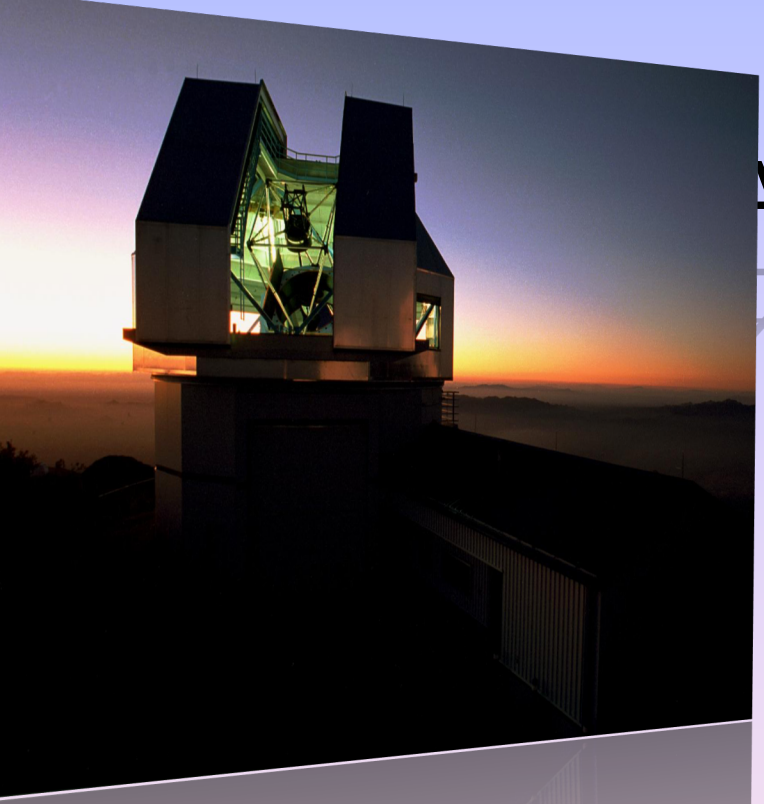


Astro 500

Techniques of Modern Observational Astrophysics

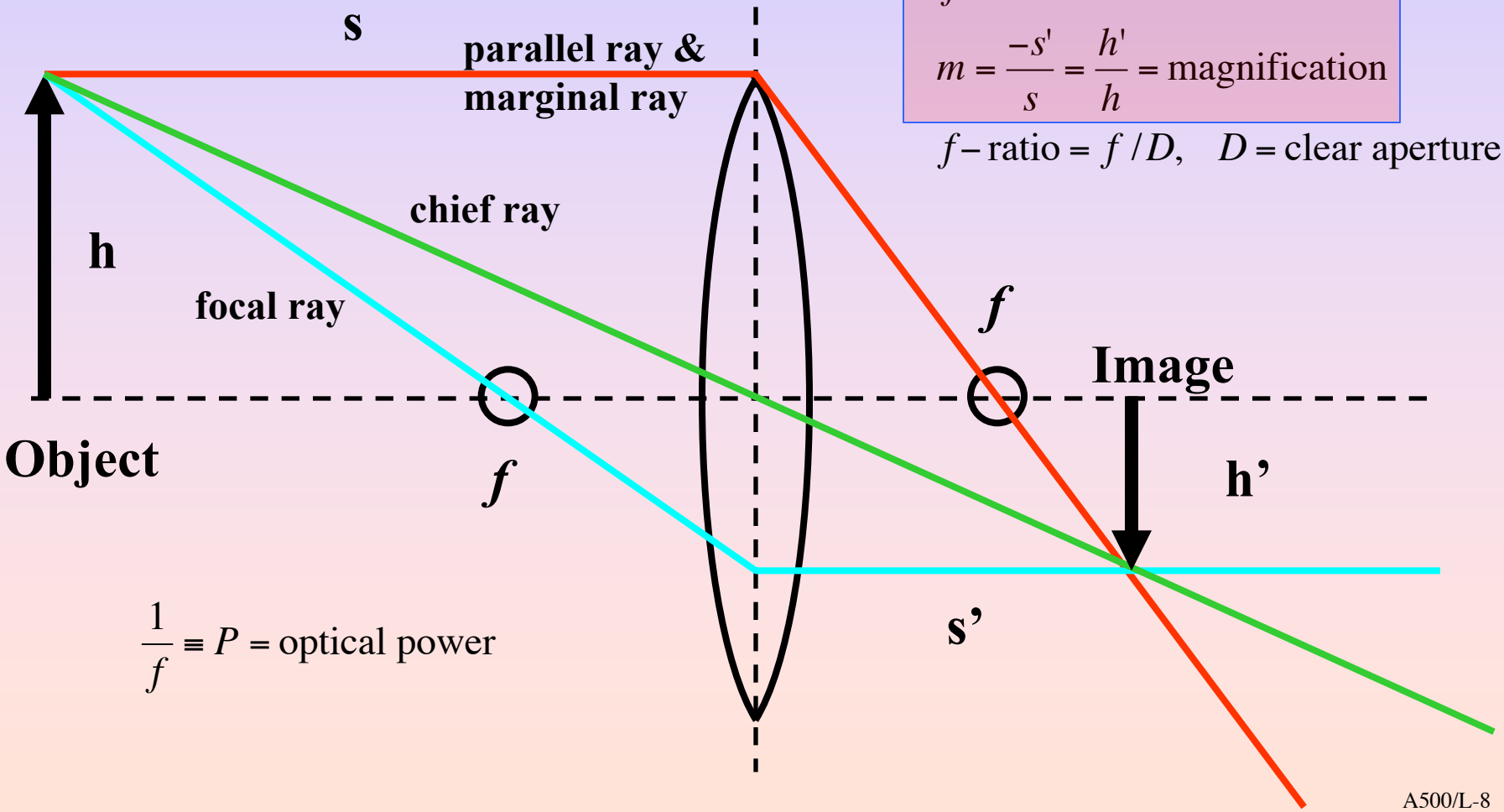
Matthew Bershady

University of Wisconsin

Outline

- Optics
  - Review
  - Compound systems:
    - Pupils, stops, and telecentricity
- Telescopes
  - Review
  - Two-mirror systems
  - Figures of merit
- Examples: WIYN & SALT

Review: The Thin Lens



$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$

$$m = \frac{-s'}{s} = \frac{h'}{h} = \text{magnification}$$

$f-\text{ratio} = f/D, \quad D = \text{clear aperture}$

$$\frac{1}{f} \equiv P = \text{optical power}$$

Review: The Thin Lens

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$

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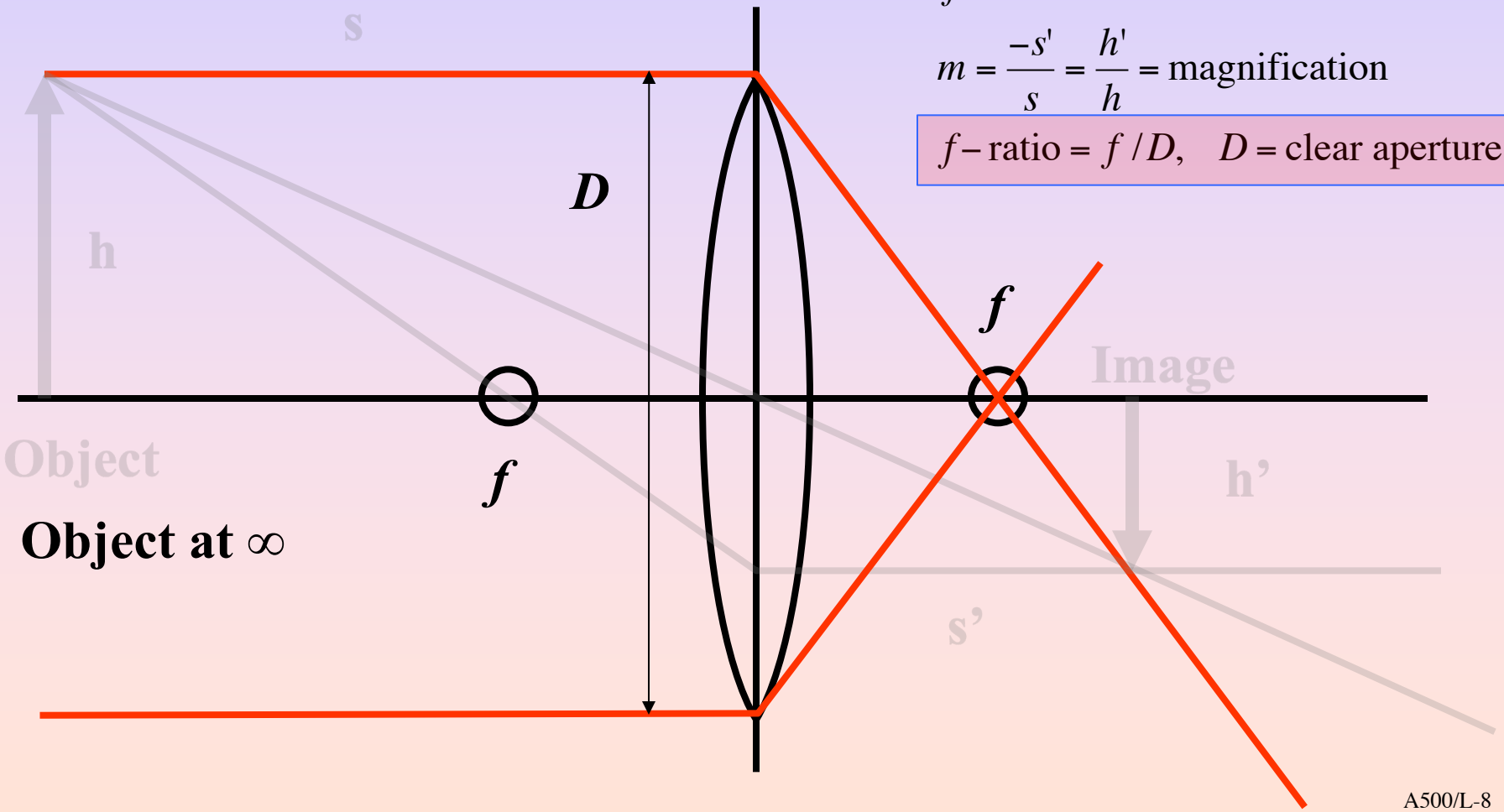
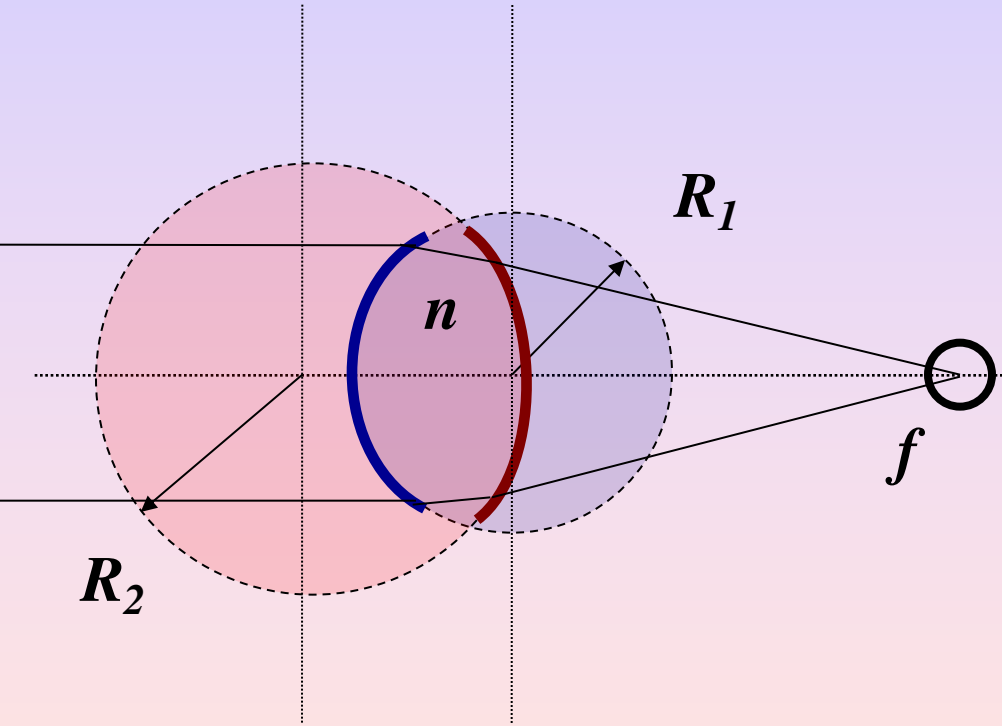


Object at ∞

Review: Optical Power, P



Two surfaces

- **separation *d***
- **index *n***

$$P \equiv \frac{1}{f} = P_1 + P_2 - \frac{d}{n} P_1 P_2$$

Two-surface spherical lens in air or vacuum

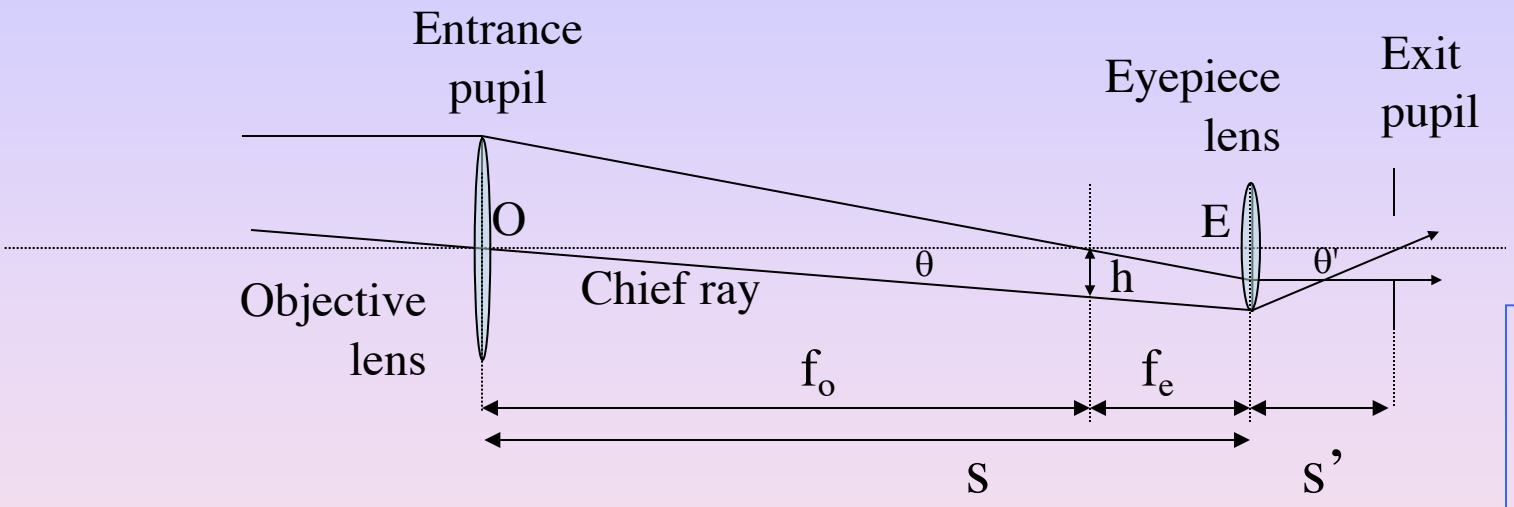
- **R_1, R_2 radii of curvature**
- **R>0: center of curvature behind lens**

Lensmaker's formula:

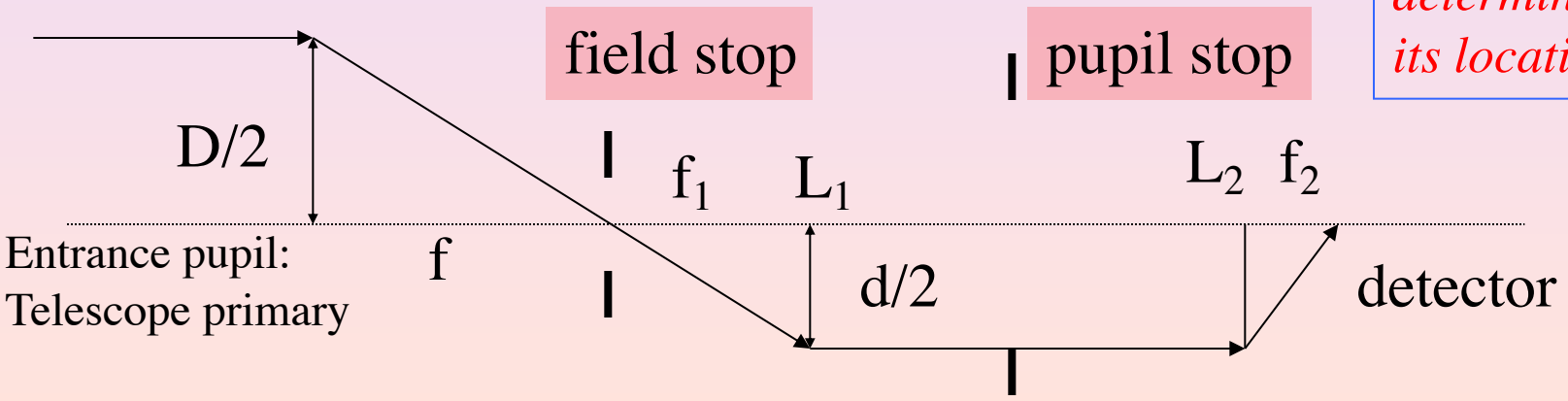
$$P = \frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{d(n-1)}{nR_1R_2}\right]$$

units : dioptor (m^{-1})

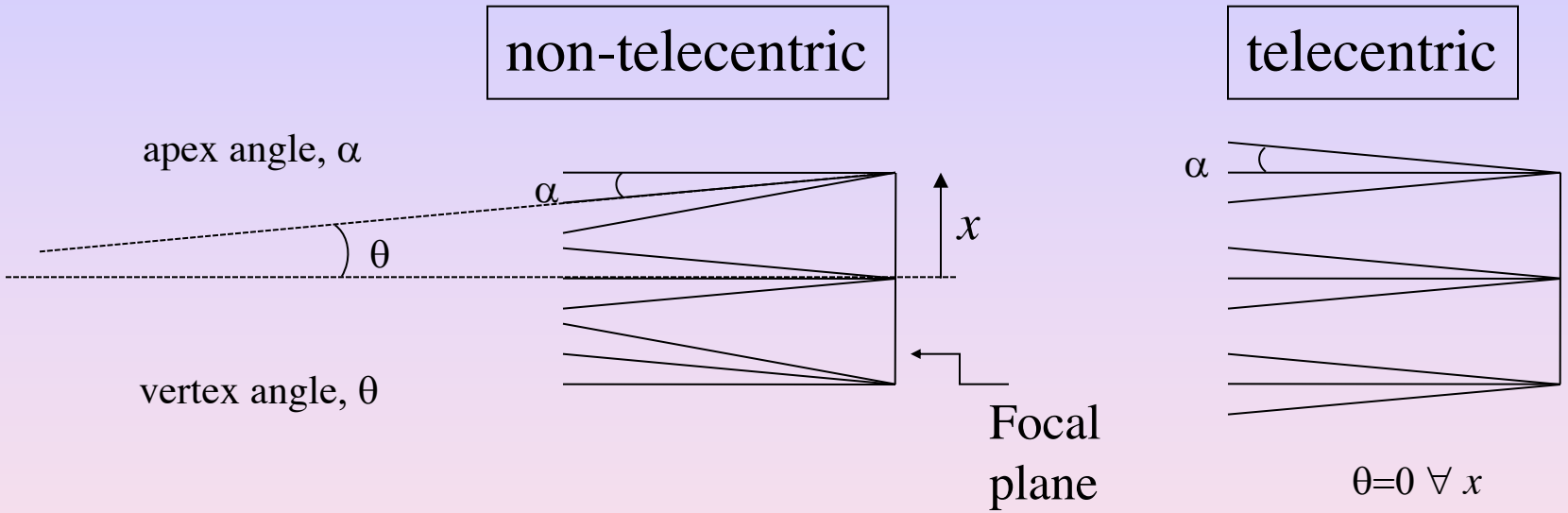
Compound systems: Pupils and layouts



What is a pupil, and what determines its location?

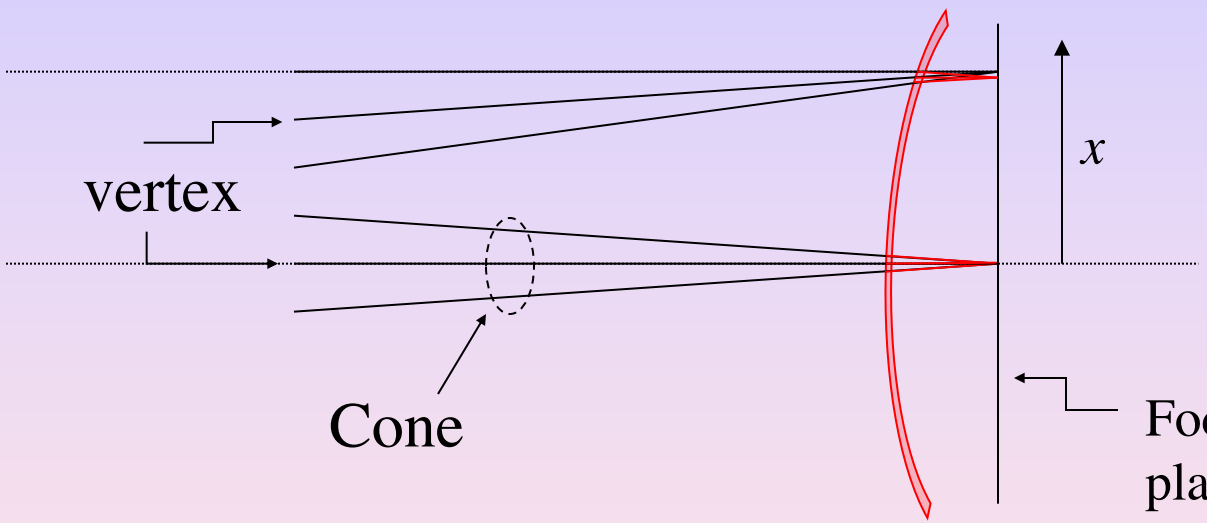


Telecentricty, pupils and field-lenses



Telecentric: light cone at all field angles have parallel vertices with zero apex angle.

When telecentric?



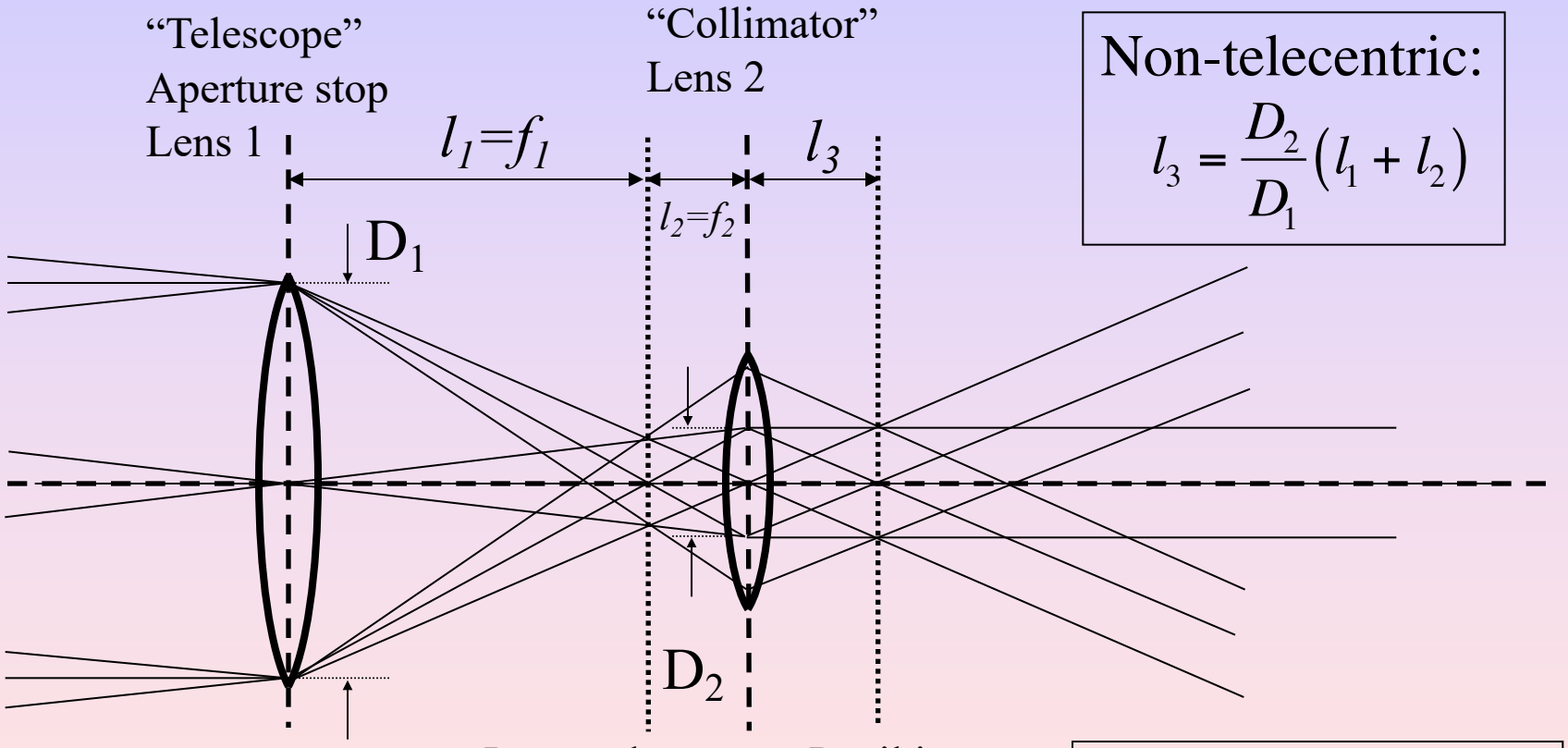
non-telecentric

telecentric

1. x/*f* << 1
2. Field lens (=lens near focus)

All rays deflected by same $\Delta\theta$ for a given *x*. Same cone (apex) angle, α, but altered vertex angle, θ.

Objects, Images, Pupils



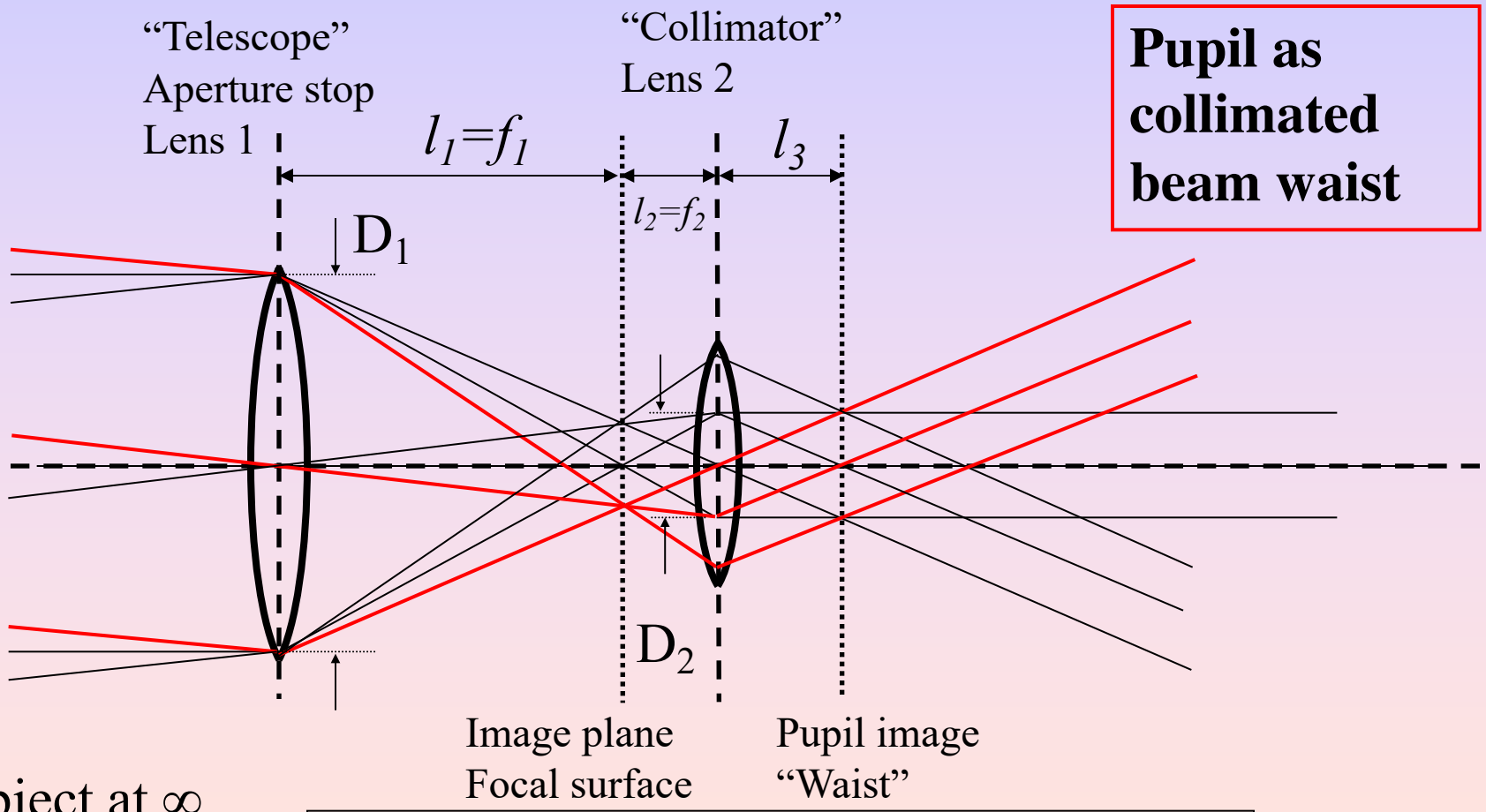
Non-telecentric:

$$l_3 = \frac{D_2}{D_1}\left(l_1 + l_2\right)$$

Object at ∞

When does $l_3=l_2$?
$l_1>>l_2$ (telecentric)

Objects, Images, Pupils

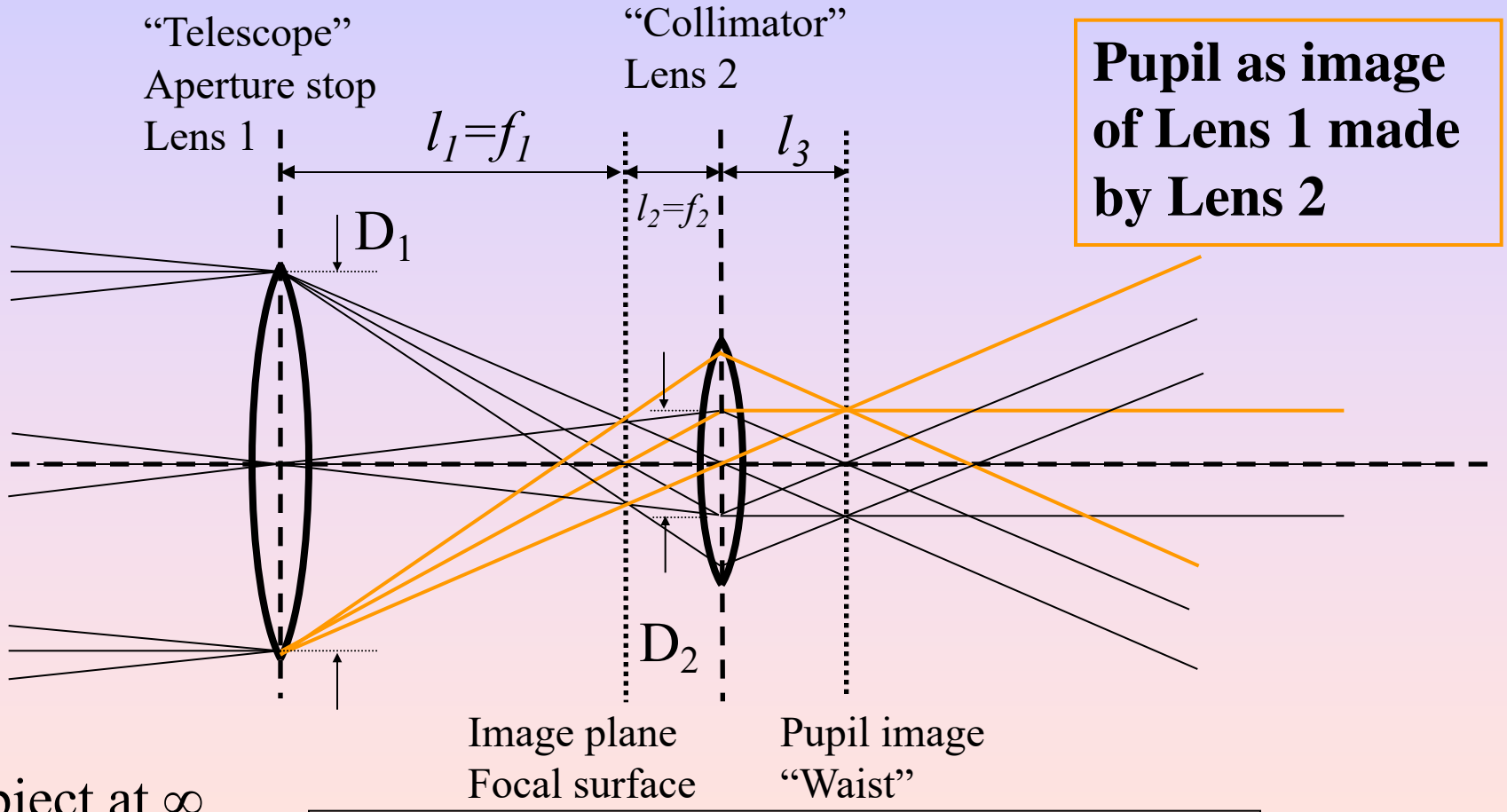


Pupil as collimated beam waist

Object at ∞

Pupil: cross-section of light-bundle where light from all field angles in focal plane completely overlap. This is an image of the telescope primary and its associated stops.

Objects, Images, Pupils

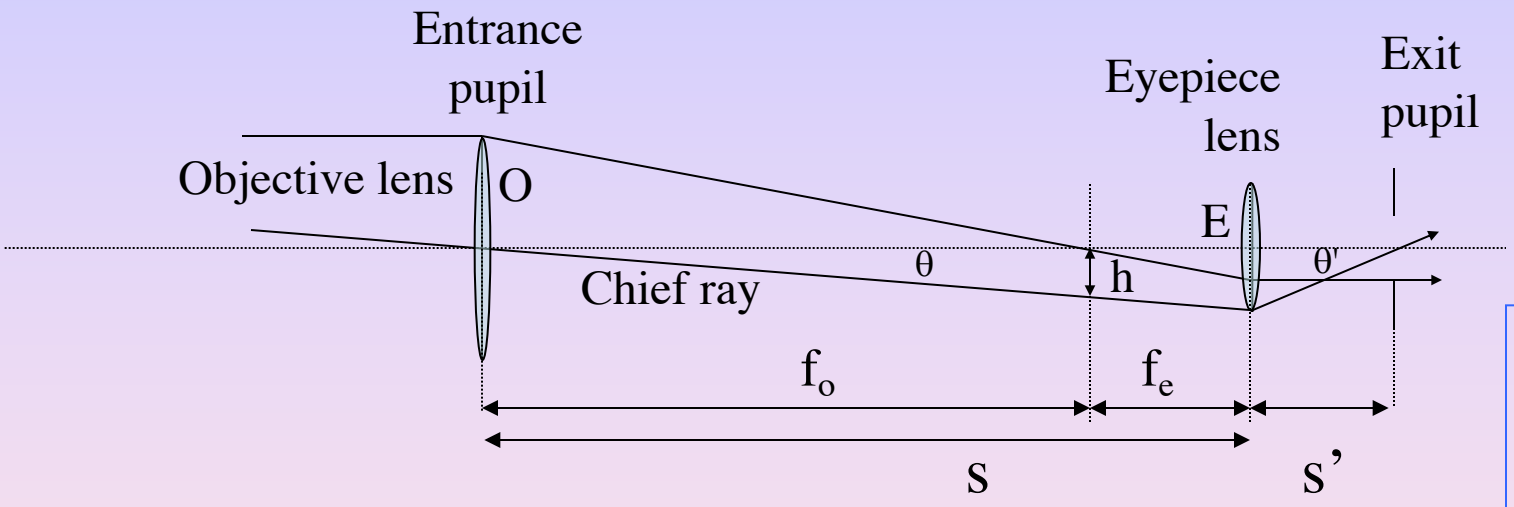


Pupil as image of Lens 1 made by Lens 2

Object at ∞

Pupil: cross-section of light-bundle where light from all field angles in focal plane completely overlap. This is an image of the telescope primary and its associated stops.

Pupils and layouts



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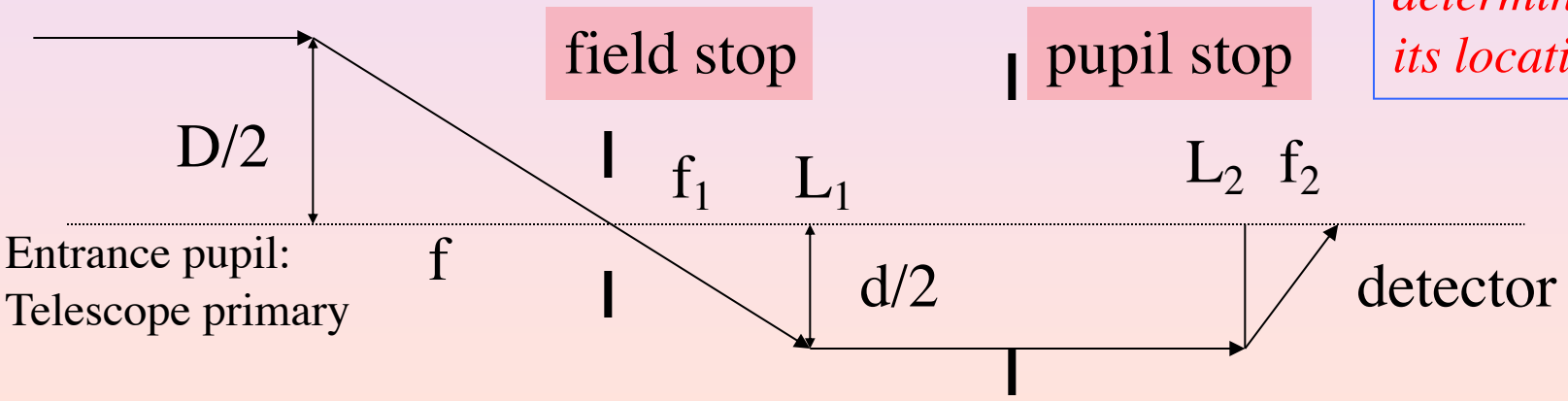
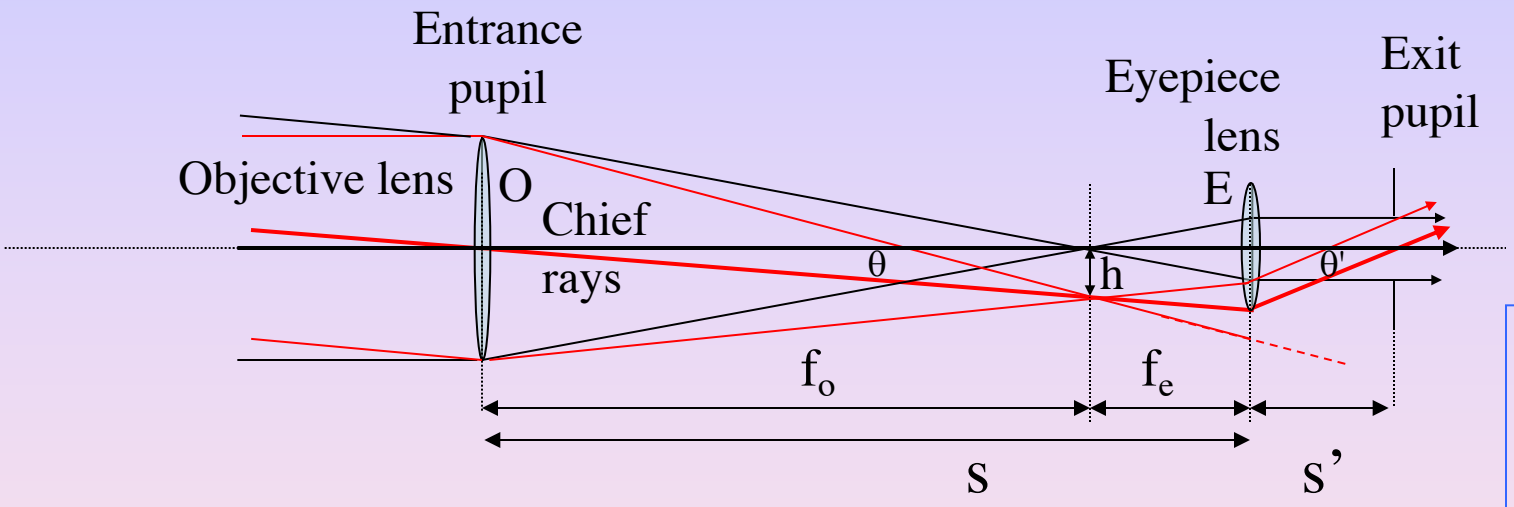


Pupils and layouts



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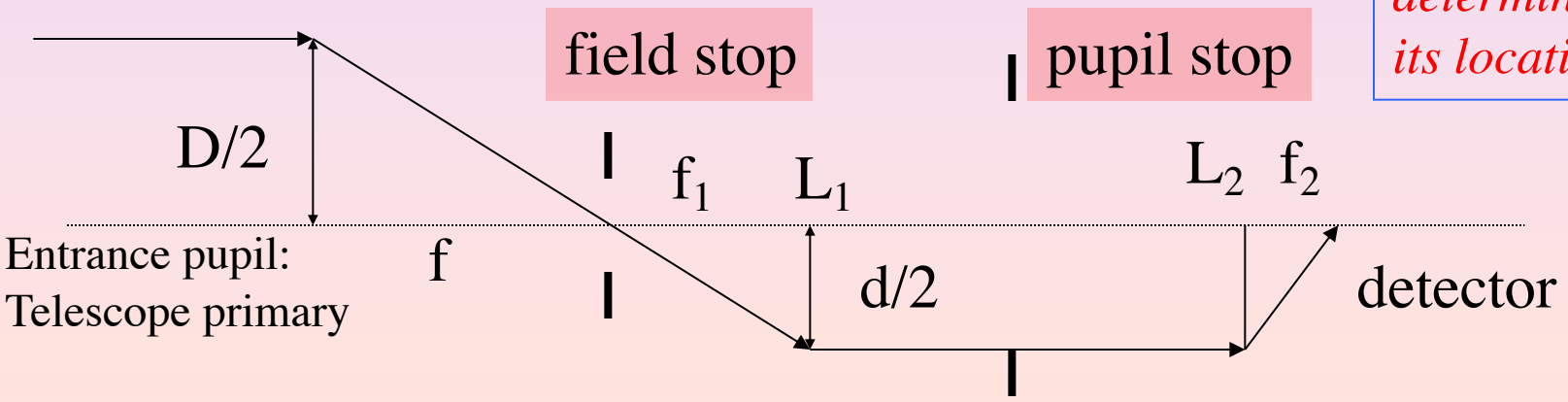
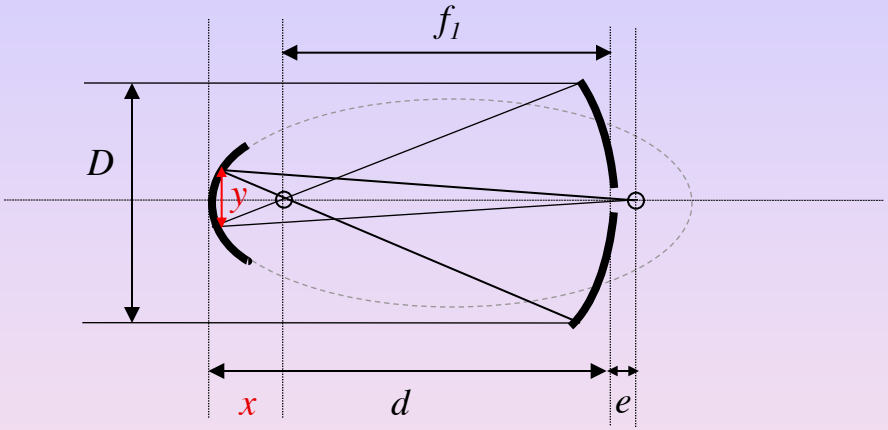


Review: Types of Telescopes

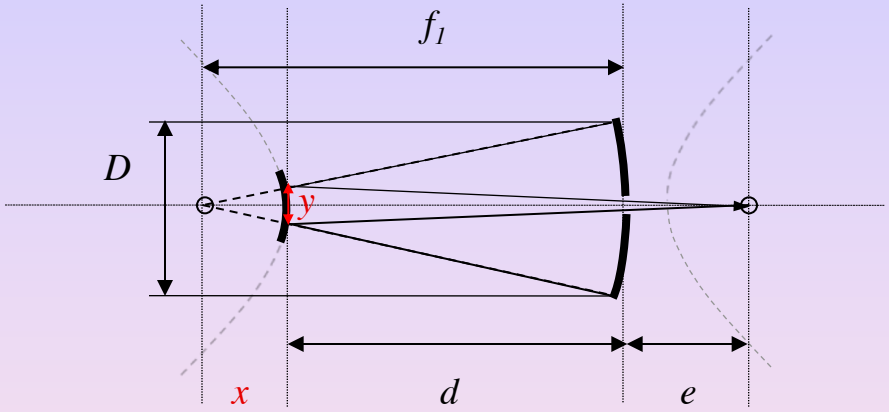
Category	Primary	Secondary	Corrector	Name	Principal Aberrations
Singlet lens	Spherical			refractor	spherical + chromatic
Singlet mirror	Paraboloid mirror			Newtonian	coma + astigmatism
Doublet mirrors	Paraboloid	Hyperbaloid		Cassegrain	coma
	Hyperbaloid	Hyperbaloid		Ritchey-Chertien (RC)	astigmatism (twice Cassegrain field)
	Parabaloid	Ellipsoid		Gregorian	field curvature
	Ellipsoid	Spherical		Dall-Kirkham	
	Ellipsoid	Ellipsoid		Aplonatic Gregorian (AG)	best images but large obstruction
Multiplets	Spherical		Aspheric lens or achromate doublet	Schmidt	v. wide field
	Spherical	Hyperbaloid	Aspheric lens	Schmidt-Cassegrain	"
	Spherical	Spherical	Spherical meniscus lens	Maksutov	"
	Spherical		4-mirror asphere	HET, SALT	Low cost

Two-mirror telescopes: Cassegrain focus

Gregorian (Aplonatic Gregorian)



Cassegrain (Ritchey-Cretien)



$$f\text{–}ratio \equiv f/D$$

Power: $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$

Focal scale: $s = 206265/(D \bullet f\text{–ratio})$ [arcsec/mm]

Back focal distance: $e = f - d\left(\frac{f}{f_1} + 1\right)$

Focal amplitude: $\Delta e = (1 + m^2)\Delta d, \quad m = f_1/f_2$

Exit pupil distance: $l = f_2 d/(f_2 - d)$

= distance behind secondary

Exit pupil diameter: $D_{pupil} = Dl/d$

Focal-plan curvature: $\frac{1}{R_{Cass}} = \frac{1}{f_1} + \frac{1}{f_2}$

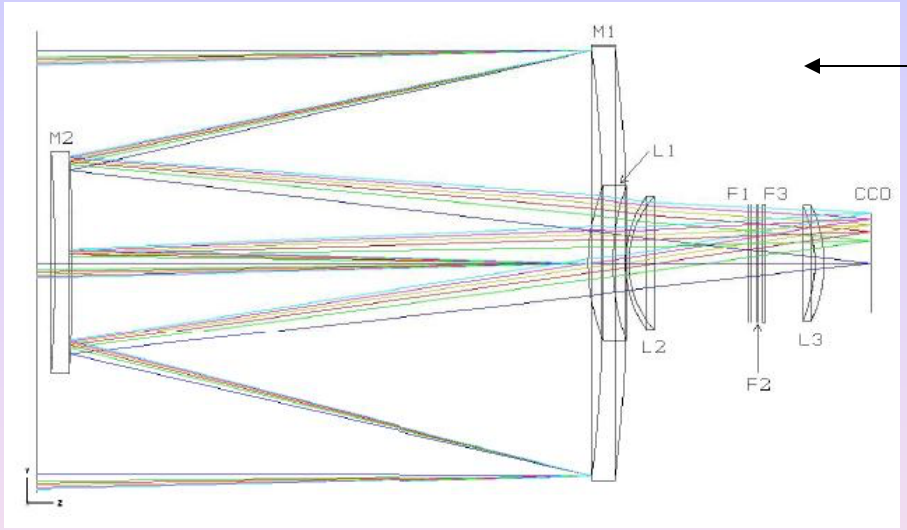
Information Gathering Power

Figure of Merit

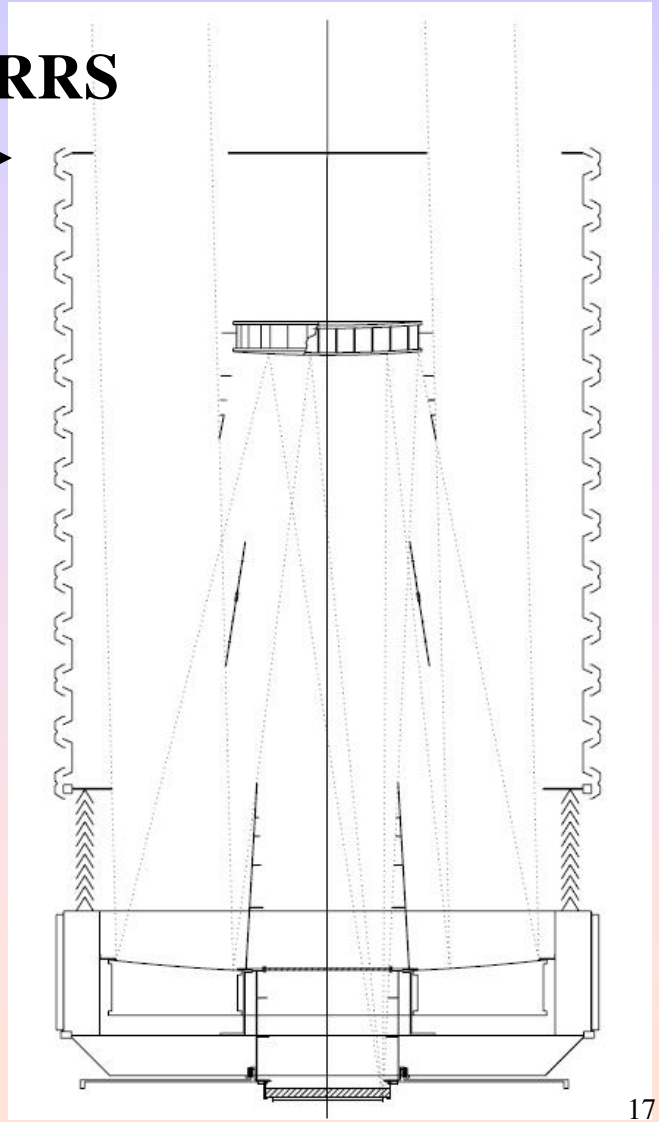
A Ω or etendue			
name	diameter	FoV	A Ω
	m	deg	m^2 deg^2
SDSS	2.5	3	35
CFHT	3.6	1	8.0
WIYN	3.5	1	7.6
PanStarrs	4x1.8	3	72
Subaru	8.1	0.2	1.6
LSST	8.4	3.5	533
SALT	10	0.13	1.0

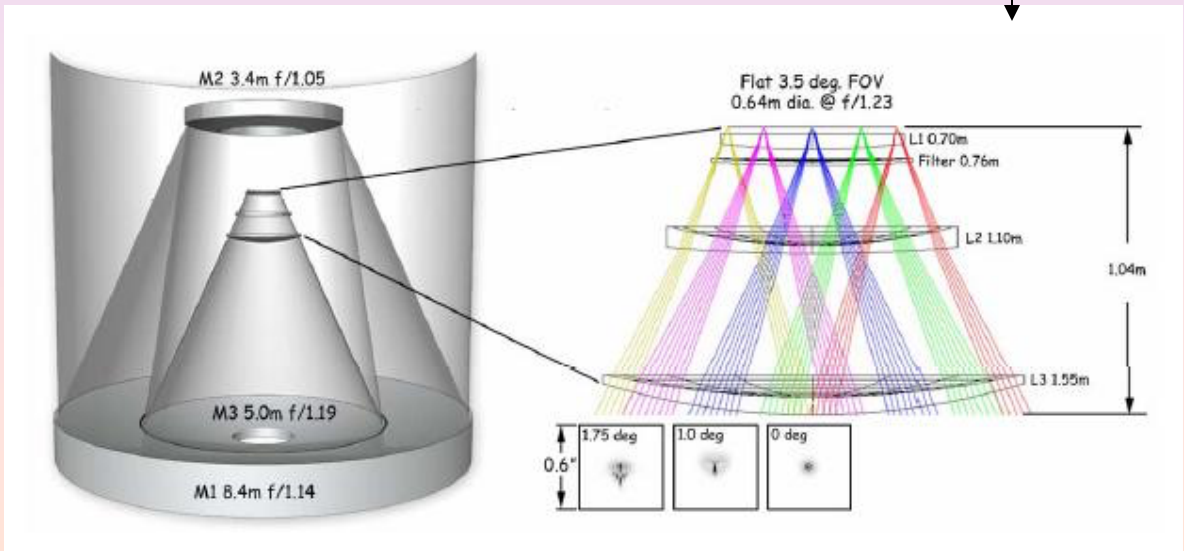
What's missing?

Wide-Field Telescopes: A vs Ω



Pan-STARRS
SDSS
LSST





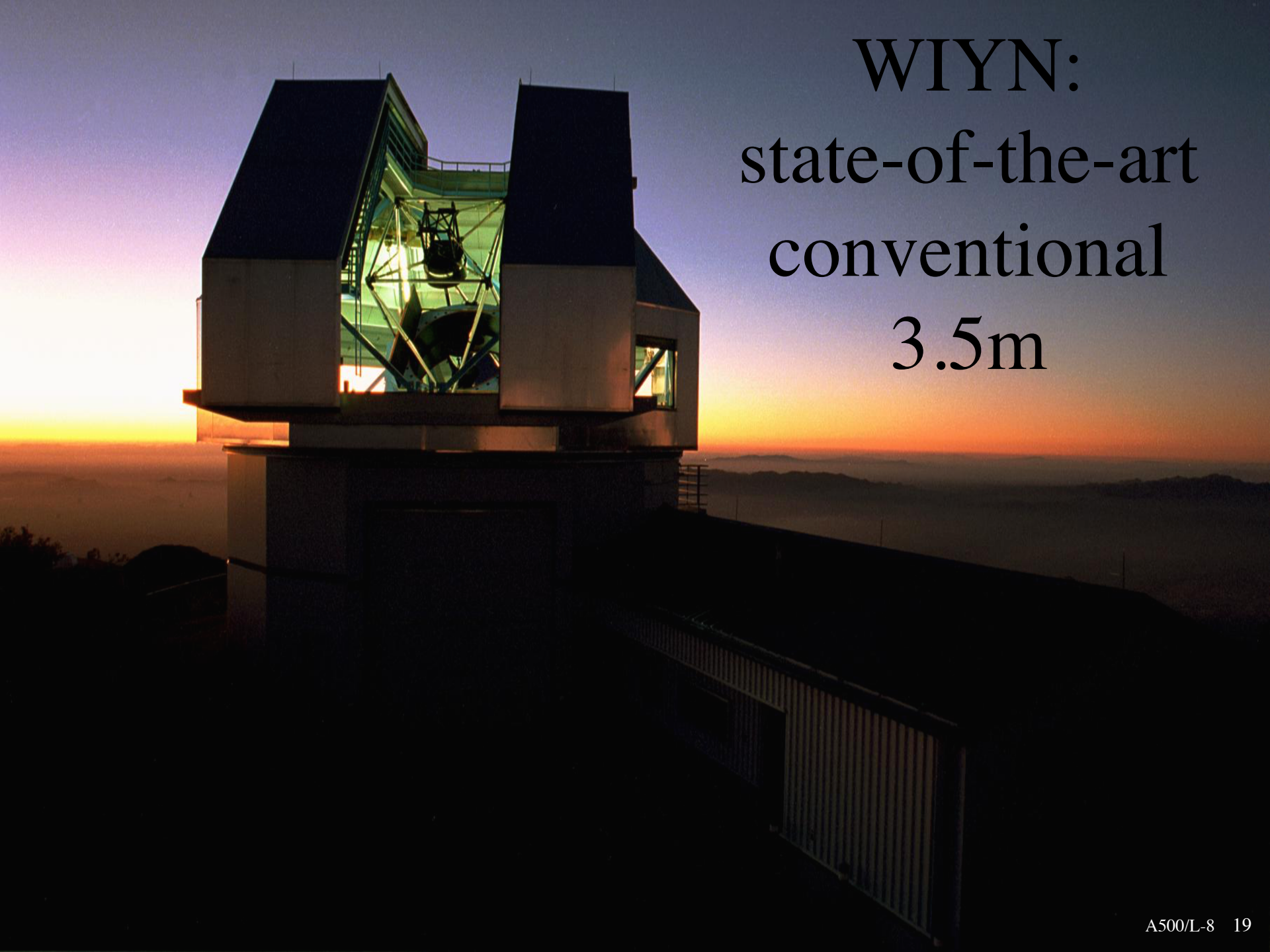
Information Gathering Power

A Ω or etendue			
name	Effective diameter	Used FoV	Survey A Ω
	m	deg	m^2 deg^2
SDSS	2.1	2.2	13
CFHT	3.4	1	7.1
WIYN	3.2	1	6.3
PanStarrs	3.0	3	50
Subaru	7.7	0.2	1.5
LSST	6.7	3.5	319
SALT	9.2	0.13	0.9

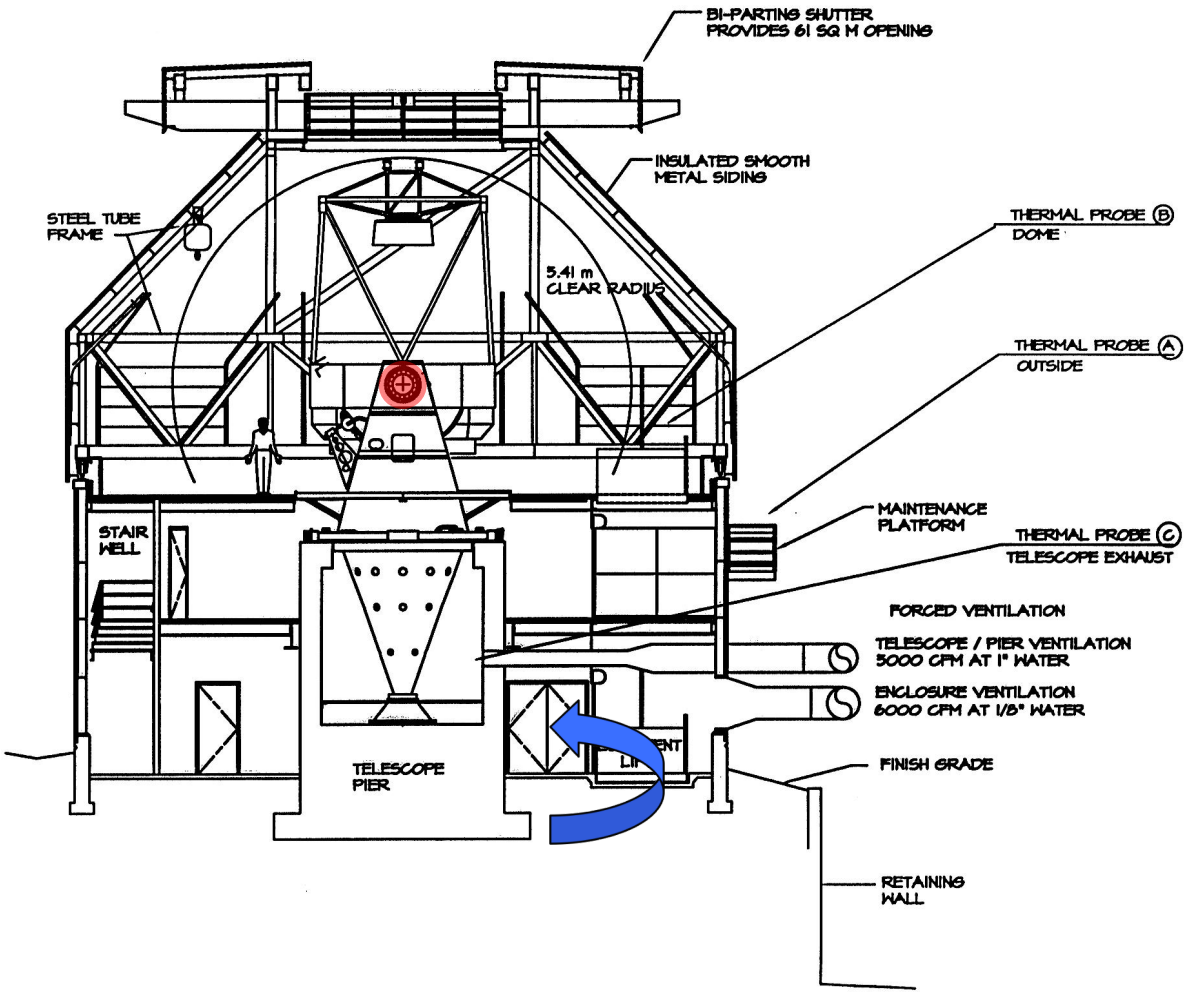
What's missing?

- **Obstructions**
- **Vignetting**
- **Instrument FoV**

…and what else?


WIYN:
state-of-the-art
conventional
3.5m

What is WIYN ?



RC optical design
Alt-Az mount
3.5m f/1.7505 primary
17% obstruction
f/6.289 Nasmyth
f/13.3 reimaged Cass.

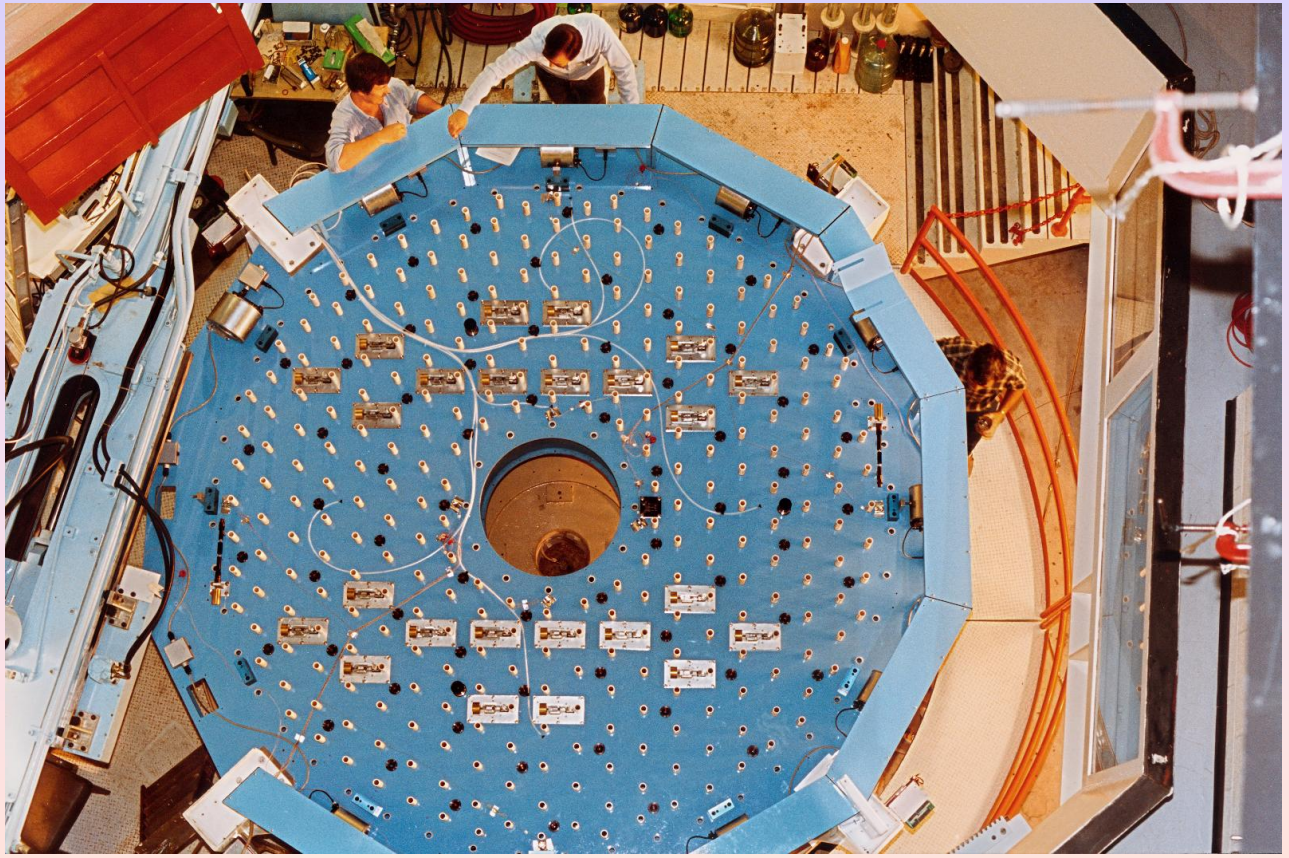
Nasmyth foci

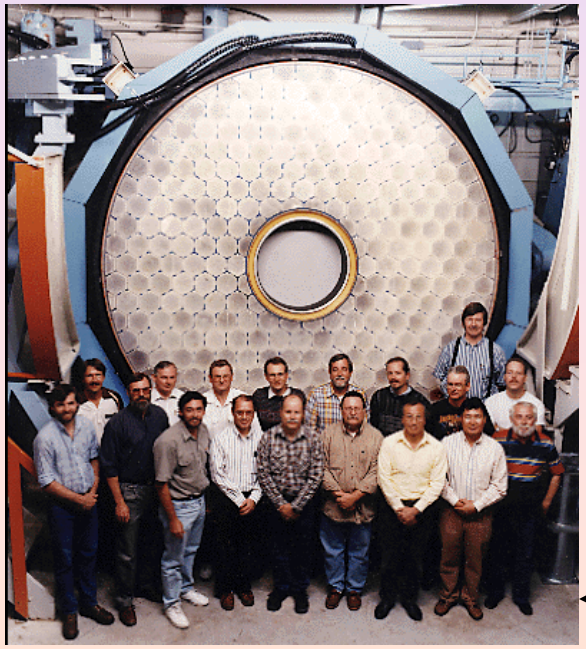
Bench
Spectrograph

Primary mirror

← Polishing

↓ Mirror cell and support

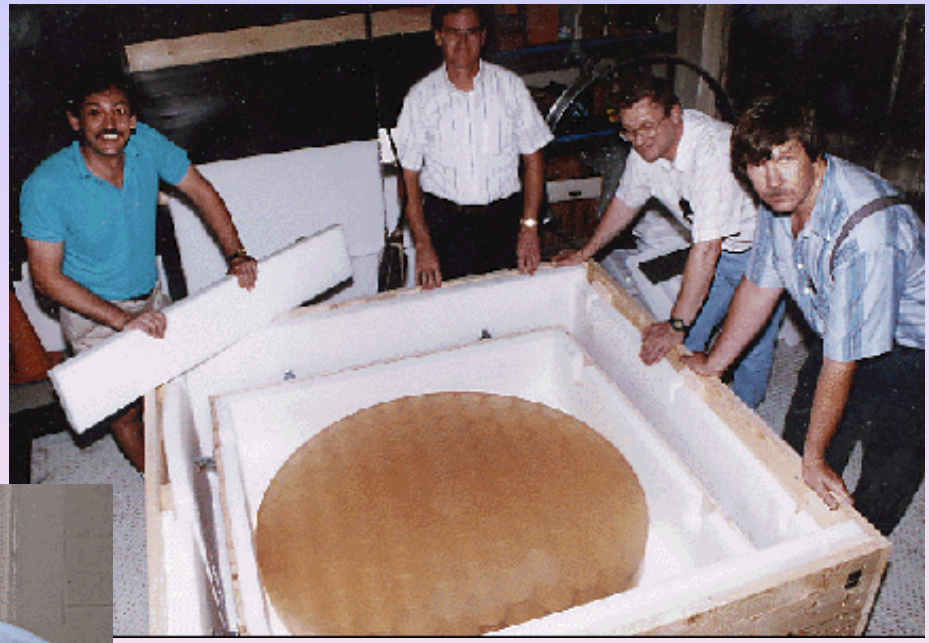


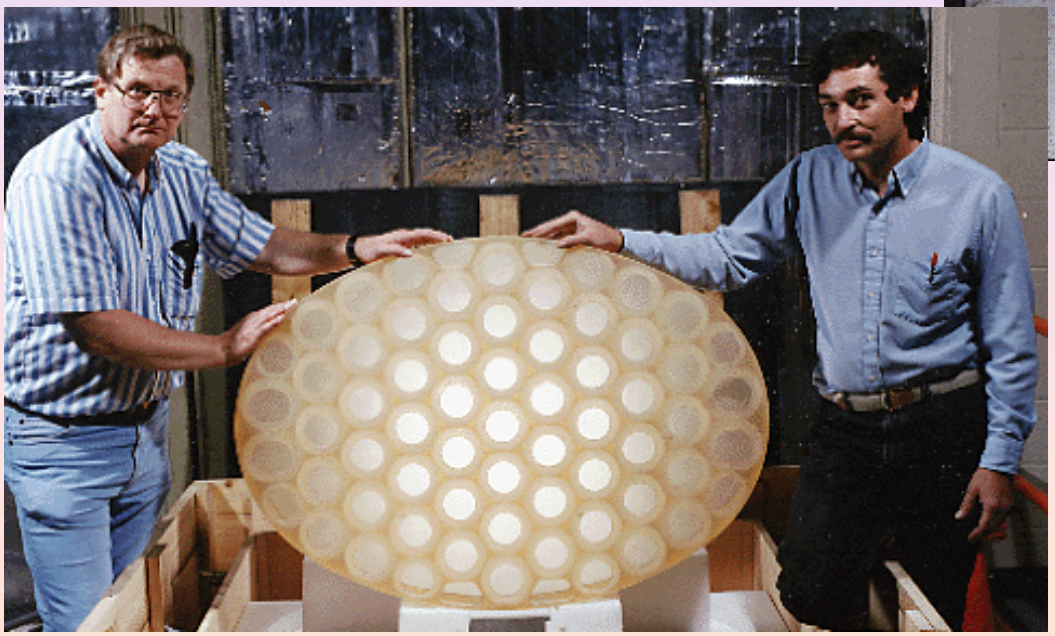


← Mirror installed in cell

M2 and M3

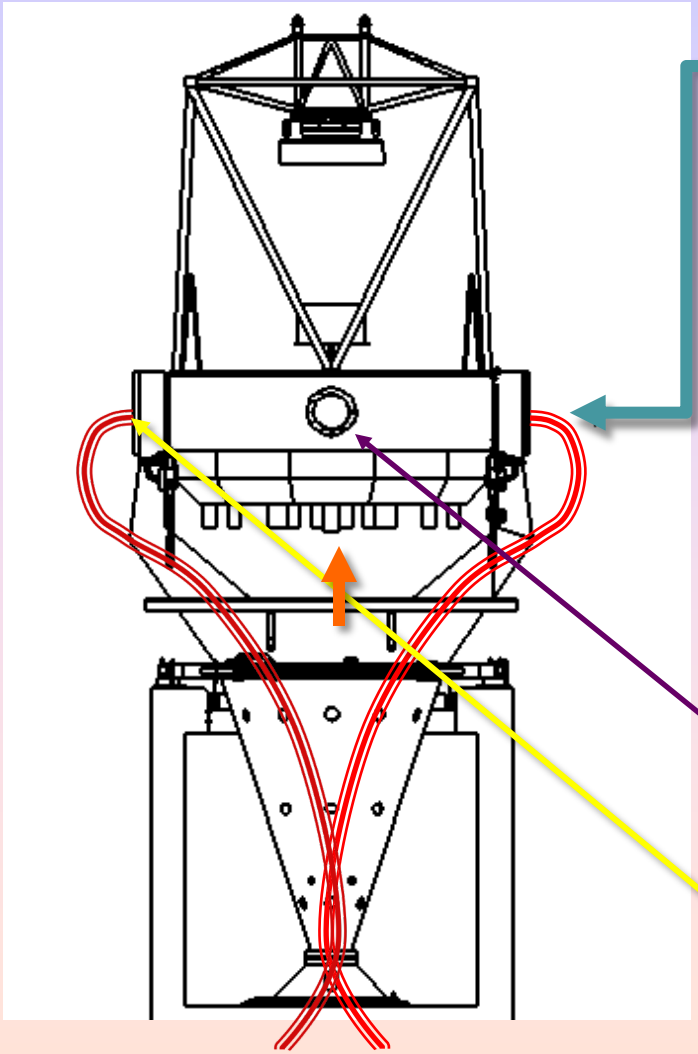
Secondary (m2)





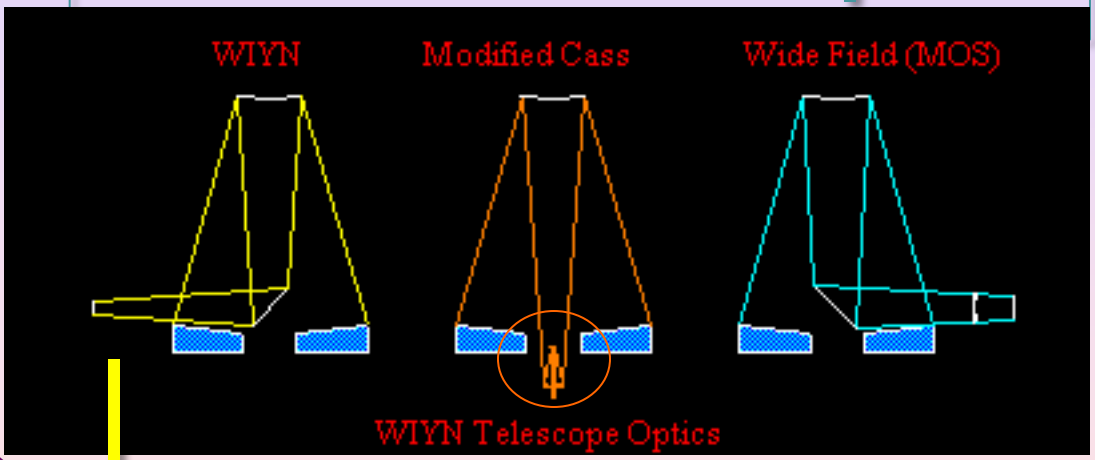
← Tertiary (m3)
fold-flat

Foci and instruments



Fiber cables to Bench Spectrograph

Today: Campaign mode
A - Corrector + Hydra
B - IAS plus its instruments
WHIRC(+WTTM), SparsePak, HexPak,▽Pak



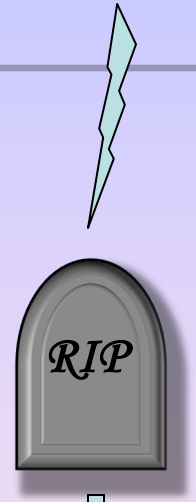
retired

New folded-Cass port for NEID

Today: ~ODI (plus new corrector)

Instruments

Hydra – ~100 fiber multi-object positioner (1 deg FoV)
~~DensePak – 90 fiber integral field unit (30” FoV)……..~~
SparsePak – 82 fiber integral field unit (1’ FoV)



Bench Spectrograph

HexPak, ▽Pak

Zombie spectroscopy

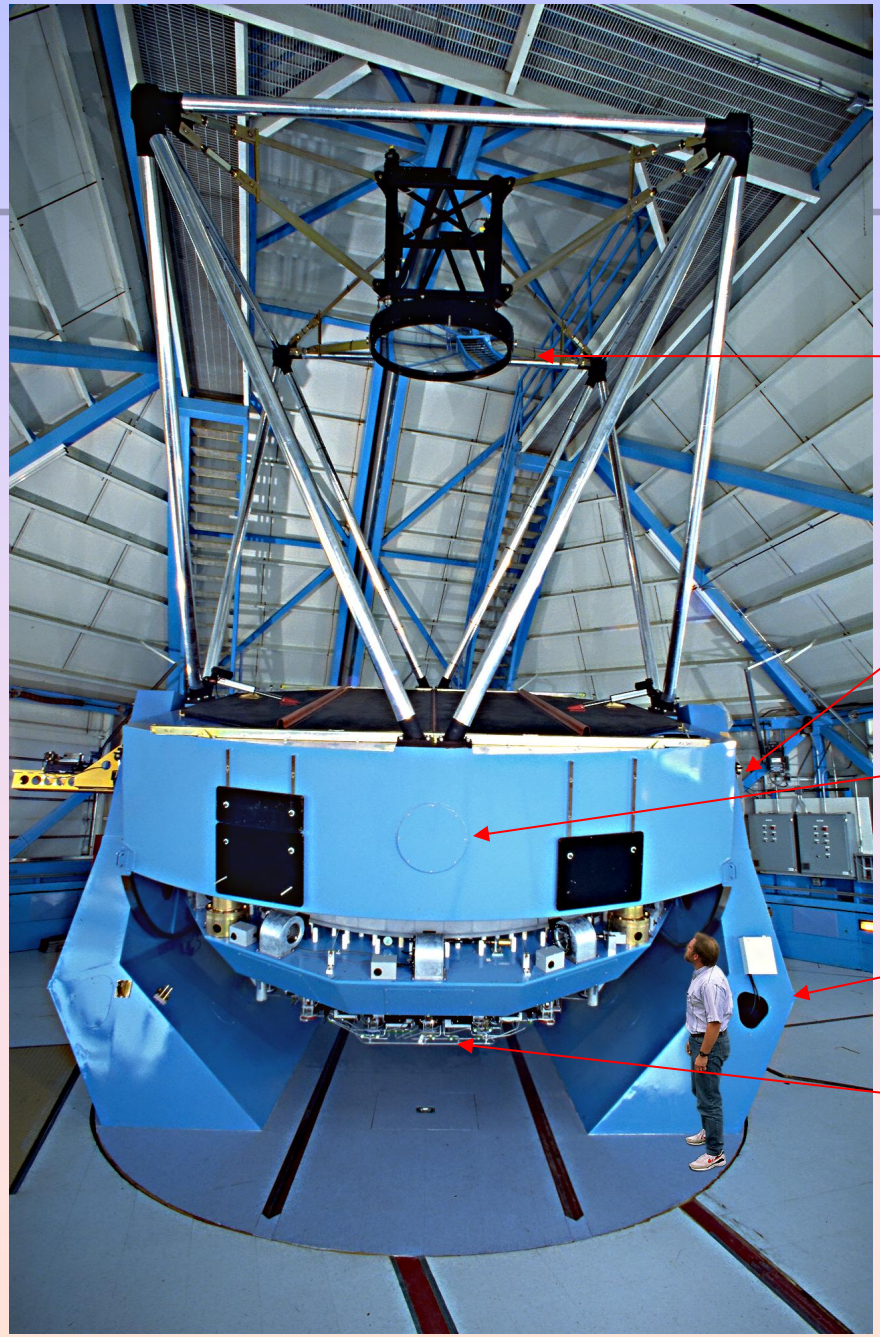
~~MiniMo – 4096^2 CCD imager (0.141” pix)~~
~~OPTIC – 4096^2 CCD imager (0.141” pix)~~
WHIRC – 2048^2 HgCdTe (NIR) imager (0.098” pix)
ODI – Giga-pixel OTA CCD, (<1 deg FoV) *gack*
Speckle camera called … ? (NESSI? Who what where???)

barely hanging on

2019

EPDS – extreme precision doppler spectrometer
NEID: shared risk 2020B

WIYN telescope



2ndary

Alt. baring and Nasmyth focus

folded-Cass port: under development

Az. fork

Reminaged Cass. port

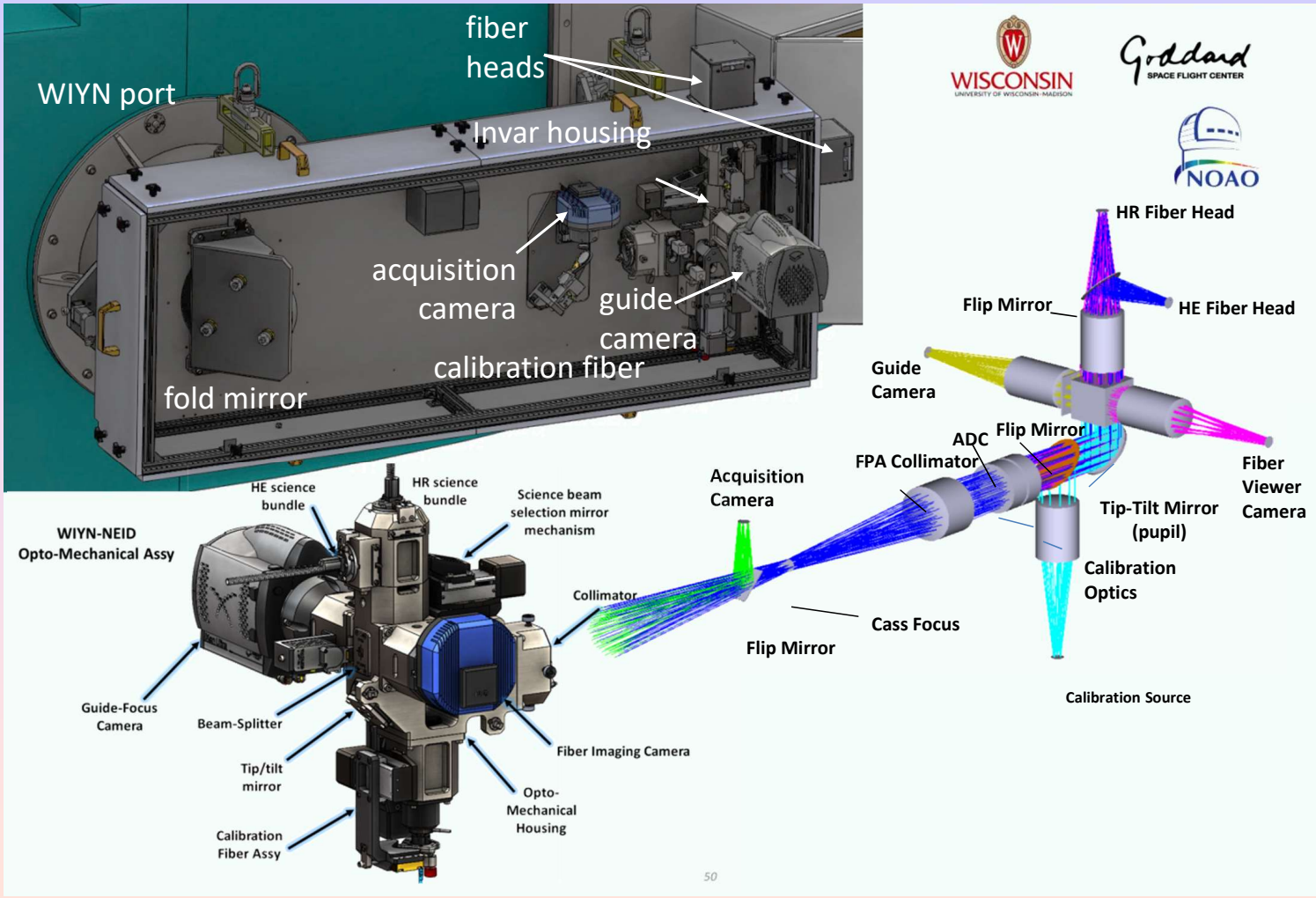
WIYN telescope

2ndary

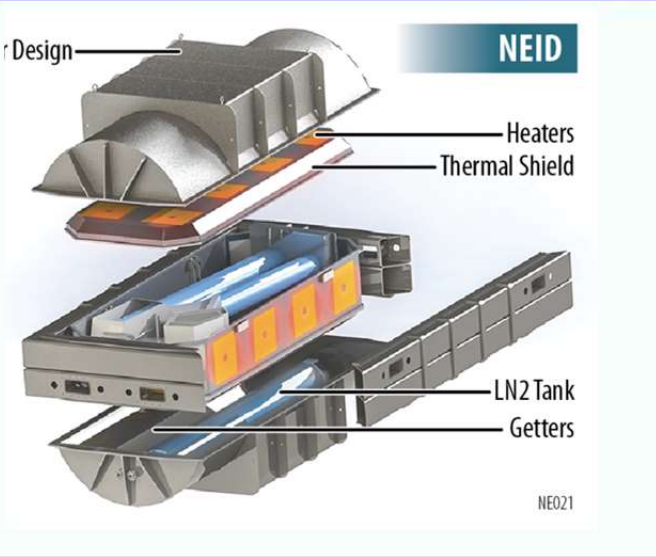
folded-Cass port: developed for NEID fiber feed

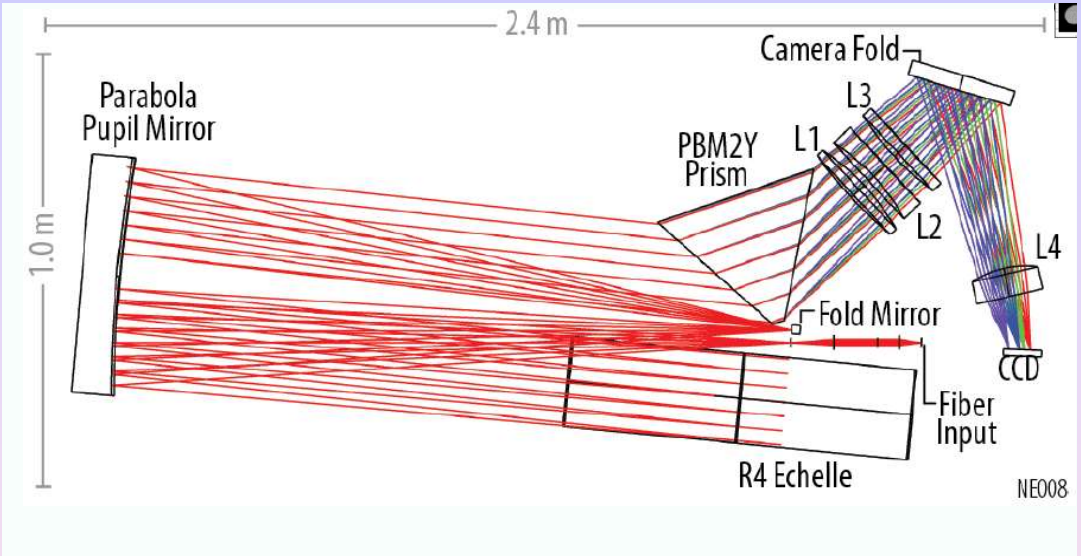
folded-Cass port: developed for NEID fiber feed

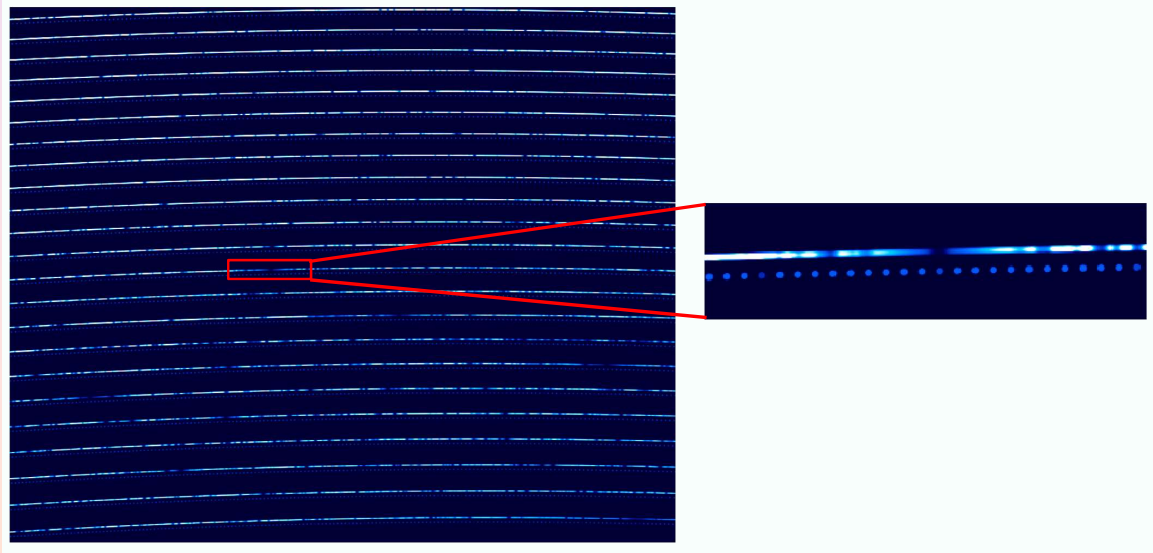
WIYN telescope



NEID spectrograph





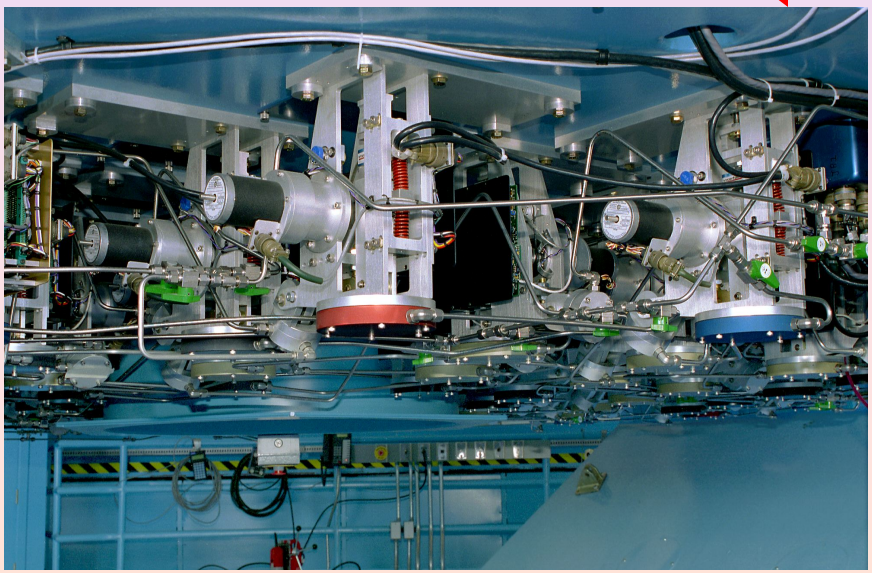


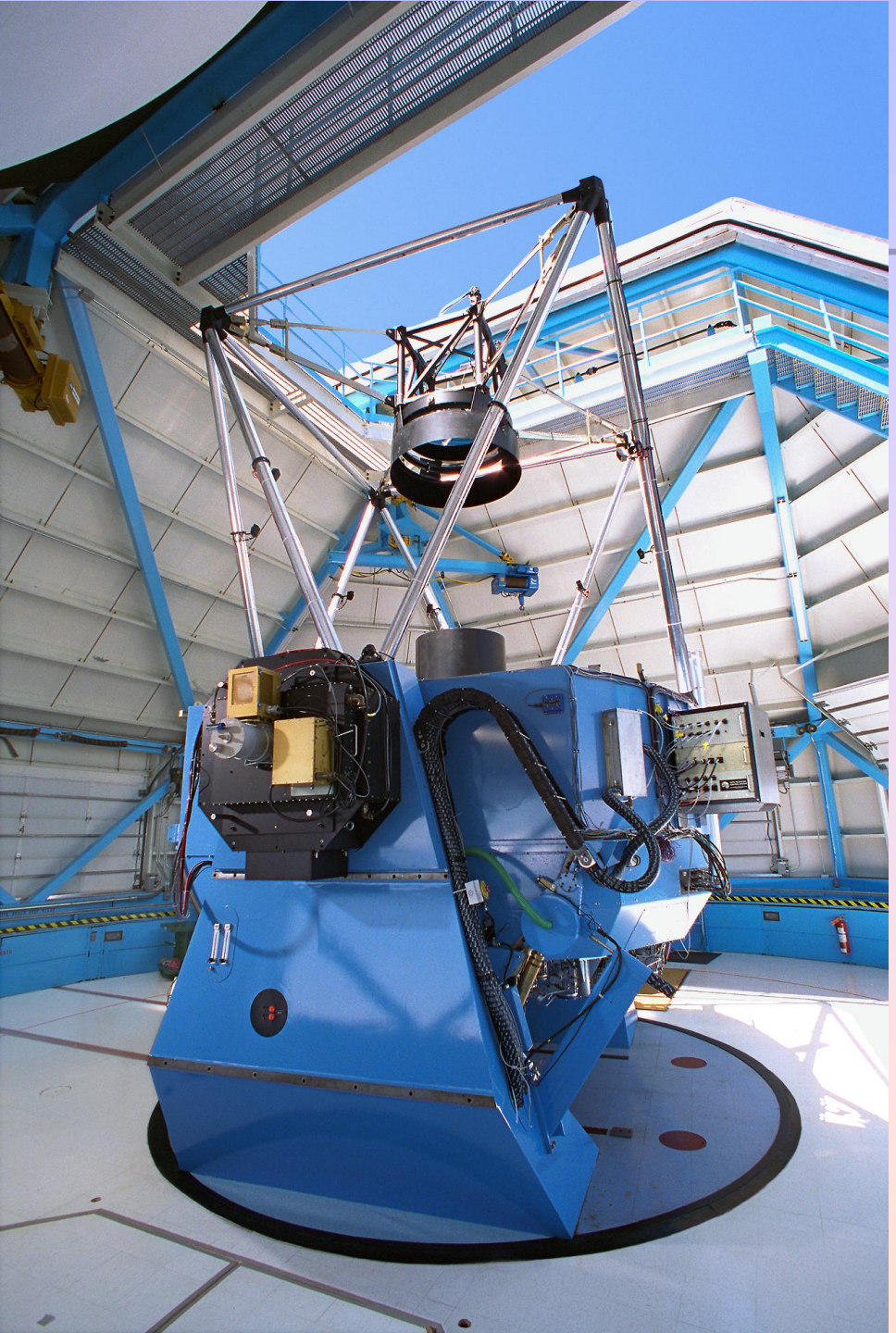
WIYN telescope

Hydra

Primary mirror thermal sensing and control (glycol) & active support sensing and control (actuators)

Reminaged Cass. port

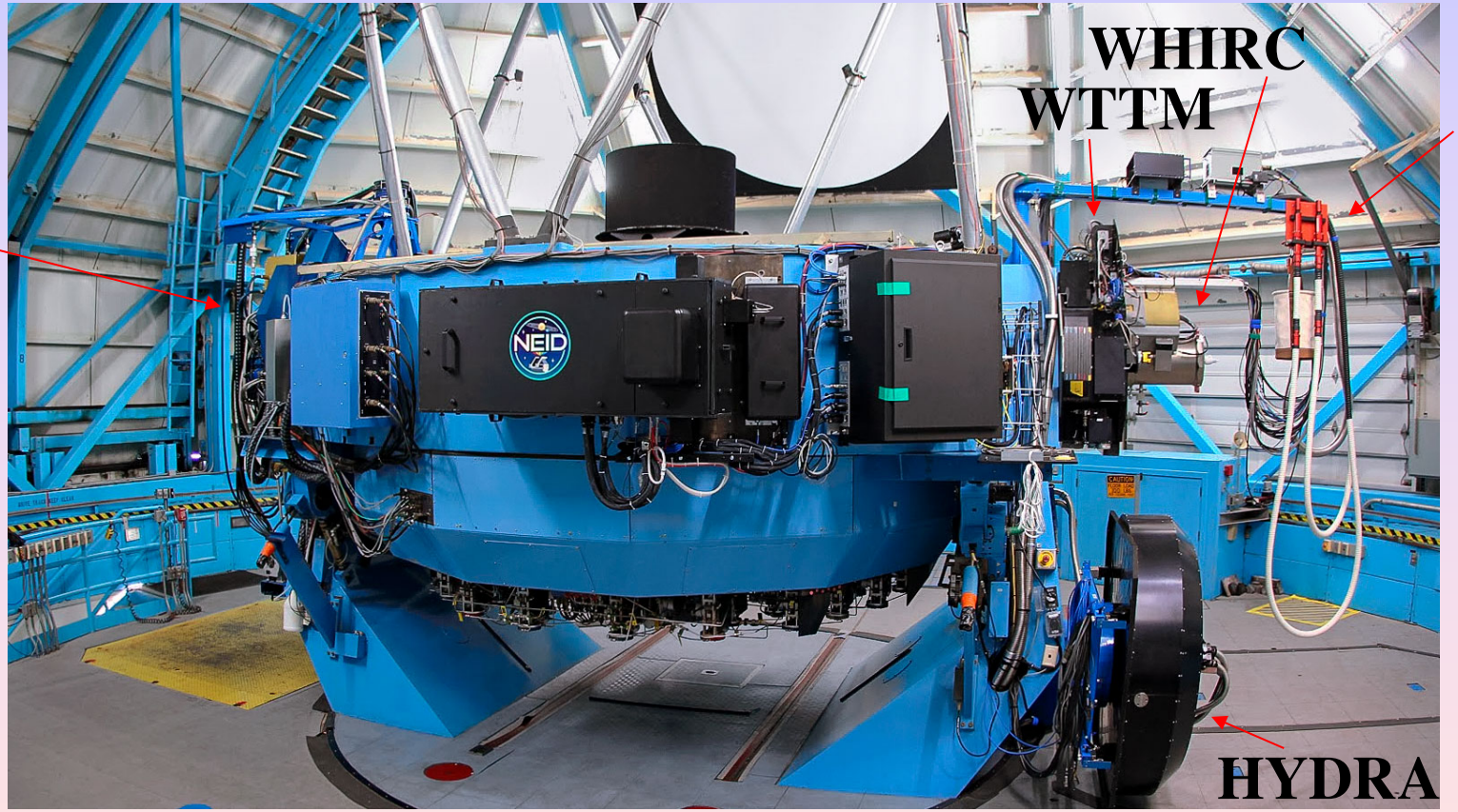




WIYN IAS

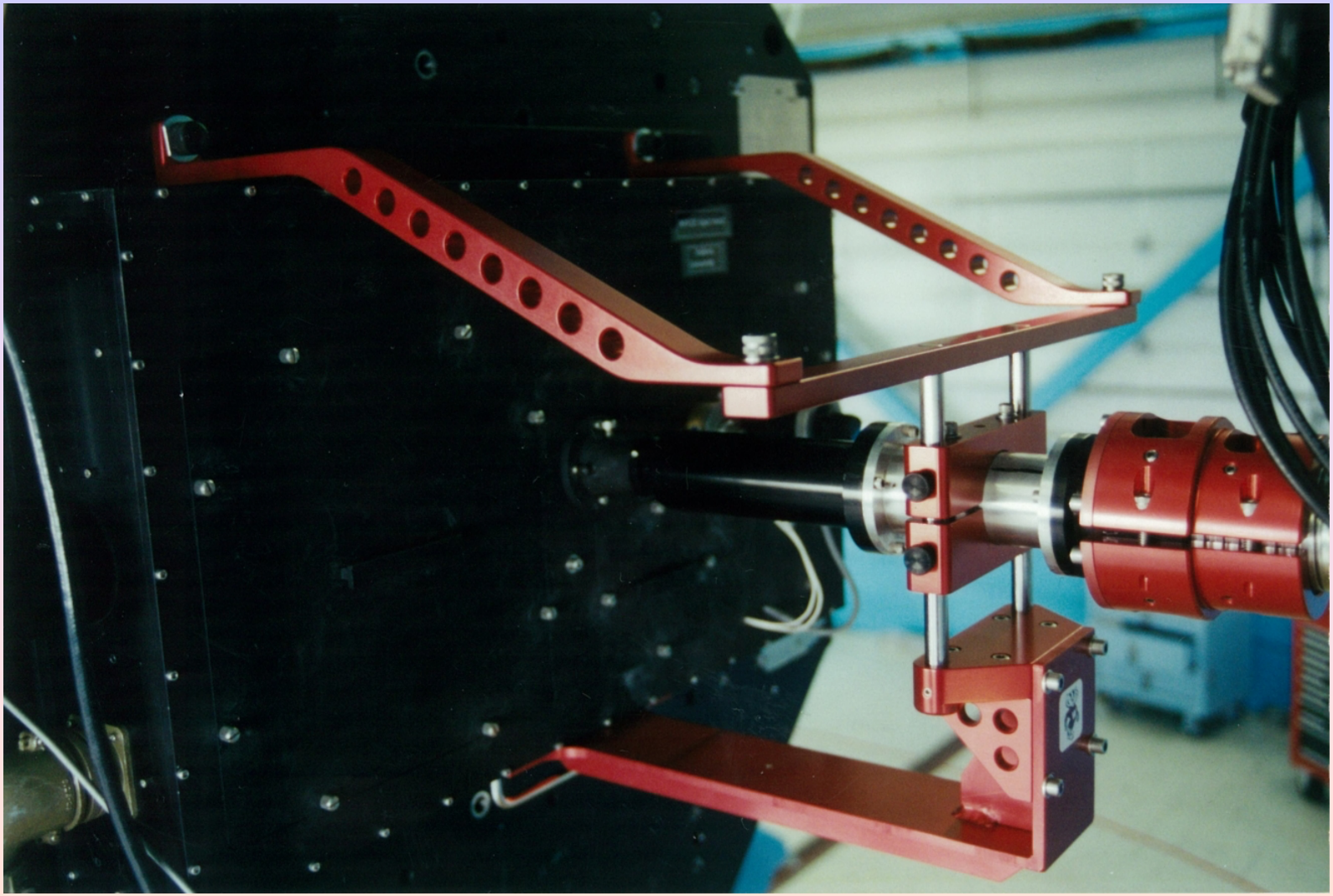
- ~~MiniMo~~ mounted
- Looks similar for ~~OPTIC~~ or **WHIRC**
- Only one camera can be mounted at at time, but SparsePak and WTTM + camera can be on simultaneously.

WIYN: Today's ports

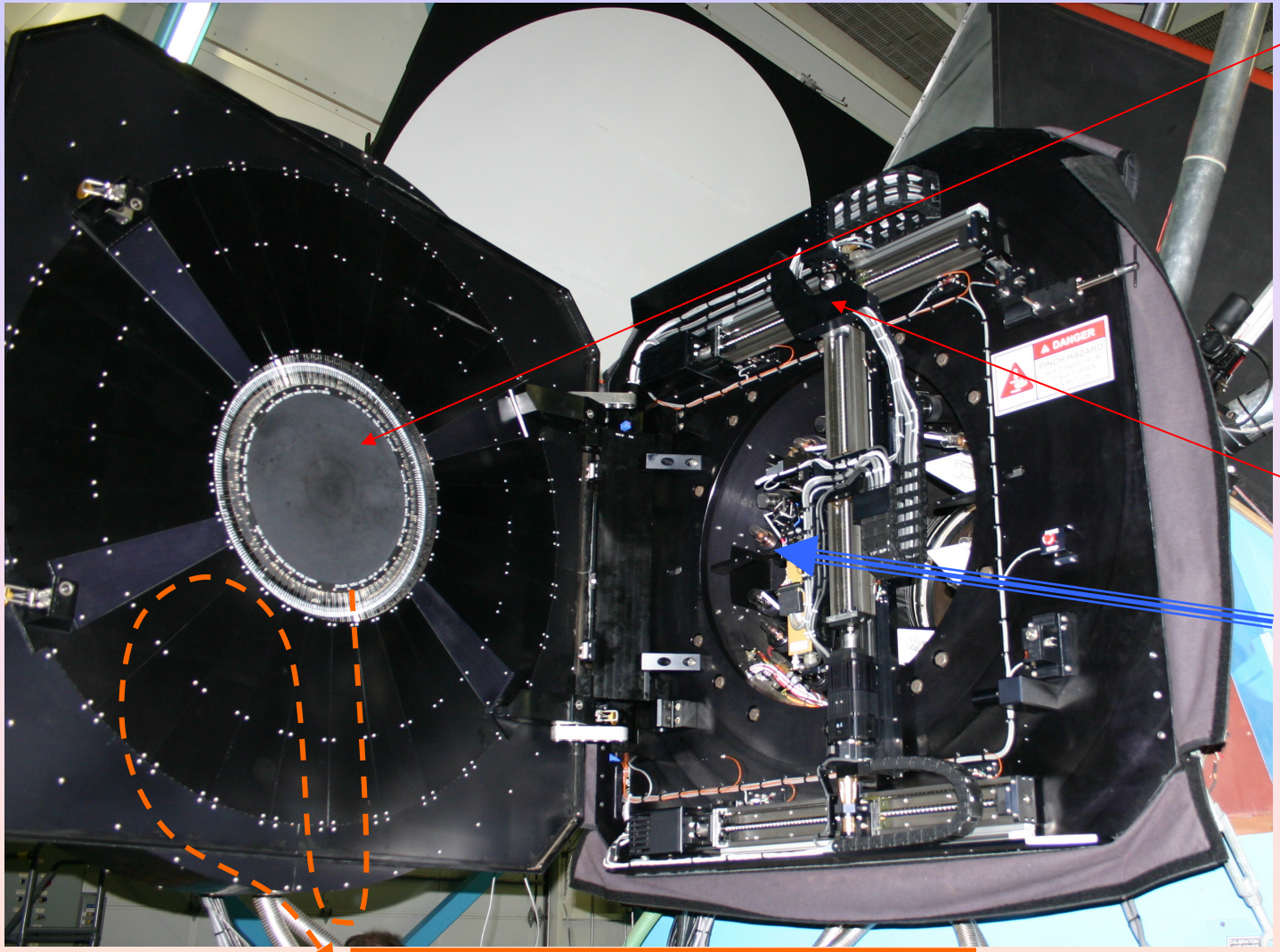


- Nasmyth port: ODI (dedicated); WHIRC + IFUs (HexPak, GradPak, SparsePak) on IAS *or* Hydra (swappable in campaign mode)
- Folded Cass: NEID fiber feed (dedicated)

WIYN IAS + SparsePak



MOS port with Hydra



1 deg warping steel plate for magnetic fiber buttons: positioning and telecentricity

Gripper/ positioner

photons

Fibers to Bench Spectrograph

(old) Bench Spectrograph