Lowell Instrument Group ADC Exhibits

Coronagraphs in Space, Wobbling Stars

History

The original concepts were developed for the ADC by KEI Space with the intention of having an external vendor develop and fabricate the exhibits, but the Lowell Instrument Group (LIG) was approached in mid August 2024 to complete these exhibits due to serious schedule delays. Only sketchy details were available on the actual work that had been completed up to that point, so we started essentially from scratch and built exhibits that were mechanically robust, fit the original exhibit size, and clearly demonstrated the concepts we were given.

Initial Timeline

The following is an abbreviated timeline of the development of both of these exhibits.

- 2024 08 15: Emergency Management Meeting #1. Prototyping and design started
- 2024 08 16: Coronagraph "Mk I" version using lab scraps for proof of concept
- 2024 08 27: Coronagraph "Mk II" version, full sized for final concept development
- 2024 08 28: Emergency Management Meeting #2
- 2024 08 30: Meeting with Juan T. from KEI Space on prototypes
- 2024 09 04: Arrival of cabinet materials from original vendor
- 2024 09 09: New 3D printer delivered (Bambu Labs X1E)
- 2024 09 13: Wobbling Stars "Mk I" completed
- 2024 09 19: Coronagraph design completed, all parts ordered
- 2024 10 11: All Coronagraph parts in hand, Wobbling Stars "Mk II" completed
- 2024 10 30: All Wobbling Stars parts in hand
- 2024 11 01: Final install of both exhibits
- 2024 11 02: First official ADC opening event
- 2024 11 08: Software fixes for both exhibits based on initial feedback
- 2024 11 16: ADC Grand Opening

Calling this a "tight timeline" is an understatement! This was a functionally impossible timeline that we made work only by working many nights and weekends.

Coronagraphs in Space

Learning Goals & Key Messages (from KEI Space Concept)

- New technologies and techniques are being created to help us detect even smaller exoplanets, including ones the same size as the Earth
- By blocking the light from a central star, we can directly observe orbiting planets
- Future space telescopes will include coronagraphs to help directly image exoplanets

Overview & Usage

The guest walks up to the exhibit and sees the mechanism on the desktop with a small video screen next to it, and underneath the screen is a lighted button. A large wheel with colored inserts holds 4 choices for the user:

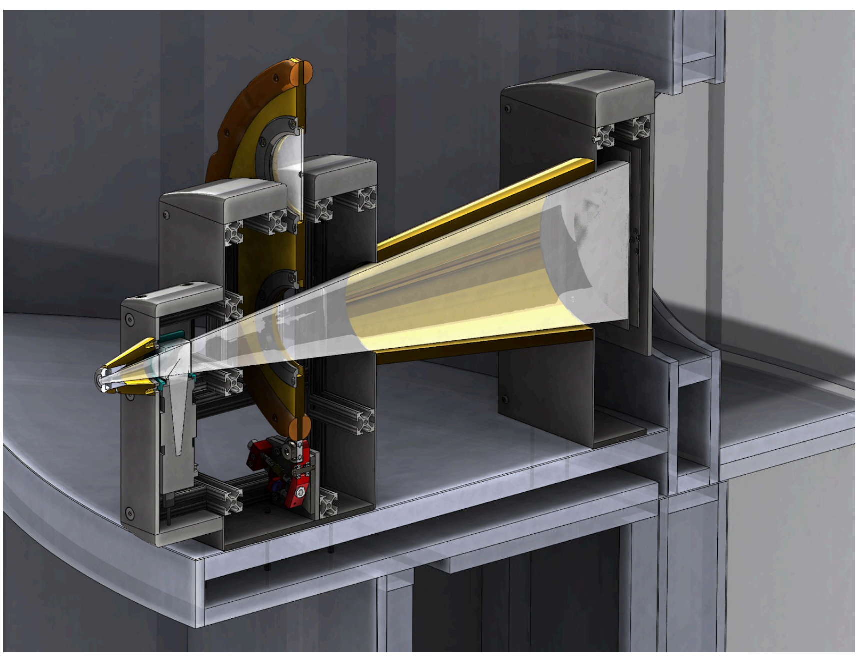
- Red: clear, no coronagraph or anything else
- Yellow: “Too small” coronagraph mask
- Green: “Just right” coronagraph mask
- Blue: “Too big” coronagraph mask

The wheel is rotated by hand, and there will be a (fairly loud and obvious) click as the wheel rotates into position and a spring-loaded arm pushes into grooves in the wheel outer edge to hold it in place. The wheel is connected to a damping mechanism so if someone spins it like they’re playing Wheel of Fortune, it will stop quickly.

If the screen is off, then the coronagraph internal light sources are also turned off - guests will need to push the button to turn things on and then look through the eyepiece. It will turn itself off after a preset amount of time to not waste energy or put undue runtime on the electronics.

If the clear plastic pieces that hold the coronagraph masks become overly smudged, clean them with a microfiber cloth. We will leave a small one underneath the exhibit behind the cabinet doors.

The view from the eyepiece is duplicated on the screen via an optical light beamsplitter that sends 50% of the light to the eyepiece and the other 50% is reflected down to a video camera underneath the eyepiece. This can be seen in the rendering below.



Design

Science Features

The sources visible to the user were designed to show observations of a real exoplanet system, HD 206893 (~40 pc away). That system (as of late 2024) is known to have two exoplanets, one of which was discovered using a ground based inteferometric coronagraph (http://dx.doi.org/10.1051/0004-6361/201629908 and https://doi.org/10.1051/0004-6361/202244727). That's a way-more complicated instrument operating in a totally different way than this exhibit, but the core principle is the same: block or otherwise cancel out starlight to see fainter sources that would otherwise be undetectable.

To translate from observations on sky to an exhibit in the ADC, we used a scale where 100 milliarcseconds in the actual observations of the planet's orbit are represented by 26.5mm on the rear of the coronagraph mechanism. This was chosen largely to fit the available space for the exhibit. The color of the central source in our mechanism was tuned to be roughly appropriate for the system's stellar colors, an F5 main sequence star with an effective temperature around 6500 K.

The two planets in this system are quite massive and are honestly better characterized as brown dwarfs instead of planets. The outermost planet (HD 206893B) is likely 28 times the mass of Jupiter, with an effective temperature of 1400 K. The innermost planet (HD206893c) is likely 13 times the mass of Jupiter, with an effective temperature of 1200 K. They represent the kind of systems we can find with current technology - the hot, massive ones are "easy" to spot with the instrumentation on large 8m+ telescopes right now. Future space-based coronagraph experiments, such as that in the upcoming Roman Space Telescope, will be better suited to observe cooler and smaller planets.

Mechanical Features

A large fraction of this exhibit was 3D printed here at Lowell in the Instrument Lab where we also build and maintain instruments and equipment for our research-focused telescopes. It was something like 50+ parts totalling 170 hours of print time and 5+ kilograms of material used.

The exhibit uses several real-world instrument parts designed or used at the Peggy and Eric Johnson 1m Telescope at Anderson Mesa:

- The wheel is held in position by the (almost exact) same mechanical assembly designed for the main science camera's filter wheel
- The coronagraph wheel uses pieces of the main science camera's physical structure
- Commercial LED controller originally picked up for controlling lighting at the facility

Fun fact: The rotary damper used to slow the wheel is commonly used in soft-closing toilet lids.

Optics

There are only really two optical elements in the mechanism: there is an aspheric condenser lens on top of the central “stellar” source to make it appear brighter, and there is the aforementioned beamsplitter. There are various optics included in the video camera’s lens to adjust zoom, aperture, and focus, but they are part of the camera package and not anything that we integrated ourselves.

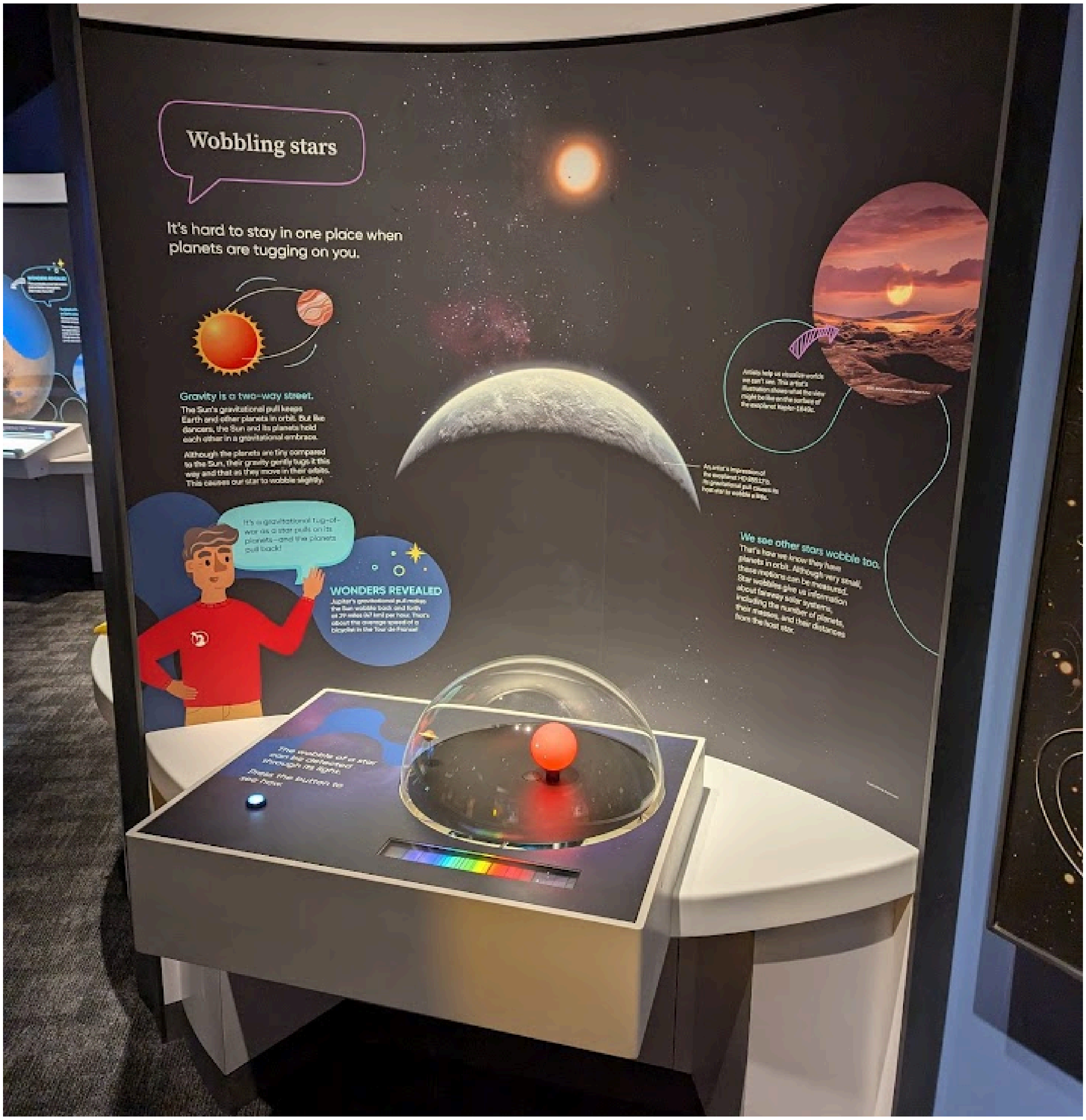
The “eyepiece” in the exhibit was a real one from our lab stock of microscope and telescope eyepieces. We removed the powered optics that were inside, and inserted a small flat window at the user end to prevent debris accumulation. That window as well as the ones that hold the coronagraph masks are all optical quality CR-39 windows from Edumnd Optics.

Fun fact: CR-39 is commonly used to make eyeglass lenses and holds up well to daily use.

Electronics

The “sources” in the rear of the coronagraph mechanism are fairly ubiquitous RGBW LEDs, specifically SK6812W. There are 3 LEDs set into a 3D printed plate, and the LEDs are controlled by a commercially available controller running open source software (WLED). That lets us easily control the various brightness levels of each LED quickly and easily when needed, and it also lets us apply a subtle flickering effect for the sources to mimic the messiness of real-world observations.

Wobbling Stars



Learning Goals & Key Messages (from KEI Space Concept)

- A star is tugged by the gravity of planets orbiting it, creating a small change in the star's position and motion — it wobbles
- The wobbles of stars can be detected and interpreted to reveal planets and some of their characteristics

- We use very sensitive techniques to detect small changes that reveal the presence of planets.

Overview & Usage

The guest walks up to the exhibit and sees the mechanism on the desktop underneath an acrylic dome, and a lighted button next to the dome. They will also see a backlit rainbow spectrum and some black lines intended to show *absorption* lines. When the button is pushed the star will light up, and the assembly under the dome will rotate and the absorption lines will move back and forth over the rainbow spectrum display, illustrating radial velocity shifts; the absorption lines are from the star as it “wobbles” about the barycenter (center) of the plate. Lines from the planetary companion are not seen; they are simply too faint compared to the light from the star

When the motion is complete, the star will dim. After 1 hour, the star will turn off entirely but the backlit spectrum will remain lit as long as power to the exhibit is on. Note that this may change if we find that the spectrum backlight is starting to burn out or get dim from use.

Design

Science Features

The physical size of this exhibit did not lend itself to adapting a real-world system, nor did the overall movement of the spectrum, so almost everything about this exhibit is oversized to demonstrate the concepts. It’s the same problem one encounters when making a scale model of the solar system, the distances between stars and their planets are usually enormous compared to the physical diameters of the stars and planets.

That said, running the numbers:

- Central star and planet are offset from the center of the plate by approximately 37mm and 184mm respectively
- The central star and planet are 80mm and 19.6mm diameter respectively

These values were chosen mainly for aesthetics, but they imply a star/planet mass ratio of about 5 (or the planet is ⅕ the mass of the star). That is quite high and means that the system basically has to be a low mass star + brown dwarf binary of some type. Under this assumption the extreme red color of the central star was chosen, with a healthy amount of flickering to mimic stellar variability endemic to low mass stars.

Fun fact: The orbital period of this particular system would be around 6.7 hours, so quite fast! We considered adding a “real-time orbit” mode for the truly dedicated visitors.

Electromechanical Features

The rotating disk and the spectrum are driven independently by two separate stepper motors, but both motors are commanded via a single microcontroller to keep them in sync. When powered on, the exhibit will "home" itself to ensure the plate and spectrum start from the correct spots. This is accomplished with strong magnets attached to both the spectrum and plate mechanisms, and fixed magnetic sensitive switches to detect the magnets as they rotate past.

The homing sequence starts by rotating the plate until the magnetic switch detects the magnet, and once found the plate+magnet is quickly rotated back and forth to allow the controls to precisely determine the exact position where the magnetic switch is triggered. This is repeated for the other spectrum mechanism with its own magnet and switch. This homing sequence can be manually triggered via a button on the underside of the exhibit if needed.

As with the Coronagraphs in Space exhibit, this exhibit features real instrument pieces from the Peggy and Eric Johnson 1m Telescope at Anderson Mesa:

- Custom circuit board originally designed to drive the main science camera filter wheel
- Commercial LED controller originally picked up for controlling lighting at the facility

It also uses a part designed for an upgrade to the DeVeny optical spectrograph at the LDT:

- Custom magnetic sensitive switch circuit boards

Fun fact: it also uses scrap metal salvaged from the old DFM system that used to run the McAllister telescope before it was replaced with the current PlaneWave system.

Electronics

The main control board runs in-house written Arduino-compatible code on a Raspberry Pi Pico microcontroller. The controller issues commands to the commercial LED controller running the open source software WLED to control the central stellar source sphere, allowing it to brighten during rotation and dim afterwards to save power and control heat output from the stellar source sphere. Inside the sphere is a fully-custom made mount that supports a total of 30 LEDs, 7 on each side and 2 on top. They're the same SK6812 RGBW LEDs used in the Coronagraph exhibit. This setup provides exceptionally uniform illumination, and also makes it possible to do really really fun effects.

Fun fact: Hold down the activation button on this exhibit for > 15 seconds and then release it.