

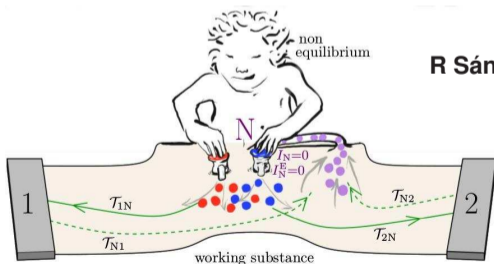


**Laboratoire de Physique et Modélisation des Milieux Condensés**  
Univ. Grenoble Alpes & CNRS, Grenoble, France

# *A non-equilibrium system as a demon*

**Robert S. Whitney**

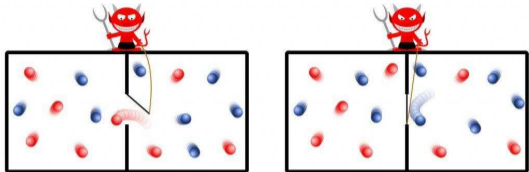
**R Sánchez, J Splettstoesser, RW**  
arXiv:1811.02453



Marseille – 16 Nov 2018

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## OVERVIEW

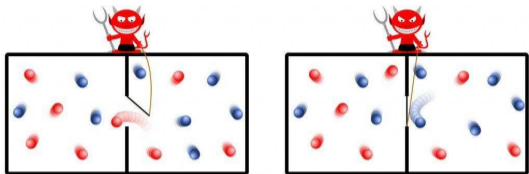


Maxwell (1867)

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## OVERVIEW



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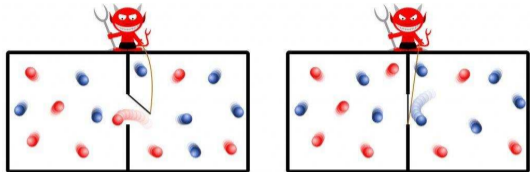


Detection

of **individual** particles

in **macroscopic** reservoirs

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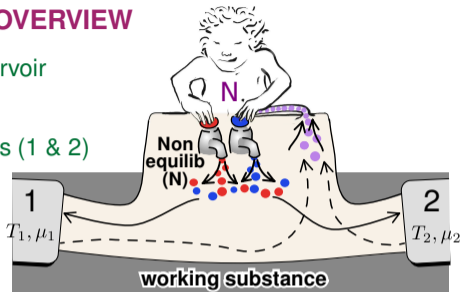
**Here we propose demons WITHOUT this**

## OVERVIEW

DEMON = non-equilibrium reservoir

WORKING SUBSTANCE

= two equilibrium reservoirs (1 & 2)



♠ Demon **reduces** entropy of working substance **WITHOUT** supplying work or other energy

(i) Heat  $\rightarrow$  electric power (reservoirs cool down)

(ii) Heat flows cold  $\rightarrow$  hot

♠ **Practical use:** spatial separation of work & heat production?

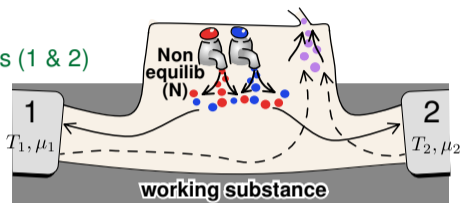
Nanoscale thermal management

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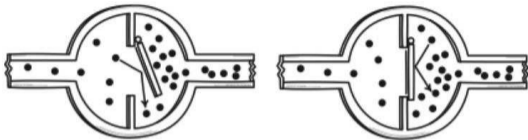
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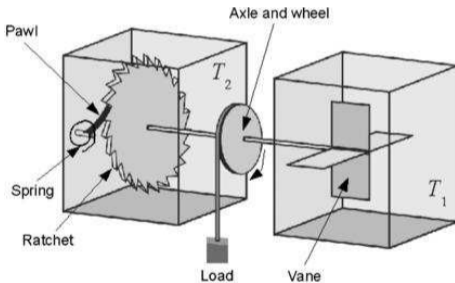
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## BRIEF HISTORY OF MAXWELL'S DEMON 1

♠ Smoluchowski (1912)



♠ Feynman ratchet  
(actually Smoluchowski, 1912)



⇒ concluded: fluctuations mean such “mechanical” demons  
do NOT violate 2nd law

## BRIEF HISTORY OF MAXWELL'S DEMON 2

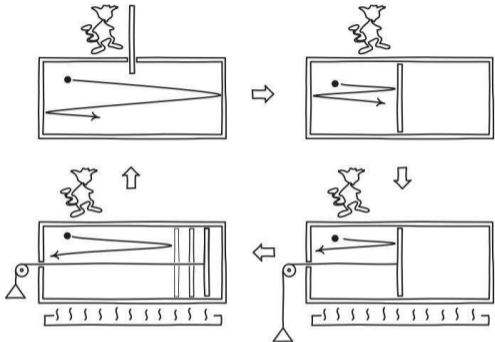
### ♠ Szilard Engine (1927)

J.D. Norton's sketch

[www.pitt.edu/~jdnorton/](http://www.pitt.edu/~jdnorton/)

+ many papers on demons

Effect not destroyed  
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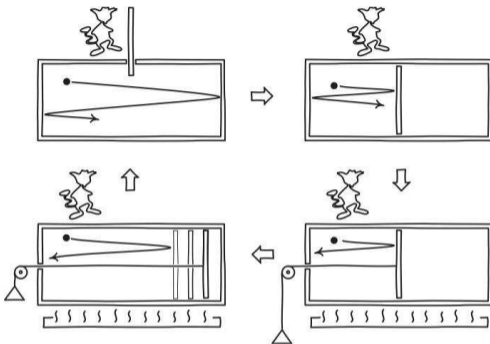
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### ♠ Bennett (1982) "Exorcizing Maxwell's demon"

Demon's memory: Starts cycle in state 0

Ends cycle in mixture 0 & 1

⇒ reset memory each cycle (Landauer erasure)

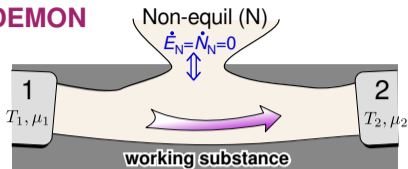
generates entropy (due to 2nd law) ⇒ 2nd law

## THERMODYNAMIC FOR OUR DEMON

Clausius (1850s): Equilib reservoir  $i$   
at temp  $T_i$  has

$$\Delta S_i = \Delta Q_i / T_i$$

heat change =  $\Delta Q_i = \Delta E_i - \mu_i \Delta N_i$



**BUT** non-equil reservoir N has  $\Delta S_N \neq \Delta Q_N / T_N$   $\Leftarrow$  since  $T_N$  not defined

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### DEFINE "DEMON CONDITIONS":

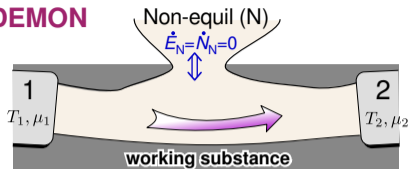
N provides no energy or particles on average ( $I_N = I_N^E = 0$ )

... but its entropy increases  $\dot{S}_N > 0$

$$\Rightarrow \text{2nd law: Total entropy} = \dot{S}_N + \frac{J_1}{T_1} + \frac{J_2}{T_2} \geq 0$$

$$\Rightarrow \text{1st law (energy conservation)} J_1 + J_2 + P = 0 \quad \text{for power output } P$$

## THERMODYNAMIC FOR OUR DEMON



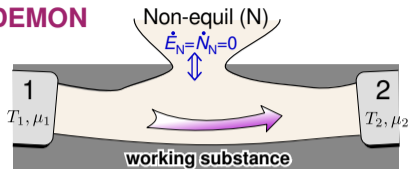
Case 1: power generation = particle flow from low  $\mu_1$  to high  $\mu_2$   
with 1 & 2 at temp  $T$

♠ non-zero power output:  $P \leq T \dot{S}_N$

♠ Cooling 1 & 2:  $J_1 + J_2 = -P$

⇒ Apparent violation of Kelvin version of 2nd law

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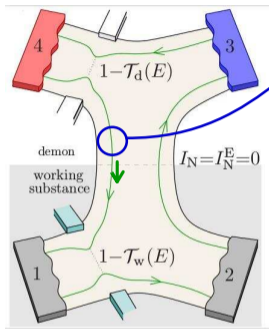
⇒ Apparent violation of Kelvin version of 2nd law

Case 2: refrigeration = heat flow from cold (1) to hot (2)  
with no work by 1 or 2:  $\mu_1 = \mu_2$

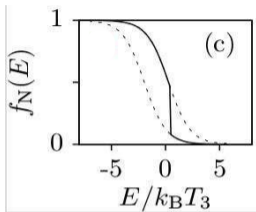
♠ negative heat flow:  $J_1 \geq -\frac{T_1 T_2}{T_2 - T_1} \dot{S}_N$

⇒ Apparent violation of Clausius version of 2nd law

## QUANTUM HALL DEMON



NON-EQUIL DISTRIBUTION

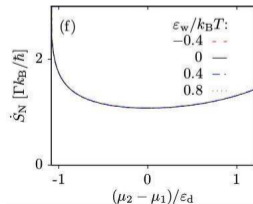
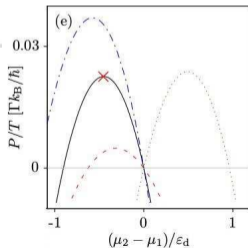
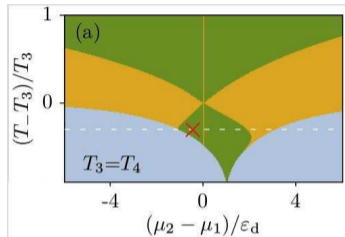
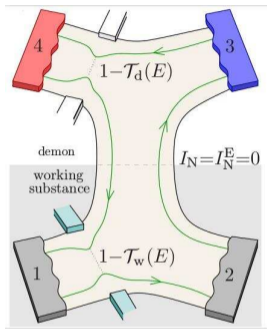


Solve using Landauer-Buttiker scattering theory for 4 reservoir system

$\Rightarrow$  calculate  $I_i$  &  $I_i^E$

energy & particles conserved

# QUANTUM HALL DEMON



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## OPTICAL DEMON

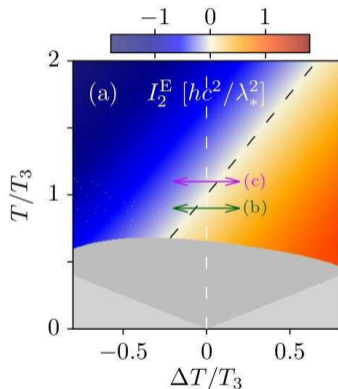
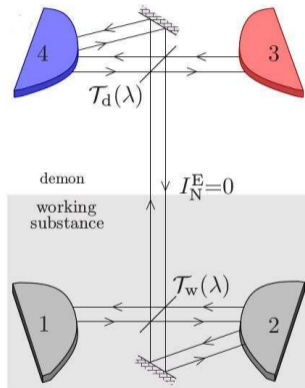
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## OPTICAL DEMON

Is it just fermions? What about bosons?



Spatial separation:

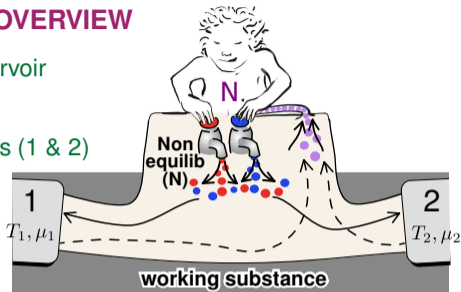
- Work production  $\Rightarrow$  working substance
- Entropy production  $\Rightarrow$  demon

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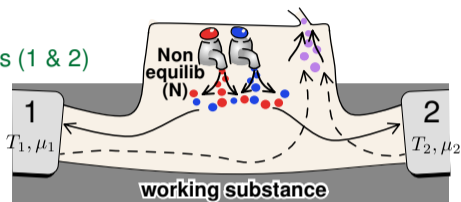
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