

*Precise modeling of atmospheric features
in high resolution astronomical spectra*

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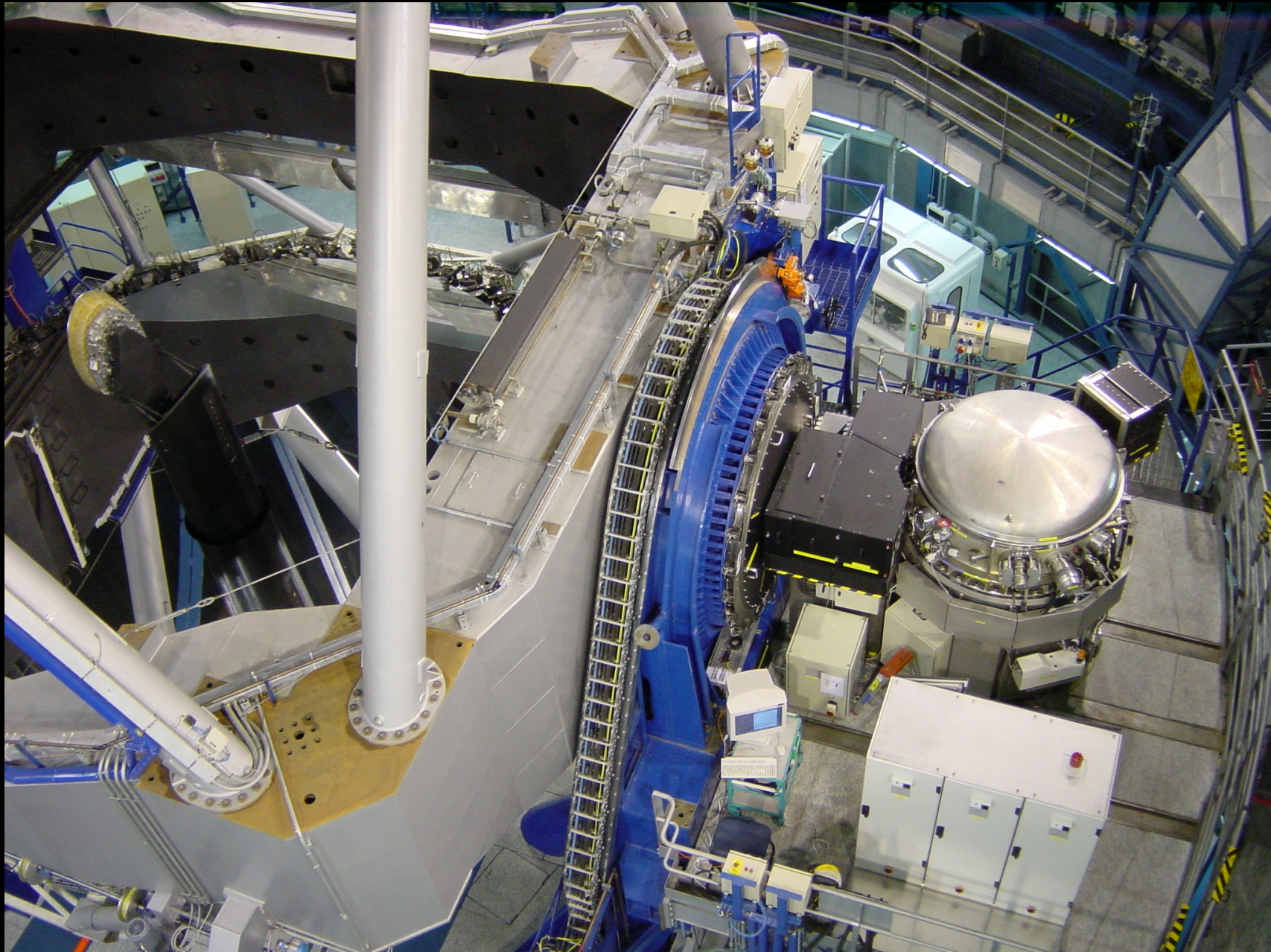
Collaborators:

Hans-Ulrich Käufl (ESO, Garching)

Günther Zaengl (LMU, München)

Jacob L. Bean (Göttingen)

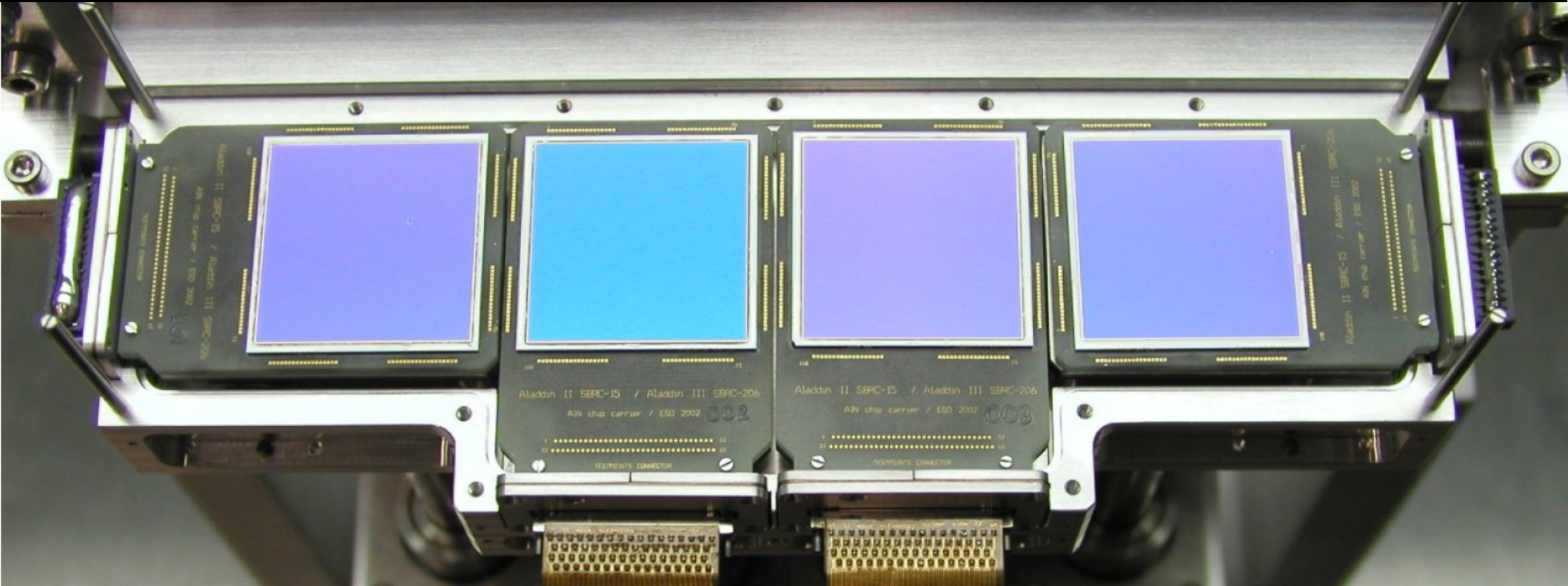
CRIRES at the VLT



CRIFES - main characteristics

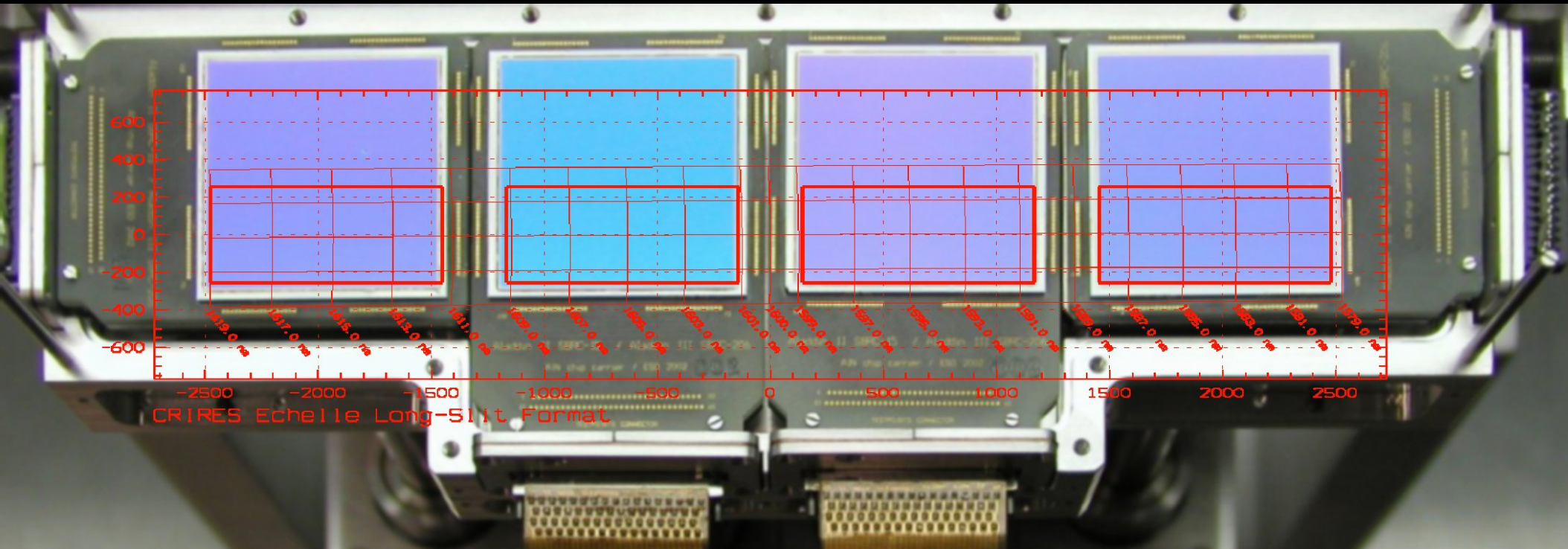
- **Wavelength coverage:** $\sim 0.95 - 5.2\mu\text{m}$
Instantaneous λ - coverage $> 2.0\%$
Pixel scale $0.1''/\text{pix}$
- **Spectral resolution:** $\lambda/\Delta\lambda \approx 10^5$ or $v/\Delta v \approx 3\text{km/s}$
for a $0.2''$ slit (2 pixel Nyquist sampling)

Spectrograph focal plane



- 4 Aladdin III (InSB) arrays
- inter-chip gap reduced to ~ 290 pixel

Spectrograph focal plane



▲ spectral format mapped on detector assembly mosaic

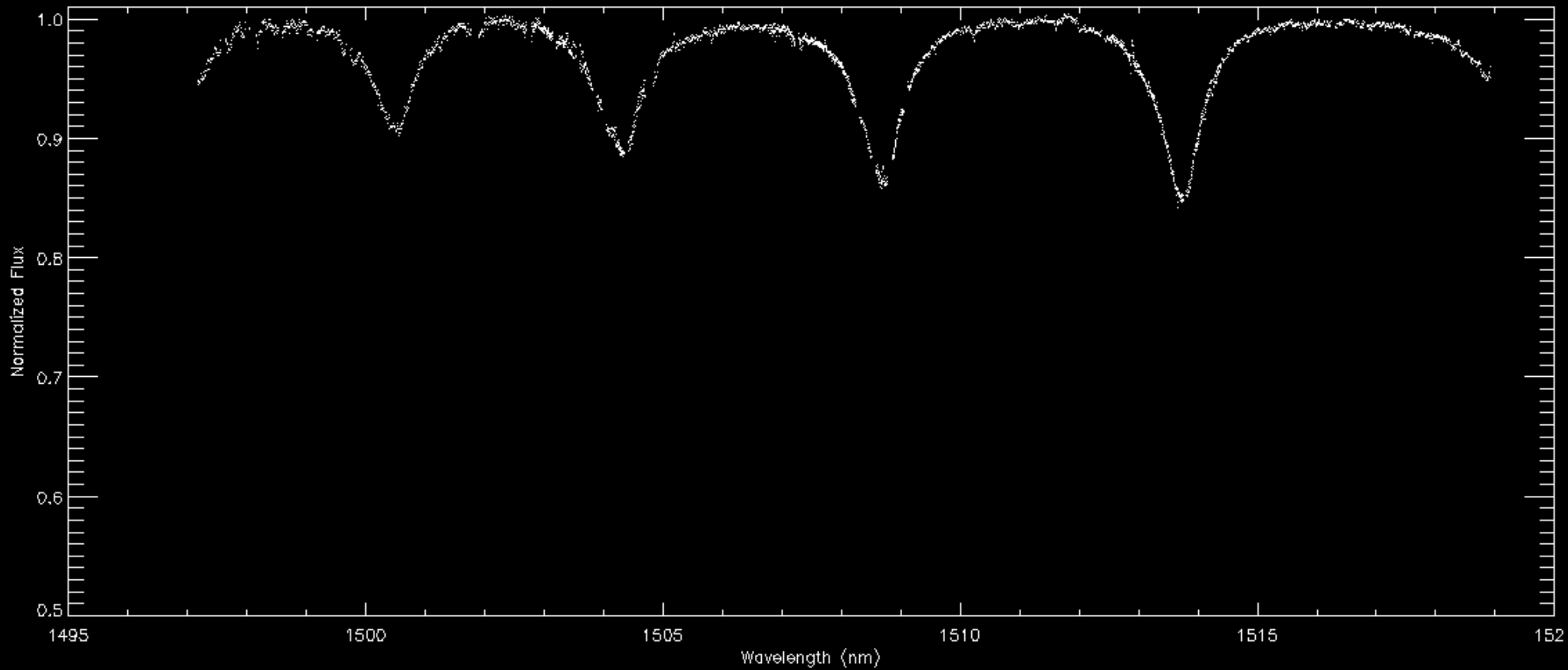
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for a $0.2''$ slit (2 pixel Nyquist sampling)
- **Infrared slit viewer** (Aladdin III) with J,H & K-filters
- **Precision** for calibration and stability $\sim 75\text{m/s}$
i.e. $1/20^{\text{th}}$ of a pixel or 5mas tracking error

CRIFES - main characteristics

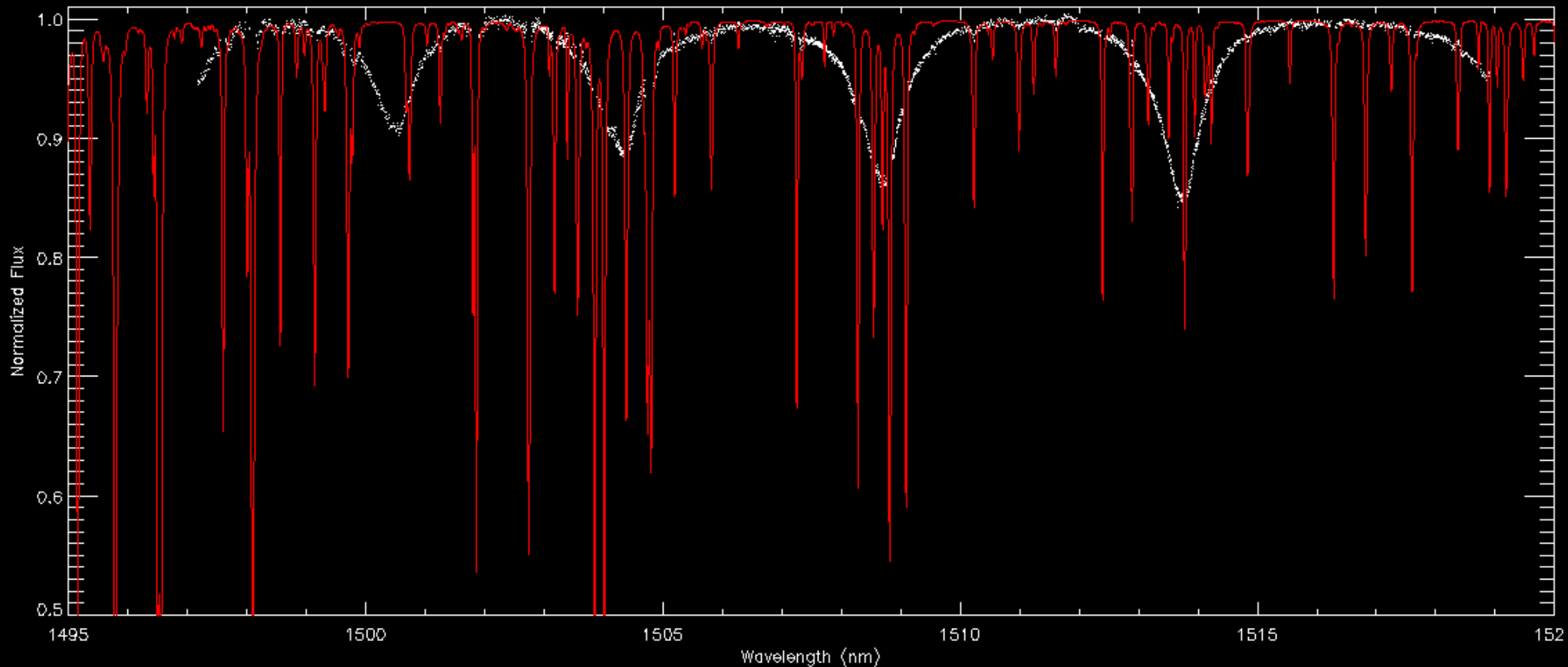
- Preference in design was given to **stability**
 - ☞ gas cells for high precision radial velocity work
- Curvature sensing **Adaptive Optics**
 - ☞ 0.2" spatial resolution for 40" slit (at 0.1"/pix sampling)
- **Spectro-polarimetry in lines** (magnetic fields)
 - goal to measure all 4 Stokes parameter
 - $\lambda/4$ Fresnel rhomb and $\lambda/2$ plate
in rotary mounts at the gas-cell slide
 - cold kinematic MgF_2 Wollaston prism in fore-optics

CRIFES: observational challenges



BA supergiants (PI N. Przykilla)

CRIFES: observational challenges



BA supergiants (PI N. Przybilla)

Atmospheric Absorption

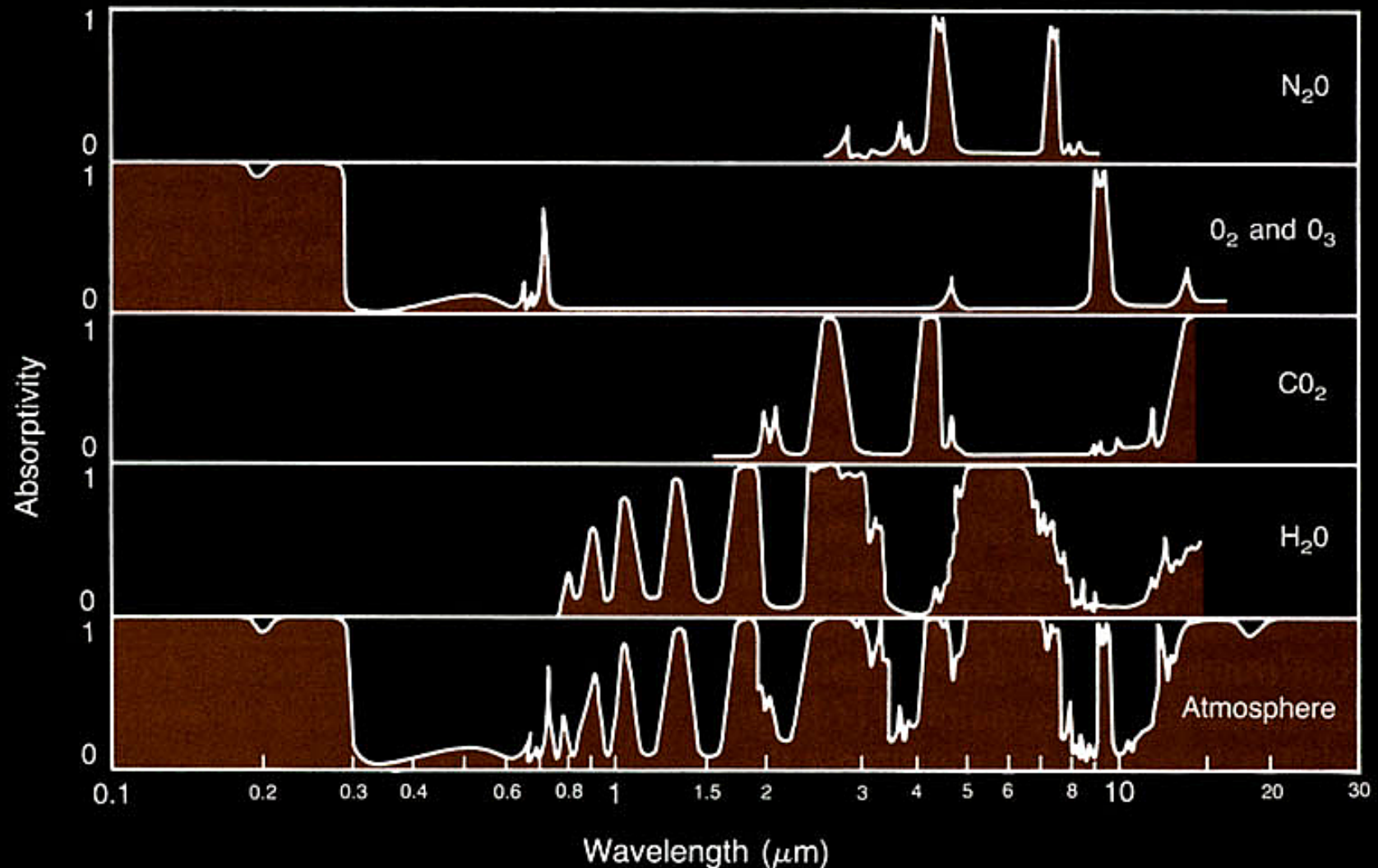


Figure 2•13 The absorptivity of selected gases of the atmosphere and the atmosphere as a whole.

(From R. G. Fleagle and J. A. Businger, *An Introduction to Atmospheric Physics*, © 1963 by Academic Press; reprinted by permission of the publisher)

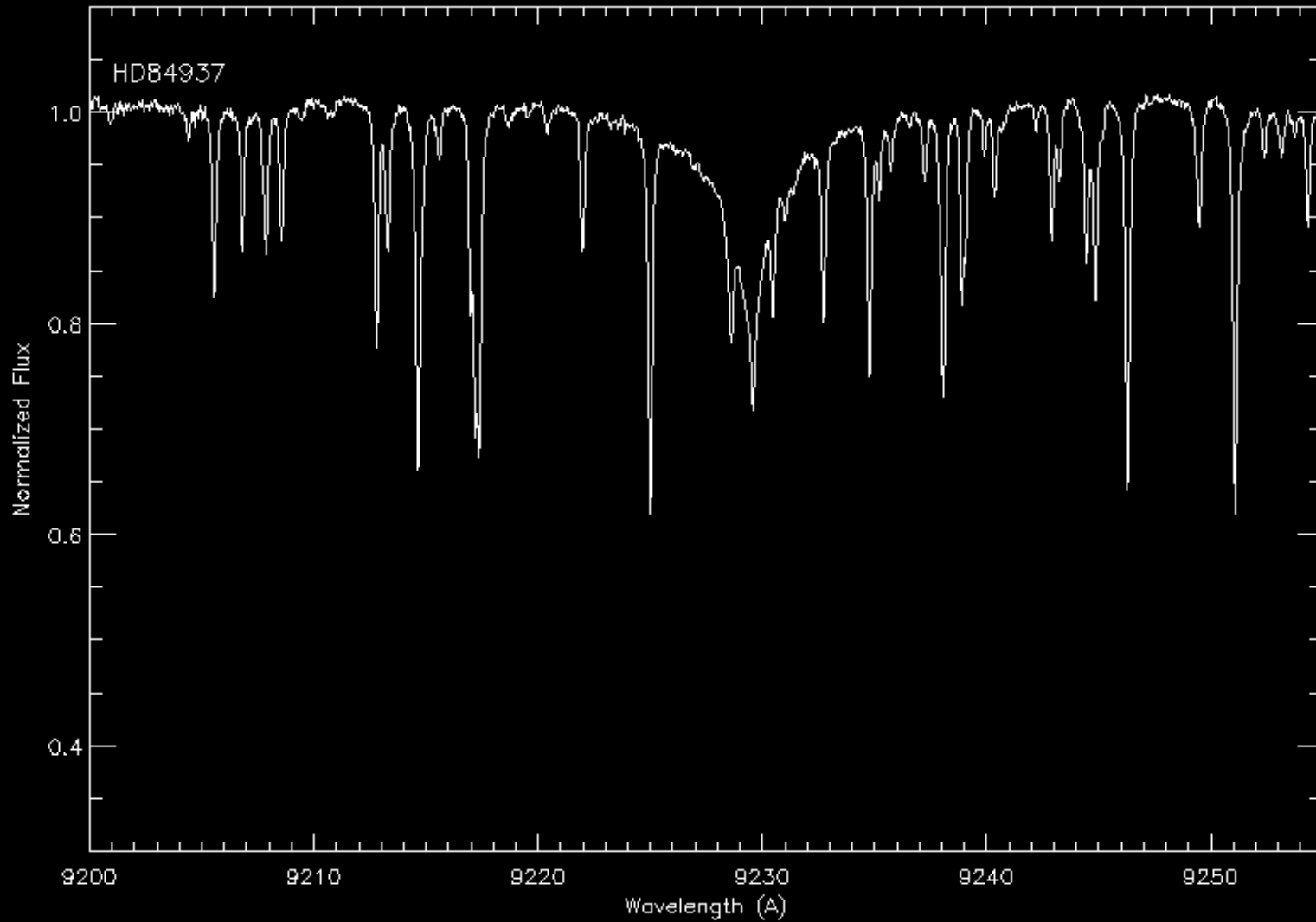
Atmospheric Absorption

To get rid of the absorption features, divide by a 'telluric standard star'....

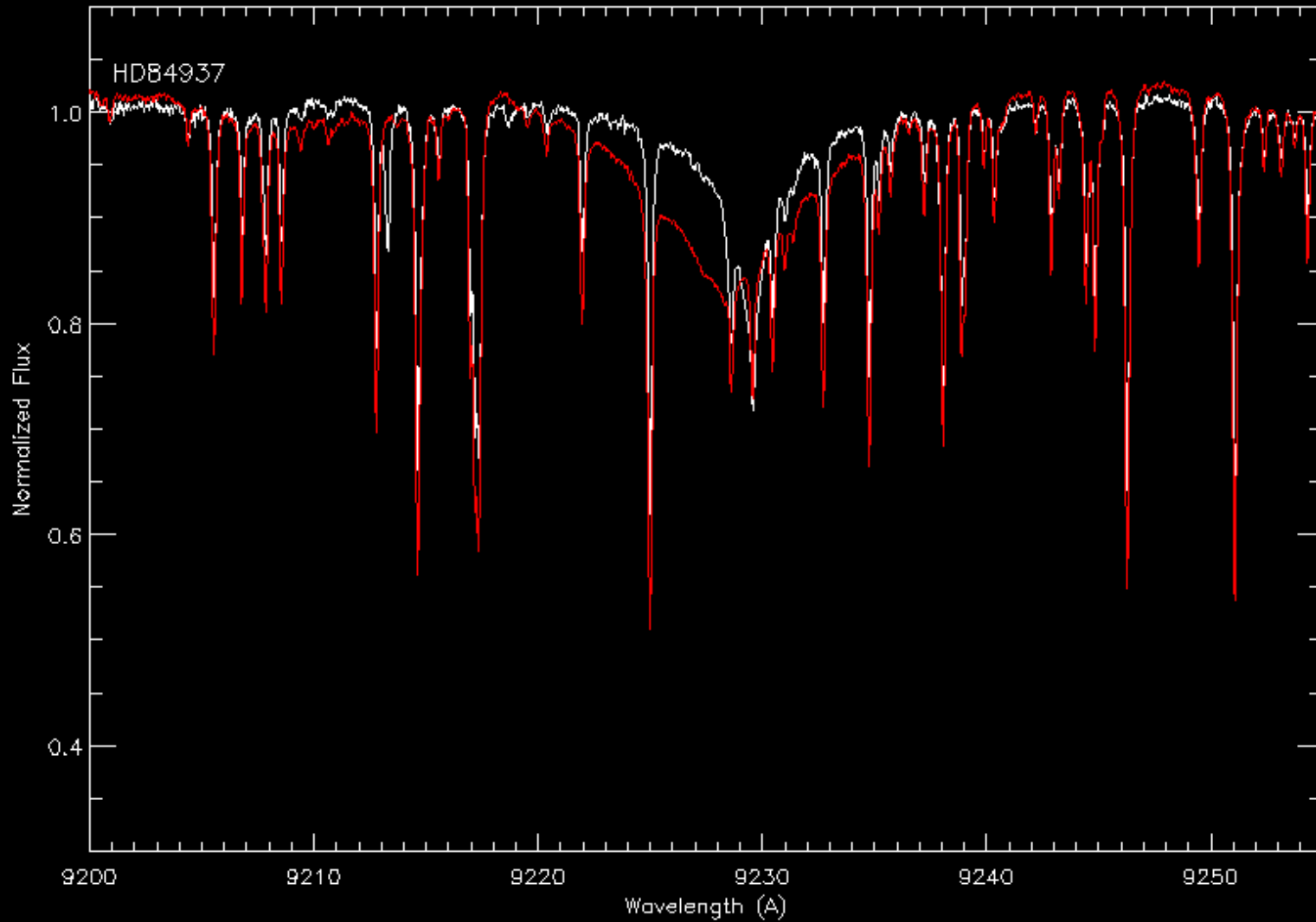
Atmospheric Absorption

To get rid of the absorption features, divide by a 'telluric standard star'....BUT....

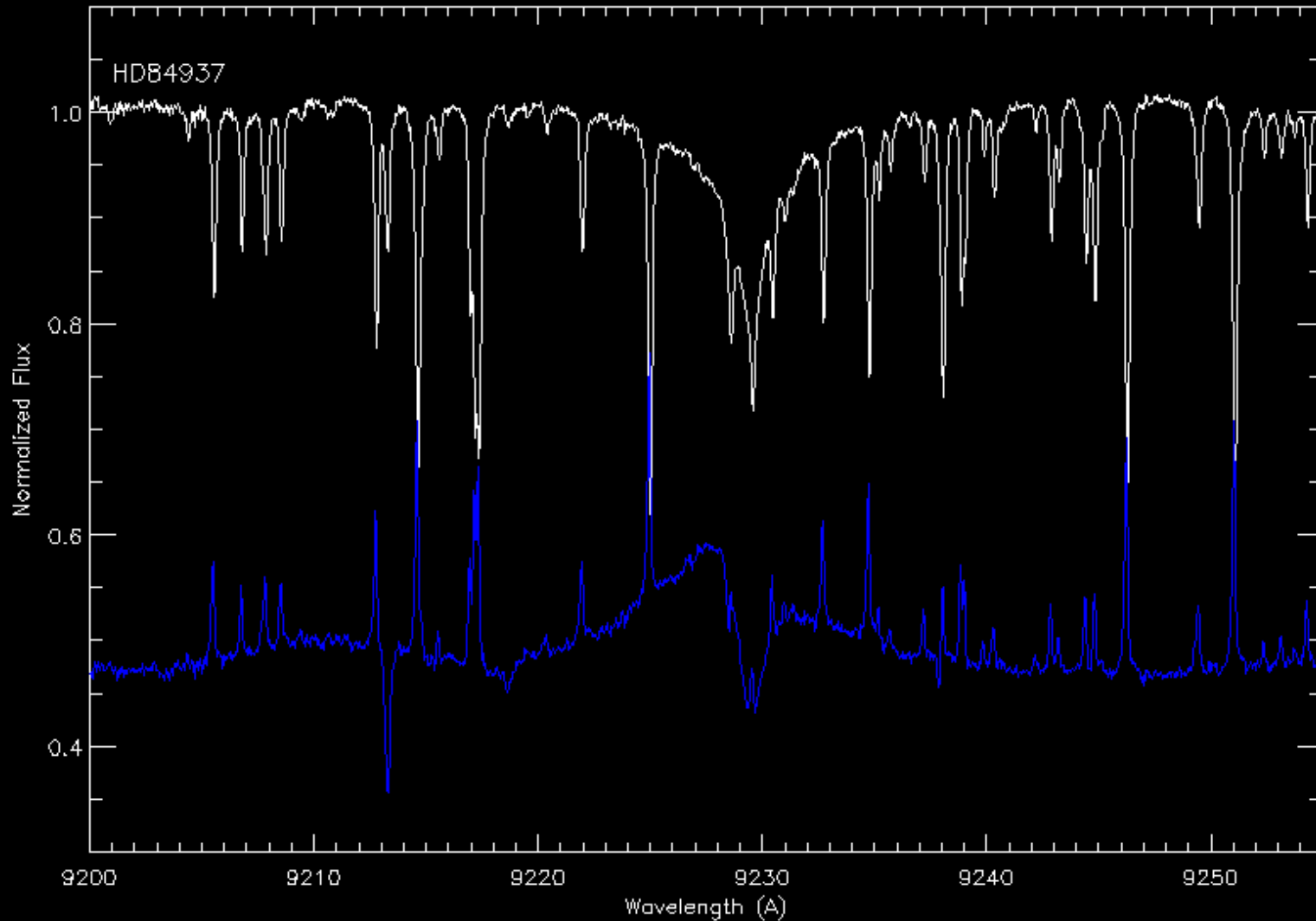
Atmospheric Absorption



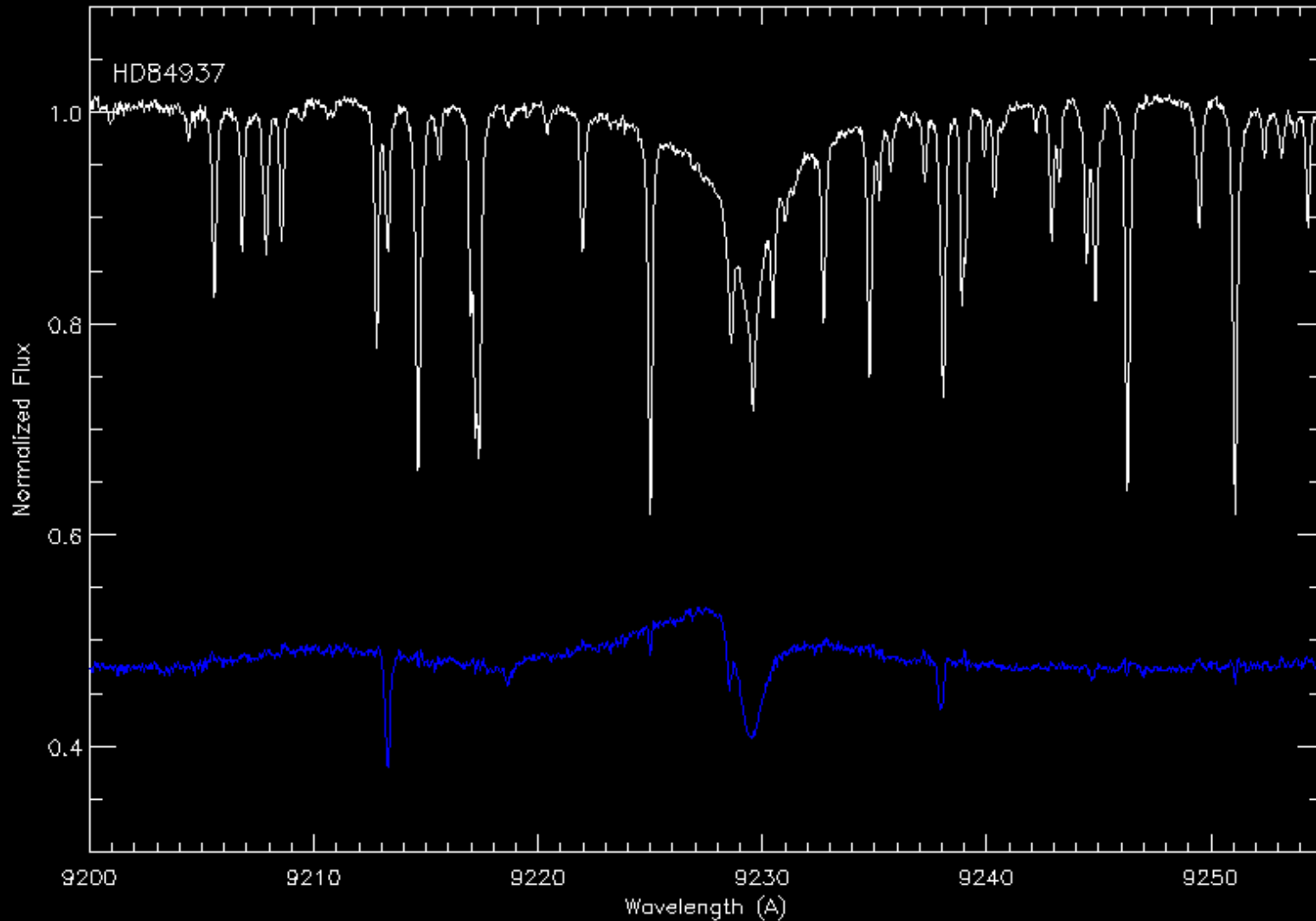
Atmospheric Absorption



Atmospheric Absorption



Atmospheric Absorption



Atmospheric Absorption

Cases where you need help from theory:

Atmospheric Absorption

Cases where you need help from theory:

- (1) No telluric standard star taken (or at wrong airmass)

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Cases where you need help from theory:

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- (II) Sharply rising or setting targets (broad airmass coverage)

Atmospheric Absorption

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- (IV) Overhead considerations (scans on faint targets)

Atmospheric Absorption

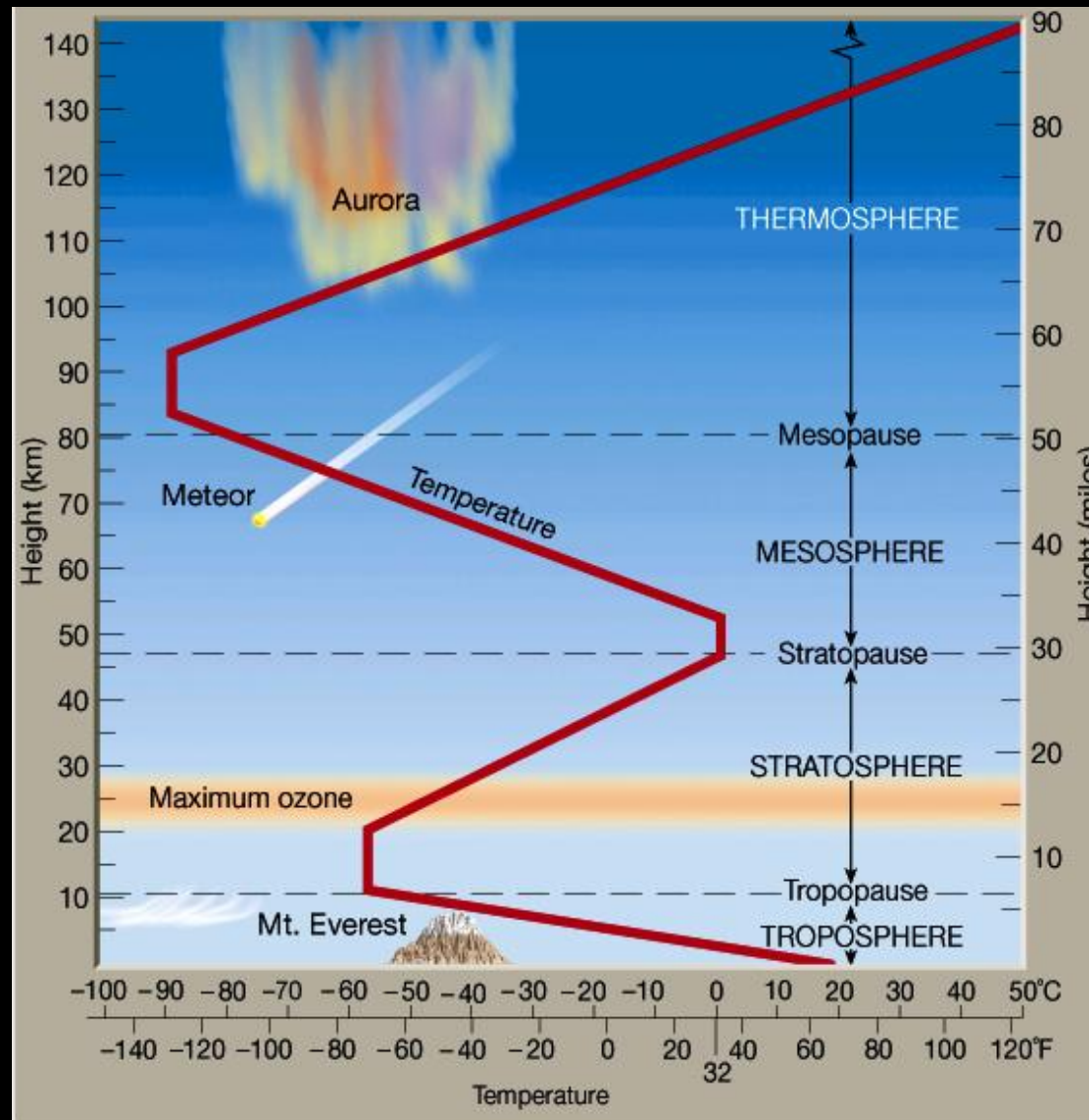
Cases where you need help from theory:

- (I) No telluric standard star taken (or at wrong airmass)
- (II) Sharply rising or setting targets (broad airmass coverage)
- (III) High S/N at the hydrogen lines wanted
- (IV) Overhead considerations (scans on faint targets)
- (V) (L)MNR bands (fast atmospheric response)

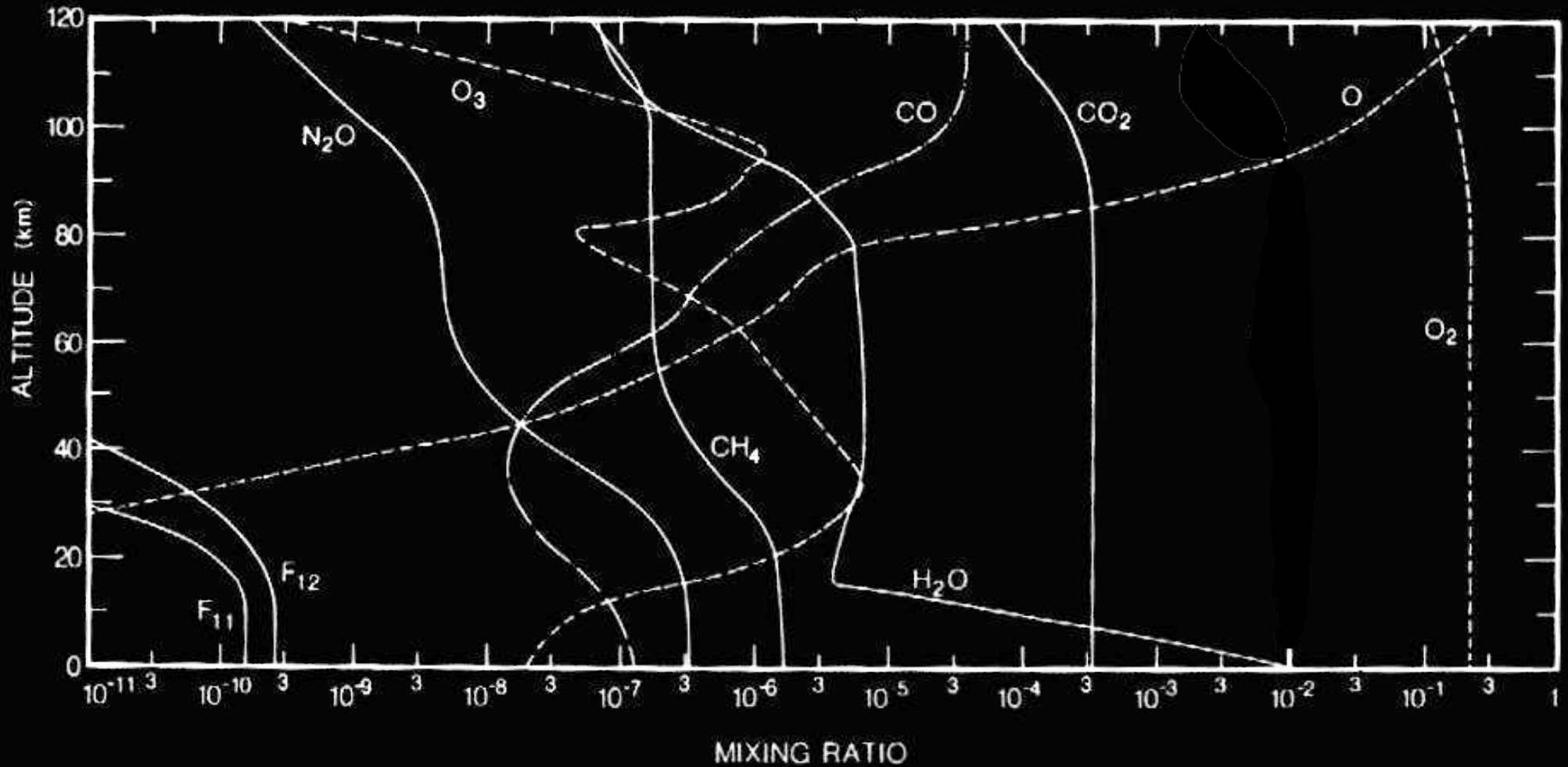
Calculating transmission & radiation

Atmospheric profiles
 $T(h), p(h), H_2O(h)...$

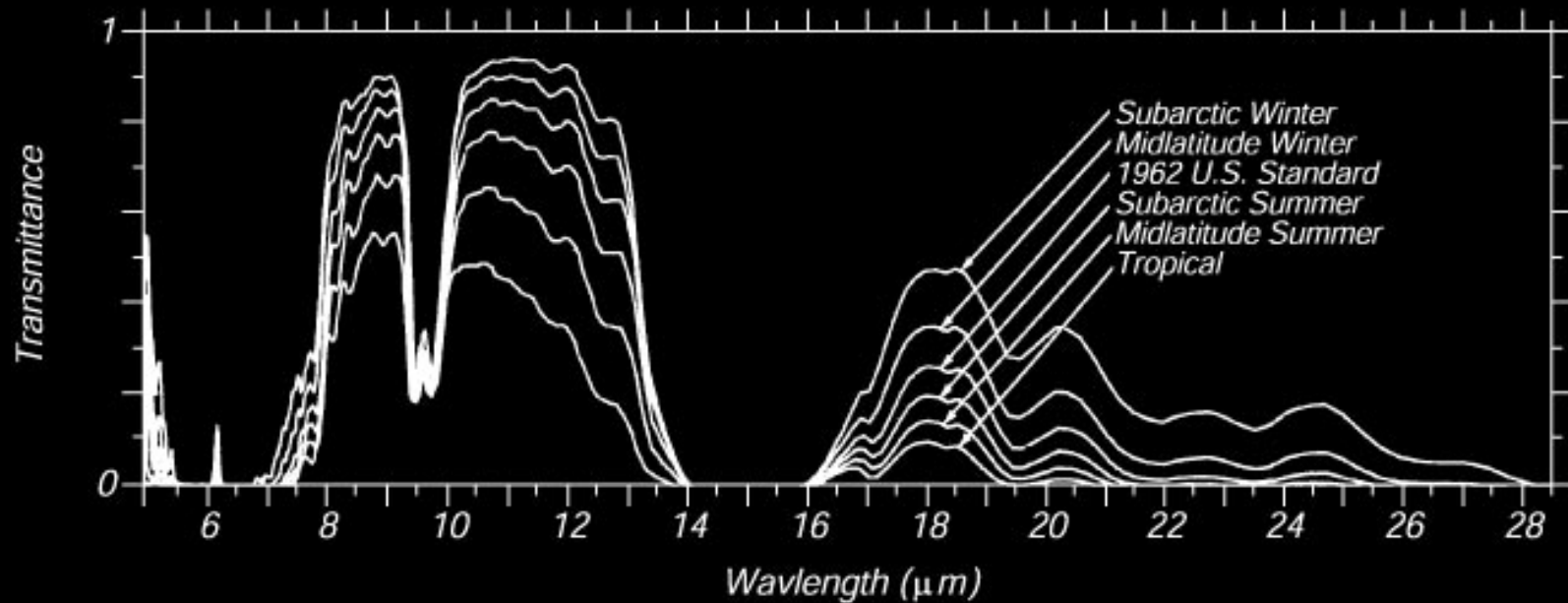
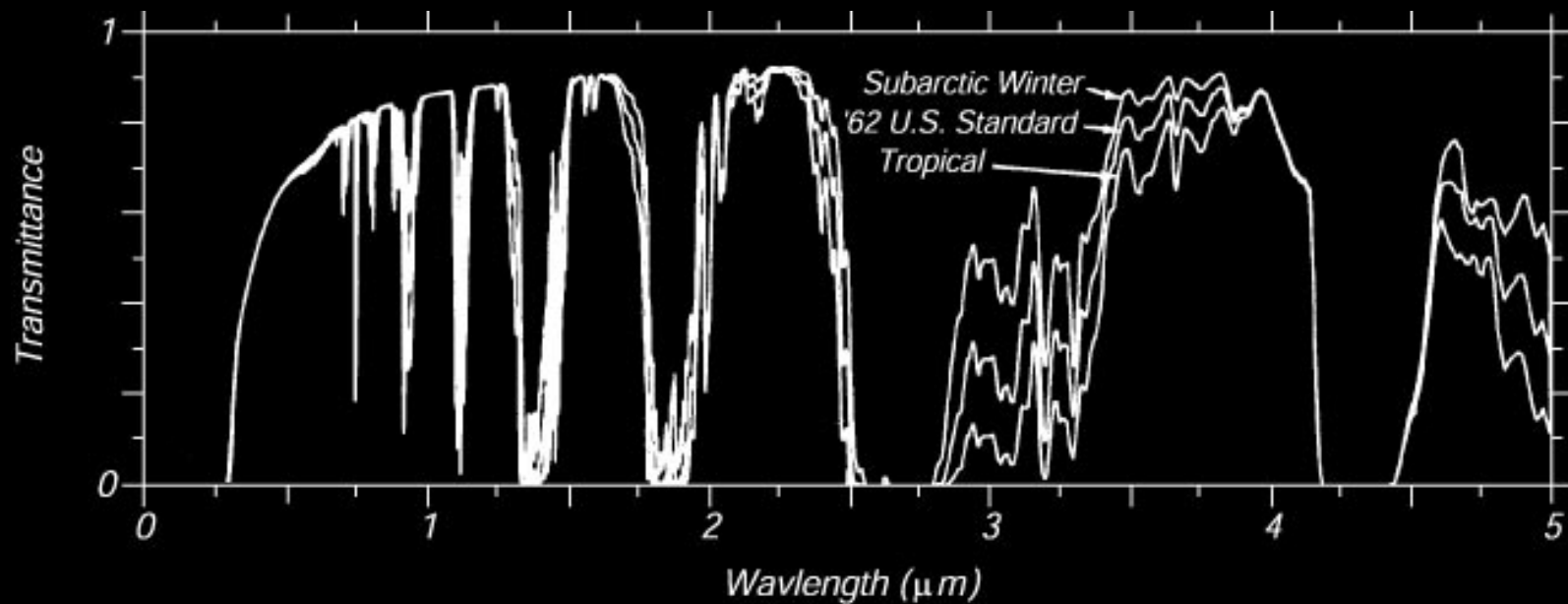
Calculating transmission & radiation



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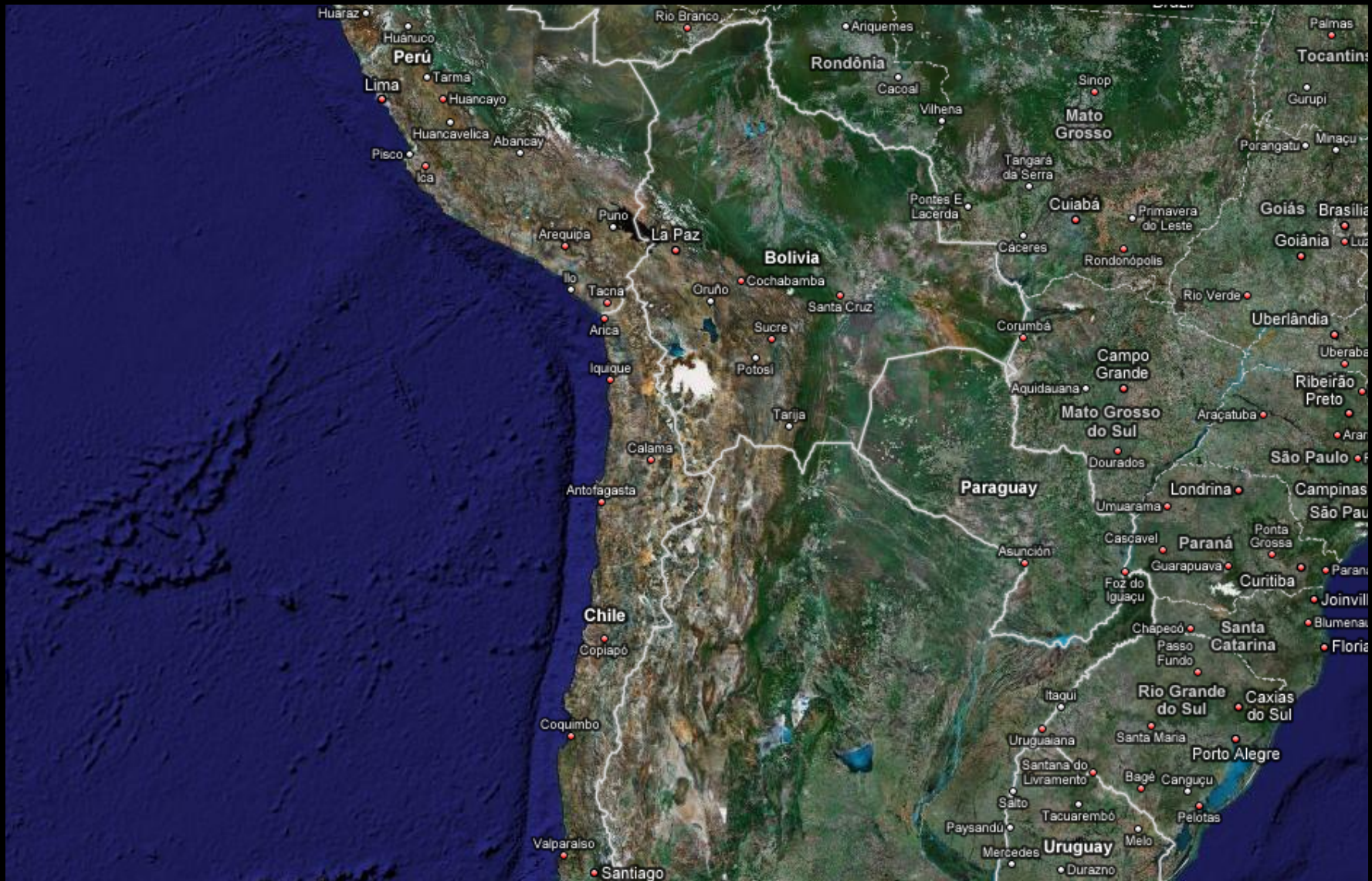
Calculating transmission & radiation

Standard profiles (mid-latitude, equatorial...)



Atmospheric profiles
 $T(h)$, $p(h)$, $H_2O(h)$...

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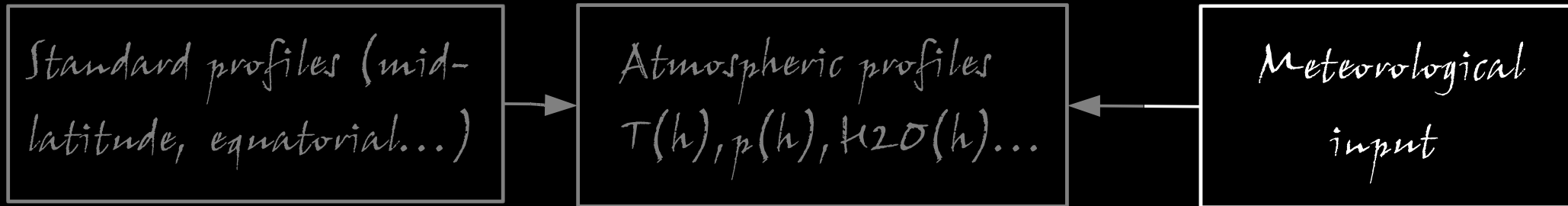
Calculating transmission & radiation

Standard profiles (mid-latitude, equatorial...)

Atmospheric profiles
 $T(h), p(h), H_2O(h)...$

Meteorological
input

Calculating transmission & radiation



Scaling of standard profiles to local conditions

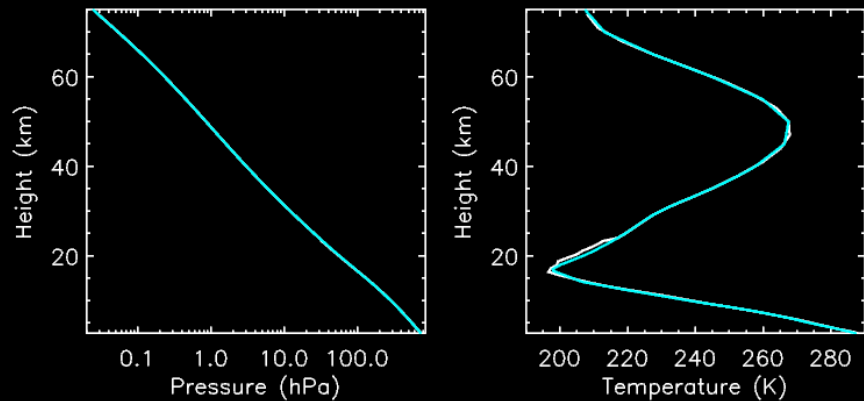
PWV prediction from satellite measurements (ESD website)

GDAS profiles from NOAA website

MMS & local topography (you need a meteorologist)

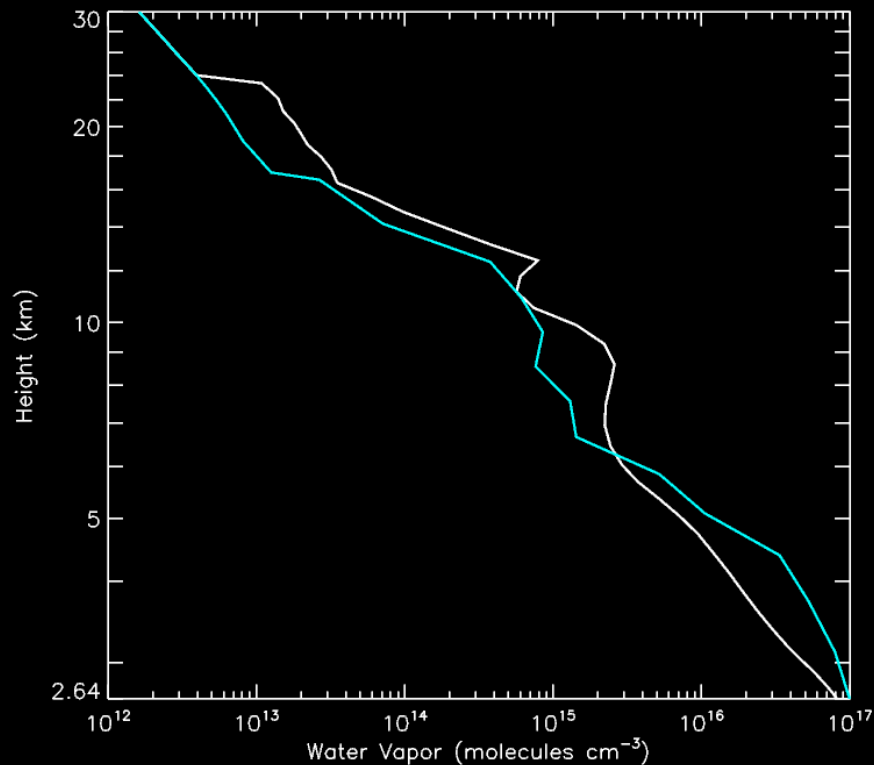


Calculating transmission & radiation



GDS profile (white)
MMS profile (green)

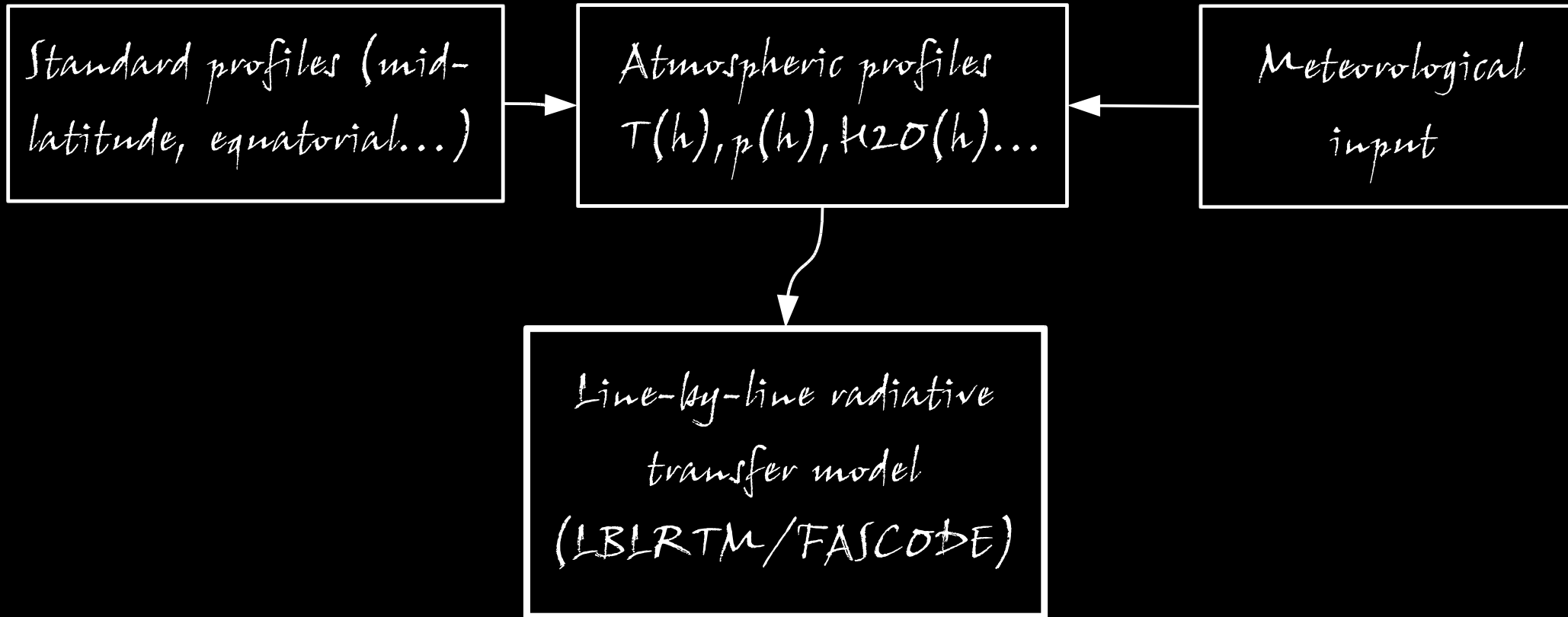
Temperature and pressure within
5 hPa and 1.5 K with observations



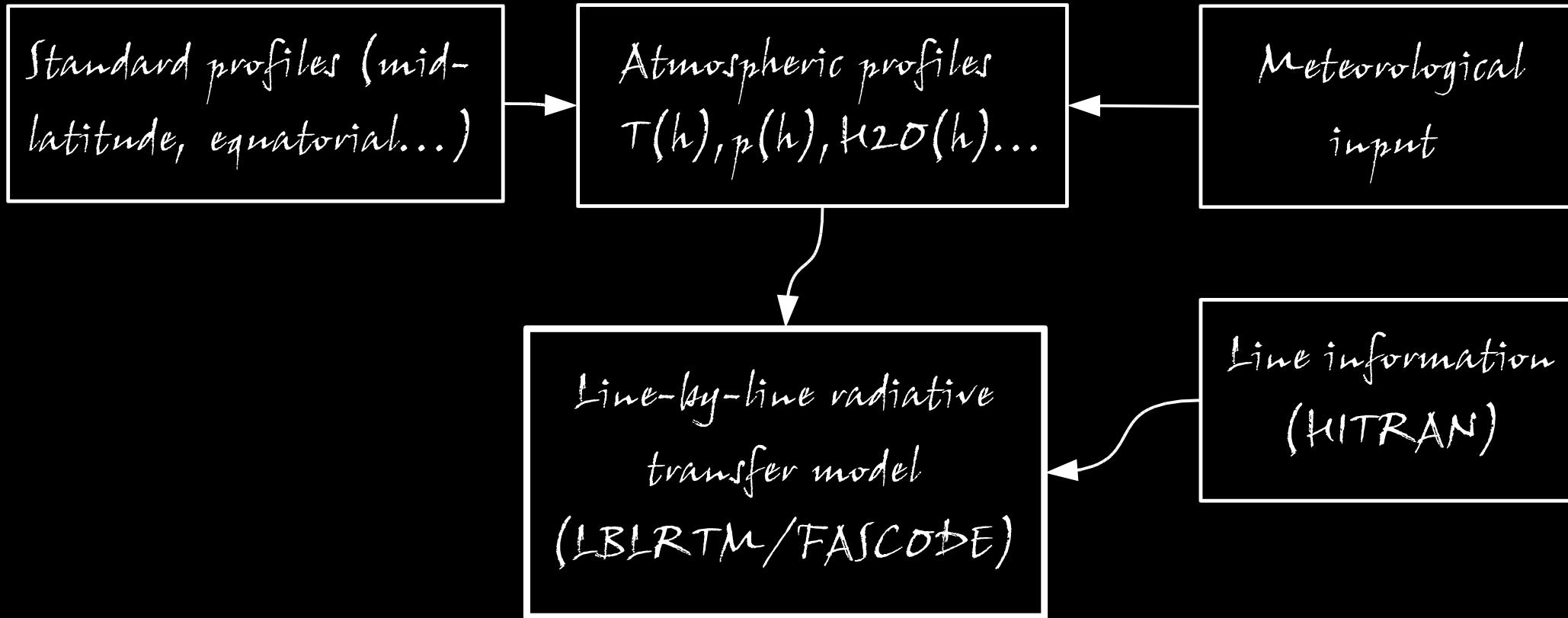
PWV predictions too high
(by up to a factor of 4 !)

PWV at Paranal: 0.3 mm - 12 mm
(few observations in 2006-2007)

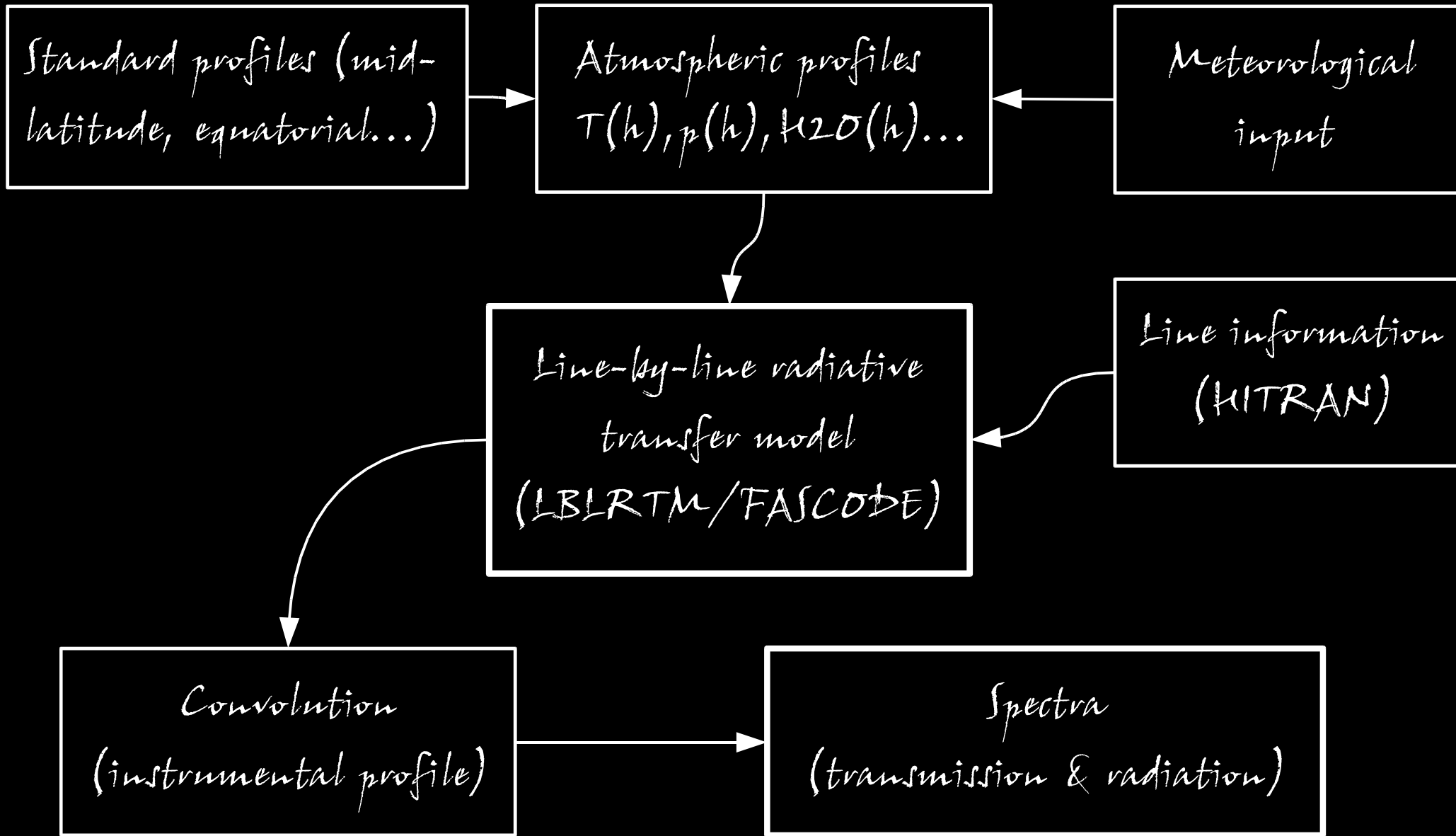
Calculating transmission & radiation



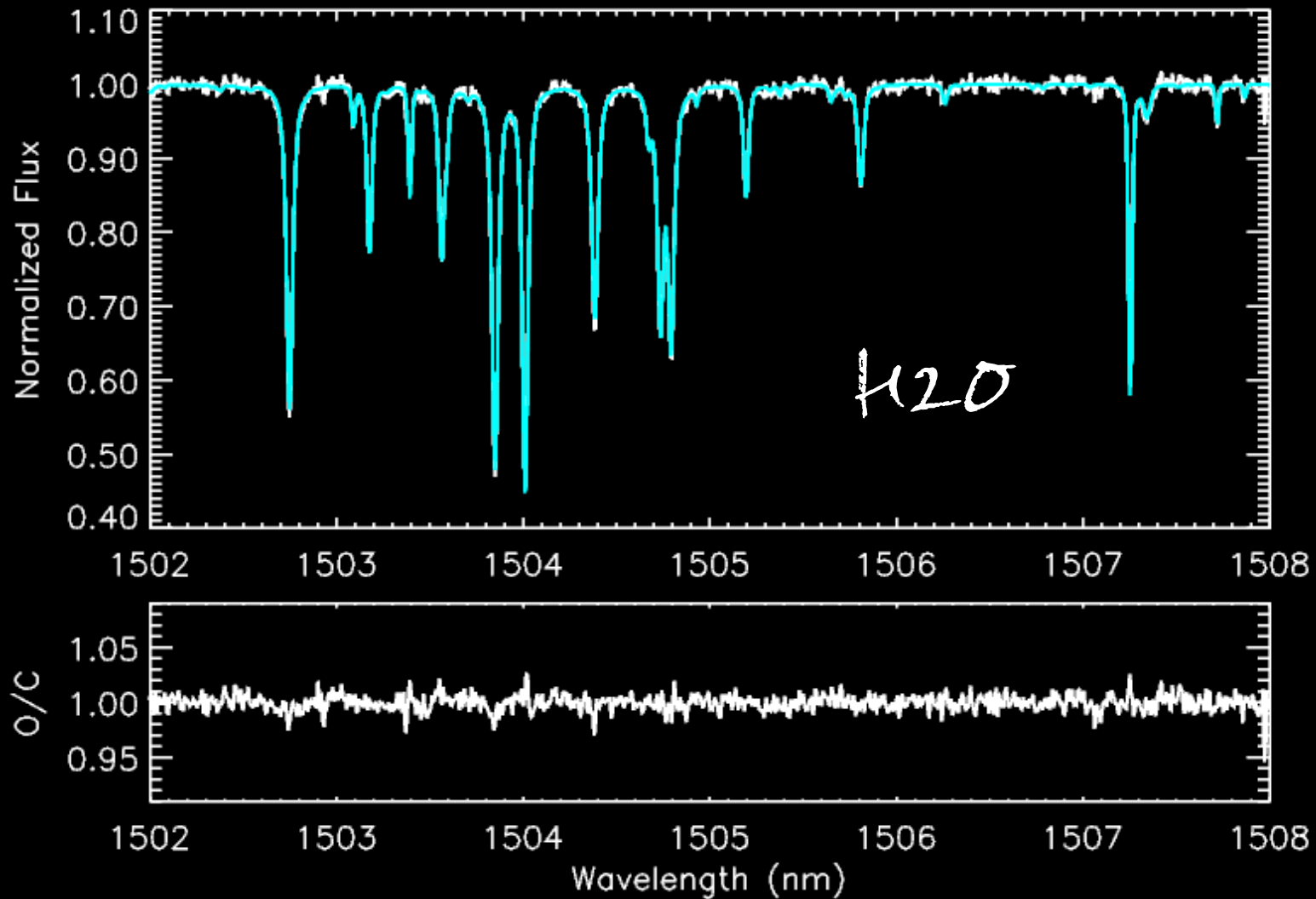
Calculating transmission & radiation



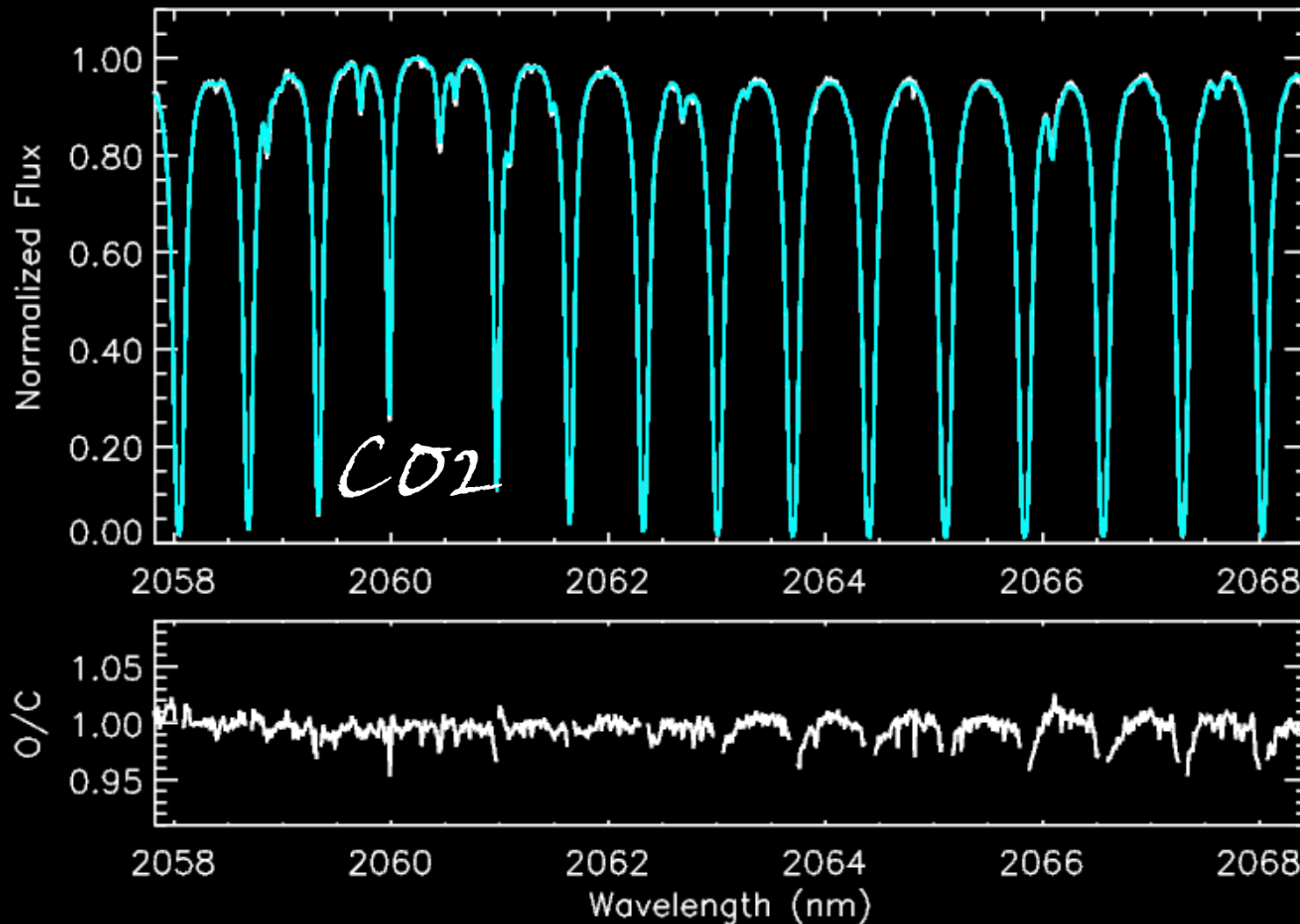
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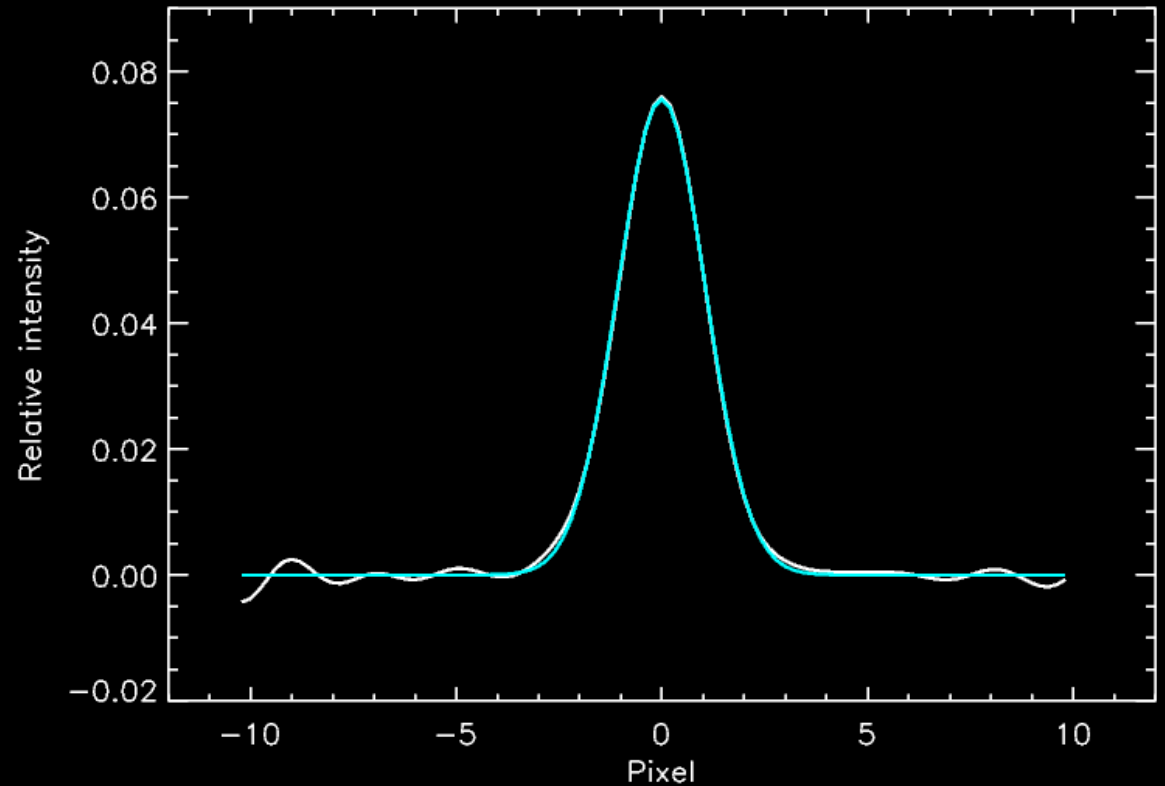
Calculating transmission & radiation



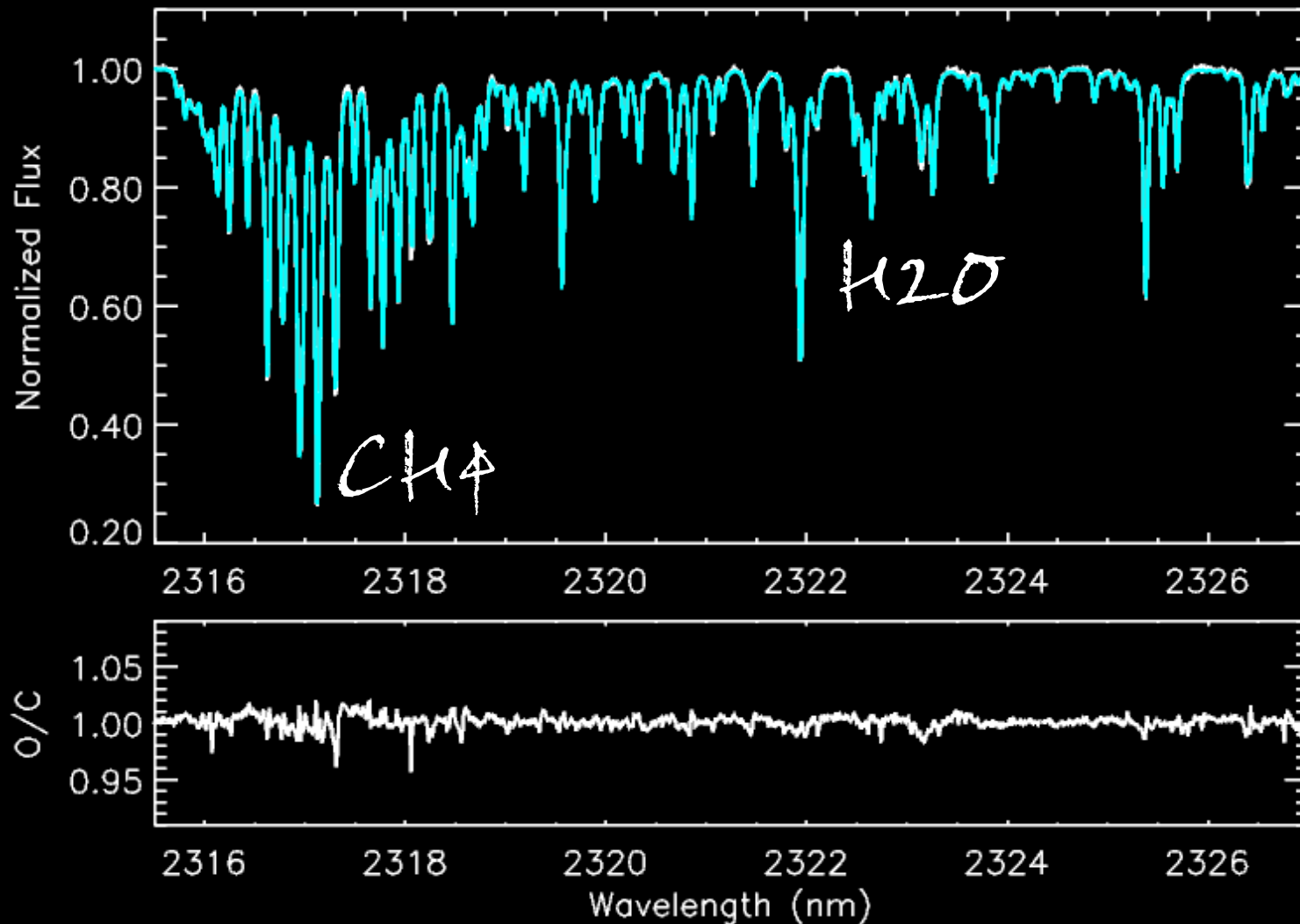
Calculating transmission & radiation

Instrumental profile well
described by a Gaussian

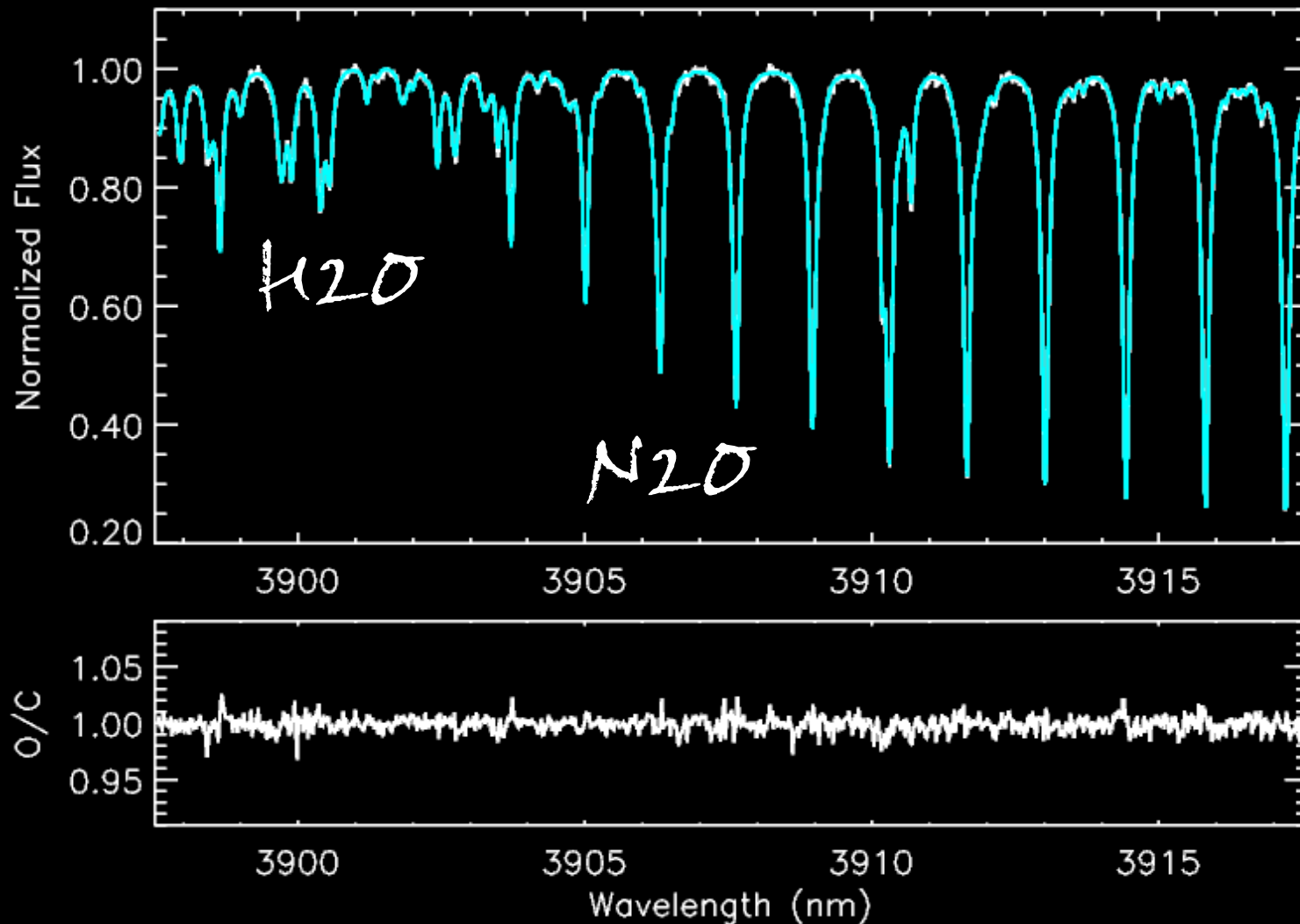
FWHM partly degenerate
with line-strength in few
cases



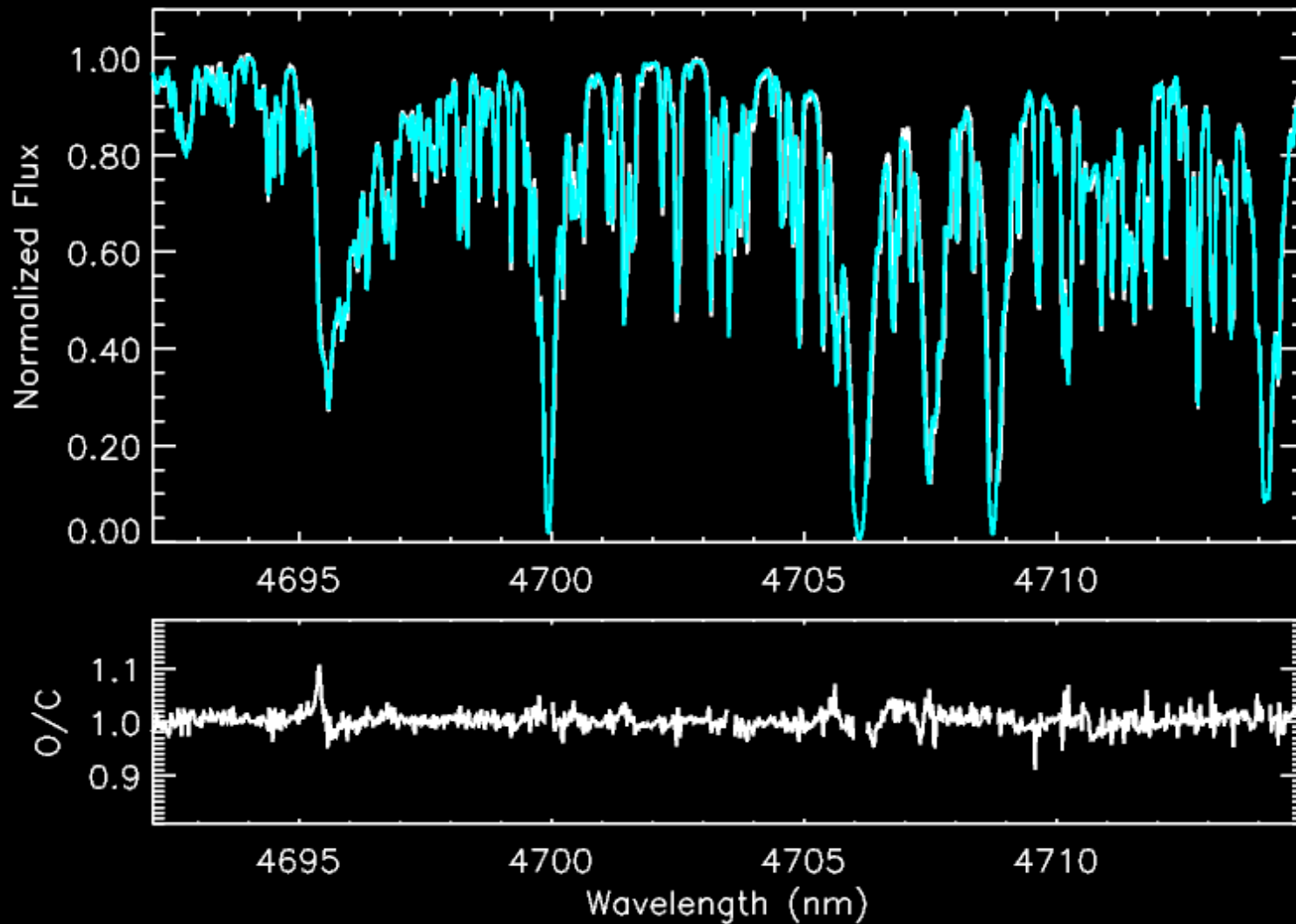
Calculating transmission & radiation



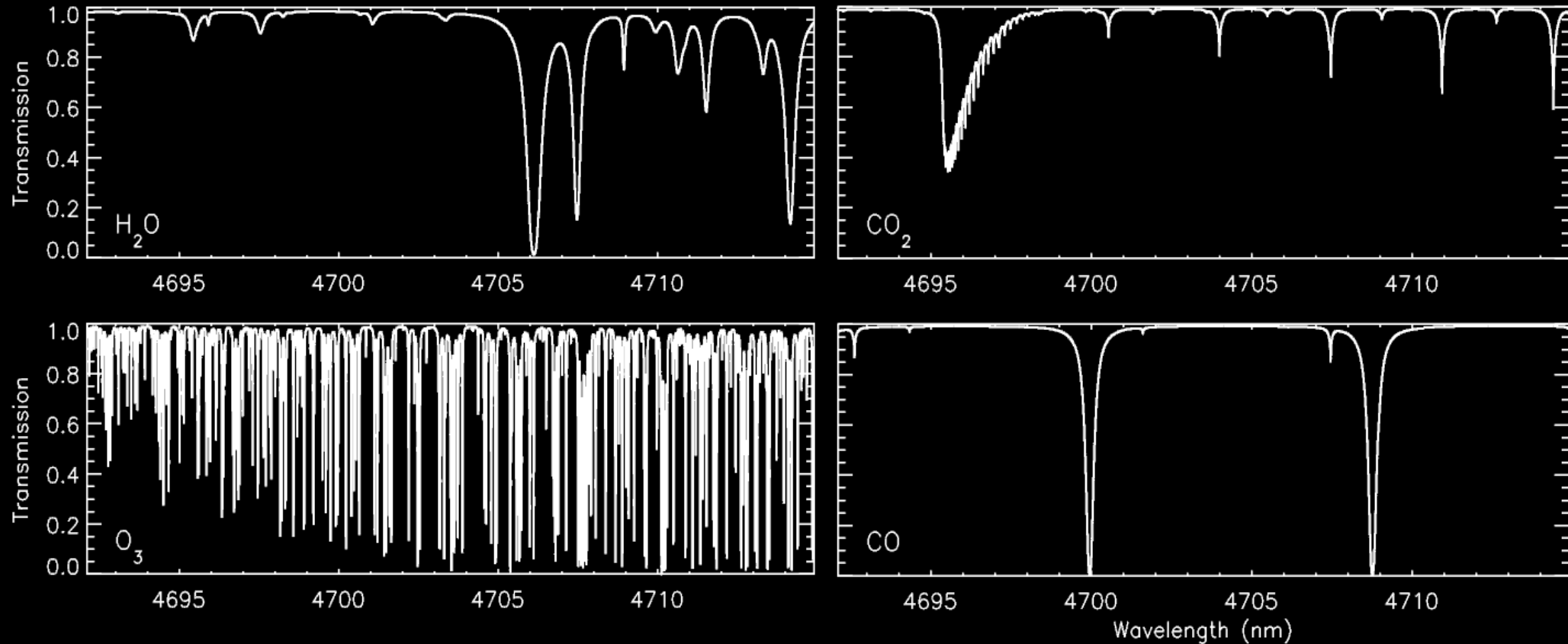
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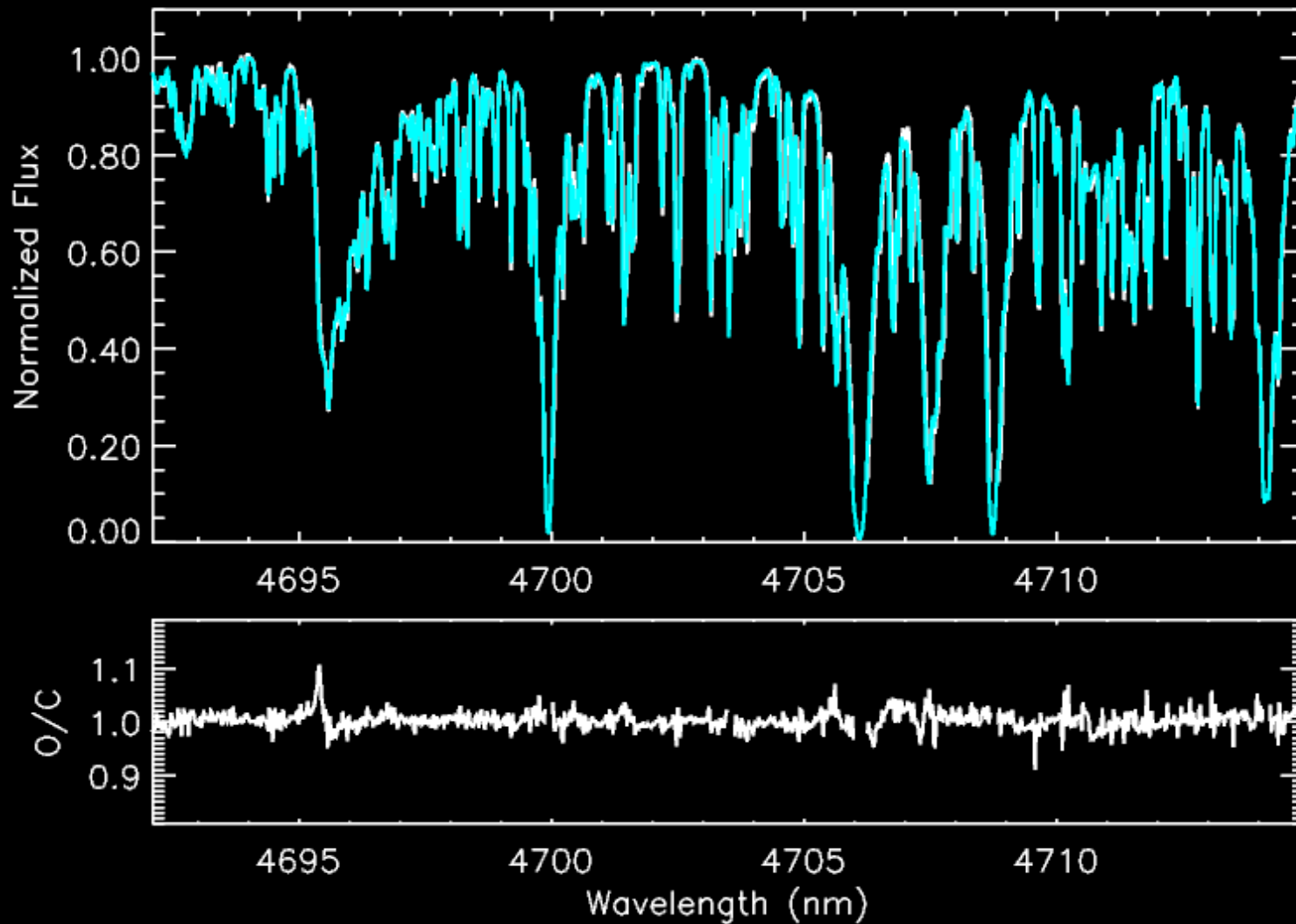
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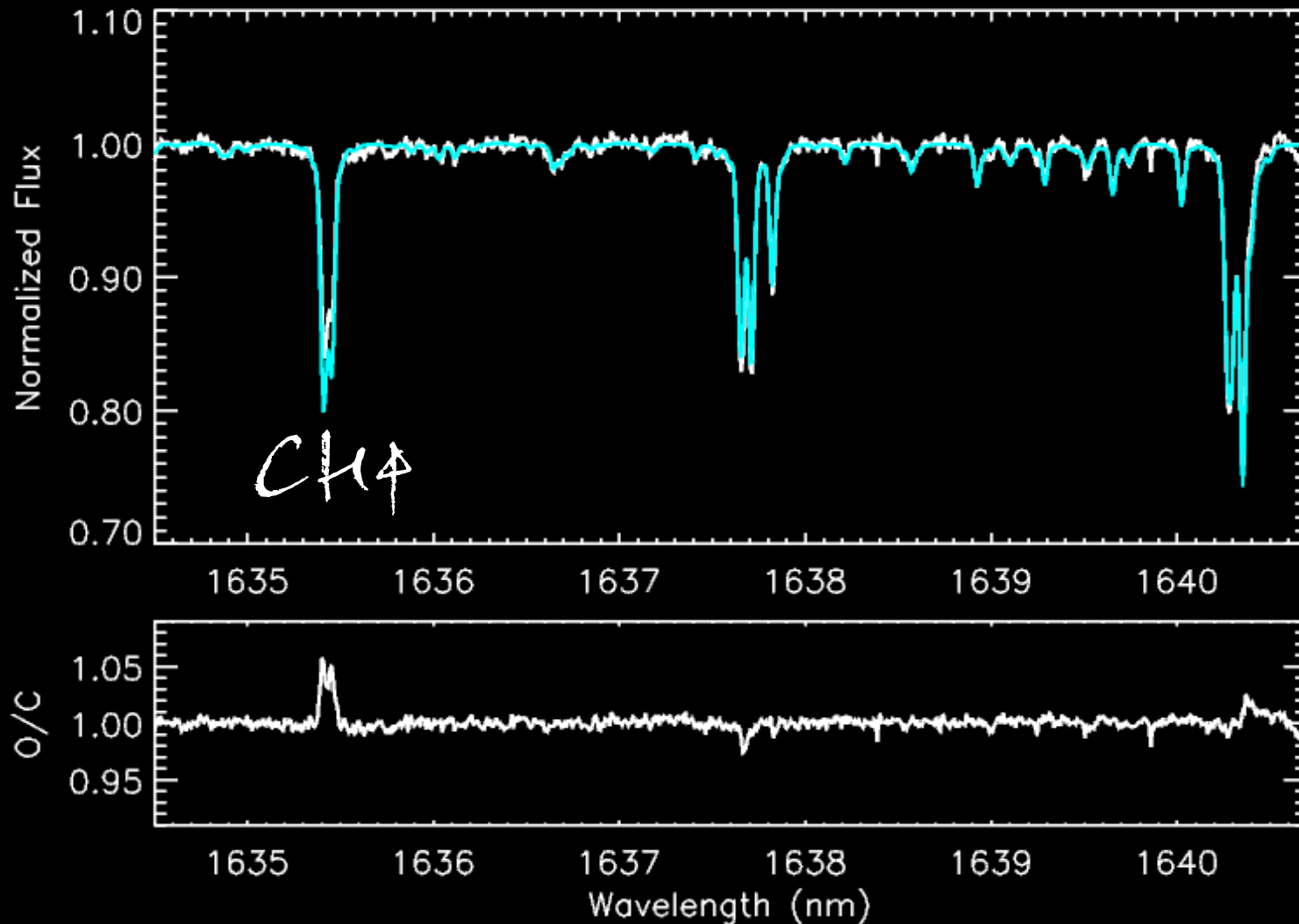
Is it always working?

Calculating transmission & radiation

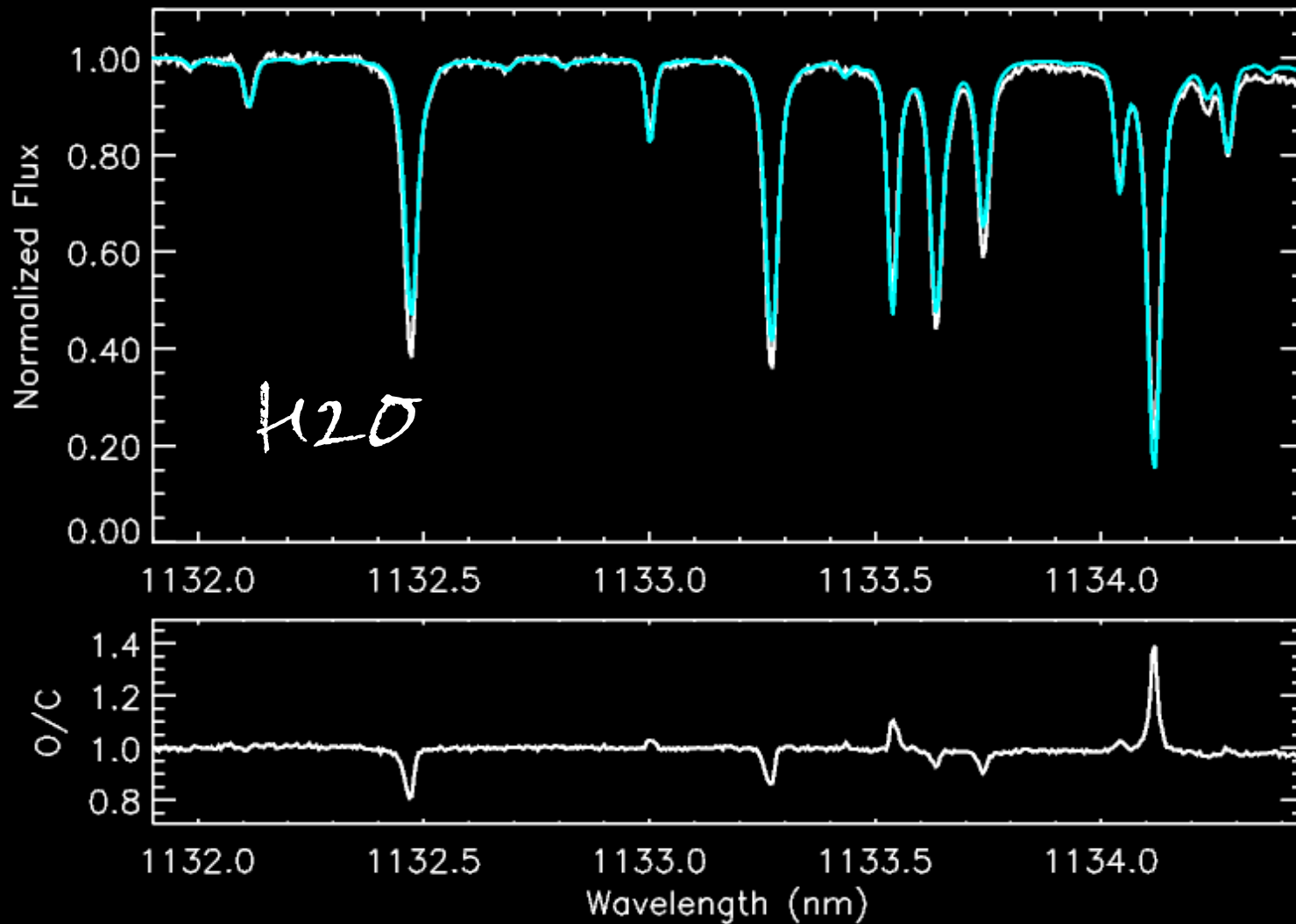
Is it always working?

No....

Calculating transmission & radiation



Calculating transmission & radiation



Calculating transmission & radiation

Current limitation: approx. 1% level in absorption

Calculating transmission & radiation

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Reasons:

Calculating transmission & radiation

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- (1) Instrumental profile needs to be fitted

Calculating transmission & radiation

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- (II) Erroneous line strength information (HITRAN)

Calculating transmission & radiation

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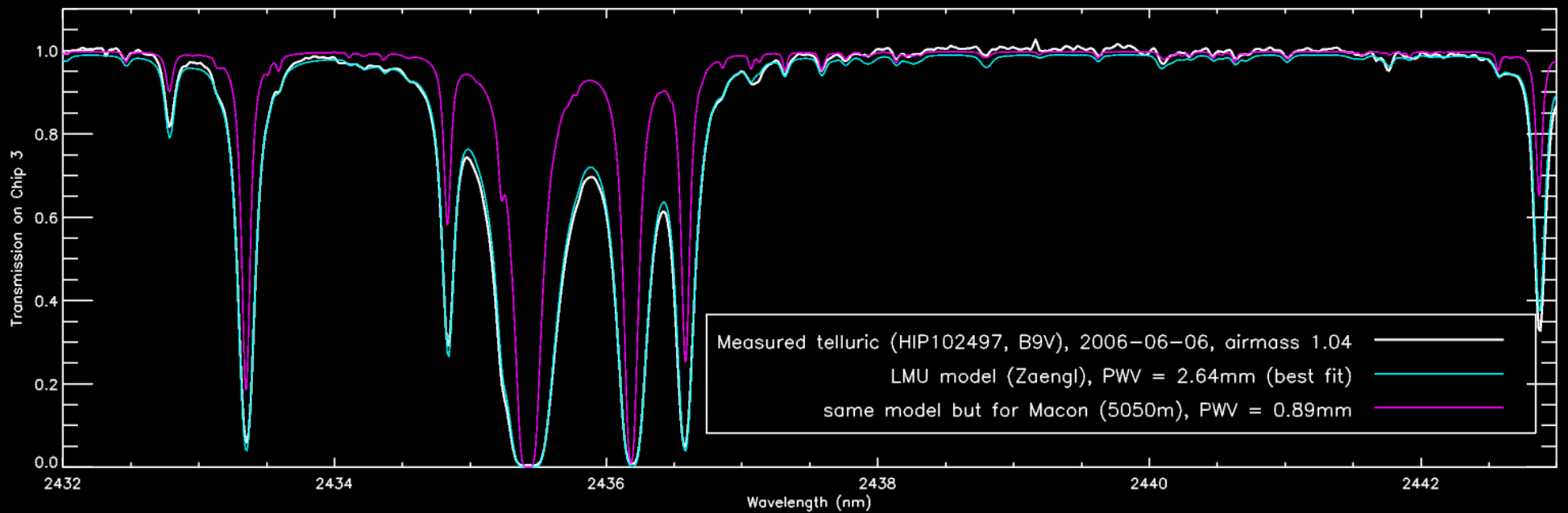
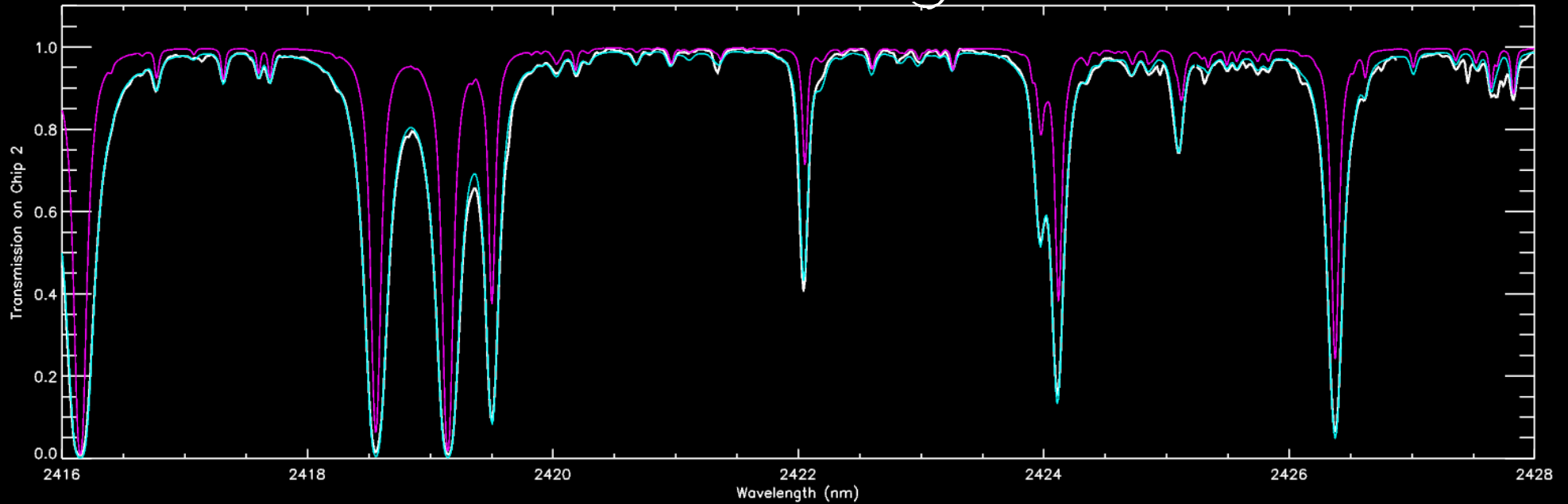
- (I) Instrumental profile needs to be fitted
- (II) Erroneous line strength information (HITRAN)
- (III) Uncertainties in atmospheric profiles (mainly H₂O)

Calculating transmission & radiation

Still, synthetic spectra outperform empirical spectra
(*'standard stars'*) in most cases!

Other applications ?

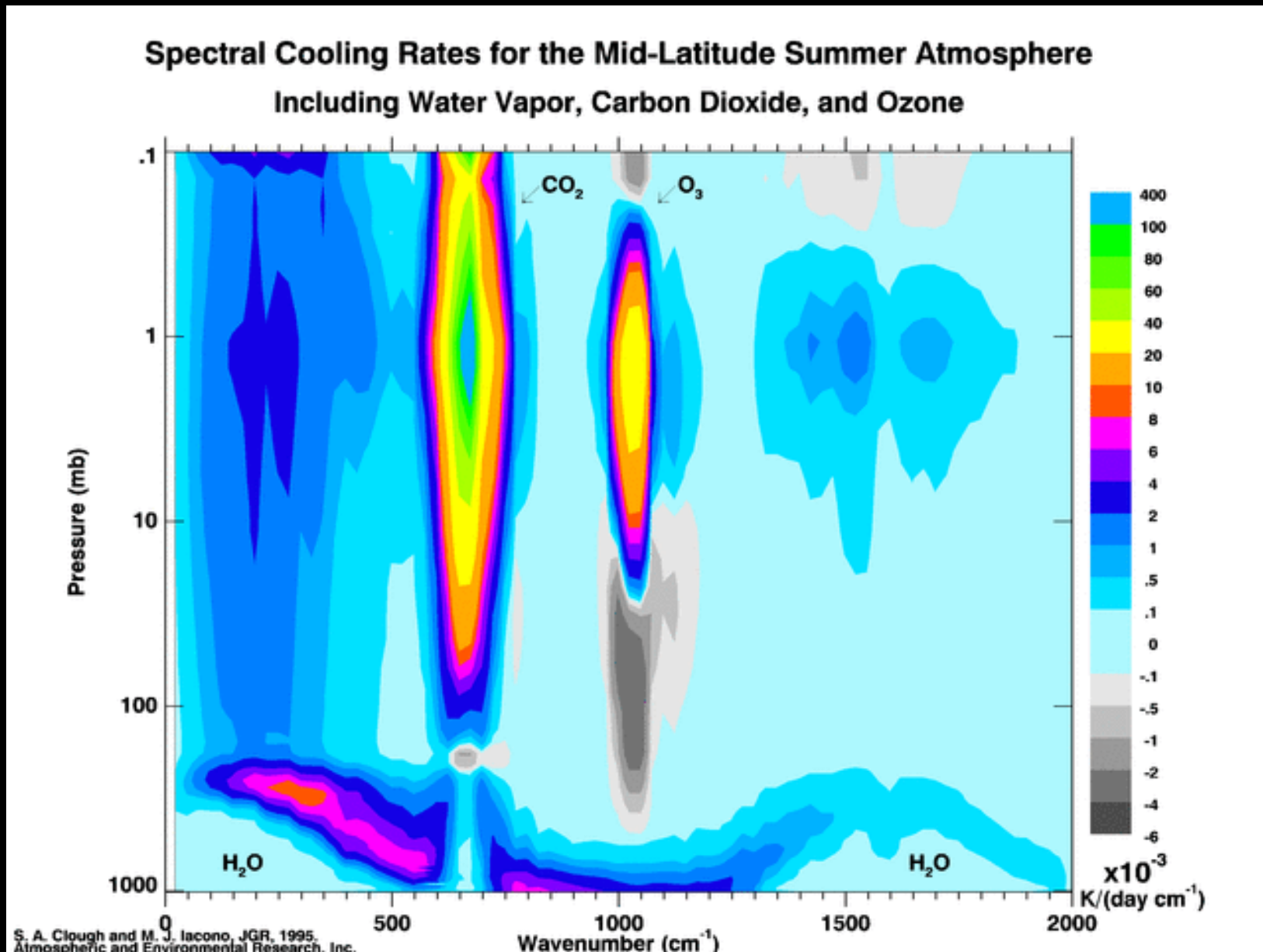
Site-testing!



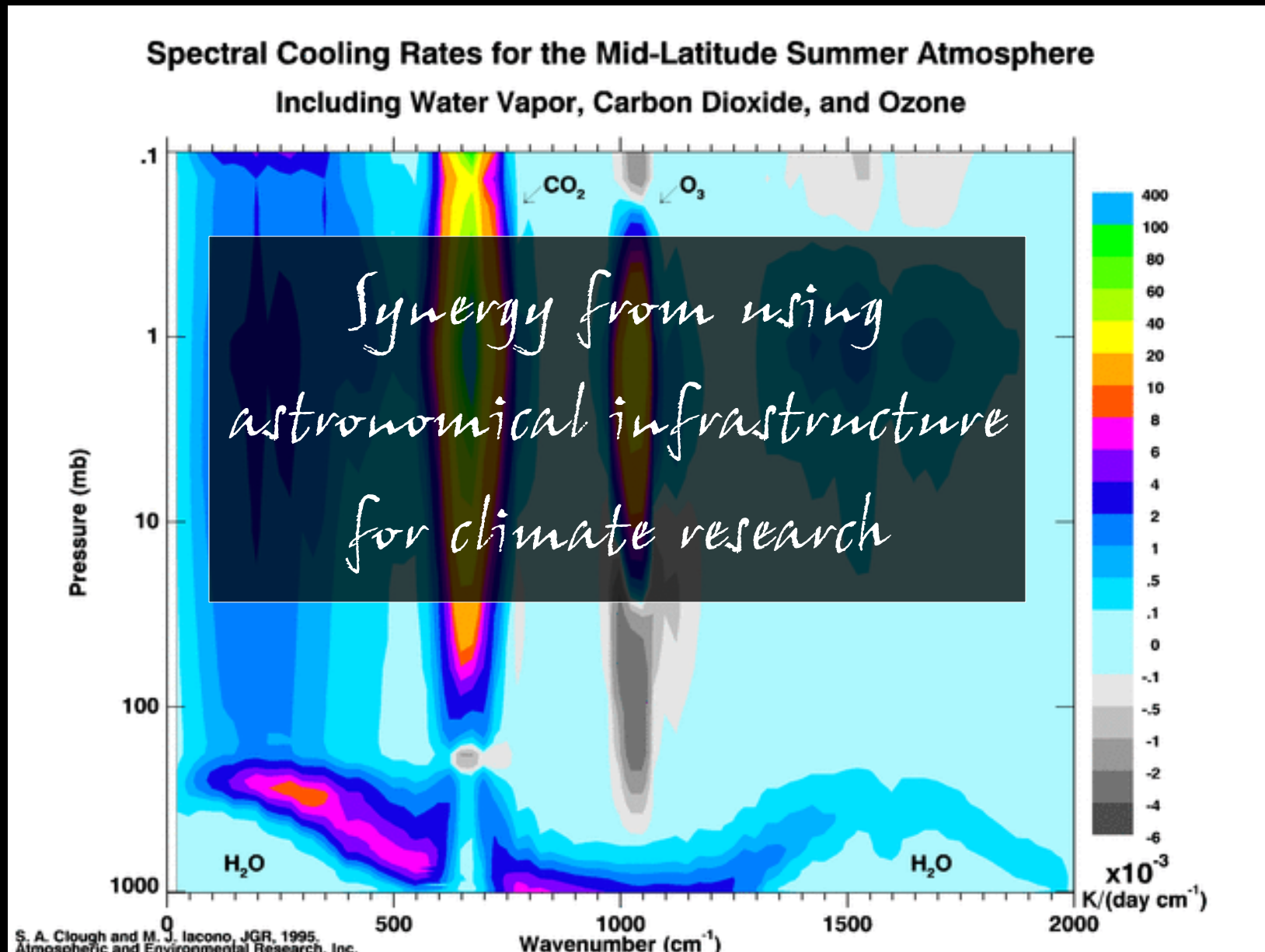
Interesting for Earth science ?

*One man's noise is
another man's signal!*

Interesting for Earth science ?



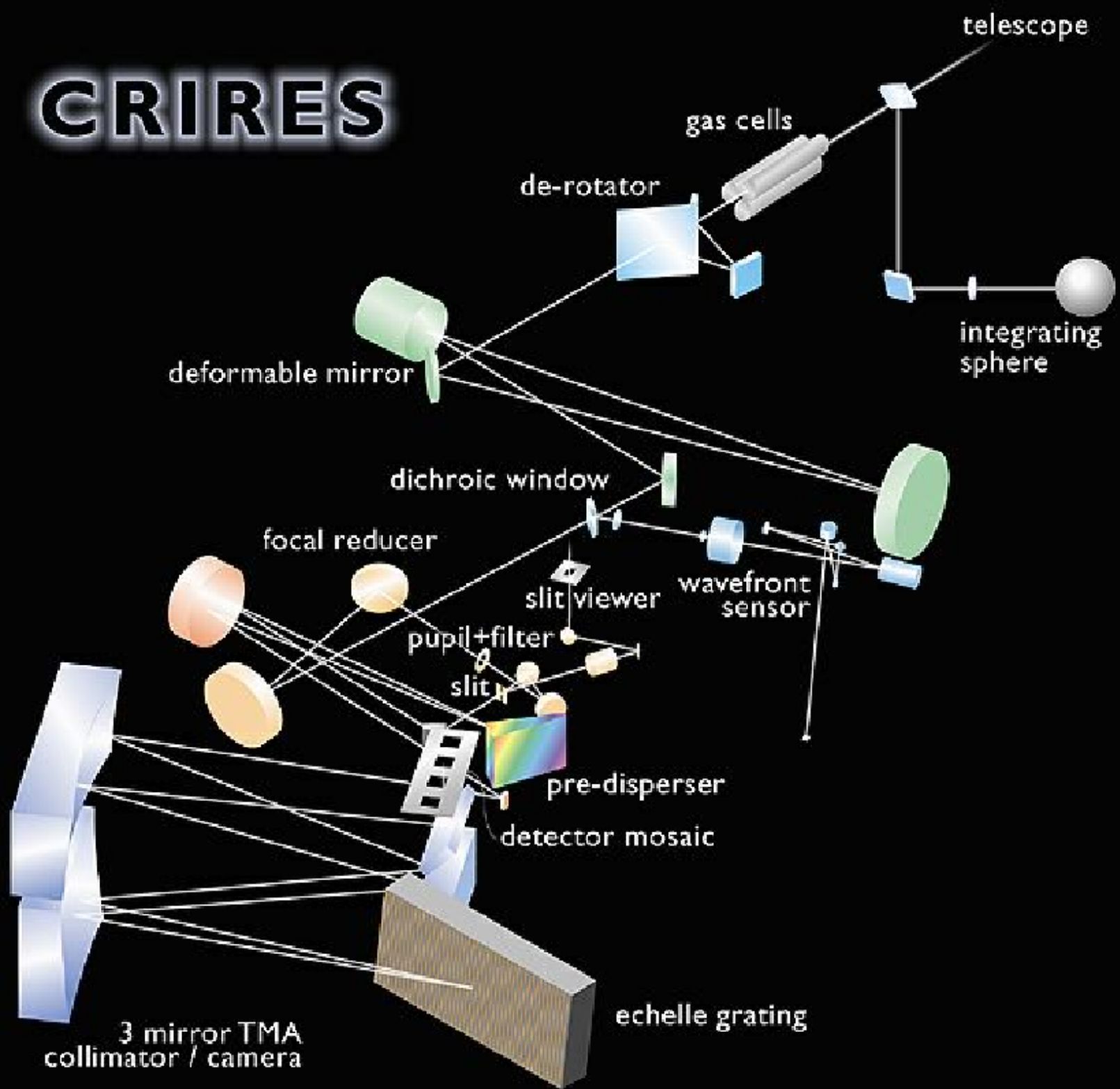
Interesting for Earth science ?





Thanks for your attention!

CRIRES



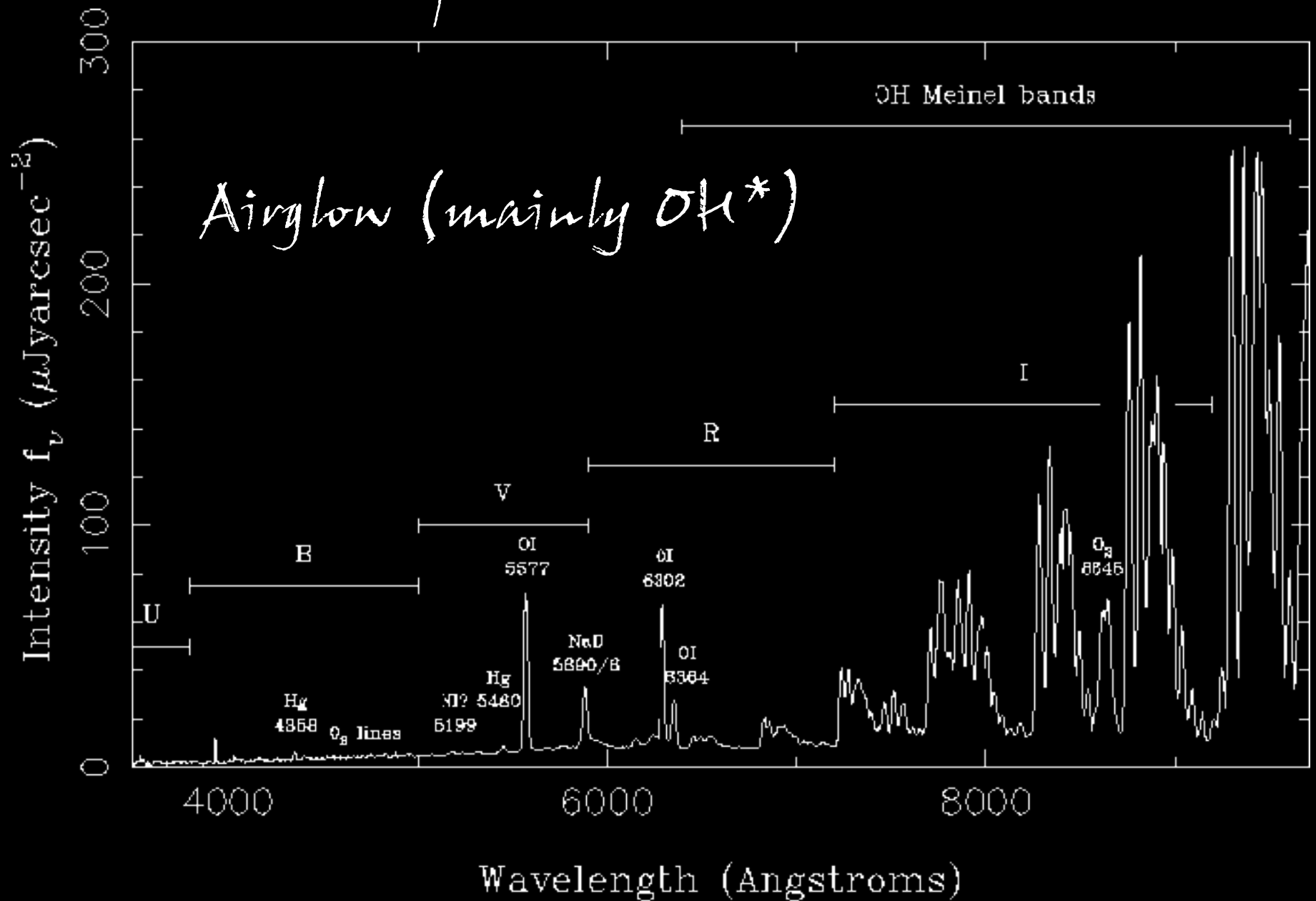
The Atmosphere above Paranal:

(1) Emission (lines & thermal)

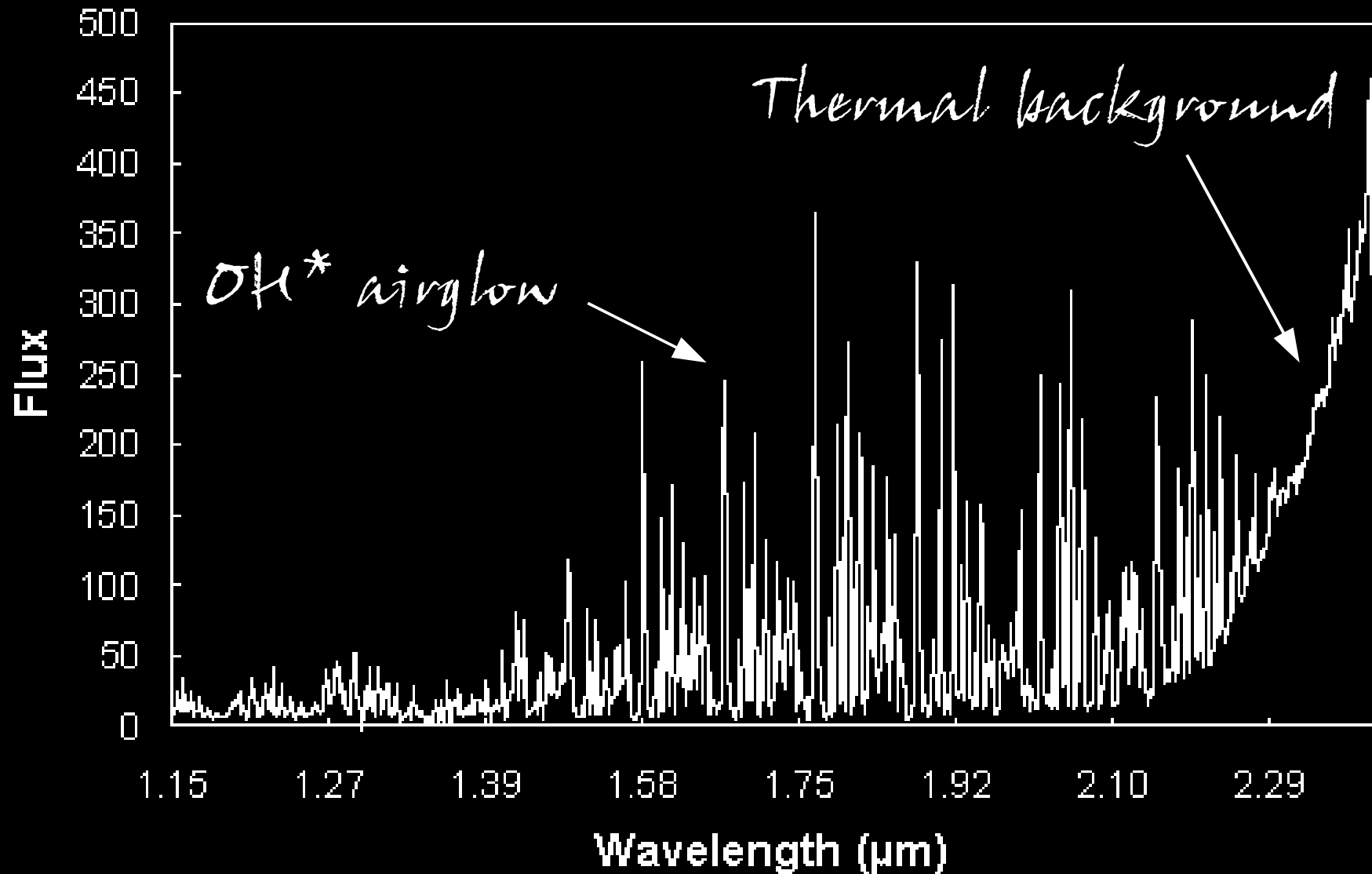
The Atmosphere above Paranal:

- (I) Emission (lines & thermal)
- (II) Absorption (lines & continuum)

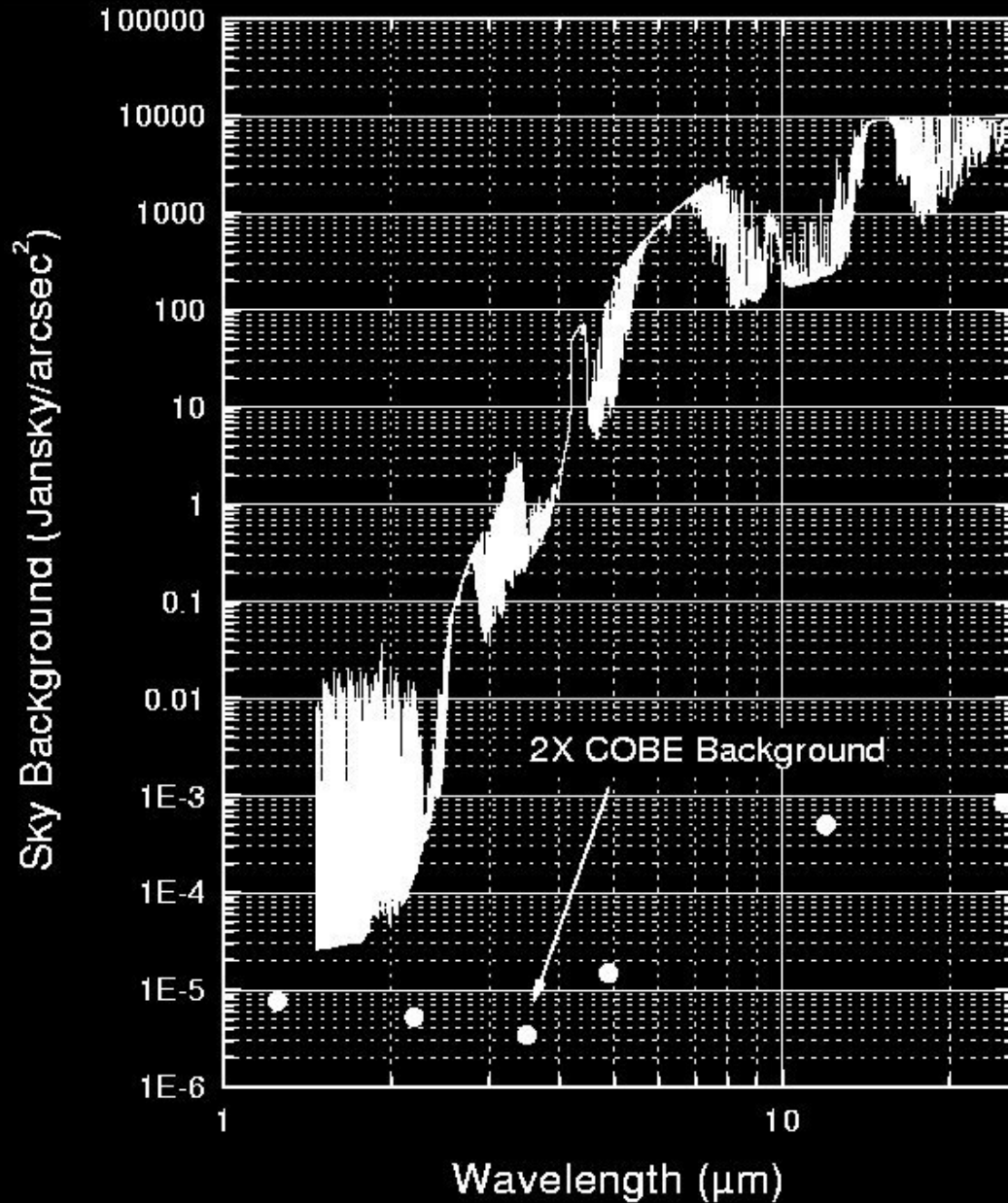
The Atmosphere above Paranal:



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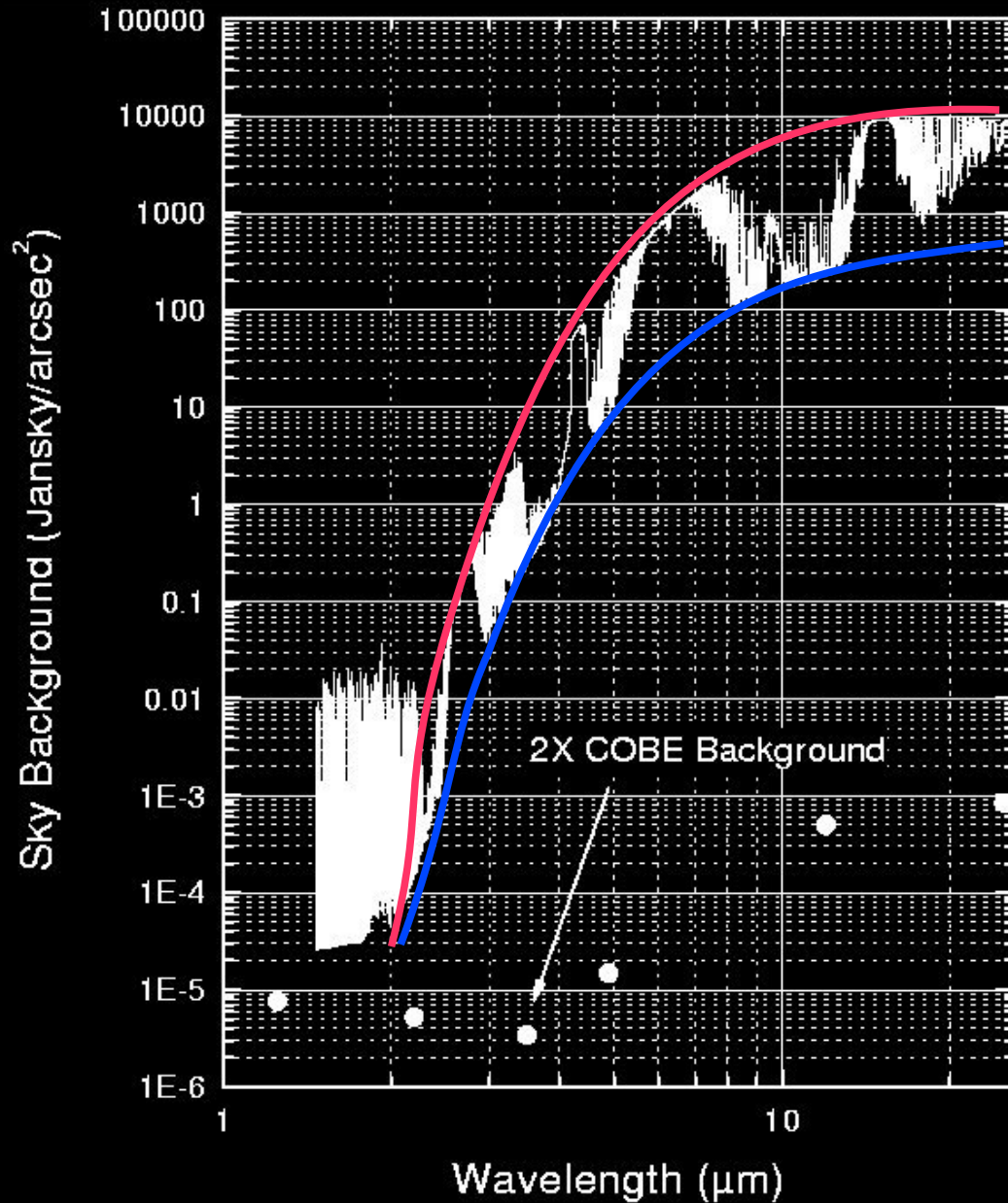


The Atmosphere above Paranal:



Thermal background
in the near- and
mid-infrared.

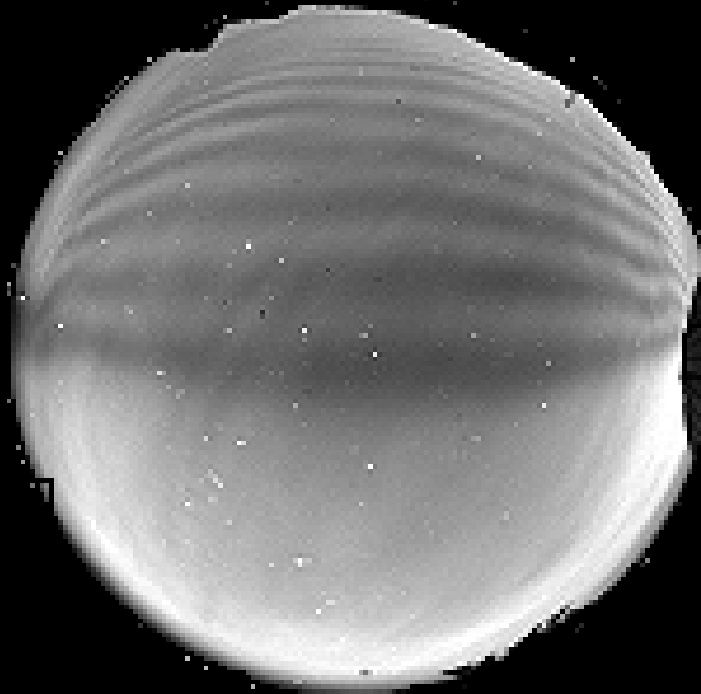
The Atmosphere above Paranal:



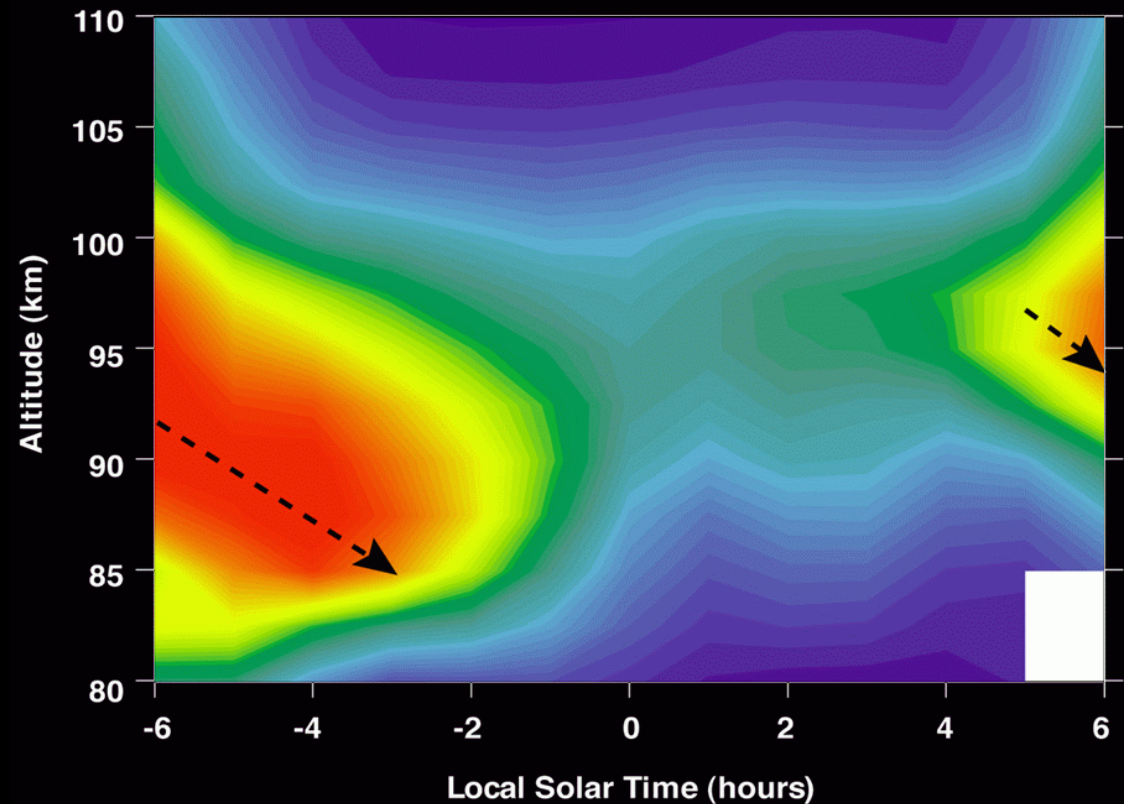
Thermal background
in the near- and
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The Atmosphere above Paranal:

OH^* airglow emission is highly variable!

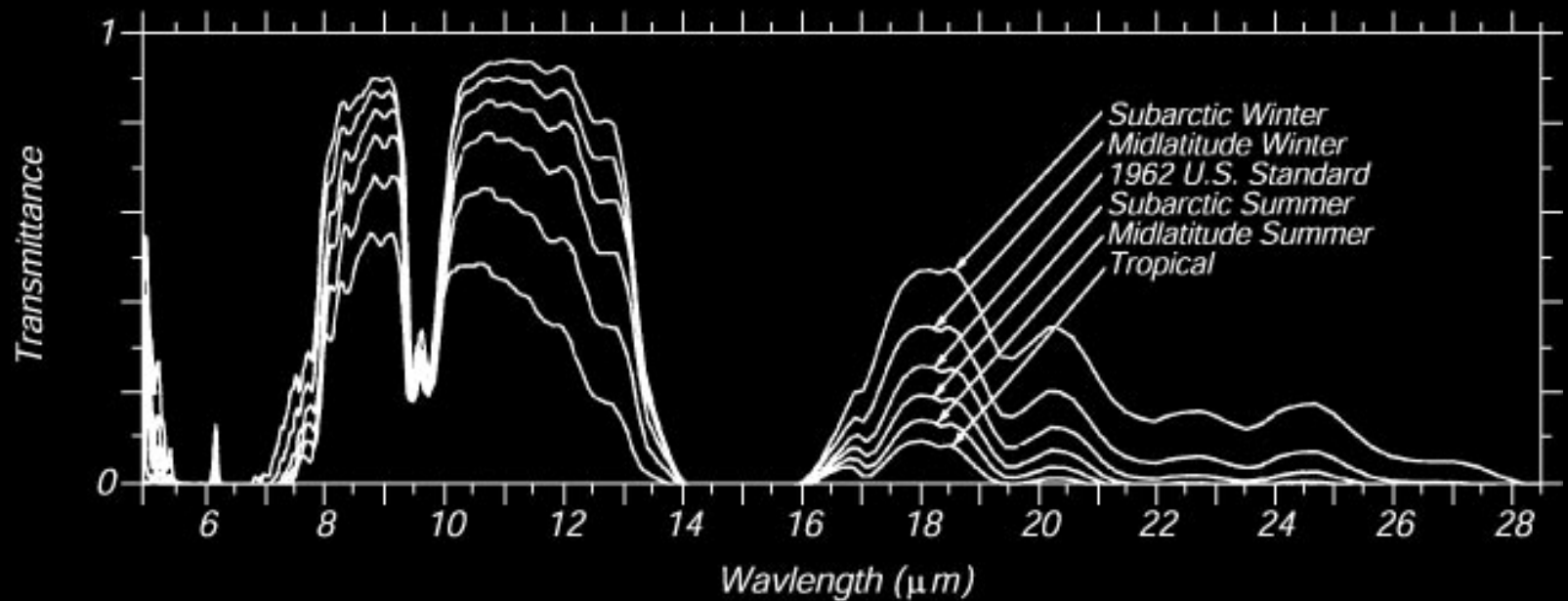
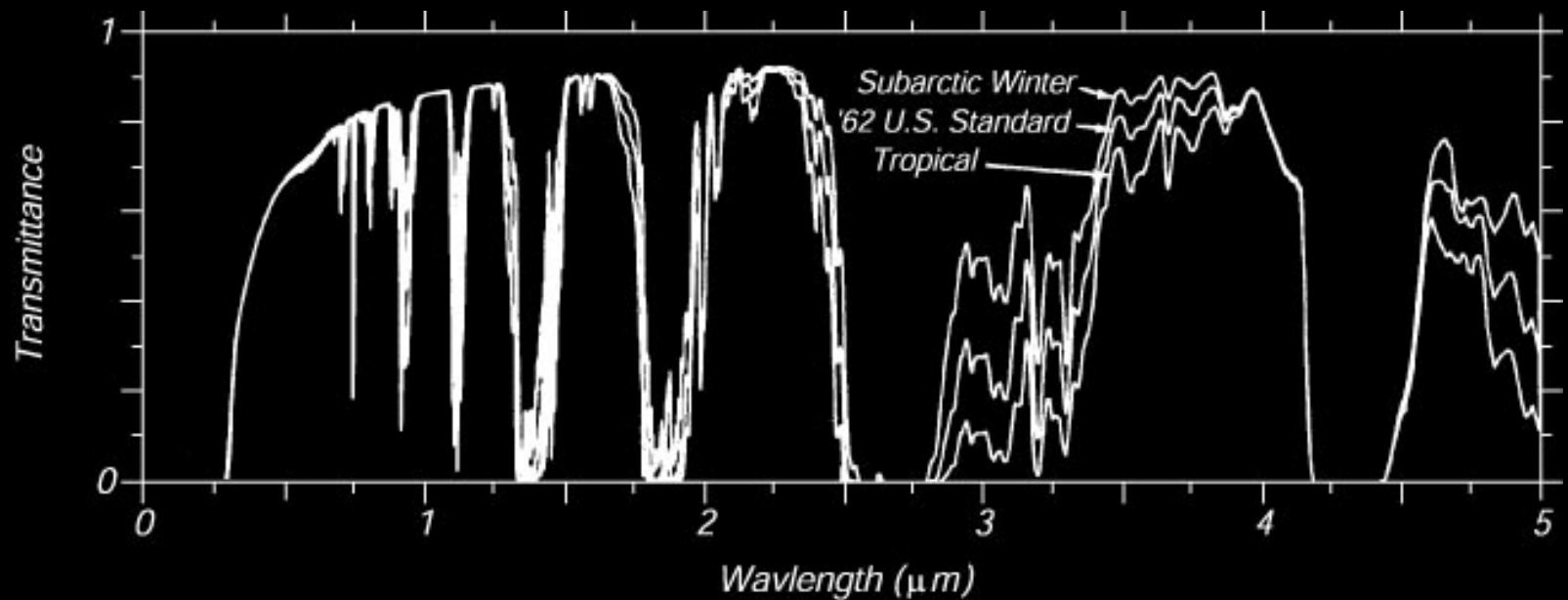


Gravitational waves over
McDonald observatory

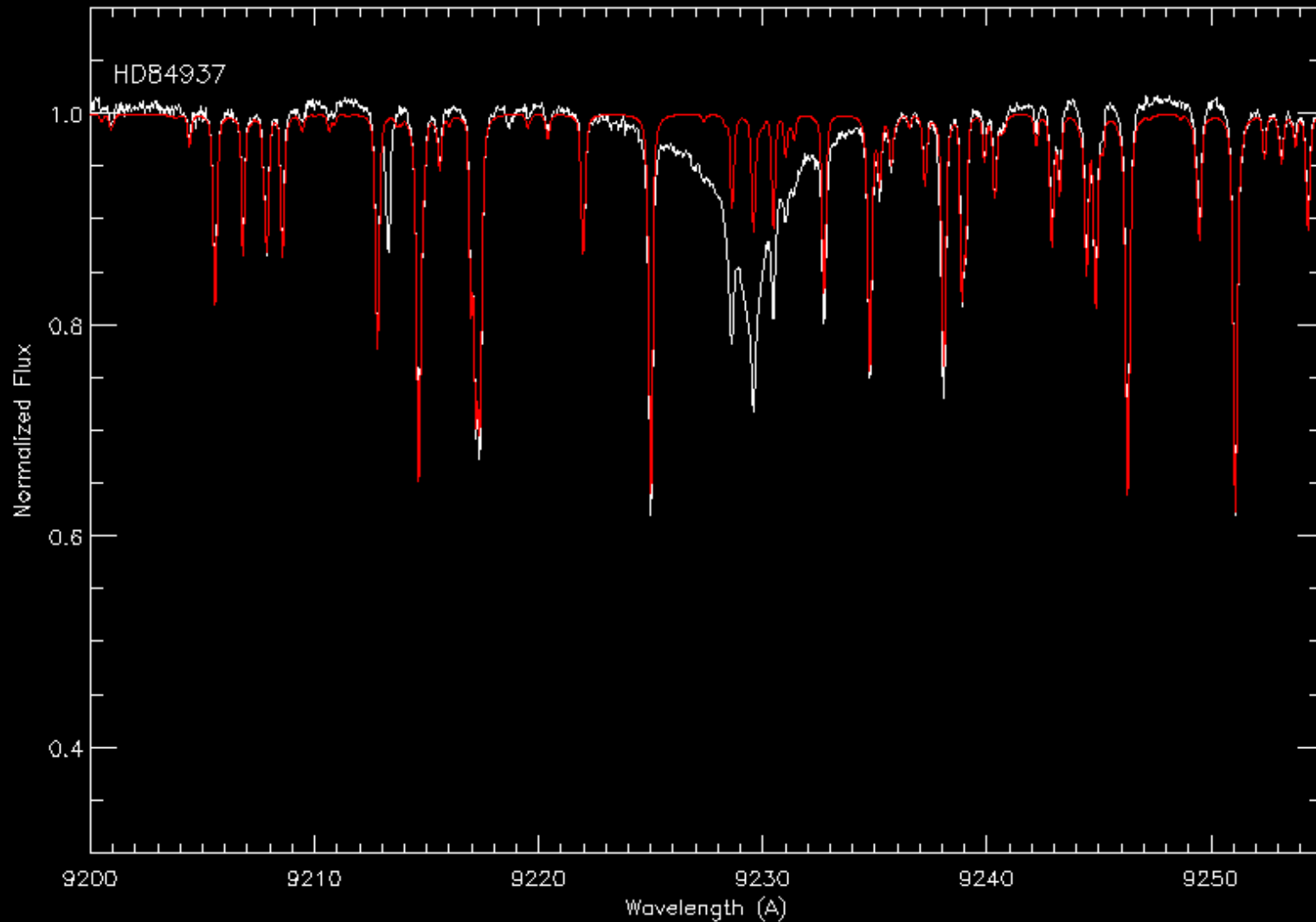


Night time variation of OH^* concentration

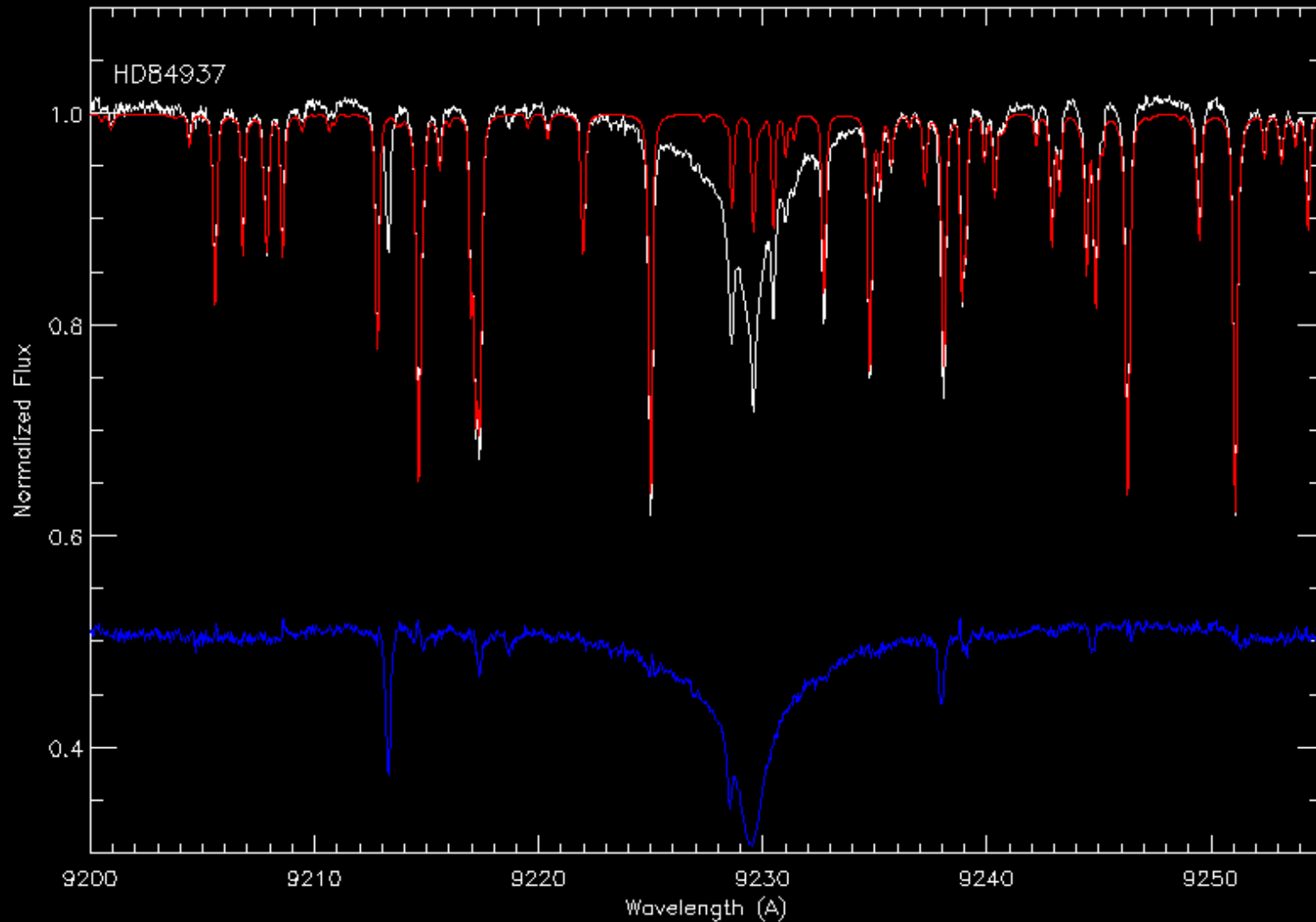
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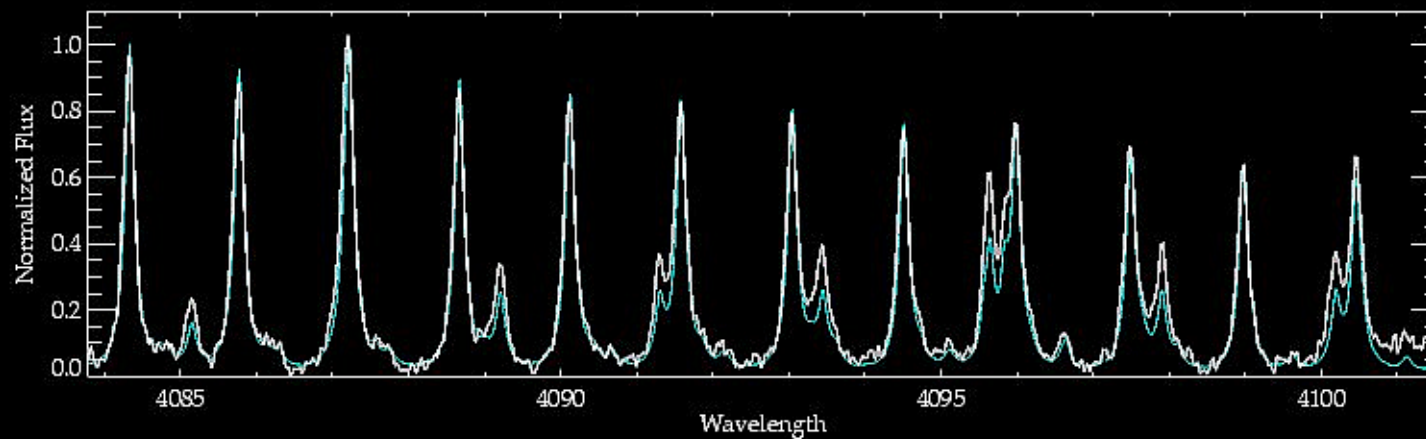
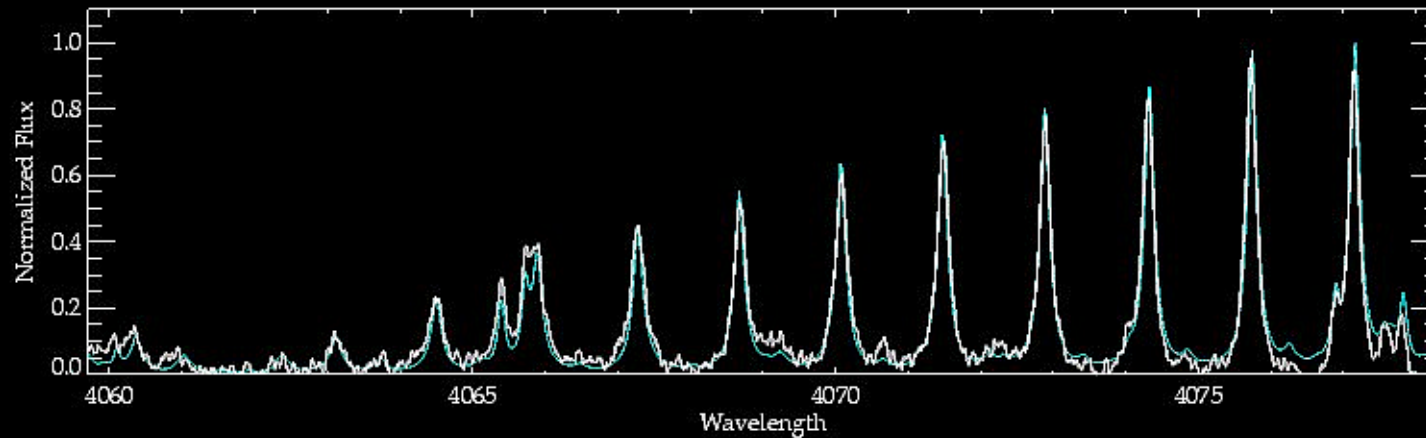
Calculating transmission & radiation



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CO₂ emission lines