Solar radiation and limb sounding: methods, missions and retrievals

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Caveat:

The academic session celebrates 50 years of space research @ BISA. This is just impossible to summarize in 30 minutes !

Most people in the room are supposed to be interested by Science. Many of them are not necessarily expert in the field. This speech is a « tour » in past, present and future scientific experiments in atmospheric remote sensing…
Objective: to give a flavor of aeronomy from space!

Apologies to past and present scientific colleagues for not being able to present all their contributions. Also, most of our achieved work would have been impossible without people from engineering, IT, accounting and program management. Thanks!

Space (?) aeronomy

- Space is a physical domain but…
- Space is also **the highway to atmospheric REMOTE SENSING**
  - Curvature of the earth: how to measure behind the horizon ?
  - Global coverage: revisit time from 1 day to a few months, everywhere !
  - High sensitivity ↔ long optical paths !
  - Multiple sounding geometries and different local solar times
  - High vertical resolution

STS-45/ATLAS-1

March 23 - 31, 1992

ATLAS-1 PAYLOAD

Solar Physics Experiments:

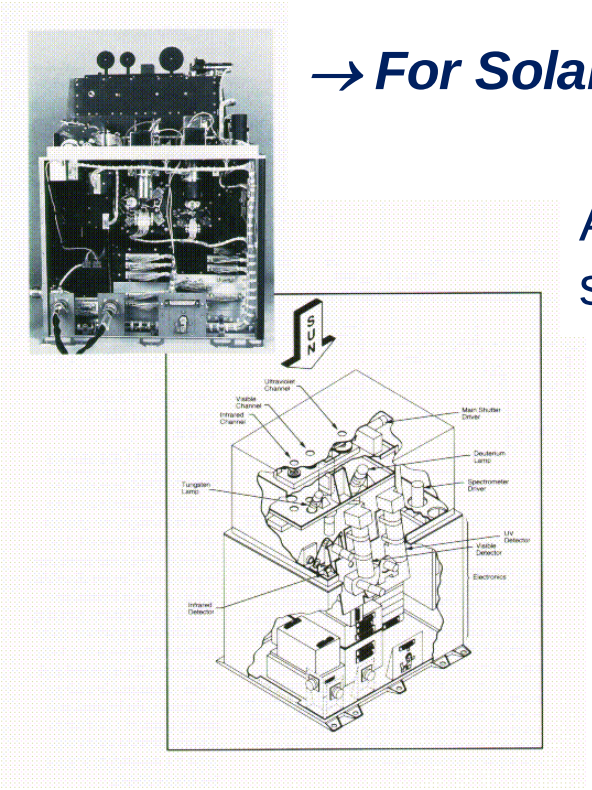
Solar Constant Radiometer (SOLCON)	**B**
Solar Spectrum Irradiance Monitor (SOLSPEC)	**F/B/D**
Solar UV Spectral irradiance Monitor (SUSIM)	USA
Active Cavity Radiometer (ACR)	USA

Atmospheric Physics Experiments:

Grille Spectrometer (GRILLE)	**B/F**
Atmospheric H and D through Measurement of Lyman-Alpha (ALAE)	**F/B**
Atmospheric Trace Molecule Spectroscopy (ATMOS)	USA
Imaging Spectrometric Observatory (ISO)	USA
Shuttle Solar Backscatter Ultraviolet Experiment (SSBUV)	USA
Space Experiments with Particle Accelerators (SEPAQ)	USA
Atmospheric Emission Photometric Imaging (AEPL)	USA
Microwave Atmospheric Sounder (MAS)	D

The SOLSPEC instrument

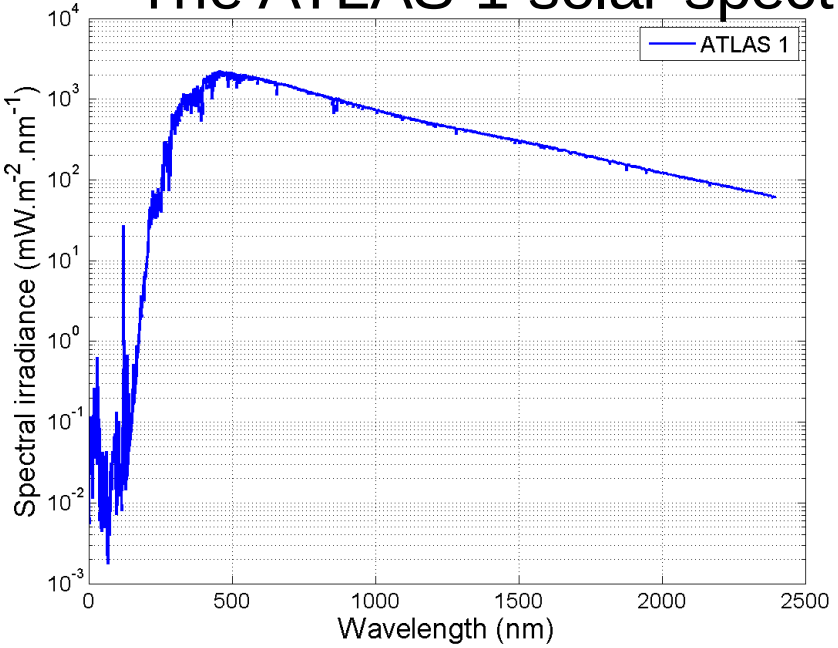
Collaboration BIRA-IASB - LATMOS



→ ***For Solar Spectral Irradiance (SSI) measurements from space***

Absolute calibration using a blackbody primary standard of spectral irradiance

The ATLAS 1 solar spectrum



First generation (1983-1994)

Missions: SPACELAB
ATLAS 1, 2 and 3
EURECA

The SOLSPEC instrument

Collaboration BIRA-IASB - LATMOS

Second generation

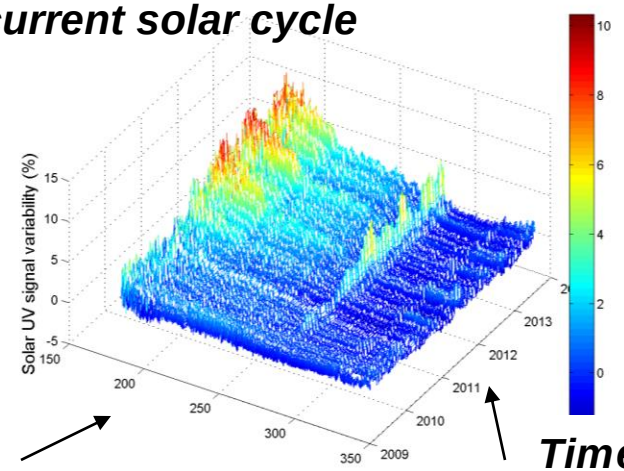
→ Improved version for the long term SOLAR mission

(International Space Station)

Spectral range 166 – 2900 nm

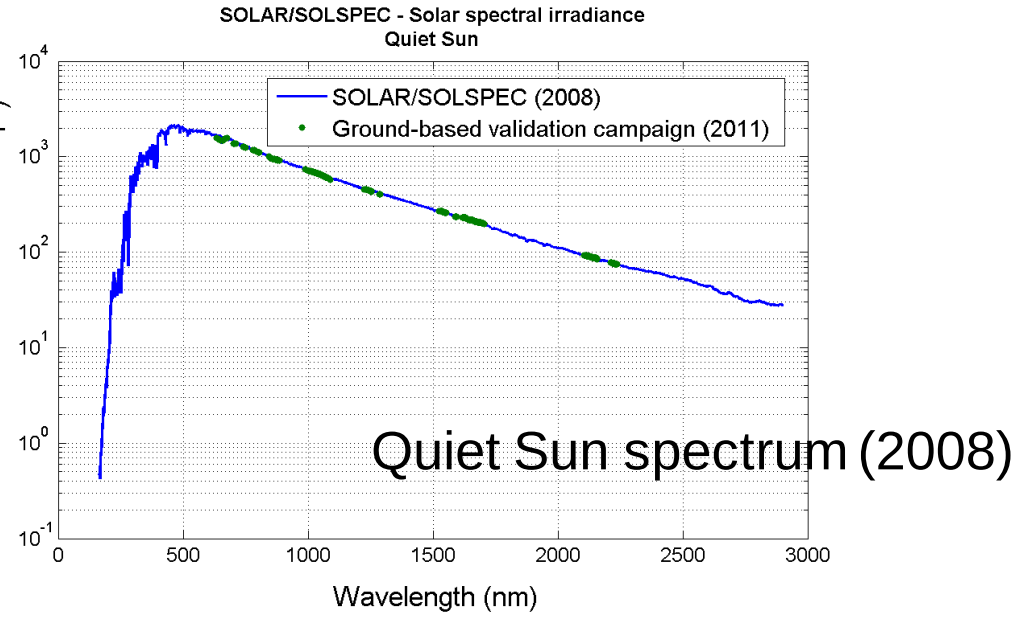
(96 % of the solar constant)

SSI UV variability (%) during the current solar cycle



Wavelength (nm)

Time (fractional year)



Quiet Sun spectrum (2008)

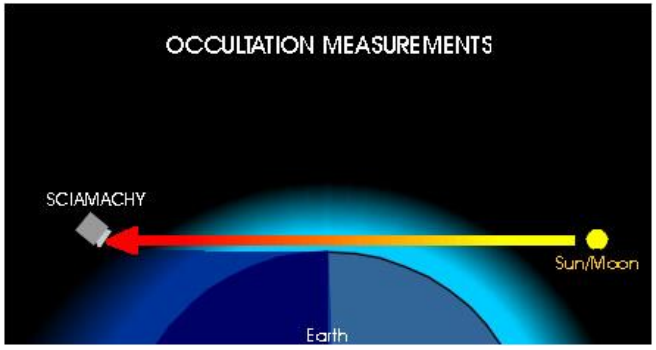
[Bolsée et al. 2014]

LIMB REMOTE SOUNDING: GENERALITIES

The simplest example of remote sounding: a sunset! Do the same from space, above and through the atmosphere: this is the **OCCULTATION** technique...

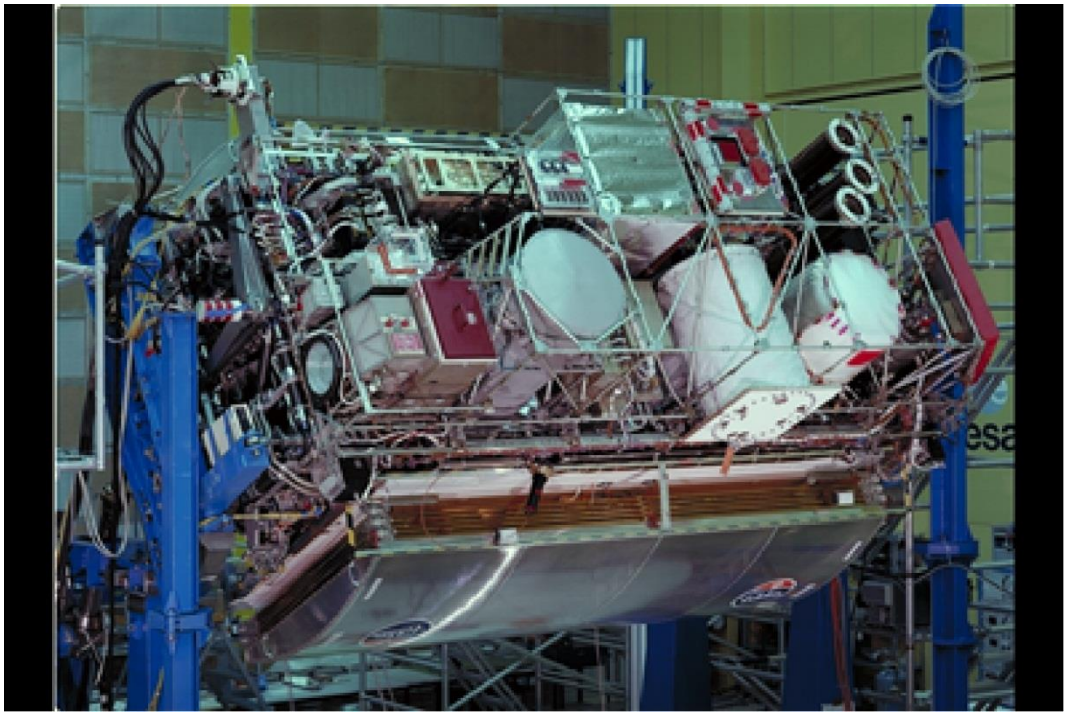
A relative measurement produces an absolute quantity: the slant optical thickness. The occultation technique is **SELF-CALIBRATING.**

The occultation technique leads, as in many fields, to several **INVERSE PROBLEMS**: vertical inversion (so-called onion peeling), spectral inversion, optical inversion... → « easy » measurements and tricky maths !



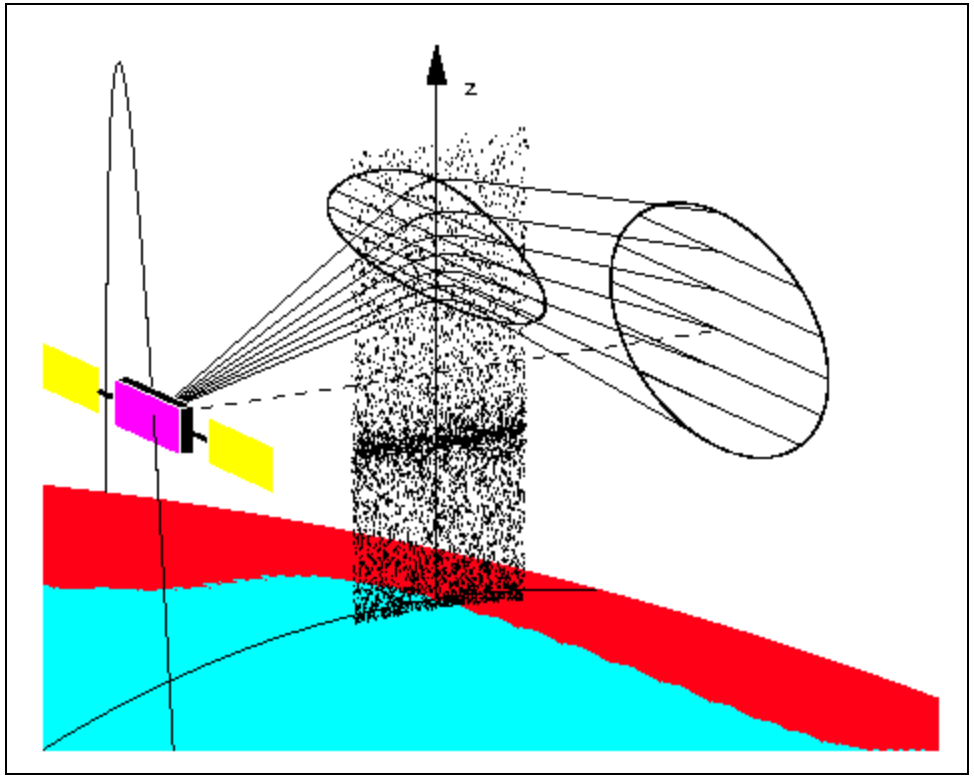
ORA onboard EURECA

(European Retrievable Carrier / 1992-1993)



In memoriam E. Arijs

A solar occultation experiment developed at IASB : ORA

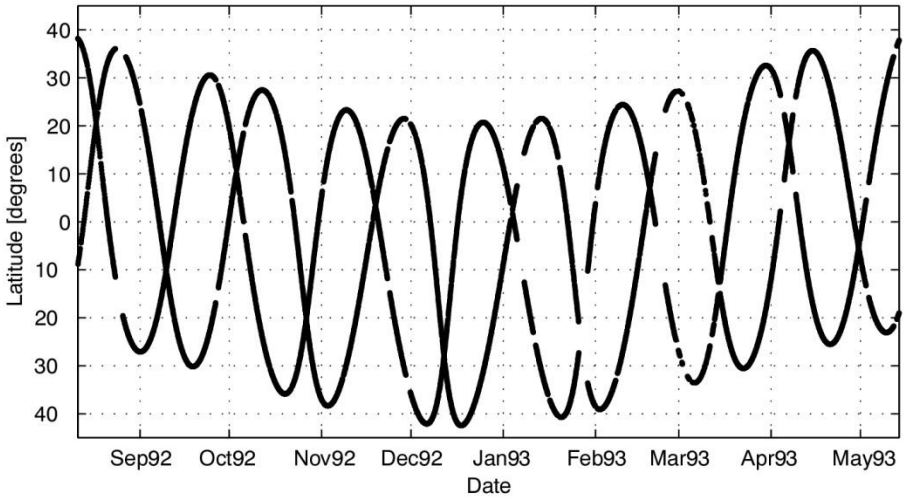


- 8 channels (259 nm -> 1013 nm): O_3, NO_2, Aerosols
- Aug. 1992 - May 1993 / Coverage 40°S-40°N / 7000 occultations
- 10 publications in international peer-reviewed journals

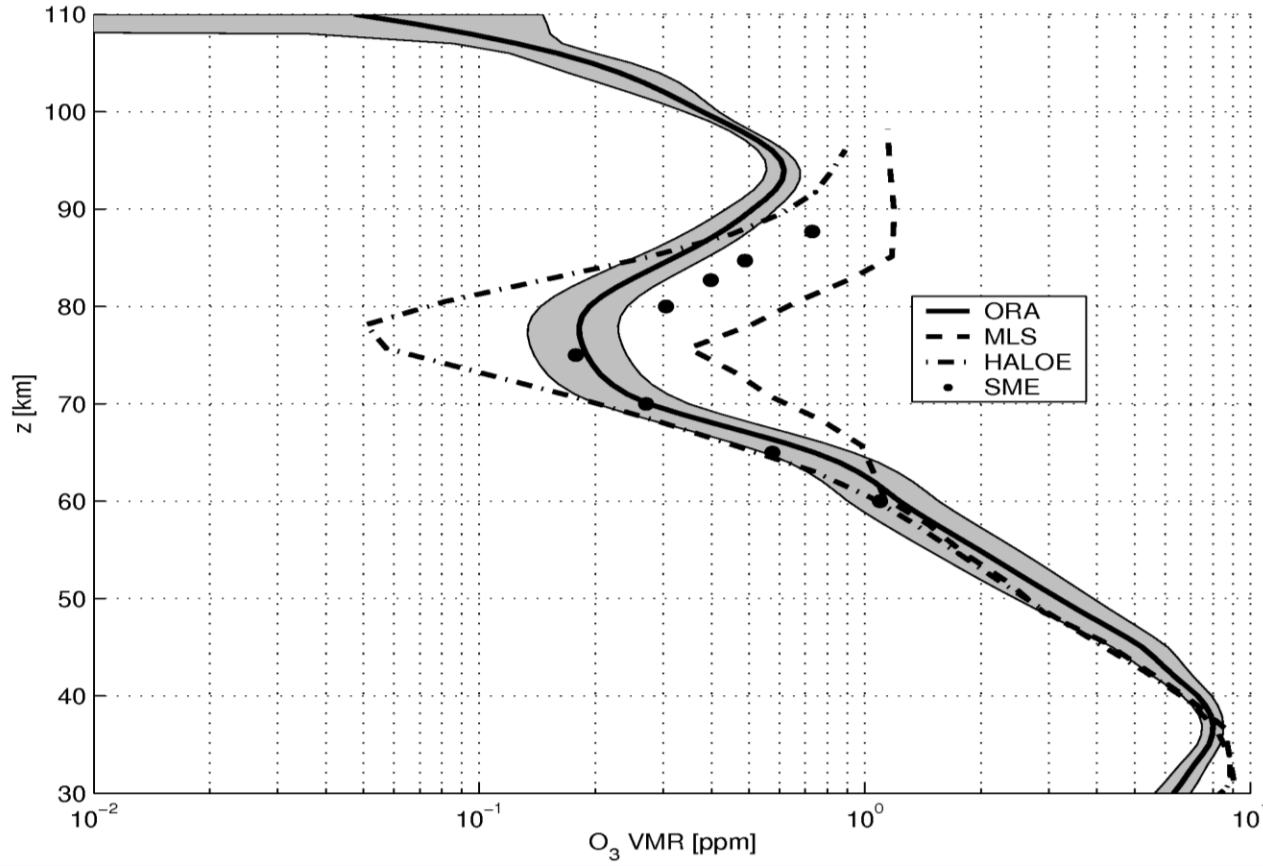
Orbital sunsets and sunrises observed from a low inclination orbit....

orbit:
- circular
- h: 508 km
- inclination: 28°

spacecraft:
- speed: 7.6 km/s
- period: 95 minutes
- 30 occultations per day



latitudes:
40°S - 40°N

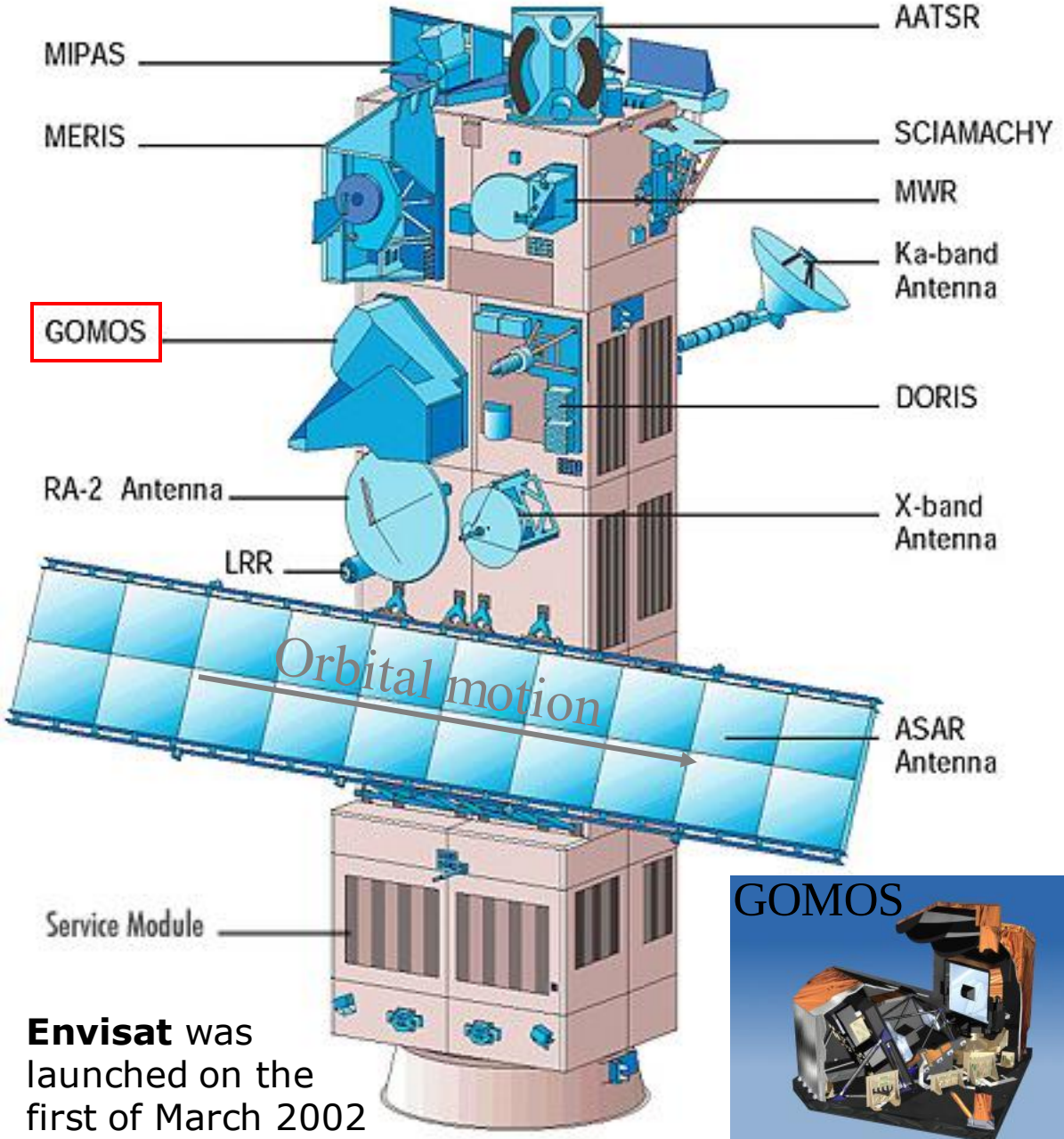


GEOPHYSICAL RESEARCH LETTERS, VOL. 27, NO. 21, PAGES 3449-3452, NOVEMBER 1, 2000

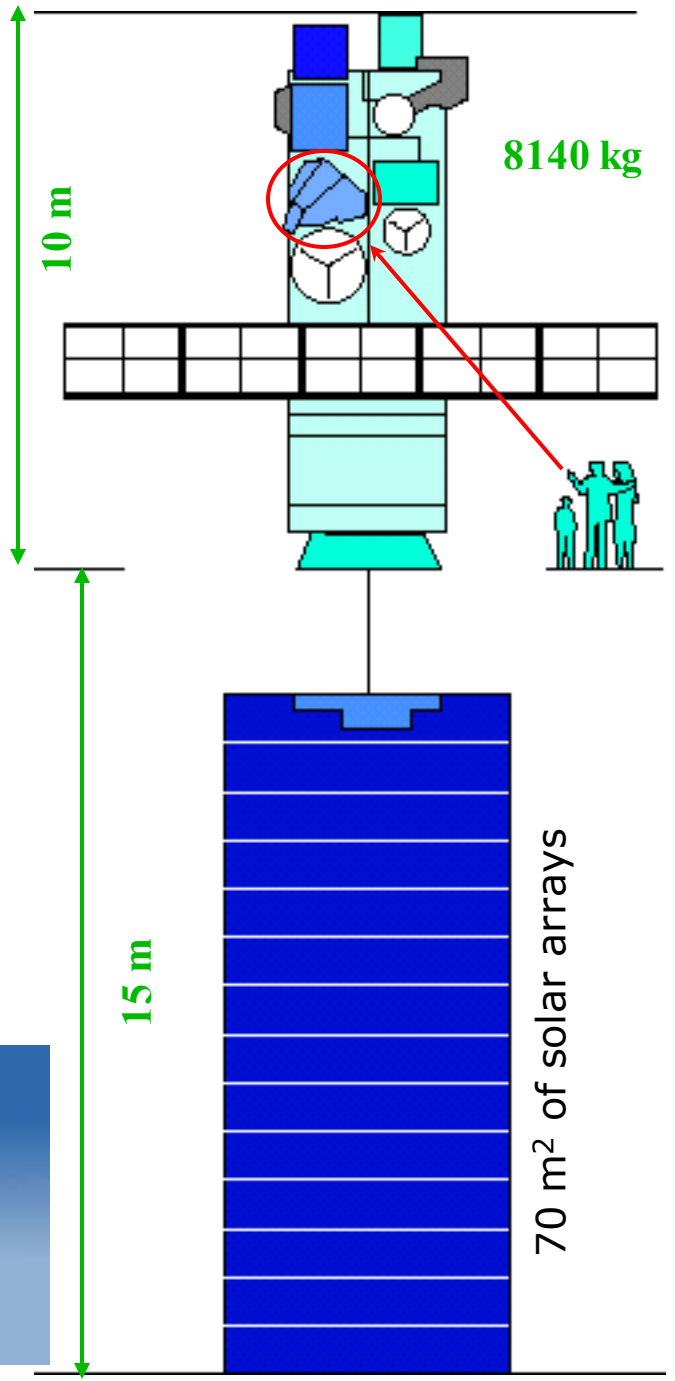
Ozone profiles from 30 to 110 km measured by the Occultation RAdiometer instrument during the period Aug 1992-Apr 1993.

Didier Fussen, Filip Vanhellemont, Christine Bingen
and Simon Chabrillat
Institut d'Aéronomie Spatiale de Belgique, Brussels

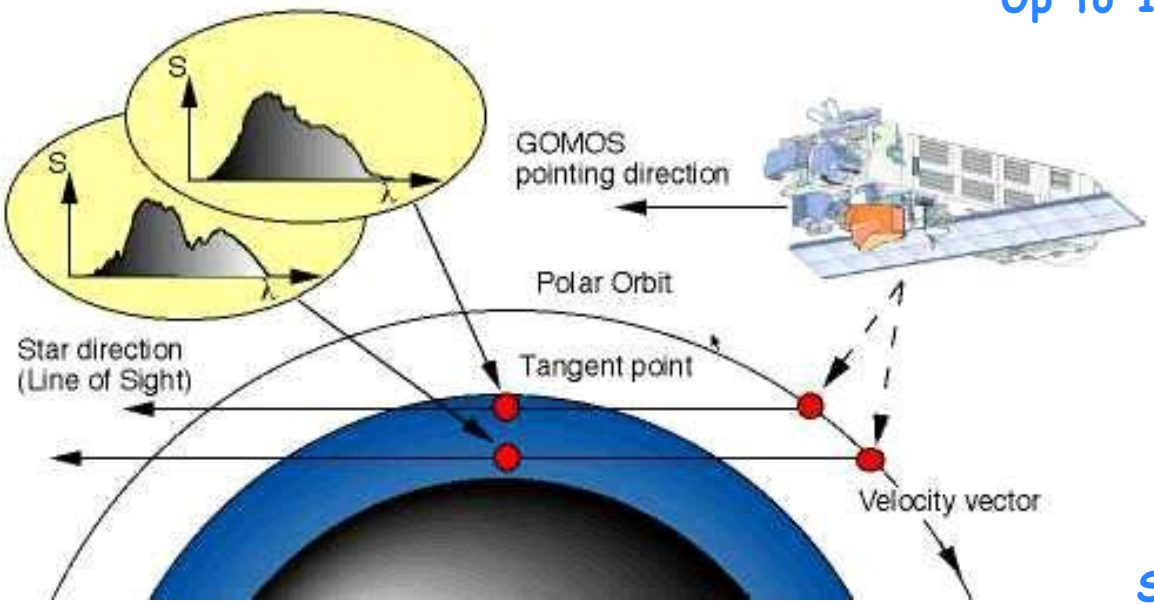
Global Ozone Monitoring by Occultation of Stars



Envisat was launched on the first of March 2002



GOMOS principle (1)



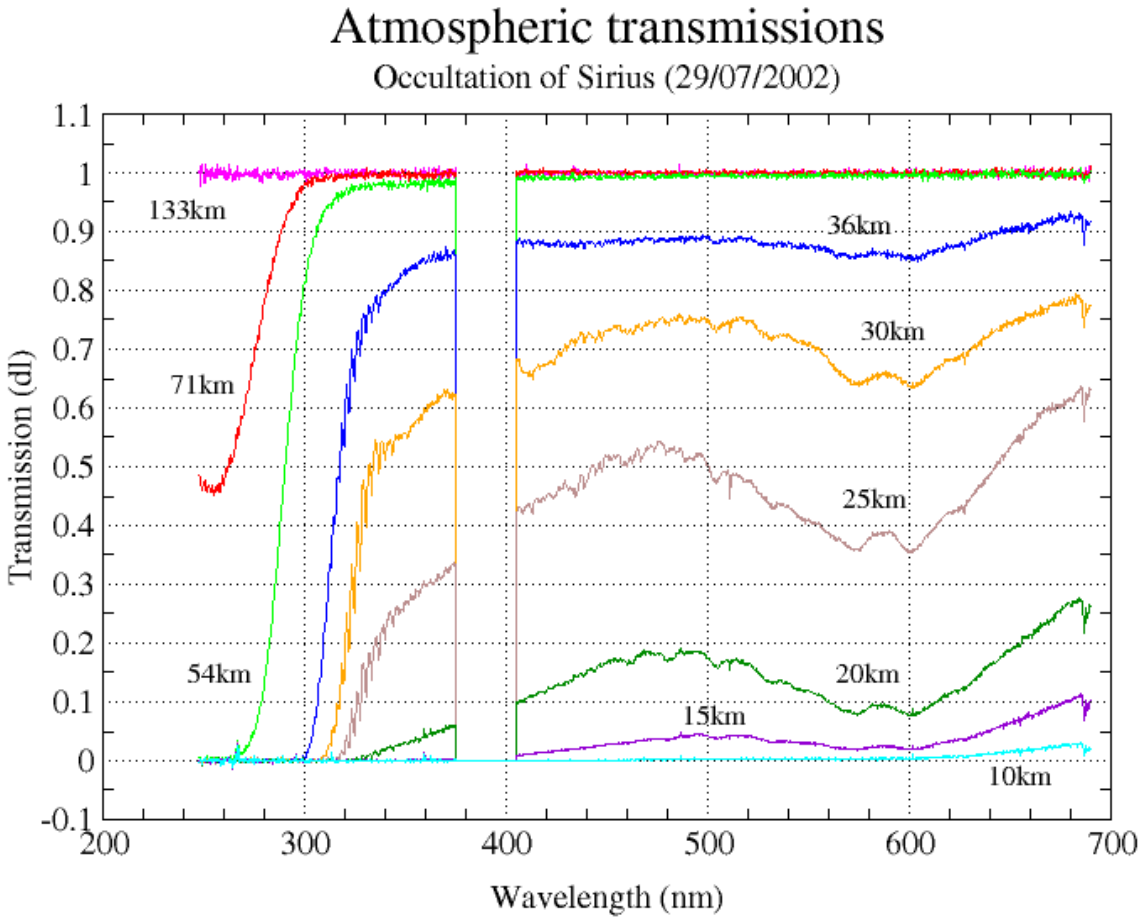
Below 10 km
Up to 120 km

One star spectrum
every 0.5 s

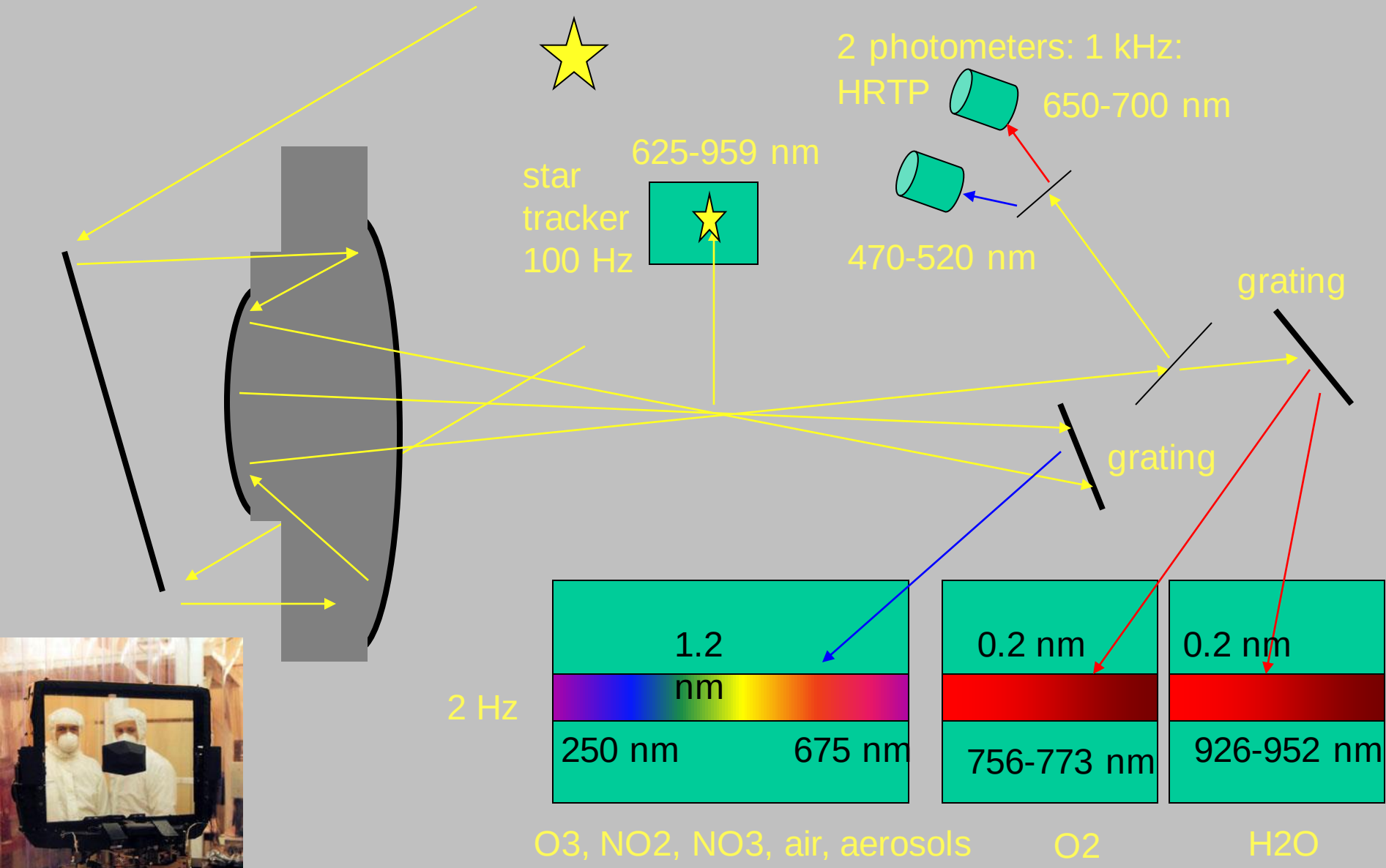
Pointing information
100 Hz

Scintillation information
1000 Hz

Transmission spectra

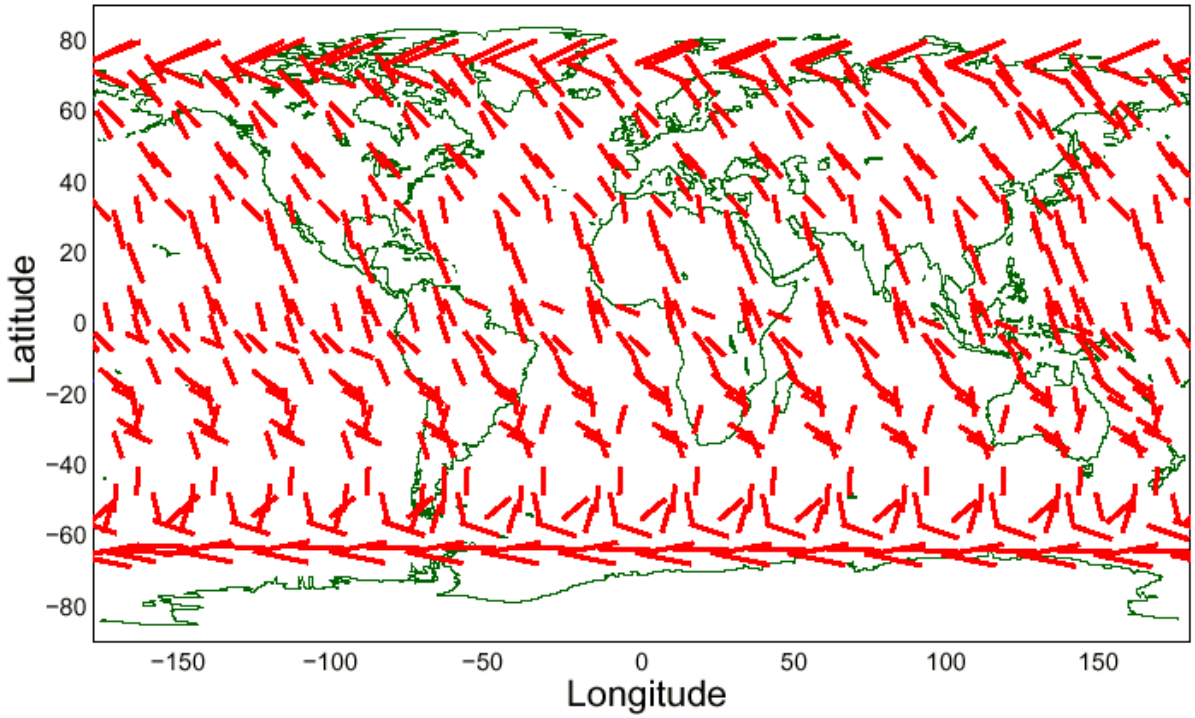


GOMOS instrument: optics and detectors

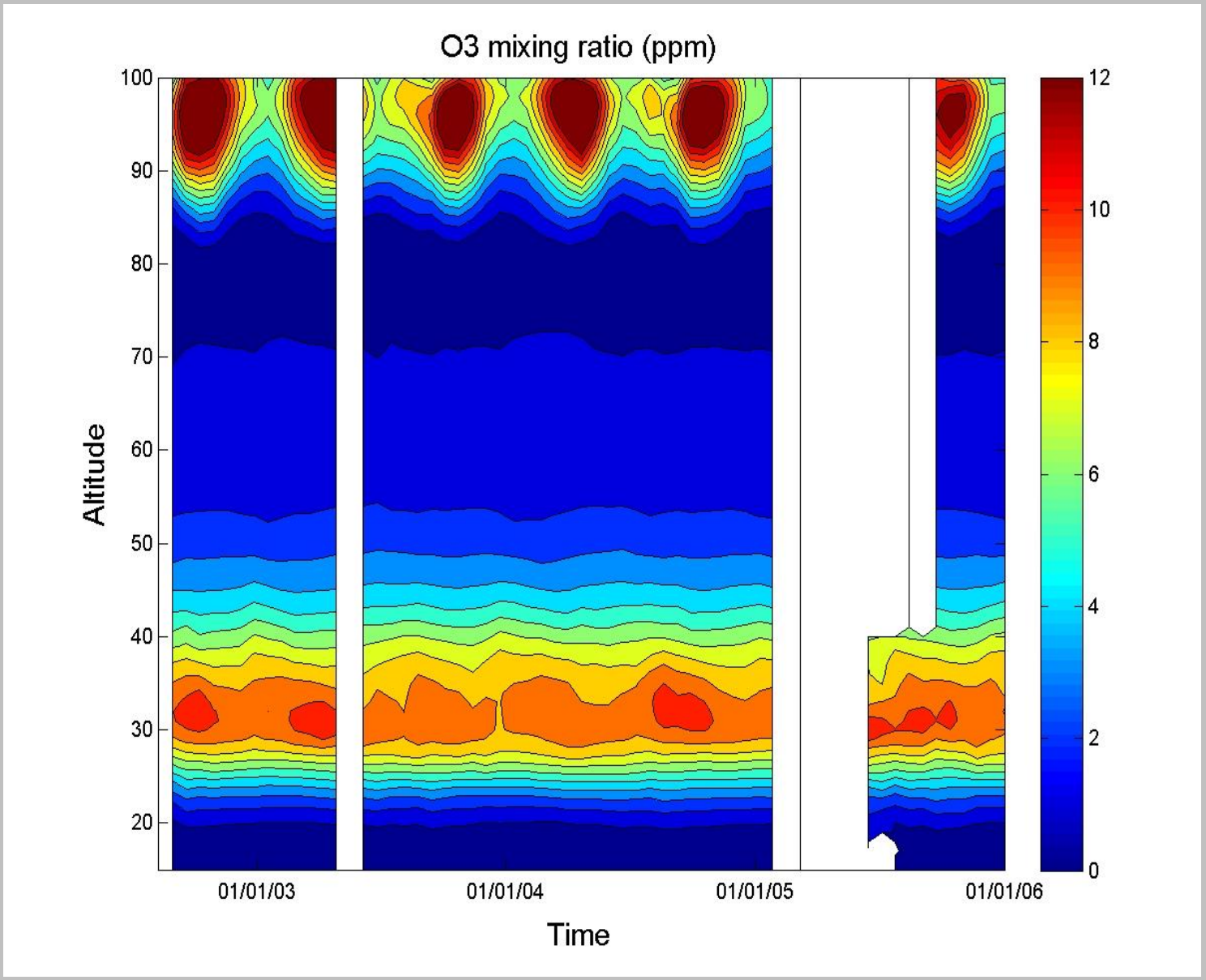


GOMOS Global Coverage

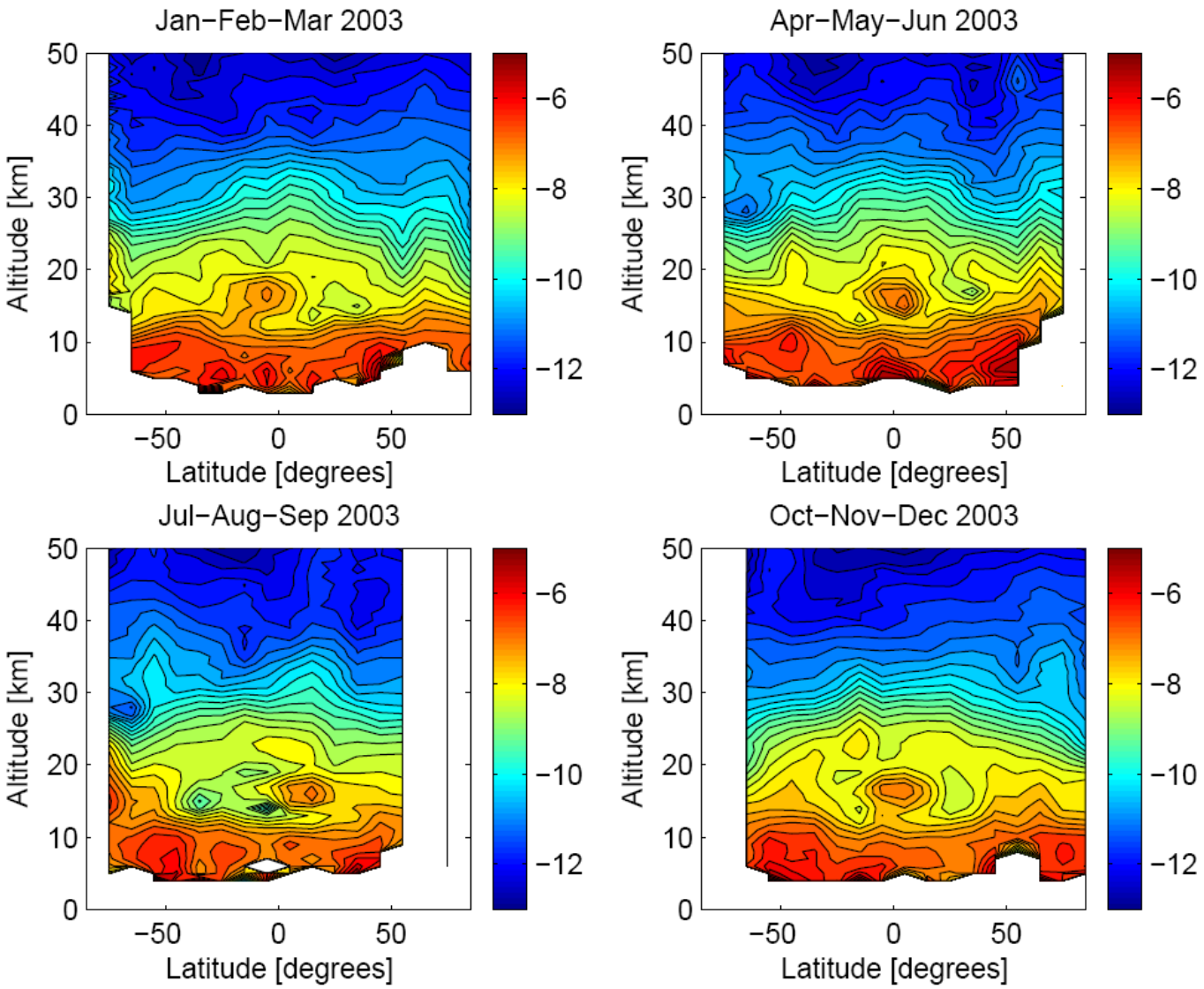
Global coverage of GOMOS during one day of measurements



Ozone mixing ratio(20 days median) in 20S-20N

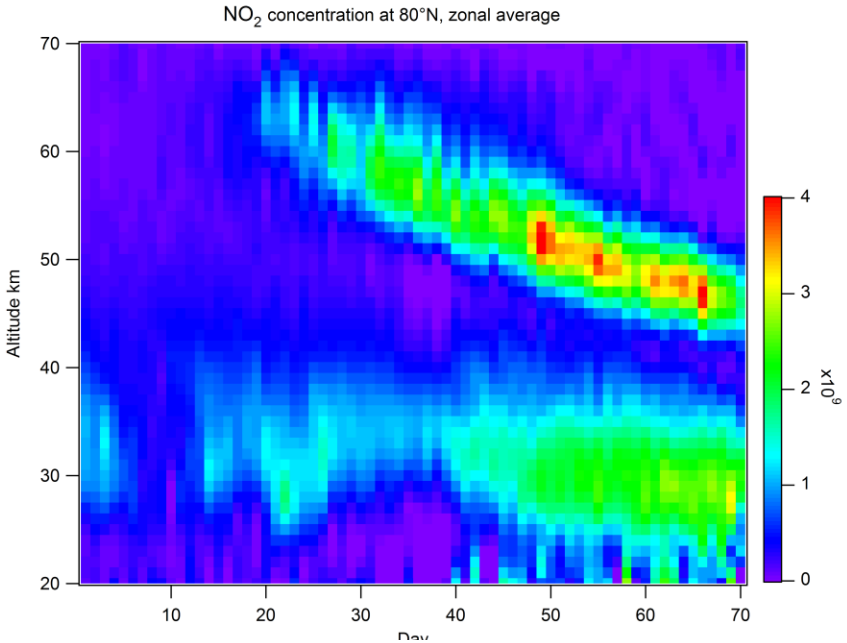


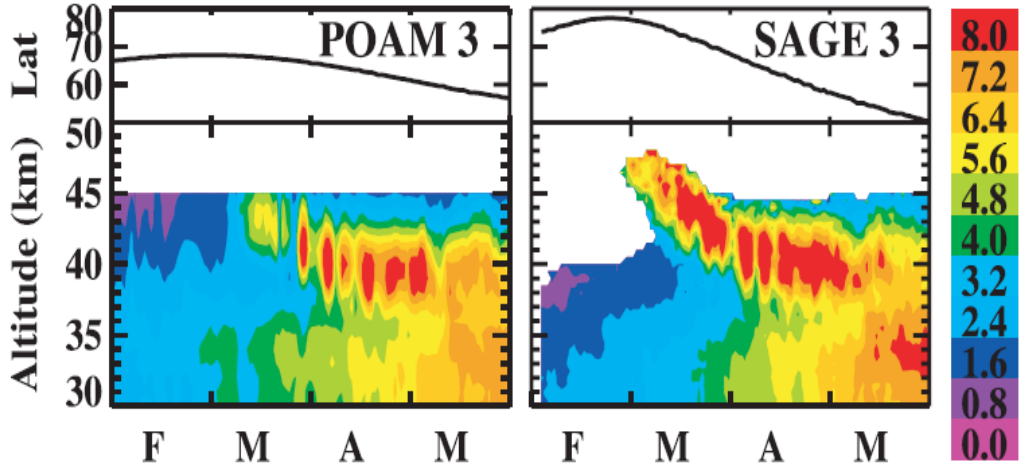
Aerosol extinction in 2003



Descent of NO2 layer in the polar vortex

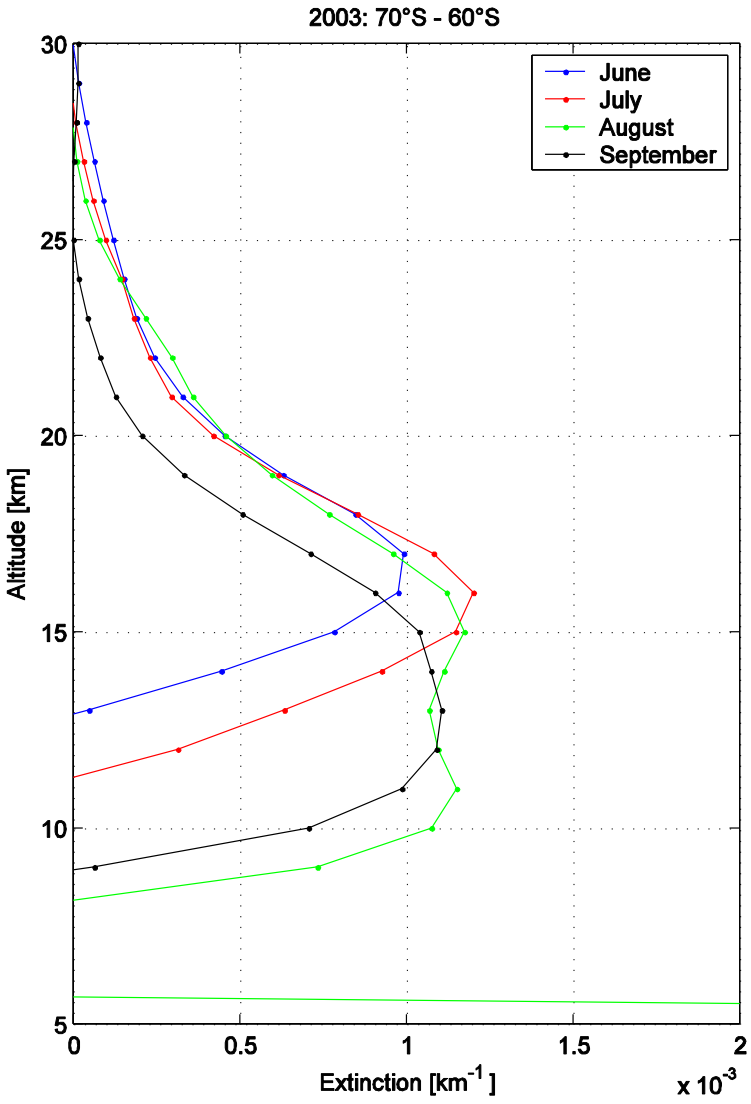
January – March 2004





Randall et al., GRL, 2005

PSC descent rates



	SCIAMACHY 2003 (*) [km/month]	GOMOS 2003 [km/month]	GOMOS 2004 [km/month]
70°S - 80°S	-1.2	-1.3	-1.0
60°S – 70°S	-2.0	-1.8	-1.5
50°S – 60°S	-2.5	-2.4	-2.7

(*)*Von Savigny et al, Atmos. Chem.Phys., 5, 3017-3079, 2005*

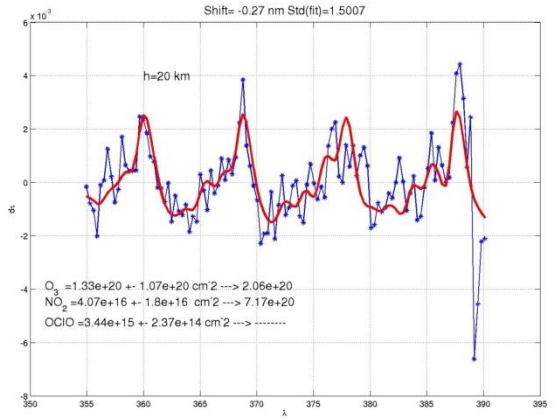
PSCs descend faster at the edge of the vortex… [Vanhellemont et al. 2010]

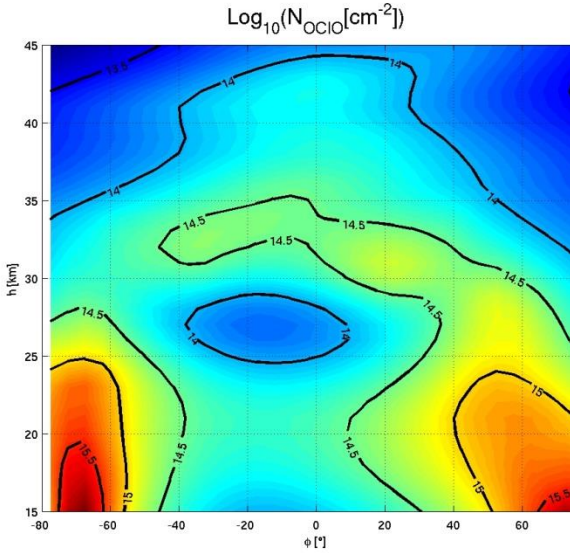
Discovery of a nightime OClO layer at about from GOMOS data

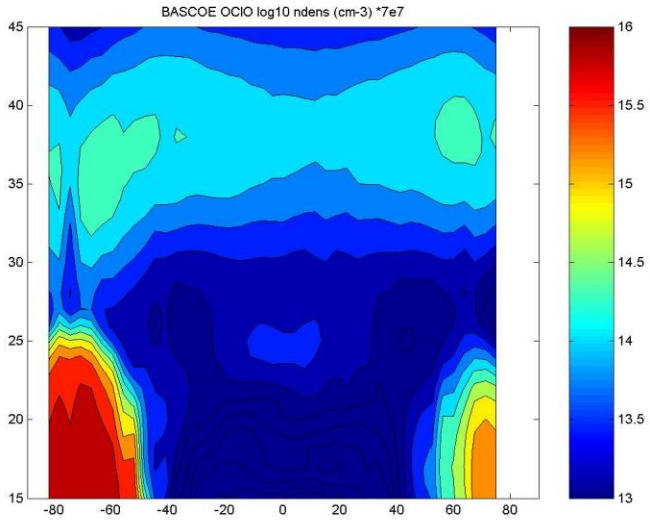
$ClO+BrO \rightarrow BrCl+O_2$

$ClO+BrO \rightarrow Br+ClOO$

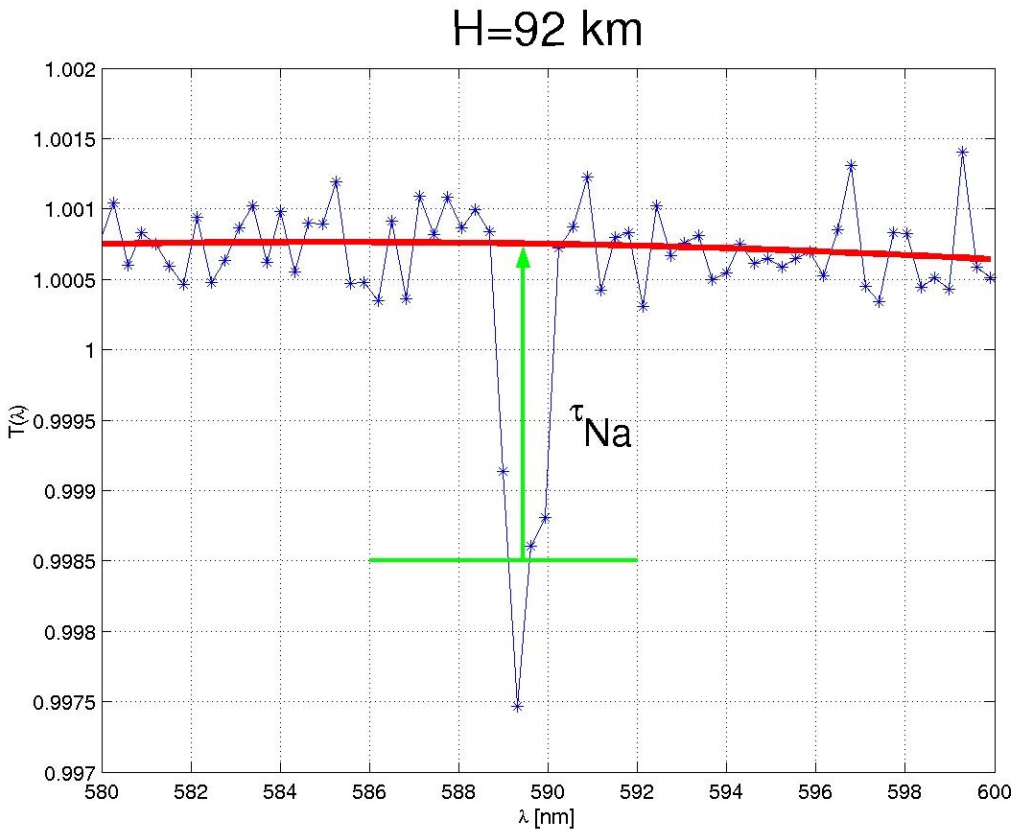
$ClO+BrO \rightarrow Br+OClO$ ←



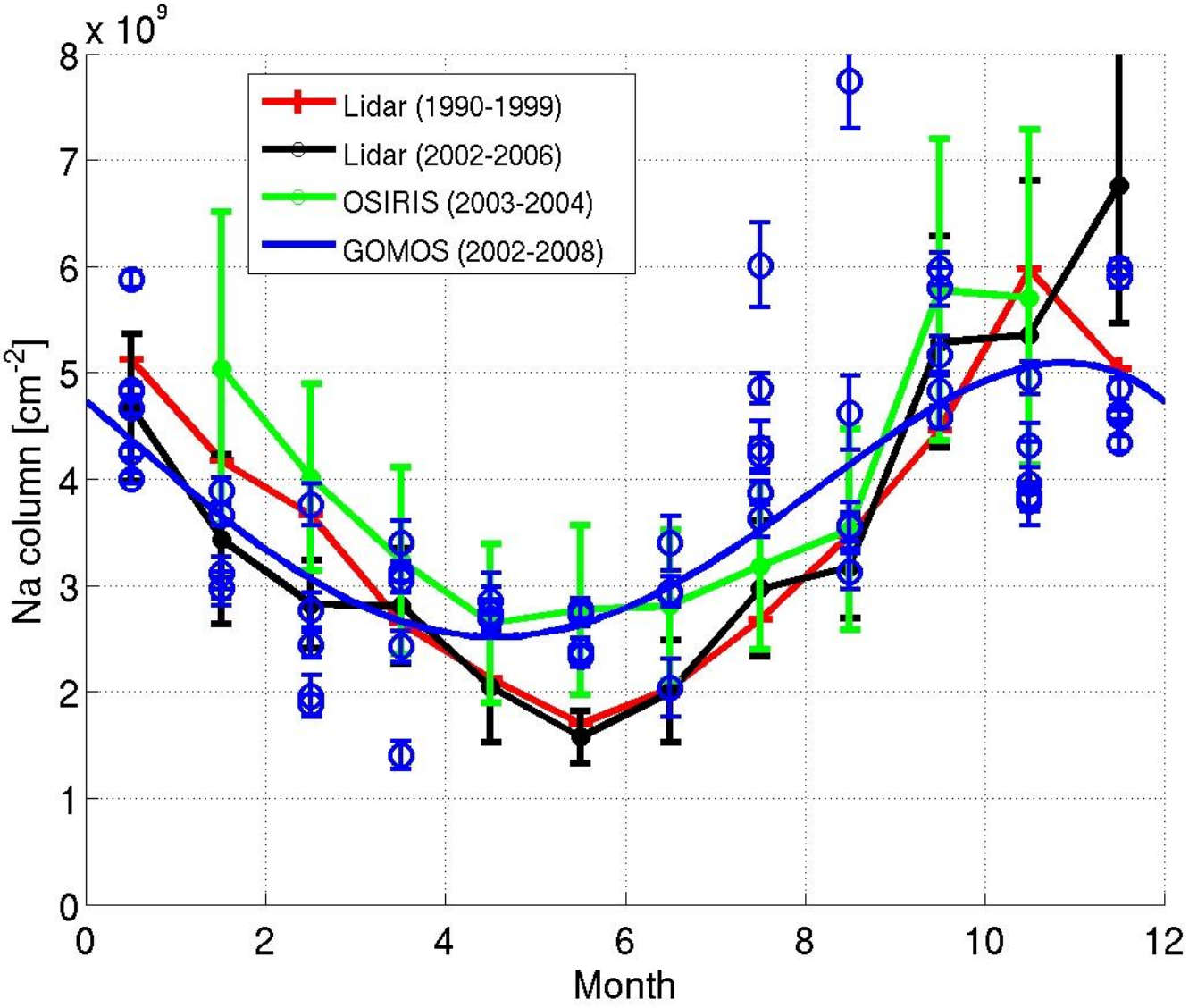




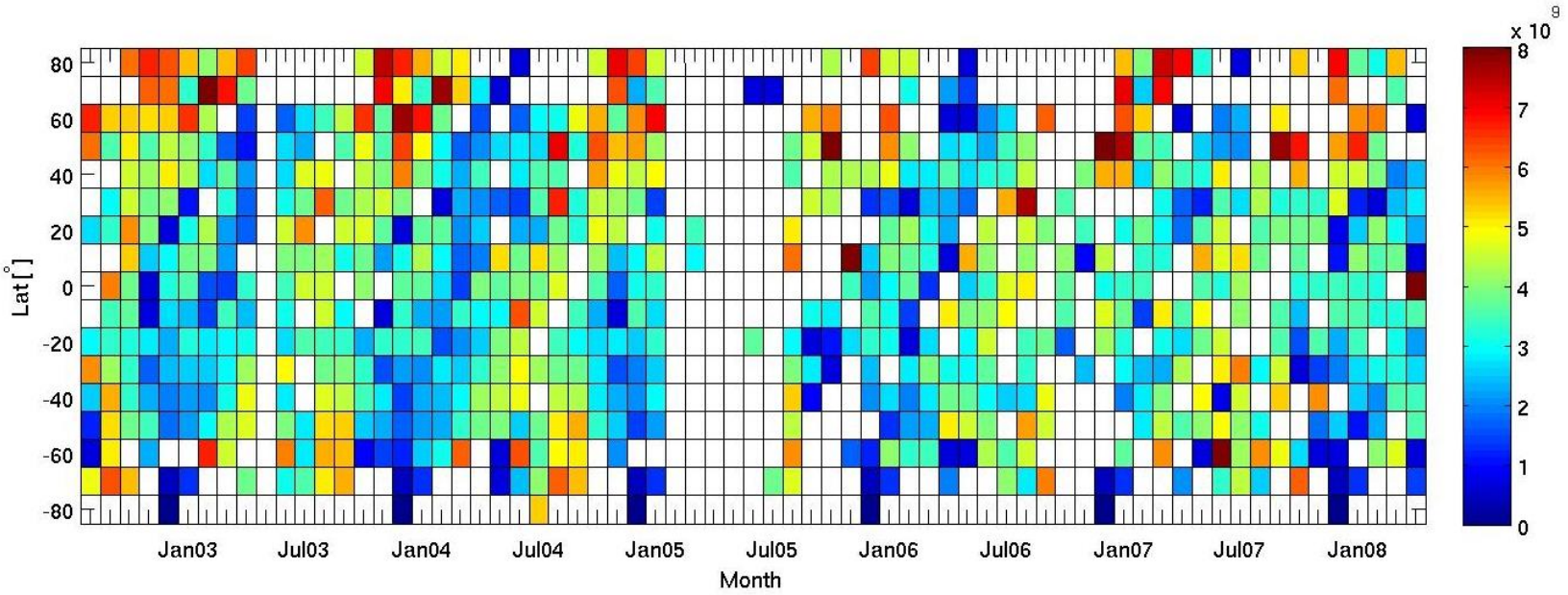
Na slant path optical thickness can be extracted by simple DOAS technique…



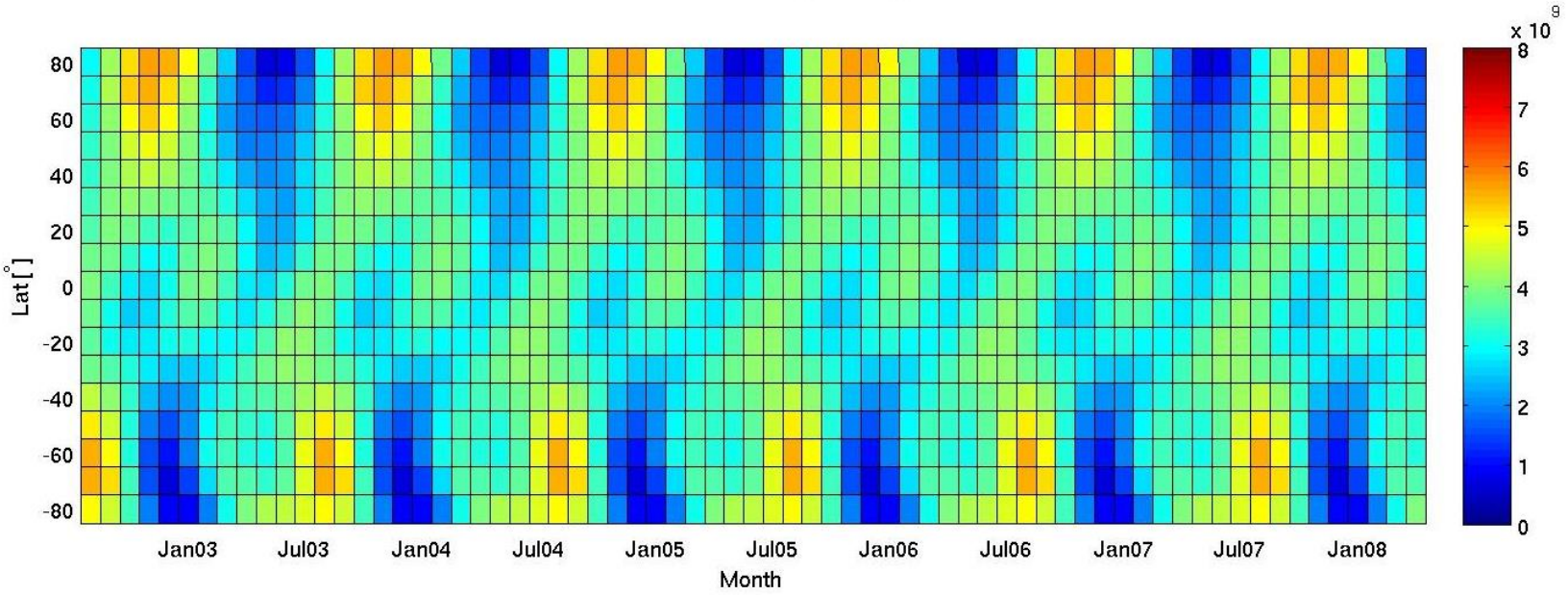
Validation wrt Fort Collins (41°N) and OSIRIS



Polar annual / equatorial semi-annual



Na column [cm^{-2}]



Atmos. Chem. Phys., 10, 9225–9236, 2010
www.atmos-chem-phys.net/10/9225/2010/
doi:10.5194/acp-10-9225-2010
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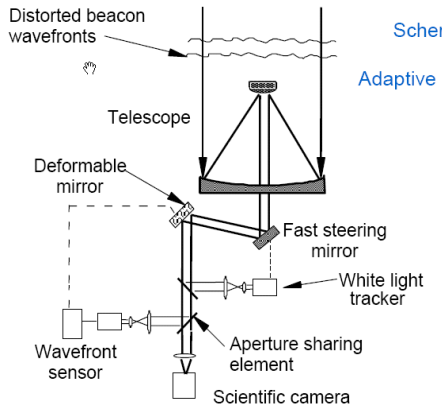
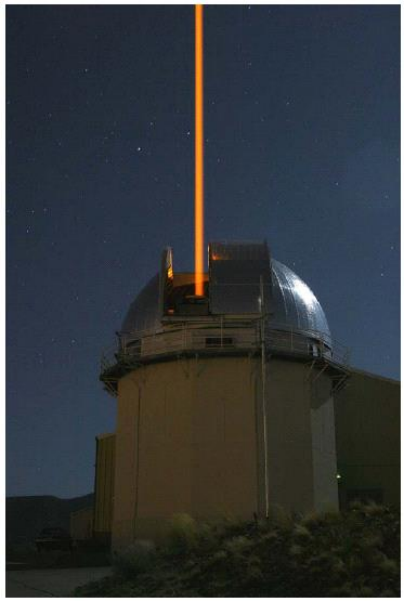
Atmospheric Chemistry and Physics



Schematic Diagram of Adaptive Optical Telescope



A global climatology of the mesospheric sodium layer from GOMOS data during the 2002–2008 period

D. Fussen[1], F. Vanhellemont[1], C. Tétard[1], N. Mateshvili[1], E. Dekemper[1], N. Loodts[1], C. Bingen[1], E. Kyrölä[2], J. Tamminen[2], V. Sofieva[2], A. Hauchecorne[3], F. Dalaudier[3], J.-L. Bertaux[3], G. Barrot[4], L. Blanot[4], O. Fanton d'Andon[4], T. Fehr[5], L. Saavedra[5], T. Yuan[6], and C.-Y. She[6]

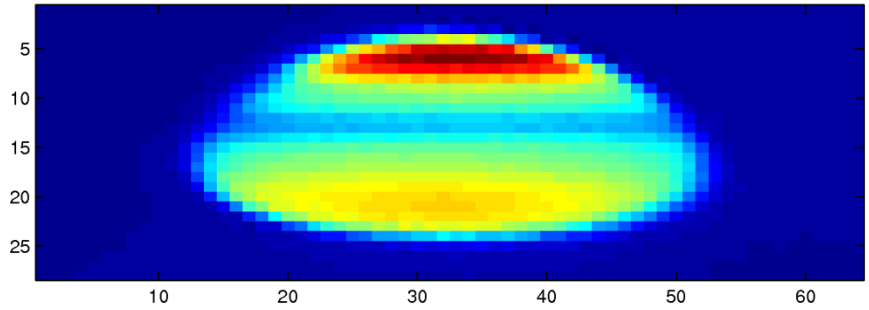
[1]Institut d'Aéronomie Spatiale de Belgique (BIRA-IASB), Brussels, Belgium
[2]Earth observation, Finnish Meteorological Institute, Helsinki, Finland
[3]LATMOS, Université Versailles Saint-Quentin, CNRS/INSU, Verrières-le-Buisson, France
[4]ACRI-ST, Sophia-Antipolis, France
[5]European Space Research Institute, European Space Agency, Frascati, Italy
[6]Department of Physics, Colorado State University, Fort Collins, USA

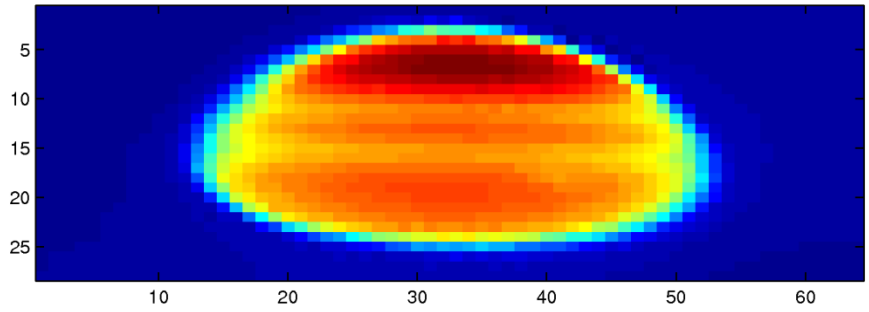
Received: 13 December 2009 – Published in Atmos. Chem. Phys. Discuss.: 3 March 2010
Revised: 8 July 2010 – Accepted: 9 September 2010 – Published: 1 October 2010

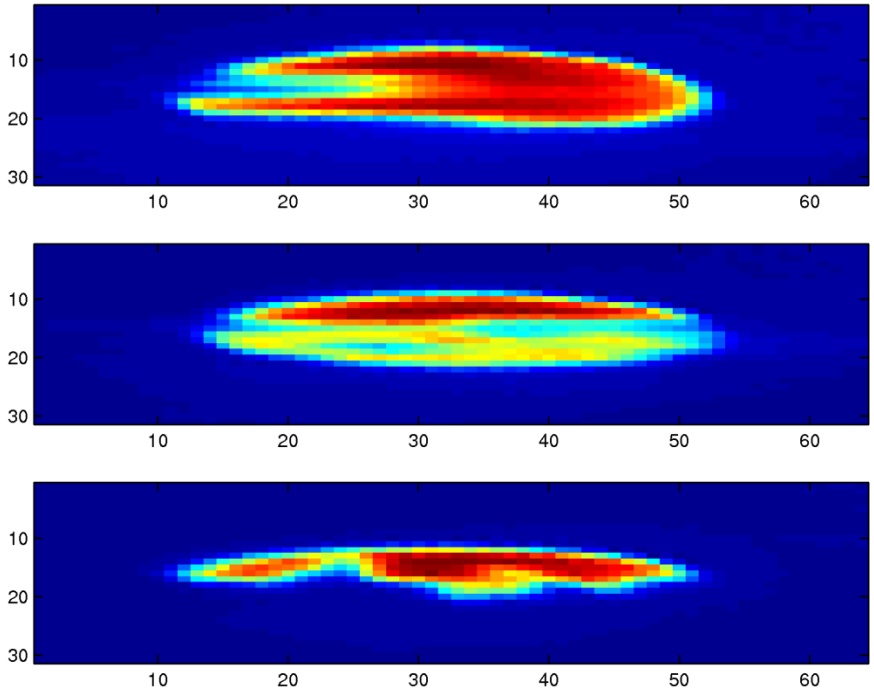
HOW fundamental research can unexpectedly feed applied research…

ACE-MAESTRO [2003-…]: a Canadian success in atmospheric composition sounding with…two Belgian imagers!

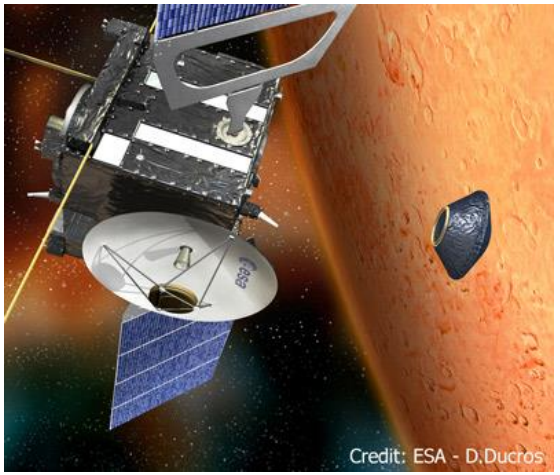
PSC's with mono- or bimodal structure can be distinguished...







MARS ! SPICAM / MEX



MEX

Launch in 2003 : more than

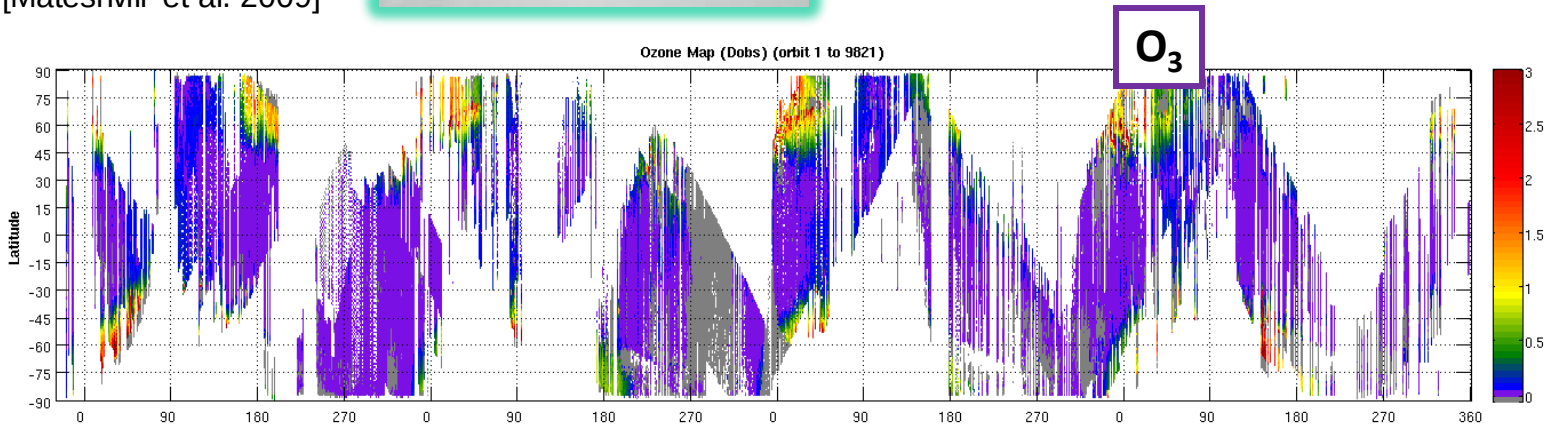
10 yrs of observation

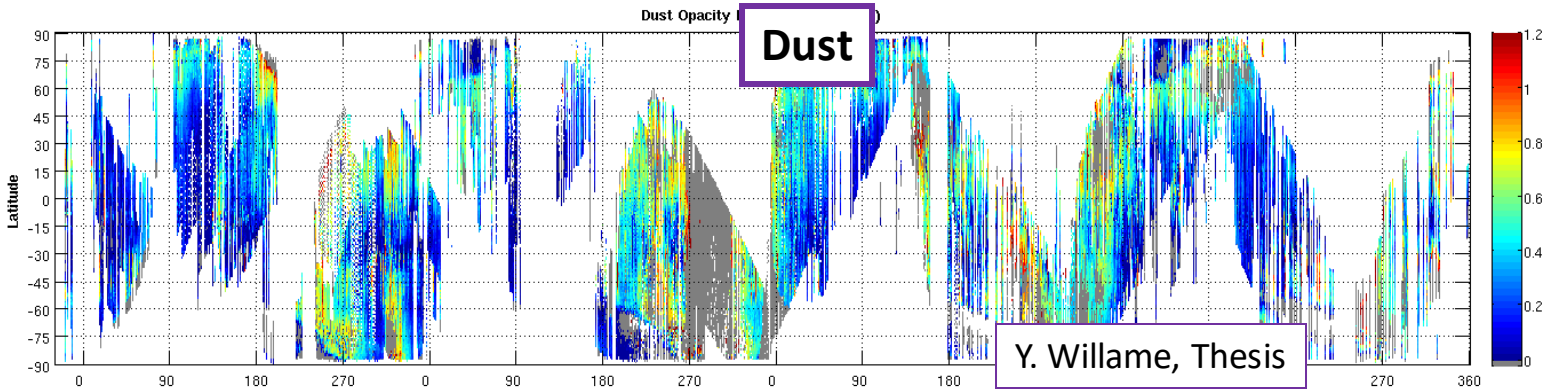
SPICAM

IR & UV channels

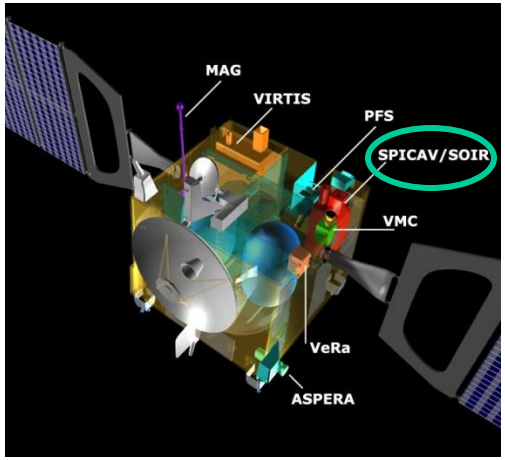
O_3 climatology

Clouds/ice/dust [Mateshvili et al. 2009]





VENUS ! SOIR / VEX



VEX

Launch from Baïkonour (Nov 2005) - Arrival in April 2006

Operational since then

Aerobraking in June-July 2014 successful

Extended until Sep. 2015

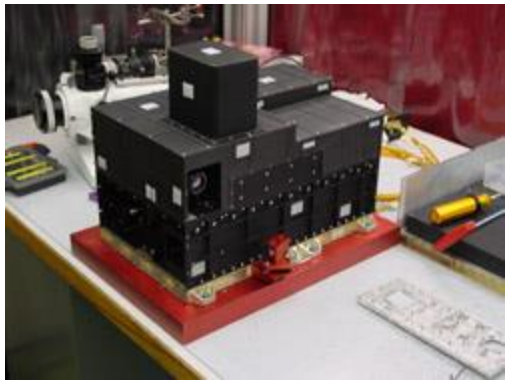
SOIR

Channel of the SPICAV/SOIR instrument
(PI: J.-L. Bertaux, LATMOS)

IR echelle spectrometer & AOTF filter : no moving parts

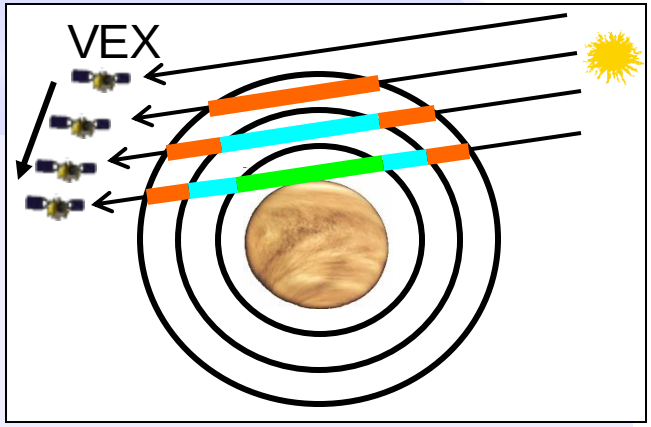
Instrument with highest spectral resolution in space

SOIR designed, built, tested in IASB-BIRA with Belgian industry (OIP)



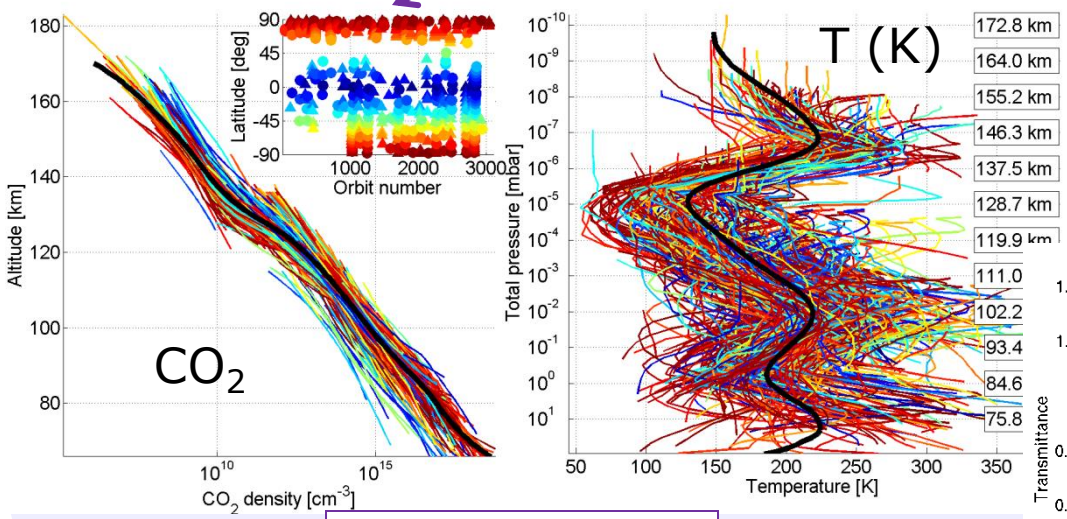
Engineering: E. Neefs Team

SOIR / VEX



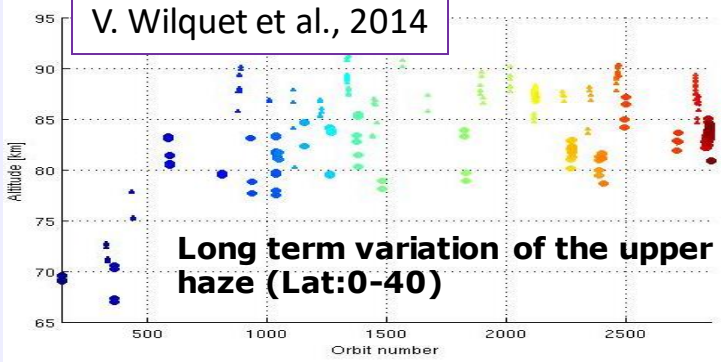
- SOIR
  - IR observation of the upper atmosphere
  - Solar occultation
  - CO_2 density, Temperature using the hydrostatic hyp.
  - Trace gases (CO,H_2O/HDO, SO_2, HCL, HF)
  - Isotopic ratios
  - Aerosols

SOIR covers all Latitudes

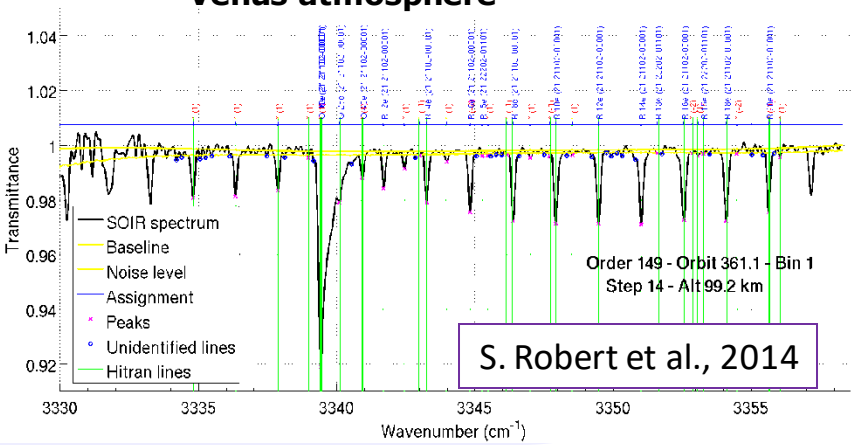


A. Mahieux et al., 2014

V. Wilquet et al., 2014



Absorption lines Atlas of the Venus atmosphere



S. Robert et al., 2014

aeronomie.be

NOMAD / ExoMars TGO 2016

NOMAD
High resolution occultation and nadir spectrometers

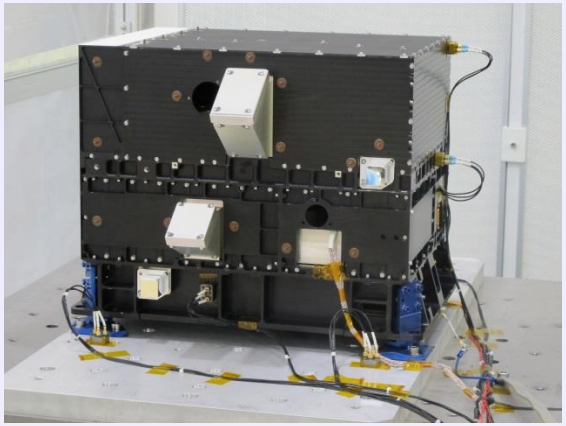
Atmospheric composition (CH_4, O_3, trace species, isotopes) dust, clouds, P&T profiles

UVIS (0.20 – 0.65 µm) λ/Δλ ~ 250	SO	Limb	Nadir
IR (2.3 – 3.8 µm) λ/Δλ ~ 10,000	SO	Limb	Nadir
IR (2.3 – 4.3 µm) λ/Δλ ~ 20,000	SO		

CaSSIS
High-resolution camera
Mapping of sources; landing site selection

ACS
Suite of 3 spectrometers
Atmospheric chemistry, aerosols, surface T, structure

FREND
Collimated neutron detector
Mapping of subsurface water



- ✓ 3 channels : 2 IR, UV
- ✓ Solar occultation, nadir, limb

- ✓ Science objectives:
  - Composition : broad suite of species & isotopologues
  - Aerosols/dust/clouds
  - Surface
  - Temporal/spatial variability - sources

- ✓ IASB-BIRA : PI A.C. Vandaele

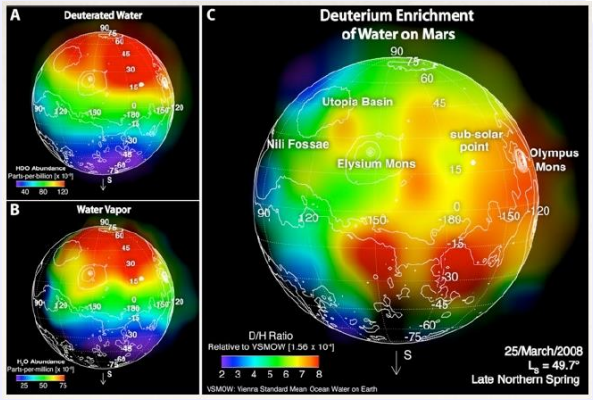
- ✓ Large international science team, in particular in Belgium:
  - ✓ ROB
  - ✓ ULg
  - ✓ CSL

- ✓ Mostly Belgian industry:
  - OIP (Prime, IR optics)
  - Lambda-X (UVIS module)
  - Thales Charleroi (electronics)
  - AMOS (optics)

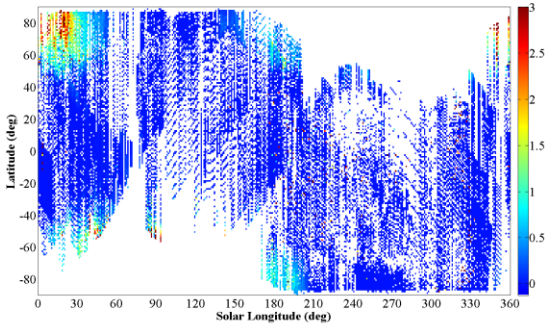
aeronomie.be

NOMAD : Science Objectives

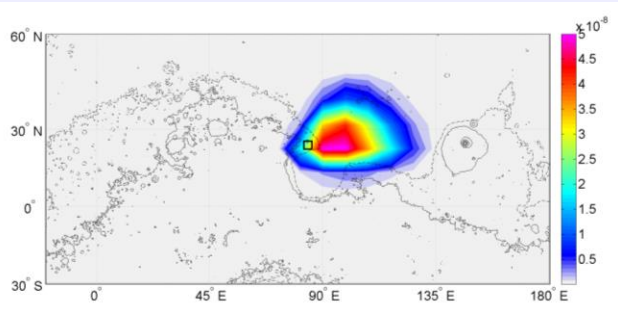
- Chemical composition
  - Detection of a broad suite of trace gases and key isotopes
    - CO_2, CO, O_3
    - CH_4 related : CH_4, $^{13}CH_4$, CH_3D, C_2H_2, C_2H_4, C_2H_6, H_2CO
    - Escape processes : H_2O, HDO -> D/H
    - Volcanism related : SO_2, H_2S, HCl
- Mars Climatology & Seasonal cycles
  - 3D spatial & temporal variability of trace gases and aerosols
  - Climatology of O_3 and UV radiation levels
- Sources & Sinks
  - Analyse correlation trace gases – dust – clouds – T&P
  - Use GCM for interpretation



Villanueva et al., 2008



Willame et al., 2014

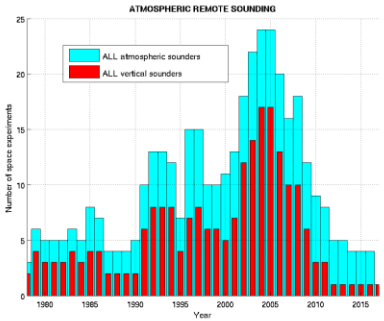


GCM simulations - F. Daerden, L. Neary, S. Viscardy

Back to Earth: there was a **dramatic** decrease in the number of vertical atmospheric sounders: during the 2005-2006 period, 4 missions were interrupted:

SAGE II , HALOE, SAGE III, POAM III

April 2012: ENVISAT died …



ENVISAT (2002-2012)

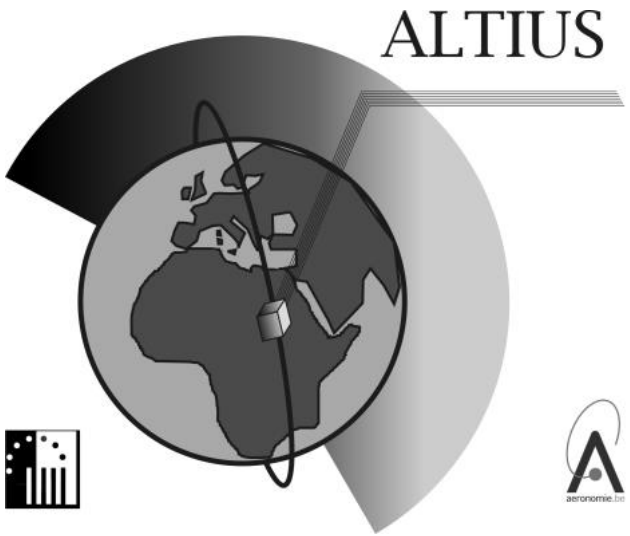
Do we enter into the dark age of atmospheric limb sounding ?

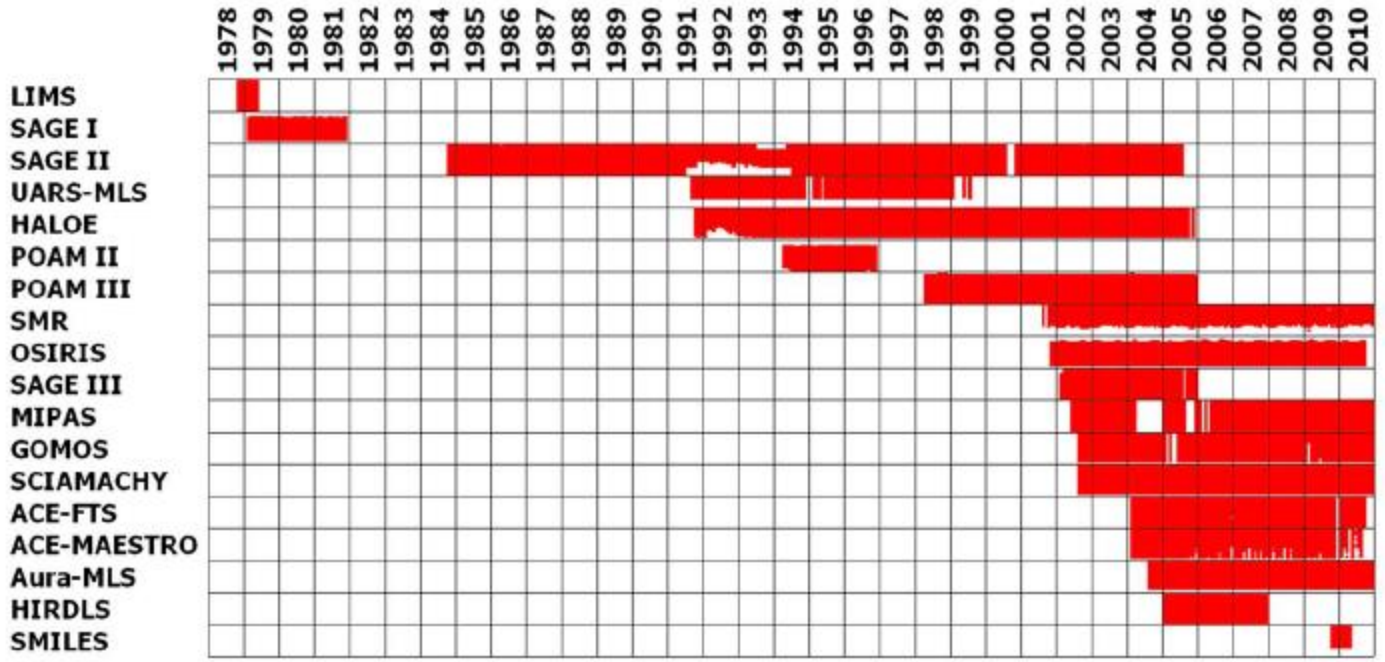
An atmospheric limb sounder proposed by the Belgian Institute for Space Aeronomy

We have the solution !

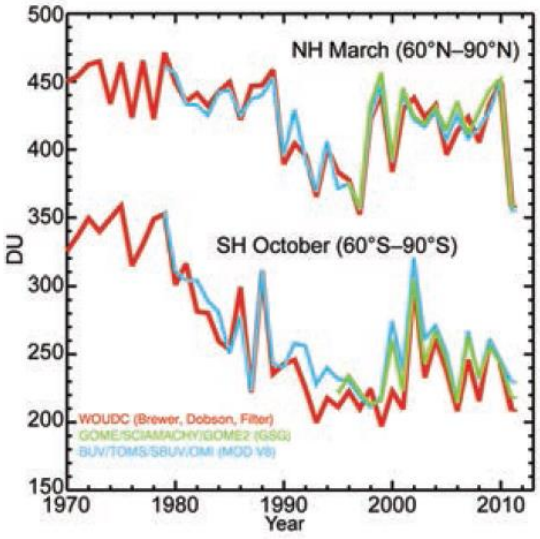
ALTIUS

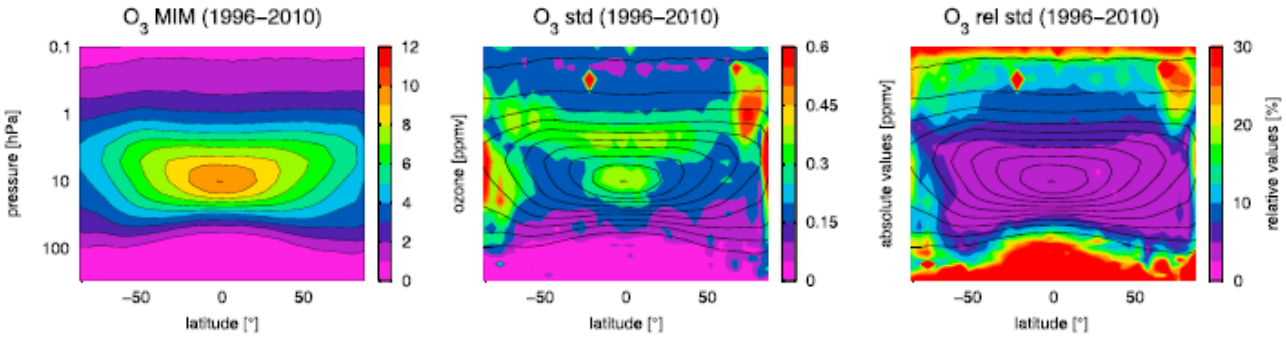
Atmospheric **L**imb **T**racker for **I**nvestigation of the **U**pcoming **S**tratosphere





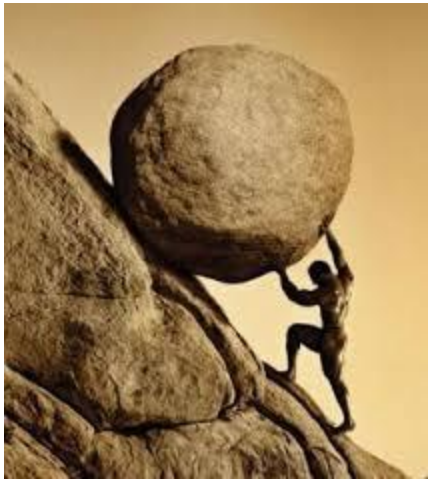
Tegtmeier, S., et al. (2013), SPARC Data Initiative: A comparison of ozone climatologies from international satellite limb sounders, J. Geophys. Res. Atmos., 118, 12,229–12,247, doi:10.1002/2013JD019877.





The ALTIUS story so far (Aug 2005 - Nov 2014)….

2005: preliminary ideas / Nov 2006: phase 0 study / CDF review / Jun 2009: phase A final review / Feb 2011: phase B0 review / Oct 2013: Phase B1 kick-off / Expecting ESA approval in Apr 2015 …

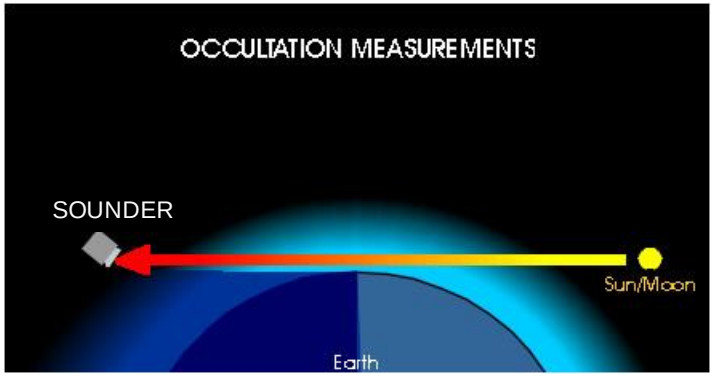


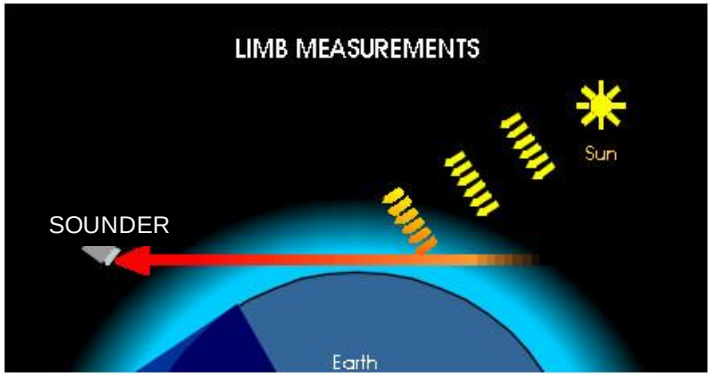
ESA ATMOS conference @ Brugge [2012]:

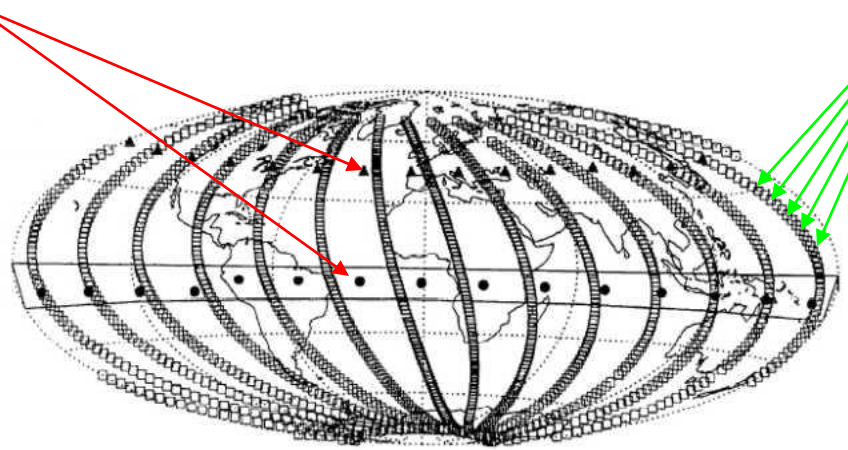
R11 There is an urgent need for the realisation of missions to observe high resolution vertical profiles from the UT/LS region, including the stratosphere, the mesosphere up to the lower thermosphere.
For the definition of a future atmospheric mission with vertical profiling capabilities existing instrument designs, inexpensively delivered, should be used as they are sufficient to meet those goals where continuity of data is more important than development of new complex instruments.

Important technological progresses are presently emerging in the field of vertical atmospheric remote sounding.

PAST → FUTURE

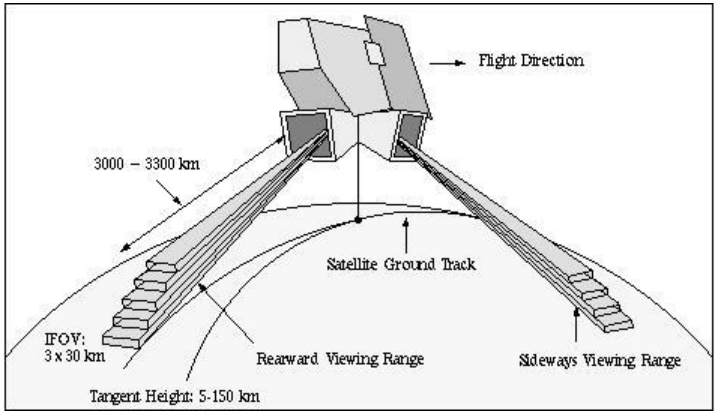


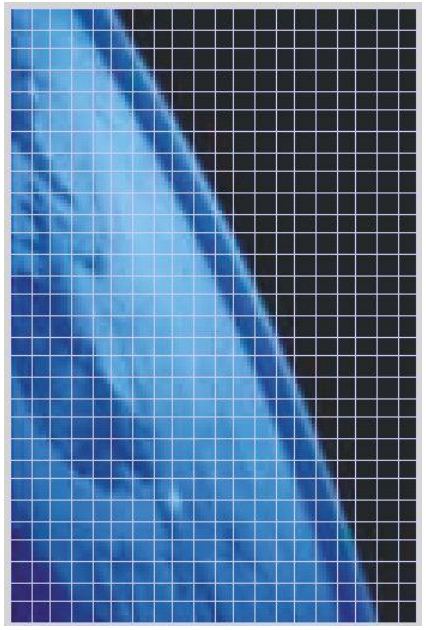




Limb sounding allows for a global coverage in 1-3 days !!!

PAST → FUTURE





Limb scan

Filter or grating spectrometers

No gradients

Full 2-D limb imaging

Acousto-optical filters

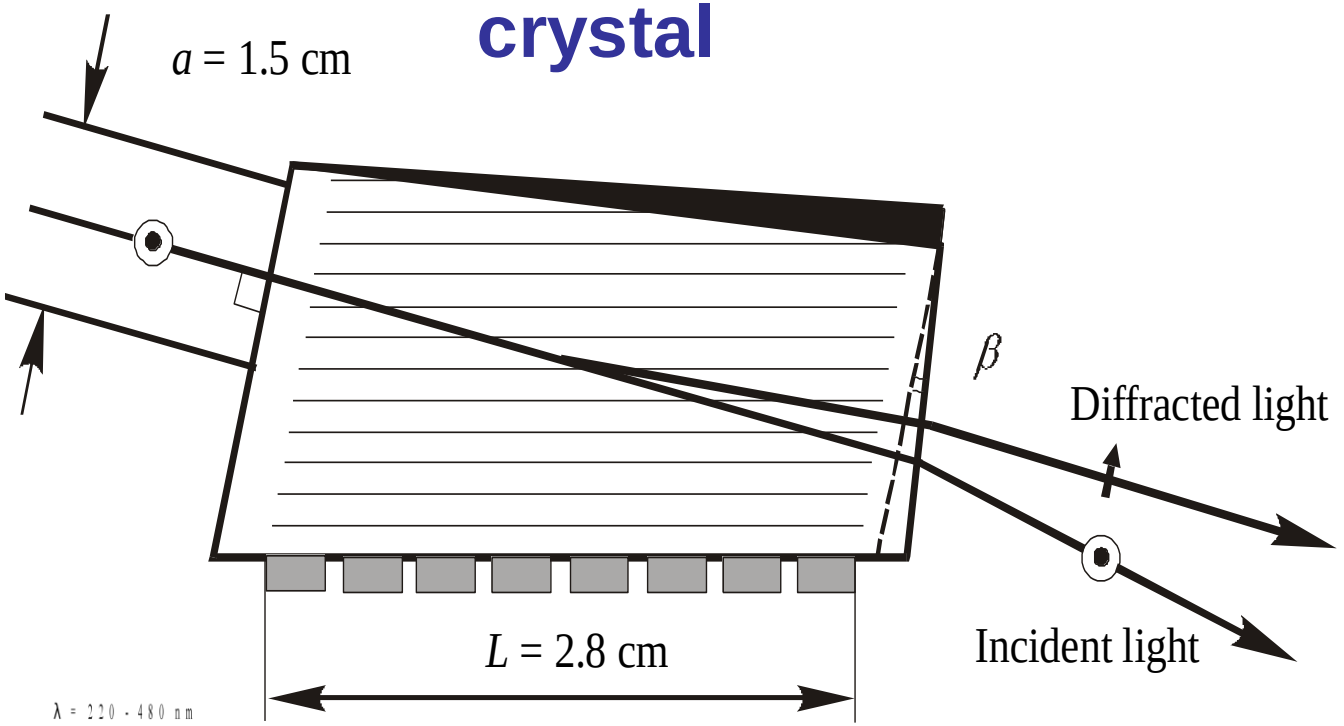
Horizontal gradients

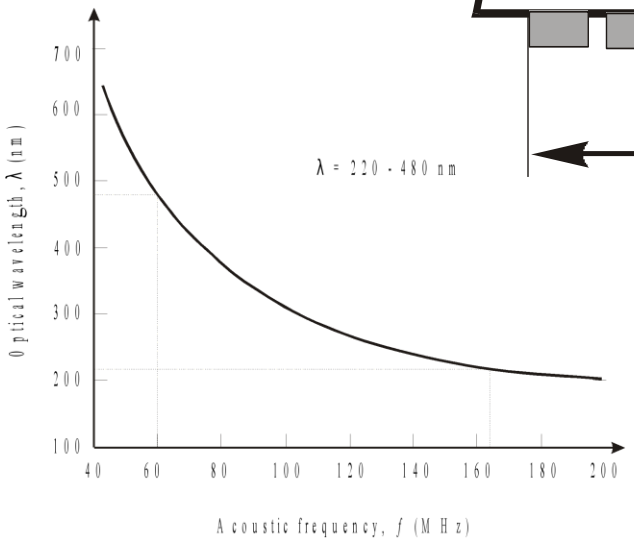
ALTIUS uses the simple concept of a spectral camera, i.e., a combination of an AOTF filter with a 2-D imager

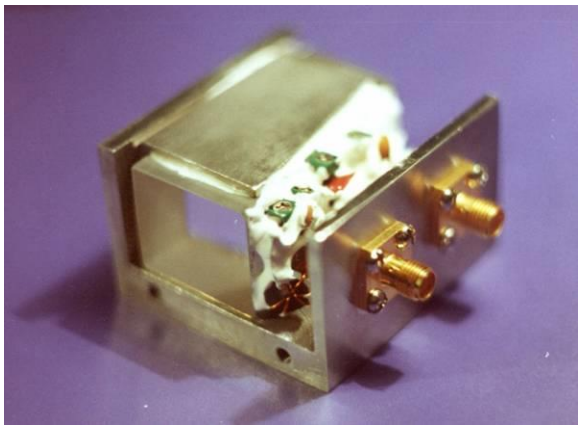
HYPERSPECTRAL CUBE

(wavelength x space) x space = wavelength x (space x space)

Acousto-optic cell of an AOTF on base of TeO_2 or KDP crystal

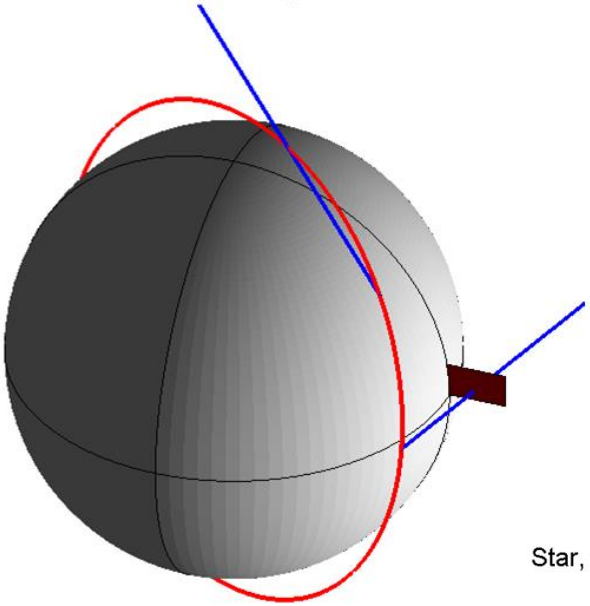




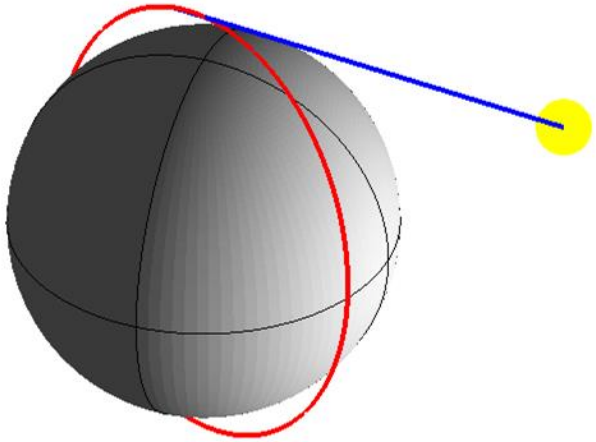


Most innovative ALTIUS concept: multimode observations

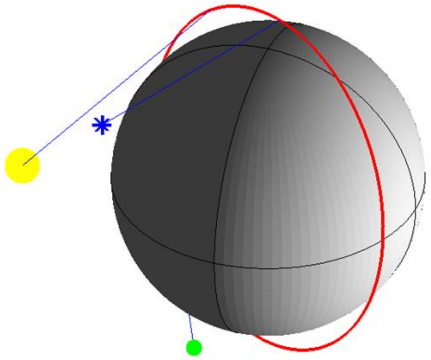
Limb scattering

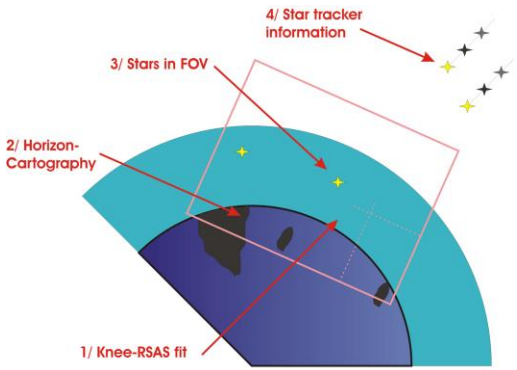


Solar occultation

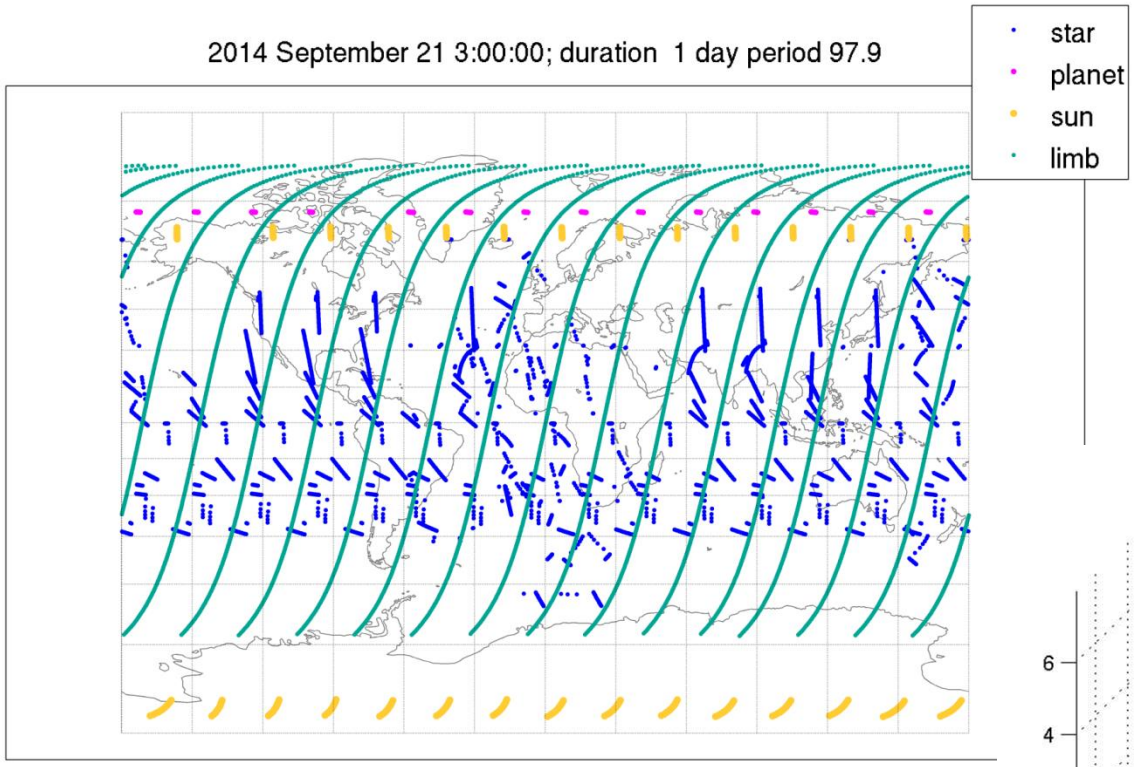


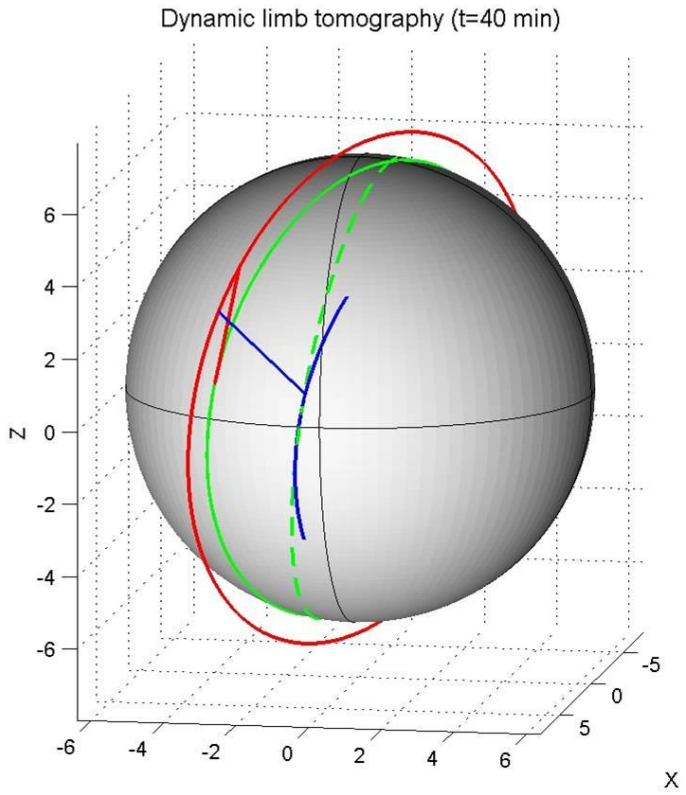
Star, planet, Moon occultations





Global coverage can easily be achieved in three days…



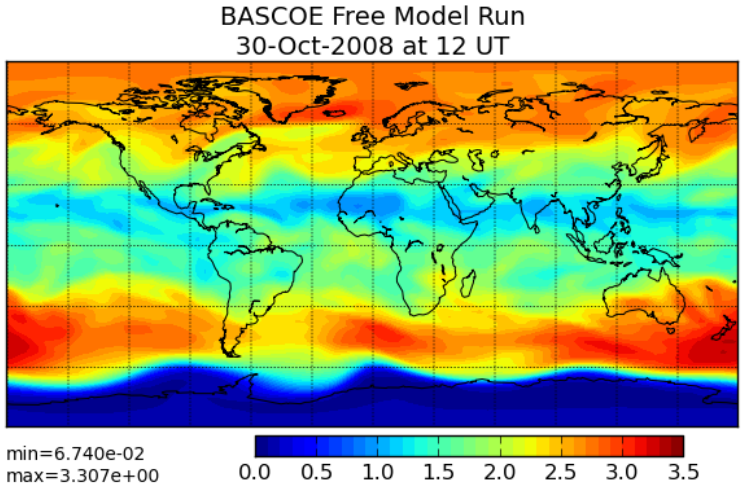


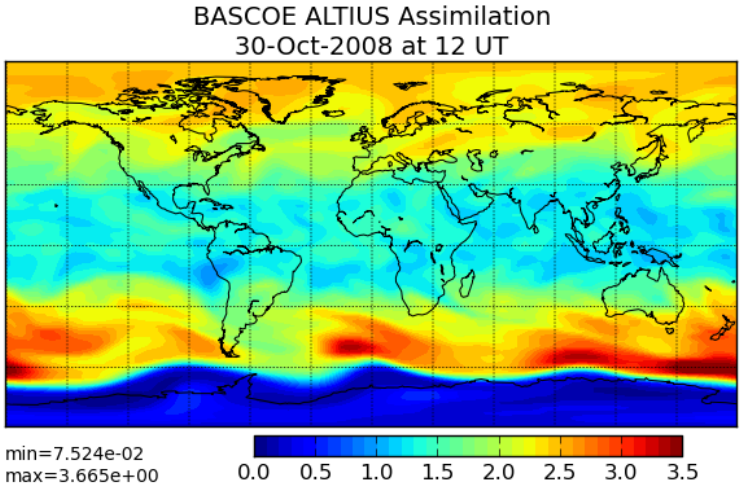
Confidence Level	Colour code and Description
3	Target matched or proven by design
2	Threshold matched
1	Not studied yet or require further studies

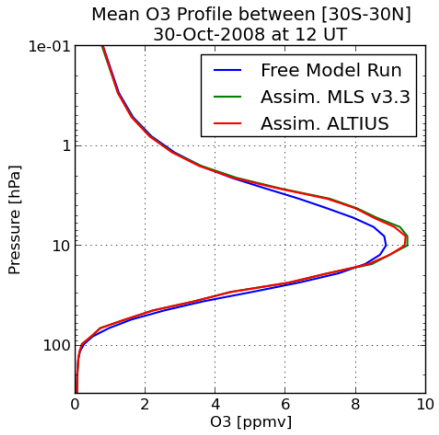
Q3

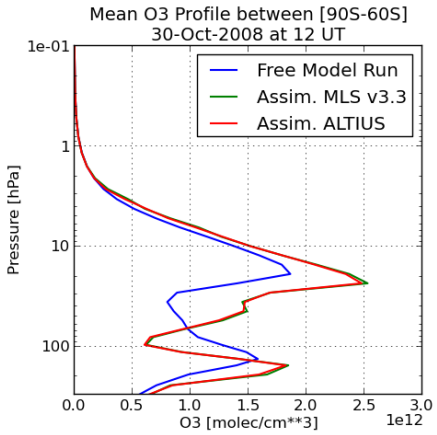
	Molecule	Vertical Region	Target/Threshold Tot. Error (%)	BL	SoO	StO
SR1	O3	UT/LS	5/20	3	3	3
SR2	O3	US	3/10	3	3	2
SR3	O3	UT/LS polar	10/30	N/A	3	2
SR4	O3	MS	10/20	N/A	3	2
SR5	NO2	Strato	15/40	2	3	2
SR6.1	H2O	UT/LS	5/20	1	2	2
SR6.2	CH4	UT/LS	2/5	1	2	2
SR7	Aerosol	UT/LS	10/100	3	3	2
SR8	PSC	UT/LS	30/100	3	3	3
SR9	PMC	MS	30/100	3	2	N/A
SR10.1	OClO	Strato	20/50	N/A	1	1
SR10.2	BrO	UT/LS	5/10	1	1	N/A
SR10.3	NO3	UT/LS night	15/40	N/A	1	1
SR11	T	UT-MS	0.5/2 (K)	N/A	1	N/A
SR12	Tomo	UT/LS	15/40	1	N/A	N/A

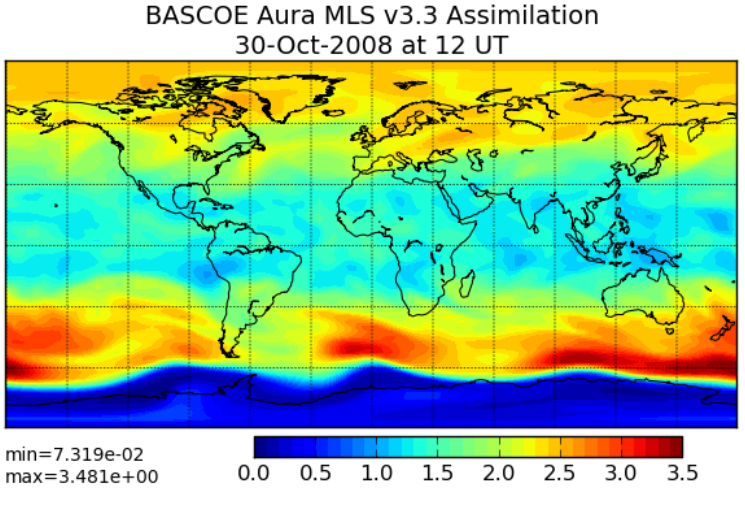
ALTIUS and Aura MLS assimilation are comparable











In a nutshell…

ALTIUS is a limb sounder spectrometer, capable of a 0.5 km vertical resolution. It consists of three independent spectral camera's (optics+AOTF+2-D imager) in the UV-Vis-NIR range (250-1800 nm).

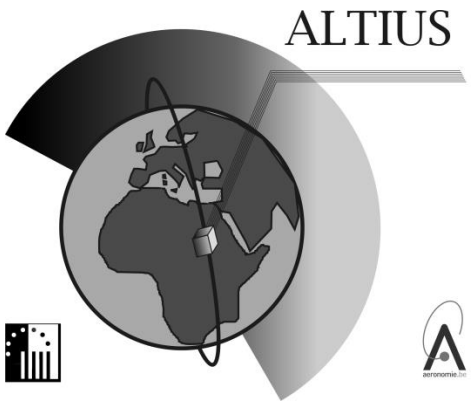
The instrument, on board a heliosynchronous micro-satellite, is operated in a multi-mode approach (limb, solar occ, stellar occ) using nominal and campaign/calibration scenarios. It allows for 3-D atmospheric tomography.

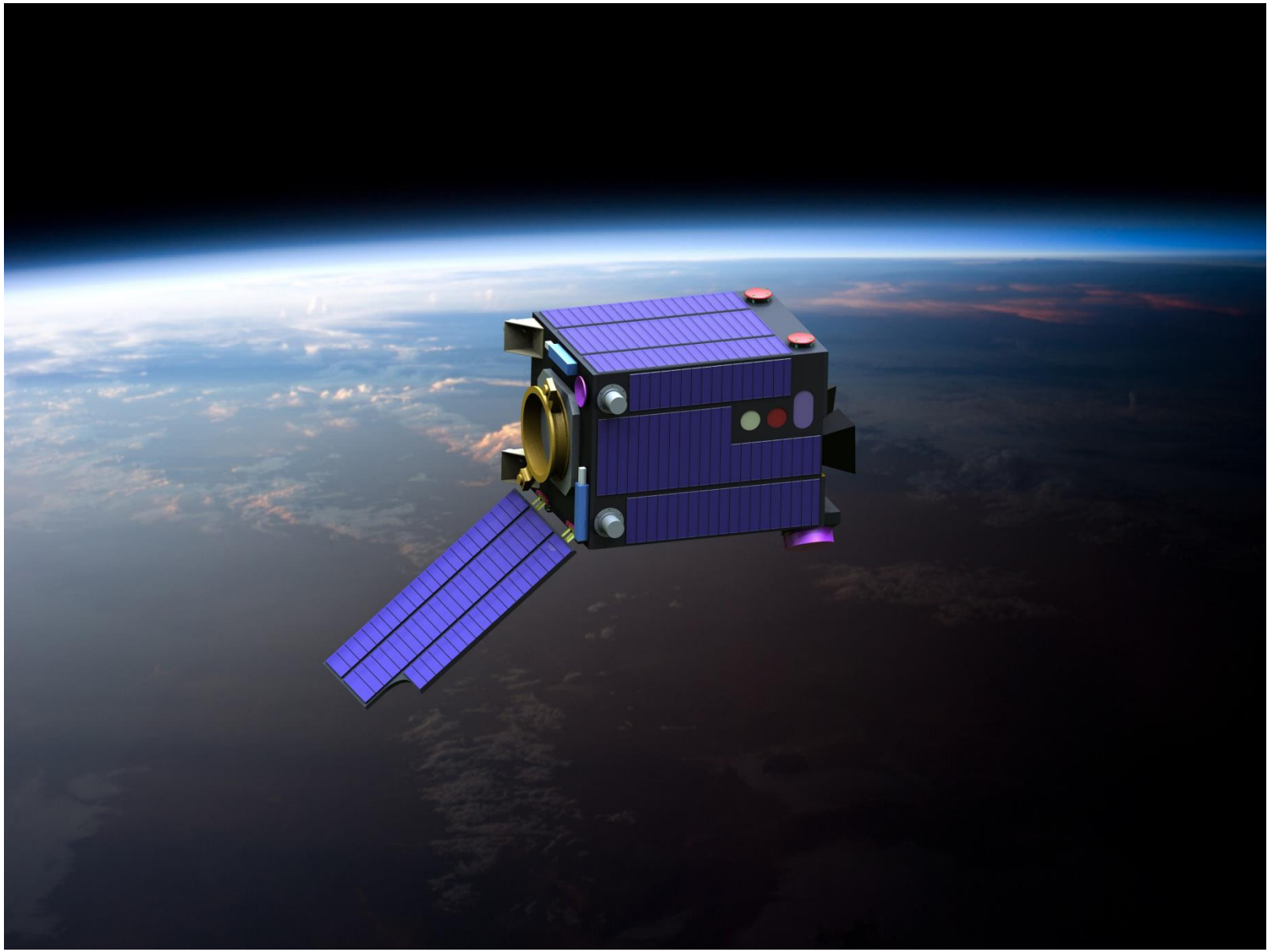
The main geophysical targets are strato/mesospheric ozone profiles and minor trace gases (NO_2,H2O, BrO, CH4, aerosols, temperature..).

Why to propose the ALTIUS mission?

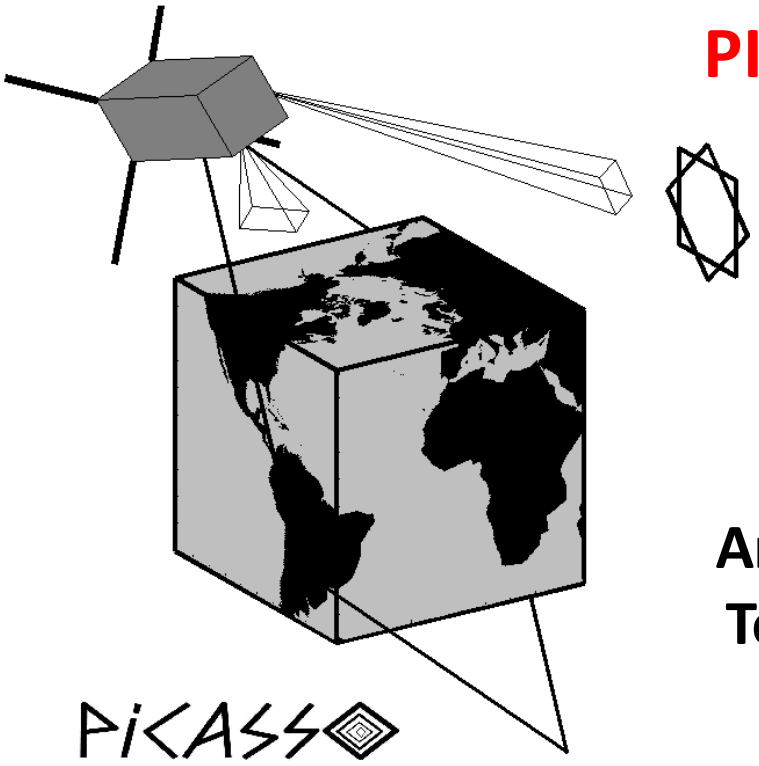
A summary:

1. ***Monitoring of global changes*** *is impossible without stratospheric measurements.*
2. *Dramatic decrease of available (and, in particular, European) instruments capable of a* ***vertical remote sounding*** *of the atmosphere.*
3. *New and* ***promising technologies*** *are emerging.*
4. *Many* ***potential communities*** *to use data and to promote the ALTIUS concepts from a scientific level to an operational capacity.*





PIC.A.S.S.O.

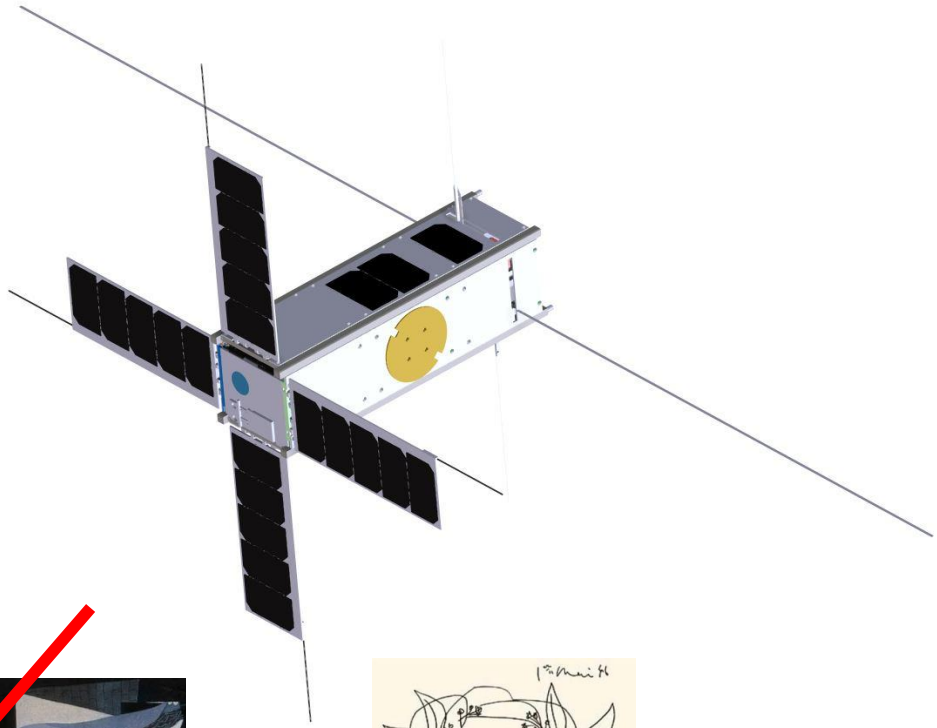


PICo-Satellite for Atmospheric and Space Science Observations

An ESA In-Orbit-Demonstration Mission
To demonstrate science from CubeSats.

(… because a Scientific Institute MUST be innovative !)

PICASSO, the future of remote sensing ? (affordable, fast, evolutive... and slightly risky)



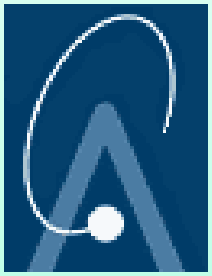
Our objectives ?

- At BISA, we believes that pico- and nano-satellites could very well play an important role in the Earth observation in a near future:
  - As they are “cheap”, they can be deployed as a fleet and be spread all around the Earth, improving the spatio-temporal coverage of the measurements
  - Due to the fleet innate redundancy, individual failures are not catastrophic
  - They can be used to test new instrument concepts at a much cheaper cost
  - They are accessible to “small” countries, and even to institutions
- So, why not to demonstrate their potential through a genuine scientific mission?
- **Objective**: to **demonstrate** Science in a CubeSat mission
  - **VISION**, a visible and near-infrared hyper-spectral imager: vertical profiles retrieval of the ozone density and of the T° via Sun occultations
  - **SLP**, a multi-Needle Langmuir Probe: electronic density and T° of the plasma

Consortium, partners and sponsors

ORB

Consortium



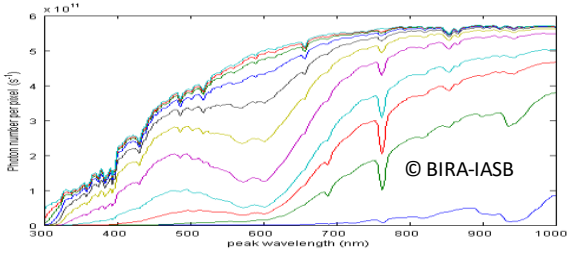
BIRA-IASB

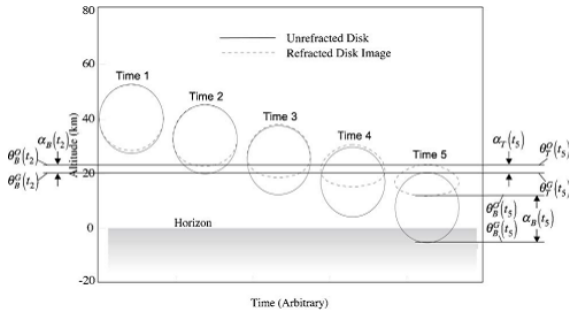
STCE

VISION

VISION stands for "**Vi**sible **S**pectral **I**mager for **O**ccultation and **N**ightglow"

Scientific goal 1: Polar and mid-latitude stratospheric ozone vertical profile retrieval (via spectral observation of Sun occultations in the Chappuis band)

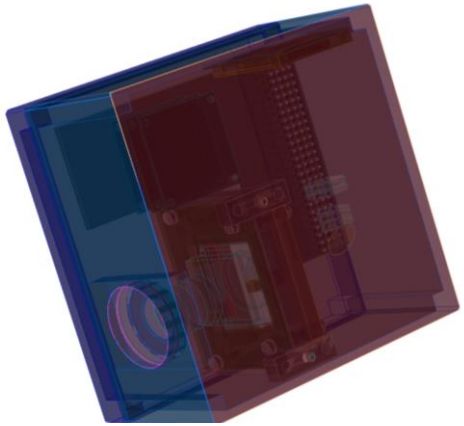




Scientific goal 2: Upper atmosphere temperature profiling based on the Sun refractive flattening: *"Atmospheric Refractivity from Inversion of Dilution"*

Instrument description

- ❑ Fabry-Pérot + spectral filters: up to 3 modes
- ❑ Detector: Commercial CMOS 2048x2048 RGB
- ❑ Field of View: 2.5°
- ❑ Range: 400-800 nm (TBC), FWHM: < 10 nm
- ❑ Heritage: AaSI on board Aalto-1



SLP

SLP stands for "**S**weeping **L**angmuir **P**robe"

The **SLP Scientific objectives** are the in-situ study of:

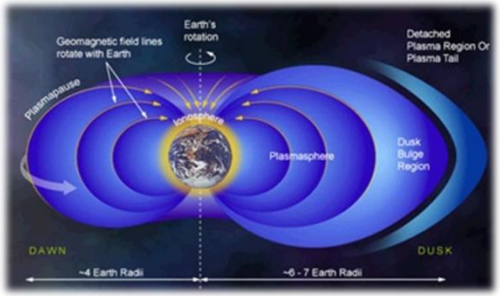
1. The ionosphere-plasmasphere coupling
2. The subauroral ionosphere and corresponding magnetospheric features
3. The aurora structure
4. The turbulence in the partially ionized ionosphere

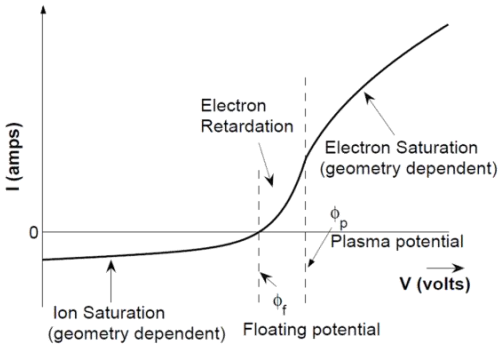
Instrument description

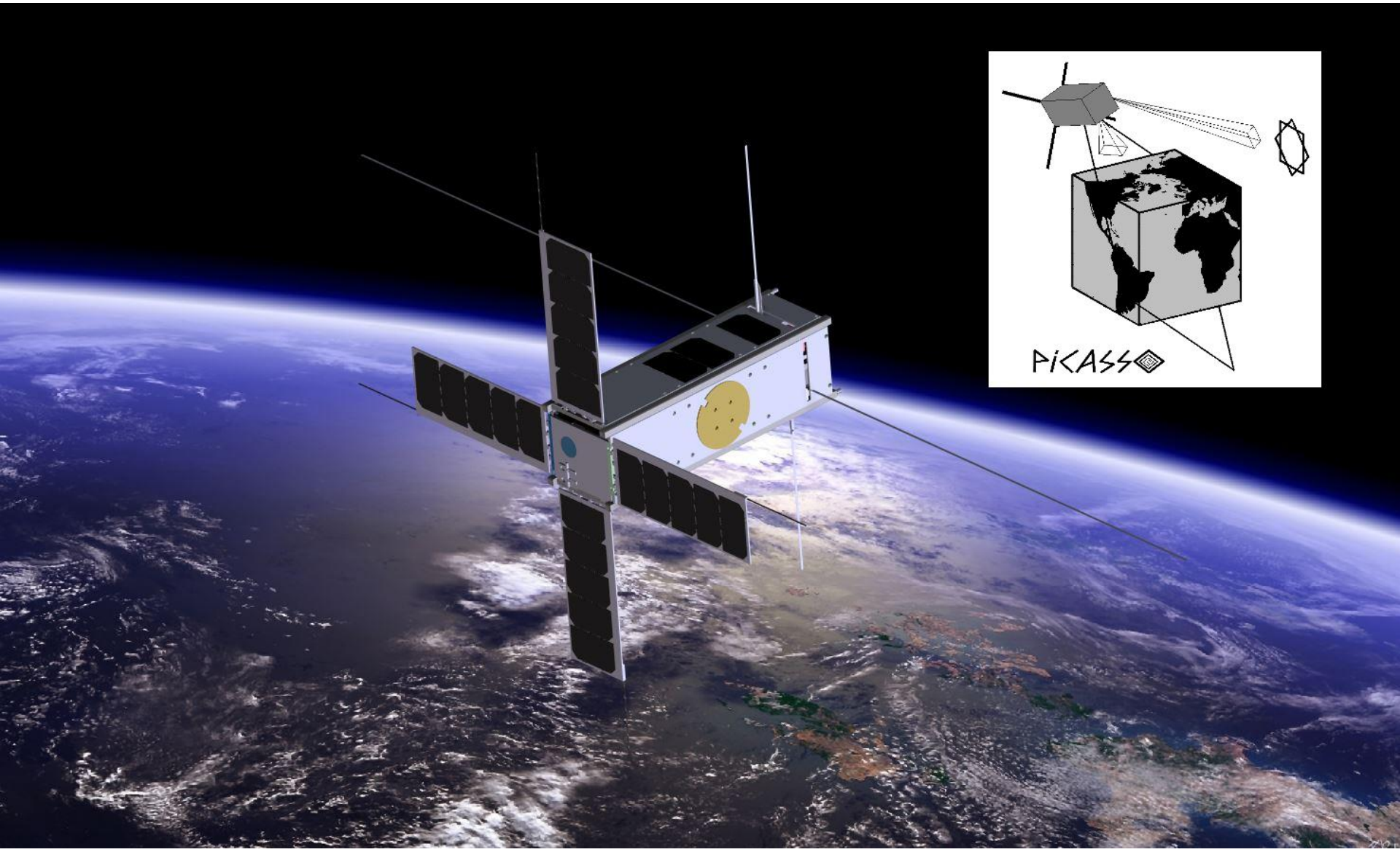
SLP is made of four needle-like Langmuir probes whose electrical potentials are periodically swept with respect to the plasma potential. From the electric current collected by each probe, the following parameters will be retrieved:

- ✓ Local electron density and temperature,
- ✓ Local ion density
- ✓ Spacecraft potential.

Note: the solar panels are used as booms for the probes.






PICASSO

Some statements about space aeronomy

- The atmosphere is 3-D. The vertical is the most important. How to measure constituent profiles ? → from space: in 3 days, on a grid of about 300 km x 300 km x 1 km !
- In the last 50 years, BISA reached a level of excellence in limb sounding of planetary atmospheres: from ideas to instruments and missions, from data processing to retrievals, from climatologies to modelization.
- We need robust « space qualified workhorses » to ensure long term series and data continuity. We also need « laboratory tiny mice » to explore new observation techniques. A scientific institute needs research, development and exploration!
- Are we expensive ? No,we are cheap! A 100 M€ mission over 10 years -> 1 € / year for each Belgian citizen… We also support Belgian industry.
- A true challenge: how to become reactive ? If climate changes can be detected over 10 years, can we spend 10 years to develop a mission? The answer is :

ALTIUS, CITIUS, FORTIUS

♦♦♦