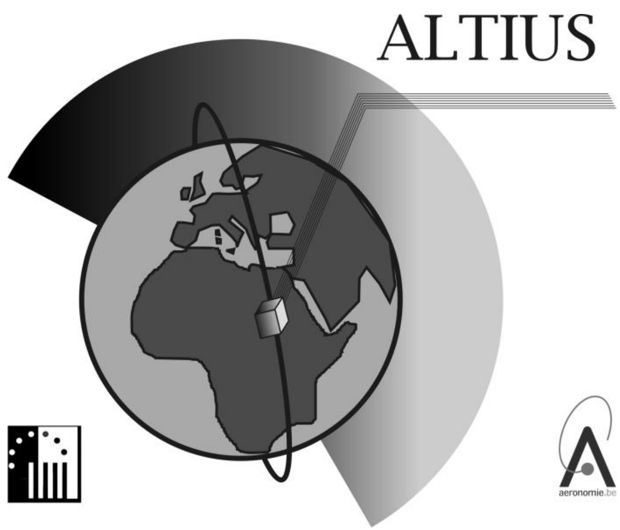
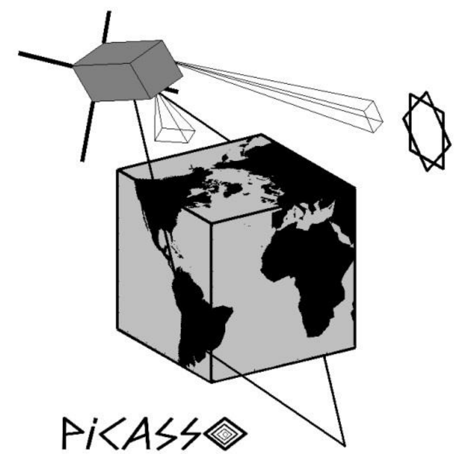
ALTIUS & PICASSO
Two small limb sounding missions to explore the forthcoming stratosphere





FUSSEN, Didier, CARDOEN, Pepijn; DEKEMPER, Emmanuel; DEMOULIN, Philippe; ERRERA, Quentin; FRANSSENS, Ghislain; MATESHVILI, Nina; PIEROUX, Didier; VANHAMEL, Jurgen; VANHELLEMONT, Filip; VAN OPSTAL Bert ***Belgian Institute for Space Aeronomy, Belgium***

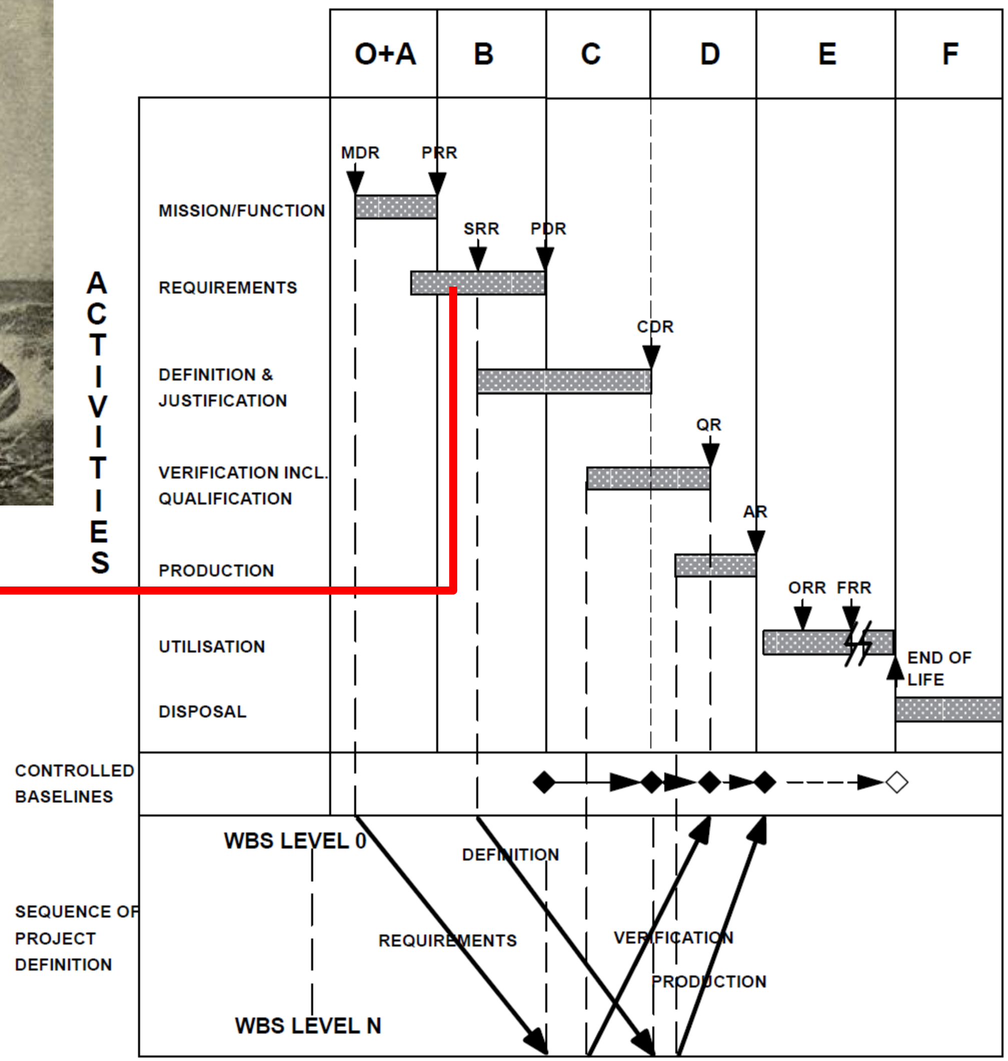
ATMOS 2015

Contact: didier@oma.be

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.



NOTE AR = Acceptance Review
CDR = Critical Design Review
FRR = Flight Readiness Review
MDR = Mission Definition Review
ORR = Operational Readiness Review
PDR = Preliminary Design Review
PRR = Preliminary Requirements Review
QR = Qualification Review
SRR = System Requirements Review
WBS = Work Breakdown Structure

Figure 1: Typical project life cycle

After a 10-year journey, ALTIUS is floating somewhere here…

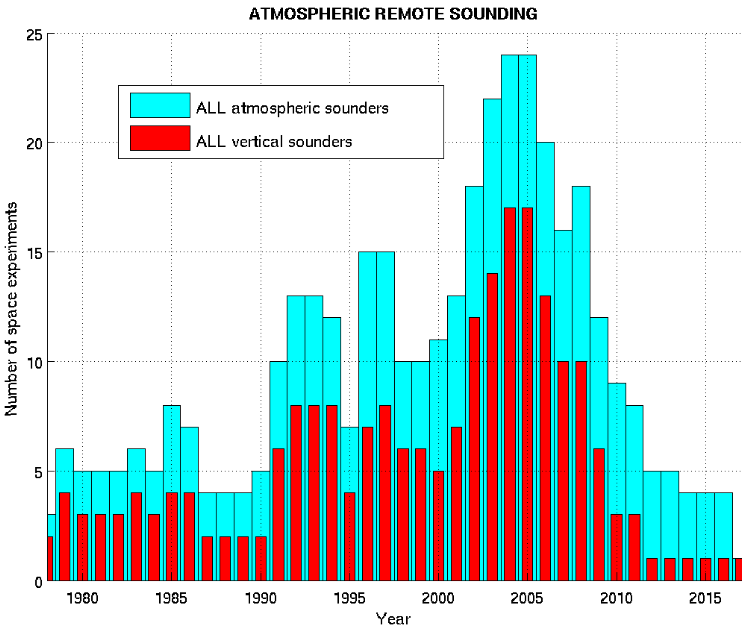
- IDR in June 2015
- SRR end 2015

Need for an ESA/BELSPO agreement !

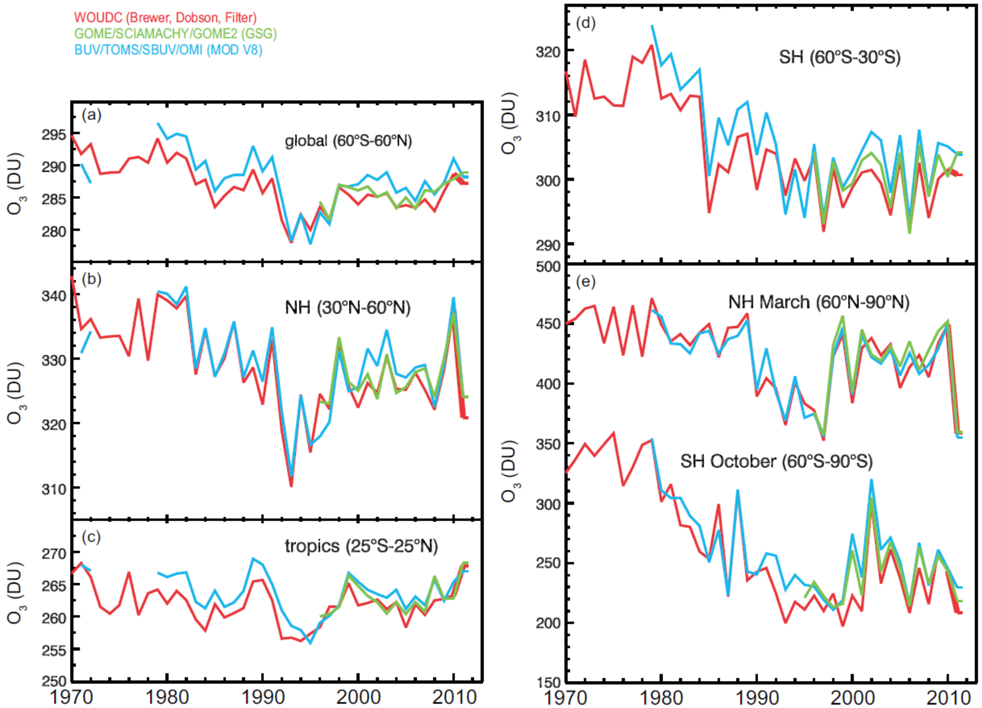
A few vintage slides …

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

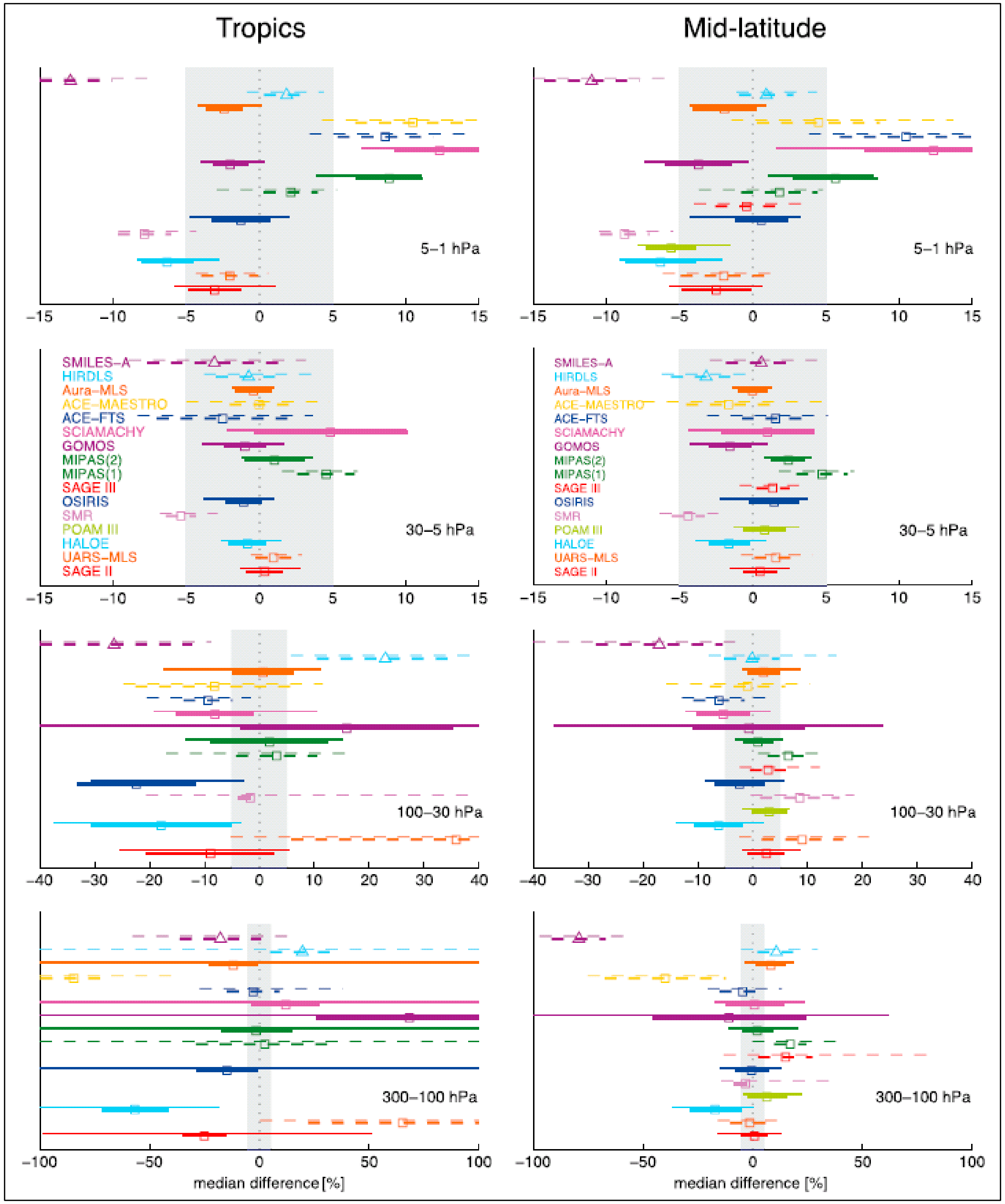
SAGE II , HALOE, SAGE III, POAM III



Only a few vertical sounders are still alive: AURA-MLS, ACE, OSIRIS, OMPS



All data sets show a small ozone increase since mid-1990, with varying levels of statistical significance but this increase cannot presently be attributed to ODS decrease because of observational uncertainty, natural ozone variability, and stratospheric cooling. Analysis of Chemistry-Climate-Models (CCM) results suggests that longer observational records are required to separate these effects from each other. **[IPCC5]**

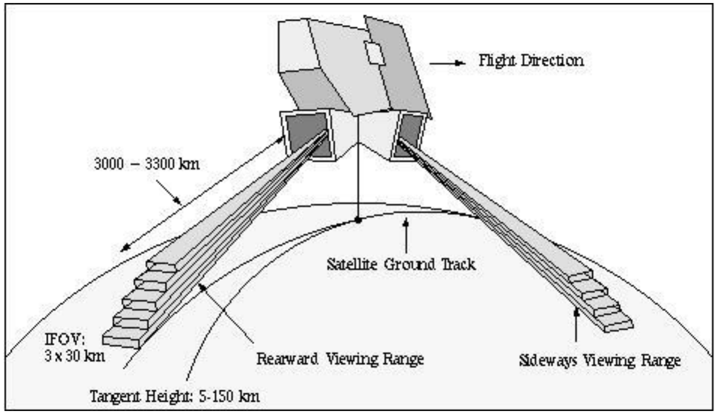


Summary of ozone differences for 1996–2010. Over a given latitude and altitude region, the median (squares), median absolute deviation (MAD, thick lines), and the standard deviation (thin lines) of the monthly mean relative differences between an individual instrument climatology and the MIM are calculated.

[S. Tegtmeier et al. , JGR, 2013]

- To go below 5 % is difficult : stability may be more important
- We need several overlapping missions

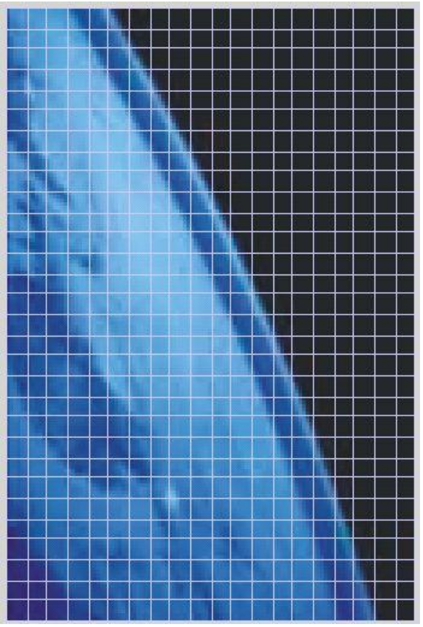
PAST → FUTURE



Limb scan

Filter or grating spectrometers

No gradients



Full 2-D limb imaging

Acousto-optical and FP filters

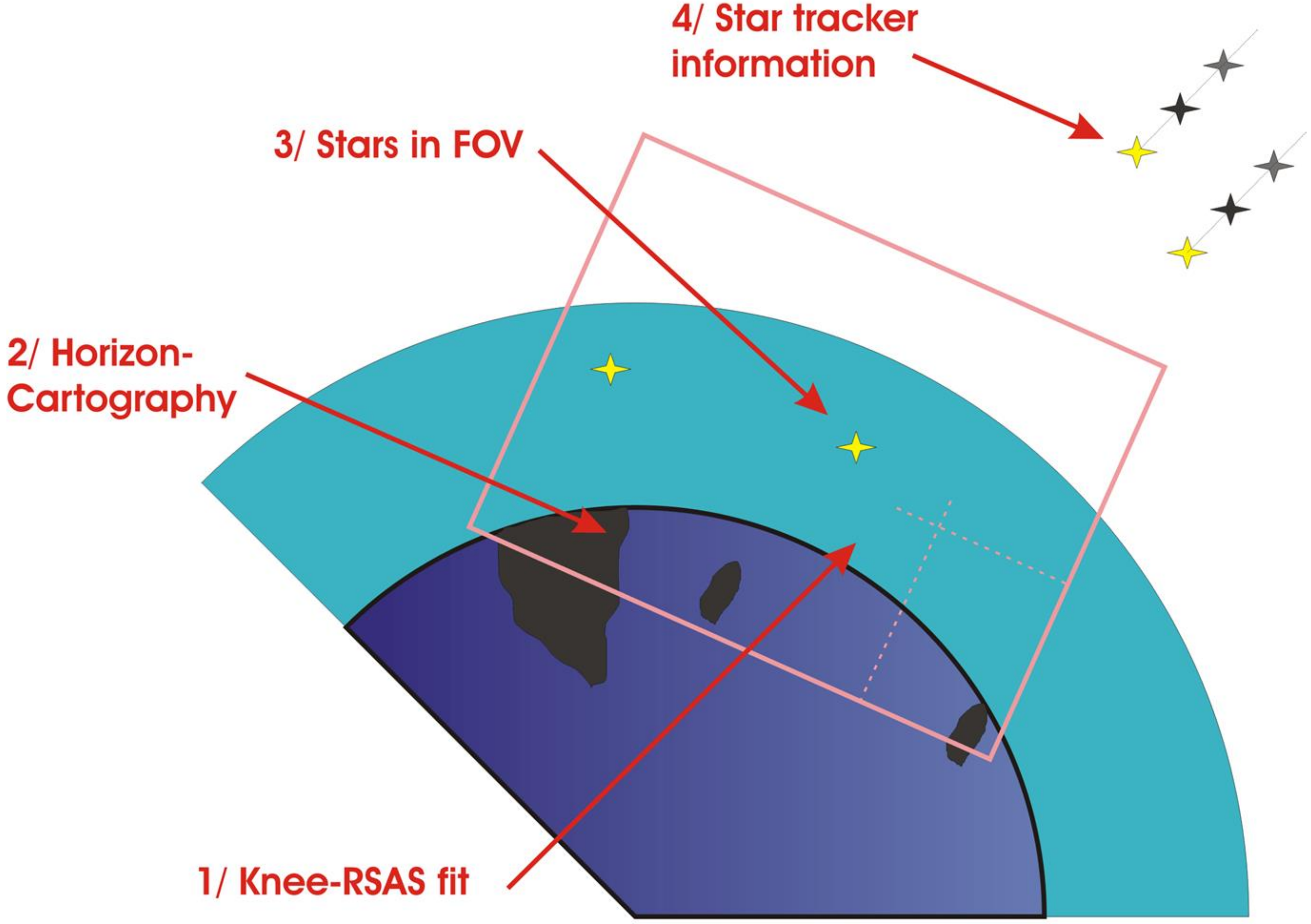
Horizontal gradients

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

HYPERSPECTRAL CUBE

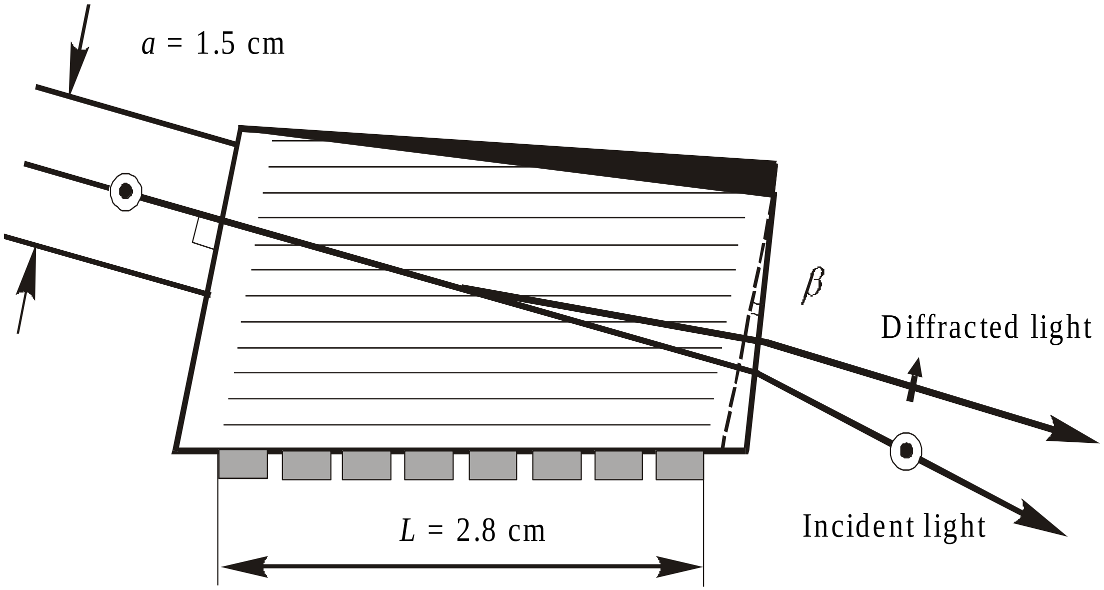
(wavelength x space) x space = wavelength x (space x space)

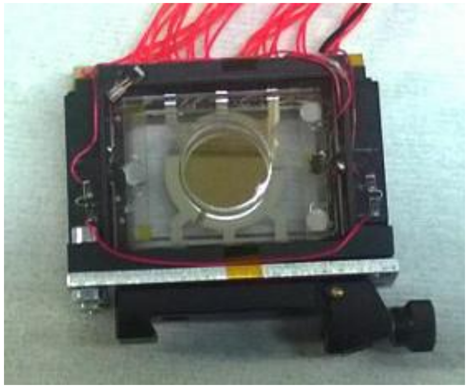
Altitude registration of ALTIUS FOV

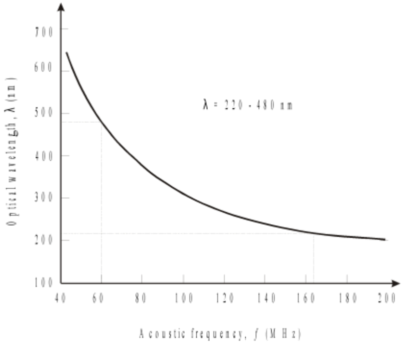


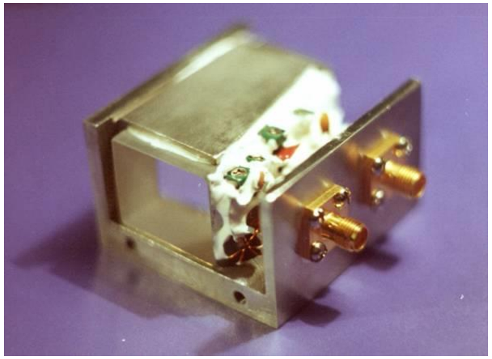
AOTF TeO_2 crystal (VIS & NIR)

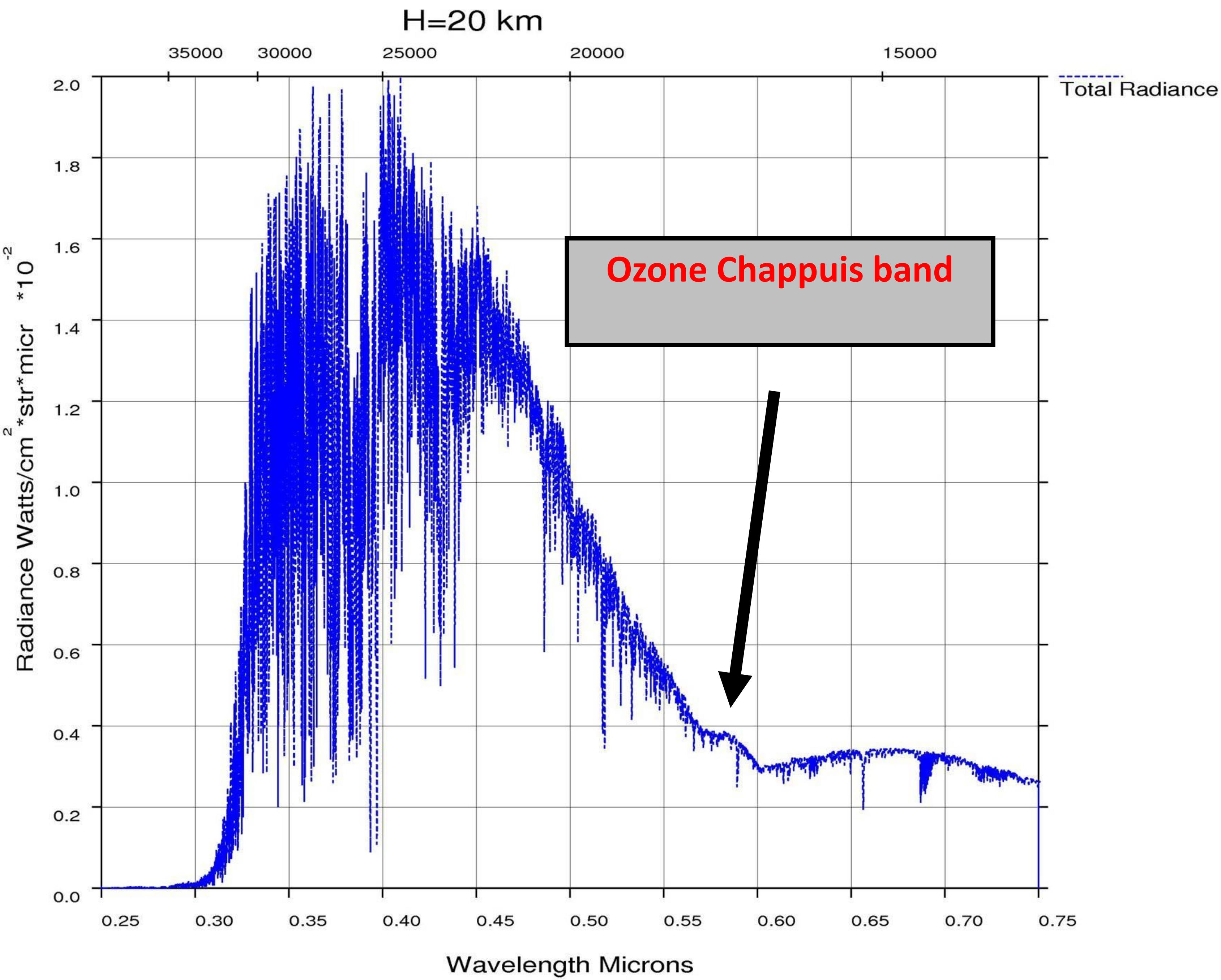
Piezo driven FABRY-PEROT (UV)





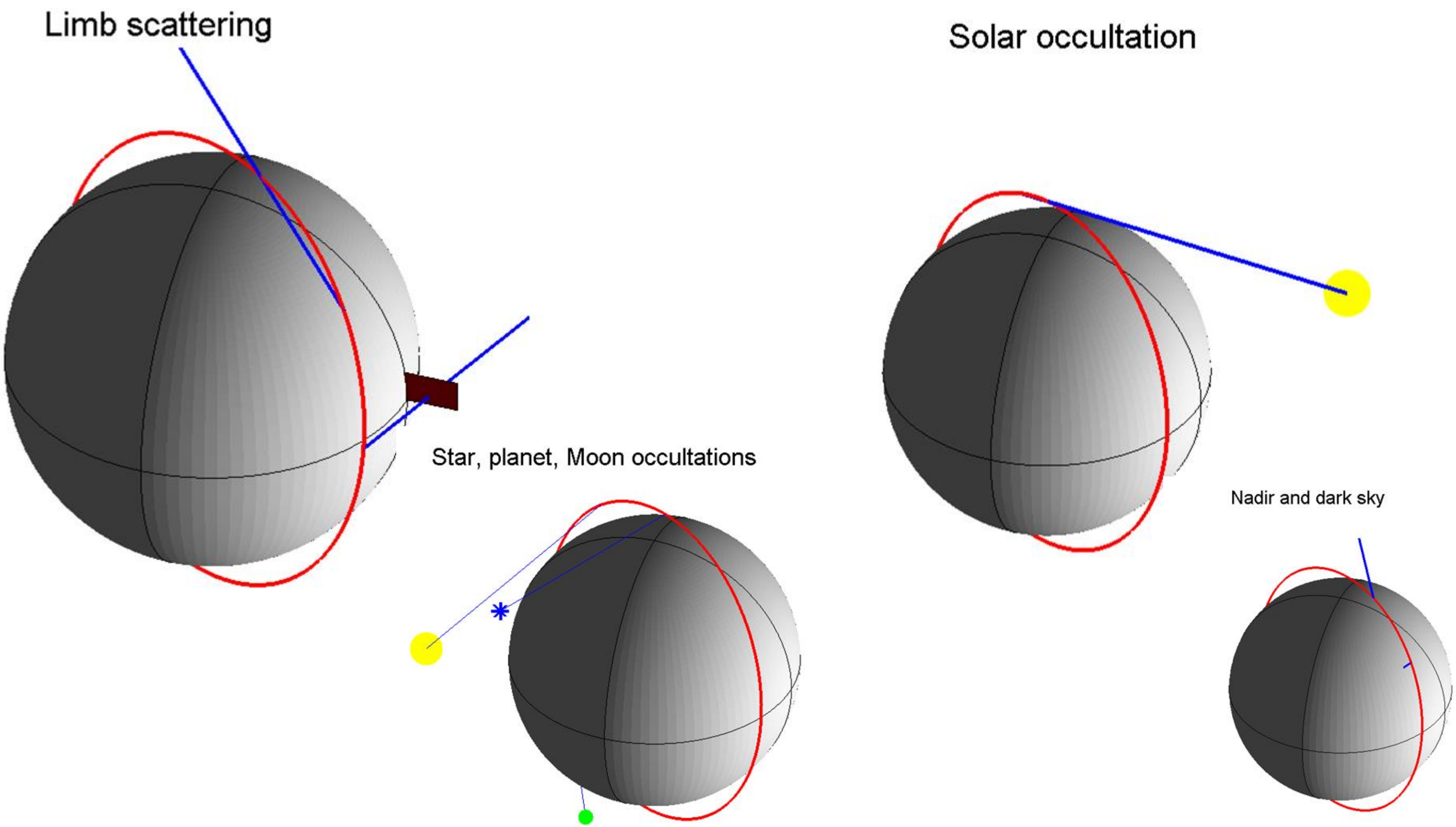


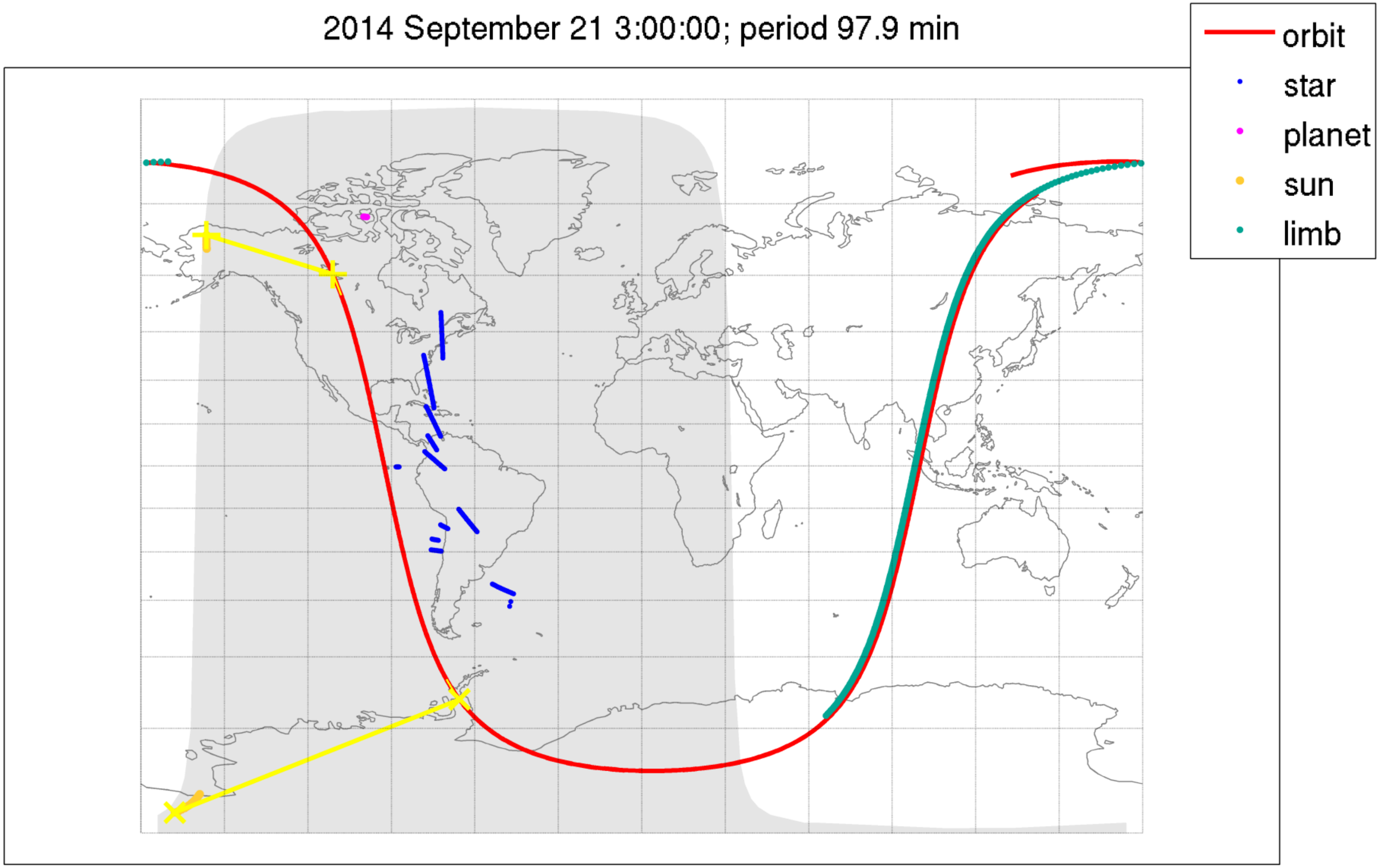




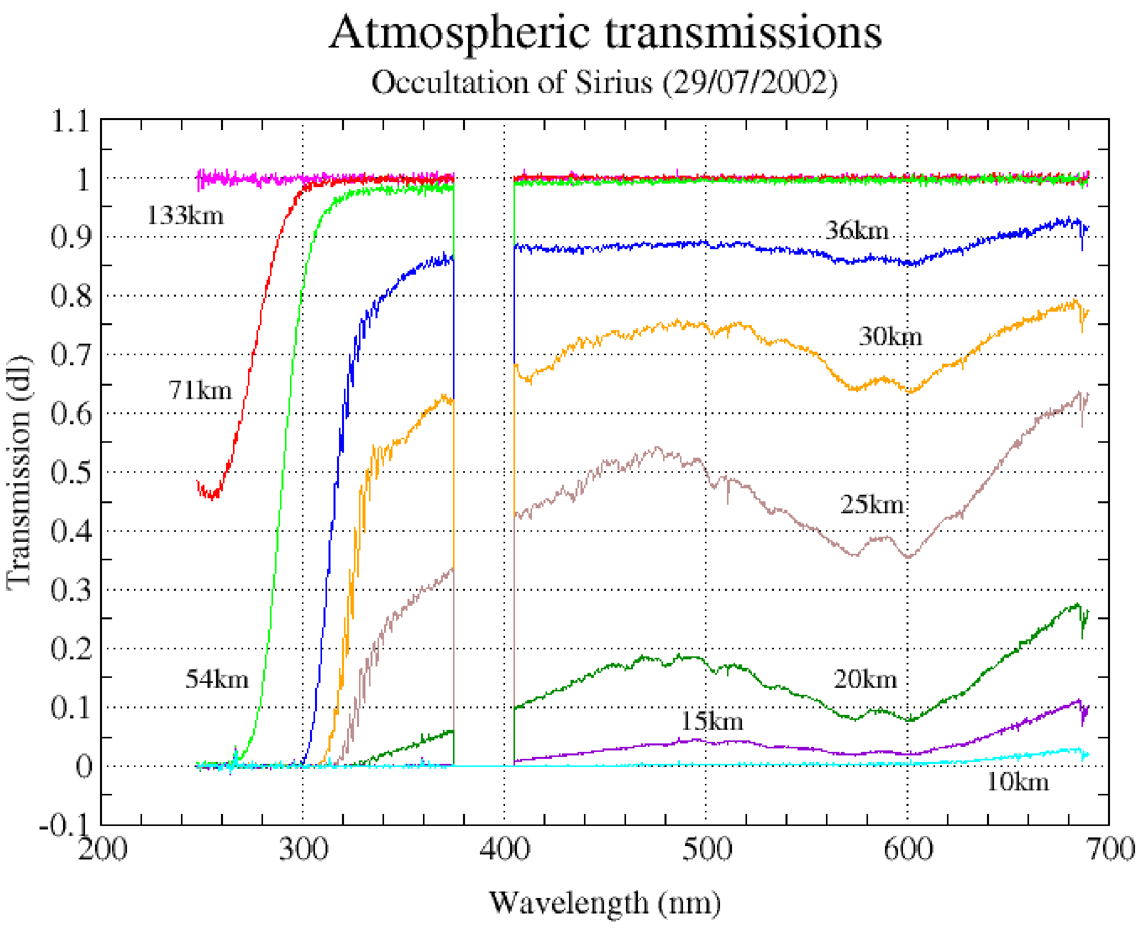
H=20 km
35000
30000
25000
20000
15000
Total Radiance
Ozone Chappuis band
Radiance Watts/cm^2*str*micr *10^{-2}
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
Wavelength Microns

Most innovative ALTIUS concept: multimode observations

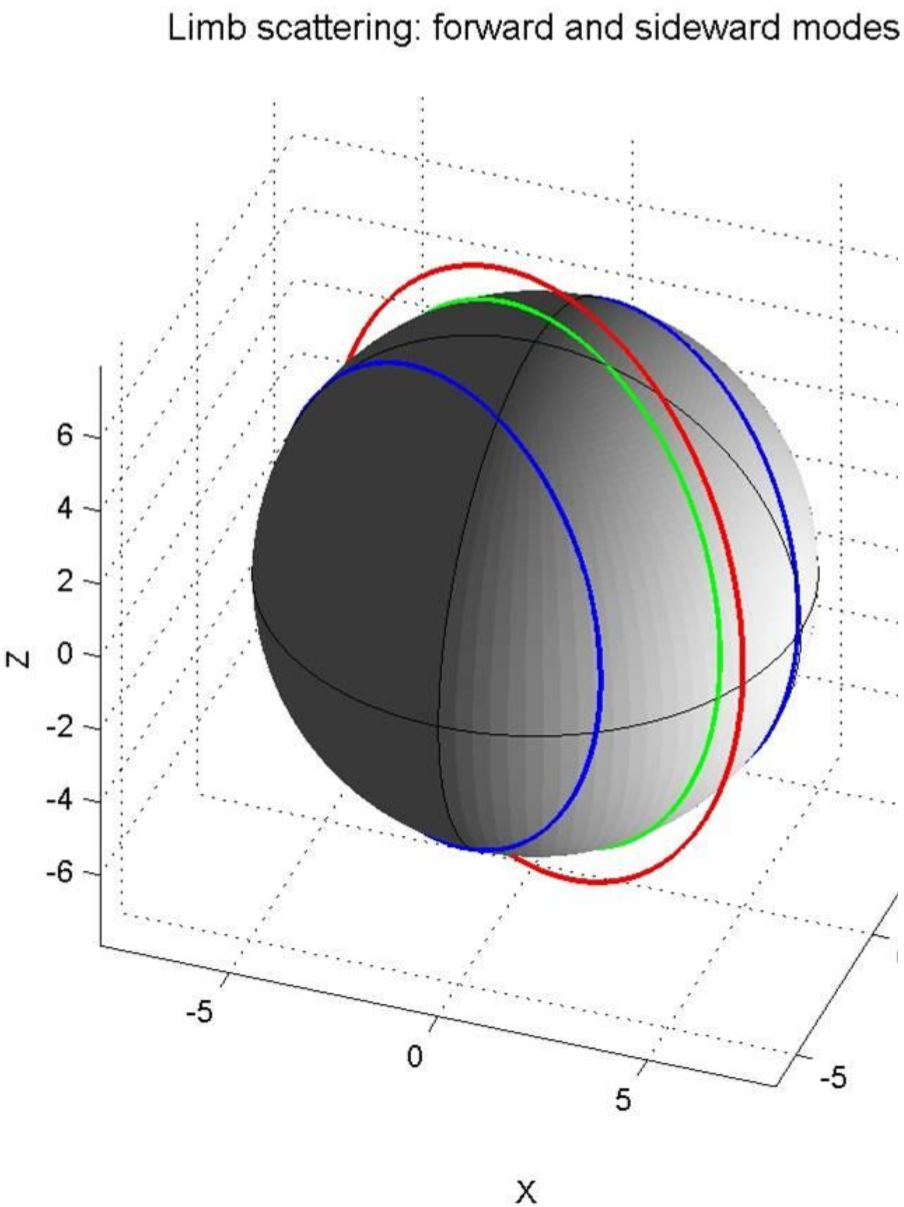


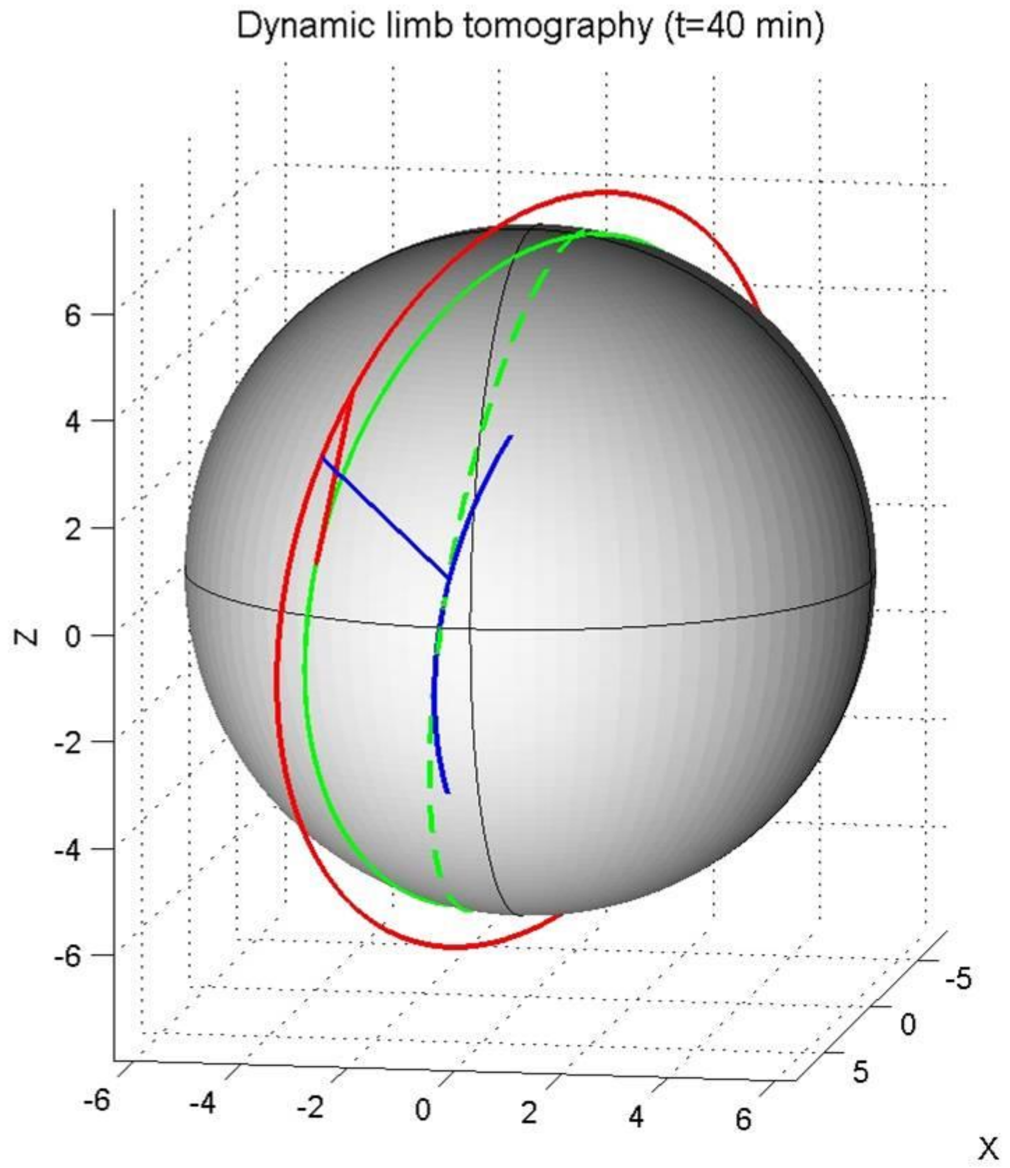

2014 September 21 3:00:00; period 97.9 min
orbit
star
planet
sun
limb

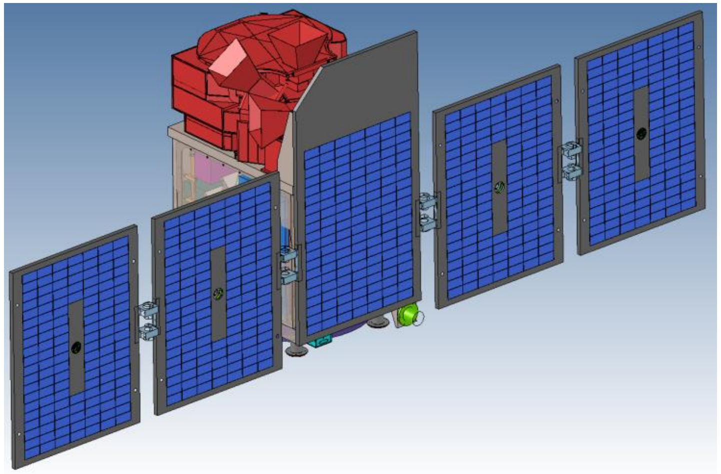
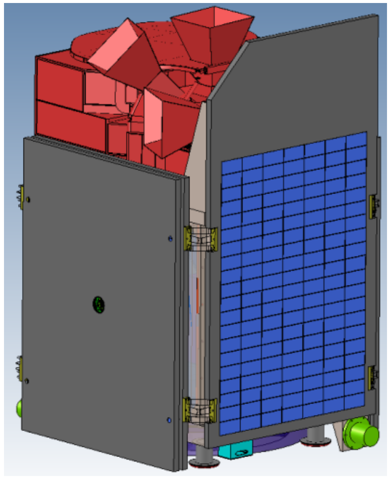
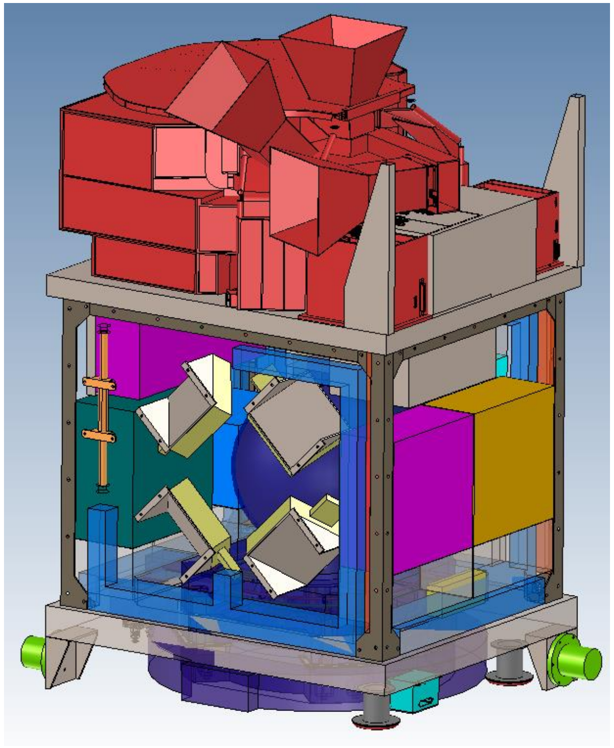
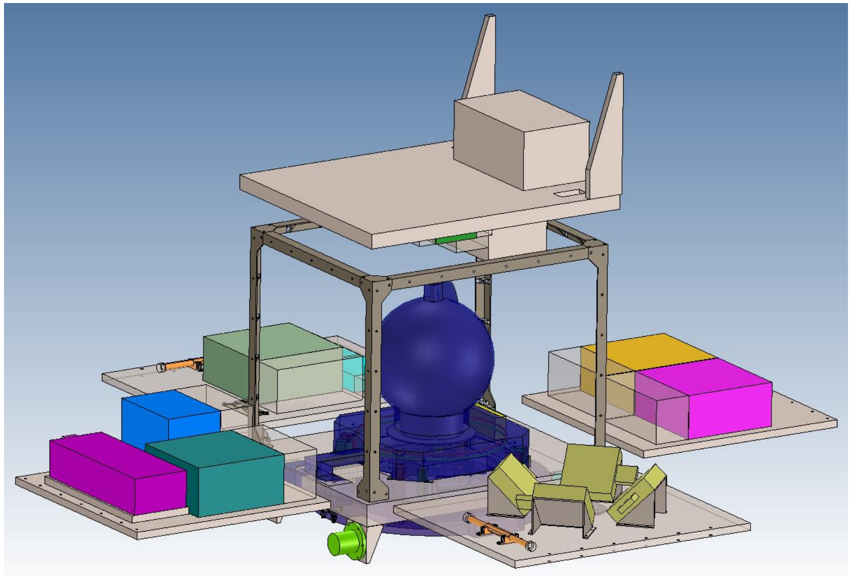
Transmission spectra

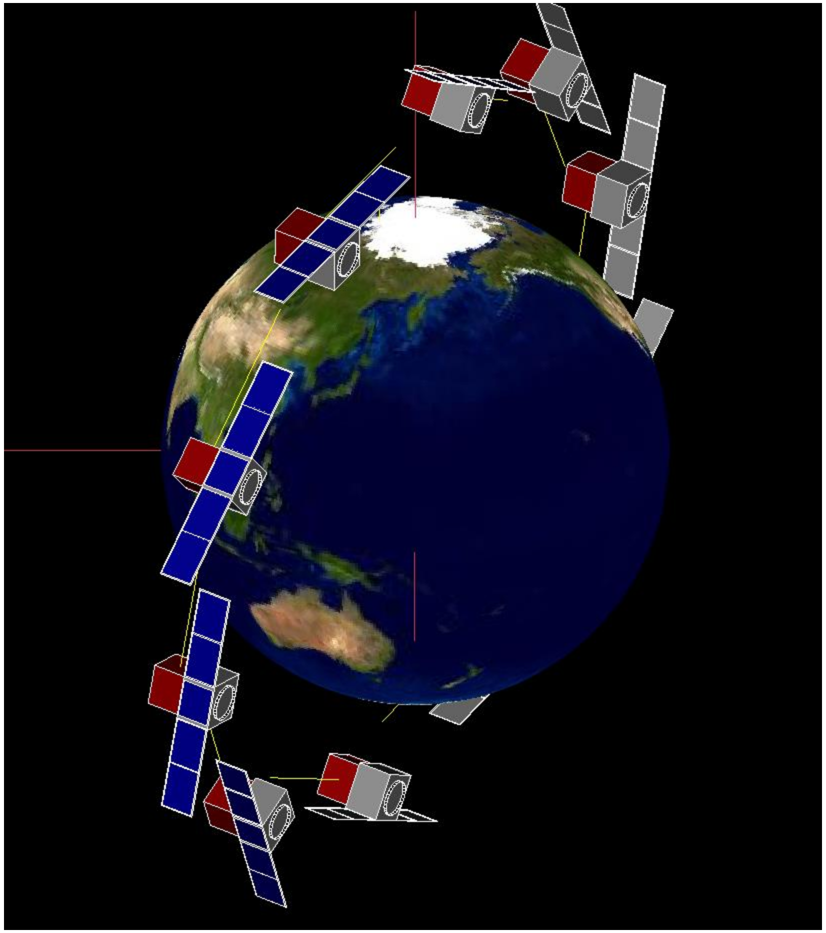


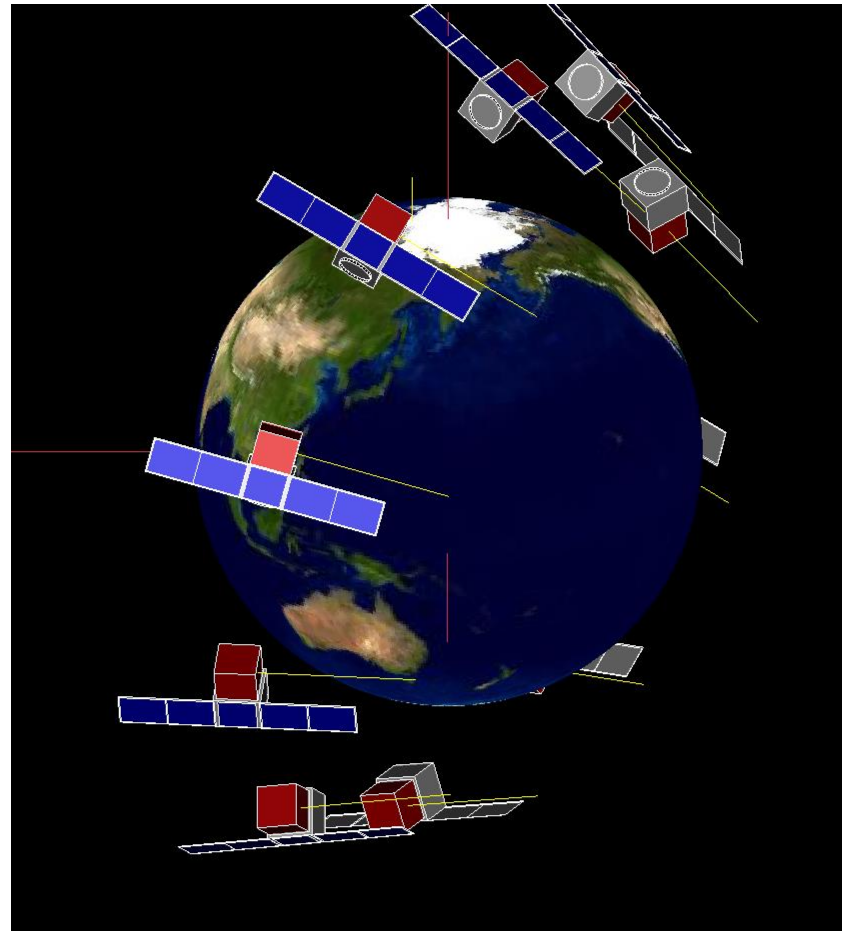
From static forward/side mode to dynamic tomography...

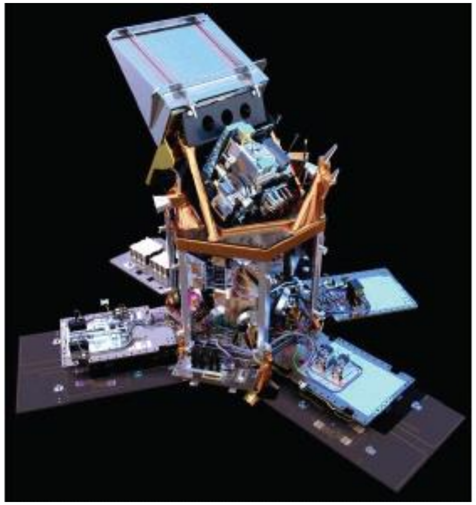


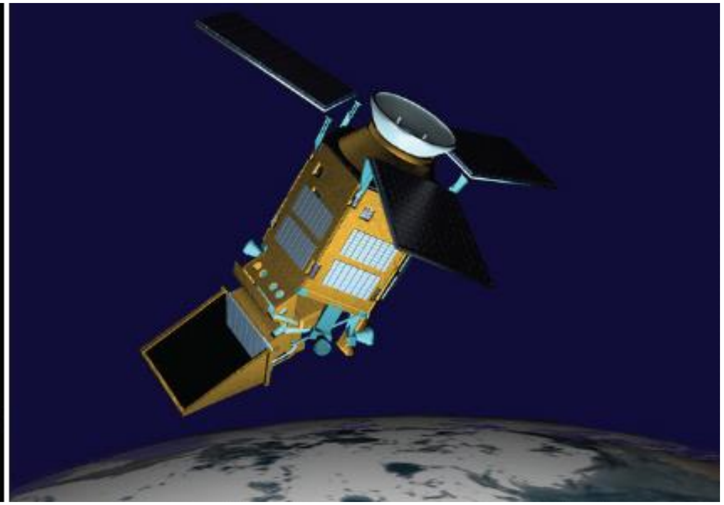




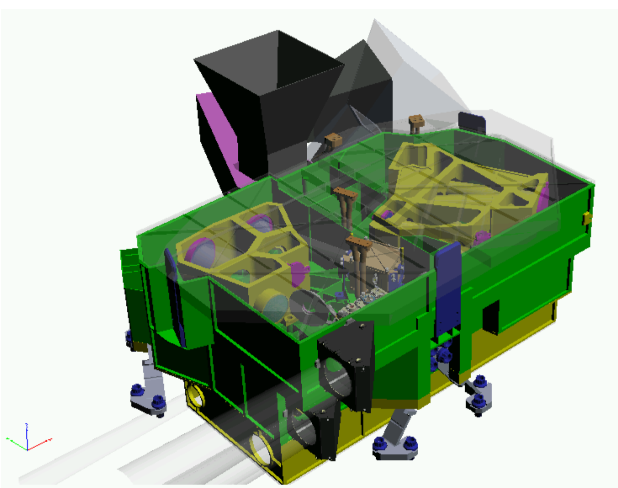


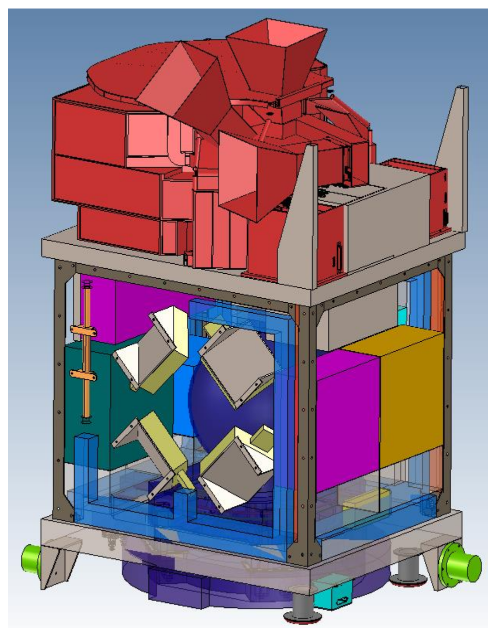




TROPOMI

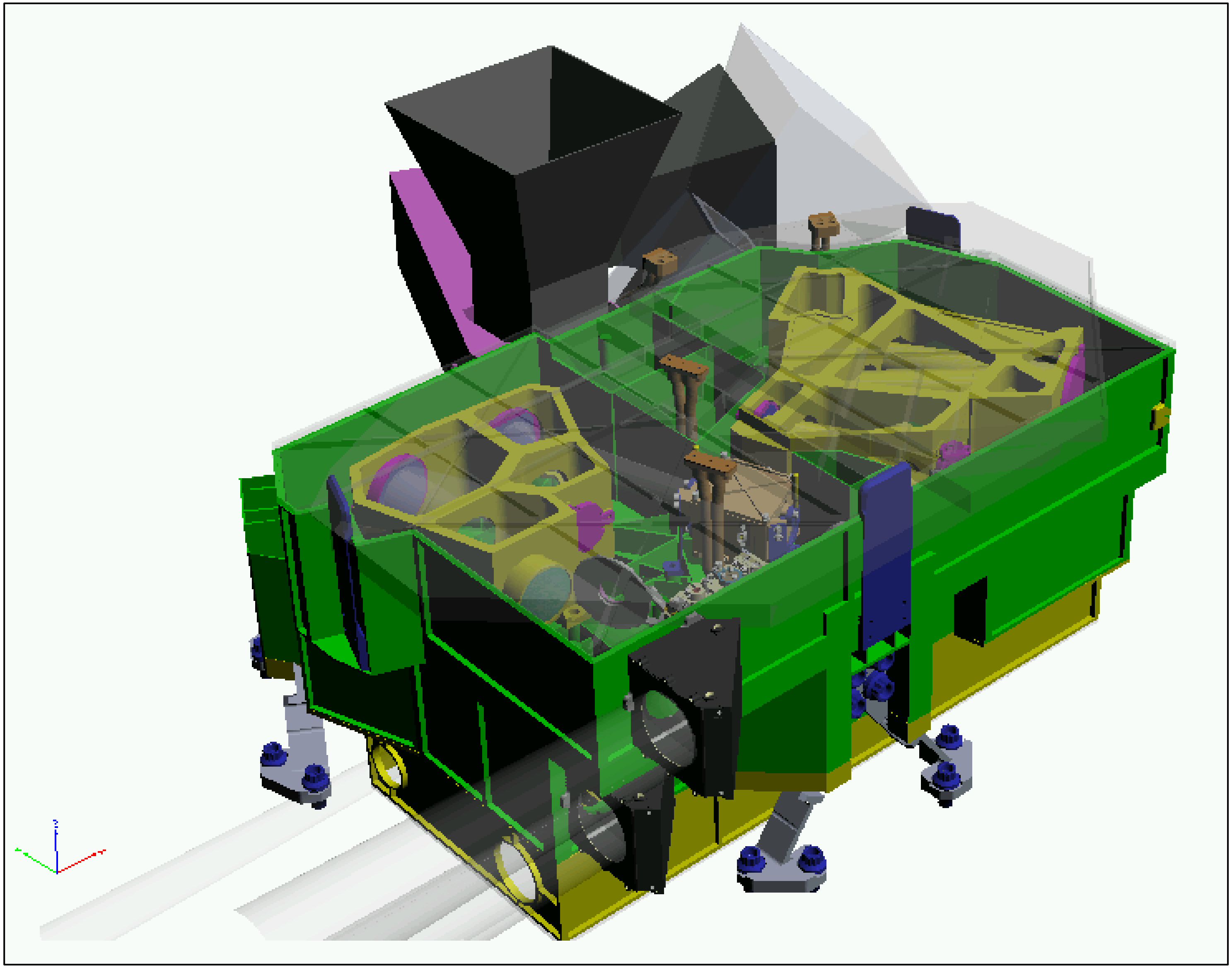
- 200 kg
- 170 W
- 2100 Gbits / day

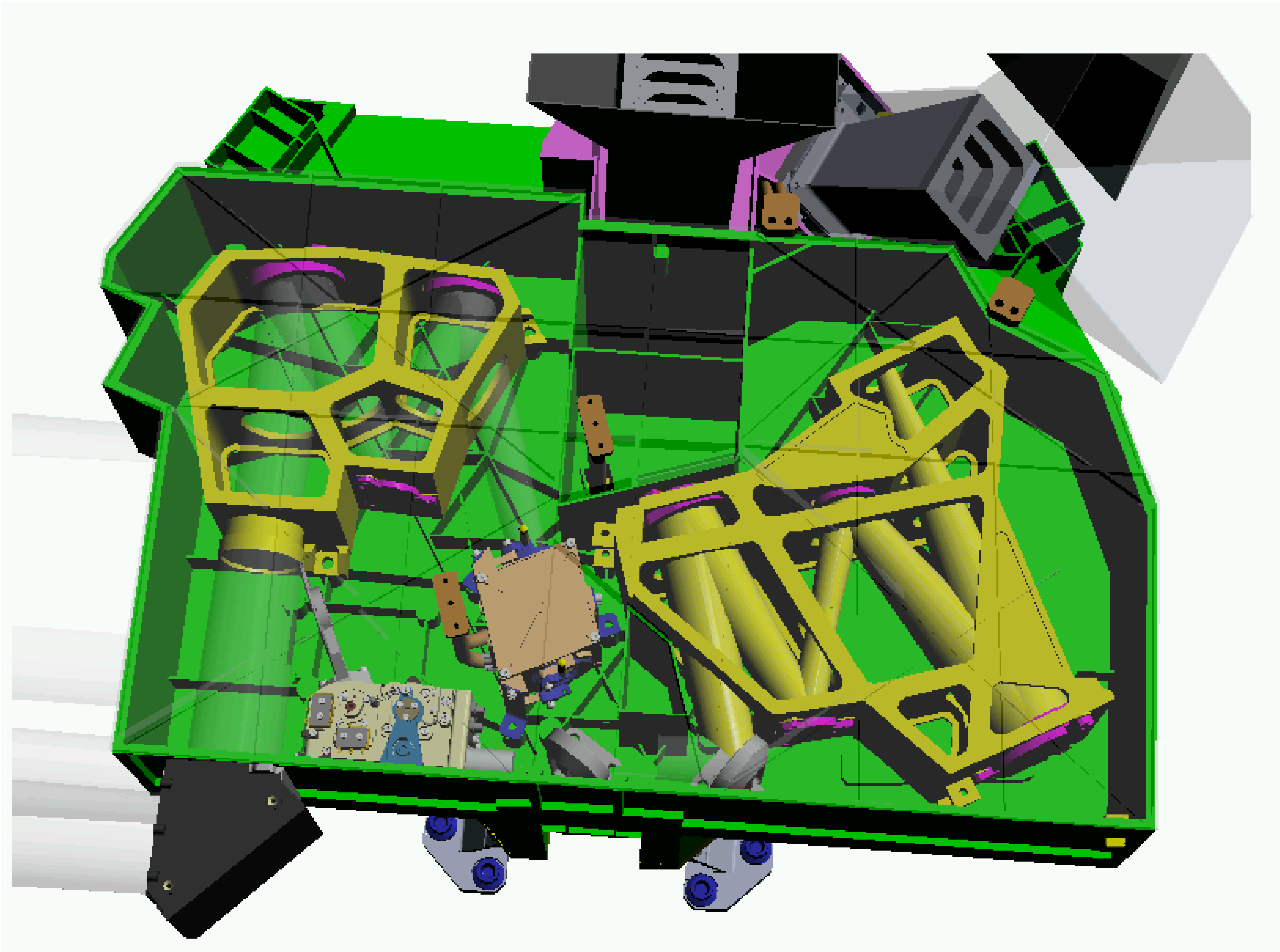




ALTIUS

- 62 kg
- 50 W
- 55 Gbits / day





	Themes			ALTIUS targets	Goals		
	CLIMATE	OZONE	SOUNDING	Red= MANDATORY / Green= IMPORTANT / Blue= RELEVANT	MONITORING	SCIENCE	METHODS
O_3				**SR1:** Global and long-term vertically resolved ozone data sets of observations in the stratosphere are urgently required to assess model behaviour and test model predictions, particularly in the UTLS, in polar regions and in the Southern Hemisphere. Today, the **ozone recovery** is probable, but still uncertain, and therefore certainly an open question.			
O_3				**SR2:** The measurement of ozone profiles in the **middle stratosphere at 5 % accuracy level** has to be continued to reinforce the significance of the existing climatologies. A special effort is needed in the UTLS region to improve the determination of trends and to detect increase in upwelling, a predicted climate change effect.			
O_3				**SR3:** The spread of ozone profile data in **ozone hole conditions** is not satisfactory. Limb observations should allow determining spatial gradients across and along the vortex, to efficiently detect screening by PSC's and correlated effects.			
O_3				**SR4:** ALTIUS will provide spatially highly resolved profiles of **mesospheric O_3**, a key species to understand the coupling, not yet well understood, from the surface to the upper stratosphere, mesosphere and lower thermosphere.			
NO_2				**SR5:** ALTIUS will provide spatially highly resolved profiles of **NO_2 from the UTLS to the upper stratosphere, mesosphere and lower thermosphere** at different local times. It shall provide intercomparison of NO_2 and O_3 abundances. It will also focus on the dynamics and the chemistry of strong NO_2 enhancements in the upper stratosphere-mesosphere.			
H_2O , CH_4				**SR6:** ALTIUS will provide **global vertical profiles of H_2O and CH_4**, with a special focus, for water vapour, on the tropical tape recorder and vortex dehydration. A major objective for these interrelated species will be the measurement of their trends in the lower stratosphere.			
AEROSOLS				**SR7:** ALTIUS will provide particle size distributions of **stratospheric aerosol** by observing vertical extinction profiles between the UV and the NIR wavelength ranges. Depending on the volcanic state of the atmosphere, it will assess the relaxation times of the volcanic contribution, or the background level of the non-volcanic contribution.			
PSC				**SR8:** ALTIUS will measure the frequency of **PSC occurrences** inside the polar vortex and their subsidence speed.			
PMC				**SR9:** ALTIUS will measure the trend and the phasing in the **occurrence of PMC** as well as their median altitude and their horizontal extent, in both hemispheres, around the summer solstice.			
NO_3 , OClO, BrO				**SR10:** ALTIUS will measure **OClO, BrO and NO_3**, which are important minor trace gases involved in the stratospheric chemistry, by means of DOAS retrieval from occultation and/or limb observation geometries.			
T				**SR11:** In solar occultation mode, by making use of its imaging capacities and the large S/N ratio, ALTIUS will retrieve density and **temperature profiles up to the mesosphere**, from refraction angle measurements.			
Tomo				**SR12:** Horizontal concentration gradients of relevant trace gases will be observed in **"along track" and "across track" geometries** by using the multiple observation modes of ALTIUS.			

User requirements for monitoring the evolution of stratospheric ozone at high vertical resolution

'Operoz': Operational ozone observations using limb geometry

Final Report

ESA 'Expro' Contract: 4000112948/14/NL/JK

Date: 1st of March 2015

Authors: Michiel van Weele (lead author), Rolf Müller, Martin Riese, Richard Engelen, Mark Parrington, Vincent-Henri Peuch, Mark Weber, Alexei Rozanov, Brian Kerridge, Alison Waterfall, Jolyon Reburn

OPEROZ

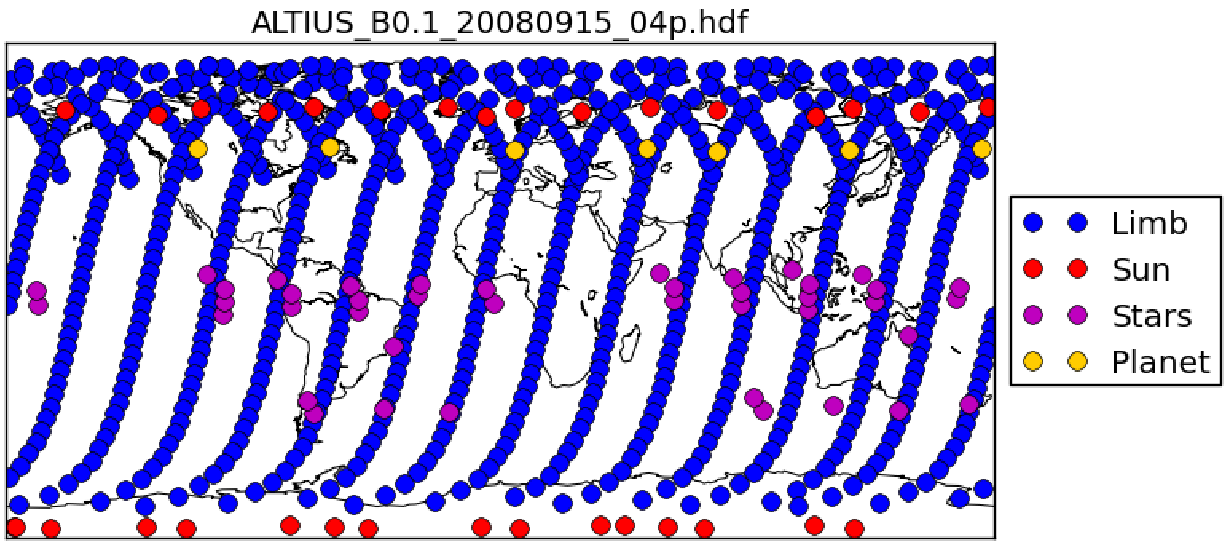
Summary of Observational Requirements for a Minimum Mission Targeting Stratospheric Ozone				Timeliness: <3h Stability: 1% / 3% per decade		
Observable	Along-track sampling (km)	Horizontal coverage	Vertical resolution (km)	Vertical coverage (km)	Update frequency	Uncertainty (*)
O_3	100 / 200	Global (incl. polar night)	1 / 2	LS	12h / 24h	8% / 16% or 50 / 100 ppbv
O_3	100 / 200	Global (incl. polar night)	1 / 2	MS	12h / 24h	4% / 8% or 50 / 100 ppbv
O_3	200 / 400	Global (incl. polar night)	2 / 4	US	Daily/weekly	4% / 8%

	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

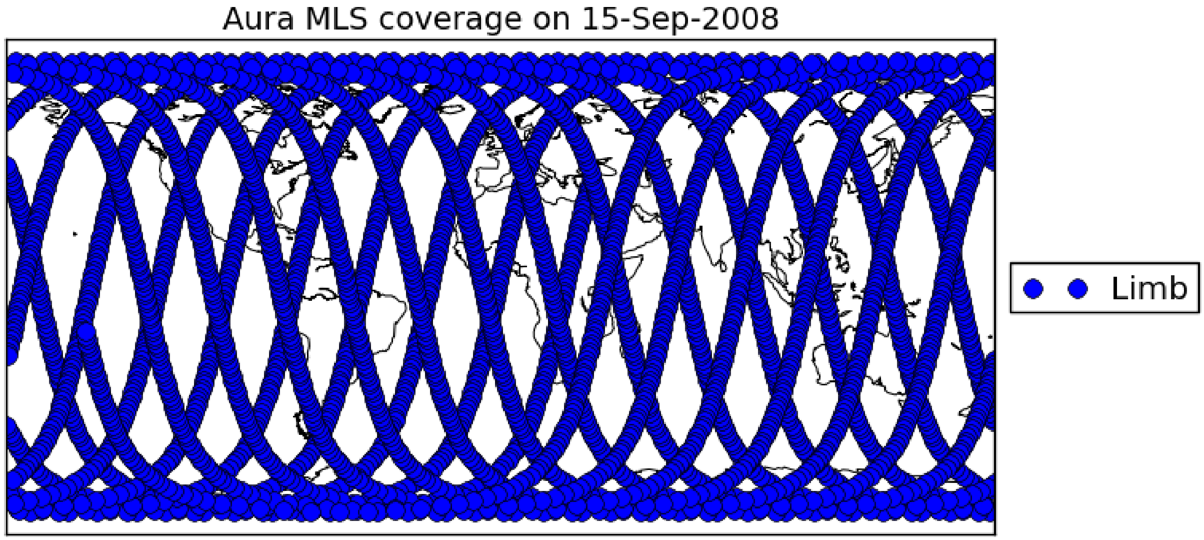
Confidence Level	Colour code and Description
3	Target met or proven by design
2	Threshold met
1	Not studied yet or require further studies

ALTIUS

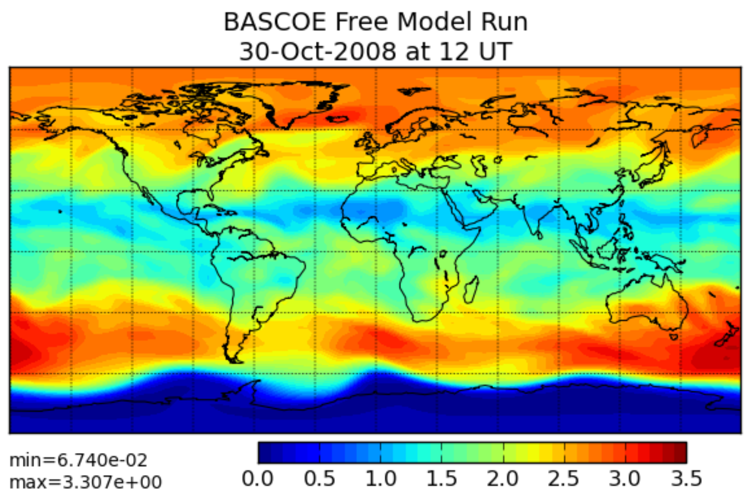
On way toward an ALTIUS level 3 product…..

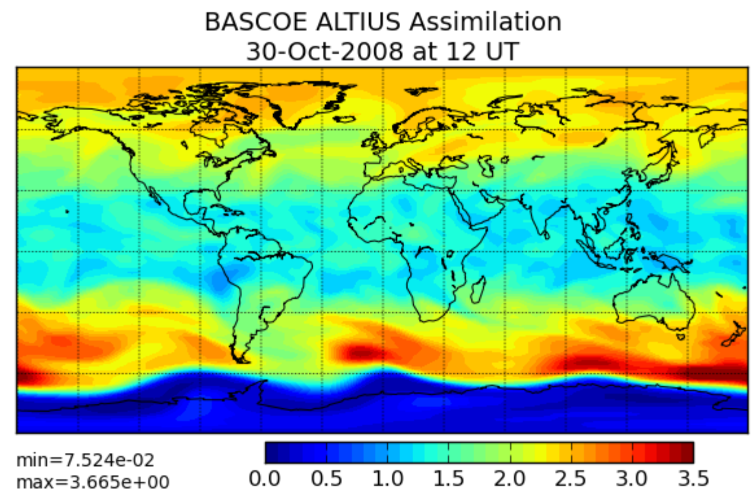


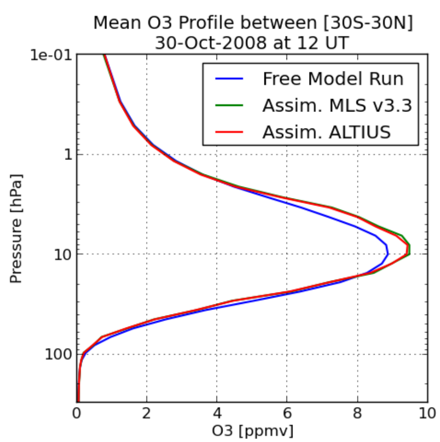
ALTIUS and Aura MLS Coverage

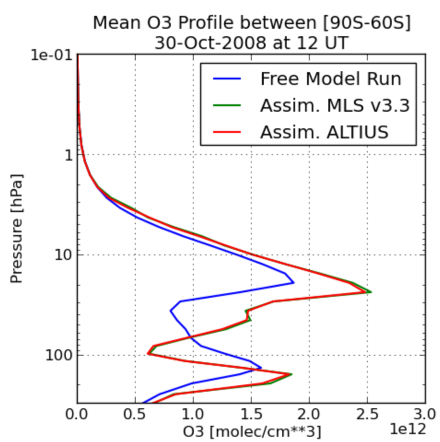


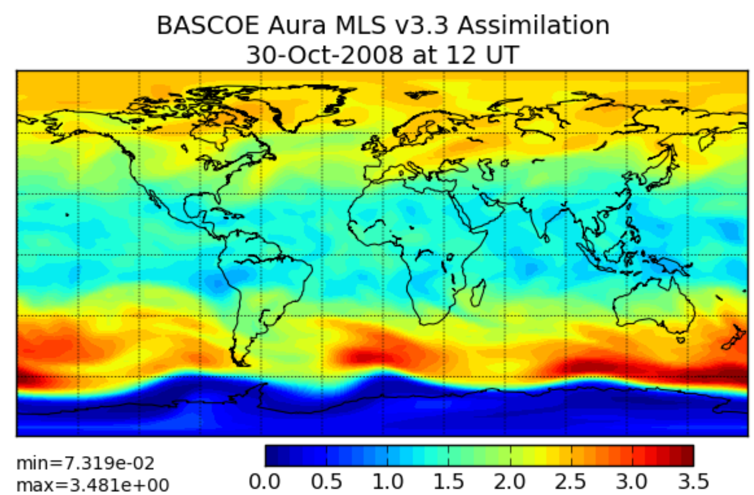
ALTIUS and Aura MLS assimilations are comparable !











Occultations can boost limb data in polar night conditions …

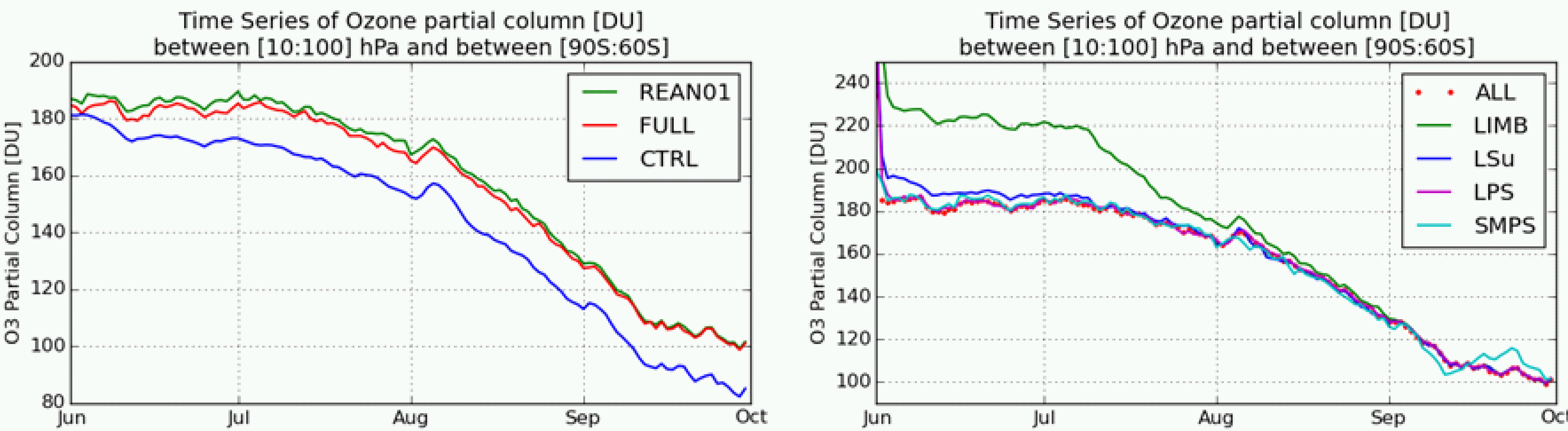


Figure 3 : Time series of ozone partial column [DU] between 10 and 100 hPa and between July and September, 2008. Left: results for REAN01, a BASCOE free model run (CTRL) and the assimilation of synthetic observations (FULL). Right: ALTIUS synthetic observations assimilated with chemistry turned off: ALL=all modes of observations assimilated, LIMB=only limb mode assimilated, LSu=limb and solar occultations assimilated, LPS=limb, planet and stellar occultations assimilated, SMPS=solar, moon, planet and stellar occultations assimilated

ALTIUS local team @ BIRA-IASB [… SINE QUA NON]

Name	Level	Role
Dr Didier FUSSEN	Head of Department	PI
Dr Ir Didier PIEROUX	Senior scientist	PM
Dr Filip VANHELLEMONT	Senior scientist	Local Science Team Lead
Dr Ghislain FRANSSENS	Senior scientist	Radiative Transfer
Dr Nina MATESHVILI	Senior scientist	Mission Scenario
Dr Emmanuel DEKEMPER	Senior scientist	Instrument Scientist
Ir Dr Eddy NEEFS	Engineering Lead	CFI coordination
Ir Jurgen VANHAMEL	Industrial Engineer	System Engineer
Ir Sophie BERKENBOSCH	Industrial Engineer	Electronic CFI
Ir Jeroen MAES	Mechanics Lead	Mechanical CFI
Ir Pepijn CARDOEN	Industrial Engineer	Payload Engineer
Ir Bert VANOPSTAL	Industrial Engineer	Payload Engineer

ALTIUS running or foreseen collaborations (so far)

Who	What
Q. ERRERA & S. CHABRILLAT	ALTIUS level 3
A-C VANDAELE & S ROBERT	NIR channel LUT (ASIMUT)
BUSOC	GS chain
V. LETOCART	RT implementation
H LAMY	VER profiles & aurora polarization
J DE KEYSER & al.	EPT/ Langmuir/COPS
M. VAN ROOZENDAEL & al.	O3 CCI
C. BINGEN & C. ROBERT	Aerosol CCI

Who	What
M. DE MAZIERE & al.	CH4, H2O validation
J-C LAMBERT & al.	AMF validation
D. BOLSEE & N. PEREIRA	SOLSPEC validation (UV,NIR)
A. MERLAUD	ALTIUS VIS breadboard
P. DEMOULIN	PICASSO / VISION refraction
J-C GERARD & B. HUBERT	Airglow
+ ---	+ ---

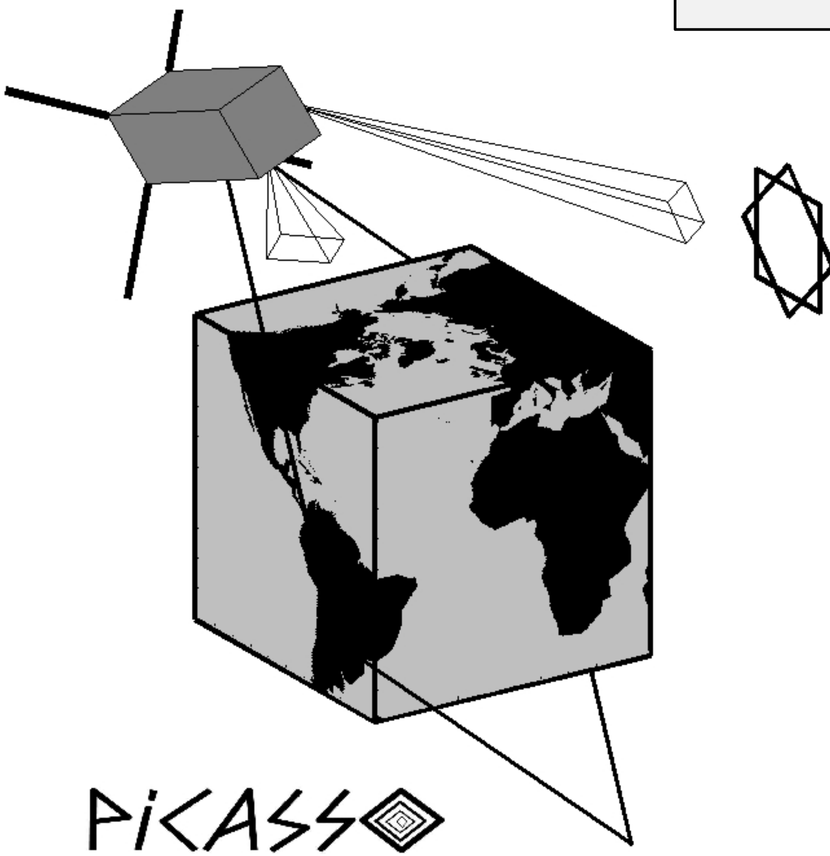
ALTIUS international Scientific Advisory Group [ASAG]

Name	Affiliation
BERNATH Peter	Old Dominion University [USA]
CAMY-PEYRET Claude	CNRS, [F]
DALAUDIER Francis	LATMOS, [F]
DEGENSTEIN Doug	U. Saskatchewan, [CAN]
FUSSEN Didier	BIRA-IASB, [B]
HAUCHECORNE Alain	LATMOS, [F]
KYROLA Erkki	Fin. Meteorological Institute, [FIN]
RAULT Didier	NASA, [USA]
SOFIEVA Viktoria	Fin. Meteorological Institute, [FIN]
VANHELLEMONT Filip	BIRA-IASB, [B]
VON CLARMANN Thomas	Karlsruhe KIT University, [D]
VON SAVIGNY Christian	Greifswald University, [D]

- Should be extended
- A « call for proposal » system should be set up, depending of available « scientific » observation time
- Important role during commissioning

ALTIUS LAUNCH DATE >= DEC 2018 …

PICASSO



PICosatellite for
Atmospheric and
Space
Science
Observations

Strategic objectives

- At BISA, we believe that pico- and nano-satellites could very well play an important role in the Earth observation in a near future:
  - They are “cheap” and thus 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?

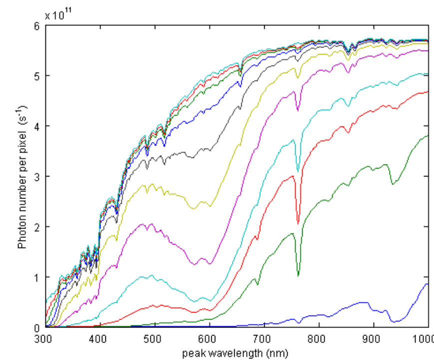
- **Objective**: to **demonstrate** Science in a CubeSat mission
  - **VISION**, a visible and near-infrared hyper-spectral imager: vertical profiles retrieval of the ozone density and of the T° via Sun occultations
  - **SLP**, a Sweeping multi-needle Langmuir Probe: electronic density and T° of the plasma

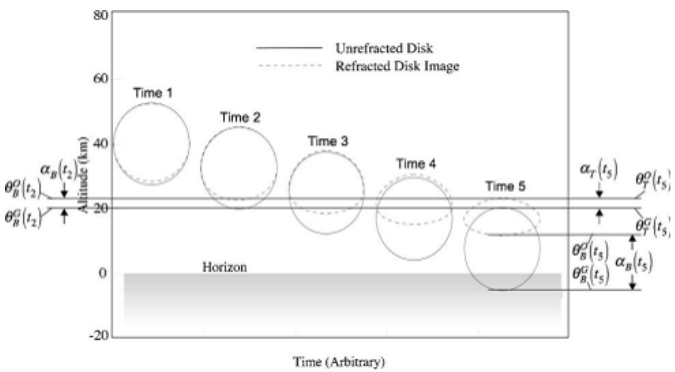

Science
$10
10 APRIL 2015
sciencemag.org
AAAS
CubeSats
take flight
Cheap, miniature satellites
democratize space p. 172

VISION: scientific objectives

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)



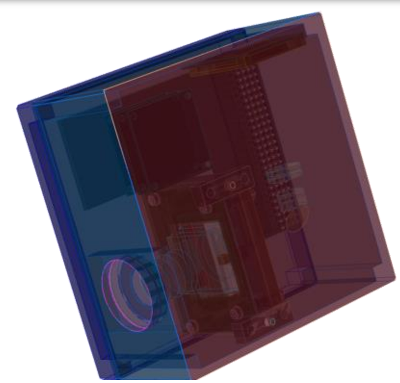


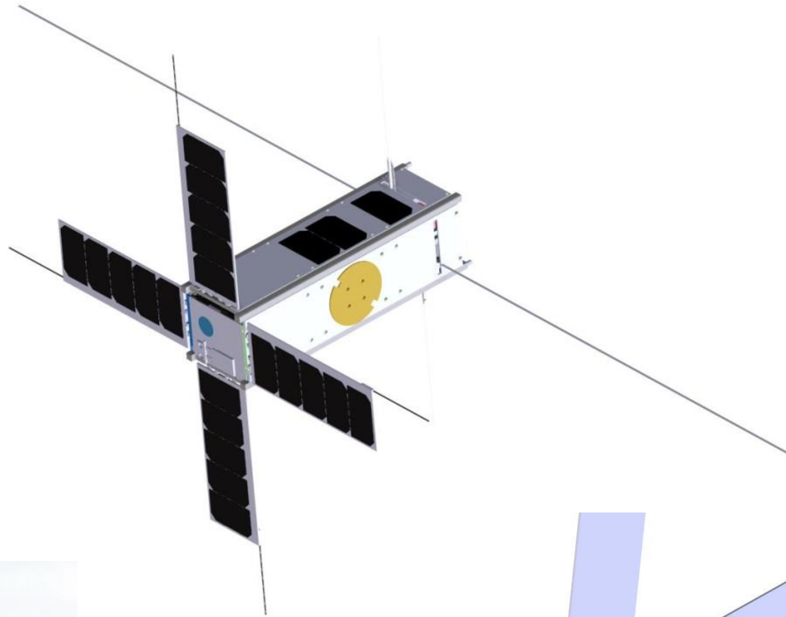
Scientific goal 2: Upper atmosphere temperature profiling based on the Sun refractive flattening: *"Atmospheric Refractivity from Inversion of Dilution"*

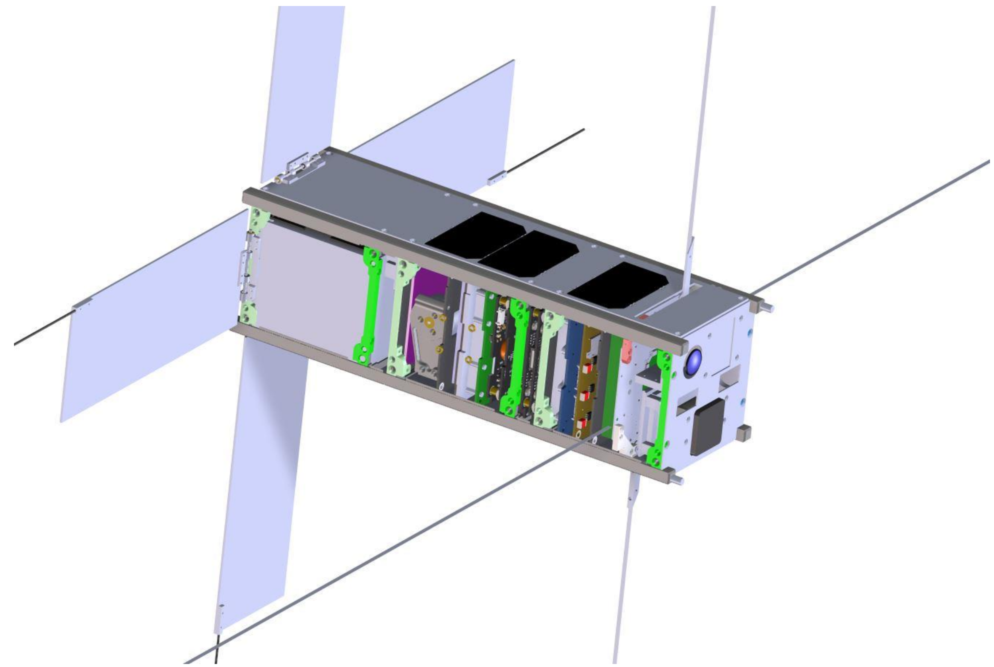
[Fussen et al., AMTD., 8, 3571-3603, doi:10.5194/amtd-8-3571-2015, 2015]

Instrument overview

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

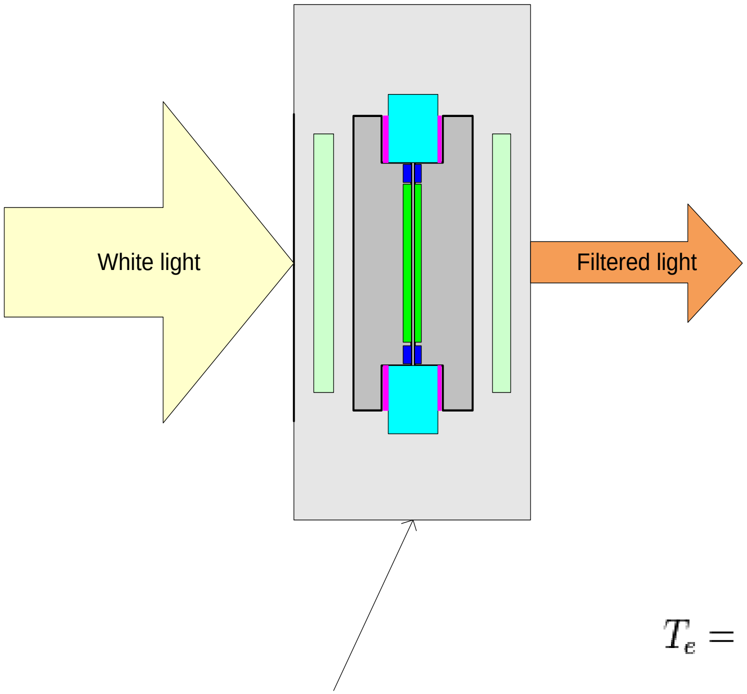




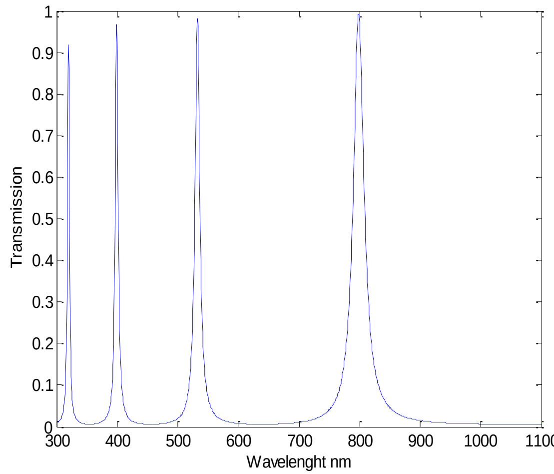


PDR almost closed out / CDR in Oct 2015

The Fabry-Perot Interferometer



Fabry-Perot Interferometer Module



$$T_e = \frac{(1-R)^2}{1+R^2-2R\cos\delta} = \frac{1}{1+F\sin^2(\delta/2)},$$

$$\delta = \left(\frac{2\pi}{\lambda}\right) 2n\ell\cos\theta.$$

Partners and sponsors

Consortium

(STCE)

ESA CubeSat Missions for Technology In-Orbit Demonstration

Roger Walker
CubeSat lead, Directorate of Technical & Quality Management
ESA/ESTEC

4S CubeSat Workshop, Porto Petro, Majorca
29 May 2014

PICASSO IOD Mission

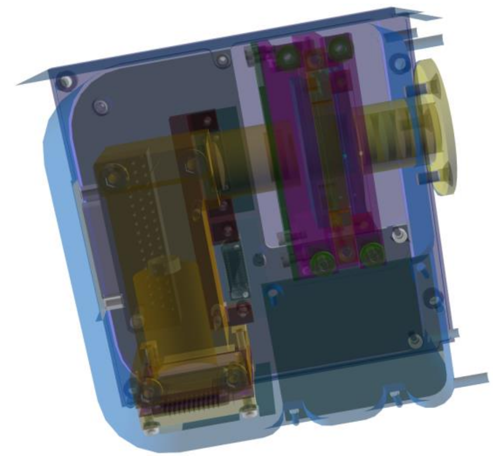
- Belgian Institute of Space Aeronomy, Royal Observatory Belgium, VTT Finland
- Atmospheric chemistry science demonstrator
  - Stratospheric Ozone distribution -> limb sounding of solar disk with multi-spectral imager
  - Mesospheric Temperature profile -> multi-spectral imager (VTT)
  - Electron density in the ionosphere -> multi-Needle Langmuir Probe
  - Earth Radiation Budget -> micro-bollimetric oscillation system
  - Platform: 3U CubeSat (Clyde Space)
  - Launch on QB50 flight in 2016 to 380x700 km altitude, 98° inclination

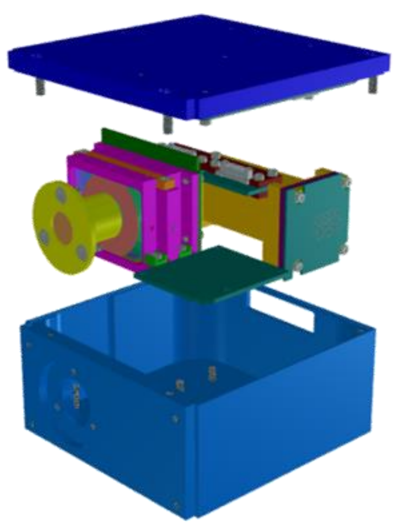
Credit: BISA

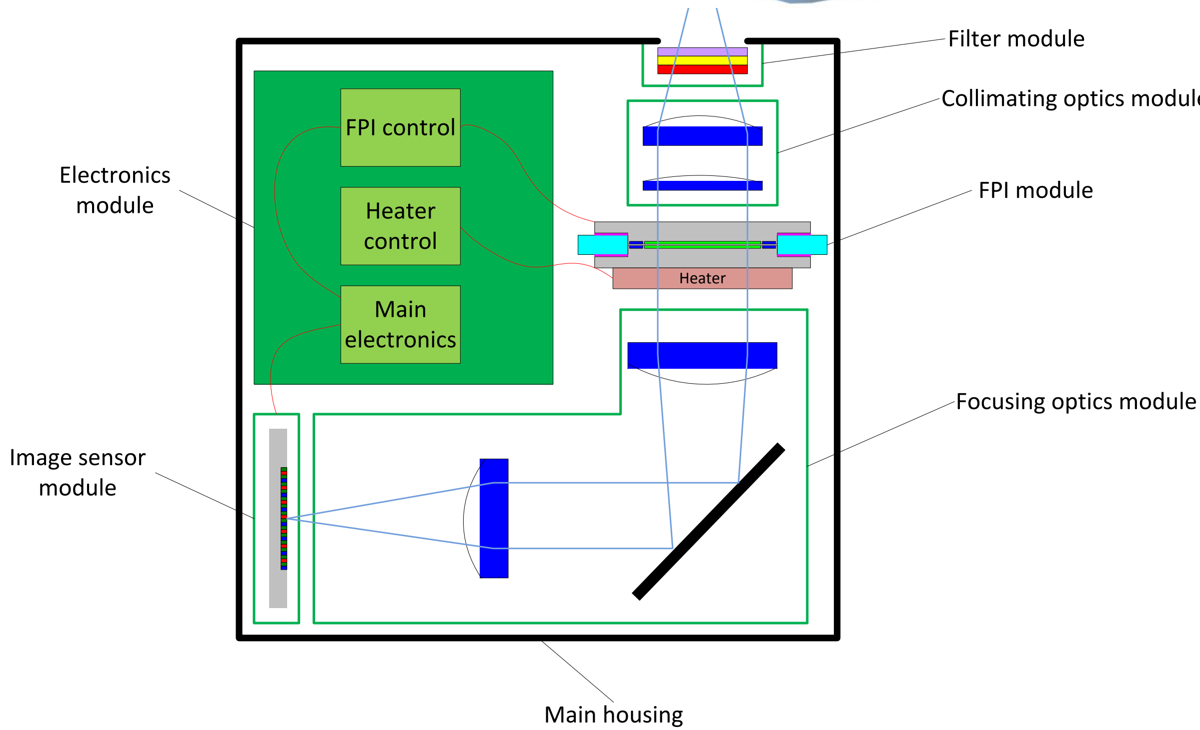
Name	Role
D. Fussen	PICASSO coordination / PI of VISION
D. Pieroux	PICASSO Project Manager (partim)
Ph. Demoulin	VISION scientist
E. Dekemper	VISION scientist [Sun refraction]
F. Vanhellemont	VISION scientist [ozone retrieval]
S. Ranvier	SLP PI
Johan De Keyser	SLP scientist
P. Cardoen	Engineer VISION / SLP
E. Equeter	Technician (tests SLP)
M. Anciaux	Engineer VISION / SLP
E. Gambi	Engineer SLP
Engineering team	Mostly in support to SLP
BUSOC	TBD
Supporting services	PgMt, Com, Accounting

VISION

- Spectral Imager inspired from the Aalto-1 Spectral Imager (AaSI)
- 430 – 800 nm, FWHM 10 nm
- Dimensions 97x97x50 mm
- Mass < 600g
- Power < 3W

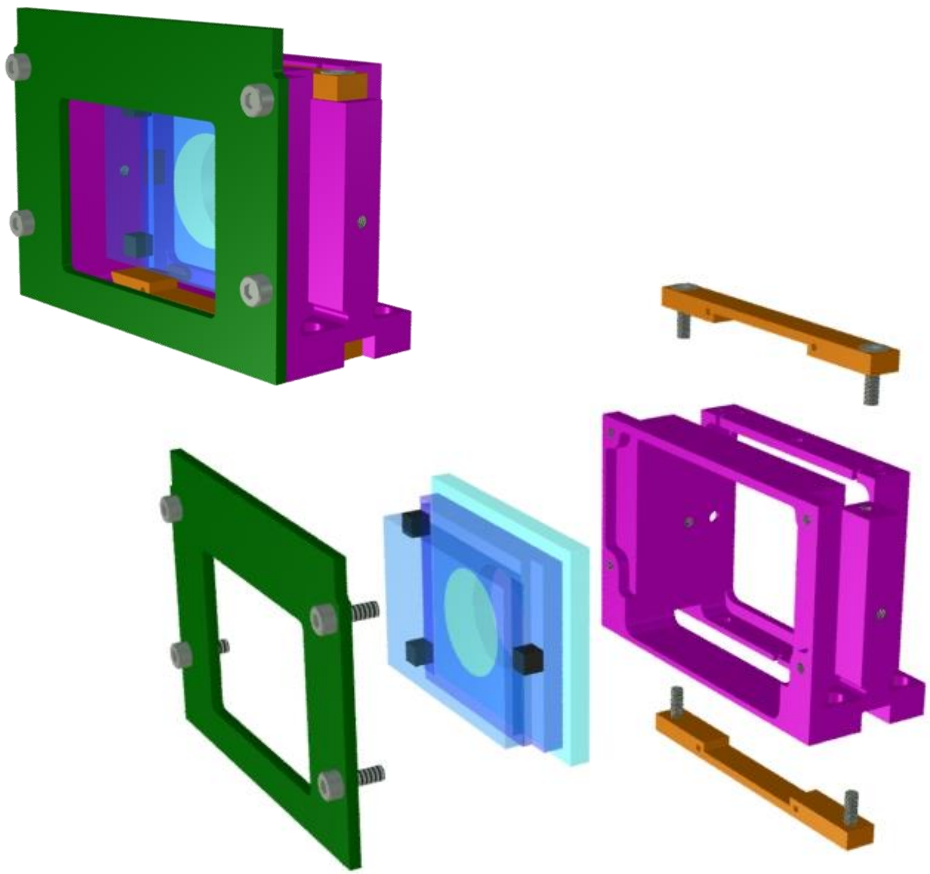


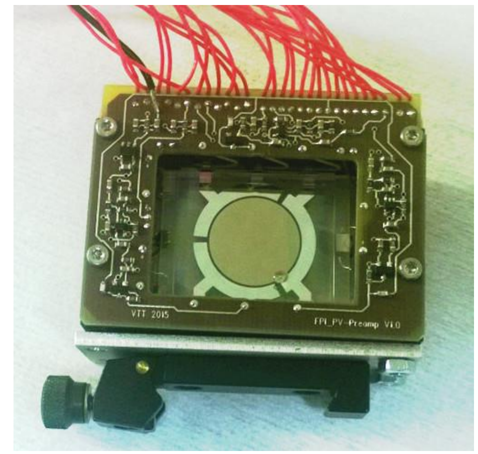


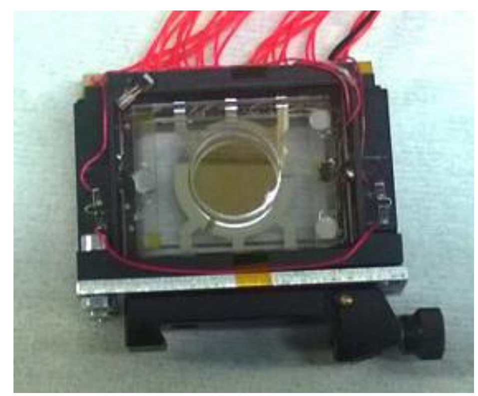


VISION

The PFPI is glued on a Support Glass (light blue) and integrated in its frame (red) with silicone tabs. Electronics board (green) for FPI proximity electronics is fixed around the FPI. Assembly support bars shown in brown.







Atmos. Meas. Tech. Discuss., 8, 3571–3603, 2015
www.atmos-meas-tech-discuss.net/8/3571/2015/
doi:10.5194/amtd-8-3571-2015

Atmospheric Measurement Techniques Discussions
Open Access

Retrieval of vertical profiles of atmospheric refraction angles by inversion of optical dilution measurements

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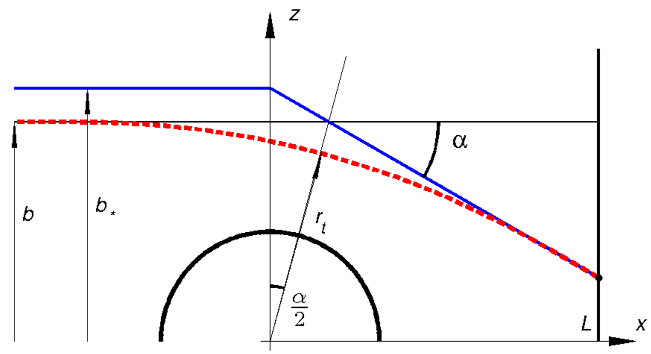
Received: 22 January 2015 – Accepted: 4 March 2015 – Published: 2 April 2015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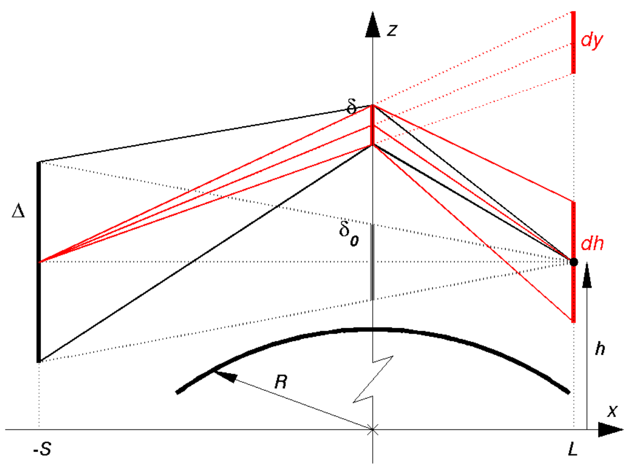
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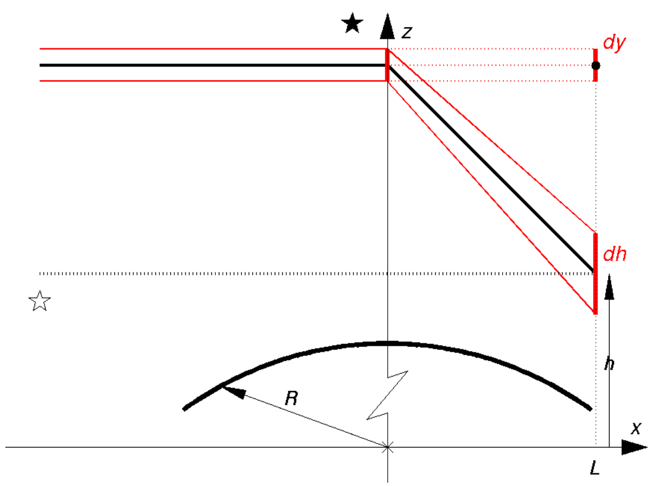
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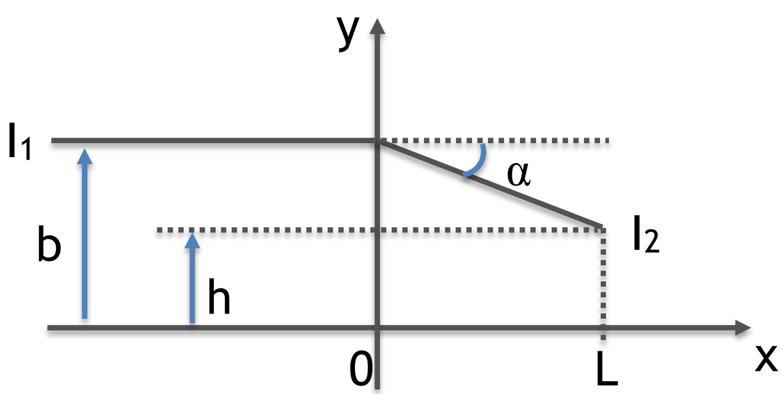
The ARID method

(Atmospheric Refraction from Inversion of Dilution)



$$h = b + \alpha L \;\; (\alpha < 0)$$

$$2\pi I_1 b db = 2\pi I_2 h dh$$

$$E = \frac{I_2}{I_1} = \frac{b}{h}\frac{db}{dh} = \left(\frac{1}{1+\alpha\frac{L}{b}}\right)\left(\frac{1}{1+L\frac{d\alpha}{db}}\right) \longrightarrow \boxed{\frac{d\alpha}{dh} = \frac{1}{L}\left(1 - E(h)\right)}$$

focalisation term (≃1) — dilution term

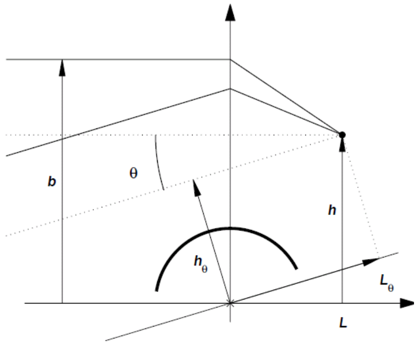


Figure 6. Geometry for angular integration across the solar disk.

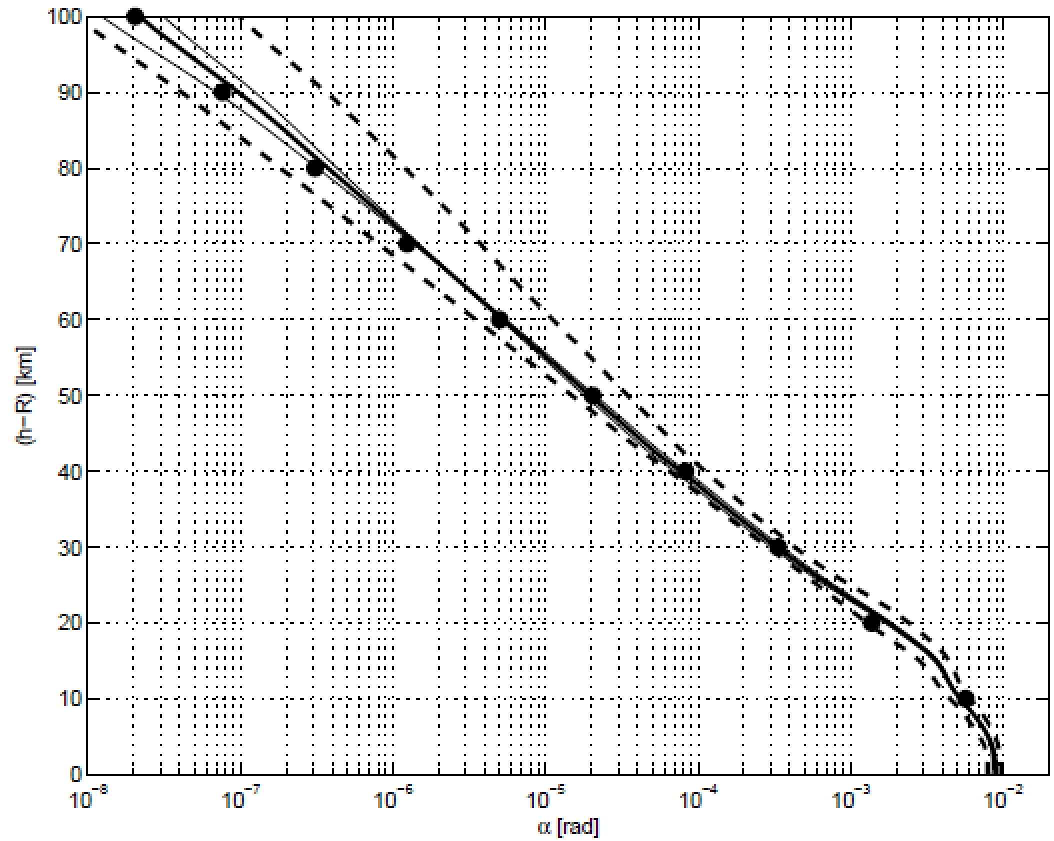


Figure 8. Median profile of atmospheric refraction angle obtained from the processing of 2836 ORA solar occultations observed between August 1992 and May 1993. Full thick line: median profile. Full dashed lines: 16 and 84 % precentiles of the retrieved profiles distribution. Full thin lines: estimated errors due to signal digitization (16 bits). Full circles: refraction angles obtained by exact ray tracing for US76 standard conditions (α_b in Table 1).

CONCLUSIONS

1. Several missions are needed:
   – For intervalidation
   – For redundancy
   – For innovation
2. Spectral imaging and satellite agility offer multimode observations and inertial pointing. Miniaturization will increase.
3. The importance of pico-, nano- and micro-satellites will grow. Costs should decrease.
4. ALTIUS >= Dec 2018 / PICASSO <= Jan 2017