Kilometer scale primary collector telescopy

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ABSTRACT

We present an improved model for a spectrographic survey telescope with a kilometer scale diffraction grating collector. Refining the initial public disclosures, the new model quantifies flux collection for telescopes of this type. An option in the new model allows a trade of reduced spectral bandwidth for increased flux collection. We provide experimental evidence to demonstrate an earlier prediction of Ångstrom spectral resolution with relaxed tolerances for grating flatness, and we show how this model is extensible in two dimensions.

Keywords: telescopy, spectrometer, primary, collector, VLT, diffraction, grating, enclosure, LMT

1. INTRODUCTION

Prior publications made at the bi-annual SPIE Astronomical Instrumentation Conference in 2002 introduced the concept of a very large primary collector telescope based on a primary objective grating (POG).[1,2,3] These disclosures asserted that apertures reaching kilometer scale could be achieved through the leverage created by placing secondary receiving components at an angle of grazing exodus relative to a POG. It was further asserted that terrestrial versions of such instruments could operate without moving parts other than the rotation of the earth itself. An additional disclosure on space deployment posited that gossamer membrane diffraction gratings could be loaded in rolls and later stretched into flat surfaces in orbit, overcoming payload restrictions endemic to parabolic mirror primary objectives.

1.1. Perceived Flaws

When these assertions were conceded for the sake of argument, the POG telescope was nonetheless seen by conferees to have several drawbacks, if not fatal flaws. First, the requisite specification for grating flatness was seen as unachievable for very large gratings. Secondly, flux collection was shown to be restricted by a narrow temporal window, the worst case being for terrestrial installations at 2.3 seconds of time per Ångstrom for objects along the Great Circle. Even with collection real estate at square kilometer scale, the available flux over such short integration periods could prove negligible for high magnitude objects. The concept was compared to the Liquid Mirror Telescope (LMT), a zenith tube that also suffers from an inherent restriction on integration time due to the rate of the rotation of the earth.

1.2. Newly Anticipated Features

Criticisms of the diffraction grating primary telescope prompted our continuing investigation, if only because this novel telescope concept suggests other unique features that address many of the drawbacks conventional mirrors face when they are conceptualized for a very large telescope (VLT). Terrestrial installations this new type of POG can be at the ground level, presenting a near-zero wind profile regardless of aperture size. In those embodiments where the secondary incorporates a parabolic reflector, that mirror can have a very long focal length without any vertical elevation penalty, since it focuses along the ground plane. Moreover, the secondary mirror is mechanically independent of the primary and is completely static. The resulting open frame eliminates the need for a secondary spyder and has no obstructions in the active ray path. Alternatively, the grating primary might be combined with an LMT to provide full coverage of the line right ascension over all angles of declination. Finally, the output of this new telescope fills a growing need in the community, since it intrinsically generates multiple-object spectrographic data.

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2. THE BASIC PRINCIPLE

Telescope power is a function of size of the primary collector. This parameter affects both flux collection and angular resolution. For this reason mirrors have been manufactured in larger and larger diameters. The current record for visible wave lengths and near IR is at 10 meters, and conceptual planning for VLT's extends to 100 meters.

The present investigation is into the efficacy of a diffraction grating rather than a mirror or a lens primary, but the size of the grating has the same fundamental importance with regard to power as traditional primary objectives. The real estate provided by the grating sets the limit for both captured flux and resolving power.

Prior art in diffraction grating primary objectives consisted of a coarse grating placed in front of the telescope[4] and have been known for over a century.[5] Spectrograms taken with such instruments are of limited utility because of superimposed background radiation and limited free spectral range between overlapping spectra. The additional grating component does nothing either to increase the magnification power of the secondary or to alter the basic tracking mechanics of the traditional astronomical telescope.

2.1 Grazing Exodus Configuration

We have proposed a paradigm shift in objective gratings by placing the grating at an angle of grazing exodus relative to the secondary. Grazing exodus refers to the wave front reconstructed along the grating plane at angles *r* approaching 90° off the grating plane normal. See Figure 1.

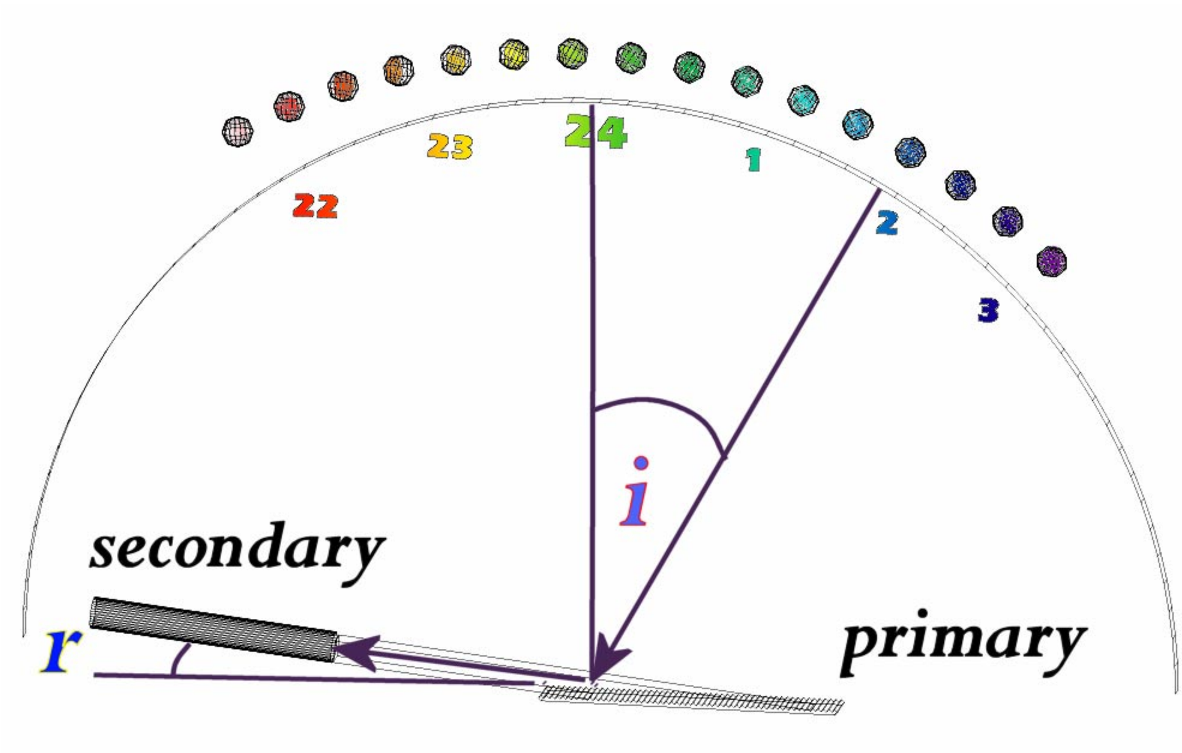

Figure 1 Grazing exodus configuration

If a grating's pitch spacing is near to or less than the wave lengths being studied, there is an unusually large free spectral range, because almost all wave front reconstruction is restricted to the first-order. If the grating is positioned in an east/west orientation, the wave length detected at the secondary is directly proportional to target elevation. The spectral wave lengths of as specific target can be acquired sequentially over the course of a night as a function of sidereal time. The grazing exodus configuration eliminates the need for the instrument to mechanically counteract the rotation of the earth in order to assemble spectra, since object spectrograms can be taken over time. Moreover, at grazing exodus, grating length is dramatically extensible, achieving limitless length when the grazing angle reaches evanescence at 90°.

2.2 Secondary Optics

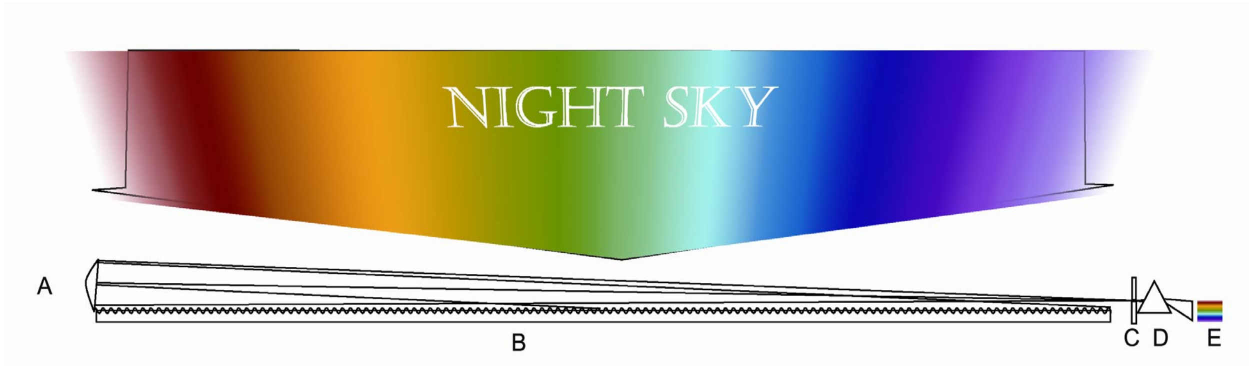

Figure 2 Schematic illustrating secondary component placements
A Parabolic reflector B Primary grating C Slit D Disperser E Sensor

Image formation requires the appropriate secondary optics. Although the primary is a diffraction grating, the primary element does not directly produce spectrograms by its action alone. Each sky object is associated with a unique wave length at any given instant of time, and all wavelengths from all visible angles of the sky are superimposed on top of one another. A secondary spectrometer or a variable bandpass filter is required to sort them out. In Figure 2, a prism is used to indicate the dispersing element in the secondary, but in a secondary that is equivalent to a telescope with a parabolic reflector, the secondary spectrometer can be modeled on high resolution types of spectrographs found in the largest astronomical instruments. Indeed, it would be possible to test this novel concept simply by pointing a conventional astronomical telescope at a ground-level grating strip. In this paper, we will use conventional telescope specifications to analyze throughput. That said, it is interesting to note differences with conventional telescopes as illustrated in the secondary of Figure 2. Firstly, it is possible to use extremely long focal length mirrors in the secondary, and secondly it is also possible to completely avoid any obstructions in the light path from input to output.

3. RESOLVING POWER AND FLUX COLLECTION

The resolving power is a dimensionless value of a plane grating that is defined as the ratio of a wave length λ to the smallest fraction of wave Δλ that can be discriminated at the detector (1).

(1) $$R \equiv \frac{\lambda}{\Delta\lambda}$$

(2) $$R_{Max} = \frac{L}{\lambda}$$

Resolving power is determined by the size of the grating. A simple relationship that governs resolving power is the retardation of a wave front from one side of a grating to the other. In effect, the greater the length of the grating *L*, the higher the resolving power *R* at any higher-order. For incident radiation at the zenith where angle of incidence *i* is 0, as the angle of reconstruction *r* approaches evanescence, the resolving power of the grating has a maximum R_{max} as per equation (2).

The grazing exodus type of POG is conceived of in term of 10's to thousands of meters in length, suggesting resolving powers that would vastly exceed any precedent. The theoretical limit of resolving power for a grating of kilometer length at visible light wave lengths is in excess of a billion. The best secondary spectrometers in service today have a practical limit in resolving power of 100,000. At first light the HIRES Keck I spectrometer was rated at a resolving power of 67,000, and the optical design is thought to be limited in theory to R_{max} 200,000. [6] Adaptive optics in front of the spectrometer optics can enhance performance by an order of magnitude, putting the limit in practice at 200,000 and suggesting a theoretical limit at 1 million. [7]

Opinions vary on the utility of six decade resolving power spectrographs, and there is no breakout need for improved resolution in the community. Although radial velocities are detected by Doppler shifts in spectrograms, the intrinsic noise of stellar light swamps discrimination at resolving powers over 100,000. Competing sources from exo-planetary systems possibly could be discriminated by high resolution spectroscopy, but there is no call for this capability today.

However, when the primary collector is a diffraction grating, the resolving power of the primary not only establishes the granularity of the spectrographic data; it also determines the angular resolution of the telescope along the axis of diffraction. If length alone were to determine the resolving power, by equation (2) a kilometer scale collector would provide R_{max} of 1 billion for $\lambda = 1\ \mu m$. The nominal limit of angular resolution for the diffraction primary would then be determined by the grating equation solved for the angle of incidence *i*.

$$i = \arcsin\left(n\frac{\lambda}{p} - \sin(r) \right) \qquad (3)$$

where *i* is the angle of incidence
r is the angle of reconstruction
n is the diffraction order
λ is the wave length
p is the grating pitch

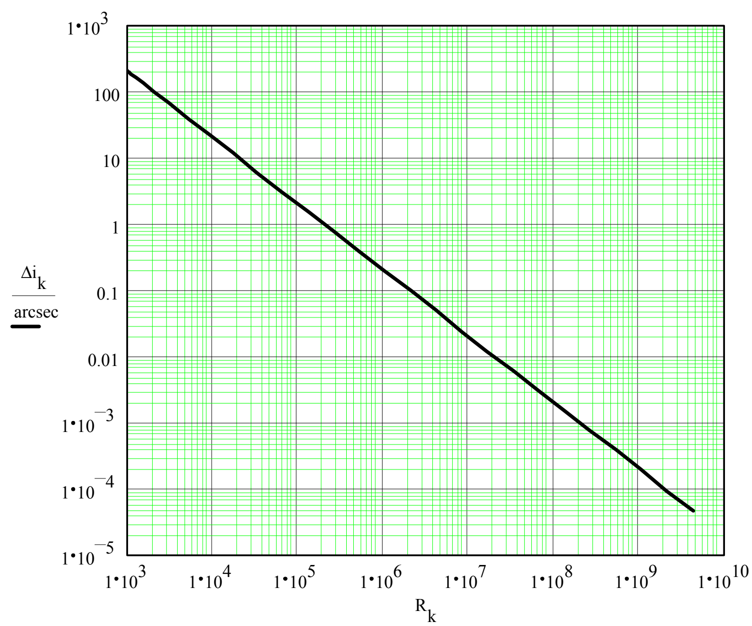

Figure 3 Δ*i* as a function of resolving power *R* (Log scale)

A graph of the angular resolution of the primary as a function of its resolving power as a diffraction grating is shown in Figure 3. The angular resolution of mirror primaries would be comparable if their lengths were equally extensible.

Regardless of the length of the primary collector, there are limiting factors that restrict the effective resolving power, and one of them is the requirement of a secondary spectrometer. If the secondary spectrometer achieves a resolving power at the limit in practice today, we can venture a prediction for the angular resolution of the entire telescope. For example, with the Echelle RIRES spectrograph in Keck I that limit would be on the order of 0.5 arc seconds. Taking secondary spectrometers up an order of magnitude in performance simply by making their gratings larger would put the diffraction primary telescope in the Terrestrial Planet Finder class which must minimally achieve 0.05 arc seconds. Given the static posture of the secondary, housing large secondary spectrometers poses less of a problem than spectrographs interfaced with motion platforms.

3.1 Flux Collection

Angular resolutions suggested by these figures do not factor in the corresponding loss of flux as the band width is narrowed. Δλ is correlated to Δ*i*. The dwell time Δ*t* at Δ*i* is determined by transit time of the target object. In essence, the flux collection is slaved to the rate of the rotation of the platform. For terrestrial installations, this rate has been shown to result in a worst case at the Great Circle of 2.3 seconds/ Ångstrom. A fleeting figure for dwell time has been fingered informally by critics as the Achilles' heel of the diffraction grating primary concept.

Flux collection is also a result of collector size. One of the strengths of the grazing exodus configuration is the potential for collector lengths equal to 100 to 1000 times the diameter of the secondary mirror. Hence, for the most difficult case, the 2.3 seconds/Angstrom of dwell time can arguably provide the same photon collection as 2300 seconds with the secondary mirror by itself if the grating is 100% efficient. Of course, grating efficiency cannot be 100%. In theory, the best case for reflective grating efficiency at all polarizations in the first-order would be 50%, and commercially available grazing angle gratings used in other applications are rated at 20-30% efficiency. Hence, for the worst case, the effective collection of a reflection grating primary relative to the mirror would be more like 1000 seconds using the secondary telescope alone. If we allow for angles of declination off the Great Circle and use an equivalency of 1200 seconds, then the kilometer scale grating would provide no greater flux than 20 minutes on a conventional telescope with the same size secondary. Notwithstanding that very large VLT's above 20 meters pose enormous mechanical problems in motion platform and enclosure design, critics will ask, "Why bother with a POG?"

Taking a pointer from the change in dwell time as a function of angle of declination, it is possible to modify the terrestrial version of a POG to increase dwell time at the expense of overall bandwidth. If the primary is rotated away from a strict east/west axis and if the primary actively rotates during the integration period to diffract the target image into the secondary mirror, then dwell times will increase while bandwidth declines.

Consider the two placements of the gratings in Figure 4. Grating A is configured east/west as per the original disclosure. Grating B is rotated toward the poles. In order for Grating B to track a region of the sky, it must counter the rotation of the earth in a manner similar to the elevation of a conventional telescope, so it must move. Moreover, in order to vary declination over the entire sky, the secondary must adjust its height, although it does not need to move during observation runs. Grating B has a much higher penalty in implementation than Grating A because of the motion platform requirements, but these are hardly outside the contemplation of VLT mirror designs where huge reflectors must track their targets with accuracy much higher than smaller telescopes, because large apertures give them extraordinary angular resolution.

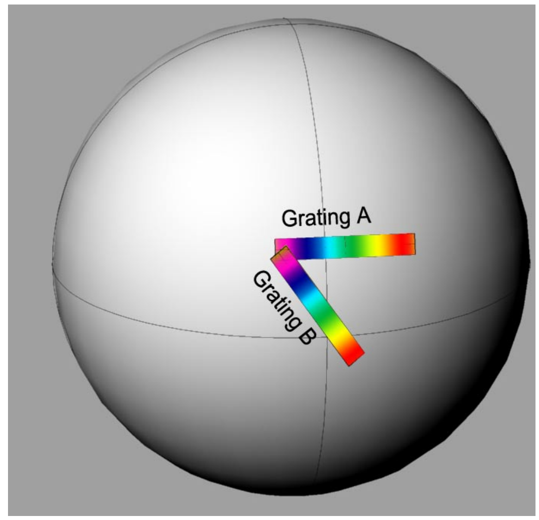

Figure 4 Alternative placements of primary

The advantage of the rotation of the grating primary toward the poles, as illustrated by Grating B, is that dwell time becomes a function of the angle of rotation. Intuitively, we can say that in a strict north/south orientation, the dwell time is all night, but the change in the angle of incidence is zero, hence the spectra taken of each star is restricted to a single wave length.

The model for angles of incidence on the grating is:

(4) $$i = (\alpha \cos(\beta))\cos(\varepsilon)$$

where α is the angle of elevation
β is the angle of declination
ε is the angle of rotation of the primary grating collector off the east/west access

We compare angles of incidence as determined by $\varepsilon = 0°$ and $\varepsilon = 75°$ in Figure 5 and the consequential change in the bandwidth of the resulting spectra in Figure 5.

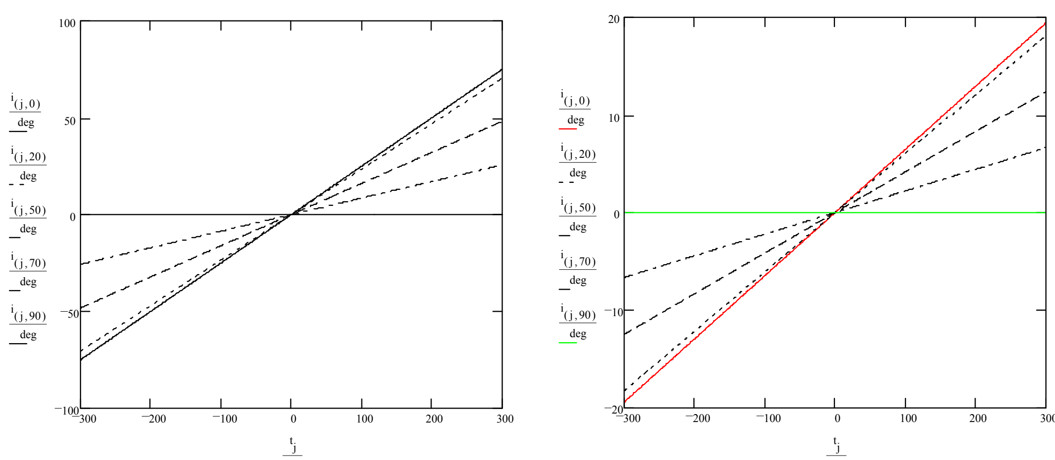

Figure 5 Angles of incidence over a night with Grating A in strict east/west orientation (left graph) and with Grating B in rotation toward the poles of 75° (right graph). Their effective transit arcs drop from 150° to 40°

By lowering the transit arc per unit time, the dwell time increases proportionately. For the example given, the dwell time in the worst case rises from 2.3 sec/Å for a strict east/west orientation to 8.63 sec/Å when the grating orientation is rotated 75° toward the poles. The worst case per Ångstrom is now equivalent to over an hour of observation on a telescope with a mirror the size of the secondary. The dwell time improves from the worst case as a function of the angle of declination. We compare the dwell times for the same configurations in Figure 6.

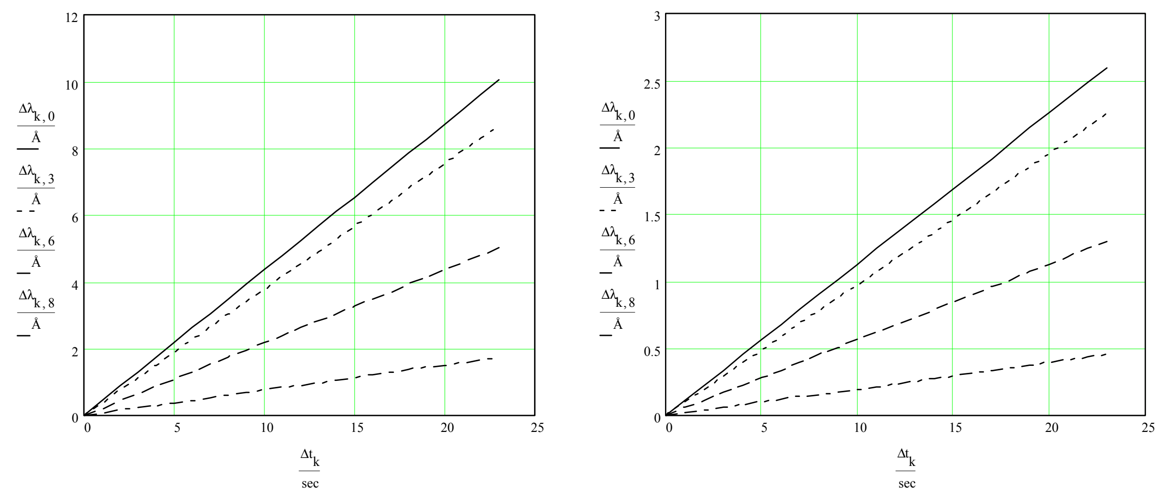

Figure 6 Comparisons of dwell times and wave length resolution at various angles of declination. The top solid line is at the Great Circle. Lines below are respectively at 30, 60 & 80 deg. Dwell times per Å with strict east/west orientation Grating A (left graph) and with 75° rotation of Grating B toward the poles (right graph). °

When the orientation is rotated from the east/west axis, the loss of spectral bandwidth for the resulting spectrograms is tolerable, because the overall bandwidth falls within conventional observation ranges. An unmediated east/west configuration spans such an enormous range that one can question its utility. We compare the performance of a 1 micron pitch grating without the reorientation and with it in Figure 7

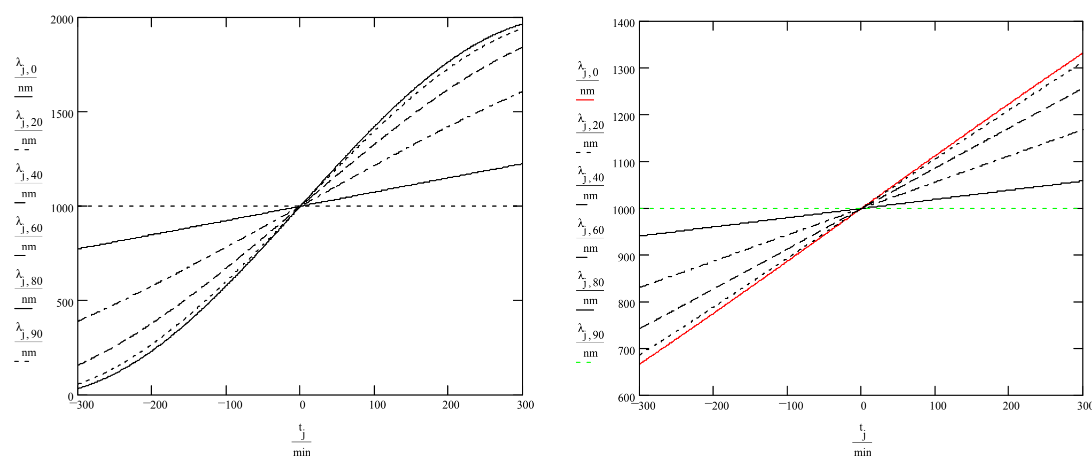

Figure 7 Comparison of wave length gamut of Grating A and Grating B.

Rotation of the grating toward the poles is not the only avenue to improving flux. Others have been proposed in earlier papers, and it is anticipated that more will be discussed, e.g., a Moon installation will increase Å/sec by a factor of 28.

4. FLATNESS TOLERANCE

Although critics have not yet published their insights, the concept of a diffraction grating primary collector has almost always been dismissed in informal discussions as impractical, because enormously large gratings are required. The original disclosure posited segmentation of gratings, and this possible means of assembling large grating arrays has not been attacked as untenable. However, it has been argued that flatness tolerances shrink as grating length increases, and flatness figures without precedent would be required to achieve the performance suggested by the Grating Equation. The criticism may have validity with large gratings that reconstruct spectra at small angles of diffraction, but at grazing exodus along the first-order, flatness affects efficiency more than spectral resolution.

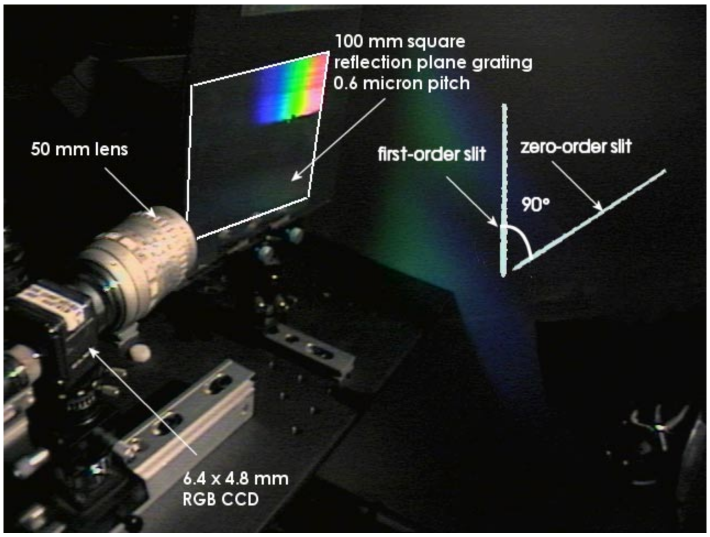

Figure 8 Set up for experiment to test flatness tolerance

The initial disclosures asserted that float glass could produce Ångstrom resolution. An experiment was conducted with a faulty grating surface. The grating material was a decorative grade of embossed plastic attached to window pane glass by means of a sticky backing. A camera was oriented to acquire the zero-order and the first-order by rotating the grating between the orders and by rotating the illumination slit 90° so that the full width of the grating would be illuminated in the zero-order. Figure 8 shows the bench. The slits have been simulated for illustrative purposes. A comparison of the zero-order and the first-order is shown in Figure 9.

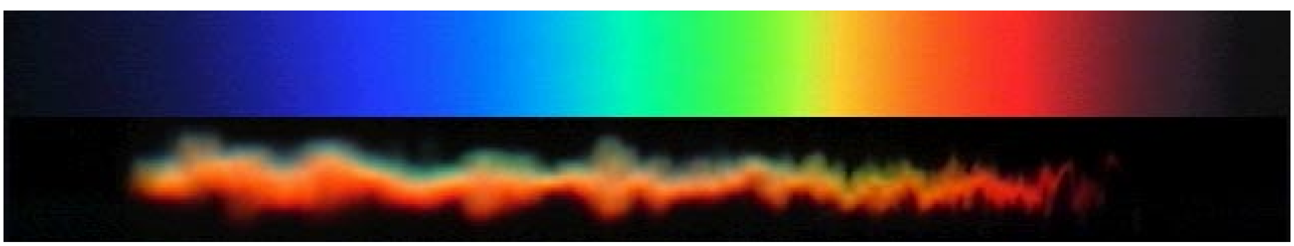

Figure 9 Comparison of first-order (above) and zero-order (below) of the same grating surface.

It is interesting to consider flatness tolerances with scientific grades of optical flat. While first-quality flats are not found in large sizes, there is nothing that prohibits their manufacture to the scale of parabolic mirror blanks used for VLT's. Placing a tolerance of one micrometer per meter on grating substrates to be used in diffraction grating fabrication could bring the angular resolution of the primary collector up to the nominal resolving power of the secondary.

The model used for determining the effect on wavelength is illustrated in Figure 10. The ratio for the error, sometimes called "waves," is the displacement d over the considerable length L. The error can be given as the angle $\Delta\alpha$ where

(5) $$\Delta\alpha = \arctan\left(\frac{d}{L}\right)$$

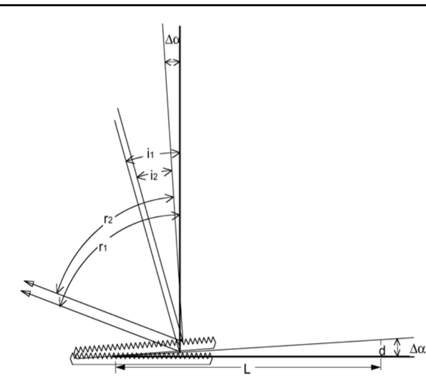

Figure 10 Model used for finding $\Delta\lambda$ caused by uneven grating surfaces

For any angle of incidence i there is a superimposed image from $i + \Delta\alpha$, and the difference forms the error Δi. Applied to the Diffraction Equation and assuming only the first-order, there is a correlated blurring of the resolved wave length which is quantized as $\Delta\lambda$.

(6) $$i_1 = \arcsin\left(\frac{\lambda}{p} - \sin(r_1)\right)$$

where r_1 is the angle of grazing exodus

There is a change in the transit angle and the receiving angle caused by the grating unevenness

(7) $$i_2 = i_1 - \Delta\alpha$$

(8) $$r_2 = r_1 - \Delta\alpha$$

Solved for λ we obtain a new wave length received as a result of the imperfect grating.

(9) $$\lambda_2 = (\sin(i_2) + \sin(r_2))\,p$$

For any λ there is an error

(10) $$\Delta\lambda = \lambda - \lambda_2$$

Figure 11 is a graph of $\Delta\lambda$ as a function of λ for the grating with one micrometer unevenness over one meter when r_1 is 88°. The angular error is shown in Figure 12.

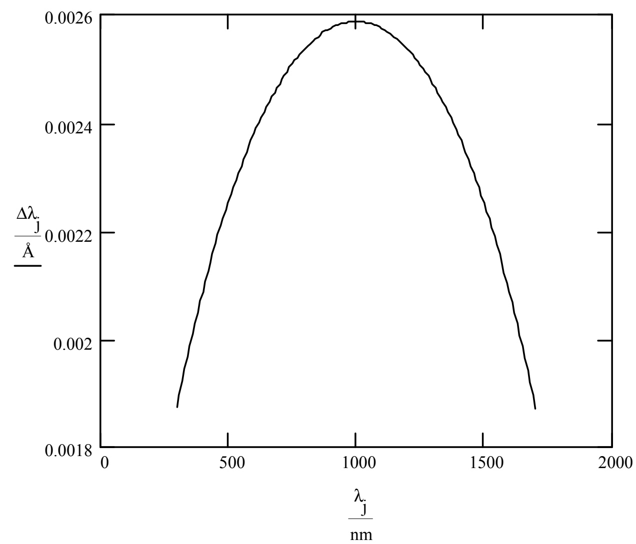

Figure 11 Chromatic aberration at grazing exodus of a scientific grade optical flat uneven to one micrometer/meter

The angular resolution that can be reached is determined by the difference of the angle as determined by the Diffraction Equation with the error minus the same angle without the error.

(11) $$\Delta i = \left(\arcsin\left(\frac{(\Delta\lambda + \lambda)}{p} - \sin(r)\right) - \left(\arcsin\left(\frac{\lambda}{p} - \sin(r)\right)\right)\right)$$

The resolving power of the same grating could be above one million were the grating of sufficient overall length.

We can use equation (5) to calculate the limit to angular resolution for the exampled optical flat. The resulting figure is roughly the same as the grating. It must be understood that unlike a grazing incidence mirror, which is not tolerant of unevenness, the zero-order of the grating is used to reflect light back along the normal to the surface. In other words, the angle of reflection is zero, and the error can be taken simply by doubling $\Delta\alpha$. The zero-order component will contribute only to the lateral displacement of the image into the secondary.

These calculations imply that a POG is robust with respect to the flatness of the grating surface. Moreover, creation of large flats could be less of a problem in fabrication than manufacture of VLT parabolic reflectors. The simplicity of polishing in two dimensions instead of three is self-evident.

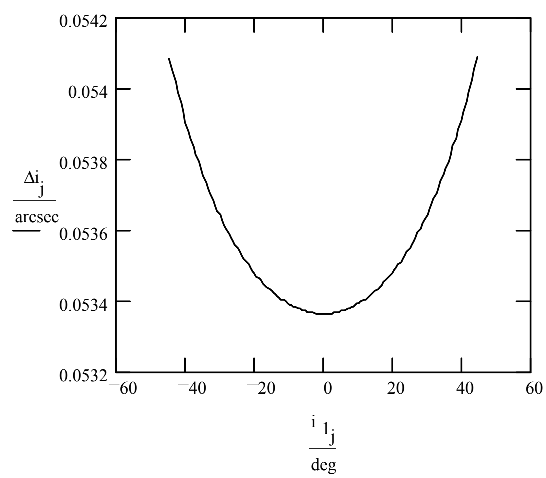

Figure 12 Angular Resolution using an optical flat

5. RESOLVING IN TWO DIMENSIONS

It may be possible to test the concept of a diffraction grating primary simply by pointing an extant telescope at a grating plane on ground level, but the theoretical limit of the lateral dimension is determined by the diameter of the secondary telescope. On the other hand, if the grating is fabricated as a two dimensional hologram, no secondary mirror is needed to form a focus.

Holography is a relatively new field of engineering. Mirror telescopes have a 400 year head start. The concept of a very large diffraction grating primary is entirely novel. Large holograms are now produced commercially to several meters in length and width. These are not holographic optical elements in the sense of diffraction equivalents to lenses or mirrors, but they do contain sub micrometer features that are extremely complex. The problem of making a hologram of a point source referenced by a plane wave is less complex than the fabrication of a life-size hologram of an automobile.

Holographic chirped frequency gratings with parabolic rules of the type formed by the interference of a coherent plane wave with a spherical wave can focus starlight to a single point from a two dimensional field. Arrays of plates that form a giant hologram of a point source can be distributed over square kilometer collection sites. The assembly can be made incrementally, changing the paradigm of "first light" from the concept of a nearly operational telescope that can only be slightly upgraded from its first use to a new notion of gradual expansion over a very long period of development. Such telescopes would gradually gain power as new holographic collection plates were installed. A schematic representation is made in Figure 13. The grating grooves and the spacing between them are microscopic and are not shown to scale.

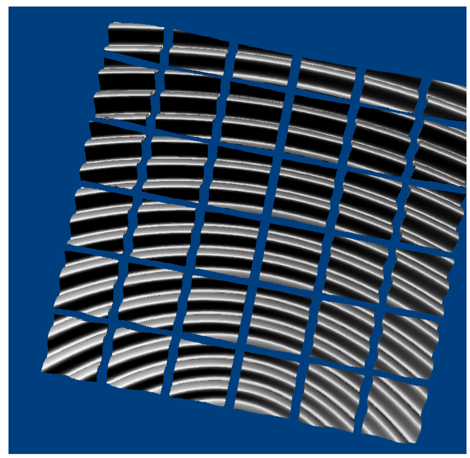

Figure 13 Grating array

If a chirp frequency grating with paraoblic rules is used in the primary, the parabolic secondary mirror can be dropped, and only a secondary spectrometer is needed. This type of chirp grating is conveniently fabricated by holographic techniques where a plane wave is referenced by a spherical wave originating from a point offset from the holographic plate. The chirp frequency grating has a pitch p such that

$$p = n\frac{\lambda}{\left(\sin(i) + \sin\left(\arctan\left(\frac{x+s}{d}\right)\right)\right)} \qquad (12)$$

where s is stand-off to the receiver
d is distance from grating plane to receiver
x is location on the grating plane

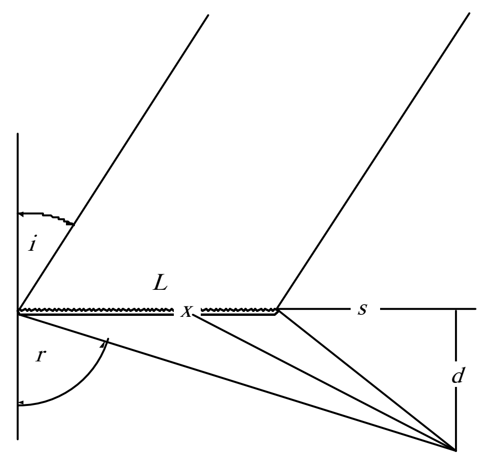

Figure 14 Variable pitch holographic grating

If a chirped frequency holographic plate with parabolic rules is used as the primary collector, its resolution is determined, in large part, by the optical system that makes it. The MTF will be affected by the pinhole in the spatial filter used to form a spherical wave during fabrication, typically around 10 microns, but theoretically much less. The angular resolution would be determined primarily by the beam divergence of the laser used in the exposure reference plane wave. Other critical factors involve precision of relay optics used in fabrication. These components could be modeled with computer simulation software and performance limits can be predicted before venturing on a program to build the device. It is interesting to note that the grazing exodus angle can be significantly elevated from the grating plane over much of the surface when the POG has a variable pitch, and this feature might prove beneficial with regard to efficiency, particularly with regard to the TE wave which is eclipsed dramatically by diffraction at grazing angles.

A special condition called evanescence occurs when the angle of reconstruction *r* is 90°. In such instances, energy is tunneled into the substrate supporting the periodic structures of the grating. Cladding on the substrate can capture the evanescent waves and transmit them losslessly to the grating edge. This concept has been studied for its applications in solar energy collection[8 & 9]. Another interesting grating architecture uses transmission gratings in a stack. The zero-order passes through the grating to grating below it. The sum of the gratings' first-orders gives the efficiency of the entire stack. When combined with evanescent tunneling, the instrument can be expected to perform with efficiency similar to a mirror of the same size.

6. MULTI-SPECTRAL IMAGING

When first disclosed, the primary objective grating at grazing exodus angles was described in terms of its applications to exo-planet discovery. The need for spectrographic data, particularly with regard to the search for life markers seemed to the inventor to serve well where interferometry and coronagraphs have less utility. However, the limited flux collection and questions about angular resolution in the non-diffraction axis led to informal dismissal of the POG concept by practiced astronomers.

One reason to pursue POG for searches such as terrestrial planet finding is that it can take spectra of all the objects in a line of ascension simultaneously. Conventional multiple object spectrographs typically use fiber optics to provide communication from the focal plane of the primary to the imaging spectrometer which is removed from the focal plane by some workable distance. In the Sloan Digital Sky Survey (SDSS) multiple object spectrometer, the fixture holding the fiber provides the entry aperture for each object, and the images chosen for spectroscopy are those that conform to the nominal size of the distal end of the fiber, about 180 μm, yielding an aperture for images that are resolved to 3 arcseconds.[10] The grism-based SDSS spectrometer is designed to have a resolving power of 2000. The key feature of the device is a quick change cartridge holding the fibers. One end interfaces with the imaging spectrometer. The other end is a plate that holds 640 fibers in positions that match the target objects at the prime focus of the 2.5 meter reflector primary objective. A study of the errors that must be overcome with this type of system has been published by Newman.[11] The plate must be drilled with great precision, and the fibers must be positioned in ferrules or held by pucks. Temperature variations in the mounting plate between manufacture and use must be predicted and factored into the production and use of the fiber plate. No object can be scheduled for spectroscopy until it is imaged and catalogued in the survey. For SDSS these factors mean that only 1% of the star catalog is slated for spectroscopy, and there is an unavoidable latency between image and spectrogram.

High resolution spectrographs are not generally conceived in terms of taking multiple spectrograms, since their slit architecture is designed to block out background radiation and provide a mask to protect illumination coming from singular objects. Slitless spectrometers produce overlapping spectra unless the primary is of very long focal length and can focus a single object into the secondary. Such a long focal length is actually possible with the grating primary, but that is not why diffraction grating primaries can take multiple spectra effectively with high resolution spectrometers. Rather the trick is performed by the intrinsic correlation of a position in the sky with its color on the ground. This feature allows all the light at any focal point of the mirror secondary to be passed to a spectrometer. The decompression algorithm applied to the full bandwidth energy reaching the secondary spectrometer identifies each target object by its wave length, and all the spectrograms are assembled temporally over the course of the night.

The numbers of objects that can be resolved simultaneously by this new design remains to be calculated, but that number will likely exceed the ~5000 per night that can be obtained by the SDSS swapping drilled plates with 640 targets per plate. With the proposed instrument, a spectrum will be taken for every object that it can image, and no special fixtures are needed. The differences between conventional multiple spectrum instruments and this new design are something like at reciprocal of each other. If the SDSS is an example, an imaging telescope can catalog 100 times more images than spectra. It is likely that the ratios would be reversed in the case of the diffraction grating primary. Moreover, the use of very high resolving powers for the secondary spectrometer works to increase the refinement of the spectra and to increase the numbers of objects that can be seen simultaneously.

CONCLUSION

The short comings of earlier grating objectives may have inhibited innovation, because the literature predicts a dead end due to extreme background noise and low resolving power. However, a novel use of grating objectives is now proposed that takes advantage of the recent developments in grating fabrication and data processing. Studies of substrate flatness, flux collection, and two dimensional resolving power suggest that these factors do not kill the idea. The contemplated instrument would take spectra both to a high degree of resolution and with a very large number of simultaneous objects. The layout of the instrument is extensible to kilometer scale collector size and can operate without moving parts. It can be made operational over an incremental development period.

Footnotes

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