Spectroscopy

Up to now we have obtained full IRSPEC spectra in the J,H,K, and L bands for 30 stars of spectral type A to K. These spectra are of medium resolution ($\lambda/\Delta\lambda \simeq 2500$) and span the following wavelength regions: 1.05–1.35 μm, 1.54 – 1.75 μm, 2.05–2.40 μm and 3.45–4.05 μm. To cover these four atmospheric windows, a total of 63 IRSPEC spectra need to be taken for each star. They are the first complete stellar spectra taken in the J,H,K and L bands and they will provide new constraints on the modeling of stellar atmospheres. We reduce the spectra with MIDAS and routines especially developed for the reduction of IRSPEC data (see also the article by R. Gredel in this issue of the *Messenger*).

The "Royal Standard Stars"

The prediction of absolute fluxes of these standard stars will be subject to severe uncertainties in model atmospheres. These uncertainties, which may lead to systematic errors in the calibration of ISO fluxes of more than 10%, are in particular errors in fundamental parameters, in temperature structure and in continuous and molecular opacities. In order to get a handle on these uncertainties, we are studying the effects of perturbations of the above-mentioned parameters on the far infrared spectra of model atmospheres. To improve the calibration, we also will make a detailed comparison of observed and synthetic spectra and fluxes of a sample of stars, selected to be representative for the full set of standard stars. We selected 22 such stars, named "Royal Standard Stars": 5 A-type stars, 4 early F stars, 8 solar-type stars and 5 K giants (see Table 1). These Royal Standard Stars will serve as a basic set for checking the calibration of the entire sample of standard stars.

Fundamental Parameters, Model Atmospheres and Far IR Fluxes

We use the NIR photometry as input for the "Infrared Flux Method" (Blackwell, 1986) and determine the effective temperatures and angular diameters of the stars. Independently we shall determine effective temperatures and gravities of the stars by comparing the observed and theoretical infrared colours, as described by Bell and Gustafsson (1989). To be able to compare the NIR data obtained at ESO with theoretical infrared colours, we will extend the work by Bell and Gustafsson for both the ESO J,H,K and L filters and the narrow-band NIR filters, described before.

We will use the fundamental parameters as input for model atmospheres: recent versions of the Kurucz models (Kurucz, 1991) for the hotter stars, and recent models from the Uppsala model atmosphere codes (updated versions of Gustafsson et al., 1975, with the Kurucz [1991] atomic line lists implemented) for the cooler stars. We will extend model atmosphere codes into the infrared, and use them in combination with the NIR data to predict infrared fluxes for the complete set of standard stars. The stars with $K > 6$ will be used as a standard system for the short wavelength range of ISO, up to 20 μm. The stars with $K \leq 6$ will be used as calibrators up to at least 50 μm.

The aim of the project is to predict the infrared fluxes of the complete sample of stars, with accuracies better than 10% for flux densities ≥ 1 Jy and to compile a list of standard stars which are suitable for wavelengths up to 50 μm. The working group plans to deliver a database of standard stars and infrared fluxes to the ISO Science Operations Team well before the launch of ISO, presently scheduled for 1995.

Acknowledgements

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SUSI Discovers Proper Motion and Identifies Geminga

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Twenty years have gone by since the discovery of the γ-ray source 195+5, the first UGO (Unidentified Gamma Object) seen by the NASA SAS-2 satellite. These years have been characterized by an endless quest for an identification of this puzzling object first in the γ-ray domain, with the ESA COS-B satellite (1975–82), then in the X-ray domain, with the NASA Einstein Observatory (78–81) and ESA EXOSAT (83–86) missions, finally in the optical (1983–today) using all the big telescopes of the world. Unfortunately, every step down in energy cost a factor of 1000 in the source strength (see table) and, adjusting the observing time, we ended up with $\sim$1000 photons in each energy range.

While wading through the intricacies of multiwavelength astronomy, the source acquired its multi-language name GEMINGA, officially for GAmma source in GEMINi, in reality a pun from the Milanese argot*, making Geminga the first celestial object named in a dialect.

The 90's found the strong gamma-ray source GEMINGA associated with 1E 0630+178, a peculiar X-ray source (Bignami et al., 1983), and (tentatively) with a very faint optical object G", first seen with the CFHT and confirmed with the ESO 3.6 (Bignami et al., 1987, 1988) and with the 5-m Palomar (Halpern and Tytler, 1988), where the γ-X association rested on the strong similarity with the Vela pulsar and the X-optical one on the peculiar colour of G". Geminga was supposed to be an isolated neutron star, since only this object could explain at once the strong γ emission and the faintness of the optical counterpart in spite of the X-ray emission. Back in 1983, we had also proposed that it ought to be very close, ~100 pc (Bignami, Caraveo, Lamb, 1983). All this was very reasonable but rested purely on astrophysical ideas, not on hard facts. During 1992, however, new γ-X and optical observations provided the facts needed to secure the identification of Geminga.

First came the discovery of the 237-msec periodicity in the ROSAT X-ray data (Halpern and Holt, 1992). The same periodicity was immediately found in the contemporary GRO/EGRET γ-ray data (Bertsch et al., 1992) and in the old archived COS-B data (Bignami and Caraveo, 1992) which, covering a long time span, provided the best estimate of the $\dot{P} = 1.099\ 10^{14}$ s/s. Apart from clinching the identification of Geminga with 1E 0630+178, this is what is needed to compute the parameters of the rotating neutron star responsible for the X/γ-ray emission. The magnetic field turns out to be 1.5 10^{12} G, a rather normal value, while the standard formula $\dot{E} = I\Omega\dot{\Omega}$ gives 3.2 10^{34} erg/sec for the overall rotational energy loss of the pulsar.

Energetics

Name	ν	# photons	Obs. time	Flux erg/cm^2 sec
Geminga 1972--->	γ-ray	~1,000	80 days	2 10^{-9}
1 E 0630+178 1983--->	X-ray	800+200	10,000 sec	2 10^{-12}
G″ 1987--->	optical	1,600	few hours	3 10^{-16}
---------	radio 21 cm	------	deep search	< 5 10^{-20}

This brings up the matter of distance: from the value of $\dot{E}$ one can immediately derive an absolute upper limit to the distance, in the assumption that all $\dot{E}$ goes into γ-rays. This upper limit is ~300 parsecs, and for a γ-ray production efficiency of, e.g. 10^{-2} similar to that of PSR 0833-45 (see e.g. Bignami and Hermsen, 1982), this would imply that Geminga is about 30 pc from us. Thus Geminga could be the neutron star nearest to us and, given the high velocities normal for pulsars, a measure of the proper motion ($\mu = 0.2 \cdot v_{100} \cdot d^{-1}_{100}$ ″/yr, with v in units of 100 km/sec and d in units of 100 pc) was the next sensible thing to do, as suggested by Bignami and Caraveo (1992).

The ESO Director General granted for this project one NTT night which, thanks to J. Breysacher, was split into two halfs: one in November 92 and one in January 93. This arrangement turned out to be a very successful one and, on November 4–5, the Geminga field was observed, in service mode, by A. Smette. Ten SUSI V frames, of 15 minutes each, were secured under very good seeing conditions (0.6–0.8″). A. Moneti combined the images right away and FTPed the sum to Milano.

The resulting image was compared with two others of the same field, obtained respectively at the CFHT 3.5-m instrument in January 84 and at the ESO 3.6-m in January 87 (Bignami et al., 1987, 1988). Figure 1 shows a composite of the three images, where the 84 and 87 ones have been re-binned and tilted to match the scale and orientation of the ESO 92 frame. The motion of G″ to the NE is apparent, showing an 84–92 displacement of about 12 pixels, with the 87 data at the correct angle and position.

To assess the effect more quantitatively, and to exclude any possible systematic error, the positions of several faint stars, beside G″, were compared in the three frames used. The pixel positions of 19 faint objects were measured in each image, then, for each star, a mean position was computed, and deviations from this mean are plotted in Figure 2 in units of pixel (0.13″) for the X and Y axis. While the comparison objects appear to lie well within the centring errors (typically < 1 pixel) in each image, G″ stands quite apart showing a clear NE displacement.

Using as reference star positions extracted from the original Hubble Space Telescope Guide Star Catalogue, kindly supplied to us by D. Golombek, we have computed the coordinates of G″ at the three epochs. A linear fit to the derived coordinates gives the following components for the proper motion of G″

μ_α= 0.14″/y μ_δ=0.10″/y

and a total of $\mu = 0.17″/y \pm 0.05″/y$

The reported evidence for a large proper motion of G″ ($m_v = 25.5$) can only be interpreted in two ways: either the object is a solar-system body (asteroid, comet, whatnot), or it is a subluminous, truly faint star. The first possibility cannot be discarded lightly, in view of the low ecliptic latitude of Geminga. Strongly against it, however, are the extremely slow motion (for a solar-system body) at a large angle with the ecliptic plane and, of course, the low probability of the event, in view of the very small area considered.

Interpreting G″ as a star, for a displacement similar to that observed, one obtains a round distance figure of 100 pc for a velocity in the plane of the sky of 100 km/sec, not far from the mean for radio pulsars (see e.g. Lyne et al., 1982). At 100 pc, the object would have an $M_v = 20.5$, to be compared, e.g., with the Vela pulsar's 15, i.e. with an "under-luminosity" only comprehensible for a neutron star. Anything more luminous would have to be correspondingly more distant and thus faster. For comparison, the Vela pulsar, at an accepted distance of 450 pc, has been measured to have a proper motion of about 0.05″/y (Bignami and Caraveo, 1988; Bailes et al., 1989; Ogelman et al.; 1989) Late-type extreme subdwarfs with large transverse velocities and with absolute magnitudes as faint as $M_v = 15$ (Monet et al., 1992), could mimic the apparent magnitude, as well as proper motion, of G″ only for extreme velocity values. Moreover, this possibility, unlikely in view of the very small area considered, is definitely ruled out by the colour of G″. Altogether, no known object other than a neutron star can explain the properties of G″. It is thus unavoidable

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* Gh'è minga means "is not there" to most northern Italians.

to conclude that the observed motion is proof of the optical identification of Geminga, the neutron star nature of which is by now firmly established from the gamma/X-ray data.

Geminga then becomes the third neutron star identified in the optical, after the Crab and Vela pulsars. The LMC pulsar 0540-69, although definitely seen to pulsate at optical wavelengths (Middleditch et al., 1987), has so far only a probable identification through imaging (Caraveo et al., 1992a and b). Geminga is the first object discovered and identified through its gamma-ray emission and the first isolated neutron star studied without the help of radio astronomy, and is surely the prototype of a class whose properties are now open for a better understanding.

It may be of interest to speculate on the birthplace of Geminga, now that its direction of motion and angular velocity are known. If its age is really 370,000 years, as suggested by its period derivative value, the object comes from a point about 16 deg roughly to the SW of its present position. Such hypothetical birthplace appears to be well outside the boundaries of the Gemini constellation, so that the present name could not have been given at birth. In view of the small distance involved, it is probably difficult to search for a SN remnant which may now well include the Earth. But if Geminga was indeed generated in a SN event, it may be more interesting to speculate on the possible environmental effects of an event which would have liberated a huge amount of energy at 100 pc or so from the Earth.

As to the physical nature of the optical emission, the data presented above do not add information, except for the possible constraint on Geminga's absolute magnitude. As discussed in the literature, thermal as well as non thermal mechanisms may contribute to the emission, which could be pulsed at 237 msec, with a still unknown duty cycle. The period-luminosity dependence originally proposed by Pacini (1971), and rediscussed more recently (Pacini and Salvati, 1987), can be applied, assuming

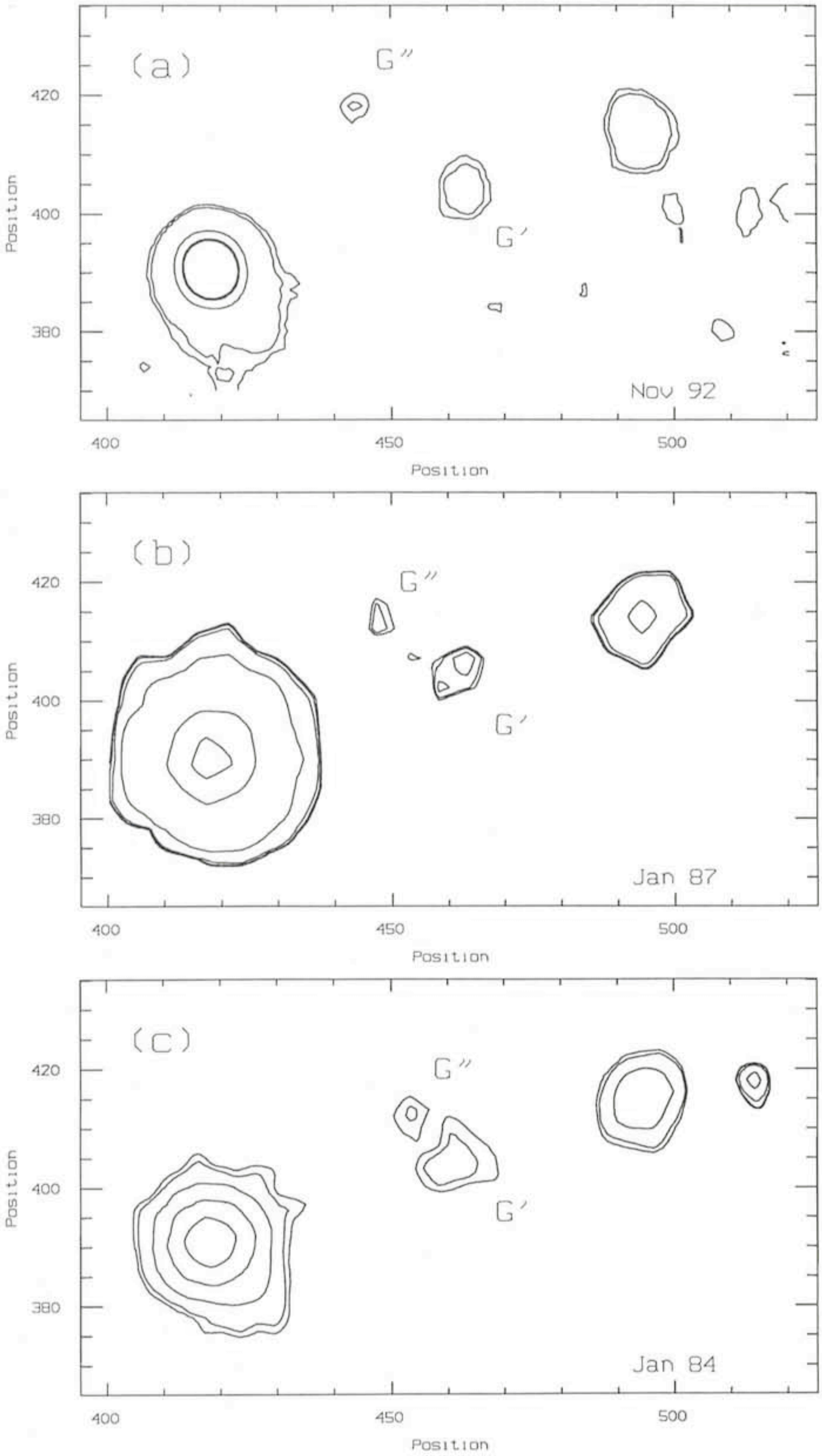

Figure 1: *Contour plots of the three data sets used, showing the motion of G″ over ~8.8 years. The overall displacement between the first and the last observation is ~12 SUSI pixel (0.13″ each), with the 87 data set showing G″ at an intermediate position.*

(a) November 4, 1992 data. Stack of 10 V exposures of 15 min each, taken at the ESO NTT with SUSI. Seeing conditions were very good (0.6-0.8″). G″ is detected at: R.A. (1950) = 6h 30m 59.15s; Decl. (1950) = 17° 48′ 33.6″ ± 0.16″. The orientation is roughly NE (an eastward tilt of ~3° is present but has not been corrected for to preserve the excellent quality of the image).

(b) January 28, 1987 data. Stack of 8 V exposures of 15 min each, taken at the ESO 3.6-m equipped with EFOSC (pixel size 0.675″). Seeing conditions were mediocre ~1.6″. The original data have been rebinned and tilted to match the SUSI field. The best position of G″ is R.A. (1950) = 6h 30m 59.10s; Decl. (1950) = 17° 48′ 33.0″±0.68″.

(c) January 7, 1984 data. Stack of 12 r exposures of 15 min each, taken under good seeing conditions (0.9″) at the CFHT. The original data (with a pixel size of 0.412″) have been rebinned and tilted to match the SUSI field. G″ was seen for the first time in this observation (Bignami et al., 1987) and its position is: R.A. (1950) = 6h 30m 59.06s; Decl. (1950) = 17° 48′ 32.7″± 0.46″

All the above coordinates have been computed in the original (not rebinned) data. The quoted uncertainties take into account the r.m.s. of the astrometry fit (0.10″, 0.12″, and 0.19″, respectively in the 1992, 1987 and 1984 data) and the error in the centring of G″ (~1 pixel in each data set).

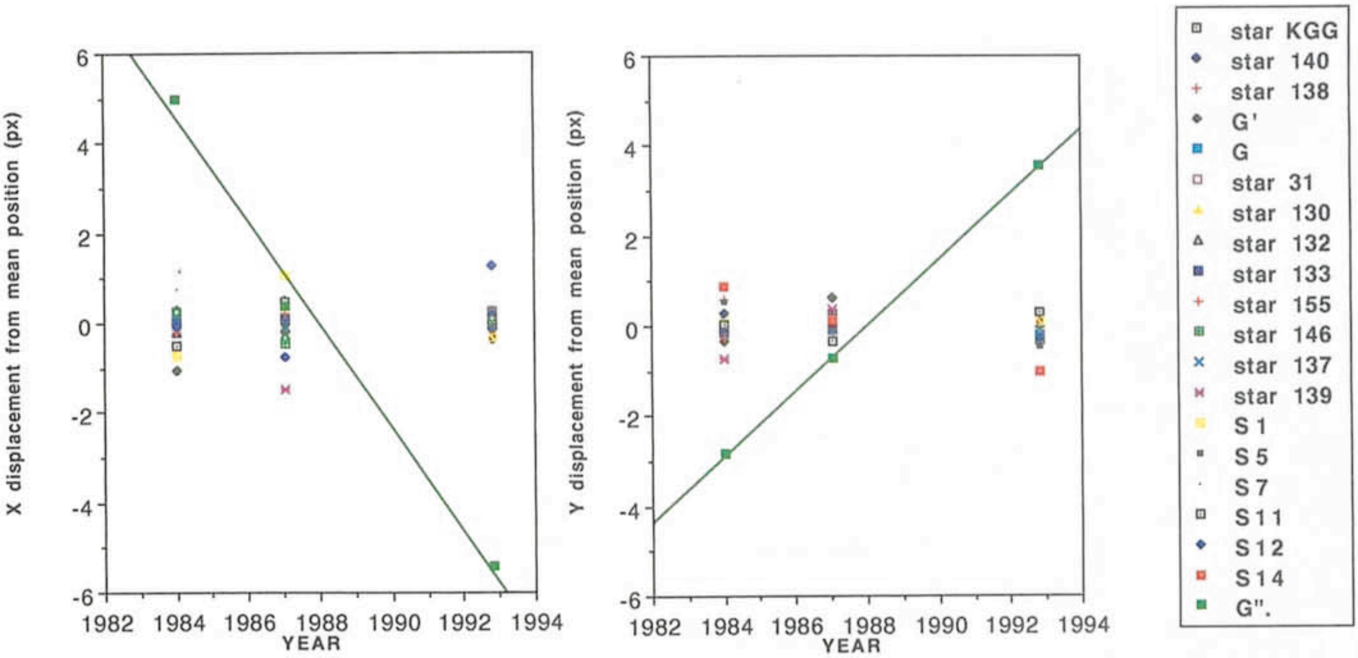

Figure 2: *X and Y displacements (in units of 0.13" pixels) from the mean position of G" together with 19 faint comparison objects. These are stars G, G', 31, 130, 132, 133, 137, 138, 139, 140, 146, and 155 (following the numbering given in Halpern and Tytler, 1988), plus other fainter ones visible in our three data sets. For each object, the positions obtained in the three frames were averaged and the three X and Y deviations from such a mean were computed and plotted in a and b.*
No systematic motion is present for the comparison objects, whose deviations appear to lie well within the centring errors (typically < 1 pixel) in each image.
G" (■) stands quite apart showing a clear NE displacement. The linear fits to the X and Y displacements of G" from the mean are also shown.

for Geminga an optical duty cycle similar to that of the Vela pulsar, as has been seen to be the case at higher energies. This yields an $M_V \sim 28$ which would place Geminga at $\sim$ 3 pc.

The observed motion of G" could also have a bearing in explaining some of the difficulties encountered recently with the timing parameters of the object (see IAU Circ 5649). In particular, the second derivative of the period, when computed over a long time history to include both GRO and COS-B data (1991-1975), might be affected not only by period glitches, but also by a different position.

What next? The parallax measurement (e.g. 0.02" for 100 pc) is then the next challenge awaiting the Geminga aficionados.

Director Discretionary time has been granted for the observation of Geminga with the Planetary Camera on the HST. The observation is planned for December, with the purpose of pinpointing the position of G" to the best possible accuracy allowed by the current PSF. Repeating such measurements six months apart, something which cannot be easily done from the ground, might conceivably lead to a parallax measurements, thus also bringing to an end the distance problem.

So far, 1992 has been a magic year for the understanding of Geminga and December should bring more crucial data.

According to Trimble (1991), 20 years are not an unreasonable time between the discovery and the understanding of an astrophysical phenomenon. Are we at the end of our quest?

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New Object at the Edge of the Solar System

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A new object, which is probably a minor planet, has been found in the outer solar system. Although the available observations do not yet allow an accurate determination of the orbit, it appears that it is situated at the record distance of about 41 AU, i.e. just outside the orbit of Pluto.

Discovery and Follow-up Observations

The new object, which received the provisional designation *1992 QB1*, was