SPECTROSCOPY WITH DARWIN: THE CASE FOR R > 100

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ABSTRACT

If DARWIN finds evidence for the existence of life on another Earth-like planet the response from the general public will be phenomenal. To infer the presence of life DARWIN's mid-infrared spectrometer must detect the $\sim 9.3-10.1\mu$m Ozone (O_3) band and it is *essential* that this detection is reliable. The proposed spectral resolution of $R \sim 20-50$ is insufficient for this purpose. To distinguish unequivocally between Earth-, Mars- and Venus-like atmospheres DAWIN's 5-20μm resolution must be $R \sim 100-200$ ($\leq 0.1\mu$m) or higher.

Key words: DARWIN; MIR spectroscopy; life tracers; dust properties: silicates.

1. THE SPECTROSCOPIC CHALLENGE

After reading the DARWIN specifications for spectroscopy we decided to estimate the 5-20μm spectroscopic features that DARWIN would detect from nearby planetary atmospheres. We digitised MIR spectra of the Earth, Venus and Mars by Hanel et al. (1992) and binned them at DARWIN's proposed resolution of R=25 and R=50. A fourth spectrum which simulates the case of a system aligned so that three planets were observed simultaneously, was obtained by averaging the spectra of the three planets. These simulated DARWIN observations are presented in Figures 1 and 2. Random noise has been added to the spectra in Figure 1 for which the signal-to-noise ratio is ~ 10 (unrealistically the noise is the same for each observation and is plotted below the main figure).

1.1. Observational Questions

The observer must answer the following questions[1]

[1]The answers to these questions are in the Answer Section after the References.

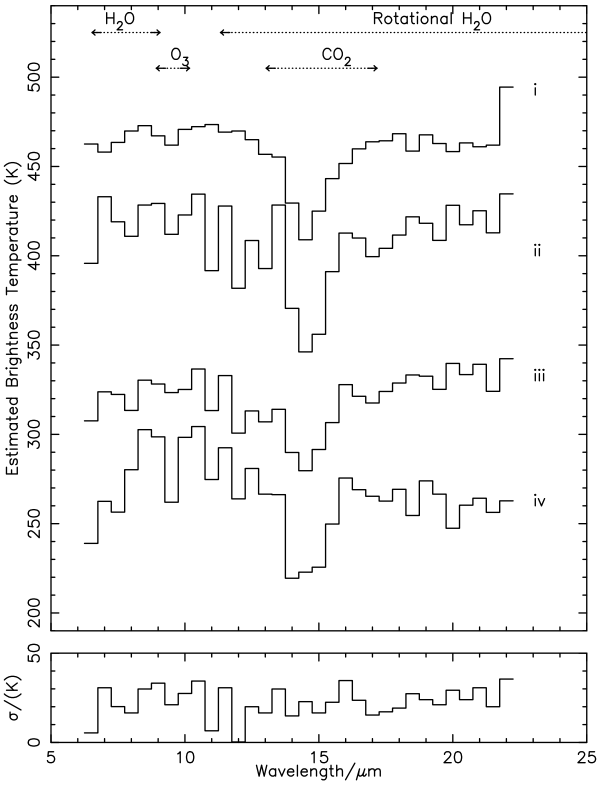

Figure 1. Spectra **i-iv** *contain noise ($s/n \sim 10$) and might contain bad pixels(s). The spectra are from the atmospheres of Mars, Earth, Venus and a composite of these three atmospheres.* **BUT WHICH IS WHICH ?** *Each spectrum is offset by 75K from the one below it. The noise spectrum is shown below the main figure. Are there any bad pixel(s) in spectra i-iv?*

1. Are there any bad pixels in the spectra displayed in Figure 1 ?
2. Is/Are CO_2, H_2O or O_3 gas indicated in any of observations **i-iv** (Figure 1) and **A-D** (Figure 2)?
3. Which planet(s) might have life ? Life would be indicated by O_3 plus H_2O.

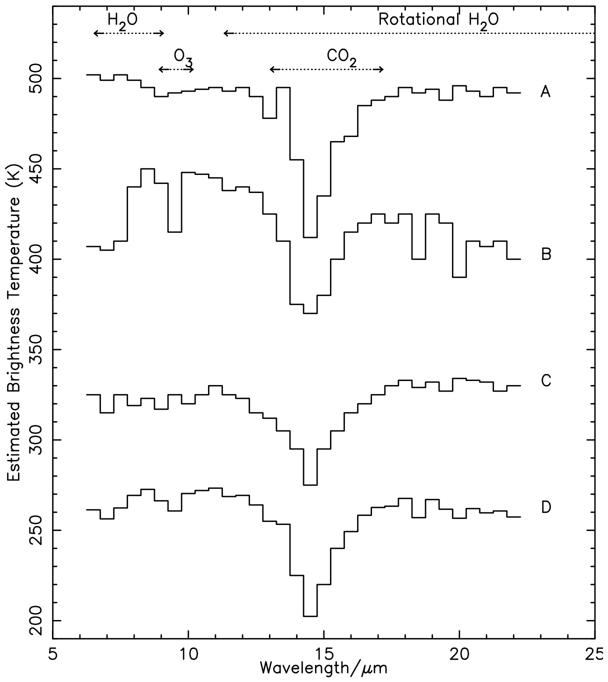

Figure 2. Digitized from high resolution spectra by Hanel et al. (1992). Each spectrum is offset by 75K from the one below it. Spectra **A-D** *include no noise or bad pixels.*

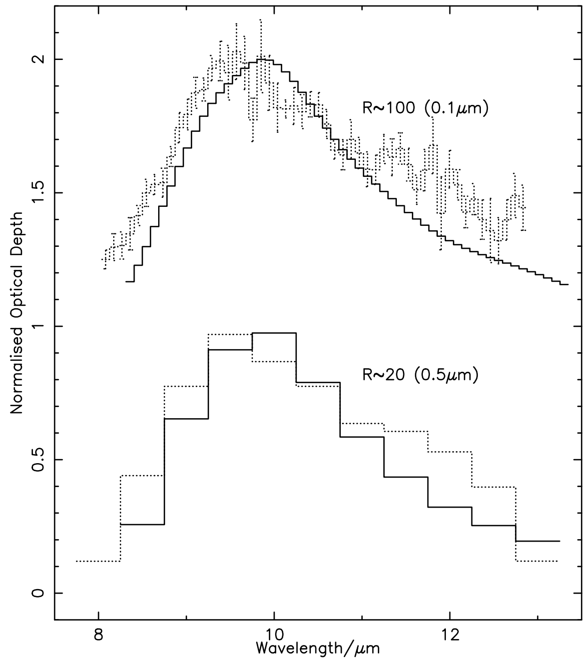

Figure 3. Spectroscopy of Circumstellar and Molecular-Cloud Silicates. emphSolid -Circumstellar profile (μ Cephei; Russell et al. 1975); dotted-*Molecular-Cloud Dust (Taurus-Elias 16; Bowey et al. 1998). Each spectrum is offset by 1.0 from the one below it.*

1.2. Discussion

We found it impossible to distinguish between the noisy spectra of the Martian, Venusian and Earth atmospheres (Figure 1). Spectrum (**iv**) contains a strong feature at 9.5μm, but how can one tell if it is a bad pixel? Figure 2 has no "noise" convolved with the signals and it is clear which spectra is Earth-like. However, the detection of ozone still relies on the response of a single pixel. An additional problem in extra-Solar observations would be the contamination of planetary spectra with 10μm silicate emission (zodiacal light) from dust grains within the planetary systems. This emission would probably alter the contrast between the atmospheric features and the continuum.

2. OBSERVATIONS OF ASTRONOMICAL SILICATE DUST

With its spectral coverage of 5-20μm DARWIN could be used to observe 10 and 18μm bands of astronomical silicate dust.

By observing dust in the outflows of late type stars, the interstellar medium (dark cores) and protostellar disks and molecular clouds DARWIN could be used to study the mineralogy and evolution of astronomical silicate dust. The high angular resolution and sensitivity together with a higher spectral resolution could be used to determine the variation of key parameters such as size distribution, composition and crystallinity within a single extended region and between diverse galactic and extragalactic environments.

However, with at the proposed resolution the spectrometer cannot even be used to distinguish between newly-formed O-rich circumstellar dust and processed molecular-cloud dust. The full-width-half-maxima of newly-formed O-rich circumstellar dust and aged molecular-cloud silicates are 2.5μm and 3.5μm, respectively (Figure 3). Hence, the R $25-50$ spectrometer would not distinguish the difference between dust from very different physical environments. Despite its excellent sensitivity, the DARWIN spectrometer will be of little use for spectroscopic observations of the interstellar medium, stellar outflows and star formation.

3. THE CHOICE OF SPECTRAL RESOLUTION

The spectrum of the Earth's atmosphere at four different resolutions is shown in Figure 4. The Earth's mid-IR atmospheric spectra taken at very high resolution is shown at the top of Figure 4. We clearly see the the double-troughed absorption features of the 6.5μm H_2O transitions; the distinctive 9.5μm O_3 feature; and the CO features between 14–16μm. The

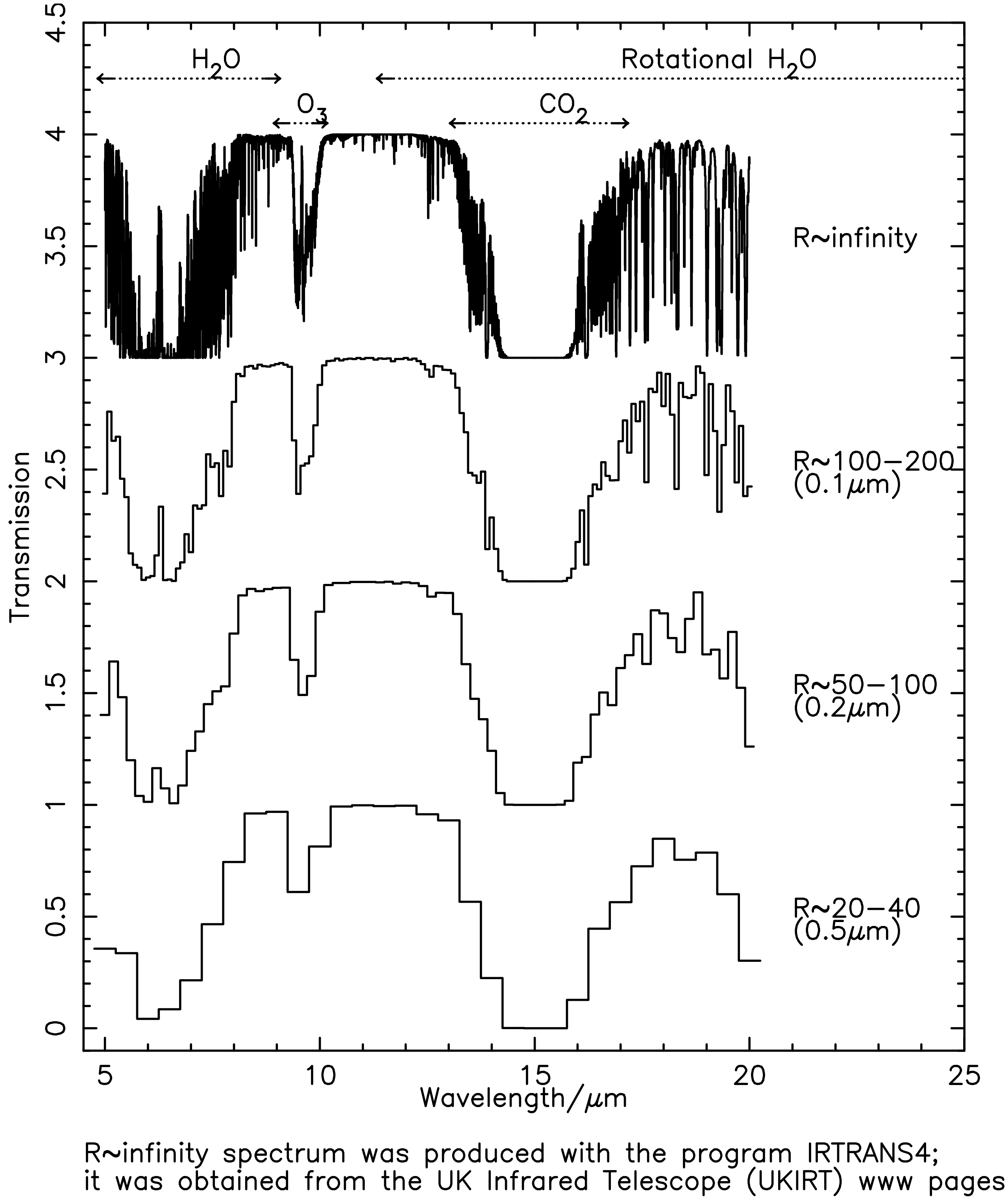

Figure 4. Spectroscopy of Earth's Atmosphere at 0.5μm, 0.2μm, 0.1μm and → ∞ resolution. Each spectrum is offset by a transmission factor of 1.0 from the one below it.

shape of these features are then shown for the proposed R's of 20-40, 50-100 and 100-200. By R=20-40 any structure in the features has disappeared and every pixel in the detector must now work to ensure that any detected dips and troughs are believable. If planetary spectra are contaminated by zodiacal light from silicates it may not be possible to separate these components if $R \sim 20 - 40$.

3.1. How many pixels are necessary to detect Ozone?

If the detection of O_3 is essential to identify a planetary atmosphere similar to the Earth's, we find that at :

- **$R \sim 20 - 40$:**
  Detection of O_3 relies on *all* **four** pixels between 9.0 and 10.5μm showing a feature since the Earth's ozone feature is 2 pixels wide.
- **$R\sim 50 - 100$:**
  four out of **six** pixels are required. The O_3 feature is clearly detected and the splitting in 6.5μm H_2O band is resolved; hence allowing water to be clearly identified.
- **$R\sim 100 - 200$:**
  four out of **ten** pixels are required. Splitting in H_2O (6.5μm and 18μm) is clear allowing unequivocal detection of H_2O. Now CO_2 features around 15μm are identifiable allowing a clear identification of this molecule.

At the proposed resolution of R$\sim$ 25-50 the perfect operation of FOUR PIXELS centred at 9.5μm is *essential* to detect an earth-type atmosphere.

If the designers of the DARWIN nulling interferometer-spectrograph select R$\sim$ 25-50, they must be certain that *all* the pixels work perfectly. A modest improvement, doubling the spectral resolution to $R \sim 50 - 100$, would allow for pixel failures, clearly detect the O_3 feature and give a low-confidence detection of H_2O vapour. Doubling the spectral resolution again to $R \sim 100 - 200$ would improve the quality of the O_3 and H_2O detections and allow unambiguous detection of CO features at 15μm. This resolution would ensure a clear distinction between the atmosphere of Earth which contains H_2O, O_3, and CO_2 and Mars and Venus which are dominated by CO_2 bands.

4. CONCLUSIONS

- To unequivocally determine the components of planetary atmospheres we *insist* that DAWIN's 5-20μm resolution, $R \geq 100 - 200$ ($\leq 0.1\mu$m).
- If R$\geq$ $100 - 200$ then DARWIN could also be used to reveal mineralogical variation between diverse astronomical environments and changes within a spatially resolved circumstellar disk or envelope.
- If $R \geq 100 - 200$ is impossible,
  the *minimum* requirement is $R = 50 - 100$ (0.2μm). At this resolution, detections of atmospheric components will be ambiguous.

We reiterate that at the current resolution of R$\sim$ 25-50 :

- the perfect operation of FOUR PIXELS centred at 9.5μm is *essential* to detect an Earth-like life-bearing atmosphere.
- if planetary spectra are contaminated by *local* zodiacal light from silicates it may not be possible to separate the silicate and O_3 spectral components.

ACKNOWLEDGEMENTS

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REFERENCES

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5. ANSWERS

1. *Are there any bad pixels in the spectra displayed in Figure 1 ?.*
   There are **NO** bad pixels. Just think what a few bad pixels would do to these already noisy spectra.
2. *Is/Are CO_2, H_2O or O_3 gas indicated in any of observations* **i**–**iv** *(Figure 1) and* **A**–**D** *(Figure 2)?*

Figure 1 : CO_2 - **i–iv**, H_2O - None, O_3 - None.
Figure 2 : CO_2 - **A–D**, H_2O - B possibly, O_3 - B possibly.

3. *Which planet(s) might have life?* Life would be indicated by O_3 plus H_2O.

   Based upon Figure 1 no planet has life. However Figure 2 suggests that B may have an earth-type atmosphere.

   The spectra were towards :

   (ii) and **A** : Mars **(iv)** and **B** : Earth **(iii)** and **C** : Venus

   Spectra **(i)** and **D** were the average of spectra **(i)-(iii)** and **A–C**, respectively.