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Compact Intraday Variable Radio Cores: New Observational Approaches

L. Fuhrmann, G. Cimò, T.P. Krichbaum, T. Beckert, A. Kraus, A. Witzel, and J. A. Zensus

Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany

Abstract. The evidence for refractive interstellar scintillation (RISS) being the main cause for rapid intraday variations (Intraday Variability, IDV) in Quasars and BL Lacs has recently become very strong. If IDV is still a complex composition of extrinsic and source intrinsic effects, the intrinsic part of the IDV pattern should show up in the millimeter and sub-millimeter regime due to the frequency dependence of RISS. Hence, observations at higher frequencies are essential in order to exclude RISS as the sole cause of IDV. Here we report on our new attempt to search for rapid variations at much higher frequencies. In addition, the possibility of a direct detection of the scattering screen in front of IDV sources will be discussed. Our recent line observations towards a few IDV sources lead to the first detection of a high latitude molecular cloud in front of an intraday variable radio core.

1. Introduction

There is still a hot debate about the origin of short term radio variations in total as well as polarized flux of flat spectrum Quasars and BL Lacs. Such variations on time scales of hours to days (Intraday Variability, IDV) are common in this type of objects and reveal the tiny dimensions of the emitting region. The cause of the variations seen in these sources is currently controversial with claims being made for either: 1) a source-intrinsic or 2) extrinsic origin due to scattering in the interstellar medium (ISM) (e.g. Wagner & Witzel 1995 and ref. therein). Observational findings suggest, that IDV is a complicated mixture of both effects (Krichbaum et al. 2002). Due to the involved small source sizes, refractive interstellar scintillation (RISS) must play an important role in the cm-radio regime, while intrinsic variations require extreme high Doppler boosting or special source geometries.

In this paper we will present our new observational approaches: In the first part we will report on the attempt to search for IDV at much higher frequencies than presently done (up to 345 GHz). In the second part we will introduce the possibility of a direct search for the required scattering screen and show first results of line observations towards IDV sources.

2. Search for Intrinsic IDV: High Frequency Observations

During 48 hours of observations in September 1998 we found significant variations in the IDV-source 0716+714 at 32 GHz with 20% peak-to-peak variations (Krichbaum et al. 2002, Kraus et al. in prep.). This is the first detection of IDV at higher frequencies. Such mm-IDV is of particular interest due to the frequency dependence of refractive interstellar scintillation. Towards higher frequencies scintillation vanishes and the intrinsic part of IDV should show up in the millimeter and sub-millimeter regime. Hence, observations of IDV sources at such high frequencies provide the most direct observational test for RISS and will help to disentangle between source intrinsic and scintillation induced IDV.

Motivated by the results from September 1998, we performed new high frequency observations with Effelsberg and the HHT during the last months.

2.1. Effelsberg Observations at 32 GHz

In April 2002 we observed a small sample of IDV sources during a 40 hours session with the Effelsberg telescope using the new module of the 32 GHz correlation receiver. As in the past, we measured using the method of cross-scans, with the number of subscans matched to the source brightness. A dense time coverage, with frequent observations of secondary calibrators in a duty cycle of 1-2 measurements per source and per 1.5 hours has been done. The data reduction is still in progress. Up to now, the first inspection of the data does not show significant variations (compared to our secondary calibrators). Perhaps this is due to the not optimal weather conditions during the run (periods of clouds and even rain), but a further and more detailed data reduction has to be performed.

2.2. HHT Observations at 345 GHz

In May 2002 we started a 3 week multi-frequency campaign with the HHT together with other radio as well as optical telescopes in order to search for short term variations at 345 GHz in flat spectrum radio sources (Cimò et al. in prep.). The data reduction is still in progress, but preliminary results may reveal IDV in at least a few sources. Here, the quasar 0716+714 is the most promising candidate and seems to be highly variable at such high frequencies during the campaign (see also Cimò et al., this conference).

3. Search for the Scattering Screen in Front of IDV sources

Another new observational approach is the attempt to directly detect the scattering screen in the foreground of intraday variables. The presence of a scattering screen in the Galaxy responsible for RISS has been suggested many years ago. Until now, only indirect hints do exist and no attempts has been performed in order to directly detect such medium in front of IDV-sources. A direct detection via spectral line observations will help to identify RISS with the location of particular features in the local ISM (LISM). In addition, physical parameters deduced from such observations would give new input for the model of interstellar scintillation.

In order to perform such search we have to deal with the following questions: 1) which component of the ISM could serve as scattering material? 2) where is its location in the Galaxy? and 3) do we have observational evidence for the material? Scintillation of extragalactic radio sources on timescales of about 1 day requires free electrons (in a layer of a few parsec thickness) at a relatively nearby position between us and the source. Such turbulent (clumpy) plasma produces a scintillation pattern onto the earth orbital plane by focusing and defocusing the radiation from the source. As the earth moves through this pattern, we observe temporal variations of the flux emitted by the extragalactic object. In order to display such variations the source size must be of the order of the scattering size of the medium, which is defined by the Fresnel scale θ_F. For source sizes larger than θ_F, the scintillations are quenched (see Beckert et al., this proceedings). The observed variability timescale is related to the velocity of the earth v relative to the scattering medium and the distance d to the screen by $t \sim \theta d/v$. For typical velocities of 30 km/s and time scales of about one day the scattering plasma should not be further away than 100–150 pc. Observational findings suggest a very inhomogeneous medium, which varies on angular scales not larger than a few degrees on the sky (Fuhrmann et al. 2002). Thus, we have to search for a somehow diffuse ionized component (with a certain amount of electron densities) of the ISM within a radius of ~ 150 pc of the Sun.

In view of the required ionized material, several forms of such gas do exist. Since an extended, diffuse material as the structure of the general ISM or large extended envelops of more compact structures are required, one may expect the warm ionized medium (WIM) or the extended low-density warm ionized medium (ELDWIM) to be connected with scintillation. Such medium has been identified through detection of radio recombination lines (RRLs) at several positions free of discrete continuum sources already 30 years ago (e.g. Gottesmann & Gordon 1970). This may give us the possibility to observe directly the postulated scattering screen in front of IDV sources via RRL observations.

The ISM surrounding the solar system within a few hundred parsecs, is known to contain several major features in the form of clouds, bubbles, supernova shells, star forming regions and molecular as well as HI clouds. While the Sun is thought to reside in the hot, low-density ($n_e \sim 0.005\, cm^{-3}$) X-ray emitting Local Bubble (LB) with a radius of $\sim$ 100 pc (e.g. Cox & Reynolds 1987), the LB itself is embedded into four large, almost circular rings, the Radio Loops I to IV (Haslam, Khan & Meabur n 1971). The sun lies more local inside the warm ($T \sim$ 7000 K), diffuse and partially ionized ($n_e \geq\ 0.12\, cm^{-3}$) local interstellar cloud (LIC) ($d \sim$ a few pc) (Lallement & Bertin 1992). The LIC extends for several parsecs in most directions and is part of the "local fluff" (Frisch 1995). This complex of warm, nearby clouds located either insight or at the edge of the LB is originated from the Sco-Cen star forming region in Loop I. In addition, the LB is surrounded by other well-known examples of nearby bubbles, star forming regions, molecular clouds and shells of SN remnants suitable to either contain or produce "scattering" material within a radius of 100–450 pc. Thus, it is quite plausible to think about such inhomogeneous clouds or shells at this distance with the required amount of ionized material and clumpiness as origin of the RISS screen.

Present galactic surveys of e.g. dust, HI, HII, Hα provide additional information and enable us to search directly for observational evidence of material in each individual source direction. From this we can deduce that nearly all our IDV-sources lie in regions of enhanced emission, while often longterm- or non-variable sources are located in regions of less emission or even in "holes". In addition, a high latitude molecular cloud (HLC) at a distance of only $\sim$ 100 pc and separated only a few degrees from 0917+624 and 0954+658 has been found (Magnani & Blitz & Mundy 1985). In this case, one could think of the ionized screen as extended envelop around the molecular cloud.

Using the Hα data from the WHAM-survey (Haffner et al. in prep.) one can derive lower limits for recombination line temperatures T_L in each individual source direction. Such temperatures are very low and will be hard to detect. However, lines of other interstellar material can be used to search for the RISS-screen (e.g. CO, HCO+).

4. Detection of CO in Front of 0954+658

During our 345 GHz monitoring at the HHT in May 2002 we were able to perform additional observations: a few spectral lines towards IDV sources has been observed in order to search for the nearby screen. Due to the existence of a CO-HLC near the IDV sources 0917+624 and 0954+658 we first used the 230 GHz SIS-receiver and were able to detect the CO(2-1)-line in the direction of the BL Lac object 0954+658. In Figure 1, a raster map of $7' \times 7'$ with a total observing time of $\sim$ 15 h is displayed. The map is centered on the position of 0954+658. A CO cloud eastern of the IDV source is seen extending in the north-south direction. 0954+658 is located in the outer western part of the cloud.

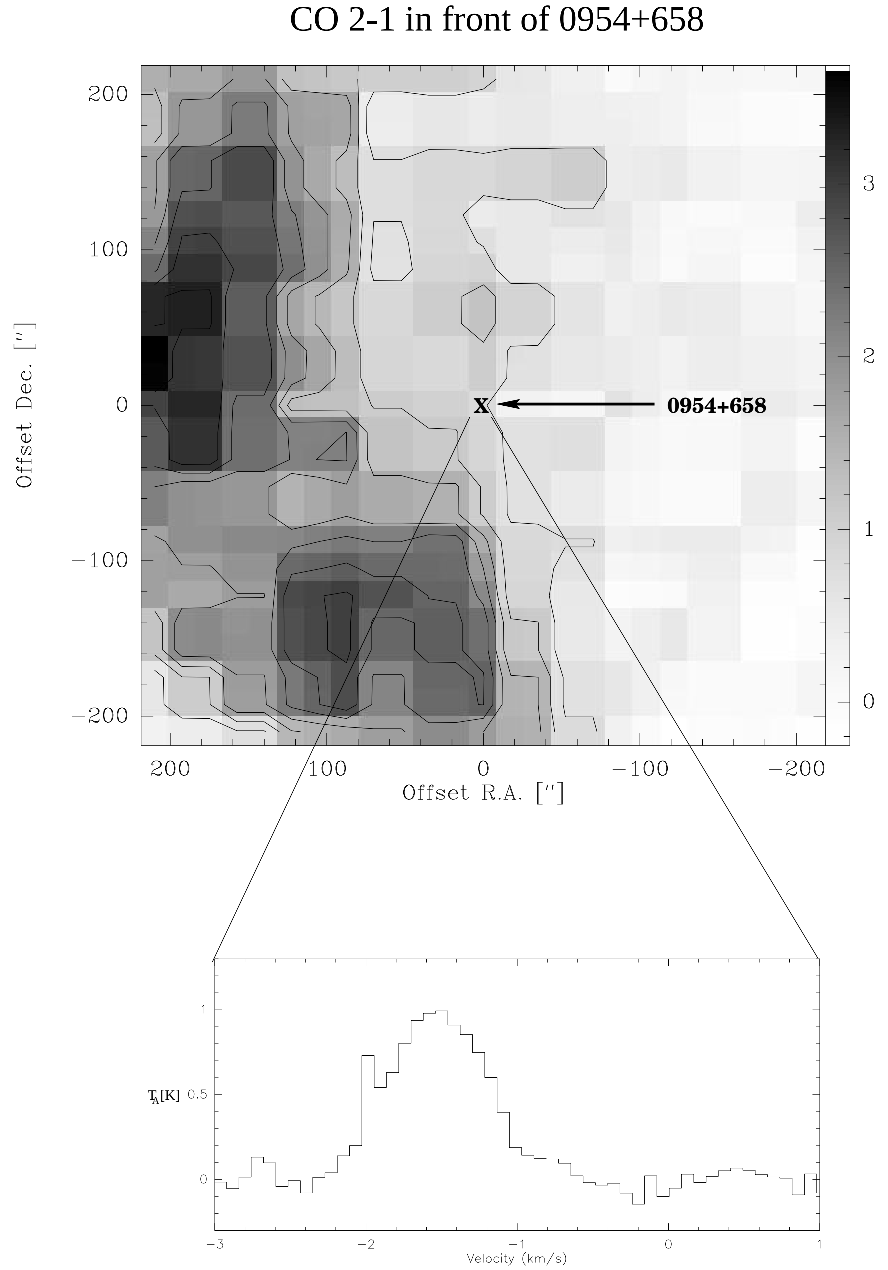

Fig. 1. The detection of a CO cloud in front of the BL Lac object 0954+658 is displayed. Upper map: the cloud is located eastern of 0954+658 and extends in the north-south direction with a minimum extension of 440″. The position of 0954+658 is marked with a cross. Contour levels are: 20, 30, 40, 50, 60, 70, 80, 90 and 100% of the maximum line emission (lowest contour $= 5\sigma$). The IDV source is located behind the outer CO-shell of the cloud. Lower panel: Spectrum at the position of 0954+658. The Intensity of the line is $T_A = 1.005K$ at a LSR velocity of $v = -1.54\,\mathrm{km\,s^{-1}}$.

5. Molecular Clouds as Harbor of the Scattering Material in Front of IDV sources ?

The larger HLC located near 0954+658 and 0917+624 is part of the Ursa Major clouds (Heithausen et al. 1993). Assuming the CO cloud in Figure 1 belongs also to this cloud complex, the distance to our detected object should not much further away than $\sim$ 100 pc. This fits nicely with the expected distance coming from RISS for typical time scale seen in this source of $\sim$10 hr. Since we have to search for ionized material, further spectral line observations have to be done (e.g. HCO+, RRL). 0954+658 resides behind the outer shell of the cloud in Figure 1. It seems quite plausible to think about an ionized shell or envelop at this position surrounding the cloud and acting as "shield" against the interstellar radiation field. Additional observations of HCO+ and H30α on the line of sight to the BL Lac object have been done and are still inconclusive but with hints of weak lines (Fuhrmann et al. in prep.). Since such lines are expected to be extremely weak, new observations with higher sensitivity are necessary (IRAM 30m).

0954+658 is of particular interest. This source was the first object in which a variability pattern resembling an extreme scattering event (ESE) was seen (Fiedler et al. 1987). Such events occur, when an isolated inhomogeneity (plasma lens) in the ISM passes through the line of sight to the extragalactic object. Such event causes ray path distortions and leads to dramatic flux density variations. In March 2000 an even more rapid ESE in 0954+658 has been observed (Cimò et al. 2002). In view of our recent findings such event suggests a very clumpy and extremely turbulent outer envelop or boundary layer around the CO cloud in Figure 1.

In order to identify CO clouds as origin of the scattering material responsible for RISS, present CO surveys provide additional information (Hartmann, Magnani & Thaddeus, 1998). Comparing the positions of all our IDV sources in the northern galactic hemisphere with the positions of HLCs it turns out that extremely often IDV sources are located near ($\leq 5° - 10°$) CO clouds or cloud complexes. This has to be investigated in more detail and will be discussed elsewhere (Fuhrmann et al. in prep.).

6. Summary

During the first half of 2002 we started two new observational approaches: a search for high frequency IDV (32 GHz and 345 GHz) and the attempt to detect directly the possible foreground screen via spectral line observations. Since in both cases the data reduction is still in progress, preliminary results show: 1) if confirmed, at least the BL Lac object 0716+714 seems to show sub-mm IDV. This can not be explained by RISS and must be due to intrinsic mechanism. 2) a CO cloud in the direction of 0954+658. Such high latitude clouds could serve as the origin of the scattering material producing interstellar scintillation. This has to be confirmed by additional investigations of ionized material, like ionized HCO or the detection of RRCS. A further option could be Faraday rotation measures on the line of sight to the source compared with those measured a few degrees away.

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