SIRAS-G, The Spaceborne Infrared Atmospheric Sounder:

The potential for high-resolution infrared imaging spectrometry from geosynchronous orbit

ITSC-XIII: Ste. Adele, Canada, 29 October - 4 November 2003
Future Systems and Processing

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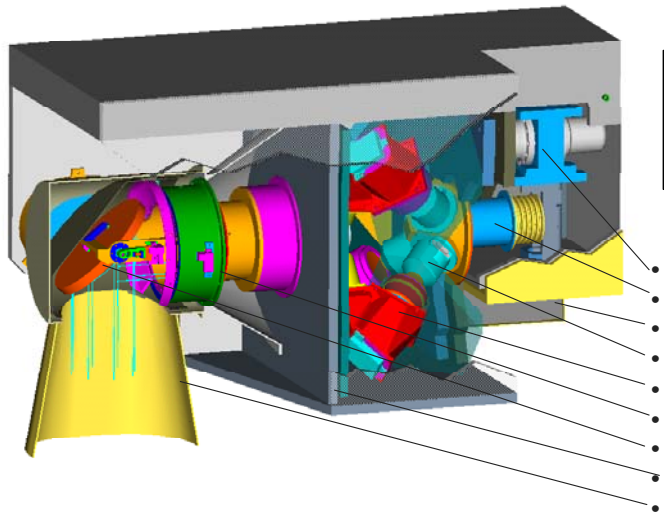
The SIRAS-G Program

- **SIRAS-G: Spaceborne Infrared Atmospheric Sounder for Geosynchronous Orbit**
  - SIRAS-G is an instrument concept for infrared sounding at a moderate spectral resolution ($\lambda/\Delta\lambda$) of 800 – 1100, operating from 3.7 – 14.8μm
  - Grating spectrometers provide fine spectral separation
  - The flight instrument divides this spectral range into 4 spectrometer channels



	SIRAS-L	SIRAS-G
Size	0.13 m^3	0.19 m^3
Mass	50 kg	50 kg
Power	100W	100W
Rate	1.42 Mbps	2.5 Mbps

Table 1. SIRAS-G Grating Spectrometers

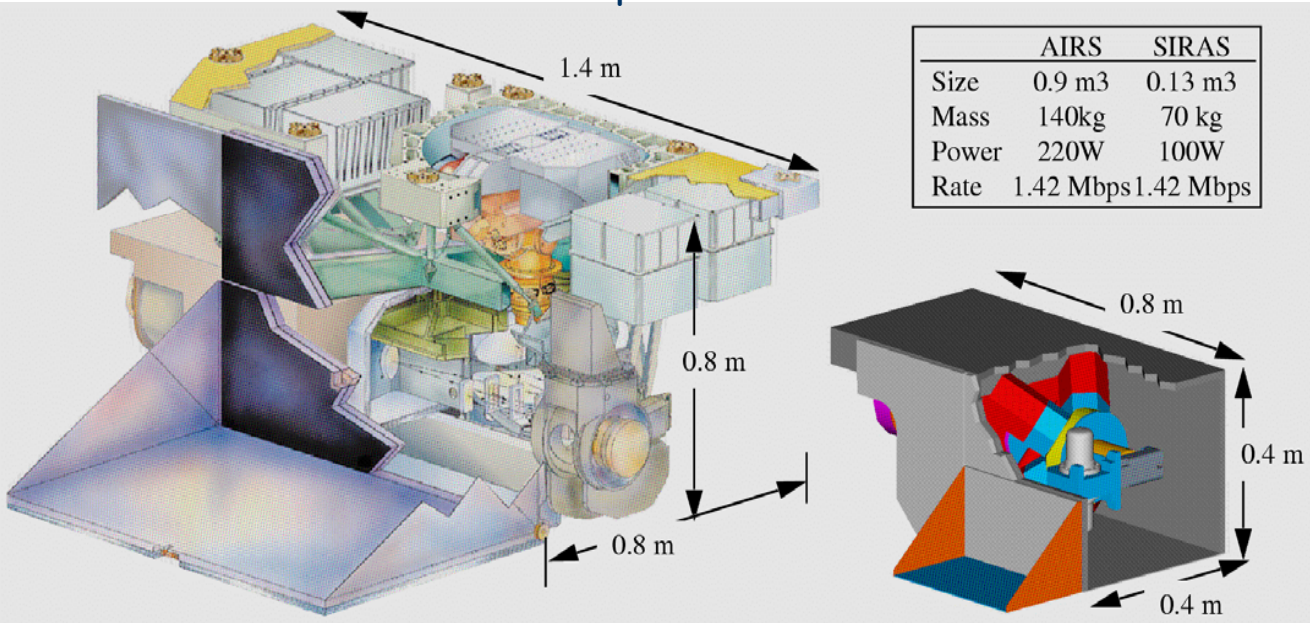
Spect	Band (μm)	Comments
1	3.7-4.8	Design in 2003 IIP
2	6.2-8.22	Design in 2003 IIP
3	8.8-12.0	Build in 2003 IIP
4	12.3-14.8	Built in 1999 IIP

*** Common Spectrometer, FPA, Dewar, and Cooler Design for LEO or GEO**

- **SIRAS-G was selected for NASA's Instrument Incubator Program in January 2003**
- IIP was developed to foster the **development of innovative remote-sensing concepts** and the assessment of these concepts in ground, aircraft, or engineering model demonstrations.
- New and innovative technologies targeted to future flight instruments that are **smaller, less resource intensive, less costly, and require less build time**.
- By investing early in the development life cycle of an instrument and **demonstrating performance in ground based or aircraft instrumentation**, flight builds will also encounter less development risk and therefore less cost and schedule uncertainty.
- The Program's aim is to provide a continuing source of mature instrument designs merging state-of-the-art technologies with measurement objectives available for use in the next generation of Earth science missions.

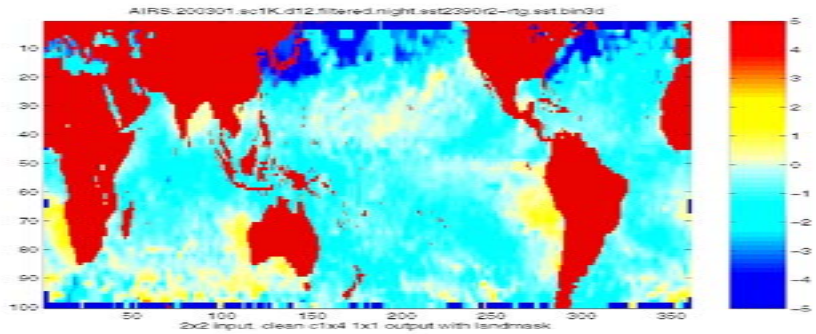
History

- SIRAS was originally conceived as a smaller, lower mass, less costly follow-on instrument for AIRS (Atmospheric Infrared Sounder)
- In 1999, JPL headed up the Spaceborne Infrared Atmospheric Sounder (SIRAS) IIP
  - PI: Harmut Aumann (JPL, Chief Scientist on AIRS)
  - Technical Lead: Tom Pagano (JPL, AIRS Program Manager)
  - Ball Technical Lead: Tom Kampe

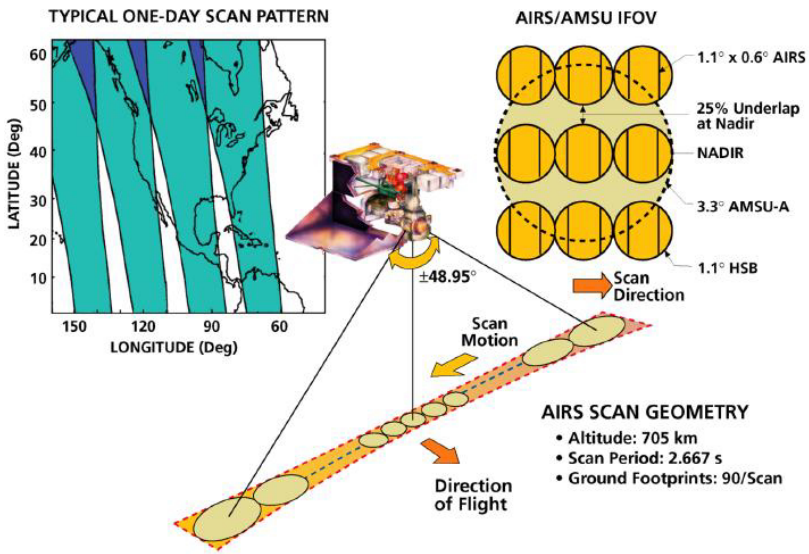


	AIRS	SIRAS
Size	0.9 m3	0.13 m3
Mass	140kg	70 kg
Power	220W	100W
Rate	1.42 Mbps	1.42 Mbps

History

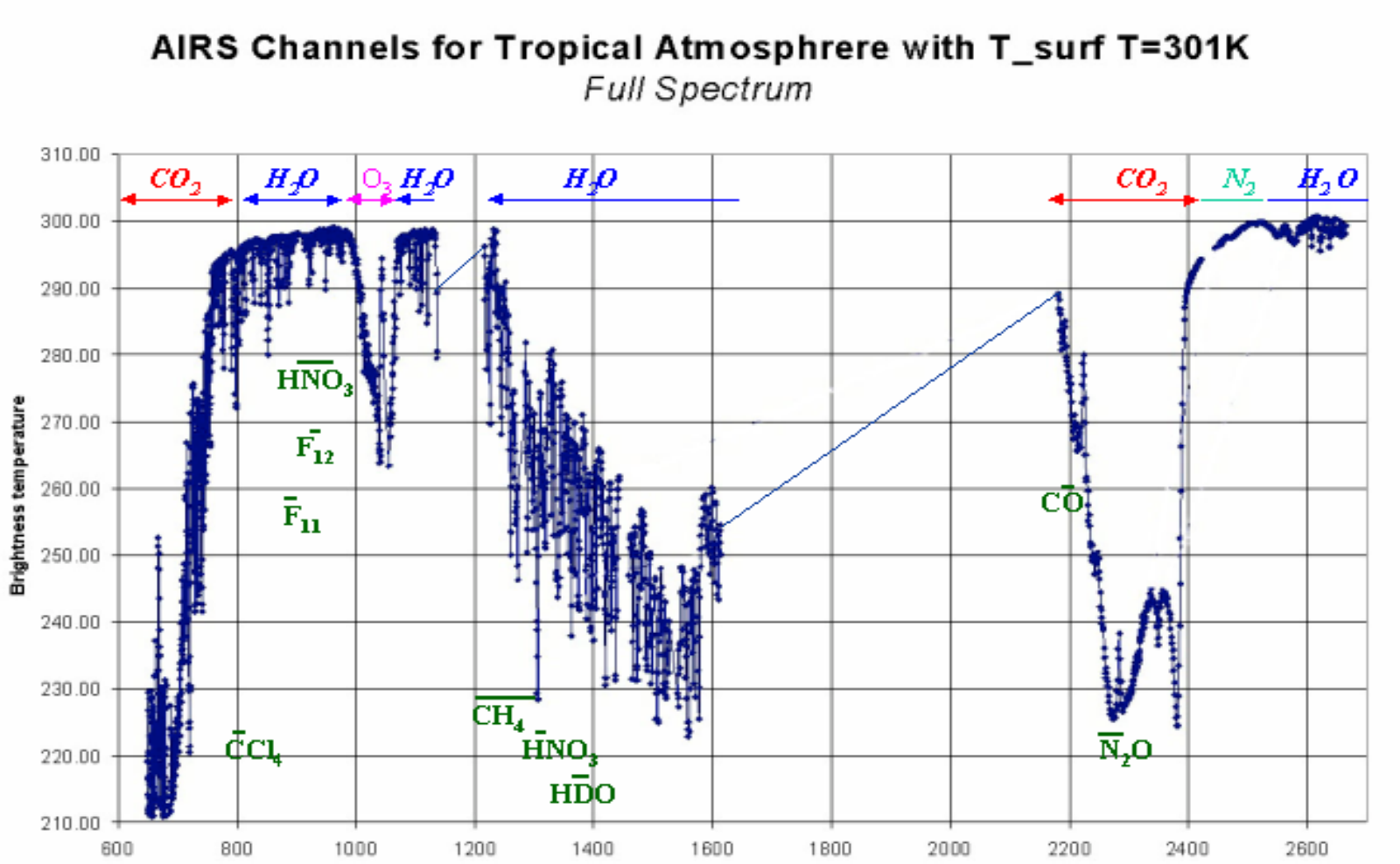


T.AIR-T.Surf for January 2003



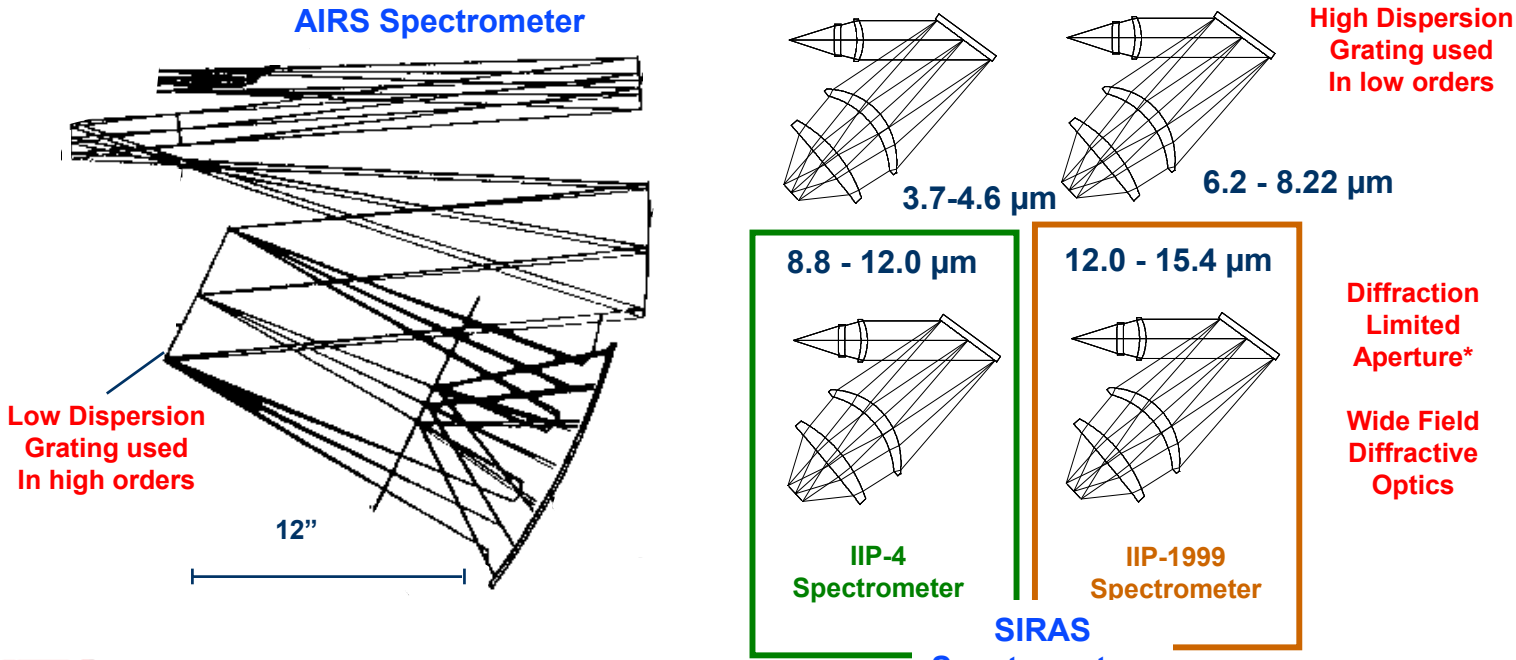
- AIRS is an IR Sounder making highly accurate measurements of air temperature, humidity, clouds, and surface temperature
- The data collected by AIRS will be used by scientists around the world to better understand weather and climate
- AIRS is one of six instruments onboard NASA's Aqua spacecraft launched May 2002
- The PI on AIRS is Dr. Moustafa Chahine (JPL)

AIRS Provides High Spectral Resolution



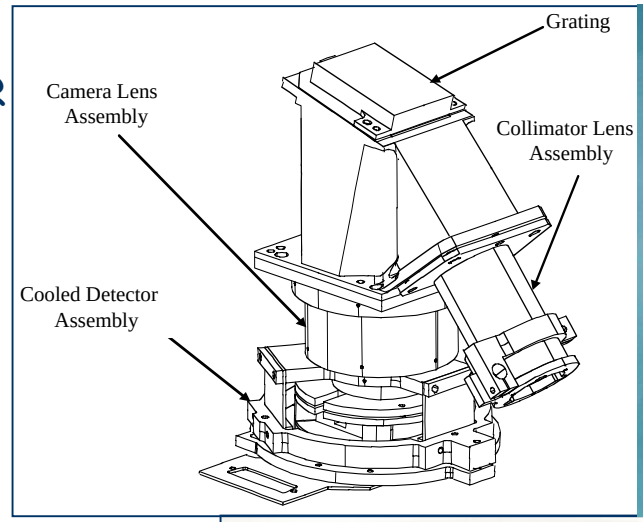
Follow-On To AIRS

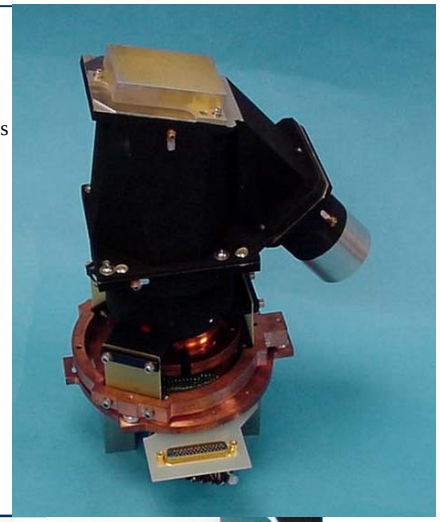
- SIRAS replaces the single large eschelle grating in the complex pupil-imaging instrument architecture of AIRS with 4 spectrometer modules
- This leads to reduced total mass, volume and power
- On the SIRAS Program, we designed, built, and tested one of the 4 spectrometer modules

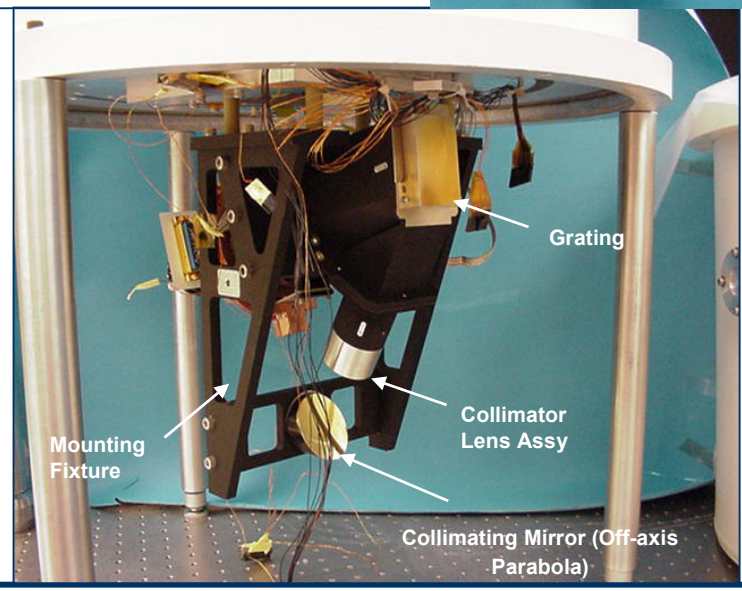


SIRAS-1999 IIP - What Was Achieved?

- We designed, built and cryogenically tested the LLWIR (12-15.4μm) spectrometer
  - Selected the LLWIR spectrometer since it represented the greatest challenge (material choices, detector cut-off, etc.)
- Developed test facilities for testing the spectrometer at cryogenic temperatures
- Integrated an AIRS M1 detector array (on-loan from the AIRS program) and used a detector test set loaned from LMIRS
- Developed data collection and control software
- **This effort completed in 12-months**

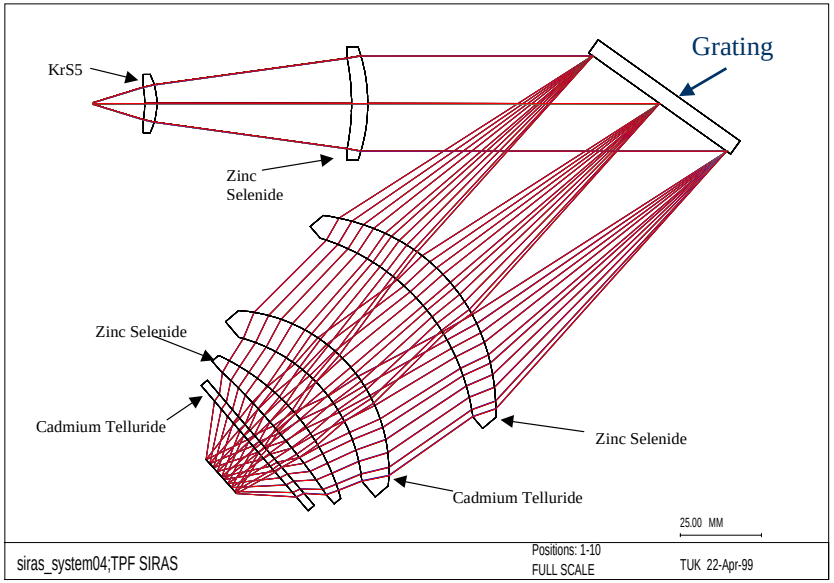






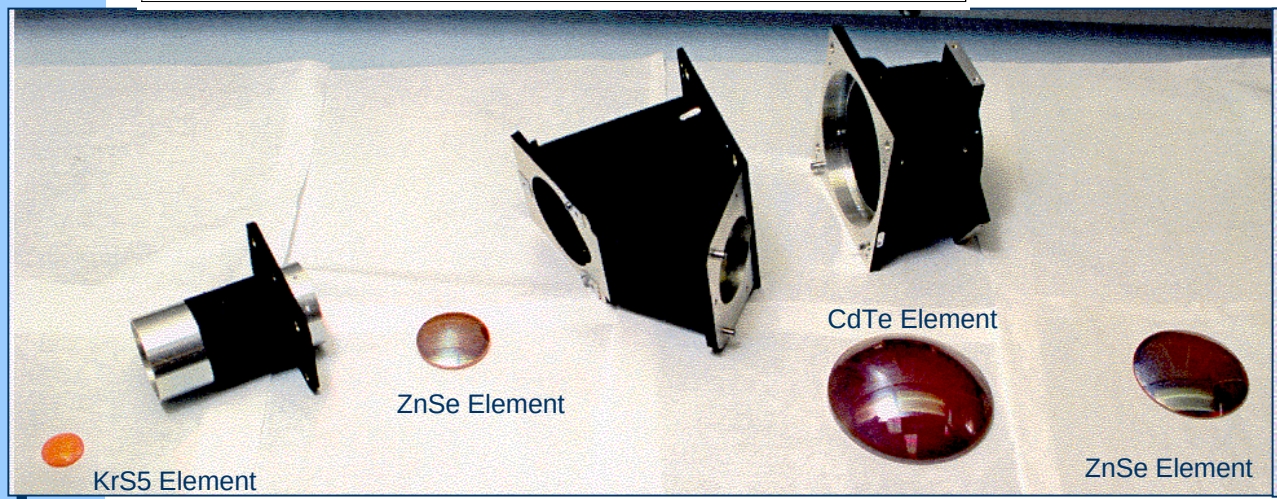
SIRAS SPECTROMETER IN TEST DEWAR

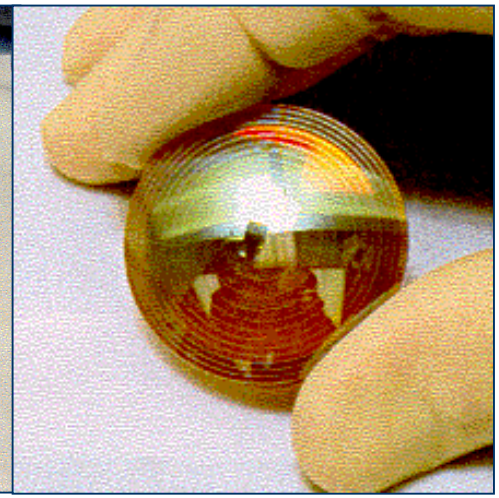
SIRAS-1999



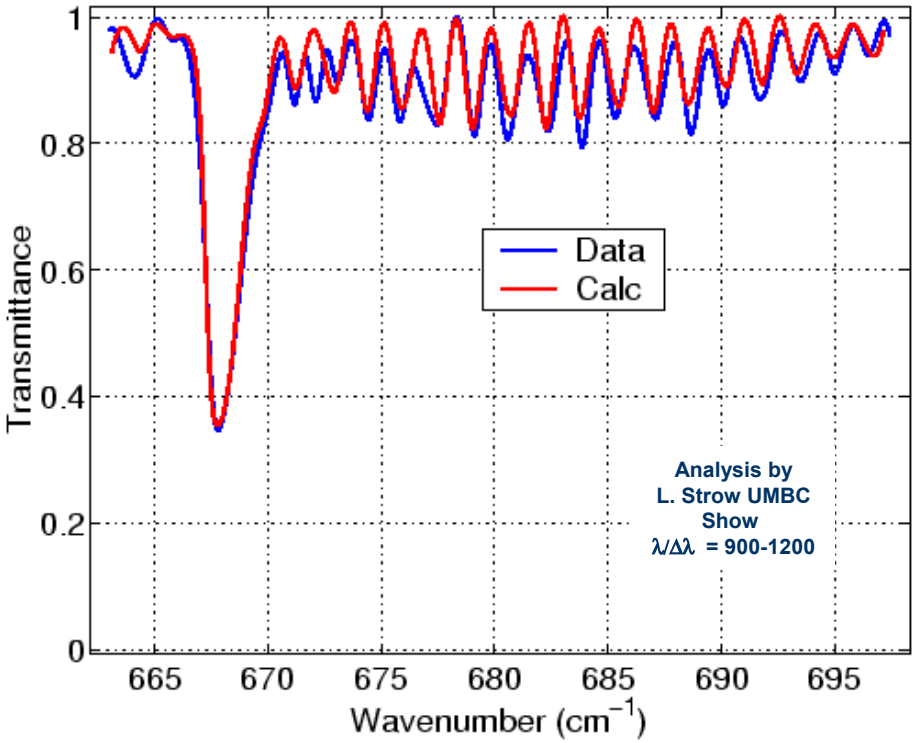
Optical Subassemblies

- 2-element Collimator
  - E1: All-spherical KrS5
  - E2: Hybrid asp/diff ZnSe
- Plane Grating
- 3-element Camera
  - E3: ZnSe element w/asp
  - E4: All-spherical CdTe
  - E5: Hybrid asp/diff ZnSe

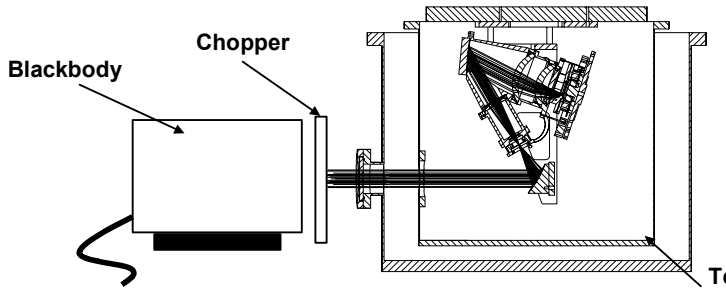


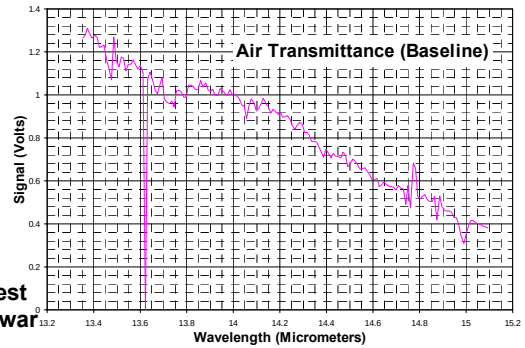


Excellent Spectral Performance on SIRAS-1999



- Measured data were analyzed for spectral resolution by comparing them to theoretical 3-m path atmospheric transmission spectra with varying spectral response widths
- Response widths were varied until the resulting convolved modeled spectra matched the measured spectra
- Measured CO_2 spectra show spectral resolution (>900) achieved



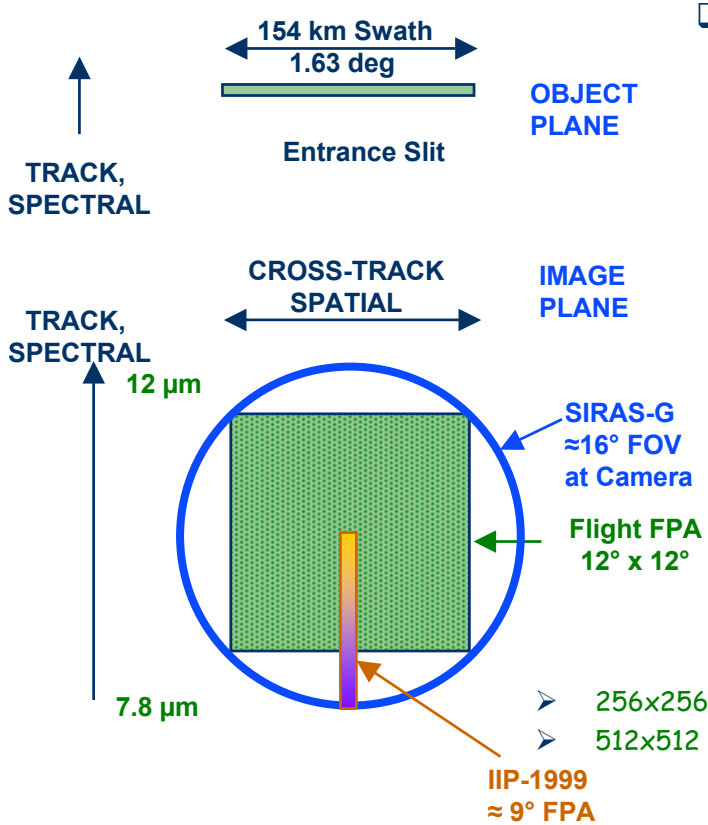


What is SIRAS-G?

- SIRAS-G is an instrument concept for an Infrared Sounder in Geosynchronous Orbit
- SIRAS-G utilizes grating spectrometer technology based on AIRS and SIRAS-1999 heritage
- The purpose of the SIRAS-G IIP program is to further develop the SIRAS-G concept and build a laboratory hardware demonstration
  - Increase Technology Readiness from TRL-3 to TRL-5 or 6
  - Demonstrate an workable end-to-end system incorporating new technologies including:
    - Refractive grating spectrometers
    - Optically-Enhanced FPA Dewar
    - Active Cooling

How Does SIRAS-G Differ From SIRAS?

SIRAS-G Provides Broad Spatial Coverage



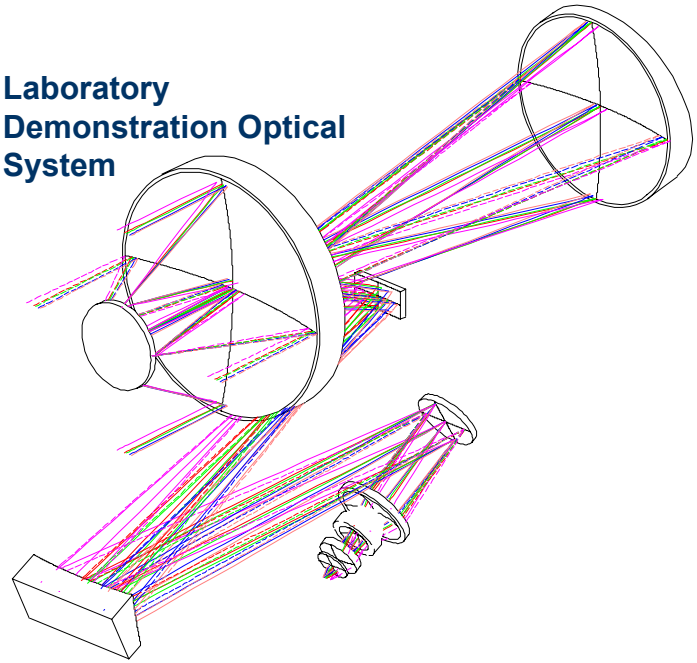
- The Spectrometer on SIRAS imaged a single ground IFOV. The spectrum was dispersed along a linear detector array.
- In SIRAS-G, we will be building a true imaging spectrometer
  - Here, we have an appreciable spatial FOV in the camera of 16^0 imaged along rows of detectors
  - Spectral information dispersed in the orthogonal direction, along columns of detectors
  - Control of Spectral Smile and Keystone Distortion are critical
    - In the baseline optical design, these are controlled to less than 25% of a pixel across the full FOV

- 256x256 @ 40 µm for SIRAS-G IIP
- 512x512 @ 20 µm for Flight

Laboratory Demonstration Instrument

- Goal is to design, build and test a nearly-complete instrument including:
  - A Telescope
    - A 3-mirror anastigmat is baselined for the flight instrument, but…
    - We will use an on-axis obscured Ritchey-Chrieten telescope w/field flattener due to funding constraints.
    - The lab demo instrument only operate over a limited wavelength range
  - A Reflective collimator
  - Spectral selection module (beamsplitter assembly)
  - A single spectrometer module (8-12 μm baseline)
  - A 128x128 (Engineering Grade) Focal Plane Array
  - An Optically-Enhanced Cryogenic Dewar
  - A BATC SB235 Active cooler

Laboratory Demonstration Optical System



Ball SB235 Cryocooler Parameters

- 3rd Generation Multi-stage 35 K Cooler
- Performance: 0.5 W @ 40 K & 3.5 W @ 100 K for 90 W motor
- 99% reliability at 10 years
- 10.5 kg mass
- Verified non-contacting operation over wide temperature range (-60 to +80 ^{0}C)
- Active vibration isolation to below 0.10 N
- Fixed-regeneration cold finger capable of withstanding high side loads
- Inherently insensitive to 1-g orientation
- Proven and verified EM control features

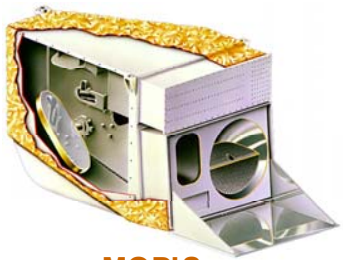
System Configuration Studies

- The feasibility of applying SIRAS to a variety of high-priority Earth science missions will be explored. Candidate missions include:
- **Next-Generation Environmental Sounder from GEO**
  - Requirements for next generation GEO IR sounder were baseline for SIRAS-G concept. A 1.0-milliradian IFOV would provide a ≤ 5 km ground footprint with an 8" aperture.
  - Unlike competing technologies, SIRAS has no moving parts, requires no transforms to obtain spectra, and uses proven AIRS spectrometer technology and data processing algorithms.
- **Geostationary Atmospheric Chemistry Mission**
  - SIRAS-G as part of an instrument suite to measure trace gases such as CO, CH_4 and NO_x, & O_3.
  - The combination of a SIRAS-G derivative and a multi-channel high-resolution spectrometer such as the IMOFPS, would provide these measurements in a compact, solid-state instrument suite.
  - IMOFPS consists of three co-boresighted correlation spectrometers for determining vertical profiles of CO and column amounts of CO_2 and CH_4. The addition of a fourth spectrometer channel for measuring NO_x would provide a tracer of motion and cloud detection.
  - A two-channel version of SIRAS-G, one channel extending from 12.3-μm to 15-μm and a second centered at the 9.6-μm ozone band, with spectral resolution "tuned" appropriately in both channels, would provide temperature and water vapor sounding and ozone column.
  - All instruments in this suite again have no moving parts, except for a scene selecting scan mirror.

AIRS Follow-On

- SIRAS-L offers the high spatial resolution of MODIS and the high spectral resolution of AIRS.
- The presence of clouds significantly degrade the ability to achieve accurate temperature and water vapor retrievals.
- Future atmospheric sounding systems will require greatly enhanced spatial resolution. SIRAS-L offers a ground footprint of less than 0.6 km (as compared to AIRS at 13.5 km) without sacrificing SNR. The system is used in "pushbroom" mode to maximize integration time.

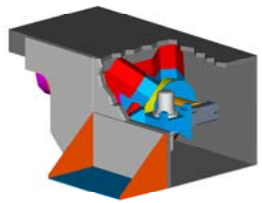
EOS Terra, Aqua



MODIS
- 1 km IR IFOV
- 3.7-14.2 µm IR
- 16 IR Channels
- $\lambda/\Delta\lambda$ = 20-50
- NEdT = 0.05 - 0.3 K
- Refractive Optics
- ± 55° FOV

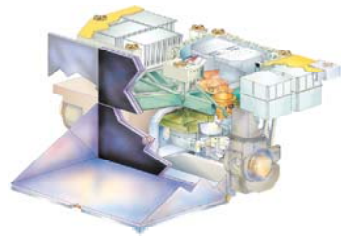
The Spaceborne Infrared Atmospheric Sounder for LEO (SIRAS-L)

Future Concept



SIRAS-L
- 0.6 km IR IFOV
- 3.7-15.4 µm IR
- 1024 IR Channels
- $\lambda/\Delta\lambda$ = 1000
- Refractive Optics
- Grating Spectrometer
- NEdT = 0.1 - 0.3 K
- 15° FOV

EOS, Aqua



AIRS
- 13.5 km IR IFOV
- 3.7-15.4 µm IR
- 2378 IR Channels
- $\lambda/\Delta\lambda$ = 1200
- Grating Spectrometer
- NEdT = 0.05 - 0.3 K
- ± 50° FOV

Other Opportunities – ESTO Measurement Priorities

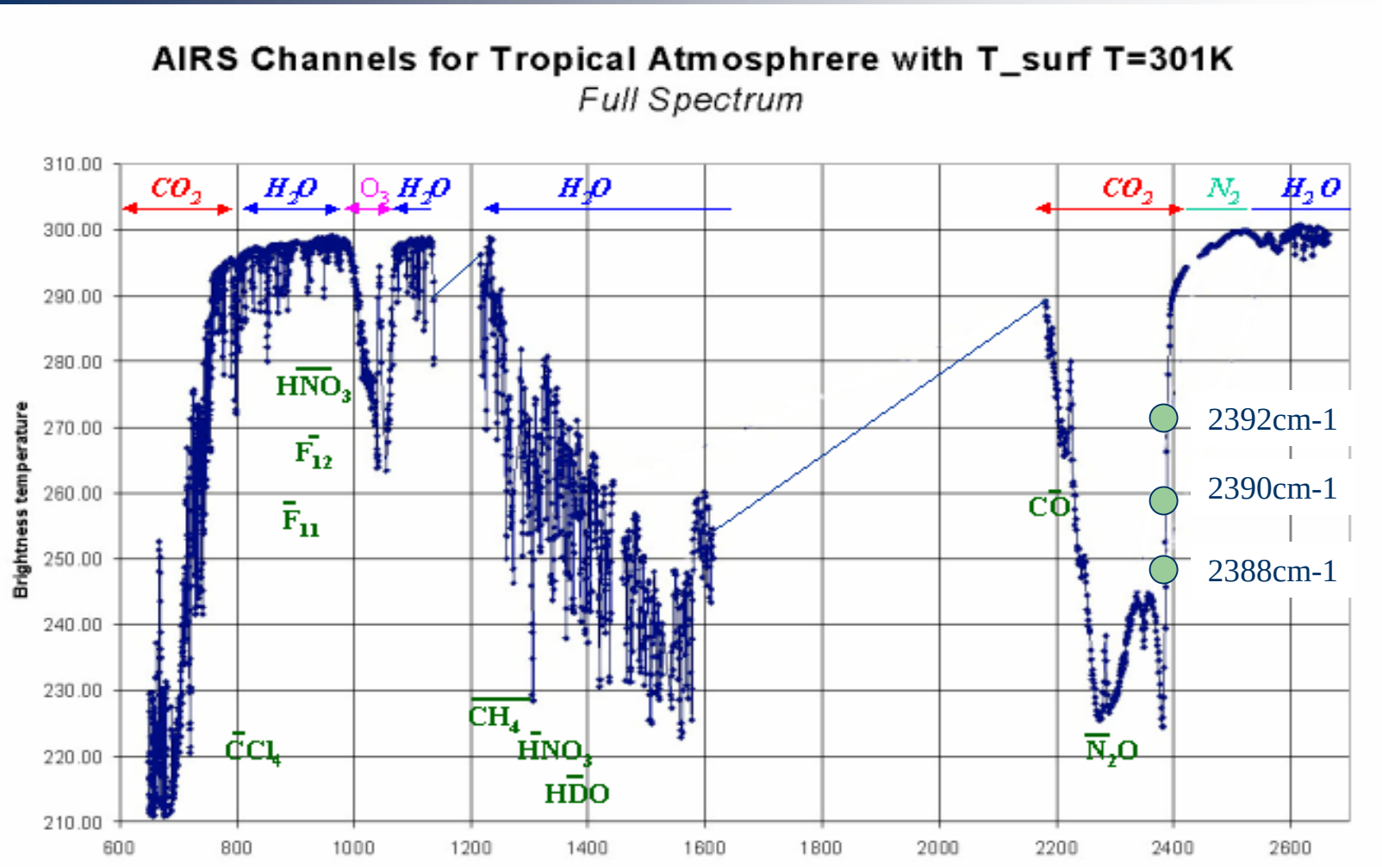
- IR Sounder for measuring cloud system structure, winds, ozone, trace gas precursors, temperature & water vapor profiles from GEO
  - 4x4 km spatial resolution
  - 0.3 cm^{-1} spectral resolution
  - Cryo-cooling to 70K
- IR Sounder to measure SST from LEO – measure atmospheric temperature & water vapor profiles, land surface temperature, cloud properties, radiative energy flux
  - ~2400 high-spectral resolution bands from 3.7-15.4μm
  - WFOV IR optics
- IR Sounder for measuring storm cell properties from UAV
  - Measure temperature and water vapor profiles in and around storm cells
  - 0.5 cm^{-1} spectral resolution over 3.6-15.4 μm
  - SIRAS ideally suited to application since it has no moving parts and it is extremely robust

The high spectral resolution and SNR possible with the SIRAS instrument opens new measurement capabilities to the weather forecasting

As an example we use AIRS data to measure T.air-T.surf for January 2003.

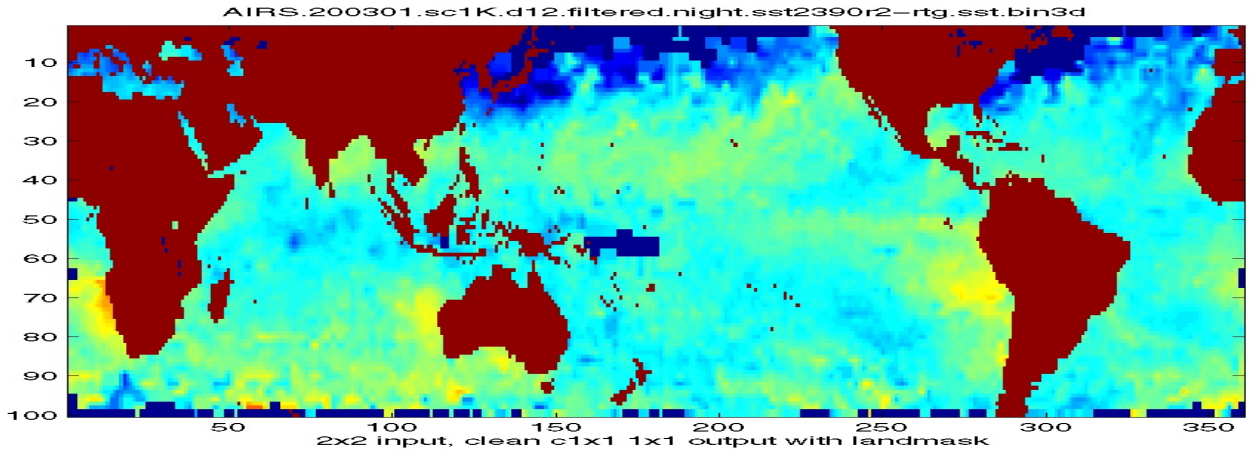
The 4.3um co2 RBranch provides a unique, essentially moisture independent measurement of the lapse rate

4.3um co2 RBranch data for global T.AIR-T.Surf measurements



The 4.3um co2 RBranch provides a moisture independent measurement of the lapse rate

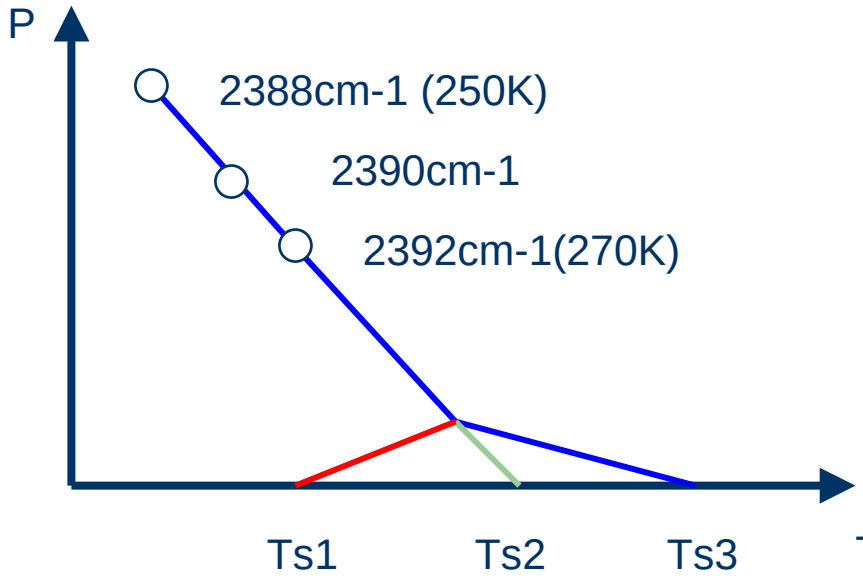
4.3um co2 RBranch data for global T.AIR-T.Surf measurements



inversion

normal

warm water under cold air



Ts2390=predicted Tsurf based on 4.3um RBranch lapse rate

Ts2390 == Ts2 normal case

Ts2390 == Ts3 surface warmer than expected

Ts2390 == Ts1 inversion if sst2616==rtg

Summary

- SIRAS represents a versatile approach to infrared imaging spectroscopy
- The SIRAS-G program will provide a hardware demonstration of this technology
- Our goal is to increase the technology readiness of this technology (TRL-6)
- Will explore the applicability of this technology to wide range of NASA Earth Science priorities
- A Long-term goal is to find an an airborne opportunity for SIRAS-G
  - Goal would be to obtain actual atmospheric temperature and water vapor (and possibly, trace gas) data from an airborne platform
  - This would go a long way in boosting confidence in this instrument concept in the scientific community

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The potential for high-resolution infrared imaging spectrometry from geosynchronous orbit

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