

ヨーロッパの目覚め：マーズ・エクスプレス

A First European mission: Mars Express:

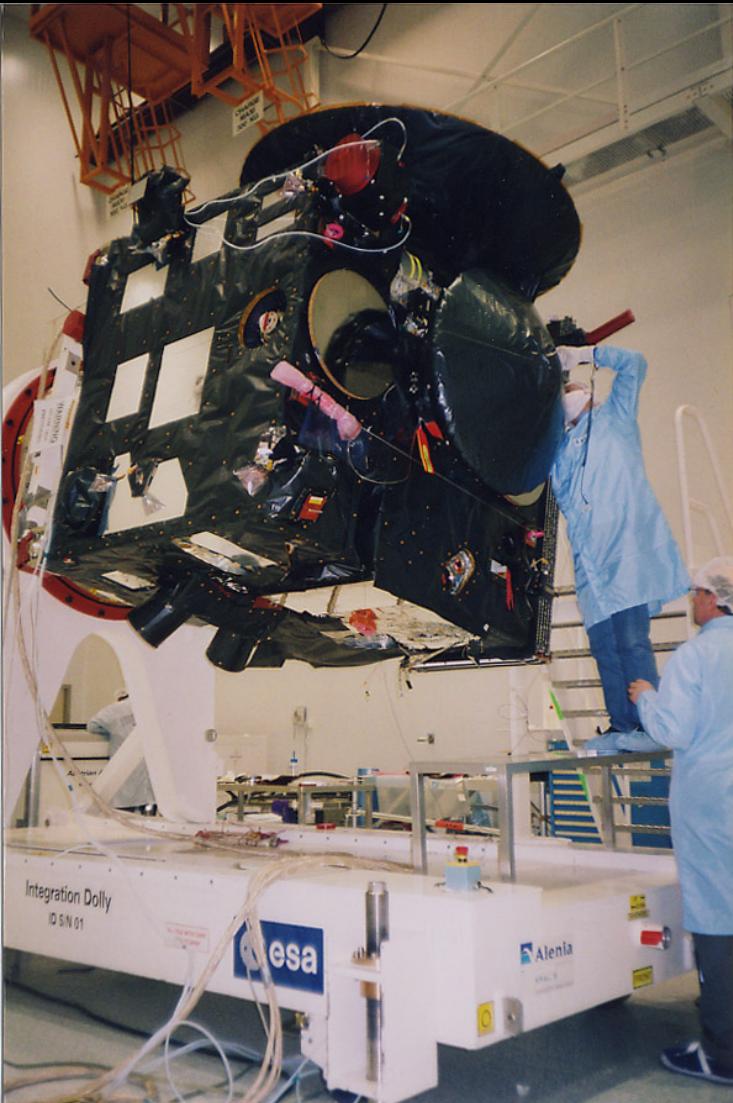
The atmospheric dataset

François FORGET

Mars Express Interdisciplinary Scientist

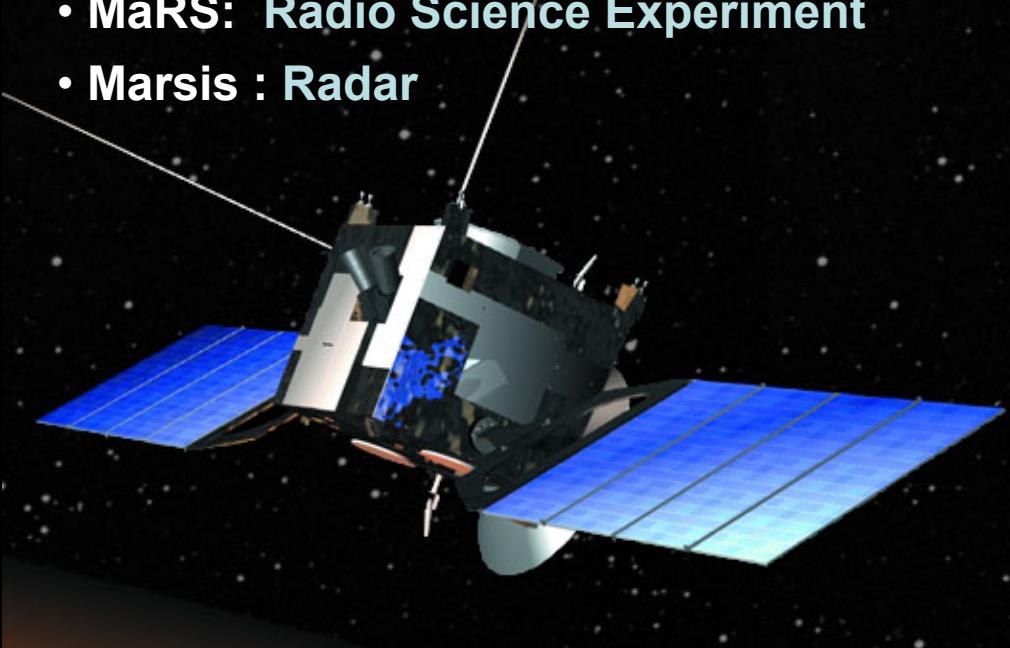
IPSL, LMD, CNRS, Paris, France

+ the Mars Express teams !

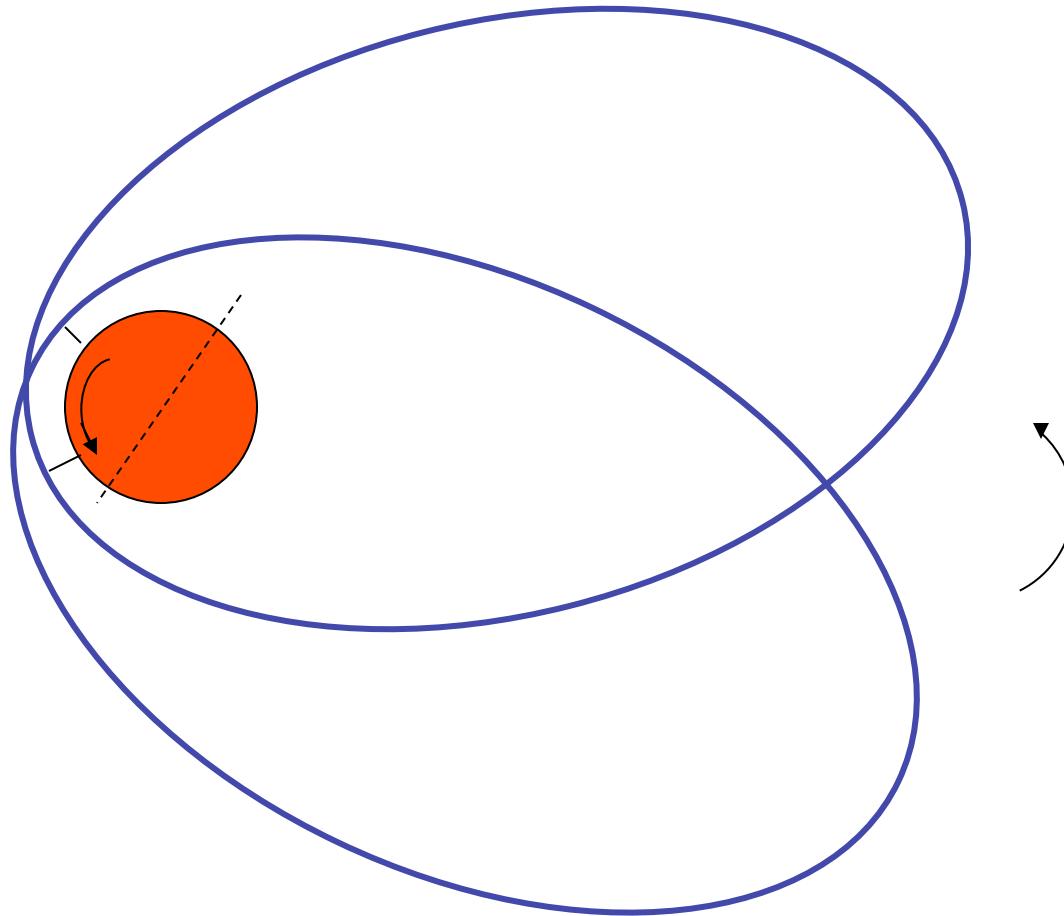


Mars Express Orbiter

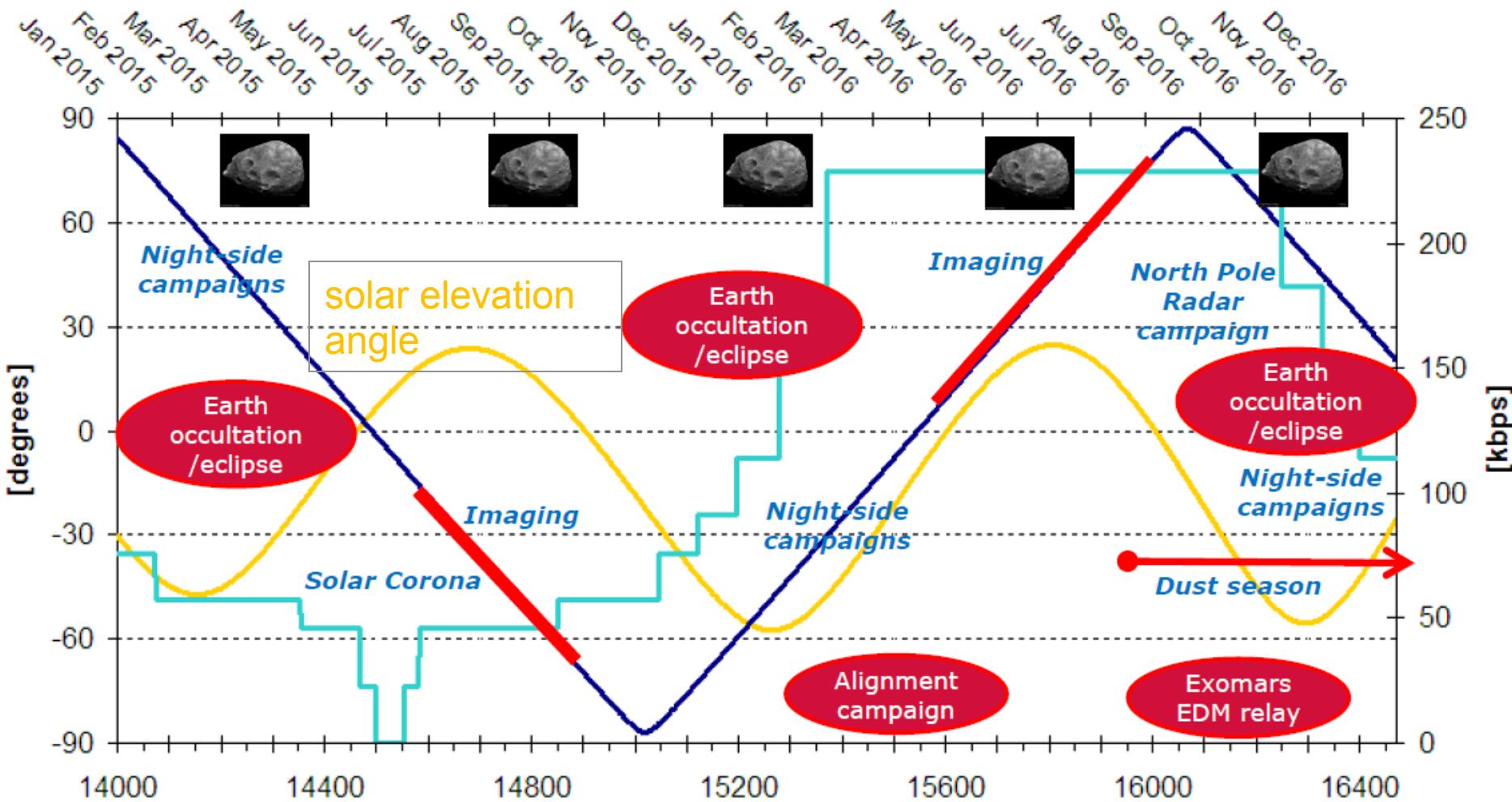
- 7 main Instruments :
 - HRSC (camera) : visible
 - OMEGA (imaging Vis and NIR spectrometer) : $0.3\text{-}5.2 \mu\text{m}$
 - PFS (NIR and thermal spectrometer): SWC: $1.2\text{-}5.8 \mu\text{m}$ + LWC $6\text{-}50 \mu\text{m}$
 - SPICAM (UV and NIR atmospheric spectrometer): $0.1\text{-}0.31 \mu\text{m}$ + $1\text{-}1.7 \mu\text{m}$
 - ASPERA (Energetic Neutral Atoms Imager)
 - MaRS: Radio Science Experiment
 - Marsis : Radar



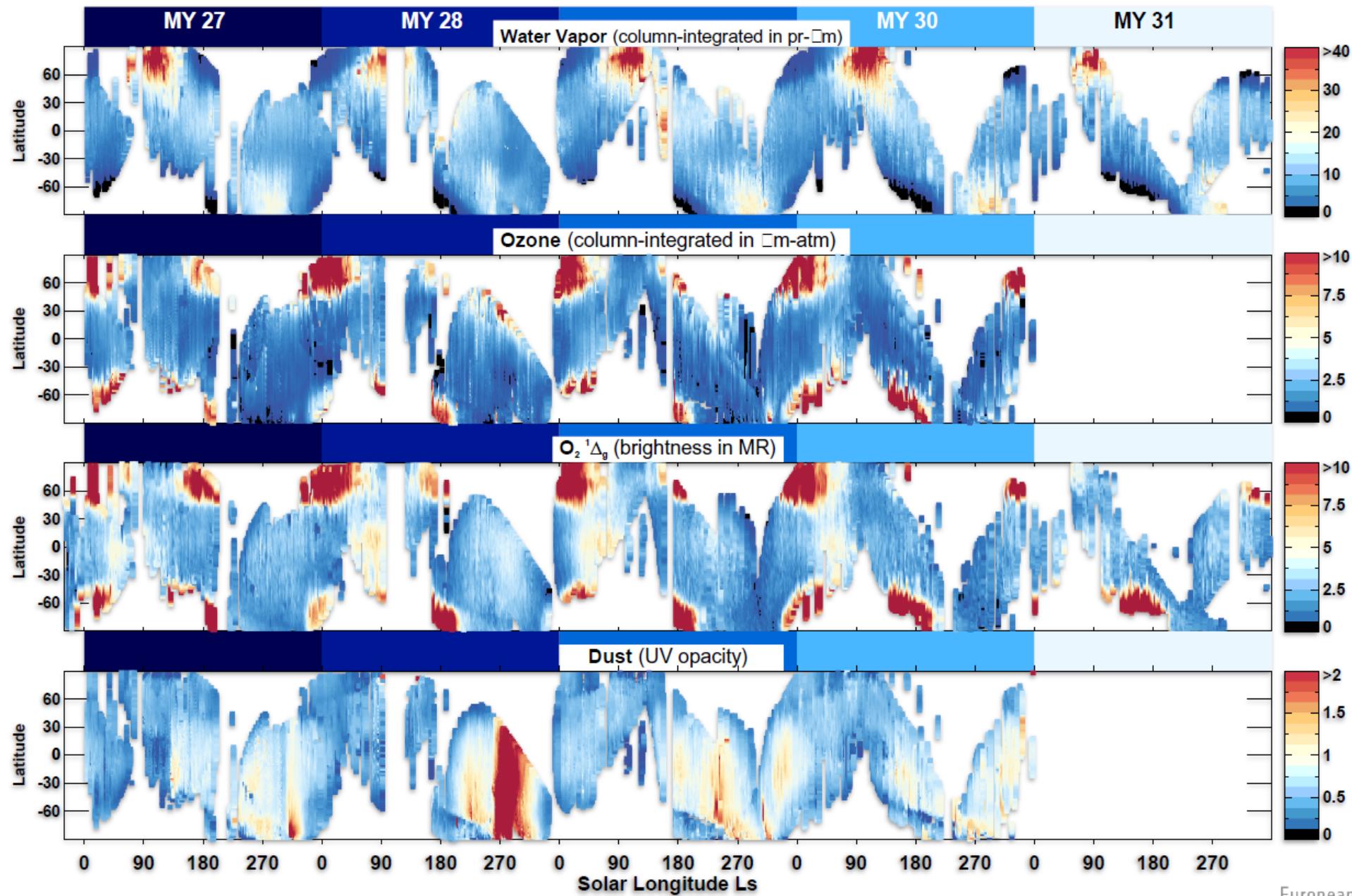
Eccentric Orbit + Pericenter latitude drift



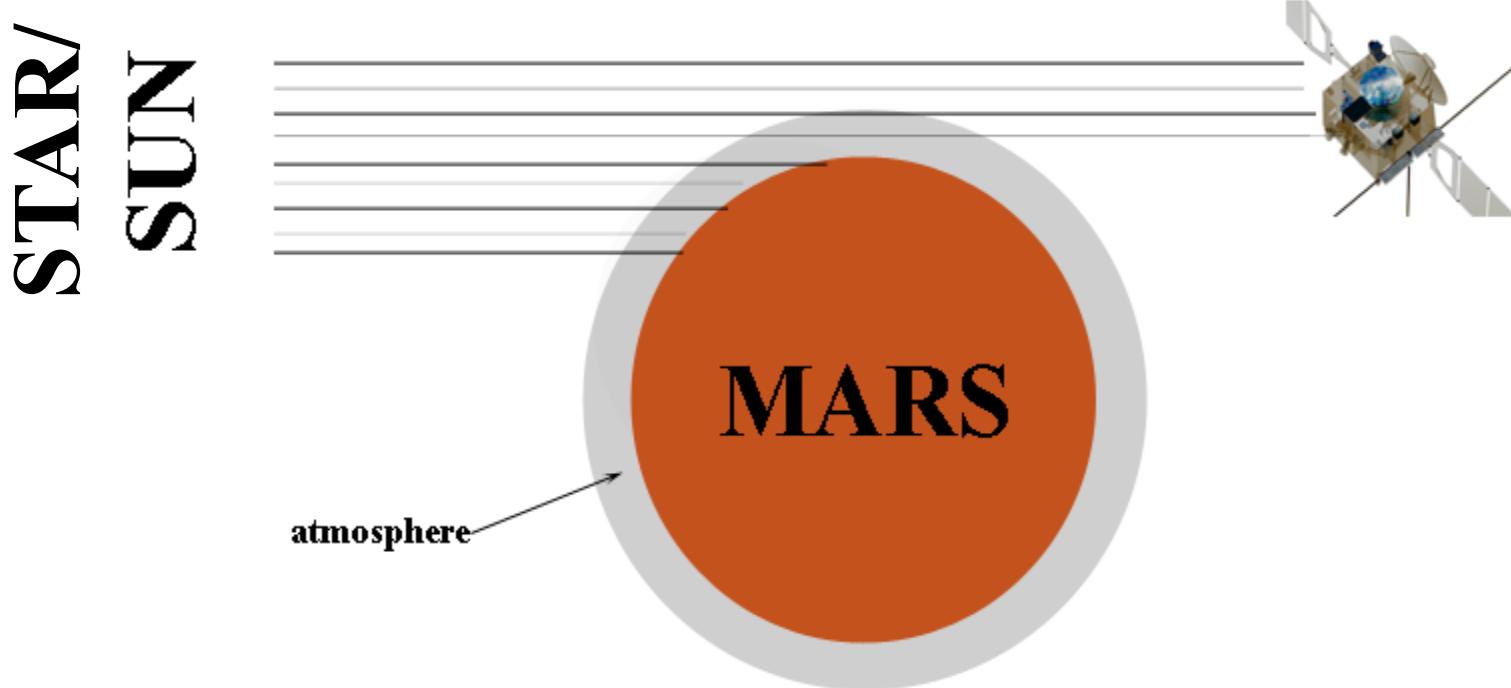
Example of Mars Express Periapsis evolution & operations



Example of coverage: SPICAM dataset MY27 – MY 31



LIMB , Star and Solar occultations



Phobos and the Martian Limb



**HRSC Phobos and Martian limb in orbit # 3868 (10 January 2007):
Distance to Phobos 1660 km**



Orbit # 1009
Ls 108.8 (northern summer)
Local afternoon
Limb close to north pole and Korolev crater
Limb haze reaches ~19 km to 31 km altitude

Jaumann et al., 2007

Mars Express atmospheric measurements datasets

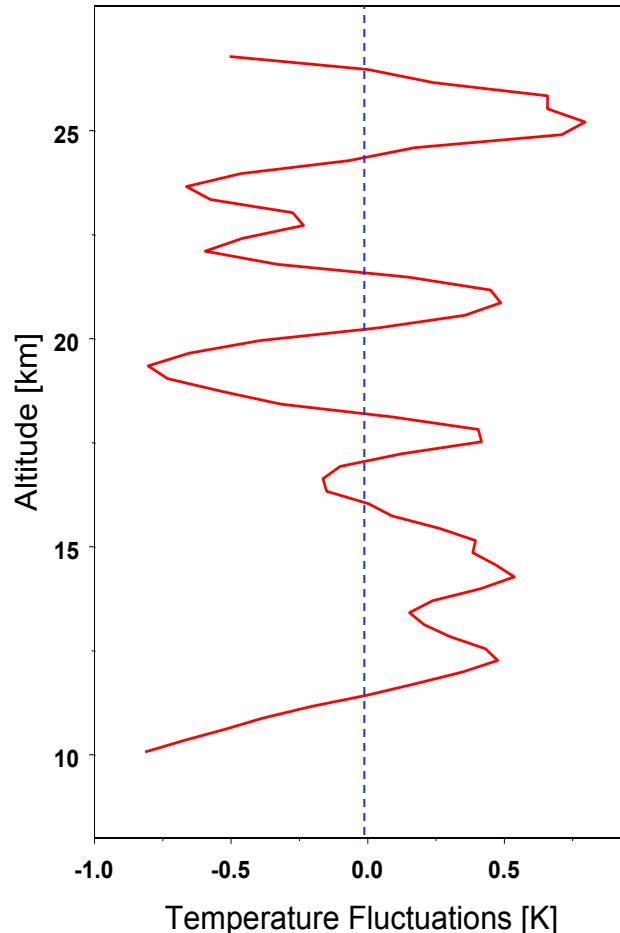
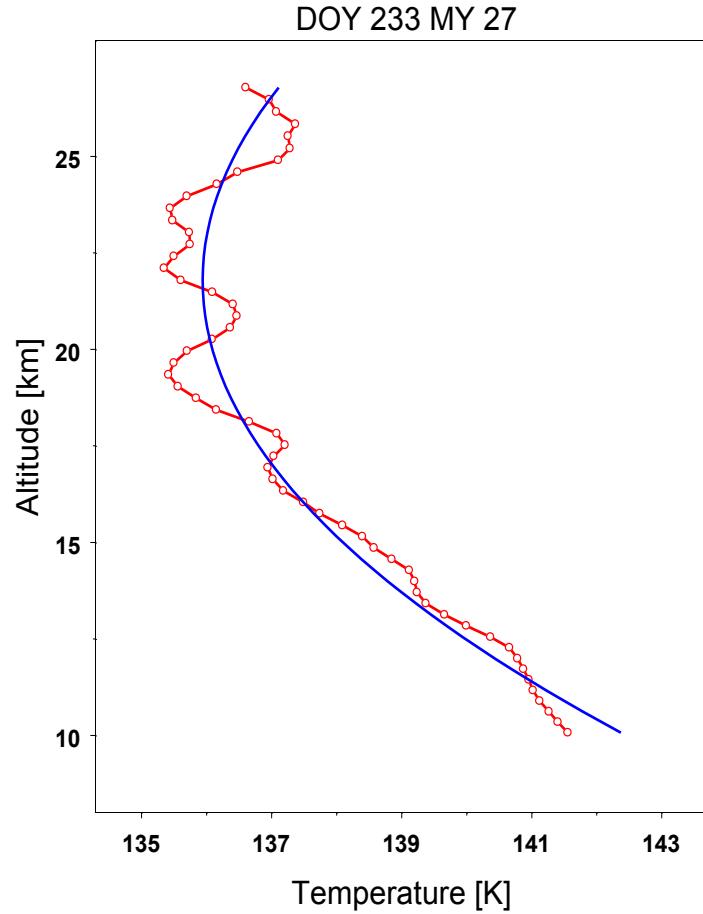
- Temperatures & pressures
- Aerosols and clouds
- Seasonal Surface Frost
- Water vapor
- Chemical species and Ions
 - Ozone
 - O_2
 - CO_2 , CO, NO, CH_4 , H_2O_2
 - Electron density

Mars Express atmospheric science datasets status (below 130 km)

Datasets	Instrument	Status and comments
<i>Temperatures, densities & pressure</i>		
Climatology of temperature profiles 0-50 km	PFS LW	Numerous publications (e.g. Grassi et al. 2005, 2007, Giuranna et al. 2008, Sato et al. 2011, Wolkenberg et al. 2010, 2011) . Several years Datasets available from the PFS team . An improved dataset is under preparation.
Temperature profiles 0-40 km by Radio occultations	MaRS	Dataset (MY 27-30) described in Tellmann et al. 2013 + publications on specific subjects (e.g. Hinson et al. 2008). Dataset available from the MaRS team.
Temperature profiles/density 70 - 130 km by stellar occultations	SPICAM	First year (MY 27) published (Forget et al. 2009, Withers et al. 2011) and available. <i>MY28-31 remain to be properly published</i>
Density/ temperature retrievals from CO2 NLTE emission in limb profiles	OMEGA, PFS	A dedicated study is planned at IAA (Granada) within the UPWARDS project
Surface pressure mapping (CO2 column)	OMEGA	Method (Forget et al. 2007) and selected maps (Spiga et al. 2007) published. Many orbits not processed but the data processing is difficult in most cases.

Example : gravity waves in the polar night

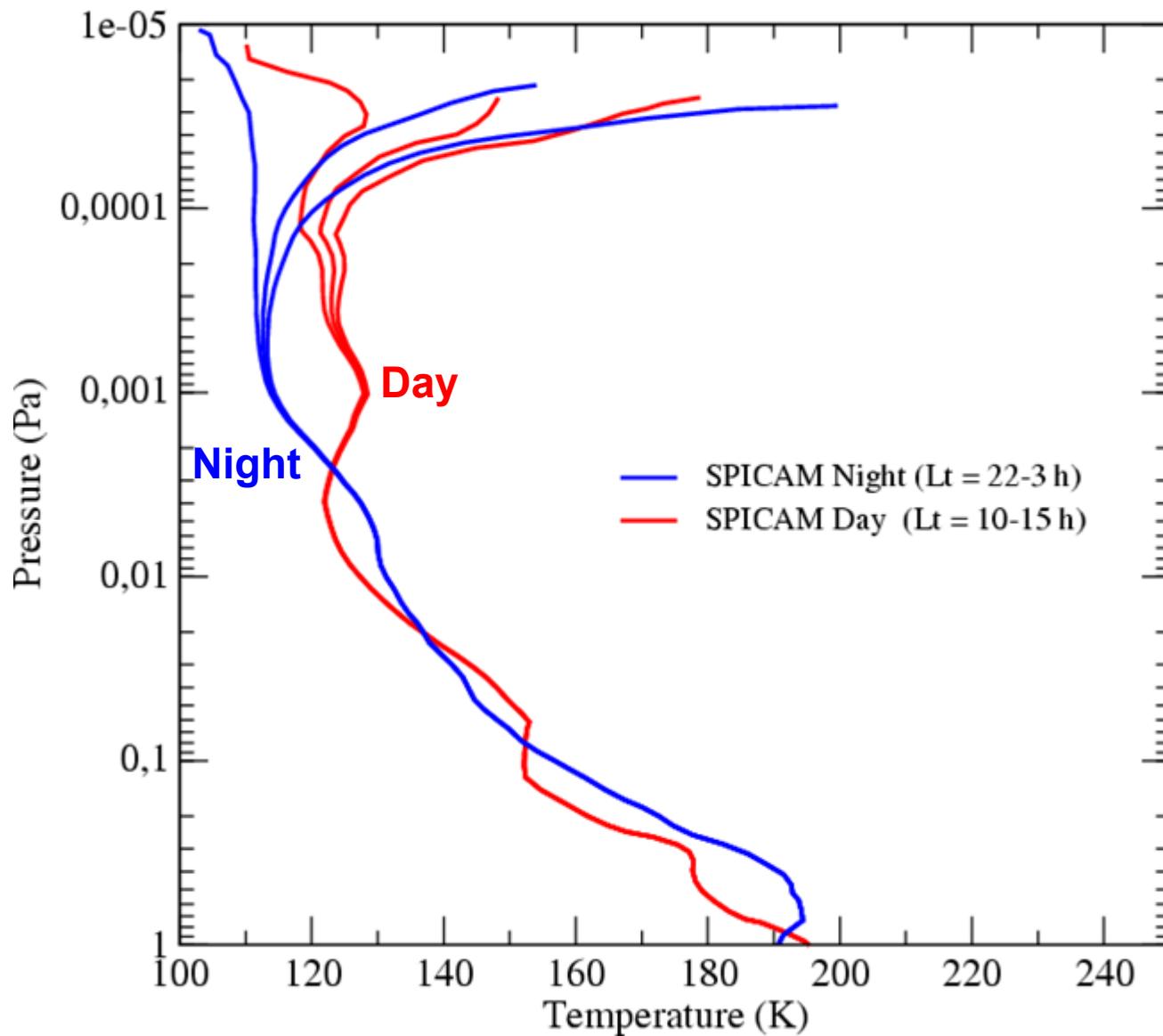
(Tellmann et al.)



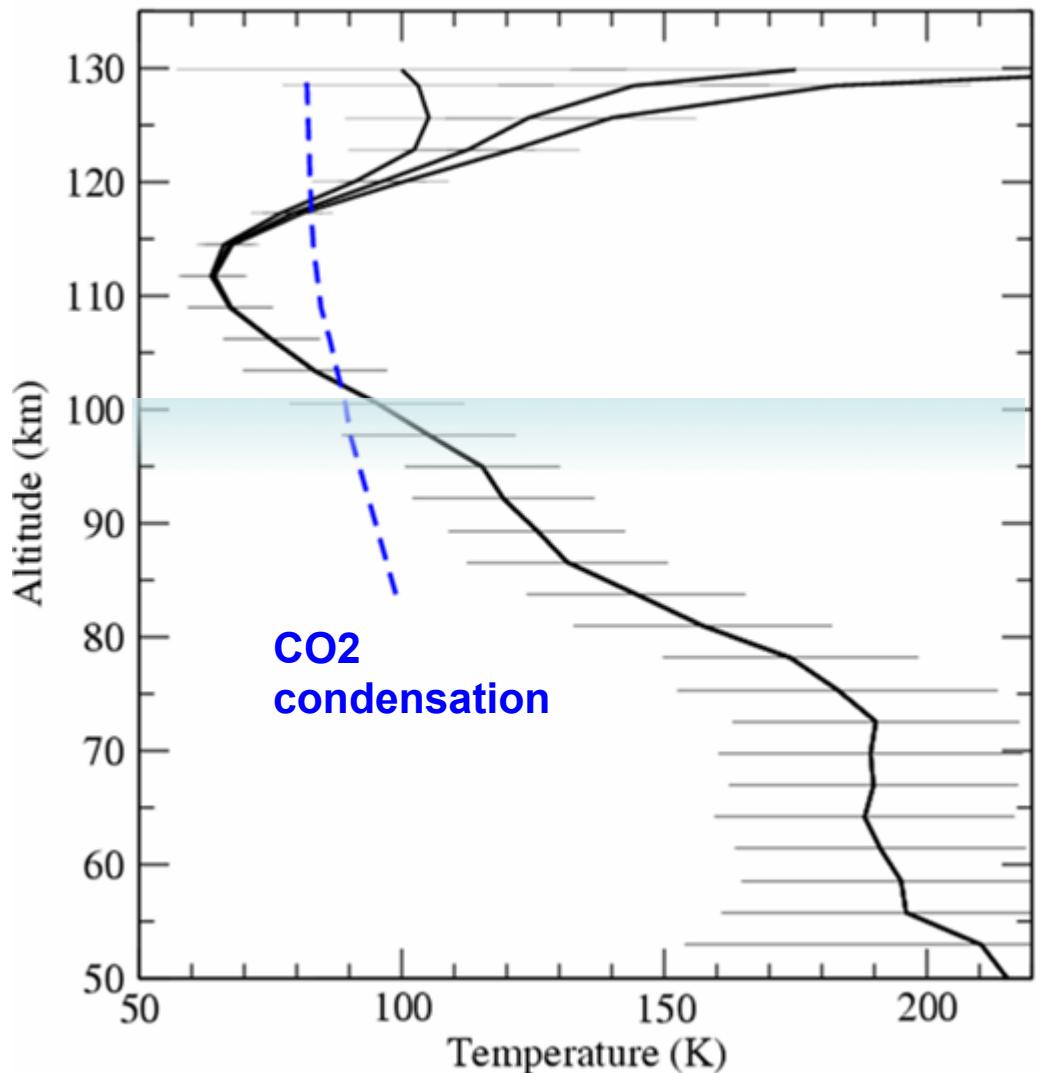
(Pätzold et al. Tellmann et al.)

SPICAM stellar occultation
Diurnal variations (N. Winter) Forget et al. 2009

$L_s = 270^\circ\text{-}330^\circ$ latitude = 40N-50N



Orbit 1226A1 [-15.7°N-276.0°E] Ls=137.4° time=1.0 hr



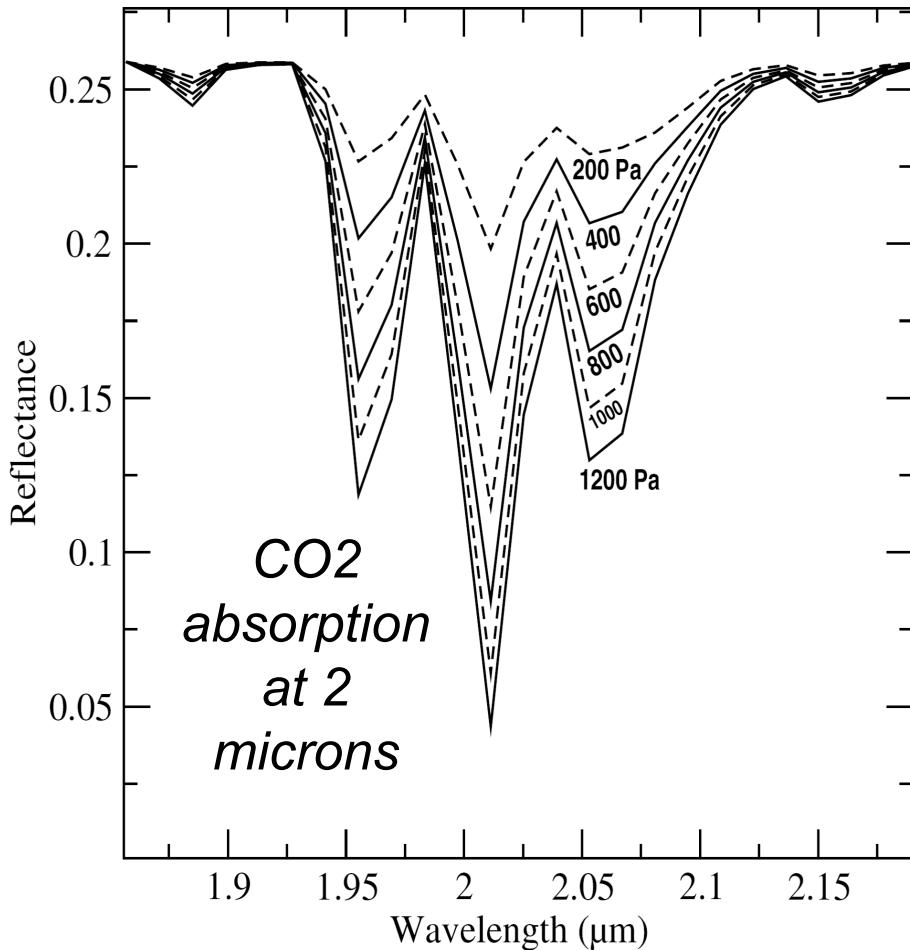
Detached aerosol layer simultaneously in the stellar occultation

Montmessin et al., Icarus 2006

Mars Express atmospheric science datasets status (below 130 km)

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Pressure retrieval using the CO₂ 2 μm band



Retrieval: Least-square fitting w/ synthetic spectra from line-by-line radiative transfer

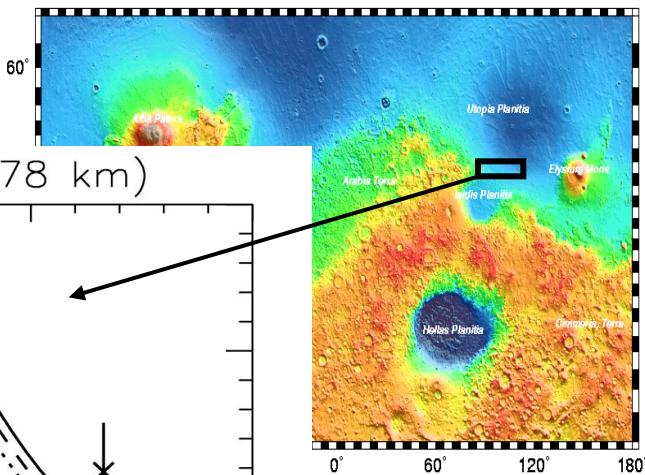
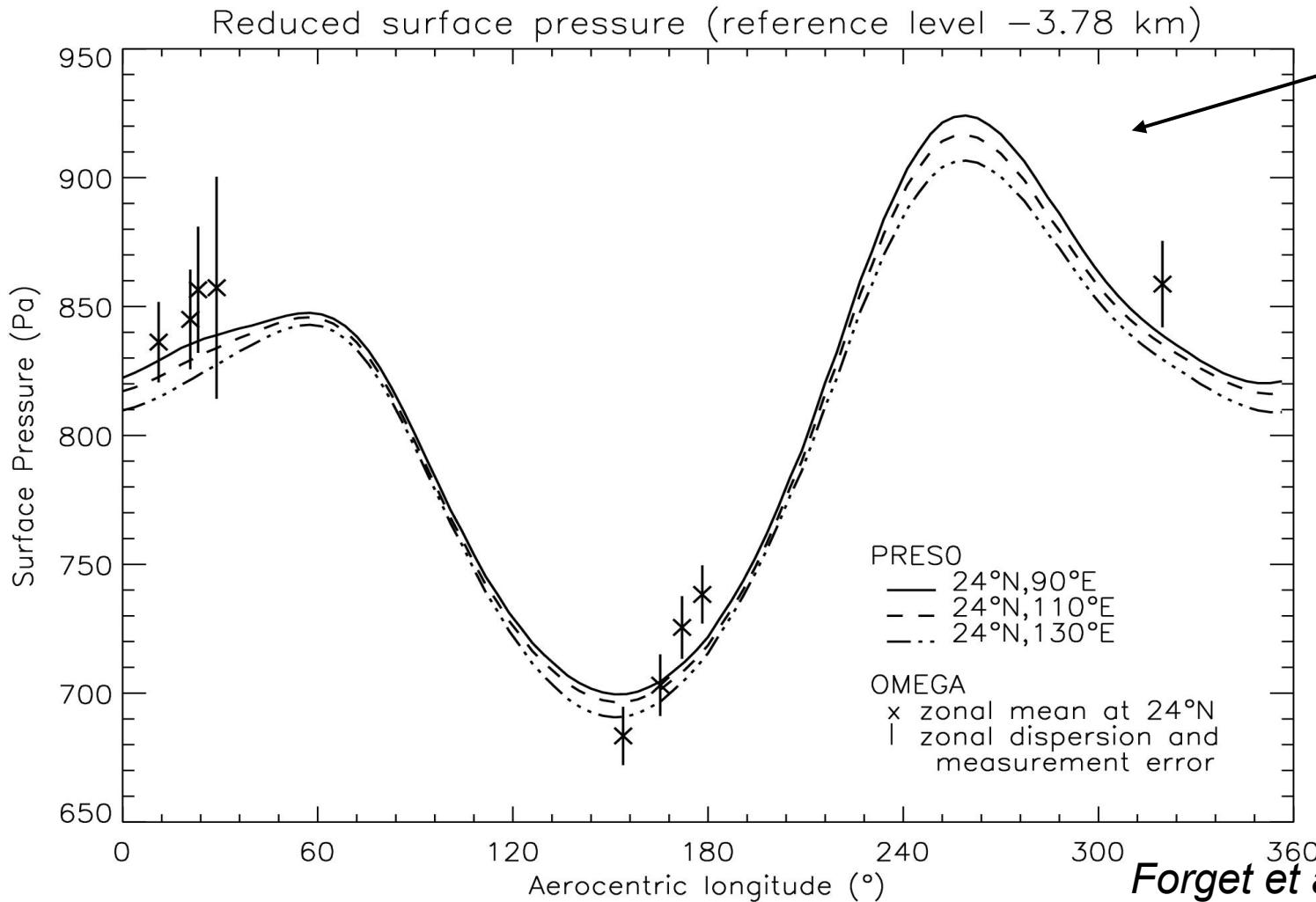
Inputs

1. Observation geometry e, i, ϕ
2. Atmospheric state T, τ
3. Surface properties
4. Surface pressure

Features

- Dust absorption / simple scattering scheme
- Multidimensional look-up tables

Seasonal CO₂ cycle monitored by OMEGA

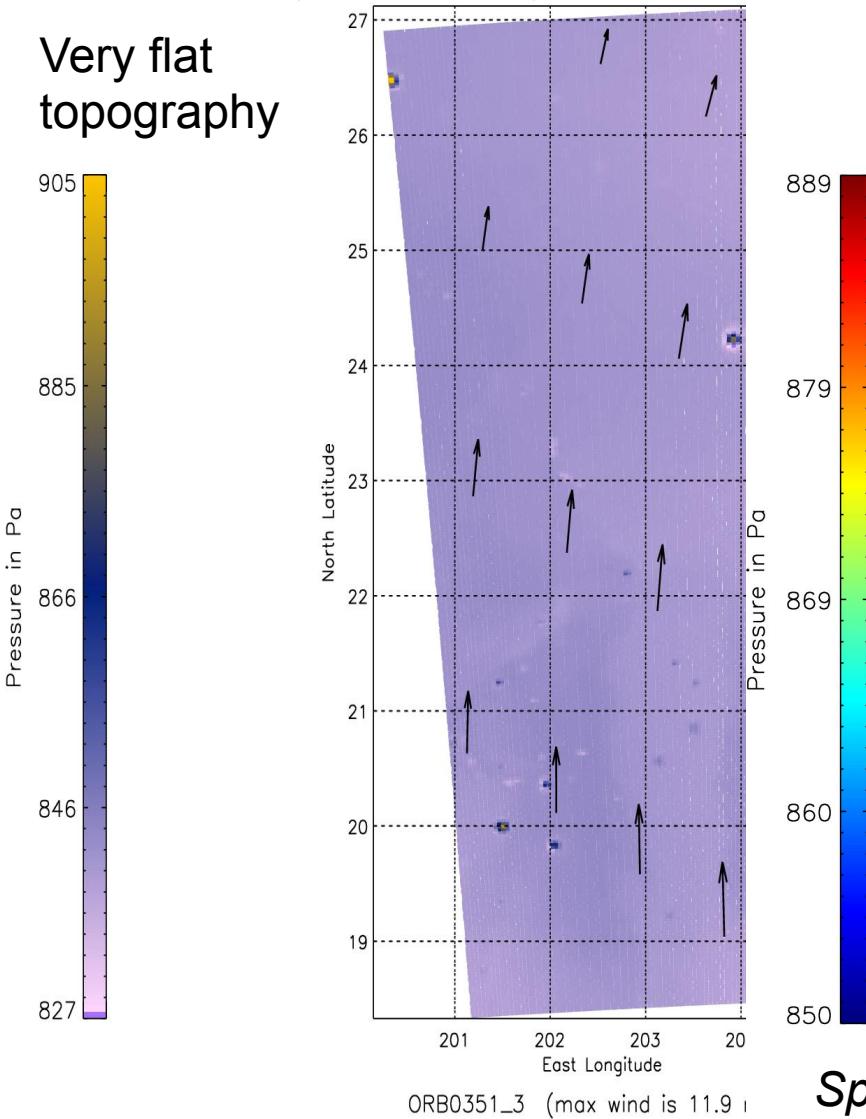


Forget et al. 2007

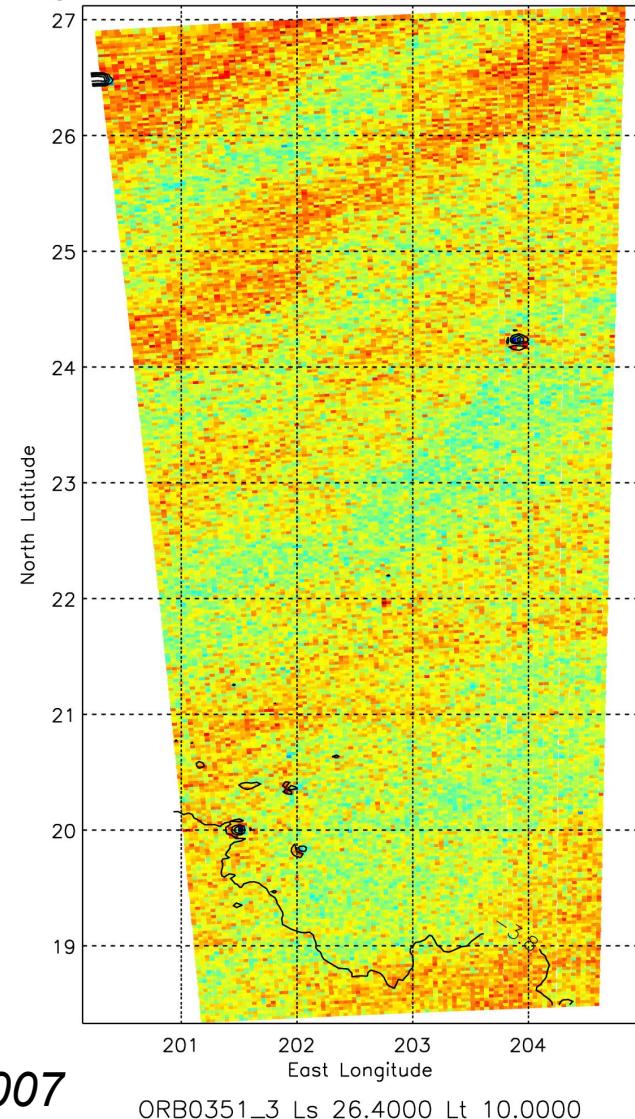
Surface pressure oscillations

MCD-predicted surface pressure & winds

Very flat
topography



Omega-derived reference level surface pressure

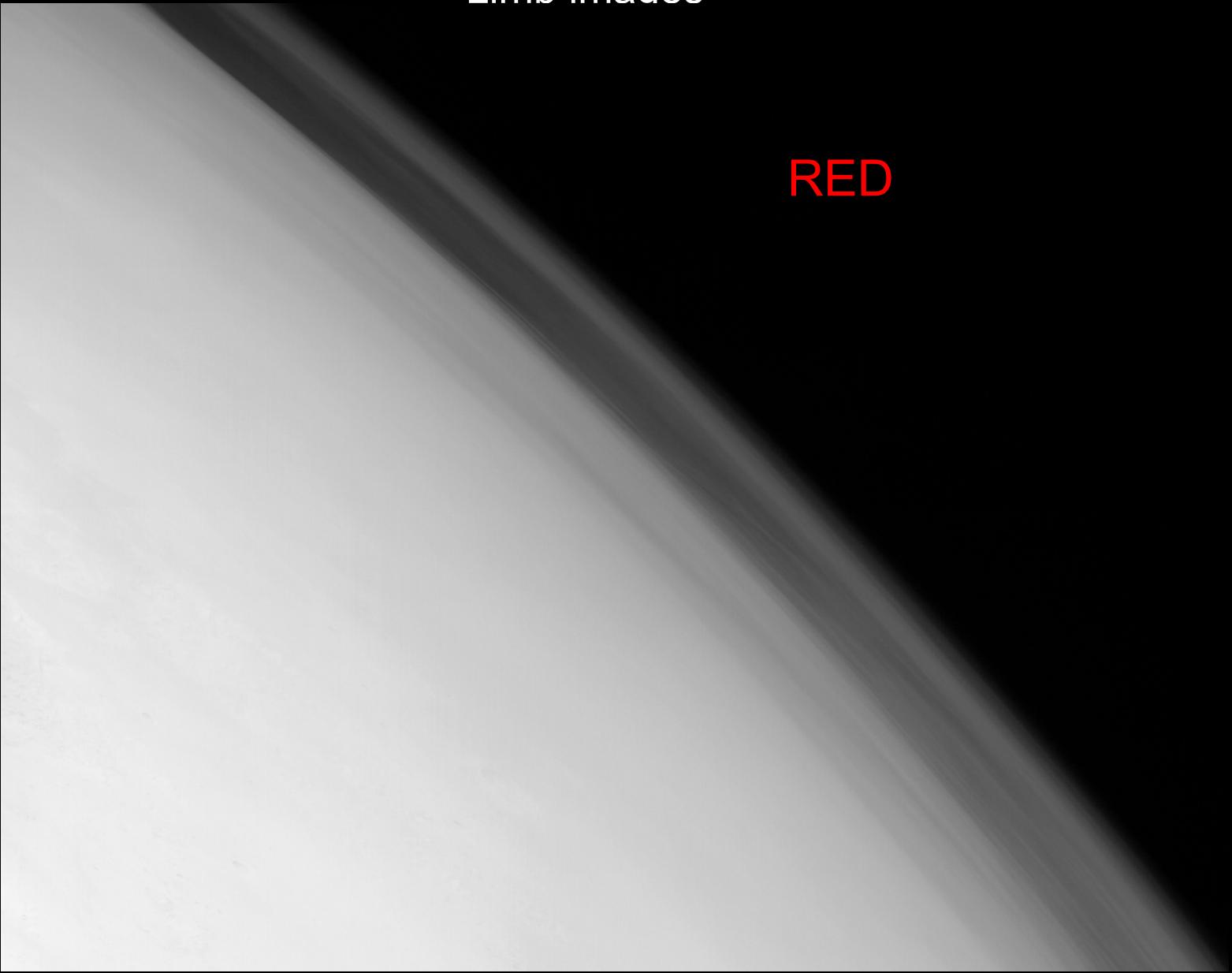


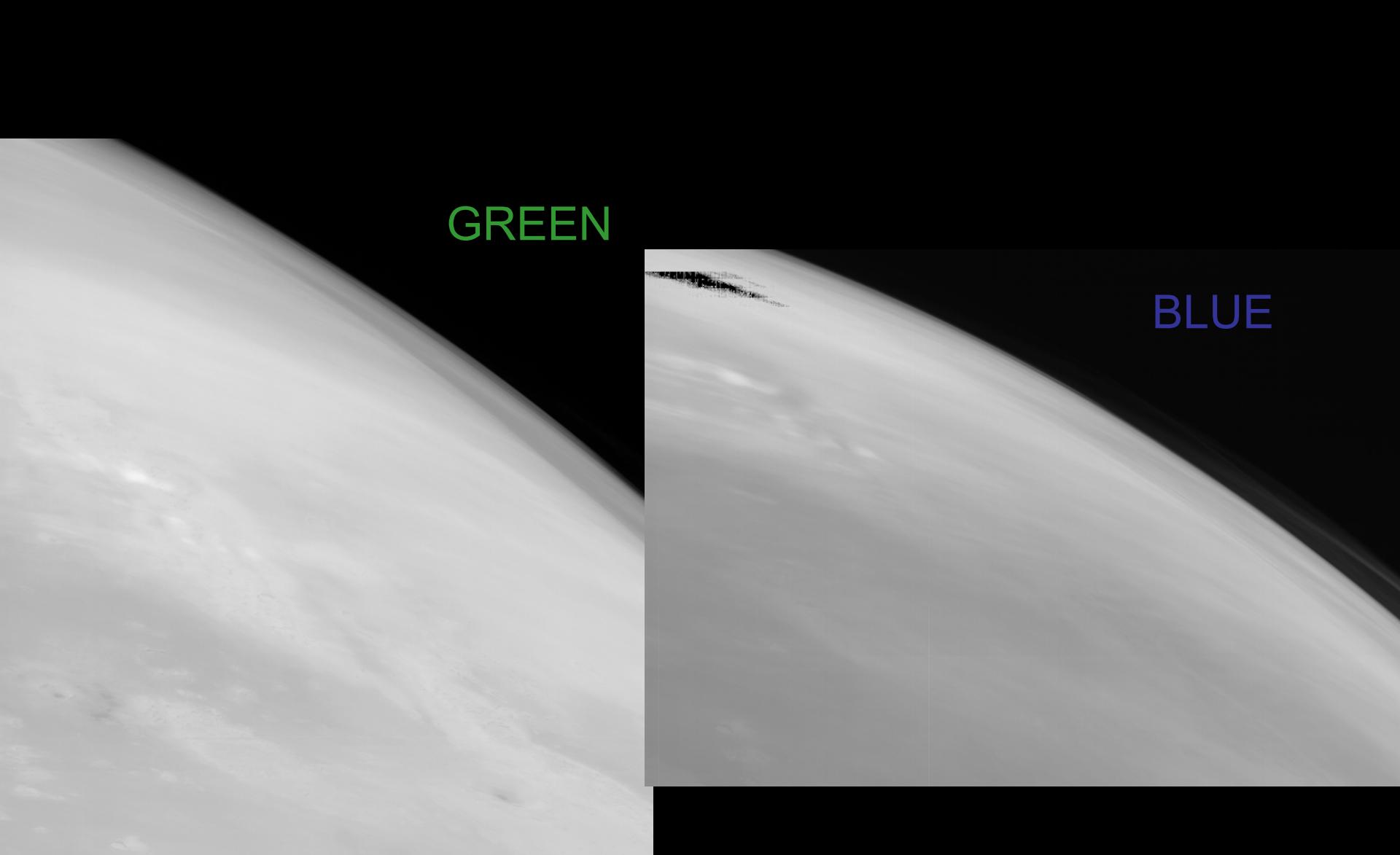
Spiga et al. 2007

Datasets	Instrument	Status and comments
Aerosols and clouds		
Aerosol profile using UV limb observations	SPICAM UV	33 profiles from MY27 analyzed in Rannou et al. (2006).
Aerosol profiles using UV stellar occultation	SPICAM UV	MY27 profiles analysed in Montmessin et al. (2006). <i>MY28-31 remains to be properly published</i>
Aerosol profiles using solar occultation	SPICAM UV+NIR	MY27-MY30 climatology of UV solar occultations published in Määttänen (2013). NIR profiles in Fedorova (2009) UV+NIR combined study used to retrieve aerosol properties in N. summer (Fedorova, 2014)
Aerosol column climatology (dust, clouds) in the TIR	PFS LW	A few early orbits published (e.g. Zasova et al. 2005, 2006). Several years datasets available from the PFS team, but the processing is not easy (the dust retrieval in the 2012 dataset was not accurate). An improved dataset is under preparation. A dedicated study of regional & global dust storm is planned within the UPWARDS project.
Cloud UV opacity mapping	SPICAM	MY27-MY28 climatology by Mateshvili et al. (2009, 2007). A complete dataset is available and will be published soon. A new retrieval is planned within the UPWARDS project at IASB (Belgium) to produce an updated climatology.
Dust column opacity mapping in the NIR	OMEGA	<ul style="list-style-type: none"> • M. Vincendon (IAS) has developed methods to retrieve dust opacity with a Monte-Carlo model in various conditions (Vincendon et al. 2007, 2009) and above the residual south polar cap for MY 27 (Vincendon et al. 2008). • Another method using the radiative coupling between dust and gas extinction has been proposed by S. Doute (IPAG) and applied to MY27 at high southern latitude (Doute et al. 2013, 2014) • See also dust properties analysed in Määttänen et al. (2008)
Dust column opacity in the visible	HRSC	Methods published in Hoekzema et al. (2010, 2011) and Petrova et al. (2012) and applied to a few images.
UV Dust properties using EPF observations	SPICAM	A new study is planned at IASB (Belgium) within the UPWARDS project.
Cloud climatology in the NIR	OMEGA	An impressive dataset is available. Subset published in Langevin et al. (2007) and Madeleine et al. (2012) and several abstracts. Full dataset publication is in preparation at LMD (France)
Mapping and studying water ice clouds in the visible	HRSC	Only a few studies published e.g. (Inada et al. 2008). <i>More could be done with this dataset ?</i>
Aerosol and cloud properties using NIR limb images	OMEGA	An impressive dataset is available. Only a few unpublished studies have been performed <i>Much more could be done with this dataset.</i> A new study is planned at INAF (Italy) within the UPWARDS project.
Aerosol and cloud properties using NIR limb spectra	OMEGA, PFS	A new study is planned at INAF (Italy) within the UPWARDS project
Water ice cloud profile using limb images	HRSC	Impressive data are available. <i>Much more could be done with this dataset.</i>
Cloud particles microphysical parameter	OMEGA	Analysis of a subset of observations published in Madeleine et al. (2012). Extension to the full OMEGA dataset planned in the UPWARDS project.
Mesospheric CO ₂ ice cloud climatology and properties	OMEGA, PFS	Several key publications (Montmessin et al. 2007, Määttänen 2010, 2013, Vincendon et al. 2011). Analyses using PFS have been performed (paper in preparation).

Limb images

RED





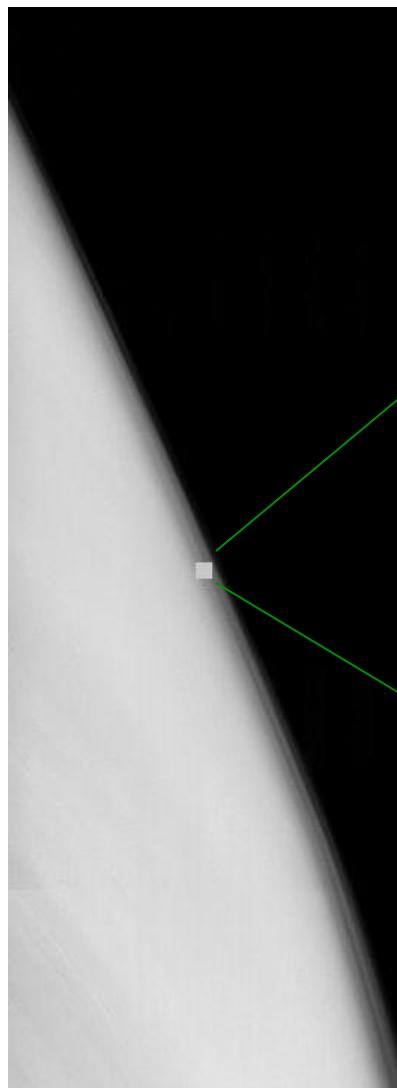
GREEN

BLUE

Limbs in different colour images at different geographic locations

Limb structure

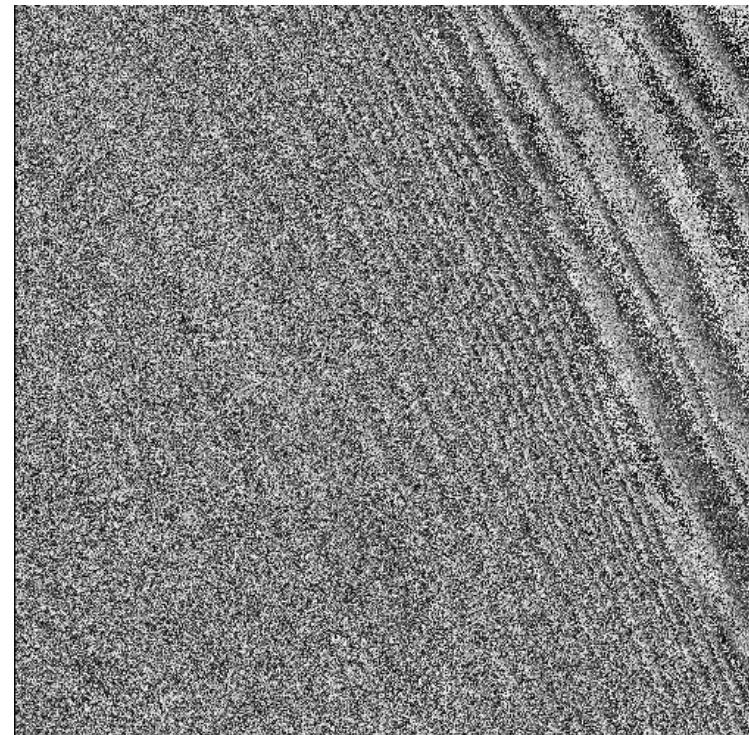
HRS



170 km

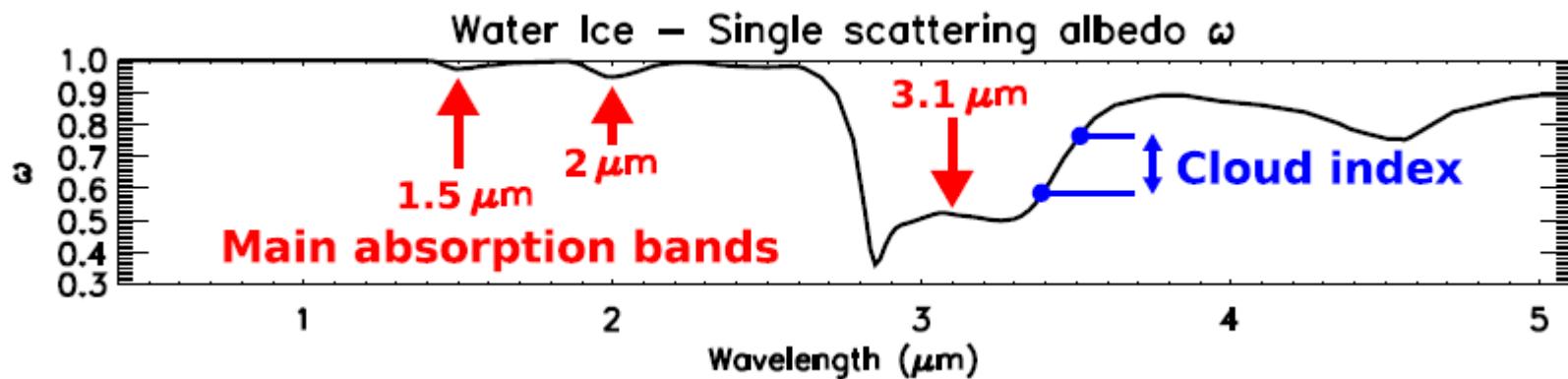
(h0044_0009.nd2)

SRC

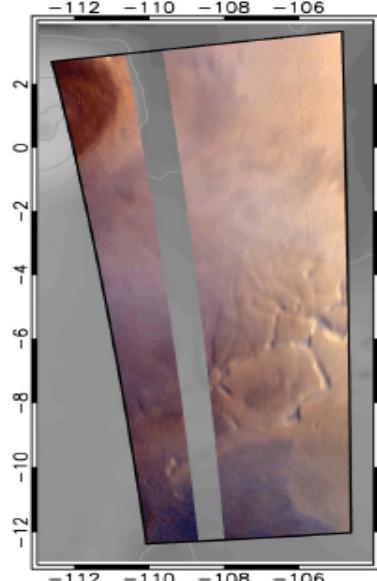


7.5 km

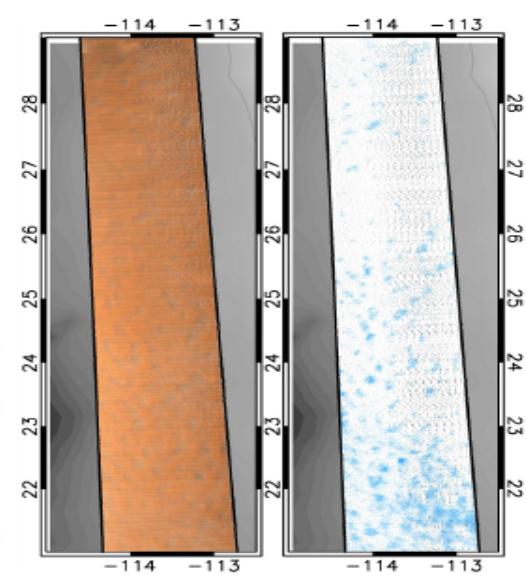
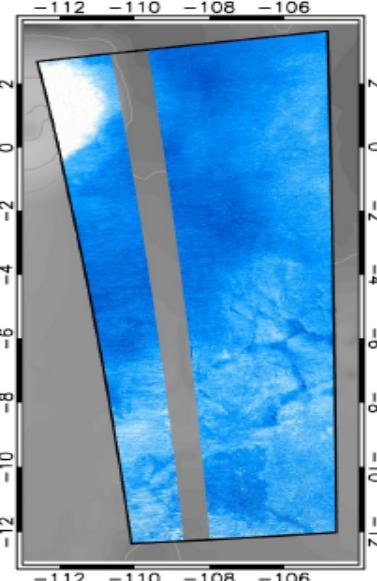
Mapping cloud optical depth and particle size using Mars Express OMEGA imaging spectrometer data



Morning hazes near Pavonis Mons
($L_s = 53.6$, LT = 8.5, orbit 563_3)



Cumulus clouds ($L_s = 115.3$, LT = 10.6, orbit 3514_1)

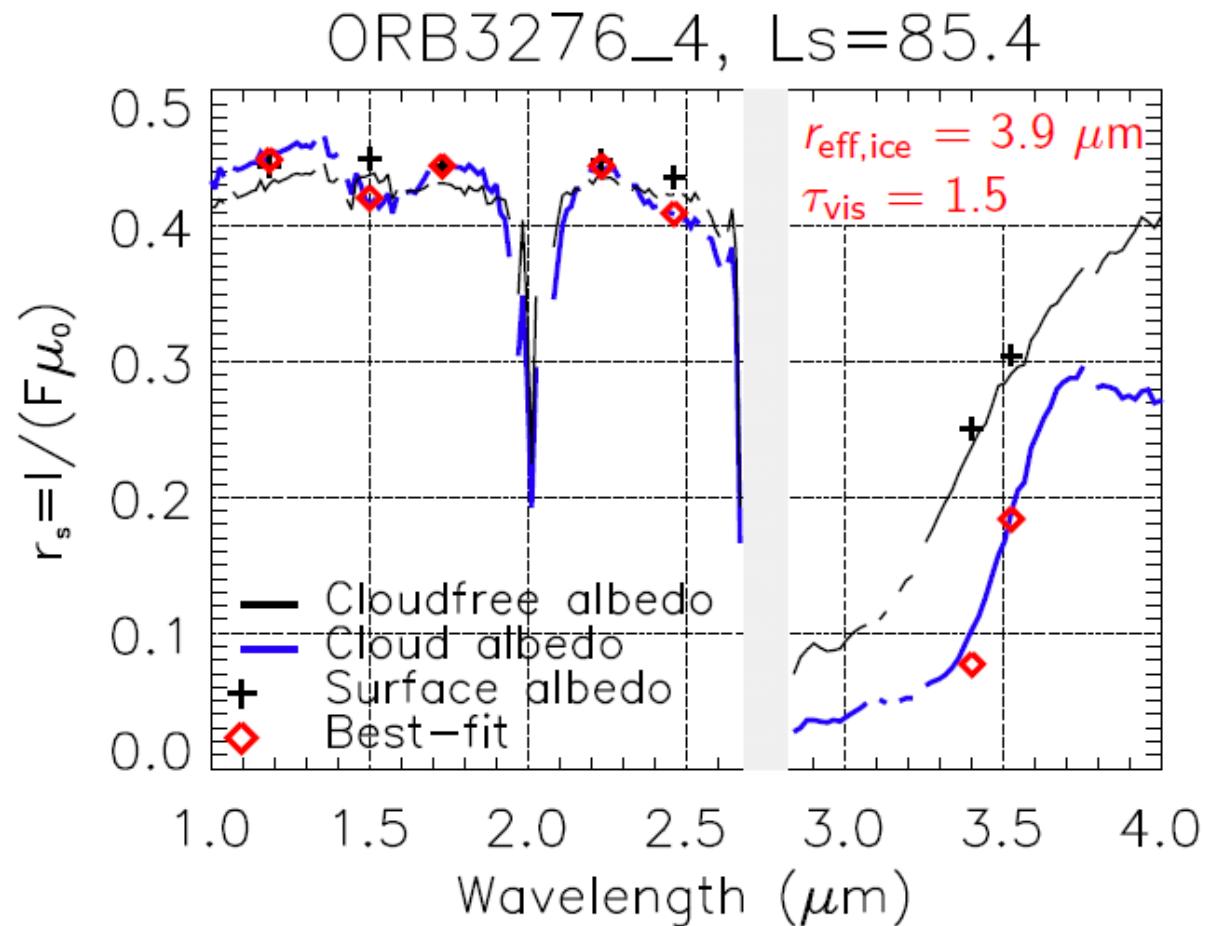
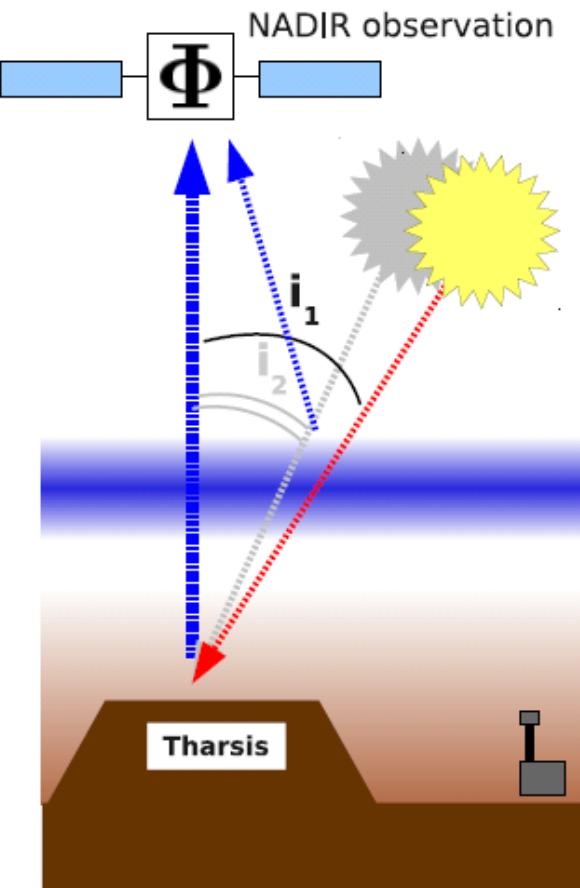


Visible channel image (left) and cloud index (right).

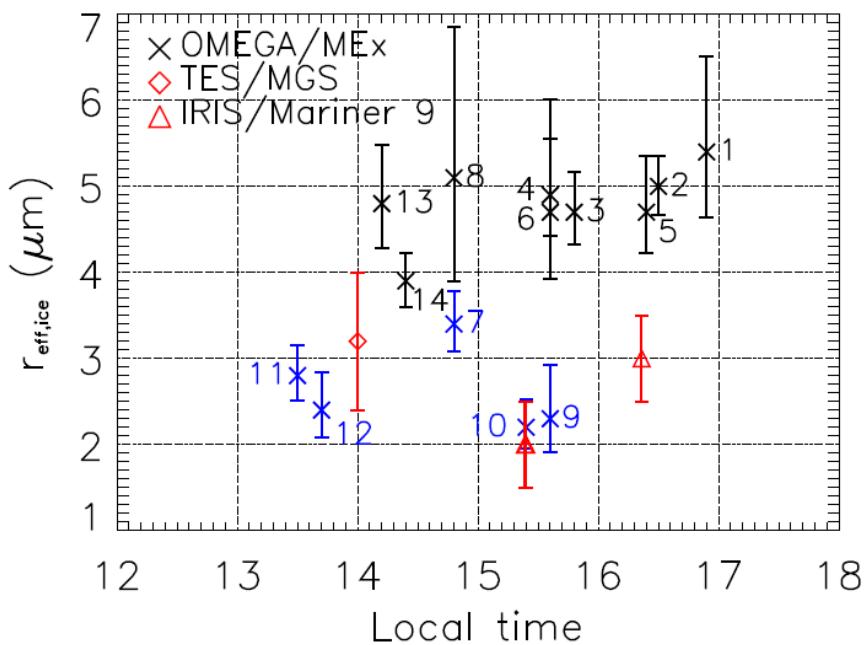
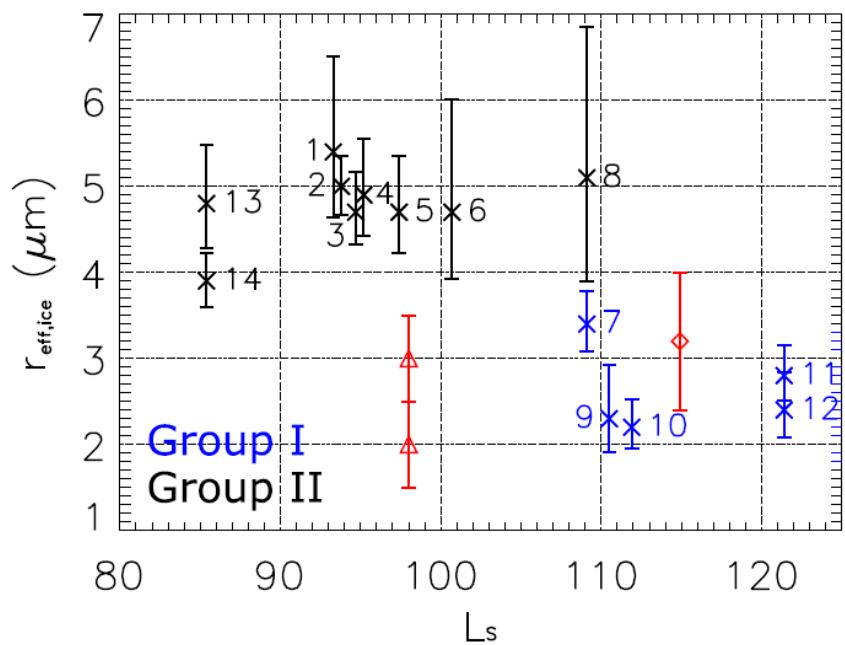
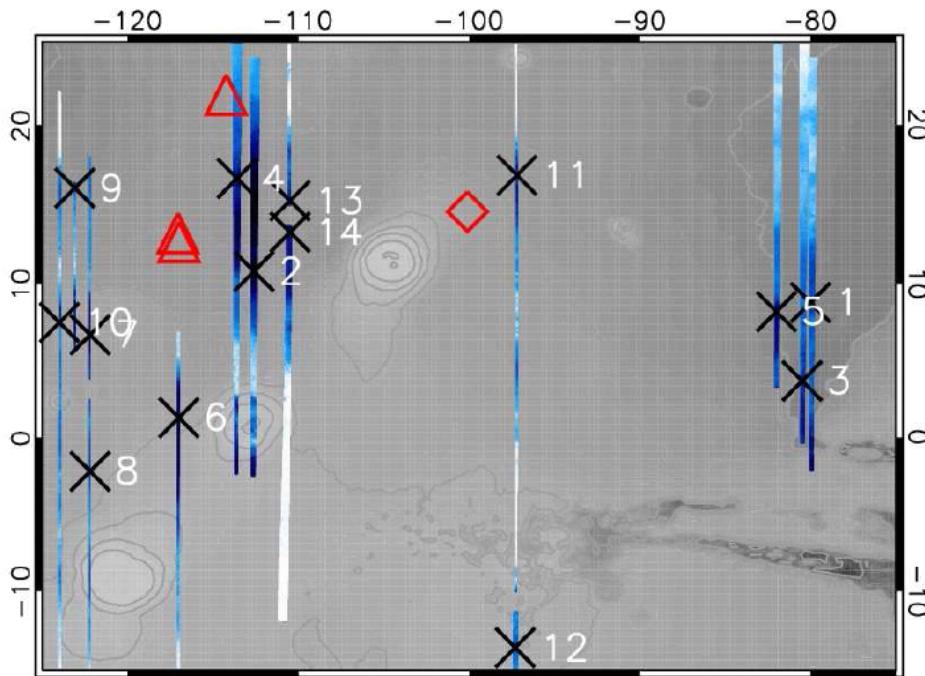
Retrieval of crystal size and cloud opacity

A difficult retrieval using two observations with and without clouds

(Madeleine et al. 2011)



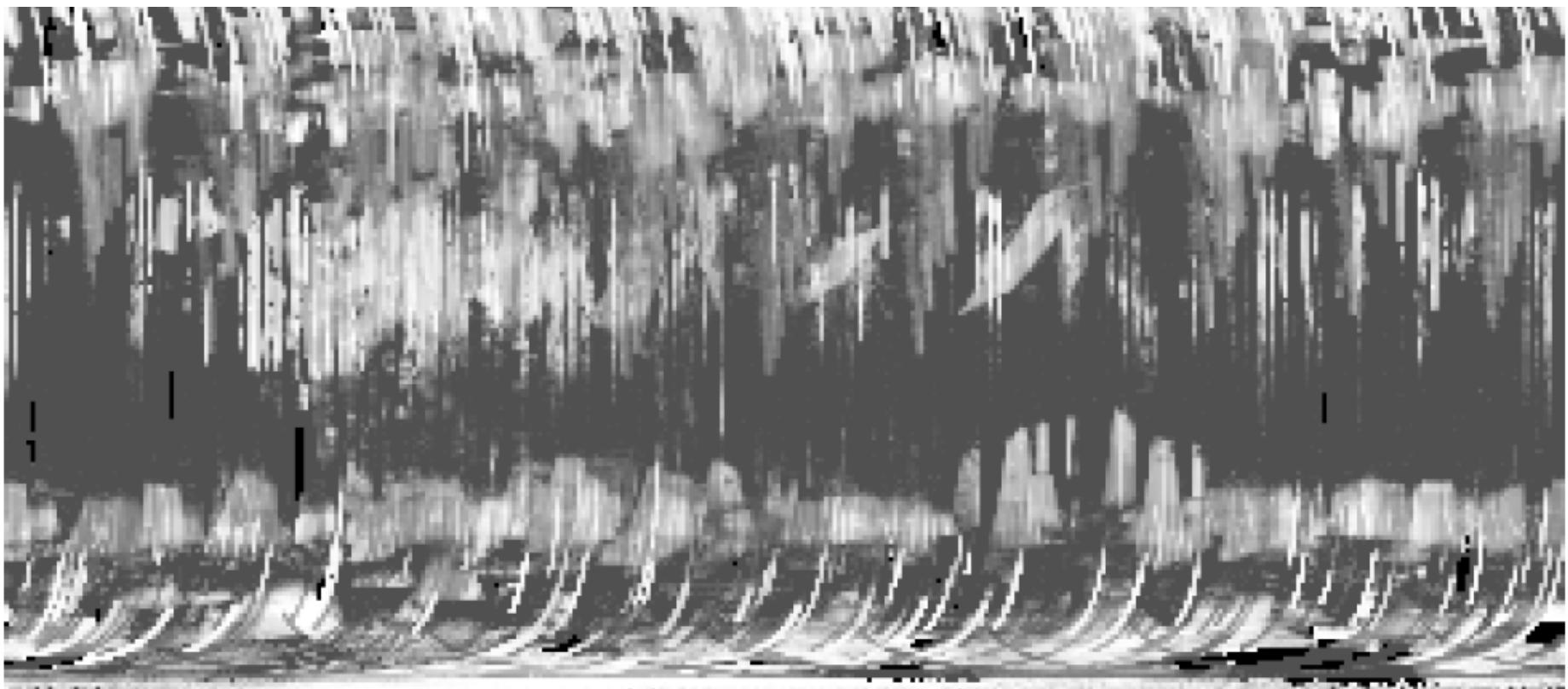
Mars water ice clouds opacity and particle size using OMEGA (Madeleine et al., JGR 2011)



Processing clouds within the entire dataset: Ongoing preliminary project: Mapping the clouds the OMEGA « cloud index » (A. Szantai, LMD)

Processing and binning of the 3.4 μm cloud index

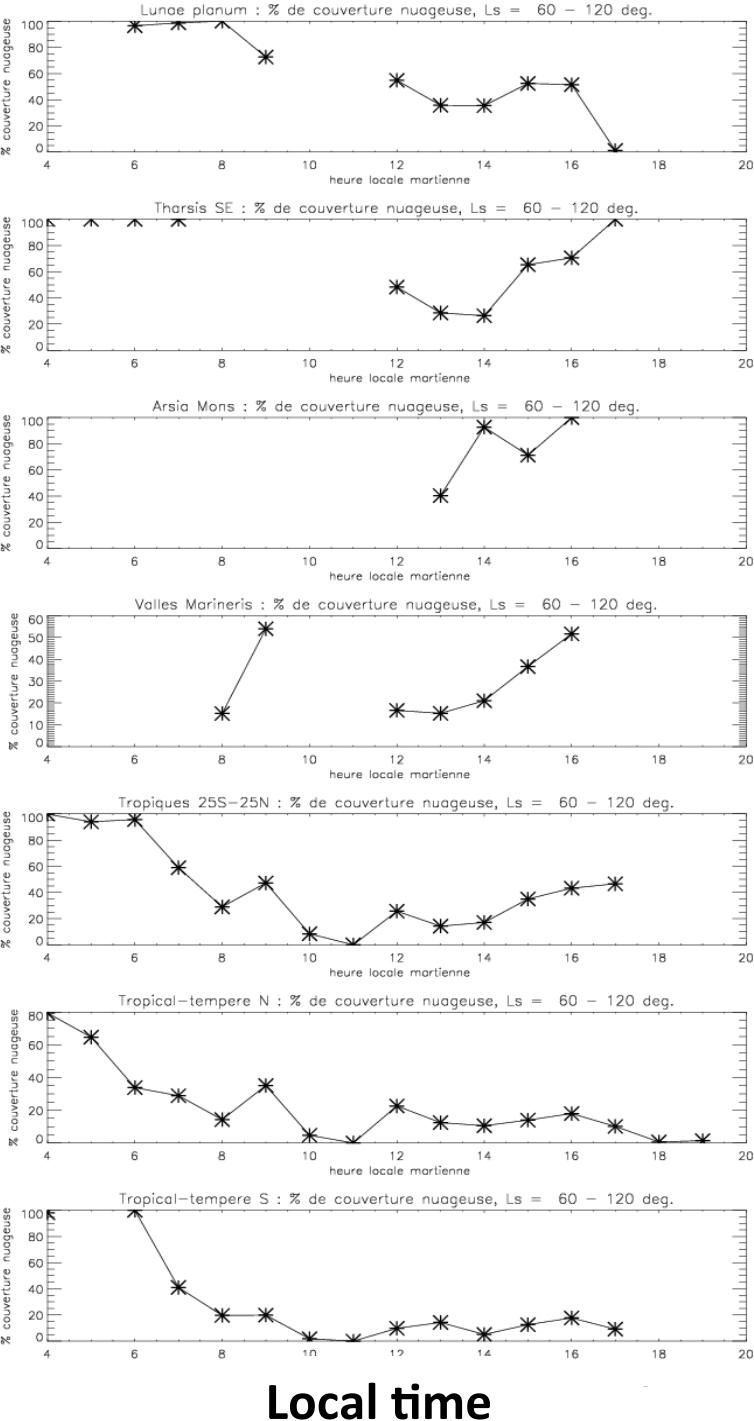
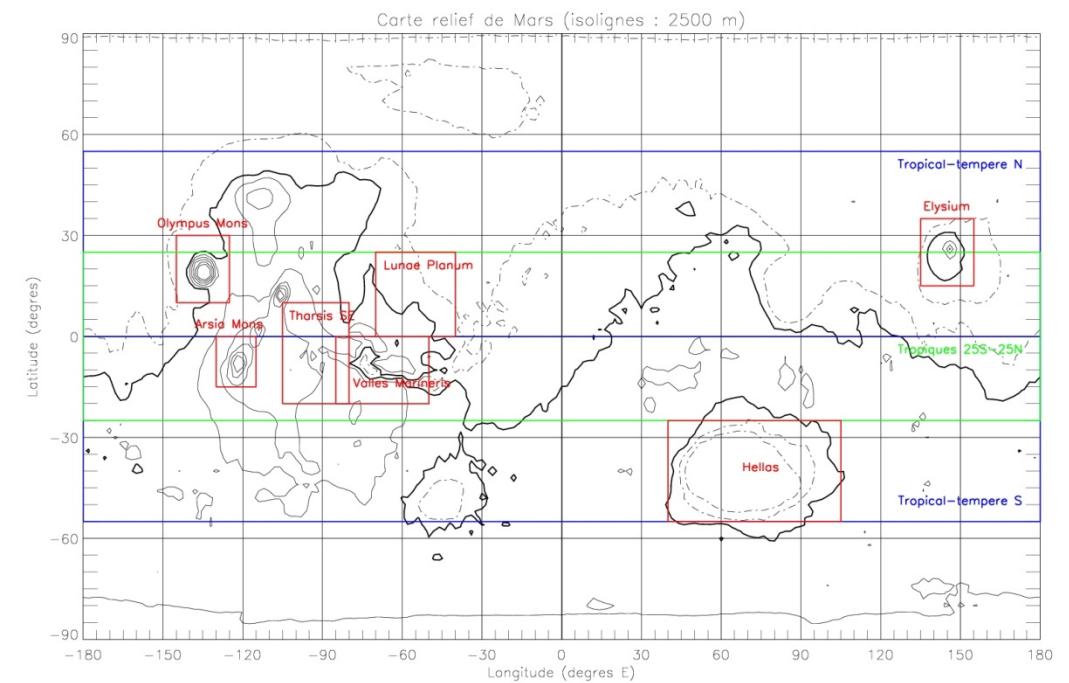
orbite 18 - 8475, = 7815 files Martian Year 26 to 30 (01/2004 - 08/2010)



Processing clouds within the entire dataset:

Ongoing preliminary project:
Mapping the clouds using the
« cloud index » (A. Szantai, LMD)

Ls =60°-120°

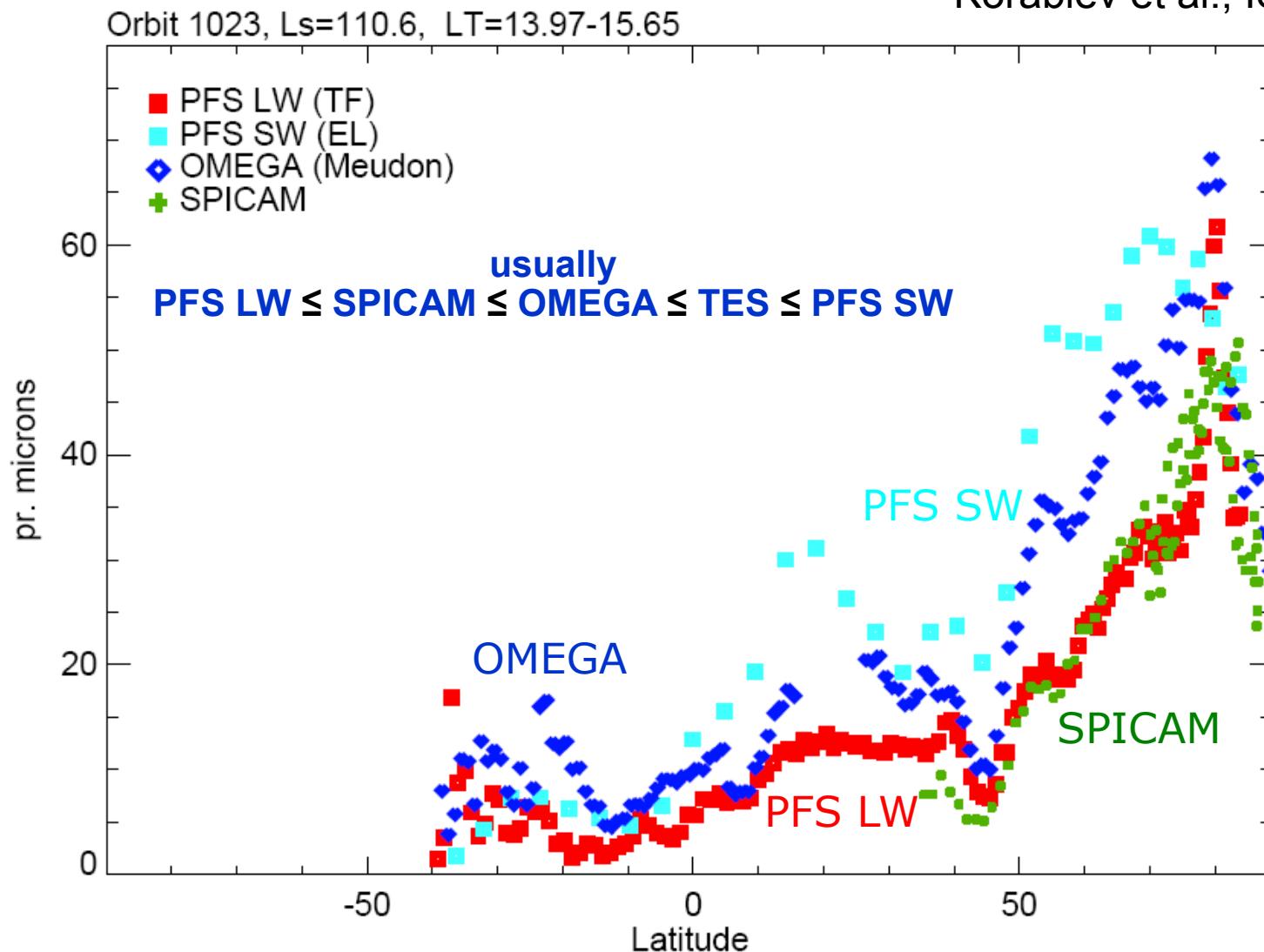


Water vapor

Water vapor column mapping (NIR)	SPICAM	Complete dataset available and to be published in the near future following Fedorova et al. (2006)
Water vapor column mapping (NIR)	PFS SW	MY27-MY29 climatology published in Sindoni et al. (2011) (see also Tschimmel et al., 2008)
Water vapor column mapping (TIR)	PFS LW	MY27 climatology published by Fouchet et al. (2007). <i>MY28-31 remains to be properly published ?</i>
Water vapor column mapping (NIR)	OMEGA	MY27 climatology published in Maltagliati (2011) following specific studies by Melchiorri et al. (2007, 2009), Maltagliati et al. (2008) Encrenaz et al. (2005)
Water vapor climatology combining several wavelength	PFS, SPICAM, OMEGA	A new study is led by F. Montmessin (LATMOS) within the UPWARDS project.
Water vapor profile using solar occultation NIR	SPICAM	MY29 climatology published in Maltagliati et al. (2011, 2013) following Fedorova et al. (2009)
Vertical profiles of H ₂ O from PFS and OMEGA limb observations	PFS OMEGA	A new study is planned at INAF (Italy) within the UPWARDS project.
HDO/H ₂ O measurements in Nadir	PFS	Revised paper submitted (Aoki et al., Icarus)

On the difficulty of measuring water vapor : comparison of Mars Express H₂O measurements

Korablev et al., ISSI group



Chemical species and ions

Ozone Column climatology (UV)	SPICAM	MY27 climatology published in Perrier et al. (2006). Full climatology to be published by Lefevre et al. in the near future. A revised study planned at IASB (Belgium) within the UPWARDS project.
Ozone profile by UV stellar occultation	SPICAM	MY 27 profiles published in Lebonnois et al. (2006) See also Montmessin and Lefevre (2013). <i>MY28-31 data remains to be properly published.</i>
O2 fluorescence at 1.27 μm Nadir Climatology	OMEGA	MY27-MY28 Climatology described in Altieri et al. (2009). Waves patterns described in Altieri et al. (2012)
O2 fluorescence at 1.27 μm Nadir Climatology	SPICAM	MY27 climatology published in Fedorova (2006)
O2 nightglow at 1.27 μm: profiles	OMEGA	Dataset published in Bertaux et al. (2012)
O2 daiglow at 1.27 μm: profiles	SPICAM	MY27-MY31 published in Guslyakova et al. (2014)
O2 profiles in UV stellar occultation	SPICAM UV	6 occultations processed and published by Sandel et al. (2015). <i>More could be done ?</i>
CO2, CO fluorescence profiles (NIR)	PFS	MY27 observations reported in Formisano et al. (2006), Lopez-Valverde et al. (2005). recent works has been reported in conferences and more is planned within the UPWARDS project.
CO2, CO fluorescence profiles (NIR)	OMEGA	<i>An impressive dataset is available, but not yet well published.</i> A study is in preparation by A. Piccialli (TBC). A more complete analysis is planned within the UPWARDS project.
Nitric oxide (NO) UV nightglow measurements	SPICAM	MY27-MY30 climatology published in Gagné et al. (2013), following Bertaux et al. (2005)
CO NIR mapping	PFS, OMEGA	Several studies published (e.g. Encrenaz 2006, Billebaud 2009, Sindoni et al., 2011) . A new study combining OMEGA and PFS data is led by A.C. Vandaele at IASB within the UWARDS project. A full dataset of PFS-retrieved CO climatology is on preparation.
CO profile	PFS OMEGA	A tentative retrieval of CO profiles is planned within the UPWARDS project.
Methane mapping	PFS	Formisano (2004) Geminale et al. (2008, 2011)
Hydrogen peroxide (H ₂ O ₂)	PFS	Search for H ₂ O ₂ reported in Aoki et al. (2015)
Electronic density Profiles by radio occultation	MaRS	Dataset described in Kerstin et al. (2014) Withers et al. (2012) Pätzold (2005). A MY27-MY31 dataset of profiles has been independently published by a Chinese team (Zhang et al. 2015)
Electronic density mapping by radar	MARSIS	Numerous publications by the MARSIS team and others

*Fluorescence by OMEGA limb
Gondet et al. 2011*

Ls=185
330E 60N

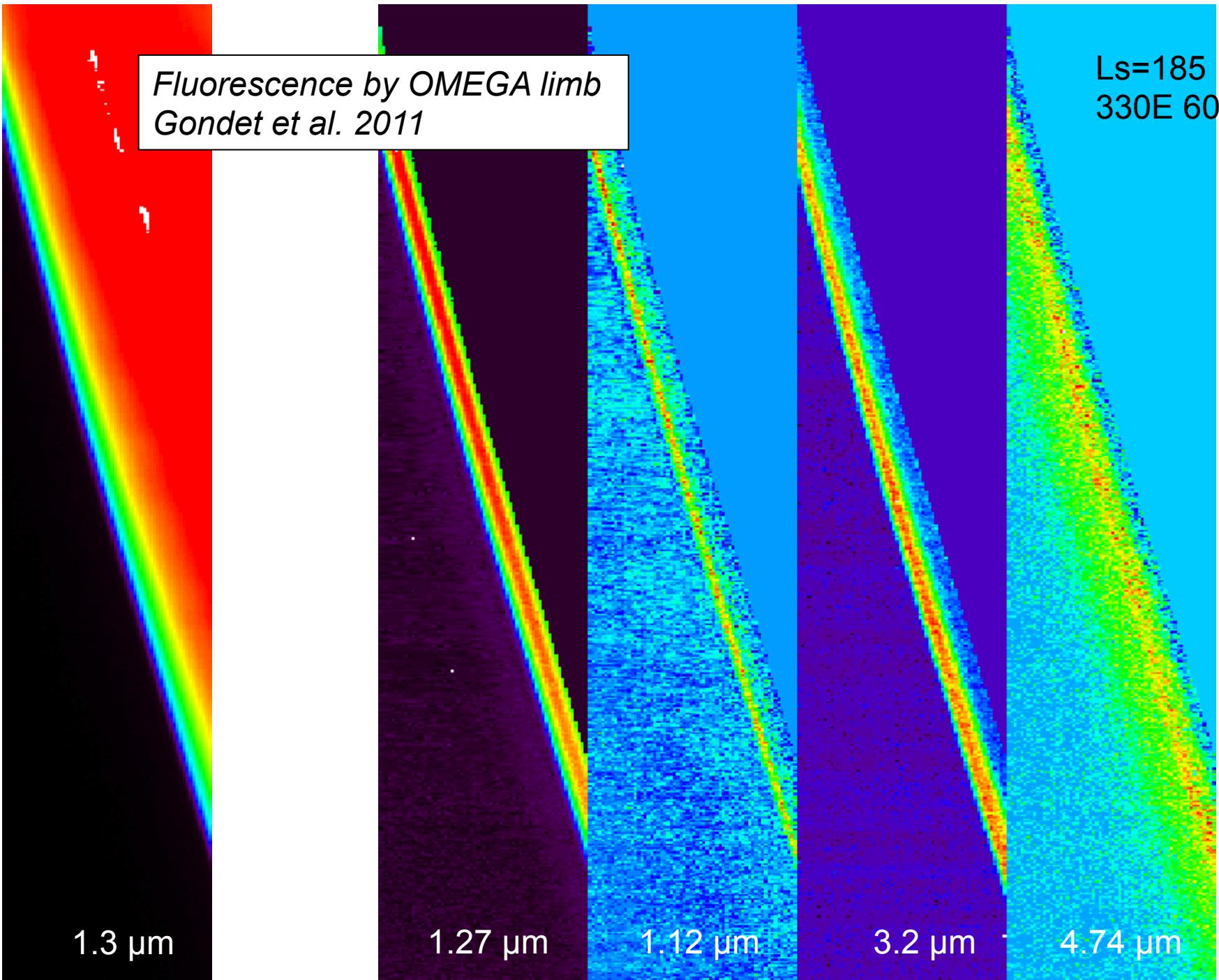
1.3 μm

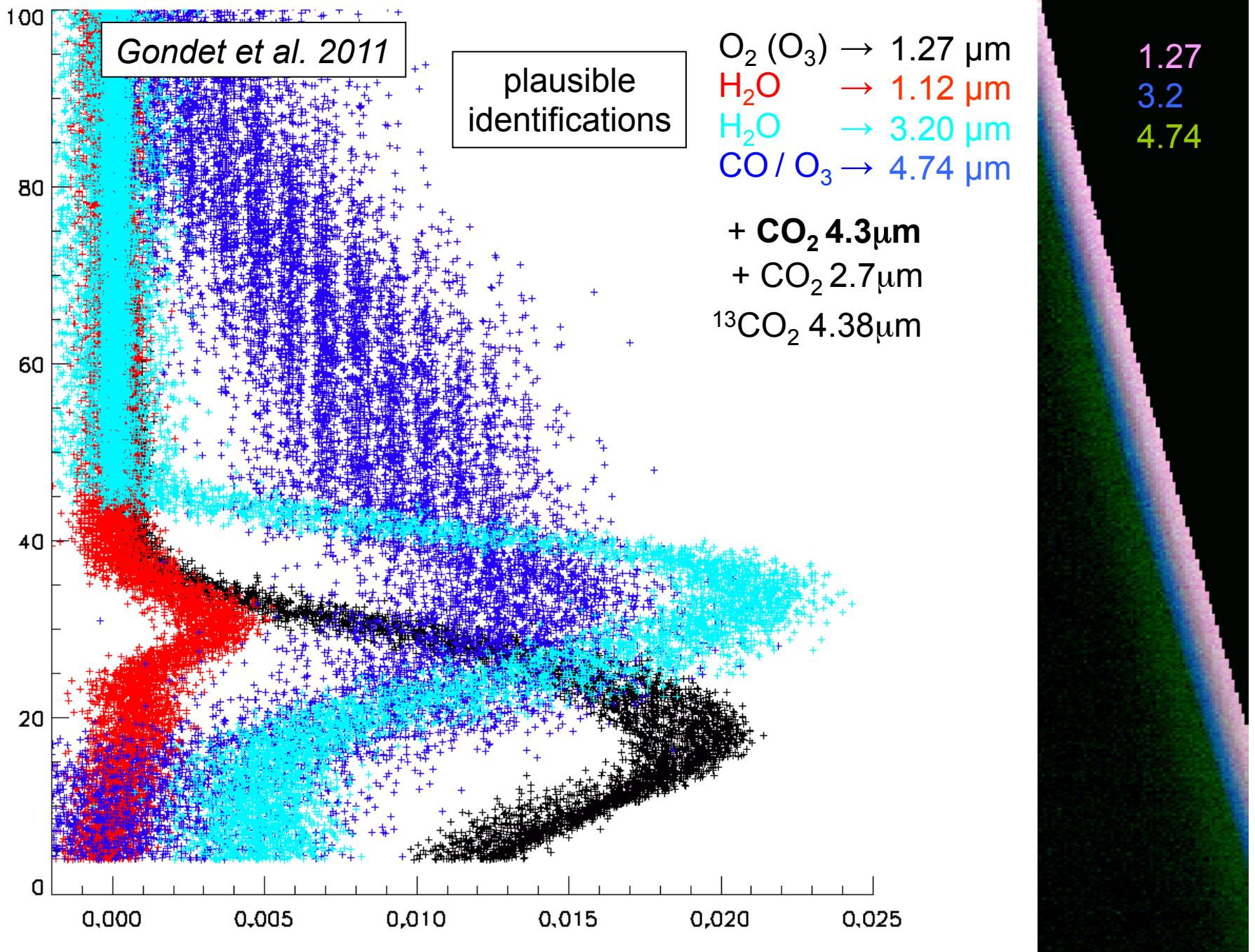
1.27 μm

1.12 μm

3.2 μm

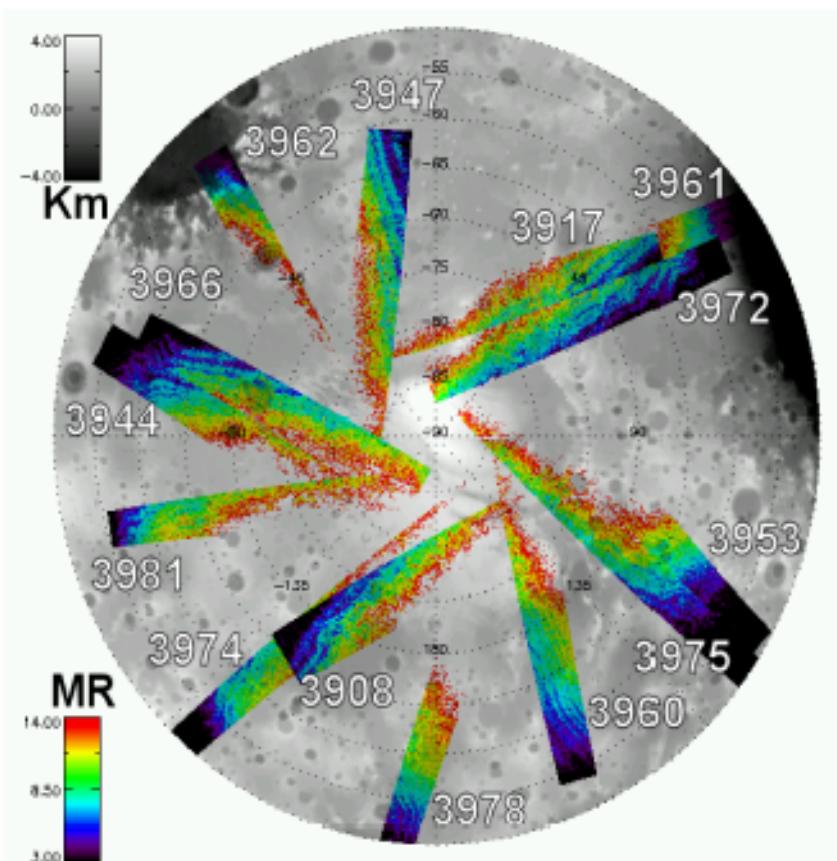
4.74 μm



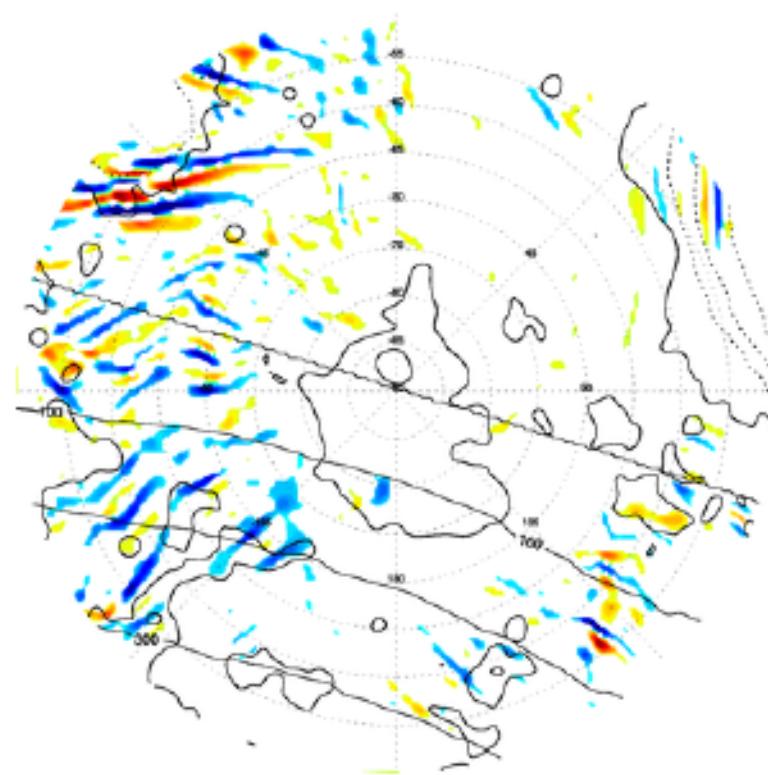


Mapping of gravity waves by O₂ airglow

OMEGA airglow observations



Mesoscale polar modeling



[Altieri et al. JGR 2012]

- Thank you