IMPACTS OF ORBITAL ECCENTRICITY ON THE CAPTURE OF WIMP DARK MATTER BY STARS IN THE GALACTIC CENTER

Hesti Wulandari

Institut Teknologi Bandung

Collaborators: Sulistiyowati, B. Dermawan, M.I. Arifyanto,
M. Ichsan

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- In a dense WIMP environment stars may gather enough WIMPs and become **Dark Stars** (stars powered by dark matter annihilation instead of nuclear fusion)

Bertone, Fairbairn 2008

Spolyar, Freese, Aguirre 2008

Yoon, Iocco, Akiyama 2008

Casanellas & Lopes 2009

Scott 2009

- First stars to form in the universe ?
- Explain young stars at the Galactic center?

How WIMPs may influence stars ?

- **How WIMPs get into stars**

  - Born with WIMPs

  - Capture WIMPs later

- **WIMP annihilation provides extra energy source**

  Stars become bigger & cooler if energy is added to them

- **May provide a new way to transport energy**

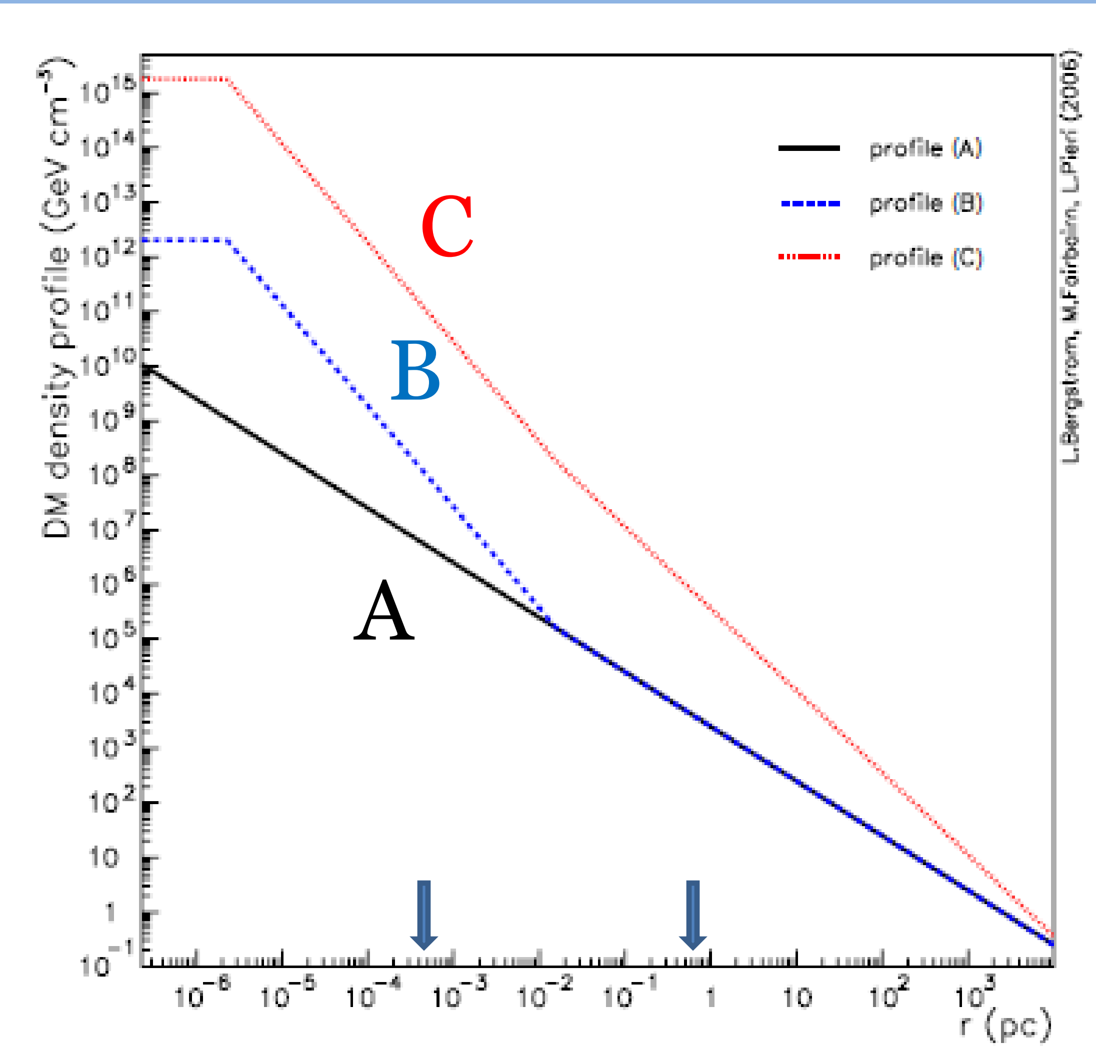
  Ordinary stars → radiation and/or convection.

  WIMPs (long mfp) → additional heat transport.

- **May produce a convective core (or a fully convective star)**

  Very compact WIMP distributions → steep T gradient → can't be maintained by radiative transport.

High Dark Matter Density → Galactic center



Galactic DM density distribution

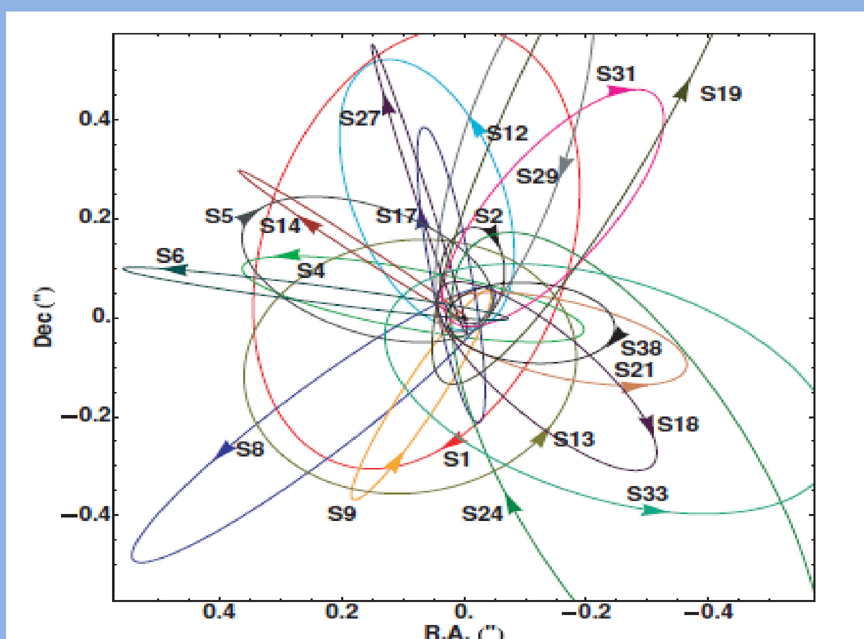
A : NFW (1996)

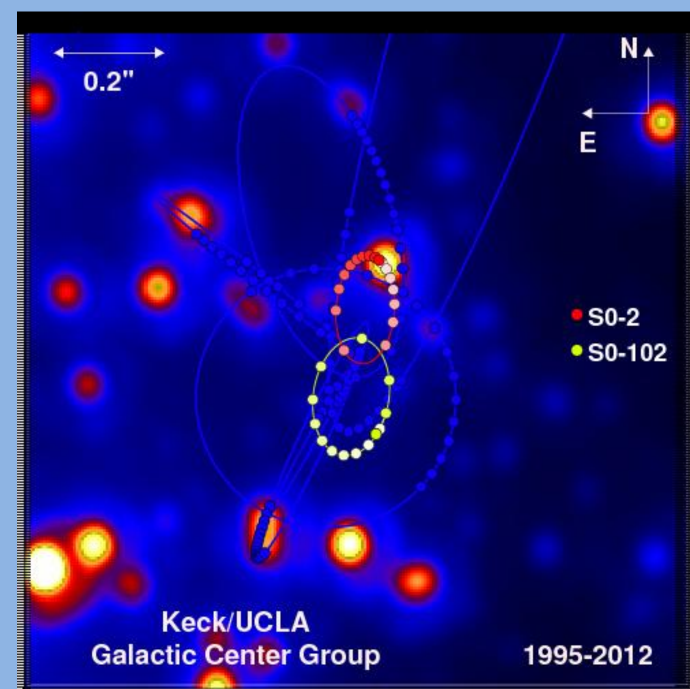
B: NFW + spike (Bergström et al. (2006))

C: AC + spike (Bergström et al. (2006))

S Stars

- Young or resemble young MS stars
- 0.29 mpc < r < 186.4 mpc
- Mass of SMBH derived : $M \approx 4x10^6 M_\Theta$
- Orbital elements for 28 stars (Gillessen et al 2009) + SO-102 (Period = 11.5 yrs, Meyer et al 2012)
- Origin : formed in situ ? Migrated from outside ?





Dark Star Code

(Scott, Fairbairn, Edsjö (2009))

- Capture routine of **DARKSUSY** (Gondolo et al. 2004) coupled to **EZ** version (Paxton 2004) of **STARS** evolution code (Eggleton 1971, 1972, Pols et al. 1995)
- The code simultaneously solves the equations of **WIMP capture and annihilation** in a star with those of **stellar evolution** assuming approximate hydrostatic equilibrium.
- DarkStars includes the most extensive WIMP microphysics of any dark evolution code to date.

Grid Simulations (1)

Scenario :

ZAMS→ stars begin to capture WIMPs → annihilation of WIMPs → competition between WIMP annihilation & nuclear burning

- m_{WIMP} = 100 GeV
- annilation cross section $\langle\sigma_a v\rangle = 3x10^{-26}\ cm^3 s^{-1}$
- WIMP-nucleon cross section :

$\sigma_{SI} = 10^{-44}\ cm^2$ (XENON 100, 2011)

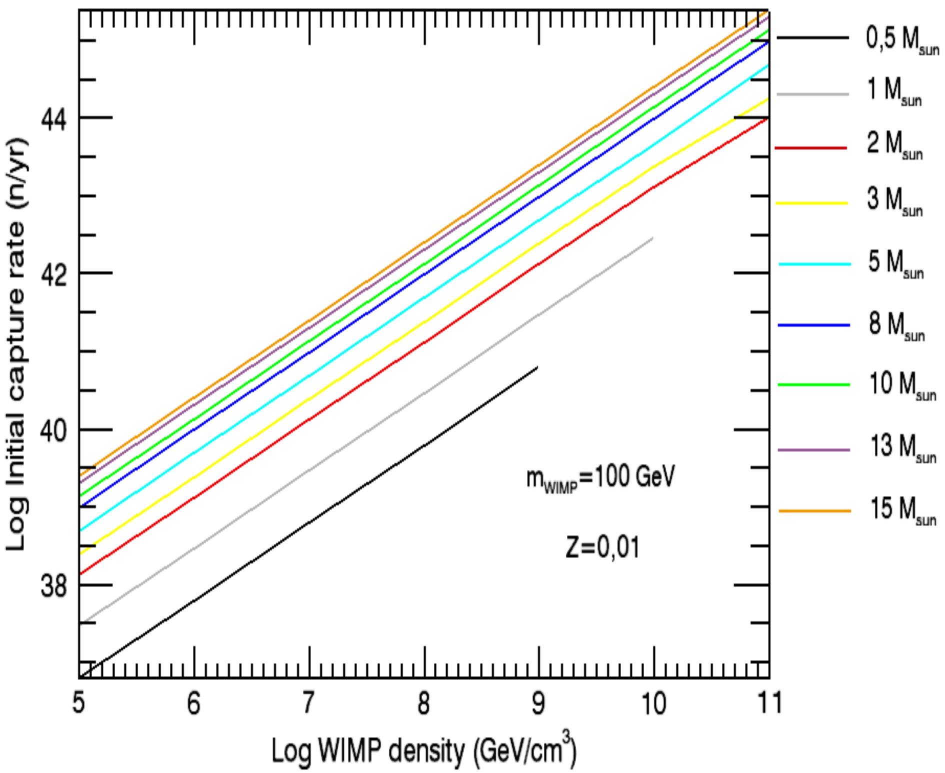
$\sigma_{SD} = 10^{-38}\ cm^2$ (Behnke et al. 2008)

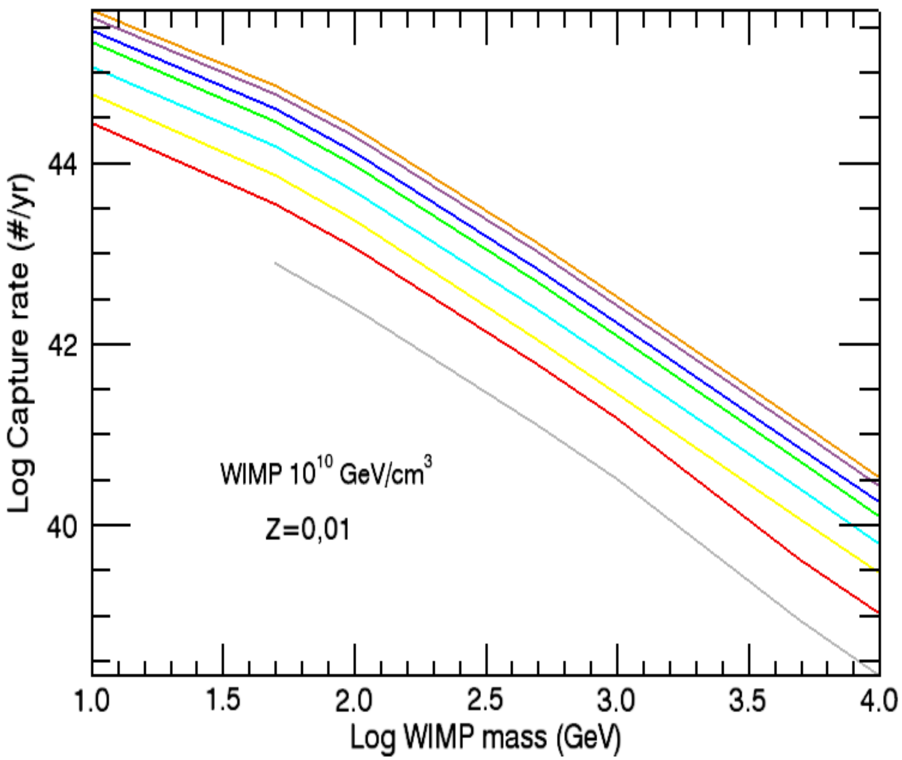
- Reference Solar Configuration (Scott et al. 2009 : circular orbits, resembles situation in the solar neighborhood except WIMP density)

Grid Simulations (2)

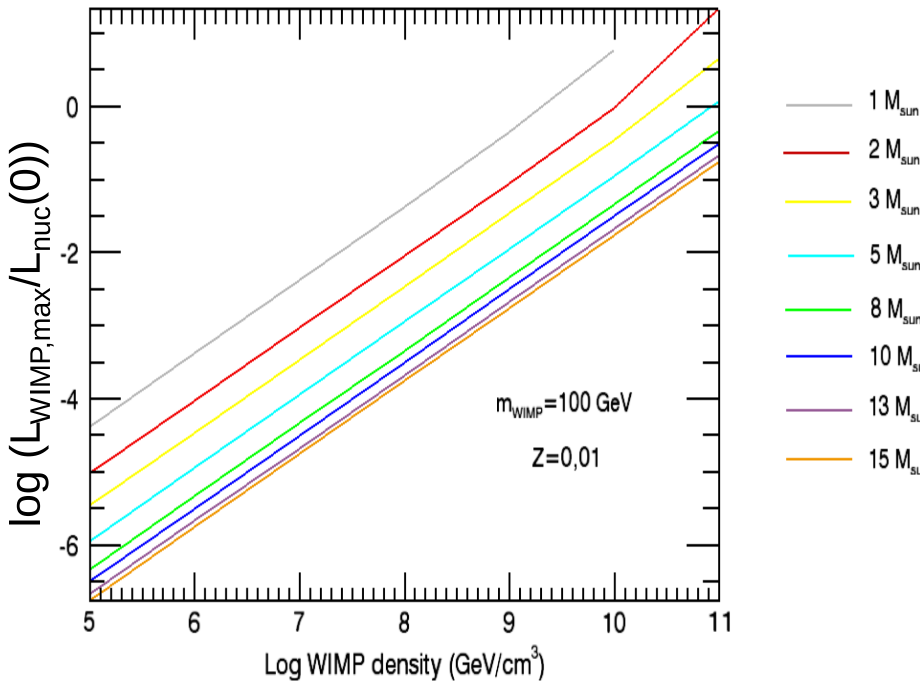
- Standard isothermal velocity distribution for dark halo
- Stopping criteria :
  - the star left MS (indicated by central $X_c < 10^{-6}$
  - the star reached a stable equilibrium (all its energy was effectively provided by WIMP annihilation ($X_c < 10^{-14}\ M_* / M_\odot$, $\log \rho_c < 10^{-10}$, $\log T_c < 10^{-10}$ over 4 consecutive time-steps)
  - the age of the star exceeded the age of the Universe

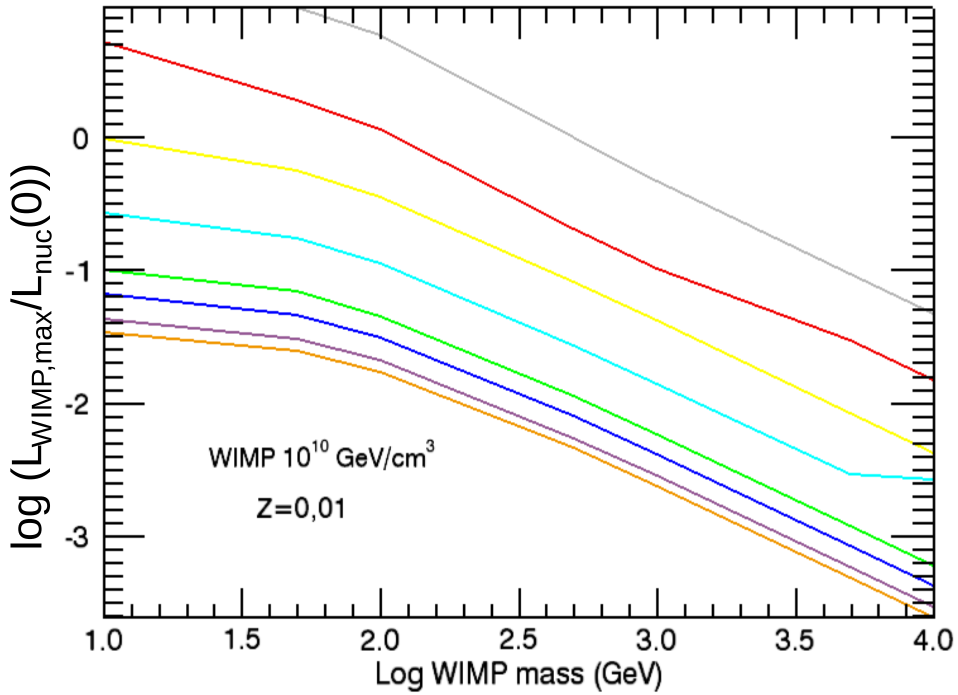
Results :





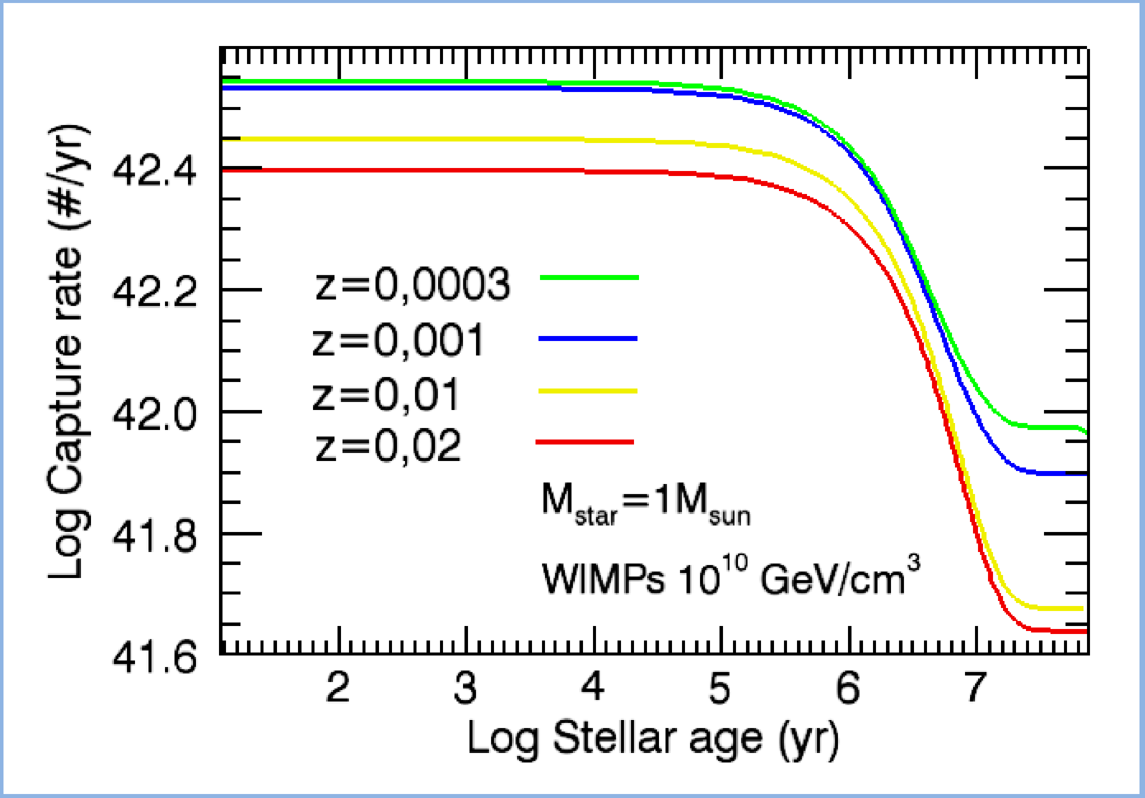
- WIMP capture rate is higher for higher ambient WIMP density, higher stellar mass, lower WIMP mass
- Notice 1-1 relationship between ambient WIMP density and capture rate





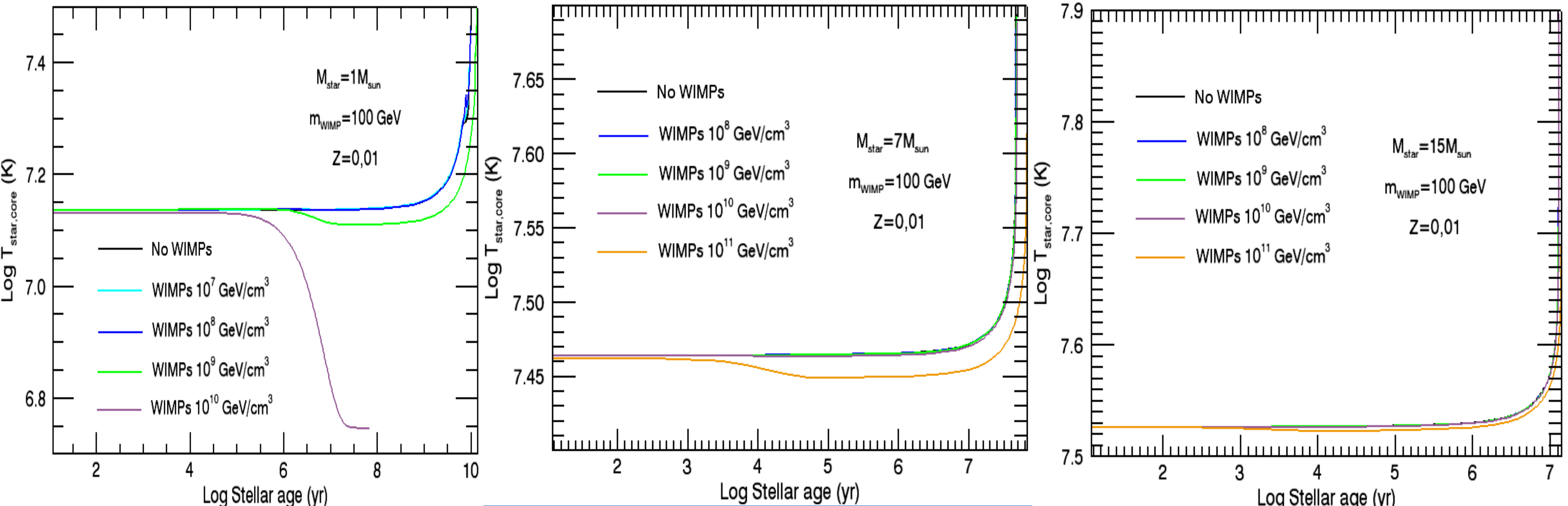
"WIMP luminosity" is higher for :

-higher WIMP density, lower stellar mass, lower WIMP mass

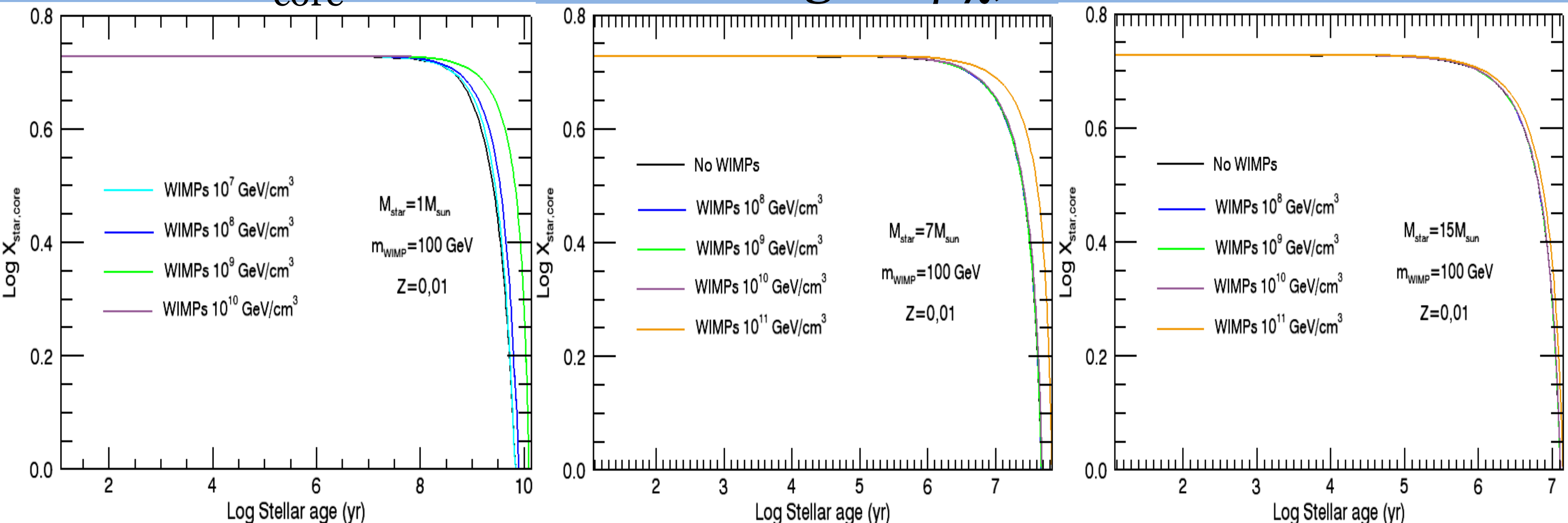


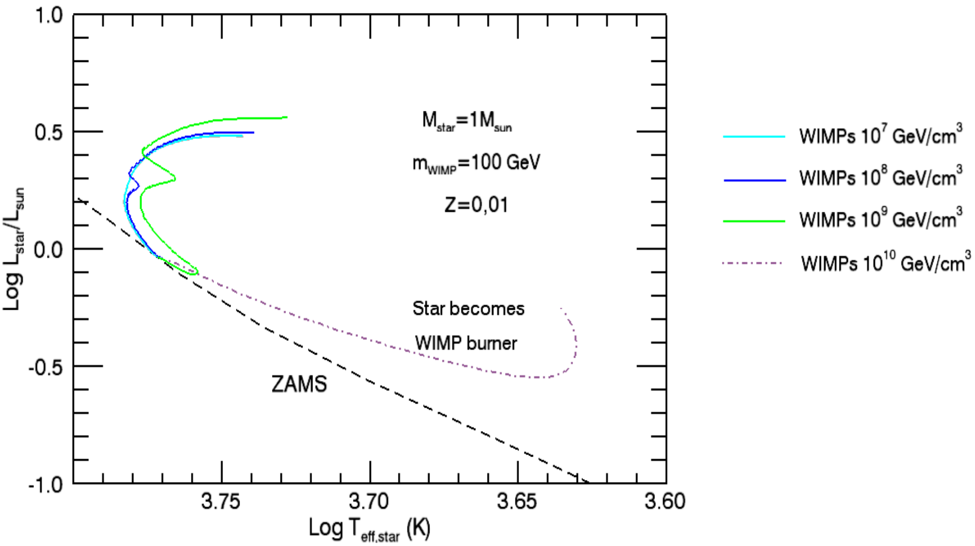
- higher capture rate for lower stellar metalicity owes to the higher limit of σ_{SD} (predominantly on H) compared to σ_{SI} (predominantly on metal)

WIMP annihilation reduces T_{core}

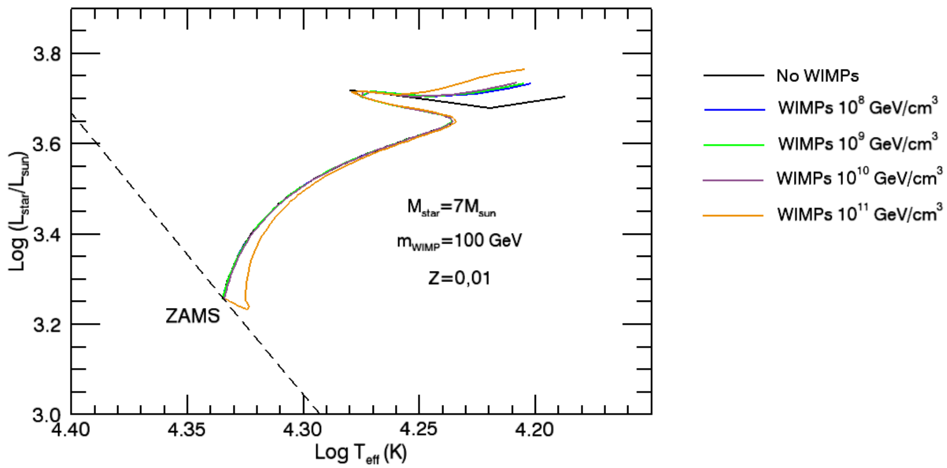


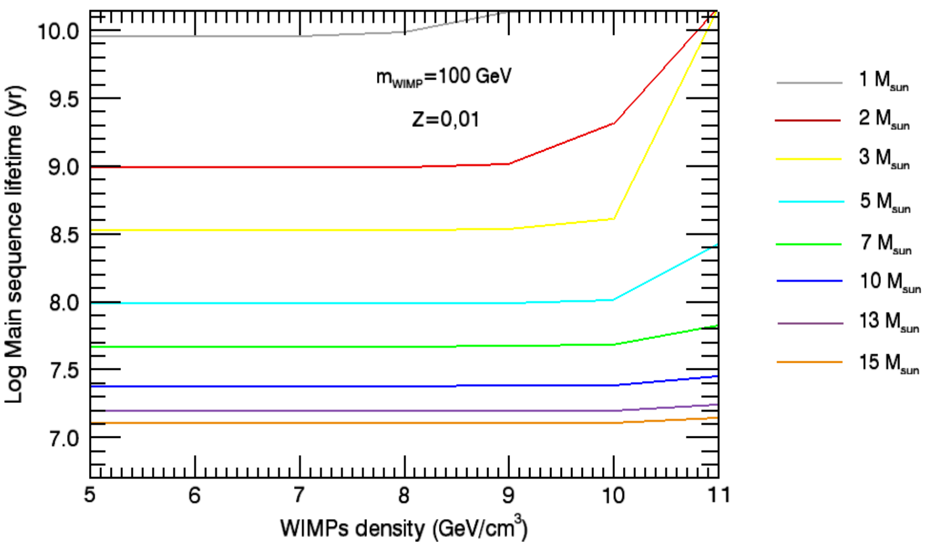
... and X_{core} . Prominent for higher $\rho\chi$, lower stellar M

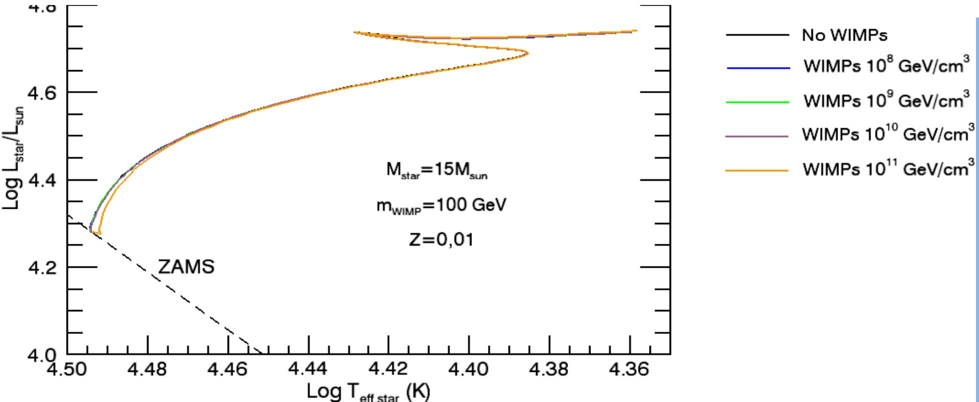




Low mass star in a very high WIMP density climbs back Hayashi track







WIMP annihilation prolongs MS lifetime

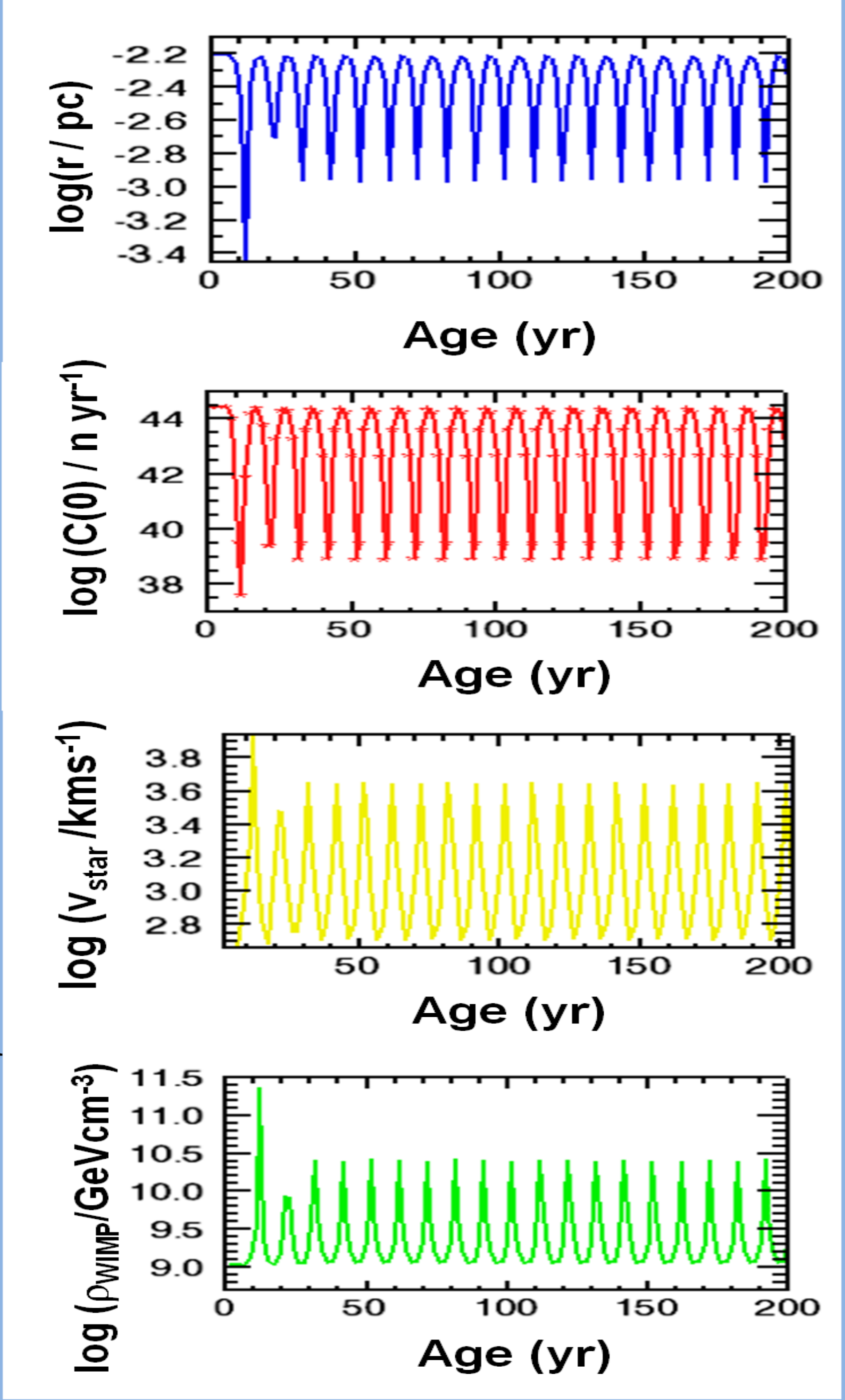
Impact of elliptical orbit

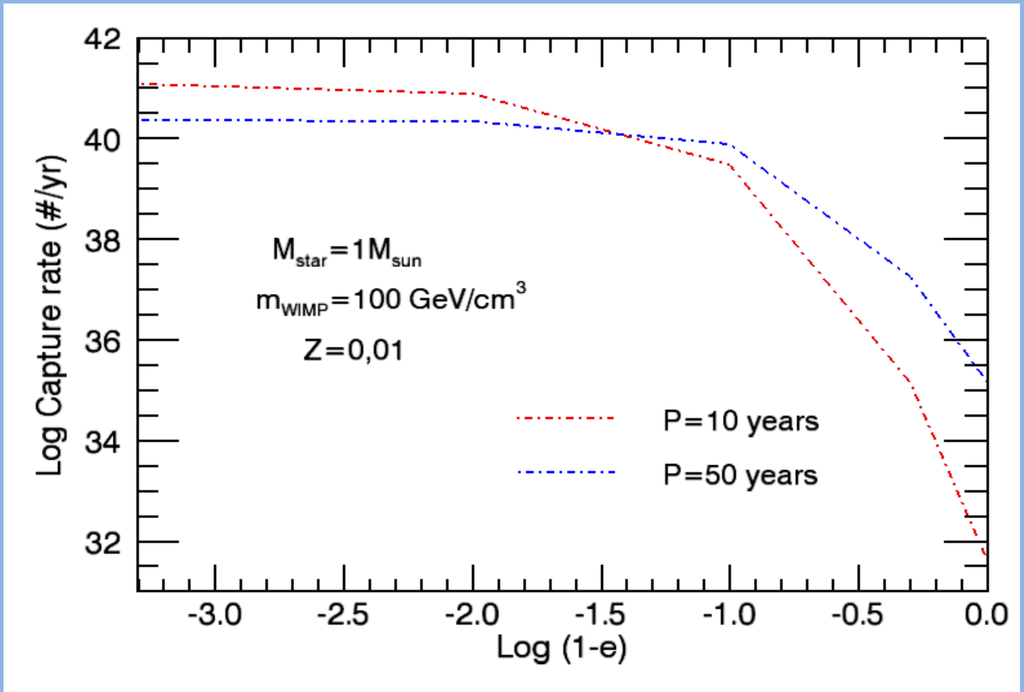
-WIMP density vs stellar velocity

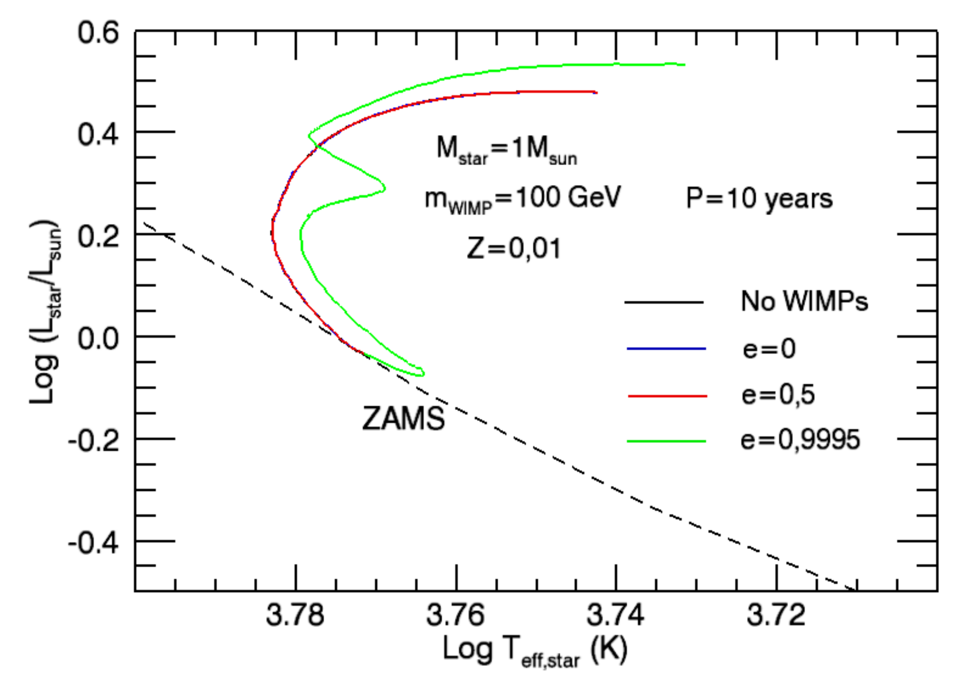
-Problem in the simulations :
 detailed orbit vs stellar evolution

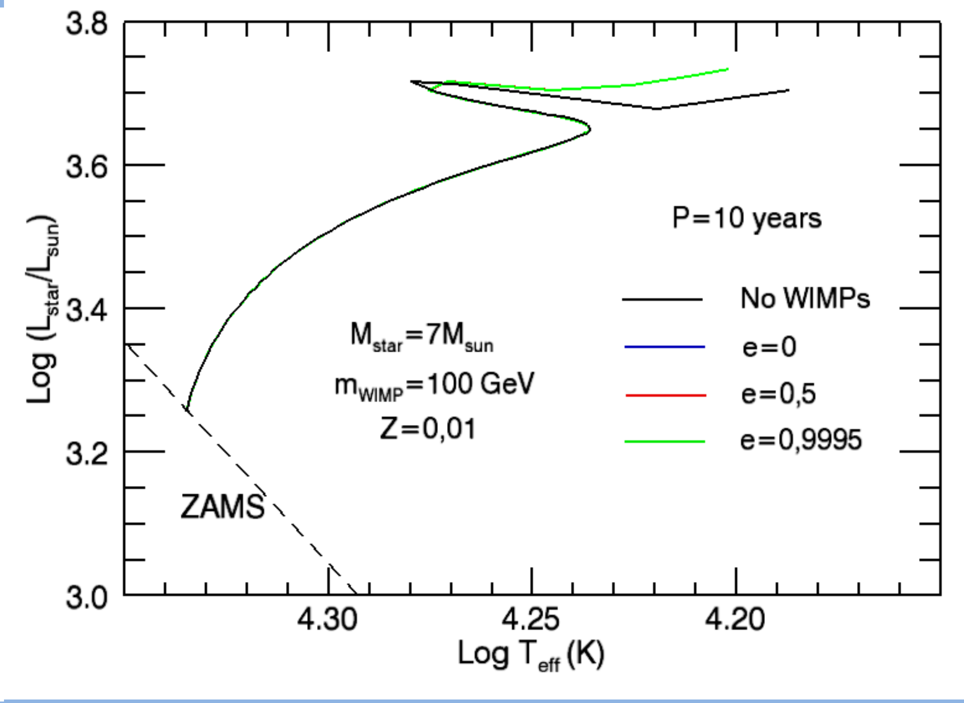
-Solution :
 simulate until 1000 years to get average capture rate, then using 1-1 relationship between capture rate and WIMP density and simulate in circular orbit with corresponding WIMP density

- WIMP density profile: AC + spike




Log Capture rate (#/yr)
Log (1-e)
M_star=1M_sun
m_WIMP=100 GeV/cm^3
Z=0,01
P=10 years
P=50 years

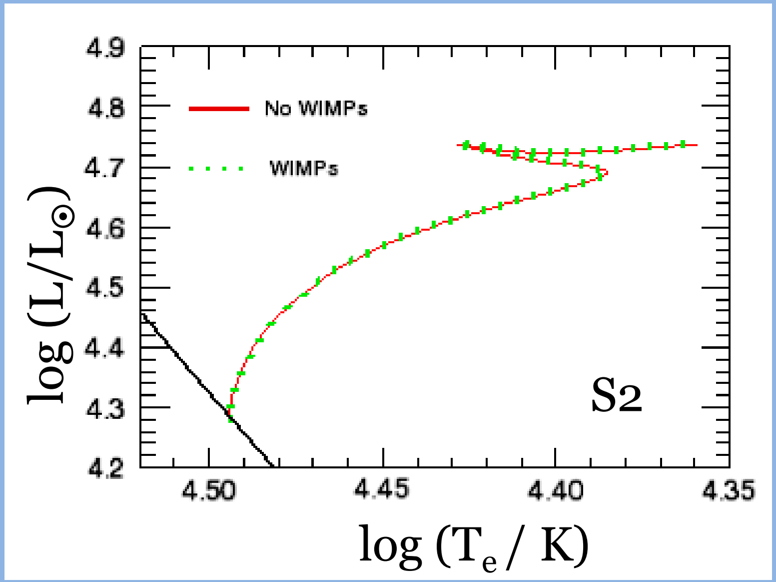

Log (L_star/L_sun)
Log T_eff,star (K)
M_star=1M_sun
m_WIMP=100 GeV
Z=0,01
P=10 years
No WIMPs
e=0
e=0,5
e=0,9995
ZAMS

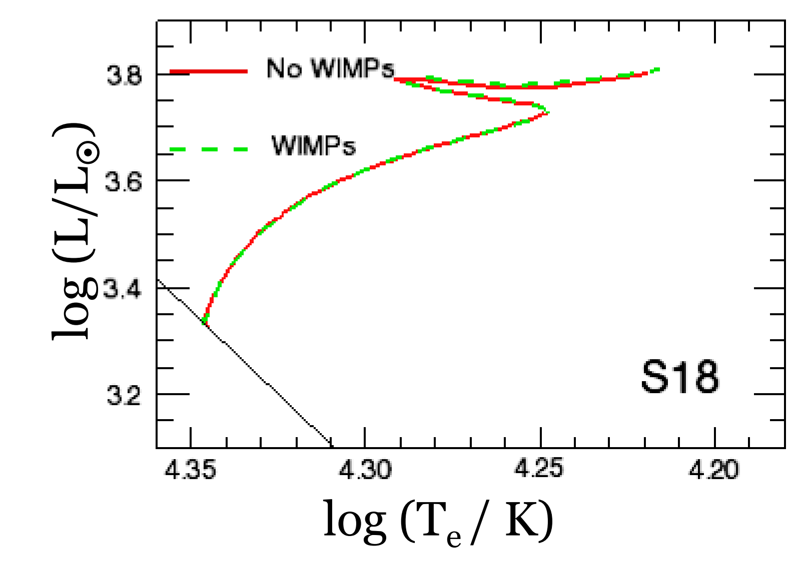

Log (L_star/L_sun)
Log T_eff (K)
P=10 years
M_star=7M_sun
m_WIMP=100 GeV
Z=0,01
No WIMPs
e=0
e=0,5
e=0,9995
ZAMS

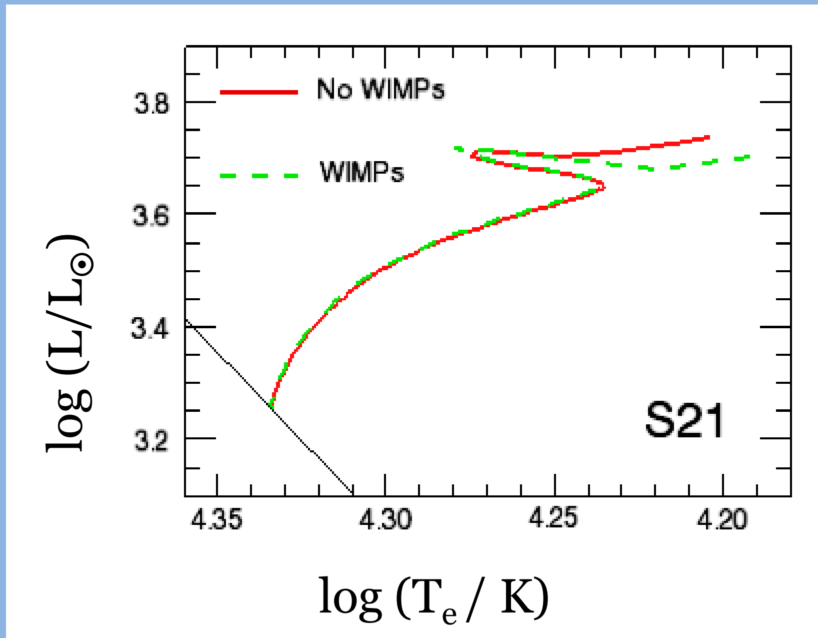
Simulating S Stars

Star	$M(M_{sun})$	e	T (years)
S2	15	0.88	15.8
S18	7.4	0.759	50
S21	7	0.78	35.8
S29	7.4	0.916	91
S38	6.8	0.8	18.9
SO-102	6.8	0.68	11.5

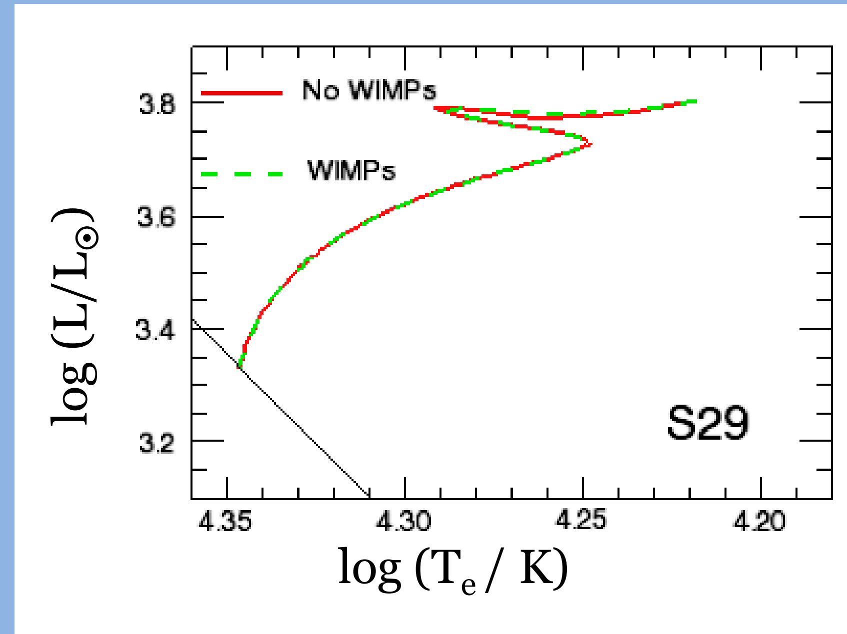
- WIMP mass : 10 GeV (DAMA, CoGeNT, CRESST II)
- Orbital parameters (Gillesen et al. 2009, Meyer et al 2012)
- AC + spike



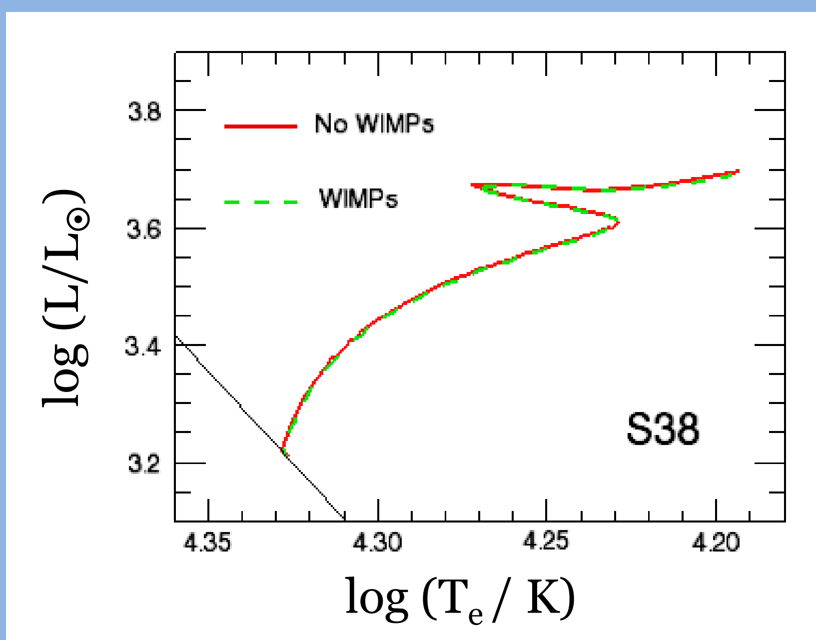




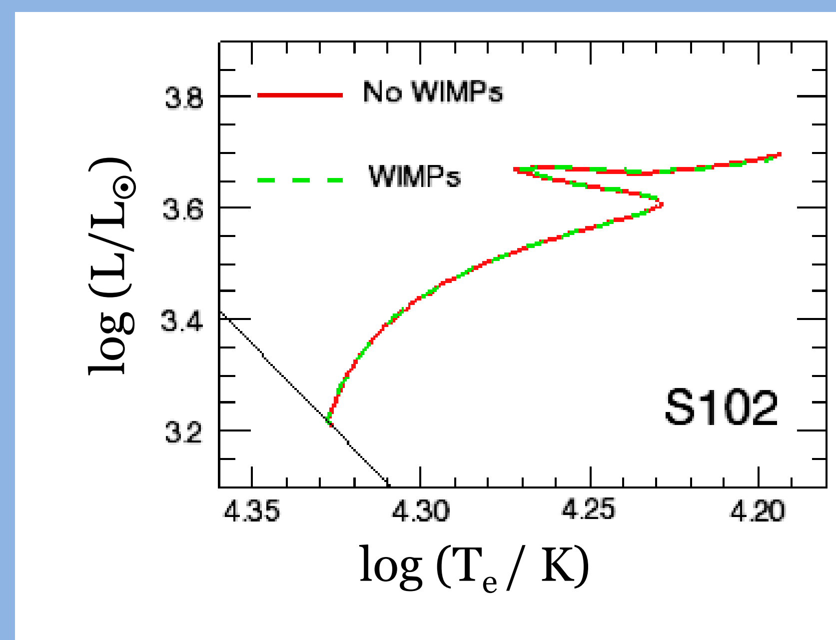
No WIMPs
WIMPs
S21
3.8
3.6
3.4
3.2
4.35
4.30
4.25
4.20
log (L/L$_\odot$)
log (T$_e$ / K)



No WIMPs
WIMPs
S29
3.8
3.6
3.4
3.2
4.35
4.30
4.25
4.20
log (L/L$_\odot$)
log (T$_e$ / K)



No WIMPs
WIMPs
S38
3.8
3.6
3.4
3.2
4.35
4.30
4.25
4.20
log (L/L$_\odot$)
log (T$_e$ / K)



No WIMPs
WIMPs
S102
3.8
3.6
3.4
3.2
4.35
4.30
4.25
4.20
log (L/L$_\odot$)
log (T$_e$ / K)

Conclusion…

- If the IMF in the Galactic center is top heavy, dense ambient WIMPs and high eccentricity of stellar orbit can't help WIMPs to significantly influence the structure and evolution of stars there

Next study…

- in situ scenario (stars born with WIMPs in the Galactic center)
- stars migrates from outer side & arrive at the Galactic center when they already reached the end of its MS lifetime → impacts of WIMP on post-main sequence stars (make the stars resemble O-B stars ? Or look outwardly as MS stars ?)