DESIGN, FABRICATION, AND TEST OF WFIRST/AFTA GRISM ASSEMBLY

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WFIRST-AFTA: A Unique Probe of Cosmic Structure Formation History

Using Observations from the High Latitude Survey and GO Programs

Detection of Large Sample of \( z > 7 \) Galaxies

Large-scale Distribution of Lyman-break Galaxies

Survey of Emission-line Galaxies

Large-scale Distribution of Galaxy Clusters

Lensing Mass Function of Clusters

Dark Matter Halos of Galaxies

<table>
<thead>
<tr>
<th>Redshift</th>
<th>Present</th>
<th>1 billion years</th>
<th>1.5 billion years</th>
<th>750 million years</th>
<th>&lt;500 million years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6 billion years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>7</td>
<td>8</td>
<td>&gt;10</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>750 million years</td>
<td></td>
<td></td>
<td></td>
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<td>7</td>
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04/30/2014

WFIRST-AFTA SDT Interim Report
WFIST/AFTA & GRISM ASSEMBLY

- Wide-Field Infra-Red Survey Telescope (WFIRST) is designed to perform wide-field imaging and slitless spectroscopic survey of the sky.
- A compound grism assembly is selected as its slitless dispersing element.
- The challenge of this grism is the wider Field Of View (FOV), larger dispersion, and smaller f/#.
- The challenge is overcome by the innovative design of using two diffractive surfaces.
GRISM Comparison: WFIRST versus HST

- Grisms have been used in a number of Hubble Space Telescope (HST) instruments: Wide Field Camera 3 (WFC3), Near Infrared Camera and Multi-Object Spectrometer (NICMOS), Advanced Camera for Surveys (ACS), etc.

- There are 3 differences that makes WFIRST grism much more challenge than HST’s:

<table>
<thead>
<tr>
<th></th>
<th>WFIRST</th>
<th>HST WFC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOV</td>
<td>0.28 degree²</td>
<td>0.0012 degree²</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>R = 700</td>
<td>R = 130</td>
</tr>
<tr>
<td>f/#</td>
<td>8</td>
<td>11</td>
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# WFIRST GRISM SPECIFICATION

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Wavelength range (μm)</td>
<td>1.35 – 1.95</td>
</tr>
<tr>
<td>FOV (°)</td>
<td>0.788 x 0.516</td>
</tr>
<tr>
<td>Beam diameter at grism (mm)</td>
<td>120</td>
</tr>
<tr>
<td>Beam f/-ratio at grism (mm)</td>
<td>~f/8</td>
</tr>
<tr>
<td>Wavefront error</td>
<td>Diffraction limited at 1.65μm</td>
</tr>
<tr>
<td>Spectral resolving power (per 2 pixels)</td>
<td>645 – 900 (461×λ)</td>
</tr>
<tr>
<td>Compactness</td>
<td>70mm total thickness for a fixed diameter ~120mm</td>
</tr>
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</table>
DESIGN CONSIDERATION

- The main challenge of the grism design is how to correct the grating introduced aberration in non-collimated space? Besides, it needs to be compact enough to fit into a filter wheel slot. It also needs to be designed parforcal to other filters.
- The aberration is huge at large incident angles (±12.5°) and the amount of aberration is proportional to wavelength.
- The wavelength dependent aberration is very difficult to correct using non-diffractive lenses, even with many freeform surfaces.
- The key is to find a right compensator: another diffractive surface “diffractive lens”
GRISM OPTICAL DESIGN

Element 1:
Substrate: fused silica
Function: bandpass filter and aberration corrector
S1 is sphere, and S2 is diffractive lens on flat

Element 2:
Substrate: fused silica
Function: prism to make grism zero deviation
Both S1 and S2 are spheres

Element 3:
Substrate: fused silica
Function: grating to provide required dispersion
S1 is sphere, and S2 is grating on flat
GRISM IN WFIRST ELEMENT WHEEL

- WFIRST/AFTA has a number of subassemblies, the element wheel is one of the major assemblies.
- Grism assembly is one element in the element wheel.
- Grism has to be compact enough in thickness to avoid conflict with the beams and other subassemblies.
GRISM MATERIAL SELECTION

- Fused silica is selected for all grism elements. Its property is well known and well characterized.
- The diffractive patterns will be ion etched into the lens substrate. The fused silica is one of the best choices for reactive ion etching.
- Because of the more reproducible and small temperature derivative of refractive index of the fused silica, the fabrication and alignment tolerance are greatly relaxed.
- Fused silica has been well characterized at WFIRST operation temperature 170°K.
DIFFRACTION LIMITED PERFORMANCE

Across the FOV

Across the wavelength
SPECTRAL RESOLVING POWER MEETS SPECS.

WFIRST Cycle 4 Spectrograph
11/25/2013
Units are μm. Airy Radius: 15.44 μm
Field | RMS radius | GEO radius |
1     | 2260.19    | 2792.93   |
2     | 2223.94    | 2749.20   |
3     | 2296.77    | 2838.90   |
4     | 2228.90    | 2754.43   |
5     | 2302.14    | 2844.31   |

Wavefront error: Collapsed Img

WFIRST v4-2-0 GRISM 111513 w-det.ZMX
Configuration 1 of 19
Spot Diagram
REMOVE UNWANTED GRATING ORDERS TO BACKGROUND

Spot diagram for different diffractive lens orders

Grating order is +1.

0\textsuperscript{th} order

Airy disk becomes tiny dot in the 0\textsuperscript{th} and 2\textsuperscript{nd} orders plots.

2\textsuperscript{nd} order

Please notice the scale difference: the 0\textsuperscript{th} and 2\textsuperscript{nd} orders scale bars are 10mm, the 1\textsuperscript{st} orders is only 0.04mm. The rough calculation shows that the intensity of combined 0\textsuperscript{th} and 2\textsuperscript{nd} orders in each pixel is only about $5 \times 10^{-5}$ of 1\textsuperscript{st} order’s, assuming 1\textsuperscript{st} order efficiency is 80\%, 0\textsuperscript{th} and 2\textsuperscript{nd} orders have same efficiency.

1\textsuperscript{st} order: fabricated to include >90% energy
PATTERNS OF TWO DIFFRACTIVE SURFACES

Grating contour. There are 165 lines between the two plotted lines.

Diffractive lens contour. There are ~10 lines between the two plotted lines.
• Titanium is selected as element mount material to minimize the wavefront distortion at 170°K.
• A ring structure tested in similar environment for another project is used to further control CTE mismatch introduced wavefront degradation.
• 5 degrees of freedom are designed into two of the three elements to provide desired adjustment.
DIFFRACTION EFFICIENCY OF SAMPLES

- Four diffractive samples have been made in one fused silica wafer.
- The samples were designed for HeNe wavelength at 632.8nm in order to simplify the measurement.
- There are two diffractive lenses and two grating patterns on the wafer.
- The measured results show the diffraction efficiency is over 90%.
GRISM TEST CONFIGURATION (ambient)

- Ambient test will be performed using interferometer.
- Even though the grism is designed for NIR wavelength, it can be tested in visible at 632.8nm with the help of a specially designed Computer Generated Interferogram (CGH).
GRISM TEST CONFIGURATION (cryogenic)

- Phase retrieval will be used for final assembly test at cryogenic temperature at 170°K.
- A few IR wavelengths between 1.35μm and 1.95μm will be used during the test.
CONCLUSION

• The analysis shows that the grism with two diffractive surfaces solves the previous problem: grism is limited to small FOV, small spectral dispersion, and in non-collimated space.

• All three lens substrates have been made. We are working with vendors (RPC Photonics and JenOptik) to etch the diffraction patterns into the two flat surfaces.