

# SATNOGS OPTICAL UNOFFICIAL GUIDE

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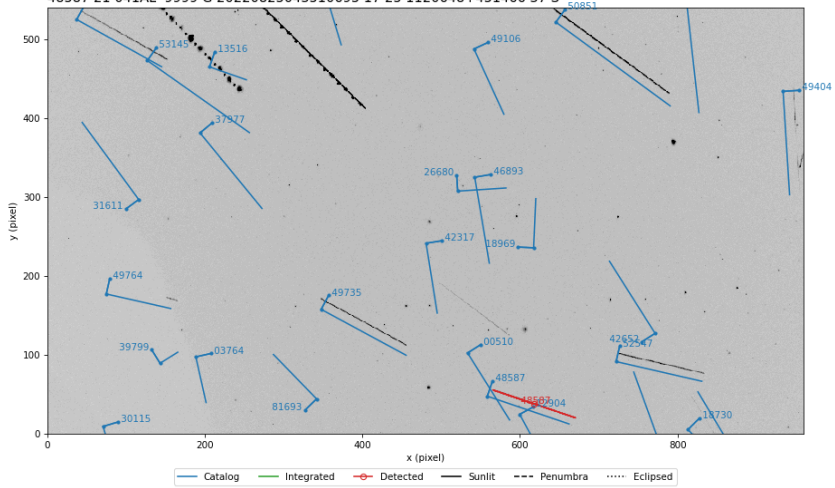
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# SatNOGS Optical

*Unofficial*

# Guide

**Jeff Moe**



*Loveland, Colorado, USA*

2022

**SatNOGS Optical Unofficial Guide**

by Jeff Moe

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Dedicated to free users

*Space should be claimed the libre  
way.*

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Libre Space Foundation

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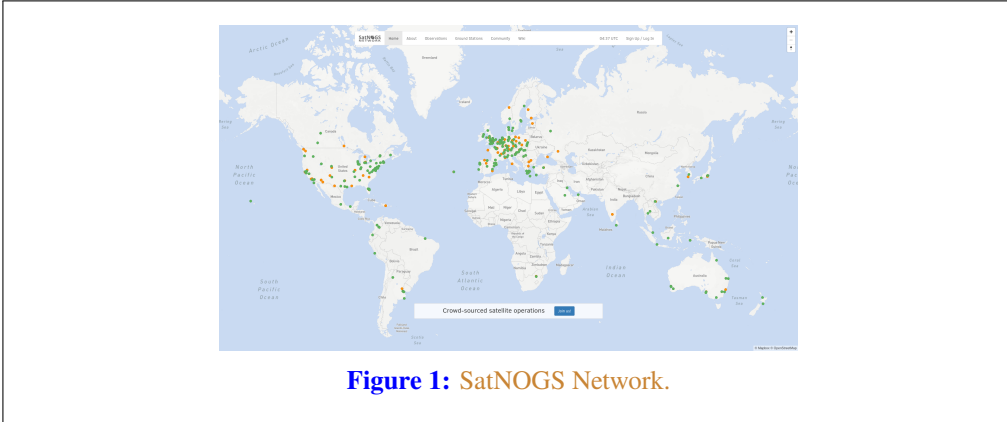
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# **Introduction**

## **SatNOGS Optical**

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The SatNOGS Optical Unofficial Guide documents how to set up and run an optical ground station for the LSF (Libre Space Foundation)'s SatNOGS network.



## Unofficial Guide Overview

First, an overview of the this text, then the LSF and some of it's key projects, such as the SatNOGS network. A cursory review of satellites and existing RF (radio frequency) ground stations will be followed by a big picture view of acquiring and processing images of satellites. Hardware is reviewed, then software to run on it, with many options, including what is best. Finally, what to do with the data (idk!). The chapters that follow are listed below.

**Satellites** — What are we looking at?

**Ground Stations** — How Earth talks to satellites and back.

**Toolchain and Process** — The big picture of what hardware and software is needed to set up an optical ground station for use on the distributed network.

**Hardware** — Details on appropriate hardware configurations, and example setups.

**Software** — A look at the myriad software related to satellites, and what works best at present for SatNOGS Optical.

**Acquire** — Convert photons to bits. Pointing a camera at the sky works.

**Solve** — Pictures of stars reveal the time and location of the photo. Plate solvers reviewed.

**Detect** — The plate solver says where the photo is, now detect if are there moving tracks that aren't stars that could be satellites.

**Identify** — With time, location, satellite detection, TLEs (two-line element sets) are overlaid and compared with detected satellites. Satellite identification by computers and humans.

**Upload** — When ready, data will be pushed to the SatNOGS network.

**Support** — Where development is occurring and questions answered!

## Libre Space Foundation

The LSF supports “free and accessible space for all, creating Open Source space technologies.”<sup>1</sup>

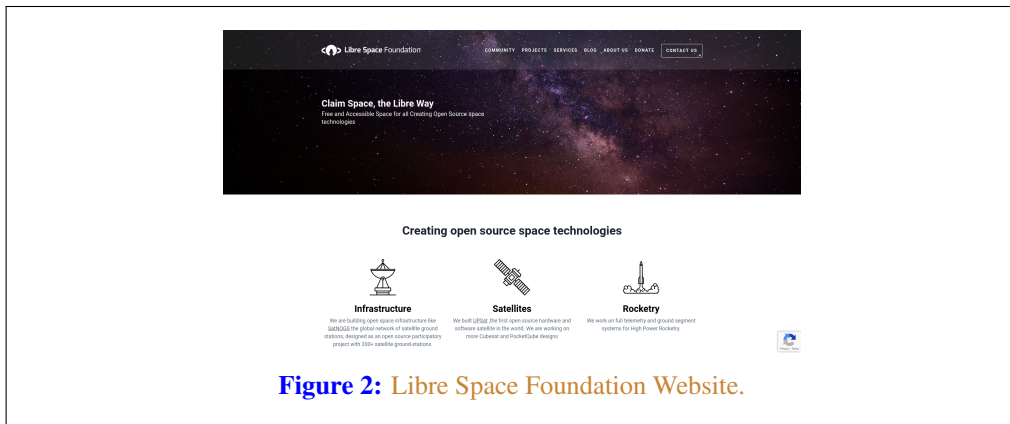


Figure 2: Libre Space Foundation Website.

Select LSF projects:

**SatNOGS** — Global network of satellite ground stations  
<https://satnogs.org>

**UPSat** — First OSH (open-source hardware) and OSS (open-source software) satellite in the world  
<https://upsat.gr/>

## SatNOGS Network

SatNOGS is the LSF’s global network of satellite ground stations. [indexground station](#)

---

<sup>1</sup><https://libre.space>



## Network Status

The SatNOGS RF network has been running successfully for years. Adding an optical network is a new development. At present there are zero nodes on the network.

Some software already exists, some is being ported from C to Python, and other parts remain to be done. There is software available for acquiring optical data of satellites. There is no facility at present for pushing data back to the network.



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# **Satellites**

## **Artificial Satellites in Space**

---

## 1.1 Overview of Satellites

This chapter gives a brief overview of satellites, with particular attention to ones using amateur RF bands.

## 1.2 SatNOGS DB

The SatNOGS DB is a database that lists satellites, many of which can be tracked by ground station operators on the SatNOGS network.

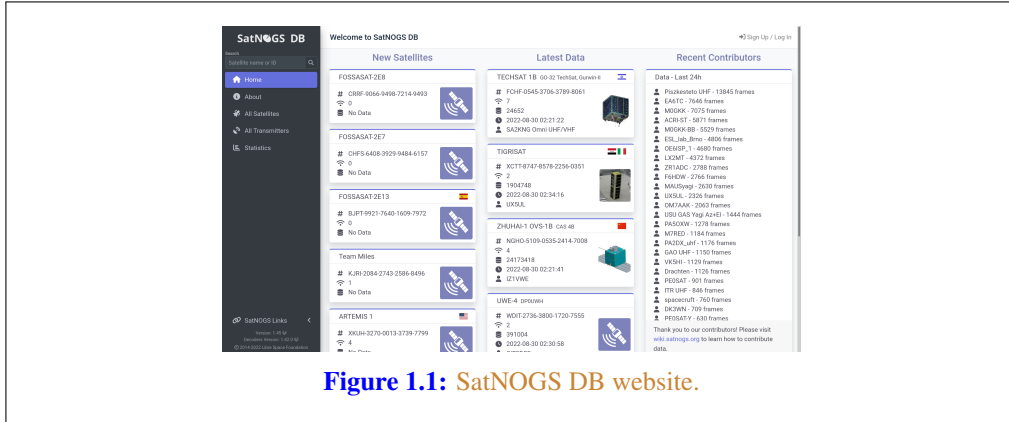


Figure 1.1: SatNOGS DB website.

Individual satellites can be viewed, such as the RamSat CubeSat.

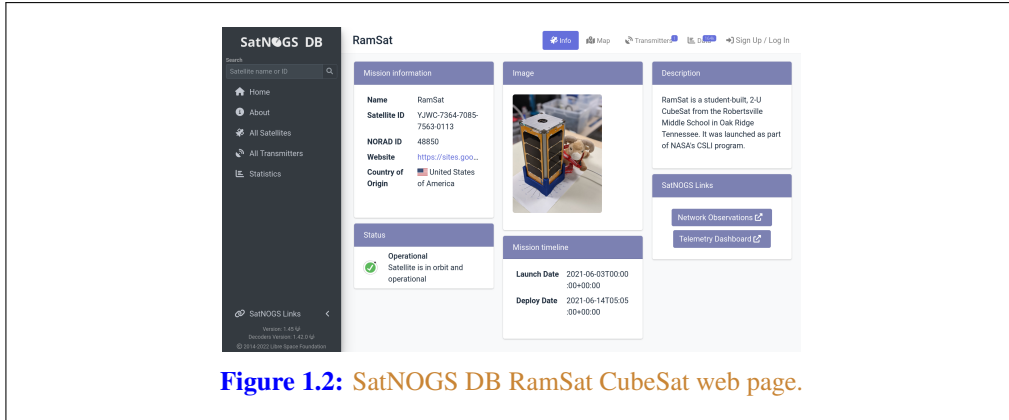
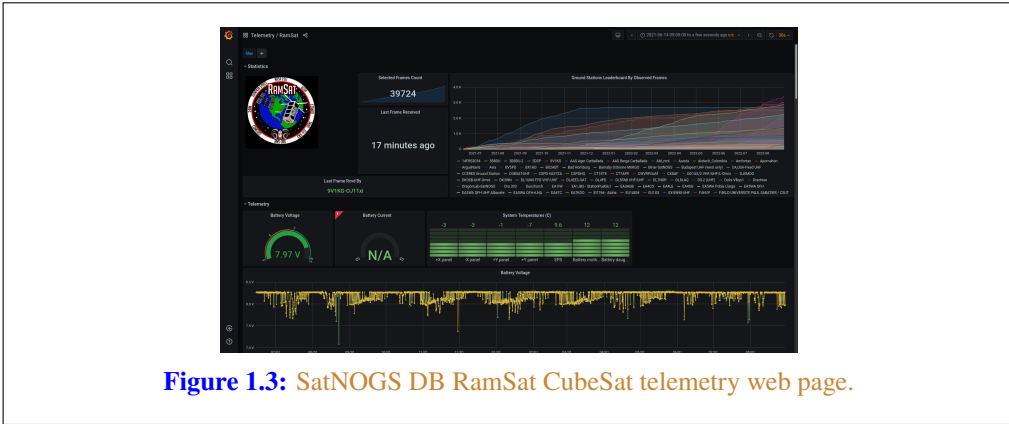


Figure 1.2: SatNOGS DB RamSat CubeSat web page.

For some satellites, telemetry is available in a Grafana dashboard. See the RamSat telemetry dashboard.

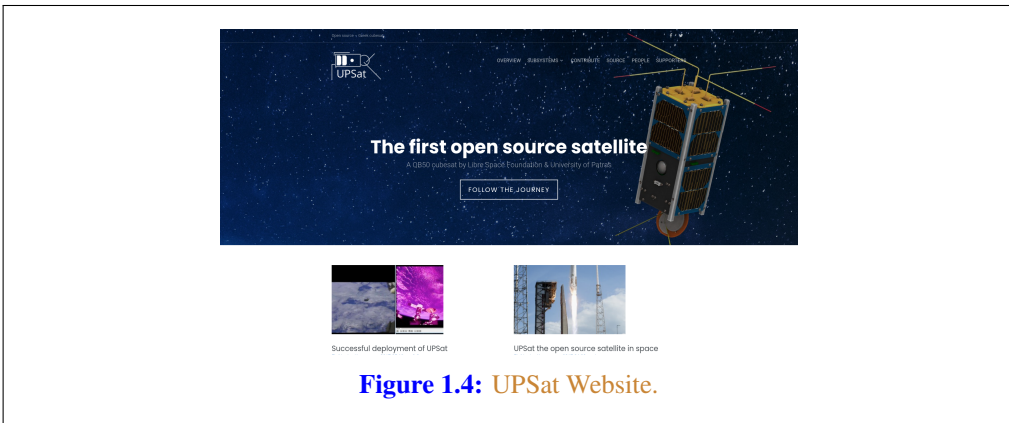
### 1.3. LIBRE SATELLITES



### 1.3 Libre Satellites

Below are satellites in orbit, decayed, or designs on Earth that generally support the libre way. These are some select libre satellites:

**UPSat** — First libre OSH and OSS satellite in the world. Created by the LSF.  
<https://upsat.gr/>

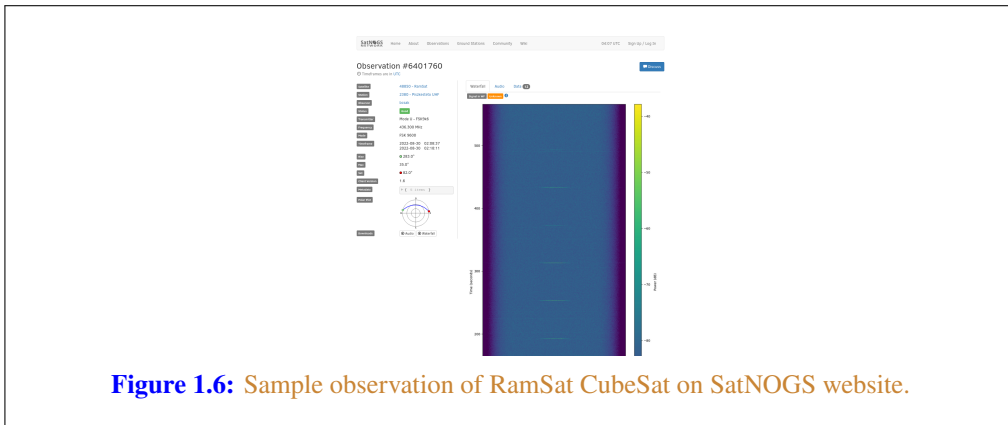
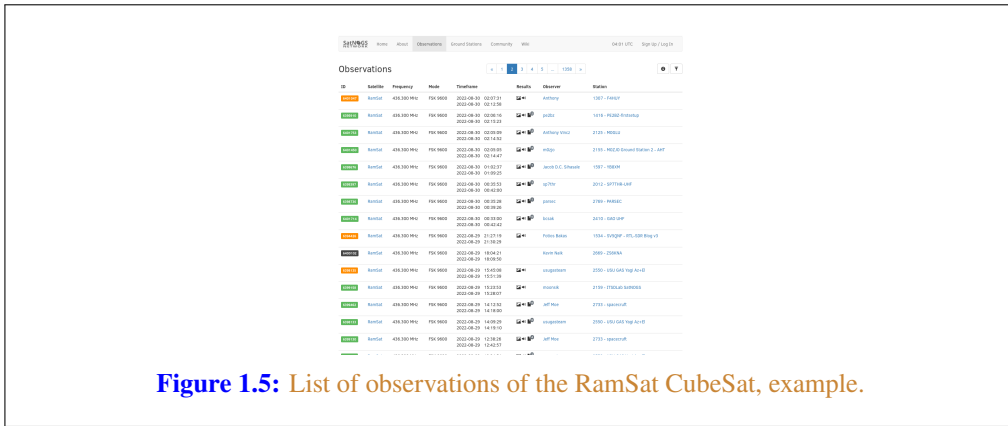


RF Observations can be scheduled on the SatNOGS network. See figure 1.5, page 18 for a example list of observations of the RamSat CubeSat.<sup>1</sup>

Individual RF observations are uploaded to the SatNOGS network, as can be seen in the example observation of the RamSat by SatNOGS ground station “2380 - Piszkesteto UHF” run by volunteer bcsak (username).

<sup>1</sup>[https://network.satnogs.org/observations/?future=0&norad=48850&observer=&station=&start=&end=&transmitter\\_mode=&page=2](https://network.satnogs.org/observations/?future=0&norad=48850&observer=&station=&start=&end=&transmitter_mode=&page=2)

## Satellites



## 1.4 Satellite Orbits

Satellite orbits. See SGP (Simplified General Perturbations) and SDP (Simplified Deep Space Perturbations).

See TLE.

---

# **Ground Stations**

## **Looking up from Earth**

---

## 2.1 Overview of Ground Stations

Ground stations are a setup of equipment such as computers, cameras, SDRs (Software-defined radios), antennas, and receivers, located on Earth, observing space.

## 2.2 SatNOGS Ground Stations

The LSF built the SatNOGS network using distributed, volunteer-run, RF ground stations using SDRs, such as in figure 2.1, page 21.<sup>1</sup> It shows a SatNOGS ground station with VHF (Very High Frequency) (right) and UHF (Ultra High Frequency) (left) antennas on a mast with an Alt/Az mount (Altazimuth mount) rotator. SDRs can be used as RF receivers.<sup>2</sup>

Ground stations can be viewed on the SatNOGS network website, such as as the example in figure 2.2, page 22.<sup>3</sup>

## 2.3 SatNOGS Optical Ground Stations

The LSF is developing SatNOGS Optical to add optical ground stations to the distributed network.

Prototype optical ground stations are being developed. An example setup, using a Skywatcher EQ6-R Pro telescope tripod and tracking mount, can be seen in Figure 2.3, page 23.

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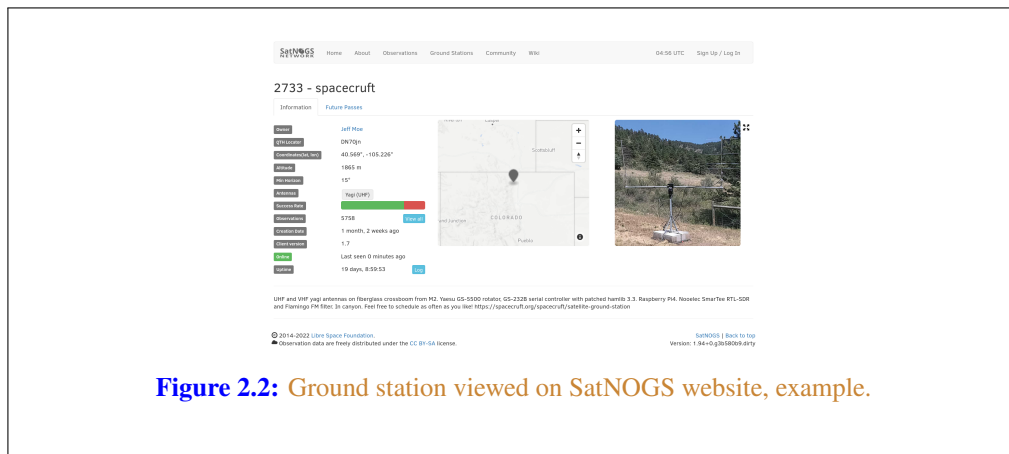
<sup>1</sup><https://spacecraft.org/assets/i/spacecraft-rotator.png>

<sup>2</sup>Wikipedia contributors. *Software-defined radio* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Software-defined\\_radio&oldid=1107093398](https://en.wikipedia.org/w/index.php?title=Software-defined_radio&oldid=1107093398). [Online; accessed 28-August-2022]. 2022

<sup>3</sup><https://network.satnogs.org/stations/2733/>



**Figure 2.1:** SatNOGS ground station with antennas.



**Figure 2.2:** Ground station viewed on SatNOGS website, example.





**Figure 2.3:** SatNOGS-Optical ground station prototype.



---

**Toolchain and Pipeline**  
**Make Old Photons Count**

---

### 3.1 SatNOGS Optical HOWTO

SatNOGS Optical is the nascent distributed network of optical ground stations.

This chapter gives a top level review what is needed in terms of hardware and software to build an operating optical ground station.

### 3.2 Toolchain

See below for a SatNOGS Optical Process Overview.<sup>1</sup> See figure 3.1, page 27, described below.

**Hardware** — Hardware, such as cameras and computers, is to be selected and set up.

**Software** — The best currently available software is to be downloaded, installed, and configured.

**Acquire** — Data samples, typically in the form of FITS (Flexible Image Transport System) file photographs, need to be acquired by running a camera outside at night taking pictures of the sky.

**Plate solver** — Acquired data samples in FITS files need to be processed by a plate solver. See 7.1, page 52.

**Detect satellites** — Using TLEs and the “solved” plates, detect satellites. See 8.1, page 56.

**Identify satellites** — With satellites detected in the previous step, identify what they are. See 9.1, page 60.

### 3.3 Hardware

Discussed in this section are some of the hardware options to be explored. More explicit instructions of a particular hardware installation can be see in section 4.1, page 32. Discussed below are camera options, for details on computers and other parts, also see hardware in section 4.1, page 32

For the purposes here, there are three main categories of hardware. Depending which category of equipment is selected, it impacts everything else, such as the software used. Main categories:

**Motion video cameras** — Moving images.

**Still camera** — Still photos.

**Allsky cameras** — Views of all, or nearly all of the sky.

<sup>1</sup><https://spacecraft.org/spacecraft/SNOPO>

### 3.3. HARDWARE

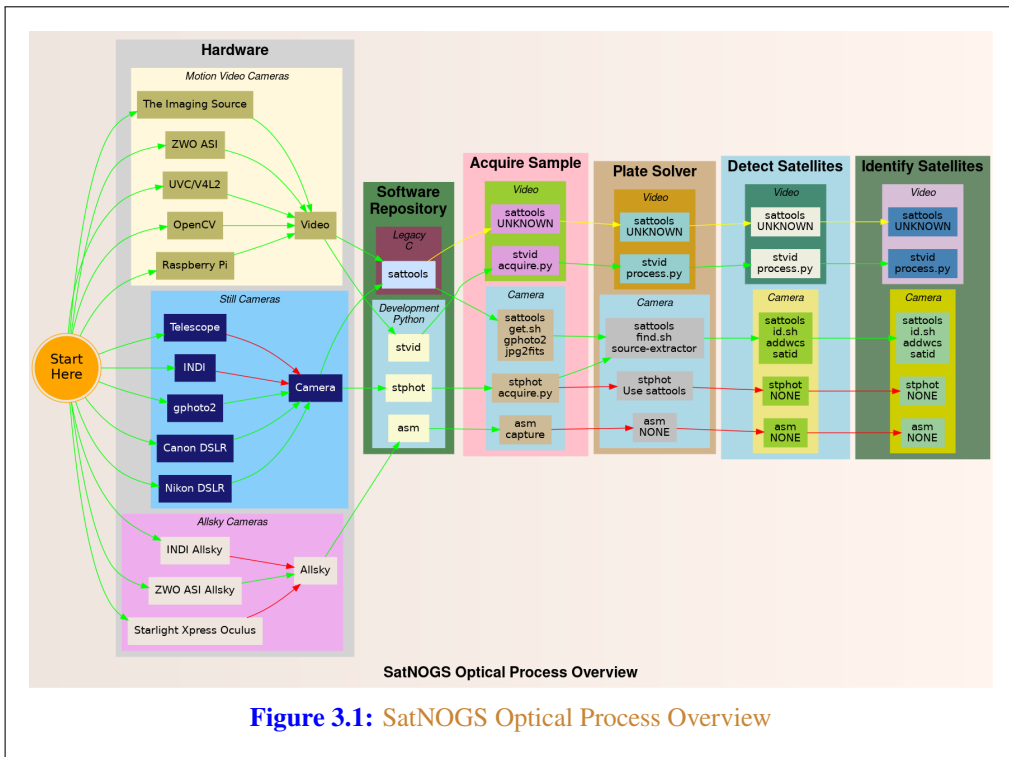


Figure 3.1: SatNOGS Optical Process Overview

Different types of equipment can be used in different categories. Some can be used in multiple setups, most just in one. If available, using motion video cameras will work best for detecting satellites with the developing SatNOGS toolchain. Examples of motion video camera sources that could be used:

**The Imaging Source Cameras based on IMX174** — Known to work. Recommended. High quality cameras, believed to be usable following DFSG (Debian Free Software Guidelines).

**ZWO ASI based on IMX174** — Known to work. Not DFSG compatible. Uses proprietary SDK. Currently in prototype development.

**UVC/Video4Linux2** — “Any” video camera that works with the Linux kernel. Typically, the device will appear similar to `/dev/video0`. A camera that works with the software isn’t necessarily sensitive enough to detect satellites, however, as most are designed for brighter environments.

**OpenCV** — Devices that work with OpenCV can be used, same as UVC. To work well, they need to be sensitive.

**Raspberry Pi** — The PiCamera can be used. A good lower cost option. Recommended. Many non-Raspberry Pi devices, such as Odroid are also compatible with the Pi MIPI interface.

Still cameras can also be used productively. The current Python toolchain is in very early development and not completely usable yet.

See the list below for still camera options:

**Telescopes** — Can definitely take images of satellites. Not the best tool at present, as it isn't well integrated into the SatNOGS Optical toolchain. The FOV (Field of View) is generally too small. The mounts are optimized for different types of tracking than satellites. This is changing, and longer term could be well-supported. Using RASA (Rowe-Ackermann Schmidt Astrograph) style astrographs is likely the best option.

**INDI (Instrument Neutral Distributed Interface)** — Typically used for control of telescopes and associated instrumentation, such as tracking mounts and cameras. Cannot be used directly with the current developing SatNOGS toolchain. It is not seen as the future path forward as it isn't well optimized for SatNOGS Optical usage. That said, it is very useful at present for running a tracking mount with KStars and Ekos, for example, in lieu of a better option. Camera software in the INDI platform typically produce image FITS files.

**gphoto** — The Linux kernel recognizes many cameras that can be used with gphoto tools and drivers, available in Debian. This is the recommended option at present for still cameras. DSLR (digital single-lens reflex) cameras, such as from major manufacturers Canon and Nikon, are used with gphoto.

Considering the hardware options above, they need to be matched with corresponding software. Not all options work (at all), and some cannot be easily used to perform all steps needed.

There are also broader “paths” that need to be considered:

**sattools** — Deprecated because it is in C, and the decision was made to move forward with applications primarily written in Python. Sattools is the most complete toolkit, however, so no matter what path is chosen, some parts of it will likely be used for now. It can be used with motion video cameras and still cameras. It includes many other software tools related to satellites.

**stvid** — This is the best path if a motion video camera is available. It is in Python and is the tool the SatNOGS Optical project is using as the basis for future development. It still depends on some C tools from sattools.

**stphot** — Written in Python this is what the SatNOGS Optical project will likely use in the future for still cameras. It is in very early development, but can acquire data (take photos) with gphoto-compatible cameras.

### 3.3. HARDWARE

`asm` — All Sky Monitor for taking pictures of all, or nearly all of the sky, such as with a 150 or 180 degree view. The `asm` application is in pre-development, but is in Python and could be the basis for future SatNOGS Optical development. The difficulty with all sky cameras is the plate solver isn't written to use images from the "fish-eye" view of an all sky camera.

**Other** — There are many other satellite and telescope software packages freely available on the Internet. Perhaps some could be adapted for usage.





---

# **Hardware**

## **Design and Set Up Equipment**

---

## 4.1 Overview of Hardware

Hardware considerations for a SatNOGS Optical ground station.

Main hardware components in an optical ground station:

- Lens.
- Camera.
- Computer.

Other components:

- Ethernet cable.
- USB cable.
- Enclosure.
- Power supply.
- Tripod.
- Manual or tracking mount.
- Power source, grid or alternative.
- Internet, wifi or ethernet.

## 4.2 Camera

Cameras being evaluated:

- The Imaging Source IMX174 based, monochrome.
- ZWO ASI174MM, monochrome.
- ZWO ASI1600MM Pro, monochrome.
- DSLR camera.
- PiCamera.

**NOTICE:**

ZWO/ASI cameras require proprietary non-libre software on host computer and is not DFSG compatible.

### 4.3 Lenses

For lenses, the faster the better. F1.2 works well. F1.8 is the maximum recommended.

Lenses being tested:

- Kowa 50mm f1.4 C-mount.
- Canon EF 50mm f1.2 USM.

### 4.4 Embedded Computer

Embedded computers, such as Raspberry Pi, that can be used.

**Odroid N2** — Confirmed working.

**Odroid M1** — Testing.

**Raspberry Pi 3** — ?

**Raspberry Pi 4** — ?

**Intel NUC** — ?

#### 4.4.1 Comparison

Comparing embedded computers for SatNOGS Optical.

Make	Model	Architecture	Max RAM	eMMC	
Odroid	N2	ARM64	4 GB	Yes	
Odroid	M1	ARM64	8 GB	Yes	

**Table 4.1:** Comparison of embedded computers

### 4.5 Example Optical Ground Station with Tracking

This is an example of a tracking ground station. It is a prototype, so there are lots of mis-matched, overbuilt/underbuilt parts. The full setup on tripod, can be seen in 2.3, page 23.

A close up of the setup can be seen at 4.1, page 34, showing the Skywatcher telescope tracking mount, a Bosch PoE (Power over Ethernet) camera enclosure, and through the glass the camera lens. In the background is a white antenna for GNSS (Global Navigation Satellite System) (GPS (Global Positioning System)) and a solar power setup.



**Figure 4.1:** SatNOGS-Optical ground station prototype.

#### 4.5. EXAMPLE OPTICAL GROUND STATION WITH TRACKING



**Figure 4.2:** Camera enclosure, front side, showing glass and lens.

The camera lens is protected by the enclosure glass, which is IP67 (Ingress Protection code 67) (XXX) rated. See a close up of the front of the enclosure and camera lens in figure 4.2, page 35.

As seen in figure 4.3, page 36, the left side of the enclosure has a hinge for opening. The bottom white component is part of the telescope mount.

Figure 4.4, page 36, shows the right side of the enclosure. Two mounting bolt access points can be seen on each end. These are unscrewed with a hex head tool (supplied) to open the enclosure.

The enclosure is opened from the right side, as shown in figure 4.4, page 36.

Inside the camera enclosure, as shown in Figure 4.6, page 39, is:

- The Imaging Source DMX camera with Sony IMX174 CMOS (Complementary metal–oxide–semiconductor).
- Kowa 50mm f1.4 C-mount lens.
- Odroid N2 running Debian GNU (GNU's Not Unix!) Linux system.
- Odroid N2 plastic enclosure, large half, hole drilled for ad-hoc mounting.
- Blower fan on top, with power cable (came with Bosch enclosure).



**Figure 4.3:** Camera enclosure, left side, showing hinge.



**Figure 4.4:** Camera enclosure, right side.

- Fan, maybe not so useful, with power cable (came with Bosch enclosure).
- Camera mounting plate (came with Bosch enclosure).
- Camera mounting screws, M6x25 (?).
- Ethernet cable, internal, short white (came with Bosch enclosure).
- PoE ethernet cable, external, plugged into PoE switch for data and power.
- USB 3 cable, internal, way too long, needs replacing, from Odroid to camera. XXX flat connector
- USB 3 cable, external, from Odroid to telescope mount. XXX large rectangle connector



**Figure 4.5:** Camera enclosure, right side, opened.

- “Custom” 12V DC power cable from Bosch PoE to Odroid.
- Assorted nuts, bolts, and washers for an ad-hoc standoff height.

The top of the enclosure shows weather protection and a sun visor. See figure 4.7, page 40.

## **4.6 Future Designs**

There is some discussion of using much larger “lenses”, such as a RASA “telescope” (See: astrograph). The primary concern is the lack of satellite tracking mounts, because telescope mounts are generally too slow, and need to leap-frog the satellite. Rotators used for antennas aren’t stable enough for a camera.





**Figure 4.6:** Camera enclosure, opened.



**Figure 4.7:** Camera enclosure, top.

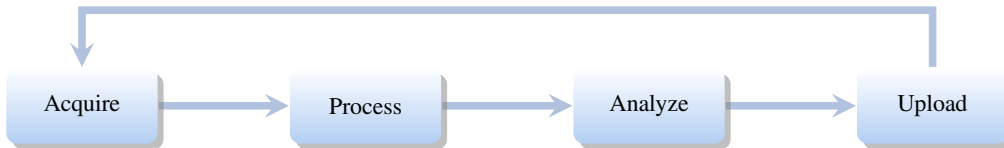
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**Software**  
**Satellite Applications on Earth**

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## 5.1 Software Overview

See 5.1, page 42 for a diagram with an overview of the software process.



**Figure 5.1:** SatNOGS Optical Operation Pipeline

## 5.2 Setup Optical Ground Station Software

HOWTO set up and configure a SatNOGS Optical ground station.

Setup an embedded computer, such as an Odroid N2, with Debian stable (11/Bullseye) or testing (Bookworm).

See each repository for latest documentation.

Install dependencies from Debian repository:

```

sudo apt update
sudo apt install python3-virtualenv python3-pip python3-dev \
source-extractor astrometry.net \
libeigen3-dev giza-dev libx11-dev \
astrometry-data-tycho2 astrometry-data-tycho2-07 \
astrometry-data-tycho2-08 astrometry-data-tycho2-09 \
astrometry-data-tycho2-10-19
  
```

Next, install the `hough3d-code` dependency.

```

git clone https://gitlab.com/pierros/hough3d-code
cd hough3d-code
make all
sudo cp -p hough3dlines /usr/local/bin/hough3dlines
  
```

Install `satpredict` from using either the `cbassa` or `spacecraft` repo.

```

cd ../
git clone https://spacecraft.org/spacecraft/satpredict
# Or
#git clone https://github.com/cbassa/satpredict
cd satpredict/
make
sudo make install
  
```

Now install `stvid`, the main acquisition and processing application. It is written in Python. Either use the `spacecraft` git repository or the `cbassa` one.

### 5.3. CONFIGURE SOFTWARE

```
cd ../
git clone https://spacecraft.org/spacecraft/stvid
# Or use upstream:
#git clone https://github.com/cbassa/stvid
```

Optionally, set up a Python virtual environment:

```
cd stvid
virtualenv -p python3 env
source env/bin/activate
pip install --upgrade pip
```

Install dependencies. Numpy needs to be installed first, or the install fails.

```
pip install --upgrade numpy
pip install --upgrade -r requirements.txt
```

If the system python3-numpy conflicts, you could try installing numpy in the virtualenv thusly:

```
pip install --upgrade --ignore-installed numpy
```

Debian in bug #941466 changed the name of the `sextractor` dependency to `source-extractor`, so a symlink is needed for now:

```
sudo ln -s /usr/bin/source-extractor /usr/local/bin/sextractor
```

## 5.3 Configure Software

Configure the embedded computer.

```
cd stvid/
cp -p configuration.ini-dist configuration.ini
# Edit
# Note for fields st-username and st-password, *don't* use quotes.
# Set:
vi configuration.ini
```

Edit various `configuration.ini` fields:

```
# For example:
observer_cospar = 9999          # COSPAR number of observer's site
observer_name = Jeff Moe       # Name of observer
observer_lat = 40.568912       # Latitude of location in decimal degrees
observer_lon = -105.225852     # Longitude of location in decimal degrees
observer_height = 1860         # Elevation of location in meters

observations_path = ./data/obs # Path for raw acquisitions
tle_path = ./data/tle         # Path where TLEs are stored (and updated)
results_path = ./data/results # Path for results of processed obs

st-username = foo
st-password = bar
```

```
# Path to source-extractor
sex_config = /usr/share/source-extractor/default.sex
```

Store downloads here:

```
mkdir -p ./data/obs ./data/tle ./data/results
```

The ST\_DATADIR variable is still used, from sattools. Maybe set all these in `.bashrc` (suit to fit directory setup):

```
export ST_DATADIR=$HOME/sattools
export ST_TLEDIR=$HOME/TLE
export ST_OBSDIR=$HOME/satobs
export ST_LOGIN="identity=foo@no:pass"
```

Set `astrometry.net` to run in parallel, assuming you have enough RAM: (This doesn't appear to work? Breaks?).

```
sudo vim /etc/astrometry.cfg
# Uncomment:
inparallel
```

## 5.4 skymap

Use `skymap` for viewing satellite orbits tracks projected on a map of the sky. `Skymap` is part of `sattools`. `Skymap` isn't a required part of the toolchain, but it is useful to see what satellites are visible at a particular time and location.

Source:

\* <https://github.com/cbassa/sattools>

My fork:

\* <https://spacecraft.org/spacecraft/sattools>

### NOTICE:

The main upstream `sattools` package requires non-libre `pgplot` on host computer which is not DFSG compatible.

Described below is how to build and install my fork of `sattools` to use `skymap` instead of upstream. Upstream requires non-libre software which also happens to be very difficult for most users to compile. My fork uses the `Giza` library which replaces `pgplot`. It is much easier to build.

```
# Install dependencies
sudo apt install giza-dev git make dos2unix source-extractor wcslib-dev \
  libgs1-dev gfortran libpng-dev libx11-dev libjpeg-dev libexif-dev

# Clone repo
git clone https://spacecraft.org/spacecraft/sattools
# Or use upstream (needs more steps)
git clone https://github.com/cbassa/sattools

cd sattools/
# Build
```

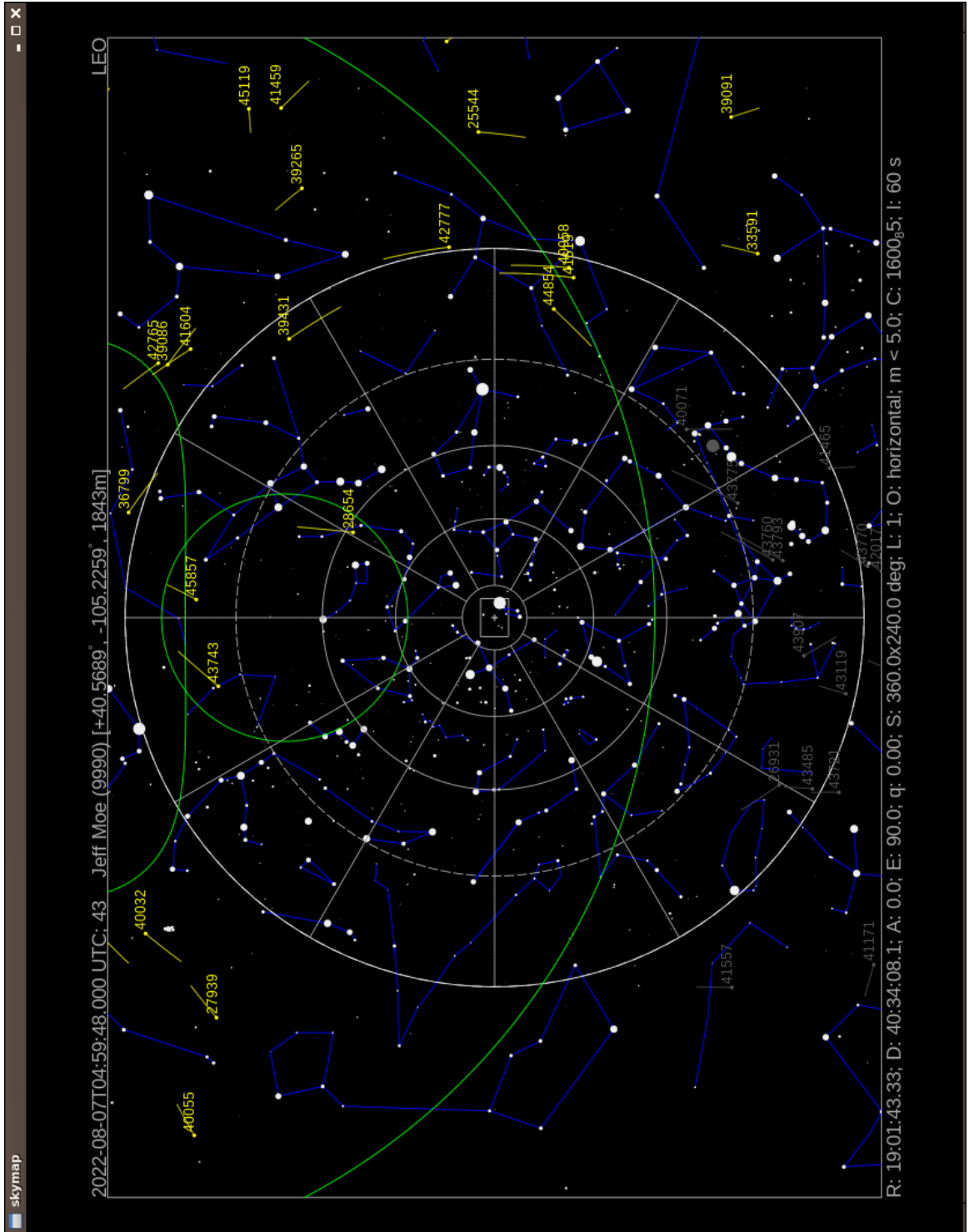


Figure 5.2: skymap example screenshot.

```

make

# Install
sudo make install

# Clean
make clean

# To rebuild
make clean
make

# To uninstall
sudo make uninstall

```

See below for skymap (fork) usage:

```

tleupdate

# set config in ~/.bashrc XXX

skymap --help
Usage: skymap [OPTION]
Visualize satellites on a map of the sky.

-t, --time      Date/time (yyyy-mm-ddThh:mm:ss.sss) [default: now]
-c, --catalog  TLE catalog file [default: satnogs.tle]
-i, --id       Satellite ID (NORAD) [default: all]
-R, --ra       R.A. [hh:mm:ss.sss]
-D, --decl     Decl. [+dd:mm:ss.ss]
-A, --azimuth  Azimuth (deg)
-E, --elevation Elevation (deg)
-w, --width    Screen width (default: 1024). Set height too.
-g, --height   Screen height (default: 768). Set width too.
-n, --nmax     nmax line resolution/speed (default 128)
-S, --all-night All night
-Q, --no-stars No stars
-a, --all-objects Show all objects from catalog (default: LEO)
-h, --help     This help
-s, --site     Site (COSPAR)
-d, --iod     IOD observations
-l, --length   Trail length [default: 60s]
-P, --planar-id planar search satellite ID
-r, --planar-alt planar search altitude
-V, --visibility-alt altitude for visibility contours
-p, --positions-file File with xyz positions
-L, --longitude manual site longitude (deg)
-B, --latitude manual site latitude (deg)
-H, --elevation manual site elevation (m)

```



---

**Acquire Data**  
**Twinkle, Twinkle, Little Starlink**

---

## 6.1 Overview of Operation

Below shows how to run a SatNOGS Optical ground station, after it has been set up and configured.

## 6.2 Setup with stvid

Acquire data with `acquire.py` from `stvid`. Enter `virtualenv`, if used:

```
cd stvid/  
source env/bin/activate
```

Get the latest TLEs:

```
./update_tle.py
```

Acquire live data from camera.

```
cd stvid/  
./acquire.py
```



**Figure 6.1:** Satellite images acquired by stvid.



---

**Plate Solvers**  
**Place from Pixels**

---

## 7.1 Plate Solver

A “plate solver” will take an image of stars and detect the time and place of the picture. There are two main steps:

1. Extract stars from an image, such as a FITS file generated by `stvid`.
2. “Solve” the image of the stars in the image against vast databases of star images.

See below for a list of software tools that detect/extract stars from images (e.g. FITS).

- Source Extractor.
- XXX Kstars with ekos adds `Internal SEP`.
- XXX Kstars with ekos adds `Builtin method for solver`.

See below for a list of plate solvers that can be used.

- `astrometry.net` locally.
- `astrometry.net` Internet.
- `astap`.
- `Watney`.

## 7.2 Source Extractor

Source Extractor, formerly SExtractor and some other names, is an application to extract stars from images. The software has been widely used for many years.

<https://www.astromatic.net/software/sextractor>

## 7.3 astrometry.net

Astrometry.net is a website and software that can be run locally to solve a plate of stars that has been extracted from Source Extractor. XXX

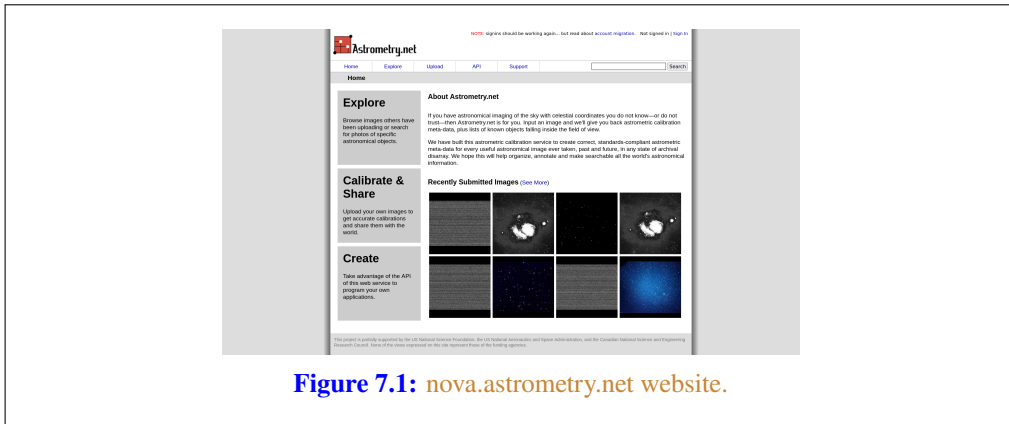
**NOTICE:**

Using `astrometry.net` online requires an account with non-libre services. The `astrometry.net` software can be installed locally to avoid this.

## 7.4 Star Catalogues

To use a plate solver, you will need star catalogues. They can get large. The `stvid` application includes a basic star catalogue. XXX The 4200 series is also recommended.

## 7.5. WORLD COORDINATE SYSTEM



### 7.5 World Coordinate System

WCS (World Coordinate System) info. XXX

### 7.6 SIP

SIP (Simple Imaging Polynomial) info. XXX

### 7.7 Plate Solving with stvid

Use the process.py scripts described in section 7.1, page 52, to solve plates with stvid.





---

**Detect**  
**Find Satellites**

---

## 8.1 Satellite Detection with stvid

This is a description of satellite detection processes. To detect satellite in a FITS file using the stvid toolchain, run `process.py` or, if it exists, the `process_new.py` Python script.

Note the stvid application's `process.py` and `process_new.py` will perform both the detection and identification steps.

### 8.1.1 process\_new.py Usage

This assumes you have installed stvid as shown in section 6.2. Adjust dated directory to actual directory name.

```
cd stvid/
# Maybe you need to update TLE
./update_tle.py
# Process directory
./process_new.py -c config_new.ini -d data/obs/20220825_1/020502/
```

### 8.1.2 process.py Usage

If there is no `process_new.py` it has likely been merged into `process.py`. Or perhaps, to use the “older” script it would be run as shown below. Note, the configuration files is between the old and new script are different.

```
cd stvid/
./process.py -c configuration.ini -d data/obs/20220825_1/020502/
```

## 8.2 AstroImageJ

Analyze data with applications, such as AstroImageJ.

FITS files are commonly used in astronomy.<sup>1</sup> AstroImageJ can read FITS format files. See 8.1, page 57, for a screenshot displaying a FITS file generated by stvid.

---

<sup>1</sup>Wikipedia contributors. *FITS* — Wikipedia, The Free Encyclopedia. <https://en.wikipedia.org/w/index.php?title=FITS&oldid=1091431488>. [Online; accessed 28-August-2022]. 2022

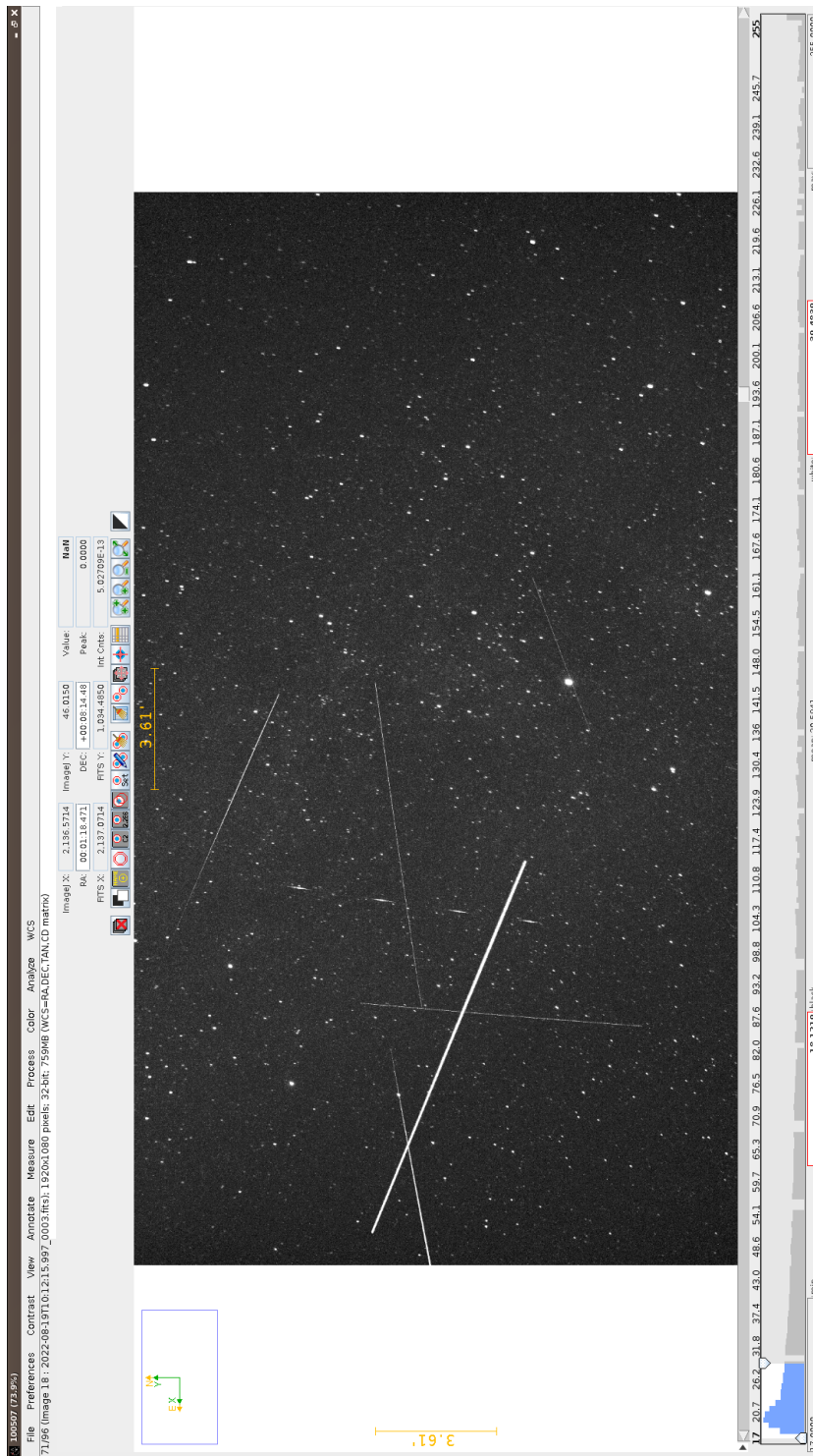


Figure 8.1: AstrometryJ screenshot viewing FITS file.



---

**Identify**  
**More Than Just Old Rocket Bodies**

---

## 9.1 Overview of Satellite Identification

The LSF is developing a project called SIDLOC (Spacecraft Identification and Localization), for satellite identification and localization. With the addition of many more satellites in orbit there is a growing need for SSA (Space Situational Awareness).

## 9.2 `stvid`'s `process.py` for Identification

The best tool for identifying satellites from FITS files is the `process.py` script from `stvid`, available here:

\* <https://github.com/cbassa/stvid>

My fork is here:

\* <https://spacecraft.org/spacecraft/stvid>

## 9.3 Identifying Satellites with `satid`

The deprecated C application, `satid` from the `sattools` package can help identify satellites. See figure 9.1, page 61 for output from my Giza port of `satid`.<sup>1</sup>

\* <https://github.com/cbassa/sattools>

My fork is here:

\* <https://spacecraft.org/spacecraft/sattools>

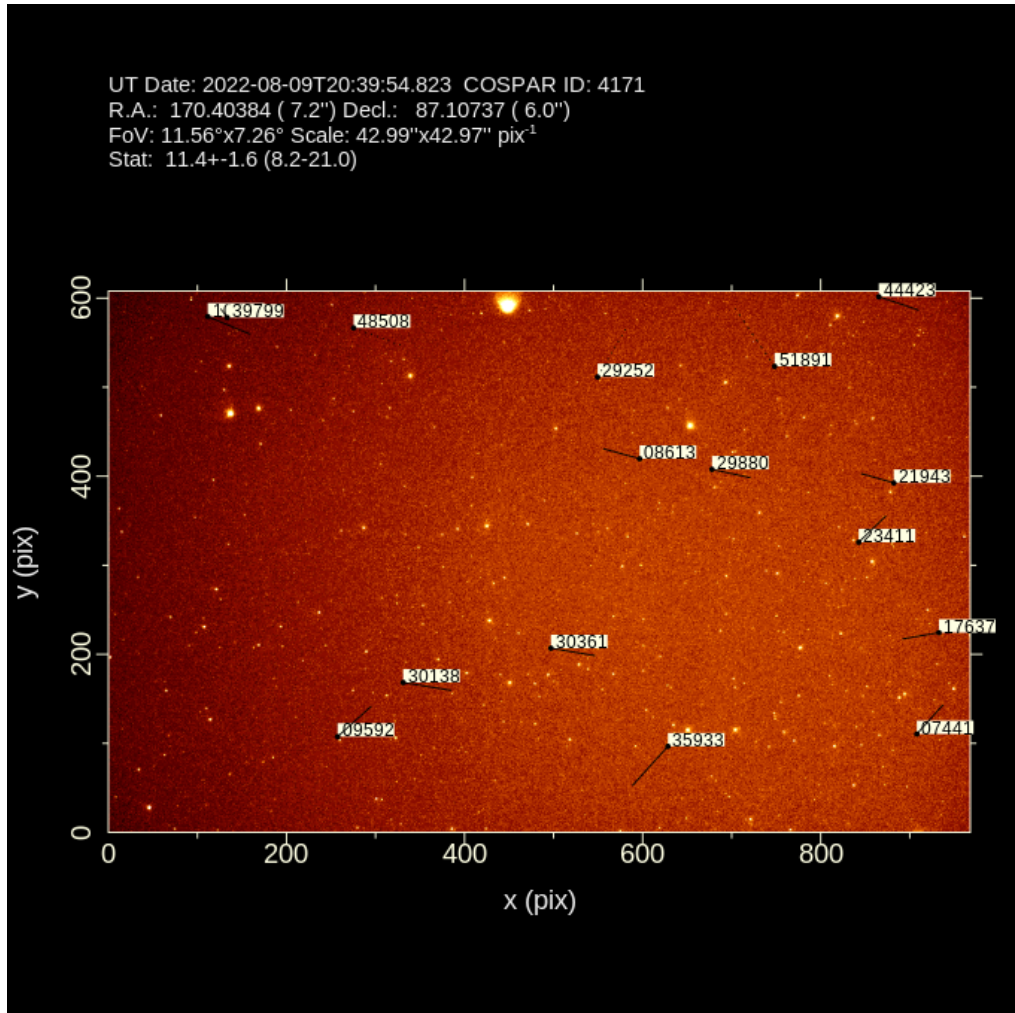
## 9.4 Identification with `stvid`

See section 8.1, page 56 for details on identification with `stvid`. The detection and identification steps are both done in one script.

See figure 9.2, page 62 for an example of from `stvid` automated processing of an input FITS file. The output image is in PNG (Portable Network Graphics) format. `stvid` will also output other files with results, such as CSV (Comma Separated Value) files.

---

<sup>1</sup><https://spacecraft.org/spacecraft/sattools/media/branch/spacecraft/img/satid-giza-3.png>



**Figure 9.1:** satid example.

UT Date: 2022-08-24T03:55:10.825 COSPAR ID: 9999  
 R.A.: 179.418313 (16.1") Decl.: 31.192162 (18.4")  
 FOV: 12.82° x 7.28° Scale: 24.03" x 24.26" pix<sup>-1</sup>

46067 20 055AS 9999 G 20220824035515817 17 25 1149037+315811 37 S

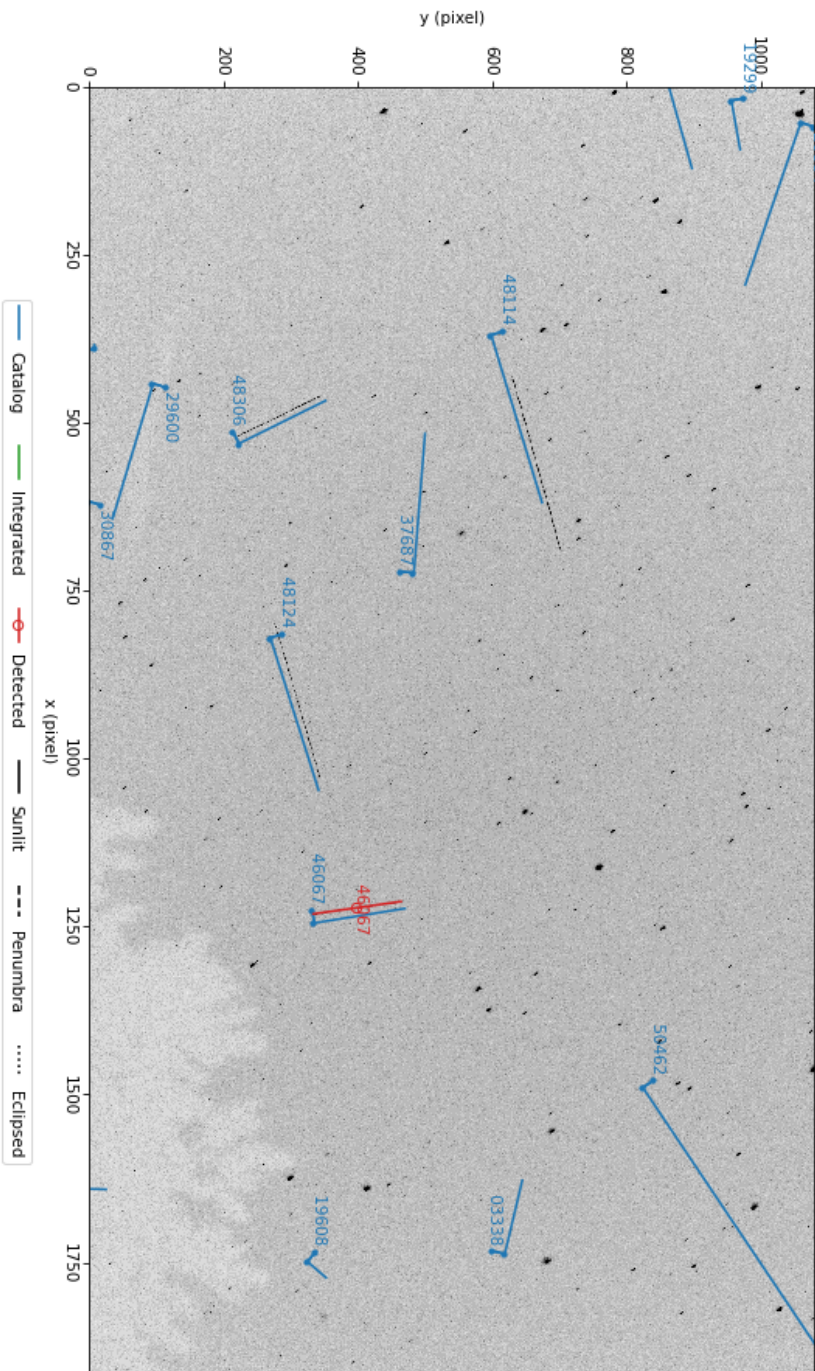


Figure 9.2: Satellite images processed by stvid.



---

**Upload**

**Send Data to the SatNOGS Network**

---

## **10.1 Upload Data**

Push. The SatNOGS network isn't ready for optical data yet.

---

**Support  
Help!**

---

## **11.1 Support**

How to get help.

- `#satnogs-optical` channel in Matrix — `#satnogs-optical:matrix.org`
- LSF Community Forum — <https://community.libre.space>

---

## Contact

**Email, Chat, Forum**

---

## **12.1 Contact**

Jeff Moe

Username: jebba

Email: [moe@spacecraft.org](mailto:moe@spacecraft.org)

---

## Glossary

---

**Alt/Az mount** a simple two-axis mount for supporting and rotating an instrument about two perpendicular axes – one vertical and the other horizontal. Rotation about the vertical axis varies the azimuth (compass bearing) of the pointing direction of the instrument. Rotation about the horizontal axis varies the altitude angle (angle of elevation) of the pointing direction. These mounts are used, for example, with telescopes, cameras, and radio antennas.<sup>1</sup>

**antenna** the interface between radio waves propagating through space and electric currents moving in metal conductors, used with a transmitter or receiver.<sup>2</sup>

**astrograph** is a telescope designed for the sole purpose of astrophotography. Astrographs are mostly used in wide-field astronomical surveys of the sky and for detection of objects such as asteroids, meteors, and comets.<sup>3</sup>

**AstroImageJ** Application for astronomy and satellite image analysis.<sup>4</sup>

**C** is a general-purpose computer programming language. It was created in the 1970s by Dennis Ritchie, and remains very widely used and influential. By design, C's features cleanly reflect the capabilities of the targeted CPUs. It has found lasting use in operating systems, device drivers, protocol stacks, though decreasingly for application software. C is commonly used on computer architectures that range from the largest supercomputers to the smallest microcontrollers and embedded systems. C is used in the sattools suite of applications.<sup>5</sup>

**CMOS** Complementary metal-oxide-semiconductor (pronounced “see-moss”).

**COTS** Commodity off the shelf.

**CSV** Comma Separated Value.

---

<sup>1</sup>Wikipedia contributors. *Altazimuth mount* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Altazimuth\\_mount&oldid=1056074953](https://en.wikipedia.org/w/index.php?title=Altazimuth_mount&oldid=1056074953). [Online; accessed 28-August-2022]. 2021

<sup>2</sup>Wikipedia contributors. *Antenna (radio)* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Antenna\\_\(radio\)&oldid=1104603350](https://en.wikipedia.org/w/index.php?title=Antenna_(radio)&oldid=1104603350). [Online; accessed 28-August-2022]. 2022

<sup>3</sup>Wikipedia contributors. *Astrograph* — *Wikipedia, The Free Encyclopedia*. <https://en.wikipedia.org/w/index.php?title=Astrograph&oldid=1106095357>. [Online; accessed 30-August-2022]. 2022

<sup>4</sup><https://www.astro.louisville.edu/software/astroimagej/>

<sup>5</sup>Wikipedia contributors. *C (programming language)* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=C\\_\(programming\\_language\)&oldid=1106686212](https://en.wikipedia.org/w/index.php?title=C_(programming_language)&oldid=1106686212). [Online; accessed 30-August-2022]. 2022

**CubeSat** is a class of miniaturized satellite based around a form factor consisting of 10 cm (3.9 in) cubes. CubeSats have a mass of no more than 2 kg (4.4 lb) per unit, and often use COTS (Commodity off the shelf) components for their electronics and structure. CubeSats are put into orbit by deployers on the International Space Station, or launched as secondary payloads on a launch vehicle. More than a thousand CubeSats have been launched.<sup>6</sup>

**DCS** distributed control system.

**Debian** a GNU/Linux distribution composed of free and open-source software, developed by the community-supported Debian Project, which was established by Ian Murdock on August 16, 1993. Debian is the basis for many other distributions, notably Ubuntu. Debian is one of the oldest operating systems based on the Linux kernel.<sup>7</sup>

**DFSG** Debian Free Software Guidelines is a set of guidelines that the Debian Project uses to determine whether a software license is a free software license, which in turn is used to determine whether a piece of software can be included in Debian. The DFSG is part of the Debian Social Contract.<sup>8</sup>

**DSLR** digital single-lens reflex.

**FITS** Flexible Image Transport System is an open standard defining a digital file format useful for storage, transmission and processing of data: formatted as multi-dimensional arrays (for example a 2D image), or tables. FITS is the most commonly used digital file format in astronomy. The FITS standard was designed specifically for astronomical data, and includes provisions such as describing photometric and spatial calibration information, together with image origin metadata.<sup>9</sup>

**FLOSS** Free/libre and open-source software. See also: FOSS (free and open-source software).

**FOSH** Free open-source hardware. See also: OSH.

**FOSS** free and open-source software is a term used to refer to groups of software consisting of both Free Software and OSS where anyone is freely licensed to use, copy, study, and change the software in any way, and the source code is openly shared so that people are encouraged to voluntarily improve the design of the software. This is in contrast to proprietary software, where the software is under restrictive copyright licensing and the source code is usually hidden from the users. FOSS maintains the software user's civil liberty rights. Other benefits of using FOSS can include decreased software costs, increased security and stability (especially in regard to malware), protecting privacy, education, and giving users more control over their own hardware. Free and open-source operating systems such as Linux and descendants of BSD are widely utilized today, powering millions of servers, desktops, smartphones (e.g., Android), and other devices. Free-software licenses and open-source licenses are used by many software packages. The free

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<sup>6</sup>Wikipedia contributors. *CubeSat* — *Wikipedia, The Free Encyclopedia*. <https://en.wikipedia.org/w/index.php?title=CubeSat&oldid=1106408835>. [Online; accessed 30-August-2022]. 2022

<sup>7</sup>Wikipedia contributors. *Debian* — *Wikipedia, The Free Encyclopedia*. <https://en.wikipedia.org/w/index.php?title=Debian&oldid=1105900486>. [Online; accessed 28-August-2022]. 2022

<sup>8</sup>Wikipedia contributors. *Debian Free Software Guidelines* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Debian\\_Free\\_Software\\_Guidelines&oldid=1086423235](https://en.wikipedia.org/w/index.php?title=Debian_Free_Software_Guidelines&oldid=1086423235). [Online; accessed 31-August-2022]. 2022

<sup>9</sup>Wikipedia contributors, *FITS* — *Wikipedia, The Free Encyclopedia*



software movement and the open-source software movement are online social movements behind widespread production and adoption of FOSS, with the former preferring to use the terms FLOSS (Free/libre and open-source software) or free/libre.<sup>10</sup>

**FOV** Field of view.

**Free Software** or libre software, is computer software distributed under terms that allow users to run the software for any purpose as well as to study, change, and distribute it and any adapted versions. Free software is a matter of liberty, not price; all users are legally free to do what they want with their copies of a free software (including profiting from them) regardless of how much is paid to obtain the program. Computer programs are deemed “free” if they give end-users (not just the developer) ultimate control over the software and, subsequently, over their devices.<sup>11</sup>

**GHz** gigahertz.

**GNSS** Global Navigation Satellite System.

**GNU** “GNU’s Not Unix!” is an extensive collection of Free Software, which can be used as an operating system or can be used in parts with other operating systems. The use of the completed GNU tools led to the family of operating systems popularly known as Linux. Most of GNU is licensed under the GNU Project’s own GPL (GNU General Public License). GNU is also the project within which the Free Software concept originated.<sup>12</sup>

**GPL** GNU General Public License is a series of widely used Free Software licenses that guarantee end users the four freedoms to run, study, share, and modify the software. The license was the first copyleft for general use. Historically, the GPL license family has been one of the most popular software licenses in the FLOSS software domain.<sup>13</sup>

**GPS** Global Positioning System.

**Grafana** is a multi-platform Open Source analytics and interactive visualization web application. It provides charts, graphs, and alerts for the web when connected to supported data sources. Users can create complex monitoring dashboards using interactive query builders. It is used by the SatNOGS project to visualize satellite telemetry.<sup>14</sup>

**ground station** a setup of equipment such as computers, cameras, SDRs, antennas, and receivers, located on Earth, observing space.

**hough3d-code** is a software application for Iterative Hough Transform for Line Detection in 3D Point Clouds.<sup>15</sup>

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<sup>10</sup>Wikipedia contributors. *Free and open-source software* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Free\\_and\\_open-source\\_software&oldid=1106343648](https://en.wikipedia.org/w/index.php?title=Free_and_open-source_software&oldid=1106343648). [Online; accessed 30-August-2022]. 2022

<sup>11</sup>Wikipedia contributors. *Free software* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Free\\_software&oldid=1106538260](https://en.wikipedia.org/w/index.php?title=Free_software&oldid=1106538260). [Online; accessed 28-August-2022]. 2022

<sup>12</sup>Wikipedia contributors. *GNU* — *Wikipedia, The Free Encyclopedia*. <https://en.wikipedia.org/w/index.php?title=GNU&oldid=1103488294>. [Online; accessed 28-August-2022]. 2022

<sup>13</sup>Wikipedia contributors. *GNU General Public License* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=GNU\\_General\\_Public\\_License&oldid=1106596497](https://en.wikipedia.org/w/index.php?title=GNU_General_Public_License&oldid=1106596497). [Online; accessed 28-August-2022]. 2022

<sup>14</sup>Wikipedia contributors. *Grafana* — *Wikipedia, The Free Encyclopedia*. <https://en.wikipedia.org/w/index.php?title=Grafana&oldid=1104046322>. [Online; accessed 30-August-2022]. 2022

<sup>15</sup><https://gitlab.com/pierros/hough3d-code>

**INDI** Instrument Neutral Distributed Interface is a DCS (distributed control system) protocol to enable control, data acquisition and exchange among hardware devices and software front ends, emphasizing astronomical instrumentation.<sup>16</sup>

**IP67** Ingress Protection code 67.

**ITU** The International Telecommunication Union is a specialized agency of the United Nations responsible for many matters related to information and communication technologies.<sup>17</sup>

**kHz** kilohertz.

**libre** The English adjective free is commonly used in one of two meanings: “at no monetary cost” (gratis) and “with little or no restriction” (libre). This ambiguity of free can cause issues where the distinction is important, as it often is in dealing with laws concerning the use of information, such as copyright and patents. The terms gratis and libre may be used to categorise computer programs, according to the licenses and legal restrictions that cover them, in the free software and open source communities, as well as the broader free culture movement. For example, they are used to distinguish freeware (software gratis) from Free Software (software libre). “Think free as in free speech, not free beer.” – Richard Stallman.<sup>18</sup>

**Linux** is a free and open-source, monolithic, modular, multitasking, Unix-like operating system kernel. It was originally authored in 1991 by Linus Torvalds for his i386-based PC, and it was soon adopted as the kernel for the GNU operating system, which was written to be a free (libre) replacement for Unix.<sup>19</sup>

**LSF** Libre Space Foundation is a non-profit foundation registered since 2015 in Greece and the creators of the SatNOGS project.<sup>20</sup>

**mast** typically tall structures designed to support antennas for telecommunications and broadcasting.<sup>21</sup>

**Matrix** an open standard and communication protocol for real-time communication.<sup>22</sup>

**MHz** megahertz.

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<sup>16</sup>Wikipedia contributors. *Instrument Neutral Distributed Interface* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Instrument\\_Neutral\\_Distributed\\_Interface&oldid=1062506145](https://en.wikipedia.org/w/index.php?title=Instrument_Neutral_Distributed_Interface&oldid=1062506145). [Online; accessed 31-August-2022]. 2021

<sup>17</sup>Wikipedia contributors. *International Telecommunication Union* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=International\\_Telecommunication\\_Union&oldid=1105915792](https://en.wikipedia.org/w/index.php?title=International_Telecommunication_Union&oldid=1105915792). [Online; accessed 28-August-2022]. 2022

<sup>18</sup>Wikipedia contributors. *Gratis versus libre* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Gratis\\_versus\\_libre&oldid=1085552810](https://en.wikipedia.org/w/index.php?title=Gratis_versus_libre&oldid=1085552810). [Online; accessed 30-August-2022]. 2022

<sup>19</sup>Wikipedia contributors. *Linux kernel* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Linux\\_kernel&oldid=1105840074](https://en.wikipedia.org/w/index.php?title=Linux_kernel&oldid=1105840074). [Online; accessed 28-August-2022]. 2022

<sup>20</sup><https://libre.space/about-us/>

<sup>21</sup>Wikipedia contributors. *Radio masts and towers* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Radio\\_masts\\_and\\_towers&oldid=1103964392](https://en.wikipedia.org/w/index.php?title=Radio_masts_and_towers&oldid=1103964392). [Online; accessed 28-August-2022]. 2022

<sup>22</sup>Wikipedia contributors. *Matrix (protocol)* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Matrix\\_\(protocol\)&oldid=1106244486](https://en.wikipedia.org/w/index.php?title=Matrix_(protocol)&oldid=1106244486). [Online; accessed 28-August-2022]. 2022

**NASA** is an independent agency of the US federal government responsible for the civil space program, aeronautics research, and space research.<sup>23</sup>

**NORAD** North American Aerospace Defense Command is a combined organization of the United States and Canada that provides aerospace warning, air sovereignty, and protection for Canada and the continental United States.<sup>24</sup>

**Open Source** is source code that is made freely available for possible modification and redistribution. Products include permission to use the source code, design documents, or content of the product. The open-source model is a decentralized software development model that encourages open collaboration. A main principle of open-source software development is peer production, with products such as source code, blueprints, and documentation freely available to the public. The open-source movement in software began as a response to the limitations of proprietary code. The model is used for projects such as in open-source appropriate technology.<sup>25</sup>

**optical ground station** a ground station using optical equipment (cameras) instead of antennas.

**orbit** is the curved trajectory of an object such as the trajectory of a planet around a star, or of a natural satellite around a planet, or of an artificial satellite around an object or position in space such as a planet, moon, asteroid, or Lagrange point. Normally, orbit refers to a regularly repeating trajectory, although it may also refer to a non-repeating trajectory. To a close approximation, planets and satellites follow elliptic orbits, with the center of mass being orbited at a focal point of the ellipse, as described by Kepler's laws of planetary motion. For most situations, orbital motion is adequately approximated by Newtonian mechanics, which explains gravity as a force obeying an inverse-square law. However, Albert Einstein's general theory of relativity, which accounts for gravity as due to curvature of spacetime, with orbits following geodesics, provides a more accurate calculation and understanding of the exact mechanics of orbital motion.<sup>26</sup>

**OSH** open-source hardware consists of physical artifacts of technology designed and offered by the open-design movement. Both FOSS and open-source hardware are created by the open-source culture movement and apply a like concept to a variety of components. It is sometimes, thus, referred to as FOSH (Free open-source hardware). The term usually means that information about the hardware is easily discerned so that others can make it—coupling it closely to the maker movement. Hardware design (i.e. mechanical drawings, schematics, bills of material, PCB layout data, HDL source code and integrated circuit layout data), in addition to the software that drives the hardware, are all released under free/libre terms. The original sharer gains feedback and potentially improvements on the design from the FOSH community. There is now significant evidence that such sharing can drive a high return on investment for the scientific community. It is not enough to

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<sup>23</sup>Wikipedia contributors. *NASA* — *Wikipedia, The Free Encyclopedia*. <https://en.wikipedia.org/w/index.php?title=NASA&oldid=1107567899>. [Online; accessed 30-August-2022]. 2022

<sup>24</sup>Wikipedia contributors. *NORAD* — *Wikipedia, The Free Encyclopedia*. <https://en.wikipedia.org/w/index.php?title=NORAD&oldid=1105457081>. [Online; accessed 30-August-2022]. 2022

<sup>25</sup>Wikipedia contributors. *Open source* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Open\\_source&oldid=1103126225](https://en.wikipedia.org/w/index.php?title=Open_source&oldid=1103126225). [Online; accessed 28-August-2022]. 2022

<sup>26</sup>Wikipedia contributors. *Orbit* — *Wikipedia, The Free Encyclopedia*. <https://en.wikipedia.org/w/index.php?title=Orbit&oldid=1106406646>. [Online; accessed 30-August-2022]. 2022

merely use an open-source license; an open source product or project will follow open source principles, such as modular design and community collaboration.<sup>27</sup>

**OSS** open-source software is computer software that is released under a license in which the copyright holder grants users the rights to use, study, change, and distribute the software and its source code to anyone and for any purpose. Open-source software may be developed in a collaborative public manner. Open-source software is a prominent example of open collaboration, meaning any capable user is able to participate online in development, making the number of possible contributors indefinite. The ability to examine the code facilitates public trust in the software. Open source code can be used for studying and allows capable end users to adapt software to their personal needs in a similar way user scripts and custom style sheets allow for web sites, and eventually publish the modification as a fork for users with similar preference.<sup>28</sup>

**perturbation** is the complex motion of a massive body subjected to forces other than the gravitational attraction of a single other massive body. The other forces can include a third (fourth, fifth, etc.) body, resistance, as from an atmosphere, and the off-center attraction of an oblate or otherwise misshapen body.<sup>29</sup>

**plate solver** is software implementing a technique used in astronomy and applied on celestial images. Solving an image is finding match between the imaged stars and a star catalogue. The solution is a math model describing the corresponding astronomical position of each image pixel. The position of reference catalogue stars has to be known to a high accuracy so an astrometric reference catalogue is used. The image solution contains a reference point, often the image centre, image scale, image orientation and in some cases an image distortion model. With the astrometric solution it is possible to: 1) Calculate the celestial coordinates of any object on the image. 2) Synchronize the telescope mount or satellite pointing position to the center of the image taken. Astrometric solving programs extract the star x,y positions from the celestial image, groups them in three-star triangles or four-star quads. Then it calculates for each group a geometric hash code based on the distance and/or angles between the stars in the group. It then compares the resulting hash codes with the hash codes created from catalogue stars to find a match. If it finds sufficient statistically reliable matches, it can calculate transformation factors. There are several conventions to model the transformation from image pixel location to the corresponding celestial coordinates. The simplest linear model is called the WCS. A more advanced convention is SIP describing the transformation in polynomials to cope with non-linear geometric distortion in the celestial image, mainly caused by the optics.<sup>30</sup>

**PNG** Portable Network Graphics.

**PoE** Power over Ethernet.

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<sup>27</sup>Wikipedia contributors. *Open-source hardware* — Wikipedia, The Free Encyclopedia. [https://en.wikipedia.org/w/index.php?title=Open-source\\_hardware&oldid=1105615869](https://en.wikipedia.org/w/index.php?title=Open-source_hardware&oldid=1105615869). [Online; accessed 30-August-2022]. 2022

<sup>28</sup>Wikipedia contributors. *Open-source software* — Wikipedia, The Free Encyclopedia. [https://en.wikipedia.org/w/index.php?title=Open-source\\_software&oldid=1104440334](https://en.wikipedia.org/w/index.php?title=Open-source_software&oldid=1104440334). [Online; accessed 30-August-2022]. 2022

<sup>29</sup>Wikipedia contributors. *Perturbation (astronomy)* — Wikipedia, The Free Encyclopedia. [https://en.wikipedia.org/w/index.php?title=Perturbation\\_\(astronomy\)&oldid=1105431363](https://en.wikipedia.org/w/index.php?title=Perturbation_(astronomy)&oldid=1105431363). [Online; accessed 30-August-2022]. 2022

<sup>30</sup>Wikipedia contributors. *Astrometric solving* — Wikipedia, The Free Encyclopedia. [https://en.wikipedia.org/w/index.php?title=Astrometric\\_solving&oldid=1099832612](https://en.wikipedia.org/w/index.php?title=Astrometric_solving&oldid=1099832612). [Online; accessed 30-August-2022]. 2022

**Python** is a high-level, interpreted, general-purpose programming language. Its design philosophy emphasizes code readability. It is often described as a “batteries included” language due to its comprehensive standard library. Python consistently ranks as one of the most popular programming languages. It is one of the main languages of the SatNOGS project and stvid.<sup>31</sup>

**RASA** Rowe-Ackermann Schmidt Astrograph.

**RF** Radio frequency is the oscillation rate of an alternating electric current or voltage or of a magnetic, electric or electromagnetic field or mechanical system in the frequency range from around 20 kHz (kilohertz) to around 300 GHz (gigahertz). This is roughly between the upper limit of audio frequencies and the lower limit of infrared frequencies; these are the frequencies at which energy from an oscillating current can radiate off a conductor into space as radio waves.<sup>32</sup>

**rotator** a device used to change the orientation, within the horizontal plane, of a directional antenna. Most antenna rotators have two parts, the rotator unit and the controller. The controller is normally placed near the equipment which the antenna is connected to, while the rotator is mounted on the antenna mast directly below the antenna. Rotators are commonly used in amateur radio.<sup>33</sup>

**satellite** is an object intentionally placed into orbit in outer space. Except for passive satellites, most satellites have an electricity generation system for equipment on board. Most satellites also have a method of communication to ground stations, called transponders. Many satellites use a standardized bus to save cost and work, the most popular of which is small CubeSats. Similar satellites can work together as a group, forming constellations.<sup>34</sup>

**satid** is part of sattools.<sup>35</sup>

**SatNOGS** Open Source global network of satellite ground stations.<sup>36</sup>

**SatNOGS Optical** is a project by the LSF to add optical ground stations to the SatNOGS network.<sup>37</sup>

**SatNOGS DB** is an effort to create an holistic, unified, global database for all artificial objects in space (satellites and spacecrafts). Users can view and export the data, contribute to it, or connect applications using an API. It is part of the SatNOGS project.<sup>38</sup>

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<sup>31</sup>Wikipedia contributors. *Python (programming language)* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Python\\_\(programming\\_language\)&oldid=1107007073](https://en.wikipedia.org/w/index.php?title=Python_(programming_language)&oldid=1107007073). [Online; accessed 30-August-2022]. 2022

<sup>32</sup>Wikipedia contributors. *Radio frequency* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Radio\\_frequency&oldid=1104615064](https://en.wikipedia.org/w/index.php?title=Radio_frequency&oldid=1104615064). [Online; accessed 28-August-2022]. 2022

<sup>33</sup>Wikipedia contributors. *Antenna rotator* — *Wikipedia, The Free Encyclopedia*. [https://en.wikipedia.org/w/index.php?title=Antenna\\_rotator&oldid=1064620974](https://en.wikipedia.org/w/index.php?title=Antenna_rotator&oldid=1064620974). [Online; accessed 28-August-2022]. 2022

<sup>34</sup>Wikipedia contributors. *Satellite* — *Wikipedia, The Free Encyclopedia*. <https://en.wikipedia.org/w/index.php?title=Satellite&oldid=1106286374>. [Online; accessed 30-August-2022]. 2022

<sup>35</sup><https://github.com/cbassa/sattools/blob/master/satid.c>

<sup>36</sup><https://satnogs.org/>

<sup>37</sup><https://satnogs.org/>

<sup>38</sup><https://db.satnogs.org/>

- satpredict** is a software application to compute satellite predictions. It is used by `stvid`.<sup>39</sup>
- sattools** Satellite Tracking Toolkit. The main `sattools` applications are being ported to `stvid` and other related Python applications.<sup>40</sup>
- SDP** Simplified Deep Space Perturbations models apply to objects with an orbital period greater than 225 minutes, which corresponds to an altitude of 5,877.5 km, assuming a circular orbit. See also: `SGP`.<sup>41</sup>
- SDR** Software-defined radio is a radio communication system where components that have been traditionally implemented in analog hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented by means of software on a personal computer or embedded system. SDRs are used in SatNOGS ground stations.<sup>42</sup>
- SGP** Simplified General Perturbations models apply to near earth objects with an orbital period of less than 225 minutes. Simplified perturbations models are a set of five mathematical models (`SGP`, `SGP4`, `SDP4`, `SGP8` and `SDP8`) used to calculate orbital state vectors of satellites and space debris relative to the Earth-centered inertial coordinate system. This set of models is often referred to collectively as `SGP4` due to the frequency of use of that model particularly with TLE sets produced by NORAD (North American Aerospace Defense Command) and NASA (National Aeronautics and Space Administration). These models predict the effect of perturbations caused by the Earth's shape, drag, radiation, and gravitation effects from other bodies such as the sun and moon. See also: `SDP`.<sup>43</sup>
- SIDLOC** Spacecraft Identification and Localization.
- SIP** Simple Imaging Polynomial.
- skymap** is part of `sattools`. Vizualize satellites on a map of the sky.<sup>44</sup>
- SSA** Space Situational Awareness.
- stvid** Satellite tools video application for acquiring and processing sky images.<sup>45</sup>
- telemetry** is the in situ collection of measurements or other data at remote points and their automatic transmission to receiving equipment (telecommunication) for monitoring. The word is derived from the Greek roots *tele*, “remote”, and *metron*, “measure”. Although the term commonly refers to wireless data transfer mechanisms (e.g., using radio, ultrasonic, or infrared systems), it also encompasses data transferred over other media such as a telephone or computer network, optical link or other wired communications like power line carriers.<sup>46</sup>

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<sup>39</sup><https://github.com/cbassa/satpredict>

<sup>40</sup><https://github.com/cbassa/sattools>

<sup>41</sup>Wikipedia contributors. *Simplified perturbations models* — Wikipedia, The Free Encyclopedia. [https://en.wikipedia.org/w/index.php?title=Simplified\\_perturbations\\_models&oldid=983925578](https://en.wikipedia.org/w/index.php?title=Simplified_perturbations_models&oldid=983925578). [Online; accessed 30-August-2022]. 2020

<sup>42</sup>Wikipedia contributors. *Software-defined radio* — Wikipedia, The Free Encyclopedia

<sup>43</sup>Wikipedia contributors. *Simplified perturbations models* — Wikipedia, The Free Encyclopedia

<sup>44</sup><https://github.com/cbassa/sattools/blob/master/skymap.c>

<sup>45</sup><https://github.com/cbassa/stvid>

<sup>46</sup>Wikipedia contributors. *Telemetry* — Wikipedia, The Free Encyclopedia. <https://en.wikipedia.org/w/index.php?title=Telemetry&oldid=1080706265>. [Online; accessed 30-August-2022]. 2022

**telescope** is an optical instrument using lenses, curved mirrors, or a combination of both to observe distant objects, or various devices used to observe distant objects by their emission, absorption, or reflection of electromagnetic radiation. The word telescope now refers to a wide range of instruments capable of detecting different regions of the electromagnetic spectrum, and in some cases other types of detectors.<sup>47</sup>

**TLE** two-line element set is a data format encoding a list of orbital elements of an Earth-orbiting object for a given point in time, the epoch. Using a suitable prediction formula, the state (position and velocity) at any point in the past or future can be estimated to some accuracy. TLEs can describe the trajectories only of Earth-orbiting objects. TLEs are widely used as input for projecting the future orbital tracks of space debris for purposes of characterizing “future debris events to support risk analysis, close approach analysis, collision avoidance maneuvering” and forensic analysis. The format was originally intended for punched cards, encoding a set of elements on two standard 80-column cards.<sup>48</sup>

**UHF** Ultra High Frequency is the ITU (International Telecommunication Union) designation for radio frequencies in the range between 300 MHz (megahertz) and 3 GHz, also known as the decimetre band as the wavelengths range from one meter to one tenth of a meter (one decimeter). Lower frequency signals fall into the VHF or lower bands.<sup>49</sup>

**VHF** Very High Frequency is the ITU designation for the range of radio frequency electromagnetic waves (radio waves) from 30 to 300 MHz, with corresponding wavelengths of ten meters to one meter. Frequencies immediately below VHF are denoted high frequency (HF), and the next higher frequencies are known as UHF.<sup>50</sup>

**WCS** World Coordinate System.

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<sup>47</sup>Wikipedia contributors. *Telescope* — Wikipedia, The Free Encyclopedia. <https://en.wikipedia.org/w/index.php?title=Telescope&oldid=1106167988>. [Online; accessed 30-August-2022]. 2022

<sup>48</sup>Wikipedia contributors. *Two-line element set* — Wikipedia, The Free Encyclopedia. [https://en.wikipedia.org/w/index.php?title=Two-line\\_element\\_set&oldid=1104028347](https://en.wikipedia.org/w/index.php?title=Two-line_element_set&oldid=1104028347). [Online; accessed 28-August-2022]. 2022

<sup>49</sup>Wikipedia contributors. *Ultra high frequency* — Wikipedia, The Free Encyclopedia. [https://en.wikipedia.org/w/index.php?title=Ultra\\_high\\_frequency&oldid=1096417717](https://en.wikipedia.org/w/index.php?title=Ultra_high_frequency&oldid=1096417717). [Online; accessed 28-August-2022]. 2022

<sup>50</sup>Wikipedia contributors. *Very high frequency* — Wikipedia, The Free Encyclopedia. [https://en.wikipedia.org/w/index.php?title=Very\\_high\\_frequency&oldid=1105564543](https://en.wikipedia.org/w/index.php?title=Very_high_frequency&oldid=1105564543). [Online; accessed 28-August-2022]. 2022





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