Radiation dominated implosion with nano-shells

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Objective

- Rapid, volume ignition in *Inertial Confinement Fusion* (ICF), to avoid **Rayleigh-Taylor** *instabilities.*
- Achieve *simultaneous ignition* by increasing absorption with **Au nano-spheres**.

Considerations for the target

Alternatives in our investigations:

- same amount of *DT fuel*, ***without compression*** of radius $R = 640\,\mu$m
- **without ablator** layer as in [11, 12]
- target density is 1.062 g/cm^3
- absorptivity $\alpha_K \approx 8$ cm^{-1}

The **sphere** of the fuel, with an internal point at *radius r*. Let us chose the x-axis so that it passes through the point at r and the center of the sphere. Then let us chose a point on the sphere, and the *angle of this point* from the x-axis is denoted by Θ. Then the length between this *surface point* and the *internal* point at r is:

$$\zeta = (R^2 + r^2 - 2Rr\cos\Theta)^{1/2} \ , \qquad (1)$$

and then the propagation time from the surface point at angle Θ to the point at r on the x-axis equals $\tau = \zeta/$c.

We intend to calculate the **temperature distribution**, $T(r,t)$, within the *sphere*, as a function of *time*, t, and the *radial distance* from the center of the sphere, i.e. *radius r*.

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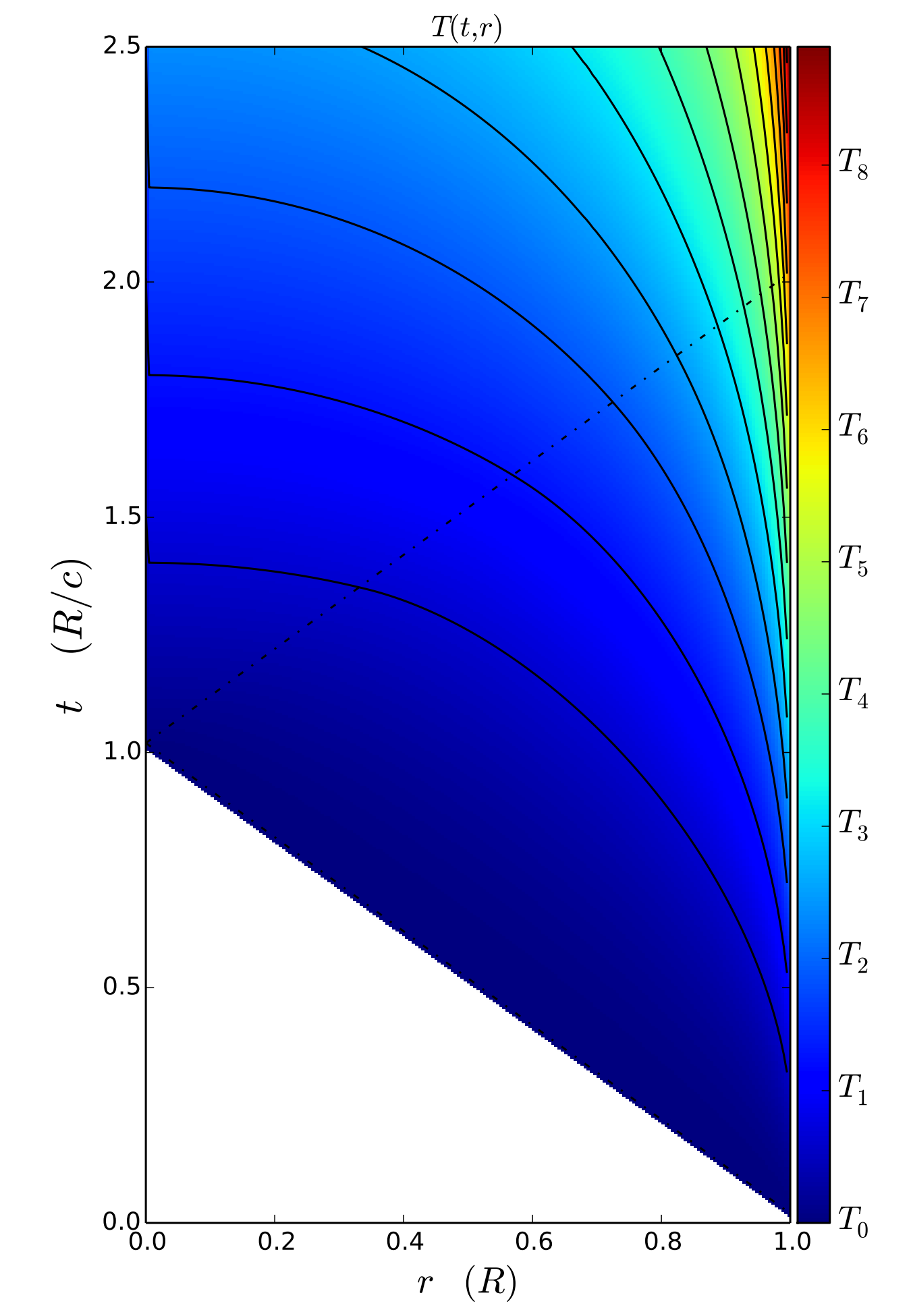
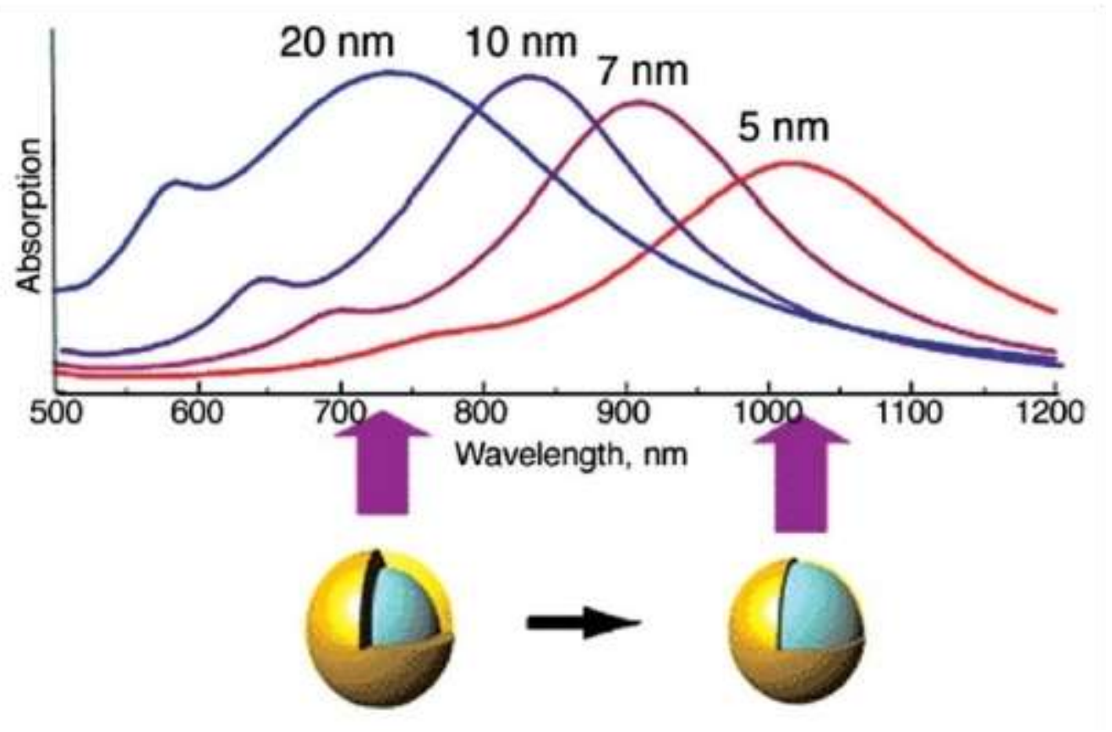
Simplified model and its evaluation



↑ The temperature distribution as function of distance and time.



↑ Golden nano-shells are imbedded in the DT target fuel for increased, resonant light absorption.

We have **two** steps of the evaluation:

- we calculate how much **energy** can reach a given point at r from the outside surface of the sphere.
- we add up the **accumulated radiation** at position r, we integrate $dU(r,t)/dt$ from $t = 0$, for **each spatial** position.

Step 1:
The radiation at distance ζ is decreasing as $1/\zeta^2$. The total radiation reaching point r from the ribbon at Θ is

$$dU(r,t) \propto \frac{1}{\zeta^2}\delta(\zeta - \sqrt{R^2 + r^2 - 2rR\cos\Theta}) \ , \qquad (2)$$

we integrate this for the surface of all ribbons.
Step 2:
Neglecting the compression and assuming **constant specific heat** c_V, **energy of** the **pulse** $Q =$ 2MJ $(4\pi)^{-1}(\cdot 640\mu\mathrm{m})^{-2}$ $(10\mathrm{ps})^{-1}$ and varying absorptivity:

$$k_B\,T(r,t) = \frac{2\pi QR}{c\,c_V\,n}\begin{cases} 0\ , & \text{if}: \quad tc < R{-}r \\ \frac{\alpha_K(r)tc}{r}\left(\ln\frac{tc}{R-r} - 1\right) + \frac{R-r}{r}\ , & \\ & \text{if}: \quad R{-}r < tc < R{+}r \\ \frac{\alpha_K(r)tc}{r}\ln\frac{R+r}{R-r} - 2\ , & \text{if}: tc > R{+}r \end{cases} \qquad (3)$$

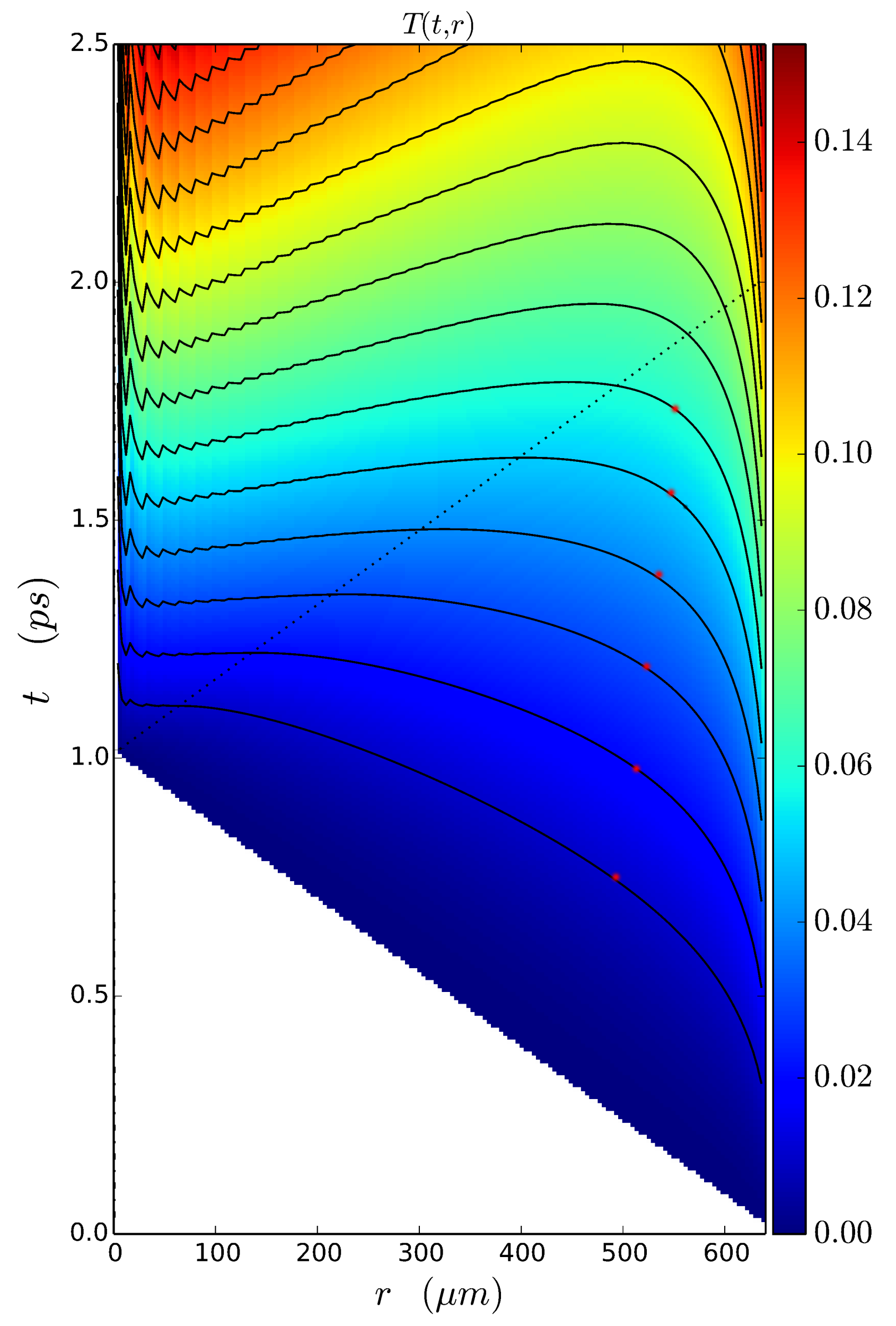
The point (r_c, t_c) where the spacelike and timelike parts of the surface meet:

$$\left(\frac{\partial r}{c\partial t}\right)_{T_c} = 1 \rightsquigarrow t_c = \left\{\frac{2cR}{R^2 - r_c^2}\left[\ln\frac{R + r_c}{R - r_c}\right]^{-1} + \left(\frac{\alpha'_K(r)}{\alpha_K(r)} - \frac{c}{r_c}\right)\right\}^{-1} \qquad (4)$$

To increase absorption in the center of the target Golden nano-shells are imbedded in the fuel pellet so that the absorption coefficient is linearly changing with the radius. In the center, $r = 0$, $\alpha_K = 30$ cm^{-1}, while at the outside edge $\alpha_K = 8$ cm^{-1}.

Discussion

Numerical solution of the model for rapid ignition



Temperature distribution in function of r and t, dotted line is the light cone. The absorption coefficient is linearly changing with the radius. In the center, $r = 0$, $\alpha_K = 30$ cm^{-1} while at the outside edge $\alpha_K = 8$ cm^{-1}. Temperature is in units of $T_1 = H \cdot R = 272\,$keV, and $T_n = n \cdot T_1$. The stars on the temperature contour lines indicate the transition from space-like front at the outside edge to time-like front in the middle.

- In this model estimate, we have **neglected** the **compression** of the *target solid fuel ball*, **as well as** the **reflectivity** of the *target* matter.
- The relatively **small absorptivity** made it possible that the **radiation could penetrate** the whole target.
- The **characteristic temperature** was $T_1 = 272\,$keV, below that the **ignition** surface is **time-like hyper-surface**, where **instabilities cannot occur**.
- The detonation at a higher critical temperatures, $T_c > T_3$ occurs after the radiation reaches from the other side.

Conclusion It is important to use the proper relativistic treatment to optimize the fastest, more complete ignition, with the least possibility of instabilities.