EXTERNAL CONTROL OF SATURN KILOMETRIC RADIATION: VOYAGER 1 AND 2 STUDIES

H. O. Rucker*

Abstract

The influence of the solar wind and the interplanetary magnetic field on the Saturn Kilometric Radiation (SKR) was analysed using Voyager 1 and 2 data from the Plasma Science experiment, the Magnetometer experiment, and the Planetary Radio Astronomy experiment. As found by Desch (1982) and Desch and Rucker (1983) the solar wind ram pressure and the associated quantity, the solar wind kinetic energy flux, are the primary drivers for initiating SKR. This result got additional proof by studying those periods, where the planet Saturn was immersed in the far distant Jupiter tail (Kurth et al., 1982). This screening off the solar wind caused several total SKR dropouts down to the Voyager 2 receiver threshold level (Desch, 1983). These papers and the most recent investigations concerning the external control of SKR will be reviewed and special emphasis is laid on the discussion of some inherent problems and open questions.

1 Introduction

One of the most recent findings in the exploration of our solar system and its planets was the detection of Saturn's radio wave emissions. Still within the reach of strong Jupiter radio noise, but close enough at Saturn to detect a true Saturnian radio signature both Voyager spacecraft brought evidence of a Saturnian kilometric radiation (SKR) since early January 1980 (Kaiser et al., 1980). On the basis of several selection criteria (signal energy level, light time delay between both Voyagers, etc.) a number of SKR events revealed a first insight into the properties of this radio emission. As an example of an SKR event Figure 1 shows simultaneous Voyager 1 (V1) and Voyager 2 (V2) observations as measured by the Planetary Radio Astronomy (PRA) experiment. In the bottom panels of each dynamic spectrum set the total emitted power is displayed in terms of a gray scale, black indicating maximum intensity, whereas in the top panels a white area represents right hand (black – left hand) polarization of the emitted radio wave.

*Space Research Institute, Austrian Academy of Sciences, Lustb"uhel Observatory, 8042 GRAZ, Austria

Thereafter continuous SKR measurements revealed a right hand polarized emission from the Northern Saturnian hemisphere (left hand from the Southern hemisphere) in the extraordinary mode. The observed SKR frequency is within the range of 3 kHz to about 1200 kHz and the peak flux density, normalized to a distance of 1 AU reaches values as high as $3 \cdot 10^{-19}$ Wm^{-2} Hz^{-1} around 150 to 175 kHz (Kaiser et al., 1981; 1984).

Concerning the periodicities of SKR a 20 dB intensity modulation occurs at a period of about 10.66 hours, which is attributed to the rotation period of Saturn (Desch and Kaiser, 1981). A probable satellite modulation of SKR like the Io–control on the Jovian decametric radio emission is found to be rather episodic. A transitory control of SKR by the Saturnian satellite Dione seems to be real at a periodicity of 65.7 hours (Kurth et al., 1981; Warwick et al., 1982).

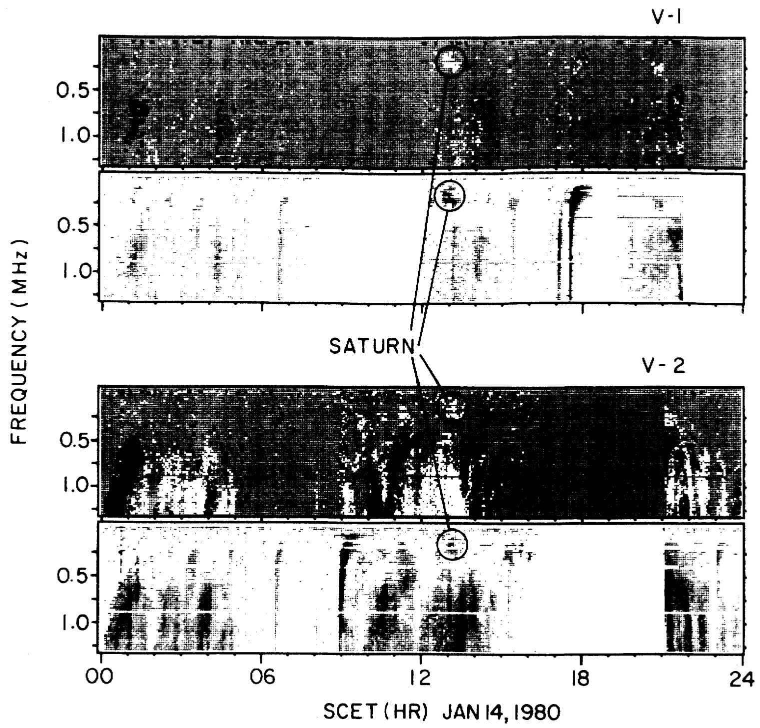

Figure 1: Dynamic spectra from Voyager 1 (V1) and Voyager 2 (V2) showing simultaneous observations of Saturnian kilometric radiation. The two panels of each set indicate total emitted power (bottom) and polarization (top): white representing right hand and black representing left hand polarization (from: Kaiser et al., 1980).

A further, and regarding the stimulation of SKR important periodicity in the SKR modulation is found at about 25 days, which is the solar rotation period as seen from Saturn. This and the fact that the SKR source location is found in the Northern and Southern dayside magnetospheric cleft regions (Kaiser and Desch, 1982a; Genova, 1984) with an almost free access for solar wind particles reaching these SKR source regions (see Figure 2), lead to the first indication of a correlation between variations in the solar wind and the level of SKR activity (see Figure 3; Desch, 1982). One basis of an accurate quantitative measure of SKR and extended to a comprehensive number of solar wind quantities this evidence for solar wind control of SKR was confirmed by subsequent investigations

(Desch and Rucker, 1983, 1985; Rucker and Desch, 1985). These papers describe in detail the apparent influence of the solar wind on SKR and provide a working hypothesis on a possible stimulation mechanism.

In the context of these results and the most recent findings concerning the external control of SKR the purpose of the present paper is to give further insight in the inherent problems and to discuss some still open questions.

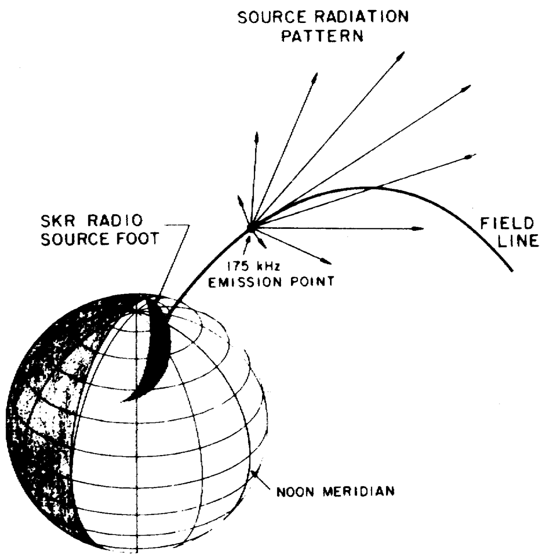

Figure 2: SKR source location in the Northern Saturnian hemisphere. The emission beam follows a three–dimensional pattern symmetrically oriented around a given magnetic field line (from: Kaiser and Desch, 1982).

2 Observations and Preparation of Data

The study on the influence of the solar wind and the interplanetary magnetic field on the Saturnian kilometric radiation made use of three experiments onboard of the Voyager spacecraft: the Plasma Science experiment (PLS), the Magnetometer experiment (MAG) and the Planetary Radio Astronomy experiment (PRA).

The PRA receiver scanned the radio waves in the high frequency band (128 channels) and low frequency band (70 channels) each 6 seconds. Within this low frequency range, which extends from 1.2 kHz up to 1320 kHz, the Saturn kilometric radiation was observed. As can be seen from Figure 1 this frequency range also covers strong Jovian kilometric as well as type III solar radio emissions, therefore a precise selection has to eliminate non–SKR bursts.

The final SKR radio energy profile, as displayed in the top panels of Figure 4 (for V1) and Figure 5 (for V2), is the result by integrating the observed SKR flux densities over the emission frequency range and then adding over one Saturn rotation period, i.e. over 10.66 hours. Within this rotation period the emitted SKR power exhibits a characteristic

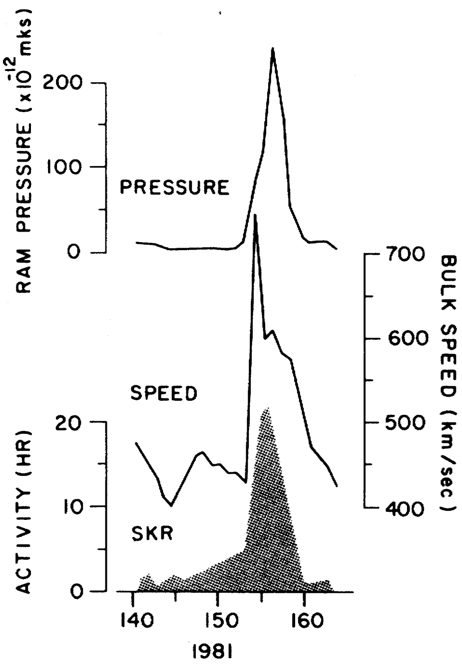

Figure 3: 24–hour averages of the solar wind ram pressure and bulk speed profiles, propagated from V2 to Saturn, and the SKR activity, during a 24 days interval in 1981. Pressure and speed enhancements coincide with an also increased SKR emission level (from: Desch, 1982).

power cycle with a maximum power at 90° SLS (Saturn longitude system; Desch and Kaiser, 1981). Therefore the 10.66–hours averaged SKR values, which are plotted in the figures, are centered at times corresponding to this rotation phase of maximum power. The SKR energy is normalized as it would appear at a distance of 1 AU. The SKR energy profiles as shown in the figures result from different flux density thresholds: For V1 (V2) only those values are considered which exceeded $3.5 \cdot 10^{-21}$ Wm^{-2} Hz^{-1} ($13 \cdot 10^{-21}$ Wm^{-2} Hz^{-1}) 1 AU.

As can be seen from both Figures 4 and 5 the SKR events with energy values higher than $5 \cdot 10^{12}$ Joules per steradiant are more frequent in the V1 profile. Considering a comparable time interval before the respective closest approach to Saturn (e.g. 170 days) the V1–SKR peaks outnumber the V2–SKR peaks at least by a factor of 4. This obviously weaker SKR activity during the V2 preencounter period is a consequence of Saturn immersions in the distant Jovian magnetic tail (Desch, 1983), as explained below in detail.

In order to visualize a relationship between the solar wind and SKR and to enable a quantitative analysis on any external control of SKR by the solar wind both the cause and effect time series must be established at a common location, which is the interaction point of the solar wind with the Saturnian magnetosphere. For any SKR event the time difference between the spacecraft observation and the actual radio emission time at Saturn is negligible compared to the averages used in this study (10.66 hours). But the time difference between the observation of solar wind features and their actual arrival times at the interaction point is of a duration of at least 15 Saturn rotations for V1 (12 rotations for V2) at the beginning of each analysed interval. So it is necessary to know

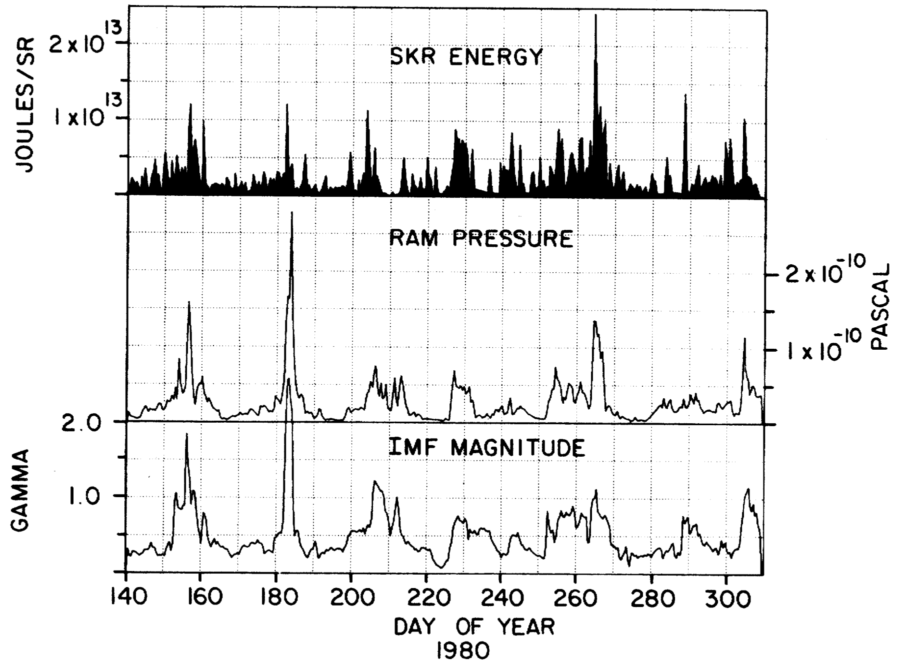

Figure 4: Voyager 1 observations of the Saturn kilometric radiation, the solar wind density and bulk velocity, combined to the solar wind ram pressure, and the interplanetary magnetic field magnitude. Both the solar wind parameters are shifted in time, as they would appear at the interaction point at the Saturnian magnetosphere (from: Desch and Rucker, 1983).

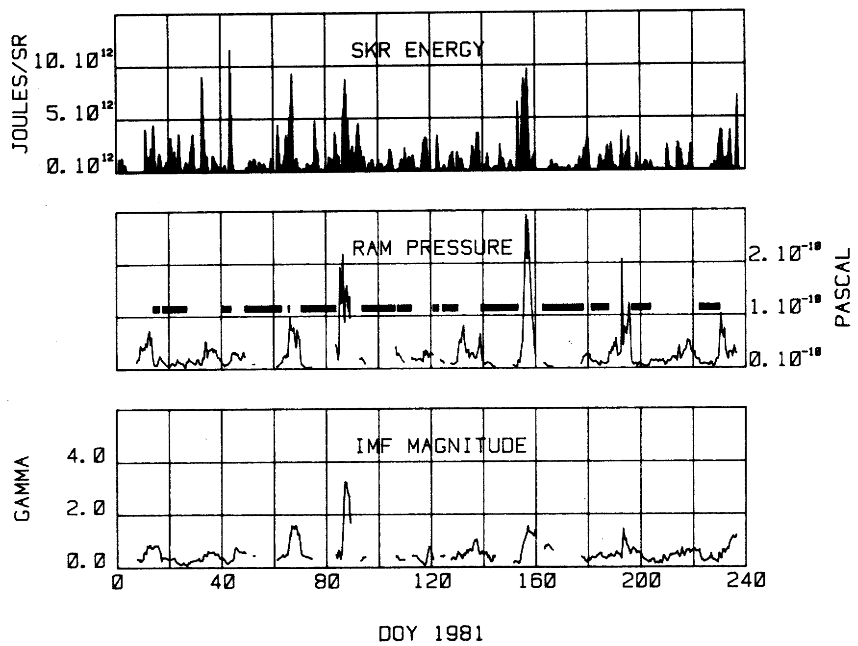

Figure 5: Voyager 2 observations from the PRA–, PLS–, and MAG–experiment. The frequent interruptions in the solar wind parameter profiles are due to the V2–Jovian magnetotail encounters, which are indicated by the bars in the second panel (from: Rucker and Desch, 1985).

the solar wind parameter profile at a remote position.

The second and the bottom panels of Figures 4 (V1) and 5 (V2) show the solar wind ram pressure and the interplanetary magnetic field (10.66 hours running averages) as these parameters would appear at Saturn. The underlying procedure of this so–called "forward propagation" is a ballistic projection of the solar wind features considering both spacecraft and Saturn positions and the measured solar wind bulk velocity. A subsequent time reordering of the data within the time series accounts for high–speed solar wind streams arriving at Saturn before low–speed features. But the interaction of high– and low–speed solar wind streams is not taken into consideration, therefore this ballistic solar wind propagation carries some uncertainty into the analysis.

The level of inaccuracy on the solar wind propagation is examined in the paper by Desch and Rucker (1983). Investigations on the propagation of solar wind features between Voyager 2 and 1 over comparable distances during the Jupiter preencounter period revealed that the time difference between the lag time, resulting from cross correlation studies, and the expected delay time, resulting from ballistic propagation studies, was usually not exceeding 10 hours. This number was applied in the reliability check by adding a random number, between ±10.66 hours (= 1 Saturn rotation), to the solar wind feature propagation time from the spacecraft position to Saturn and by analysing the change in the correlation between SKR and any solar wind parameter. The observed decrease in the correlation coefficient might not affect the conclusions, but should be a reason to look for improved solar wind propagation models, such as developed recently (Kömle and Lichtenegger, 1984).

Unlike the V1 solar wind profiles (Figure 4) the corresponding panels of Figure 5 show frequent interruptions, which could not be bridged by interpolation as done for V1. Though both V1– and V2– data sets have been prepared in the same way, they have to be analysed by different treatments due to these gaps, which will be described in the following section.

3 Saturn Kilometric Radiation During Normal Solar Wind Conditions

Since the generation mechanism of SKR is still under discussion (with the Maser Synchrotron Instability as a candidate process for the SKR generation, Lecacheux and Le Queau, 1985) the trigger parameter for the stimulation of SKR might be found under a number of solar wind quantities and combinations, which are known to be important in driving magnetospheric and auroral processes. In order to examine any relationship to SKR a time series of each of these quantities was generated and treated in the manner as described in the previous section. Solar wind plasma parameters as solar wind speed V, density ρ, ram pressure P and kinetic energy flux ρV^3 as well as parameters incorporating magnetic properties like the interplanetary magnetic field (IMF) magnitude B, the so–called Akasofu–parameter ϵ (Akasofu, 1983), the interplanetary electric field $|V \times B|$, the IMF component B_z (aligned to the Saturnian dipole direction), the IMF component B_y (almost aligned to IMF sector boundaries at the orbit of Saturn), and some more quantities resulting from various combinations, were analysed using Voyager 1 (Desch and Rucker, 1983) and Voyager 2 (Rucker and Desch, 1985; Desch and Rucker, 1985) data.

The main difference between both data sets is the occurrence of the Jovian magnetotail during the V2–Saturn preencounter period, which decisively changed the solar wind conditions. Both the V2 spacecraft and Saturn were engulfed by Jupiter's magnetotail several times, a phenomenon, which occurs to Saturn with a periodicity of about 19.9 years due to the orbital periods of Jupiter and Saturn (Desch, 1983).

Using "normal" solar wind conditions in the investigation on the solar wind – SKR relationship, the so–called "Jupiter tail periods", which are indicated by bars in the second panel of Figure 5, had to be eliminated. More details on the tail indicators and the SKR effects due to these changed solar wind conditions will be explained subsequently.

The continuous solar wind and SKR time series, as observed from V1, enabled a cross correlation study, whereby some correlation coefficients (in terms of the standard deviation) are plotted in the first columns of the Figures 6 and 7 (Desch and Rucker, 1983). However, due to the frequent "Jovian magnetotail" interruptions in the V2 time series a superposed epoch method, the so–called CHREE analysis (Bell and Glazer, 1958; Barrow, 1978) was applied. Using the solar wind parameters as epoches against SKR the second columns in the Figures 6 and 7 exhibit the relationship between the solar wind and the emitted SKR energy with respect to time as well as amplitude, as measured by V2 (Rucker and Desch, 1985).

Since the solar wind profiles are already propagated from the spacecraft position to the point of interaction at Saturn, the parameters with a correlation peak lag time of more than 1 Saturn rotation must be rejected. Additionally the used convention in the cross correlation study requires that negative lag times violate physical causality.

An evaluation of the V1 results yields that out of those parameters with a zero correlation peak lag time the quantities ρv^n, $1 \leq n \leq 3$ exhibit a tremendous superiority in predicting SKR. The solar wind momentum ρV, the ram pressure ρV^2 and the kinetic energy flux ρV^3 show peak correlation coefficients almost reaching 6σ (standard deviation). These findings are confirmed by the V2–CHREE analysis, where an almost one–to–one correspondence between the profiles of the ram pressure and kinetic energy flux, and the respective SKR energy can be seen. The importance of these ρV^n–quantities and the minor influence of other solar wind parameters or parameter combinations, especially those with magnetic properties, have certain implications on the theory of the SKR stimulation, which will be discussed in the last section.

Some further topics should be addressed in the context with the used analysis and the results. It is worth mentioning that the solar wind quantities have an inherent relationship between each other. This means that a certain quantity might have a good correlation with SKR, because it is related to another quantity, which is regarded as the primary driver of SKR. Within the frame of the present studies on the external control of SKR this problem of intercorrelation is yet not fully investigated.

Another problem concerns the possibility that still other combinations of solar wind quantities might exhibit a closer relationship to SKR than the ρV^n–combinations. Although

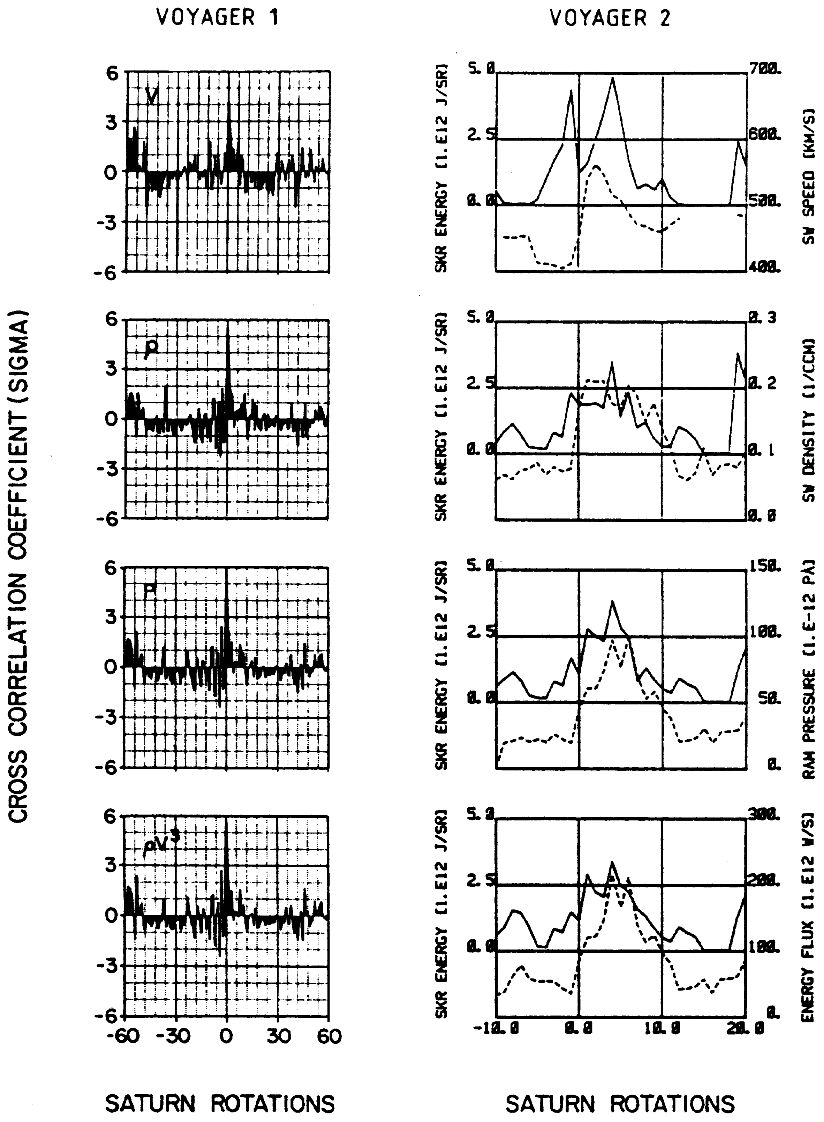

Figure 6: Results from the cross correlation (V1) and CHREE analysis (V2) showing the relationship between SKR and some solar wind plasma parameters (adapted from Desch and Rucker, 1983; Rucker and Desch, 1985).

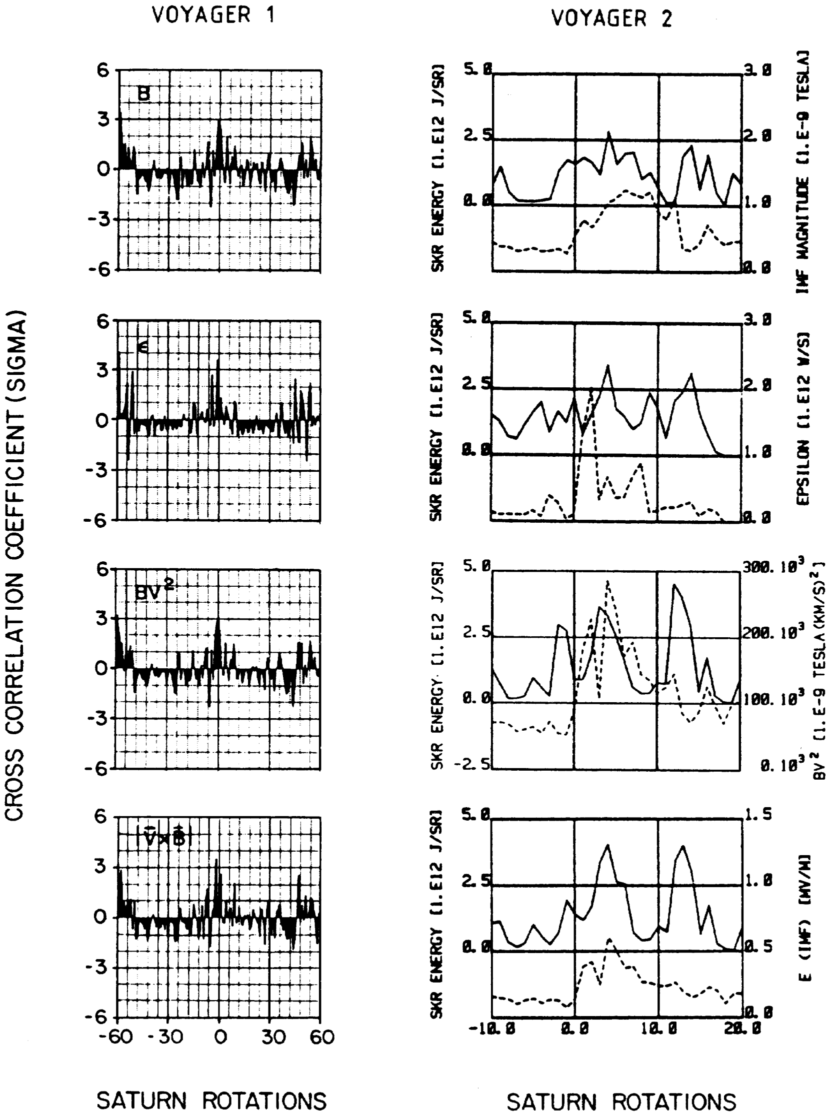

Figure 7: Cross correlation (V1) and CHREE analysis (V2) results displaying the relationship between SKR and some solar wind parameters, which incorporate IMF properties (adapted from Desch and Rucker, 1983; Rucker and Desch, 1985).

conceding the above results a high degree of reliability some attention should be focussed to the suggestion that additionally to the solar wind ram pressure and energy flux there might be some further condition relevant in stimulating SKR, which is not yet specified in detail. This suggestion is strengthened by means of Figure 8 displaying Voyager 2 measurements during a period, in which any error due to solar wind propagation effects is minimized. Two SKR events, now given in Watts per second as an isotropically emitted power, at DOY (day of year) 180 and DOY 193 in 1981, which have a comparable power of about $1.2 cdot 10^9$ W/s, coincide in time with solar wind kinetic energy fluxes different by an order of magnitude. (At this point it should be mentioned that the output of SKR power is 5 orders of magnitude below the input of solar wind kinetic energy per second over the entire Saturnian magnetospheric cross section, which is the usually known conversion efficiency rate for solar wind energies fed into magnetospheric processes).

For reasons of comparison the Akasofu–parameter ϵ is plotted in the bottom panel of Figure 8 describing the interplanetary Poynting flux entering the magnetosphere (Akasofu, 1983):

$$\epsilon = VB^2 \sin^4 \left(\frac{\Theta}{2}\right) l_0^2$$

(V = solar wind bulk velocity, B = IMF magnitude, Θ = polar angle of the IMF, l_0 = magnetospheric cross section). This energy flux containing both the IMF magnitude and direction (for our purposes ϵ is redefined and adjusted to Saturn's dipole direction) is known as an energy coupling function and correlates with the power consumption in the magnetosphere (Kan et al., 1980). The V1– and V2–results on the relationship between ϵ and SKR (Figure 7) demonstrate a minor importance of this parameter in stimulating SKR. Recently the Akasofu–parameter is called in question to a certain extent (Vasyliunas, 1982; Rossberg, 1984) and new forms of a solar wind input parameter are introduced (Bargatze et al., 1984). The question of whether or not a new energy coupling function might result in an improved relationship to SKR is still left open.

4 Saturn Kilometric Radiation During Jovian Magnetotail Encounter Periods

A number of arguments provided evidence of multiple immersions of the Voyager 2 spacecraft in the distant Jovian magnetic tail. The primary signature in the Voyager 2 plasma wave data during such encounter periods was the Jovian nonthermal continuum radiation with a spectral range from a few hundred Hz to several tens of kHz (Kurth et al., 1982). Besides the geometry of the V2 trajectory approaching the radial sun–Jupiter line (with an increased probability of tail encounters), further indicators for a tail event were magnetic field measurements corresponding to the field orientation due to the tail direction and observations of low plasma densities. Apparently the Jovian magnetospheric tail is a plasma–depleted region shielding off the solar wind and tracing the Jovian continuum radiation within the magnetotail.

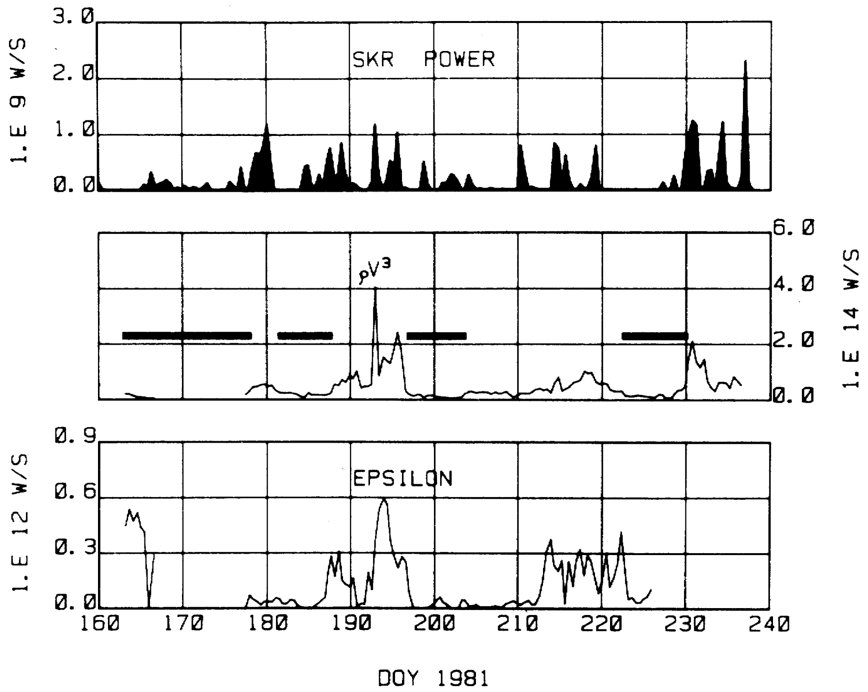

Figure 8: Saturn kilometric radiation and solar wind quantities as measured by Voyager 2 during the last 78 days before closest approach to Saturn. The three panels display isotropic SKR power, solar wind kinetic energy flux, and the Akasofu-parameter ϵ. The bars in the second panel indicate Jovian magnetotail encounter periods.

While Voyager 2 obviously was within the Jovian magnetic tail, the above mentioned arguments are not necessarily sufficient for a proved immersion of Saturn in Jupiter's tail. Evidence of this phenomenon was found by repeated total dropouts of SKR (Desch, 1983).

Figure 9 shows the emitted SKR energy per rotation during an interval from DOY 110, 1981 through DOY 244, 1981, which also includes a few days after the V2–Saturn closest approach. Due to the decreasing spacecraft–Saturn distance the receiver becomes more sensitive to weaker Saturn radio signatures and the minimum detectable radio energy for the V2–PRA receiver (indicated by the dashed line in Figure 9) also decreases.

As can easily be seen from Figure 9 most of the time the SXR energy remains above a level of about $7.5 \cdot 10^{11}$ Joules per rotation, whereas at certain instants a total dropout of SKR occurs as indicated by the shaded areas. Desch (1983) could also show that during the Voyager 1 Saturn preencounter period no comparable SKR dropout occurred and that the SKR energy remained well above the V1–detection threshold. The uniqueness of SKR dropouts evident in the V2 data is consistent with the fact that the Saturn kilometric radiation is controlled or even driven by the solar wind ram pressure and kinetic energy flux. (Desch and Rucker, 1983; Rucker and Desch, 1985). Since both the plasma density and velocity are low inside the Jovian magnetotail, consequently the ram pressure and kinetic energy flux are extremely low as compared with the normal solar wind conditions.

A direct association of SKR dropouts with the Jovian magnetotail events can be derived

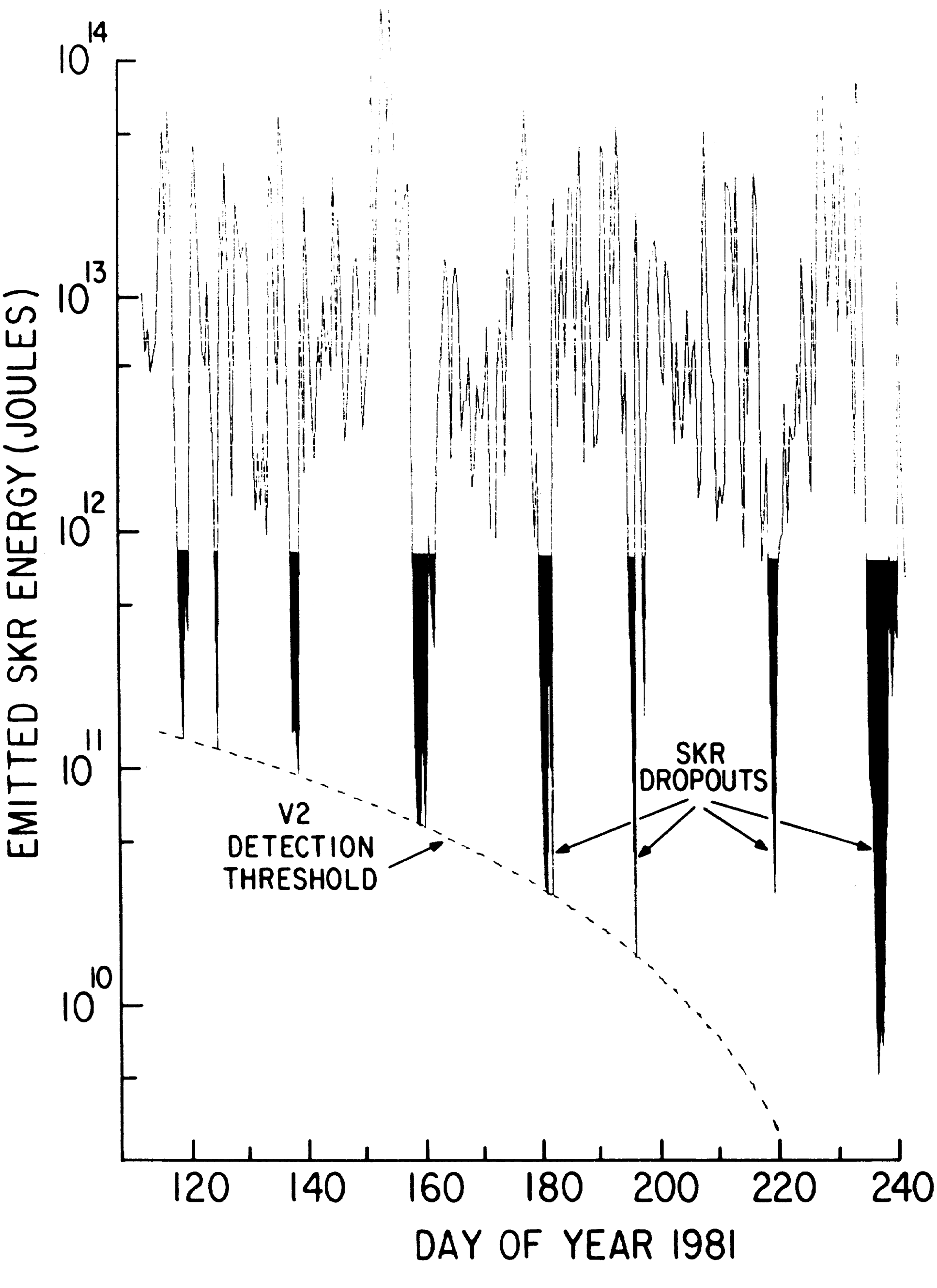

Figure 9: SKR energy per Saturn rotation during the V2–Saturn preencounter period. The decrease of SKR energy down to the V2–PRA receiver detection threshold (shaded areas), is unique for the V2 data and does not occur during the V1–Saturn preencounter period (from: Desch, 1983).

from Figure 10 showing a superposed epoch analysis of SKR dropouts and the occurrence of low density plasma events. All episodes but the last SKR dropout as shown in Figure 9, are summarized and plotted against the plasma density profile. On the average the SKR energy abruptly decreases over 2 orders of magnitude, from about 10^{13} Joules per rotation down to 10^{11} Joules per rotation. This is accompanied by a plasma density decrease from a few 10^2 cm^{-3} down to about 10^3 cm^{-3}. (As tabled by Kurth et al. (1982) a so–called "tail" event is defined by a plasma density below 0.03 cm^{-3} over at least 6 hours, and a "core" event by a density below 0.01 cm^{-3}. The bars in the second panel of Figures 5 and 8, respectively, indicate "propagated" tail events, i.e. low density events as measured by the V2–Plasma Science (PLS) experiment, and then ballistically propagated to the position of Saturn.)

While these tail–related SKR dropouts confirm the solar wind driven SKR, a still unsolved problem appeared in the SKR dropout–low plasma density correspondence. As visible in Figure 10 the onset of both the SKR dropout and plasma decrease occurs within a day (their respective start times are 1.75 days and 2.5 days before the zero epoch, which is defined as the first rotation with energy per rotation below $7.5 \cdot 10^{11}$ Joules/rotation), but the recovery of both parameters back to normal levels occurs on different time scales. Throughout the analysis a premature recovery of the SKR is observed, which complicates any explanation.

The idea that SKR might react on the change of a solar wind quantity rather than on the quantity itself is relevant in the discussion of the premature SKR recovery. Although the cross correlation between the time derivative of some solar wind quantities and the SKR energy was performed in the V1–study analysing normal solar wind conditions (Desch and Rucker, 1983), which yielded less good correlation coefficients, an investigation on the external control of SKR around the SKR dropout events seems to be still necessary.

5 Conclusions

In the light of the known results on the external control of SKR it is suitable to distinguish the "normal" solar wind periods from those, which are "contaminated" by the Jovian magnetotail. Using the periods with normal solar wind conditions from the Voyager 2 data both V1– and V2–investigations conformably yielded the following: The most strongly interaction occurs between the solar wind quantity ρV^n, $1 \leq n \leq 3$, and the SKR energy, whereby solar wind quantities incorporating properties of the interplanetary magnetic field show insignificant results in stimulating SKR.

A direct stimulation mechanism of the Saturnian kilometric radiation might be possible by a continuous mass transfer from the solar wind into the low–altitude dayside cusps of the Saturnian magnetosphere. This process might be accomplished by eddy convection, which depends on solar wind ram pressure fluctuations. Then an increased plasma transfer might lead to an amplification of the SKR power (Desch and Rucker, 1983).

Although the chain of processes seems to be feasible the time scales of the involved processes differ to a certain extent. For lack of direct and in–situ measurements in the

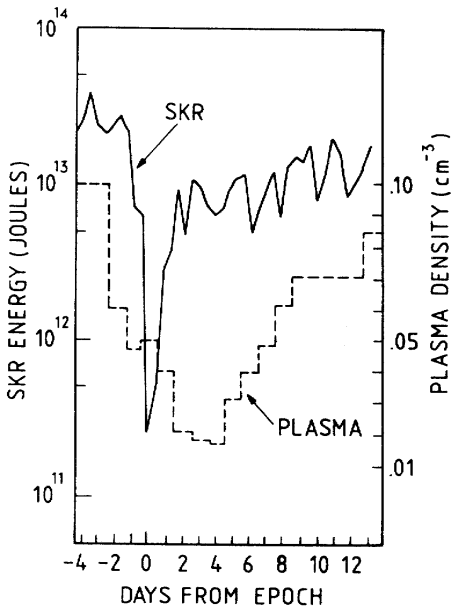

Figure 10: SKR dropouts and low density plasma events analysed by the method of superposed epochs. The SKR dropouts, as observed by V2, coincide with the immersion of Saturn into Jupiter's distant magnetotail (from: Desch, 1983).

dayside Saturnian cleft regions and due to the high degree of complexity in describing the SKR generation mechanism a comprehensive and quantitative model of the solar wind energy input, conversion and SKR energy output is still far from realization.

Finally an idea proposed by Kaiser and Desch (1982b) should round off the discussion on the relationship between the solar wind and SKR. Since a varying solar wind ram pressure always changes the dayside shape of a planetary magnetosphere it might be possible that pressure enhancements might change the field line structure around the SKR generation region and therefore might change the beaming of the SKR. At the spacecraft position this would directly lead to modulations of SKR. But the sole explanation for the observed SKR modulation cannot be claimed by this idea, because an argument against it is the rather small dB–change across the radio emission cone contrary to the observed 20 dB SKR modulation. Of course, this is not to say that the SKR beaming effect does not contribute to the observed SKR modulations.

Further insight into the dynamics of the Saturnian magnetosphere and the relationship between the solar wind and the Saturn kilometric radiation will be provided by the ESA/NASA Cassini mission, which should facilitate to answer some of the still many open questions.

Acknowledgements: I am grateful to M. D. Desch, NASA/GSFC, for helpful discussions and to N. F. Ness, Voyager Magnetometer team principal investigator, and to H. S. Bridge, Plasma Science team principal investigator, for making the necessary data available for this study. I am also grateful to J. K. Alexander, NASA/GSFC, to S. J. Bauer, University Graz and Austrian Academy of Sciences, to J. Ortner, Austrian Solar and Space Agency, and to the Provincial Government of Styria for their assistance in preparing and performing the International Workshop on "Planetary Radio Emissions", Graz, July 1984.

6 References

Akasofu, S.-I., Solar–wind disturbances and the solar wind–magnetosphere energy coupling function, *Space Sci. Rev.*, **34**, 173, 1983.

Bargatze, L. F., R. L. McPherron, D. N. Baker, and E. W. Hones, Jr., The application of dimensional analysis to the problem of solar wind – magnetosphere energy coupling, *Proc. Conf. Achievements of the IMS*, ESA SP–217, p. 157, 1984.

Barrow, C. H., Jupiter's decametric radio emission and solar activity, *Planet. Space Sci.*, **26**, 1193, 1978.

Bell, B. and H. Glazer, Sunspots and Geomagnetism, *Smithsonian Contr. Astrophys.*, **2**, 161, 1958.

Desch, M. D., Evidence for solar wind control of Saturn radio emission, *J. Geophys. Res.*, **87**, 4549, 1982.

Desch, M. D., Radio emission signature of Saturn immersions in Jupiter's magnetic tail, *J. Geophys. Res.*, **88**, 6904, 1983.

Desch, M. D. and M. L. Kaiser, Voyager measurement of the rotation period of Saturn's magnetic field, *Geophys. Res. Lett.*, **8**, 253, 1981.

Desch, M. D. and H. O. Rucker, The relationship between Saturn kilometric radiation and the solar wind, *J. Geophys. Res.*, **88**, 8999. 1983.

Desch, M. D. and H. O. Rucker, Saturn radio emission and the solar wind: Voyager 2 studies, COSPAR proceedings, *Adv. Space Res.*, **5(4)**, 333, 1985.

Genova, F., Source location of planetary radio–emissions, *International Workshop on "Planetary Radio Emissions"*, Proceedings, Graz, 1984, this issue.

Kaiser, M. L. and M. D. Desch, Saturnian kilometric radiation: source locations, *J. Geophys. Res.*, **87**, 4555, 1982a.

Kaiser, M. L. and M. D. Desch, Beaming properties of Saturnian kilometric radiation (abstract), *EOS Trans. AGU*, **63**, 1068, 1982b.

Kaiser, M. L., M. D. Desch, J. W. Warwick, and J. B. Pearce, Voyager detection of nonthermal radio emission from Saturn, *Science*, **209**, 1238, 1980.

Kaiser, M. L., M. D. Desch, and A. Lecacheux, Saturnian kilometric radiation: statistical properties and beam geometry, *Nature*, **292**, 731, 1981.

Kaiser, M. L., M. D. Desch, W. S. Kurth, A. Lecacheux, F. Genova, B. M. Pedersen, and D. R. Evans, Saturn as a radio source, in *Saturn*, edited by T. Gehrels and M. S. Matthews, The University of Arizona Press, p. 378, 1984.

Kan, J. R., L. C. Lee, and S.-I. Akasofu, The energy coupling function and the power generated by the solar wind–magnetosphere dynamo, *Planet. Space Sci.*, **28**, 823, 1980.

Kömle, N. I. and H. I. M. Lichtenegger, Shock formation and decay in hydromagnetic flows with mass loading, *Comp. Phys. Comm.*, **34**, 47, 1984.

Kurth, W. S., D. A. Gurnett, and F. L. Scarf, Control of Saturn's kilometric radiation by Dione, *Nature*, **292**, 742, 1981.

Kurth, W. S., J. D. Sullivan, D. A. Gurnett, F. L. Scarf, H. S. Bridge, and E. C. Sittler, Jr., Observations of Jupiter's distant magnetotail and wake, *J. Geophys. Res.*, **87**, 10.373, 1982.

Lecacheux, A. and D. Le Queau, Saturnian kilometric radioemission, *J. Geomagn. Geoelectr.*, in press, 1985.

Rossberg, L., A close look at the solar wind–magnetosphere interaction, *J. Geophys. Res.*, **89**, 2162, 1984.

Rucker, H. O., and M. D. Desch, Influence of the solar wind/interplanetary medium on Saturnian kilometric radiation, *J. Geomagn. Geoelectr.*, **42**, 1351, 1990.

Vasyliunas, V. M., J. R. Kan, G. L. Siscoe, and S.-I. Akasofu, Scaling relations governing magnetospheric energy transfer, *Planet. Space Sci.*, **30**, 359, 1982.

Warwick, J. W., D. R. Evans, J. H. Romig, J. K. Alexander, M. D. Desch, M. L. Kaiser, M. Aubier, Y. Leblanc, A. Lecacheux, and B. M. Pedersen, Planetary Radio Astronomy observations from Voyager 2 near Saturn, *Science*, **215**, 582, 1982.

Discussion

Question:

In your superposed epoch analysis you used the solar wind parameters as the epoch against the SKR energy. How did you define the zero epoch?

Rucker:

The zero epochs are determined by those points of time, where the time derivative of the solar wind time series reached or exceeded the three sigma level (sigma = standard deviation).

Question:

From several terrestrial observations it is known that the cusp region varies not with the magnetic field component but with the variation of the field component. There is a differential dependence. Did you consider the implications of this fact in your studies?

Rucker:

This concerns the problem of whether a solar wind quantity or its time derivative show a closer relationship to SKR. Till now this question is only partially analysed as explained above, but should be investigated especially in connection with the premature recovery of SKR during Jovian magnetotail events.