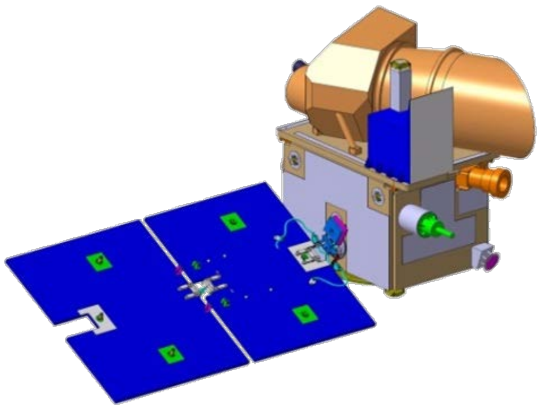


UKSA-CNES Bilateral Carbon Mission (BCM) Support Study

prepared by Hartmut Boesch and the Study Team

presented by Hugh Kelliher

CEOI Technology Conference 2015, Cosener's House, Abingdon, 21-22 April 2015

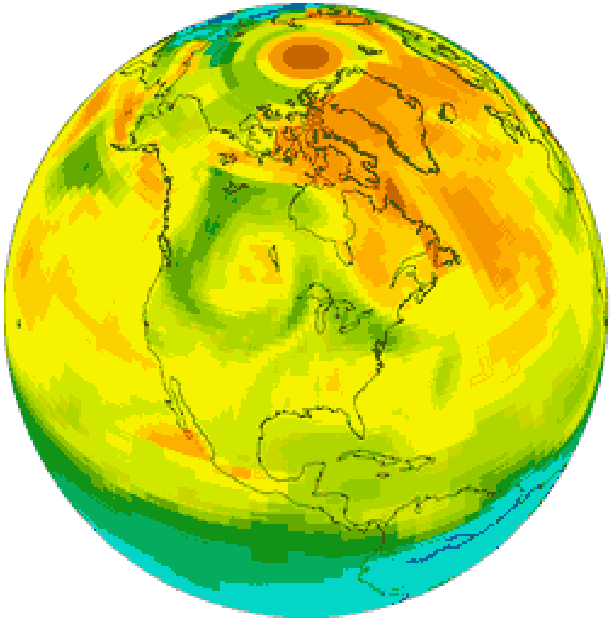
Global Measurements from Space are Essential for Monitoring Atmospheric CO_2

To limit the rate of atmospheric carbon dioxide buildup, we must

- **Control emissions associated with human activities**
- **Understand & exploit natural processes that absorb carbon dioxide**

We can only manage what we can measure

Plumes from medium-sized power plants (4 MtC/yr) elevate X_{CO2} levels by ~2 ppm for 10's of km downwind [Yang and Fung, 2010].

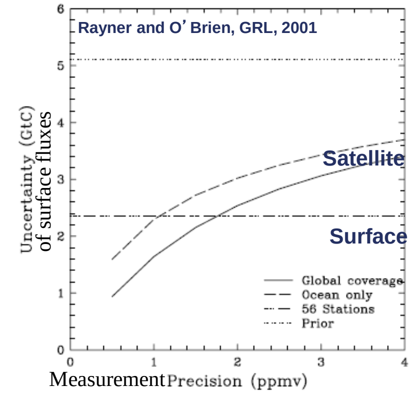


These variations are superimposed on a background of "**CO_2 weather**"

Driving Requirements for Space-based CO_2 Measurements

- **Precision and accuracy**
  - High precision required to resolve small (0.2-0.3%) variations in CO_2 associated with sources and sinks
  - High accuracy essential to avoid regional-scale biases

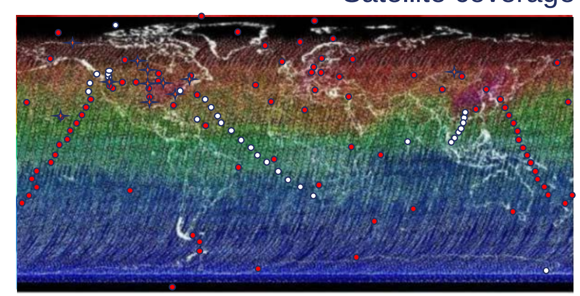
Column measurements vs. surface



- **Spatial coverage**
  - Near-global sampling required over continents and ocean

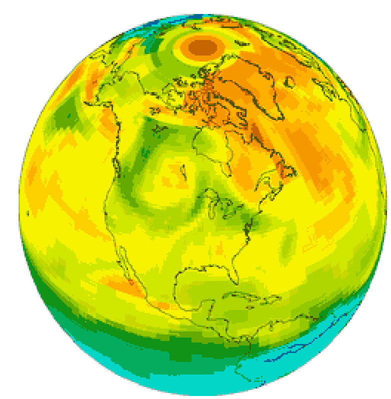
Surface network

Satellite coverage

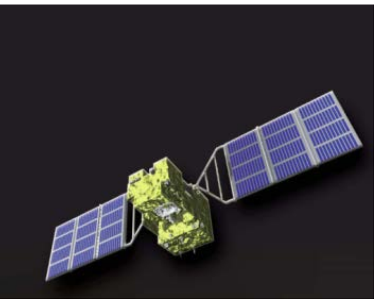


- **Spatial resolution and sampling**
  - Small measurement footprints reduce impacts of clouds

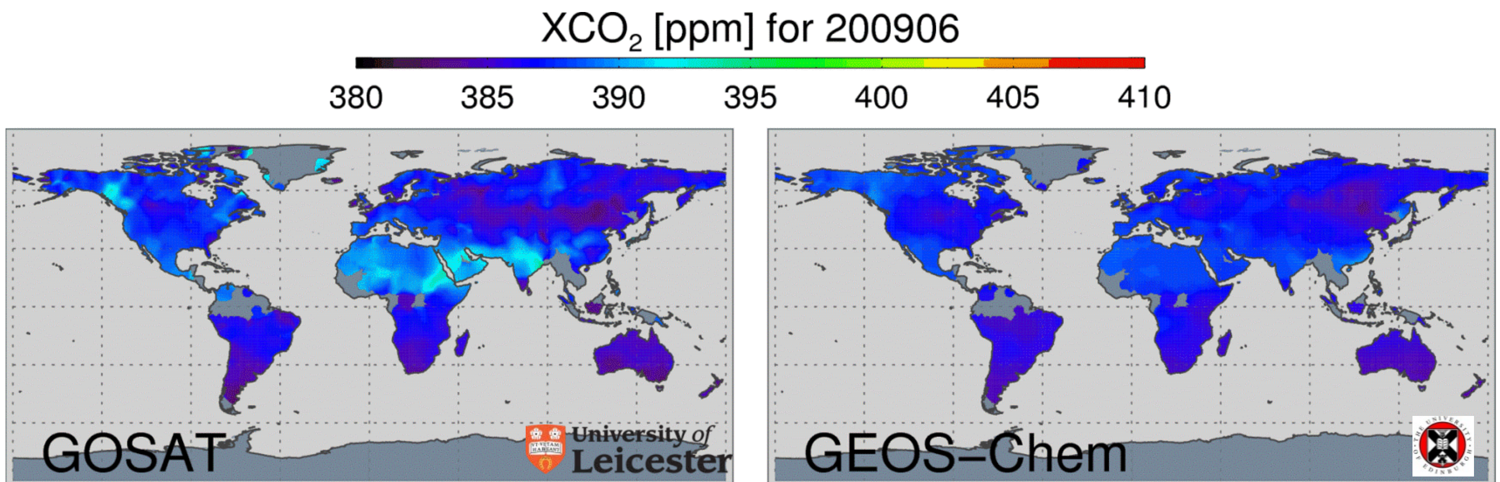
- **Temporal sampling**
  - Synoptic-scale sampling with a 1-4 day repeat cycle needed to resolve transport of CO_2 by local weather systems



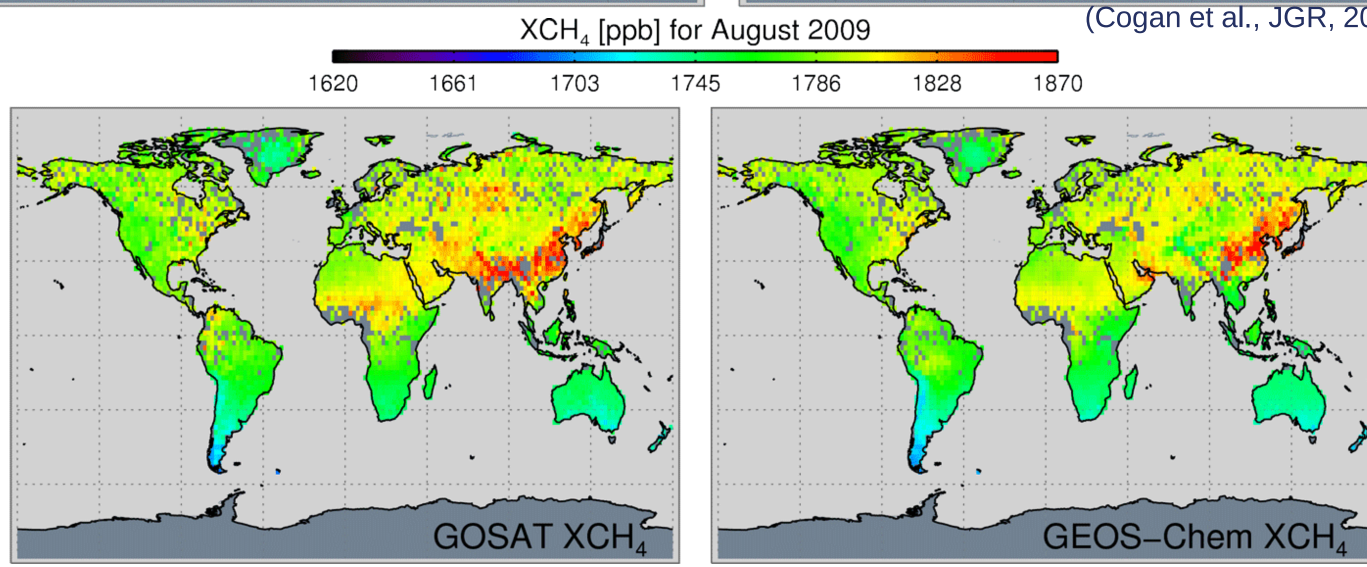
Feasibility of space-based CO_2 & CH_4 observations is well established by GOSAT & OCO-2 demo missions



GOSAT – first dedicated GHG satellite



(Cogan et al., JGR, 2012)

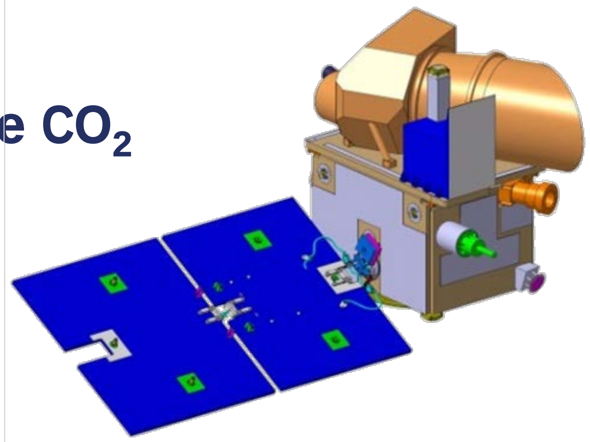


(Parker et al., GRL, 2011)

esa

GHG CCI

MicroCarb Mission



- MicroCarb is a CNES mission concept to measure CO_2 and CH_4 concentrations
  - To quantify CO_2 and CH_4 surface fluxes at regional scales
  - To identify and monitor global carbon sources and sinks
- CO_2 and CH_4 concentration will be retrieved by measurements of absorption of reflected sunlight by CO_2 and CH_4 in near infrared
- Mission design will use technology with moderate development schedule and risks:
  - A compact and low cost concept mission
- Payload is based on a passive optic instrument compatible with a MicroSatellite bus accommodation
  - Opens the way for long-term monitoring of atmospheric CO_2 and CH_4 using a constellation of MicroSat platforms

UKSA-CNES Bilateral Carbon Mission Support Study

The study consists of three major tasks:

1) **Investigation of potential UK contributions to bilateral UK-French mission**
   - Develop specific options for UK contributions to the MicroCarb mission based on the assumption that the instrument itself will be provided by France.

2) **Demonstration of UK technology with an airborne demonstrator**
   - Demonstrate cutting-edge UK instrument technology for GHG observations.

3) **Assessment of Mission Design**
   - Evaluate and optimize the science return.
   - Assess the potential of constellation concepts and for commercial downstream services.

The study started in April 2014 and will finish in September 2015.

Study team Structure

Project Leader
Boesch , UoL

Project Manager
Kelliher, SCL

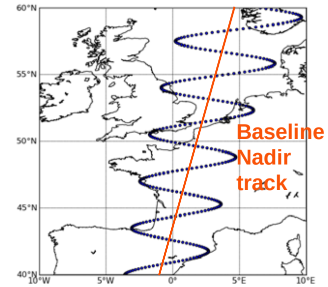
Industry Team
Barnes, Selex
Graham, SSTL
Atkinson, Airbus

Demonstration Team
Boesch, UoL
Vick, UK-ATC

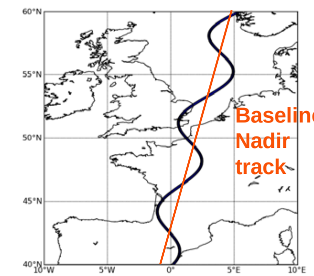
Mission Design Team
Boesch, UoL
Palmer, UoE
Atkinson, Airbus

Orbit and Sampling Strategy

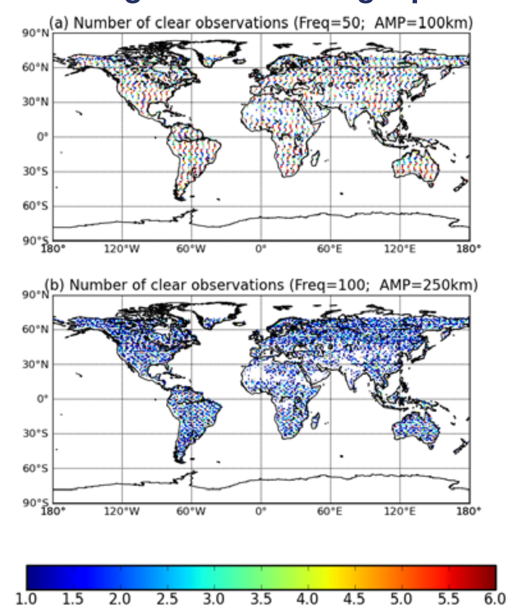
- **MicroCarb missions uses 3 observation modes:**
  - **<u>Nadir</u> mode is primary mode over land with narrow nadir track with 10 km swath**
  - **<u>Sunglint</u> tracking- LoS pointing toward sun glint on ocean to maximise SNR performance**
  - **<u>Target</u> mode- instrument is pointed towards target e.g. on-ground power station**
- **MicroCarb baseline concept assumes pointing of dedicated platform**
- **A payload pointing device would allow:**
  - **Scientific gains by spreading out nadir ground pixels to obtain more independent observations**
  - **Relax the pointing requirements on the platform**
  - **Piggy-backing the MicroCarb payload as a secondary payload (constellations)**



Spreading out Soundings with Pointing Device



Coverage for 2 Pointing Options



Instrument Pointing and Steerability Trade-off

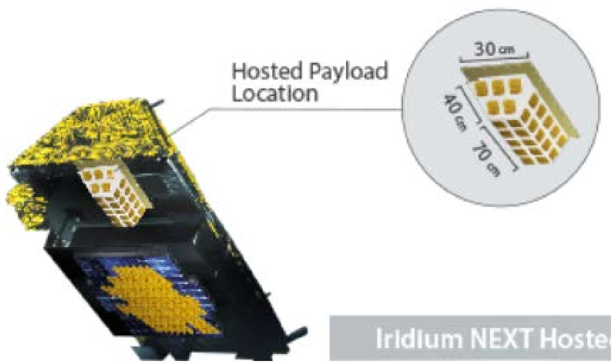
Hosting:

- **Cost effective way by piggy-backing payload as secondary payload by sharing S/C bus between two (or more) payloads with own financial backing**
- **Investigate possibility of sharing spacecraft platform considering requirements on volume, mass, power, data rate, interfaces and pointing needs**

→ identify future candidate missions that could host the BCM payload

Conclusion: a number of options look interesting (e.g. Iridium NEXT constellation). However, few options meet current instrument mass and volume requirements although efforts are underway to decrease these demands

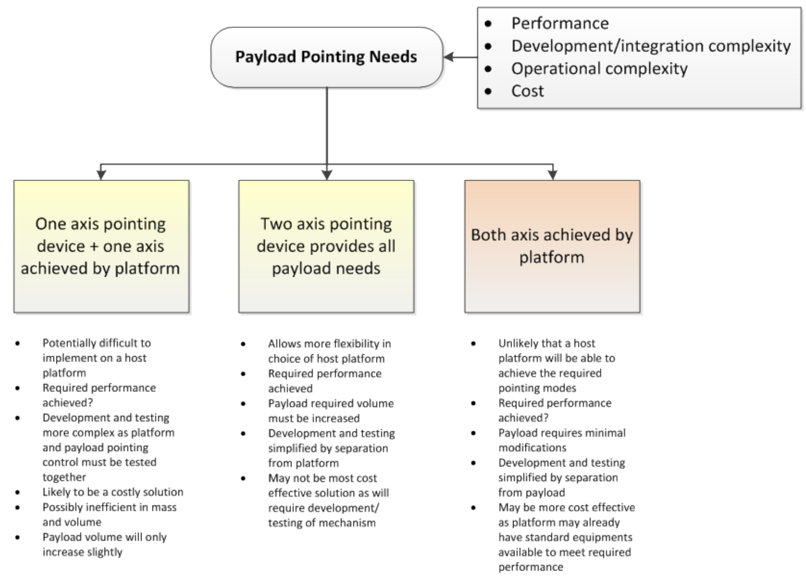
Iridium NEXT constellation consisting of 66 LEO spacecraft



Instrument Pointing and Steerability Trade-off

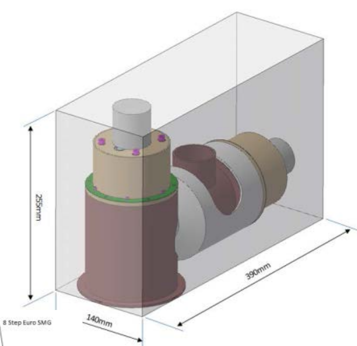
Pointing:

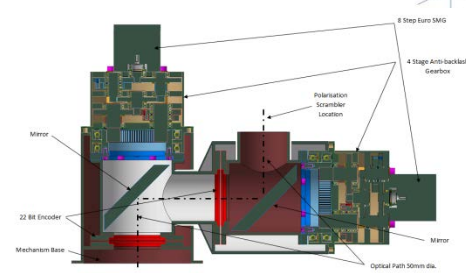
- Investigate options for pointing device for MicroCarb to allow:
  - sharing spacecraft platform
  - additional scientific gains by spreading out ground pixels
  - Technology trade-off based on pointing accuracy & knowledge, agility, mass, power, pointing range



Conclusion: Several devices investigated to meet agility requirements relating to across track sampling. A stepper motor based two axis system may be best to meet both axis requirements with low mass (< 6kg) and low power use (4W)

Two-axis Pointing mechanism Designs





Hosting MicroCarb Payload on UK Platform

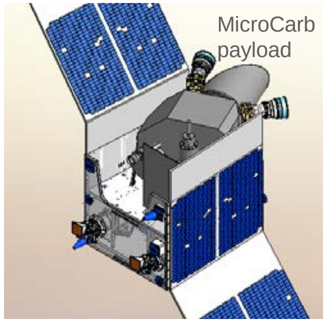
- **Evaluated SSTL platforms for hosting the MicroCarb payload**
- **Main trade-offs: mass, power and thermal budgets, accommodation, pointing requirement, ΔV (orbit maintenance and de-orbiting), launcher options, operational assumptions, data budgets**

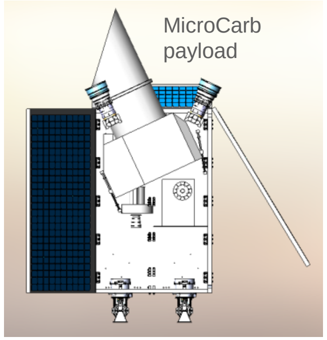
	SSTL-X50	SSTL-150	SSTL-150L
Mass	219kg	275 kg	326 kg
Solar array configuration	Two deployed fixed wings	Two deployed fixed wings	One deployed sun tracking wing
OAP generated	211W	211W	319W
ΔV capability	15.5m/s	20.2m/s	80m/s
Deorbit method	Passive device	Passive device	Propulsion system
Operations concepts supported	b) and c)	a), b) and c)	a), b) and c)

Table 5-8: Summary table

	SSTL-X50	SSTL-150	SSTL-150L
Meets the 200kg limit?	No - provisionally	No	No
CCSDS compatibility?	No	Yes	Yes
Meets the pointing requirements?	Yes	Yes	Yes
Meets the ΔV requirements?	No	No	Yes
Meets the 100% duty cycle requirement?	No	Yes	Yes
Risk level	High	Medium	Low

Table 5-9: Trade off table



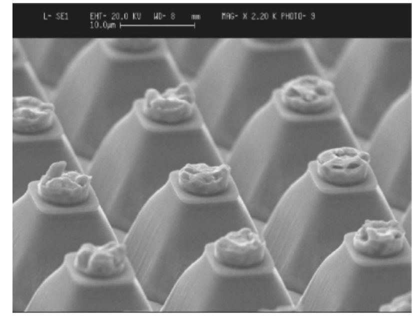


- **SSTL-150 is a potential option with low cost**
- **A lower operational orbit to the OCO A-train orbit and a de-orbit device (e.g. solar sail) would be needed**
- **More work would be needed to reduce launch mass**

- **SSTL-150L option is a strong option which meets all requirements except the launch mass requirement**
- **Higher cost**

UK SWIR Detector Options

- **Baseline CNES MicroCarb instrument design has 2 detectors – band 1 and bands 2/3 with demanding performance requirements**
- **Performance of Selex detectors has been analysed against requirements and compared to other detectors from Sofradir, Teledyne, and Raytheon**
- **Selex large format NIR array (over) achieves most requirements for bands 2/3. Main exception is linearity, owing to source follower design.**
- **Selex has provided recommendations for further work to achieve TRL5 incl.**
    - **Gamma and proton testing of ESA large format array**
    - **Package development**
    - **Optional re-spin of ROIC to include CTIA**



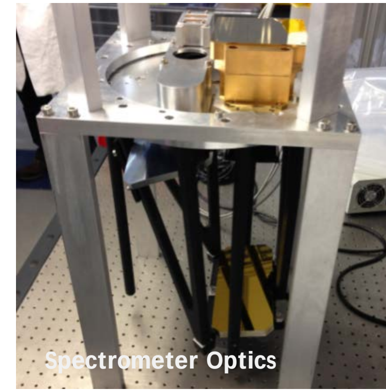
Selex ES has developed a technology to manufacture large NIR/SWIR arrays based on MCT heterostructures grown by MOVPE on GaAs substrates

Parameter	Units	Requirement	Compliance	Selex Achievement
Pixel pitch	µm	15 - 30 TBC	Y	15
Array width	pixels	>1000 TBC	Y	1274
Array height	pixels	>1000 (goal) TBC >256 (threshold)	Y	1024
FWC	e/pix	90k TBC	Y	100k
B1 QE	%	>50 TBC	N	Not currently achieved by Selex MCT but under development. Possible with a separate detector such as a CCD
B2 QE	%	>70 TBC	Y	75% demonstrated in H band
B3 QE	%	>70 TBC	Y	75% demonstrated in H band
PRNU	%	<5 TBC	N	6% demonstrated in H band
Cut-on wavelength	µm	TBD	Y (B2, B3)	1.3 for B2 and B3 response
Cut-off wavelength	µm	TBD	Y (B2, B3)	2.15 demonstrated but easily adapted to 2.3 or higher. The same dark current should be achieved for 2.3 cut-off at temperatures 7% lower.
Dark current	e/pix/s	<2000 @ 150K	Y	8 predicted. Operating temperature could be increased, although read noise has a weak increasing trend with operating temperature
DSNU	%	< 20 TBC	N	50 but note low mean value
Readout noise	e	<50 (goal) TBC <150 threshold	Y	20 CDS
Reading/Integrating mode		Rolling possible	Y	Rolling possible. At nominal 100kHz clock speed, read time per frame is 0.42s (in 32-output mode) up to 3.3s (in 4-output mode)
Operability	%	>99.5	Y	>99.9% routinely achieved with 3-5um MOVPE arrays
MTF		> 0.4 at Nyquist TBC	Y	Predict 0.6 for B2/B3
Power consumption	mW	<200 TBC	Y	34 with 4 outputs 54 with 32 outputs
Linearity	%	0.5 peak to valley 2ke - 70ke	N	3, but see note 1

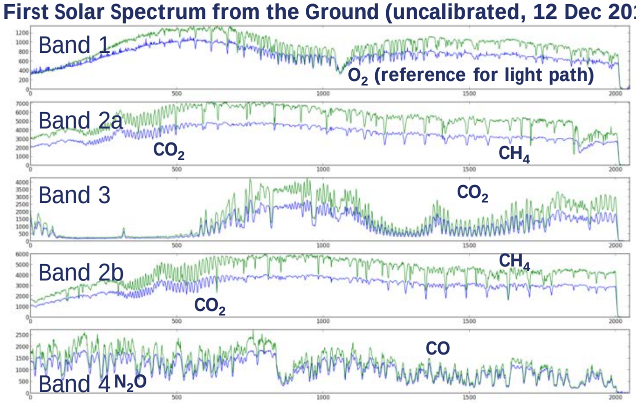
Compliance Table

Demonstration of UK Instrument Technology using GHOST

- **GHOST is a novel SWIR spectrometer designed to simultaneously measure total column observation of carbon gases CO_2, CH_4, H_2O and CO**
  - **Similar technology to MicroCarb and other space-based mission**



First Solar Spectrum from the Ground (uncalibrated, 12 Dec 2015)



- **GHOST is a joint development by U Leicester, U Edinburgh and UK ATC, funded by NERC and STFC**

- **GHOST has been successfully operated on the NASA Global Hawk with data obtained during 2 science flights over the Pacific Ocean (March 2015)**

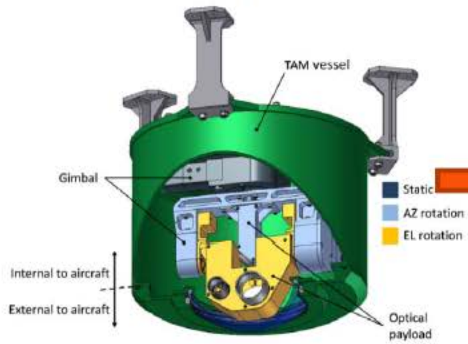
Airborne Demonstration over UK

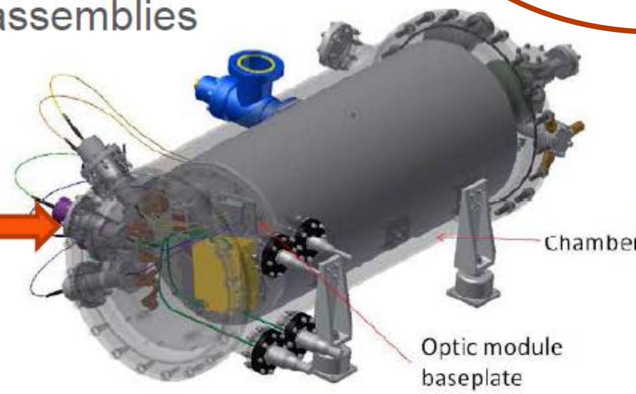
GHOST will be installed and flown in April/May on ARSF aircraft over selected UK emission targets (city, power plants, landfill sites)

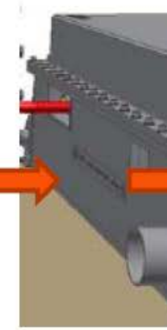
Designed to fly on the Global Hawk UAV at ~53000FT in unpressurised bay (min temp -65°C)

Objective is to fly re-fly instrument on ARSF Aircraft at low altitude (~1000ft)
4 x 2 hour flights in April 2015
MUST BE A CLEAR SUNNY DAY FOR BEST SCIENCE!

GHOST – 3 independent subassemblies







Aircraft communications and control

Target Acquisition Module (TAM) ~30kg

Preference is to use existing TAM on Dornier. However, option to replace with a simplified unit:
- Only needs to point downwards
- Environmental controls should not be necessary

Spectrograph ~140kg

- For 20 hour mission cooled with 9.7kg of LN_2
- Chamber has a vacuum pump to operate at low pressure

Air Transport Rack (ATR)~110kg

- Communications and control system
- Mass attributable to environmental controlled housing

~10kg of harness supplied by NASA to suit Global Hawk electrical layout and configuration
Total mass **~290kg**
Electrical Power ~645W (max. 15A 28V DC).

The Business Case

Two business cases have been investigated: a <u>carbon measurement service</u> and a <u>societal benefit service</u>

- First business case looked at providing carbon measurement service focussed on anthropogenic emissions → lack of regulations at present make this case difficult. However UNFCCC COP 2015 may significantly change this.

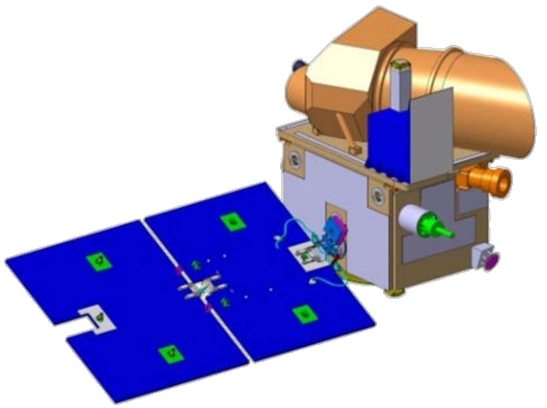
- Alternative business case, 'societal benefit', focuses on:
  - Measuring natural sources and sinks
  - Achieving a more accurate understanding of the global carbon cycle through improved identification and classification (e.g. type, magnitude) and also evolution with time

- Information derived from satellite data will help us to:
  - Understand processes and help to predict the evolution of CO_2 levels
  - See how changing concentrations will impact the Earth's climate and help policymakers to form effective strategies to mitigate impacts
  - Manage mitigation and adaptation strategies (monitor effectiveness of policy)

- Investigating single BCM satellite but could be augmented by constellation → OSSE calculations underway to investigate benefit of 2 satellites at similar or different orbits (e.g. TRMM or ISS).

Conclusions

- The collaboration between CNES and UKSA is a great opportunity for a bilateral carbon mission that can act as a demonstrator for a space-based carbon monitoring system.
- MicroCarb could act as a key gap filler between OCO and the next major carbon mission e.g. Carbonsat?
- The BCM project has shown that UK industry can make key technology contributions to the MicroCarb mission.
- We will also demonstrate UK instrument technology with an airborne demonstrator (GHOST) to be flown in the UK.
- The final project meeting is planned for September and a full project report will become available shortly after.



Any Questions?

CEOI Technology Conference 2015, Cosener's House, Abingdon, 21-22 April 2015