Observational properties of Type Ia Supernovae according to the Double Degenerate model

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Supernovae

Explosive events that are able to release $\sim 10^{51}$ erg in **electromagnetic** energy and **kinetic** energy of the ejected materials.
Some events release an amount of $\sim 10^{53}$ erg.

Core Collapse
(Types Ib/c, II)

Thermonuclear ignition
(Type Ia)

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Thermonuclear ignition
(Type Ia)

C-ignition in a degenerate environment.

The exploding star is a **Carbon-Oxygen White Dwarf** that accretes matter from a companion star until it reaches the **Chandrasekhar mass**.

Problem: There is no trace about the companion star in the archive sky frames.

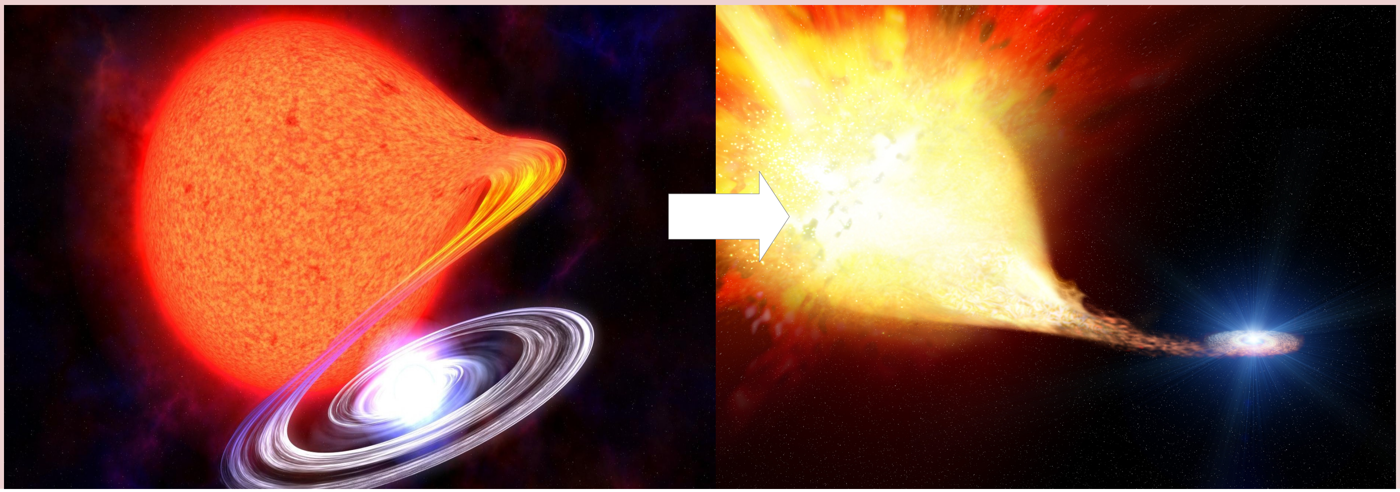
WHO IS THE COMPANION STAR?

SNe in physics

- **Astrophysics.** SNe induce **star formation** and contribute on the galaxy **metal enrichment**. They are also used as a **feedback factor** in the galaxies formation theory. [*Mo et al., 2010*]
- **Particle physics.** CC SNe are great factory of **neutinos** and **cosmic rays.** This is relevant in the studies about the neutrinos nature and about the discovery of some new exothic particle.
- **General relativity.** Asimmetric core collapse of Type II and Ib/c SNe are relevant **gravitational waves** sources and some Type Ia SNe progenitor systems involve close binaries able to emit **gravitational waves** radiation that could be revealed by modern gravitational interferometers. [*Nelemans, 2009*]
- **Cosmology.** Type Ia SNe are used as **standard candles** for distance measurements at high redshift because of the regularity of the light curves (**Phillips relationship**). SNe Ia are used to set **cosmological parameters.** [*Phillips, 1993*]

Progenitors scenarios

Single Degenate:



PRO: Evidence of single degenerate binary systems.

CON: No evidence about H-lines in SN Ia spectra.

Double Degenerate:

PRO: The lack of H lines in SN Ia spectra are explained.

CON: Theoretical problems affect the accretion models.

Progenitors scenarios

In order to know the correct **progenitor system** it is necessary to find **observational evidence** about such accreting mass systems.

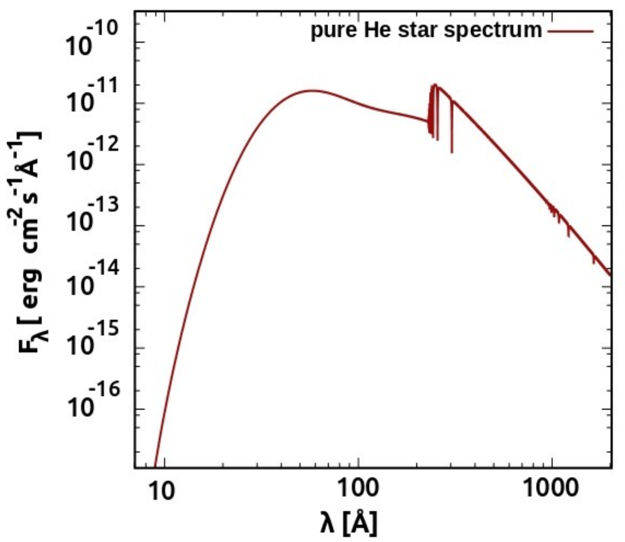
Single Degenerate system

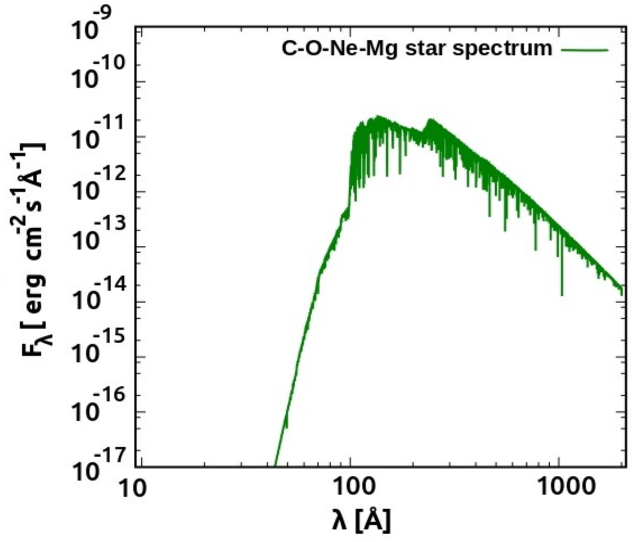
Two stars and an accretion disk spectra.

Double Degenerate system

One star and an accretion disk spectra.

Catalogs of stars spectra are available according to the **physical parameters**. **Absorption lines** depend on the chemical composition of the stellar atmosphere.





The disk spectrum has to be constructed

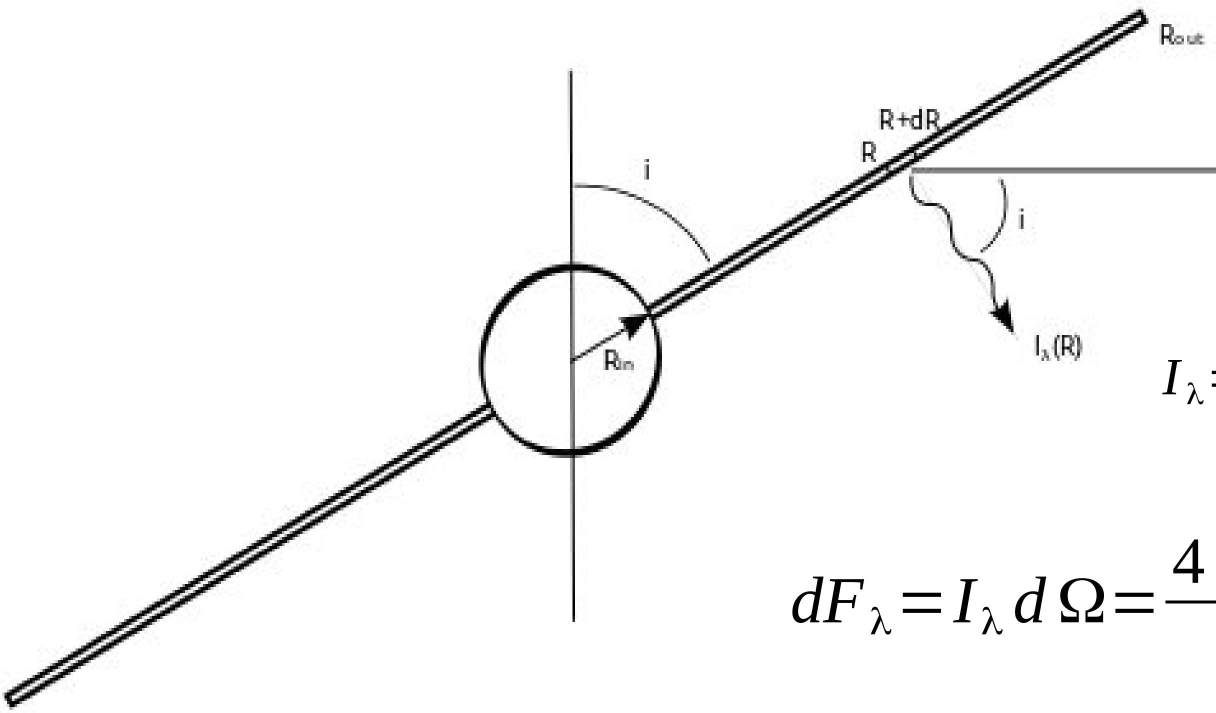
Outlines

The aim is to verify if the Double Degenerate model of SNe Ia progenitors
Is able to provide observational counterparts whose existence can be **observationally tested**.

- **Construct spectra** of the **total system** composed by the White Dwarf and the disk in each phase of the accretion sequence.
- Generate a **synthetic population** for the accreting mass systems in the Milky Way according to the SN Ia rate.
- Assign the **position** of each synthetic source to obtain the expected flux.
- Evaluate the **total extinction** due to the **dust** in the Milky Way.
- **Spectral deconvolution** in the bands used to construct catalogs.
- Comparisons between the magnitudes of **real sources** and the magnitudes obtained for the **synthetic sources** of the systems of the DD model in the Milky Way.

Accretion disk

The disk is **optically thick** therefore the anulus of the disk between R and R+dR emits as a black body at the **local thermodynamical equilibrium** temperature T(R).



$$I_\lambda = B_\lambda(T(R)) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{hc/\lambda k_B T(R)}-1}$$

$$dF_\lambda = I_\lambda d\Omega = \frac{4\pi h c^2 R\, dR \cos i}{D^2 \lambda^5}\frac{1}{e^{hc/\lambda k_B T(R)}-1}$$

$$F_\lambda = \frac{4\pi h c^2 \cos i}{D^2\lambda^5}\int_{R_{in}}^{R_{out}} \frac{R\, dR}{e^{hc/\lambda k_B T(R)}-1}$$

$$R_{in} = R_{WD}$$

Accretion disk

Continuity + Euler equations: $$\frac{\partial \Sigma}{\partial t} - \frac{3}{R}\frac{\partial}{\partial R}\left[\sqrt{R}\frac{\partial}{\partial R}\left(\Sigma \nu \sqrt{R}\right)\right] = 0$$

$$\nu = C R^p \Sigma^q$$

where p, q depend on the opacity regime. [*Ertan et al., 2009*]

$$\Sigma(R) = \Sigma_0 k_{p,q}^{\frac{p}{2q-p+2}} \left(\frac{R}{R_{out}}\right)^{-\frac{p}{q+1}} \left[1 - \left(\frac{R}{R_{out}}\right)^{2-\frac{p}{q+1}}\right]^{1/q}$$

$$R_{out} = R_0 k_{p,q}^{-\frac{q+1}{2q-p+2}} \qquad k_{p,q} = \frac{q}{(4q-2p+4)(5q-2p+4)}$$

where R_0 and Σ_0 depend by M_{disk} and J_{disk}.

Viscous shear energy release

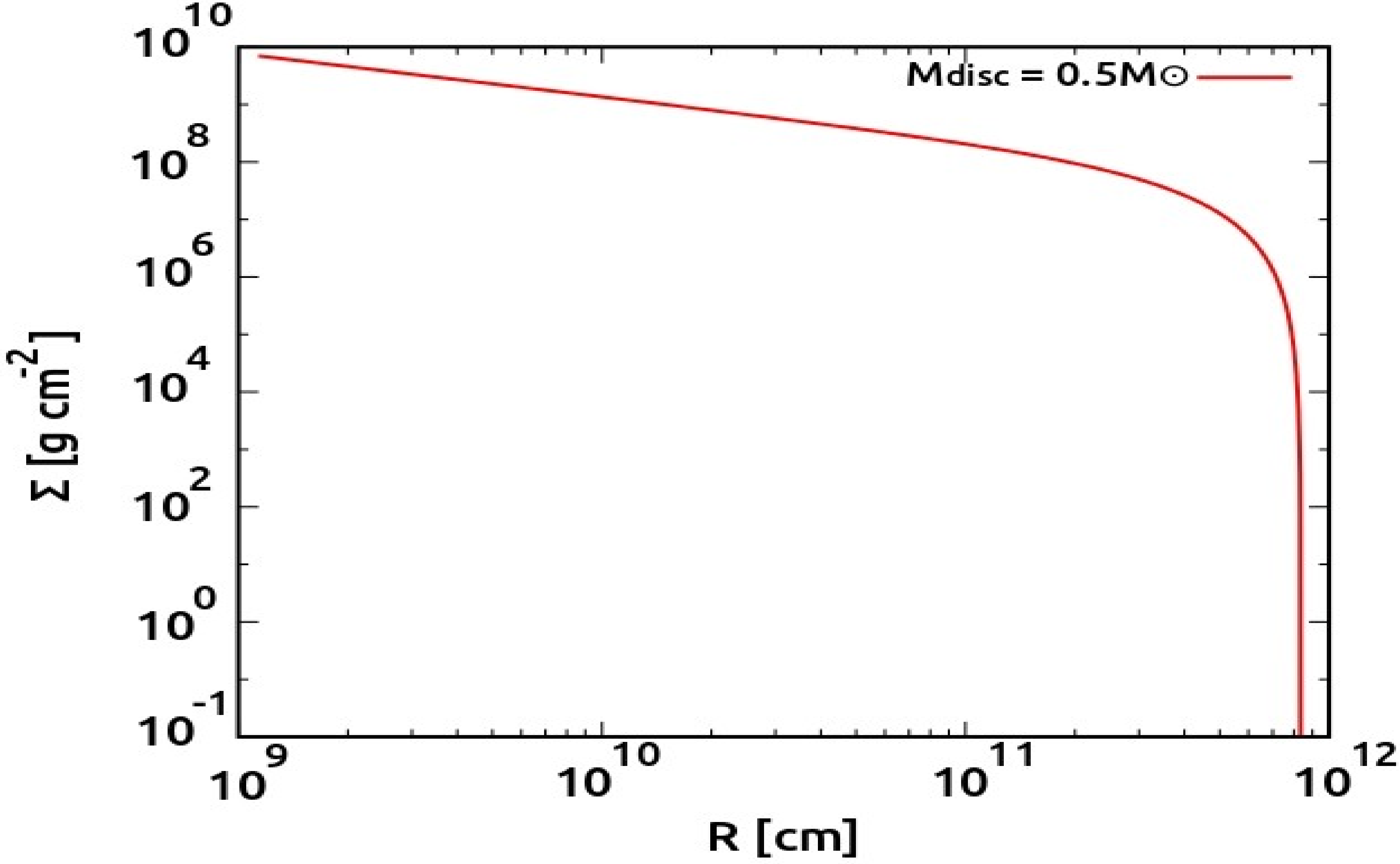
$$D(R) = \frac{9}{8}\Sigma(R)\nu\frac{G M_{WD}}{R^3}$$

Stefan-Boltzmann law

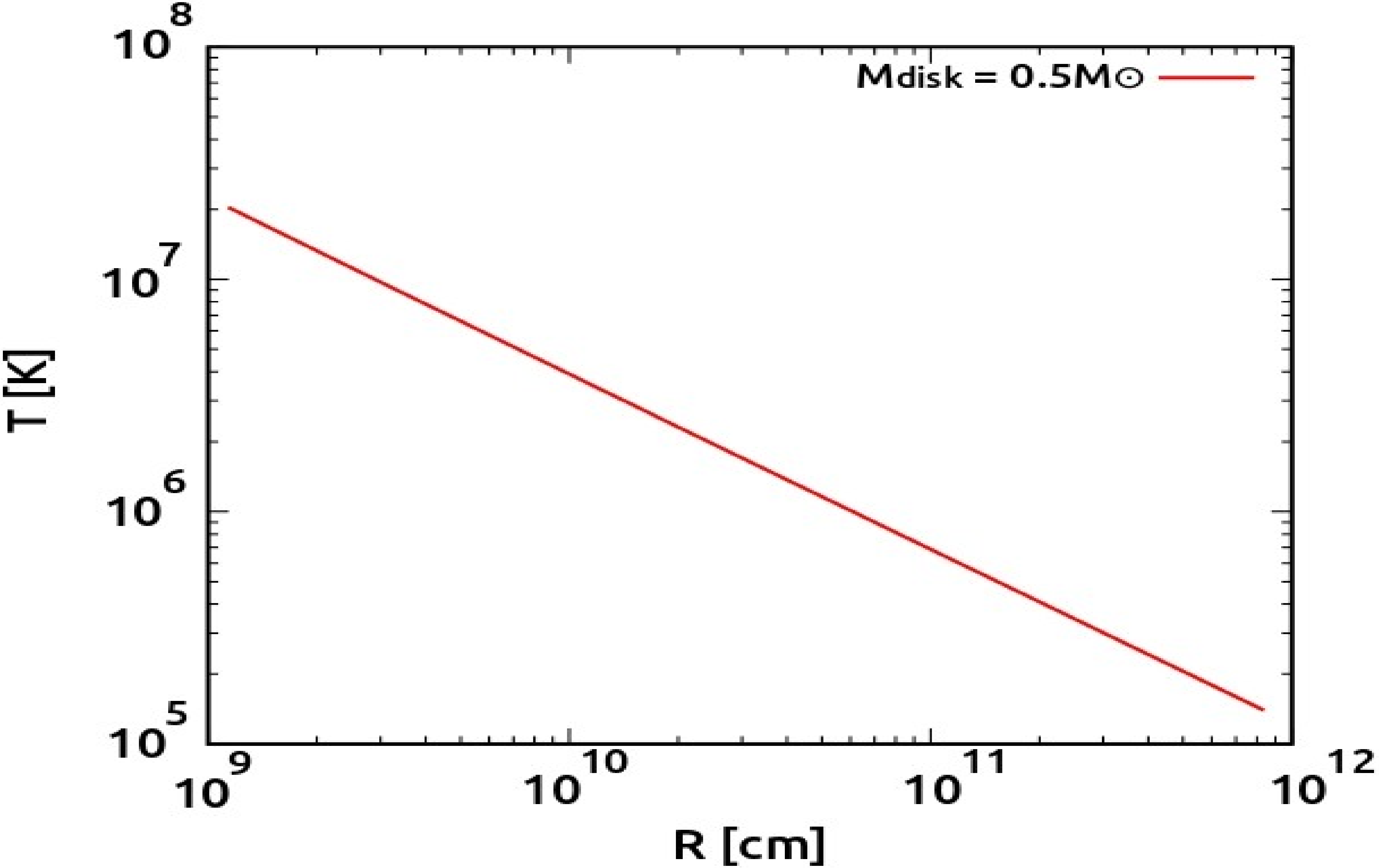
$$D(R) = \sigma_{SB} T(R)^4$$

$$T(R) = \left\{\frac{3 G M_{WD} \dot{M}}{8\pi\sigma_{SB} R_{out}^3}\left[1 - \left(\frac{R_{WD}}{R_{out}}\right)^{2-\frac{p}{q+1}}\right]^{-1/q}\left[1 - \frac{5q-2p+4}{q}\left(\frac{R_{WD}}{R_{out}}\right)^{2-\frac{p}{q+1}}\right]\right\}^{1/4}\left(\frac{R}{R_{out}}\right)^{-3/4}\left[1 - \left(\frac{R}{R_{out}}\right)^{2-\frac{p}{q+1}}\right]^{\frac{q+1}{4q}}$$

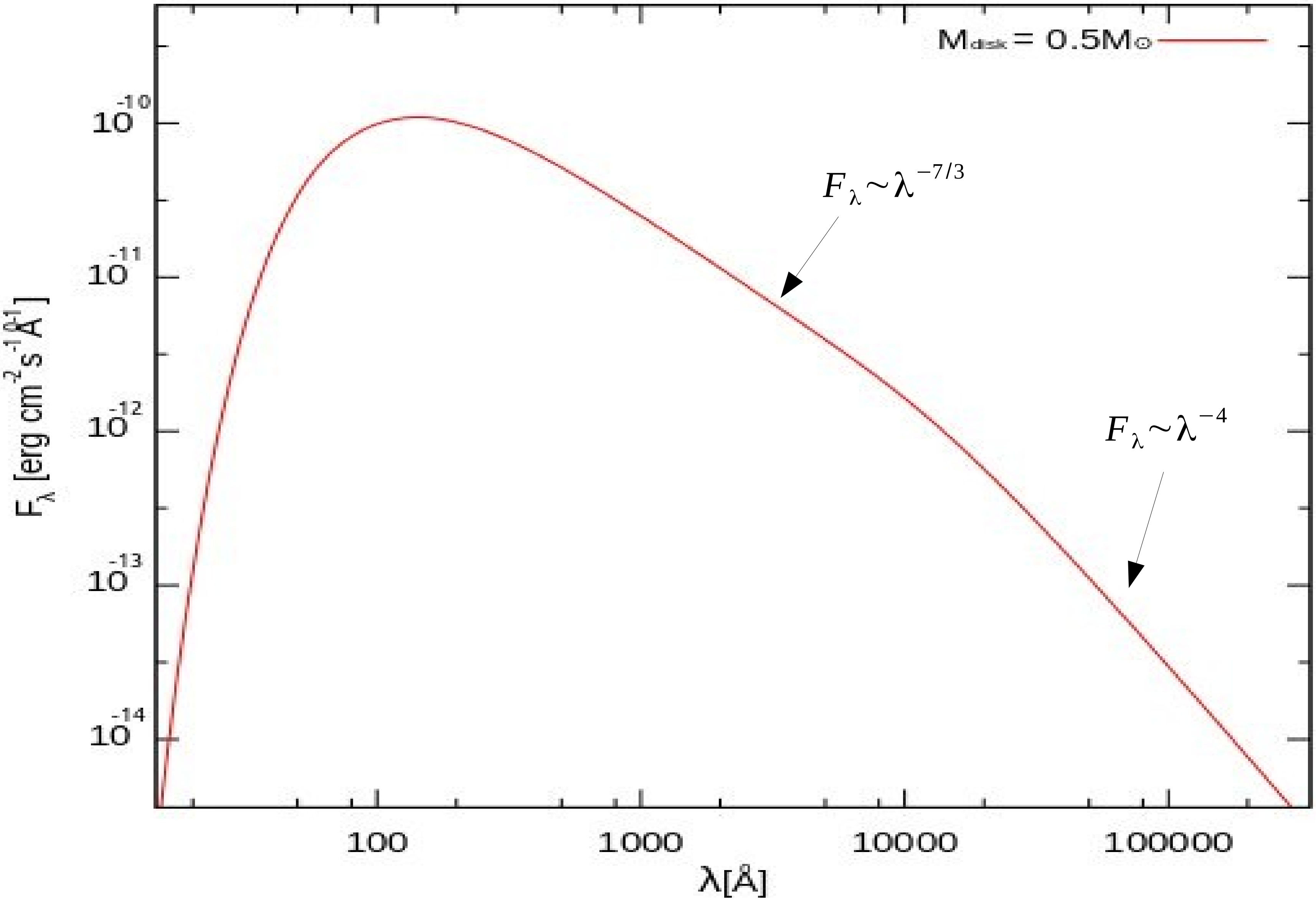
Accretion disk



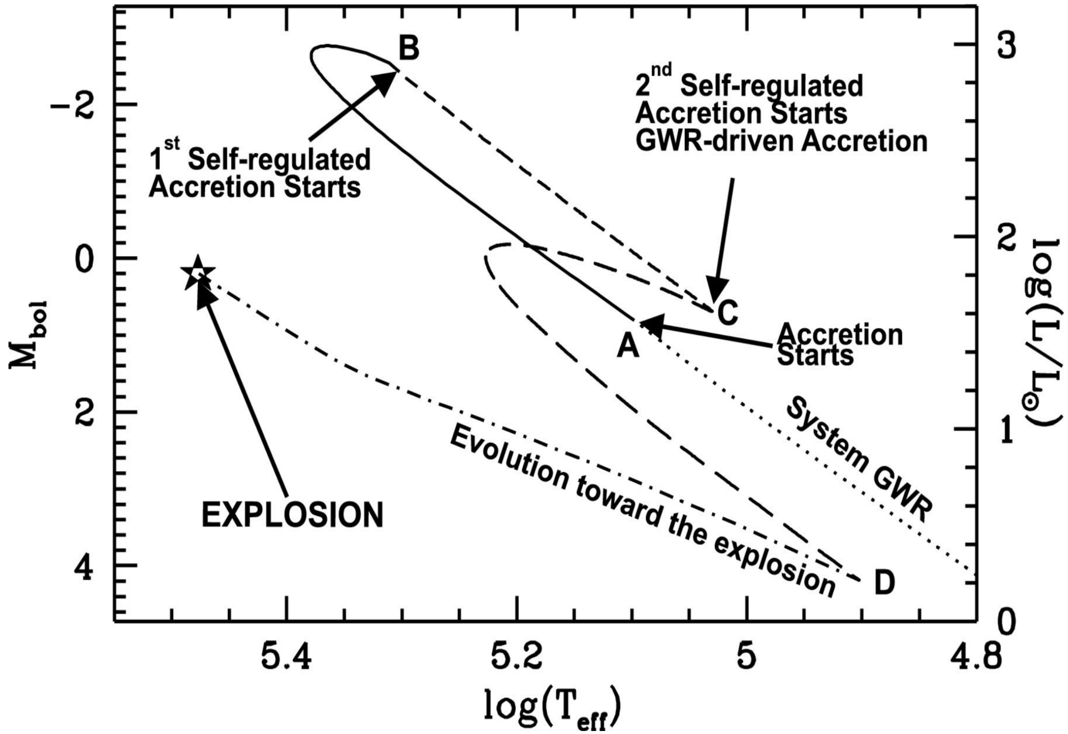
Accretion disk



Accretion disk



Accretion model

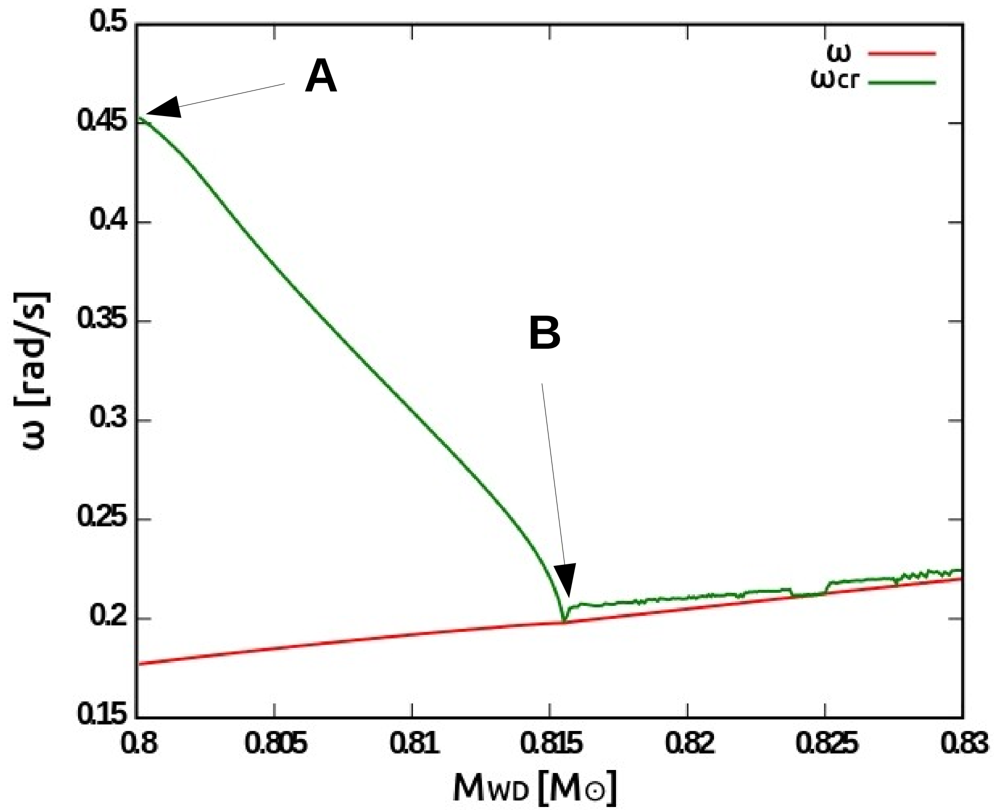


[*Tornambé & Piersanti, 2013*]

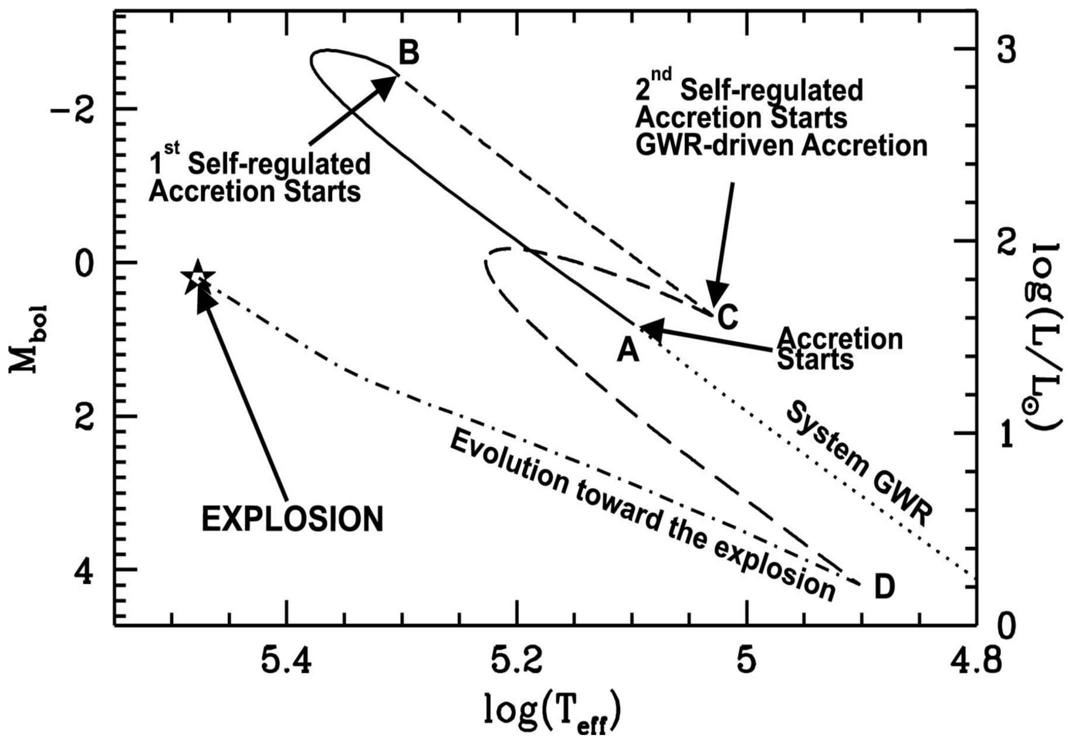
From A to B: Constant accretion rate until the critical condition $\omega = \omega_{cr} = \sqrt{G\, M_{WD} / R^3_{WD}}$ is reached. [*Piersanti et al., 2003*]

The accretion process stops.

From B to C: First **self-regulated** accretion phase due to the star thermal diffusion.



Accretion model



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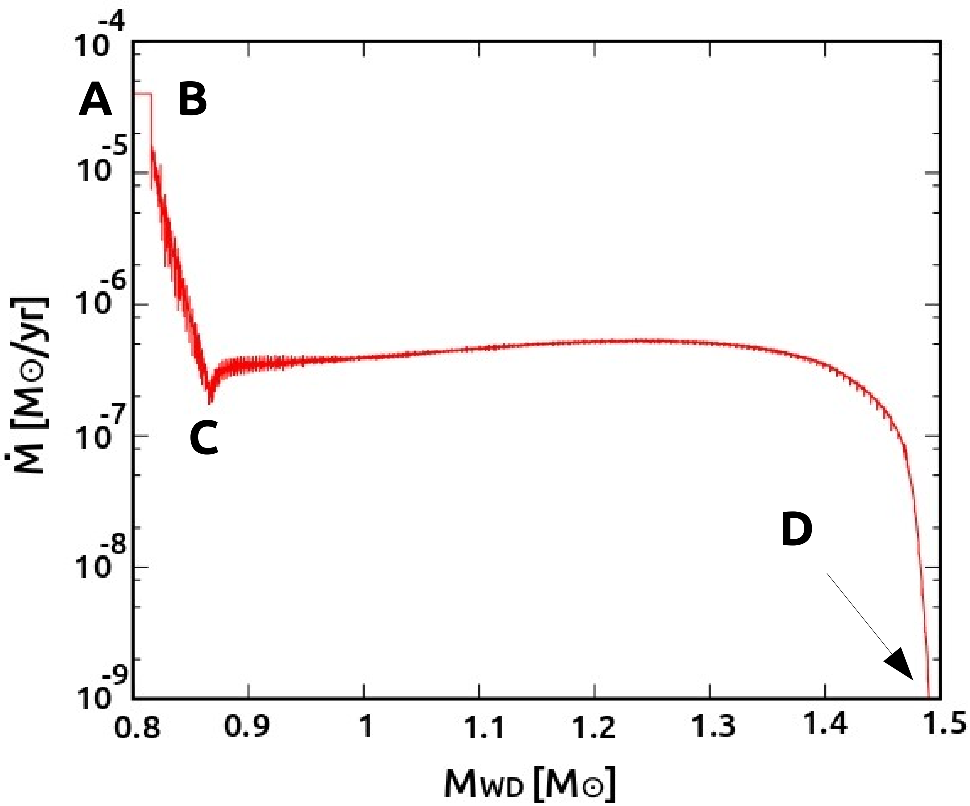


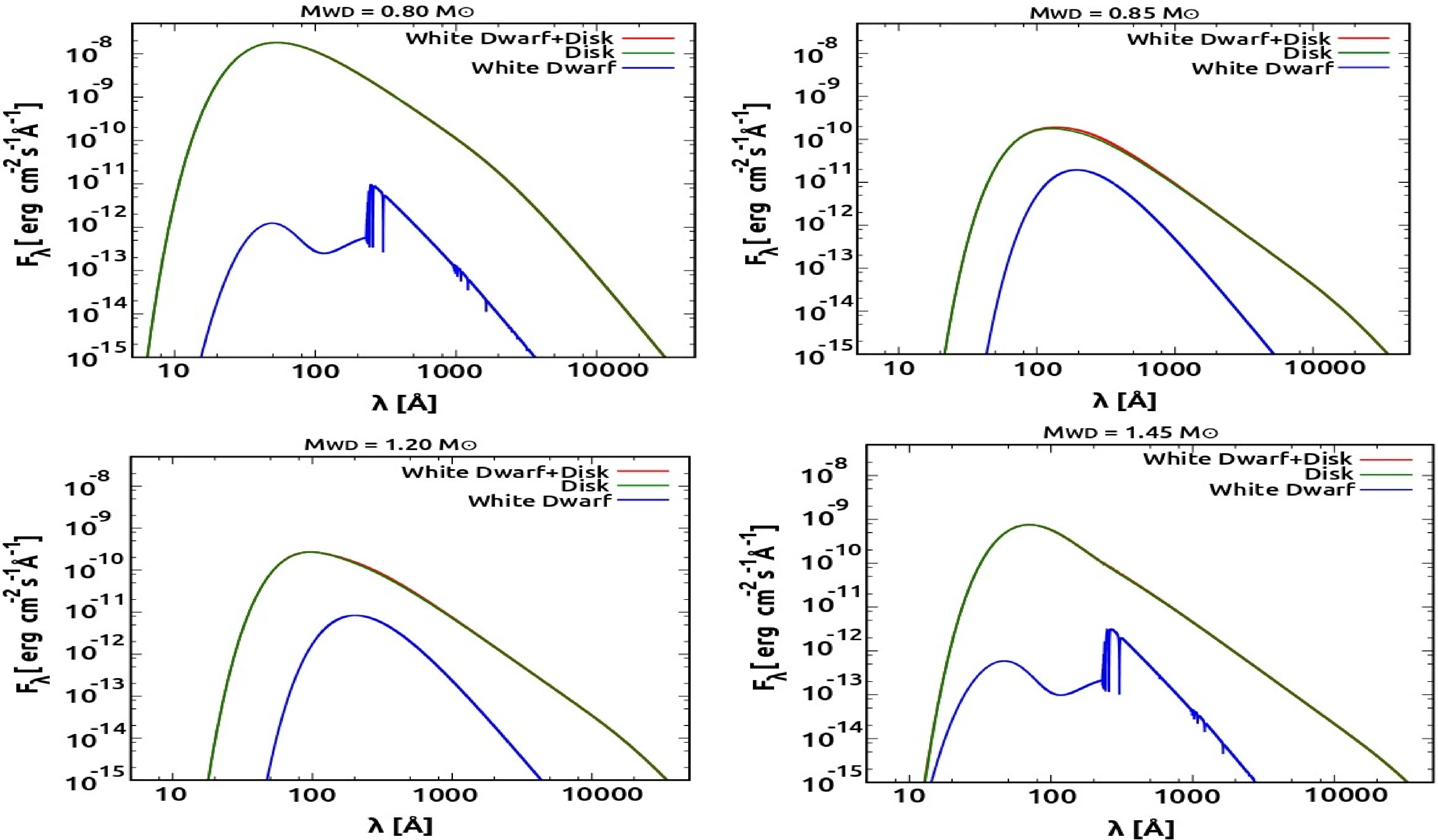
From C to D: Second **self-regulated** accretion phase due to the Gravitational Waves emission.

At the point D of the evolution sequence the accretion process definitively stops.

Total system spectra

Distance: D=1Kpc

Disk inclination: i=60°



Synthetic sources

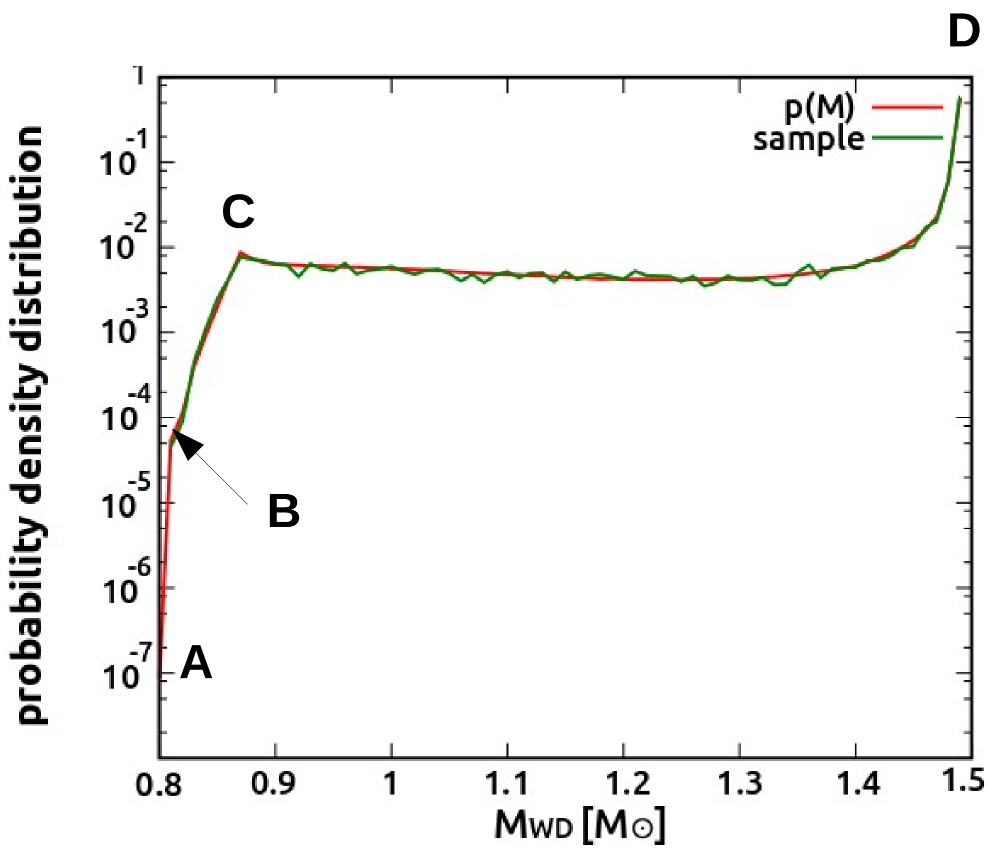
The expected number of systems of the model in the Milky Way are ≈ 22000

Synthetic sources population

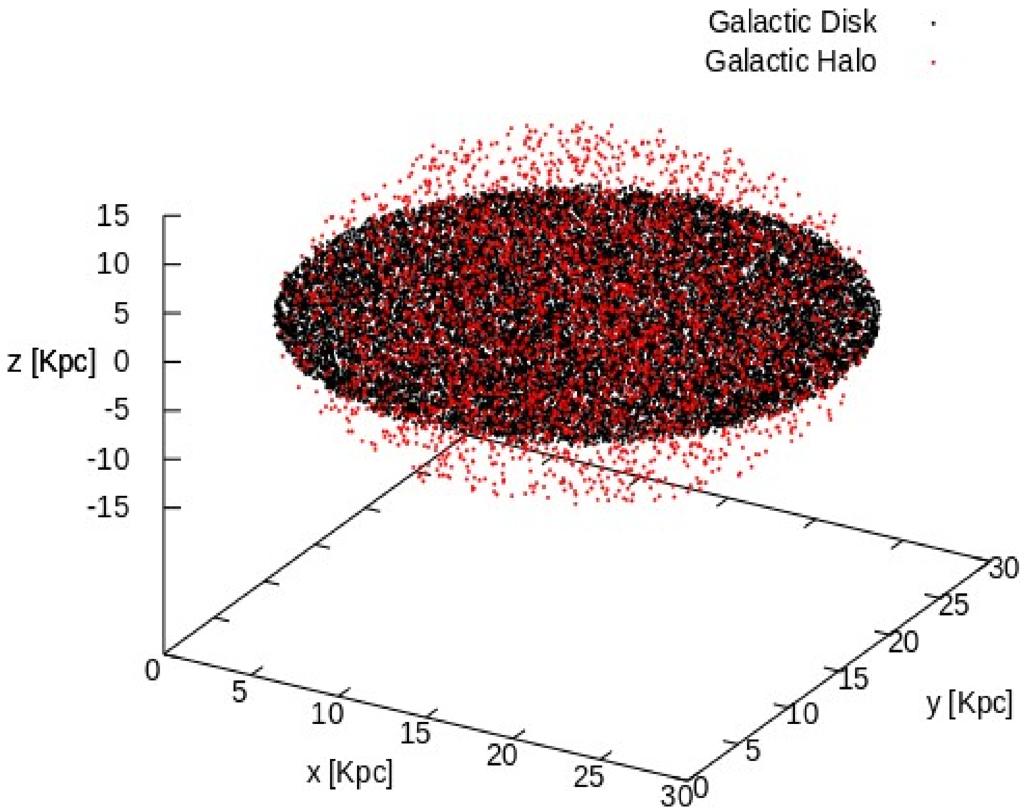
The number of sources in each accretion phase is given by the probability to find a source in the range of mass of that phase.

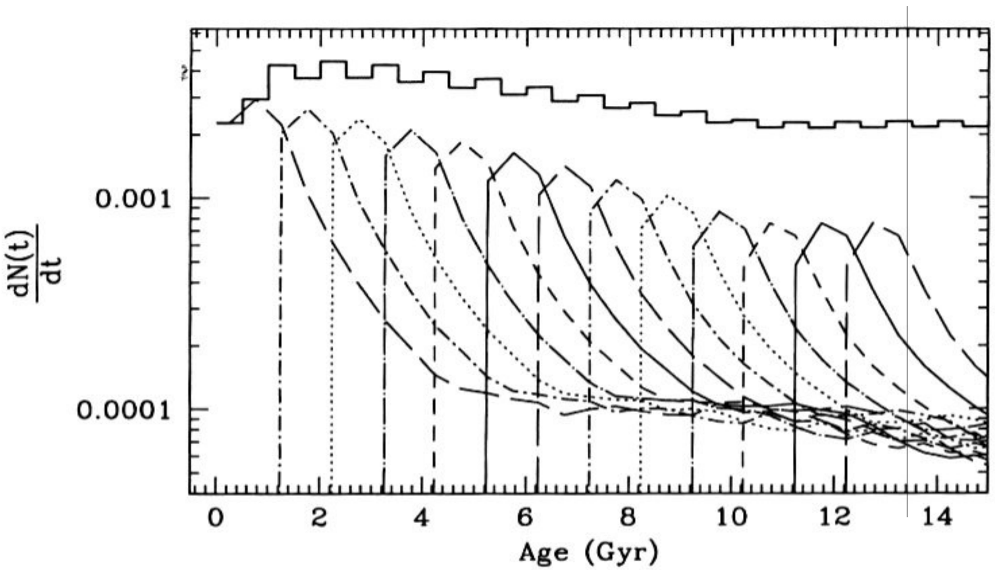
$$p(M)=\frac{N(M)}{N_{AD}}=\frac{\Delta t(M)}{\Delta t_{AD}}$$

$$N(M)=N_{AD}\frac{\Delta t(M)}{\Delta t_{AD}}$$



Synthetic sources





~13.5 Gyr

[*Piersanti et al., 2009*]

Halo: $\sim 15\,\%$ **Disk**: $\sim 85\,\%$

Earth coordinates:

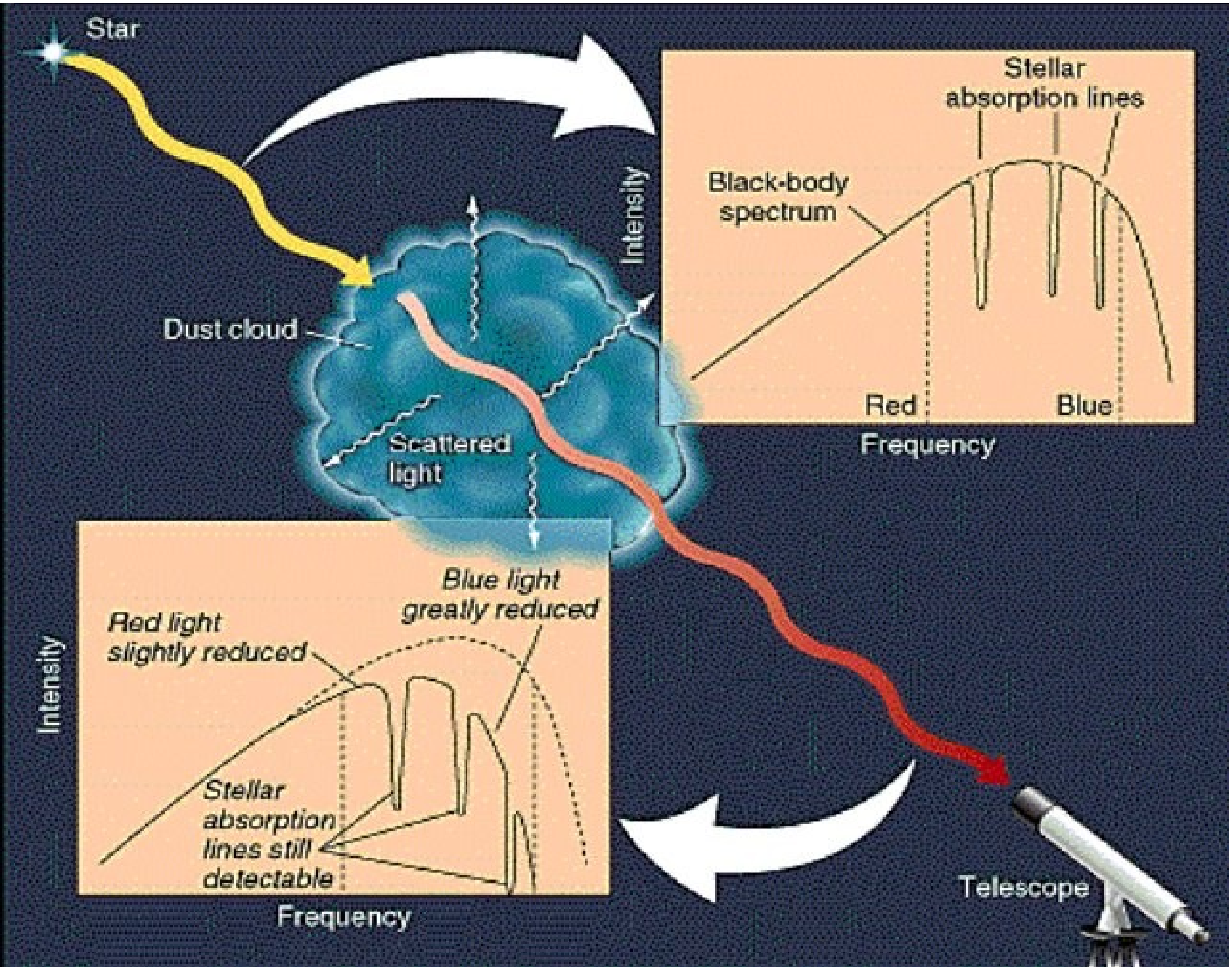
$$(x_E, y_E, z_E) = (15, 7.5, 0)$$

Galactic center coordinates:

$$(x_C, y_C, z_C) = (15, 15, 0)$$

The position of each source has been assigned randomly by taking into account of both the Halo and galactic disk stellar populations.

Dust extinction



$$F_\lambda = F_{\lambda 0} e^{-\frac{A_\lambda}{2.5 \log e}}$$

The total extinction coefficient A_λ has been evaluated according to the interstellar extiction model in the Milky Way from Amôres & Lépine (2005).

Expected magnitudes

GALEX (Galaxy Evolution Explorer) → Sky surveys in the Far and Near UV bands

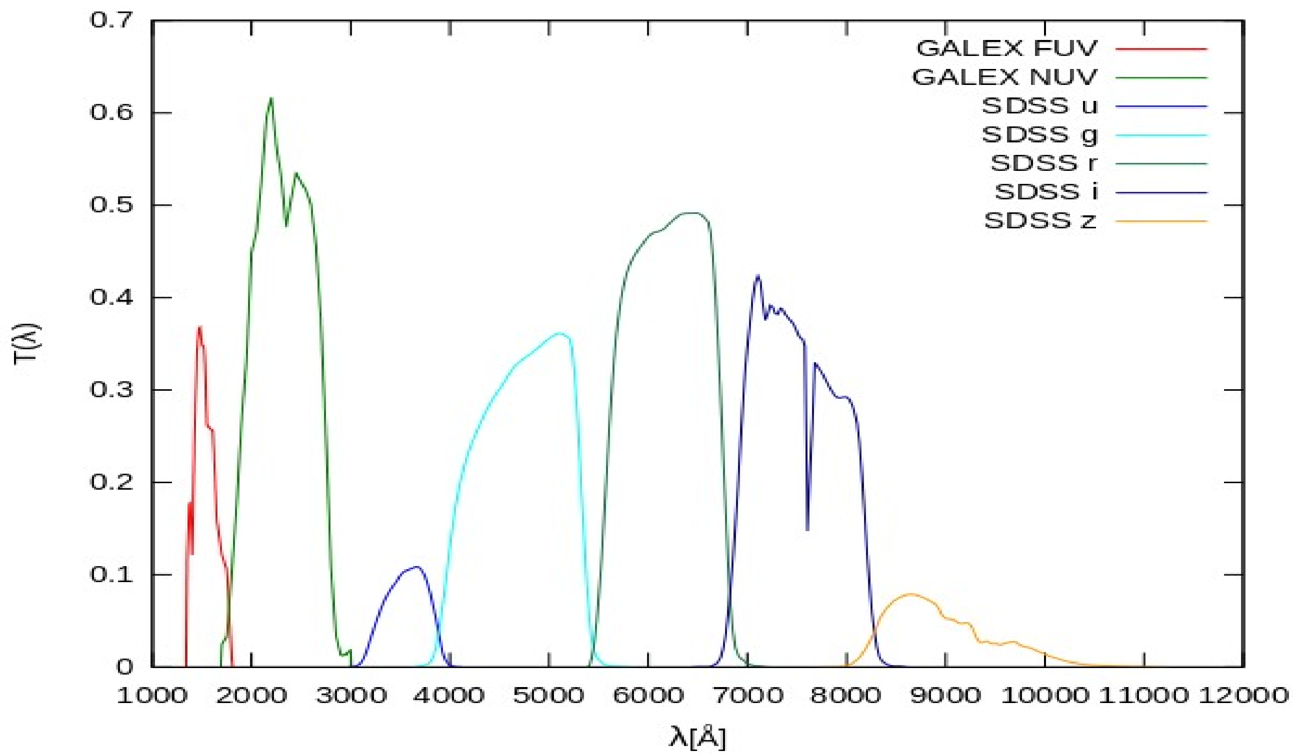
SDSS (Sloan Digital Sky Survey) → Sky surveys in five optical bands

Filtered specific flux

$$f_{T0} = \frac{\int f_{\nu 0} T(\nu) d\nu}{\int T(\nu) d\nu} = \frac{\int f_{\lambda 0} T(\lambda) d\lambda}{\int T(\nu) d\nu}$$

Filtered total extinction

$$A_T = \frac{\int A_\nu T(\nu) d\nu}{\int T(\nu) d\nu} = \frac{\int A_\lambda T(\lambda) d\lambda}{\int T(\lambda) d\lambda}$$



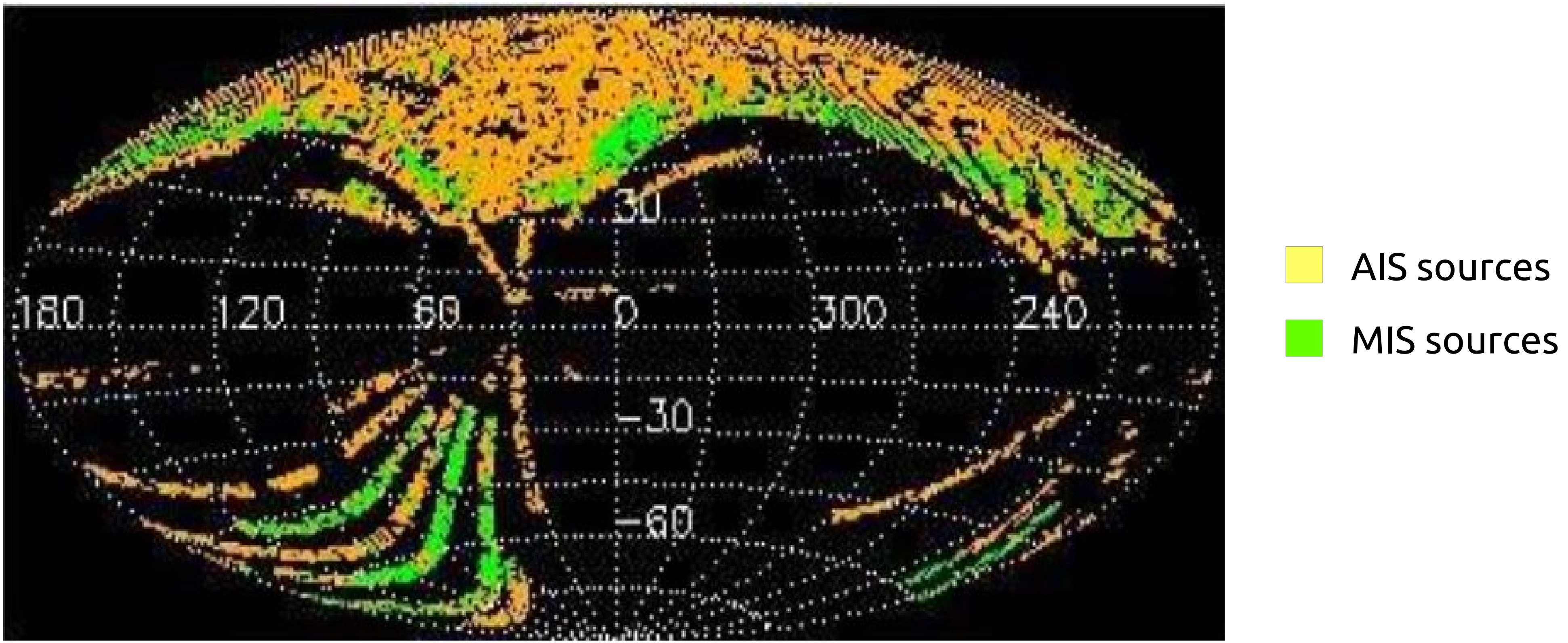
AB magnitude: $m_T^{AB} = -2.5 \log \left(\frac{f_{T0}}{\text{erg cm}^2 \text{ s}^{-1} \text{ Hz}^{-1}} \right) + A_T + 5 \log \left(\frac{D}{1 \text{ Kpc}} \right) - 48.60$

Color indexes: $T - T' = m_T^{AB} - m_{T'}^{AB} = 2.5 \log \left(\frac{f_{T'0}}{f_{T0}} \right) + A_T - A_{T'}$

Comparisons with catalogs

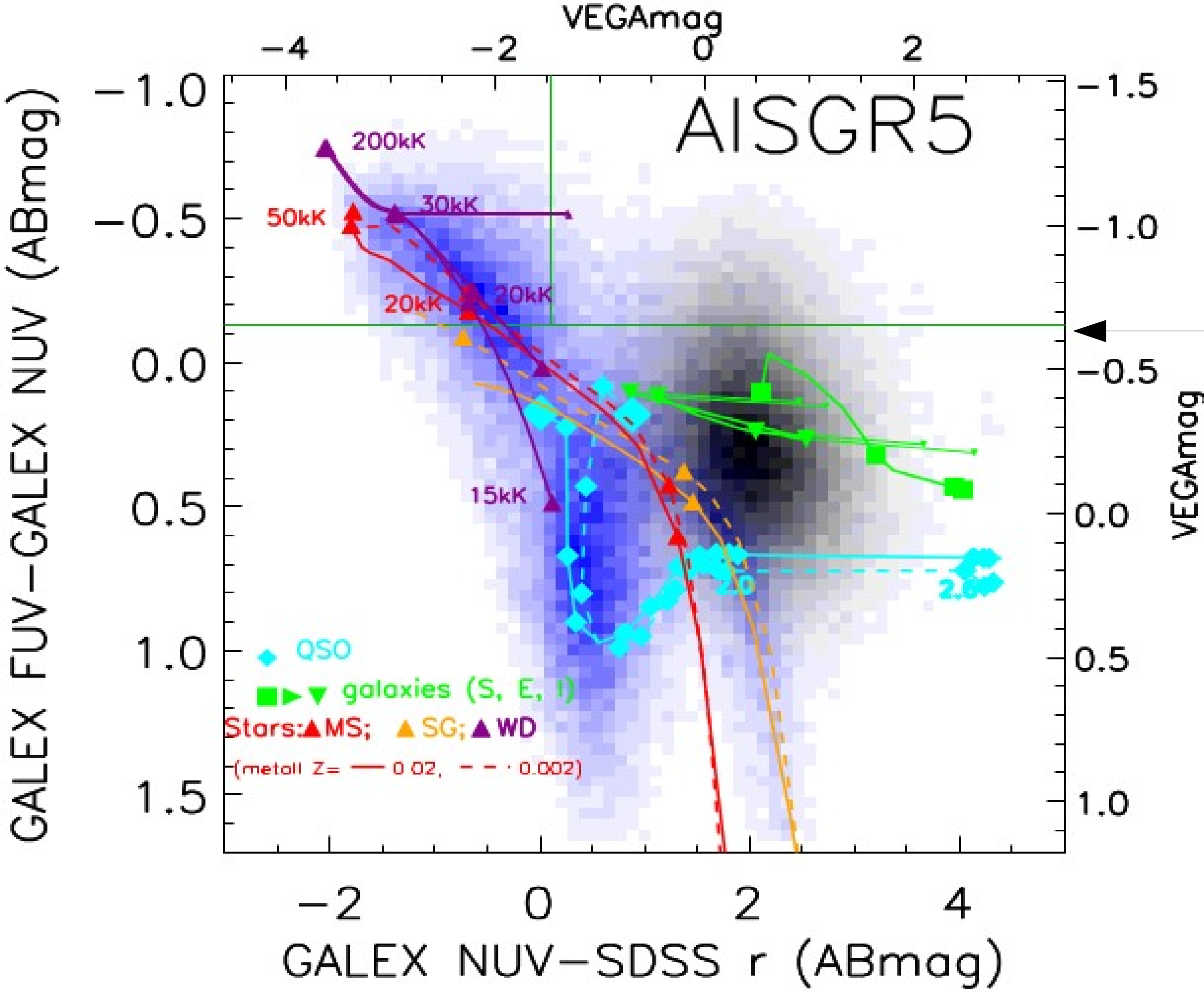
All-Sky Imaging Survey (AIS) → **Magnitude depth**: 19.9/20.8 AB mag in the FUV/NUV bands

Medium-depth Imaging Survey (MIS) → **Magnitude depth**: 22.6/22.7 AB mag in the FUV/NUV bands



[*Bianchi et al., 2011*]

AIS catalog

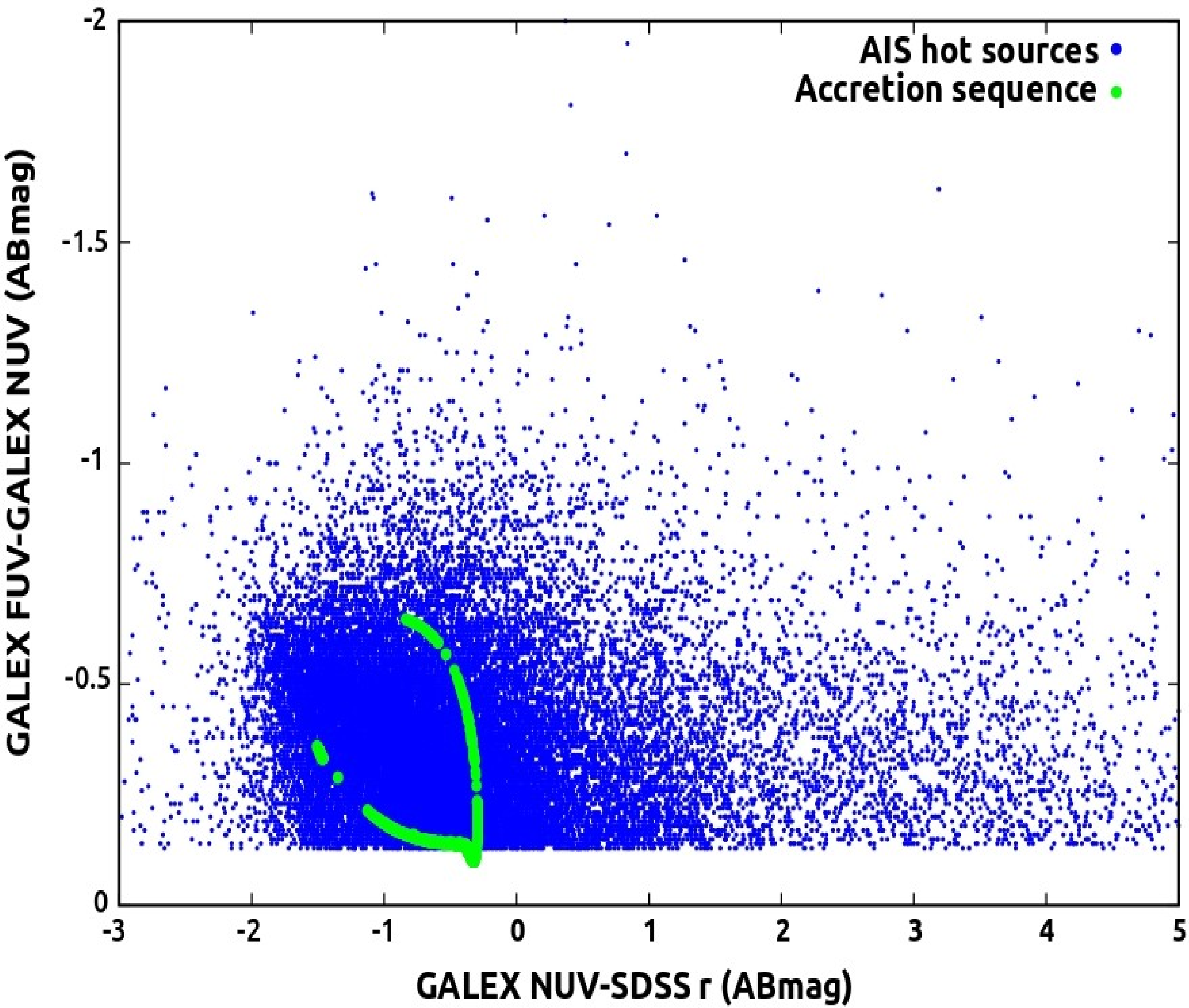


[*Bianchi et al., 2011*]

Extragalactic contaminations have been excluded

FUV-NUV = -0.13

AIS catalog



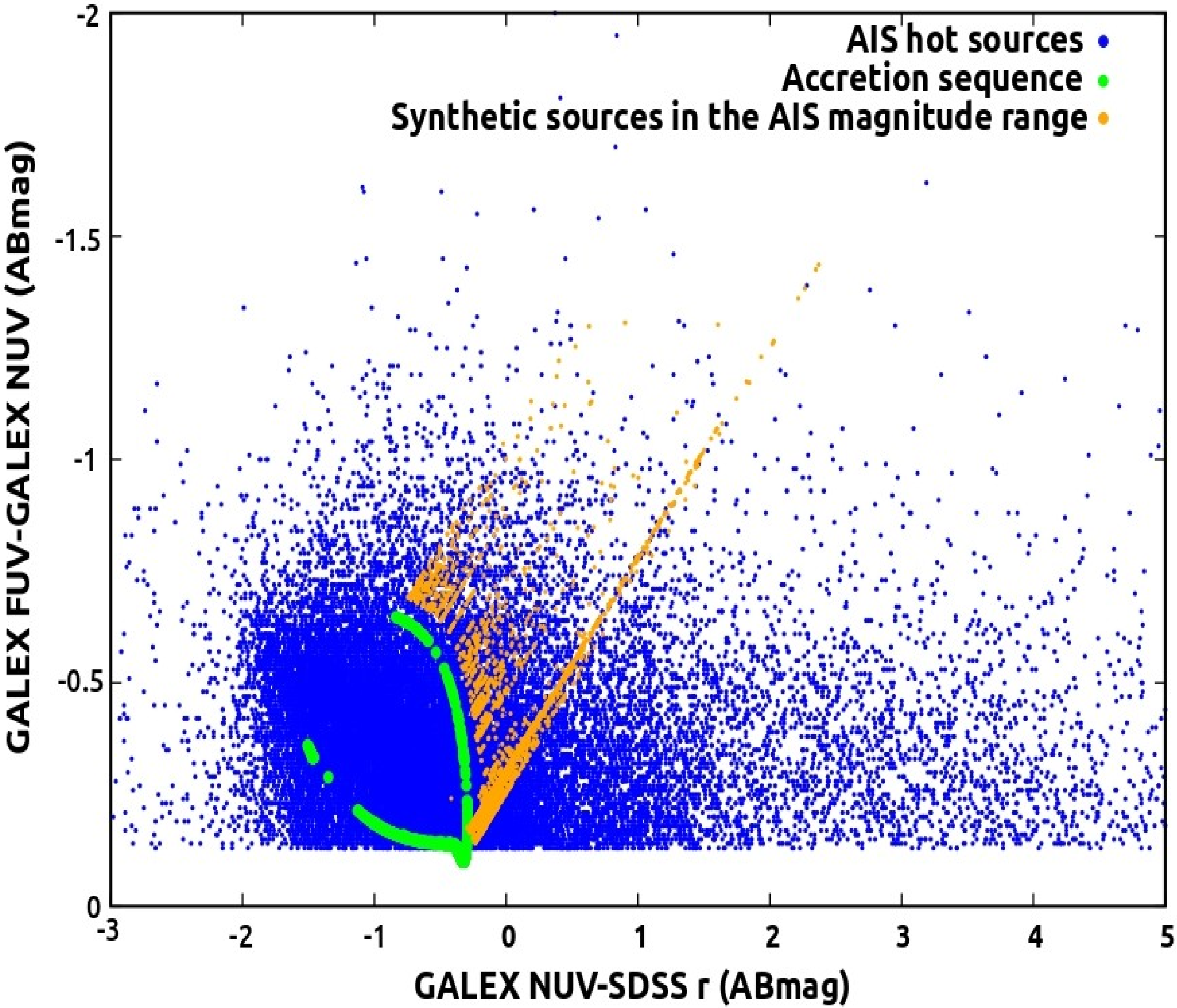
First result

The accretion sequence is displayed in the region where the real sources are.

The observables obtained for the systems of the analyzed DD model are compatible with those of the real sources.

The DD model can be supported by observations.

AIS catalog

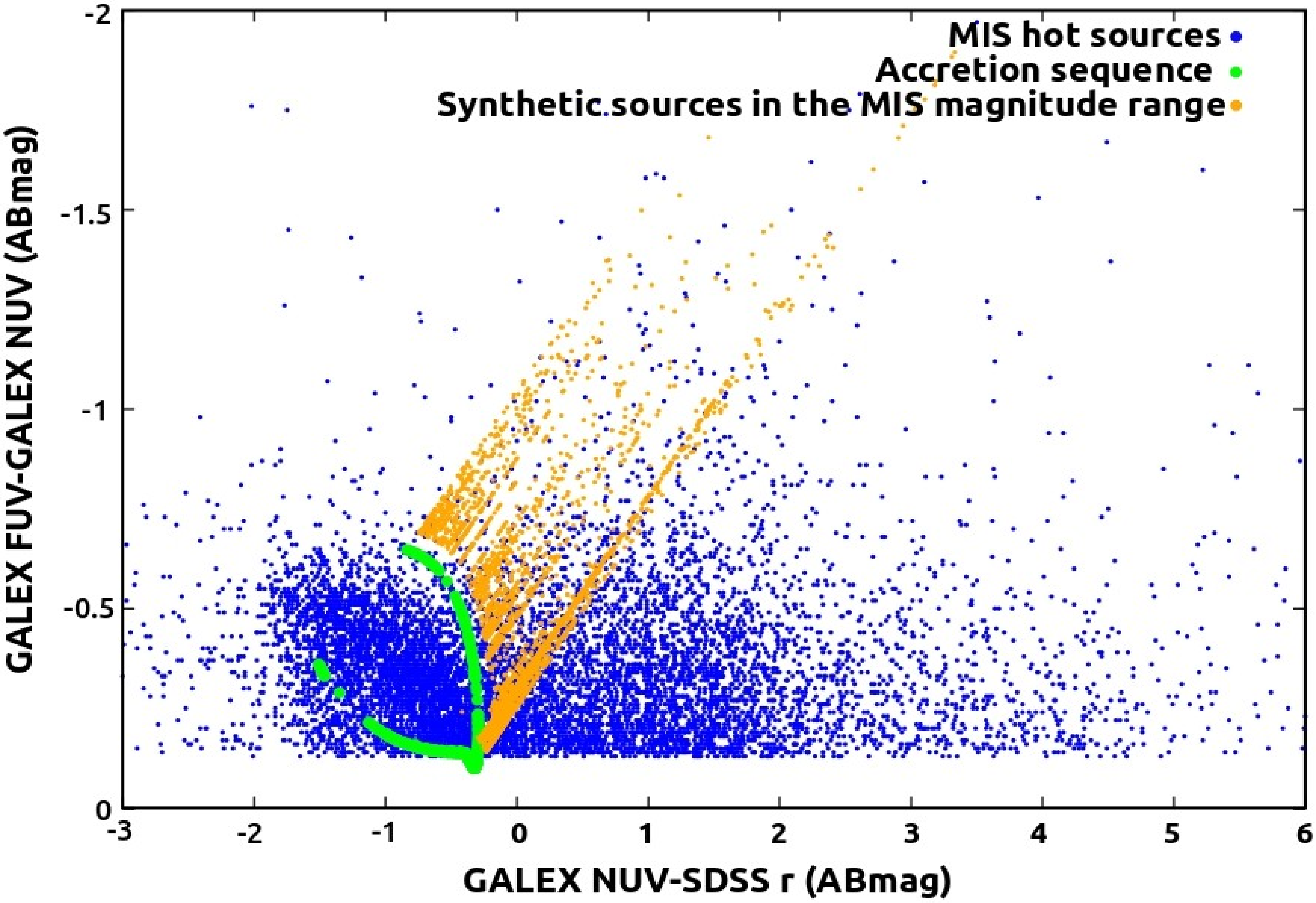


Second result

The synthetic sorces for the quoted model in the Milky Way cover a real sources dense-region in the color-color diagram.

It has been defined a region in the color-color diagram where the sources of the model can be founded.

MIS catalog



MIS hot sources
Accretion sequence
Synthetic sources in the MIS magnitude range
GALEX FUV-GALEX NUV (ABmag)
GALEX NUV-SDSS r (ABmag)
-2
-1.5
-1
-0.5
0
-3
-2
-1
0
1
2
3
4
5
6

Conclusions

Results:

- The accretion sequence for the analyzed Double Degenerate model is displayed in the color-color diagram region populated by real sources. This means that the Double Degenerate model should be further inquired.
- It has been possible to define a **region** in the analyzed color-color diagram where the systems of the model can be found and it overlaps the real sources region .
- The disk spectra have been constructed from the accretion disk theory and they can be use also to study the Single Degenerate model and to define **new physical constraints** to restrict the Double Degenerate region in the analyzed color-color diagram.