Prospects and Issues for Spaceborne Imaging Spectrometers that Achieve AVIRIS Levels of Performance

Pantazis Mouroulis
Jet Propulsion Laboratory
California Institute of Technology
Schematic of ideal spectrum produced by a pushbroom imaging spectrometer.
Imaging spectrometers provide spectrum of every pixel in a two-dimensional image

Two basic forms:
- Whiskbroom
- Pushbroom

Whiskbroom:
- spectrometer input is a pinhole
- scans point in raster fashion to acquire 2-D image
- uses linear detector array (‘easy’ calibration)
- all ground points have their spectra recorded by same one array
- good SNR for air, inadequate for space systems

Pushbroom:
- spectrometer input is a slit
- uses motion perpendicular to slit to acquire 2-D image
- uses area array (difficult calibration)
- is equivalent to many different spectrometers for each point on the slit (row of array)
- has adequate SNR for space systems
Modeled Total Upwelling Radiance
mid latitude summer atmosphere
23 km visibility
0.25 reflectance
seakevel
45 degree zenith angle

Radiance (µW/cm²·cm²·sr)

Wavelength (nm)
Schematic of real spectrum from a pushbroom imaging spectrometer
Dyson spectrometer example
### Spectrometer example first-order parameters

<table>
<thead>
<tr>
<th></th>
<th>Offner</th>
<th>Dyson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral range</td>
<td>1 – 2.5 μm</td>
<td>1 – 2.5 μm</td>
</tr>
<tr>
<td>Spectral sampling</td>
<td>10 nm</td>
<td>10 nm</td>
</tr>
<tr>
<td>Pixel size (square)</td>
<td>27 μm</td>
<td>18 μm</td>
</tr>
<tr>
<td>Slit length</td>
<td>19.44 mm</td>
<td>12.96 mm</td>
</tr>
<tr>
<td>No. of spatial pixels</td>
<td>720</td>
<td>720</td>
</tr>
<tr>
<td>f-number</td>
<td>4</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Spot diagrams for Offner example

MATRIX SPOT DIAGRAM

20MM SLIT LO DIST OFFNER
FRI JUL 16 1999
WAVELENGTH UNITS ARE MICRONS.

BOX WIDTH : 27
REFERENCE : CENTROID
CONFIGURATION 1 OF 1
Worst-case PSF's for Offner example

27 µm
1000 nm

27 µm
2500 nm
(Strehl: 0.73)
Worst-case SRF variation for Offner example
Worst-case SiRF variation for Offner example
Spot diagrams for Dyson example

SURFACE: IMR

MATRIX SPOT DIAGRAM

1.000000 1.750000 2.500000

0.0000, 0.0000 MM

5.0000, 0.0000 MM

6.4000, 0.0000 MM

1.2 MICRON, 18 MICRON PIXELS
FRI JUL 16 1999
WAVELENGTH UNITS ARE MICRONS.

BOX WIDTH: 18 - REFERENCE: CENTROID

CONFIGURATION 1 OF 1
Worst-case PSF's for Dyson example

18 µm  1000 nm

18 µm  2500 nm

(Strehl: 0.85)
FFT DIFFRACTION ENSQUARED ENERGY
Worst-case SRF variation for Dyson example
Worst-case SiRF variation for Dyson example
Imaging Spectrometer Modeled Spatial Keystone Effect

- Potatoes
- Desert Sage
- 5 Percent
- 10 Percent
- 50 Percent

Reflectance

Wavelength (nm)
Radiance error induced by channel center wavelength position
Spectrometer Design Performance

<table>
<thead>
<tr>
<th></th>
<th>Strehl</th>
<th>PSF energy in pixel</th>
<th>MTF (tan.)</th>
<th>MTF (sag.)</th>
<th>Smile</th>
<th>Keystone</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 nm</td>
<td>0.43-0.84</td>
<td>&gt; 94%</td>
<td>0.86-0.93</td>
<td>0.93-0.95</td>
<td>1.8%</td>
<td></td>
</tr>
<tr>
<td>1000 nm</td>
<td>0.85-0.90</td>
<td>&gt; 90%</td>
<td>0.83-0.86</td>
<td>0.84-0.85</td>
<td>1.5%</td>
<td>1%</td>
</tr>
</tbody>
</table>
Offner Grating Spectrometer

- Can operate at relatively low f# (>~f/2)
- Accepts a long slit
- It has very small distortion in both spectral and spatial directions if appropriately optimized
- It has only three (two) optical surfaces
- Can be designed with spherical and centered surfaces (ease of fabrication, can reach theoretical performance)
- Utilizes high-performance E-beam gratings
Dyson Grating Spectrometer

- Can operate at very low f# (<f/1)
- Accepts reasonably long slit
- It has very small distortion in both spectral and spatial directions if appropriately optimized
- It has only three optical surfaces
- Simple to align (can reach theoretical performance)
- Utilizes blazed holographic or x-ray lithography gratings (experimental)
Offner vs. Dyson

- Speed difference favors Dyson (but typically smaller pixels)

- Offner is all reflective, can be made with advanced materials (SiC) for ‘easy’ athermalization

- Grating technology for small convex gratings is better developed than for large, steep, concave gratings

- Antireflection coatings are needed for Dyson – can limit useful spectral range

- Ghosts can be a problem with Dyson, analysis needed

- Dyson can handle greater dispersion/better spectral resolution

- Dyson can be more compact
Offner spectrometer example

in

grating

10 mm

slit & slit image