HOLMS,
Heterodyne OH Lunar Miniaturized Spectrometer

Sona Hosseini[1], Negar Fehyar[2], Tony Colaporate[3], Amanda Hendrix[4], James WU[1], Bjorn Davidsson[1], Bob West[1], Mike Davis[5], Chris Webster[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, [2]SSL, [3]NASA Ames, [4]Planetary Science Institue, [5]Southwest Research Institute

Pushing the Boundaries

Interplanetary SmallSats

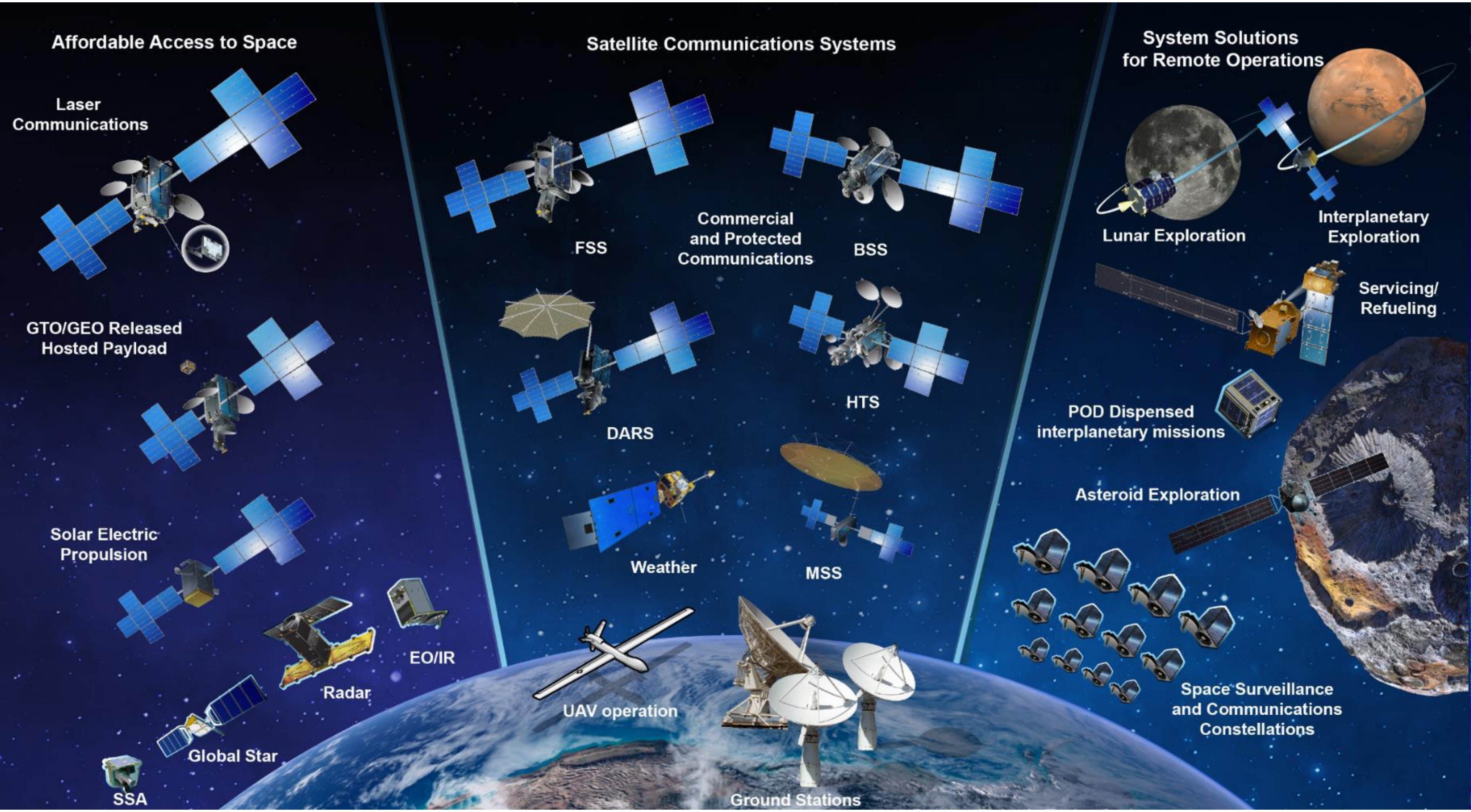
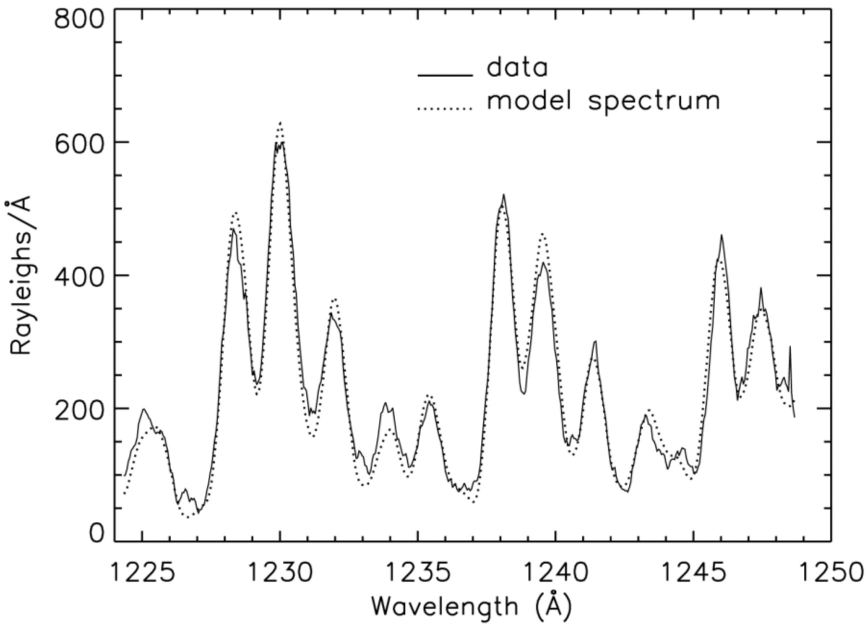


Image: SSL

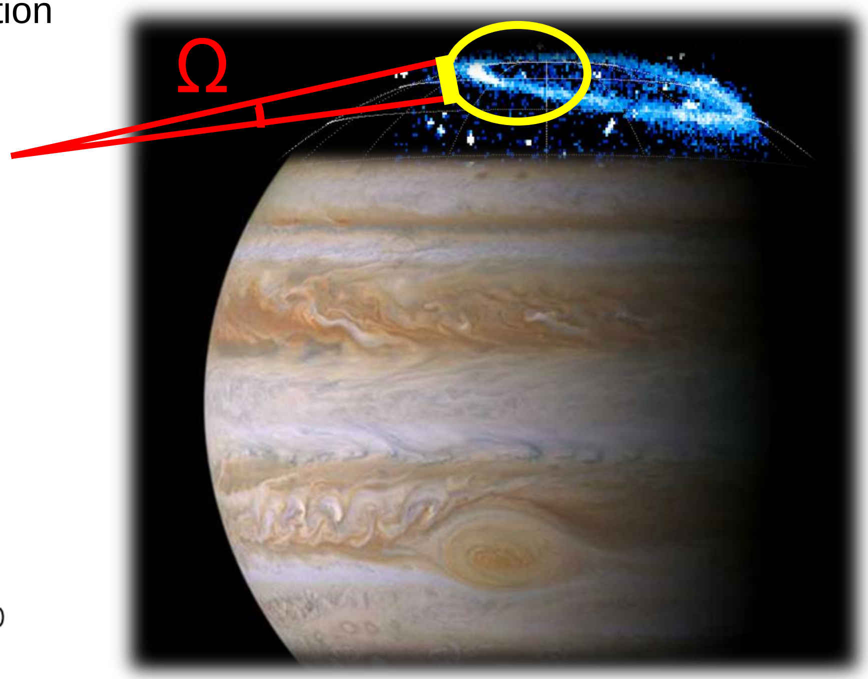
High Spectral Resolution Spectroscopy

High spectral resolution is needed for fine relative motions, multiple sources, isotope ratios, temperature, turbulence, currents, and etc.

sulfur and oxygen line shapes for ion precipitation



Trafton *et al.*, 1998

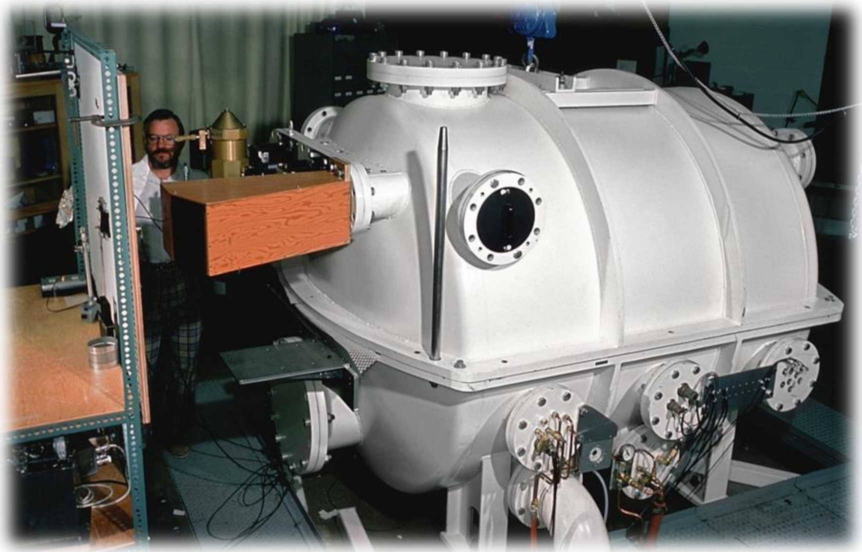


Jupiter's northern aurora, *(~1 Å) from Hubble-STIS*

Upper panel: image of the FUV Jovian northern aurora observed with WFPC2

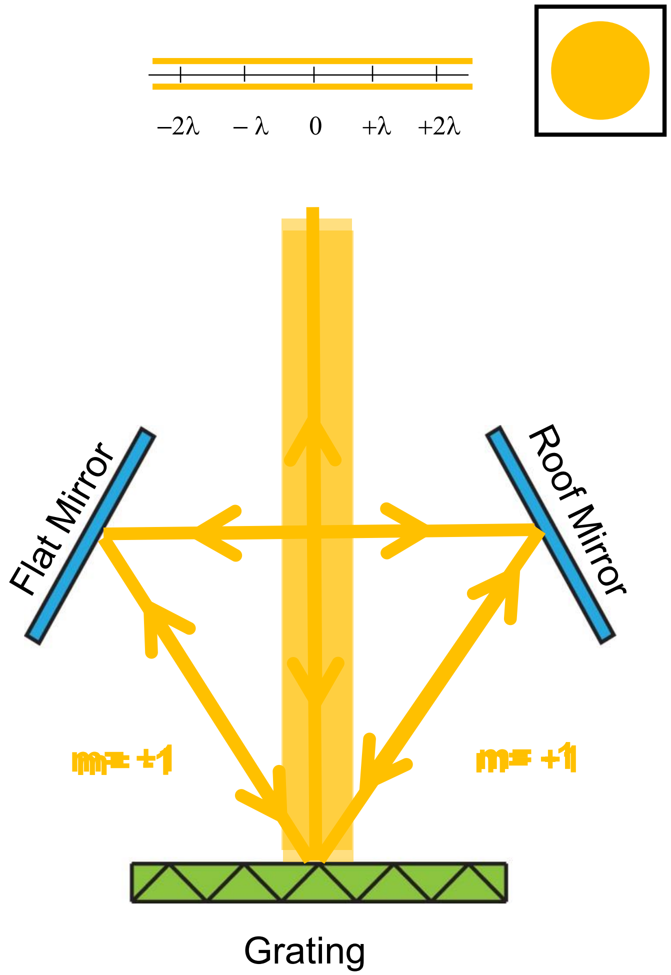
Current state of the art doesn't combine high spectral resolution with wide FOV and high throughput

Large Telescopes
Grating Spectrometers



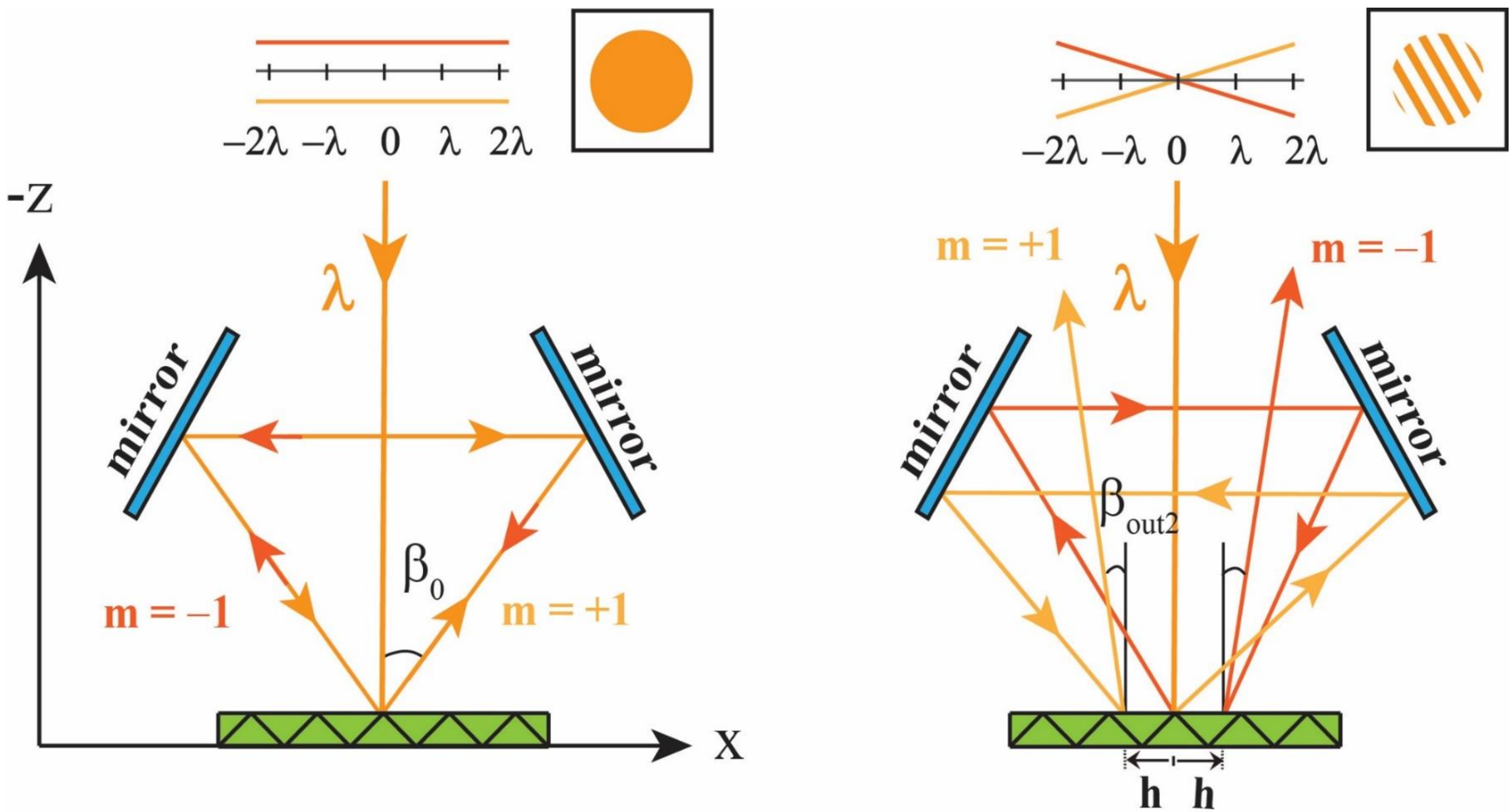
Small Telescopes
Interferometers

SHS is a cyclical interferometer

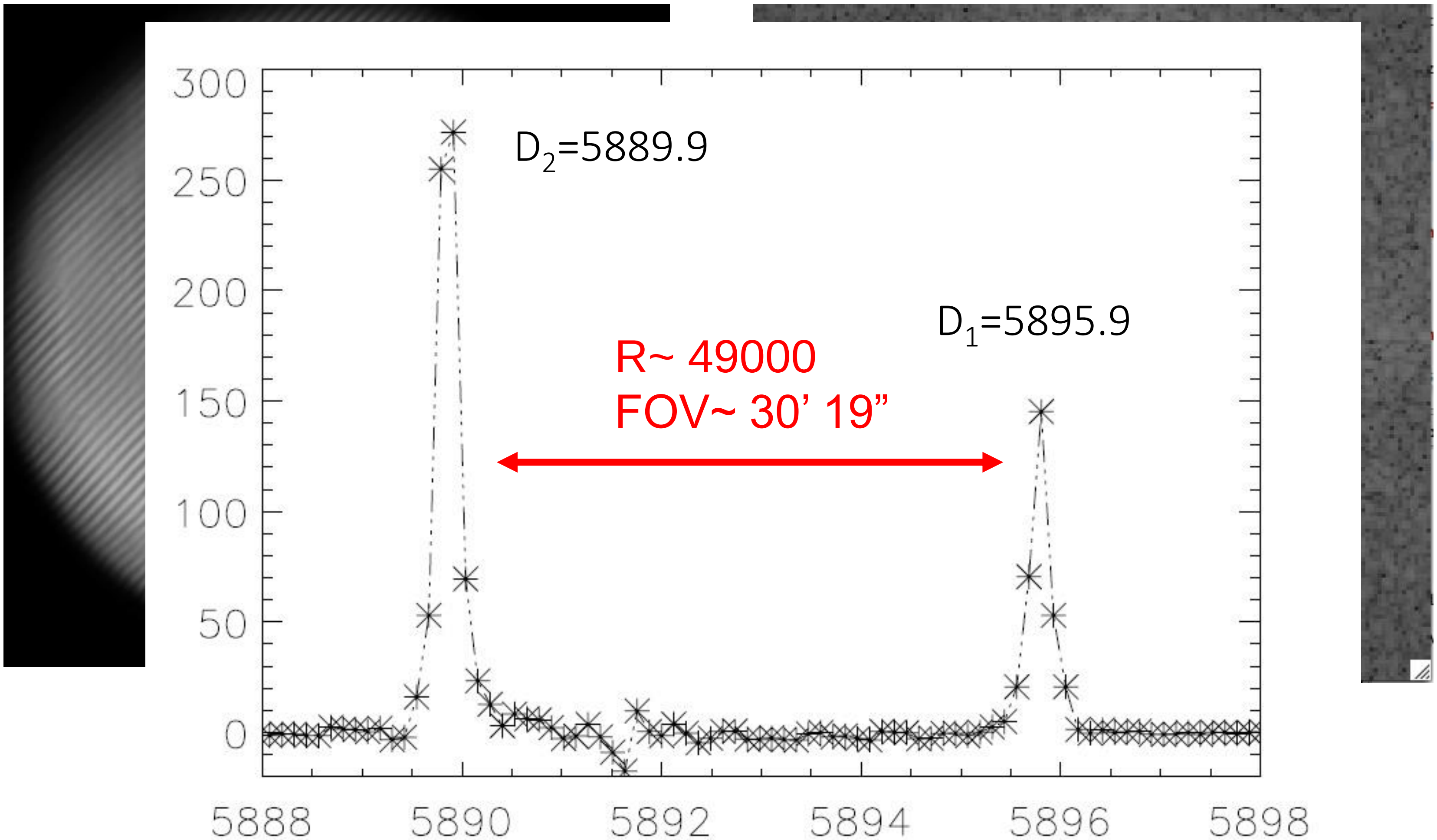


SHS is a cyclical interferometer

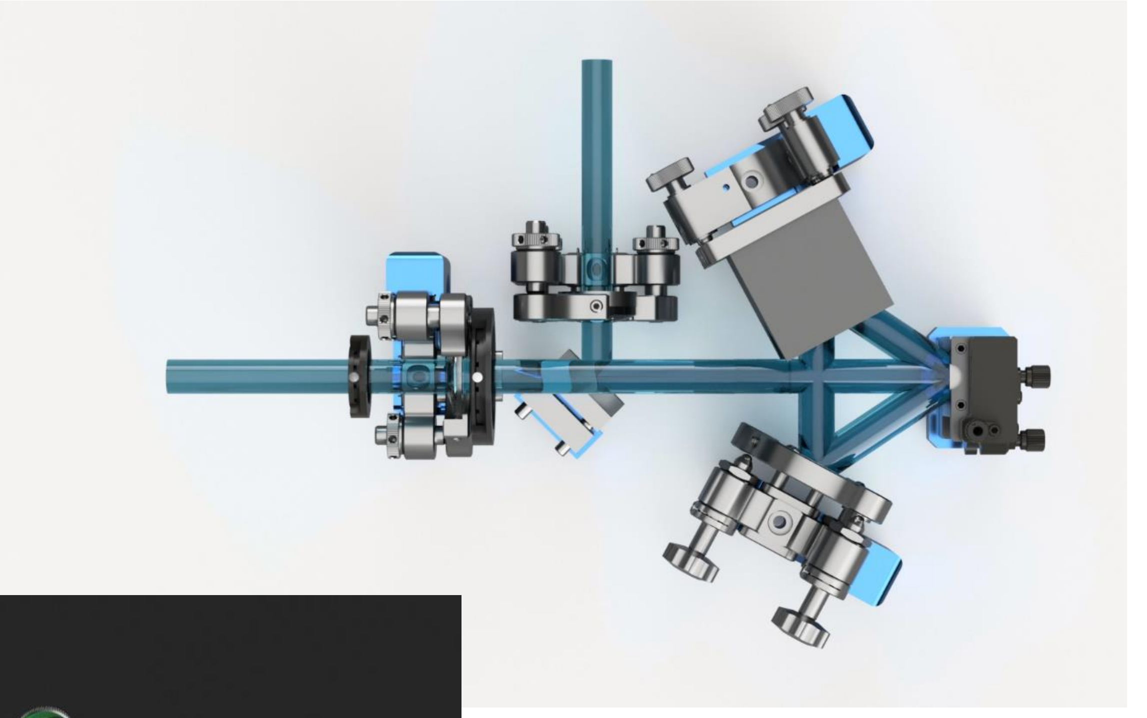
$$E_{01}\,.\,E_{02}\cos((k_1 - k_2).r + \varepsilon_1 - \varepsilon_2) \neq 0$$

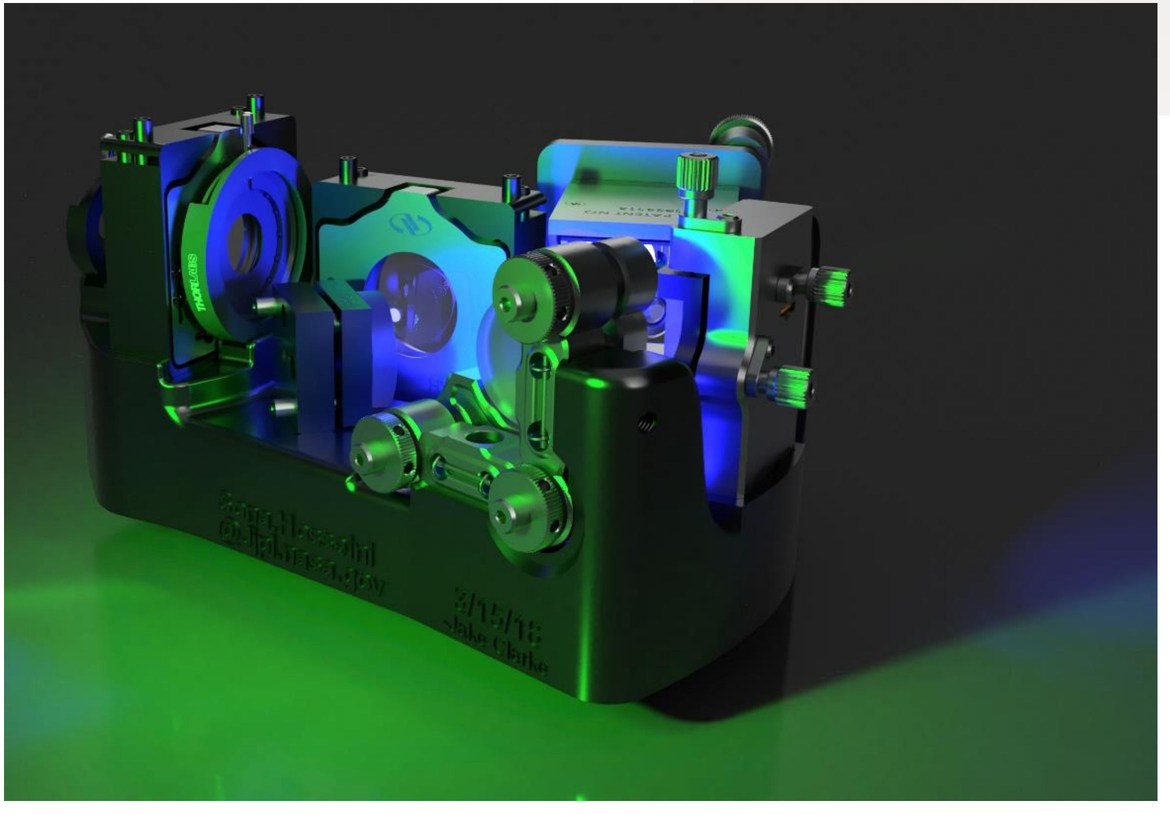


Na Lamp D lines

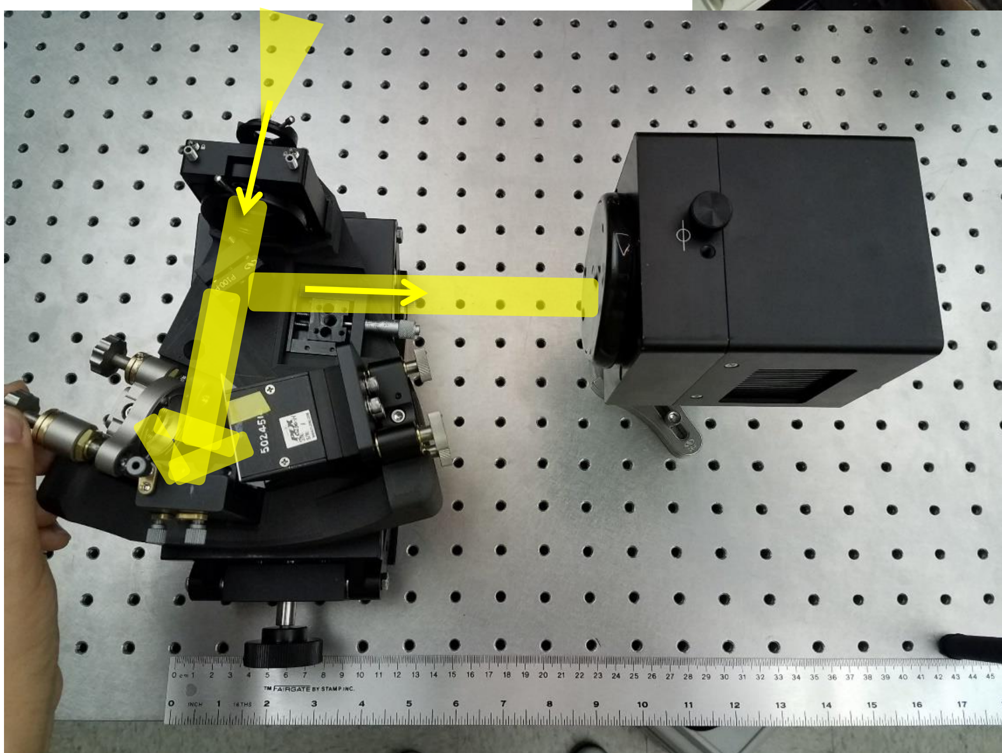


Developing the next generation of miniaturized high spectral resolution spectrometer

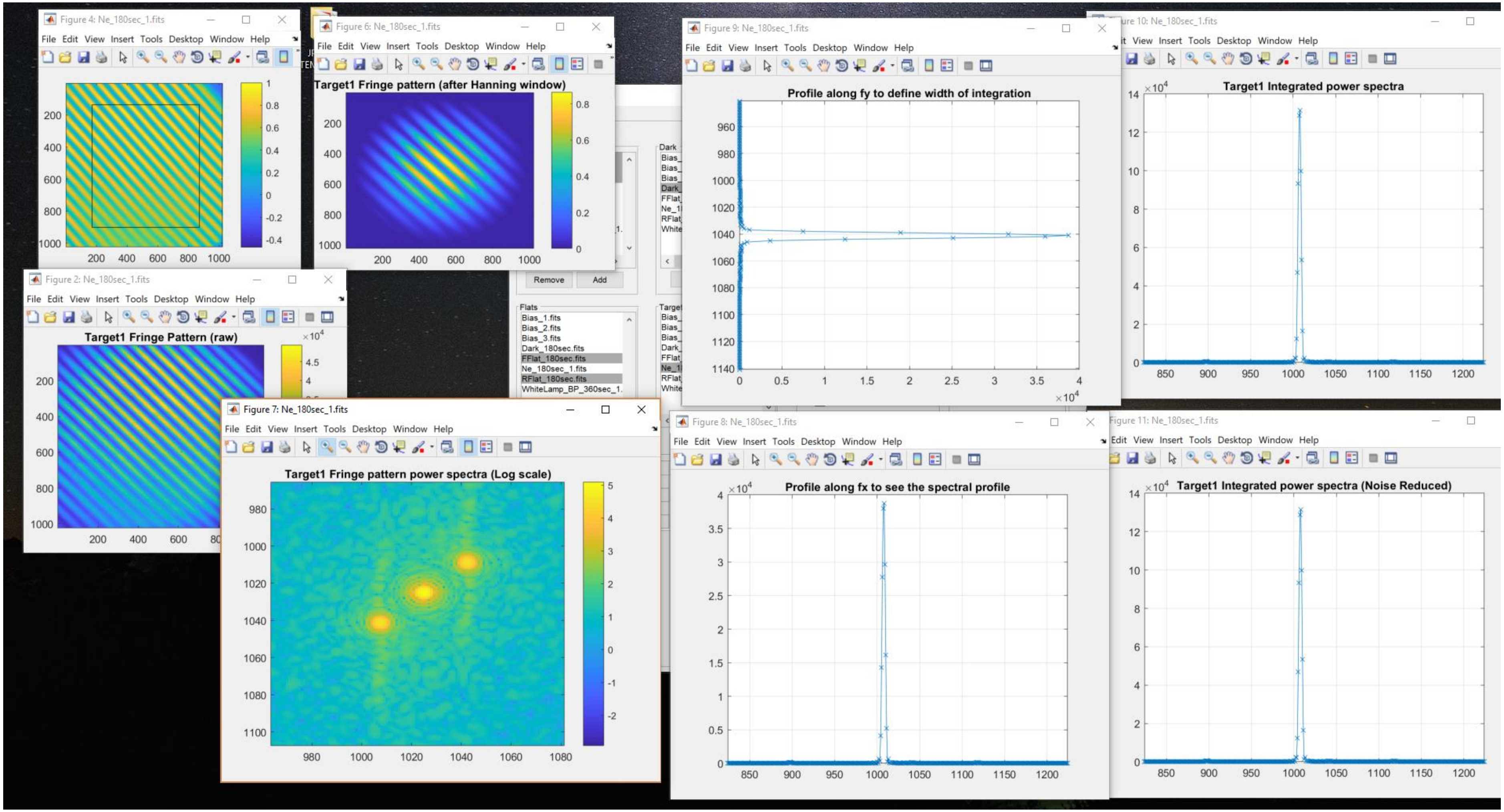





ORIEL

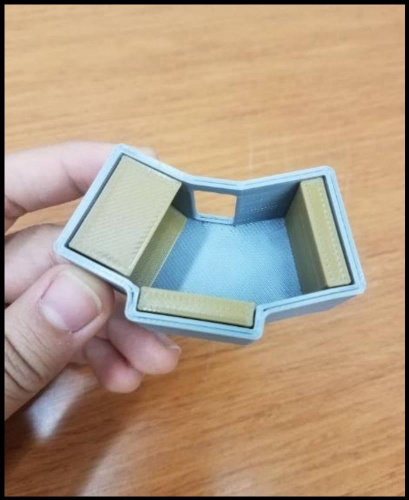


Data Reduction and Analysis Algorithm



In comparison with similar spectral resolution instruments

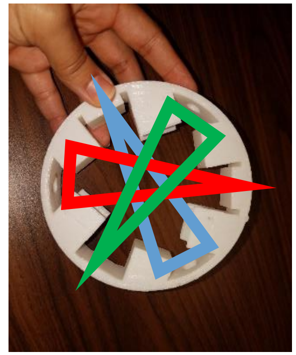
R ~ 200 – 3000
Wide bandpass
Low throughput

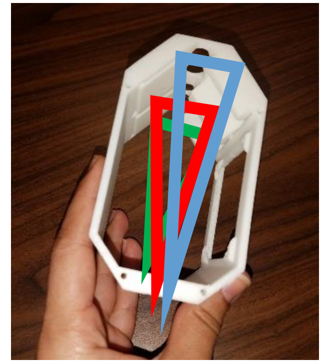


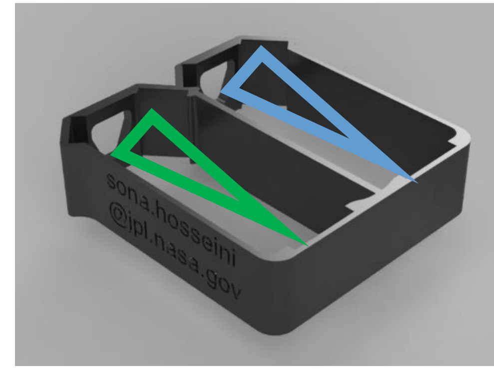
R ~ 20,000 – 150,000
Narrow bandpass
High throughput

Multi-channel RSHS covering multiple species with no moving mechanism

Multi-channel

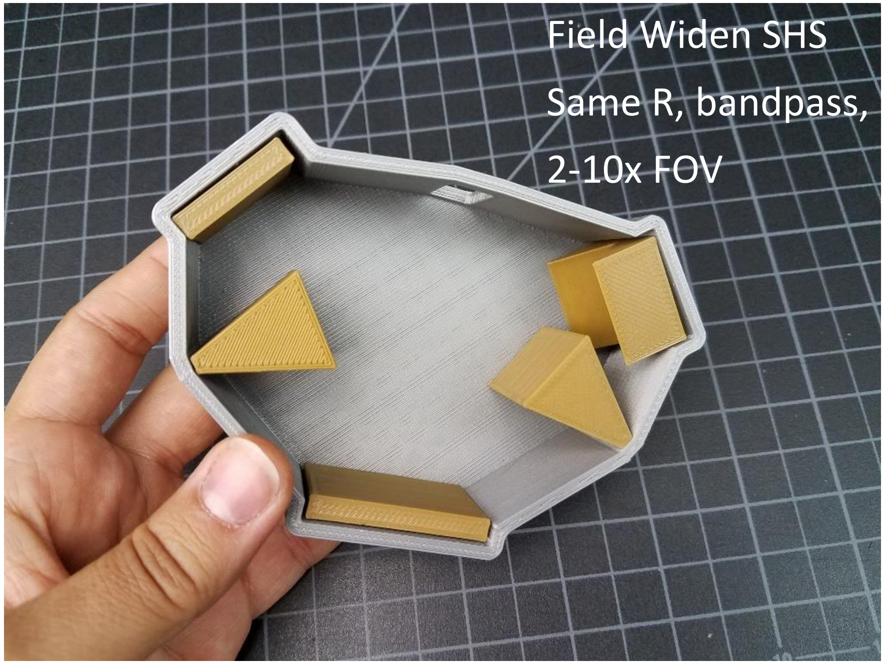


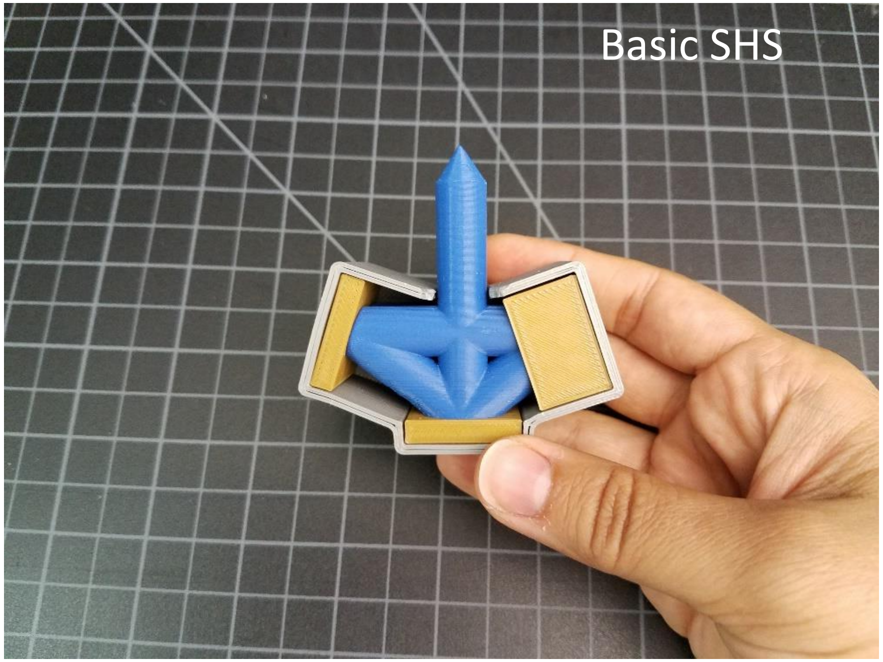


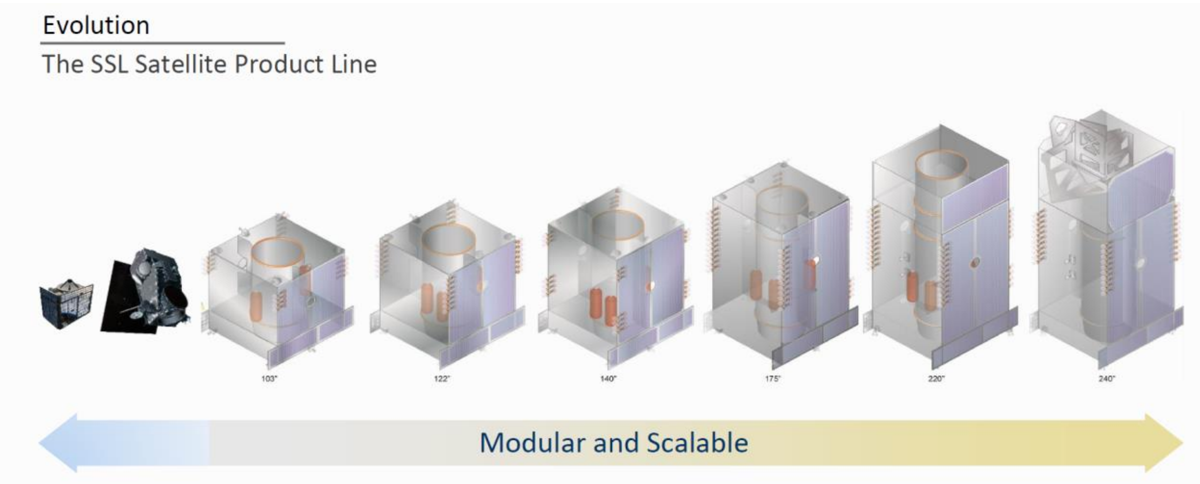


Isotope ratios	
OD/OH	308 Å separated by ~6 Å
$^{18}O/^{16}O$	16OH and 18OH at 3121Å separated by < 0.3Å
$^{15}N/^{14}N$	N^{2+} at 3914 Å
Abundance ratios	
C_2/CN and CN/OH	C2 at 5165Å (note ^{13}CC at 5120-5170Å), CN at 3883Å
CO/OH and CO_2/OH	CO at 1510 Å, CO+ at 3954 Å, CO_2^+ at 3509 Å, OH at 3090 Å.

Monolithic SHS
Cost Effective Innovative Solutions





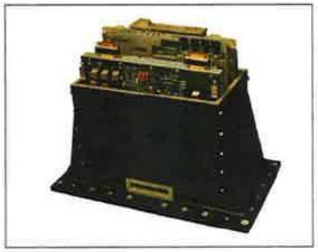


Multiple Hosted Payloads - SSL

<u>Low risk satellite platforms</u>

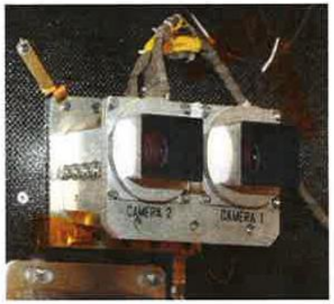
- Standardized Modular platform
- Dedicated manufacturing facility
- Supply chain management
- Systems engineering
- Sensor system integration and testing
- SmallSat launch support services
- SmallSat operations services

SES Sirius 5 – EGNOS



IRIS Payload

Optus-C1 – UHF



On-board Cameras

MTSAT Payload Suite

X-Band Rx Phased Array

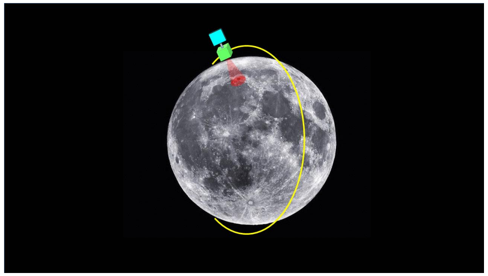
HOLMS, Heterodyne OH Lunar Miniaturized Spectrometer

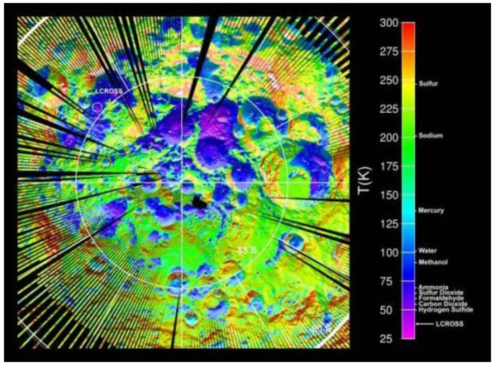
Currently a “mission concept study”,

HOLMS is a orbiter, that will observe the Lunar exosphere (from both sides) and the lunar tail.

The goal is to measure OH intensity in 308nm vs.

- Solar photons
- Solar Energetic Particles
- Solar wind
- Meteoric influx
- Large impacts





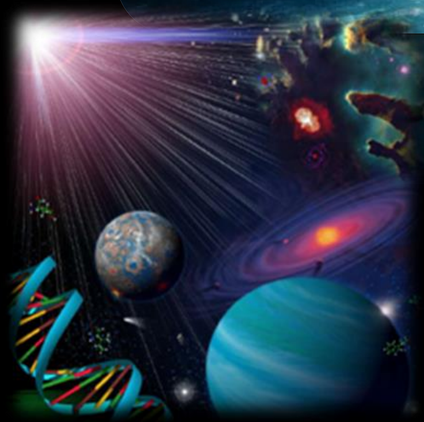
UM SUPRP

HOLMS needs to observe both sides of the Moon. Possible orbits can be:

- a series of small flybys using the Earth-Moon two body gravity, similar to mapping Europa with Cassini
- Moon-Earth Lagrange point
- Orbiting Earth or flybys around the Earth

Sona Hosseini
sona.hosseini@jpl.nasa.gov

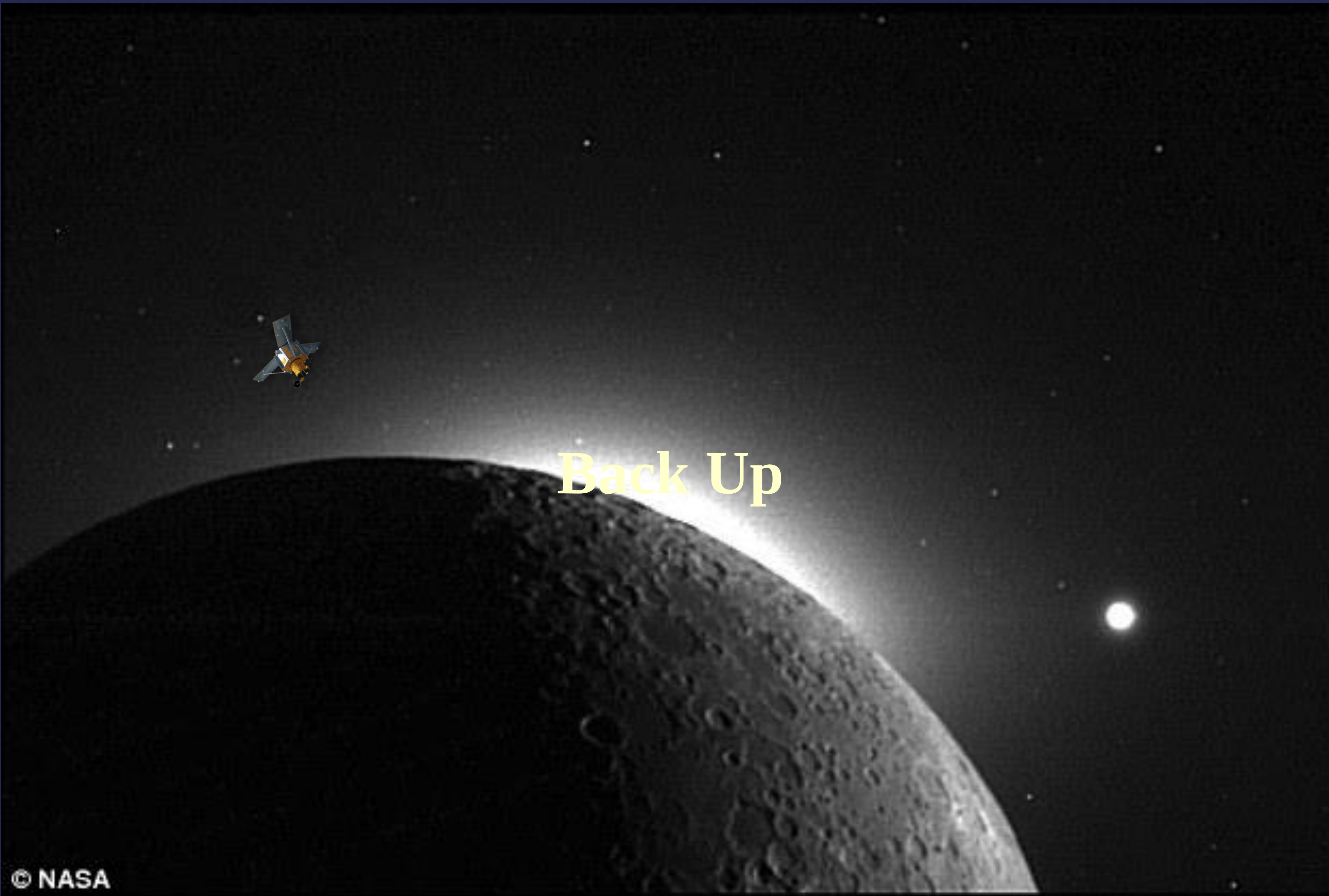
Planetary Science
Mars atmosphere
Cometary Coma
Io Plasma Torus
Venus night airglow
Lunar sodium tail



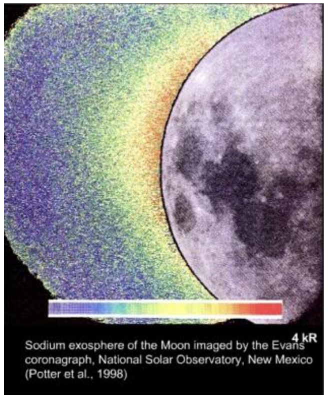
Earth Science
Wind and Temperature profiles
OH Measurements

Astrophysics
Interstellar Medium
H-alpha mapping of Nebula and Galaxies
Solar wind interface

Back Up



Mission Objectives



Sodium exosphere of the Moon imaged by the Evans coronagraph, National Solar Observatory, New Mexico (Potter et al., 1998)

- Characterize the existence of a lunar OH
- Potential detection of the full extent of the lunar OH tail
- Acquire seasonal lunar limb observations
- Acquire high-resolution observations of the surface
- Map the lunar surface for Global coverage

Spatial resolution: 1.7km

Spectral resolution- Band 307.3 nm

- Resolving power R=72,000
- Resolution: $\Delta\lambda$=0.1 Å

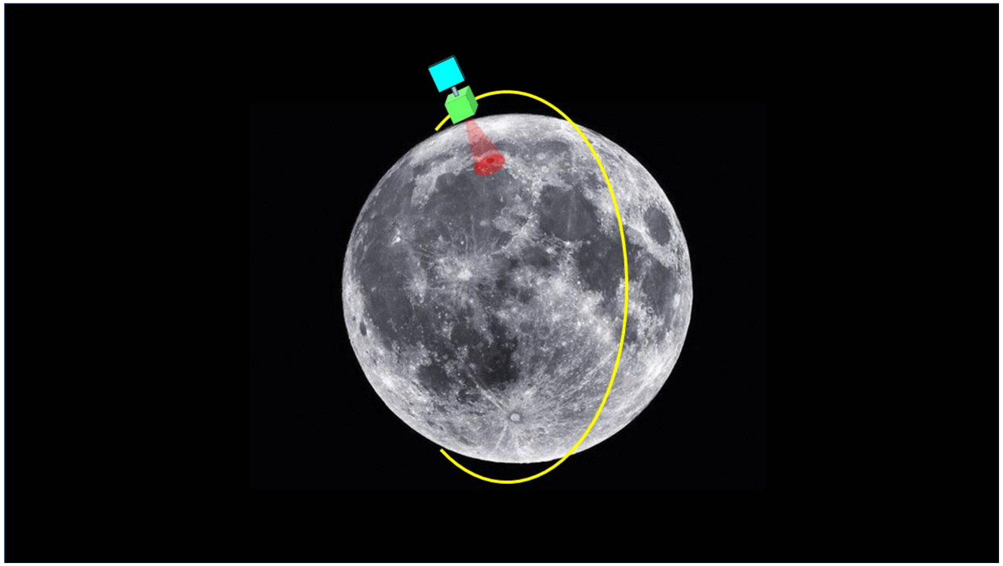
Detector temperature: -20 C

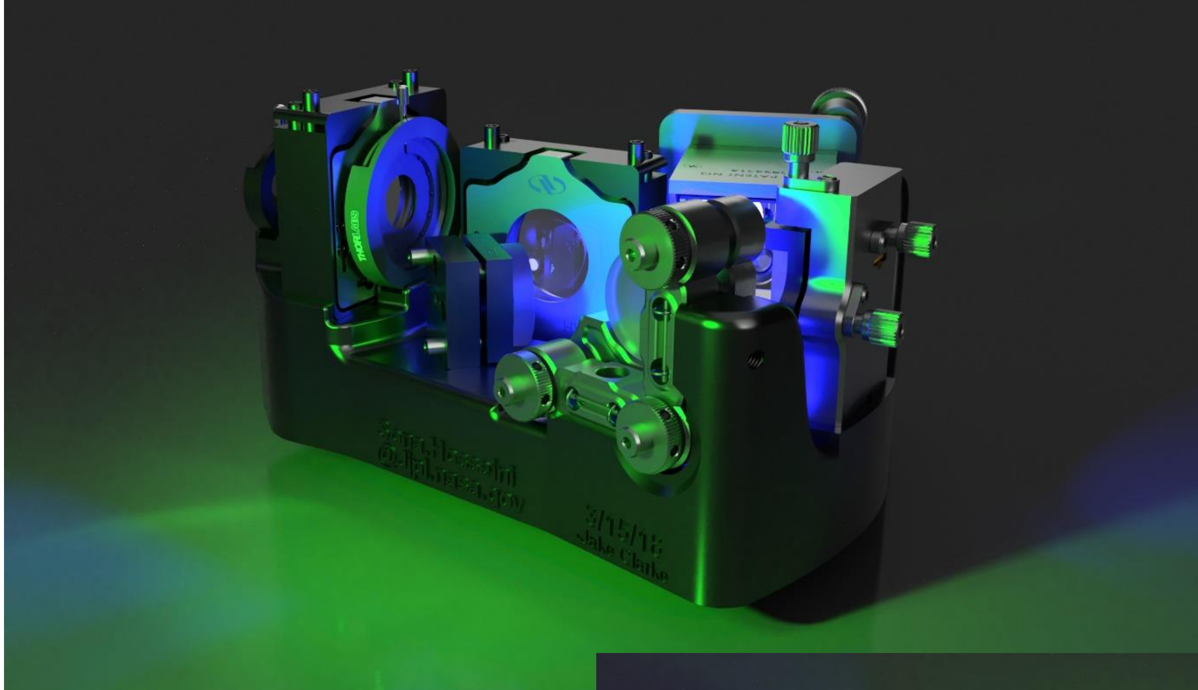
Exposure time: 7sec

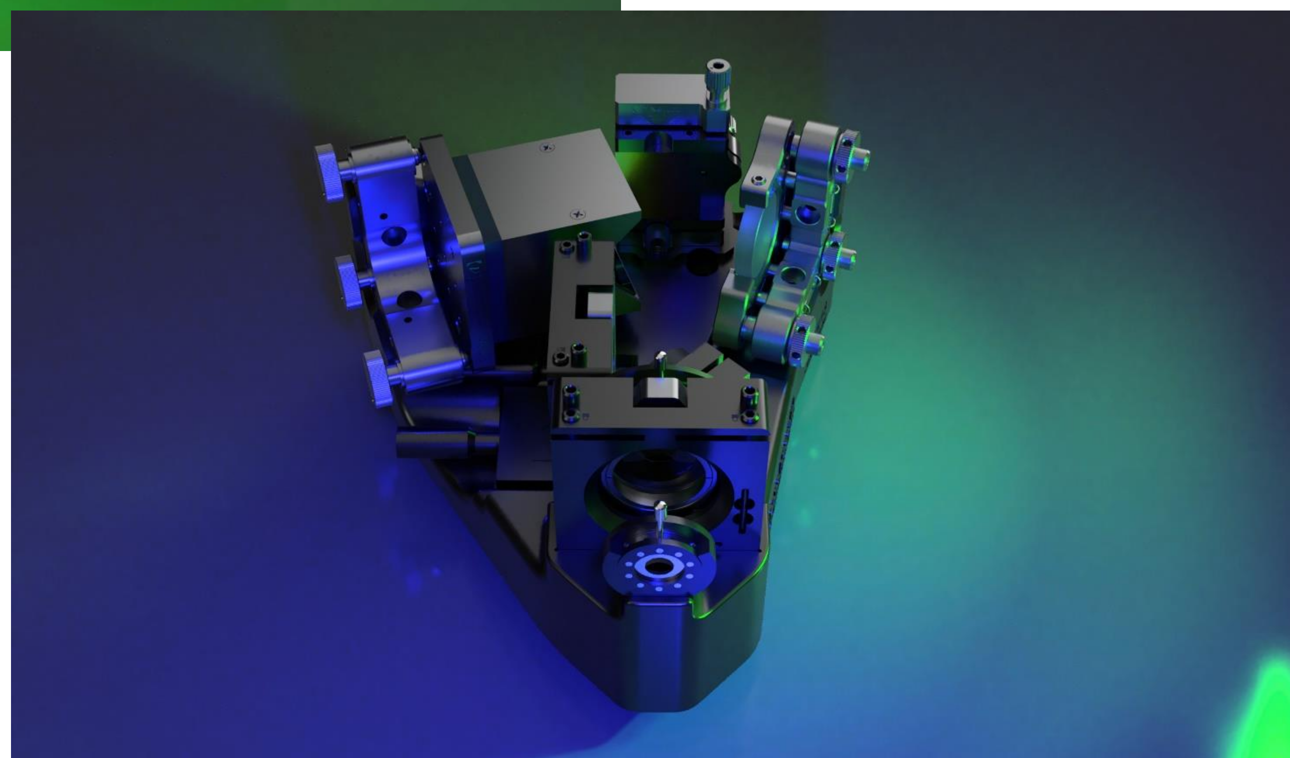
No mechanisms or moving parts

Very low data volume

Passive cooling for detector

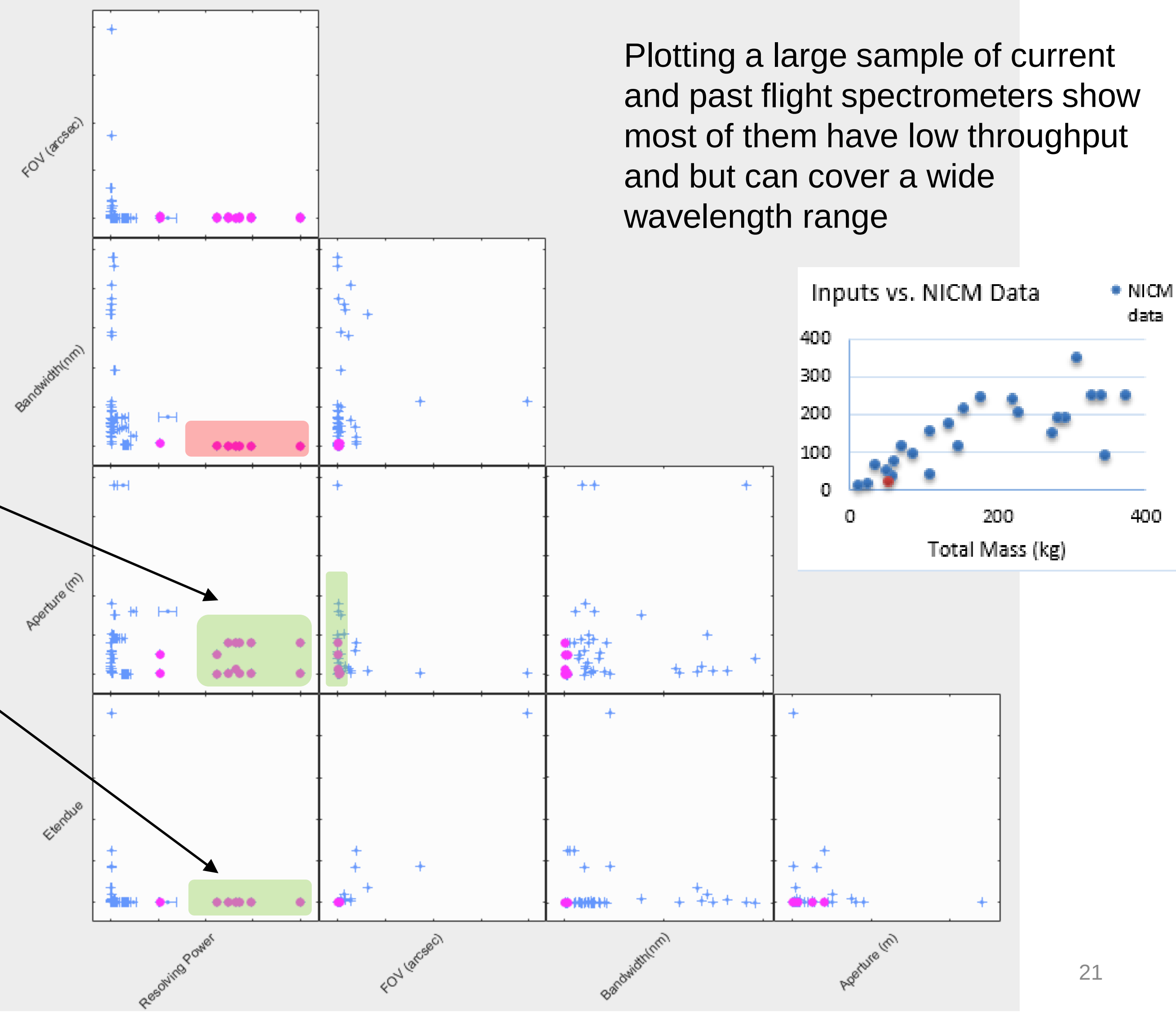



3/15/18
Jake Clarke



SHS breaks out off the high spectral resolution spectrometers restrictions

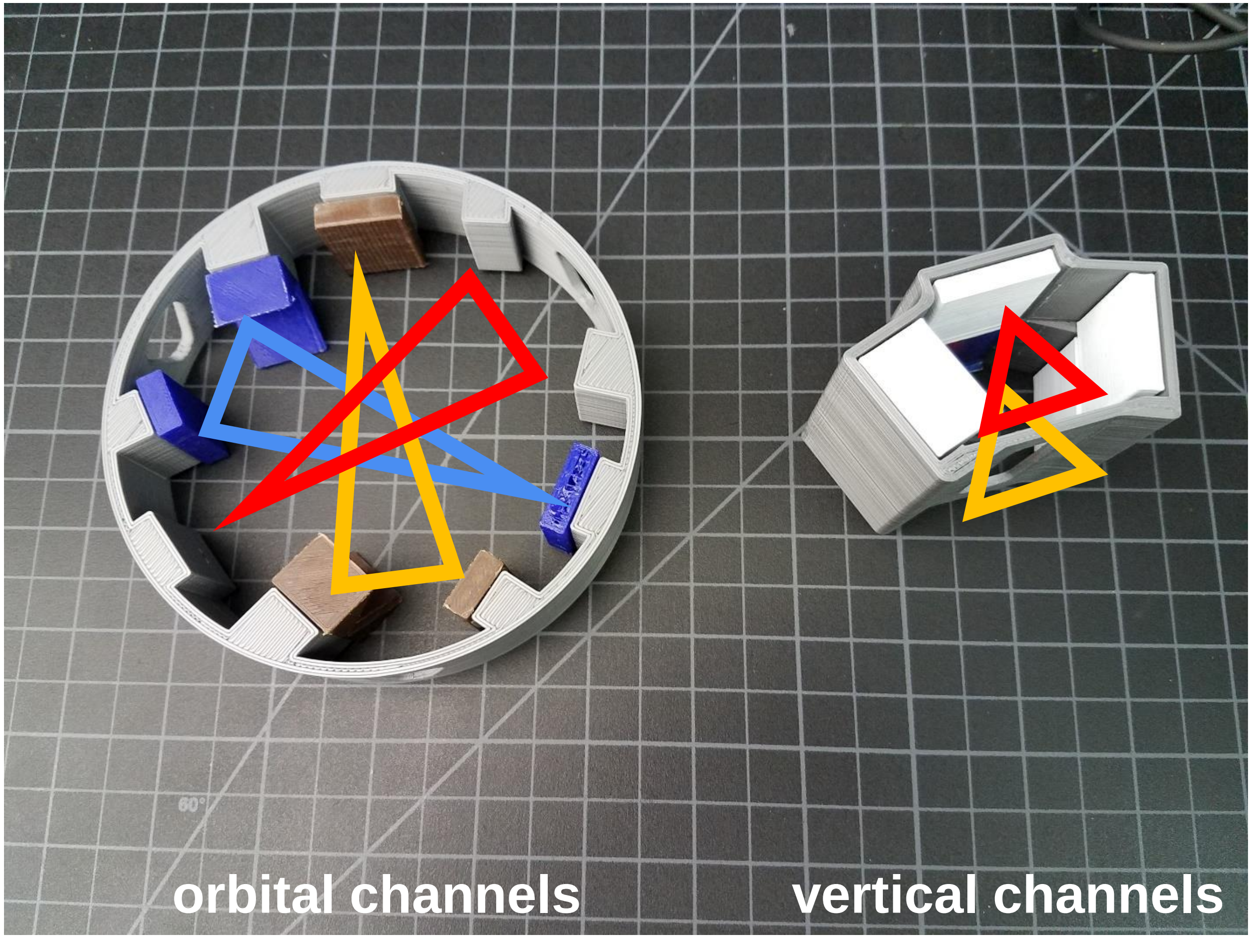
SHS can access high throughput with high R that is not possible with grating spectrometers



Plotting a large sample of current and past flight spectrometers show most of them have low throughput and but can cover a wide wavelength range

Multi-channel SHS

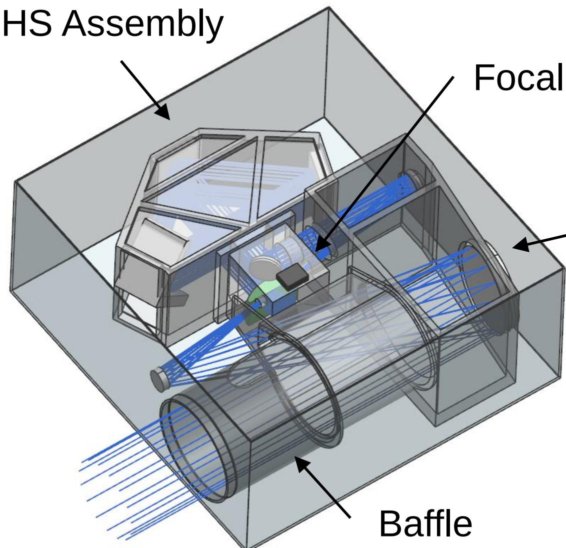
Each channel is 0.5 – 2nm bandpass and targets a specific spectra future at 20,000 to 70,000 resolving power.

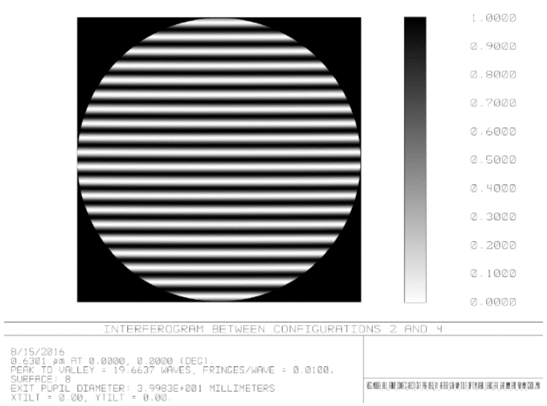


Lunar OH measurment

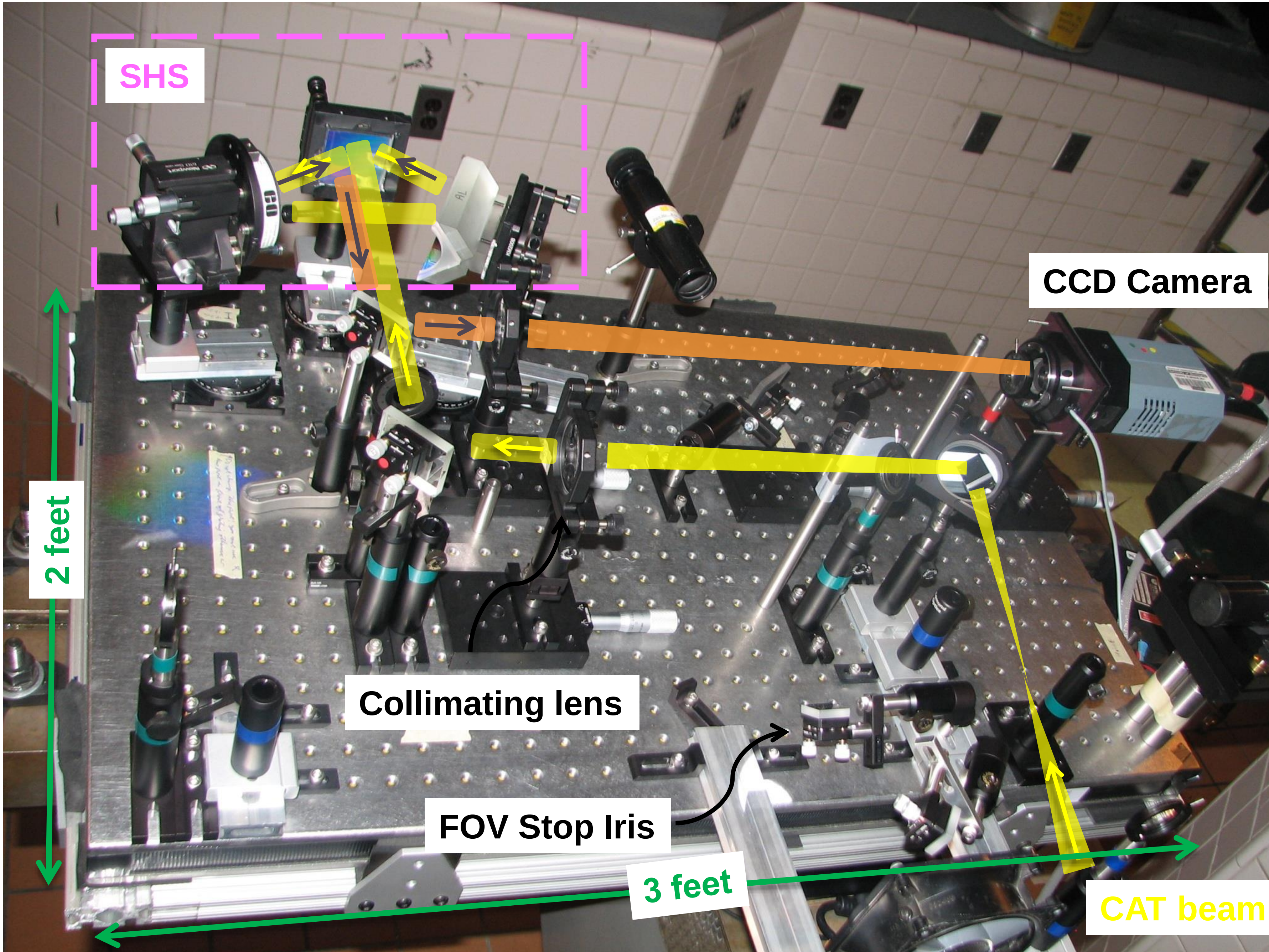
Top level description of the mission

- UV spectrometer with positive SNR
- Volume: 1.35m x 1.30m x .6m
- Mass: 75 kg (includes contingency)
- Power: 30 W
- Data: 125 kbps

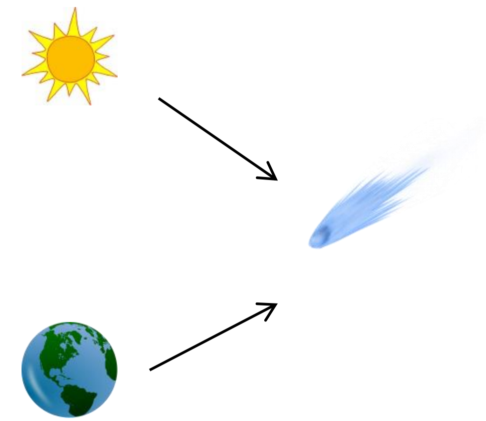




With a 30cm telescope,
Volume: 1.35m x 1.30m x .6m


SHS
CCD Camera
2 feet
Collimating lens
FOV Stop Iris
3 feet
CAT beam

Cometary Survey Mission Concept



Top level description of the mission

- Observe and survey cometary coma
- UV spectrometer with positive SNR
- Does not fit in 6U CubeSat, Fits into an ESPA class SC
- Volume: 1.35m x 1.30m x .6m
- Mass: 75 kg (includes contingency)
- Power: 30 W
- Data: 125 kbps
- Cost is ~ $ 50M, $10M extra for each extra channel, FY$2017

Mission profile

- Polar Earth orbiting satellite, Sun synchronous terminator orbit
- OR Polar Sun
- Comet is 1AU fromo rbiting satellite the sun
- Looking 90 degrees to the sun
- FOV: 3’28” (3.5 arcmin)
- Ultra-hyper spectral imager
- Band 307.5 nm
- Resolution R=336,000
- Temperature – 173 K

To observe D/H we need an instrument that can tailor to …

Diffuse and extended

Needs → Wide FOV, High Étendue

- arc-minutes to degrees in extent
- Typical low surface brightness

Faint and low-energy environment

Needs → High Étendue, High spectral R

- Velocities of order 0.1-10 km/sec
- Temperatures of order 100-1000 K

Temporally variable

Needs → High temporal coverage, Wide FOV

- Heterogeneity
- Outbursts, diurnal variations
- Seasonal changes (long time scale)

Interference Pattern

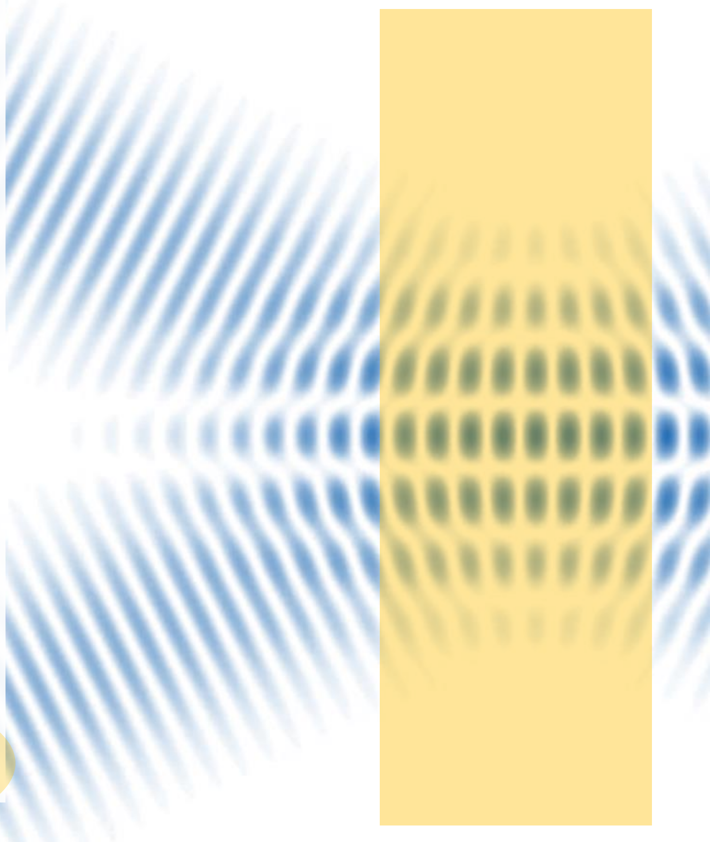
$$E_1(r,t) = E_{01}\cos(k_1.r - \omega t + \varepsilon_1)$$
$$E_2(r,t) = E_{02}\cos(k_2.r - \omega t + \varepsilon_2)$$

$$I = E_1^2 + E_2^2 + 2 < E_1.E_2 >$$

$$< E_1.E_2 > = E_{01}.E_{02}\cos((k_1 - k_2).r + \varepsilon_1 - \varepsilon_2)$$

Conventional Interferometry

SHS



Technical Findings

Performance

- Spatial
  - FOV: 3’28” (3.5 arcmin)
  - Ultra-hyper spectral imager
- Spectral
  - Band 307.5 nm
  - Resolution R=336,000
- Temporal
  - Integration time per frame = 10 sec exposure
  - Co-add frames for 10 hrs
- Sensitivity
  - ~15 photo-electrons/sec

Detector

- Temperature – 173 K
- Stability – 0.1 K
- Power – 0.2 W

Electronics

- Temperature – 0 C< T < 40 C
- Stability – N/A
- Power – 20 W

Spacecraft

- Sun Sync

Mission Design Summary

Optics
- FOV 3.5 arcmin, 30cm diameter primary
- 307.5 nm center wavelength; ? BW

Detectors
- E2V CCD201
- 1024 x 1024 detector
- 173K passively cooled

Electronics
- Data Processing / Storage handled by a JPL-built Sphinx card
- New Detector Readout PC104card, example: ask NuVu to re-layout their driver board and test for space

Mechanical
- Structures: support 30 cm off-axis mirrored telescope, potential baffle
- Mechanisms: no mechanism
- Thermal: passive only, sun-sync orbit allows a cold side for radiators

Technical Resources (Mass, Power, Data)

Mass
- 75 kg (includes contingency)

Power
- 30 W

Data
- 12 bits x 1024 x 1024 pixels = 12 Mbits (1.5 MB) over 10 hrs
- If 2 images per day = 24 Mbits
- With overhead, ~30 Mbits/day (~4 MB/day)
- For a 4 min down link pass, needed data rate is 125 kbps

SNR
- SNR margins are low and dependent on temperature
- Photon counting mode (thresholding) to achieve higher SNRs in reasonable times compared to conventional modes
- Dark noise limited operation (cooling dependent)

IUE

The IUE satellite was launched on January 26, 1978. It had an expected lifetime of 3 years, with a goal of 5 years, but exceeded that beyond anyone's wildest dreams. When it was shut down on September 30, 1996, it had been in continuous operation for 18 years and 9 months.

14 th magnetud

R= 0.02 nm and 0.6 nm

FOV 10x20 arcsec, 3x20arcsec

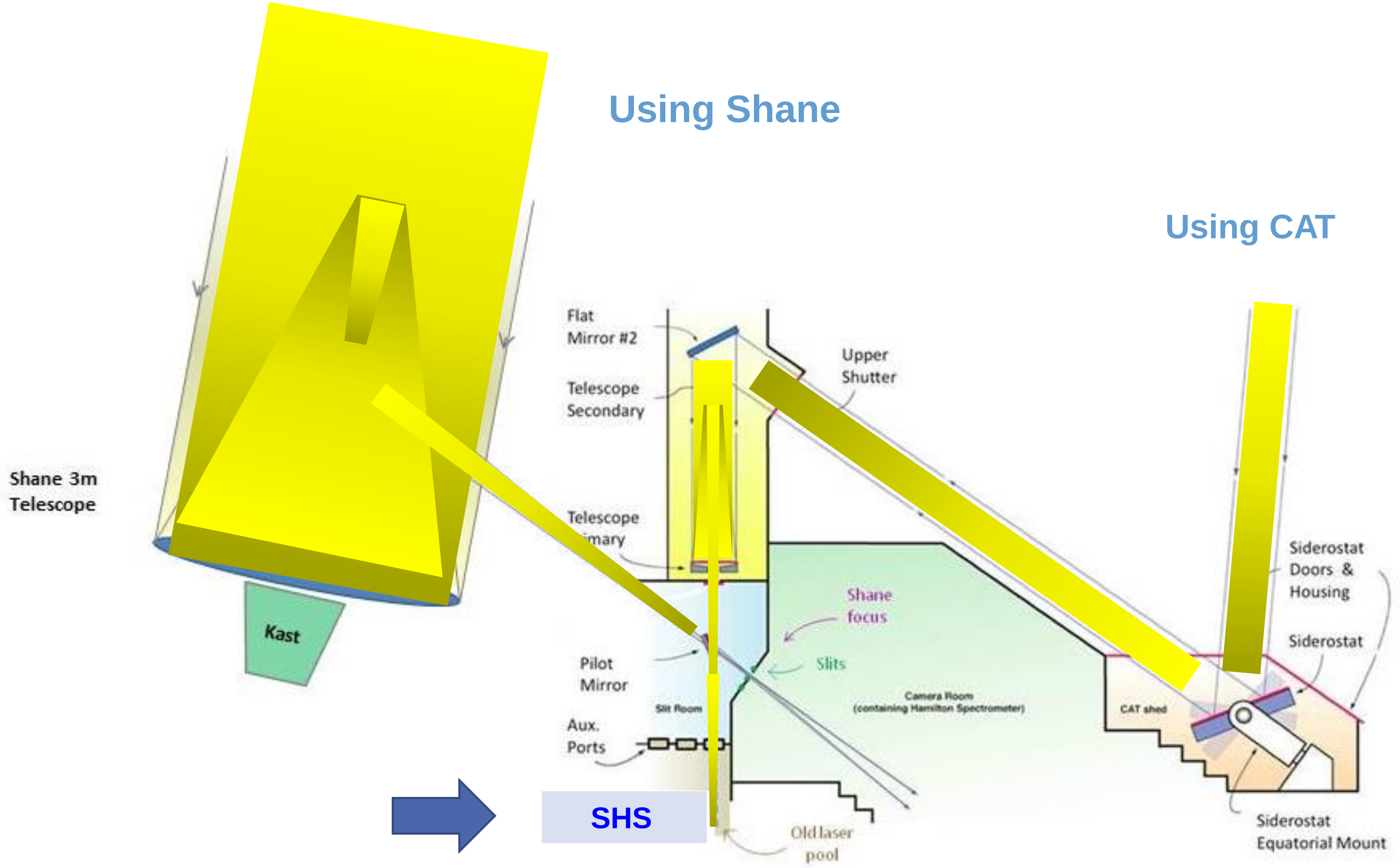
Wavelength: 115-200 and 185-330 nm

A= 45cm,

Mass: 312 kg

Orbit: geosynchronous 36000 km, Hubble: 600km

Coupling SHS to the Coudé Auxiliary Telescope (CAT)

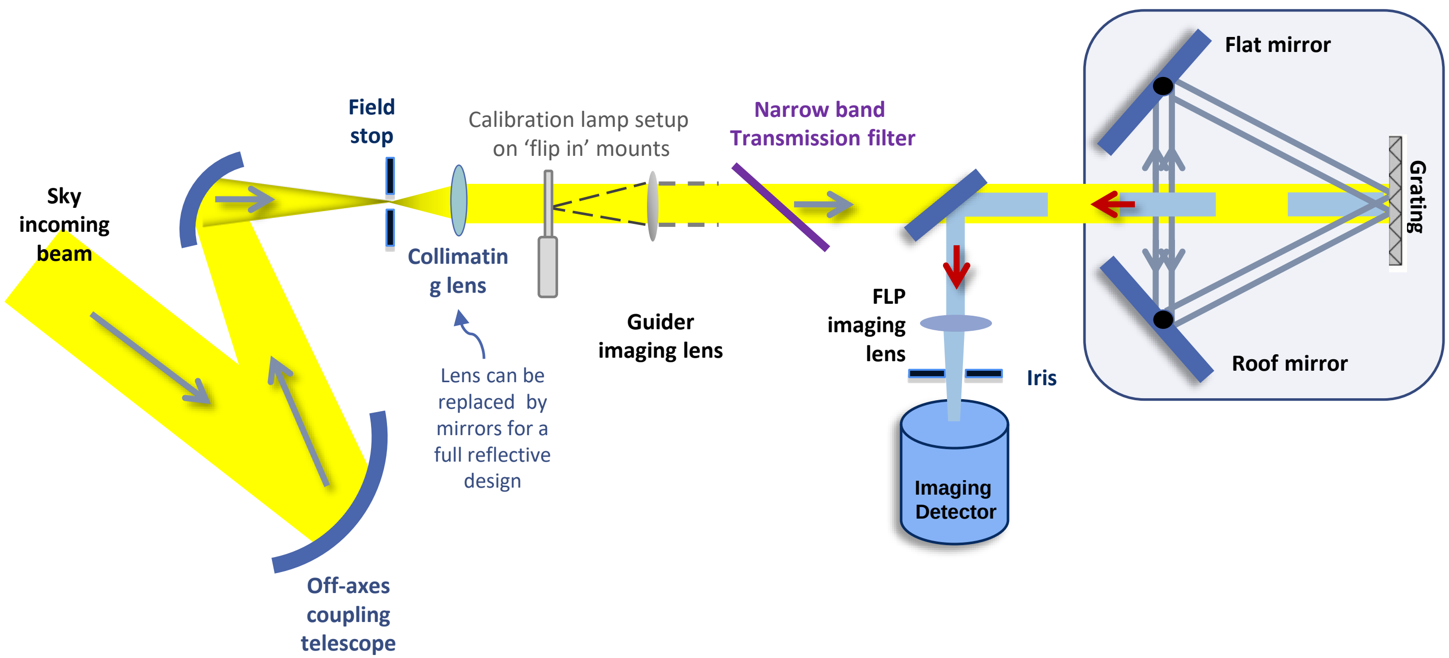


ROSINA

67/P: 50 observations over 8 August and 5 September 2014, looking at $HD^{16}O/H_2{}^{16}O$

The mass analysis in the **R**eflectron **T**ime-**o**f-**F**light (RTOF) sensor is performed using the time-of-flight technique. This technique allows the combination of extremely high mass resolution (m/Δm = 3000 at 50% peak height) and time resolution (theoretically limited by the extraction frequency of 10 kHz). The instantaneous recording of the whole mass range (1 to 1000 amu) is possible.

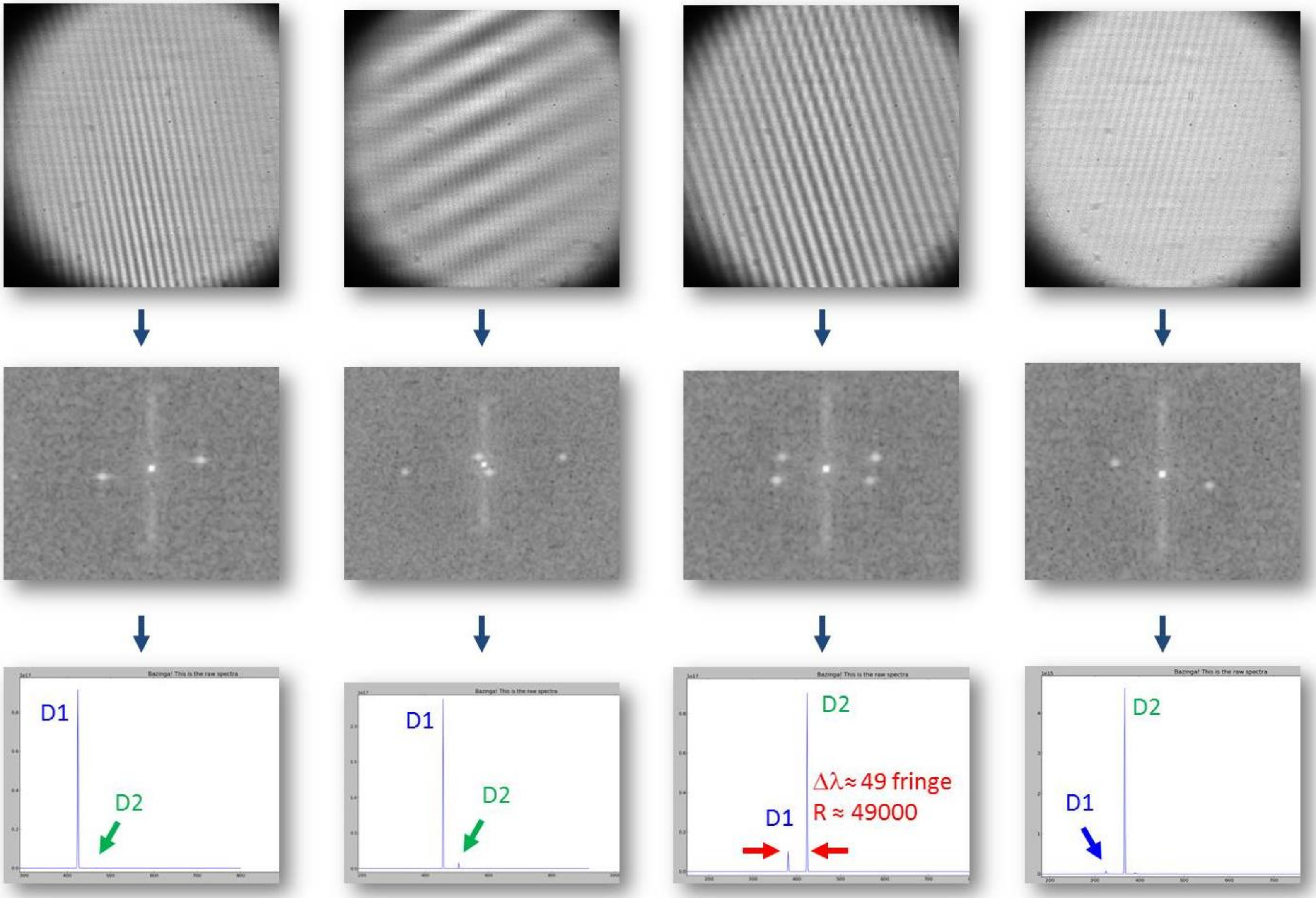
Optical layout



Tuning in Na D lines

D1 = 5895.92 Å

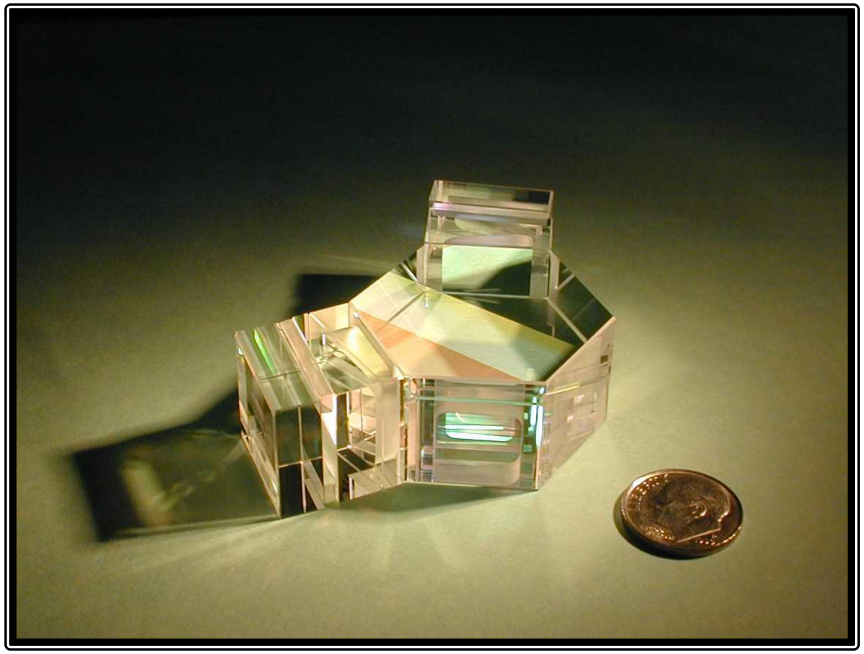
D2 = 5889.95 Å



SHIMMER on STPSat-1

Launched 2007, decommissioned after completing 2.5 years of successful on-orbit operation

Mesospheric hydroxyl (OH)



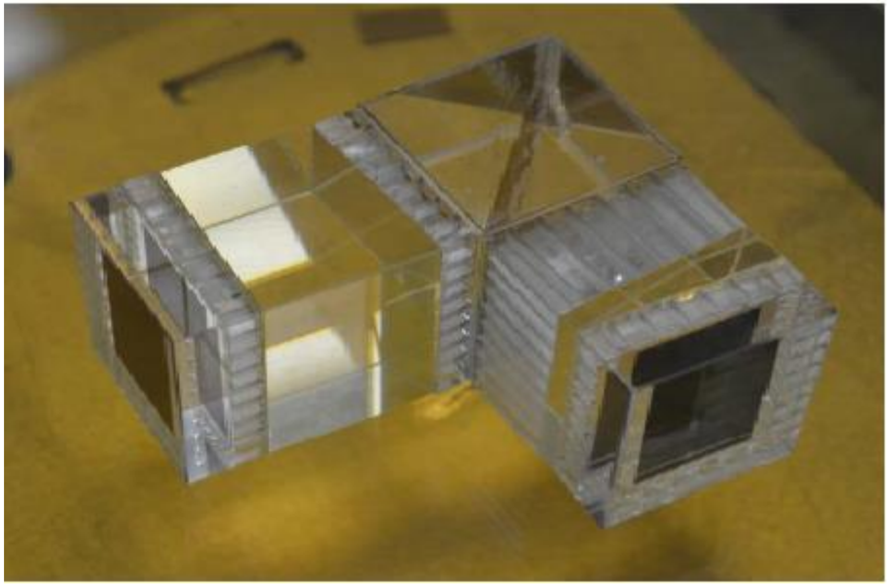
The STPSat-1 small satellite, built for the Department of Defense (DoD) Space Test Program (STP) and operated by the DoD STP for the first year then transitioned to NRL.

MIGHTI on ICON Heliophysics Explorer Mission will launch at 2017

$200 M ICON mission

(Tom Immel, UCB; Orbital Sciences)

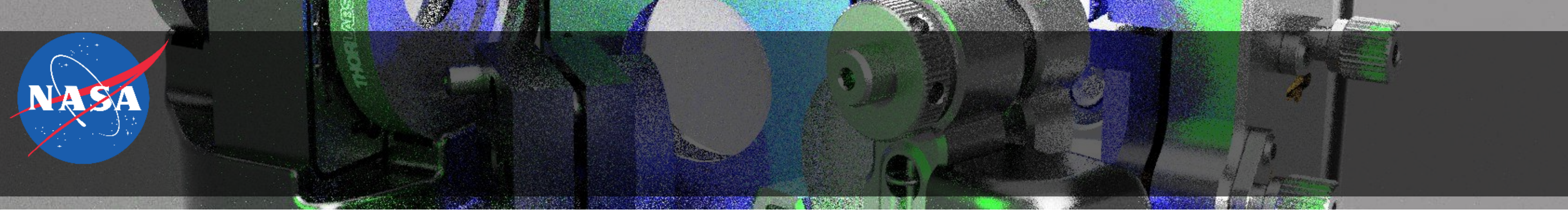
Earth's thermospheric winds and temperatures at altitudes 90-300 km



Engineering model of the MIGHTI interferometer

MANIC: direct detection of nearby Jupiter-like exoplanets

Boston University, MA with input from Light Machinery Inc.

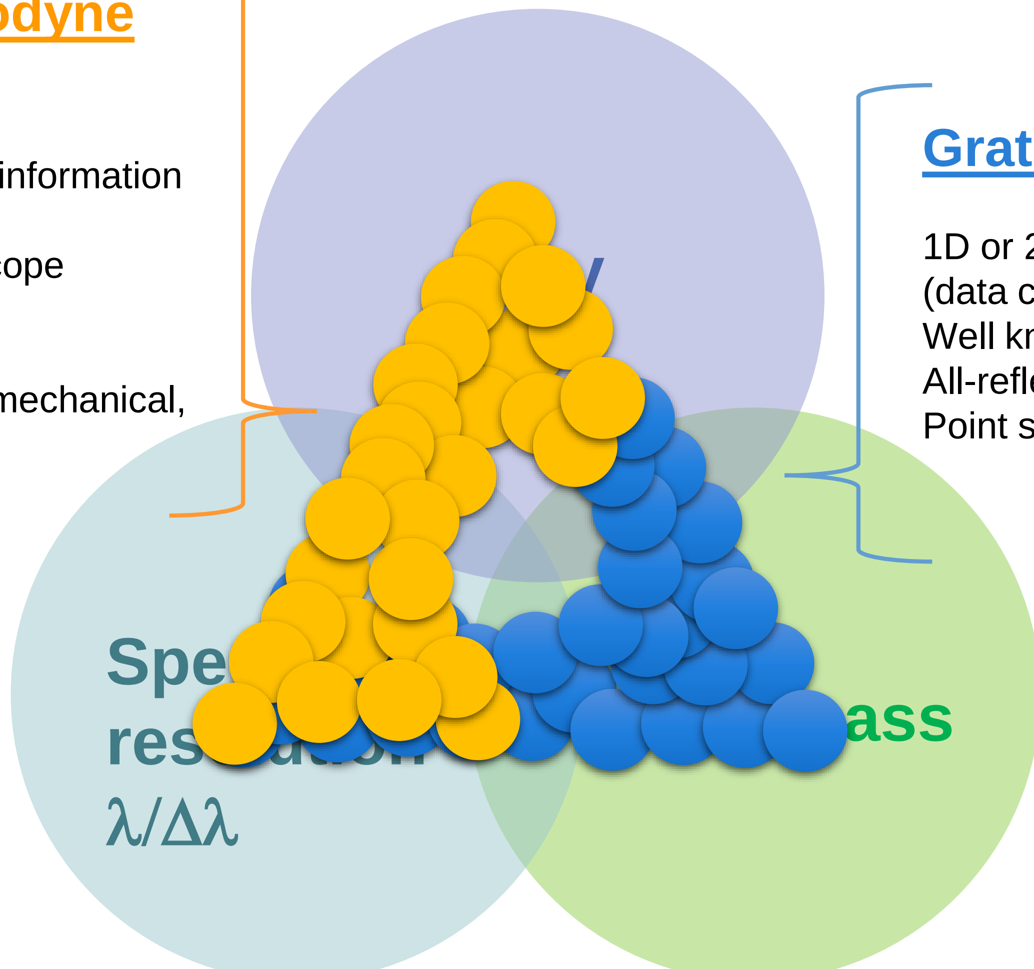


Competitiveness	
Usefulness	
Customer base	

High Spectral Resolution Spectrometry

Spatial Heterodyne Spectromter

No, 1D or 2D spatial information
Compact/miniature
Small aperture telescope
Low data volume
All-reflective design
High tolerance (optomechanical, temperature)



Grating spectrometer

1D or 2D spatial information (data cube capability)
Well known concept/heritage
All-reflective design
Point sources