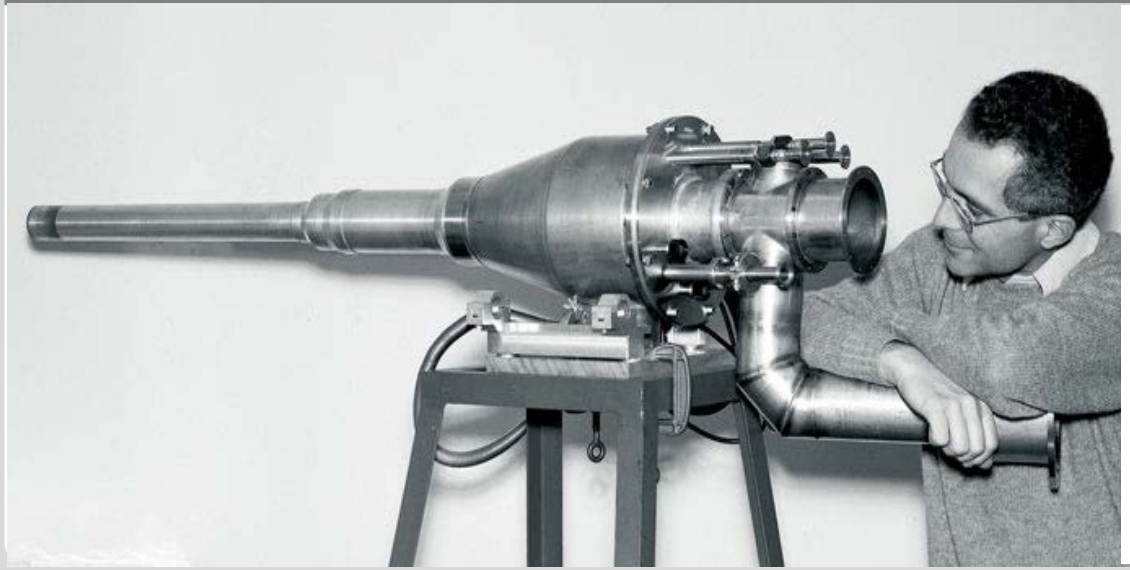
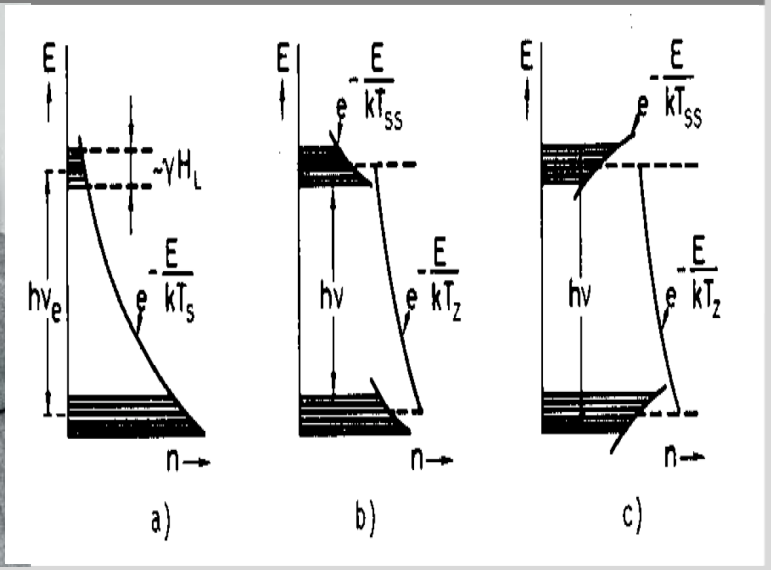
Karlsruhe Institute of Technology

In Memoriam, Dr. Michel Borghini

Wim de Boer, KIT, Karlsruhe, Germany presented by Alan Krisch, UoM, Ann Arbor, USA

Institut für Experimentelle Kernphysik





My work with Michel Borghini - I

- **Aug. 1970 Dr. Morimoto traveled Europe and passed by at Delft, NL to visit the low temperature lab from Prof. Blaise and told us about the interest in polarised targets at CERN.**
- **In the low temperature lab at Delft I was just finishing my master thesis, using Electron Nuclear Double Resonance (ENDOR) to manipulate electron and proton spins simultaneously. This is what is needed for polarised targets as well, so in search of a job I decided to visit Dr. Borghini at CERN**
- **Since we were both shy we did not talk very much, but he asked me to apply for a CERN fellowship. This worked out well, so I started May, 1971 working in Borghini's group.**
- **I heard about the interesting results of high polarization in propanediol doped with CrV complexes at PSI and started to optimize the parameters, like Cr-V concentration and elimination of water in the samples. We finally reached about 100% polarisation** (de Boer, NIM 107 (1973) 99, de Boer and Niinikoski, NIM 114(1974) 495)
- **This would have been impossible by the classical solid state effect, so finally Borghini's new theory about polarisation using a thermodynamical model, called spin temperature** theory (M. Borghini, PRL 20(1968) 419)**, started to be confirmed by experiment.**

My work with Michel Borghini - II

- **Michel got excited and explained me the differences between the spin temperature theory and the solid-state-effect. He gave me a copy of his unpublished thesis, describing everything in detail (see later). We then did a series of experiments which confirmed the spin-temperature theory. Among them:**
- **Measuring the polarisation of different nuclei (D, ^{13}C, H) in the SAME sample and check if these nuclei all got the same temperature of the electron spin-spin interaction reservoir, as predicted by Michel** (de Boer, Borghini, Morimoto, Niinikosko, F. Udo, Phys.Lett. B46 (1973) 143; de Boer, Borghini, Morimoto, Niinikoski and F. Udo, J.Low.Temp.Phys.,15 (1974)249)
- **Perform measurements at different magnetic fields up to 5T and temperatures (down to the mK range using Tapio Niinikoski's dilution refrigerator)**
- **Perform measurements with a free radical with a small width of the ESR line, which showed simultaneously the solid-state effect (for protons) and the spin-temperature effect (for D and ^{13}C)** (Borghini, de Boer, Morimoto, PL A48 (1974) 244)
- **These measurements reached spin temperatures of a few uK. For these low temperatures the „high temperature approximation" used by Michel was not valid anymore. I extended the theory to low temperatures, which allowed a quantitative comparison. Excellent agreement was found** (W. de Boer, Thesis Yellow Report, http://cds.cern.ch/record/186203/files/CERN-74-11.pdf, W. de Boer, Phys.Rev. B12 (1975) 828, 29 pp., W. de Boer J.Low.Temp.Phys. 22 (1976) 185, 37 pp.)

Michel as member of my thesis committee

After the thesis defense

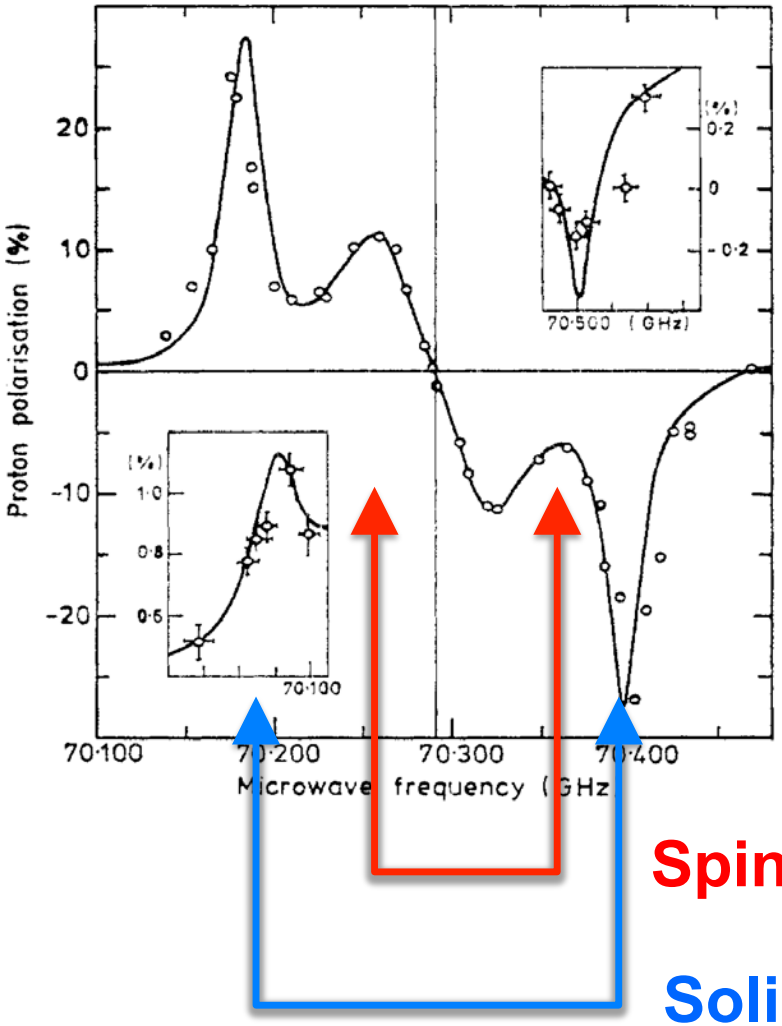
Michel‘s unpublished thesis

Michel wrote an excellent thesis on the spin temperature theory in the group of Prof. Abragam, the NMR guru in Saclay, but it was rejected by Abragam for reasons unknown to me, but I expect, because it disagreed with his proposed mechanism of dynamic polarization and/or he did not believe in it. After our beautiful results at CERN, Abragam recognizes that Borghini‘s theory is right and he writes in an extensive review (A. Abragam and M Goldman, Prinicples of dynamic nuclear polarisation, Rep. Prog. Phys. 41(1978)):

p. 37: „A special solution has been proposed by Borghini (1968) for a simplified model of the ESR line. We shall outline in some detail the derivation and the discussion of the formula arrived at by Borghini, because to the best of our knowledge it cannot be found in the published literature.“

In this review all our results are beautifully explained, especially our famous results, which show that in some materials, both Abragam‘s solid state effect and Borghini‘s spin temperature effect occur simultaneously at different frequencies, thus proving that they are physically different processes (next slide)

The two effects of dynamic polarization



Borghini M, de Boer W and Morimoto K 1974 Phys. Lett. 48A 244

All our results are discussed extensively in the Abragam+Goldman review, Figs. 13-17.

Spin temperature theory (Borghini)

Solid-state-effect (Abragam)

“Hyperpolarization” in Cancer Research

- **Dynamic polarization has found an actively pursued application in cancer research: polarized ^{13}C nuclei in tracers of tumors yield a strongly enhanced signal, so much smaller tumors or precise growth of tumors can be discovered. The medical people call this hyperpolarization, but the polarization happens in setups similar to the ones used in polarized targets, see e.g.** T. Eichhorn et al., Hyperpolarization without persistent radicals for in vivo real-time metabolic imaging, doi: 10.1073/pnas 1314928110
- **The surprising discovery: after thawing the samples in a magnetic field, the polarization is largely maintained in the gas phase. Dissolving the gas into a liquid and injecting it into the body yields strongly enhanced NMR signals of the tumors (the polarization lasts only minutes, but this is enough for an NMR picture in a modern tomograph)**
- **For details, see e.g a recent review**: Brindle et al., **Tumor Imaging Using Hyperpolarized ^{13}C Magnetic Resonance Spectroscopy,** Magnetic Resonance in Medicine 66(2011) 505**.**
- **First in vivo human applications for diagnosing prostate cancer have been reported** (Nelson SJ, et al. (2013) Metabolic imaging of patients with prostate cancer using hyperpolarized [1-^{13}C]pyruvate. Sci Transl Med 5(198):198ra108.)
- **The relative high ^{13}C polarizations of up to 60% is a clear manifestation that Borghini‘s proposed mechanism of the dynamic polarisation by cooling of the electron spin-spin interaction reservoir is at work.**
- **Michel certainly would have been delighted to see that his ideas of dynamic polarization find such important applications in fields, we never dreamed off before. The spin temperature theory will certainly be talked about in the long-time future.**