

**Rolf Hagedorn**  
**July 20, 1919 – March 9, 2003**



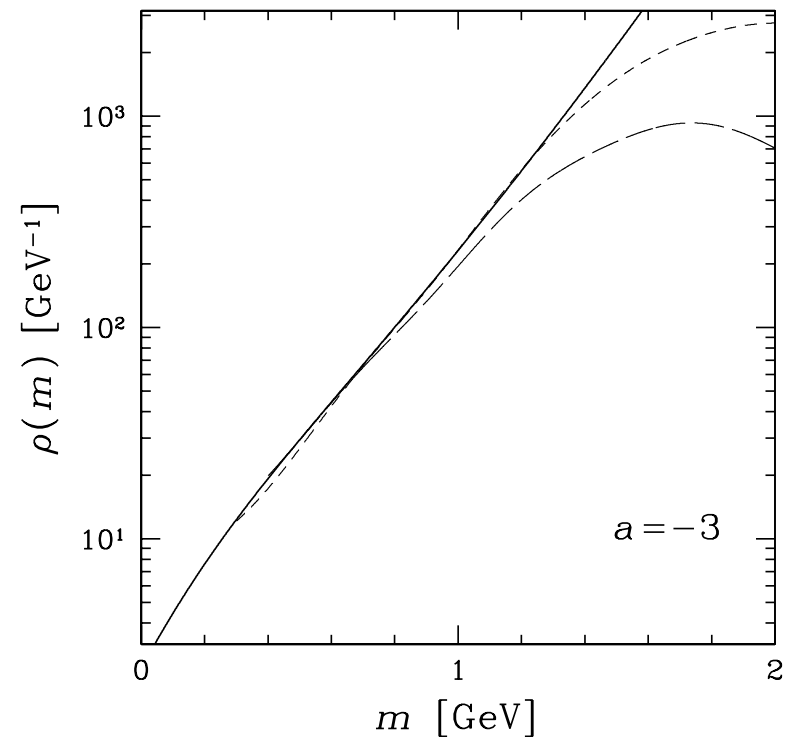
Hagedorn at CERN 1977



**Rolf Hagedorn in 1983**

## Limiting Hadronic Temperature

Rolf Hagedorn proposed and developed the idea of maximal temperature due to exponentially rising mass spectrum of hadronic resonances:





**Rolf Hagedorn  
75th Birthday**

## Statistical Bootstrap

Rolf Hagedorn constructed a theoretical model *Statistical Bootstrap* in which the exponentially rising hadron mass spectrum naturally occurred.

STATISTICAL THERMODYNAMICS  
OF STRONG INTERACTIONS AT  
HIGH-ENERGIES.

Nuovo Cim. Supp. 3 (2): 147 (1965)

*citation classic*

ON HADRONIC MASS SPECTRUM

Nuovo Cim. A 52 (4): 1336 (1967)

HADRONIC MATTER NEAR  
BOILING POINT

Nuovo Cim. A 56 (4): 1027 (1968)

ion to strangeness. Thus, assuming equilibrium in the quark plasma, we find the density of the strange quarks to be (two spins and three colours):

$$\frac{\bar{s}}{V} = \frac{\bar{s}}{V} = 6 \int \frac{d^3p}{(2\pi)^3} e^{-\sqrt{p^2 + m_s^2}/T} = 3 \frac{T m_s^2}{\pi^2} K_2 \left( \frac{m_s}{T} \right) \quad (26)$$

(neglecting, for the time being, the perturbative corrections and, of course, ignoring weak decays). As the mass of the strange quarks,  $m_s$ , in the perturbative vacuum is believed to be of the order of 280 - 300 MeV, the assumption of equilibrium for  $m_s/T \sim 2$  may indeed be correct. In Eq. (26) we were able to use the Boltzmann distribution again, as the density of strangeness is relatively low. Similarly, there is a certain light antiquark density ( $\bar{q}$  stands for either  $\bar{u}$  or  $\bar{d}$ ):

$$\frac{\bar{q}}{V} \approx 6 \int \frac{d^3p}{(2\pi)^3} e^{-|p|/T - \mu_q/T} = e^{-\mu_q/T} \cdot T^3 \frac{6}{\pi^2} \quad (27)$$

where the quark chemical potential is, as given by Eq. (3)  $\mu_q = \mu/3$ . This exponent suppresses the  $q\bar{q}$  pair production as only for energies higher than  $\mu_q$  is there a large number of empty states available for the  $q$ .

What we intend to show is that there are many more  $\bar{s}$  quarks than antiquarks of each light flavour. Indeed:

$$\frac{\bar{s}}{\bar{q}} = \frac{1}{2} \left( \frac{m_s}{T} \right)^2 K_2 \left( \frac{m_s}{T} \right) e^{\mu/3T} \quad (28)$$

The function  $x^2 K_2(x)$  is, for example, tabulated in Ref. 15). For  $x = m_s/T$  between 1.5 and 2, it varies between 1.3 and 1. Thus, we almost always have more  $\bar{s}$  than  $\bar{q}$  quarks and, in many cases of interest,  $\bar{s}/\bar{q} \sim 5$ . As  $\mu \rightarrow 0$  there are about as many  $\bar{u}$  and  $\bar{d}$  quarks as there are  $\bar{s}$  quarks.

When the quark matter dissociates into hadrons, some of the numerous  $\bar{s}$  may, instead of being bound in a  $q\bar{s}$  kaon, enter into a  $(\bar{q}\bar{q}\bar{s})$  antibaryon and, in particular, a  $\bar{\Lambda}$  or  $\bar{\Sigma}^0$ . The probability for this process seems to be comparable to the similar one for the production of antinucleons by the antiquarks present in the plasma.

## Strangeness

In 1978–1980 we adapted the statistical bootstrap to describe hadrons of finite size. The limiting temperature was recognized as a phase transition temperature into a new state of matter.

First mention of strangeness as signature of QGP appears in CERN Theory preprint CERN-TH-2969 of October 1980 (Rafelski-Hagedorn). Both strangeness enhancement, and strange antibaryons are discussed as signatures of deconfined QGP phase.

## Influence

Before Hagedorn's period 1964-84, statistical methods were not accepted, Fermi hadronization model was slowly falling into oblivion.

Hagedorn single-handedly and against significant and important opposition has opened up a new field of physics, the study of thermal properties of strongly interacting matter, in which we participate.

*Hagedorn Temperature*  $T_H = 160 \text{ MeV}$  is today a 'household brand'. Thermal equilibration in strongly interacting hadronic matter is an accepted research direction.

Hagedorn has introduced methods in study of divergent properties of equations of state which since have been adopted in 'more fundamental' fields, one finds the following recent titles on the web:

**HAGEDORN INFLATION: OPEN STRINGS ON BRANES CAN DRIVE INFLATION.**

**THE SUPERSTRING HAGEDORN TEMPERATURE IN A PP WAVE BACKGROUND.**

**BRANE - ANTI-BRANE SYSTEMS AT FINITE TEMPERATURE AND PHASE TRANSITION NEAR THE HAGEDORN TEMPERATURE.**

**CLIFFORD STATISTICS, QUANTUM HALL EFFECT, AND THE HAGEDORN LIMIT.**

**HAGEDORN BEHAVIOR OF LITTLE STRING THEORIES.**

and many more....

## Personal Remarks

I first met Hagedorn (as he wanted to be called) in Winter 1975/76, when I attended his Colloquium on the Statistical Bootstrap Model. After the lecture I asked him privately a few quite ignorant questions. He took every matter very seriously, did not dismiss any remark, and followed with very clear explanations. When I asked if I could visit him at CERN and he suggested I consider a short term position application. I arrived as fellow at CERN in September 1977. Rolf was an extraordinary teacher in the two years of our very close collaboration and subsequent occasional cooperation that lasted till his retirement in 1985.

Hagedorn taught me statistical hadron physics, patiently, repeating many details till I understood everything. We often worked in his office from the morning till the evening. Rolf has critically influenced my development as a Physicist. I am at this meeting today, for he taught me the methods I need and use today.

One day, we had begun to implement a few ideas into publications. Hagedorn enjoyed showing me how simple it was to make computations with *Sigma*, the user oriented computer language he had helped to develop. He was able to complete all the calculations very rapidly, to obtain graphic representations of our results – remember it was 1978 – he was kind enough to assist me with numerical work on other projects.

**Rolf Hagedorn always was available to help those who were in need.**