21. LIGHT OF THE NIGHT SKY / LUMIÈRE DU CIEL NOCTURNE

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1. INTRODUCTION

The light of the night sky is a difficult to disentangle mixture of tropospherically scattered light, airglow, zodiacal light (including the thermal emission by interplanetary dust particles), unresolved stellar light, diffuse scattering and emission by interstellar dust and gas, and finally an extragalactic component. It has the reputation of being a very traditional field of astronomy, which certainly is true if we look at the long history of the subject. The recent renewed interest in this topic, which continued during this triennium, appears mainly to come from three sources: – first from the impressive results of the IRAS and COBE infrared satellites. They brought to general consciousness the fact that the infrared sky is characterised by strong emission from interplanetary and interstellar dust, and made clear that this emission may interfere with the study of faint interesting sources. – then from the development of sensitive detectors and arrays for essentially all of the wavelength range to be covered in this report, from the Lyman limit to $\approx$ 300 μm. Now the difficult measurements of the ultraviolet diffuse radiation and of the extragalactic background light in the infrared cosmological windows around 3 μm and 200 μm have become feasible and state of the art projects. – finally, the threat to astronomical observations arising from man-made development and lighting has become important enough to further studies of uncontaminated and contaminated night sky brightnesses. This report will refer mainly to those areas and is meant to highlight noteworthy developments. It was prepared with the help of Drs. Bowyer and Mattila.

2. CONFERENCES AND REVIEWS

The following conferences, as their titles show, were relevant for the field of commission 21 although not all of them have been sponsored by it. Because of the different reviews contained in them, they give a wide and varied overview on the activity in this interdiscipinary field, independent of and complementing the present report:

- "Back to the Galaxy", eds. S.S. Holt and F. Verter. AIP Conference Proceedings No. 278, American Institute of Physics, Woodbury 1993.
- "The First Symposium on the Infrared Cirrus and Diffuse Interstellar Clouds", eds. R.M. Cutri and W.B. Latter. ASP Conference Series No. 58, Astronomical Society of the Pacific, San Francisco 1994.
- "Dust around young stars – how related to solar system dust?", extended summary by Martha S. Hanner in "Highlights of Astronomy", vol. 10, p. 349, Kluwer Academic Publishers, Dordrecht 1995. Joint Discussion No. 17 at the General Assembly in Den Haag, Netherlands, August 1993 (involving commissions 21 and 34).
- "Examining the Big Bang and diffuse background radiations", eds. M. Kafatos and Y. Kondo. Kluwer Academic Publishers, Dordrecht 1995. IAU Symposium No. 168 at the General Assembly in Den Haag, Netherlands, August 1993 (co-sponsored by commission 21).
- "Extragalactic background radiation", eds. D. Calzetti, M. Livio and P. Madau. Space Telescope Science Institute Symposium Series No. 7, Cambridge University Press, Cambridge 1995.
- "Unveiling the cosmic infrared background", ed. Eli Dwek. AIP Conference Proceedings 348, American Institute of Physics, Woodbury 1996. COBE workshop in College Park, Maryland, USA, April 1995.

I. Appenzeller (ed.), Reports on Astronomy, Vol. XXIIIA, 231–236.

- "Physics, chemistry, and dynamics of interplanetary dust", eds. Bo Å.S. Gustafson and Martha S. Hanner. ASP Conference Series No. 104, Astronomical Society of the Pacific, San Francisco 1996. IAU Colloquium No. 150 in Gainesville, Florida, USA, August 1995 (sponsored by commissions 21 and 22).

One more review article is of specific interest:

- M. S. Longair: "The Physics of Background Radiation", in 'The Deep Universe', eds. A.R. Sandage, R.G. Kron and M.S. Longair. Springer Verlag, Berlin/Heidelberg/New York 1995, p.317.

3. TOTAL NIGHT SKY BRIGHTNESS

Observations at La Silla, Chile from 1987 to 1988 (Mattila et al., A&A Suppl. 119, 153, 1996) and at Calar Alto, Spain from 1989 to 1995 (Leinert et al., A&A Suppl. 112, 99, 1995) confirmed that the sky brightness at a good observatory site is ≈ 22 mag/arcsec^2 in V and ≈ 23 mag/arcsec^2 in B. The authors also give a comparison with earlier measurements at other observatories, and they include absolutely calibrated sky brightnesses in eight intermediate bands between 390 nm and 820 nm. Nawar et al. (Earth, Moon and Planets 70, 133, 1995) and Osman (Thesis, Cairo 1996) measure the somewhat enhanced sky brightness at Kottamia observatory, Egypt, at 56 km from the big city of Cairo. The question of sky brightness contamination by man-made interference is generally of growing concern to the astronomical community (see, e.g. "The Vanishing Universe – adverse environmental impacts on astronomy", ed. D. McNally, Cambridge University Press 1994) and will be followed at the upcoming General Assembly in Kyoto, Japan, by a Joint Discussion.

4. ZODIACAL LIGHT

4.1. ULTRAVIOLET

Waller et al. (AJ 110, 1255, 1994) analyzed images obtained by the Shuttle-borne Ultraviolet Imaging Telescope in search of a cosmic background. Away from the galactic plane, the nighttime far-UV (FUV, 91.2 nm – 180 nm) backgrounds were confused by OI nightglow emission and possible photometric errors. The more tightly constrained near-UV (180 nm – 310 nm) intensities correlate with those predicted from optical measurements of the zodiacal light (Levasseur-Regourd and Dumont, A&A 84, 277, 1980), yielding a near-UV/Vis colour ratio of 0.5 ± 0.2 for the zodiacal light, where a value of 1.0 would correspond to solar colour. From these data, the limit for a possible isotropic extragalactic contribution is 300 photons cm^{-2} s^{-1} sr^{-1} Å^{-1}.

4.2. OPTICAL AND NEAR-INFRARED RANGE

The emphasis in optical zodiacal light studies has been on comparison of dust properties with comets (Levasseur-Regourd et al., A&A 313, 327, 1996) and asteroids (Goidet-Devel et al., Planet. Space Sci. 43, 779, 1995). The similarity in polarisation phase curves implies similarity in albedo and structural properties of the different dust ensembles. Otherwise, optical and near-infrared work concentrated on the innermost regions of interplanetary space. Observations of the solar corona at 2.12 μm during the total solar eclipse of July 11, 1991, were analysed (MacQueen and Greeley, ApJ 440, 361, 1995); they show a slower increase of brightness towards the sun than would be expected on the basis of standard models of interplanetary dust distribution. The cameras onboard the small space probe Clementine, launched on January 25, 1994, during the lunar orbiting phase of its flight took unfiltered wideband images of the inner zodiacal light (1° – 22° from the sun), which will allow to study the structure of the inner parts of the interplanetary dust cloud (Cooper et al., ASP Conf. 104, p. 333). Satellite SOHO, launched on December 2, 1995, with its large angle spectroscopic coronagraph LASCO (Brückner et al., Solar Phys. 162, 357, 1995), is obtaining detailed measurements from 30 $R_\odot$ down to the solar limb. It hopefully will resolve the long-standing uncertainty on the amount of polarisation of the F corona. Consequently, most modelling referred to aspects of the circumsolar dust properties and spatial distribution (Mann et al. A&A 291, 1011, 1994, Davidson et al., Planet.Space Sci. 43, 1395, 1995); see also the review by Mann (ASP Conf. 104, p. 315) and several contributions in the same proceedings volume. In the same spirit, plans for a close-in solar probe are being discussed (Randolph, Adv. Space Res. 17(3), 3, 1996).

4.3. MID- AND FAR-INFRARED

The COBE Diffuse Infrared Background Experiment (DIRBE, Silverberg et al., SPIE 2019, 180, 1993) has provided full-sky absolute brightness maps in ten photometric bands from 1.2 μm to 240 μum, and linear polarization maps at 1.2 μm, 2.2 μm, and 3.5 μm. DIRBE was the first dedicated space experiment to measure the IR sky brightness and its results have meant a quantum leap for quantitative studies of the IR sky brightness. This is true for the study of zodiacal light and interplanetary dust discussed here as well as for the study of galactic and extragalactic contributions summarised in section 5, where also additional general references on COBE are given.

The near-IR polarisation maps, of which preliminary results have been discussed by Berriman et al. (ApJ 431, L63, 1994), represent a new data base, important for future modelling of the dust cloud. Otherwise, the trend goes toward increasing structural detail in the interplanetary dust cloud, with most of the effects already known from IRAS. The representation of IRAS zodiacal light measurements by an *empirical formula* (Vrtilek and Hauser, ApJ 355, 677, 1995) has enabled Renard et al. (A&A 304, 602, 1995) to deconvolve the brightness contributions in a plane at 90° from the sun perpendicular to the ecliptic with help of their "nodes of lesser uncertainty" analysis. Decrease of temperature and increase of particle albedo with increasing height above the ecliptic plane require that the interplanetary dust cloud is composed out of at least two different populations.

The DIRBE data (see Kelsall et al., SPIE 2019, 190, 1993, for a first presentation) now are publicly available (Leisawitz, AIP Conf. 348, p.287). The final model for zodiacal light is so intimitely related to the determination of extragalactic background light that these two data products will be the last ones to be released. The resonant near-earth orbit circumsolar dust ring, postulated by Dermott et al. (Nature 369, 719, 1994) as source of a leading/trailing asymmetry in the IRAS data, has now been definitely confirmed from DIRBE data (Reach et al., Nature 374, 521, 1995), and traces of it have been found in optical data (Renard et al., ASP Conf. 104, p.329). Similarly, DIRBE also studied the asteroidal bands (Spiesman et al., ApJ 442, 662, 1995), the particles of which have a high albedo ($\approx$ 0.22), different from cometary material. Dynamical studies of these structures, which apparently are of asteroidal origin, led to the conclusion that about 1/3 of the interplanetary dust is of asteroidal origin (Dermott et al. in "Asteroids, Comets, Meteors 1993", eds. A. Milani and M. Di Martino, Kluwer, Dordrecht 1994, p.217). This fits the study of inclination distribution which was interpreted by Liou et al. (Planet. Space Sci. 43, 717, 1995) as indicating that about 2/3 of the interplanetary dust cloud are of cometary origin, but Mann et al. (Icarus 120, 399, 1996) questioned the high proportion of asteroidal dust on the basis of ULYSSES in-situ particle detections. An attempt is being made to recognise the interstellar dust particles detected with the Ulysses space probe (Grün et al, A&A 286, 915, 1994) by the particular pattern their trajectories might imprint onto the general infrared emission (Grogan et al., ApJ 1996, in press), an effect expected to be by an order of magnitude smaller than that of thee asteroidal structures.

For additional topics and references see the reviews of Levasseur-Regourd and Hauser in ASP Conf. 104, p.301 and p.309.

4.4. SCATTERING BY PARTICLES

Yu-lin Xu (Applied Opt. 34, 4573, 1995) has extended the Mie theory to the general case of an arbitrary incident wavefront. He used this generalisation to calculate the solution to the classical problem of light scattering by aggregates of an arbitrary number of arbitralily configured spheres, one possible approximation to the structure of real interplanetary dust particles. For other calculations of optical properties of dust particles see Muinonen et al. (J.Quant.Spectr.Rad. Transfer 1996, in press) and several presentations in the ASP 104 conference volume.

A broad-band microwave scattering facility, covering the size range from near the Rayleigh limit to geometric optics, has been set up by Gustafson (J.Quant.Spectrosc. Radiat. Transfer 55, 663, 1996). It is intended to allow the study of physically justified models of interplanetary dust particles and to test theoretical predictions of scattering by interplanetary dust like those of Xu mentioned above (Gustafson, ASP Conf. 104, p.401).

Devices for a direct *optical* study of the scattering properties of dust particles have been brought into operation by Combet and Lamy (ASP Conf. 104, p. 409) and Worms et al. (ASP Conf. 104, p. 415).

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5. GALACTIC AND EXTRAGALACTIC COMPONENTS

5.1. ULTRAVIOLET BACKGROUND (91.2 nm – 310 nm)

Reviews on the observational aspects of the FUV background ($\lambda < 180$ nm) have been presented by Henry and Murthy (STScI Symp. 7, p.51) and Henry (ASP Conf. 80, 56 ,1995), and a review on the theoretical aspects by Jakobsen (STScI Symp. 7, p. 75). The available limits on FUV extragalactic background light have been used to constrain the contribution of different kinds of elementary particles to the dark matter (Overduin and Wesson, ApJ 414, 449, 1993).

New extensive FUV sky brightness data have been collected by two recent space experiments: (1) The University of Bochum GAUSS camera obtained photographic images with 140 deg FoV during the D2-mission of Spacelab. Pass bands between 121 nm and 360 nm were used to study primarily the Milky Way between $l = 230°$ and $85°$ (Schmidtobreick et al. AG Abstr. 11, 129, 1995). (2) The SWAN experiment on board satellite SOHO has been scanning the whole sky with 1° resolution between 110 and 180 nm, separately for continuum and the Lyα line emission (Bertaux et al. BAAS 28, 898, 1996). Murthy and Henry (ApJ 448, 848, 1994) developed a model to describe the FUV sky brightness distribution, including the contribution of individual stars, scattered light (for different scattering functions) and an extragalactic component of 100 - 400 photons/cm^{-2}s^{-1} sr^{-1}Å^{-1}.

Several studies have determined the scattering properties of interstellar dust in the UV range, usually resulting in a high albedo (≥ 0.5, except for a minimum around 230 nm) and strong forward scattering. This includes a reanalysis of the 1986 Ultraviolet Experiment (UVX) measurements (Henry and Murthy, ApJ 418, L17, 1993; Hurwitz, ApJ 433, 149, 1994), FUV observations from Voyager 2 of the Eridanus superbubble (Murthy et al., ApJ 419, 739, 1993) and of the Coalsack (Murthy et al., ApJ 428, 233, 1994), images of Upper Scorpius obtained with the FUV camera onboard the space shuttle in 1991 (Gordon et al., ApJ 432, 641, 1994), and IUE observations of the reflection nebula IC 435 (Calzetti et al., ApJ 446, L97, 1995).

The discussion around the amount of extragalactic FUV has not yet settled. Witt and Petersohn (ASP Conf. 58, p. 91) reanalysed the 150 nm sky background data of the Dynamics Explorer 1 spacecraft and find evidence for a large value of the cosmic isotropic background, 300 ± 80 photons cm^{-2} s^{-1} sr^{-1} Å^{-1}. Armand et al. (A&A 284, 12, 1994) have used galaxy counts at 200 nm down to 18 mag to calculate the FUV integrated light of galaxies. Depending on the models used for extrapolation they obtain values of 40 to 130 photons cm^{-2} s^{-1} sr^{-1} Å^{-1}. But new tools are becoming available: Observing with the Far Ultraviolet Space Telescope (FAUST), flown on the space shuttle in March 1992, Haikala et al. (ApJ 443, L33, 1995) obtained for the first time a UV image of a cirrus cloud. The FUV surface brightness, due to scattering off dust, was shown to have a good correlation with the optical extinction and 100 μm IRAS emission in the cloud. Apart from modelling of grain properties, the important qualitative result of this study was that a major part of the far UV sky brightness at high galactic latitudes is definitely due to scattering off interstellar dust. An extension of this study, sampling both high and low galactic latitude clouds, has been performed by Sasseen and Deharveng (A&A 1996, in press).

Sasseen et al. (ApJ 447, 630, 1995) then used FAUST images to search for the EBL fluctuations. However, through a comparison of the spatial power spectrum and autocorrelation of the observed FUV fluctuations with the corresponding quantities for the 100 μm IRAS data in the same fields they were led to conclude that the FUV fluctuations were entirely due to foreground galactic cirrus. Furthermore, they argued that the earlier detections of EBL fluctuations, in the FUV by Martin and Bowyer (ApJ 338, 677, 1989) and in the optical by Schectman (ApJ 179, 681, 1974), were also caused by the galactic foreground cirrus alone. The Martin and Bowyer estimate for the FUV EBL intensity of ≈ 50 photons cm^{-2} s^{-1} sr^{-1} Å^{-1} resulting from their fluctuation analysis should consequently be considered as an upper limit only. This study leads to a new level of the discussion.

5.2. OPTICAL BACKGROUND (310 nm – 1 μm)

A new all-sky survey of the optical background light in B and V has become available as a byproduct of the Hipparcos Tycho star mapper observations. Wicenec and van Leeuwen (A&A 304, 160, 1995) and Wicenec (PhD Thesis, Tübingen, 1995) have presented the methods of analysis and some first results of this project. Due to its uniformity and good spatial resolution (0.25°) this survey will undoubtedly form an important basis for the diffuse galactic light and integrated starlight studies.

In the Bochum photographic surface photometry project a high resolution (0.25 °) map of the southern Milky Way ($l = 200$ to $60°$, $|b| \leq 40°$) in the B band has been published by Kimeswenger et al. (A&AS 97, 517, 1993). Similar maps in the U and R bands soon will be available and will enable detailed studies in a three-colour U-B, B-V, V-R diagram (Hoffmann et al., A&A 1997, in press).

A review of the extragalactic background light (EBL) based on optical and near IR galaxy counts has been presented by Tyson (STScI Symp. 7, p.103). EBL values based on new deep galaxy counts have been presented also by Cowie et al. (ApJ 434, 114, 1994) and Morgan and Driver (STScI Symp. 7, p. 285). Bernstein et al. (AIP Conf. 348, p. 333) have started a new ground-based and Hubble Space Telescope observing program to measure the total intensity and spectral energy distribution of the EBL.

The spatial EBL fluctuations have been discussed in connection with detecting large low-surface-brightness galaxies (Davies et al. MN 269, 349, 1994) and distant clusters of galaxies (Dalcanton, BAAS 26, 796, 1994). As already said above, the fluctuations detected by Schectman (ApJ 179, 681, 1973) now are viewed as due to foreground reflections on interstellar dust clouds.

Modeling the EBL, Väisänen (A&A in press, 1996) has considered the contribution by the newly discovered classes of faint and low-surface-brightness galaxies. He finds that the presence of these galaxies could increase the EBL by a factor of 3 to 5, whithout changing the current number count data. Estimates of the total EBL intensity from UV to FIR have also been obtained on the basis of the amount of the cosmic abundance of processed nuclear material. The EBL levels predicted in this way by Pagel (in The Cold Universe, eds. Th. Montmerle et al.,395, 1994) agree well with the extrapolated galaxy count predictions. Similar, more detailed model estimates have been presented by Fall et al. (ApJ 464, L43, 1996).

5.3. INFRARED BACKGROUND (1 μm - 300 μm)

The importance of the COBE/DIRBE sky mapping results has been stressed above. The ultimate purpose of this experiment is to detect the cosmic (i.e. extragalactic) infrared background radiation (CIBR), which carries important information on the formation and early evolution of the galaxies. The main hurdle in this task is the question of how to separate it from the different foreground components. Progress reports on this work have been given by Hauser in STScI Symp. 7, p. 135, in IAU Symp. 168, p. 99, and in AIP Conf. 348, p. 11. A wealth of other important observational and theoretical papers on the IR background, including predictions of the CIBR brightness, are contained in the latter reference.

Puget et al. (Ad&A 308, L5, 1996), using data from the COBE Far Infrared Absolute Spectrometer (FIRAS) instrument, have announced a tentative detection of the extragalactic far IR background in the 200 μm to 1000 μm region, with a shallow maximum of 0.3 to 0.6 MJy/sr near 250 μmm. The derived CIBR values are compatible with earlier FIRAS upper limits given in Mather et al. (ApJ 420, 439, 1994). The Nagoya-Berkeley team has used a rocket-borne photometer flown in February 1992 to measure the FIR sky brightness at $\lambda = 134$ μm, 154 μm, and 186 μm in a high-galactic-latitude field near the so-called Lockman hole (Kawada et al. ApJ 425, L89, 1994). They derived an upper limit to the CIBR at 154 μm of 1.3 MJy/sr. Flown on the same rocket was also a near-IR spectrometer which measured the 1.4 μm - 4 μm sky brightness (Matsuura et al. PASP 106, 770, 1994). Upper limits of 0.17 and 0.33 MJy/sr were set to the CIBR at 2.5 μm and 4.0 μm, respectively. Kashlinski et al. (ApJ 1996, in press) used the near-IR DIRBE maps to set limits in the J, K, and L bands of $\nu I_\nu = 200$, 78, and 26 nW m^{-2} sr^{-1} for contributions to the CIBR due to clustered matter.

A surprising new technique for measuring the CIBR, first proposed by Nikishov (Sov.Phys. JETP 14, 393, 1962), has been applied repeatedly during the last few years, by Stecker et al. (ApJ 390, L49, 1992; ApJ 415, L71, 1993), De Jager et al. (Nat 369, 294, 1994), Dwek and Slavin (ApJ 436, 696, 1994), MacMinn and Primack (Spa.Sci.Rev. 75, 413, 1996), Biller et al. (ApJ 445, 227, 1995), and Madau and Phinney (ApJ 456, 124, 1996). γ-ray photons emitted by a distant source (galactic nucleus) can produce an e^+e^- pair by interacting with cosmic IR photons. Measuring the frequency-dependent TeV γ-ray absorption of a background source one can thus estimate the CIBR density. Observations of Mk421 have given first estimates of the order of 0.1 MJy/sr for the CIBR intensity in the 15 μm - 40 μm wavelength range.

The DIRBE experiment has also provided a wealth of new results on the galactic IR background radiation, both on the stellar and the interstellar components (see the review by Hauser in AIP Conf. 278, p. 201). Many of the DIRBE results first presented in the same Proceedings volume have since been published in a more comprehensive form: on far-infrared observations of the galaxy (Reach et al.,ApJ

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451, 188, 1995), on the near-IR colours of stellar populations (Arendt et al., ApJ 425, L85, 1994), on the galactic bulge (Weiland et al., ApJ 425, L81, 1994; Dwek et al., ApJ 445, 716, 1995), on the interstellar dust layer (Freudenreich et al., ApJ 429, L69, 1994), on the large-scale distribution and temperature of interstellar dust (Sodroski et al., ApJ 428, 638, 1994), on the H_2 to ^{12}CO ratio (Sodroski et al., ApJ 452, 262, 1994), and on Orion (Wall et al., ApJ 456, 566, 1996).

The main cooling line of the interstellar clouds is the C^+ line at 158 μm. Its distribution over the whole sky was mapped with 7° resolution by COBE/FIRAS (Bennett et al., ApJ 434, 587, 1994) and along the galactic plane with a better spatial resolution during several Japanese balloon flights (e.g. Nakagawa ASP Conf. 41, 373, 1993). A rocket-borne experiment by the Nagoya-Berkeley group succeeded for the first time in detecting the C^+ 158 μm line also from the diffuse interstellar clouds at high galactic latitude (Bock et al., ApJ 410, L115, 1993).

Light scattered off interstellar dust is a dominant component of the night-sky brightness at optical and UV wavelengths. Lehtinen and Mattila (A&A 309, 570, 1996) have for the first time measured it also at 1.25 μm – 2.2 μm on a normal dark cloud (globule) exposed only to the general interstellar radiation field. It appears that near-IR scattered light is an important radiation component of the disk of our Milky Way and of other dusty galaxies.

6. NEW SPACE EXPERIMENTS

The year 1995 has seen the launch of two infrared satellites which undoubtedly will make valuable contributions to the study of the diffuse sky background. On March 18, the japanese satellite IRTS was launched into earth orbit with four instruments – two spectrometers, one photometer and one line mapping experiment – covering the wavelength range from 1 μm to 1000 μm. During its 40-day-mission it succesfully surveyed 10 % of the sky and collected, among others, data on interplanetary and interstellar dust and gas emissions as well as on extragalactic background radiation. Results will be presented at a special symposium in November 1996 in Sagamihara, Japan. On November 17, the european infrared observatory ISO entered its 24 hour elliptical orbit for a 24-month mission. Although specialised with its two spectrometers, a camera and a photometer on the observation of individual sources between 2.5 μm and 240 μm, ISO also yielded new data on zodiacal light, interstellar cirrus emission and extragalactic background light, including a serendipity survey at 175 μm performed during the slews from source to source. The ISO results will be the topic of a Special Session at the Kyoto General Assembly. Special journal issues with first results are being prepared (in PASJ and A&A, respectively) for each of these two satellites for late 1996.

Let me finish with an Utopia: the real experiment for measuring the extragalactic (and galactic) optical and IR background would be a well calibrated telescope with good imaging quality (to allow post-observation subtraction of individual stars) beyond the bulk of the interplanetary dust cloud, i.e. at $r > 3$ AU or high above the plane of the ecliptic. A concept for such a mission has been discussed by Mather and Beichman (AIP Conf. 348, p. 271).

Heidelberg, October 15, 1996 Christoph Leinert