Progress toward a theory for excess heat in metal deuterides

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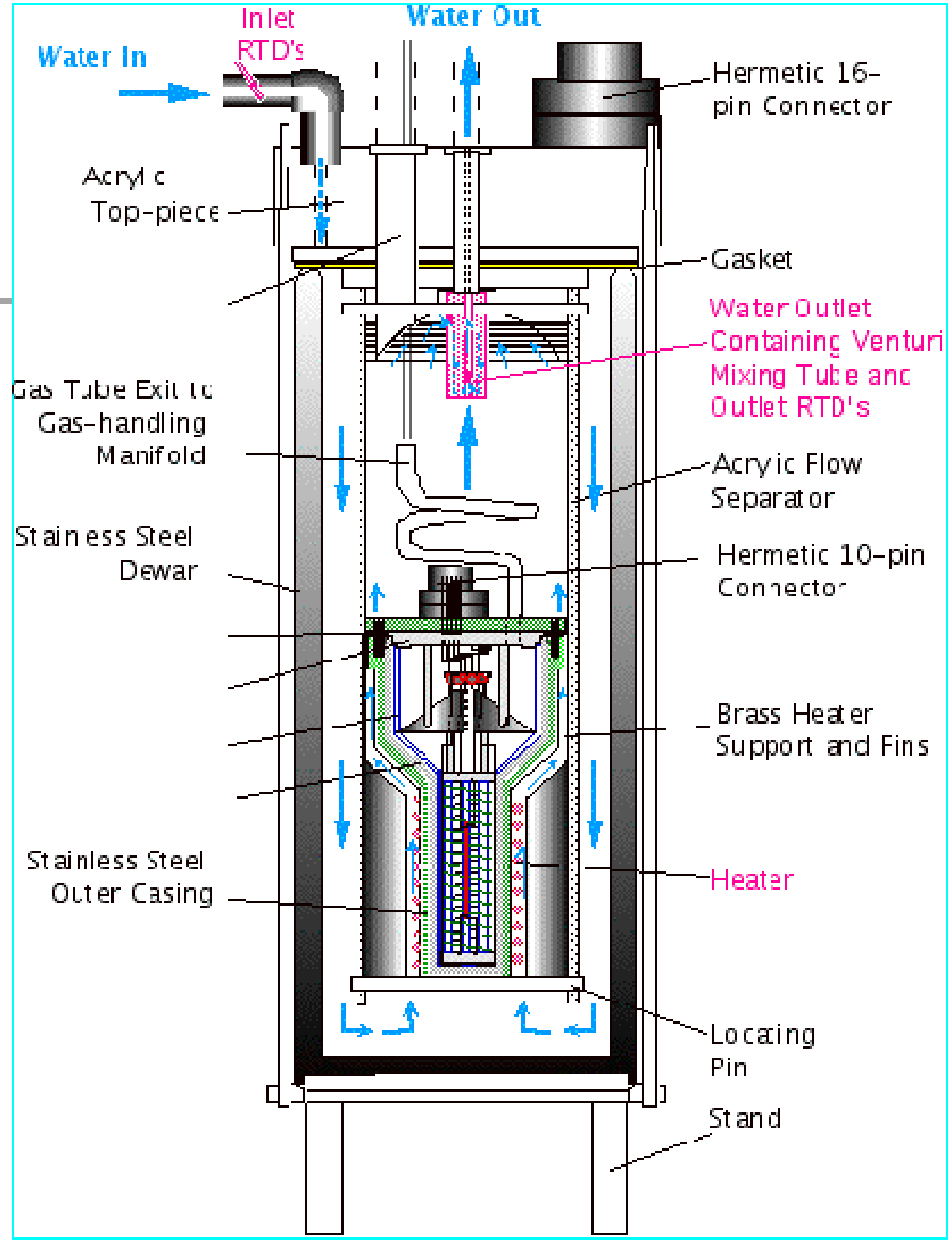
Experiments

Evidence for new physical effects

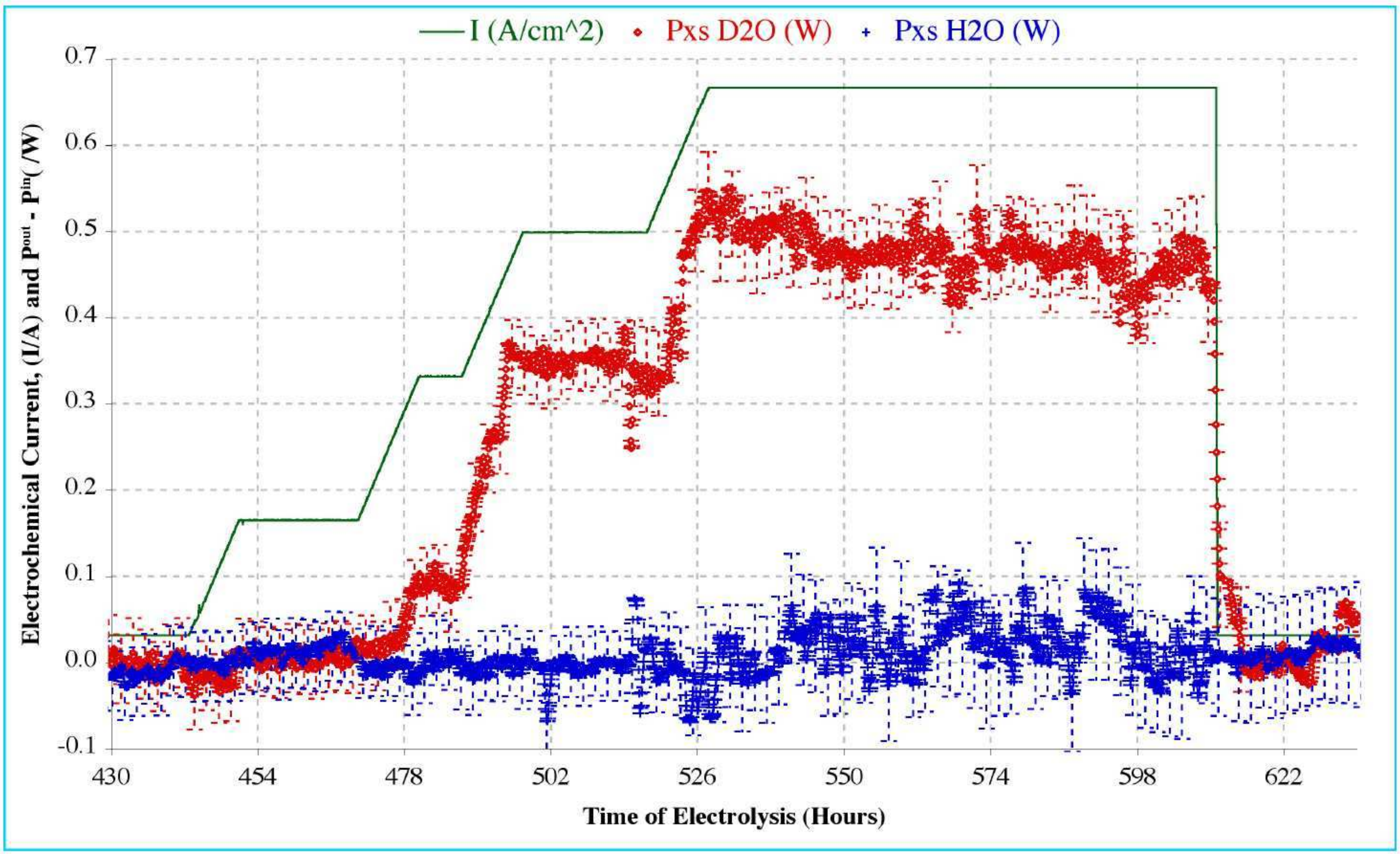
- Excess heat
- Helium correlated with excess heat
- Tritium
- Neutrons
- Charged particles
- Other effects

Flow calorimeter developed at SRI:

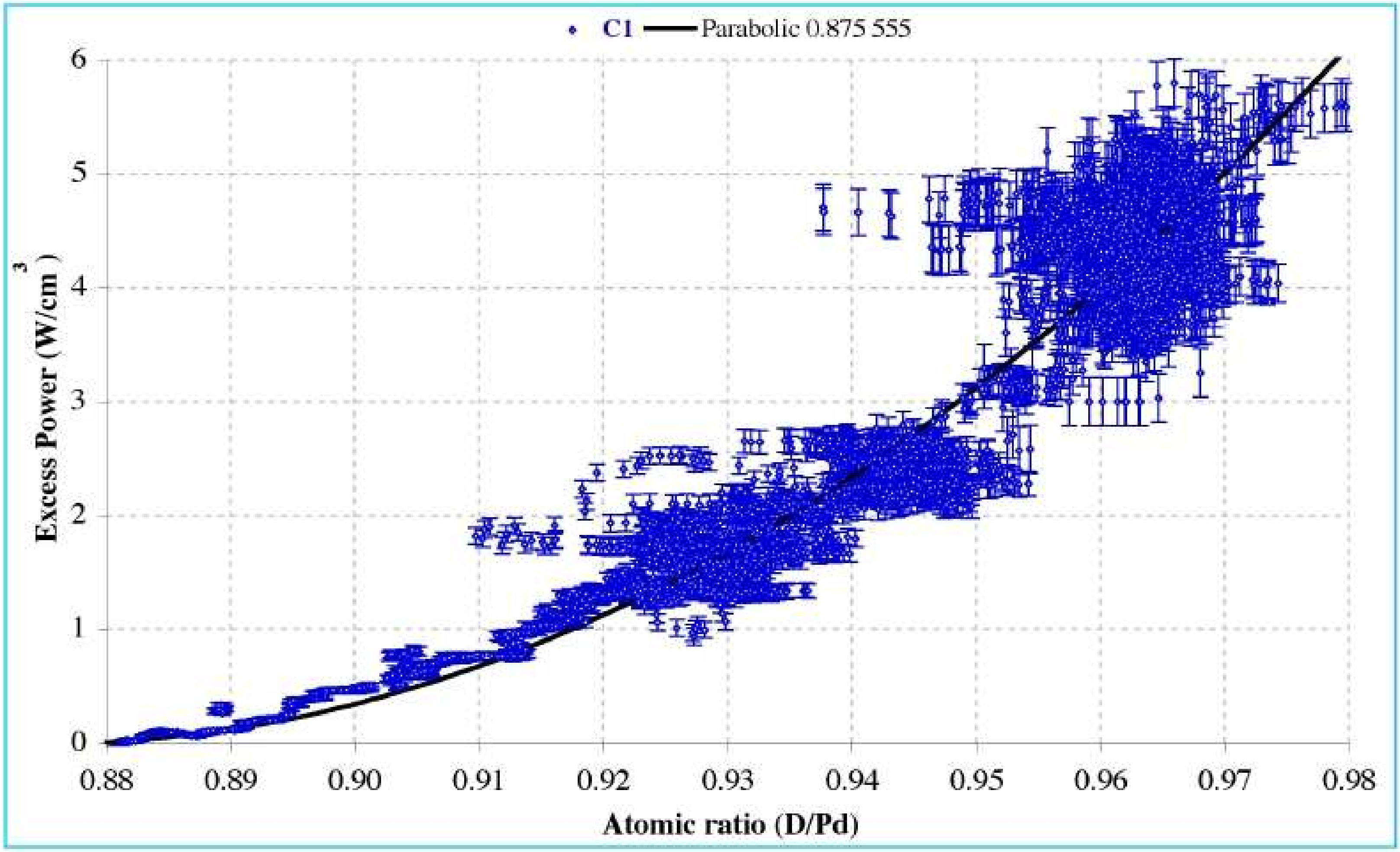
- 95% of heat captured by flow
- Fick’s law for remaining 5%
- Overall accuracy 0.4-0.5%



Excess power as a function of time taken at SRI



Excess power as a function of loading taken at SRI



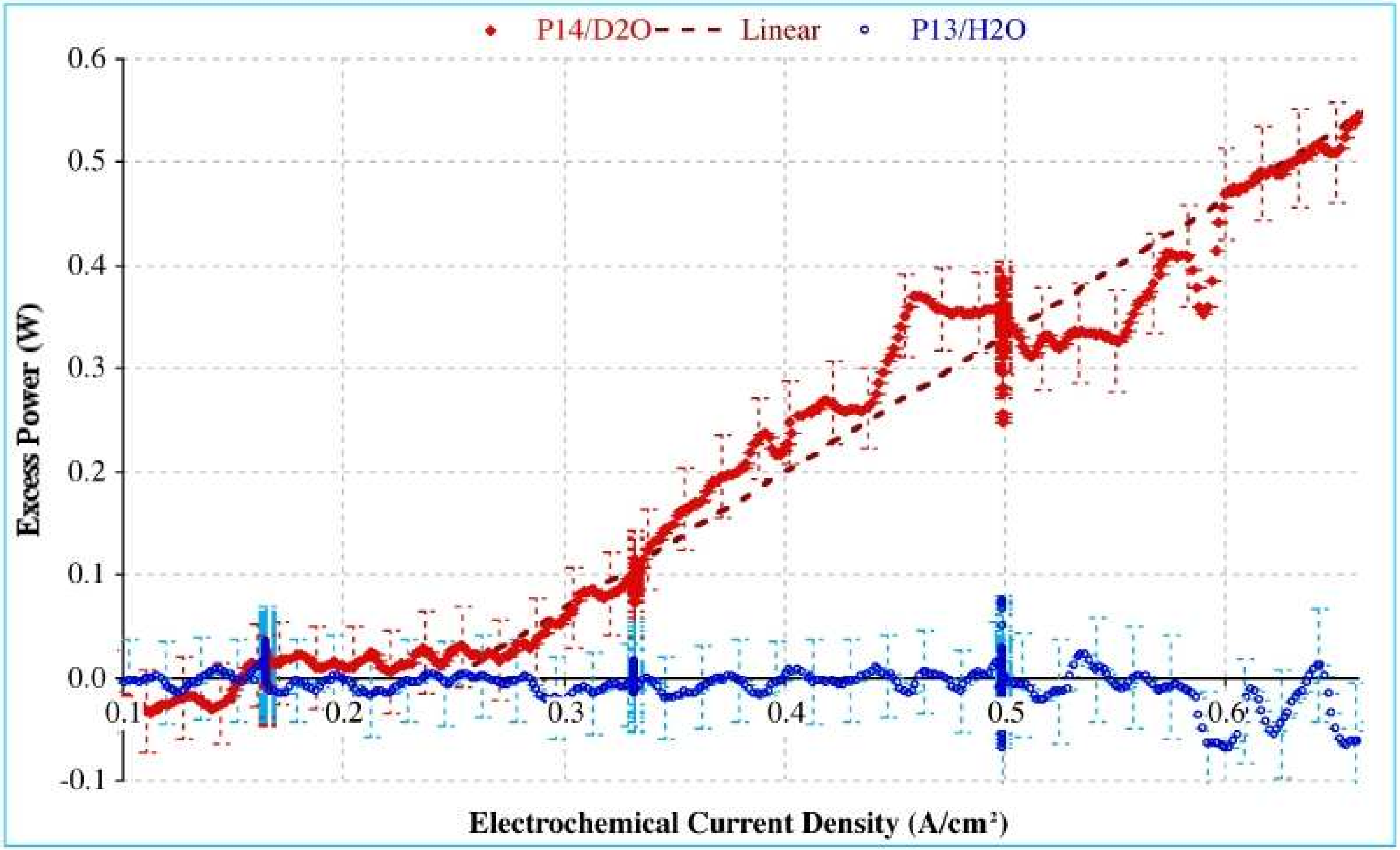
Temperature dependence

Excess power is a function of temperature

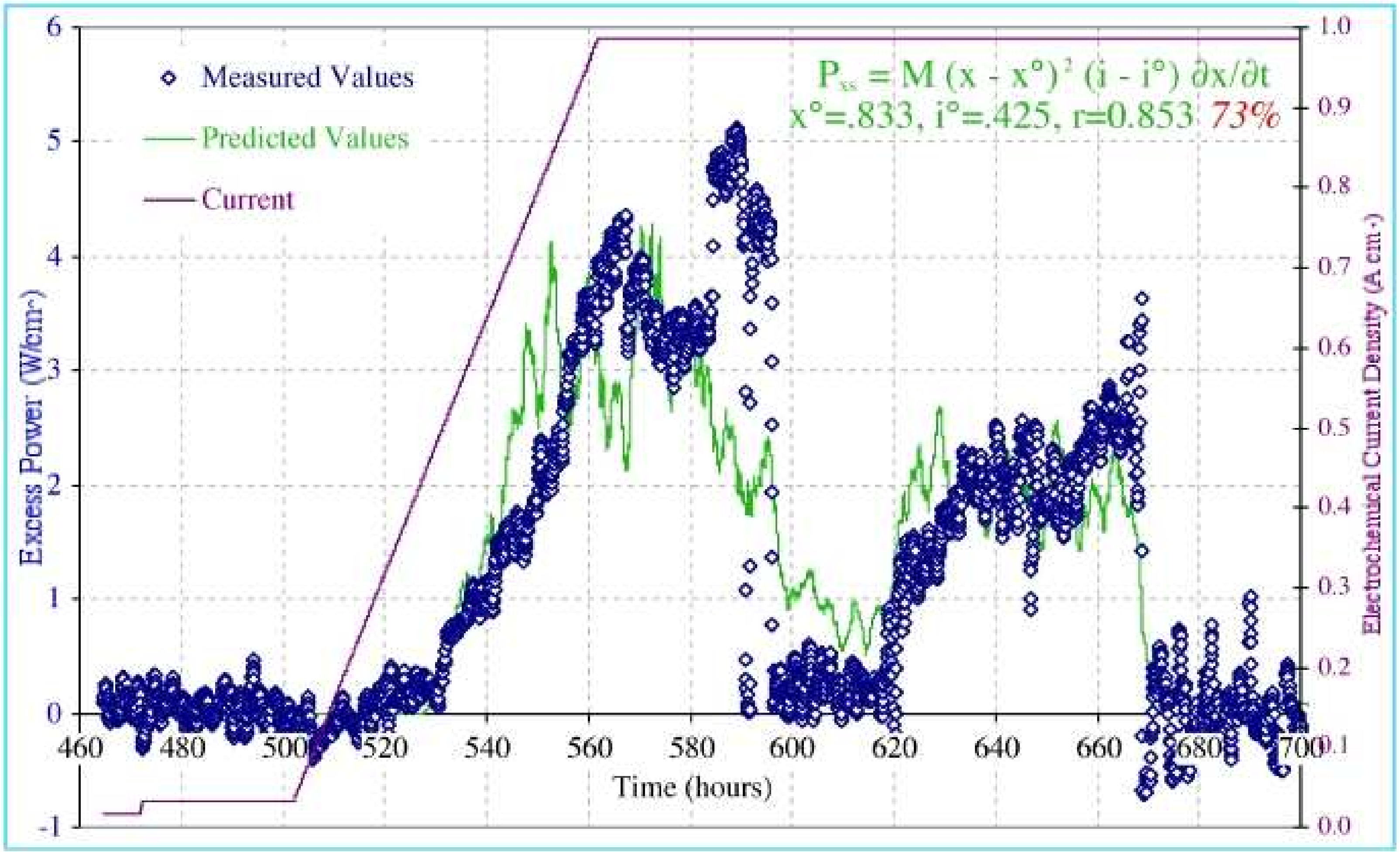
$$P_{xs} = P_0 e^{-\Delta E / kT}$$

- Fleischmann and Pons made use of this early on in their protocol
- Storms measured ΔE to be 670 meV
- Swartz measured ΔE to be slightly lower
- Case reported ΔE to be about 560 meV for a gas loaded catalyst at elevated temperature

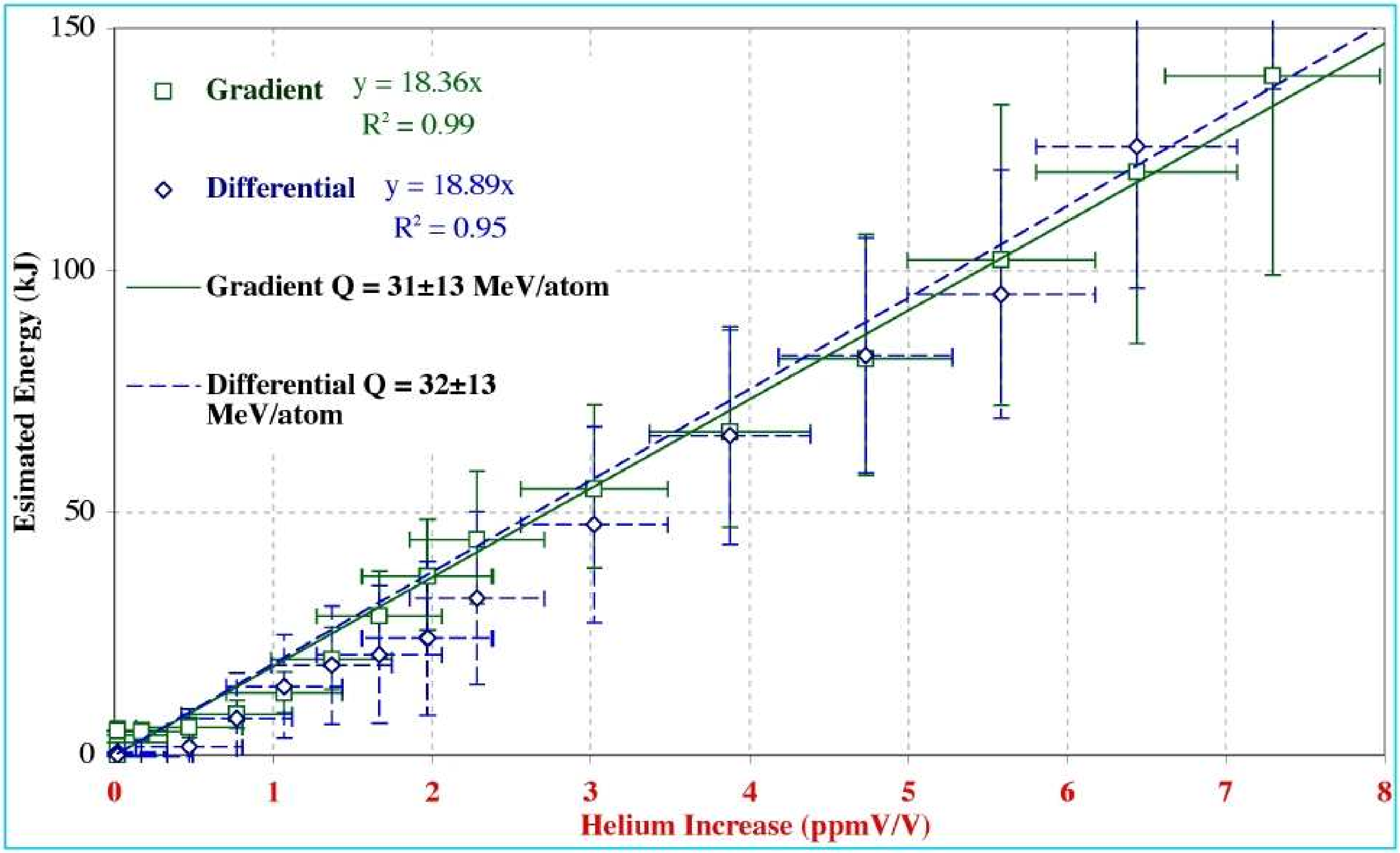
Excess power as a function of current density taken at SRI



Excess power depends on flux of deuterium, from SRI expts



Correlation of ^4He and excess energy, Case expt at SRI



Reaction energy

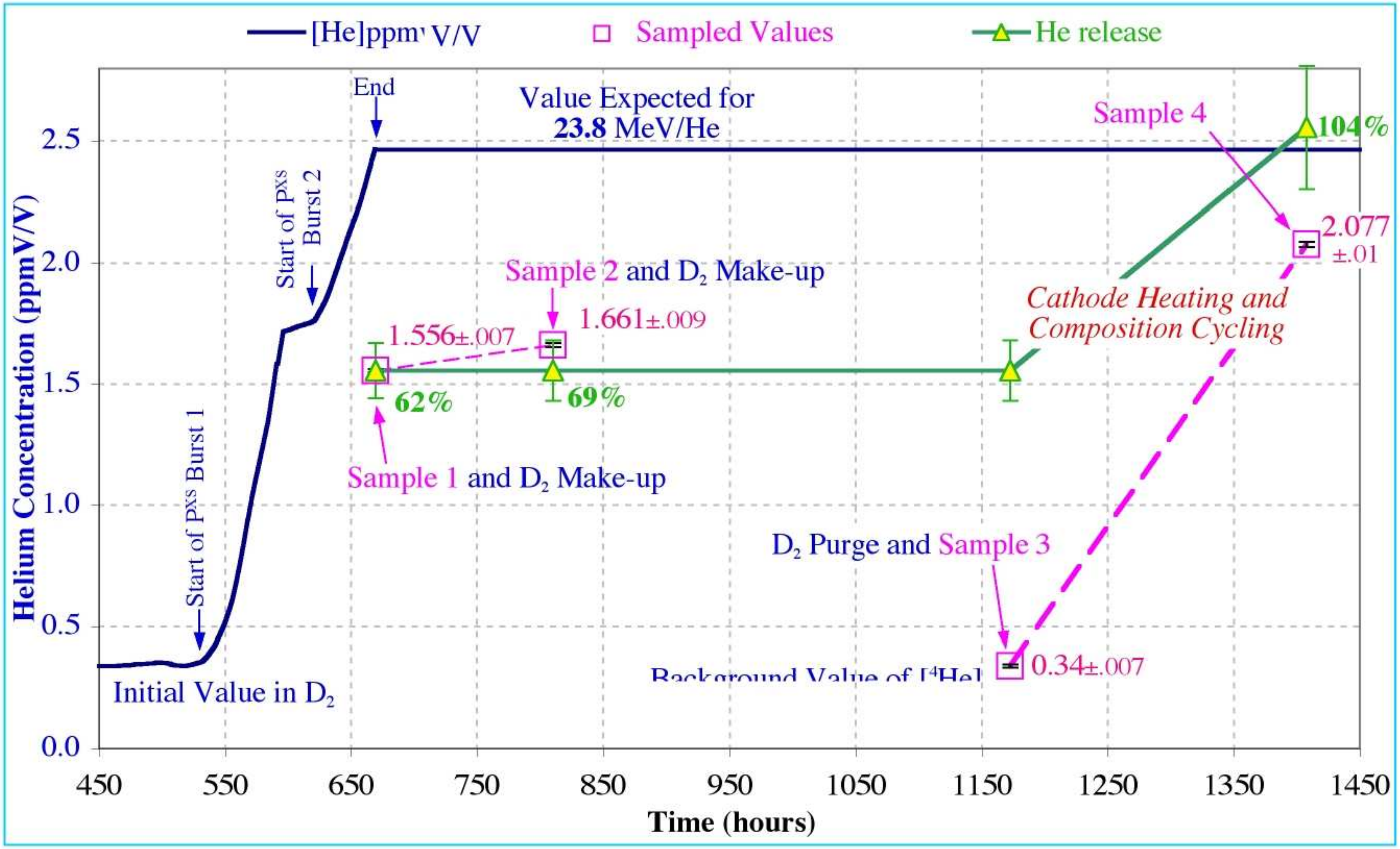
From correlation between ^{4}He and energy, one can get Q

- About 65% appears in gas in Fleischmann-Pons expts
- Suggests that ^{4}He formed near surface
- Remaining can be pulled out by cycling deuterium in and out of cathode
- Reaction Q from experiment consistent with

$$D+D \rightarrow {}^4He + 24\ MeV$$

- No energetic particles in association with energy

Measurement of Q, taken at SRI



Heat after death

Excess power observed in some cases after electrolysis terminated

•Effect observed by Fleischmann and Pons early on

•Energetics experiments have shown strong heat after death effects

•Swartz has demonstrated amount of energy related to V_{oc}

$$P_{xs} = \text{Constant}\,(V_{oc} - V_{th})^2$$

Excess power gain

Excess power effect improved with time

- In early experiments mostly 10%-30% effect, reproducibility issues
- Energetics reported 6x energy gain in Pd glow discharge experiment (ICCF10)
- Energetics reported 30x energy gain in Pd electrolysis experiment (ICCF11)
- Mizuno reported 800x energy gain in W electrolysis experiment (ICCF12)
- Swartz reports good reproducibility at 3x and higher in Pd electrolysis

Energetic particles not quantitatively associated with energy

Excess energy not correlated with energetic particles

- Neutrons not observed with excess heat effect
- Evidence for different regimes
- Cathodes showing excess heat showed neutrons at lower current density
- Excess heat in F&P expt above 200 mA/cm^2
- Tritium reported near 70 mA/cm^2
- Neutron emission reported at 10-30 mA/cm^2

For more information

See the DoE review document:

Hagelstein, P. L., M. C. H. McKubre, D. J. Nagel, T. A. Chubb, and R. J. Hekman, "New physical effects in metal deuterides," *Proceedings of the 11th International Conference on Cold Fusion*, Marseilles, France, November 2004, p. 23, 2006. Available on the DoE website.

Also see proceedings papers of the ICCF conference series

Theory

Require new models for anomalies

- Many new models proposed
- Major focus on tunneling
- Our work focuses on phonon exchange mechanisms

Thinking about excess heat effect

Must be a new physical process to happen at all consistent with experiment

- New physical process must be able to convert a large MeV quantum into many small quanta
- Absence of energetic (MeV) products to be interpreted as feature of new mechanism
- Lack of energetic particles commensurate with energy consistent with absence of vacuum nuclear reactions as source of energy

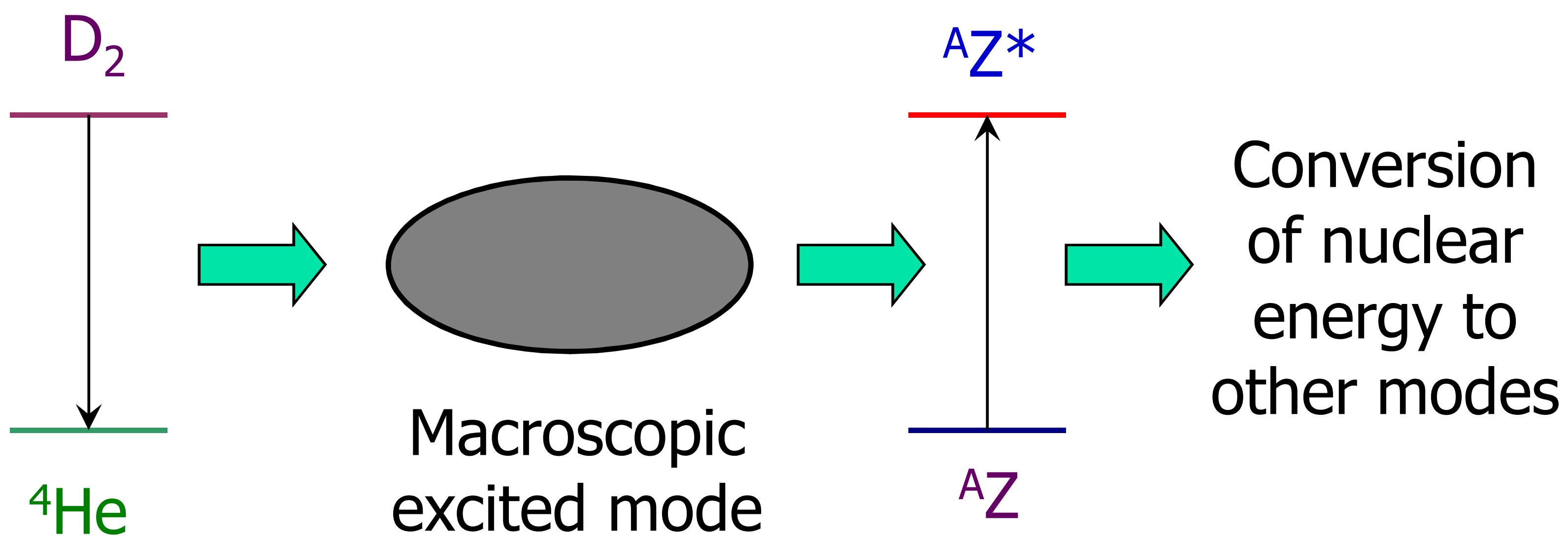
Phonon exchange approach

- We have considered phonon exchange models for anomalies in metal deuterides

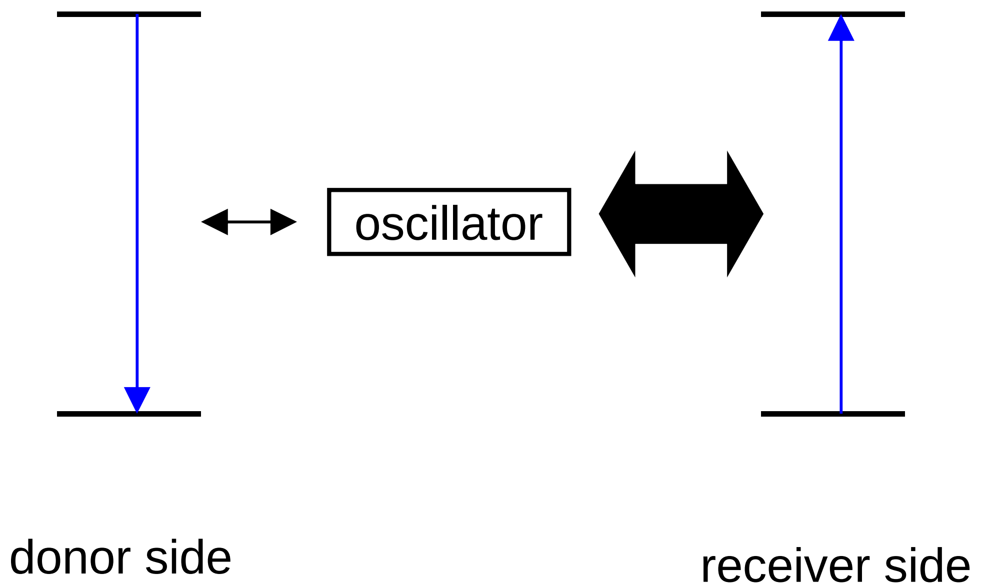
- Approach is based on quantum coupling between reactions at different sites through phonon exchange with a common highly excited phonon mode

- This approach leads to new reaction pathways which differ from vacuum nuclear reaction mechanisms

Overview of model



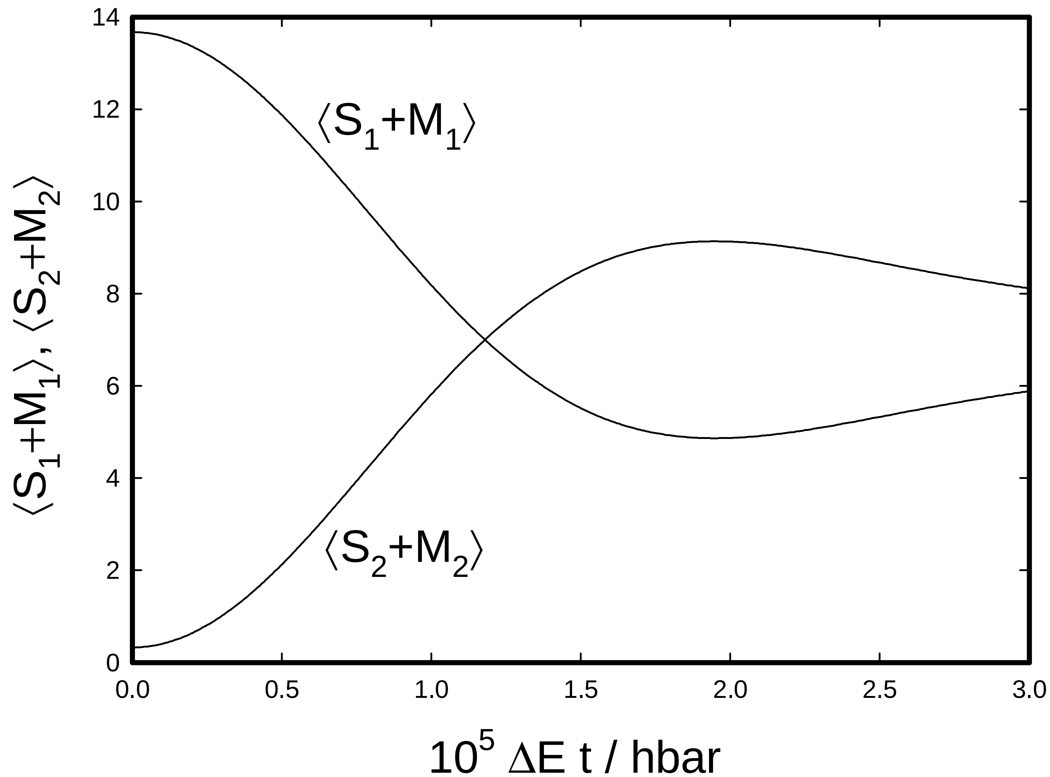
Two-level systems and oscillator



Basic model

$$\hat{H} = \Delta E_1 \frac{\hat{S}_z^{(1)}}{\hbar} + \Delta E_2 \frac{\hat{S}_z^{(2)}}{\hbar} + \hbar\omega_0 \hat{a}\hat{a}^\dagger + V_1 e^{-G} \frac{2S_x^{(1)}}{\hbar}\left(\hat{a} + \hat{a}^\dagger\right) + V_2 \frac{2S_x^{(2)}}{\hbar}\left(\hat{a} + \hat{a}^\dagger\right)$$

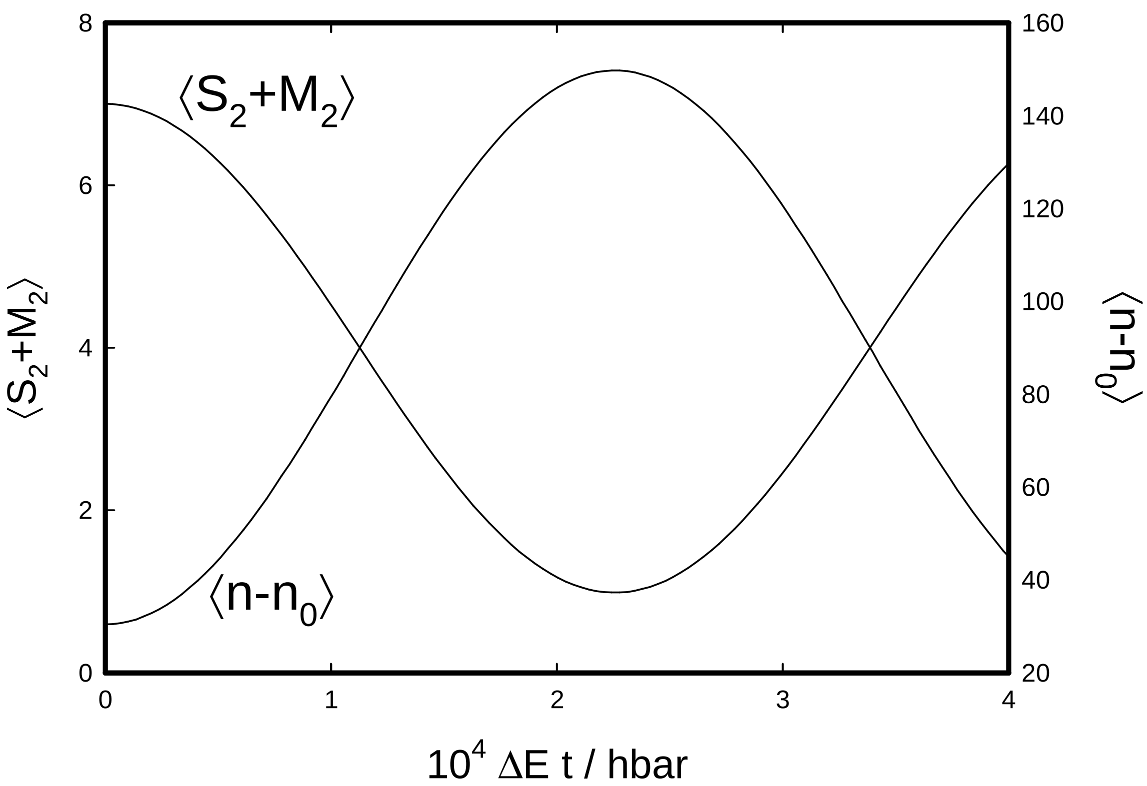
Excitation transfer effect



Thinking about it

- Excitation transferred from one set of two-level systems to the other
- No direct coupling
- Indirect coupling through low energy oscillator (with hbar $\omega = 0.03\ \Delta E$)
- Coupling is very slow
- Requires precise matching of levels

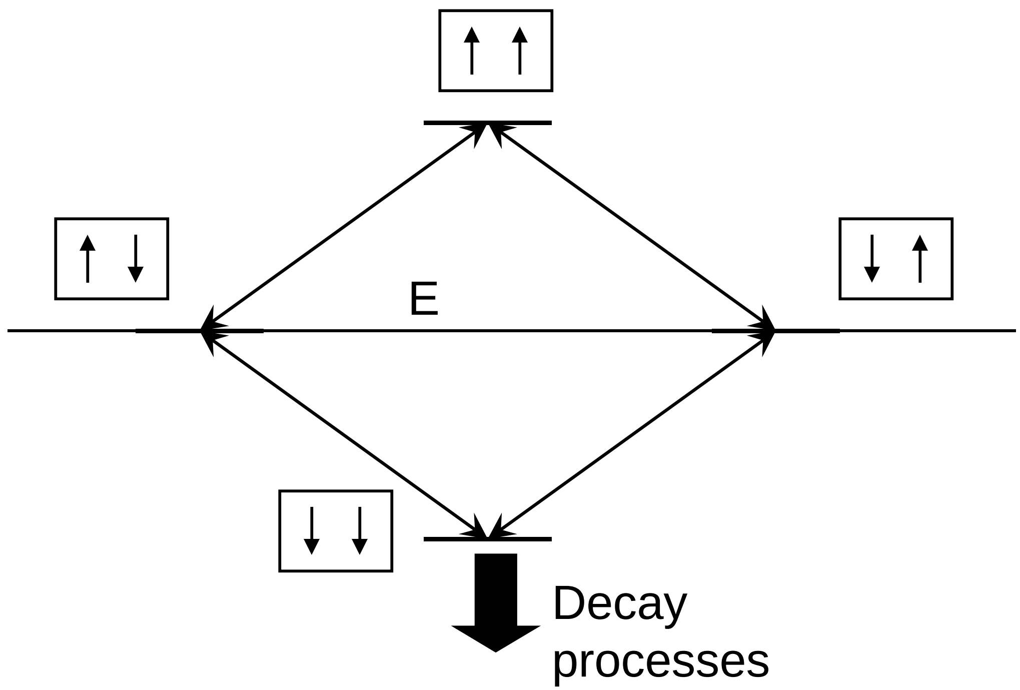
Energy exchange effect



Thinking about it

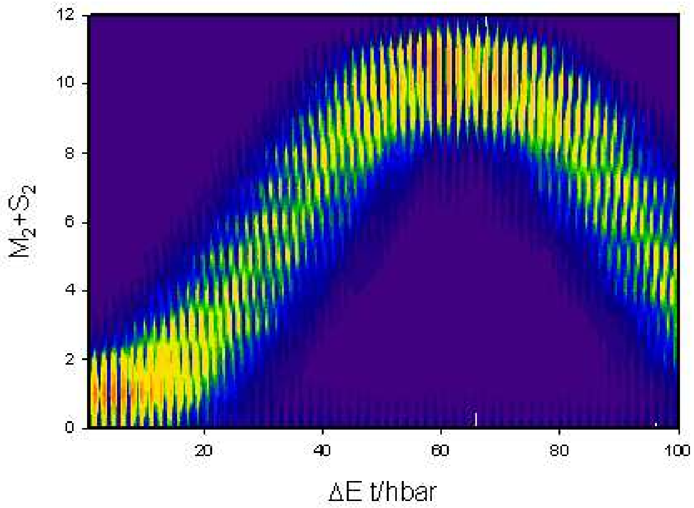
- Direct conversion of two-level energy quantum into oscillator quanta
- Roughly 20 oscillator quanta created for loss of single two-level system
- Effect is slow
- Requires precise matching of levels

Add loss...

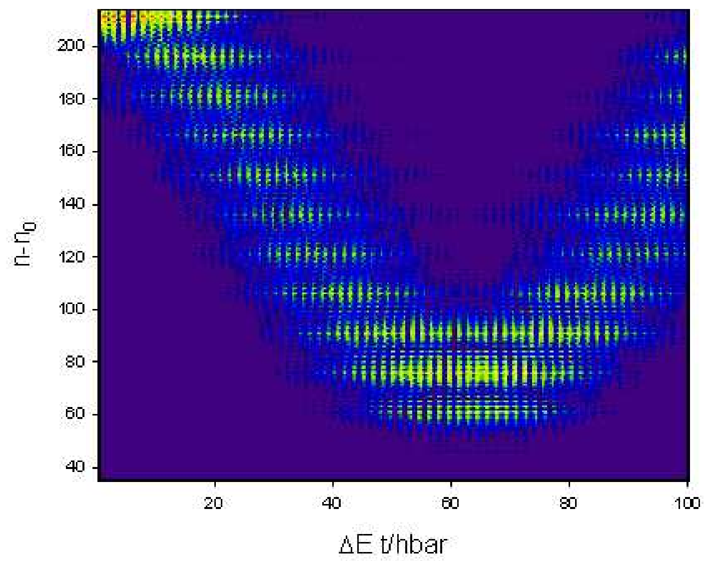


Energy exchange

Two-level system excitation



Oscillator excitation

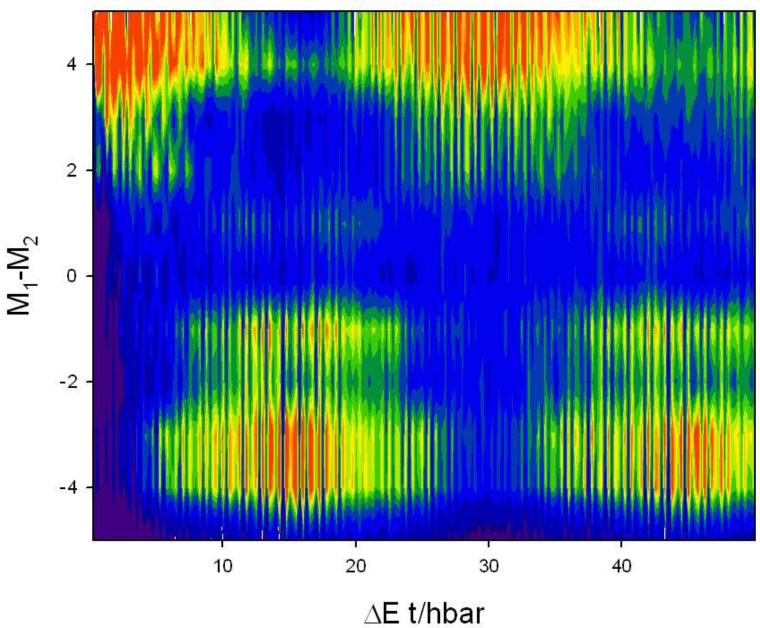


Thinking about the result

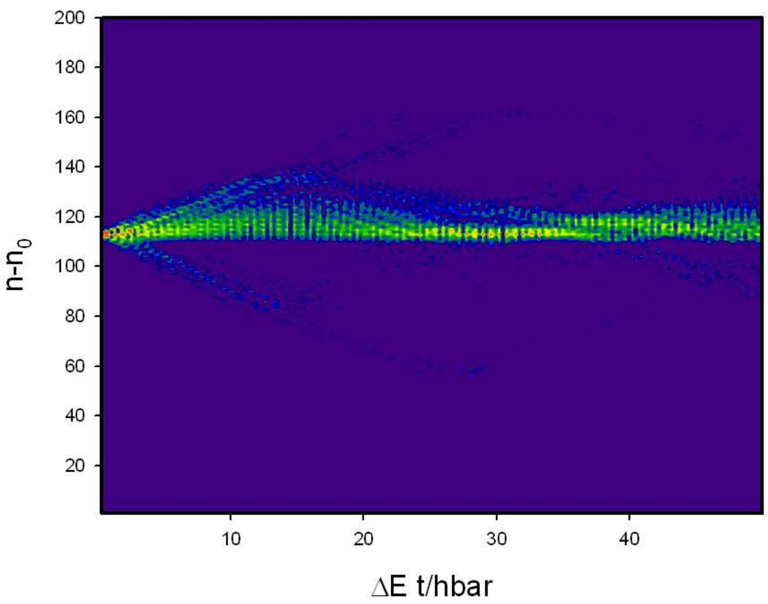
- Coherent energy exchange between two-level systems and oscillator
- Low oscillator energy (ΔE = 15 hbar ω)
- Effect now much faster in presence of loss

Excitation transfer

Two-level systems



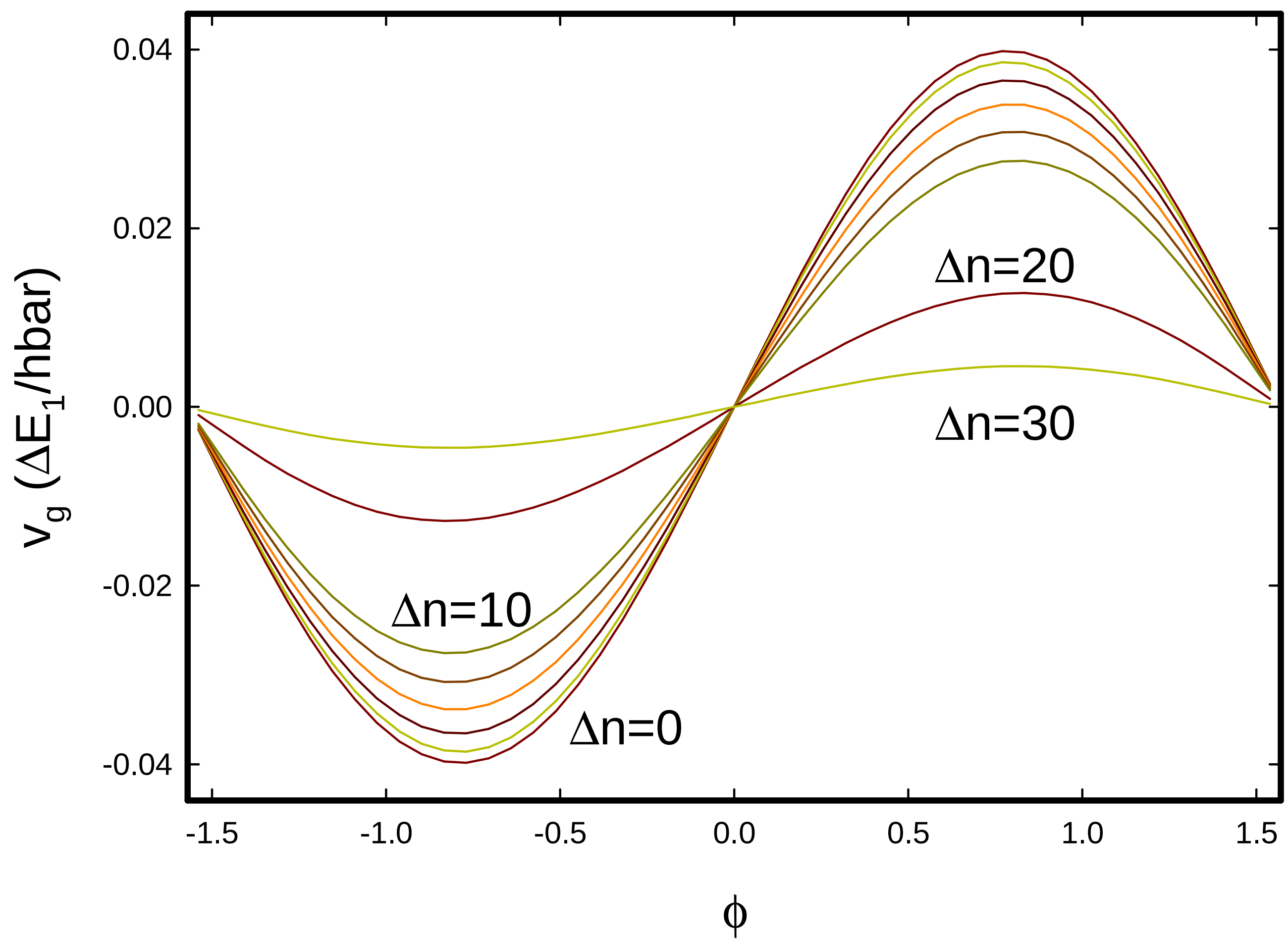
Oscillator



Thinking about the result

- Excitation transfer between two-level systems
- Effect much faster with loss
- Precise resonance no longer required
- Can see small energy exchange effect in this calculation to make up mismatch in resonance

Transfer rates with mismatch, for $\Delta E = 101$ hbar ω



Thinking about the result

- Receiver side nuclei strongly coupled to oscillator
- Energy readily exchanged with oscillator
- If mismatch in two-level system energy, oscillator can make it up
- Dynamics rate limited by donor-side transfer

For more information…

- P. L. Hagelstein and I. U. Chaudhary, “Two-level systems coupled to an oscillator: Excitation transfer and energy exchange,” ArXiv cond-mat 0612306

- I. U. Chaudhary and P. L. Hagelstein, “Inclusion of phonon exchange in a nuclear matrix element,” ArXiv cond-mat 0606585

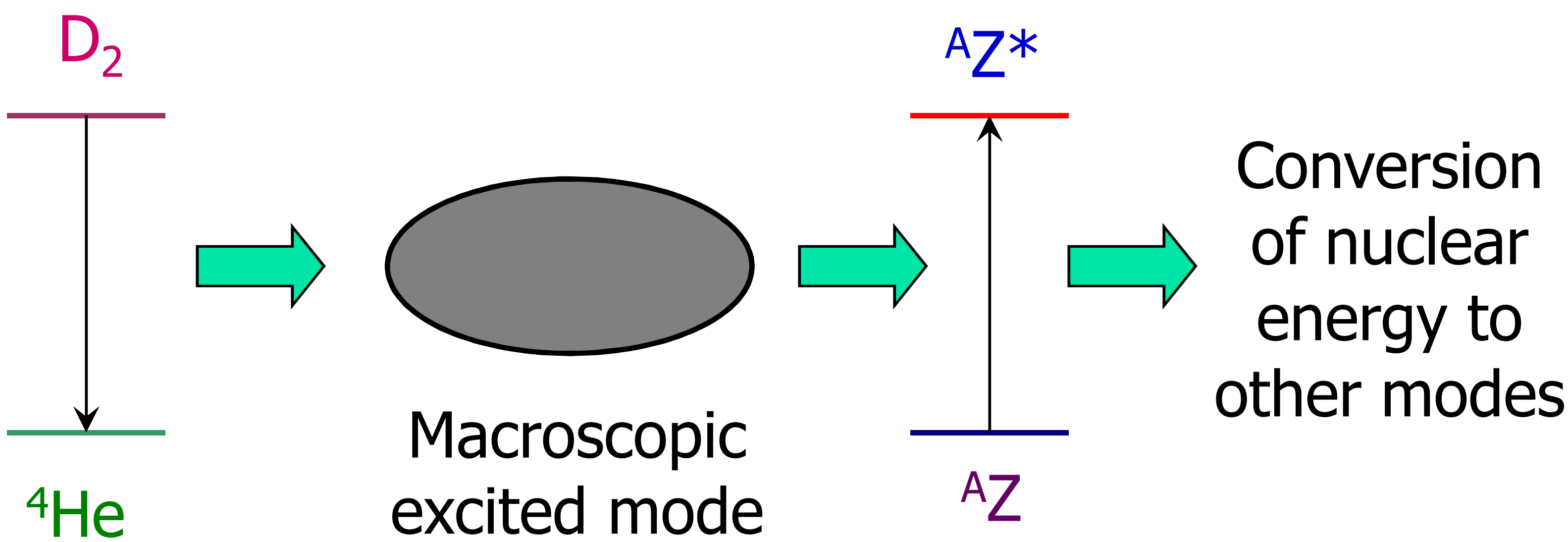
Conclusions [I]

- Considered two-level systems coupled to a common oscillator
- Coherent excitation transfer effect
- Coherent energy exchange effect
- Rates slow in lossless model
- Rates fast with loss

Conclusions [II]

- Analytic estimates for rates in weak coupling limit
- Also for strong coupling limit
- Agreement with numerical results

Overview of model



Conclusions [III]

- Model applicable to excess heat production
- Excitation transfer assumed to be bottleneck
- Excess power rate predicted consistent with experiment
- Uncertainty in screening parameters
- Energy exchanges easily with lattice in this model