SatNOGS Optical Unofficial Guide

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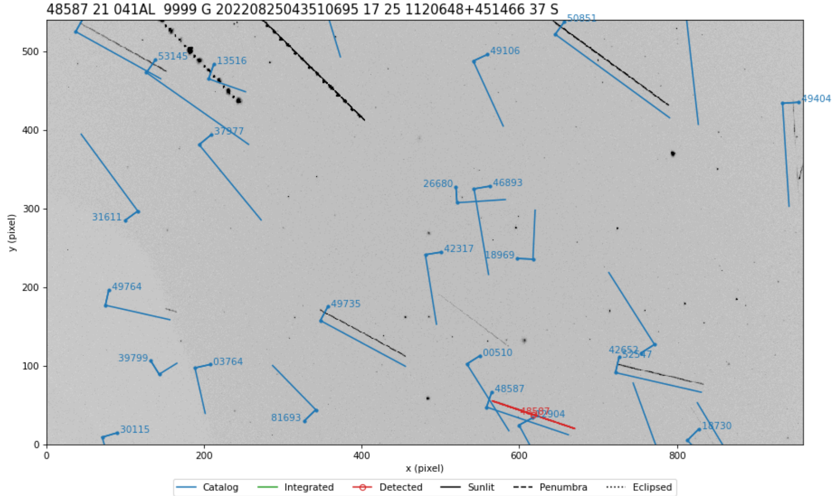

SatNOGS Optical

Unofficial

Guide

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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.

Libre Space Foundation

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SatNOGS Optical

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.

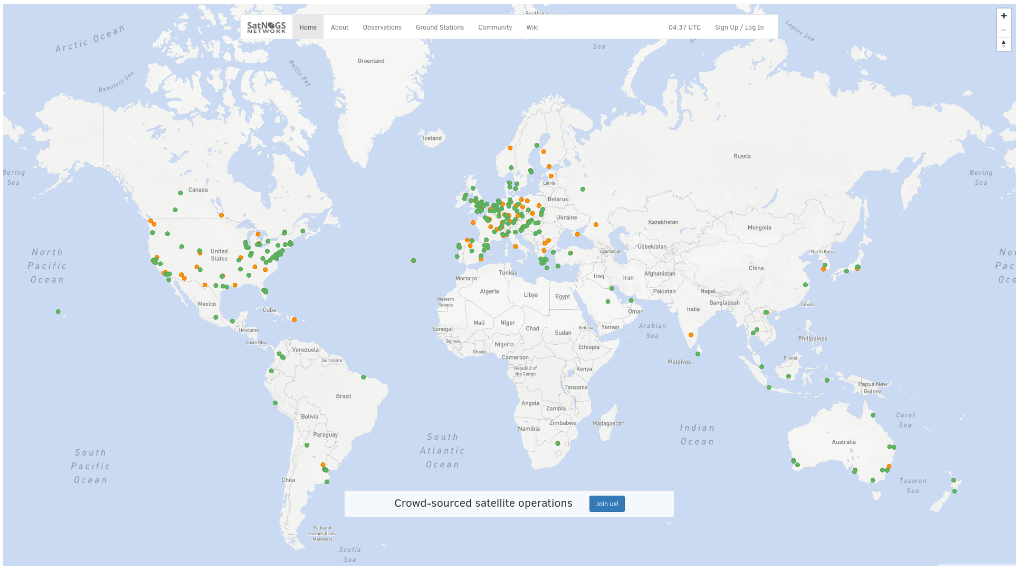


Figure 1: SatNOGS Network.

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."[1]

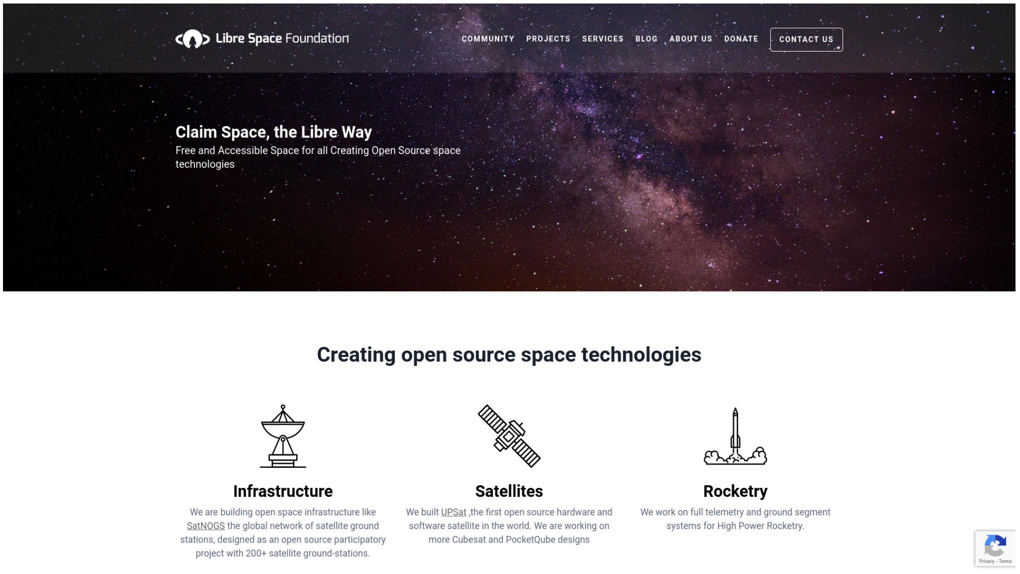


Figure 2: Libre Space Foundation Website.

Select LSF projects:

- SatNOGS — Global network of satellite ground stations
  `https://satnogs.org`
- UPSat — First open source hardware and software satellite in the world
  `https://upsat.gr/`

[1] https://libre.space

SatNOGS Network

SatNOGS is the LSF's global network of satellite ground stations.

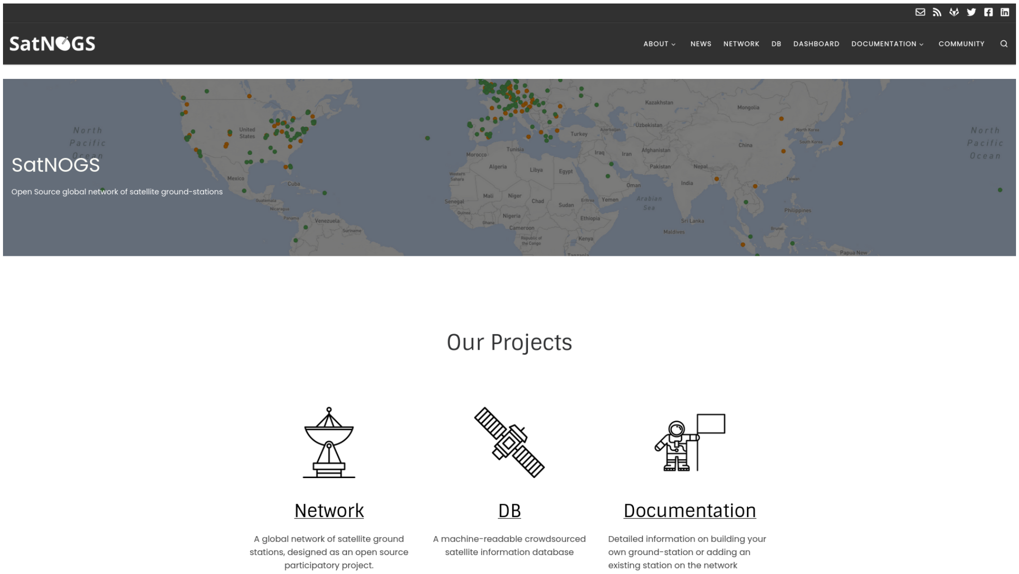


Figure 3: SatNOGS Website.

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.

Satellites

Artificial Satellites in Space

1.1 Overview of Satellites

Artificial satellites are rocks with modems.

1.2 SatNOGS DB

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

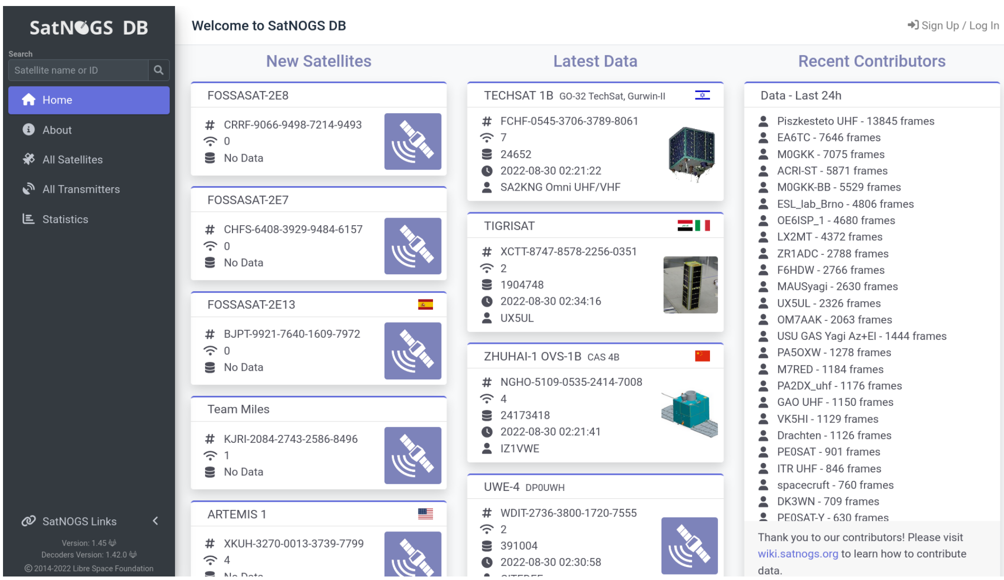


Figure 1.1: SatNOGS DB website.

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

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

1.3 Libre Satellites

Satellites in orbit, decayed, or designs on Earth that generally support the libre way. Select libre satellites:

- UPSat — First libre open source hardware and software satellite in the world. Created by the LSF.
  `https://upsat.gr/`

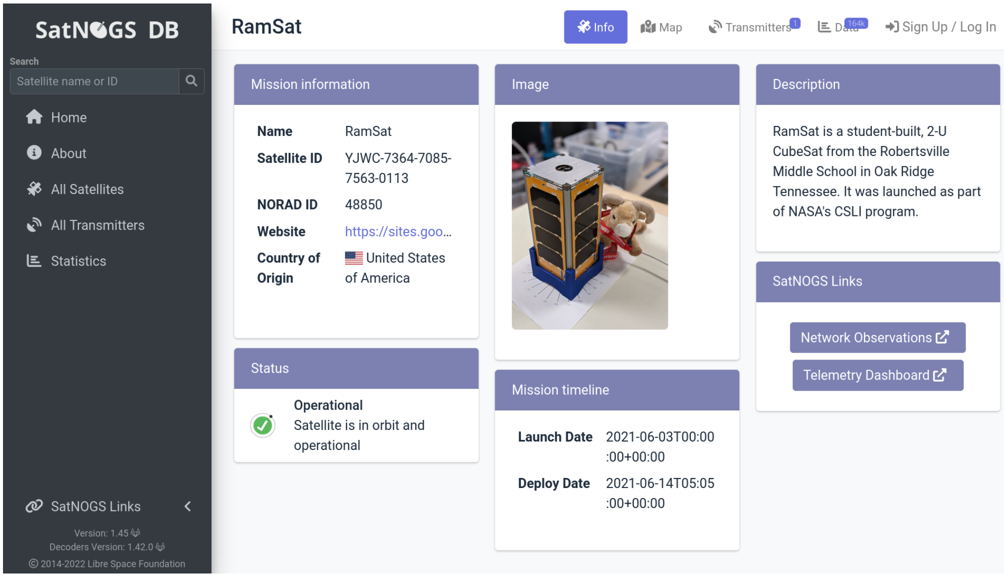


Figure 1.2: SatNOGS DB RamSat CubeSat web page.

Figure 1.3: SatNOGS DB RamSat CubeSat telemetry web page.

RF Observations can be scheduled on the SatNOGS network. See 1.5, page 16 for a sample list of observations of the RamSat CubeSat.[1]

[1] https://network.satnogs.org/observations/?future=0&norad=48850&observer=&station=&start=&end=&transmitter_mode=&page=2

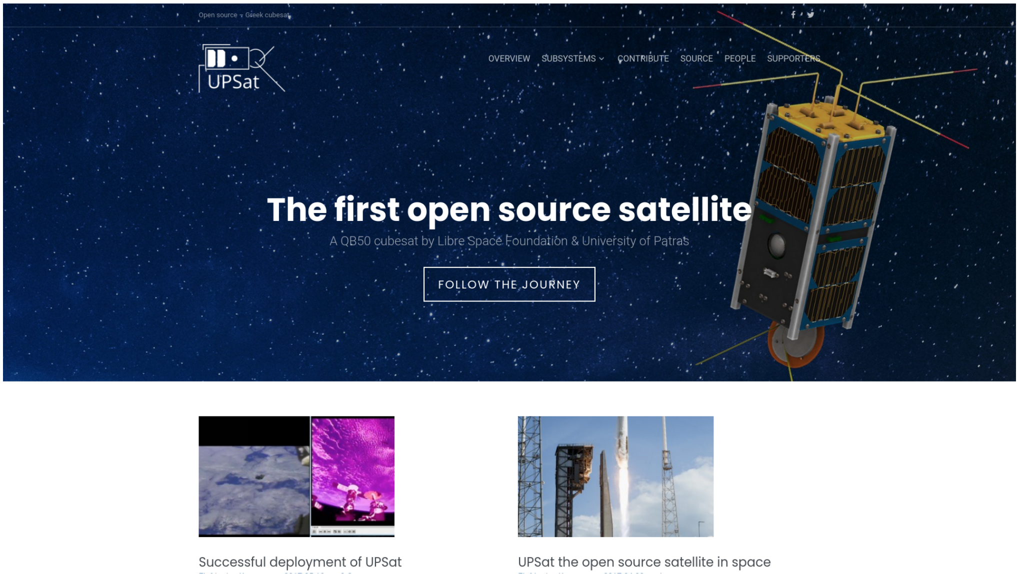
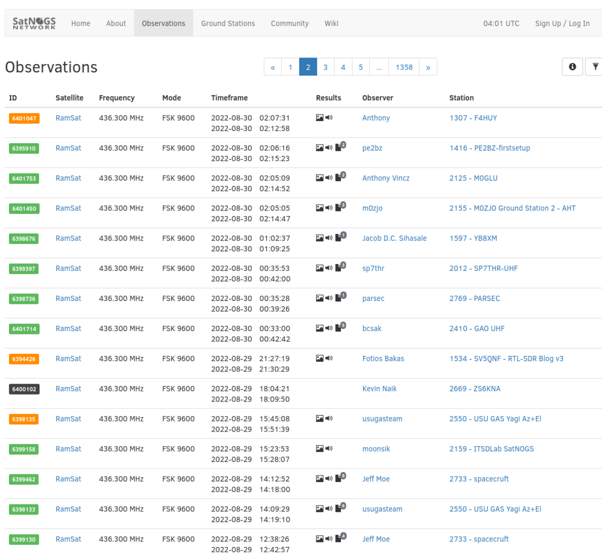


Figure 1.4: UPSat Website.



ID	Satellite	Frequency	Mode	Timeframe	Results	Observer	Station
6401047	RamSat	436.300 MHz	FSK 9600	2022-08-30 02:07:31 2022-08-30 02:12:58		Anthony	1307 - F4HUY
6395910	RamSat	436.300 MHz	FSK 9600	2022-08-30 02:06:16 2022-08-30 02:15:23	2	pe2bz	1416 - PE2BZ-firstsetup
6401753	RamSat	436.300 MHz	FSK 9600	2022-08-30 02:05:09 2022-08-30 02:14:52	2	Anthony Vincz	2125 - M0GLU
6401450	RamSat	436.300 MHz	FSK 9600	2022-08-30 02:05:05 2022-08-30 02:14:47	3	m0zjo	2155 - M0ZJO Ground Station 2 - AHT
6398676	RamSat	436.300 MHz	FSK 9600	2022-08-30 01:02:37 2022-08-30 01:09:25	1	Jacob D.C. Sihasale	1597 - YB8XM
6399397	RamSat	436.300 MHz	FSK 9600	2022-08-30 00:35:53 2022-08-30 00:42:00	3	sp7thr	2012 - SP7THR-UHF
6398736	RamSat	436.300 MHz	FSK 9600	2022-08-30 00:35:28 2022-08-30 00:39:26	1	parsec	2769 - PARSEC
6401714	RamSat	436.300 MHz	FSK 9600	2022-08-30 00:33:00 2022-08-30 00:42:42	5	bcsak	2410 - GAO UHF
6394426	RamSat	436.300 MHz	FSK 9600	2022-08-29 21:27:19 2022-08-29 21:30:29		Fotios Bakas	1534 - SV5QNF - RTL-SDR Blog v3
6400102	RamSat	436.300 MHz	FSK 9600	2022-08-29 18:04:21 2022-08-29 18:09:50		Kevin Naik	2669 - ZS6KNA
6398135	RamSat	436.300 MHz	FSK 9600	2022-08-29 15:45:08 2022-08-29 15:51:39		usugasteam	2550 - USU GAS Yagi Az+El
6399158	RamSat	436.300 MHz	FSK 9600	2022-08-29 15:23:53 2022-08-29 15:28:07		moonsik	2159 - ITSDLab SatNOGS
6399462	RamSat	436.300 MHz	FSK 9600	2022-08-29 14:12:52 2022-08-29 14:18:00	8	Jeff Moe	2733 - spacecruft
6398133	RamSat	436.300 MHz	FSK 9600	2022-08-29 14:09:29 2022-08-29 14:19:10	6	usugasteam	2550 - USU GAS Yagi Az+El
6399130	RamSat	436.300 MHz	FSK 9600	2022-08-29 12:38:26 2022-08-29 12:42:57	4	Jeff Moe	2733 - spacecruft

Figure 1.5: List of observations of the RamSat CubeSat, example.

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).

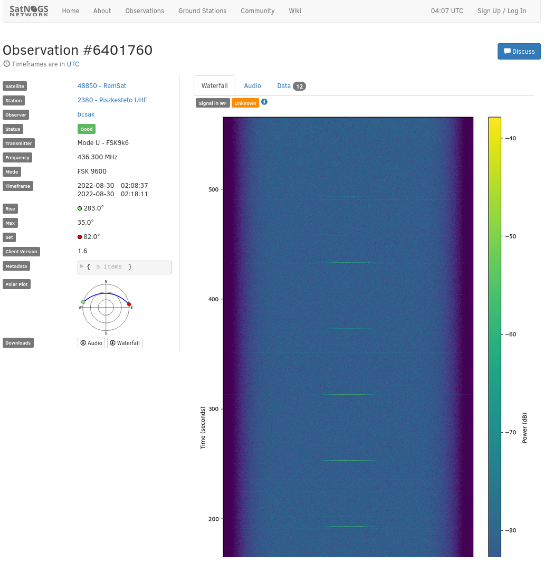


Figure 1.6: Sample observation of RamSat CubeSat on SatNOGS website.

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 20.[1] 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.[2]

Figure 2.1: SatNOGS ground station with antennas.

Ground stations can be viewed on the SatNOGS network website, such as as the example in figure 2.2, page 21.[3]

[1] https://spacecruft.org/assets/i/spacecruft-rotator.png

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

[3] https://network.satnogs.org/stations/2733/

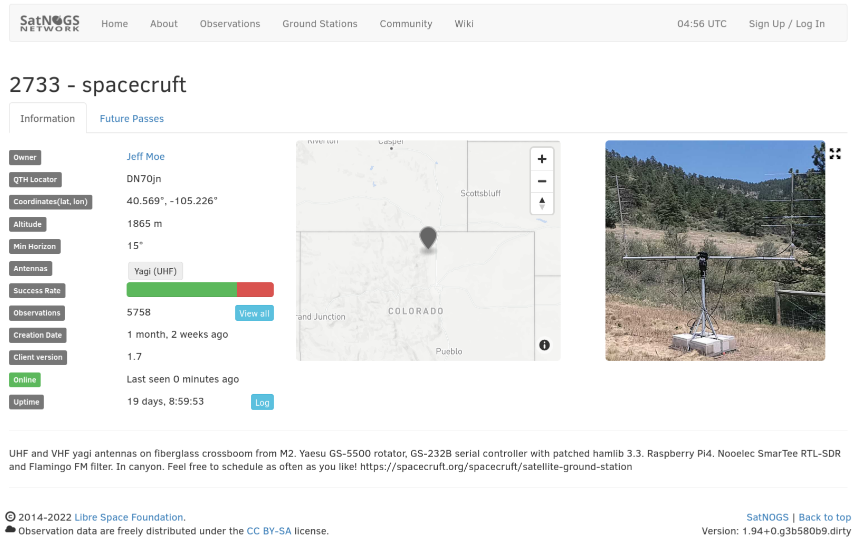


Figure 2.2: Ground station viewed on SatNOGS website, example.

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 22.

Figure 2.3: SatNOGS-Optical ground station prototype.

Toolchain and Process

Make Old Photons Useful Again

3.1 SatNOGS Optical HOWTO

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

This chapter reviews what is needed in terms of hardware and software to build an operating optical ground station.

3.2 Toolchain

SatNOGS Optical Process Overview.[1] See figure 3.1, page 24.

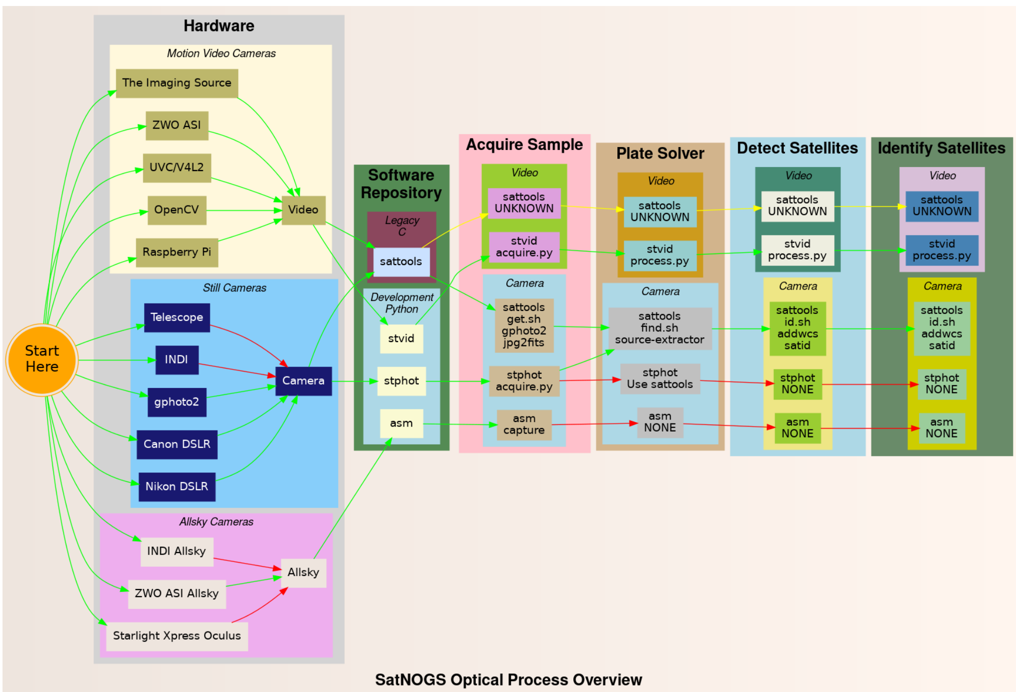


Figure 3.1: SatNOGS Optical Process Overview

[1] https://spacecruft.org/spacecruft/SNOPO

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 tested:

- The Imaging Source IMX174 based.
- ZWO ASI IMX174 based monochrome.
- DSLR (digital single-lens reflex) camera.
- PiCamera.

> NOTICE:
> ZWO/ASI cameras require proprietary non-libre software on host computer.

4.3 Lenses

Lenses being tested:

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

4.4 Embedded Computer

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 Tracking Ground Station

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 22.

A close up of the setup can be seen at 4.1, page 28, 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.

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 28.

As seen in figure 4.3, page 29, 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 29, 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 29.

Inside the camera enclosure, as shown in Figure 4.6, page 31, is:

- The Imaging Source DMX camera with Sony IMX174 CMOS.

Figure 4.1: SatNOGS-Optical ground station prototype.

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

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

Figure 4.4: Camera enclosure, right side.

- 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).
- 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

Figure 4.5: Camera enclosure, right side, opened.

- USB 3 cable, external, from Odroid to telescope mount. XXX large rectangle connector
- “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 31.

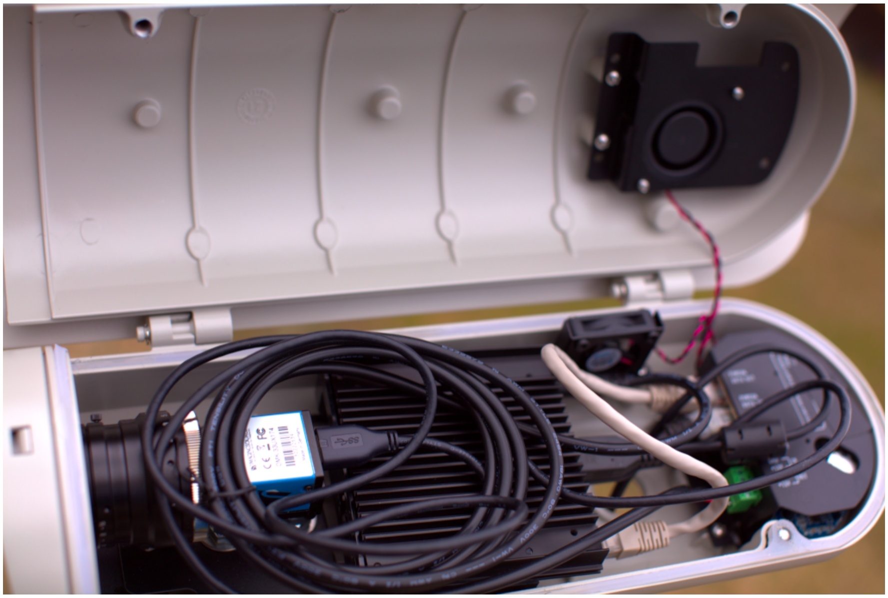


Figure 4.6: Camera enclosure, opened.

Figure 4.7: Camera enclosure, top.

Software

Satellite Applications on Earth

5.1 Software Overview

See 5.1, page 34 for a diagram with an overview of the software process.

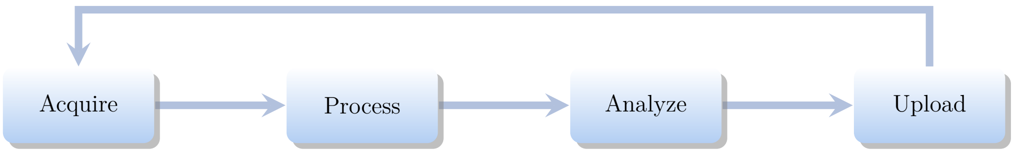


Figure 5.1: SatNOGS Optical Operation Process

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 spacecruft repo.

```
cd ../
git clone https://spacecruft.org/spacecruft/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 spacecruft `git` repository or the cbassa one.

```
cd ../
git clone https://spacecruft.org/spacecruft/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

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
```

Acquire

Twinkle, Twinkle, Little Starlink

6.1 Overview of Operation

HOWTO 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.

6.3 Process Data

Process data with using stvid. Adjust dated directory to actual directory name.

```
cd stvid/
./process_new.py -c config_new.ini -d data/obs/20220825_1/020502/
```

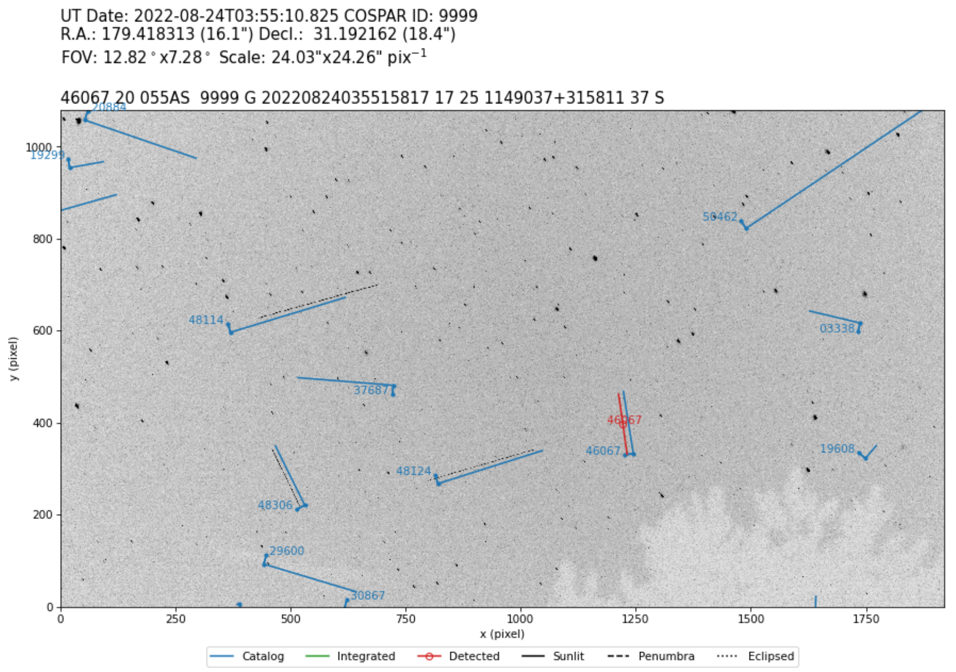


Figure 6.2: Satellite images processed by stvid.

Solve

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 (Flexible Image Transport System) 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 Databases

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

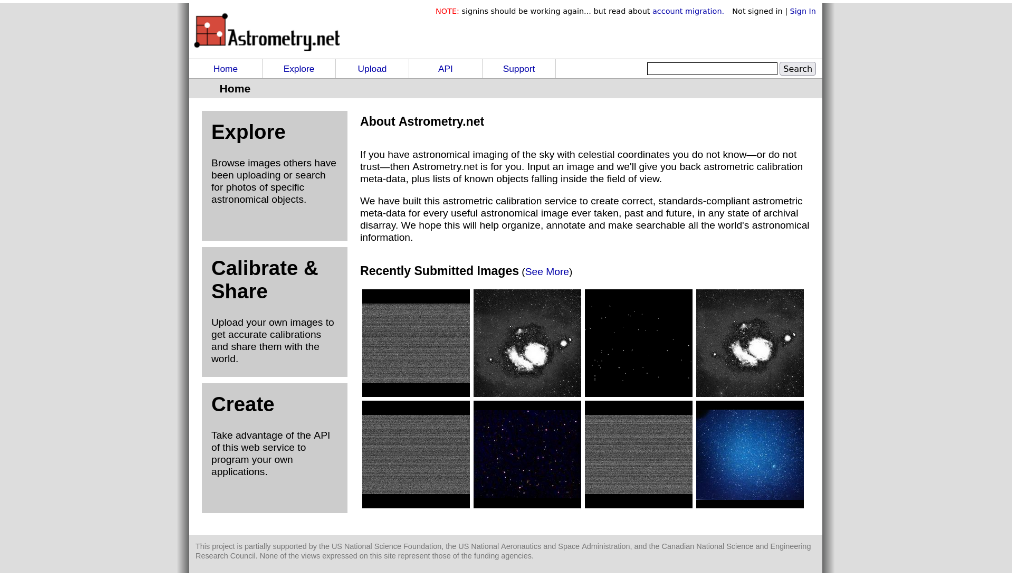


Figure 7.1: nova.astrometry.net website.

7.5 World Coordinate System

WCS info. XXX

7.6 Plate Solving with `stvid`

Use the `process.py` scripts described at XXX to solve plates with `stvid`.

Detect

Find Satellites

8.1 Satellite Detection

Description of satellite detection processes.

8.2 stvid Detection with `process.py`

To detect satellite in a FITS file using the stvid toolchain, the `process.py` or, if it exists, the `process_new.py` Python script.

8.2.1 `process.py` Operation

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_new.py -c config_new.ini -d data/obs/20220825_1/020502/
```

Identify

More Than Just Old Rocket Bodies

9.1 Overview of Satellite Identification

The LSF is developing a project called SIDLOC, for satellite identification and localization. With the addition of many more satellites in orbit there is a growing need for SSA.

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://spacecruft.org/spacecruft/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 48 for output from my Giza port of `satid`.[1]

* `https://github.com/cbassa/sattools`

My fork is here:

* `https://spacecruft.org/spacecruft/sattools`

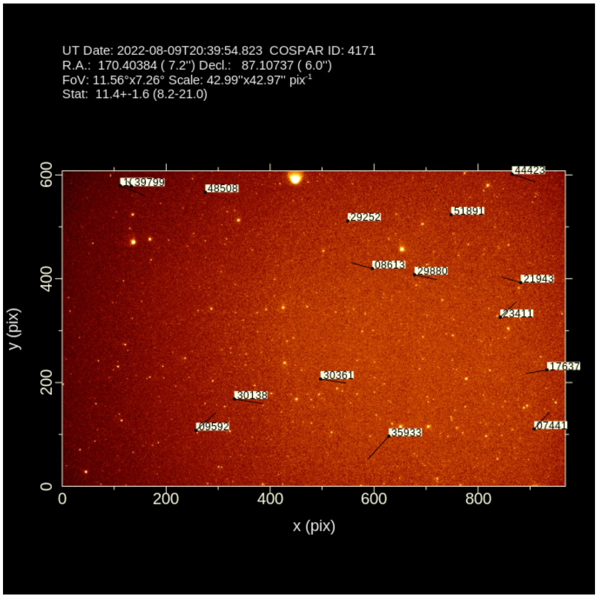


Figure 9.1: `satid` example.

[1] `https://spacecruft.org/spacecruft/sattools/media/branch/spacecruft/img/satid-giza-3.png`

9.4 AstroImageJ

Analyze data with applications, such as AstroImageJ.

FITS files are commonly used in astronomy.[2] AstroImageJ can read FITS format files. See 9.2, page 49, for a screenshot displaying a FITS file generated by `stvid`.

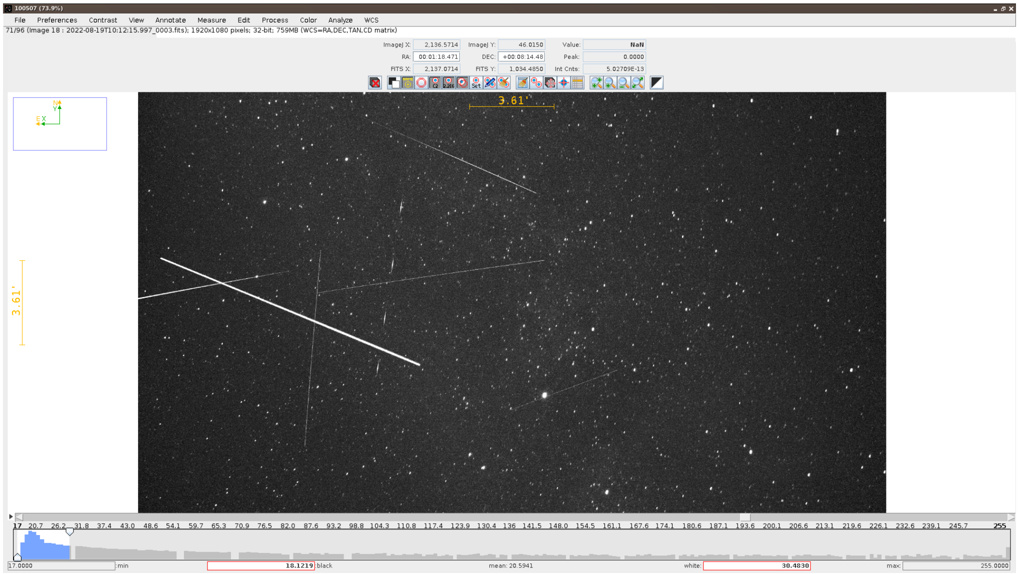


Figure 9.2: AstroImageJ screenshot viewing FITS file.

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

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@spacecruft.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.[1]

antenna the interface between radio waves propagating through space and electric currents moving in metal conductors, used with a transmitter or receiver.[2]

artificial satellite Satellite launched by teh hoomans.

AstroImageJ Application for astronomy and satellite image analysis.

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.[3]

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.[4]

GHz gigahertz.

GNSS Global Navigation Satellite System.

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

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

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

[4] Wikipedia contributors, FITS — Wikipedia, The Free Encyclopedia

GNU 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.[5]

GPL 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 free and open-source software domain.[6]

GPS Global Positioning System.

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

hough3d-code Software application for Iterative Hough Transform for Line Detection in 3D Point Clouds.[7]

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.[8]

kHz kilohertz.

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.[9]

LSF Libre Space Foundation is a non-profit foundation registered since 2015 in Greece and the creators of the SatNOGS project.[10]

mast typically tall structures designed to support antennas for telecommunications and broadcasting.[11]

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

[6] Wikipedia contributors. GNU General Public License — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=GNU_General_Public_License&oldid=1106596497. [Online; accessed 28-August-2022]. 2022

[7] https://gitlab.com/pierros/hough3d-code

[8] Wikipedia contributors. International Telecommunication Union — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=International_Telecommunication_Union&oldid=1105915792. [Online; accessed 28-August-2022]. 2022

[9] Wikipedia contributors. Linux kernel — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Linux_kernel&oldid=1105840074. [Online; accessed 28-August-2022]. 2022

[10] https://libre.space/about-us/

[11] Wikipedia contributors. Radio masts and towers — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Radio_masts_and_towers&oldid=1103964392. [Online; accessed 28-August-2022]. 2022

Matrix an open standard and communication protocol for real-time communication.[12]

MHz megahertz.

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.[13]

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

PoE Power over Ethernet.

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.[14]

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.[15]

SatNOGS Open Source global network of satellite ground stations.[16]

SatNOGS Optical Project by the LSF to expand the SatNOGS network to add optical ground stations.

satpredict Software application to compute satellite predictions.[17]

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.[18]

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

[13] Wikipedia contributors. Open source — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=Open_source&oldid=1103126225`. [Online; accessed 28-August-2022]. 2022

[14] Wikipedia contributors. Radio frequency — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=Radio_frequency&oldid=1104615064`. [Online; accessed 28-August-2022]. 2022

[15] Wikipedia contributors. Antenna rotator — Wikipedia, The Free Encyclopedia. `https://en.wikipedia.org/w/index.php?title=Antenna_rotator&oldid=1064620974`. [Online; accessed 28-August-2022]. 2022

[16] `https://satnogs.org/`

[17] `https://github.com/cbassa/satpredict`

[18] Wikipedia contributors, Software-defined radio — Wikipedia, The Free Encyclopedia

stvid Satellite tools video application for acquiring and processing sky images[19]

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.[20]

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.[21]

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.[22]

[19] https://github.com/cbassa/stvid

[20] Wikipedia contributors. Two-line element set — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Two-line_element_set&oldid=1104028347. [Online; accessed 28-August-2022]. 2022

[21] Wikipedia contributors. Ultra high frequency — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Ultra_high_frequency&oldid=1096417717. [Online; accessed 28-August-2022]. 2022

[22] Wikipedia contributors. Very high frequency — Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/w/index.php?title=Very_high_frequency&oldid=1105564543. [Online; accessed 28-August-2022]. 2022

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Colophon

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