A Silicon and KRS-5 Grism Suite for FORCAST on SOFIA

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About FORCAST:

The **F**aint **O**bject infra**R**ed **CA**mera for the **S**OFIA **T**elescope (**FORCAST**) is a mid-infrared (5-40 µm) camera being built at Cornell University. While the sensitivity of Spitzer exceeds that of FORCAST, the angular resolution afforded by the 2.5 m telescope improves by a factor of ~3 over that of Spitzer at λ>15µm. The camera provides a 3.2' x 3.2' field of view. Figure 2 shows the optical path layout of a single FORCAST channel.

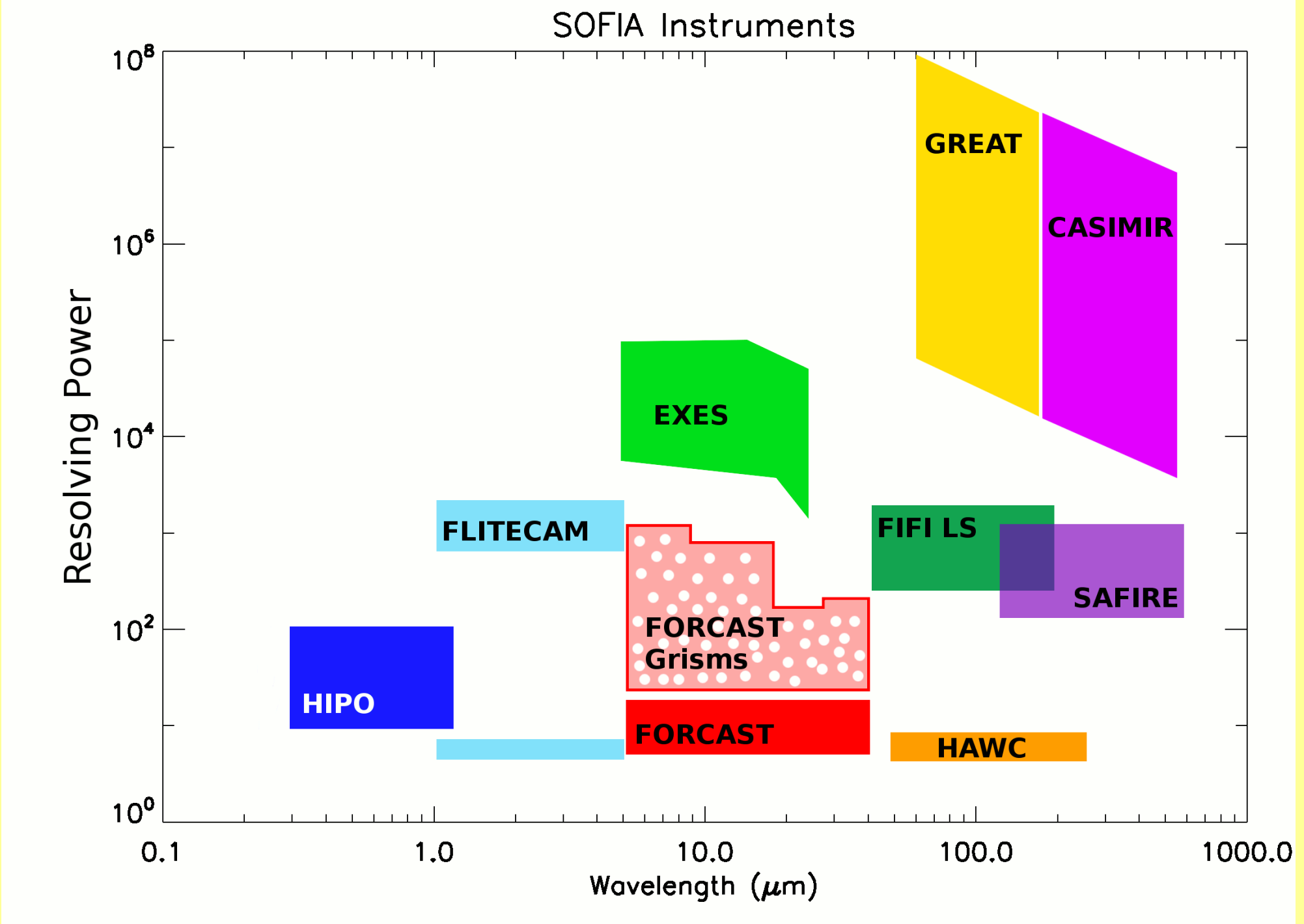

Figure 1: Wavelength vs. Resolving Power plot of the first generation of SOFIA instruments. One capability which the current SOFIA instrument complement lacks is mid-IR spectroscopy at moderate resolving power (R ~ 100−1000). We report on the fabrication and testing of a suite of grisms for the FORCAST instrument which allows observers to use FORCAST as a low to medium resolution spectrometer.

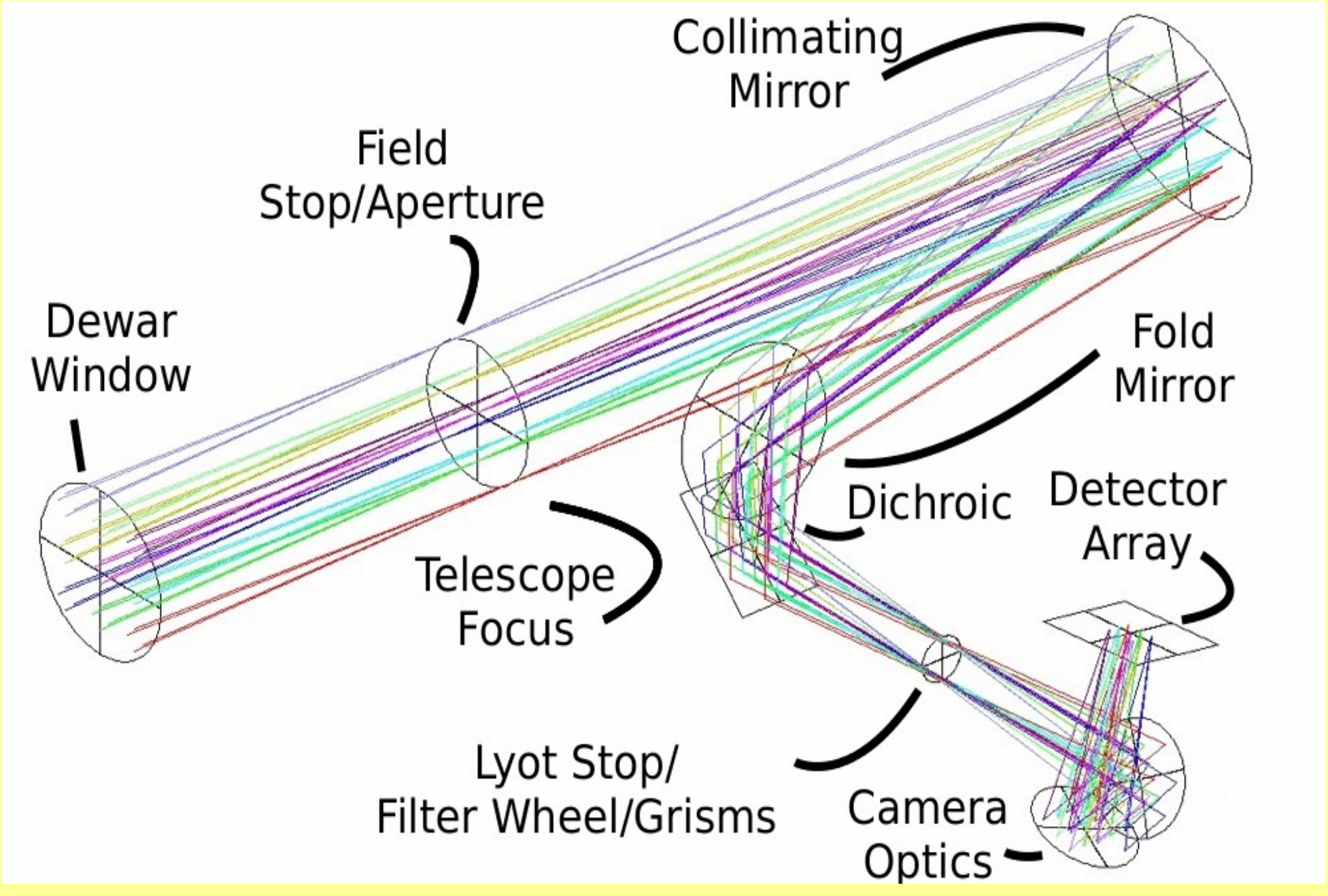

Figure 2: Optical path of FORCAST short-wavelength channel. The grisms are mounted in filter wheels on either side of the Lyot stop.

About Silicon Grisms:

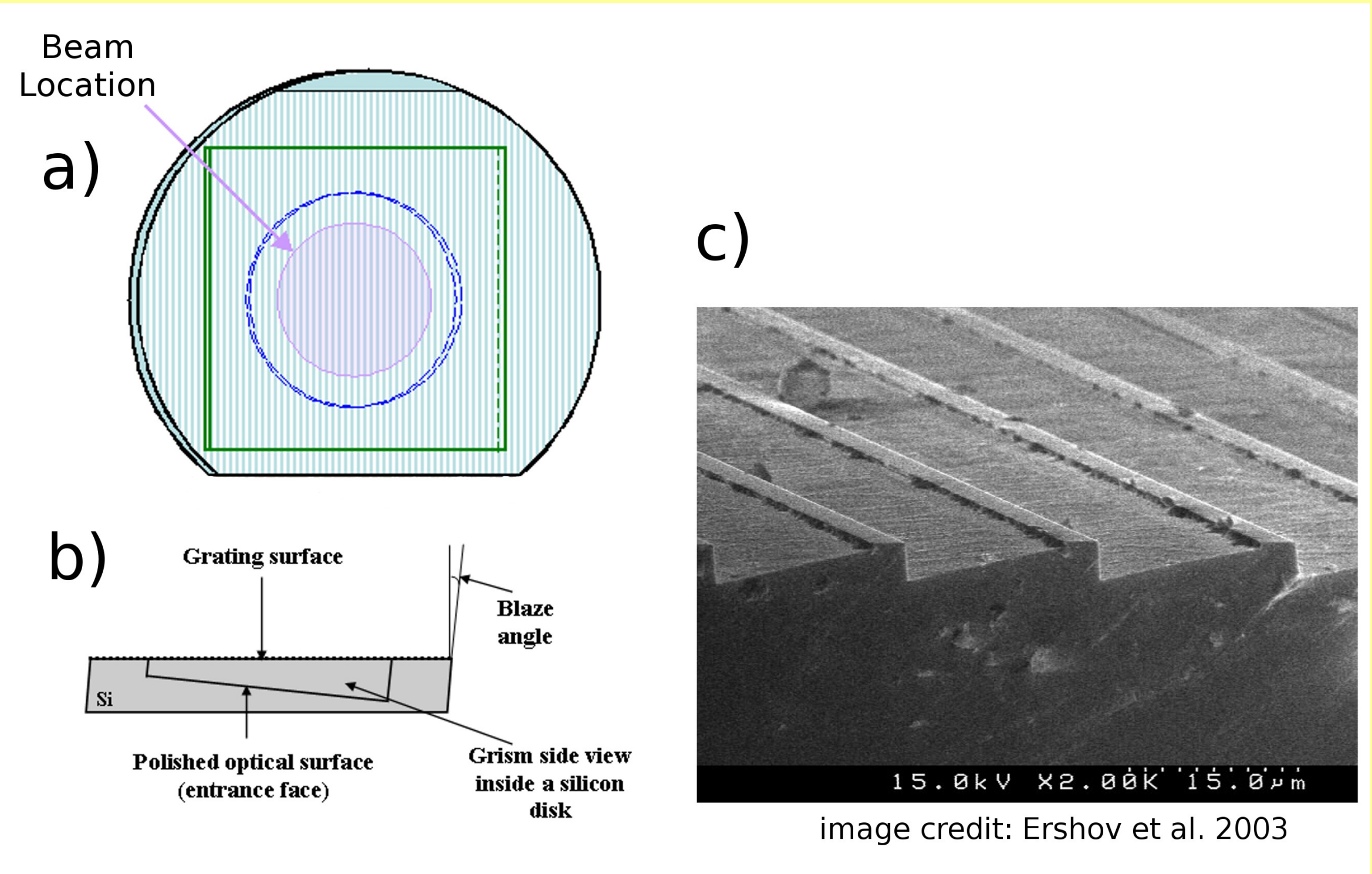

image credit: Ershov et al. 2003

Figure 3: Grisms 1,2, 5 and 6 were manufactured by chemically ruling groves into silicon crystal. The details of this process can be found in Marsh et al. 2007 or Mar et al. (submitted to App Opt). In panel a, silicon disks are cut from the boule and polished. Thin lines are patterned onto the surface of the disk using lithographic techniques. During an anisotropic etch of silicon using a solution of KOH, grooves are "cut" along crystal planes, as shown in the SEM image of grooves in panel c. The grism is then cut from the silicon disk (panel b) and the entrance face is polished to optical flatness.

Abstract

We have designed and fabricated a suite of grisms for use in FORCAST, a mid-infrared camera scheduled as a first light instrument on SOFIA. The grism suite gives SOFIA a new capability: low and moderate resolution spectroscopy from 5-37µm, without the addition of a new instrument. We fabricated four silicon (*n* = 3.44) grisms using photolithographic techniques and purchased two additional mechanically ruled KRS-5 (*n*=2.3) grisms. One pair of silicon grisms permits observations of the 5-8µm micron band with a long slit at resolving power (R) of ~200, or in a cross-dispersed mode at R~1200. In the 8 − 14µm region, where silicon absorbs heavily, the KRS-5 grisms will provide the spectroscopic capability at predicted resolving powers of 300 and 800 in long-slit and cross-dispersed mode, respectively. The remaining two silicon grisms cover 17 − 37µm at resolving powers of 140 and 250. We have thoroughly tested the silicon grisms in the laboratory, measuring efficiencies in transmission at 1.4 − 1.8µm. We report on these measurements as well as on cryogenic performance tests of the silicon and KRS-5 devices after installation in FORCAST.

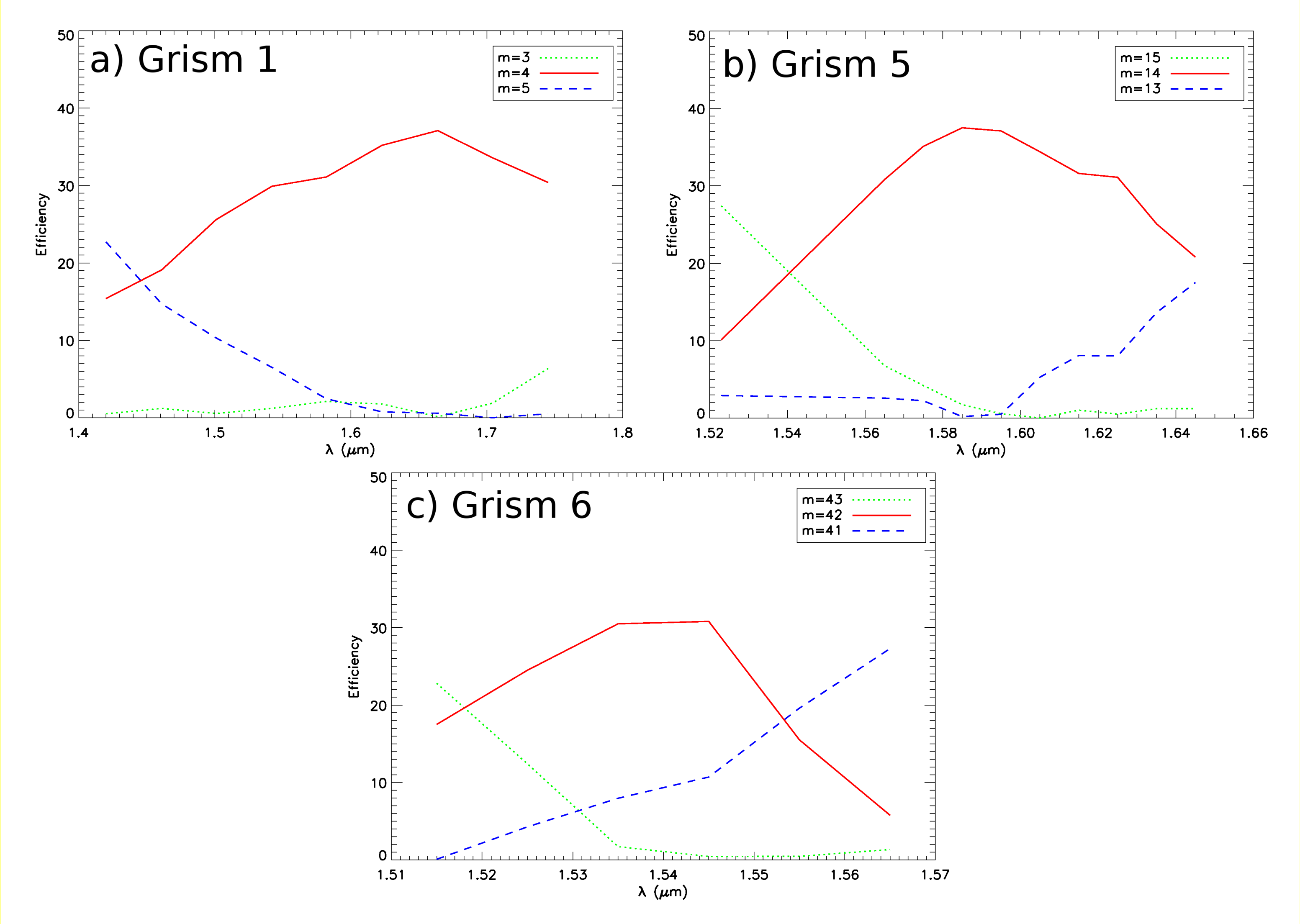

Figure 4: Measuring the blaze function of uncoated silicon grisms: Before installation in FORCAST, three out of four silicon grisms were tested using a scanning monochromator. We measured throughput efficiencies at several different wavelengths (1.4-1.8 µm) by collimating light from the output of a scanning monochromator into a 10mm diameter beam centered and normal to the grism entrance face and comparing it to the throughput of the system when no grism was present in the beam. The efficiency of the grism at a particular wavelength is then the intensity of the light integrated over several orders divided by the intensity measured with no grism in place. We did not measure the blaze function of grism 2 because the output of the monochromator was a significant fraction of the grism's free spectral range. Assuming 30% Fresnel losses at each surface and considering geometric losses appropriate to each grism, the measured efficiencies agree well with predicted efficiencies. The geometric losses are due to groove tops and groove shadowing, and are typically on the order of 10% for small wedge angles, but increase with the wedge angle.

In Figure 5, we show the results of FORCAST cooldown tests done in November 2006 and March 2008. Both silicon and KRS-5 grisms were fully integrated in FORCAST during these measurements. The two principal results are outlined below and in figures 5a-f on the right.

Wavelength Calibration: For the silicon grisms, one way to determine a wavelength calibration is to use water vapor emission lines. The wavelength calibration for G1, G1xG2, G5, and G6 was determined using the ATRAN model of telluric (mostly water vapor) lines smoothed to the specified resolution of each grism. A dewar of liquid nitrogen (LN2) was placed in the field of view of the camera. A path length of about 1 m of room-temperature water-vapor separated the camera window from the LN2 surface. The much warmer water vapor is seen in emission against the 77 K blackbody of the LN2.
In the wavelength range of the KRS-5 grisms, (G3 and G3xG4, 8 − 13.7µm) there are no significant water vapor lines to use as a wavelength calibration standard. Instead, we placed a hotplate at ~ 350K and placed a thin (1.5 mil) sheet of polystyrene across the camera window. The polystyrene has several broad absorption features in the spectral range of grisms 3 and 4 which served as wavelength calibration standards.

Spectral Resolution: Measuring the FWHM of unresolved water lines yielded resolutions of ~250 and ~1400 for grisms 1 and 2. Resolution measurements were not possible for grisms 3 and 4 since none of the polystyrene absorption lines are narrow enough to be unresolved. Grisms 5 and 6 show resolving powers of 185 and 265, respectively.

Anti-Reflection Coating: The entrance faces of Grisms 1 and 2 have been coated with a broad-band anti-reflection coating to reduce Frenel losses and improve transmission. Grisms 3 and 4 were purchased with anti-reflection coatings already applied to the entrance faces.

Grism	Material	Physical characteristics	Wavelength band	Slit size	Design R	Measured R	Measured efficiency at 1.4-1.8µm
1	Si	σ=25µm, δ=6.16°, m=1	5 - 8µm	3'x2"	200	225	40±3%
2	Si	σ=87µm, δ=32.6°, m=1	5 - 8µm	2"x15"	1200	1400	-
3	KRS-5	σ=32µm, δ=15.2°, m=1	8.1 - 13.7µm	3'x2"	300	-	-
4	KRS-5	σ=130µm, δ=36.8°, m=1	8.1 – 13.7µm	2"x15"	800	-	-
5	Si	σ=87µm, δ=6.16°, m=1	17.1 – 28.1µm	3'x2"	140	185	39±3%
6	Si	σ=142µm, δ=11.07°, m=2	28.7 – 40.0µm	3'x3"	250	265	41±3%

Table 1. FORCAST grism suite. The physical characteristics in column 3 are groove spacing (σ), prism angle (δ), and order in which grism will operate (m).

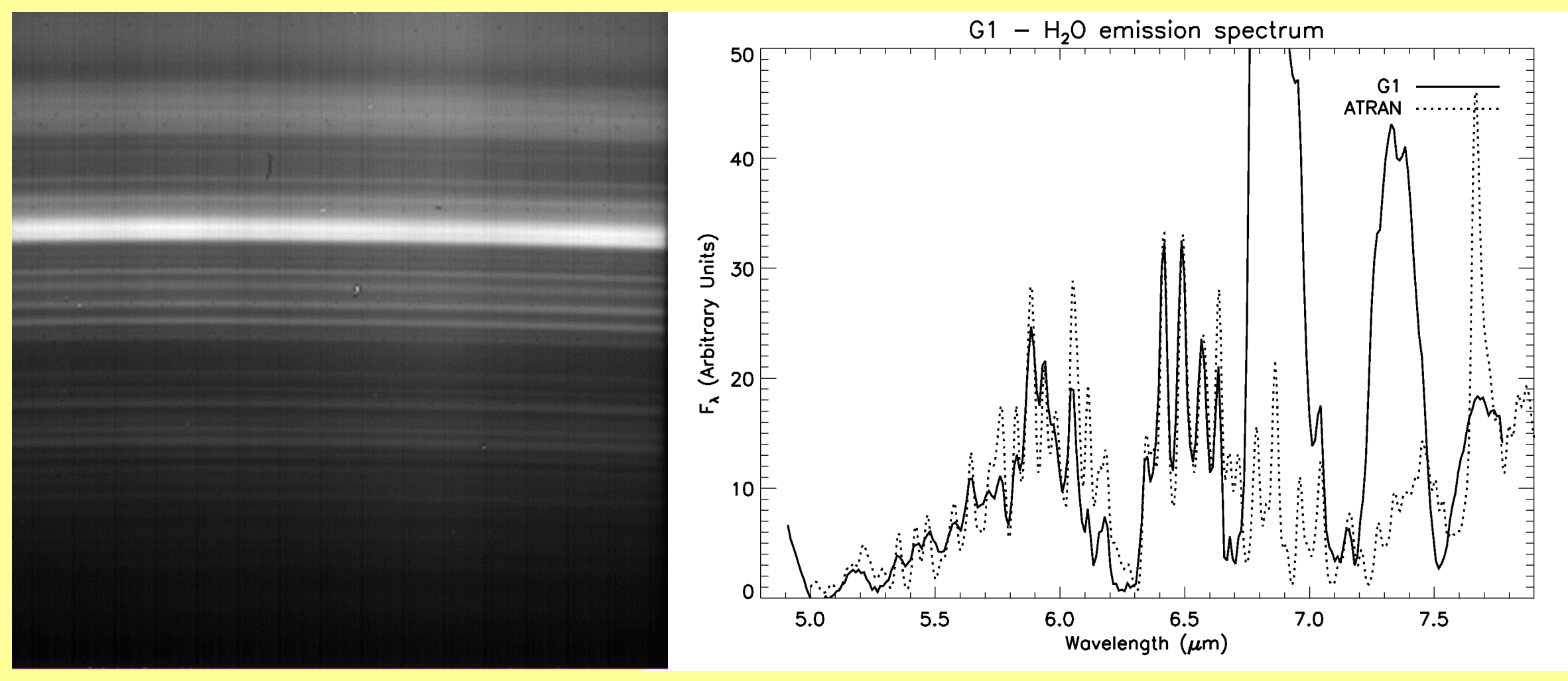

Figure 5a: Detector image and G1 extracted long slit spectrum of water vapor in emission above a liquid nitrogen background

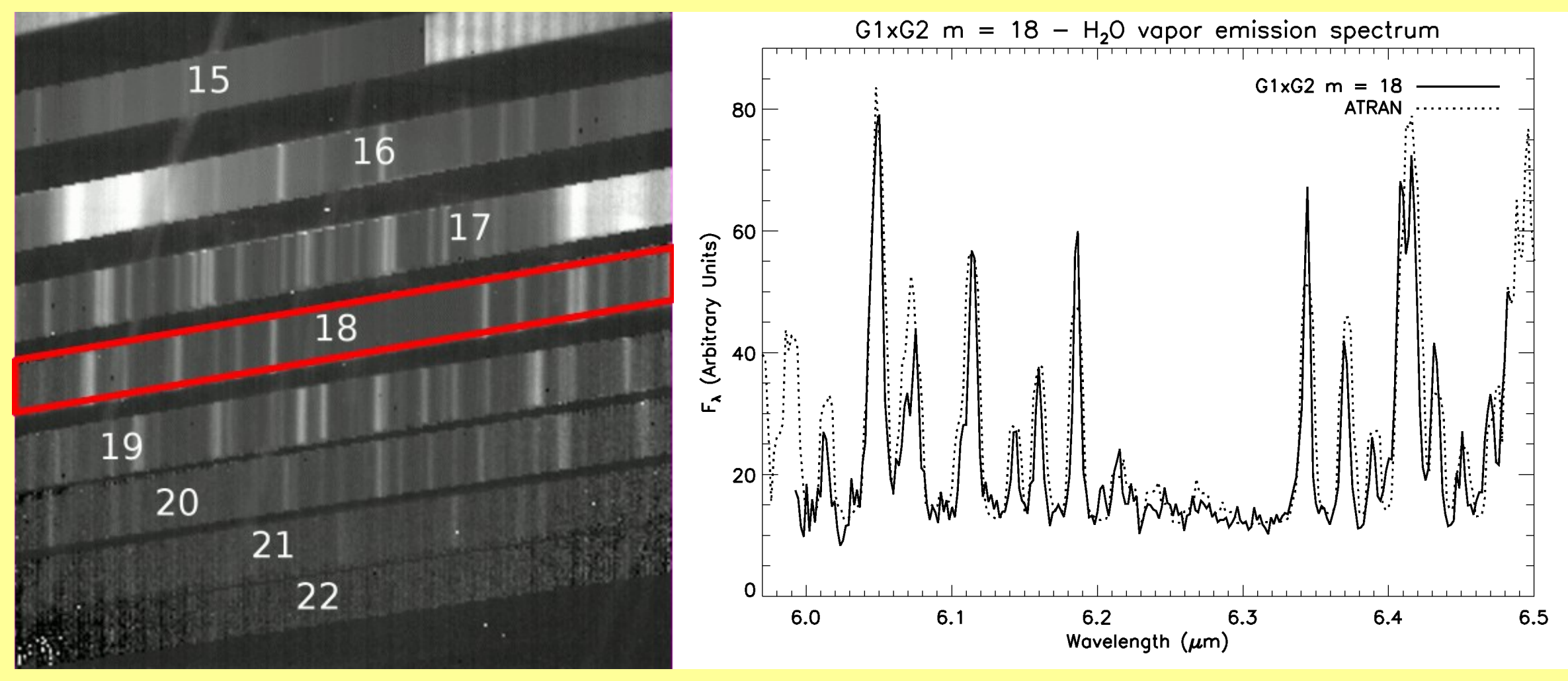

Figure 5b: Detector image and G1xG2 extracted cross dispersed spectrum of water vapor in emission over a liquid nitrogen background. Only the 18th order (highlighted in red) is extracted

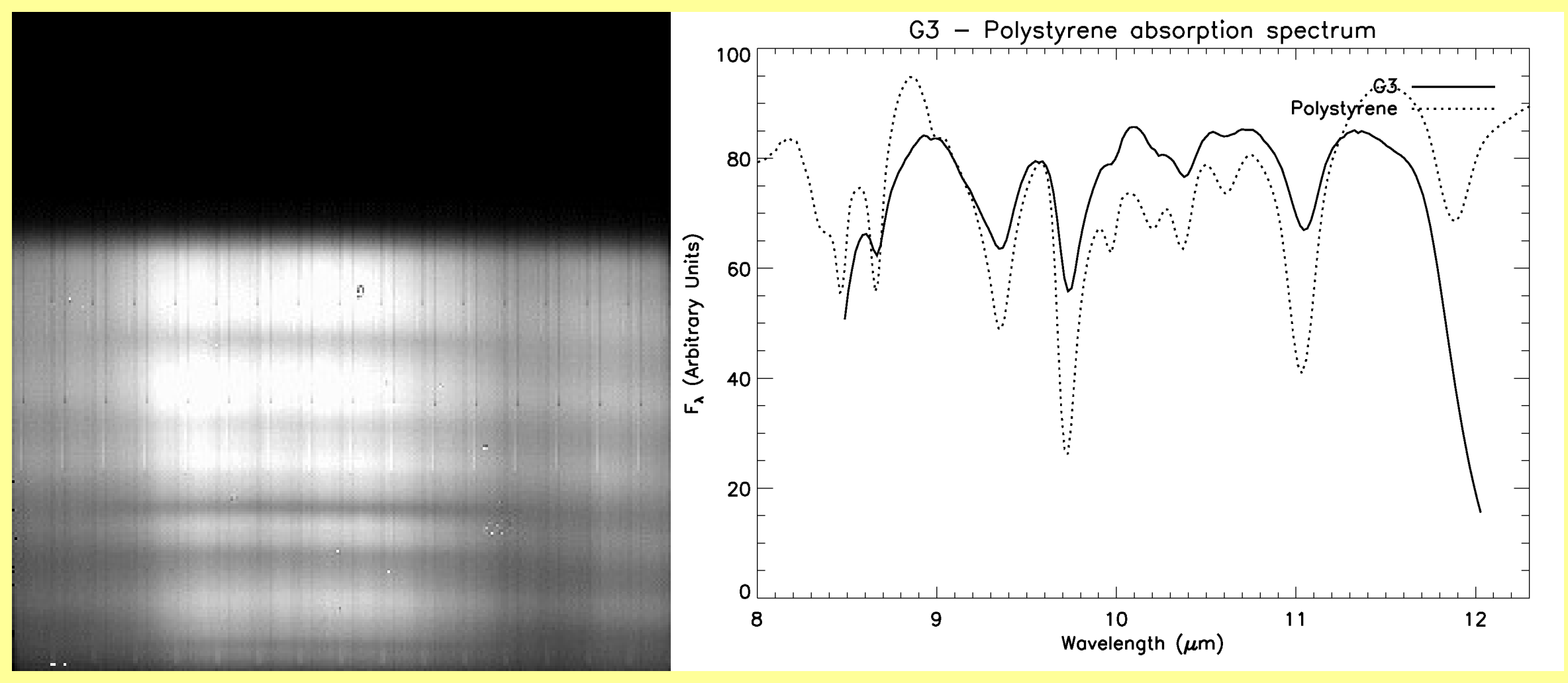

Figure 5c: Detector image and G3 extracted long slit spectrum of polystyrene film in absorption above a hotplate background

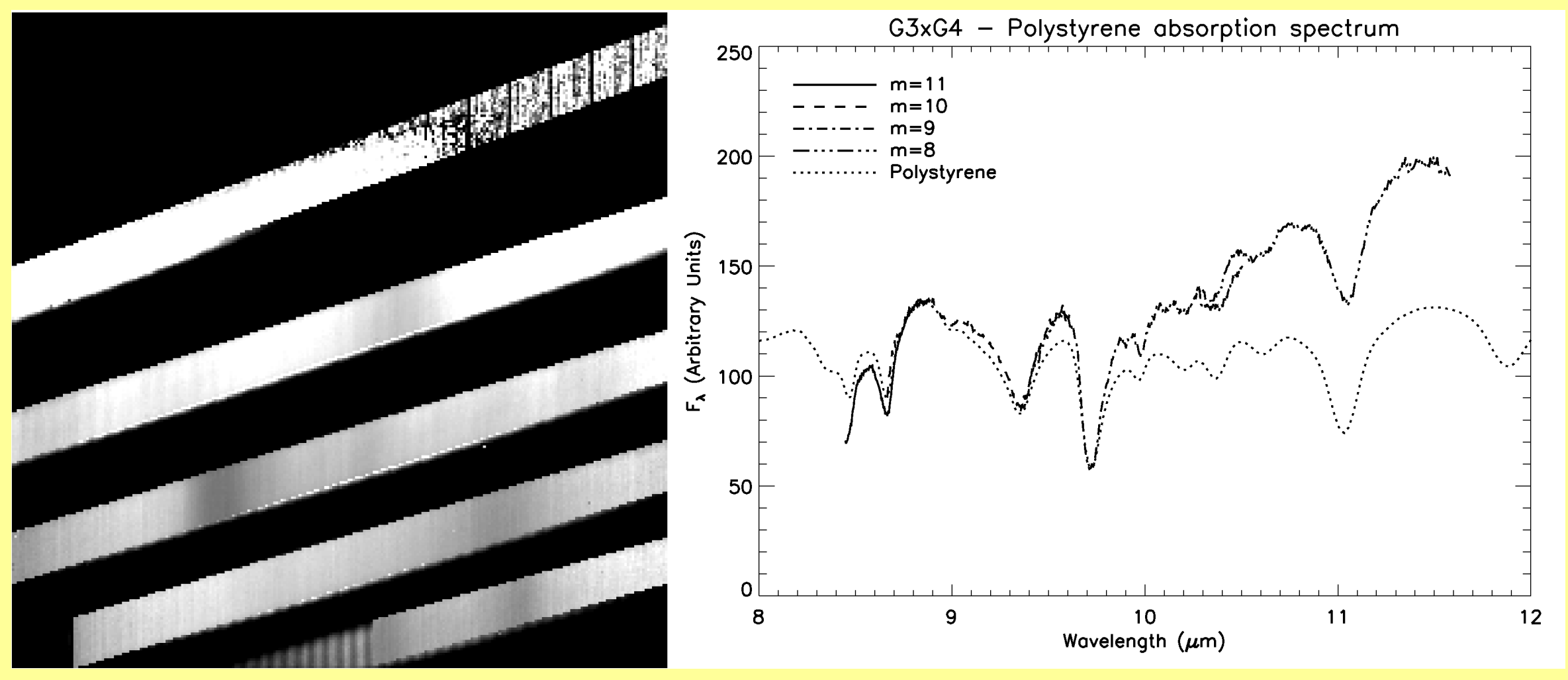

Figure 5d: Detector image and G3xG4 extracted cross-dispersed spectrum of polystyrene film in absorption above a hotplate background

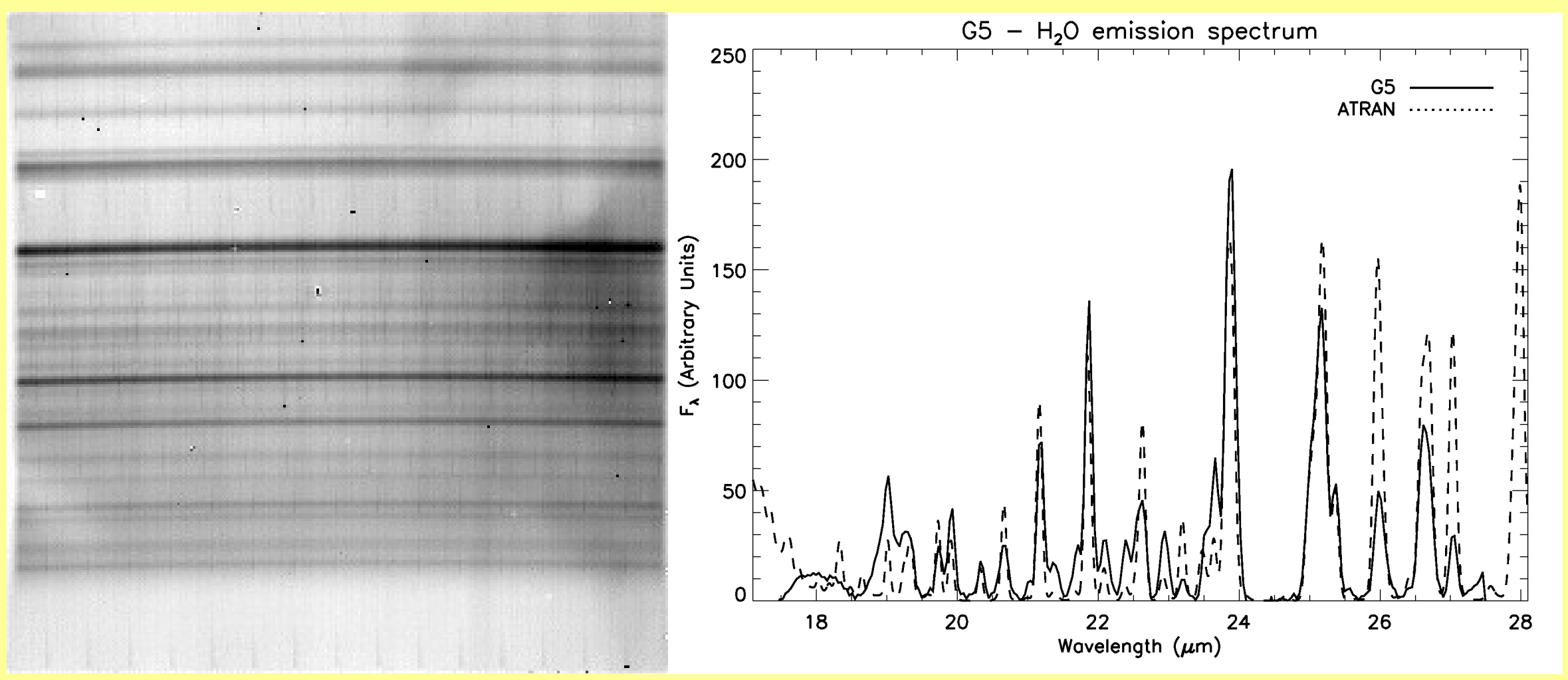

Figure 5e: Detector image and G5 extracted spectrum of water vapor in emission above a liquid nitrogen background

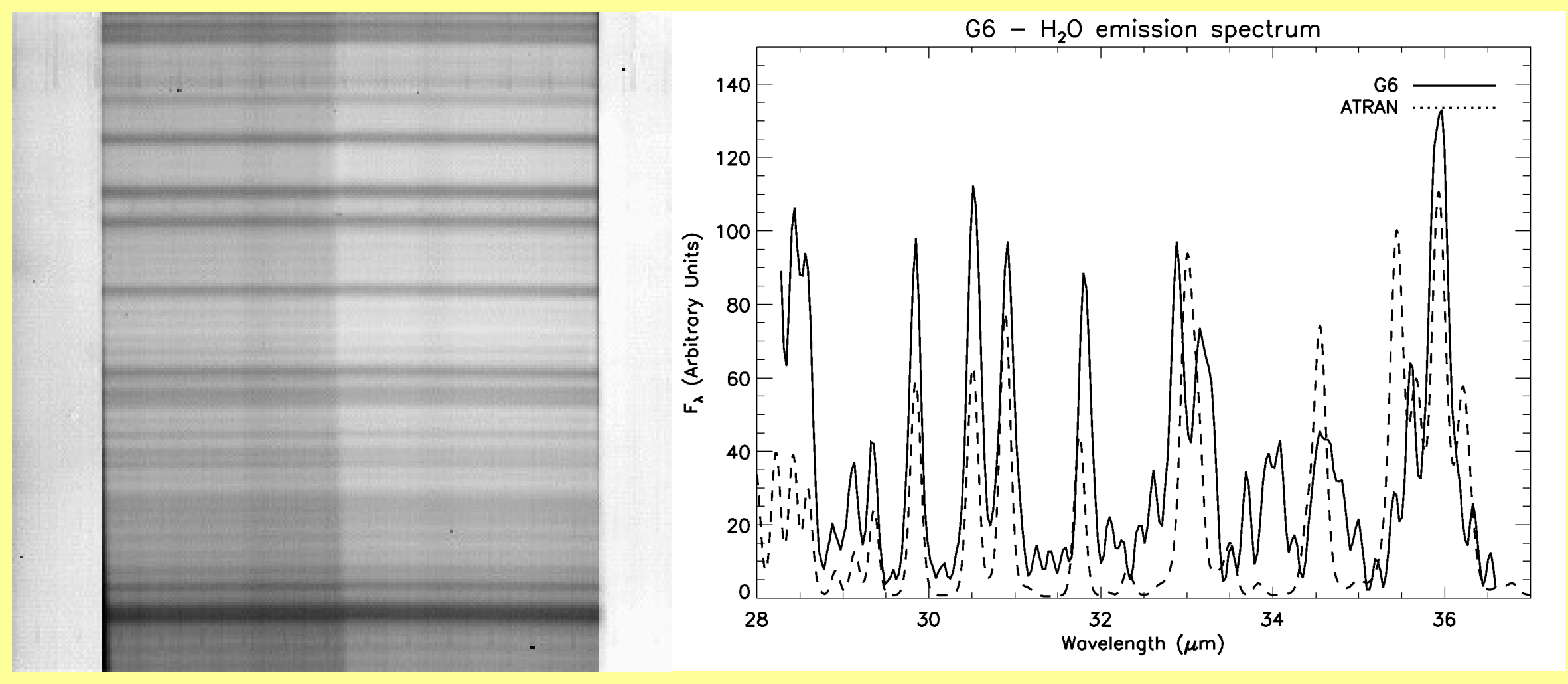

Figure 5f: Detector image and G6 extracted spectrum of water vapor in emission above a liquid nitrogen background. G6 operates in second order, and was not used with the correct blocking filter in this exposure. The features at 33 and 36 microns are due to blue leaks in the filter showing up in third order.