Ultra-Compact Raman Spectrometer for Planetary Explorations

Team

Derek Davis

Computer Engineering, Electrical Engineering

In collaboration with:

James Hornef (ECE 487 senior design team)

John Lucas (ECE 487 senior design team)

Faculty Adviser:

Dr. Hani Elsayed-Ali

NASA Adviser:
Dr. M Nurul Abedin

Objective

To develop a compact Raman spectroscopy system with features that will make it suitable for future space missions which require surface landing. Specifically, this system will be appropriate for any mission in which planetary surface samples need to be measured and analyzed.

What is Raman Spectroscopy?

When light hits matter, how does it react?

- Absorbed
- Reflected
- **Scattered**

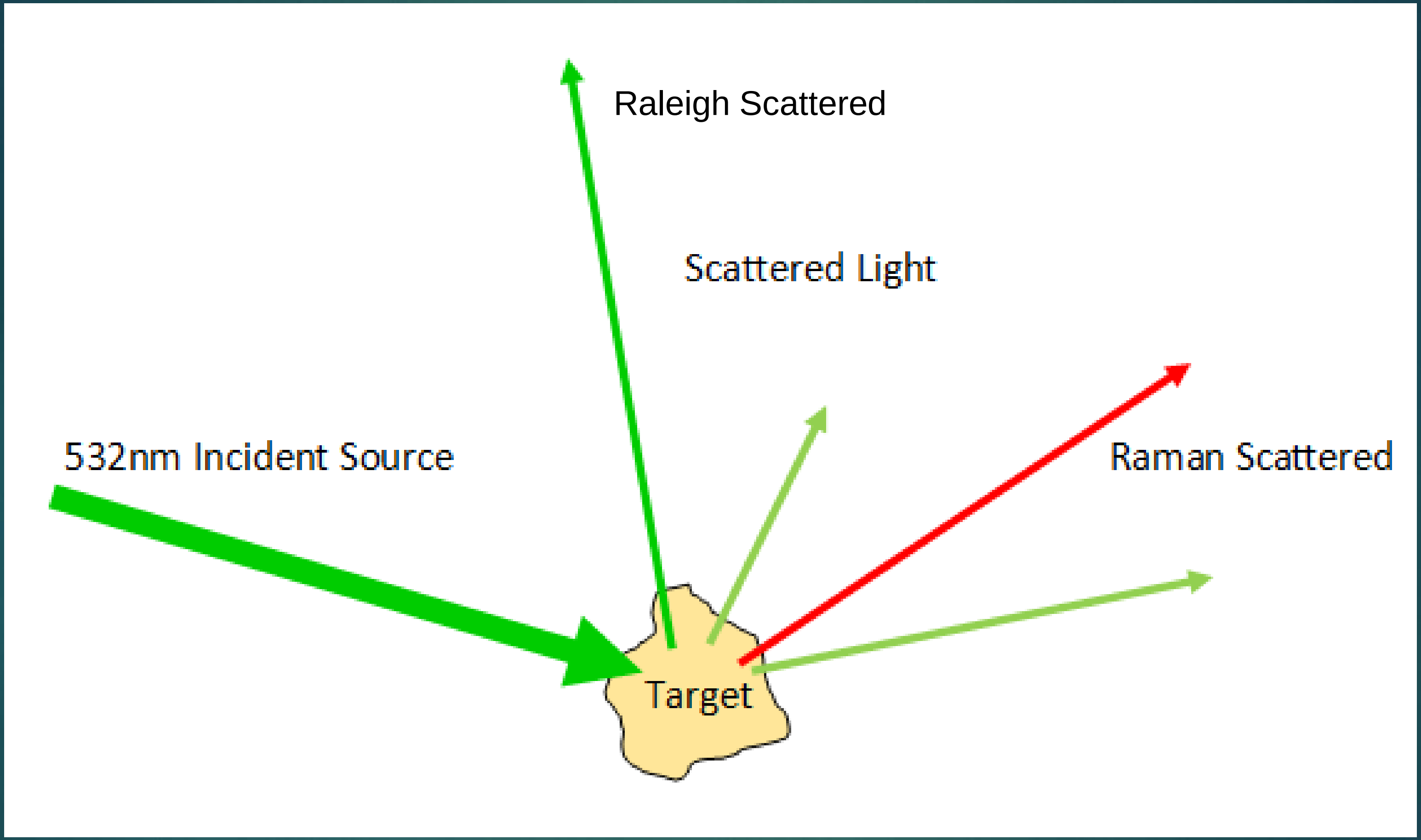
What is Raman Spectroscopy?

Scattered Light

- Determined by properties of target
- Unique “fingerprint” for different molecules

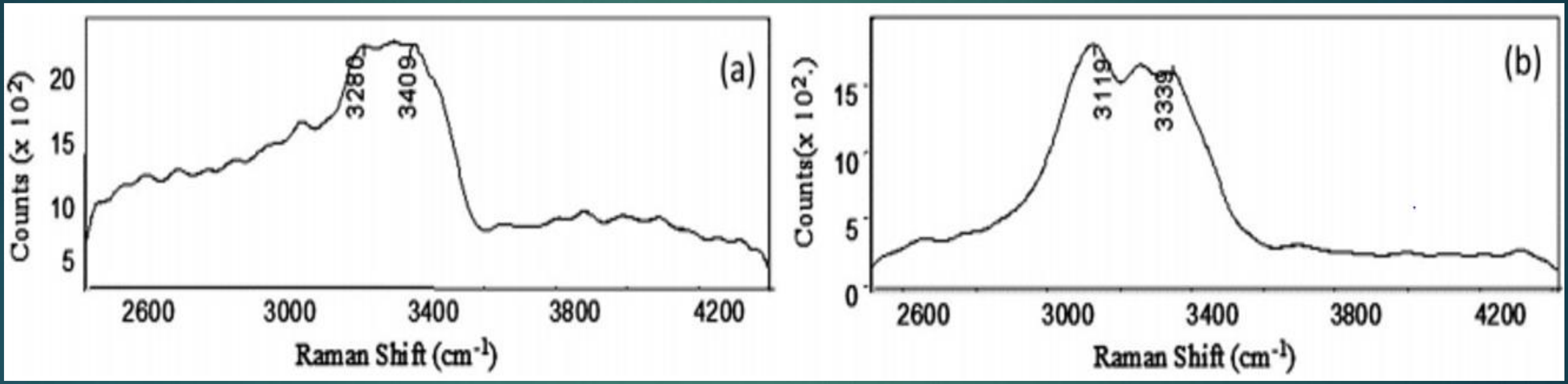
- Note: Not all materials create Raman scattered signals

What is Raman Spectroscopy?



Example of photon behavior when hitting polarizable material

What is Raman Spectroscopy?

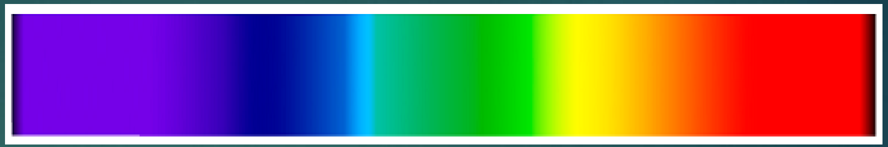


Example Raman spectra of (a) water, and (b) ice [2]

Recap: Raman Spectroscopy

- Powerful technique for detecting both organic and inorganic materials inside of a sample material
- Uses lasers to excite and vibrate molecules inside of unknown material
- Vibrational pattern of material can be measured to identify molecular composition

Spectrometer



Device that takes in light and disperses it into its component wavelengths

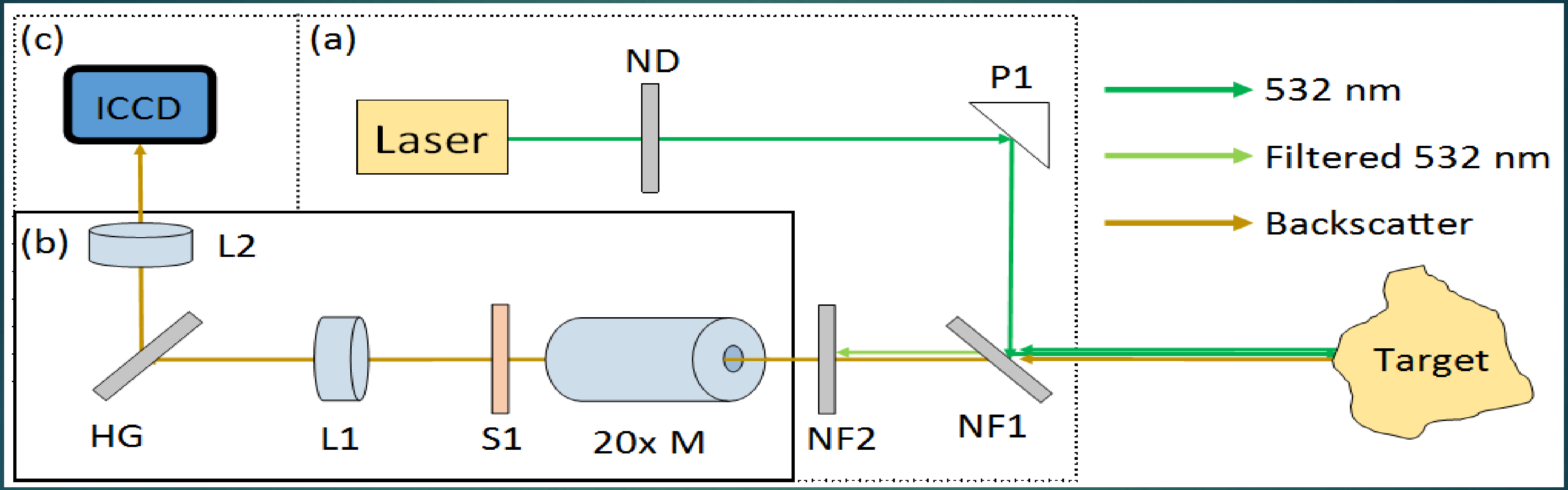
Uses:

- Carbon Dating
- Respiratory gas analysis
- protein characterization
- **Raman Spectroscopy**

Realistic Constraints

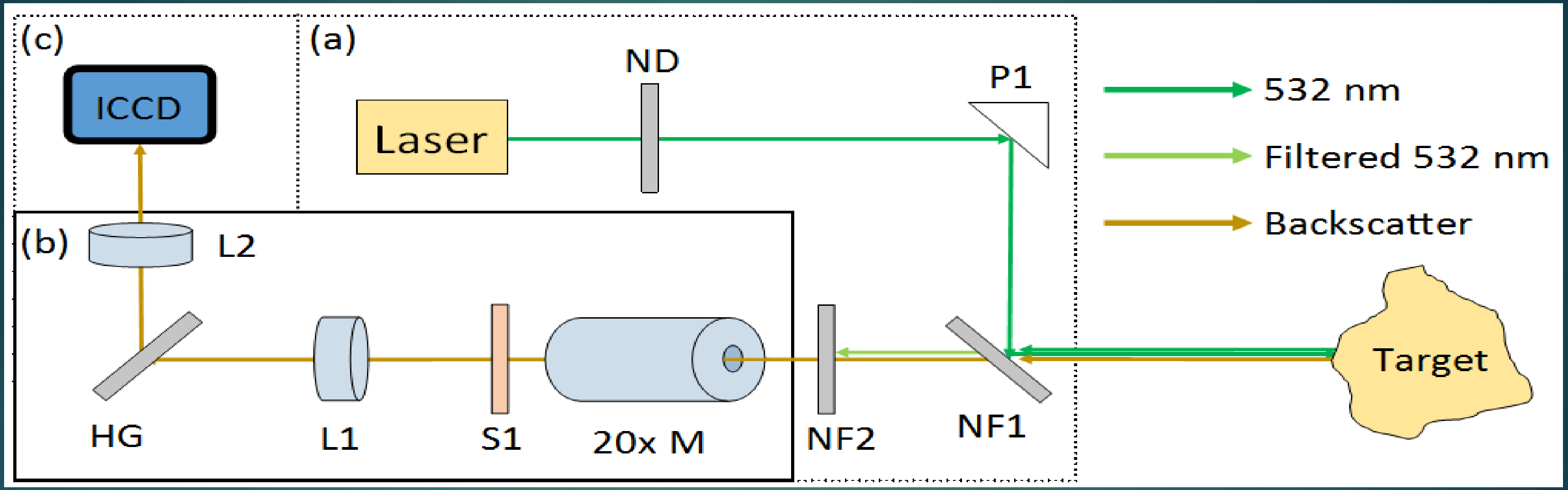
- Lightweight, small footprint, for installation on planetary rovers
- Ability to measure samples within a range of < 20 cm with no physical samples taken
- Ability to operate in bright light (daytime), and low light (nighttime) environments
- Ability to detect water, biological, and organic compounds
- Ability to detect all minerals, regardless of physical appearance (light / dark)
- Ability to detect Raman signals in the presence of fluorescence

Design Approach



Block diagram of proposed system using a laser, neutral density filter (ND), a 45° mirror (P1), notch filters (NF1, NF2), A 20x magnification microscope objective (20x M), a slit (S1), achromatic lenses (L1, L2) a volume phase holographic grating (HG), and a mini ICCD camera.

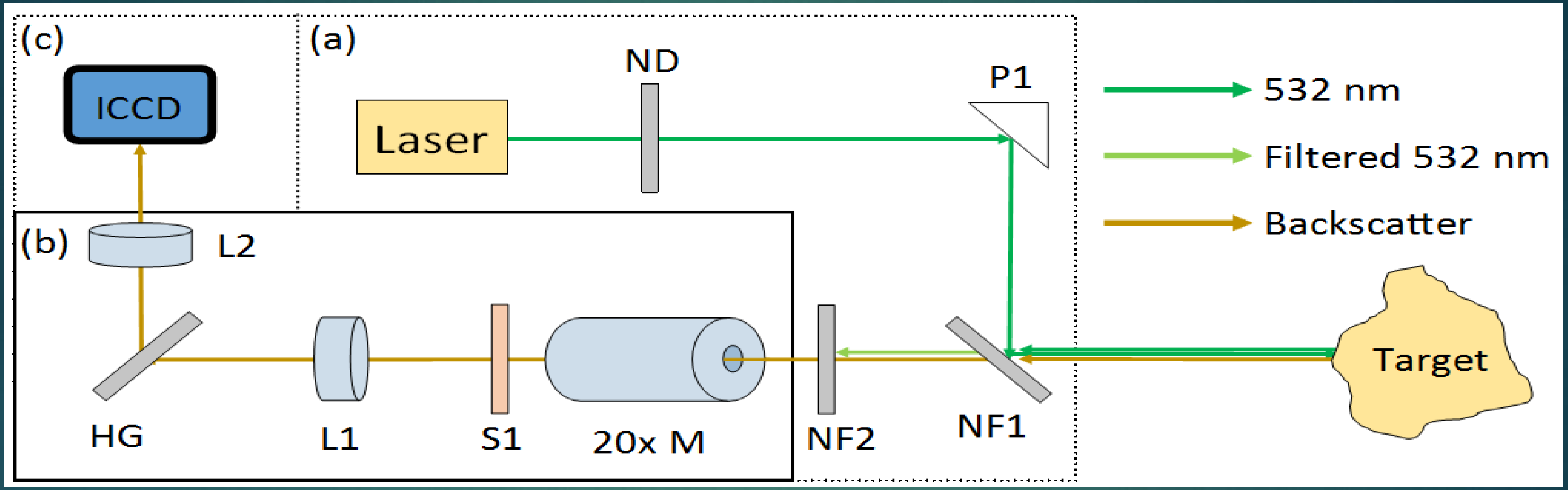
Spectrometer



Laser

Nd:YAG (Neodymium-Doped Yttrium Aluminum Garnet; Nd:Y3Al5O12), diode pumped, Q-switched Laser model number QL532-500. Manufactured by Crystal Laser LC, this **532nm 500 mW** laser will be operating at a switched rate of **1 kHz.**

Spectrometer

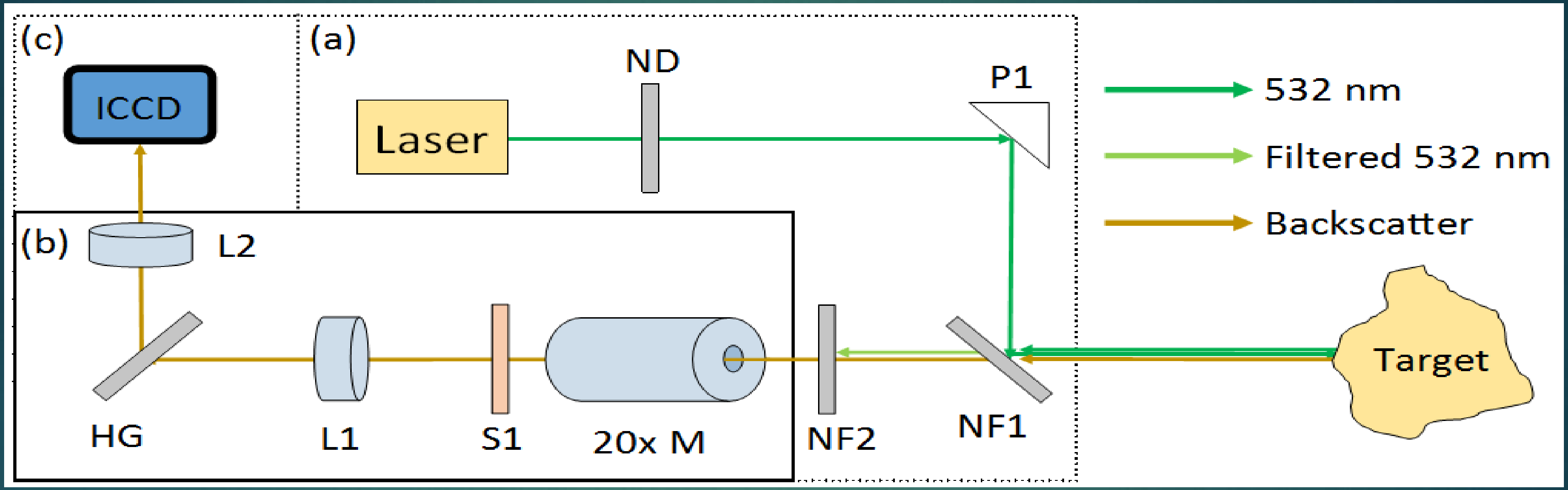


ND: Neutral Density Filter

Lowers the intensity of the output laser without affecting the wavelength

Protects back end optics from damage

Spectrometer



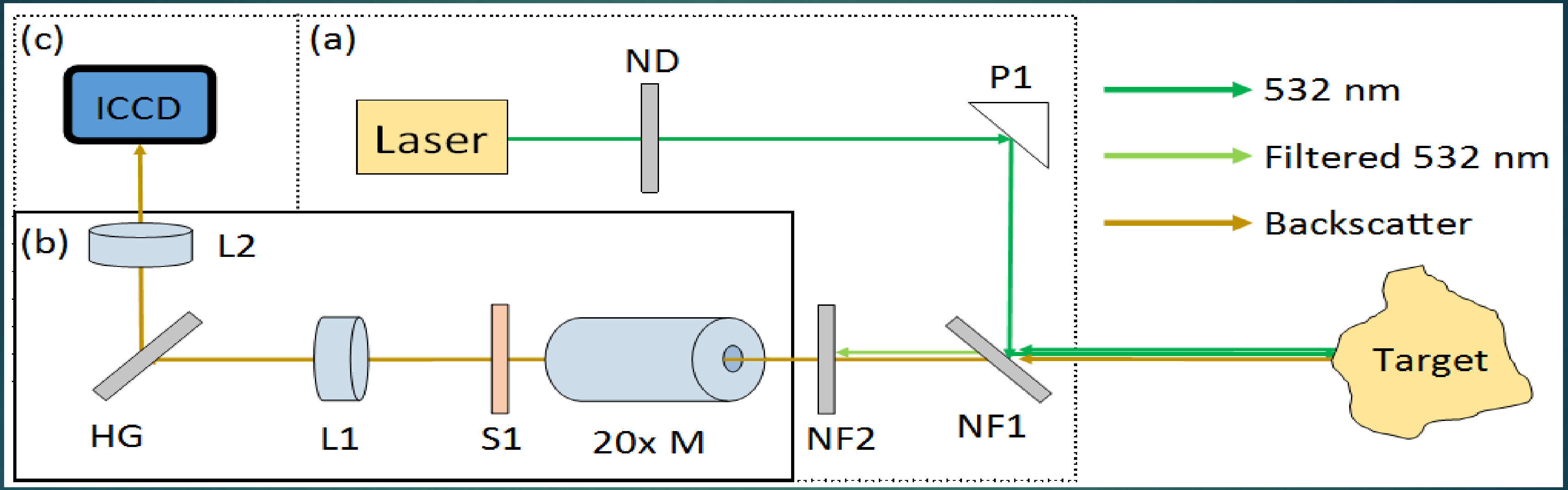
NF1: Dichroic 532nm Mirror

Reflects 90% of 532nm light while passing other wavelengths

NF2: 532nm Notch Filter

Filters remaining 532nm light

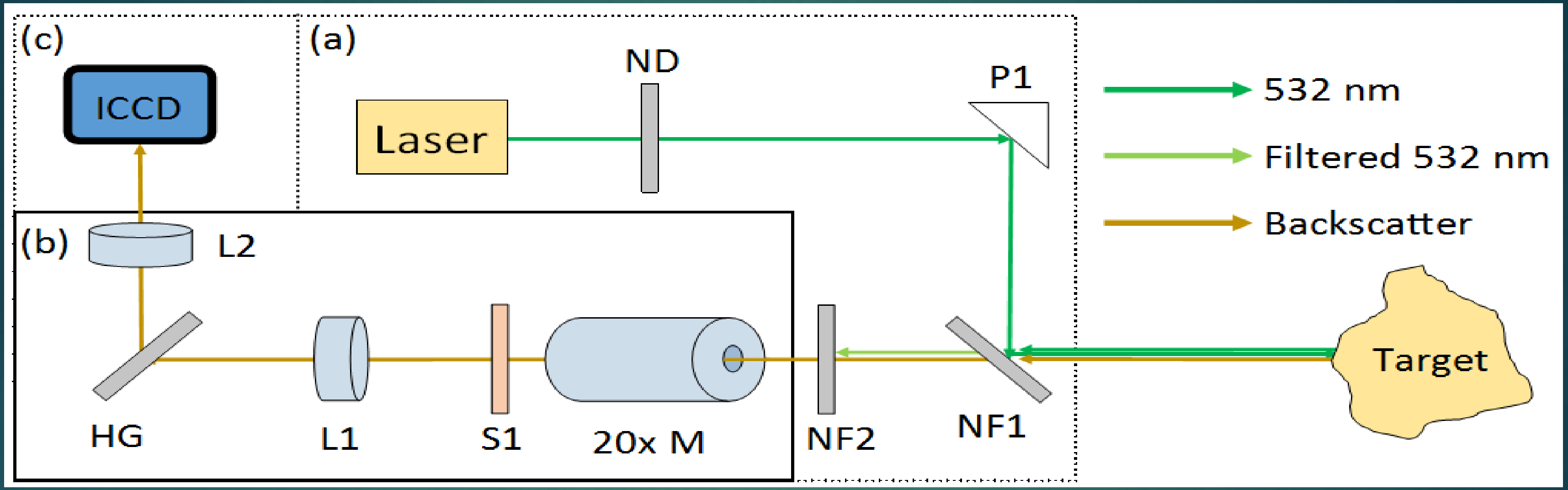
Spectrometer



20x M: Microscope Objective

Intensifies captured Raman signal. Allows the spectrometer to capture and analyze weak signals.

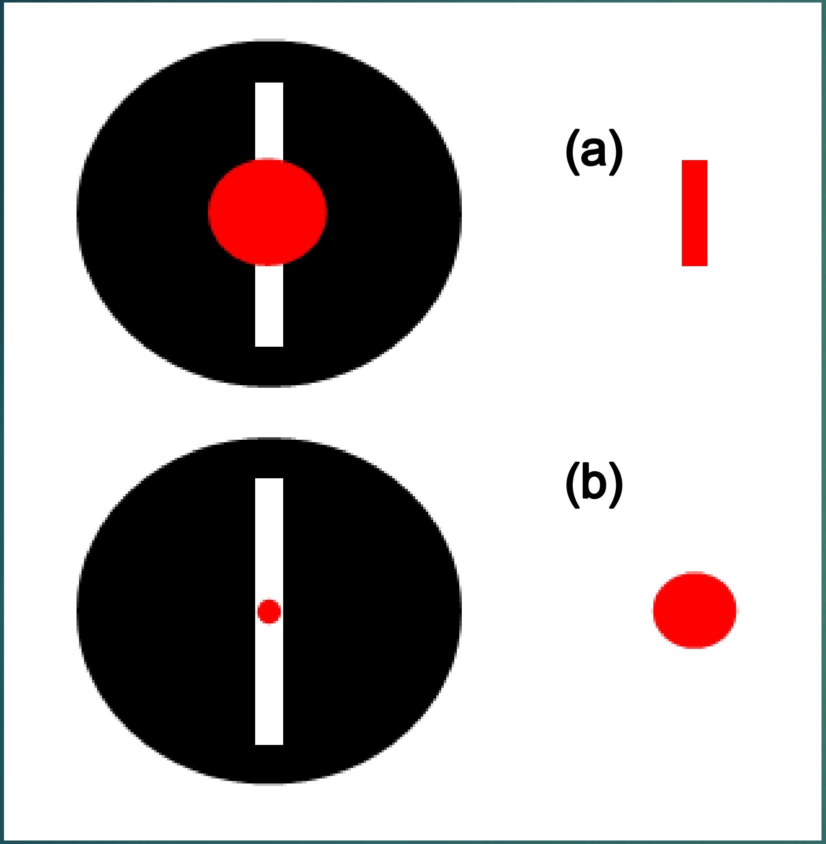
Spectrometer



S1: 50μm Slit

Determines the amount of light that is allowed into the spectrometer

Setting the Slit focal length

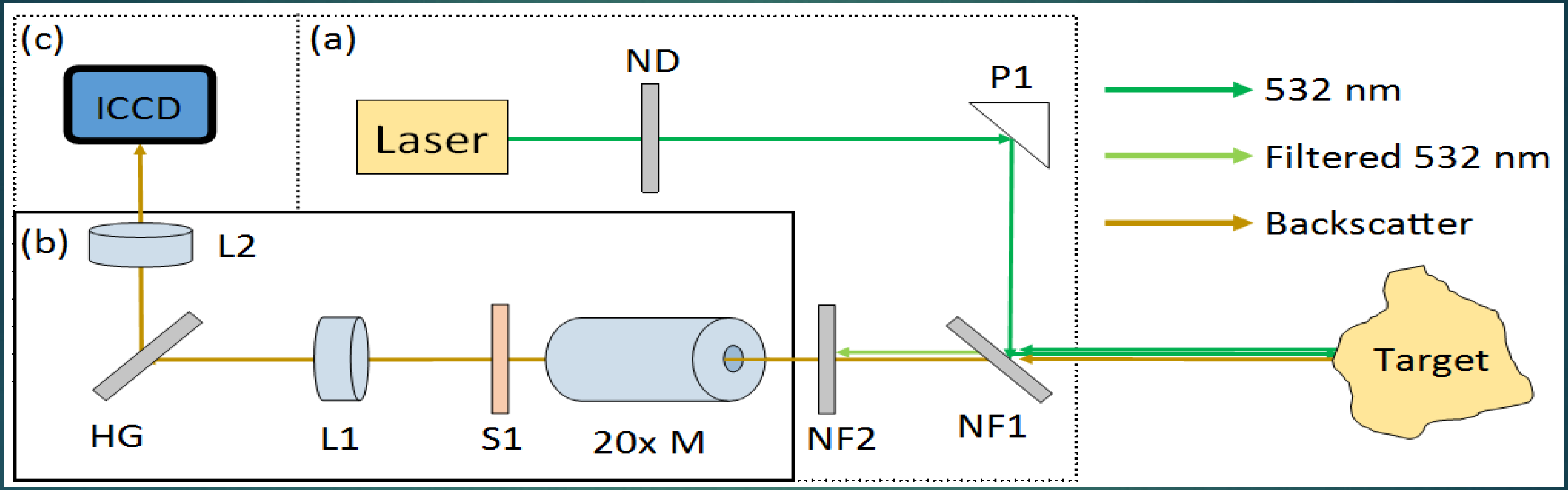


Lost signal

Full signal

Example of (a), incorrect length and (b) correct focal length

Spectrometer



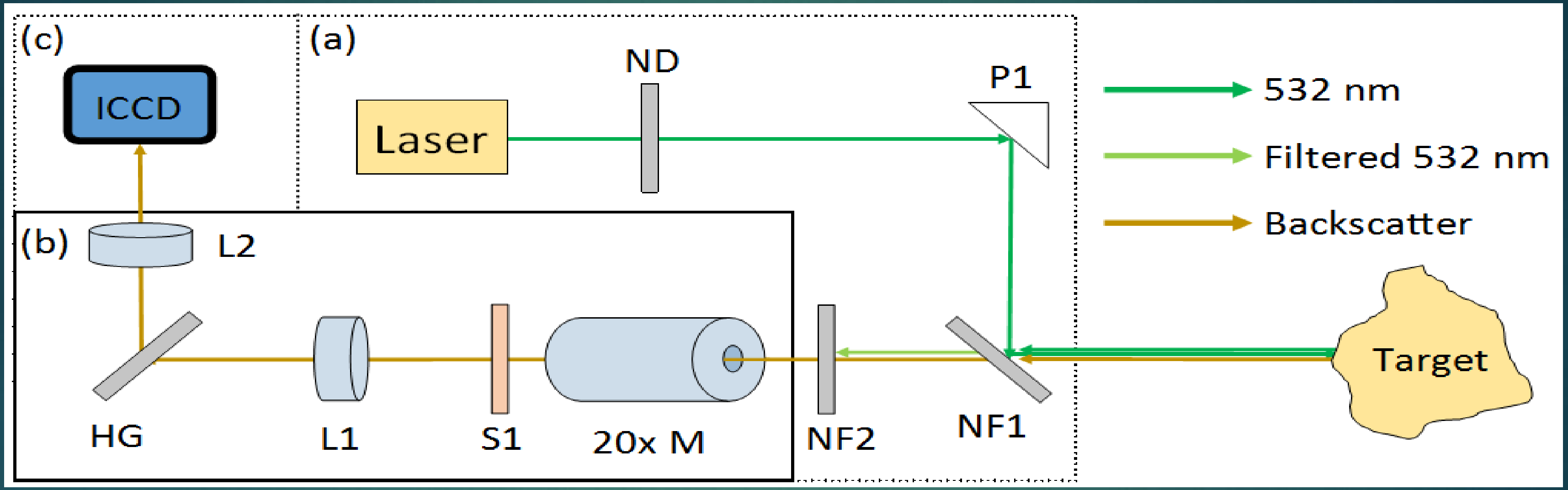
L1: Focusing Lens

5mm achromatic doublet

1 cm focal length

Maximizes signal intensity into the holographic grating.

Spectrometer



HG: Holographic Grating

Transmission grating with angles of incidence and transmission of 45°

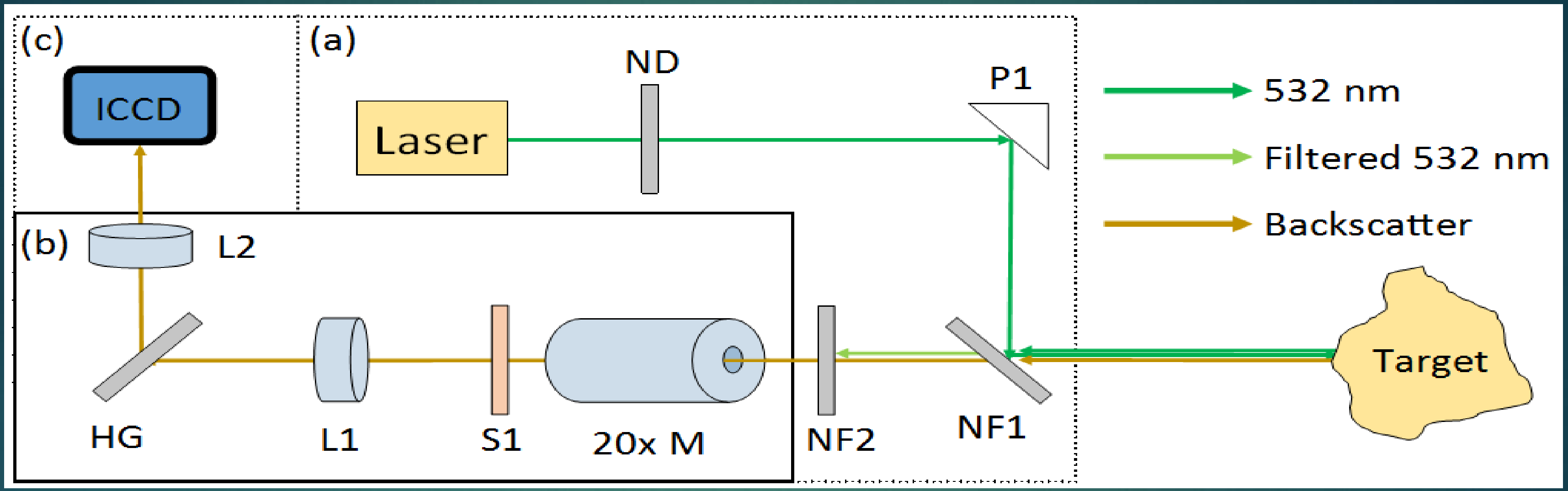
Splits incoming light into component wavelengths

2x Fused gratings

Output from grating

Output of grating using all visible light

Spectrometer



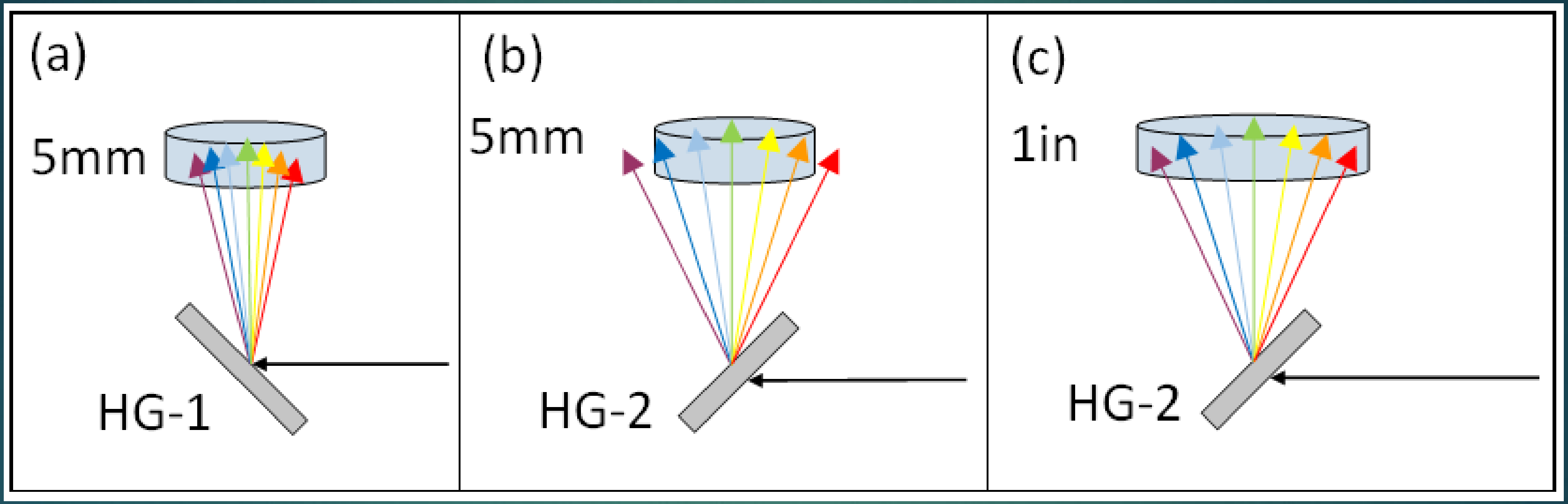
L2: Collection Lens

10mm achromatic doublet

3 cm focal length

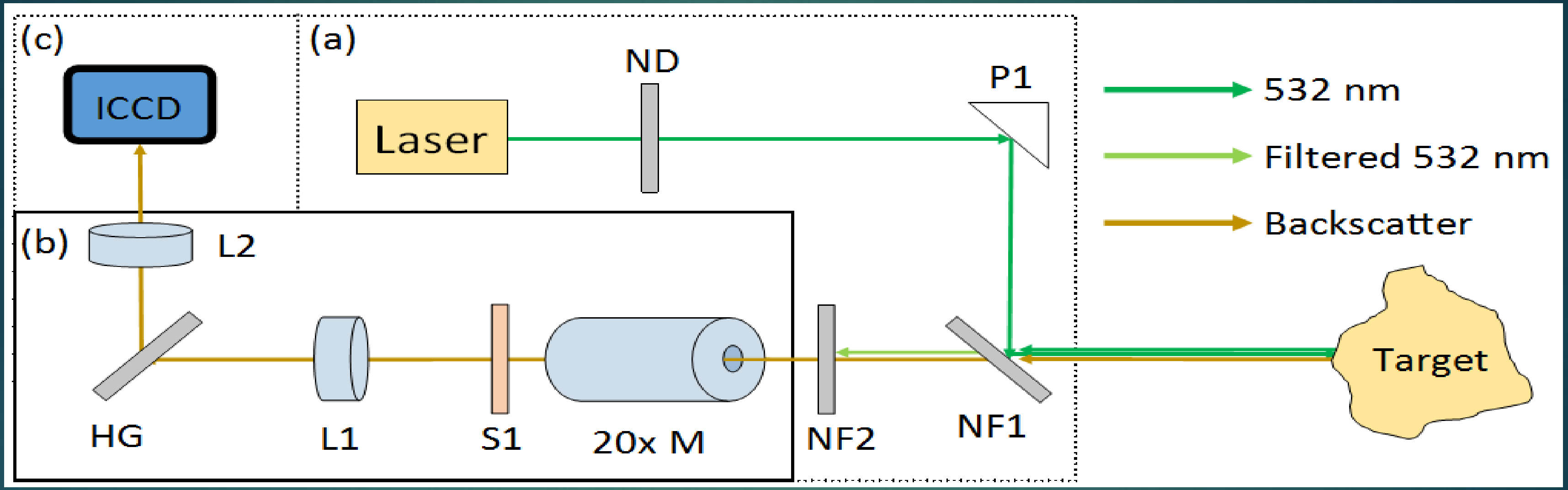
Captures light spectrum generated by the holographic grating and directs it into the ICCD

Choosing a collection lens



(a) Reflective grating with 5mm collection lens capturing full spectrum, (b) Transmission grating with 5mm collection lens capturing partial spectrum, and (c) Transmission grating with 1in collection lens capturing full spectrum.

Spectrometer

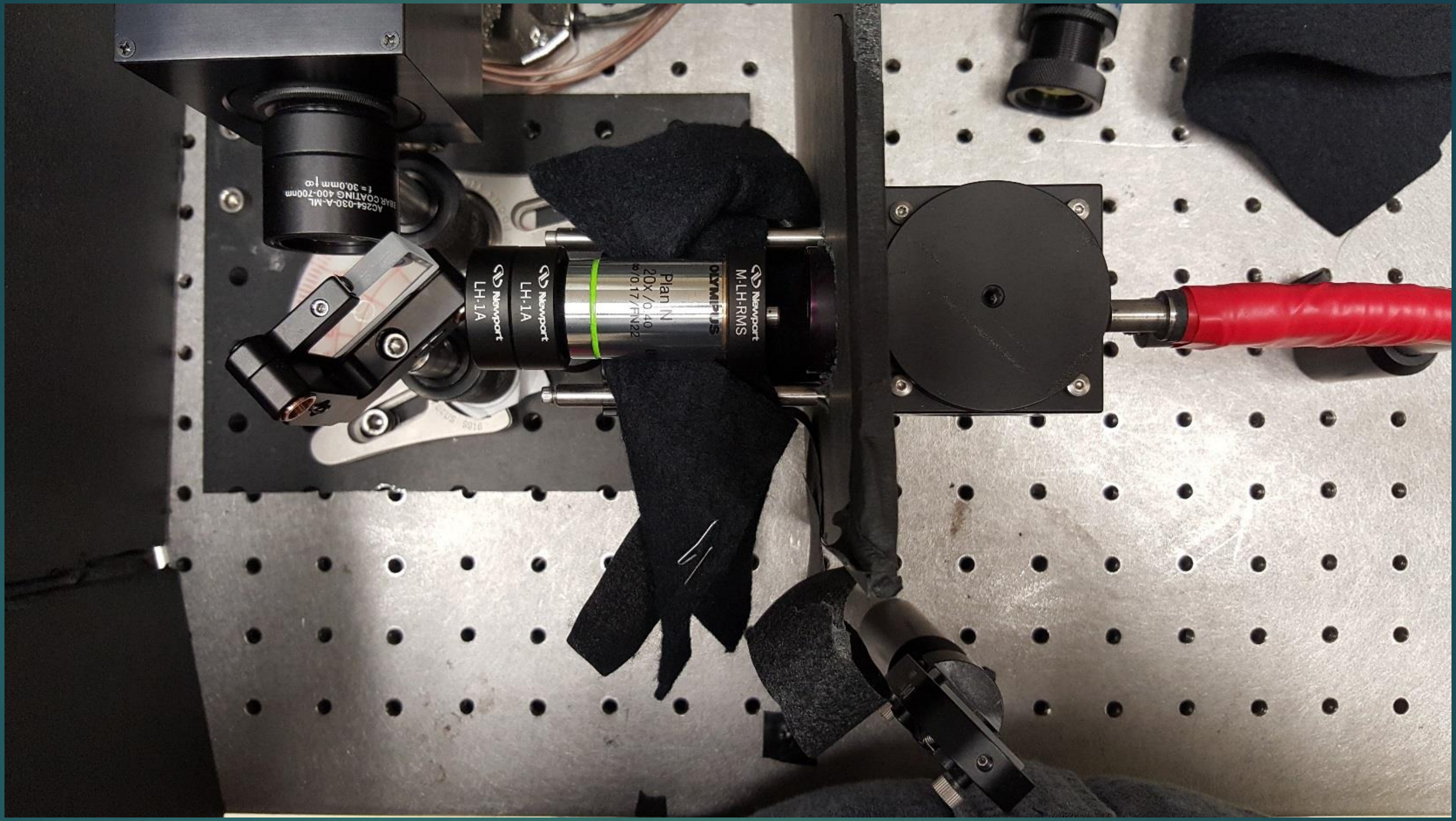


ICCD

Captures the image from the collection lens and converts it into a digital image

2048 X 2048 pixel resolution

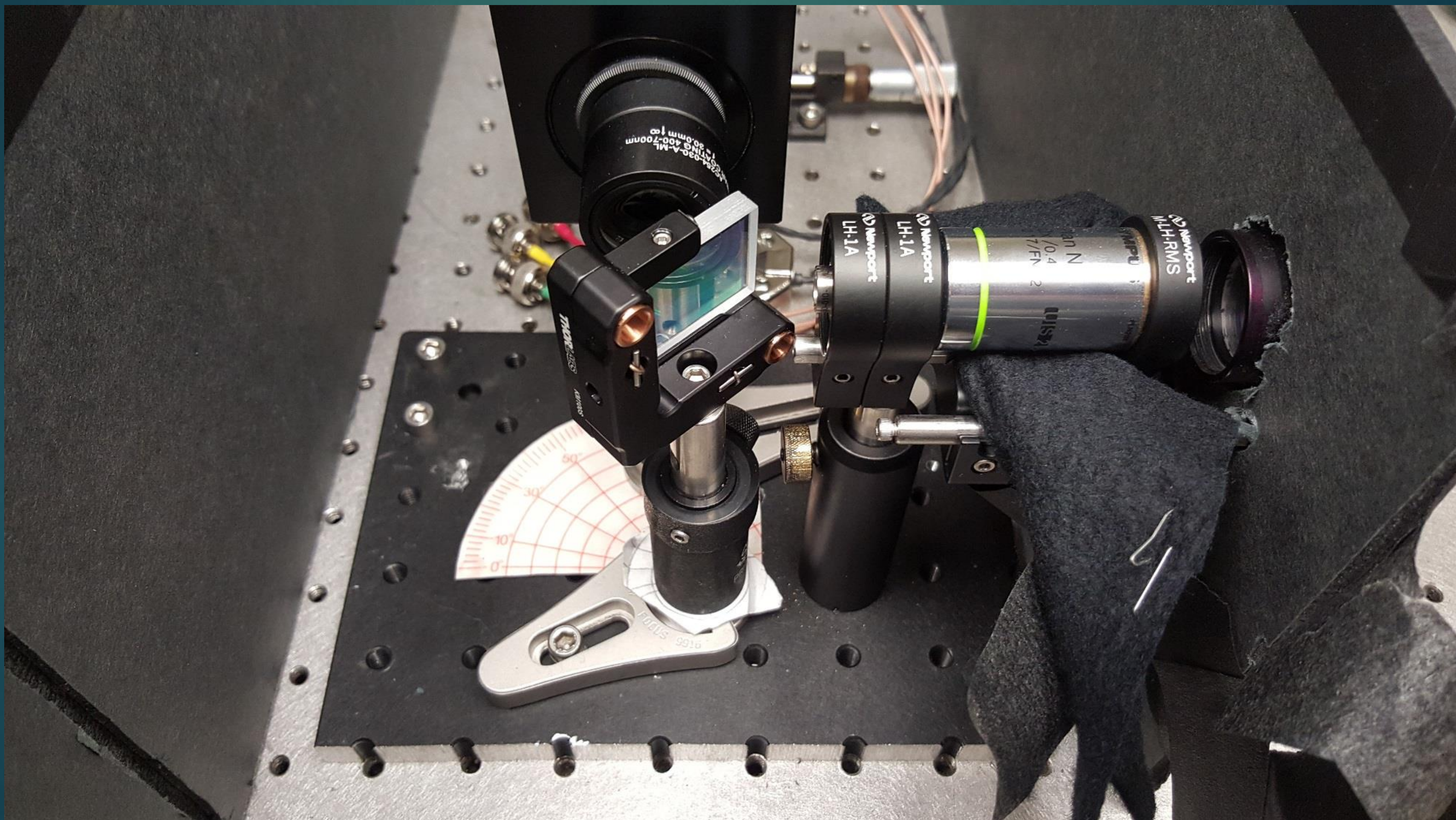
Prototype System



Laser aligned breadboard system

8.79cm x 2.03cm

Prototype System



Engineering Standards

- ASNI Z136.1-2007: The American Nation Standard for Safe Use of Lasers
- NASA-STD-(I)-0007 NASA Computer-Aided Design Interoperability
- NASA-STD 8739.6 Implementation Requirements for NASA Workmanship Standards
- IEEE 1394-2008 IEEE Standard for a High-Performance Serial Bus
- ExpressCard 2.0 Standard

References

1. S. Sharma, A. Misra and P. Lucey, "A combined remote Raman and fluorescence spectrometer system for detecting inorganic and biological materials", *Lidar Remote Sensing for Environmental Monitoring VII*, 2006.
2. N. Abedin, *et al.,* "Compact remote multi-sensing instrument for planetary surfaces and atmospheres characterization", *Applied Optics, vol.* 52, pp. 3116-3126, 2013.
3. C. Walker, "Spectrometer Technology and Applications", *Azom.com*, 2013. [Online]. Available: http://www.azom.com/article.aspx?ArticleID=10245. [Accessed: 26- Mar- 2016].
4. *ASNI Z136.1-2007*, 1st ed. Orlando, Fla.: Laser Institute of America, 2015, pp. 1-81. [PDF] Available: https://www.lia.org/PDF/Z136_1_s.pdf [Accessed: 20-Mar- 2016]
5. *NASA-STD-(I)-0007 NASA COMPUTER-AIDED DESIGN INTEROPERABILITY*, 1st ed. Washington, DC: National Aeronautics and Space Administration, 2009.
6. *NASA-STD 8739.6 IMPLEMENTATION REQUIREMENTS FOR NASA WORKMANSHIP STANDARDS*, 1st ed. Washington, DC: National Aeronautics and Space Administration, 2012.
7. *IEEE Std 1394™-2008: IEEE Standard for a High-Performance Serial Bus*, 1st ed. New York, NY: IEEE-SA Standards Board, 2008.
8. *ExpressCard Standard 2.0*, 1st ed. San Jose, CA: PCMCIA, 2009.