Kilometer area telescope collector deployable in a Shuttle payload

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ABSTRACT

We propose a space telescope that has a diffraction grating as its primary objective element. A membrane grating in the shape of a ribbon could enjoy collection areas above a square kilometer. This novel configuration would be particularly useful for very high resolution spectrographic astronomy as required in Doppler shift searches for extra-solar planets due to its very wide aperture in the one dimension used for dispersion and its unprecedented spectral resolving power. Rolls can be stowed in the payload bay for Shuttle delivery into orbit, then unfurled and kept flat using inertial guidance from gyroscopes and centrifugal forces. The large primary collector would not require formation flying since the membrane would provide a mechanical tether. We suggest experiments to establish feasibility of the deployment. We also suggest studies for the tensile mechanics and environmental stresses on the device. Our analysis investigates the parameters of surface flatness, membrane thickness, metallic coating conductivity, grating period, groove blaze and depth. We analyze options for fabrication such as roll embossing of multiple-kilometer length membrane substrates. We also consider an evanescent mode grating in a transmission medium which can be formed using methods now commonplace in telecommunication fiber optics.

Keywords: membrane, telescope, diffraction, grating, embossing, grazing, evanescence, spectroscopy

INTRODUCTION

Membrane substrates have been contemplated as the most cost effective materials for space telescopes. However, it has been difficult to force membranes to take the classical reflector shape of parabolic dish, especially to the figure expected of astronomical telescopes. Inflatable structures must cope with outgassing and an obscuring cover over the primary optic. It proved difficult to find plastics that possess uniform thickness equal to the sub wave flatness required in diffraction limited astronomical mirrors. Maintaining a mirror's figure in the hostile space environment presents challenges too. As research and development continued over the years, designers turned to exo-skeletal frames that held membranes in place. These metal structures were not nearly as cost effective as the membranes themselves. Packaging for stowage in the Shuttle Bay requires disassembly. Space assembly of struts and trusses and subsequent stretching of the vulnerable membrane itself seems risky. One project funded by NIAC that was to develop a membrane mirror then changed course mid-stream and works now with extremely thin spun glass reflectors that are rigid, if brittle.

To gain maximum angular resolution from minimal parts, complex segmented space telescopes are being planned. These require formation flying of disparate elements which, when combined, form either a single focal point or can be linked by the principles of interferometric telescopy. However, these modules do not greatly increase collecting area, they just make better use of the collectors that are in a group. When the available energy from exo-planets is 1/10 photon per square meter/sec, direct observation would be impossible without very long exposures, even with the benefit of interferometric nulling or coronagraphic masking, if these technologies can be made to work at all in space.

The chemical composition of stars, the red shift of galaxies, and the recent discovery of exo-planets are all based on what could be called "spectronomy," a specialized form of telescopy that results in one dimensional spectrographic signatures. Yet despite the enormous utility of spectroscopy in astronomy, telescope designs remain as they were 400 years ago with primary collectors that were intended to magnify a two dimensional image for the human eye. If expansion of primary collector real estate is a key goal in the design of space telescopes, and the intended function of the telescope is spectroscopy, then, the options include using diffraction gratings as primary collectors.

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1 DIFFRACTION GRATING AS PRIMARY COLLECTOR

The active portion of a diffraction grating is a microstructure, and typically the greatest mass in a diffraction grating is devoted to its substrate. In space applications where “gossamer” structures are desirable, the diffraction grating would seem be a suitable candidate for a large primary collector. The enormous chromatic aberration of diffraction may have been historically a disincentive for the use of a grating as a primary objective, but the bug is a feature where the output of the telescope is a spectrogram.

1.1 MAGNIFICATION

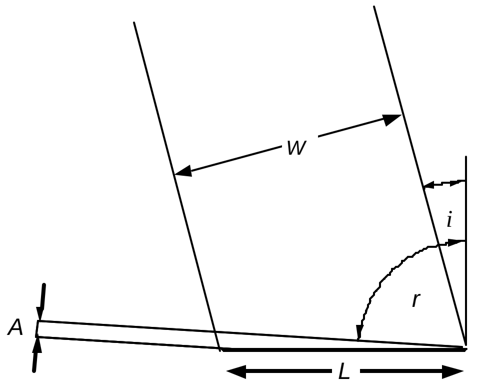

Figure 1 Waist and Aperture

Humble plane gratings with fixed rules can be used as magnifiers. The magnification is along the axis of diffraction and is completely anamorphic. Where W is the waist of a wave front striking a grating of length L and A is the aperture of a receiving pupil, the magnification can be characterized as

$$M = \frac{W}{A} \tag{1}$$

The power is a function of the relative angles of incidence i and reconstruction r. If $r > i$ then $M > 1$. We can see from Figure 2 that

$$w = \frac{L}{\tan(i)} \quad \text{and} \quad W = w\cos(i) \tag{2 a \& b}$$

Hence,

$$W = L\frac{\sin(i)}{\tan(i)} \tag{3}$$

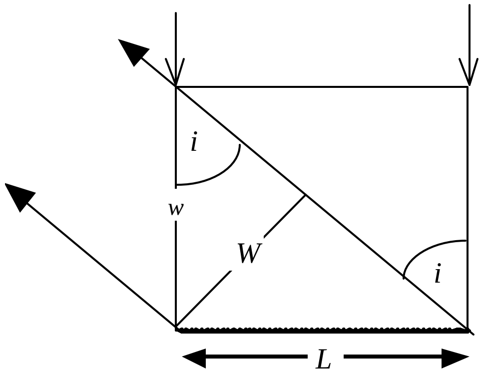

Figure 2 Waist changes as a function of i.

The same relationship governs A. As one would expect, if $r = i$ then $M = 1$. The region around unity magnification is graphed in Figure 3a. However, if r approaches 90º, then A approaches 0 , and the magnification increases by orders of magnitude, Figure 3b.

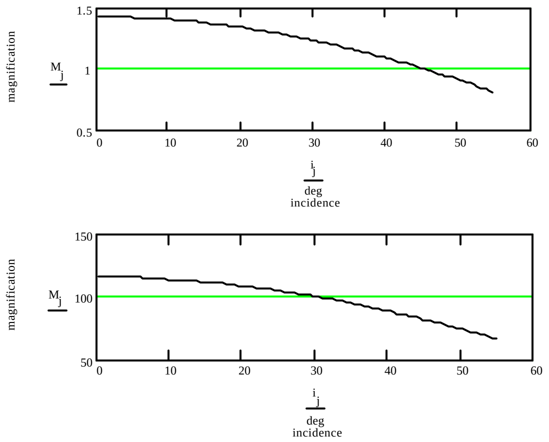

Figure 3 a (above) Unity Magnification
Figure 3 b (below) Gain at grazing exodus

1.2 CHIRPED FREQUENCY GRATING PRIMARY

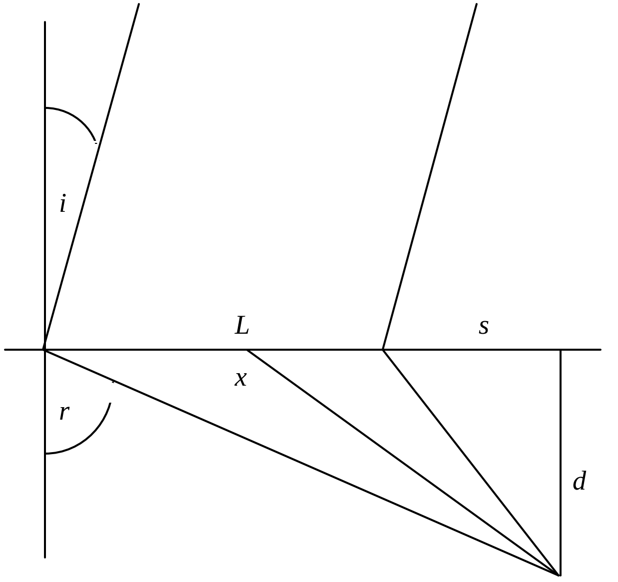

Figure 4 Chirp grating focuses to a point

Magnification can be further increased using variable line spacing in a “chirp frequency” diffraction grating. Much as the parabolic dish focuses light, a hyperbolic chirp in line spacing will reconstruct diffracted waves so that for any fixed wave length, diffracted waves focus to a point at the receiver. We have shown how such chirp gratings can be incorporated into near-field range finders where spacing between diffraction orders changes as a function of wave front curvature[1]. In star light, however, geometric optics are simpler, since the incident wave front is a plane wave.

Following diagram of Figure 4, we can characterize the receiving angle r at any point x along the grating

$$r = \arctan\left(\frac{x+s}{d}\right) \qquad (4)$$

where s is the stand-off to the receiver, and d is the distance from the grating plane to receiver. If the expression for r is substituted into the Grating Equation we can calculate the pitch at x which focuses the waves at the receiver.

$$p = n\frac{\lambda}{\left(\sin(i)+\sin\left(arctran\left(\frac{x+s}{d}\right)\right)\right)} \qquad (5)$$

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

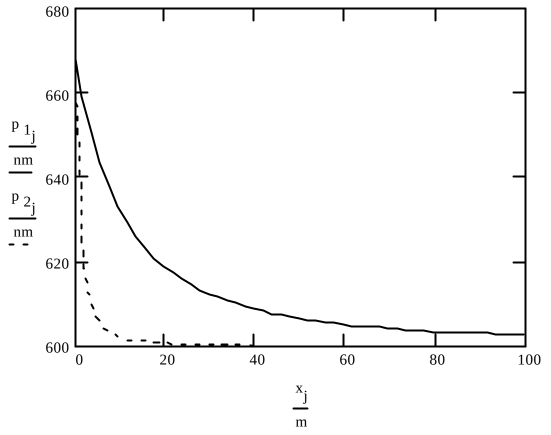

Figure 5 Hyperbolic chirp of grating pitch

The graph of Figure 5 is for the first-order of a 100 meter length grating focusing a star at $i = 0°$. If the receiver is at (s,d) of 20 and 10 meters respectively (the unbroken trace in the graph of Figure 5), the hyperbola has a gentle slope, but at grazing exodus where $s = 2$ m and $d = 1$ m (dashed trace), the chirp is shallow in the far-field and steep in the near-field.

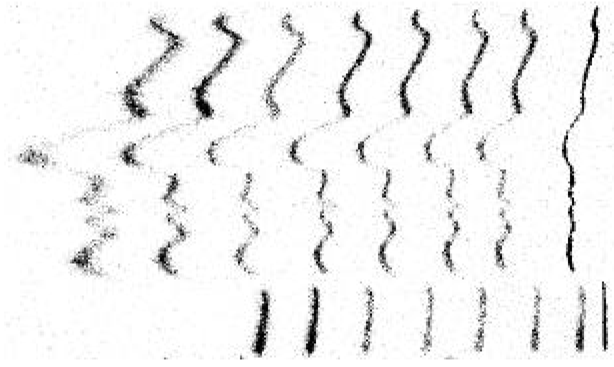

Figure 6 Near-field magnification with a chirp grating

For a target at $i = 0°$, we can calculate the magnification of a chirped frequency grating using the ratio of the grating length to the length of a sensor plane in the secondary. The illustration in Figure 6 shows a 6:1 magnification in a near-field target where the grating was 5 cm and the receiver had a length of 6.4 mm. This published experiment[2] shows how the magnification changes as the target is rotated, and the waist of the incident wave front is changed as per equation (3). Figure 6 is a composite made from no magnification (on the right) to the maximum recorded, on the left.

1.3 EFFICIENCY

Compared to refraction and reflection, garden varieties of diffraction gratings suffer from poor efficiency. In astronomy, where light is scarce, this is a serious shortfall. Grazing exodus efficiencies are particularly troublesome, because phase variations in the groove spacing will cause erratic swings in polarization. My preliminary simulation using the program PCGrate® suggests that efficiencies of 50% are achievable (Figure 7), but the programmers warn that their models are not well posed for the grazing incidence configuration.[3]

As we have shown, chirp gratings can maintain high magnification off the grazing exodus angle, but I have not found simulation software that will characterize the efficiency of chirp gratings. In my practice building 3D cameras with chirp gratings, I have found that when the incident and receiving angles are nearly the same, efficiency can be maximized. This is not surprising, since when $i = r$, the theoretical efficiency is 100%.

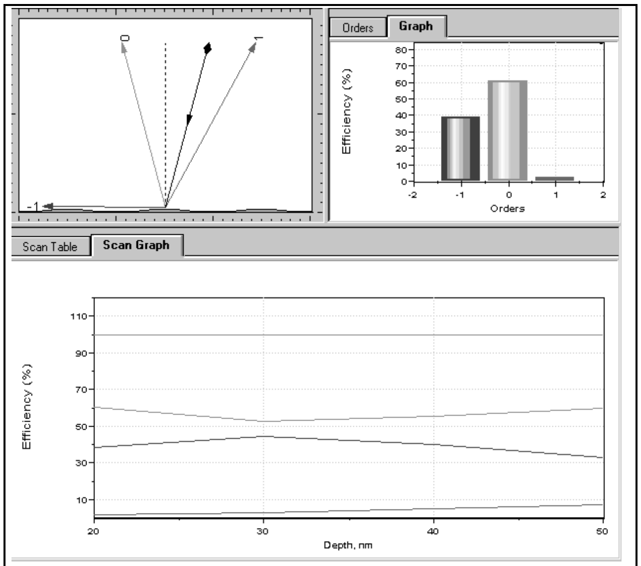

Figure 7 Efficiency prediction for a 30 nm groove depth with a sinusoidal 600 nm pitch grating for $\lambda = 450$ nm

Variations in the efficiency of a grating as a function of the angle of incidence present serious calibration problems in spectroscopy where the measured variable is intensity. Considering exo-planet searches, where the requisite sensitivity to flux may require 30 bits above the noise floor, low efficiency and non-linear response are obvious hob goblins. The convention in space telescope spectroscopy is to place the grating in the protected environment of the secondary. The long history of designing spectrometers as part of the secondary optics of a telescope for mirror primary collectors has the advantage that the spectrometer can be qualified on the ground, and the efficiency can be optimized, often reaching 90% with high-order echelles. Once in orbit, the spectrometer is housed in the controlled environment of the space craft. Indeed, in so-called imaging spectrographic applications, gratings are often eschewed completely for band pass filters that measure intensity in selected regions.

1.4 GRATING SIZE

Flux lost to poor efficiency can be made up by enlarging grating size. For example, a 50% efficiency can be made up by doubling the size of the collector. Normally, this would incur a weight penalty, but the active portion of the grating is a microstructure. This physical characteristic of a grating collector addresses a vexing problem in space-based telescopy, mass to area ratios. The options for substrates include "gossamer" membranes for which mass to area ratios are extremely low compared to conventional primary collectors.

Consider the considerable area of a plane grating primary collector relative to a secondary receiver at grazing exodus. A diagram in Figure 8 shows the configuration. As the grazing angle r approaches 90º the considerable length of the grating L increases exponentially since

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

where A is the aperture of the receiving telescope.

It is interesting to contemplate the potential collection real estate if a HST scale mirror is used as the secondary for a grating primary collector. The mirror itself enjoys about three square meters of collection area, but when it serves as

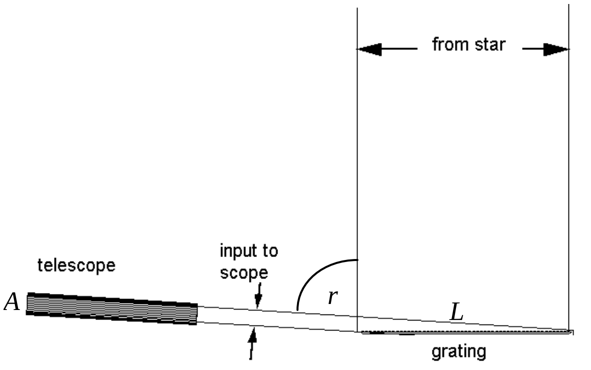

Figure 8 Secondary at grazing exodus

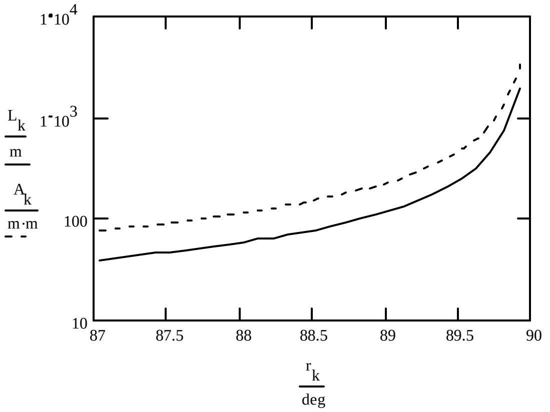

Figure 9 Grating collector length and area given a 2 meter secondary mirror. Log scale for y-axis.

the secondary collector for a grating that has a width equal to its two meter diameter, at r = 87°, the grating length is 40 m^2 and the area of the collector is 80 m^2. As the graph in Figure 9 shows, as the r approaches 90° the length of the grating goes beyond 1 kilometer. At r = 88° the collection area would be in excess of 100 m^2.

Hubs that store 100 m length plastics on a dispensing reel are typically less than a 10 cm in diameter. A ribbon-shaped grating collector would present a very small stowage footprint in the Shuttle payload bay.

If the grating collector is given a slight chirp over its considerable length, the focal length of the secondary can be shortened, and the width of the ribbon can be expanded. The resulting trapezoidal collector can enjoy 1000 m^2 of real estate without crowding the Shuttle bay. For example, a 3 x 12 x 140 m grating would cover 1005 m^2. The 140 m length would be wrapped around a mandrel that was 12 m long. We illustrated the deployed primary with the secondary telescope in Figure 10.

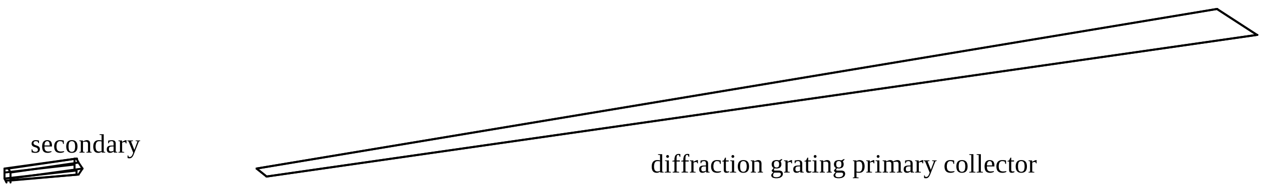

Figure 10 A 2 m secondary mirror can accommodate a 3 x 12 x 140 m primary if the grating is slightly chirped.

If the primary grating is folded before it is placed on a roll, it can present a collection area that is in multiples of 2 for each fold. For example, a 1 km (~2^{10} m) grating on a membrane substrate that was folded 10 times would have a considerable width before deployment of 2 m. If the grating was also 1000 m in length, the collection area would be 1 km^2. A square collector would not be the appropriate geometry for grazing exodus where we can envision a folded grating being much longer than wide. If the grating was folded four times, so that it was 16 m wide on the shorter side, then a length comparable to the aspect ratio of the collector illustrated in Figure 10 would amount to a length of 760 meters. It would have a distal width of 64 m and a collection area of 30,000 m^2.

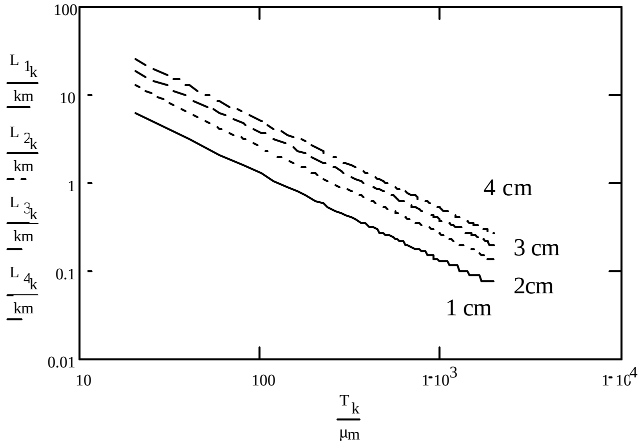

Figure 11 Lengths of membranes in 4 m rolls with cm deep wraps

If these huge collectors are stowed in rolls, their Shuttle payload bay displacements are nonetheless unobtrusive. We can use the approximation for a grating length L in rolls by

$$L = \sum_{n=0}^{N} \pi\left(OD - nT\right) \qquad (7)$$

where OD is the outside diameter of the roll
T is the thickness of the grating
N is the number of wraps of the grating on the roll

$$N = \frac{OD - ID}{T} \qquad (8)$$

where ID is the inside diameter of the roll

In Figure 11, rolls of *OD* = 4 m and *ID* of various dimensions from 3.99 to 3.97 m in 1 cm increments are graphed for *L* vs *T*. Such hollow cylinders as illustrated in Figure 12 could be used in transport as the outer cover of a conventional telescope which would serve as the secondary receiver in the combined instrument. Alternatively, the grating can be transported on a discreet roller that occupies a section of the payload bay while the secondary reciver is loaded in tandem, as illustrated in Figure 13. The capacity of a reel with a narrow inside diamter can be modeled by Equations (7) & (8). Lengths of hundreds of kilometers are numerically possible.

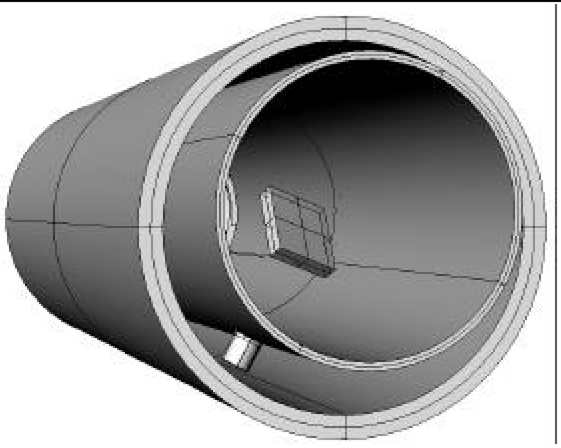

Figure 12 Stowage roll used as a telescope cover.

Figure 11 graphs how thickness of 10 µm to 2 mm play out in length when a grating is unfurled from a hollow drum. Lengths from 10's of meters to 10's of kilometers can be stowed. The thickest wraps considered here would be folded versions of thinner substrates. A robust grating substrate thickness for a membrane suitable for space deployment might be 200 µm. If transported on a roll with an outer diameter of 4 m and an inner diameter of 3.96 m and with 4 folds, the considerable length after deployment would be 1 km. If the 16 m length of the payload bay were the limit, this grating would achieve a collecting area of about 64,000 m^2. On the other hand, a grating roll in tandem to the secondary, as per Figure 13, the inner diameter of the roll might be 20 cm, and the outer diameter could range all the way up to limit permited by the ceiling of the bay. We make a prediction in Figure 14 that such rolls could store gratings 100 kilometers in length with a thickness of 200 µm.

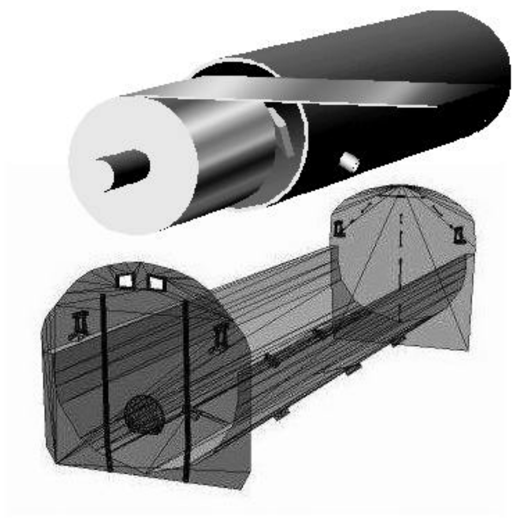

Figure 13 Roll and secondary placed in tandem in Shuttle bay.

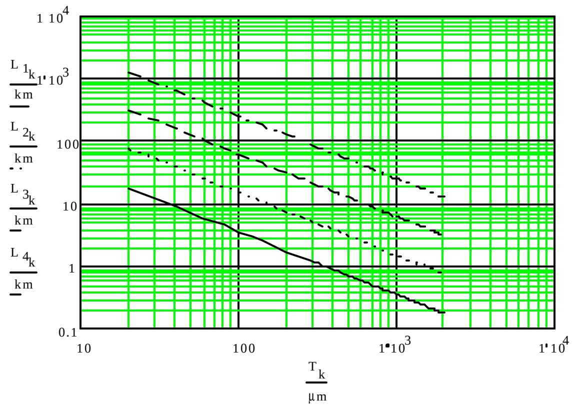

Figure 14 Grating lengths with *ID* = 20 cm and *OD* in steps of 0.5, 1, 2 and 4 meters.

In a sense, I am making up these sizes "from whole cloth," as the expression goes. I am not addressing the obvious concerns of the stowed hardware and Shuttle maneuvers required to unfurl huge stowed membranes, nor have I addressed the zero-gravity behavior of these large materials in either deployment or operation. Yet it cannot be denied that collection surfaces which would be commensurate with t exo-planet detection are easily contemplated in these calculations, and the deployment and assembly issues are not the same ones that are routinely studied when parabolic dishes are the end product of the membrane deployment. Here the surface need only be held to a flat figure in the diffraction axis, and the surface flatness tolerance is not the same as that required in a plane mirror.

1.5 GRATING FLATNESS

There are at least two factors to consider when specifying surface flatness in a diffraction grating used for spectroscopy. First, the localized unevenness on the grating surface will cause phase errors in adjacent rays as they proceed toward the secondary. For this calculation we can assume that the star and receiver positions are invariant relative to a baseline. On the other hand, the surface can be said to have an error in its surface given in waves. This term "waves" reduces to an error of distance *d* per unit length *L*. The geometry is represented in Figure 15. From this parameter, the grating can be said to have a variation of $\Delta\alpha$ in its plane. And it can be quantified as

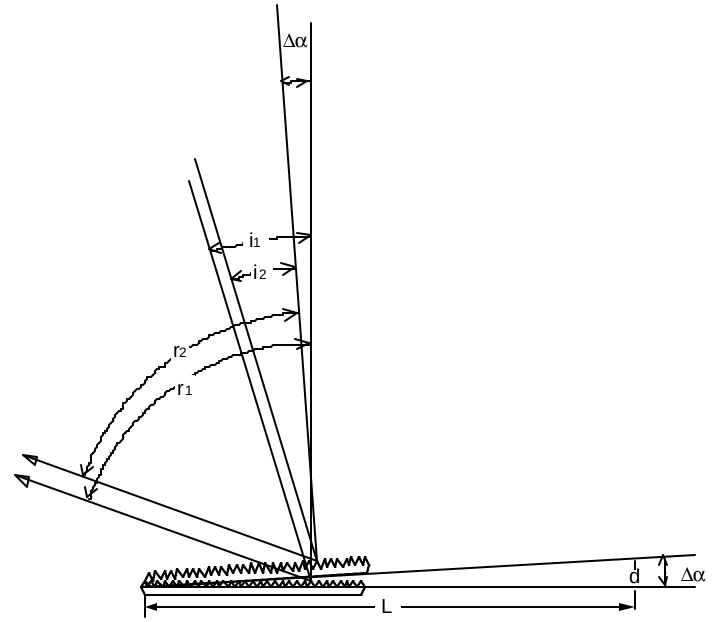

Figure 15 Localized error introduced by an uneven grating

$$(9) \qquad \Delta\alpha = \arctan\left(\frac{d}{L}\right)$$

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 according the Diffraction Equation

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

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

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

We show the outcome of this error analysis in the visible spectrum using cheap plate glass possessing a tolerance of 8 waves/inch in Figure 16. The worst error is at the zenith, since the wave retardation is most pronounced perpendicular to the grating plane. In Figure 17 we rerun the calculation to determine how the error escalates as the grating surface roughens. The calculation is taken at the zenith. It shows that sub-Angstrom resolution is maintained with gratings with an unevenness of less than 200 µm/m. Commercial plastics such DuPont Kapton polyimide film have been shown to hold this tolerance. The common parlance of an error "in waves" as it applies to mirrors is intended to convey the tolerance of the entire reflecting surface. However, for the this part of our analysis, we are examining a localized error in a diffraction grating.

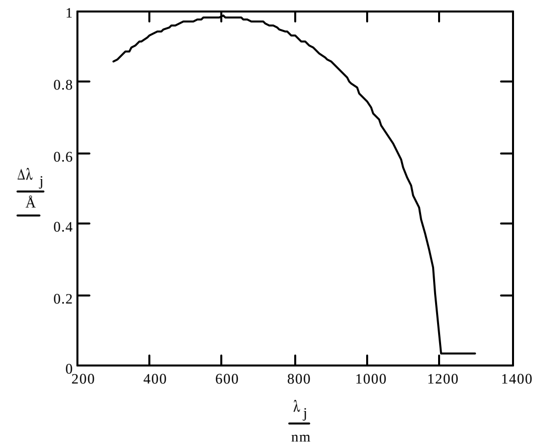

Figure 16 Approximation of error in wave length for a 600 nm grating made on cheap plate glass

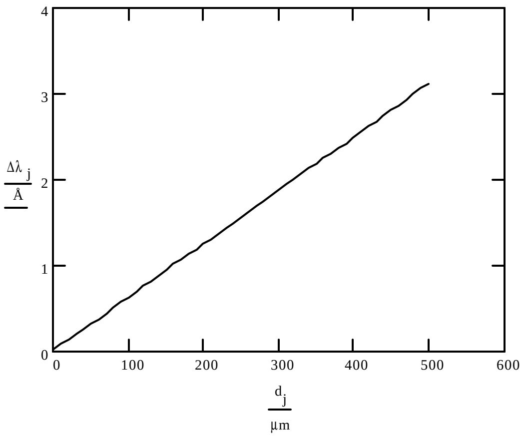

Figure 17 The wave length error in Å compared with unevenness of the substrate in µm/m

1.7 FLATTENING THE MEMBRANE AFTER DEPLOYMENT

Almost all contemplated membrane telescopes have curved primaries, but the diffraction grating primary is a flat surface. As a result, the choices for maintaining a working figure differ from most experimental methods previously investigated, and the problem is simplified. One method that has been investigated already is to use a rigid frame over which the membrane is stretched. This research assumed that many modular flat surfaces would be assembled into a giant curved dish, so the research has used small modules.[4] A conservative approach to making a large flat surface would simply scale up a large grating from hexagonal modules such as those intended for a very large pseudo-parabolic reflector. Alternatively, the modules could be made from edge-illuminated holograms[5] which enjoy thin rigid substrates. These devices can have modular internal photon counters or complete spectrometer secondary receivers. A “farm” of such modules can be grown gradually from a demonstration unit to faint target collector over a long term project period.

Any brace and truss system adds weight, complicates assembly, and is not practical for kilometer scale devices. However, researchers report that “Contact with the membrane need not be continuous, only discrete attachment points are required to tension the material.”[6] This observation allows speculation on discrete attachment points that are maintained by inertial devices such as gyroscopes or centrifugal vectors from anchors in motion.

The *bolo* is an Argentinean lasso, a rope with two or more end weights. Thrown at the legs of cattle by the *gaucho*, it maintains a taut rope while in flight. Of course, gravity brings it to the ground. A similar tensile structure could be stabilized in zero-gravity if it spins and if the *extrema* are much heavier than the inner spine. Given the lack of friction, once such a *bolo* was spinning in space, it would continue indefinitely without any further expenditure of energy. As it happens, the kinetics of a *bolo* fit the form of the ribbon diffraction grating collector. The collector by itself does not complete the instrument, but a secondary made as a conventional telescope could be in place as the outer weights in this configuration. It is convenient to use multiple telescopes at opposite ends of the grating, because the efficiency can be doubled if light is collected from both directions. The receivers would see the wave lengths change in the opposite direction. A further increase in effective efficiency can be obtained if both sides of the grating are used. Now we imagine four secondary telescopes in place. The concept is illustrated in Figure 18.

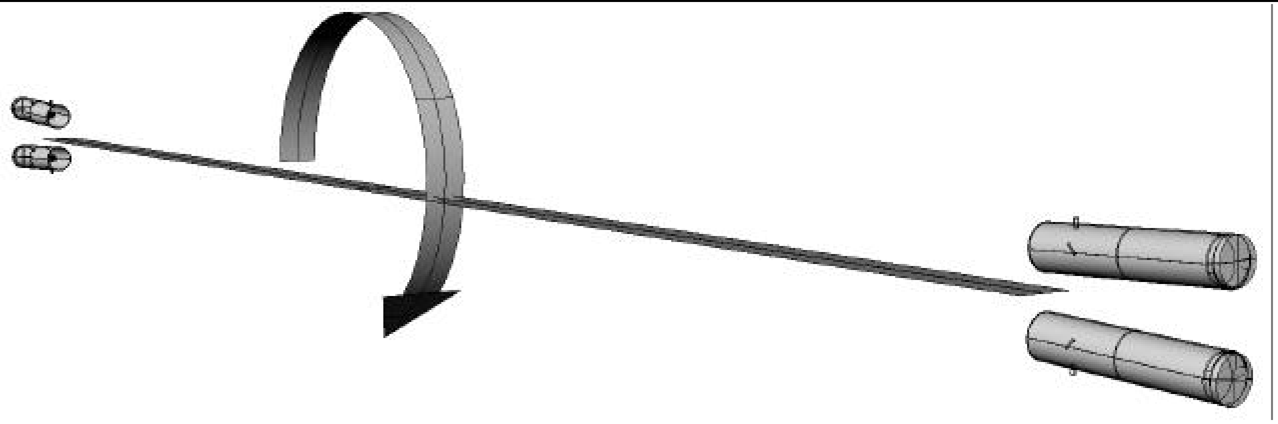

Figure 18 As the *bolo* rotates, centrifugal force from the mass of four telescopes stretches a ribbon grating flat

The rotation of the *bolo* collector might seem to work against the integration of the star light, but the rotation is actually required in order to make a temporal spectrogram. Diffraction collectors of this type build up spectral data over time as the angle of incidence changes - much as a monochromator varies wave length by the rotation of the grating relative to a source. In each rotation, the collector can take spectra of all the stars in the band of stars at the declination of the ribbon.

Temporal spectrometry lends itself to ground testing, because a terrestrial version of the *bolo* could use the earth’s rotation to vary the angle of incidence. In the ground-based version, sidereal time can be correlated to any star’s instantaneous wave length at the receiver. Of course, this will not test the method of using centrifugal force to stretch the grating, but simulations can be made by stretching a ribbon held in a vertical posture.

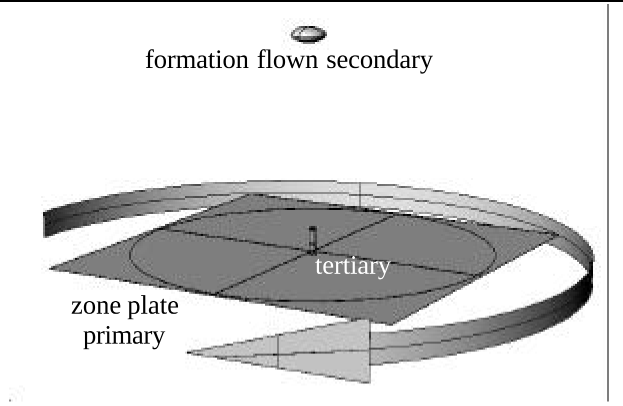

Figure 19 Galaxy configuration for symmetrical grating

A square shaped membrane can be made by folding a kilometer length grating ten times onto a 2 meter roll. Once deployed, the symmetry of this membrane allows flattening by rotation in the axis normal to the grating surface, Figure 19. For stability, a central mass is also required. This could be a tertiary receiver, if a secondary was positioned outboard along the axis of the normal. We might call this a *galaxy* configuration, because the tension on the membrane acts like gravity in a spinning galaxy. We could nickname the central tertiary receiver “the black hole.” The outboard secondary could be used to calibrate as well as to correct the diffracted waves. The grating itself would have to be in the form of a zone plate, that is, a symmetrical circular pattern with chirped spacing. At kilometer scale, this would be difficult to fabricate before launch. However, another use of the outboard secondary might be to write the grating *in situ* using an electron beam, as suggested by Bekey[7]. Here electron beam addressing would be used to make a diffraction grating using technology found in *Eidophor* type video projectors.[8] The galaxy would produce two dimensional images with extreme chromatic aberration. The secondary and tertiary optics would be used to convert the planes of focus into spectra at the same time that composites of the two dimensional image were being computed. It is possible to model such optics on the ground.

2 SECONDARY RECEIVER

When the primary of a telescope is a mirror, its secondary is intended to form a two-dimensional image. The receiver of a diffraction collector can be thought of in terms of resolving wave lengths. A well crafted design would accommodate this purpose rather than imitate conventional telescope receivers.

2.1 PHASE COHERENCE AT THE SENSOR

Phase errors over the considerable length of a long grating are inevitably going to affect the resolving power of the instrument. In Section 1.5 we have seen how grating surface flatness can be characterized over localized regions. The composite phase error of all local regions on the grating would sum at the receiver if the wave front was brought to a single point. However, the secondary is not without a considerable width of its own, and if the mirror surface and sensor cell spacing have considerable width, they can ameliorate the effect of the phase error over the grating as a whole.

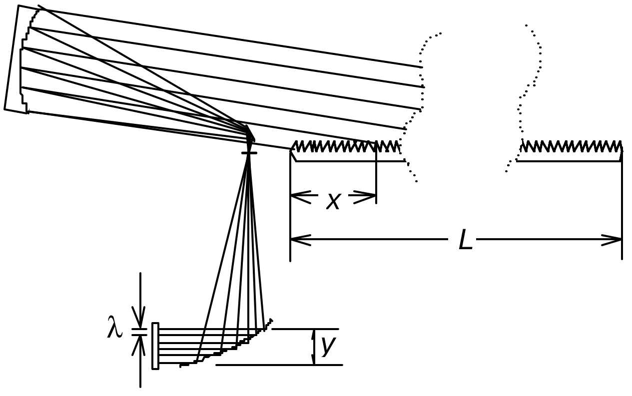

Figure 20 Coherence length phase error

Consider the secondary illustrated in Figure 20. The ray path from grating to secondary collector to sensor can be subdivided into segments spaced by the distance of a single wave length. 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 then 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

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

By this analysis, gratings of kilometer length would require localized phase coherence over each 3 mm of grating length for detection of 1 μm radiation, if the sensor enjoyed a considerable length of 0.3 m. Linear sensors with lengths of 21 cm are commonplace today in certain flatbed scanners that use hard bars of integrated CMOS sensors. Typical conversion for these consumer-grade linear arrays is 12 bits of flux. Cell density is typically 1200 dpi for photocell triads, making the total sensor density over a 33 cm length about 16,000 cells. Summing the 12 bits of flux 16,000 times suggests that the sensors in a $100 flatbed scanner would provide spectral flux measurements accurate to one part in 60 million. This is inside the ball park for exo-planet detection even in the full glare of the host star over the infrared emission lines utilized in biometrics. Put an infrared array of equivalent dimensions on the telescope, and an exo-planet's Doppler moment could be picked out inside the host star's light.

3.2 TARGET DISCIMINATION AT THE SECONDARY

The purpose of a spectrometer is to resolve wave length intensities, a one dimensional signal. If the angle of incidence *i* and the angle of reconstruction *r* are known for a diffraction grating, then along the axis over which the diffraction takes place, any star can be identified simply by its wave length. As a grating is rotated, a cataloged star and its possible planetary system will not produce any wave length at the receiver other than the one wave length predicted by the Grating Equation for the specific angles *i* and *r* at a known point in time. The pose of the primary grating must be known by guidance systems to an accuracy Δ*i* of 0.02° in order to achieve 1 Å wave length resolution for radiation at 600 nm.

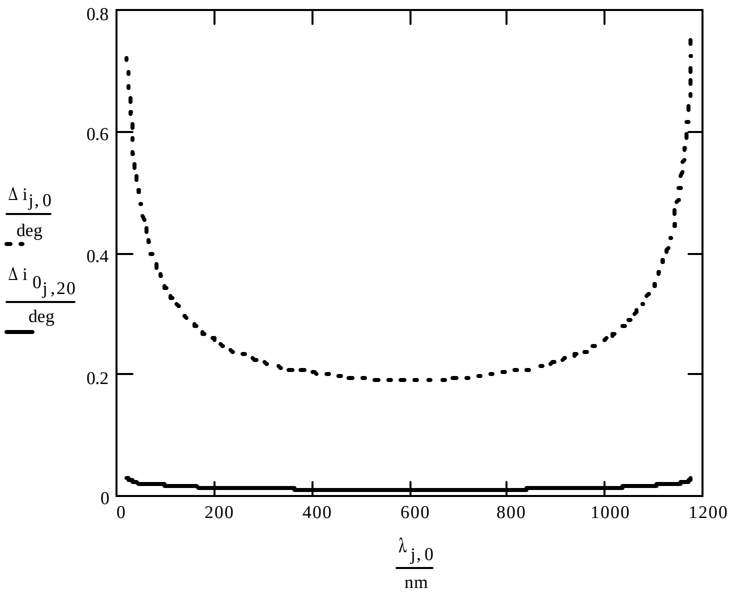

Figure 21 Dashed trace shows extinction window for competing stars with a 2 nm band pass filter. Continuous trace shows precision in pointing required to achieve 1 Å resolution in the resulting spectrogram

As it happens with this same knowledge of pointing angle, a star can be discriminated from adjacent stars along the axis of diffraction, unless the competing star falls within the Δ*i* window.

One means to discriminate by wave length is to band pass the radiation so that only a target star is visible at the secondary sensor. A variable band pass filter such as the bifringent LCD made by CRI.[9] These filters can window 20 nm to 2 nm with transmission losses inside the window being about 20%. The secondary would have such a filter at an iris in the ray path. We can characterize the separation of a star from adjacent stars by the angle subtended by the band pass wave length over the studied angle of incidence.

A conventional spectrometer in the receiver could simultaneously detect all stars in the band of stars that were forming diffraction spectra, and this feature would improve the efficacy of the instrument by allowing simultaneous surveys of all incident starlight. The receiver spectrometer would produce a motion picture of discrete frames that would be analyzed to separate the target stars from each other and record the amplitude of their wave lengths. Unlike the band pass filter, there would be no transmission losses to absorption.

Although stars can be discriminated along the axis of diffraction by their wave length, there is no such provision in the lateral dimension, and a plane grating would have no greater angular resolution that the secondary telescope itself. Even with the best of parabolic collectors, we know that target stars must be segregated by occluding blocks inside the secondary of a conventional focal plane spectrometer, and something like this provision such as "decker plates" would need to be made in the design. Secondary receiver design for a diffraction primary collector presents many new problems which I do not pretend to have posed much less solved.

3 FURTHER ASPECTS

The diffraction collector does not appear in the literature. There are many aspects that merit detailed examination. There are broad concepts that can be proposed and countless details that must be worked out for reductions-to-practice.

3.1 TERRESTRIAL SECONDARY

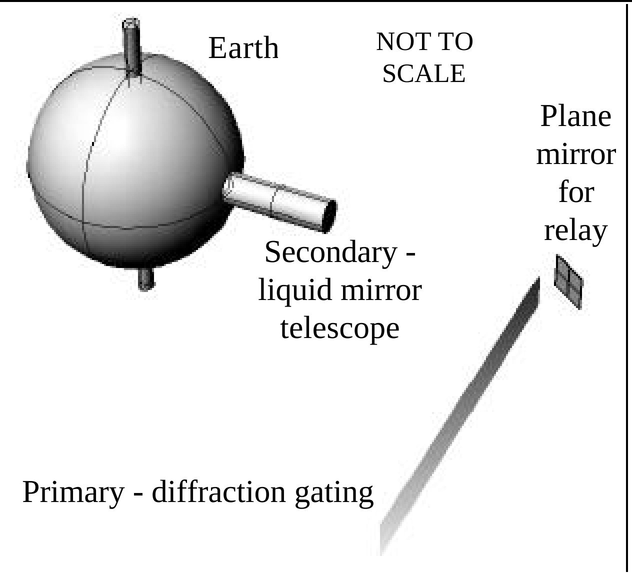

Figure 22 Earth-based secondary - Space-based primary

It is interesting to contemplate how a very large grating can be used as the primary collector for a ground-based secondary. The large collector sizes involved make it possible for the receiver to be many thousands of kilometers distant and yet exploit the collecting surface. For example, a geo-stationary space-based grating could be imaged by a zenith tube on the earth's equator below. This proposition allows contemplation of very large liquid mirror telescopes at the secondary. Although mercury mirrors cannot be steered, if the primary collector was overhead, the orbiter would merely need to be declined north/south for the ground-based observatory to survey all stars. The configuration does require a plane relay mirror, since the grating primary must be in an east/west orientation as illustrated in Figure 22. Even in Low Earth Orbit, a large grating collector might be shared by many conventional ground-based telescopes. These concepts of a relay collector in space for ground-based stations is not new, but the idea has never been explored for astronomical observations just for telecommunications.

3.2 TRUSS FRAME

A long thin ribbon-shaped grating can be reshaped into a parabolic cross section by fixing its *extrema* to rigid trusses. This geometry of the primary and its truss work is illustrated in Figure 23. A parabolic trough can be used to narrow the field-of-view in the lateral dimension to more closely match the resolving power in the diffraction axis. Light which is not diffracted is a reflected, and the long parabolic trough is a reflection telescope in the short dimension. If the ribbon is 12 m at the narrow side, the trusses that create the parabola would fit in the shuttle payload bay. The truss work is also a suitable site for active tensioning devices that can be used to remove vibrations in the long membrane and as a mooring for the telescope secondary..

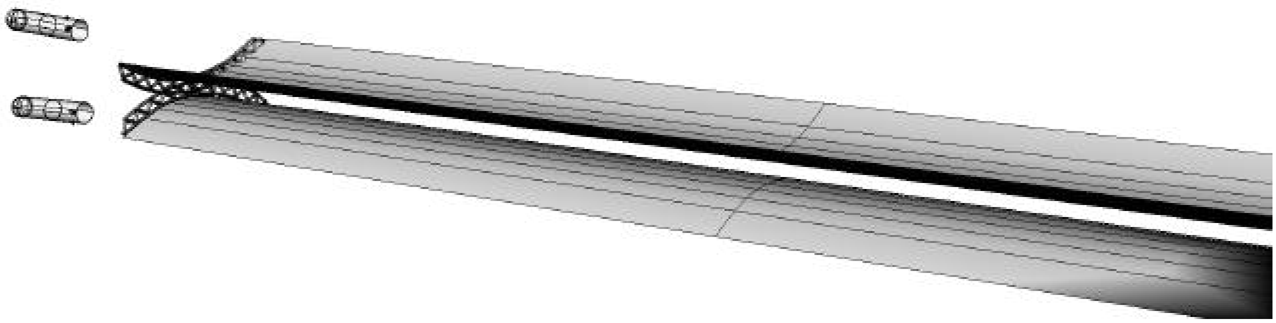

Figure 23 The narrow side of a ribbon collector can be bent into a parabolic cross section with a transportable truss.

3.3 GRATING FABRICATION

The first grating was made by hand winding hair over a centimeter length screw thread. Today gratings are mass produced by embossing methods that resemble the printing press. The revolution is no less significant to diffraction optics than Gutenberg's press was to literacy. It may be true that the best gratings are still made on ruling machines, but this is because of their high efficiency blazes at high-orders. Ruled masters for echelles have thick substrates and demanding specifications that do not lend themselves to primary collector sizes. Holographic masters have replaced ruling machine gratings where first-order sinusoidal grooves are preferable. Holograms can be made in single exposures at 1 x 1 meter scale. Shims made from these masters can emboss kilometer length plastic substrates at production costs little greater than the substrates themselves. These replicas suffer from stitching error, phase error and uneven surfaces, but when they are deployed to full length, their theoretical resolving power ameliorates some of their localized flaws, and their modest efficiency is made up by their size. Embossing plants in Los Angeles[10] and Spokane[11] have corresponded with the author and stand ready to investigate the use of their products in space telescopes. Their techniques are new and evolving. It is possible to entertain novel improvements that will overcome some of the obvious short falls in quality, and there are further steps that could be taken to make their presses produced the small chirps required to focus wave fronts.

CONCLUSION

Membrane collectors have long been contemplated as cost effective in space-based telescopes, but the conventional parabolic mirror is a three-dimensional structure that does not lend itself to being deployed as a stretched surface. On the other hand, diffraction gratings have flat substrates in the axis of diffraction, and they can be stretched taut. The micro structures that reshape the incident wave front typically have a thickness of the wave lengths they reshape. Diffraction grating primary collectors that have considerable areas greater than multiple square kilometers can be stowed in a Shuttle bay load bay on reels. These surfaces can be used in spectrometric applications. Since these include some of the most common astronomical observations such as velocity and chemical composition, telescopes restricted to spectroscopy would have utility.

ACKNOWLEGEMENTS

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

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