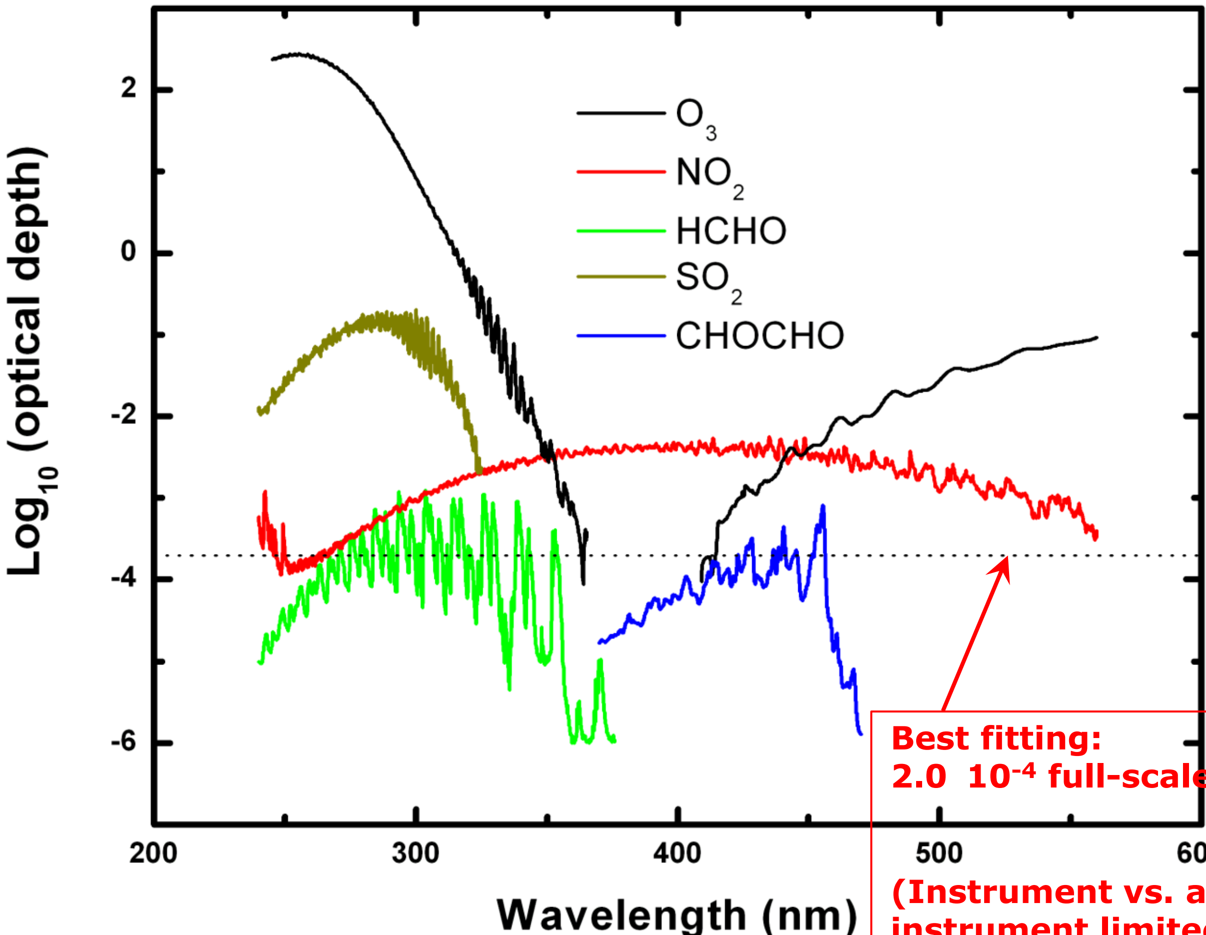
Optical Depths for Typical GEO Measurement Geometry



Best fitting:
2.0 10^{-4} full-scale radiance

(Instrument vs. algorithm: instrument limited → telescope optics size)

Required Concentrations*

European Requirements‡

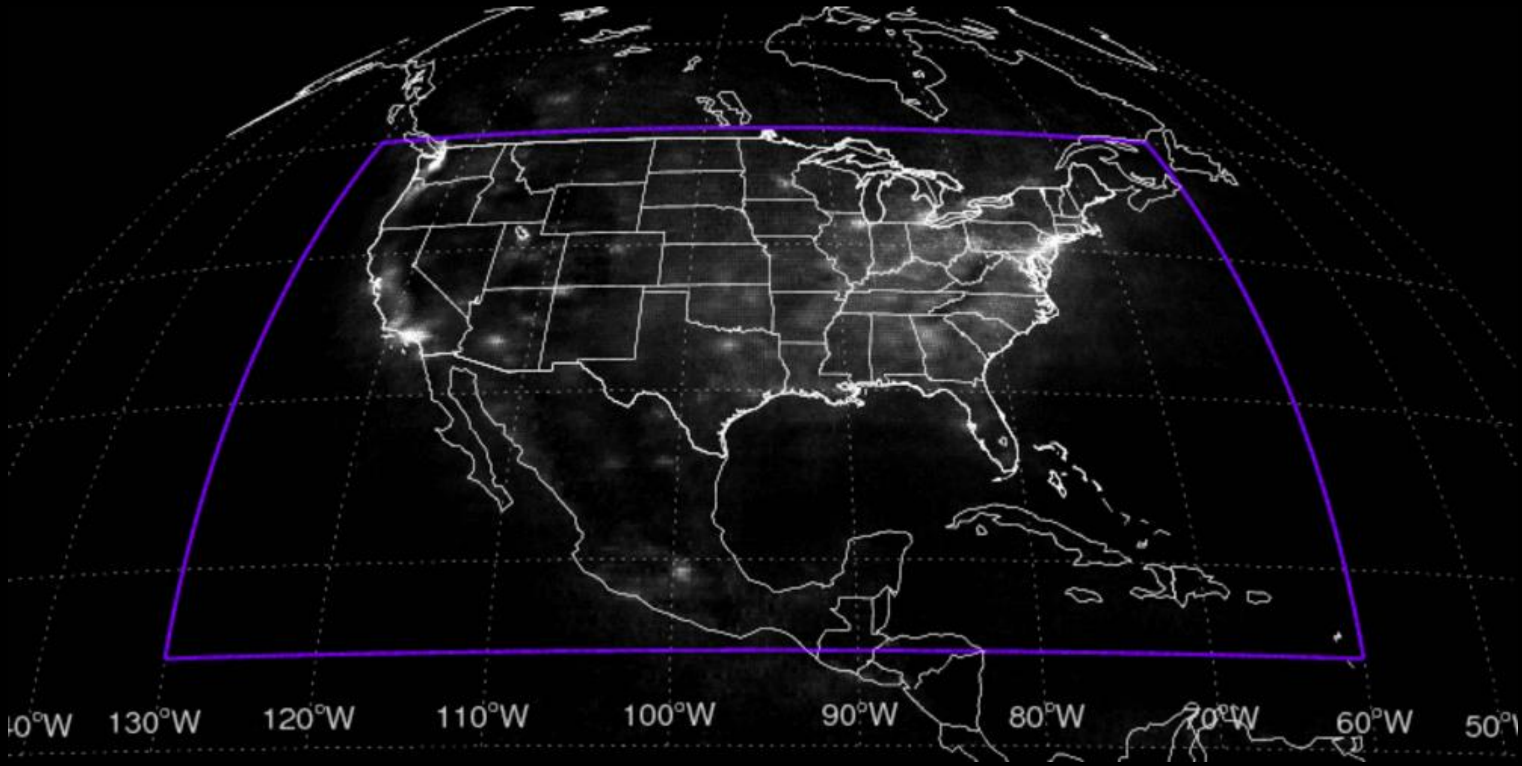
Molecule	Vertical Column [mol cm^{-2}]	Sensitivity Driver
O_3	2.4×10^{16} 10-25%	~10ppbv in PBL; reality (profiling) is more complicated 10% of PBL; 20% of free trop; 25% of troposphere
NO_2	3.0×10^{15} 1.3×10^{15}	distinguish clean from moderately polluted scenes 10% of PBL; 20% of free trop; 1.3×10^{15} ≡ background
SO_2	1.0×10^{16} 1.3×10^{15}	distinguish structures for anthropogenic sources 20% of PBL; 20% of free trop; 1.3×10^{15} ≡ background
HCHO	1.0×10^{16} 1.3×10^{15}	distinguish clean from moderately polluted scenes 20% of PBL; 20% of free trop; 1.3×10^{15} ≡ background
CHO-CHO	4.0×10^{14} n.a.	tracking of most urban diurnal variation n.a.

*In PBL. One of two issues needing the most work (traceability from AQ reqs and modeling)

‡AQ requirements from CAPACITY; Mission Requirements for Sentinel 4&5: Generic at present (1.3×10^{15} = 1 ppbv in 0.5 km). Need further consideration of actual AQ requirements and flowdown to measurement requirements

Scalable Strawman

North American Version



15° - 50°N, 60° - 130°W (parked at 0°N, 95°W)

SZAs ~ 0° – 70°

VZAs ≤ 57°

Spatial resolution 10 10 km^2 footprints

Sampling every <½ hour (27 min)

Sizing for 10 10 km^2 Footprint, 1 Second Integration Time

Molecule	|Rad|	φ cm^{-2} px^{-1}	RMS	φ px^{-1}	$a\times$Eff
O_3	3.57×10^{12}	2.51×10^{4}	1.40×10^{-3}	1.28×10^{5}	5.09
NO_2	6.25×10^{12}	4.87×10^{4}	8.99×10^{-3}	3.09×10^{3}	0.063
SO_2	2.94×10^{12}	2.06×10^{4}	7.25×10^{-3}	4.76×10^{3}	0.230
HCHO	5.65×10^{12}	3.97×10^{4}	5.51×10^{-4}	8.23×10^{5}	20.8
CHO-CHO	6.22×10^{12}	4.85×10^{4}	3.56×10^{-4}	1.98×10^{6}	40.7

Formaldehyde (HCHO) is the driver for almost any conceivable choice of requirements! (Unless VOCs are considered unimportant, in which case O_3 would be the driver, with the above as a low estimate).

20.76 cm^2 is a 16-cm diameter telescope @ 10% optical efficiency (GOME, a much simpler instrument, is 15–20% efficient in this wavelength range).

IR needs (CO, O_3, climate gases) must be addressed.

Outstanding Needs

Science Requirements

(S/N, geophysical, spatial, temporal) from sensitivity and modeling studies (OSSEs), providing traceability for AQ forecast improvement and other uses.

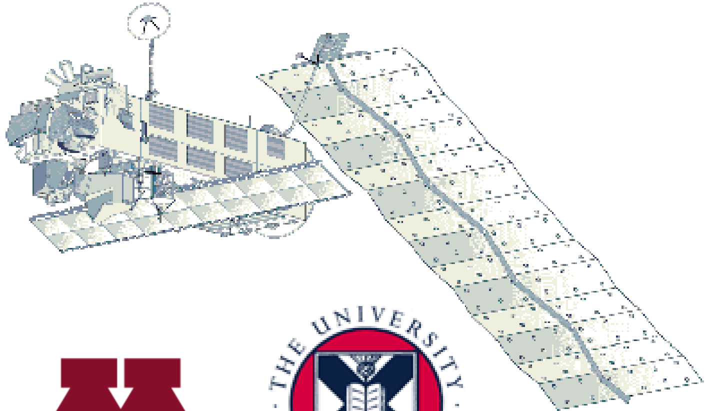
Unless things change a lot, *HCHO will be the driver* for instrument requirements. Then address trade space.

Instrument Design

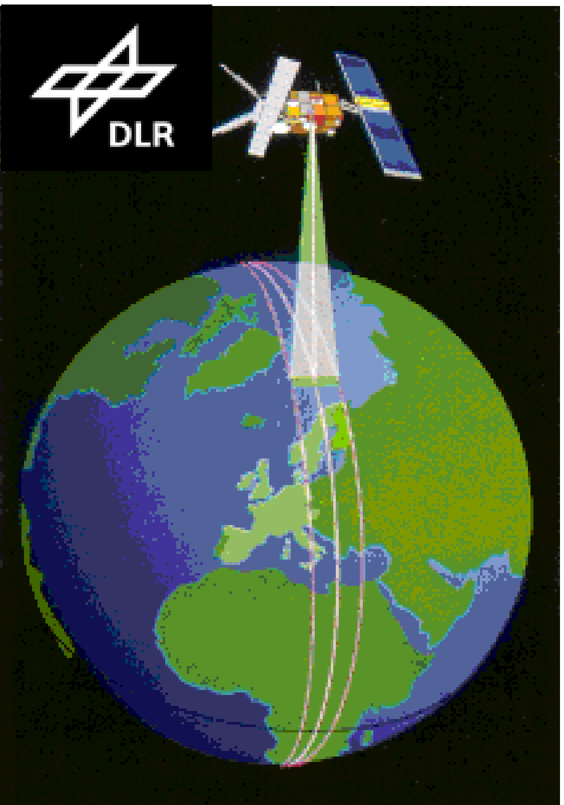
Reducing “smile”, enabling multiple readouts, increasing efficiency, optimizing ITF shape …

GEO instrument is not just a super-OMI with CMOS/Si detectors instead of CCDs. Minimal geostationary requirements imply scanning instead of a pushbroom and they imply getting many more spectra onto a rectangular detector than OMI and OMPS have obtained.

Instrument optical and spectrograph design, *including fully-informed choice of detector type*, is the single most important outstanding issue in demonstrating the feasibility of geostationary pollution measurements. *N.B. PBL O_3 instrument drivers!*



The End!

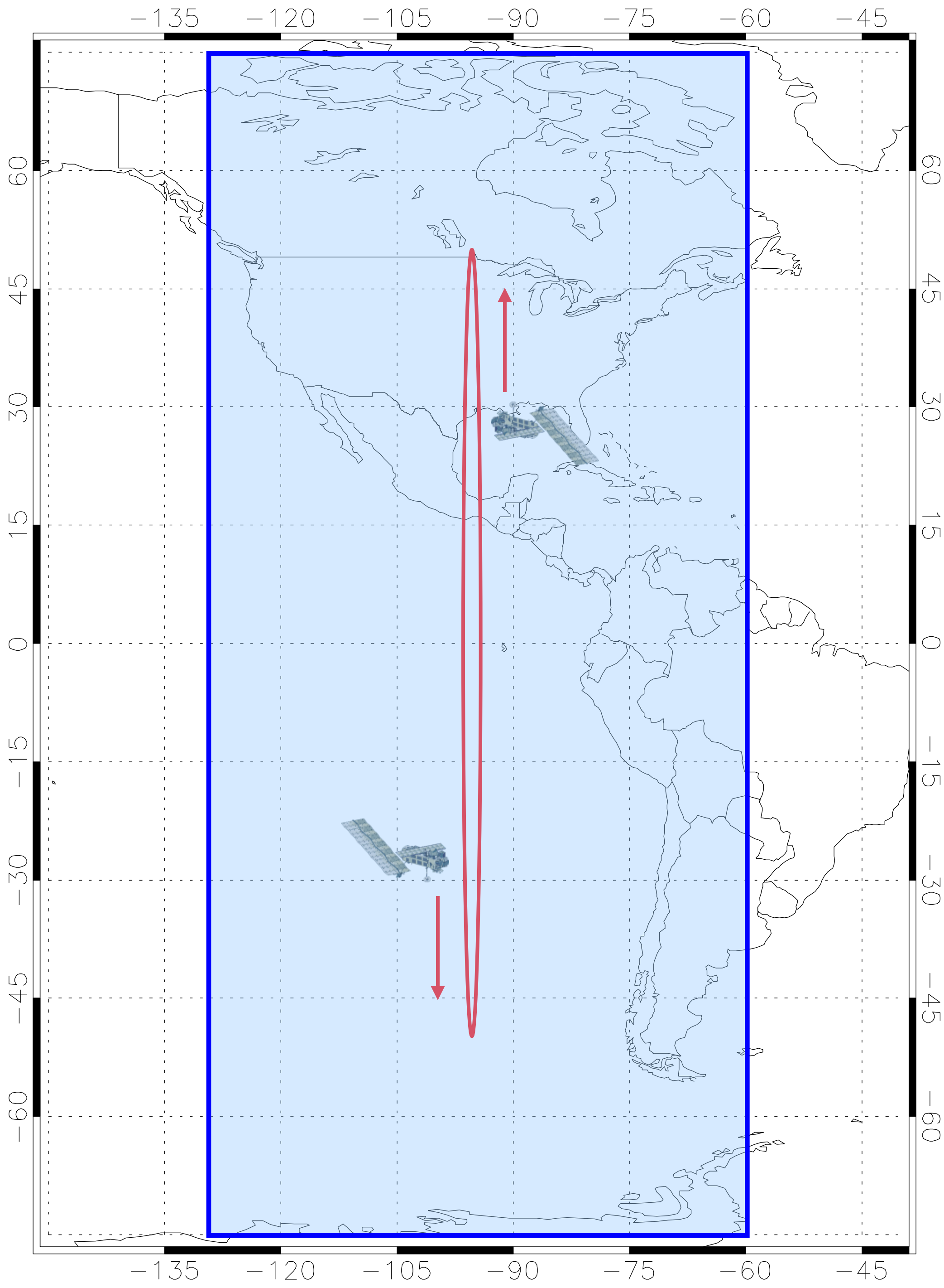


An alternative (not in baseline):
Inclined 24 hour orbits!

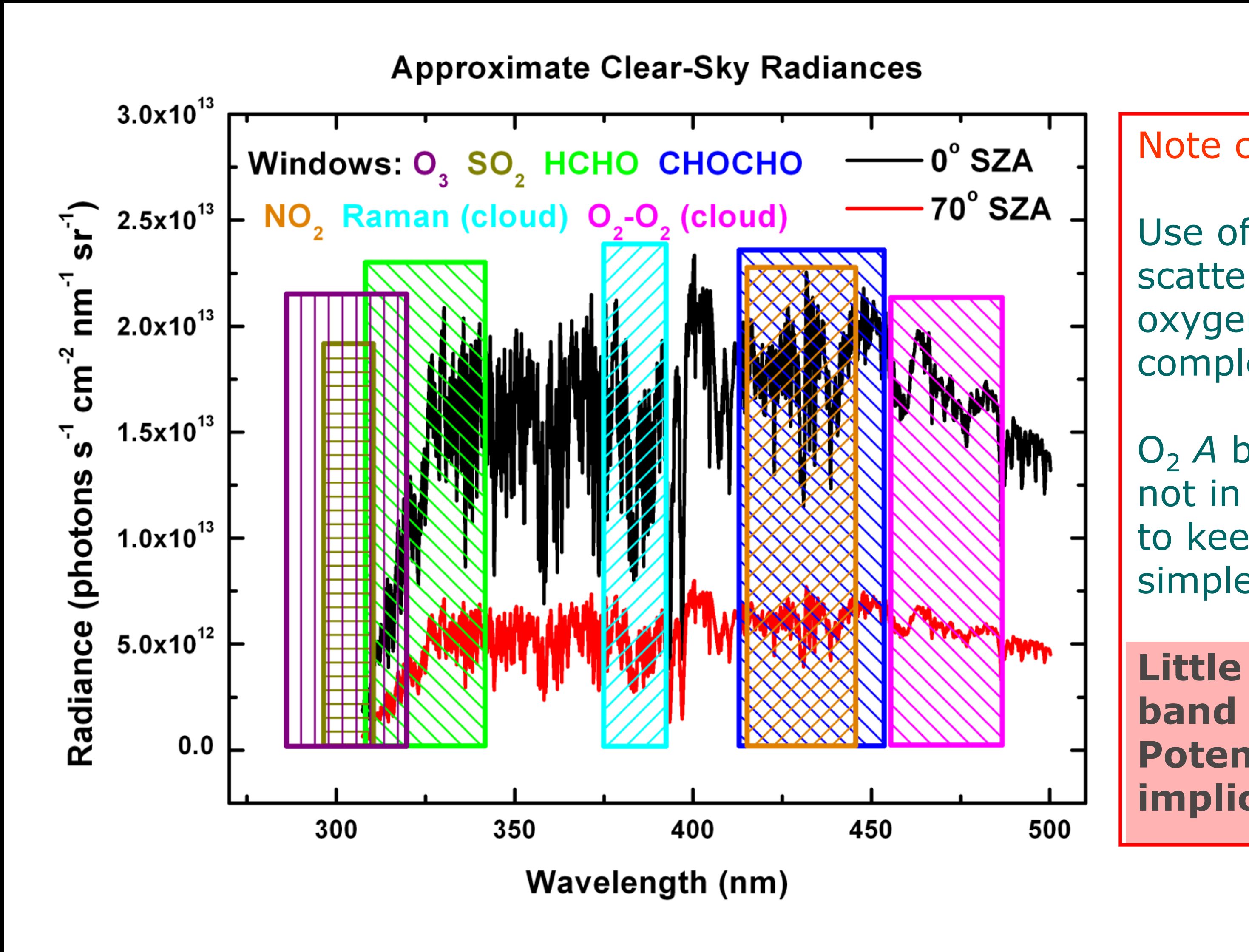
Better viewing zenith angles at high latitudes

Possibility to measure same location at different VZAs ➔ *profile information*

(Thanx, RVM!)



Radiative Transfer Modeling and Fitting Studies



Note cloud windows:

Use of Raman scattering and of the oxygen collision complex.

O_2 *A* band @762 nm not in baseline design, to keep it small and simple

Little Chappuis band coverage: Potential PBL O_3 implications

Measurement Requirements

Molecule	Fitting Window [nm]	Vertical Column [mol cm^{-2}]	Slant Column [mol cm^{-2}]
O_3	315-335	2.4×10^{16}	5.0×10^{15}
NO_2	423-451	3.0×10^{15}	1.1×10^{15}
SO_2	315-325	1.0×10^{16}	1.5×10^{15}
HCHO	327-356	1.0×10^{16}	2.3×10^{15}
CHO-CHO	433-465	4.0×10^{14}	1.5×10^{14}

The slant column measurement requirements come from full multiple scattering calculations, including gas loading, aerosols, and the GOME-derived (Koelemeijer *et al*., 2003) albedo database, and assume a 1 km boundary layer height.

Scalable Strawman

Instrument Characteristics (1)

Spatial Resolution and Sampling

Latitude/longitude limits are ~3892 km N/S and 7815-5003 km E/W (6565 average), or about 390×657 10×10 km^2 footprints.

- Measure 400 spectra N/S in two 200-spectrum integrations (each on two 1024^2 detector arrays – 1 UV and 1 visible).
- 2.5 seconds per longitude (2×1 s integration, 0.5 s step and flyback) → total sampling every < ½ hour (27 min).

Detectors

Rockwell HyViSi TCM8050A CMOS/Si PIN (as used by OCO)

- 3×10^6 e^- well depth; will need several rows (or readouts) per spectrum to reach the necessary statistical noise levels.
- Complicated by brightness issues; can't always have full wells.
- Conclusions from OCO characterization of these detectors must be fully understood.

Scalable Strawman
Instrument Characteristics (2)

Spectral Characteristics

200 spectra on each of two 1024^2 arrays; each spectrum uses four detector rows (800 total out of 1024).

- Channel 1: 280-370 nm @ 0.09 nm sample, 0.36 nm resolution (FWHM).
- Channel 2: 390-490 nm @ 0.1 nm sample, 0.4 nm resolution (FWHM); includes O_2-O_2 @ 477 nm.
- 4 samples per FWHM virtually eliminates undersampling for a symmetric instrument transfer (slit) function [Chance *et al*., 2005].

Pointing

to 1 km = 1/35,800 = 6 arcsecond (readily achievable)*

Telescope size

Size optics to fill sufficiently in 1 second (≈ 1 cm^2 (GOME size) × √1.5 (GOME integration time) × 35,800 km / 800 km = 55 cm "telescope" optics).

More realistically ....

*Spitzer points to 1 arcsecond 0^{th} order, correctable to ≤ 0.1

Sizing for 10 10 km^2 Footprint, 1 Second Integration Time

Molecule	⟨Rad⟩	φ cm^{-2} px^{-1}	RMS	φ px^{-1}	a×Eff
O_3	3.57×10^{12}	2.51×10^{4}	1.40×10^{-3}	1.28×10^{5}	5.09
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⟨Rad⟩ Minimum clear-sky radiance, cross-section weighted (phot s^{-1} nm^{-1} sr^{-1} cm^{-2})

φ cm^{-2} px^{-1} # photons cm^{-2} $pixel^{-1}$ @ instrument in 1 second; 10×10 km^2
→ 7.80×10^{-8} sr solid angle

RMS Fitting RMS required for the minimum detectable amount = 1 / required S/N

φ px^{-1} # photons $pixel^{-1}$ needed in 1 second to meet RMS-S/N requirements; includes factor of 4 for 4 detectors rows per spectrum

a×Eff Telescope collecting area (cm^2) × overall optical efficiency

Major Tradeoffs and Questions

Tradeoffs:

#samples (footprint) vs. sensitivity (S/N) vs. integration time vs. geographical coverage vs. max SZA vs. optical size:

- 5 5 km^2 footprints in 1/2 hour with a 32 cm diameter telescope, if the instrument is 10% efficient (Spatial resolution: rows vs. # readouts; could do 5×5 km^2 on 1 chip with multiple readouts).
- Spatial Nyquist sampling must be carefully addressed.

Questions:

Are latitude and longitude sampling necessarily the same? Is constant sampling necessary?

Options and extensions (near-term GEO-CAPE attention!):

MODIS channels for aerosols? (TOMS AAI is automatic, but little else is operational.)

- OMI aerosol products should be reviewed.
- Should include polarization-resolved measurements;
- Several such UV channels will improve PBL O_3 [Hasekamp and Landgraf, 2002a,b; Jiang *et al*., 2003].

PANCHROMATIC!

Visible (Chappuis) band to further improve PBL O_3? (Discrete?)

Major Tradeoffs and Questions

Everything is Debatable

this is why it is a strawman, <u>but</u> we must show why alternatives are better.