# The Role of 3D Printing in Spectrograph and Small Telescope Science

Robert Buchheim, Jerry Foote, Wayne Green, Paul Gerlach,
Anthony Rodda, Forrest Sims, Thomas Smith, Clarke Yeager

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**Abstract**

Anthony Roddy, following Paul Gerlach's LOWSPEC design, introduced this team to the power of 3D printing for astronomical purposes at the AAVSO Fall Conference in 2018. This was reinforced at the Sacramento Mountain Spectroscopy Workshop 2 (SMSW-2) in Las Cruses, NM in February. This repository contains results, videos and other resources in support of 3D spectroscopy. The poster presents a host of considerations about calibration lamps, thermal expansion issues related to ABS,PETG and other 3D media, optics, automation, telemetry, and adapting to other focal-lengths. This poster introduces a repository at https://github.com/dxwayne/RRRRR. This paper introduces 3D printing for other areas of small telescope science.



## REMOVE CONTENTS FROM PAPER



## List of Figures

# List of Tables

# 1 Overview

Foote [?] during the SAS 2019 Symposium presented the results of an international collaboration of small telescope scientists to replicate, explore and to adapt the Lowspec 2 project [?] for 3D printing R∼1000 spectroraph. This paper presents details that this collaboration has taken towards a new and improved Tenative Lowspec 4device.

Yeager discovered discrepancies with the Lowspec 2 under thermal loads encountered during the winter conditions in Colorado, USA. This lead to using an Arduino and Maxim/Dallas 18B20 temperature sensors to monitor differential temperatures while taking calibration exposures. The spectrograph was not moved between exposures to rule out flexure and other aspects. The conclusion is a shift in the position of the calibration lines shift with respetc to emperature over a duration matching a nominal exposure sequence.

He also experimented with introducing flexure into the instrument by proping up a corner. This also demonstrated a shift in the position of the calibration lines shift with respect to orientation is an issue.

See figures ...

The layout of the Lowspec is:

ACTION: LS Layout[1]

Other general issues include the orientation of the spectrograph to correct for parallactic angle, guiding, using more than two cameras at the same time with one computer, the cabling associated with the instruments, length of the cables required for larger diameter OTAs, several aspects of focusing the instrument,

...

# 2 Issues Addressed

## 2.1 Calibration Lamp

The group experimented with local Ne/Ar ballast lamps for fluorescent lights. These are small easily acquired modules from the local home improvement stores. They consist of a simple resistor in series with a sealed bulb. Neon only lamps are available (replacements for indicator lamps on older appliances like freezers, etc) from hardware stores. These operate on 60 Hz 120 VAC mains in the United States with a peak RMS of around 180 VAC. This is sufficient to trigger these lamps. Most ballast bulbs have a built-in bi-metallic strip that heats up and shorts across the filiments causing light output to all but disappear. In Europe, 50Hz 250 VAC is the norm. The European Relco™lamps last longer on US mains, but the bi-metallic strip still hampers direct mains to the payload operation.

Walker [?] published a 555 timer / transformer circuit using a German transformer. Green and Yeager located a transform TODO Transformermore readily available in the US and Yeager adapted the circuit and produced a preliminary Printed Circuit Board (PCB). The design runs the transformer backwards by hooking 6-12 VAC to the output side causing a 250 VAC output. The DC input is converted to a pulse modulated signal by the 555 timer. The best operating frequency is around 500Hz.

ACTION: 555 Circuit[2]

After this initial experiment, the group decided that the real-estate on the PCB was low, and what other features could be adapted to the box to support other peripheral sensors.

Experiments were done along the lines of shape of the input beam into the slit of the spectrograph. The premise assumed a converging beam that more closely matched the Point Spread Functon (PSF) of the instrument would be best. Foote and Smith devised a moterized device to lower a mirror into place and choose Ne/Ar or flat tungsten lamp light input.

Avaliablilty of calibration lamps other than Neon are a problem. Argon based lamps are not as readily available as they once were.

ACTION: Jerry's Decice[3]

Rodda took the expediency of placing the bulb directly adjacent to the Schmidt Cassegrain Telescopes's (SCT) secondary. This eliminated the need for extra weight etc on the payload.

## 2.2 Moment of Inertia

Most spectrographs are developed along the optical axis. This results in placing the camera at a position farther from the back of the OTA and poses a clearance issue with fork mounted scopes. The lowspec is no issue.

## 2.3 Thermal Shifts

The southern part of the United States experiences large shifts in diurnal temperature. The expansion co-efficent of the printing plastics are on the order of 50 microns per meter per K. The coefficents are on the order of 21 and 9 $\mu m$/m/K respectivly. The current layout of the Lowspecs 2 and 3 have a larger solid block to hold the guide camera. This block comes to equilibrium slower than the rest of the box and introduces torque on the optical axis. Other observers, located in Europe for example do not experience these fast temperature swings.

## 2.4 Focus

Focusing the spectrograph's collimination lens, the camera lens the placement of the camera onto the body, and the orientation of the camera is an issue. The weight of the camera was too high to use printed threads so metalic camera adapters were embedded into the body.

## 2.5 Guiding

Placement, orientation, field of view and focus of the guide camera has been re-designed. A LED was added inside the spectrograph to momentarily illuminate the slit to establish its orientation w.r.t. the guider sensor.

A deep exposure is taken to establish the field, and plate-solved. The plate solution can be achieved by visiting a field at the same declination with sufficent stars to solve - and the WCS coordinates can be altered and transferred to the new field. Once distortoins are known, it is possible to synthesize a astrometric WCS to reasobable precision.

The Field of View (FOV) of the guide camera has to be large enough to allow guiding software to work but wide enough to grab an off-slit star when seeing is particullary good.

### 2.6 Gratings and Grating Orientation

The working dispersion range is controlled by the focal length of the “camera” lens as well as the number of lines per mm of the grating. Orientation of the grating is critical to avoid order-overlap. We developed software to assist with the planning and layout of the optical components. Anamorphic magnification is also a consideration.

### 2.7 The Slit and Slit Assembly

The slit assembly has been redesigned several times. The new approach will employ a motor to select the slit at the scope. New slits are being considered as well.

## 3 Camera and Instrument Control

John Hoot [] introduced the idea of using a ODroid XU4 Single Board Computer (SBC) using an eMMC flash drive and running an ARMxxx Ubuntu 18.04. The heart of the main software suite includes KStars, Ekos, and INDI capable of controlling 2 USB cameras. The SBC is small and light enough to be attached to the SBC. The SBC requires only Power, Ground and an Ethernet cable and is controlle through X-Windows protocols. The software suite has been augmented by compiling ds9 [] from source on the SBC, adding Sextractor [] and Astrometry.net [] with a subset of the index files as required for the field size. The ds9 program assists with focus.

Images are acquired and stored on the SBC, and may be simultaneously written via SMB or NFS protocols to a remote computer. The SBC also supports a distributed MQTT broker service and handles telemetry reports from various additional instruments discussed herein.

ACTION: XU4 Processor[4]

## 4 Telemetry

The Arduino Nano 33 is a single board computer that supports a number of sensors on the card. The main sensors are a microphone, a 9-axis accellerometer, temperature sensors and light sensors. The Arduino computers use a subset of C++ and classes have been written to adapt each sensor to the small telescope spectroscopy needs. Telemetry is “published” by the Arduino, and managed by a MQTT broker, here on the ODroid. C++ and Python classes are available, see the electronic appendices for this paper. [1]

MQTT [] is a Publish/Subscribe protocol. Messages are simple, but may include embedded text-only JSON structures. Each sensor may publish its data and many subscribers may receive the messages. The sensor module may subscribe to a topic as well and recieve instructions. A non-MQTT out-of-band serial control structure has been developed to allow one or more Arduino devices to take sensor readings, perform basic actions etc in a distributed manner.

Overall, the MQTT is well known and well supported. Control can be by special code modules or via the Node-RED [] web-based mechanism and a simple browser.

[1] A public GitHub repository may be found at `https://github.com/dxwayne/RRRRR` and documentation is at `https://RRRRR.ReadTheDocs.io/index.html`.

# 5 New Directions

The main box is being replaced with a commercially available metal box. This requires some machining. Clever hand tools and additional printing can be employed. Several of the authors have small machine shops at their disposal. The optical layout is achieved with printed parts to hold each of the components.

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# 6 Conclusions

The new design will address the moment arm issue,

## Action Items:

[1]Two figures LS2/3 with callouts for parts mentioned and arrows for differences.

[2]Show waveforms, spectra etc.

[3]Show diagrams etc of this.

[4]Get the description of ODroid together