DLR

esa

living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

EUMETSAT ECMWF EUSPA

Keystone

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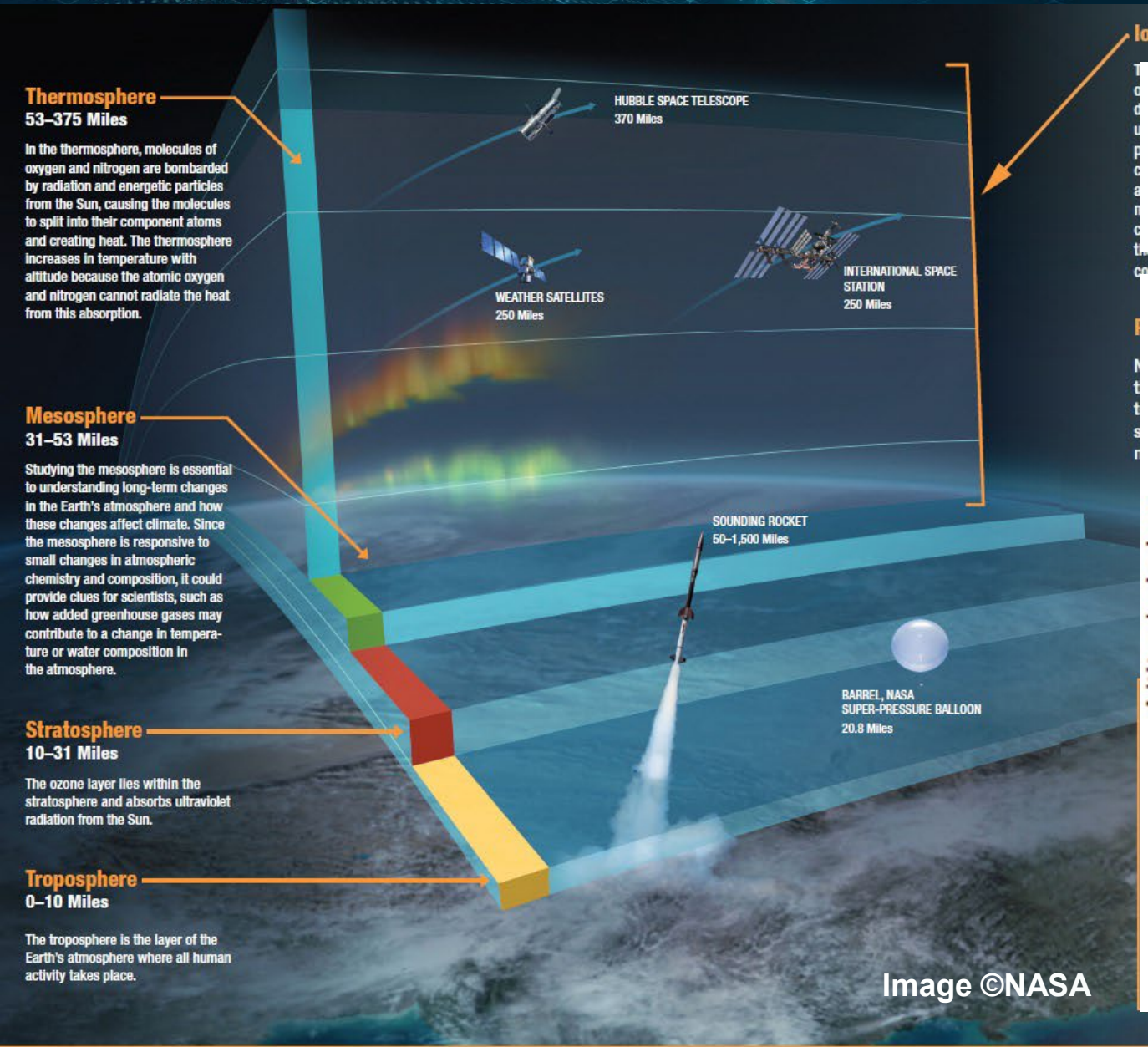
24 May 2022

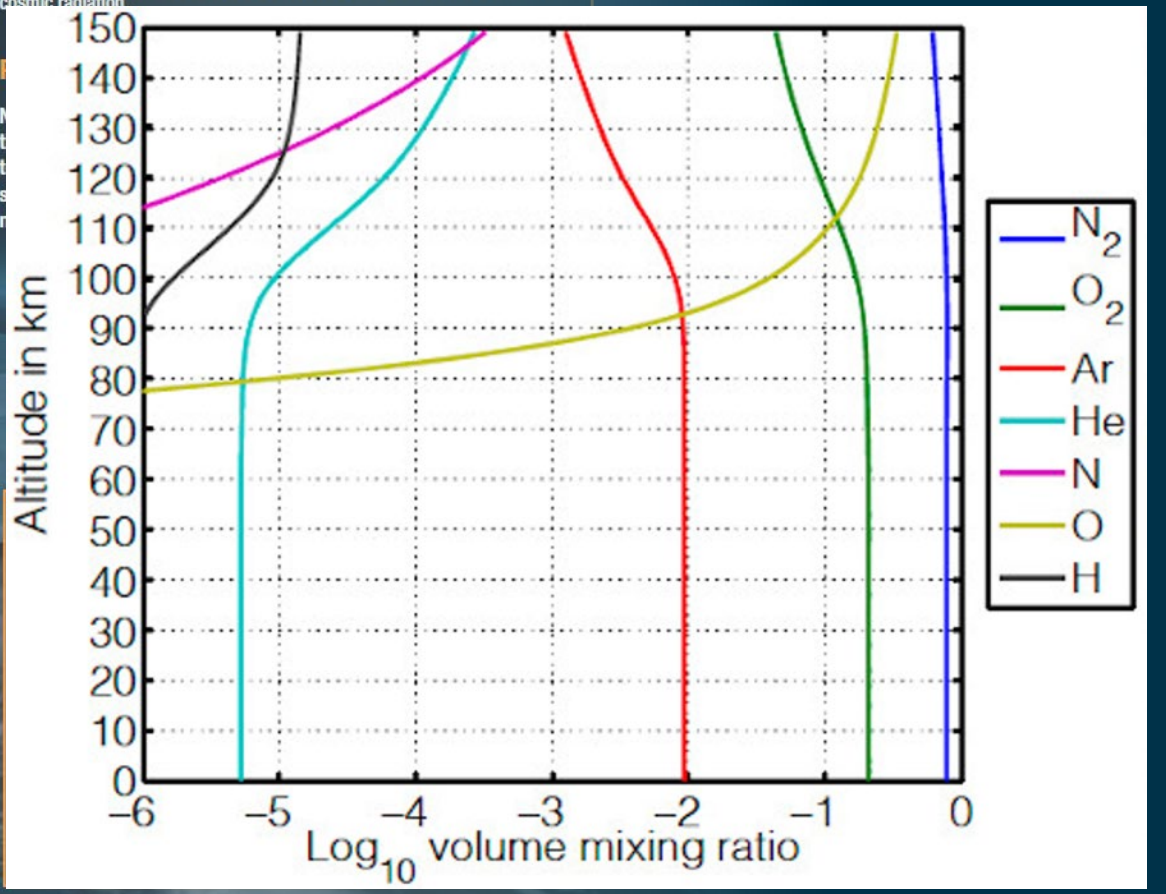
What is Keystone?

- Limb-sounder to measure the composition and radiative /thermal structure of the mesosphere—lower thermosphere (MLT)
- EE-11 candidate mission (commended, not selected for Phase-0)
- Evolution of LOCUS (EE-10, EE-9)

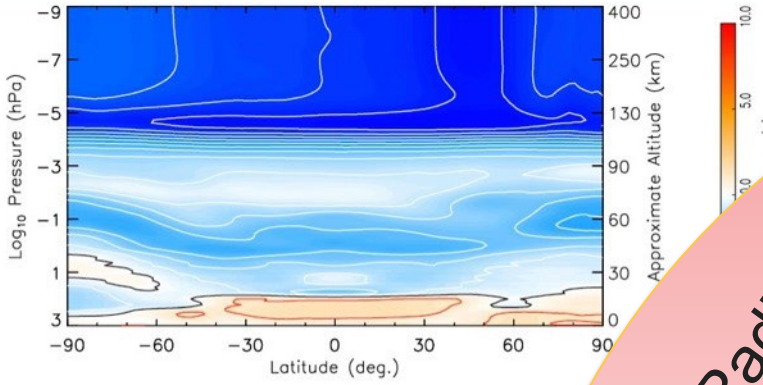
The Upper Atmosphere



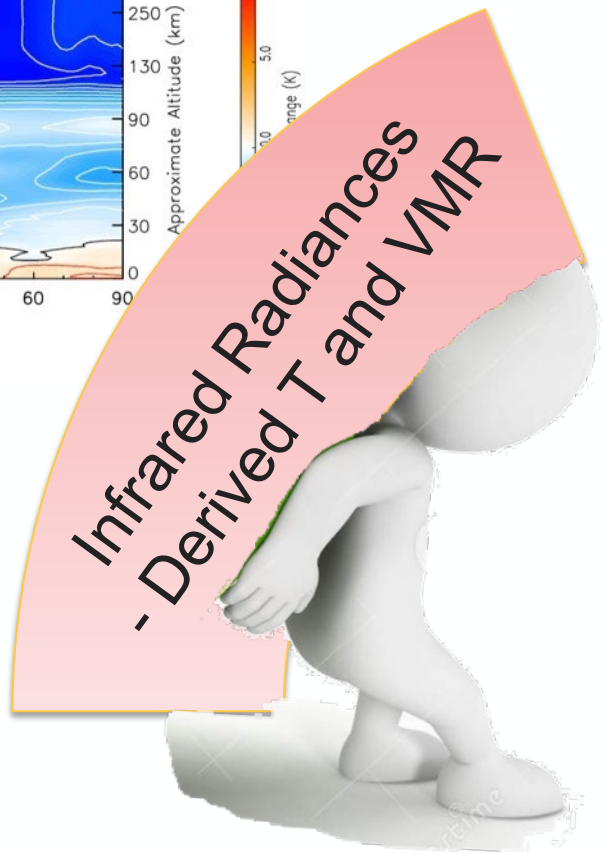
- The Mesosphere-–Lower Thermosphere (50km-250km) is the least well known region of the atmosphere
- Atomic oxygen [O] is a key component of the so called "*Agnostosphere*"



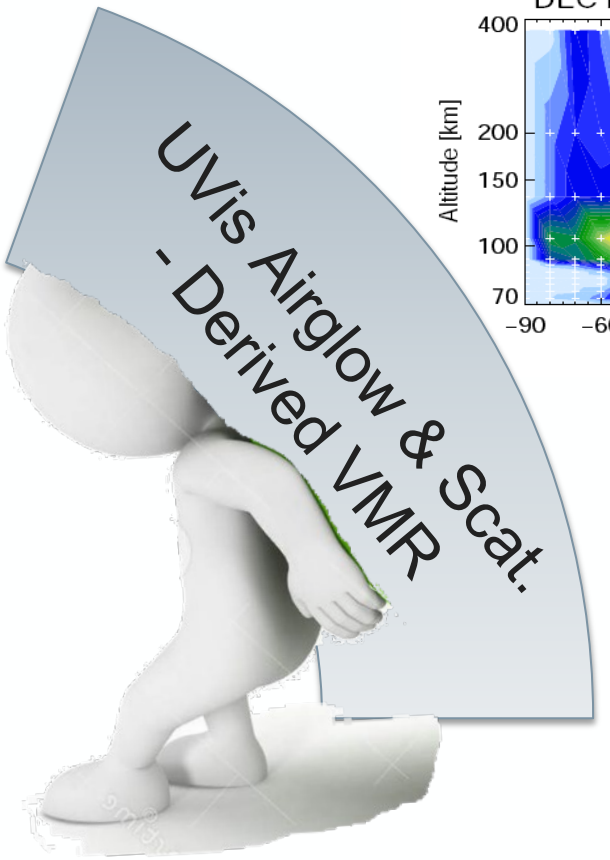
Existing IR and UVIS Measurements Rely on [O] Model Assumptions



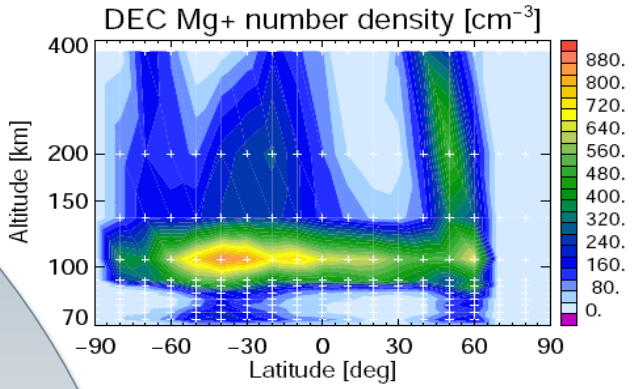
e.g. MLT cooling trend indicated by IR radiances, [Solomon 2018]



Model assumptions on O quenching rates

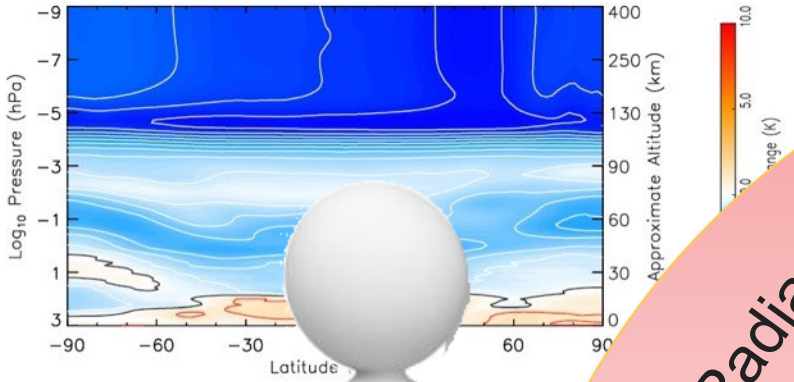


Model assumptions on O/O_2 photochemistry



e.g. Mg+ distribution from UVis (SCIAMACHY) [Scharringhausen 2009]

Existing IR and UVIS Measurements Rely on [O] Model Assumptions

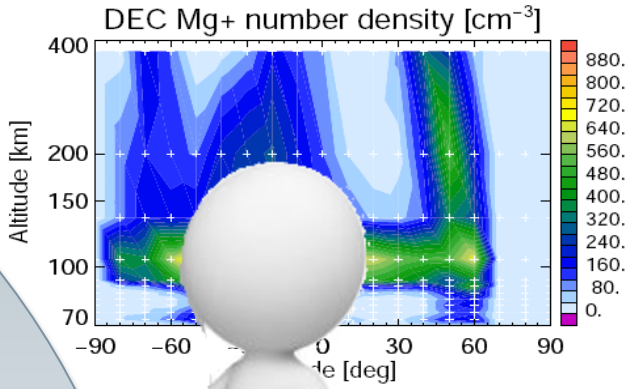


e.g. MLT coo
trend indicat
radiances, [S
2018]

Infrared Radiances
- Derived T and VMR

THz
Retrieved O
& T

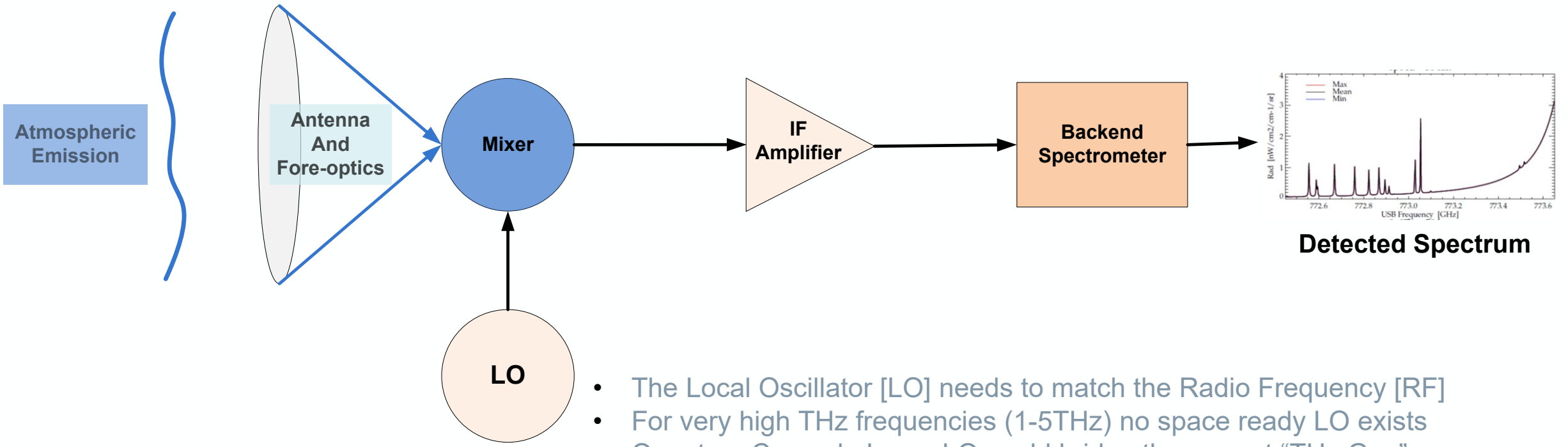
UVis Airglow & Scat.
- Derived VMR



distribution from
AMACHY)
ghausen 2009]

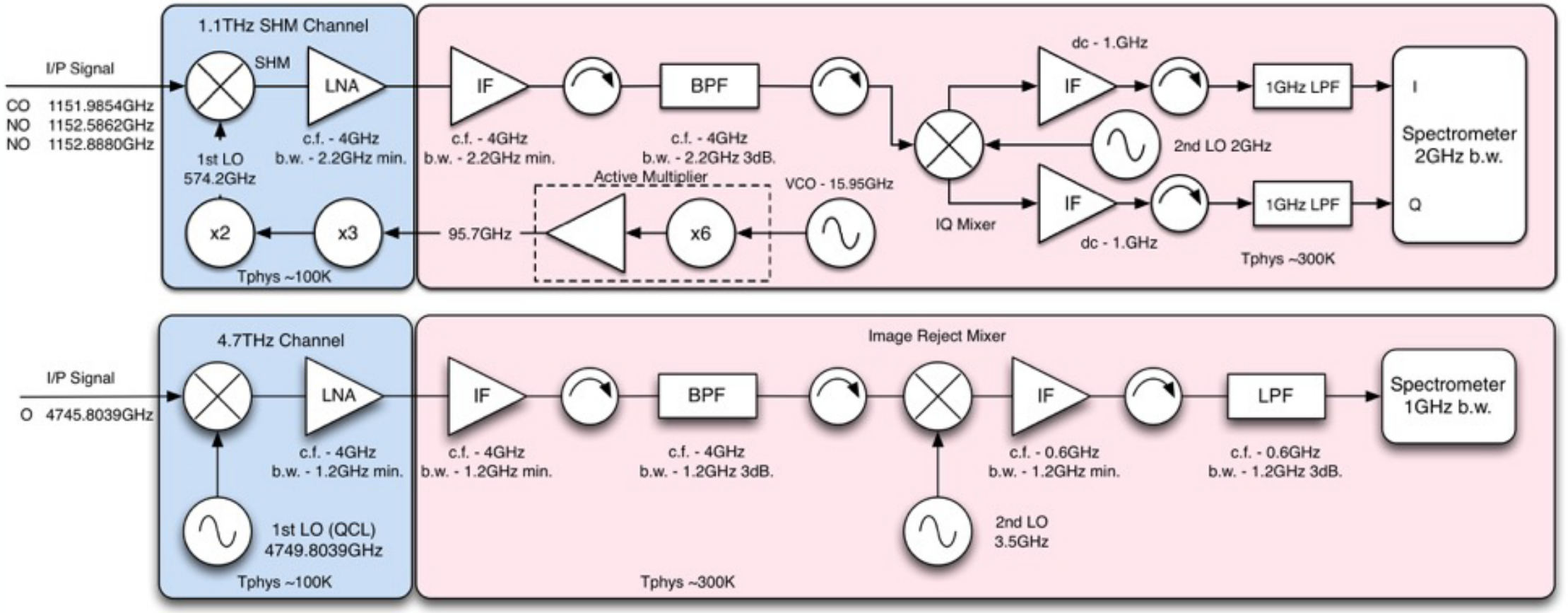
Direct retrievals of O and T are the missing link that combines existing science bites into a self-consistent representation of the upper atmosphere

Heterodyne Detection for High Frequency Spectroscopy



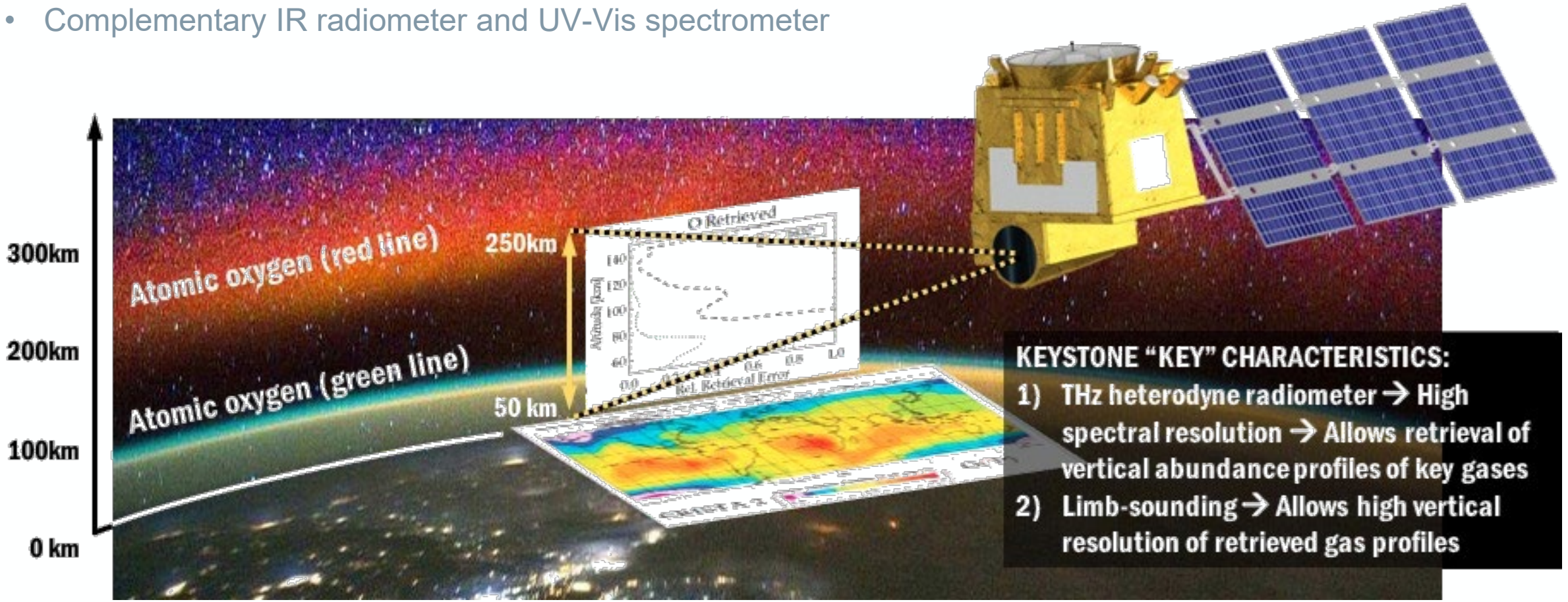
- The Local Oscillator [LO] needs to match the Radio Frequency [RF]
- For very high THz frequencies (1-5THz) no space ready LO exists
- Quantum Cascade Laser LO could bridge the current “THz Gap”

QCL Oscillators Enable Supra-THz Receviers



Keystone Mission Design

- Supra-THz radiometers for trace gas and T retrievals
- Complementary IR radiometer and UV-Vis spectrometer



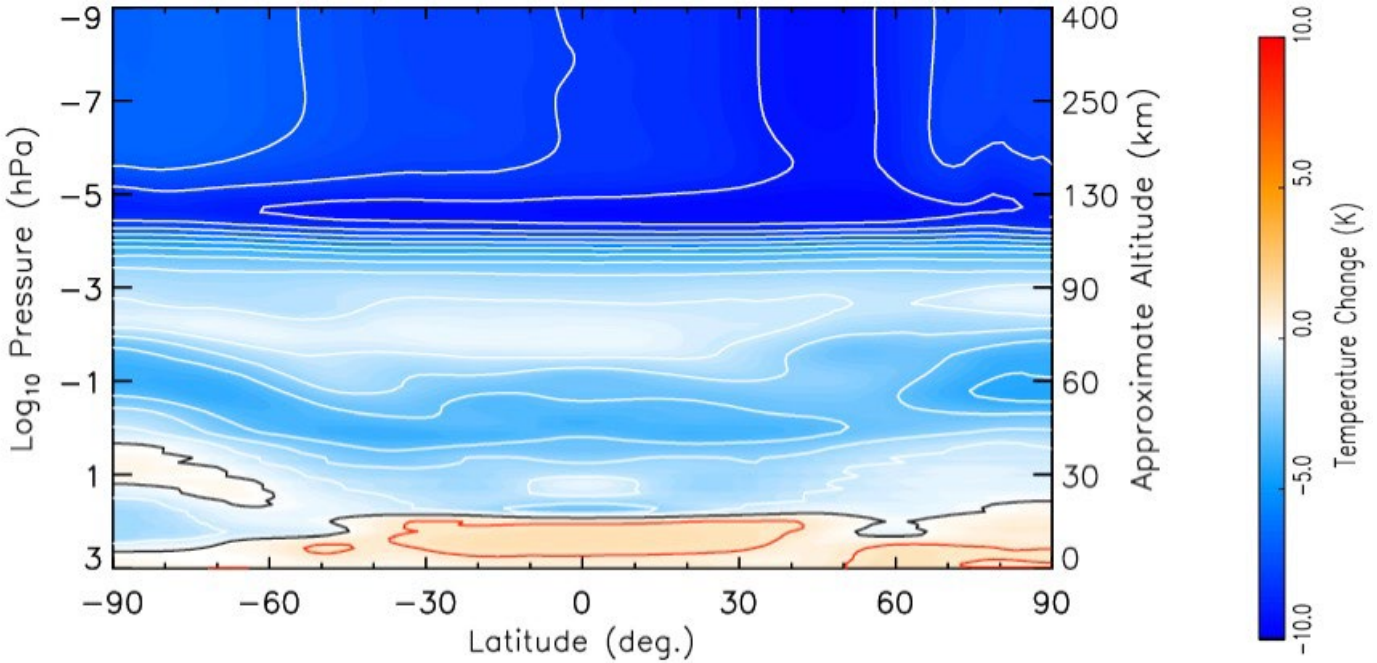
Science Objectives & Societal Benefits

1. **Fundamental Science**
   - Resolution of the decades old “quenching rate conundrum”
   - Resolution of decades old uncertainties in photochemical models
2. **Climate Science**
   - Understanding the upper atmospheric cooling from greenhouse gases
3. **Space Weather**
   - Understanding the chemical changes in the upper and middle atmosphere due to electrically charged particles from space weather
4. **Orbital Science**
   - Improving space situational awareness models (thermal contraction)
5. **Meteorology**
   - Providing assimilation measurements for full-atmosphere NWP models
   - Providing mesospheric wind retrievals

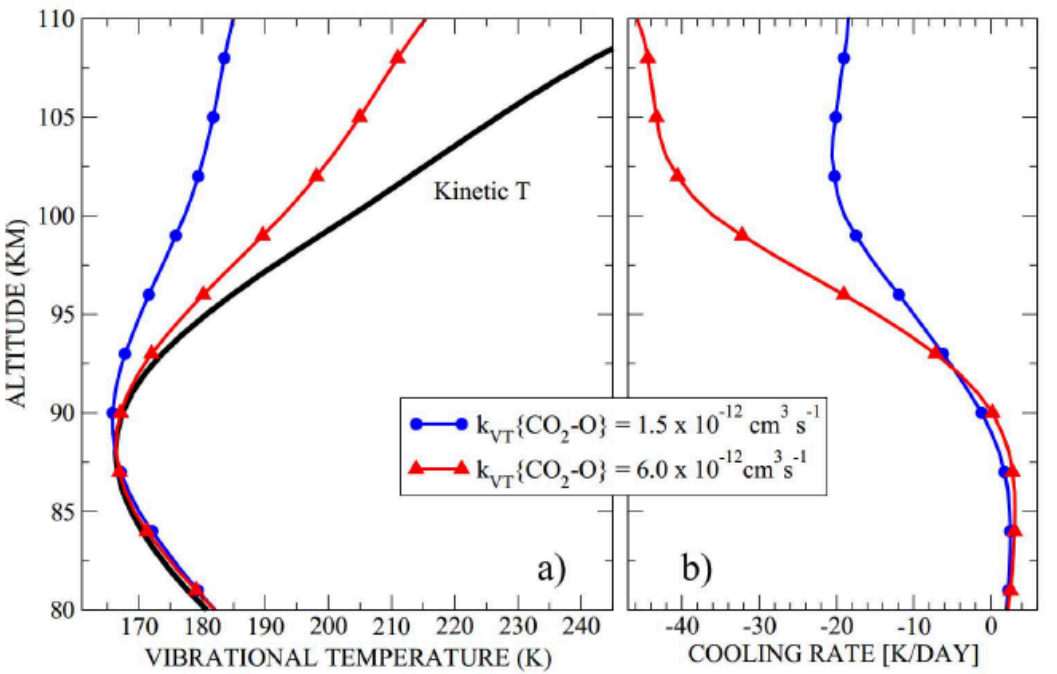
Science Objective – Climate Change

- Upper atmospheric cooling trend is stronger than surface warming
- Role of GHG unclear, because quenching rates with [O] are unknown

Factor 4 Uncertainty!



[Solomon et al. 2018]



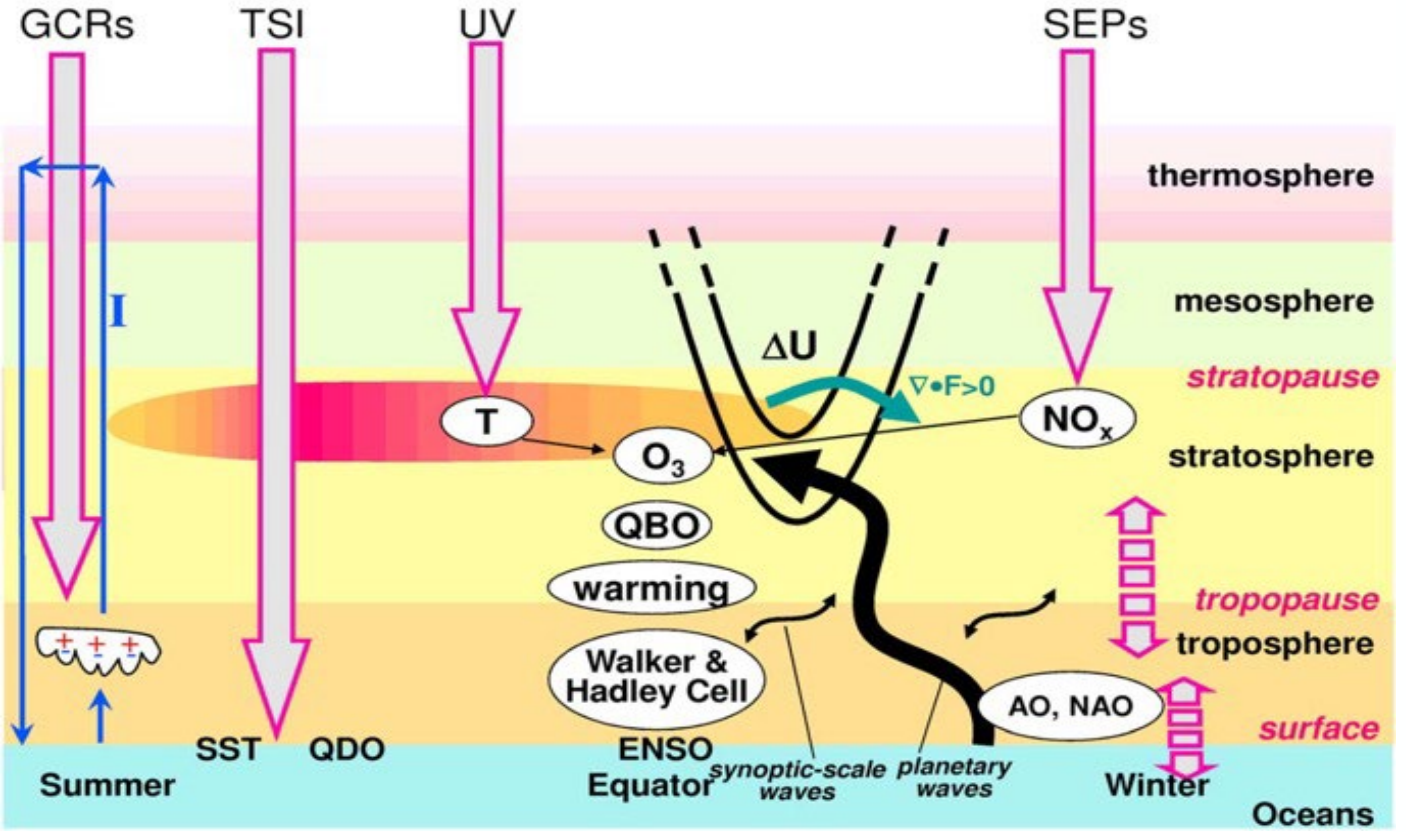
[Feofilov et al. 2012]

Science Objective - Space Weather

There are established teleconnections from the Upper Atmosphere to surface climate via O_3

MLT NO_X from space weather events leads to increased O_3 formation

Research suggests that the NO_X impact could match the direct UV solar forcing



[Gray et al. 2010]

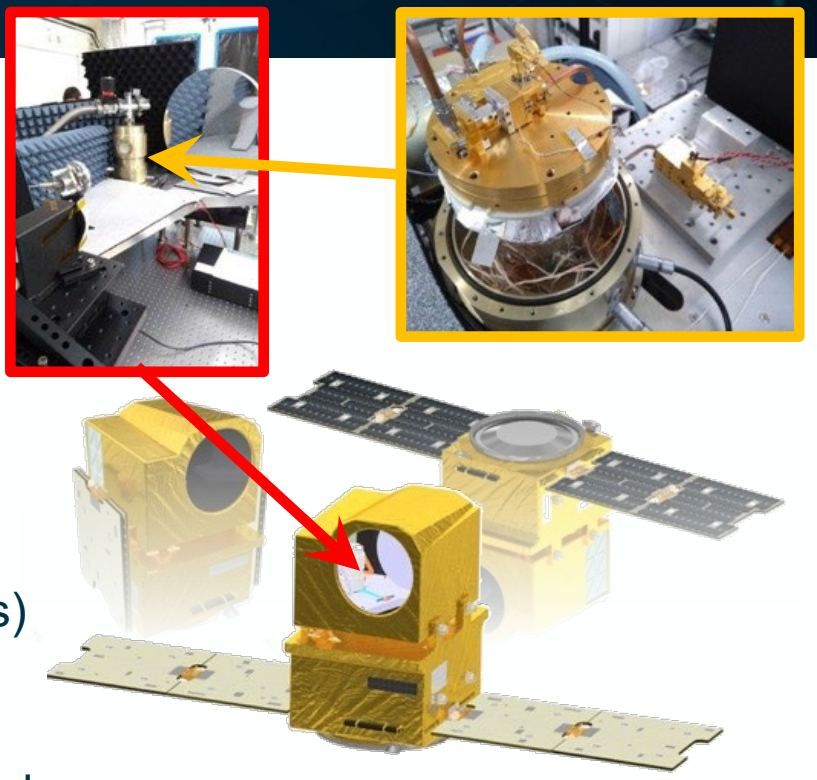
Payload Overview & Heritage

Limb-scanning, sun-synchronous LEO satellite

Evolution of the LOCUS concept (EE-10 compliance)

Critical TRL: 2-4.7 THz receivers (TRL 3)

Core novelty is the **synergy of IR, UVis and THz** techniques



IR Instrument

(SABER/LOCUS)

- 15.2µm (narrow): CO_2 (thermosphere)
- 15.14µm (wide): CO_2 (thermosphere)
- 9.39µm: O_3
- 5.41µm: NO
- 4.27µm: CO_2 (MLT)

THz Instrument

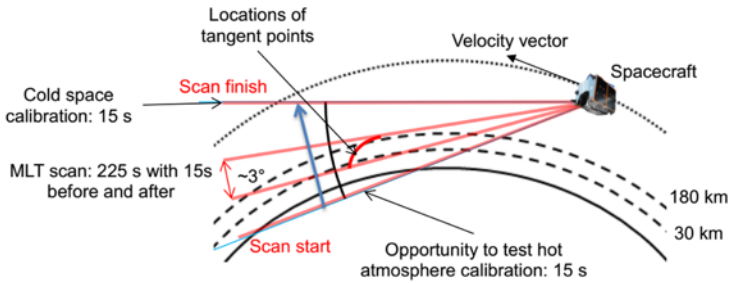
(modified, LOCUS)

- 4.7THz: O (thermosphere), O_3
- 3.5THz: OH, HO_2, CO
- 2THz: O (MLT), NO, O_3
- 1.1THz: NO, CO, H_2O, O_3
- 0.8THz: O_2, O_3, H_2O

UVis Instrument

(new, NOMAD/Osiris)

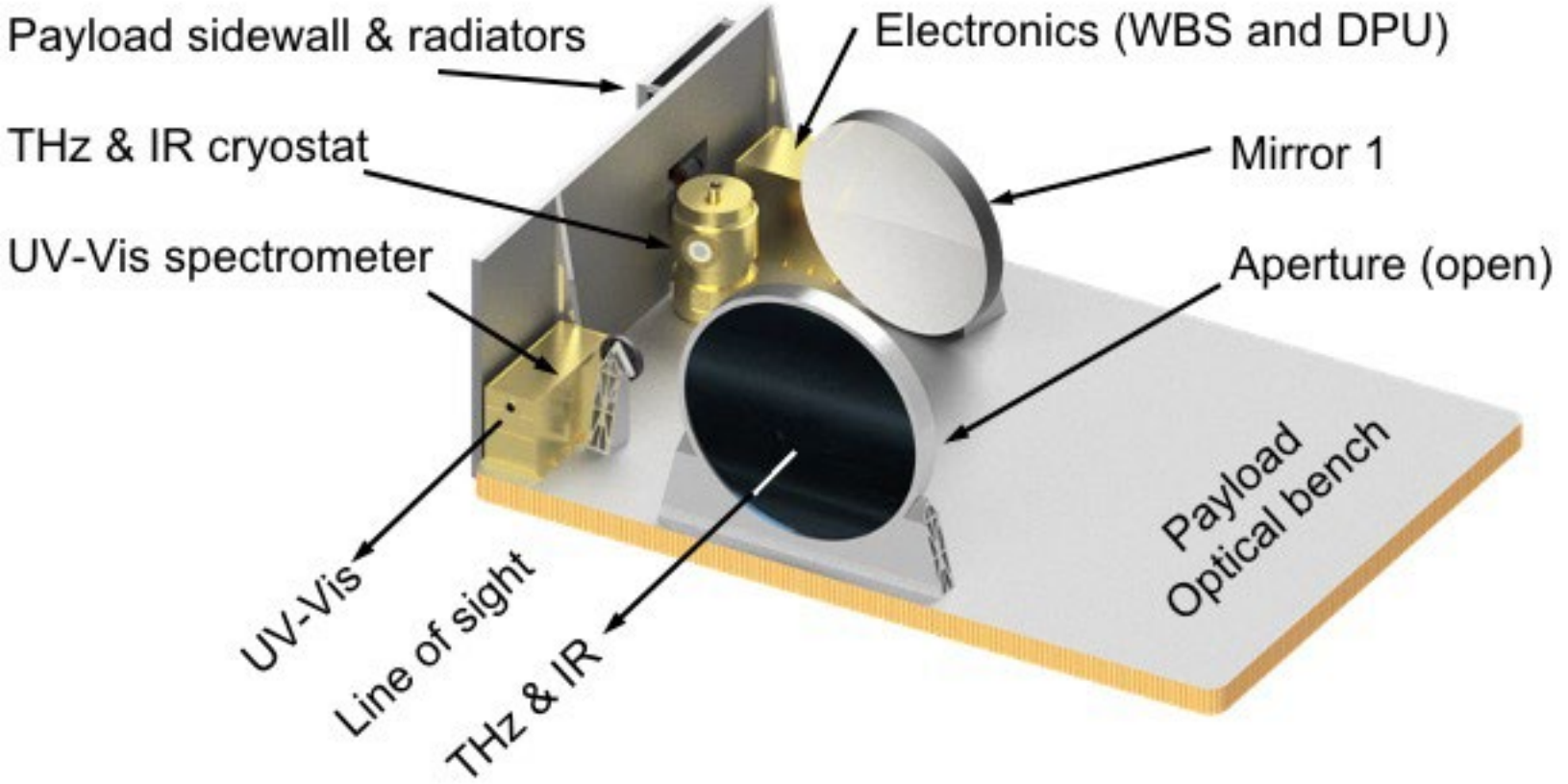
- 200-600nm: O (green and red lines), Na, Mg+ and Mg
- 600-800nm: OH Meinel band and O_2 A-Band

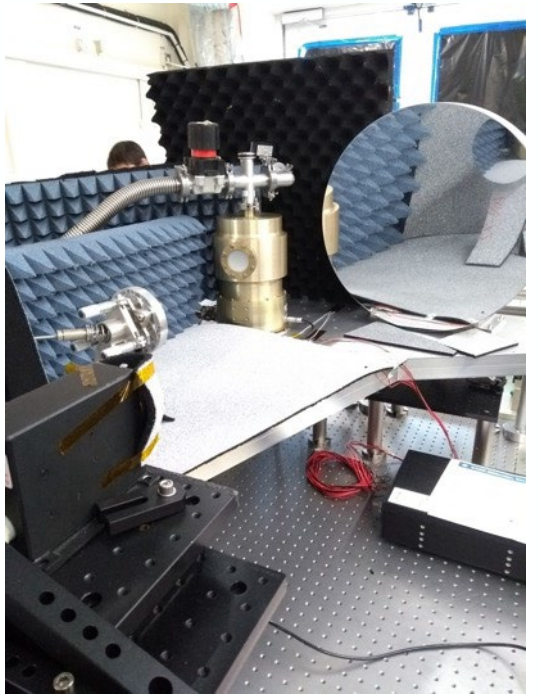


Keystone Oberservables [THz, IR, UV-Vis]

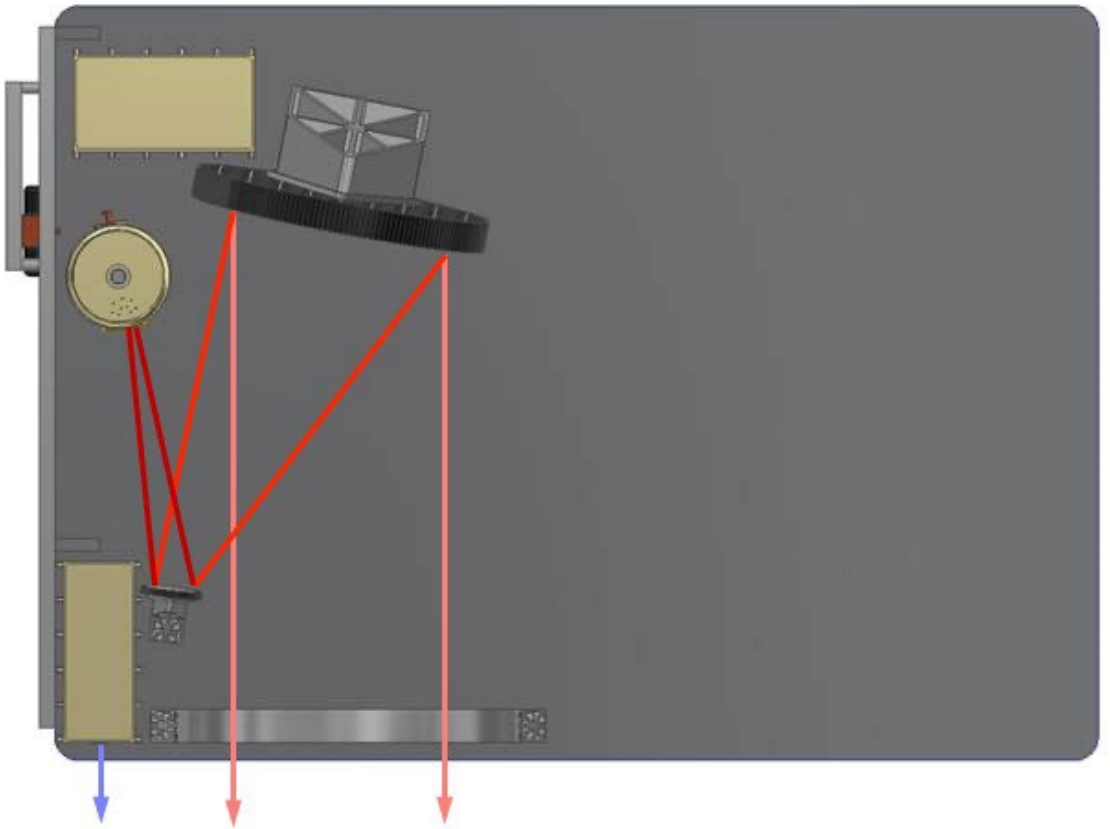
Variable	Data Product	Altitude Range	Estimated Precision	Vertical Sampling
O	Single Profile [ppmv]	90km – 150km	60% – 20%	10km
	100 Averaged Profiles [ppmv]	80km – 150km	20% – 20%	5km
OH	Single Profile [ppmv]	50km – 90km	20% – 20%	5km
	100 Averaged Profiles [ppmv]	50km – 110km	10% – 20%	5km
HO_2	Single Profile [ppmv]	50km – 85km	20% – 20%	10km
	100 Averaged Profiles [ppmv]	50km – 100km	10% – 40%	5km
H_2O	Single Profile [ppmv]	50km – 100km	10% – 20%	2km
	100 Averaged Profiles [ppmv]	50km – 120km	10% – 40%	2km
NO	Single Profile [ppmv]	50km – 150km	20%-60%	5km
	100 Averaged Profiles [ppmv]	50km – 150km	10%-10%	5km
NO^+	Single Profile [ppmv]	N/A	N/A	N/A
	100 Averaged Profiles [ppmv]	70km – 150km	40%-20%	5km
CO	Single Profile [ppmv]	50km – 100km	10%-20%	5km
	100 Averaged Profiles [ppmv]	50km – 150km	10%-20%	5km
O_3	Single Profile [ppmv]	50km – 100km	10%-40%	5km
	100 Averaged Profiles [ppmv]	50km – 120km	10%-40%	5km
Temperature	Temperature Profile	50km – 150km	5% (0.5-50K)	2km
CO_2 (15mm)	T, Density, IR cooling rate	50km – 130km¨	□	□
O3 (9.6mm)	O_3 concentration, cooling rate	50km – 100km¨	□	□
CO_2 (4.3mm)	CO_2 concentration, mesospheric solar heating	85km – 150km¨	□	□
NO (5.3mm)	Thermosphere cooling	90km – 180km¨	□	□
Airglow (230-780nm)	O, O_2, O_3 Photochemistry, O+, Mg/Mg+ , Fe/Fe+ ion density, Temp. profile, Pointing	100km -250km	SNR > 10	

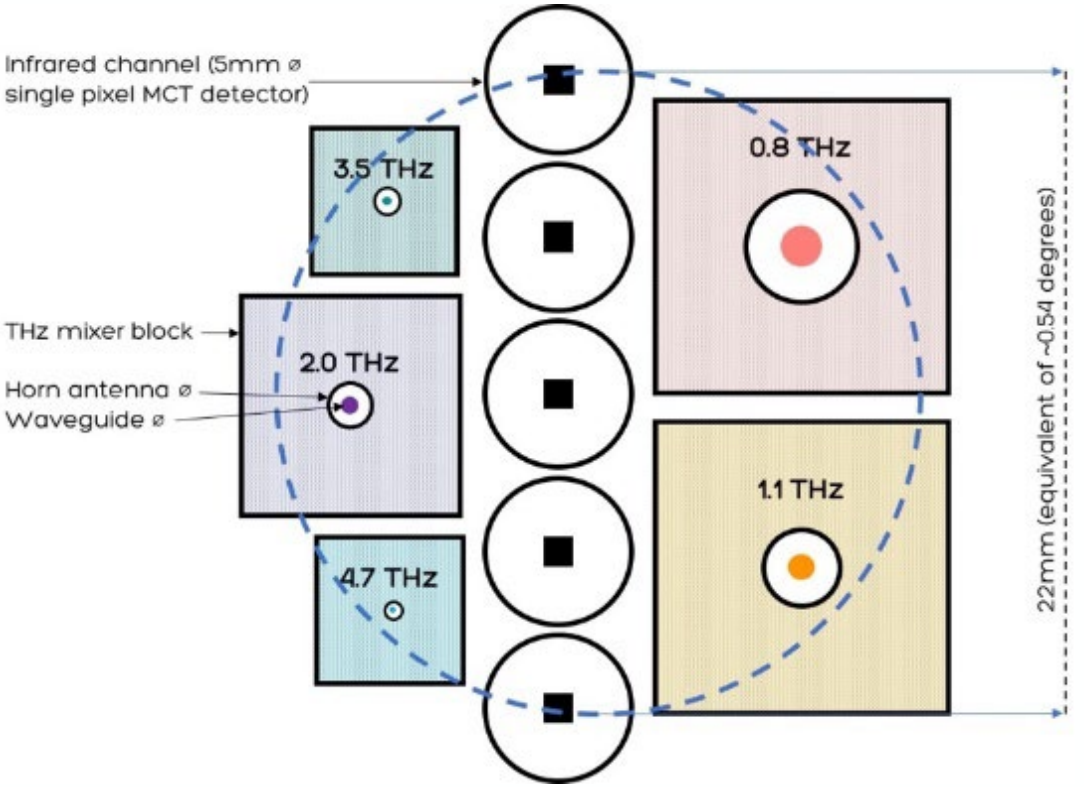
Keystone Payload Design





Keystone Optical Design



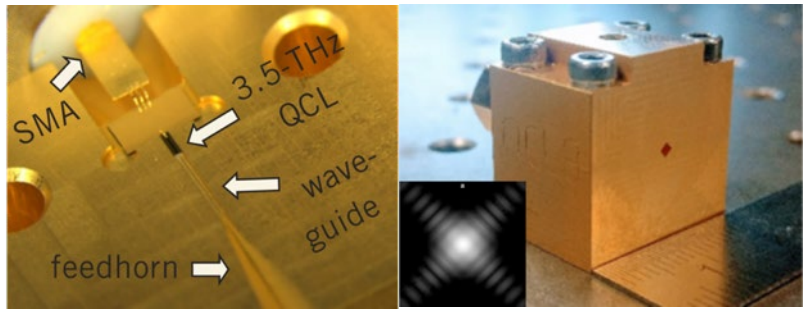


Keystone THz Receiver Technologies

The Keystone (Supra-) THz heterodyne instrument depends on some key technologies that are only now becoming viable

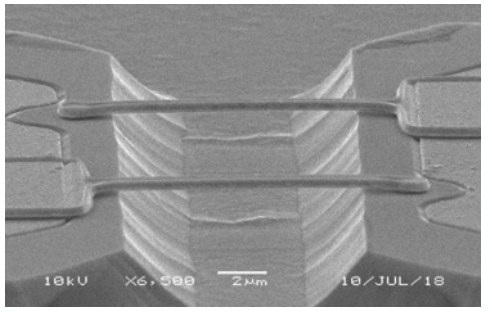
UK National technology pre-development includes:

Quantum Cascade Laser (QCL) devices as a high-power source to pump heterodyne Schottky mixers



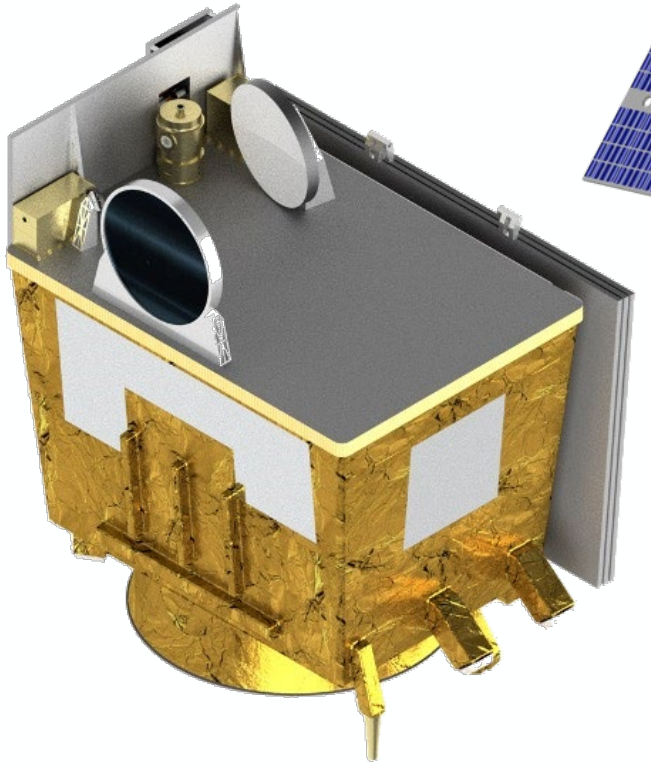
Miniature space coolers to provide QCL cooling (~70K)

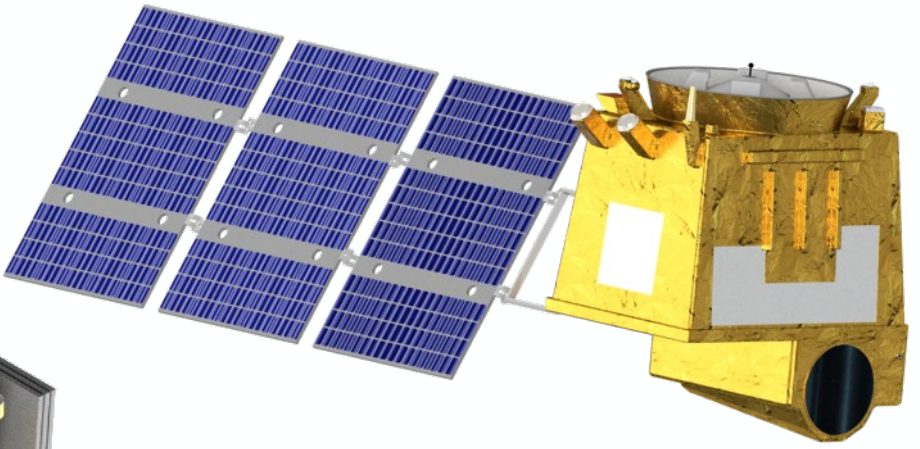
Improved Schottky diode & mixer manufacturing for THz frequencies



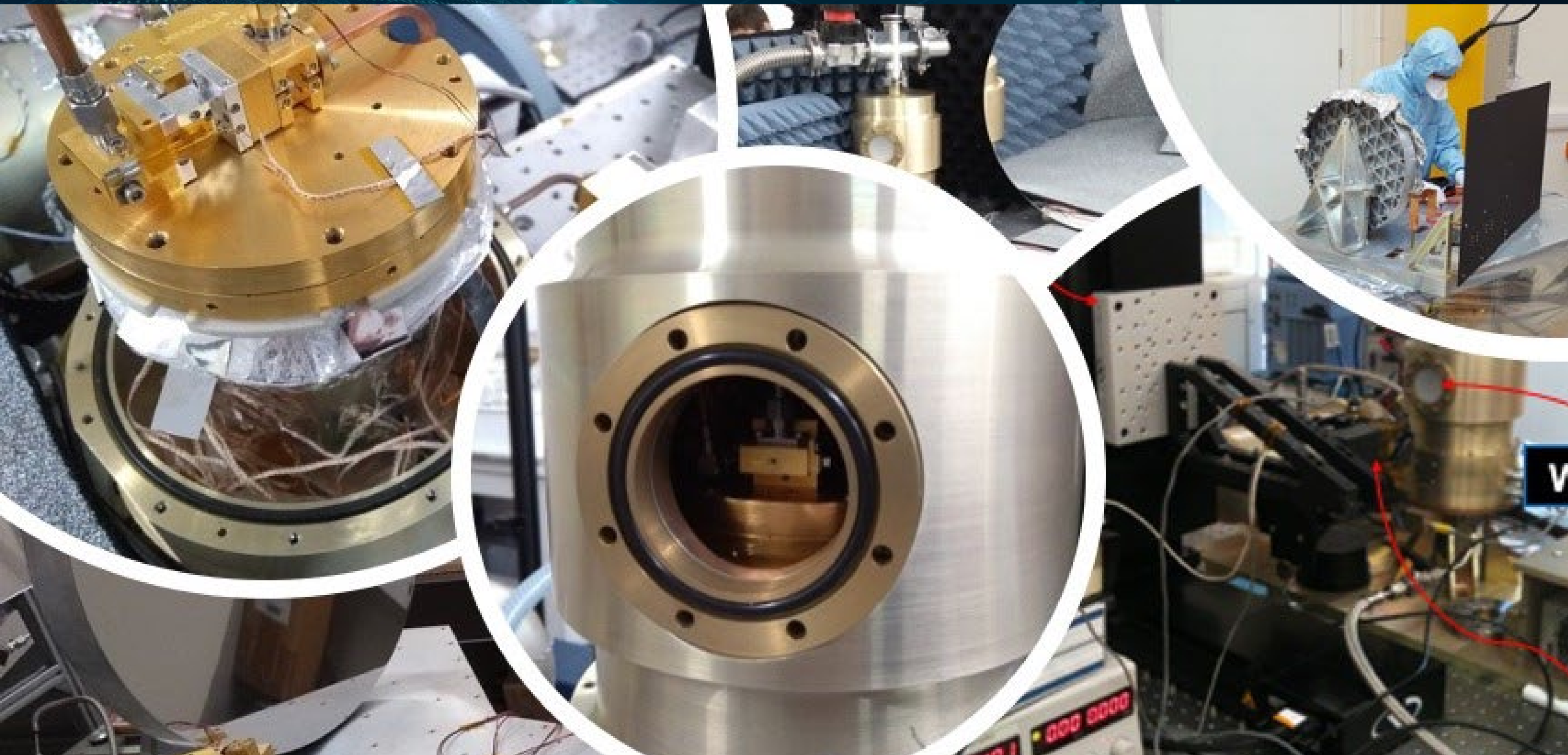
Compact, high-speed, power efficient digital spectrometers

Keystone Payload on Astrobus S/C and Vega-C Launcher





Impressions of Ongoing Technology Pre-Development



Thank You!