Saturation 2005 (mini-review)

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Abstract. This talk is a brief review of ups and downs of high density QCD during the past year.

SATURATION AT HERA AND RHIC

Before discussing the high density QCD news we would like to summarize what we have learned about saturation at HERA and RHIC.
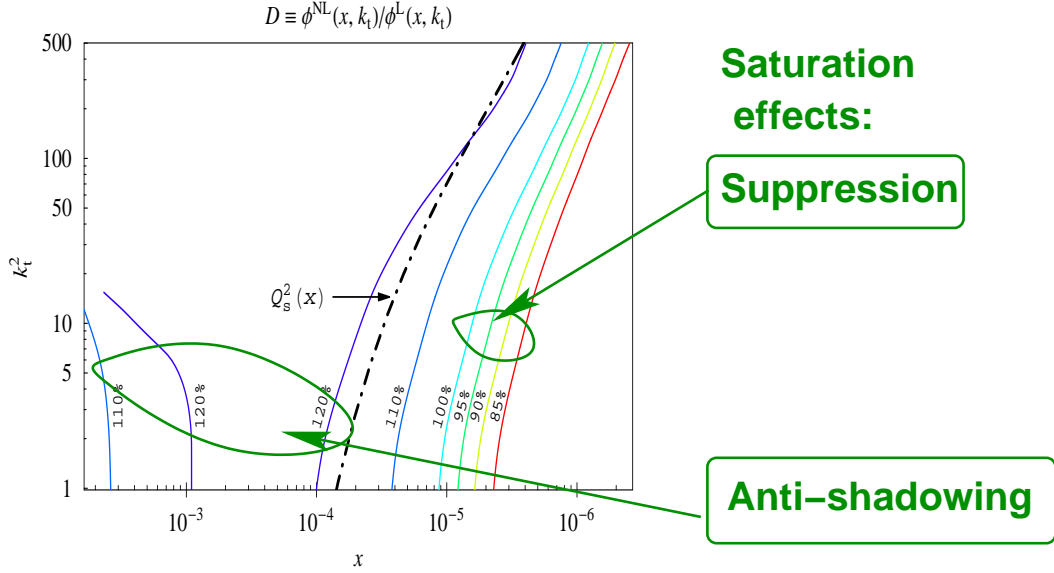   HERA:

- The power - like growth of $xG(x, Q^2)$ at low x ($xG(x, Q^2) \propto x^{-\lambda}$ with $\lambda \approx 0.3$;
- The geometrical scaling behaviour for $x \leq 10^{-2}$;
- Fit of all HERA data for $Q^2 = 0 \div 500\,GeV^2$ with $\chi^2/d.o.f. \leq 1$ based on non-linear equation [1, 2];

RHIC:

- Saturation approach for dN/dy versus y, energy and number of participants predicted and led to a reasonable description of the experimental data [3];
- Prediction for suppression of the hadron production in dA collision and confirmation in the experimental data [4, 5].

    The only consistent explanation all these observations is to assume that at HERA we have started to approach a new phase of QCD, with large gluon density but still with small coupling constant. The regime of high parton density at HERA is reached due to the QCD emission of gluons that was incorporated in the QCD evolution equations. The independent check of the effects of high gluon density at HERA was performed by RHIC experiment in heavy ion-ion collisions. In this reaction the energies are much lower than at HERA, but the large values of the parton densities were achieved due to the large number of nucleons in a nucleus. Based on these experimental observations we can anticipate that the LHC will be a machine for discovery a new phase of QCD: colour glass condensate with saturated gluon density.

FIGURE 1. The ratio ϕ^{NL}/ϕ^L which shows the influence of non-linear correction on the predictions for inclusive gluon jet production at LHC energies

PREDICTIONS FOR THE LHC RANGE OF ENERGIES

Our main challenge is to provide reliable estimates for the influence of high density QCD (saturation) effects in the LHC range of energies. The first such estimates have been discussed [6, 7], and the results for the ratio of the unintegrated structure functions $D = \phi^{NL}/\phi^L$ are plotted in Fig.1 where

$$\frac{d\sigma}{dyd^2p_t} \propto \frac{\alpha_S}{p_t^2} \int d^2k_t\, \phi(k_t^2)\, \phi((\vec{p} - \vec{k})_t^2) \tag{1}$$

and $\phi^{NL}(\phi^L)$ is solution of the non-linear (linear) equation.

It should be stressed that non-linear evolution predicts not only suppression in the saturation region, but also the anti-shadowing effect which results in an increase of the value of ϕ for $Q^2 > Q_s^2(x)$, where Q_s is the saturation scale. One can see that the suppression and increase could be rather large leading to an inclusive cross section twice as large or twice as small, as the predictions based on routine linear evolution.

THEORETICAL DEVELOPMENT

B- JIMWLK approach $\longleftrightarrow$ BFKL Pomeron Calculus

The good news is that it turns out that Balitsky-JIMWLK approach [8] can be reduced to BFKL Pomeron calculus [9], and JIMWLK effective Lagrangian give us possibility to calculate all multi-Pomeron vertices. For the first time, we can do such calculations using operator formalism without spending years to obtain result just summing Feyman

diagrams. Since the colour dipoles are the 'wee' partons of the BFKL equation the Balitsky-JIMWLK formalism can be discussed in terms of the dipole approach.

The bad news is that we have not achieved any progress in Pomeron calculus.

Probabilistic interpretation

Our last hope is the probabilistic approach to Pomeron interaction. The best way to express our optimism is to cite Grassberger and Sundermeyer [10] who proposed this interpretation: " *Reggeon field theory is equivalent to a chemical process where a radical can undergo diffusion, absorption, recombination, and autocatalytic production. Physically, these "radicals" are wee partons (*colour dipoles*)*".

It turns out that B-WLKJIM approach can be written as a typical death-birth process (Markov's chain)[11, 12]

$$\frac{\partial P_n}{\partial Y} = -\sum_i \Gamma(1 \to 2) \bigotimes (P_n(...x_i, y_i...; Y) - P_{n-1}(...x_i, y_i...; Y)) \qquad (2)$$

where P_n - probability to find n-dipoles at rapidity Y, $\Gamma(1 \to 2)$ describe the decay of one dipole into two dipoles and $\bigotimes$ denotes all needed integration. This equation can be a basis for the Monte Carlo code which will be able to solve high density QCD equations, and which will lead to theoretical treatment of the multiparticle production.

Hunt for Pomeron loops

The process of two Pomeron merging into one Pomeron is naturally included in Pomeron calculus with the same vertex as the process of Pomeron splitting. However, we need correctly normalize this process if we wish to use the probabilistic interpretation. Such normalization was suggested in Ref. [13] and this vertex $\Gamma(2 \to 1)$ has been calculated [13, 14, 12]. Using this vertex, we can generalize Eq.(2) which takes the form

$$\frac{\partial P_n}{\partial Y} = \text{Eq.}(2) - \sum_i \Gamma(2 \to 1) \bigotimes \left(P_n(...x_i, y_i...; Y) - \sum_k P_{n+1}(...x_i, y_i...x_k, y_k; Y) \right) \quad (3)$$

Solution

Attempts to solve Eqs.(3) have been made in Refs.[15, 16, 17]. The result is surprisingly unexpected, namely,

- Asymptotic solution leads to a *gray* disc (*not black!!!*);
- Using the large parameters of our theory ($\Gamma(1 \to 2)/\Gamma(2 \to 1) \approx N_c^2/\alpha_S^2$ and $\Gamma(1 \to 2)/\Gamma(2 \to 3) \approx N_c^2$) the semiclassical approach can be developed for searching for both the asymptotic solution and the corrections to it, at high energy;

- The corrections to the asymptotic solution decrease at large values of Y, and can be found from the Liouville-type linear equation;
- The important role in searching for high energy asymptotic behaviour of the amplitude plays the role of t-channel unitarity constraint, which specifies the value of the typical amplitude for dipole-dipole interaction.

Topics which I have no room to discuss

This brief review is my personal view on news in low x (high density) QCD. Unfortunately, I had no room even to express my point of view. It is pity since I think that a more microscopic approach, related to the new effective Lagrangian, and to a search for a Bogolubov transformation between dipole and quarks (antiquark) and gluon degrees of freedom [9, 18, 19], looks very interesting. It is very attractive approach and I hope that my references provide the reader with names of active players in this field. However, I must admit that the theory becomes dangerously complicated and reminds me more and more my nightmare that Lipatov [20] is correct with his effective action, which is not easier to solve than the full QCD Lagrangian.

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