Observables and initial conditions from exact rotational hydro solutions

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Continuation: observables
Two different family of equations of state
Single particle spectra
Elliptic and higher order flows
Oscillations of HBT radii
What have we learnt?
Summary

Manuscript in preparation
arXiv:1309.4390v2

Rotated Gaussian solutions

$$n(t, \mathbf{r}') = n_0 \frac{V_0}{V} \exp\left(-\frac{r_x'^2}{2X^2} - \frac{r_y'^2}{2Y^2} - \frac{r_z'^2}{2Z^2} \right),$$

$$\mathbf{v}'(t, \mathbf{r}') = \left(\frac{\dot X}{X} r_x', \frac{\dot Y}{Y} r_y', \frac{\dot Z}{Z} r_z' \right),$$

Note: (r′, k′) in fireball frame
rotated wrt lab frame (r,k)

$$\ddot X X - X^2\omega^2 = \ddot Y Y = \ddot Z Z - Z^2\omega^2 = \frac{T}{m},$$

$$\dot T \frac{d}{dT}(\kappa T) + T\left(\frac{\dot X}{X} + \frac{\dot Y}{Y} + \frac{\dot Z}{Z} \right) = 0,,$$

$$X = Z \equiv R$$

$$\dot X = \dot Z \equiv \dot R$$

Note: in this talk, rotation in the
(X,Z) impact parameter plane !

Role of EoS on acceleration

$$\ddot{X}X - X^2\omega^2 = \ddot{Y}Y = \ddot{Z}Z - Z^2\omega^2 = \frac{1}{1+\kappa}.$$

$$\ddot{X}X - X^2\omega^2 = \ddot{Y}Y = \ddot{Z}Z - Z^2\omega^2 = \frac{T}{m},$$

Lattice QCD type Eos is explosive

$$\begin{aligned}
\theta(t) &= \theta_0 + \int \mathrm{d}t\, \omega(t), \\
\omega &= \omega_0 \frac{R_0^2}{R^2}, \\
R &= X = Z \neq Y, \\
s &= s_T + s_Z = \frac{r_x^2 + r_z^2}{R^2} + \frac{r_y^2}{Y^2}, \\
V &= XYZ = R^2 Y.
\end{aligned}$$

Tilt angle θ integrates rotation
in (X,Z) plane: sensitive to EoS!

Single particle spectra

$$
\begin{aligned}
E\frac{d^3n}{d\mathbf{k}'} &\propto E\exp\left(-\frac{k_x'^2}{2mT_x'}-\frac{k_y'^2}{2mT_y'}-\frac{k_z'^2}{2mT_z'}\right),\\
T_x' &= T_f + m(\dot{X}_f^2+\omega^2 Z^2)\\
T_y' &= T_f + m\dot{Y}_f^2\\
T_z' &= T_f + m(\dot{Z}_f^2+\omega^2 X^2),
\end{aligned}
$$

In the rest frame of the fireball:

Rotation increases effective temperatures both in the longitudinal and impact parameter direction

in addition to Hubble flows

Directed, elliptic and other flows

From the single particle spectra
→ flow coefficents v_n

$$\frac{d^3n}{dk_z k_t dk_t d\phi} = \frac{d^2n}{2\pi dk_z k_t dk_t}\left[1 + 2\sum_{n=1}^{\infty} v_n \cos(n\phi)\right].$$

$$\begin{aligned} v_1 &= 0, \\ v_2 &= \frac{I_1(w)}{I_0(w)}, \\ v_3 &= 0, \ldots \\ v_{2n} &= \frac{I_n(w)}{I_0(w)}, \end{aligned}$$

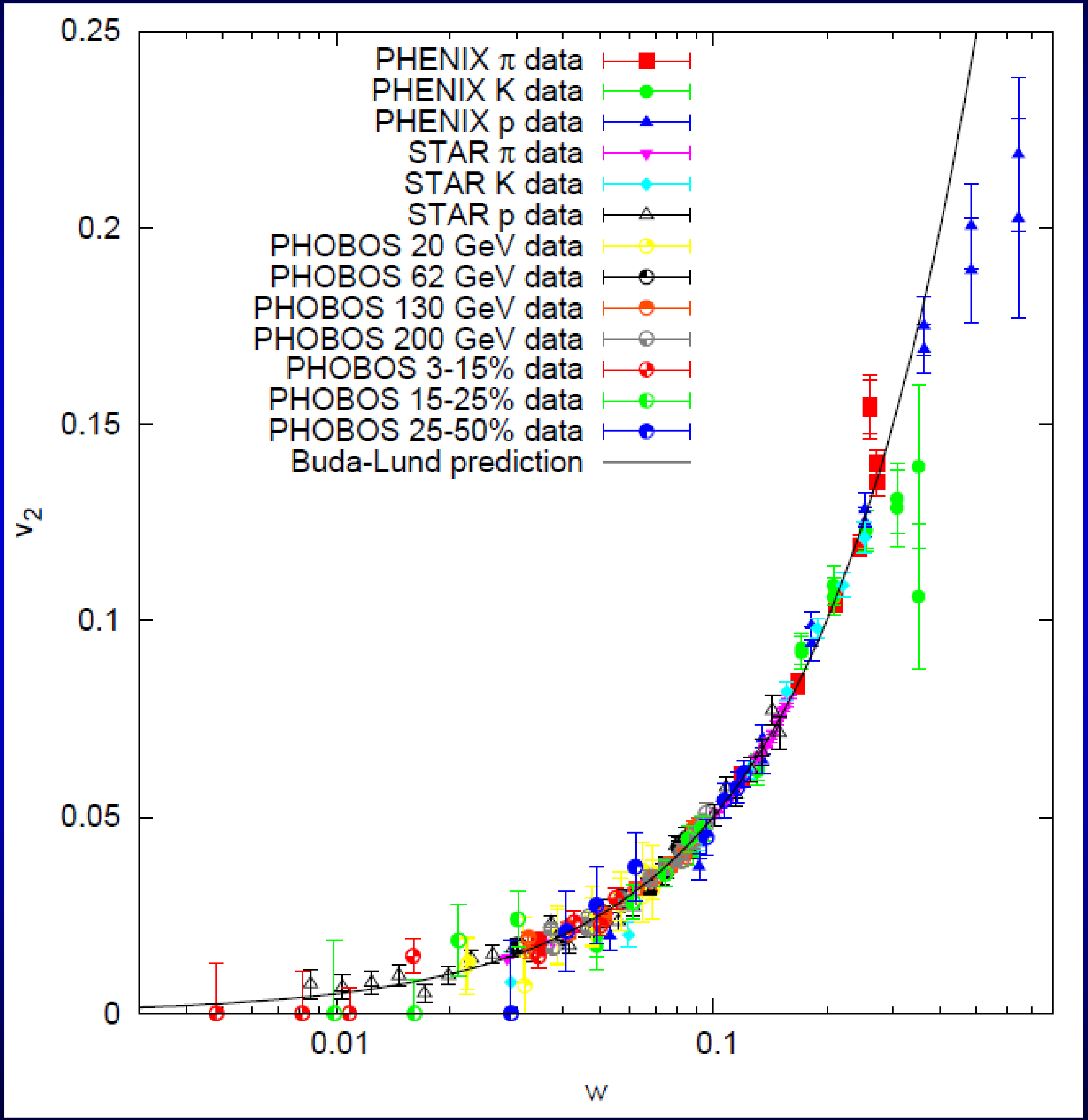
Note:
model is fully analytic

As of now, only X = Z = R(t)
spheroidal solutions are found

→ vanishing odd order flows

See next talk for fluctuations

Reminder: Universal w scaling of v_2



$$v_2 = \frac{I_1(w)}{I_0(w)},$$

Notes:
Rotation does not change this
Just modifies
Radial flow parameters

See
+for more details

HBT radii for rotating spheroids

Diagonal Gaussians in natural frame

$$
\begin{aligned}
C(\mathbf{K}', \mathbf{q}') &= 1 + \lambda \exp\left(-q_x'^2 R_x'^2 - q_y'^2 R_y'^2 - q_z'^2 R_z'^2\right), \\
\mathbf{K}' &= \mathbf{K}'_{12} = 0.5(\mathbf{k}'_1 + \mathbf{k}'_2),
\end{aligned}
$$

$$
\begin{aligned}
\mathbf{q}' &= \mathbf{q}'_{12} = \mathbf{k}'_1 - \mathbf{k}'_2 = (q'_x, q'_y, q'_z), \\
R_x'^{-2} &= X_f^{-2}\left(1 + \frac{m}{T_f}(\dot{X}_f^2 + Y_f^2\omega^2)\right), \\
R_y'^{-2} &= Y_f^{-2}\left(1 + \frac{m}{T_f}\dot{Y}_f^2\right), \\
R_z'^{-2} &= Z_f^{-2}\left(1 + (\frac{m}{T_f}\dot{Z}_f^2 + X_f^2\omega^2)\right).
\end{aligned}
$$

New terms with blue

→ Rotation decreases HBT radii similarly to Hubble flow.

HBT radii in the lab frame

$$C_2(\mathbf{K},\mathbf{q}) = 1+\lambda\exp\left(-\sum_{i,j=\mathrm{s,o,l}} q_i q_j R_{ij}^2\right),$$

$$R_\mathrm{s}^2 = R_y'^2\cos^2\phi + R_x^2\sin^2\phi\,,$$

$$R_\mathrm{o}^2 = R_x^2\cos^2\phi + R_y'^2\sin^2\phi + \beta_t^2\Delta t^2,$$

HBT radii without flow

$$R_\mathrm{l}^2 = R_z'^2\cos^2\theta + R_x'^2\sin^2\theta + \beta_\mathrm{l}^2\Delta t^2,$$

$$R_\mathrm{ol}^2 = (R_x'^2 - R_z'^2)\cos\theta\sin\theta\cos\phi + \beta_t\beta_\mathrm{l}\Delta t^2,$$

$$R_\mathrm{os}^2 = (R_x^2 - R_y'^2)\cos\phi\sin\phi\,,$$

$$R_\mathrm{sl}^2 = (R_x'^2 - R_z'^2)\cos\theta\sin\theta\sin\phi\,,$$

$$R_x^2 = R_x'^2\cos^2\theta + R_z'^2\sin^2\theta$$

But spheriodal symmetry of the solution
Makes several cross terms vanish → need for ellipsoidal solutions

HBT radii in the lab frame

HBT radii without flow

$$C_2(\mathbf{K},\mathbf{q}) = 1 + \lambda \exp\left(-\sum_{i,j=\mathrm{s,o,l}} q_i q_j R_{ij}^2\right),$$

$$R_\mathrm{s}^2 = R_y'^2 \cos^2\phi + R_x^2 \sin^2\phi\,,$$

$$R_\mathrm{o}^2 = R_x^2 \cos^2 \ldots$$

$$R_\mathrm{l}^2 = R_z'^2 \cos^2\theta + \ldots$$

$$R_\mathrm{ol}^2 = (R_x'^2 - R_z'^2)\,\mathrm{c}\ldots$$

$$R_\mathrm{os}^2 = (R_x^2 - R_y'^2)\,\mathrm{co}\ldots$$

$$R_\mathrm{sl}^2 = (R_x'^2 - R_z'^2)\,\mathrm{c}\ldots$$

$$R_x^2 = R_x'^2 \cos^2\theta + R_z' \ldots$$

$$C_2(\mathbf{K},\mathbf{q}) = 1 + \lambda \exp\left(-\sum_{i,j=\mathrm{s,o,l}} q_i q_j R_{ij}^2\right),$$

$$R_\mathrm{s}^2 = R_y'^2 \cos^2\phi + R_x^2 \sin^2\phi\,,$$

$$R_\mathrm{o}^2 = R_x^2 \cos^2\phi + R_y'^2 \sin^2\phi + \beta_t^2 \Delta t^2,$$

$$R_\mathrm{l}^2 = 0 + \beta_\mathrm{l}^2 \Delta t^2,$$

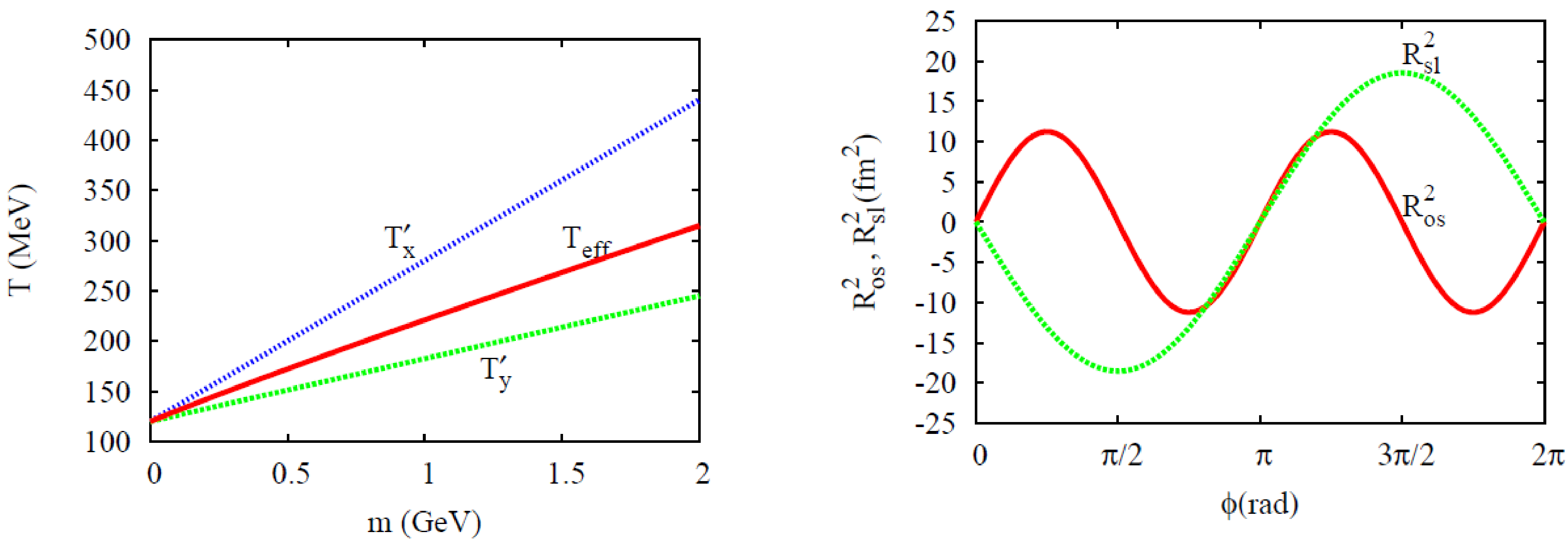
$$R_\mathrm{ol}^2 = 0 + \beta_t \beta_\mathrm{l} \Delta t^2,$$

$$R_\mathrm{os}^2 = (R_x^2 - R_y'^2)\cos\phi\sin\phi\,,$$

$$R_\mathrm{sl}^2 = 0.$$

But spheriodal symmetry of the solution
Makes several cross terms vanish → need for ellipsoidal solutions

Qualitatively rotation and flow similar



But need more time dependent calculations

and less academic studies (relativistic solutions)

Summary

Observables calculated

Effects of rotation and flow
Combine and have same mass dependence

Spectra: slope increases
v_2: universal w scaling remains valid
HBT radii:
Decrease with mass intensifies

Even for spherical expansions:
v_2 from rotation.

Picture: vulcano
How to detect the rotation?
Next step: penetrating probes

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