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Concept of an Innovative Photoluminescent Sensor for Radiative Heat Flux Measurement during Super-orbital Re-entry

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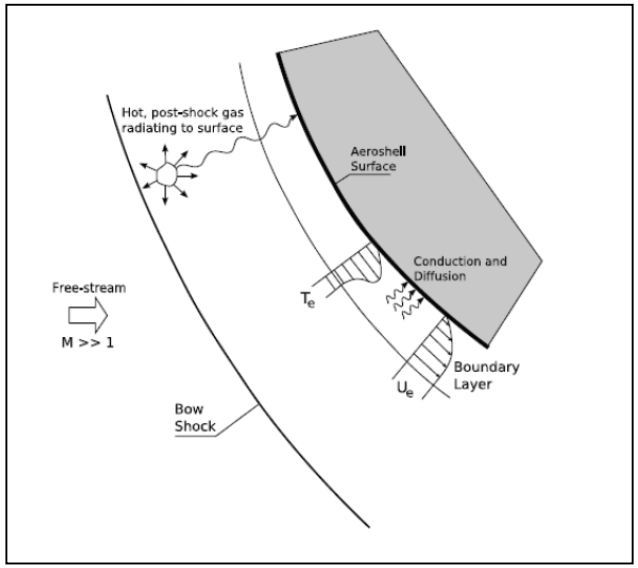
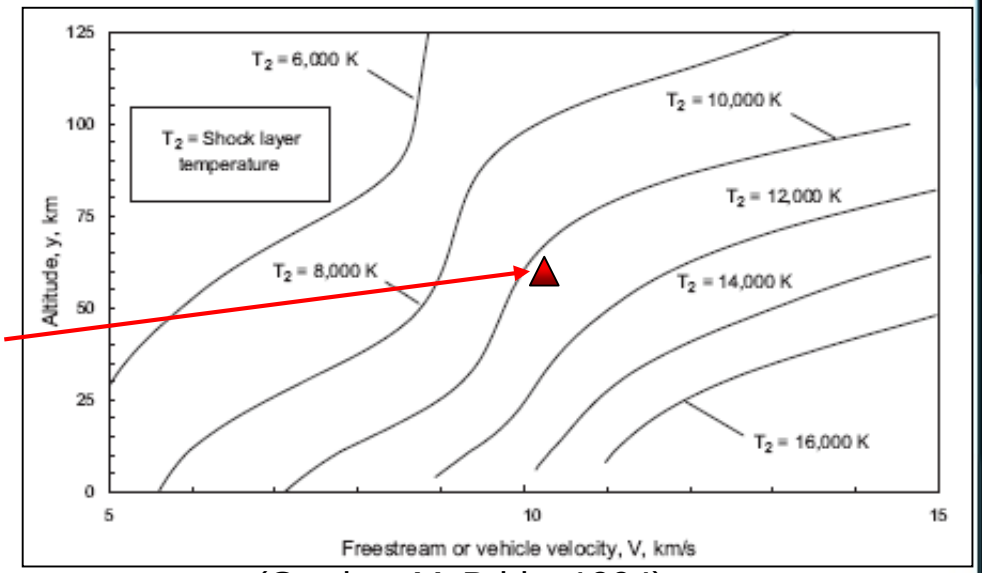
Radiative heat flux



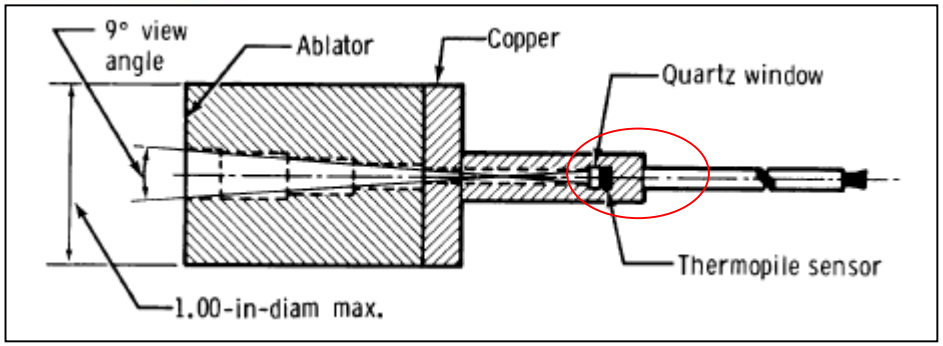
(Morgan, McIntyre, 2012)



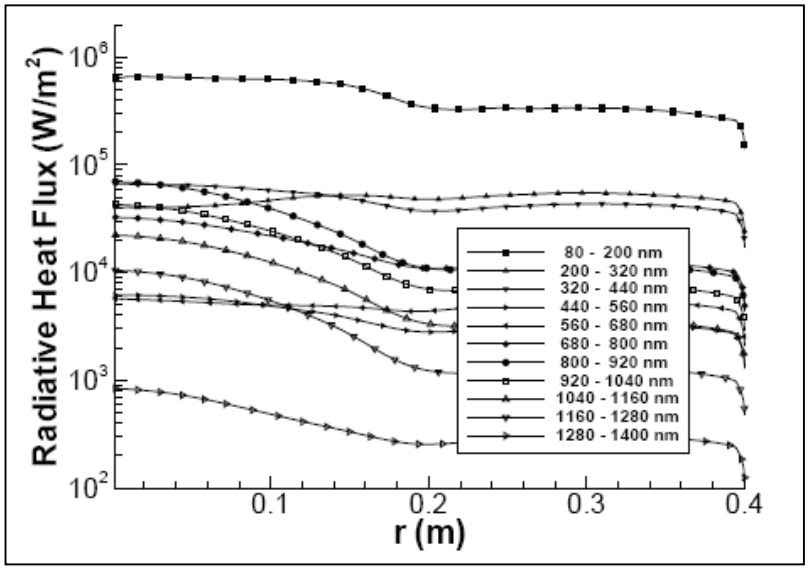
(Gordon, McBride, 1994)

- At super-orbital re-entry speeds (>10 km/s), such as of a sample return capsule, a very strong shock wave is generated around the vehicle surface
- Starting from shock layer temperatures of 10,000 K, the radiative heat flux to the vehicle surface can generally no longer be neglected and reaches the same order of magnitude of the convective heat flux

VUV: the dark side of the radiative heat flux



Apollo 4 radiometer (Ried, Rochelle, Milhoan, 1972)

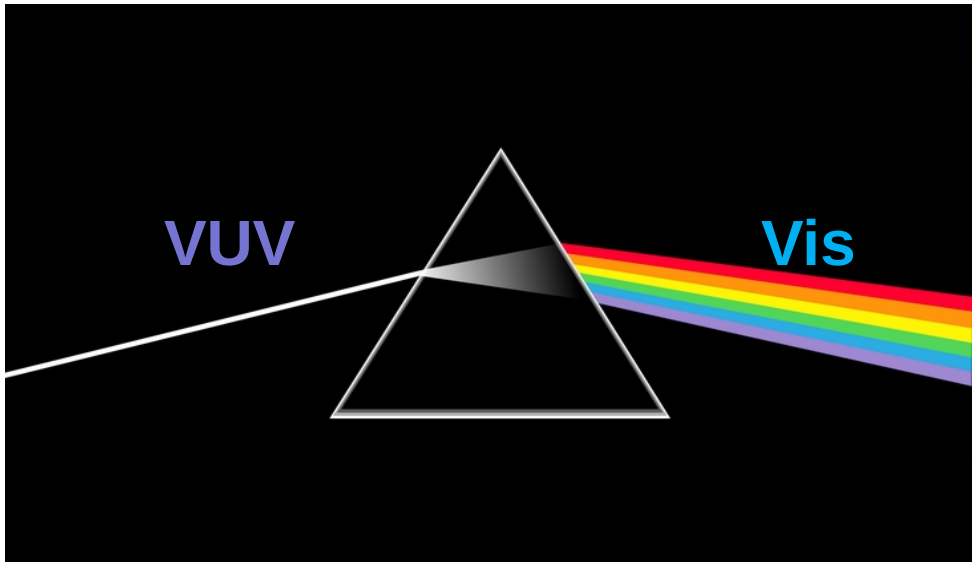


RadFlight (Liebhart, Herdrich, Röser, Fertig, 2010)

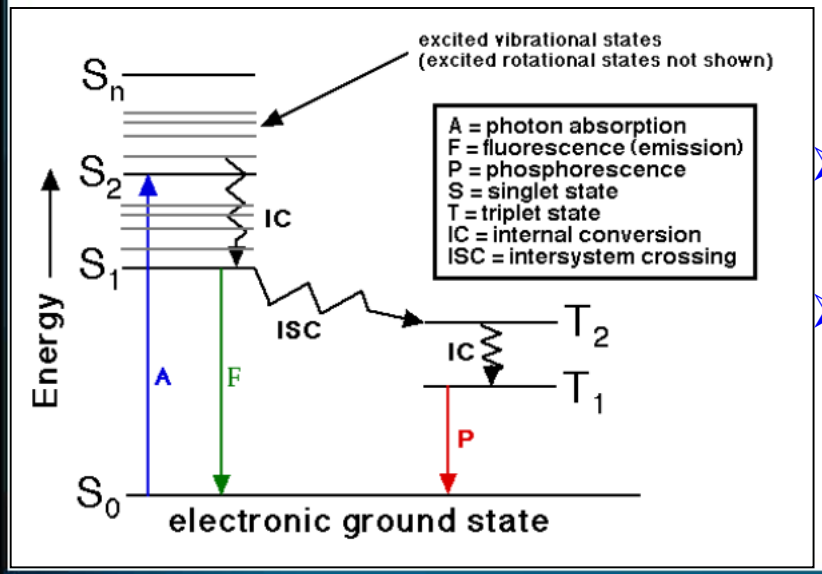
- The radiometer technology allows to measure only the radiation >200 nm due to Quartz window cutoff and black coating absorptance
  - No experimental flight data on VUV (10-200 nm) radiative heat flux; based on CFD predictions the VUV contribution could be the major!
  - VUV is hard to be measured due to absorption by oxygen, water and optical materials (evacuated light path or nitrogen purge required)

Photoluminescent conversion of VUV

Convert the VUV incident radiation into visible one and measure it!

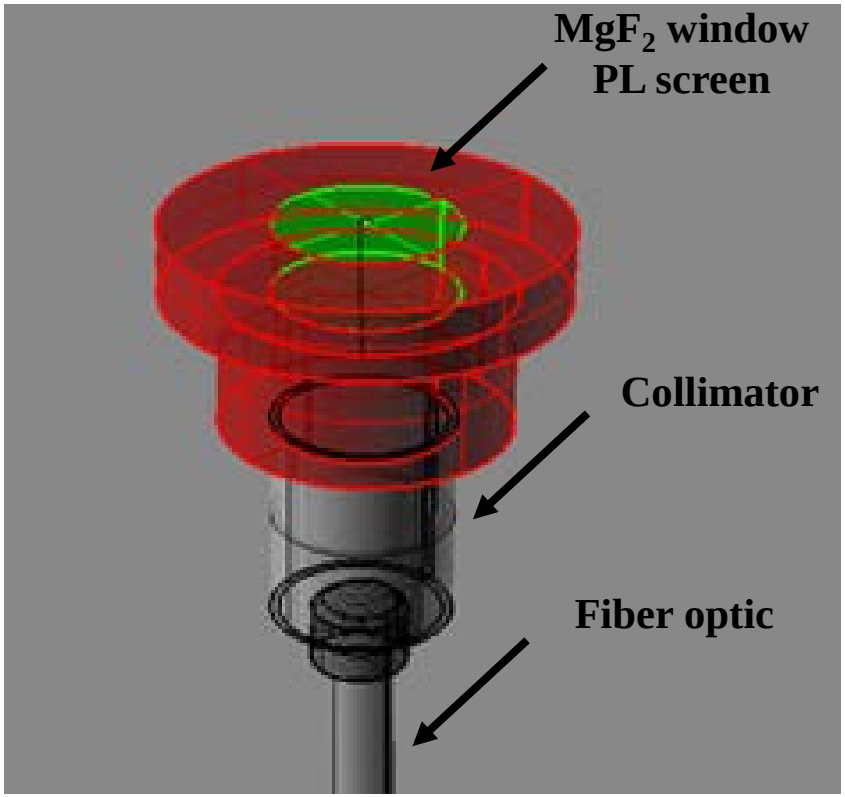


- The photoluminescence is a physical phenomenon consisting in light emission from any form of matter after Absorption of photons



- The emitted photons have lower energy, higher wavelength, than the absorbed photons (Stokes shift)
- If the luminescence ends rapidly after the excitation source is turned off, then the material is Fluorescent (it will luminesce only as long as it is excited); if the luminescence continues, the material is Phosphorescent (light emission persists)

Photoluminescent Sensor

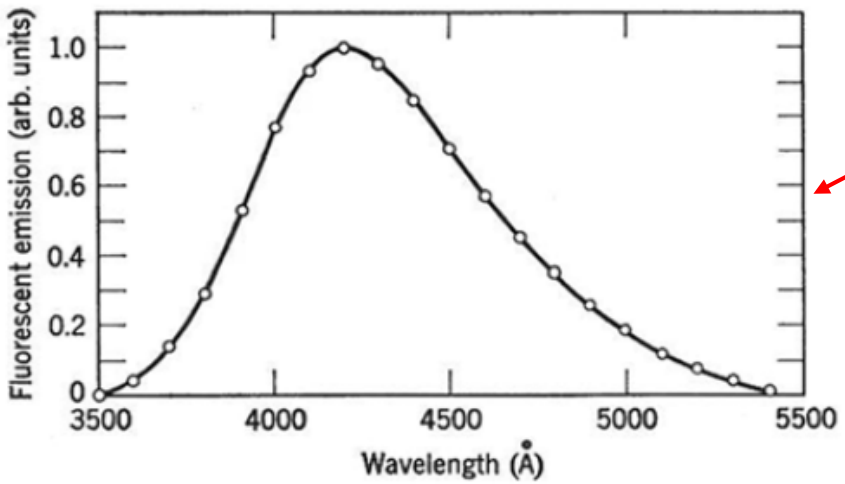


The PL screen must be protected from harsh environment by a MgF_2 window!

- The incident radiation is absorbed by a photoluminescent material (PL screen) and re-emitted as visible light and transmitted by fiber optic if necessary
- The intensity of the re-emitted visible light is easily measured by a photodetector (photodiode, PMT) or a spectroscope
- The intensity of the re-emitted visible light I_f is directly proportional to the intensity of the incident radiation I_o

$$I_f \propto \Phi I_o$$

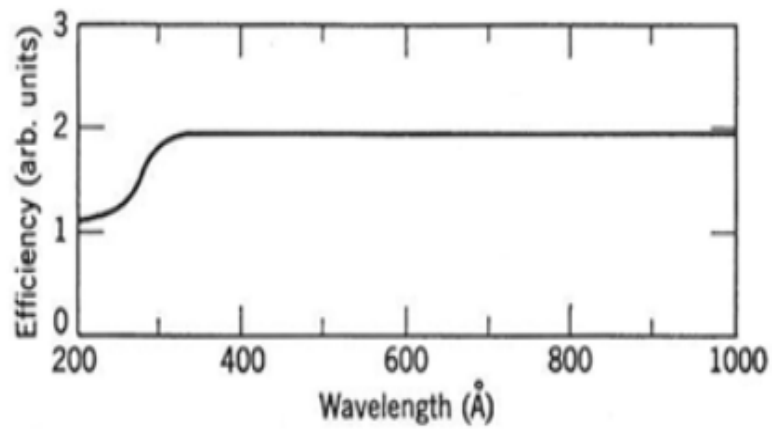
The PL screen: Sodium salicylate



Fluorescent emission spectrum of sodium salicylate

(Samson, 1967)

- Sodium salicylate emits blue luminescence in the 350-550 nm spectral region, peaking at 420 nm
- The emission wavelength is independent of the excitation wavelength (Kasha's rule)
- Sodium salicylate has excellent absolute quantum efficiency Φ nearly constant of 65% in the 40-340 nm spectral region (VUV/UV)



Relative quantum efficiency of sodium salicylate between 200 and 1000 Å

(Samson, 1967)

Evaluation of the incident intensity I_o

incident intensity

$$Io = \frac{If}{k\Phi}$$

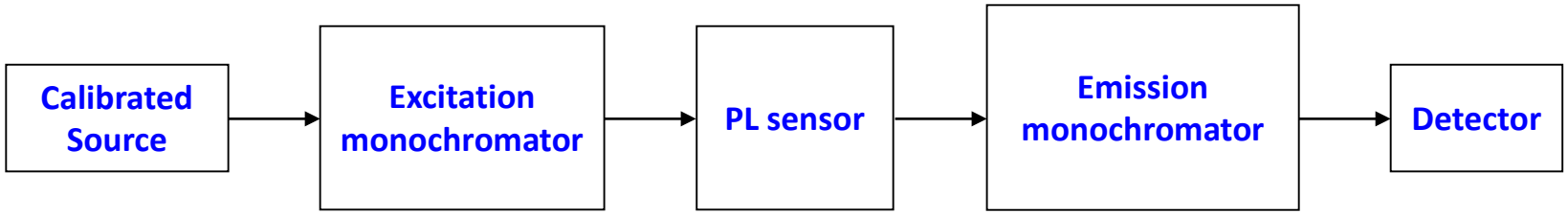
measured emission intensity

$$If = \int_{\lambda 2}^{\lambda 1} S(\lambda)\, d\lambda$$

proportional factor
(calibration phase)

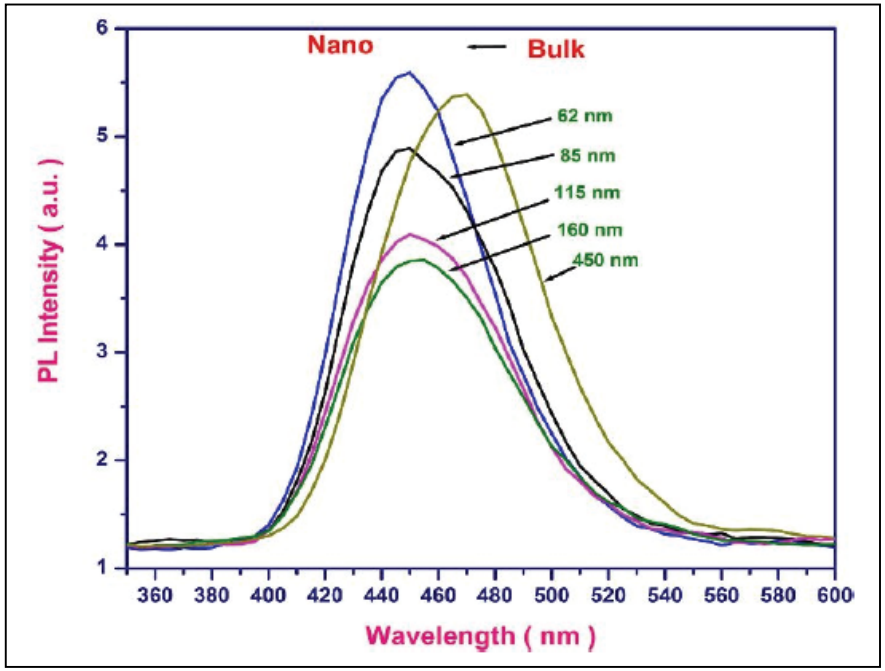
$$k\Phi = \frac{If}{Io}$$

Calibration apparatus



Advanced PL materials for spectral analysis

The photons aren't only numbers, they have personality



PL spectra of nanophosphor under 147 nm excitation

- With the present PL material it is possible to determine the incident intensity of the radiation but not to discriminate the contribution of the single wavelength components of the incident radiation (the emission wavelength is independent of the excitation wavelength)

- Eu^{2+} nanophosphors are promising for the spectral analysis since their emission wavelength is dependent on excitation wavelength (varying the size of the nanostructure) so the single wavelength components of the incident radiation could be discriminated

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Thank You for your attention