

# Frontiers of QCD

## Frontiers of High-Density

$(\rho \gg, T \ll)$  QCD

- "Solvability" of High-Density QCD
  - Inadequacy of perturbation theory
  - QCD meets BCS
    - ↳ # of quark flavors, masses matter

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- An Ideal Idealization: CFL

(3  $m=0$  flavors)

↑ crucial    ↑ negotiable

- $\langle q_{Li a}(p) q_{Lj b}^\beta(-p) \rangle = -(L \rightarrow R)$   
 $= \epsilon_{ij} (K_1(p) \delta_a^\alpha \delta_b^\beta + K_2(|p|) \delta_b^\alpha \delta_a^\beta)$

- $SU(3)_c \times SU(3)_L \times SU(3)_R + U(1)_B$   
 $\downarrow$   
 $SU(3)_\Delta \times \mathbb{Z}_2$

- No Infrared Divergences  
Remain ( $\Rightarrow$  "perturbative")

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• Quark - Hadron Continuity

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- Response to Unequal Masses

- Rigidity (?)
- Meson Condensates (?)

The long arm of  
pairing correlations  
( $m_K^2 \propto m_s^2/\mu$ )

- Pairing at  $\vec{q} \neq 0$  and  
crystallization



- (Interior gaps)



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- Some Remaining Challenges

- Systematic, controlled  
expansions ?
- Numerics ?
- Neutron/Quark Star  
Phenomenology ?

## (Some) Frontiers of High-Temperature QCD

- Phase Structure 'Classics'
  - Deconfinement in Pure Glue Theory ( $SU(2)$  vs.  $SU(3)$ )
  - Chiral Symmetry Restoration (2 massless flavours vs. 3)
- \* Quasi-free phase ("quark-gluon plasma") at remarkably low  $T$

## Some Remaining Challenges

- What is the Actual Case?  
(is  $m_s \ll 0$ , or  $\approx \infty$ ?)
- Is there a tricritical point? Where?  $\left\{ \begin{array}{l} \text{theory} \\ \text{expt.} \end{array} \right.$   
( $\downarrow$ )
- Can we penetrate into  $\mu \neq 0$  numerically ( $\mu \gg T$ )?

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- Addressing RHI Experiments

- Plasma signatures

(jet damping, hard photons  
and lepton pairs, heavy quarks)

- Collective phenomena

elliptic flow,

fluctuations  $\rightarrow$  critical?  
DCC?

coherent fields?

... )

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- Importance/Calculability  
of the Initial State  
(gluonization, freezing)
- Surprises!



# Frontiers of "Perturbative"

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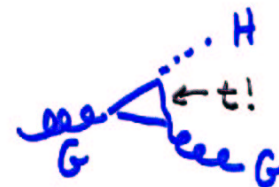
## QCD

- Classics : Jets and Deep Inelastic Scattering
- More, and More Sophisticated, Applications
  - Factorization; Fragmentation; Heavy Quark symmetry; Exclusive processes
  - Combinatorics - string-based and recursive techniques

# • Challenges / Old Questions

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- Fractional charge?
- Regge and Diffractive scattering
- Higgs Phenomenology
  - HGG vertex and fusion



- Rapidity gaps?

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## QCD and Natural Philosophy

- Origin of Mass
- Feebleness of Gravity
- Quantitative "anthropics"  
( $m_u = m_d?$ ,  $m_u + m_d?$ ,  $m_s?$ )
- Why is QCD so good?
  - "Overly effective" theory
- Does Nature really require limiting processes?

