Field Spectroscopy: instrumental issues, characterization and calibration

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Environmental Remote Sensing and Spectroscopy Laboratory (SpecLab) - CSIC

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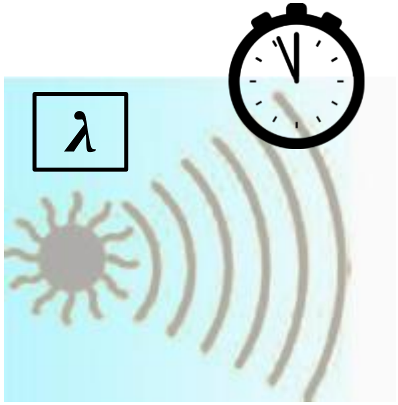
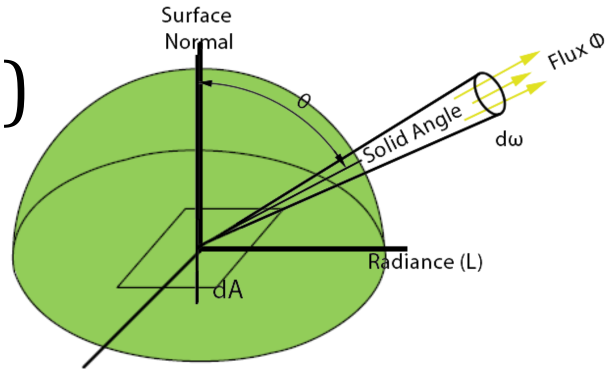
Laboratorio de Espectro-radiometría y Teledetección Ambiental

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

1. Radiometric quantities

- Radiant Energy (Q_e; J)
- Radiant flux ($\phi_e = \frac{\partial Q_e}{\partial t}$; W)
- Spectral flux ($\phi_{e,\lambda} = \frac{\partial \phi_e}{\partial \lambda}$; W nm^{-1})
- Radiant exitance ($M_\lambda = \frac{\partial \phi_{e,\lambda\uparrow}}{\partial A}$; W m^{-2} nm^{-1})
- Irradiance ($E_\lambda = \frac{\partial \phi_{e,\lambda\downarrow}}{\partial A}$; W m^{-2} nm^{-1})
- Radiance (L_λ; W m^{-2} sr^{-1} nm^{-1})

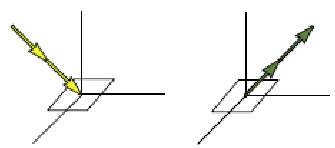
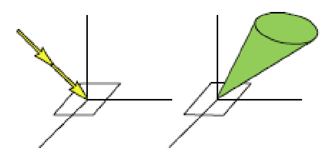
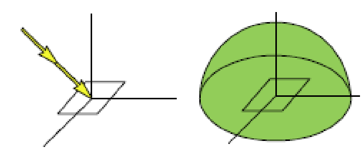
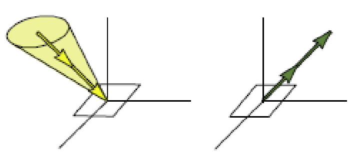
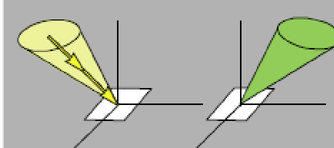
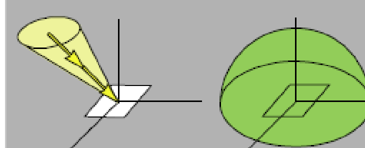
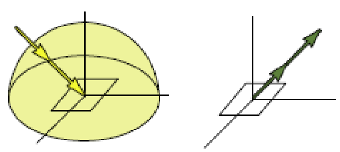
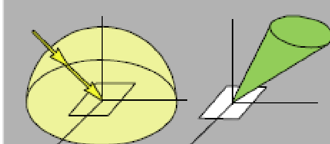
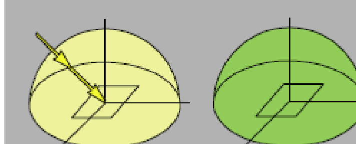




Schaepman-Strub *et al*, 2006

1. Radiometric quantities

Relation of incoming and reflected radiance terminology used to describe reflectance quantities

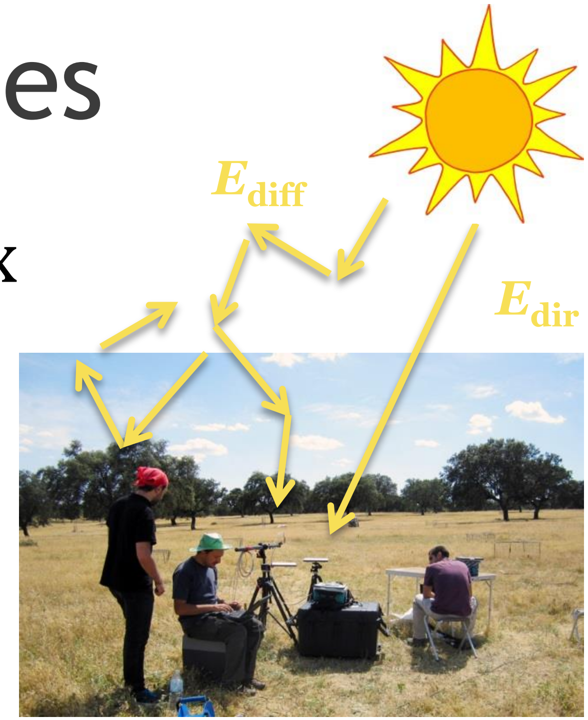
Incoming/Reflected	Directional	Conical	Hemispherical
Directional	Bidirectional CASE 1 	Directional–conical CASE 2 	Directional–hemispherical CASE 3 
Conical	Conical–directional CASE 4 	Biconical CASE 5 	Conical–hemispherical CASE 6 
Hemispherical	Hemispherical–directional CASE 7 	Hemispherical–conical CASE 8 	Bihemispherical CASE 9 

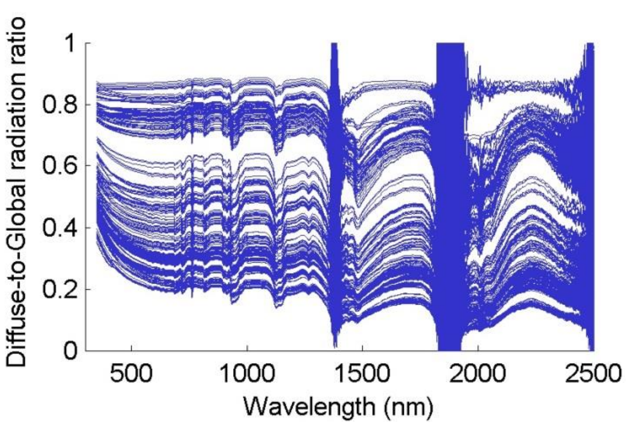
The labeling with 'Case' corresponds to the nomenclature of Nicodemus et al. (1977). Grey fields correspond to measurable quantities (Cases 5, 8), the others (Cases 1–4, 6, 7, 9) denote conceptual quantities. Please refer to the text for the explanation on measurable and conceptual quantities.

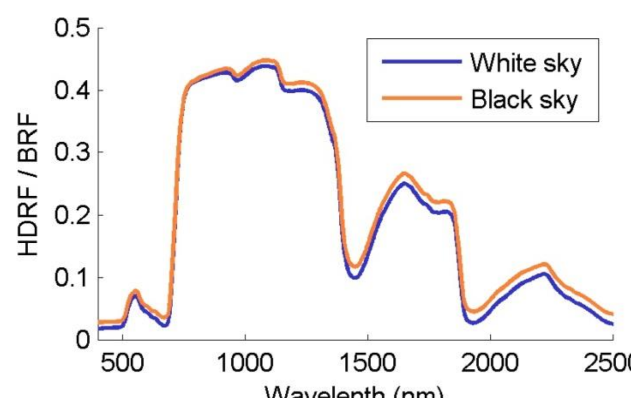
Schaepman-Strub *et al*, 2006

1. Radiometric quantities

- Hemispherical down-welling flux
  - Field (HCRF)
  - $E_{tot} = E_{dir} + E_{diff}$
  - $DGr = E_{diff} / E_{tot}$

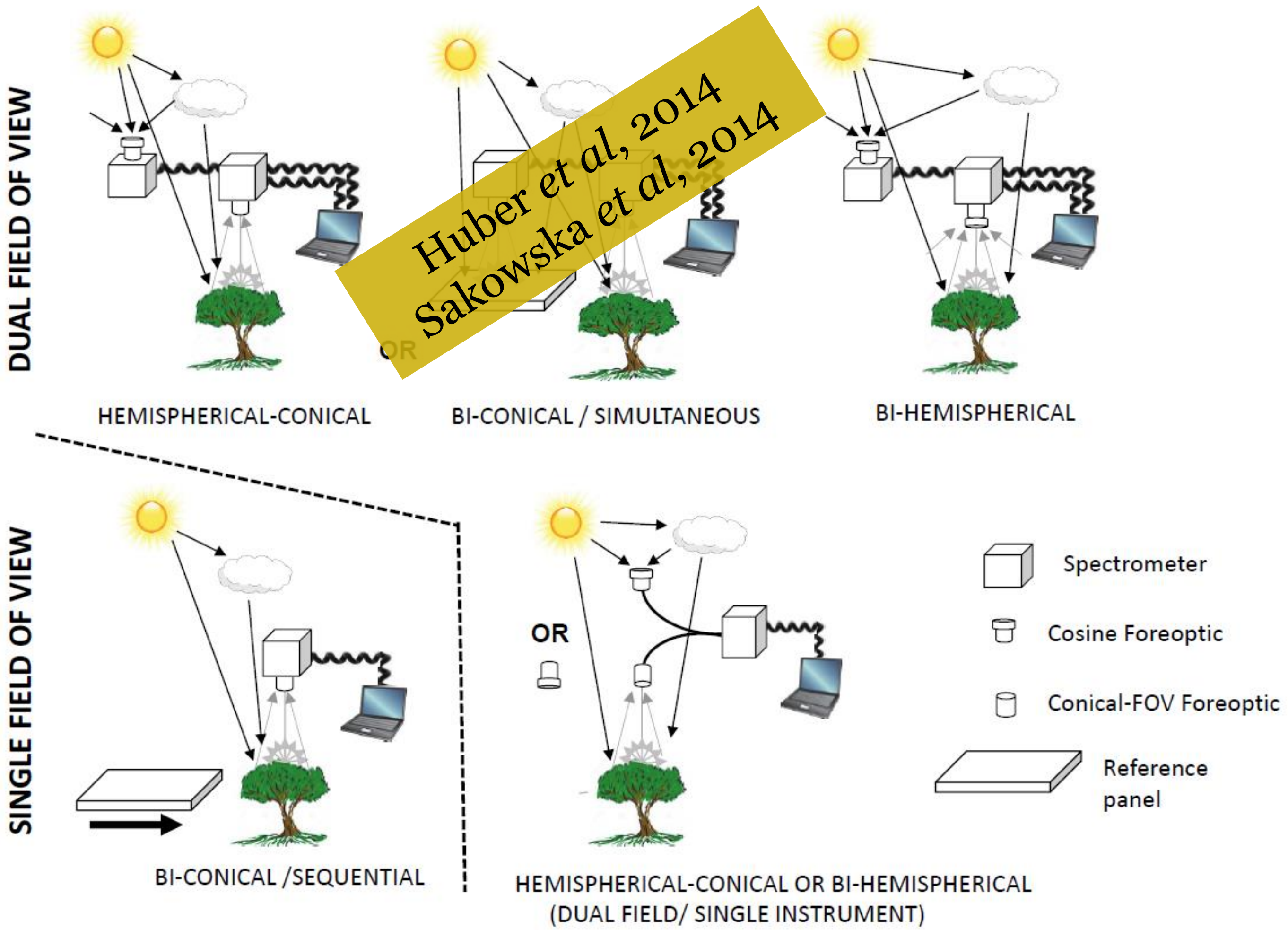






2. Sampling radiant fluxes

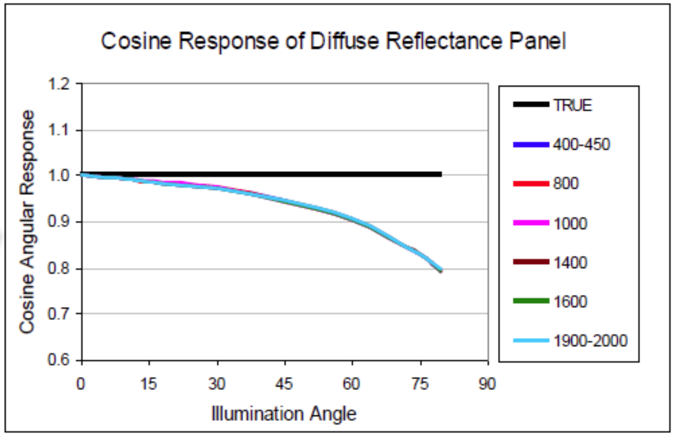
- Sampling strategies



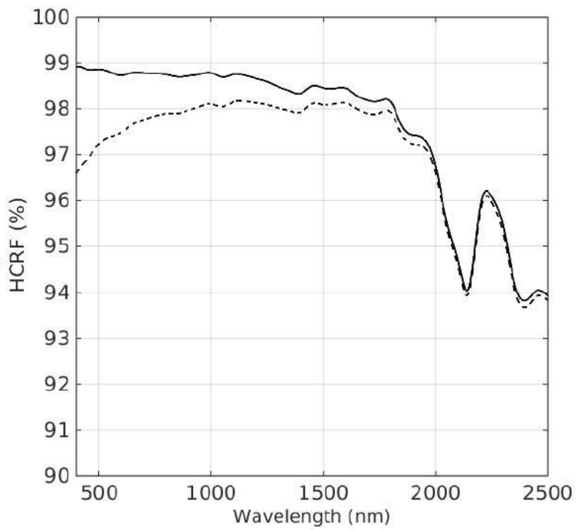
Porcar-Castell *et al*, 2015

2. Sampling radiant fluxes

T. Malthus *et al* 2010. ASD workshop ,Boulder



- Down-welling spectal flux
  - Hemispherical
    - Cosine diffuser head
    - Spectralon® panels
      - $E_\lambda \approx \frac{L_\lambda \cdot \pi}{\rho_{Spectralon}}$
  - Issues
    - Directional response
    - Panel calibration



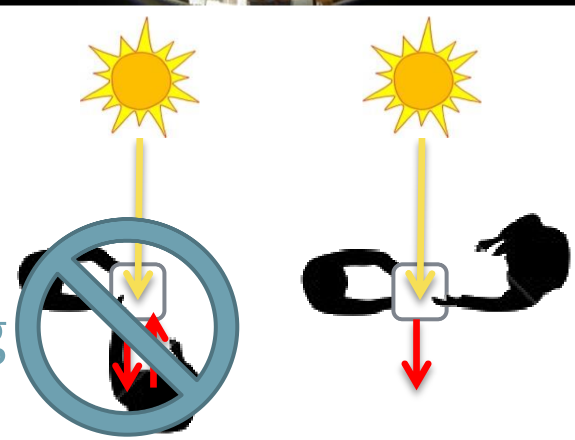
Mac Arthur, 2015. SWAMP Training Course, Poznan

2. Sampling radiant fluxes

Midday normalized irradiance, 1st August 2013

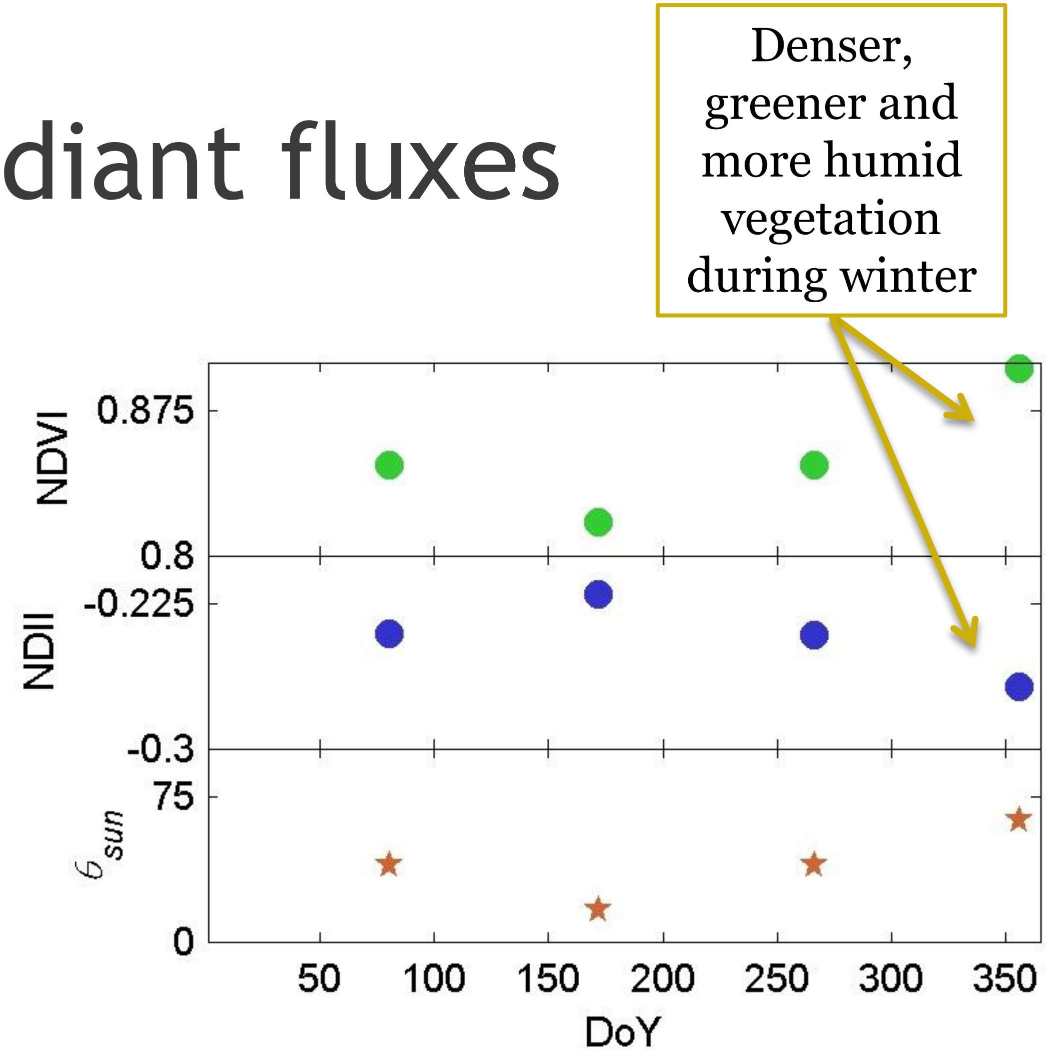
- Atmospheric variations
  - Not everything is visible
    - R-T-T-T-T-T-T-T-T-T-T-T-T
    - R-T-T-T-R-T-T-T-R-T-T-T-R
    - R-T-R-T-R-T-R-T-R-T-R-T

- Covering the hemisphere
  - Macroscopic Heisenberg's Uncertainty Principle
  - Diffuse conditions = larger effect
- Pistol grip shade / speckle
- Avoid backwards scatter / shading



2. Sampling radiant fluxes

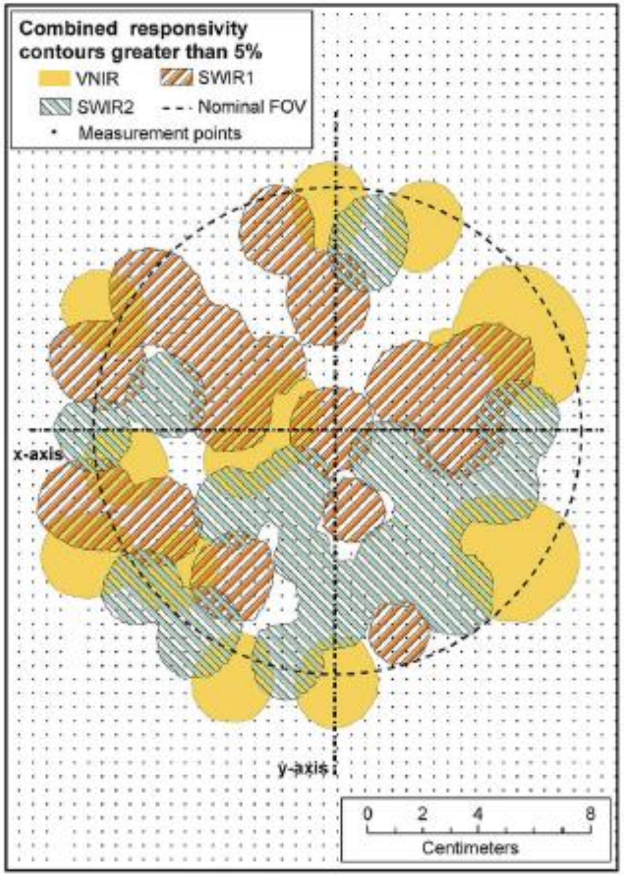
- Solar elevation
  - Rule of thumb: midday ±1 h
  - Seasonal variation of solar zenith angle!



SVIs for the same vegetation canopy and atmospheric conditions under different θ_{sun} during 2016 equinoxes and solstices, Cáceres, Spain

2. Sampling radiant fluxes

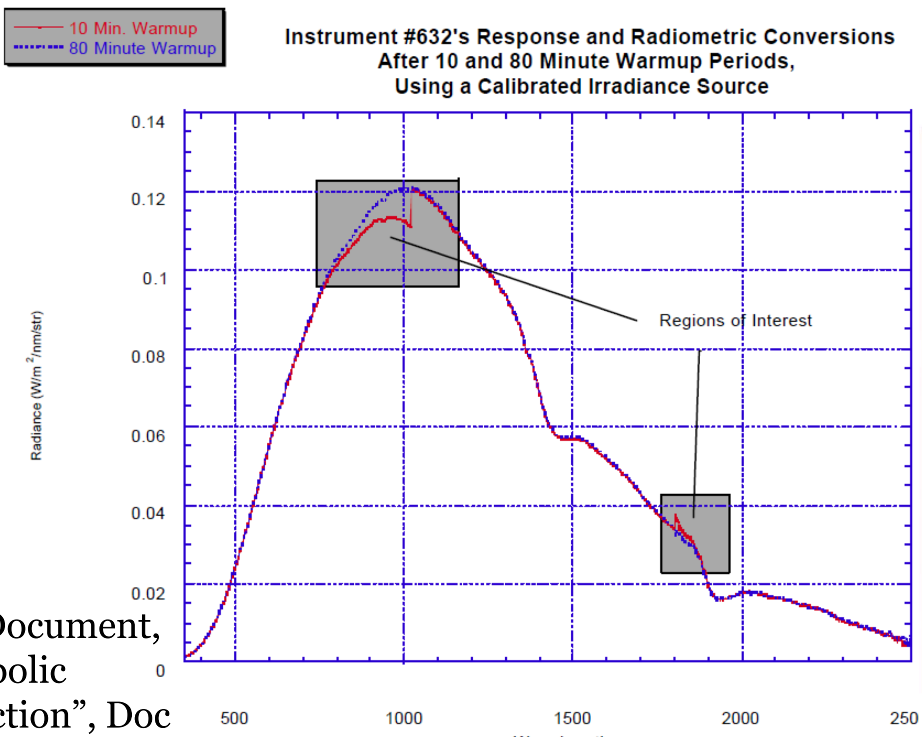
- Up-welling spectral flux (& down)
  - Conical
  - Issues
    - FOV definition
      - Full Width Half Maximum
      - From where does L_λ comes from?
    - Directional Response (λ)
      - Single core fiber
      - Lens
      - Fiber bundle



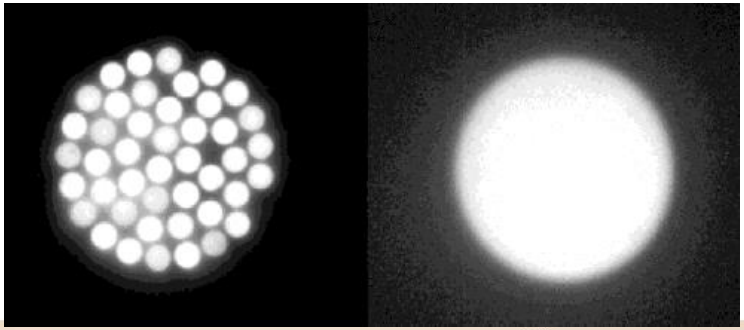
Mac Arthur *et al*, 2012

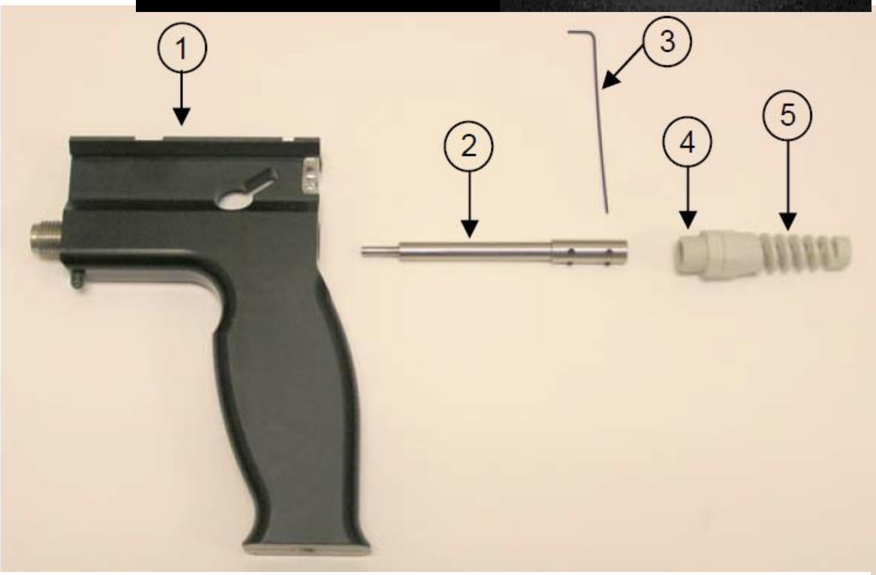
2. Sampling radiant fluxes

- ASD FR Field of View



ASD Document, "Parabolic Correction", Doc ID 65, 2009/07/21

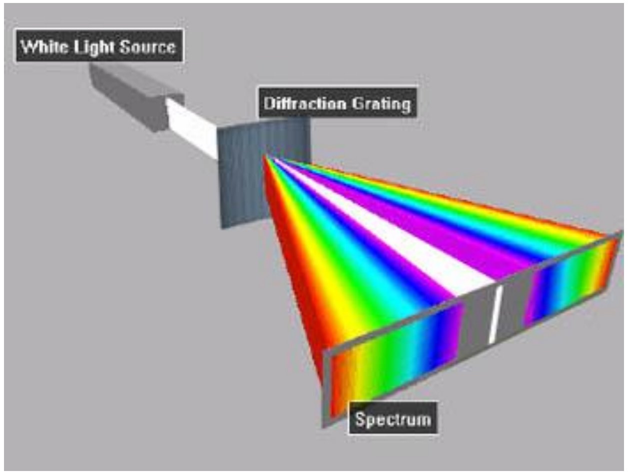


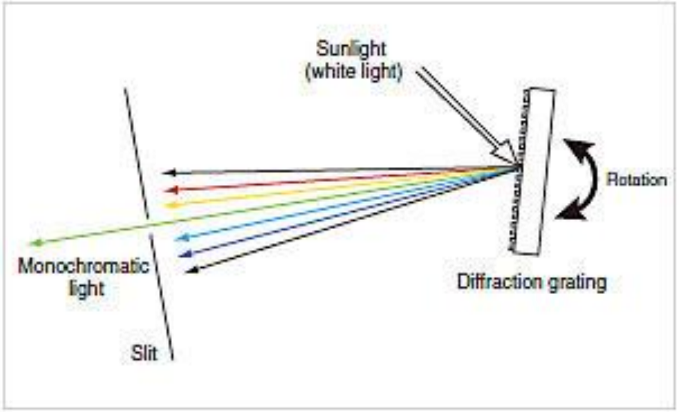


ASD Scrambler, ASD# 600967 Rev A

3. Splitting the signal

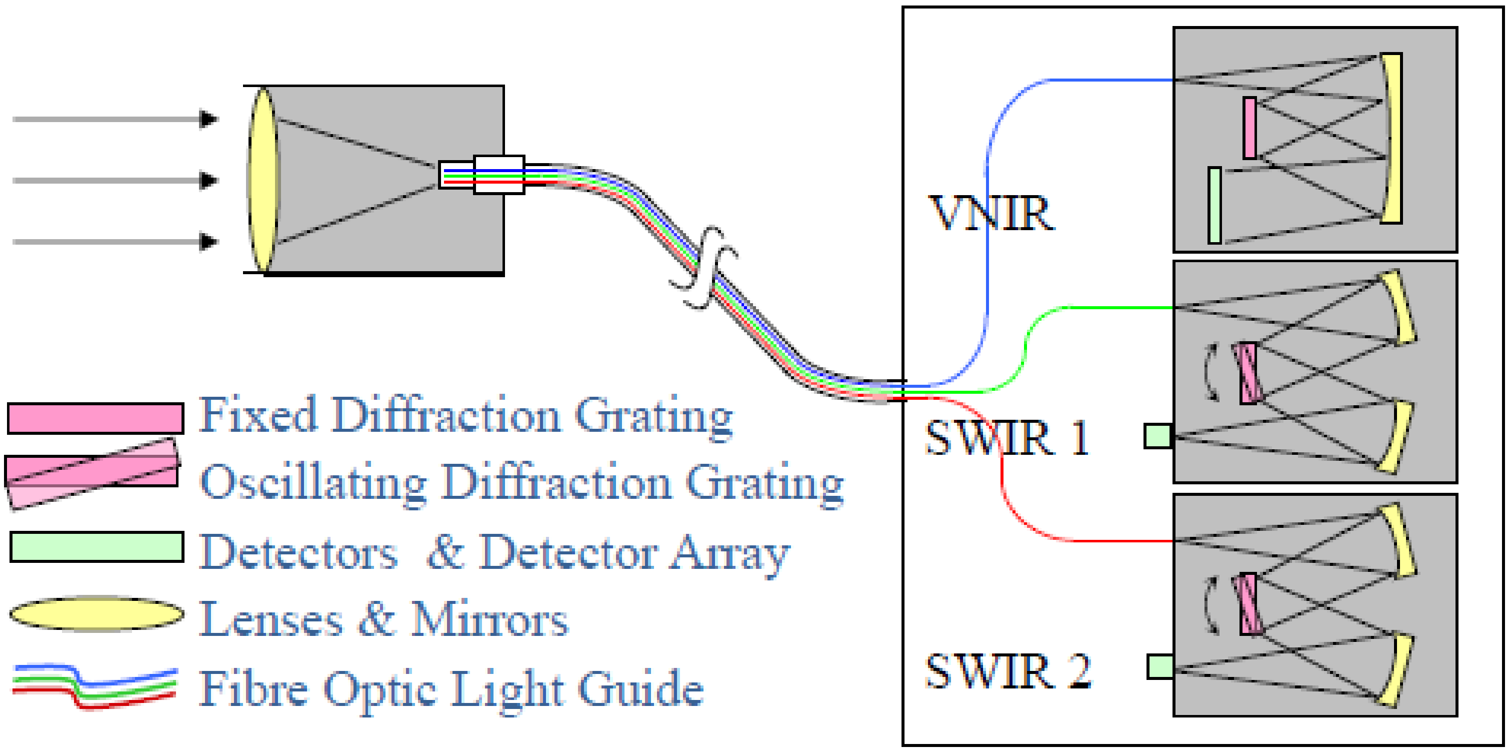
- Diffraction grating
  - Grooved surface that splits and diffracts light into several beams travelling in different directions as function of λ
  - Fixed
    - Array photodiodes
  - Oscillating
    - Single sensor





3. Splitting the signal

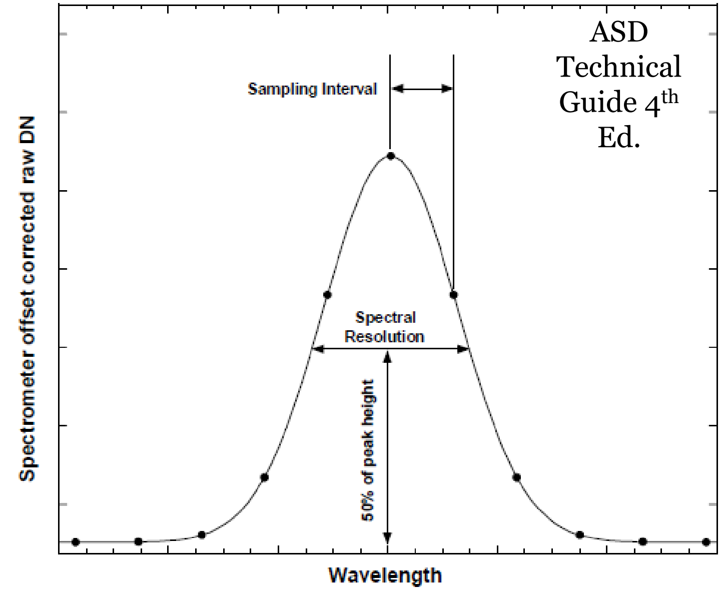
ASD FieldSpec™ systems



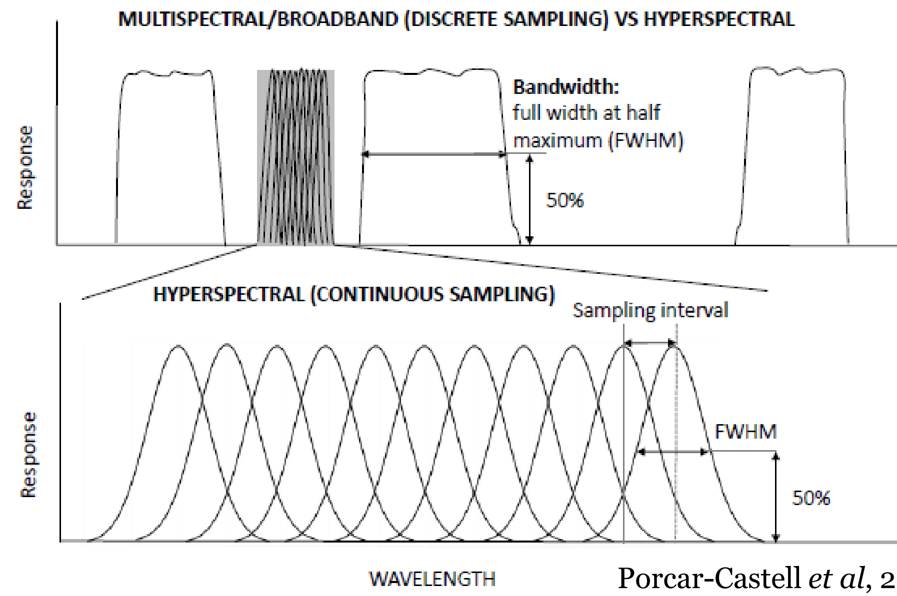
Mac Arthur , 2006., RSPSoc , Cambridge.

3. Splitting the signal

- Spectral resolution
  - FWHM
- Spectral Sampling Interval
  - 2-5 times FWHM



ASD Technical Guide 4th Ed.

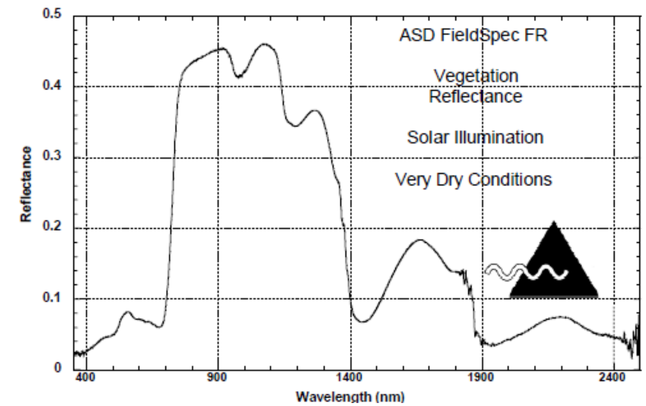


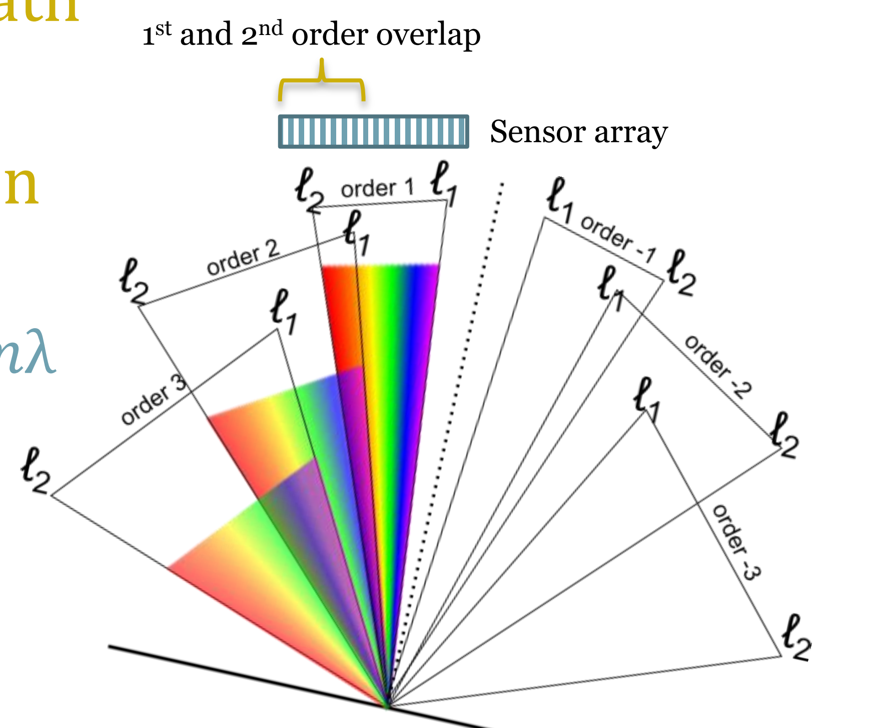
Porcar-Castell *et al*, 2015

3. Splitting the signal

- Stray light
  - Radiance reflected by elements in the optical path
  - Ghost orders in diffraction gratings
    - $d(\sin\theta_{\mathrm{inc}} \pm \sin\theta_{\mathrm{diff}}) = m\lambda$
      - d: grooves distance
      - m: order [-3,3]

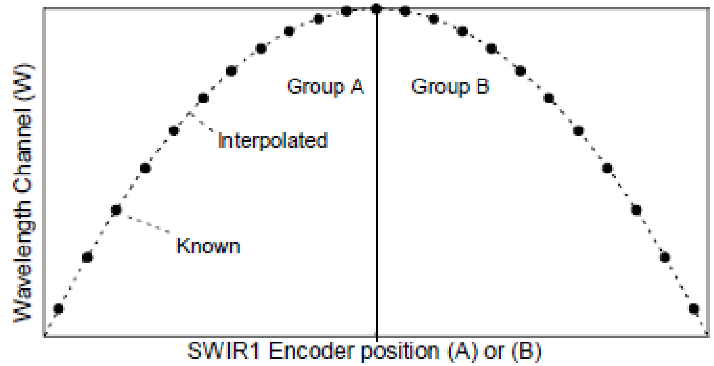
ASD Technical Guide 4th Ed.





3. Splitting the signal

- Spectral calibration
  - λ = F(n); n: pixel number
  - Methods
    - Emission lamps
      - Hg-Ar, Kr, Ne, Xe, Na…
    - Filters
      - Maylar, Erbium and holmium oxide



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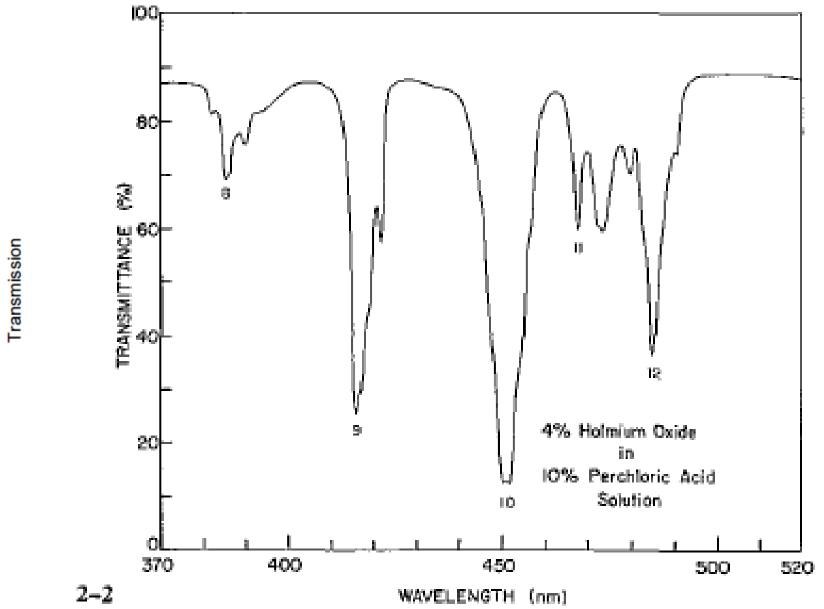


Weidner *et al*, 1985

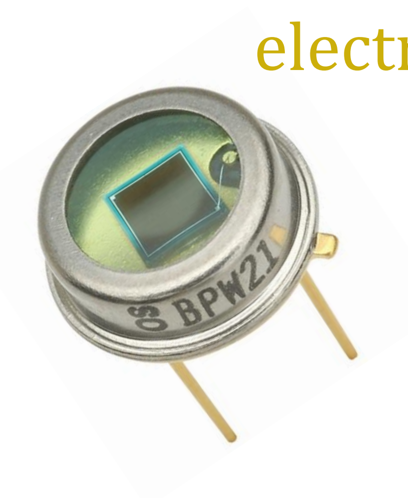
3. Splitting the signal

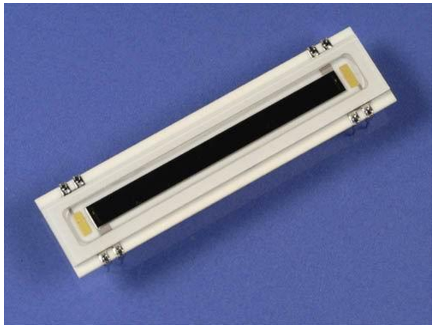
- Issues:
  - Spectrometer spectral features are thermally dependent
    - Thermally-induced expansion/contraction of spectrometer and optical system
      - Variations in optical path/system geometry
      - Spectral calibration, SSI, FWHM
        - Subtle changes, significance application-dependent

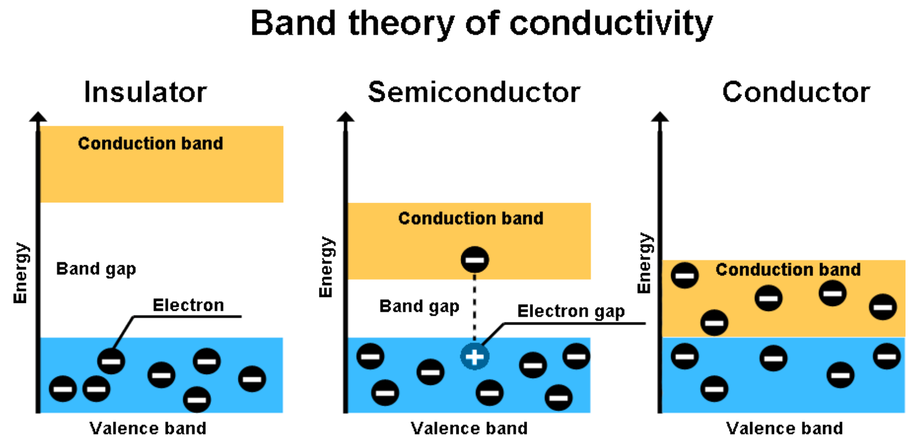
4. Sensing the photons

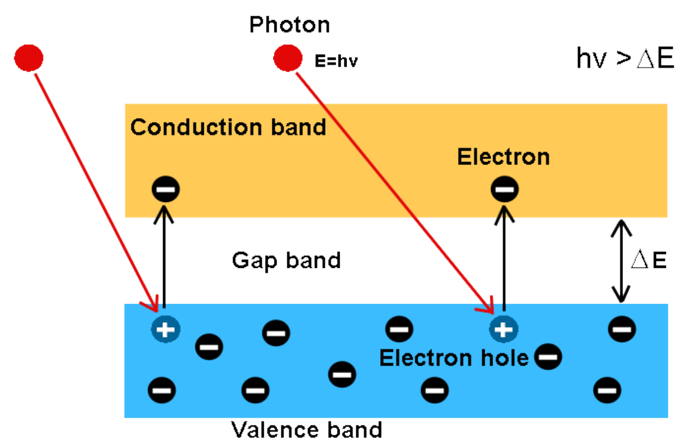
http://www.physicsexperiment.co.uk

- Photodiode
  - A photodiode is a semiconductor device that converts radiation into a electrical current

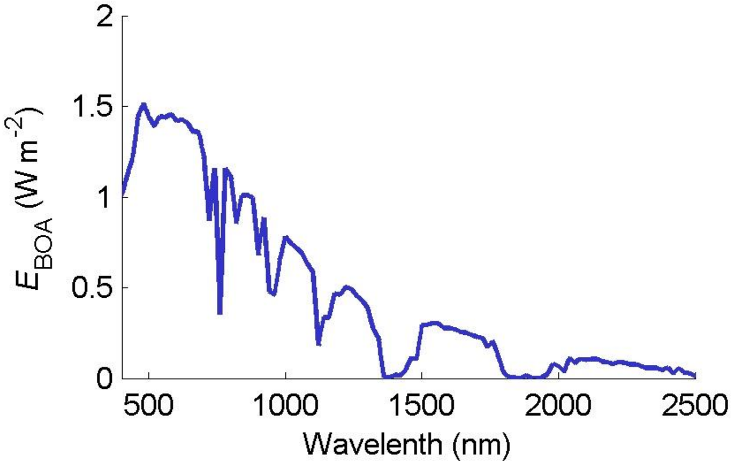


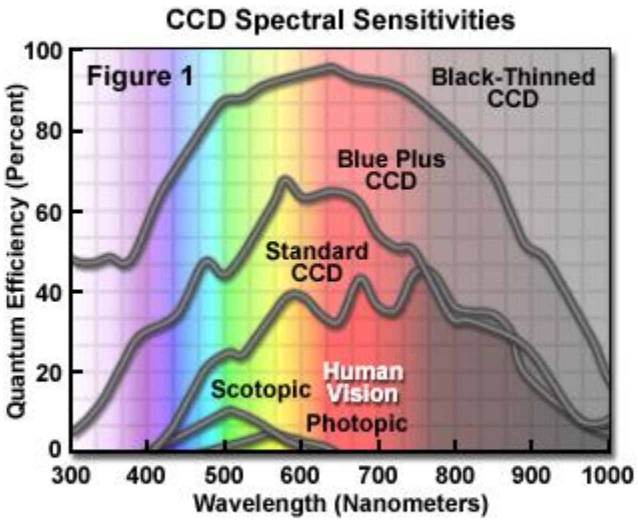






4. Sensing the photons

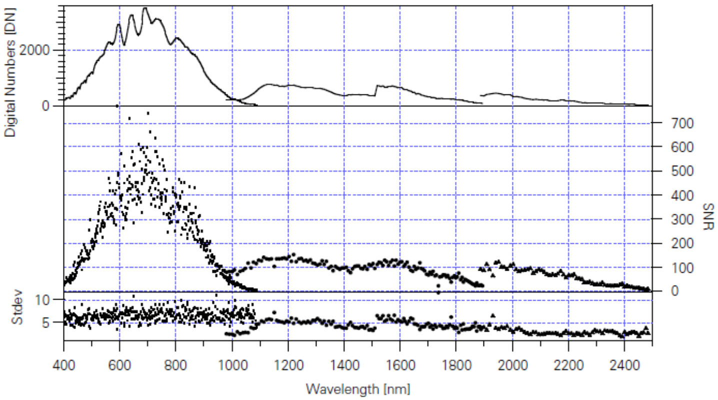




Hamamatsu Learning Center

- Signal-to-noise ratio (SNR)

$$SNR = \frac{N_{total} - N_{dark}}{\sqrt{\sigma^2(N_{total}) + \sigma^2(N_{dark})}}$$

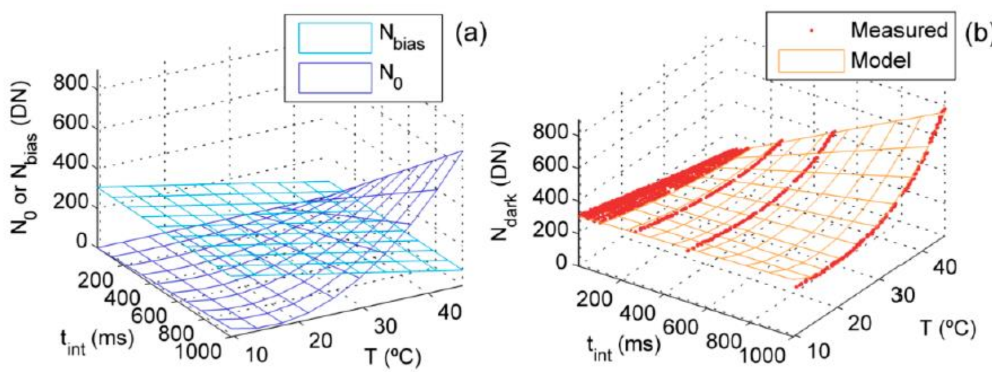


Schaepman, 1998

4. Sensing the photons

Take Dark Current measurements frequently!!

- Dark current
  - Electric current generated in absence of radiation by due to the random generation of electrons and holes within the depletion region of the device.
    - $N_{dark} = F(t_{int}, T)$
  - Electronics can introduce biases (T)

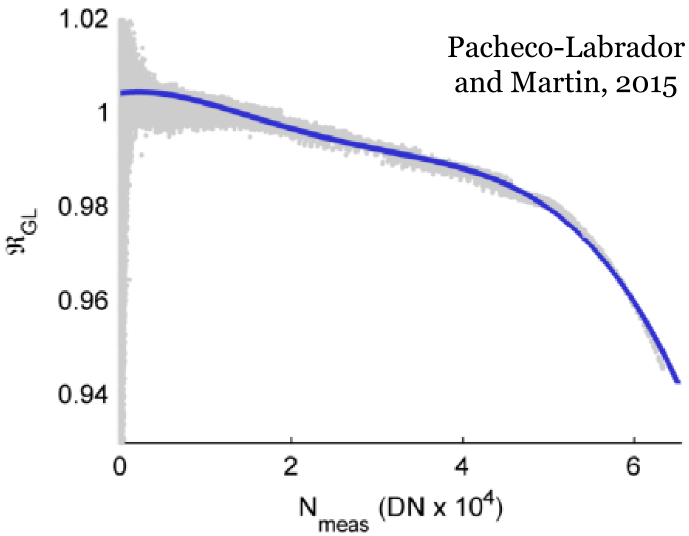


Pacheco-Labrador and Martin, 2015

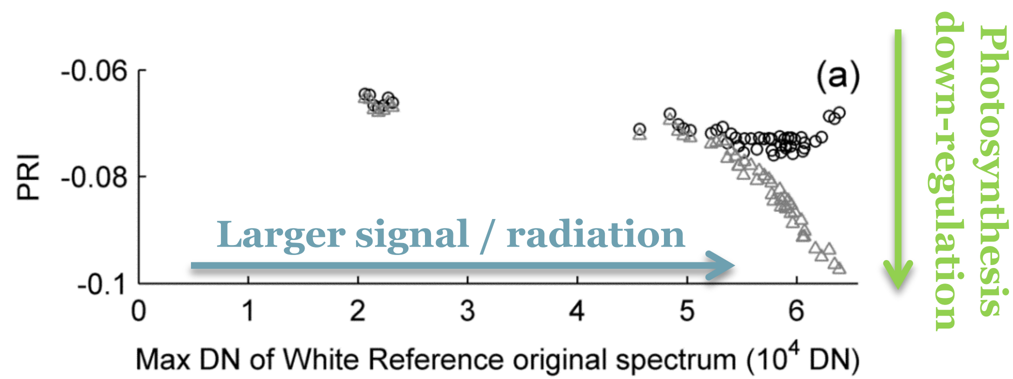
4. Sensing the photons

Optimize!!

- Linearity and Non-Linearity (NL)
  - Input-Output relationship
  - Gray-level-related NL
    - Signal transformations due to transport and reading



Pacheco-Labrador and Martin, 2015

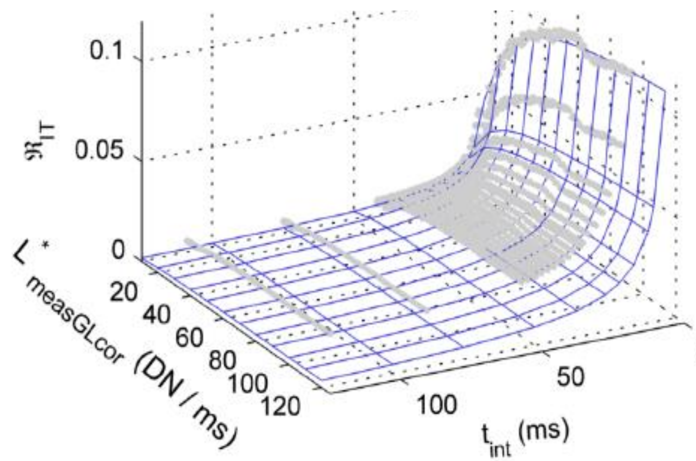


Pacheco-Labrador and Martin, 2014

4. Sensing the photons

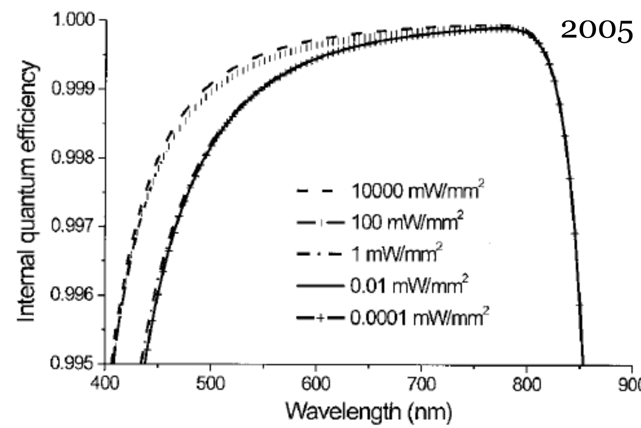
$$\Re_{IT} = 1 + r\frac{t_{\text{readout}}}{t_{\text{int}}}$$

Pacheco-Labrador and Martin, 2015



- Integration time-related NL
  - Photons striking the sensor during readout time
- Irradiance-related NL
  - Supraresponsivity: responsivity increase in response to a rise in incident radiation.
  - Recombination saturates and more charge contributes to response

Ferrero *et al*, 2005



4. Sensing the photons

- Temperature dependence of responsivity
  - Sensitivity increases, λ dependent

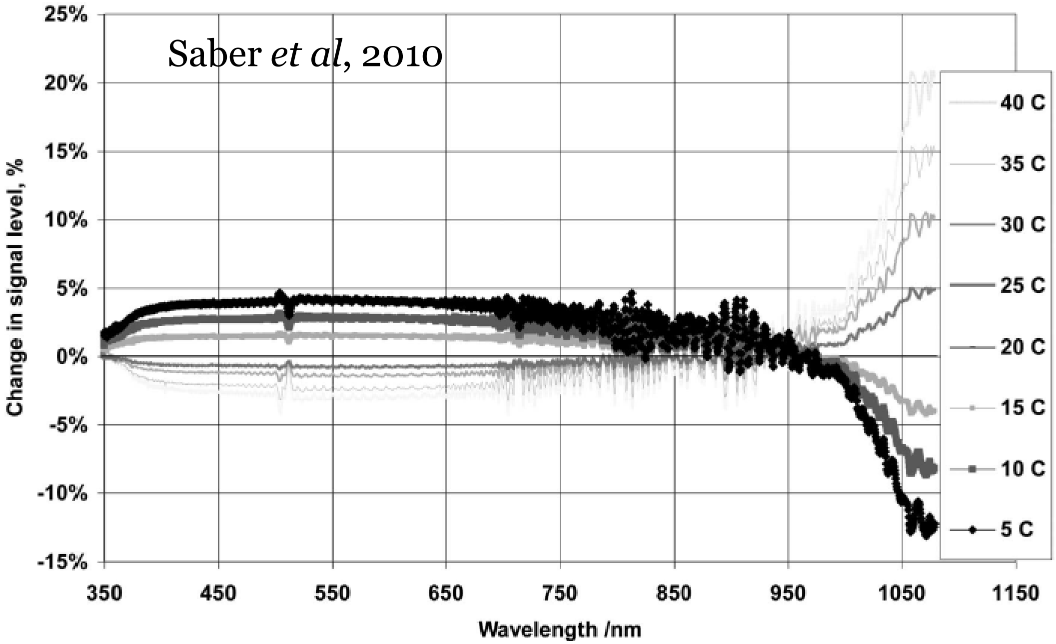
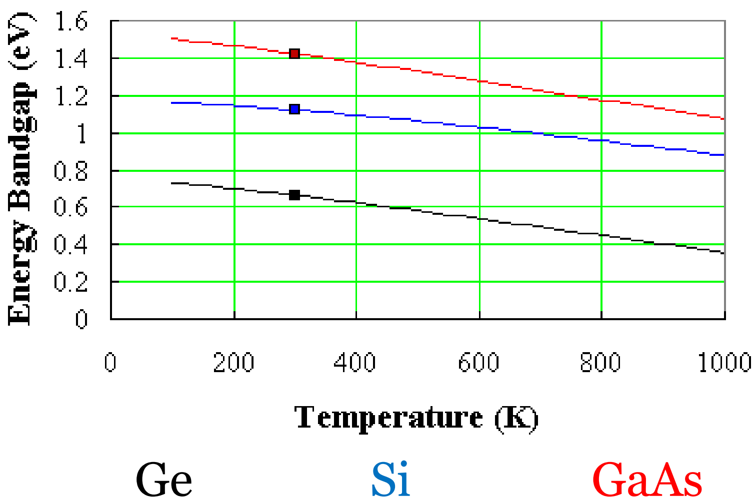


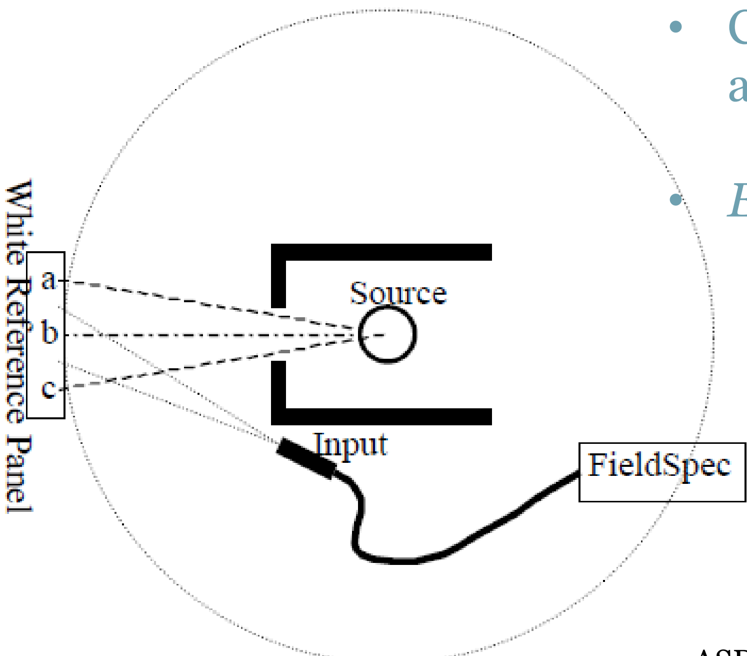
Fig. 2. Percentage change in the spectrometer response at different temperatures, relative to its response at 20 °C.

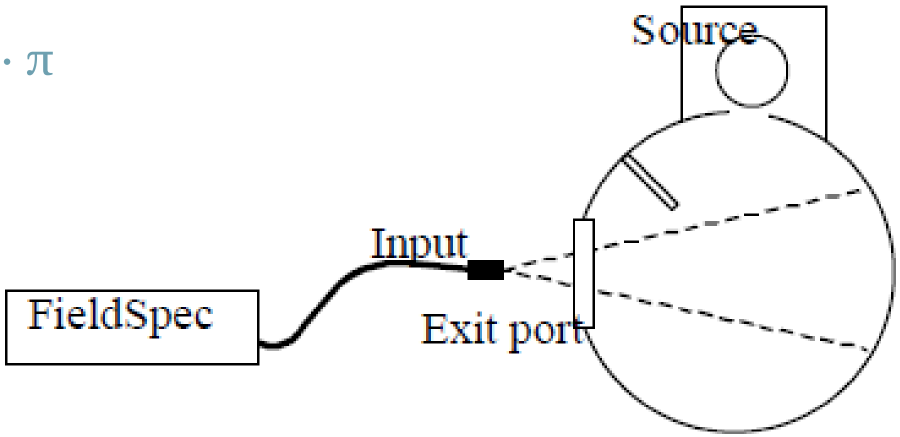


4. Sensing the photons

- Radiometric Calibration
  - $L = \mathrm{F(DN)}$

- Instrument warm-up for 1.5 hours
- Calibrated (NIST traceable) E source powered by a stable DC current-regulated supply
- $E \approx L \cdot \pi$





ASD doc. “FieldSpec Radiometric Calibrations (Rev F)”

5. Conclusions

- Several instrumental and environmental factors affect our measurements, confounding or producing spurious relationships with variables of interest
- Operator decisions, instrumentation setup and sampling protocol can reduce or enhance those effects
  - Understand what you do
    - Develop protocols that ensure reliability
    - Make quick decisions and adapt to changing conditions
- Sources of uncertainty must be known and considered when results are analyzed, uncertainty should be quantified

5. Conclusions

- Instrumentation characterization allo… rrecting and quantifying the impact of … and make decisions.
  - First an…
  - C… y w…
- Car… magnitudes (L), calib… boratory under controlled cond… when measurements are done in the field
- The error you can afford depends on the needs of each specific application!!

In the field, perform Dark Current, Optimization and Reference measurements as frequently as possible!!

Thanks!!