Transient Spectrograph for Bok

Project 2

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Science team

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Optical design

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Mechanics

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Project Management

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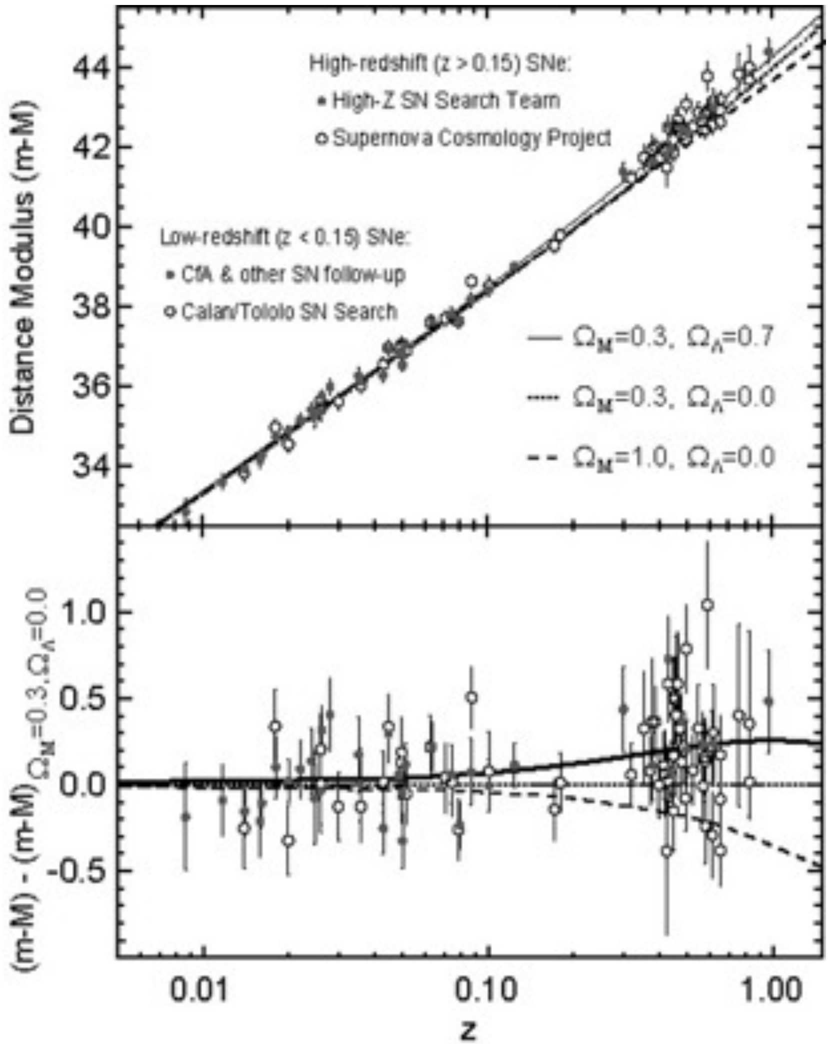
Transient Studies

- Supernovae
  - Thermonuclear
  - Core-collapse
- Other transients
  - GRBs
  - AGN
  - CVs
  - X-ray binaries

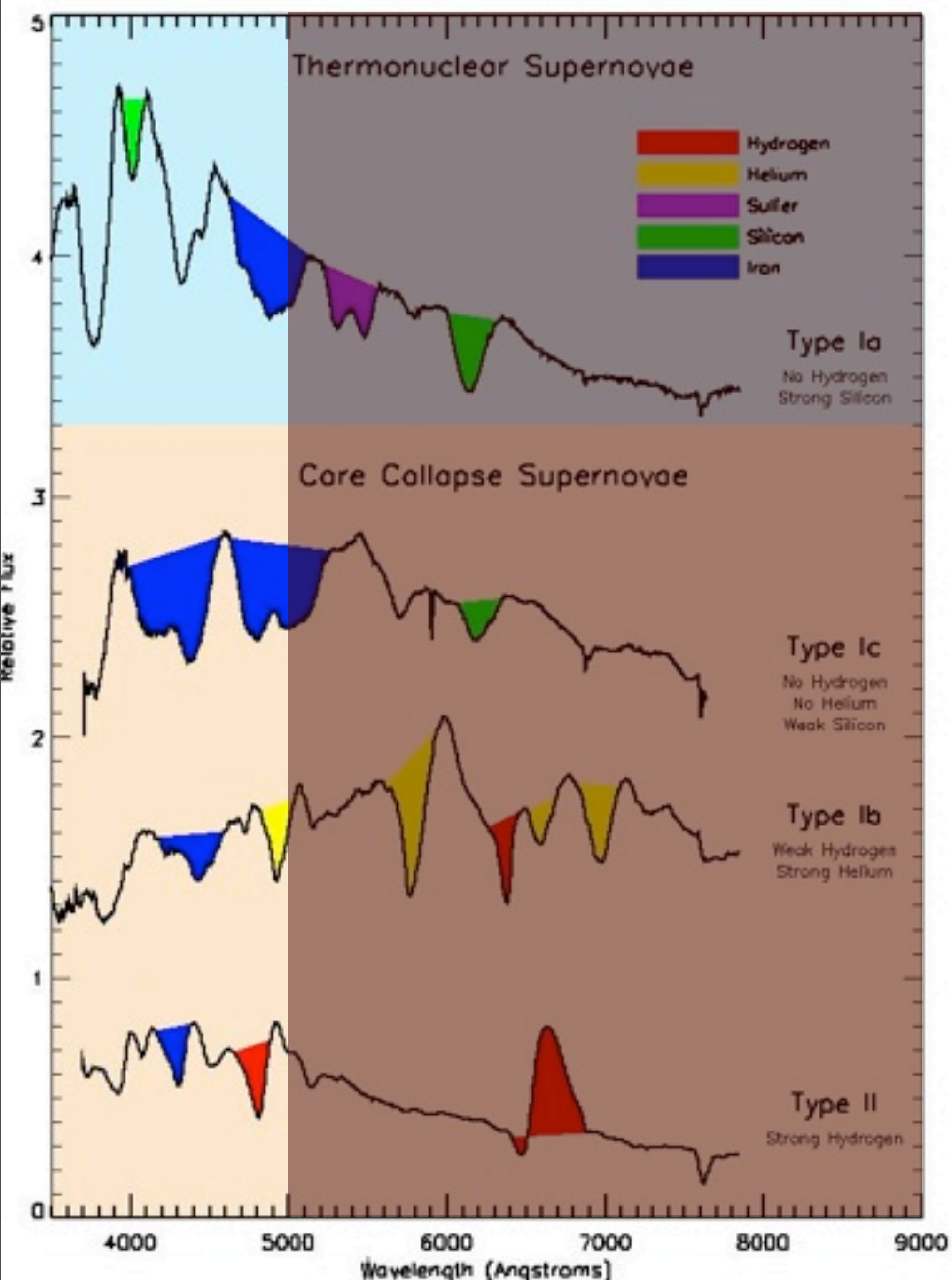


Science drivers for R=100

- R=100 will allow us to distinguish between types of SNe, and "i don't know what the hell this is"
- R=100 is a good trade-off between throughput and accurate classification for **most** transients.
- Most transients in a given night are SNe
- Real goal: identify ~ few–5% of "weird" transients

Science drivers for R=3000

- Follow up:
  - weird supernovae
  - massive star eruptions
  - pulsational pair instability eruptions
  - stellar mergers and collisions
  - tidal disruption events
  - luminous novae
  - failed supernovae
  - etc.
- Measure expansion velocities: few hundred km s^{-1}
- Measure line profiles



Wavelength

- 5000 Å so we can identify features to z=1.0 (5000 Å shifted to 10,000 Å)

Sensitivity, R=100

$M_{SN} \sim -19$

$m_{SN} \sim 24$

$\mu \sim 43$ (at $z=0.7$)

$t \sim 1800$ s (0.5 hr)

$f_{SN} \sim 10^{11}\ 10^{-0.4*24} \sim 25$ photons $s^{-1}\ m^{-2}\ \mu m^{-1} \times 0.75 / 100\ \mu m$

$f_{BG} \sim 10^{11}\ 10^{-0.4*21} \sim 400$ photons $s^{-1}\ m^{-2}\ arcsec^{-2}\ \mu m^{-1} \times 0.75 / 100\ \mu m$

Sensitivity, R=3000

$M_{SN} \sim -19$

$m_{SN} \sim 23$

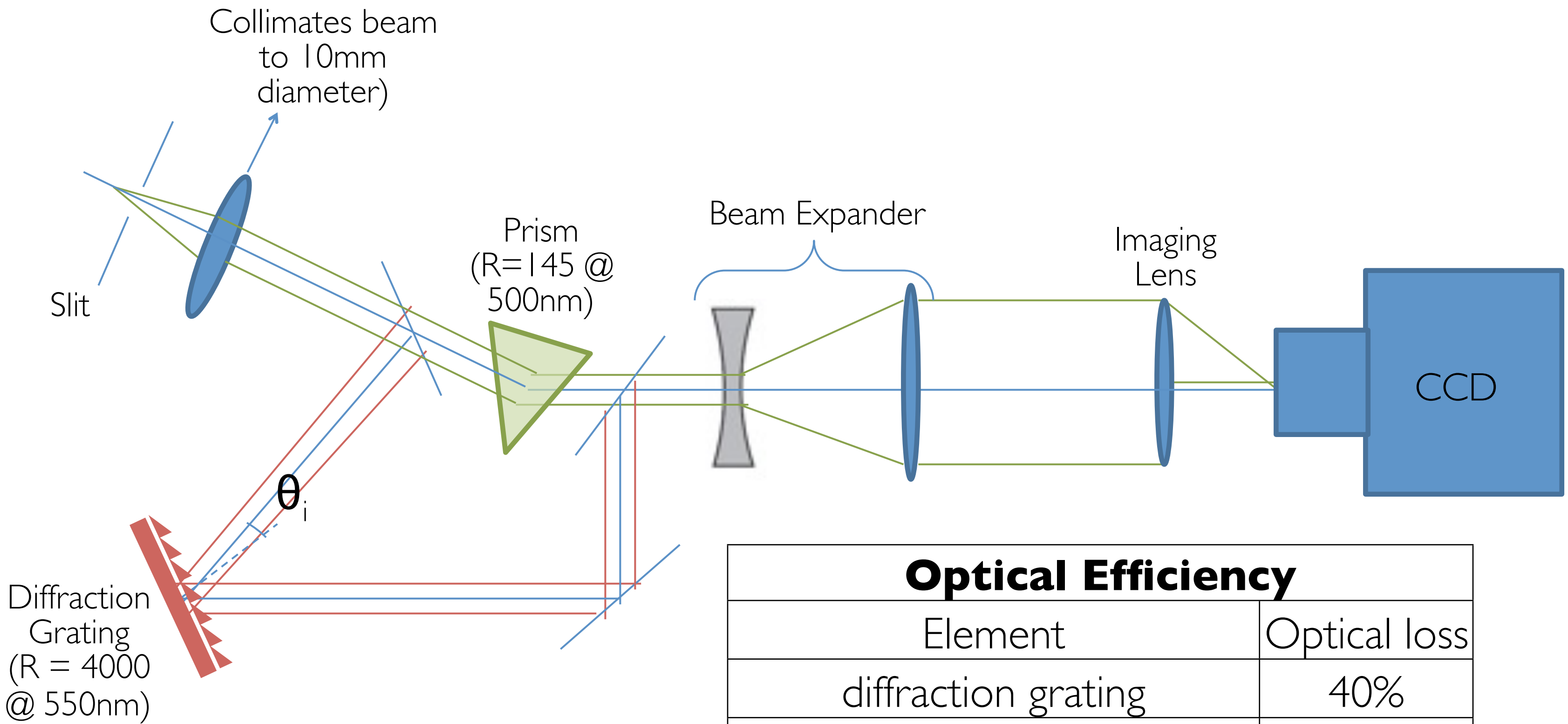
$\mu \sim 42$ (at $z=0.5$)

$t \sim 14\,400$ s (4 hr)

$f_{SN} \sim 10^{11}\ 10^{-0.4*23} \sim 60$ photons $s^{-1}\ m^{-2}\ \mu m^{-1} \times 0.75 / 3000\ \mu m$

$f_{BG} \sim 10^{11}\ 10^{-0.4*21} \sim 400$ photons $s^{-1}\ m^{-2}$ arcsec$^{-2}\ \mu m^{-1} \times 0.75 / 3000\ \mu m$

Optical Layout



Optical Efficiency	
Element	Optical loss
diffraction grating	40%
Lenses (4 lenses, 8 surfaces, 2% per surface)	16%
detector	10%
RMS total	44%
Efficiency (1-RMS)	**56%**

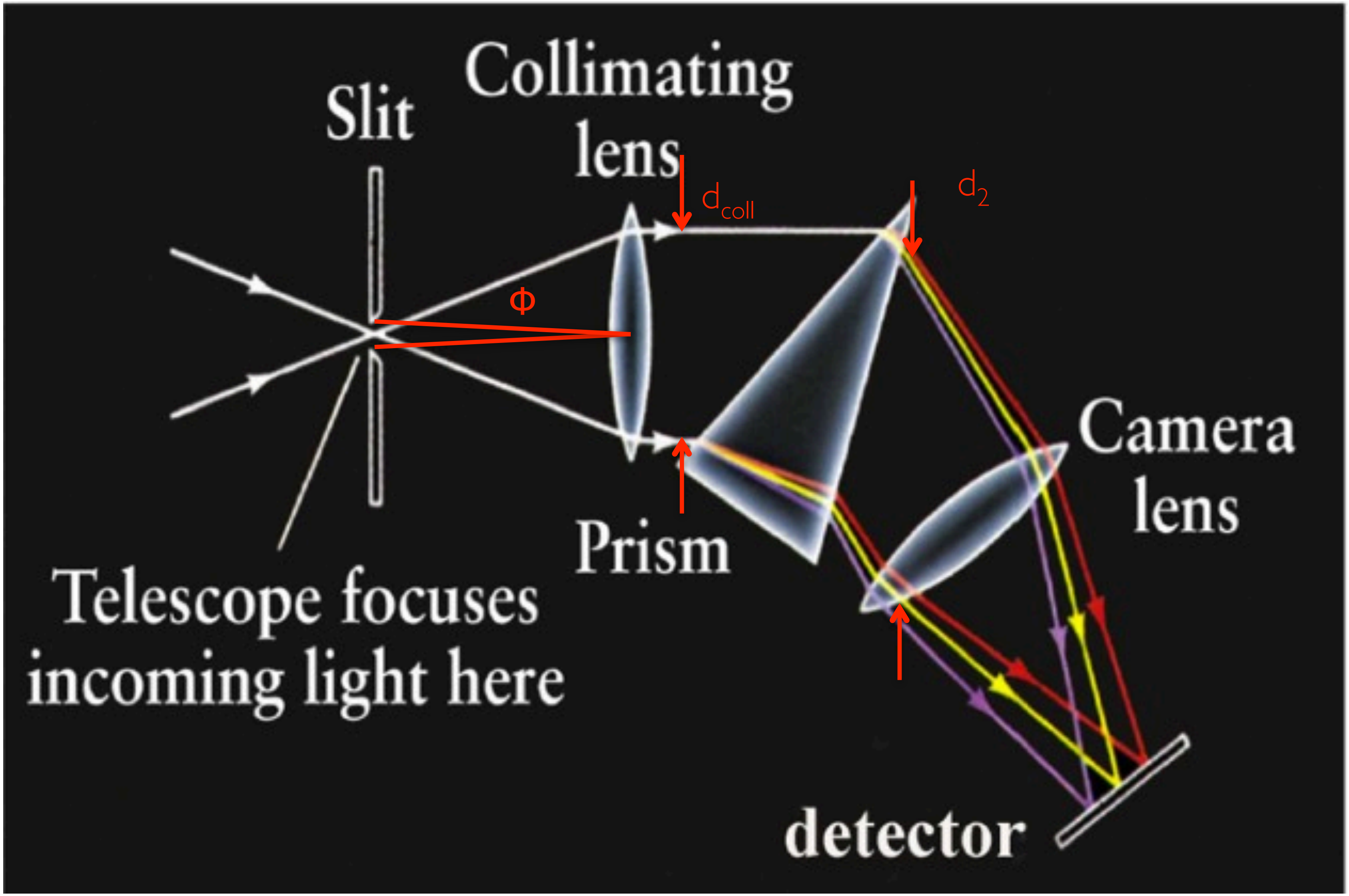
Spectrograph resolution (Prism)

- **Spectrograph resolution is**

$$R = \frac{\lambda}{\Delta\lambda} = \frac{\lambda A}{r\phi}\frac{d_{coll}}{D}$$

- Where
  - A=Angular dispersion (deg/λ)
  - Φ=Angle subtended by the slit on the sky (w/f)
  - w= slit width
  - f= telescope focal length
  - d_{coll}= Diameter of collimated beam
  - D = Telescope aperture
  - r= Anamorphic magnification of the beam size (d_{coll}/d2).

Spectrograph resolution (Prism)



Diffraction Grating

- Resolution of the Grating is given by

$$R = \frac{\lambda}{\Delta\lambda} = mN = 4000$$

- This can be achieved by using a commercially available Newport grating with 4000 lines/mm and a 10mm ruled width
- Dispersion of the grating is given by

$$\frac{d\theta_M}{d\lambda} = \frac{m}{a\cos\theta_M} = 23.06°$$

- In the focal plane, two spots will be separated by

$$fd\theta_M = f\frac{m}{a\cos\theta_M}d\lambda$$

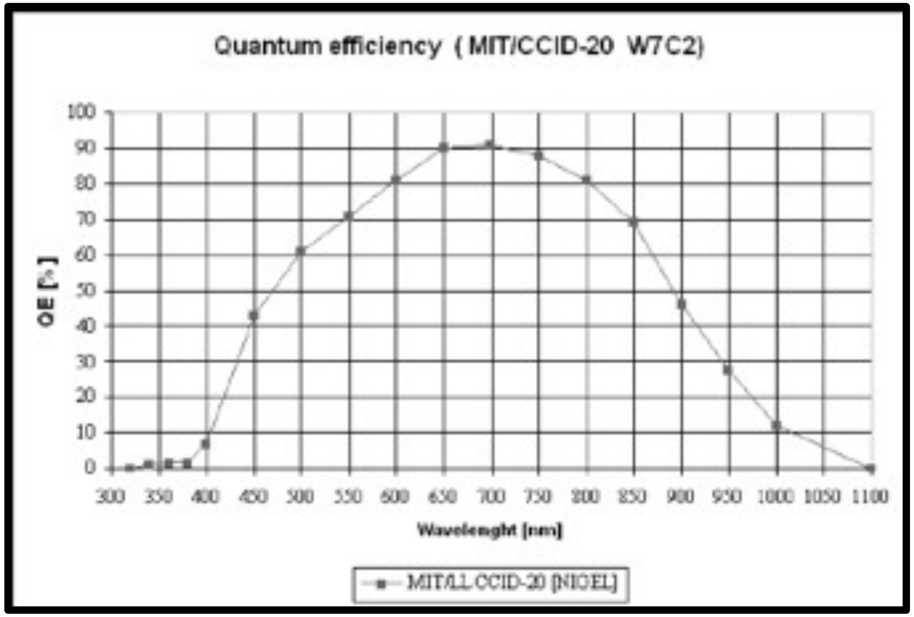
- From this equation, a 50mm focal length imaging lens will require a CCD with 2.77μm pixels

- Efficiency of the grating is ~70% over 400-800nm bandpass

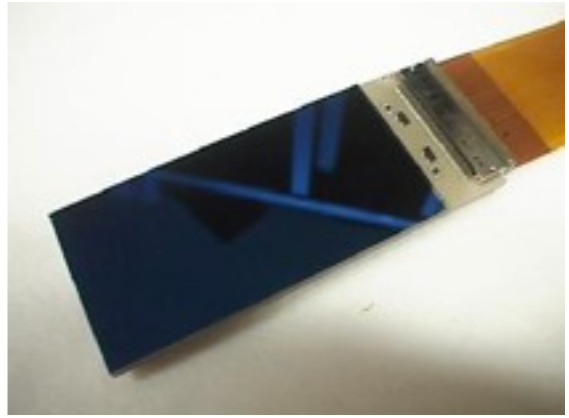
Grooves per mm	Nominal Blaze Wavelength (1st Order Littrow)	Nominal Blaze Angle	Maximum Ruled Area (Groove Length x Ruled Width, mm)
400	550 nm	6.3°	102 x 128

Detector

- CCD MIT/Lincoln Labs CCID-20
- 2k x 4k array
- 15 μm px size.
- QE up to 90% (600- 700nm)



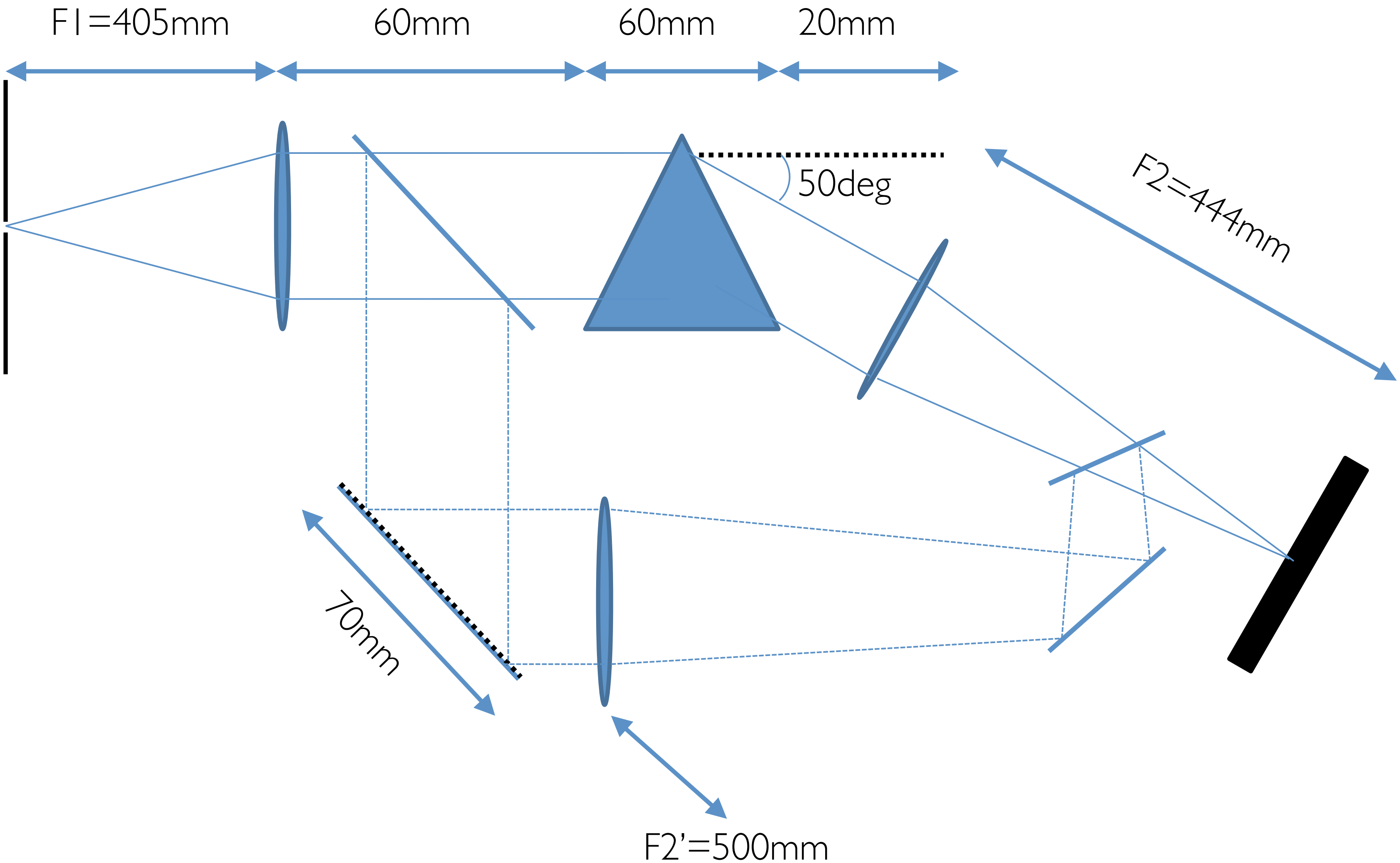
Courtesy: ESO



Optical Design

	Prism	**Grating**
Resolution	100	4000
$\Delta\lambda$ (500nm/ R)	5 nm	0.125 nm

- The detector is imaging the slit. Assuming a diffraction limited system, the **$\Delta\lambda$** on the detector plane must be separated by the size of the slit image.


F1=405mm
60mm
60mm
20mm
50deg
F2=444mm
70mm
F2'=500mm

Optical Components

- The following optical system parameters are chosen based on the previous equations and the requirements:

Slit width	100 μm
Collimate lens	f=405 mm; diameter 50mm
Prism	50X50mm, 47.9° min angle of deviation, ν=36.37
Imaging lens for prism	f=450 mm; diameter 60mm
Grating	70X70mm, 2400 line/mm hologram, 3.03 mrad/nm
Imaging lens for grating	F=500 mm; diameter 50mm

Spectrometer Mechanical Components

Artifex AKPM-DP-2
< $500

50mm Prism Mount

- Holds prism securely with low stress
- Fine locking adjustments

Newport DGM-1
$1,271.00

50mm Diffraction Grating Mount

- 10 arcsec sensitivity
- Lockable adjustments

Mid-Range Linear Travel Stage

- 150mm travel with stepper motor
- Anti-backlash preloading

Newport UTS150PP
$3,564.00

Newport URS150BCC
$4,106.00

Precision Rotation Stage

- 1.8 arcsec resolution
- 7.2 arcsec repeatability
- 8000 cts/rev rotary encoder

Costs

		Estimated Costs ($K)	
Hardware			$200
		Wks of labor	
Labor*	Optical Engineer	32	$64
	Optical Technician	32	$64
	Mechanical Engineer	24	$48
	Electrical Engineer	16	$32
	Software Engineer	16	$32
*Assume all labor is $50/hr			
		Total	**$440**

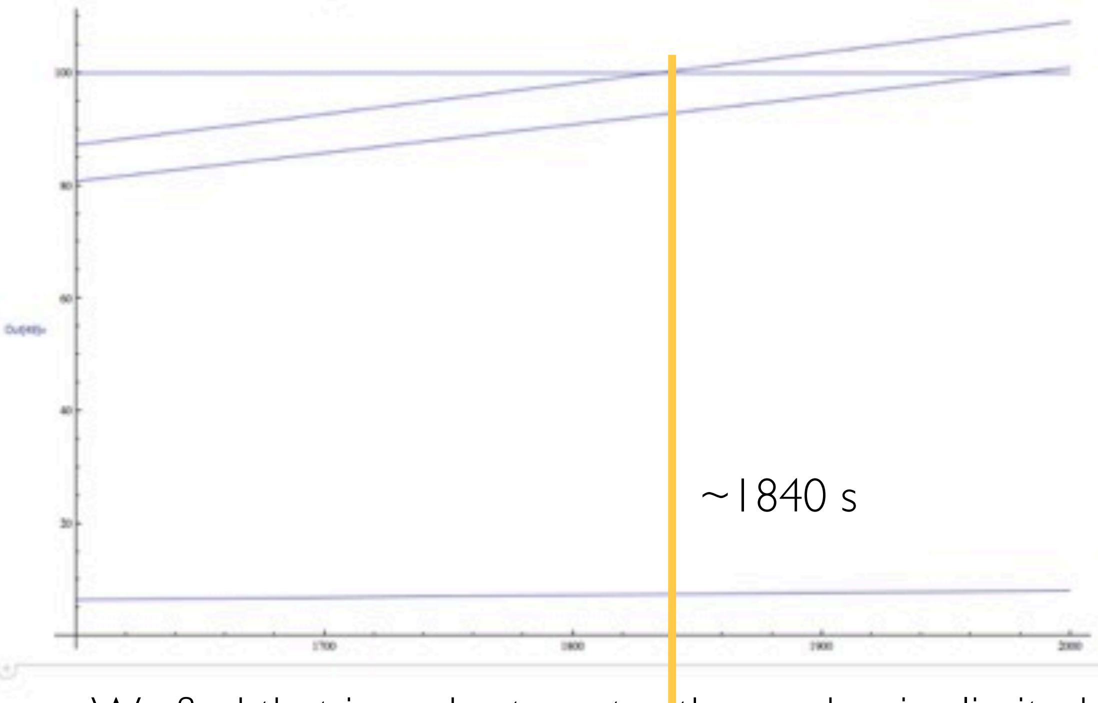
Total Cost ≈ $440K

ADDENDUM
REQUESTED
SLIDES BELOW

```
Plot[
 {ε (10^11 10^-0.4 m_s) (π (d/2)^2) t (λ/R), ε (10^11 10^-0.4 m_BG) (π (d/2)^2) t (λ/R) π (θ/2)^2,
     ε (10^11 10^-0.4 m_s) (π (d/2)^2) t (λ/R) + ε (10^11 10^-0.4 m_BG) (π (d/2)^2) t (λ/R) π (θ/2)^2, 100} /. m_s → 24 /.
    m_BG → 21 /. d → 2.3 /. SNR → 10 /. ε → 0.57 /. λ → 0.75 /. R → 11000 /. θ → 1.0,
 {t, 1600, 2000}]
```

R for read-nosie limited spectra

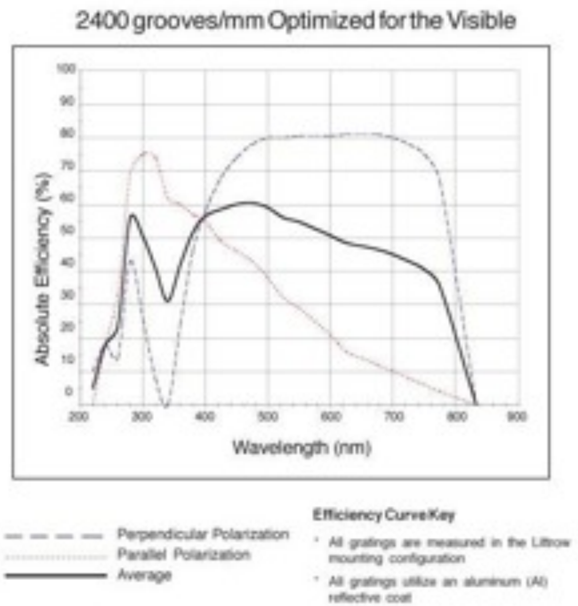
read noise for 4 pixels at 5 counts per pixel per read



We find that in order to enter the read-noise limited regime, we must increase our resolution quite a bit–to ~11,000–in order to sufficiently dilute our background noise. This implies that we could gain resolution "for free", but we note that at higher resolutions, we have less spectral coverage for the same detector size, and this is a trade-off we may not wish to make. We also note that this calculation is for one long exposure. In this long exposure, we don't saturate, but would be susceptible to cosmic rays and other unforeseen problems. If we used several shorter exposures, read noise would increase relative to background noise, and our read-noise regime would correspond to smaller R value.

Reflective Holographic Grating

Part #	Grooves (line/	Dispersion(mrad/	Size (mm)
Thorlab GH50-24V	2400	3.03 @ 500 nm	50X50



- Holographic gratings do not suffer from periodic errors that can occur in ruled gratings, thus ghosted images are nonexistent.
- The line density is chosen by the dispersion we need.