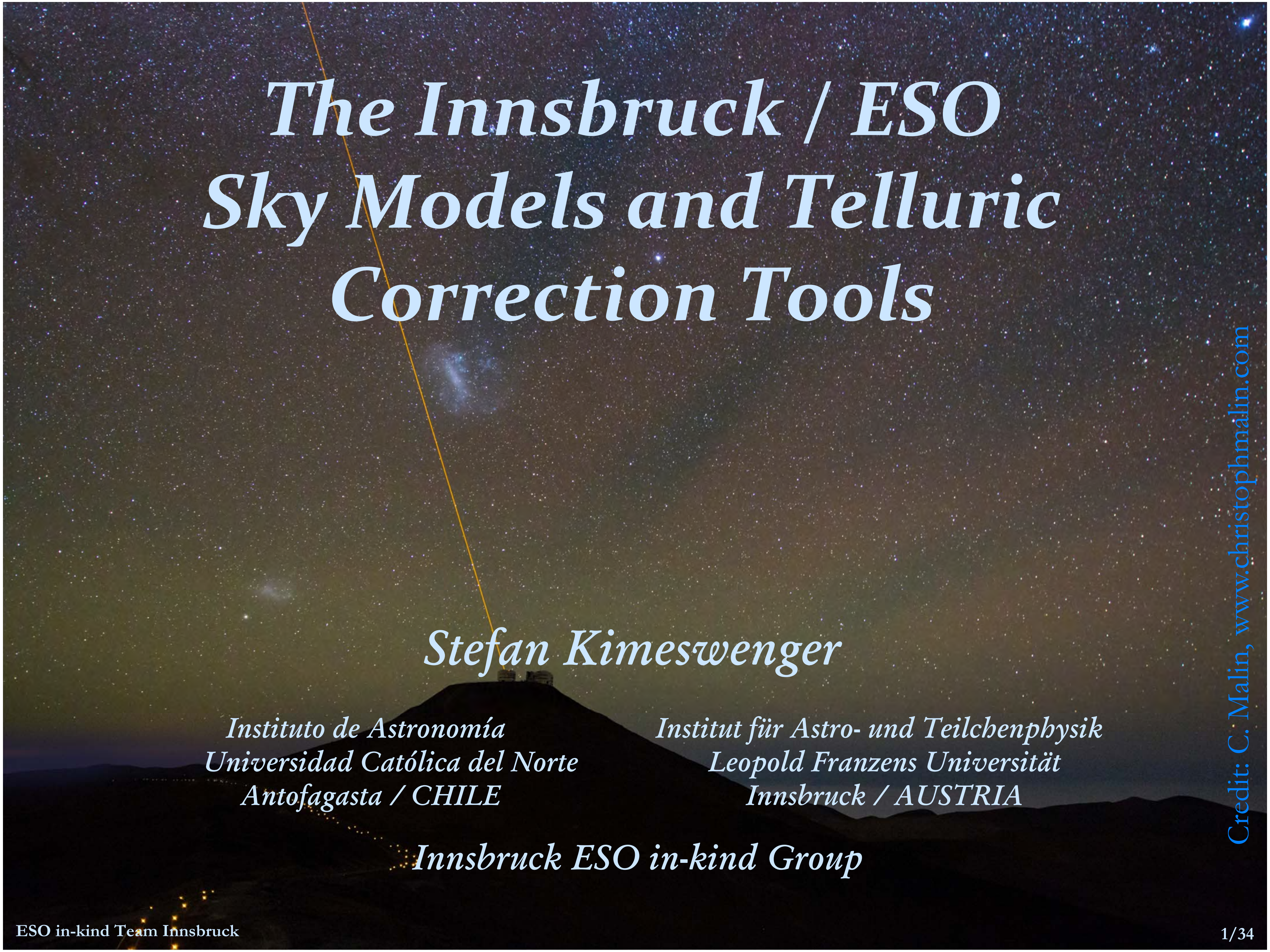


The Innsbruck / ESO Sky Models and Telluric Correction Tools

Stefan Kimeswenger

Instituto de Astronomía
Universidad Católica del Norte
Antofagasta / CHILE

Institut für Astro- und Teilchenphysik
Leopold Franzens Universität
Innsbruck / AUSTRIA

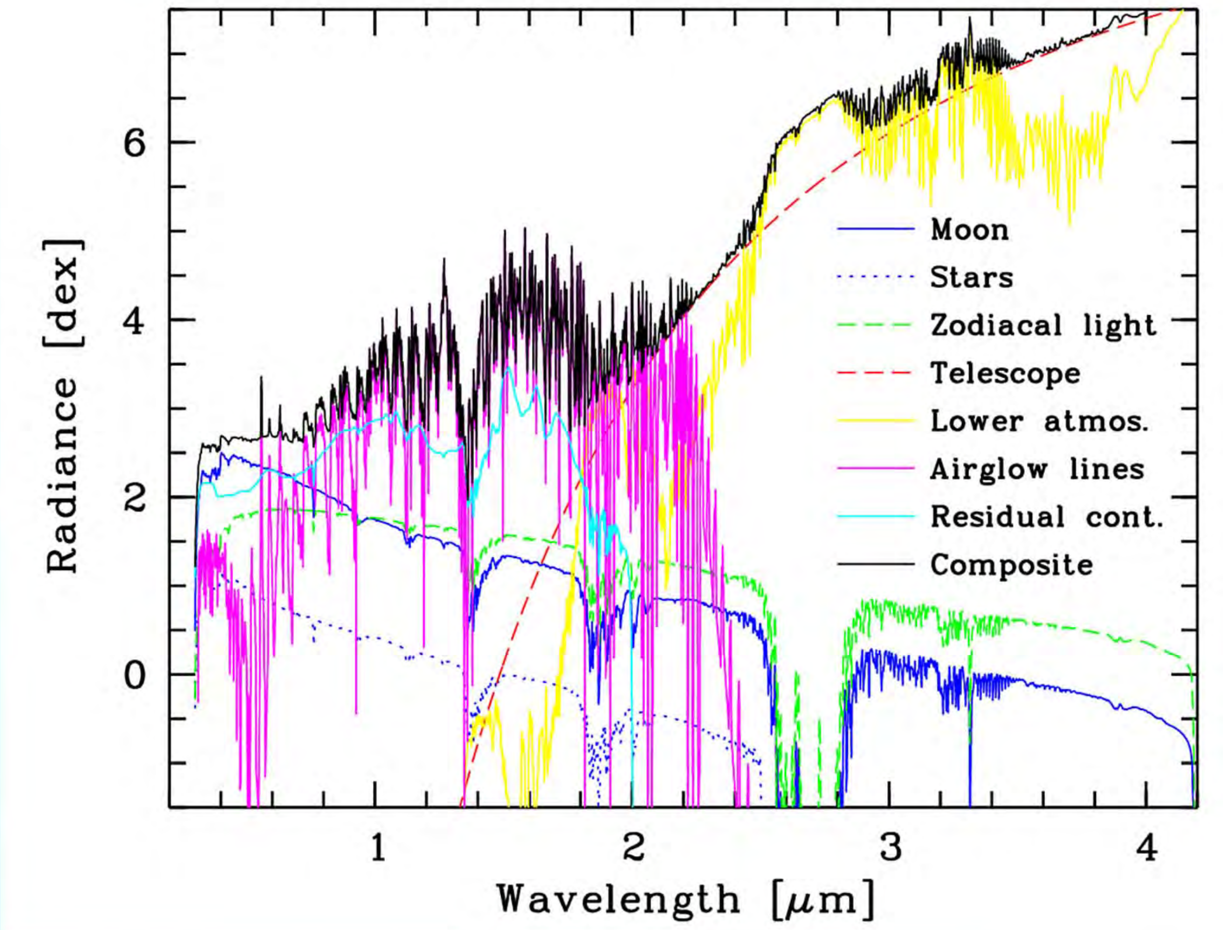
Innsbruck ESO in-kind Group

Credit: C. Malin, www.christophmalin.com

Outline of my talk

- Design
- Ingredients of the Model
- Status and Results
- Research
- Adaption (other facilities, sites and requirements)

Cerro Paranal Advanced Sky Model



General description (optical): Noll et al. 2012, A&A, 543, A92

Scattered moonlight model: Jones et al. 2013, A&A, 560, A91

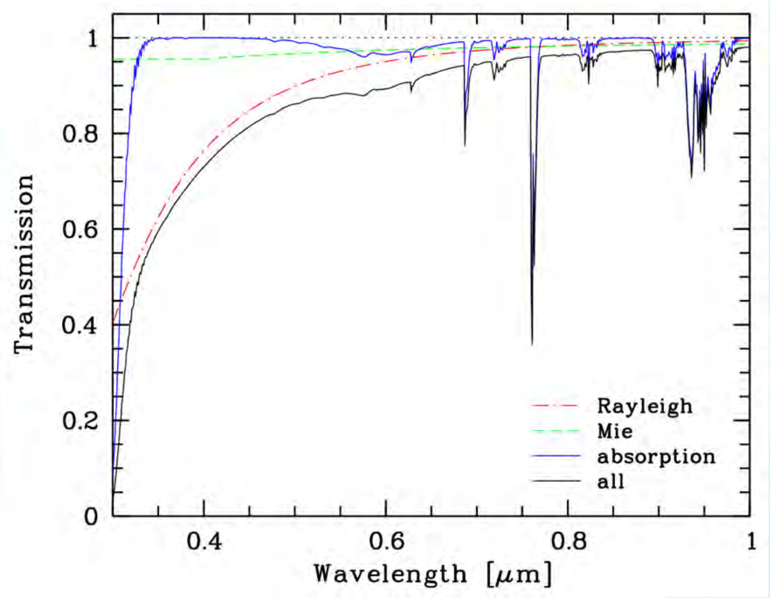
Processes in the lower atmosphere

Scattering, absorption, and thermal radiation by molecules in the troposphere and stratosphere

Calculation of spectra by atmospheric radiative transfer code LBLRTM (Line-By-Line Radiative Transfer Model)

Required input:

- HITRAN line data base
  (39 molecules and > 2.7 million lines)
- Profiles of pressure, temperature, and molecular abundances

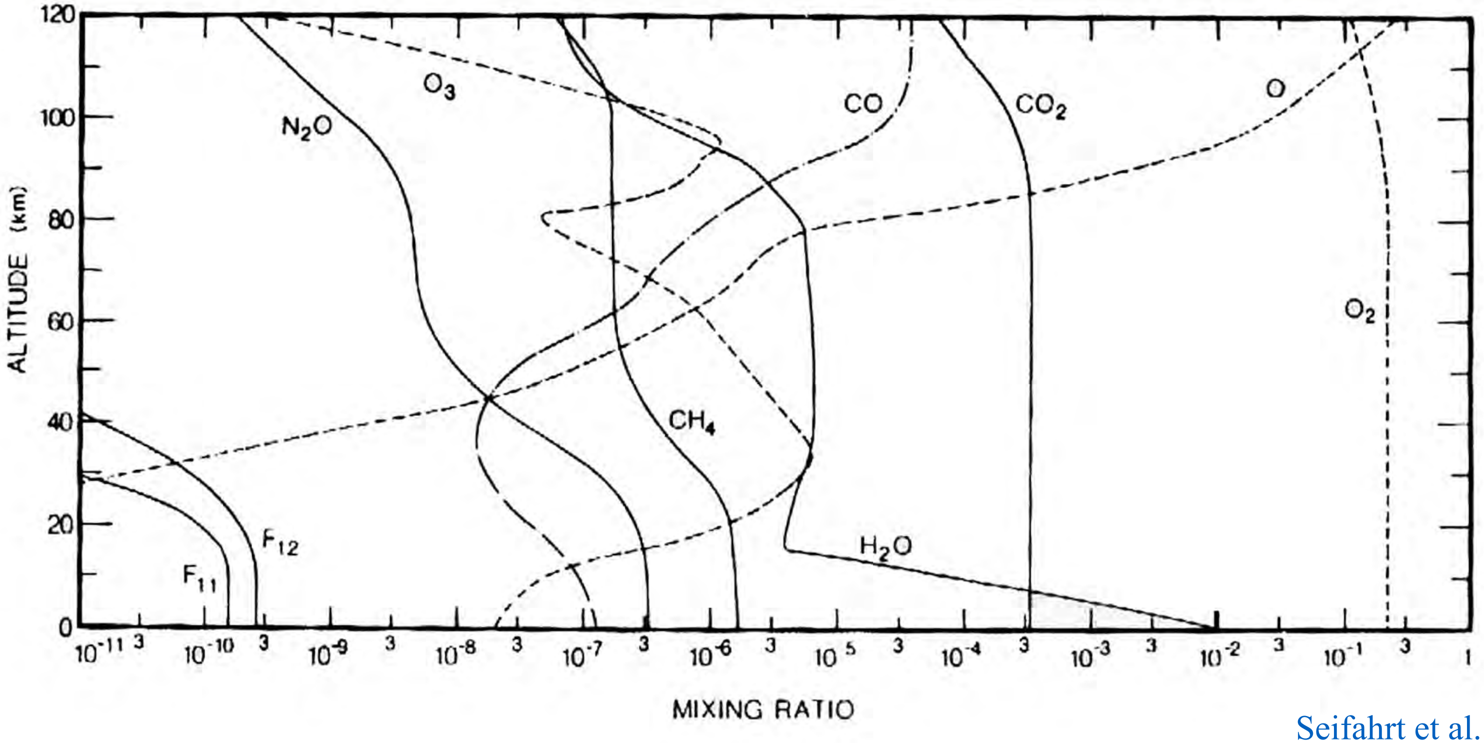


Molecular absorption: LBLRTM calculations depending on season

Rayleigh scattering (molecules): parametrisation by Liou (2002)

Aerosol extinction: Ångström-law fit by Patat et al. (2011) for Paranal and extension (Jones et al. 2014, A&A submitted)

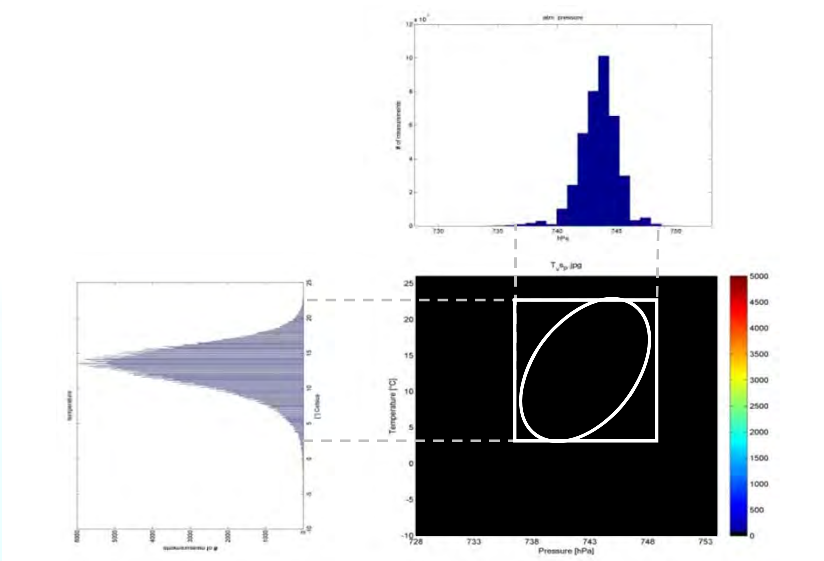
Atmospheric profiles

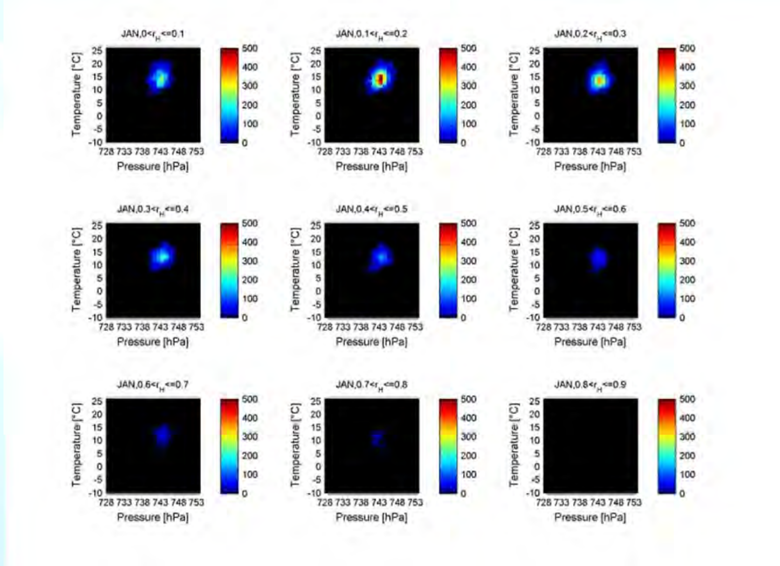


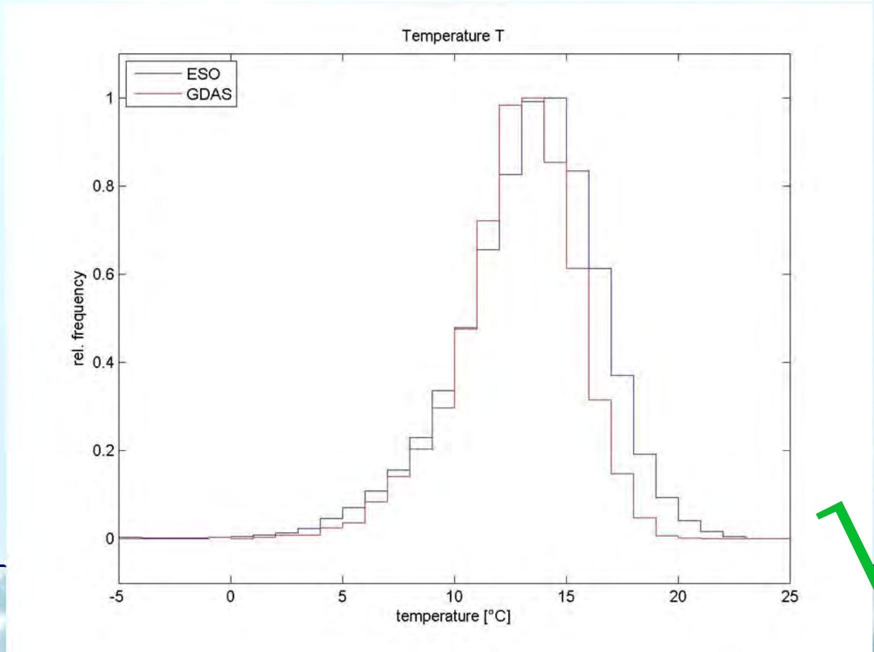
Seifahrt et al. 2010

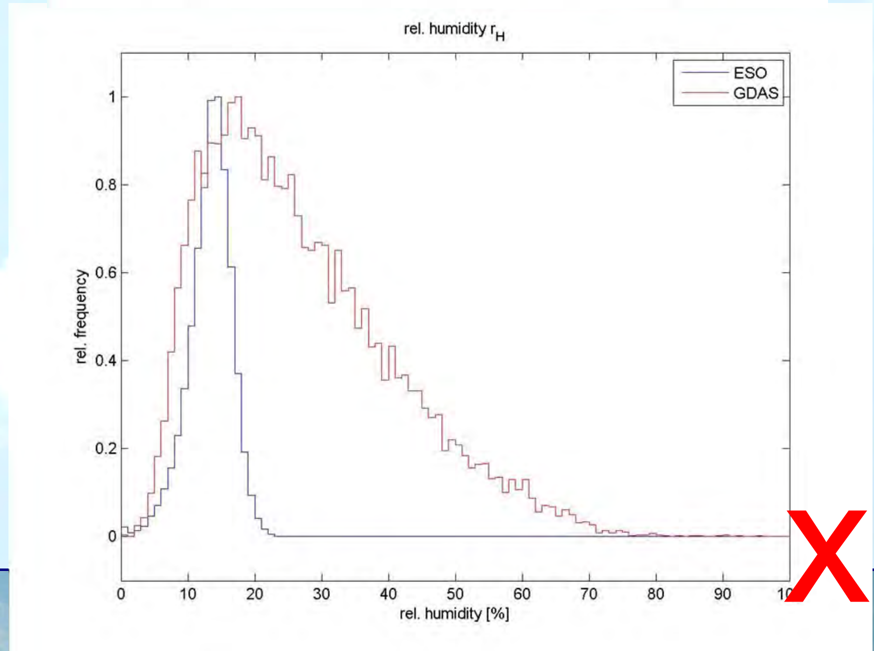
Optimisation for Cerro Paranal: standard profiles (MIPAS@ENVISAT) + weather-dependent pressure, temperature, and humidity (H_2O) from GDAS weather models (profiles up to 26 km; 1° x 1° and 3 h resolution), and ESO meteo monitor at 2.6 km

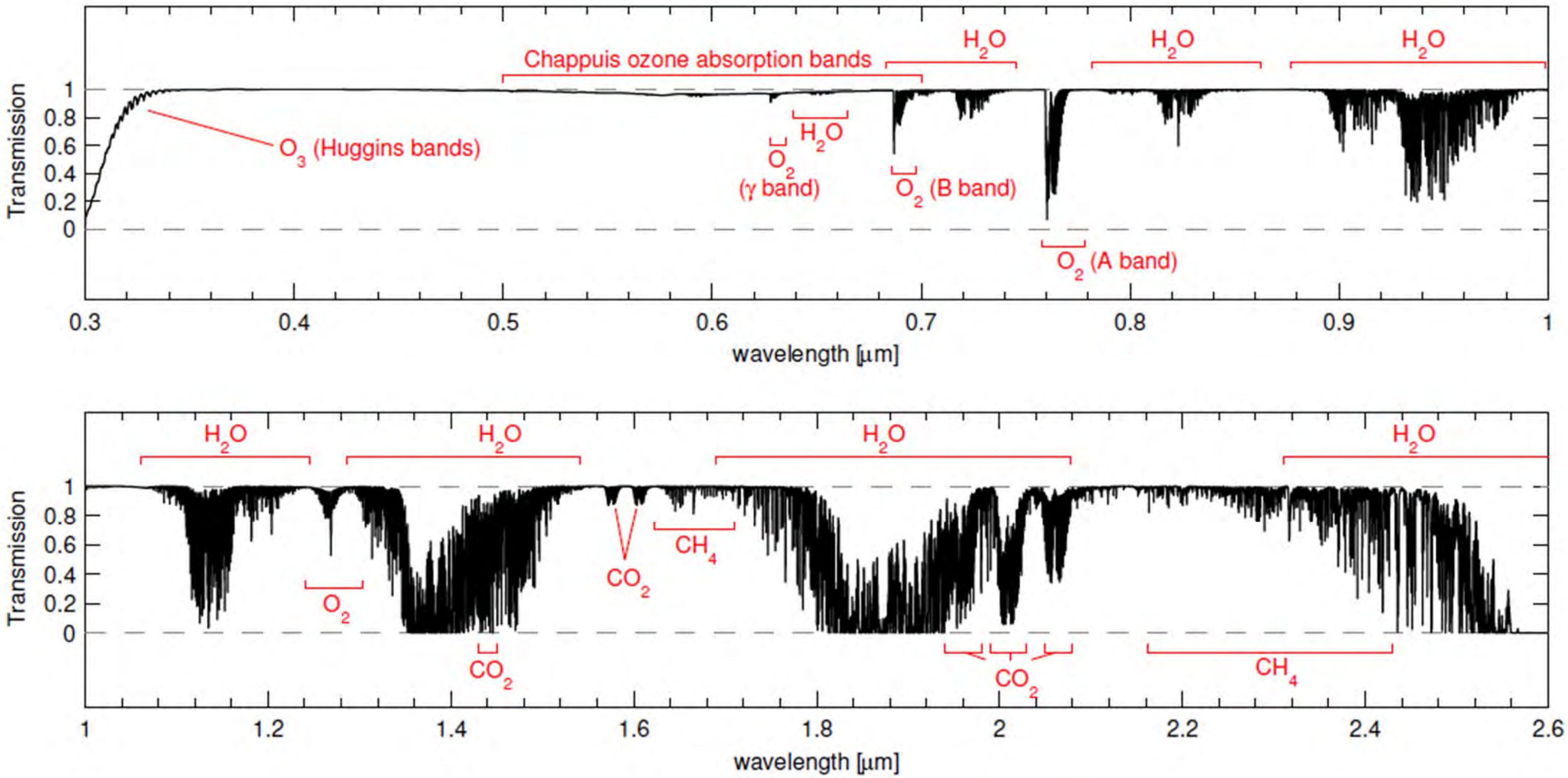
GDAS vs. ESO MeteoMonitor










Transmission
wavelength [μm]
Chappuis ozone absorption bands
H_2O
O_3 (Huggins bands)
O_2 (γ band)
O_2 (B band)
O_2 (A band)
O_2
CO_2
CH_4
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6

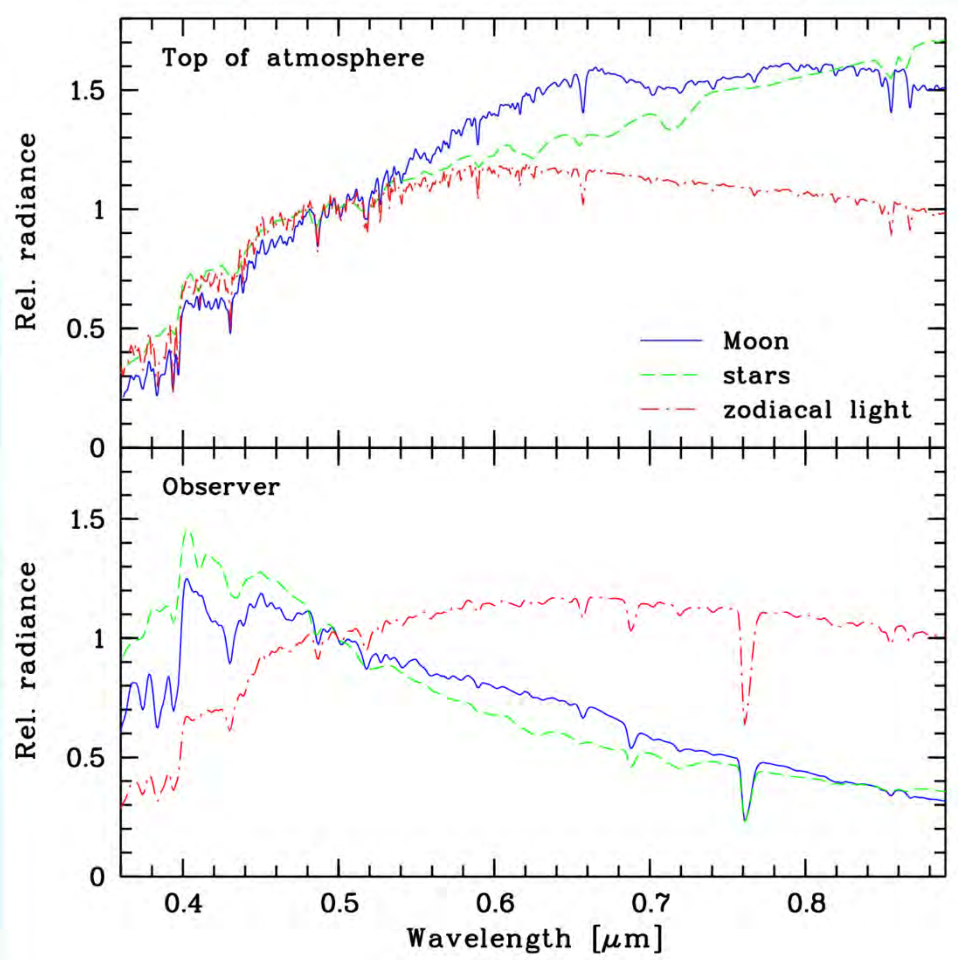
Background Light

Zodiacal light and integrated starlight: Leinert et al. (1998)

Starlight spectrum: Mattila (1980)

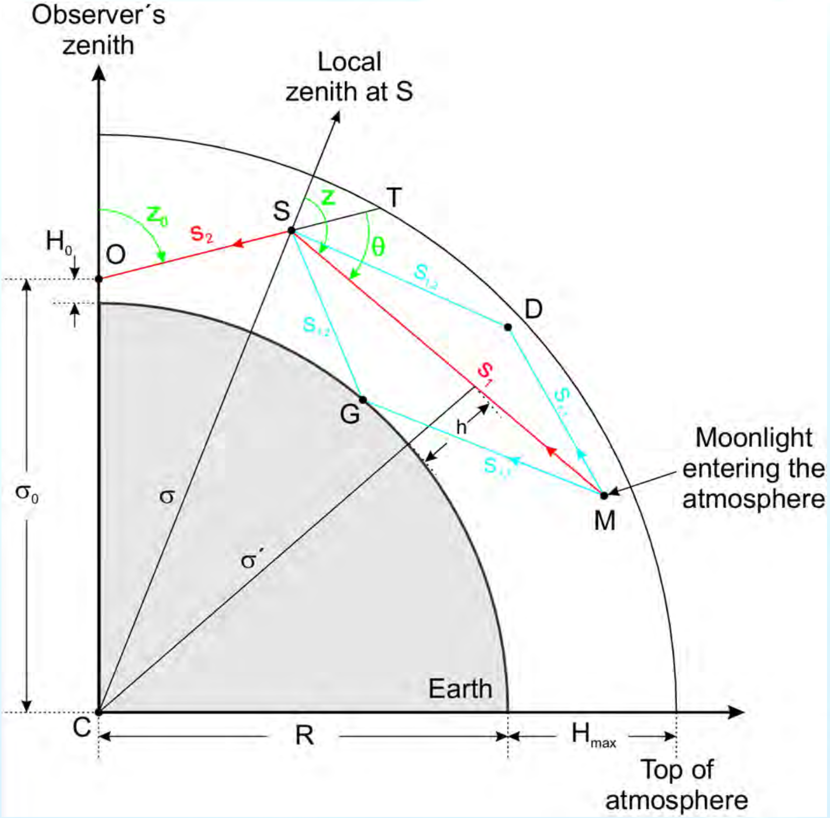
Moon albedo: ROLO (Kieffer & Stone 2005)

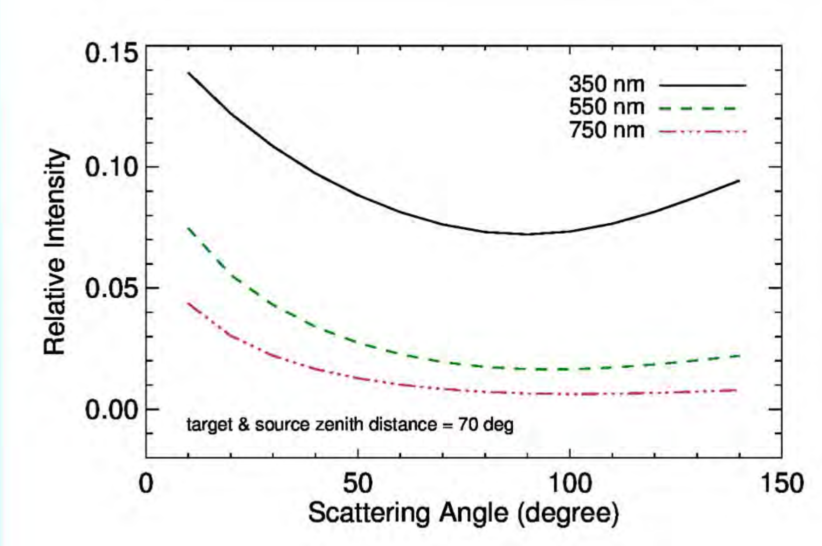
Radiative transfer: own 3D scattering code (Noll et al. 2012; Jones et al. 2013)



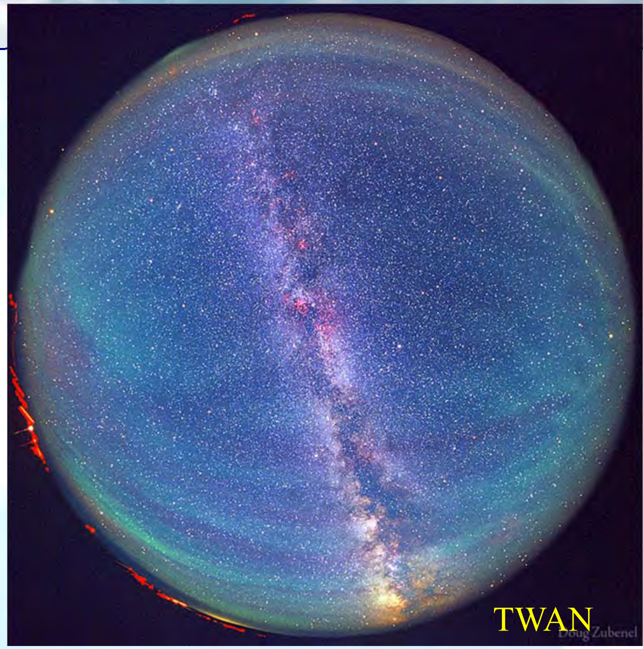
Radiative transfer of moonlight

Single and double scattering at molecules, aerosols, and the ground with multiple scattering correction (Jones et al. 2013, 2014)





Airglow



Chemiluminescence (light emission by chemical reactions)

Solar UV radiation starts chain reactions by photochemical reactions (airglow reaction can be significantly delayed).

Dayglow much brighter than nightglow

Origin in mesopause / lower thermosphere (MLT) region ($P < 0.01$ mbar □ thin gas)

Usually very thin emission layers of a few km thickness only

Airglow variability

Diurnal variations (sun altitude)

Seasonal variations

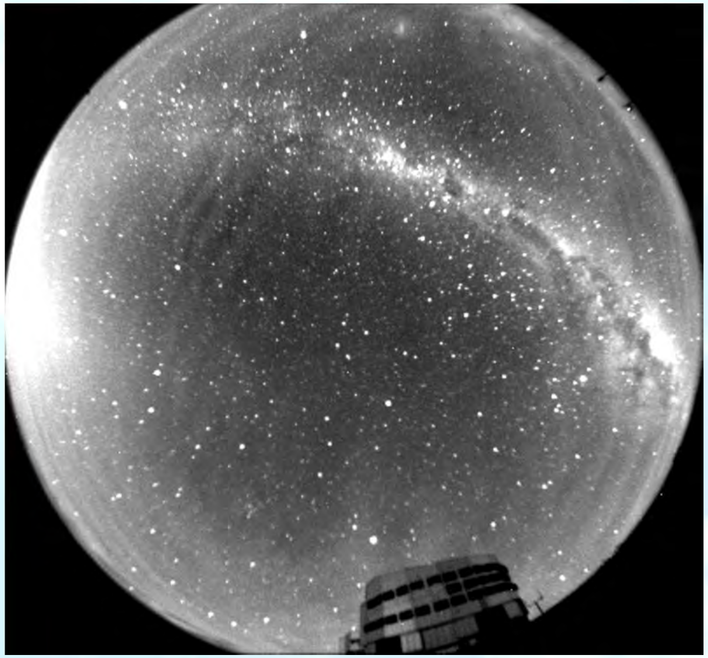
11-yr solar activity cycle

Lunar variations (e.g. tides)

Dependence on latitude

Gravity waves (P > 5 min; caused by mountains / weather fronts)

Longterm trend (→ climate change)



MASCOT/Paranal/ESO

Site-dependent semi-empirical airglow model required!

Noll et al. 2014, A&A, in press

Airglow variability

Diurnal variations (sun altitude)

Seasonal variations

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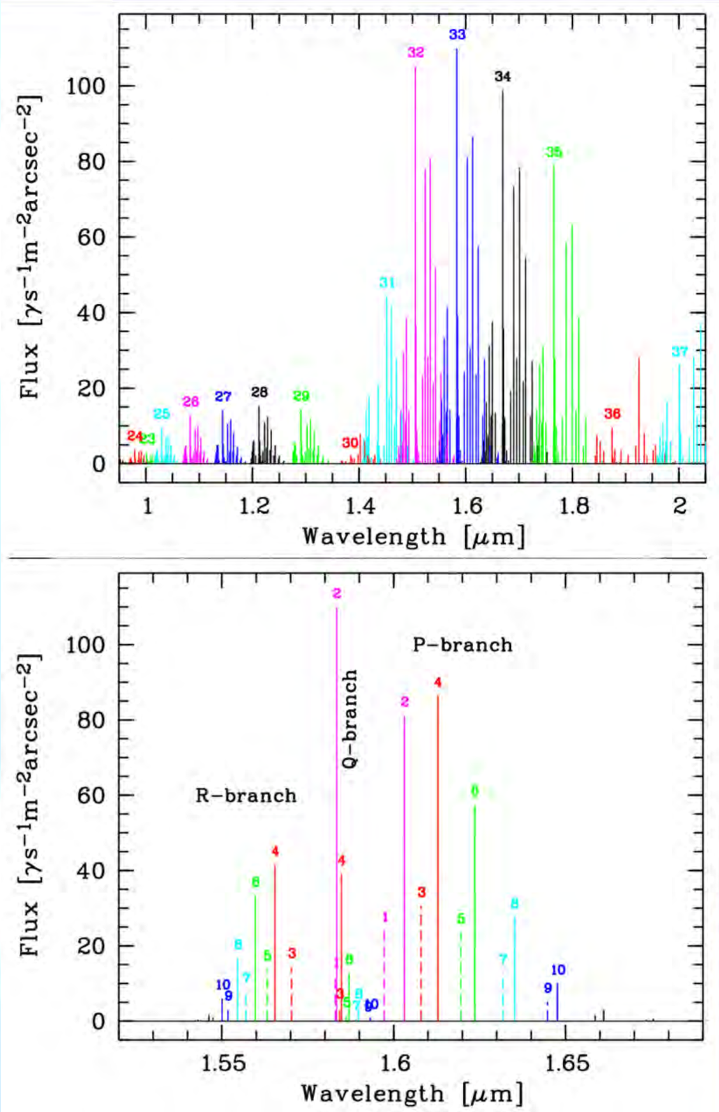
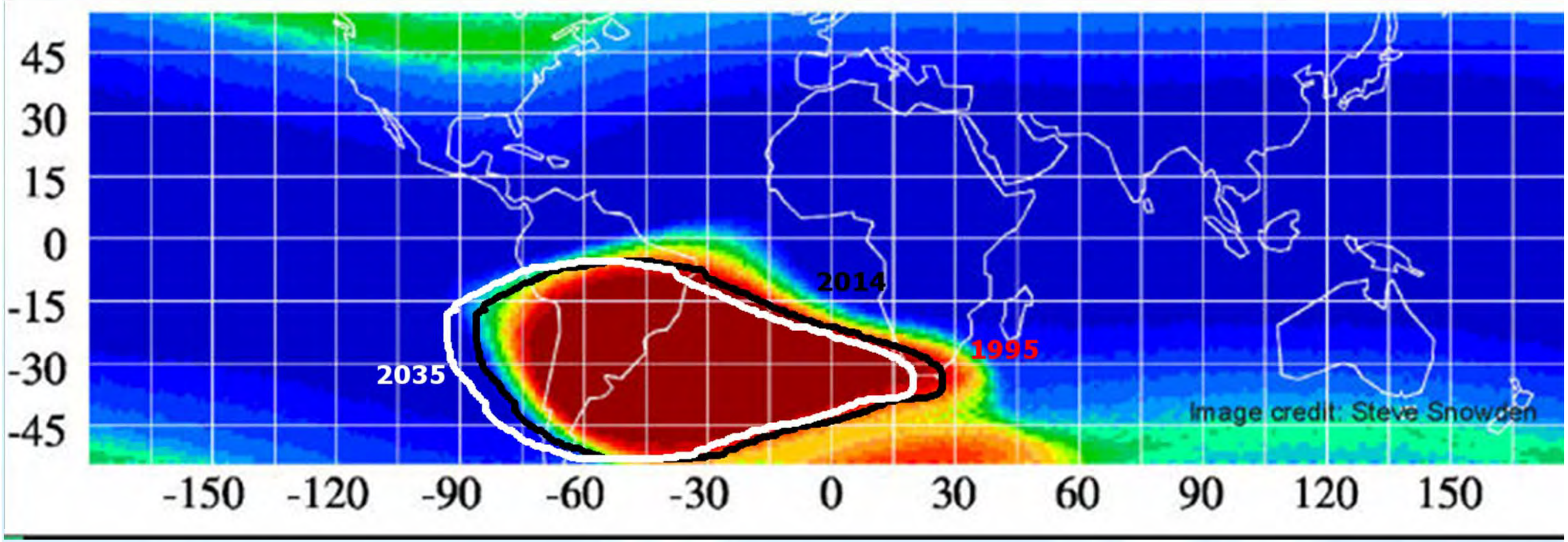


Airglow changes over a project period ?

The South Atlantic Anomaly
moves about 0.3° / year westwards
(Stassinopoulos, E.G.; Staffer, C.A. 2007)



CODES (molecfit, skycorr)

Fitting from spectre (if available in that wavelength range) parameters of molecules and water vapour

Instrument-independent and for world-wide use
(although parameter sets currently optimised for Cerro Paranal)

The code has been designed to minimise user interaction. Very robust automatic sequences with little or no user adaption of parameters:

→ **pipeline ready**

Programming language: strict ANSI standard C
(involving ESO's CPL library)

First public release was on 1st of April 2014 (see http://www.eso.org/pipelines/skytools/)

Fitting procedure

χ^2 minimisation by a Levenberg-Marquardt technique (MPFIT)

Fitting parameters:

- Scaling factors for molecular profiles
- Coefficients of polynomials for continuum fit
- Coefficients of Chebyshev polynomials for modification of wavelength grid
- Widths of boxcar, Gaussian, and Lorentzian for instrumental profile (alternative: user-provided kernel)
- Emissivity of additional greybody (only for fit of sky emission spectra in the thermal IR)

CODES (molecfit, skycorr)

Parameter files in ASCII:

easy to use – and moreover easy to create in automatic procedures in any scripting language

Input allows already now many different FITS file structures commonly used for optical and NIR spectra.

Output try to follow as far as possible input structure + one set ´normalized´ to one common type strictly defined data structure.

Driver for MOLECFIT
Base directory (default: ".")
basedir: /home/stefan/ESO_SKYTOOLS/molecfit

user working directory
user_workdir: /home/stefan/Mrk359_2/reflex_end_products/hr9087

INPUT DATA
filename: /home/stefan/Mrk359_2/reflex_end_products/hr9087/uvb_hr.fits

Names of the file columns (table) or extensions (image) containing:
Wavelength Flux Flux_Err Mask
columns: NULL NULL NULL NULL

Initial constant term for wavelength correction (shift relative to half
wavelength range)
wlc_const: 0.0
Telescope altitude angle in deg
telalt
telalt_key: ESO TEL ALT

BACKGROUND AND CONTINUUM

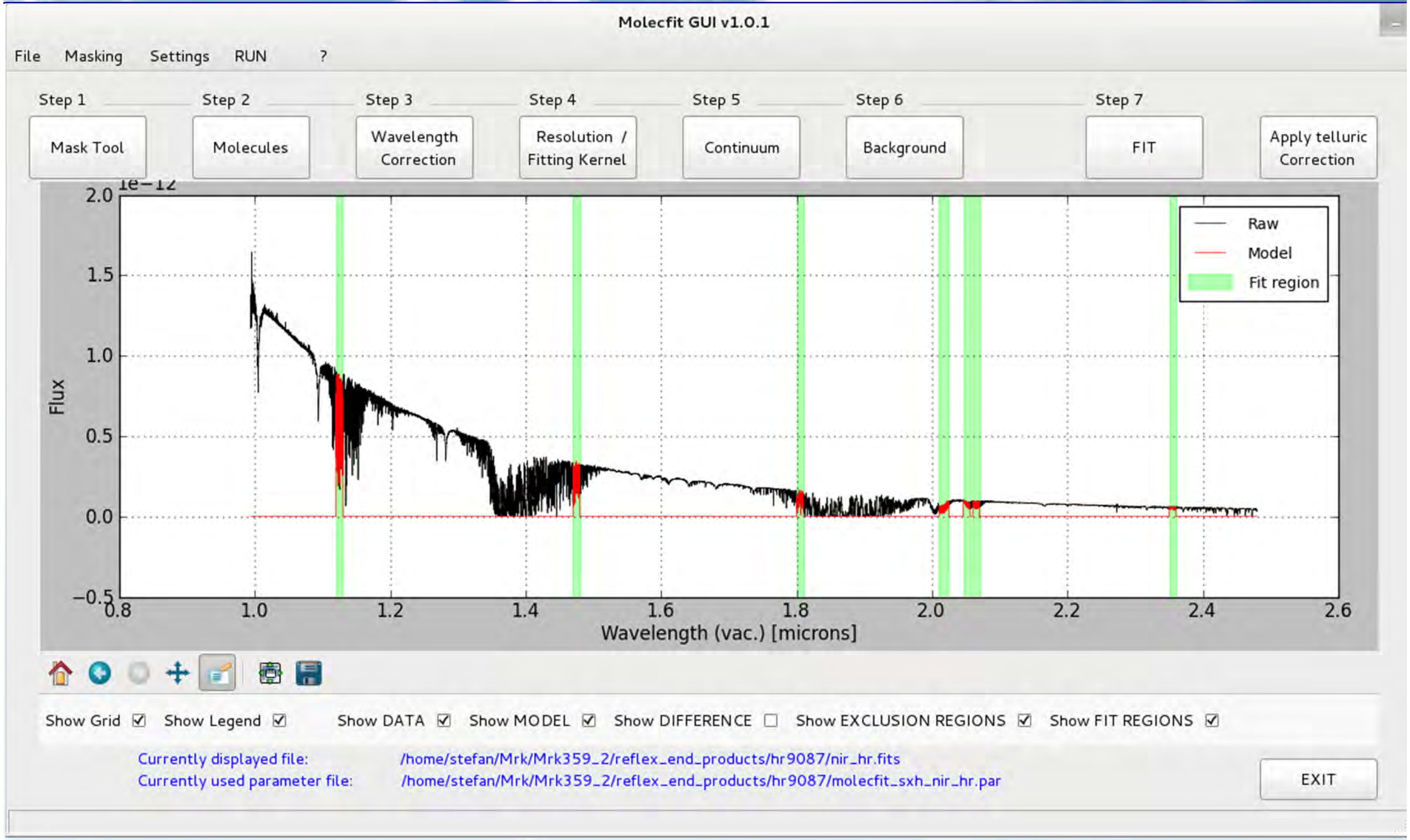
Conversion of fluxes from phot/(s*m2*mum*as2) (emission spectrum only) to
flux unit of observed spectrum:
0: phot/(s*m^2*mum*as^2) [no conversion]
1: W/(m^2*mum*as^2)
2: erg/(s*cm^2*A*as^2)
3: mJy/as^2
For other units the conversion factor has to be considered as constant term
of the continuum fit.
flux_unit: 0

WAVELENGTH SOLUTION

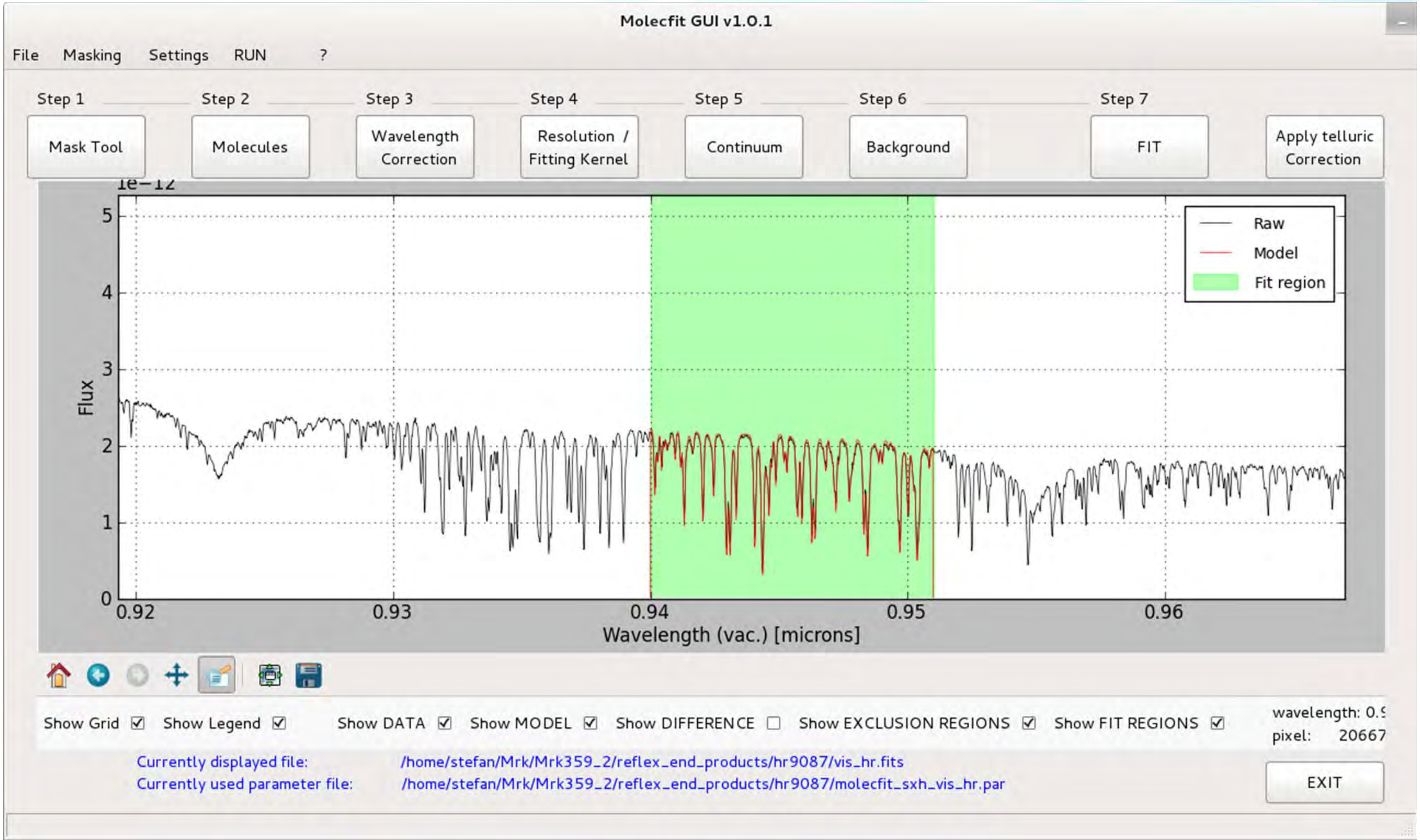
Refinement of wavelength solution using a polynomial of degree wlc_n
fit_wlc: 1

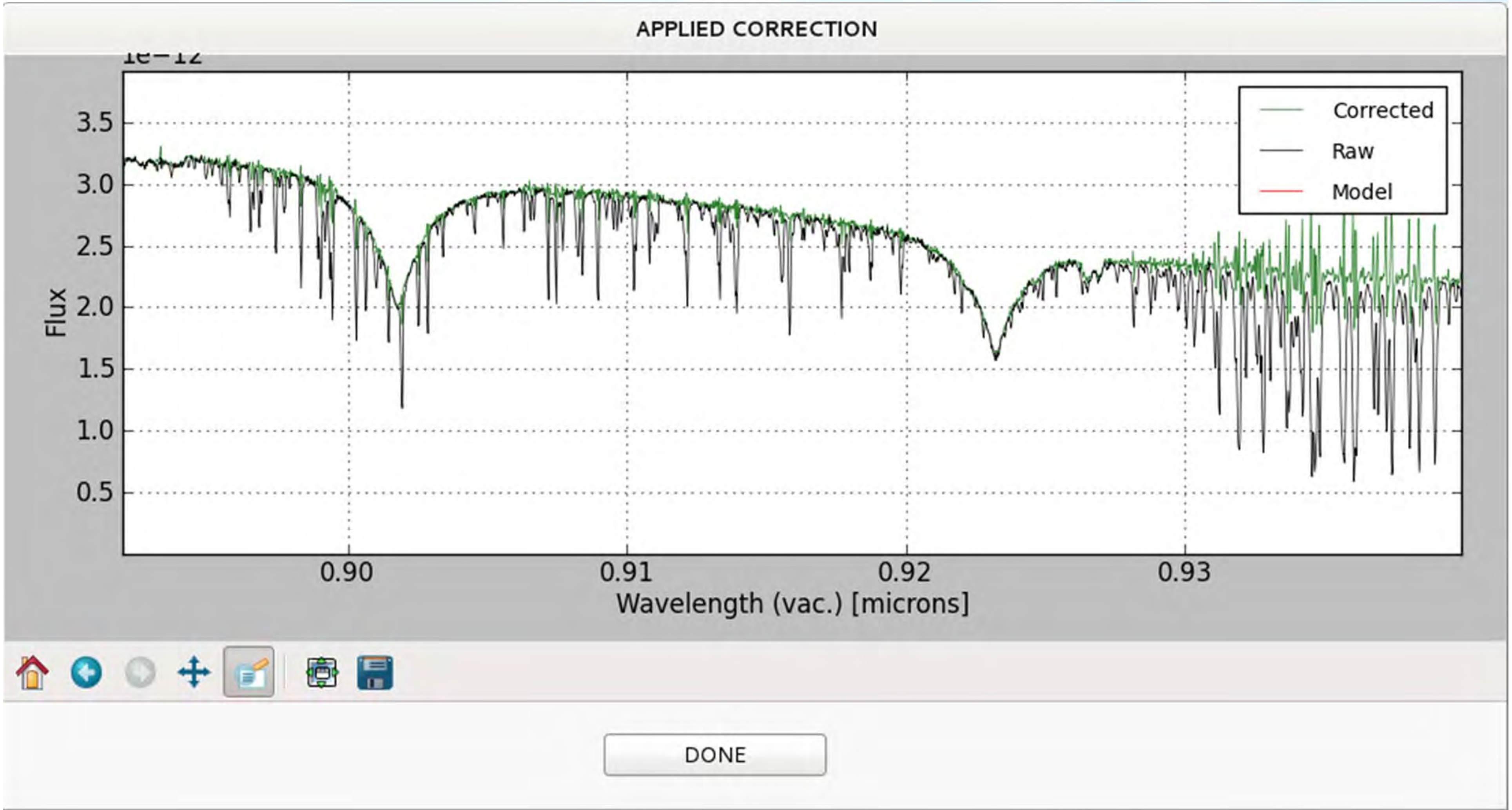
Polynomial degree of the refined wavelength solution
wlc_n: 1

Measuring Molecules

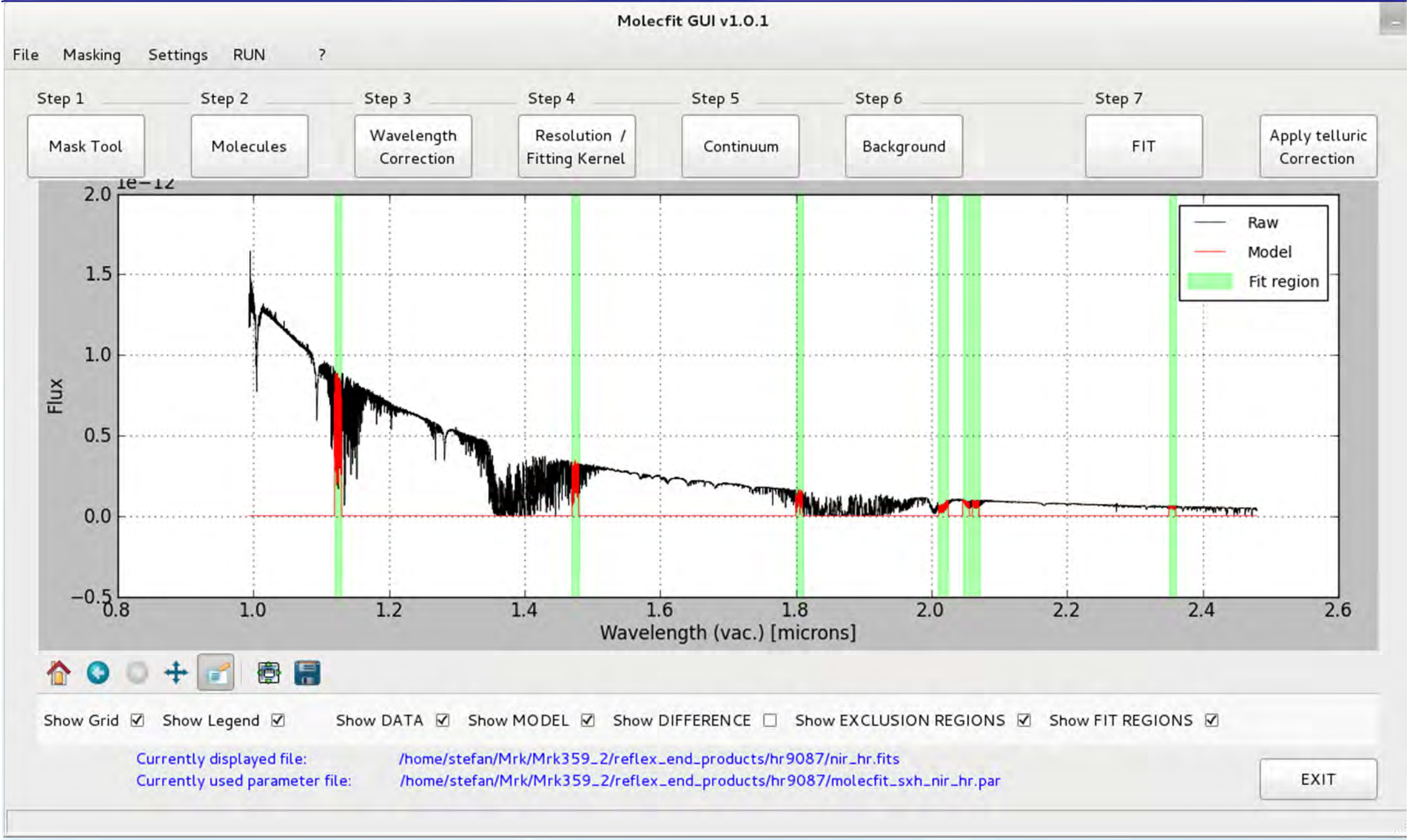


How accurately can we measure the water vapor content with astronomical spectra? (Kausch et al. 2014)



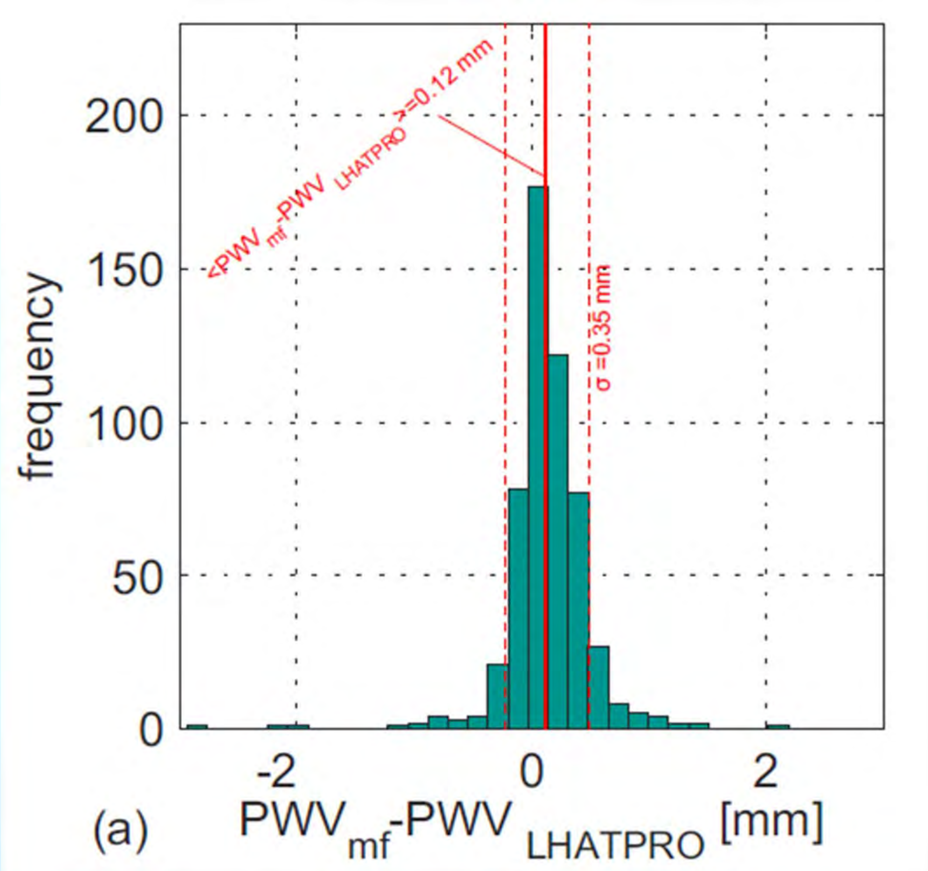

APPLIED CORRECTION
1e−12
3.5
3.0
2.5
2.0
1.5
1.0
0.5
Flux
0.90
0.91
0.92
0.93
Wavelength (vac.) [microns]
Corrected
Raw
Model
DONE

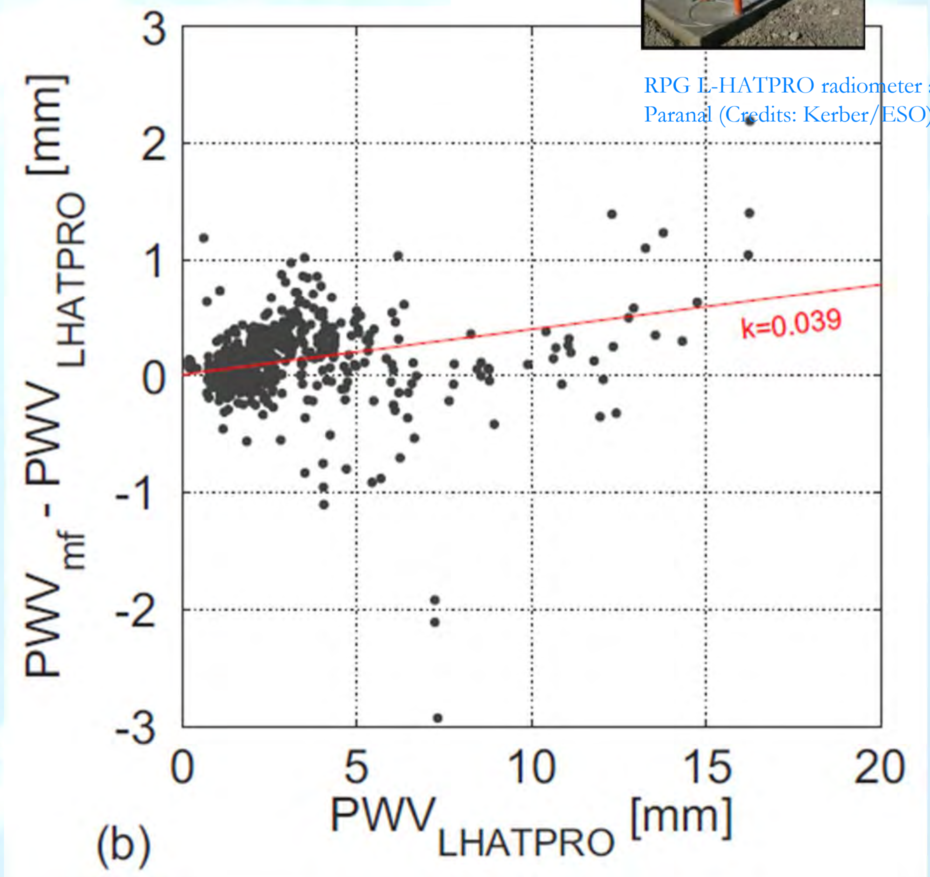
How accurately can we measure the water vapor content with astronomical spectra? (Kausch et al. 2014)



How accurately can we measure the water vapor content with astronomical spectra?

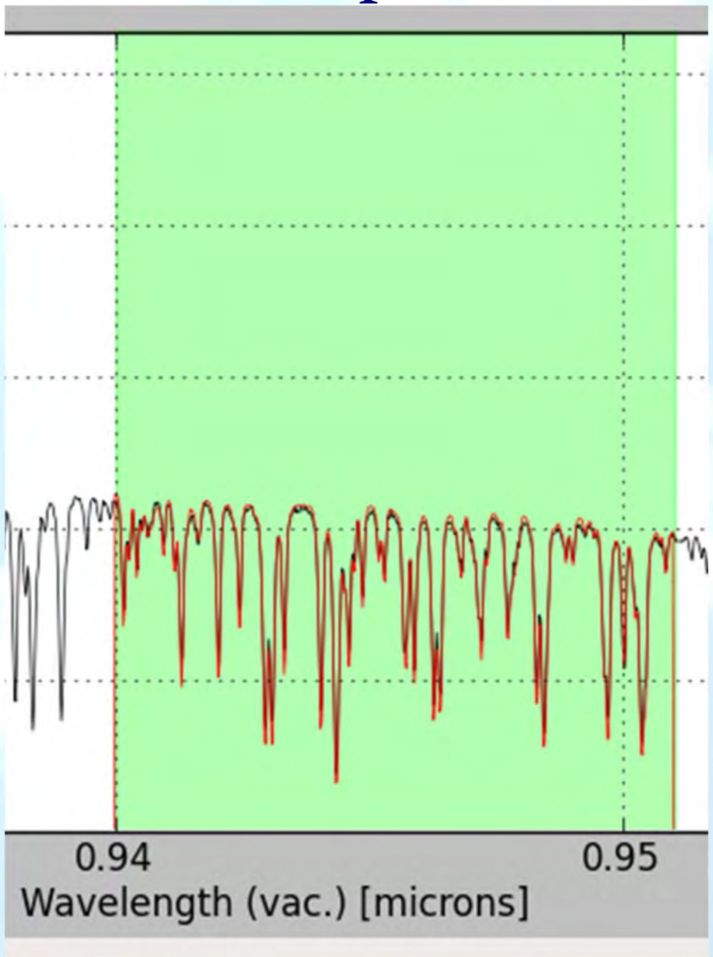
RPG L-HATPRO radiometer at Paranal (Credits: Kerber/ESO)





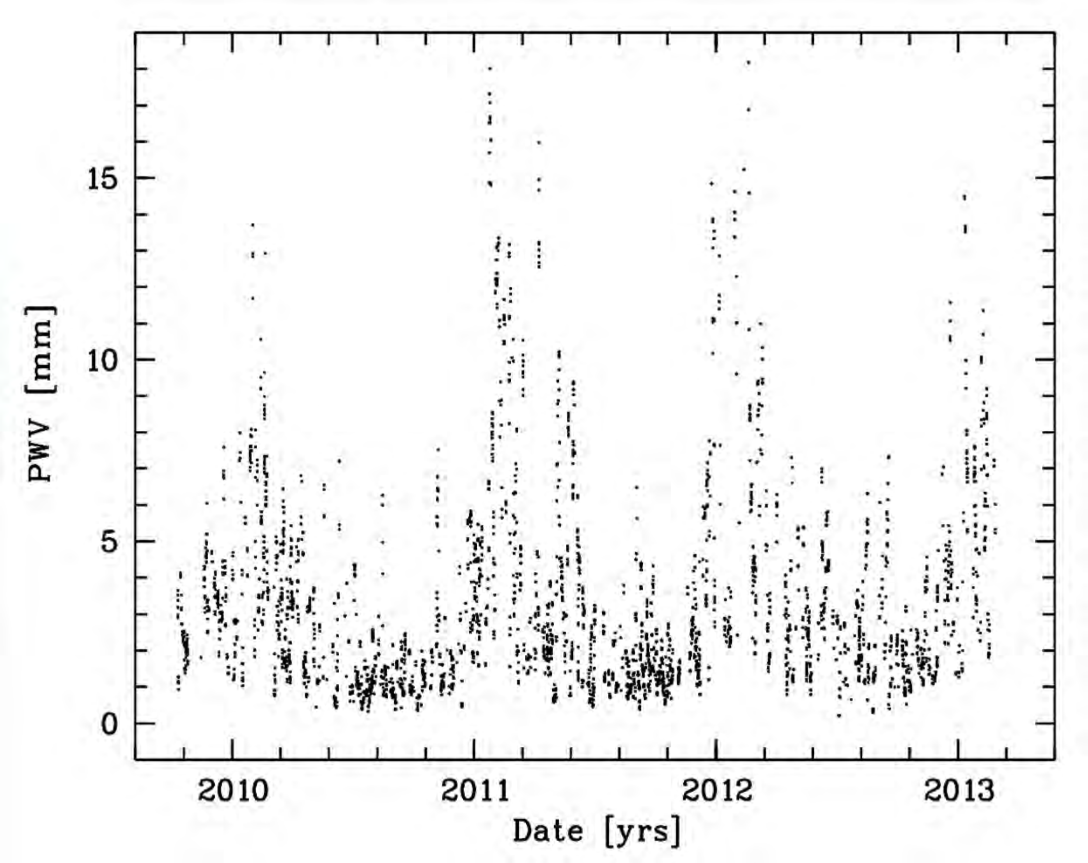
(Kausch et al. 2014, EGU)

direct FIT vs. applying NIR result to optical arm



Molecular abundances by MOLECFIT

PWV (precipitable water vapour)

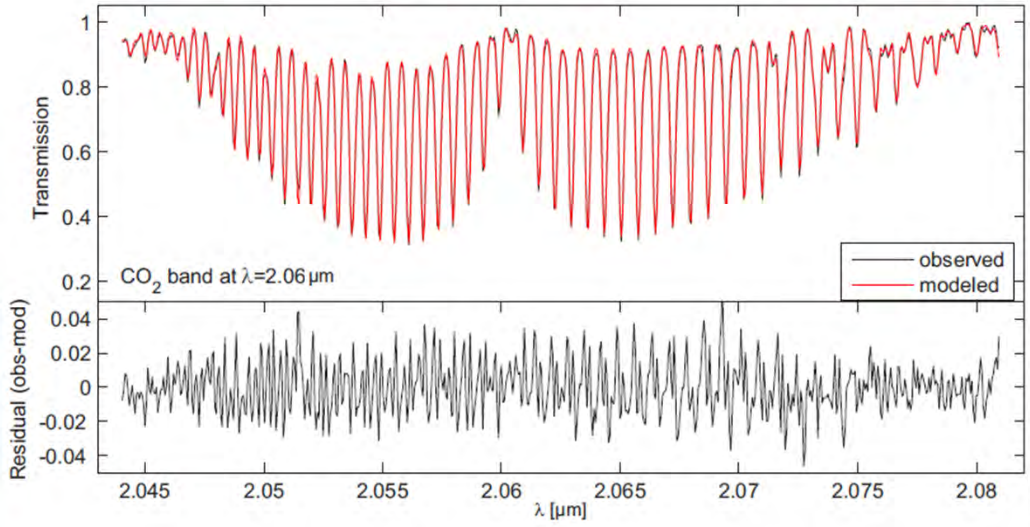


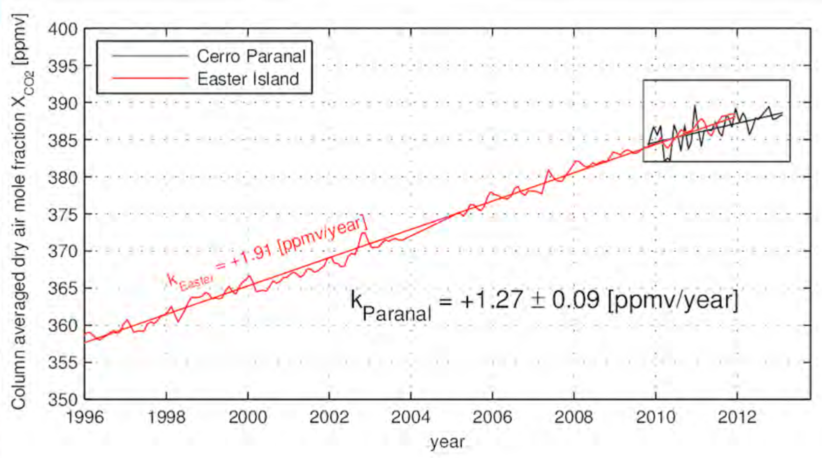
All measurements based on X-Shooter telluric standard star spectra

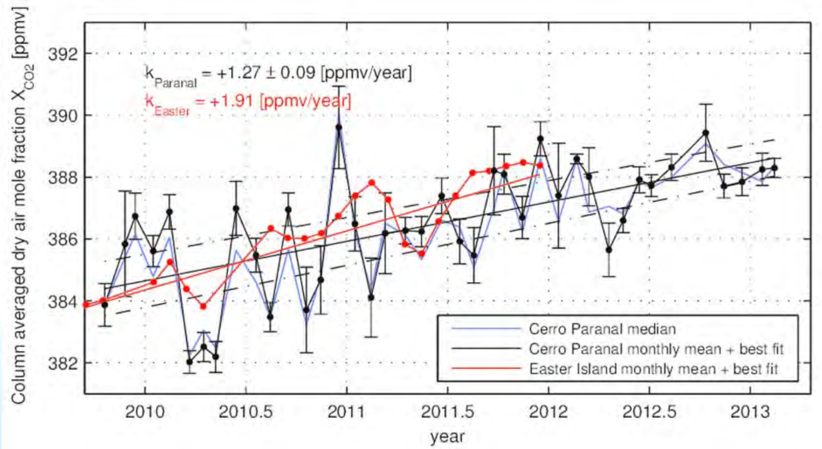
Kausch et al. 2013, EGU

Molecular abundances by MOLECFIT

and CO_2



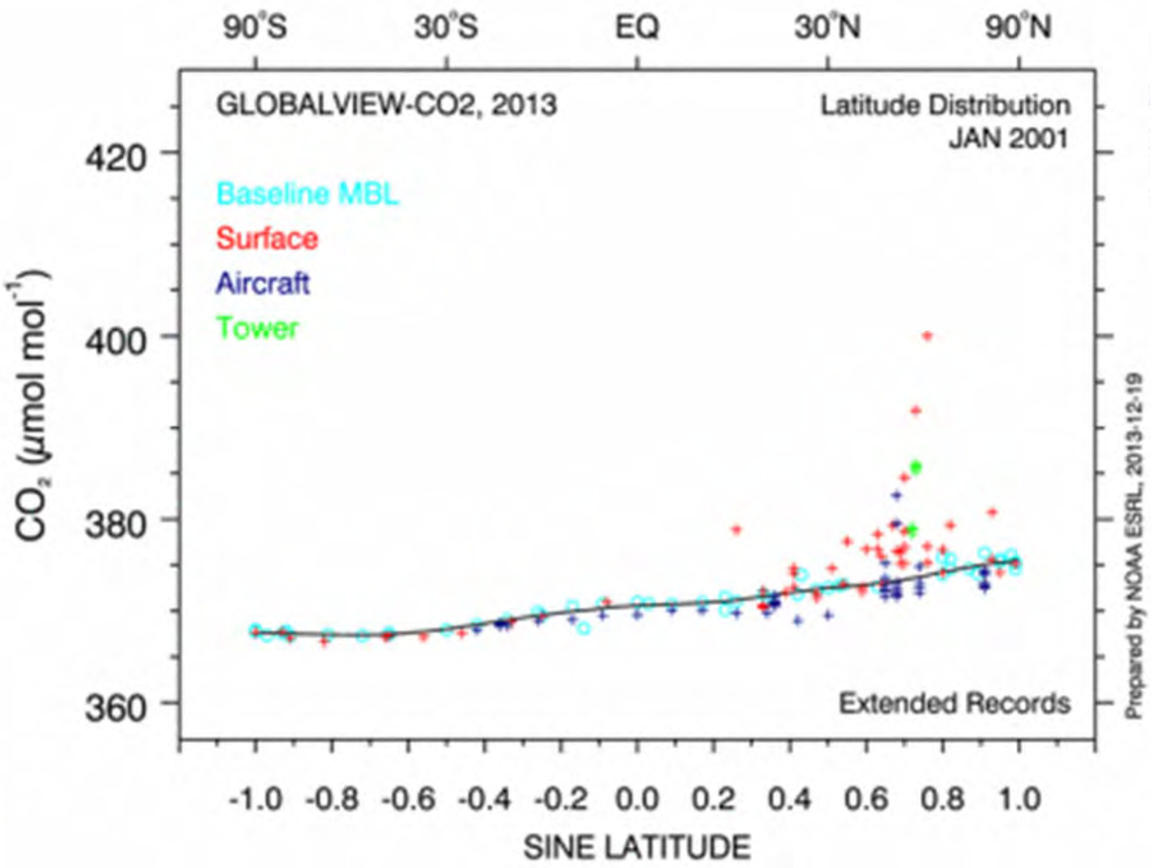


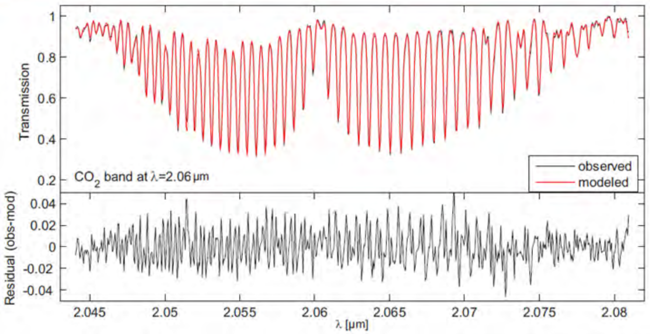


All measurements based on X-Shooter telluric standard star spectra

Kausch et al. 2013, EGU

CO_2



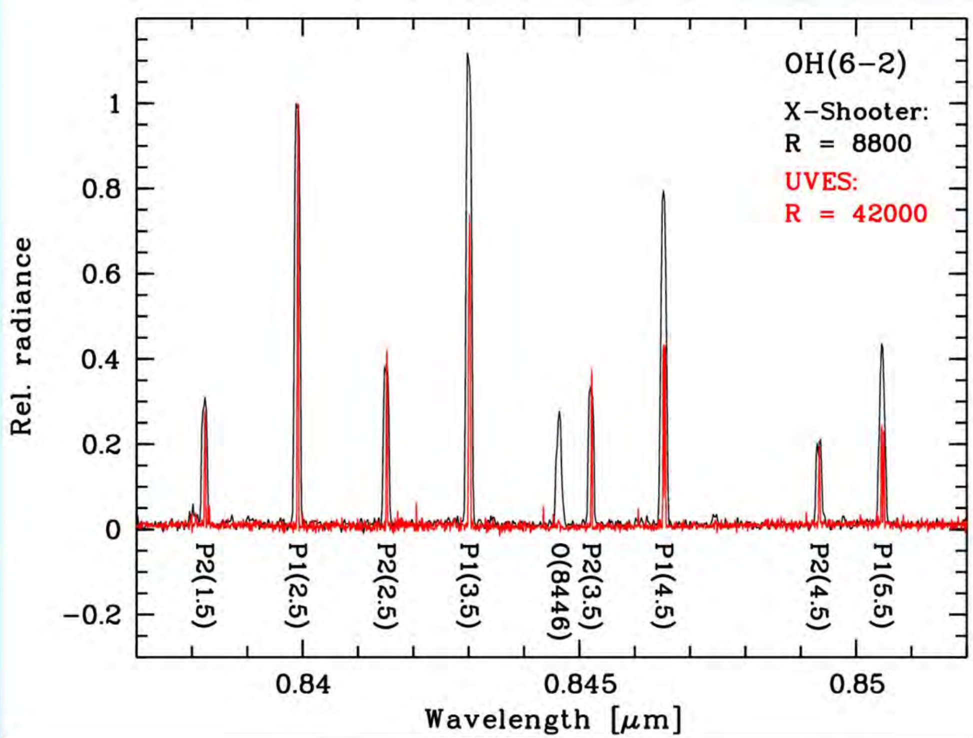


Kausch et al. 2013, EGU

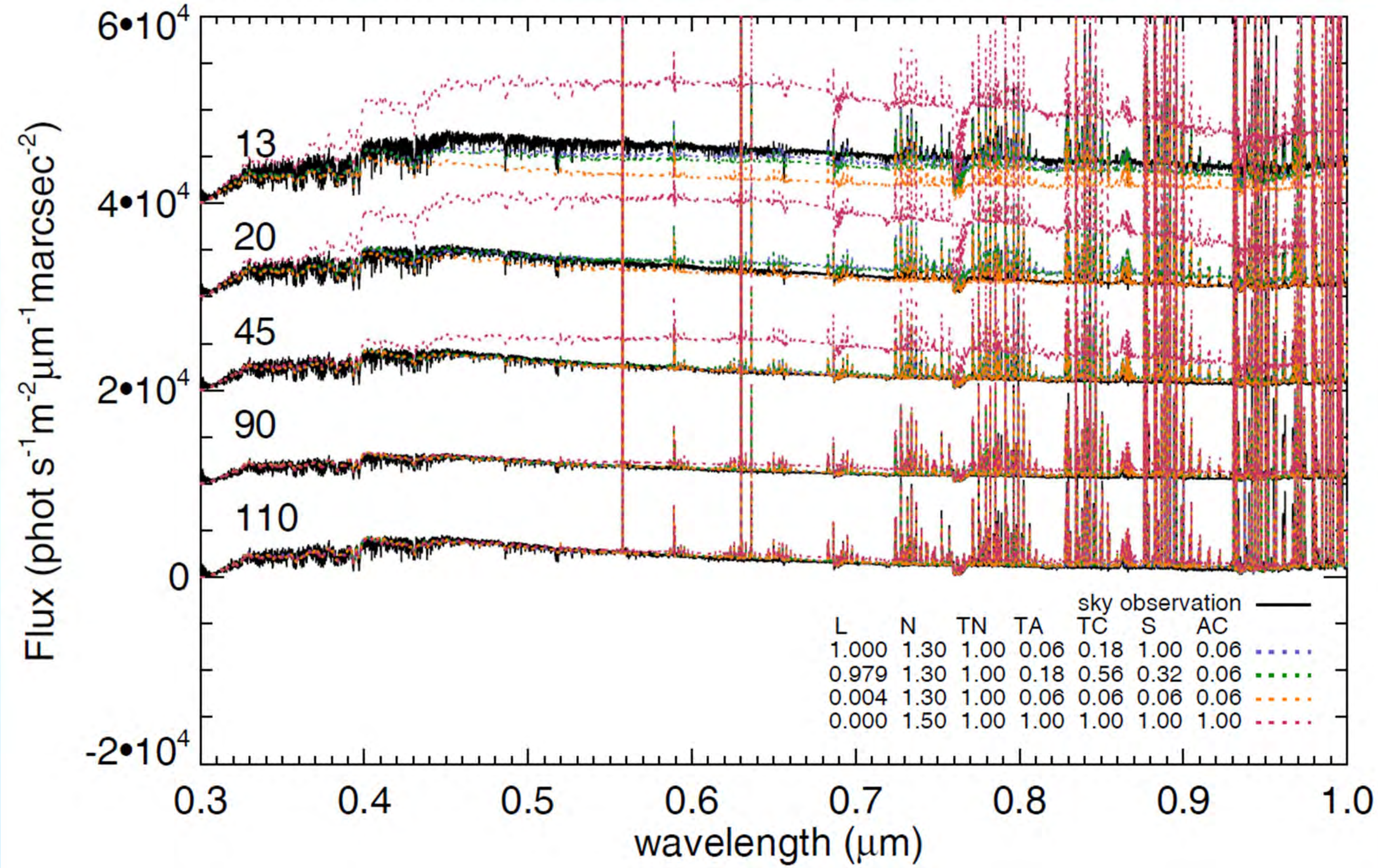
full video at
http://www.esrl.noaa.gov/gmd/ccgg/globalview/co2/co2_intro.html

Temperature profile by OH lines (Noll et al. 2014, EGU)

- Regression analysis reveals a slightly long-term trend of about 1 K/decade (cf. Beig et al. 2011).
- The T_{rot} differences might be related to *v*'-emission altitudes (Khomich et al. 2008).
- The mean nocturnal T_{rot} variations depending on *v*'. For *v*' = 8, the minimum is reached about 1 h earlier than for *v*'= 5.

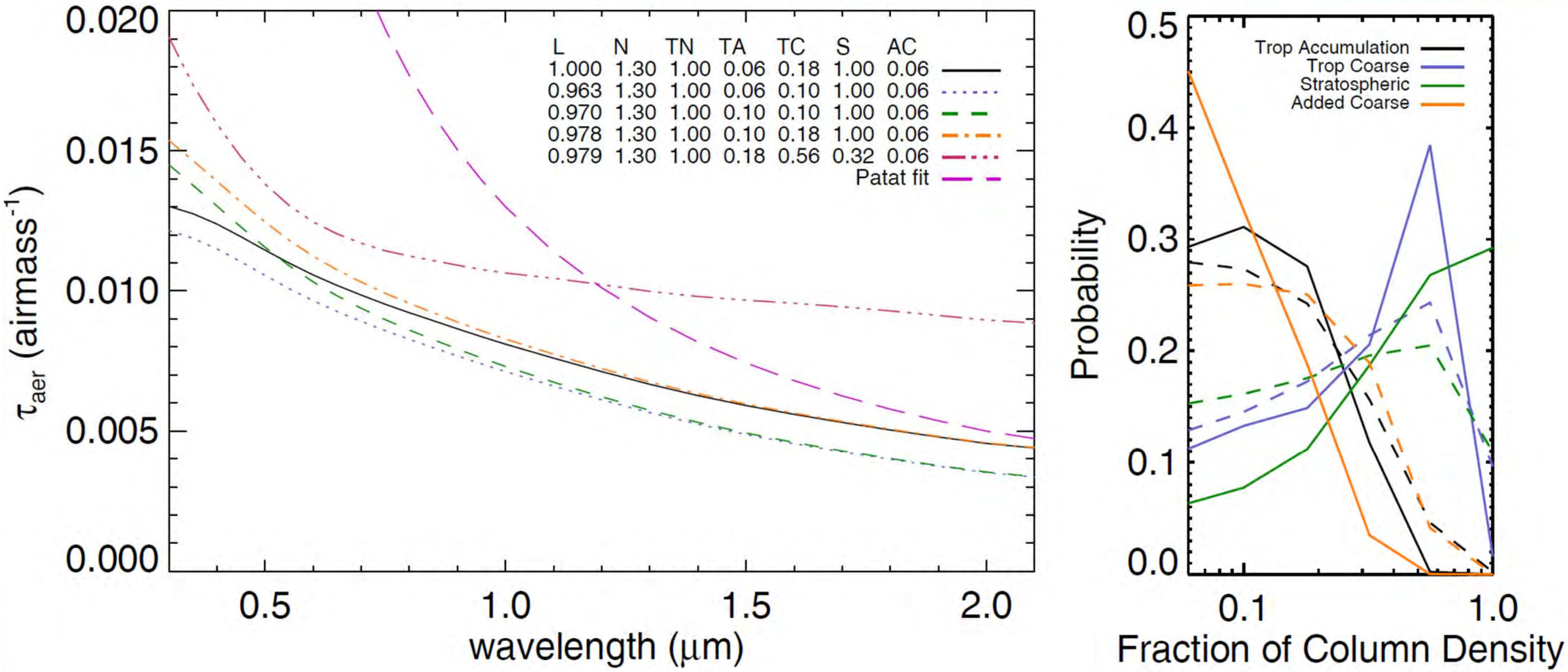


Aerosol Scattering



Jones et al. (2014, A&A submitted)

Aerosol Scattering



Jones et al. (2014, A&A submitted)

Site

going from Paranal

to Armazones

will be not much of a difference

Site

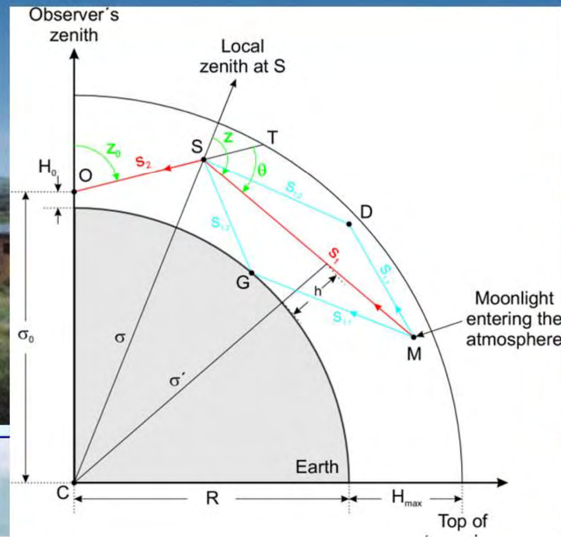
http://www.ipp.phys.ethz.ch/research/magic_telescope

season dependent

http://commons.wikimedia.org/wiki/File:H.E.S.S._II_Telescope_Array.jpg

albedo of the ground

http://en.wikipedia.org/wiki/File:HESS-dark-full.jpg



Site 'testbed'

http://de.wikipedia.org/wiki/Universit%C3%A4ts-Sternwarte_Innsbruck

1982MitAG..55..179F

G. Felkel, G. Schlemmer, D. Kuhn, J. Pfleiderer, Innsbruck: Eine Apparatur zur Messung von Lichtblitzen im Nanosekundenbereich

Die von der sekundären kosmischen Strahlung in der Atmosphäre induzierten Cerenkovblitze dauern im Mittel 5 – 10 ns. Ihre Registrierung wird durch den relativ hellen Nachthimmel (Beitrag des Cerenkovlichts zur Helligkeit des Nachthimmels ca. 10^{-4}) und durch das relativ seltene Auftreten von Cerenkovereignissen (ca. 1 registrierter Cerenkovimpuls pro 5 min mit der hier beschriebenen Apparatur) erschwert.

Am Astronomischen Institut und am Institut für Experimentalphysik, Abteilung Hoch-

1987MitAG..70..448H

448

G. HUEMER, J. PFLEIDERER (Inst. f. Astronomie, Innsbruck), G. RUDOLPH (Inst. f. Experimentalphysik und Inst. f. Astronomie, Innsbruck)

UNTERSUCHUNG DES ENERGIESPEKTRUMS DER PRIMÄREN KOSMISCHEN STRAHLUNG IM BEREICH DES KNICKES

Das Energiespektrum der primären kosmischen Strahlung läßt sich mit guter Genauigkeit durch zwei Potenzgesetze der Form $N(E) = k/E^{\gamma}$ beschreiben, die am sogenannten Knick bei etwa 5×10^{15} eV zusammenstoßen. Das flachere Spektrum bei niedrigeren Energien hat etwa $\gamma_1=2.5$, das steilere bei höheren Energien etwa $\gamma_2= 3.0$. Der Bereich um den Knick ist mit üblichen Methoden (Ballon- und Satellitenexperimente, EAS Teilchenarrays) schwer vermeßbar.

project funeral

1991AGAb....6...87K

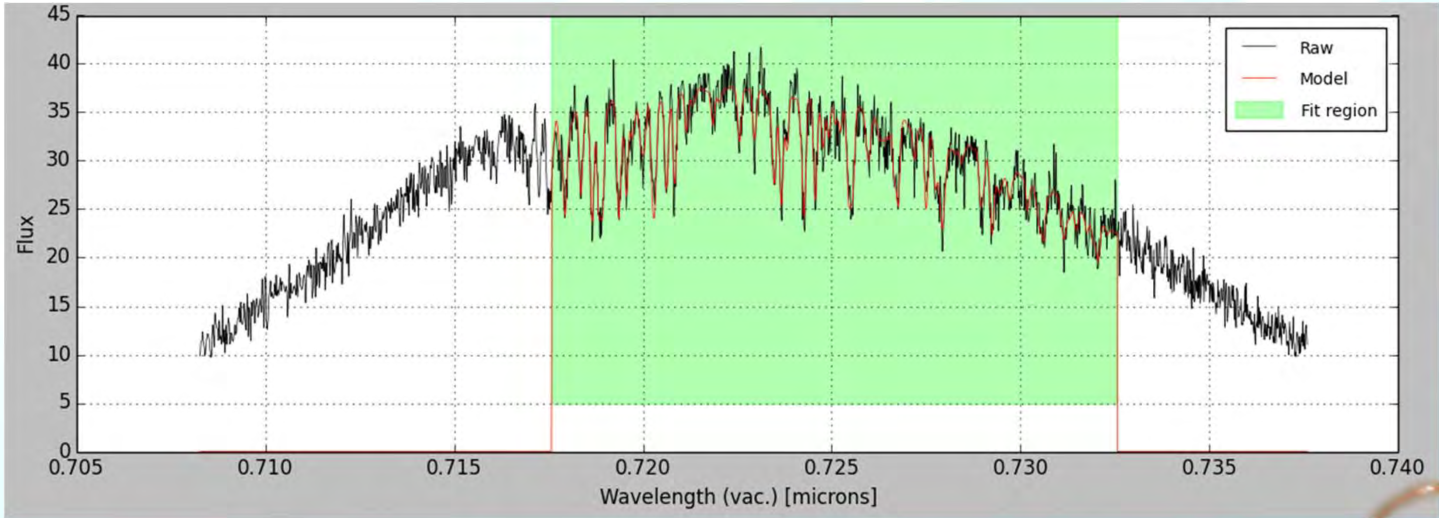
P 35

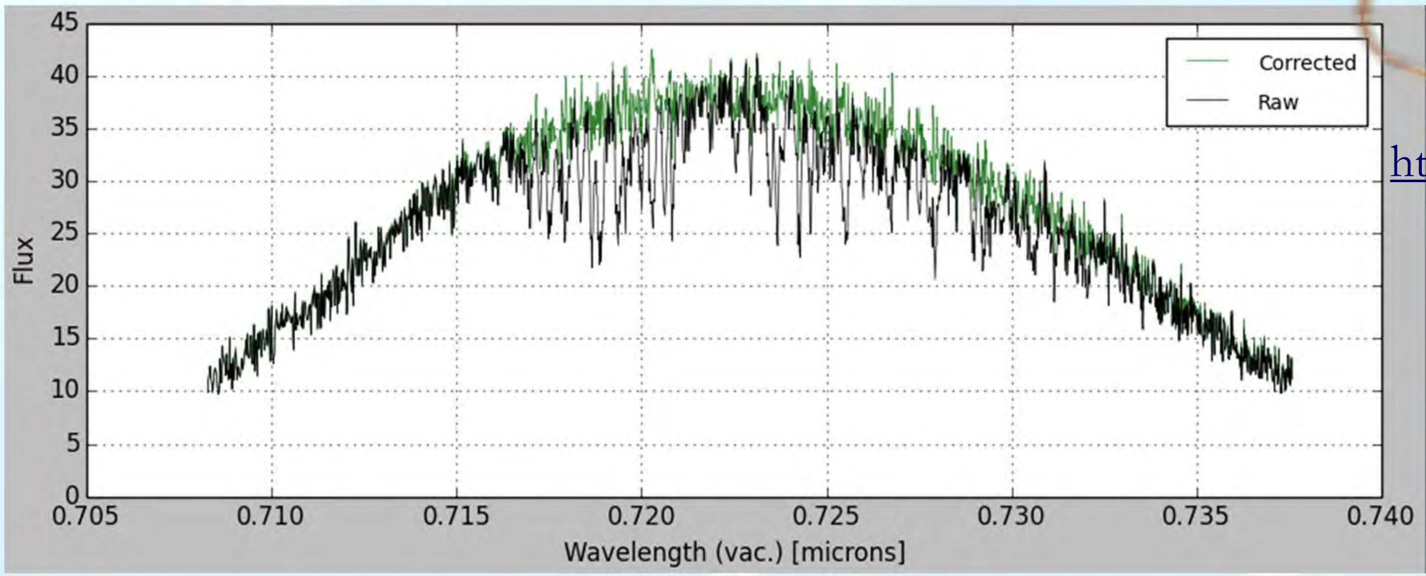
Statistics of Atmospheric Čerenkov Radiation around 5.10^{15} eV

S. KIMESWENGER and J. PFLEIDERER (Institut für Astronomie der Leopold-Franzens-Universität Innsbruck)

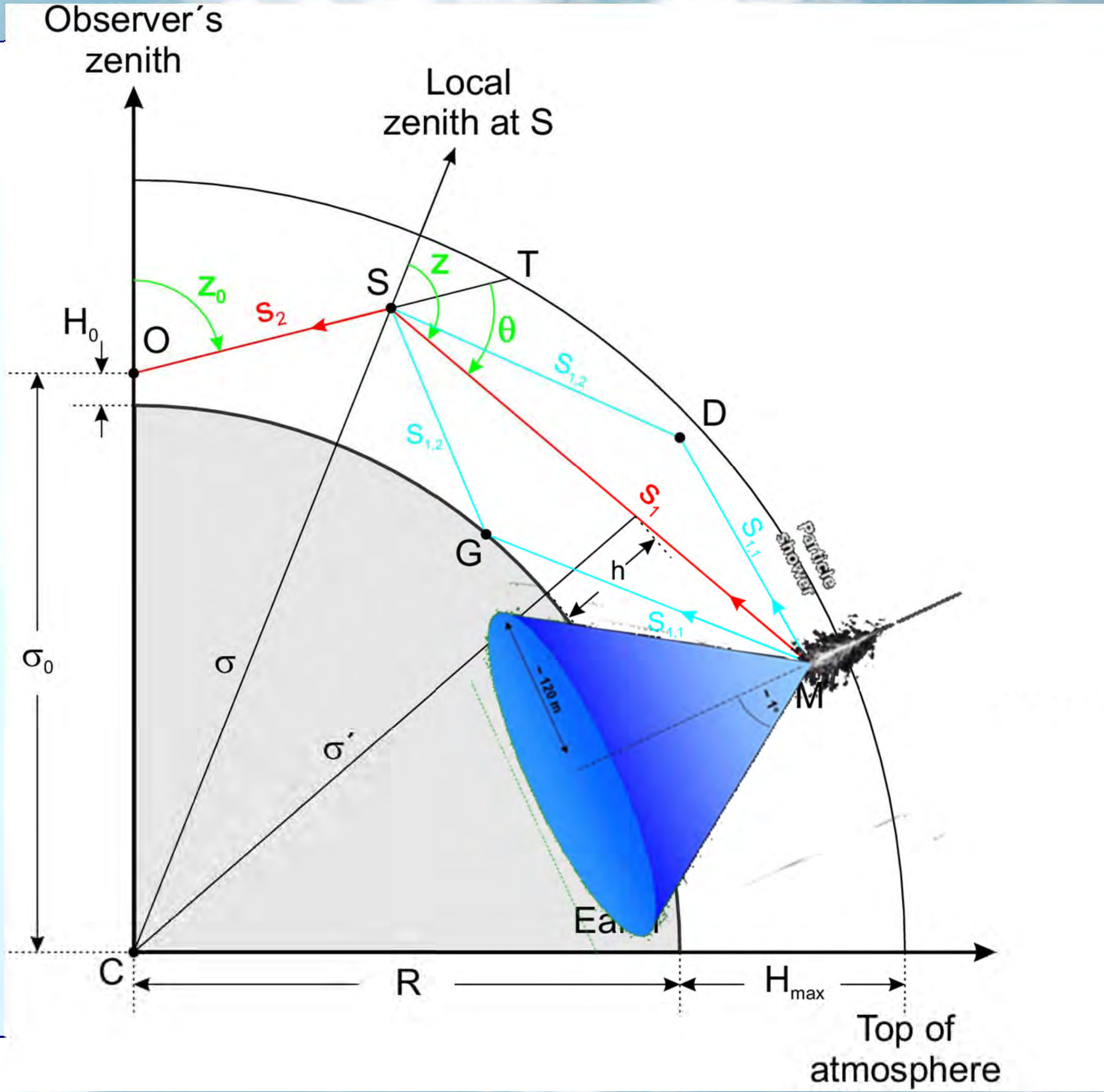
Some time ago, results on observations of the atmospheric Čerenkov radiation caused by Cosmic Rays with energies of a few 10^{15} eV were given on an AG meeting (Huemer, Pfleiderer and Rudolph, 1987, *Mitt. AG* **70**, 448). A recent rediscussion showed that an improvement of

Site 'testbed'

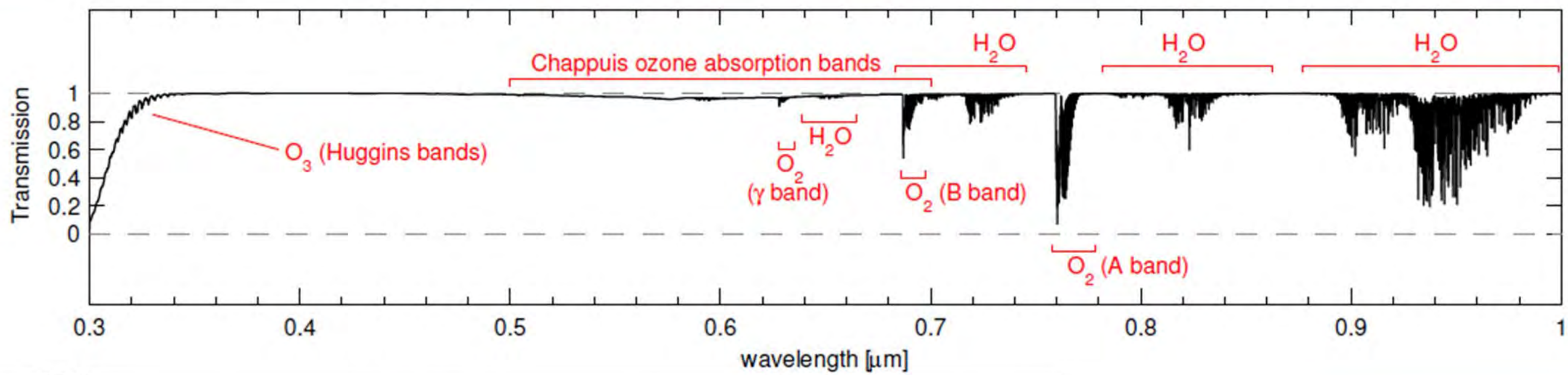




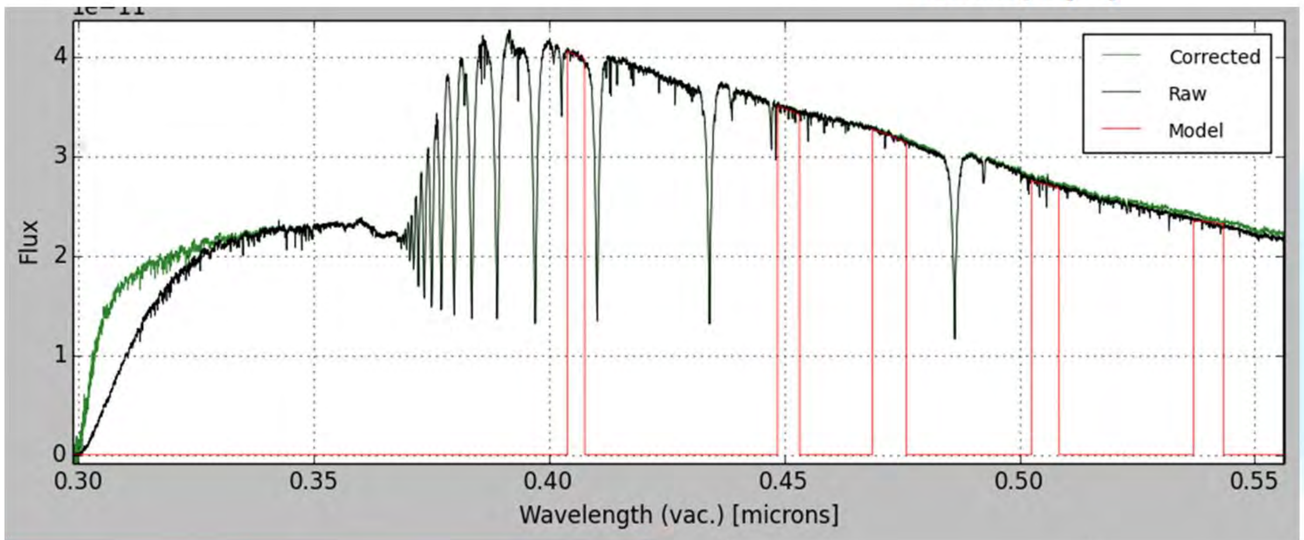
http://www.shelyak.com/



Observer´s zenith
Local zenith at S
T
S
z
z_0
s_2
θ
H_0
O
$S_{1,2}$
D
$S_{1,2}$
s_1
$S_{1,1}$
Particle shower
G
h
$S_{1,1}$
~120 m
~1°
M
σ_0
σ
σ´
Ea
C
R
H_{max}
Top of atmosphere



Chappuis ozone absorption bands
H2O
H2O
H2O
1
0.8
0.6
0.4
0.2
0
Transmission
O3 (Huggins bands)
H2O
O2
(γ band)
O2 (B band)
O2 (A band)
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
wavelength [µm]



Corrected
Raw
Model
Flux
4
3
2
1
0
0.30
0.35
0.40
0.45
0.50
0.55
Wavelength (vac.) [microns]

Corrected
Raw
Model
Flux
2.0
1.5
1.0
0.5

http://www.uibk.ac.at/eso/

it is always a TEAM

ESO In-kind Project:

- Home
- Innsbruck
- calculators (
- DR06: Fitting routi… determinatio… abundances…
- …he NIR.

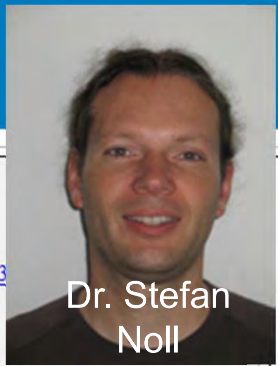
…ted in 2012:

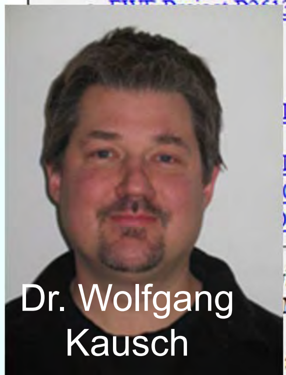
… Model

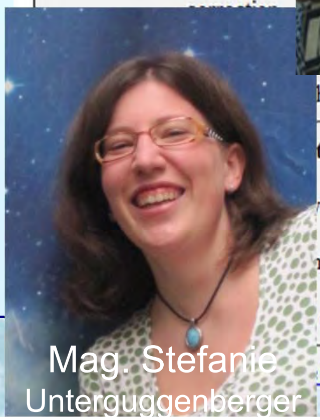
…nospheric Parameters

… the Sky Signature

… Project







Scientific Publikations (peer review)

Investigating the aerosol extinction using an advanced scattered moonlight mo…
A. M. Jones, S. Noll, W. Kausch, C. Szyszka, and S. Kimeswenger, 2014, submitted to A&A.

Molecfit: A general tool for telluric absorption correction I. Method and application to ESO instruments
A. Smette, H. Sana, S. Noll, H. Horst, W. Kausch, S. Kimeswenger, M.Barden, C. Szyszka, A. M. Jones, A. Gal…, J. Vinther, and P. Ballester, 2014, submitted to A&A. (preprint)

Molecfit: A general tool for telluric absorption correction II. Quantitative evaluation on ESO-VLT/X-Shooter spectra
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