

Searching for Stable, Strange Particles on Earth

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- Theoretical Proposals
- Past searches
- Searching for helium-like particles

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Theoretical Proposals

Motivation

Superheavy elementary particles, $10 - 10^5$ amu

R. N. Cahn and S. L. Glashow, *Science* 213, 607 (1981)

Collapsed nuclei based on phenomenological nuclear-force model

A. R. Bodmer, *Phys. Rev. D* 4, 1601 (1971)

Abnormal nuclear states and vacuum excitation

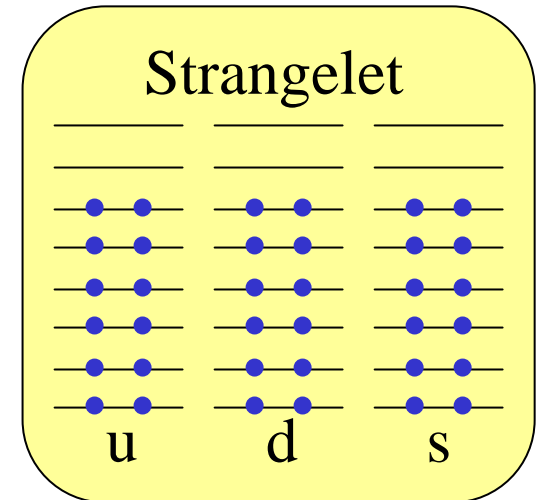
T. D. Lee, *Rev. Mod. Phys.* 47, 267 (1975)

Strange quark matter, quark nuggets, strangelets...

E. Witten, *Phys. Rev. D* 30, 272 (1984)

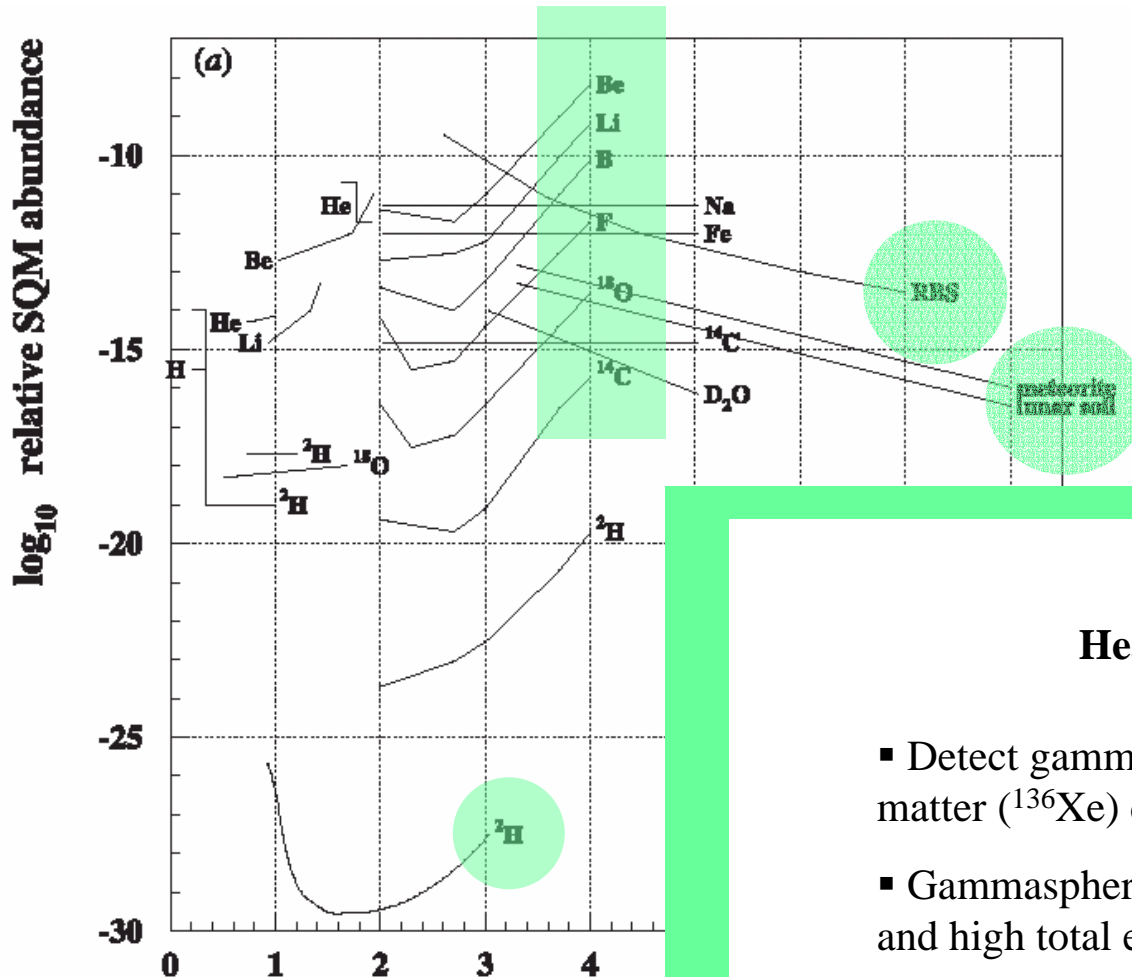
E. Farhi and R. L. Jaffe, *Phys. Rev. D* 32, 2452 (1985)

Dark matter – $\sim 1/4$ of the critical density may be due to exotic particles



Experimental Limits

“Strange quark matter searches”, R. Klingenberg, J. Phys. G25, R273 (1999).



Heavy Ion Activation

- Detect gamma rays emitted when normal matter (^{136}Xe) dissolve into strange matter;
- Gammasphere detector for high-multiplicity and high total energy events
- M.C. Perillo Isaac *et al.*, PRL 81, 2416 (1998)

Search for Anomalously Heavy Isotopes of Helium

P. Mueller,¹ L.-B. Wang,^{1,2} R. J. Holt,¹ Z.-T. Lu,¹ T. P. O'Connor,¹ J. P. Schiffer^{1,3}

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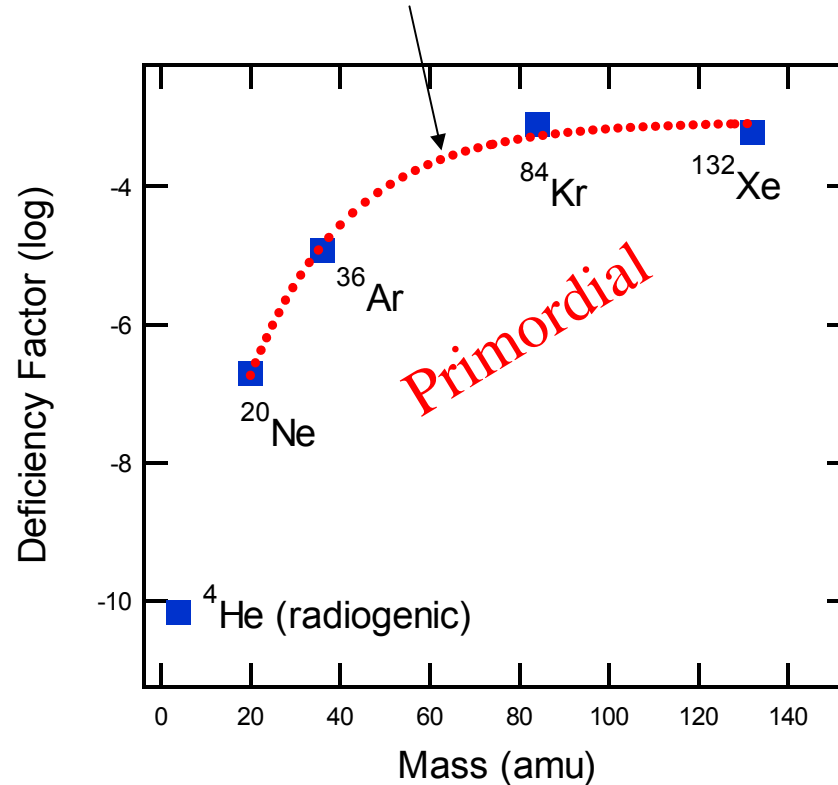
³ *Physics Department, University of Chicago, Chicago, IL 60637*

P. Mueller *et al.*, [arXiv:nucl-ex/0302025](https://arxiv.org/abs/nucl-ex/0302025) (2003)

Noble Gases on Earth and in the Solar System

$$\text{Deficiency Factor} = \frac{\text{Terrestrial Atomic Abundance}}{\text{Solar Atomic Abundance}}$$

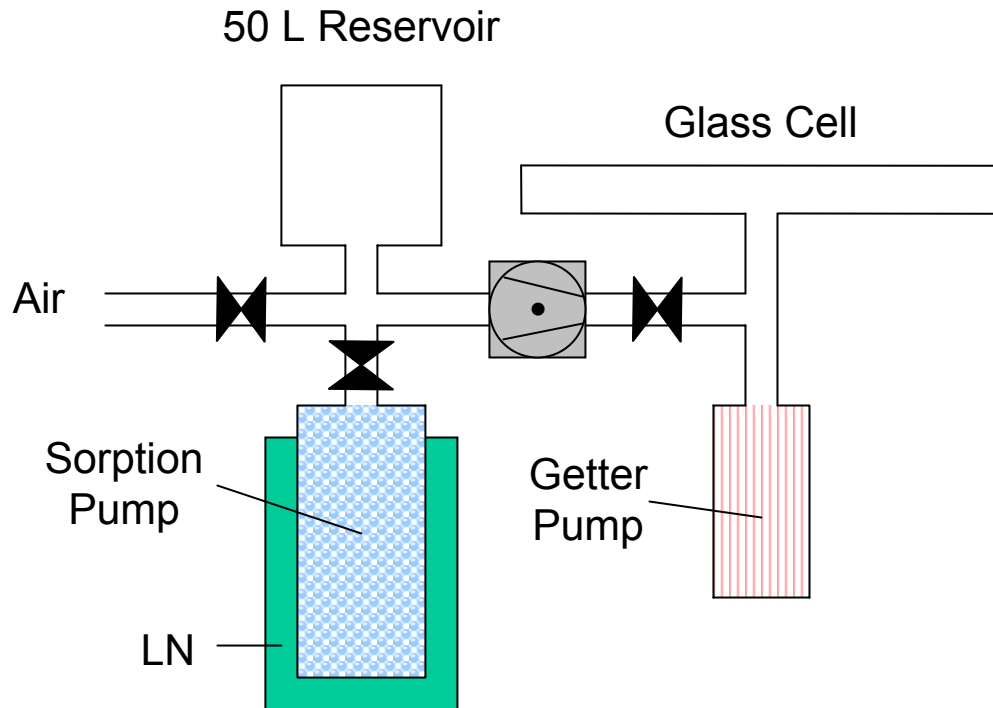
$$\log(\text{Def}) = -3.1 - 9.0 \cdot \exp(-0.045 \cdot M)$$



H. E. Suess. Some chemical aspects of the evolution of the terrestrial atmosphere, Tellus 18, 207-211 (1966)

Anders and N. Grevesse. Abundances of the elements: meteoritic and solar. Geochim. Cosmochim. Acta 53, 197-214 (1989)

Extraction of He Sample from Air

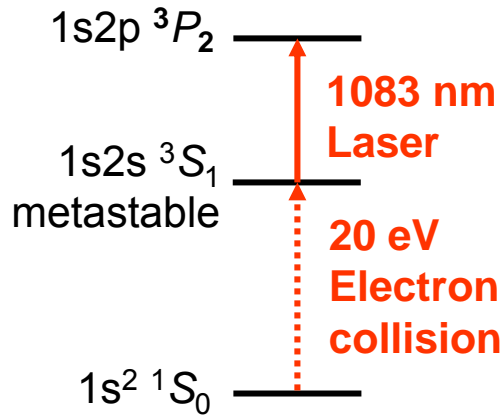


Gas composition of dry air

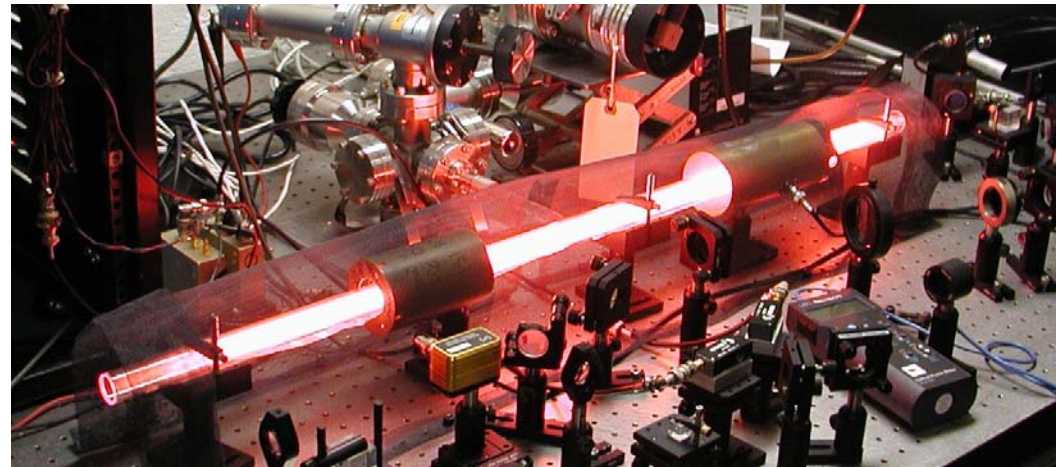
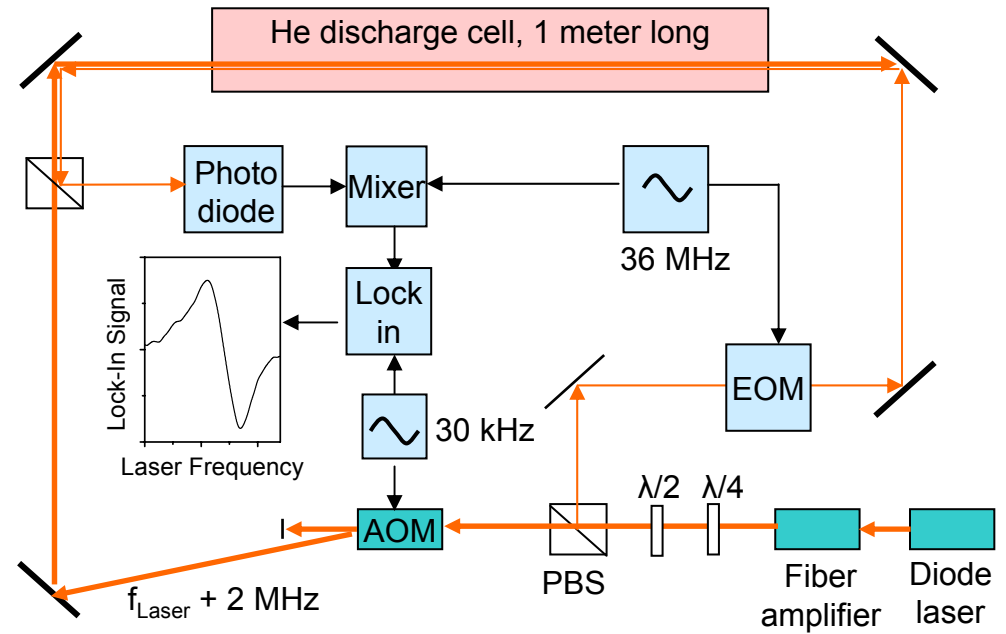
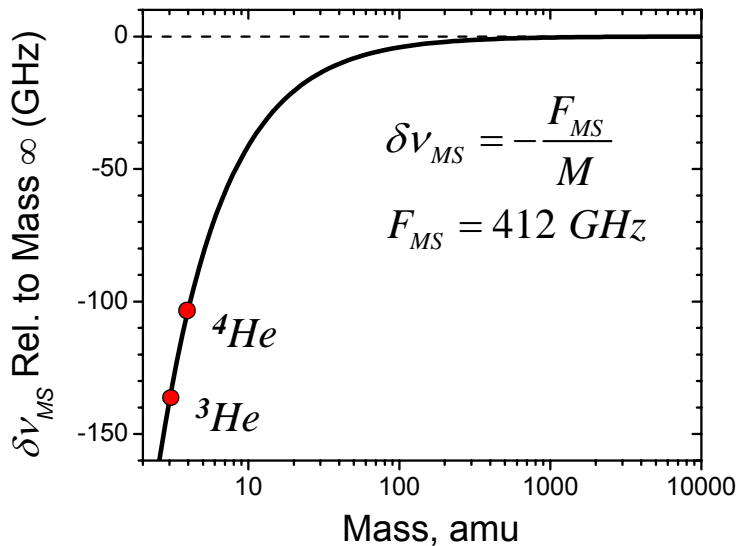
N ₂	593	Torr
O ₂	159	
Ar	7098	mTorr
CO ₂	274	
Ne	13.82	
He	3.98	
CH ₄	1.29	
Kr	0.87	
H ₂	0.40	
N ₂ O	0.24	
Xe	0.07	

- Extract Helium/Neon mixture from lab air with sorption pump
- Compress into sampling volume to 200 mTorr (He:Ne ~ 1:4)

Frequency-Modulation Saturation Spectroscopy of He*

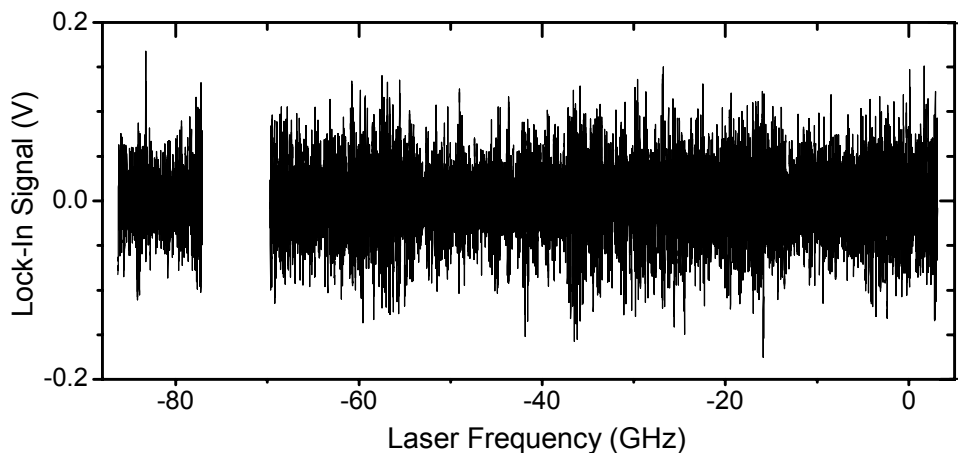


Isotope Shift vs. Mass

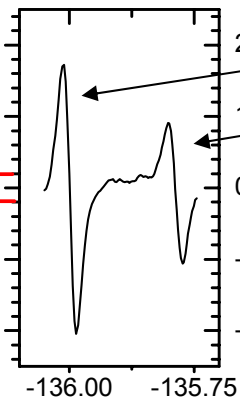


Analysis of the Spectroscopic Data

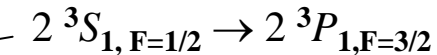
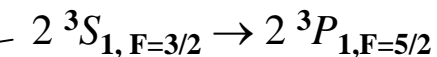
Scan Data



³He



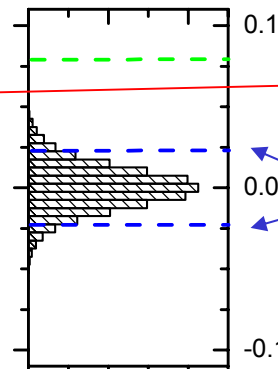
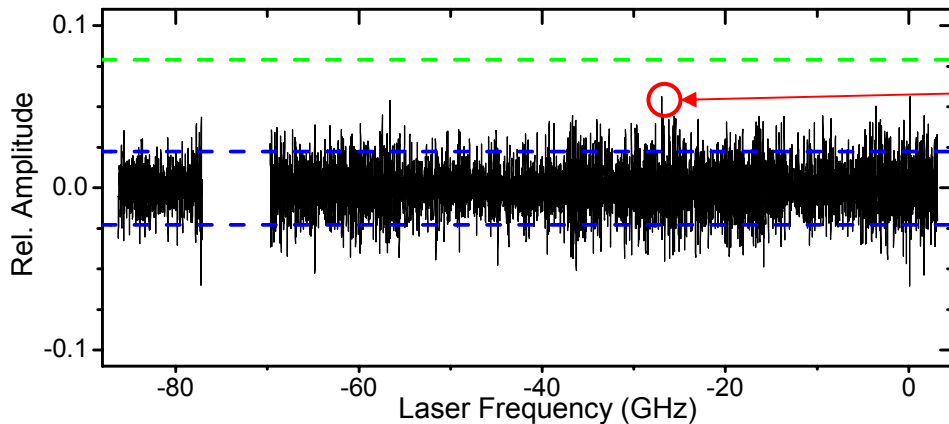
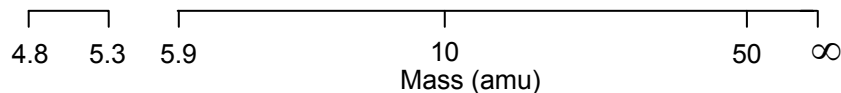
Transitions



Isotopic Abundance

$^3\text{He}/^4\text{He} = 1.4 \times 10^{-6}$

S/N ~ 70



Maximum

0.056 (@15.3 amu)

5th / 95th - Percentile

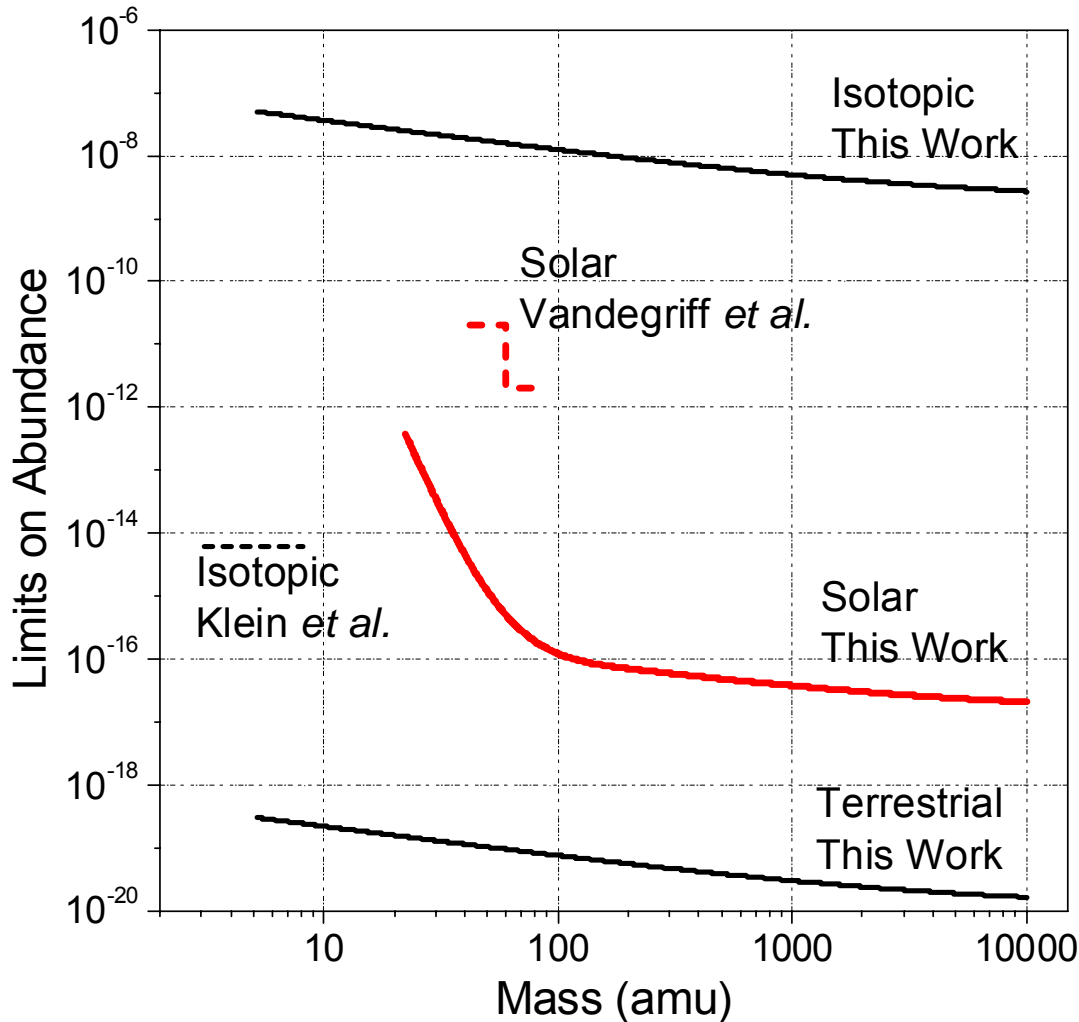
±0.023

95% Conf. Limit

<0.079

Fit Amplitudes relative to ³He

Limits on the Abundance of Anomally Heavy Helium



Isotopic “per ^4He in Earth’s atmosphere”

Solar “per atom of all elements in Sun”

Terrestrial “per atom of all elements on Earth”

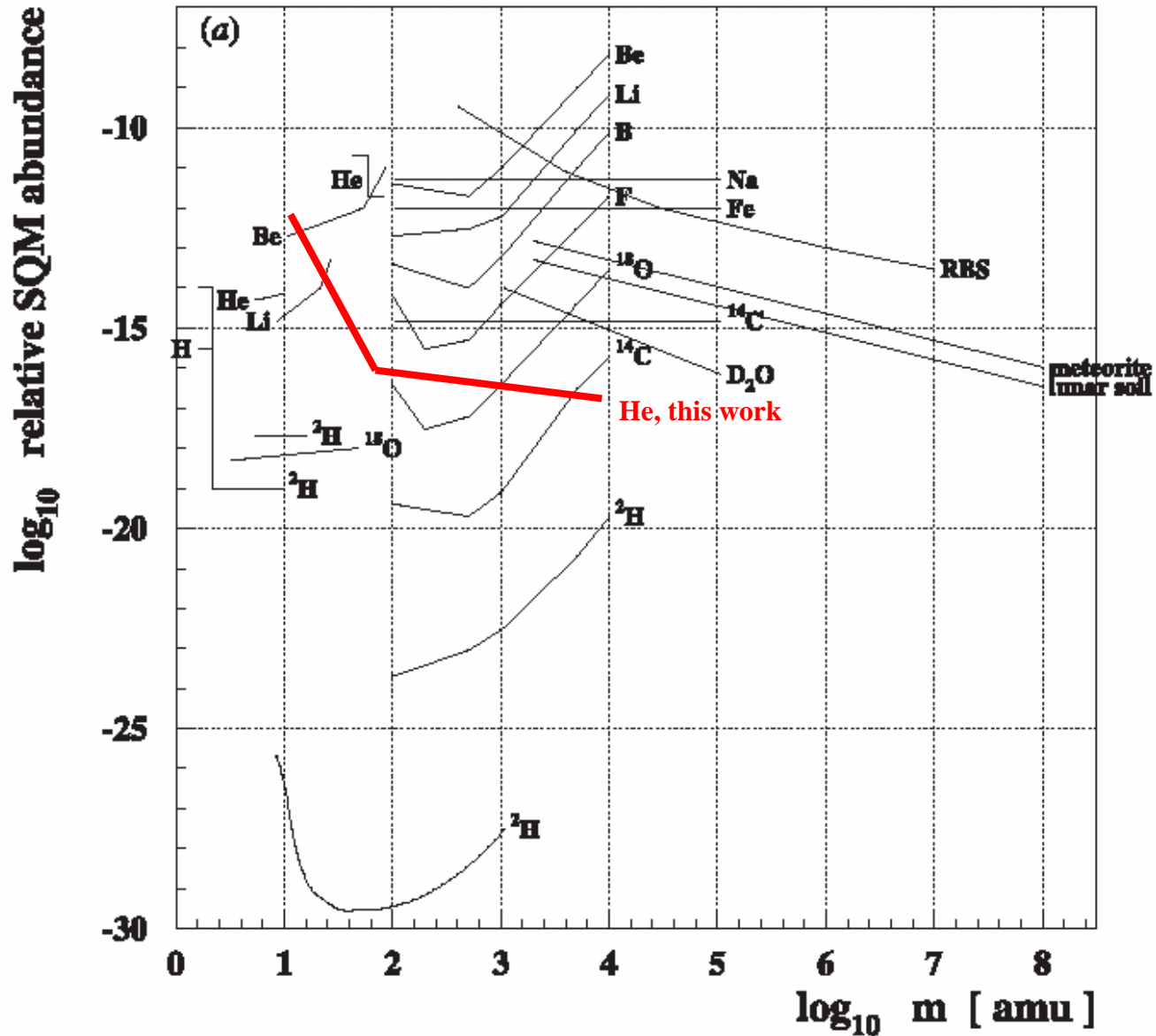
References:

This work -- P. Mueller *et al.*, arXiv:nucl-ex/0302025 (2003)

Klein *et al.* in Proc. of Symp. on Accelerator Mass Spectrometry, ANL/PHY-81-1 (1981)

Vandegriff *et al.*, Phys. Lett. B365, 418 (1996)

Experimental Limits



Outlook

Possible improvements

- build-up cavity x 100
- reach shot noise limit x 5
- freeze out Neon x 5 (?)
- pre-enrich sample (centrifuge) x ???

Alternative application:

- Use setup to measure $^3\text{He}/^4\text{He}$ ratio
- Current detection limit $\sim 5 \times 10^{-9}$ in pure Helium
- L.-B. Wang *et al.*, Geophys. Res. Lett. 30, 1592 (2003)