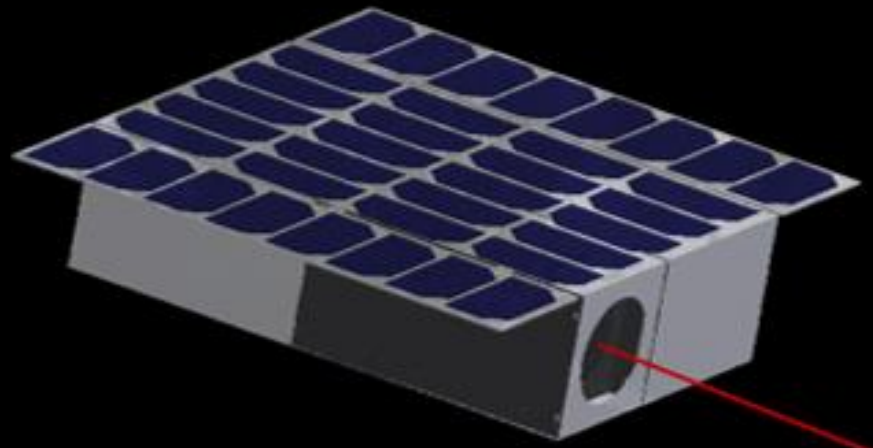
A Small Satellite Payload for Airglow Measurements in the Upper Atmosphere by Spatial Heterodyne Interferometry



Friedhelm Olschewski, University of Wuppertal
Martin Kaufmann, Research Center Juelich
Klaus Mantel, Max Planck Institute for the Science of Light
Tom Neubert, Research Center Juelich
Heinz Rongen, Research Center Juelich
Martin Riese, Research Center Juelich
Ralf Koppmann, University of Wuppertal

Small Satellite Conference
USU, Logan, Utah, USA
August 3-8, 2019

BERGISCHE UNIVERSITÄT WUPPERTAL

Institut für Atmosphären- und Umweltforschung

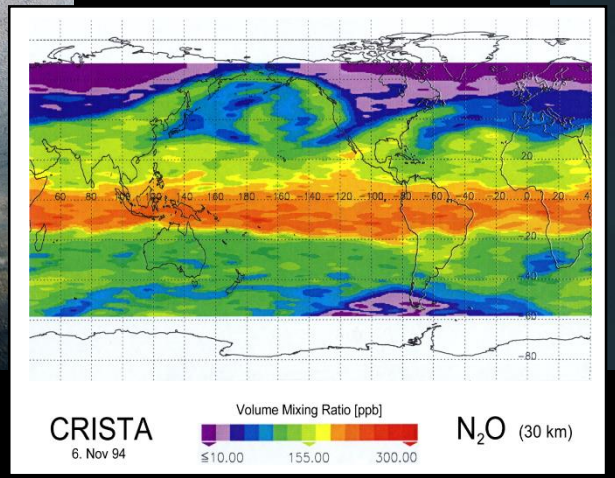
Atmospheric Physics in Wuppertal since 1976

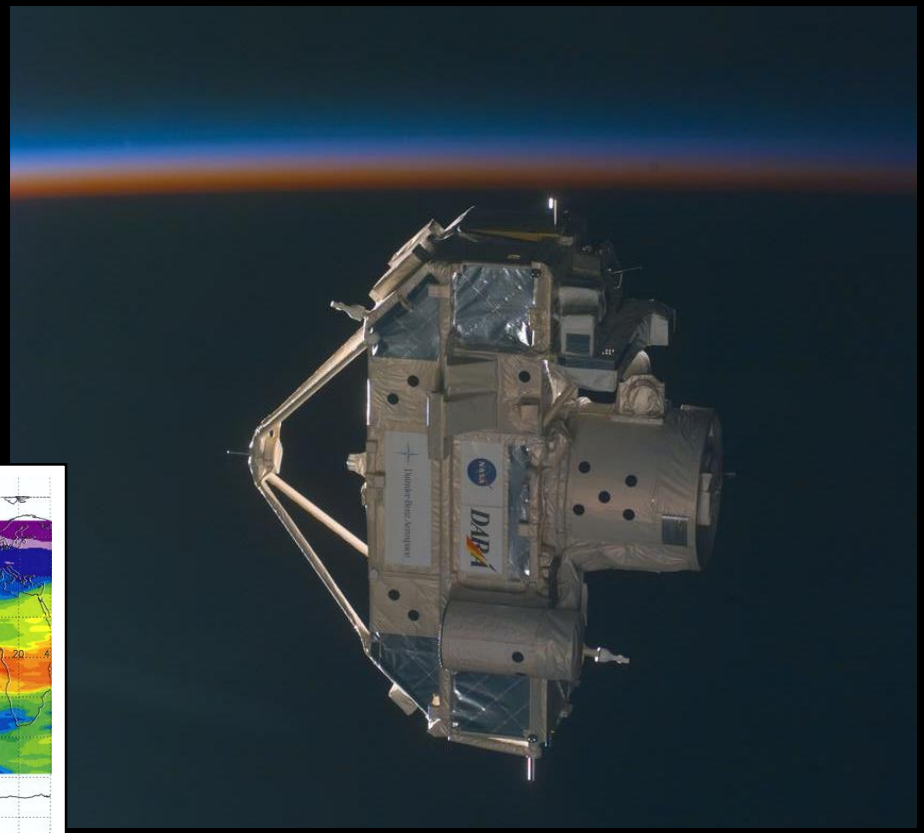
BERGISCHE UNIVERSITÄT WUPPERTAL

Institut für Atmosphären- und Umweltforschung

CRISTA – Cryogenic Infrared Telescopes and Spectrometers for the Atmosphere

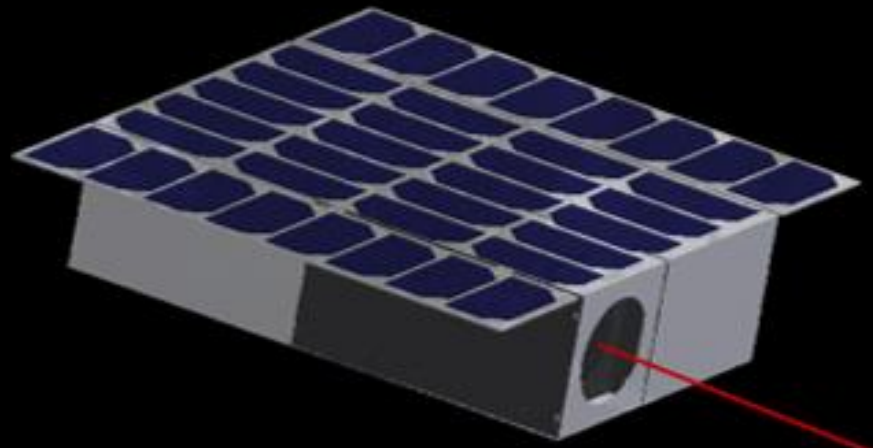
STS 66, Nov 1994





STS 85, Aug 1997

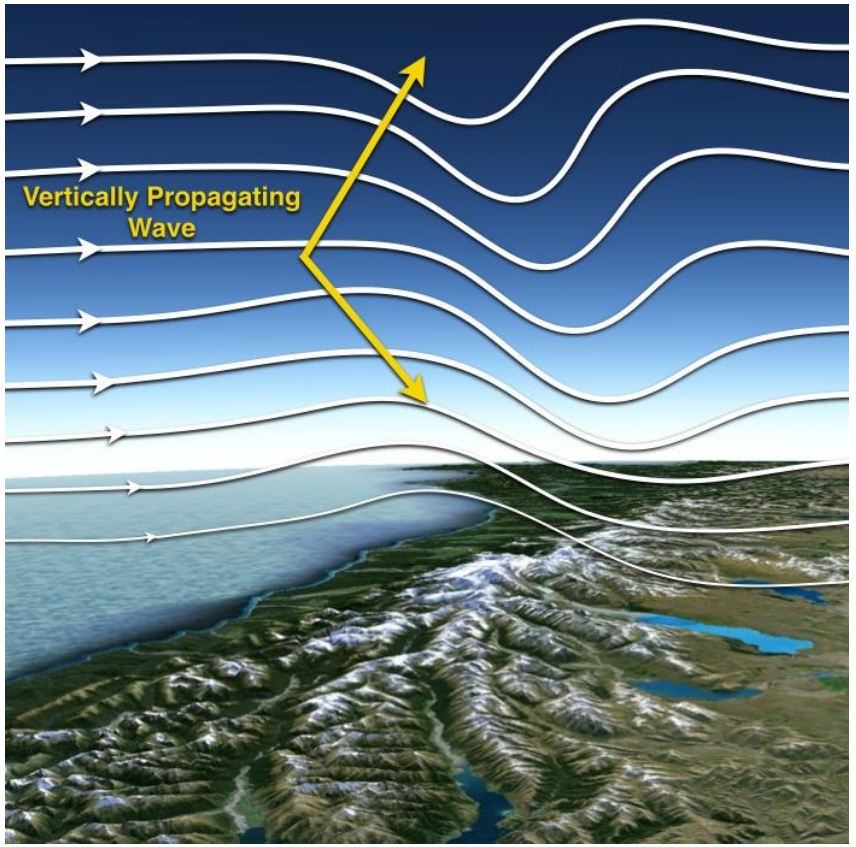
AtmoCube A1



Objectives:

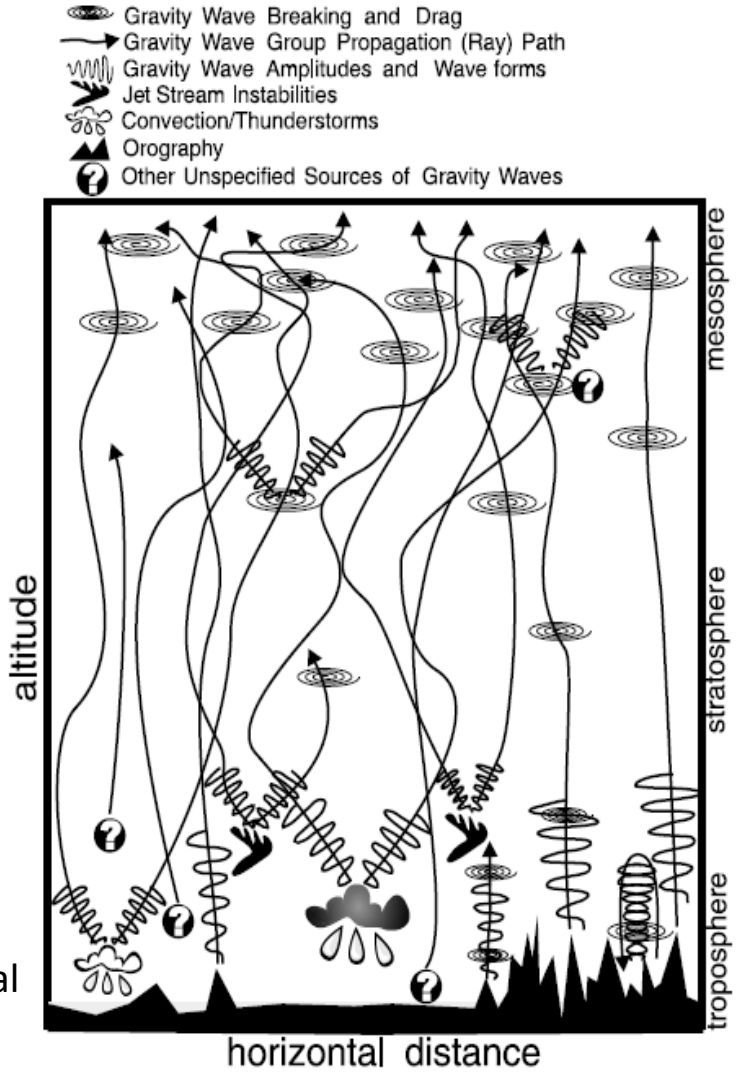
- Analyse dynamical wave structures in the upper atmosphere
- Measure temperature and gravity waves at high spatial resolution
- Gain high optical throughput in a small volume
- Design instrument with no movable parts (power + reliability)

Gravity Waves in the Atmosphere

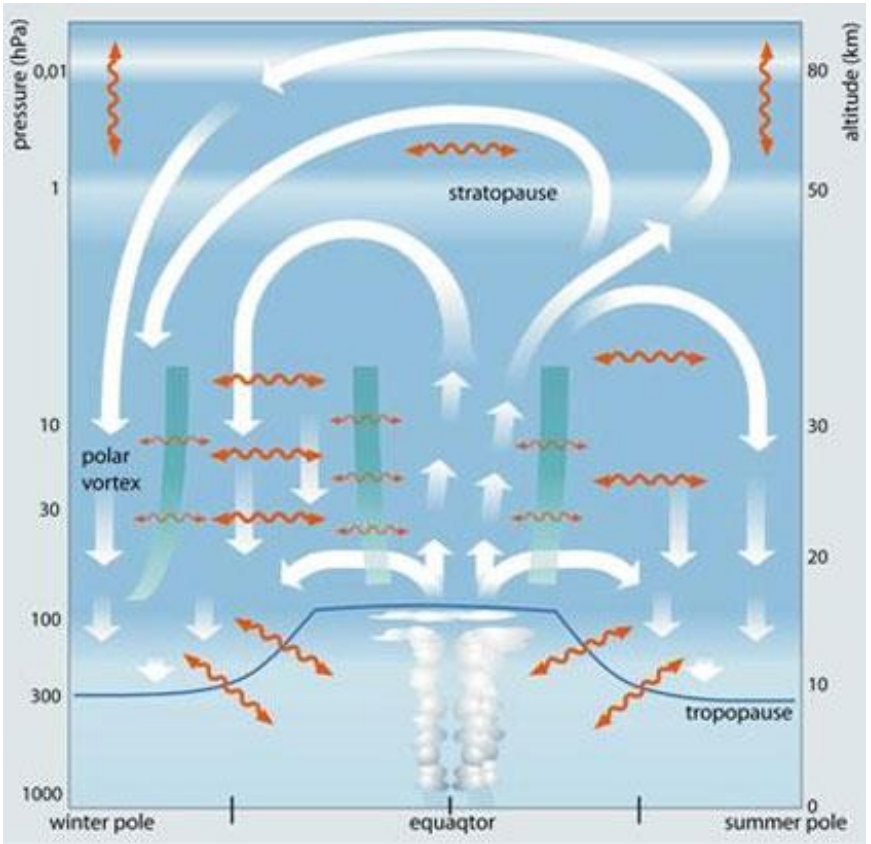


NCAR Earth Observing Laboratory

The wavelength is several kilometers in the vertical and tens to hundreds kilometers in the horizontal



Kim et al., 2003

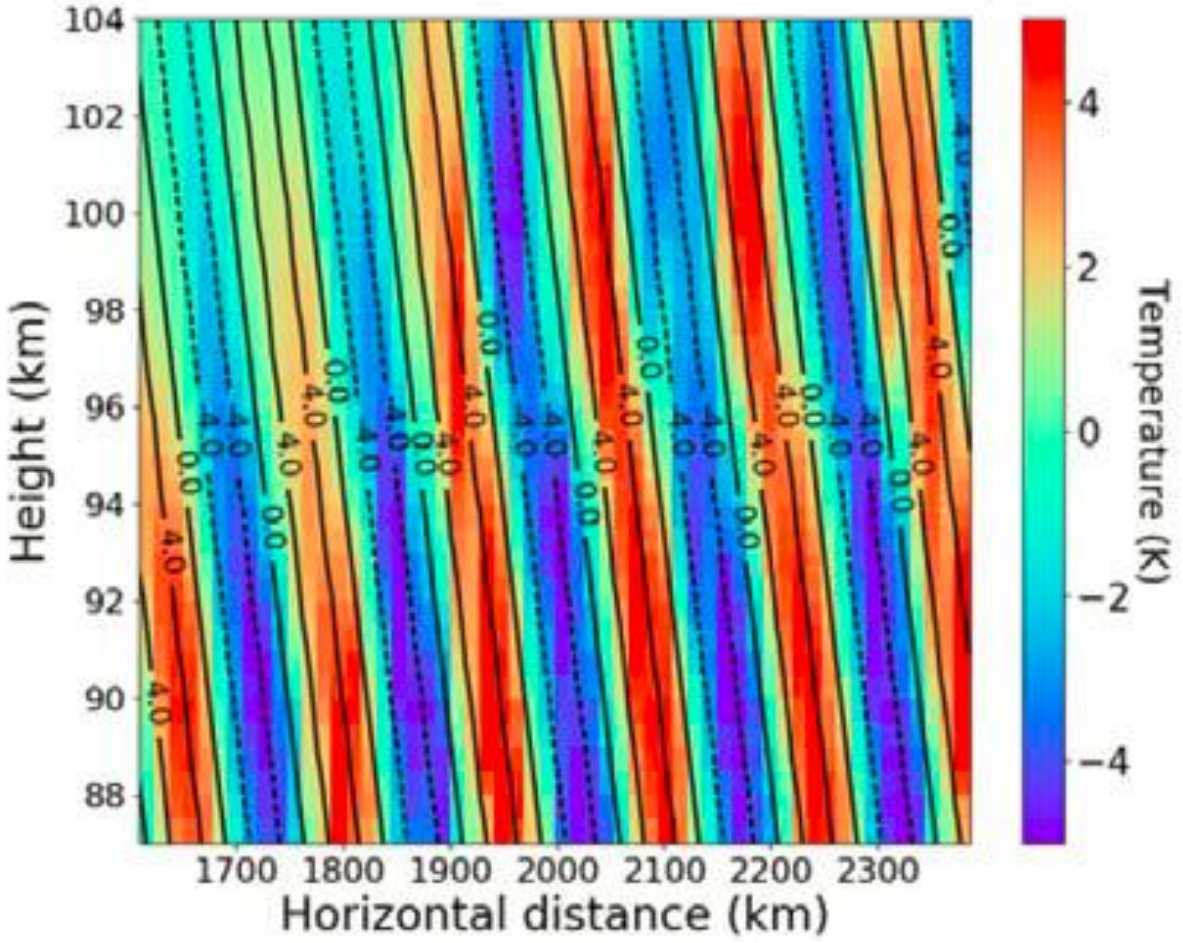


iau.uni-frankfurt.de

Gravity Waves seen in Noctilucent Clouds @ 80 km

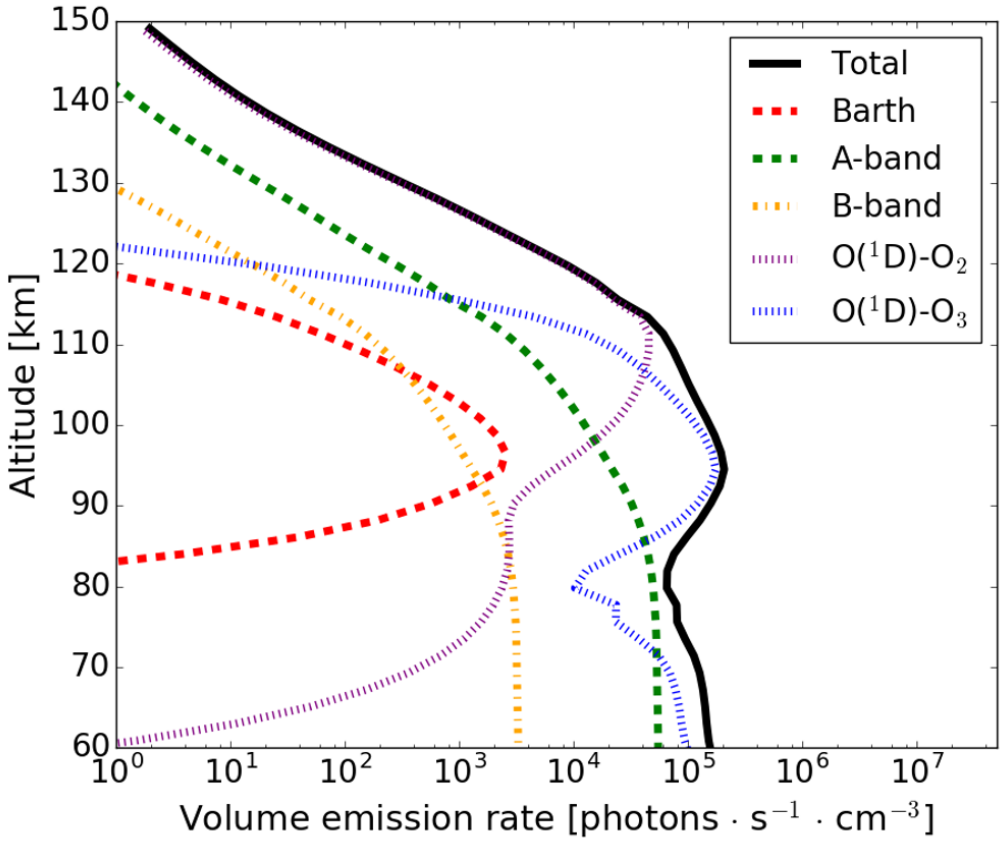
The spatial, temporal and spectral distribution of gravity waves is still one of the biggest challenges in climate research.

Gravity Waves detectable in temperature distribution

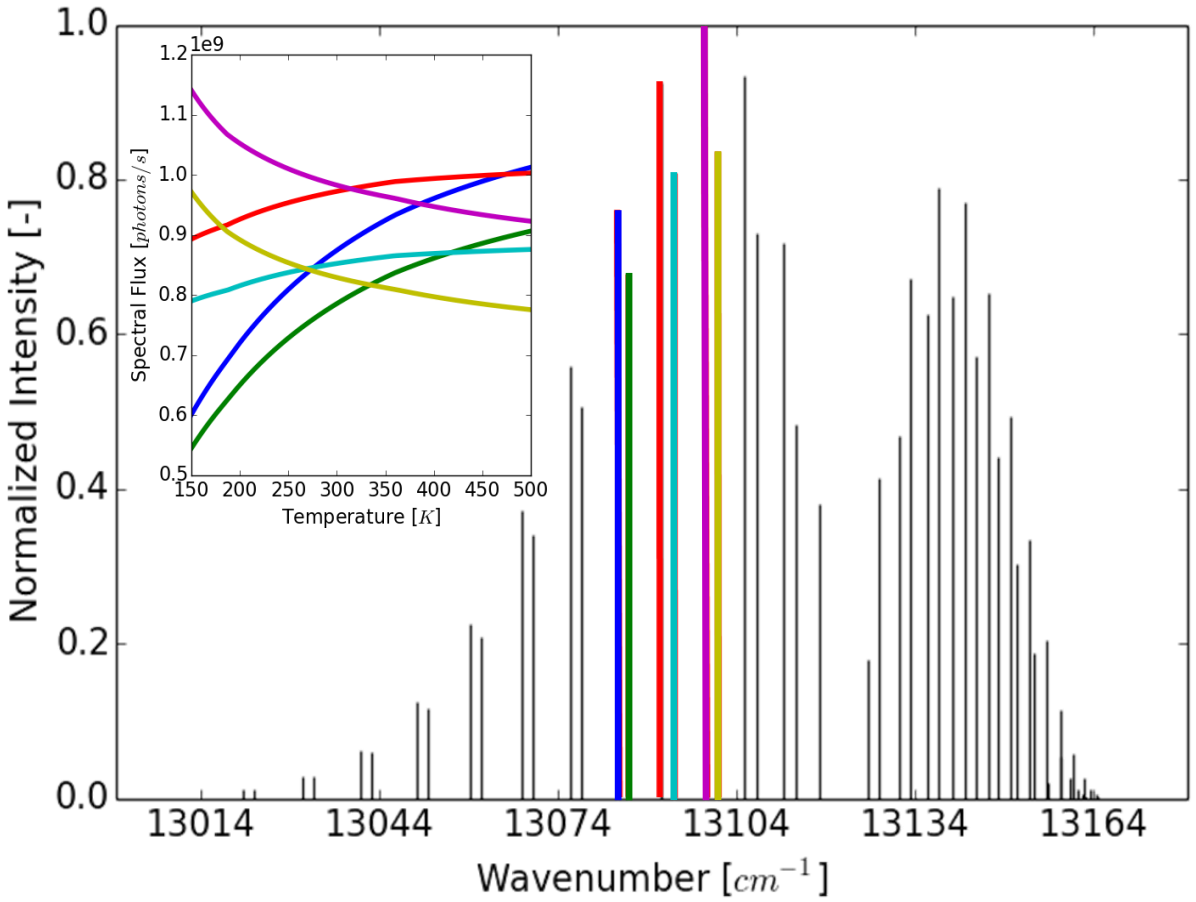


Simulation of a characteristic temperature distribution of a gravity wave

Oxygen A-Band Emission (Airglow)

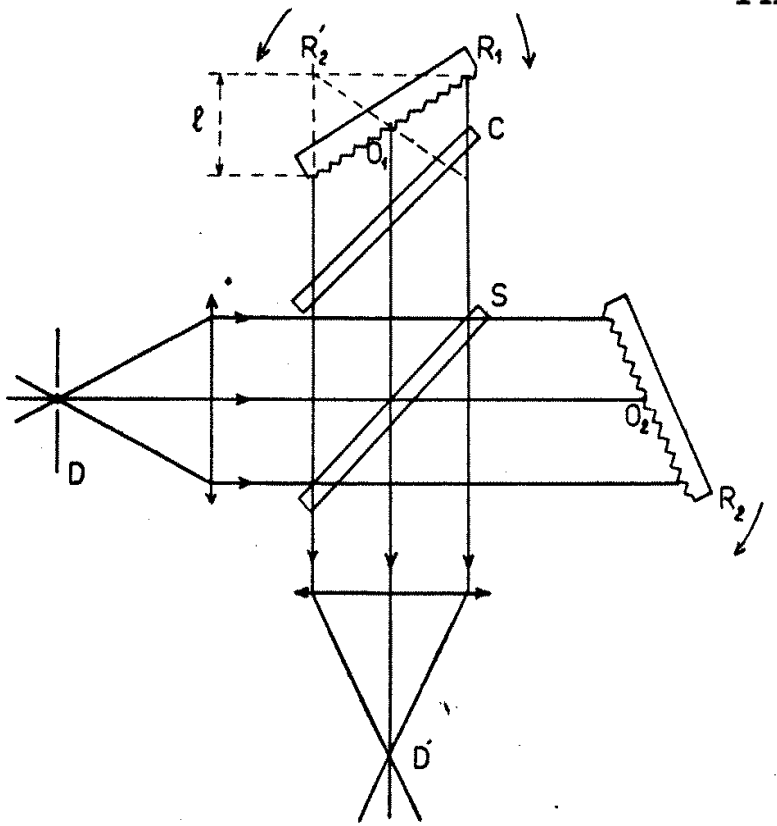


Vertical distribution of the O_2 A-band (762 nm) emissions



Temperature derivation from rotational structure of O_2 A-band

The Spatial Heterodyne Interferometer



J. Phys. Radium **19**, 215-222 (1958)
DOI: 10.1051/jphysrad:01958001903021500

SPECTROMÈTRE INTERFÉRENTIEL A SÉLECTION PAR L'AMPLITUDE DE MODULATION (1)

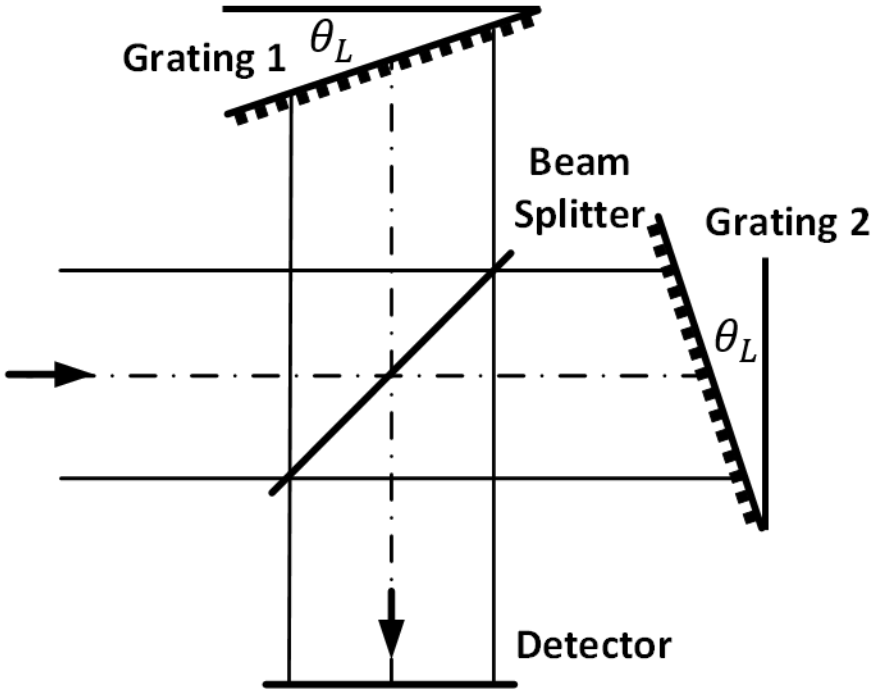
Par P. CONNES,
Laboratoire de Bellevue.

Advantages

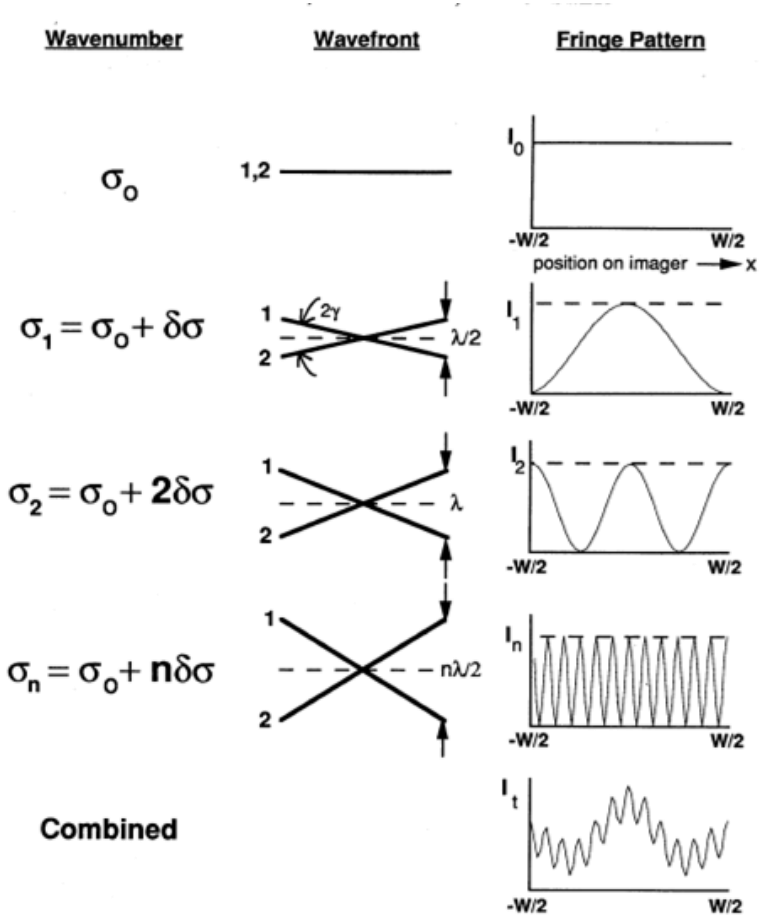
- No moveable parts
- Solid block of glass pieces
- Field-of-View can be widened
- High optical throughput
- Spectral and spatial dimension

AtmoCube A1 SHI prototype (38 mm x 38 mm x 27 mm)

The Spatial Heterodyne Interferometer



$Littrow\ Angle\ \theta_L$
$Littrow\ Wavenumber\ \sigma_L = \sigma_0$



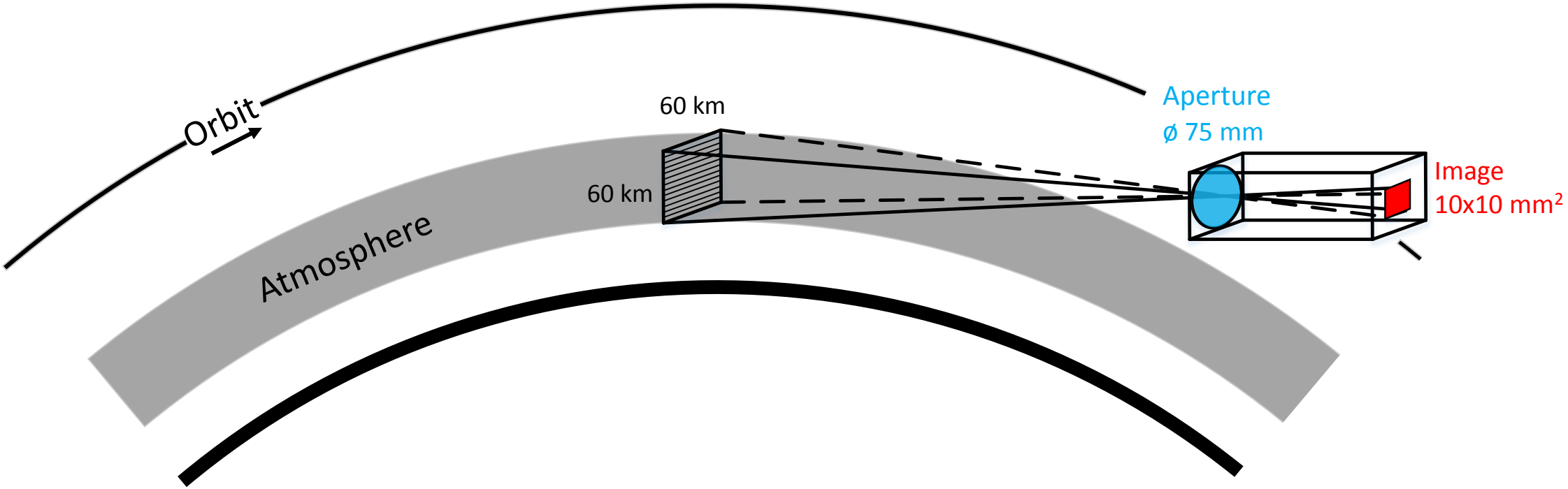
(Harlander, et. al., 1992)

$$\sigma_L = \frac{1}{2d \sin\theta_L}$$

$$v_F = 4\left(\frac{\left(\frac{m}{2d\sigma_L}\right)}{\sqrt{1-\left(\frac{m}{2d\sigma_L}\right)^2}}\right)(\sigma - \sigma_L)$$

$v_F = spatial\ frequency\ [cm^{-1}]$
$m = diffraction\ order$
$\sigma = emission\ wavenumber\ [cm^{-1}]$
$1/d = grating\ groove\ density\ [cm^{-1}]$

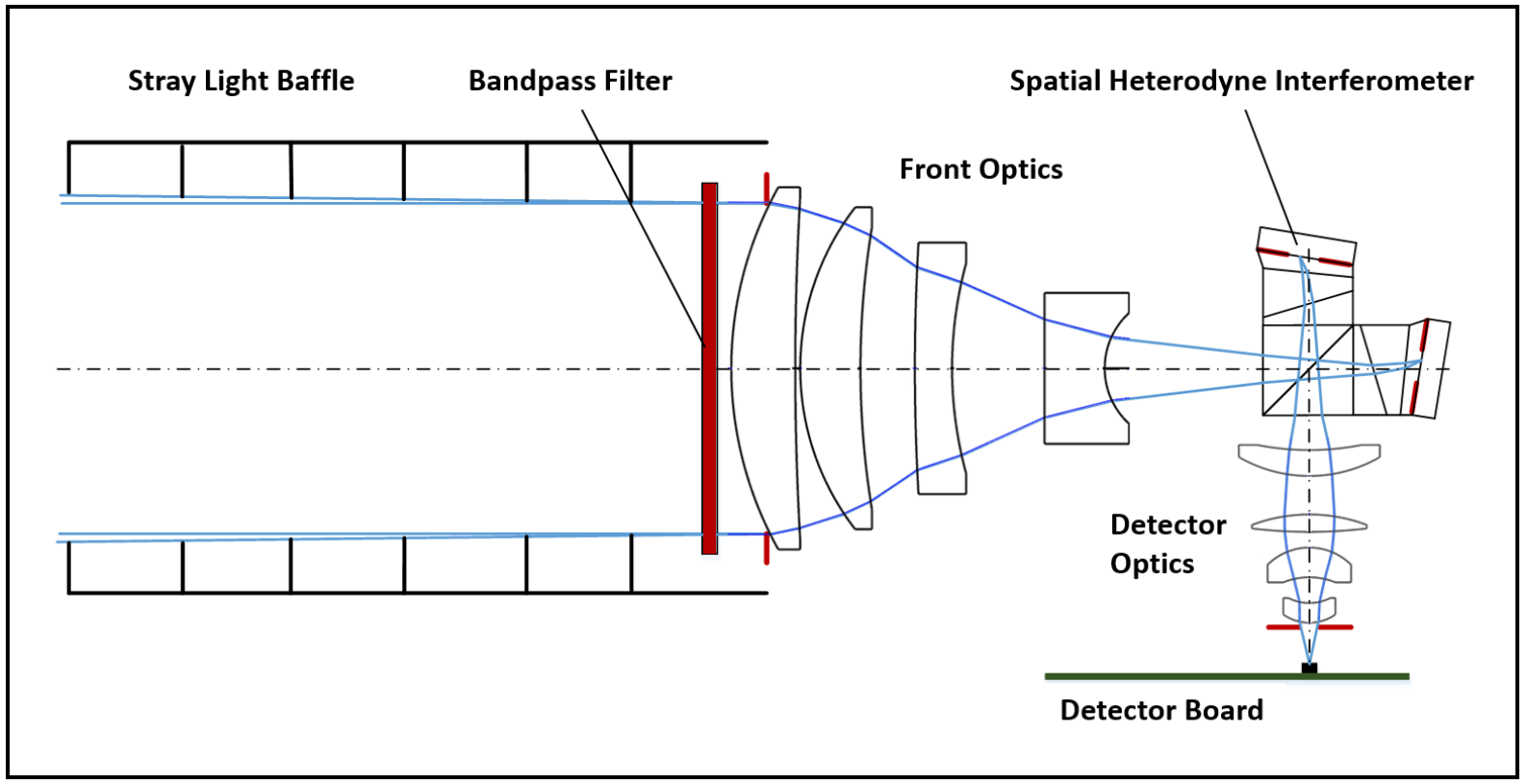
AtmoCube A1 Observation Concept

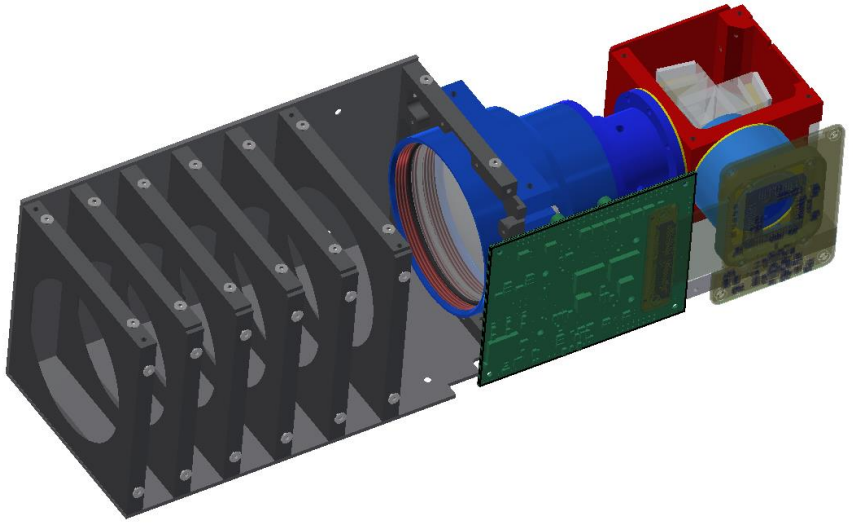


Satellite Orbit: 400 – 1200 km
Variable Observation Altitude Range: 60 – 150 km

Limb view of the AtmoCube A1 satellite requires a highly precise ADCS in the sub-arcmin range.

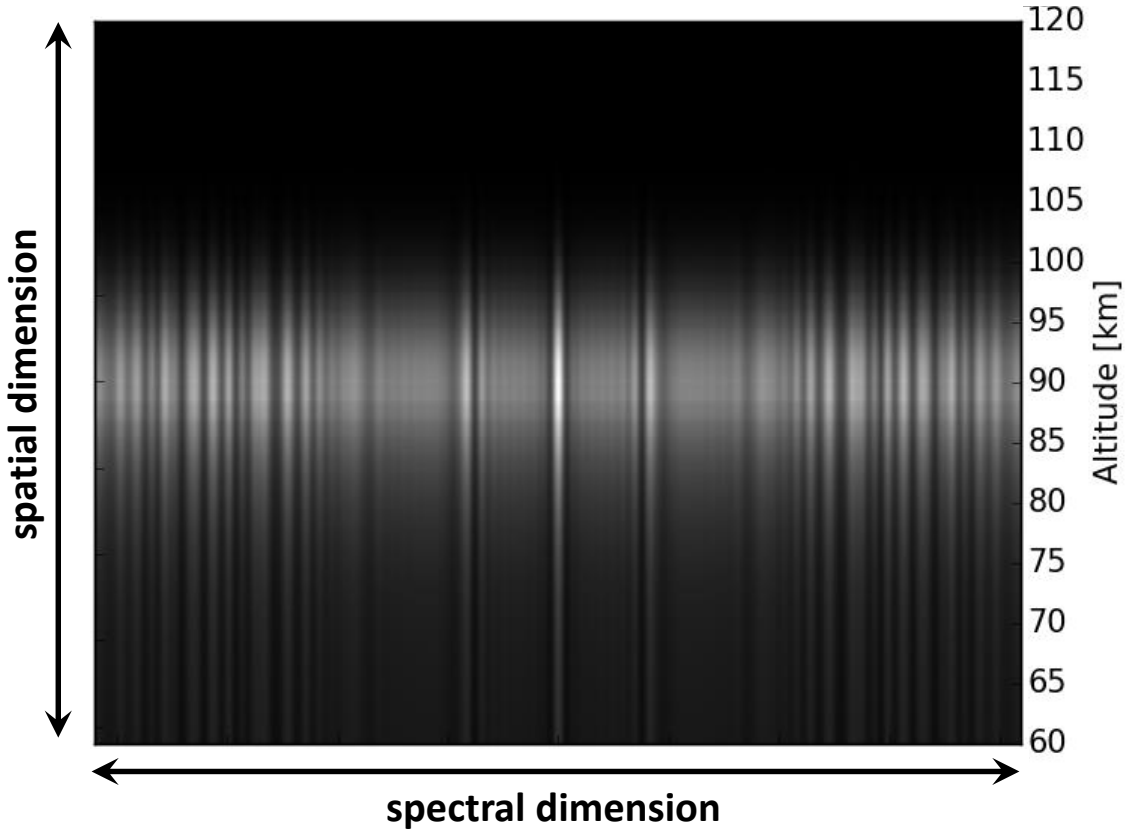
AtmoCube A1 Optical Design



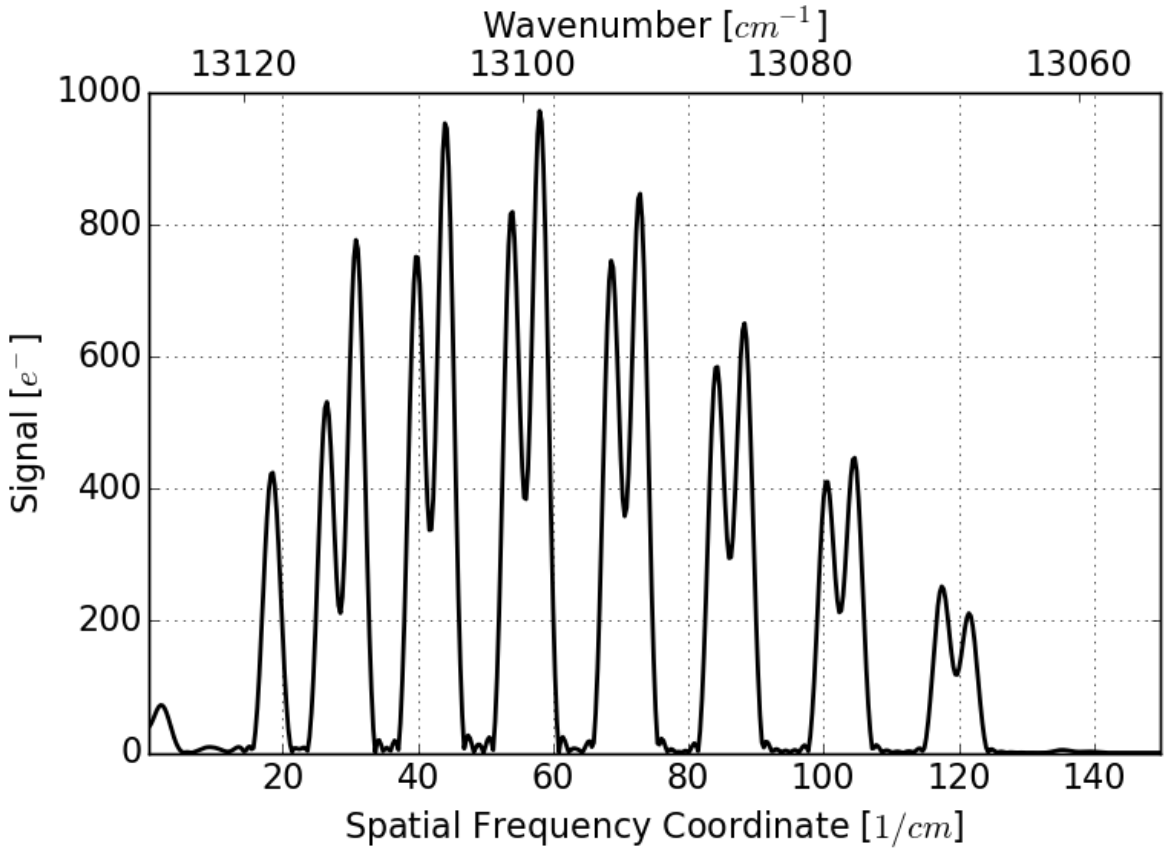


(see also Deiml, 2017)

Simulated SHI Image of the O_2 A-band Nighttime Emission

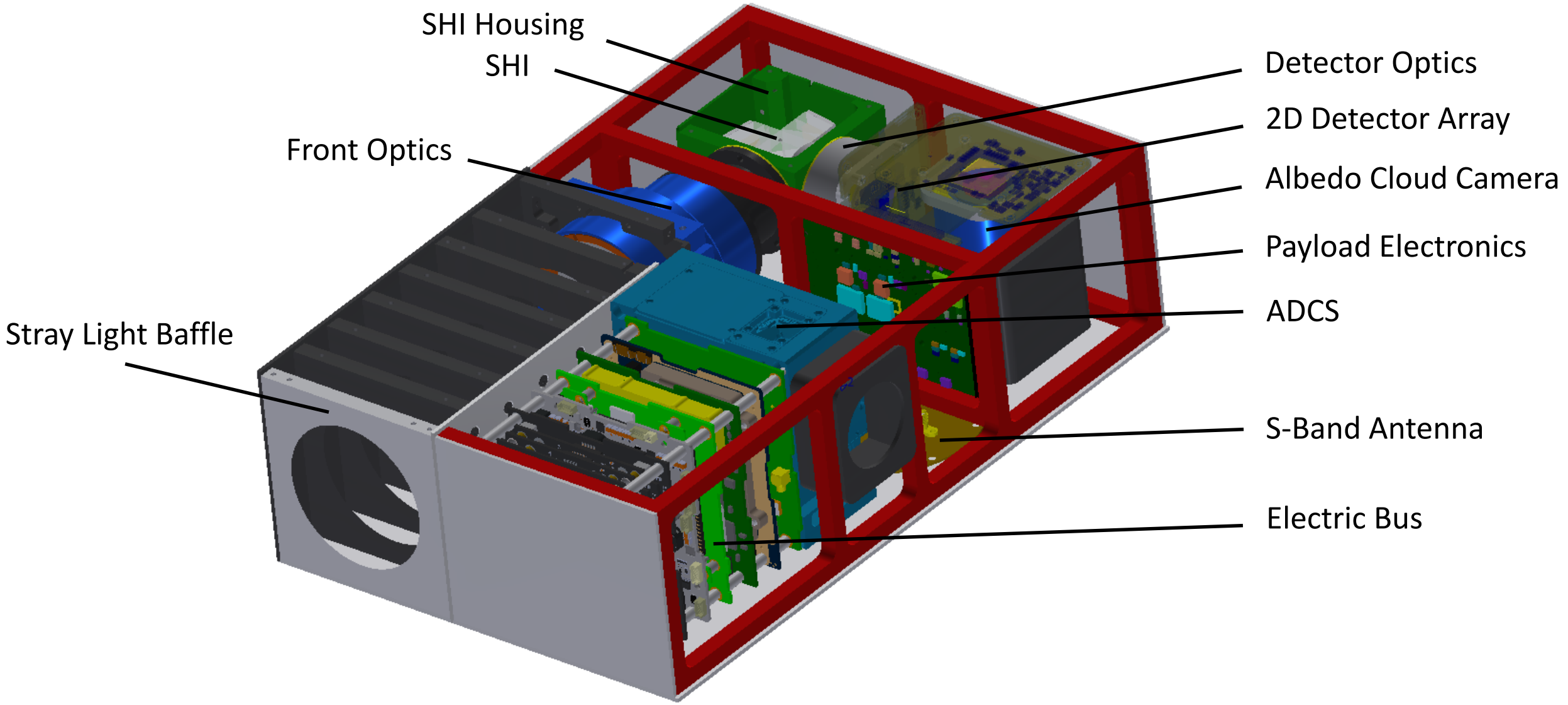


Detector image

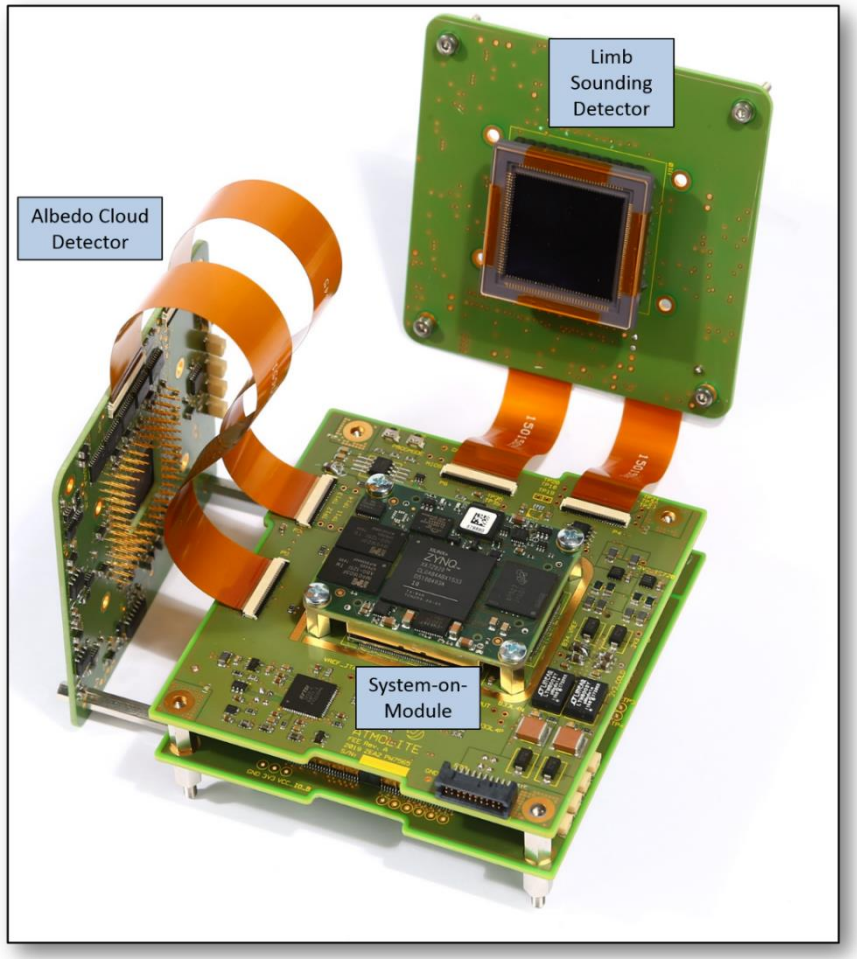


Spectrum of an idealized Fourier-transformed interferogram

AtmoCube A1 Satellite Design



AtmoCube A1 Payload Electronics



System-on-Module Architecture

- Processing system (PS): Dual-core ARM Cortex-A9 MPCore™, 667MHz
- Programmable logic (PL): Artix-7 FPGA:4.9 MB BRAM, 220 DSP slices
- Up to 1 GByte DDR3 SDRAM memory
- 32 MByte Quad SPI Flash NAND memory

Limb Sounding Detector (GSENSE 400BSI)

- Image Area: 2048 x 2048 pixels
- Spectral range: 380 – 850nm (QE=0.5)
- Pixel size: 11.0µm x 11.0µm
- Readout noise 1.6e- (rms)
- Dark current: <0.2 e- /pixels @ -50°C

Albedo Cloud Detector (HWK 1910A)

- Image Area: 1920 x 1080 pixels
- Spectral range: 420 – 800nm (QE=0.3)
- Pixel size: 5.04µm x 5.04µm
- Readout noise 1e- (rms)
- Dark current: 2.5 e- /pixels @ 20°C

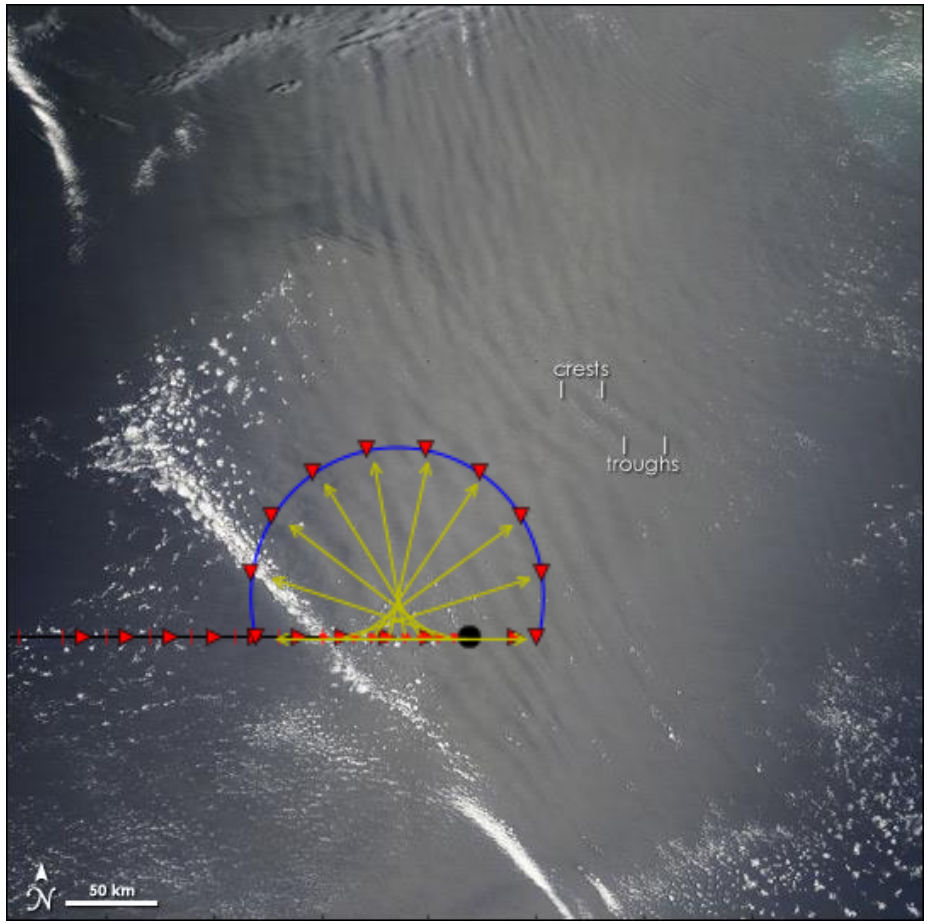
for details see poster @ Poster Session II: **SSC19-P2-27**
“Dual Imaging Readout Electronics for long-term Remote Sensing Measurements from CubeSats in Low-Earth-Orbits” (Tom Neubert et al.)

AtmoCube A1 Payload Specifications

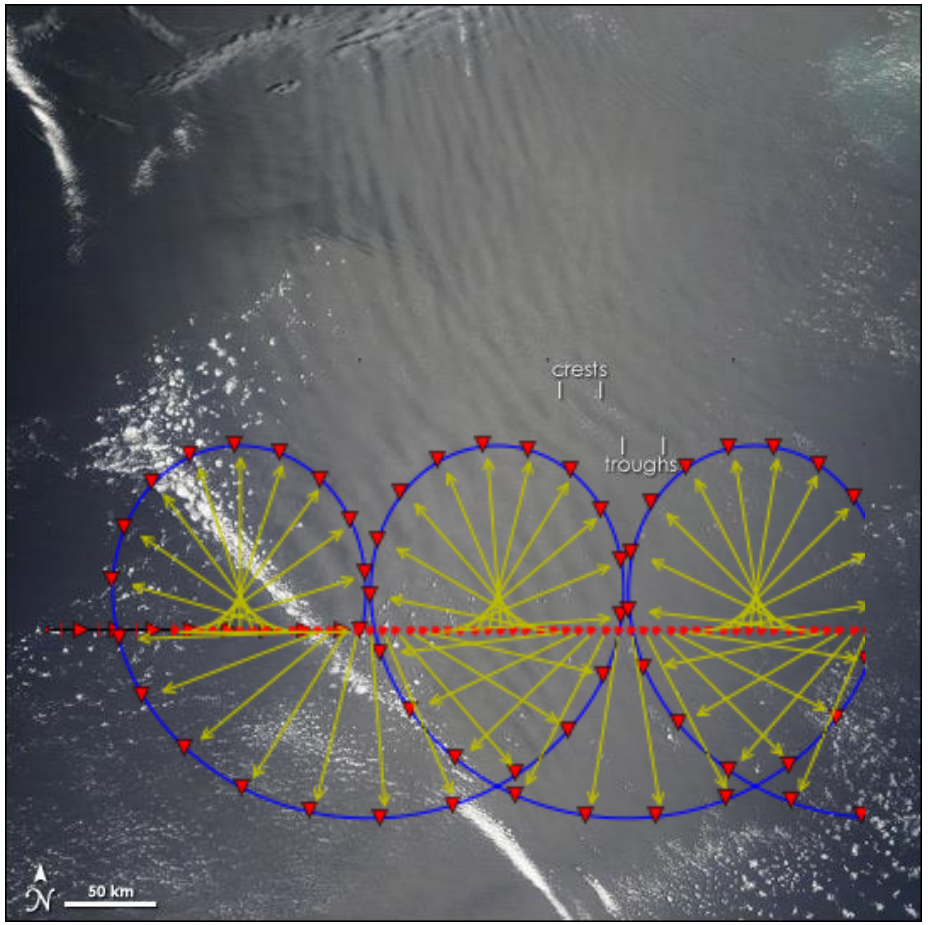
Optics		
	Aperture	Ø 75 mm
	Etendue (Throughput)	0.02 cm^2sr
	Atmospheric limb image	60 km x 60 km
	Variable altitude range	60 km – 150 km
	Altitude resolution	< 1.5 km
	Spectral range	761 – 765 nm
	Max. resolving power (λ/Δλ)	18 500 (9 000)
Limb Detector		
	Image sensor	CMOS FPA
	Number of used pixels	1000 x 1000
	Pixel pitch	11 µm
	Thermal control	deep space radiator
Instrument		
	Mass budget	< 3 kg
	Power consumption	< 8 W
	Data rate after binning	300 kbit/s
	Attitude control accuracy	0.003 deg (pitch)
	Operating Temperature	-40 °C to 50 °C

Preliminary AtmoCube A1 Operation Modes

Slew Mode



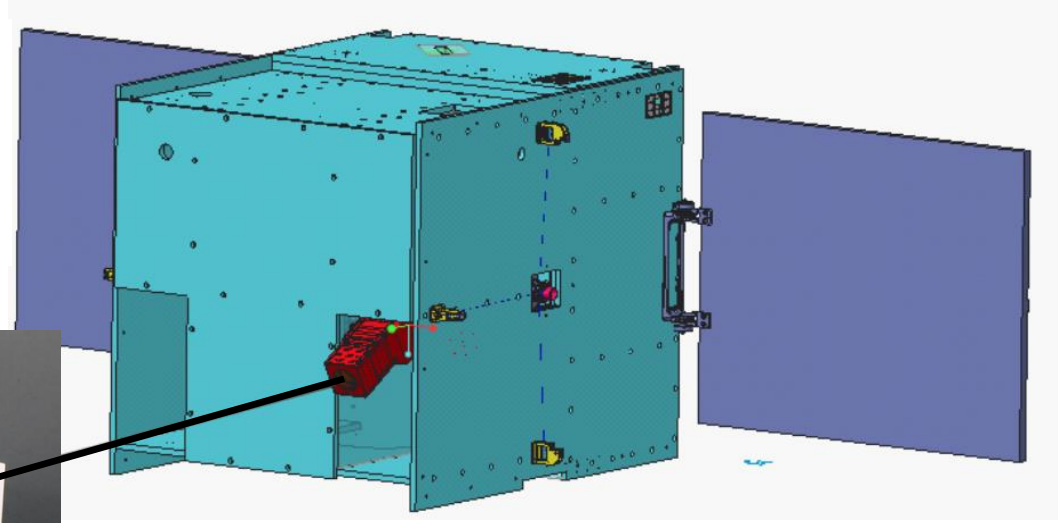
Spin Mode

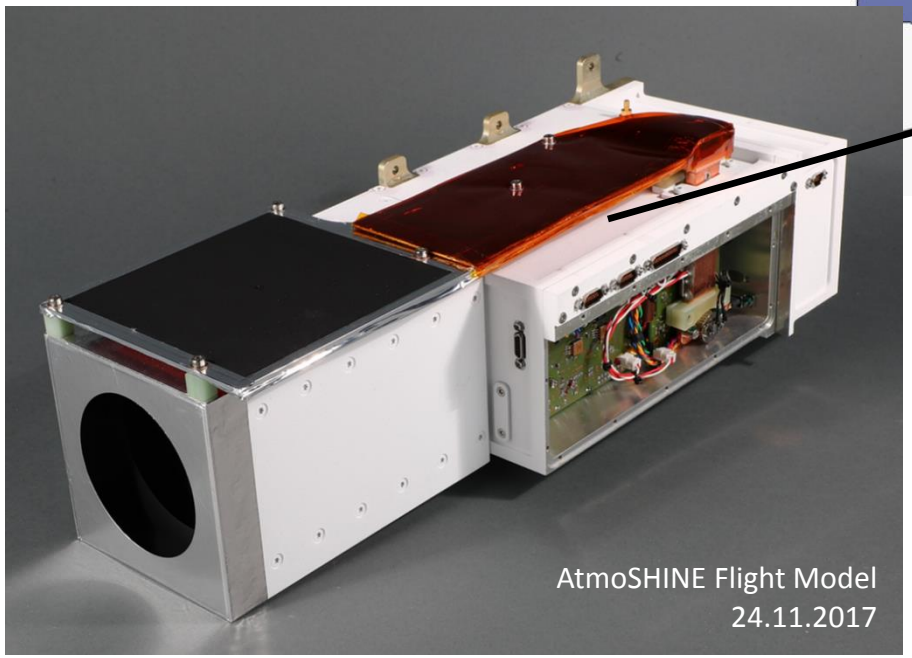


AtmoSHINE – Payload In-Orbit Verification Test

AtmoSHINE

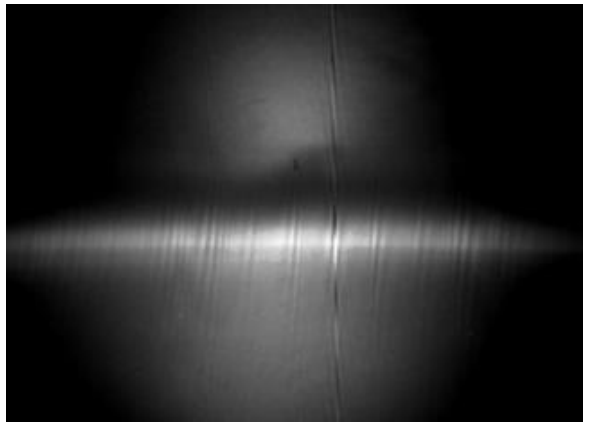
Atmospheric **S**patial **H**eterodyne **I**nterferometer **N**ext **E**xploration





AtmoSHINE Flight Model
24.11.2017

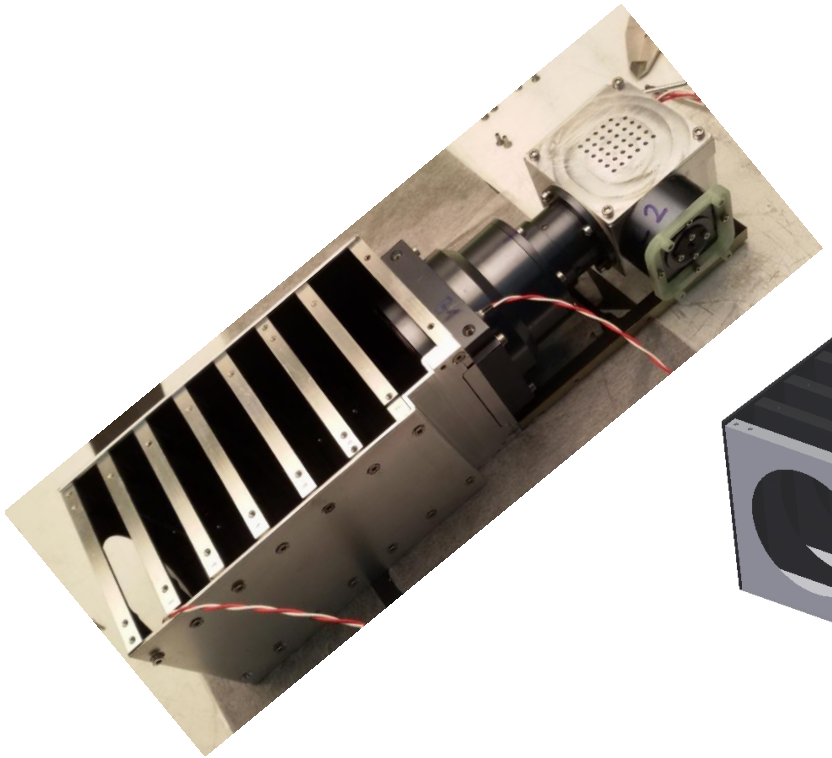
- launched on a Chinese satellite in a dust-dawn orbit on Dec 22, 2018.
- measures the global distribution of the oxygen A-band nightglow emissions.

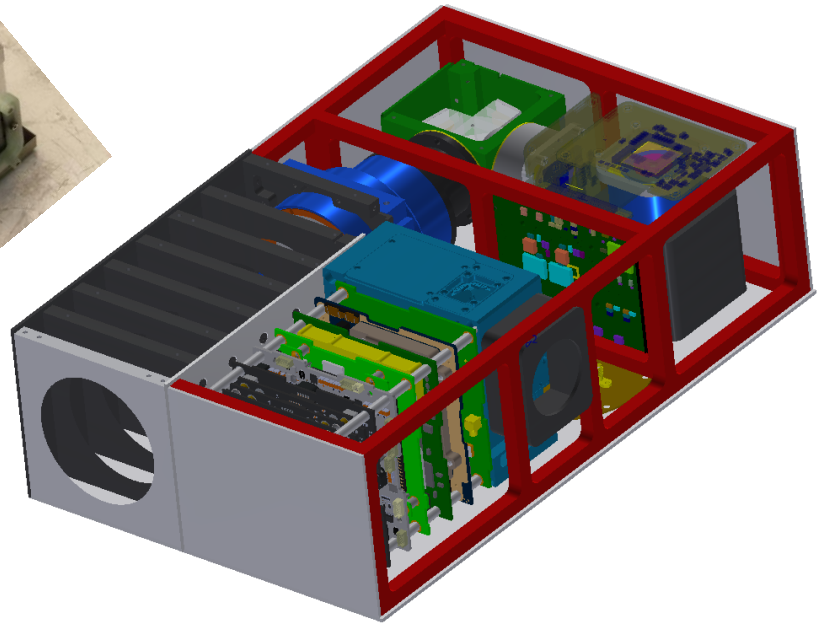


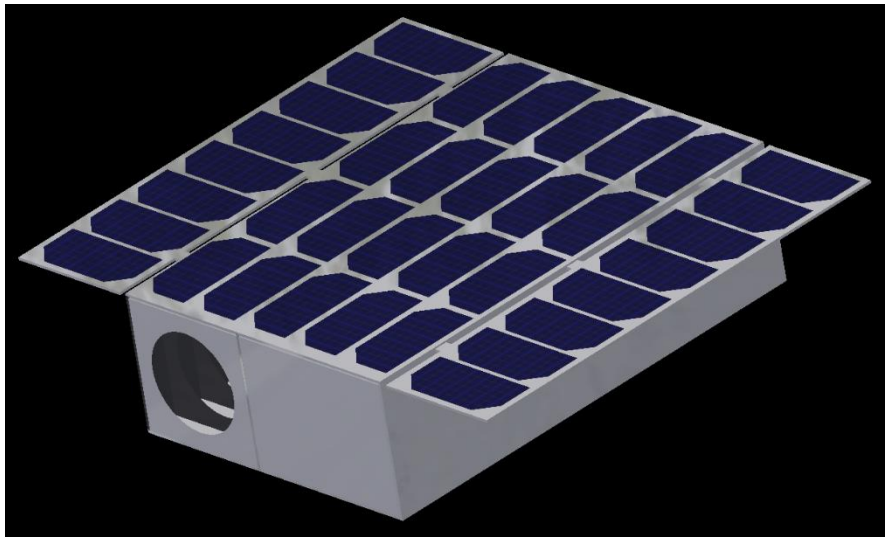
AtmoSHINE first light Dec 23, 2018

AtmoCube A1 next steps

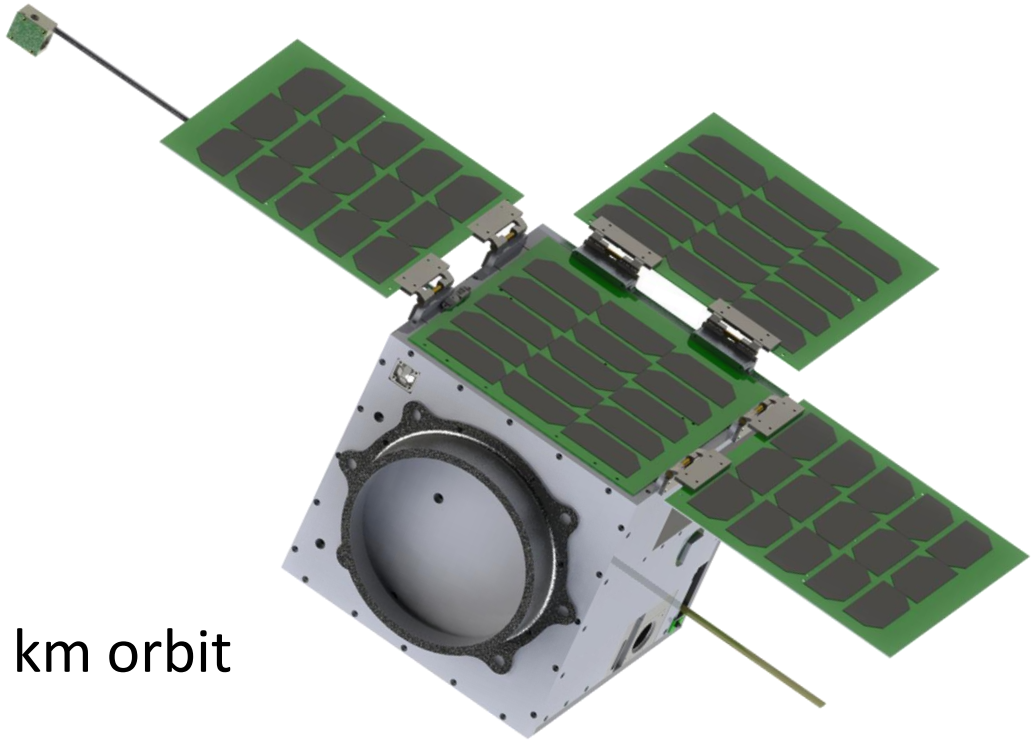
Payload is ready to fly!







AtmoLITE - Atmospheric Limb Interferometer for Temperature Exploration



AtmoLITE will be deployed on two INSPIRE missions

INSPIRESat-4*: Launch Nov. 2020, 5° inclined 535x450 km orbit

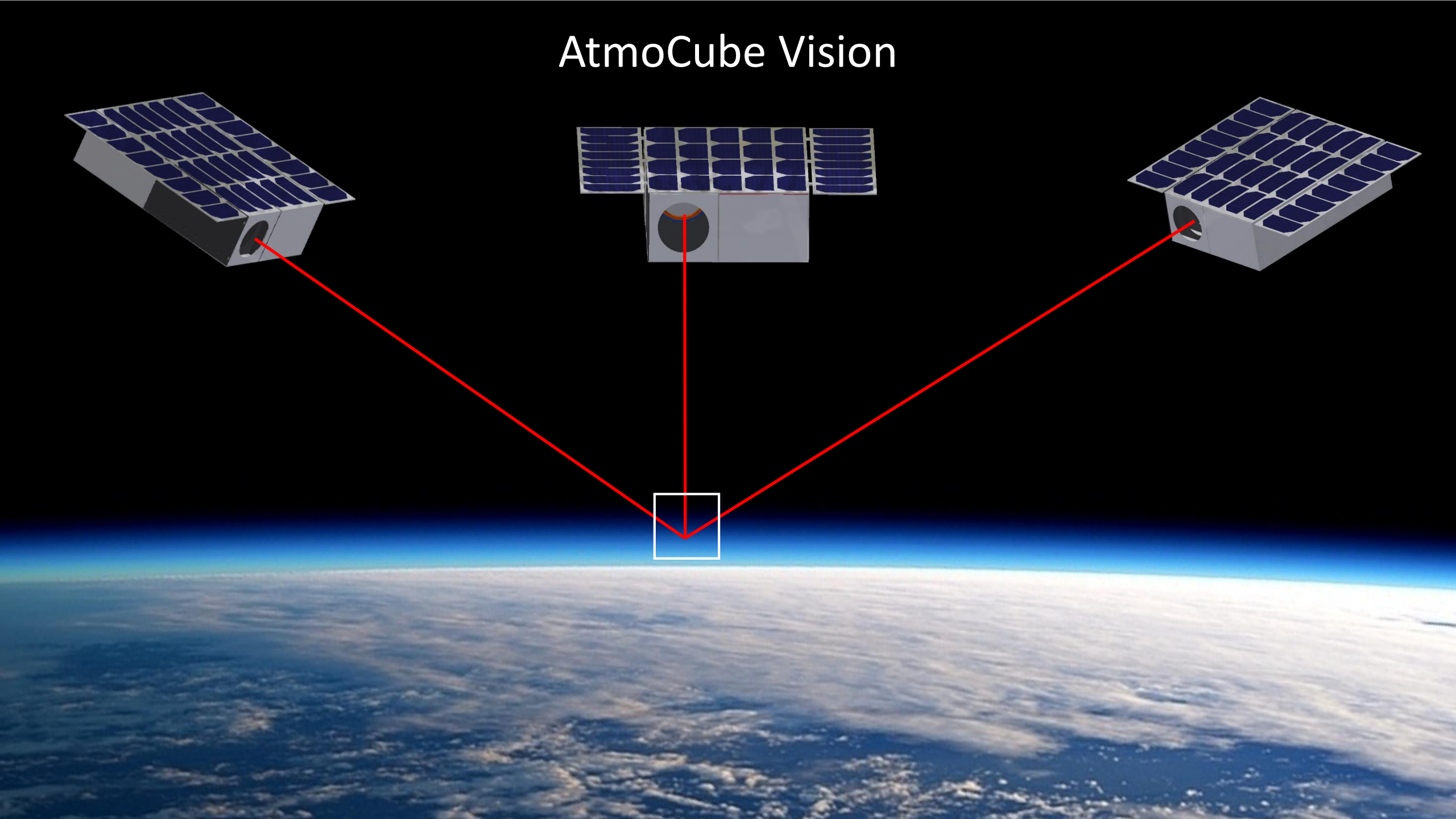
INSPIRESat-3: Launch Nov. 2021, SSO – Noon-Midnight (550-600 km)

*) Session V Next on the Pad @2:15 PM:
"A Very Low Altitude Satellite for Equatorial Ionosphere Measurements" (Amal Chandran et.al.)

Summary and Outlook

- Dynamical processes in the mesosphere and lower thermosphere (MLT) region are still an important research topic.
- A Spatial Heterodyne Interferometer has been developed to measure oxygen A-band emissions between 60 and 150 km altitude, globally.
- The payload is flying on a Chinese technology demonstration satellite for in orbit verification testing and will be deployed on INSPIRESat-4 and -3.
- The agility of a CubeSat shall be used to characterize dynamical structures in the MLT region by tomography.

AtmoCube Vision



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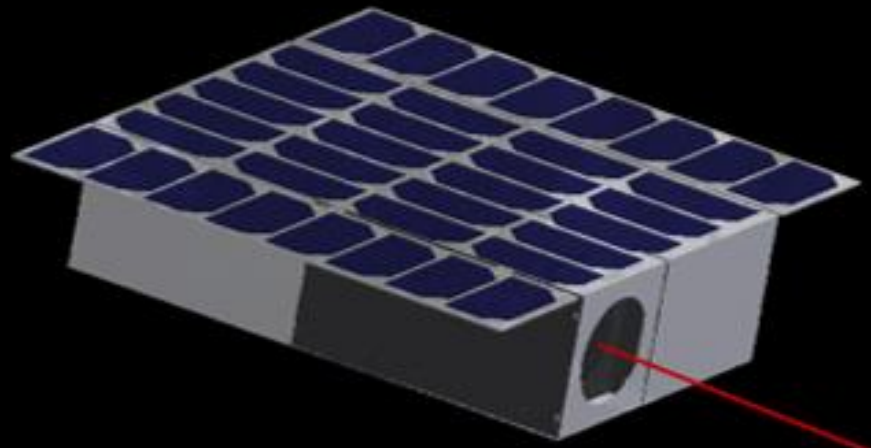

Thank you for your attention

S.D.G.