Infrared Correlation Radiometer for GEO-CAPE
Earth Science Technology Forum 2010

JUNE 22, 2010

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Decadal Survey specifies an infrared correlation radiometer for GEO-CAPE

- Measurement of tropospheric CO from space requires a technique capable of high effective spectral resolution and high signal-to-noise.
- Correlation radiometry excels in providing both.
- Correlation Radiometer Terra/MOPITT has delivered 10 years of the global distribution and seasonal variability of CO in the mid-troposphere measured in MWIR (4.7 um).
- Combining MWIR and SWIR (2.3 um) CO from space achieves vertical resolution as required by Decadal Survey.
- MOPITT team estimates a factor of 5 more instrument noise in SWIR than in MWIR measurements.
- This IIP addresses the signal to noise challenges for 2.3 um measurements for CO.

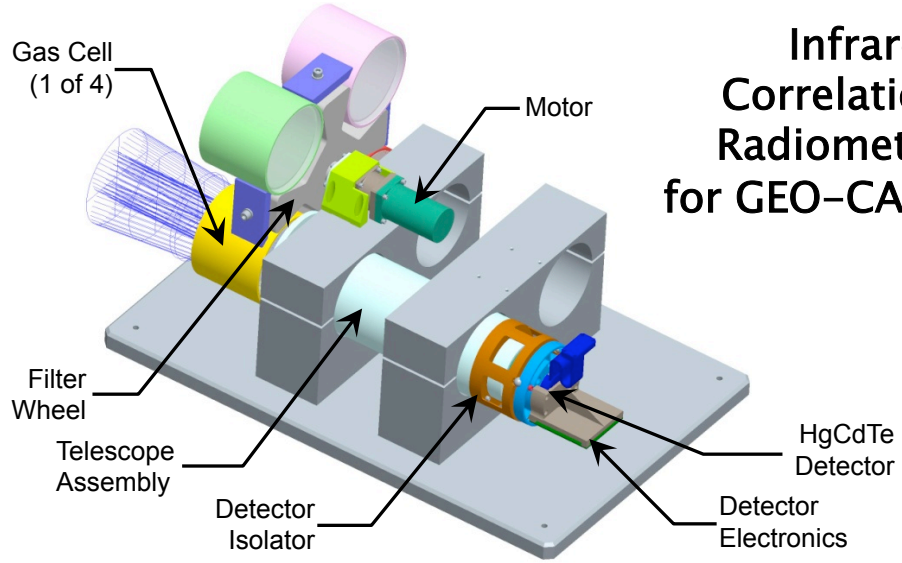
Infrared Correlation Radiometer for GEO-CAPE (IRCRg)*

PI: Doreen Neil / NASA (LaRC)

Objective

- Characterize the noise and spectral performance of a laboratory prototype of the SWIR (2.3 mm) subsystem of an infrared gas filter correlation radiometer for geostationary carbon monoxide (CO) measurements.
- Verify the analytical instrument model to guide evolving GEO-CAPE mission implementation decisions.

Measurements at both 2.3 µm and 4.6 µm are required to obtain lower tropospheric CO. The Decadal Survey's focus on the lower troposphere placed emphasis on the 2.3 µm measurements.



Infrared Correlation Radiometer for GEO-CAPE

Approach:

- Design and fabricate the 2.3 µm subsystem of an infrared gas filter correlation radiometer specifically tailored for geostationary measurements.
- Characterize performance to quantify instrument response functions (spectral , spatial, radiometric, and polarization), and explicitly, an end-to-end noise performance characterization.
- Incorporate these characterizations into the CO measurement modeling system for use in GEO-CAPE mission formulation and payload system engineering.

Co-Investigators: John Boldt (APL), David Edwards (NCAR); Sam Yee (APL). Advisors: Jack Fishman, William Luck, James Crawford (LaRC), Lackson Marufu (UMd); Larry Zanetti (APL).

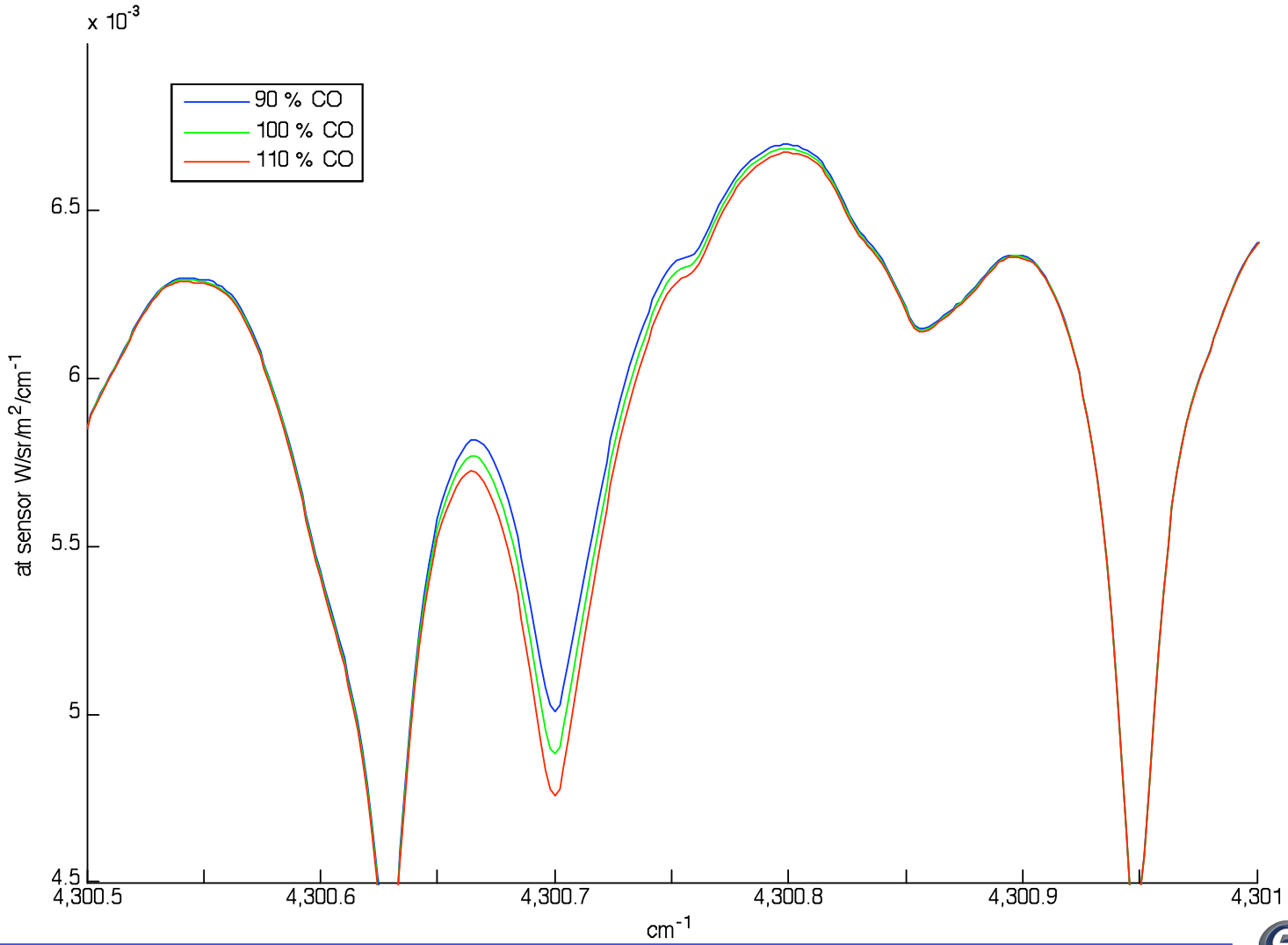
Key Milestones *

• Internal design and cost	08/08
• Contracts in place	02/09
• System Requirements Review	06/09
• Critical Design review	11/09
• Test Plan Review	04/10
• Breadboard Assembly complete	09/10
• Characterizations complete	11/10
• Instrument Performance Model complete	01/11
• IRCRg Final report	01/11

Breadboard Hardware TRL_{in} 3 → TRL_{now} 4 → TRL_{out} 5-6

Instrument Model TRL_{in} 3 → TRL_{now} 4 → TRL_{out} 6

Example Spectral Radiance for different CO Concentrations at 2.3um SWIR lines



IRCRg IIP Project Objectives

To develop a software-based IRCRg instrument performance simulation model that can be used to:

(1) simulate end-to-end IRCRg system performance and CO measurement capability in a "dynamic" environment, and

(2) quantify individual critical IRCRg CO measurement error sources, by the "static" state of the instrument as well as the "dynamic" state of the instrument/host vehicle.

To construct a breadboard laboratory CO IR Gas Correlation Radiometer (IRCRg) instrument that will be used to:

(1) populate the model with actual performance data and, where appropriate, test model performance against laboratory test data.

(2) raise TRLs of critical subsystems of future flight IRCRg instrument for the GEOCAPE mission to provide continental-scale CO mapping from a geosynchronous platform.

Pointing is part of the L1 Requirements for GEO

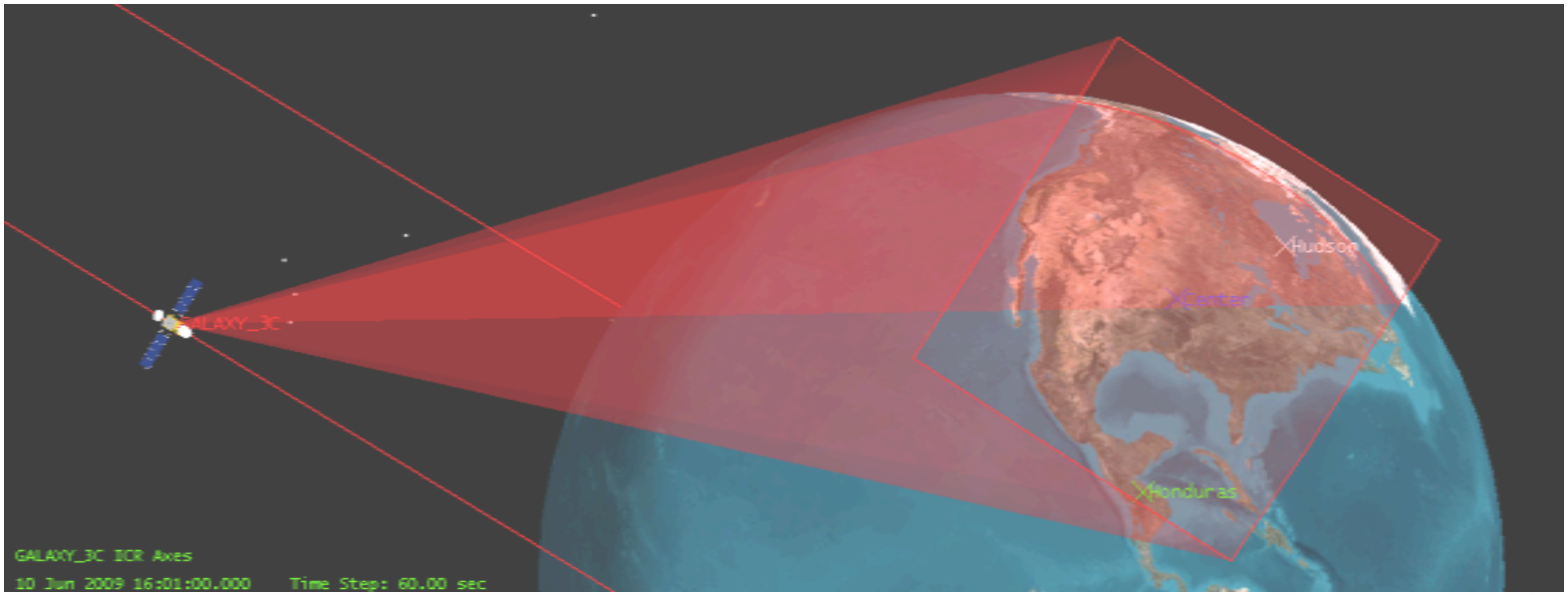
	Terra	GEO
Altitude, km	705	35,786
Surface size of pixel, km	22	4
Pixel viewed angle, degree	1.7874	0.0064
Pixel viewed angle, microradians	31,196	112

- The angular size of a GEO-CAPE pixel is 0.0036 of a MOPITT pixel.
- A GEO-CAPE pixel sees an angle smaller than 1 percent of the angle seen by a MOPITT pixel.
- To co-add repeated samples of a pixel, one needs to know which pixels to co-add, therefore one needs to know pointing.

IRCRg Field of View Requirement

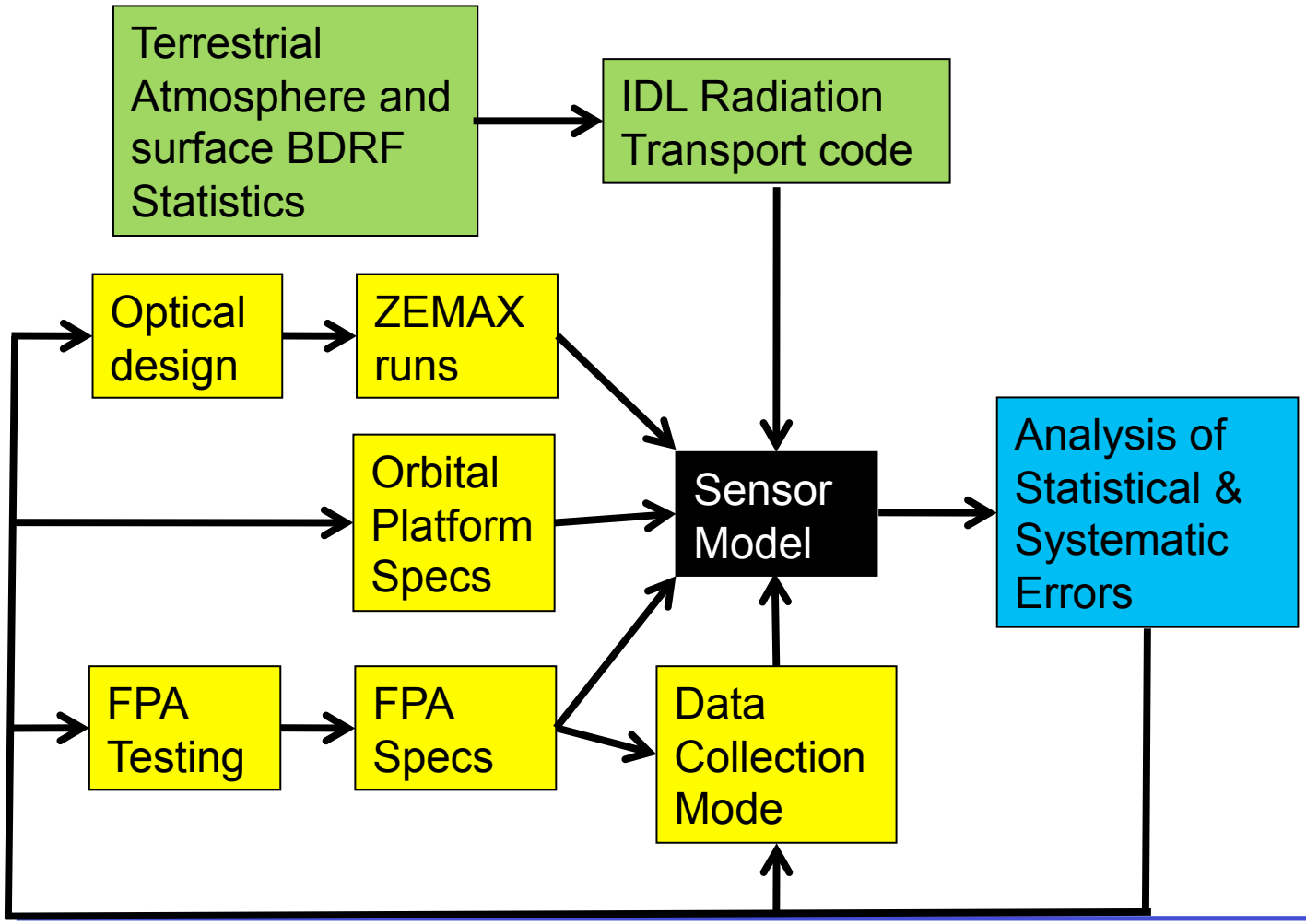
- **Requirement : Field of view covers US "Lower 48"**

- Coverage of the US "Lower 48" requires a 7° horizontal instrument field of view
- Use of a 1024 x 1024 detector array results in:
  - Pixel field of view (IFOV) ~112 microradian
  - Pixel foot print **~4 km (center of US)**

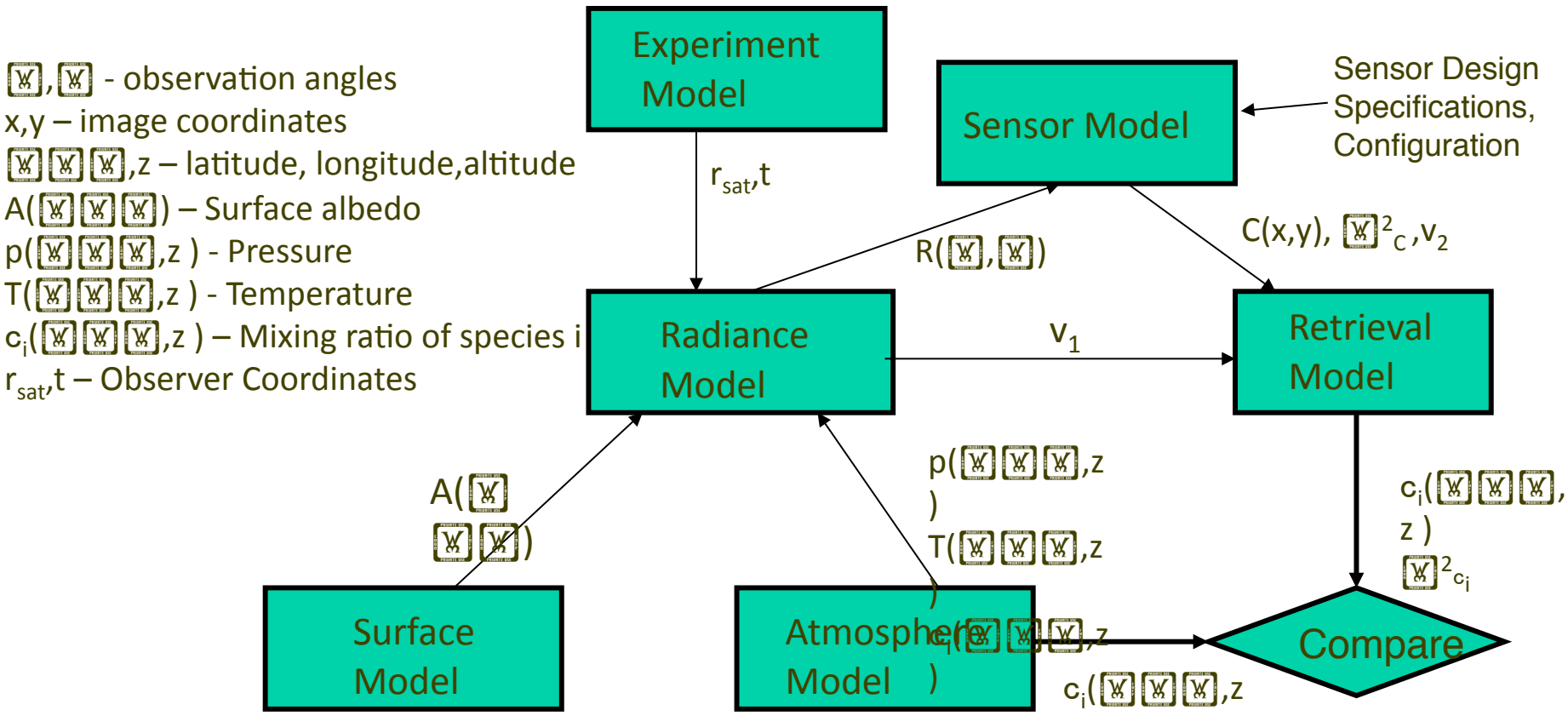


The Simulator: Nuts & Bolts

Modeling Block Diagram



Performance Model: Realistic Instrument Optimization and Performance Assessment Tools



, - observation angles
x,y – image coordinates
,z – latitude, longitude,altitude
A( ) – Surface albedo
p(,z) - Pressure
T(,z) - Temperature
c_i(,z) – Mixing ratio of species i
r_{sat},t – Observer Coordinates

R(,) – Radiance
C(x,y) – Instrument counts
^2_C –Covariance of instrument counts

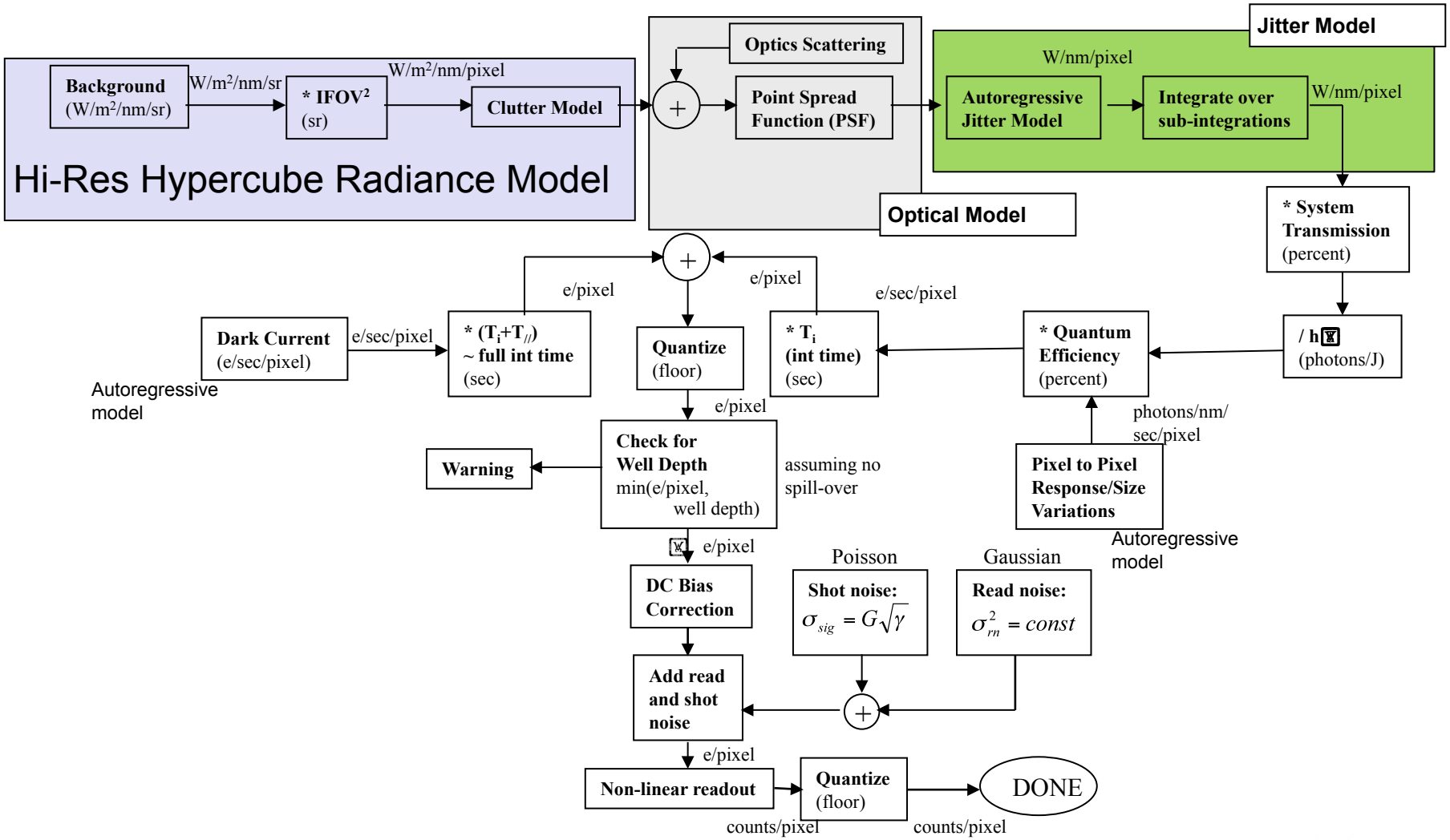
v_1, v_2 – *a priori* vectors
i – gas id N_2O, CO, CH_4, H_2O
k – gas filter id for N_2O, CO-low, CO-high, CH_4
$^2_{c_i}$ – Mixing Ratio Covariance

Sensor Model Inputs

Each run of the sensor model C code takes an input hypercube (binary file) and a range of sensor parameters, specified in a text file, but shown is a list of considered parameters

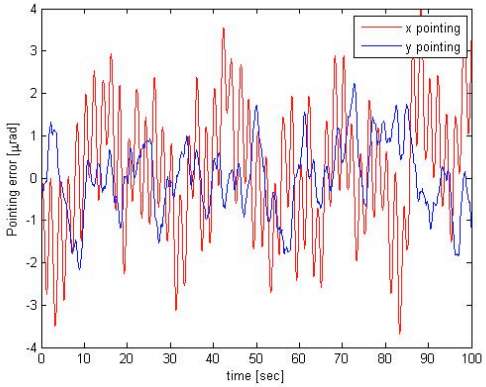
- Radiance model output (high spatial res, 500m GSD input)
- Orbital Parameters
  - range, viewing angle, etc
- Optical Parameters
  - focal length, Zernike polynomials, transmission, stray light
- FPA Characteristics
  - noises, per pixel gain/offset curves, hot/cold pixels, array dimensions, crosstalk, well capacity, ADC non-linearity, residual charge
- Platform Characteristics
  - Attitude Control Parameters
- General Parameters
  - Frames to compute, input and output filenames, seeds for PRNGs

Sensor Model

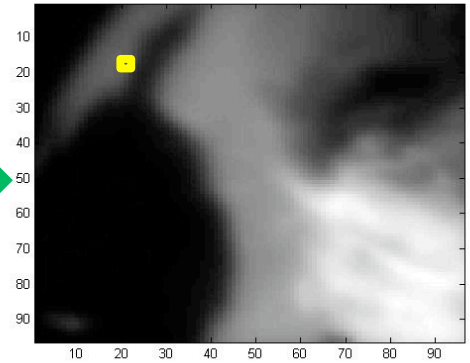


Program Flow

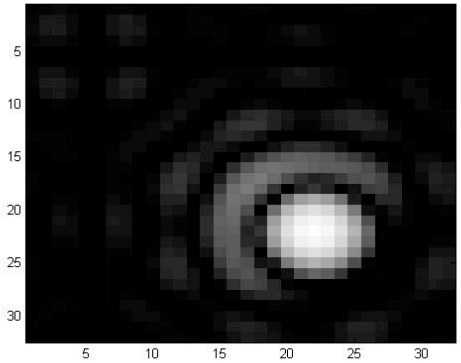
Subdivide given integration time and determine instantaneous pointing



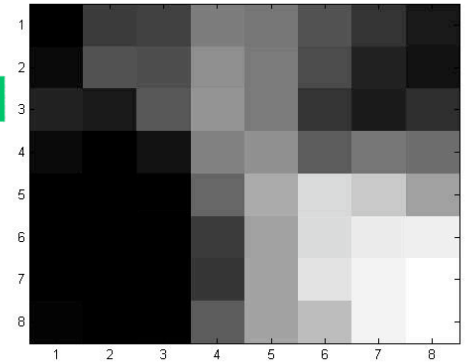
Sample hi-res background data after shifting for jitter



Compute optical path difference to get point spread function for this ray



Use PSF to spread the flux for this (x,y) ray onto the focal plane as # of photoelectrons



Repeat process until all rays and all sub-integration times are complete, then loop advance to the next filter position/frame.

Once all looping is complete, add in the dark current, shot noise, read-out-noise, well depth, ADC gain curves, detector non-uniformities, and record in file.

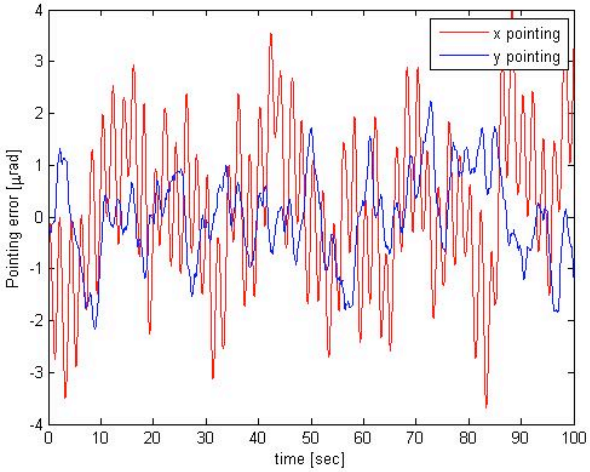
List of Possible Sources of Measurement Sensitivities Currently in the Model

- The sensor model currently incorporates the following:
  - Shot noise from photon statistics (courtesy S.D.Poisson)
  - Scene gradient statistics (from MODIS data @ 2um)
  - Read-out noise from FPA (from testing)
  - Detector dark current, non-uniformity factors, normal/hot/cold pixels, crosstalk, ADC non-linearity, residual charge (from testing)
  - Jitter from orbital platform (from nominal satellite specifications)
  - Optical imperfections (from ZEMAX model)
  - Thermal expansion (from joint run of ZEMAX and CAD models)

Dynamic Process Modeling

- 3 PRNG Seeds
  - Jitter, Noises, Detector Non-Uniformity
  - Allow rerunning cases again using the “same” random noise

- Autoregressive models used:
  - Estimate future values from previous output



- See paper for a thorough description of pointing effects

Status of Sensor Model Simulations

- Graphical user interface has been completed
  - Generates input parameter files through web browser interface

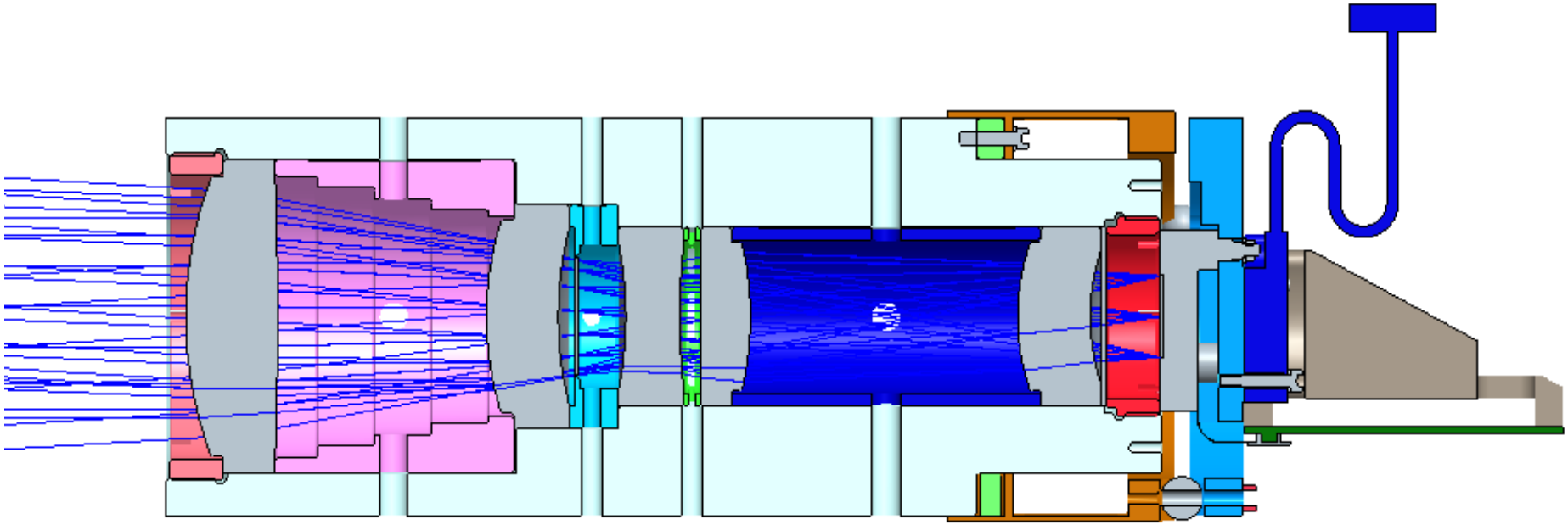
- Simulation of sensor output frames in digital numbers (DN)
  - Written as a MPI parallelized C code
  - Takes output of radiance code, integrates all other pertinent parameters and turns into digital images
  - Utilizes optical design (aberrations), satellite stability (attitude control model), and nominal focal plane array characteristics

- Matlab code to do basic statistical retrieval of CO concentration using only N_2O and CO_{400} filter positions (CH4 not needed as we have not varied CH4 levels yet)

- Completed Work
  - Started determining the trade-space between:
    - Well depth and fill %
    - Readout noise
    - Detector offset and gain drift
    - Jitter

The Simulator: Current Verification

Cutaway view of IRCR telescope assembly

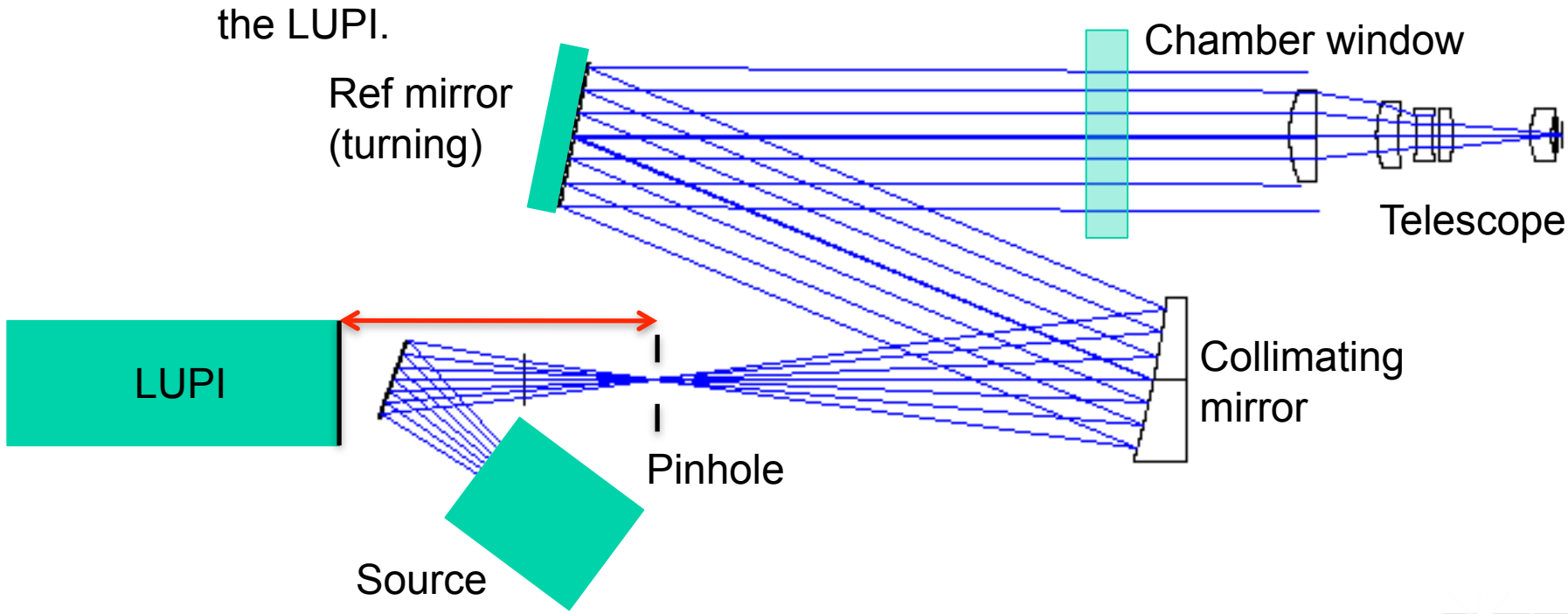


IRCR Optical Alignment and Characterization

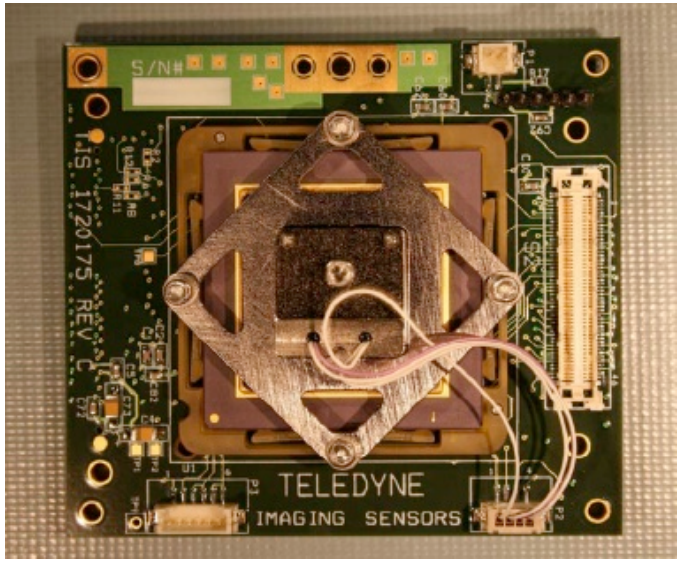
- **Measure effective focal length (EFFL)**
  - ❑ Via image magnification from measurements in visible wavelengths and extrapolate to target wavelength.
- **Demonstrate focus**
  - ❑ Probe the focus position by making systematic measurements of the PSF in visible wavelengths and at target wavelength.
- **Measure transmission (covered in OCF operations)**
  - ❑ Probe the system response in the design spectral band-pass and at points outside to demonstrate out-of-band rejection using a spectrophotometer.
- **Measure stray light (covered in OCF operations)**
  - ❑ Perform a point source transmittance evaluation.
- **Measure f-number**
  - ❑ Exiting beam diameter and EFFL.
- **Determine Zernike coefficients**
  - ❑ Interferometery.

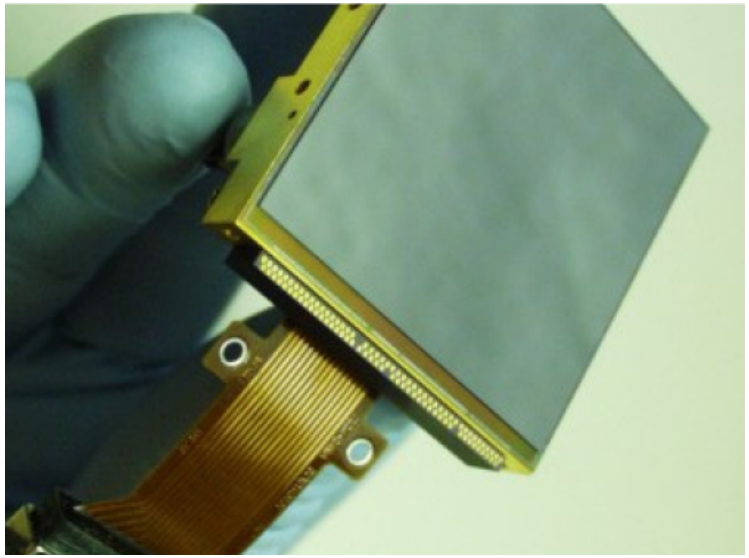
Example detail: Demonstrate focus in vacuum

- Demonstrating focus in the vacuum chamber is accomplished using the design focal plane.
- Once the LUPI and collimator alignment is established, a mirror and target wavelength source is introduced to the beam.
  - A pinhole (100-µm) is located at the focus which is rigidly connected to the LUPI.



IRCR Incubator – Detector System





- Teledyne H2RG - HgCdTe tailored cutoff 2.5 um for stable 2.3 um response
- Teledyne H2RG HgCdTe detector for 4.6 um response also available
- H2RG is 2K*2K, 32-channel readout. 1K*1K also available
- SIDECAR ASIC board is mounted next to the H2RG in cryogenic environment
  - 36 channels of pre-amps,16-bit ADCs
  - Outputs data to computer via JADE2 board and USB

Detector Testing – System Noise, Linearity, and Latency

Test noise performance of the combined detector (ROIC) and A/D converter (SIDECAR) system

- Cover readout mode(s) and temperatures not tested by manufacturer or in the literature

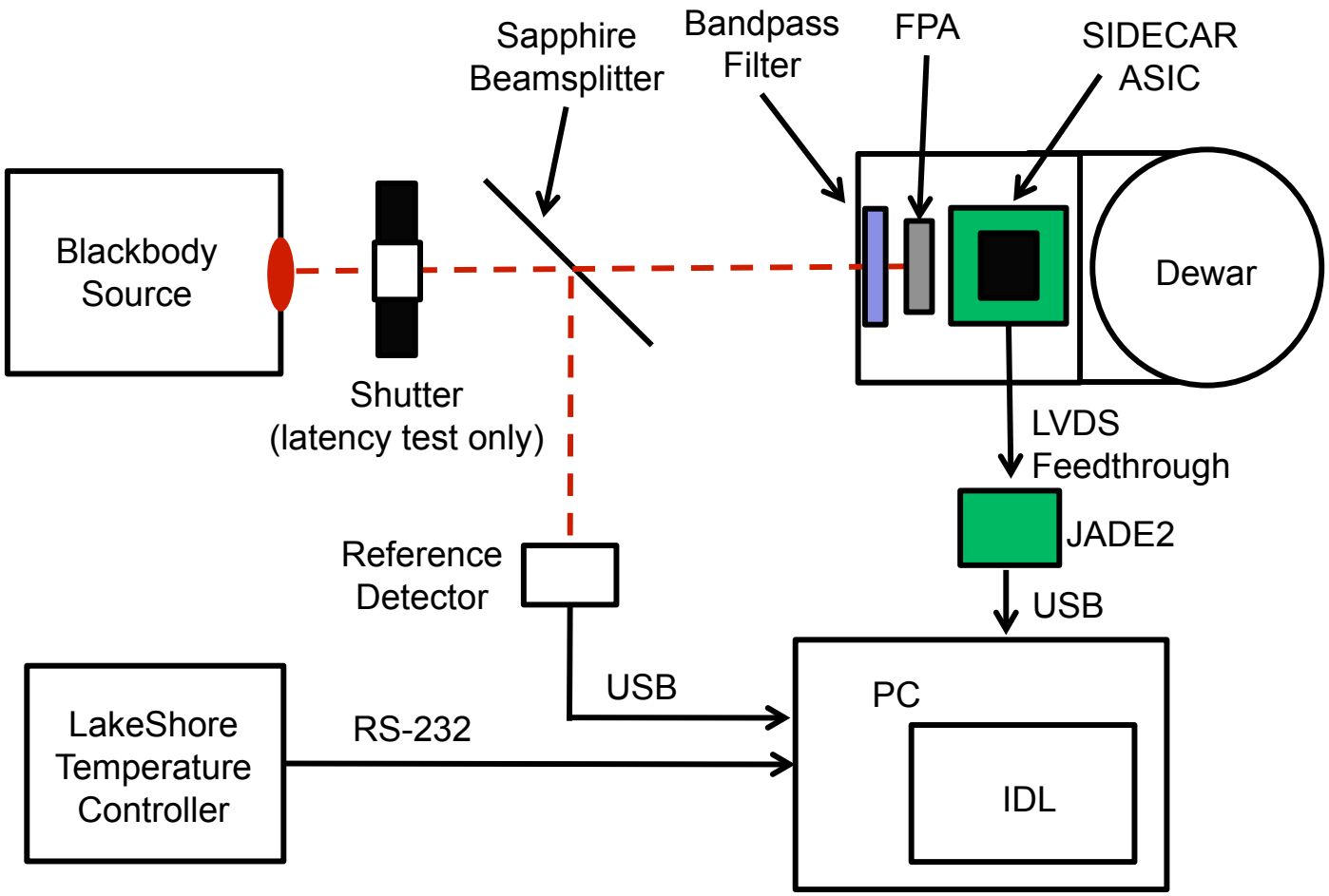
Test response of detector over a range of illumination levels

- Test at the flux levels higher than those measured by manufacturer or in the literature

Test temporal response of detector to removal of irradiance

- Test with shorter recovery time than manufacturer

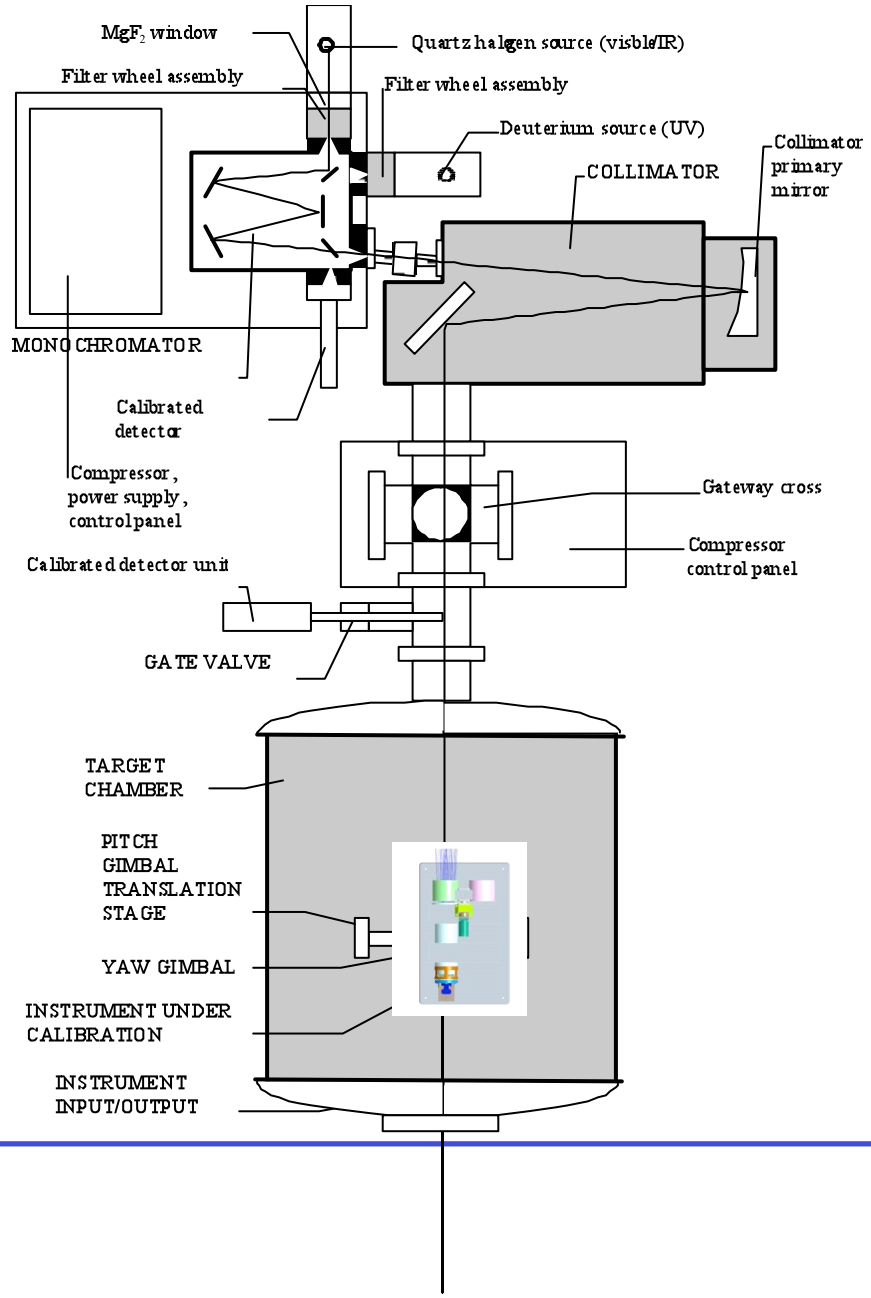
Detector Test Block Diagram



Purpose of End to End Testing

- Determine accurate instrument parameters for use as input into model
- Validate model predictions against hardware testing
  - Use external CO/CH4 cells of known concentration to simulate atmosphere
  - Simulate surface gradients to validate effects of sensor jitter on CO retrieval

End to End Testing



Summary

- Develop a simulator model for a correlation radiometer in the 2.3um band to perform tropospheric CO measurements that includes dynamic effects of the platform

- Current Status
  - On target to finish the IIP first of the year (Jan 2011)
  - End to End testing scheduled to begin in October
  - Simulator currently under use to determine sensitivity to input parameters