CHARGES ON STRANGE QUARK NUGGETS IN SPACE

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Basic Idea/History

- Witten (1984): 3 quark flavors implies same P.E., but less K.E. by Pauli Principle
- Farhi and Jaffe find SQN B.E./q rises to asymptotic value as N=A/3 rises
- De Rujula and S. Glashow Identify bunch of methods of detecting SQNs
- Alcock, Farhi&Olinto address SQS as NS
- Alford, Rajagopal, Wilczek find pairing in SQNs

Production

- Primordial: depends on cooling by evaporation being less than cooling by neutrino emission and any other mechanisms
- Evap~$M^{2/3}$; neutrinos~M. M>10^{20} gives enough ν cooling, but there is diffusion prob.

- Collisions of SQS's from NS binaries

Selected Searches

TABLE I: Some Strange Quark Nugget Searches.

Experiment/Observation	Mass Range (g)	Result
AMS[a]	$10^{-24} - 10^{-22}$	not done
RHIC[a]	$< 3 \times 10^{-21}$	not found
Mica Tracks[b]	$10^{-20} - 10^{-14}$	$<< \rho_{DM}$
ICE CUBE[c]	$10^{-3} - 10^{-2}$	not done
Seismometers:		
Future Lunar [d]	$10^{3} - 10^{6}$	not done
Apollo[e]	$10^{4} - 10^{6}$	$< \rho_{DM}/10$
USGS Reports[c]	$10^{6} - 10^{8}$	$< \rho_{DM}$

Settings

TABLE II: Settings.

Location	Radiation Source		
	Extragalactic	*Galactic*	*Solar*
Extragalactic	$(1+z)T_0$; CBR	DBR	—
Galactic	$z_{rec} > z \geq 0$; DBR	$r_{sc} > r > r_{bh}$	—
Solar	$r > r_S$; DBR	$r > r_S$	$r > r_S$

SQN Structure

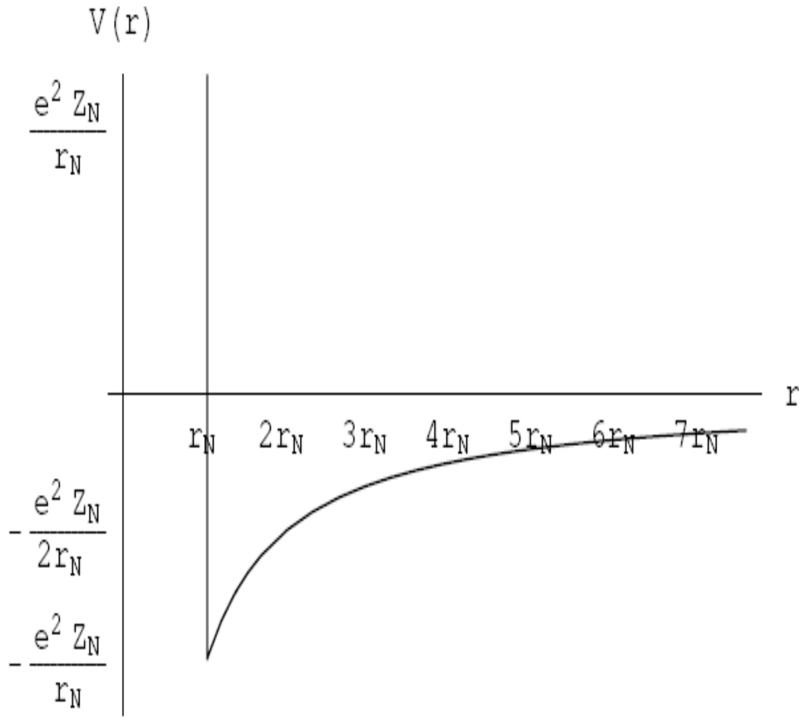


FIG. 1: Potential for least bound electron.

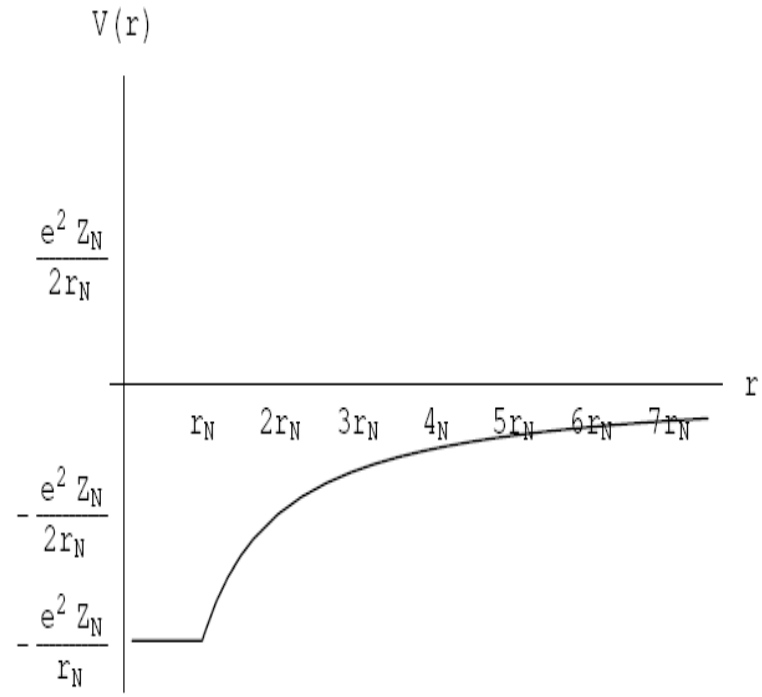


FIG. 2: Approximation to potential for least bound electron.

Our Calculation

- Find Z_N such that rate ambient photons ionize SQN electrons =rate ambient e's replace them.
- LHS falls with increasing Z_N; RHS rises.
- SQN radius (r_N) < r_B/Z_N: Coulomb;
- $r_N > r_B/Z_N$: electrons feel 2d potential and assume K.E.<<P.E.=$Z_N\,\alpha/r_N$ (conservative)

Rates

$$\dot{Z}_+ = \pi b^2 \int_{Z_N e^2/r_N}^{\infty} dE\, N_\gamma(E)$$
$$[N_e(E_B < E)\,\sigma(\gamma + SQN \rightarrow e + SQN), 1]$$

$$\dot{Z}_- = \pi r_N^2 \int_{m_e - E_B}^{\infty} v_e(E) n_e(E)\,[1 + f_e(E, Z_N)]$$
$$h(E) g(e + SQN \rightarrow SQN + X, E)\, dE$$

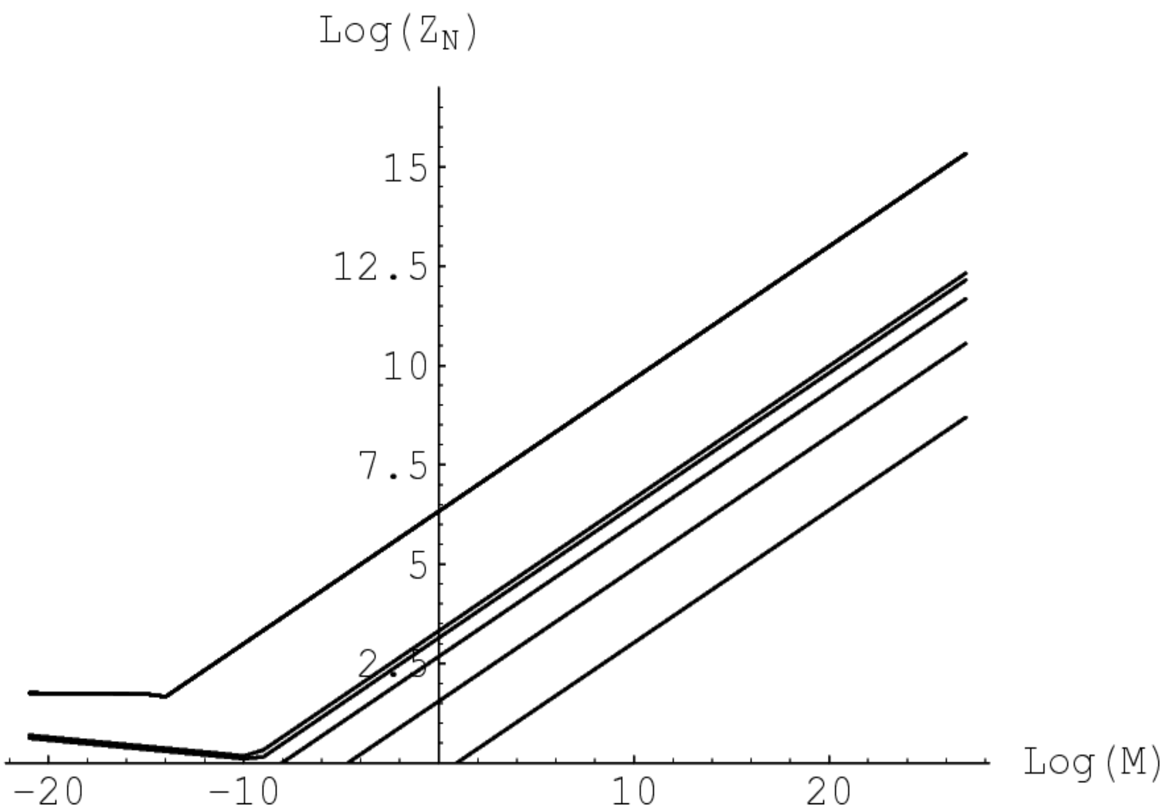
$$f_e = 4\alpha\hbar c Z_N/(r_N E_e)$$

$$\pi b^2 c F_\gamma(E > E_B) = \pi r_N^2 n_e \bar{v}_e (1 + f_e)$$

Parameters

SQN Location	Radiation	n_e	$v_e/10^6$
Solar Xray Flare	$T = 10^3$eV	7	50
Galaxy Center	DBR $N_\gamma = 1.5 \times 10^5 F_H$	.05	8
IGM Today	DBR $N_\gamma = F_H$	4×10^{-9}	1
Quiet Sun	$T = 0.5$ eV	7	50
IGM Pre Recombo	CBR $T = 0.26$ eV	5	30
DBR near sun	$N_\gamma = 15 F_H$	7	50
IGM Today	CBR $T = 2.75K$	4×10^{-9}	1

Results $Z_N(M)$



xray flare

D(G&EG)RB

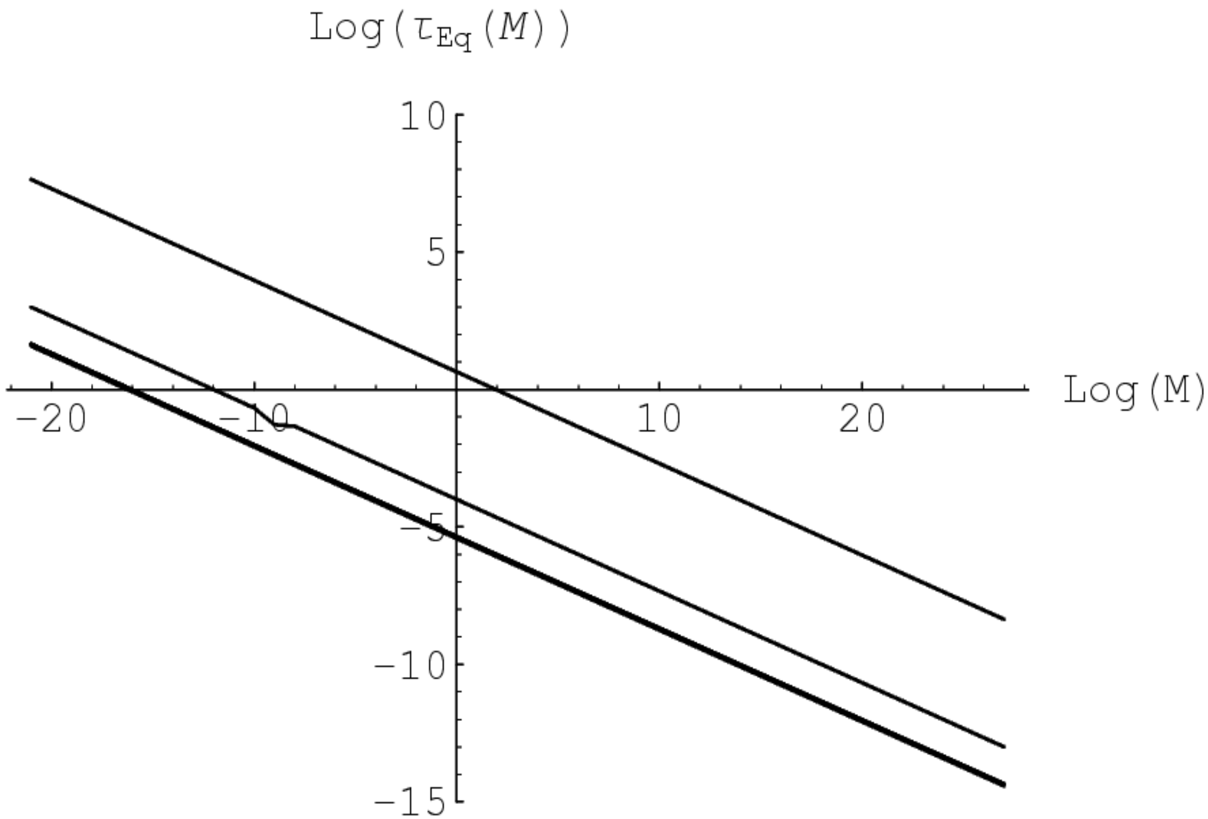
iq/s&recomb

DGBR on SS

CBR on

;QN

Results: Time to Reach Equilibrium



- IGM Today
- COG
- SS at 1 AU and Univ at Recombo

Results: Binding Energies

Setting	$M^{1/3}\tau_{Eq}$(y)	$E_B(eV)$ $M > 10^{-10}$g	E_B(eV) 10^{-21}g
Galactic Center	10^{-4}	39	330
IGM Today: DBR	4.4	26	240
Solar system:			
during X-ray flare	4.5×10^{-6}	3.8×10^{4}	4.2×10^{4}
from DBR	0.66		240
Quiet Sun	4.5×10^{-6}	14	18
Recombo with CBR	3.8×10^{-6}	9.5	12
Today from CBR	4.4	8.7×10^{-3}	0.012

Features of Results

- Shape of $Z_N(M)$ expected.
- IGM e-numbers chosen as geometric mean between complete and residual H-ionization.
- Largest Z_N is case of solar X-ray flare.
- Closed form

$$\pi b^2 c F_\gamma(E > E_B) = \pi r_N^2 n_e \bar{v}_e (1 + f_e)$$

- Vacuum breakdown for B.E.>2m(el)

Particle Detectors

$$dN_{ev}/dt = n_{SQN} v_{SQN} A$$

- Let N(SQN)=ρ(DM)/M; get Aτ/M~10^{17}
- Note expect primordial M~10^{24}g
- If “lucky,” could have shower of SQNs from

SQS-SQS collision

Absorption and Emission Lines and Edges

- Explosive events could give trifecta: gamma absorption for E>2m(e); emission at 2m(e); and emission at m(e-) from e+ production.
- There are questions of e+ production in COG, and of pair instability Sne. SQM roles possible
- Possible detection of SQN emission line from e- capture during X-ray flare needs estimate.

Early Universe Effects

- CMB effects such as possible oscillations of Debye cloud around primordial SQNs??
- Entropy prod’n: gamma+SQN->2gamma+SQN?
- SQN catalysis of molecular hydrogen formation before pop III stars?

Summary and Future Work

- Have calculated Z_N, t(eq) and B.E. for 7 settings in limits of SQN radius greater or less than Bohr radius divided by Z_N.

- Need look at transition region.
- Need see if any of effects cited are detectable.

BACKUP

SQM problems

- SQS as NS: pulsar glitches; superburst QPOs.
- Negative results of terrestrial, lunar searches.
- Primordial production seems precluded by neutrino diffusion nixing inhomogeneities

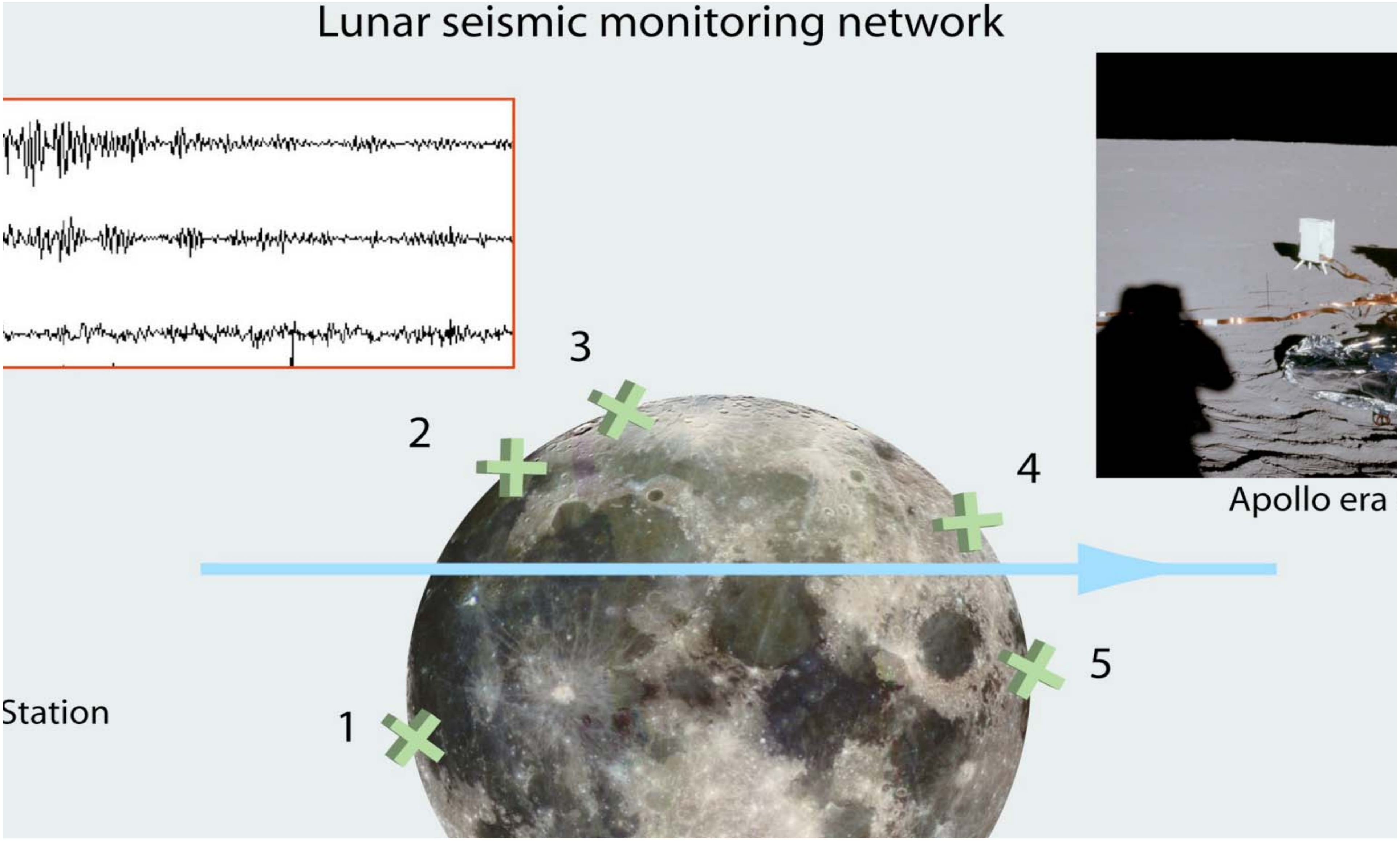


Figure shows signals from a quake (point event) at the SQN entry point would have signal first arrival times t2<t1<t3<t4<t5.
For a SQN with speed much greater than that of sound, first arrival times would have t4<t2<t5<t1<t3.

Alcock, C., Fahri, E., and Olinto, A., 1986, Astrophys. J. 310
Alford, M., Rajagopal, K. & Wilczek, F. 1998, Phys. Lett 422, 247 (**Cooper pairs**)
Anderson, D.P., Herrin, E.T., Teplitz, V.L. & Tibuleac, I.M. 2003, Bull. Seis. Soc. of Am. 93, 2363 (**USGS seismic reports search**)
Banerdt, W.B., Chui, T., Herrin, E.T., Rosenbaum, D. & Teplitz, V.L., 2004, IDM 2004: 5th International Workshop on the Identification of Dark Matter, World Scientific: Edinburgh, 581 (**Earth-Moon comparison**)
Chodos, A. et al. 1974, Phys. Rev D9, 3471 (**MIT Bag Model**)
de Rujula, A. \& Glashow, S. 1984 Nature: London 312, 734 (**SQN phenomenology**)
Farhi, E. \& Jaffe, R.L. 1984, Phys. Rev. D30, 2379 (**SQM nuclear physics**)
Herrin, E.T., Rosenbaum, D.C. & Teplitz, V.L. 2006, Phys. Rev. D73 043511 (**SQN limits**)
Herrin, E.T. \& Teplitz, V.L. 1996, Phys. Rev. D 53 6762 (**SQN Monte Carlo**)
Price, P.B., Shirk, E.K. W.Z. Osborne, & Pinsky, L.S. 1988, Phys. Rev. D3813 (**Mica**)
Sandweiss, J. 2004, J. Phys. G30, 551 (**AMS**)
Spiering, C. 2001, Proceedings of ICRC2001: 1242 (**Ice Cube**)
Witten, E. 1984, Phys. Rev D 30, 279 K. 1979 (**Seminal SQM paper**)