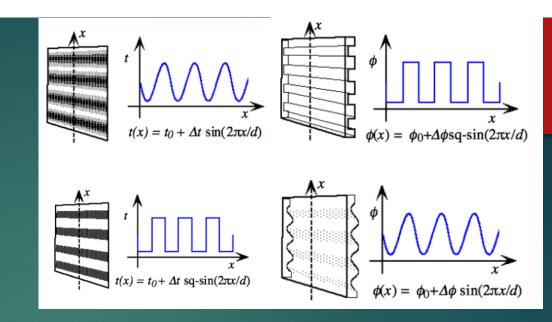


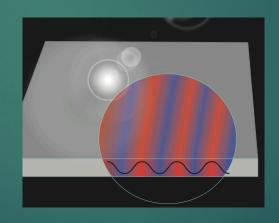
# Advances in the manufacturing of photopolymer based VPHG for astronomy

**ALESSIO ZANUTTA**, INAF – OSSERVATORIO ASTRONOMICO DI BRERA

### VPHG technology: advantages, why choose this type of DE

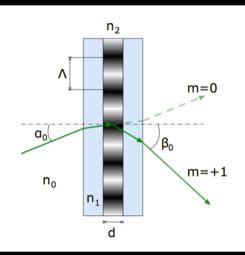
- high peak efficiency (>90%);
- tunable efficiency (super blaze);
- large dimension (limited by the optics);
- high dispersion (more than 5000 lines/mm);
- simple process;
- capable of complex optical structures.
- Moreover, can be used as a tool for characterize the holographic materials...





#### **VPHG** behavior

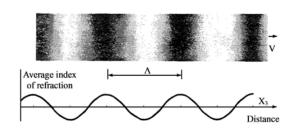
#### GEOMETRIC



dispersion is related to the grating equation

$$\frac{m\lambda}{n_i} = \Lambda \left( \sin \alpha_i + \sin \beta_i \right)$$

#### **FFFICIENCY**



efficiency related to Bragg diffraction

$$m\lambda = 2\Lambda \sin \alpha$$
$$\eta \propto d \cdot \Delta n$$



## The design of an astronomical VPHG

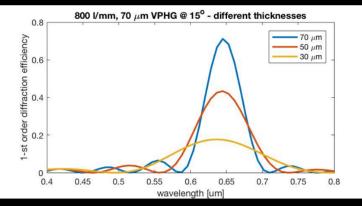
PROCESS:

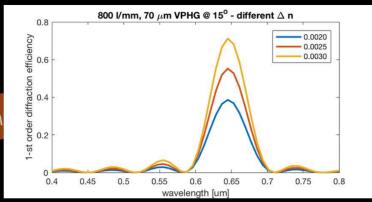
START FROM THE OBSERVATION REQS

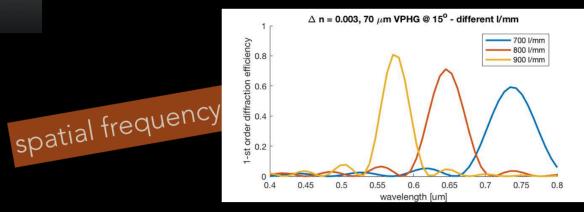
DEFINE THE
BANDWIDTH RANGE

MAXIMIZE THE EFFICIENCY

thickness







Trough Kogelnik [1] or RCWA[2] models

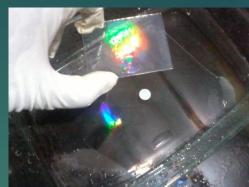
[1] H. Kogelnik, Bell Syst. Tech. J. 48(9), 2909–2947 (1969)

[2] Magnusson & Gaylord (1978); Moharam and Gaylord (1981)

DCGs



Silver halides

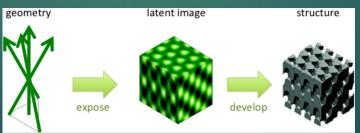


## Common holographic materials

Not easy to industrialize the production process

Latent hologram formation during recording

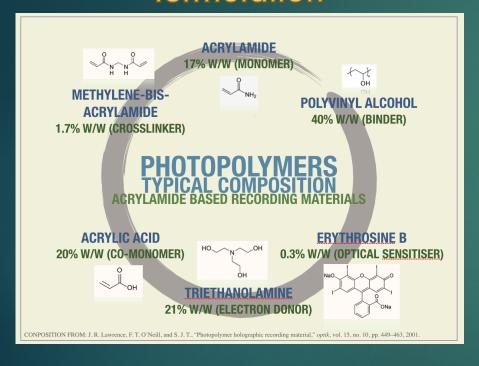




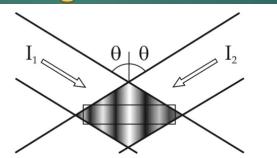
You have to be very skilled to transform properly this materials and to reach the target specs in the produced diffraction grating

### Solid Photopolymeric material

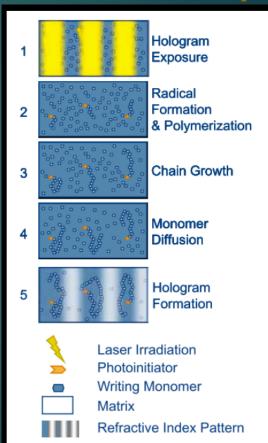
#### formulation



#### light stimulus



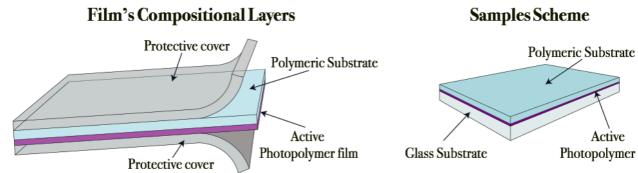
#### material response



Bruder, F. K. et al. J. Photopolym. Sci. Technol. 22, 257–260 (2009).

### BayfolHX

fixed thickness solid film





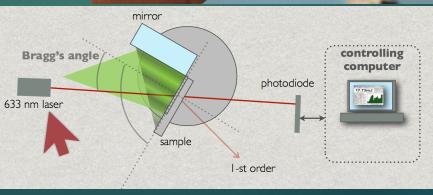
Active

- Uniform thickness (5, 10, 16, 20, 34, 50, 60 um)
- A4 sheets or rolls
- Different polymeric cover available
- Green or RGB sensitive
- ▶ Post-processing: UV+vis flood to eliminate residual dye

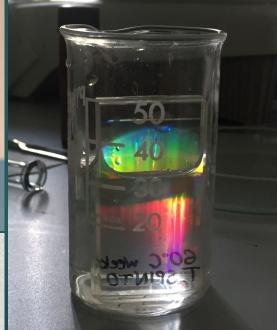
## Advantages in using photopolymeric films for DE

- Easy lamination of the film
  - ► (clean environment requirement)
- Can be repositioned like a sticker, the holo is safely stored in the layer
- Can be bended
- No chem. post process, no latent hologram, ready to be evaluated
  - One can even monitor in real time the hologram formation







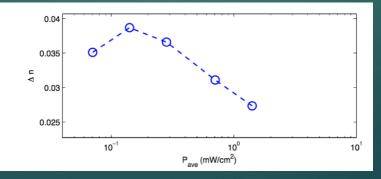


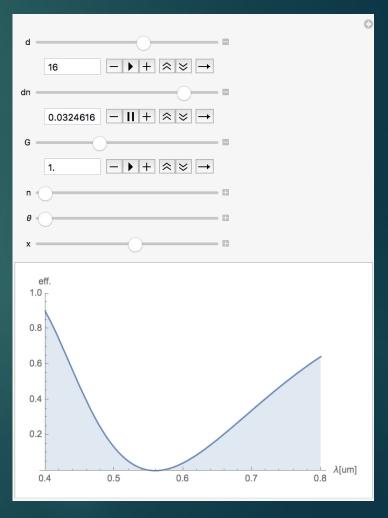
## DE Performance is energy dose dependent

This allows to design objects with very stringent and critical parameters/tolerances

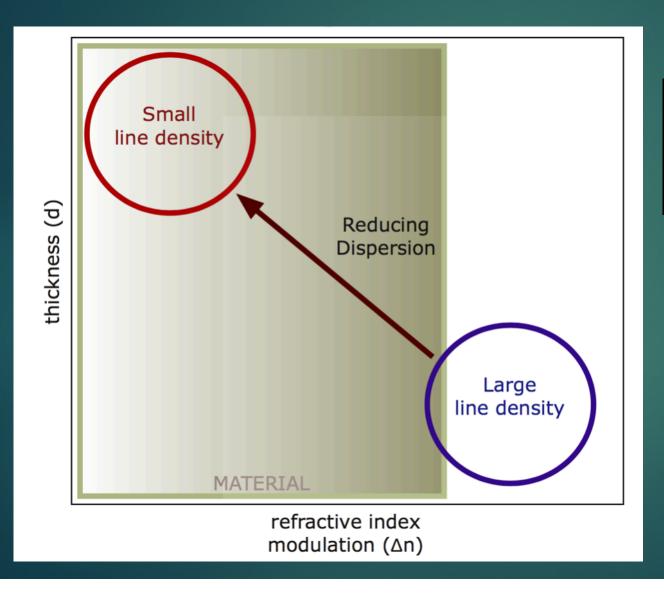
Example: how the eff. varies with index modulation...

Δn tunability writing power dependence





### Material requirements for astronomy



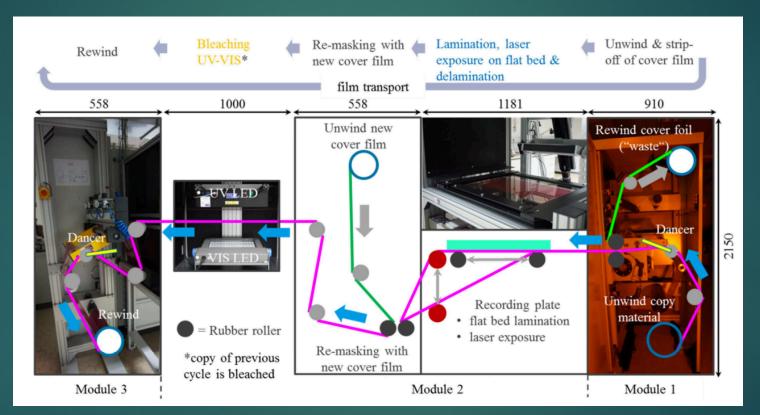
Spatial Freq. 100 - 5000 I/mm

Thickness 4 - 100 um

Index Modulation 0,005 - 0,1

### Industrial capabilities

▶ Roll to roll machine by Covestro as example of continuous holographic exposure



[1] F.-K. Bruder, T. Fäcke, F. Grote, R. Hagen, D. Hönel, E. Koch, C. Rewitz, G. Walze, B. Wewer, 10127 (2017) 101270A. doi:10.1117/12.2250933.

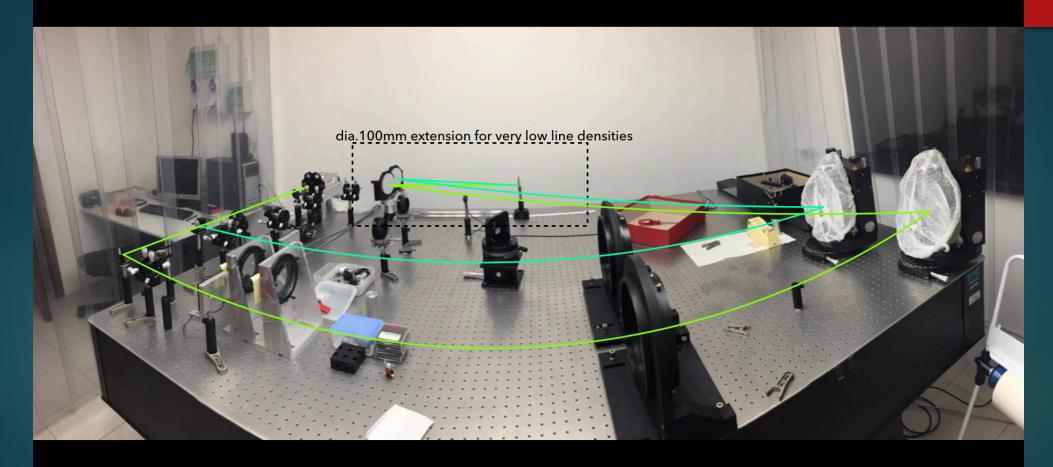
### Our capabilities

- ▶ Big lamination machine
  - ▶ Substrates up to 200 x 200 mm
- Detach & Transfer VPHGs to polymeric substrates PC, PE, etc.
- Apply films to complex surfaces, prisms, cylinders (aim: to reduce DE overall thickness)
- Emboss or cut smaller identical parts of a big hologram

How Holograms Work Divisible Properties



### HOLOGRAPHIC SETUP TWO PLANE MIRRORS



Capabilities max 20 cm diameter from 90 to 5000 l/mm LASER 532 nm (1,5 W), 660 (0,5 W)



#### **VPHGS FOR AFOSC (ASIAGO, ITA)**

1. **VPH8** (620 - 980 nm) - 90% peak eff.

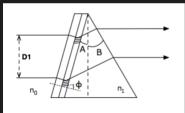
d=34 um, Dn=0.011, 600 l/mm;

2. **VPH6** (600 - 800 nm) - 90% peak eff.

d=16 um, Dn=0.017, 285 l/mm;

3. SINGLE PRISM slanted VPHG

d=34 um, Dn=0.007, 280 l/mm; phi= 5.25°;



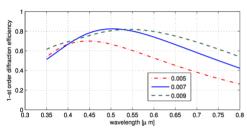
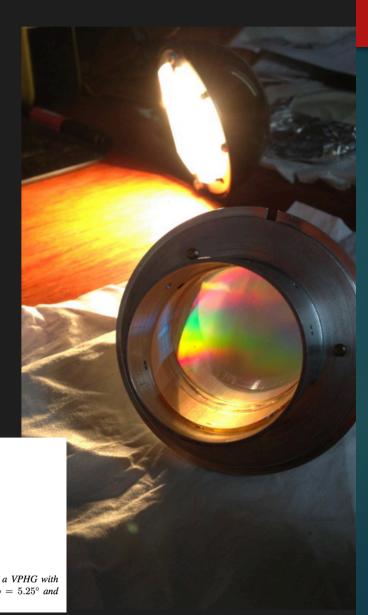
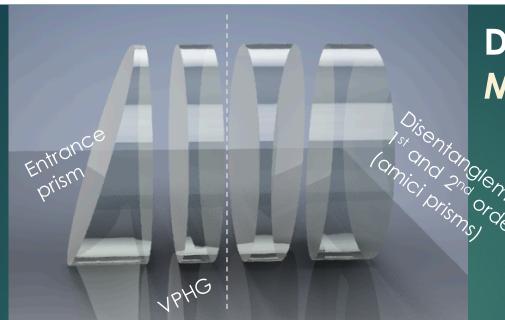


Figure 4.27: RCWA efficiency simulation of the 1-st diffracted order of a VPHG with incidence angle of 4.4°,  $d=34~\mu m$ , 280 lines/mm, slanting angle  $\phi=5.25^{\circ}$  and variable  $\Delta n$ 



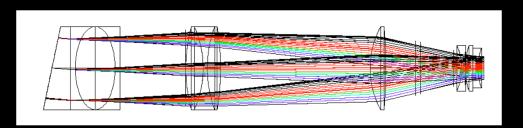


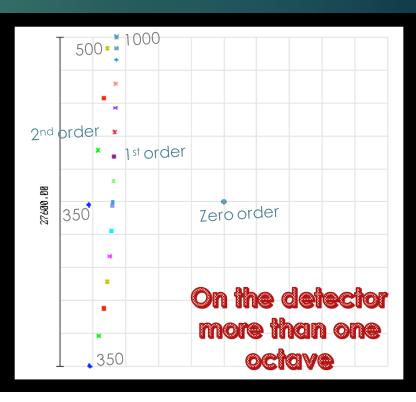
## DOLORES @ TNG - Multispectral VPHG

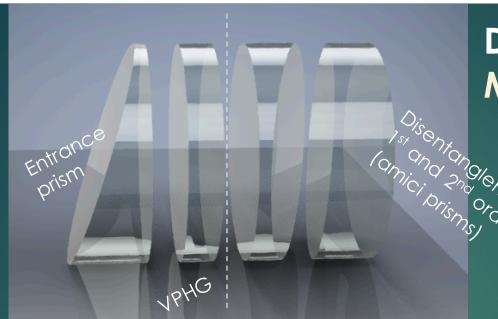
(See Paola Galli's poster)

at a glance:
Very low dispersion VPHG
&
Very thick grating layer

Parameter	Value
Line density of the grating [lines/mm]	170
Incidence in angle (equivalent in air)	6.42°
f(prism_mat)	
Resolving power (w 1" slit)	ca. 500
Reciprocal Linear Dispersion	ca. 23.5
[nm/mm]	
Theoretical Peak diffraction efficiency	81





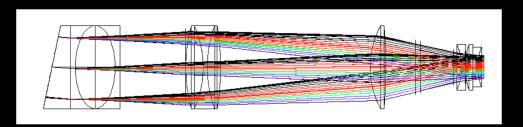


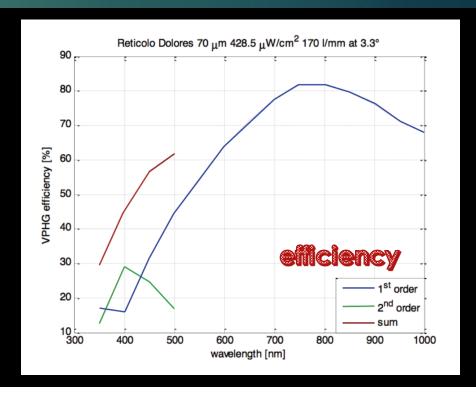
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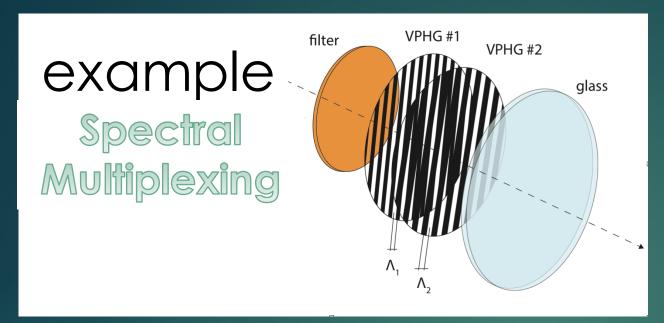
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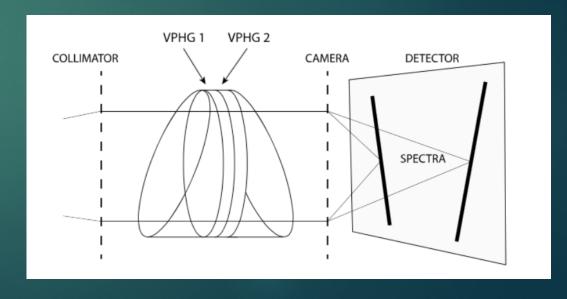




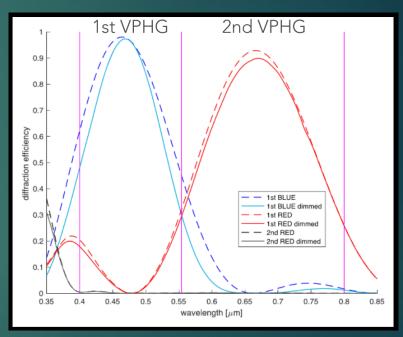
more than one spectrum in a single shot

Plug & play device
Designable to upgrade only the
DE in the spectrograph

crucial point: the curves must not interfere with each other, ideally each layer has to "consume" only the photons in its wavelength range



- material compactness and manufacturing precision allowed us to design a novel architecture for dispersing elements
- multiple VPHG layers
- phase pattern rotation to separate the generated spectra
- different I/mm, thickness and Δn will shift the position of the curve in the correct band



[1] Zanutta, A., Landoni, M., Riva, M., Bianco, A., Mon. Not. R. Astron. Soc. 469(2), 2412–2422, Oxford University Press (2017).

a piona - ghost niboltore off

Lato

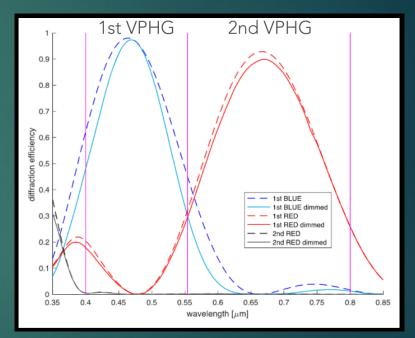
#### Essential:

Achieve precisely the target performances in each layer!

#### Moreover ...

The idea can be extended to more layers: 3, 4, etc.

... prototype currently in production



[1] Zanutta, A., Landoni, M., Riva, M., Bianco, A., Mon. Not. R. Astron. Soc. 469(2), 2412–2422, Oxford University Press (2017).

### perspectives

- Propose upgrades to spectrographs with refurbishing needs (plug and play solutions)
- Design new VPHG concepts for new instruments

#### conclusions

- With photopolymeric VPHGs we are entering an era of design innovation for the spectroscopical field
- We proposed complex architectures with outstanding performances
- VPHG Industrialization through easy procedures is feasible with photopolymeric matrials