Physics 1901

Experimental Astronomy – Graduate Course

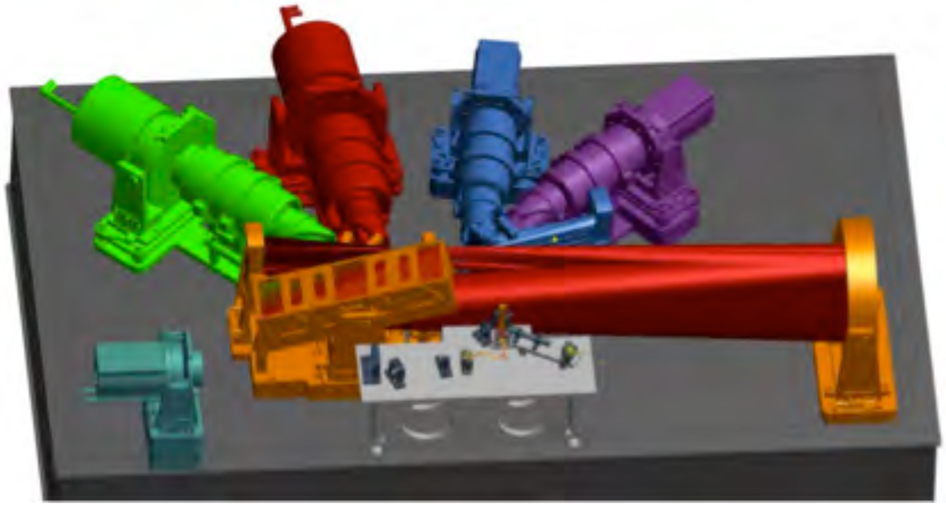
Autumn (Apr-May 2014)

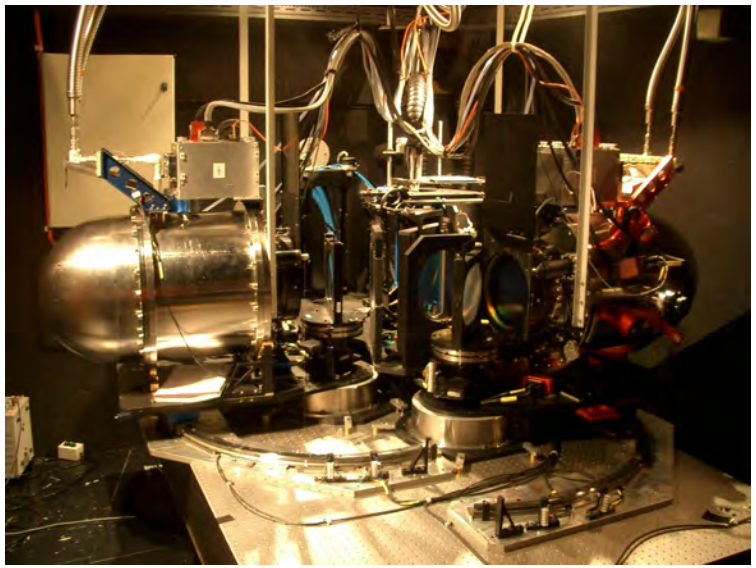
Assoc. Prof. Andrew I. Sheinis ,
Australian Astronomical Observatory

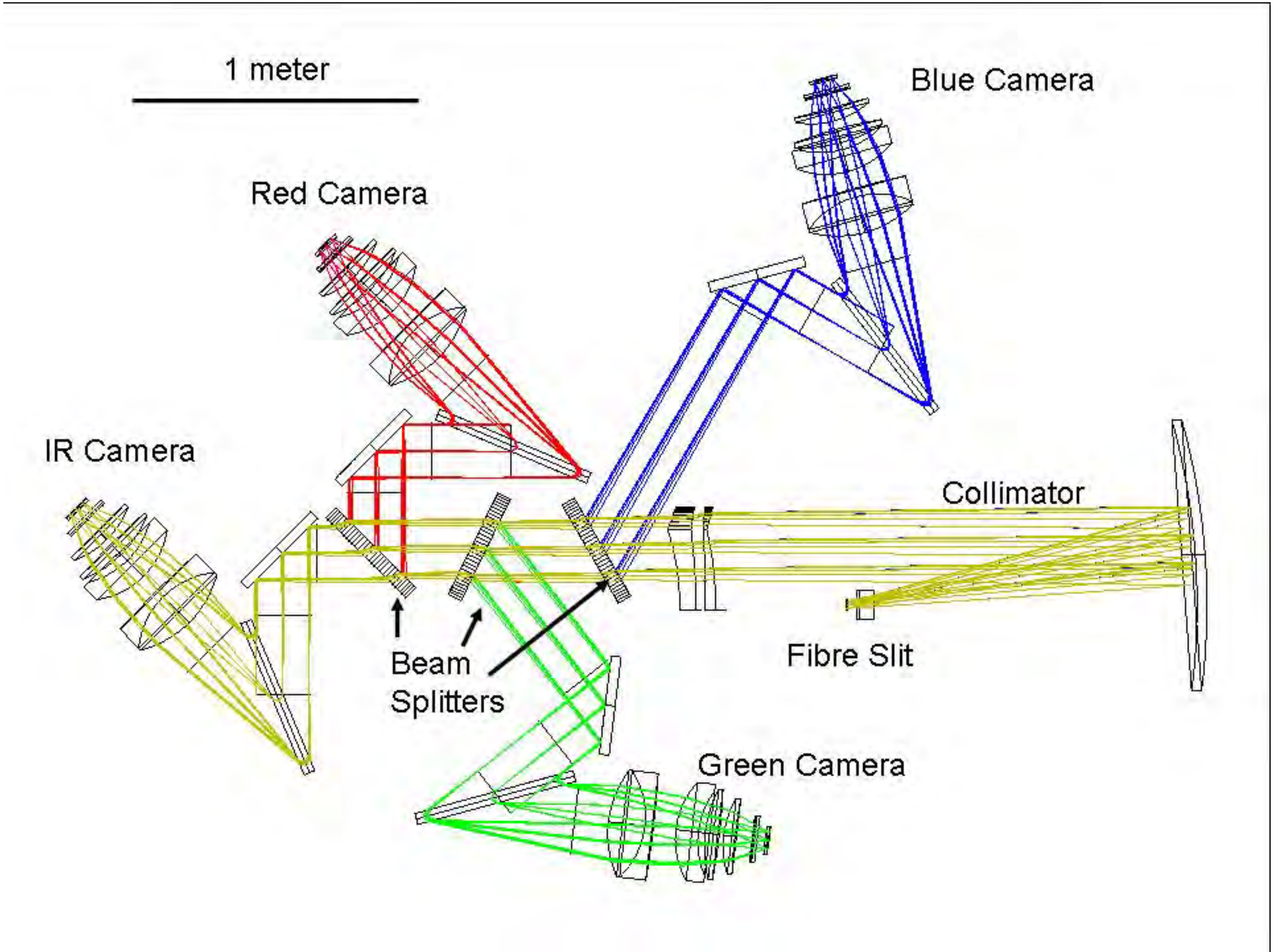
Prof. Joss Bland-Hawthorn
Sydney Institute for Astronomy

Some questions:
(which you should be able to answer at the end of the course)

- What are the parts of a spectrograph
- Why are spectrographs so big?
- What sets the sensitivity?
- How do I estimate the exposure time?






1 meter
Blue Camera
Red Camera
IR Camera
Collimator
Beam
Splitters
Fibre Slit
Green Camera

How do you really build an Instrument? What is the process?

- Science: determine the need.
- (need to have some idea what is possible first though)
- iterate between first order design and science goals
- Get community buy in
- End result: set of science requirements: Functional performance requirements document. (FPRD)

Requirements Entity	ID	Title	Description	Derivation	Version History
Science	**REQ-1000**		**Science**		
Science	REQ-1001.01	Wavelength range	GHOST shall provide simultaneous wavelength coverage from 363 nm to 1000 nm.	Science white papers	14May12: Initial
Science	REQ-1002.01	Spectral resolution	GHOST shall have two selectable spectral resolution modes: standard resolution mode with R>50,000 and high resolution mode with R>75,000.	Science white papers	14May12: Initial
Science	REQ-1003.01	Sensitivity	GHOST shall obtain a sensitivity of m=18.0 in a 1 hour observation for 30 sigma per resolution element in standard resolution mode in dark time (50th sky brightness percentile) at a wavelength of 500 nm.	Science white papers	14May12: Initial
Science	REQ-1004.01	Targets and field size	GHOST shall have the capability to observe 2 targets simultaneously over a 7.5 arcmin diameter field of view.	Science white papers	14May12: Initial
Science	REQ-1005.01	Radial velocity precision	GHOST shall provide a radial velocity precision of 200 m/s over the full wavelength range in standard resolution mode and shall have the capability to provide a radial velocity precision of 2 m/s over the full wavelength range for the high spectral resolution mode.	Science white papers	14May12: Initial
Science	REQ-1006.01	Spatial sampling	GHOST shall spatially sample each target object over a field size of 1.2 arcsec.	Science white papers	14May12: Initial
Science	REQ-1007.01	Spectro-polarimetry	GHOST should provide a spectropolarimetric capability that can distinguish all Stokes parameters.	Science white papers	14May12: Initial
Operational	**REQ-2000**		**Operation**		
Operational	REQ-2001.01	Observing Efficiency	The observing time (as defined as science instrument acquiring science	Gemini	6May11: Initial v

		Verification Stage/Method:								Verification Matrix
	Assumptions	CoDR	PDP	FD	BP	PreD	PostD	Comm.	Test Description	CoDR
								T		
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Design and Development process

- **RFP > science requirements**
- **Telescope?**
- **Budget?**
- First order: geometric optics
- Second order: raytracing (Zemax)
- Costing based on second order
- **CoDR**

Design and Development process

- **Win CoDR!**
- Update the 2nd order design
- Initial mechanical layout
- Design downselect based on decision matrix (cost, peformance, science, risk, reliability)
- Availability of glasses, detectors
- Preliminary electronics design
- Preliminary software design
- **PDR**

Design and Development process

- **Pass PDR!**
- Final design
- Tolerance analysis(monte Carlo simulation of all optical fabrication and assembly errors), > expectation of real performance
- Final drawings > final price quote
- Real mechanical design, thermal flexural issues
- Final electronics design
- Final software design
- **FDR**

Design and Development process

- **Pass FDR! Start the Build**
- Vendor selection > testplate design
- Purchase materials > melt data design
- Build, vendor test/verification
- Take component delivery and begin AIT
- Finish > customer acceptance testing
- **Deliver**> commission > publish
- Service > upgrade

Design Example

Science flow down to constraints

- Telescope diameter- F/#:
- Median Seeing > slit width:
- Detector:
- Detector pitch > collimator/camera ratio:
- Science >
  - R> $D_{coll} \tan\theta_b$
  - FOV > camera requirements
- Physical size:

constraints

- Telescope diameter- F/#: 10 meter, F/15
- Median Seeing > slit width: 0.5”
- Detector: 2K x 4K x 15um pixels
- Detector pitch > collimator/camera ratio: 1” slit onto 3 pixels
- Science > R= 8600/median seeing at 1 um, FSR = 0.4-1um
  - R> $D_{coll} \tan\theta_b$
  - FOV > camera requirements: 20” slit length
- Physical size: 2.3 meter box

20 arcsec long X 0.5 arcsec wide

Telescope and seeing

- Telescope plate scale=206265/f("/mm)

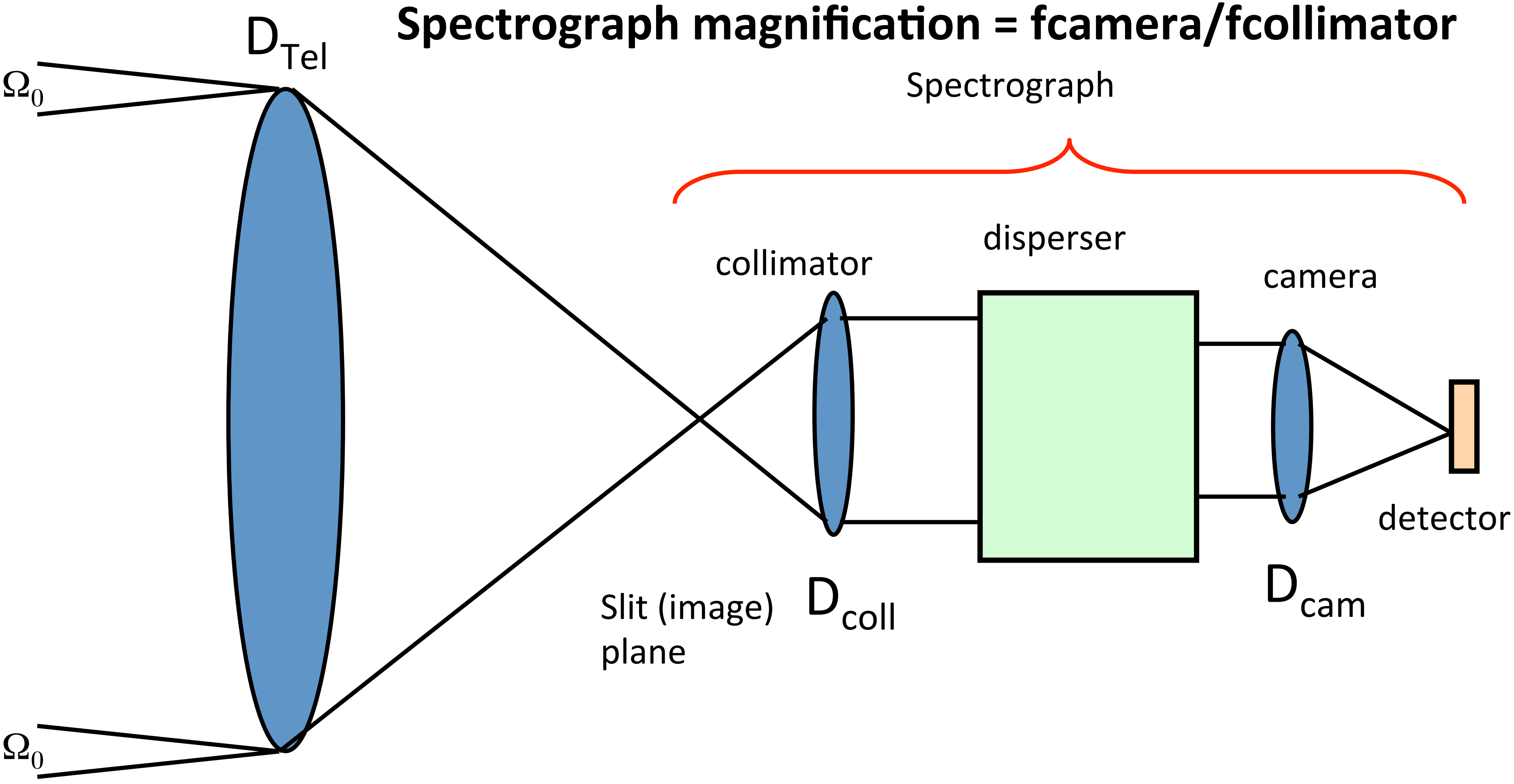
  Plate scale = 1.375 "/mm>727um/"

- Optimal sampling= 3 pixels for median seeing

  6 pixels/">0.1667 "/pixel

- R= 8600/median seeing slit at 1um
  - >R=4300/"
  - R=26000/pixel

Spectrograph magnification = fcamera/fcollimator



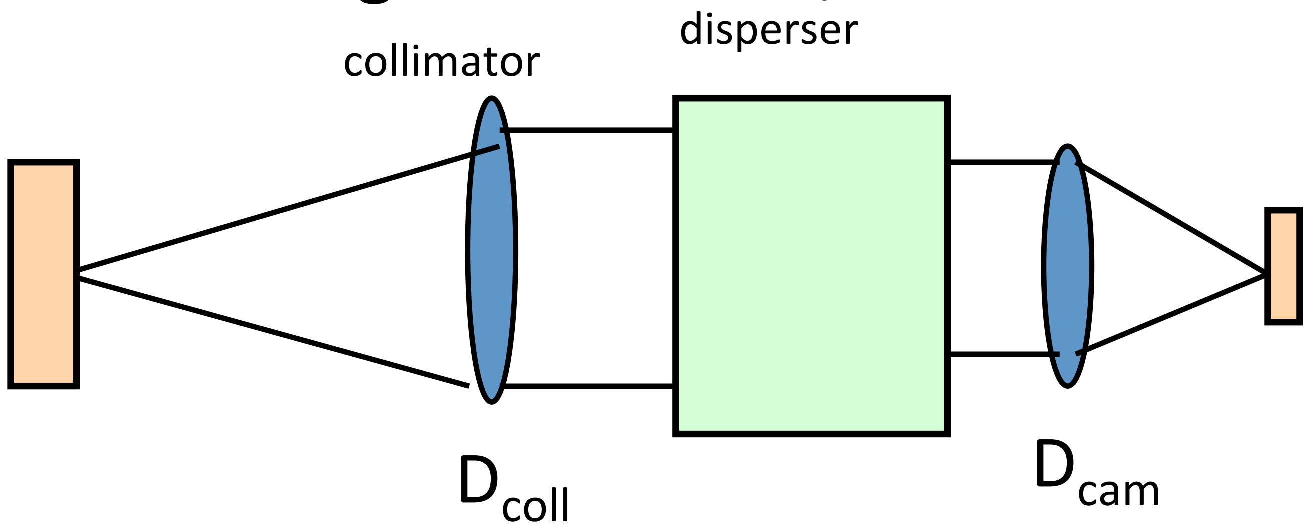
Telescope

Anamorphic factor,

$r = D_{coll}/D_{cam}$

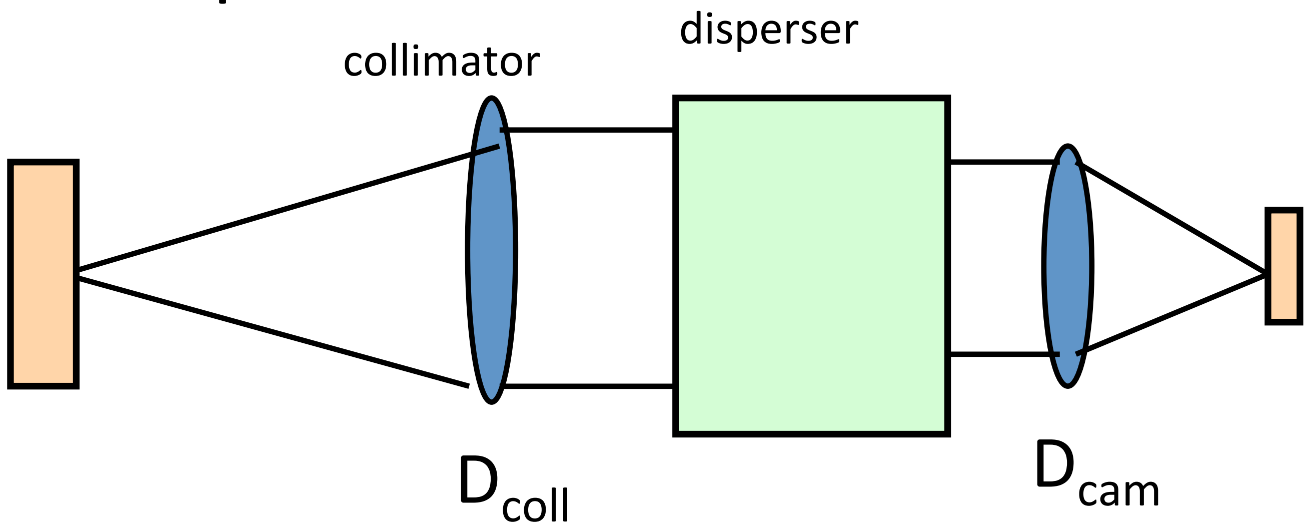
Collimator/camera

- Big as possible make grating work less hard
- Box=2.3meter: collimator f=2300mm
- Pupil diameter=2300mm/15=153mm
- 6 pixels/" > M=727um/90um=8.077
- Camera focal length=2300mm/8.077=285mm



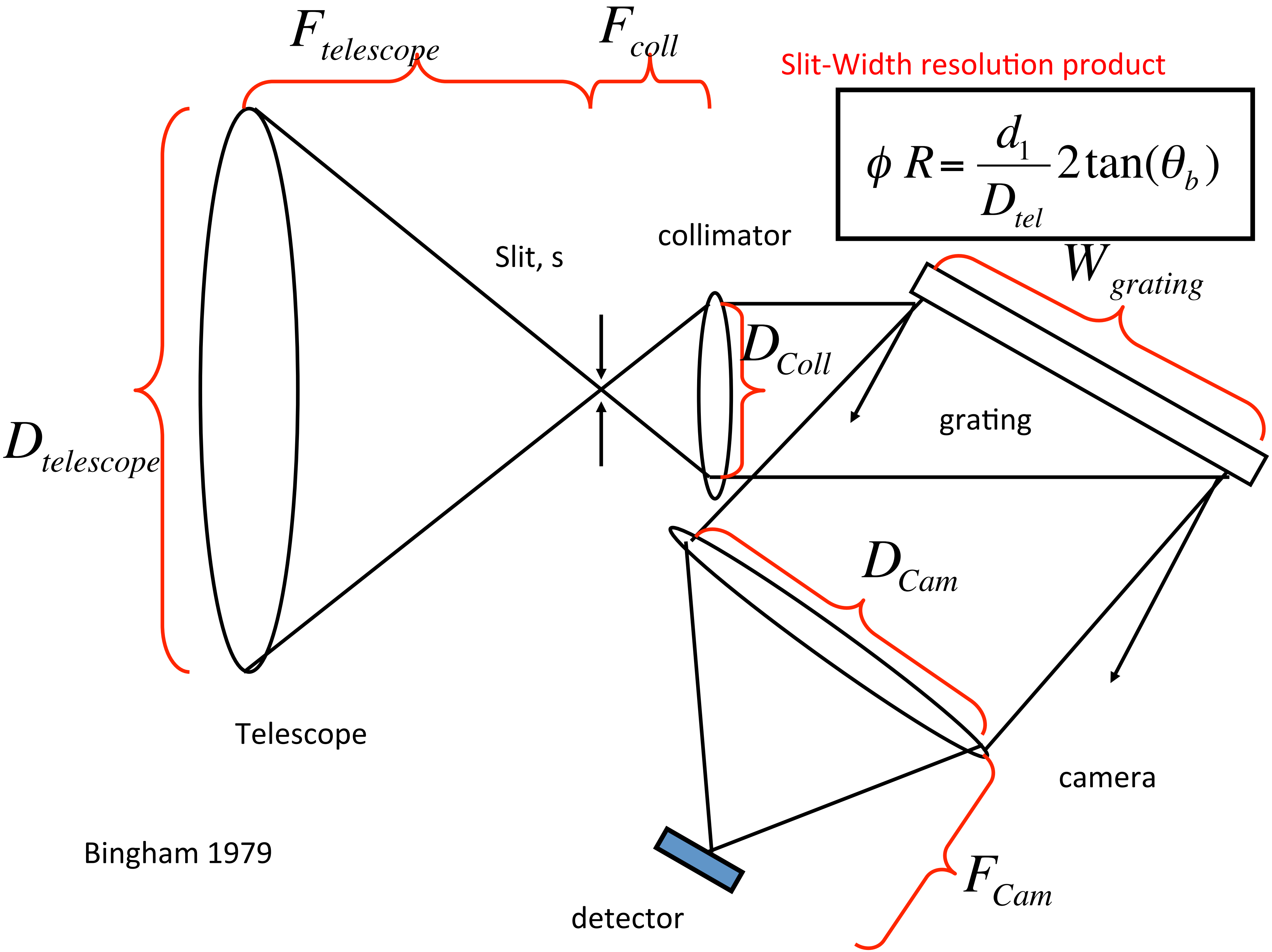
Collimator/camera

- Pupil diameter=2300mm/15=153mm
- Camera focal length=2300mm/8.077=285mm
- Camera speed is F/#=F/D=285/153=1.85
- Lenses are bigger if not at pupil
- Use matrix optics to determine lens size



Slit-Width resolution product

$$\phi R = \frac{d_1}{D_{tel}} 2\tan(\theta_b)$$



Bingham 1979

Blaze angle

- Assume Littrow for now

$$\phi R = \frac{d_1}{D_{tel}} 2\tan(\theta_b)$$

$$\tan(\theta_b) = \phi R \frac{D_{tel}}{2d_1}$$

- Θ=arctan(4300*1e4/(206265*2*153)
- Θ=34.2 degrees

Free spectral range

- FSR=0.4-1.0 um
- Slit length = 20 “
- How many orders?
- Allow 10” between slit images = 30”/image
- 2048 pixels/(6pix*30)=11 orders

Free spectral range and order numbers?

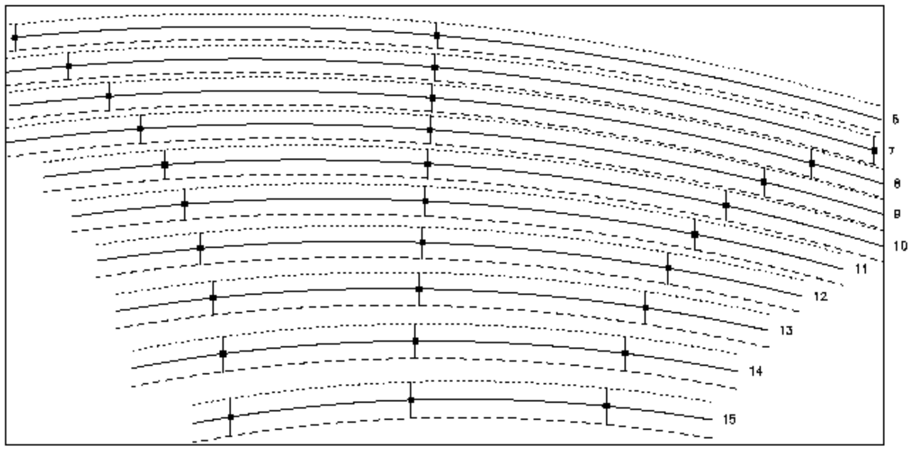
- Longest order should just fit on detector

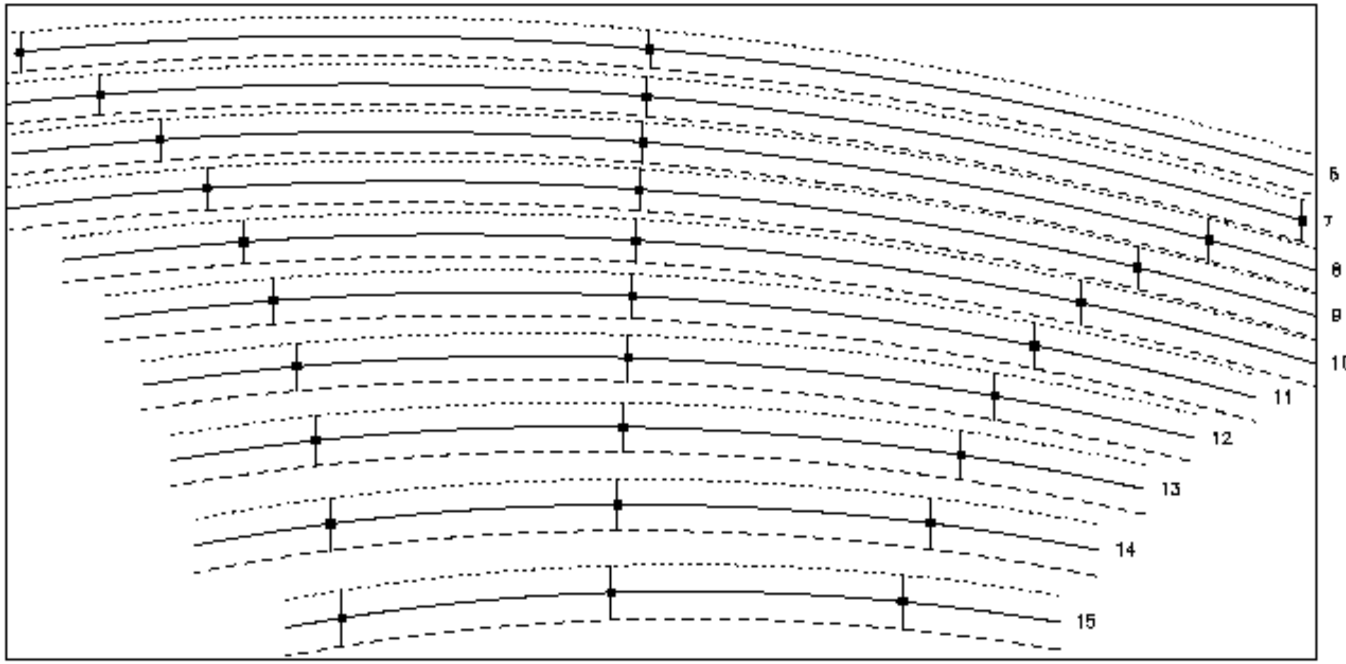
  =4096pix/26000um/pix=0.157um

- Higher orders will use detector more efficiently

$$FSR = \lambda / n$$

- 1um/0.157um=6
- N=6

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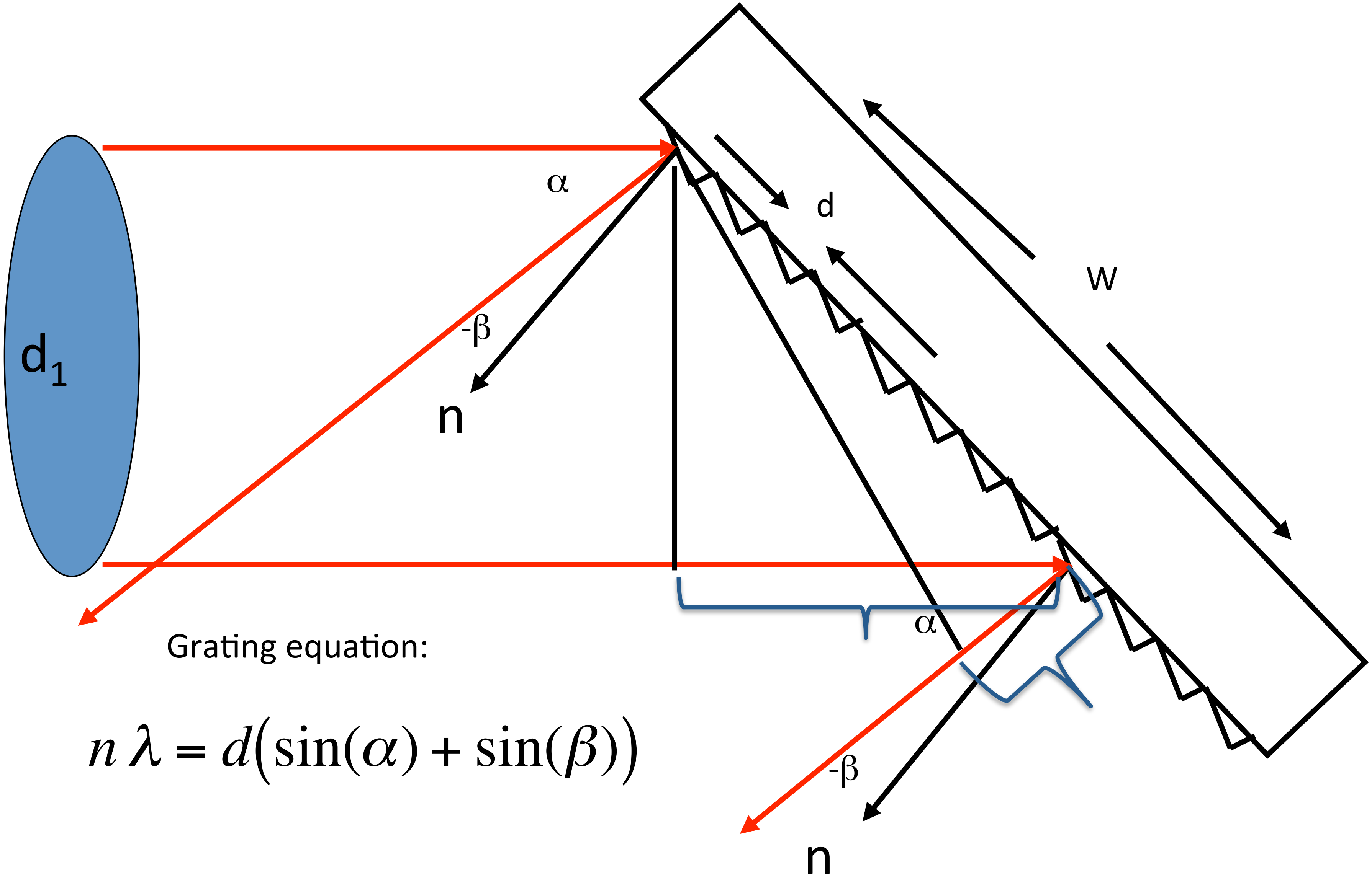

Grating equation:

$$n\,\lambda = d\left(\sin(\alpha) + \sin(\beta)\right)$$

grating

- Grating equation

$$n\,\lambda = d\left(\sin(\alpha) + \sin(\beta)\right)$$

- Littrow

$$n\,\lambda = 2d\left(\sin(\theta)\right)$$

- N=6, λ=1um, Θ=34.25, d=187.5l/mm
- Grating length=153/cos(34.25)=185mm

Put it all together

- Collimator: 2300mm f/15
- Camera: 285mm f/1.86
- Grating=185mm, 187.5l/mm blazed at 34.25 degrees
- Operating in littrow
- Orders 6-17

In reality many things are missing

- Need to find a stock grating and adjust design
- Need to consider anamorphic factor
- Need camera and collimator fields
- Can’t usually operate at Littrow
- Need to design the cross-disperser
- Distortion, aberrations, and a million other things……

End lecture 5