Magnetoplasmon resonance in a two-dimensional electron system driven into a zero-resistance state

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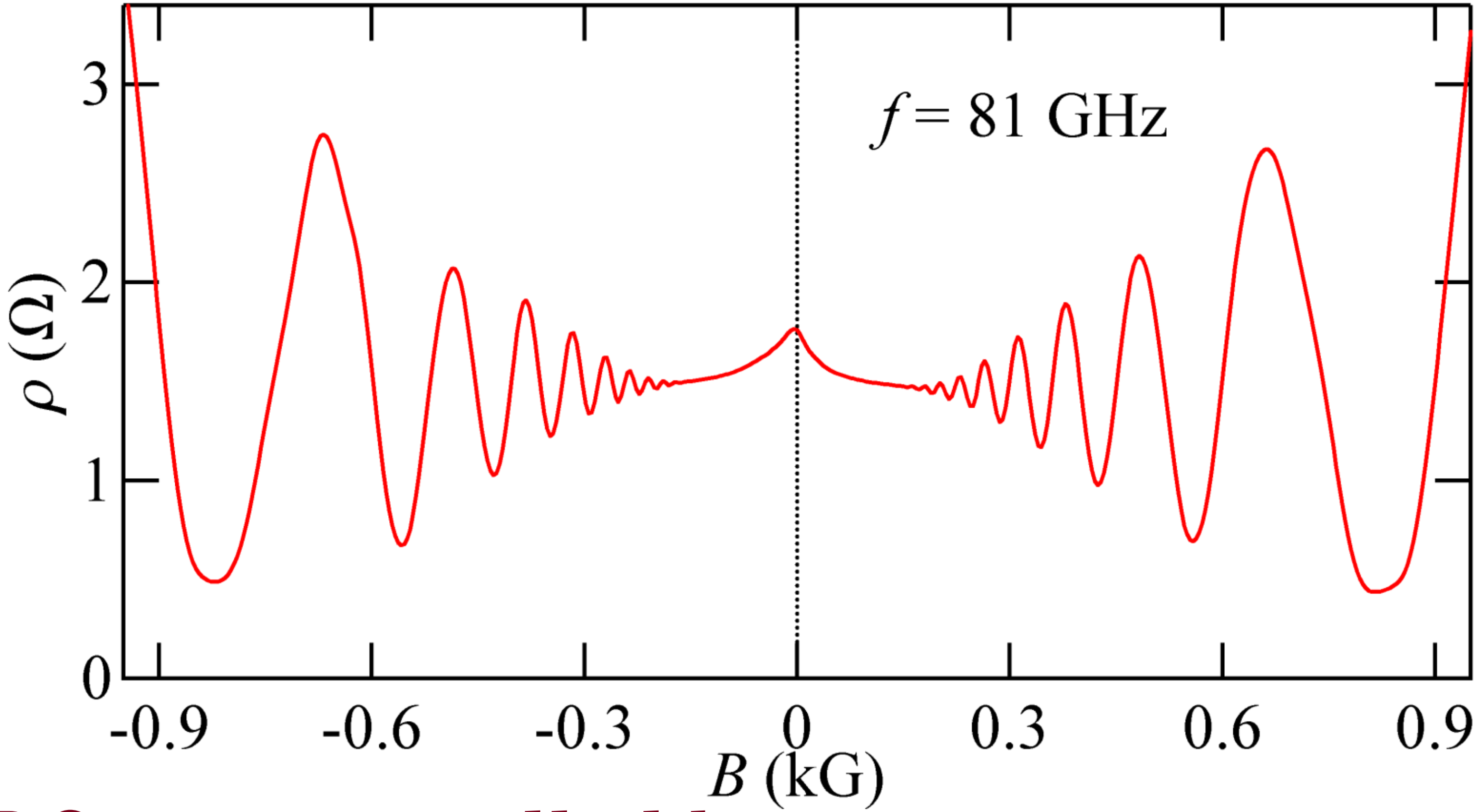
Outline

- Introduction
  - Microwave-induced zero-resistance states
    - Absolute negative resistance and domains
  - Magnetoplasmon resonance (MPR)
- Motivation
  - Can one probe absolute negative resistance using MPR?
- Experimental results
  - Concurrent observation of MPR and ZRS
- Summary

Microwave-induced resistance oscillations

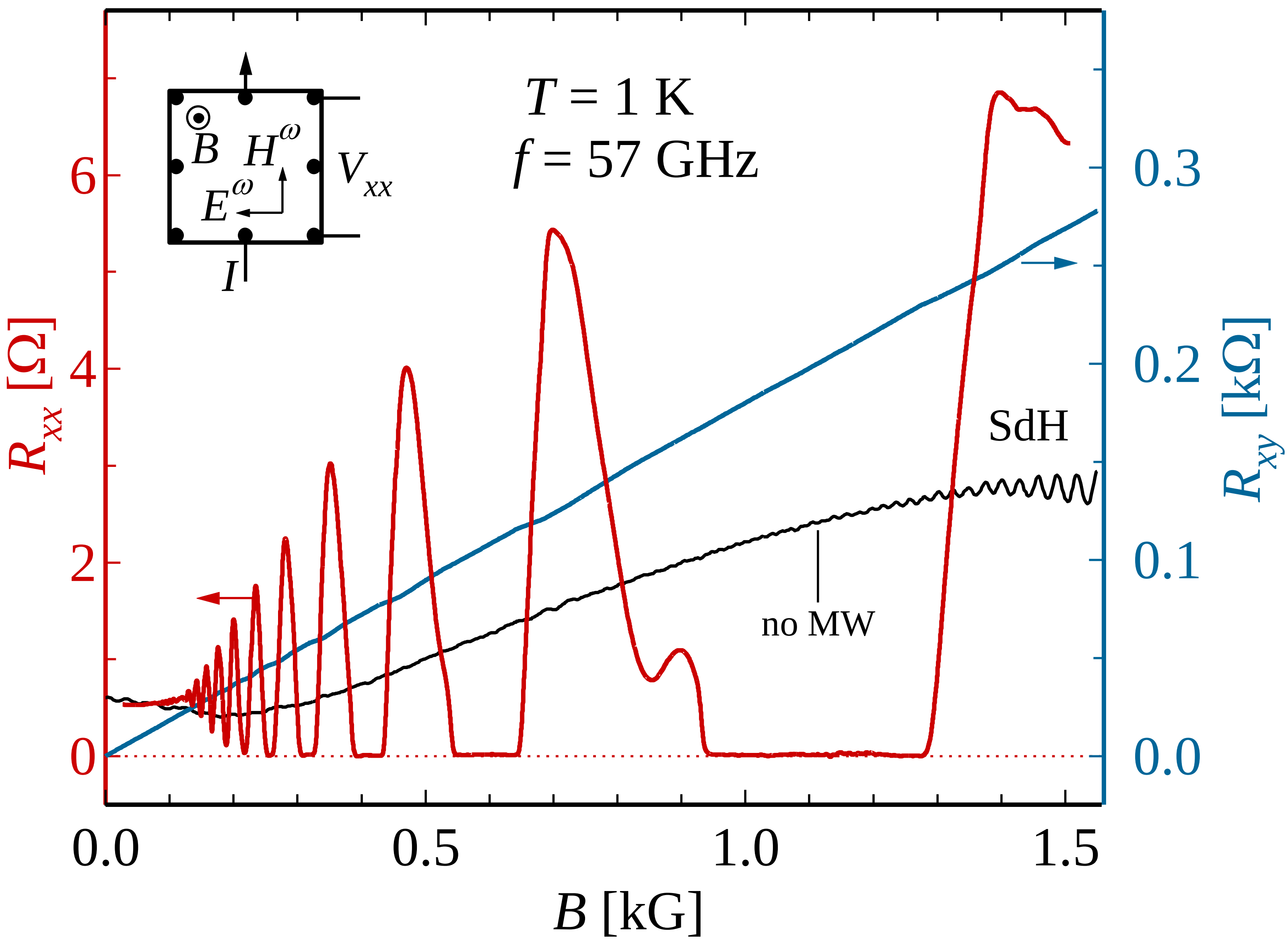


- MIRO are controlled by:

$$\boxed{\epsilon \equiv \frac{\omega}{\omega_c} = \frac{2\pi m^\star}{e}\frac{f}{B}}$$

Zudov, Du, Simmons, Reno, PRB **64**, 201311(R) (2001)
Ye, Engel, Tsui, Simmons, Wendt, Vawter, Reno, APL **79**, 2193 (2001)

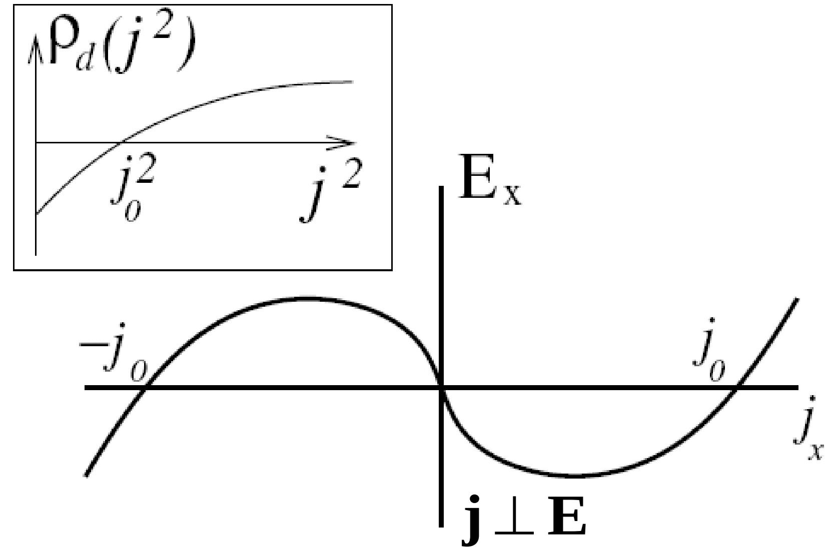
Zero-resistance states (ZRS)

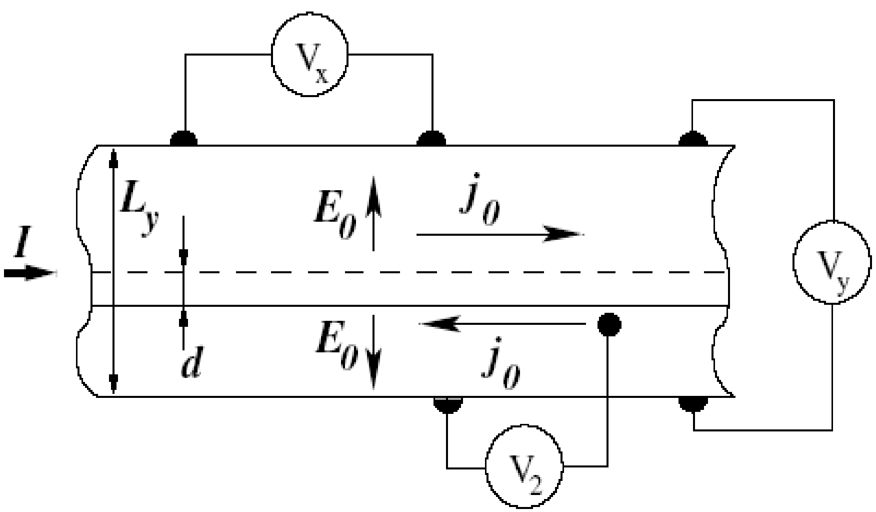


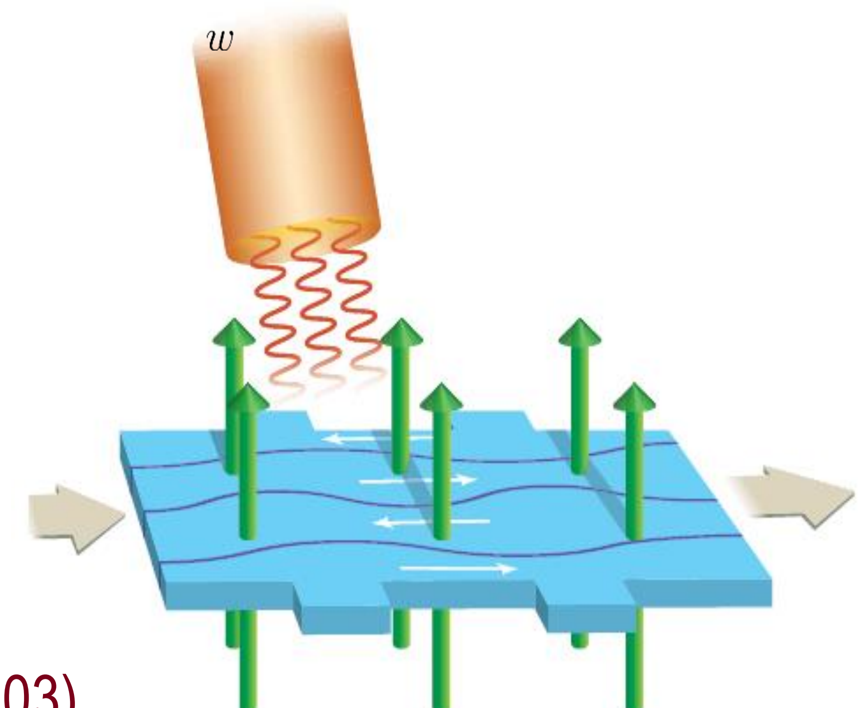
Mani, et al., Nature **420**, 646 (2002)   Zudov, et al.Rev. Lett. **90**, 46807 (2003)

ZRS and current domains

- Current-Voltage curve of irradiated 2DES:
  - **negative resistance (at low currents)**
- **Negative resistance** is unstable! ZRS!
- Current domains with j_0

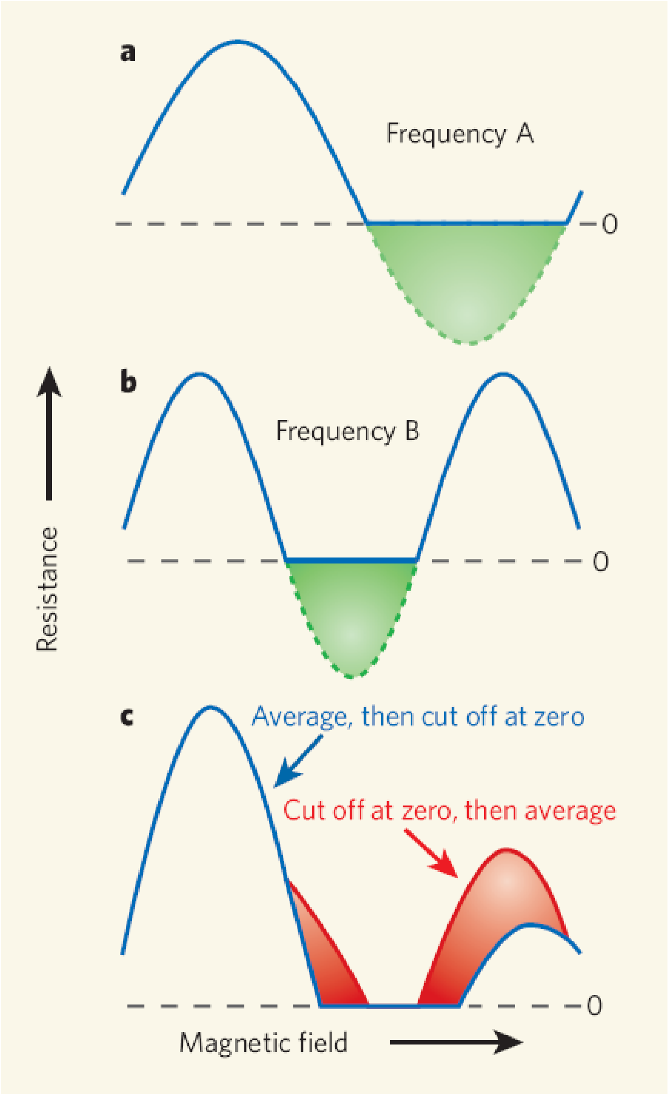


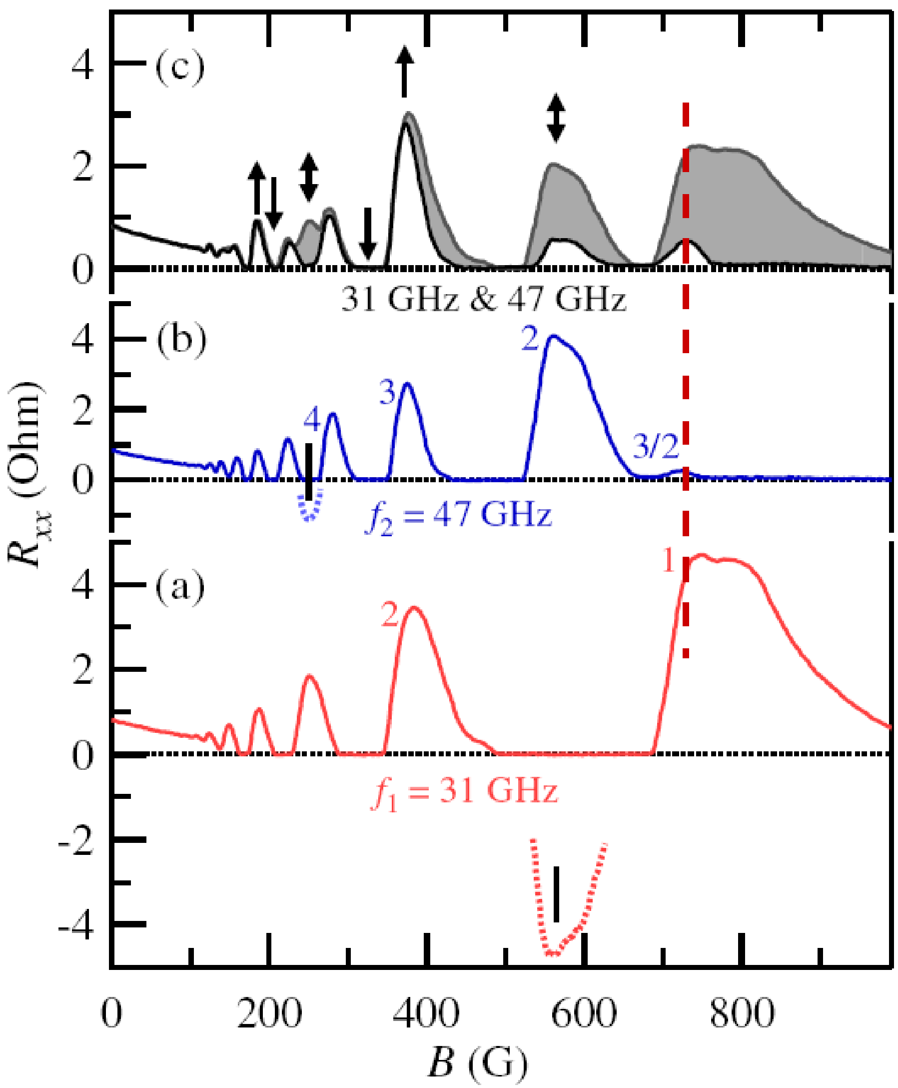




Andreev, Aleiner, Millis, PRL **91**, 056803 (2003)

Studies with bichromatic microwaves





Zudov, Du, Pfeiffer, West, PRL **96**, 236804 (2006)
Durst, Nature **442**, 752 (2006)

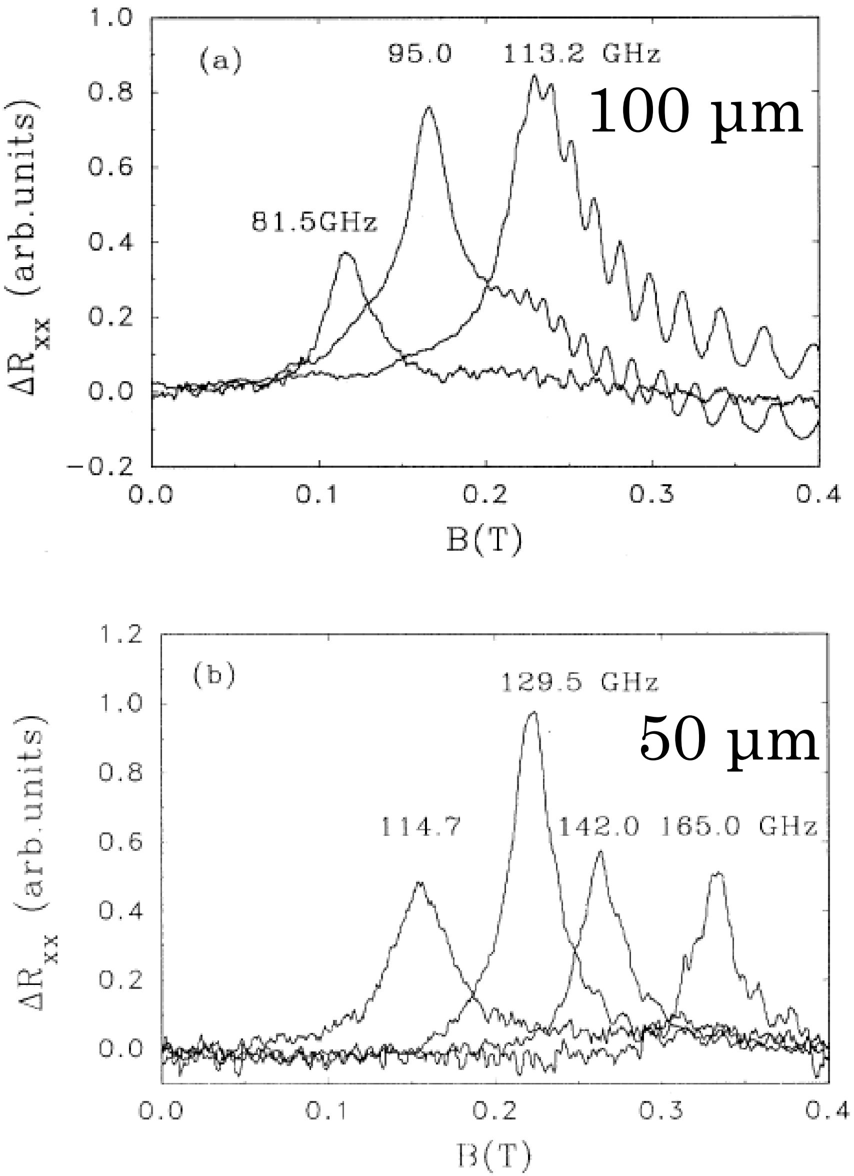
Magnetoplasmon resonance (MPR)

- 2D Plasmon:

$$\omega_{\mathrm{p}}^2 = \frac{e^2 n_e \pi}{2\varepsilon_0 \bar{\varepsilon} m^\star \mathrm{w}}$$

- Magnetoplasmon:

$$\omega^2 = \omega_{\mathrm{c}}^2 + \omega_{\mathrm{p}}^2$$



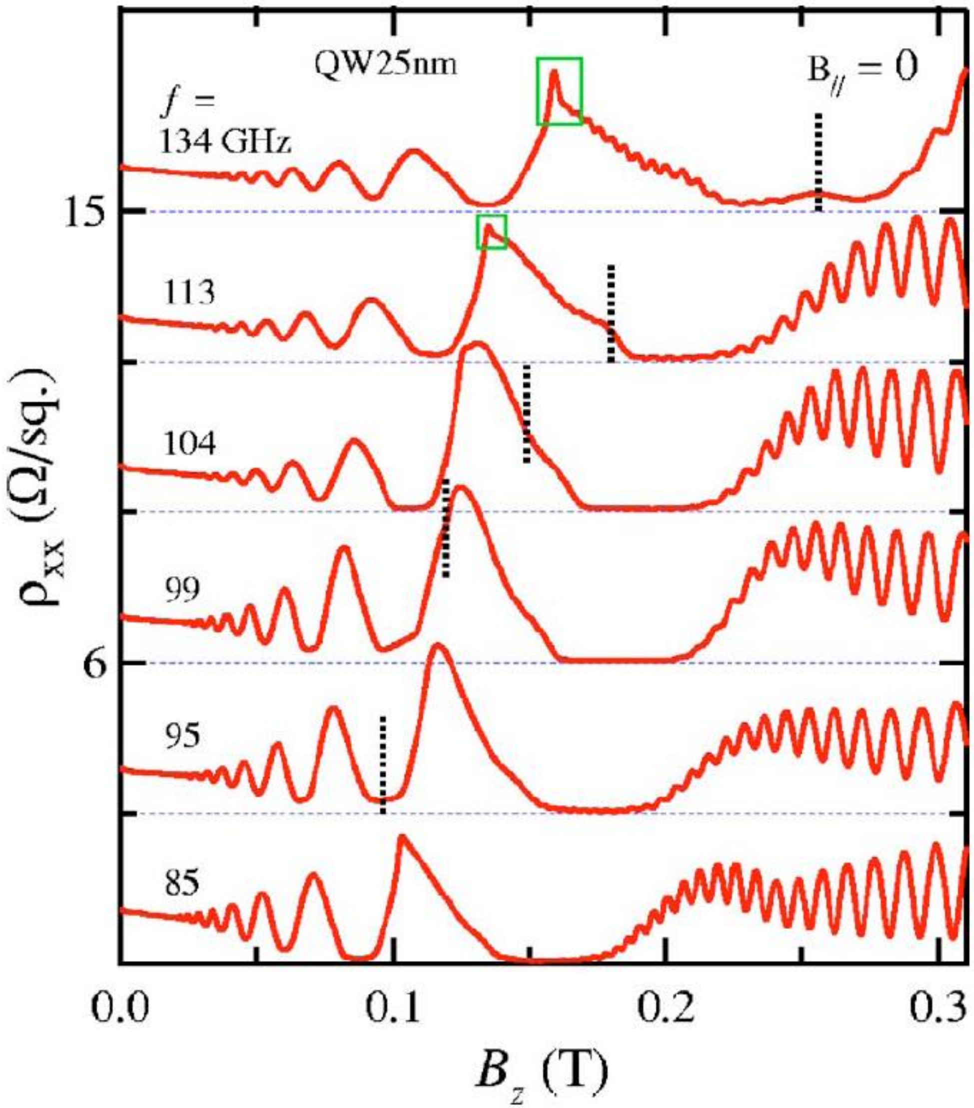
Vasiliadou, Miller, Heitmann, Weiss, von Klitzing, PRB **48**, 17145 (1993)

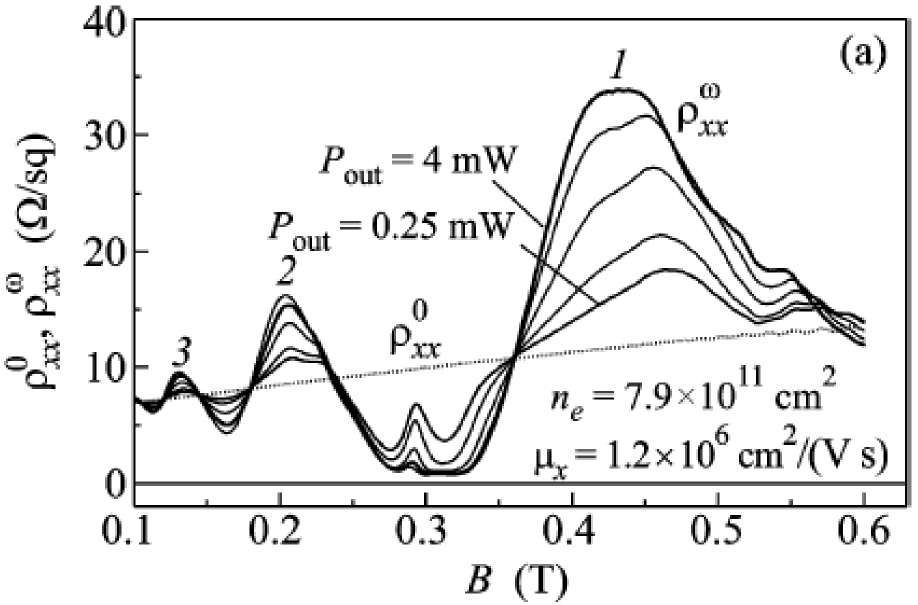
MPR as a probe of negative resistance?

- Question:
  - Can one use magneto-plasmon resonance to probe absolute negative resistance?
- The tuning:
  - ZRS and MPR have different dispersions:
    - MIRO minimum: $\omega_{\mathrm{C}} = (i + 1/4)^{-1}\omega$
    - MPR: $\omega_{\mathrm{C}} = \sqrt{\omega^2 - \omega_{\mathrm{p}}^2}$
  - One can adjust microwave frequency and overlap MPR and ZRS

Hatke, Zudov, Watson, Manfra, PRB **85**, 121306(R) (2012)

Previous observations of MPR/MIRO/ZRS

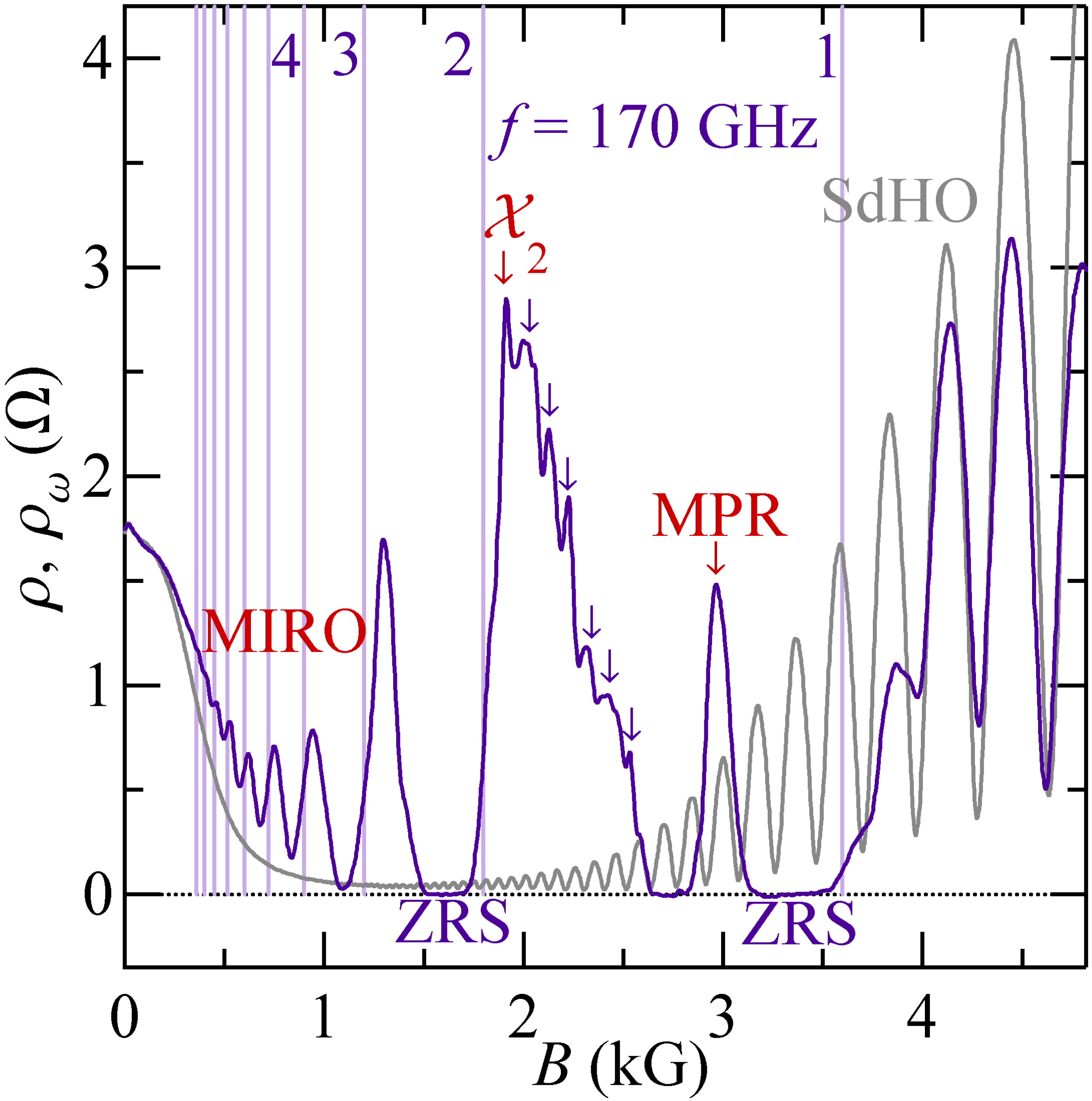




- ZRS is destroyed completely
  - even in ultra high mobility samples!

Yang, Du, Pfeiffer, West, PRB **74**, 045315 (2006)
Bykov, JETP Lett. **87**, 551 (2008)

Unusual properties of the MPR peak



- The MPR peak is:
  1). Strong!
  - similar to MIRO
  - order of magnitude larger than dark resistance

  2). Narrow!
  - ZRS is *not* completely destroyed but split into two parts

Hatke, Zudov, Watson, Manfra, PRB **85**, 121306(R) (2012)

MPR dispersion

- Dispersion:

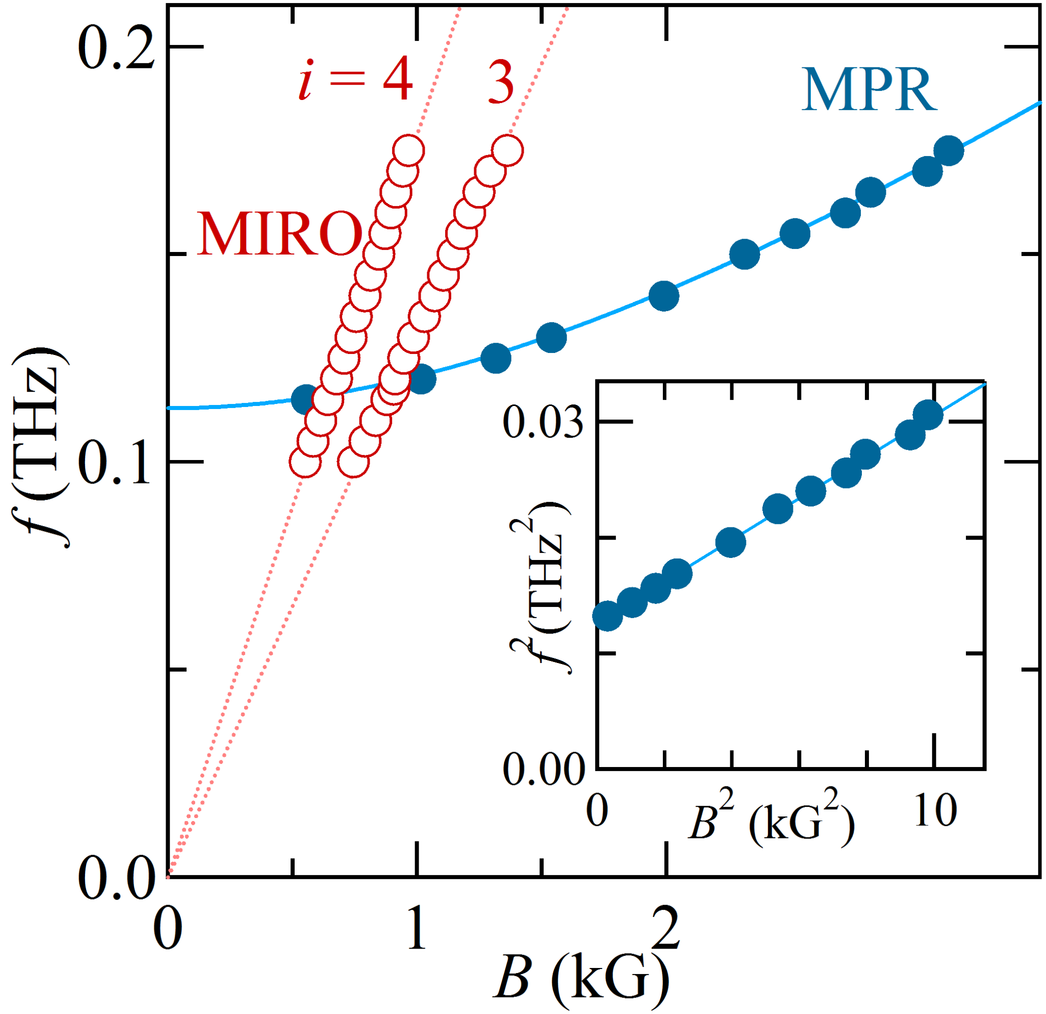
$$\omega^2 = \omega_c^2 + \omega_p^2$$

- Plasmon (calculated):

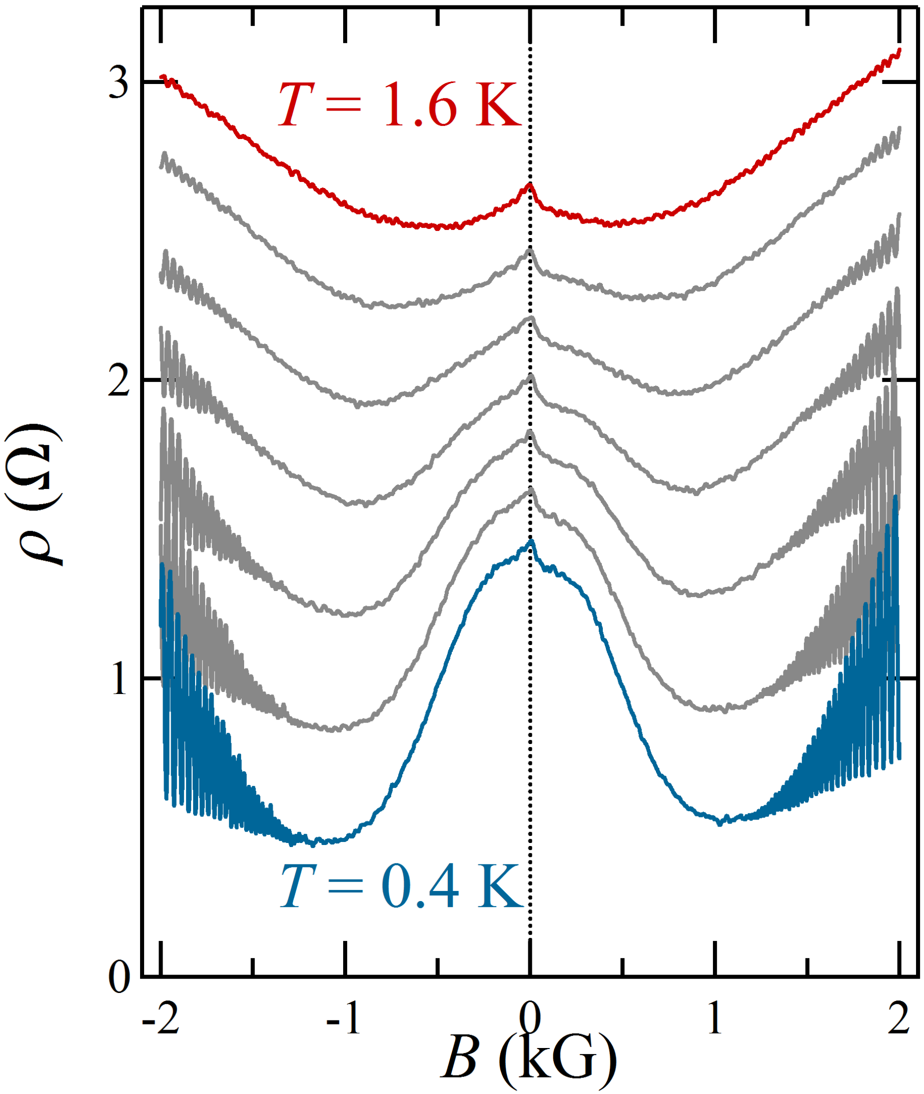
$$f_p \approx 107\ \mathrm{GHz}$$

- Plasmon (measured):

$$f_p \approx 112\ \mathrm{GHz}$$



Negative magnetoresistance



- Deep minimum:

$$B_0 \approx 1\ \mathrm{kG}$$

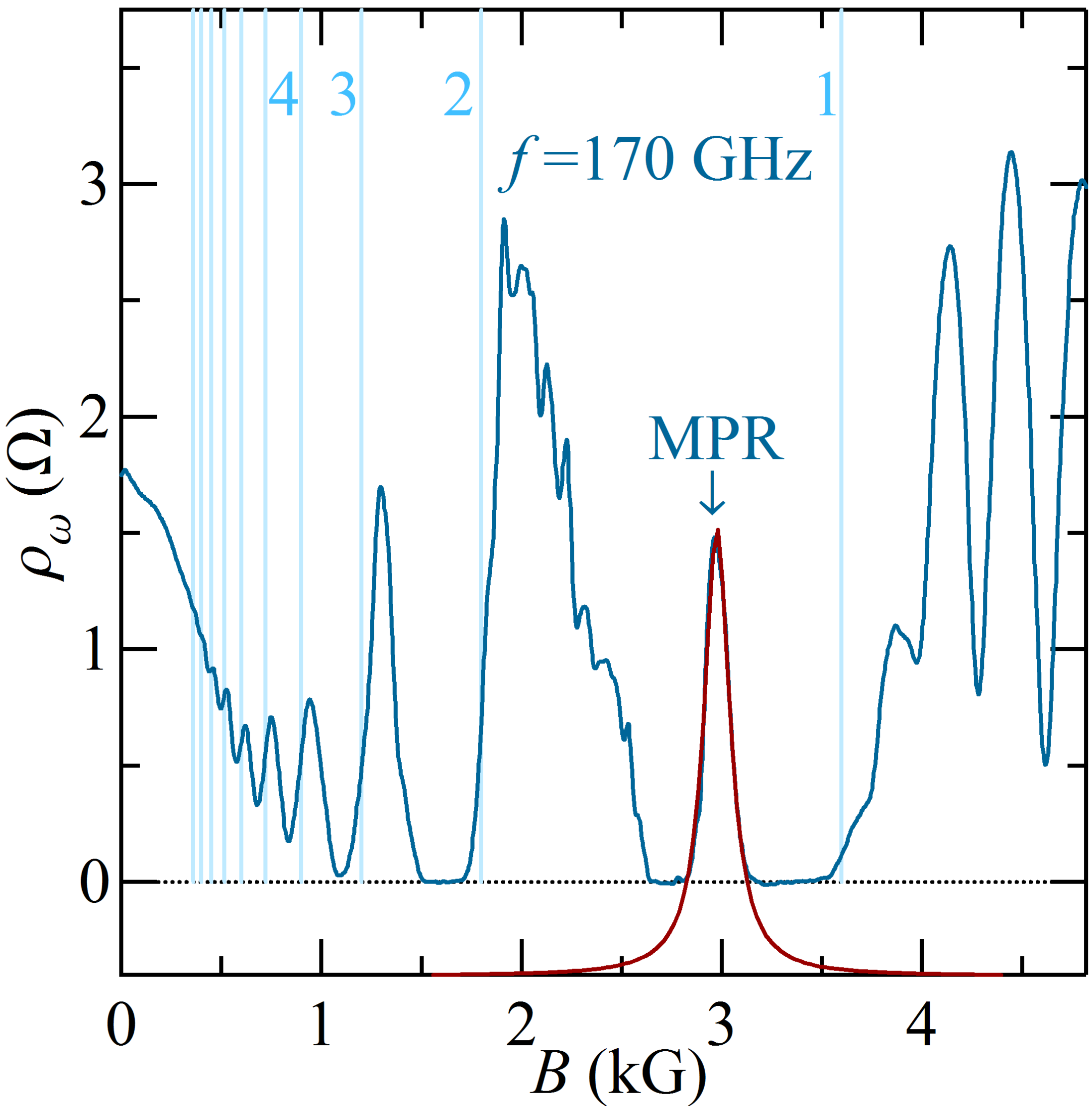
- Low T:

$$\frac{\rho_{\min}}{\rho_0} \approx 0.2$$

- Temperature dependence is strongest at lowest temperature

Hatke, Zudov, Reno, Pfeiffer, West, PRB **85**, 081304(R) (2012)

Probing negative resistance

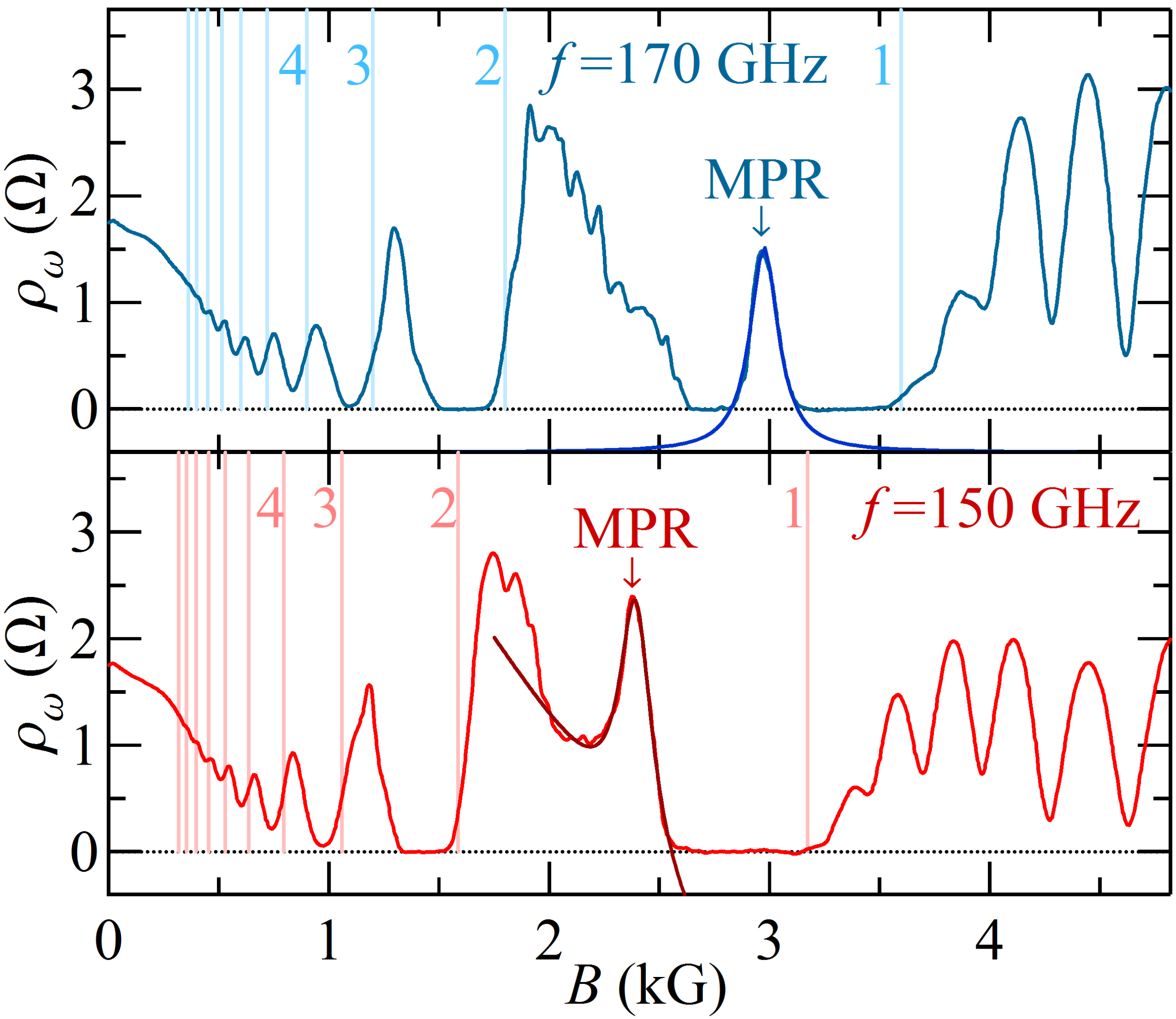


- Origin of MPR photoresistance:
  - no theory!
  - likely originates from heating
- The idea:
  - Fit the MPR peak with a Lorentzian
- The fit generates
  - Negative background:

$$\approx -0.45\,\Omega$$

Hatke, Zudov, Watson, Manfra, PRB **85**, 121306(R) (2012)

MPR + ZRS



- In the ZRS regime
  - Negative background
- Outside the ZRS regime:
  - Positive background

Hatke, Zudov, Watson, Manfra, PRB **85**, 121306(R) (2012)

Summary

- Photoresistance due to MPR can be several times larger than dark resistance
  - Due to strong negative magnetoresistance
- When overlapped with a zero resistance state, MPR can be used to probe absolute negative resistance

Hatke, Zudov, Watson, Manfra, PRB **85**, 121306(R) (2012)