dmEFT

A New Tool for Studying Dark Matter

José Maria Lopes

a work supervised by

Prof. Ilídio Lopes

centra costar TÉCNICO LISBOA IDPASC FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR
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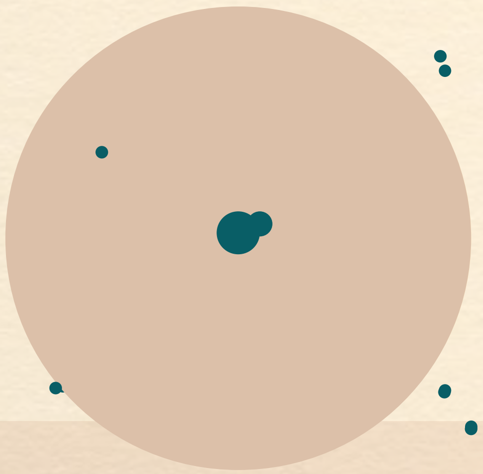
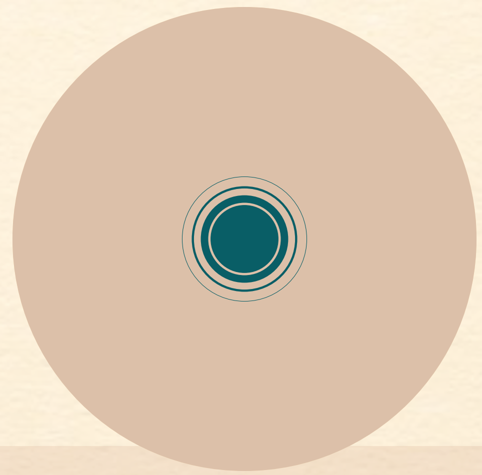


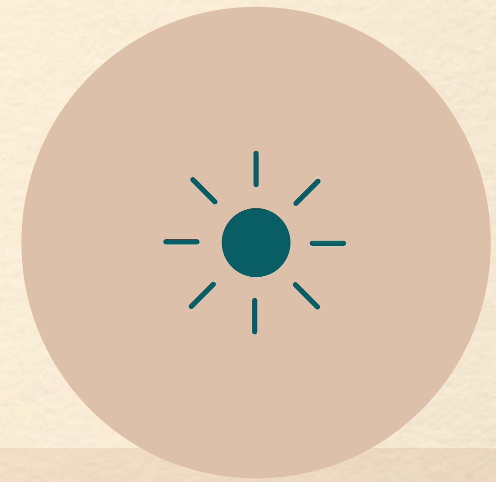
Capture

Massive Dark Matter Particles in the vicinity of a Star will get **trapped** in its gravitational potential and will build up **large densities** in the stellar core. (Steigman et al. 1978)



Transport

Interactions between nuclei and Dark Matter Particles in the stellar core will act as a **energy transport** mechanism by diffusion. (Spergel & Press 1985)



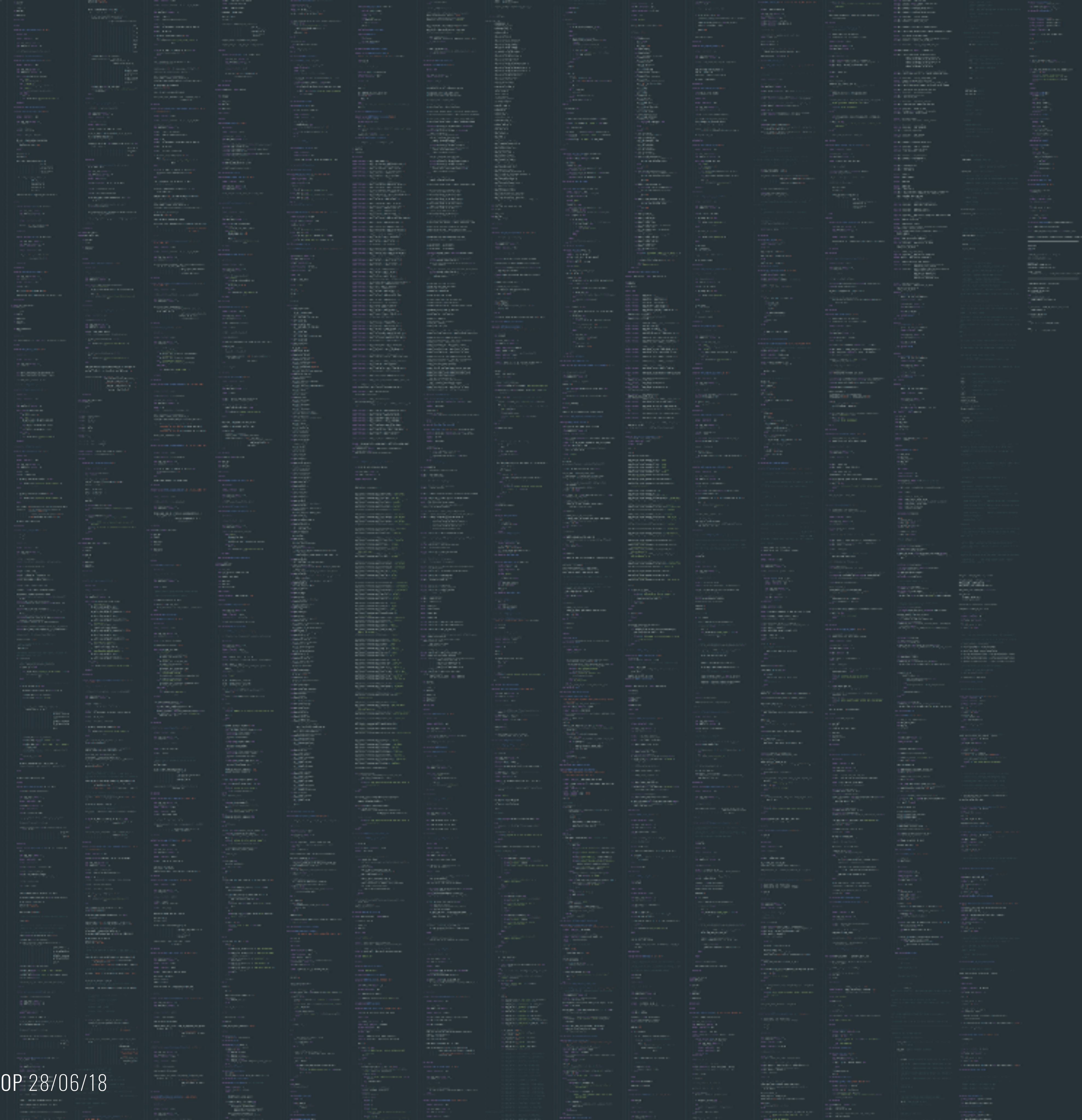
Production

In the case of Majorana Particles, Dark Matter particles will **self-annihilate** providing an additional **energy source** term to the stellar evolution equations. (Salati & Silk 1989)

Objective

- Tackle the Dark Matter problem using a model independent strategy - **Low Energy Effective Field Theory (EFT)**.
- Model the **interplay** between EFT Dark Matter models and Stars.
- Study the **phenomenology** of EFT Dark Matter in different Stars - certain EFT interactions will have more impact on different stages of stellar evolution.
- Obtain ***Asteroseismic* diagnostics** to constraint EFT interactions and parameters.
- Provide new Dark Matter studying strategies for **future Asteroseismology experiences** (e.g.: PLATO space observatory, planned for 2026).

```fortran
module dmEFT_annihilation

    use const_def
    use star_def

    use dmEFT_const
    use dmEFT_def

    use dmEFT_utils

    implicit none

    contains

    subroutine dmEFT_annihilation_coef(s, d, ierr)

        implicit none

        integer, intent(out) :: ierr

        type (star_info), pointer :: s
        type (dmEFT_info), pointer :: d

        call dmEFT_annihilation_control(s, d, ierr)

    end subroutine dmEFT_annihilation_coef

    subroutine dmEFT_annihilation_control(s, d, ierr)

        integer, intent(out) :: ierr

        type (star_info), pointer :: s
        type (dmEFT_info), pointer :: d

        select case (d% annihilation_coef_name)
            case ('none')
                d% annihilation_coef = 0
            case ('griest86')
                call annihilation_coef_griest(s,d,ierr)
            case ('cesam')
                call annihilation_coef_cesam(s,d,ierr)
            case default
                ierr = -1
                call failed_inlist('annihilation_coef_name', &
                                   &ierr)
        end select

    end subroutine dmEFT_annihilation_control

    subroutine annihilation_coef_griest(s,d,ierr)

        integer, intent(out) :: ierr

        type (star_info), pointer :: s
        type (dmEFT_info), pointer :: d

        real(dp) :: th_av_cs
        real(dp) :: vol1, vol2

        integer :: shell_min, shell_max

        th_av_cs = d%annihilation_cross_section
        if(th_av_cs == 0d0) then
            d%annihilation_coef = 0d0
            return
        endif

        shell_min = s% nz
```



dmEFT 1.2

- EFT Dark Matter framework build upon **MESA**, a modular and robust stellar evolution code with a large community of active users with frequent updates (860 registered users as of January 2018).
- Study the impact of EFT Dark Matter Models during **different stellar evolution stages** (from the collapse of protostars to degenerate White Dwarfs).
- **Modular** and **User Friendly**, i.e., written to be easily used, **shared,** and built upon (e.g.: version control, output system etc.).
- **Not Complete**. Only energy independent EFT interactions have been implemented. Other interactions will come in later versions.

RESULTS

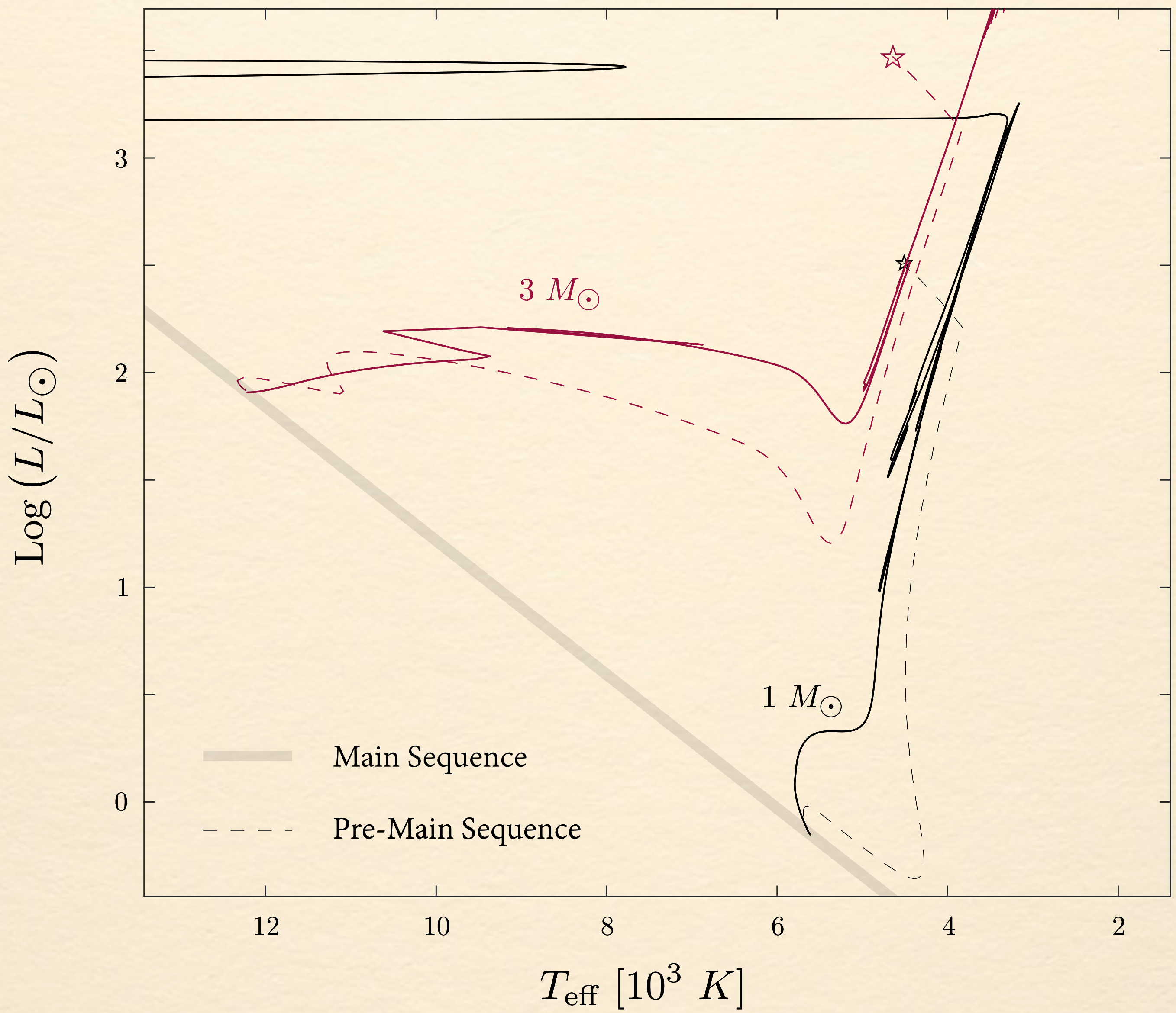
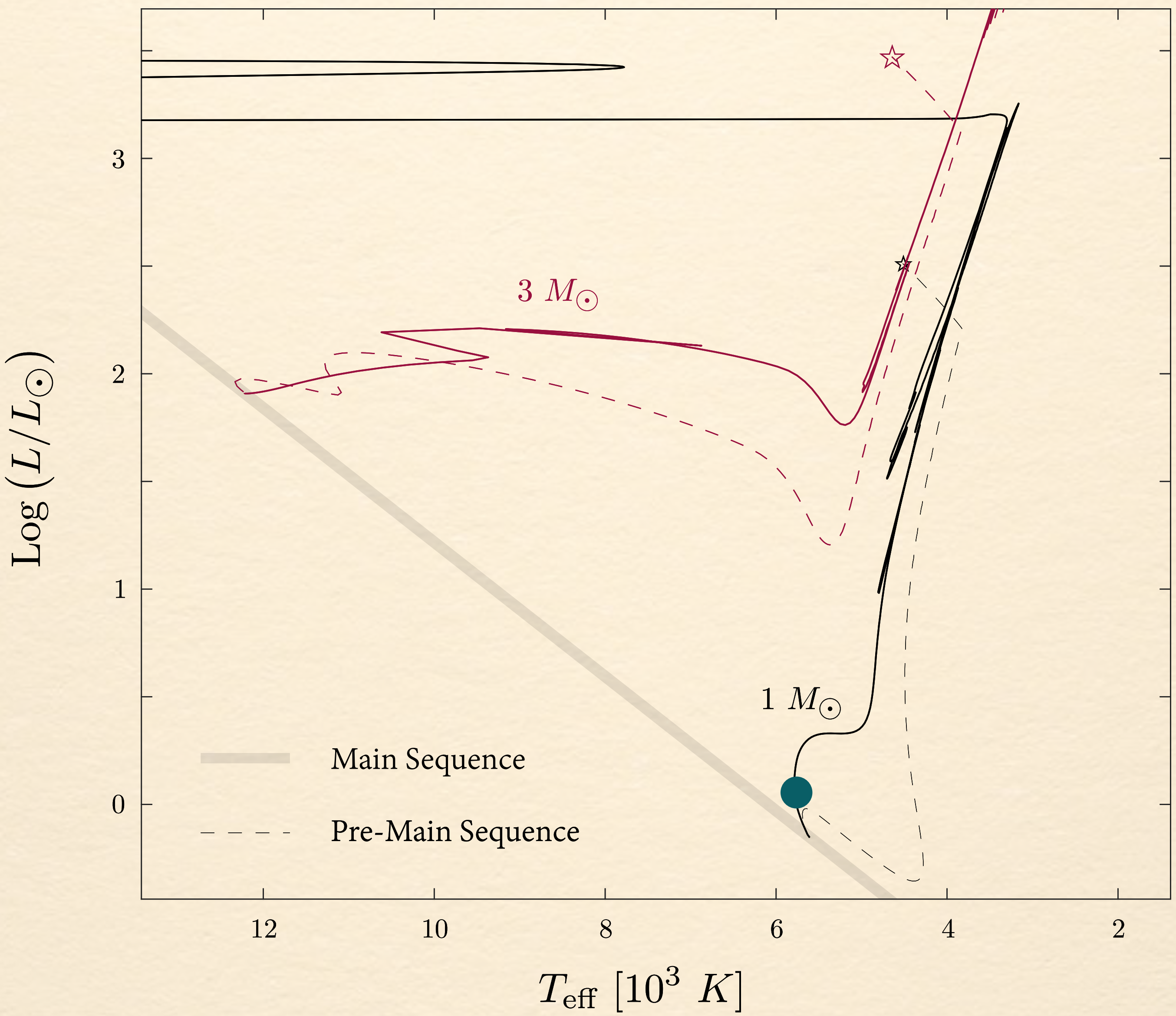


FIG. 1 Hertzprung Russel (HR) diagram showing the evolution of Stars with 1 and 3 Solar masses. **Dashed lines** represent the pre-main sequence phase. The **shaded area** illustrates the Main Sequence.

RESULTS



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Results

The Sun

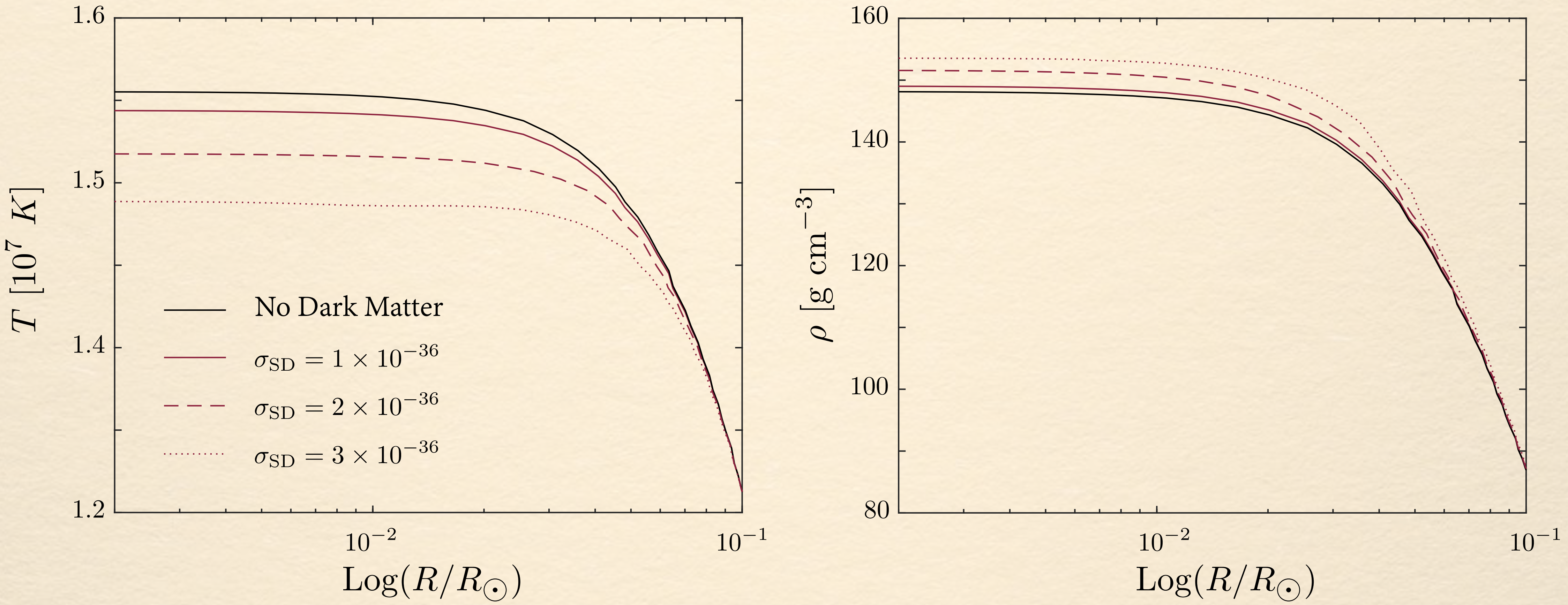
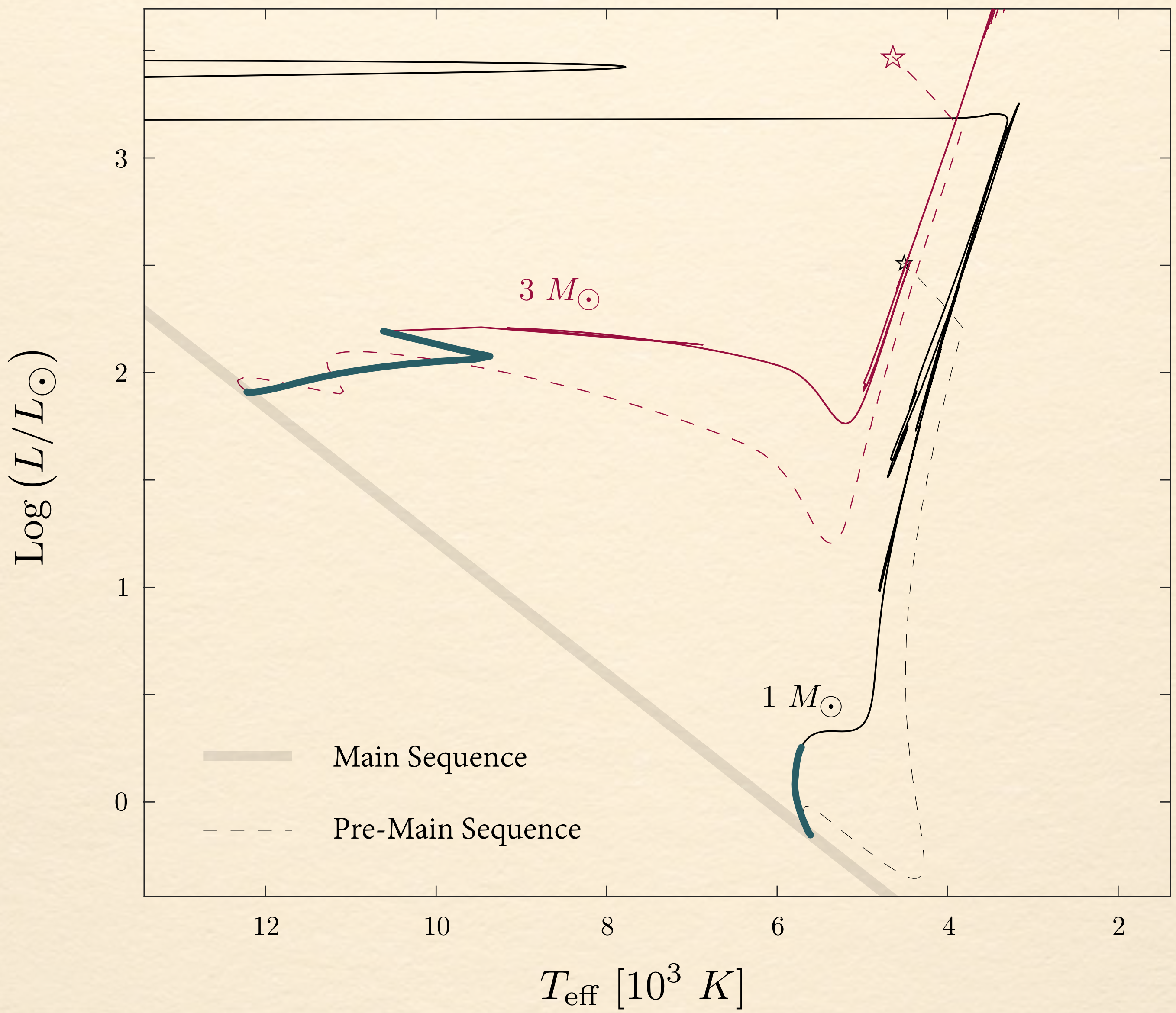


FIG. 2 Inner region of the Solar temperature (**left**) and density (**right**) profiles with and without Dark Matter (m = 7 GeV).

RESULTS



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RESULTS

Main Sequence Stars

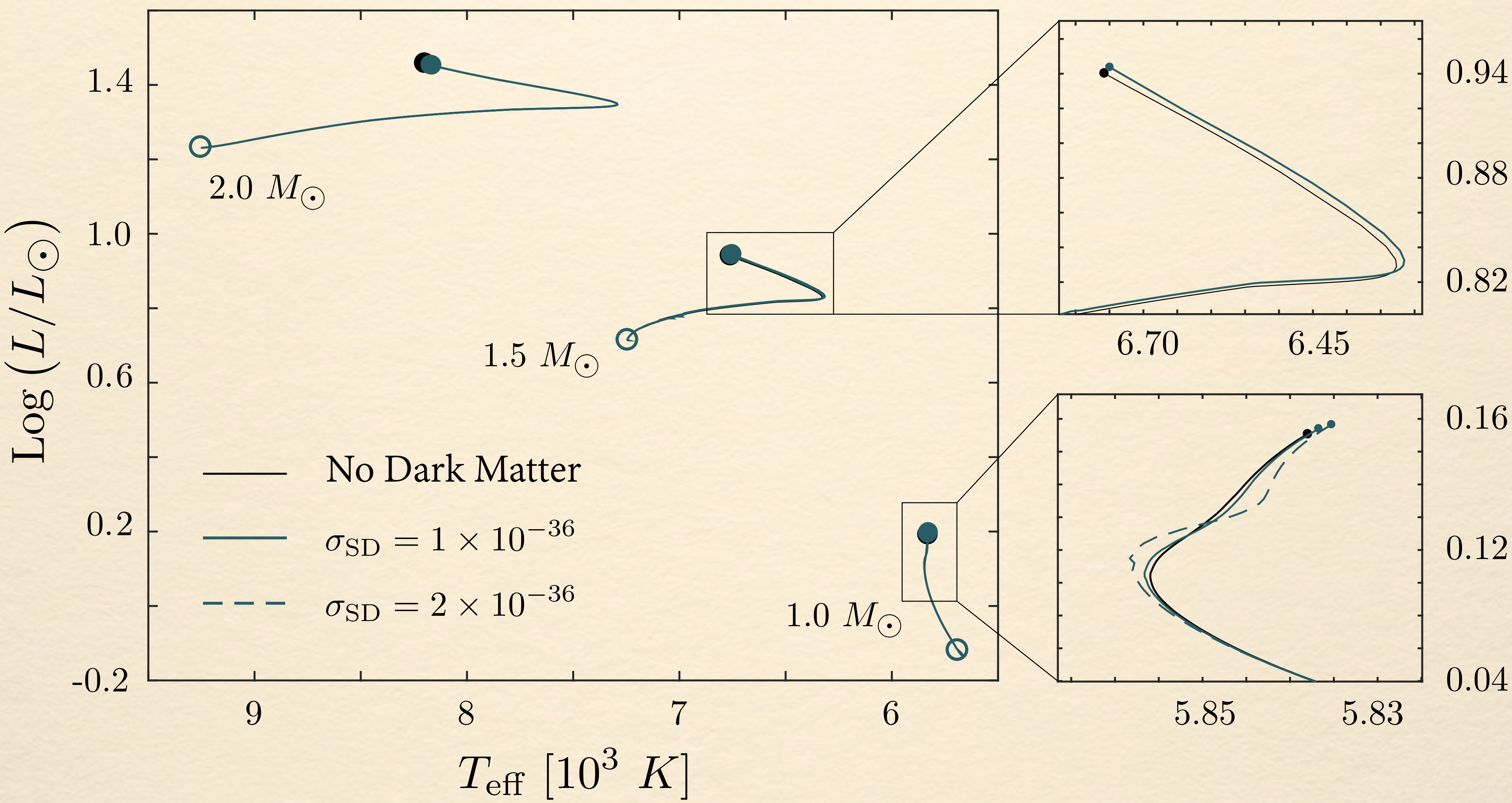
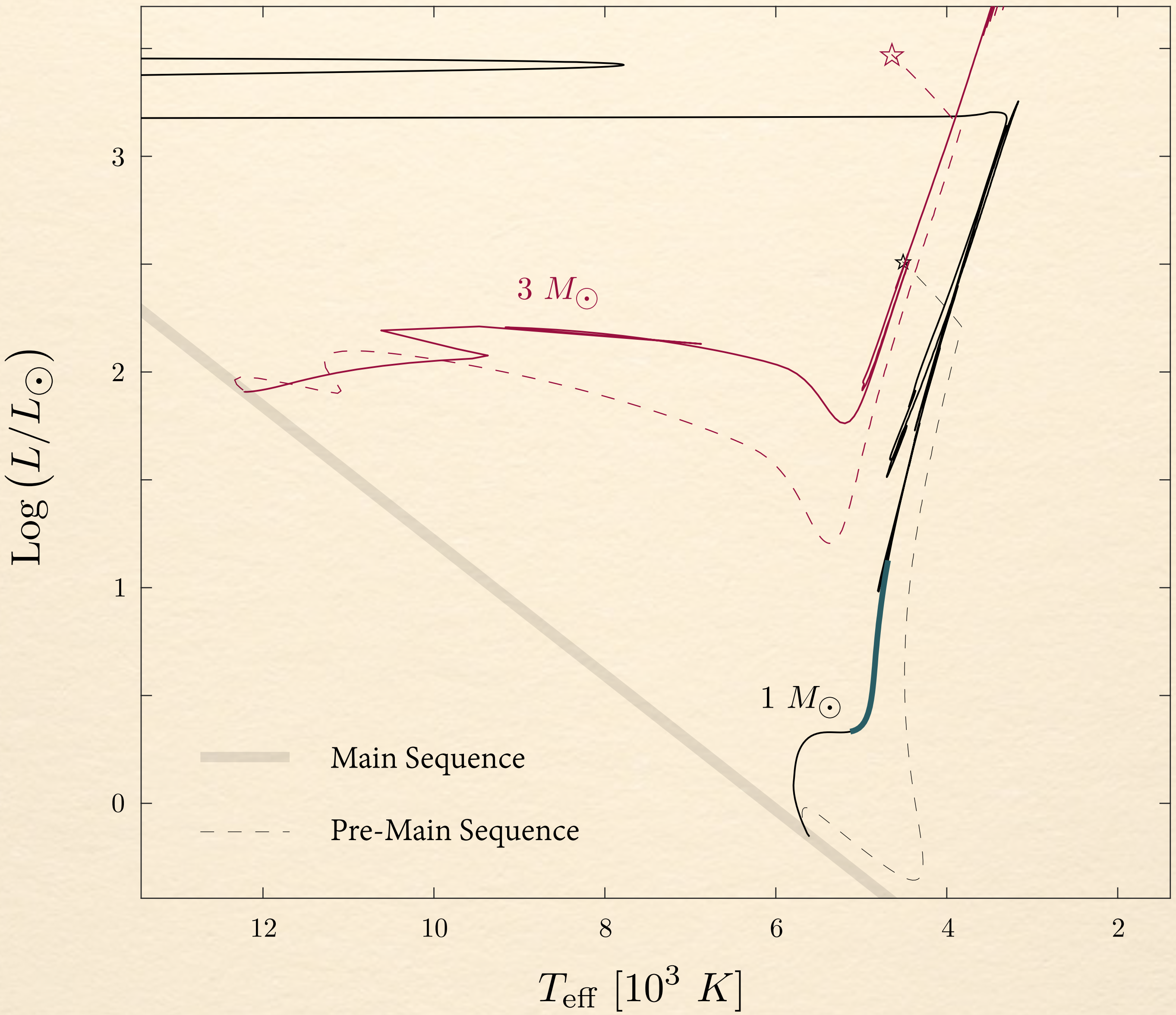


FIG. 3 Hertzprung Russel (HR) diagram showing the evolution of Stars with 1.0, 1.5 and 2.0 Solar masses with and without Dark Matter (m = 7 GeV).

RESULTS



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RESULTS

Red Giant Branch

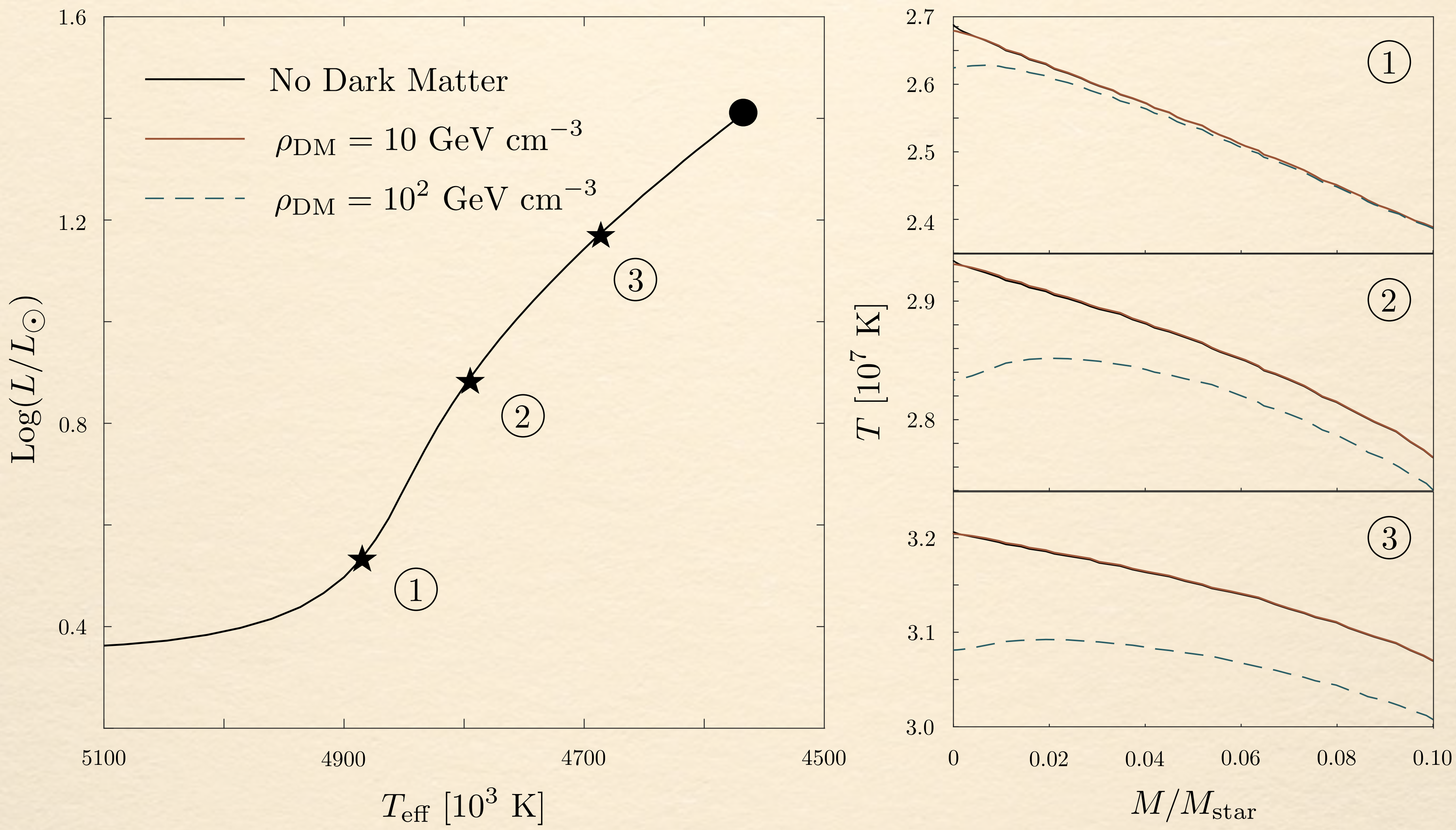
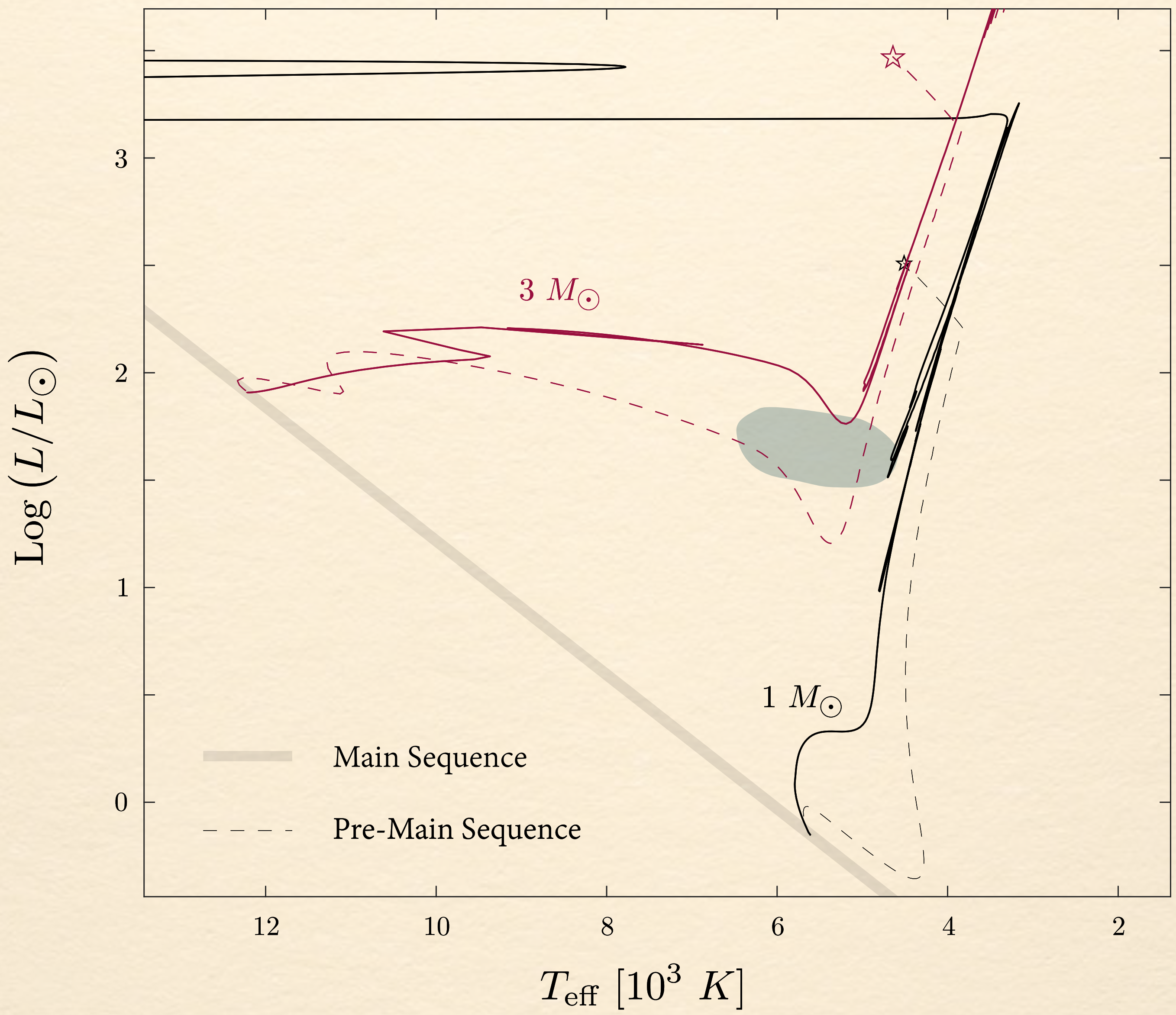


FIG. 4 Temperature profile in the center **(right)** for three different models (a reference model and two models with different DM density) in three different stages of the Red Giant Branch **(left)** (m=5 GeV).

RESULTS



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RESULTS

Horizontal Branch Stars

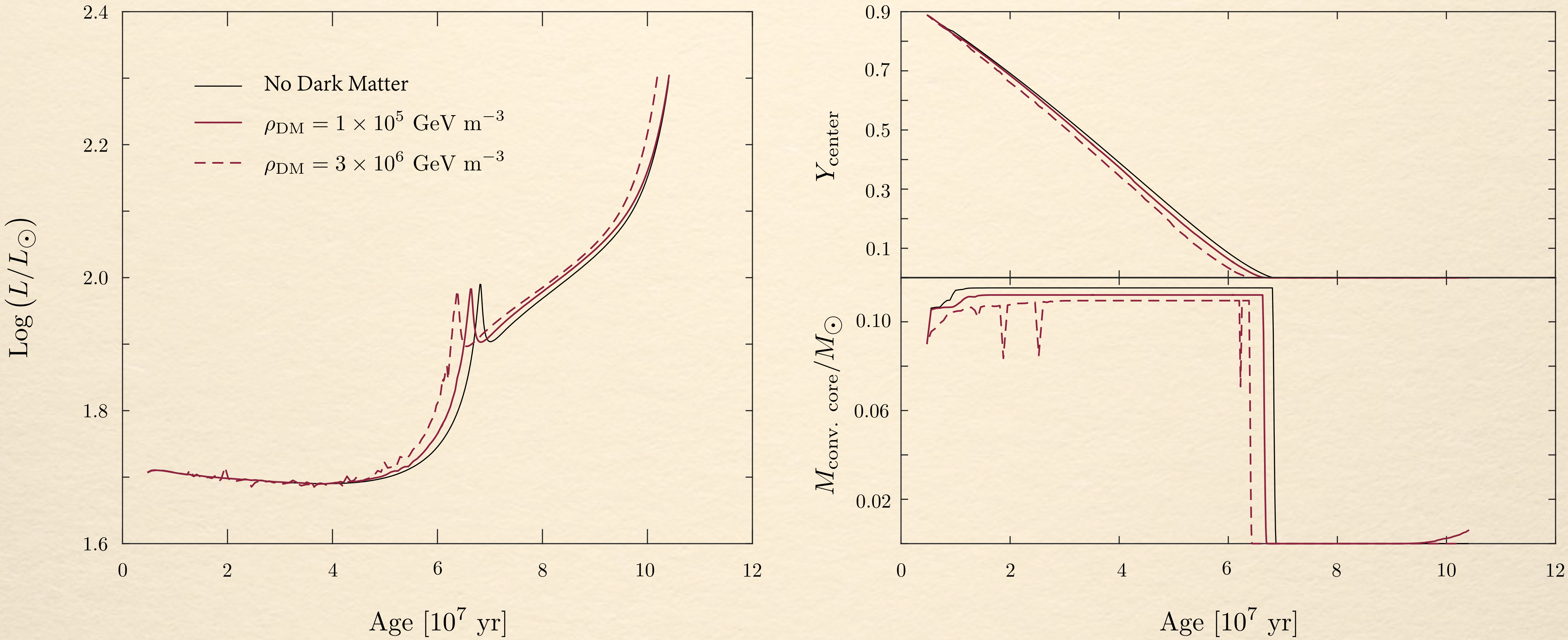

FIG. 5 Luminosity (**left**), Center Helium and Convective Core Mass (**right**) evolution for a 1 Solar Mass Horizontal Branch star with and without Dark Matter (m = 7 GeV).

WHAT FOLLOWS?

- Understand and handle **divergences** that arise for dramatic Dark Matter scenarios (high interaction cross-sections, large galactic halo abundance, etc.).

- Identify **interesting** and **meaningful scientific cases**, including predictions for future observations.

- Implement all the Dark Matter **EFT allowed interactions** with Baryonic Matter.

- Release a **public version** along with the full documentation and code description.

CONCLUSIONS

- `dmEFT1.2` results are coherent with what has been previously studied, including what has been published in literature.
- With `dmEFT1.2` we can study the effects that Dark Matter *(not the full framework yet!)* can have across most of a star's life span.
- Results are already showing some interesting scientific cases.
- There is much work to be done.

Thank You

Steigman, G., Sarazin, C. L., Quintana, H., & Faulkner, J. (1978). ***Astronomical Journal*, *83*, 1050–1061.**

Spergel, D. N., & Press, W. H. (1985). ***Astrophysical Journal*, *294*, 663–673.**

Salati, P., & Silk, J. (1989). ***Astrophysical Journal*, *338*, 24–31.**