



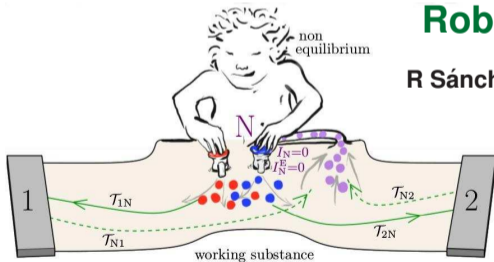
A non-equilibrium system as a demon

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arXiv:1811.02453

OVERVIEW

Thermodynamic (steady-state) machines
when thermalization is NOT smallest scale

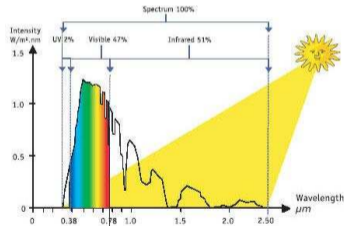
interference effects
entanglement
single-particle interactions
far from equilibrium

- ♣ We are surrounded by non-equilibrium reservoirs
(often without quantum correlations)

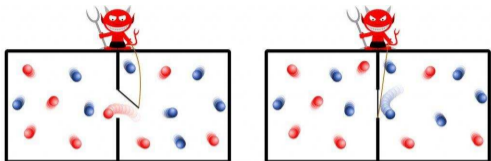
LET'S EXPLOIT THEM!!

- ♣ Experimental proposals
 - Optical
 - Quantum Hall edge-states

- ♣ Similar to Maxwell demon → “N-demon”



Maxwell's Demon versus N-Demon



Maxwell (1867) in letter to Tait

“... the hot system has got hotter and the cold colder,
and yet **no work has been done**,

~~only the intelligence of a **very observant and neat fingered being**~~
~~has been employed”~~



~~Detection~~

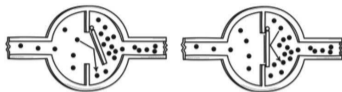
~~of individual particles~~

only a **non-equilibrium reservoir** has been employed

⇒ *we call it an N-demon* (“N” for non-equilibrium)

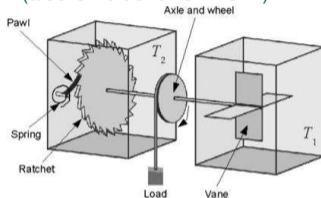
AUTONOMOUS MAXWELL'S DEMONS

♠ Smoluchowski (1912)

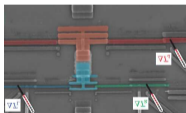
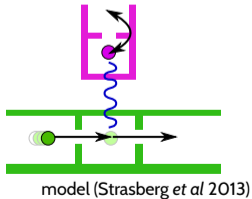


⇒ He concluded: no violation
of 2nd law due of fluctuations

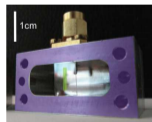
"Feynman" ratchet (also Smoluchowski 1912)



♠ Autonomous demons in recent experiments



2 single-electron devices
(Kosti et al, 2015)



Qubit + cavity mode
(Cottet et al, 2018)

NON-EQUILIBRIUM AS DEMON (N-demon)

STEADY-STATE:

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

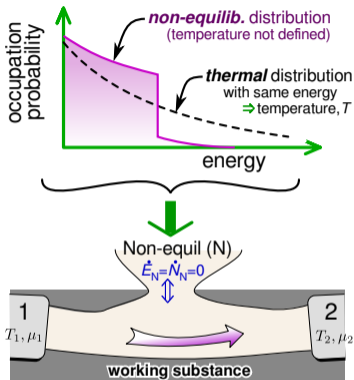
~~$$\dot{S}_i = J_i/T_i$$~~

heat current $J_i = \dot{E}_i - \mu_i \dot{N}_i$

Non-equilibrium reservoir N has

$$\dot{S}_N \neq J_N/T_N$$

since T_N not defined



Exploit reservoir N's "non-equilibrium" **without** exploiting its heat/work

\Rightarrow *Demon conditions*: $\dot{E}_N = \dot{N}_N = J_N = 0$ so N provides no heat/work
... but its entropy increases $\dot{S}_N > 0$

NON-EQUILIBRIUM AS DEMON (N-demon)

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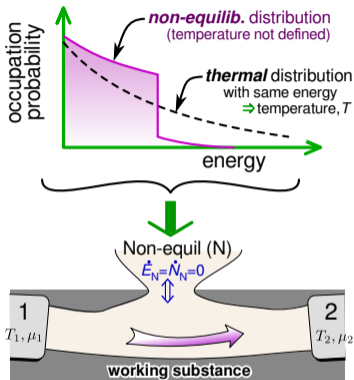
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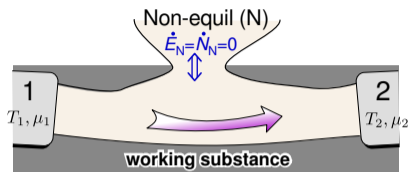


♠ Connecton to “DEMONIC ERGOTROPY” & “PASSIVITY”???

Non-passive state of N — more common than squeezed states, etc

N-demon = experimentally accessible unlike some *global unitaries*

NON-EQUILIBRIUM AS DEMON (N-demon)



Case 1: particle flow from low μ_1 to high μ_2 (with 1 & 2 at temp T)

♠ Power output obeys $0 < P \leq T \dot{S}_N$

♠ Cooling 1 & 2: $J_1 + J_2 = -P$

⇒ Apparent violation of 2nd law (Kelvin version)

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

♠ Heat flow out of 1 obeys $0 < J_1 \leq \frac{T_1 T_2}{T_2 - T_1} \dot{S}_N$

⇒ Apparent violation of 2nd law (Clausius version)

Example - OPTICAL DEMON

EXAMPLE OF CASE 2

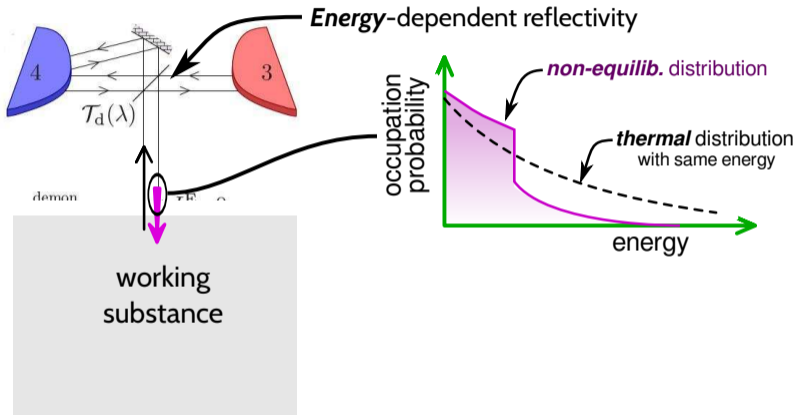
N-demon provides no heat/work
but it causes

COLD $\xrightarrow{\text{heat}}$ **HOT**

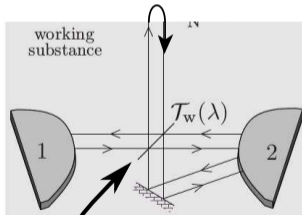
in working substance

(decreasing entropy in working substance)

Example - OPTICAL DEMON

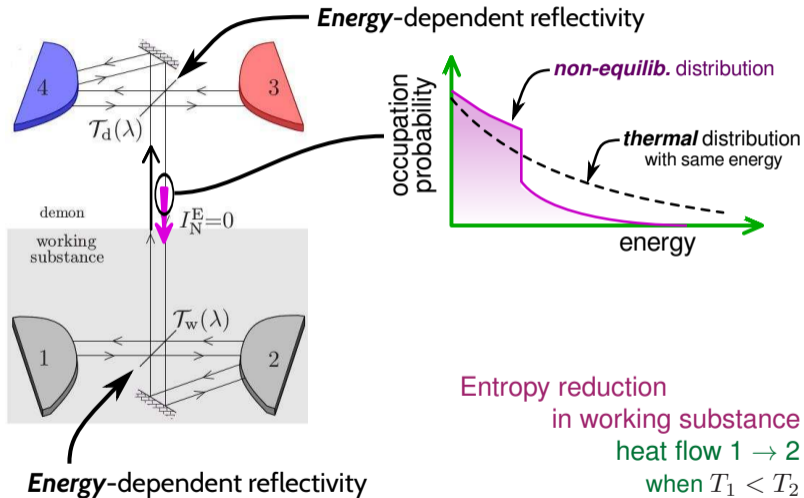


Example - OPTICAL DEMON



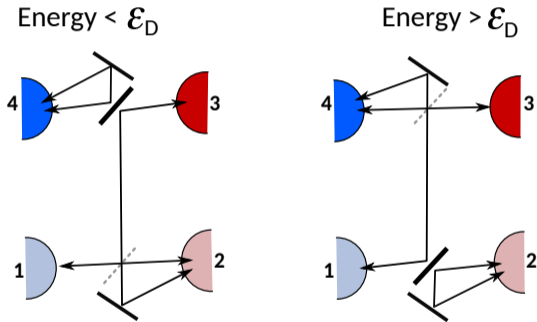
Energy-dependent reflectivity

Example - OPTICAL DEMON



OPTICAL DEMON: example of how it works

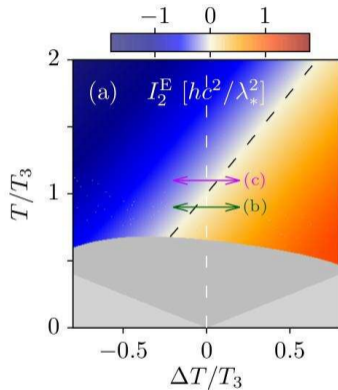
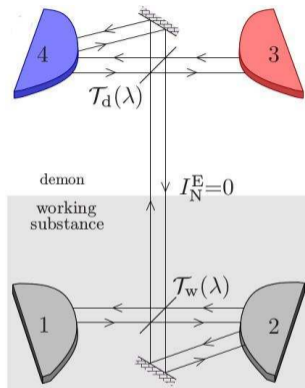
consider temperatures: $T_4 < T_1 < T_2 < T_3$



- Low energies: heat flows $3 \rightarrow 2$
- High energies: heat flows $1 \rightarrow 4$

} NET EFFECT : heat flow $1 \rightarrow 2$
when $T_1 < T_2$

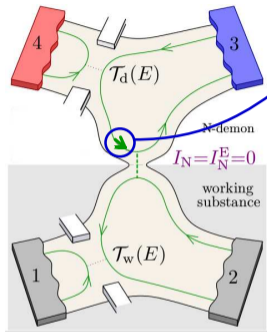
OPTICAL DEMON



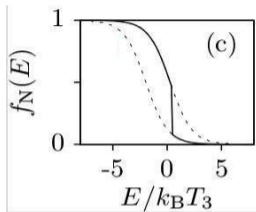
Spatial separation:

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

QUANTUM HALL DEMON



NON-EQUIL DISTRIBUTION

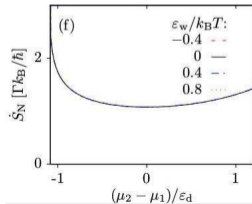
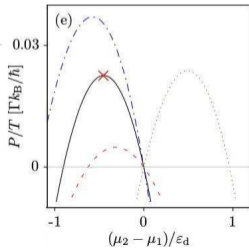
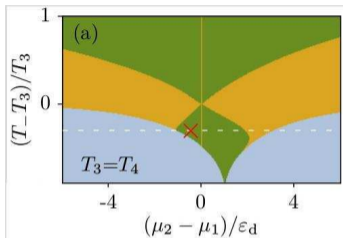
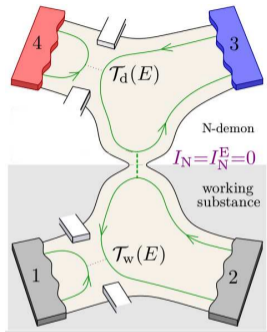


Solve using Landauer-Buttiker scattering theory for 4 reservoir system

\Rightarrow calculate I_i & I_i^E

energy & particles conserved

QUANTUM HALL DEMON

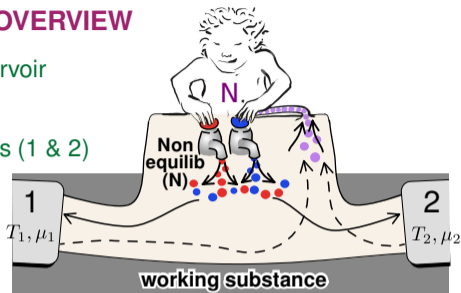


OVERVIEW

DEMON = non-equilibrium reservoir

WORKING SUBSTANCE

= two equilibrium reservoirs (1 & 2)



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

(ii) Heat flows cold \rightarrow hot

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

♠ **Practical use:** work generation (+cooling) from exploiting non-equilibrium
Nanoscale thermal management