Thermal relaxation of charm in hadronic matter

Min He, Rainer J. Fries, and Ralf Rapp

Heavy-flavor hadrons can serve as a direct probe for the hot and dense matter created in ultra-relativistic heavy ion collisions (URHICs) [1]. Recently, heavy-quark diffusion and thermalization in the quark-gluon plasma (QGP) have been subject of intense studies [1,2]. Heavy-quark interactions with the QGP medium can be characterized by transport coefficients, i.e., a thermal relaxation rate or spatial diffusion coefficient, as calculated, for example by a non-perturbative T-matrix approach [3]. However, a complete description of heavy-flavor probes in URHICs requires to account for the effect of the hadronic phase on heavy-flavor transport.

In the present work [4], we calculate the thermal relaxation rate of open-charm (D) mesons in hot and dense hadronic matter using empirical elastic scattering amplitudes. D-meson interactions with thermal pions are approximated by D* resonances, while scattering off other hadrons (K, eta, rho, omega, K*, N, Delta) is evaluated using vacuum scattering amplitudes as available in the literature based on effective Lagrangians and constrained by realistic spectroscopy. Fig.1 shows the empirical cross sections of D-meson scattering off various hadrons

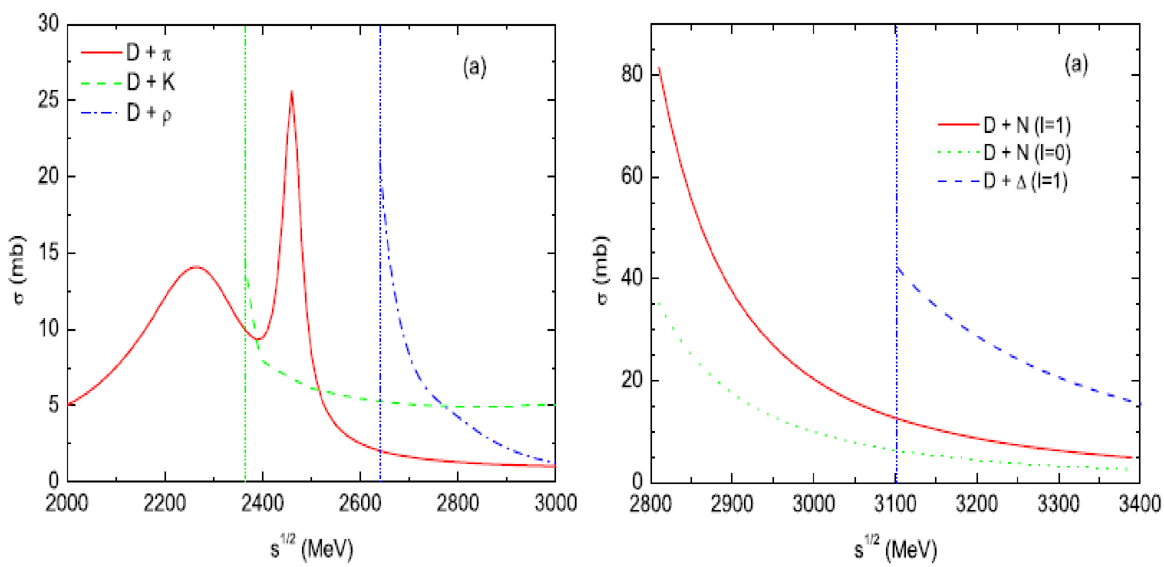

FIG. 1. Empirical cross sections of D-meson scatterings off mesons (left) and baryons (right).

The resulting D-meson thermal relaxation rate is shown in the left panel of Fig. 2. At T=180 MeV, it turns out to be comparable to the charm-quark relaxation rate in the QGP as calculated by the T-matrix approach [3], indicative for a "quark-hadron duality". Under RHIC conditions, with off-equilibrium chemical potentials, the average D-meson relaxation rate of A~0.04/fm translates into a relaxation time of ~25 fm/c. For a hadronic evolution lasting for ~5 fm/c, the D-meson spectrum is expected to be modified by ~20%.

The D-meson spatial diffusion coefficient $D_s=T/(m_D A)$ is displayed in the right panel of Fig. 2. When normalized to the medium's thermal wavelength, $1/(2\pi T)$, D_s decreases with temperature and reaches a value of ~5 at T=180 MeV. Again, this is surprisingly close to the T-matrix results for charm quarks in the QGP phase [3], and together with those results, suggests a minimum across the hadron-to-quark transition. This behavior is analogous to a widely discussed transport coefficient characterizinng the fluidity of the matter, i.e. the ratio of shear viscosity to entropy-density, η/s. Specifically, our value for D_s translates into $\eta/s \sim (2\text{-}5)/4\pi$ at T=180 MeV, not far from the postulated lower quantum bound of $1/4\pi$ from AdS/CFT correspondence.

Our findings may help improve the theoretical accuracy in heavy-flavor phenomenology for the upcoming precision measurements at RHIC and LHC.

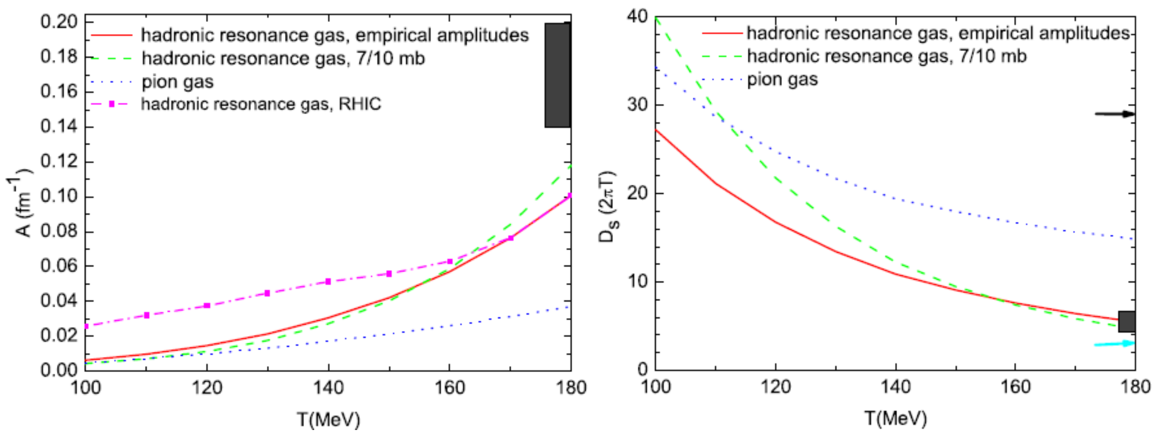

FIG. 2. Left panel: D-meson thermal relaxation rate as a function of temperature in a hadron gas. Right panel: D-meson spatial diffusion coefficient in units of the thermal wavelength $1/(2\pi T)$; to the right, estimates for charm-quark diffusion in the QGP are indicated (filled box: T-matrix approach at $1.2T_c$, lower arrow: AdS/CFT correspondence, upper arrow: perturbative QCD).

[1] R. Rapp, H. van Hees, in: R. Hwa, X.N. Wang (Eds.), Quark-Gluon Plasma, vol. 4, World Scientific, Singapore, 2010, p. 111, arXiv:0903.1096 [hep-ph].

[2] H. van Hees and R. Rapp, Phys. Rev. C **71**, 034907 (2005); G. D. Moore and D. Teaney, Phys. Rev. C **71**, 06 4904 (2005).

[3] F. Riek and R. Rapp, Phys. Rev. C **82**, 035201 (2010); New J. Phys. **13**, 045007 (2011).

[4] Min He, Rainer J. Fries, and Ralf Rapp, Phys. Lett. **B 701**, 445 (2011).