

The Dittoscope

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ABSTRACT

If a collector is very large – square kilometers in size – it may be easier to fabricate flat optics than curved optics. If the primary objective is a flat diffraction grating, microscopic grooves would reshape the incident wave front rather than the 3D surface of a conventional parabolic reflector. I discuss diffractive optics that potentially can cover areas of square kilometers. The geometry of grazing incidence and evanescence allows for very large grating surfaces in ribbons or aggregated segmented modules. Diffraction grating primaries are attractive in that they are well suited for spectrographic astronomy, particularly the Doppler shift studies that have recently been useful in extra-solar planet detection. I propose a unique static mount for ground-based observations where the only moving part is the earth itself. For space-based installations, a new type of membrane telescope is disclosed that can be orbited as a roll of plastic and unfurled over multiple kilometer lengths. Holographic gratings are capable of very fine angular resolution, and only their extreme chromatic dispersion has inhibited their use. The bug is a feature. When taking spectra, chromatic dispersion is useful.

Keywords: spectroscopy, hologram, diffraction, grating, extra-solar, planet, telescope, grazing, incidence

1. INTRODUCTION

Among the classical sciences, astronomy seems unique in the longevity of its most common instrumentation, the telescope. In a brief period of enormous invention spanning not much more than a single generation during the Seventeenth century, the concepts of the lens and reflector telescopes were outlined and largely demonstrated. That was nearly 400 years ago. As modifications and improvements on these devices were introduced in subsequent years, advances were simply piggy-backed onto the original architecture of the known primary collectors. Dispersion elements were added to secondary receivers. Sensors were refined in sensitivity and band width. Permanent image recording media were invented. Mechanical systems of both great strength and delicacy were manufactured to hold and point an array of ever larger mirrors and lenses. However, strip away the innovations, and the underlying designs were consonant with instruments of Galileo and Newton.

Once spectroscopy had demonstrated its utility as a means for astronomical observation, designs based on the mirror primary could have been revised, because a spectrum is ultimately a one dimensional signal, whereas almost every mirror produces a two dimensional image. It is true that diffraction gratings, first disclosed by Rittenhouse in 1785, postdate the telescope mirror by over a century. However, little was done in the subsequent two centuries to take advantage of the diffraction grating as a primary element in telescope design.

It can be noted that sophisticated telescope designs based on Fizeau's principles of interferometry were unattainable by the technology of his own day, and Mersenne's dual parabolic reflector of 1636 wasn't realized until recently. Such latency between conceptual vision and requisite supporting technology can also be said to extend to the diffraction grating as a primary element for telescopicy, since sizeable gratings have traditionally presented fabrication hurdles that exceed those of parabolic mirrors. Construction may be an obstacle, but we cannot invoke that constraint when contemplating the future. Moreover, periodic microstructures of almost any scale can be made today by replication methods that take their cue from the printing press. Now more than ever, the question must be asked, "Can diffraction gratings be used as large primary collectors?" The literature available to the author has not uncovered any rigorous or even frivolous contemplation of this seemingly obvious question. For that reason, this paper must begin with basic principles.

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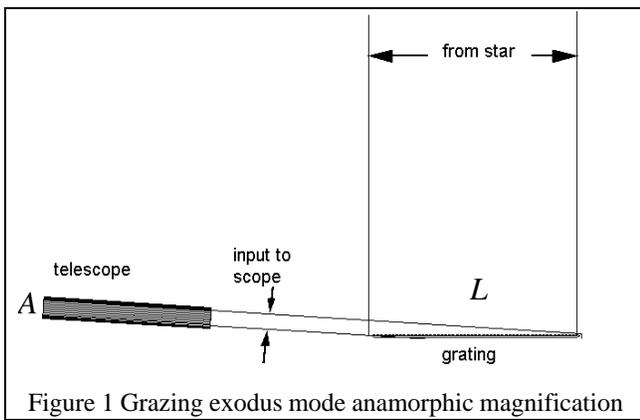
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2 COLLECTING ALONG THE GRATING PLANE

A collector is like a funnel. It provides a larger input aperture than its output pupil. The physics of lens and parabolic mirror collection are among the most widely studied topics in telescope engineering, and these venerable optical elements are perfected in their embodiments.

A plane grating can also collect periodic wave front energy along one dimension when the angle of incidence is less than the receiving angle. The effect is noted as a kind of anamorphism, a distortion which is considered to be an aberration when found in lenses or mirrors. However, for the purposes of a spectroscopy, the unidirectional effect of plane grating anamorphic magnification does not interfere with the measured variables of wave length versus intensity.

2.1 MAGNIFICATION



Anamorphic magnification of a plane grating becomes significant as the line of exodus approaches the grating plane itself. The geometry is peculiar to dispersion optics. While it is well understood that grazing angles can be realized with mirrors (curved mirror segments are used for x-ray radiation telescopes), exodus angles of mirrors must be equal to their angles of grazing incidence. With diffraction gratings, on the other hand, the angle of incidence is not constrained to the receiving angle. As a result there can be leverage. A diagram (Figure 1) of the relationship between the incident wave front and the receiving wave front in a plane grating in a grazing exodus configuration makes it clear that the aperture L at incidence can be much greater than the receiving pupil A .

For the model of Figure 1, magnification M can be expressed as the ratio of the grating length L to receiver pupil A .

$$(1) \quad M = \frac{L}{A}$$

At the zenith, for a given grating length L , and a receiving angle r there is a corresponding receiving aperture A .

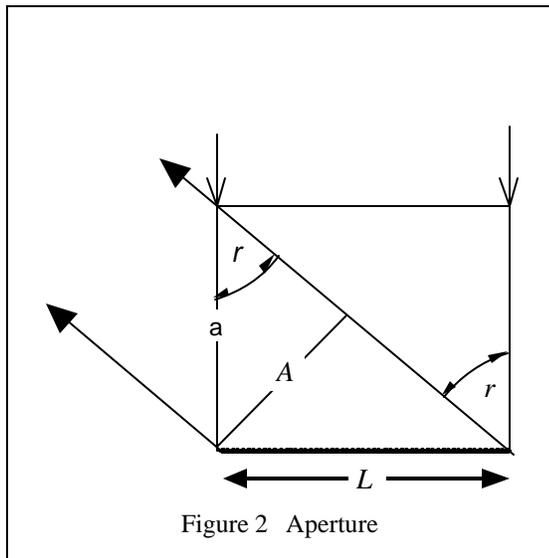
$$(2) \quad A = L \frac{\sin(r)}{\tan(r)}$$

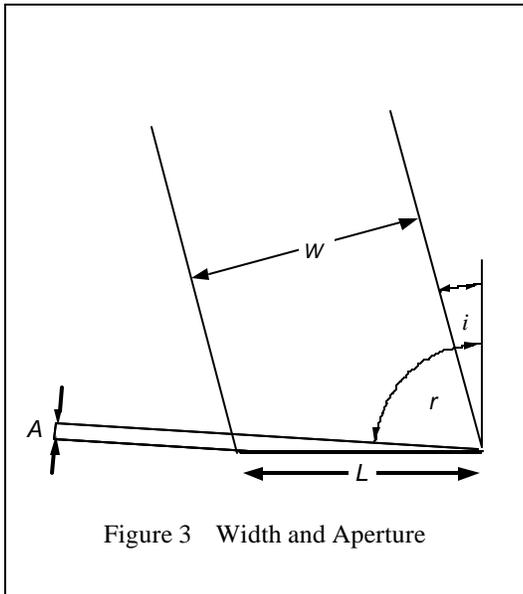
We know this because, as per Figure 2, we see that

$$(3 \text{ a \& b}) \quad a = \frac{L}{\tan(r)} \quad \text{and} \quad A = a \cos(r)$$

Similarly, when the width W of a wave front incident upon the grating of length L varies as a function of the angle of incidence, then exactly same geometry applies, and we can write

$$(4) \quad W = L \frac{\sin(i)}{\tan(i)}$$



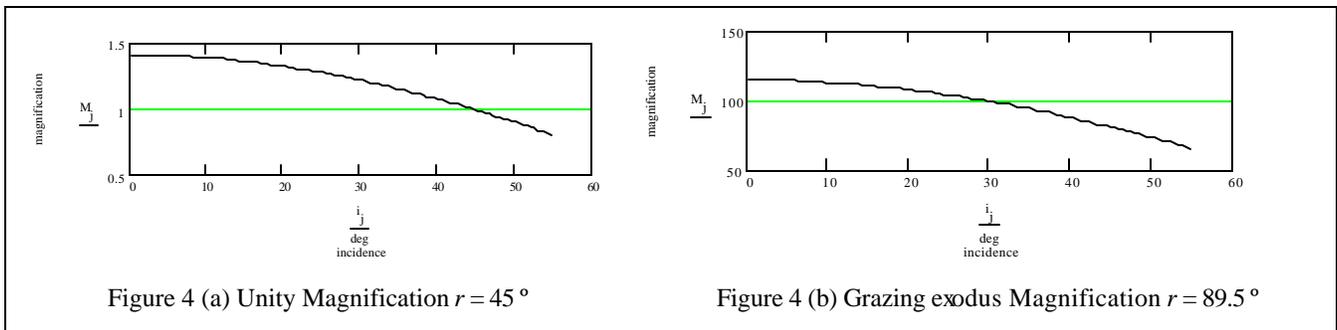


This relationship accounts for the incident angle i as per Figure 3. If the receiving angle is constant, and the angle of incidence changes, magnification can be expressed as

$$(5) \quad M = \frac{W}{A}$$

where W is a variable and A is a constant. The width of the incident wave front from a star decreases off the zenith, but we can show that when an angle of incidence is greater than an angle of exodus, there will always be an anamorphic magnification with a plane grating. Figure 4 (a) shows a near-unity magnification, and 45° is at unity, that is, when equal angles of incidence i and reconstruction (receiving) r are at 45° , $M=1$. However, at a grazing exodus angle of 89.5° we show the considerable magnification that occurs in Figure 4 (b).

We chose to calculate an excursion around the zenith. Our graphs cover $i = 0$ to 55° , one quadrant of a telescope mount. The result shown in Figure 4 (b) comports to the implication of Figure 1. A grating collector that is laid out flat will magnify stars in transit above.



2.2 SCALE OF A GRAZING EXODUS COLLECTOR

Sighting a surface from a grazing angle vastly stretches the length of the surface visible to a secondary receiver. Admittedly, a grazing angle collector area does not expand as the square of the length whereas mirror area does expand as the square of the mirror radius. However, in the grazing exodus configuration, length stretches exponentially with the angle off the normal. At evanescence (the angle at which diffracted waves are radiated directly into the substrate of the grating itself) the length of a grating that is visible to a secondary receiver has no finite length.

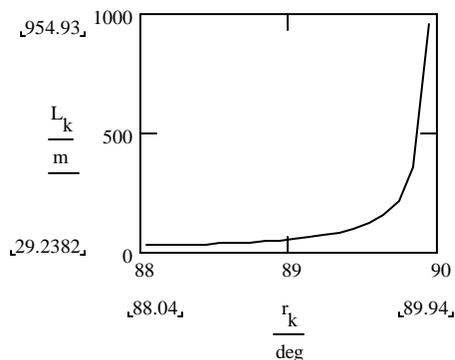


Figure 5 Grating length vs grazing angle with a one meter aperture

Change in length is linear with respect to aperture A , but L changes exponentially with respect to r . Figure 5 is a graph of L vs. r where the secondary is a one meter collimating collector. This shows that in the grazing exodus configuration, where r approaches 90° , kilometer length gratings can be imaged by meter width secondary apertures. Since the parameter of aperture A is linear as per (6), a Keck scale 10 m mirror used as a secondary collector would alter L in

The geometry of grating size is dictated by the grazing angle and the size of the secondary receiver. Rewriting (2) we can say

$$(6) \quad L = A \frac{\tan(r)}{\sin(r)}$$

Figure 10 by an order of magnitude, that is, at 88° grazing exodus, grating length would be 300 m, and at 89.94°, a secondary of Keck scale would encompass a grating of length 10 kilometers. Multiplying by collector width, the corresponding collector areas would be 3,000 sq. meters at 88° and 100,000 sq. meters at 88.94°. By way of contrast, the Keck, itself, has a primary collecting area of only 80 sq. meters. It is the largest optical telescope ever built.

3 SPECTROSCOPY

Spectrometers are seemingly an afterthought in telescope design. Historically, Newton demonstrated dispersion contemporaneously with the reflection collector. He used a prism, which exhibits anamorphic magnification similar to the diffraction grating, but this feature was not developed. Perhaps fabrication of a large prism was prohibitive. In any event, since then spectroscopy has been instrumental in astrophysics where it has the functions of determining the composition of stars, their distances, rates of motion and the detection of exo-planets; yet spectroscopy does not dictate telescope design. If a telescope was designed exclusively for spectroscopy, there could be a collector design based on dispersion.

3.1 TEMPORAL SPECTROSCOPY

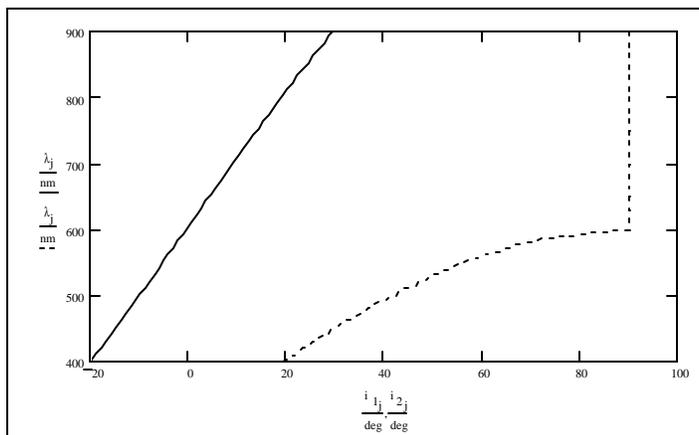


Figure 6 1st- and 2nd-order incidence angles for 400 - 900 nm

The Grating Equation is

$$(7) \quad \sin(i) + \sin(r) = n \frac{\lambda}{p}$$

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

Hence with λ as the variable we can write

$$(8) \quad i = \arcsin \left[n \frac{\lambda}{p} - \sin(r) \right]$$

By way of example in Figure 6 we graph for two orders the angles of incidence i vs the dispersed wave lengths λ for a grazing exodus $r = 88^\circ$ using a grating which has a ruling pitch of $p = 600$ nm.

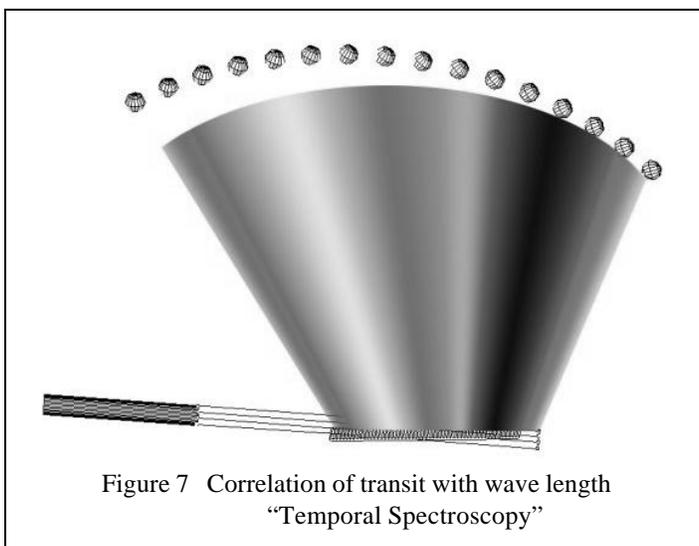


Figure 7 Correlation of transit with wave length
 "Temporal Spectroscopy"

When a star transits, at any moment in time t , it will diffract a unique wave length from a grating configured in grazing exodus. This is temporal spectroscopy.

The movement of the earth provides the necessary change in incident angle to identify any star at any point in time by its wave length at the receiver. The concept is illustrated by the diagram in Figure 7. In the example of Figure 6 covering a nominal $\pm 20^\circ$ arc, 2.5 hours of sidereal time t will elapse while a star passes through the spectrum visible to a silicon photo diode. Under the constraints of the example illustrated in Figure 6, for wave lengths 400 nm to 800 nm, a star in the Great Circle would alter its wave length at the receiver by $1 \text{ \AA} \Delta t = 2.33$ seconds of time, or in alternative units, 1 nm per 23.3 seconds.

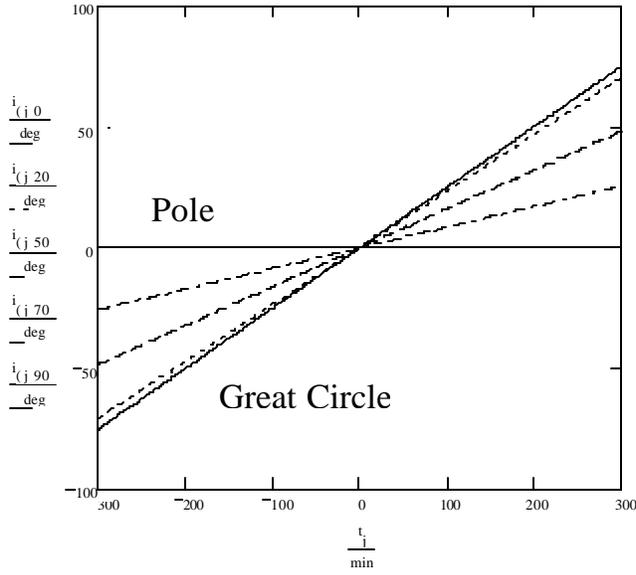


Figure 8 Angle of incidence

Figure 9 illustrates the dwell time of a 600 nm pitch grating. A pole star will dwell on a single wave length, but for most angles of declination, broad spectra can be taken. At the zenith, 20 nm to nearly 1200 nm wave lengths are reconstructed at the receiver. The graph shows steps of 20° in the declination. There are broad spectra available almost to the pole star where only a single wave length can be collected. As a positive trade-off, it can be argued that the narrowed spectra of polar circle stars offer longer exposure times over their shortened spectral ranges. When grating pitch is chosen for bio-metric sampling, exquisite spectral detail can be seen in polar stars over the narrowed range of wave lengths.

The diffraction primary collector must be declined to the circle of transit for an observed star, and the declination will affect the transit angles. If the transit angle i is set to $i=0^\circ$ for midnight, then for angles of declination β we can say

$$(9) \quad i = 2\pi \frac{t}{T} \cos(\beta)$$

where t is time of day and T is length of day

In Figure 8 we compare the angle of incidence for five discrete angles of declination from the zenith (Great Circle) to 90° (Pole). These angles of incidence will report spectral wave lengths as per the equation

$$(10) \quad \lambda = \frac{(\sin(i) + \sin(r))}{n} p$$

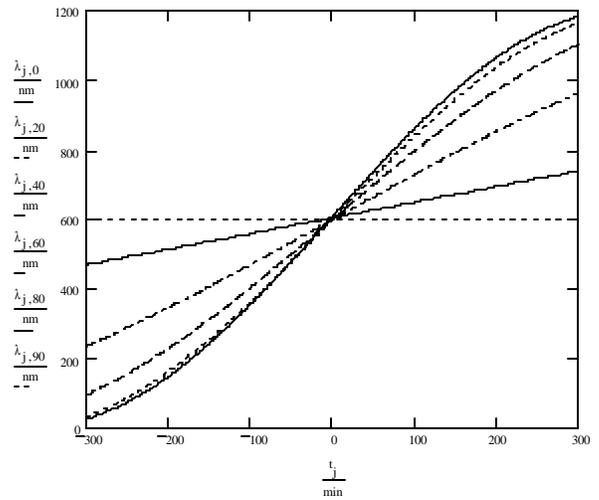


Figure 9 Wavelengths over a 10 hour night

3.2 RESOLVING POWER

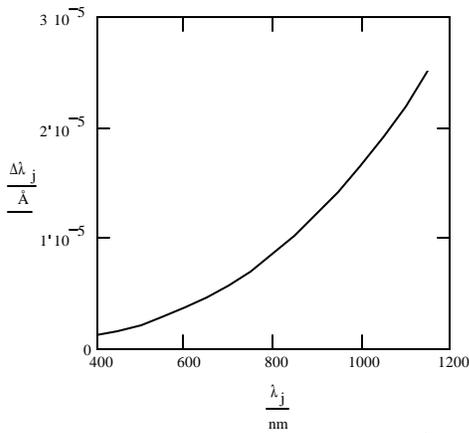


Figure 10 Discernable spectral spacing in Å

If perfectly ruled on a perfect surface, grating resolving power R is directly proportional to grating length and inversely proportional to wave length.

$$(11) \quad R = L \frac{(\sin(i) + \sin(r))}{\lambda}$$

Contemporary large grating spectrometers such as the HIRES spectrometer on Keck I boast resolving powers in five figures, and this has been deemed a practical benchmark, since it can measure the Doppler moments for radial velocities of stellar spectra in meters/sec. By way of contrast, gratings of kilometer length would have theoretical resolving powers in nine figures. In Figure 10 we graph the theoretical spectral separation possible with a kilometer length grating of 1650 lines per mm ($p=606.06$ nm) in the spectral range recorded by garden variety silicon photodiodes. Theory predicts resolution on the order of $1/100,000$ Å.

It can be argued that the enormous theoretical resolving power of a very long grating has no utility, but regardless of any potential application against which its power might be used, a large grating does provide a substantial amount of overhead

for a less than perfect surfaces. The *Diffraction Grating Handbook* tells us “Any departure greater than $\lambda/10$ from flatness for a plane grating, or sphericity from a concave grating, will result in loss of resolving power.”¹ Unfortunately, this reference does not cite the length over which the $1/10^{\text{th}}$ wave must be maintained or what the loss would be.

Without a textbook to guide him, the author here attempts a description of the error introduced by an uneven grating surface. This calculation assumes that only the wave front at the angle of reconstruction r can be received at the secondary. In a corresponding assumption, the angle of incidence i relative to the baseline is restricted to a single fixed value, as would correspond to a star target. However, a rotation of the grating $\Delta\alpha$ which can be expressed in wave lengths d over distance L is an independent variable that controls the possible error $\Delta\lambda$ at the receiver.

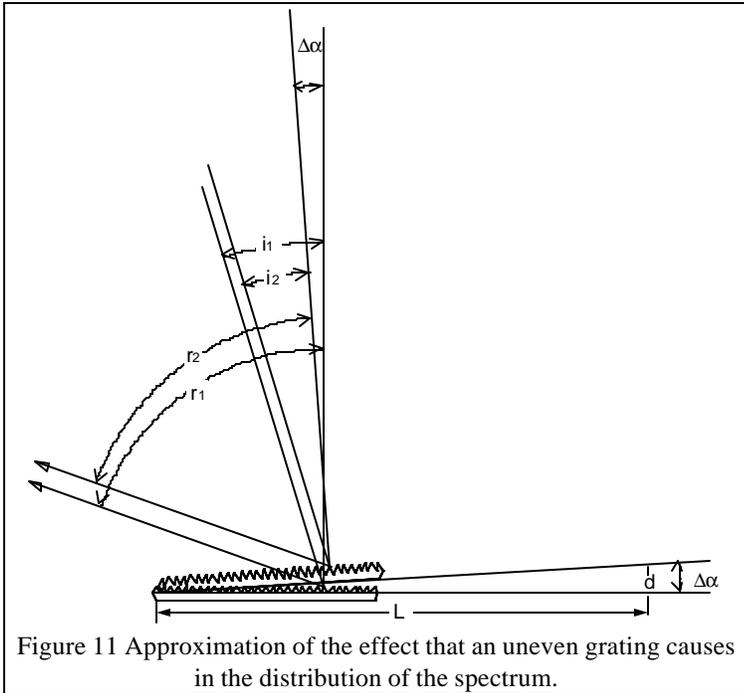


Figure 11 Approximation of the effect that an uneven grating causes in the distribution of the spectrum.

$$(12) \quad \Delta\alpha = \arctan\left(\frac{d}{L}\right)$$

Given the rotation of the grating, there are altered values i_2 and r_2 that reconstruct a separate wavelength λ_2 at the receiver such that

$$(13) \quad \lambda_2 = \frac{(\sin(i_2) + \sin(r_2))}{n} p$$

For any λ reconstructed along the flat baseline with unaltered angles of incidence i and reconstruction r there is an error $\Delta\lambda$

$$(14) \quad \Delta\lambda = \lambda - \lambda_2$$

Given a real world value to surface flatness of 8 waves per inch, the worst case for garden variety float glass, we have determined the localized error within wave lengths reconstructed at the receiver to be less than one Ångstrom. The detailed calculation is self-published.² A predicted error in wave length for this rough grating is

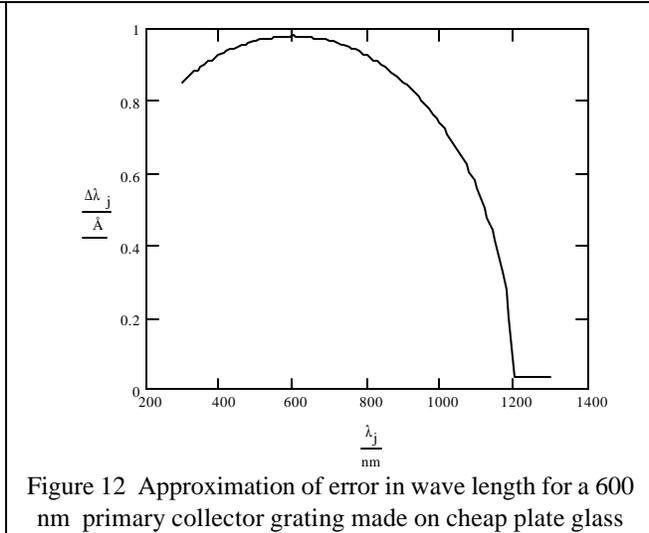


Figure 12 Approximation of error in wave length for a 600 nm primary collector grating made on cheap plate glass

illustrated in Figure 12. The calculation assumes a grazing exodus angle of 88° , and this restricts reconstruction of wave lengths longer than 1200 nm at any angle of incidence for the example grating. The prediction conforms to expectation, because the error is greatest at the zenith where phase error in wave length caused by surface roughness would be most noticeable. This approximation does not pretend to refute all skeptical critiques about the effects of surface roughness, but it does address the question of localized resolving power. To extend this calculation over grating lengths of kilometers would require a detailed assessment of what happens at the secondary where these errors accumulate. A related analysis addresses the effects of localized phase error. See Section 4.1, Figure 17, below.

3.3 EFFICIENCY

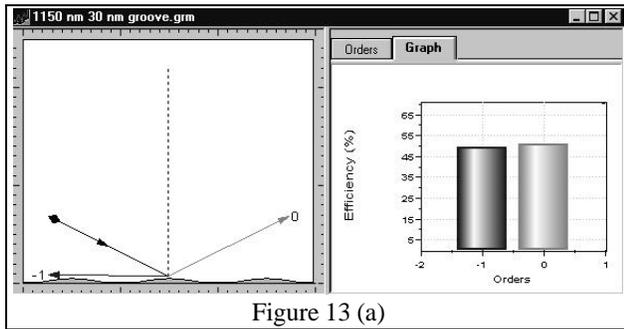


Figure 13 (a)

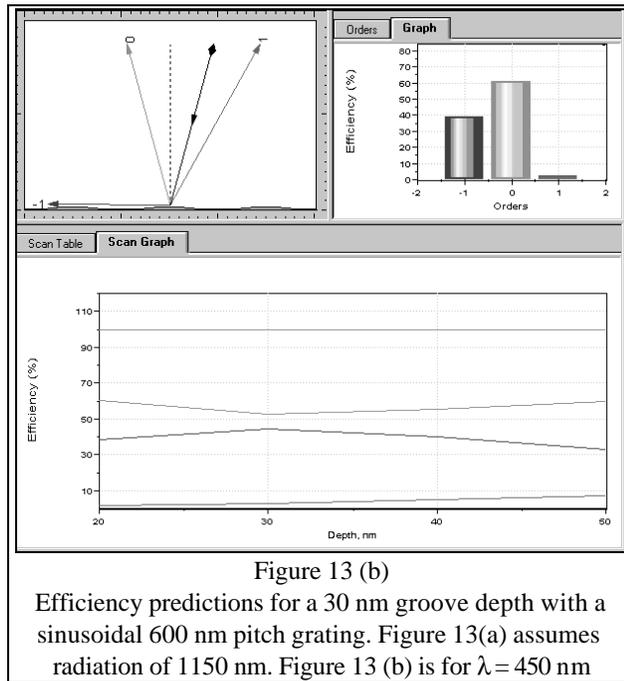


Figure 13 (b)

Efficiency predictions for a 30 nm groove depth with a sinusoidal 600 nm pitch grating. Figure 13(a) assumes radiation of 1150 nm. Figure 13 (b) is for $\lambda = 450$ nm

If transmission gratings are used, then zero-order radiation passes largely untouched through the grating. If secondary transmission gratings and/or a terminal reflection grating are positioned to receive the passed zero-order, the efficiency of the primary collector can be increased to the net of all layers in the grating stack. With many layers, the effective efficiency of the stack could approach 100%. A stack of collectors is illustrated in Figure 14.

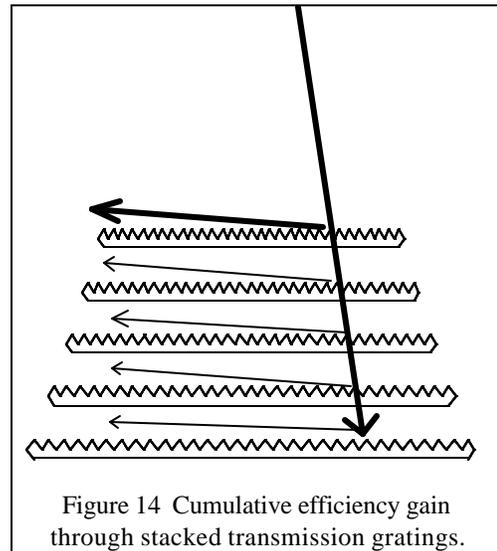


Figure 14 Cumulative efficiency gain through stacked transmission gratings.

Additionally, the effective efficiency can be increased by placing secondary receivers to both sides of the primary. The behavior of the two would be symmetrical, each taking spectra in reverse as a function of time of night. Secondary design has many alternative configurations that could improve the utilization of the available diffracted radiation. Among these alternatives are secondary spectrometers of conventional design which would distribute all incident radiation into spectral bands. With such secondaries, the aforementioned restrictions of dwell time would still apply, but entire bands of stars would be detected simultaneously. The sum of all starlight incident upon the grating would better utilized. Surveys for exoplanets which now require wide angle telescopes sacrifice resolution in order to encompass a field of stars. A Dittoscope with a spectrometer in the secondary would not sacrifice resolving power, and more available light is used.

The collection of radiation is the principal job of a primary objective, and compared to a well realized mirror, diffraction gratings have poor efficiency. Grating efficiency can be estimated using Maxwell's equations, and these have been coded into the iterative numerical approximation program PCGrate³. A disclaimer from the programmers warns that grazing incidence is a special case, so results must be taken with a grain of salt. In some respects reconstruction of wave front interference along the grating plane is little different than at the normal, but polarization swings are not regular. When gratings with low ratios of $p:\lambda$ are used, and the reconstruction $r \cong 90^\circ$ PCGrate is not reliable. However, empirically, the efficiency of the surface relief embossed holographic gratings does not disappear near grazing exodus, and I believe that the failure of the calculation is less in the predicted efficiency than in the predicted groove depth. For what it is worth, a model of a Dittoscope type of grating in reflection mode, without consideration for surface conductivity, showed 40-50% efficiency over the visible spectrum. Sample calculations appear in Figures 13 (a & b).

4 EMBODIMENTS

Some of the assumed components in spectrometer design such as slit, collimator and cross dispersion do not apply to the Dittoscope, at least, not as they are understood in conventional spectrometers where the spectrometer is the secondary and a mirror is the primary collector. To start with, the incident wave front is nominally a plane wave with its source tens of light years distant from the grating surface. In a conventional astronomical spectrometer, a slit is used to create a spatial filter, and a collimator mirror must be employed to flatten the wave front following the slit. When the grating is the primary collector, nature has already made the plane wave. If the primary collector grating is a first-order type, such as a holographic grating, high-order cross dispersion is not needed. Thanks to the large free spectral range of first-order types such as conventional holograms, any interfering second-order can simply be masked out. Because of its size, there are significant atmospheric distortions in the wave front reaching terrestrial versions of the Dittoscope, and while the resultant wave front distortion must ultimately be addressed, perhaps by adaptive optics, these refinements are beyond the scope of this initial disclosure. The problems are probably no worse than for mirror primaries.

4.1 SECONDARY RECEIVER

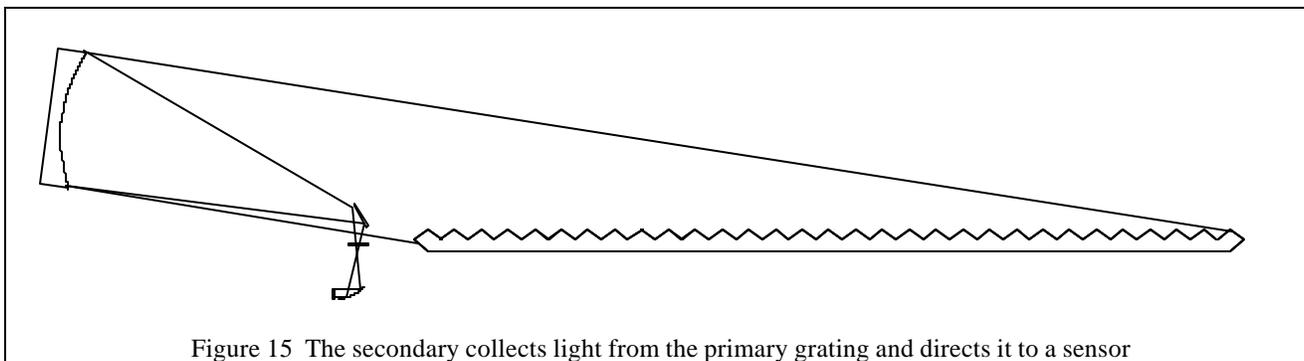


Figure 15 The secondary collects light from the primary grating and directs it to a sensor

For any star in the received band of stars there is a unique wave length for time of night, and these wave lengths must be processed in the secondary so that stars can be discriminated from each other. In the diffracted axis, the discrimination between stars is made on the basis of wave length, because every star has a known wave length as a function of time of night. The window in the non-diffracted axis must be narrowed to occlude adjacent stars along the axis of declination. This masking function in the non-diffracted axis is similar to “decker plates” found in some telescope spectrometers, “the decker's principle use is to mask out unwanted stars that might lie on the slit.”⁴

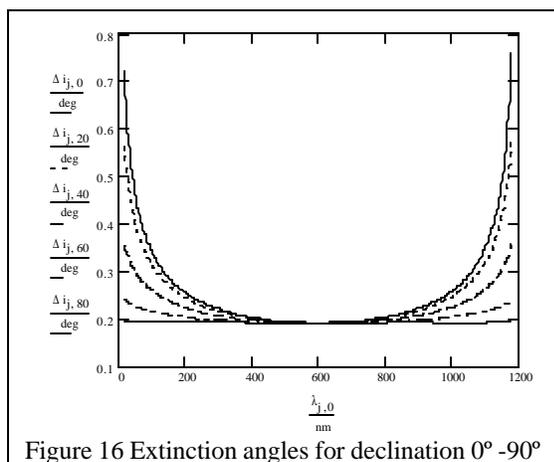


Figure 16 Extinction angles for declination 0° -90°

grating.

Unlike conventional telescopes that must discriminate planets on the basis of their angular separation from their host star, the Dittoscope makes the discrimination of exo-planets on the basis of the Doppler shifted spectra within the star's spectra. In order for the planets' spectra to be taken, competing stars near to the same angular separation must be masked out. One approach is to band pass filter the wave lengths received at the secondary. The band pass must be altered dynamically. There are filters based on birefringent polarization that vary the angle of a liquid crystal under a control voltage⁵. Such filters have extinction windows of 20 nm to 2 nm and transmission losses of 50 to 80%. A band pass of 10 nm will extinguish competing spectra within 2° over 90% of a star's transit, and a band pass of 2 nm will narrow the window to better than 0.25° over 90% of the acquired spectra. Figure 16 uses the example of a 2 nm bandpass and a 600 nm pitch primary collector

The variable band pass method of star selection can be bettered by a more complex secondary which houses its own conventional spectrometer. This approach promises significant utility, because it would allow sampling of all visible stars simultaneously. The temporal spectroscopy principle dictates that for any frame time Δt stars will be identified by their corresponding wave length. A two-dimensional motion picture of the changing spectra recorded by such a secondary can be converted into the temporal spectrographs of all stars visible within the acquired line of declination. A spectrometer secondary would permit isolation of planetary targets within the spectra of a star. We have shown that the resolving power of a kilometer length grating can be parts per billion. This could be dismissed as overkill when stellar surface turbulence swamps finer measurements than m/sec that can measured with resolving powers well below 1 million. However, in the case of the Dittoscope, the very fine grain of spectral resolution can distinguish a planet from a background star or galaxy. Moreover, this very fine wave length discrimination could be used to distinguish exo-planets from each other as well as from their own satellites.

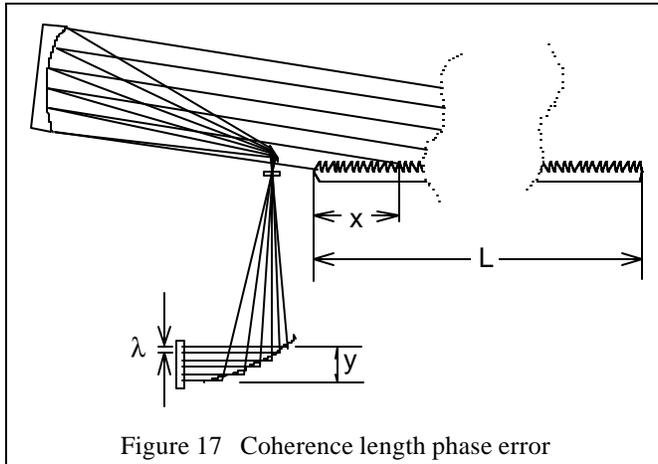


Figure 17 Coherence length phase error

The secondary receiver design plays a role in determining the error introduced by phase errors in the primary collector grating. The ray path from grating to secondary collector to sensor can be subdivided into segments spaced by the distance of a single wave length (Figure 17). Phase errors outside these segmented steps will not affect the amplitude of the energy recorded by the sensor. If the sensor is a strip of considerable length y any wave length segment λ can be mapped back to the grating of length L to determine the incremental steps x over which phase error must be within tolerance. The relationship is

$$(15) \quad x = L \frac{\lambda}{y}$$

By this analysis, gratings of kilometer length L would require localized phase coherence over each 3 mm of grating length x for detection of $1 \mu\text{m}$ radiation λ , if the sensor enjoyed a considerable length y equal to 0.3 m. Linear sensors of 12 inches are commonplace today in certain flatbed scanners that use hard bars of integrated CMOS sensors and LEDs. Typical conversion is 14 bits of flux. Cell density is typically 600 dpi for red, green and blue, making the total sensor density over 1 foot about 14,000 cells. Summing the 14 bits of flux 14,000 times suggests that a garden variety flatbed scanner would provide spectral intensities accurate to one part in 100 million. This is inside the ball park for exo-planet detection in the full glare of the host star.

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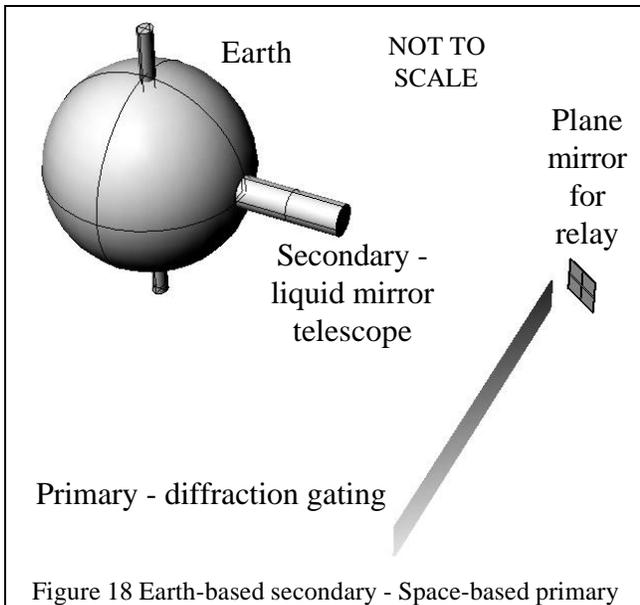


Figure 18 Earth-based secondary - Space-based primary

It is interesting to note that since the secondary can consist of a conventional telescope, the primary collector and the secondary to need not be located in the same place. In one configuration, the secondary is ground-based while the primary is in earth orbit. This allows a single primary collector to be shared by many existing ground-based telescopes. The pointing aerobatics required of the space-based primary are non-trivial, but given the potential for a very large primary, it can be argued that a geo-stationary grating would provide a full-field target for a contemporary earth-based astronomical telescope. One type of large reflector that cannot itself be pointed is the liquid mirror zenith tube. If such a telescope was the secondary, and the primary was in geo-stationary orbit, the rotation of the earth would provide scanning over the spectra. The configuration probably would require a space-based relay mirror which would be the target of the fixed earth-based secondary (Figure 18).

4.2 PRIMARY COLLECTOR

There are several features that make the Dittoscope worthy of a rigorous study, even if a grating method proves to be relatively inefficient at collecting star light per square meter when compared to mirrors.

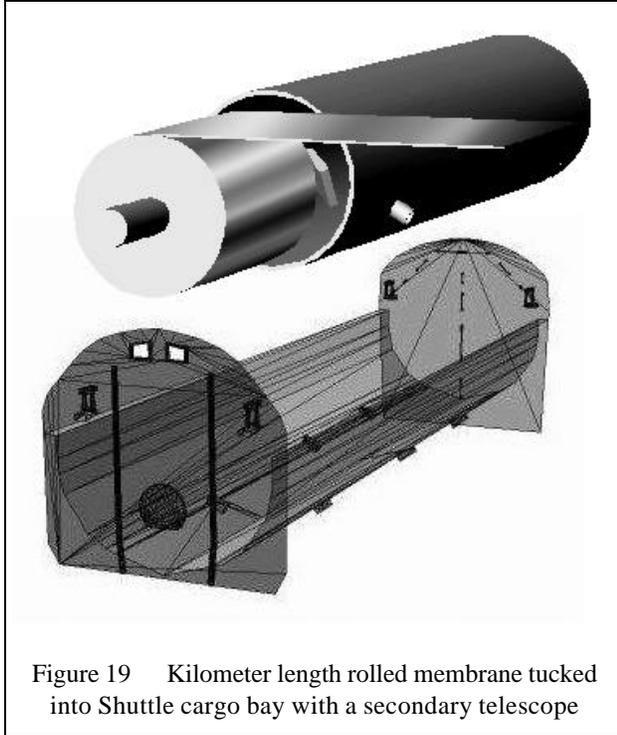


Figure 19 Kilometer length rolled membrane tucked into Shuttle cargo bay with a secondary telescope

First, the diffraction grating primary collector is a flat optic. This two dimensional geometry lowers fabrication hurdles that affect 3D optics such as large scale parabolic reflectors. We have shown here that the tolerance specification for flatness in the axis of diffraction may not be prohibitive; even plate glass can be contemplated. As a result, it may be possible to make very large collectors at a reasonable cost. Additionally, in space-based deployment, the benefit of a long but narrow flat collector is that rolls of kilometer length membrane can be stowed on-board the Shuttle (Figure 19). Inertial devices and induced centrifugal forces might be used to flatten such ribbon collectors once they are deployed.

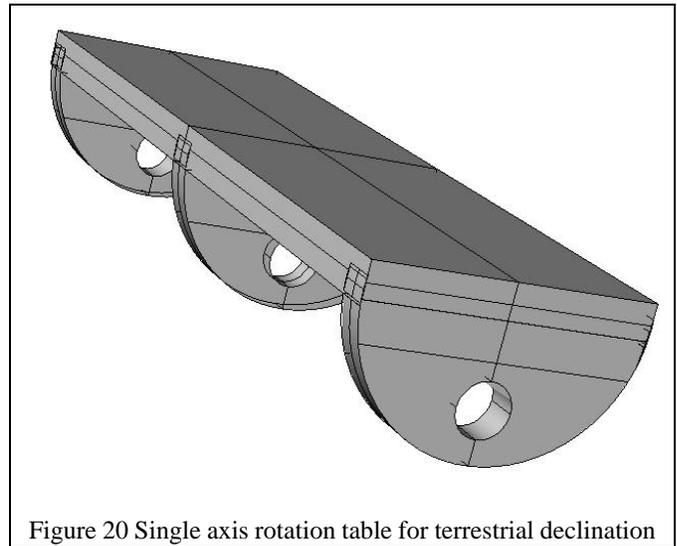


Figure 20 Single axis rotation table for terrestrial declination

A second feature is that in terrestrial installations the collector does not need to be moved during observations, because the rotation of the earth provides the requisite change in incident angle to acquire spectral sequences over time. The diffraction grating primary must tilt to obtain an angle of declination (Figure 20), but once that angle is established, the grating can be locked down. As it happens, this rotation is along the narrow waist of the grating. The longer dimension of a grazing exodus telescope does not need to tilt. The mechanics work out to benefit very long and narrow collectors, and this geometry matches the grating shape as dictated by grazing exodus.

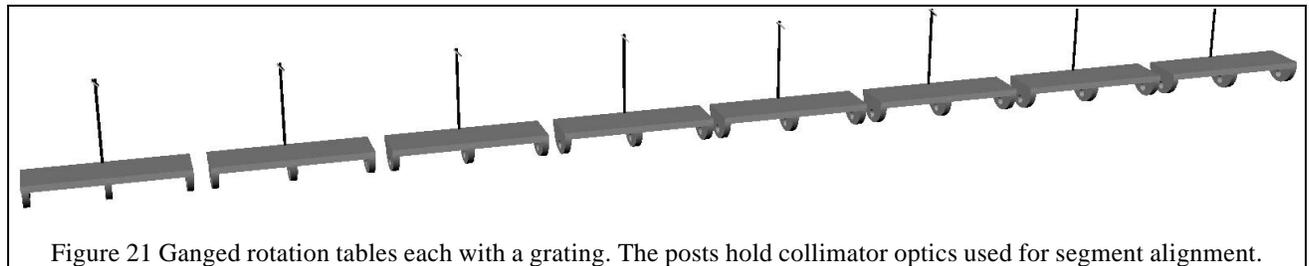


Figure 21 Ganged rotation tables each with a grating. The posts hold collimator optics used for segment alignment.

A third feature of a Dittoscope is that it can be conveniently segmented. A very large collector can be constructed from thousands of identical smaller gratings on individual supports. Groups of tables might take the shape of the illustration in Figure 21. Each table could support glass substrates for the grating elements. Piezo positioners or other micro-adjusters would be used to slide gratings into alignment relative to each other. Alignment of disparate segments could be achieved

using a laser that targeted a test patch on each grating. The laser would work like a collimating laser. The adjusters would be used so that a calibration wave length appeared superimposed at the same position of the secondary sensors. This suggests planet finder projects where telescopes grow incrementally, starting with demonstration models in the 100 sq. meters, followed by working versions for bright stars in the 10,000 sq. meter scale, and finally imaging faint targets using square kilometers of collector built from modules as small as 1 sq. meter.

Materials used in grating fabrication have proliferated over the past century to the point that diffraction gratings of very high quality can be seen everywhere. Integrated circuits are fabricated with rulings that could meet astronomical specifications for regularity and blaze. Decorative embossed gratings are made in rolls as large as 50,000 foot length by five foot width costing approximately \$1 sq/ft. These include the Holosheen grating made by Spectratek.⁶ In a world where large telescope primaries cost millions per square meter, such grating materials are virtually free. Even commonplace compact discs and DVD's are diffraction optical elements that can take coarse absorption spectra.⁷ Every hologram of a 3D surface is a diffraction grating of extraordinary complexity. A hologram of two plane waves or a point source and plane wave, the types being discussed here, can be mastered on the bench where slow emulsions and vibrations are less of a challenge than with typical 3D subjects. Angular resolution of point source or plane wave holograms is limited by the angular resolution of the laser, and lasers achieve the diffraction limit at their wave length.

One type of holographic grating that merits study is the edge-lit hologram. Conceived in terms of a display medium and then further developed as a means of illumination for LCD displays and fingerprint stations⁸, in the Dittoscope this type of hologram provides an extremely high angle of grazing exodus. The edge lit hologram has a substrate that serves as a light pipe. Diffracted light is tunneled into the substrate near the evanescent angle, and the trapped waves exodus at the distal end (Figure 22). In such a device there is no secondary mirror. The edge illumination is sampled directly by a sensor. Identical modules of evanescent wave receivers would be in a collection "farm" for star light. In a configuration that studies one star at a time, the target is segregated from other stars using a blocking plate in the non-diffracted axis and a variable bandpass filter along the axis of diffraction. The sensors can be sensitive to photon events. While it is true that the photons captured must be at the wave length that conforms to the star's angle of incidence, there may be enough photons arriving to allow exoplanet detection and spectrographic characterization when large arrays of evanescent receivers cover square kilometers. The modularity of such a device suggests economies of scale in mass production.

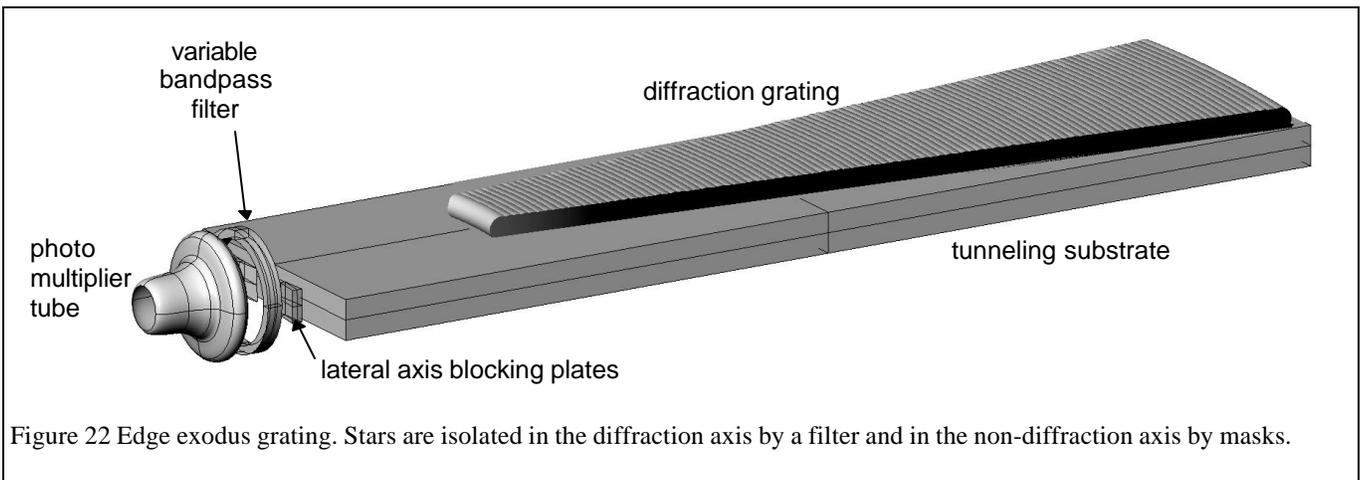
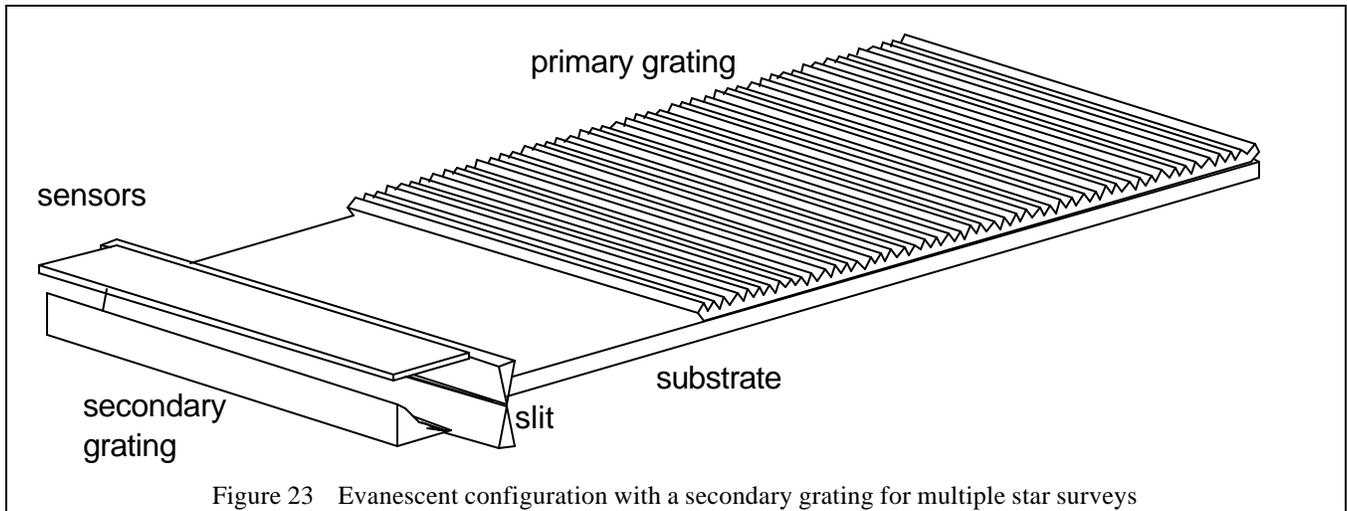


Figure 22 Edge exodus grating. Stars are isolated in the diffraction axis by a filter and in the non-diffraction axis by masks.

A related configuration of grazing exodus collector (Figure 23) could be used for surveys. Rather than block adjacent stars from view, it provides for a continuous 2D spectrograms where lateral position corresponds to the non-diffracted axis whilst instantaneous wave length would be identified with a star's corresponding angle of transit at that point in the night sky. Narrowing lateral field-of-view would probably require a cylindrical surface (not illustrated).



CONCLUSION

The economics of very large collectors favor diffraction. There are expenses associated with the mounts, but the mechanical complexity is reduced to a single axis which is static during observation runs; the support structures are load-limited thanks to segmentation; the substrates are flat, and tolerances for flatness are only sub wave length in the non-diffracted dimension. Experimentation can be ramped up from a demonstration to a practical observatory in discreet incremental steps, thereby limiting risk.

The Dittoscope is not a telescope for imaging in two dimensions, but it will provide exquisite spectra suitable for exo-planet discovery as well as for conventional velocity detection and chemical spectral analysis.

ACKNOWLEDGEMENTS

This research has been supported by DeWitt Brothers Tool Company, Inc. Mike Metz of ImEdge Technologies helped proof read it. Its presentation at SPIE's Astronomical Telescopes and Instrumentation Conference was underwritten by my sister, Alice Pero, a poet who follows her stars.

¹ http://www.thermo.com/eThermo/CDA/Technology/Technology_Detail/0,1213,1-11984-152,00.html#REsolvingPower

² http://www.drillamerica.com/PDF/plate_calc.pdf

³ www.pcgrate.com

⁴ <http://cosmos.colorado.edu/sbo/manuals/24inch/spectrograph.pdf> p. 7

⁵ http://www.cri-inc.com/products/imaging_varispec.shtml

⁶ <http://www.spectratek.net>

⁷ <http://www.astroman.fsnet.co.uk/begin.htm>

⁸ <http://www.imedge.com>