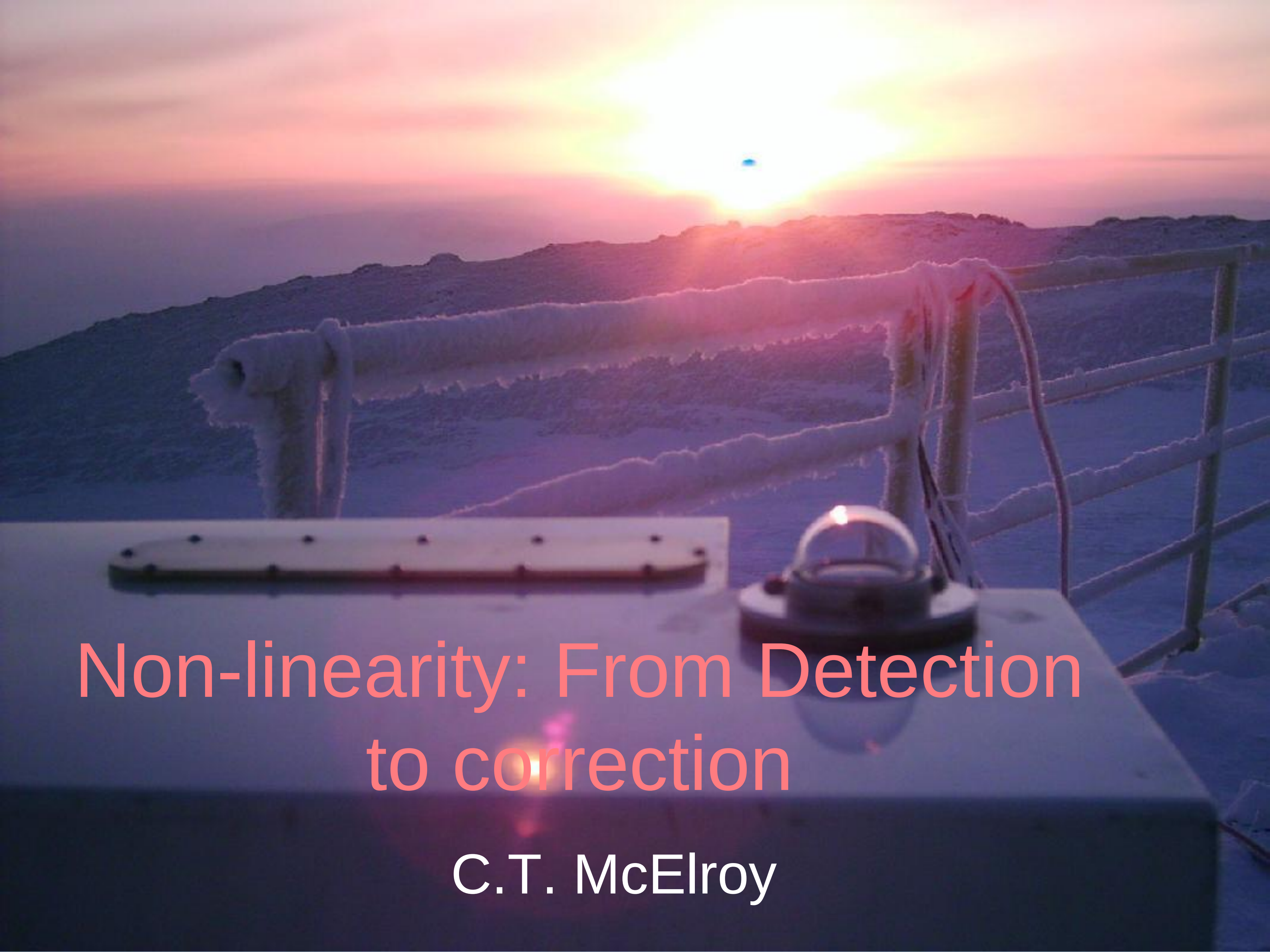


Non-linearity: From Detection to correction

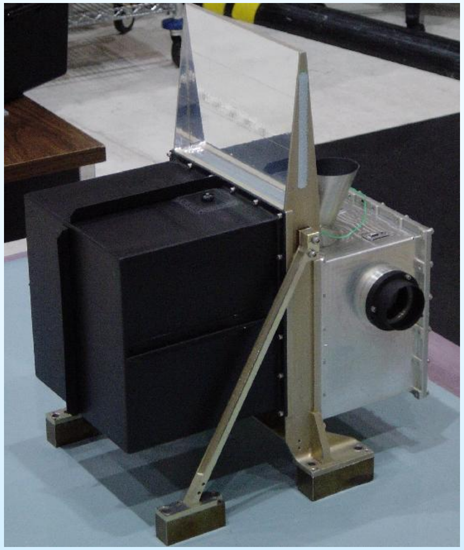
C.T. McElroy

Stray Light & Linearity

- Brewer Spectrophotometer and Stray Light
- SunPhotoSpectrometer and Stray Light
- MAESTRO and Stray Light

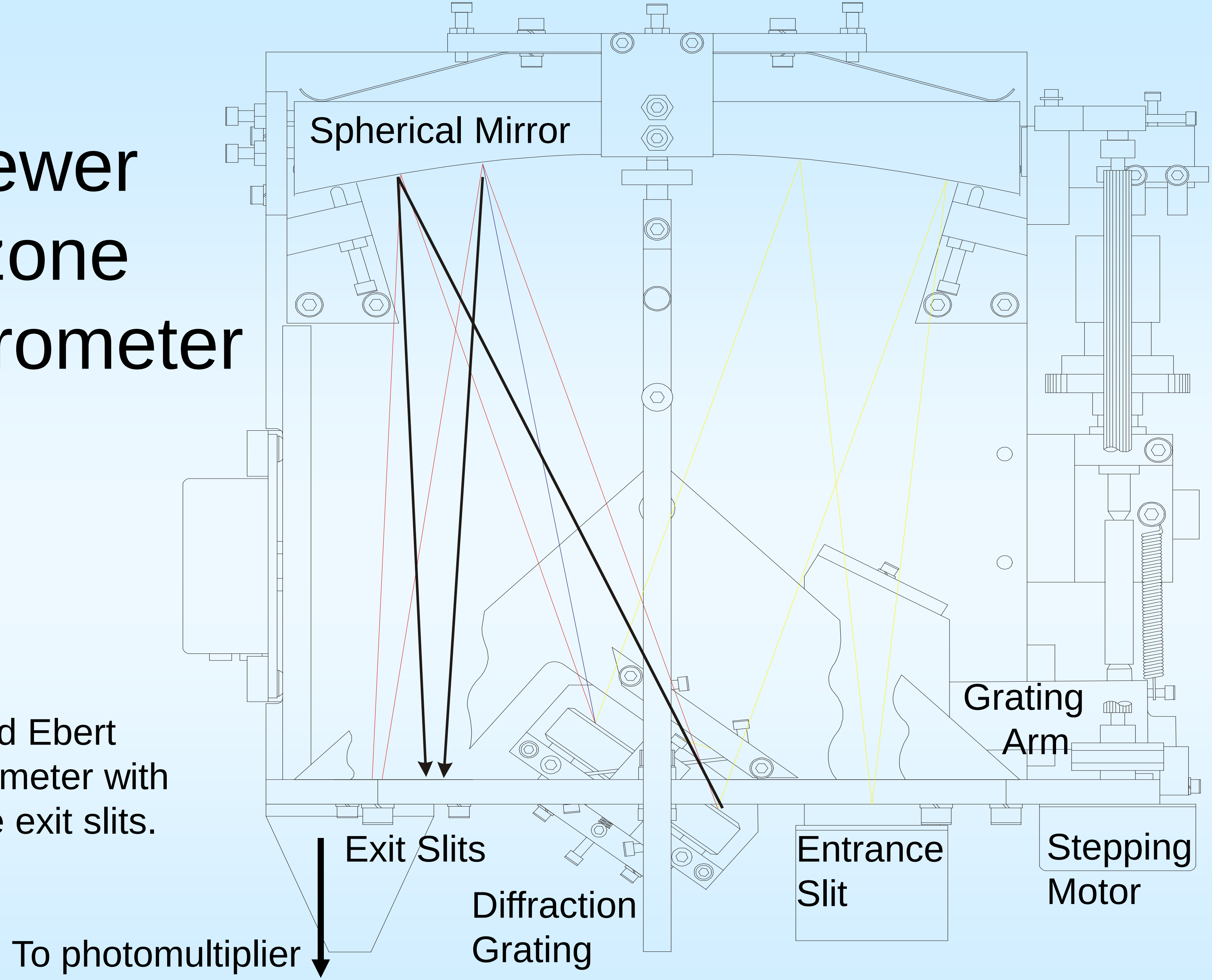
Brewer

SPS



MAESTRO

Brewer Ozone Spectrometer



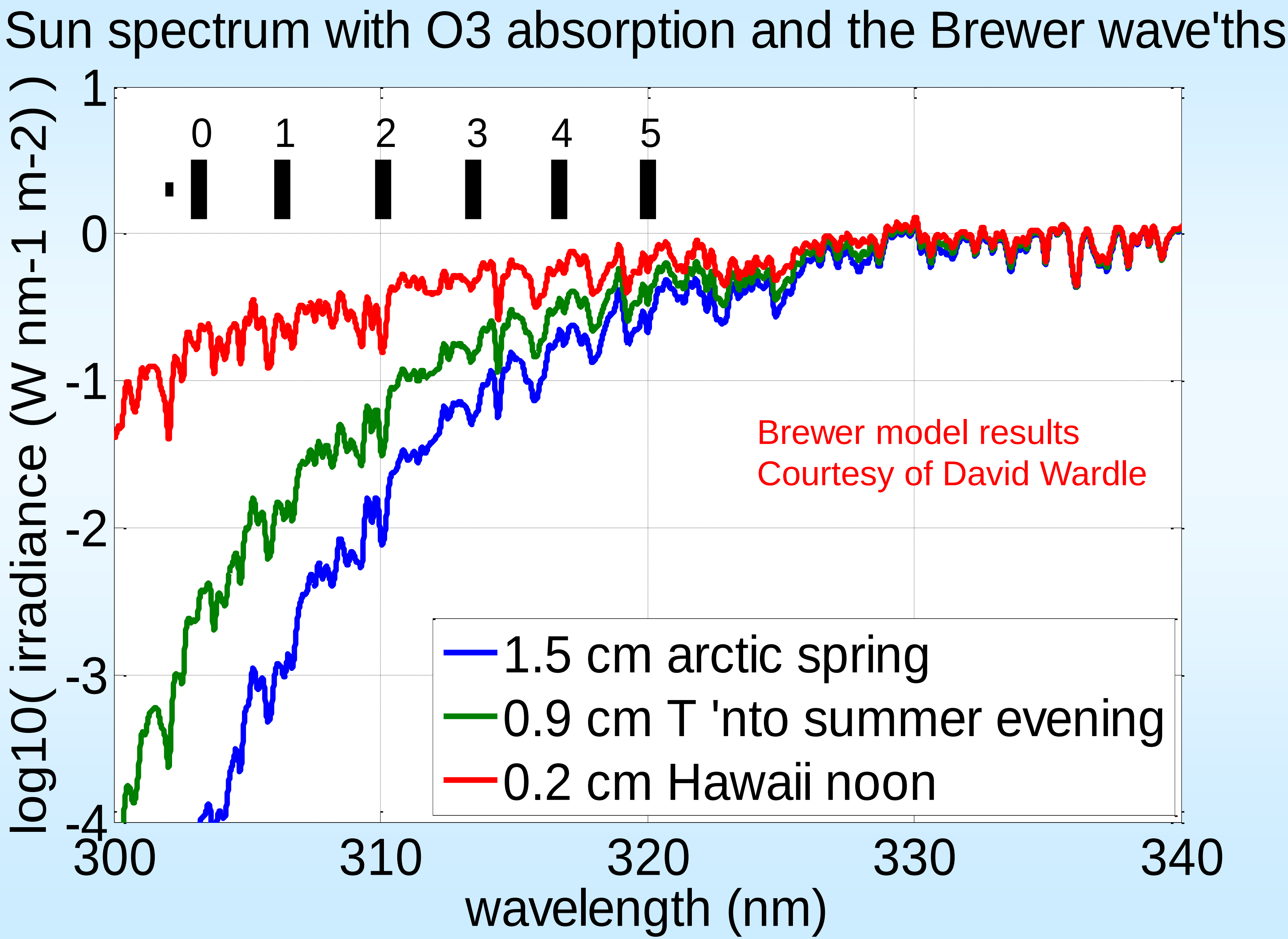
Modified Ebert spectrometer with multiple exit slits.


MSC
Toronto
Single
Double
Double

Serious Issues…

- Slit Function characterization
- Sensitivity, Etalonning & Pixel-to-pixel Gain
- Dynamic Range, Dark Count & Noise Level
- Stray Light, Linearity & Thermal drift (analog)
- Resolution, Free Spectral Range
- Wavelength Assignment
- Geolocation

Solar spectrum and Brewer wavelengths



Some dogma....................

For a single wavelength input to a linear spectrometer we can write

Signal = intensity of input * $f(\lambda, \lambda_s)$

where λ is the wavelength of the input radiation
& λs is the wavelength setting.
$f(\lambda, \lambda_s)$ is a response function converting intensity to count rate
Note: the dispersion function is $\lambda_s = G(steps)$

We often do a line scan in which we
use a constant input λ, and vary the setting λ_s.
(What is more relevant is changing the input λ given a constant setting.)

dogma continued……………….

For a spectrum of input radiation:

$$\text{Signal}(\lambda_s) = \int P(\lambda) * f(\lambda, \lambda_s) * d\lambda$$

Where $P(\lambda)$ is the spectral irradiance (watts m^{-2} nm^{-1})

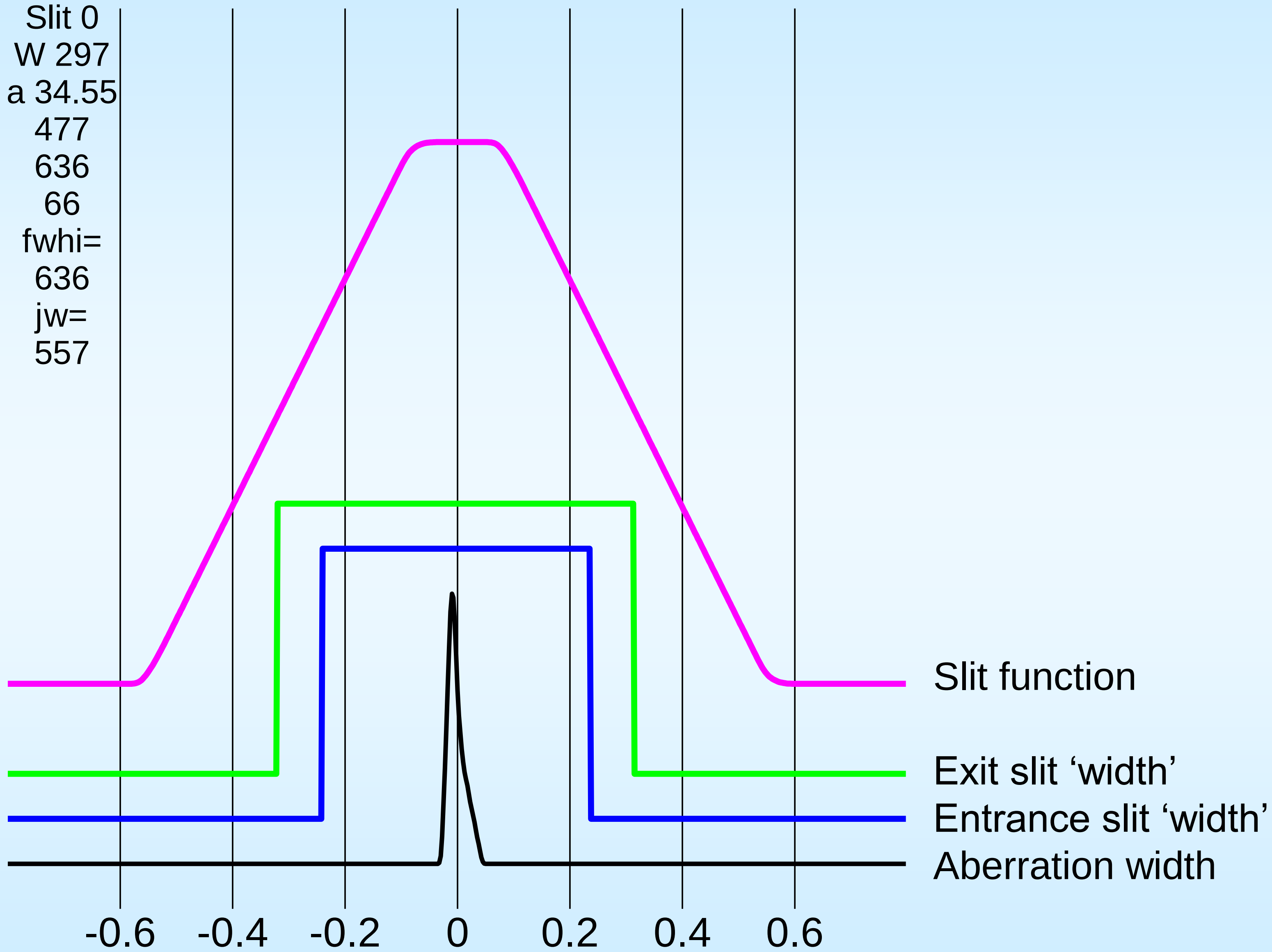
Most spectrometer users assume the above can be simplified to:

$$\text{Signal}(\lambda_s) = \int P(\lambda) * R(\lambda) * q(\lambda - \lambda_s) * d\lambda$$

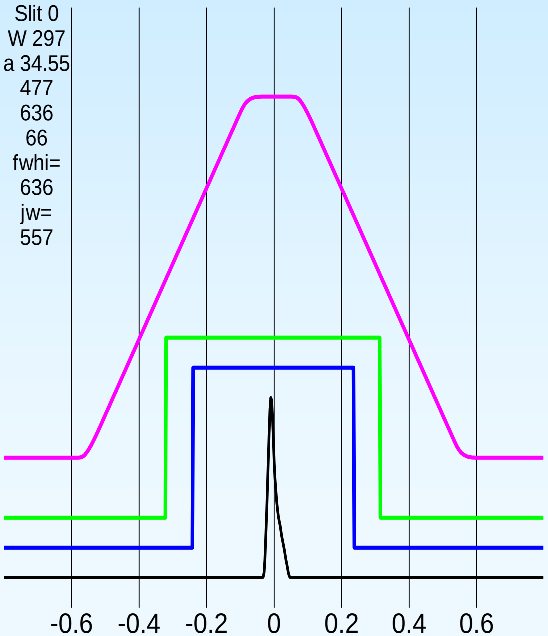
R may be called the responsivity and q the “slit function,” and q(0)=1.

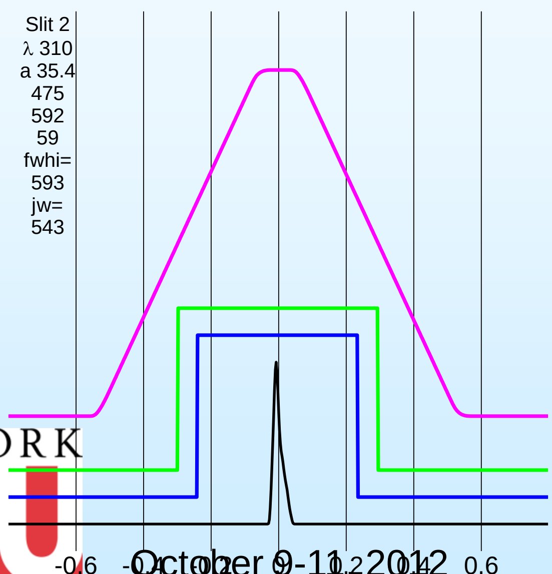
Not entirely correct.

Slit #0 “slit function”



Ray-traced response functions



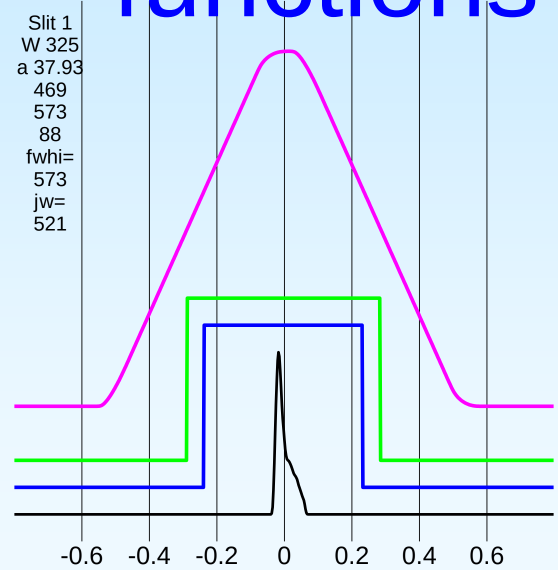


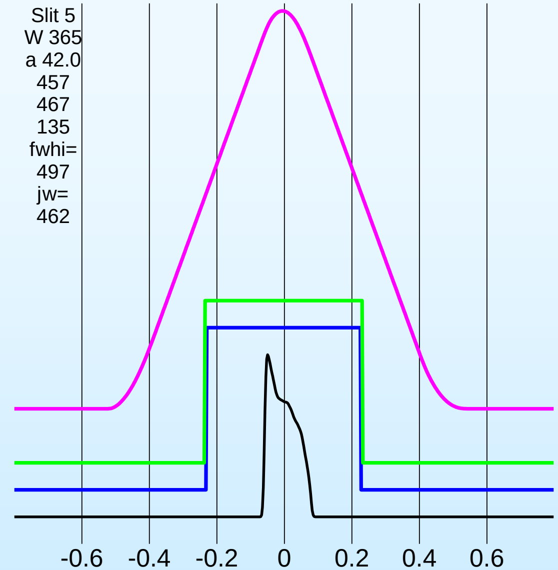
Starting from the bottom, the curves in each panel show:

1:aberration limited transmission function (very narrow slits and the actual optics*)
2: the entrance slit width
3: the exit slit width
4: the overall (calculated) transmission function with the given slit widths.
Abscissa- wavelength (nm) from centre
Ordinate- relative transmission.

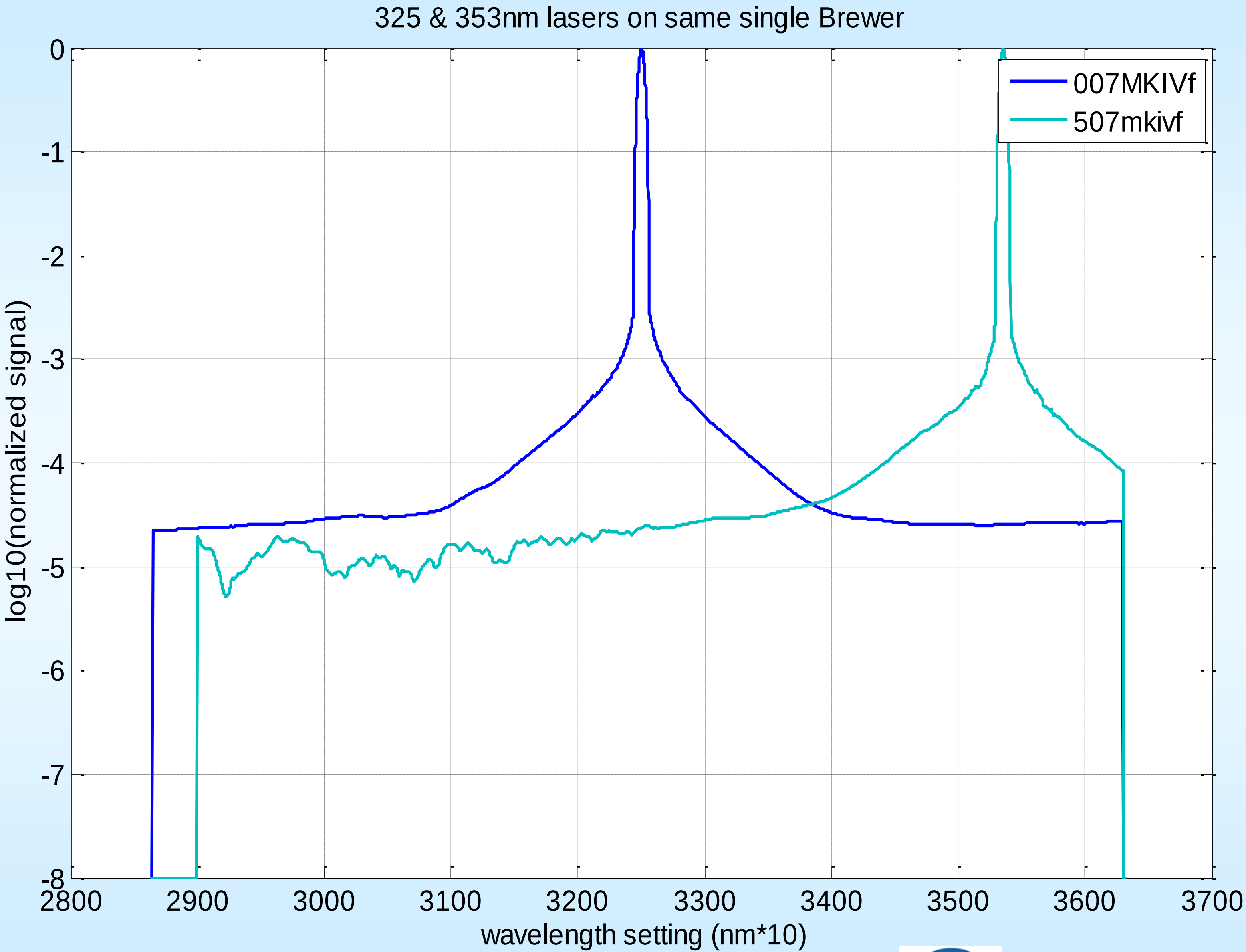
Legends show, slit #, centre wavelength (nm), grating angle (degrees), entrance and exit slit equivalent widths, aberration width (abw), the full width at half intensity, and the slit width parameter from a Brewer algorithm, (last five in pm).

297 nm slit 0 - the Hg line and slit recommended for overall focusing.
310 nm - the ozone setting for slit 2.
325 nm on slit 1 - HeCd laser on the slit (often) used for wavelength scanning.
365 nm, the recommended long wavelength limit (necessarily on slit 5).

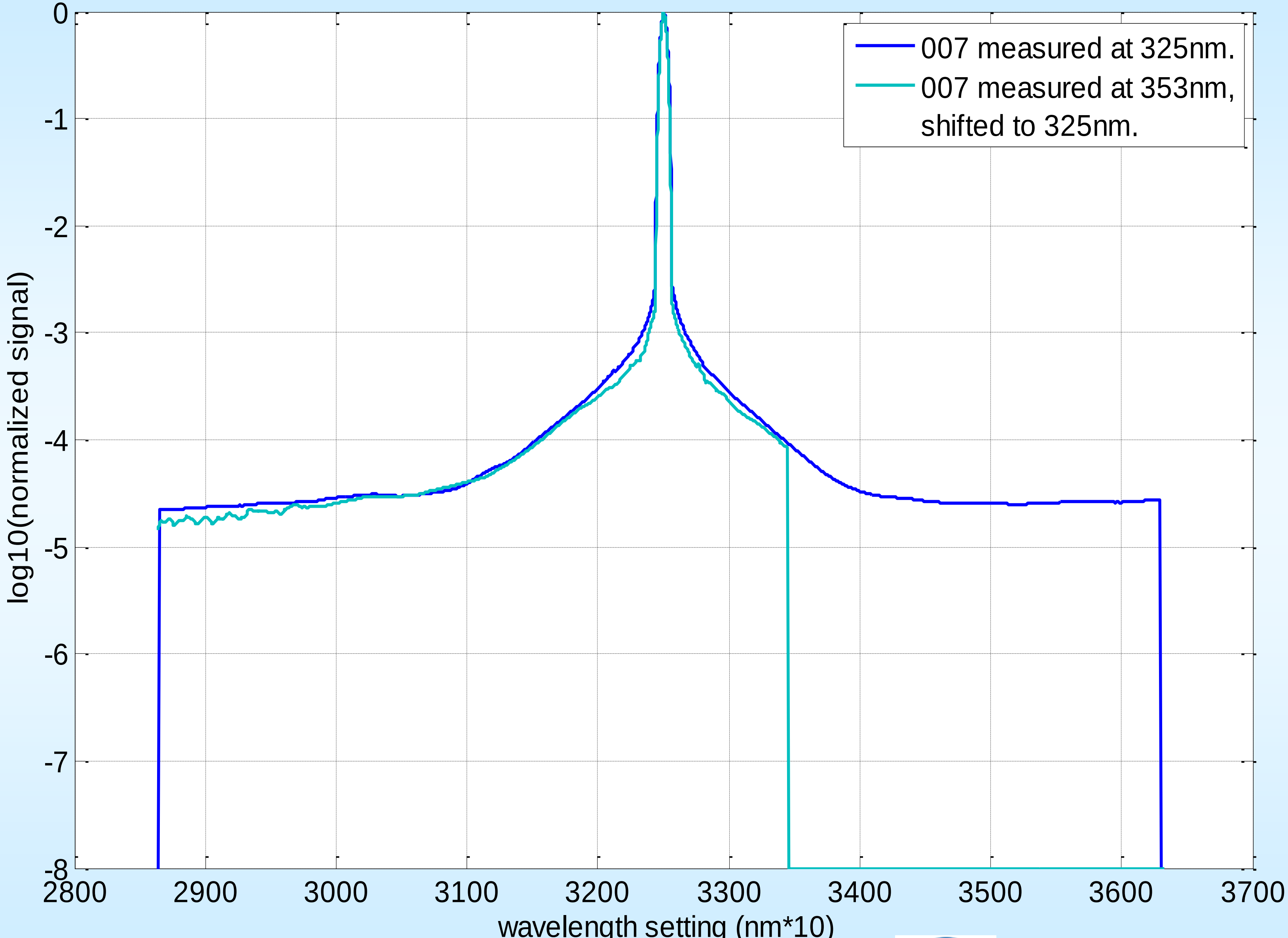




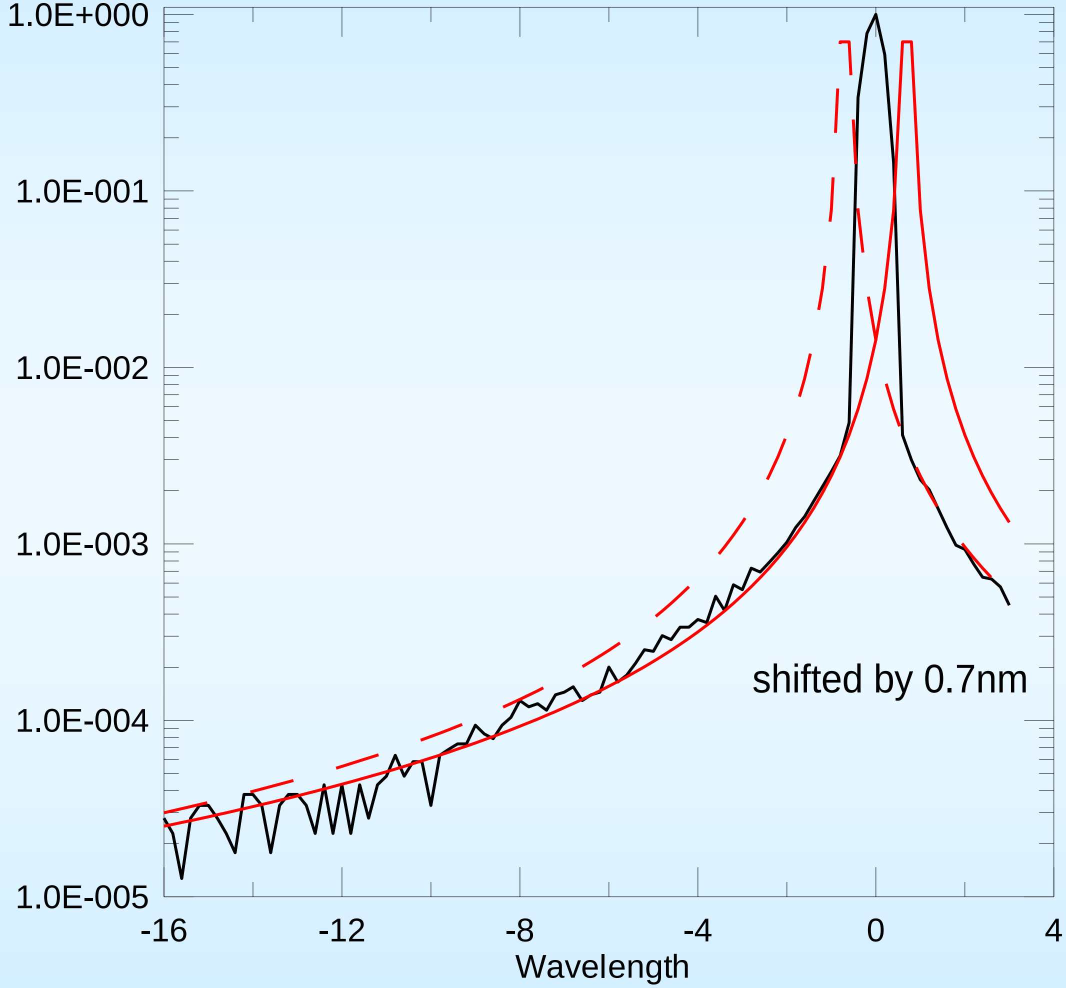
325 & 352 nm laser scans…………………



325 & shifted 353 laser scans………………..



Double Brewer Stray Light



Courtesy
C. McLinden

325 & 353 nm comments………

So yes the shape is the same, or is it?

Actually

the centre is ~10% narrower as the optics dictate

has ~10% less energy

wings are ~20% lower

have ~20% less energy

The reasoning: the ratio of good to bad should be constant regardless of slit width, assuming the aberration-and-diffraction-determined width is smaller than the geometrical (slit-size-determined) width which appears to be the case.

Brewer Stray Light Corrections

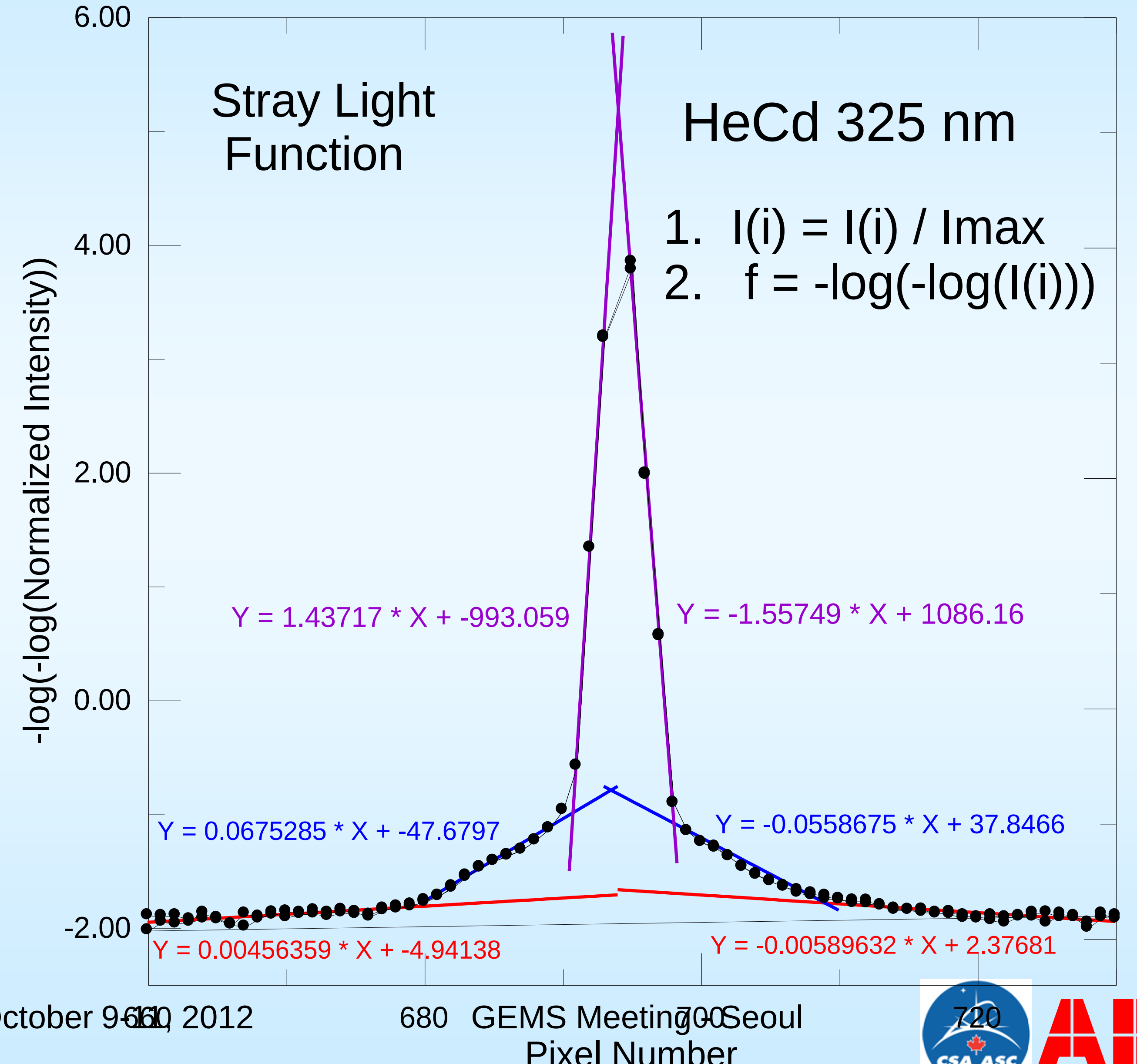
- Zero order correction:

  - counts between 290 and 292.5 averaged and subtracted from all other wavelengths

- Vitali Fioletov's somewhat better correction

  - a theoretical correction made by convolving a spectrum with the stray light function scaled to match the value at 290 and then subtracted

CPFM Stray Light Function



Stray Light Correction Algorithm

Write $I_m(w) = I_t(w) + I_s(w)$

Calculate $I_s(w) = \int I_g(w') \, q(w, w') \, dw'$

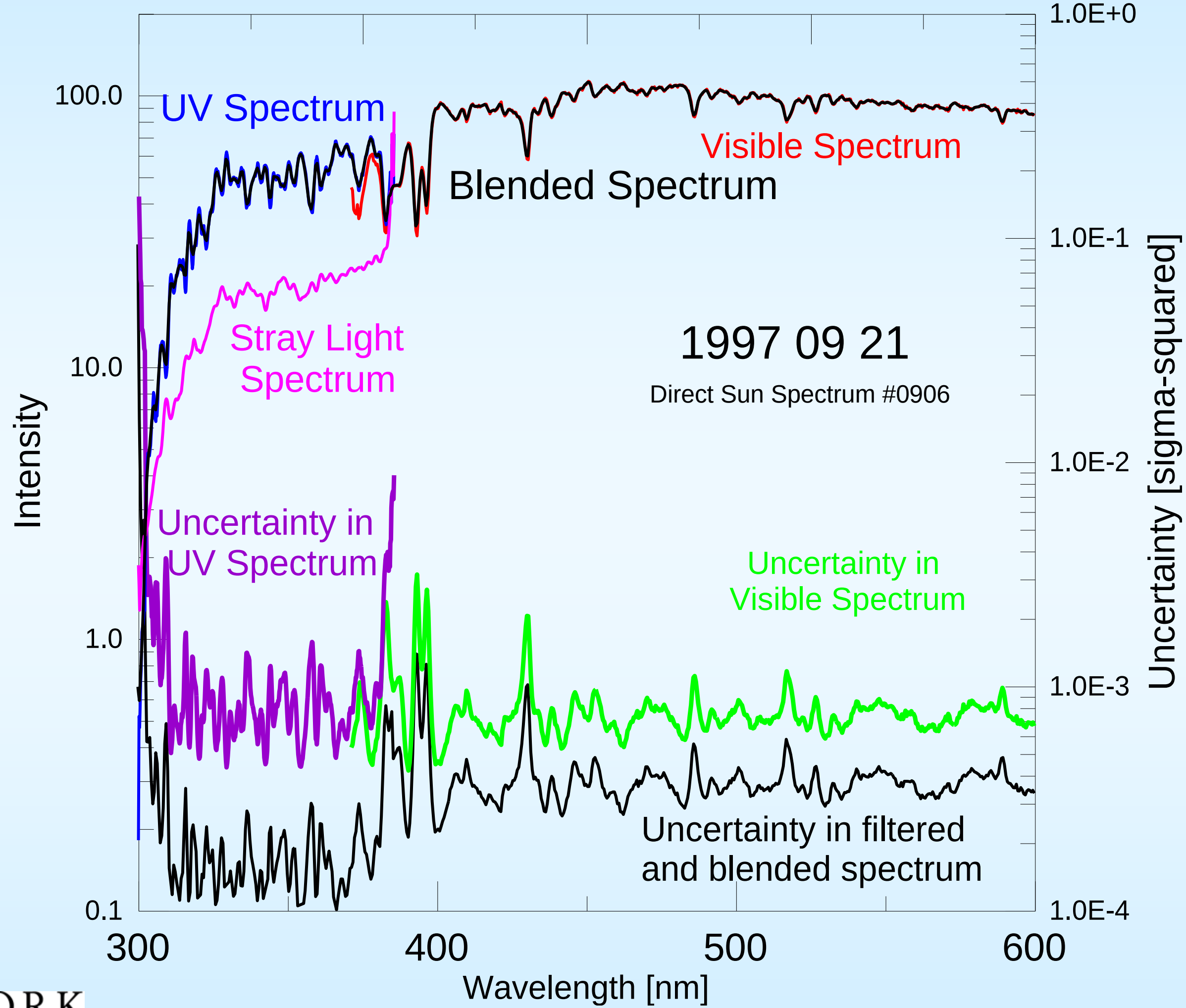
Using a ‘guessed’ $I_g(w) \sim I_t(w)$ to generate a better estimate of the true spectrum:

$$I_e(w) = I_m(w) - I_s(w)$$

It converges in a few iterations

Can be combined with a dark correction

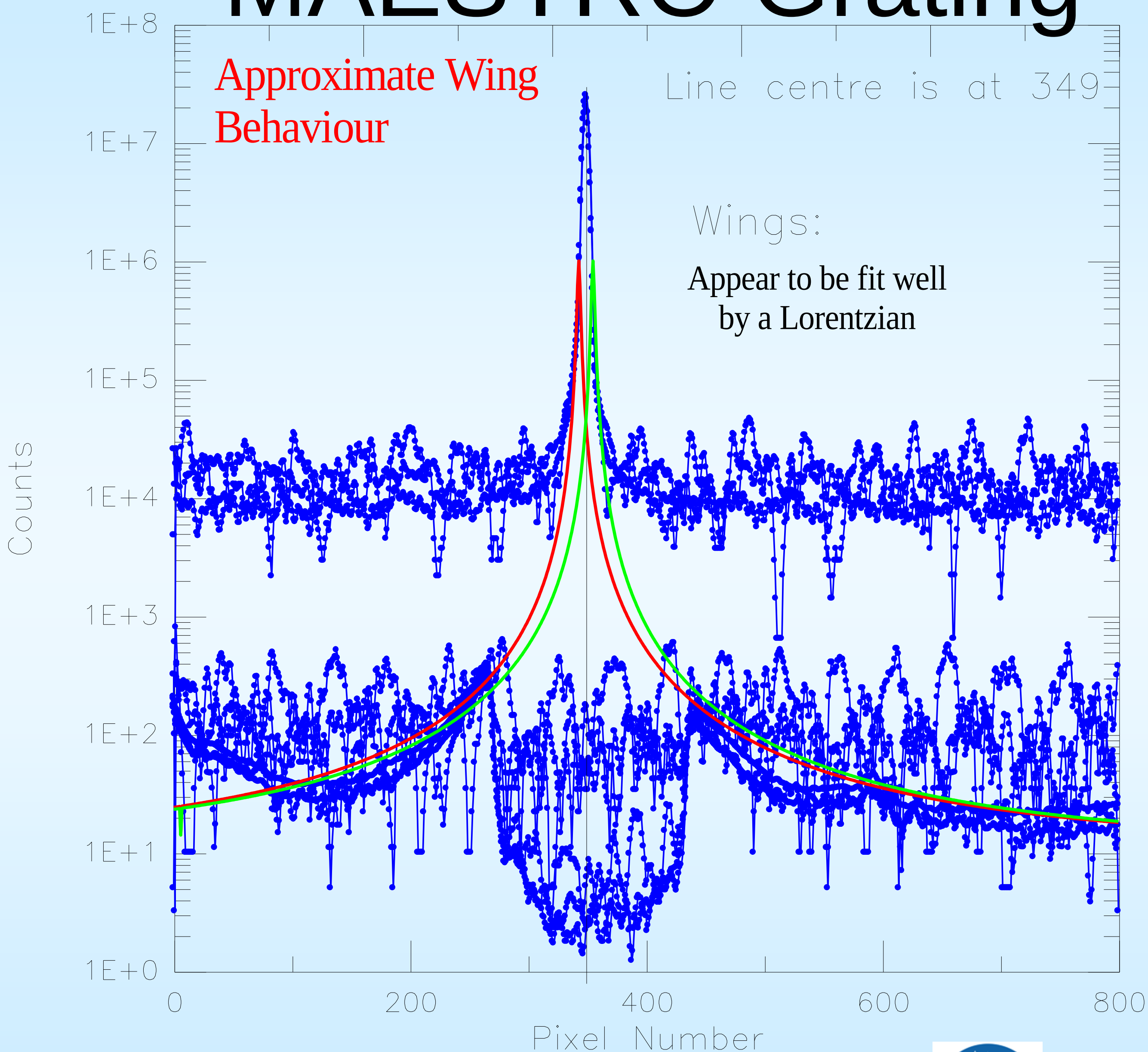
Sample Spectrum



The uncertainty in the combined spectrum is lower because some smoothing is applied and the smoothing function is wider in the UV to better match the resolution between the UV and visible.

Stray light becomes 60%
Of the total signal at 300 nm.

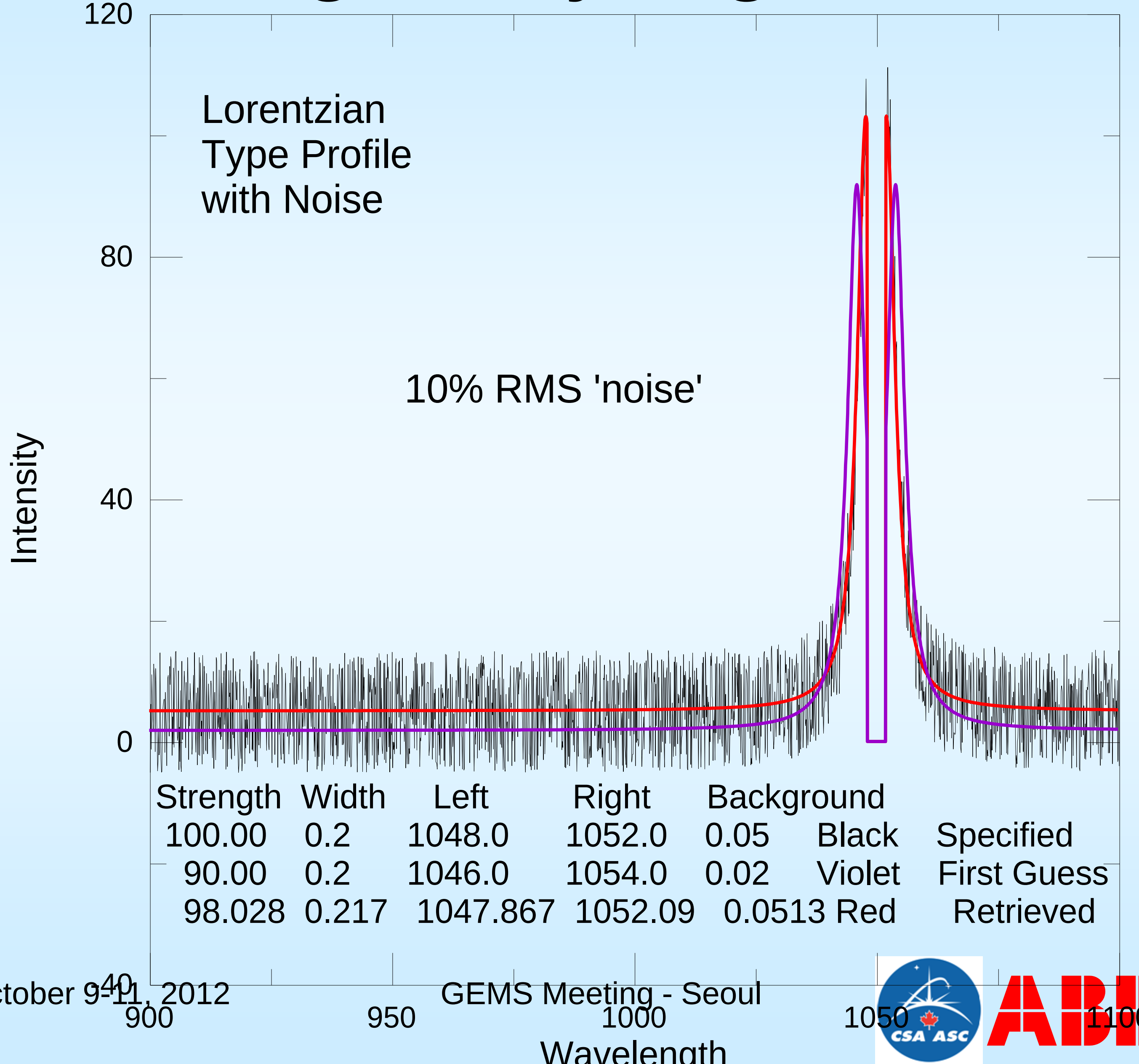
MAESTRO Grating



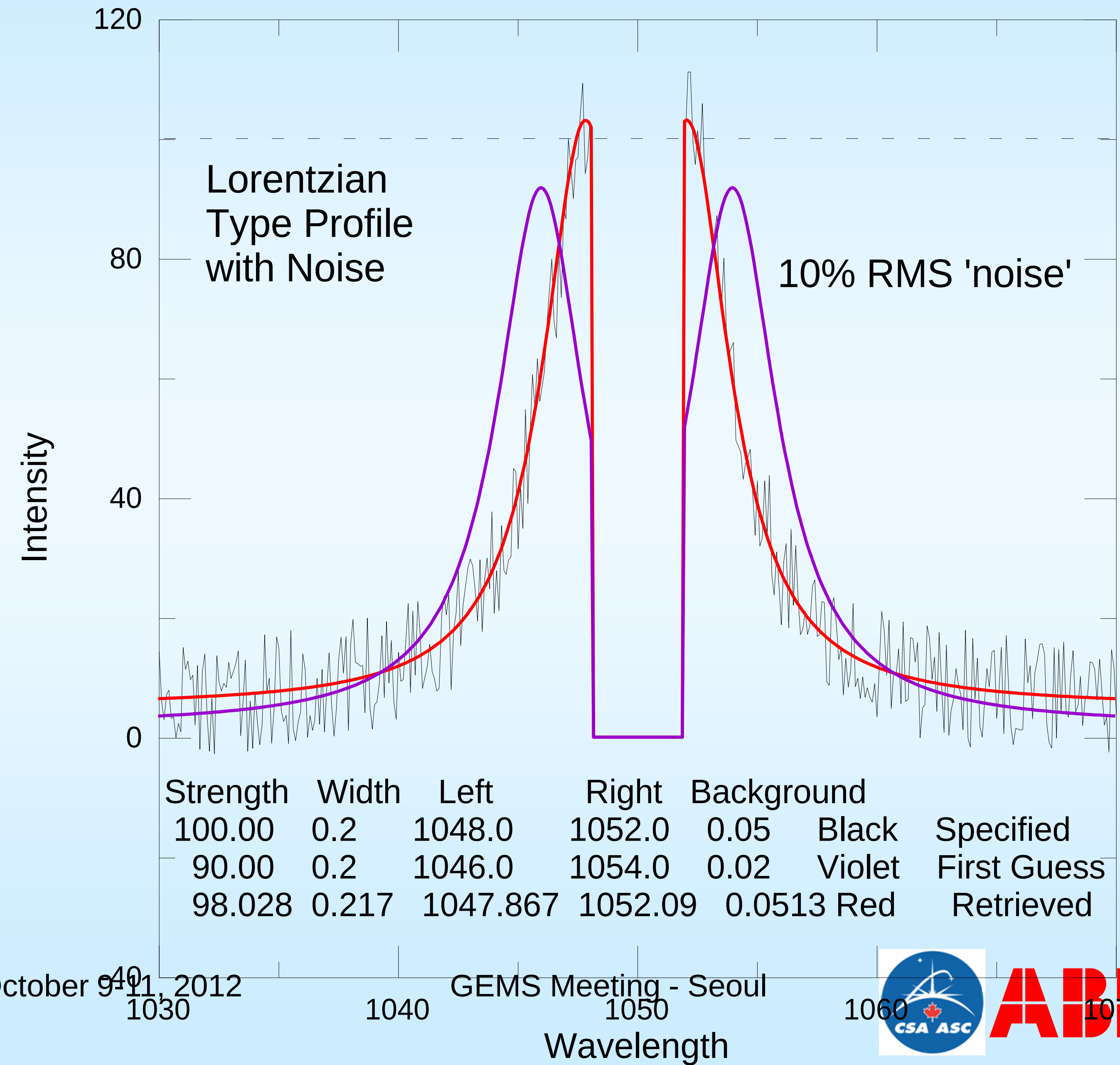
Full laser illumination

Centre of line blocked

Grating Stray Light - Wide



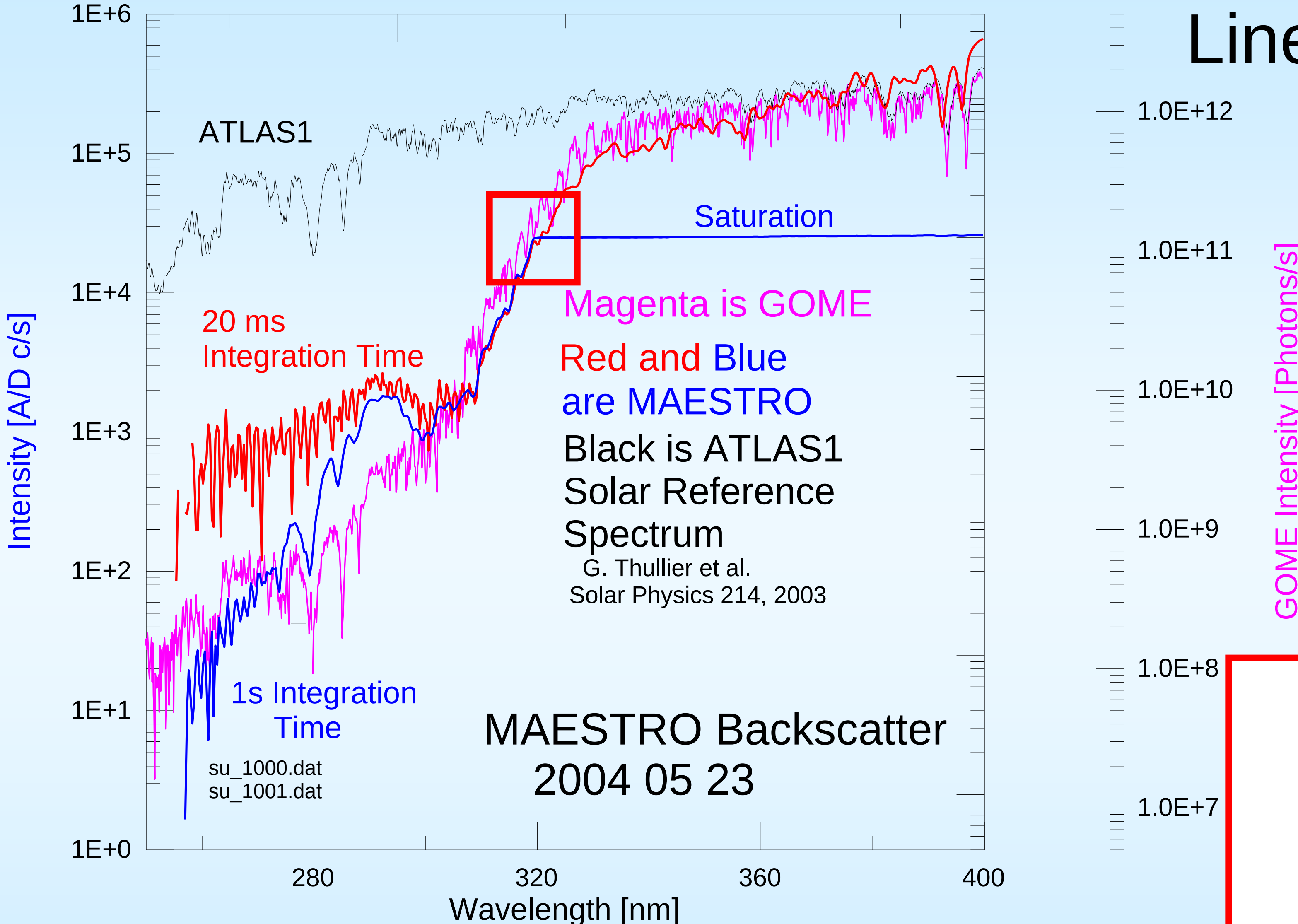
Grating Stray Light Function

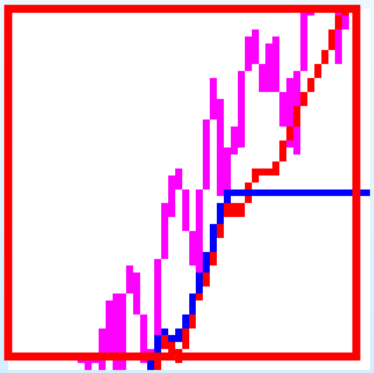


Analysis….

- Detector readout is very fast
- About 5% integrated charge is carried forward (Can be very problematic with CCDs)
- Stray light shape function from pre-flight data
- Corrected using an empirical constant derived from very short wavelength region in the solar occultation UV measurements
- Stray light correction amplitude ‘tuned’ to make the O_2 ‘A’ band centre zero

Linearity





The RETICON array has very independent detectors.

EG&G Reticon Detector - Details

Commercial detector

Used by ESA's GOME(2) & SCIA

Large dynamic range

High resistance to non-linearity

<u>No blooming</u>

Randomly addressable

UV-enhanced Si photodiodes

Electrometer amplifier

16 bit A/D input

Controlled by soft-programmable

FPGA (XILINX)

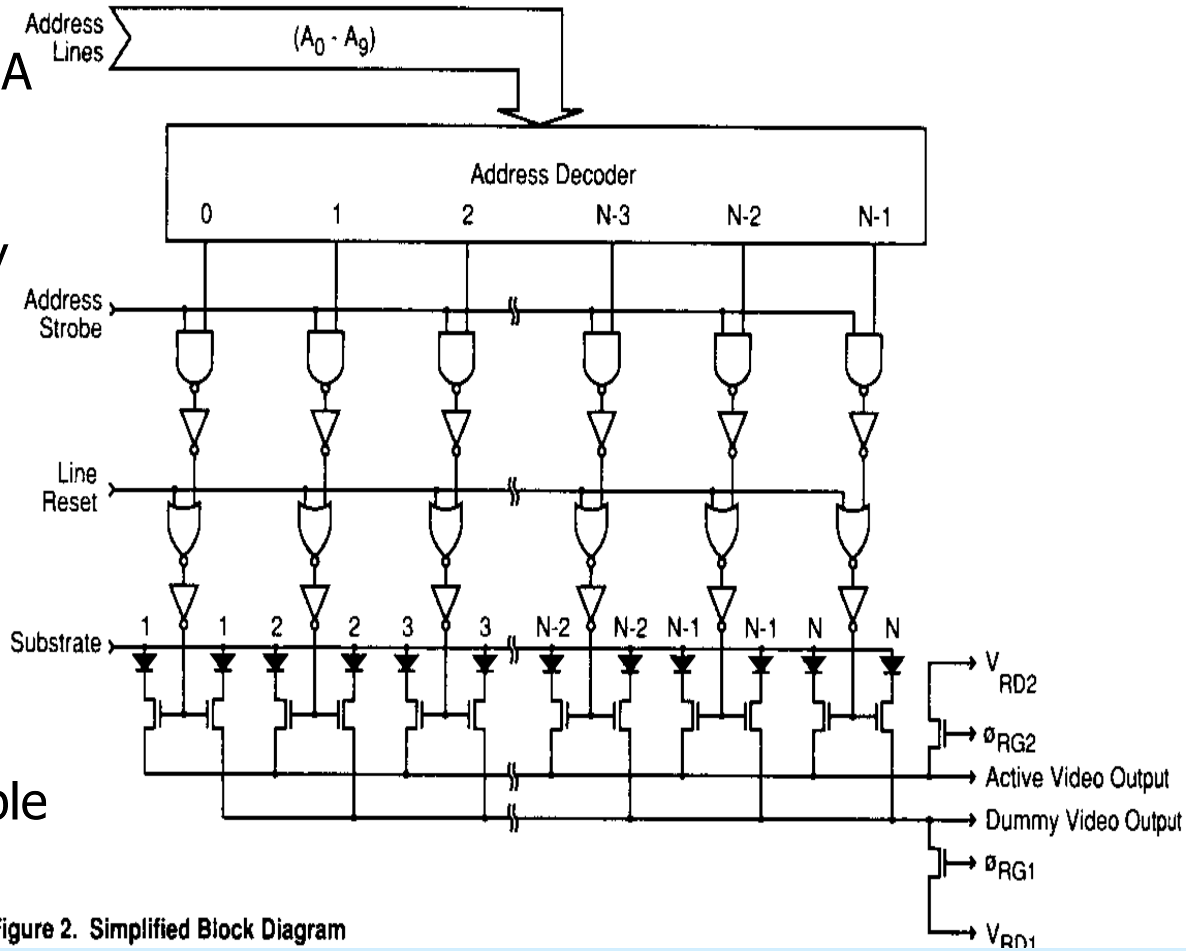


Figure 2. Simplified Block Diagram

Requirements

- Develop a model for the electronic offset
  (Extrapolate to zero integration time)
- Model dark count spectrum (key to dark pixels)
- Correct for imperfect detector reading
  (Charge carry-over – pixels in a region with no 'real' light)
- Correct for stray light
- Best done by including a representation of all of these effects in the forward instrument model. Then the parameters may be – at least partially – retrieved using on-orbit data. For example by reading detectors that are not illuminated and at very short wavelength

Retrieving Model Parameters

- Different types of measurements for different purposes
- Long integration times can test the linearity of signal processing
- Laser measurements for stray light at different wavelengths
- Blocked line center measurements to separate electronic offset from stray light
- Glass filters can also be used for this

(They look like ozone)

- Laser light can be added on top of white light background for testing

Consider how much can be done on orbit to track changes…


unrise during the
E Arctic Campaign
Sunrise 2010
The End. Thank you.