The U.S. Air Force Academy Falcon Telescope Network

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ABSTRACT

The Falcon Telescope Network (FTN) is a global network of small aperture telescopes developed by the Center for Space Situational Awareness Research in the Department of Physics at the United States Air Force Academy (USAFA). Consisting of commercially available equipment, the FTN is a collaborative effort between USAFA and other educational institutions ranging from two- and four-year colleges to major research universities. USAFA provides the equipment (e.g. telescope, mount, camera, filter wheel, dome, weather station, computers and storage devices) while the educational partners provide the building and infrastructure to support an observatory. The user base includes USAFA along with K-12 and higher education faculty and students. Since the FTN has a general use purpose, objects of interest include satellites, astronomical research, and STEM support images. The raw imagery, all in the public domain, will be accessible to FTN partners and will be archived at USAFA in the Cadet Space Operations Center. FTN users will be able to submit observational requests via a web interface. The requests will then be prioritized based on the type of user, the object of interest, and a user-defined priority. A network wide schedule will be developed every 24 hours and each FTN site will autonomously execute its portion of the schedule. After an observational request is completed, the FTN user will receive notification of collection and a link to the data. The Falcon Telescope Network is an ambitious endeavor, but demonstrates the cooperation that can be achieved by multiple educational institutions.

1. INTRODUCTION

The Department of Physics at the United States Air Force Academy (USAFA) is developing a global network of small aperture telescopes called the Falcon Telescope Network (FTN). Led by the Department's Center for Space Situational Awareness Research (CSSAR), the FTN will provide USAFA cadets and faculty with world-class capability to conduct research in satellite characterization and astronomy. Partnering with USAFA are educational institutions around the world consisting of two- and four-year colleges as well as major research universities. USAFA provides the equipment (e.g. telescope, mount, camera, filter wheel, dome, weather station, computers, network and storage devices) while the educational partners provide the building and infrastructure to support an observatory. The formal partnership framework is the Cooperative Research and Development Agreement (CRADA) which allows USAFA to provide the equipment and share the raw image data with every partner.

Table 1 provides information on the current and approved FTN educational partners. Five FTN observatories are located in the United States, four in the State of Colorado and one in Pennsylvania. The Colorado educational partners include Colorado Mesa University (Grand Junction), Fort Lewis College (Durango), Northeastern Junior College (Sterling), and Otero Junior College (La Junta). The Pennsylvania educational partner is Penn State University (State College). Overseas, the educational partners are the University of La Serena and Mamalluca Observatory (Chile), University of New South Wales and Electric Optics Systems (Canberra, Australia), and Australian International Gravity Research Centre and the Catholic Education Office of Western Australia (Perth). Potential locations and educational partners include Kauai Community College (Hawaii, USA), University of Cape Town (South Africa), and the Technical University of Braunschweig (Germany). The FTN will be centrally controlled from USAFA such that only objects in the public domain will be observed. Thus regardless of whether

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they are U.S. or international educational institutions, all FTN partners will have access to the raw image data collected by anyone in the network.

Table 1. Educational partners in the Falcon Telescope Network (current and planned)

Education Institute	City	State	Country	Longitude (east)	Latitude	Elevation (meters)
Colorado Mesa University	Grand Junction	CO	USA	251.45	39.08	1380
Fort Lewis College	Durango	CO	USA	251.93	37.23	1969
Northeastern Junior College	Sterling	CO	USA	256.80	40.65	1177
Otero Junior College	La Junta	CO	USA	256.46	37.97	1221
Penn State University	State College	PA	USA	289.17	40.86	347
Mamalluca Observatory	Vicuna		Chile	289.32	-29.99	1139
University of New South Wales and EOS	Canberra	ACT	Australia	149.17	-35.29	606
Gravity Discovery Centre and Catholic Education Office of Western Australia	Perth	WA	Australia	115.86	-31.95	0
Kauai Community College (TBD)	Lihue	HI	USA	TBD	TBD	TBD
University of Cape Town (TBD)	Cape Town		South Africa	TBD	TBD	TBD
Technical University of Braunschweig (TBD)	TBD		Germany	TBD	TBD	TBD

The power of collaborating with educational partners around the world and locating the Falcon telescopes in geographically diverse locations are two-fold. One, multiple locations prevents the entire network for experiencing weather outage, even within relative near distances such as the Colorado sites. Two, the FTN offers the ability to conduct simultaneous observations of many manmade and celestial objects from a variety of geometric look angles and directions. This unique capability is illustrated in Fig. 1 which shows the fields of regard for the individual FTN observatories. The left panel depicts the fields of regard for satellites in geosynchronous orbit, while the right panel shows the fields of regards for satellites at low-earth orbits (LEO) of 1,000 kilometers. The fields of regard were constrained to elevations above 20° above the horizon. For the most part, the entire geosynchronous belt is visible from more than one site and in some instances visible simultaneously from both the north and south hemispheres. For LEO satellites, there is overlap from within the U.S. as well as Australian sites. Additionally, depending on their orbit parameters, the FTN would be capable of tracking some LEO satellites throughout more of their orbits as compared to a single site alone by demonstrating the ability to handover object track from telescope to telescope.

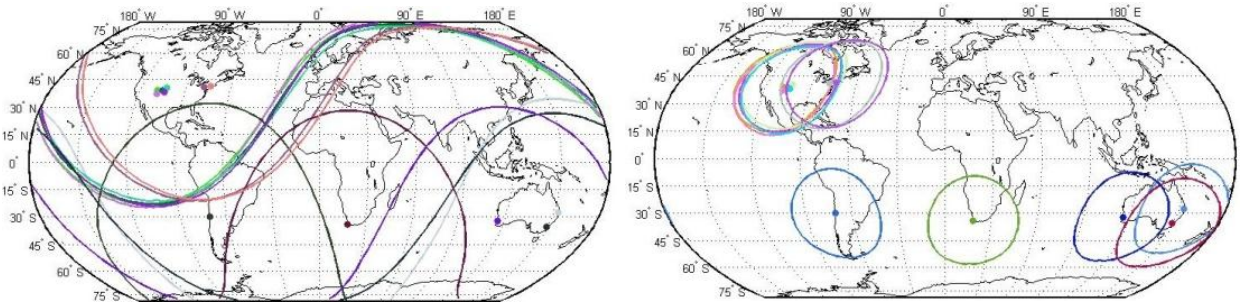

Fig. 1. Field of regard coverage of the FTN for geosynchronous orbits (left panel) and low-earth orbits of 1,000 kilometers (right panel).

The FTN will have a general use purpose consisting of satellite observations and astronomy research, with support to science, technology, engineering and mathematics (STEM) programs. Thus the user base will include USAFA along with K-12 and higher education faculty and students. The FTN will only observe objects in the public domain and all the raw image data will be accessible to every FTN partners. Control of the FTN will be via the USAFA Cadet Space Operations Center (CSOC) using service-oriented software architecture, allowing for ease of maintenance and testing of new services and algorithms. FTN users will be able to submit observational requests via a web interface. The requests will then be prioritized based on the type of user, the object of interest, and a user-defined priority. A network wide schedule will be developed every 24 hours and each FTN site will autonomously execute its portion of the schedule, weather permitting. After an observational request is completed, the FTN user will receive notification of collection and a link to the data for downloading.

2. FTN Equipment and Observatories

All the FTN equipment is commercially available and exportable to international partners. The cost of the equipment provide by USAFA is approximately $155,000 U.S. dollars. A list of the equipment (hardware and software) is listed below. The specifications of the telescope and camera provide a plate scale of 0.65 arc seconds per pixel and a field-of-view of approximately 11 arc minutes.

- Officina Stellare 20-inch, f/8.1 Ritchey–Chrétien
- Software Bisque Paramount ME2
- Apogee Alta F47: 1024x1024, 13µm
- Apogee 9-position Filter Wheel: B, V, R, g', r', i', z', grating, exoplanet
- Astro Haven 12-foot Clamshell Dome
- Boltwood Cloud Sensor II
- Symmetricom GPS Antenna
- Advantech Gen II Computers w/ Intel SSD DC S3700 Series
- Synology NAS (12-20 TB)
- Cisco ASA 5505 Router
- Cisco Small Business 200 Series Switch
- Tripp Lite UPS SMART1000/2000
- Foscam Pan/Tilt IP Camera (FI8919W and FI9826W)
- Software Bisque TheSkyX Suite
- FalconExec

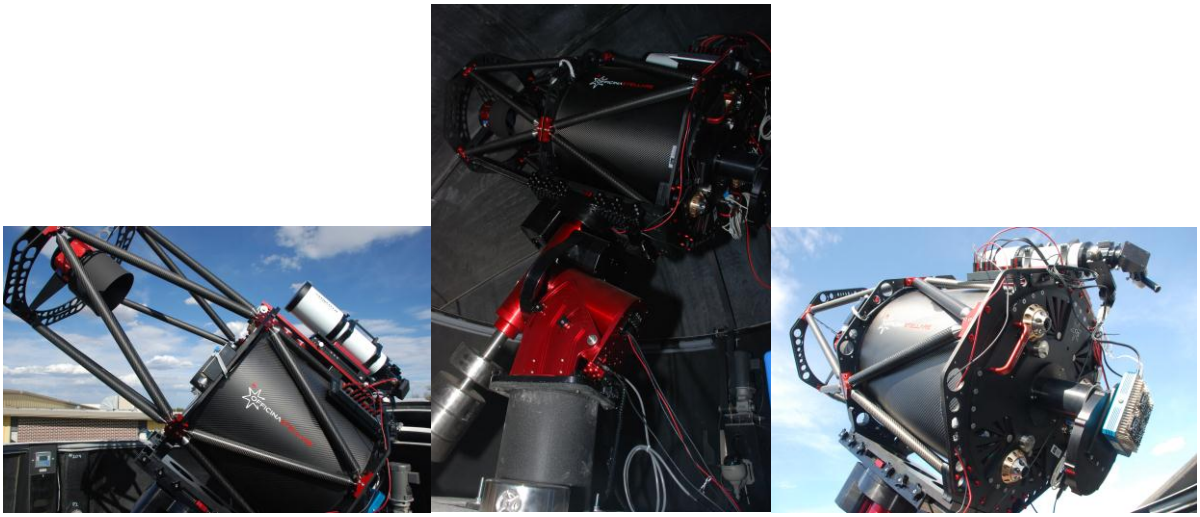

Fig. 2. Pictures of the installed FTN telescope equipment.

Currently, we have installed Falcon telescopes at five locations; two in Colorado, and one each in Pennsylvania, Chile, and Canberra Australia. Fig. 3 and Fig. 4 are pictures of the installed FTN observatories. One can easily see that although all partners received the same basic observatory building design, the choice of materials and location were left to them. Every partner was allowed to choose the materials that best met their budget and a location that was easily accessible to their students, faculty and staff. Thus except for the Chile-Falcon, all the FTN observatories are located on campus property close to support facilities. The Chile-Falcon is located at the Mamalluca Municipal Observatory in the town of Vicuña which is approximately 100 kilometers east of the University of La Serena (La Serena, Chile).

Fig. 3. FTN Observatories currently in the U.S.: Otero-Falcon (left), Northeastern-Falcon (middle), and PSU-Falcon (right).

Fig. 4. FTN Observatories currently overseas: Canberra-Falcon (left) and Chile-Falcon (right).

3. COMMUNICATIONS AND NODE SET UP

The primary means of communications between the USAFA CSOC and an individual FTN observatory node is via HTTPS. Additionally, we have one-way VPN capability into the local area network of the FTN observatory to conduct software updates and administrative tasks. Fig. 5 below illustrates the communications scheme. Within the FTN observatory node (Fig. 5 right panel), communication between devices is primarily through USB and Cat-5 cables, and the entire observatory is on its own local area network.

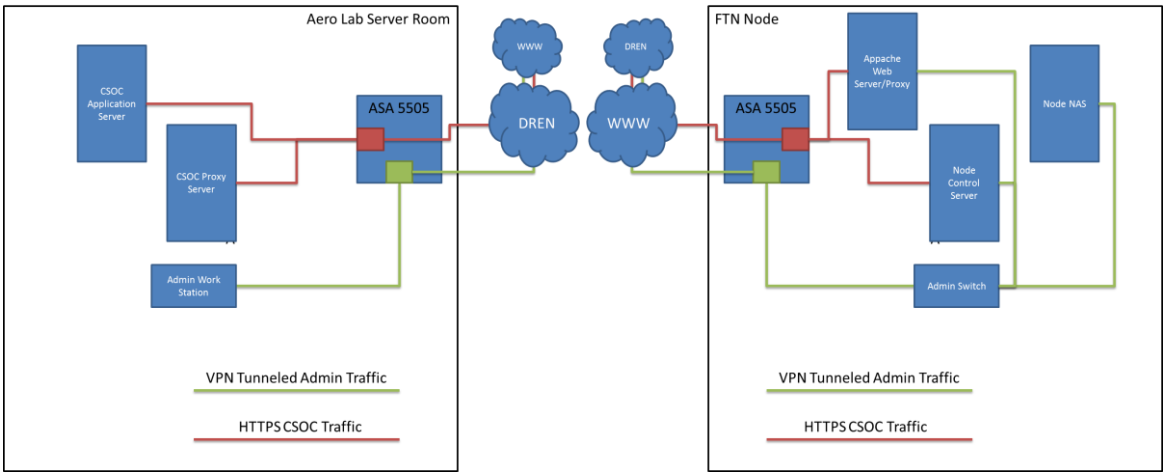

Fig. 5. Communications between the USAFA CSOC (left) and an FTN observatory node (right).

Fig. 6 is the typical arrangement for the various devices at the FTN site, with most of the equipment located within the observatory while a few of the network devices (e.g. router, switch, Linux computer and network attached storage (NAS)) are located in a nearby climate controlled room on site. The devices within the observatory are all connected to uninterrupted power supplies (UPS) either into switchable or non-switchable ports. The devices plugged into the switchable UPS outlets are usually the 12-volt power supply (which controls the camera/filter wheel, telescope controls, and robo-focus), Paramount ME2, the Windows computer and the dome, which allows us to remotely turn on and off these systems. All other devices are kept on and powered.

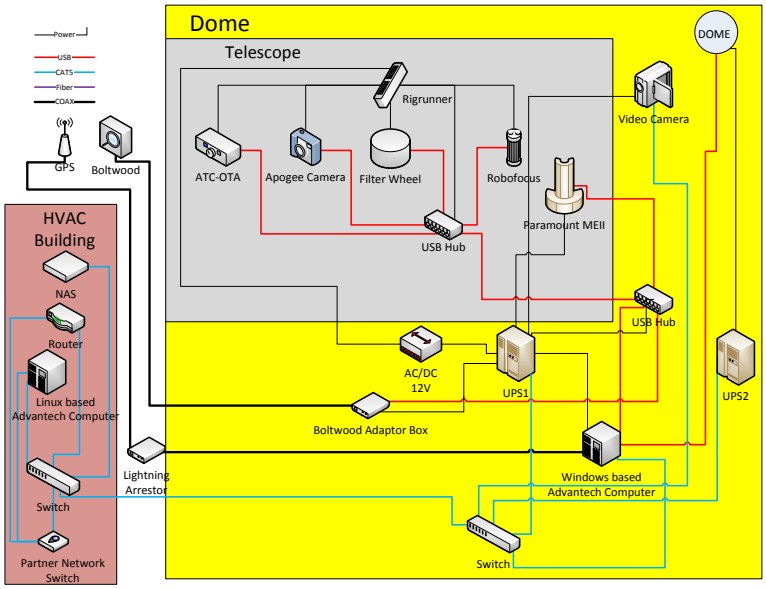

Fig. 6. Typical FTN observatory node setup.

4. SAMPLE IMAGES AND CONCLUSIONS

Fig. 7-10 are sample raw, un-calibrated images taken by the various installed Falcon telescopes. These sample images are of satellites and astronomical objects that support research in those areas as well as STEM outreach, and are examples of the FTN's general use purpose. The images also illustrate the global nature of the FTN allowing USAFA and its educational partners to observe objects that are not visible from their own local sites (i.e. observing the Large Magellanic Cloud which is usually not visible to a northern hemisphere observer).

The Falcon Telescope Network is an ambitious endeavor, but demonstrates the cooperation that can be achieved by multiple educational institutions. We hope to complete the entire network in 2016, but also are striving to complete the command and control services for the active nodes in 2015.

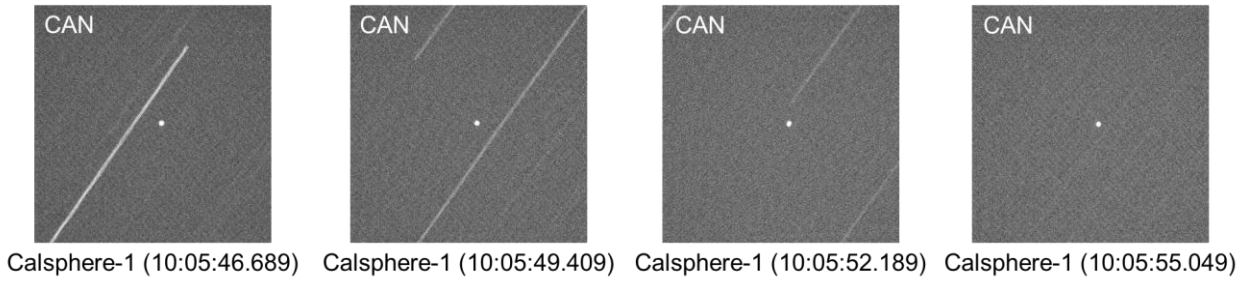

Fig. 7. Sample raw images (no calibration) of low-earth orbiting satellite taken by the Canberra-Falcon.

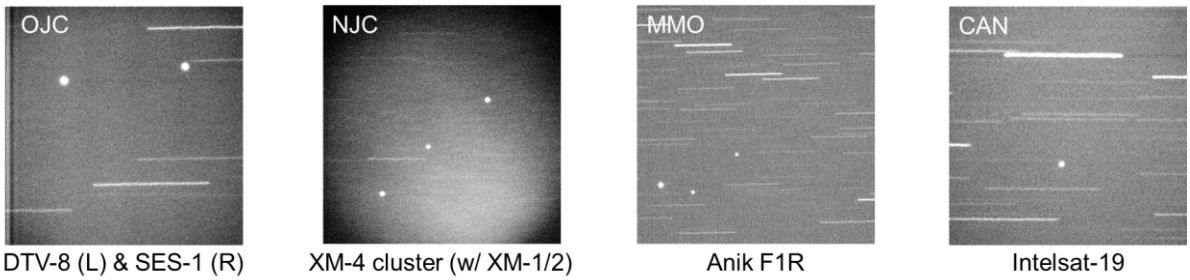

Fig. 8. Sample raw images of geosynchronous satellites taken by the FTN.

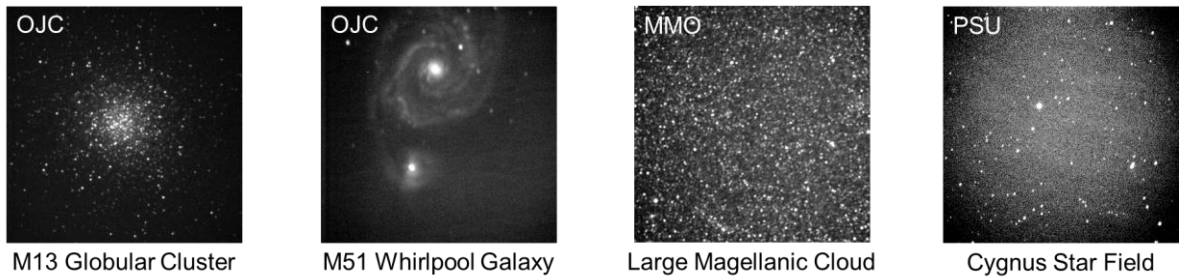

Fig. 9. Sample raw images of astronomical research-type objects taken by the FTN

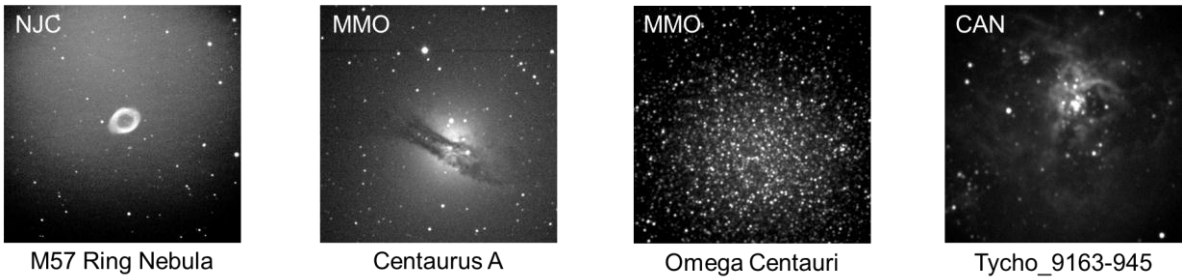

Fig. 10. Sample raw images of STEM objects taken by the FTN

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