The Space Surveillance Research and Analysis Laboratory

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INTRODUCTION

The Space Surveillance Research and Analysis Laboratory (SSRAL) at the Royal Military College (RMC) was founded in 1996 to establish an optical sensor to be used specifically for high altitude satellite tracking. The laboratory began its research into tracking Russian Molniya communications satellites in the summer of 1997 in order to study their high eccentricity orbits. This work spawned other research into the dynamics of satellites, such as determining satellite tumbling periods and orbit decay.

The history of the SSRAL is a short but very interesting one. When the laboratory began, it had virtually no equipment in which to accurately track satellites. As the laboratory grew, it was introduced to technologies that would greatly increase its data output and data precision.

Today, SSRAL has nearly completed the construction of its fully autonomous satellite tracking facility called The Canadian Automated Small Telescope for Orbital Research (CASTOR). In the summer of 2001, Canada will have its first fully automated optical satellite tracking facility.

This is a brief description of the past, present and future of the SSRAL as viewed through the eyes of the senior technician who has worked within the lab since May 1997.

HISTORY

When the senior technician began his new employment at the SSRAL on May 5, 1997, he did not know anything about satellite tracking except for the fact that artificial satellites orbited the Earth and that he could see some of them transiting the sky at night.

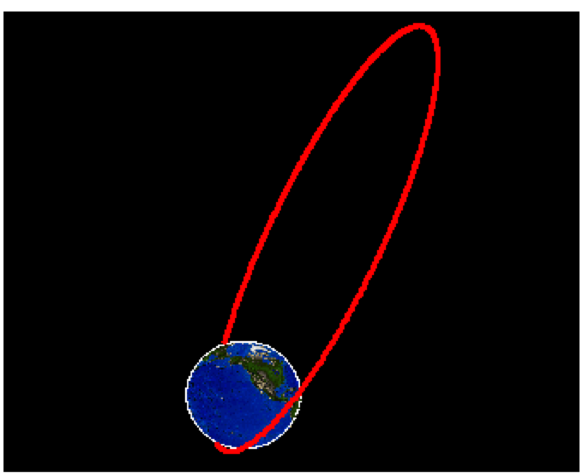
He was, however, a veteran, so to speak, of observational backyard astronomy. He had been vigorously interested in the subject for 20 years.
In May, 1997 the SSRAL had not yet assembled its office furniture which lay in boxes in one corner of the lab. It owned no telescopes in which to track satellites. The only thing it did have was four Sun workstations with satellite analysis software installed on them. The new technician was to learn how to use this analysis software and to use it to analyze data collected by the University of Victoria (UVic). The aim at that time was to determine the orbital characteristics of a satellite using the tracking data.

Very little data was actually taken at Uvic before the satellite tracking project there ran out of funding and closed down. The SSRAL was then left in a quandary over how to proceed. The SSRAL still had no equipment to perform the data collection, but the new technician did. He owned an 8-inch Schmidt-Cassegrain reflector he had been using for ten years. He decided to attempt to see a Russian Molniya satellite from the roof of the Sawyer building at RMC.

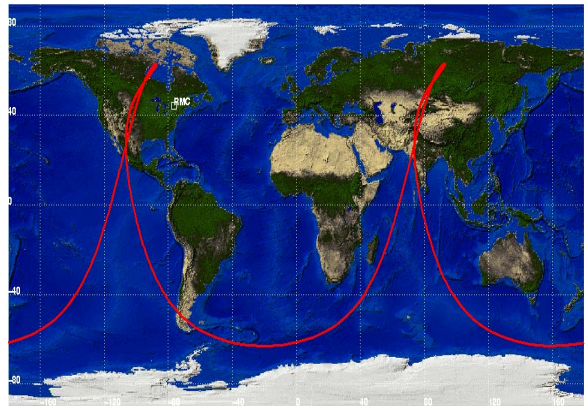
The Molniya satellite is a Russian communications satellite first launched by the Soviet Union in 1965 to provide television, telephone and telegraph services for much of the Russian sub-continent. Its orbit is inclined at 63 degrees to the equatorial plane of the Earth and its orbital eccentricity is generally around 0.7. As a result, the difference between the apogee and perigee of the satellite is substantial. At apogee the satellite can reach altitudes of 40,000km while at perigee the altitude is a mere 400km. This brings the satellite near the altitude of both Mir and the International

Space Station. The high eccentricity of orbit is to ensure that the satellites are well placed over Russia for a large portion of their orbit. They generally stay over the Northern Hemisphere for about 10 hours of their 12-hour total orbit period. Since the Earth turns on its axis once every 24 hours the Molniya satellites orbit twice a day. This means that half the time the satellite is over North America and not Russia. The satellite will alternate between these continents once every day. To those readers who are wondering, some of the Molniya satellites were indeed used as spy satellites during the Cold War.

A typical Molniya satellite has a cylinder of 1.6-meter diameter and 3.4 meter length surrounded by six 5-meter solar arrays. Its mass is 1600 kg. There are currently 73 of these satellites in orbit. Only 25 percent of the still orbiting Molniya satellites are still operational.



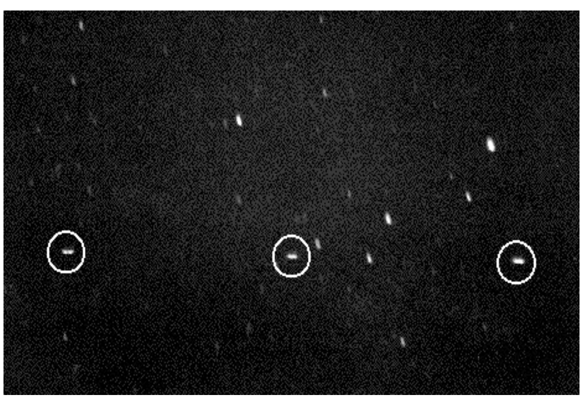
The orbit of a typical Molniya satellite has a 12 hour period, an inclination of 63 degrees to the Earth's equatorial plane and an eccentricity of 0.7. The high altitude at apogee ensures a long observing opportunity for satellite trackers in the Northern Hemisphere.



The ground track of a satellite is the plot of those points where a line drawn from the satellite would intersect the tangent plane on the Earth's surface. In simpler terms, the ground track illustrates all the locations on the Earth's surface where the satellite would appear at zenith of the observer's sky. The ground track of a Molniya satellite is asymmetric due to the high eccentricity of its orbit.

In order to predict where a specific Molniya satellite would be, it was necessary to use the satellite analysis software that SSRAL had at the time, the Satellite Tool Kit (STK). It could generate an ephemeris for an observer's location, but it only generated coordinates in the alt-azimuth coordinate system. The telescope that the technician was using had an equatorial fork mount. It was necessary to do a coordinate conversion from alt-azimuth to equatorial coordinates (R.A. and Dec.). A few months before working at RMC, the new technician had written a program that would do coordinate transformations from equatorial to alt-azimuth coordinates. All that was needed was to make another program that would do the opposite. To cut a long story short, he did manage to accomplish this and make predictions for a few Molniya satellites. At 03:10 U.T.C. on June 15, 1997, he successfully detected the satellite Molniya 3-37 passing through his field of view. The satellite was about 17,000km in range from RMC at the time. Its brightness was estimated to be about 9th magnitude. He detected the satellite again five minutes later to make sure he had seen the right one. The most memorable Molniya satellite seen by this technician was Molniya 1-75. When he first glimpsed this object at 5:00 U.T.C. on July 31, 1997, it appeared to be flashing brightly once every minute. The satellite was actually tumbling and the bright flashes were due to the reflection of sunlight off its solar panels. The brightness of the flashes were estimated to be at around 6th magnitude. Because of the brightness, the color of the satellite could be seen as a brilliant yellow-gold. This satellite was about 40,000km from RMC at the time and could only be seen visually when the flashes occurred. The brightness when it was not flashing had to be greater than 13th magnitude for it to disappear from detection by eye in an 8-inch telescope. A peculiar aspect of the sighting of this object was that it had entered the field of view a full 1 1/2 minutes before the ephemeral predicted time. The next day SSRAL investigated this and discovered that the orbital elements for that particular satellite had not been updated since May 1997. Normally, the orbital elements are updated every day or two. In effect, the satellite had been lost for approximately two months. Quickly, SSRAL contacted the U.S. Space Command at Cheyenne Mountain, Colorado and reported its sightings. The orbital elements for Molniya 1-75 were updated the following day. The SSRAL had successfully done positive work without having taken an image.

The next step was to obtain actual images of a Molniya satellite in orbit. The technician once again set up his 8-inch reflector and mounted his 35mm camera to it at the prime focus. His aim was to obtain images of the Molniya 1-75 satellite that exhibited bright flashes. He had never taken an image of a satellite before. At 06:30 U.T. August 6, 1997 SSRAL obtained its first film images of a Molniya satellite. The flashes were easily seen within the image. Since these were test images, they were not used for analysis. SSRAL now knew it could obtain images of a Molniya satellite provided it exhibited bright flashes like those of Molniya 1-75.



This is one of the first photographs of a Molniya satellite taken at the Royal Military College. Molniya 1-75 appeared to have a flash period of about one minute. The small streaks made by the satellite as it was orbiting the Earth are circled. This photo was taken at about 06:30 U.T. on August 6, 1997. The telescope used was a Criterion 8-inch Schmidt-Cassegrain reflecting telescope with a 35mm camera mounted at prime focus. The exposure time was 5 minutes with Fuji 1600 I.S.O. film. The field of view is 38 by 57 arc-minutes.

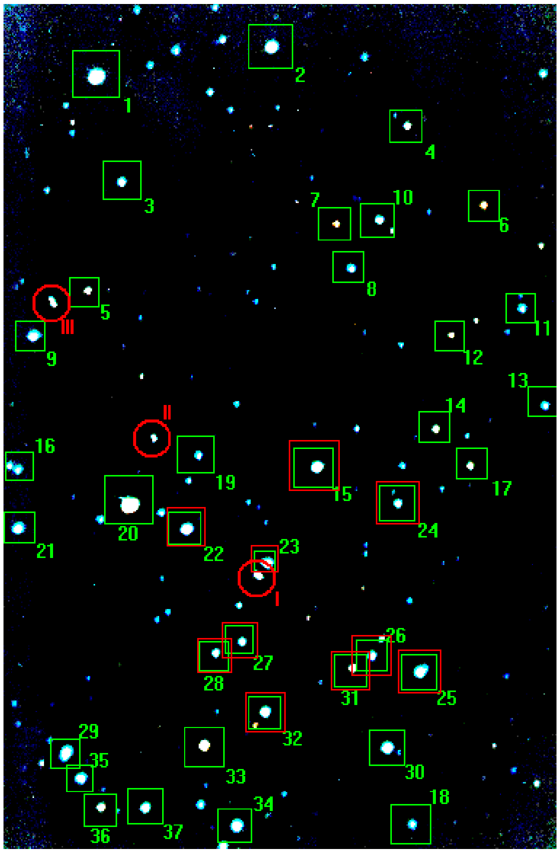
On August 19, 1997, Mr. Phil Somers (one of the founders of the SSRAL) and the technician set up two telescopes on the roof of the Sawyer building to do an all-night visual satellite tracking session of the satellite Molniya 1-75. This satellite had been exhibiting 6th magnitude flashes since it was found by SSRAL. The aim was to gather as accurate data as possible on the satellite's position. Star maps of the predicted positions of the satellite at specific times were created. When the satellite was seen to flash in a specific part of that field of view, the position of the satellite would be drawn on the appropriate star map. This was done every 5 minutes for the entire night. The U.T.C. time of every flash was also recorded. Nearly 100 observations of the satellite were made during this night.

While these observations were being carried out, the satellite's flashing became unusual. Instead of flashing brightly once every minute, every alternate flash was growing dimmer as the night progressed. At the end of the observing session every alternate flash was seen. What this had told us was that Molniya 1-75 had not been tumbling once every minute as had been believed, but every two minutes since we were seeing two different sides of the satellite.

The data that was collected was used to update the orbital elements of the satellite in order to find it again at a later time. That later time was September 4, 1997. At that time film images of Molniya 1-75 would be collected for analysis purposes. From 03:54 to 05:02 U.T. that night, twelve photos were made. The technician analyzed the images using his own astrometry software. The data collected would be used to update the orbital elements of the satellite.

It was obvious that analyzing film images of the satellite streaks was an impractical exercise and that more efficient means of imaging was needed. In January 1998, SSRAL had learned that the astronomy lab had in its possession a Meade 10-inch Schmidt-Cassegrain telescope and an SBIG ST-6 CCD camera that was not being used at the time. SSRAL decided to acquire this equipment to begin investigating the tracking of Molniya satellites using CCD technology. Unlike the technician's 8-inch telescope the Meade 10-inch was stepper-motor driven and could be controlled via a telescope controller assembly.

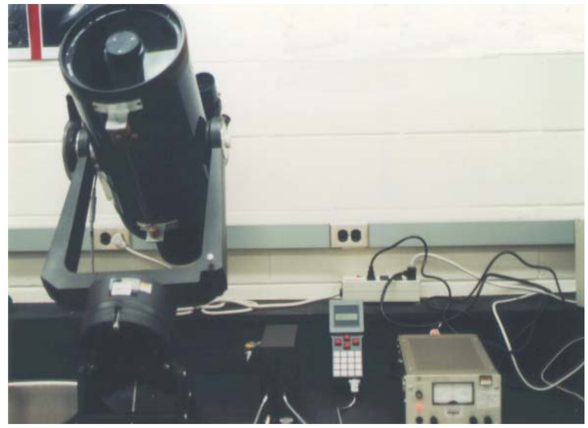
There were obvious advantages to using a CCD camera instead of film. The major advantage was the superior sensitivity of the CCD chip compared to that of film. This would mean that theoretically the CCD could detect more than those satellites that exhibited bright flashes. Another advantage over film was that



The first of twelve images taken of the satellite Molniya 1-75 on September 4, 1997. These were the first images of the satellite that were used for analysis by SSRAL. The satellite is seen inside the red circles. The roman numerals beside the circles denote the order of the flashes in time. The green squares encircle those stars that were used to perform the analysis on the scale of the image (0.37 arc-minutes per mm). The red squares encircle those stars that were used to perform the astrometry on the first flash (I). Astrometry was performed by using every combination of three stars within the ten that were chosen giving 120 combinations in all. This image was a 4 minute exposure on 1600 I.S.O. Fuji film. The telescope used was a Criterion 8-inch Schmidt-Cassegrain. The satellite flashes were approximately 6th magnitude in brightness. Notice how they rival the background stars even though those stars were exposed for 4 minutes while the flashes were exposed for only a few seconds.

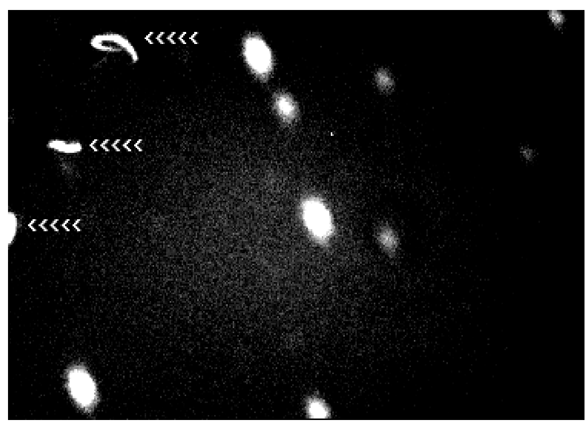
CCD images did not cost money to develop.

The first SSRAL satellite tracking apparatus that employed a CCD camera was used for the first time on February 6, 1998 to track the satellite Molniya 3-10. The telescope was not enclosed in an observatory dome, so the wind had a definite effect on the image quality. The first image did contain a satellite, but the high winds that night had distorted the image. By coincidence, the satellite Molniya 3-10



The Meade 10-inch Schmidt-Cassegrain reflecting telescope is seen with the equipment used to control it. This was the primary satellite tracking system used by SSRAL until its more advanced system went online on January 29, 2000.

also exhibited bright flashes. This was the only reason why SSRAL could detect the satellite in such windy conditions. More practical CCD images of a Molniya satellite (Molniya 1-75) were taken three days later on February 9th. From 00:10 to 04:10 U.T. on that night Molniya 1-75 had been tracked at

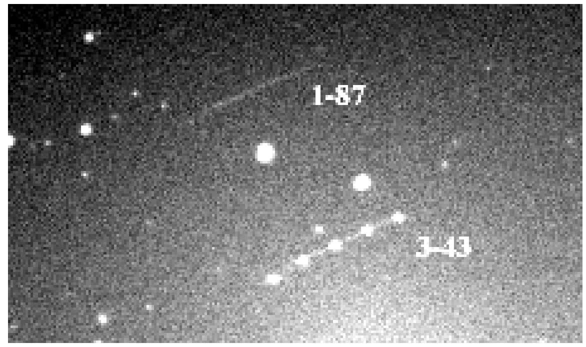


This was the first SSRAL image of a satellite taken with the SBIG ST-6 CCD camera through the Meade 10-inch telescope. The wind had been high that night so the telescope was not as stable as it could have been. The arrows denote the positions of the satellite as it exhibited flashes. The period of the flashes was about 5 seconds. The field of view was 11 by 14 arc-minutes. This image was taken on the roof of the Sawyer Building at RMC on February 6, 1998 from 02:11:30 to 02:12:30 U.T. (60 seconds).

10-minute intervals. A total of 24 images of the satellite had been acquired for analysis. During that tracking run, the satellite had decreased in range from 38,000 km to 13,500 km as the satellite headed for its perigee. As the range decreased the apparent angular velocity increased. As a result, shorter exposure times were needed as the tracking progressed. The exposure time decreased from 60 seconds at 00:10 U.T. to a mere 2 seconds at 04:10 U.T.

The satellite Molniya 1-75 as it appeared at 03:50 U.T. on February 9, 1998. This was number 22 of 24 images taken of the satellite that were first used for analysis. During the CCD exposure the satellite exhibited a brilliant flash of magnitude 6. The satellite was about 16,730 km from RMC at the time and required a 5-second exposure. At that range the satellite could have been seen through the eyepiece easily through an 8-inch telescope and would have been about 8 to 9 magnitude when it was not flashing. The limiting visual magnitude of stars in this image is about 15.

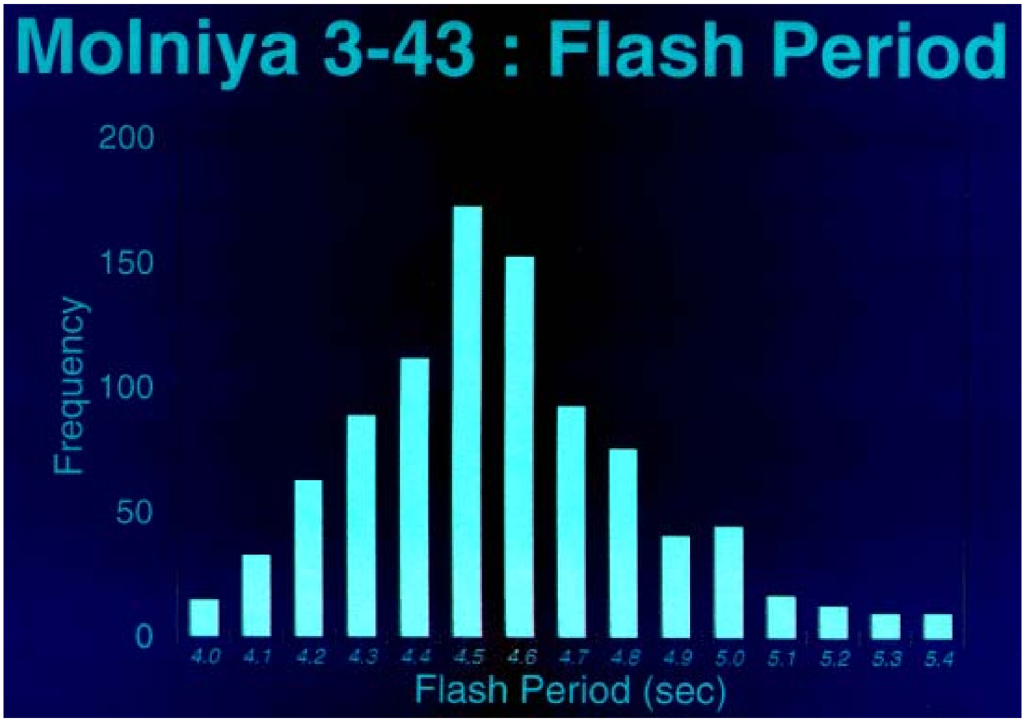
After the initial CCD success with Molniya 1-75, SSRAL set out to do an analysis of how sensitive the CCD camera was with other Molniya satellites over many viewing conditions. During that analysis, SSRAL obtained many images of those Molniya satellites that exhibited flashes with periods much smaller than that of Molniya 1-75. SSRAL began doing tumble analysis of every Molniya satellite it found that exhibited flashes. The most notable at that time was Molniya 3-43. This satellite had been accidentally imaged by SSRAL during routine tracking of the Molniya 1-87 satellite. On April 12, 1998 an all-night tracking session of the satellite was undertaken to provide the data for the most accurate tumble analysis of that satellite to date. A total of 159 images of the satellite were gathered during that night yielding a total of 450 individual flashes. The tumble period was later found using the data collected from the images. The tumble period for Molniya 3-43 was found to be about 4.5 seconds. The tumble analysis was done in a simple way. Astrometry on the streak's endpoints and of each individual flash was carried out. Since the time of exposure was known, the



Molniya 1-87 was being tracked on March 17, 1998 when another satellite appeared in the field of view. Later analysis confirmed this object as Molniya 3-43. It is extremely rare that two Molniya satellites are seen in the same 11 by 14 arc-minute field of view. Molniya 3-43 would be the most analyzed satellite as far as tumble period is concerned because of its easily seen flashes and small flash time. This was a 20-second exposure using the Meade 10-inch reflector and SBIG ST-6 CCD camera at prime focus. This image was taken on April 12, 1998.

angular velocity of the satellite at the time of exposure could be determined by using the coordinates of the endpoints of the detected streak. The angle between subsequent flashes was also determined. Using the angular velocity and the angle between the flashes one could then determine the time between the flashes. A major problem with tumbling satellites is that detection of the endpoints of a streak can be very tricky. If a flash occurs while the CCD shutter is opening and/or closing it is a trivial affair to detect the endpoints. If the satellite is not flashing while the shutter is opening and/or closing however, the brightness could get too low for the CCD camera to detect the satellite. It is for this reason that many images be taken of a tumbling satellite in order to obtain enough data to ensure a good accuracy. Tumbling satellites exhibit much varied light curves since many different sides of the satellite are being illuminated as it tumbles. This could confuse the observer into believing that the satellite is tumbling at a much faster rate than it actually is. To date, fourteen other Molniya satellites have been found to flash and therefore could have their tumble periods determined. The tumble periods range from as low as 3.5 seconds (for Molniya 3-39) to 2 minutes 30 seconds (for Molniya 1-75).

The process of streak detection and astrometry was the most time-consuming aspect of satellite tracking at SSRAL at that time. Streak detection itself was still done manually. Astrometry was done by the Image Reduction and Analysis Facility (IRAF) until January 2000. Even the astrometry was time-consuming in the sense that the manually detected

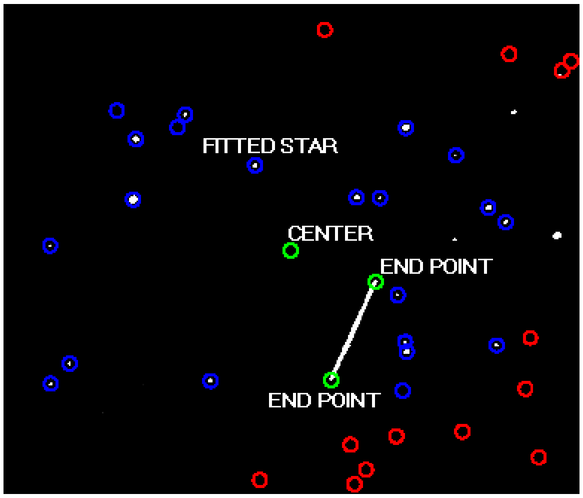


SSRAL's first tumble period analysis results of the satellite Molniya 3-43. This graph was compiled using 450 individual flashes of the satellite captured from 01:04:30 to 08:05:05 U.T. April 12, 1998. The tumble period was about 4.5 seconds. The angular velocity of this satellite's tumble is therefore about 80 degrees per second. Many more Molniya satellites would be discovered to exhibit tumble periods as low as this one. The tumbles generally indicate that the satellite's attitude is no longer being controlled and is in fact inactive.

endpoints had specific image coordinates (X and Y pixel values) that had to be entered manually every time a new image was being analyzed. Normally it would take 3 to 4 minutes to analyze a single image as far as detecting satellites are concerned.

When analyzing an image, the SSRAL would take a specific approach. First, the image was looked over to make sure there was a satellite streak to analyze. If the image contains a satellite streak, the image was then loaded into IRAF. Any object that was not a satellite (such as a faint galaxy, asteroid, nebula, etc.) had astrometry performed on it as well so that if a comet or nova should be discovered the exact coordinates of the object could be reported. The J2000 R.A. and Dec. coordinates of the center of the image were also determined in order to construct an index of images taken of the sky. SSRAL may be requested to provide an image of a certain portion of the sky and therefore it would need a quick reference of its image archive contents. This index contains the coordinates of the center of the image, the year, month, date and time of the exposure, and the name of the satellite(s) contained within the image. The image itself is stored in the SSRAL image archive.

This process would generally take 3 minutes per



Until January 2000 the Image Reduction and Analysis Facility (IRAF) was used by SSRAL to perform the necessary astrometry to determine the coordinates of the center of the image and the satellite streak endpoints. The accuracy of the determined coordinates was within 2 arc-seconds. The green circles are user-defined objects. The red circles denote the Hubble Guide Stars that do not fit the stars in the field of view. The blue stars denote fitted stars.

image if only a satellite streak was being analyzed. The maximum time would be about 10 minutes per image. The data extracted from the images would be used to update the orbital elements of the satellite.

Molniya satellites were tracked regularly throughout the 1998 year. At the beginning of 1999, the SSRAL began to upgrade its facility with remote control and automation in mind.

THE PRESENT

THE CANADIAN AUTOMATED SMALL TELESCOPE FOR ORBITAL RESEARCH (CASTOR)

Before January 1999, the SSRAL had a skeleton satellite tracking facility in the sense that it had the means to track satellites, but it did so impracticably. Steps were taken to upgrade the existing system during 1999. These steps included acquiring a more sensitive CCD camera, a larger aperture telescope, and astronomical software that allowed telescope automation.

SSRAL initially obtained new astronomical software manufactured by Software Bisque called TheSky. This software provided a virtual display of the objects in the sky over RMC, including Molniya satellites. This software could also be used to control the Meade 10-inch scope. Before TheSky was acquired, it was necessary to type in the equatorial coordinates of the object you wanted the telescope to slew to. With TheSky, all that was needed was a point and click onto the object and then another click onto the "slew" command.

The trick was getting the software to communicate with the telescope controller CPU. After one week's worth of work, the technician finally managed to control the telescope with TheSky software. He then could successfully point and click onto a satellite's position in the virtual sky and tell the telescope to slew there. Once there he could obtain an image of the satellite. Before this was done, an image of a satellite could be taken every three to five minutes. After, an image could be taken every two to three minutes. The bulk of the time was the download time of the ST-6 CCD camera (1 minute 30 seconds).

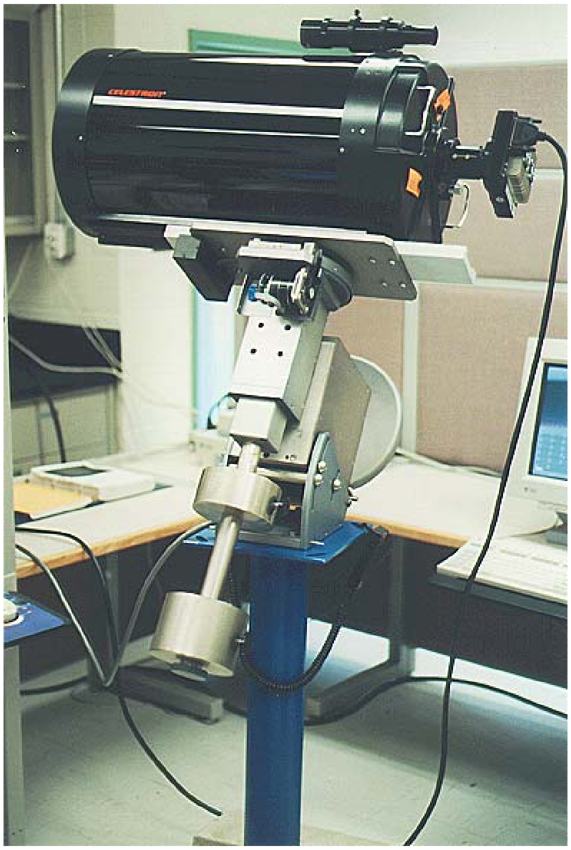
SSRAL received the Celestron 14-inch Schmidt-Cassegrain optical tube assembly in December 1998 and the Apogee model AP-7 CCD camera in May 1999. The CCD camera could be used right away since it could be attached to the Meade 10-inch telescope without difficulty. The new CCD camera had many advantages over the older ST-6. One such advantage was that the Apogee CCD chip was larger (512 by 512 pixels). Another advantage was that the Apogee AP-7 camera had a maximum of 85% quantum efficiency over 600nm to 800nm wavelengths. A definite advantage was that the download time was 10 seconds which was 1/9 the time for the SBIG ST-6 CCD.

The SBIG ST-6 CCD camera was officially retired on May 13, 1999 when the Apogee camera took its first images of the satellite Molniya 3-14. At the time this satellite was undergoing slow orbital decay. SSRAL did get an image of the satellite, but the satellite appeared in the field of view of the camera a full minute after the predicted ephemeris time. This was expected since satellites that are decaying in their orbits have rapidly changing orbital elements. The period of the orbit decreases steadily as the decay progresses.

The Celestron model CM-1400 14-inch Schmidt-Cassegrain reflecting telescope and the Software Bisque Paramount model GT-1100 robotic mount. These two components would be used for the CASTOR facility once preliminary testing in the laboratory had been completed.

The senior technician of SSRAL came up with the CASTOR name in February 1999 after his supervisors had requested that he come up with a name that would suggest a Canadian identity in the space surveillance realm. Several acronyms had been originally thought up, but CASTOR seemed to be the best overall. CASTOR made an excellent acronym (Canadian Automated Small Telescope for Orbital Research) and it is French for beaver (a Canadian symbol). Since the name is French, it also encompasses this bilingual nation. Castor is also a star in Gemini (Alpha Geminorum) and therefore suggests the astronomical nature of the facility.

The summer and fall of 1999 would be a busy time for the SSRAL because of the acquisition and testing of new equipment. The observatory dome that would

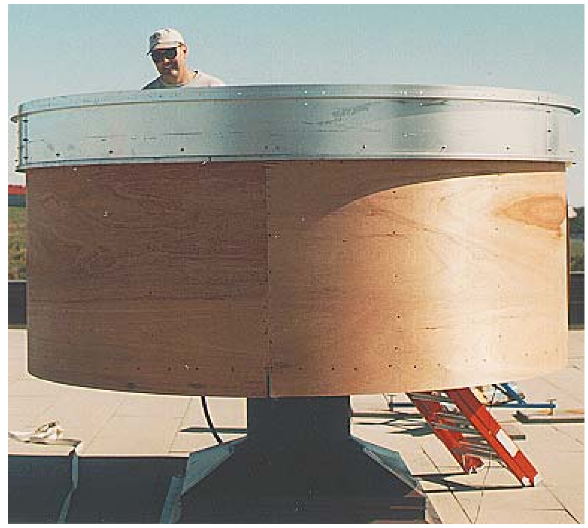


The Celestron 14-inch Schmidt-Cassegrain reflecting telescope and the Software Bisque Paramout GT-1100 robotic mount are thoroughly tested in the SSRAL lab before being sent to the new observatory dome for preliminary night viewing trials. The Apogee AP-7 CCD camera is shown at the prime focus of the telescope.

eventually house the new CASTOR facility had to be assembled and tested and the robotic mount and the CCD camera had to be tested in the lab before they could be used for serious satellite tracking.

The construction of the 10 foot 6 inch diameter observatory dome that would house the CASTOR components had to be planned thoroughly. Mr. Orest Koroluk and Mr. Steve Lockridge, both of RMC, planned and carried out the dome's construction. Thanks to their expertise and professionalism the dome was built by October 1999.

The telescope, robotic mount, and the CCD camera were all brought up to the newly constructed dome in November 1999. Preliminary alignments had to be done, such as proper balancing and polar alignment of the robotic mount and power installation. On December 8, 1999 the CASTOR satellite tracking facility saw first light when Polaris was viewed through a 26mm focal length eyepiece. A preliminary polar alignment was performed using



Mr. Steve Lockridge peeks out from behind the partially constructed CASTOR observatory dome. Mr. Lockridge was a primary planner and builder of the dome and had also built RMC's first observatory dome in 1992.

The finished 10 foot 6 inch diameter observatory dome sits atop the roof of the Sawyer building. Mr. Steve Lockridge constructed the wall cylinder of the dome entirely from scratch and provided the siding for it. The green colour was used to mimic that of copper roofs that adorn the older college buildings.

Polaris so that the telescope could be used on other objects. Jupiter, Saturn and the Orion nebula were viewed that night to initially gauge the tracking accuracy by eye. A Molniya satellite was also viewed through the telescope in order to test the tracking efficiency of the mount. The colour of the satellite

This image of a portion of the lab's clock face was one of the first images taken with SSRAL's new Apogee AP-7 CCD camera. It was necessary to test the camera out in the lab before using it for satellite tracking. The camera was used with a 3-inch Schmidt-Cassegrain telephoto lens. As the second hand of the clock indicates the exposure time was 1 second.

An image of Saturn taken with the CASTOR satellite tracking facility during a preliminary image testing run on December 9, 1999. A 35mm camera was attached to the prime focus of the scope in order to obtain full colour images before the CCD camera was attached. The large focal length of the telescope allowed for a good magnification of the planet even at prime focus. This was a hand exposure of 1/4 second on FUJI Superia 800 ISO film.

was easily detected as a golden yellow, which is the colour of the solar panels of the satellite. The computer link to the robotic mount was tested that night by writing a script that would tell the mount to follow the Molniya satellite to keep it in the field of view. The scripting software called Orchestrate allows the user to automate many processes including the pointing of the scope itself. One night later on December 9, 1999, images of Saturn were taken with a 35mm camera attached to the prime focus of the 14-inch telescope.

The first CCD image of a Molniya satellite was obtained on the same night. The CCD camera did not yet have a cable long enough to reach the lab from the observatory so the controlling computer had to be physically brought up to the dome in order to obtain CCD images. The first CCD images of a Molniya satellite taken with the CASTOR facility were taken at 00:40 U.T. on December 10, 1999. Since the mount was not precisely polar aligned at that time, the stars could not be tracked precisely. Molniya 1-75 was about 35,000 km in range when the first images of it were taken.

Today, the CASTOR facility can be totally controlled from within the lab itself. The facility will be automated as soon as automatic dome control hardware is installed in the fall of 2000. Regular satellite tracking runs are made whenever clear skies

One of the first images of a Molniya satellite obtained with the new CASTOR satellite tracking facility. The trail is dashed because a shutter strobing option was used. Molniya 1-75 was about 35,000 km away from RMC when this image of it was taken.

present themselves. Even in its present state the CASTOR facility has already been used for masters thesis projects and provides accurate satellite tracking data for data analysis in both Canada and the U.S. At present the timing accuracy of the CCD camera is accurate to 1 millisecond. Plans are being made to better this accuracy to 0.1 millisecond. The present accuracy of the astrometry performed on images is about 2 arc-seconds. This will be made more accurate as automated astrometry software is currently being developed by Mr. Phil Somers, formerly of SSRAL but now at the Defense Research Establishment Ottawa (DREO). His image analysis software automatically detects satellite streaks and performs the necessary astrometry. This software should be ready by this fall to be integrated into the CASTOR project.

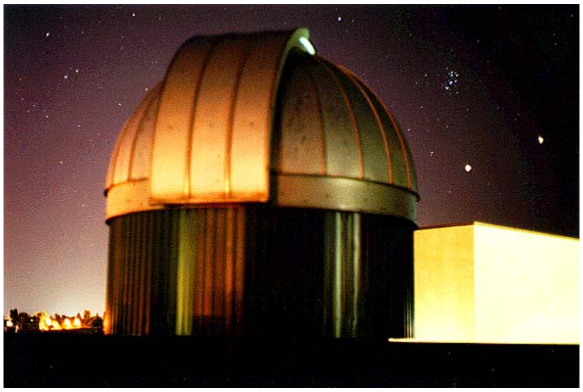
Since there are many satellites to track for a given night, it is necessary to find some way of automating the scheduling process as well. Scheduling involves finding those satellites that are accessible to the facility at a specific time and creating a schedule that would optimize the tracking of these objects. Obvious factors for a satellite schedule are the apparent angular velocity of the satellite, the brightness (phase angle) of the satellite, and the elevation of the satellite above the horizon at different times. A scheduling software has been developed by the senior technician of SSRAL that reads ephemerides of chosen satellites and automatically writes a script for the telescope controller software to follow. The scheduler automatically chooses the exposure time for the satellite based on its range from the facility and its elevation above the horizon (for sight obliquity). This scheduler has been thoroughly tested and it is now ready to be integrated into the CASTOR system for future automation.

The CASTOR project is currently in its research and development stage and the first CASTOR facility in Kingston should be totally automated by the summer of 2001.

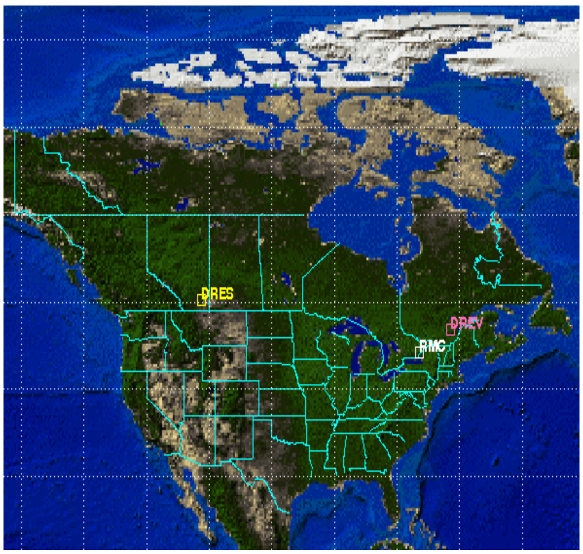
THE FUTURE

The CASTOR facility at RMC in Kingston (CASTOR K) will be the first of three CASTOR facilities located in Canada. The second CASTOR facility (CASTOR S) will be located at the Defense Research Establishment Suffield (DRES) in southern Alberta. The third CASTOR facility (CASTOR V) has been proposed for the Defense Research Establishment Valcartier (DREV) in southern Quebec. The purpose for three facilities is twofold. First, the weather is a major concern for optical telescopes. The probability for overcast skies to prevail in all three facilities is smaller than that of one single facility. Second, satellite tracking data obtained from more than one facility is better than that obtained from a single one. This is mainly due to the fact that data from two or more facilities can be used for parallax determinations of the satellite's range from both facilities. As a result, not only angle data is obtained from the facilities, but range data as well. This improves the orbital determination accuracy and therefore will provide a better ephemeris for finding the satellite at a later time.

These three facilities will be linked via a secure network by a single command center located at the SSRAL. After this link is established the three facilities will be used remotely from the command center. Weather sensors at each site will provide a



The CASTOR K observatory at night near dawn in early July, 2000. The Pleiadies, Jupiter and Saturn are seen just to the right of the dome. CASTOR K will be one of three Canadian automated satellite tracking facilities that will regularly comb the skies for satellites.



The locales of the three proposed CASTOR facilities. The three facilities will provide a wide base for improved satellite accessibility and a better probability for favorable weather.

The senior technician of the SSRAL looks out from the shutter of the CASTOR observatory. The telescopes encircling the dome are some of the many reflecting telescopes that RMC has in its possession for general purpose work such as open houses and undergraduate astronomy labs.

synopsis of the respective facility's sky conditions in real-time.

ASTRONOMY AT RMC

The Royal Military College of Canada has in its possession many astronomical telescopes for general purpose uses such as open houses and undergraduate projects. The Department of Physics currently owns ten five inch Celestron Schmidt-Cassegrain (S-C) reflecting telescopes, two eight inch Celestron S-C telescopes, and a ten inch Meade Quartz S-C telescope that can be controlled by computer via astronomical software.

Apart from the Apogee AP-7 CCD camera used with CASTOR, SSRAL also owns an SBIG ST-6 CCD camera formerly used with the CASTOR prototype system.

Plans are being made for at least three open houses to be held every summer. These open houses are generally for the staff at RMC and RASC members.

RMC also offers undergraduate and graduate degrees in Space Science. See the RMC web site for more details: www.rmc.ca .

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Both of RMC's observatory domes are located on the roof of Module 3 of the Sawyer building. The SSRAL is located just below the CASTOR observatory (the dome on the left). The larger dome (the dome on the right) houses an older 24-inch reflecting telescope that is currently in the process of being restored and renovated. This telescope will eventually be controlled from the RMC Astronomy Lab (located just below the larger dome). The Sawyer building roof sports a dark and unobstructed sky with the added bonus of having power and network facilities.