Colours from Earth

an inward perspective

Bob Fosbury (The^Bob)
@
Villa Aureli, May 2011

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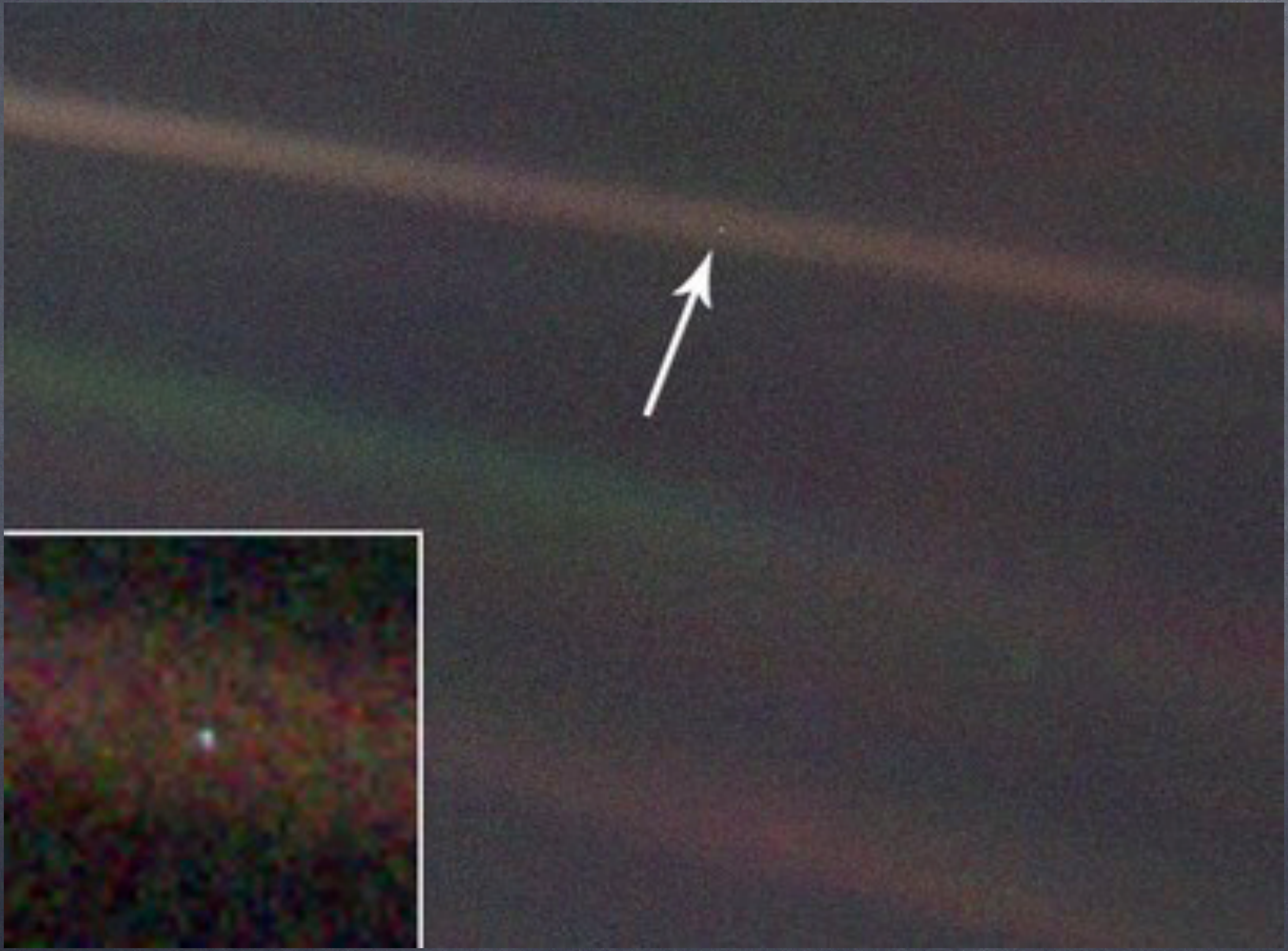
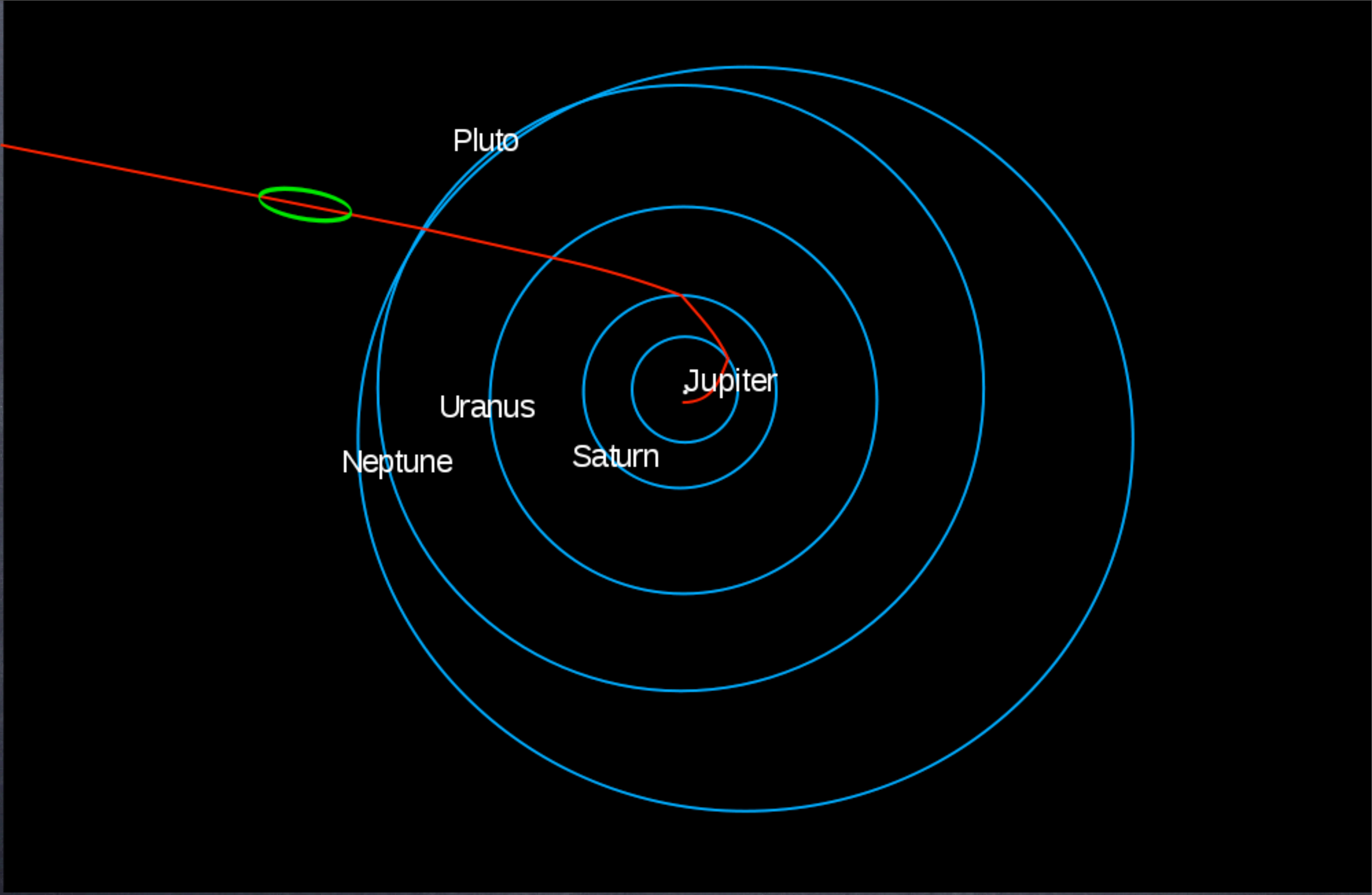
The “Pale Blue Dot”



…taken in 1990 by Voyager 1 from 6.1 billion km



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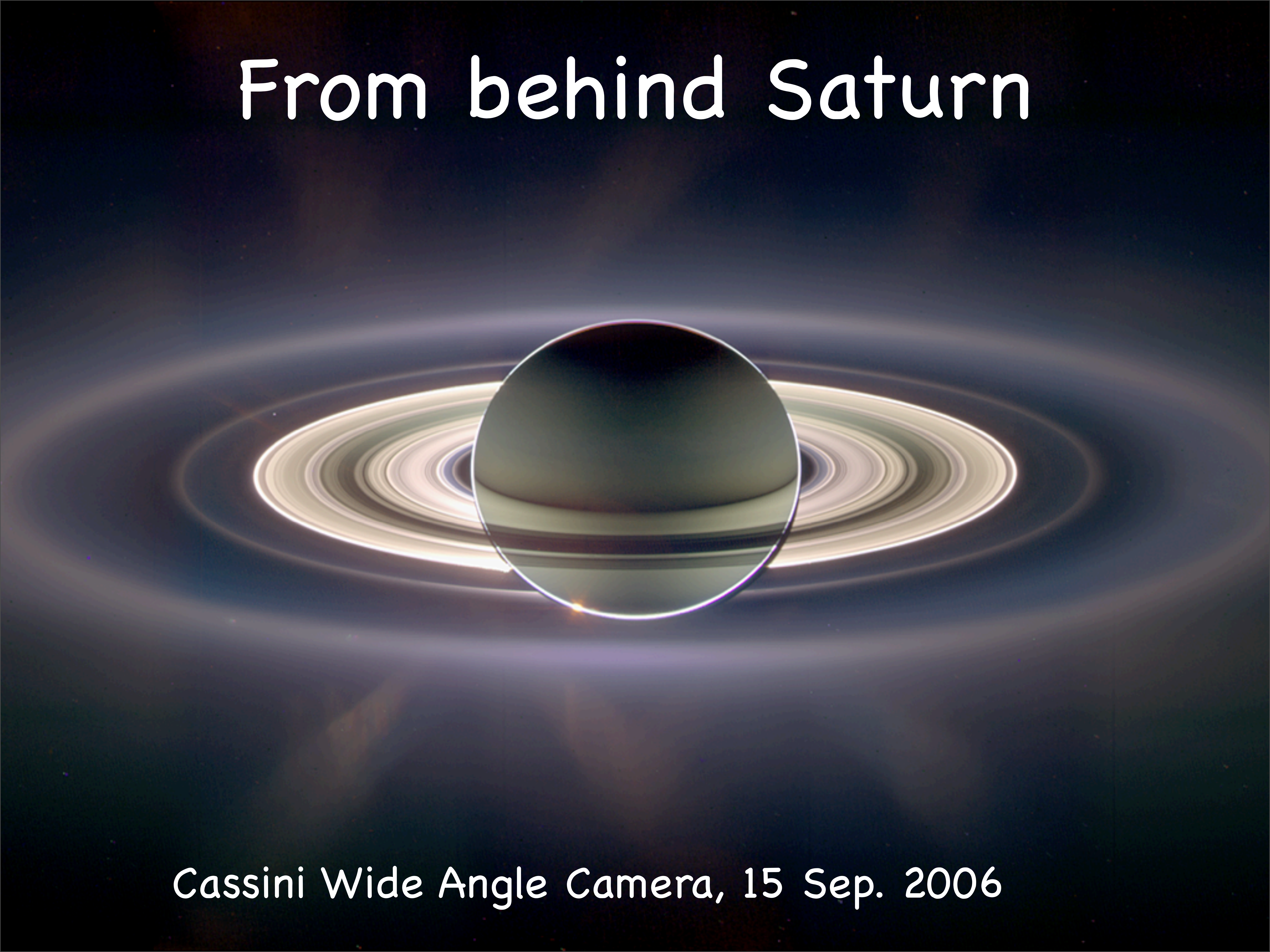
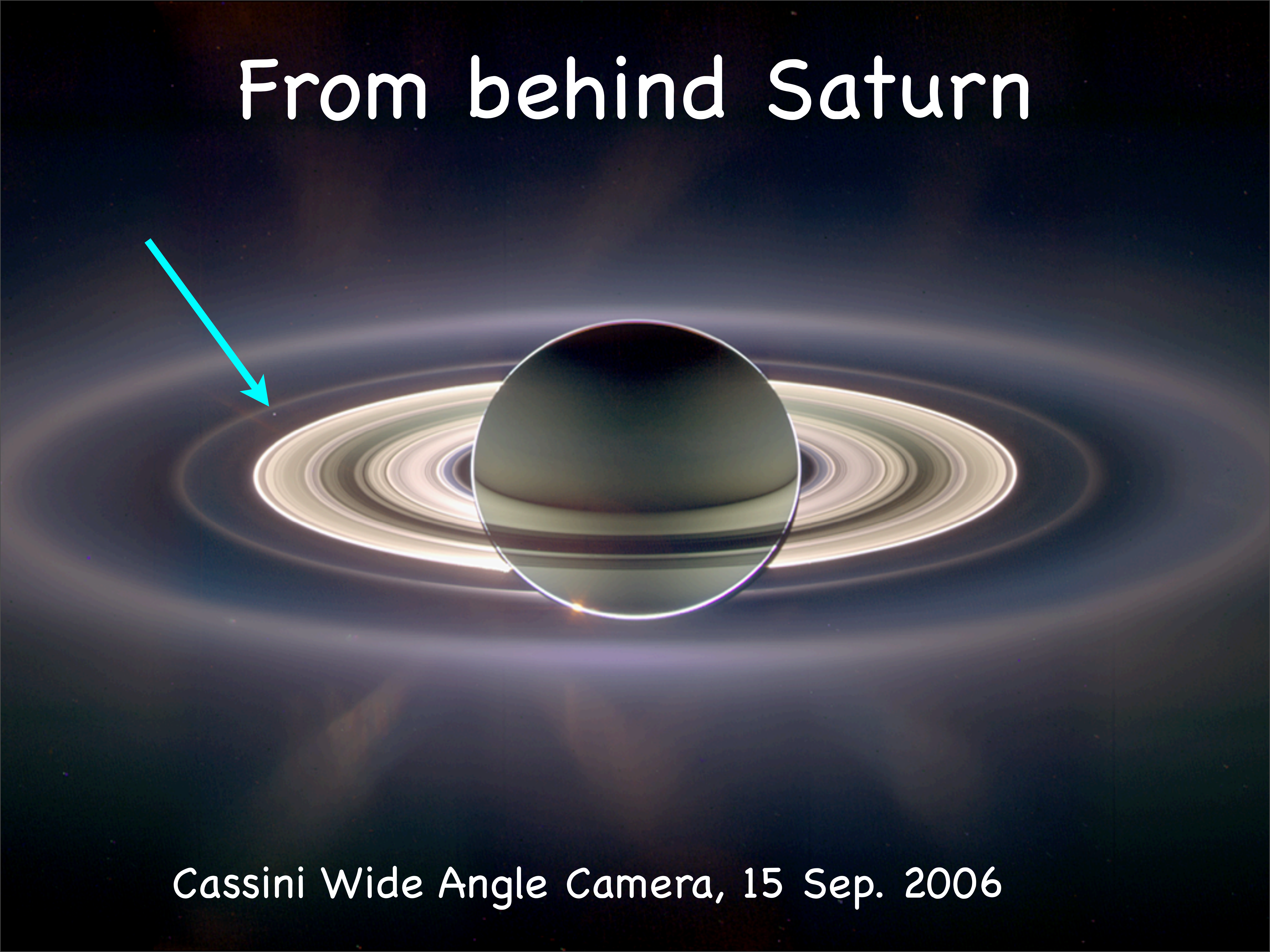
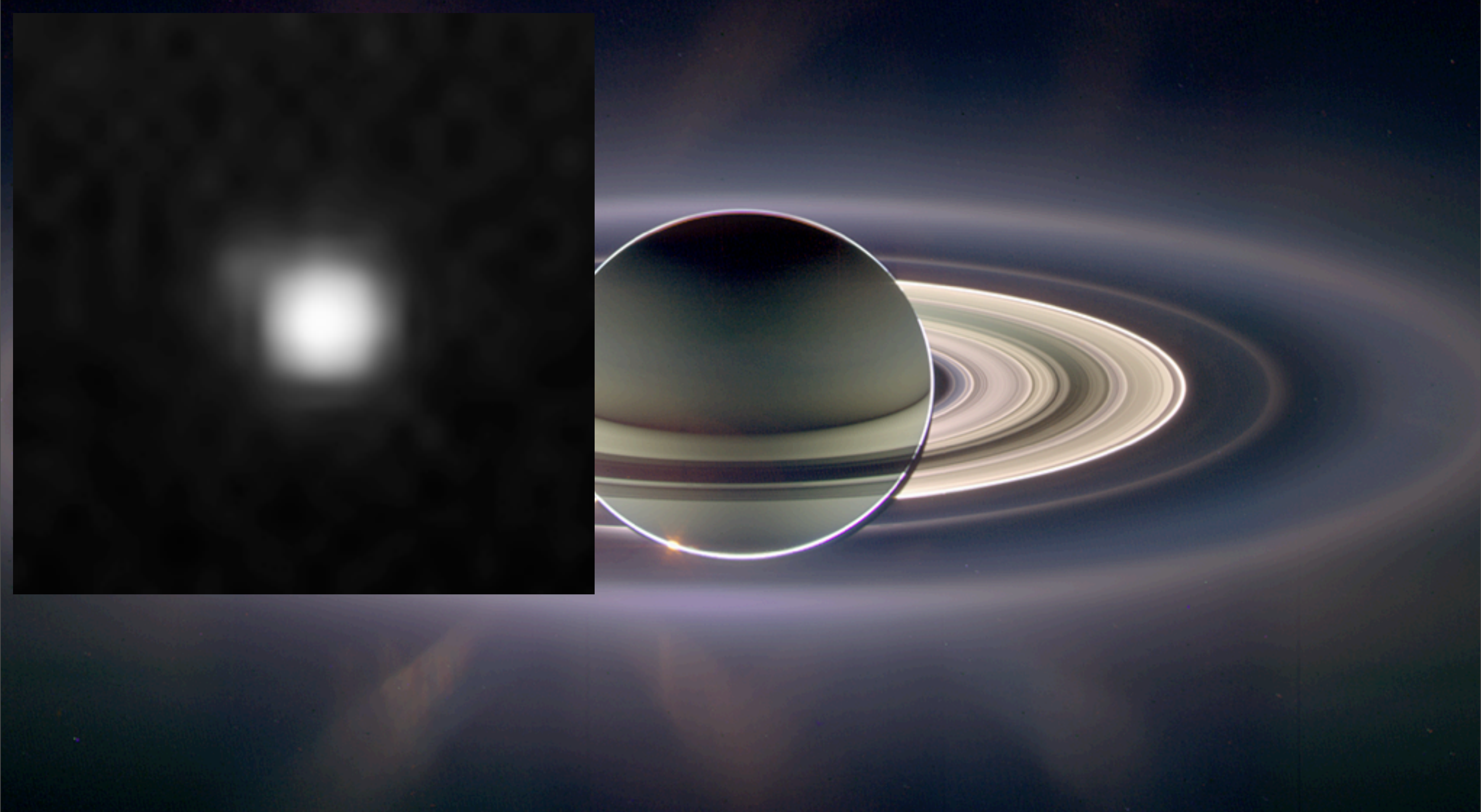

From behind Saturn
Cassini Wide Angle Camera, 15 Sep. 2006


From behind Saturn
Cassini Wide Angle Camera, 15 Sep. 2006

From behind Saturn

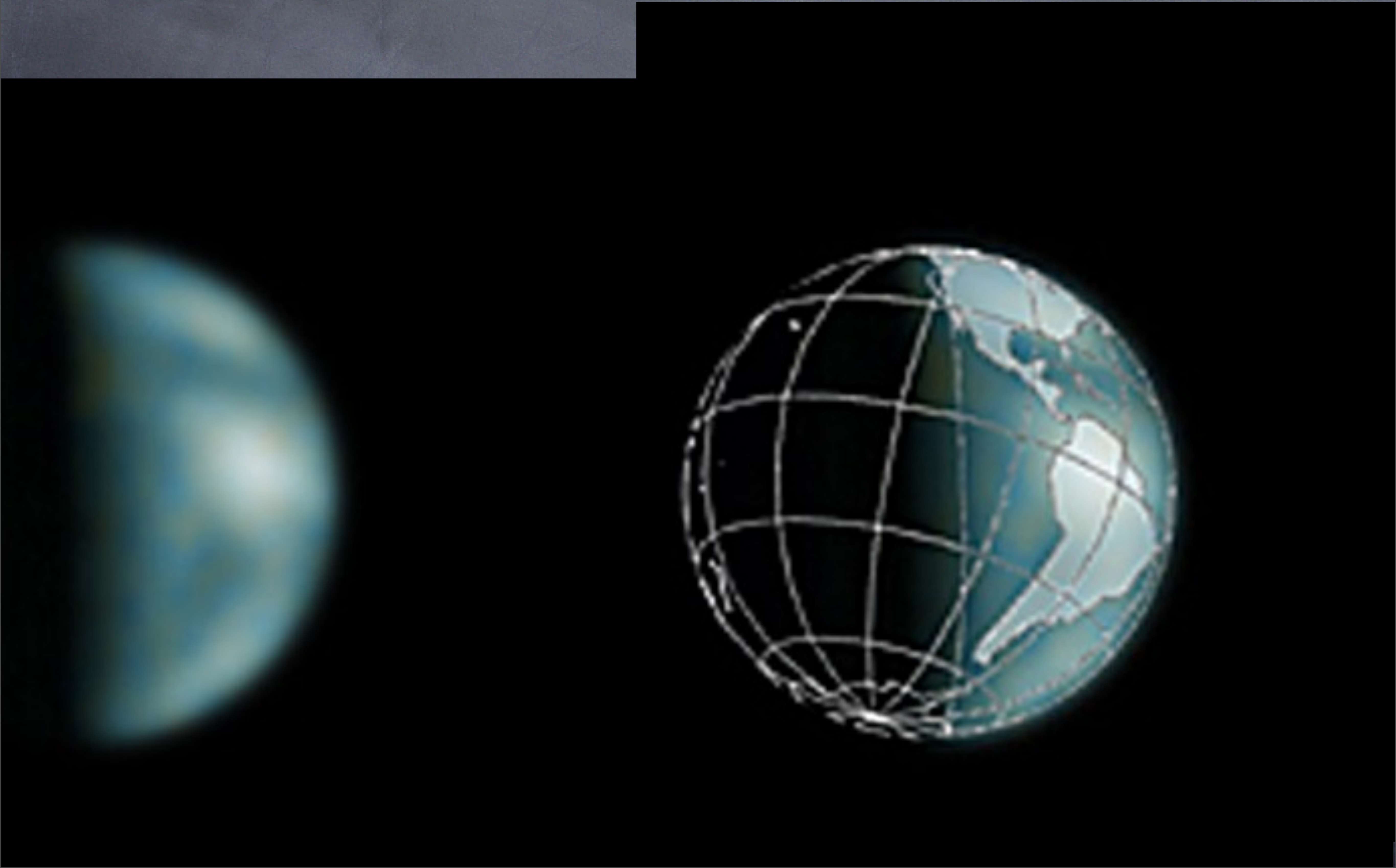


Cassini Wide Angle Camera, 15 Sep. 2006

From a neighbour

Mars Global Surveyor
Mars Orbiter Camera
on
8 May 2003
from 139 million km

From a neighbour




Earthrise
… from the Moon: Apollo 8, December 1968

From Earth orbit

The “Blue Planet”
The “Pale Blue Dot”

Why blue?

The simple answer: because of air and water
But we can look a bit deeper…

The "Blue Planet"
The "Pale Blue Dot"

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The "Blue Planet"
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But we can look a bit deeper...

Water is blue

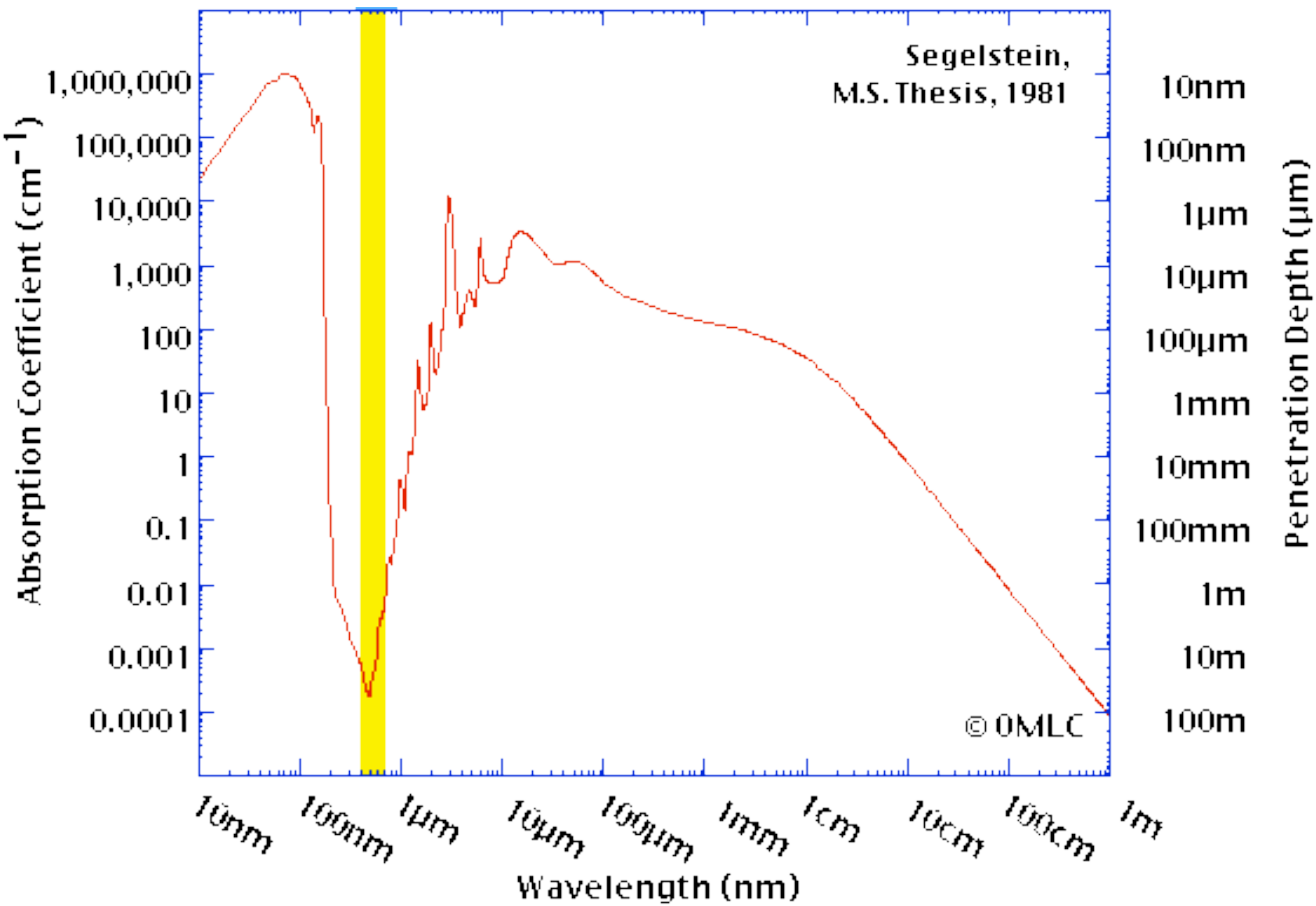
Unlike many blues in nature, water **is** actually blue

Water molecules absorb red light; in fact water absorbs pretty much all electromagnetic radiation except blue light and metre-length radio waves

Very clear seawater on the Cornish coast

Iceberg, Glacier Bay, Alaska

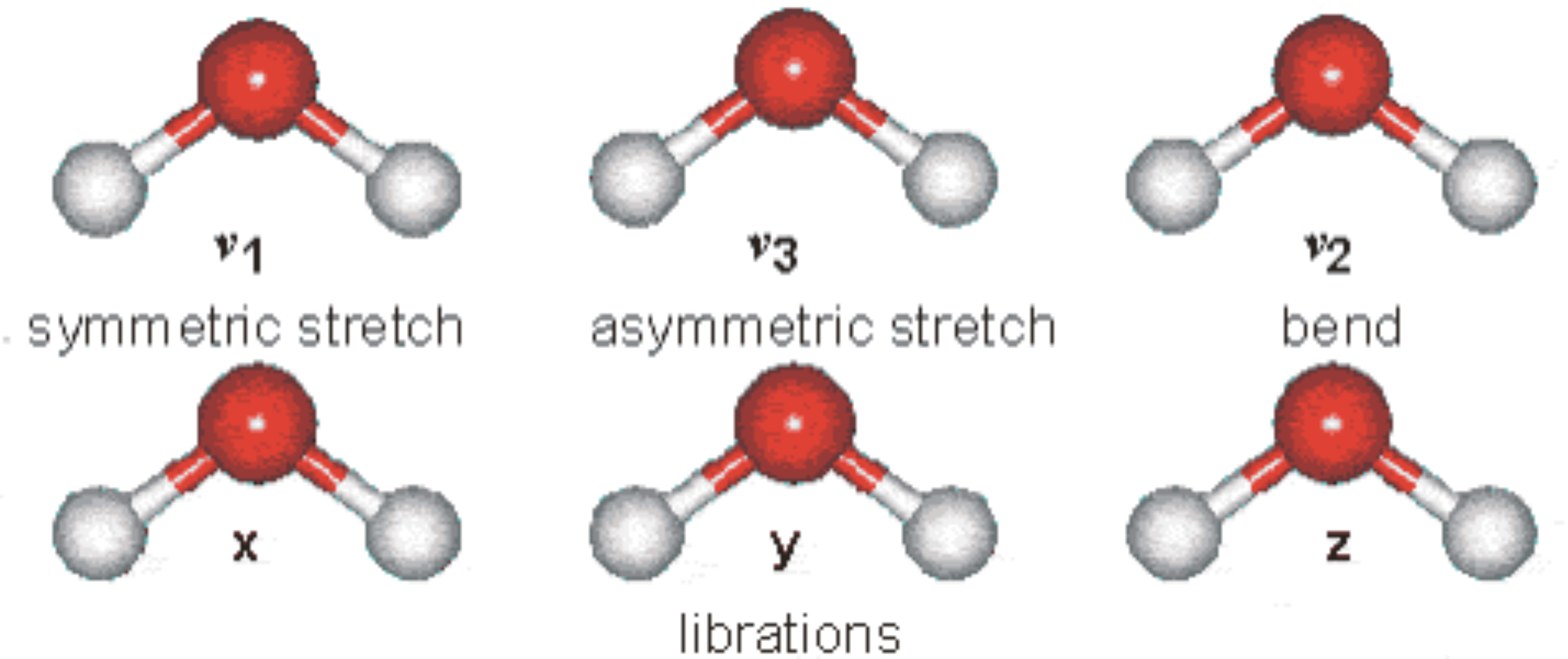
The "Water hole"



Assignment of the IR vibrational absorption spectrum of liquid water

Wavelength	cm^{-1}	Assignment		Wavelength	cm^{-1}	Assignment
0.2 mm	50	intermolecular bend		1470 nm	6800	$av_1 + bv_3$; a+b=2
55 µm	183.4	intermolecular stretch		1200 nm	8330	$av_1 + v_2 + bv_3$; a+b=2
25 µm	395.5	L_1, librations		970 nm	10310	$av_1 + bv_3$; a+b=3
15 µm	686.3	L_2, librations		836 nm	11960	$av_1 + v_2 + bv_3$; a+b=3
6.08 µm	1645	v_2, bend		739 nm	13530	$av_1 + bv_3$; a+b=4
4.65 µm	2150	$v_2 + L_2$ [b]		660 nm	15150	$av_1 + v_2 + bv_3$; a+b=4
3.05 µm	3277	v_1, symmetric stretch		606 nm	16500	$av_1 + bv_3$; a+b=5
2.87 µm	3490	v_3, asymmetric stretch		514 nm	19460	$av_1 + bv_3$; a+b=6
1900 nm	5260	$av_1 + v_2 + bv_3$; a+b=1		Note that a and b are integers, ≥ 0 ms.		

Thanks to martin.chaplin@btinternet.com



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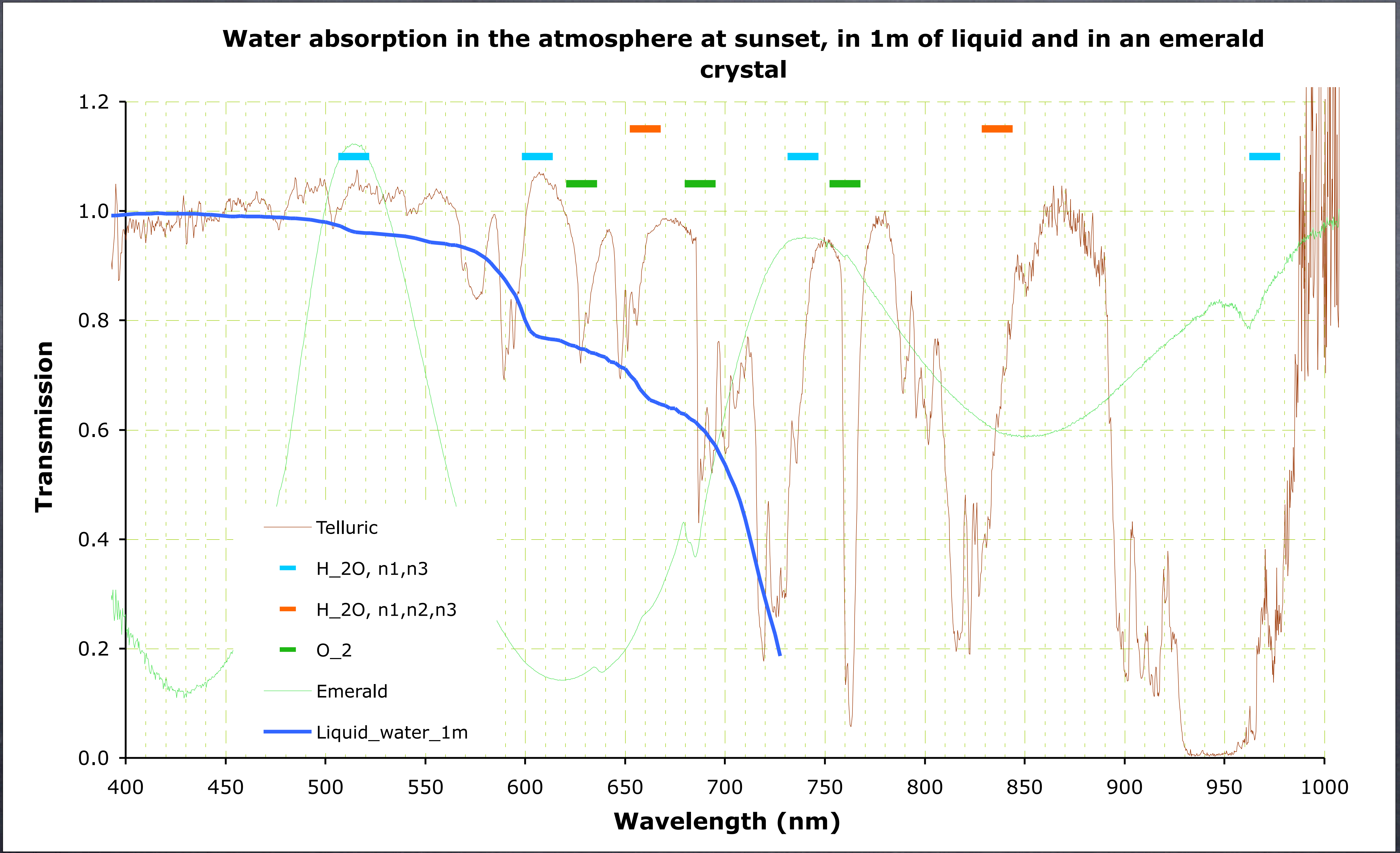

Water absorption in the atmosphere at sunset, in 1m of liquid and in an emerald crystal
Transmission
1.2
1.0
0.8
0.6
0.4
0.2
0.0
400
450
500
550
600
650
700
750
800
850
900
950
1000
Wavelength (nm)
Telluric
H_2O, n1,n3
H_2O, n1,n2,n3
O_2
Emerald
Liquid_water_1m

The blue colour of heavily overcast skies

Lee et al. 2005

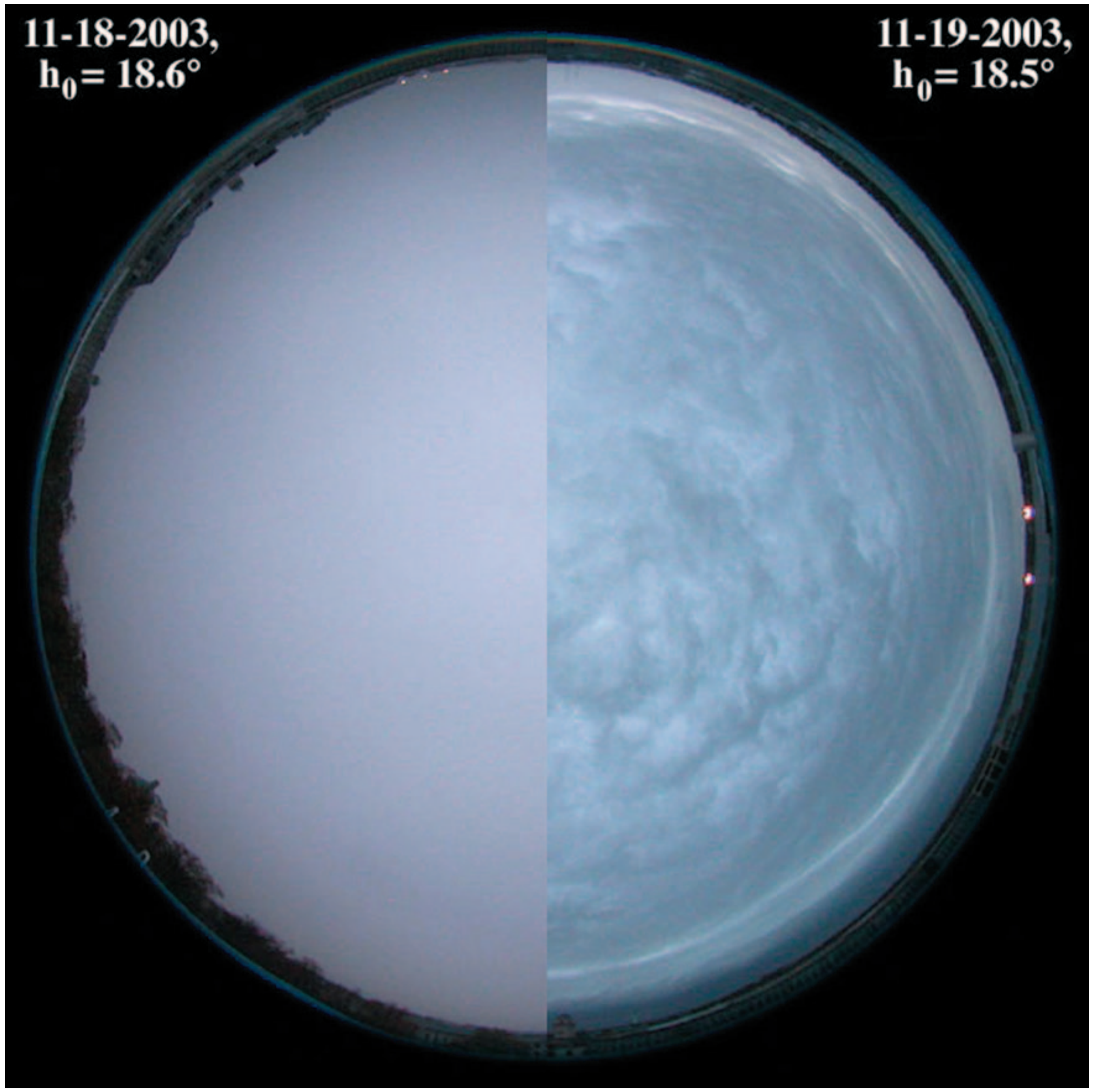


Fig. 5. Composite fisheye image of a bright stratus overcast (left half, $E = 24.3$ W m^{-2}) and a much darker stratocumulus overcast (right half, $E \sim 3.6$ W m^{-2}) at USNA on 11-18-03 and 11-19-03, respectively. Note that the darker overcast is distinctly bluer. Although exposures differ, in both original photographs the digital camera's white-balance setting was the same and $h_0 \sim 18.5°$.

Mostriamo in figura 4.1 il grafico della distribuzione del numero di interazioni

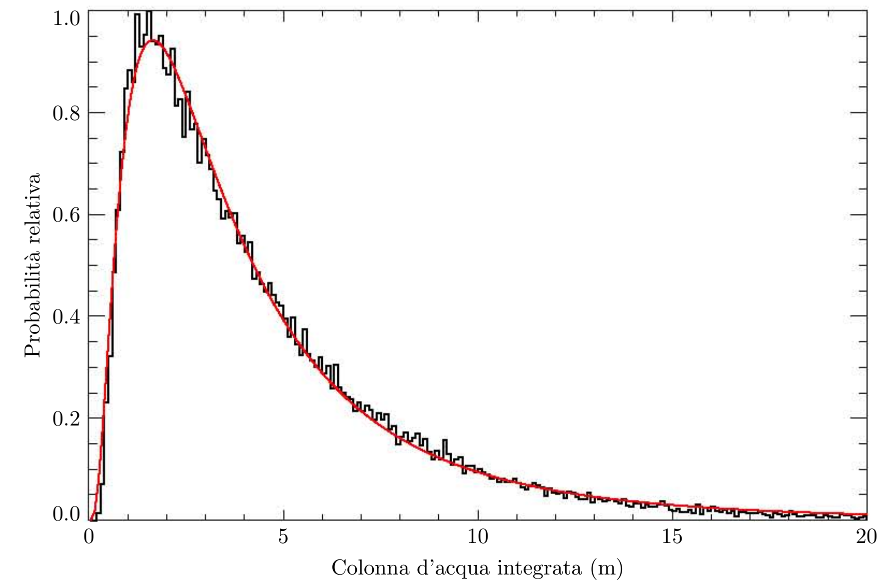


Figura 4.1: Istogramma dei valori della colonna d'acqua. In rosso è rappresentata la curva di fit con andamento log-normale.

Il numero di conteggi inizialmente presente sull'ordinata è stato sostituito con una distribuzione di probabilità normalizzata sul valore di conteggi maggiore (posto quindi uguale a 1). Riportiamo i valori della colonna d'acqua ottenuti dalla simulazione:

$$W \text{ (valor medio)} = 4.38 \text{ m} ,$$

$$W \text{ (mediana)} = 3.32 \text{ m} ,$$

$$\sigma = 2.77 \text{ m} . \tag{4.1}$$

il fit migliore dell'istogramma è dato dalla curva log-normale; la distribuzione log-normale con cui abbiamo fittato l'istogramma presenta una sigma molto alta, cosa che del resto si riscontra nella σ dei nostri dati (eq. 4.1).

Plot for 1cm precipitable liquid water

Air is blue

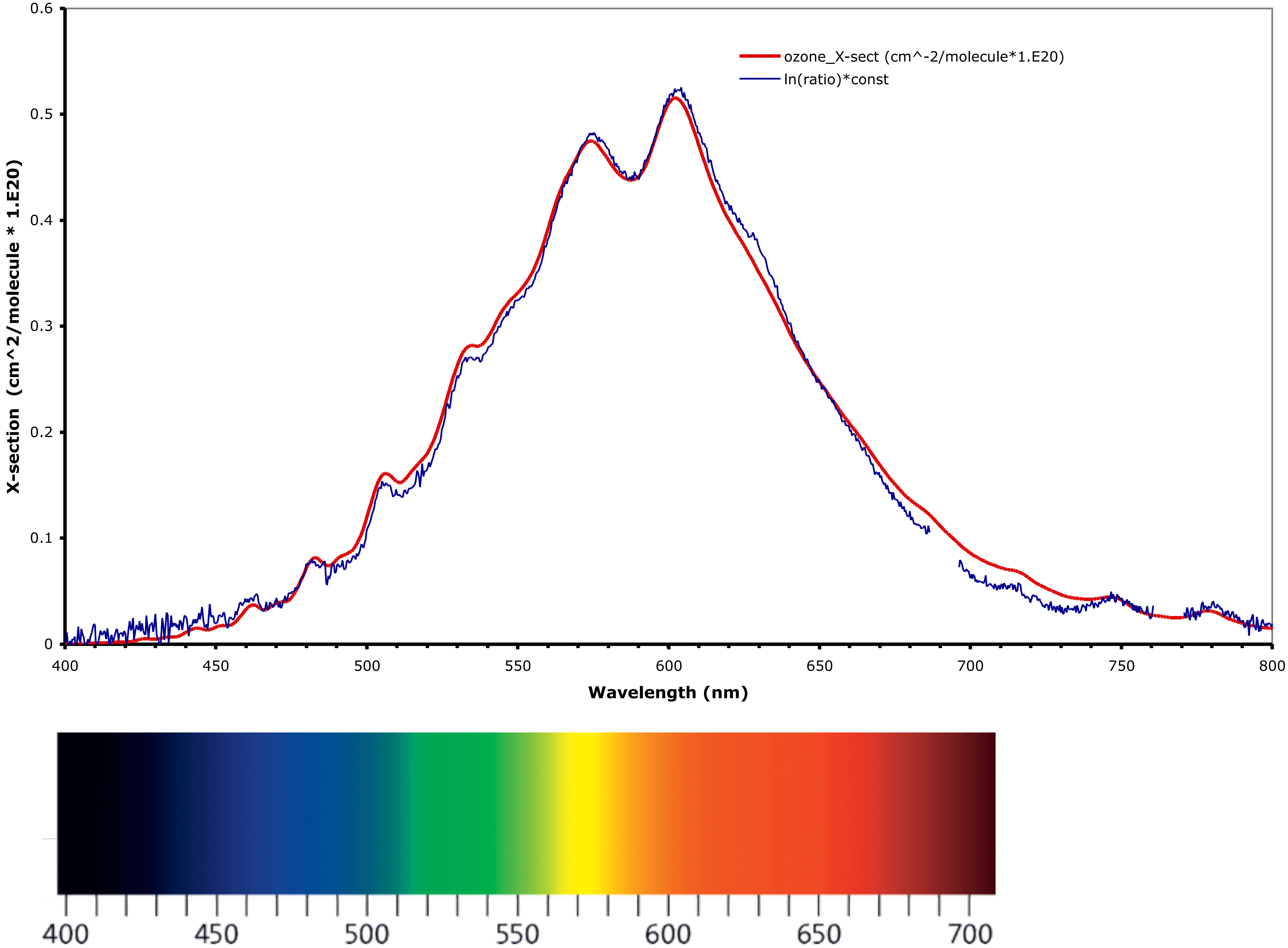
Yes, we all know the clear sky is blue because of Rayleigh scattering from molecules and density fluctuations, but air **is** actually blue as well!

This is because of ozone, the unstable allotrope of oxygen, which exists mostly between 15 and 40 km altitude in the atmosphere

Rayleigh scattering blue

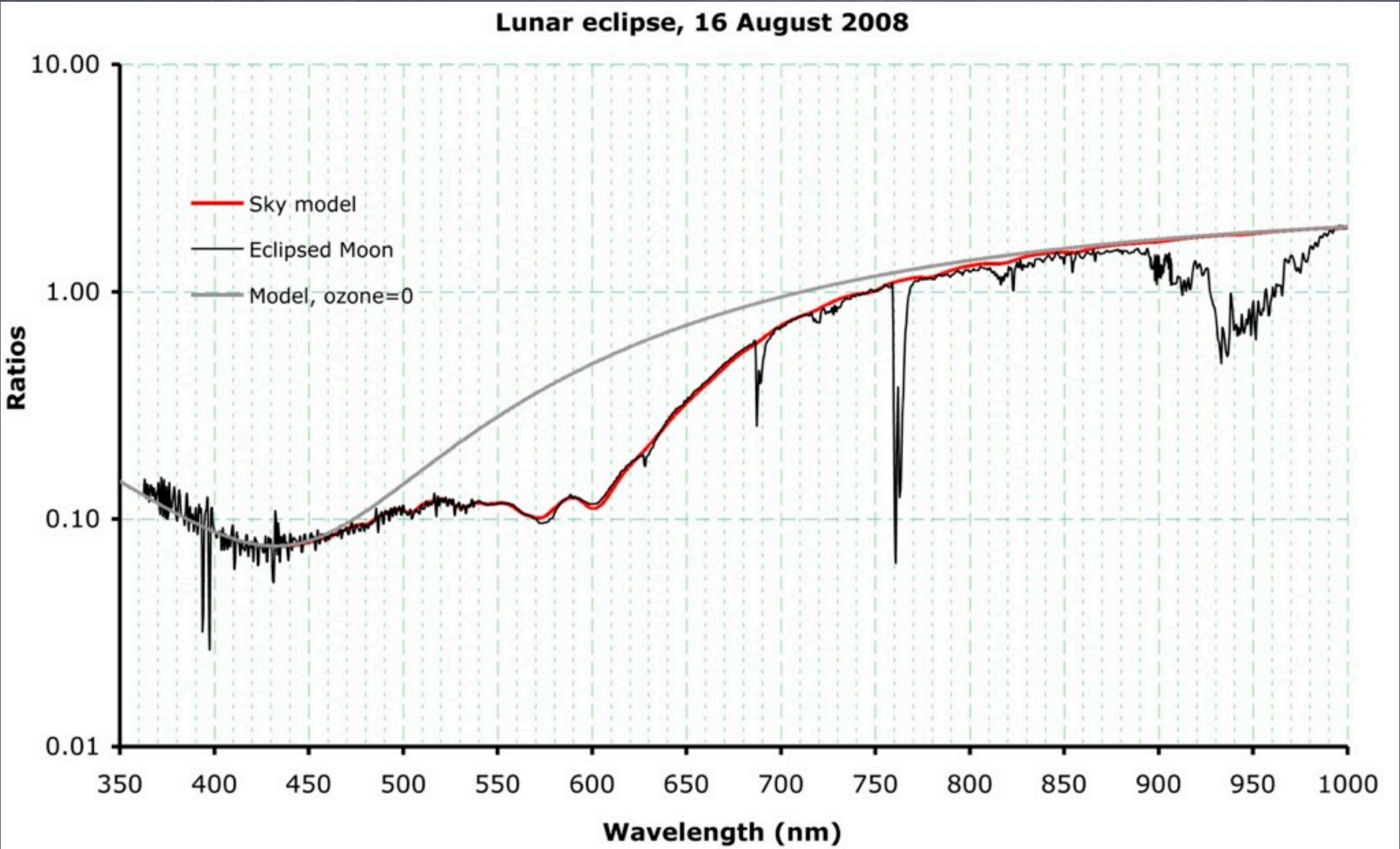

Rayleigh scattering blue
Mie scattering
white

The Chappuis band of ozone

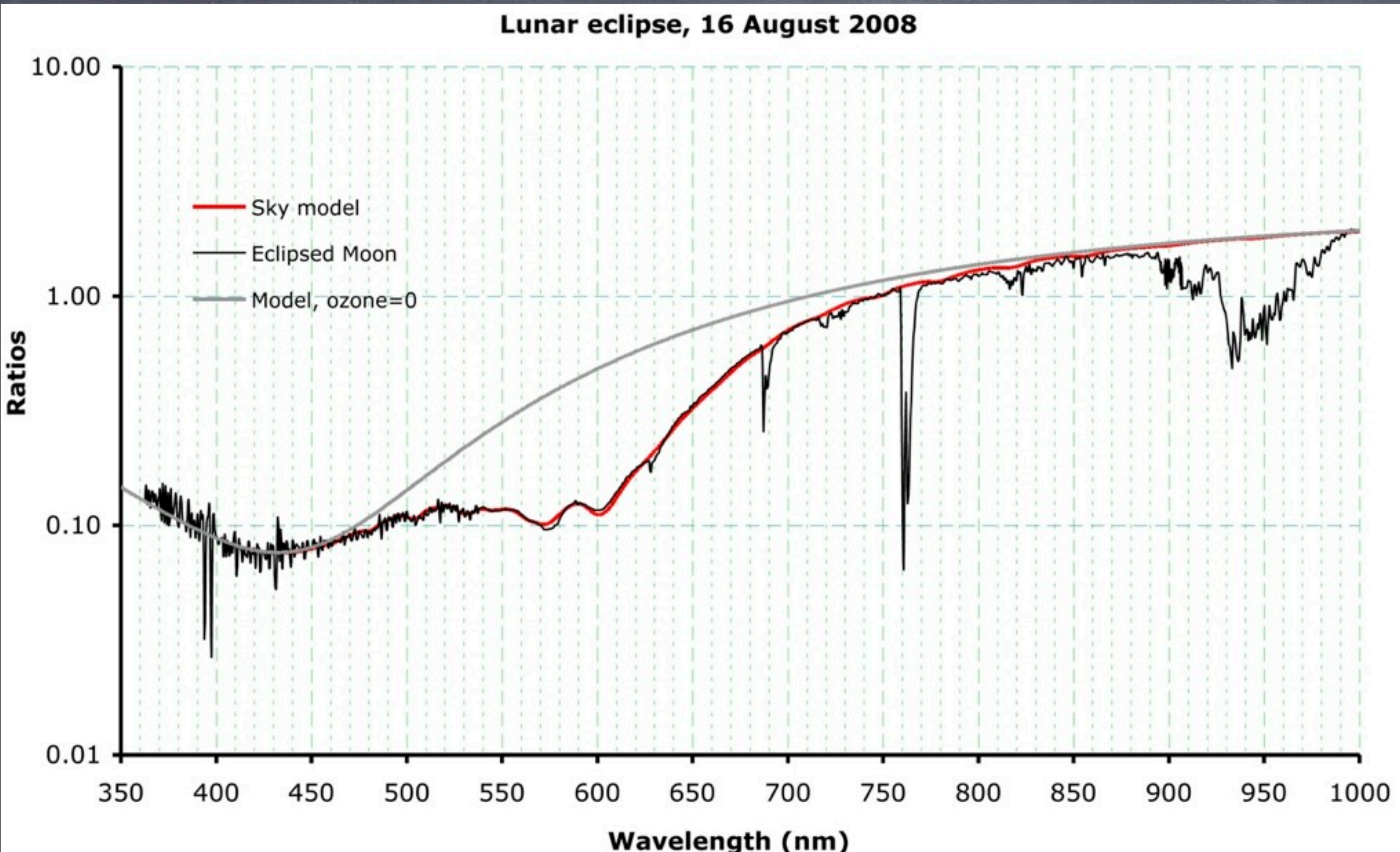



This is the sky seen by the eclipsed Moon
at the boundary of the umbra/penumbra

Thanks to Zolt Levay



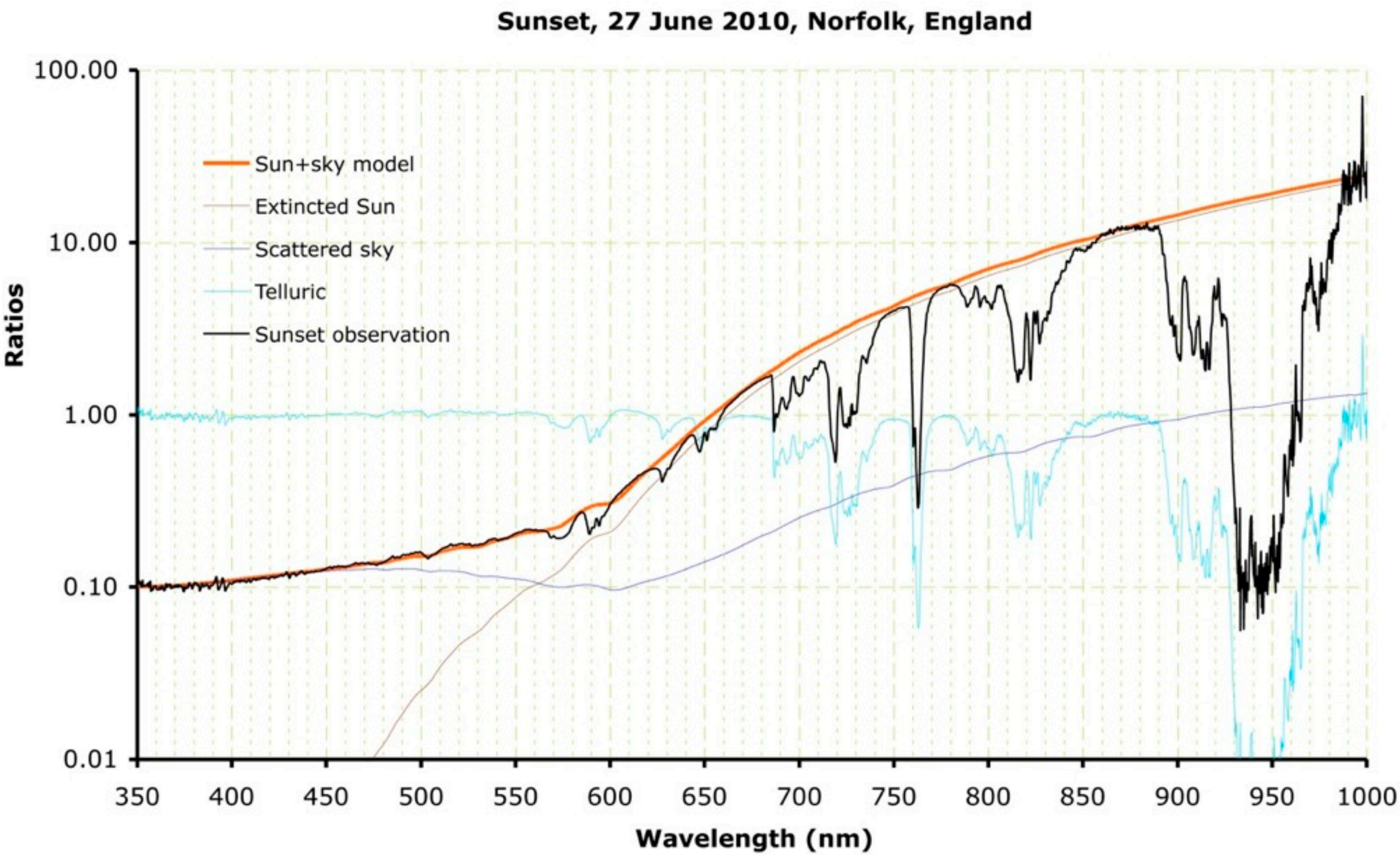
Lunar eclipse, 16 August 2008
Sky model
Eclipsed Moon
Model, ozone=0
Ratios
10.00
1.00
0.10
0.01
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
Wavelength (nm)



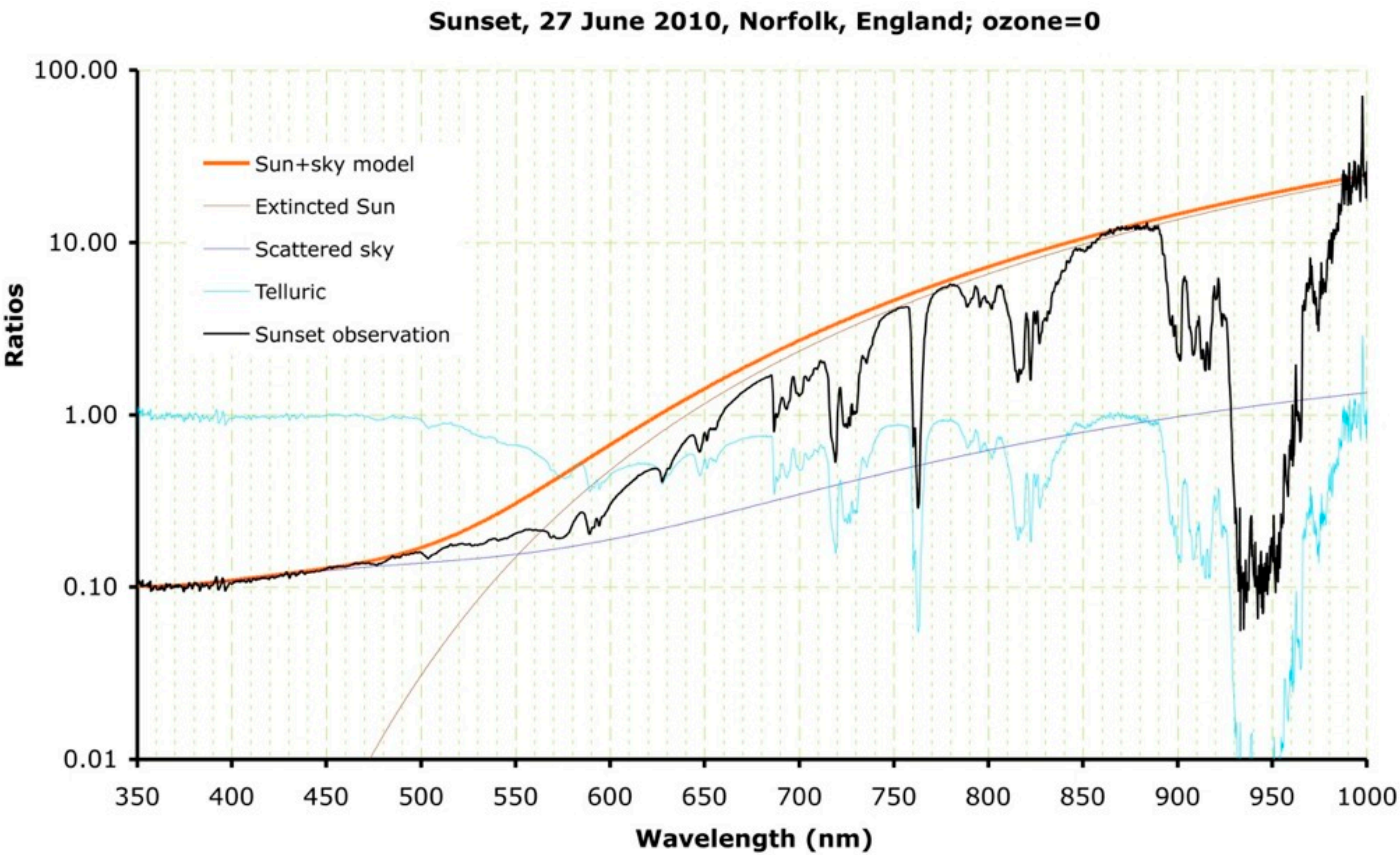
Data from Enric Pallé


Spectrometer input aperture

Sunset spectra



Sunset spectra

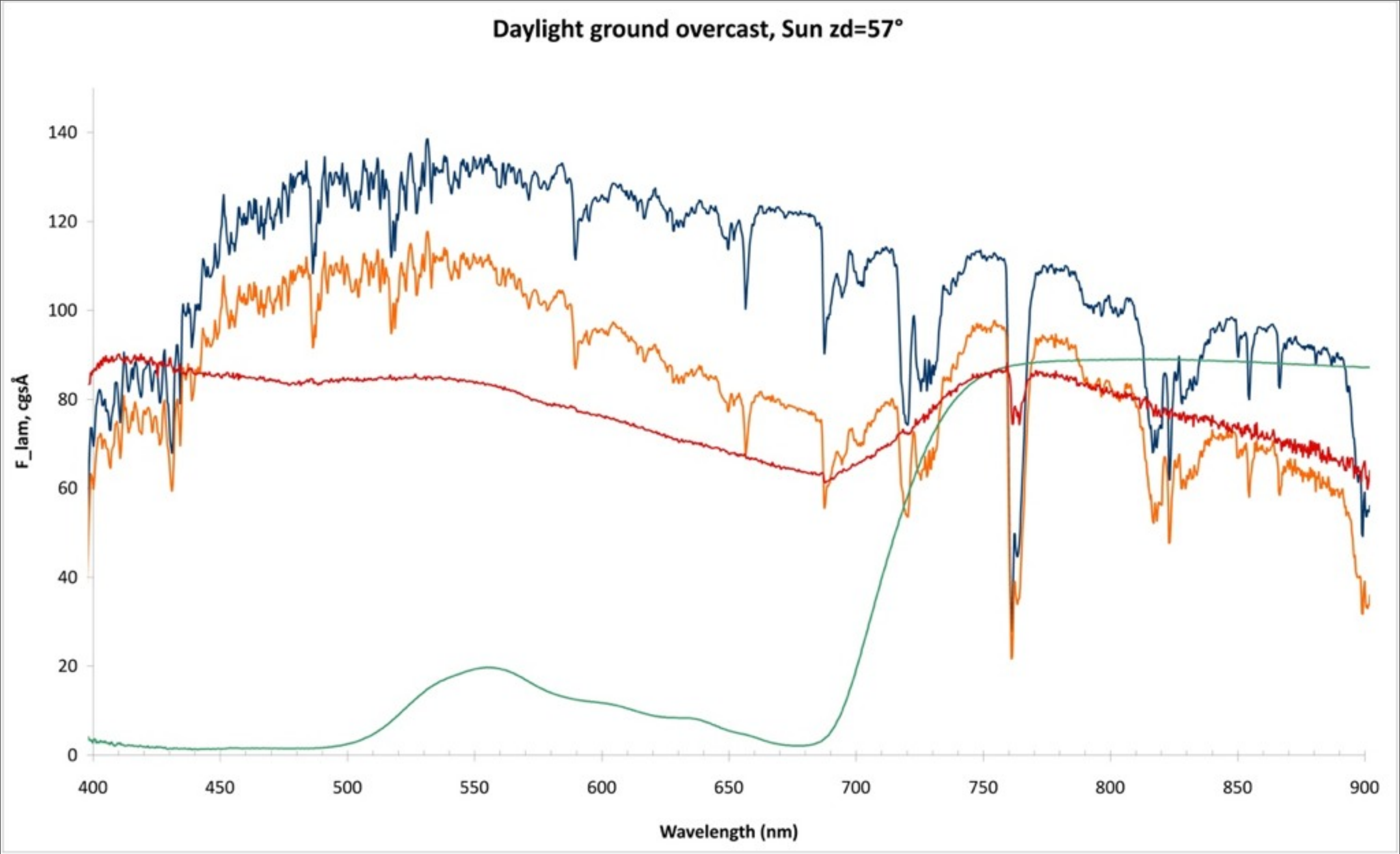


Sunset sky (model)

No ozone

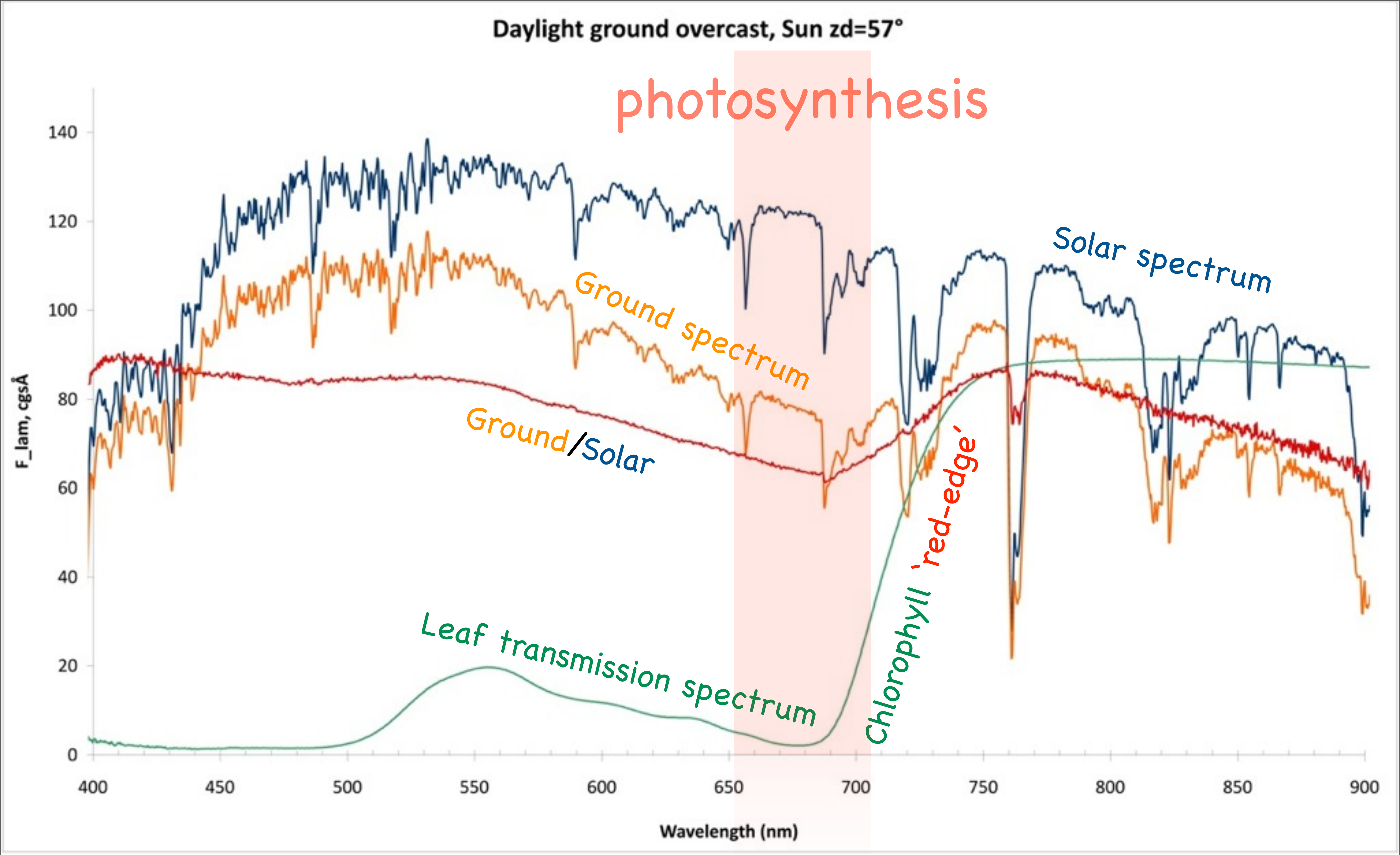
The Green Planet

Chlorophyll in action



Spectrum of the ground: mixed buildings, grass and trees

Seeing the chlorophyll 'red-edge'



Spectrum of the ground: mixed buildings, grass and trees
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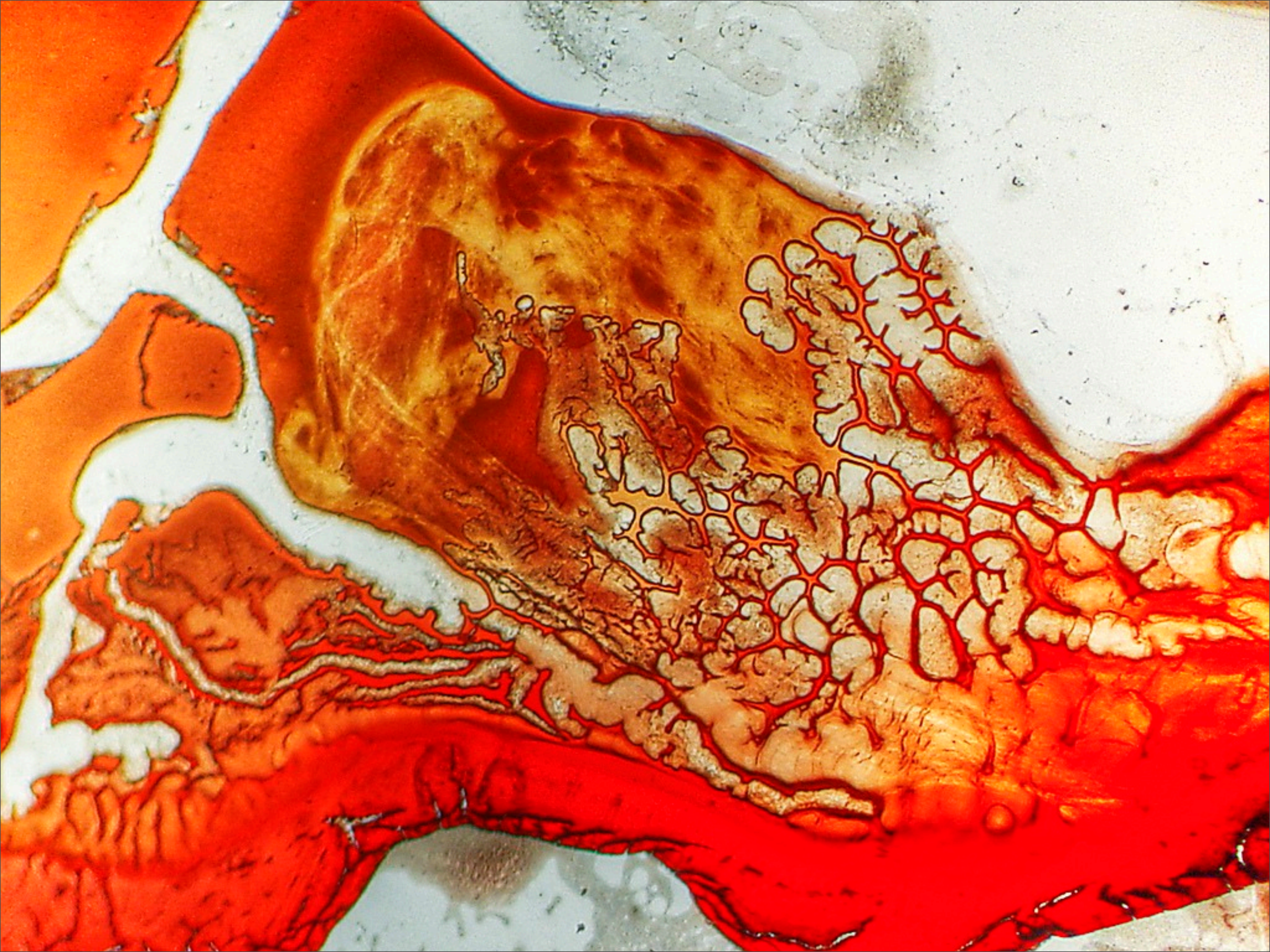
Seeing the chlorophyll 'red-edge'

Natural colours on Earth

Chlorophyll, like haemaglobin, is a 'porphyrin' and there are other examples of this class that produce colours we see

The brown of a hen's eggshell is actually a white matrix speckled with purple protoporphyrin and, like chlorophyll, fluoresces red under UV light

Seaweeds contain auxiliary pigments that transfer energy from underwater (mostly blue!) photons to the photosynthetic mechanisms in chlorophyll



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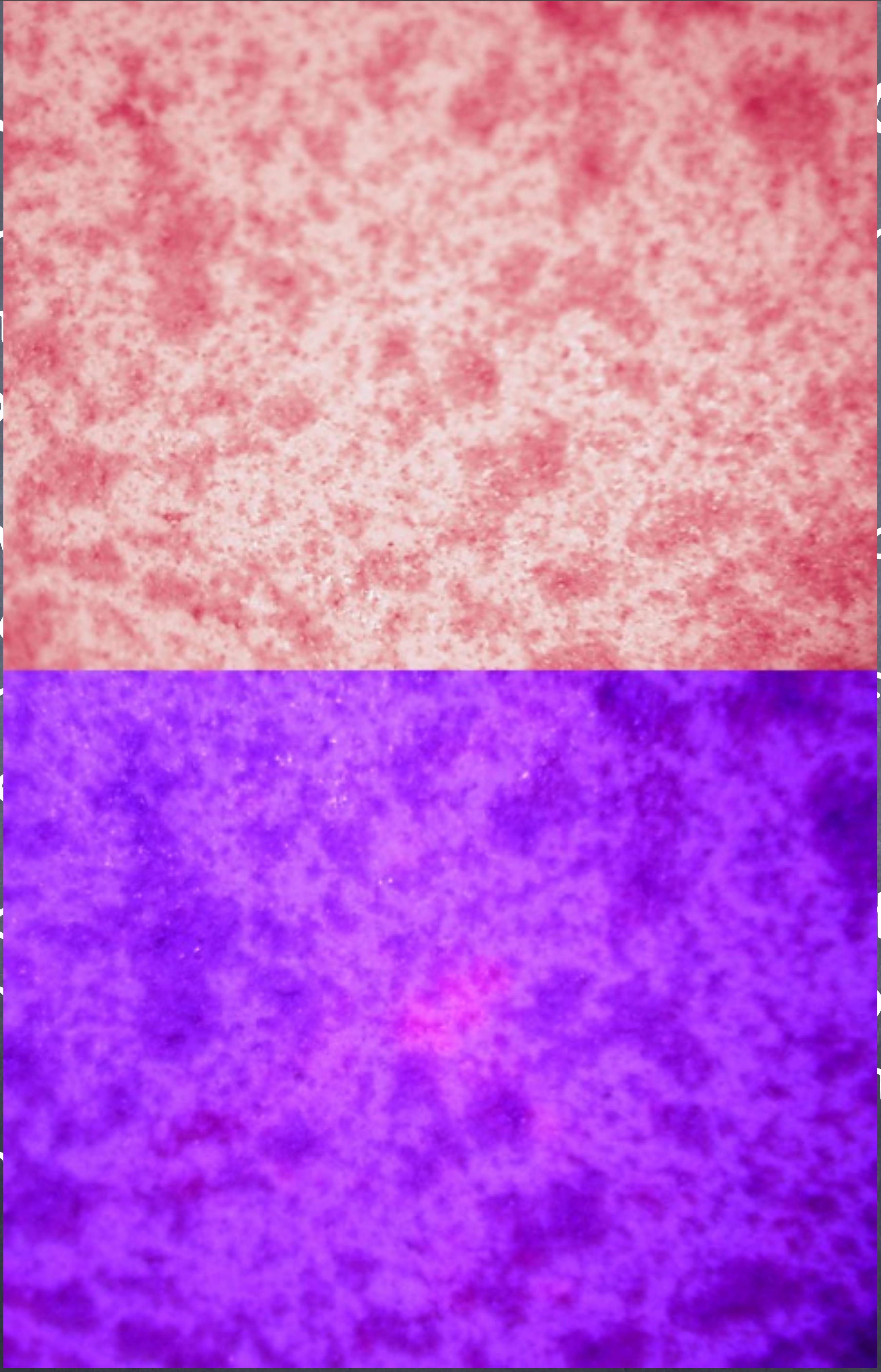

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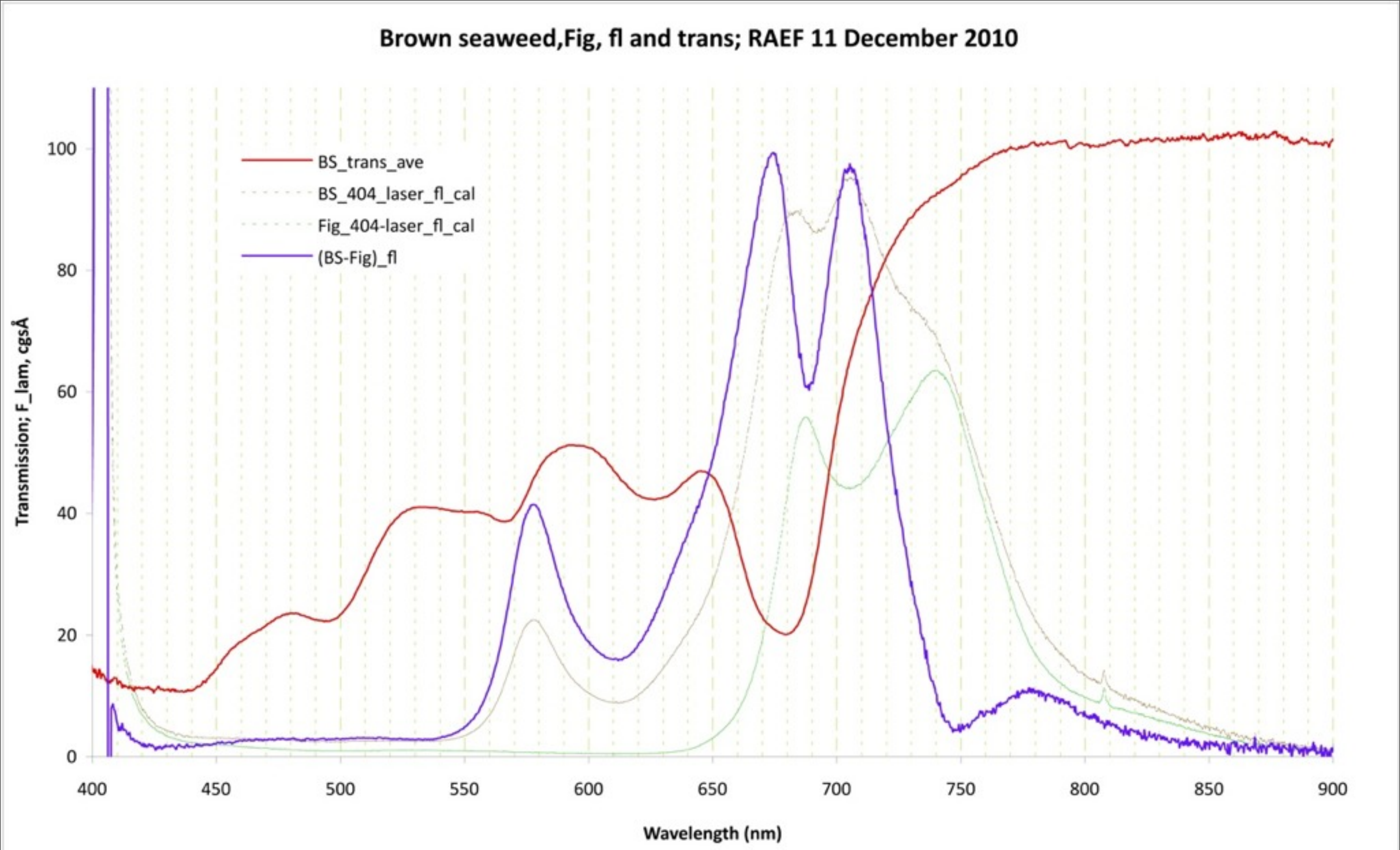
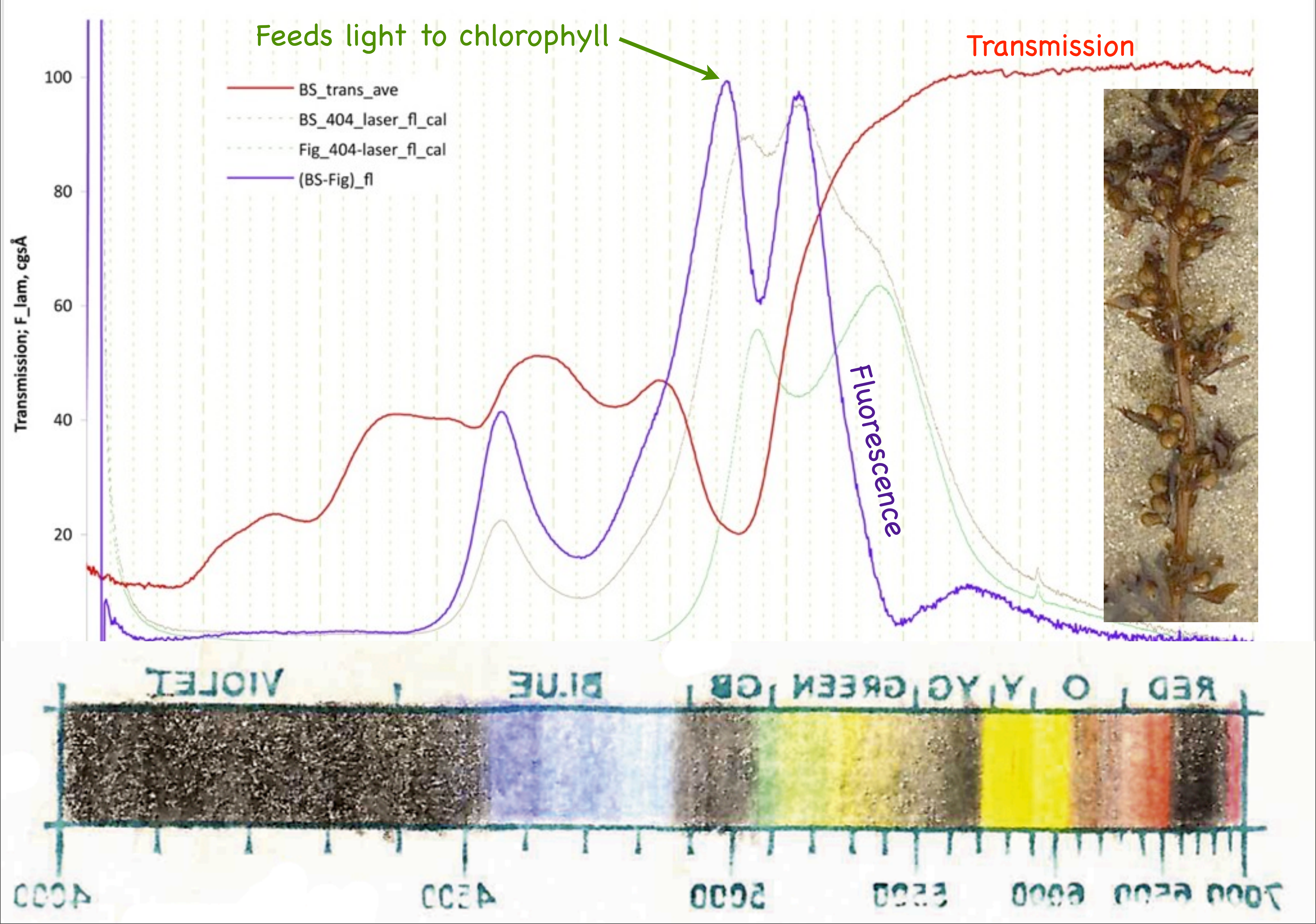


Brown seaweed with phycoerythrin and chlorophyll

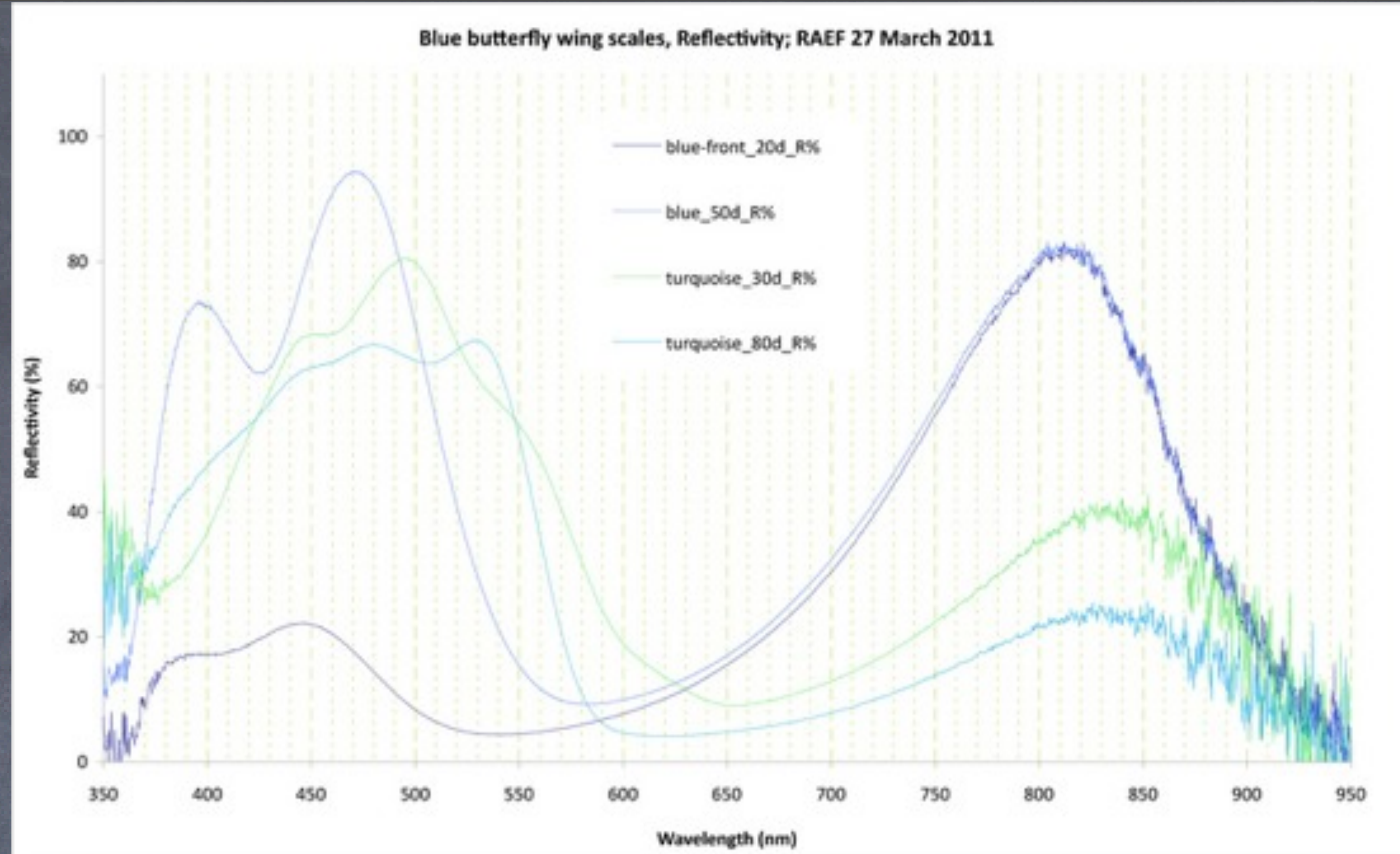
Brown seaweed,Fig, fl and trans; RAEF 11 December 2010

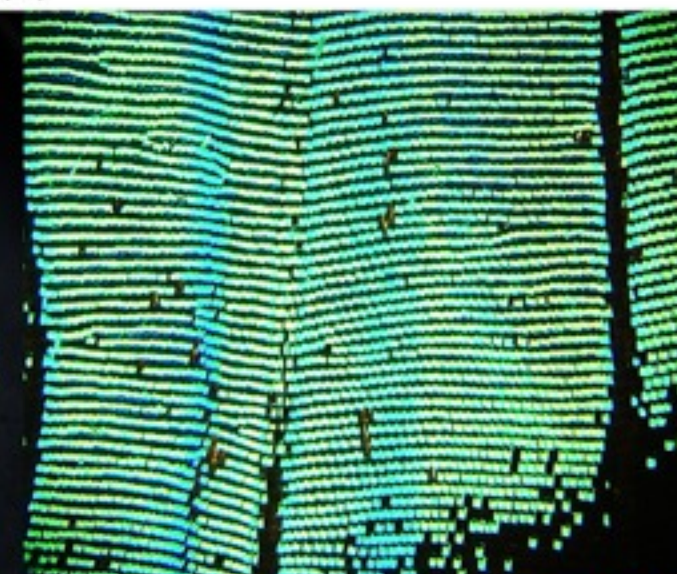


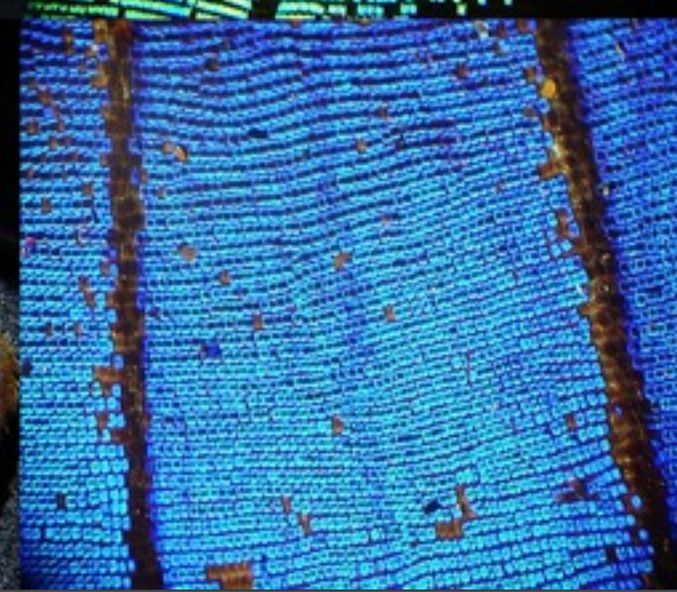
Animal blues

Many animal blues are not caused by pigments but are ‘structural‘ — basically Tyndall (Rayleigh) scattering and/or interference phenomena

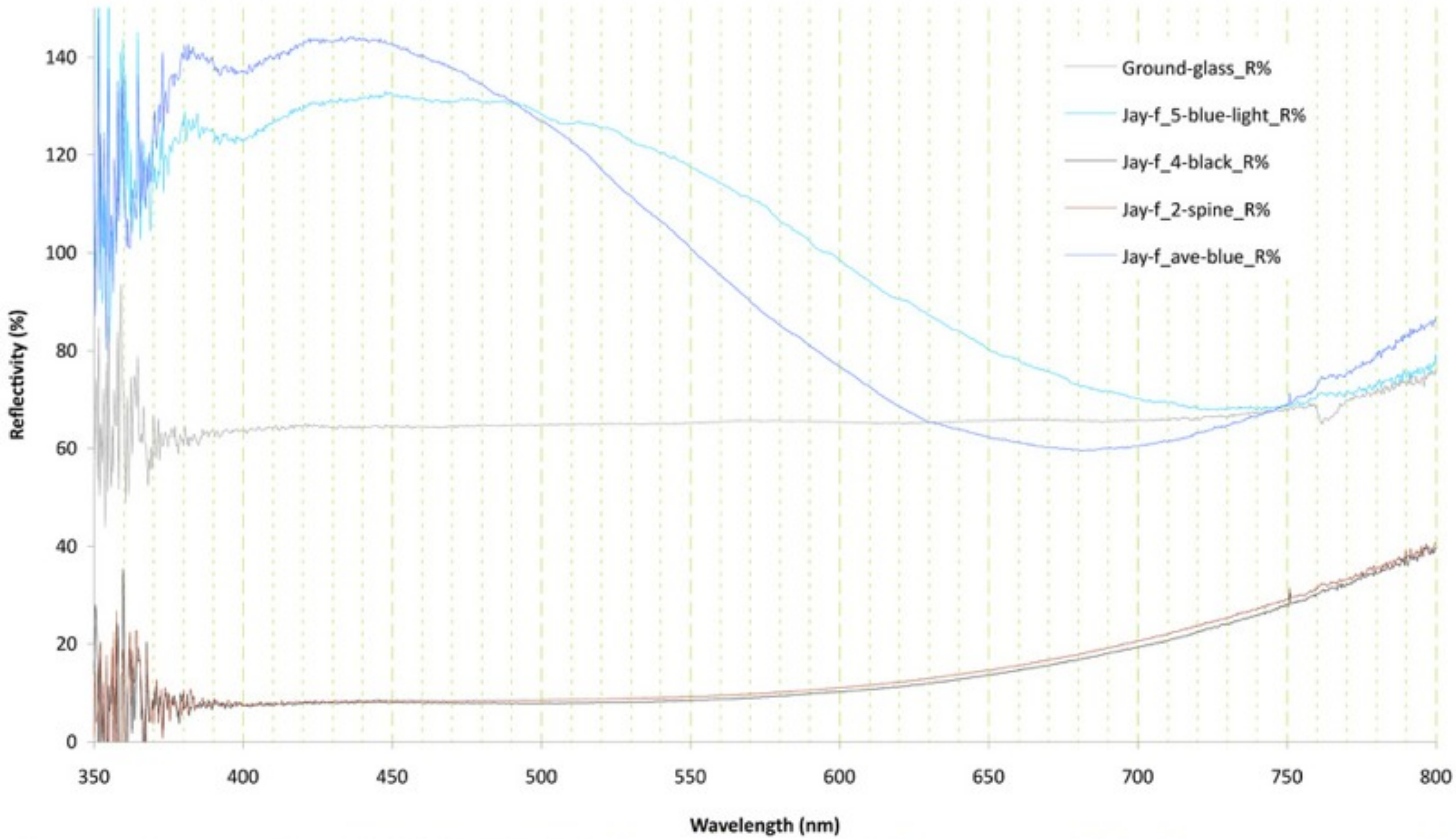
Animal blues


Blue butterfly wing scales, Reflectivity; RAEF 27 March 2011
blue-front_20d_R%
blue_50d_R%
turquoise_30d_R%
turquoise_80d_R%
Reflectivity (%)
0
20
40
60
80
100
350
400
450
500
550
600
650
700
750
800
850
900
950
Wavelength (nm)

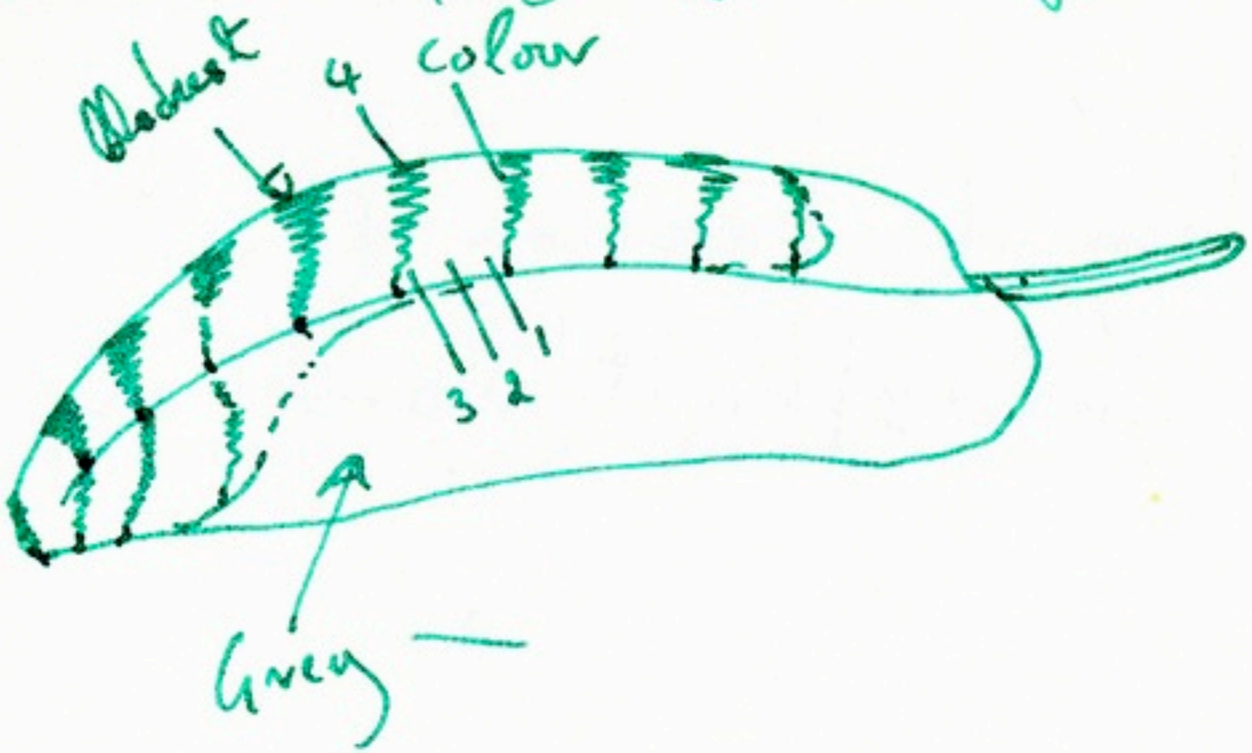




Jay's feather reflectivity; RAEF 26 March 2011

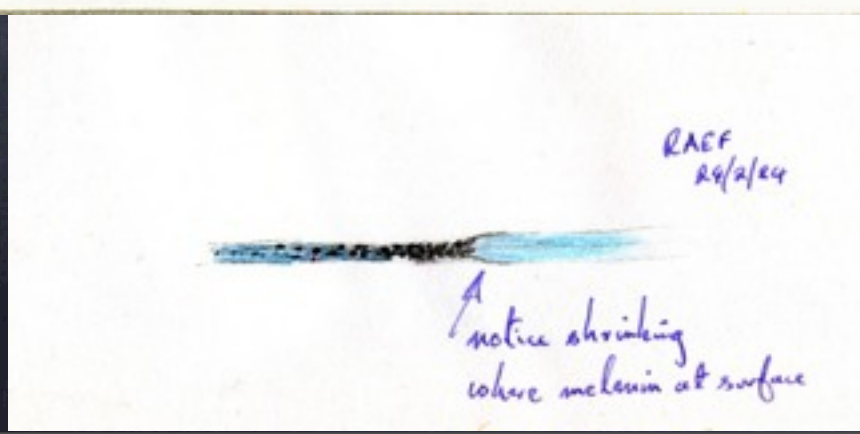


13/9/81 Jay's feather found by Richard Bingham. 99

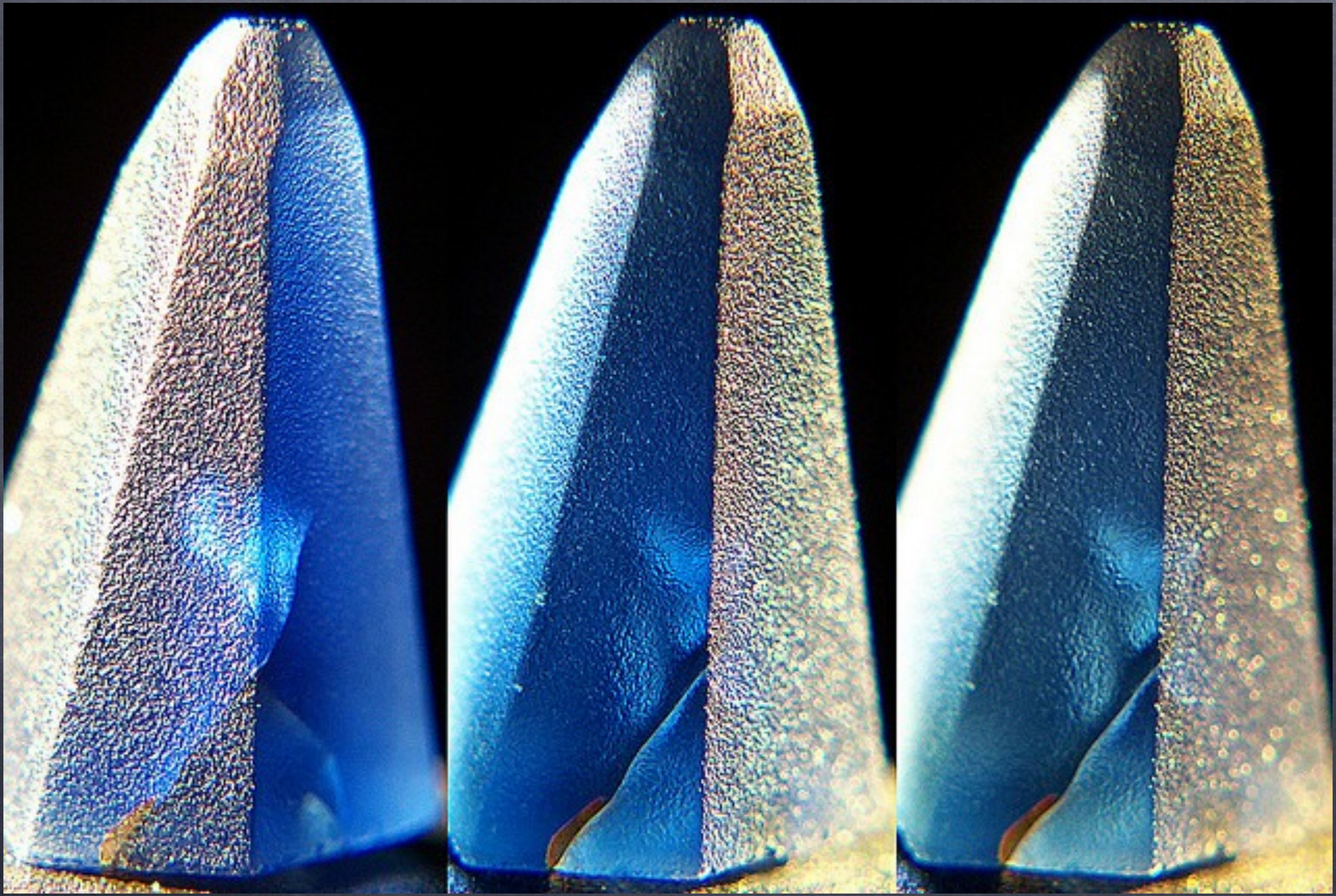


1. light sky-blue
2. medium blue
3. dark blue
4. tar-black.

Uniform Tyndall scattering medium. Gradation of colour caused by increase near surface of black melanin blobs.

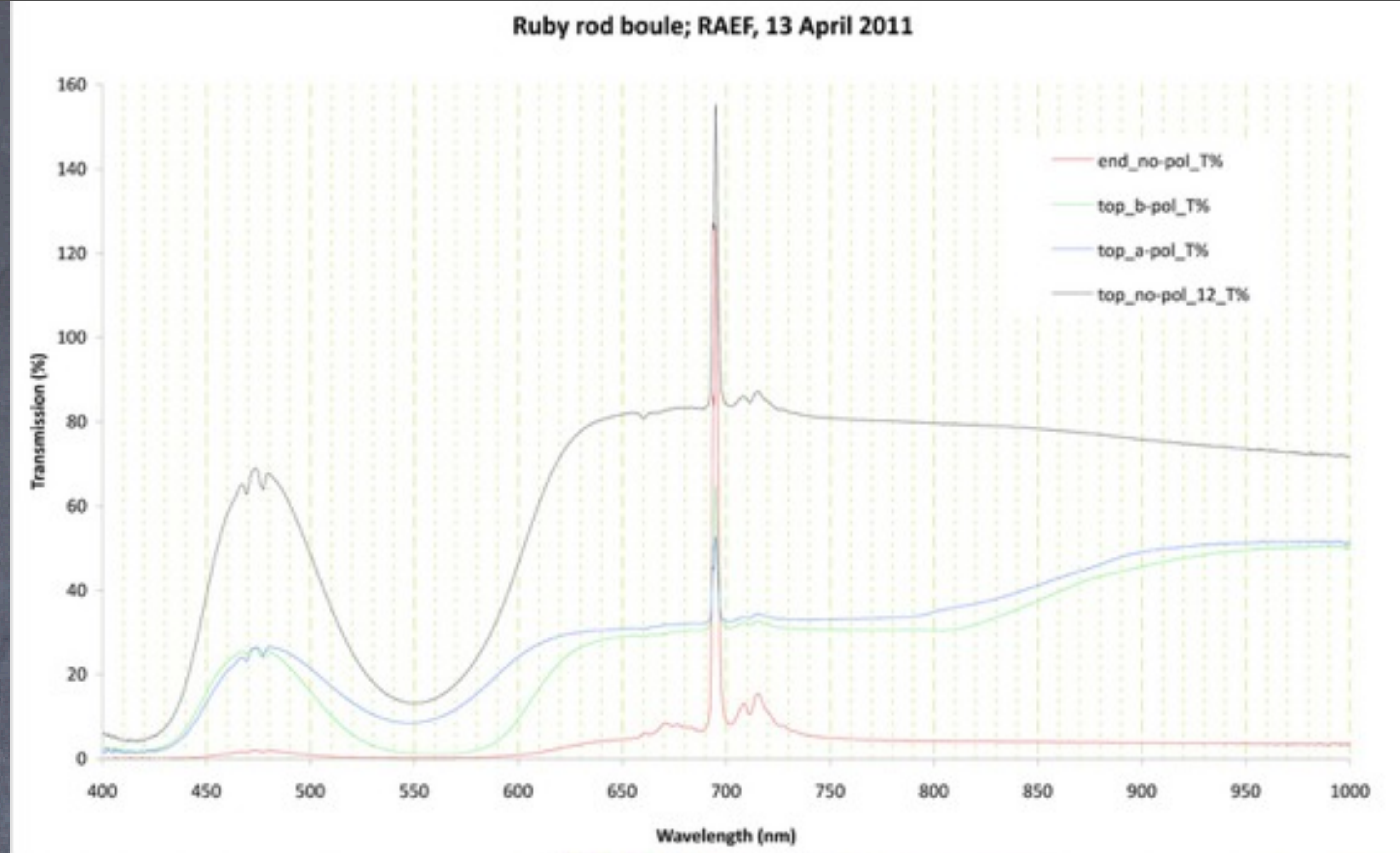


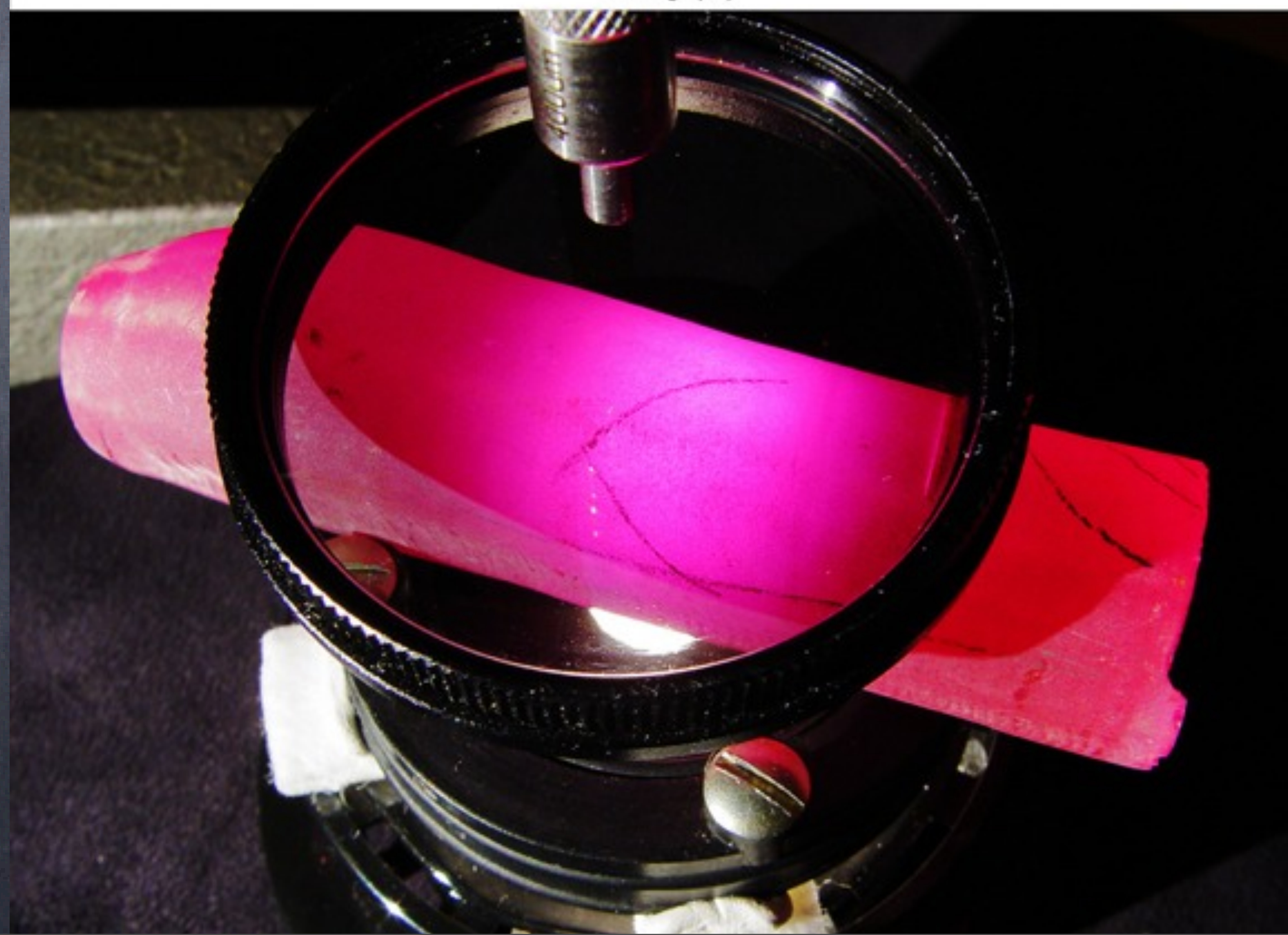
Solids (gemstones)

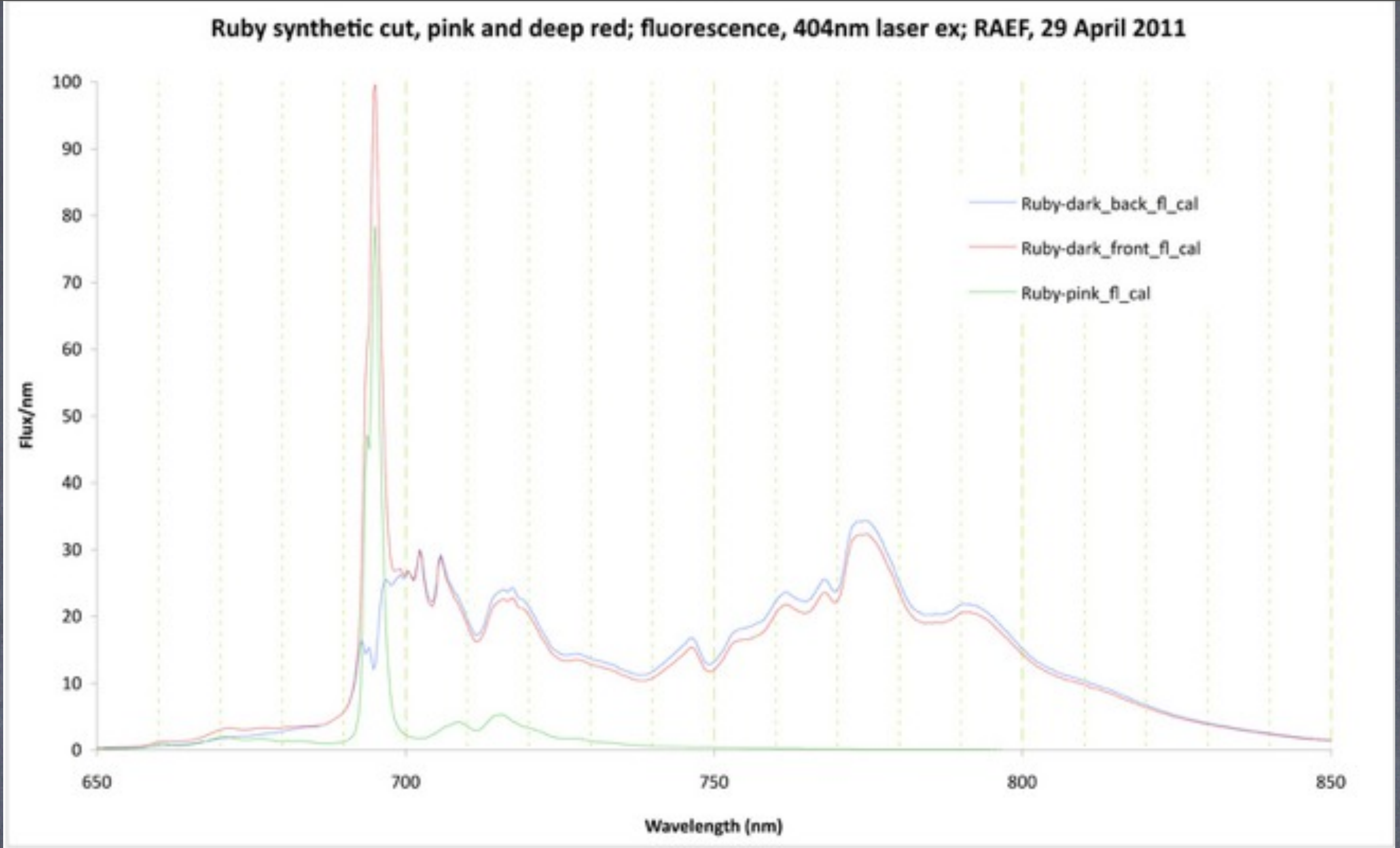


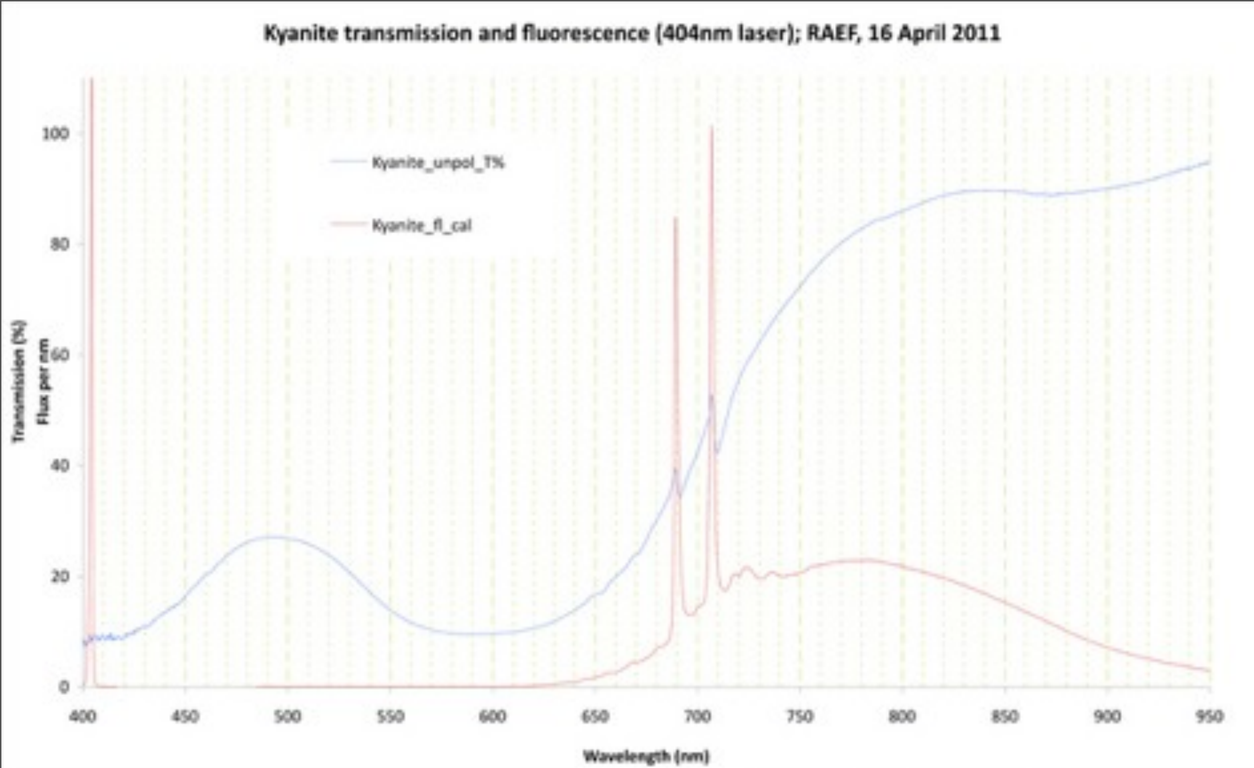
Solids (gemstones)

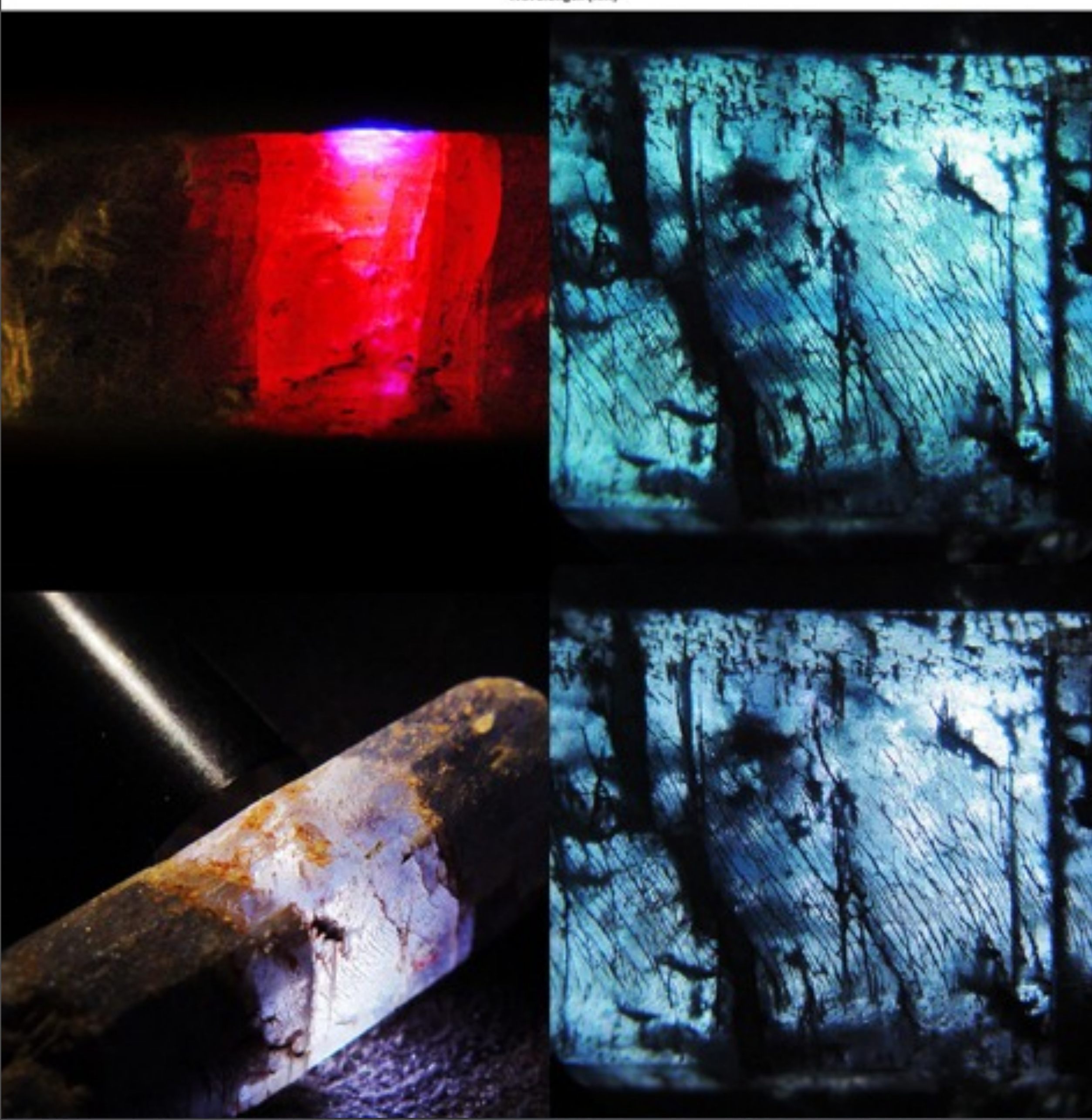
Different mechanisms produce colour in solids – sometimes this is intrinsic to the basic material but is often due to 'impurities'. The most famous is the role of impurity chromium in ruby, emerald, spinel, kyanite etc. where the surrounding crystal structure generates a ligand field that allows optical transitions. Transitions from metastable levels can lase (the ruby laser)

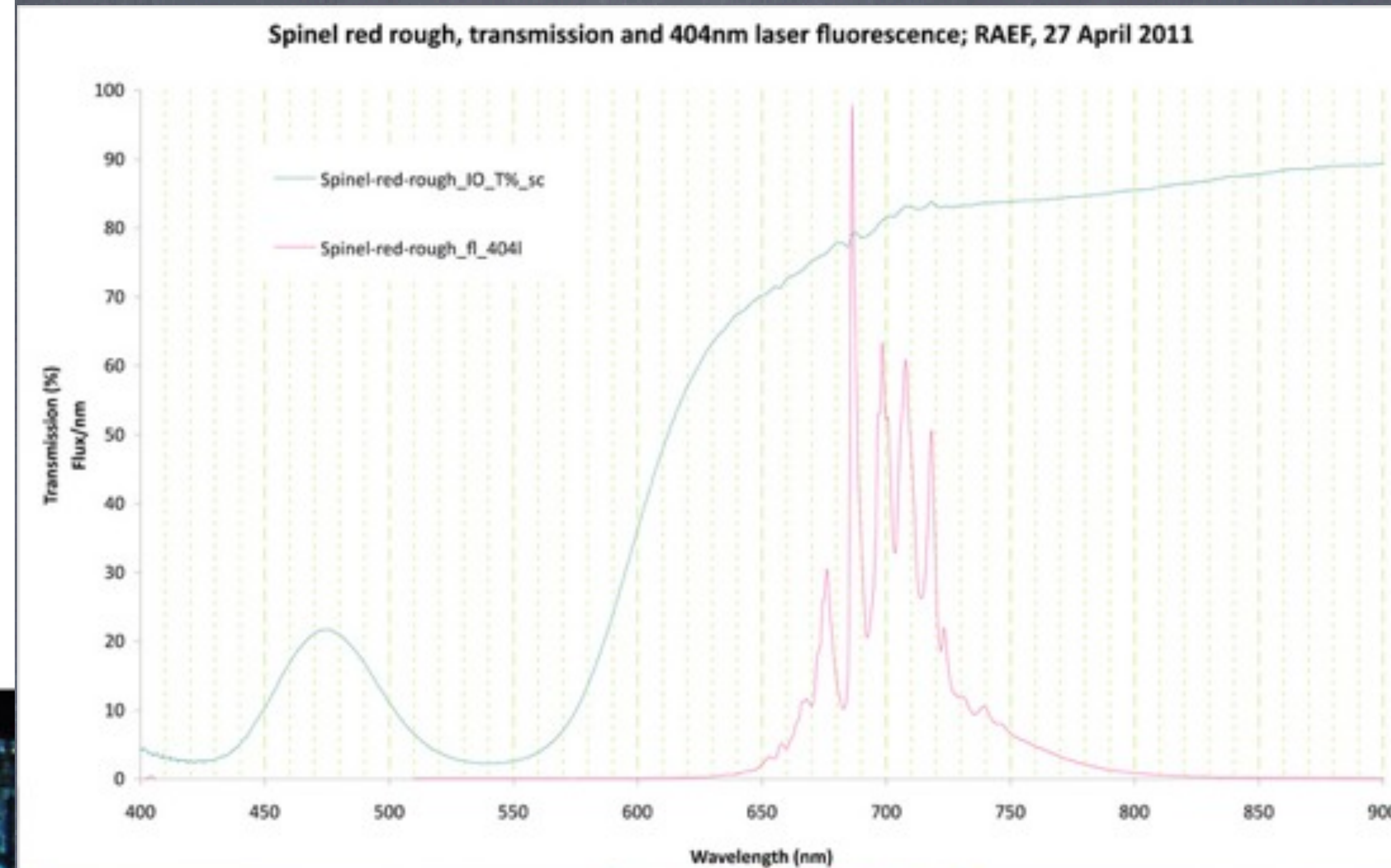

Ruby rod boule; RAEF, 13 April 2011
Transmission (%)
160
140
120
100
80
60
40
20
0
400
450
500
550
600
650
700
750
800
850
900
950
1000
Wavelength (nm)
end_no-pol_T%
top_b-pol_T%
top_a-pol_T%
top_no-pol_12_T%




Ruby synthetic cut, pink and deep red; fluorescence, 404nm laser ex; RAEF, 29 April 2011
Ruby-dark_back_fl_cal
Ruby-dark_front_fl_cal
Ruby-pink_fl_cal
Flux/nm
Wavelength (nm)
0
10
20
30
40
50
60
70
80
90
100
650
700
750
800
850


Kyanite transmission and fluorescence (404nm laser); RAEF, 16 April 2011
Kyanite_unpol_T%
Kyanite_fl_cal
Transmission (%)
Flux per nm
Wavelength (nm)
0
20
40
60
80
100
400
450
500
550
600
650
700
750
800
850
900
950

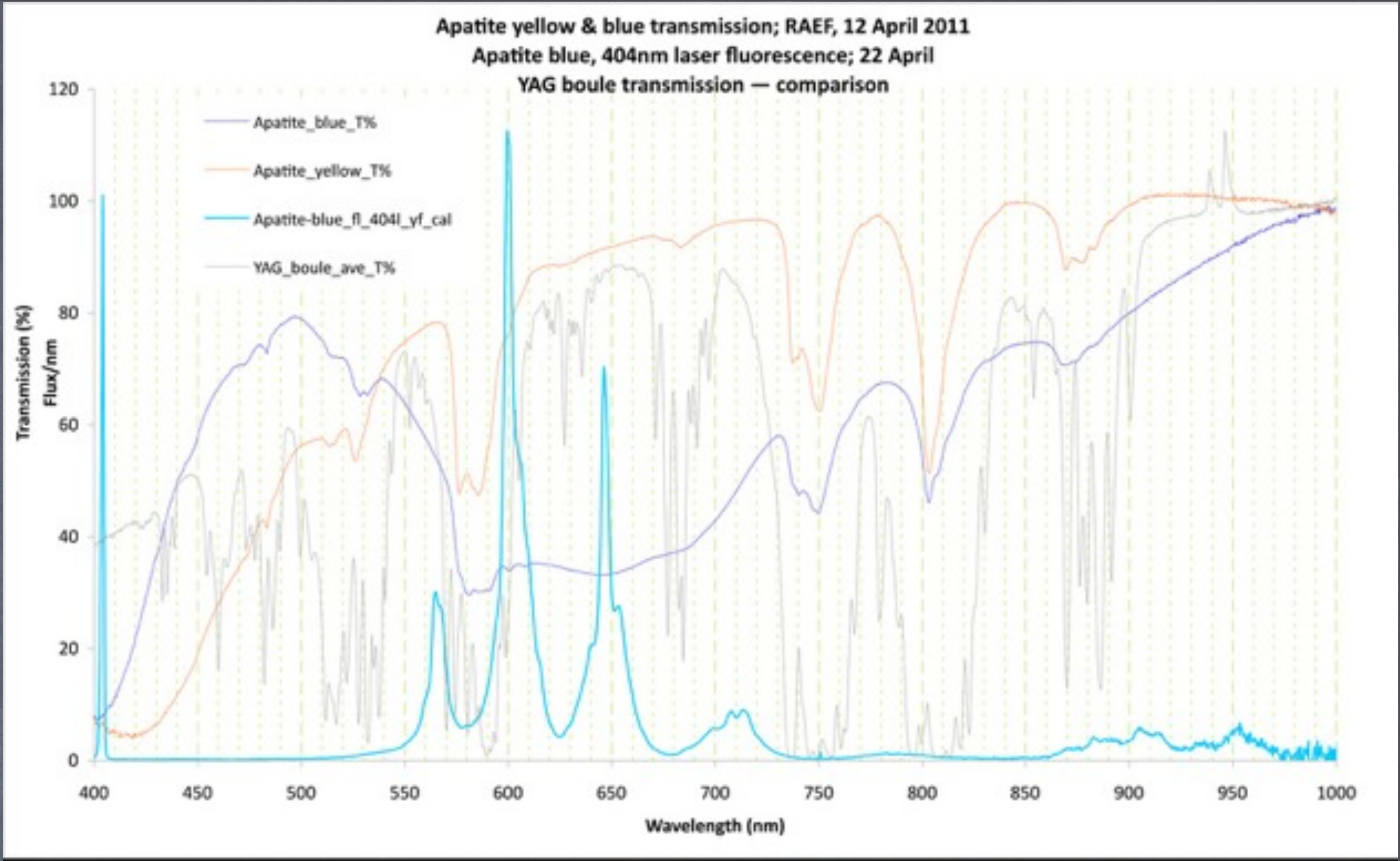



Spinel red rough, transmission and 404nm laser fluorescence; RAEF, 27 April 2011
Spinel-red-rough_IO_T%_sc
Spinel-red-rough_fl_404l
Transmission (%)
Flux/nm
Wavelength (nm)
0
10
20
30
40
50
60
70
80
90
100
400
450
500
550
600
650
700
750
800
850
900

Apatite (calcium phosphate - Chloride Fluoride Hydroxide) contains rare earths (eg. neodymium) that make inner-shell transitions and produce rich absorption spectra. The Nd^3+ emits the strong NIR fluorescence lines that are exploited in Nd YAG lasers

The transmission spectrum of YAG is shown as the faint grey line

There is lots of apatite in your bones and teeth



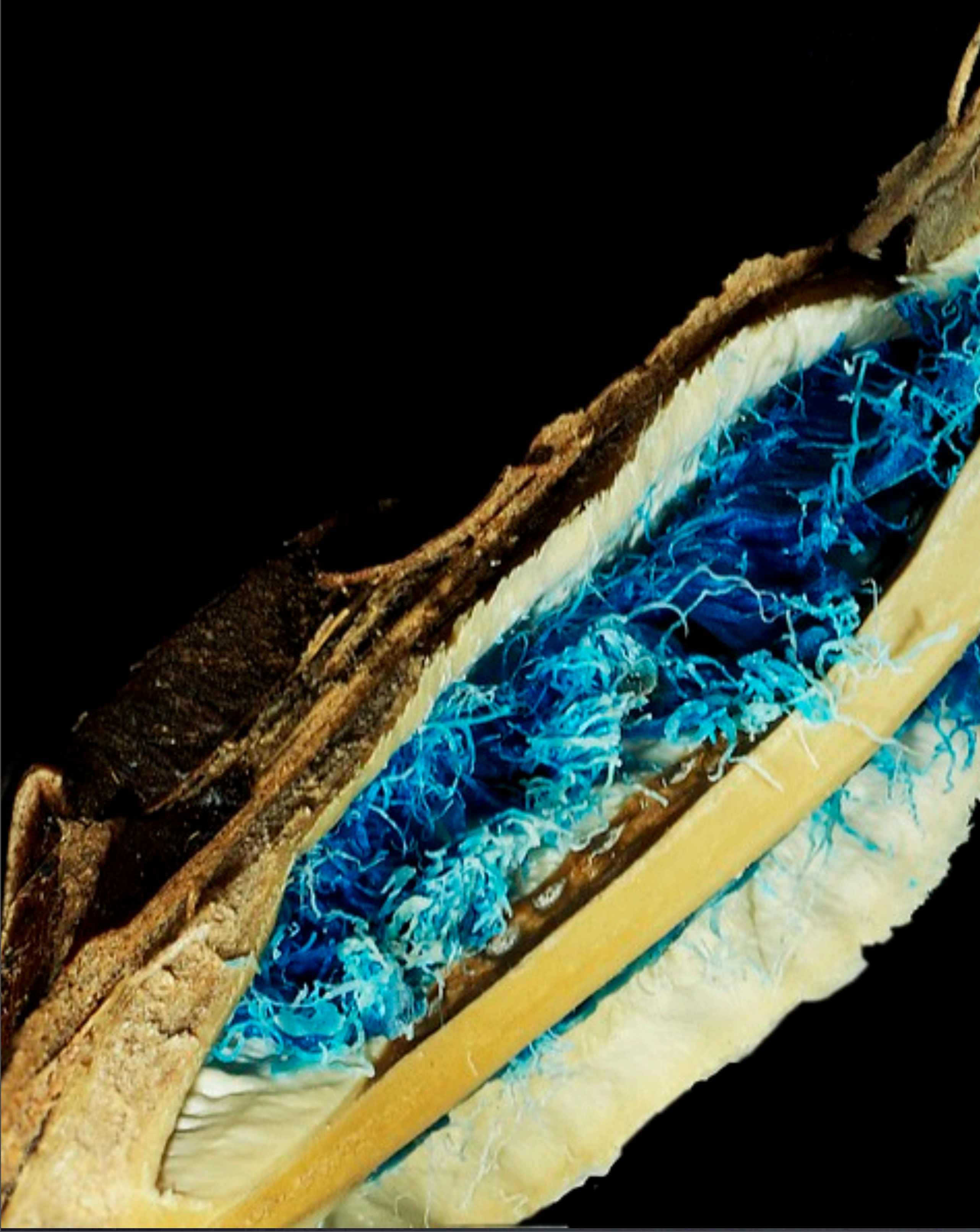
The effect of decades of desert sunlight on glass containing manganese and iron

This old glass telephone insulator was found on a fallen (unused!) telegraph pole by Trish on a trip from Parkes to Sydney

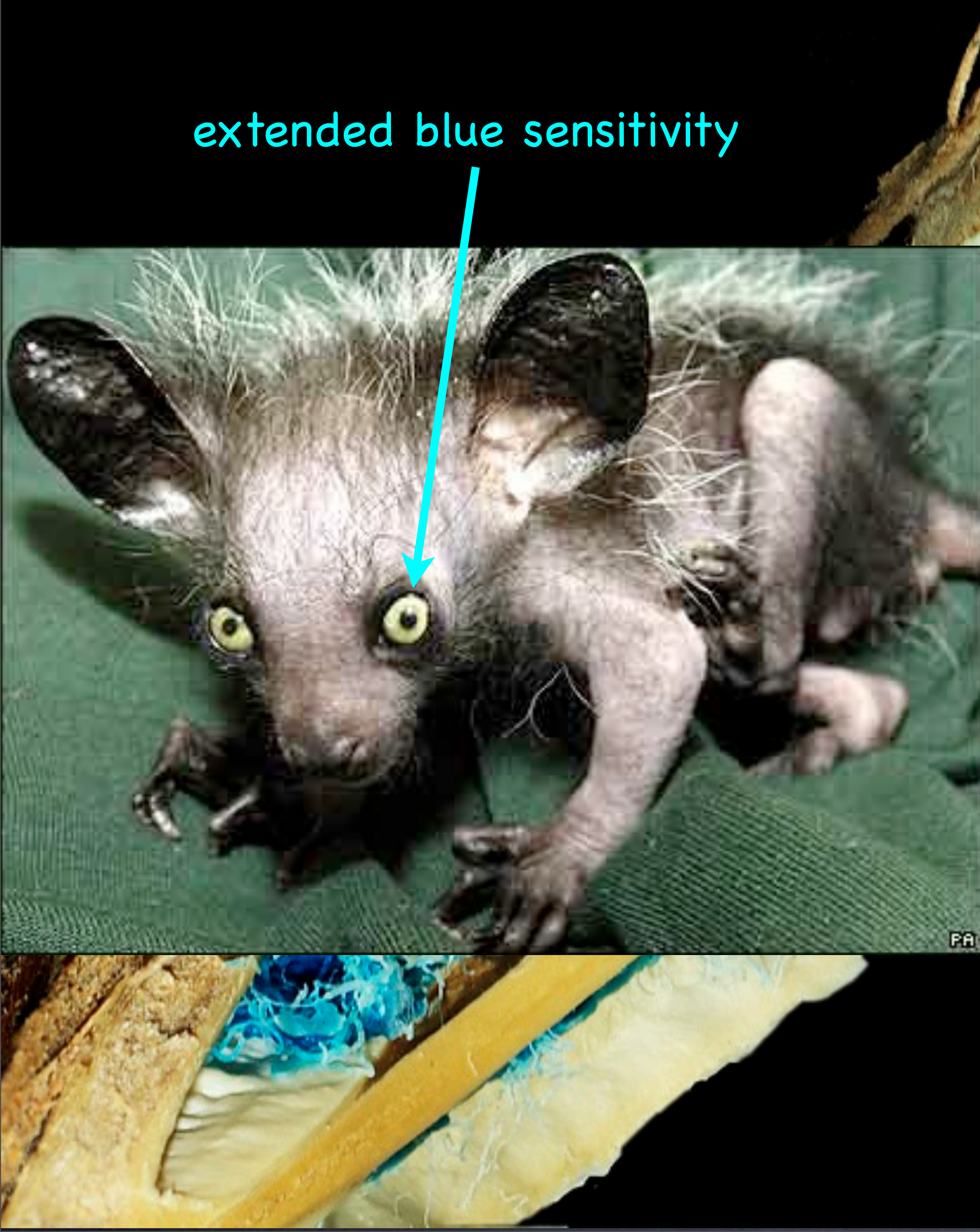
The colour (purple with high transparency in the blue) is from UV-induced colour-centres similar to those in adaptive spectacles

Ravenala Madagascariensis
A ‘new’ blue

Ravenala Madagascariensis
A 'new' blue



Ravenala Madagascariensis
A 'new' blue

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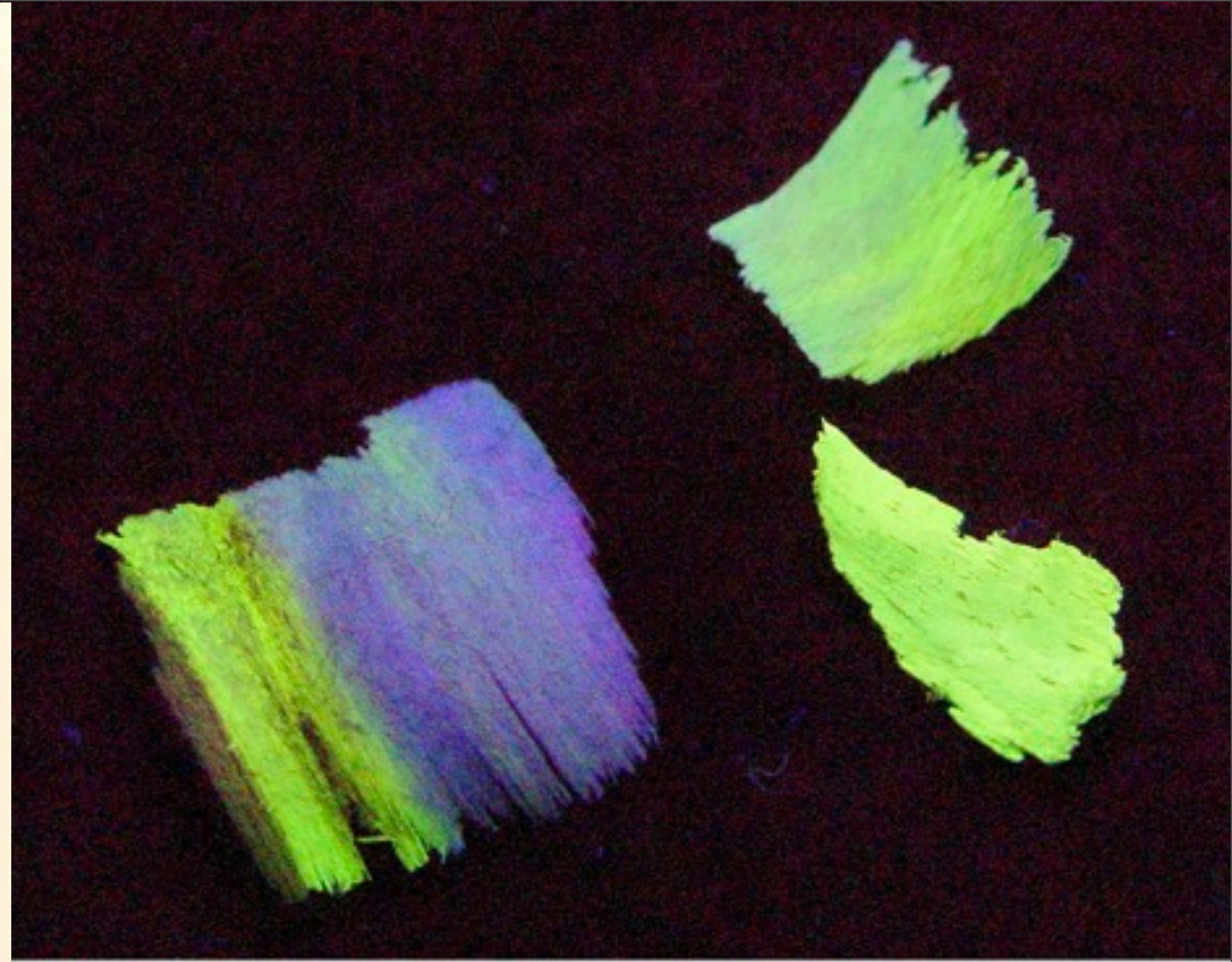

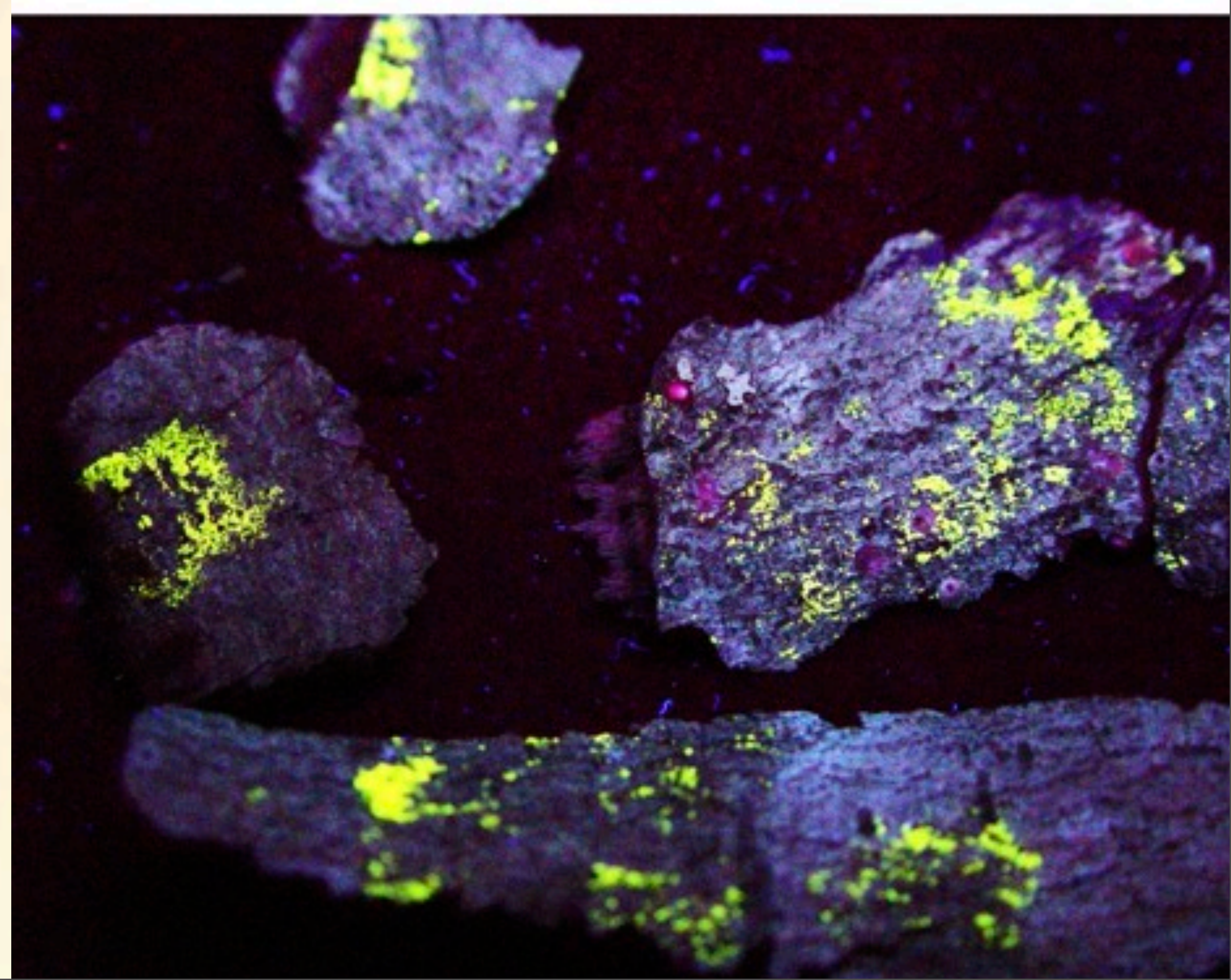

The colours discussed in the first part of the talk are (and will be) important for characterising exo-Earths. It may be a while, however, before the later examples become of interest to astrophysicists (except to me of course!)

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ho of
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co