すばる望遠鏡およびTMT、E-ELT用の新しい回折格子

Novel gratings for Subaru Telescope, TMT and E-ELT

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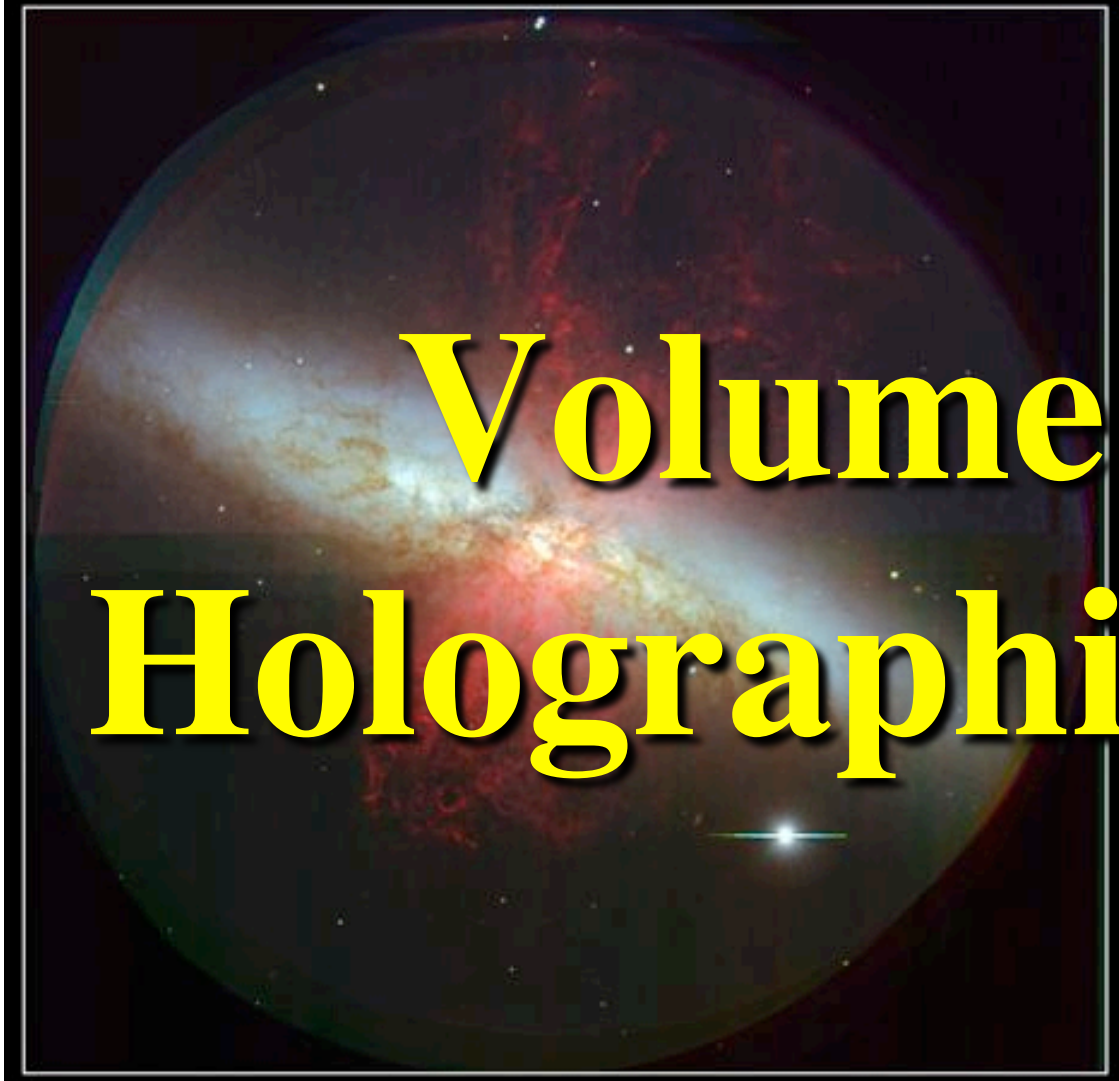
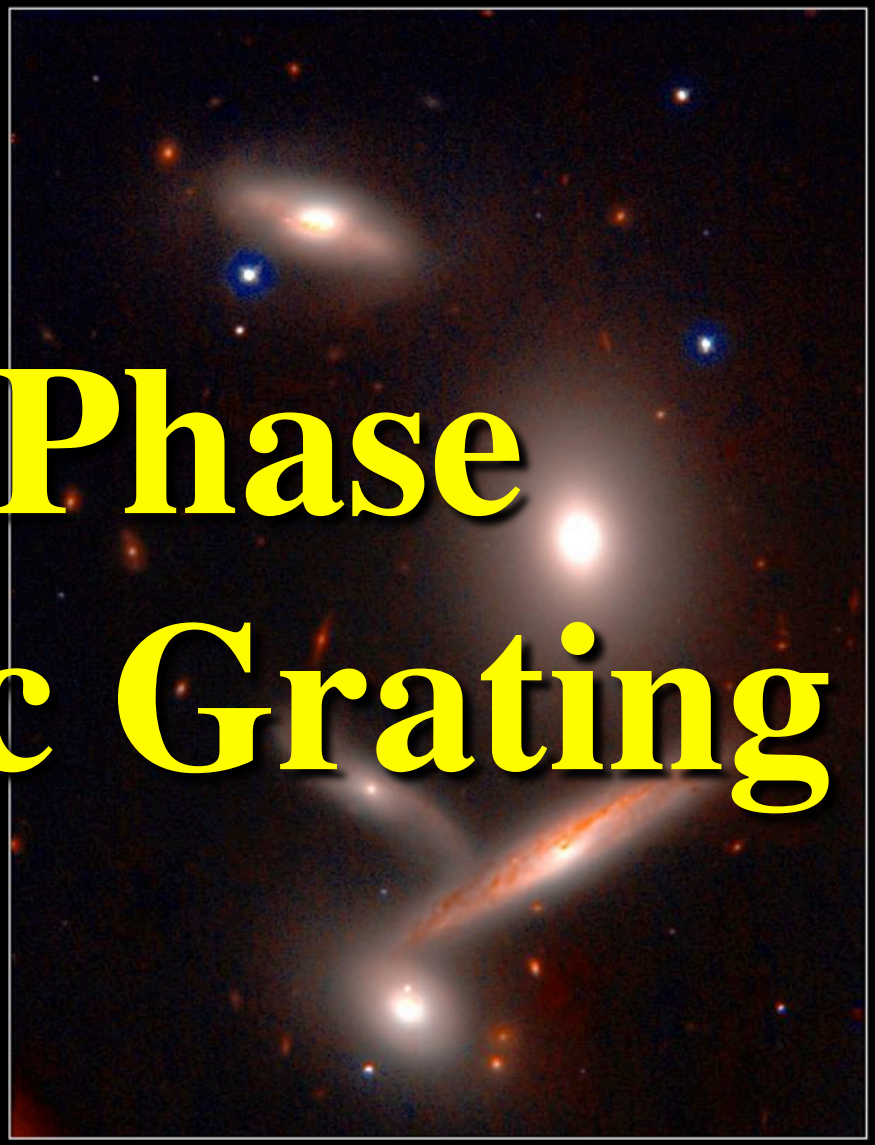
すばる将来装置計画ワークショップ

January 18, 2011

Volume Phase Holographic Grating

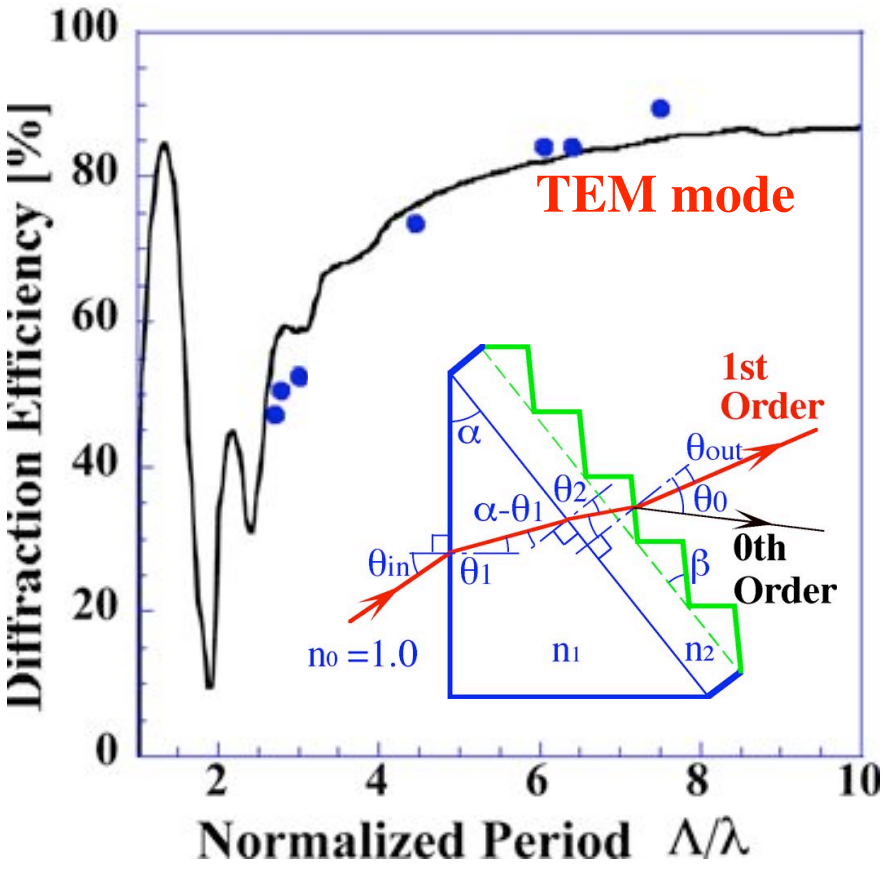


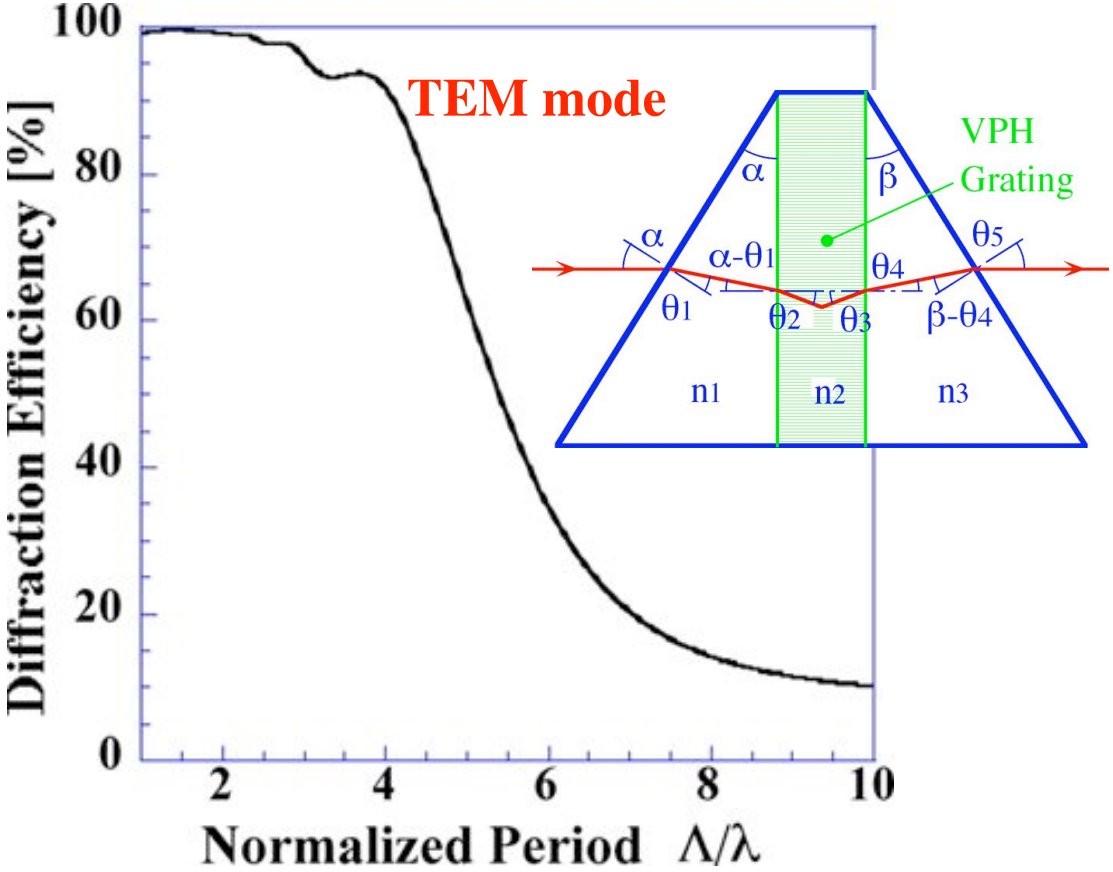
M 82 (NGC 3034)
Subaru Telescope, National Astronomical Observatory of Japan
FOCAS (B, V, Hα)
March 24, 2000



Hickson Compact Group 40
Subaru Telescope, National Astronomical Observatory of Japan
CISCO (J & K′)
January 28, 1999

Efficiencies of Gratings





Surface relief grating: Efficiency decreases steeply below 4 Λ/λ

VPH (Volume Phase Holographic) grating ($\Delta n \sim 0.02$): Efficiency increases up to 100% below 4 Λ/λ.

(K. Oka et. al., SPIE 5005, 2003)

Fabrication of Hologram Plate

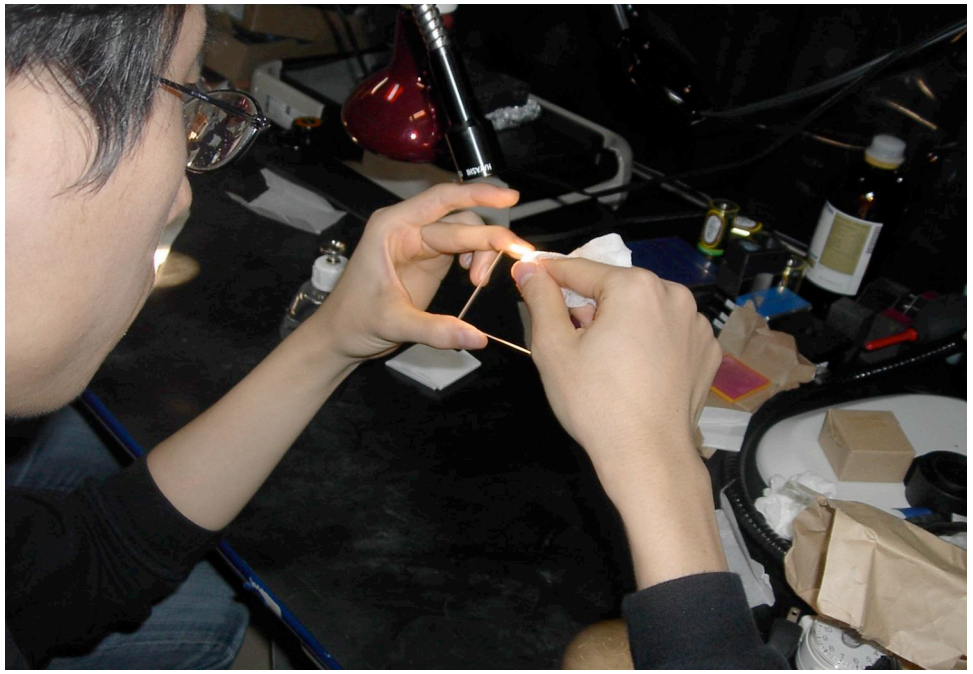
Cleaning of substrates (Hand polish)

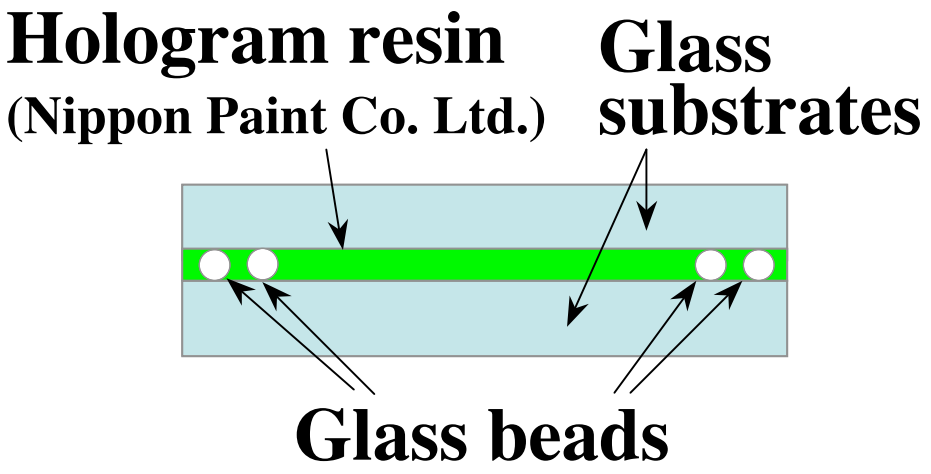
▼

Dropping liquid hologram resin onto a substrate, heating up to 80℃

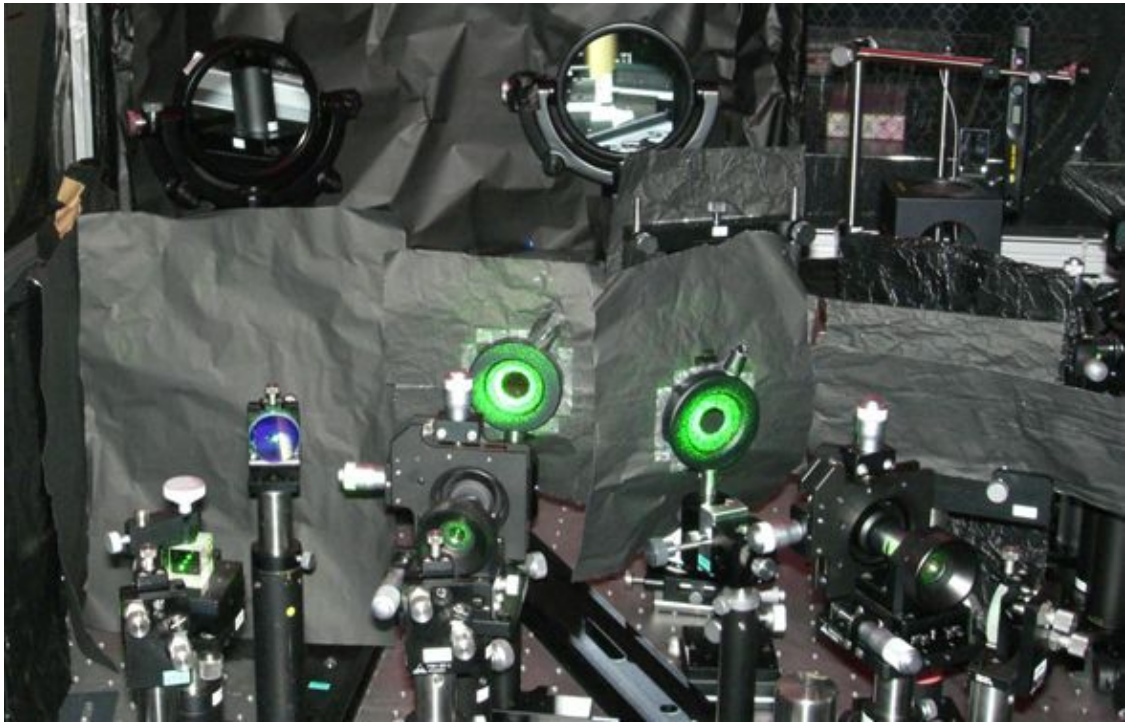
▼

Covered by another substrate. Thickness of resin layer is given by glass or plastic beads.

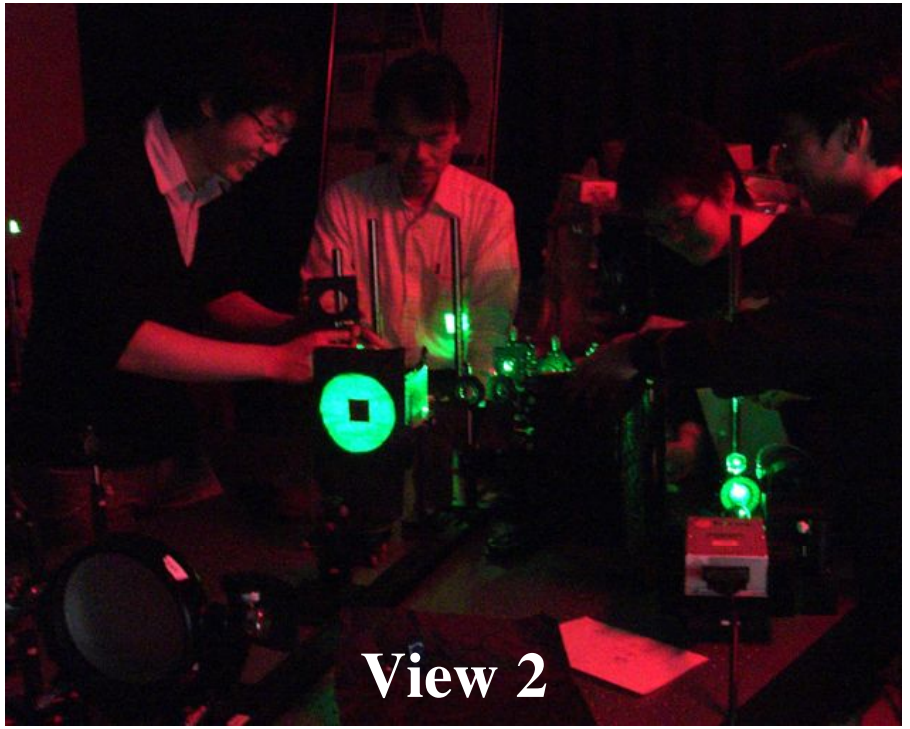


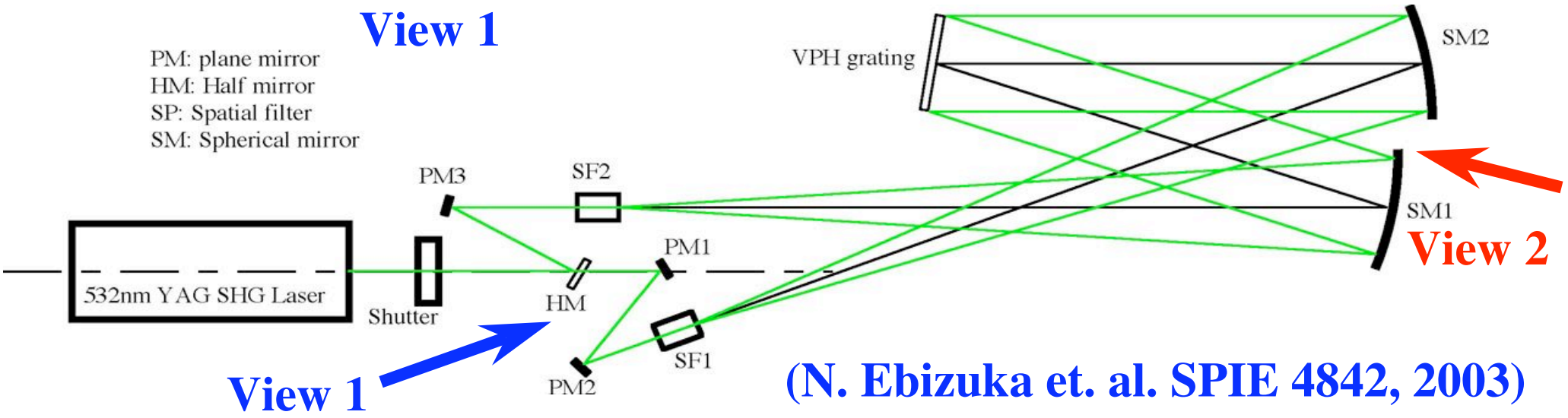


Two Beam Interferometer for Holographic Exposure

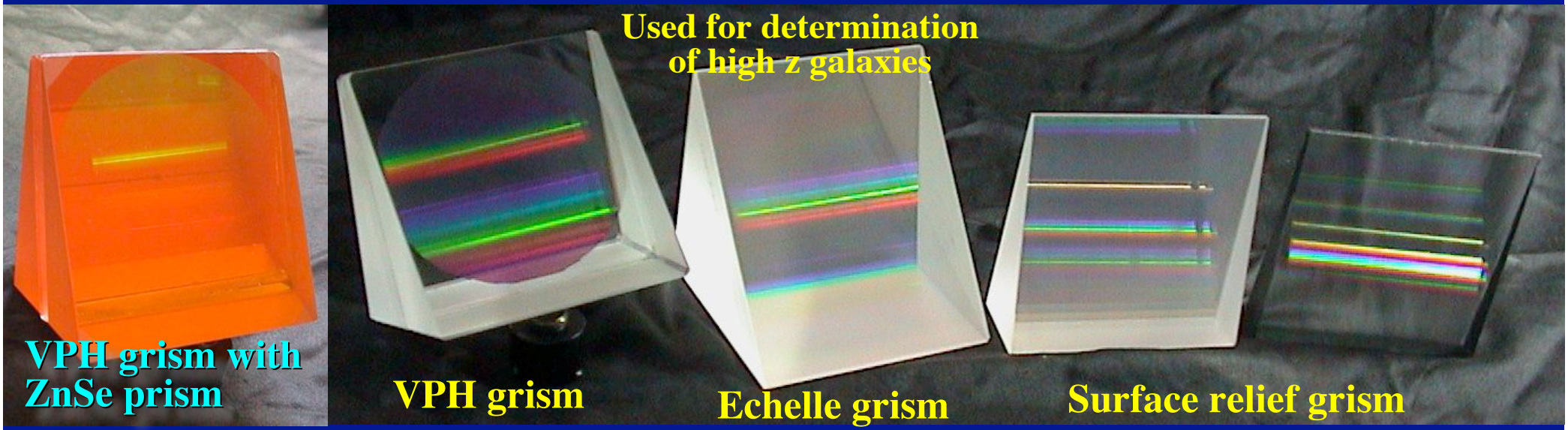


View 1





(N. Ebizuka et. al. SPIE 4842, 2003)

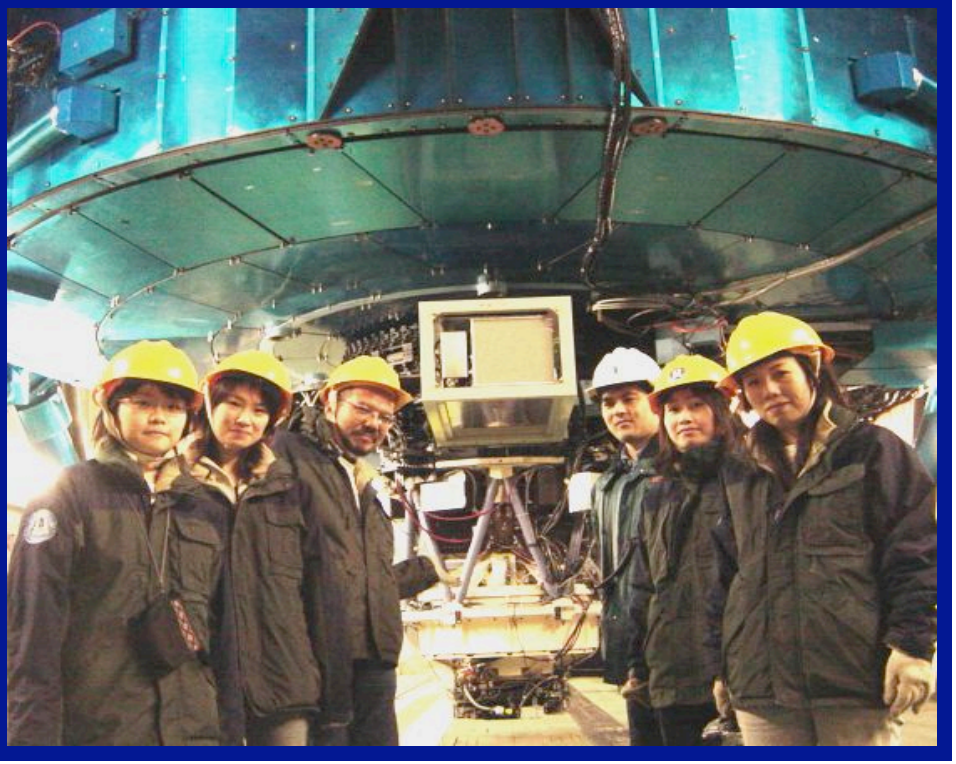


FOCAS Grisms

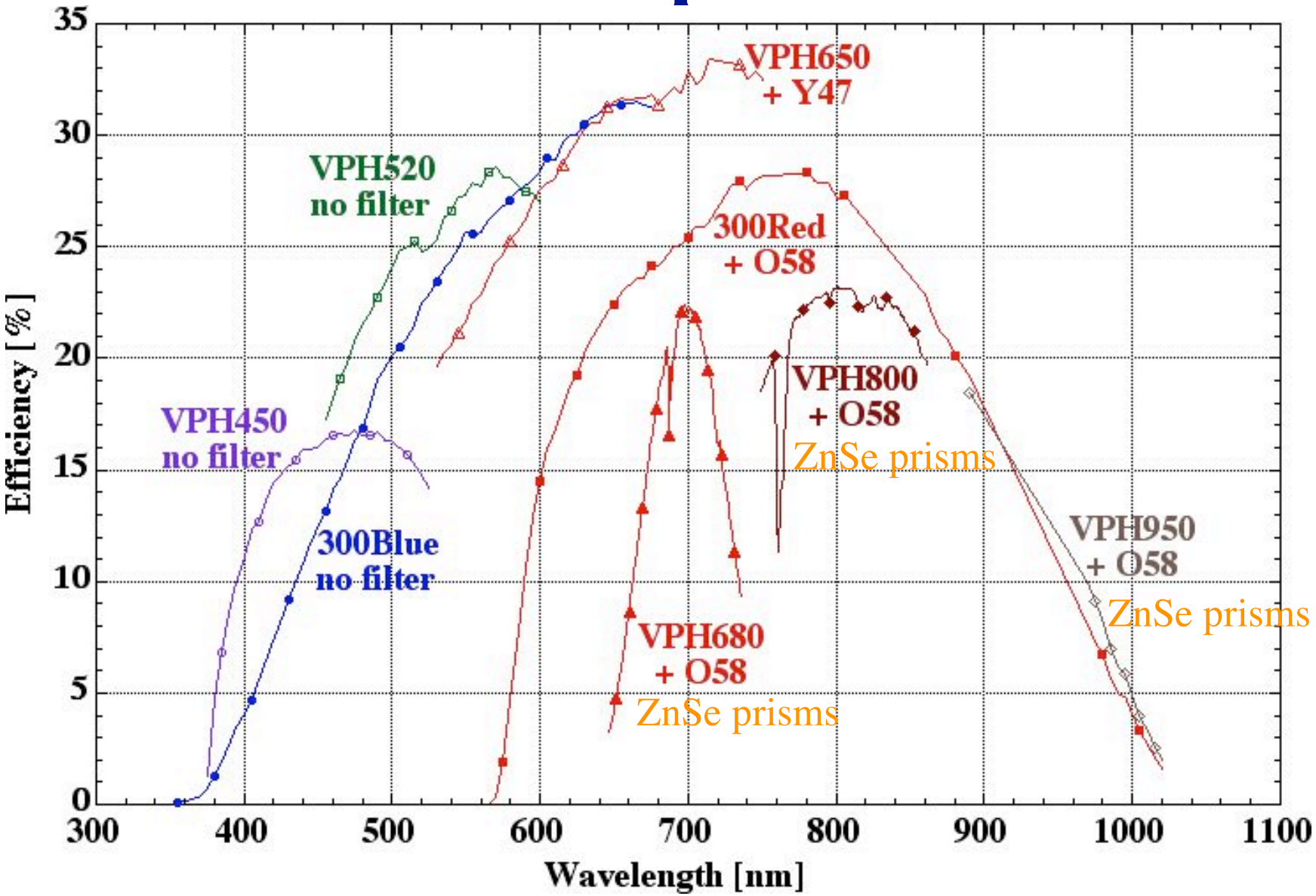
Size: 110 × 106 × 106 (max).

4 SR grisms: 300 < R < 1,400.
1 Echelle grism: R~2,500.

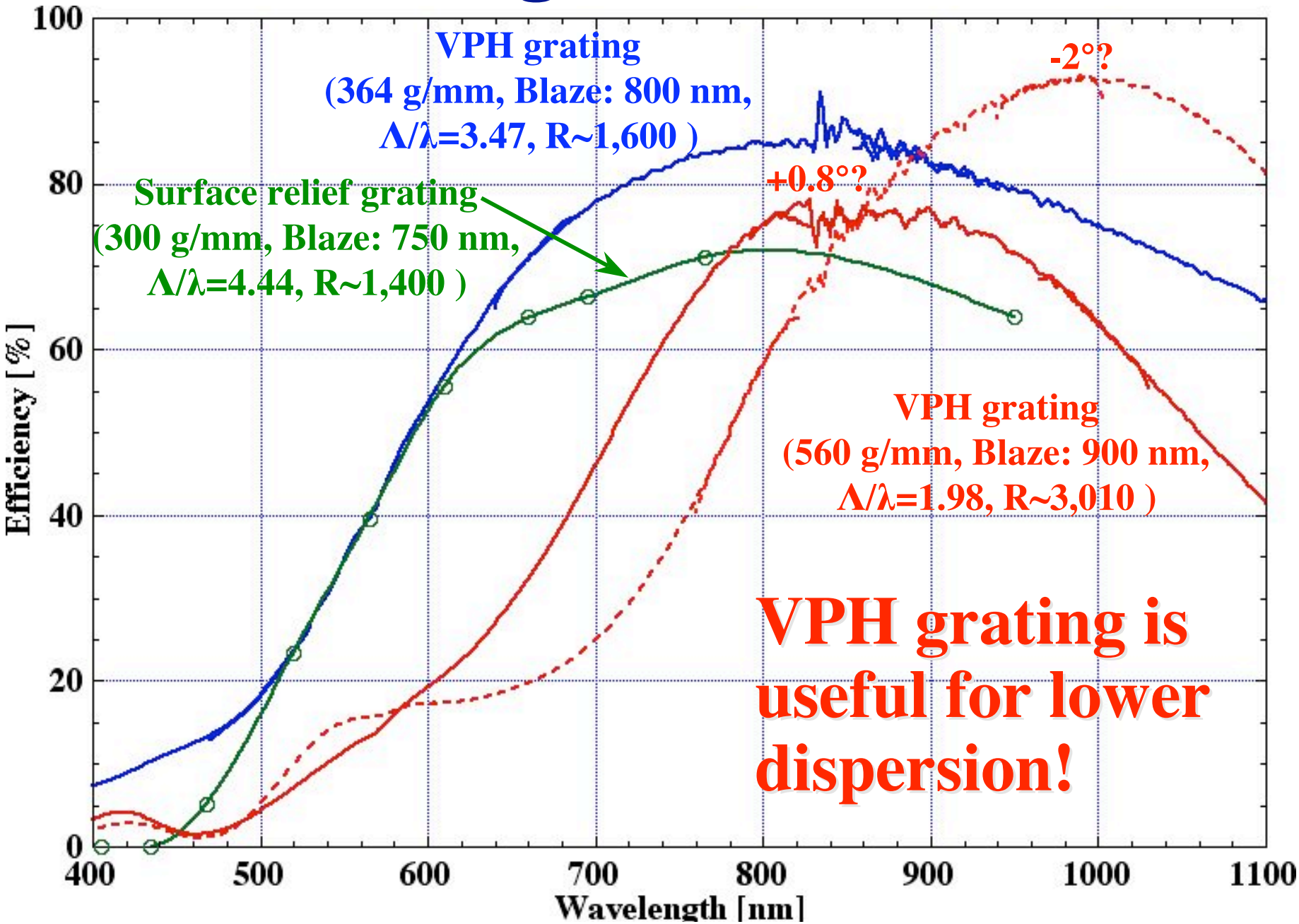
8 VPH grisms (3 grisms with ZnSe prisms): 1,600 < R < 7,000, Collaboration of JWU (Japan Wemen's Univ.) and NAOJ.



Relative Efficiencies of Grisms within Subaru Telescope and FOCAS

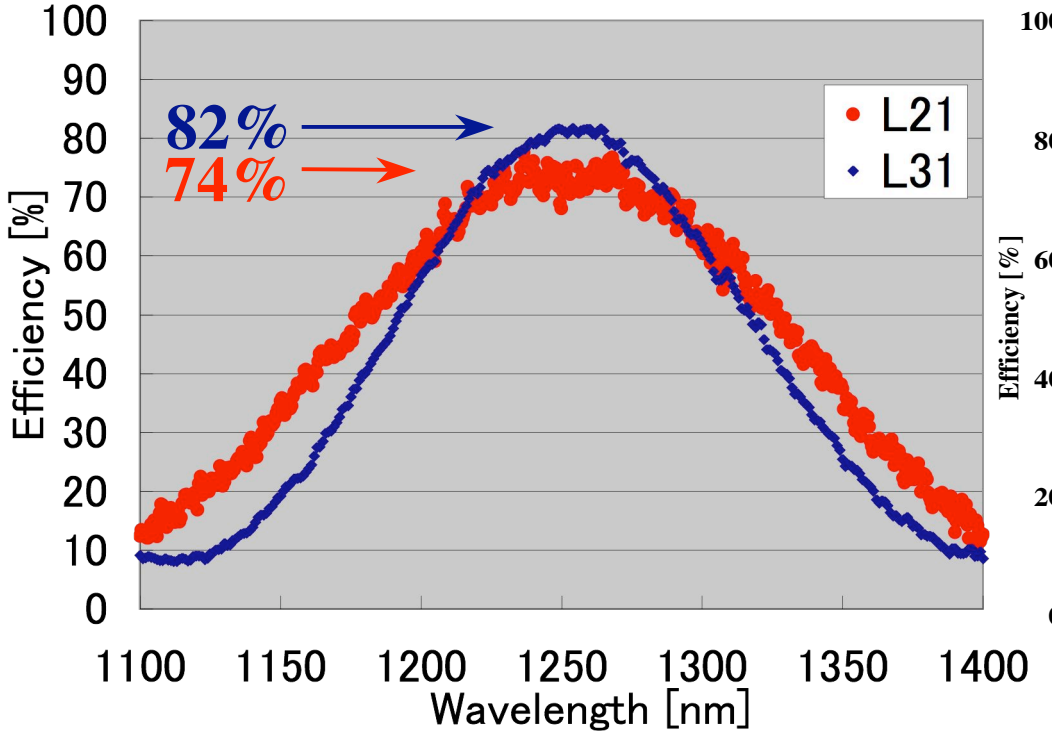


New VPH grisms for FOCAS

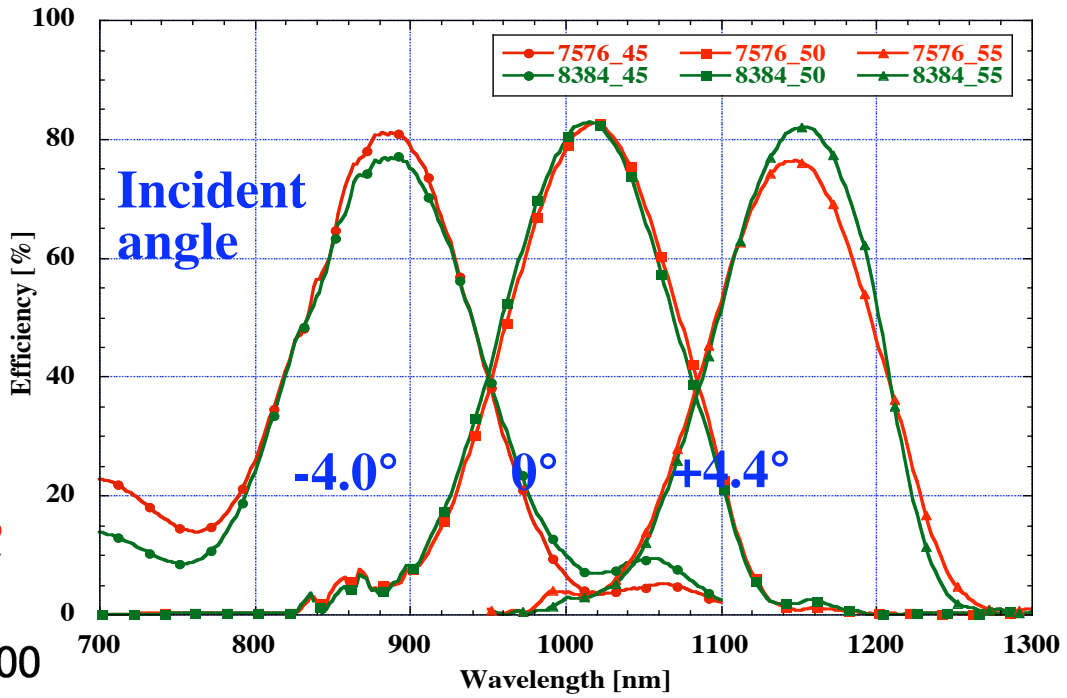


MOIRCS VPH grisms

Band	Center [μm]	Range [μm]	R (Δλ/λ) @0.5" Slit	Efficiency (Peak)	Developer
Y	1.02	0.94 – 1.09	3,200	~ 0.80	Soma Opt.
J	1.25	1.13 – 1.37	3,100	0.82, 0.74	Tohoku Univ.
H	1.65	1.52 – 1.78	3,000	~ 0.75	Tohoku Univ.
K	2.20	2.00 – 2.40	2,600	> 0.80	JWU

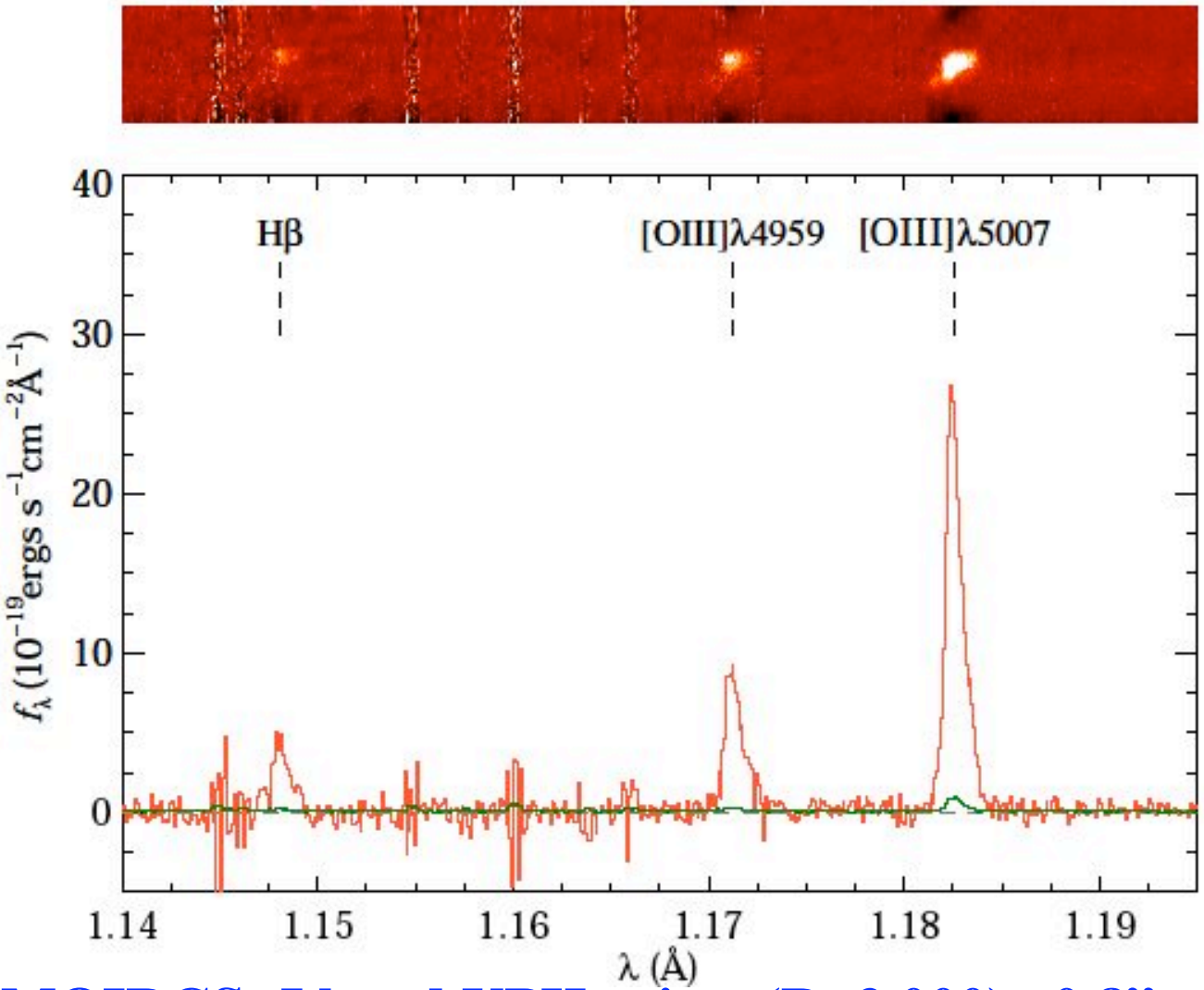


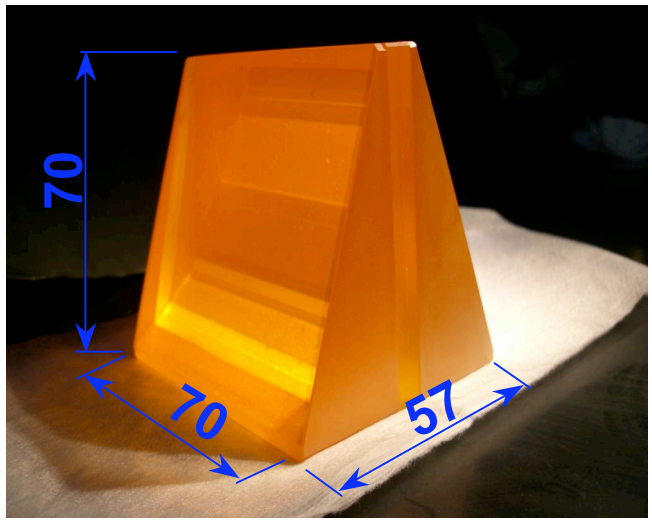
J band



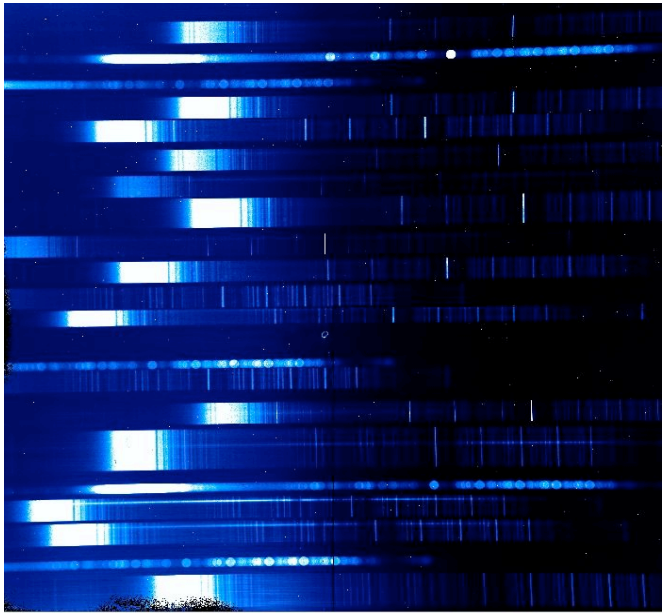
Y band

Spectrum of High-z Galaxy (z = 1.618)





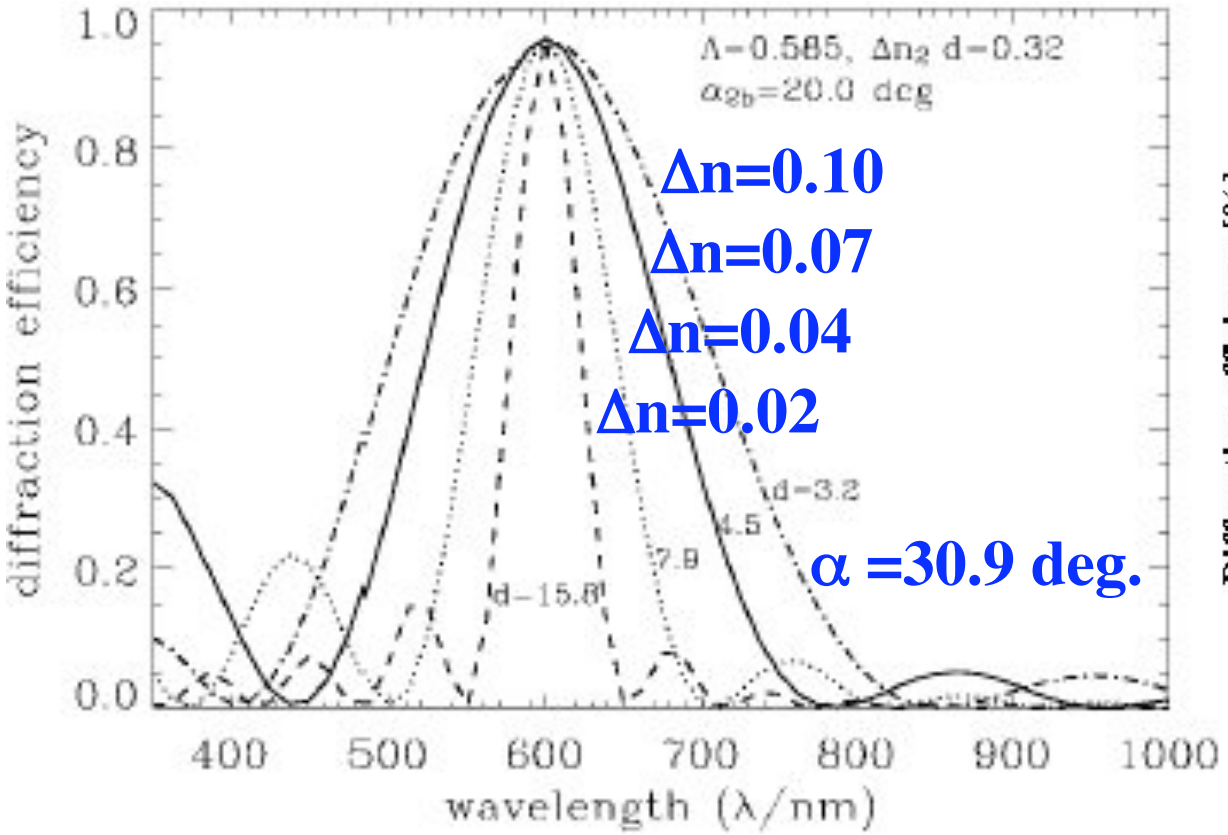
Size: 70 x 70 x 57 (max) mm.

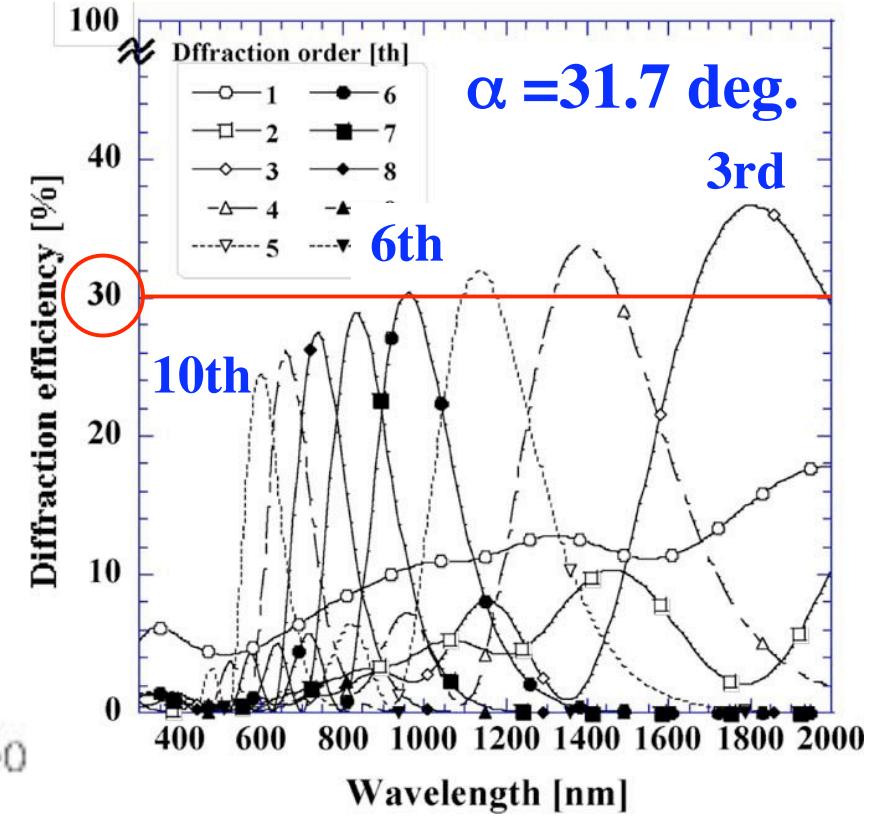


MOIRCS, J band VPH grism (R~3,000) , 0.8" slit [Onodera in private communication].

(T. Ichikawa et. al., SPIE 7014, 2008)

Limitation of VPH grating





Band width of VPH grating becomes narrow in diffraction angle: α above 30 degree because semi-amplitude of index modulation (Δn) of dichromated gelatin (DCG) is up to 0.15~0.2.
(Baldry et al., PASP, 116, 2004)

Diffraction efficiency of VPH grating decrease toward higher orders.
(Oka et. al., SPIE, 5290, 2004)

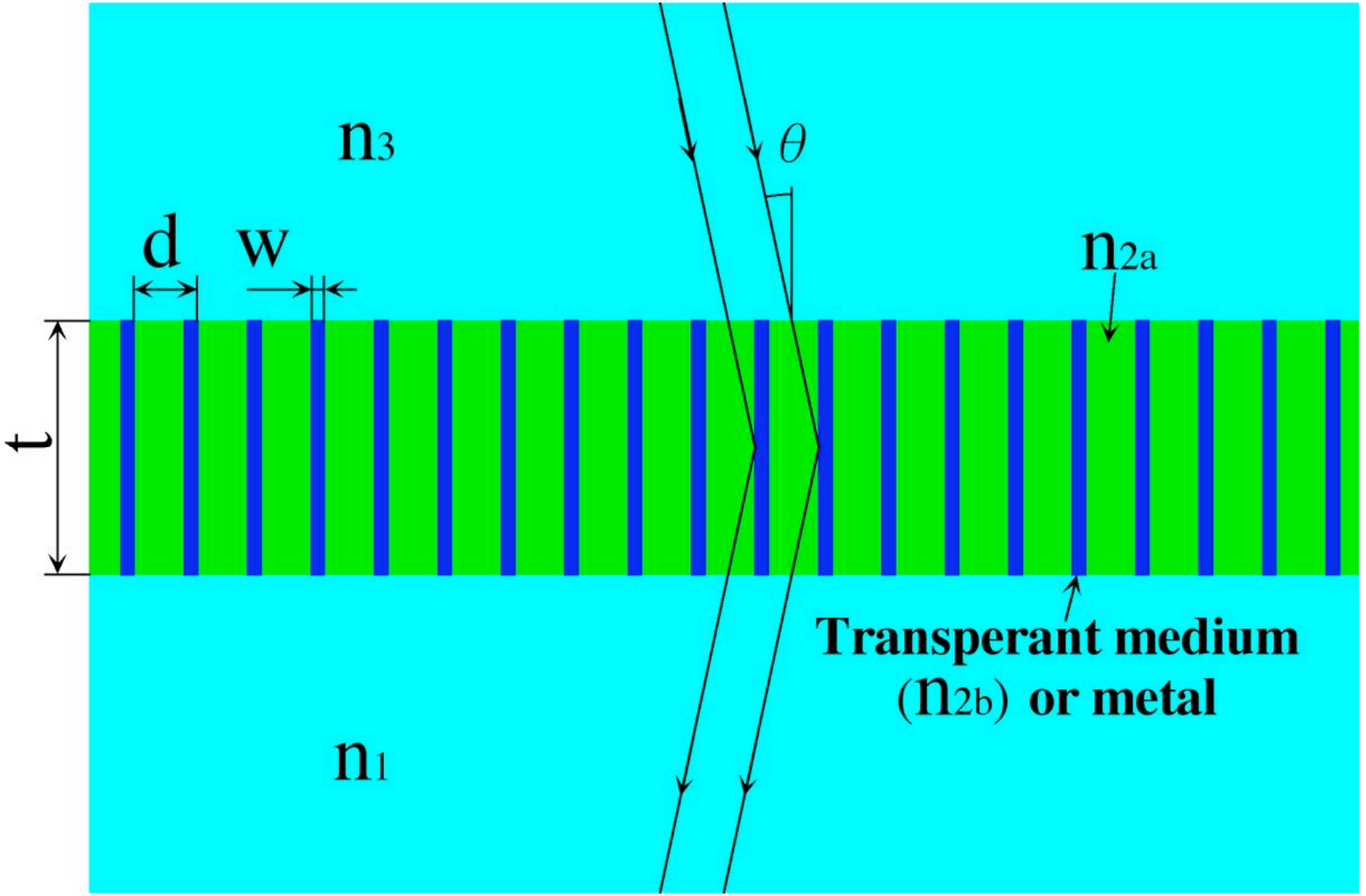
Grating Used for Higher Diffraction Orders

IC 434 (Horse-head Nebula)

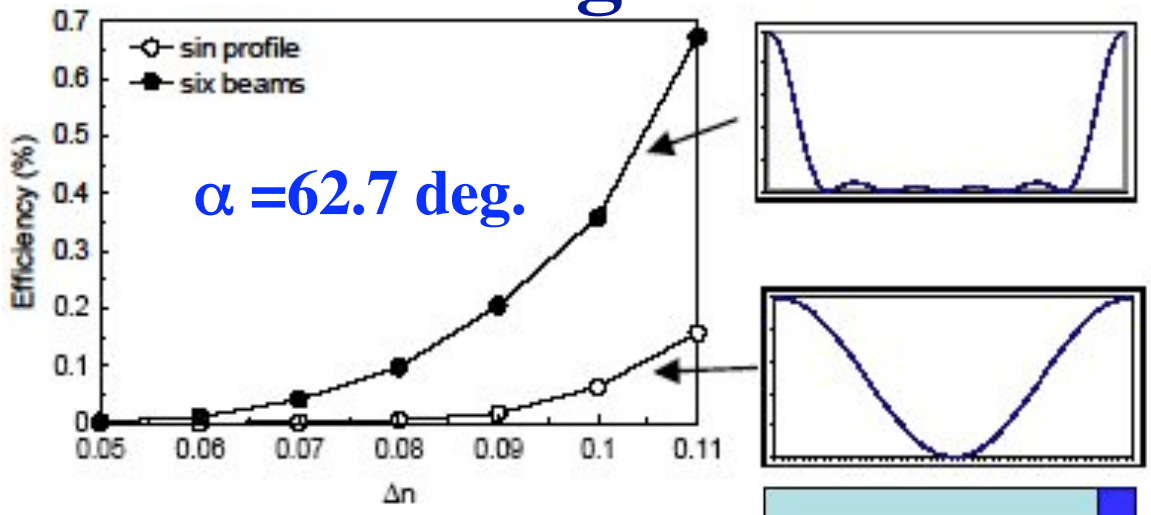
Ultra-high-sensitivity HDTV I.I. color camera (NHK)
Exp. 22 sec. (11 frames coadded) January 16, 1999

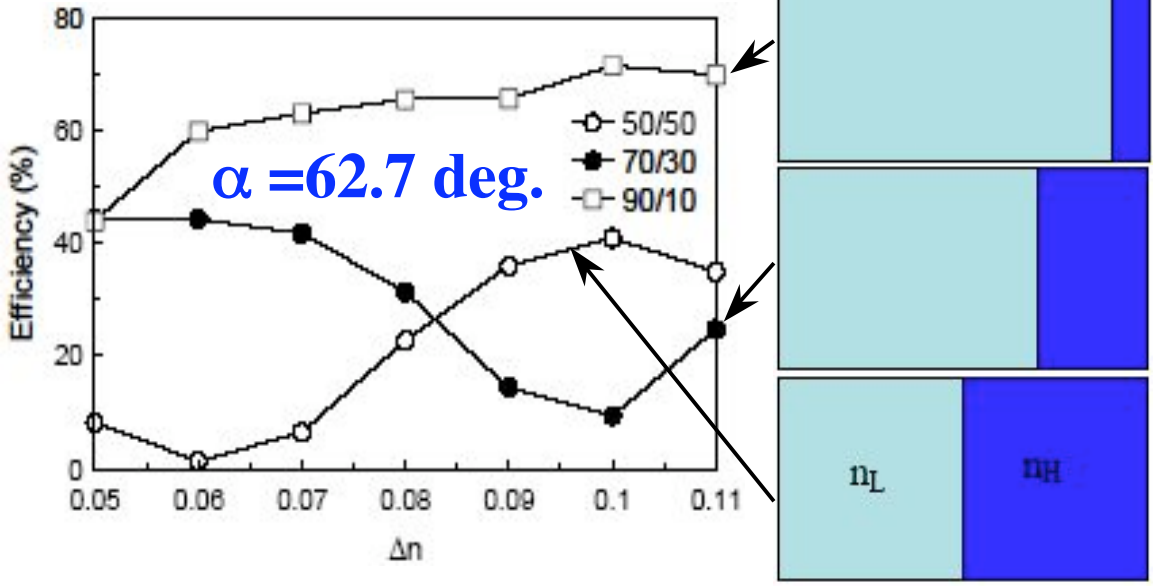
Subaru Telescope, National Astronomical Observatory of Japan

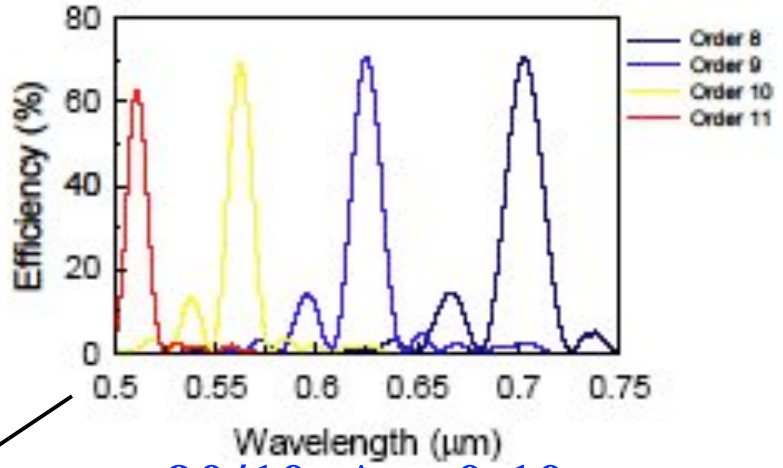
Thick Binary Grating and Quasi-Bragg Grating



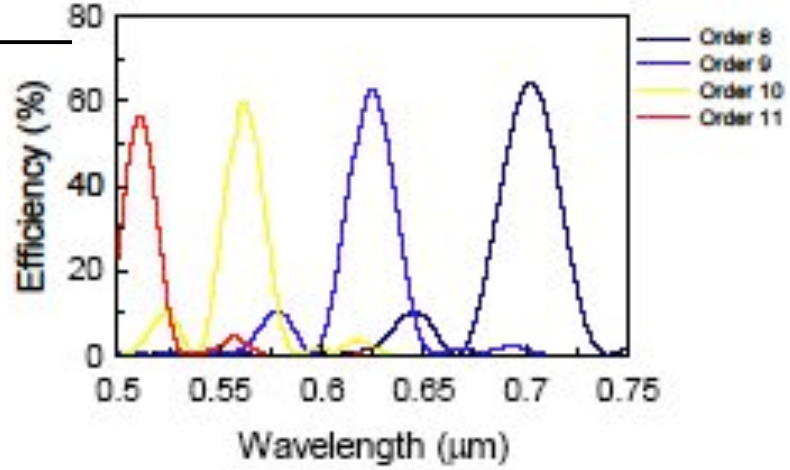
Diffraction Efficiencies of VPH Grating and Thick Binary Grating







90/10, Δn=0.10.



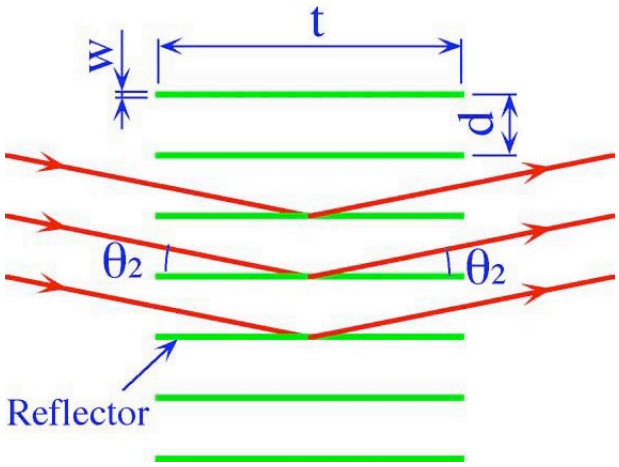
90/10, Δn=0.11.

VPH gratings (above) and binary gratings (below) at the 9th order.

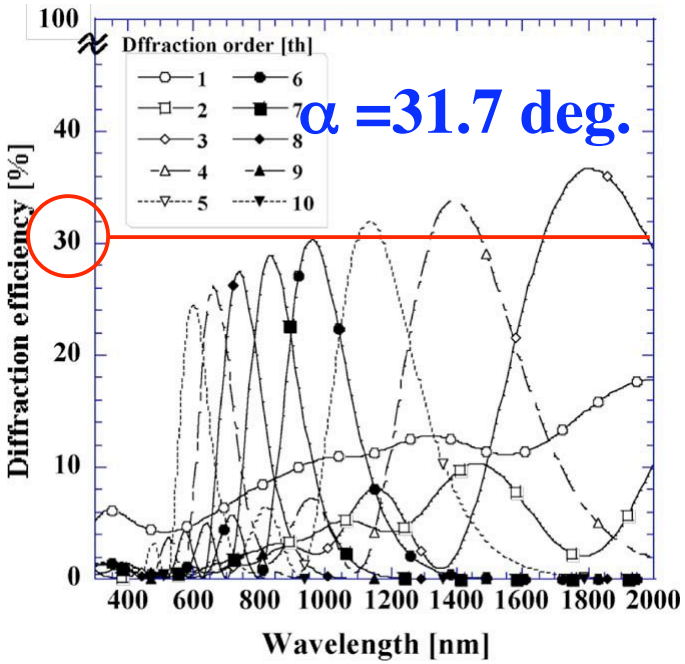
(Bianco et al. SPIE 7739, 2010)

Echellegram

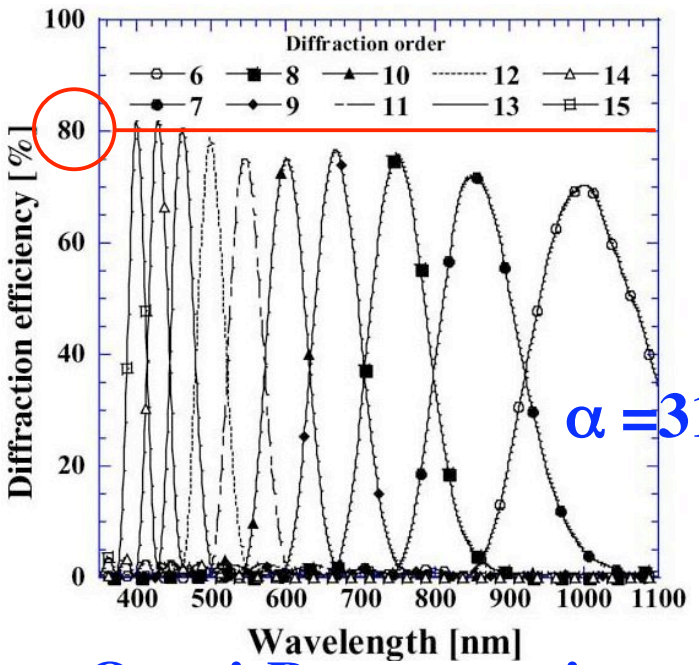
Quasi-Bragg Grating



- SR grating slightly changes spectral characteristics.
- VPH grating becomes lower efficiency toward higher order.



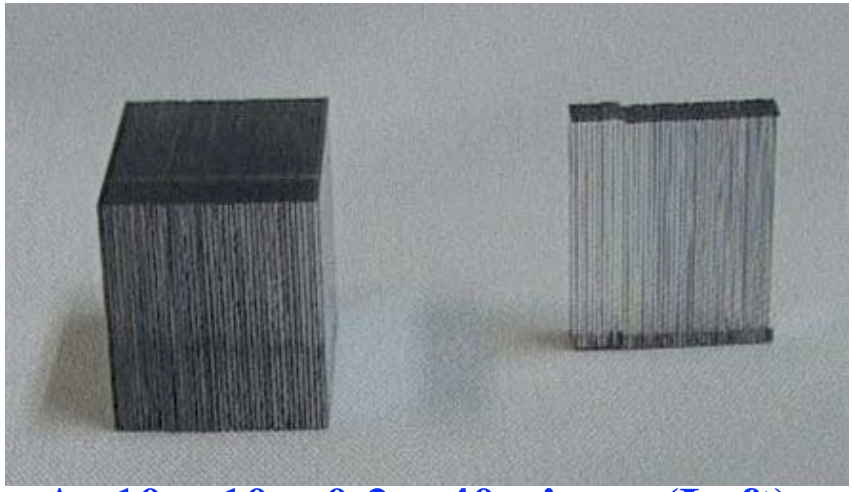
VPH grating



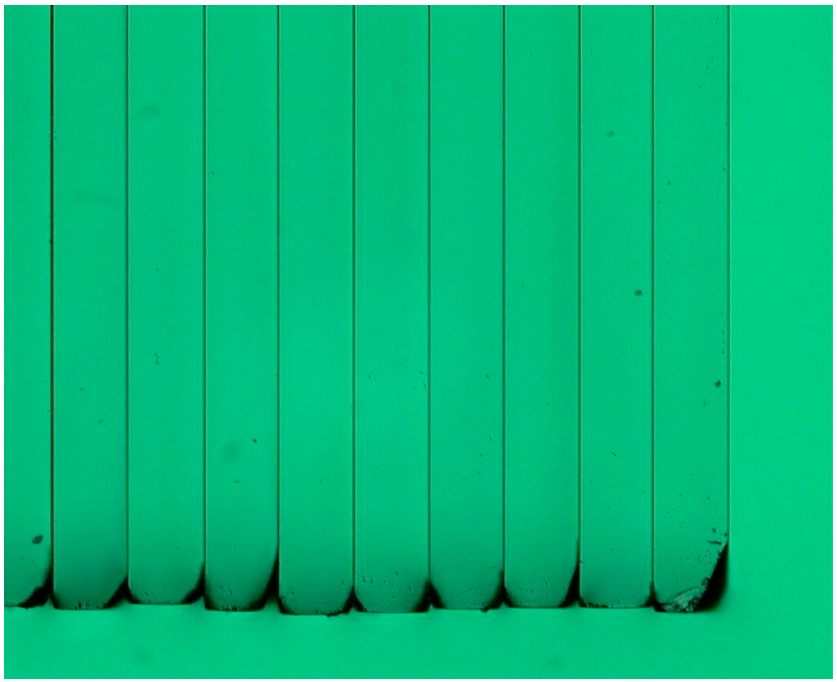
Quasi-Bragg grating

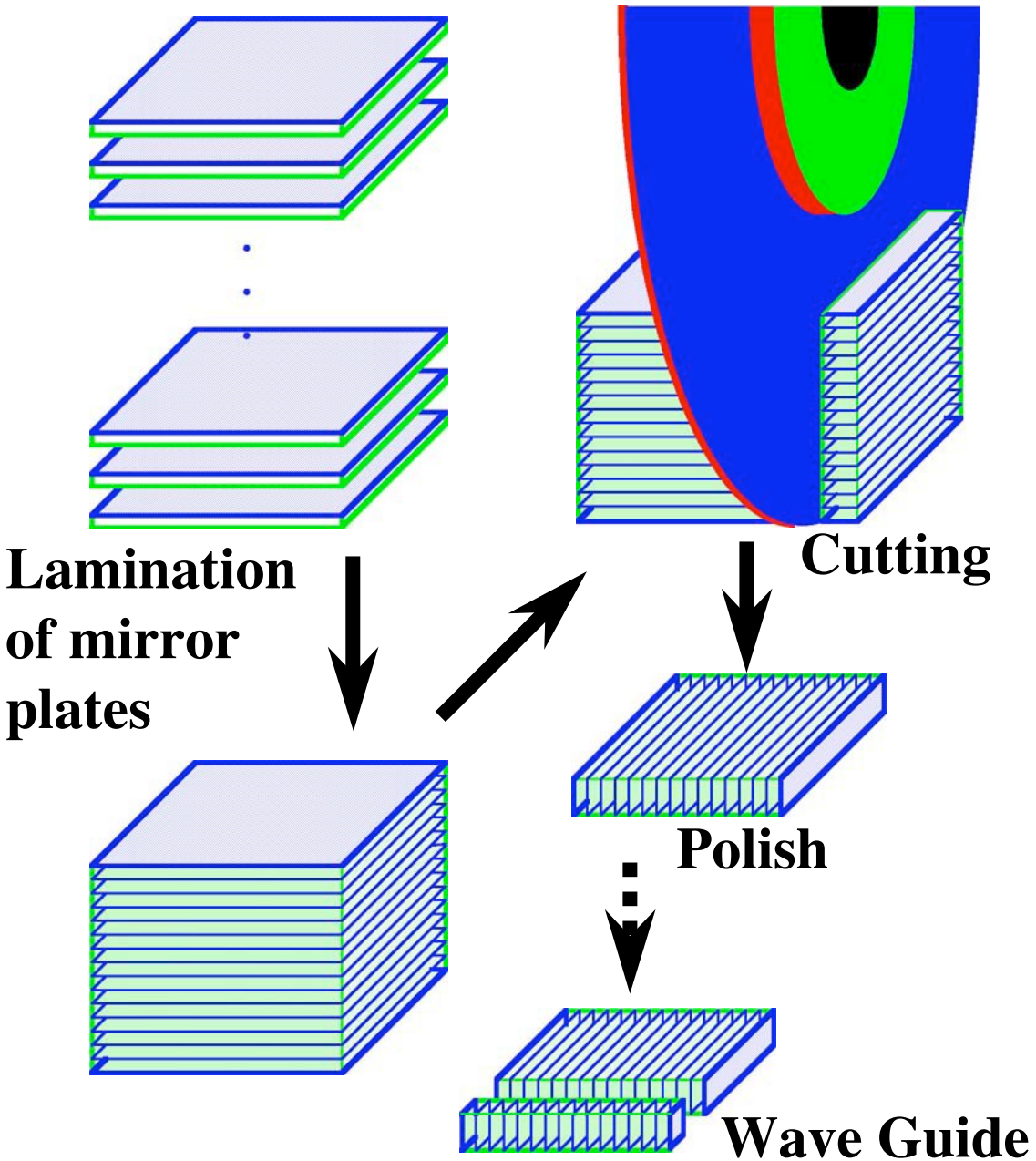
(Oka, et. al., SPIE 5290, 2004)

Trial Fabrication of Quasi-Bragg Grating

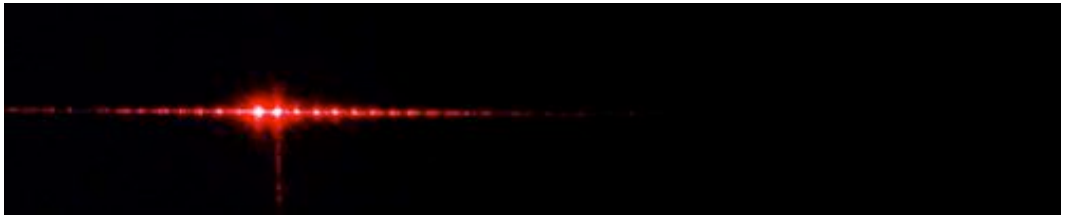


A: 10 x 10 x 0.2 x 40 pieces (Left),
B: 1.5 x 10 x 0.2 x 40 pieces (Right)

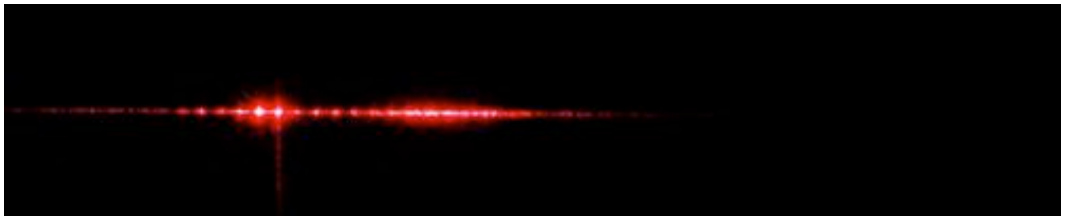




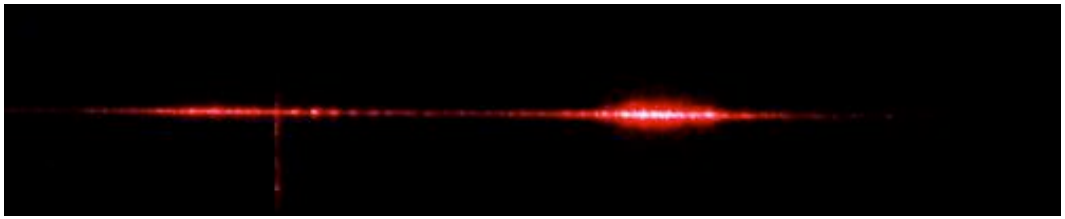
Diffraction by Quasi-Bragg Grating



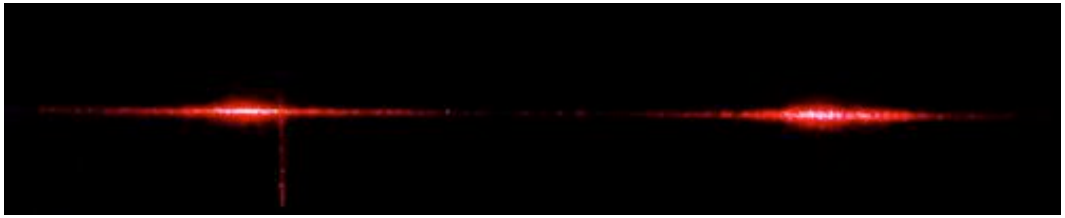
Vertical ($\theta = 0$)



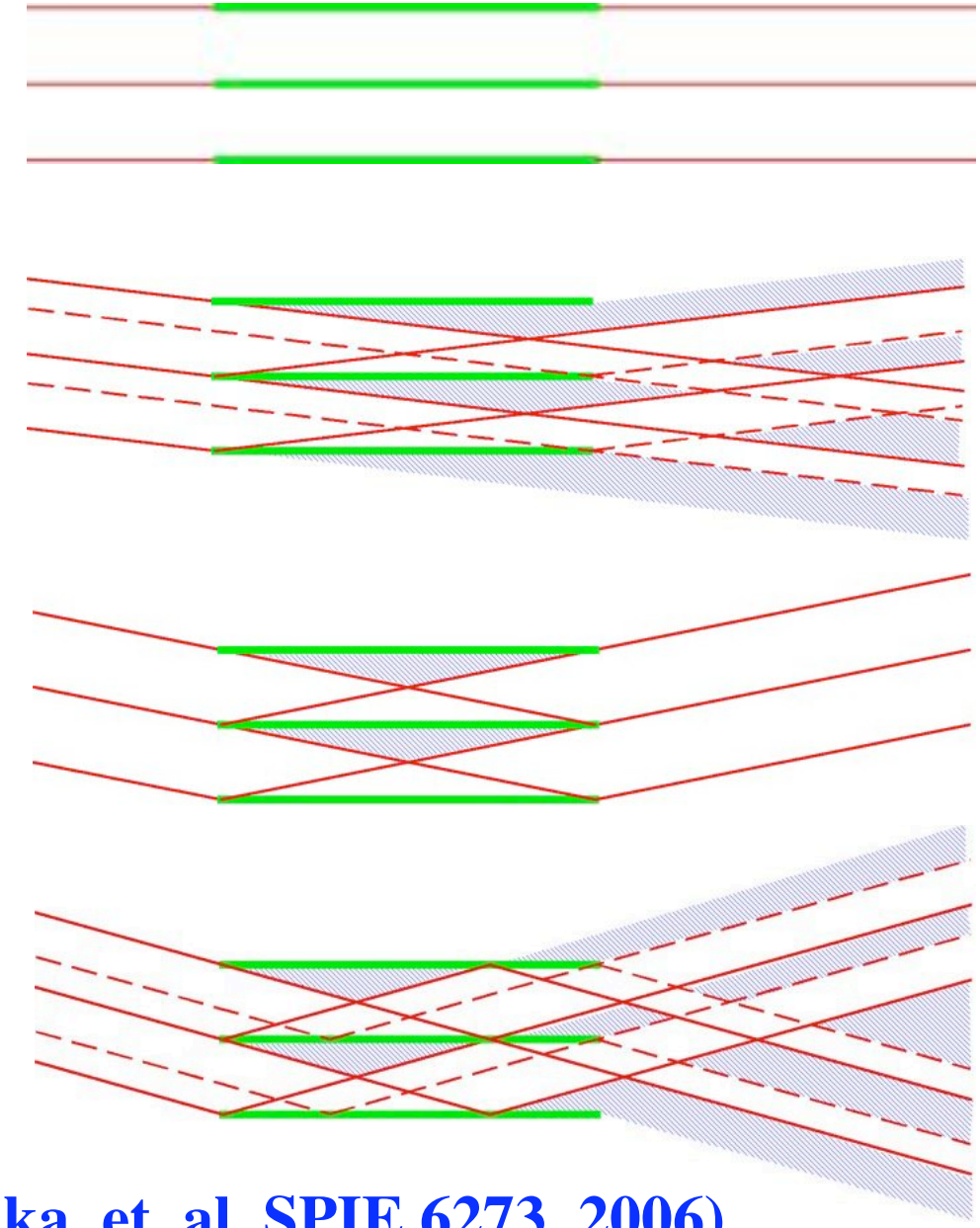
Small incident angle ($\theta = 0.6$)



Ideal incident angle($\theta = 1.2$)



Large incident angle($\theta = 1.8$)



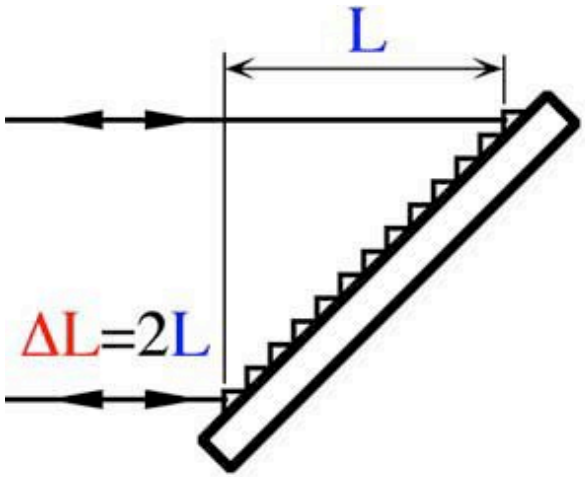
(Ebizuka, et. al. SPIE 6273, 2006)

Immersion Grating

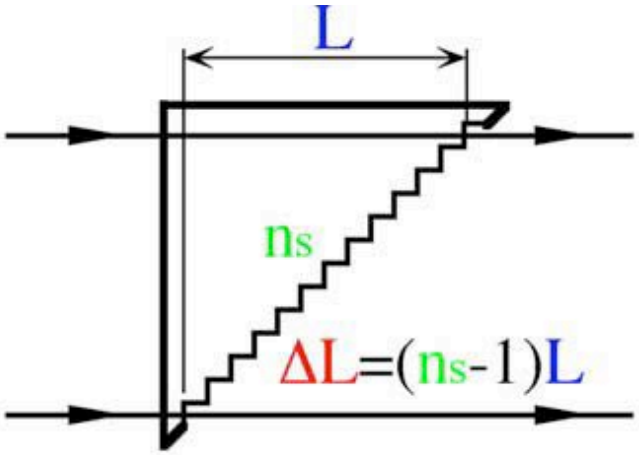
Orion Nebula CISCO (J, K′ & H_2 (v=1-0 S(1))
Subaru Telescope, National Astronomical Observatory of Japan January 28, 1999

Star-forming Region S106 IRS4 CISCO (J, H, K')
Subaru Telescope, National Astronomical Observatory of Japan February 13, 2001

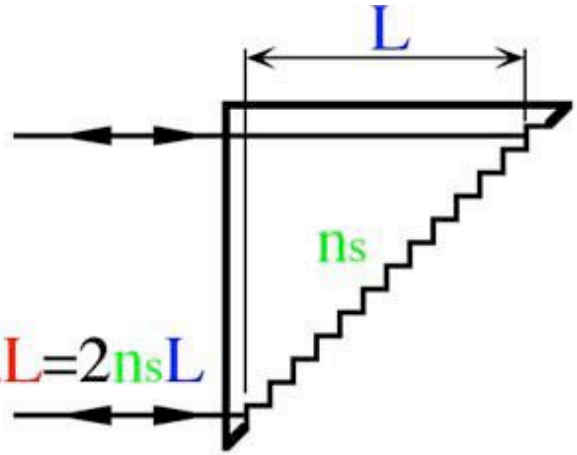
Development of High Dispersion Gratings



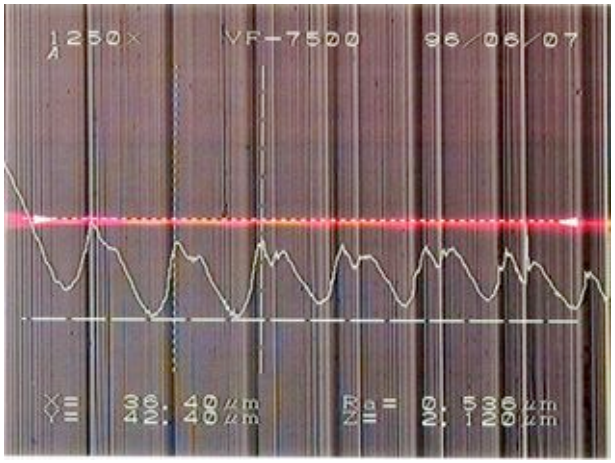
(a) Reflection grating



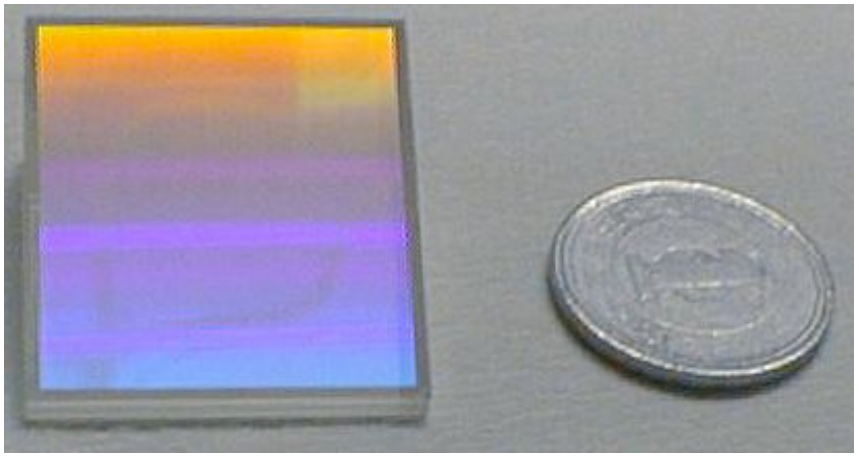
(b) Grism



(c) Immersion grating

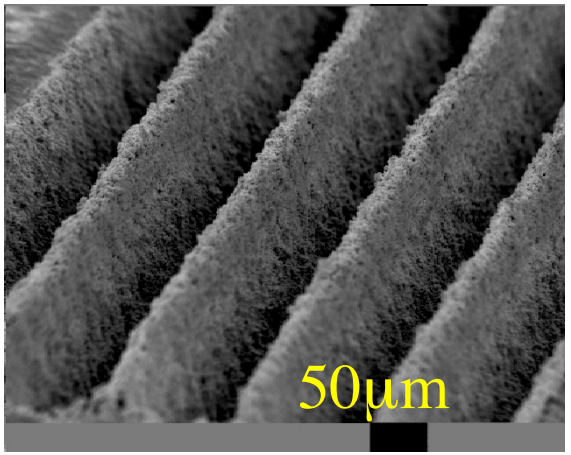


$LiNbO_3$ (n = 2.3) grating, 30 g/mm, Dicing Saw



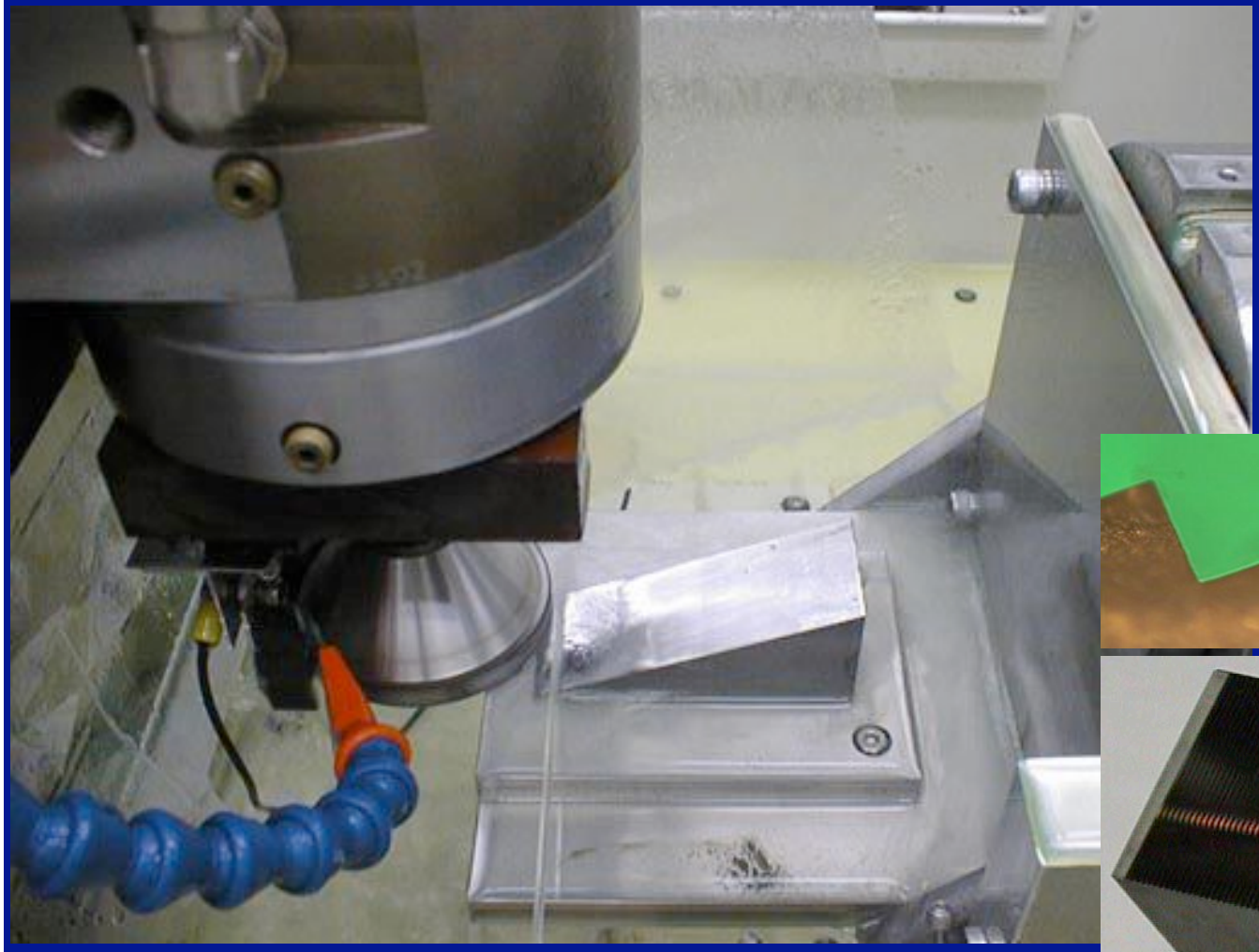
$LiNbO_3$ (n = 2.3) Grism, 444 g/mm, Ion etching

(Ebizuka et. al. SPIE 3355, 1998)

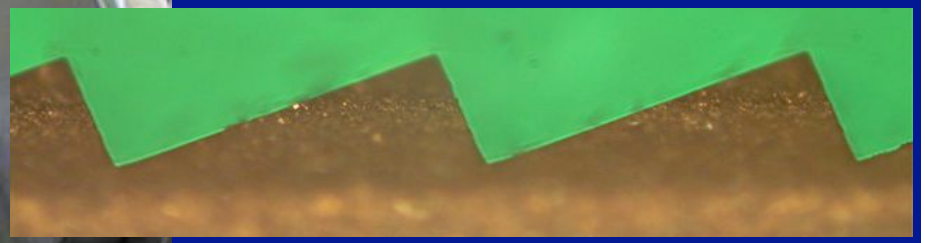


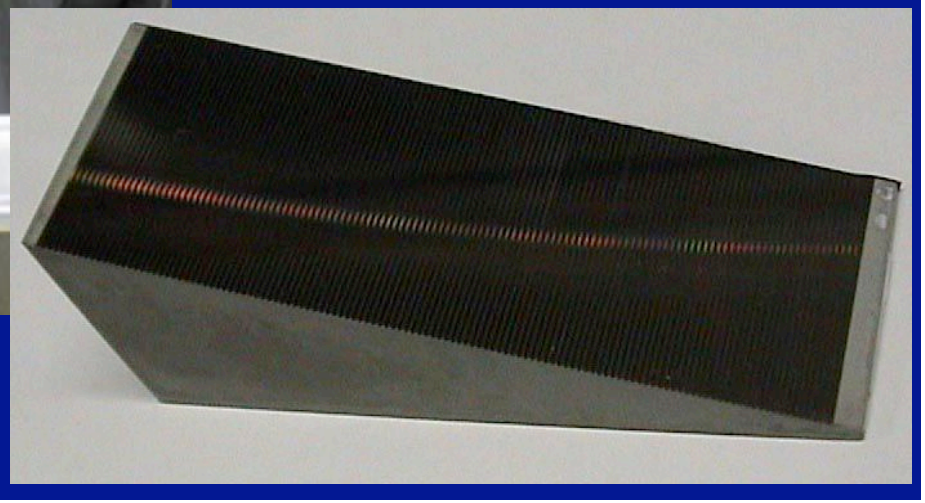
Ge (n=4.0) grating, Excimer Laser Ablation

Fabrications of Germanium Immersion Grating for Prototype IRHS



Nano precision machine and ELID grinding method.
30 x 30 x 72 [mm],
α = 68.75°

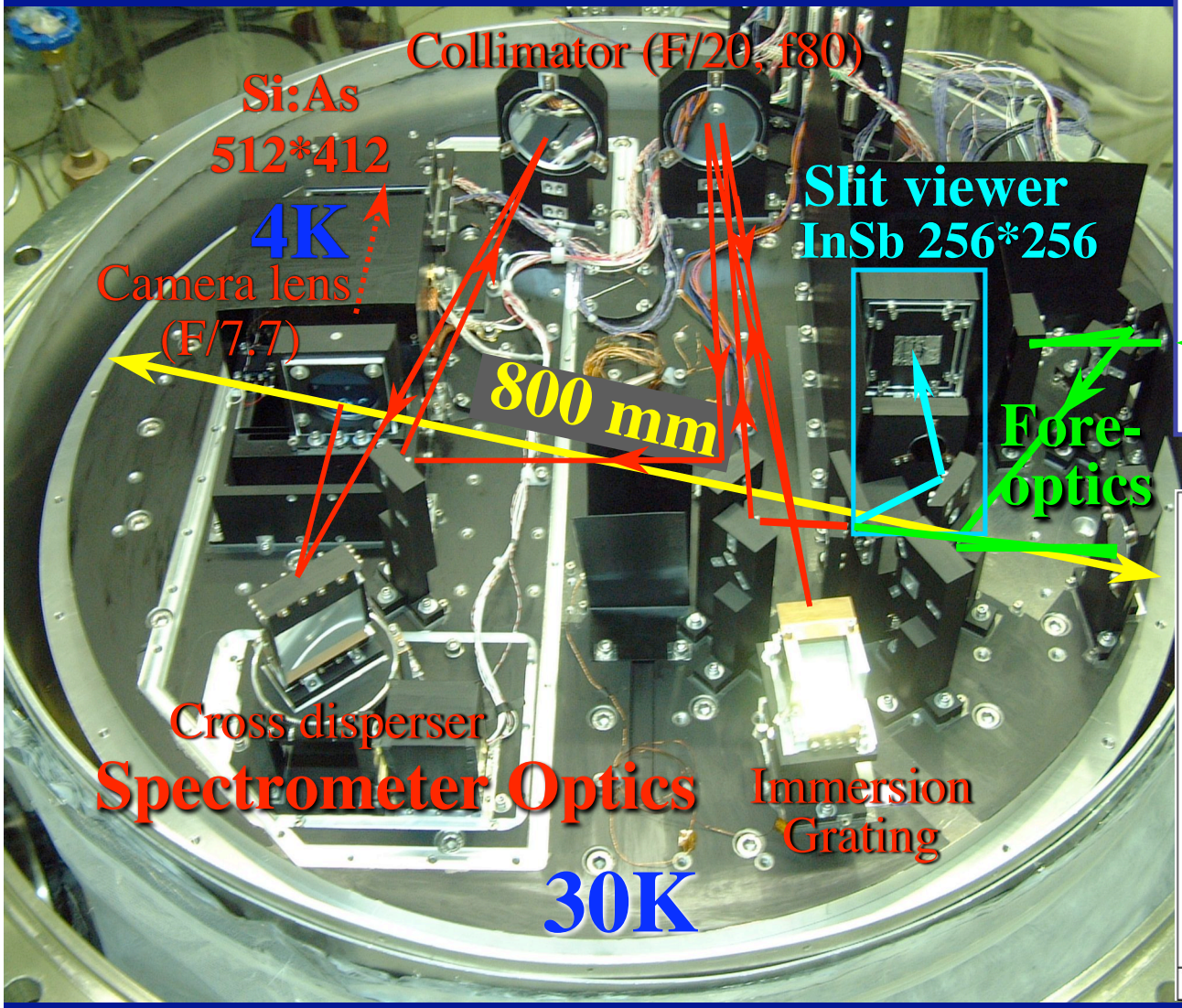


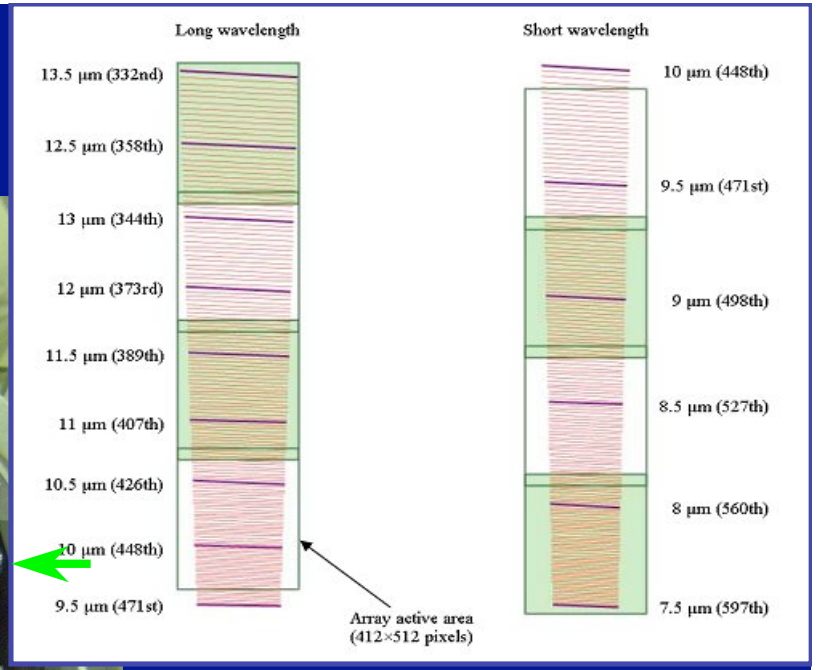


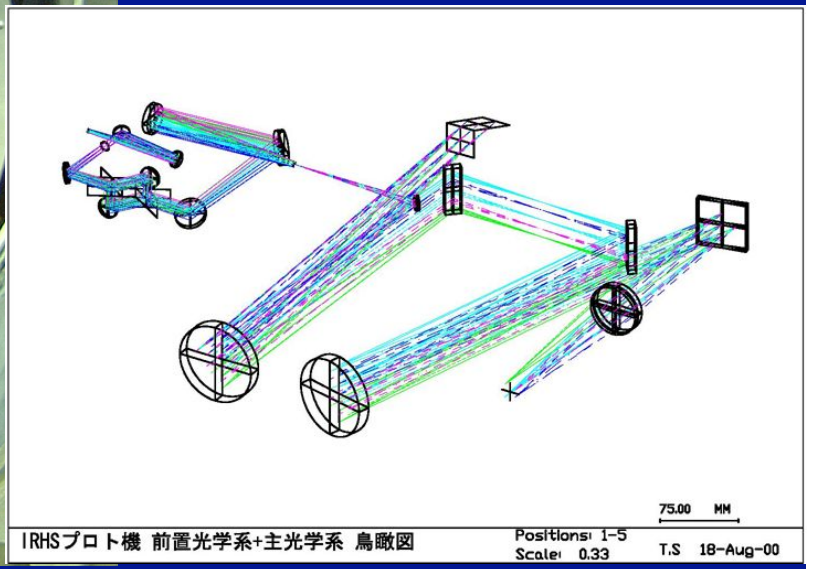
Spent about 400 hours for fabrication

(Ebizuka et. al. SPIE 4842, 2003)

GIGMICS

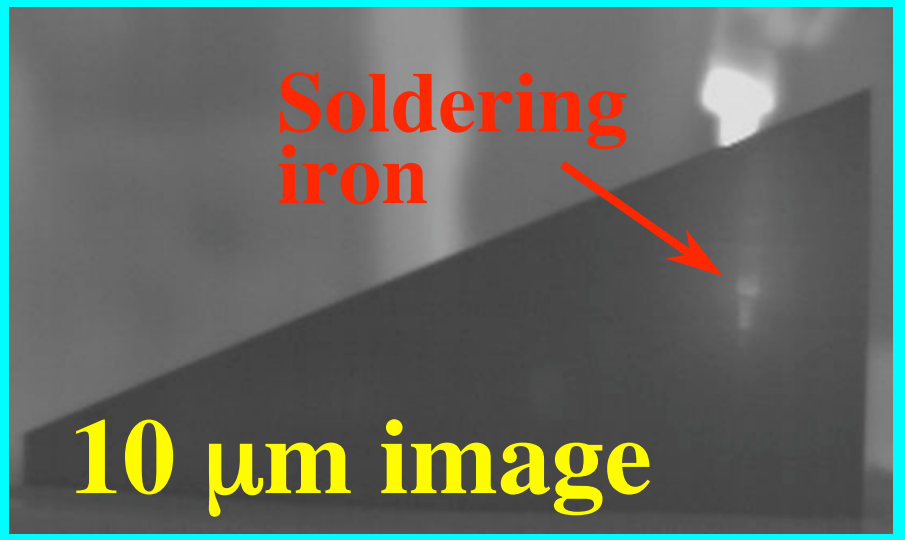




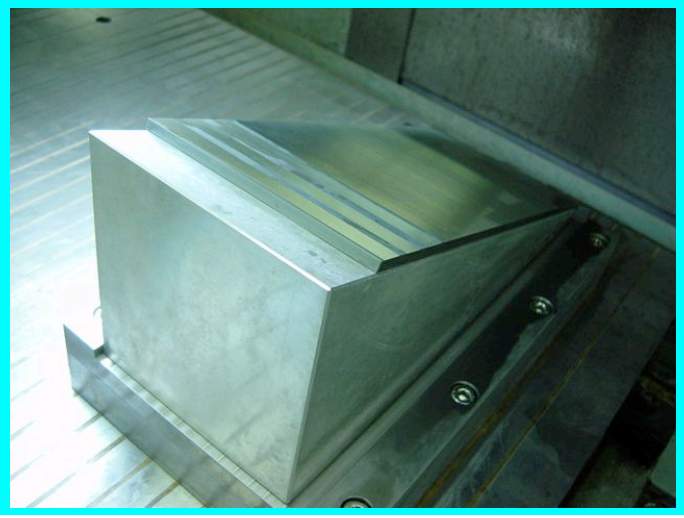


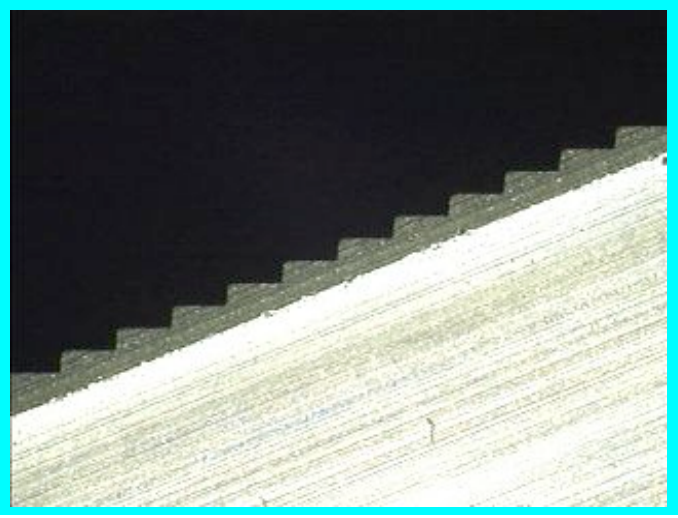
R~ 50,000@10μm, developed by Hirahara lab., Nagoya Univ.
(Hirahara et. al., SPIE 7735, 2010)

Trial Fabrications of Germanium Immersion Grating for Practical IRHS

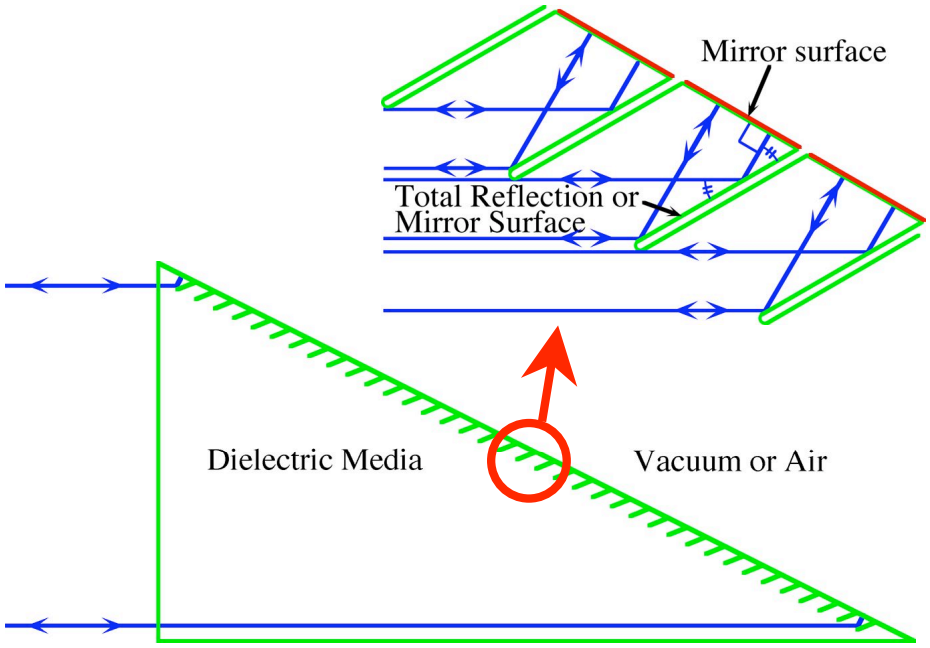


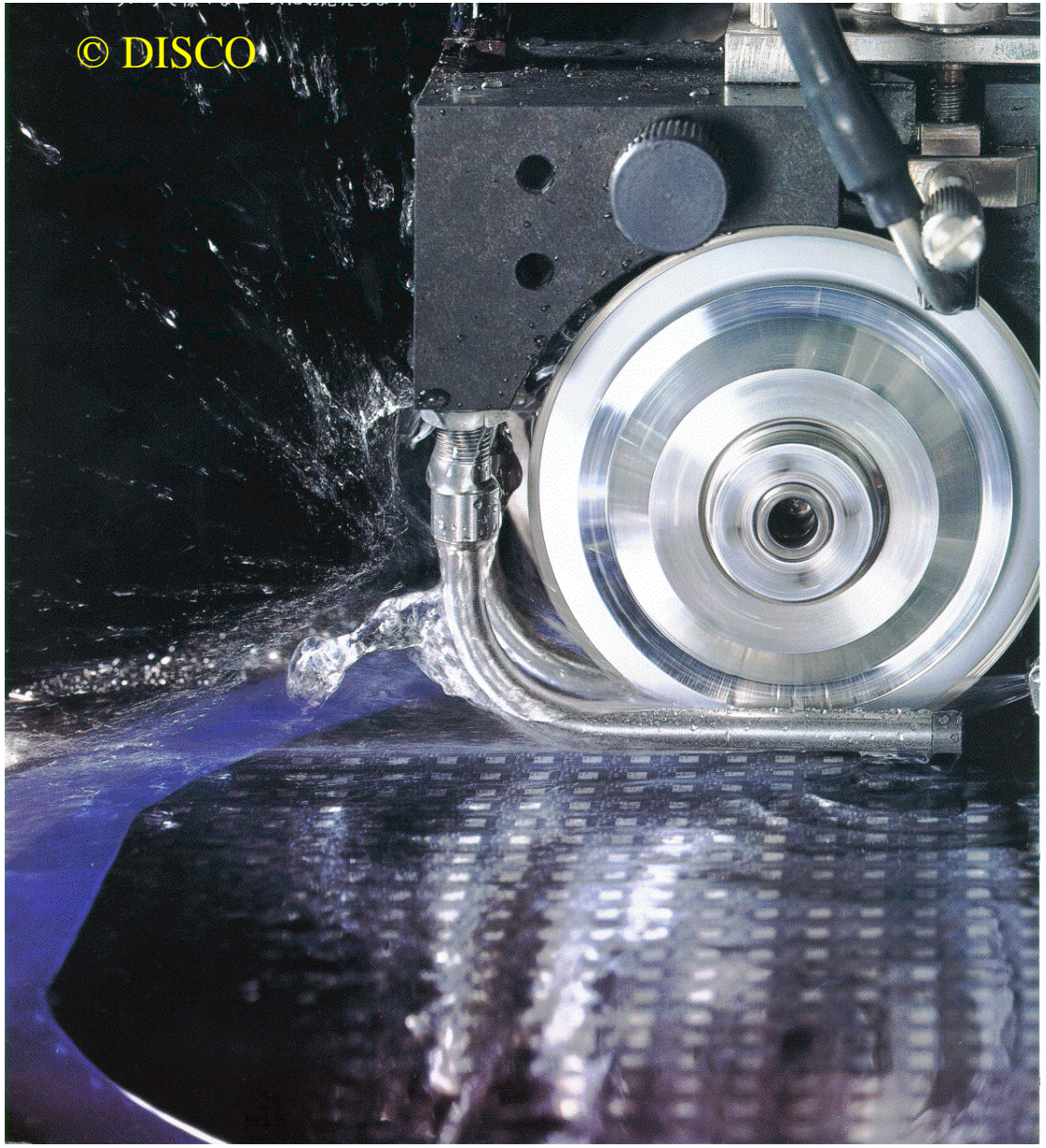
R～200,000@10μm → Size: 120 x 120 x 270 mm
→ Fabrication time: several 1000 hours





Novel Immersion Grating

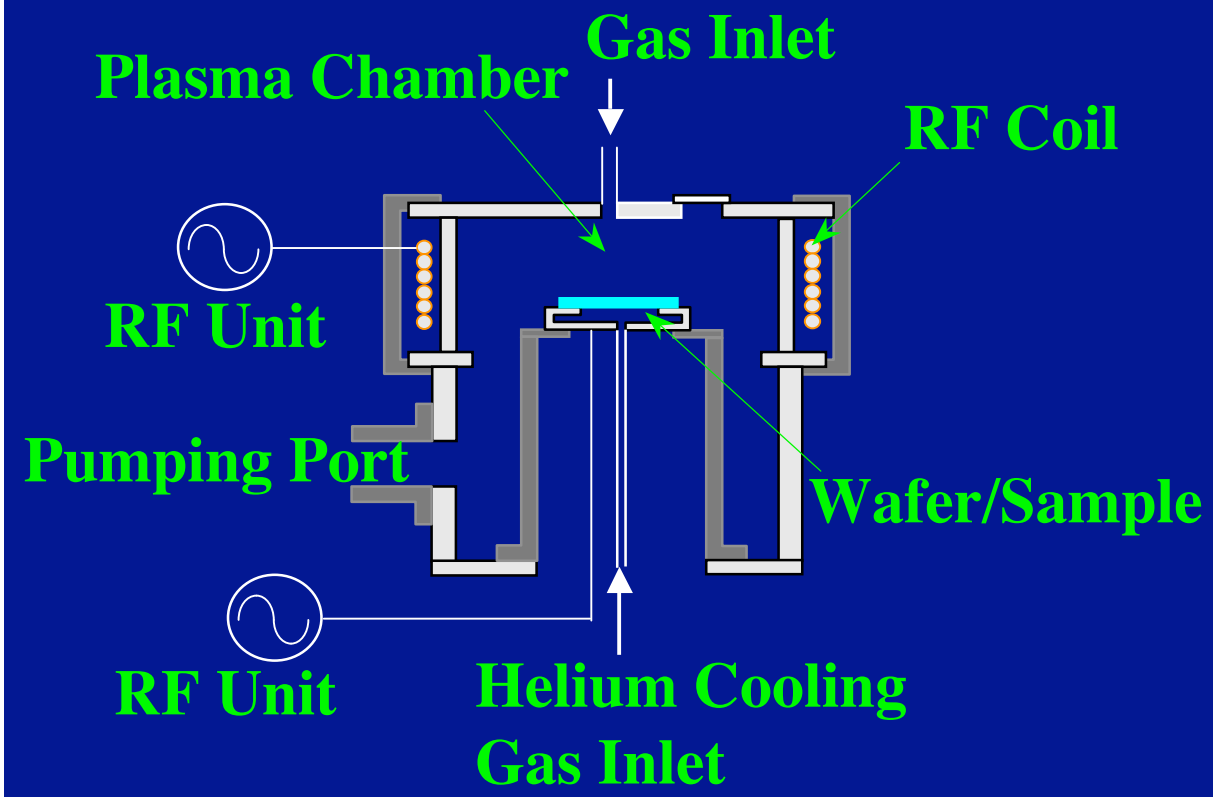




- **Machining of dicing saw makes smooth surface**
- **Easy tooling.**
- **Fabrication time for grating with 120 x 120 x 270 mm→ Several 100 hours?**

(Ebizuka et. al. SPIE 6273, 2006)

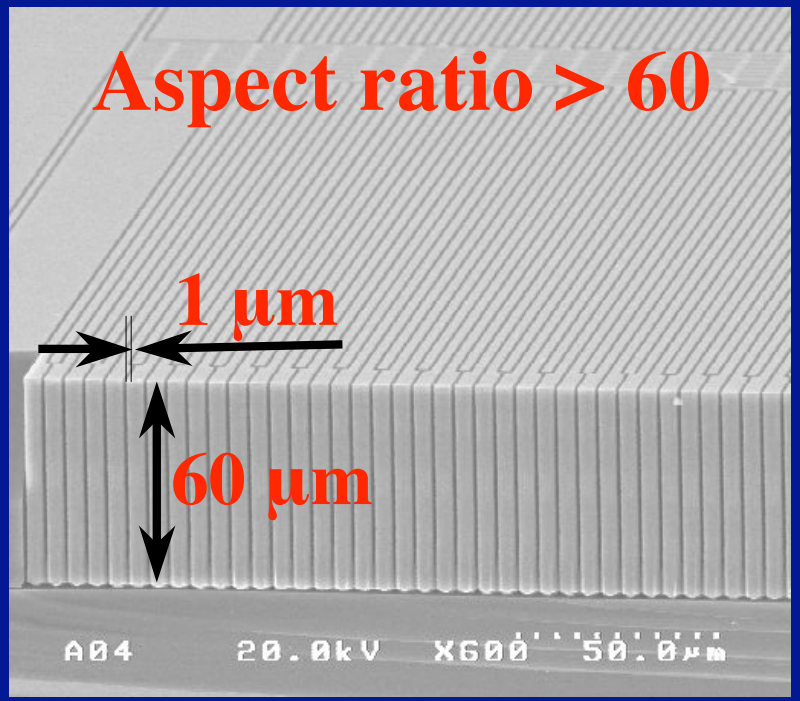
D-RIE (Deep Reactive Ion Etching)



ICP Etcher

Inductively Coupled Plasma

DENSO



G sensor of capacitance type

Oblique etching → Novel immersion grating for vis. - NIR,
Filling dielectric → Thick binary grating,
Filling metal → Quasi-Bragg grating.

Collaborations with National Institute of Astronomy in Italy and Nagoya University

Two researcher of Osservatorio Astronomico di Brera, Dr. Filippo Maria Zerbi and Dr. Andrea Bianco, visited to NAOJ to discuss about development of novel gratings in the beginning of November 2010.

Filippo and Andrea had obtained a grants for optics of E-ELT for five years.

We will start the collaboration on the novel gratings for next generation instruments of E-ELT, TMT, VLT and Subaru Telescope.

Conclusions

- VPH grating is useful for lower dispersion.
- Bandwidth of VPH grating decrease in higher dispersion ($\alpha < 30°$).
- Quasi-Bragg grating and thick binary grating are utilized for an echelle spectrograph.
- Novel immersion grating achieves small scattering loss and reduces fabrication cost.
- Deep reactive ion etching is hopeful method for fabrications of the high dispersion gratings.