particular Claire Moutou, Merieme Chadid, Emmanuel Jehin, Herman Boehnhardt and Ricardo Scarpa. Géraldine Letawe is a teaching assistant supported by the University of Liège, Belgium. Frédéric Courbin acknowledges financial support through Chilean grant FONDECYT/3990024 and from the European Southern Observatory. Marie Curie grant MCFI-2001-00242 is also gratefully acknowledged.

References

Alloin, D., Galliano, E., Cuby, J.G., 2001, *A&A* **369**, L33.

Bahcall J.N., Kirhakos S., Saxe D.H., Schneider D.P., 1997, *ApJ* **479**, 642.

Boroson T.A., Persson S.E., Oke J.B., 1985, *ApJ* **293**, 120.

Canalizo G., Stockton A., 2000, *ApJ* **528**, 201.

Chatzichristou E.T., Vanderriest C., Jaffe W., 1999, *A&A* **343**, 407.

Courbin, F., Letawe, G., Magain, P., et al. 2002, in preparation.

Courbin F., Magain P., Kirkove M., Sohy S., 2000a, *ApJ* **539**, 1136.

Courbin F., Lidman C., Burud I., et al. 2000, *The Messenger* **101**, 17.

Courbin F., Magain P., Sohy, S. et al. 1999, *The Messenger* **97**, 26.

Crawford, C. S., Vanderriest, C., 2000, *MNRAS* **315**, 433.

Disney M.J., Boyce P. J., Blades J. C., 1995, *Nature* **376**, 150.

Hammer, F., Sayède F., Gendron, E., et al. 2002, astro-ph/0109289, in press in *Scientific Drivers for ESO Future VLT/VLTI Instrumentation.*

Kennicutt R.C., 1992a, *ApJS* **79**, 255.

Kennicutt R.C., 1992b, *ApJ*, **388**, 310.

Lidman C., Courbin F., Kneib J.-P., et al. 2000, *A&A* **364**, L62.

McLeod K.K., Rieke G.H., 1995a, *ApJ* **454**, L77.

McLeod K.K., Rieke G.H., 1995b, *ApJ* **441**, 96.

McLeod K.K., Rieke, G.H., Storrie-Lombardi, L.J., 1999, *ApJ* **511**, L67.

McLure R. J., Kukula M. J., Dunlop J. S., et al. 1999, *MNRAS* **308**, 377.

Magain P., Courbin F., Sohy S., 1998, *ApJ* **494**, 452.

Magorrian J., Tremaine S., Richstone D., et al. 1998, *AJ* **115**, 2285.

Marco, O., Alloin, D. 2000, *A&A* **353**, 465.

Percival W. J., Miller L., McLure R. J., Dunlop J. S., 2001, *MNRAS* **322**,843.

Stockton A., Canalizo G., Close L., 1998, *ApJ* **500**, L121.

Trager S.C., Worthey G., Faber S.M., et al. 1998, *ApJS* **116**, 1.

Wisotzki L., Christlieb N., Bade N., et al., 2000, *A&A* **358**,77.

The Crab Pulsar and its Environment

J. SOLLERMAN (ESO, Stockholm Observatory) and
V. FLYCKT (ESO, Luleå University of Technology)

1. Introduction

The Crab Nebula is a supernova remnant. The supernova exploded in 1054 AD, and was monitored by contemporary Chinese astronomers (see e.g., Sollerman, Kozma, & Lundqvist 2001). Today the nebula offers a spectacular view, with a tangled web of line-emitting filaments confining an amorphous part ghostly shining in synchrotron light. The beauty of the Crab makes it repeatedly appear in PR pictures, even from a southern observatory like the VLT (Fig. 1).

Figure 1: The VLT (UT2 + FORS2) view of the Crab nebula. A composite of images in B(blue), R and S II(red), taken in November 1999 as part of commissioning. ESO PR photo 40f.

At the heart of the nebula resides the energetic 33-ms Crab pulsar. This $m_V \sim 16$ object actually powers the whole visible nebula. The Crab nebula and its pulsar are among the most studied objects in the sky. This astrophysical laboratory still holds many secrets about how supernovae explode and about how pulsars radiate and energise their surrounding nebulae.

A main theme for pulsar research has been to understand the emission mechanism for the non-thermal pulsar radiation. This is still to be accomplished. No comprehensive model exists that can explain all the observed features of the radiation. Observationally, only recently was a broad range UV-optical spectrum of the pulsar published (Sollerman et al. 2000). We have now extended the study into the infrared (IR).

But even if most of the research on the Crab pulsar has concerned the radiation mechanism, almost all of the spin-down energy actually comes out in the particle wind. This is the power source of the Crab nebula. The stunning image of the pulsar environment obtained with CHANDRA (Fig. 2) captures a glimpse of the energetic processes at work. Direct evidence of the pulsar activity has long been seen in the system of moving synchrotron wisps close to the pulsar itself.

The detailed study of the wisps was started by Scargle (1969) using observations obtained before the authors of this article were born. Hester et al. (1995) used the HST to study the wisps at higher resolution, and presented their observations as the spectacular 'The Crab Movie'[1], where the constant activity in the region around the pulsar is highlighted.

The most stunning discovery in these HST images was the knot sitting just 0.6 arcseconds from the pulsar. At 2 kpc this amounts to a projected distance of only 1000 AU. Hester et al. interpreted this feature as a shock in the pulsar polar wind. Our IR observations also allowed us to have a look at these manifestations of the magnetic relativistic wind from the pulsar.

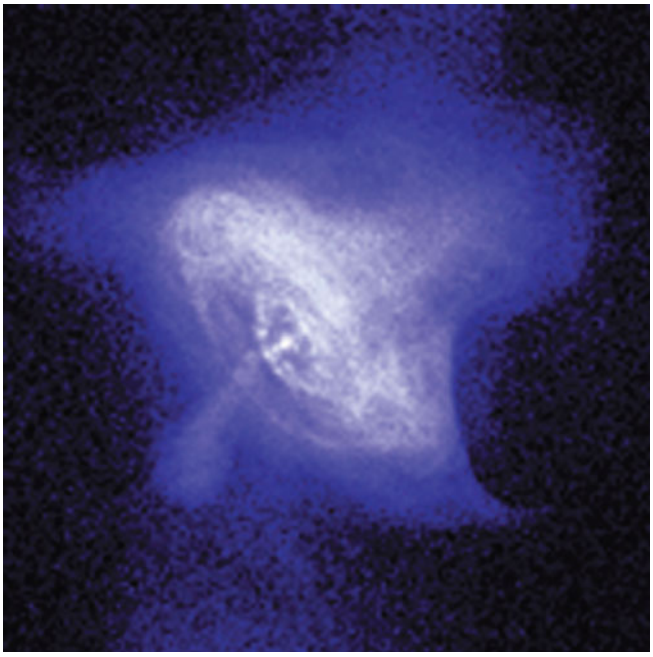

Figure 2: The CHANDRA X-ray view of the pulsar. The spectacular torus and a long jet is clearly seen in this space-based 45-minute exposure from August 1999. The field of view is 2.5 arcminutes. With some imagination, the same structures can be seen in the VLT 5-minute B-band image (Fig. 1). Photo NASA/CXC/SAO.

2. IR Photometry, Reductions and Results

IR imaging in the short wavelength (SW) mode of ISAAC was obtained in service mode on the VLT on October 13, 2000. The exposures were taken in *Js*, *H* and *Ks* with a total exposure time of 156 seconds per band. The main goal of these short exposures was to properly calibrate our IR spectroscopy. However, the image quality provided by Paranal also allowed a detailed view of the central region of the Crab nebula. The near-IR images are displayed next to each other in Figure 3.

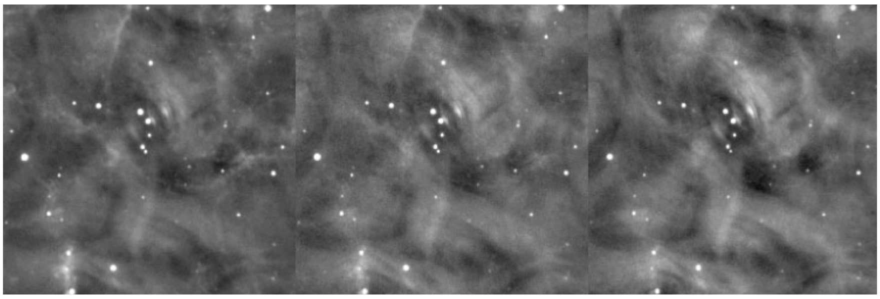

Figure 3: The central part of the Crab nebula in the infrared, Js, H and Ks. Observations with ISAAC on 13 October 2000. The pulsar is the lower right (South Preceding) of the two bright objects near the centre of the field.

Photometry was obtained of the Crab pulsar and some of the stars in the field using PSF-fitting (DAOPHOT). We estimate that our magnitude measurements of the pulsar are correct to about 0.05 magnitudes.

In Figure 4 we plot our measurements as de-reddened fluxes together with the optical-UV data from Sollerman et al. (2000). We note that our IR fluxes deviate significantly from the most recent results published by Eikenberry et al. (1997). Our measurements give a fainter pulsar by some 0.3 magnitudes.

The pulsar magnitudes of Eikenberry et al. agree with those in the 2MASS point source catalogue. As our relatively isolated standards in the field show good agreement with 2MASS, we do not think the difference in pulsar magnitudes is due to an offset in the zero-point. Instead, our measurements of the Crab pulsar agree well with previous time-resolved photometry of the Crab (Penny 1982; Ransom et al. 1994). Such measurements generally use a large aperture and simply assume any non-varying contribution to be due to the background. By integrating under the pulsar light curve, they measure only the pulsating contribution of the flux. Our ISAAC photometry has excellent signal and image quality. In the complex region around the pulsar, this significantly improves the background subtraction. In particular, PSF subtraction excludes contributions from

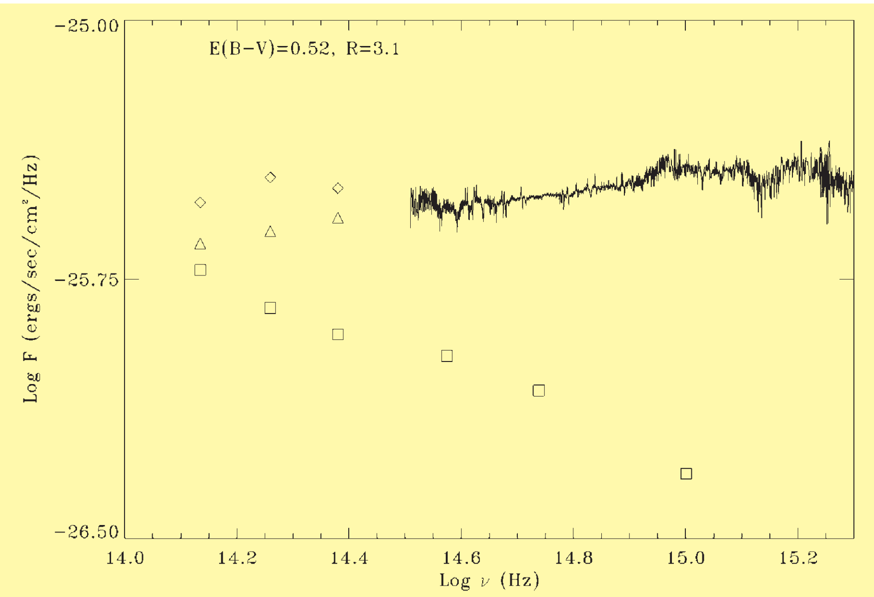

Figure 4: Spectral energy distribution of the Crab pulsar. The optical and UV data are from Sollerman et al. (2000). The diamonds show the IR flux as published by Eikenberry et al. (1997). The triangles are our new ISAAC measurements. Also shown (squares) are the fluxes of the knot, here multiplied by a factor ten. The optical data for the knot is from HST. All observed fluxes were de-reddened using R = 3.1 and E(B – V) = 0.52 (Sollerman et al. 2000).

[1]http://oposite.stsci.edu/pubinfo/pr/1996/22.html

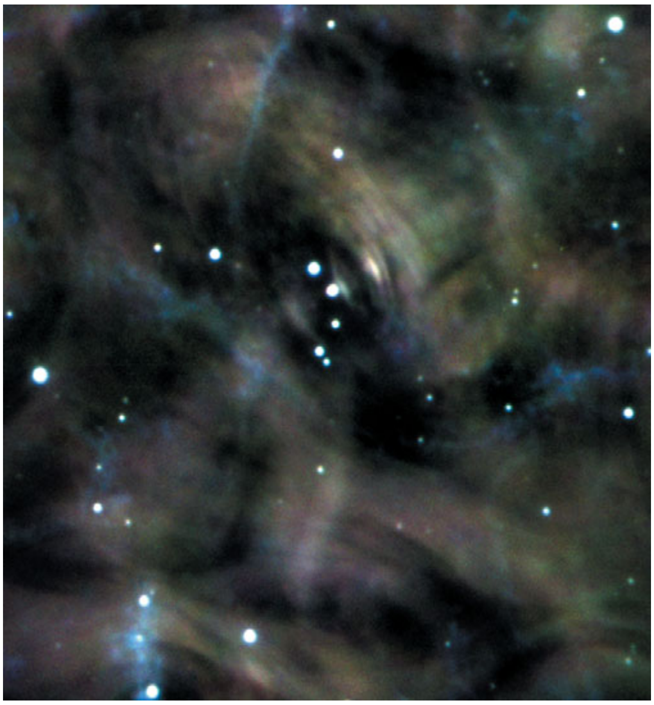

Figure 5: The Crab nebula in the infrared. This is a colour composite of the frames shown in Figure 3. North is up and East to the left.

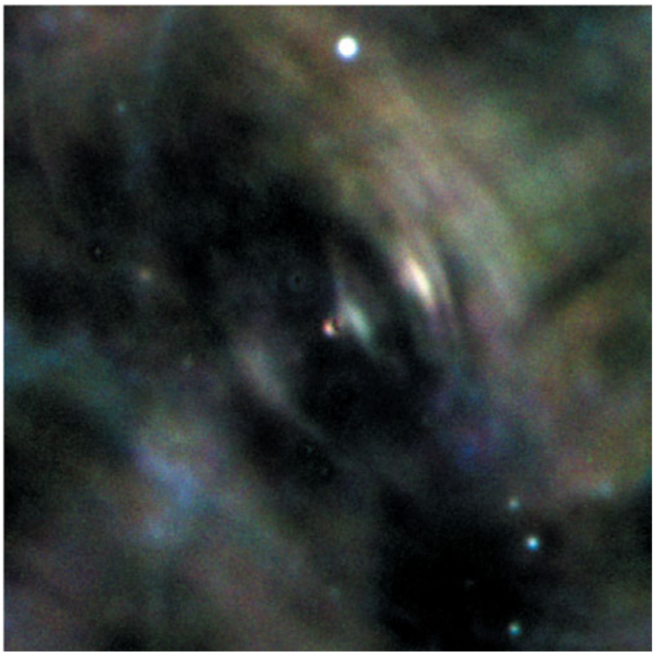

Figure 6: The centre of the Crab nebula in the infrared. After the central stars have been removed using PSF subtraction, the knot close to the pulsar position is revealed. The FOV shown in this ISAAC image is 55.6 arcseconds, as provided by the NAOS/CONICA C12S camera.

the wisps and the nearby knot. We believe that the difference with 2MASS is simply a matter of resolution, and that we are now able to subtract virtually all background from the pulsar.

The 3-colour image of the central parts of the Crab (Fig. 5) is colour coded with *J*s = blue, *H* = green and *K*s = red. In an attempt to keep some physical information in this image, the individual frames were scaled to make an object with a flat de-reddened F_V spectrum appear white.

This image shows the well-known features of the inner Crab. The wisps are clearly visible in higher detail than previously obtained in the IR. Some filaments are also seen, most strongly in the *J*s band. This is most likely due to the [Fe II] 1.26 μm emission line. The Ks band is instead dominated by amorphous synchrotron emission (Fig. 3). With suitable cuts the pulsar image appears slightly elongated. This is due to the presence of the knot first identified by Hester et al. (1995) on a HST image. To reveal this structure in our images we constructed and subtracted a PSF from the stellar images. After subtraction, the knot is clearly revealed in all three bands. A colour image made out of the PSF subtracted frames is shown in Figure 6. The image directly gives the impression that the knot is redder than for example the wisps.

Quantifying this we have estimated the magnitudes of the knot as well as of the nearby wisp 1. The knot was measured within an aperture of 0.9 arcseconds and the wisp was simply measured with an aperture of 1.2 arcseconds. The spectral energy distribution of the knot is shown in Figure 4. It is clearly red. In the *K*s-band the flux from the knot amounts to about 8% of the flux of the pulsar. The stationary wisp appears to have a flatter spectrum in this regime.

3. Optical Data from VLT and HST

To extend the wavelength region over which to derive the spectral characteristics of the inner Crab components, several optical images are available in the ESO and HST data archives.

The VLT PR image (Fig. 1) was taken with FORS2 on 10 November 1999, just two weeks after first light. On the five-minute *B*-band and the one-minute *R*-band exposures, we could PSF-subtract the pulsar to reveal the knot. The knot appears clearly in both frames, and amounts to a few per cent of the pulsar light at these wavelengths.

Data on the Crab pulsar are also available in the HST archive. Most of the observations are from Jeff Hester's comprehensive monitoring programme of the inner parts of the nebula, which has shown just how active the Crab nebula really is. These frames allow a detailed study of both the spectral and temporal properties of the knot. In August 1995 the region was observed in three filters (F300W, F574M, F814W). We measured the de-reddened spectral index for the knot to be $\alpha_V \sim -0.8$, which agrees well with our IR data (Fig. 4).

Furthermore, a wealth of data in the F574M filter allows a study of the tem-

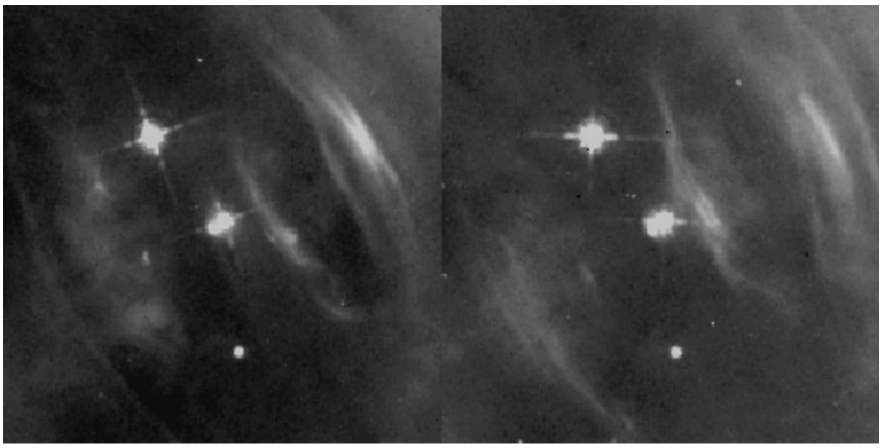

Figure 7: HST F547M images of the very centre of the nebula. The leftmost frame is obtained on March 1994, and the right frame on October 2000, simultaneous with our IR imaging. Note that the wisp structures are very dynamic, but that the knot seen south-east of the central pulsar has persisted over more than 6 years. The FOV is 20 arcseconds, North is up and East to the left.

poral behaviour (Fig. 7). First of all we note that the knot is indeed present in all frames. It thus appears quasi-stationary for more than six years, although the position appears to vary at the 0.1 arcsecond level. The de-reddened flux of the knot (Fig. 4) is measured to be 9×10^{-28} ergs s^{-1} cm^{-2} Hz^{-1} but variations of the flux by at least 50% are observed.

4. Discussion and Implications

For the pulsar itself we have added new information in the IR. Together with the optical-UV data in Sollerman et al. (2000) this significantly revises the observational basis for the pulsar emission mechanism. In fact, most of the theoretical efforts have been based on the old optical data from Oke (1969) and the IR continuation of Middleditch, Pennypacker & Burns (1983). Our new results call for a fresh look on the emission mechanism scenarios for young pulsars.

For the knot, we have shown that the structure is indeed quasi-stationary, and that the emission has a red spectrum. Few models are available for the knot. Lou (1998) presented a formation scenario in terms of MHD theory, while Shapakidze & Machabeli (1999) argue for a plasma mechanism. None of these scenarios predict a very red spectral distribution.

Another area where caution may be required is in the recent claims of weak and red off-pulse emission from the Crab pulsar in the visible (Golden, Shearer & Beskin 1999). It is clear that the knot close to the pulsar has to be seriously considered in these kinds of studies.

5. Future Plans

The Crab pulsar and its environment continue to be the prime astrophysical laboratory for the study of the pulsar emission mechanism and the spin-down powering of pulsar nebulae. Although much observational effort has been put into this object, a modern re-investigation is likely to clean up the many contradictory measurements. Optical imaging in good seeing would require only a few minutes with the VLT, and would directly determine the knot-subtracted spectral energy distribution. ISAAC in the LW range can in less than 3 hours clarify if the knot is significantly contributing to the emission at these frequencies, and would establish if the IR drop of the pulsar is real.

Most interesting is the possibility to monitor the very central parts of the pulsar environment with NAOS/CONICA. With a resolution superseding HST we will be able to monitor the structures close to the pulsar, with 2 pixels corresponding to merely 50 AU. This would provide an unique opportunity to study the structure and dynamics of the inner pulsar wind and its interaction with the surroundings.

References

Eikenberry, S.S., Fazio, G.G., Ransom, S.M., Middleditch, J., Kristian, J., & Pennypacker, C.R. 1997, *ApJ*, **477**, 465.
Golden, A., Shearer, A., & Beskin, G.M. 2000, *ApJ*, **535**, 373.
Hester, J.J, Scowen, P.A., Sankrit, R., et al. 1995, *ApJ*, **448**, 240.
Lou, Y.-Q. 1998, *MNRAS*, **294**, 443.
Middleditch, J., Pennypacker, C., & Burns, M.S. 1983, *ApJ*, **273**, 261.
Oke., J.B. 1969, *ApJ*, **158**, 90.
Penny, A.J. 1982, *MNRAS*, **198**, 773.
Ransom, S.M., Fazio, G.G., Eikenberry, S. S., Middleditch, J., Kristian, J., Hays, K., & Pennypacker, C.R. 1994, *ApJ*, **431**, 43.
Scargle, J.D. 1969, *ApJ*, **156**, 401.
Shapakidze, D. & Machabeli, M. 1999, ptep.proc, 371.
Sollerman, J., Lundqvist, P., Lindier, D., et al. 2000, *ApJ*, **537**, 861.
Sollerman, J., Kozma, C., & Lundqvist, P. 2001, *A&A*, **366**, 197.

SOFI Discovers a Dust Enshrouded Supernova

L. VANZI, ESO, Chile
F. MANNUCCI, CNR, Italy
R. MAIOLINO and M. DELLA VALLE, Observatory of Arcetri, Italy

1. An IR Search for SN

Luminous Infrared Galaxies (LIRGs) are characterised by luminosities larger than 10^{11} $L_{\odot}$ mostly emitted in the far-IR spectral range. Since the discovery of a handful of these objects by Rieke & Low (1972), and afterward the extensive list produced by IRAS, the source of energy of the LIRGs phenomenon has been matter of debate. The radiation observed is mostly thermal emission by dust heated by some primary source. Dust extinction in LIRGs can exceed several magnitudes in the optical and this makes any optical study more difficult than in normal galaxies. Recent IR observations, mostly by ISO, allowed to shed new light on the problem and to identify the starburst (SB) activity as the main source of energy for most LIRGs (Genzel et al. 1998). However, the presence of obscured AGNs, which are elusive in the optical, has also been identified in a few cases raising again the issue on the relative contribution of active nuclei to the bolometric luminosity. Yet, if most of the lumi-

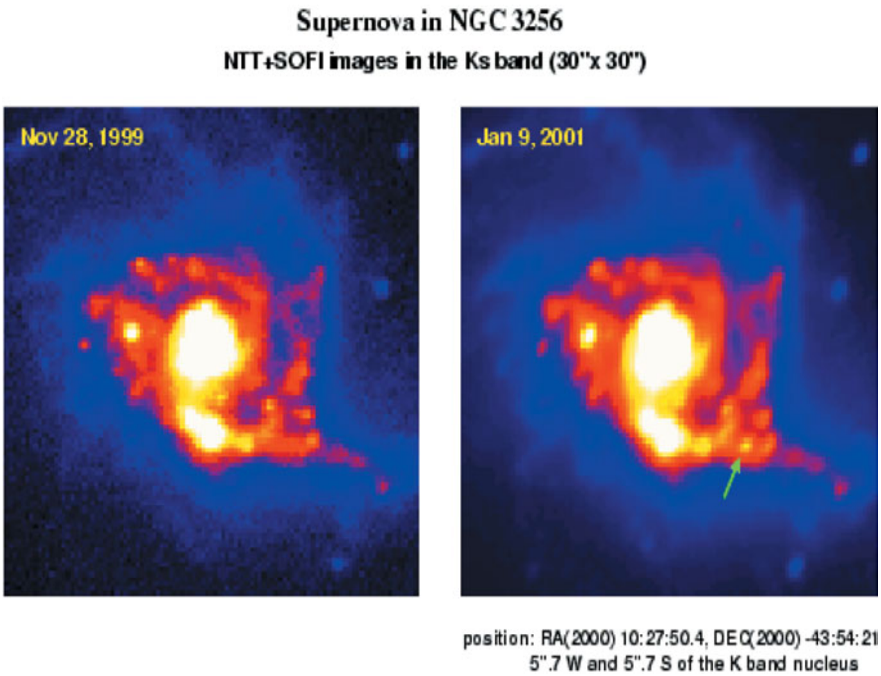

Figure 1: SN2001db is detected in the Ks image of NGC 3256 observed on January 9, 2001 with SOFI (right) when compared with an archival image (left).