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Magellan Instrumentation Calibration

Plan and Issues

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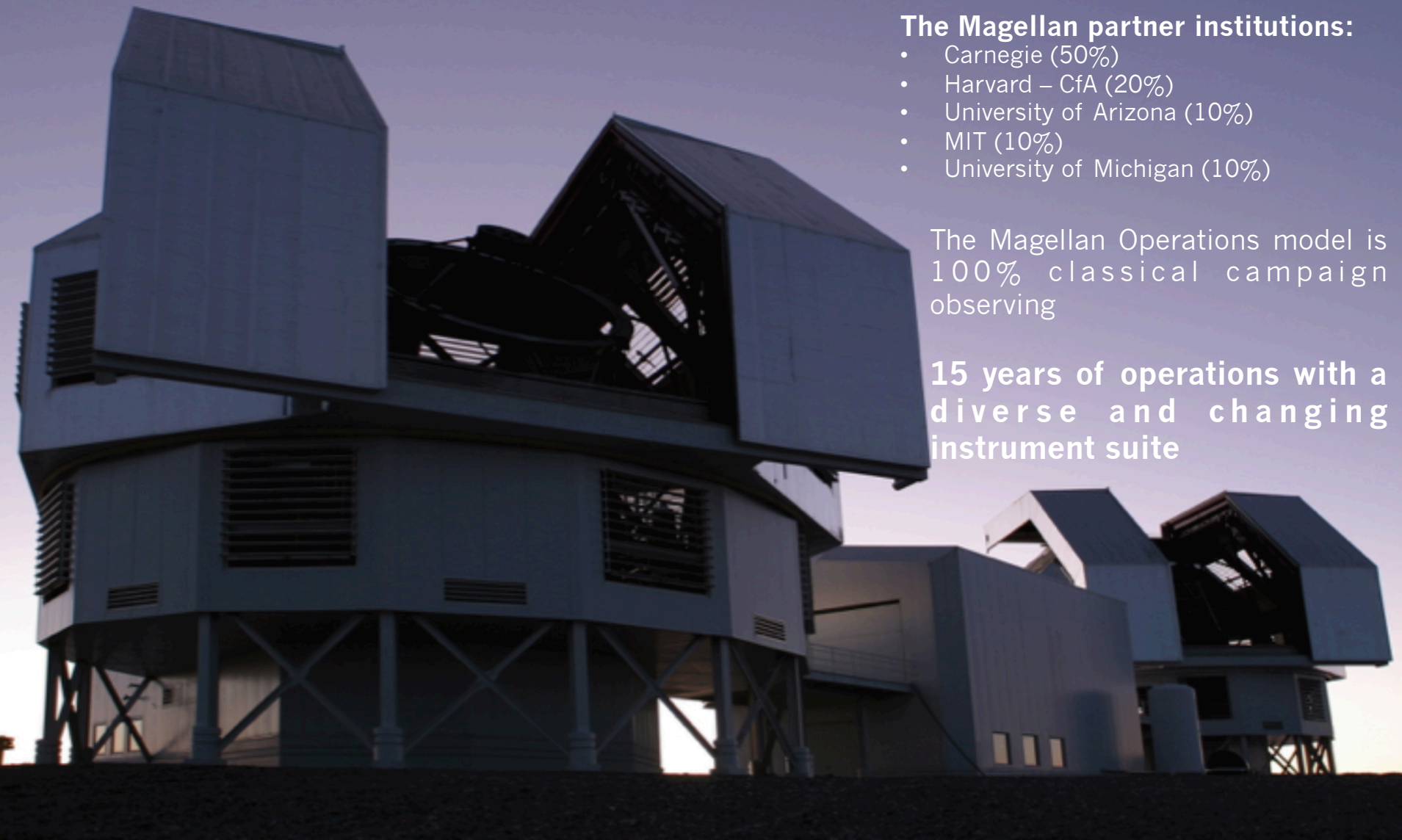
Magellan 6.5m

Baade - 2001

Clay - 2002



The Magellan partner institutions:

- Carnegie (50%)
- Harvard – CfA (20%)
- University of Arizona (10%)
- MIT (10%)
- University of Michigan (10%)

The Magellan Operations model is 100% classical campaign observing

15 years of operations with a diverse and changing instrument suite

The Magellan Telescopes

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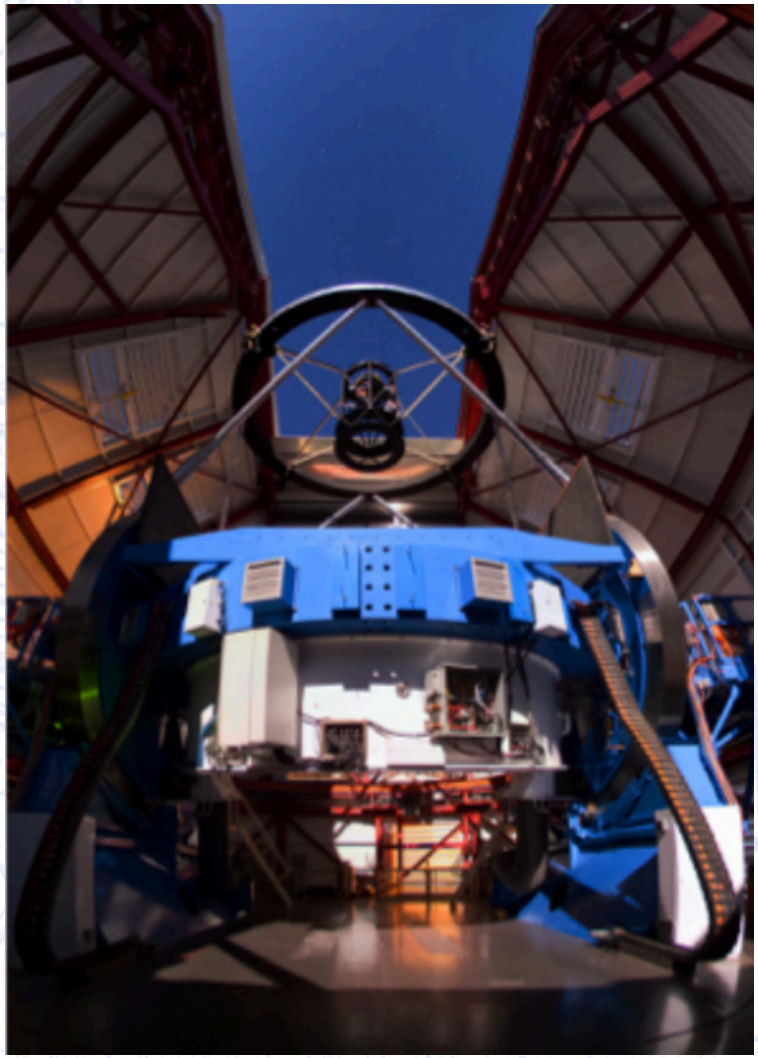
The telescopes are an alt-azimuth design.

Foci:

- **f/11:** at the two Nasmyth locations and three auxiliary ports accessible by the tertiary mirror. The **Gregorian** configuration has been selected to optimize performance of the collimator optics. The wide field configuration includes an ADC corrector for unvignetted field up to 24'.
- **f/5:** in the Cassegrain position
- **f/16:** used by MagAO

M1 and M3 of each telescope are aluminized every other year. The year between aluminizations they are washed and weekly they get cleaned with CO2.
Reflectivity and scattering are measured before and after every CO2 cleaning.



The Magellan Instrument Suite

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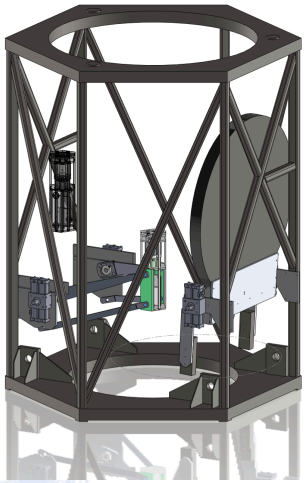
Telescope	Instrument	Type	Wavelength	Wavelength range	FOV (arcmin)	R (for spectrographs)	Pixelscale, arsec/pix
6.5-m Magellan Baade	**IMACS**	imager / multislit spectrograph	optical	365-1000 nm	14' or 24-27'	500 .. 20000	0.11 or 0.2
	FOURSTAR	imager	infrared	1000 - 2510 nm	10.8 x 10.8'	-	0.16
	FIRE	spectrograph	infrared	820 - 2510 nm	7" slit	500 .. 6000	0.18
	MAGE	spectrograph	optical	310 .. 1100 nm	10" slit	4000 .. 8000	0.3
6.5-m Magellan Clay	**LDSS3**	imager / multislit spectrograph	optical	360 .. 1100 nm	8.3' (diameter)	850 .. 1900	0.189
	MIKE	spectrograph	optical	320 .. 1000 nm	5" slit	22000 .. 83000	
	PFS	spectrograph	optical	388..668 nm	3.7" slit	38000 .. 127000	
	M2FS	double-arm fiber spectrograph	optical	370 .. 1050 nm	30'	1500 .. 34000	
	PISCO	multi-band imager	optical	g' , r' , i' , z'	9'	-	0.16
	MEGACAM	imager	optical	350 .. 900 nm	25'	-	0.08
	VISAO	imager / Adaptive optics	optical	600 .. 1000 nm	8"x8"	-	0.008
	CLIO	imager / Adaptive optics	infrared	1000 .. 5300 nm	16" x 8" 28" x 14"	-	0.016 0.027

Deployable Calibration Unit



In front of the Gregorian secondary there is a deployable calibration unit.
It includes a retractable Flat Field screen at the pupil of the telescope.
It includes two fixed voltage quartz-halogen lamps (high and low intensity) and one variable for flat fielding.
Currently it holds: He, Ar, Ne and Kr lamps. The arc lamps can be swapped to accommodate specific requirements.

The illumination of the instrument through the pupil screen is greatly preferred because it closely matches the light coming from the sky itself.

At Clay the DCU includes the Mcal structure that holds light sources for (1) wavelength, (2) continuum and (3) fiber positioning for M2FS – a multi-fiber spectrograph (PI instrument)

The Inamori Magellan Areal Camera and Spectrograph – IMACS

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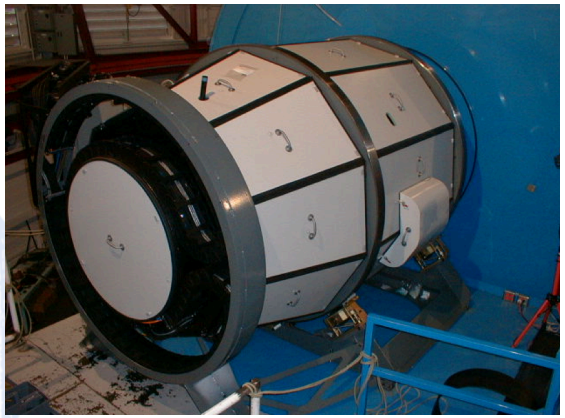
IMACS is an extremely versatile wide field imager and multi–object spectrograph that covers a wavelength range of 3650 – 10000 Å. It has two 8Kx8K CCD with 20<R<20000.

f/4: FoV : 15.4x15.4 arcmin
Pixel scale: 0.111 “/pixel

f/2: FoV : 27.4 arcmin diameter field
Pixel scale: 0.200 “/pixel



IMACS **shutters** are based on a blade system. 1sec exposures where found to be accurate to 2% over the entire field of view. Thus calibration frames (i.e. very bright standard stars, short flat fields) do not suffer shutter delay effects.

Here the DCU is well suited for science calibrations. The flat fields obtained with the quartz lamps using the fully illuminated pupil provide wide field flat fields good to the 1% level. Nevertheless, sky flats are a good alternative for the blue bands .
Spectral flat fields should be taken immediately after spectral observations, before the slitmask, grating, or grism has been retired.
Monthly calibrations in IMACS include: series of dome/sky flats to evaluate stability, photometric standards for measuring zero-points and spectrophotometric standards for measuring throughput.

The Inamori Magellan Areal Camera and Spectrograph – IMACS

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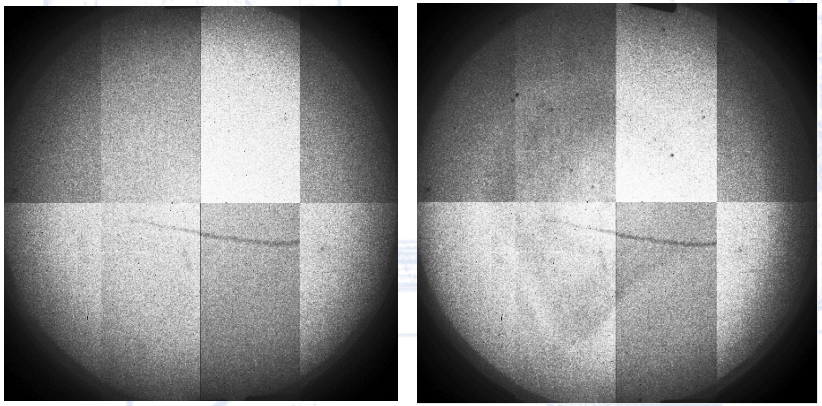
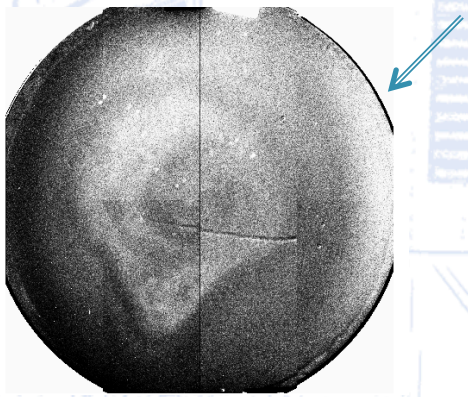
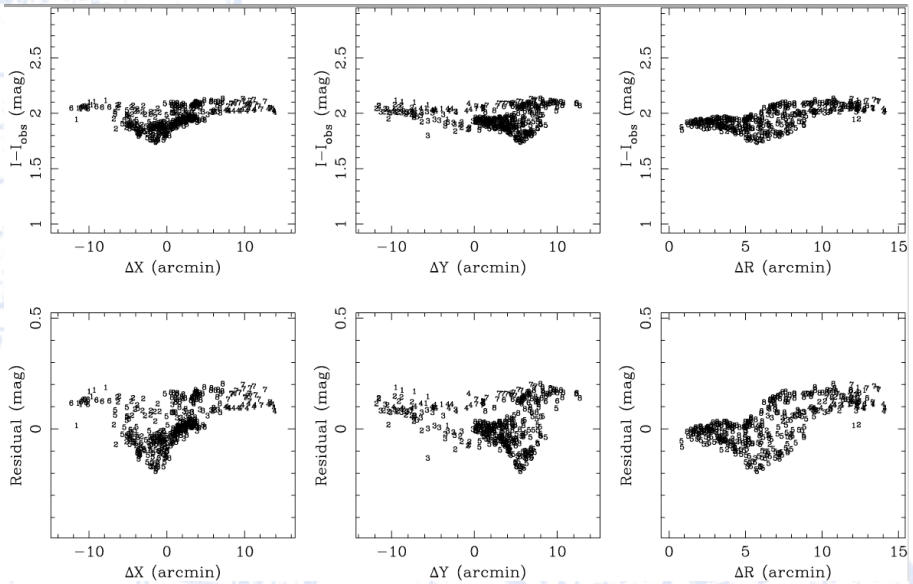
Example of humidity contamination at the dewar window







Monitoring flat stability, especially in wide-field imagers is crucial!

In this particular case we found that a ~3% variation of the flat field resulted in ~20% variation in photometry across the field.
This pattern, being inhomogeneous, affects differently spectra across the field (difficult to identify). It also increases background light in the slits because of scattering and reflections.

The Low Dispersion Survey Spectrograph LDSS–3

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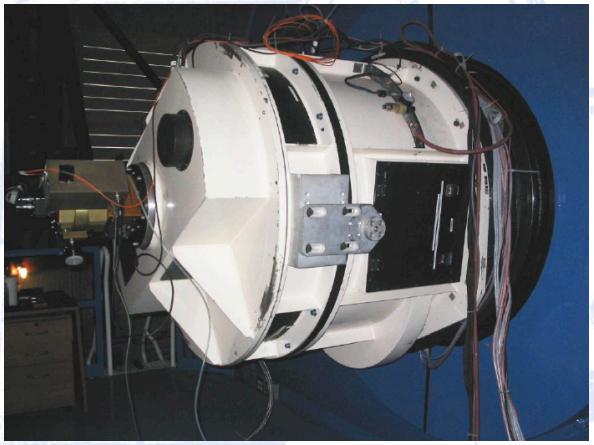


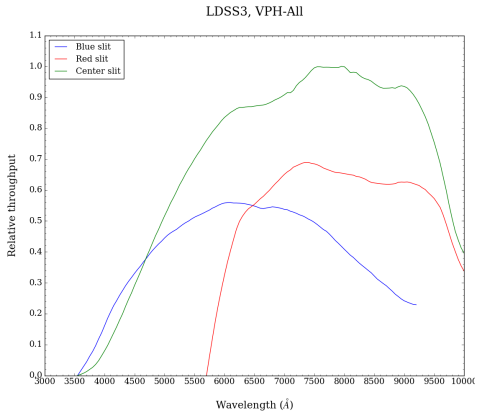
It is a high efficiency optical wide field imager and multi-object spectrograph. After the CCD upgrade it is very efficient in the red wavelength.
The field of view is 8.3' diameter trimmed to 6.4' in the spatial direction.
The pixel scale is 0.189"/pix.

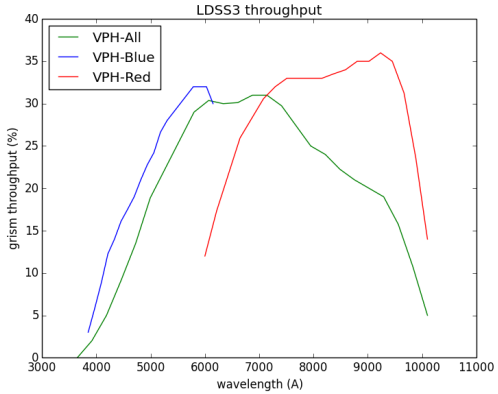
Grism	Ruling density, (lines/ mm)	Resolution, (0.75" slit)	Central,Wavelength, (Angstroms)	Wavelength, Range, (Angstroms)	Dispersion, (Angstronms/ pixel)	Peak efficiency, (%)
VPH-ALL	400	860	7100	4250-10000	1.890	32
VPH-Blue	1090	1900	5000	3800-6200	0.682	32
VPH-Red	660	1810	8000	6000-10000	1.175	37

VPH grisms are characterized by high throughput BUT present variable transmission and spectral calibration across the frame

Standard calibrations

During engineering we obtain standard fields to measure the zero points in various locations on the two amplifiers and astrometric fields for distortions.





The Low Dispersion Survey Spectrograph LDSS–3

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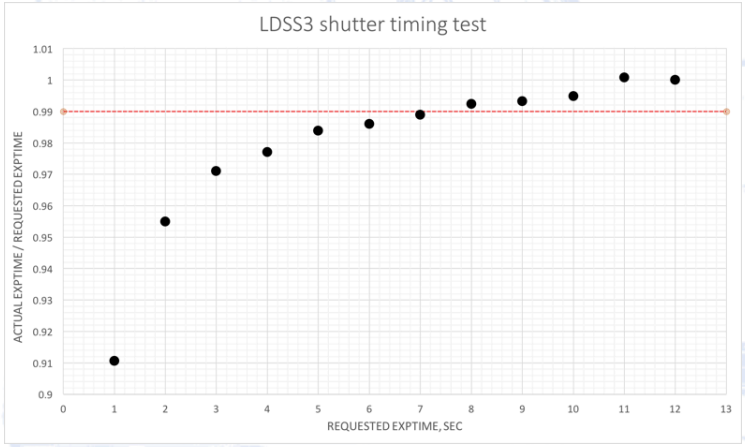


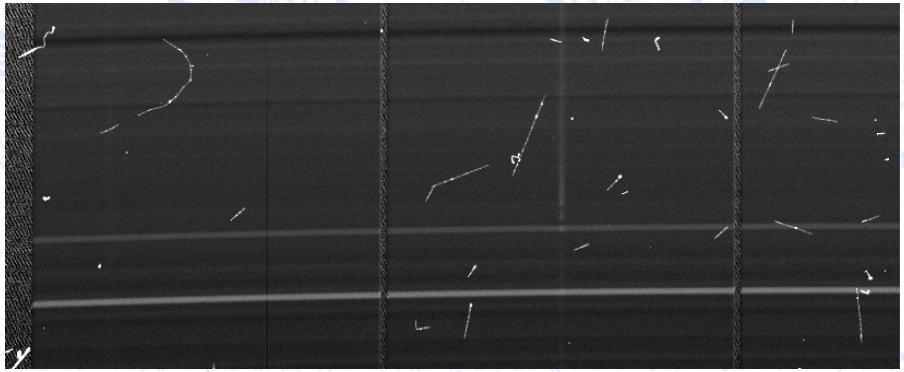
Shutter effects:

LDSS-3 includes an iris shutter. Shutter timing is good to 1% for exposure times longer than 7sec.
This can introduce correction patterns for shorter exposure times.

Filter	Zeropoint
g′	27.61
r′	27.76
i′	27.72
z′	27.76

Detector:

The new CCD has a very high red throughput (QE>50% at 1000nm) and presents no fringing BUT this makes it very sensitive to cosmic rays and limits total single exposure times.



The Magellan Inamori Kyocera Echelle MIKE

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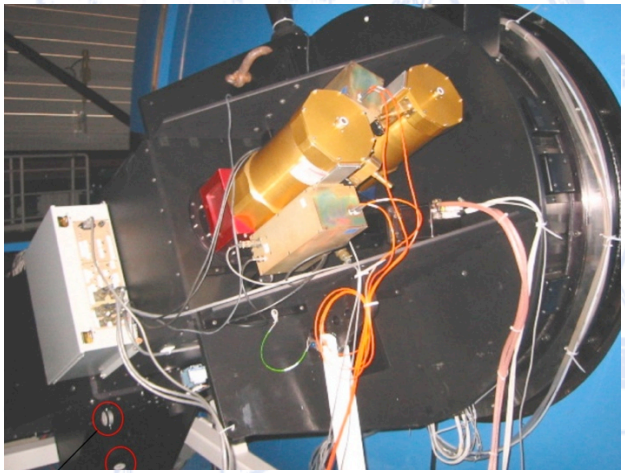
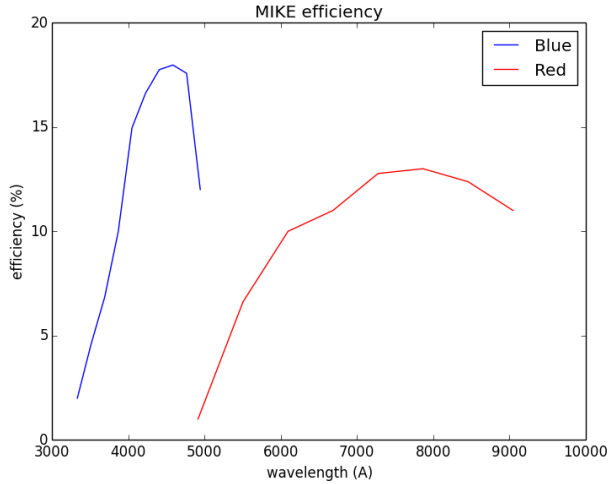
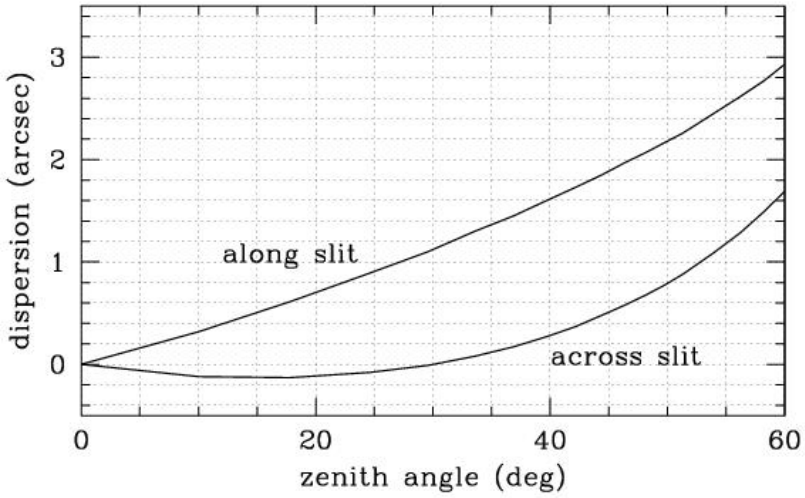


A double arm high resolution optical spectrograph. The two arms (red and blue) are separated with a dichroic and can be used either simultaneously or separately.
A particularity of this instrument is that it is not connected to the telescope rotator, thus it is used in a gravity invariant mode.
Limitations: the slit orientation on the sky cannot be changed. Observing at a zenith angle of 30deg will have atmospheric dispersion lying along the slit.





An ADC is on the way...

The Magellan Inamori Kyocera Echelle MIKE

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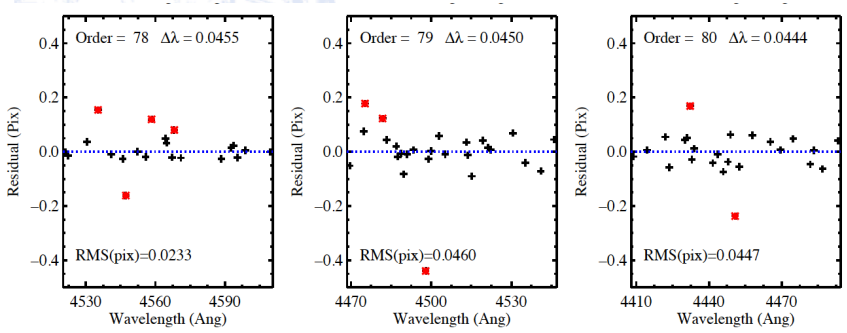
Internal lamps: MIKE includes a suite for internal lamps for calibrations. The setup includes a ThAr lamp for wavelength calibrations and incandescent lamps for flats. The setup includes a mirror in the beam to feed the spectrograph.

Wavelength calibration caveats:
(1) good counts in blue mean saturation in the red side;
(2) the reddest orders have few lines.

The solution is good to 0.045pix rms



Residuals in pixels from Legendre fits of auto-identified and centroided ThAr lines in a series of echelle orders (Bernstein et al. 2015)

Milky flats:
To get a good pixel to pixel sensitivity correction the CCD needs to be evenly illuminated between orders. For this reason a **diffuser** is used to obtain milky flats. Since the internal lamp is not very efficient in the blue it is strongly suggested to take milky flats during twilight using O or B stars. In order to have the inter-order region better illuminated it is suggested to have half flats with the star in one end of the slit and half in the other.
There is a catalog of high radial-velocity standard stars that have features broad enough to be smoothed out.

The Magellan Inamori Kyocera Echelle MIKE

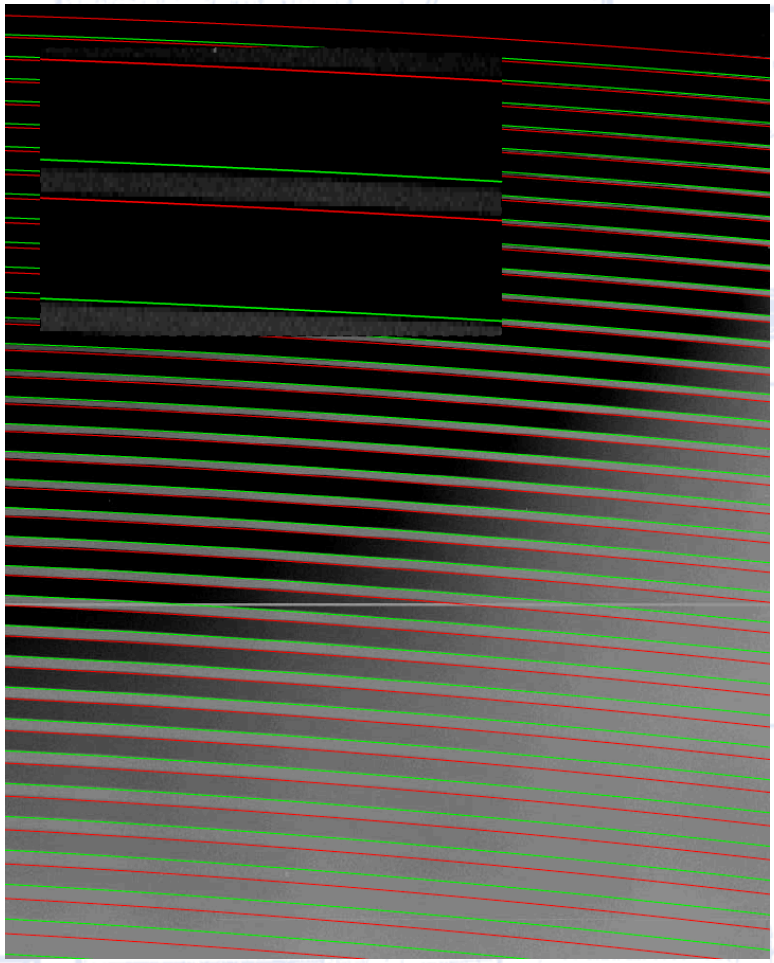


Image of a trace flat (Bernstein et al. 2015)

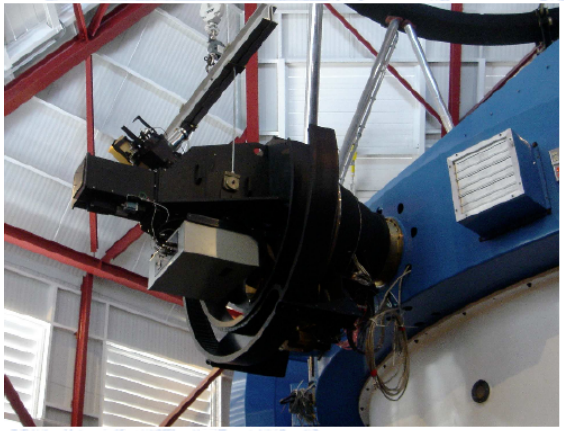
Suggested strategy:

Flats with and without the diffuser can be used for illumination correction and to trace the edge of the order. These should be accompanied by arcs to provide an easy way to identify the offset between the order position in the flat and the order position in the science exposure.

Good idea to take arcs between long exposures because there is motion due to temperature changes in the air/glass/metal and could cause small shift in the cross dispersion direction.

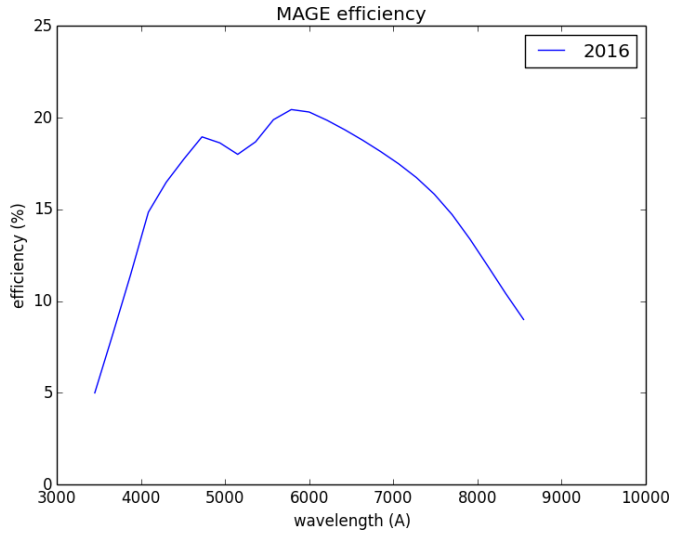
There is a MIKE pipeline (part of CarPy) for data reduction that requires specific sets of calibrations.

MagE



The Magellan Echellette Spectrograph is a moderate resolution optical echellette. With a wavelength coverage between 3100 Å to 1micron, it was designed to have excellent throughput in the blue.

There is one grating with 175 lines/mm blazed at 6.2 micron. It gives a resolution of R=4100 for the 1" slit. The central wavelength of each order is 6.2micron/ (order number).



Other available slits: 0.5", 0.7", 0.85", 1.0", 1.5", 2.0", 5.0"

The plate scale is 0.3"/pixel

Iris shutter with limitations for shorter exposures

Camera	Pixel scale, ("/pix)	Spectral Resolution, (1.0" slit)	Wavelength,Range, (Angstroms)	Peak efficiency, (%)
MagE	0.3	4100	3200-10000	20

MAGE

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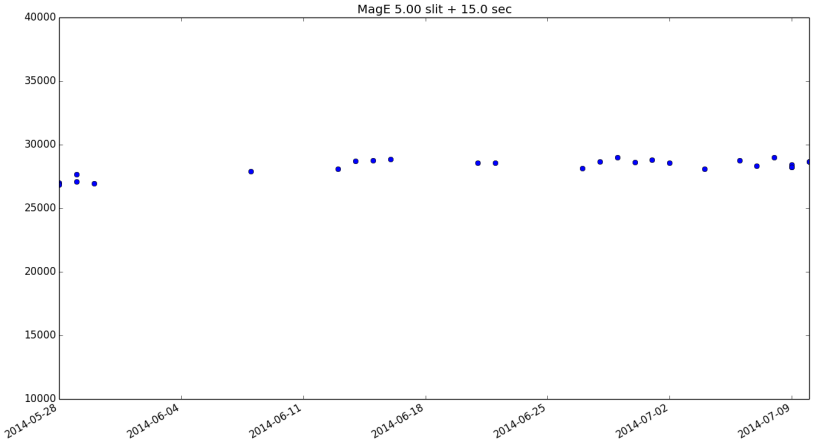
Wavelength calibration: A ThAr hollow cathode tube provides suitable lines for the entire wavelength range. The typical wavelength solution gives an rms of 0.06Å for 500arc lines

Flats: The broad wavelength coverage makes it difficult to obtain good flats. There are two flat field lamps: (1) *Xe–flash lamps*: flashes pulses of light at constant frequency and (2) *Incandescent lamps*: the lamps in the DCU



Monitoring lamp stability for MagE

Suggested calibrations:

- a series of Xe–flash lamp flats used to define the individual orders of the spectrum.
- a Xe–flash lamp exposure taken with the collimator out of focus to define pixel-to-pixel flat field in the blue end. This includes:
  - Blue flats: with the 5” slit and the collimator out of focus.
  - Very blue flats: For the bluest two orders (3100Å - 3500Å) long exposures are recommended (~100sec).
- flat field observations of the incandescent lamps illuminating the flat field screen to construct a pixel-to-pixel flat for the red end of the spectrum and correct fringing.

FIRE

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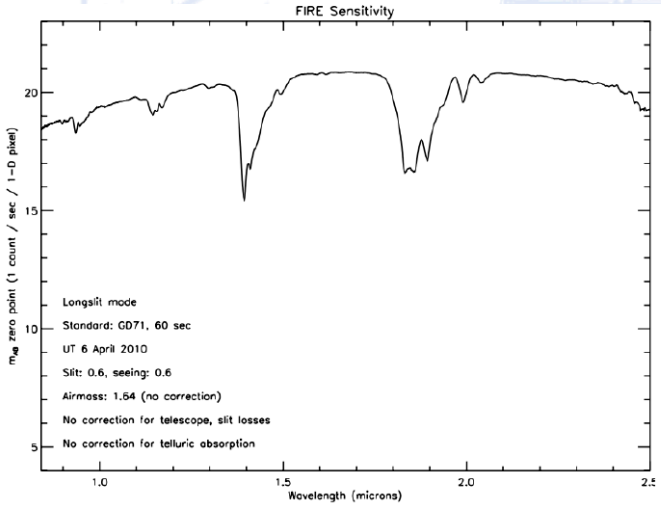
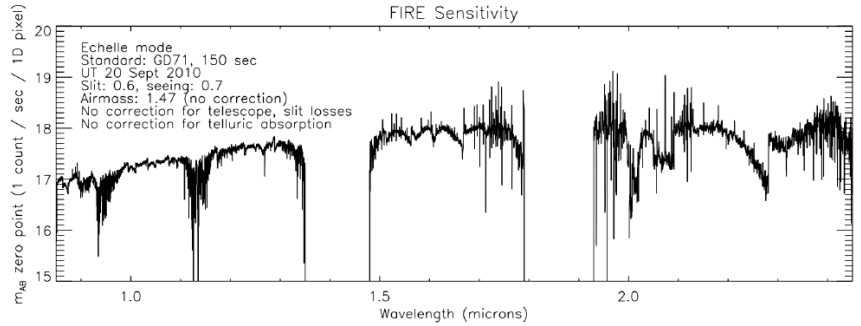
The Folded-port InfraRed Echellette is a near-infrared dual-mode spectrometer that operated in the 0.82-2.51 micron wavelength range.
It delivers continuous single-shot spectra from Y to K bands with a resolution of 37.5-50km/s for a 0.6" or 0.45" slit.
A full sequence of calibrations includes pixel flat fields, wavelength calibrations and illumination (sky) flats. The instrument contains a set of internal calibration lamps, that provide good calibrations for echelle mode but not in longslit mode.

	High Resolution Echellete Mode	High Throughput Prism Mode
Spectral resolution	R=6000 (0.6" slit)	R_J=500, R_H=450, R_K=300
Spatial resolution	0.18"/pixel	0.15"/pixel
Continuous bandpass	0.82-2.51 microns	0.82-2.51 microns
Slit widths	nominal 0.6" - selectable 0.45"-1"	nominal 0.6", selectable 0.4"-1.0"



Zero point calibration in low dispersion mode (Simcoe et al. 2013)



Zero point calibration obtained in R=6000 echelle mode (Simcoe et al. 2013)

FIRE

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Echelle calibrations:

FIRE's footprint includes two orders with relatively few lines for wavelength calibration in echelle mode.

- If Texp <8min it is critical to obtain arcs with sufficient depth to bring out several lines for a proper fit to the tilt and curvature of the orders.
- If Texp >8min night sky OH lines can be used.

Because of flexures at the 1pix level with different gravity orientation, it is advisable to obtain arcs at every pointing.

Flat field counts should be kept bellow 18k-20k to avoid saturation effects. In principle the internal quartz lamps produce reasonable count rates.

Longslit calibrations:

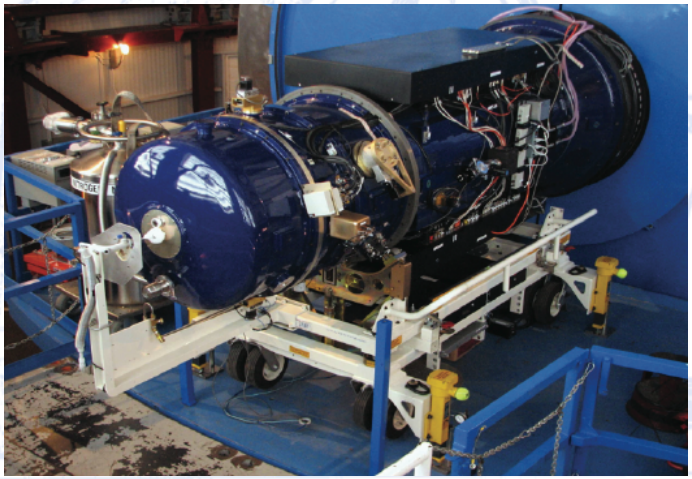
The internal lamp does not provide very uniform illumination, thus the flat field screen (DCU) should be used. For adequate counts across the wavelength range two sets of flats are necessary: (1) High voltage for z and J bands; (2) Low voltage for H and K.

For wavelength calibration sky lines are blended thus a NeNeAr setup should be used.

Twilight flats: to calculate the slit illumination function, for accurate sky subtraction.

A0V telluric standards: to be observed between science objects for calibrating atmospheric absorption features and flux. A dedicated software exists that for a given RA&Dec produces a list of stars matching in airmass and sky angle

FourStar



FourStar is a wide-area infrared camera.
Field of view: 10.8'x 10.8'
Pixel scale: 0.159"/pixel
Wavelength coverage: 1 – 2.5micron
Dark count rate: ~0.3 e-/sec

Spectrophotometric standards were convolved with the FourStar bandpasses to create a set of standard stars of appropriate brightness.
http://www.stsci.edu/hst/observatory/cdbs/calspec.html

The data acquisition system allows the reduction of incoming data in quasi-real time.
The FSMOS script, using telescope offsets from the header, combines dithered images after subtracting the background to create deeper mosaics.
The tmc option will find the 2MASS stars in the field and bring up an interactive display to calculate the photometric zero-point of the image.
Both the system and the detector have proved to be stable over time.

Filter	Typical Background		AB Mag		Vega Mag	
	[e-/s/pix]	[mag/sq"]	Zeropoint	Depth	Zeropoint	Depth
J1 (Y)	200	16.9	27.3	25.4	26.6	24.7
J	850	15.6	27.9	25.7	26.9	24.4
H	4100	13.8	28.1	24.8	26.8	23.5
Ks	3100	13.1	27.9	27.9	25.8	22.7

Open questions

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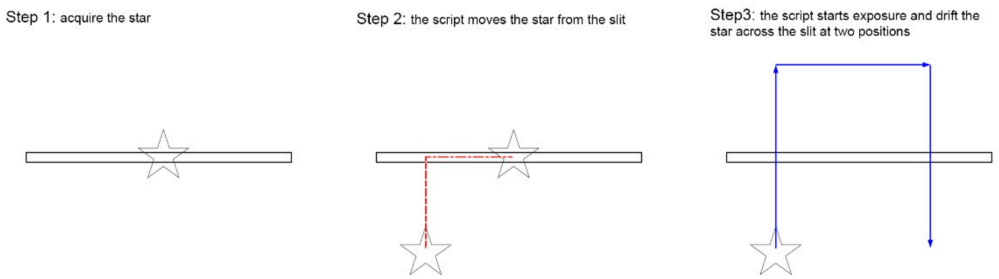
Is there place for perfectionism in the NIR spectral data reduction?
Talk by I. Chilingarian

Slit loss free spectroscopy: implemented a slit scanning technique for high-precision relative spectrophotometry
See poster by Y. Beletsky



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Thank you very much!

We acknowledge the dedicated efforts of the large number of personnel at OCIW and the various Magellan consortium partners that have had a role in bringing these Magellan instruments to fruition. It is also a great pleasure to acknowledge the superb team at the Las Campanas Observatory, Magellan Telescopes that prepare, operate, troubleshoot, and maintain these instruments.