FROM QUANTUM NOISE TO HEAT: ACCELERATION TEMPERATURE, BLACK HOLE EVAPORATION AND THE DYNAMICAL CASIMIR EFFECT

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ADAM MARBLESTONE

Noise: Fluctuation, Dissipation, Amplification and Information

Fall 2008

AGENDA

ACCELERATION TEMPERATURE

PARTICLE CREATION BY SCHWARZSCHILD BLACK HOLES

DYNAMICAL CASIMIR EFFECT OBSERVED IN QUANTUM LIMITED AMPLIFIERS

ACCELERATION TEMPERATURE (THE UNRUH EFFECT):

TO AN ACCELERATING OBSERVER THE ORDINARY VACUUM CONTAINS A THERMAL SPECTRUM OF PARTICLES

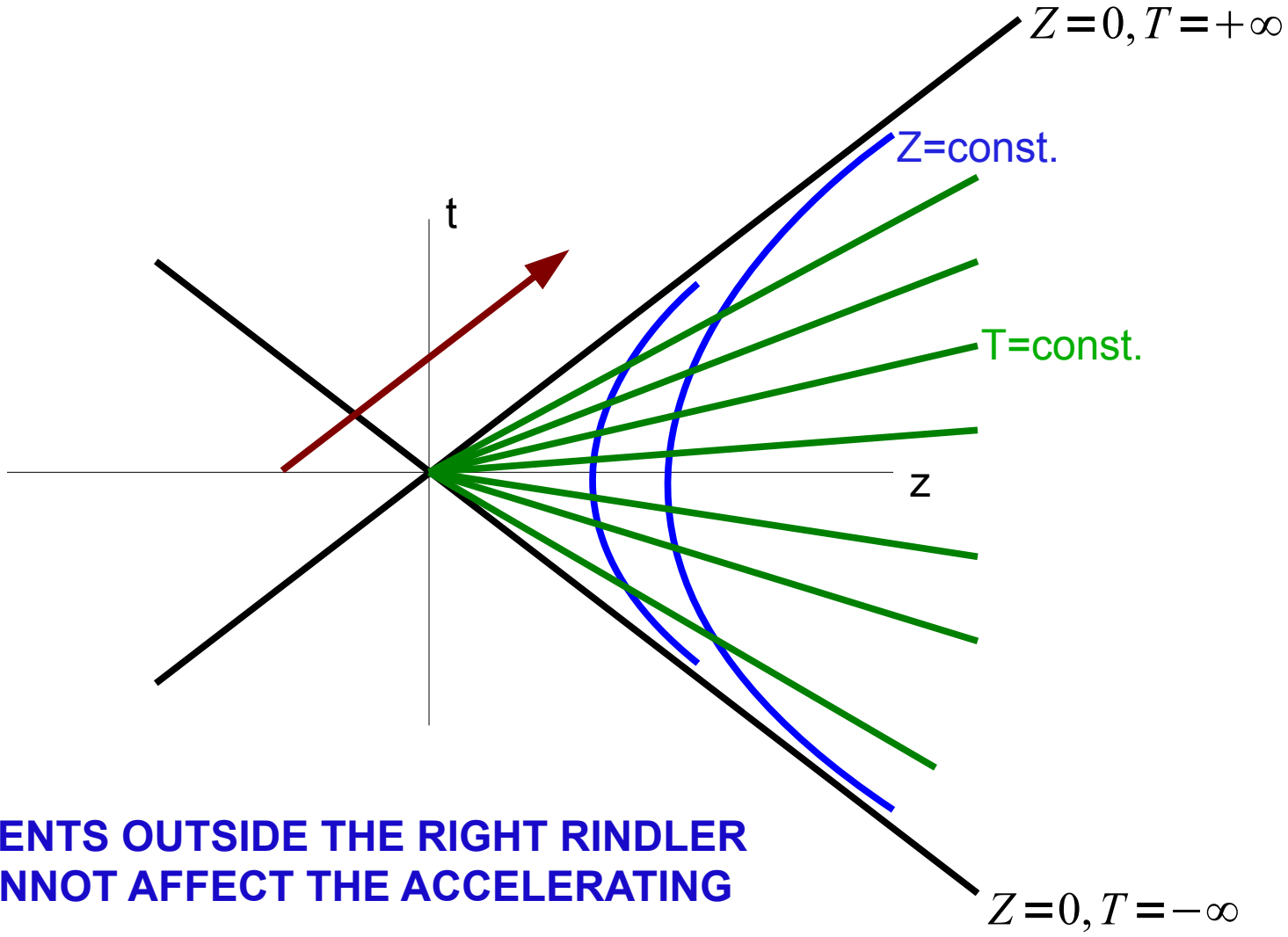
“RIGID” ACCELERATION IN SR

t = 0: ROD AT REST

SUPPLY A “UNIFORM”, “CONSTANT” PROPER ACCELERATION TO THE ROD (THESE ARE SUBTLE IN SR)

FIX A COORDINATE SYSTEM TO THE ROD WHICH ALIGNS WITH INERTIAL COORDINATE SYSTEM AT t=0

“RIGID” ACCELERATION IN SR



FOR t>0 EVENTS OUTSIDE THE RIGHT RINDLER WEDGE CANNOT AFFECT THE ACCELERATING OBSERVER

COORD. DEPENDENCE OF FIELD QUANTIZATION

$$-\frac{\partial^2 \phi}{\partial t^2}+\nabla^2 \phi=0$$

$$\phi(x,t)=\sum_k a_k \cdot f_k(x,t)+\bar{a}_k \cdot \bar{f}_k(x,t)$$

$$a_k\left|0_f\right\rangle=0$$
$$[a_k, a_{k'}]=[\bar{a}_k, \bar{a}_{k'}]=0$$
$$[a_k, \bar{a}_{k'}]=\delta_{kk'}$$

$f_k(x,t)$ **IS POSITIVE-FREQUENCY**

$\bar{f}_k(x,t)$ **IS NEGATIVE-FREQUENCY**

POSITIVE VS. NEGATIVE FREQUENCY DEFINES THE DISTINCTION BETWEEN ANNIHILATION AND CREATION OPERATORS

COORD. DEPENDENCE OF FIELD QUANTIZATION

$f_k(x,t)$ **IS POSITIVE-FREQUENCY** $\bar{f}_k(x,t)$ **IS NEGATIVE-FREQUENCY**

POSITIVE FREQUENCY CONDITION IS OBSERVER-DEPENDENT

ACCELERATED AND INERTIAL OBSERVERS DISAGREE ABOUT WHICH MODES HAVE POSITIVE FREQUENCY!

THEREFORE ACCELERATED AND INERTIAL OBSERVERS QUANTIZE FIELD DIFFERENTLY----> HAVE DIFFERENT VACUUM STATES

COORD. DEPENDENCE OF FIELD QUANTIZATION

BOGOLIUBOV TRANSFORM BETWEEN ACCELERATED AND INERTIAL VACUA

$$\phi(x,t)=\sum_k a_k\cdot f_k(x,t)+\bar{a}_k\cdot\bar{f}_k(x,t)=\sum_k b_k\cdot g_k(x,t)+\bar{b}_k\cdot\bar{g}_k(x,t)$$

$$a_k|0_f\rangle=0 \qquad b_k|0_g\rangle=0$$
$$[a_k,a_{k'}]=[\bar{a}_k,\bar{a}_{k'}]=0 \qquad [b_k,b_{k'}]=[\bar{b}_k,\bar{b}_{k'}]=0$$
$$[a_k,\bar{a}_{k'}]=\delta_{kk'} \qquad [b_k,\bar{b}_{k'}]=\delta_{kk'}$$

SINCE EACH BASIS OF MODE FUNCTIONS IS COMPLETE, CAN EXPAND ONE IN TERMS OF THE OTHER, BUT POSITIVE AND NEGATIVE FREQUENCIES MAY BE MIXED BY THE TRANSFORMATION

$$g_k=\sum_{k'}\alpha_{kk'}f_{k'}+\beta_{kk'}\bar{f}_{k'}$$

DIFFERENCE IN VACUUM STATES IS DUE ONLY TO THE MIXING

$$\langle 0_f|\bar{a}_k a_k|0_f\rangle=0 \qquad \langle 0_f|\bar{b}_k b_k|0_f\rangle=\sum_{k'}|\beta_{kk'}|^2$$

ACCEL. TEMP.

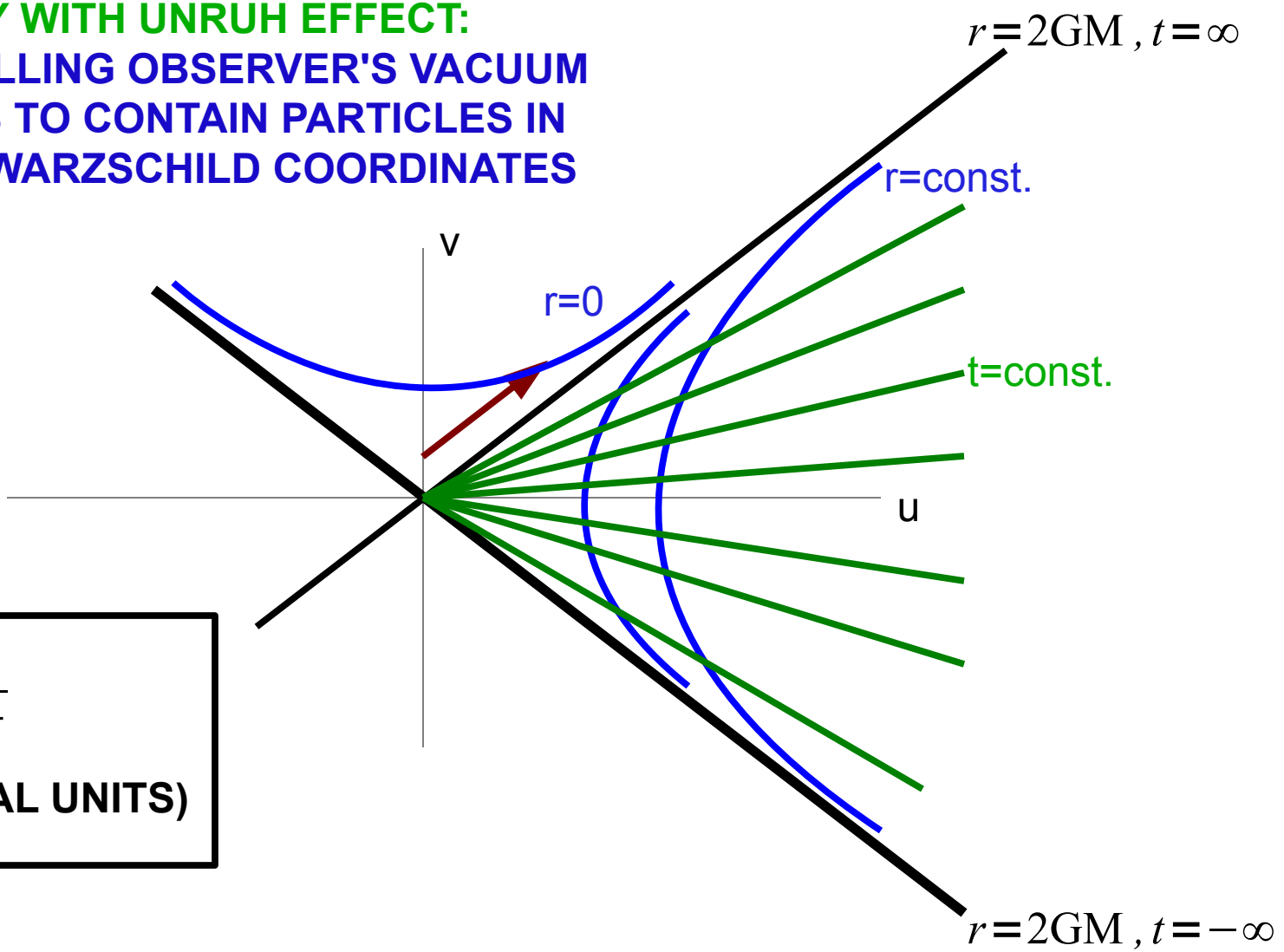
$$\langle 0_M | \bar{b}_k^R b_k^R | 0_M \rangle = \sum_{k'} |\beta_{k k'}|^2 = \frac{1}{e^{2\pi |k|/a} - 1}$$

ACCELERATING OBSERVER SEES THE MINKOWSKI VACUUM TO CONTAIN A BLACKBODY SPECTRUM!

$$T_a = \frac{\hbar a}{2\pi c k_B}$$

BLACK HOLE EVAP.

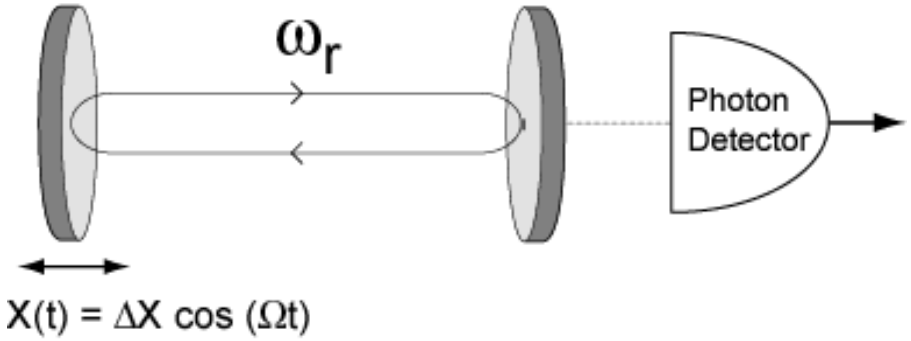
ANALOGY WITH UNRUH EFFECT:
THE INFALLING OBSERVER'S VACUUM APPEARS TO CONTAIN PARTICLES IN THE SCHWARZSCHILD COORDINATES



$$T_{bh}=\frac{\kappa}{2\pi}$$

(NATURAL UNITS)

DYNAMICAL CASIMIR EFFECT

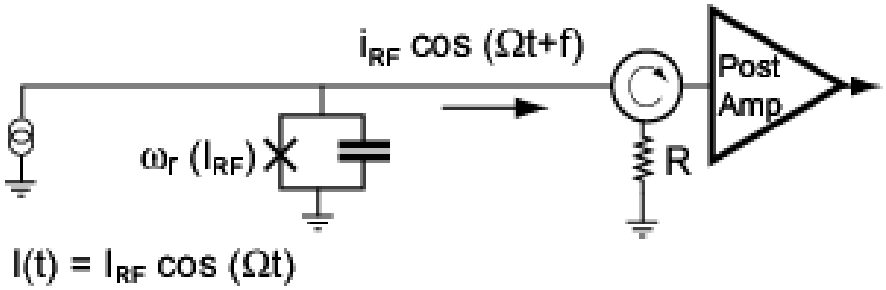


PARAMETRICALLY DRIVEN CAVITY IN GROUND STATE (ONLY 0-PT FLUCTUATIONS) PRODUCES THERMAL PHOTONS

CAVITY RESONANT FREQ VARIES AT TWICE THE FREQ OF THE GROUND STATE MODE

DYNAMICAL CASIMIR EFFECT

JBA



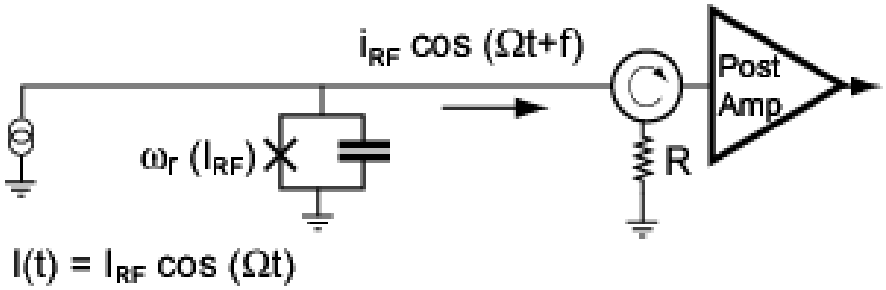
PARAMETRICALLY DRIVEN NONLINEAR JOSEPHSON OSCILLATOR EXCITED BY QUANTUM NOISE FROM TRANSMISSION LINE (ONLY 0-PT FLUCTUATIONS) PRODUCES THERMAL PHOTONS

BEHAVES LIKE RESONATOR WITH FREQ VARIED AT TWICE THE DRIVE FREQ ~ RESONANT FREQ

ALSO ACTS AS A PARAMETRIC AMPLIFIER IN SCATTERING MODE

DYNAMICAL CASIMIR EFFECT

JBA



THERMAL PHOTONS PRODUCED BY DCE

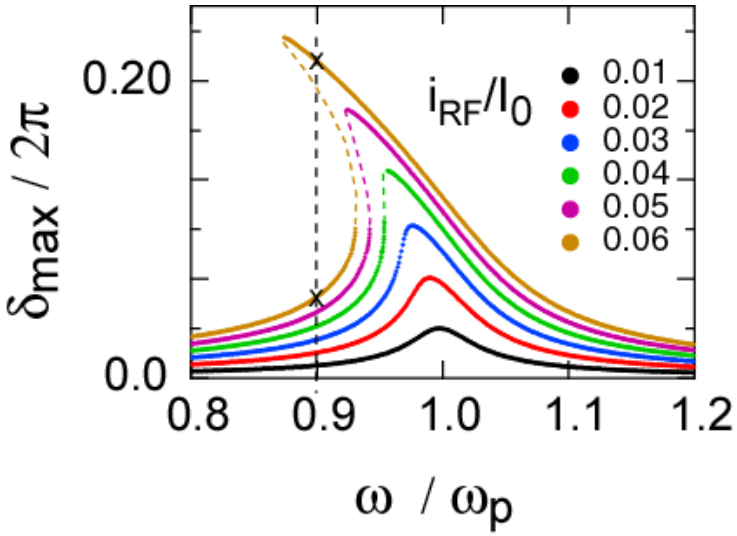
=

ADDED QUANTUM NOISE FOR PHASE-PRESERVING AMPLIFIER

MINIMUM PHASE-PRESERVING AMPLIFIER NOISE TEMPERATURE VIA CAVES' THEOREM:

$$T_N = \frac{\hbar \Omega}{2 k_B} \longleftrightarrow T_a = \frac{\hbar a}{2 \pi c k_B}$$

DYNAMICAL CASIMIR EFFECT



$$T_{activation} = \frac{\hbar\Omega}{2k_B}\coth\left(\frac{\hbar\Omega}{2k_BT}\right) \rightarrow T_N = \frac{\hbar\Omega}{2k_B}$$

OBSERVE ARRHENIUS LAW FOR THERMALLY ACTIVATED TRANSITIONS BETWEEN METASTABLE OSCILLATION STATES IN JBA NONLINEAR OSCILLATOR

AS "REAL" BATH TEMPERATURE GOES TO ZERO, ACTIVATION TEMPERATURE GOES TO CAVES' MINIMAL PHASE PRESERVING AMPLIFIER NOISE TEMPERATURE

CONCLUSIONS

NATURAL UNITS

$$T_N = \frac{\Omega}{2} \quad \longleftrightarrow \quad T_a = \frac{a}{2\pi} \quad \longleftrightarrow \quad T_{bh} = \frac{\kappa}{2\pi}$$

AMPLIFICATION **ACCELERATION** **EVAPORATION**

MECHANISMS NOT AS DISSIMILAR AS THEY MIGHT APPEAR

CONVERT QUANTUM NOISE INTO HEAT

VIA BOGOLIUBOV TRANSFORMATION OF FIELD OPERATORS IN PRESENCE OF DETERMINISTIC ENERGY SOURCE...

ADDITIONAL SLIDES

COORD. DEPENDENCE OF FIELD QUANTIZATION

$f_k(x,t)$ **IS POSITIVE-FREQUENCY** $\bar{f}_k(x,t)$ **IS NEGATIVE-FREQUENCY**

POSITIVE FREQUENCY CONDITION IS OBSERVER-DEPENDENT

A DETECTOR ON A PATH THROUGH FLAT SPACETIME PARAMETRIZED BY PROPER TIME WILL DEFINE A WAVE MODE f_k ON SPACETIME TO BE POSITIVE-FREQUENCY IF:

$$\frac{dx^\mu}{d\tau}\partial_\mu f_k = -i\cdot\omega f_k$$

$$\omega > 0$$

ACCELERATED AND INTERTIAL OBSERVERS DISAGREE ABOUT WHICH MODES HAVE POSITIVE FREQUENCY!