Multiwavelength analysis of Gl355 (LQ Hya)

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Abstract. We discuss ROSAT, ASCA, BeppoSAX and optical observations of the young active star Gl355. During the ROSAT observation a strong flare was detected with a peak flux more than an order of magnitude larger than the quiescent level. Spectral analysis of the data allows us to study the temperature and emission measure distribution, and the coronal metal abundance, for the quiescent phase and, in the case of ROSAT, also during the evolution of the flare. We have modeled the flare and derived a loop semi–length of the order of \( \sim 1.5 \) stellar radii. ROSAT, ASCA and BeppoSAX data suggest that the coronal abundance of Gl355 is subsolar, in the range \( 0.1 \div 0.3 Z/Z_\odot \). A preliminary analysis of optical spectra allows us to compare the photospheric and coronal metal abundances.

1. Introduction

We present here the analysis of X–ray and optical observations of Gl355 performed on a time–scale of 10 years with ROSAT, ASCA, BeppoSAX, the 80cm Automated Photometric Telescope (APT) in Catania (Italy) and the ESO 1.5m spectrographic telescope. Gl355 is a relatively well known nearby (\( d \sim 18 \) pc) star of spectral type K2Ve. The high lithium abundance and rotation rate suggest a young age, possibly that of a pre–main sequence object (Vilhu et al. 1991) or more likely a ZAMS star. The high count–rate of the ROSAT observations has allowed us to perform a time–resolved spectral analysis of an intense flare to discuss the temporal evolution of plasma parameters such as the temperature \( T \), the emission measure \( EM \), the global coronal metallicity \( Z \), and of the absorbing column density \( N_H \). The quiescent emission was studied using ROSAT, ASCA and also BeppoSAX observations and the long–term behavior was investigated comparing measurements performed at different epochs. Optical monitoring of
Figure 1. Total light curve obtained by the ROSAT PSPC observations. The count rate is not background subtracted. Observations were performed starting on 1992, November 5.

Gl 355 was also performed with the APT to compare the variability in the X–ray and optical band. High resolution spectra obtained at ESO allows us to directly determine the photospheric metal abundance, a parameter still lacking for this object, and to compare in a more meaningful way its coronal and photospheric metallicities. Part of the data here reported was already discussed in detail in Covino et al. (2001).

2. Observations and analysis

The X–ray observations discussed in this paper were performed by the ROSAT, ASCA, and BeppoSAX satellites in Nov 1992, May 1993, December 2000, respectively.

The ROSAT light curve shows an evident flare which occurred on 1992, Nov 5, at ~ 18 UT. The count rate increases by more than an order of magnitude. Fig. 1 shows the complete light curve with superimposed the identification codes of the specific pointings. The flare maximum can be located close to the observation 200999 or just before it.

The ASCA count rate is essentially constant for the first half of the observation, ~ 0.4 cts for the SIS. The second half, on the contrary, shows an increase of ~ 50% in particular in the softest band. However, the hardness ratio does not show significant variations due to the relatively poor statistics involved.

The BeppoSAX observation lasted for 280 ks and allows us to study in detail the short term variability of this object. No intense flares were detected even if a continuous low–level activity is clearly present (Fig. 2).
Figure 2. Total light curve obtained with the BeppoSAX LECS, MECS and PDS detectors. Observations cover the time-interval from December 5 to 12, 2000.

Optical monitoring of Gl 355 was performed from December 2000 to March 2001. The observations were performed with the APT of Catania Observatory (Mt. Etna, Italy). It is a 0.8-m reflector equipped with an uncooled Hamamatsu R1414 SbCs phototube and standard UBV filters. Apart from a long term variability a flare in the optical was also observed (Fig. 3).

A high-resolution spectrum was obtained on Nov. 3rd, 2000 with the FEROS spectrograph (Kaufer et al. 1997) at the ESO 1.5m telescope. The spectrum covers the entire optical band from 370 to 920 nm with a resolving power of $R = 48,000$. A detailed abundance analysis is in progress; preliminary results suggest that the global photospheric metallicity of Gl 355 is slightly over-solar.

3. Results

3.1. Quiescent Emission

The ROSAT, ASCA and BeppoSAX observations and the RASS data allow us to study the quiescent emission of Gl 355 on long and short time-scales. Long- and short-term variability is clearly present amounting up to a factor of $2 \div 3$ in flux.
Figure 3. A flare observed in the optical. The flare evolution is superposed to a general trend likely due to spots on the star's surface.

The ROSAT PSPC observations outside of the flare were fitted with a 1T model with free global metallicity. The absorbing column across the line of sight is not well constrained (errors of the order of 50% of the best fit value, or larger). The metal abundance is highly subsolar ($Z/Z_\odot = 0.03 \div 0.14$ at the 90% confidence level) and is confirmed by the analysis of the ASCA spectra. The best–fit temperature is $\sim 0.7$ keV. The flux in the 0.1–2.4 keV energy band ranges from $\sim 1.4$ to $\sim 3.5 \times 10^{-11}$ erg cm$^{-2}$s$^{-1}$, directly linked to the EM variations from $\sim 9$ to $\sim 21 \times 10^{32}$ cm$^{-3}$. The spectral parameters derived for the pre– and post–flare emissions are comparable and the moderate (a factor of $2 \div 3$) flux variability seems to be due mainly to EM variations which in turn might be due to changes in either the volume or the density of the emitting regions.

Considering the ASCA observation on May 1993 1T spectral fits gave satisfactory results only for the low resolution GIS detectors. The best fit temperature appears slightly harder (but comparable within the errors) than the one derived from the ROSAT analysis, while the metal abundance is essentially the same. Acceptable fits to the SIS spectra were obtained only with the addition of a second thermal component, with the global metallicity free to vary. An analysis of the single element abundance shows (Fig.4) a possible inverse First Ionization Potential (FIP)–effect, but the error bars are large (see Covino et al. 2000 for a brief discussion).

BeppoSAX data analysis is still preliminary, but reveals a complex 3T structure thanks to the wider energy range. The temperatures are rather well con-
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Figure 4. Comparison of metal abundance derived by ASCA data and FIP for single elements. The error bars are large but a possible trend for an inverse FIP effect seems to be present.

strained ($T_1 = 0.25 \div 0.45$, $T_2 = 0.9 \div 1.1$, $T_3 = 2.3 \div 3.5$ keV) and the metal abundance is again strongly subsolar, around $0.2 \div 0.3 Z/Z_\odot$.

Therefore, the metal abundance measured by ASCA and BeppoSAX is comparable to that obtained from the analysis of the ROSAT data and is well below solar. Since ASCA and BeppoSAX are much more effective than ROSAT in measuring metal abundances, this result clearly shows that a low metal abundance is indeed needed to model the corona of Gl 355 in contrast with its young age and about solar photospheric metallicity (see Sect(s). 2 and 4).

3.2. Flare analysis and modeling

Considering the ROSAT observations 200999, 201000, 201001 and 201002, i.e. the observations performed during the flare, we performed 2T fits with the global metallicity left free to vary. The fits gave acceptable results, but the hotter component is badly constrained. The intense dynamic evolution of the flare prevents a detector with a limited energy band as the ROSAT PSPC to constrain the hot component.

As shown in Fig. 5, the temperature of the flare cooler component is essentially constant around 0.6–0.7 keV, in full agreement with the temperature derived for the quiescent emission. The absorbing column density is also essentially constant during the flare, i.e. with no increase at the flare onset or at the peak. The metal abundance close to the flare peak is not well constrained but a hint (admittedly very weak) for an increase during the flare evolution seems to be present. In any case a hot component is clearly needed, although being
Figure 5. 1T and 2T best fit parameters for the ROSAT PSPC observations. The first observation and the last three were fitted by 1T models, while the observations performed during the flare were fitted with 2T models (see Fig. 1).

not well constrained due to the limited ROSAT energy range. The flare event is totally due to hot plasma superimposed to the quiescent corona.

The flare observed by ROSAT has been analyzed considering the so called hydrodynamic decay–sustained heating scenario (Reale et al. 1997), which assumes that the flaring plasma is confined in a closed loop structure whose geometry does not change during the event. Detailed hydrodynamical simulations (Peres et al. 1982, Betta et al. 1997) show that flares decay approximately along a straight line in the $\log \sqrt{EM} - \log T$ diagram, and that the value of the slope $\zeta$ of the decay path is related to the ratio between the observed decay time $\tau_{lc}$ of the light curve and the thermodynamic cooling time of the loop $\tau_{th}$ in the absence of heating during the flare decay. This allows deriving the length of the flaring loop as a function of observable quantities. An application of this technique to stellar flares observed with the ROSAT PSPC, and the appropriate
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7 calibrations, are given by Reale & Micela (1998) and Favata et al. (2000). See also Pallavicini et al. (2000) and Covino et al. (2001) for a discussion of the method.

In the present case, the slope $\zeta$ in the log $\sqrt{EM} - \log T$ is $0.86 \pm 0.27$. Very low values of $\zeta$ mean that the flare decay is entirely driven by the sustained heating, so that the thermodynamic cooling time, $\tau_{th}$, cannot be determined in a reliable way, and $L$ does not depend any more on $\tau_{lc}$. On the other extreme, no sustained heating occurs and $\tau_{lc} \sim \tau_{th}$. Our result shows that indeed a large amount of sustained heating is actually present in line with the results obtained for other flares (Reale & Micela 1998; Ortolani et al. 1998, Favata & Schmitt 1999; Favata et al. 2000a; Favata et al. 2000b; Favata et al. 2000c; Maggio et al. 2000, Franciosini et al. 2001).

Given the decay e–folding time, $\tau_{lc} = 10.1 \pm 0.5$ ks, the loop semi–length turns out to be $L = 83(\pm 22) \times 10^9$ cm or, in units of the stellar radius, $L \sim 1.5 R_\star$.

4. Summary and conclusions

The spectral analysis of the ROSAT, ASCA and BeppoSAX data shows that this young star has coronal metal abundances highly sub–solar. Preliminary abundance analysis of the optical spectrum indicates a metallicity close to solar. Thus, as in the case of other young objects, e.g. AB Dor (Mewe et al. 1996) and HD 35850 (Tagliaferri et al. 1997), we have a star that shows coronal abundances much lower than the photospheric ones. This is also true for other more evolved stars, as e.g. IF Peg (Mewe et al. 1997; Covino et al. 2000). These ROSAT, ASCA and BeppoSAX findings are now confirmed with the gratings observations of Chandra for HR 1099 (Drake et al. 2001) and of XMM-Newton for AB Dor, Castor and HR 1099 (Brinkmann et al. 2001, Güdel et al. 2001a, 2001b).

Besides the strong flare detected by ROSAT, variability of a factor of 2-3 has been detected in both ROSAT, ASCA and BeppoSAX light curves of Gl 355. This variability is mainly due to EM changes, while the temperature of the quiescent corona remains approximately constant. For the ROSAT data, outside the flare, the coronal plasma is well represented by a single temperature model with very low metal abundances. For the ASCA data, due to the harder energy band, a second component is required while the wider BeppoSAX energy range also requires a third component.

The coronal spectrum during the flare can be represented with a 2T model, with the cooler component compatible with the quiescent one. From these fits we have a weak indication of an increase of the metal abundance during the flare although the large error bars do not allow for a strong claim.

We modeled the flare using the hydrodynamic decay–sustained heating scenario (Reale et al. 1997) and assumed that in the 2T best fit model the hotter temperature represents the flare plasma, while the cooler temperature represents the quiescent coronal plasma. We then derived the flare loop semi–length that turns out to be quite large, $\sim 1.5 R_\star$. Note that our flare temperature (the hotter component) in not well constrained at higher values, due to the ROSAT energy band. In any case, since the downward error bars for the temperature are well constrained by the fit, the loop semi–length that we derived should be regarded as a lower limit.
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