VPH gratings and low-dispersion spectrograph design

Will Saunders, AAO

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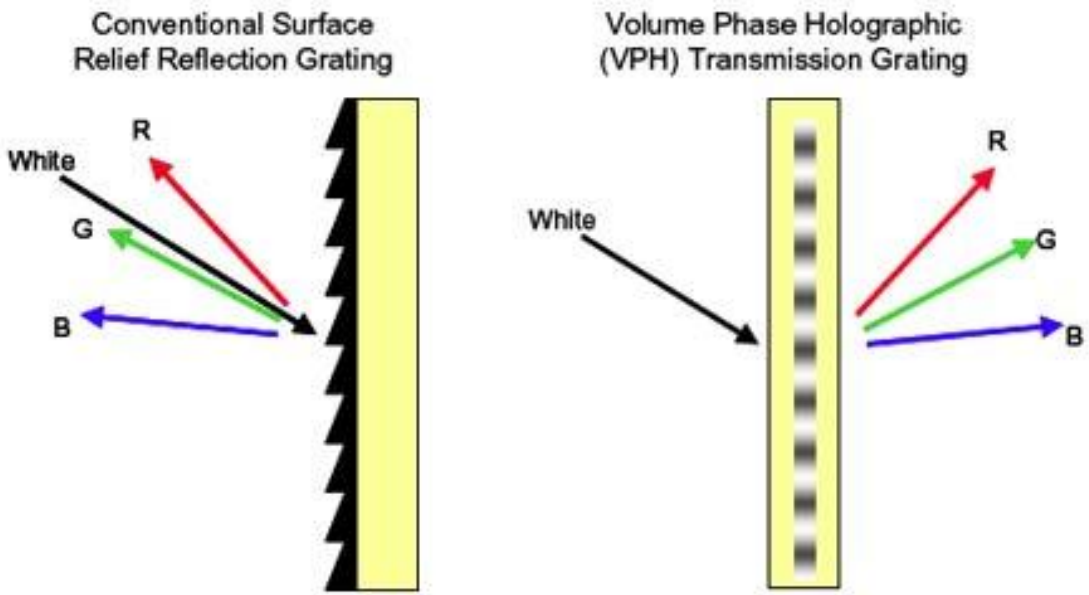
VPH gratings

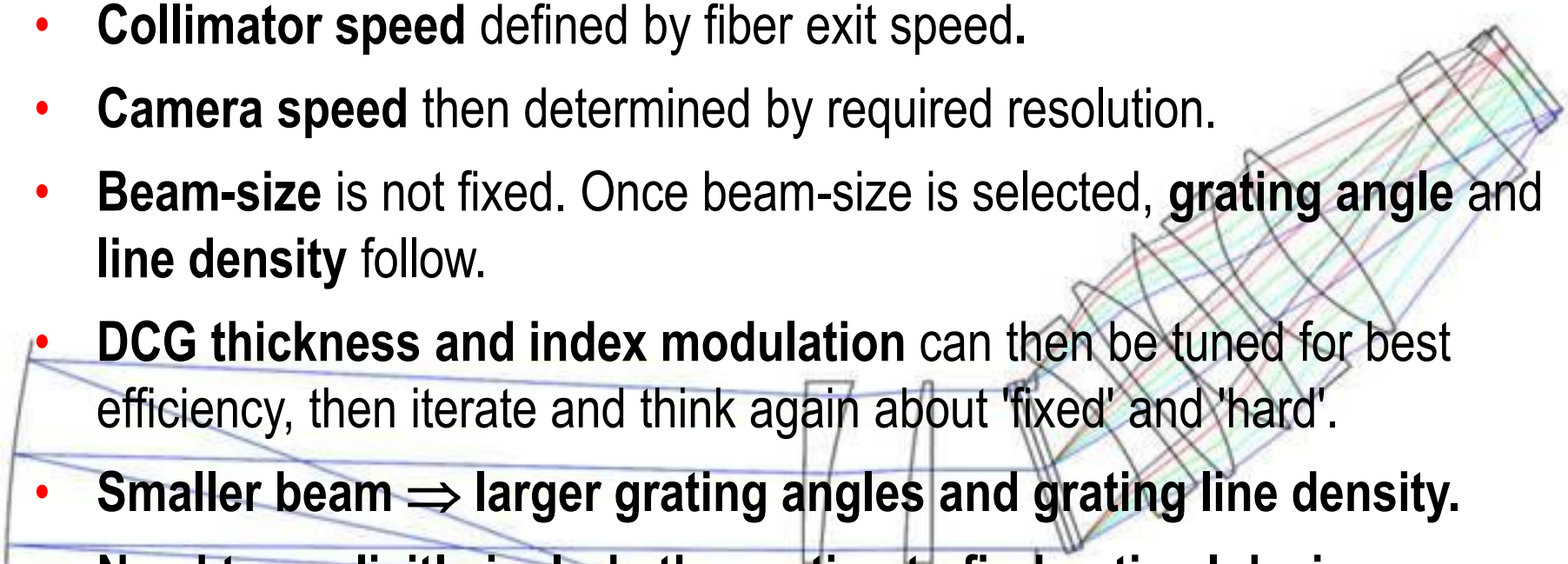
- Thin layer of DCG (Dichromated gelatin) with sinusoidal refractive index modulation.
- Efficient, tuneable, cheap, multiple vendors, large beams ok, low scattered light.



- Now universal in low-dispersion spectrograph design.
- But three primary degrees of freedom (line spacing, thickness, index variation), **all with strong effects on efficiency envelope**.

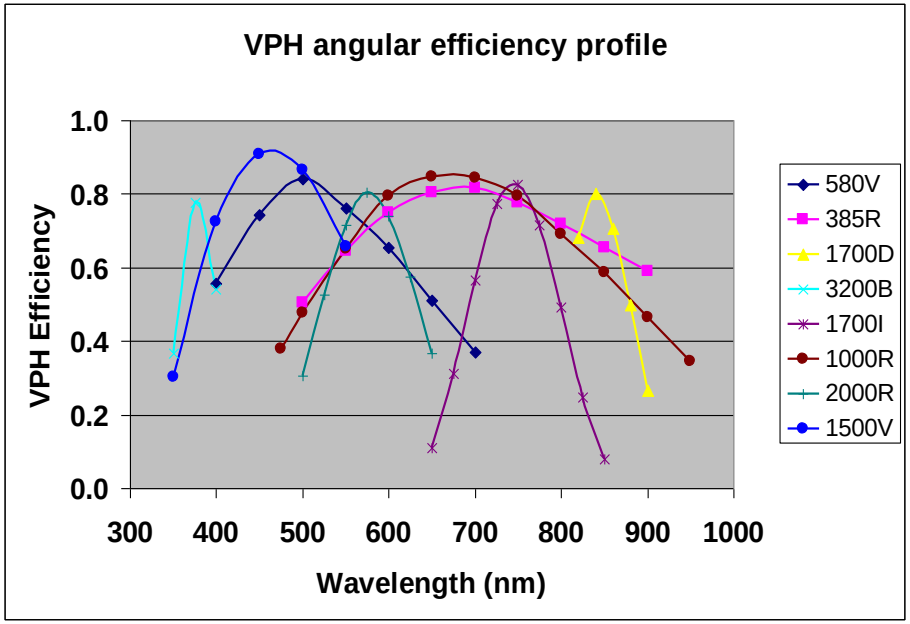
Fixed-format spectrograph design

- **Fiber diameter, fiber exit speed, detector spectral pixels** are all fixed parameters.
- Hard requirements are **wavelength coverage** and **resolution**.
- Soft requirements are **efficiency envelope** and **cost**.
- **Collimator speed** defined by fiber exit speed**.**
- **Camera speed** then determined by required resolution.
- **Beam-size** is not fixed. Once beam-size is selected, **grating angle** and **line density** follow.
- **DCG thickness and index modulation** can then be tuned for best efficiency, then iterate and think again about 'fixed' and 'hard'.
- **Smaller beam $\Rightarrow$ larger grating angles and grating line density.**
- **Need to explicitly include the grating to find optimal design.**



VPH efficiency 1

- Up to 90% efficient at peak.
- Lower at higher dispersions because *s* and *p* polarisations cannot be simultaneously optimised.
- Narrower bandwidth than reflection gratings.

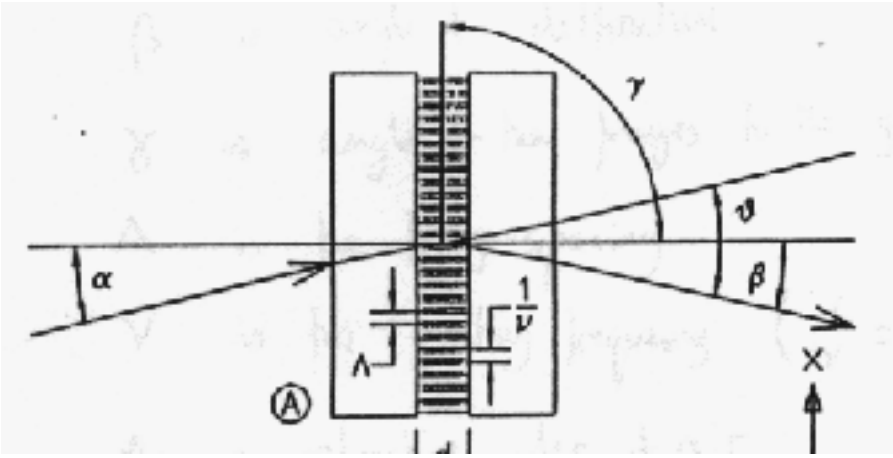


- Can shift efficiency peak to red or blue by tweaking input angle, but overall efficiency drops when used away from 'superblaze'
- To zeroth order, *angular* bandwidth is fixed. Would favour larger beamwidths.

VPH efficiency 2

Gratings are defined by DCG thickness d, line spacing Λ, refractive index n, and index variation Δn

Useage defined by input grating angle α and wavelength λ



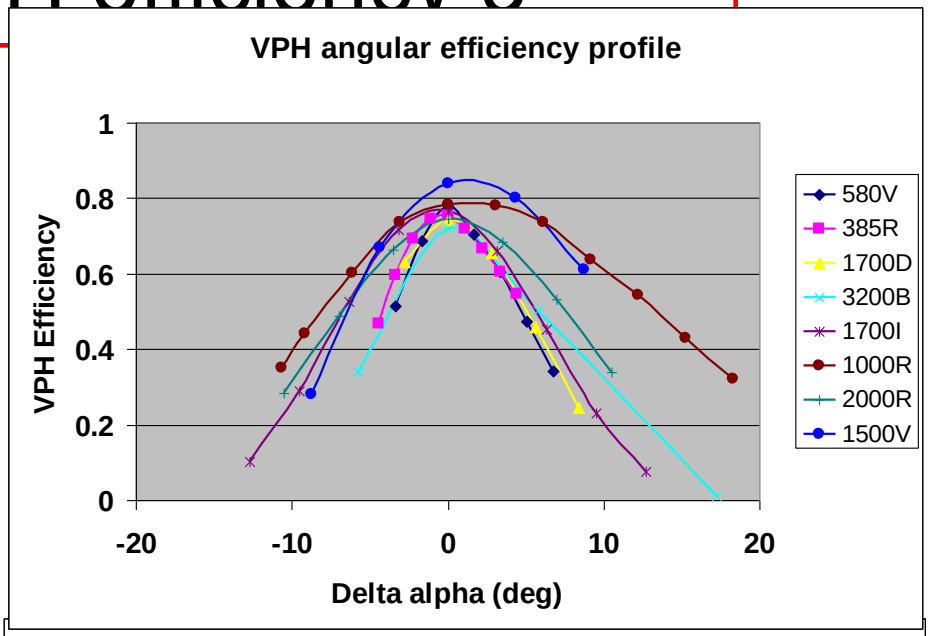
- $\lambda = 2\Lambda \sin\alpha$ (grating equation), $\Lambda \approx \lambda/2\alpha$
- $d\,\Delta n \sim \lambda/2$ for maximum peak efficiency
- Efficiency bandwidth maximised by large Δn and small d.
- But losses to 0th order when $\alpha d \leq \Lambda$ or $d \leq \lambda/2\alpha^2$

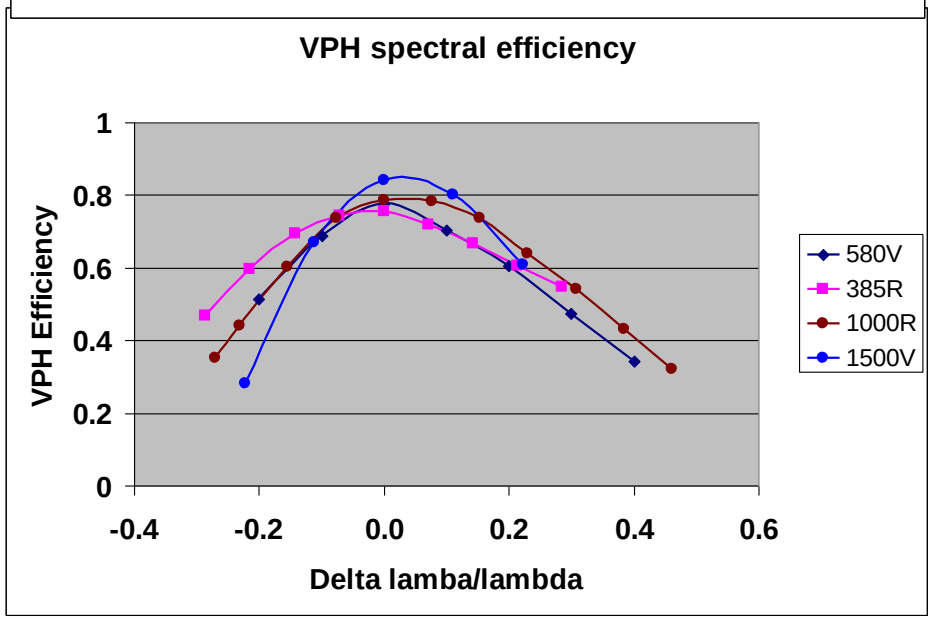
$\Rightarrow$ at low dispersion, need larger $d \Rightarrow$ lower Δn

$\Rightarrow$ **Angular bandwidth is less at low dispersion**

VPH efficiency 3

- At higher dispersions, want highest possible Δn, and smallest d.
- *Angular* bandwidth $\Delta\alpha \sim \lambda/2d$, ~ constant with dispersion
- But peak efficiency dropping (*s* vs *p* issues). Sweet spot at grating angles ~20°.
- Below this, *spectral* bandwidth is nearly constant.
- So there is a minimum beam size, giving grating angle ~20°. But above that, VPH efficiency is constant.





VPH Spectrographs for DESpec

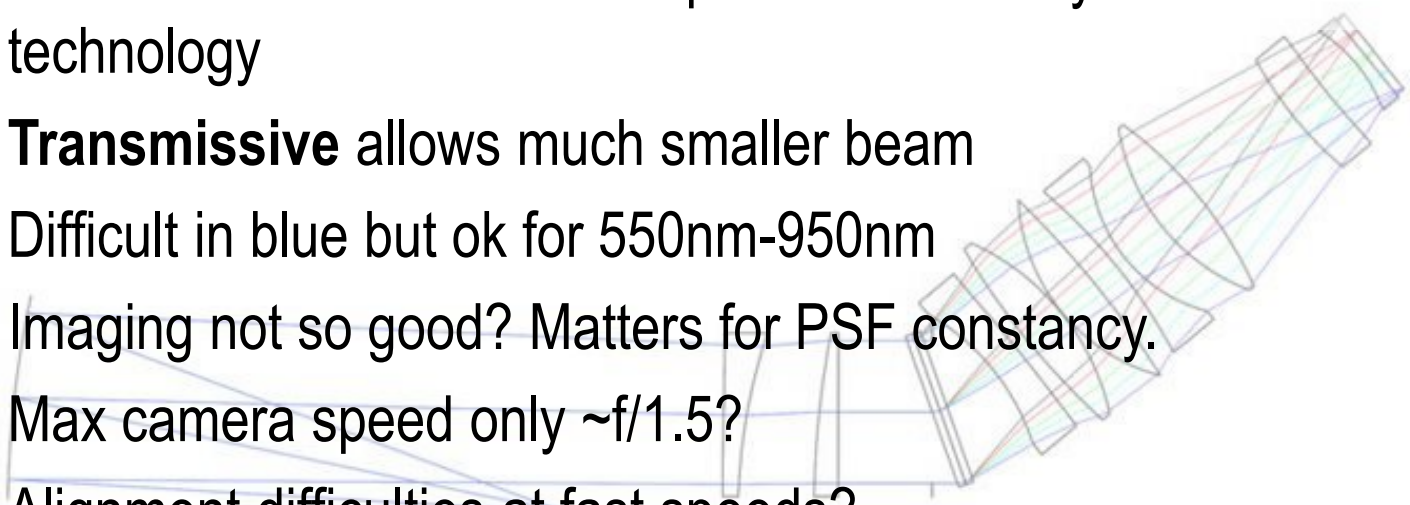
General considerations:

- Assume 550-950nm, 4000 spectral pixels, 100μm fibers, f/2.75 collimator, 2.5pix FWHM on detector (=0.25nm).
- Camera speed is then f/1.24! Very fast for transmissive.
- 20° grating angle corresponds to minimum beam-size ~125mm.

- Could shrink fiber size to 90μm and/or increase pixels/FWHM, to get ~f/1.5 camera (for transmissive design). Then minimum beam-size becomes even smaller, ~100mm.

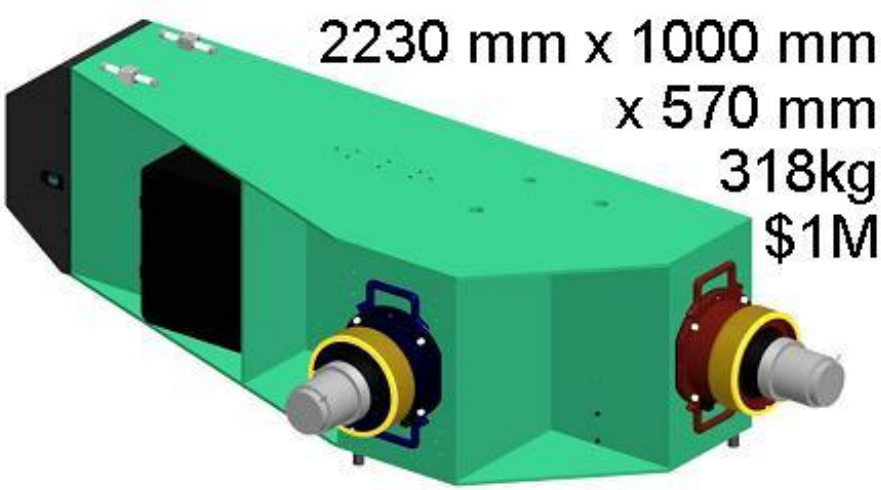
Reflective vs transmissive

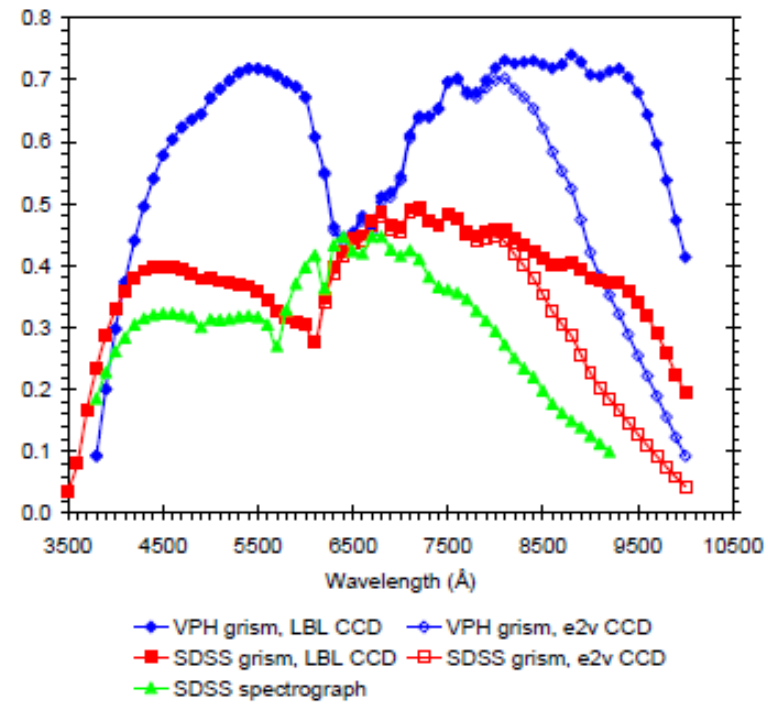
- **Reflective** (Schmidt-style) allows faster cameras, fewer optical components, superb imaging. Camera speeds up to ~f/1.2
- But detector is in beam ⇒ obstruction losses
- Camera-as-dewar adds additional complexity
- Obstruction losses ⇒ large beam (250mm+) preferred
- Schmidt correctors now cheaper and less risky with MRF technology
- **Transmissive** allows much smaller beam
- Difficult in blue but ok for 550nm-950nm
- Imaging not so good? Matters for PSF constancy.
- Max camera speed only ~f/1.5?
- Alignment difficulties at fast speeds?



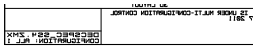
Strawman transmissive design:

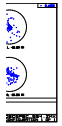
- JHU WFMOS design (SDSS pushed to 4K x 4K detectors) is lovely
- 159mm beam, 2 x f/1.5 cameras,λ= 390-1000 nm, R~ 3000
- Compact and affordable @ $1M each.
- Very efficient (70% peak)
- ~600 fibres/spectrograph for MOS





Reflective design A





Schmidt/Schmidt design, 250mm beam, F/1.3 camera.

Fixed format, so can put prisms between VPH and correctors, to reduce air-glass surfaces.

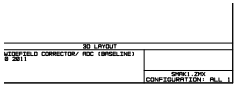
Lollipop dewar with field-flattener as dewar window

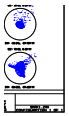
Optics are good (rms radius < 10μm).

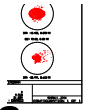
Total hardware cost ~$300K (optics, dewar, detector, controller)

Two-armed version possible, twice the hardware costs.

Reflective design B







Maksutov design is much more compact. Double pass idea is new??? Detector is now outside camera.

All surfaces except field flattener are spherical.

Can go to F/1.2 camera (with <10μm rms spots)

Obstruction is at pupil, so very good shadowing between top-end obstruction on telescope and detector package ⇒ more efficient, >70% peak, competitive with transmissive designs