# NEMETODE Technical Note #04

# Video Meteor Spectroscopy

This document provides a guide to the basics of meteor spectroscopy and is intended to help observers take the first steps in this fascinating field. The recommendations are based on user experience within the NEMETODE team and on input from others, in particular Bill Ward, without whom this document simply would not exist. Where possible the author has included references to the rationale behind the recommendations provided.

## Introduction

In recent years the widespread deployment of video systems has led to a significant increase in the regular detection and triangulation of meteors which in turn has led to large datasets detailing, amongst other things, activity levels, absolute magnitude and orbital information. One aspect however that is of interest but which standard systems cannot determine is the chemical composition of the meteoroid itself, something which could be determined from an analysis of a meteor's spectrum.

Many readers will be familiar with the idea of passing a beam of light through a narrow slit and into a prism in order to split the light into its constituent colours (a spectrum). A diffraction grating performs the same function (albeit in a more efficient manner) and by incorporating one into a video meteor detection system, it is possible to record a spectrum of a meteor as it streaks across the sky. The simplicity of the approach is that a meteor, being a narrow beam of light, acts as its own slit. There are however multiple complications including meteor magnitude requirements, resolution, position on the sky, focussing and spectra from other (non-meteor) sources. Patience and tenacity are therefore essential!

## Equipment

The system requirements are identical to those required for basic video meteor detection (a typical configuration is described here[1]) except for the addition of a diffraction grating. This document discusses the use of a transmission diffraction grating where the light from the meteor passes through the grating before entering the lens and falling on to the camera sensor. It is possible to use a reflective diffraction grating (where the light falls on to the grating and the resultant reflected spectrum is imaged by the lens / camera combination) but this configuration is outside the scope of this document.

Typically, video systems use fast (better than *f/1.0*) lenses of focal lengths between 3.6mm and 12mm. An ability to see fine detail within the spectrum is key to determining chemical composition and hence angular resolution is an important factor: for this reason lenses that are at the upper end of this range (i.e. 12mm) are recommended. Longer focal length lenses would provide even greater angular resolution however the reduced FOV makes it increasing unlikely that a complete spectrum would be obtained. In addition making use of the B/W Aberration Compensation Filter, that the manufacturers suggest are incorporated into the optical train when such lenses are used with monochrome cameras, is also recommended.

Some observations in the UK are conducted "in the open air" with the camera, lens and diffraction grating exposed to the elements. While this approach will lead to the best quality data it does necessitate careful monitoring in order to ensure the equipment does not suffer damage due to inclement weather. Dew heaters are also mandatory to ensure the grating / lens remains clear. These anxieties result in the systems only being deployed when there is confidence of extended periods of good weather. Concerns about internal reflections / light loss have historically limited deployment within systems protected within weatherproof CCTV housings (which can run all night, every night, irrespective of the weather) though the work of Graham Roche[2] has demonstrated that good results can be obtained from indoors. Since then, systems enclosed within CCTV housings have been deployed.

## CCTV Housing

A normal CCTV housing can be used though one with a demist heater (to prevent the front window from fogging up) is highly recommended. Moisture accumulation can significantly degrade diffraction gratings and the heat from the demist heater can help in this regard.

One enhancement that can be considered is to replace the standard plate glass window on the front of the housing with one that has had anti-reflection (AR) coatings applied. In the case of the housing used at Ravensmoor, the author was able to remove the 3" square, 3mm thick plate glass window with ease by gently heating it with a hair-dryer to soften the glue then applying slight pressure to lift the window up and out of the enclosure. The original window was replaced with a 3" square, 1mm thick AR window obtained from Edmund Optics (see Table 1) that was simply glued into position in the same way the original had. AR windows are available from other vendors[3]. While the AR coating did initially seem resistant to the worst weather Cheshire could throw at it, a particularly violent shower of hailstones has damaged the coating and the author now intends to switch back to the original clear glass window.

**Transmission Diffraction Grating**

Basic information relating to diffraction gratings is available here[4] and here[5]

Gratings are available with a number of different grooves per millimetre (g/mm) – typical values are 300, 600, 830 and 1200 though others are available. The number of g/mm determines the degree of dispersion (i.e. how "spread out" the spectrum is): the greater the g/mm, the greater the dispersion and the easier it is to see fine detail (as adjacent lines won't be merged into each other). Too much dispersion however results in the capture of only partial spectra as they will spread out beyond the edges of the FOV. Another problem relates to the absolute efficiency of the grating: the higher the g/mm, the fainter the resultant spectrum will be for a given brightness of meteor. A typical graph is shown in Figure 1.

Obtaining useable data is dependent on the signal:noise of the resultant spectra (i.e. how bright the lines are compared to the background noise in the image). A bright spectra with low dispersion may yield more information that a faint spectra with high dispersion. This posting[6] provides a good example of the pros and cons of high vs. moderate dispersion.

A reasonable compromise that provides a good level of dispersion (enough to begin to see some detail in the closely spaced iron lines towards the blue end of the spectrum), a bright enough spectrum from a sub fireball class meteor (which happen with reasonable frequency) and has a good chance of fitting the whole spectrum into the FOV given by a 12mm lens is to use a grating with 600 or 830 g/mm.

The simplest approach is to use ruled plastic film mounted across the front of the lens. These are inexpensive and readily available as rolls or sheets (search online for "*diffraction grating sheet*"). The downside is the lesser quality of the resulting spectra and for this reason blazed glass gratings are recommended.

Blazed diffraction gratings[7] optimise the diffraction efficiency in a given order for a given wavelength and in addition preferentially maximise the dispersion to one side of the dispersion axis. In short, they give a brighter spectrum that an un-blazed grating.

The grating itself should be sufficiently large to completely cover the front element of the lens – this generally means that one that is 50mm square is required. Typical vendors include Edmund Optics[8] and Thorlabs[9].

**Mounting**

Lenses often have a filter thread on the front around the objective lens and this can be used to securely mount the diffraction grating. Typically 2" / 50mm filter mounts are used. Edmund Optics also offers a Threaded Filter Holder (see Table 1).

Once mounted, it is important to be able to rotate the diffraction grating in order that the dispersion axis is orthogonal to the path of the meteor. While it is not possible to know in advance the path a *sporadic* meteor, it is possible to estimate the path a shower meteor may take across the FOV and consideration should be given to rotating the grating such that its dispersion axis is at right angles to the radiant. This however can be somewhat of a compromise for a fixed camera as the radiant position changes throughout the night.

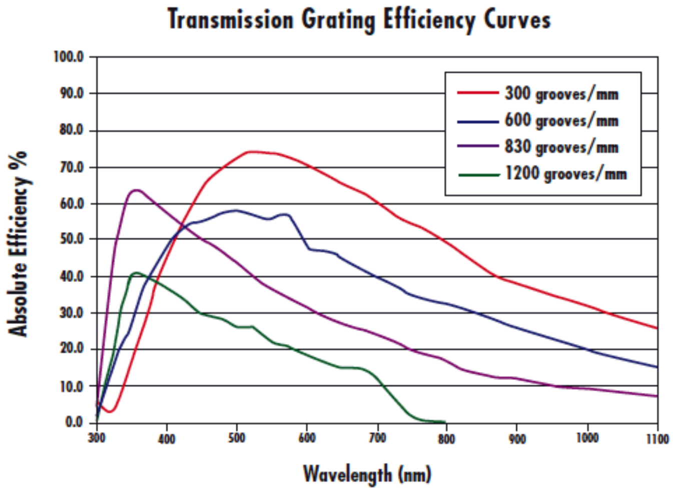



**Figure 1:** Typical transmission grating efficiency curves for gratings with different numbers of grooves per millimetre (g/mm). Note the significant fall off in transmission towards longer (red) wavelengths for gratings with higher g/mm, the net effect of which is fainter spectra for a given brightness of meteor.

**Figure 2:** Close up views of the spectral camera installation at Ravensmoor. Left: Inside the CCTV housing is a standard setup comprising a Watec 902H2 Ultimate with a Computar 12mm f0.8 lens. A step-up adapter ring is affixed to the front of the lens to which is attached a filter holder containing a diffraction grating. Right: The AR coating renders the front window of the CCTV housing almost invisible. Note the rotation of the diffraction grating, in this case to have the axis of dispersion run along the diagonal of the rectangular sensor in order to maximise the chance of obtaining the complete spectrum.

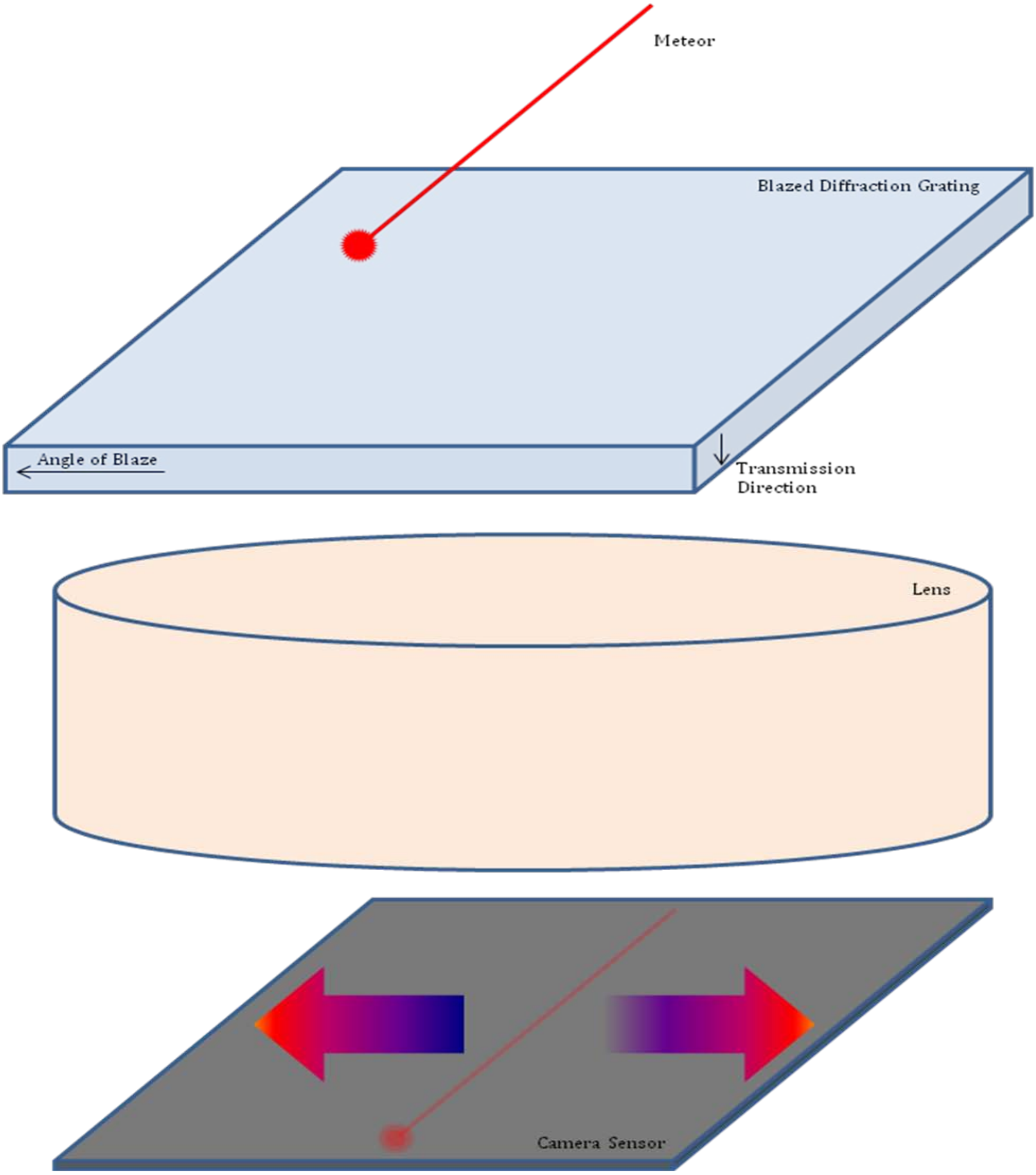



**Figure 3:** Schematic of a typical setup. At the top of the schematic a meteor passes across the sky with the light falling on to the grating. Note that the edges of a blazed grating typically have arrows inscribed on them showing the Transmission Direction (the direction the light should take through the grating) and the Angle of Blaze (the side towards which a brighter spectrum is formed – in the above example the Angle of Blaze is pointing to the left and the brighter spectrum is on the left). Note that the un-diffracted track of the meteor may also be captured and that the blue end of the spectrum is closest to the meteor track.

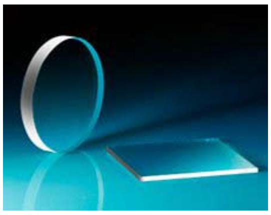
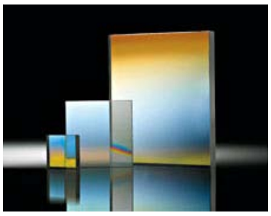
| Item | Supplier Reference | Image |
|---|---|---|
| Threaded Filter Holder (M52 x 0.75)* | [Edmund Optics #59445] |  |
| M40.5 to M52 Step-up Adapter Ring‡ | Internet Auction Site |   |
| 3” (76.2mm) Square AR Window | [Edmund Optics #48927] |  |
| 600g/mm, 50mm Square 28.7° Blaze Angle Grating | [Edmund Optics #49584] |  |

**Table 1:** Additional items used by William Stewart to convert a standard video meteor detection system (based around a Watec 902H2 Ultimate and a Computar 12mm f0.8 lens) into one suitable for meteor spectroscopy. *The Edmund Optics website does suggest that the filter holder can be rotated once it is affixed to the lens – this however is incorrect. Once firmly screwed on to the camera, the Computar lens can be rotated on a friction fit to allow the dispersion axis to be set appropriately. Other lenses may not however offer similar functionality – in this case the mount may need to be partially unscrewed in order to orientate the dispersion axis to the desired angle. ‡Versions of these are available on the Edmunds Optics website however much cheaper equivalents are readily available elsewhere. Check the diameter and thread pitch of the lens to which you intend to mount the holder in order to ensure you order the correct step-up adapter.

## Focusing

Accurate focus is critical to obtaining good spectra and is challenge when a diffraction grating is introduced into the configuration. When focussing the lens without a grating in position, it is relatively straightforward to initially achieve a rough focus on bright starts before using faint starts to optimise the situation: either side of critical focus the light from faint stars is smeared out to the extent that they disappear from view. Critical focus can therefore be achieved by selecting the mid point between the two positions where the faint stars disappear.

With a grating, the key thing to remember is that the focal plane of the diffracted light is not only different to that of the focal plane for un-diffracted light, it is also tilted with respect to the plane of the diffraction grating itself: the focal point for blue light being further away from the grating surface than that for red light. One way that this can be accounted for is to tilt the grating with respect to the front optical element of the lens. This paper[10] describes one implementation of this approach though it does add an additional complexity to a deployment and is beyond the scope of this document.

Bill Ward[11] offers the following guidance:

***Preparation***

*i. Choose a time when there is a bright point source high in the sky (thus reducing the effects of atmospheric scintillation). While bright stars may suffice, it is easier with a bright planet such as Jupiter: it is bright enough that it generates a viable spectrum but also not too bright which can be misleading. Extended bright sources such as the moon are not appropriate.*

*ii. It is essential that you are able to watch the video output screen as you adjust the focus.*

***Workflow***

1. *Focus on Jupiter. This will no doubt be a blob but it's instructive to observe it closely.*
2. *As you adjust the focus you will see the focus start to sharpen and Jupiter go out of focus a little.*
3. *It's difficult to describe verbally, but continue to move the focus and you'll see the point of best focus "run" along the length of the spectrum.*
4. *Due to the characteristics of the actual glass in the lens combined with the inherent near IR sensitivity of a silicon detector really good sharp focus is easily obtained in the near IR. Due to Jupiter's brightness and the near IR sensitivity of the camera, you should be able to clearly see the atmospheric absorption bands come cleanly into focus.*
5. *Move the focus the other direction and you'll see the broad line begin to tighten up towards shorter wavelengths again. You may think running it right to the end would give the best blue focus but it doesn't. Due (primarily) to the glass, what you actually do is indeed produce the least blur but it's still not actually in focus.*
6. *Once you've "scanned" the focus you'll get a feel of where is the optimum. I try to tighten up the blue then move it back once more a fraction till it just starts to increase in width.*
7. *Lock the lens, I've found even when moving the cameras in and out of the house the focus will stay good for a around a year. Temperature changes will cause the focus to creep and degrade over time.*

*And that's that. The images show the result. The defocus in the blue is unavoidable, the lens quickly comes to good focus around 400nm and stays well focussed until longer that 750nm and then the width of the spectrum lines start to widen as the lens starts to reach the defocus on the longer near IR where the glass/design begin to degrade performance once more.*

**Camera Alignment**

As already mentioned, capturing meteor spectra allows the chemical composition of the meteoroid to be determined. Combining this data with knowledge of the meteoroid's atmospheric trajectory and orbit provides a comprehensive dataset. For this reason it is worth considering aligning the spectral camera system such that it is able to obtain spectra from meteors that pass through that part of the ablation layer that is already well covered by other "normal" video cameras (that can allow the trajectory and orbit to be determined).

**Final Thoughts**

Capturing meteor spectra is highly rewarding and scientifically valuable – as of the time of writing, very few individuals around the world are active in this area. Obtaining good data is a challenge for multiple reasons:

i. As the light is spread out (dispersed) by the grating, the intensity on the sensor is reduced, hence good spectra can only be obtained from bright meteors (which are relatively infrequent).

ii. It is impossible to know in advance where in the sky a meteor will occur (and hence where to point the system).

iii. The angle of the diffracted light across the sensor depends on the dispersion axis of the diffraction grating. This is random for sporadic meteors.

iv. Better quality data comes from higher focal length lenses and gratings with greater dispersion (i.e. higher values of g/mm), factors which decrease the chance that a complete meteor spectra will fall within the field of view (FOV).

Obtaining good data therefore requires patience and a degree of luck: a bright meteor travelling across the sky at an angle orthogonal to the dispersion axis of the grating and in a position that allows the spectra to fall within the FOV. Maximising imaging time on the sky is the key, hence observers are encouraged to deploy permanent setups.

**References**

[1] http://nemetode.org/Papers/NEMETODE%20Overview%20WGN%20June%202013.pdf
[2] http://nemetode.org/NEMETODE%20Team/Graham%20Roche.htm
[3] http://www.uqgoptics.com/catalogue/Windows/AR_COATED_THIN_GLASS_-_WINDOWS_PLATES_$_SHEETS.aspx
[4] https://en.wikipedia.org/wiki/Diffraction_grating
[5] http://www.shimadzu.com/opt/guide/diffraction/01.html
[6] http://meteorobserver.proboards.com/thread/198/gratings-dispersion-magnitudes
[7] https://en.wikipedia.org/wiki/Blazed_grating
[8] http://www.edmundoptics.co.uk/optics/gratings/transmission-gratings/2934/
[9] https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=1123
[10] http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?letter=.&classic=YES&bibcode=2014pim3.conf...13G&page=&type=SCREEN_VIEW&data_type=PDF_HIGH&send=GET&filetype=.pdf
[11] Bill Ward, *personnel communication*, 03rd November 2015.

**Version 1**

William Stewart, First Issue, Released 16th July 2016

**Acknowledgements & Feedback**

Sharing best practice within the video meteor observing community was the rationale behind creating this document and the author, William Stewart, is extremely grateful to the Bill Ward and to the NEMETODE team members who have provided valuable input to this document. This was very much a team effort!

If you have any questions, feedback or recommendations then please contact the author at ws@nemetode.org