calibration

The process of determining the performance parameters of an artifact, instrument, or system by comparing it with measurement standards.

Adjustment may be a part of a calibration, but not necessarily.

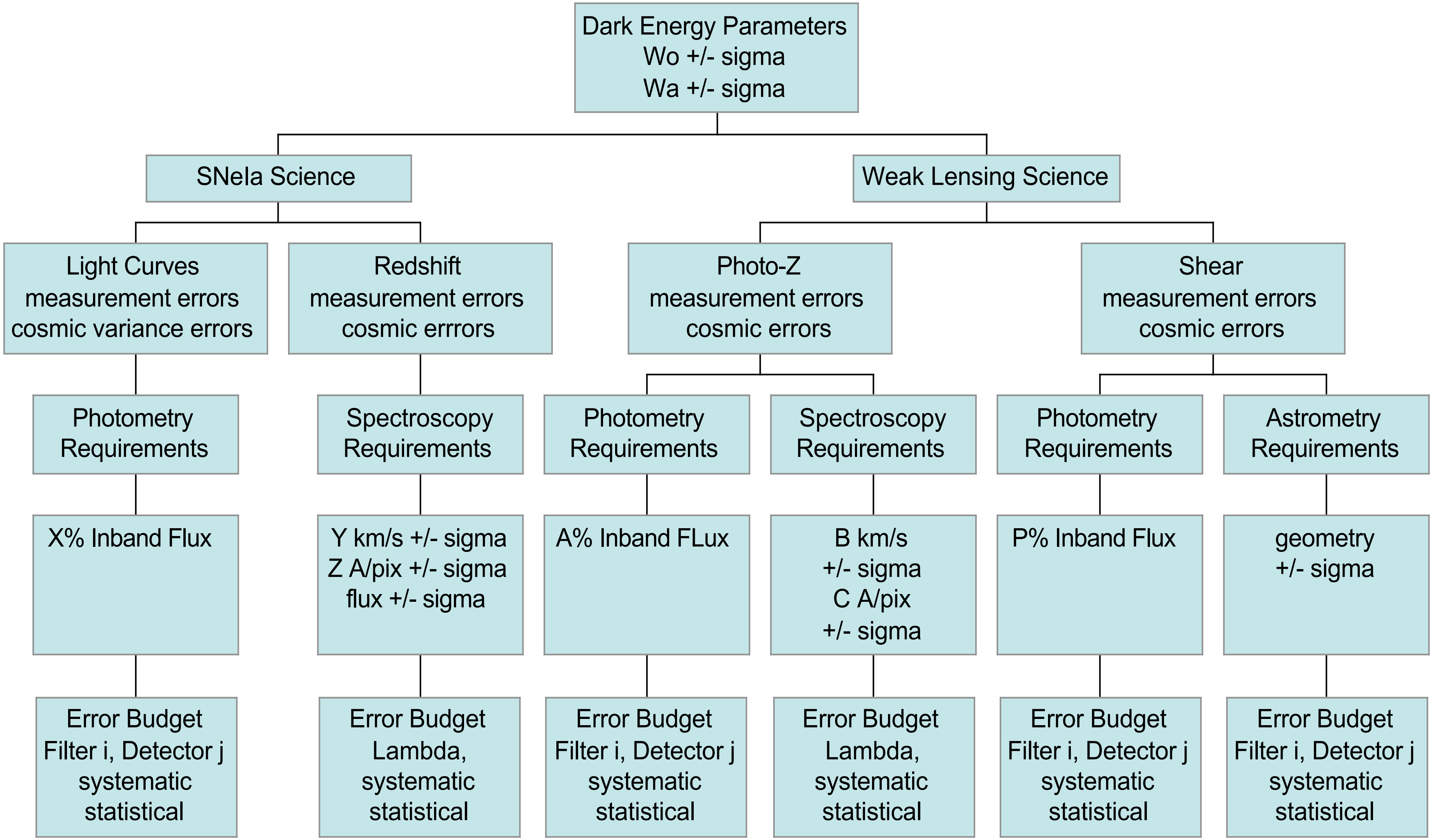
A calibration assures that a device or system will produce results which meet or exceed some defined criteria with a specified degree of confidence.

JDEM Reference Mission

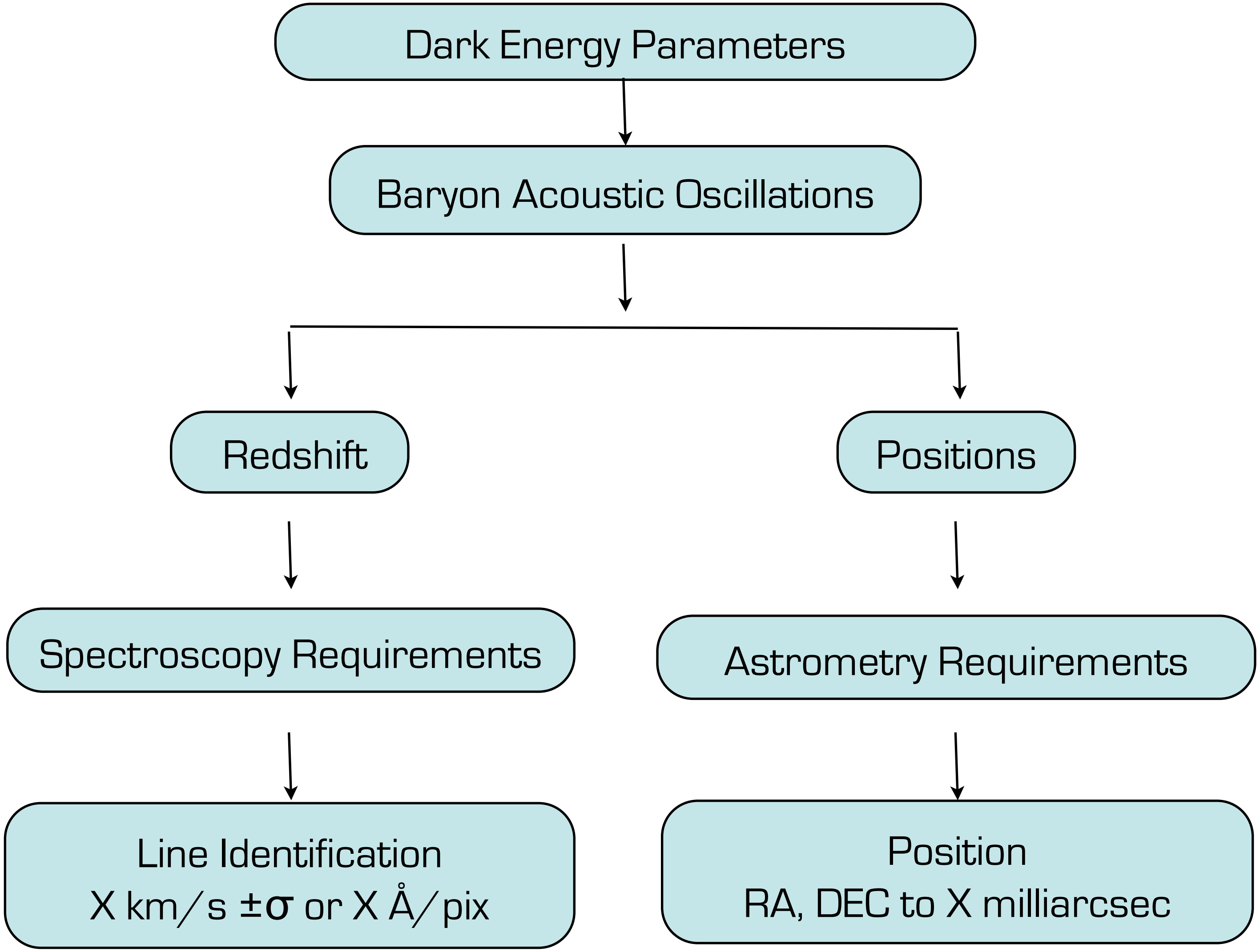
4 observing channels

* 2 spectrometers
    * Prism, MCT detectors
* Imager, Dichroic split
    * UVIS, CCD detectors
    * NIR, MCT detectors

Science Measurement Uncertainties



Science Measurement Uncertainties



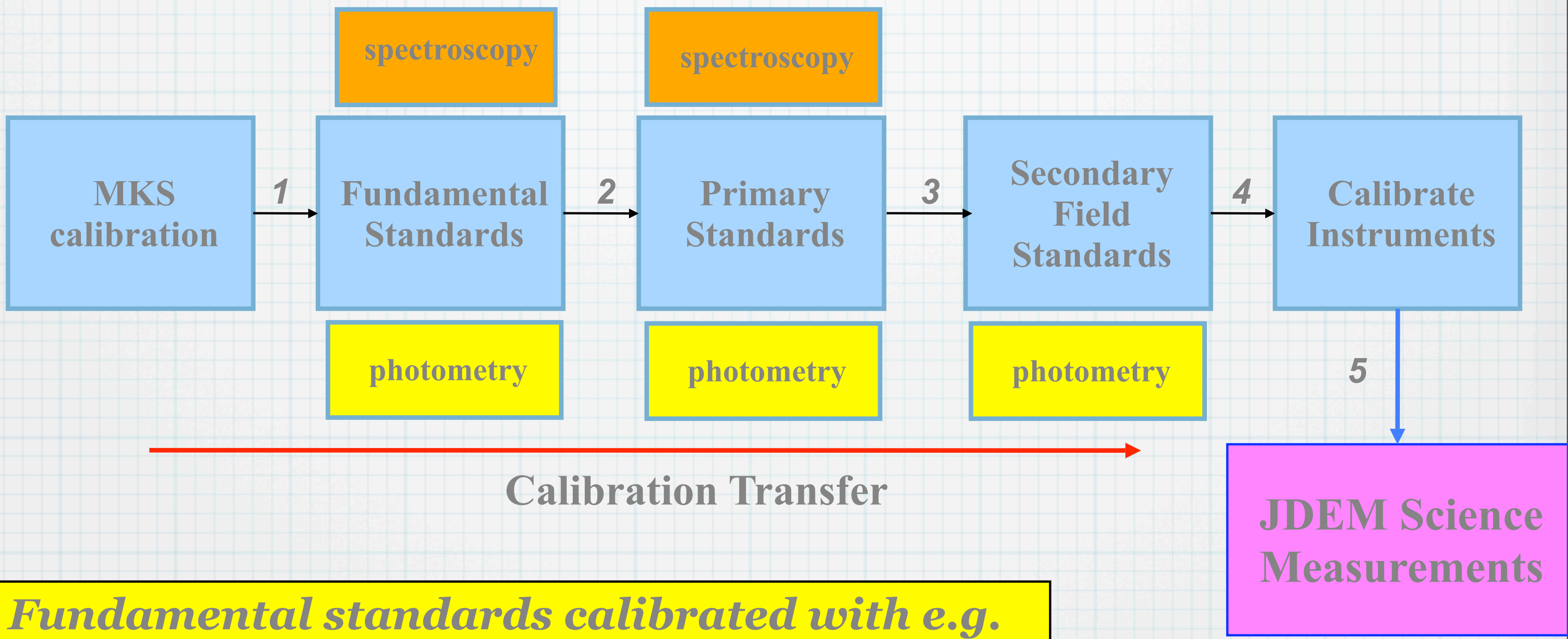
Calibration Roadmap

* Establish Science Requirements
* Flow down to Calibration Requirements
* Construct Calibration Error Budget
* Design Calibration Hardware:
    * In flight
    * Ground stimulus

Calibration Roadmap

* Identify good calibration standards
* Establish standard star network
* Develop in-orbit calibration strategies
* Design spectrophotometric calibration experiment
* Develop on-board calibration observing program
  * Cruise phase
  * Commissioning
  * Operational
* Determine impact of on-board calibration on
  * observatory management
  * observing strategy
  * observatory design

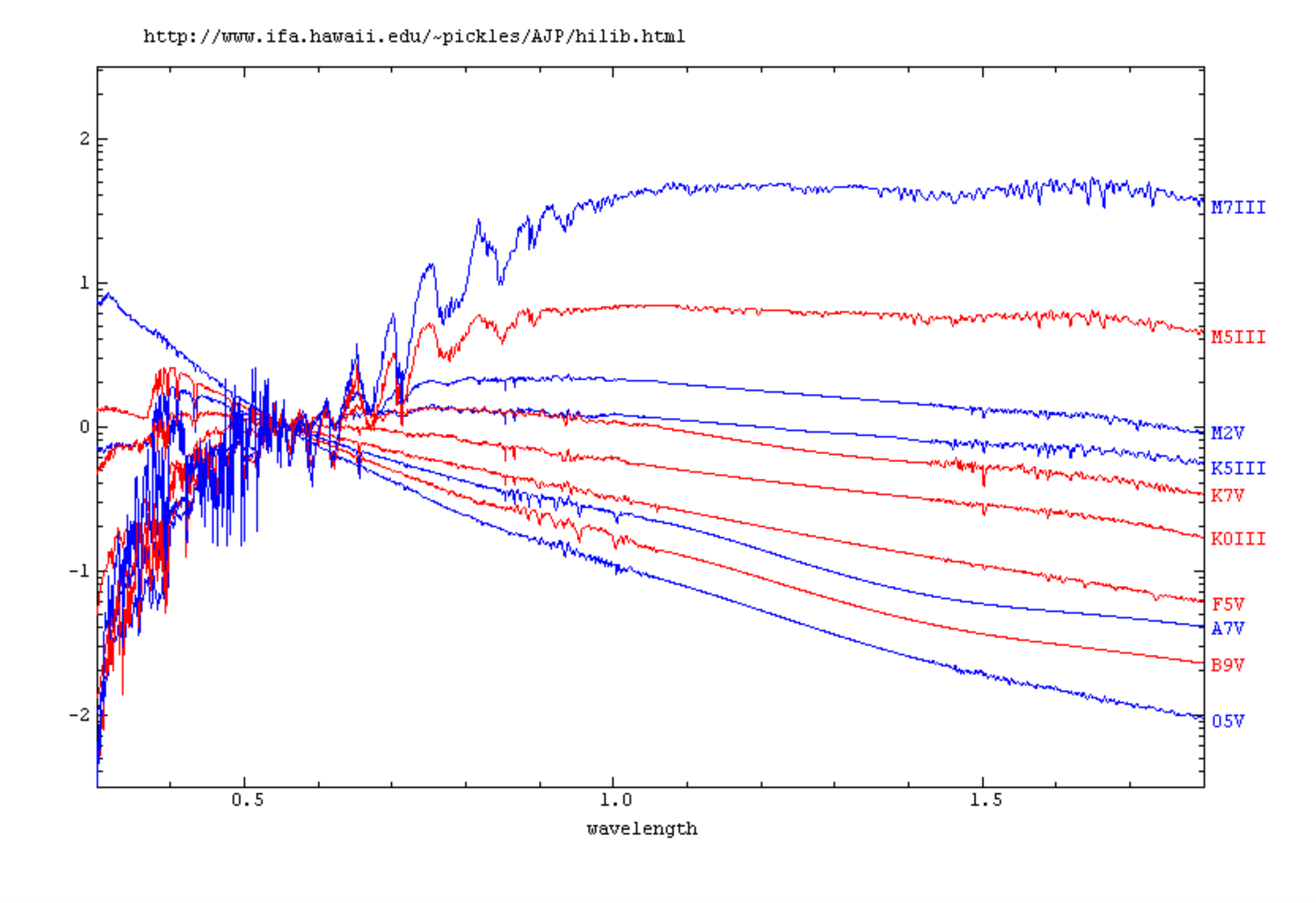
Steps to Spectrophotometric Calibration



Fundamental standards calibrated with e.g. ACCESS, calibration transferred to primary and secondary standards, which calibrate instruments.
=>Results in well calibrated spectrograph and imager

Primary Standard

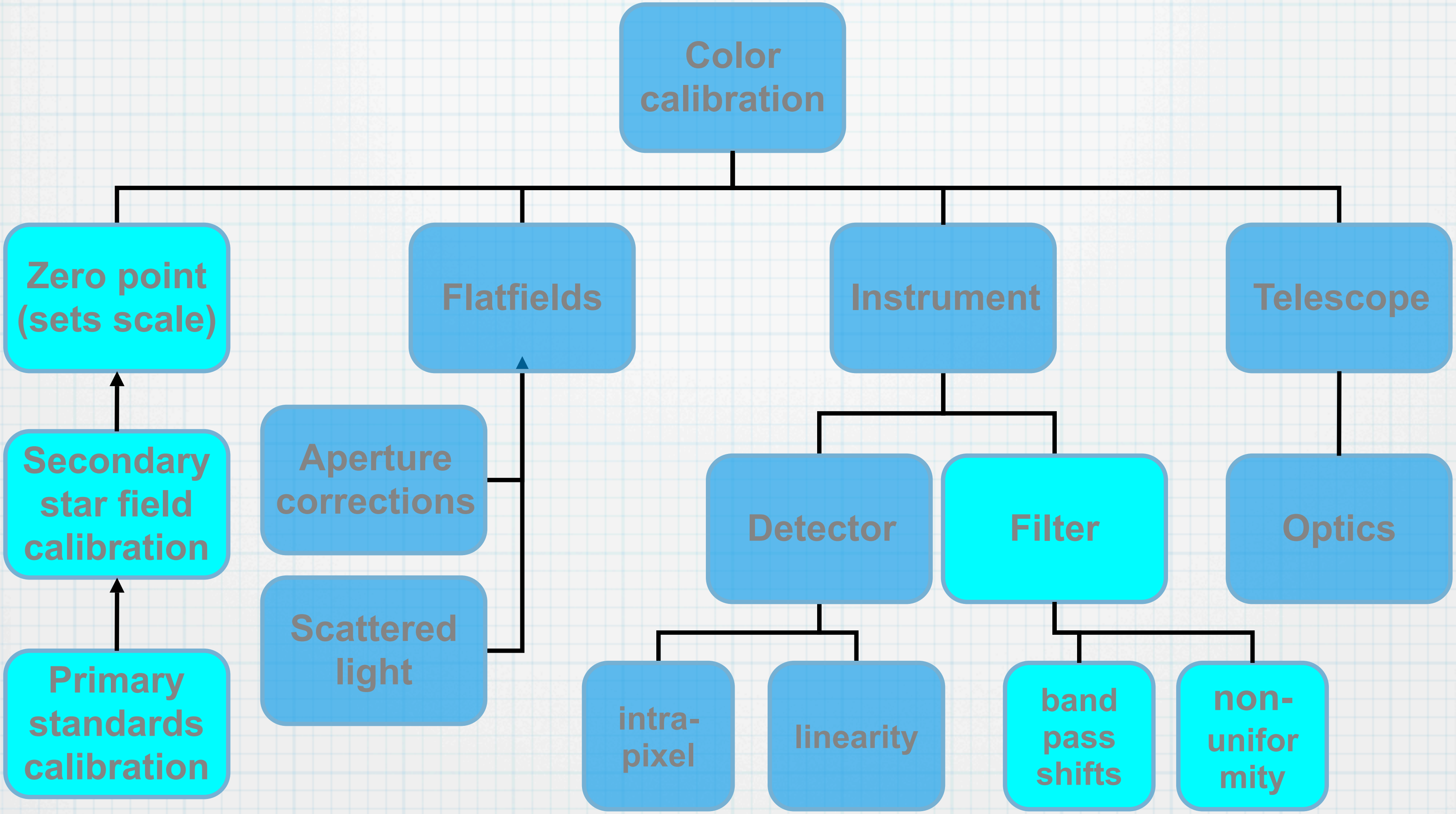
Normalized to 0.6 micron.



"Lampton 10/ Richmond 8" V=16-19 mag

- Full range of stellar spectral classes (O-M) - multiple colors
- include WD and SA Primary Standards
- Establish pre-launch

Photometric Calibration Error Budget Framework



How do calibration transfer errors propagate down the network?
How well can imagers (prism, filters) be calibrated?

Example Imager Calibration Error Budget

	Uncertainty					
Source of Uncertainty	**Goal**	**Requirement**	**Maximum Uncertainty**	**Reference**	**4x300 sec exposures**	**limits on the error**
Accuracy of flat field calibration	0.005	0.01		lab	0.0100	statistical
Stability of flat field calibration	0.01	0.01		lab	0.0200	statistical
Repeatability of the spectrophotometric calibration	0.01	0.01		simulation	0.01	statistical
Accuracy of the spectrophotometric calibration	0.014	0.01		simulation	0.01	systematic
				total	0.024	
Total (quadratic sum)	0.021	0.020				
Requirement (rms)	0.02	0.02		science		
Contingency or Margin (rms)						

Flat Fielding Uncertainties	**0.010**					systematic
Steps in Flatfielding	Uncertainties in each step					
Subtract Bias	0.001		0.003			
Subtract Dark	0.001		0.003			
Average 7 frames for each flat	0.004		0.011			
Uniformity						systematic
interpixel variation %	0.005		0.006	lab		
intrapixel variation %	0.005		0.006	lab		
linearity %	0.005		0.005	lab		
total	0.009		0.010			
Detector Errors						
bias subtraction (percentage)	0.001			experience/simulaiton	0.002	systematic
dark subtraction (percentage)	0.001			at T = 140 K, 0.00056 electron per pixel per sec	0.002	systematic
flat fielding (percentage)	0.01			informed simulation	0	systematic
read noise (electrons)	0	2			4	
read noise(ADU)	0	1.429			2.857	
cosmic ray hits	0	0		estimate, pre flight,	?	statistical
gain (electron/ADU)		1.4		measure		
point spread function (microns)	4	0		simulation/measure		systematic
Point spread function (percent)	0.03					

Example Calib PLAN based on SNAP Concept

Test	Target	Requirement	Exp. Time	Readout	Repeat /Dither	#fields	#Slews	# Det	Obs. Time hours
IMAGER									
Absolute Astrometry	Deep Field	(1.5”)	1	30	4	10	0	1	**0.3**
Absolute Flux, Imager	WD stars	0.30%	1	30	4	24	4	1	**1.8**
Geometry	Deep Field	1.00E-004	0	0	4	0	0	1	**0.0**
PSF	High Density	.01”	1	30	4	1	2	1	**0.5**
	Pocket Pump		0	30	4	1	0	1	**0.0**
FIlter+Detector Bandpass	R.O.F	0.07%	30	30	4	720	0	1	**48.0**
PFLAT - CCD	R.O.F	0.10%	30	30	20	1	0	1	**0.3**
PFLAT - MCT	R.O.F.	0.10%	30	30	20	1	0	1	**0.3**
LFLAT - CCD	High Density	TBD%	100	30	4	900	2	1	**130.5**
LFLAT - MCT	High Density	TBD%	100	30	4	900	2	1	**130.5**
Linearity	R.O.F	0.10%	30	30	20	1	0	1	**0.3**
	R.O.F.	0.10%	30	30	20	1	0	1	**0.3**
Dark	None	0.10%	200	30	10	1	0	1	**0.6**
Read noise/Bias	None	0.10%	0	30	10	1	0	1	**0.1**
Fringing	R.O.F.	1.00%	None - use PFLAT-CCD						
CTE	High Density	0.1”	None - use same as PSF						
Persistence									
Bad Pixel Maps									
Gain									
EE									
SPECTROGRAPH									
Spectro Flatfield/Linearity	R.O.F.	0.50%	10	0.1	4	12	1	1	**0.4**
	Darks							1	**0.0**
Spectro abs spetrophotom.	HST WD stars	1.00%	25	0.1	15	5	6	2	**2.5**
	Secondary WD		220	30	15	5	6	2	**11.9**
PSF Mapping	Stars		10	30	20	15	2	2	**7.2**
Spectro Wavelength	F-P + ROF	0.1 pixel	10	0.1	4	12	1	1	**0.4**
	PN	0.1 pixel	15	30	1	15	3	2	**1.1**
Spectrograph Geometry									
GRISM									
Flatfields	R.O.F.	1.00%	None - use PFLAT-MCT						
Spectrophotometric Calib	WD stars	1.00%	30	30	4	24	4	1	**2.6**
Wavelength Calib									
SHUTTER									
Timing characterization									
								TOTAL	**339.9**

Error Budget Assumptions

* Generic properties of
  * detectors
  * filters
  * prisms/grisms
  * light source(s)
* Errors add in quadrature - best case scenario
* When possible use values
  * from experiments,
  * literature or
  * best estimates from experience
* Assign uniform uncertainty of 0.1 % to unknowns

Questions and Issues

* Filter tests: frequency
* End to end tests of the entire OTA to detectors - photons in, counts out
* Cryogenic tests?
* Run tests in vacuum?
* Ground experiments -- simulate real observing conditions?

From Science to Measurements to Instrumentation

Science Calibration				Calibration Measurements	Instrument			Calibration Flight Equipment (CX)
Photometry	**RMS shear error**	**Photo-Z**	**Spectro-Z**		**Imager**	**Dispersive (Grism)**	**Spectroscope (IFU)**	
				Imaging				
x	**X**	x	x	Point spread function	A	A	A	
	x		x	Imaging scale (mapping / distortion)	A	A	A	
				Spectrophotometry				
X		**X**	x	Photometric spectral response	C1	A	A	Monochromator, Source, Photo-diode, shutters
X	x	**X**	x	Focal plane response uniformity	C2	C2	C2	Flat Field illumination
X	x	**X**	x	Sensor temporal / rate response	C3	C3	C3	Variable intensity (illumination / filters, shutters)
X		x	**X**	Spectral scale (mapping / distortion)		C4	C4	Spectral reference (lamps / filters)

Building JDEM Calibration Program

Calibration method trades
- Science impact & resources vs. maturity
- Method capability analysis (e.g. Astronomical sources)
- Hardware capability & minimization (e.g. Filters, lamp types)
- Identify risks and mitigation (e.g. redundant calibration paths)

Calibration Error Budget
- Measurement error science impact analysis (Simulations)
- Distribution of science errors (Calibration Budget).

Calibration Plan:
- Flight Operational Method & Resources
- Ground Calibration interaction with I & T flow

Hardware Plan:
- GSE & Flight calibration hardware scheme & development plan

Program: Content, costing, scheduling

Calibration Considerations

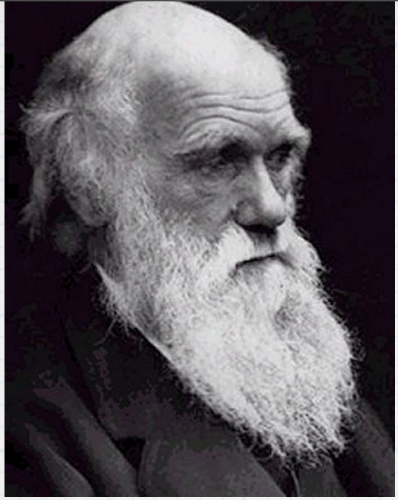
* Bandpass variation as a function of position on the focal plane
* Telescope efficiency calibration obtained though the observation of standard stars
* Pixel-level simulations of photometry processes
* Correlated residual errors in flat field calibration
* NIR Linearity response measurement effects
* SNE Specific:
  * Study of color effects from SNIa host dust environments
  * Zeropoints & simultaneous fitting of all SNIa in redshift bins
  * Calibration offset between low-z and space-based datasets

Calibration Philosophy

- Must have sensitivity calibrated across the entire FOV over entire bandwidth and all times to < 1% (entire error budget not to exceed this value)
- Product to derive: Absolute QE(λ , pix#, time)
- Must be monitored and demonstrated repeatedly on station (convenient intervals in multiples of cadence).
- Start with high-quality external ground flats vs. wavelength - cross-calibrate with internal flats - this defines pre-launch external/internal transformation.
- Internal flats on station thus transform to external; updated by monitoring of field stars across wide timescale range.
- Produce absolute reference by referencing internal source & field stars to "standard" DA white dwarf stars and known ACCESS standard stars. Stars raster-scanned for absolute photometric scale at many pixels.

Calibration System Key Points

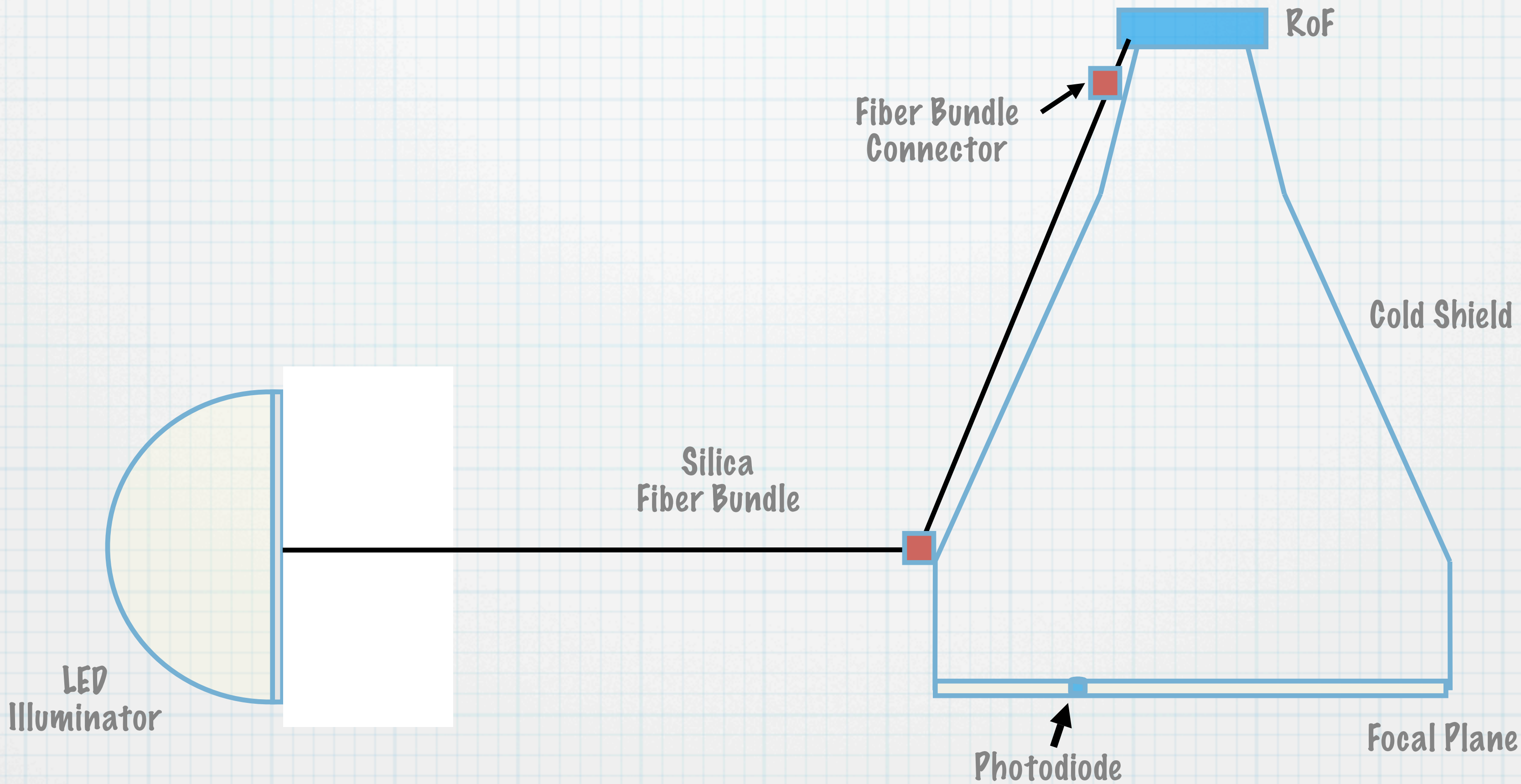
- Calibration is crucial to JDEM's success
  - Knowledge of the JDEM focal plane array behavior.
  - Critical is knowledge of CHANGE in FPA behavior.
- An internal flat field system:
  - Can be used to generate monochromatic flat fields periodically: required for prism solutions, good for filter-per-array solutions.
  - The system uses tungsten halogen bulbs (QTH) or LEDs with a monochromator to feed a diffuser providing smooth (although not necessarily uniform) illumination on FPA.
  - Three moving parts might be required: the shutter, the diffuser, and wavelength selector.
- External system:
  - For ground tests, project monochromatic calibratable flat field and/or point sources into telescope front end.



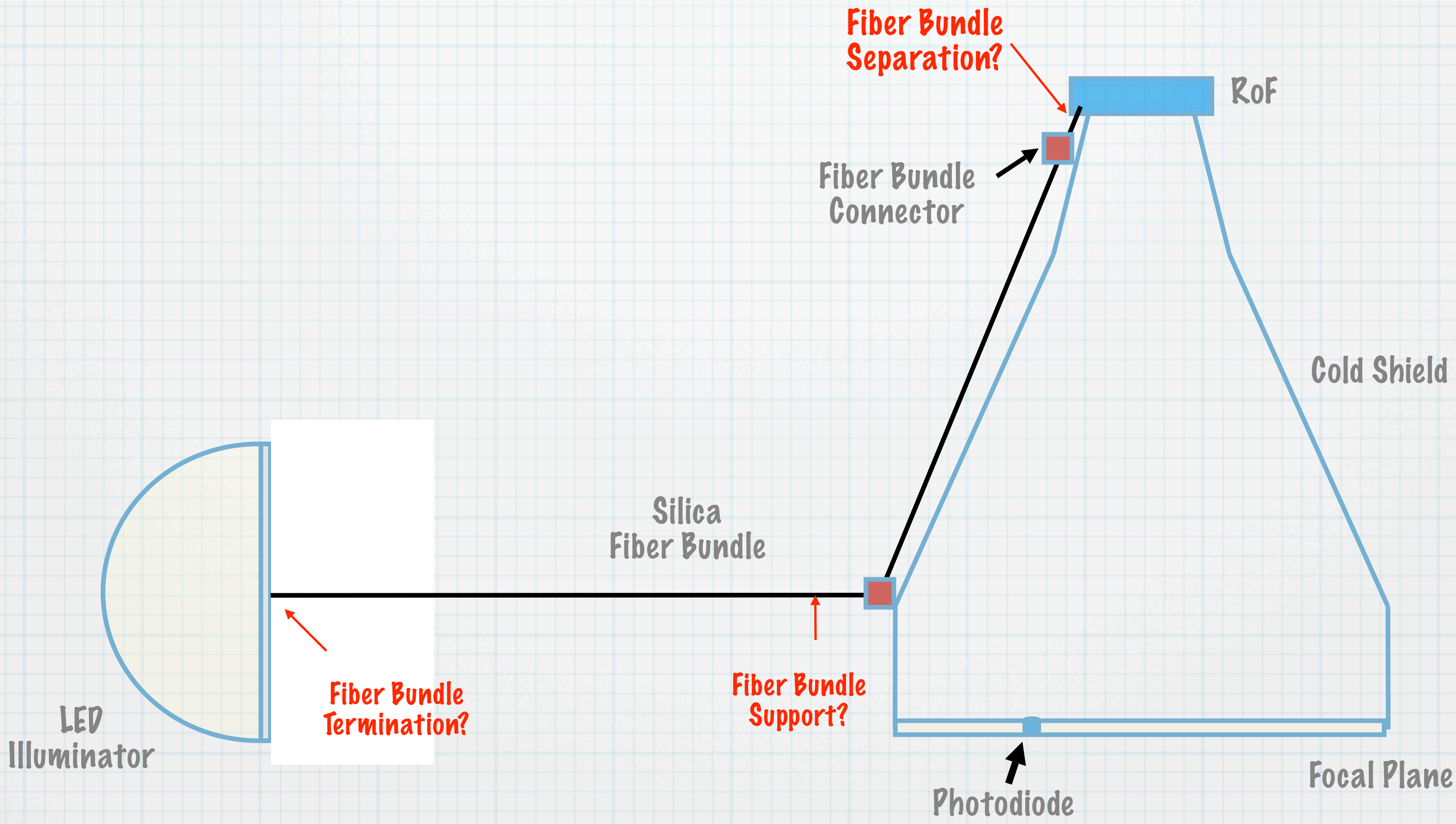
Convergent Evolution

DESTINY & SNAP calibration subsystems

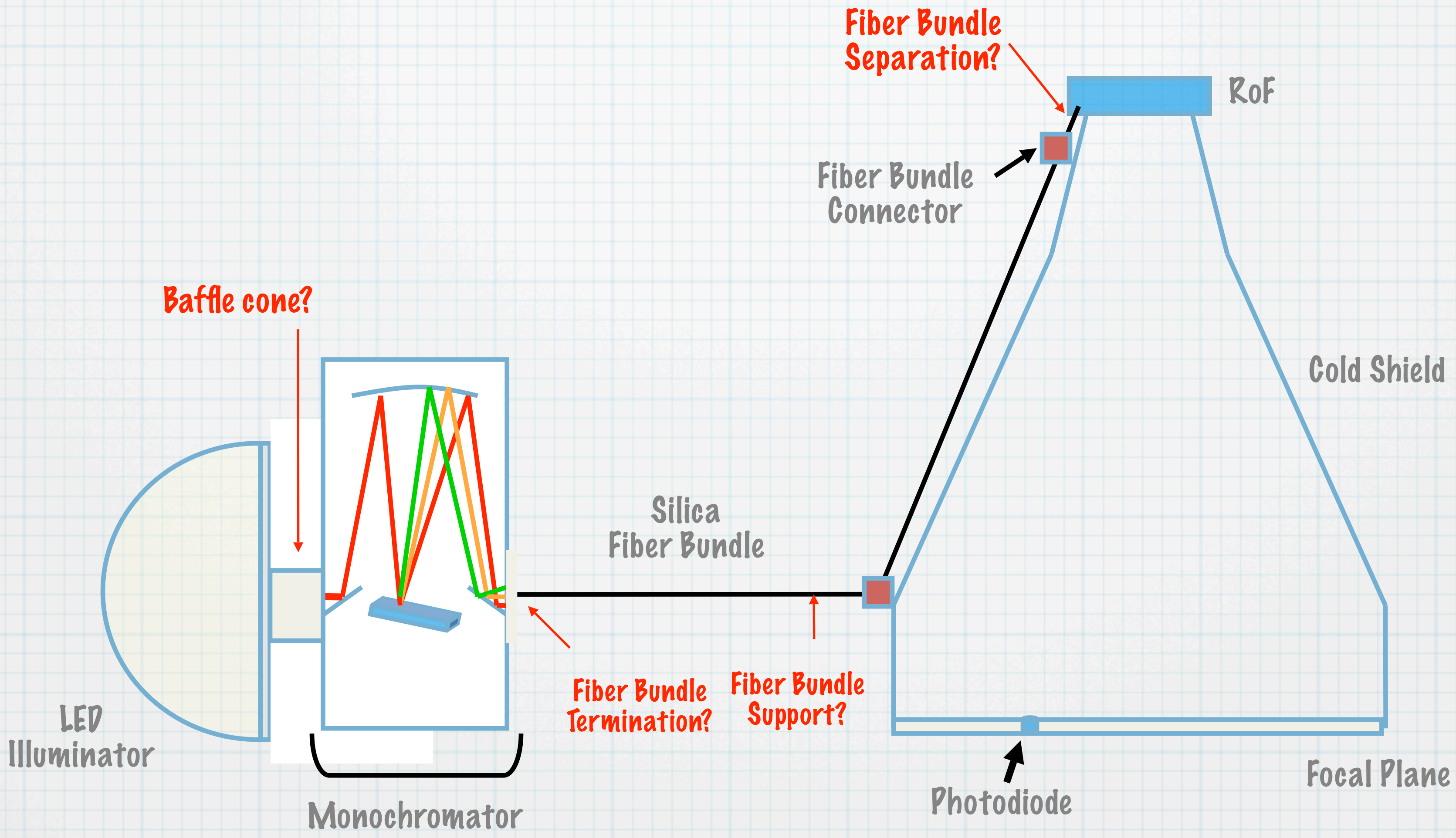
SNAP Calibration Light System Overview; near-pupil version



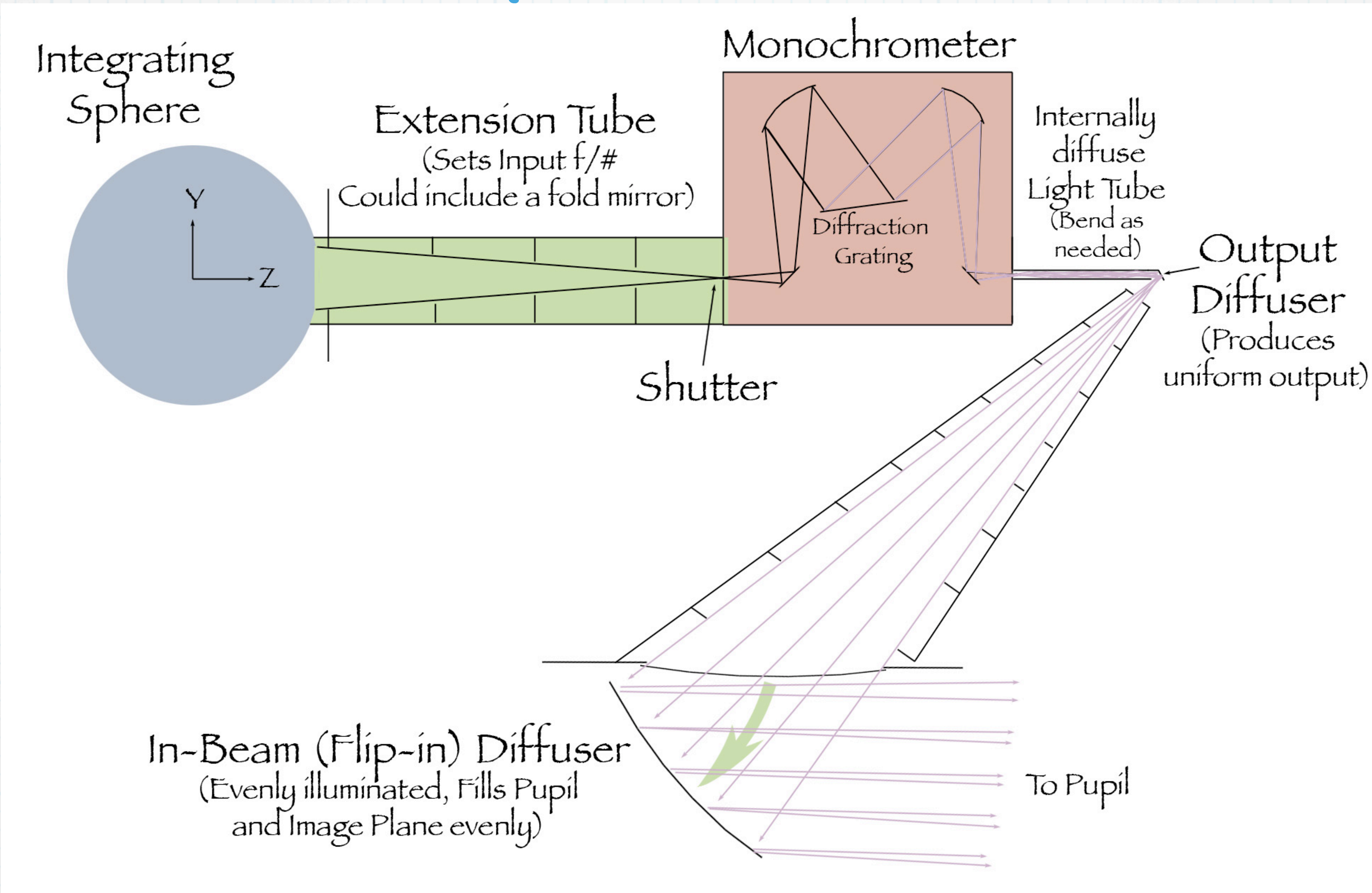
SNAP Calibration Light System Overview; near-pupil version



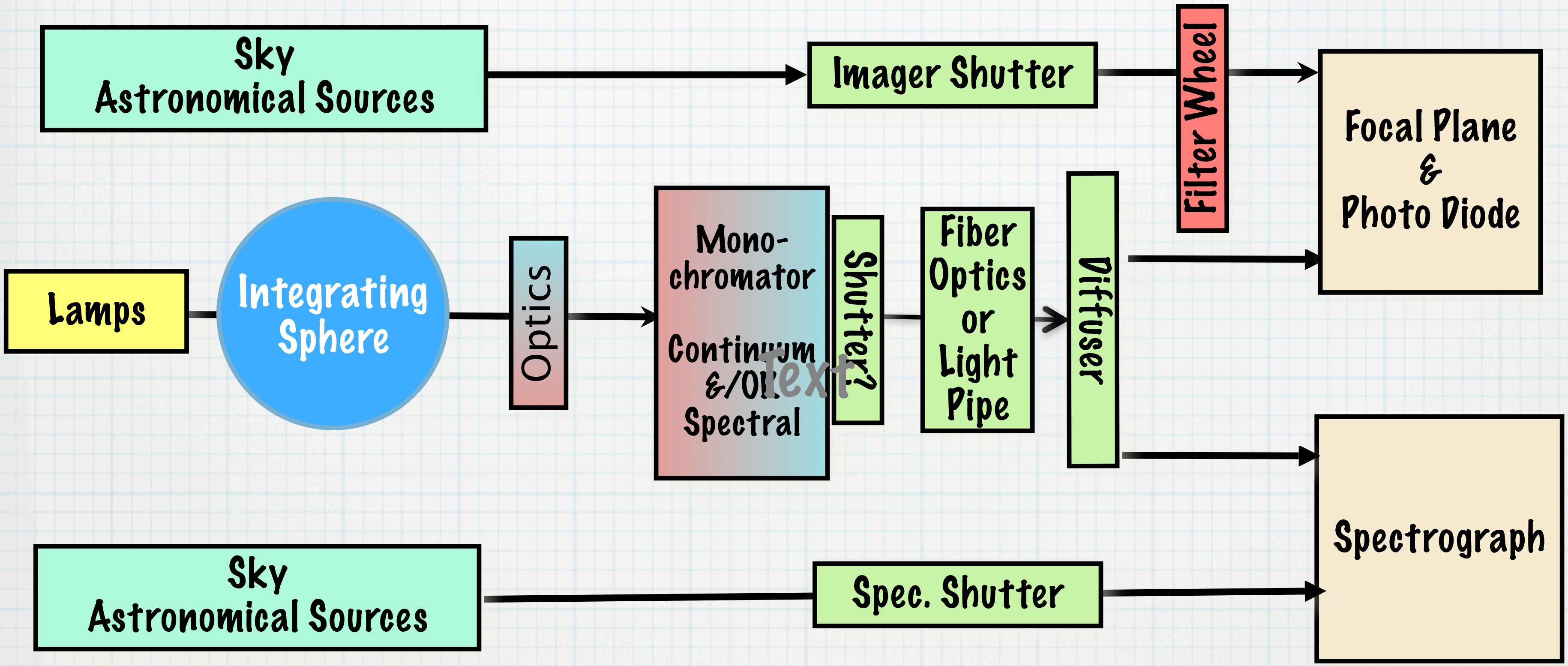
SNAP Calibration Light System Overview; near-pupil version



DESTINY Calibration Subsystem (anywhere in beam)



JDEM On-Board Calibration Scheme



Source System
Source Lamps
Filters &
Attenuation
Spectral reference

Monochromator
Continuum mode
Spectral Mode

Illumination Distribution
Shuttering
Fiber distribution
Diffuser

focal plane photodiodes

Calibration Hardware

- Common Filter on MCT and CCDs
- Monochromator --
  - check filters edges, flat field prism/grisms
- Flat Field Illumination System
  - Use back of Shutter as diffuse screen

- Calibration Light sources: LEDS, Emission Line lamps, QTH
- Integrating Sphere
- Fibers
- Photodiodes on Focal Plane

SUMMARY

1. End-to-end calibration crucial
    1. photons in -> OTA -> FPA -> counts out

2. Ground calibration efforts are a key component of the overall calibration strategy
    1. Ground Calibration
    2. Space external Cal
    3. Internal space cal hardware

3. Test at all levels on ground

4. Stability requirements have a crucial interplay with calibration requirements.