SED Machine

Spectral Energy Distribution Machine

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Some inspirations

SNIFS

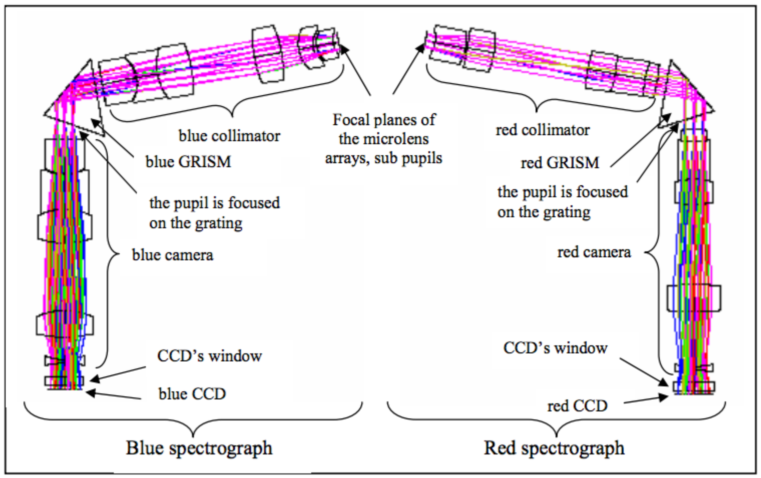
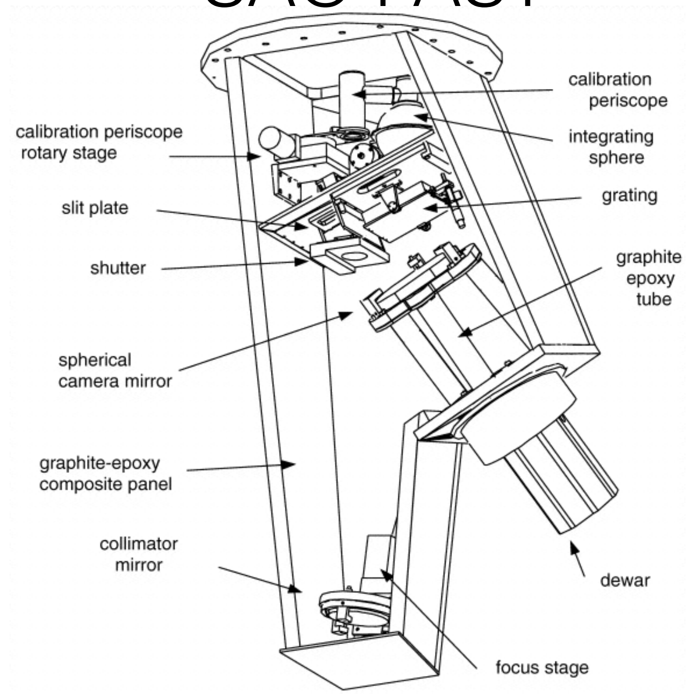


Figure 7: layout of the two spectrographs

Lantz+ (2004)
IFU: 6" x 6" FOV
R~1,000

SAO FAST



Fabricant+ (1998)
Slit / R~1,000

There are two spectrographs that we felt could be combined into one. SNIFS also had a "rainbow camera" with even medium- and narrow-band filters to observe night sky features.

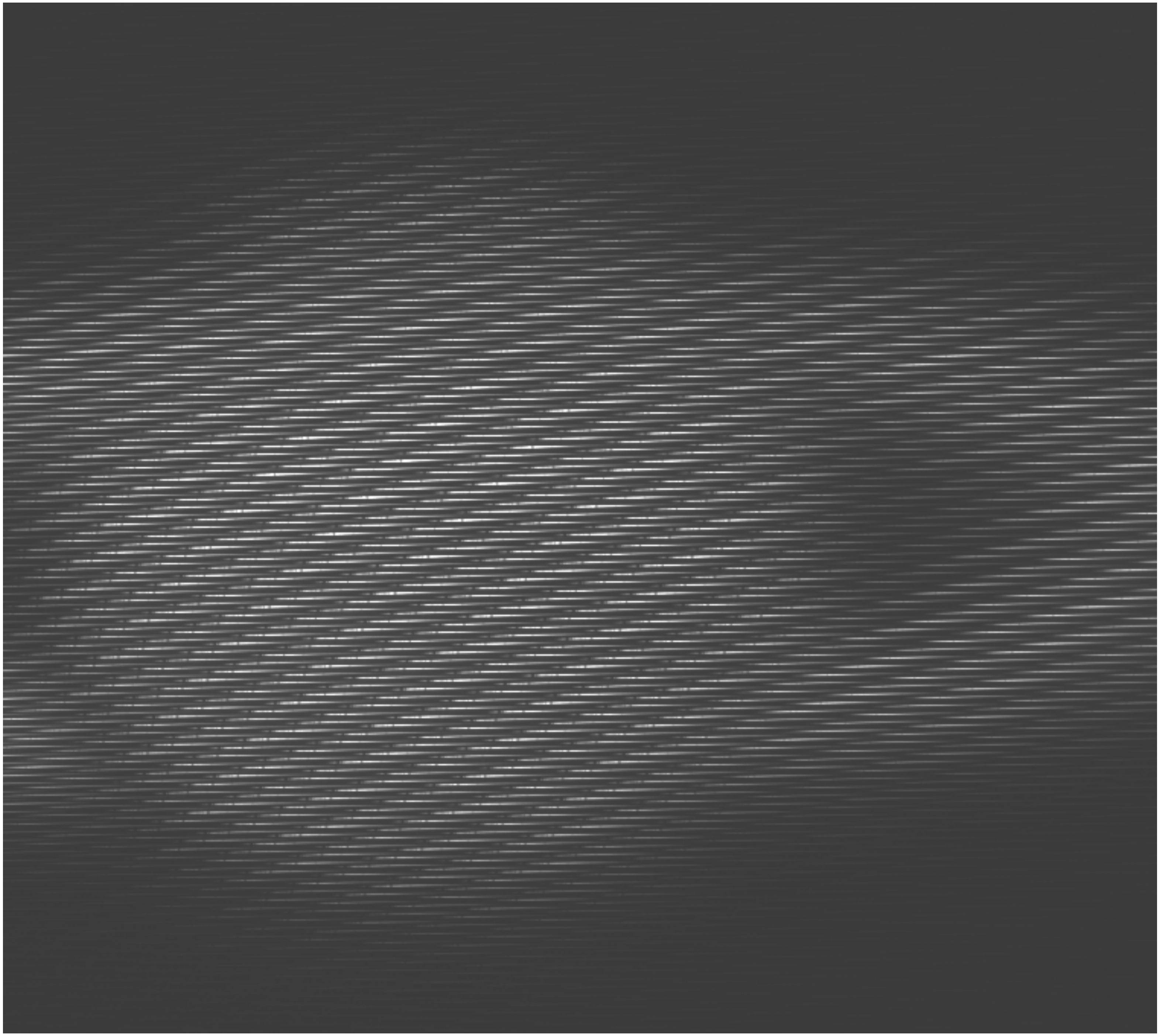
Milestones

- Pasadena Postdoc Retreat: April 2009
- Palomar Retreat: Dec 2009
- ATI Submitted: Nov 2010
- Project start: July 2011: $675 K
- First light on sky: June 2013
- DRP1/DRP2 operational in Jan 2014/May 2015
- Full time operations June 2016

SED Machine is the result of a simple metric

- Maximize the efficiency of taking classification by:
  - Ensuring acquisition efficiency is as high as possible. This is accomplished with a wide-field (30”) integral-field unit.
  - Ensuring the instrument minimizes the time on spectrophotometric standards by simultaneously monitoring in u, g, r, and i and then correcting the resulting spectra for grey absorption.
  - Ensuring the instrument is of the highest possible efficiency.

A spectrum of Saturn taken with SED Machine — demonstrating the enormous field of view of the instrument. Alignment onto the slit is “easy”!



An example from 4 Jan 2019

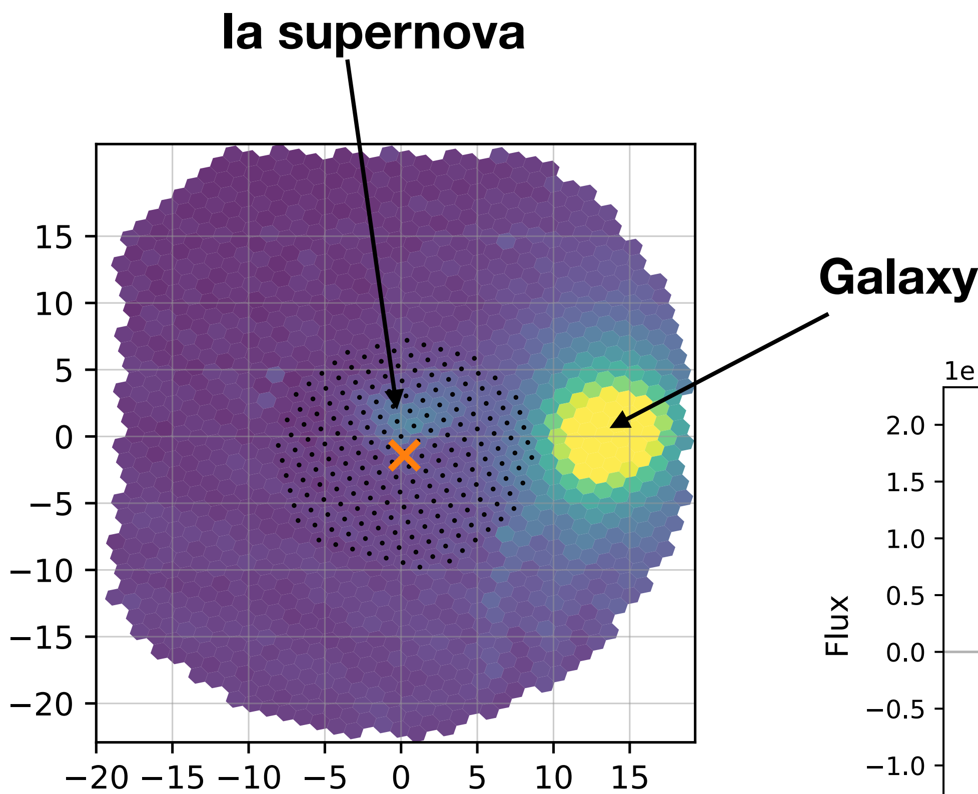


Figure shows the collapsed data cube

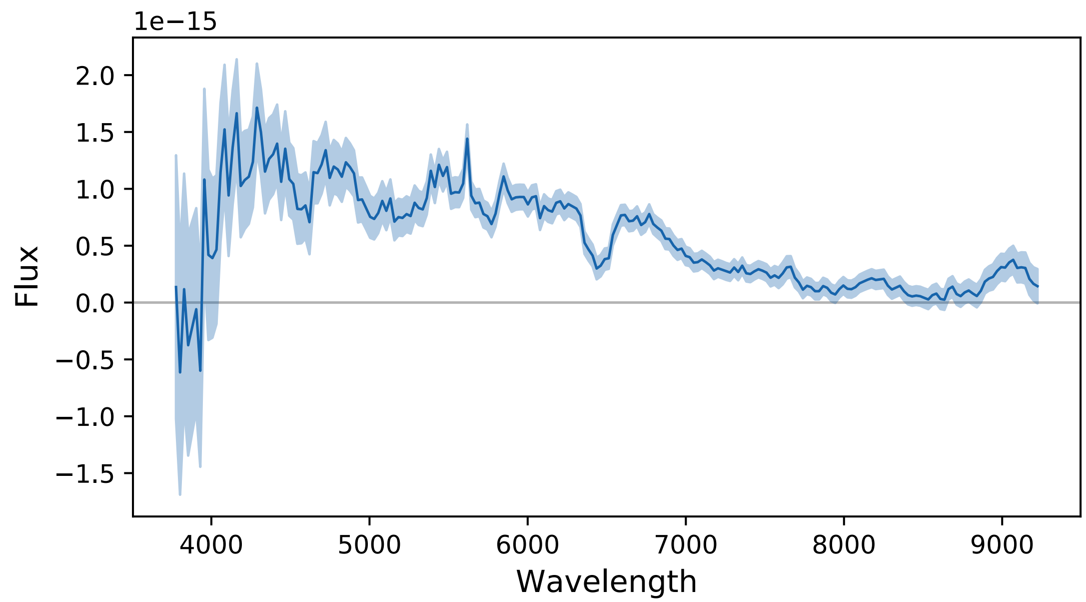
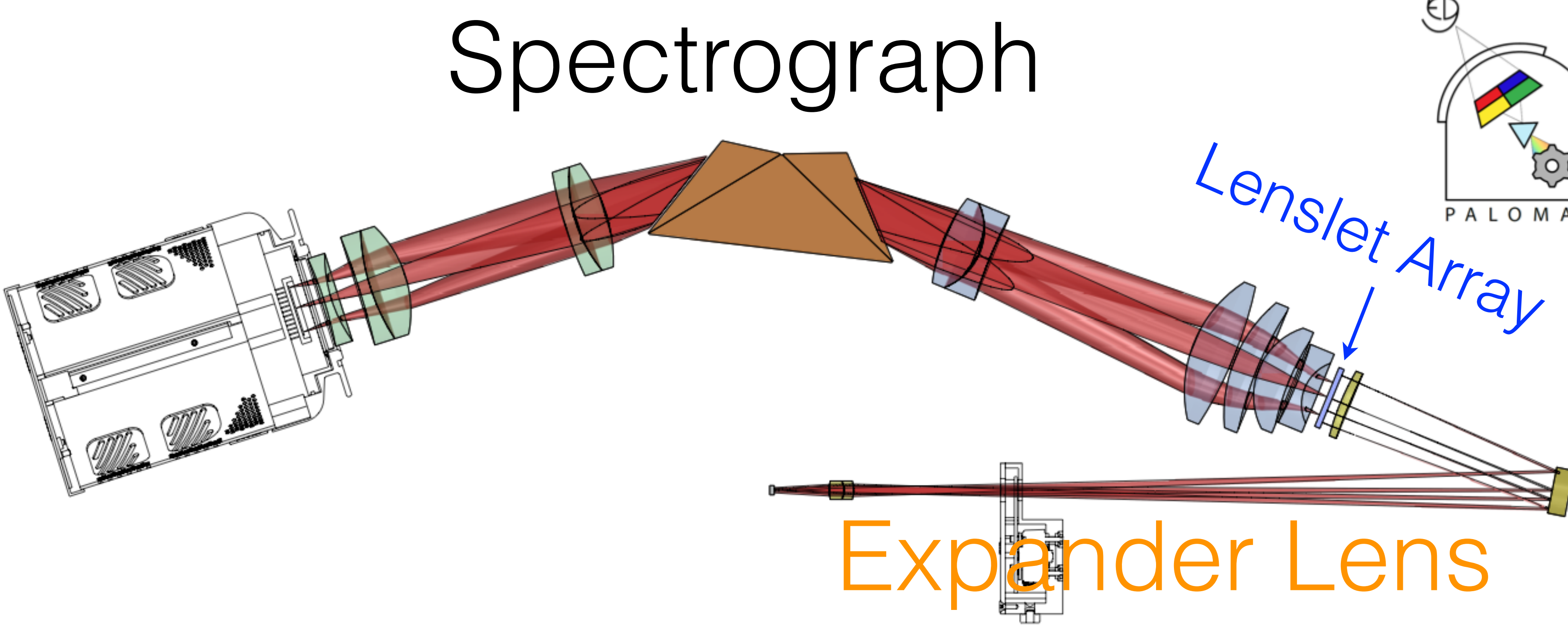


Figure shows sky-subtracted spectrum

Achieved with a lenslet array ("TIGER" style)



PALOMAR

Spectrophotometric accuracy- Key metric

- Observe the imaging fields flanking the science fields. Measure the atmospheric zero points. Correct via a bootstrap approach the extinction over the course of the night.

- SNIFS recognized that the medium-band filters were unnecessary so we chose to observe in u-i simultaneously. (This is actually technically hard to achieve without refocus. Excellent work by Sagi Ben-Ami to achieve the design).

Extinction: how to determine?

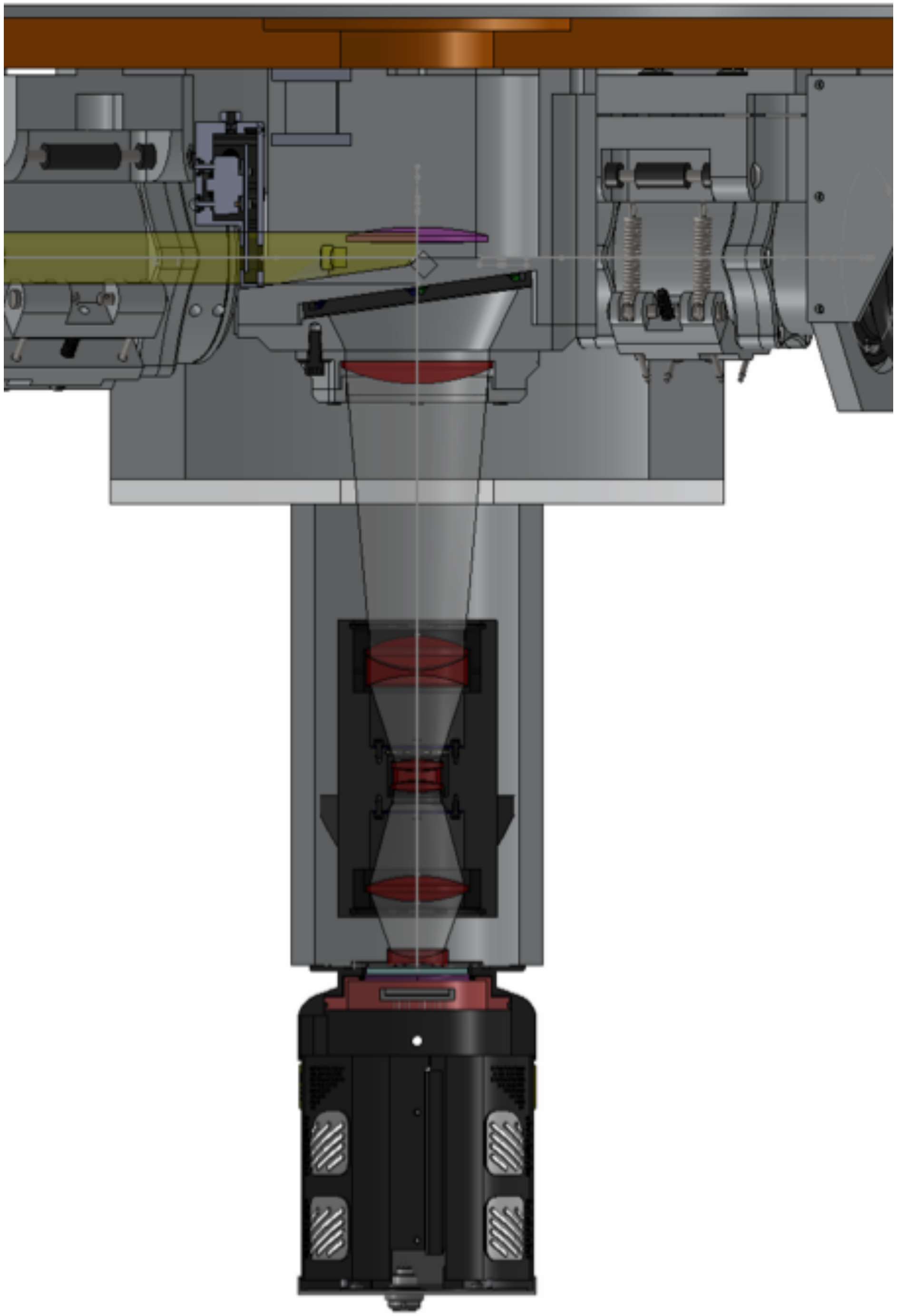
- Extinction is the main factor that affects the SED Machine's spectrophotometric accuracy. The SNIFS spectrograph inspired us

- It is the combination of a variety of physical processes:

$$\text{Rayleigh Scattering} \propto \lambda^{-4}$$

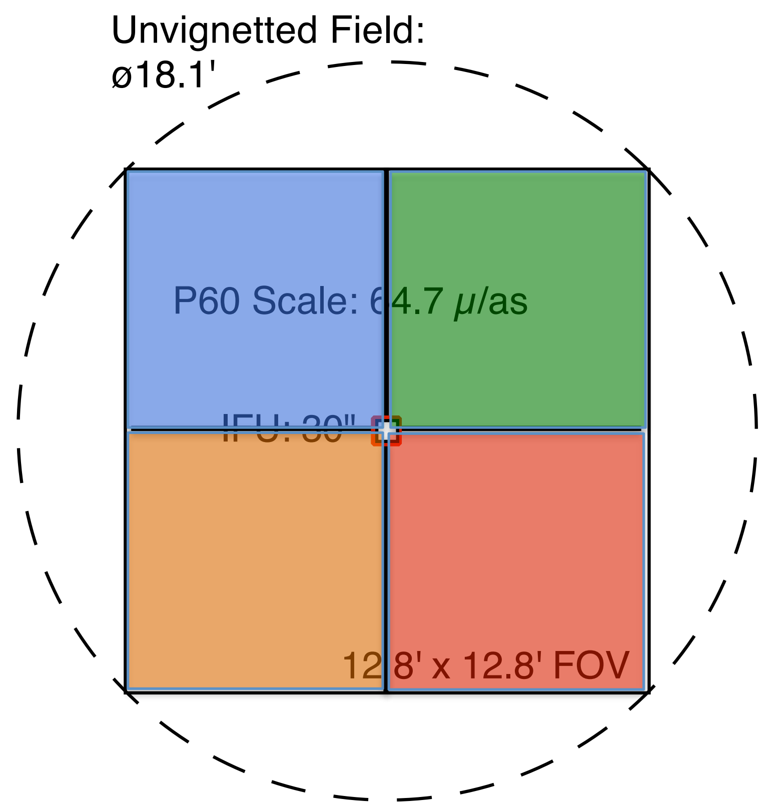
$$\text{Mie Scattering} \propto \lambda^{-1}$$

$$\text{H}_2\text{O Absorption} \propto \lambda^{0}$$



Rainbow Camera

Palomar 60" Focal Plane



High throughput- Key metric

- The instrument is designed to have high throughput from 365 nm - 1 μm.

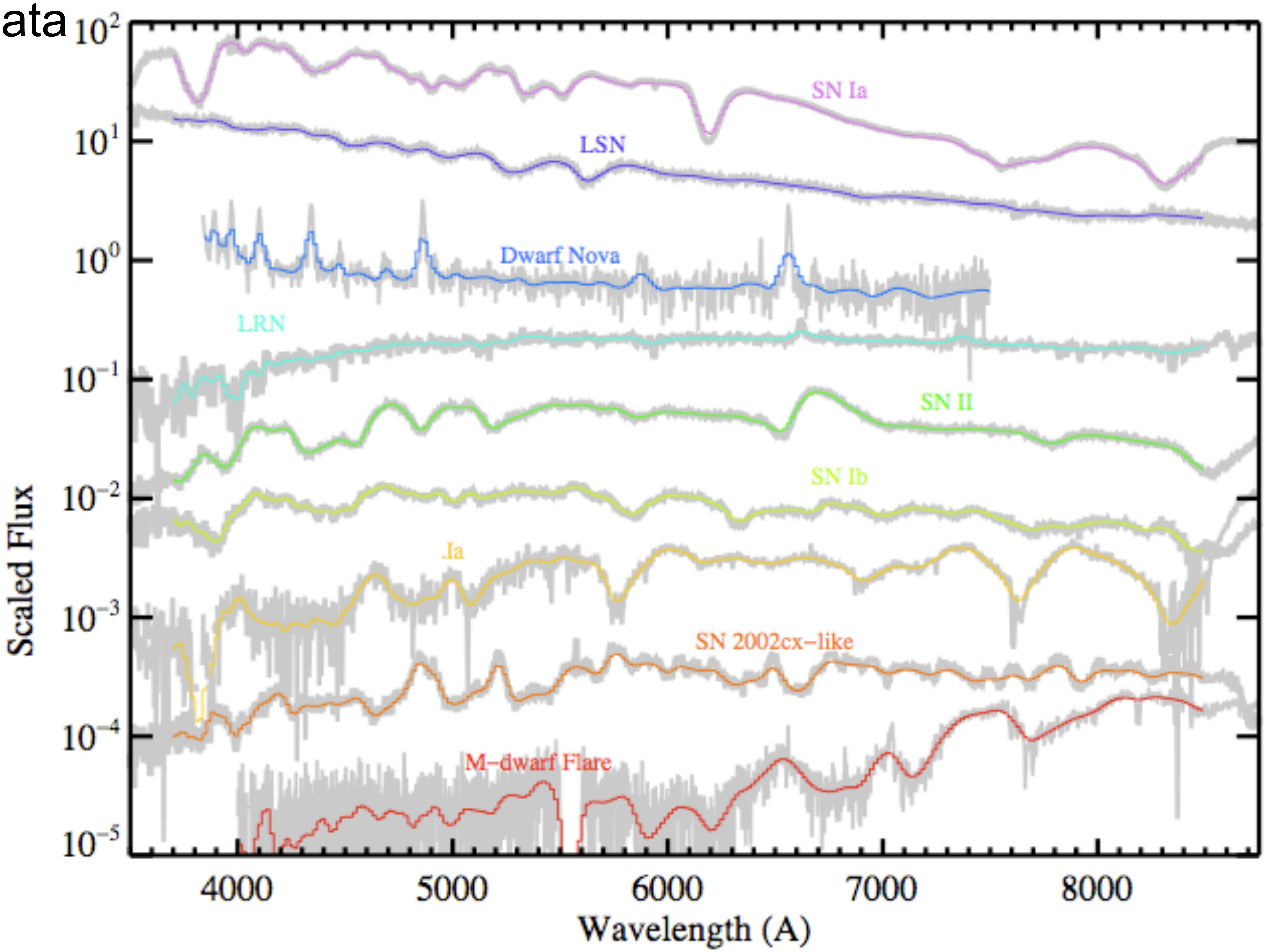
- A lot of work went into picking a spectral resolution ($R=\lambda/\Delta\lambda=100$) that would allow for efficient classifications.

- Low resolution means high-throughput prism rather than lossy gratings

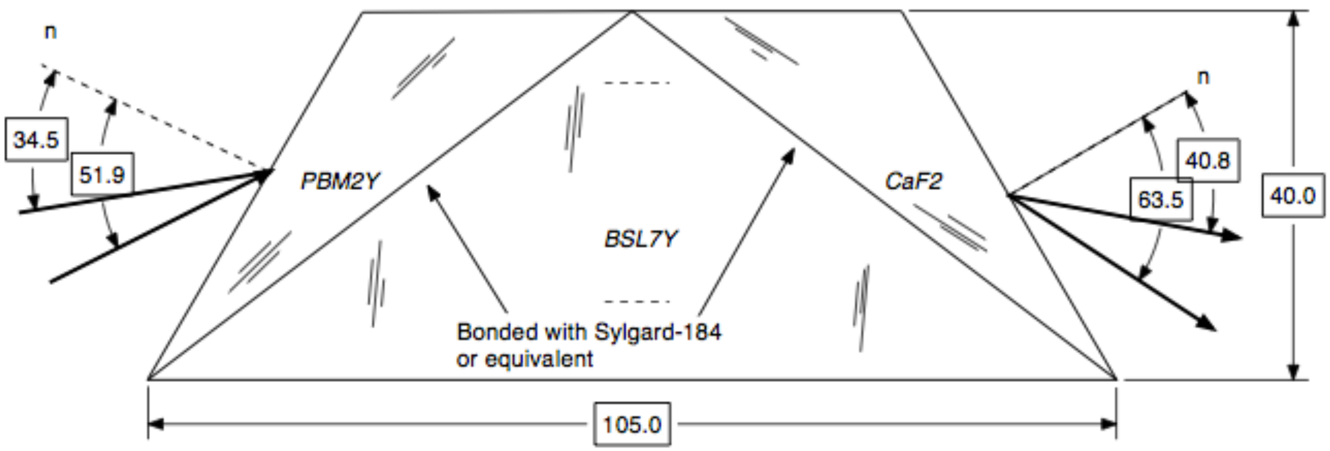
- (But throughput has never been as good as designed for reasons that have yet to be determined).

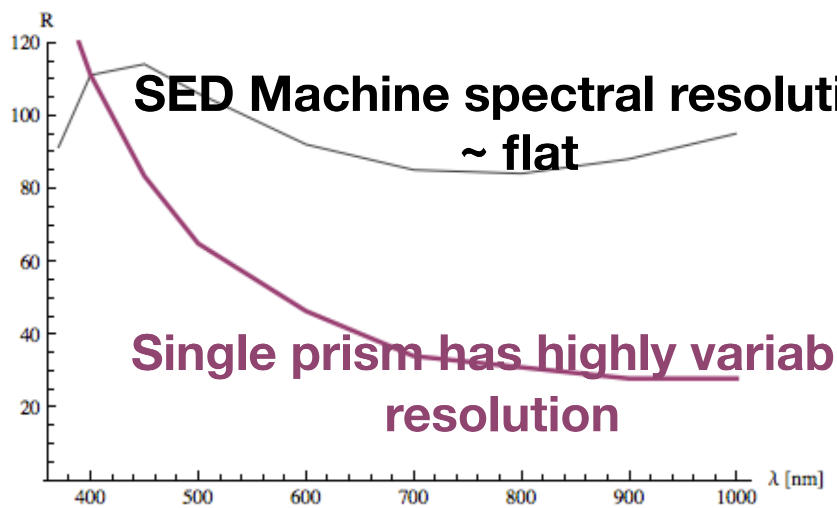
To classify with a single observation, R=100 is sufficient:

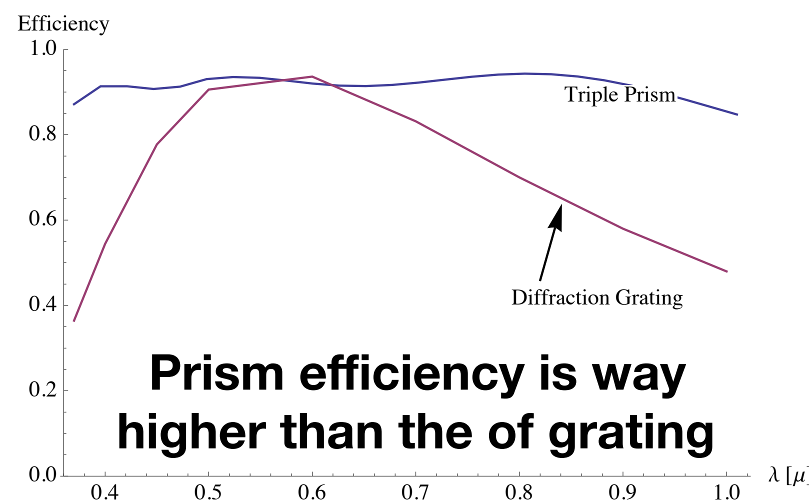
data



A lot of work went into designing an elaborate prism for SED Machine.







Results and future

- Pipeline was a journey to finish. Though we had some excellent starts, the first working end-to-end pipeline was written by Nick and finished a year after first light.
- SED Machine has been rebranded to SEDM. Fair because there has been a ton of work on improving the data reduction pipeline!
- SEDM now in routine use.

9 obj/ (good) night

Report generated on Thu Sep 29 08:52:01 2016

SEDM DRP run in /scr2/sedmdrp/redux/20160929
Found 15 sp_*.npy files

Object	Obs	Method	Exptime	Qual	Skysb	Airmass
STD-BD+28d4211	obs1	Single	300.0	0	on	1.004
STD-BD+25d4655	obs1	Single	300.0	0	on	1.007
STD-HZ4	obs1	Single	420.0	0	on	1.098
STD-HZ2	obs1	Single	300.0	0	on	1.118
STD-HZ2	obs2	Single	300.0	0	on	1.130
PTF16gox	-	A / B	2700.0	1	on	1.007
PTF16gmh	-	A / B	2700.0	1	on	1.071
PTF16gmw	-	A / B	2100.0	1	on	1.297
PTF16geh	obs1	Single	1350.0	1	on	1.235
PTF16gqj	-	A / B	2100.0	1	on	1.051
PTF16gop	-	A / B	2100.0	1	on	1.393
SolarHD210078	obs1	Single	180.0	1	on	1.417
NGC_884-8	obs1	Single	300.0	2	on	1.220
NGC_884-16	obs1	Single	420.0	1	on	1.204
NGC_884-12	obs1	Single	300.0	1	on	1.123

Total quality (1-3) science exposure time = 15870.0 s

Lessons learned

- The instrument's lack of throughput and no (as far as I know) diagnosis has been made.
- Despite throughput that is at least half of what we designed and hoped for — yet the instrument has been unbelievably useful in early-light spectra and imaging (TDE 14fnl, 14hls, the COW)
- Even underperforming SED Machine is a key tool and more could be used.

What's next?

- Whole idea of SED Machine was to build many copies. What lessons?
  - IFU is essential but lensless probably wrong approach (Carnegie Fellow McGurk has figured out a very low cost way to build slicers)
  - We could benefit from R~1,000 spectral resolution — slicer enables this. (I'd love to discuss this point).
  - Rainbow camera never really got used as intended as far as I know.
  - **MORE are needed**
- Single Planewave 1-m is \$730 k, a new SED Machine with slicer is probably \$600 k:
  - SED machine next gen + 1m planewave is \$1.4 MUSD / m^2
  - DBSP on a new 6.5 m is \$3.6 MUSD / m^2
  - The cost of a SED machine + Planewave is within reach for a small department. It's possible to build a farm of followup machines.
- Array v monolithic argument goes back to probably photographic plates — I think the science has changed such that an array of small telescopes is more exciting.