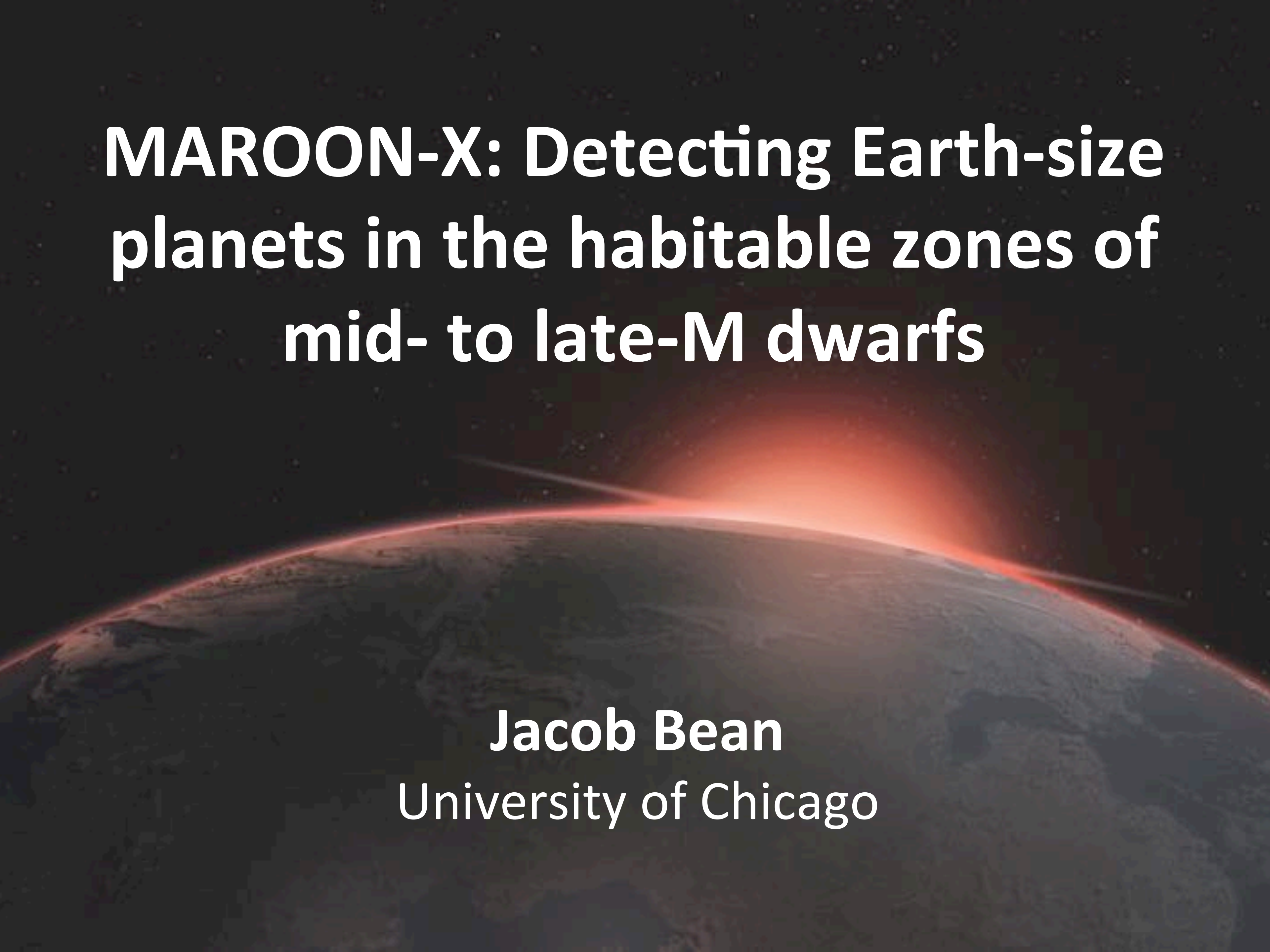


MAROON-X: Detecting Earth-size planets in the habitable zones of mid- to late-M dwarfs

Jacob Bean
University of Chicago

MAROON-X

Primary science driver: RV follow-up of transiting, temperate, and terrestrial planets that are feasible targets for atmospheric spectroscopy.

Goal: $\sigma = 1\ \mathrm{m\ s^{-1}}$ in 30 min for a late M dwarf at 20 pc (V=17.0).

Approach: a highly-stabilized, fiber-fed spectrograph covering 500 – 900nm at R=80k with simultaneous calibration feed and pupil slicing.

Currently: Spectrograph delivered to Chicago November 2016; further integration and testing ongoing; commissioning in 4th quarter 2018.

New Radial Velocity Instrument for M Dwarfs at Gemini-N

See Seifahrt+ 2016a for an overview

MAROON-X: Who?

Jacob Bean

The suit

Ben Montet

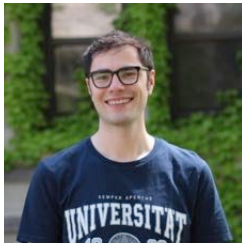
Sagan Fellow since 2016

Andreas Seifahrt

Research scientist and lab manager

Emily Gilbert

Graduate student



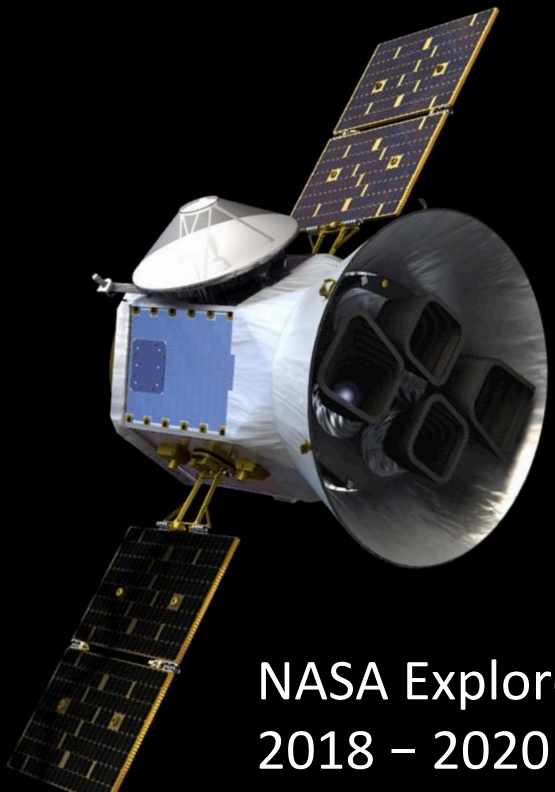
Julian Stürmer

Postdoc since May 2015

Leonardo dos Santos

Former visiting student from Brazil

Thanks to former undergrads Adam Sutherland and Katrina Miller!



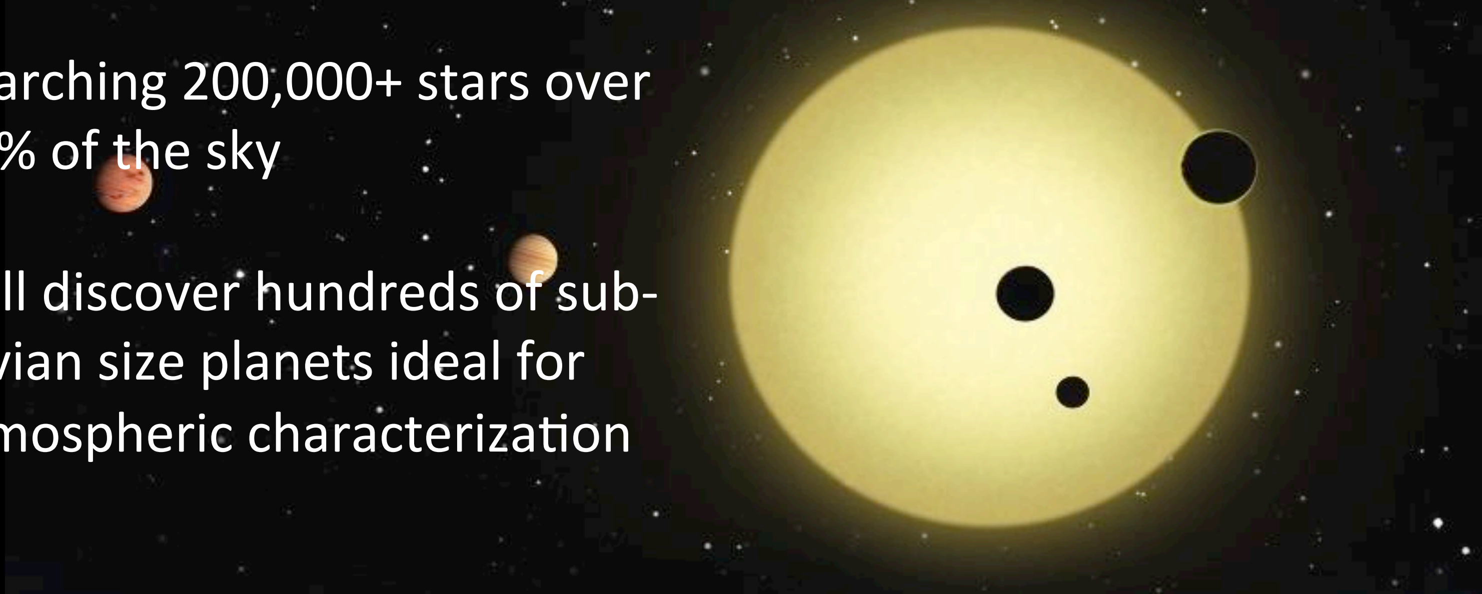
TESS

Transiting Exoplanet Survey Satellite

NASA Explorer Mission,
2018 − 2020

Searching 200,000+ stars over 90% of the sky

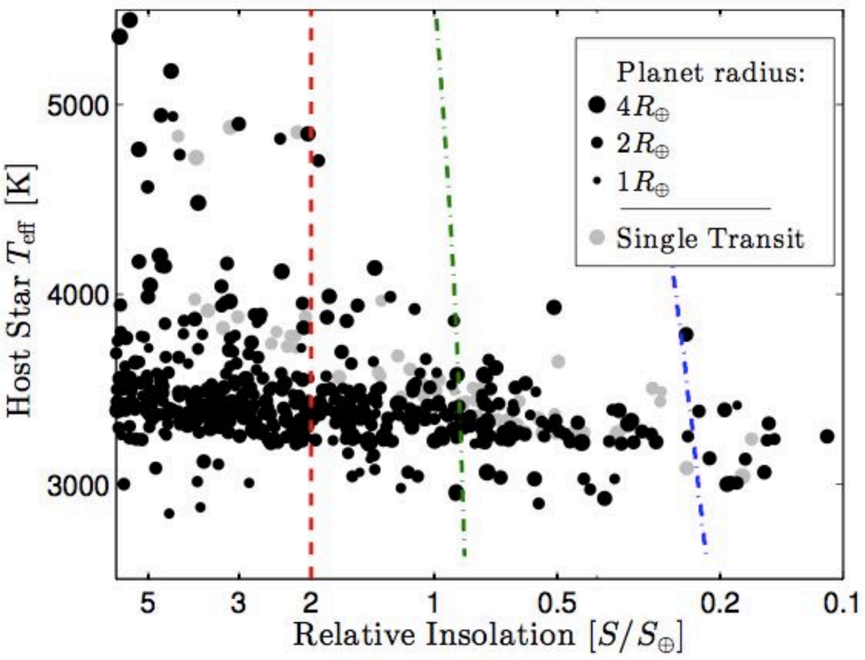
Will discover hundreds of sub-Jovian size planets ideal for atmospheric characterization

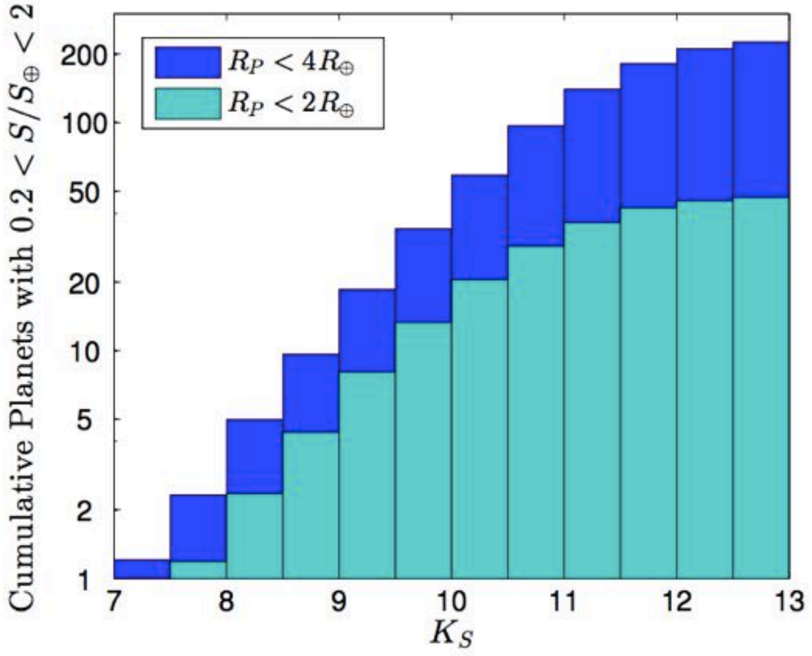


Ricker+ 2015

MAROON-X: Why (on a large telescope)?

TESS Yield Simulations

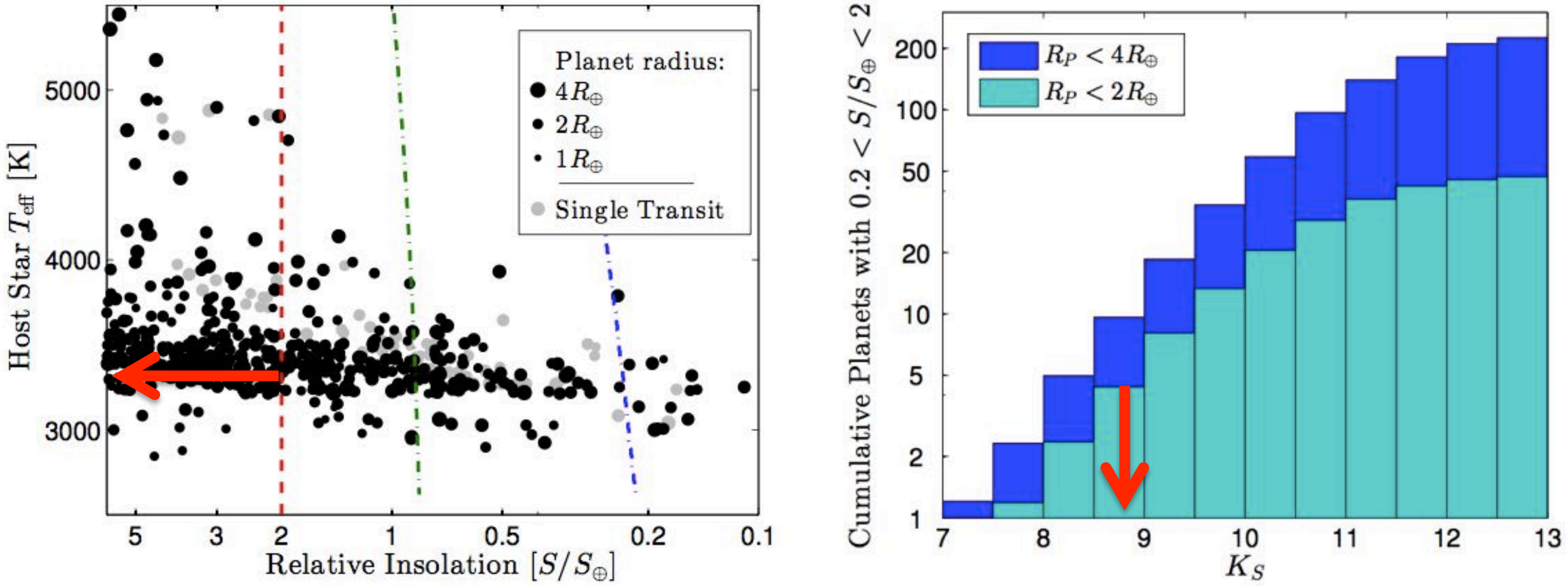




Sullivan+ 2015
Based on *Kepler* statistics from
Dressing & Charbonneau 2015

MAROON-X: Why (on a large telescope)?

TESS Yield Simulations



-- GJ 1214 values in **red** --

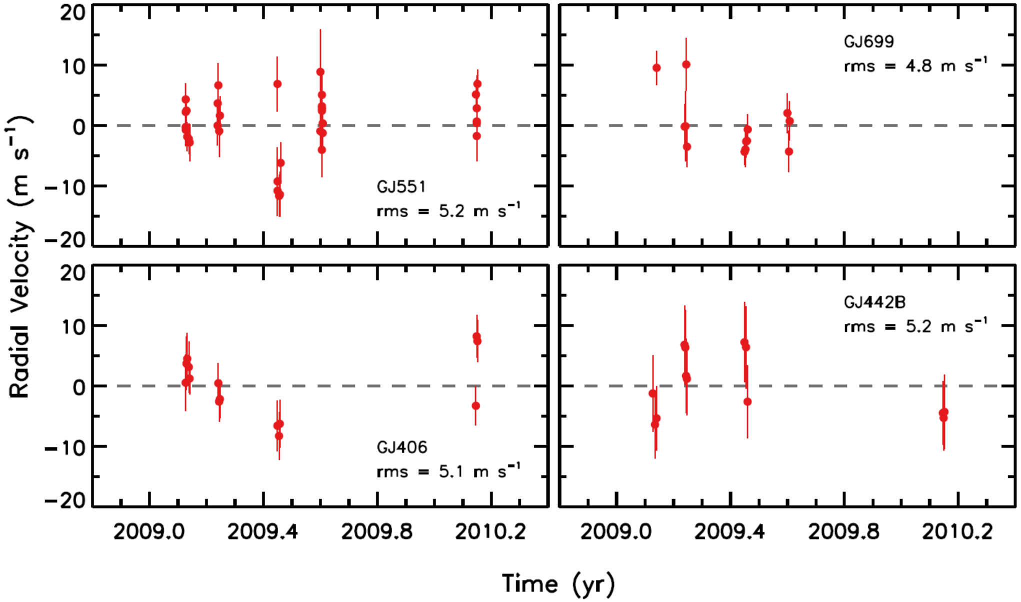
Reminder: HARPS RVs of GJ 1214 yield 3.5 m s^{-1} precision in 45 min.

Sullivan+ 2015
Based on *Kepler* statistics from
Dressing & Charbonneau 2015

MAROON-X: Heritage

Ammonia gas cell

Precise NIR RVs from CRIRES



Bean+ 2010a

Limitations of CRIRES + NH_3 cell approach

- Telluric line contamination

- Small spectral coverage
- Lack of image scrambling
- Instrument not stabilized
- Gas cell calibration imperfect and inefficient
- K-band (2.3μm) not at the peak of the SED, nor the max RV information content

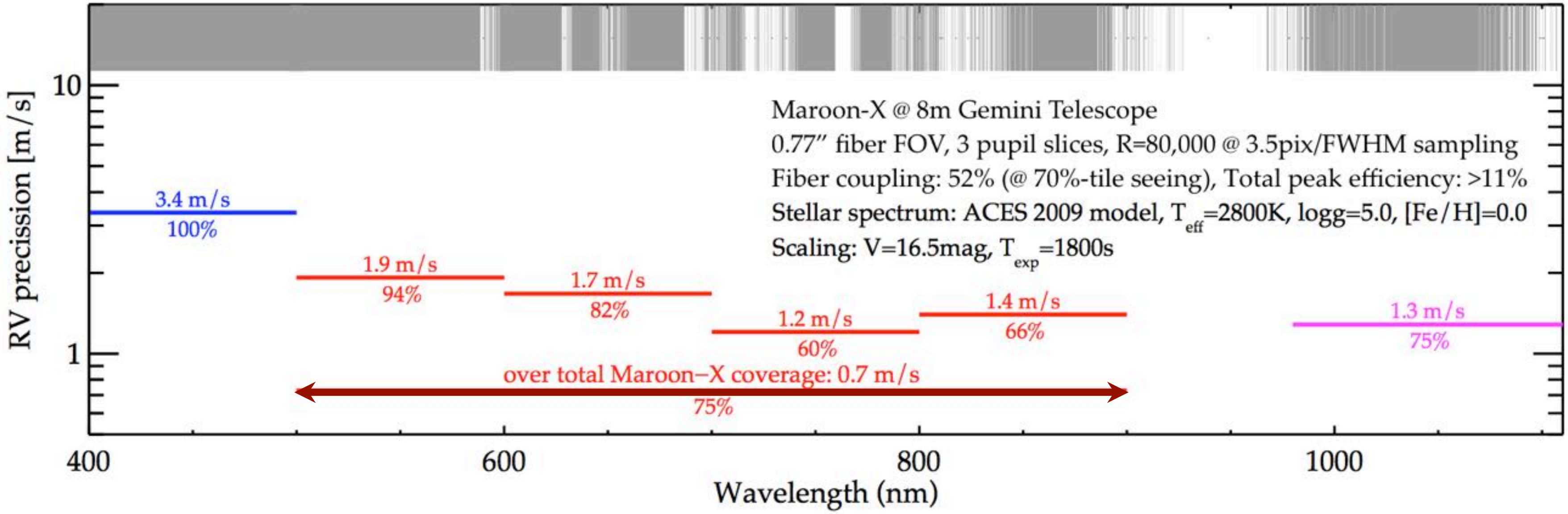
Towards New Instruments: Other Issues

- Detectors: CCD vs hybrid CMOS
    - Size
    - Cost
    - Operating temperature
    - Read out noise
    - Dark current
    - Oddities
- Instrument temperature
- Fiber modal noise
- Calibration
- Use of AO
- Heritage
- Sky background

Green: advantage optical
Orange: advantage NIR

MAROON-X: Wavelength Coverage

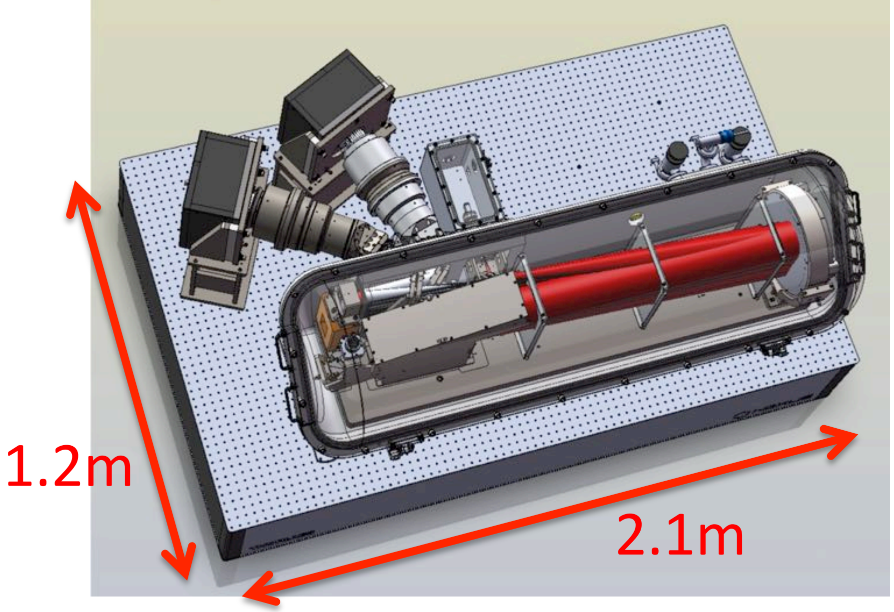
calculations benchmarked on real spectra

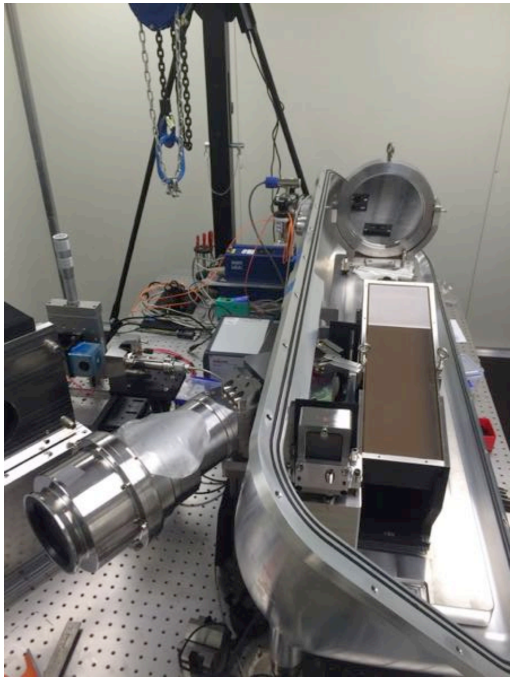


Seifahrt+ 2016a

See also: Reiners+ 2010, Rodler+ 2011, Bottom+ 2013, Figueira+ 2016

MAROON-X: Kiwispec R4-100





Timeline:

- June 2014 – PDR (thanks to Andy Szentgyorgyi & Francesco Pepe!)
- July 2015 – Signed contract for purchase of single arm spectrograph
- August 2015 – FDR
- September 2016 – Final integration and first light in the lab
- January 2017 – Installation of spectrograph in U. Chicago lab
- Late 2018 – Commissioning at Gemini

MAROON-X: First Light!

MAROON-X: Pupil Slicer

For an astronomical spectrograph:

$$R = \frac{2d \tan\theta}{sD}$$

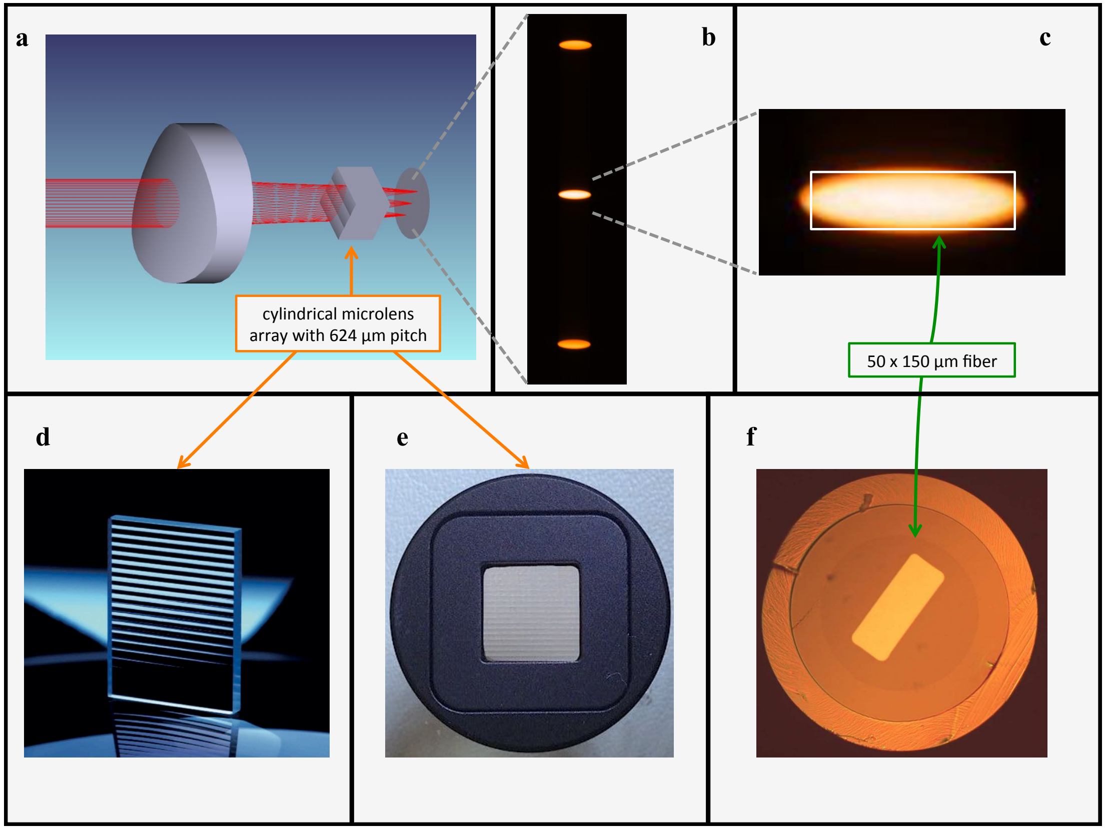
R: spectral resolving power

d: beam diameter on the grating

θ: incidence angle

s: sky projected slit size

D: diameter of the telescope



Seifahrt+ 2016b

MAROON-X: Pupil Slicer

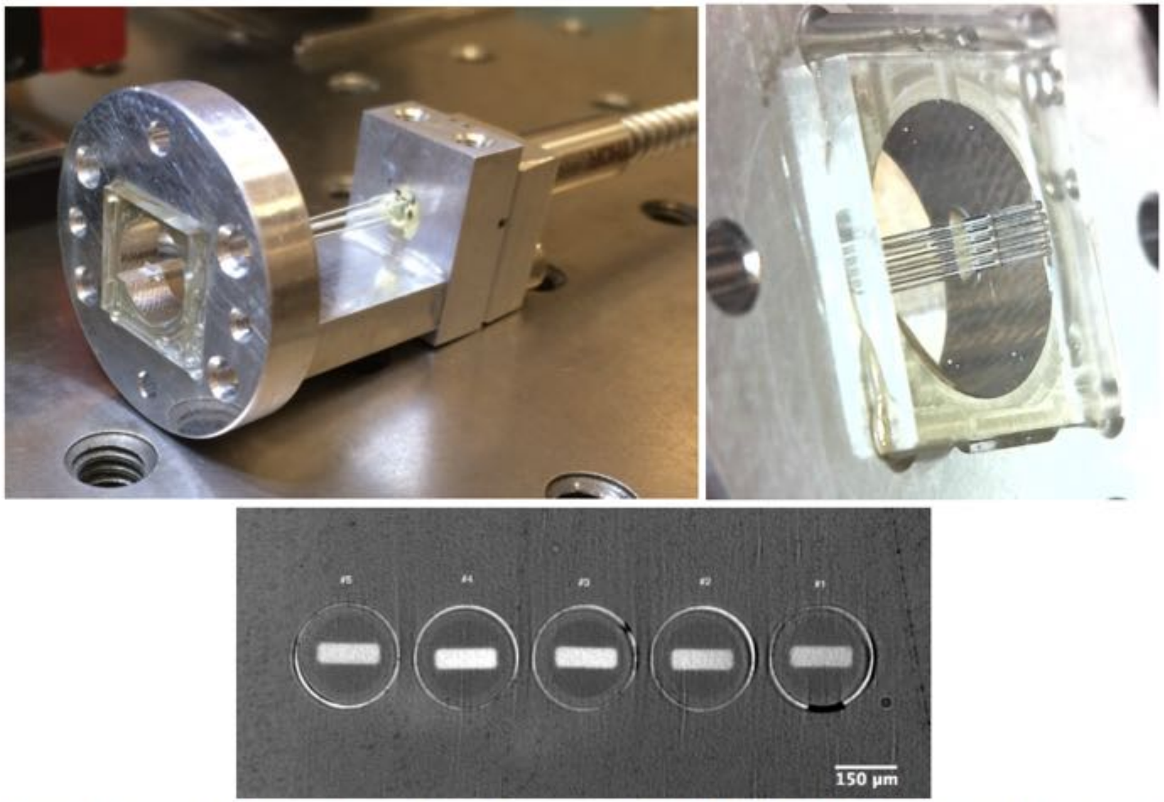


Figure 5: **Prototype linear fiber array and pseudo-slit for MAROON-X**. Top left: FEMTOprint fiber slit plate in a custom mount fixture with five Ceramoptec $50\,\mu\mathrm{m} \times 150\,\mu\mathrm{m}$ rectangular fibers already inserted. Top right: Close-up of the slit plate. The fibers stick out a couple mm from the front of the plate. At this step the fibers are already glued into the guide block for strain relief and to fix their rotation angle but adhesive is not yet applied to the bare fiber ends in the slit plate. Bottom: Same assembly after polishing. While technically within specification, the prototype slit plate shown here has still sub-optimal alignment. The fibers were etched slightly too long, making them $5\,\mu\mathrm{m}$ to $6\,\mu\mathrm{m}$ smaller than the holes in the plate, which leads to offsets. Likewise, rotational alignment of two fibers (#3 and #4) is off by $-1.5°$ and $1.1°$, respectively.

Seifahrt+ 2016b

MAROON-X: Wavelength Calibration

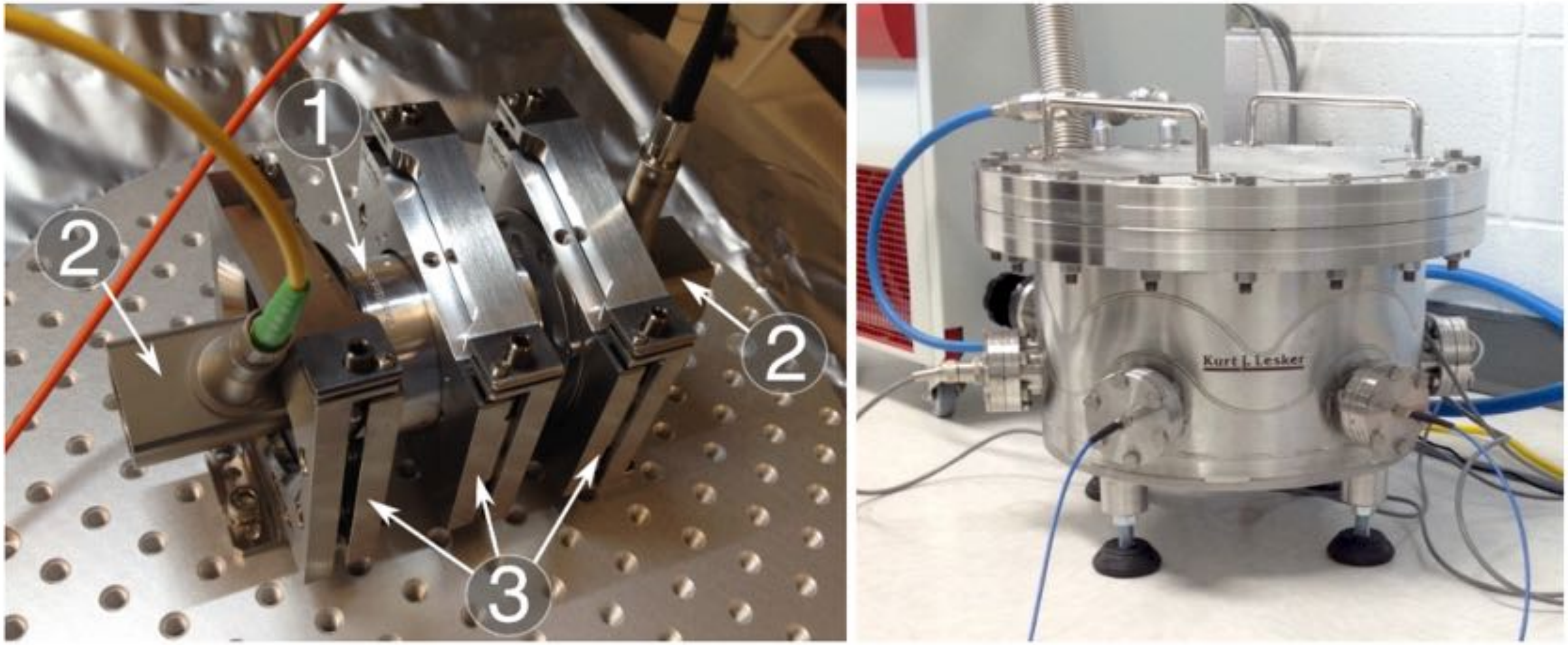
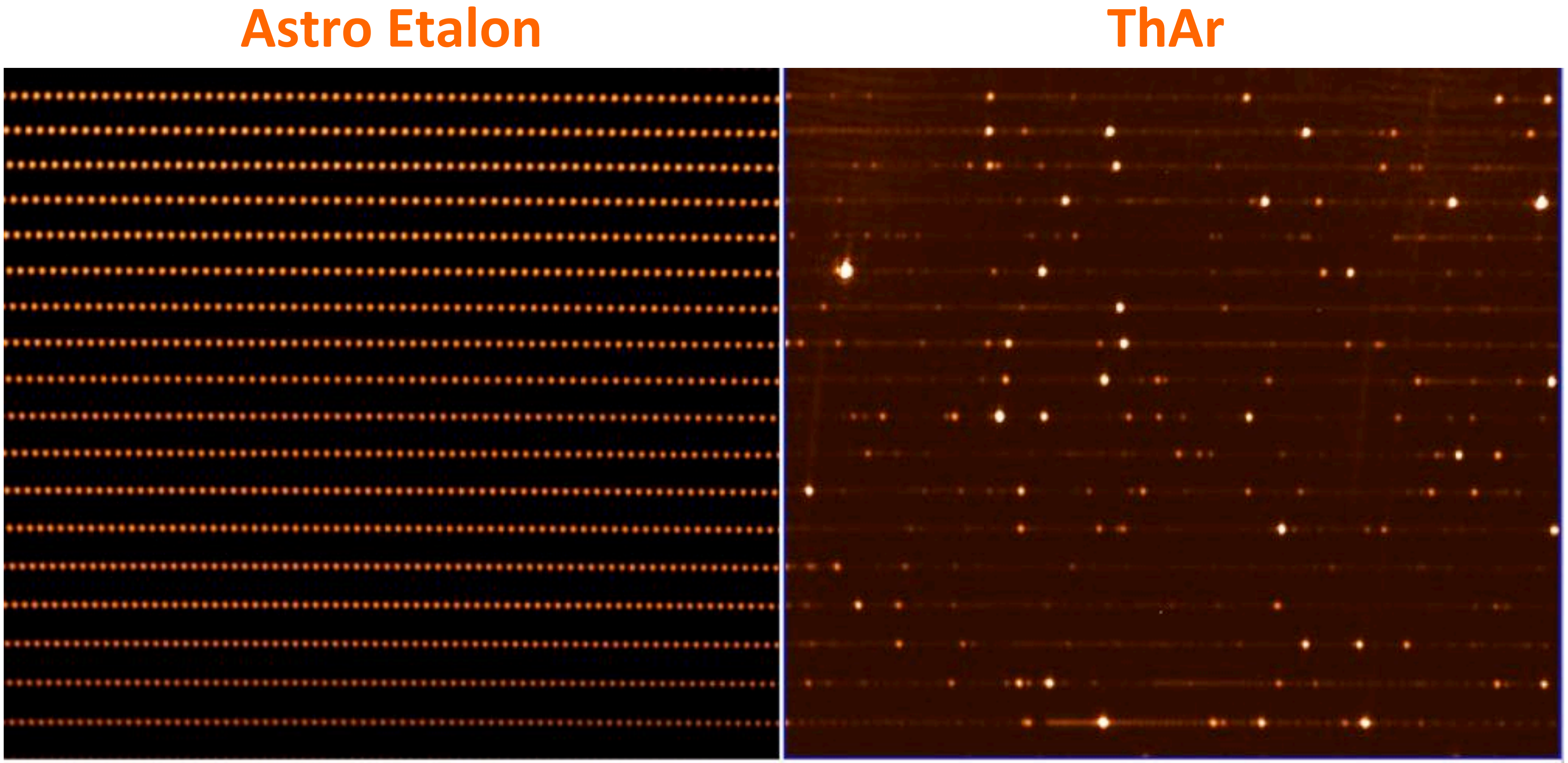


Figure 1. FP etalon opto-mechanics and vacuum chamber. Left: FP etalon (1) and OAP collimators (2) in vacuum compatible tip-tilt mounts (3) on a breadboard before vacuum integration. Right: System integrated in a vacuum chamber from J.K. Lesker with in-built channels for liquid circulation to provide temperature control at the $\leq 5\,\mathrm{mK}$ level with an external bath thermostat (not shown). During operation the vacuum vessel is contained in another insulation box (also not shown here) to attenuate temperature variation of the room.

Stürmer+ 2016b

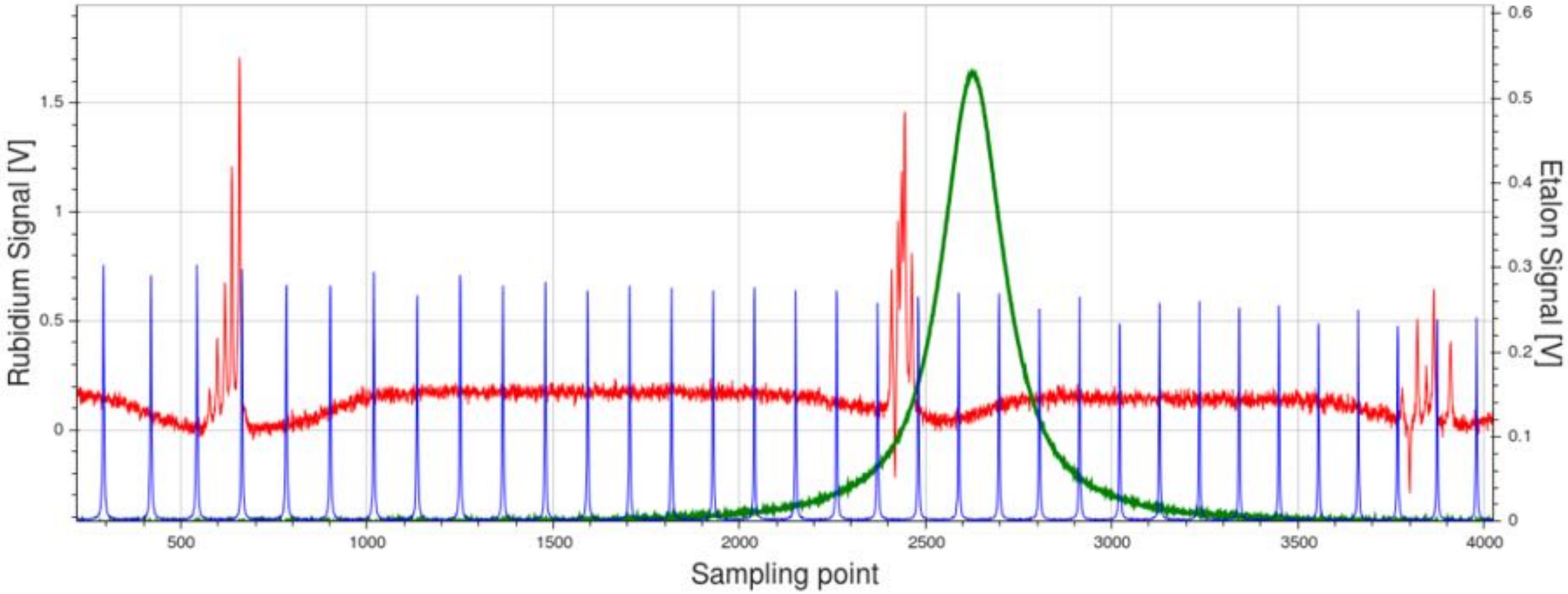
MAROON-X: Wavelength Calibration



Stürmer+ 2016b

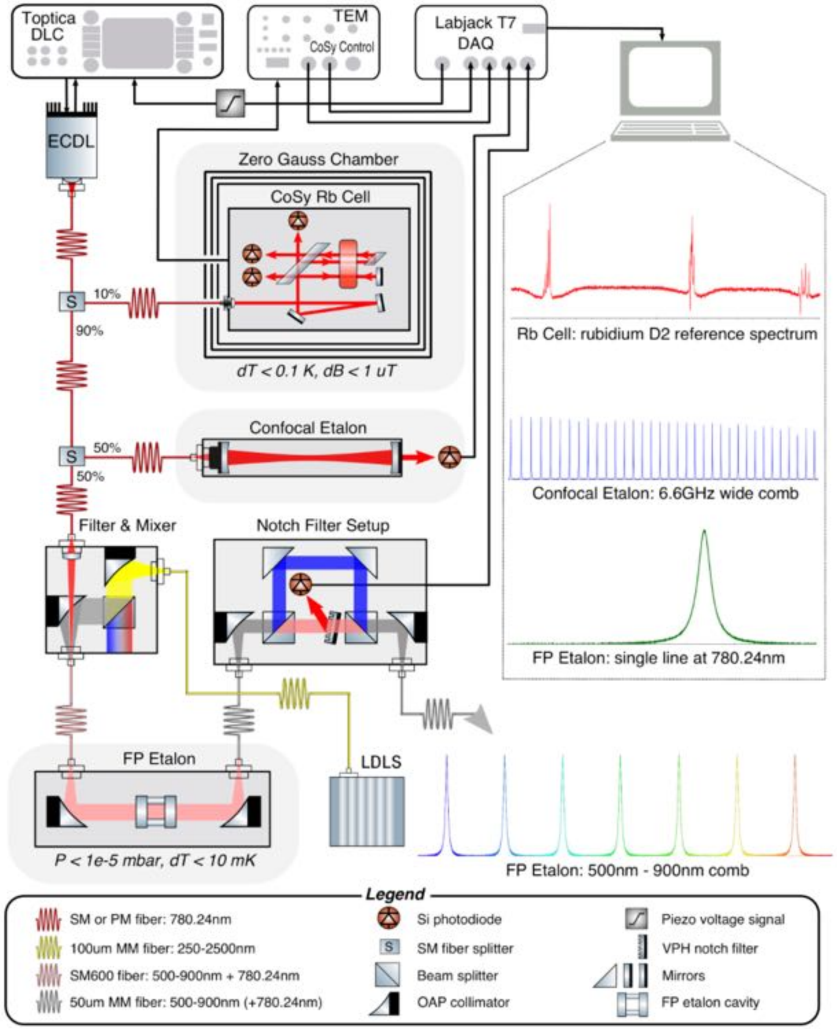
MAROON-X: Wavelength Calibration

rubidium gas cell confocal etalon astro etalon



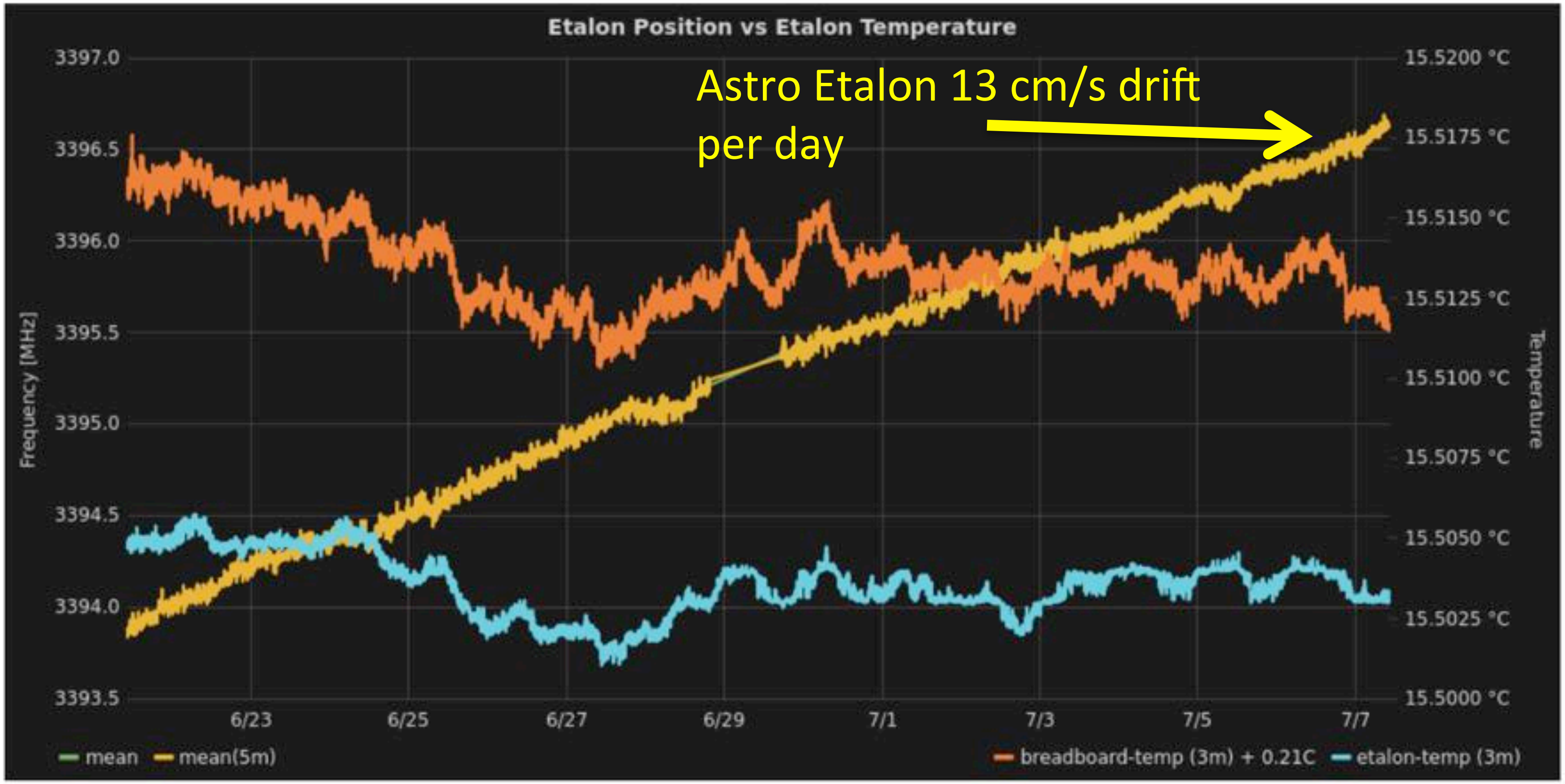
Stürmer+ 2016b

MAROON-X: Wavelength Calibration



Stürmer+ 2016b

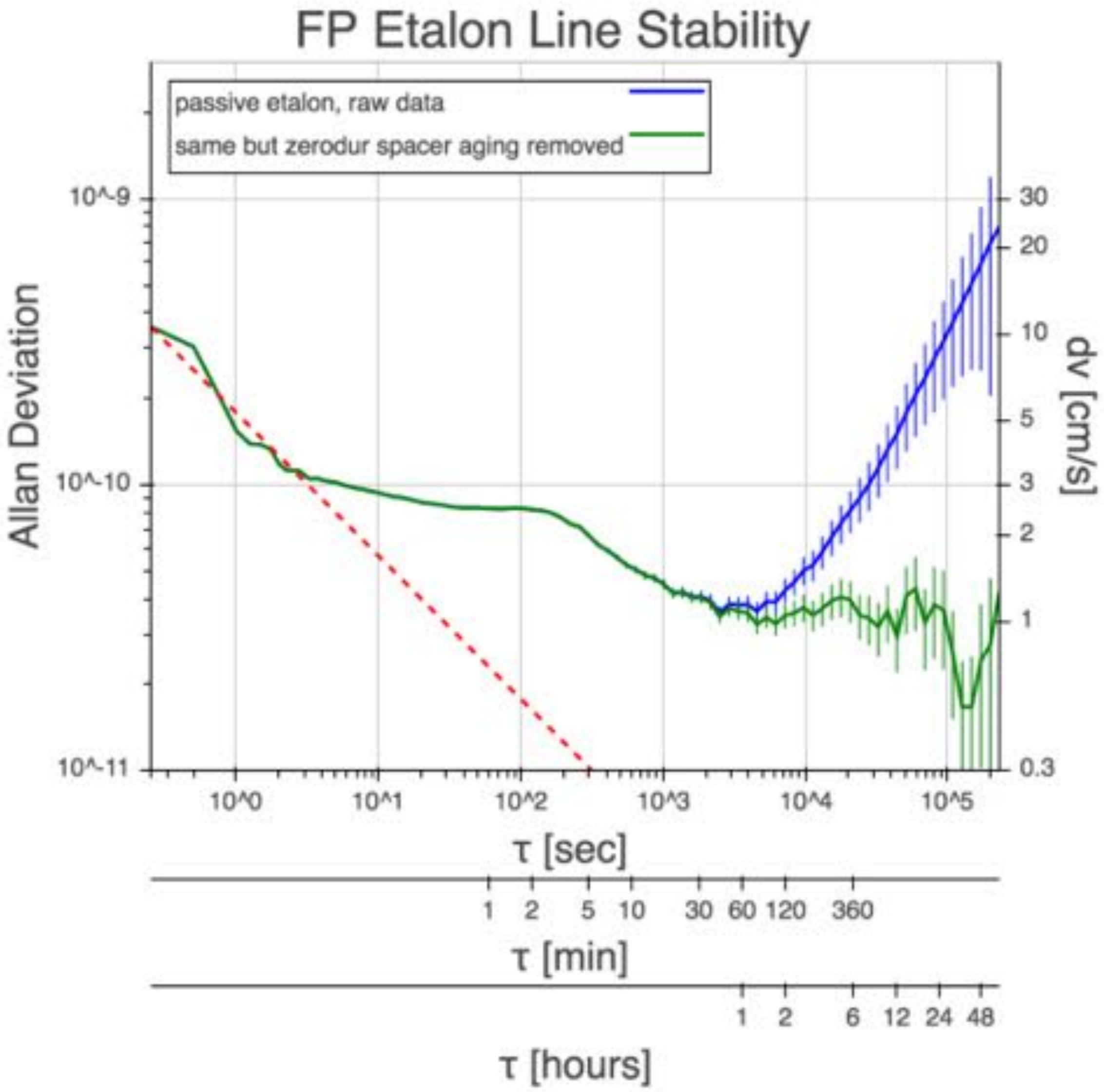
MAROON-X: Wavelength Calibration



Astro Etalon 13 cm/s drift per day

Stürmer+ 2016b

MAROON-X: Wavelength Calibration



Stürmer+ 2016b

MAROON-X: Fiber Characterization

Classical scrambling gain metric:

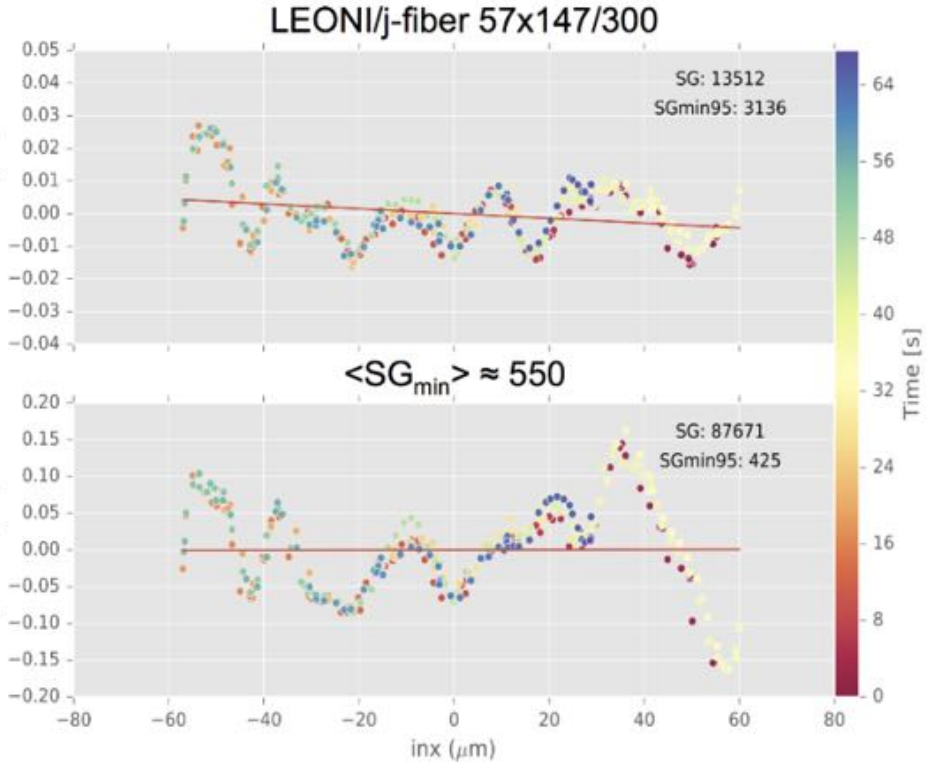
$$SG = \frac{(d_{input}/D_{input})}{(d_{output}/D_{output})}$$

d_{input}: shift of image at the fiber input

d_{output}: shift of the image at the fiber output

D_{input}: fiber size

D_{output}: near-field image size



Sutherland+ 2016

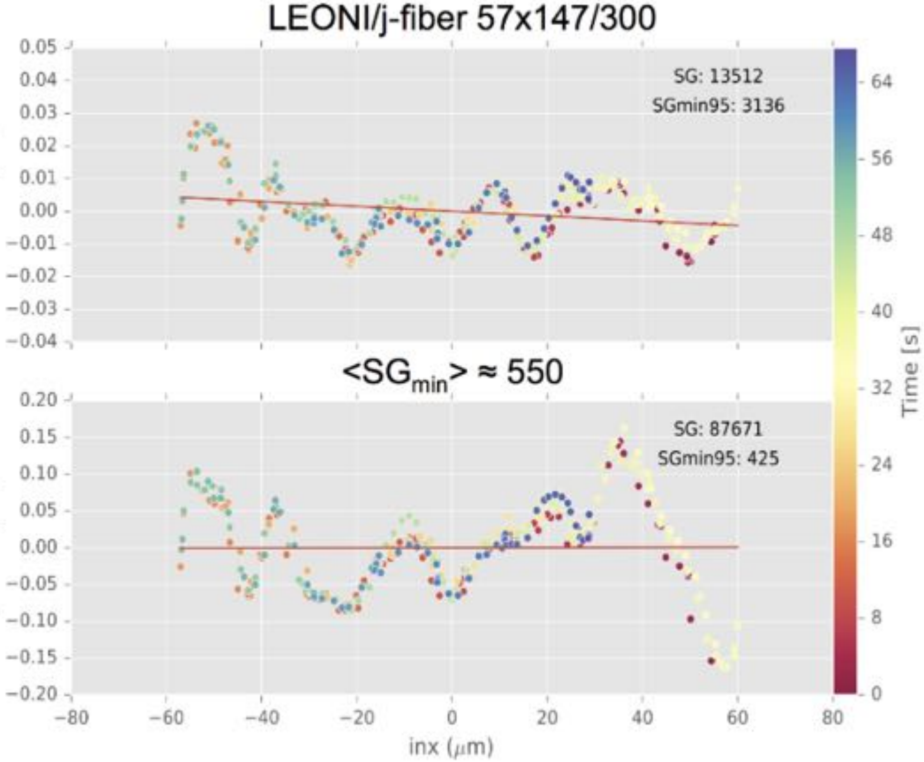
MAROON-X: Fiber Characterization

New scrambling gain metric:

$$SG_{min} = \frac{D_{input}}{\max(d_{output})}$$

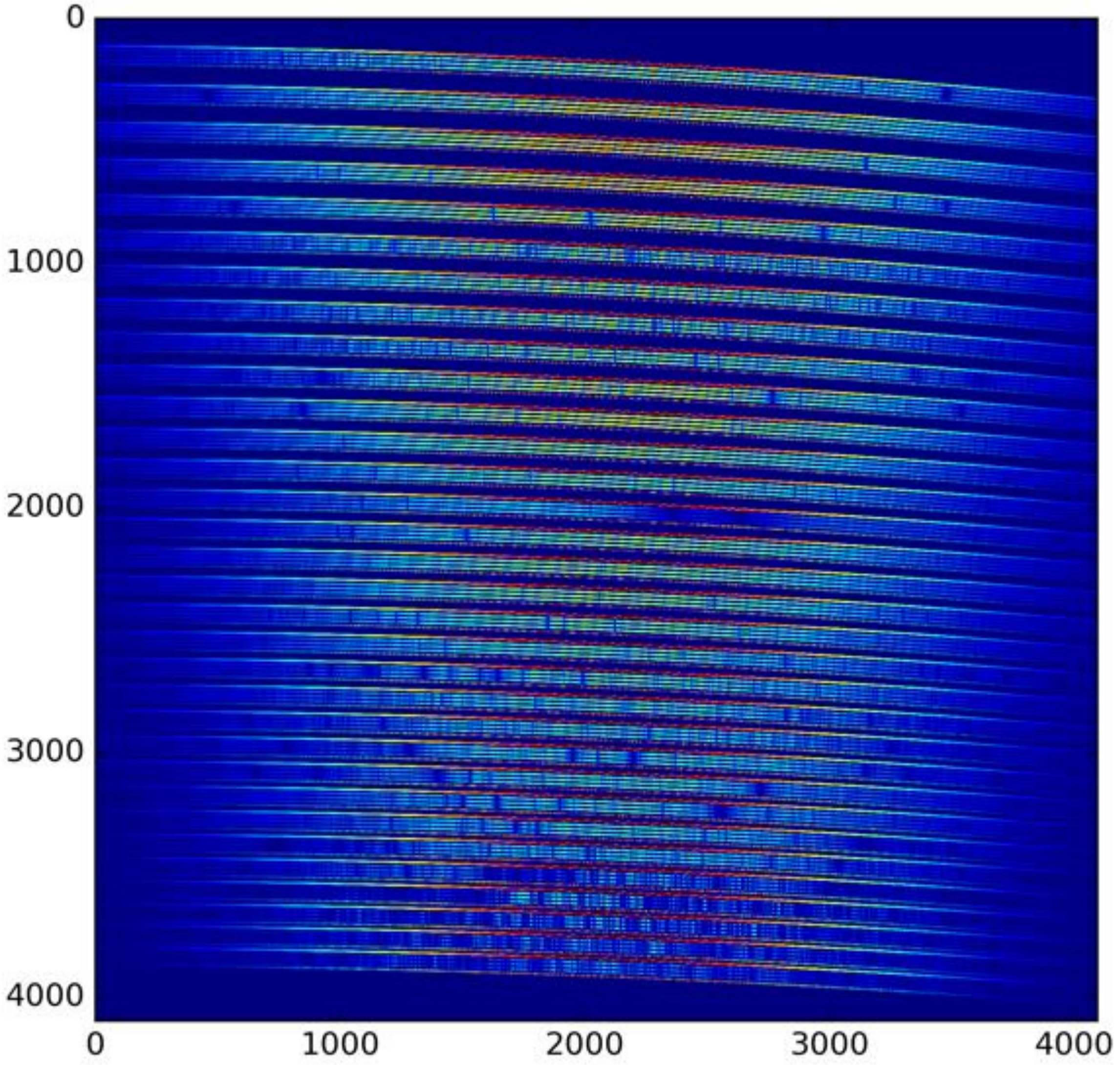
d_{output}: shift of the image at the fiber output

D_{input}: fiber size



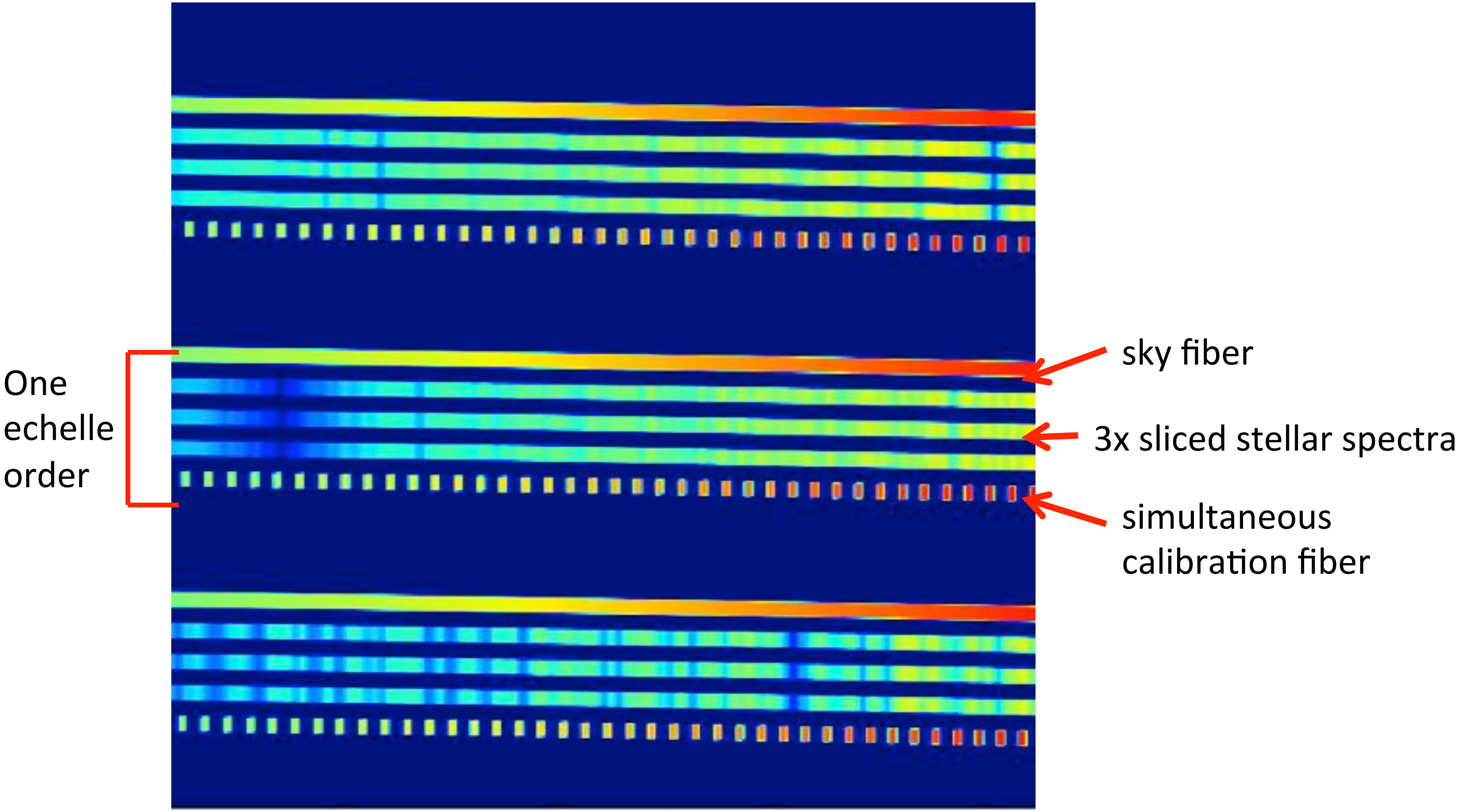
Sutherland+ 2016

MAROON-X: Spectrum Simulator



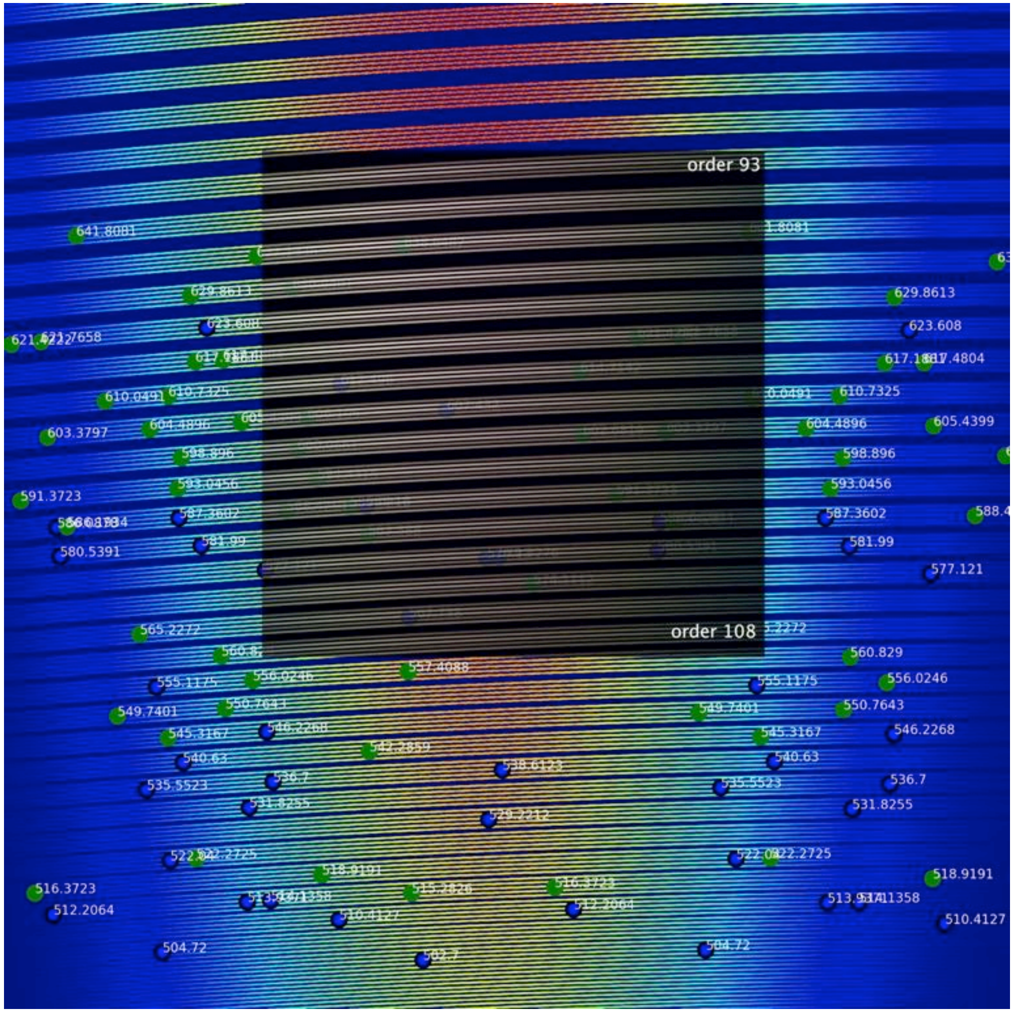
Simulation by Julian Stürmer

MAROON-X: Spectrum Simulator

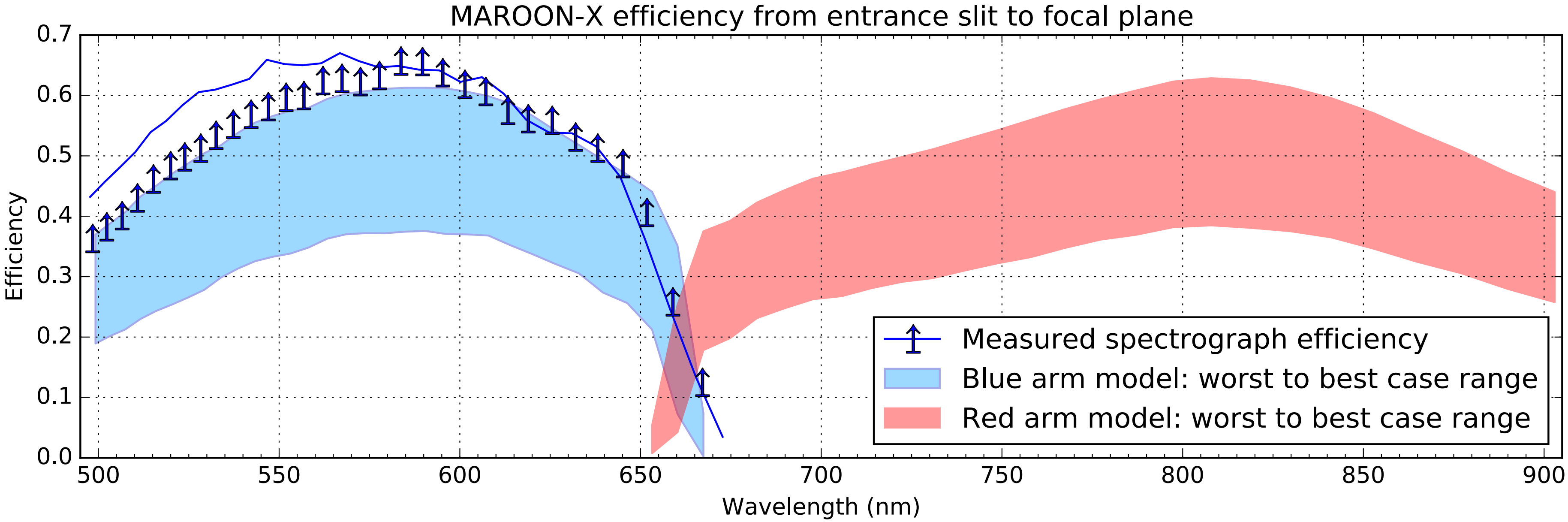


Simulation by Julian Stürmer

MAROON-X: First Light



MAROON-X: Performance



MAROON-X: Adventures in PPE

MAROON-X

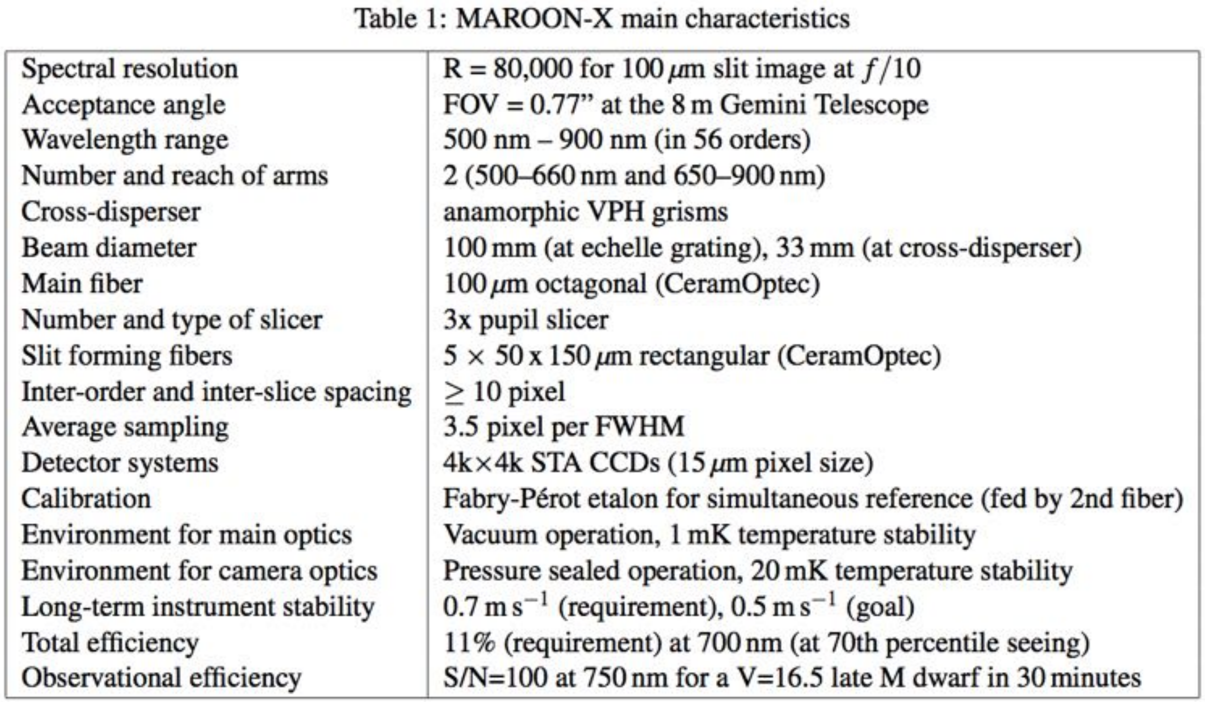


Table 1: MAROON-X main characteristics

Spectral resolution	R = 80,000 for 100 μm slit image at $f/10$
Acceptance angle	FOV = 0.77" at the 8 m Gemini Telescope
Wavelength range	500 nm – 900 nm (in 56 orders)
Number and reach of arms	2 (500–660 nm and 650–900 nm)
Cross-disperser	anamorphic VPH grisms
Beam diameter	100 mm (at echelle grating), 33 mm (at cross-disperser)
Main fiber	100 μm octagonal (CeramOptec)
Number and type of slicer	3x pupil slicer
Slit forming fibers	5 × 50 x 150 μm rectangular (CeramOptec)
Inter-order and inter-slice spacing	$\geq$ 10 pixel
Average sampling	3.5 pixel per FWHM
Detector systems	4k×4k STA CCDs (15 μm pixel size)
Calibration	Fabry-Pérot etalon for simultaneous reference (fed by 2nd fiber)
Environment for main optics	Vacuum operation, 1 mK temperature stability
Environment for camera optics	Pressure sealed operation, 20 mK temperature stability
Long-term instrument stability	0.7 m s^{-1} (requirement), 0.5 m s^{-1} (goal)
Total efficiency	11% (requirement) at 700 nm (at 70th percentile seeing)
Observational efficiency	S/N=100 at 750 nm for a V=16.5 late M dwarf in 30 minutes

See our recent papers…

MAROON-X overview: Seifahrt+, arXiv:1606.07140

Pupil slicer: Seifahrt+, arXiv:1606.07139

Fiber scrambling: Sutherland+, arXiv:1607.02490

Non-symmetric fibers: Stürmer+, arXiv:1607.02494

Astro etalon: Stürmer+, arXiv:1607.05172