# Thermal Infrared Imager Development for CubeSat Constellation

## Abstract


Wildfires are becoming a major challenge to our civilization today. Early warning and detection of wildfires not only helps in managing them but also mitigates the loss of lives and property. To meet this challenge, OroraTech is developing a constellation of CubeSats for wildfire detection to alert about wildfire hazards within minutes instead of hours.

**Figure 1**: Image of an active wildfire.

Onboard these CubeSats, a thermal infrared imager will scan the surface in multiple spectral bands to identify fires. Radiometric simulations with influences of sun glint, daylight and atmospheric absorption were done. A prototype of the imager based on an uncooled micro-bolometer focal plane array was developed including a shutter system, thermal stabilization, mounting structure and a data processing unit. The imager was tested for absolute temperature accuracy and noise behavior. With image processing the performance of the imager was further improved. The prototype is scheduled to fly on a stratospheric balloon late 2020, and the on-orbit demonstration is planned for early 2021.


## Motivation and Theory

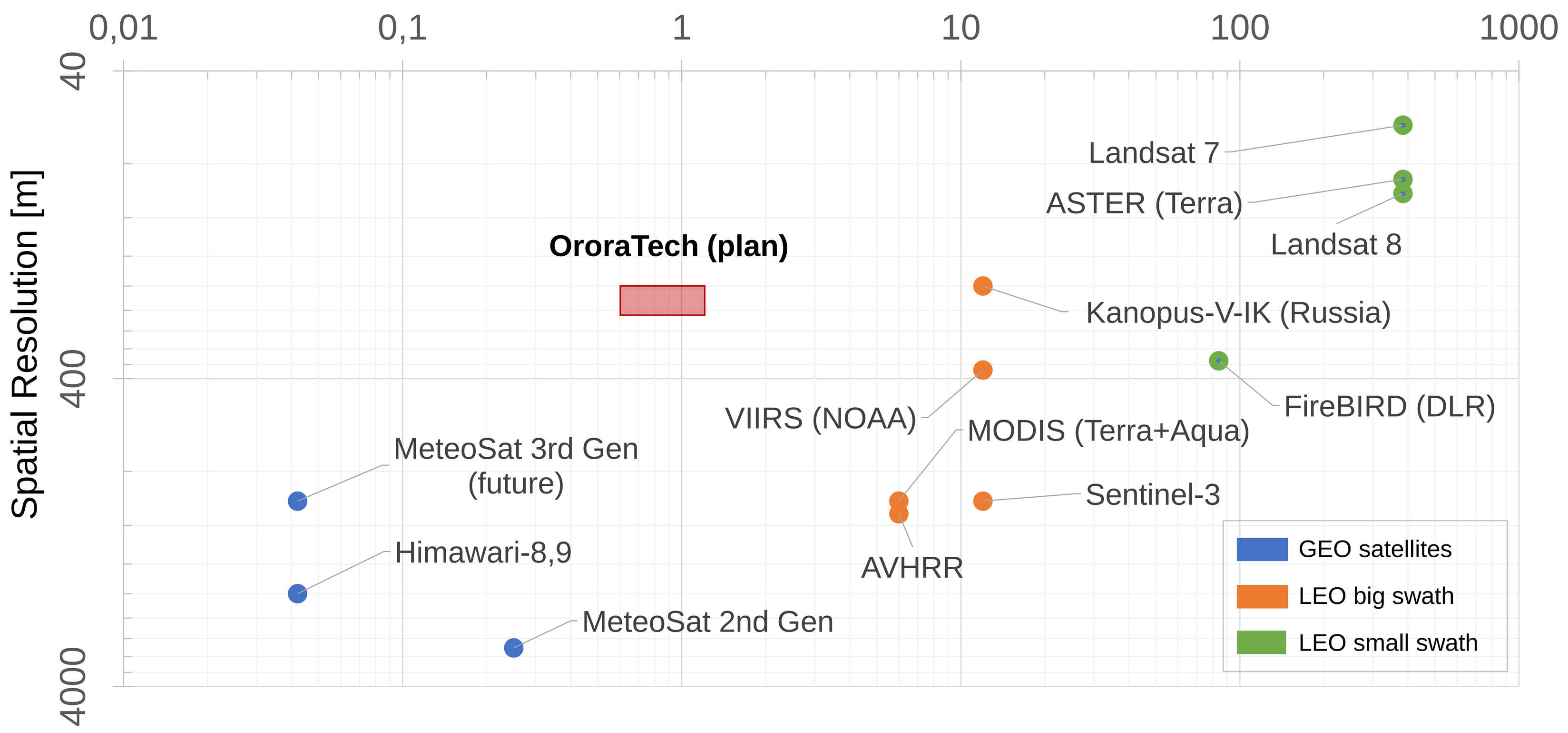


**Figure 2**: Spatial & temporal resolution of existing satellites with thermal imaging bands and OroraTech's constellation. **[1]**

Objects with a temperature higher than absolute zero emit radiation as per Plank's law. Thus, the emission spectra of an ideal black body can be calculated from its temperature as shown in Figure 3. Note the shift of emssions peak into mid-wave infrared for hotter objects from room temperatures.

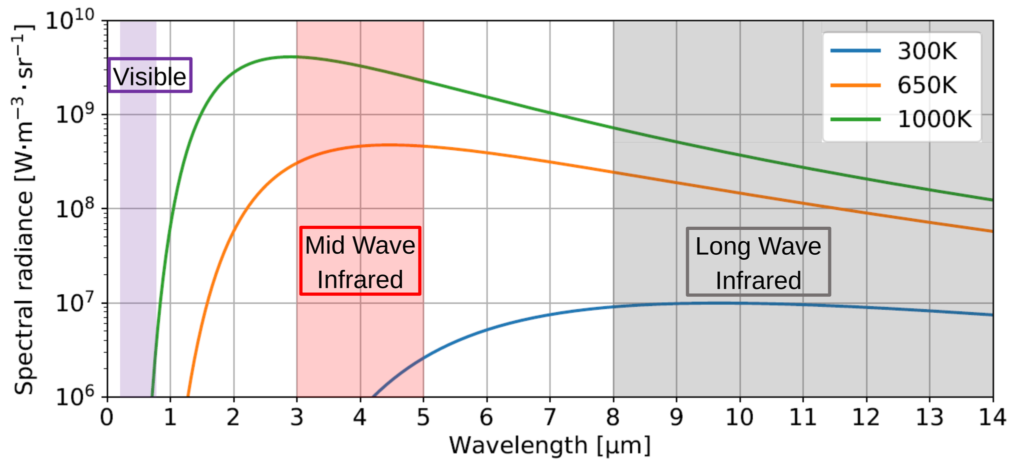


**Figure 3**: Ideal black body radiation spectrum.

## Radiometric Simulation

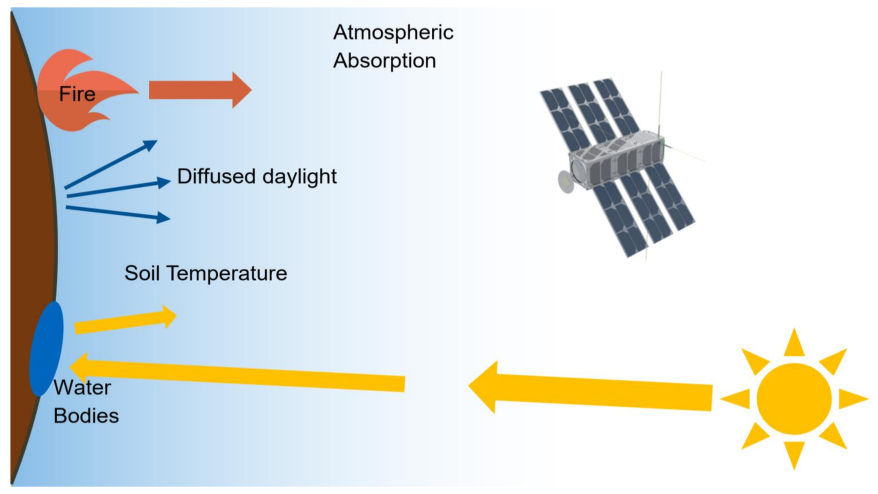


**Figure 4**: Illustration of the effects included in the radiometric simulation.

To prove the feasibility of the infrared imager, the conditions were modelled including:

- Radiation from soil temperature
- Atmospheric absorption
- Diffuse reflection of the sun
- Specular reflections of the sun
- Small sized fires

The results are plotted in Figure 5.

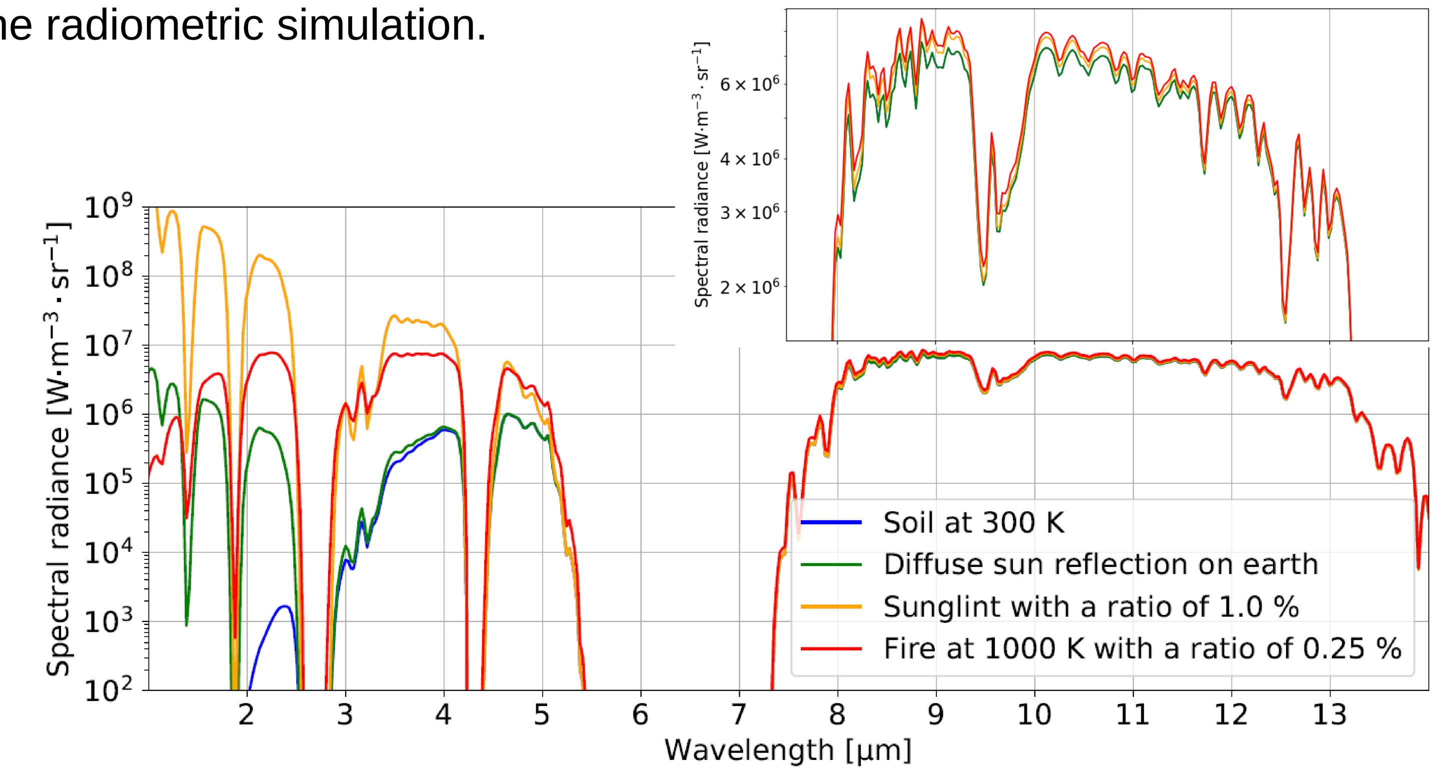


**Figure 5**: The simulated spectral radiance expected in space with a comparison of the effects included in the simulation. In mid wave infrared the sun glint dominates, in long wave infrared the emission by the fire is higher than sun glint.

## Infrared Imager Setup

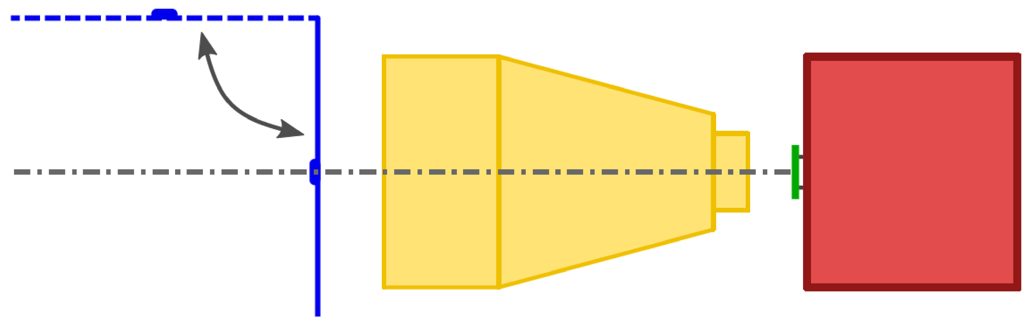

**Figure 6**: Main components of the imager (L to R): Shutter, optics, detector & read out electronics.

The infrared imager built consists of three main components. The shutter used for off-set correction, the optics and the detector which is an uncooled micro-bolometer. The whole setup is depicted in Figure 6.

Even though it is uncooled, the temperature of the detector has a significant impact on the measurements. Thus a thermal control system was developed to maintain the detector at a stable operating temperature achieving 8 mK standard deviation. See stabilization at 35°C in Figure 7.

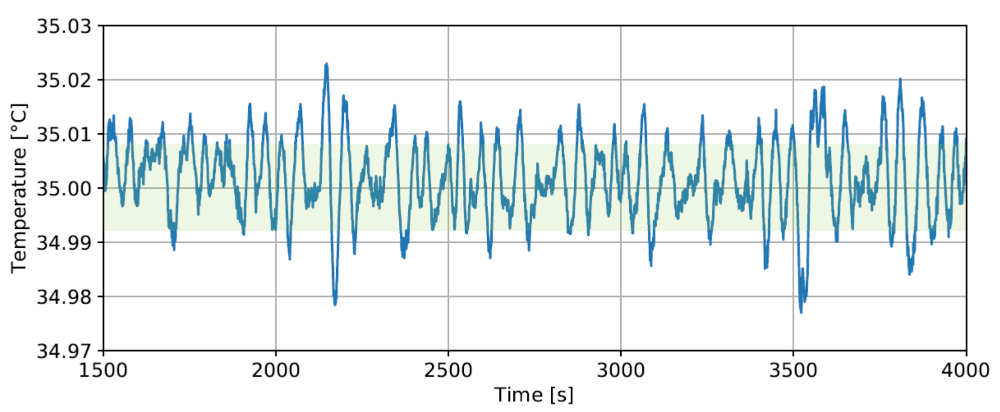


**Figure 7**: Thermal stabilization performance.

## Experiments

To test the performance of the setup built, a set of experiments were conducted. In the following list, the experiments are presented along with their results.

1. **Noise behavior:**
   - Evaluated by measuring the NETD (noise equivalent temperature difference)
   - NETD < 100 mK
2. **Absolute temperature accuracy**
   - Measured known surface at 4 m distance
   - Sample image shown in Figure 8
   - Maximum deviation of 2.5 K
   - Deviation due to size of source effect
3. **Impact of detector temperature**
   - Noise increases with higher temperature
   - Best performance measured at 20°C
4. **Sub-pixel hotspot detection**
   - Black body source behind an aperture
   - Object at the hyperfocal plane, 10 m
   - Aperture area at 1% of the pixel with a temperature difference of 25 K detectable
   - Figure 9 shows a detected sub-pixel hotspot

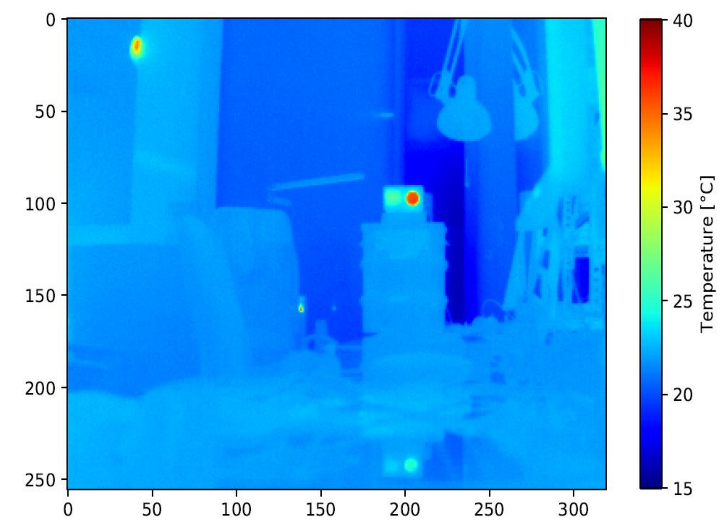


**Figure 8**: Infrared image obtained during the temperature accuracy test.

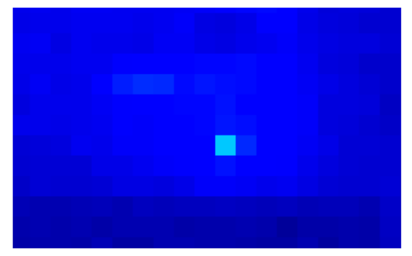

**Figure 9**: Hotspot covering less than one pixel during the sub-pixel test.

## Conclusion and Outlook

**Conclusion of the work:**

- Radiometric simulation conducted including multiple expected effects
- Infrared imager developed and built, Figure 10 shows a photo of the prototype
- Experiments conducted to characterize the performance of the infrared imager
- Requirements for a possible space mission fulfilled

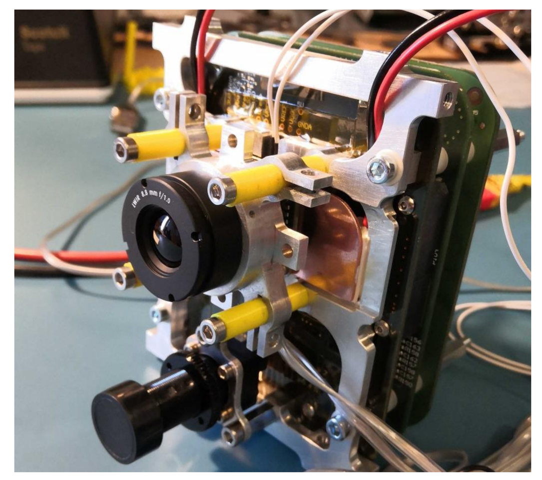

**Figure 10**: Photo of infrared imager.

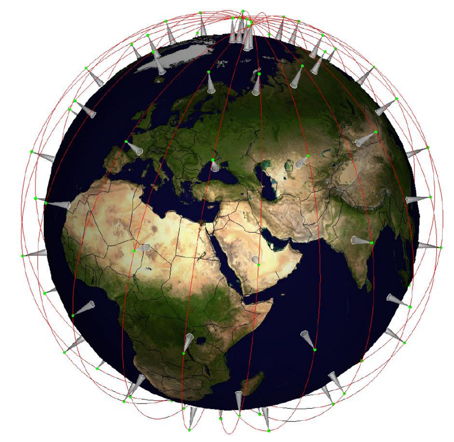

**Figure 11**: Possible constellation.

The short-term goal is to fly the system on a stratospheric balloon later this year. With the experience gained from this mission, further development of the system are planned and will finally fly on satellites forming a constellation to achieve the temporal resolution target. An example Walker-Star constellation of 96 satellites is shown in Figure 11.

## References


**[1]** S. B. Shah, T. Grübler, L. Krempel, S. Ernst, F. Mauracher, and S. Contractor. Real-Time Wildfire Detection from Space: A Trade-Off Between Sensor Quality, Physical Limitations & Payload Size: [Poster]. ISPRS, XLII-2/W16:209-213, 2019.



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