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The shift to HTS magnets for compact fusion reactors: modelling needs and numerical tools

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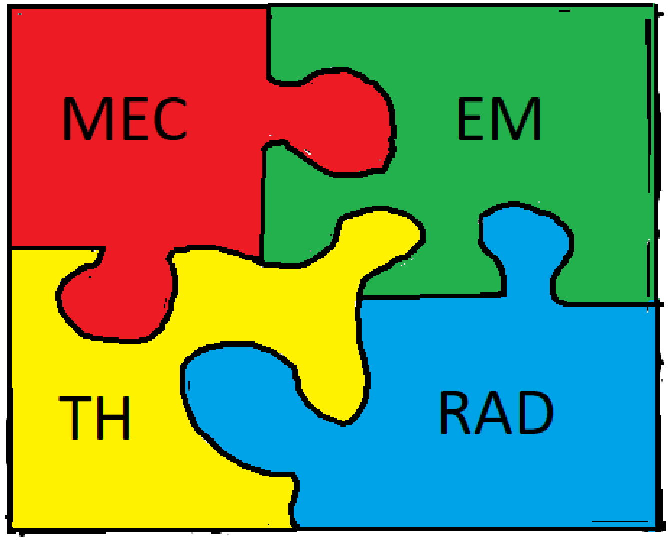
HTS magnets for fusion: key facts (I)

New paradigms are emerging for HTS fusion magnets:

- Increasing **operating temperatures** (≥ 20 K):
    1) higher **energy efficiency**
    2) different **material properties** (higher heat capacity of solids, lower cryogen inventory)
- **Cable-in-Conduit** and forced flow concepts (as for LTS magnets), but also
- **Non-insulated** or **partially-insulated coil** layouts gaining relevance

HTS magnets for fusion: key facts (II)

- Several **new challenges cannot be ignored** in the behaviour (→ modelling → design) of the future HTS magnets:



Do the new challenges push to an EVOLUTION or to a REVOLUTION in the magnet design?

L. Savoldi et al., IREF 2023

Here:

- Identify the **characteristics times** of the main phenomena occurring during transition to the normal state in the case of HTS-CICC
- Highlight **main modeling challenges**

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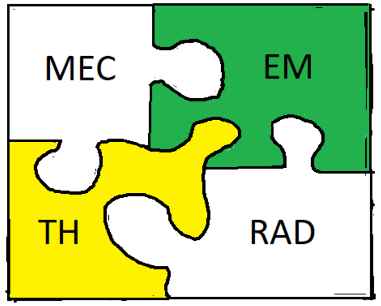
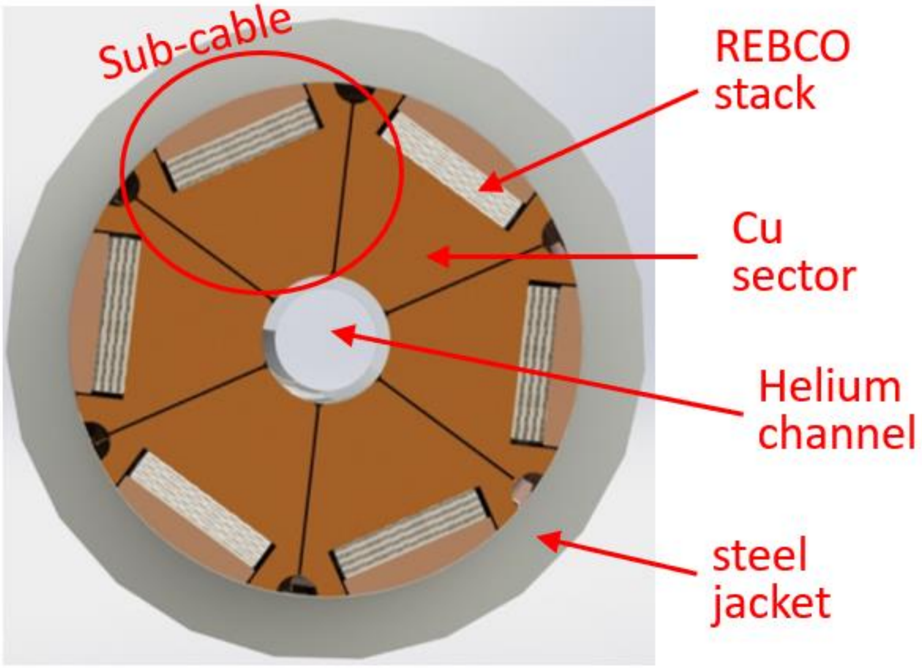
Relevant characteristics times for a HTS forced-flow CICC - I



SECtor-ASsembled (SECAS) conductor based on BRAided STacks (BRAST)

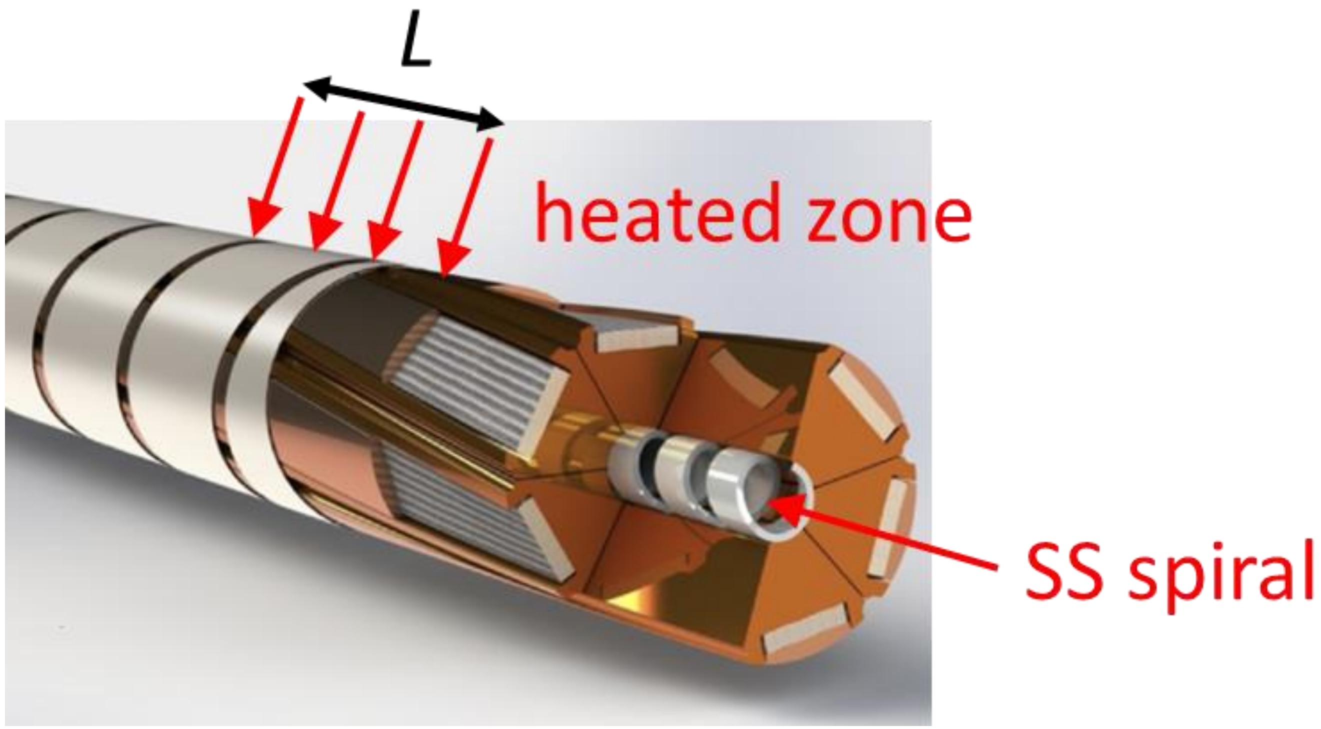


- A range of the **characteristics times** useful for stability studies in CICCs was previously identified for LTS cables [*]
- Here: identification of the **electrical, thermal, hydraulic characteristics times** for the SECAS HTS fusion conductors
- **Computations** both at 4.5 K and at 20 K.
- **Magnetic field** from 1 T to 13 T, **RRR in the Cu sector** from 100 to 300, **RRR in the REBCO tape Cu stabilizer** from 20 to 30.

[*] L. Bottura, *Physica C*, 310, pp. 316–326, 1998

Relevant characteristics times for a HTS forced-flow CICC - II

SECtor-ASsembled (SECAS) conductor based on BRAided STacks (BRAST)

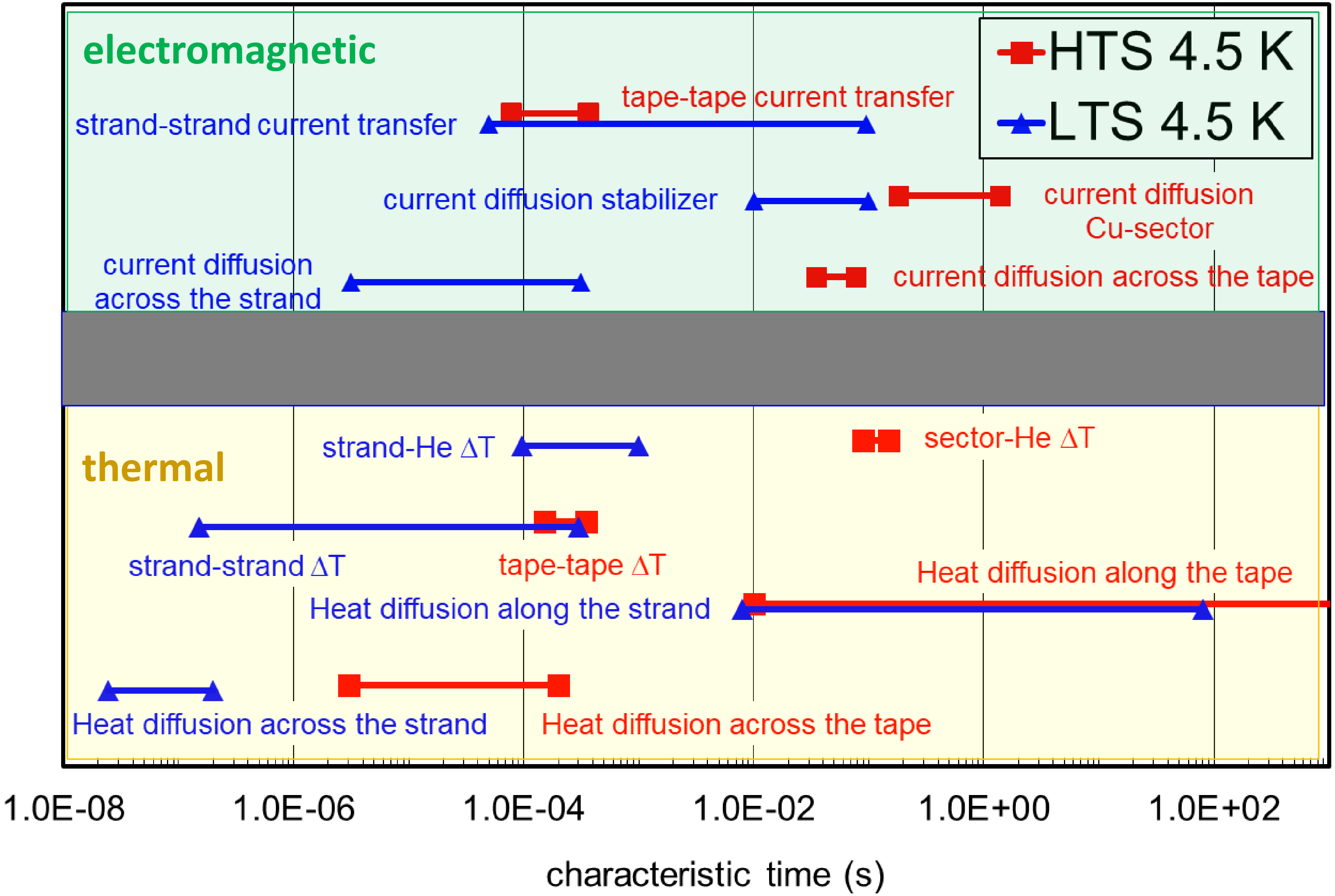


- Electrical and thermal **contact resistances** varied in a range of measured values
- A heated region of **length *L*** is considered for the calculation of the time constants.
- $L \sim 0.1$ m

Measurements of $R_{contact}$ ongoing by E. Tamagnini in collaboration with the team @Fermi Lab

LTS vs HTS characteristic times

- The characteristic electric and thermal timescales of the HTS conductor are generally greater than the corresponding ones of the LTS conductor



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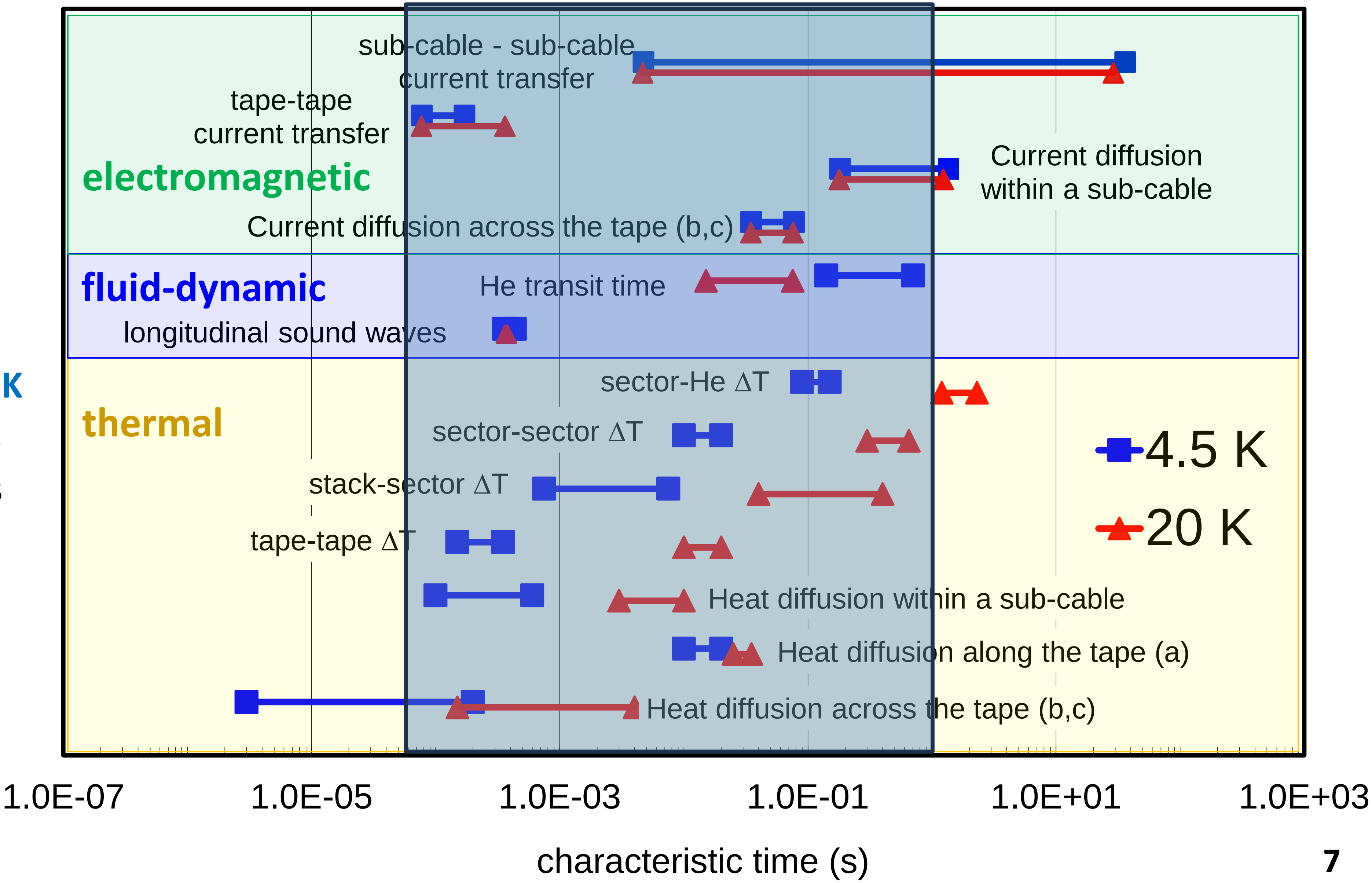
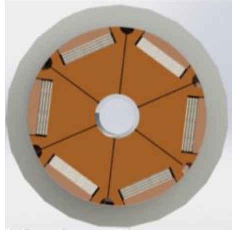
Relevant characteristics times (HTS): summary (*)

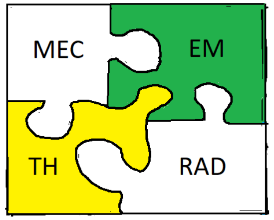
[*] M. Breschi et al, *submitted to IEEE Trans. Appl. Supercond., 2024*

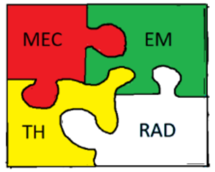
- No impact of temperature on electromagnetic time constants
- He transit time becomes faster at **20 K**
- At **20 K** characteristics times for heat diffusion become **larger than at 4.5 K**
- In the region from 10^{-4} s to 1 s the characteristic times of thermal, electrical and hydraulic phenomena are similar → **coupling between physics is required**

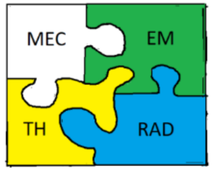


Modeling challenges

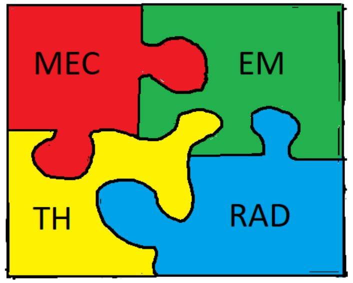
- For  : multi-physic models including
  - EM: Strong anisotropy of HTS tapes
  - TH: Suitability of lumped thermal modelling?
  - MEC: Stress management at tape level
  - RAD: damage to be assessed at tape level, heat deposition @ coil level
  - ***TOOLS?***







- For non-insulated or partially-insulated coils:
  - MEC+RAD at tape level, influencing electrical and thermal behavior
  - EM: current distribution on larger/longer spatial/time scales
  - T(H) at coil level (conduction cooling)
  - ***TOOLS?***



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Thank you for your kind attention !

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