Magnetic field stabilization in superconducting magnets for high-precision Penning trap experiments

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Why do we need an extremely stable magnetic field?

We are measuring:

the g-factor of a single H-like ion stored in a Penning trap by determination of the spin flip resonance in a magnetic field
J.Verdu et al.

the masses of short-lived radionuclides by determination of the cyclotron frequency of stored ions in a Penning trap
K. Blaum et al.

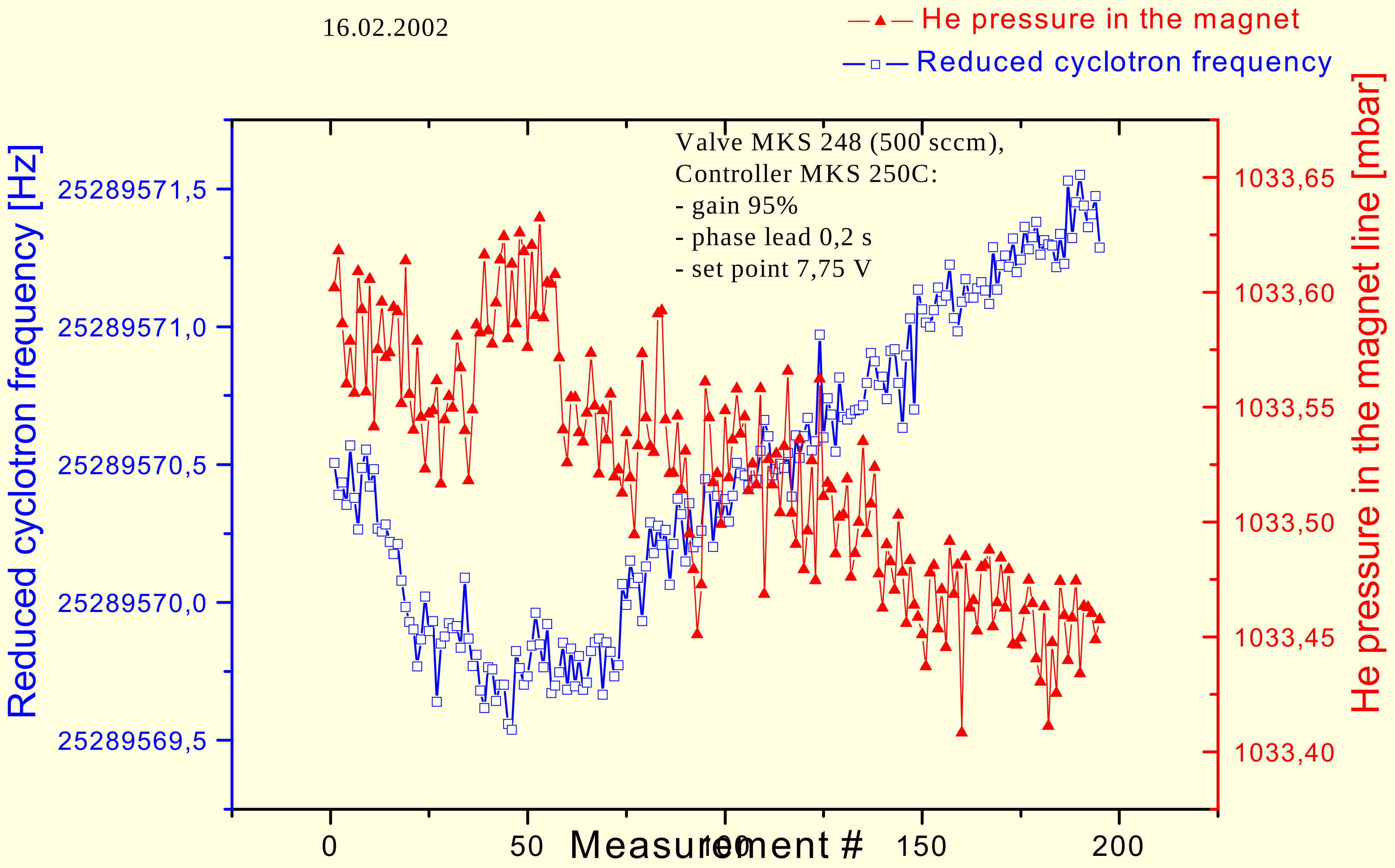
The line shape and precision of both measurements depend directly on the magnetic field stability.

(K. Blaum *et al*. PRL **91**, 260801, 2003
J. Verdú *et al*. PRL **92**, 093002, 2004)

Sources of magnetic field instabilities

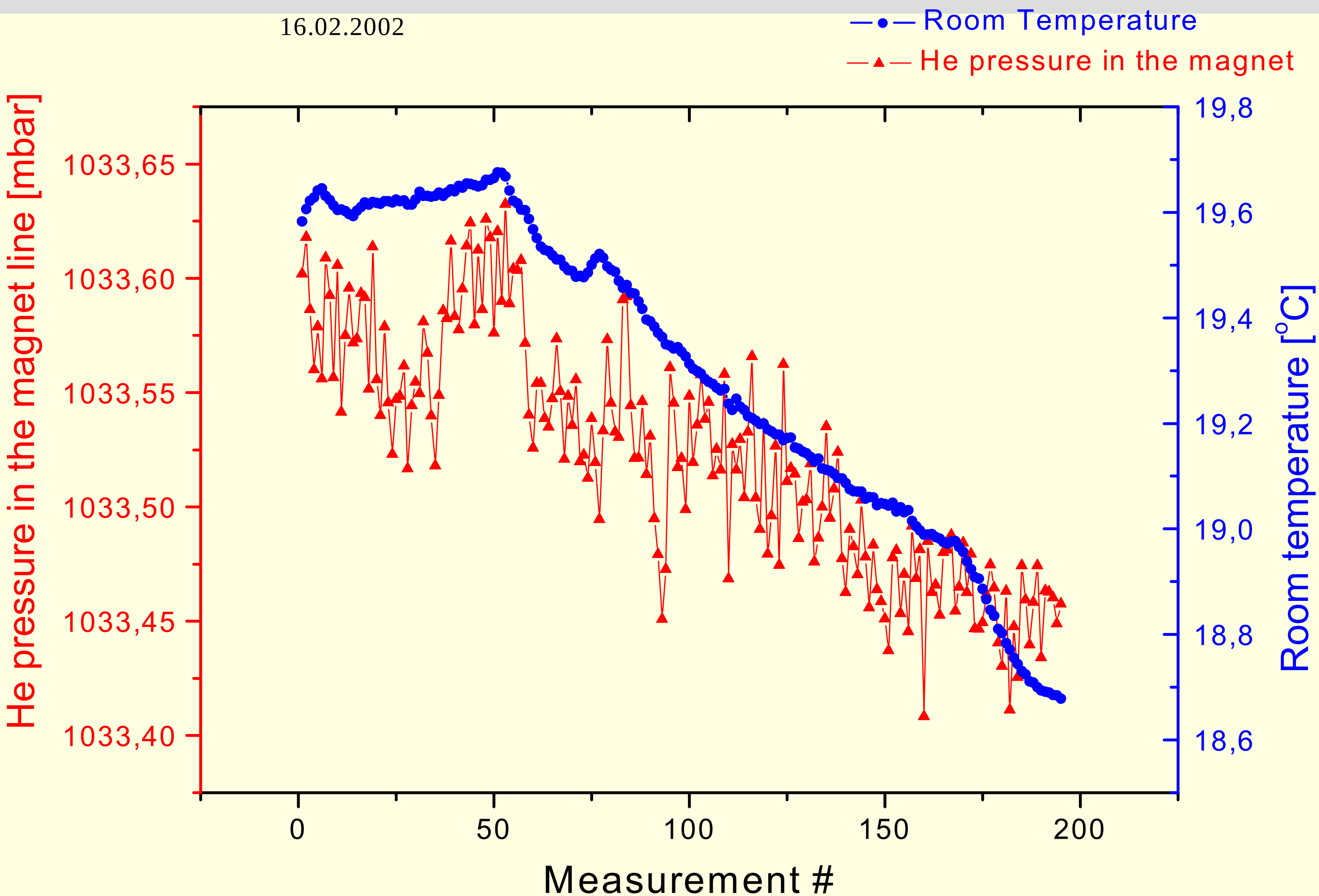
1. External
   - Movement of magnetic objects
   - Magnetic field fluctuations
2. Natural decay of the magnet‘s field
3. Internal
   - Pressure instabilities in the recovery lines
   - Temperature fluctuations
     - Environmental
     - Magnet‘s surface or magnet‘s bore

Influence of He pressure on cyclotron frequency

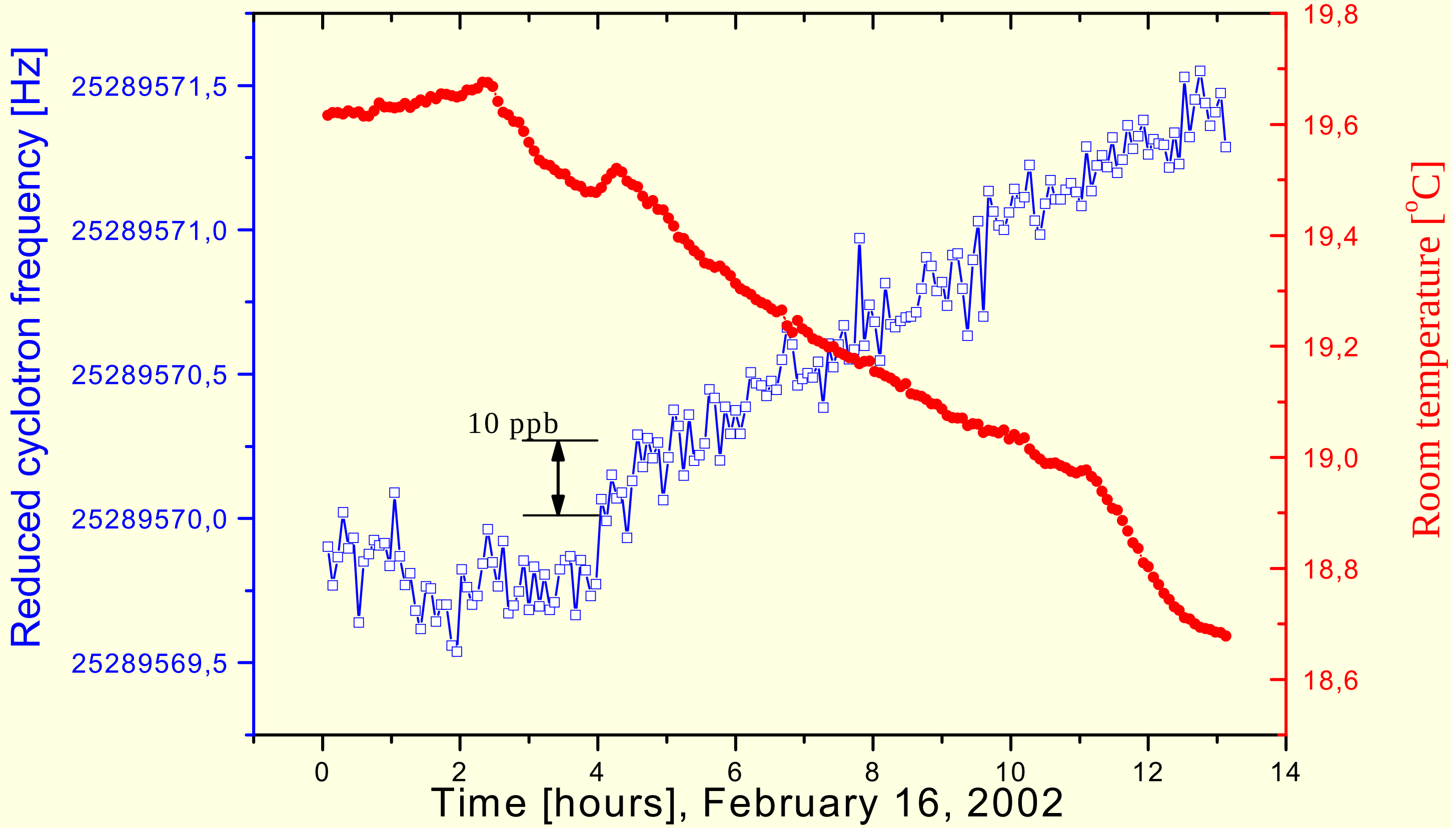


Linear correlation between He pressure and room temperature

16.02.2002

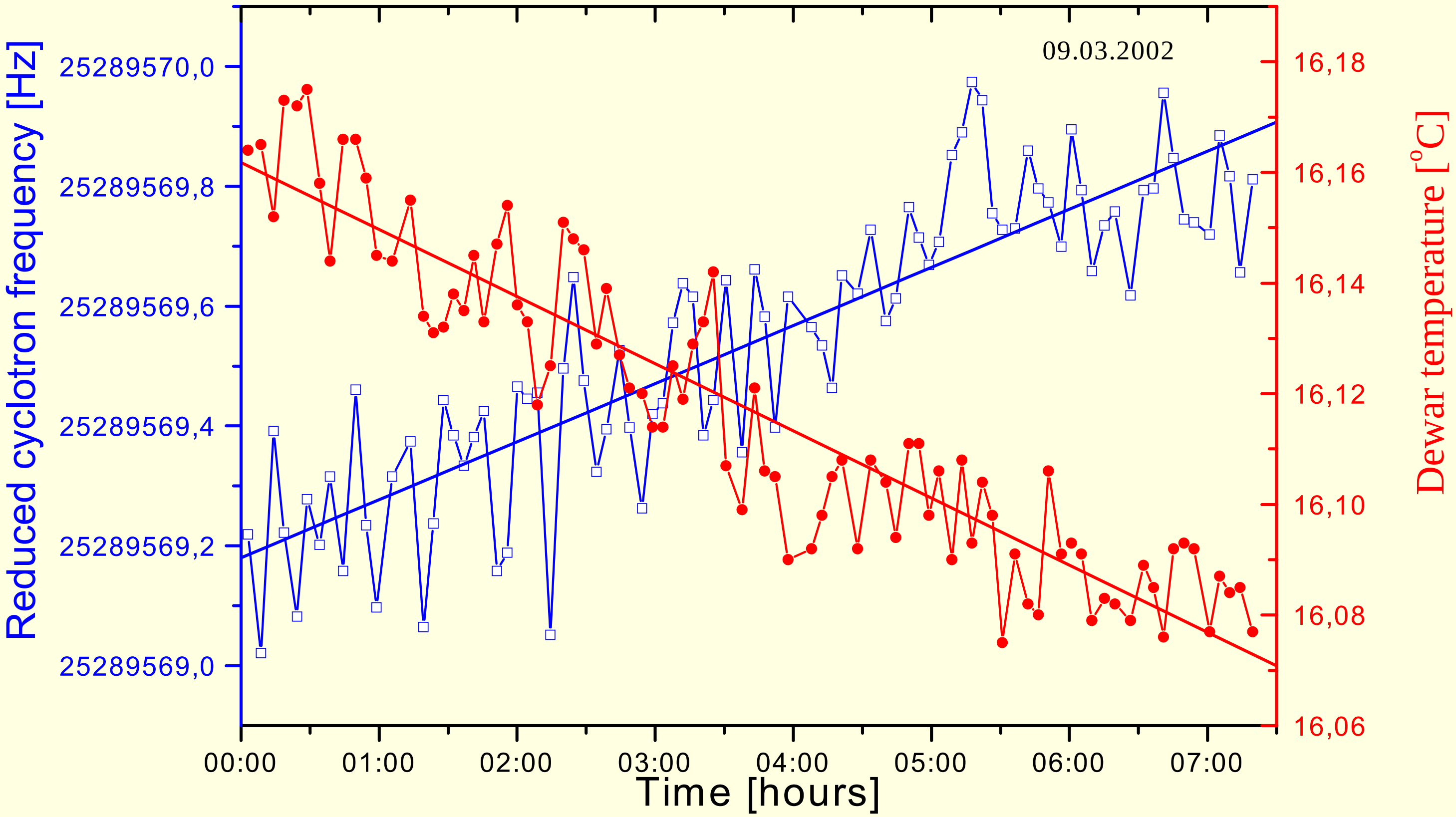


Anticorrelation between the frequency and room temperature (measured with a single O^{7+} ion)



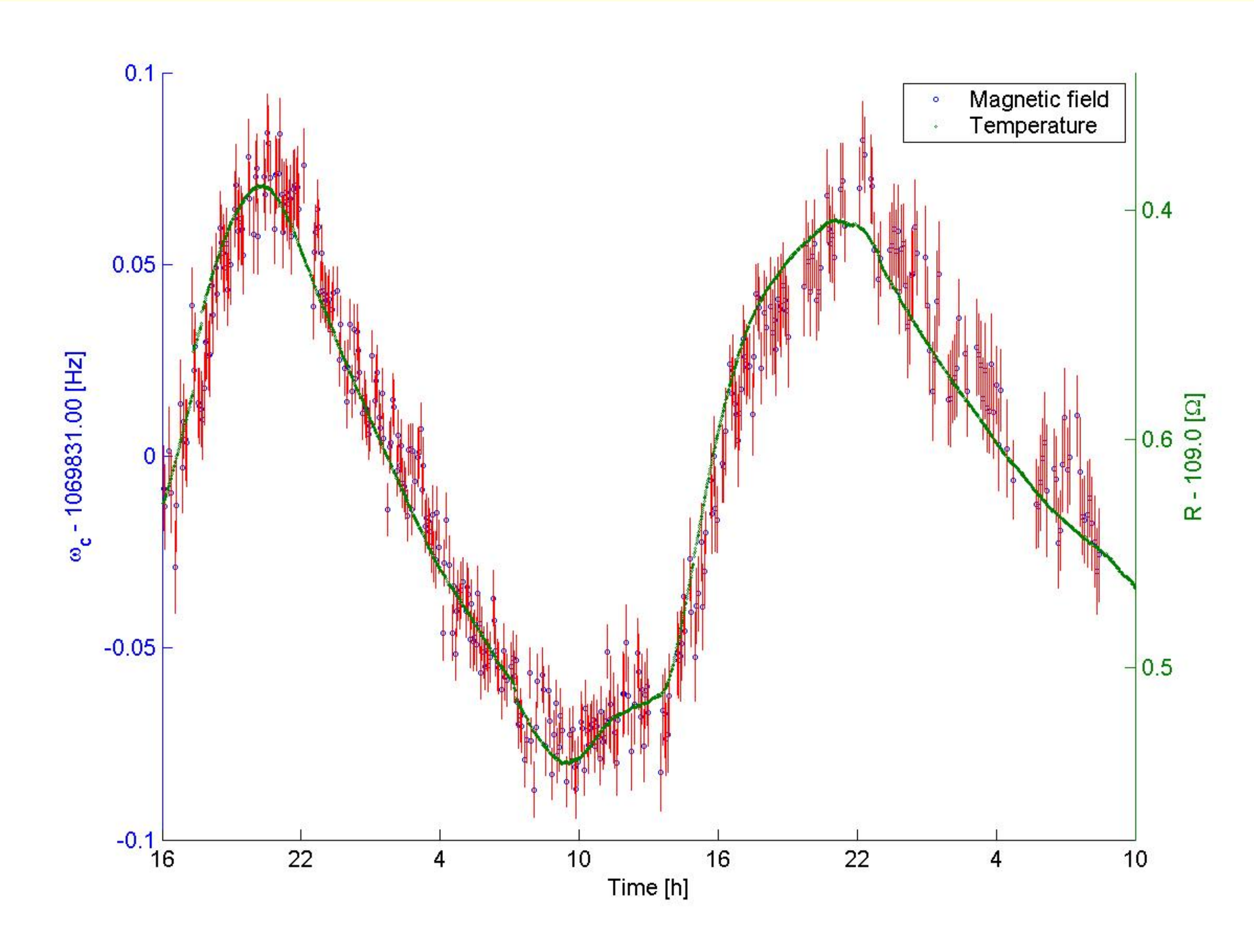
• Room temperature decrease with rate 0.1 K/h induce increase of reduced cyclotron frequency with rate 0.2 Hz/h (8 ppb/h)

Anticorrelation between the frequency and dewar temperature



- dewar temperature decrease with rate 0.01 K/h induce increase of reduced cyclotron frequency with rate 0.1 Hz/h (4 ppb/h)

Correlation between cyclotron frequency and temperature at ISOLTRAP

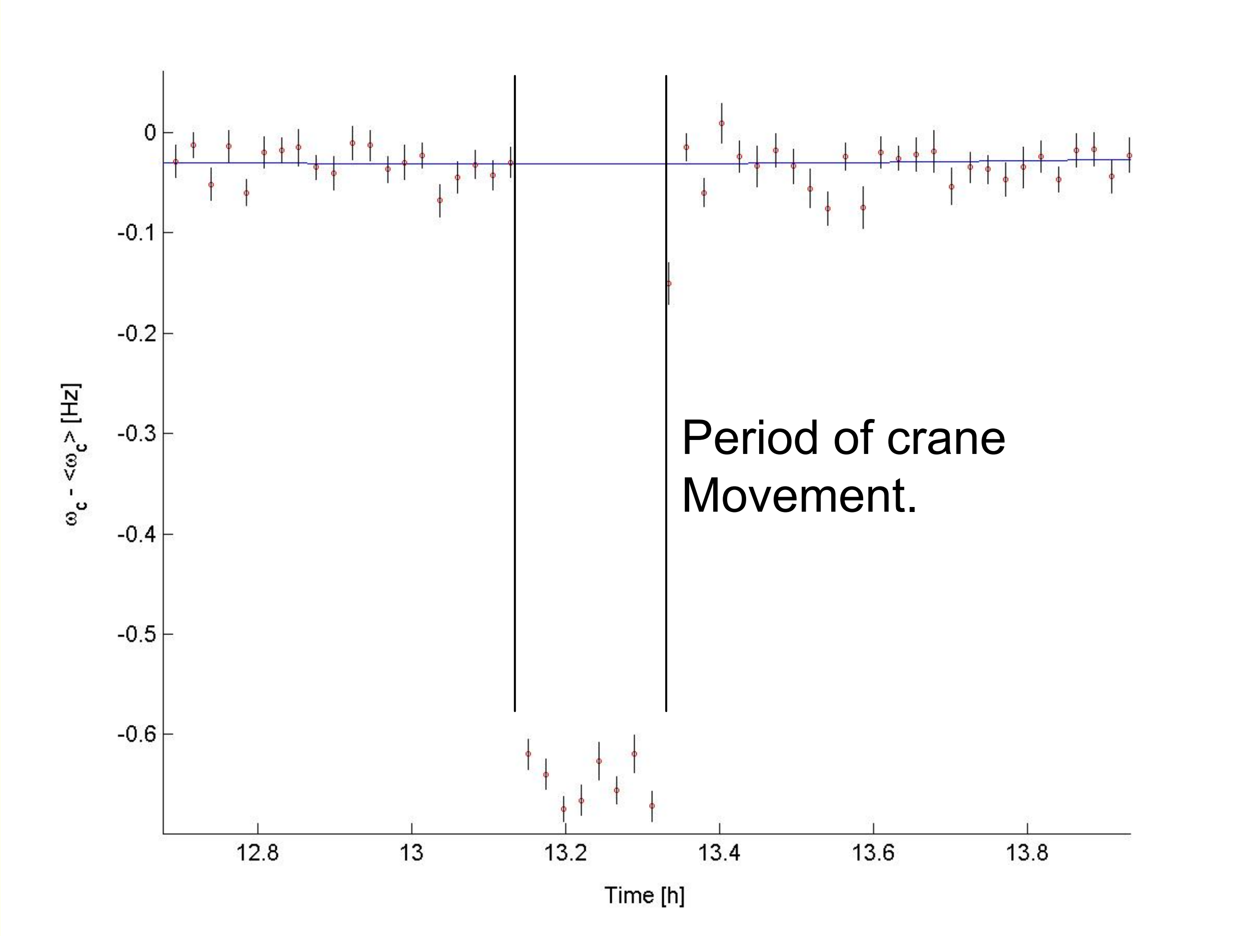


Magnetic field drift
-2.7 ppb/h
Linear drift in the magnetic field already corrected for.

Night day temperature variation
0.61 ^{o}C

Linear correlation of magnetic field and temperature of 220 ppb/K

External magnetic field disturbances at ISOLTRAP

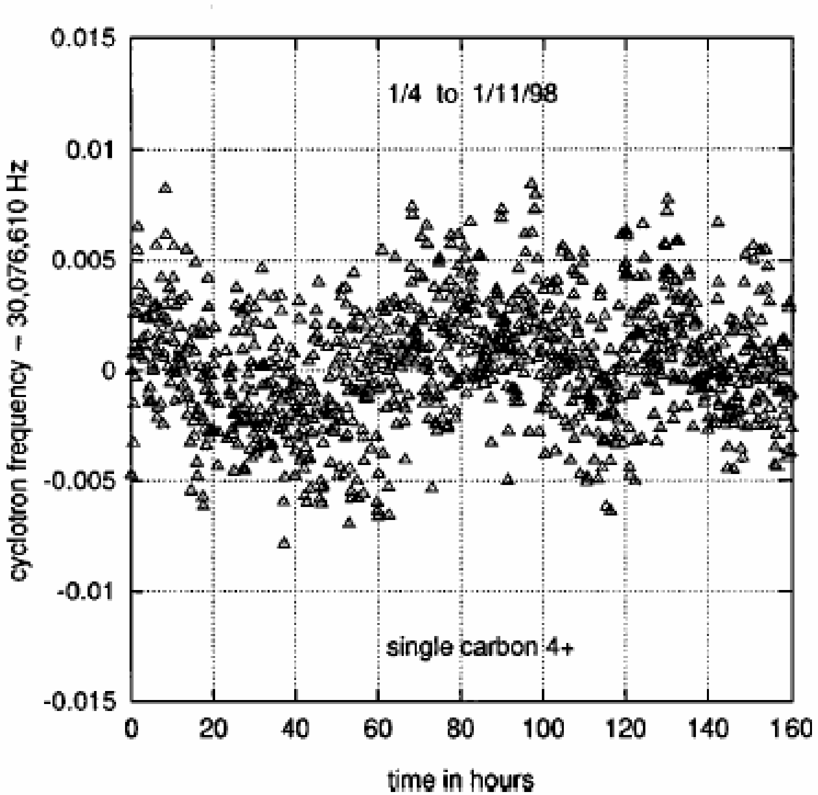


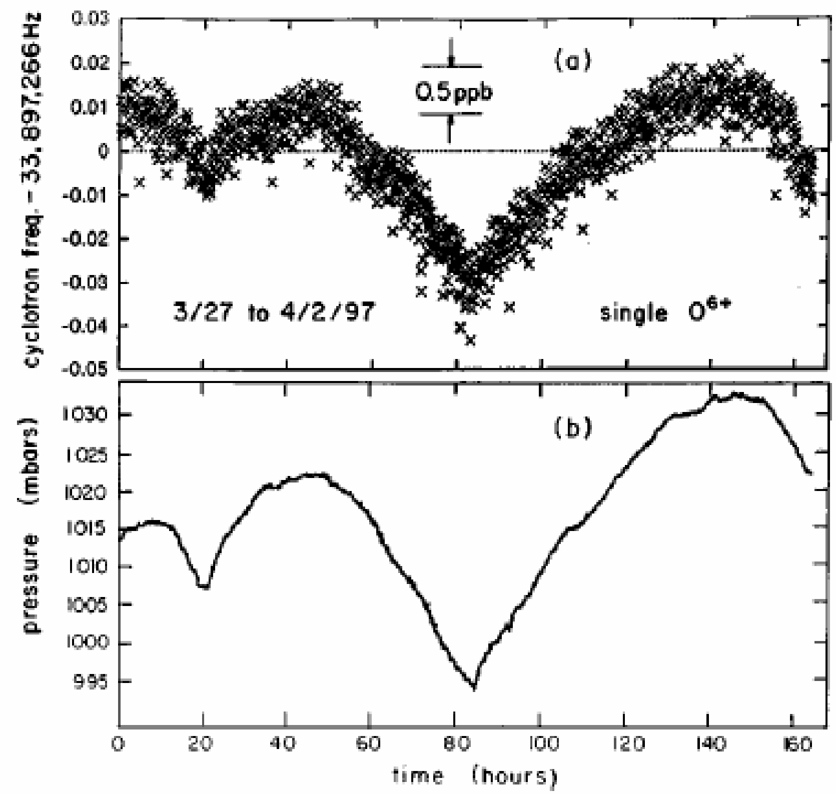
Crane movement
in the ISOLDE hall:

Impossible to measure

Ultrastable superconducting magnet system

R. S. Van Dyck, et.al; RSI 70, 1665(1999)





Residual structure is believed to be associated with temperature effects of electronic parts in various control systems.

The cyclotron resonances for a single O^{6+} with a linear drift of -52 ppt/h removed.

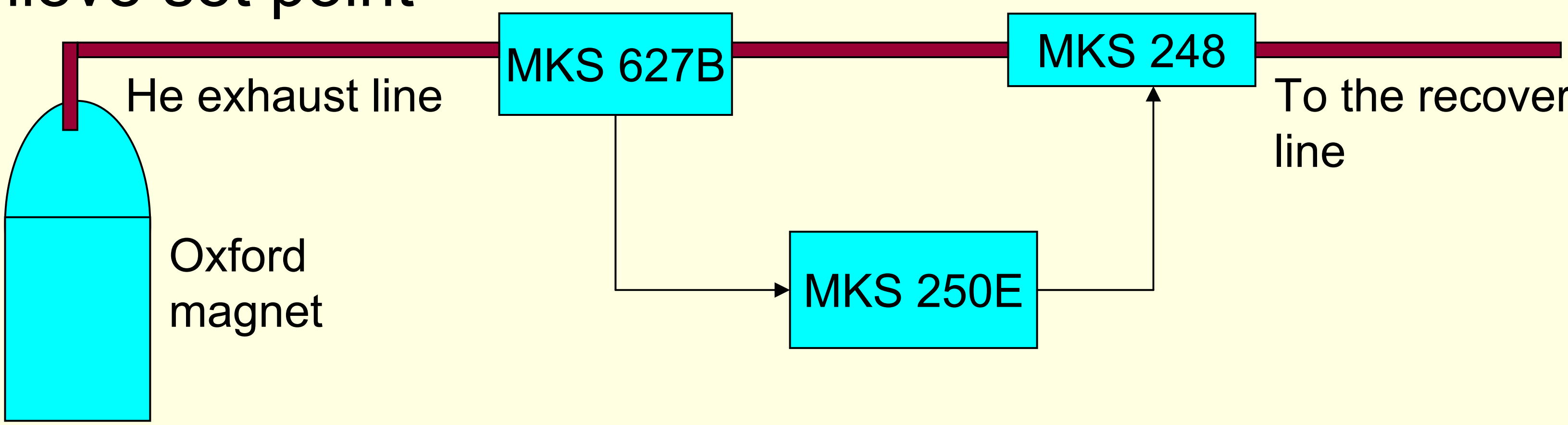
Results from the other labs

- Gabrielse and collaborators:
  - Linear correlation of magnetic field and pressure of 1.1 ppb/mbar
  - To keep drifts below 1 ppb/h
    1. Flow regulated to 0.1 %/h
    2. Pressure drifts less than 0.01 mbar/h
    3. Ambient temperature regulated to 0.1 K

- Fritioff and collaborators:
  - Linear correlation of magnetic field and temperature of 300 ppb/K
  - To keep drifts below 1 ppb/h
    1. Pressure stabilize to ±0.02 mbar
    2. Ambient temperature regulated to ±0.5 K
    3. Air temperature in the magnet bore ±0.03 K

Pressure control system at Mainz, planned for ISOLTRAP

- Consists of three basic parts
  1. Process sensor: Baratron capacitance manometer (MKS 627B)
  2. PID controller: Pressure control module (MKS 250E)
  3. Control element: Compatible control valve (MKS 248)
- Controller compares mesured pressure to the desired set point and adjust the gas flow control valve to reach achieve set point



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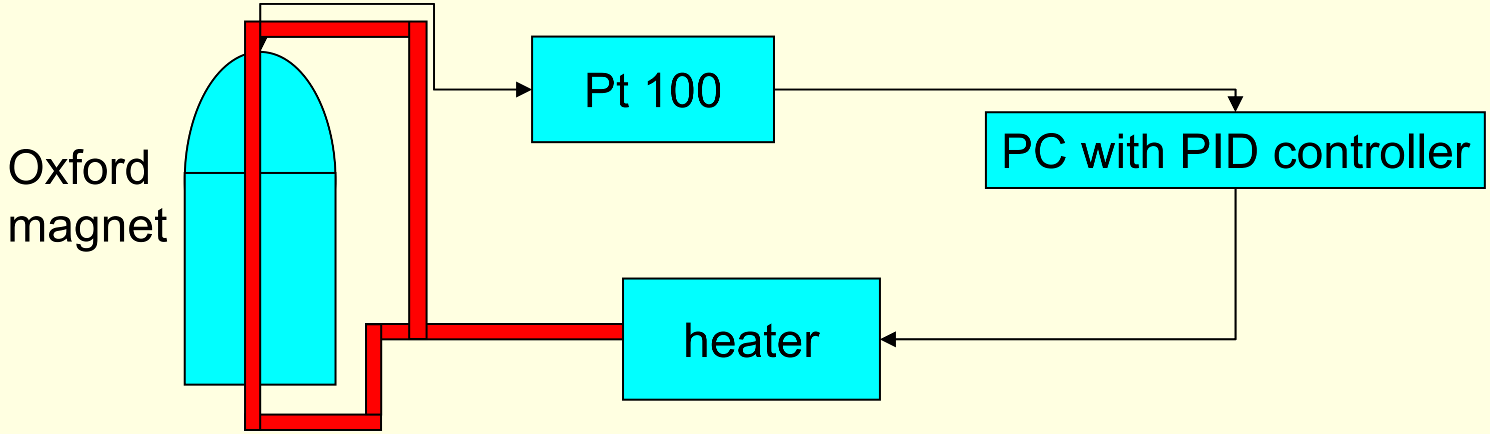
Planned temperature stabilization system for ISOLTRAP

- Consists of:
  1. Process sensor: Pt 100 temperature sensor with readout unit
  2. PID controller: Labview programed module with DAC card
  3. Control element: Standard 250 W heater
- Computer PID control module compares mesured temperature to the desired set point and adjust the heat current in the heater to achieve set point



Conclusion

Solutions for the different sources of magnetic field instabilities

- **External B field changes**
  - Self shielding superconducting solenoid
  - Measurement stopped during crane movement
- **Natural decay** of the magnet should be taken into account (normally) only for the subppb level accuracy
- **Internal B field changes**
  - Pressure stabilization system with extreme stability ±0.02 mbar
  - Environmental temperature regulated better than ±0.1 K/h
  - Magnet surface or magnet bore temperature regulation system with accuracy ±0.01 K/h

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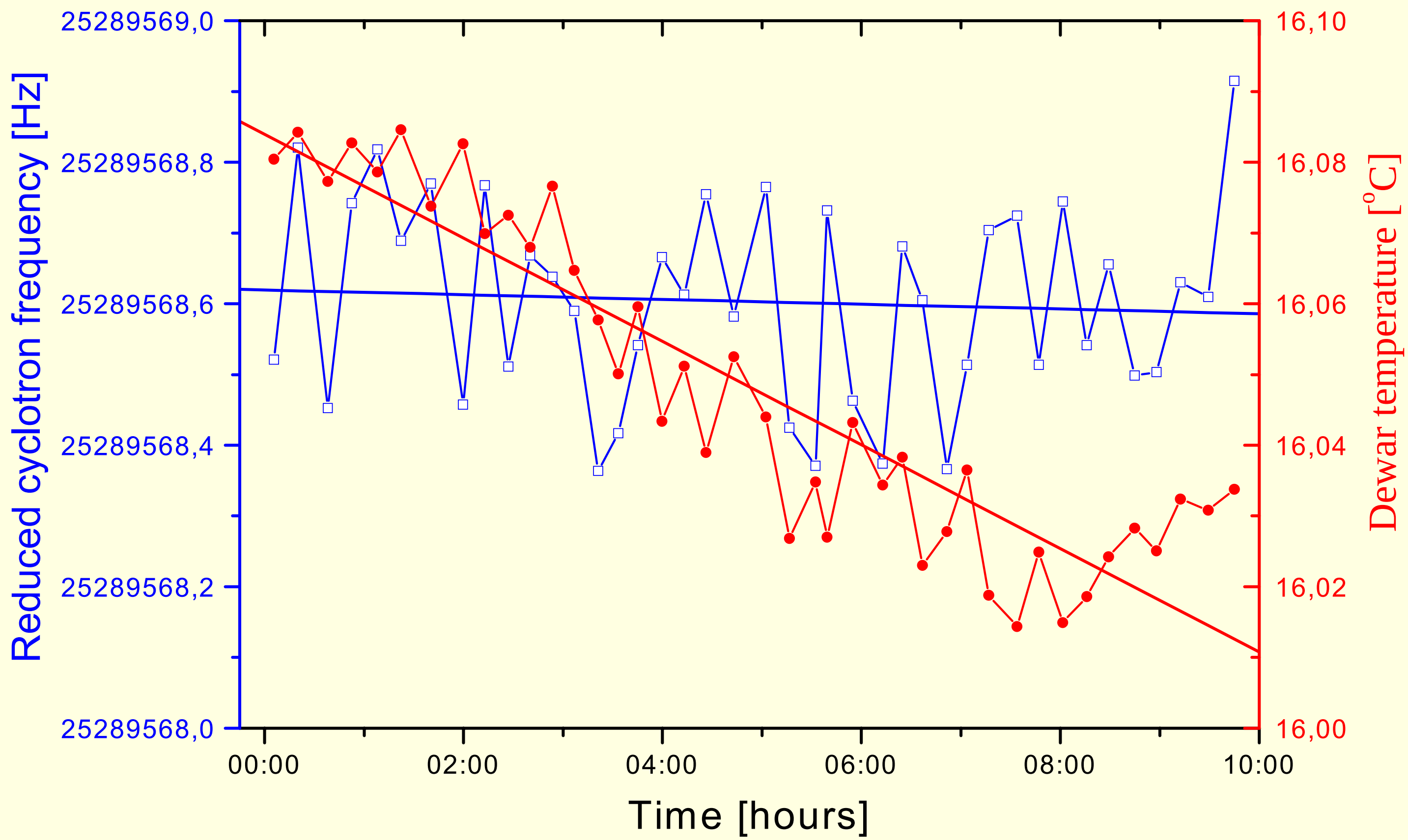
- And the ISOLTRAP collaboration

Necessary stability of the dewar tempearture

08.03.2002



• dewar temperature decrease with rate 0.006 K/h induce no increase in reduced cyclotron frequency only drift of 4 ppb remains