

Tools for supernovae: Discovery and follow up

Tom Boles

The 2005 Presidential Address, delivered on 2005 October 26 at the Geological Society, Burlington House, London W1

Have you ever wondered what motivates someone to search for supernovae? There is the thrill of discovery of course, but if this were all, you would tire of it very quickly. It takes between three and four thousand patrols to discover one supernova, so it could be very disheartening. To put it another way, between one hundred and two hundred hours' work are needed between each discovery report, not to mention the extra hours that the vagaries of our maritime climate add to that total. I wonder what other branch of observing there can be where, even with a GoTo system, it takes 110 hours to find what you're looking for. Seriously, there has to be something else motivating the observer.

Unless the patrol itself is fun it would seem like very hard work. Patrolling lets you look at a myriad of magnificent galaxies, many of which are recognisable, not by their names or numbers, but by the wonderful patterns that they display on the computer screen.

I am often asked when I visit local societies, 'What did it feel like to make your first discovery?' You might well be able to imagine that feeling, the first time you spot an interloper in a distant galaxy... a new object newly visible... something a few hundred million light years away... and you are the only person on Earth and maybe in the galaxy who knows that it is there. You pause for a few minutes' deliberation enjoying this unique privilege... then you start to record your observation...

Well, I can tell you, it's nothing like that! The first reaction is panic: I've been looking for this for months; what do I do now? How do I know that it is real? What if I'm making a mistake? Somewhere perhaps a two metre telescope might be requisitioned to take a spectrum and prove its type – its very authenticity. If it's false, good telescope time would be wasted and valuable observing time, long awaited and fought over by a young professional astronomer, could be lost.

There are many obstacles in the way if a patroller wants to be as confident as possible before reporting a discovery. I will introduce these and show how to overcome them. In doing this I will also attempt to demonstrate some different things that motivate me and help to keep me enthusiastic about looking for supernovae.

The process of supernova discovery involves three, not so simple, stages. First you find them, then you check and test them and finally you report them. The second of these stages

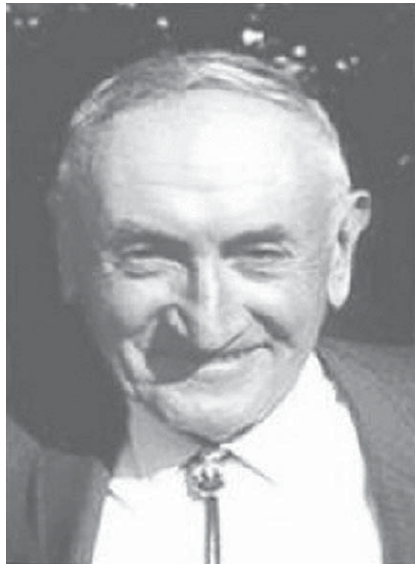


Figure 1. Fritz Zwicky. *Fritz Zwicky Stiftung*.

is the most important; it is here that most suspects are rejected. I will take each of these in order.

Finding supernovae – the first patrols

It would be wrong not to consider who started the first supernova patrol. The first systematic search for supernovae was undertaken by Fritz Zwicky (1898–1974). In total Zwicky (Figure 1) discovered a total of 123 supernovae between 1921 and 1973. In fact it was he who first introduced the name supernova to describe these most energetic of explo-

sions. It was also Zwicky along with Walter Baade who first proposed, in 1934, the existence of neutron stars. This was not long after the neutron itself had been identified. Before Zwicky, only 12 extragalactic supernovae had previously been discovered.¹

Being based mainly at Mount Palomar, I doubt very much if Zwicky would have experienced the frustrations of the climate so familiar to patrollers in the UK, but I do suspect secretly that this famous picture of Zwicky (Figure 2) might have been his feeling after 14 cloudy nights on Mount Wilson.

Zwicky's work, searching for SNe, was pioneering at that time. Although he used the 18" (45cm) Schmidt and eventually the 48" (122cm) Schmidt telescopes on Mounts Wilson and Palomar for his patrols, we also need to remember that he was using conventional chemical films. Some of these were quite primitive in the earlier days. This helps level the playing field when modern methods are considered. Although he enjoyed quality skies and telescopes with high light grasp and wide fields, he did not have the benefit of CCD cameras which as well as their increased sensitivity can produce near instantaneous images without chemical processing.

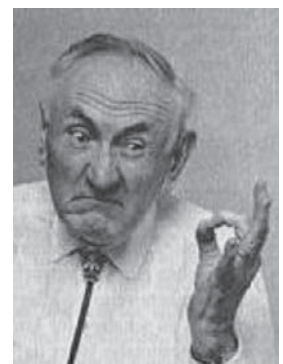


Figure 2. Another image of Zwicky. *Floyd Clark/Caltech*.



Figure 3. UK supernova patrollers. *Top left:* Mark Armstrong; *top right:* Tom Boles; *bottom:* Ron Arbour.

numbers, is the automatic supernova detection software that it uses to analyse the large number of images that are acquired each night. This is proprietary software which they received grants to develop and is for their own in-house use only. Both Filippenko and Li are extremely helpful and cooperative in assisting the UK team to confirm or disprove supernova candidates.

The Puckett team³

Tim Puckett runs a telescope manufacturing business in the US. He has designed and manufactured the telescopes that he uses for his patrol, which are based in some of the better parts of the US weather-wise. Tim uses a system of

Some contemporary patrollers

The UK team

Figure 3 shows our team of regular patrollers here in the UK. It is made up of Boles, Armstrong and Arbour: the names are listed in this order as they are sometimes jokingly referred to as ‘BAA.’ To date, in spite of the British weather and other problems their discovery tally is fast approaching 200. Mark Armstrong and myself both use similar Celestron 14" (35cm) Schmidt–Cassegrain telescopes (SCT) on Paramount German Equatorial mountings. Our choice of CCD camera differs but we use identical software to control the robotic patrolling and image acquisition. Ron Arbour is currently using a 30cm equatorially mounted Meade SCT with Starlight Xpress cameras and home-written software. The picture of Ron shows him with his home-built 60cm reflector which he is developing for future patrols.

Lick Observatory Supernova Search (LOSS) team²

The most productive team by far worldwide is the Lick Observatory Supernova Search (LOSS). This is a team of professional astronomers and undergraduates at Berkeley headed overall by Alex Filippenko. Weidong Li is in charge of the night time operational group. The Lick team discovers between 60 and 85 SNe per year. The search is conducted on the 76cm Katzman Automatic Imaging Telescope (KAIT) using integration times of 30 seconds on a back-illuminated thinned CCD camera. The strength of this team, besides its

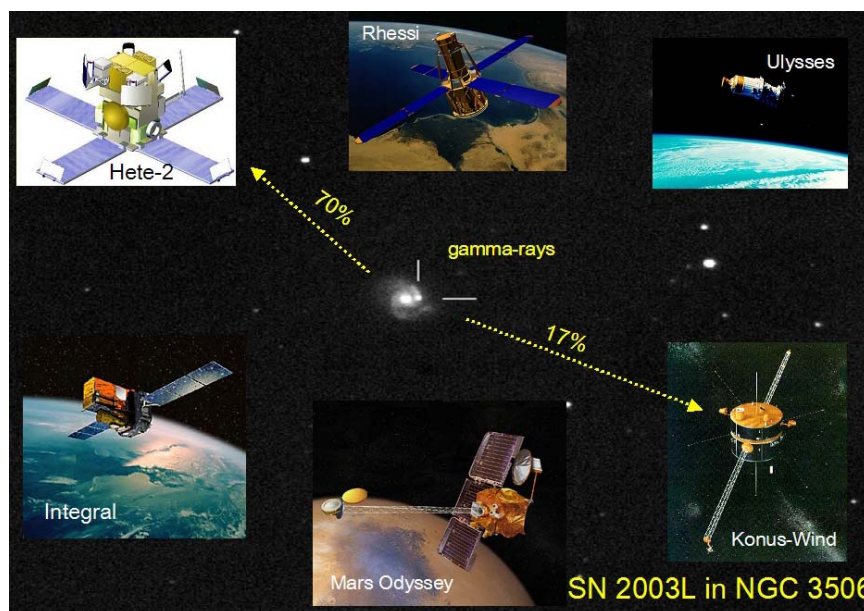


Figure 13. Using the Inter-Planetary Network to make a possible identification of a supernova with a GRB (see page 236). NASA.



Figure 17. SNAP: the SuperNova Acceleration Probe. Lawrence Berkeley National Laboratory.

farming out patrol images to approximately 30 members of his search team who analyse them and report potential discoveries back to him. At the time of delivering this talk Tim had recently broken the 100 barrier, and is now fast approaching his 200th discovery.

Michael Schwartz (Tenagra)⁴

Michael retired from running his own software company and has spent most of his time doing a vast range of astronomical work. From his Tenagra Observatories he does patrol for SNe but they are not his only area of interest. Part of his concept is the hire of internet-controlled telescopes to anyone requiring a remote robotic system. He has purchased and distributed systems similar to those used by Mark Armstrong and myself to places as far away as Australia. Michael means business; his medium term plans are for seven telescopes in the southern hemisphere. Recently Paul Lucas in Perth, Western Australia reported his first discovery with a C14 and Paramount combination, and using Tenagra's Norwegian telescope Odd Trondal has been reporting impressive results for some time.

Other prominent amateurs

Other amateurs who have consistently patrolled over the years have been Masakatsu Aoki from Japan and Doug Rich of the US. Many observers dip into SN patrolling, make a few discoveries and stop or find different interests. Berto Monard of South Africa has had notable success in recent years in patrolling for SNe with his 30cm SCT.

New patrols are being set up every year. The All Sky Southern Supernova Search⁵ is led by Brian Schmidt from Siding Spring in Australia. Brian led the team which raced Filippenko to announce the results from their type Ia supernova research that the expansion of the universe was accelerating. For their patrols they use a camera with an f1 0.5m lens to image large areas of the southern sky. In addition to the LOSS team, this team also has the benefit of automatic detection software to make its image search easier.

No discussion on supernova patrolling would be complete without mentioning the Revd Bob Evans, also in Australia. He has made a total of 46 discoveries to date with the majority of these being made visually using a 40cm reflecting telescope. By memorising star patterns around his selected galaxies he is able to visually patrol around 400 galaxies per night. Evans' method has the advantage that the SNe that he discovers are nearly always bright and useful.

Patrolling: how to find them

Let us first look at image acquisition. If we consider what the objectives of patrolling are, then it is relatively simple to narrow down exactly what we must do. The objectives are to:

- take as many galaxy images as possible when sky conditions allow
- get to as faint a magnitude as possible using an economic integration time
- get the target galaxy at least somewhere on the CCD chip without manual intervention and do it consistently.

Given that these are the three prime objectives for image acquisition then the system we use must be quick, sensitive and accurate. Accuracy can be achieved by investing in a high quality mount. The mount needs to be accurate mechanically and also be able to make use of suitable software for reliable pointing. The best mounts in the world, including the large professional mounts, all suffer from some form of mechanical flexure and misalignment. The software should therefore also incorporate the ability to correct any mechanical inadequacy in the mount.

Sensitivity and speed come from a combination of several factors. Firstly, the pixel size in the CCD camera increases its sensitivity; the larger the pixels, generally the more sensitive is the camera. I say generally because the signal to noise ratio must also be kept under control. This problem increases with increasing pixel size. Another area important to sensitivity is the tracking performance of the mount. Poor tracking results in the image of any star being spread over a number of pixels. This reduces the limiting magnitude that the camera can achieve on any given night.

Crucial to speed is the time taken to get your telescope pointing to each target before the imaging starts. This requires the mount to be fast enough to find the next galaxy and settle within a few seconds of the last image being downloaded. Last and by no means least is the need to control the telescope robotically. This is not a luxury, although I admit it is far easier than doing the pointing manually. Robotic operation increases the speed of the system significantly. It does not tire in the early morning hours, it rarely makes mistakes and it can do multiple tasks at once e.g. an image can be downloaded while the telescope is slewing to the next target. If all these things come together efficiently then the acquisition of images, although technically complex, can be the least onerous of all the patroller's tasks.

There are several commercial packages available to do this and others have been developed privately by separate patrollers and institutions. They all follow similar methods to achieve the required results. I use an integrated package from Software Bisque called *The_SKY*. Other packages work in similar ways but my experience has been with this package. A schematic of this system is shown in Figure 4.

There are three items to be automatically controlled: the mount; the camera and the image filing (saving) system. The process starts on the left hand side of Figure 4 with a program called *Orchestrate*. This is a scripting application which contains a list of galaxies to be patrolled, how long to image them and how much time to allocate to allow the mount to settle. The better the mount, the shorter can be the settling time.

Figure 5 shows a screen shot of *Orchestrate* with the script running. The two left hand columns contain the necessary commands. The columns to the right can be ignored

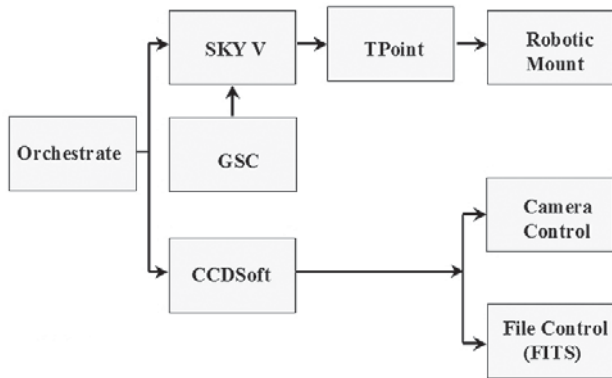


Figure 4. Schematic of patrol system for full robotic operation.

and are there just to show how the function has been completed. There is a very useful command here called, 'ImageThenSlewTo.' This was put in at the request of supernova patrollers to speed up the process. It allows the telescope to slew immediately after the image is taken and before it is fully downloaded.

It can be seen from Figure 4 that *Orchestrator* sends instructions to both the mount and the camera to execute its commands.

The instruction to the mount is to slew to the relevant right ascension (RA) and declination (Dec) of the listed galaxy. These coordinates are acquired from a catalogue which is built into the system. After the RA and Dec are sent from the catalogue they are intercepted by a clever routine called *TPoint*. This is the same software that is used by the major professional observatories worldwide. Its task is to modify the RA and Dec sent to the mount so that errors due to flexure and other predictable errors can be eliminated. *TPoint* takes some time to set up for each system. It involves 'training' the system so that it remembers what errors were made at each altitude and azimuth during the training run. These errors are then cleverly reversed through a set of formulae that can be selected to suit each type of mount.

Figure 6 shows what is available from inside *TPoint*. The first four columns show the errors during the training run. Columns 1 and 2 show the target object's position and columns 3 and 4 show where the scope would point. Column 5

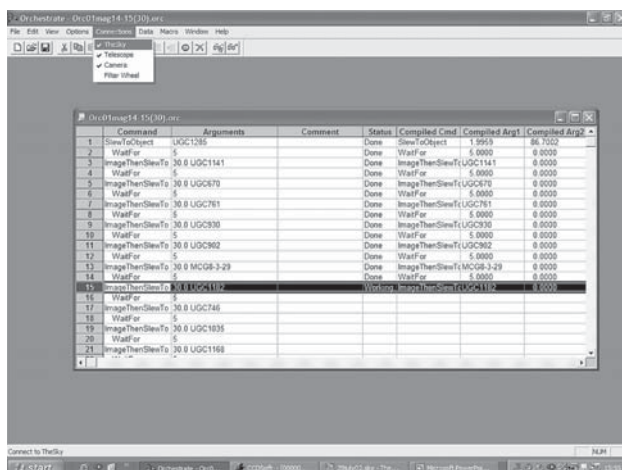


Figure 5. A screen shot from *Orchestrator*. Software Bisque.

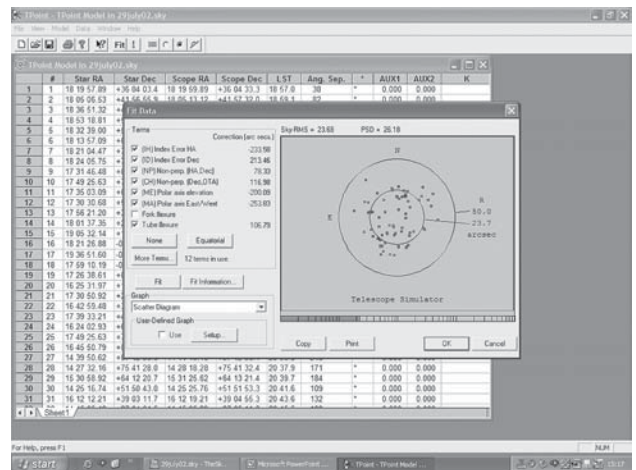


Figure 6. What is available inside *Tpoint*. Software Bisque.

shows the corrections needed for this point in the sky to get the target correctly centred on the CCD chip. The large inset window shows a scatter diagram of the pointing errors of the system after the *TPoint* corrections have been applied. This is quite an impressive result with an error over the whole sky of 26.18 arcseconds (PSD): the check boxes on the left hand side show some of the correction terms being selected to achieve this accuracy. A very nice additional benefit from *TPoint* is that it also provides polar alignment information that tells you how far in arcseconds the polar axis of the mount is away from the pole.

While this is happening, *The_Sky* displays a virtual image of the sky as seen in Figure 7. This shows clearly both the current pointing direction of the telescope (white target circle) and the next selected target (red target circle) During a patrol the circles can be viewed in real time so tracking the telescope and giving some comfort to a remote observer. The meridian is clearly visible, which is important to those using German Equatorial mounts, and the ecliptic, which shows the area where minor planets are likely to infiltrate the images. The inset window gives the name and details of the next patrol target, in this case M74.

After a while the observer learns to have confidence in the equipment's reliability and trusts it to get on with its tasks almost unsupervised. What is always a cause for con-

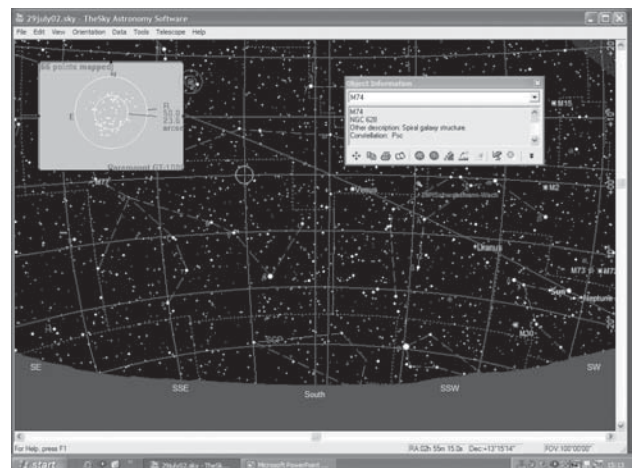


Figure 7. *The_Sky* displays a virtual image of the sky while patrolling. Software Bisque.

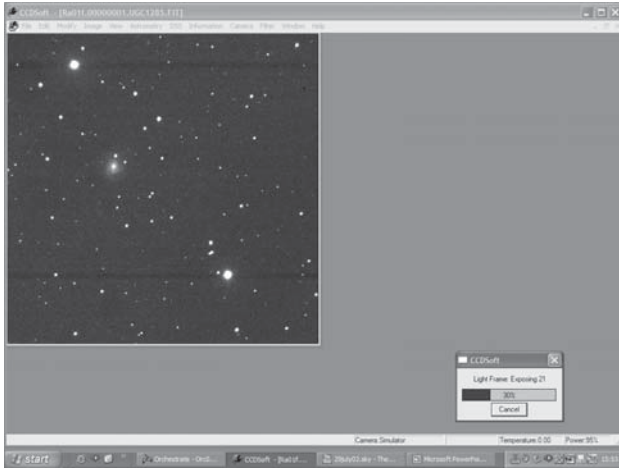


Figure 8. The screen normally on top in *CCDSOft*. *Software Bisque*.

cern is the weather and sudden changes in conditions. It is for this reason that I personally choose to keep the screen shown in Figure 8 permanently visible on all three telescopes. This shows the last image taken and also shows the progress of the next image in the small inset window. I can see from this immediately that the sky conditions are good and that the last slew function has completed successfully, otherwise the camera integration shown in the inset would not have started. From the top of the image you can see the galaxy name and its sequence number in the script that is currently running.

This screen is generated from *CCDSOft*, the camera control application. Its tasks are to trigger the camera shutter and to store the resulting image in a file set up earlier by the observer. This system works well for me and on a good night, using three telescopes, it can store up to 210 images per hour if I am using 30 seconds integration and 135 if I am using 60 seconds. (The reason why the number is not halved for 60 seconds integration is of course because the slew time and mount settling time are the same in each case.) I find 60 seconds the most productive exposure except on the very best of nights.

Checking: how to test them

Finding an apparently new object on a patrol image is far from being a guarantee that a supernova has been discovered. This is true even in cases where the object is embedded well within a galaxy's spiral arms and intuition tells you that it is obviously a supernova. Beware! There are many things to trick the unwary observer. Here are the ones I have discovered so far and the ones that I check for meticulously before any discovery claim is made. I have also summarised in Table 1 how best to eliminate them from the search.

Culprit: Asteroids are a very common cause of false alarms.

These sneak into images any time that you are patrolling close to the ecliptic and even on occasions when you think you are safely far enough away from it.

The things that can mislead the unwary patroller:

- Asteroids
- Cosmic Ray Hits
- Variable Stars
- Some HII and OB Regions (and these change)
- Noise “clumps”
- Old supernovae (already discovered)

Test: The most efficient way to eliminate them, if they are already known, is to work out their positions accurately. If this information is input to the SN Candidate Minor Planet Checker (MPC)⁶ then the culprit will be identified and eliminated without using valuable telescope time. If the MPC software does not identify it then multiple images need to be taken over a period of hours or even the next day if this is your last imaging test, the objective being to have its movement give itself away. If it does turn out to be an unknown asteroid of course you have still made a discovery, but of a different kind. If a discovered asteroid has not yet reached its first opposition the MPC may not report its presence.

Culprit: Cosmic ray hits are extremely frequent. They are caused by stray subatomic particles hitting the CCD chip.

Test: On many occasions these can easily be eliminated visually. Either they are a very sharp spot similar to a hot pixel or they have an unusual shape. I have also noticed that they are frequently double or multiple. In cases where they are ill-defined and might resemble a star the only option is to re-image the galaxy.

Culprit: Variable stars can sneak in anywhere. The type causing problems are those which lie dormant in quiescence for some time then flare up increasing their magnitude many-fold.

Test: There is no 100% test for variable stars as there are many still to be discovered and catalogued. The tests available included looking in catalogues, going through your old patrol archive (I have archived every image ever taken when patrolling), and checking the Digitized Sky Survey II⁷ images. The NED near location search⁸ is also

	MULTIPLE IMAGES	ASTROMETRY	PALOMAR DESHI	LIST OF RECENT SNG	FALSELY REPORTED SNG	MINOR PLANET CENTER	NED NEAR LOCATION SEARCH	ARCHIVED PATROLS	SECOND MASTER
ASTEROIDS	X	X				X			
GAMMA RAY HITS	X								
VARIABLE STARS			X	X		X	X		
HII & OB REGIONS			X	X			X	X	
NOISE CLUMPS	X	X							
OLD SUPRNOVAE				X			X		
WRONG ID FOR GALAXY		X	X				X		

Table 1. The things that can trap an unwary observer, and some problems with the likely solutions.

useful for some candidates. I also keep a list of all historical falsely reported supernovae, some of which were caused by variable stars in the foreground.

Culprit: HII and OB regions in galaxies can be very difficult to eliminate. Galaxies can change their appearance depending on the transparency of the sky. On evenings of low transparency HII regions will appear brighter, due to absorption of blue wavelengths, and on very clear nights the OB regions will dominate as more blue is transmitted. Where these areas are only a few arcseconds across they can be mistaken for new stars.

Test: Again tests are not 100% foolproof. This is a common reason for falsely reported supernovae so checking them out is worthwhile. Colour characteristics of different CCD camera models vary. It is useful to check images from another camera, perhaps using a friend's image as a second master. Failing this the scanned Palomar DSSII plates in red and blue can be a very good guide. If you have been patrolling for several years then your archived images will contain images of the galaxy under many variable sky conditions. These images must be checked. If you have catalogued them well they shouldn't be difficult to locate.

Culprit: Noise clumps are artefacts that appear on nights where the sky conditions are very poor or where the ambient temperature of the camera is higher than normal. These can appear very similar to stars and can display a very good Point Spread Function (PSF)

Test: These can usually be easily eliminated but nearly always require a second image to be taken. Even when this is done coincidence can make noise seem similar to the original appearance. To overcome this either more images need to be taken or astrometry of the suspected star can be done on two or more images to check that its position on all images is identical to within one second of arc and preferably half of one second of arc, unless the evening is exceptionally poor.

Culprit: Old supernovae can lead you on a false trail and of course they pass nearly every test.

Test: If they have been seen before they will appear on the Recent Supernova Page.⁹ This has been extended in recent years and now covers nearly two years. With the increased number of surveys etc discovering supernovae I have now made this the *FIRST* test I do of all suspects. It is one of the quickest and involves no wasted telescope or measurement time. Another source to check is the last patrol that you made of this galaxy. If the suspect is there then you have checked it already. One extra hint here: the circulars reporting supernovae can be very lax when reporting the names of host galaxies, assuming they actually have one. It is therefore a better idea to search on something else than name. I usually use the degree value in the declination field in my FIT header on the image. This helps overcome any ambiguity in naming that can cause a previous discovery to be overlooked.

Culprit: Getting the name of the galaxy wrong when reporting is not really a false supernova, but it will lead to a falsely reported one. This is actually very easy to do if there is more than one galaxy in the field of your image.

The camera header will report the name of the galaxy you tried to find and not necessarily that which contains your suspect. To overcome this I look on the Palomar DSSII plates using a small field of view, usually 3 arcminutes. If you recognise the galaxy then that is fine. If you don't, then put its coordinates, derived from a program like *Astrometrica* into the NED near-position search. It will then identify whatever object is at that point in the sky.

Of course all these checks are meant to eliminate something new that appears on your image. They cannot help to overcome basic human error which is likely to creep in during the small hours of the morning. I have lost much time over the years just through carelessness brought on through tiredness. I have been checking on a 'new' star which is on my master image rather than my new patrol. When you check thousands of images it is easy to get both images mixed up. I always expect to see more stars on a master image because it should be the highest quality image I have taken.

When using say the Minor Planet Checker it is so easy to get wrong coordinates entered or reversed. This could report no known object present when indeed there is one.

The order in which checks are done is important, not to the final result but to the amount of time that you take to eliminate candidates. There will always be more candidates to eliminate than report therefore checking these efficiently is important to your productivity. For example, as mentioned above, I now always check the recent supernovae page first if it is a good candidate. This will most likely eliminate it soonest.

Because of the high chances of making an error during the night, I re-check everything again as soon as I have failed to eliminate a candidate and I will re-check again several times before making a formal report. It is always better to check them in a different order on subsequent checks. This helps to prevent the same errors being repeated through habit. In spite of all this at least minor errors will still happen. The importance of a check list cannot be over emphasised. If you have a routine check list to start with and mark each check off then there is less chance of one being omitted. Do not rely on your memory for anything.

Reporting: How to record them

Anyone starting off would be well advised to work alongside someone else for a while until they gain experience. Either enrol with the Supernova Group of the BAA/*Astronomer* magazine via Guy Hurst, or contact any of the regular patrollers who will be happy to assist. A lot of this sounds daunting but it is not that complicated and with a little guidance it becomes easier and can prevent that first report being a problem one.

When a suspect is first reported there are certain basic things that must be known about it. The time and date of supposed discovery is required, the position in the sky to approximately one arcsecond, (via a program like *Astrometrica*), its approximate magnitude, and the offsets (in arcseconds) from the galaxy's core. These offsets help whoever

will be taking the spectrogram to find the supernova. They also help eliminate the not unknown problem of there being more than one supernova in the same galaxy at the same time. The Central Bureau for Astronomical Telegrams will also want to know the limiting

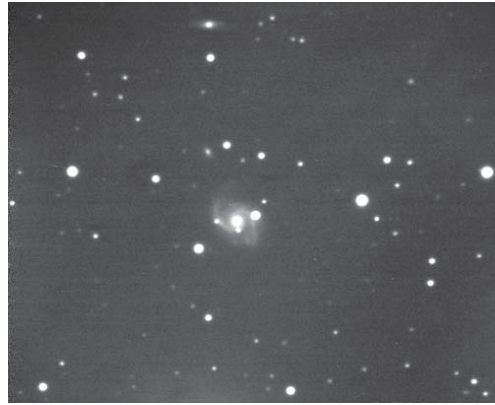


Figure 9. Old friends returning – NGC783 with SN 2004fz. T. Boles.

magnitude of your discovery image and of two or three quality archived images where the object is not visible. It will be necessary to show that you have checked the DSS II red and blue plates, give the dates that they were taken and estimate each plate's limiting magnitude. At this stage your candidate will be recorded but it is unlikely to be announced until a confirmation image is produced on a second night either by yourself or someone else.

Although it will not appear on the formal report, spectroscopists using some of the older telescopes welcome an offset to be calculated from a bright star close to the galaxy. This helps overcome errors in pointing on older telescopes by manually aligning on the bright star first of all.

I use a small *Excel* spreadsheet to do the offset arithmetic. While it is rare that I actually miscalculate the values, I often get the directions of the offsets incorrect. The image coming from a German equatorial does not help to spot this because of 'flipping' at the meridian. In addition, one of my CCD cameras has its chip inserted the other way around.

Even when all these checks are done bad luck can easily get a hold. So always use that checklist. Leave nothing to chance.

Where does the motivation come from?

I would now like to look at what motivates me to continue patrolling. In doing so not only will it explain the triggers that keep me going, but will also introduce many of the tools that are used to follow up and identify supernovae. The thrill of discovery was mentioned earlier and some special occasions can be very powerful. Such occasions would be the first time you make two discoveries on a single night, or as on a recent occasion when four supernovae were discovered with sequential designations.

Old friends returning

By far the biggest motivator, because it is present every observing night, is the pleasure that comes from seeing the

same seasonal galaxies return each year, all 12,000 of them. By this I don't mean the large bright galaxies, such as seeing M51 in the zenith in springtime, but seeing lesser known galaxies which other than the attention they get from we patrollers go largely neglected. Figure 9 shows such an example and not even a particularly minor one. NGC 783 is a small beautiful galaxy which is a pleasure to see each year. If it has a new visitor present as in this case (SN2004fz)¹⁰ then it is an extra bonus.

Great telescopes being used

Pleasure is also derived from the knowledge that many of the world's greatest ground-based optical and radio telescopes and orbiting observatories including the Hubble Space Telescope have been deployed to observe supernovae that one has discovered. It is very motivational to see reports produced showing the follow up observations from these great observatories. Having said that, when I first became interested in astronomy the telescope that fired the imagination, and the largest in the world for some time, was the 200-inch at Mount Palomar. Every library book at that time proudly displayed images of, and taken by, that great reflector. When my discoveries are followed up by the Hale Reflector it therefore gives me a special thrill, even more so than when the follow-up is done by one of the larger twin Keck reflectors or the HST.

SN2003L – a special supernova

Every now and again a supernova is discovered that has some exceptional properties. When this happens a secret dream can be fulfilled: that of making a discovery which results in real science being done that reveals something new about our Universe.

Supernova SN2003L was such a discovery. SN2003L (Figure 10) was discovered on 2003 January 12,¹¹ at magnitude 16.9. It was situated 9".0 west and 1".5 north of NGC 3506, close to its leading western spiral arm.

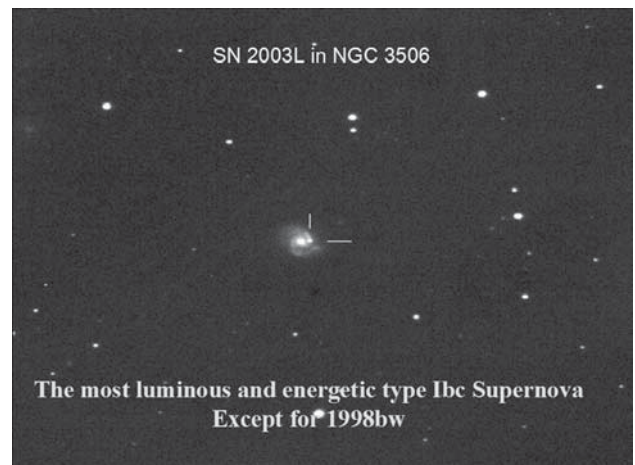


Figure 10. SN 2003L in NGC 3506. The most luminous and energetic Type Ibc supernova yet found, after SN 1998bw. T. Boles.

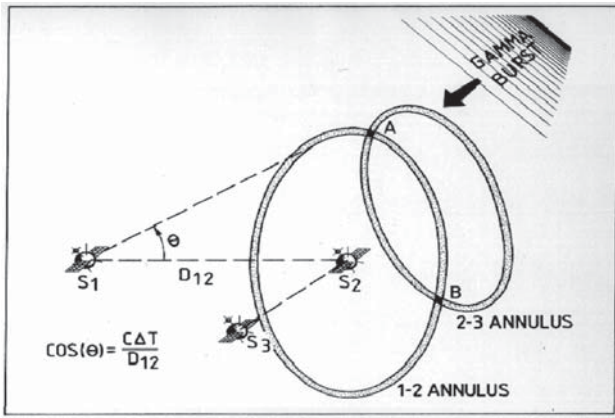


Figure 11. Schematic of the IPN (Interplanetary Network). See also Figure 13 on page 230. NASA.

The KAIT at Berkeley was also patrolling that night and, by good luck, imaged NGC 3506 a short time after the first image was taken from Coddendam. This resulted in two benefits, an independent discovery for KAIT and an almost immediate confirmation for the supernova. This serendipitous event enabled the 1.82 metre Asiago reflector (+AFOSC spectrograph) to obtain a spectrogram,¹² which revealed it to be a type Ic supernova slightly past maximum, with relatively low velocity ejecta.

Type Ic supernovae are of particular interest to radio astronomers, as they can be associated with radio emissions. The Very Large Array (VLA) radio telescope in New Mexico followed up and discovered a remarkably strong radio signal coming from SN2003L.¹³ Interest was now building. It took a quantum leap when the *Chandra* orbiting X-ray observatory detected strong X-ray emissions.¹⁴ These combined observations led Alicia Soderberg to suggest that SN2003L was indeed a hypernova, an exceptionally energetic supernova generated from the core collapse of a higher than usual mass star.

Type Ib/c supernovae are often associated with gamma ray bursts (GRBs). The gamma rays however appear before the optical counterpart is observed and moreover this SN was not discovered until after its optical maximum. There is fortunately a way to attempt to link a supernova with a past GRB event by using the IPN (3D InterPlanetary Network) – this consists of a network of satellites and space probes which are capable of detecting GRBs (see Figures 11 [above] and 13 [p. 230]). By recording the arrival time of the burst at

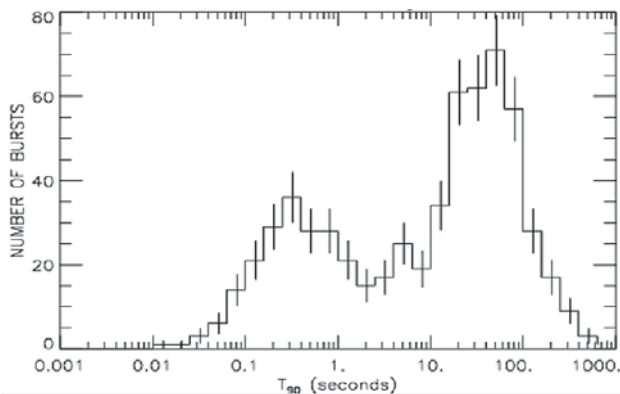


Figure 12. The BATSE satellite identified long and short duration GRBs. NASA.

each satellite/probe and calculating its relative delay at each known location, an error window can be deduced that locates the position of the GRB in the sky.

GRBs are known to come in two types, one having a longer duration emission than the other (Figure 12). Being a type Ic supernova would require the GRB to have a longer pulse since it was associated with a core collapse event.

Two possible gamma ray events were associated statistically with the SN. One came from the *HETE* satellite but this had a probability of 70% of having happened by chance. Another, at a later time, was detected by *Konus-Wind*. The probability looked better with the chance of a coincidental alignment of only 17%. In other words, there was a confidence level of 83% that the super-

nova was associated with this GRB.¹⁵ To improve the confidence level more than one probe has to detect the GRB signal. To ascertain a definite alignment three probes need to make the detection. In this case this was not achieved. However, more was to follow.

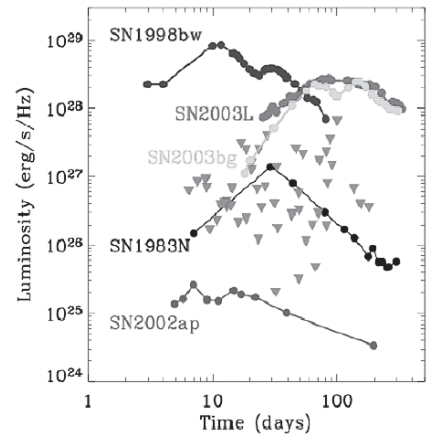


Figure 14. A summary of radio observations of SNe from 1998–2004. SN2003L was a powerful radio source.

Further follow-up observations by Alicia Soderberg on the VLA showed that this was indeed a very powerful radio source. So powerful in fact that it is the second most powerful radio SN ever observed, other than 1998bw,^{16,17} which itself was the counterpart of a recognised GRB (Figure 14). This strengthened the belief that most type Ib/c supernovae are associated with core collapse hypernovae, strong radio and X-ray emission and possibly long duration GRBs. It has also been calculated that given the increased distance of SN2003L relative to 1998bw and the power of its associated GRB, then it was unlikely that given the sensitivity of the instruments in the IPN, any of the network members other than *Konus-Wind* could have detected gamma rays associated with SN 2993L. This would explain the single detection by only *Konus-Wind*.

One thing didn't fit the pattern. SN2003L had a low emission speed for its ejecta as measured by the Asiago reflector. This is incompatible with the current type of central engine believed to be responsible for generating the high energy needed to create the high X-ray and radio emissions and possible gamma rays observed with these events.

The Fred Whipple 6.5 metre reflector followed up with a high resolution spectrogram and confirmed the Asiago findings.¹⁸ The ejecta velocity was indeed much less than required by the current theories (12000 km/s SII). This has led Soderberg to suggest that SN2003L could be a new sub-class of type Ib/c supernovae.¹⁷ Observations of similar events will be necessary to determine this. If true, these low velocity ejecta SNe are only a fraction of the high energy events associated with type Ib/c events, which are

themselves less than 2% of all SNe observed. The proof could therefore take some time.

What does the future hold for patrollers?

Planned projects for the future will bring a mixture of new resources and more competition for the private patroller.

The **Sloan Digital Sky Survey**,¹⁹ using a 2.5m telescope, is currently mapping the sky in multi-wavelengths. Some of these excellent images are already in the public domain and the area of sky covered is continually increasing. This is becoming a marvellous resource. It is far superior to the DSS II images in resolution and has the advantage that, being originally digital, both the faint and bright areas of galaxies can be processed and viewed. (Many of the DSS II scanned images are burned out near the galaxy cores.) In a competitive sense SDSS has recently started to report many newly discovered supernovae. Many of these are much fainter than most patrollers reach but a few are not.

The **Supernova Integral Field Spectrograph** (SNIFS)²⁰ (Figure 16) is currently attached to the 88-inch (2.2m) telescope at the University of Hawaii. This is a really advantageous resource. The challenge after every discovery is to get a spectral signature from each supernova to define its age and type as soon as possible. SNIFS helps greatly in this area. It is operated by the Supernova Factory and as such, it tends to give priority to their discoveries, but having said that, it has also recently analysed other discoveries including mine. Whether it does so or not it is useful in that it relieves the load from other telescopes and frees them to obtain spectrograms of other candidates. In the last 12 months the speed at which spectra have been obtained has increased in spite of the greatly increased number of teams searching for SNe.

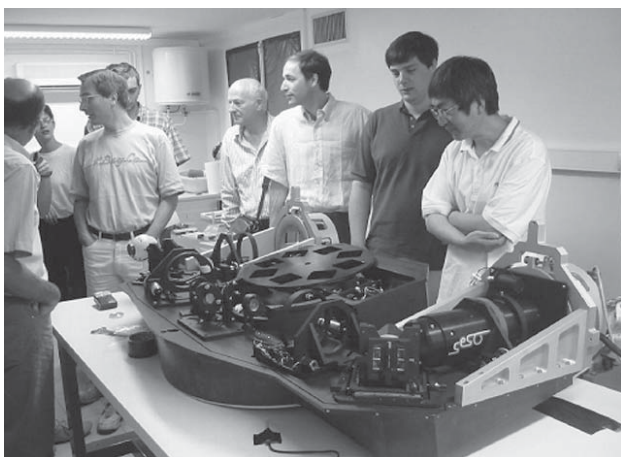


Figure 16. SNIFS: the SuperNova Integral Field Spectrograph. SNFactory.

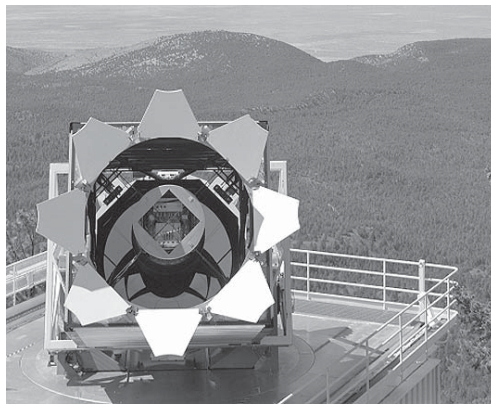


Figure 15. The 2.5m survey telescope of the Sloan Digital Sky Survey in New Mexico. SDSS.

When the **Supernova Acceleration Probe** (SNAP)²¹ (Figure 17, page 230) is released it will make a significant impact on the rate of supernova discovery. This is a 2m, 3-mirror system with a 0.7 degree imaging field, which is around 15 times larger than most patrollers use today. There are two CCD detectors sharing the focal plane, one of which (HgCdTe) is optimised for infrared wavelengths. This will enable it to see further back in time and also detect some other possibly invisible SNe. Its objective is to discover around 2000 type Ia supernovae between $z = 0.1$ and 1.7.

If you recall the diagram in Figure 18 from my first Presidential Address²² you will see the predicted SNAP results superimposed on it. The error ellipse is so small that it will eliminate any doubts about the acceleration of the Universe if it performs as designed.

It will of course discover every other supernova within its field of view and anything else that trespasses too. It will scan its area every four days, quite a strong programme. It will mainly be searching the polar area. If it is still operational after the initial project is complete then it may well be assigned to other areas of the sky.

Pan Starrs, the **Panoramic Survey Telescope and Rapid Response System**²³, currently being developed at the University of Hawaii, is by far the most aggressive future project. It will be a 3.6m telescope (4×1.8m mirrors) with a limiting working magnitude of 24. It is expected that it will reach magnitude 29 by subsequently stacking its best patrol images. It has an enormous field of 7×7 degrees. This is achieved by the use of a huge CCD array, made up of 1,000,000,000 pixels. This measures 40×40cm, or nearly 16 inches square. It will be capable of imaging 6000 square degrees in an eight hour night. Moreover

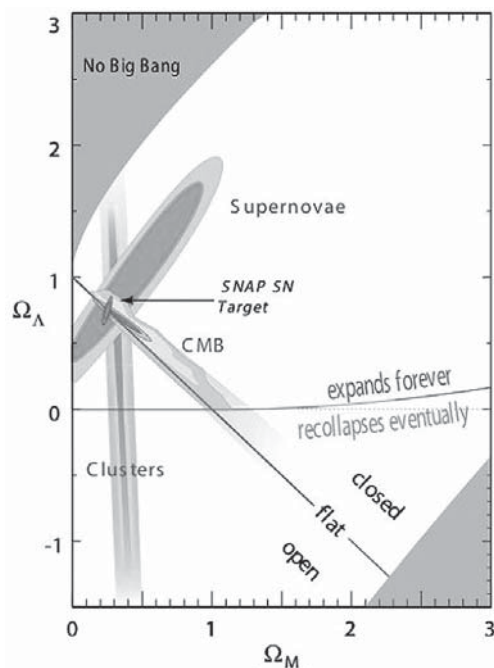


Figure 18. SNAP objectives superimposed on a cosmological diagram of the age of the Universe. Lawrence Berkeley National Laboratory.

it is designed to have a resolution of 0.07 arcseconds, which is achieved by using the orthogonal transfer feature of its CCD chip as an adaptive optics system. This is an earth-based system and will not suffer the maintenance problems associated with telescopes in space. As of February 2006, the first prototype 1.8m mirror was still waiting to be installed. First light is now expected later this year.

What is the limiting factor now?

As far as patrolling for new objects is concerned, both for supernovae, novae and asteroids, the limiting factor will always be quality software. It is (relatively) easy to build mechanical parts for systems which will work consistently as designed. The same is not true for image comparison software. The sky changes its properties from hour to hour. The simple point spread function (PSF) of a star, which is the way that its light displays an ideally normal (statistical) distribution about its point source, can vary from minute to minute. Writing efficient software to do this in a reliable way is very difficult, and despite claims, I do not think that this has been 100% reliably accomplished. Some teams have excellent software. The KAIT is one. Weidong Li has developed their software to be amongst the best in the world. Although it is exceptionally good I do know that it can miss some difficult candidates. The poorer skies in the UK would make even good software fail more often.

Ideal software would be able to find the master image automatically; align it with the patrol image, then automatically detect any suspects and raise an alarm. The best compromise for conditions that we experience in the UK would be to have an application that would automatically find and align the two images, blink them and allow some degree of manual processing to each image, and then still rely on the human eye to detect changes in the image. After this all the standard checks would need to be completed in the usual way.

Let me finish on a High!

Dominic Ford, our BAA Meetings Recorder, has developed an application which does exactly that. His program can open two folders, one for master images and the other for patrol images; it can automatically align them, blink them and allow the user to vary either the brightness of the master or patrol or both together. This program saves a tremendous amount of time. I have been using it continually since it became available. Not only is time saved but fainter suspects can be spotted than by simply comparing two static images on the screen.

The program is called *GrepNova*. Dominic is happy for you to use it free of charge from his website²⁴ but would like to hear what you achieve with it. *GrepNova* was originally intended for use with FITS format images but recently it has

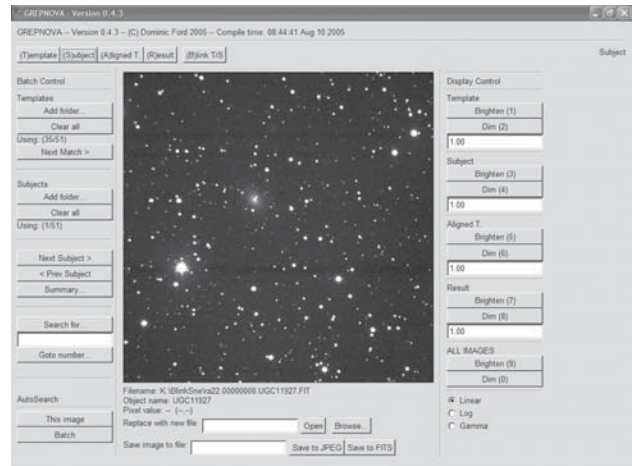


Figure 19. *GrepNova*, now available to patrollers. Dominic Ford.

been extended to cover other formats as well. Figure 19 shows the various control keys, which are quite intuitive to use.

Supernova patrolling has changed greatly since Fritz Zwicky first became involved in 1921. Technology has improved as has the control software. In the meantime skies have deteriorated and competition from professional surveys has increased. It will be interesting to see what the next 20 years will bring. I don't look forward to the day when my telescope can wake me up to tell me it has completed the entire process and even sent off the discovery report automatically. In the meantime, I'll continue to curse full moons and cloudy skies.

Address: Peel House, Coddendam, Suffolk IP6 9QY. [tomboles@coddenhamobservatories.org]

References

- 1 <http://cfa-www.harvard.edu/iau/lists/Supernovae.html>
- 2 <http://astro.berkeley.edu/~bait/kait.html>
- 3 <http://www.cometwatch.com/>
- 4 <http://www.tenagraobservatories.com/>
- 5 <http://www.mso.anu.edu.au/~salvo/snsearch.html>
- 6 Minor Planet Checker: <http://scully.harvard.edu/~cgi/CheckMP>
- 7 http://archive.stsci.edu/cgi-bin/dss_form
- 8 <http://nedwww.ipac.caltech.edu/index.html>
- 9 <http://cfa-www.harvard.edu/iau/lists/RecentSupernovae.html>
- 10 *IAUC* 8437 & 8440
- 11 *IAUC* 8048
- 12 *IAUC* 8057
- 13 *IAUC* 8061
- 14 *IAUC* 8073
- 15 *GCN* 1939
- 16 Soderberg A. M. *et al.*, *Ap.J.*, 621 (Issue 2), 908–920 (2005)
- 17 *IAUC* 6895
- 18 *GCN* 1846
- 19 <http://www.sdss.org/>
- 20 <http://snovae.in2p3.fr/doc/plot/snifs/status/>
- 21 <http://snap.lbl.gov/>
- 22 Boles T., *J. Brit. Astron. Assoc.*, **115**(4), 197–207 (2005)
- 23 <http://pan-starrs.ifa.hawaii.edu/public/>
- 24 <http://www.jcsu.jesus.cam.ac.uk/~dcf21/astronomy.html>

Other useful websites

- 2MASS All sky Survey: <http://www.ipac.caltech.edu/2mass/releases/second/index.html>
ESO Digital Sky Survey: <http://archive.eso.org/dss/dss/>
USNO Images and catalogue: <http://www.nofs.navy.mil/data/fchpix/>