# NEW BOUNDS ON LIGHT MILLICHARGED PARTICLES FROM THE TIP OF THE RED-GIANT BRANCH

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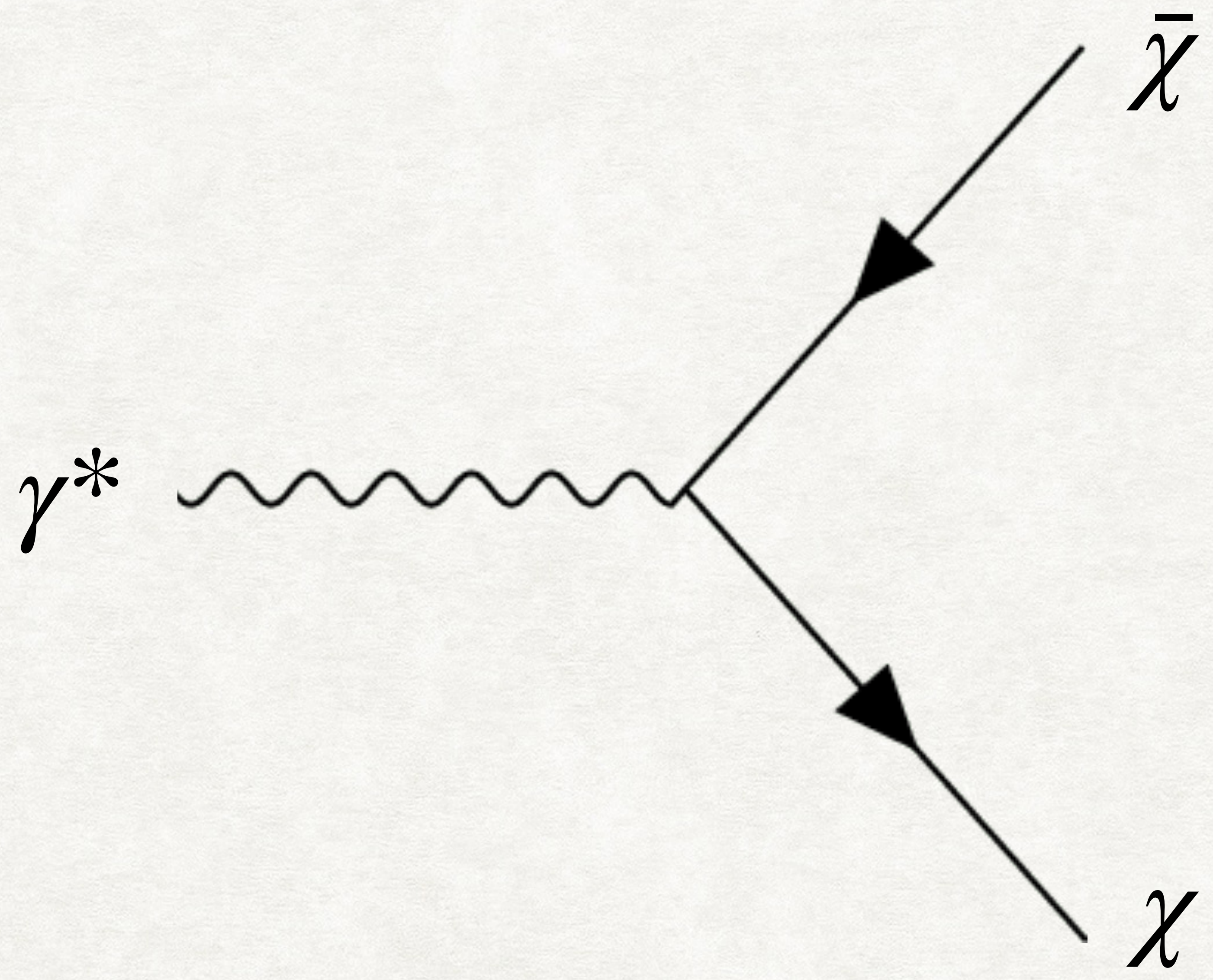
TEVPA 2023, NAPOLI

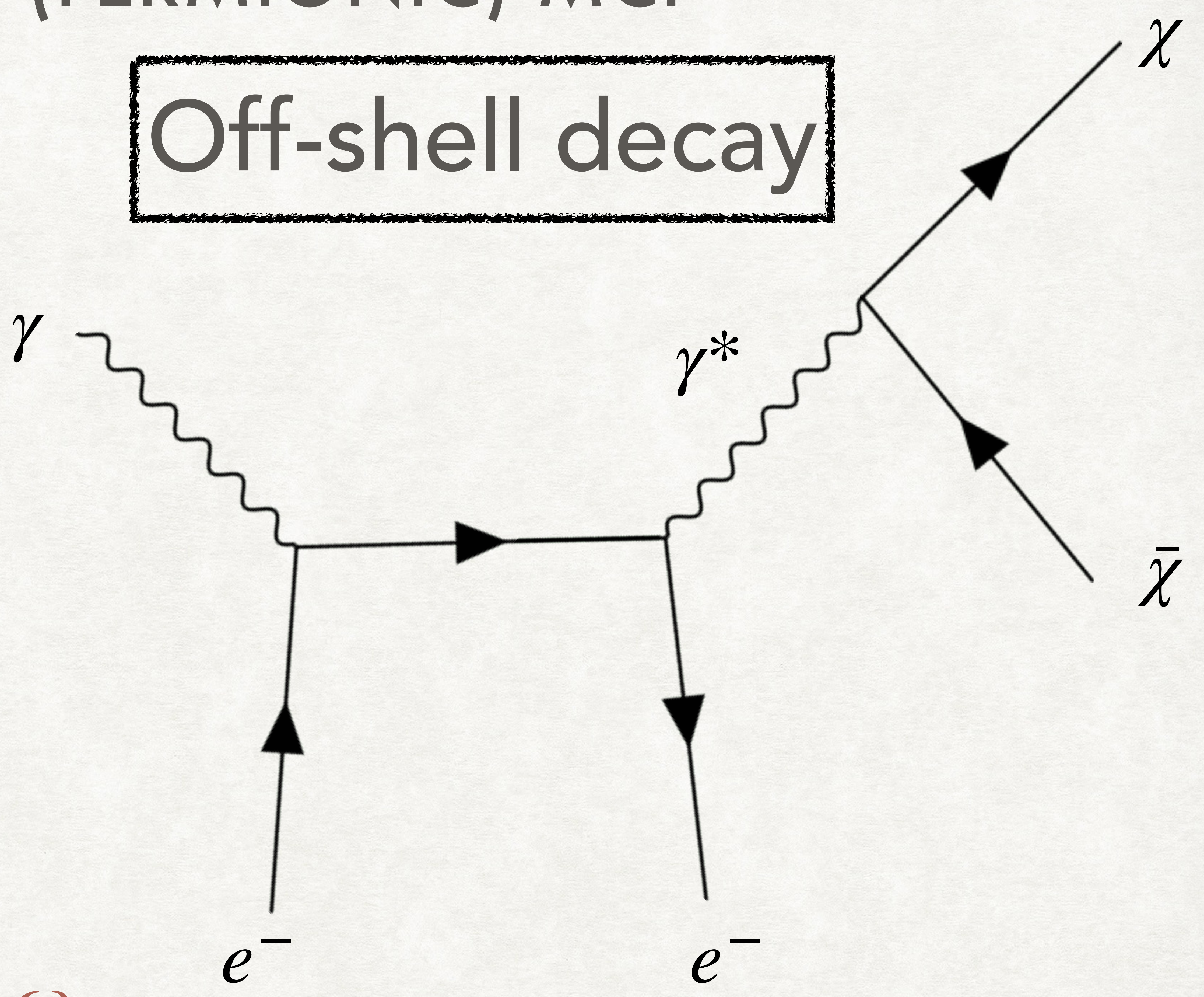
BASED ON ARXIV:2309.06465

# I. PLASMON DECAY → (FERMIONIC) MCP

**On-shell decay**



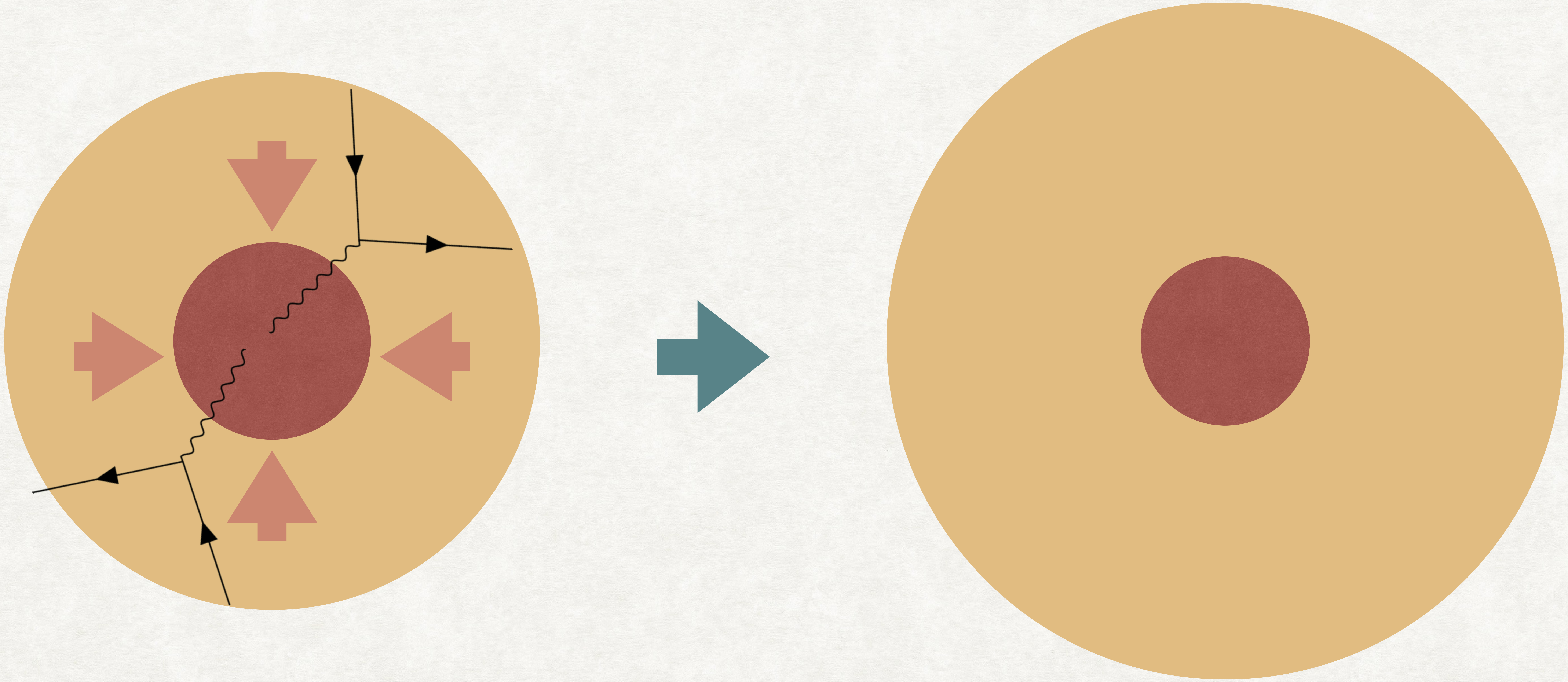

**Off-shell decay**




**longitudinal:** $\omega_L = \omega_p$

**Transverse:** $\omega_T^2 = k^2 + \omega_p^2$

# I. PRODUCTION OF MCPS IN STARS



# I. ASSUMPTIONS MADE IN THE LITERATURE

1. only transverse plasmon was considered

∴ we included longitudinal plasmon

+ a more proper treatment of the off-shell decay rate

2. Constant temperature and plasma frequency over the entire star and throughout the lifetime of the star

3. MCP rate = rescaled neutrino rates

∴ we ran simulations to properly quantify the effect

# II. TRGB IN GLOBULAR CLUSTERS

## WHY GLOBULAR CLUSTERS?

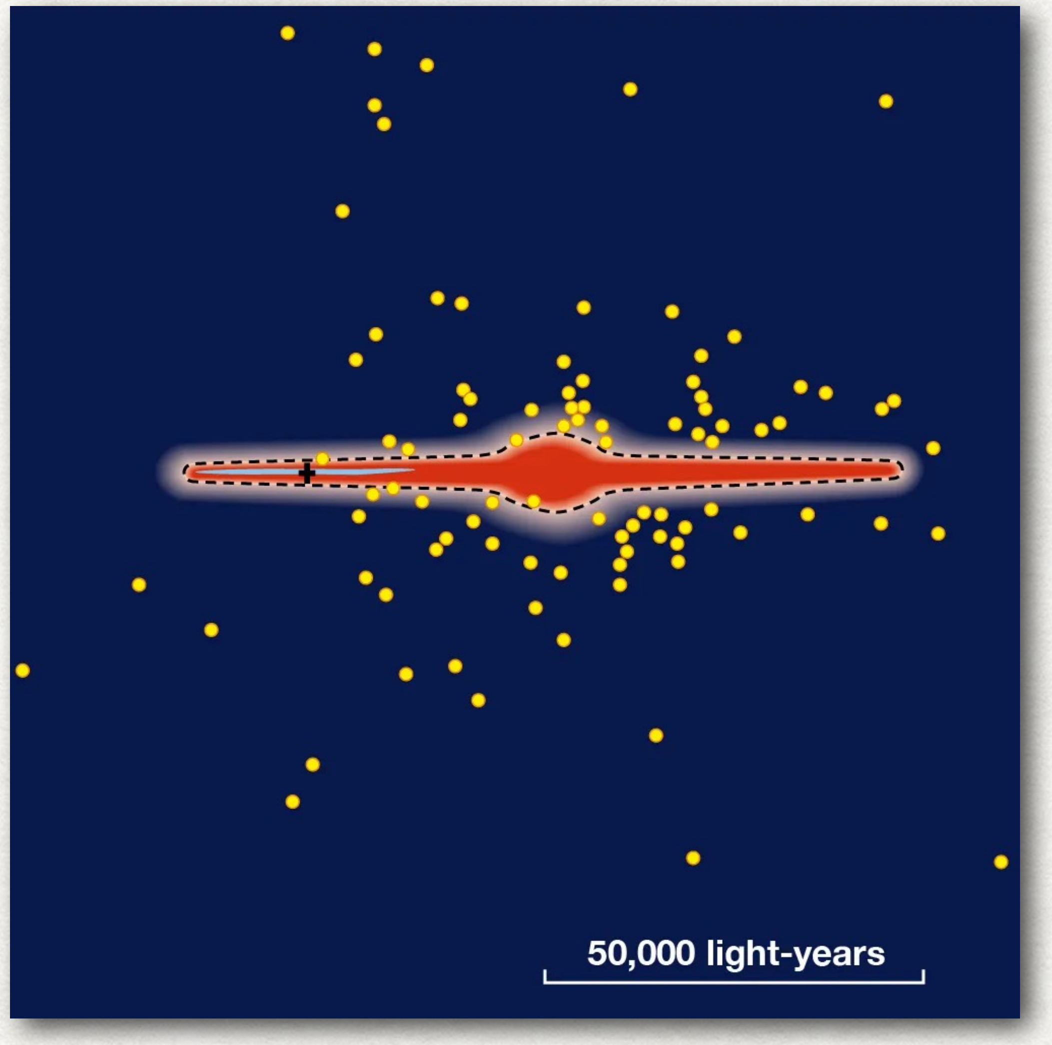
- globular clusters are old - only stars that remain are the low mass ones

∴ stellar mass ✗

- globular clusters contain coeval stars - metallicities are the same

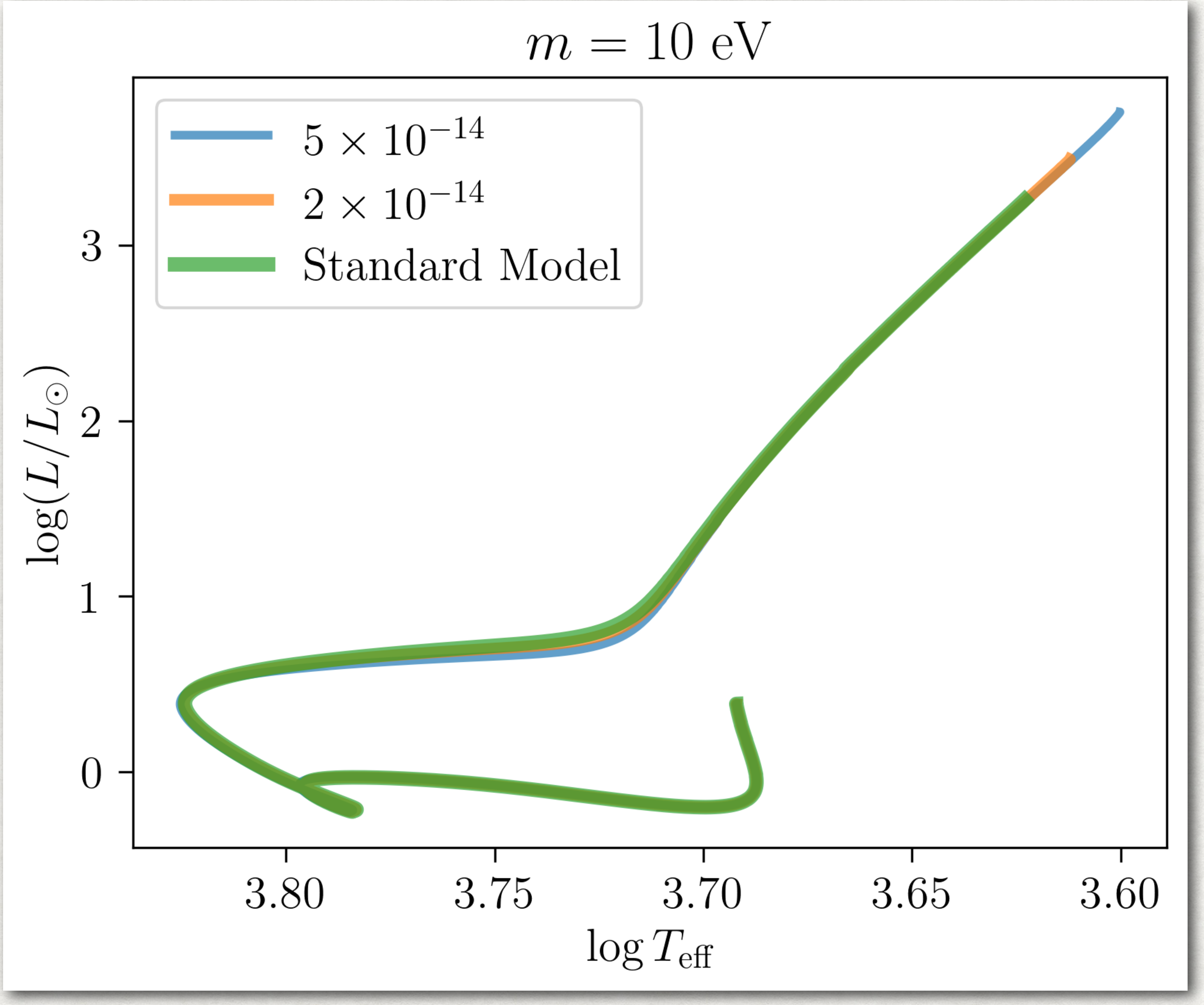
∴ metallicities, age ✗

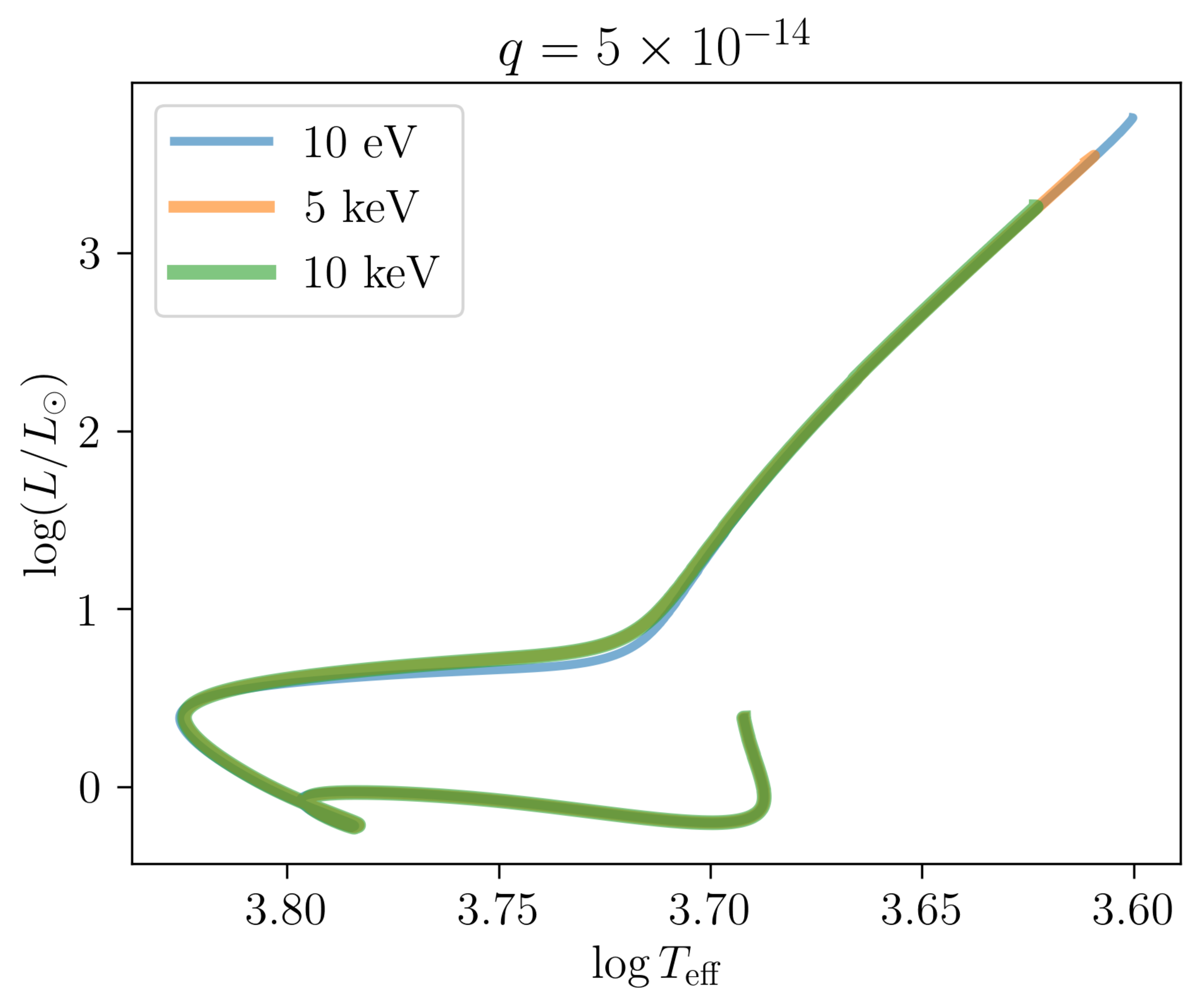
https://www.eso.org/public/images/eso0844a/



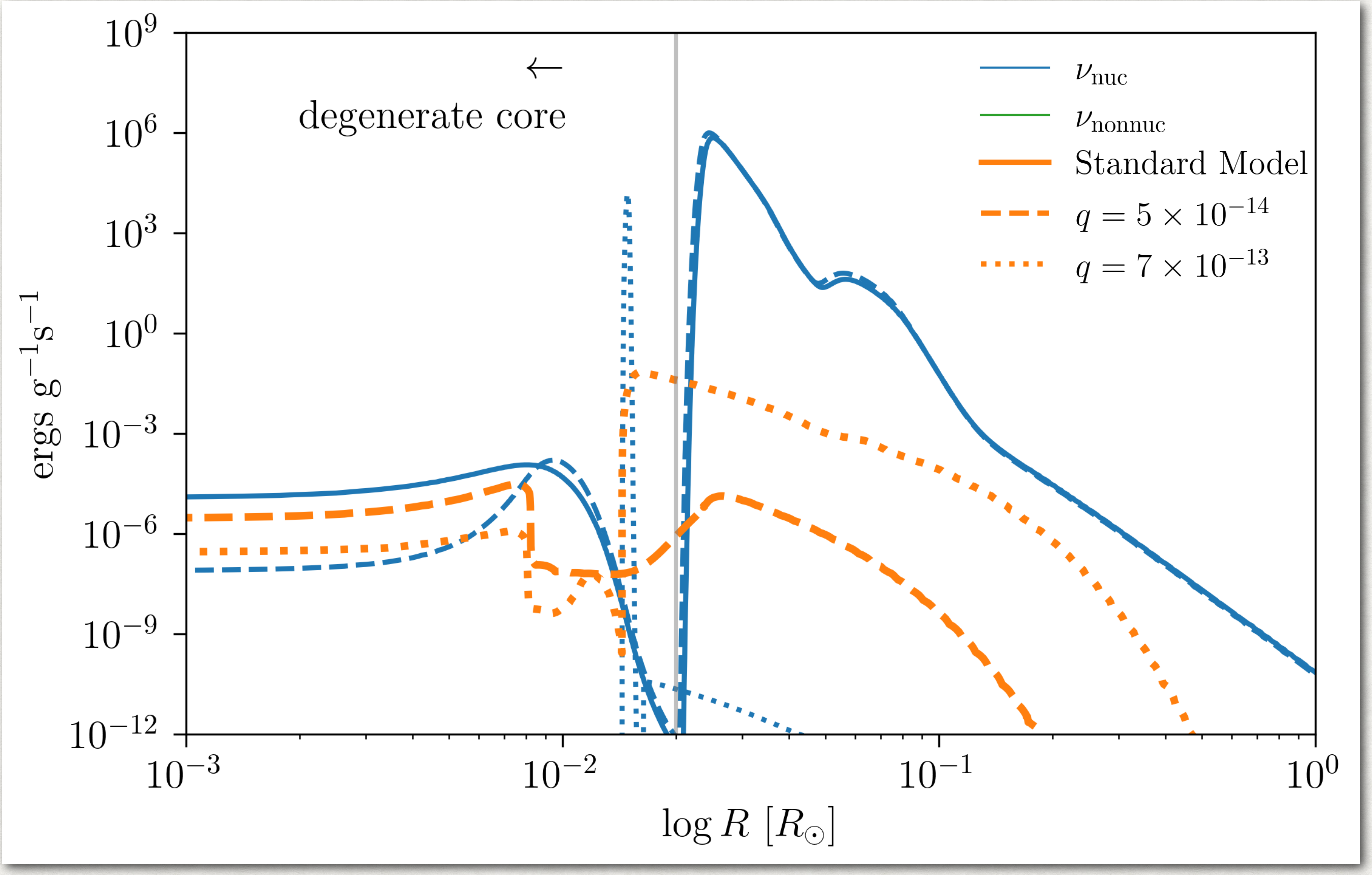

https://www.britannica.com/science/globular-cluster#/media/1/235470/3648

# III. MCPS INCREASE TRGB BRIGHTNESS



# III. ENERGY PROFILE AT HE FLASH



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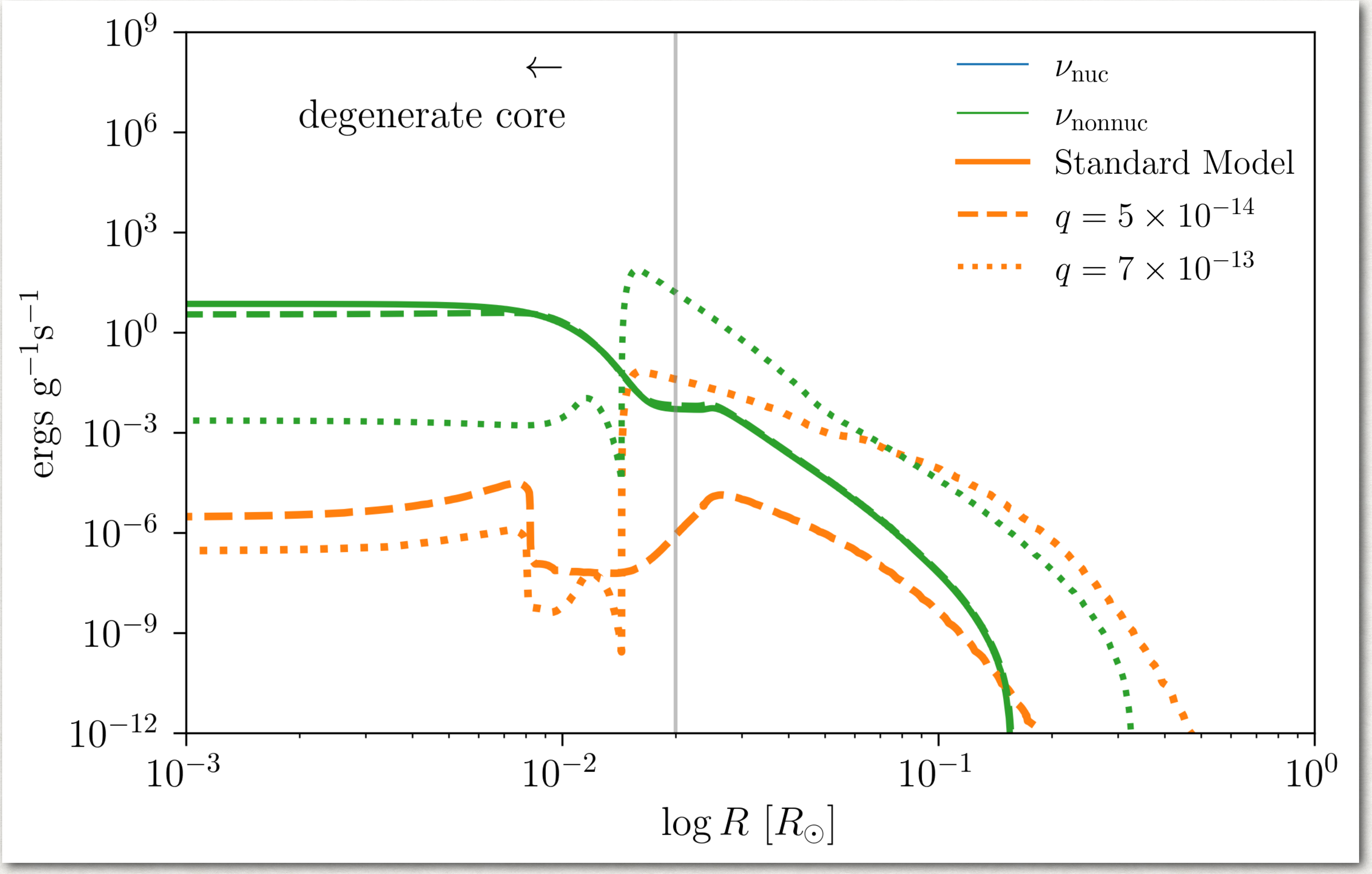
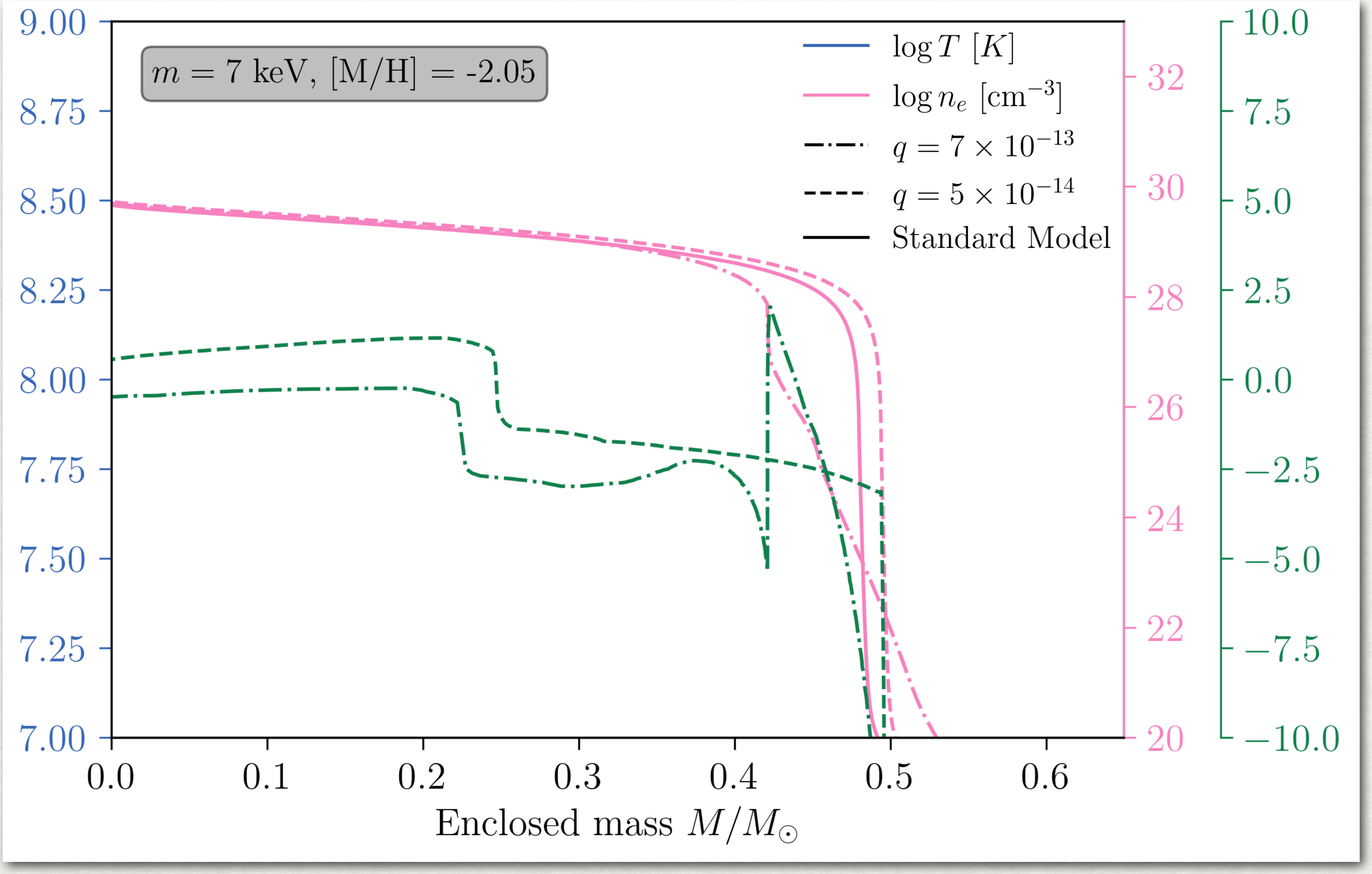


# III. MCP CHANGES STELLAR STRUCTURE

## $0.8 M_\odot$ AT HE FLASH



# III. OBSERVATION DATA

- Straniero, O et al. (2020) obtained photometric data from HST and ground-based optical measurements

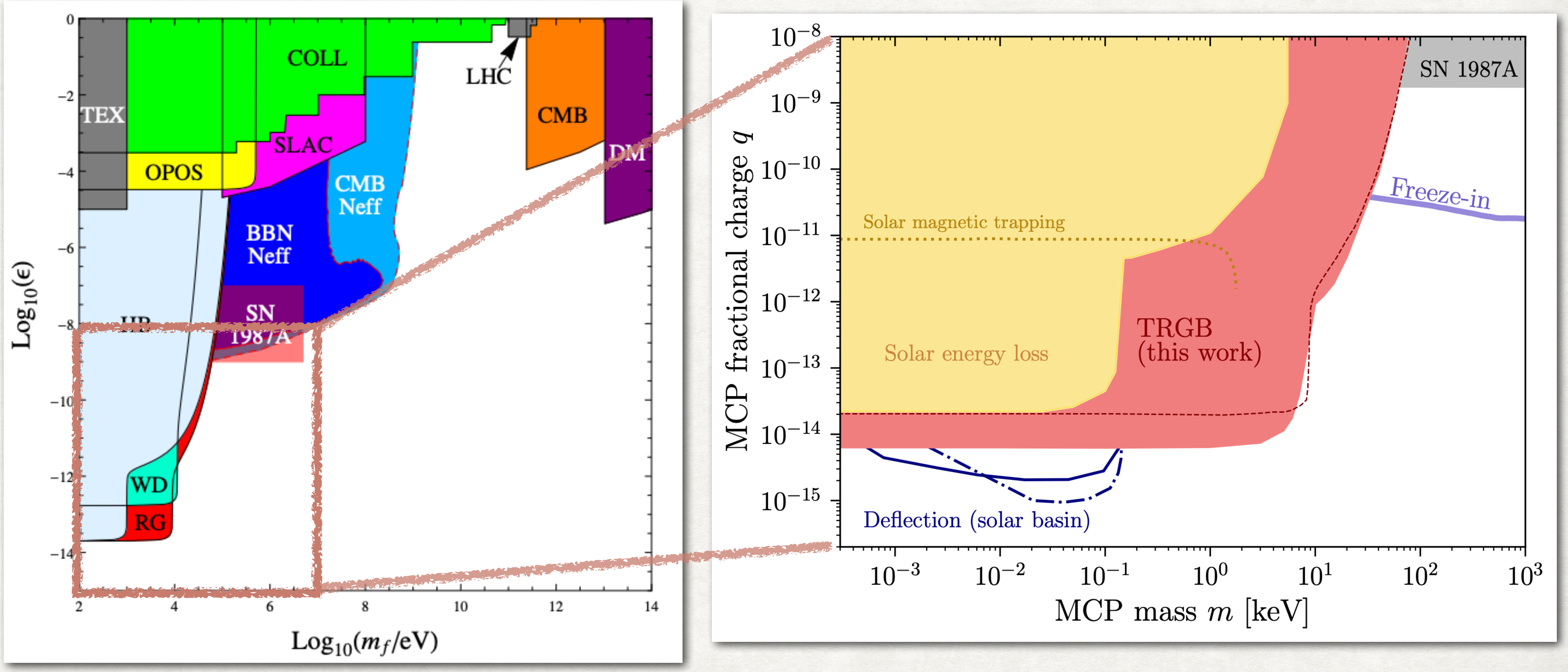
- parallax measurments of 15 globular clusters

- avoided ZAHB

**Table 6.** RGB tip bolometric magnitudes as obtained under different assumtion for the distance scale.

| | [M/H] | m-M (ZAHB) | m-M (CH2018) | m-M (B2019) | $M_{bol}$ (ZAHB) | $M_{bol}$ (CH2018) | $M_{bol}$ (B2019) |
|---|---|---|---|---|---|---|---|
| | | | | near-IR photometry | | | |
| M92 | −2.05 ± 0.20 | 14.76 ± 0.20 | | 14.64 ± 0.08 | −3.63 ± 0.25 | | −3.51 ± 0.16 |
| M15 | −2.03 ± 0.20 | 15.14 ± 0.20 | | 15.05 ± 0.03 | −3.53 ± 0.24 | | −3.44 ± 0.13 |
| M68 | −1.97 ± 0.20 | 15.14 ± 0.20 | | | −3.34 ± 0.32 | | |
| M30 | −2.03 ± 0.20 | 14.73 ± 0.20 | | 14.48 ± 0.24 | −3.65 ± 0.28 | | −3.41 ± 0.31 |
| M55 | −1.71 ± 0.20 | 13.84 ± 0.20 | | 13.63 ± 0.09 | −3.66 ± 0.25 | | −3.44 ± 0.18 |
| $\omega$ Cen | −1.42 ± 0.20 | 13.67 ± 0.20 | | 13.60 ± 0.02 | −3.59 ± 0.23 | | −3.52 ± 0.12 |
| NGC 6752 | −1.33 ± 0.20 | 13.17 ± 0.20 | | 13.15 ± 0.05 | −3.63 ± 0.25 | | −3.61 ± 0.16 |
| M13 | −1.36 ± 0.20 | 14.43 ± 0.20 | | 14.15 ± 0.10 | −3.56 ± 0.27 | | −3.28 ± 0.20 |
| M3 | −1.28 ± 0.20 | 15.02 ± 0.20 | | 14.88 ± 0.10 | −3.59 ± 0.24 | | −3.45 ± 0.17 |
| NGC 362 | −1.08 ± 0.20 | 14.64 ± 0.20 | 14.66 ± 0.12 | 14.82 ± 0.07 | −3.48 ± 0.24 | −3.50 ± 0.17 | −3.66 ± 0.14 |
| M5 | −1.11 ± 0.20 | 14.38 ± 0.20 | | 14.40 ± 0.04 | −3.60 ± 0.25 | | −3.61 ± 0.16 |
| NGC 288 | −1.10 ± 0.20 | 14.73 ± 0.20 | | 15.03 ± 0.07 | −3.77 ± 0.24 | | −4.07 ± 0.16 |
| M107 | −0.81 ± 0.20 | 13.94 ± 0.20 | | 13.86 ± 0.14 | −3.55 ± 0.32 | | −3.47 ± 0.28 |
| NGC 6380 | −0.29 ± 0.20 | 14.65 ± 0.20 | | | −3.97 ± 0.24 | | |
| NGC 6342 | −0.36 ± 0.20 | 14.54 ± 0.20 | | | −3.76 ± 0.27 | | |
| 47 Tuc | −0.55 ± 0.20 | 13.25 ± 0.20 | 13.24 ± 0.06 | 13.24 ± 0.02 | −3.78 ± 0.23 | −3.77 ± 0.13 | −3.77 ± 0.12 |
| M69 | −0.43 ± 0.20 | 14.59 ± 0.20 | | | −3.53 ± 0.24 | | |
| NGC 6441 | −0.32 ± 0.20 | 15.56 ± 0.20 | | 15.36 ± 0.03 | −3.96 ± 0.24 | | −3.77 ± 0.13 |
| NGC 6624 | −0.31 ± 0.20 | 14.55 ± 0.20 | | 14.21 ± 0.13 | −3.90 ± 0.26 | | −3.56 ± 0.21 |
| NGC 6440 | −0.15 ± 0.20 | 14.37 ± 0.20 | | | −4.00 ± 0.24 | | |
| NGC 6553 | −0.12 ± 0.20 | 13.36 ± 0.20 | | 14.19 ± 0.08 | −3.93 ± 0.25 | | −4.76 ± 0.17 |
| NGC 6528 | 0.07 ± 0.20 | 14.24 ± 0.20 | | | −4.07 ± 0.24 | | |
| | | | | VI photometry | | | |
| NGC 362 | −1.08 ± 0.20 | 14.64 ± 0.20 | 14.66 ± 0.12 | 14.82 ± 0.07 | −3.51 ± 0.26 | −3.53 ± 0.21 | −3.69 ± 0.17 |
| M5 | −1.11 ± 0.20 | 14.38 ± 0.20 | | 14.40 ± 0.04 | −3.63 ± 0.26 | | −3.64 ± 0.18 |
| 47 Tuc | −0.55 ± 0.20 | 13.25 ± 0.20 | 13.24 ± 0.06 | 13.24 ± 0.02 | −3.80 ± 0.26 | −3.79 ± 0.17 | −3.79 ± 0.16 |

# III. CONSTRAINTS ON MILLICHARGED PARTICLES




Hendrik Vogel and Javier Redondo, "Dark Radiation constraints on minicharged particles in models with a hidden photon," JCAP 02, 029 (2014), arXiv:1311.2600 [hep-ph].

# IV. CLOSING REMARKS

- Longitudinal + transverse + on-shell + off-shell ✅
- MCPs change the stellar structure ✅
- Simulation is the most precise way to quantify the impact of MCPs ✅
- Using parallax data, we obtained new bounds ✨🎉

- Future work 1: scalar MCPs 🔜
- Future work 2: MCPs in horziontal branch stars 🔜

# THANK YOU!

# EXTRA

# OUTLINE

I. Production of millicharged particles (MCP) in stars

II. Astrophysical sources

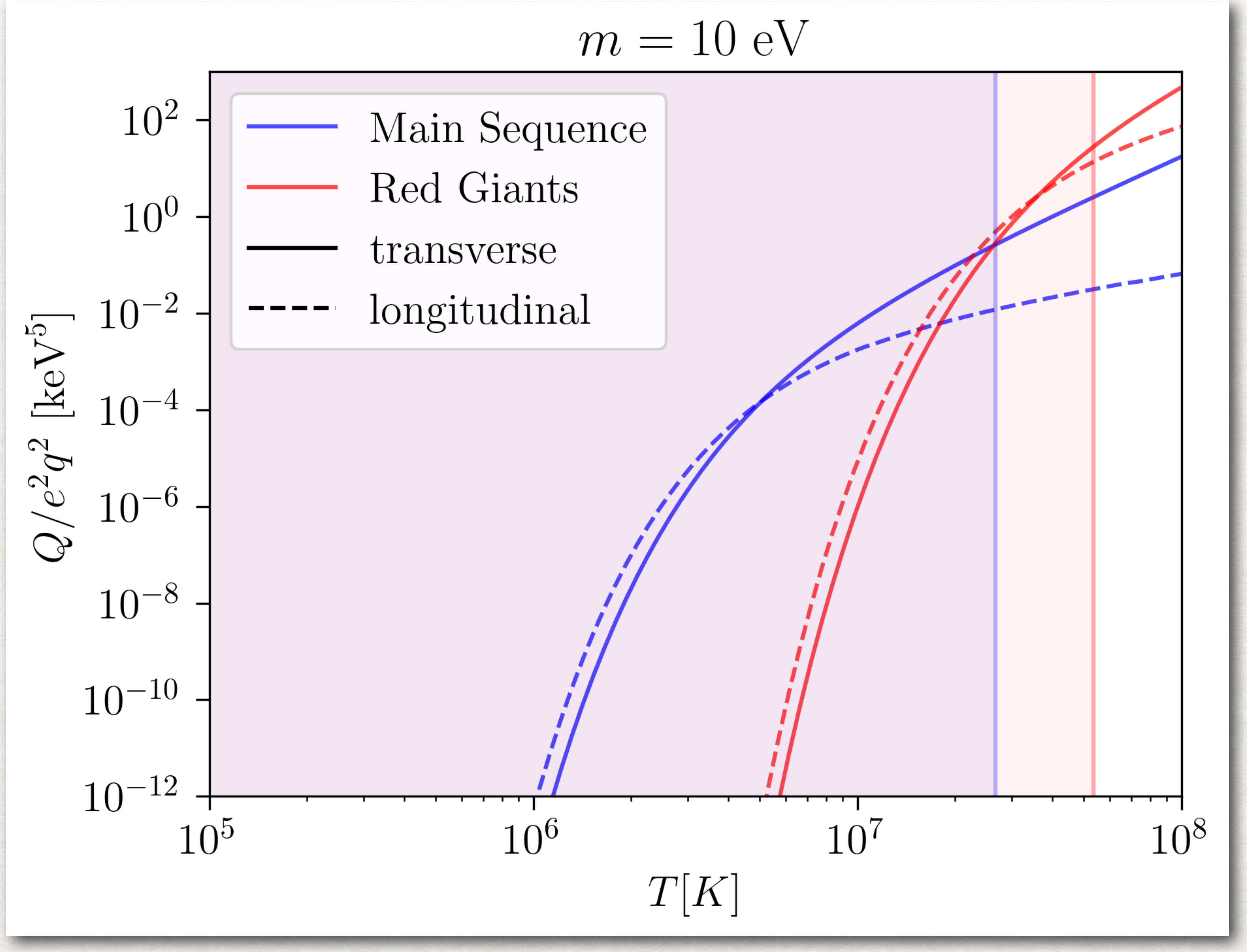
III. Red giants with extra energy loss

IV. Closing remarks

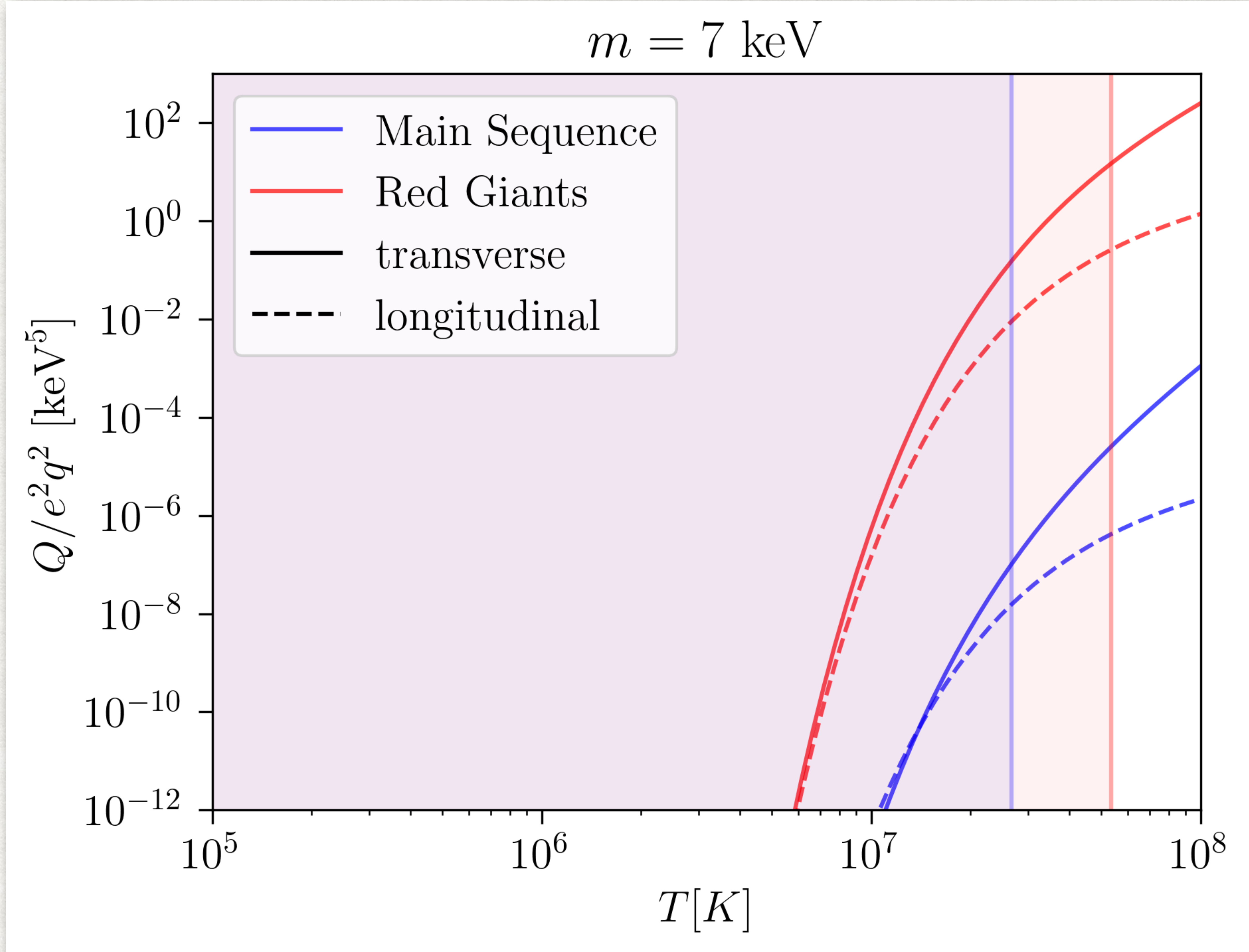
# I. DEPENDENCES OF EMISSION RATES ON STELLAR INTERIOR

## DONEC QUIS NUNC

- typical $\omega_p \sim \mathcal{O}(1)$ keV in MS




- typical $\omega_p \sim \mathcal{O}(10)$ keV in RG



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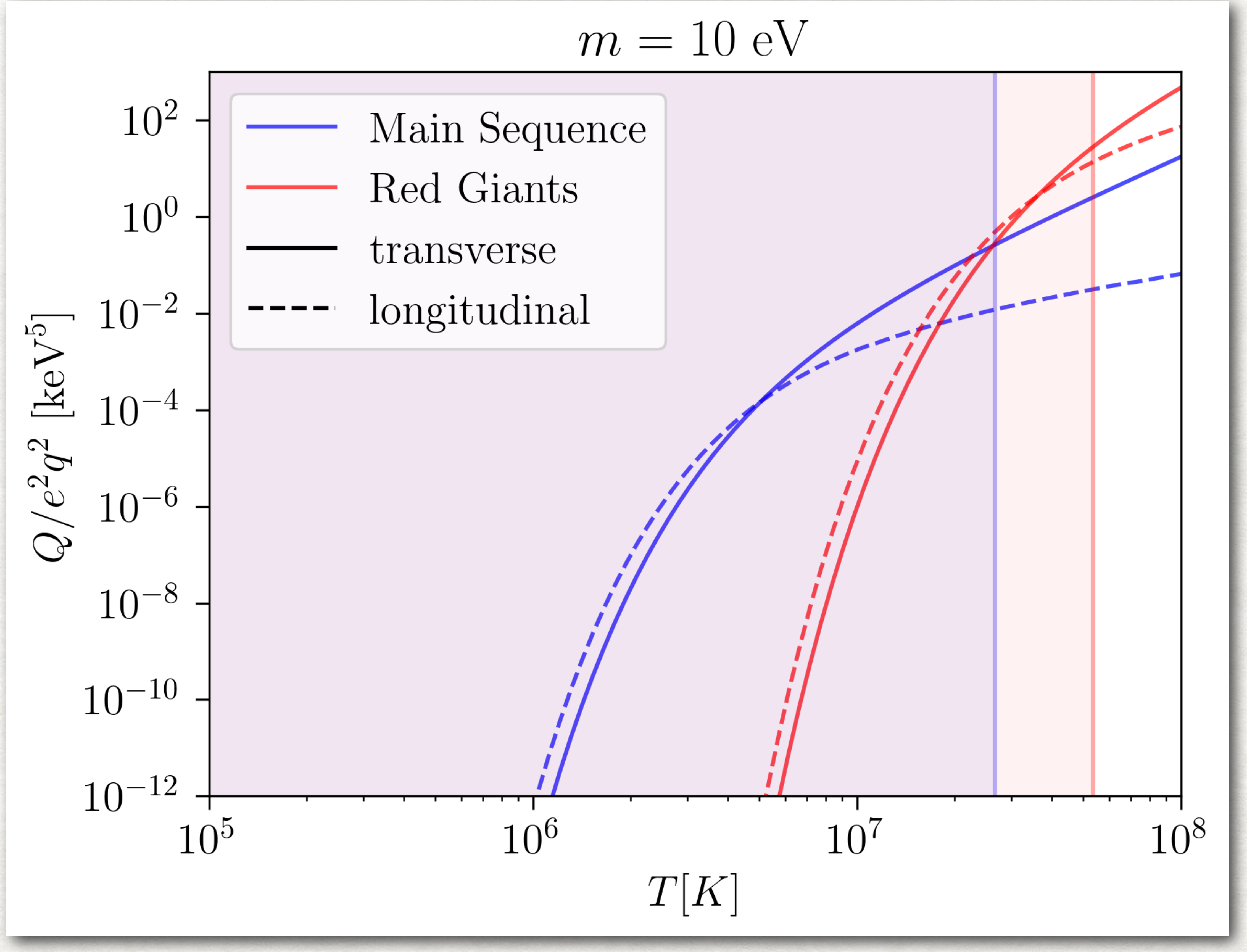
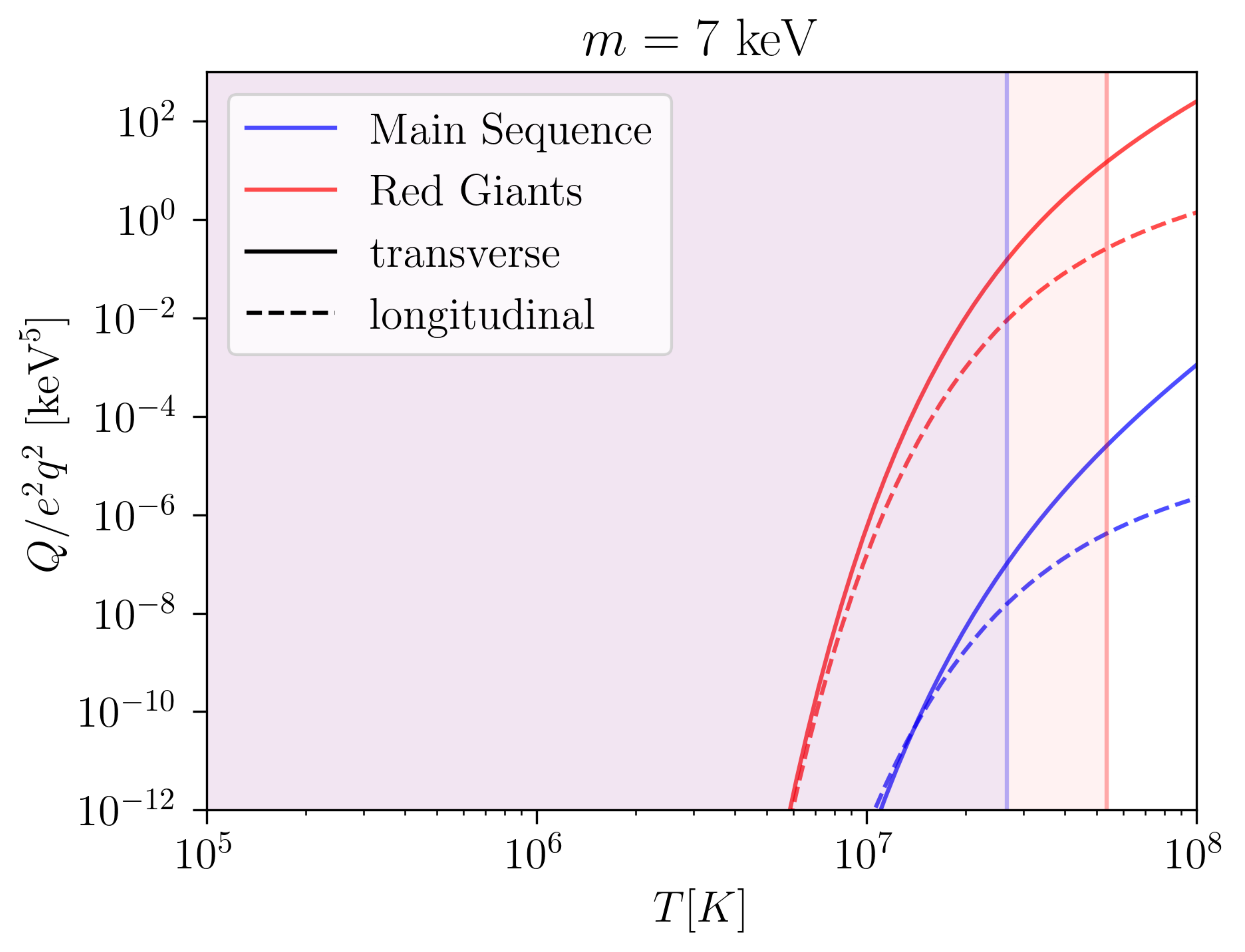


# I. DEPENDENCES OF EMISSION RATES ON STELLAR INTERIOR

## DONEC QUIS NUNC

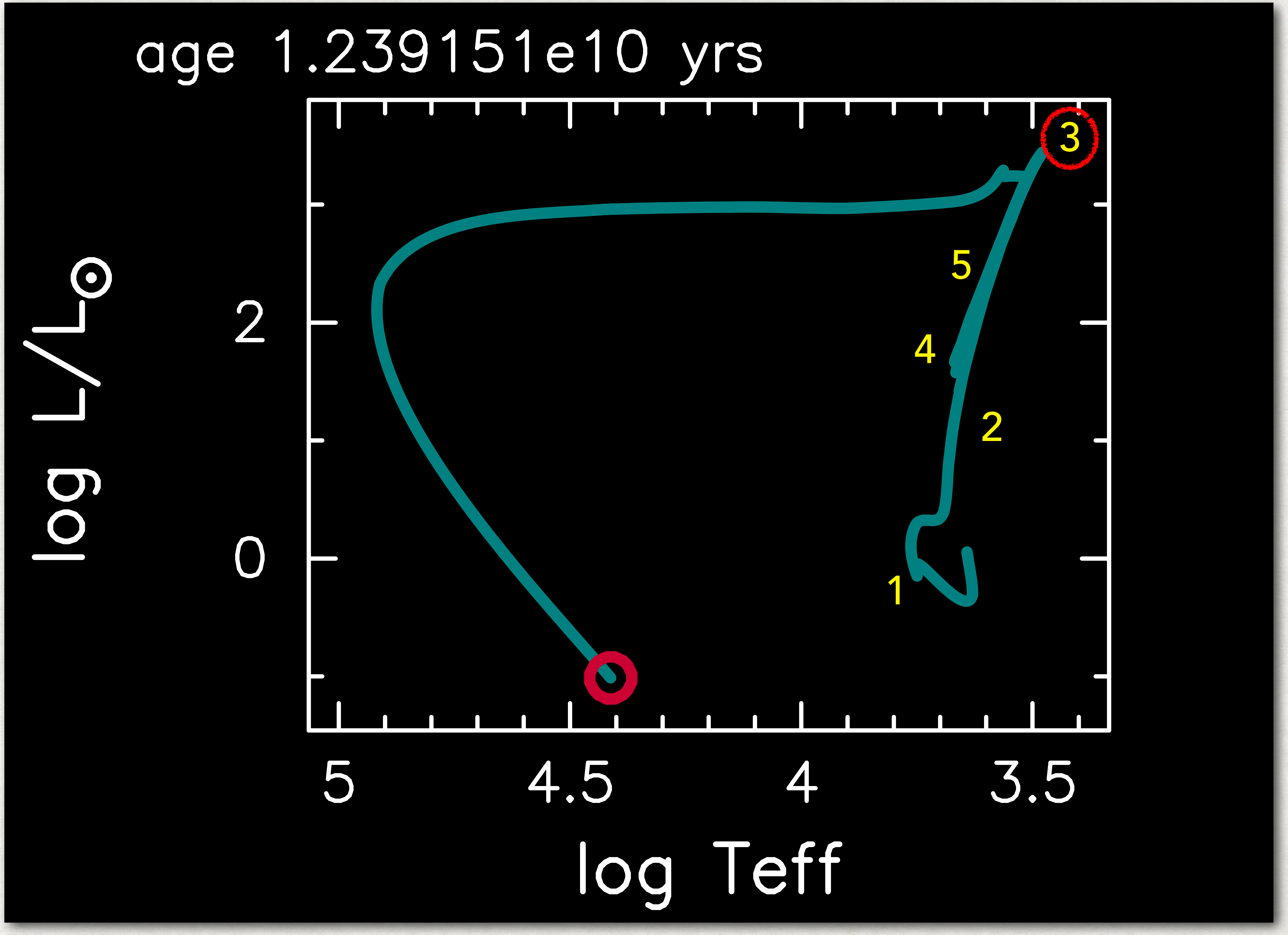
- typical $\omega_p \sim 0.01 - 1$ keV in MS

- typical $\omega_p \sim 0.1 - 10$ keV in MS



# II. STANDARD STELLAR EVOLUTION OF LOW MASS STARS

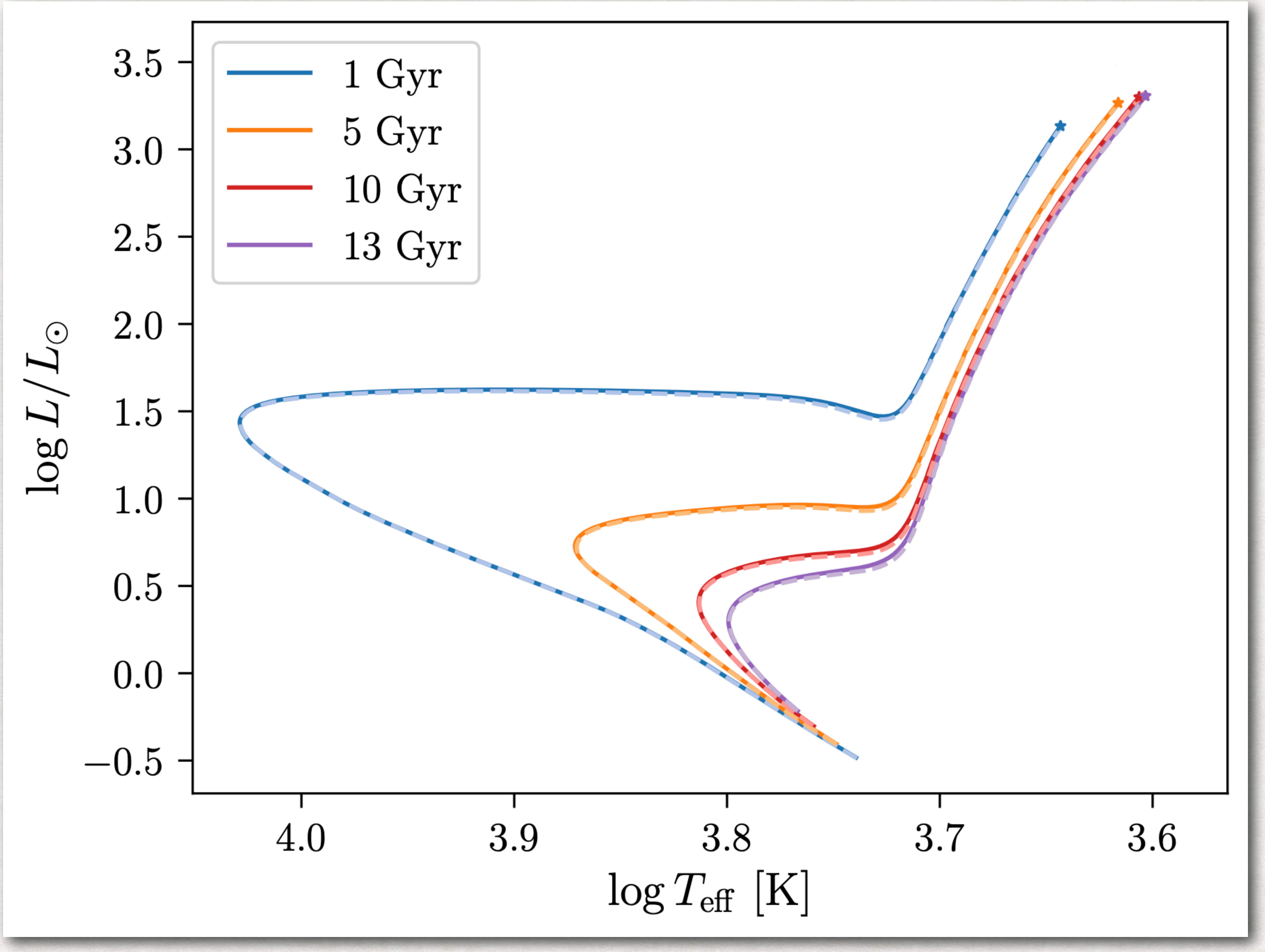
1. Main sequence - H core burning
2. Red giant branch - steady H shell burning
3. tip of the red giant (TRGB) - He flash
4. horizontal branch - He core burning
5. Asymptotic giant branch - He shell burning



# II. TRGB IN GLOBULAR CLUSTERS

## WHY TRGB?

- TRGB brightness only depends on the He core mass at the time of He ignition
- TRGBs are used as standard candles



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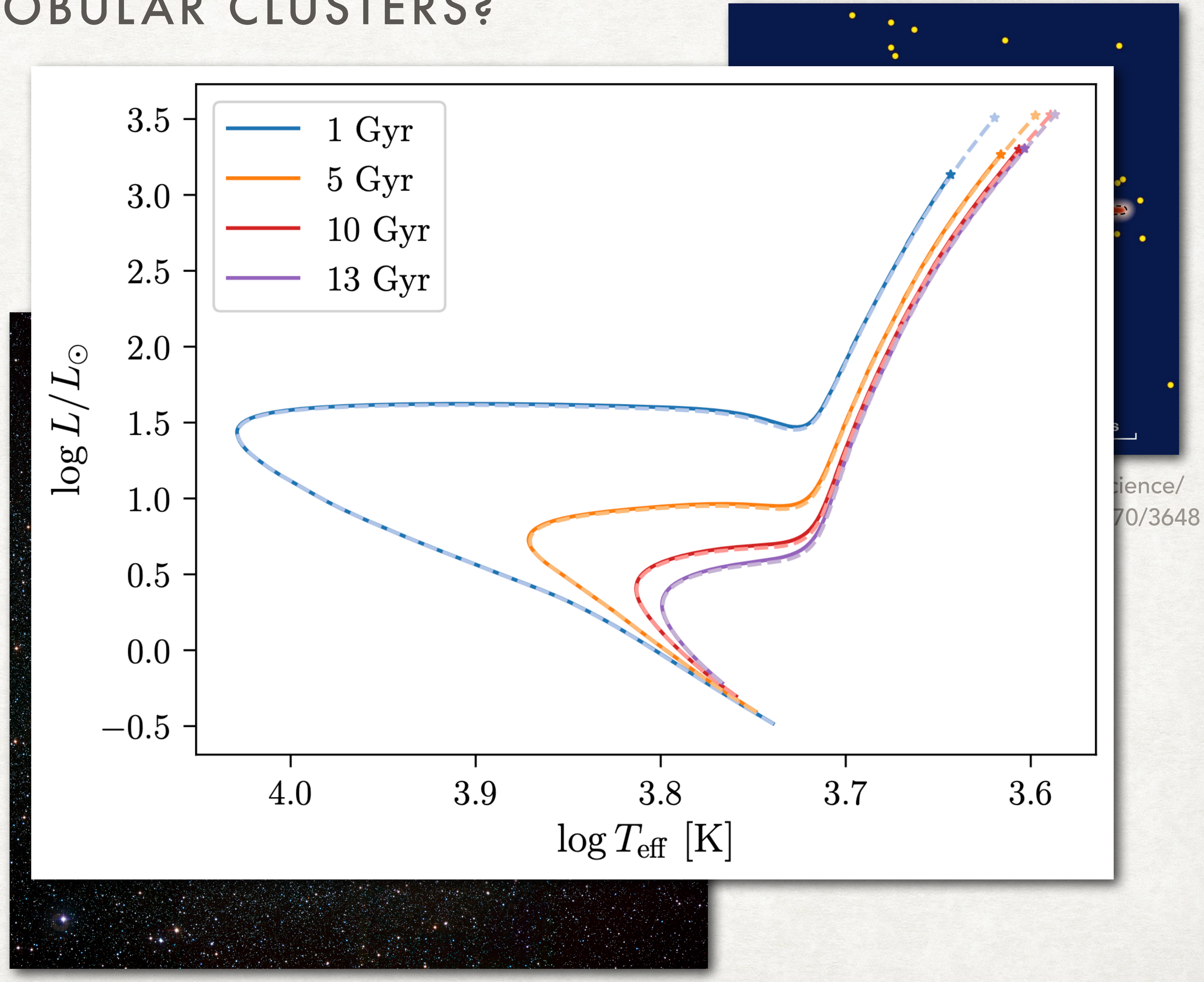


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https://www.eso.org/public/images/eso0844a/

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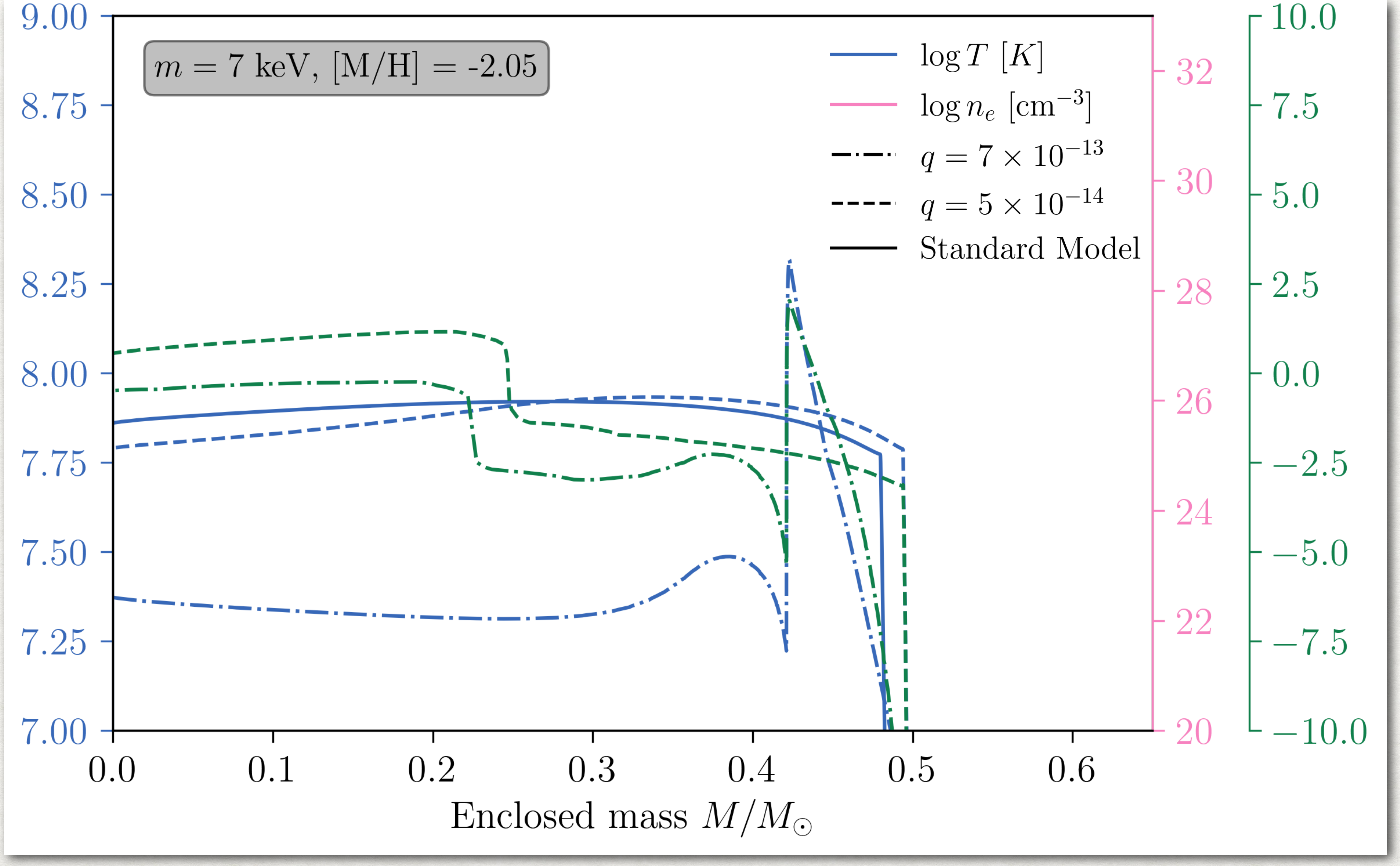

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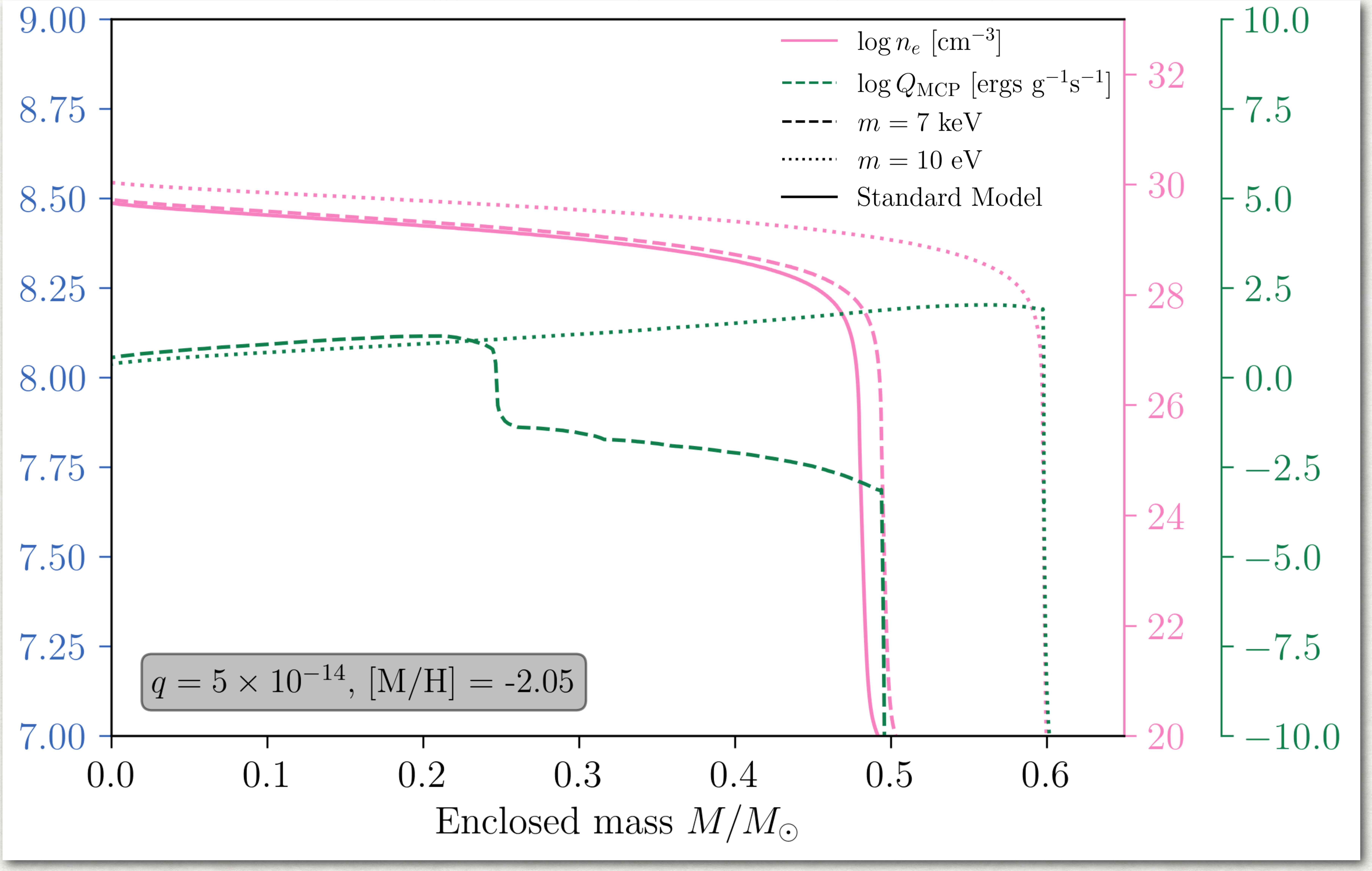

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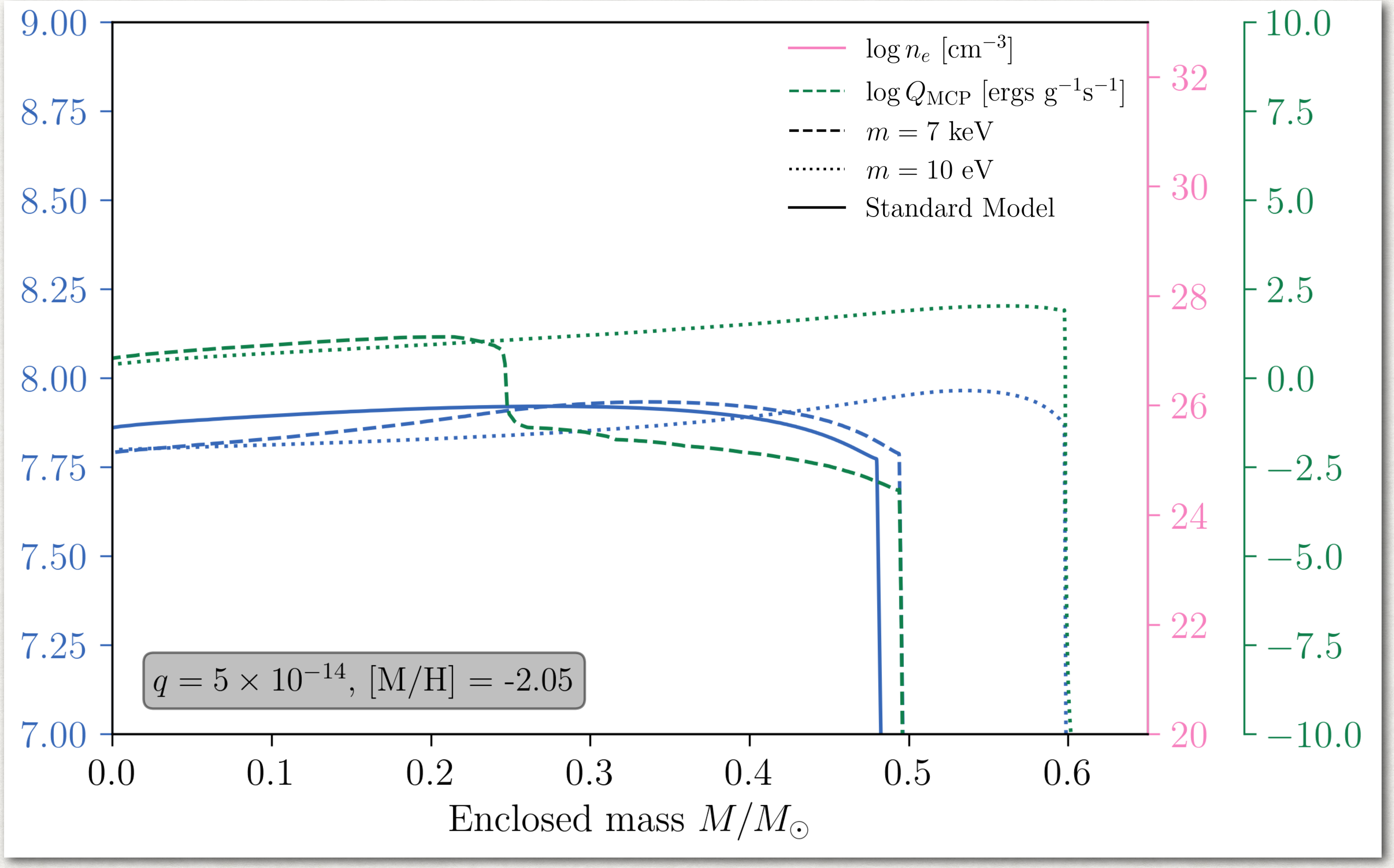

# III. MCPS CHANGE STELLAR STRUCTURE

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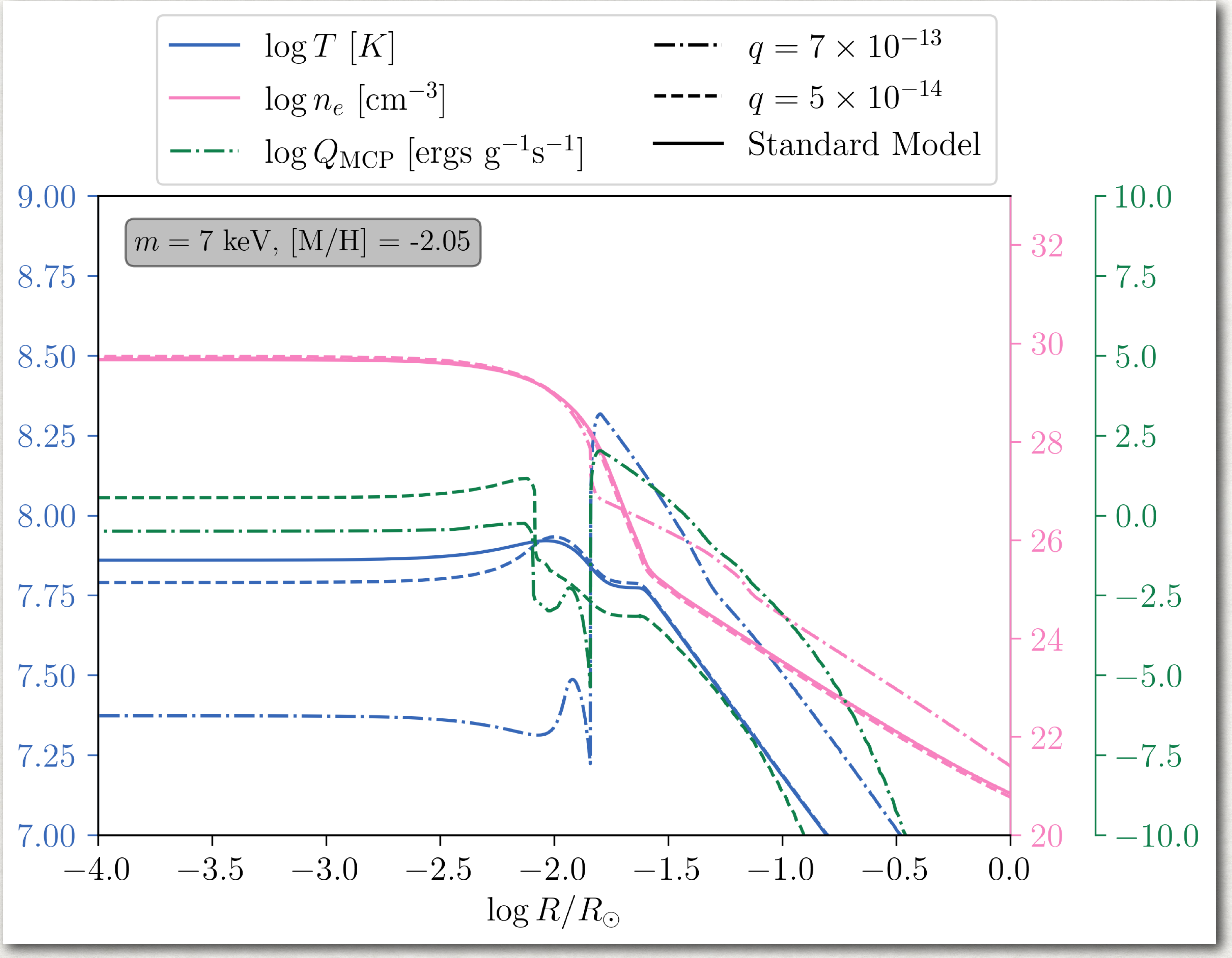

# III. MCPS CHANGE STELLAR STRUCTURE

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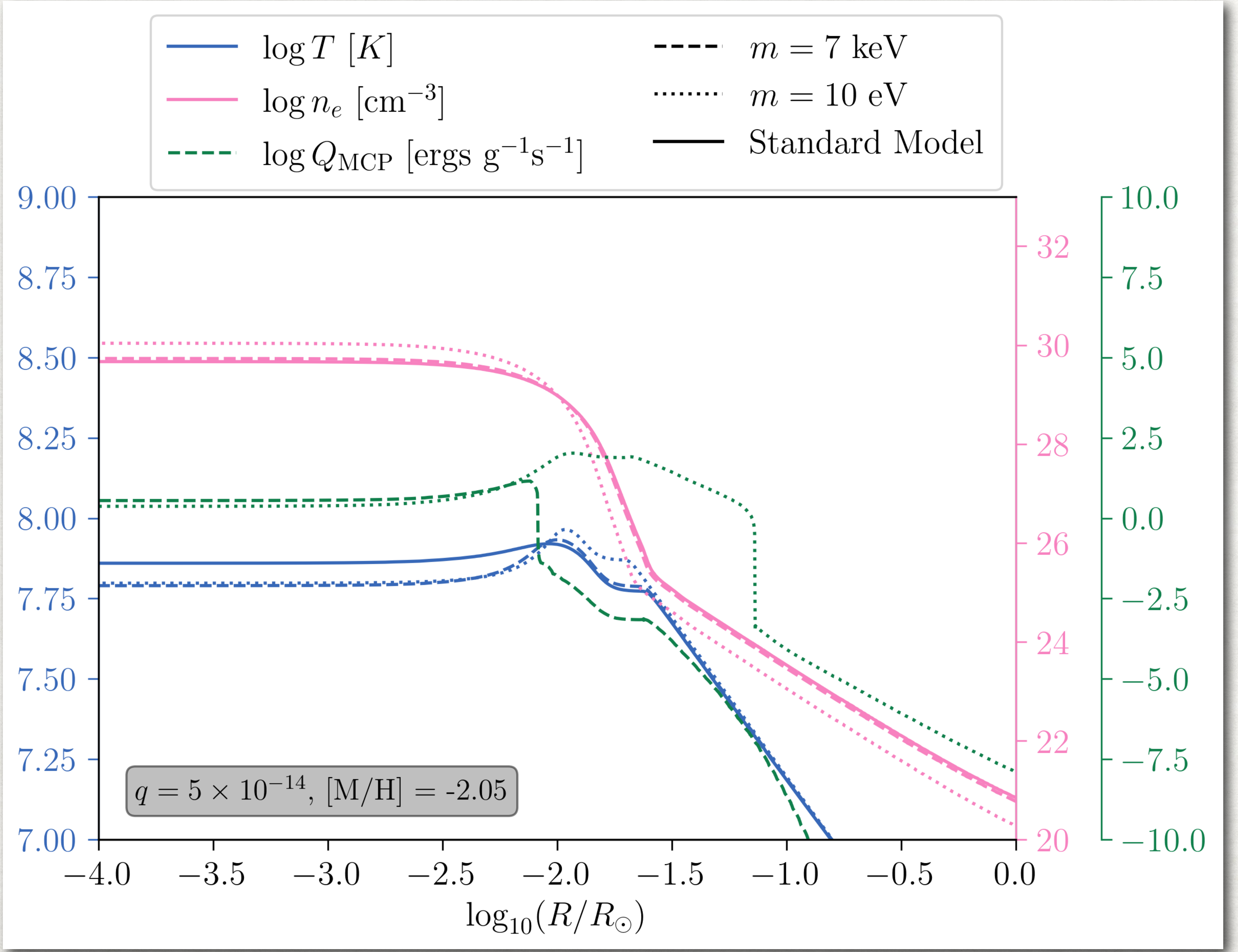

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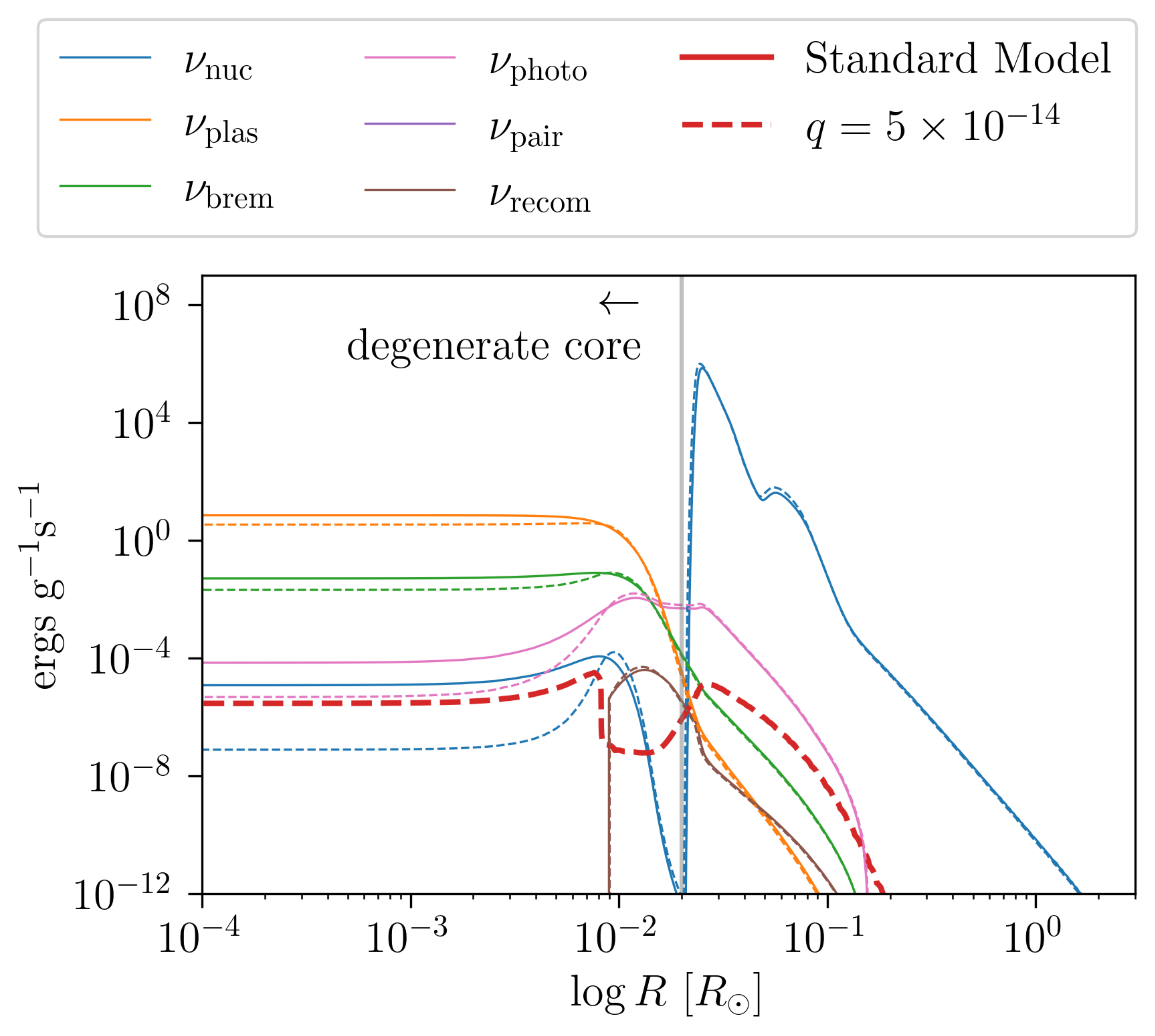

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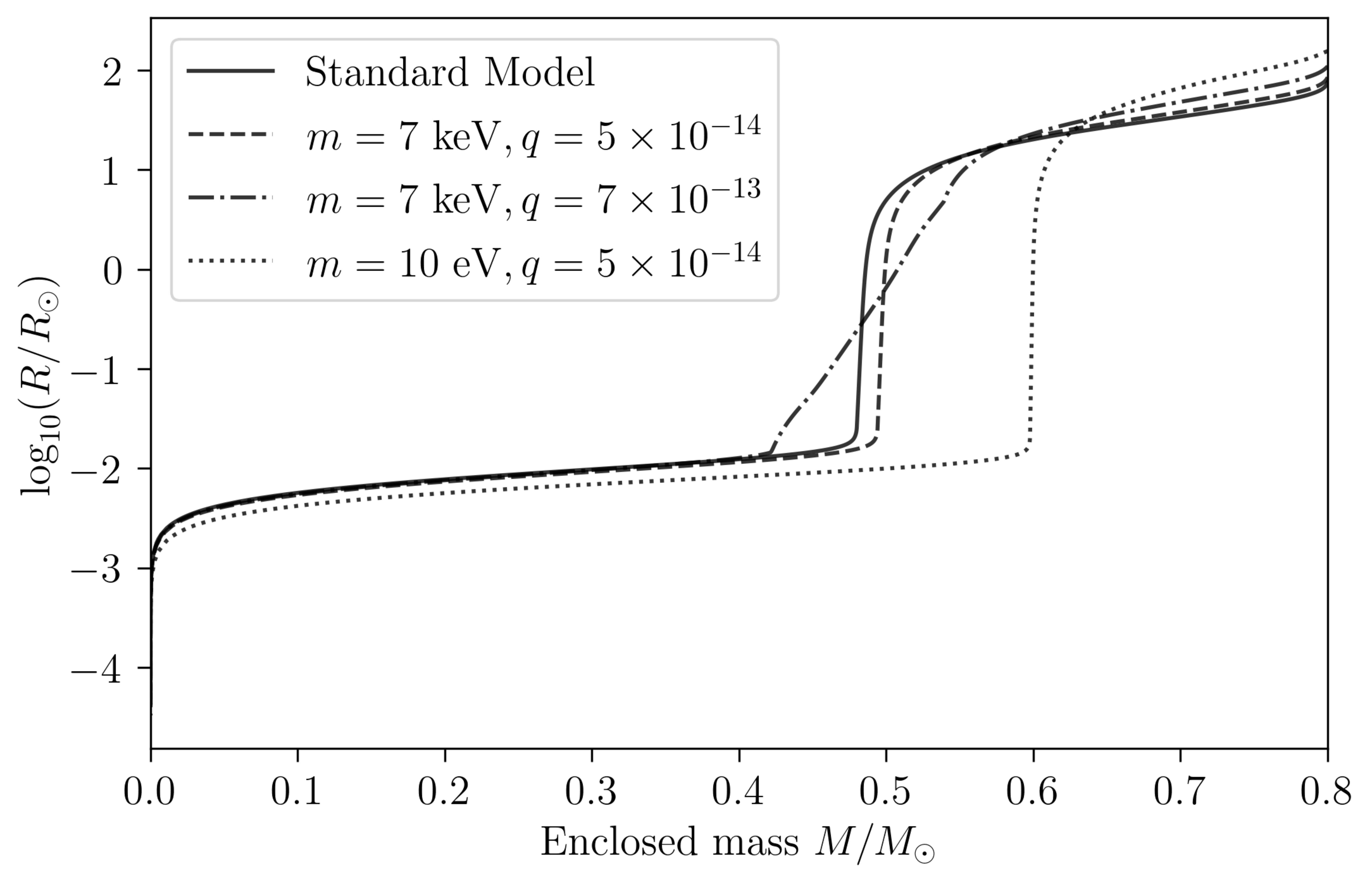
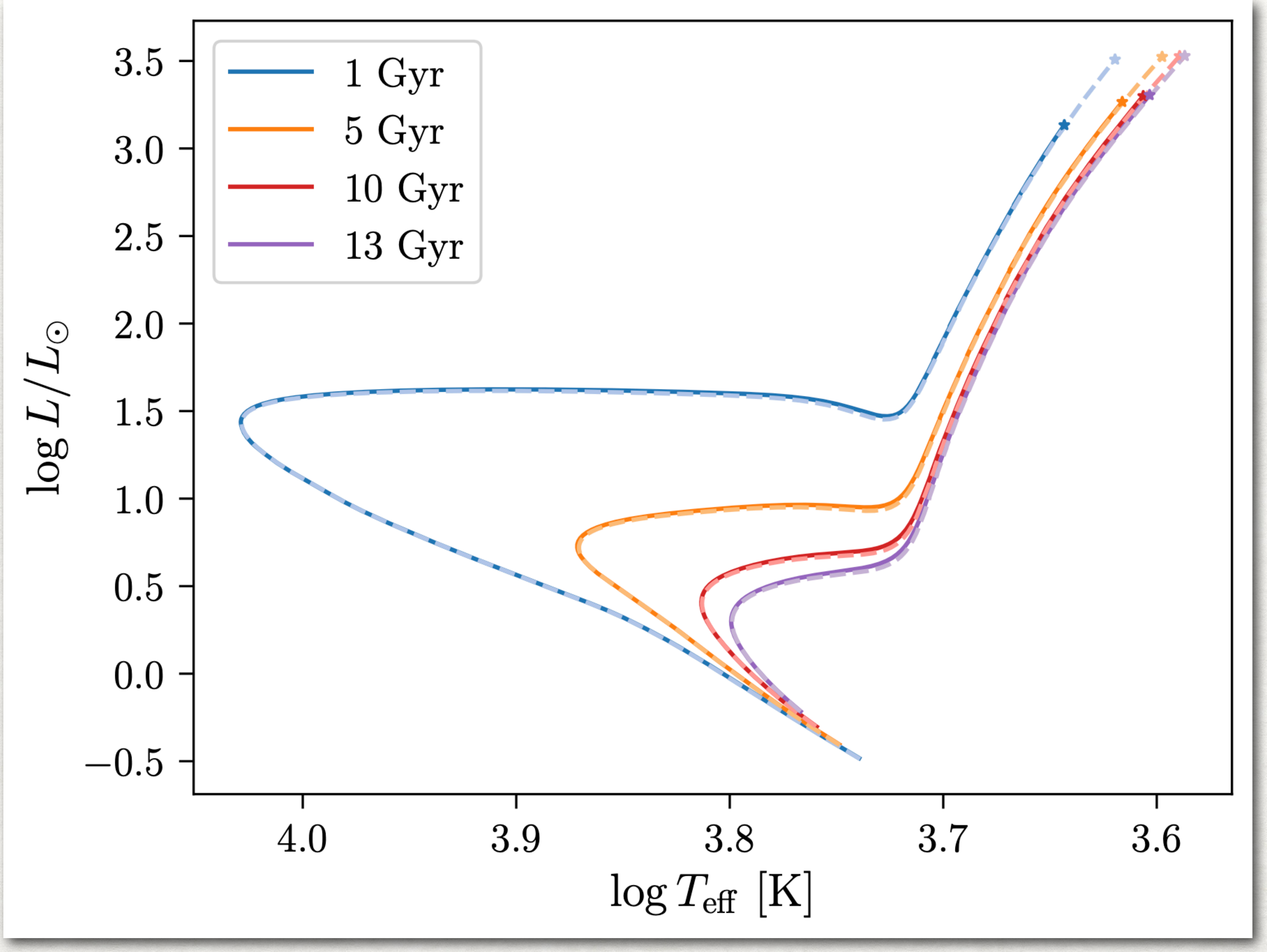
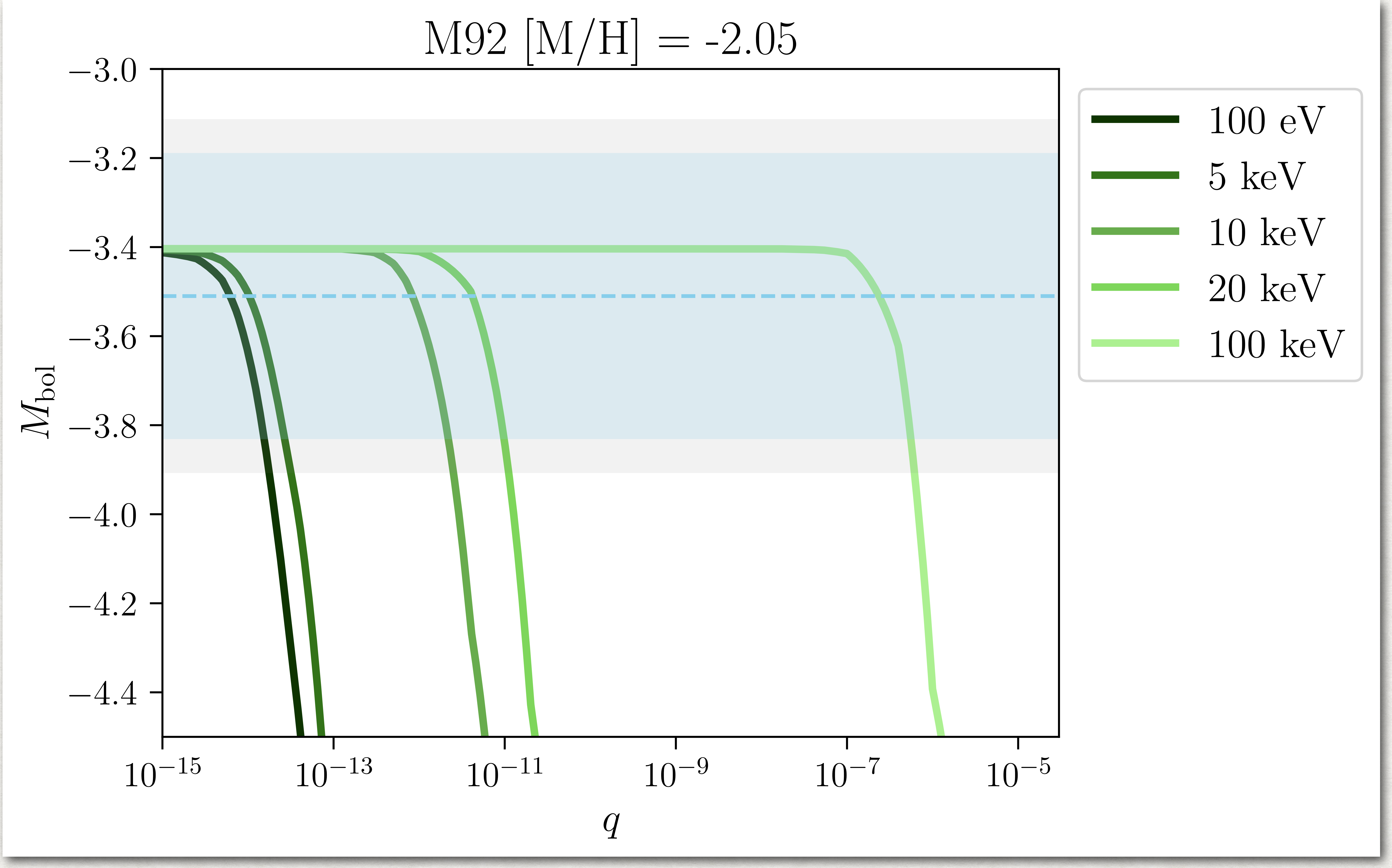
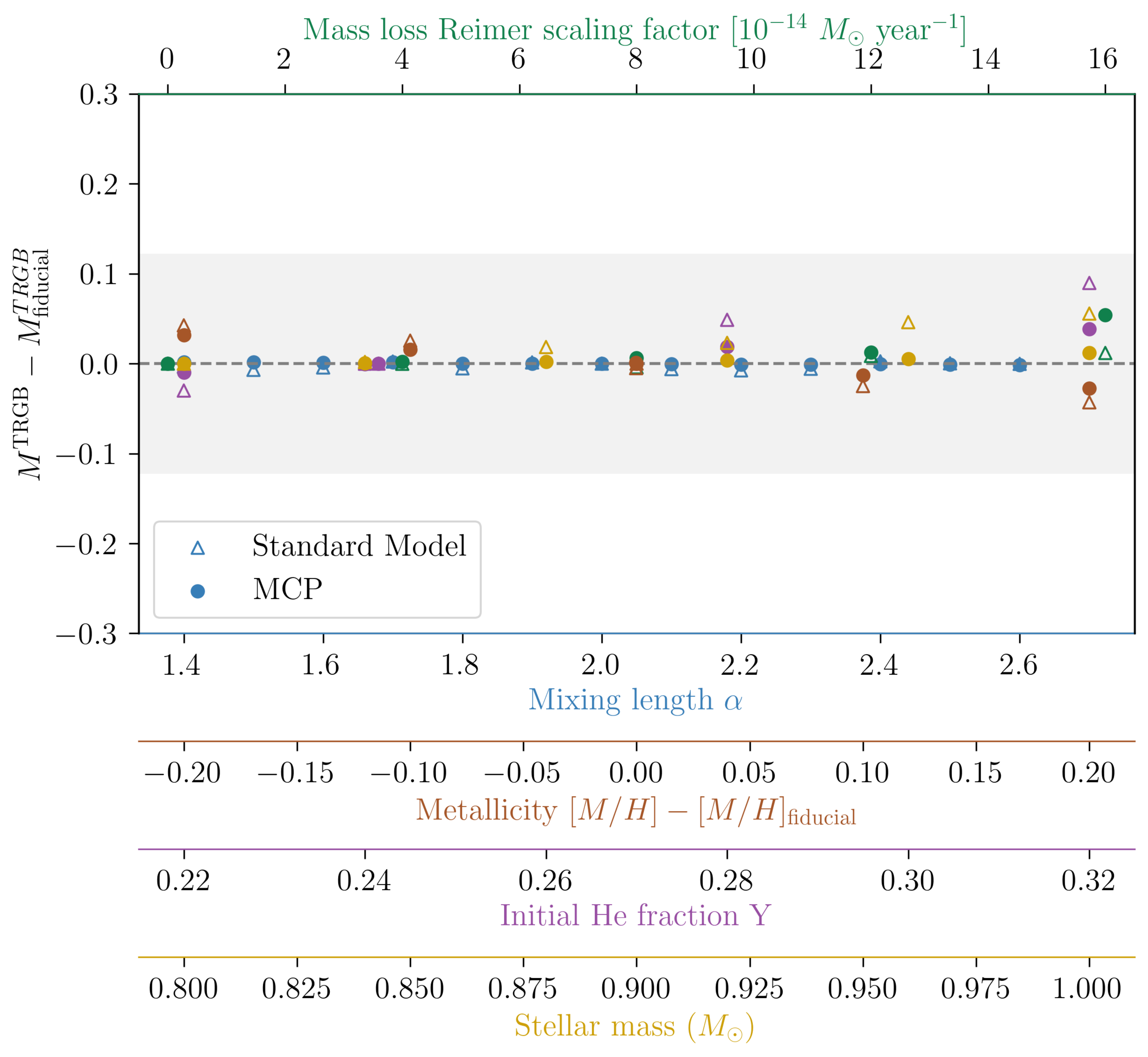


# DONEC QUIS NUNC



# III. BOLOMETRIC MAGNITUDE VS MCP CHARGEQ





Mass loss Reimer scaling factor [$10^{-14}$ $M_\odot$ year$^{-1}$]
0 2 4 6 8 10 12 14 16
0.3 0.2 0.1 0.0 −0.1 −0.2 −0.3
$M^{\mathrm{TRGB}} - M^{TRGB}_{\mathrm{fiducial}}$
Standard Model
MCP
1.4 1.6 1.8 2.0 2.2 2.4 2.6
Mixing length $\alpha$
−0.20 −0.15 −0.10 −0.05 0.00 0.05 0.10 0.15 0.20
Metallicity $[M/H] - [M/H]_{\mathrm{fiducial}}$
0.22 0.24 0.26 0.28 0.30 0.32
Initial He fraction Y
0.800 0.825 0.850 0.875 0.900 0.925 0.950 0.975 1.000
Stellar mass ($M_\odot$)

# 1. MOTIVATIONS

- Main objective: search for MCPs
- address charge quantization
- constrain BSM models
- our assumptions: MCPs couple to photons
- our assumptions: MCPs are stable

# OTHER CONSTRAINTS ON MCPS

## DONEC QUIS NUNC