Remote sounding performance of a thermal IR LHR for atmospheric trace gases

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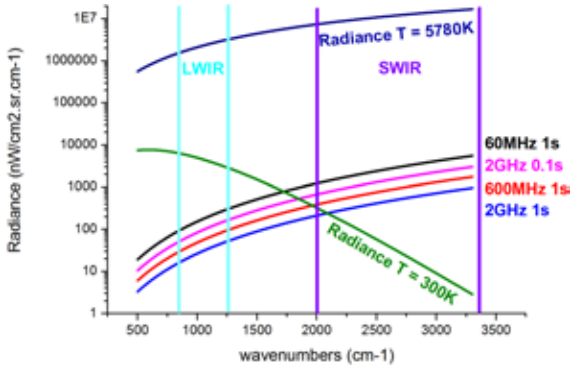
Project Introduction

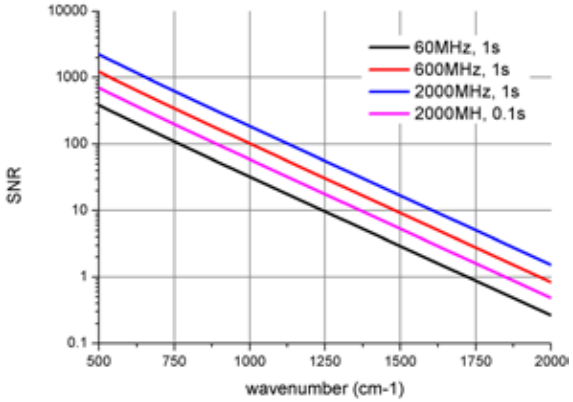
Ø Project objectives
- Identify best sounding performances to drive developments
- Survey solar occultation, nadir and limb
- CO, NO, O3, CH4, N2O, SO2, CO2

Ø Case for LHR
- High spectral resolution (0.001 – 0.02 cm^{-1})
  - Turns into altitudinal resolution
- High spatial resolution (100's m LEO / few km's GEO)
  - Local observations
- Miniaturized through integration
  - Lower cost, piggy backing, constellation

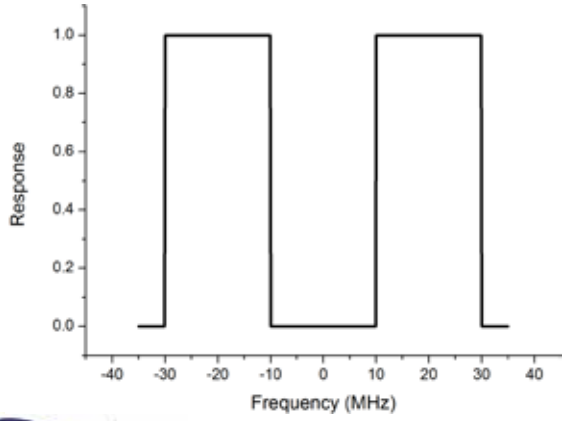
Instrument Model

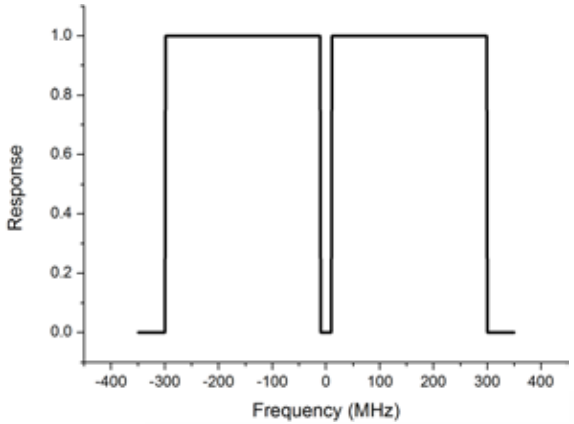
Ø Noise





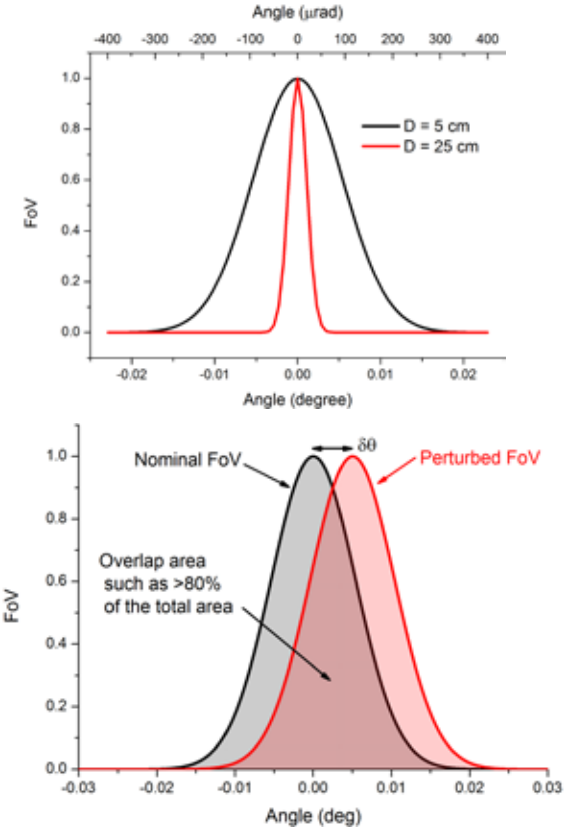
Ø Instrument lineshape

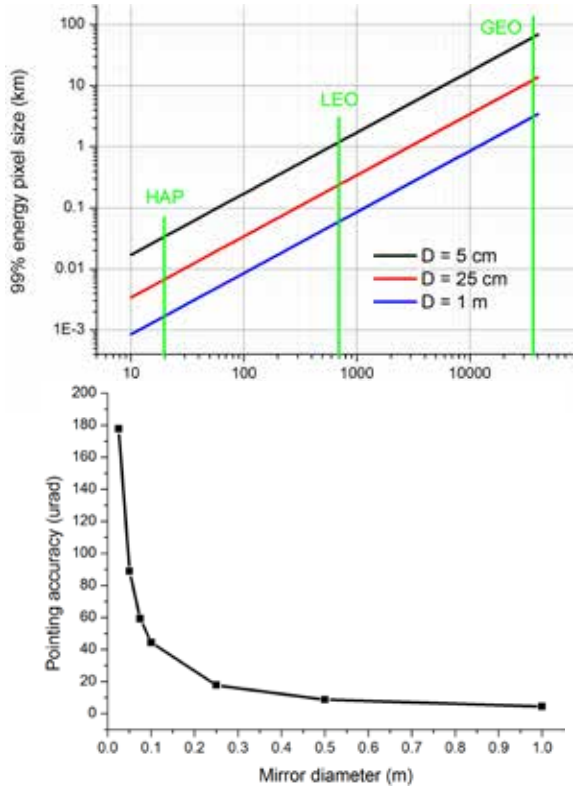




Instrument Model

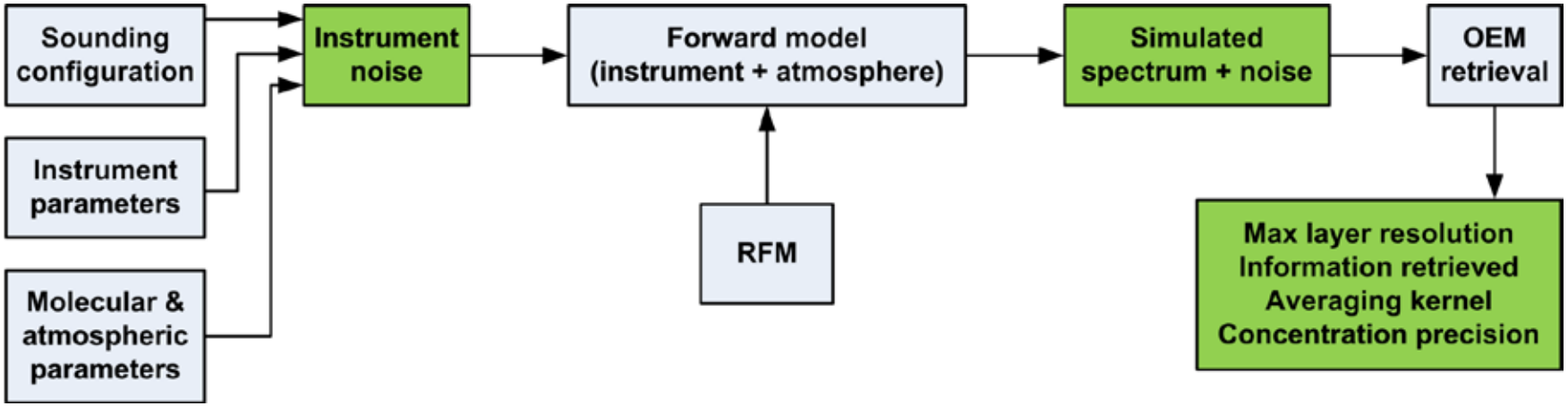
Ø Field of view





Analysis Methodology

Ø Analysis flowchart



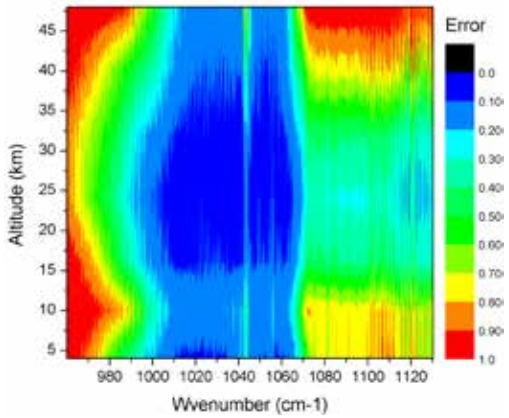
Ø Optimized narrow spectral window 0.5 cm^{-1}

Ø Vertical sensitivity and precision

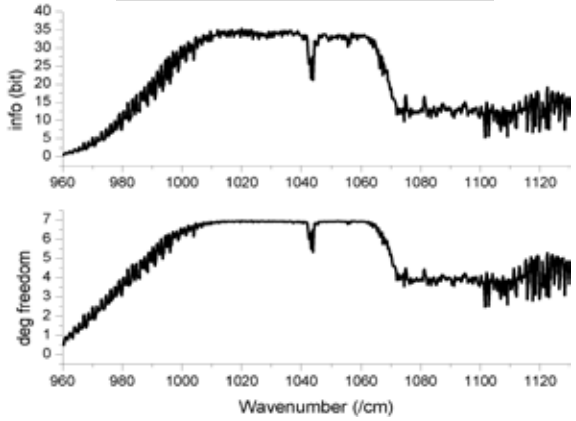
Ø Effect of integration time and sampling resolution

Example of Ozone (nadir)

Retrieval error across the nu3 band



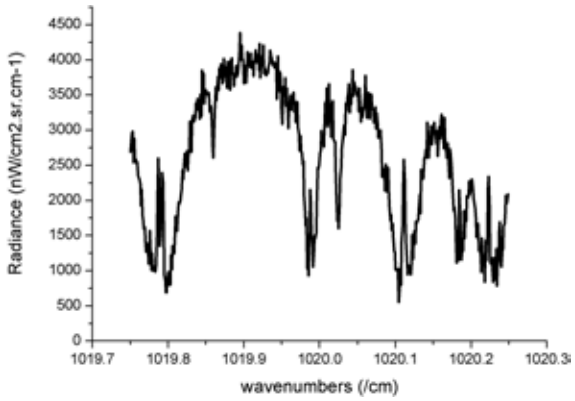
Information content



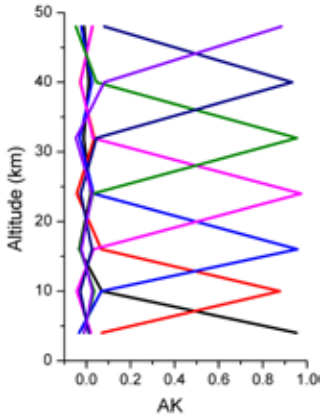
- Optimum 0.5 cm^{-1} spectral window 1019.75 – 1020.25 cm^{-1}

- Optimum 7 layer altitudinal grid 4 -10 -16 - 24 – 32 – 40 - 48 km

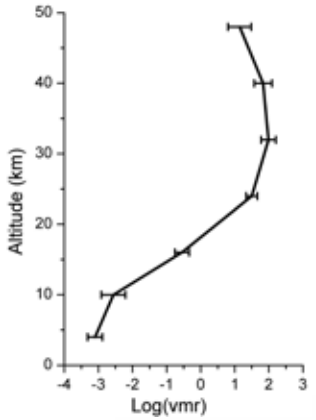
Simulated spectrum



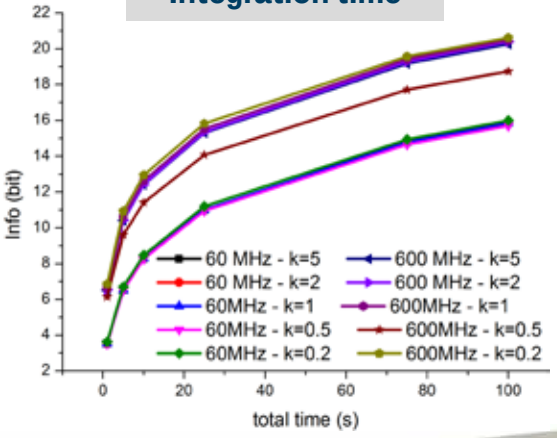
Sensitivity / resolution



Profile & precision



Integration time



Outcomes

Molecule	Viewing mode	Optimum window (cm^{-1})	Resolved layers	Info (bit)	For 5s acquisition
CO	Nadir	N/A			
	Limb	N/A			
	Solar occ.	2146.75 – 2147.25	8	40	
NO	Nadir	N/A			
	Limb	N/A			
	Solar occ.	1900.00 – 1900.50	2	4	
O3	Nadir	1019.75 – 1020.25	7	35	11 bit - 4 layers
	Limb	1009.25 – 1009.75	6	15	
	Solar occ.	1133.75 – 1134.25	10	65	
CH4	Nadir	1230.00 – 1230.50	3	14	5 bit - 2 layers
	Limb	1247.75 – 1248.25	2	4	
	Solar occ.	1230.00 – 1230.50	8	50	
N2O	Nadir	1155.50 – 1156.00	4	14	4 bit - 1 layer
	Limb	1150.75 – 1151.25	2	3	
	Solar occ.	1179.75 – 1180.25	9	70	
SO2	Nadir	1136.00 – 1136.50	N/A	N/A	
	Limb	N/A			
	Solar occ.	N/A			
CO2	Nadir	727.00 – 727.50	9	45	20 bit - 5 layers
	Limb	653.00 – 653.50	12	50	
	Solar occ.	738.25 – 738.75	12	90	

Achievement Against Goals

Ø Identify the best candidates for LHR deployment
- Ozone for lower troposphere air quality
- Carbon dioxide lower troposphere for carbon cycle studies (<1% precision)
- Sub-city scale spatial resolution (even from GEO)

Ø Technological developments required
- 13.7 um QCL development for CO2
- High speed mixers for spectral multiplexing
  - E.g. MIM diodes with 100's GHz bandwidth

Issues & Problems

Ø Originally planned to look at isotopologues signals

- LHR can obtain altitudinal information from a single lines
- Should have isotopologue sensitivity

Ø Key trained staff left early January

- Unable to conduct the study in time

Positioning

Ø Presentations

- "A Fully Integrated, Miniaturised Quantum Cascade Laser Heterodyne Radiometer for Earth Observation", Joint NCEO/CEOI conference, Nottingham, 2012
- "Getting QCL-based Remote Sensors to the Harsh Real World of Space". NSF Mid Infrared Technologies for Health and Environment Engineering center, Workshop, Baltimore, USA, 2012
- "Mid-Infrared Laser Heterodyne Systems From Earth Observation to Security and Defence", CEOI showcase conference, 2013
- Posters at the NCEO/CEOI conference and CEOI showcase

Ø Publication

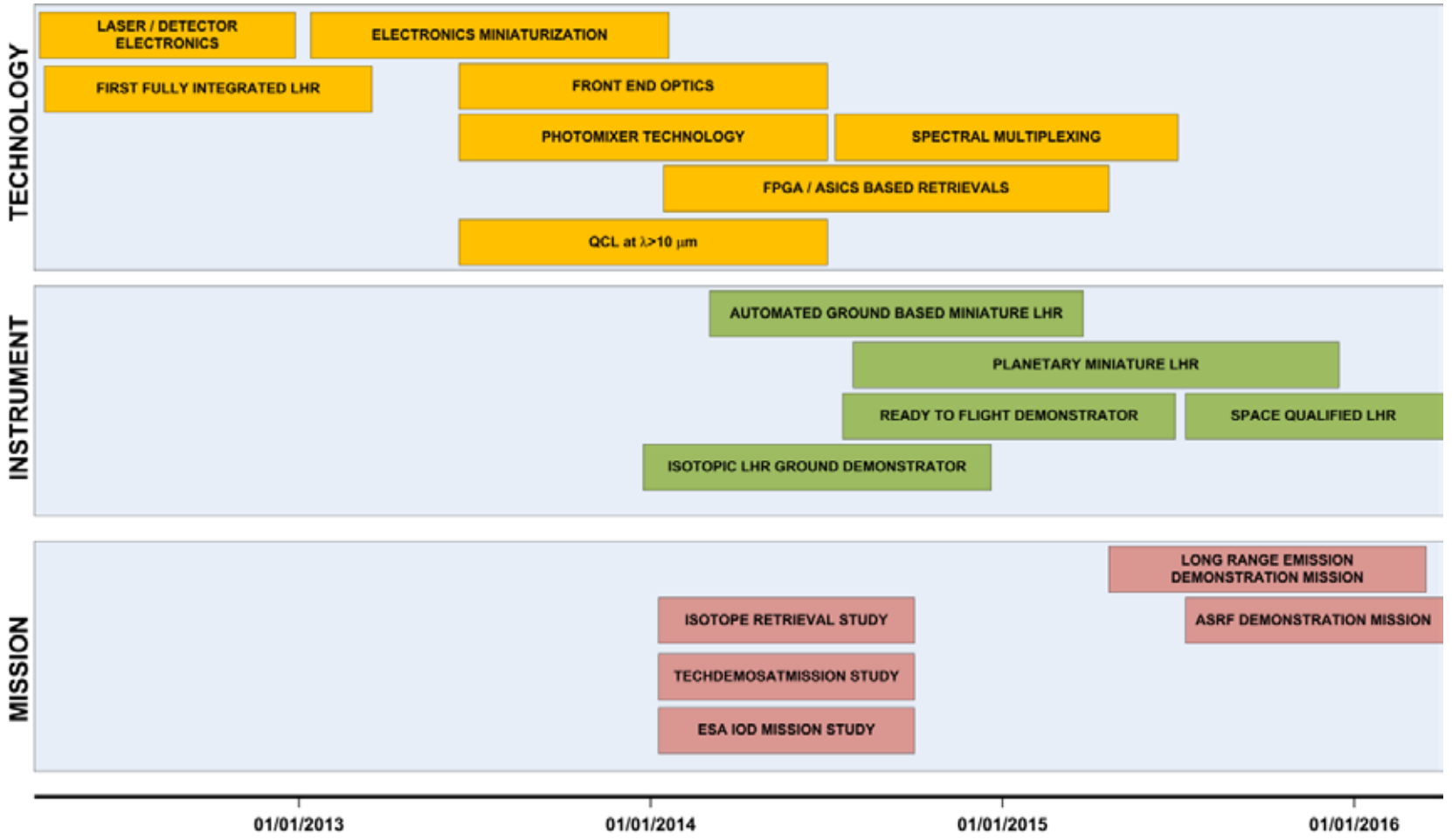
- "Atmospheric vertical profiles of O3, N2O, CH4, CCl2F2, and H2O retrieved from external-cavity quantum-cascade laser heterodyne radiometer measurements" , Tsai et al. Applied Optics, 51, 36, 8779-8792, 2012

Positioning

- Leverage
  - Proposal to evolve miniature LHR for planetary applications
    - E.g. Mars isotopologues sounding

- UK capability enhancement
  - Outcomes indicated further paths for development
    - CO2 to be investigated
    - Key to develop spectral multiplexing capability to fully exploit the LHR concept
    - Informed the roadmap for development

Roadmap


TECHNOLOGY
LASER / DETECTOR ELECTRONICS
ELECTRONICS MINIATURIZATION
FIRST FULLY INTEGRATED LHR
FRONT END OPTICS
PHOTOMIXER TECHNOLOGY
SPECTRAL MULTIPLEXING
FPGA / ASICS BASED RETRIEVALS
QCL at λ>10 μm
INSTRUMENT
AUTOMATED GROUND BASED MINIATURE LHR
PLANETARY MINIATURE LHR
READY TO FLIGHT DEMONSTRATOR
SPACE QUALIFIED LHR
ISOTOPIC LHR GROUND DEMONSTRATOR
MISSION
LONG RANGE EMISSION DEMONSTRATION MISSION
ISOTOPE RETRIEVAL STUDY
ASRF DEMONSTRATION MISSION
TECHDEMOSATMISSION STUDY
ESA IOD MISSION STUDY
01/01/2013
01/01/2014
01/01/2015
01/01/2016