基于粒子符合和量子探测技术的磁单极子/轴子探测

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中国科学技术大学

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研究背景：粒子物理新物理搜寻

Topic	Crucial measurement	Significance
Higgs boson	M =125 GeV	Confirm spontaneous symmetry breaking in gauge theory
Gravitational waves (Graviton)	Existence	Support general relativity
Glueball, exotic hadron	Existence	QCD
Dark matter	Existence	Missing mass in the universe
Antimatter	Existence	Baryon number asymmetry
Neutrino oscillation and mass	M < 1 eV	Structure of GUTs. Eventual fate of the universe
Proton decay	t > 1.67×10^{34} years	Evidence for validity of GUTs
Magnetic monopole	Existence, mass, electric charge	Electric and magnetic charge symmetry predicted by Dirac. Structure of gauge field configuration
Fractionally charged particle	Existence	Would confuse all current prejudice
Super-symmetric particles	Existence, M > 1 TeV	Hope of understanding gravity
Extra dimension	Existence, Heavy W/Z like particle, graviton, microscopic black hole	Hierarchy problem

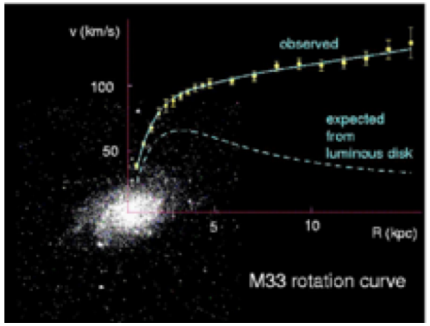
轴子理论假设

轴子

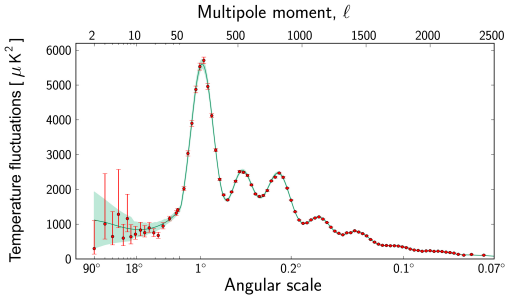
- 强相互作用中电荷-宇称守恒问题
- 暗物质候选者
- 轴子的电磁作用极其微弱

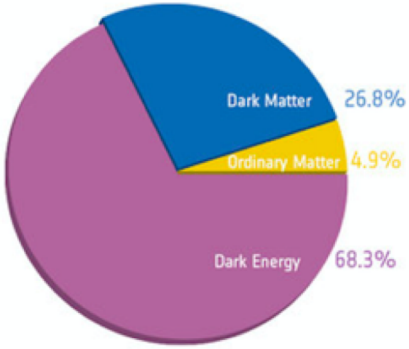
Bullet cluster collision

Galaxy rotation curve

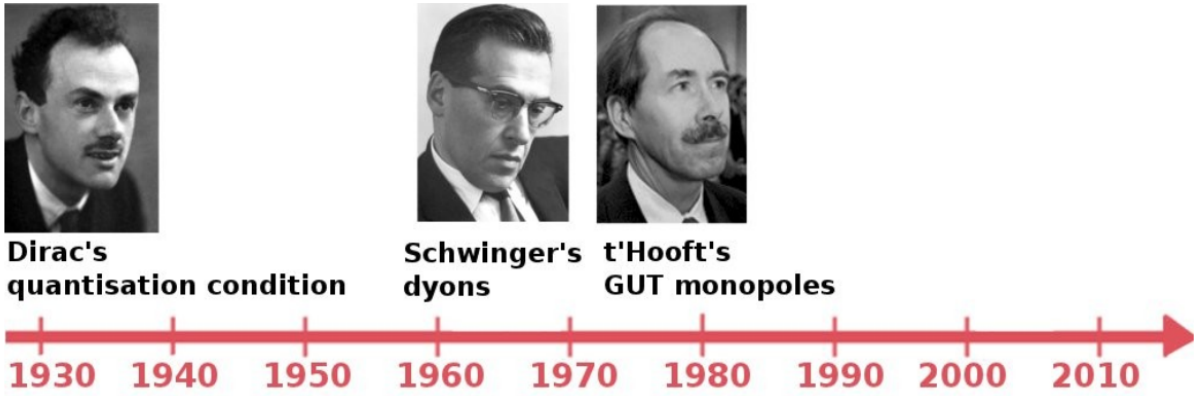


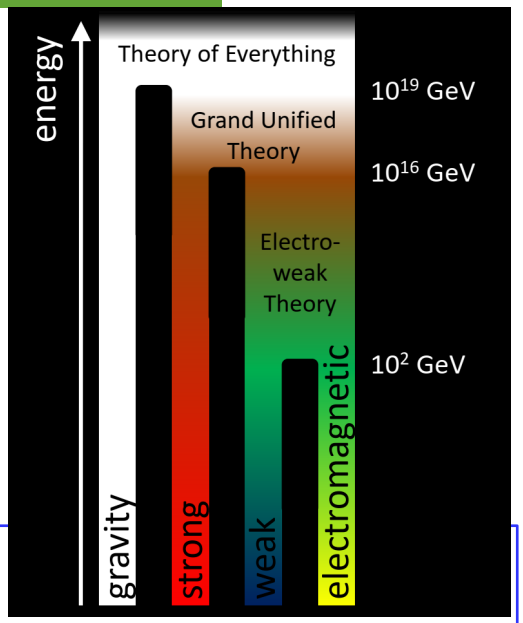
Cosmic Microwave Background

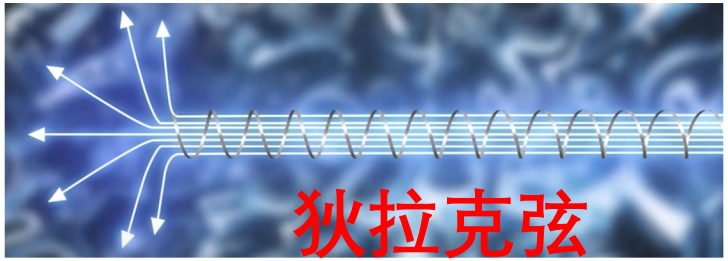


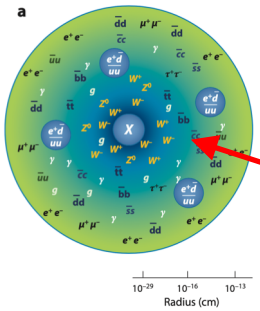


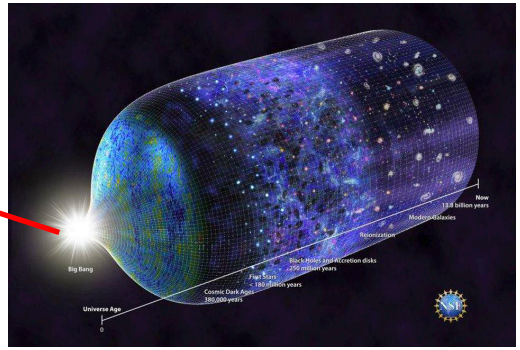
磁单极子理论假设







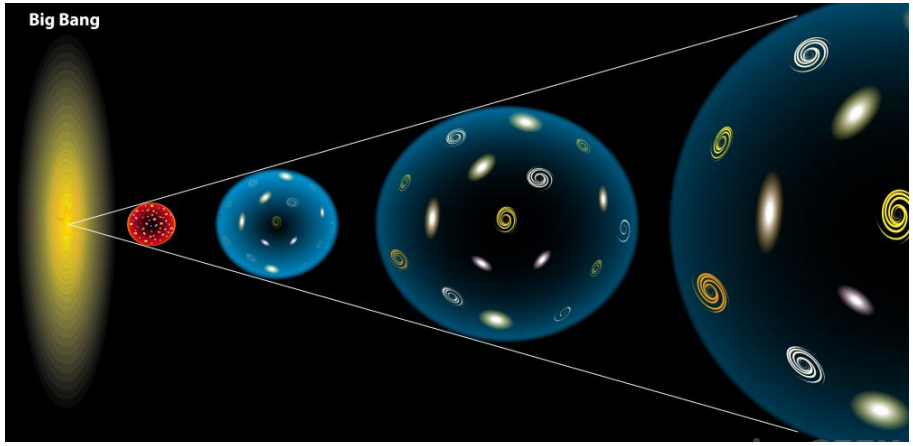


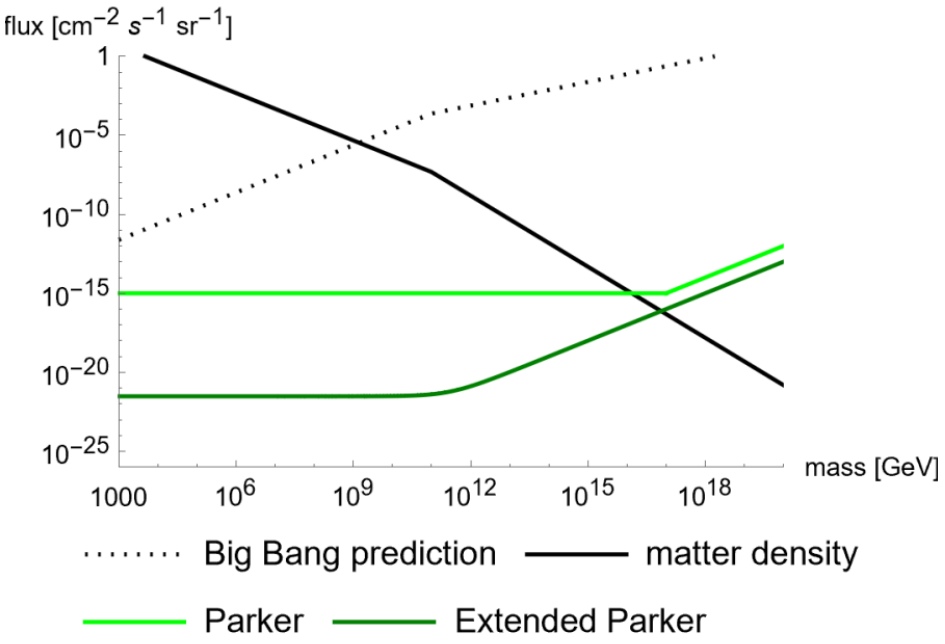


磁单极子：

- 标准模型电荷量子化
- 宇宙起源大爆炸膨胀期
- 理论预言，大统一理论(GUT)，弦论，普朗克能标；
- 极其稀有（实验结果, 宇宙学限制等）
- 稳定（只带有电磁荷，电磁相互作用）

磁单极子与宇宙演化



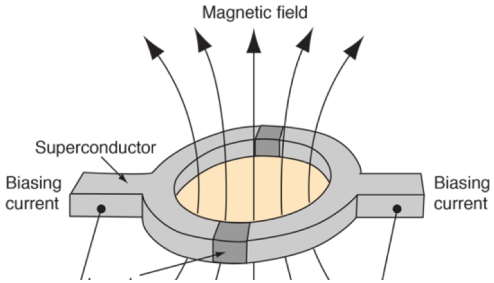


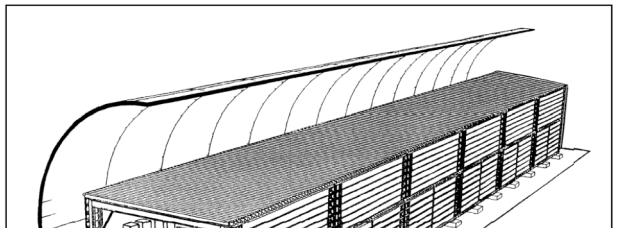
- 宇宙大爆炸理论表述宇宙原点之后的演化；“暴涨”大爆炸理论，极大稀释了磁单极子产生，解决此问题以及其余多个问题，成为主流；
- GUT磁单极子在宇宙早期有重要地位，质量更小的磁单极子有可能在后续星际形成中产生；

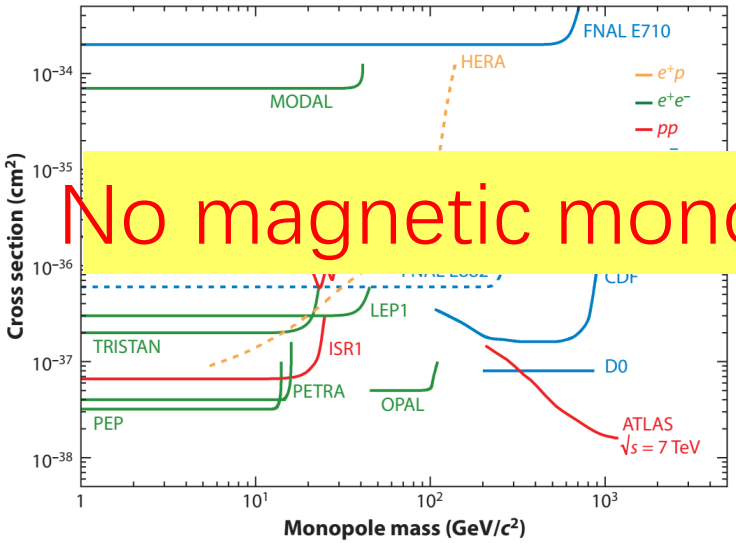
$$v_{\rm mag} \sim \begin{cases} c, & M \lesssim 10^{11}\,{\rm GeV}\,, \\ 10^{-3} c \left(\frac{10^{17}\,{\rm GeV}}{M}\right)^{1/2}, & M \gtrsim 10^{11}\,{\rm GeV}\,. \end{cases}$$

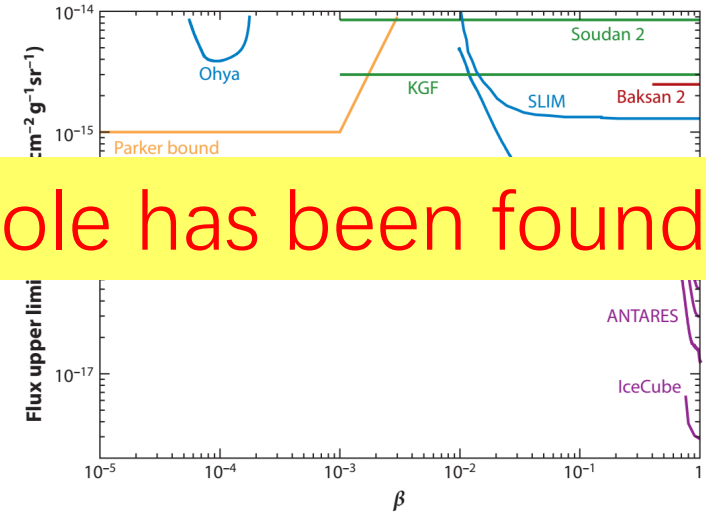
Parker: 过多磁单极子会抵消星际磁场
Density: 过多重磁单极子会明显与星际总质量不匹配

磁单极子实验探测

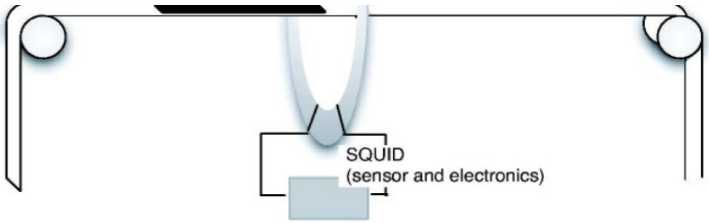




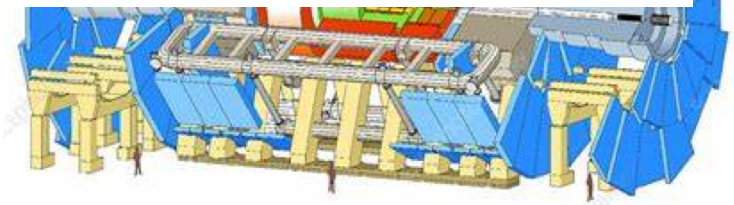




No magnetic monopole has been found

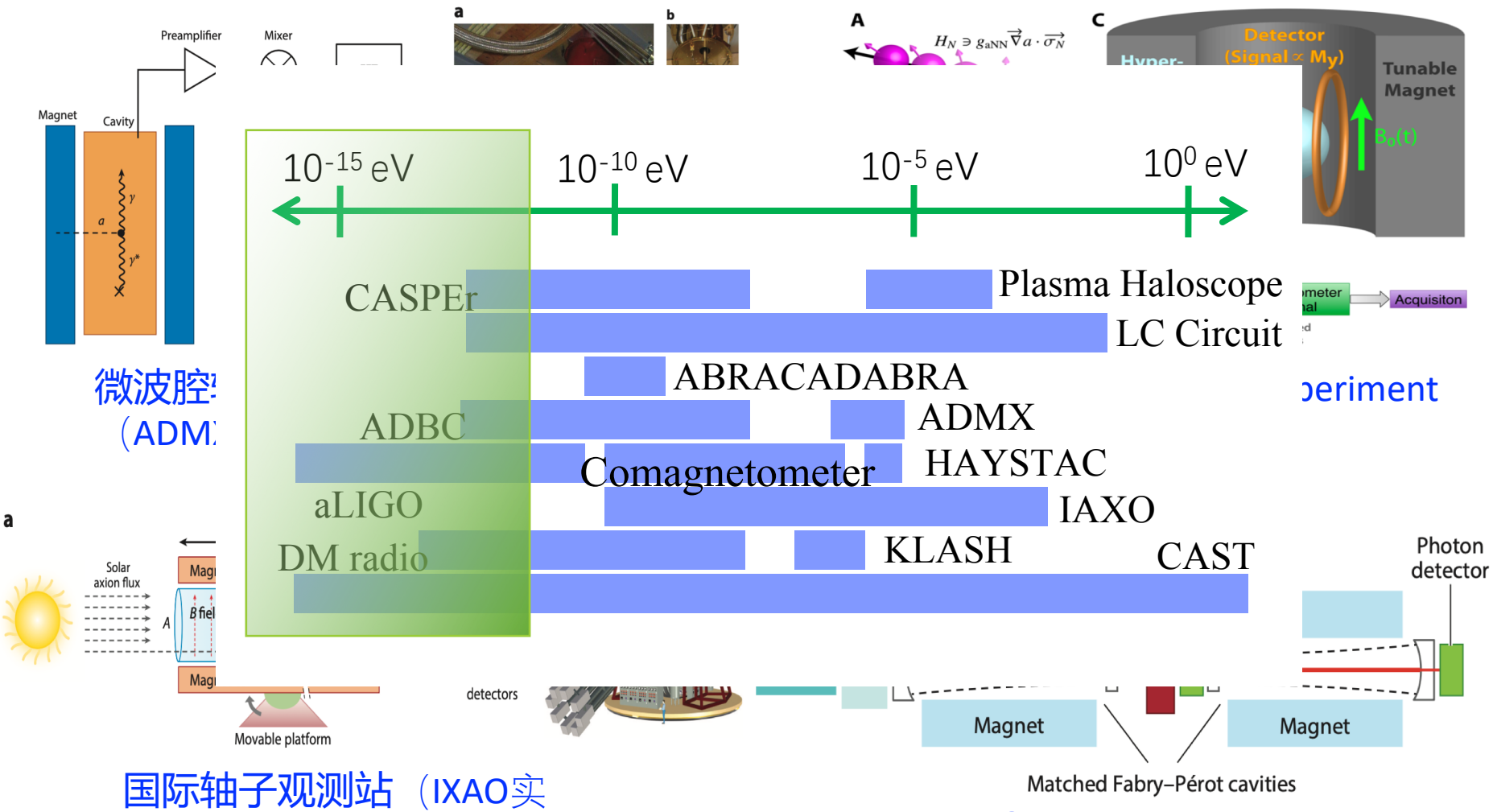


月球及陨石样本



在大型强子对撞机实验上

轴子实验探测



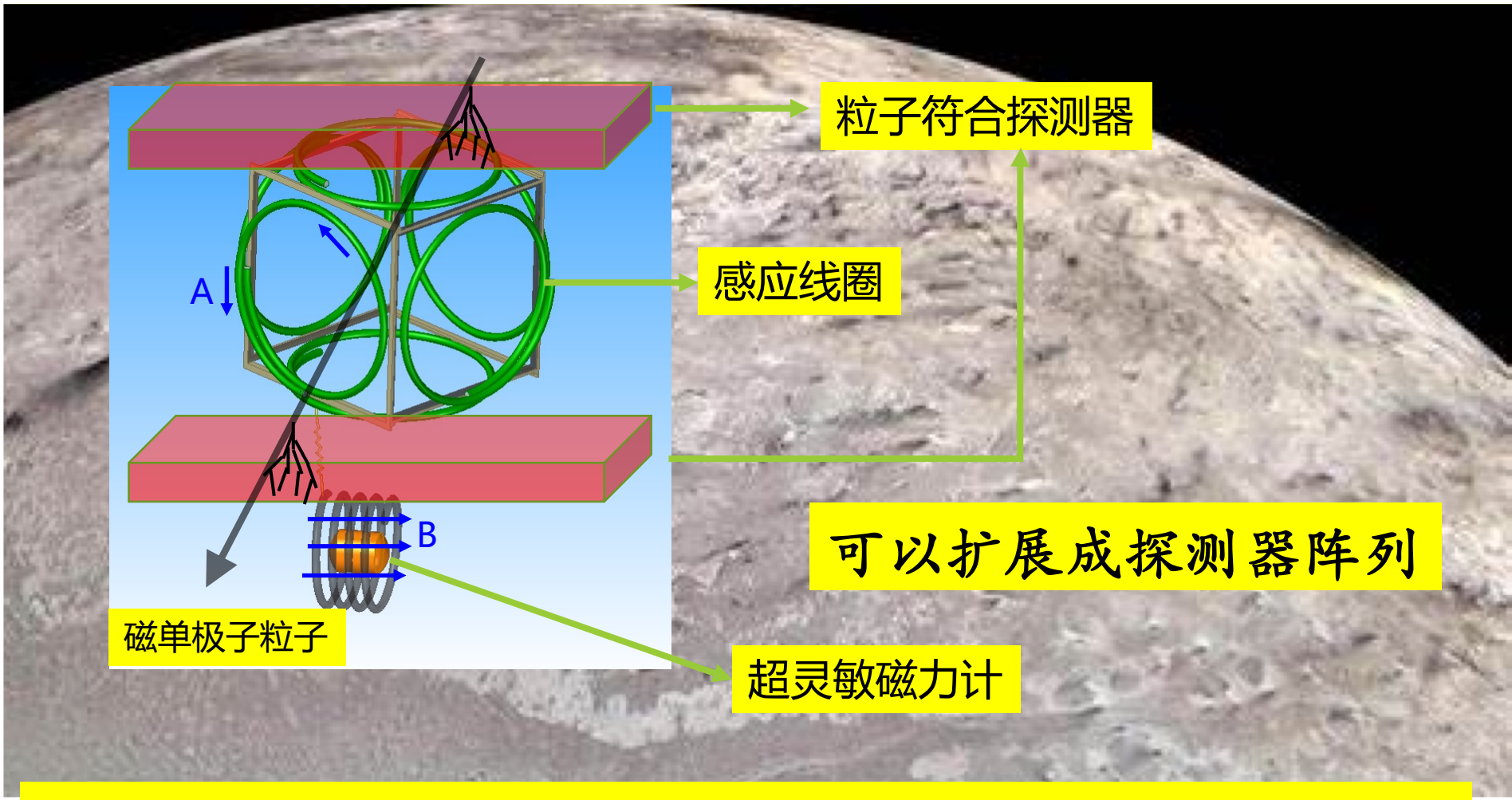
微波腔
（ADM

periment

国际轴子观测站（IXAO实验）

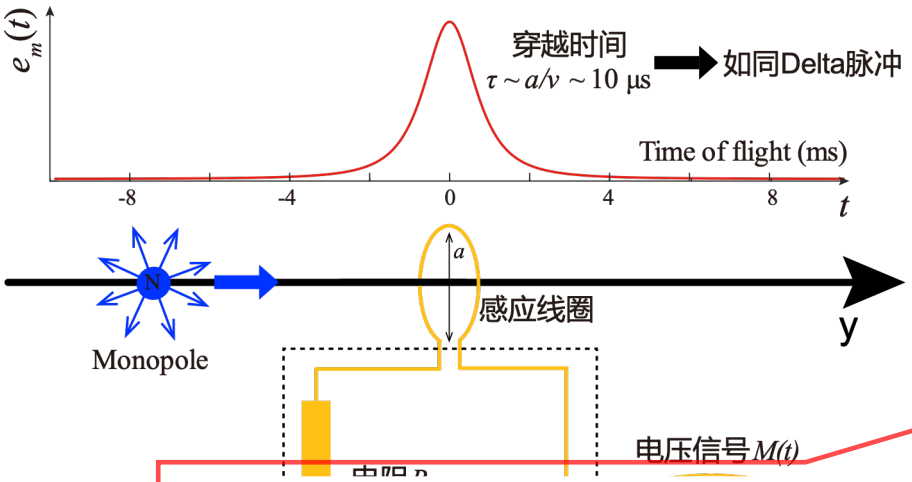
Light Shining Through Walls

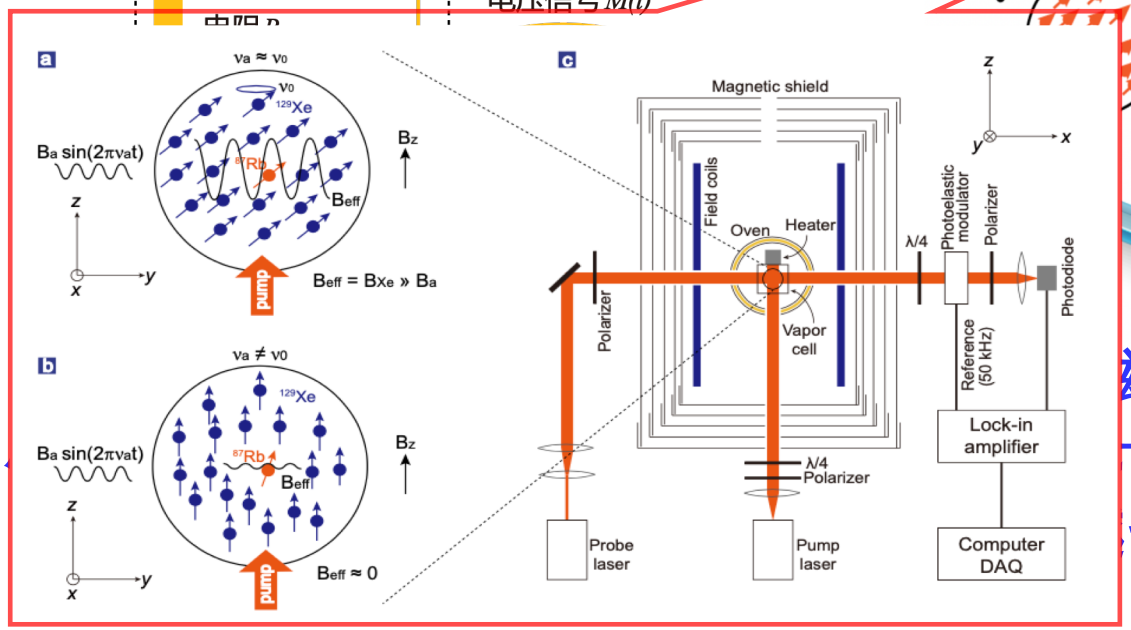
粒子符合与量子传感器结合搜寻新粒子

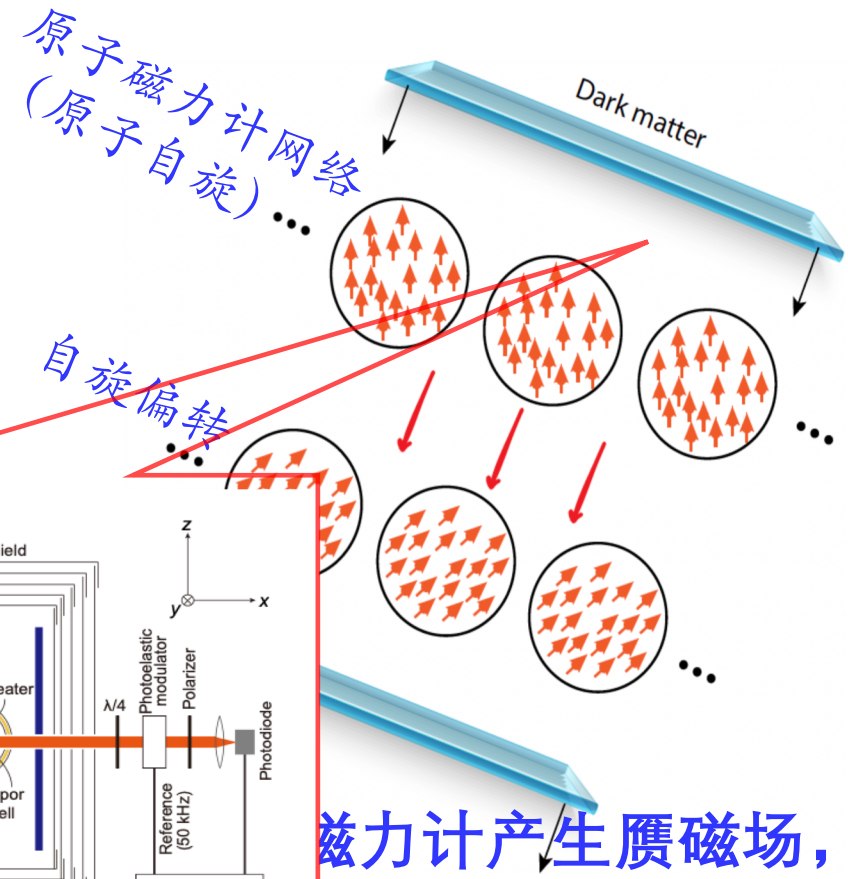


- 月球或深空环境提供了测量极微弱信号的低本底实验环境：无大气层、极低磁场

探测原理







利 … 磁力计产生赝磁场，
…计探测，低速磁单极
…也会有脉冲信号

可以覆盖中低速磁单极子参数范围！

为什么要在月球/空间上搜寻新粒子

月球独特场所 → **寻找新粒子**

月球没有大气

稀缺环境

磁单极子

极弱的背景磁场
(一般只有几nT)和本底噪声

超灵敏磁探测（无需磁屏蔽）

地月距离38.4万公里
（约30倍地球直径）

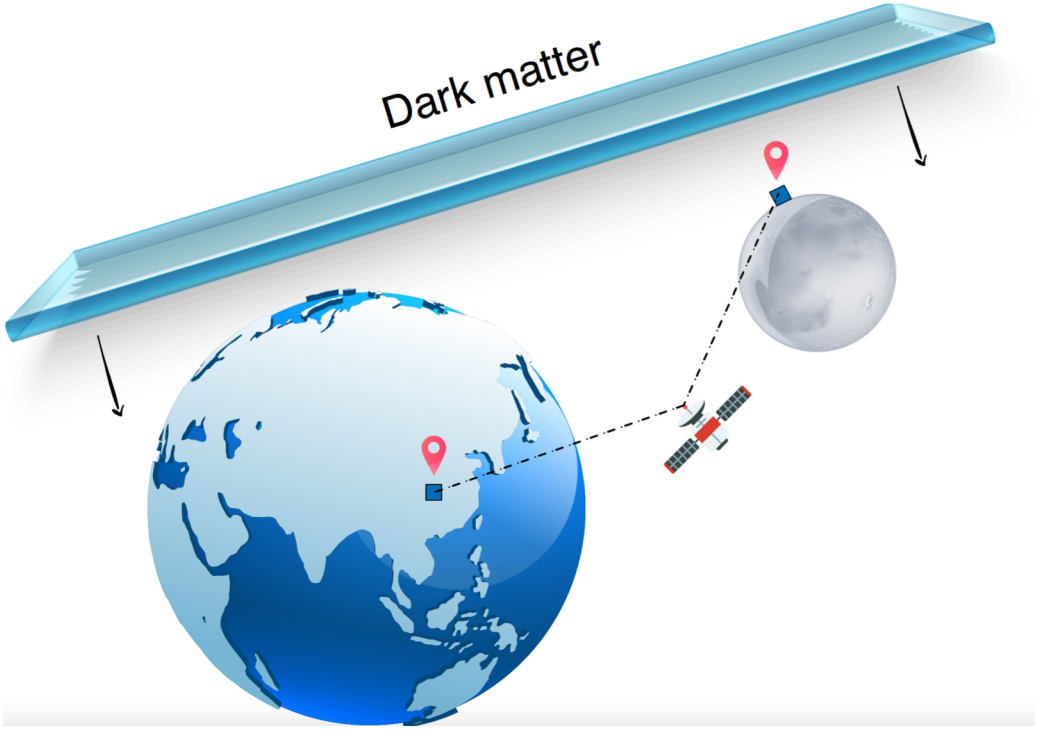
长基线

轴子及其他新玻色子

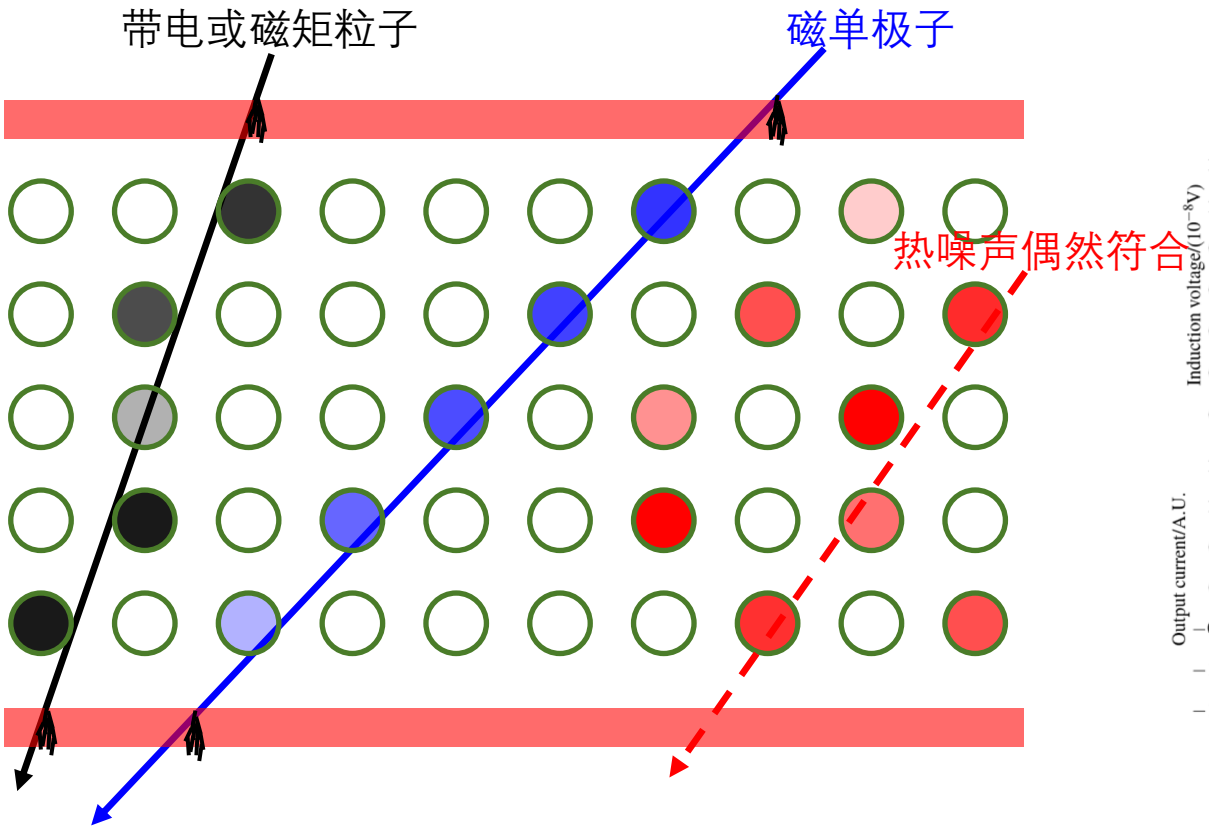
轴子探测网络

地面实验缺失信息：
传播方向、空间关联

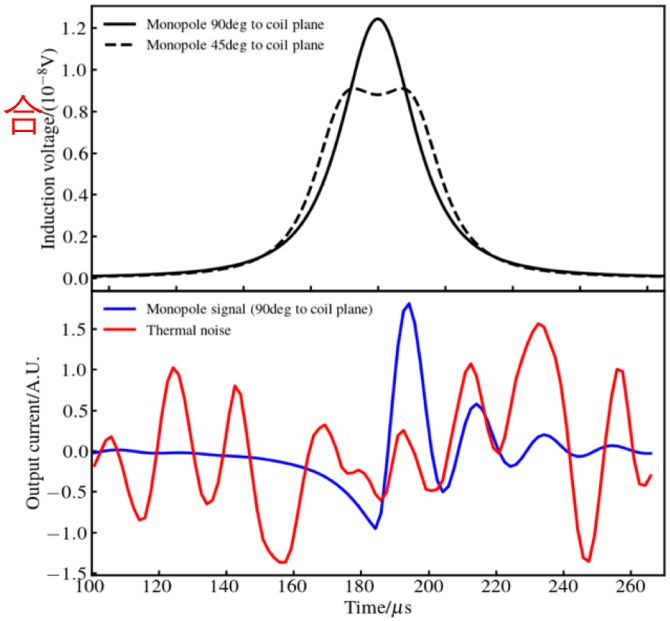
- 月球可避免地球上人类活动造成的辐射本底
- 深空、月球和地球可以形成轴子探测网络进行联合测量
- 溯源可能的轴子波来源
- 揭示轴子波大尺度的结构



粒子与磁力计符合测量



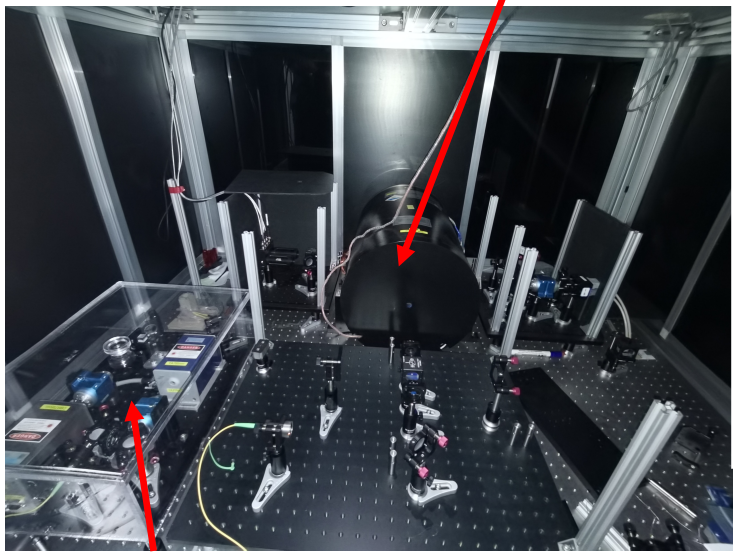
谐振前后波形（信噪比1:1.5）



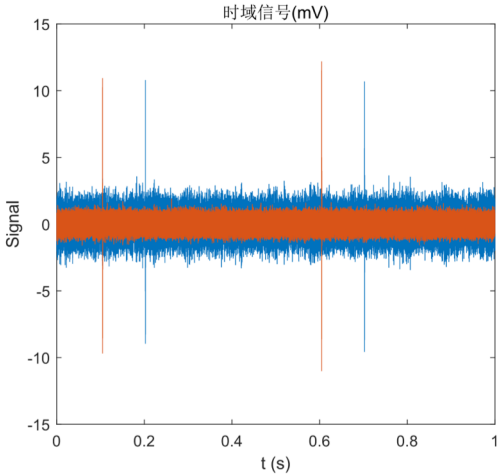
- 只有磁单极子同时产生电离和感应信号；
- 粒子探测和量子传感器同时可以给出磁单极子速度和极性。
- 粒子探测器指标（位置能量分辨）预研中。

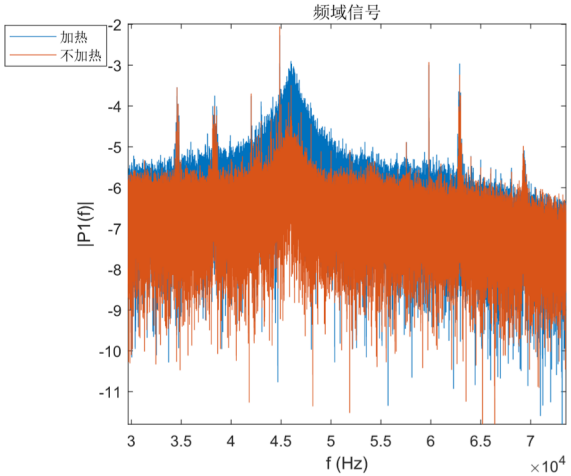
现阶段进展：磁力计样机

磁力计&磁屏蔽

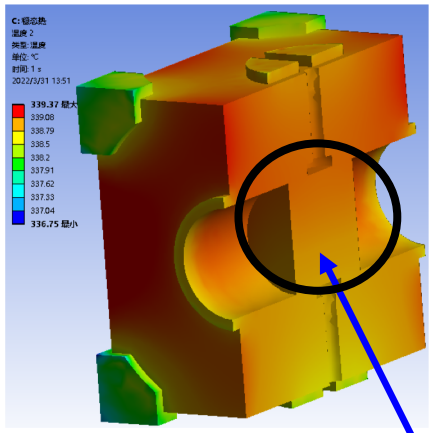


激光系统

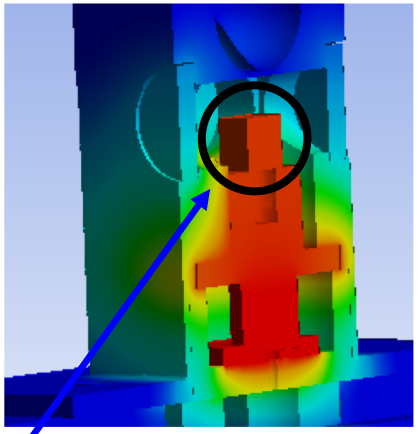




新设计：最高340度



旧设计：最高140度



磁力计气泡室

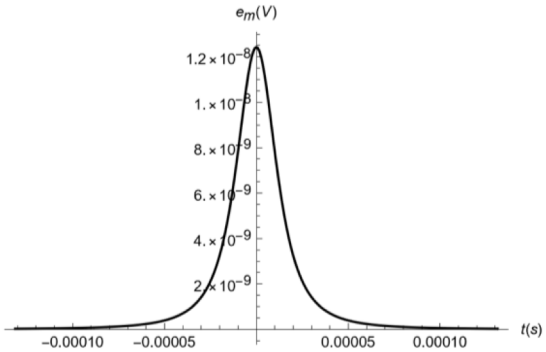
磁力仪观测到较高噪声，原因经过分析后认为有两种：

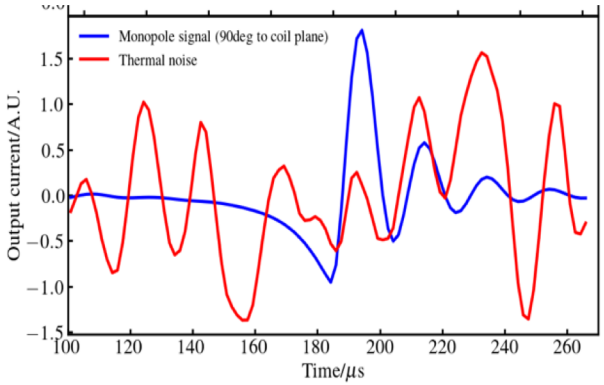
- 激光功率不够；
- 磁力计气泡加热不均，造成气泡室内原子数密度低；

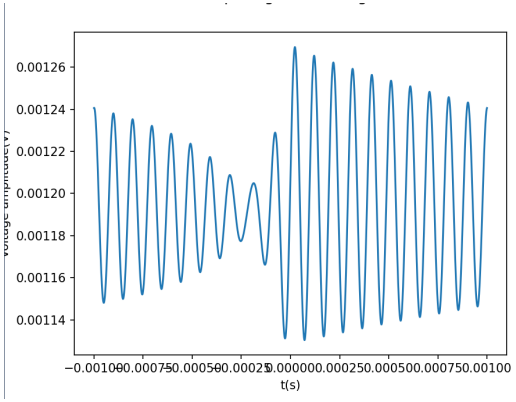
目前已经**升级激光器**以及**优化加热室设计**，重新测试中。

现阶段进展：信号模拟

感应电动势 → 谐振电路shaping → 磁力计读出

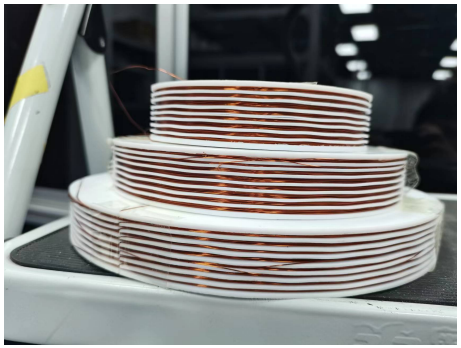




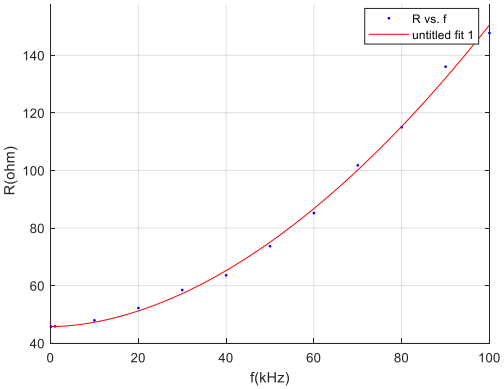


降低信噪比关键参数：

- 电路中元件电阻 电容 电感；
- 感应线圈的交流电阻（与线圈几何与绕制有关，热噪声来源）



室温下其中一个测试



交流电阻我们通过实际绕制线圈进行液氮和室温下测试。

Summary

- 磁单极子存在可以很自然解决麦克斯韦方程电磁不对称问题，以及解释电荷量子化现象;轴子是热门的暗物质候选粒子，并可解释强CP问题。
- 计划使用粒子符合技术和量子传感技术结合，同时对磁单极子以及轴子进行探测;
- 依托于新成立的深空实验室已经开始预研工作;
- 最终目标为深空及月基环境磁单极子/轴子探测，先期可在地球环境阵列测试;
- 模拟信号以及磁力计样机测试正同步开展。

感谢聆听！