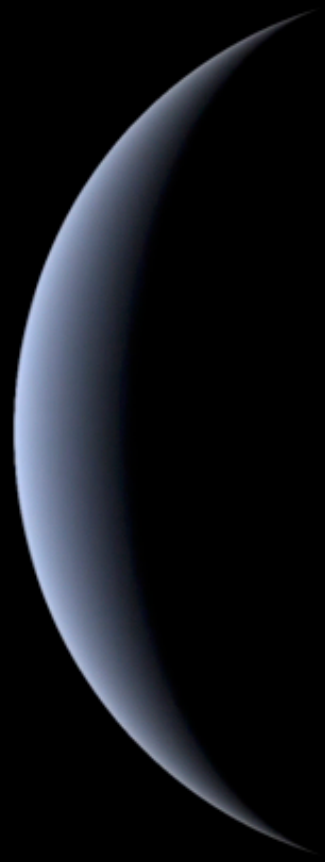
Modelling the expected observations of the Advanced Ice Giants Net Flux Radiometer (IG-NFR) instrument concept under study for future entry probe missions to Uranus or Neptune.



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M. Roos-Serote (Lightcurve Films),
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Advanced Ice Giants Net Flux Radiometer (IG-NFR)

- Instrument proposal, led by NASA Goddard Space Flight Center, for possible future Uranus or Neptune descent probes.
- Possible launch window near 2030 to get Jupiter gravity assist. More opportunities for Uranus than Neptune.
- Much interest in having a descent probe as well as orbiter. Probe would be delivered on arrival and make descent while orbiter went into orbit. Would get ~2-hour window to make descent, take data and return to orbiter before probe sinks out of sight.
- Geometry of approach indicates solar altitude for descent of 10^{o}.
- One possible instrument is a Net Flux Radiometer, sampling visible through to thermal IR upwards and downwards radiation to measure radiative heat budget and also measure abundance of methane and clouds.

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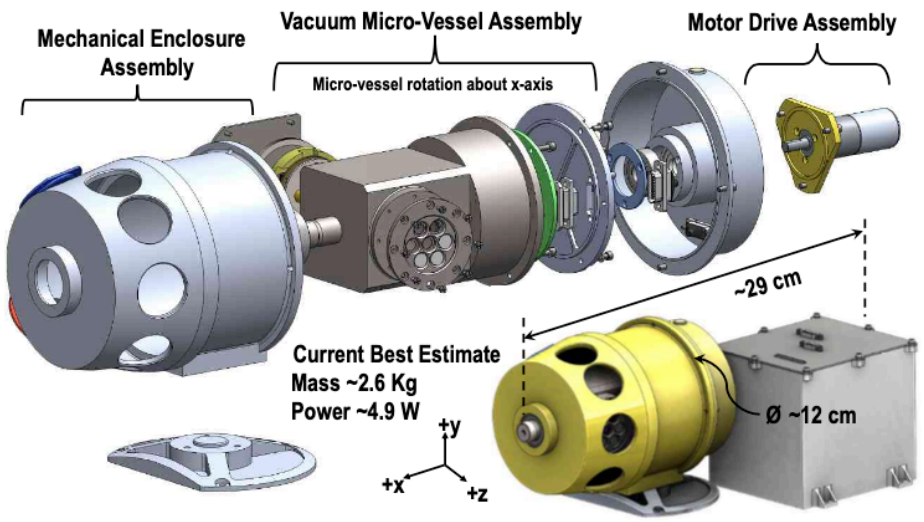
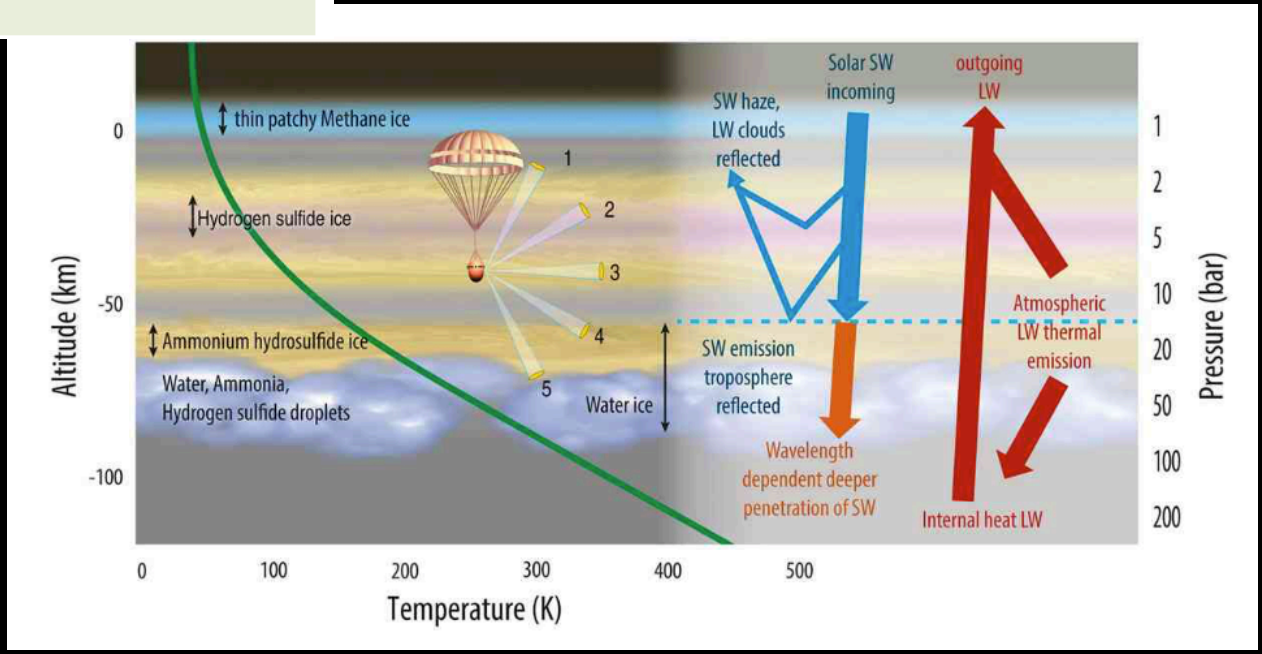
IG-NFR



- 7 spectral channels
- Thermopile detectors
- ASIC parallel readout
- 10° FOV for each channel
- 5 viewing angles ±80°, ±45° and 0° relative to zenith and nadir
- Mitigation of rapidly changing ambient environment from ~50 K (0.1 bar) to ~160 K (10 bar) using a vacuum micro-vessel



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Radiative Transfer Analysis

NEMESIS

- **N**on-linear Optimal **E**stimator for **M**ultivariat**E** Spectral Analy**SIS**
- Originally developed for solar system studies, but extended for exoplanets/brown dwarfs.
- Core retrieval code based on **Optimal Estimation**, but also extended for Bayesian **Nested-Sampling** retrievals.
- For multiple-scattering NEMESIS used plane-parallel Matrix operator scattering code.
- Line-by-line and correlated-k.

PSG

- **Planetary Spectrum Generator (PSG)** is a radiative-transfer and retrieval application, accessible online (~1 million hits/month).
- Line-by-line and correlated-k capabilities (for RP<5000) with access to hundreds of species from several databases.
- Multiple scattering is enabled using the discrete ordinates method, with access to +100 aerosol models (Mie and T-matrix).
- PSG includes a noise simulator for a range of instruments (e.g., radiometer, interferometer, coronagraph, LIDAR).
- The retrieval module employs Optimal Estimation, and PSG has been ported as a collaboration with Google to AI/NN and Bayesian sampling retrieval methods.

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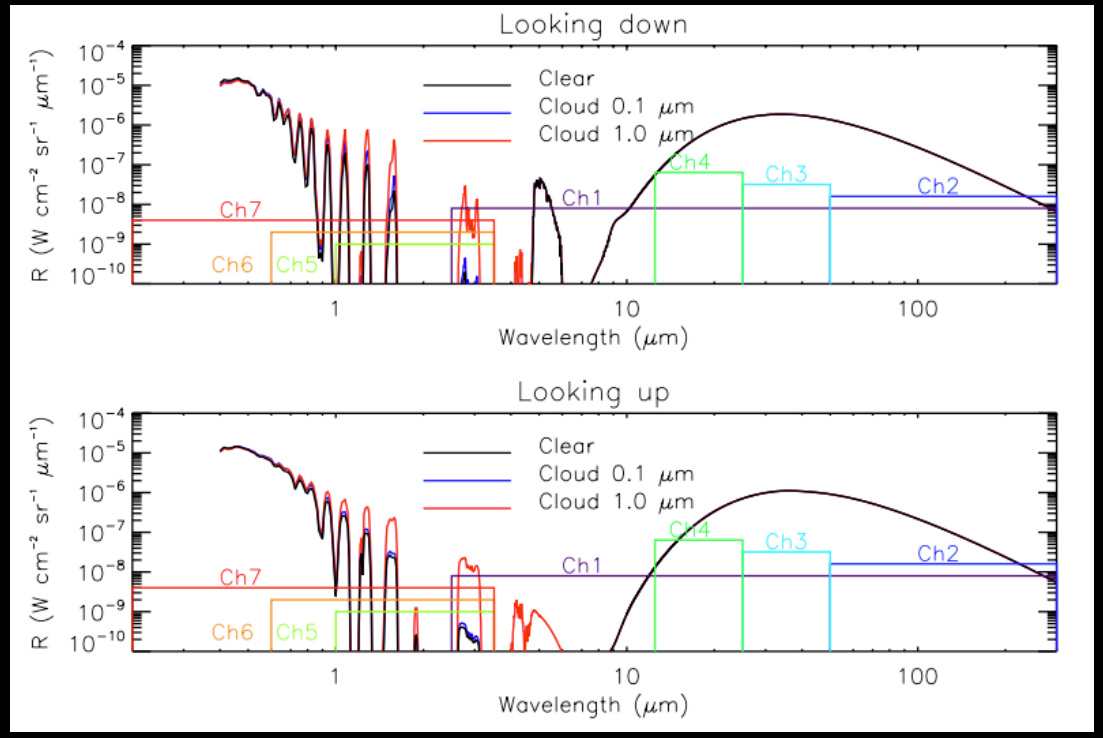
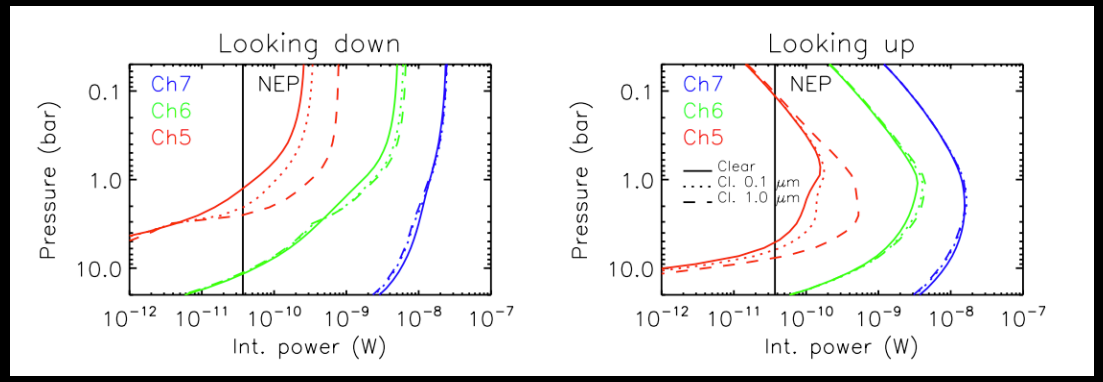
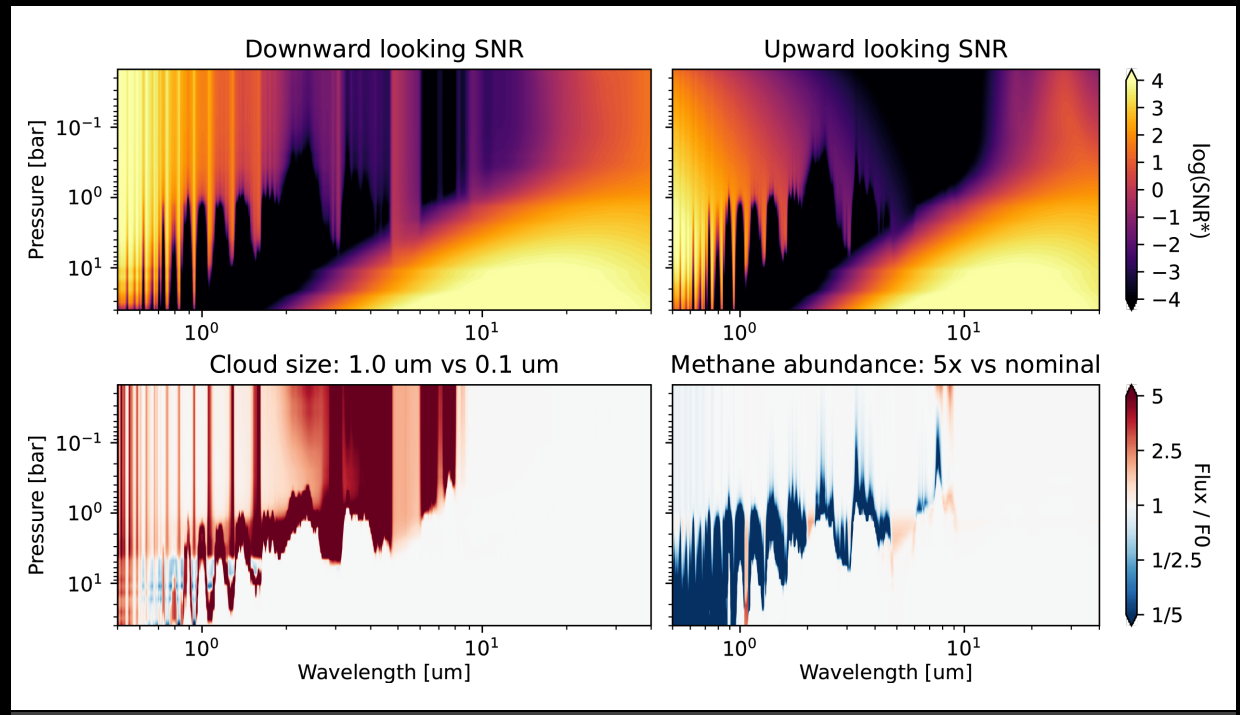
NASA Planetary Spectrum Generator

NEMESIS





PSG



Sensitivity study: the simulations are done considering a 10°FOV, a solar zenith angle of 0°, emission angle of 45°, an integration time of 2-seconds, and a hypothetical filter width of 1 μm

psg.gsfc.nasa.gov

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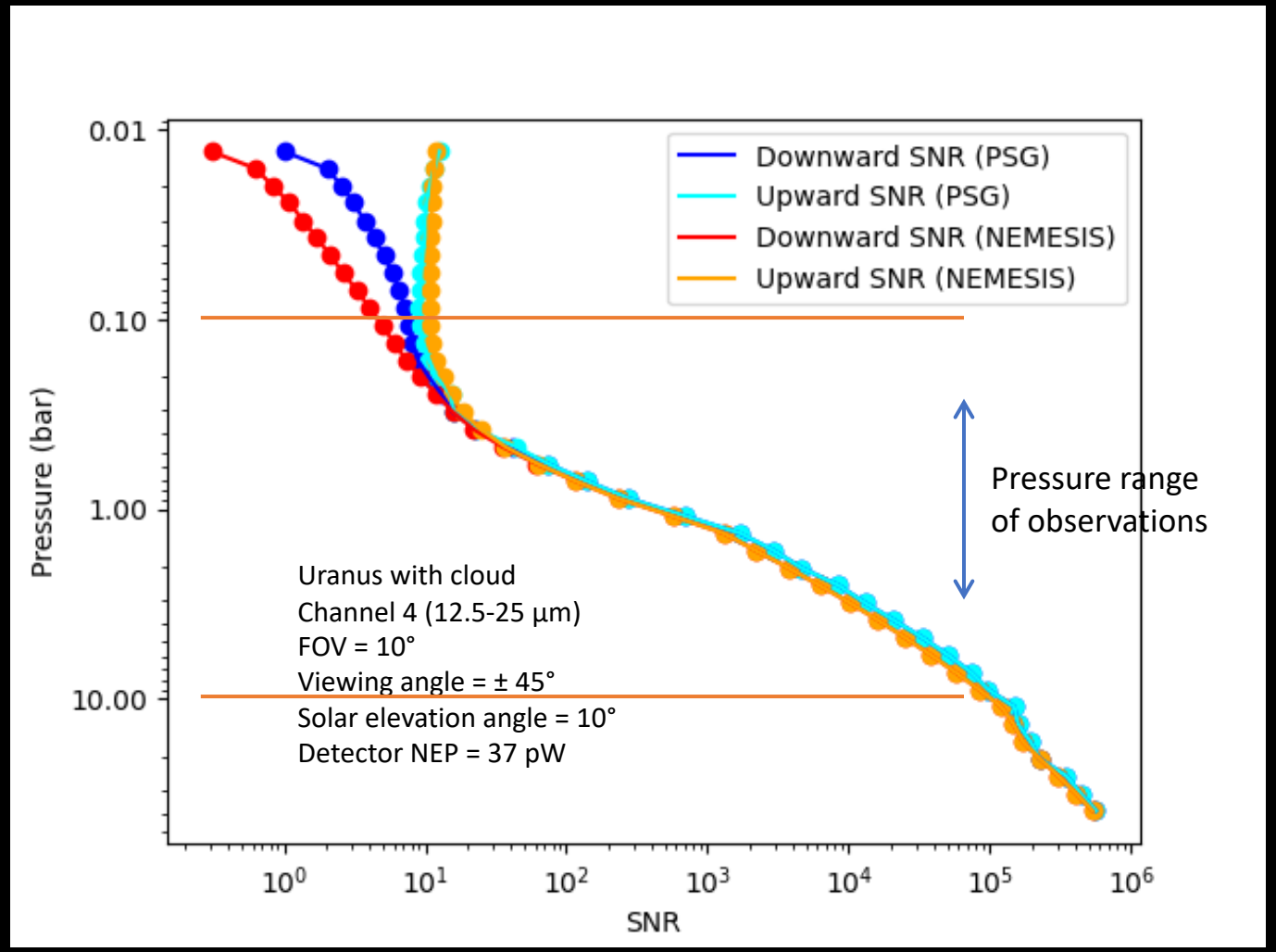
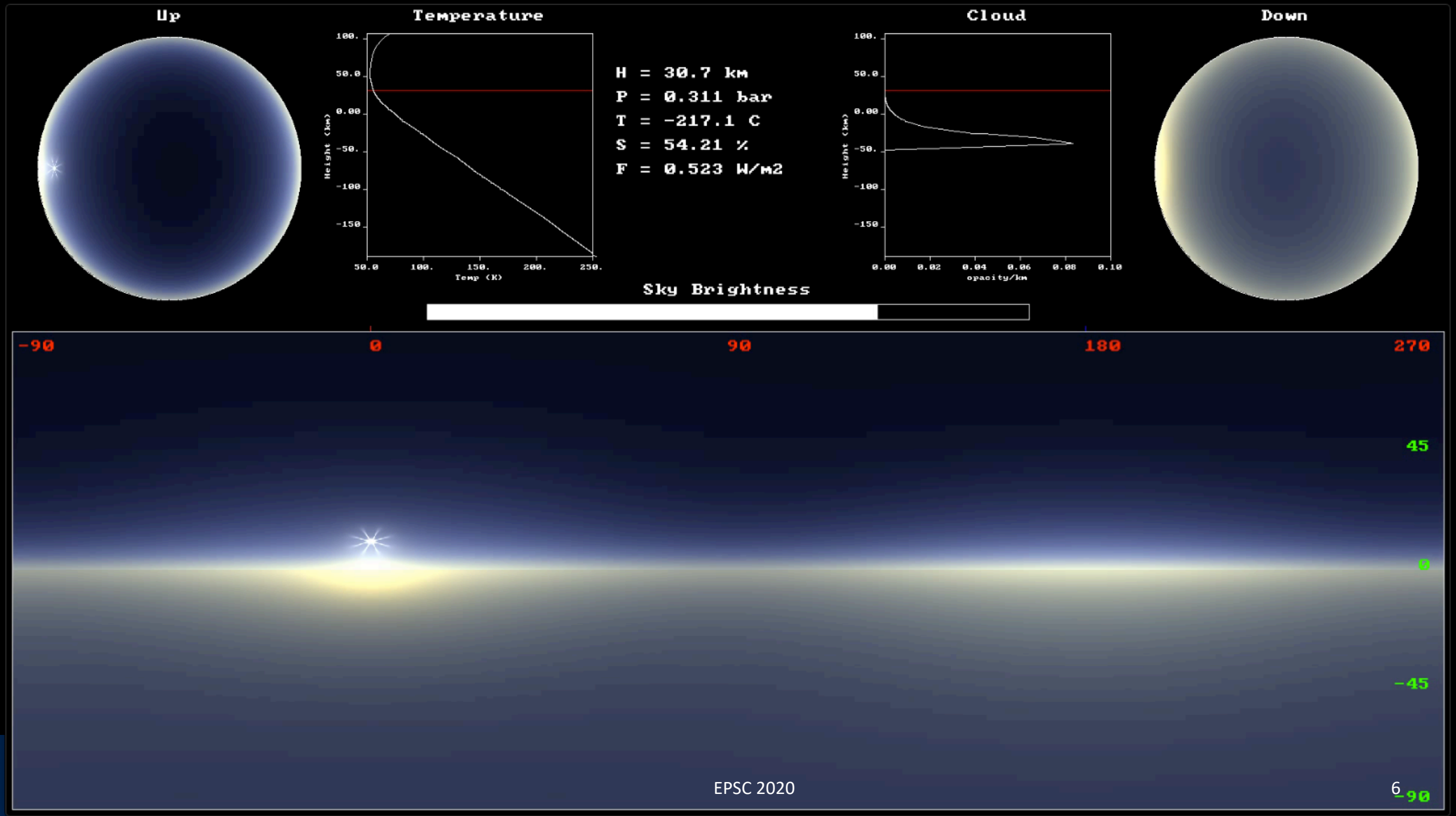
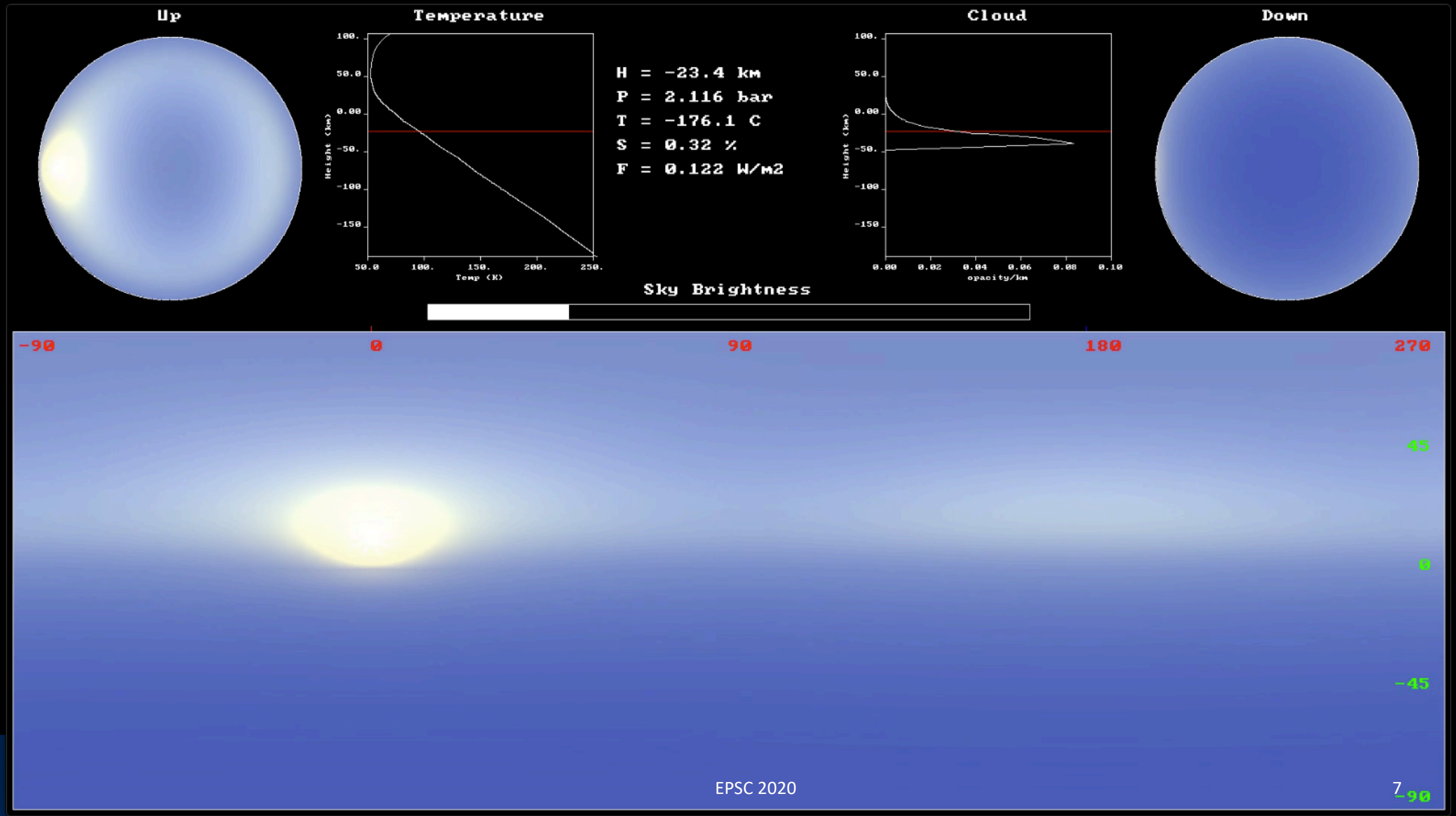
NEMISIS vs PSG Signal-to-Noise Calculations for Weakest Filter Channel 12.5-25 μm




Up
Temperature
Cloud
Down
H = 30.7 km
P = 0.311 bar
T = -217.1 C
S = 54.21 %
F = 0.523 W/m2
Height (km)
Temp (K)
opacity/km
Sky Brightness
-90
0
90
180
270
45
0
-45
-90


Up
Temperature
Cloud
Down
H = -23.4 km
P = 2.116 bar
T = -176.1 C
S = 0.32 %
F = 0.122 W/m2
Height (km)
Temp (K)
opacity/km
Sky Brightness
-90
0
90
180
270
45
0
-45
-90

3D-Modelling with Plane-Parallel Code

- Matrix-Operator multiple-scattering code assumes plane-parallel atmosphere.
- However can be used to simulate 3-D planets by assuming conditions locally plane-parallel, but setting solar zenith, viewing zenith and azimuth angles to those computed at points on planet using 3-D geometry.

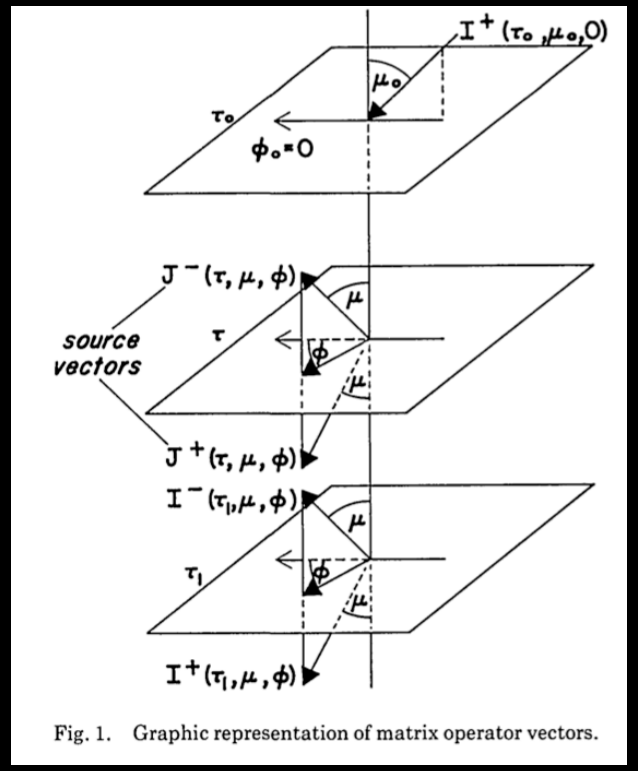


Fig. 1. Graphic representation of matrix operator vectors.

Plass et al., (1973)

Conclusion

- IG-NFR study ongoing, but modelling shows such an instrument can return uniquely useful in-situ determinations of Uranus's or Neptune's atmospheric structure and radiative forcing and should be a top priority for possible probe missions.
- Combined analysis with independent NEMESIS and PSG models adds confidence that IP-NFR simulations are robust and reliable.
- Work has already led to spin-off study of potential Venus NFR observations and probe missions (EPSC2020-312).
- https://www.youtube.com/watch?v=1MIgMIt_g3A
- https://www2.physics.ox.ac.uk/news/2020/07/24/flights-of-fancy-exploring-uranus-and-landing-on-venus