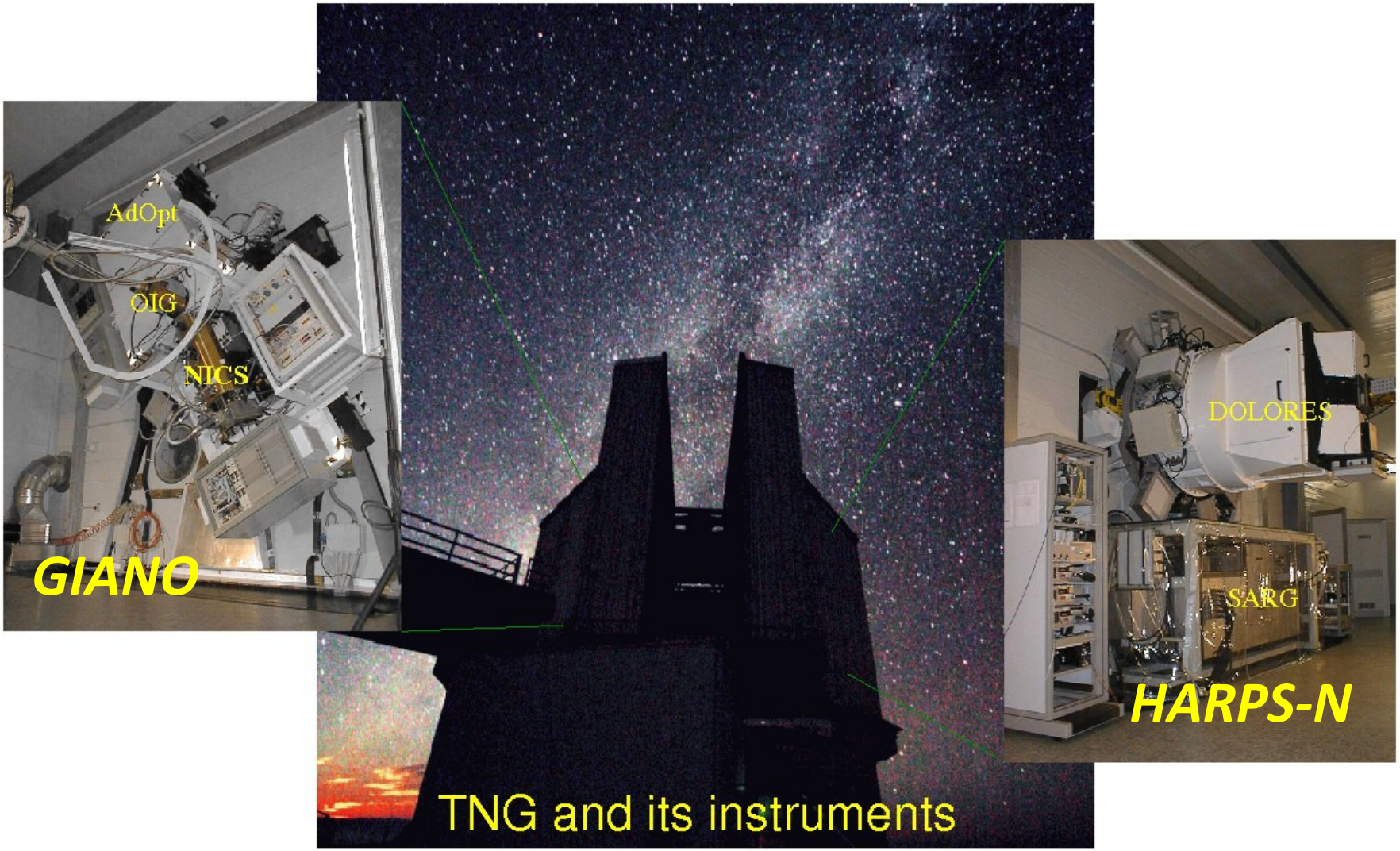
“Adaptive” mechanics

Opto-mech-cryo-elect. integration



… flying away from Arcetri…

… landing at the telescope in La Palma ….



… landing at the telescope in La Palma ….

Pushing HR spectroscopy to the photons-noise limit.

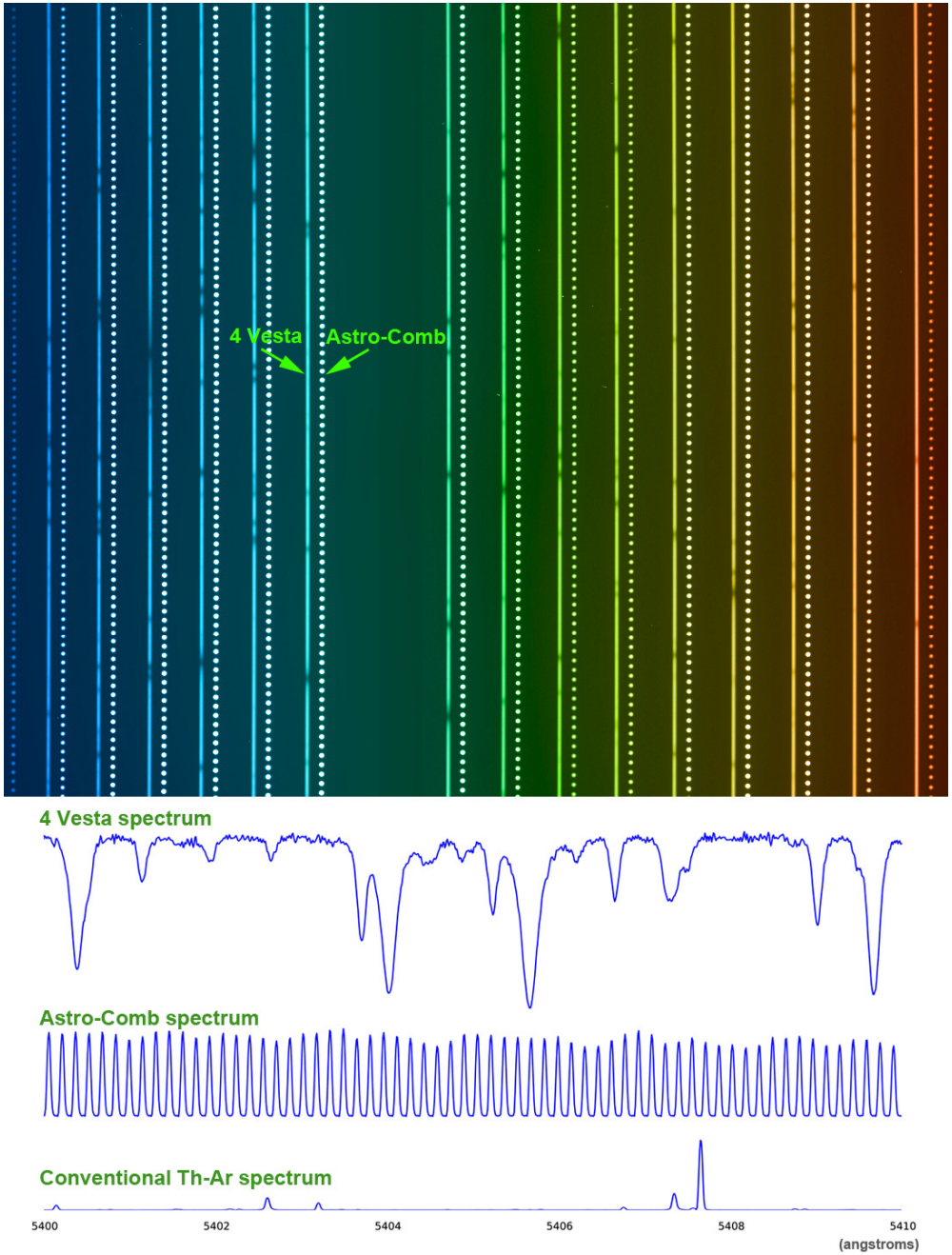
Measuring Doppler's shifts down to a few $x10^{-4}$ of resolving power

Need very high s/n ratio and perfect control of the systematic errors which may affect the measurements.

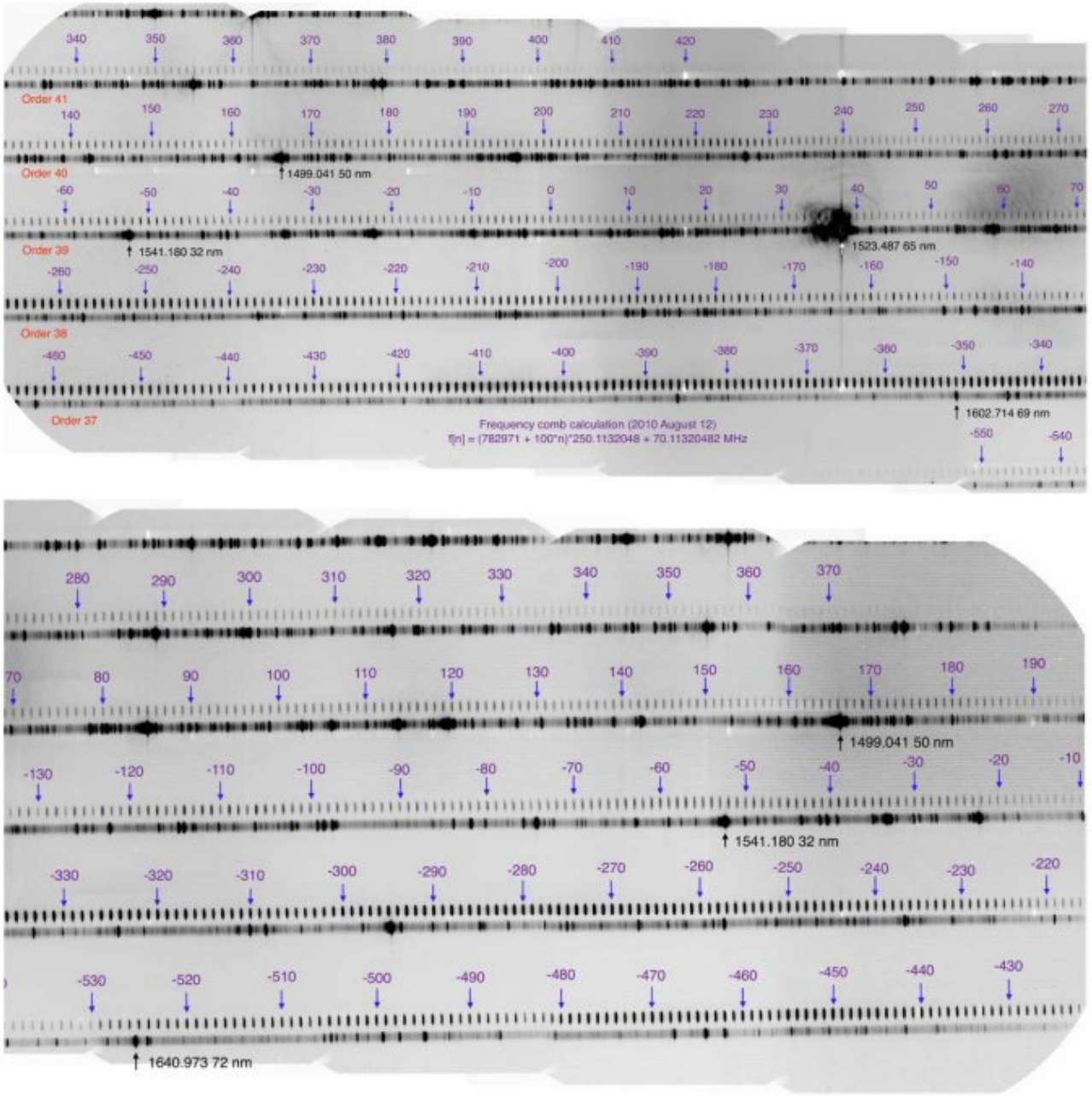
Ideal calibration source: uniformly spaced lines with similar intensities over the whole spectral range

→ Laser comb

First experiments with laser comb in astronomy

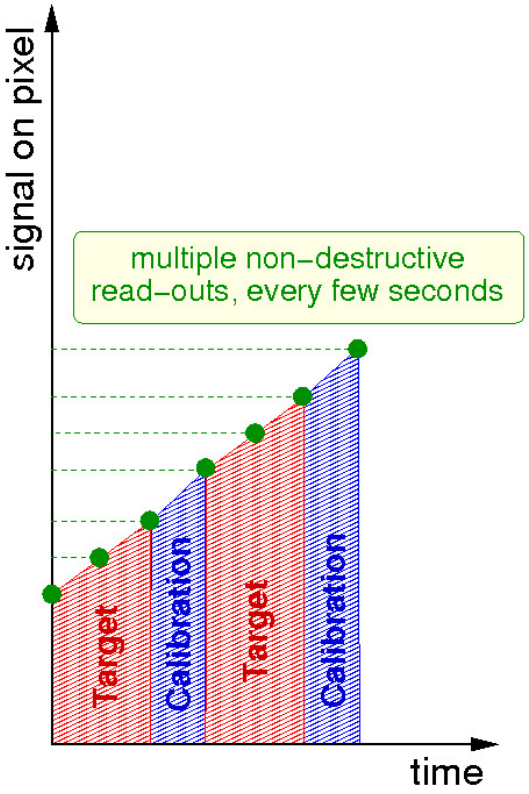


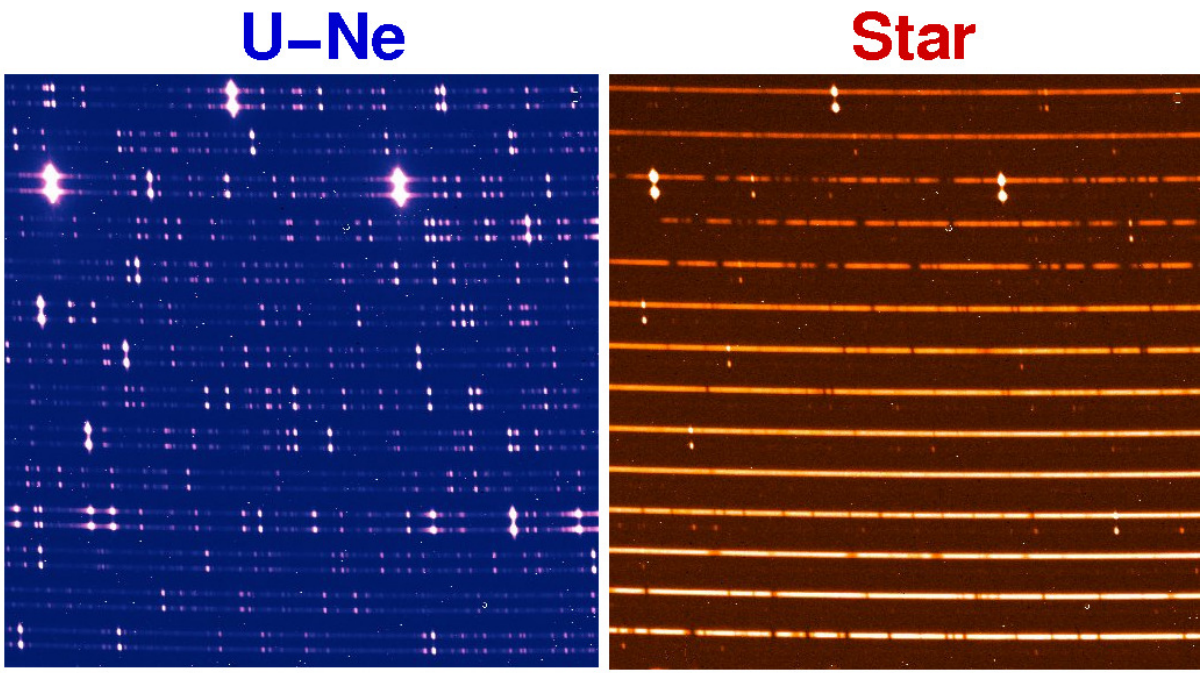
First experiments with laser comb in astronomy



Other strategies to optimize calibration

- "Wave on chip": (quasi) simultaneous calibration
- Possible with CMOS arrays



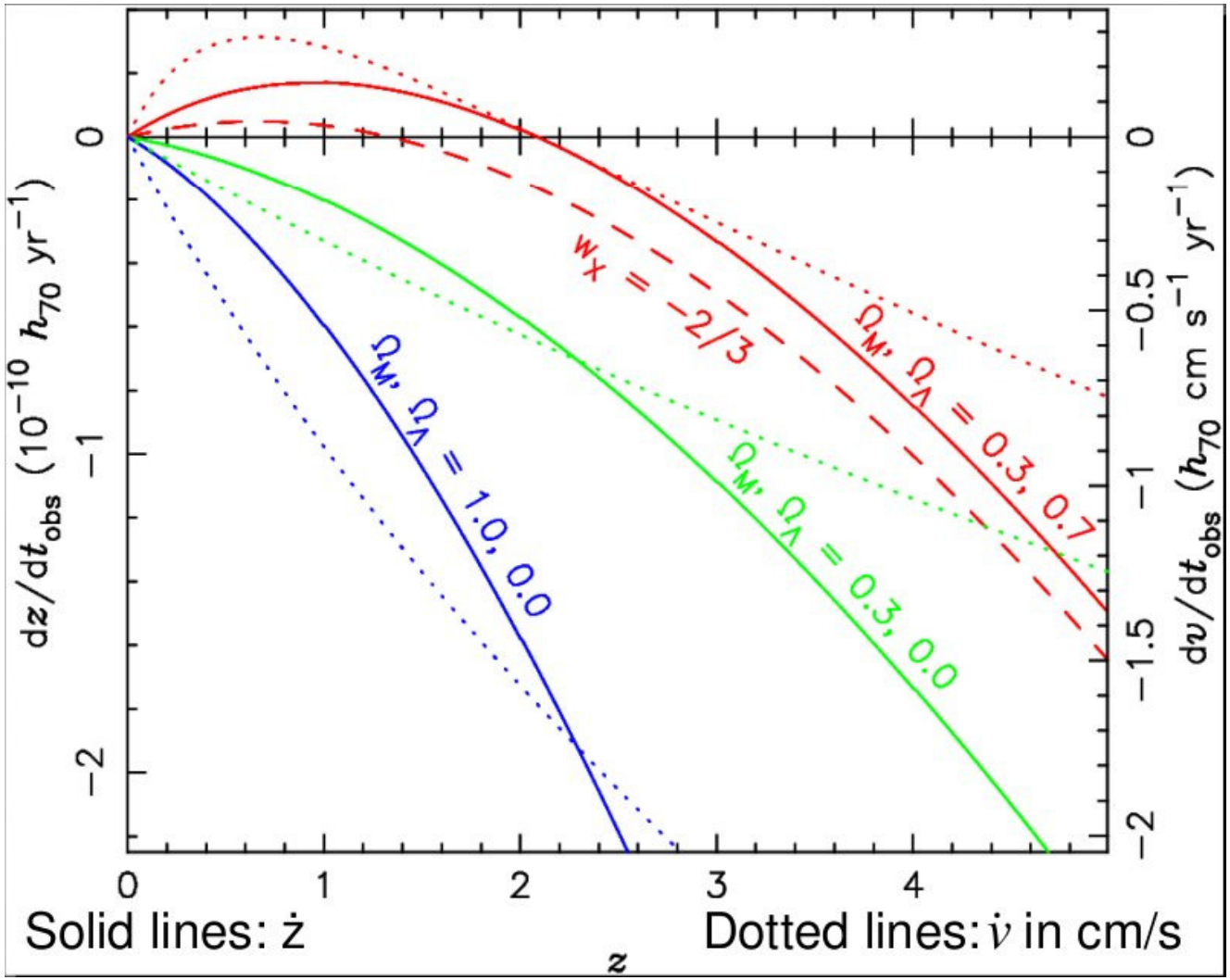


Reconstructed images (section of GIANO echellogram)

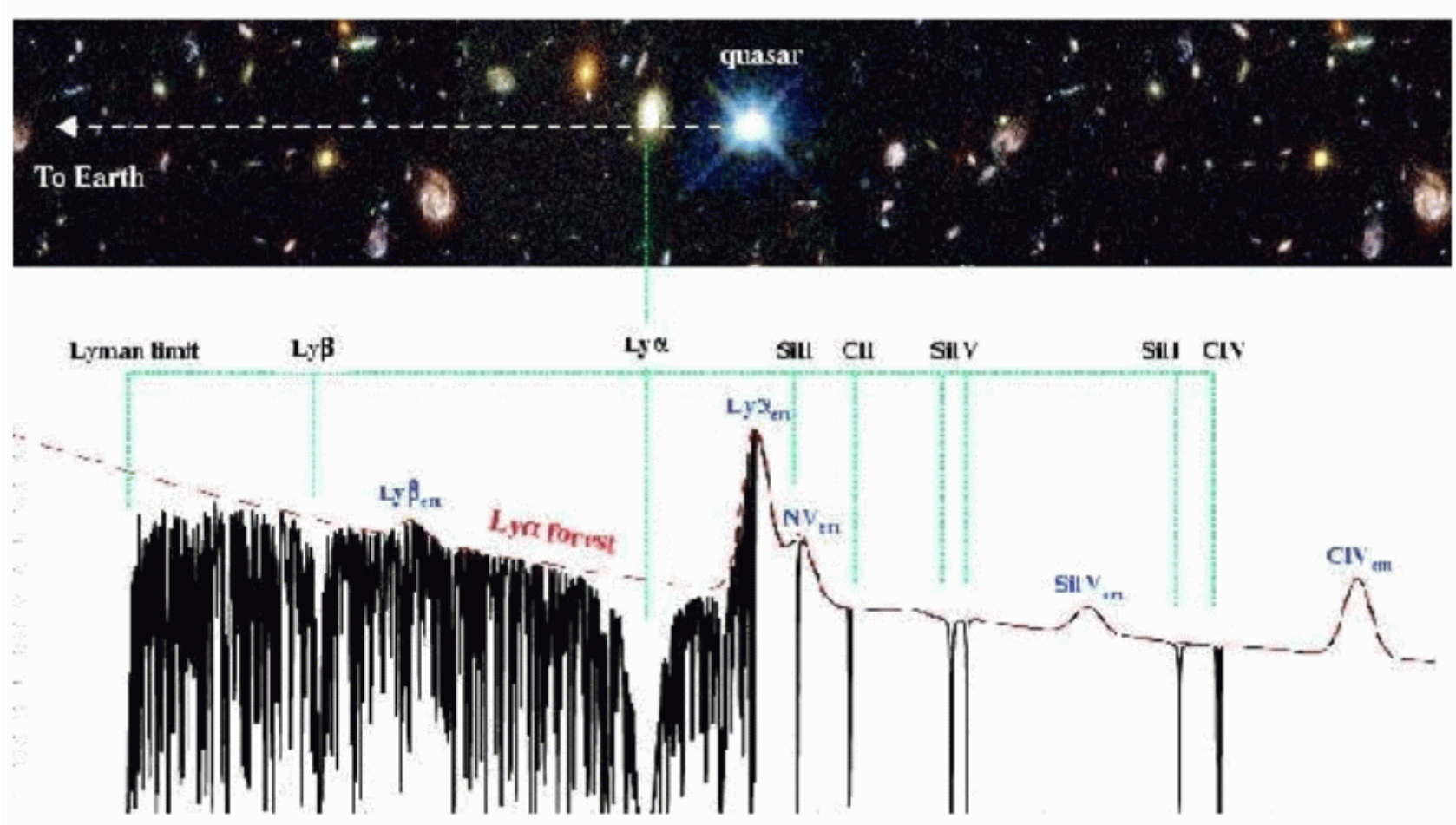
Pushing HR spectroscopy further, using more photons

Measuring the expansion of the Universe.

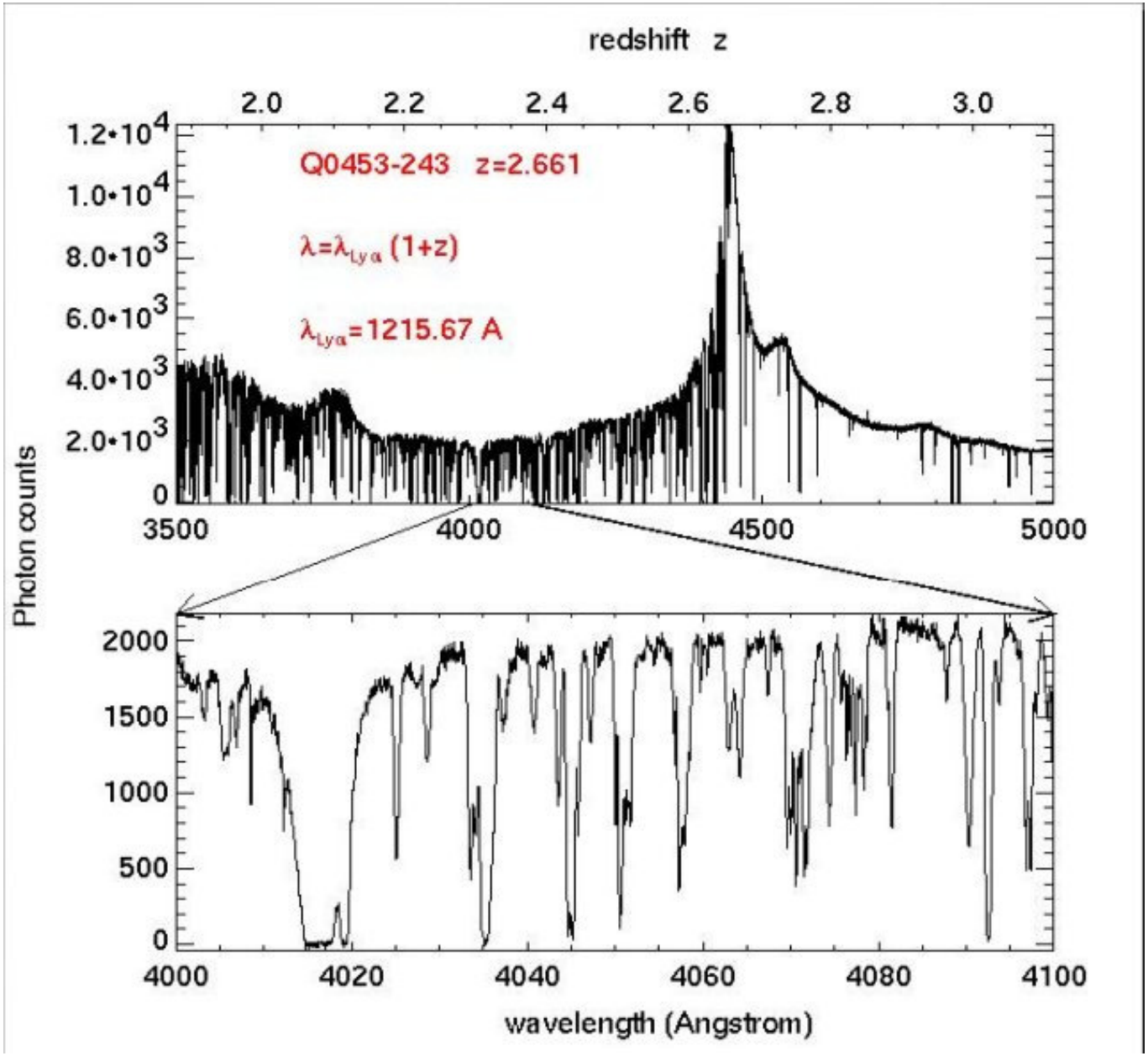
Cosmological variation of physical constants



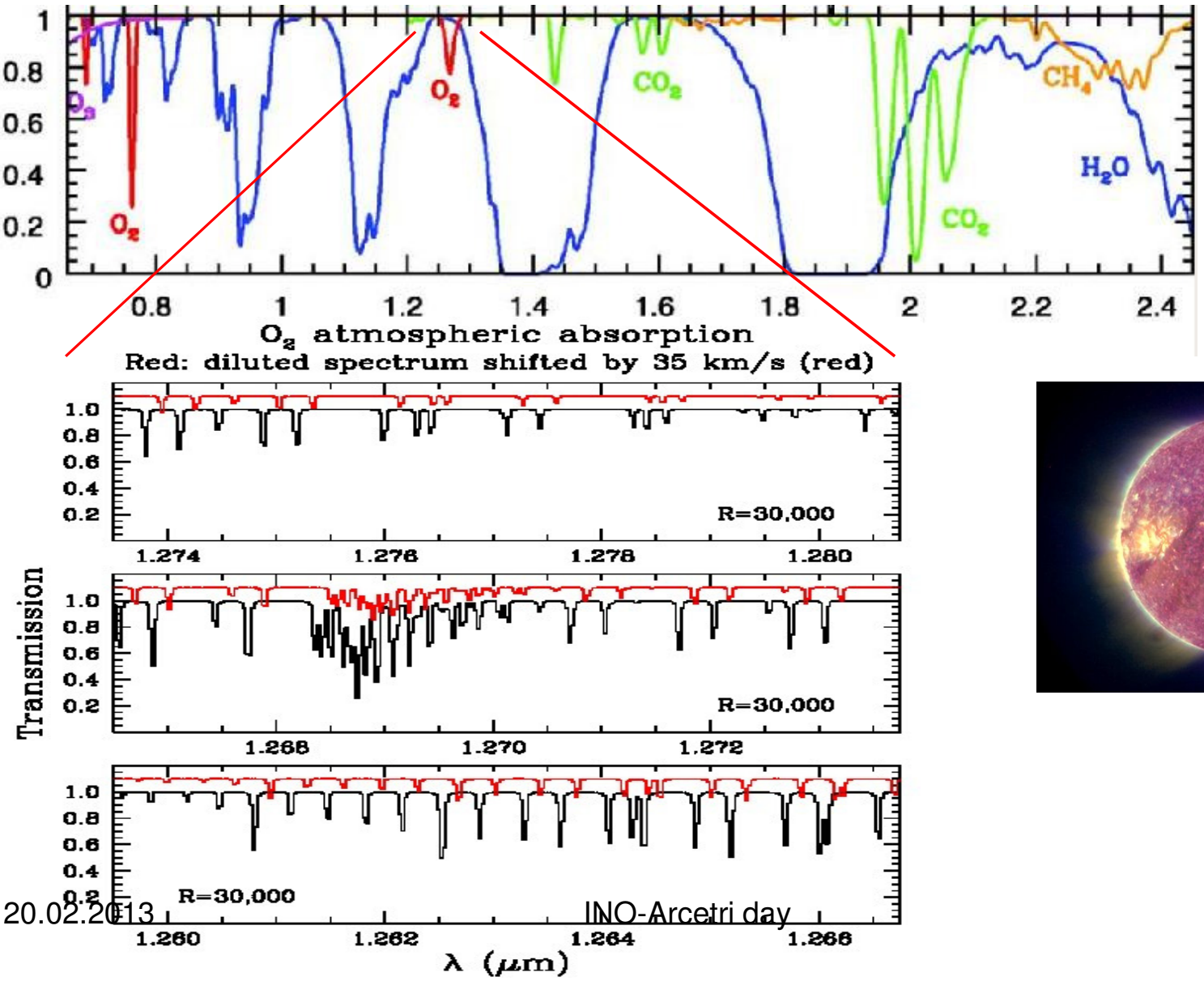
Pushing HR spectroscopy even further

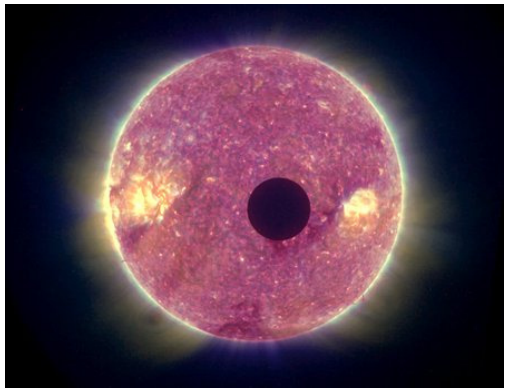


Spectra of inter-galactic gas clouds



Transmission spectra of extra-solar planets & life signatures





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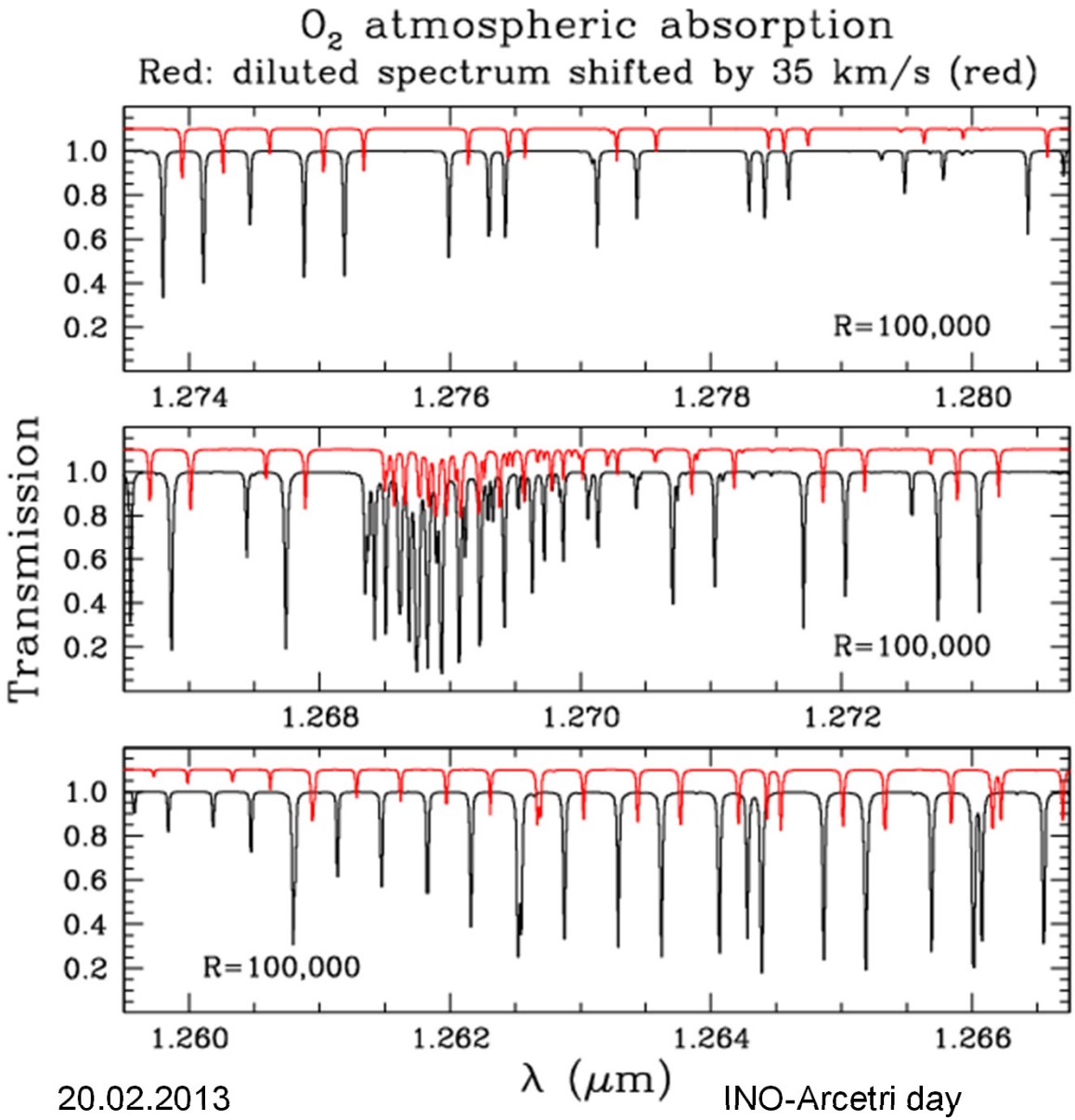

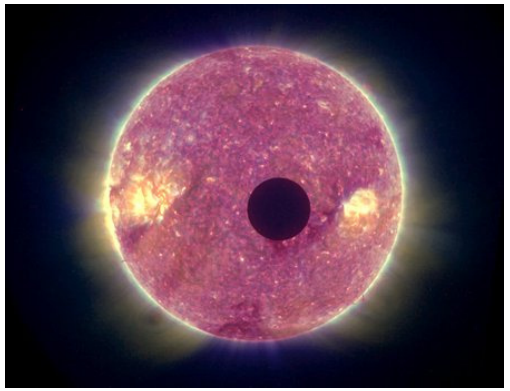

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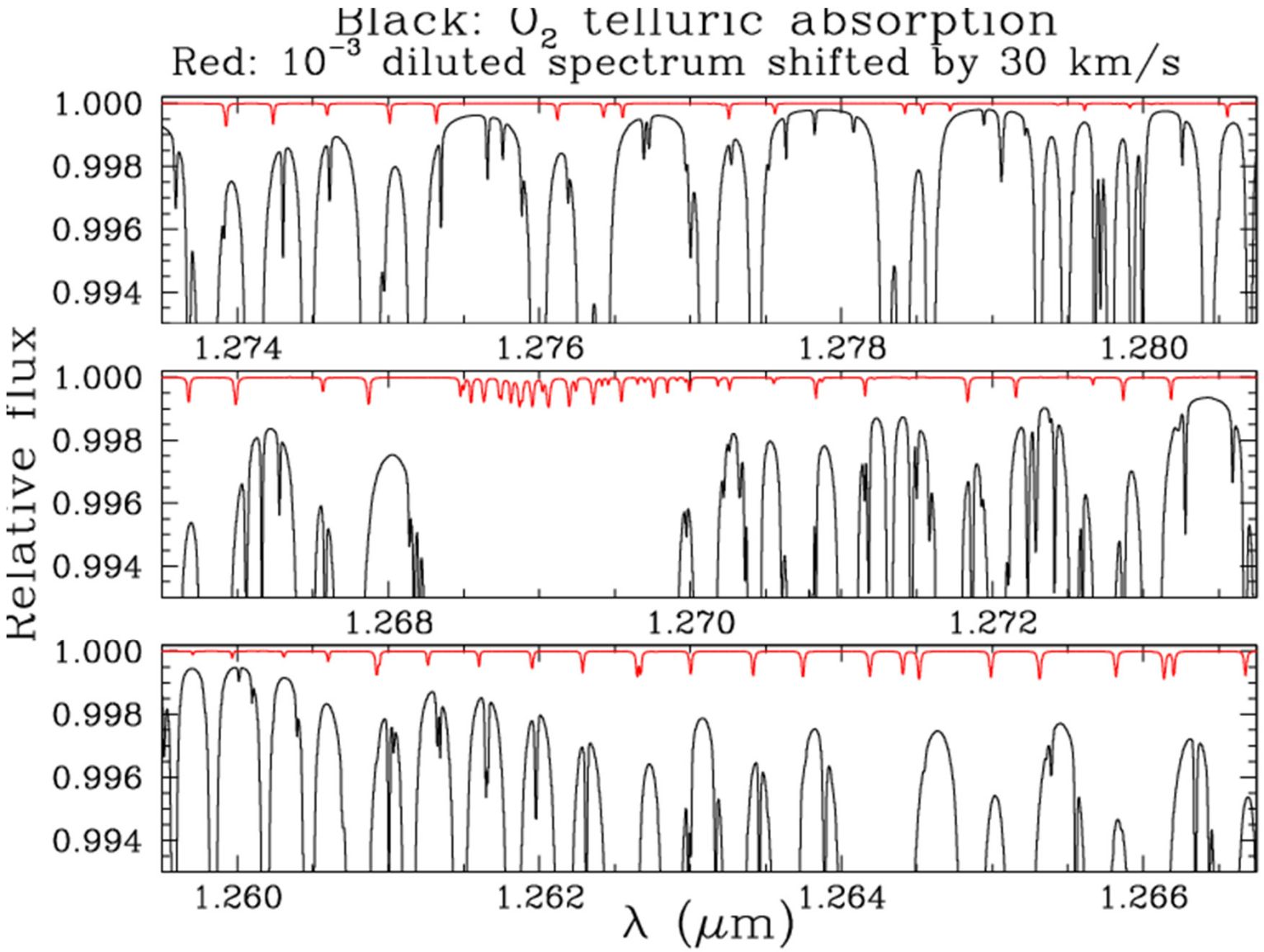
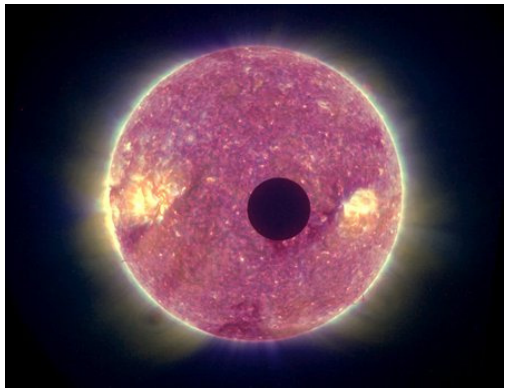


Transmission spectra of extra-solar planets & life signatures

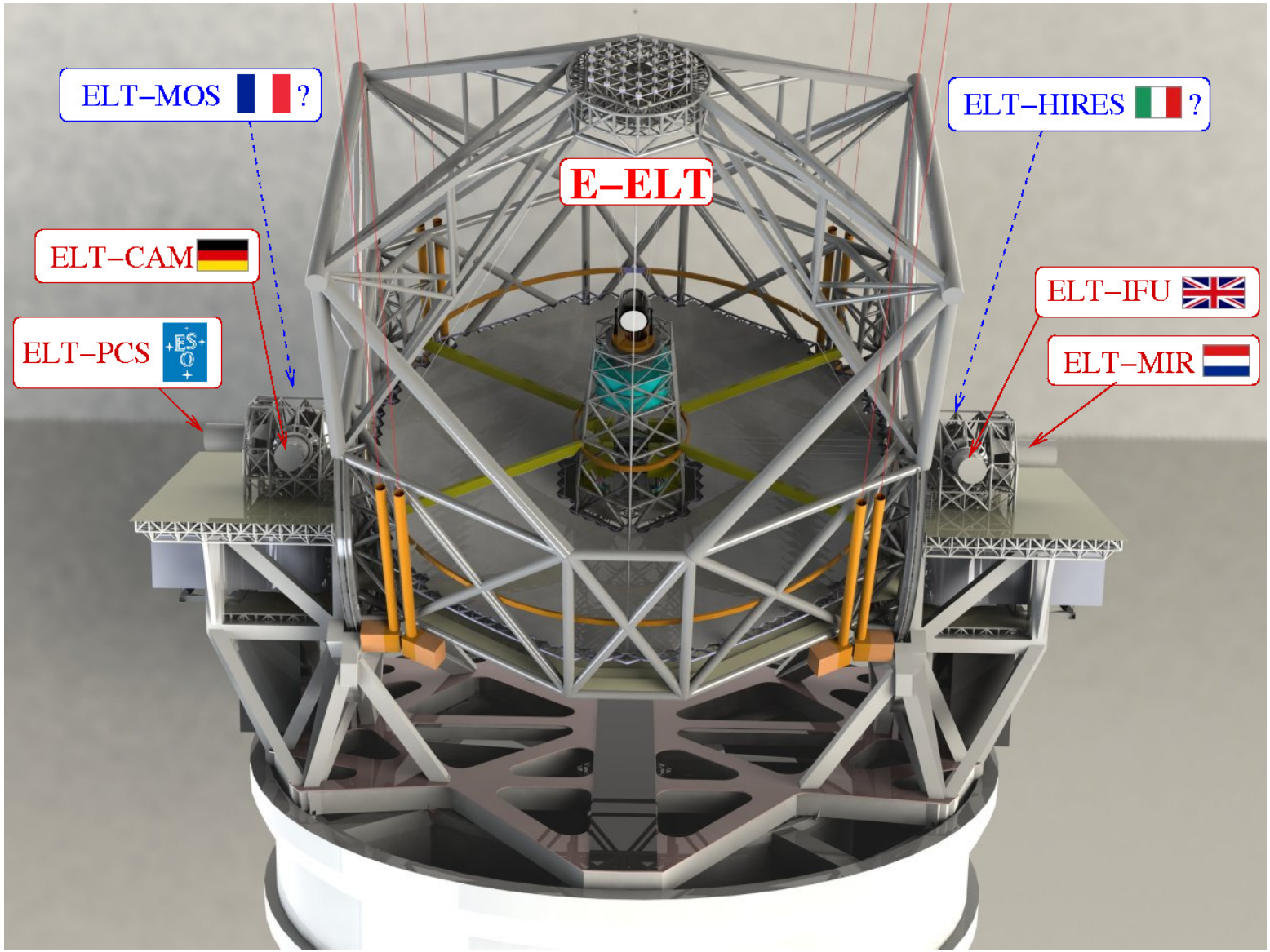
Need extremely high (up to 10^4) s/n ratio.

Fundamental tools:

- λ–calibration
- Perfect control of detector systematics
- Perfect control of spectral profile



E-ELT (~1G€) HIRES (~50M€)



From ELT-SIMPLE to ELT-HIRES

ELT-HIRES INSTRUMENT PARAMETERS	
Telescope	E-ELT (39m)
Wavelength	0.37μm-2.5μm Full spectrum in one shot
Resolutions	Medium = 15,000 High = 100,000
Entrance aperture	0.7”-1” (seeing limited) Also AO-fed HR^2 mode