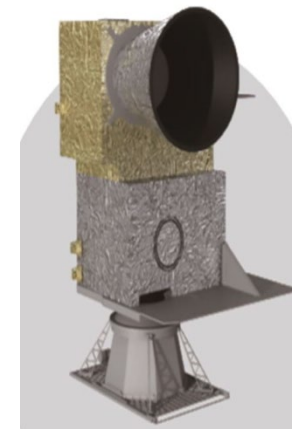


4 October 2017



**GIIRS  
(NSMC/CMA)**

# **Hyperspectral Imaging Infrared Sounding from a Geostationary Orbit**

**Hank Revercomb, Bill Smith, Bob Knuteson,  
Dave Tobin, Joe Taylor, Fred Best, Jon Gero**

**University of Wisconsin - Madison  
Space Science and Engineering Center (SSEC)**



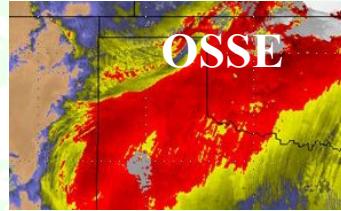
**ITSC-22  
Saint-Saveur, Canada, 31 Oct - 6 Nov 2019**



# Expeditious implementation of GEO HIIS



A. Why GEO

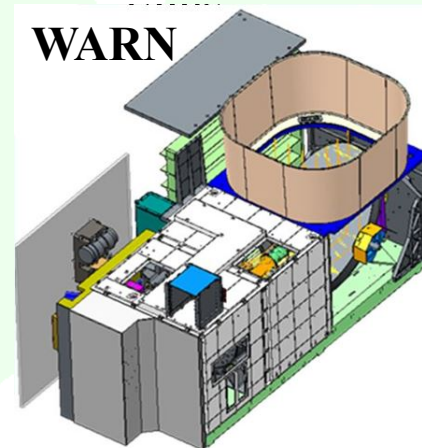
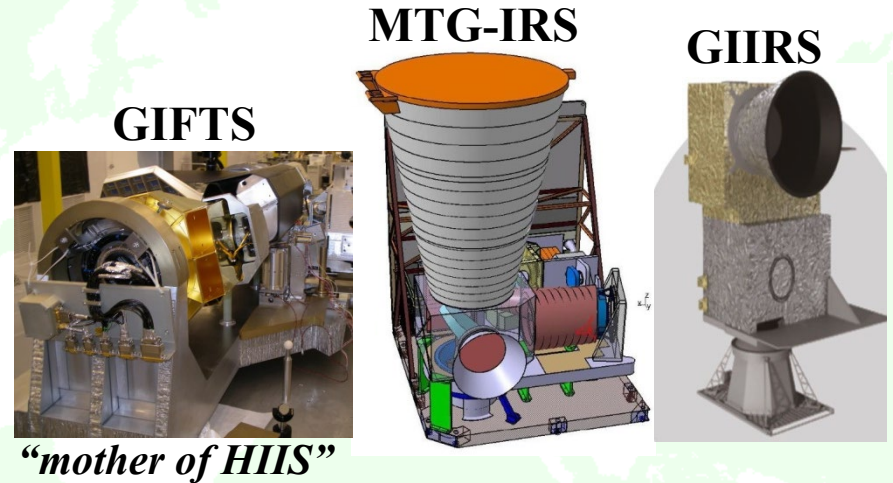


B. History 

C. WARN: a NASA Earth Venture Proposal

2 US Pathfinder Options

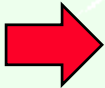
D. ABX: Harris/UW NOAA White Paper



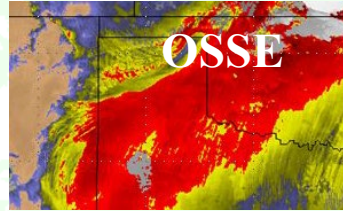
ABX from ABI



# Expeditious implementation of GEO HIIS



A. Why GEO



B. History

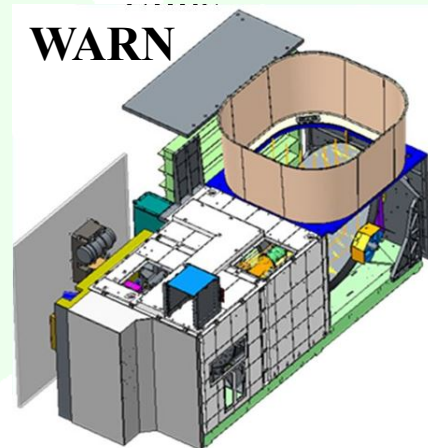
C.

*Unique capability for early severe weather alerts & a global NWP "game changer"*

D. ABX: Harris/UW  
NOAA White Paper



Proposal 2 US Pathfinder Options

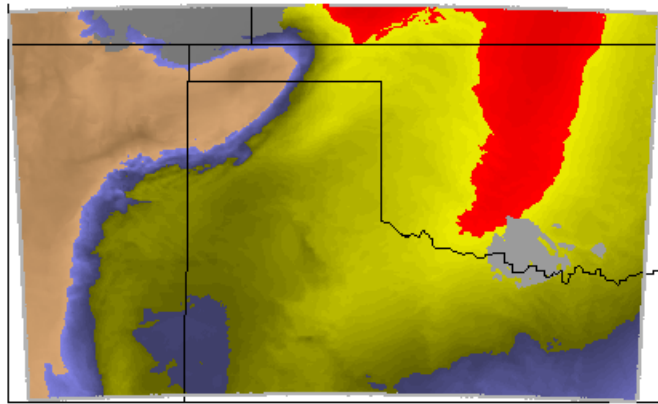


ABX from ABI

# OSSE of GEO advanced IR sounder for storm nowcasting

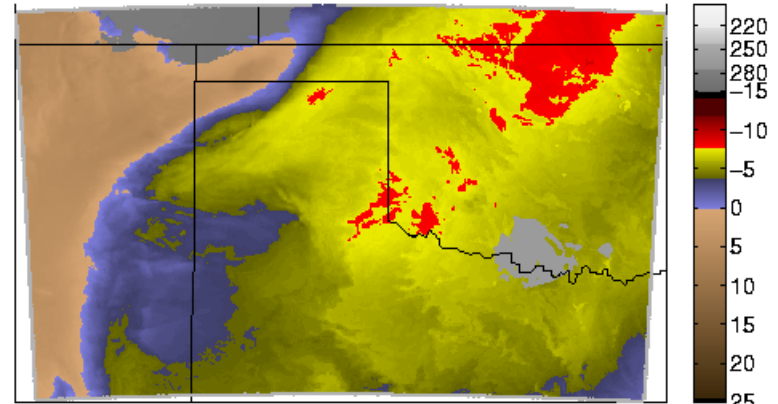
**True**

06-12-2002, 1200 UTC  
Lifted Index [°C]



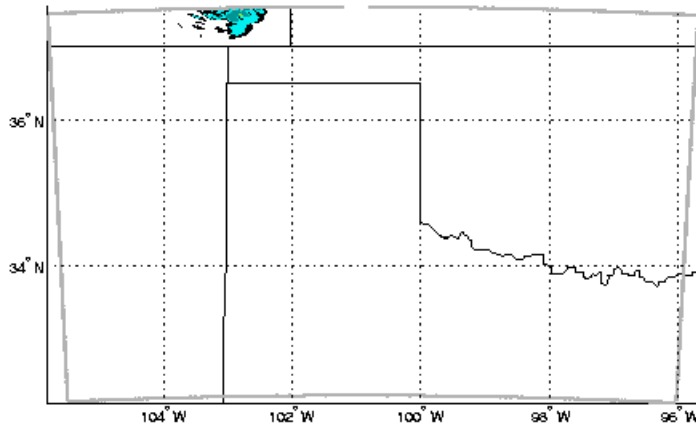
**GIFTS/HES/IRS**

06-12-2002, 1200 UTC  
Lifted Index [°C]



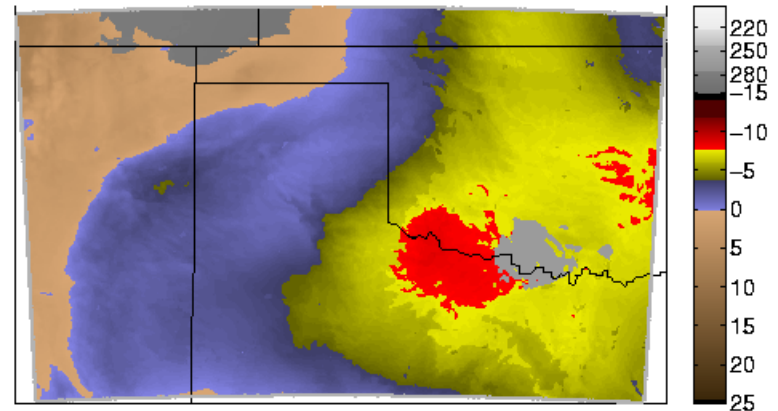
*Red = extreme instability*

06-12-2002, 1200 UTC  
Radar reflectivity [DBZ]



**Simulated Radar**

06-12-2002, 1200 UTC  
Lifted Index [°C]



**ABI/GOES Sounder like**

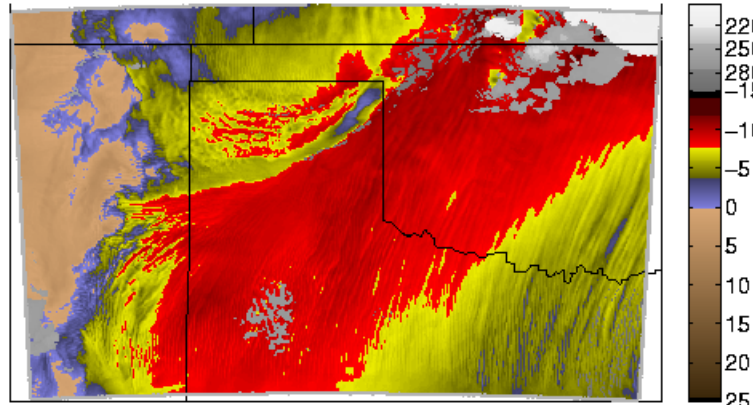
*Oldy but Goody from Jun Li: Shown at 2010 AMS*

*Accurate Lifted Index pattern sensed 2 hours before Radar rain*

# OSSE of GEO advanced IR sounder for storm nowcasting

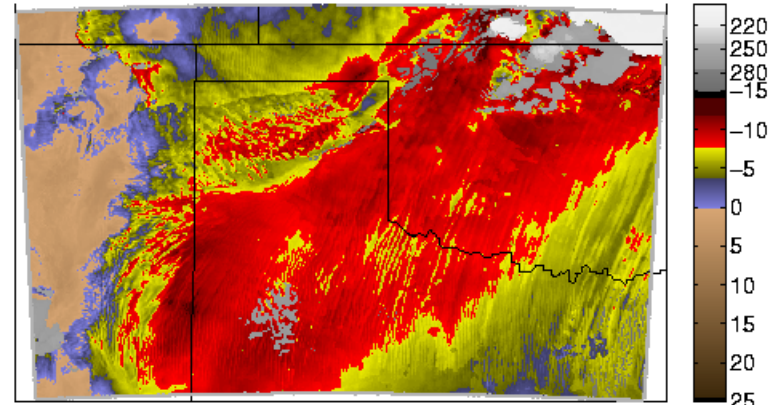
**True**

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Lifted Index [°C]

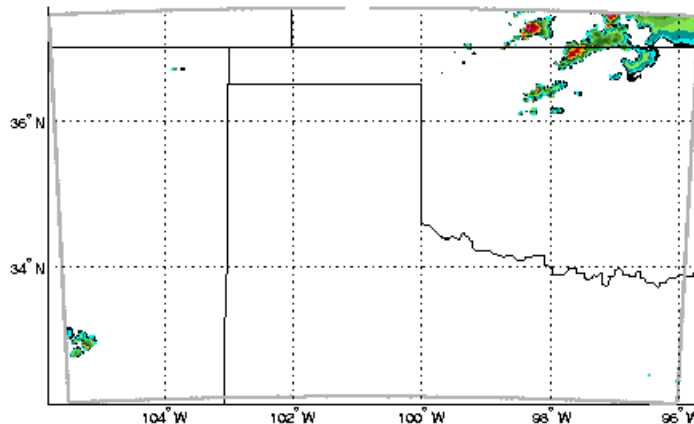


**GIFTS/HES/IRS**

06-12-2002, 1900 UTC  
Lifted Index [°C]

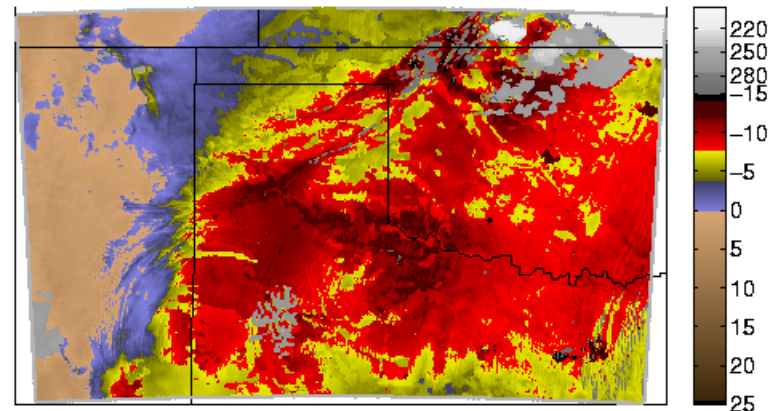


06-12-2002, 1900 UTC  
Radar reflectivity [DBZ]



**Simulated Radar**

06-12-2002, 1900 UTC  
Lifted Index [°C]



**ABI/GOES Sounder like**

***Oldy but Goody from Jun Li: Shown at 2010 AMS***

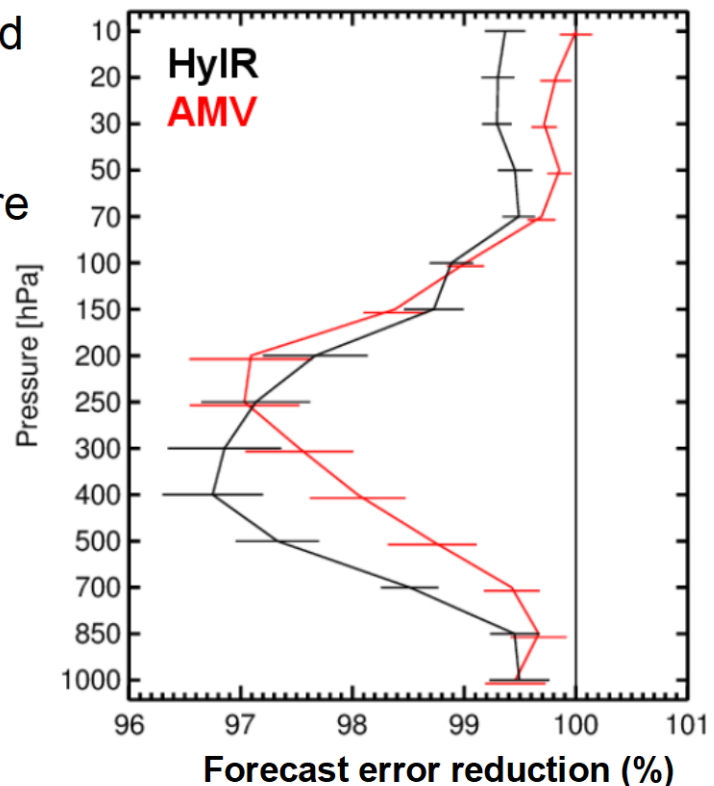
***Accurate Lifted Index pattern sensed 2 hours before Radar rain***

# Global Impact on Wind Forecasts

## Wind tracing hyper-spectral IR humidity in 4D-Var

- Current hyperspectral IR sounders onboard LEO spacecraft provide a **significant amount of wind information** to the ECMWF NWP system (more than the entire AMV network)
- Most of this this wind information comes from **4D-Var tracing** the movement of in atmospheric humidity structures in the radiance data
- This impact increases with **more frequent time sampling**

Global impact on wind forecasts verified by comparison radiosonde network



From 'Satellite observation use at ECMWF...and a role of hyper-spectral GEO', Tony McNally

See also: "Enhancing the hyperspectral infrared radiance assimilation in the ECMWF system", Kirsti Salonen, presentation 9.02 ITSC-22

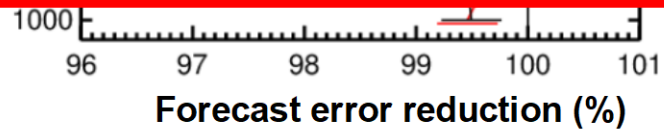
# Global Impact on Wind Forecasts

## Wind tracing hyper-spectral IR humidity in 4D-Var

Global impact on wind forecasts verified

- This increasing wind impact with increasing time sampling shows no sign of saturation ...so we expect hyperspectral radiances with GEO time sampling to deliver a very significant impact on NWP winds!

time sampling



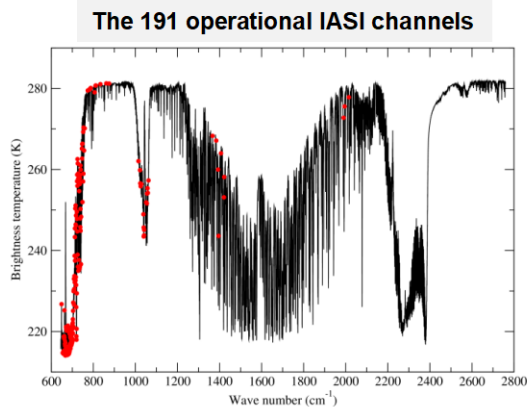
From 'Satellite observation use at ECMWF...and a role of hyper-spectral GEO', Tony McNally

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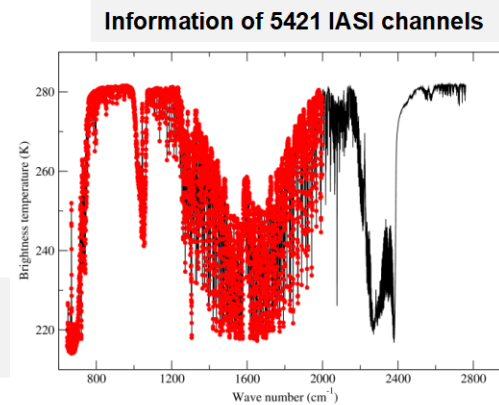


# Improving hyper-spectral IR assimilation techniques

## Exploiting the full IR spectrum with PCA



Assimilating 400 reconstructed radiances

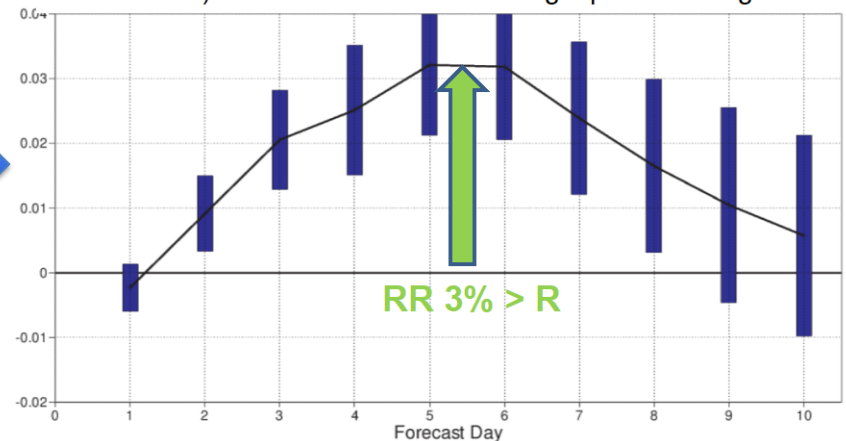


By assimilating the full IASI LW/MW spectrum via reconstructed radiances derived from truncated PCA we can extract even more forecast impact from these observations.

Latest results show PCA/RR consistently outperforming traditional radiance channels assimilation



Improvement (compared to operational IASI radiance baseline assimilation) in SH forecasts of 500hPa geopotential height





# GEO Hyperspectral IR Imaging Sounder capability is unique

## *A 4D-Var measurement for 4D-Var problem*

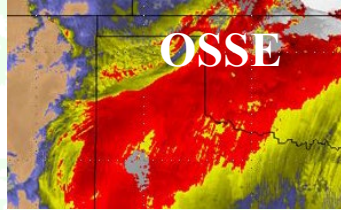
Unique capability for early severe weather alerts & a global NWP “game changer”

- **Polar Operational Sounders:**  
Inadequate temporal coverage
- **GPS:** Inadequate spatial resolution and temporal coverage
- **ABI GEO Imager:**  
Inadequate vertical resolution
- **GEO Microwave:**  
Lower vertical resolution
- **SmallSat Swarm:** Cannot concentrate resources on regions of current severe threats & capability not yet proven

# Expeditious implementation of GEO HIIS



A. Why GEO



B. History



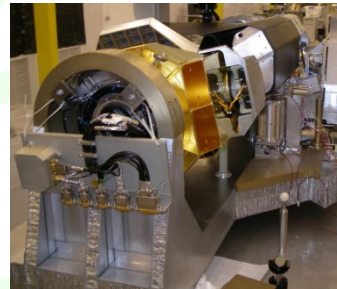
C. WARP

D. WARP

**Mature Technology & Happening in Asia & Europe**

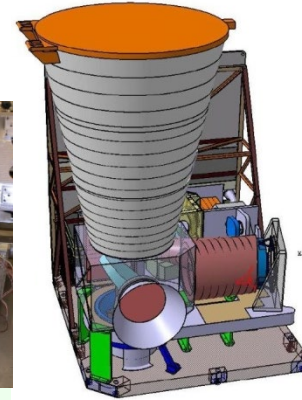
WARP White Paper

GIFTS

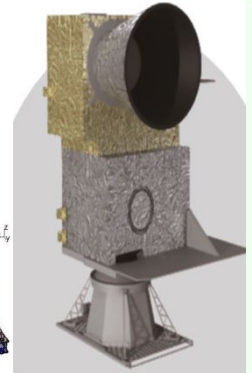


"mother of HIIS"

MTG-IRS



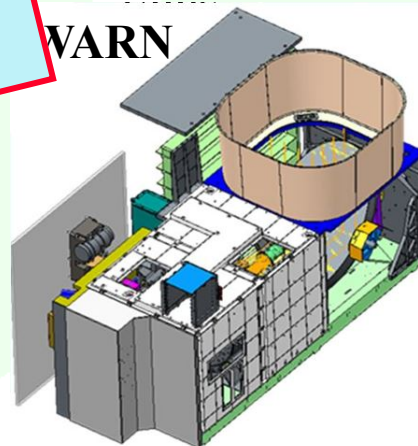
GIIRS



sal

2 US Pathfinder Options

WARP



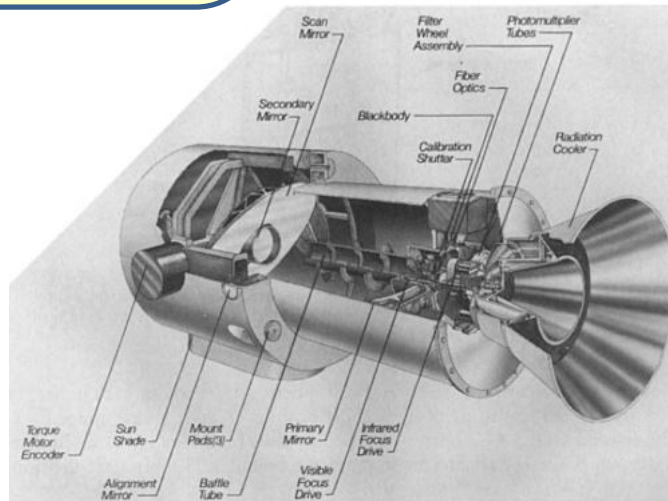
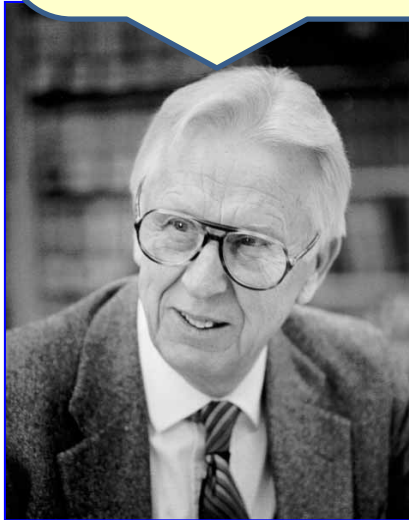
ABX from ABI

GEO Sounding was introduced in the 1980

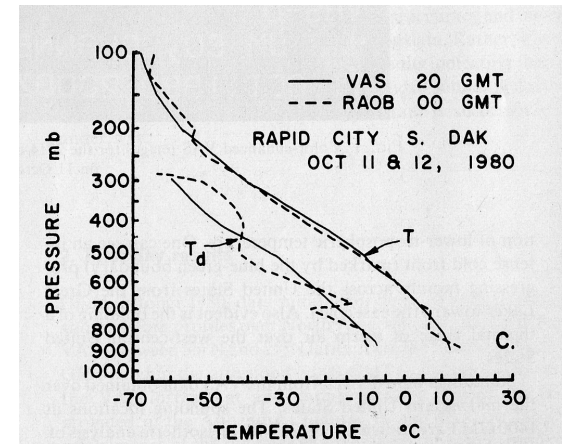
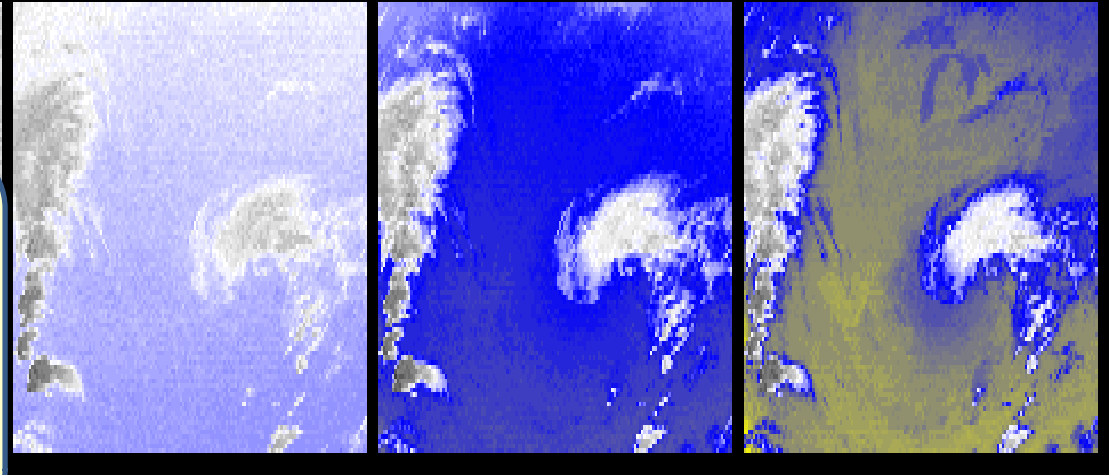
## VISSR Atmospheric Sounder (VAS) Demonstration

*Verner Suomi realized that a lot could be done from GEO, because compared to LEO, time is on your side*

*“Weather is air in motion, and VAS allows us to observe atmospheric changes as they occur”*

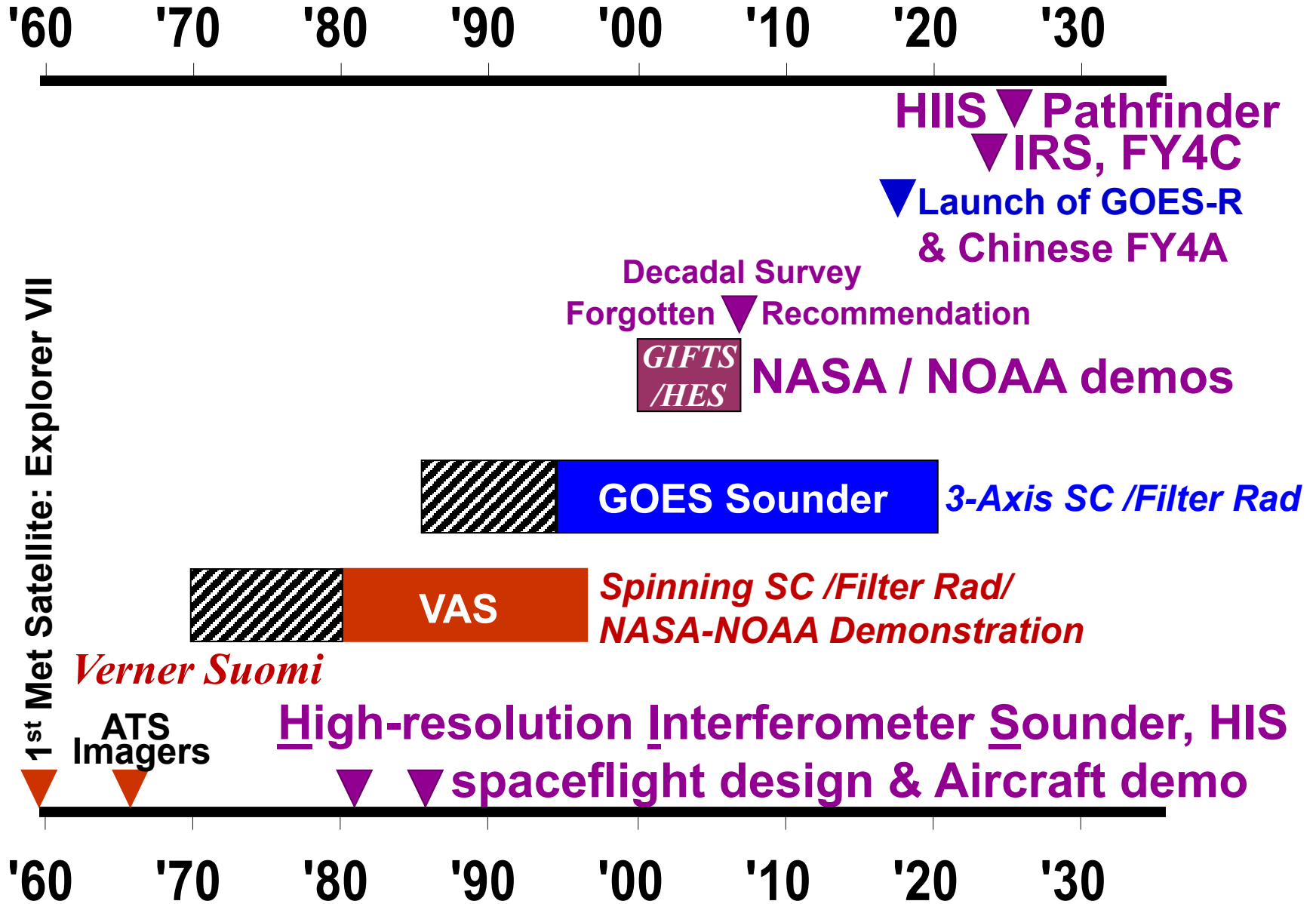


12 Infrared Channels (1 Vis)



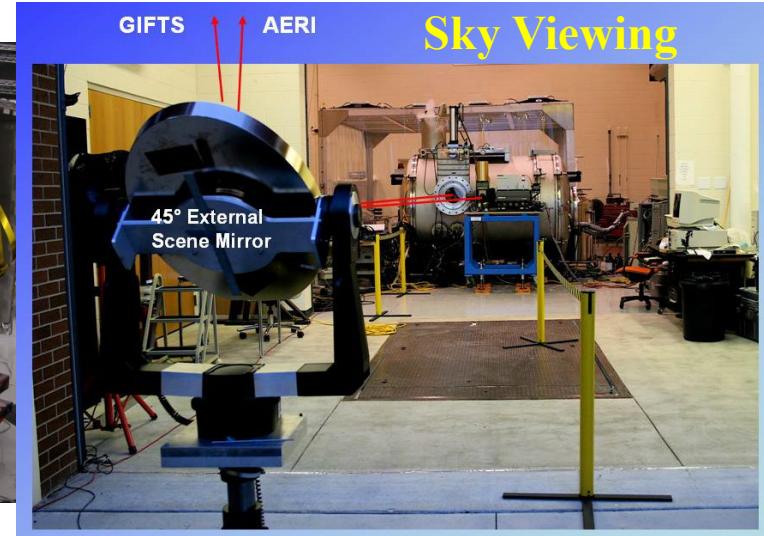
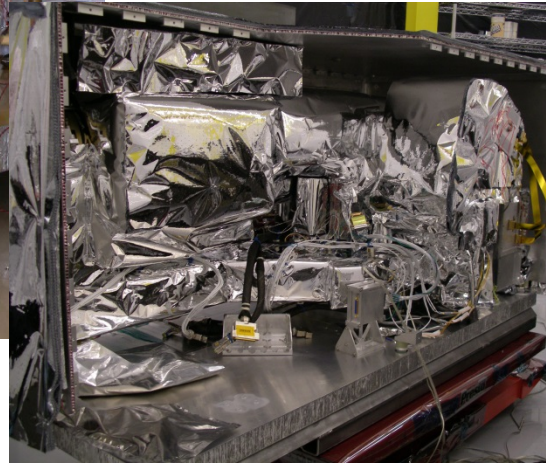
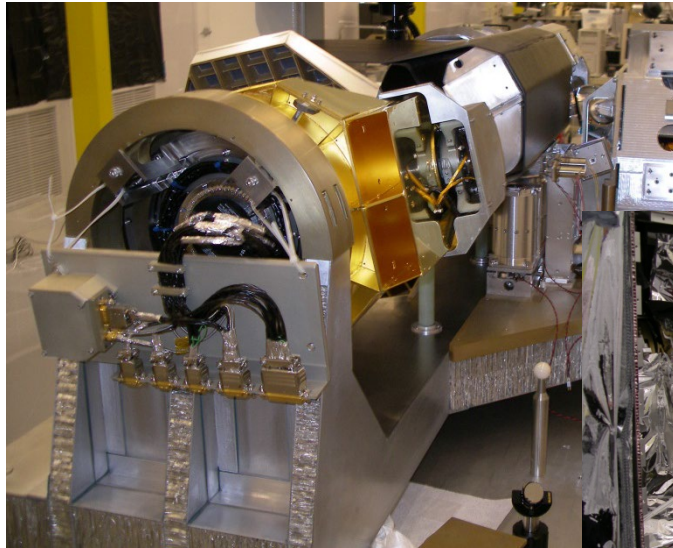
The first VAS sounding  
*Smith et al 1981*

# GEO Sounder History





# GIFTS (128x128, 4km) Geosynchronous Imaging FTS

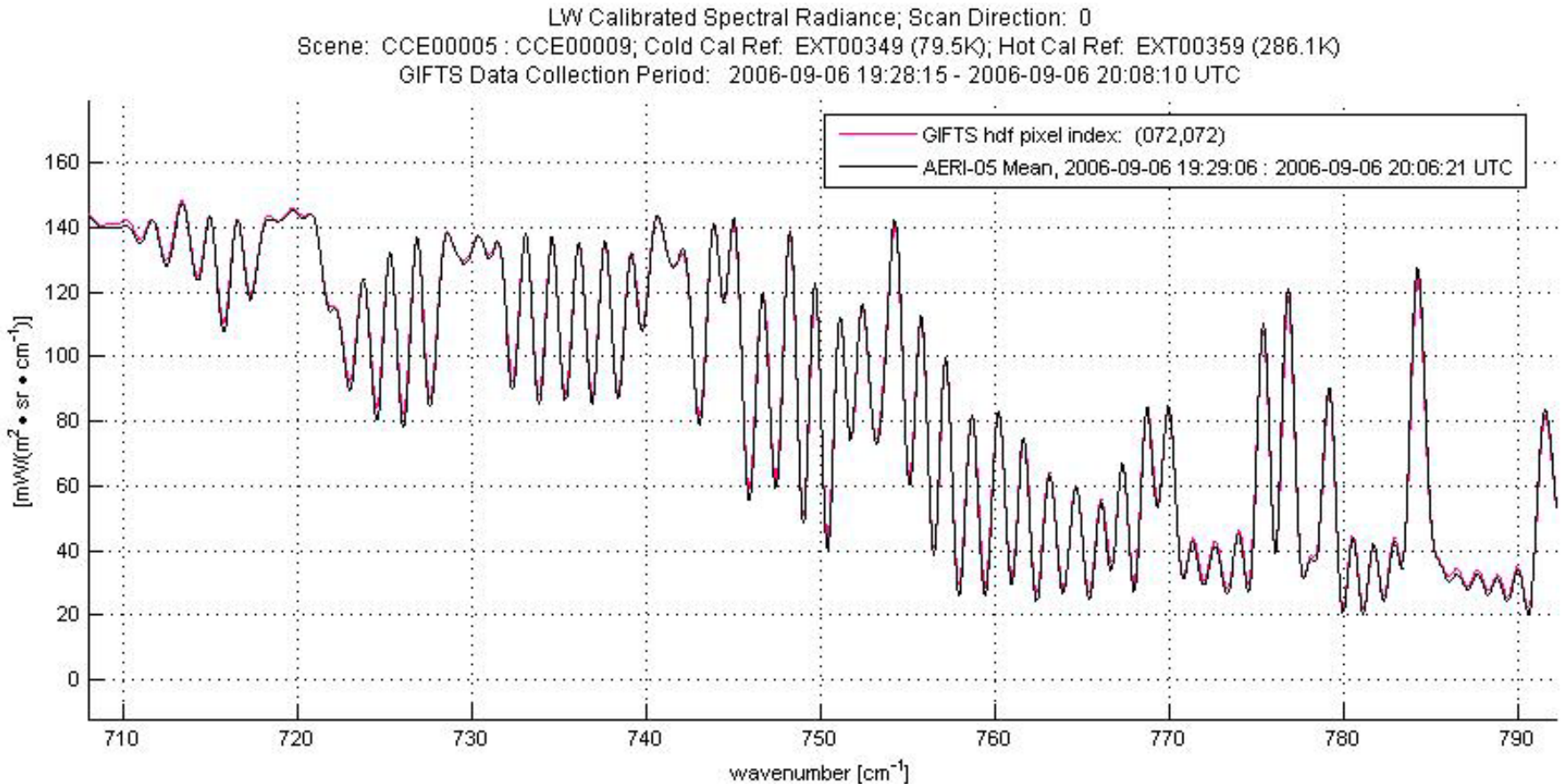


## GIFTS EDU

- **NASA GIFTS Proof of Concept was successfully demonstrated in 2006 with the Engineering Development Unit Thermal/Vacuum & Sky Viewing Tests**  
(expected “long-poles” worked well: LW detector with good sensitivity and operability, Long-lived stable laser, mechanical cooler and cryogenic thermal design, imaging FTS radiometric integrity, etc)
- **Results Demonstrate that NOAA HES Requirements for a Successful GOES Imaging Spectrometer are achievable**  
(spatial coverage and resolution, spectral coverage, spectral calibration and Instrument line shape knowledge, and spectral scale standardization)



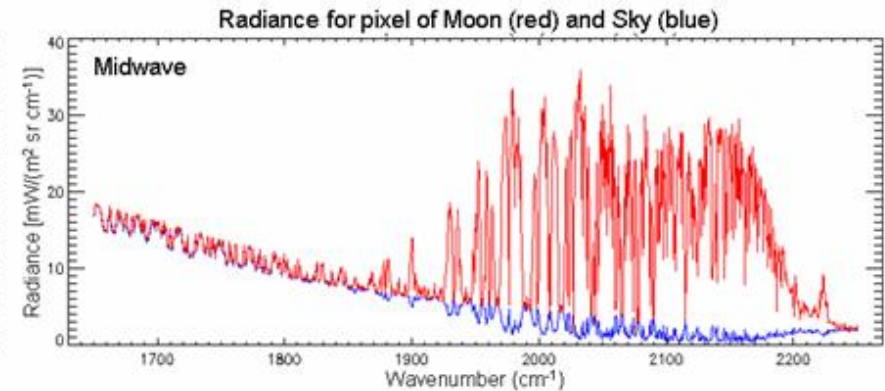
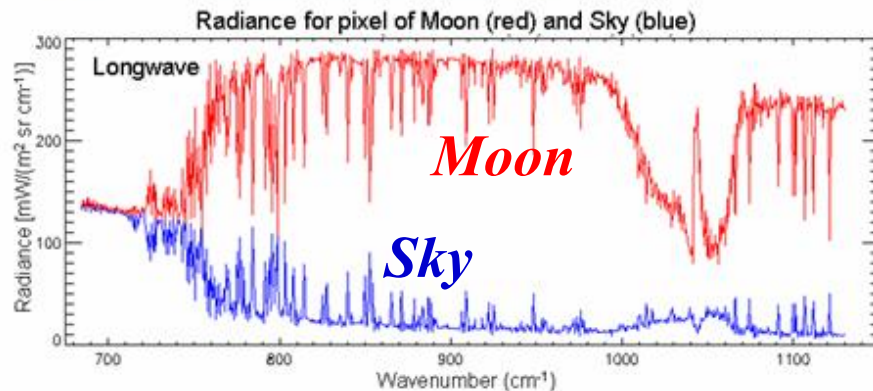
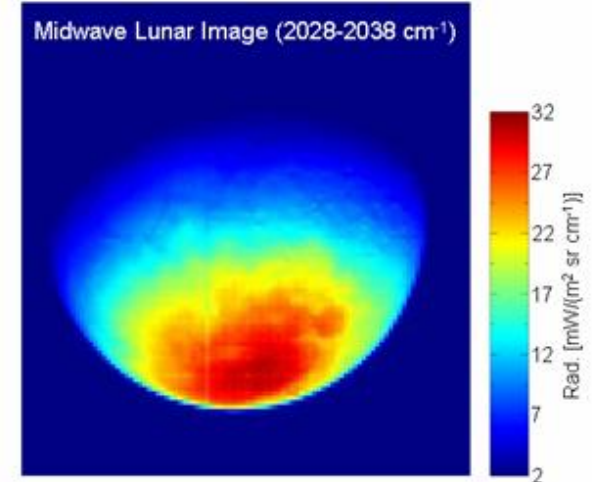
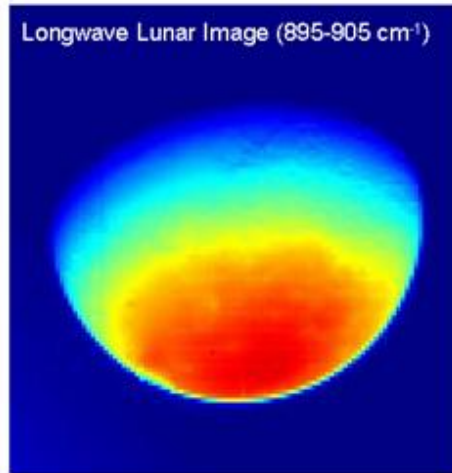
# AERI Comparisons Demonstrate GIFTS as Spectro-radiometer LW, GIFTS pixel 72,72 & AERI05



**708-792 cm<sup>-1</sup>, 15 micron CO<sub>2</sub> band**



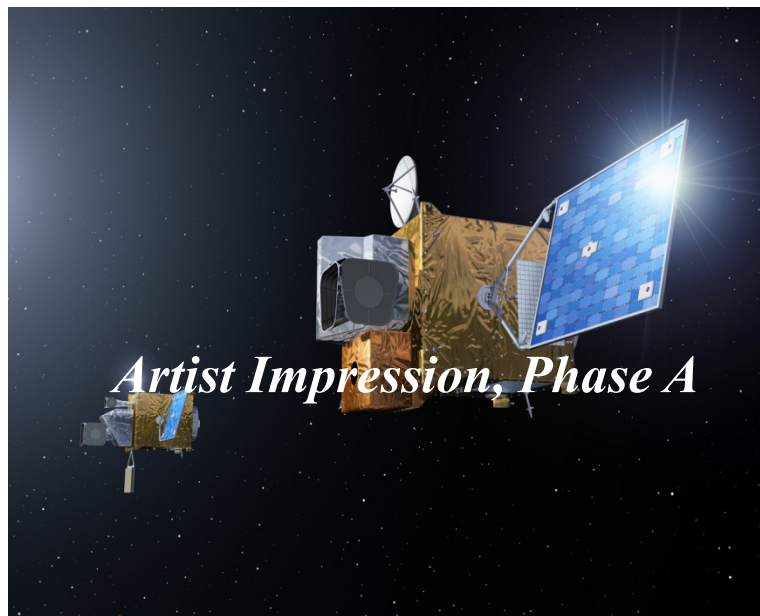
# Lunar Views Demonstrate GIFTS Imaging Capability



Results from a single interferometer scan of the moon, viewed in the visible, mid-wave IR, and long-wave IR. Also the spectral intensities of two selected pixels from the IR images, one viewing the moon, the other the clear sky background.



## *Europe: Metop and Meteosat*



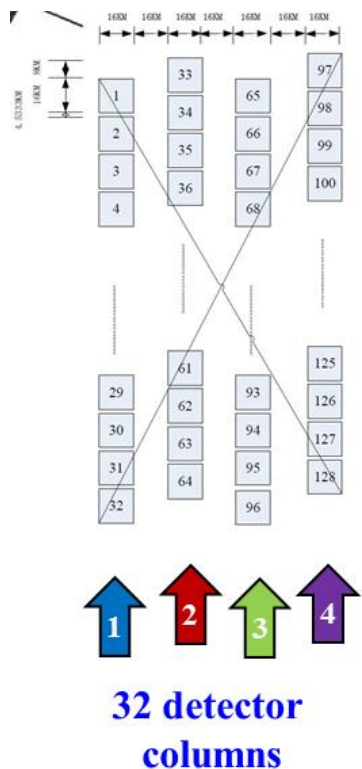
**EUMETSAT/ESA plan  
GIFTS-like **IR Sounder  
(IRS)** to fly on  
Meteosat 3<sup>rd</sup> Generation  
(MTG) in 2022/2023**



# GIIRS

*Designed & built at Shanghai Institute of Technical Physics  
Launch date: FY4A, 11 December 2016*

*The First IR  
Hyperspectral  
Sounder in  
GEO!*



## Geo. Interferometric Infrared Sounder (GIIRS)

GIIRS is the first space-borne interferometer that flies in geostationary orbit to make measurements of three-dimensional atmospheric structure from interference by split light beams. Technically featuring a 32×4 sensor array plane, it is equipped with a Michelson interferometer working over different infrared bands for large-area, continuous, fast, and accurate vertical air sounding of temperature and humidity.

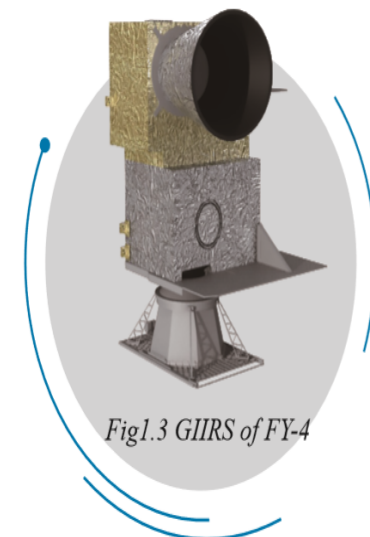


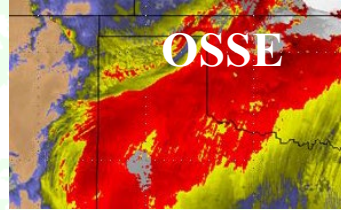
Table 1.4 Specifications of GIIRS

Working bands	<b>GIFTS-like spectra</b> 700-1130cm <sup>-1</sup> (8.85-14.29μm) 1650-2250cm <sup>-1</sup> (4.44-6.06μm)
Spectral resolution	0.625cm <sup>-1</sup> (actual measurement)
Spectral channels	1650 (actual measurement)
Spatial resolution	<b>16 km / pixel</b> 16km <b>128 km E-W</b>
Temporal resolution	768km×960km (30min.) <b>640 km N-S</b> 4480km×5000km (60min.) <b>in 21 sec</b>
Radiation calibration accuracy	1.5K
Spectral calibration accuracy	10ppm

# Expeditious implementation of GEO HIIS



A. Why GEO



B. History



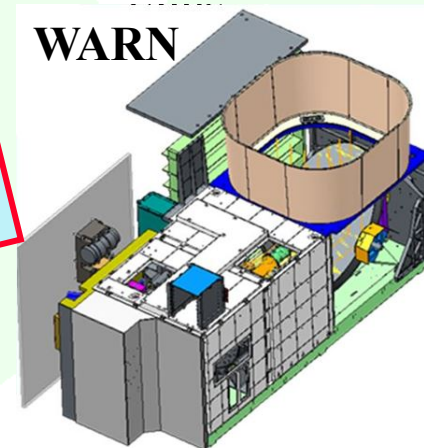
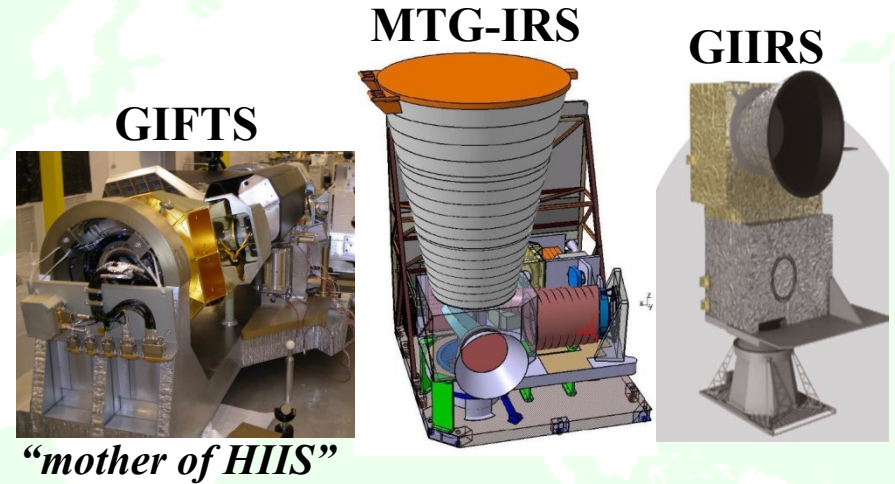
C. WARN: a NASA

Earth Venture Proposal

2 US Pathfinder Options

D. ABX

Affordable, Low Risk  
US Pathfinder (1)



ABX from ABI



# NASA EVI-4 Proposal (Earth Venture Instruments)

Using earlier US

Developments:

Combining

(1) HES Interferometer

Module, 25x25 2 km array

(2) GOES Q Flight Model



## Weather Alert Remote Nowcasting

Exploring the Predictability of Severe Storms using  
Geostationary Hyperspectral Sounding Observations

In response to:

Second Stand Alone Missions of Opportunity Notice (SALMON-2)  
Program Element Appendix S: Earth Venture Instrument (EVI)-4.  
NNH12ZDA0060

A handwritten signature in black ink that reads "William L. Smith".

Principal Investigator:

**William L. Smith**

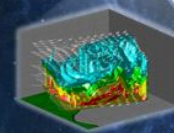
Space Science and Engineering Center  
University of Wisconsin - Madison

A handwritten signature in black ink that reads "Brenda Egan".

Authorizing Official:

**Brenda Egan**

Managing Officer, Pre-Award Services  
Research and Sponsored Programs Office  
University of Wisconsin - Madison



## B. Fact Sheet

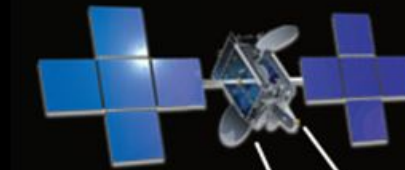
### Goal

Explore the potential to vastly improve warning times and location predictions for severe weather hazards, including thunderstorms, tornados, and hurricanes

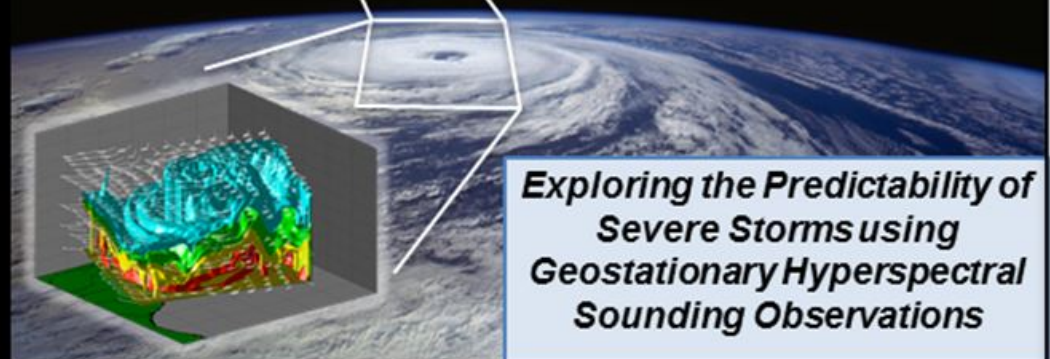
### Science Objectives

#### Weather Alert Remote Nowcasting (WARN)

- Understanding and prediction of severe convective storm initiation from all-sky thermodynamic profiles and time tendencies
- Understanding and prediction of hurricane intensity and landfall position from vertically resolved wind profiles



- ▶ Provides >250,000 Atmospheric Soundings every 16 minutes over an Area of 1000 km x 1000 km
- ▶ A modified GOES-Q Sounder to make vastly improved four-dimensional atmospheric temperature, moisture, and wind measurements



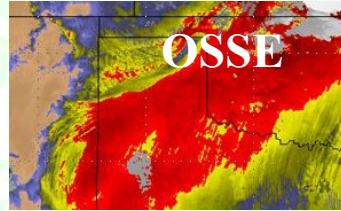
*Exploring the Predictability of Severe Storms using Geostationary Hyperspectral Sounding Observations*



# Expeditious implementation of GEO HIIS



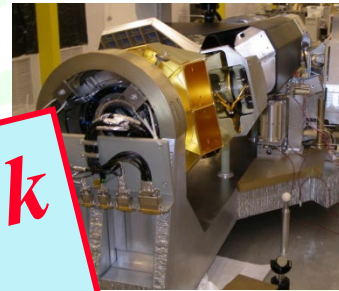
A. Why GEO



B. History

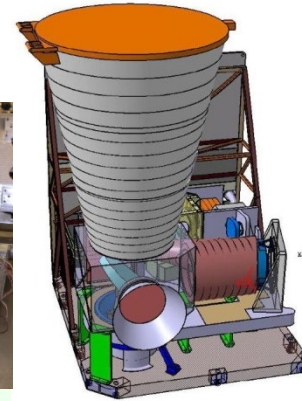
C. *Affordable, Low Risk  
US Pathfinder (2)*

GIFTS

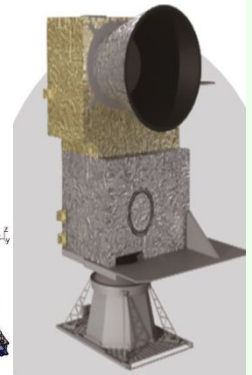


"Mother of HIIS"

MTG-IRS



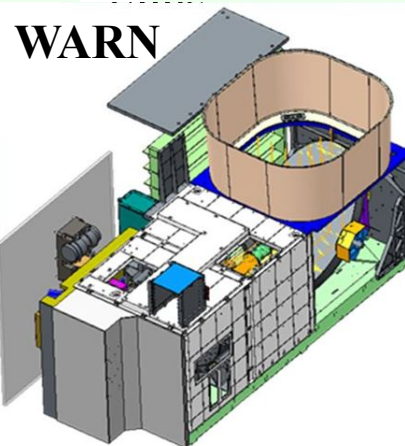
GIIRS



D. Proposal

2 US Pathfinder Options

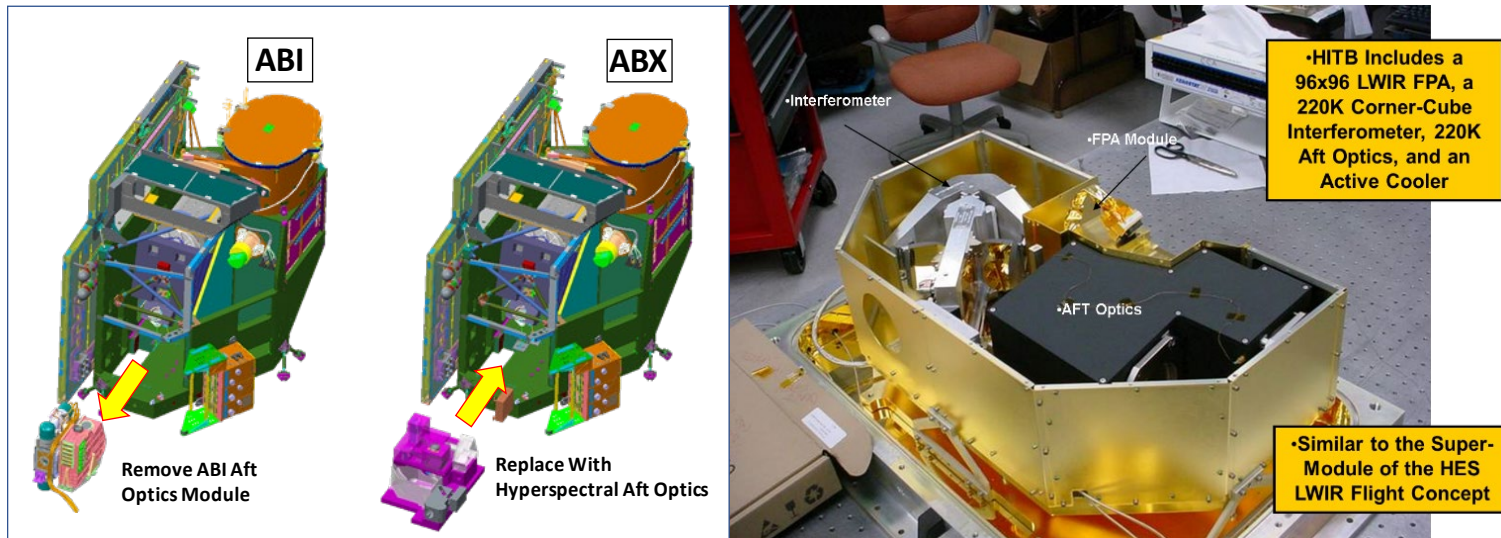
→ D. ABX: Harris/UW  
NOAA White Paper



ABX from ABI

# Pathfinder 2 Option: Hyperspectral ABI-class instrument

**Using earlier US Developments: Combining**  
**(1) HES Interferometer Module,**  
**imaging array (4 km GSD)**  
**(2) ABI Prototype Model**

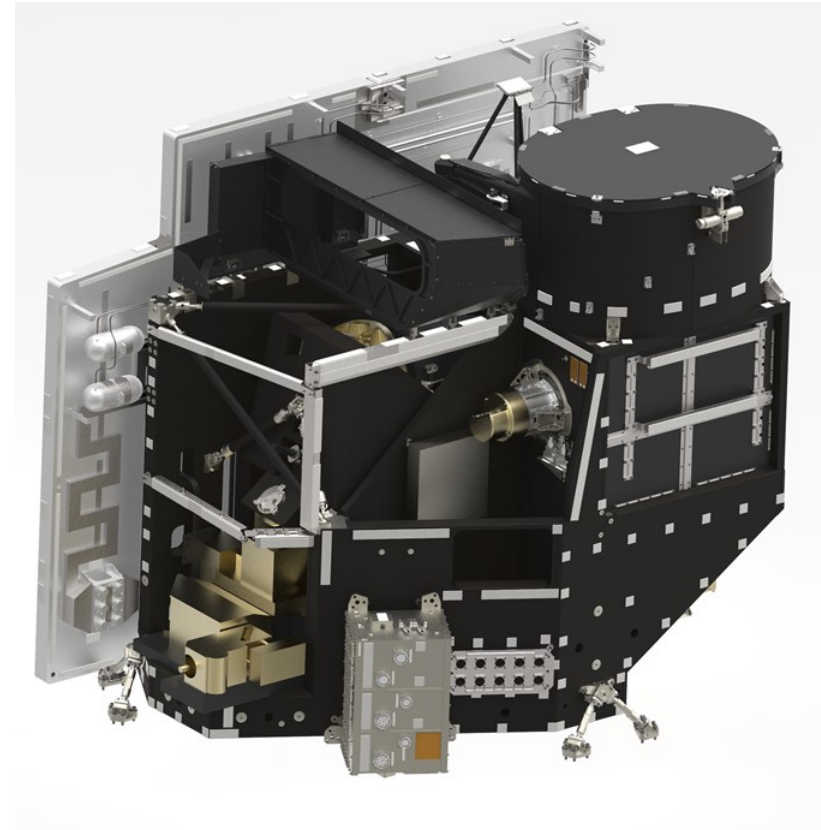


*Conversion of ABI to Hyperspectral ABX  
is Straightforward and Low Risk*

# Agile GEO IR Hyperspectral Sounder (ABX) Concept



- GEO Sounder based on the successful Advanced Baseline Imager (ABI) platform
  - ~85% re-use of ABI hardware: telescope, scanner, thermal control, structure, control electronics
- Highly-flexible, very rapid scan patterns with interleaved data collection capability
  - For example, simultaneous collects of:
    - Full Disk soundings every 30 minutes (2X MTG/IRS)
    - Mesoscale soundings every 2.5 minutes (for severe weather)
    - 4 km IR resolution / 0.6 km day/night Visible resolution
- No new technology
  - Uses Harris R&D FPAs and interferometer
  - Originally developed for NOAA's HES program
  - Leverages CrIS experience



*“Agile GEO IR Hyperspectral Sounder”*

*Ronald Glumb and Paul Griffith*

*L3Harris Space and Airborne Systems, Fort Wayne, Indiana, USA*

*American Meteorological Society, 2019 Joint Satellite Conference, Paper No. 19A.4*

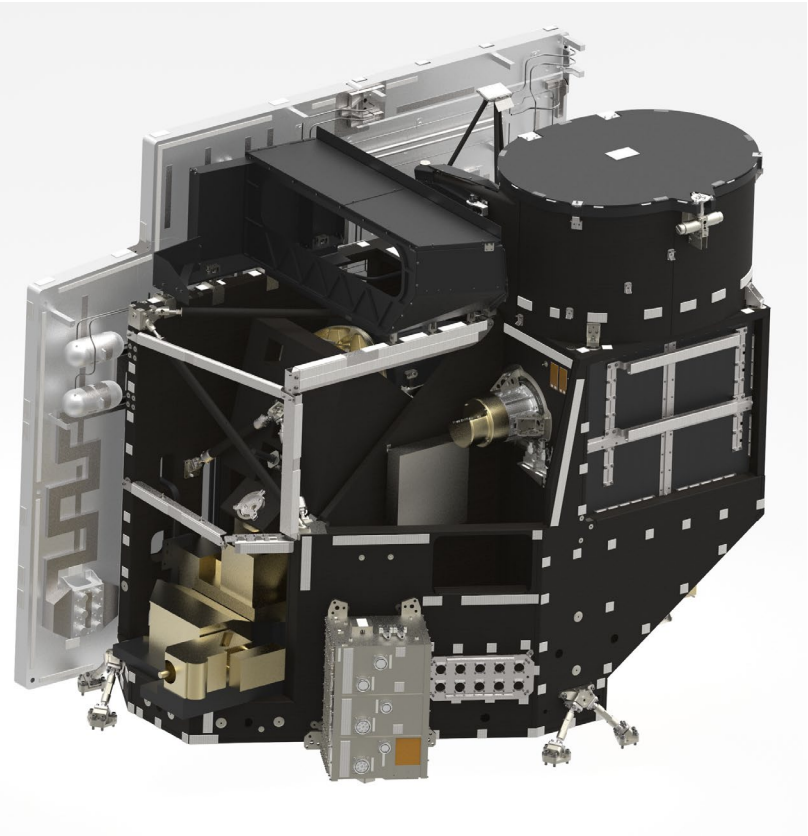
*<https://ams.confex.com/ams/JOINTSATMET/meetingapp.cgi/Paper/359886>*



# Conversion of ABI to ABX is straightforward



- ABX hyperspectral assembly provides MWIR/LWIR hyperspectral (>1600 channels) plus VIS
  - Minimizes changes to ABI hardware to reduce risk and cost
- Optical and mechanical interfaces to ABI sensor unit are unchanged
- In addition, higher-performance onboard processing boards replace the current ABI boards
- Remains compatible as hosted payload



*“Agile GEO IR Hyperspectral Sounder”*

*Ronald Glumb and Paul Griffith*

*L3Harris Space and Airborne Systems, Fort Wayne, Indiana, USA*

*American Meteorological Society, 2019 Joint Satellite Conference, Paper No. 19A.4*

*<https://ams.confex.com/ams/JOINTSATMET/meetingapp.cgi/Paper/359886>*

# Projected Capabilities of ABX Instruments

Parameter	ABX Capability
Spatial Resolution	4km (IR) 0.6km (VIS)
LWIR Spectral Range	680 - 1120 $\text{cm}^{-1}$
MWIR Spectral Range	1210-1750 $\text{cm}^{-1}$ or 1650 - 2250 $\text{cm}^{-1}$
VIS	Day/Night Pan Band for Cloud Detection
Spectral Resolution	Selectable, with nominal value of 0.625 $\text{cm}^{-1}$
Temporal Refresh	Interleaved, Flexible Collects: Capable of Full Disks in 30 min with interleaved Meso's every 2.5 min
Calibration (300K scene)	< 0.5K

***Would satisfy GIFTS/HES-type Requirements  
and add a Day / Night Band***

# Summary: Expeditious implementation of GEO HIIS



- **Hyperspectral Infrared Imaging Sounder technology is mature and expected to be a game changer in the new frontier of rapid sampling**
- **International near-Global coverage is still possible before 2025**
- **The US should proceed as fast as possible toward an affordable Pathfinder mission, emphasizing severe storm life saving**
- **The full-up operational GEO HIIS should emphasize global as well as mesoscale coverage**