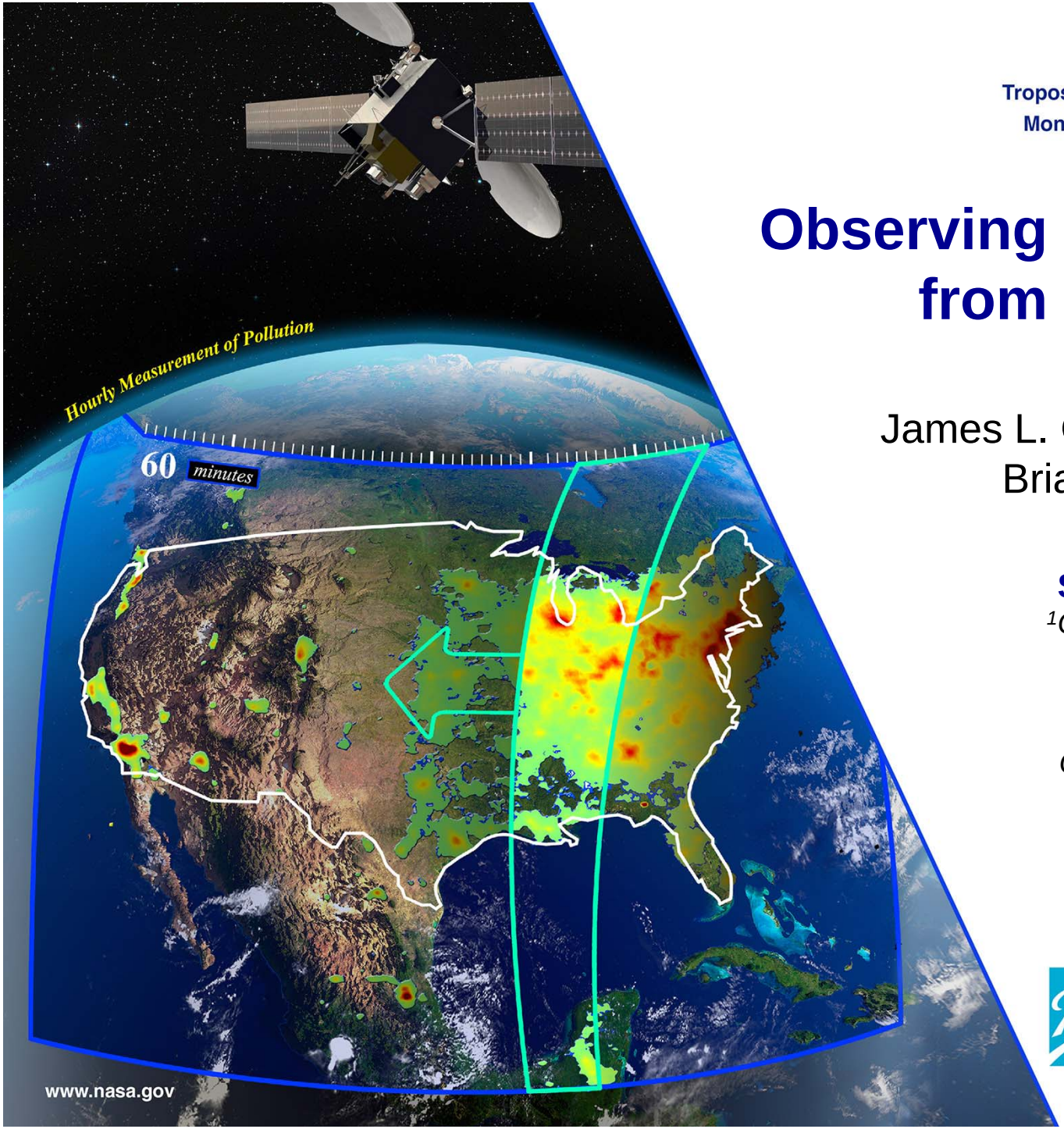

Tropospheric Emissions:
Monitoring of Pollution

TEMPO

Observing Nightlights from Space with TEMPO

James L. Carr[1], Xiong Liu[2], Brian D. Baker[3] and Kelly Chance[2]

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Ball

Smithsonian

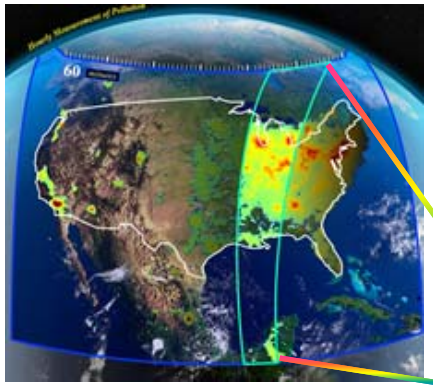
NASA

TEMPO Mission

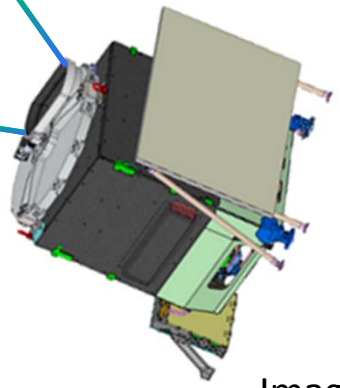
- **Tropospheric Emissions: Monitoring of Pollution (TEMPO)**
  - NASA Earth Venture Instrument (EV-I)
    - Hosted on a geostationary commercial communications satellite over North America
    - Launch date TBD: 2018 – 2021
  - Primary Mission: Air Quality / Atmospheric Chemistry
  - Lead Institution: Smithsonian Astrophysical Observatory (PI: Kelly Chance, Deputy PI: Xiong Liu)
  - NASA Implementing Center: NASA Langley Research Center
  - Instrument Manufacturer: Ball Aerospace & Technologies Co.
- **Future International Constellation for Air Quality Observations**
  - Geostationary Orbit:
    - Geostationary Environment Monitoring Spectrometer (GEMS) – Korea, 2019
    - Sentinel-4 – Europe, 2022
  - Low-Earth Orbit: Sentinel-5p (TROPOMI, 2017) and -5 (2021)

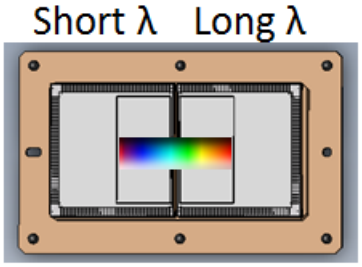
TEMPO Operations: Step / Stare Imaging over Field of Regard

Parameter	Current Best Estimate
Frame Integration Time	118 ms
Image Frame Rate	7.92 Hz
Image Frame Time	2.65 s
Number of Coadds	21
Scan Mirror Step Size	114 µrad
Number of Scan Mirror Steps	1283
Coverage Time	59.1 min



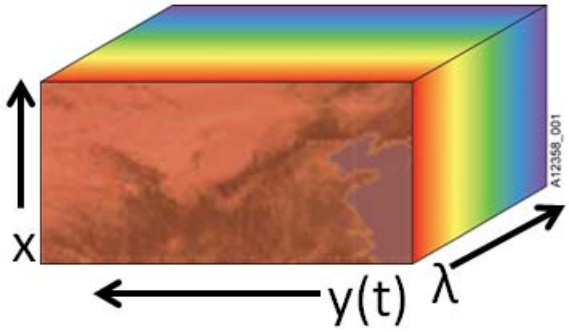
TEMPO step / stares over "Greater North America" in 1283 steps from East to West over 59.1 minutes



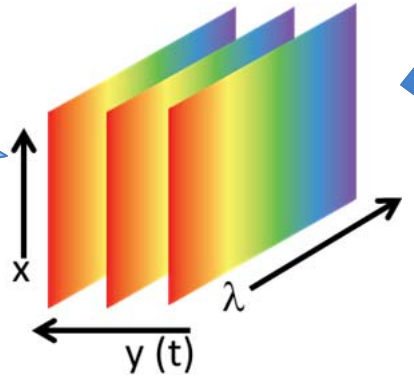


Ground processing spatially bins and geo-locates image

Images from each scan mirror position are co-added on board



Transmit co-added images to ground



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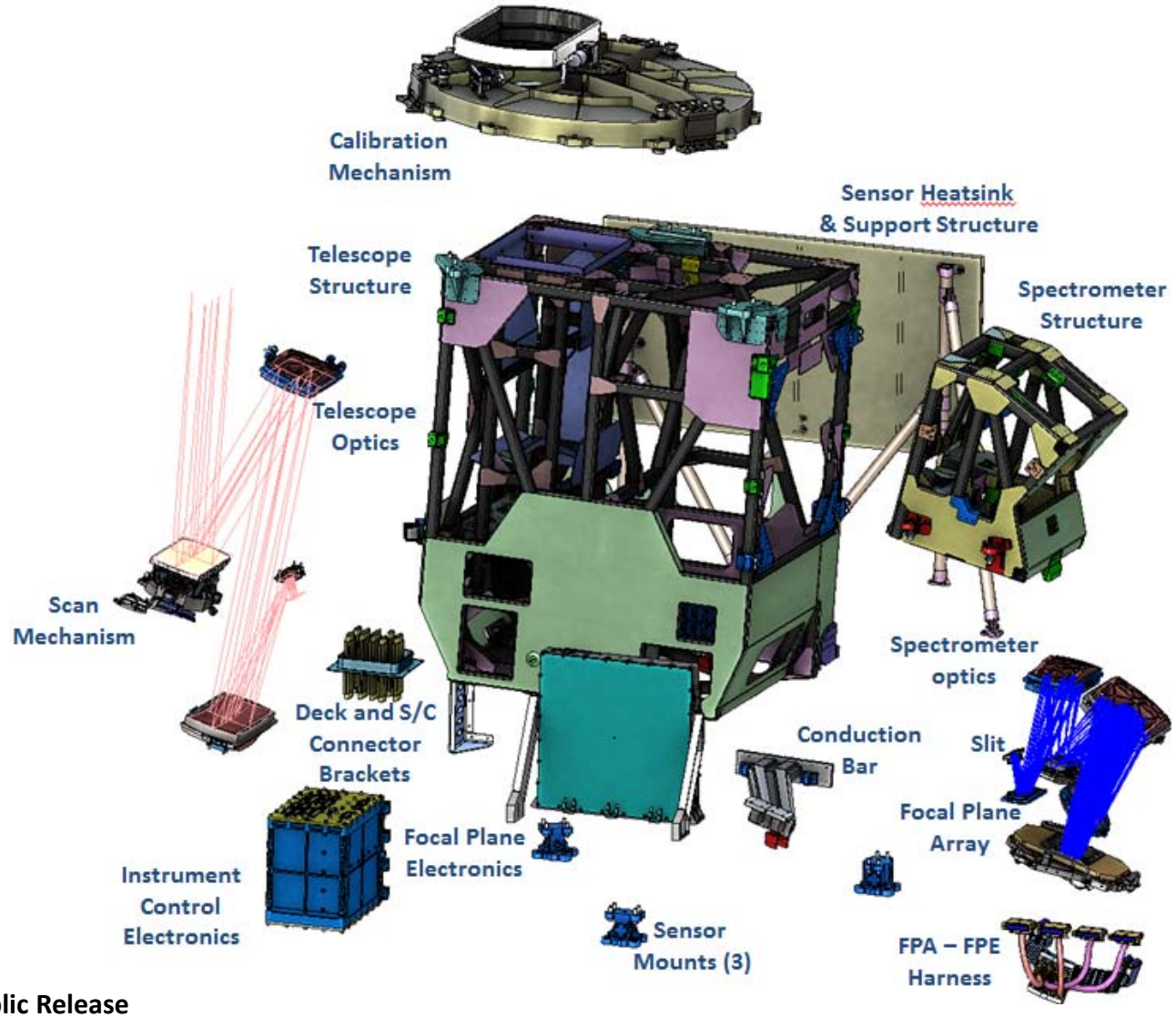
TEMPO Instrument: Expanded View



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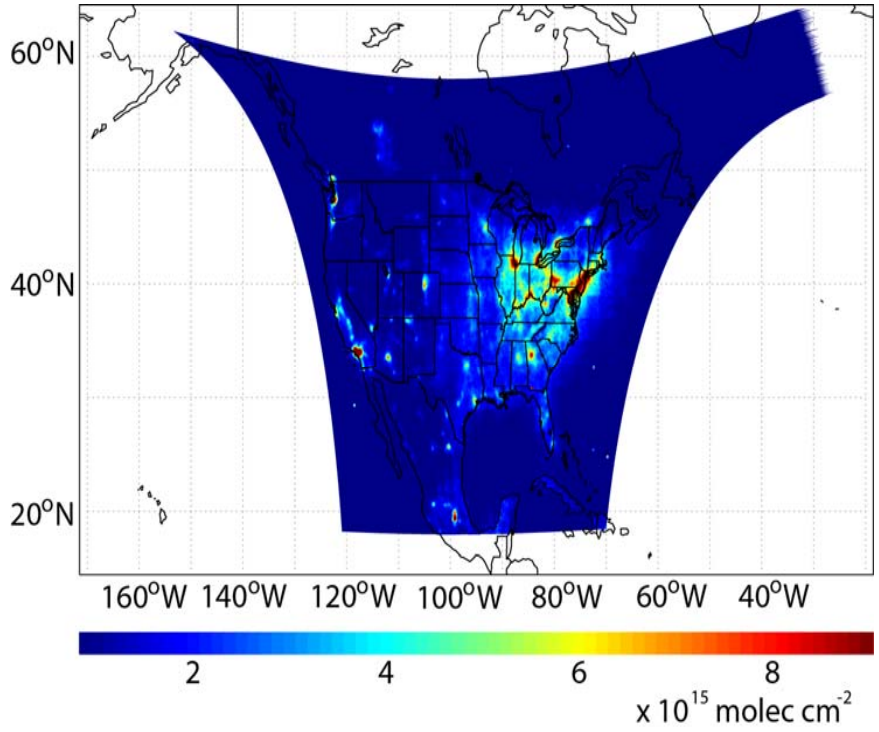
Daytime Mission

- Cover Greater North America from a geostationary orbital station 80°W to 115°W
- Retrieve concentrations of trace gases, including O_3, NO_2, SO_2, H_2CO, $C_2H_2O_2$, BrO, IO, and H_2O from the spectra of reflected sunlight, plus other objectives (aerosols, clouds, chlorophyll fluorescence)
- Revisits < 1 hour during daylight to follow the creation and dispersal of pollutants
- Ground Footprint: 2.1km x 4.4km at Field of Regard center from GEO at 100°W
- Dwell per pixel: 2.478 s

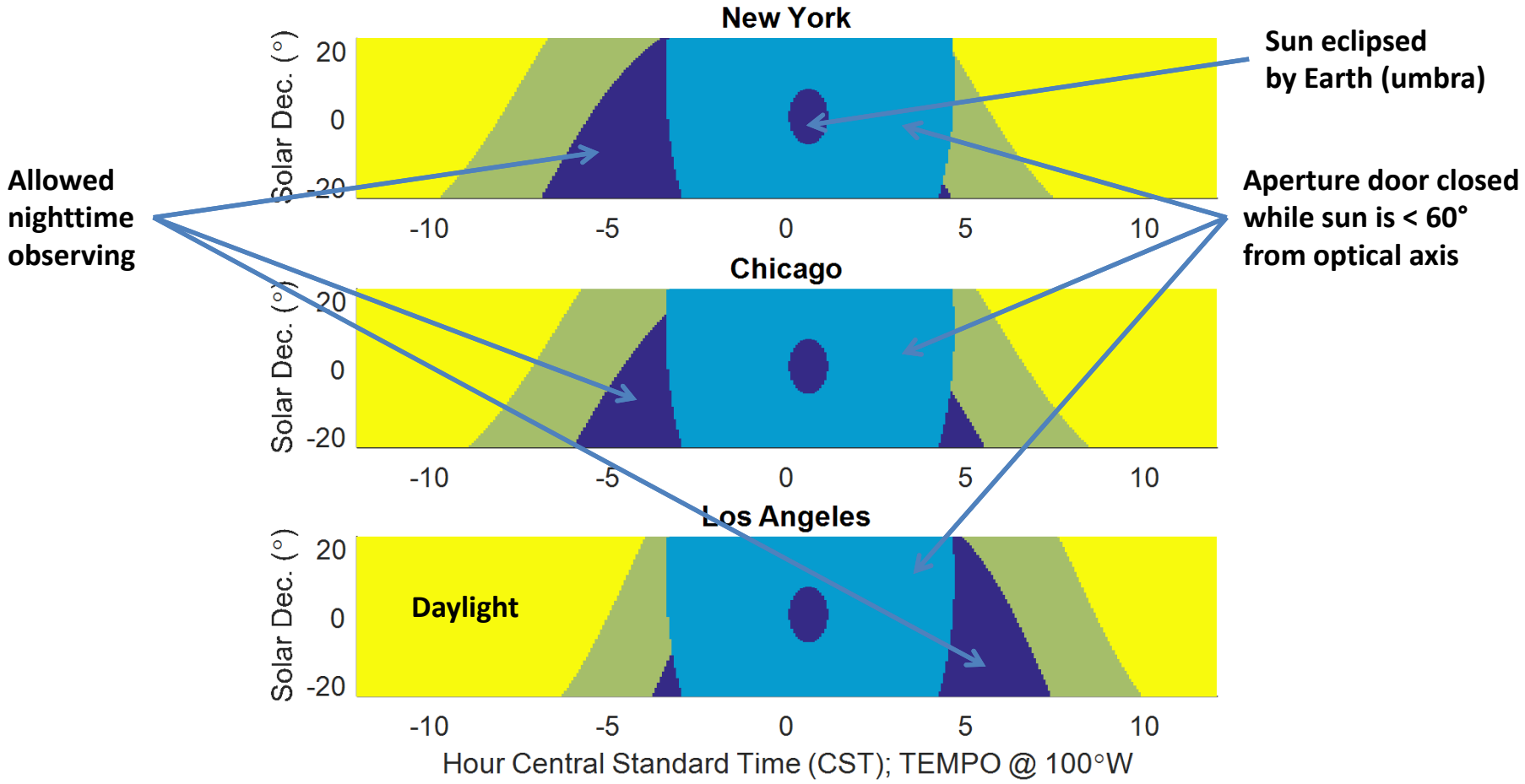
P. Zoogman, *et. al.*, "Tropospheric Emissions: Monitoring of Pollution (TEMPO)", *Journal of Quantitative Spectroscopy and Radiative Transfer*, in press.



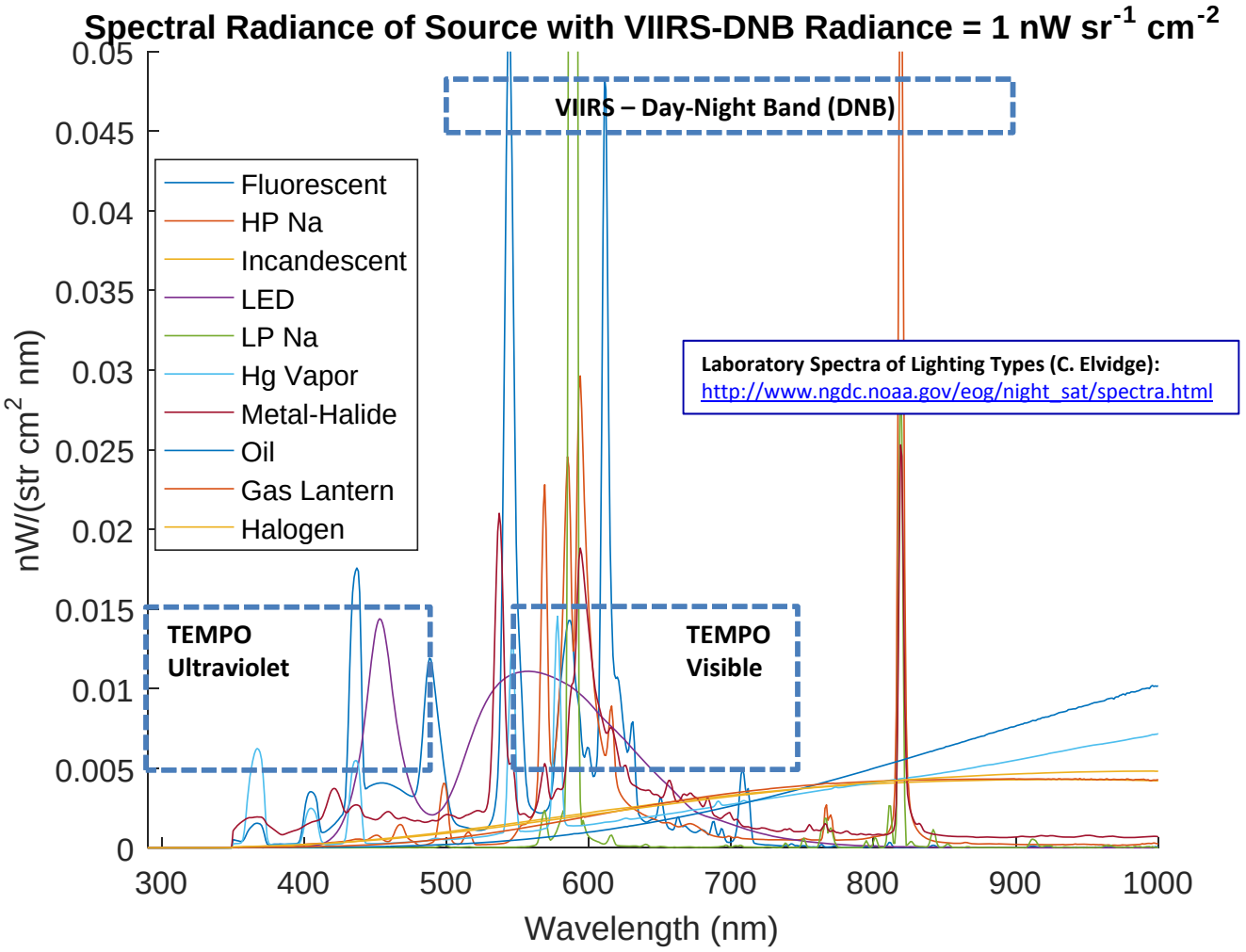
NO_2 column densities over the TEMPO Field of Regard (derived from OMI)

Nighttime Observing

- Sun safety constraint limits nighttime observing opportunities
- Best times for TEMPO nighttime observations are during winter

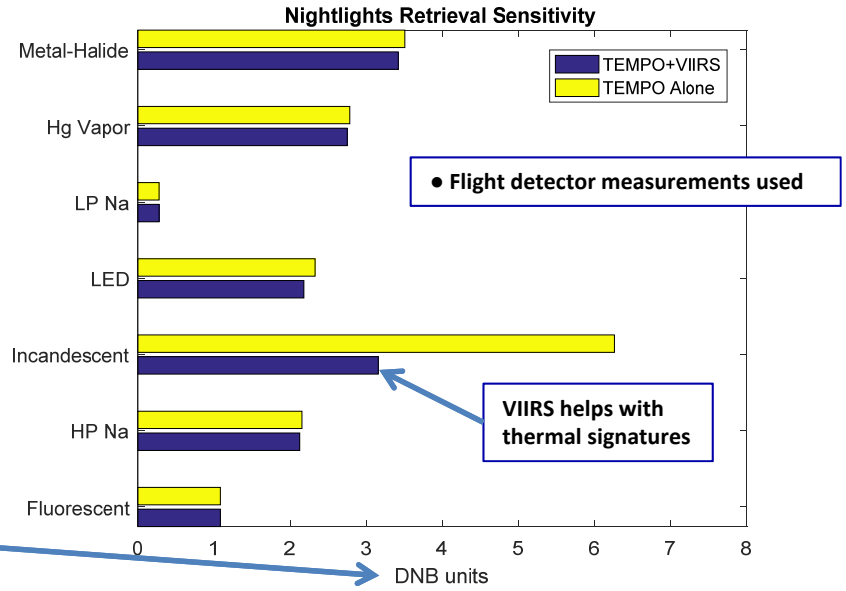


Spectroscopic Signatures



Nightlight Retrievals

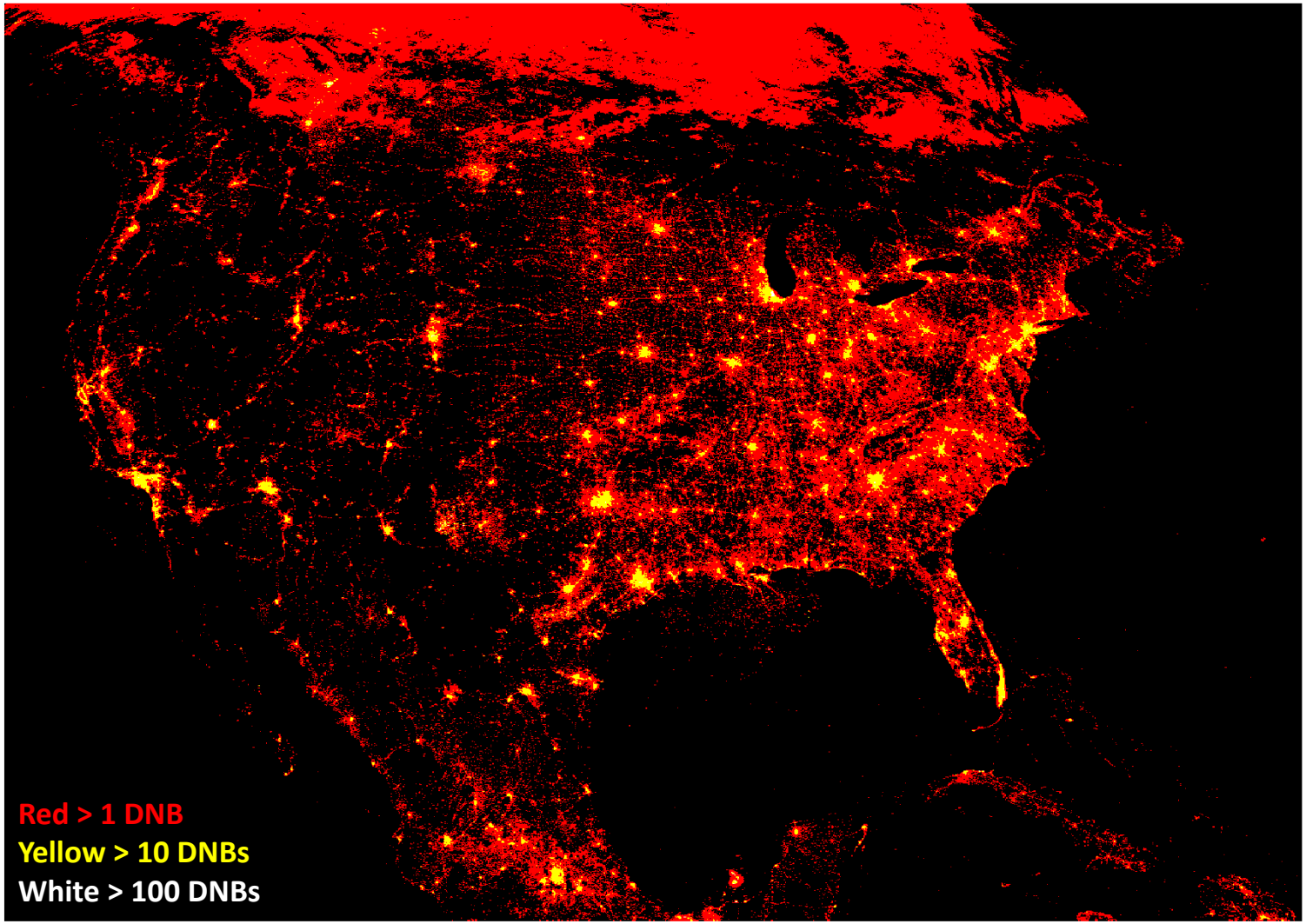
- **TEMPO nighttime observing Operations Concept**
  - Plan for clear skies over areas of interest & sun constraint
  - Increase dwell time to ~10s per pixel
  - Calibrate dark current with aperture shut 16x 10 dwells
  - Open aperture and collect over designated area
  - Recalibrate dark current with aperture shut ~160s
  - Leave aperture shut while waiting to resume daylight operations
- Nightlights spectral fitting "retrieves" nightlight radiances from each lighting type in our library and accounts for moon
- Poisson noise in TEMPO dark current is limiting factor



Uncertainty in retrieved radiances are in units of an equivalent response in the VIIRS-DNB. One "DNB" unit = 1 nW sr^{-1} cm^{-2}.

What TEMPO Might See

December 2015 Clear-Sky Mean VIIRS-DNB Radiances (NOAA/NGDC)
Remapped to the TEMPO Field of Regard and Resolution



Conclusions

- Fine spectral resolution of the TEMPO spectrometer enables discrimination of different lighting types that is simply not possible using the VIIRS-DNB

- TEMPO nightlights retrievals will be sufficiently sensitive to characterize outdoor lighting types over North America
  - Enhanced pixel dwell times for low light
  - Sensitivity is limited by Poisson noise in dark current
  - Most sensitive to sources with highly structured spectra
  - Best observing is during winter at Beginning of Life

- We encourage our Korean and European colleagues to look at the capabilities of GEMS and Sentienel-4 to do similar exciting new science with their instruments


TEMPO