Wide Range Spectral Study Of OB Supergiants: Optical To X Rays

Raul E. Puebla Ph.D.[1,2]

[1]Centro de Física.
[2]Facultad de Ingeniería, Ciencias Físicas y Matemática
Universidad Central del Ecuador

XVI Encuentro de Física



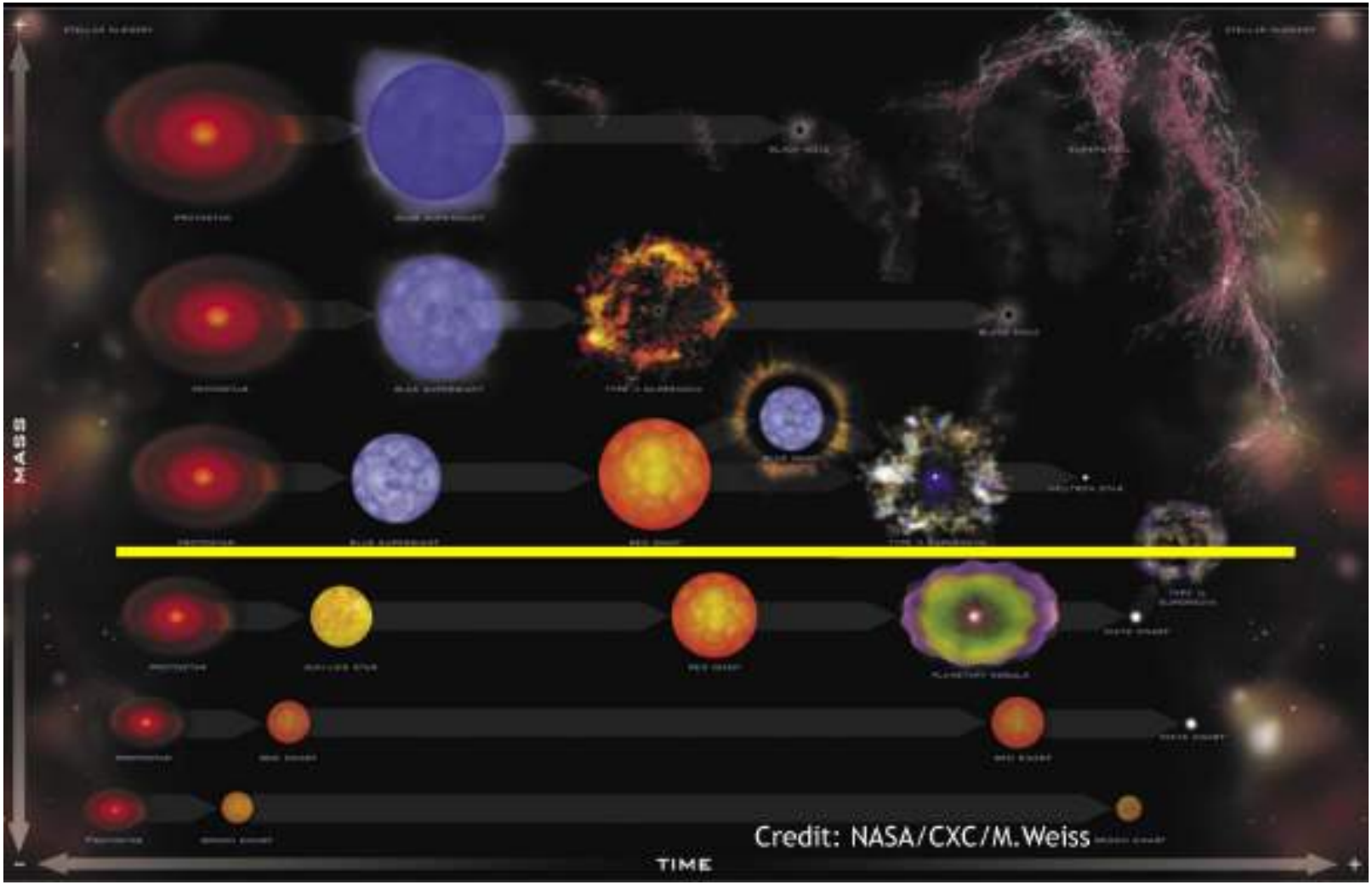
Outline

1. Introducción
2. Vientos Estelares
3. Evidencias Observacionales
4. Condensaciones en Vientos
5. Emision de Rayos X
6. Instrumentos y Detectores
7. Rayos X en Estrellas Masivas
8. El caso de ϵ Ori
9. Fislab y Geolab

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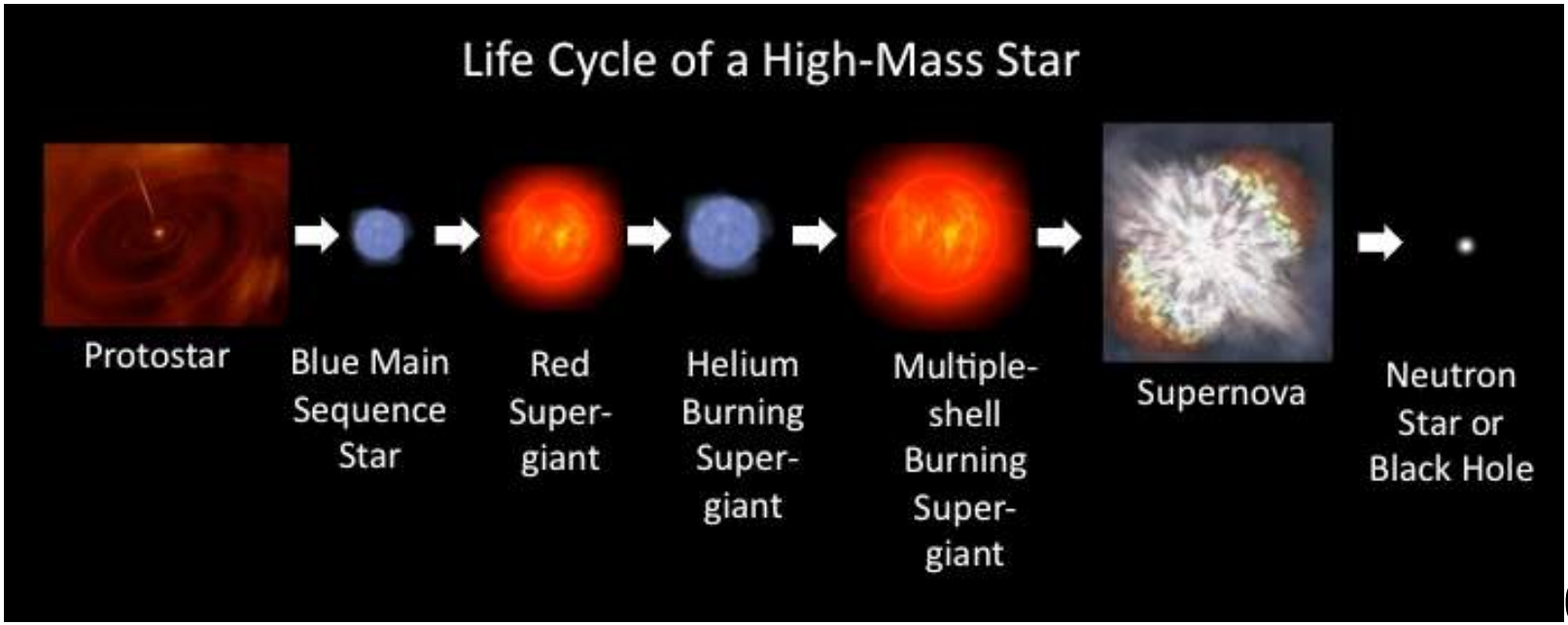
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Evolución Estelar



Meynet 2011

Evolución Estelar



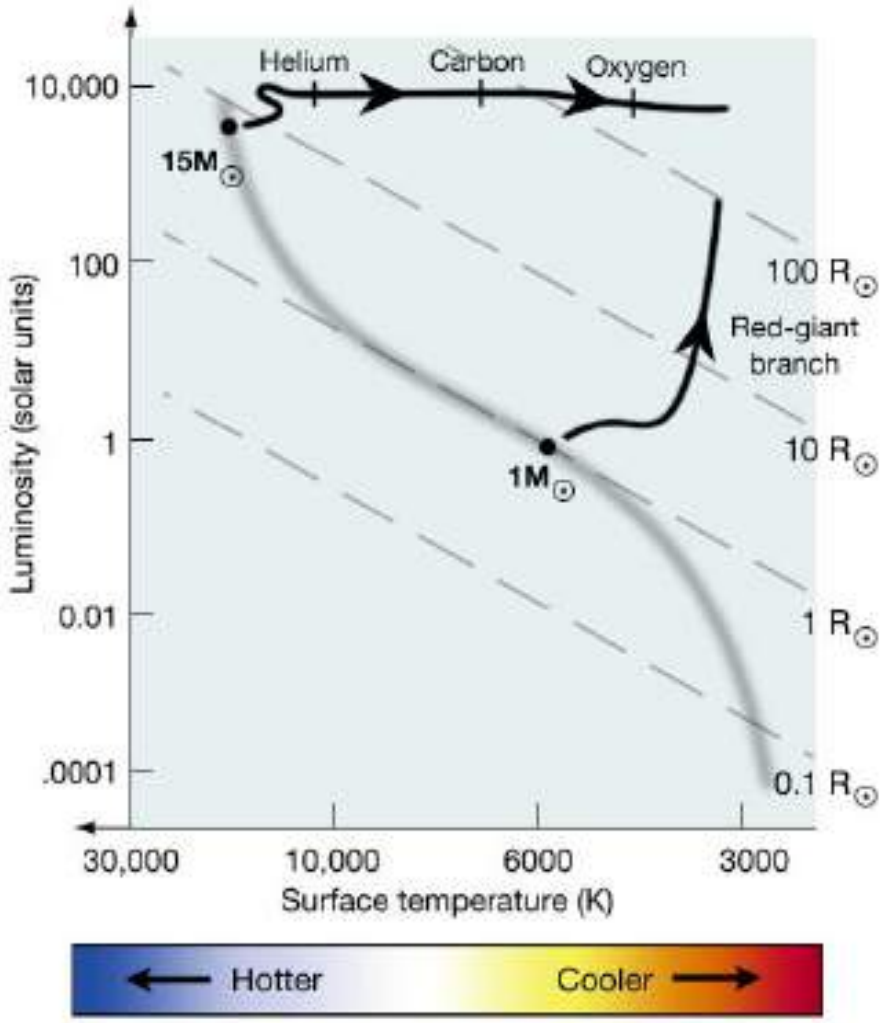
$0.1 < M/M_\odot < 1 \Rightarrow 61\%$

$1 < M/M_\odot < 8 \Rightarrow 25\%$

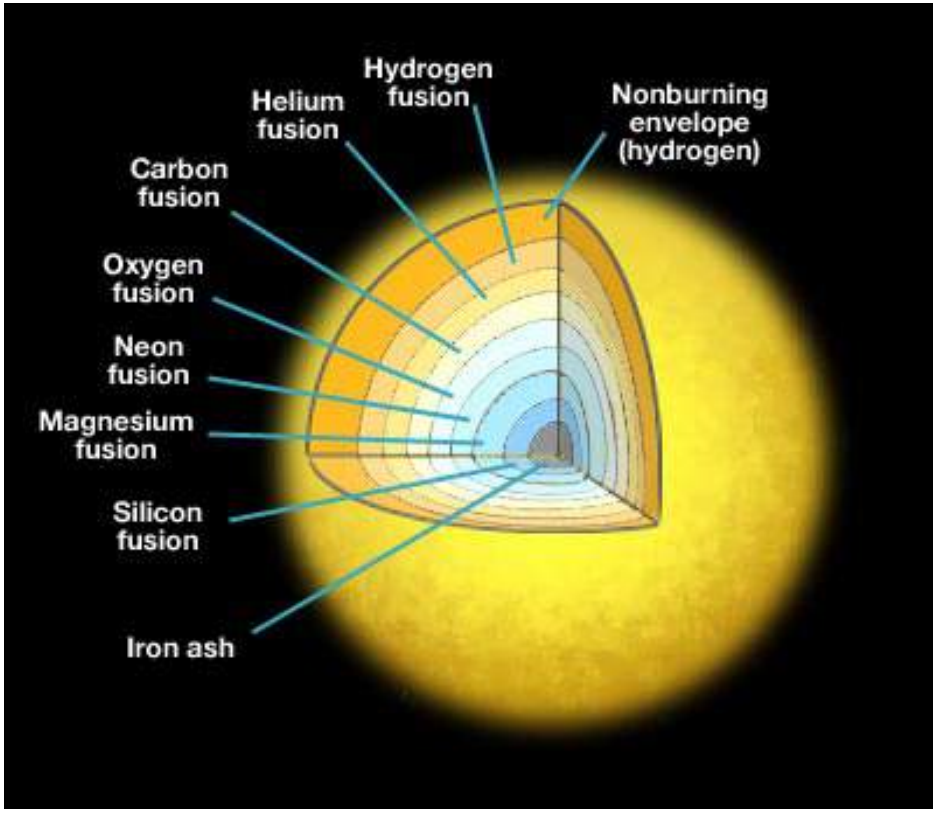
$M/M_\odot > 8 \Rightarrow 14\%$

Meynet 2011

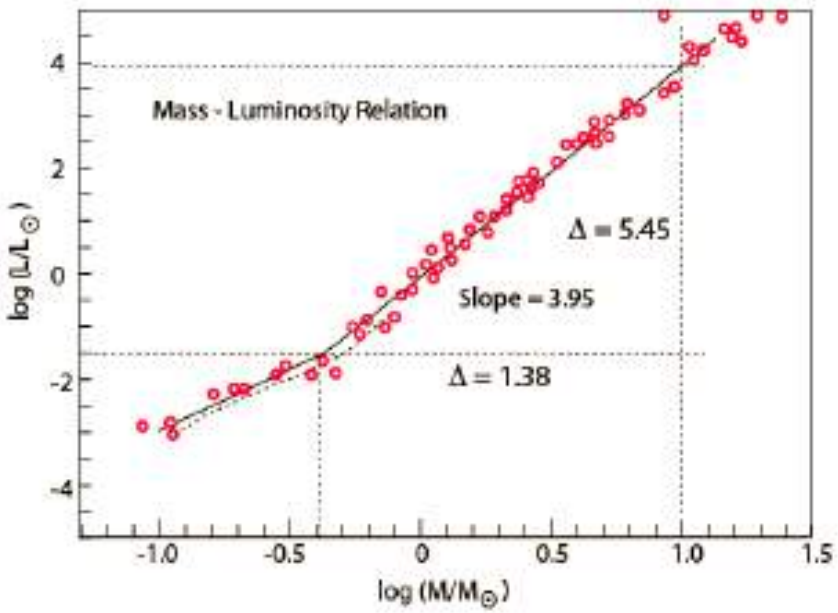
Evolución Estelar



Evolución Estelar

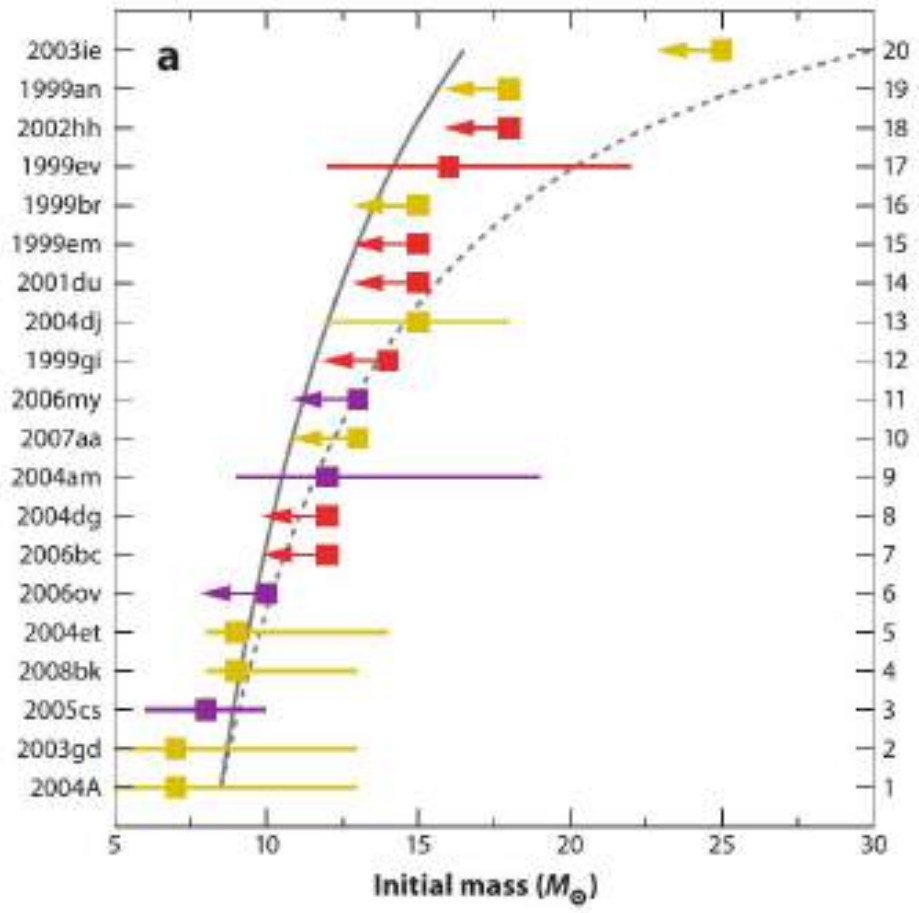


Evolución Estelar



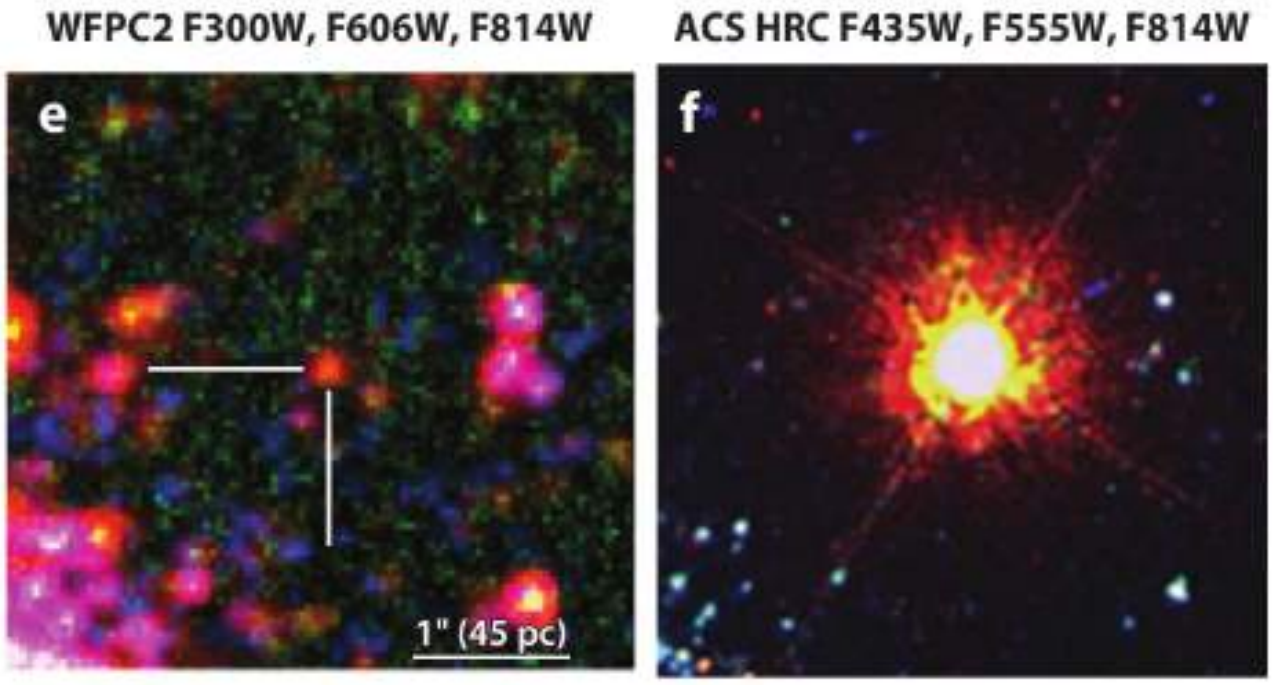
$$L \propto M^3 \quad M \leq 8M\odot$$
$$L \propto M \quad M > 8M\odot$$

Evolución Estelar



Smartt 2009

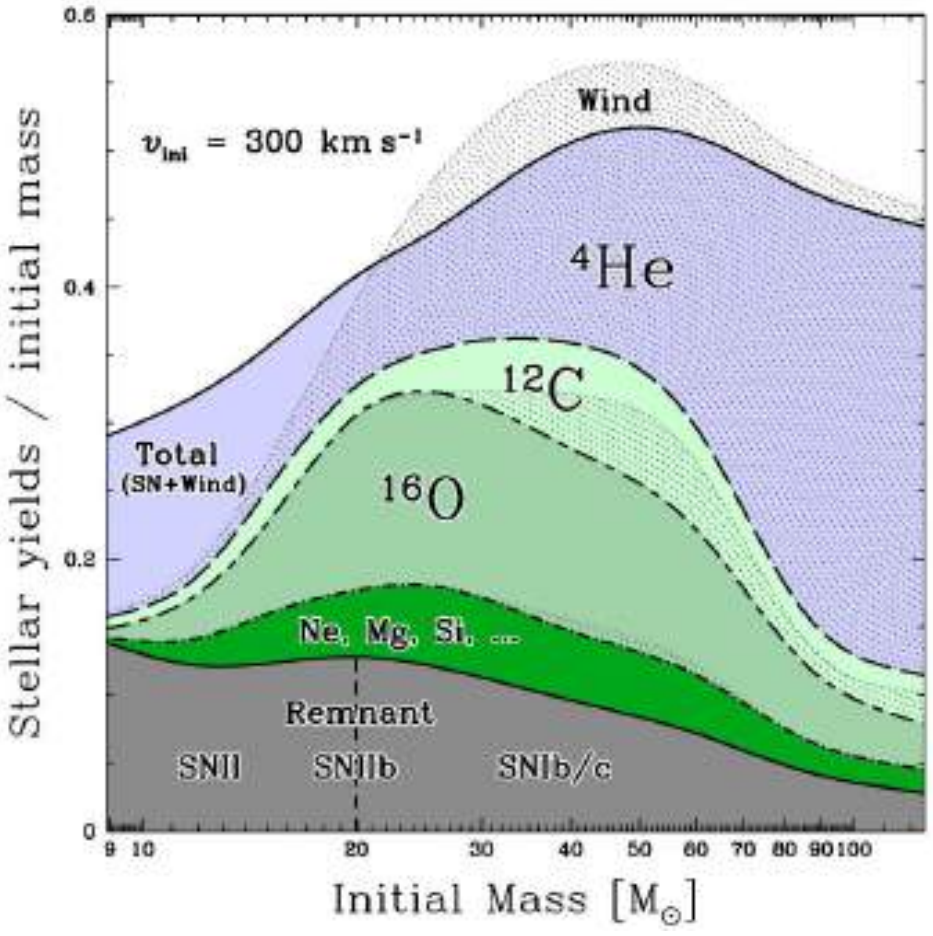
Evolución Estelar



Supernova SN2003gd

Smartt 2009

Evolución Estelar



Hirschi 2005

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Luminosidad de Eddington

$$L_{Edd} = \frac{4\pi GMm_p c}{\sigma_T}$$

$$L_{Edd} = 3.2 \times 10^4 \left(\frac{M}{M_\odot}\right) L_\odot$$

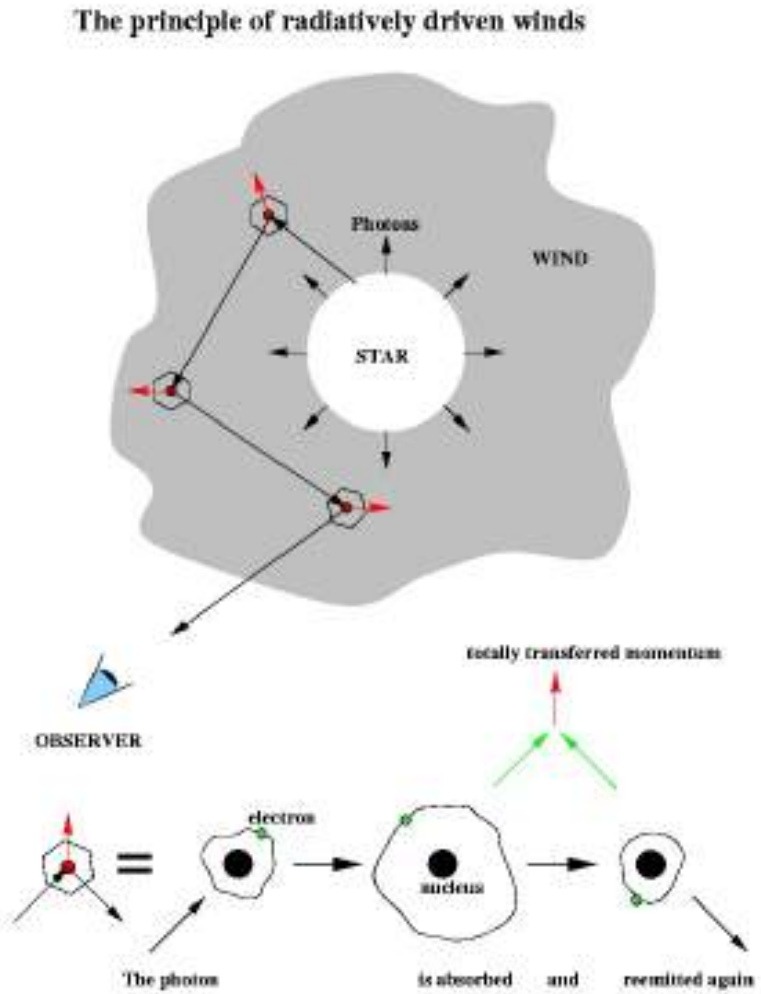
σ_T es sección eficaz de dispersión de Thomson.
c es la velocidad de la luz.
m_p es la masa del protón.

Vientos Estelares

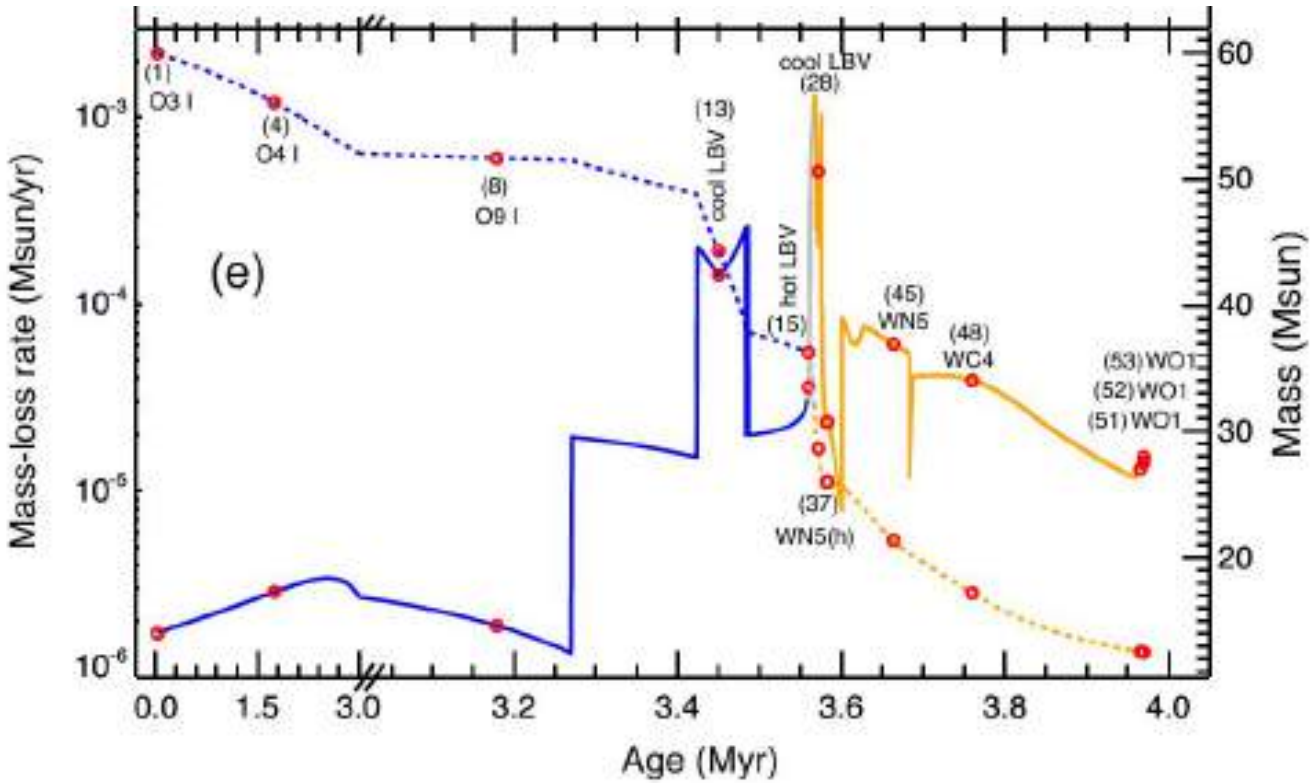
- Inyectan masa y energía al medio interestelar
- Enriquecen químicamente el medio interestelar



Vientos Estelares



Vientos Estelares



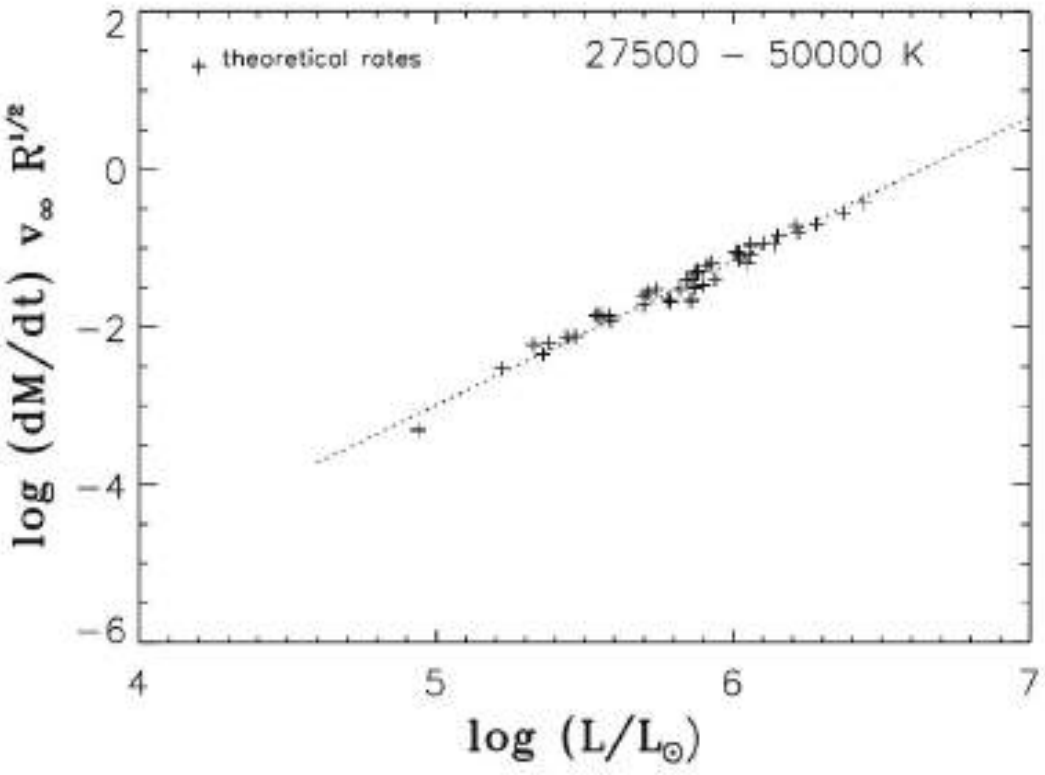
Vientos Estelares

$$
\begin{aligned}
\dot{M} &= 4\pi r^2 \rho(r) v(r) = constante \\
v\frac{dv}{dr} &= -\frac{GM}{r^2} - \frac{1}{\rho}\frac{dp}{dr} + g_{rad} \\
g_{rad} &= \frac{1}{mc}\int_0^\infty \sigma_\nu F_\nu d\nu \\
\sigma_\nu &= f(n_e, N_T, n_s, T, F_\nu) \\
F_\nu &= f(n_e, N_T, n_s, T, \sigma_\nu)
\end{aligned}
$$

Vientos Estelares

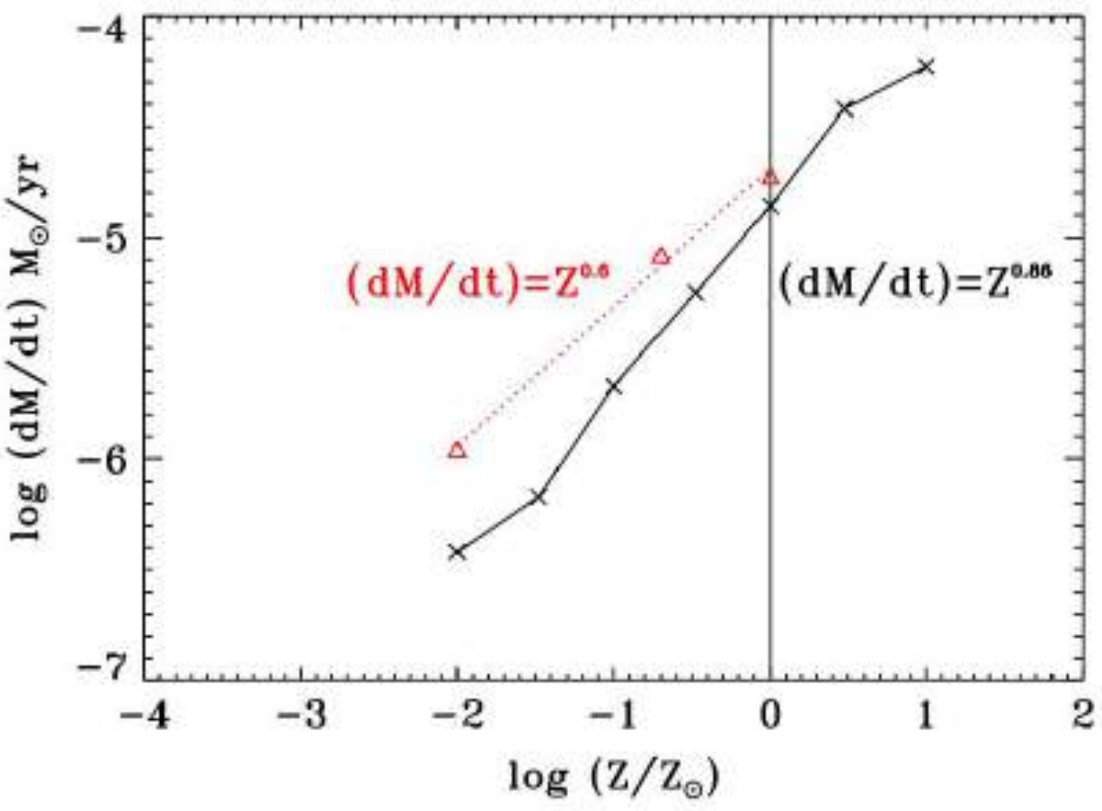
$$
\begin{aligned}
g_{rad}^{Th} &= \frac{1}{c\rho}\frac{\sigma_e L}{4\pi r^2} \\
g_{rad,i}^{Line} &= \frac{L_\nu}{4\pi r^2 c^2 \rho}\left(\frac{dv}{dr}\right)(1-e^{-\tau}) \\
\tau &\approx \chi\lambda/(dv/dr)
\end{aligned}
$$

Vientos Estelares



$$\dot{M} \propto L^{2.2} M^{-1.3} T_{eff} (v_\infty / v_{esc})$$

Vientos Estelares



Puls 2008

Vientos Estelares

$$L_{mechanic} = \frac{1}{2}\dot{M} v_{\infty}^{2}, \qquad v_{\infty} = 3000 \text{ km/s}$$

$$L_{mechanic} \approx 30000 L_{sol}, \qquad \frac{L}{L_{mechanic}} \approx 0.1$$

During 500 000 years

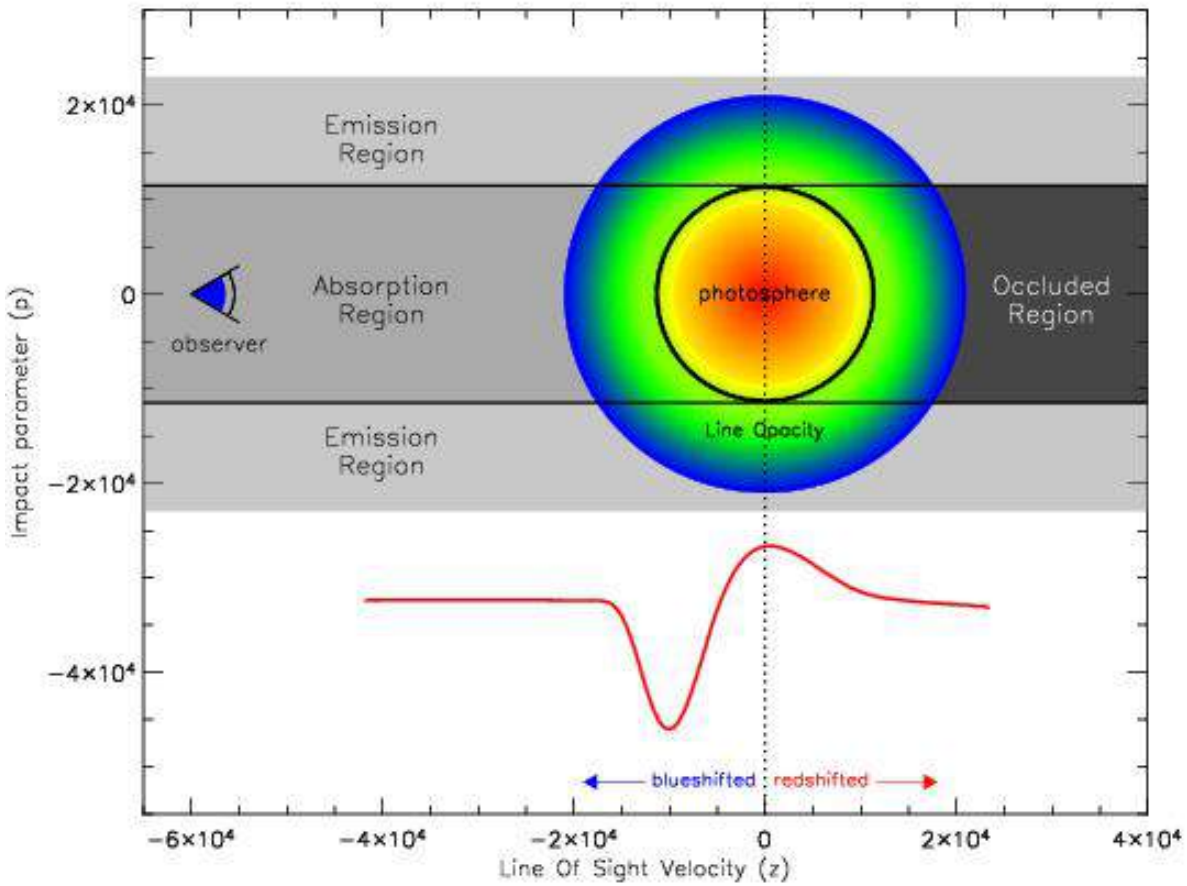
$E_{mechanic} \approx 2 \; X \; 10^{51}$ ergs similar to SNe!

Smartt 2009

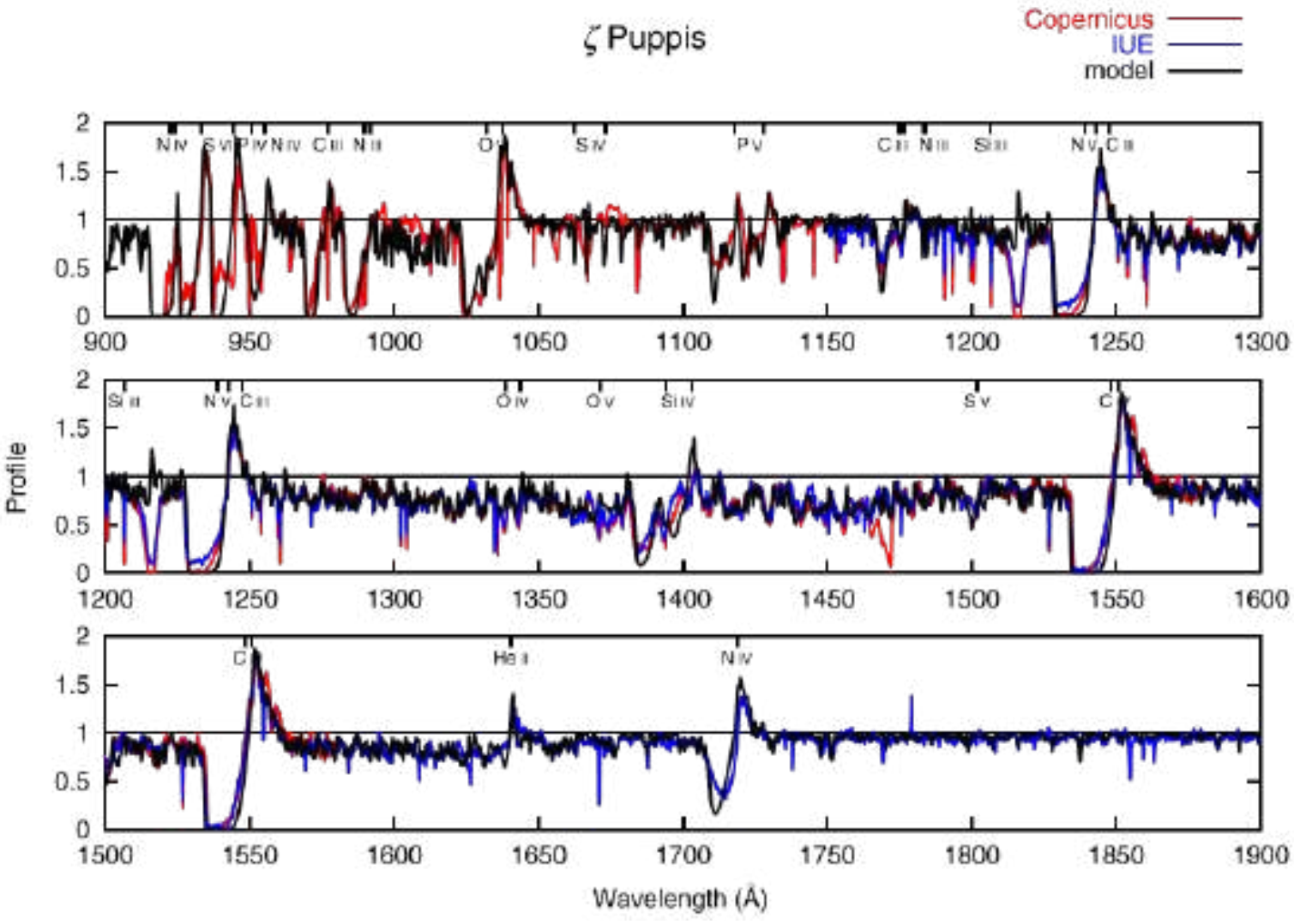
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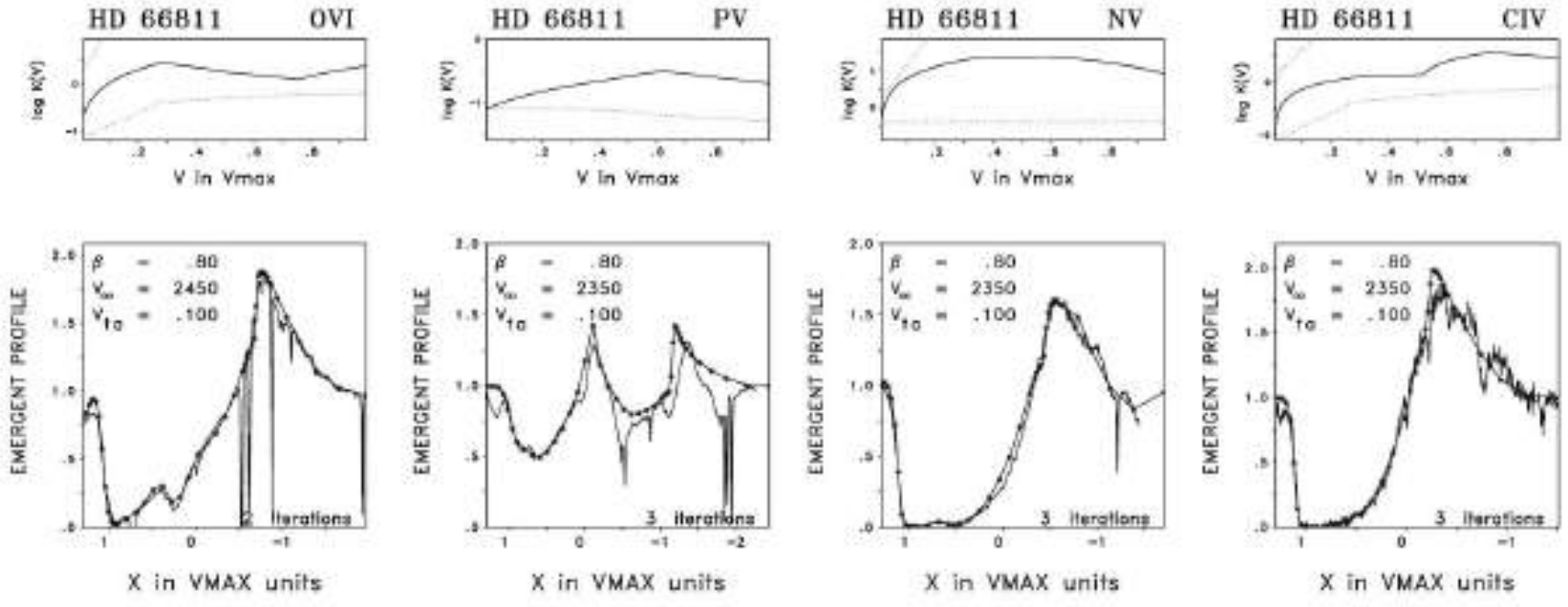
Evidencias Observacionales



Evidencias Observacionales



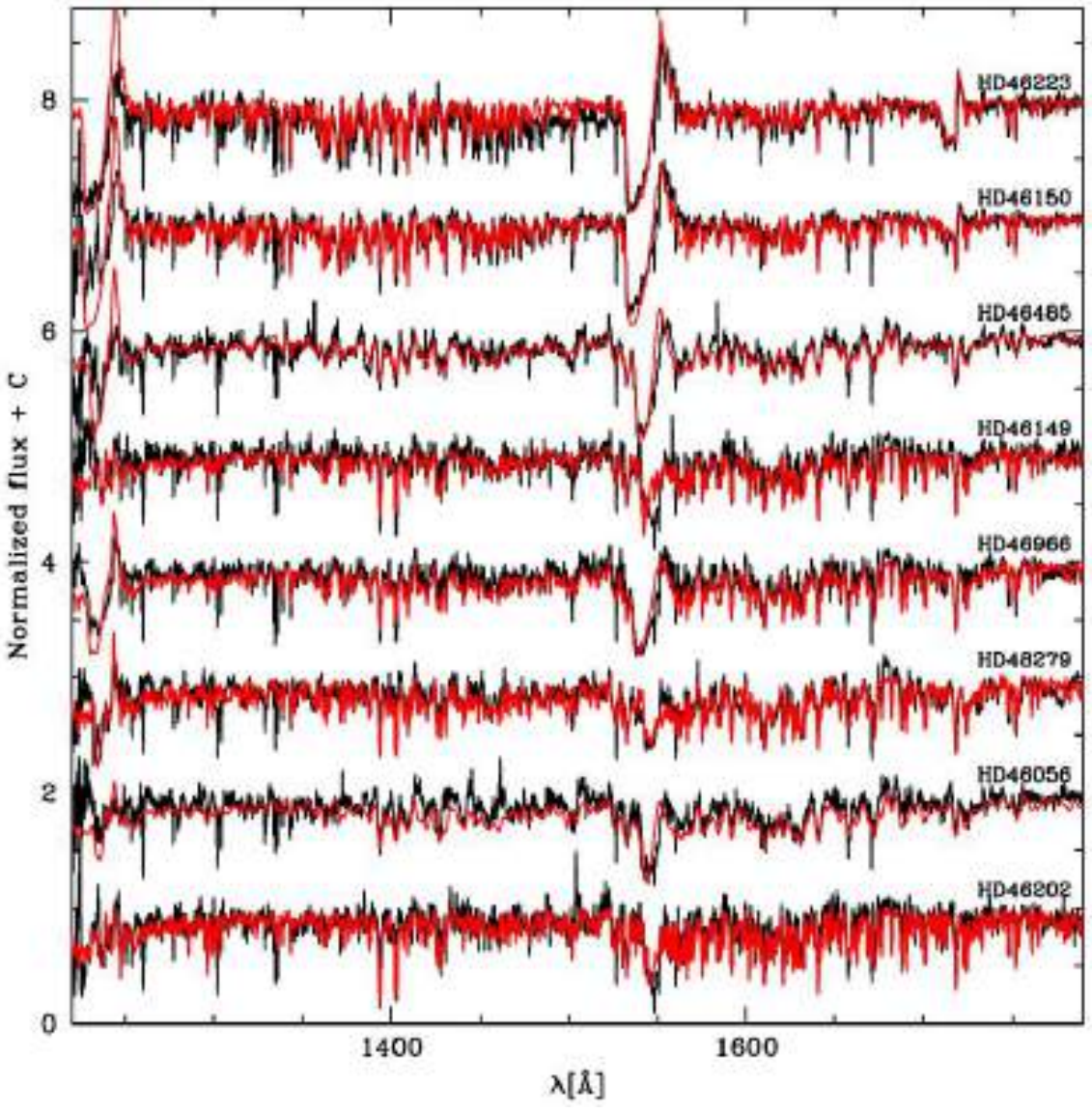
Evidencias Observacionales



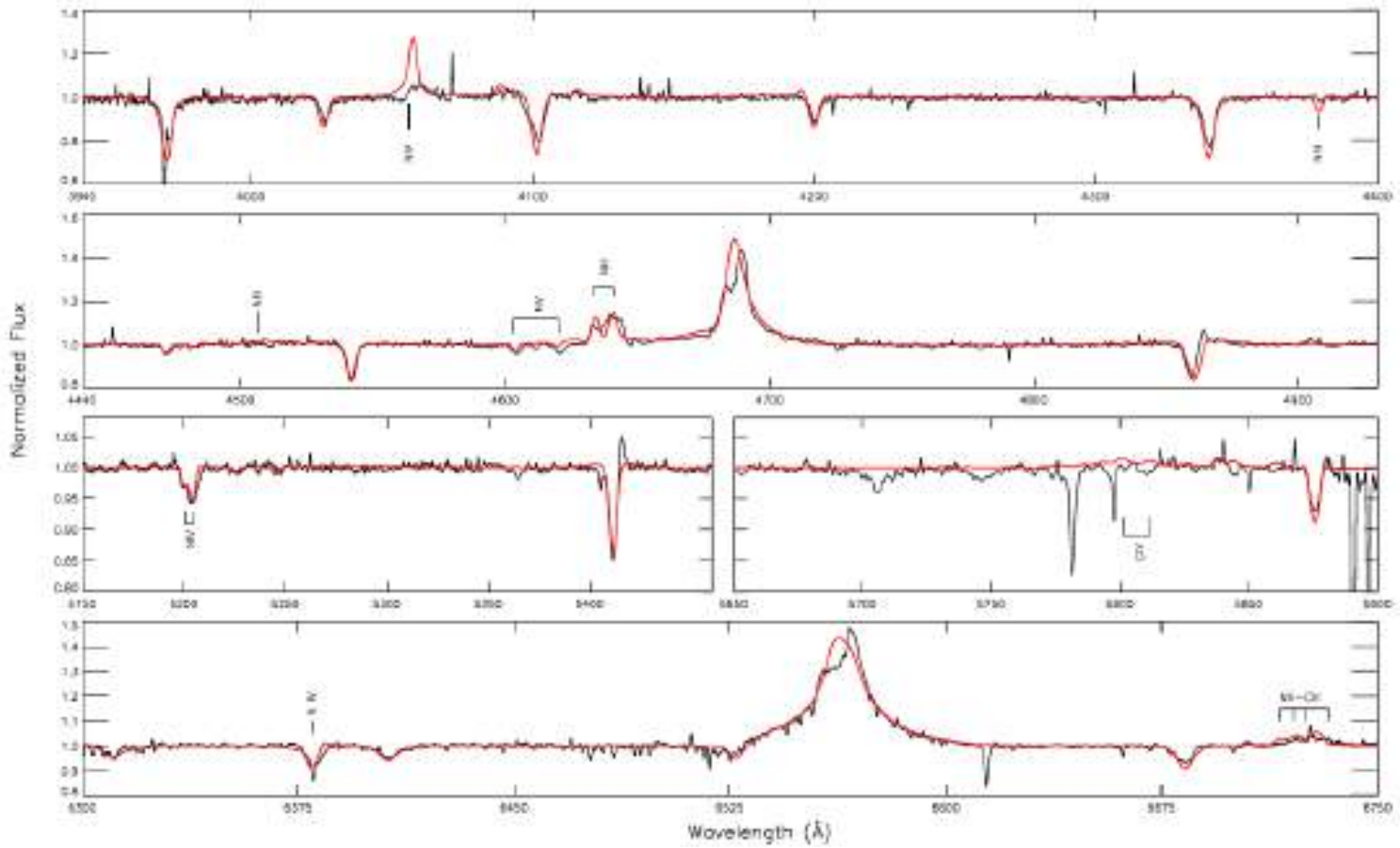
ζ Pup

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Evidencias Observacionales



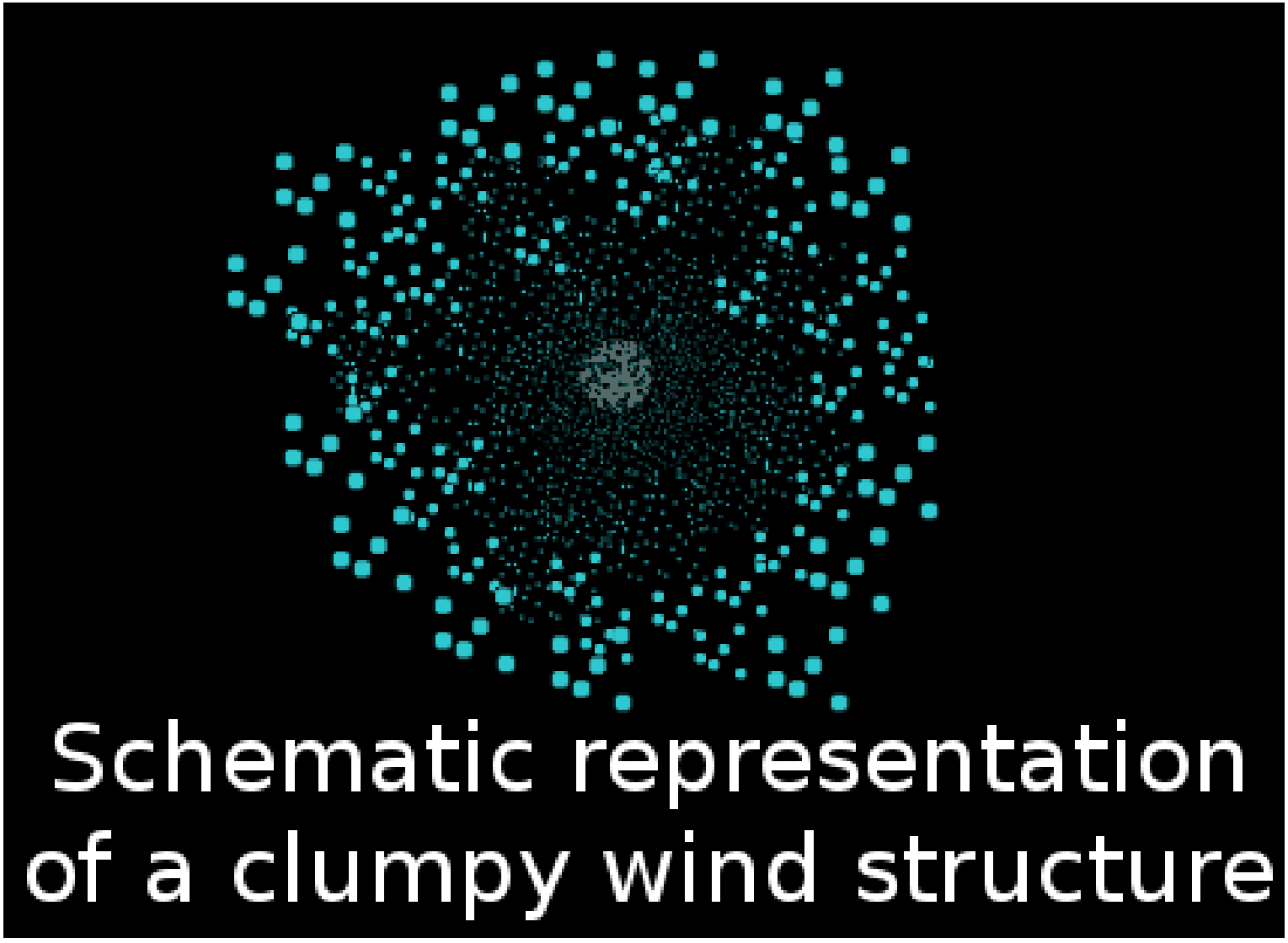
Evidencias Observacionales



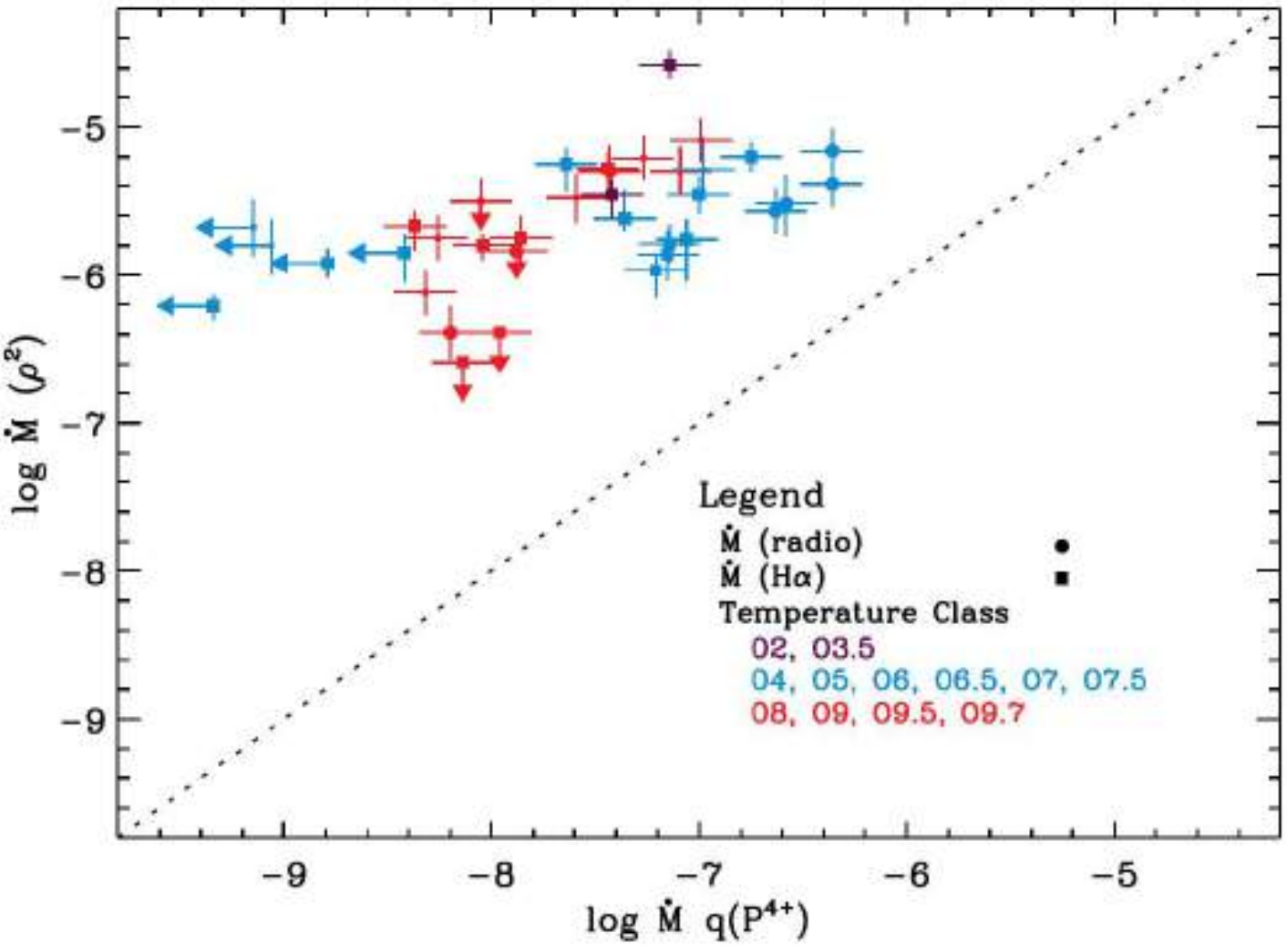
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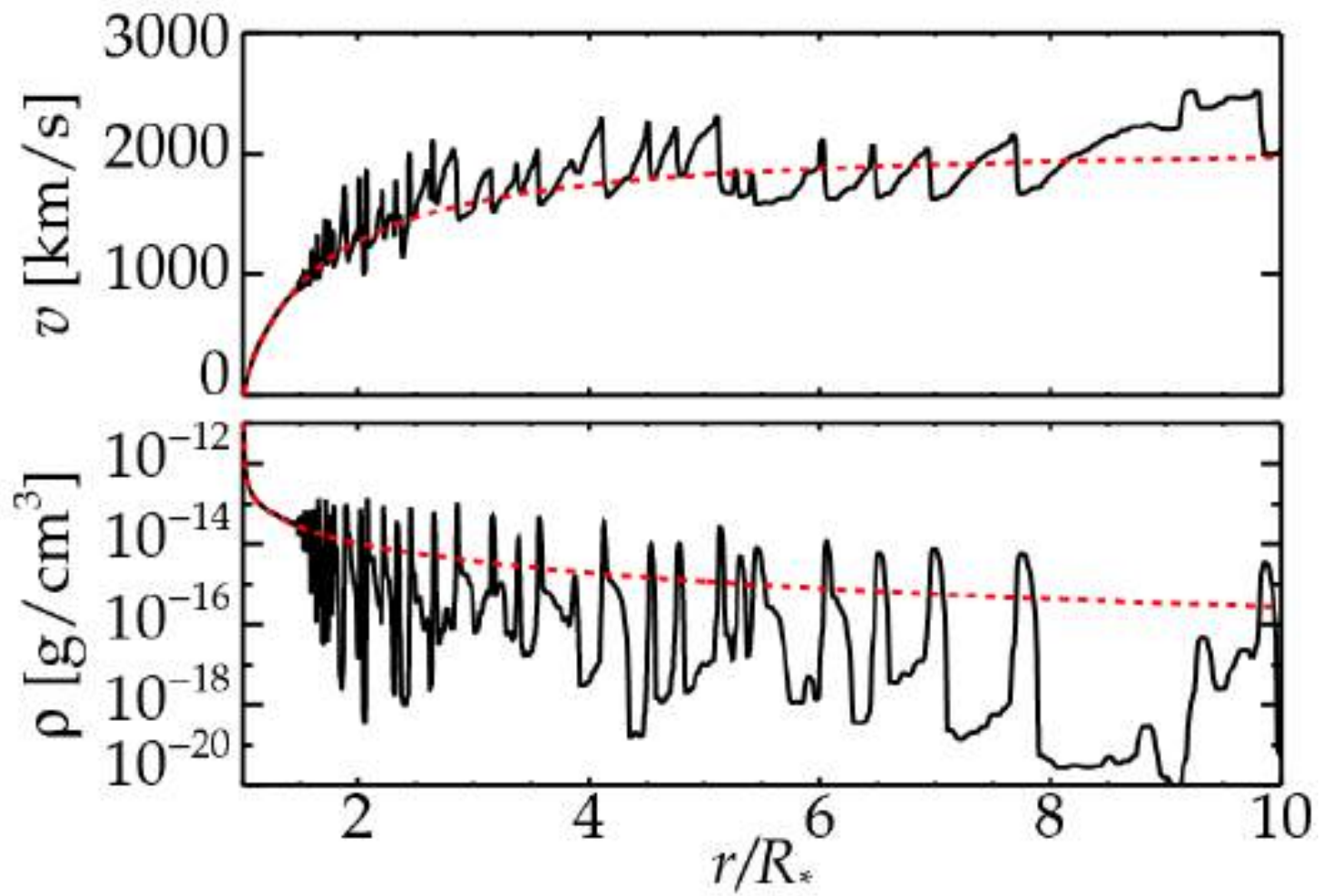
Condensaciones en Vientos



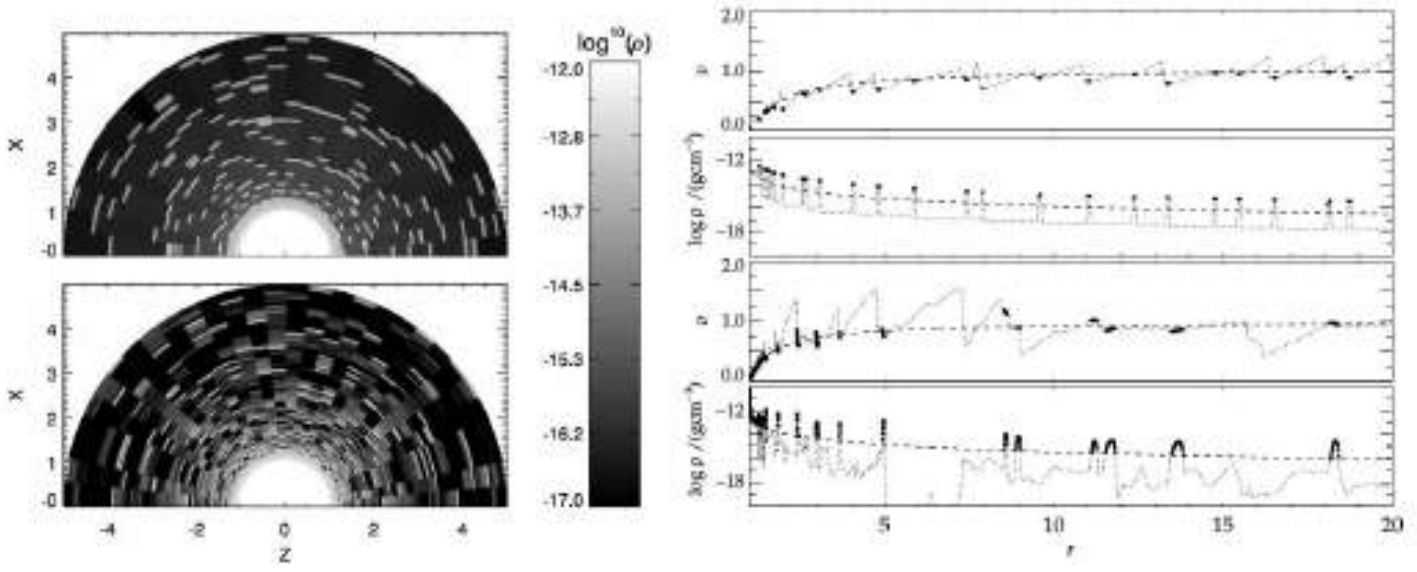
Condensaciones en Vientos



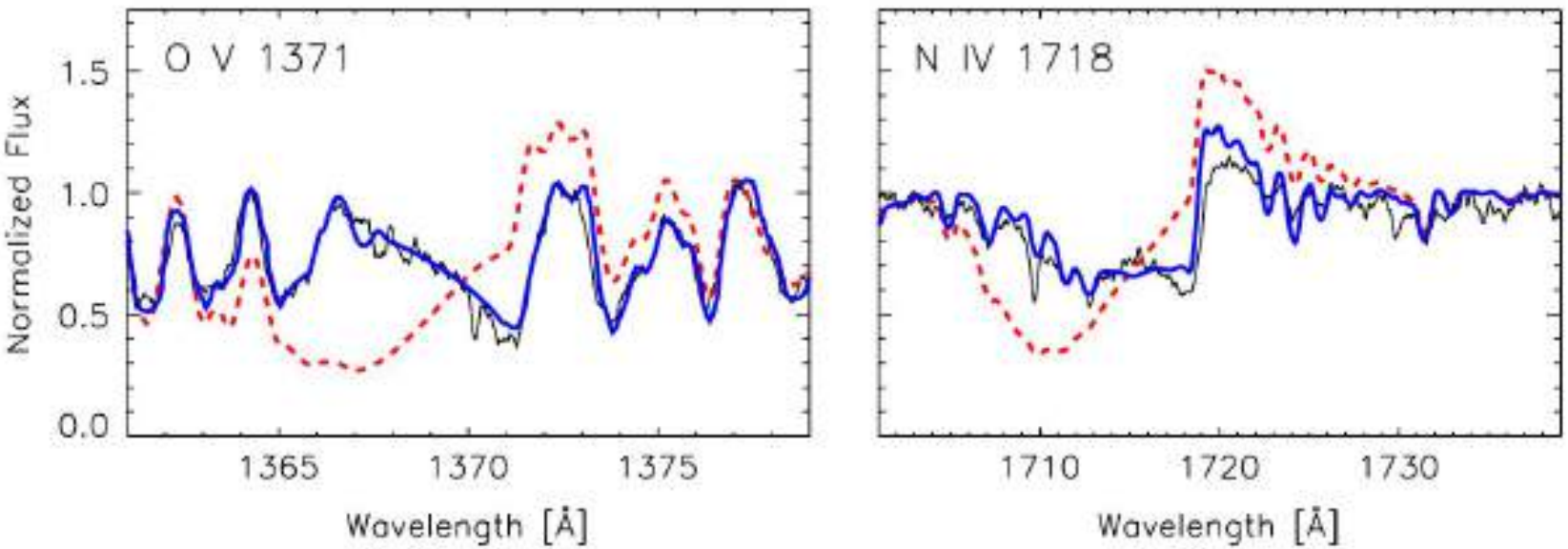
Condensaciones en Vientos



Condensaciones en Vientos



Inestabilidades en Vientos



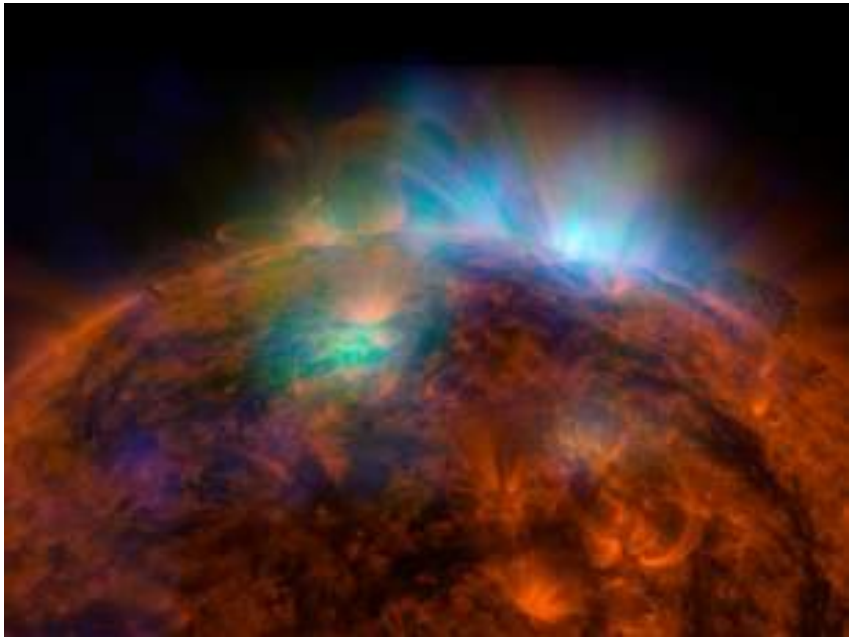
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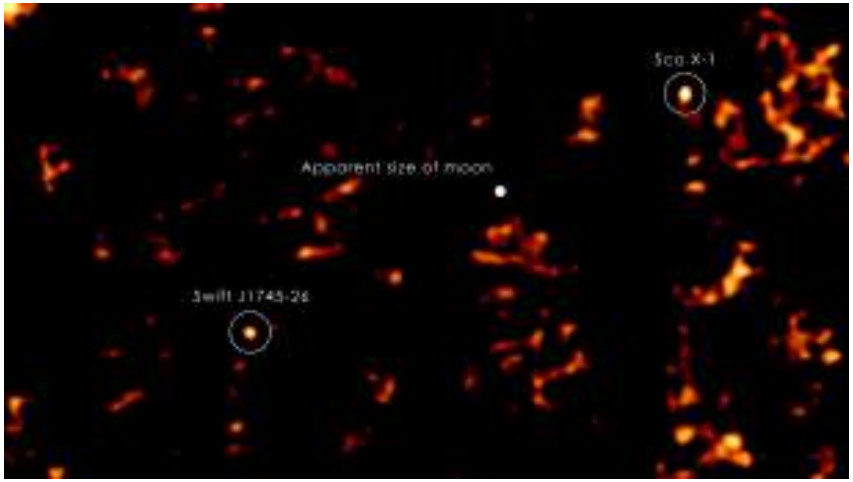
Rayos X en Estrellas

Las primeras detecciones de rayos X fueron hechas con cohetes en la alta atmósfera. La primera fuente de rayos X detectada fue el Sol (1948).



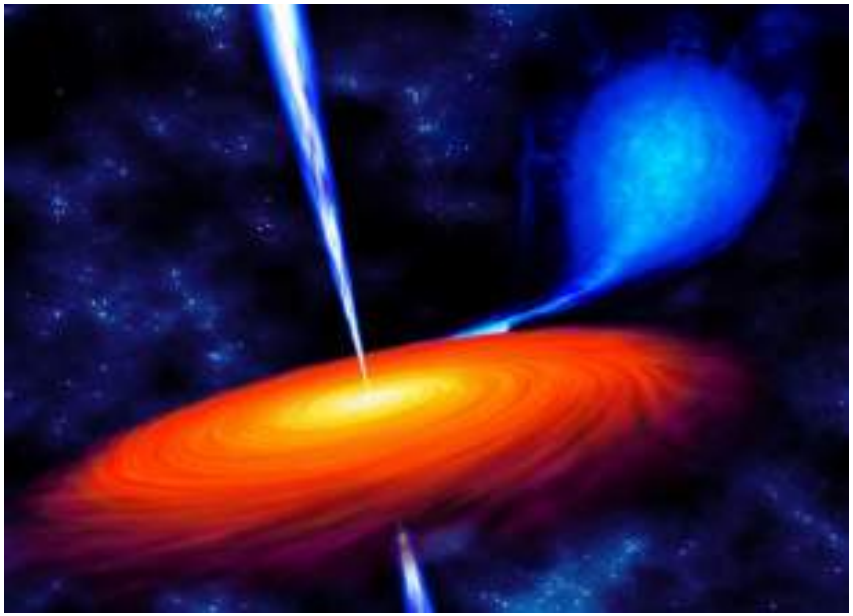
Rayos X en Estrellas

La primera fuente fuera del sistema solar detectada fue Sco X-1 (Giacconni, 1962). Usando un cohete y un detector Geiger.

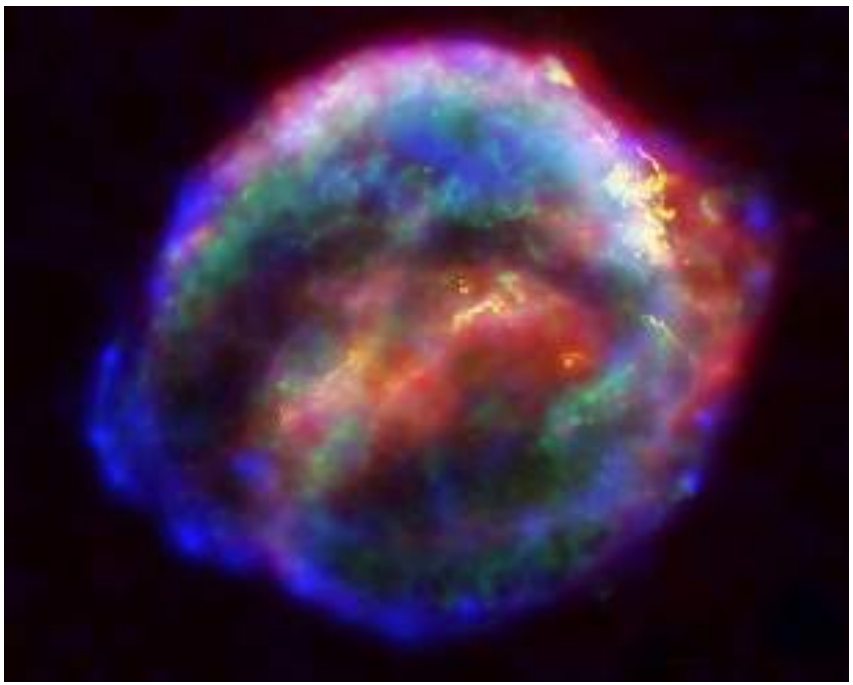


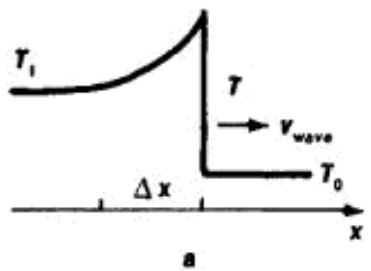
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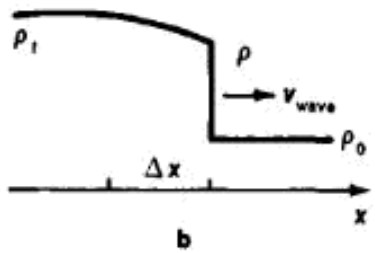
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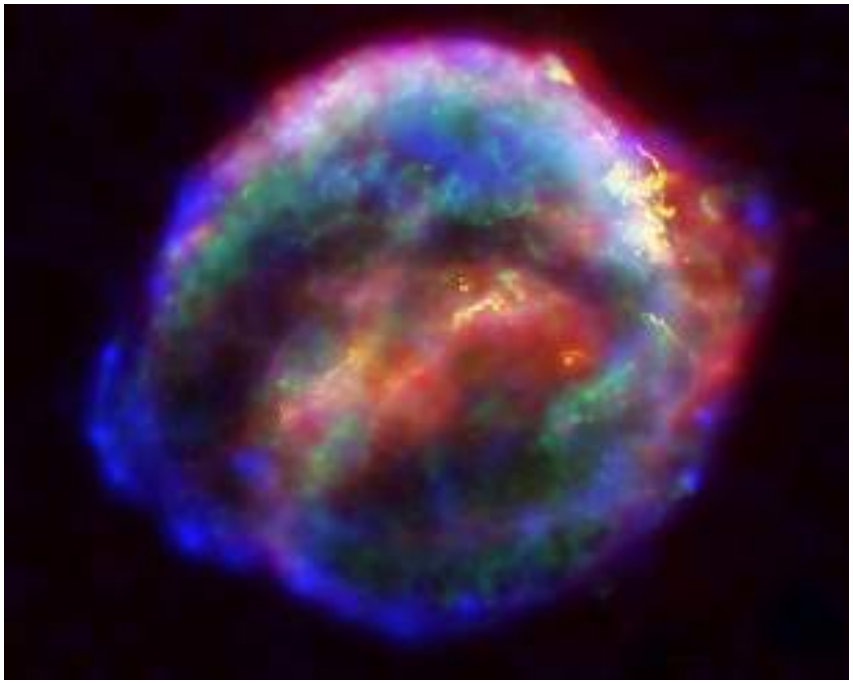
Emsión de Rayos X en Plasmas Astrofísicos.

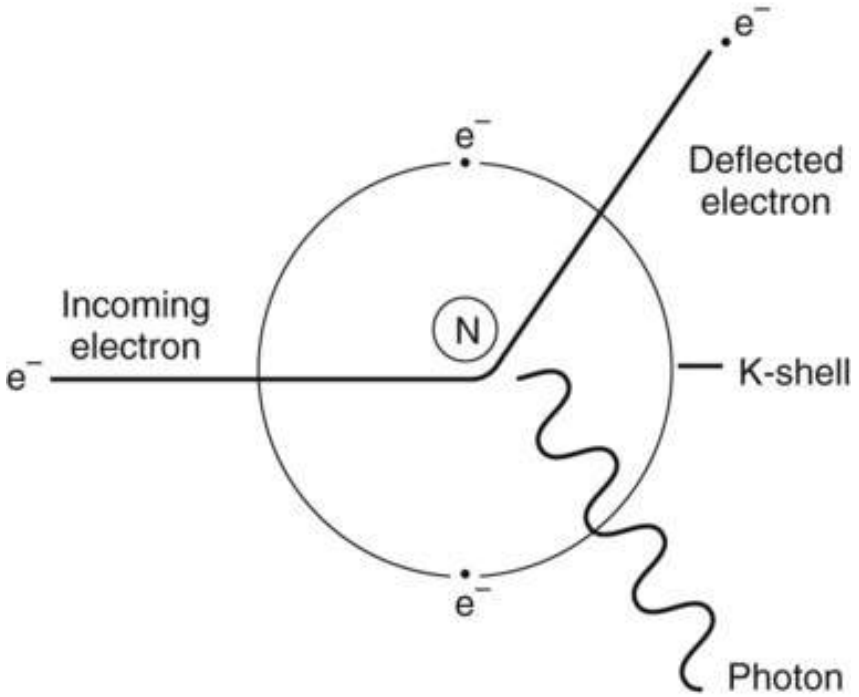




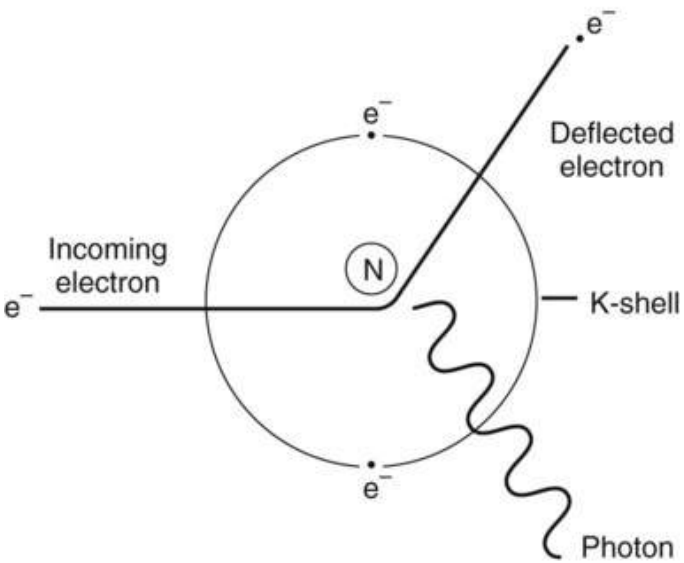


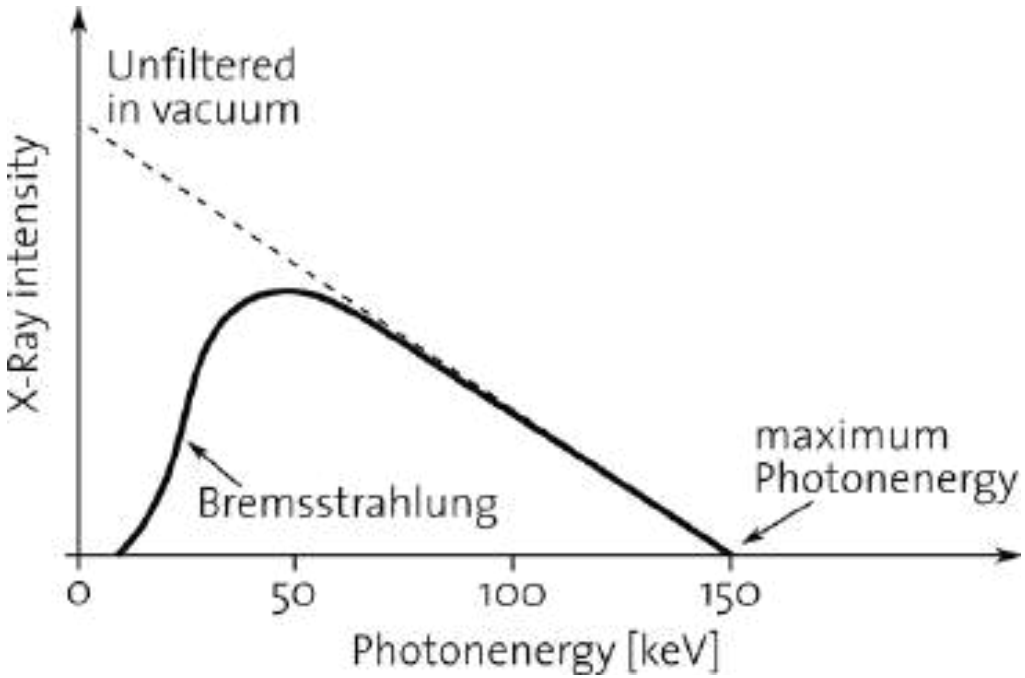
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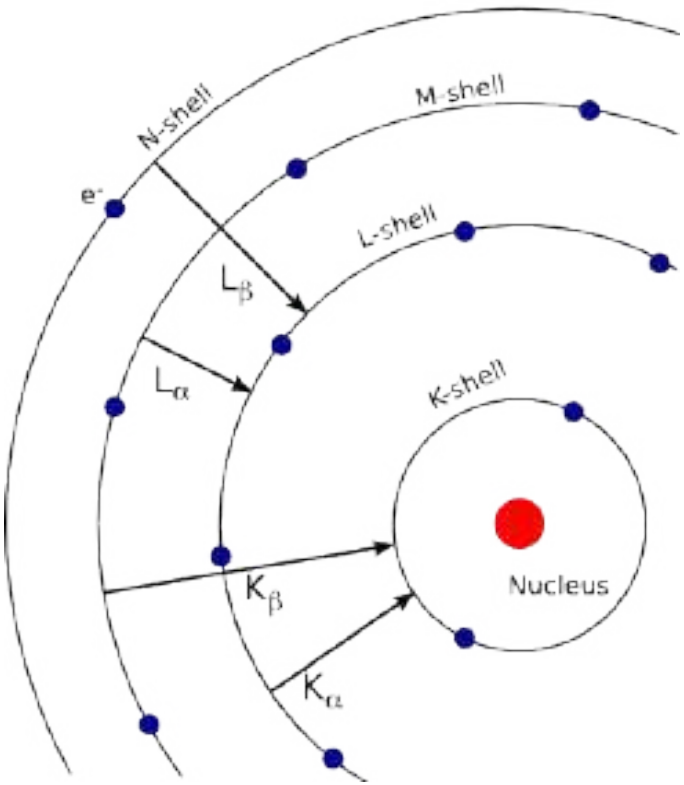


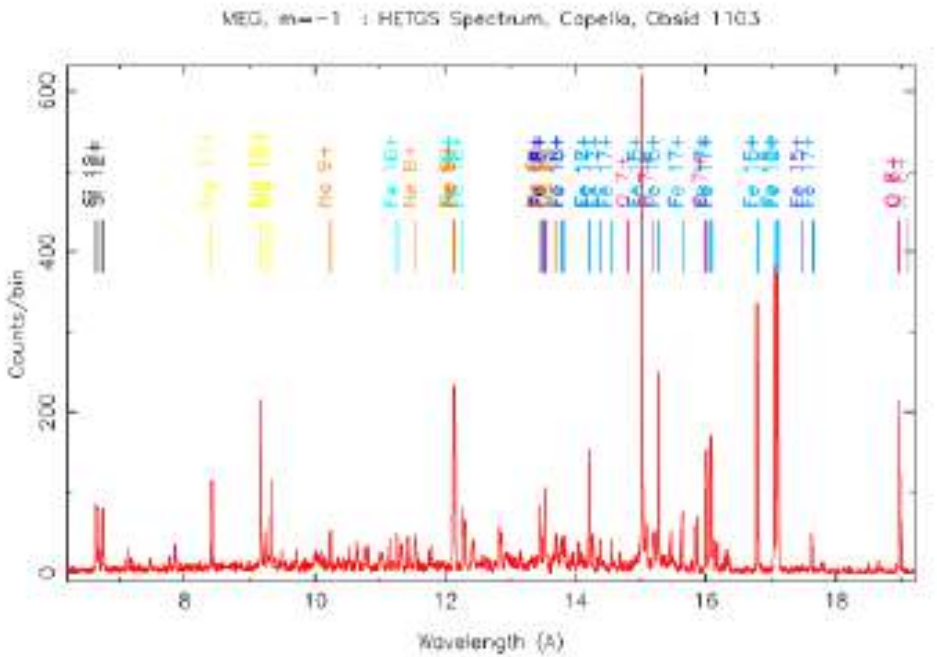
Emsión de Rayos X en Plasmas Astrofísicos.



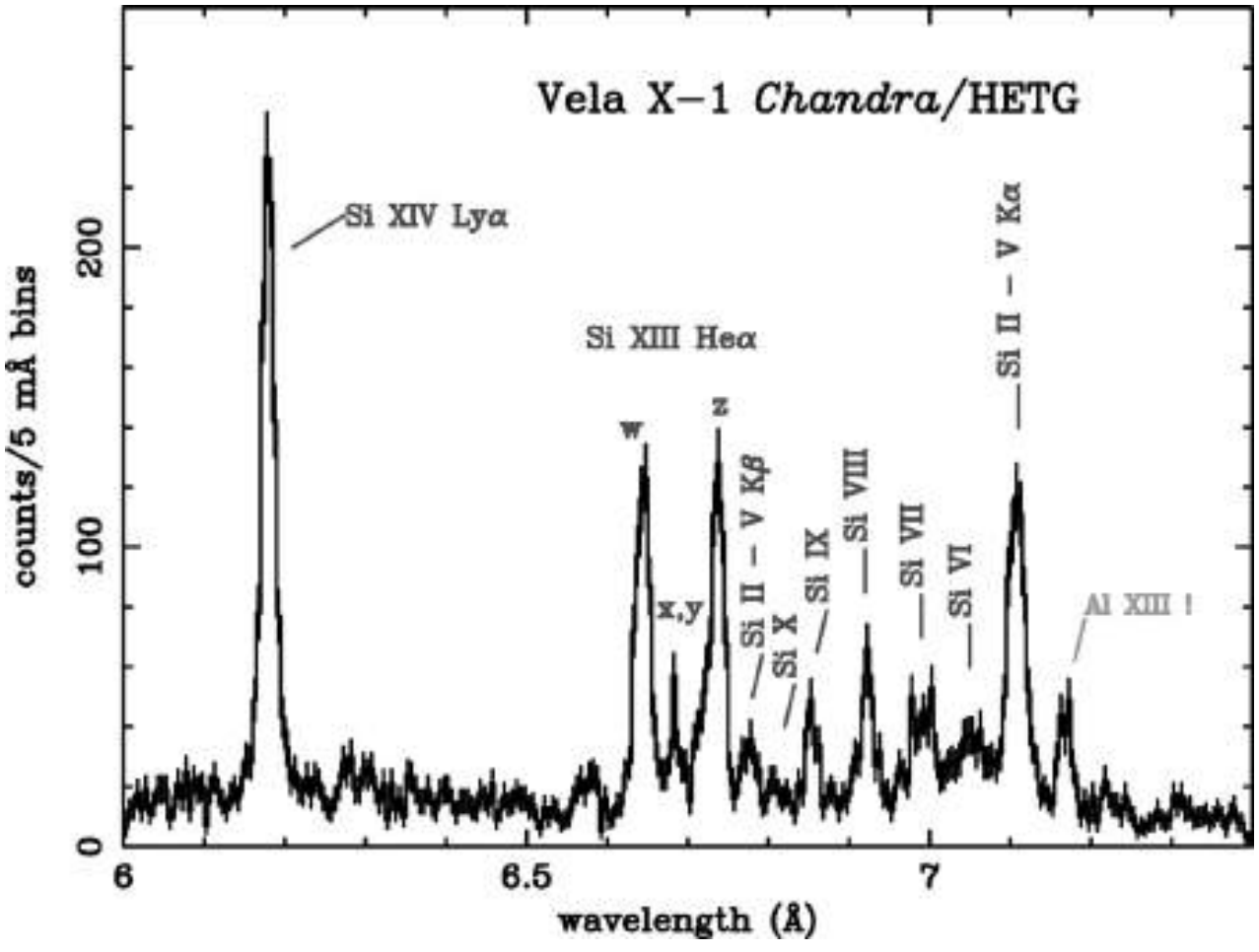


Emision de líneas en rayos X.





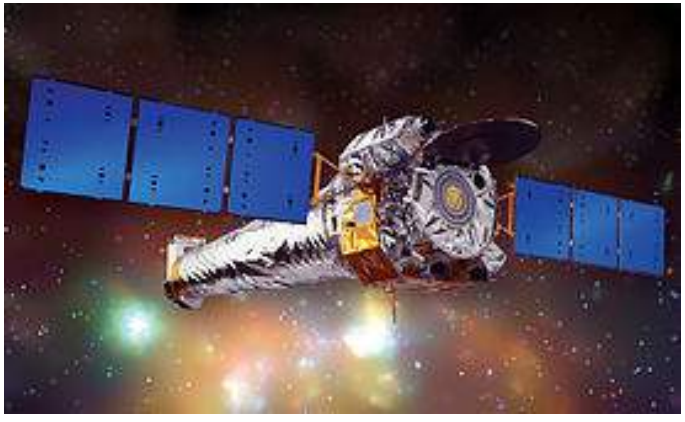
Emision de líneas en rayos X.



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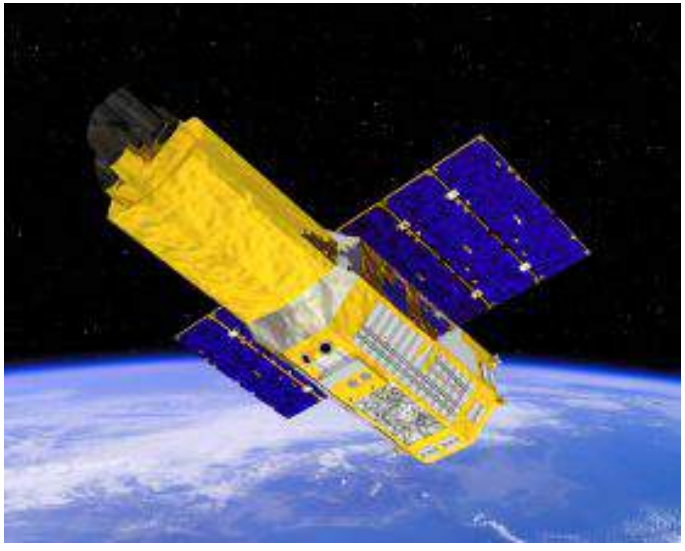
Satélites



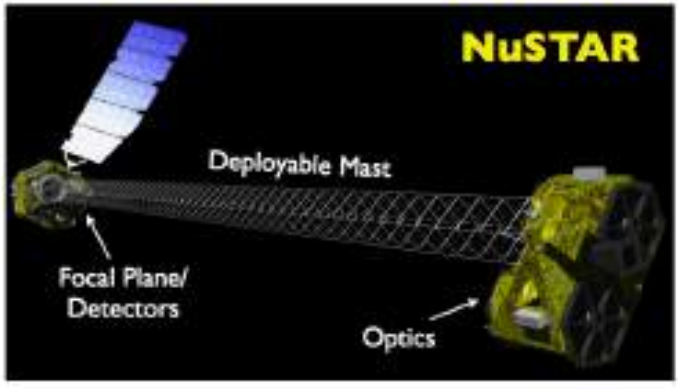
Chandra



XMM-Newton

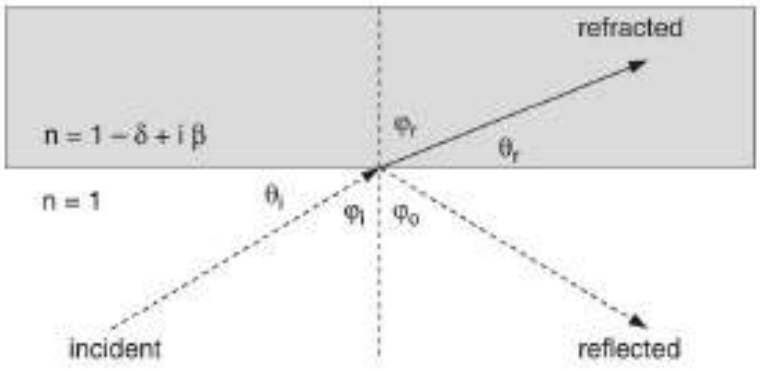


Suzaku

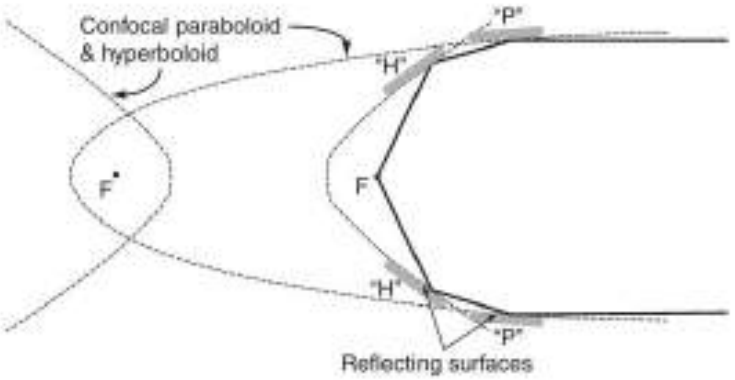


NuStar

Óptica

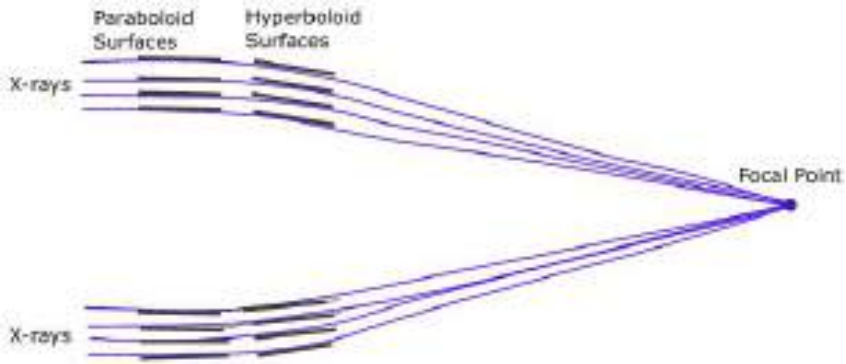


Reflexión, Refracción y Absorsión.

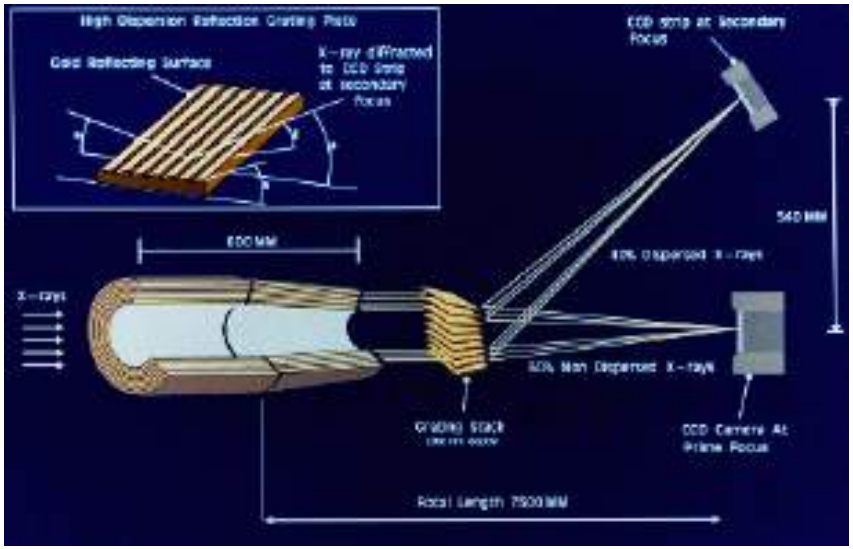


Un "Espejo"para rayos X.

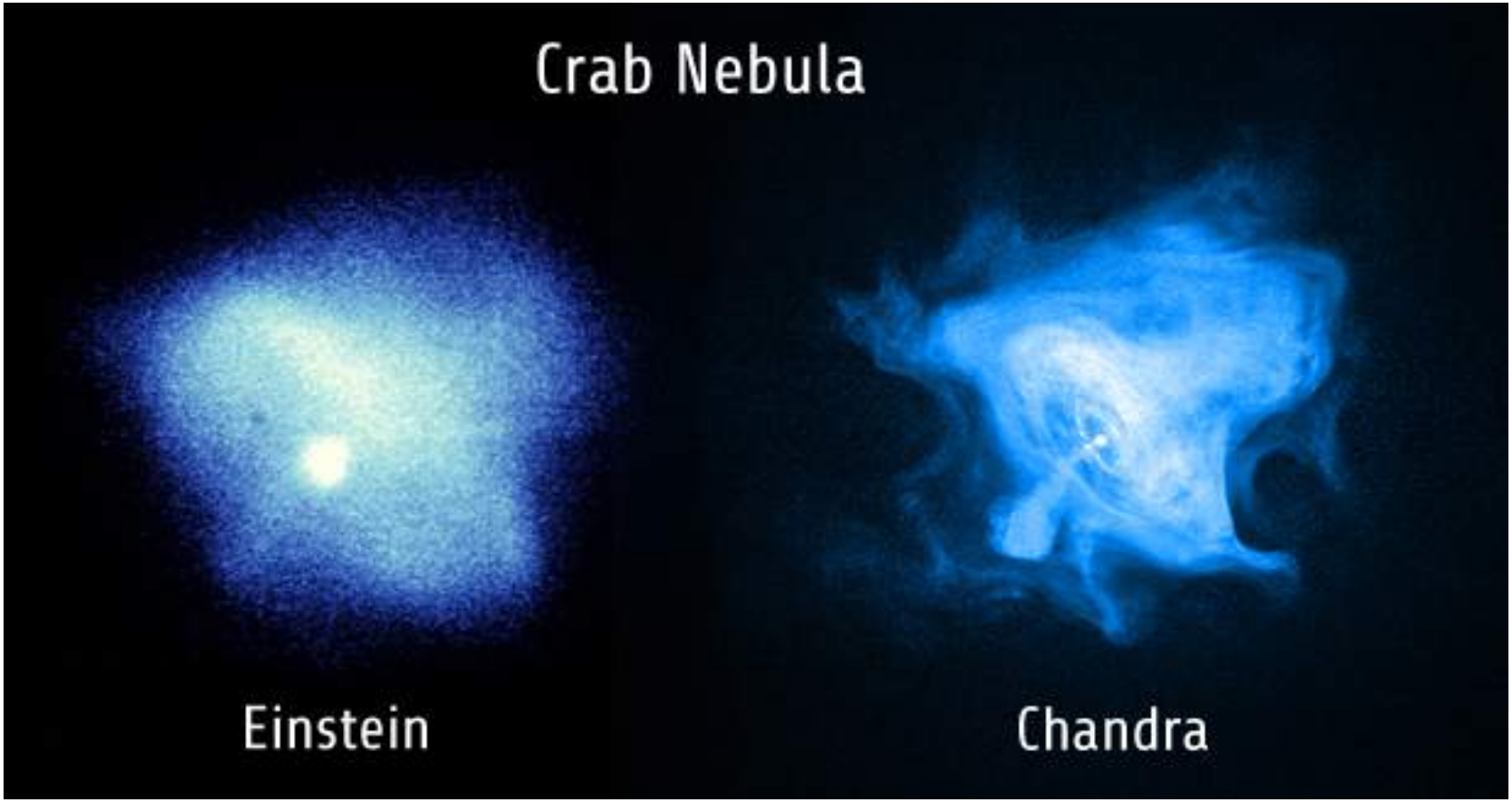
Óptica



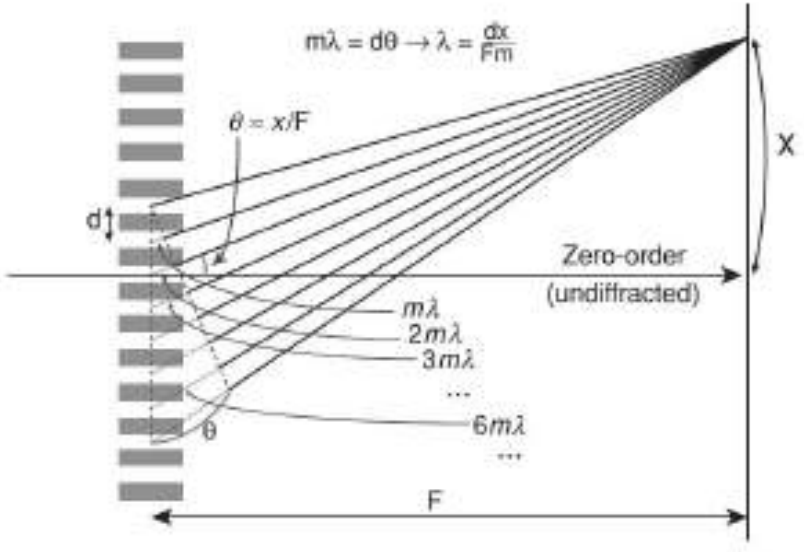
Óptica del telescopio XMM-Newton.



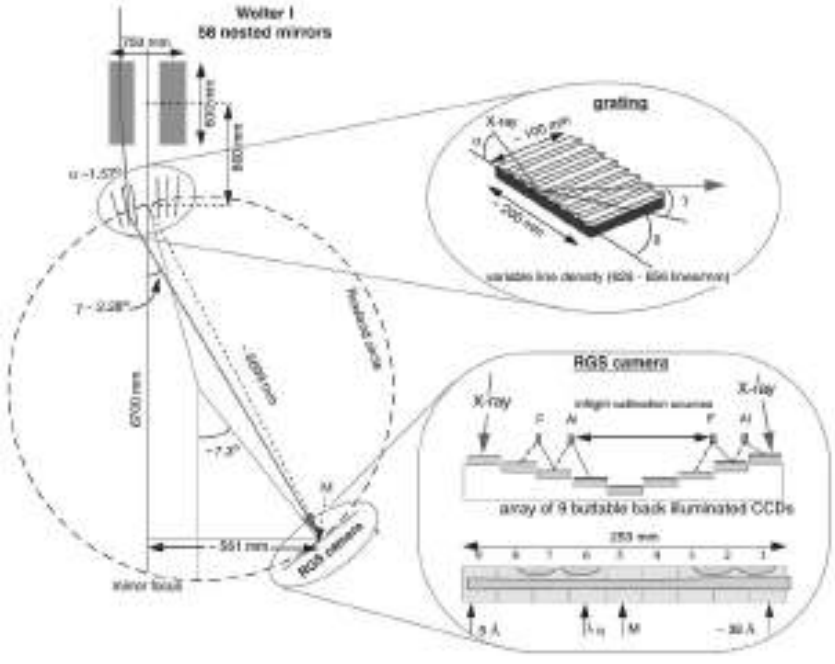
Óptica del telescopio XMM-Newton.


Crab Nebula
Einstein
Chandra

Espectroscopía de Rejilla



Interferencia en una rejilla.



Espectrómetro RGS del XMM-Newton.

Espectroscopía de Rejilla

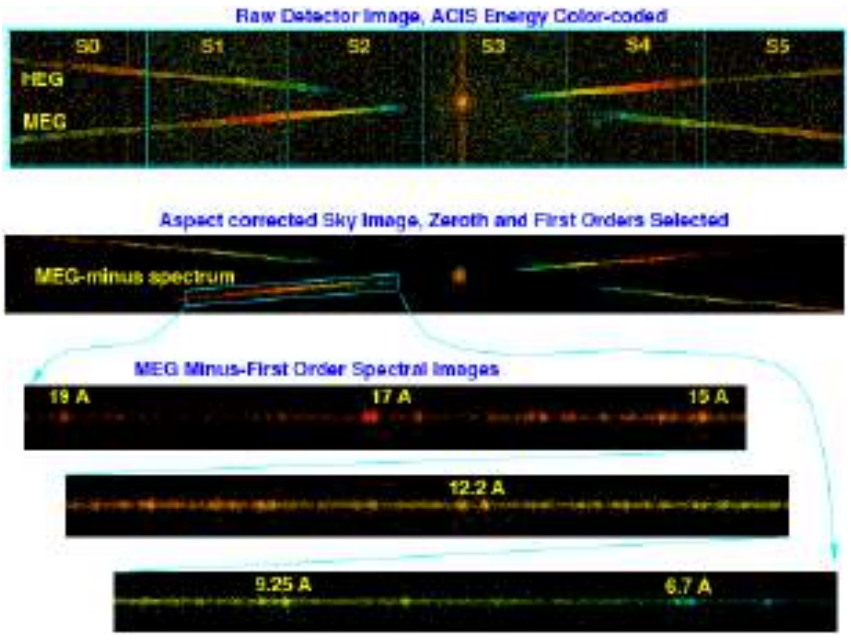
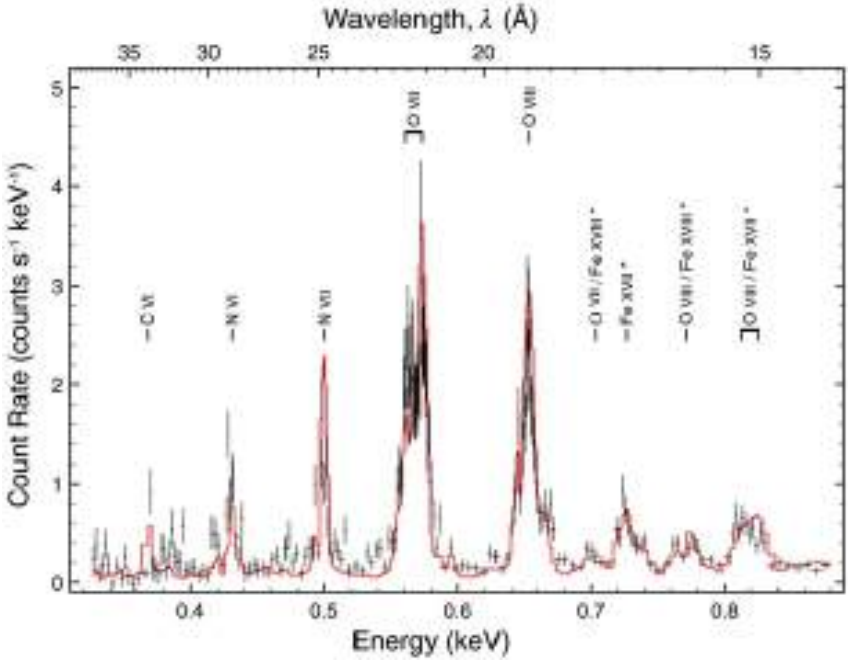


Imagen del espectrómetro HEG (Chandra)
Crédito: NASA/Chandra.



Espectro RGS de SUPERNOVA REMNANT G296.1-0.5
Credito: D. Castro et al. 2011.

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8 El caso de ϵ Ori
9 Fislab y Geolab

Estrellas Masivas



Estrellas Masivas del cinturón de Orión

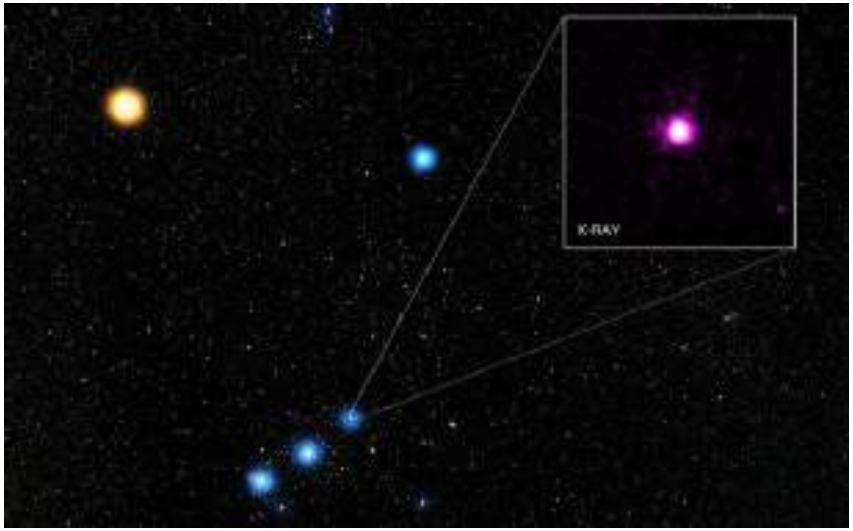
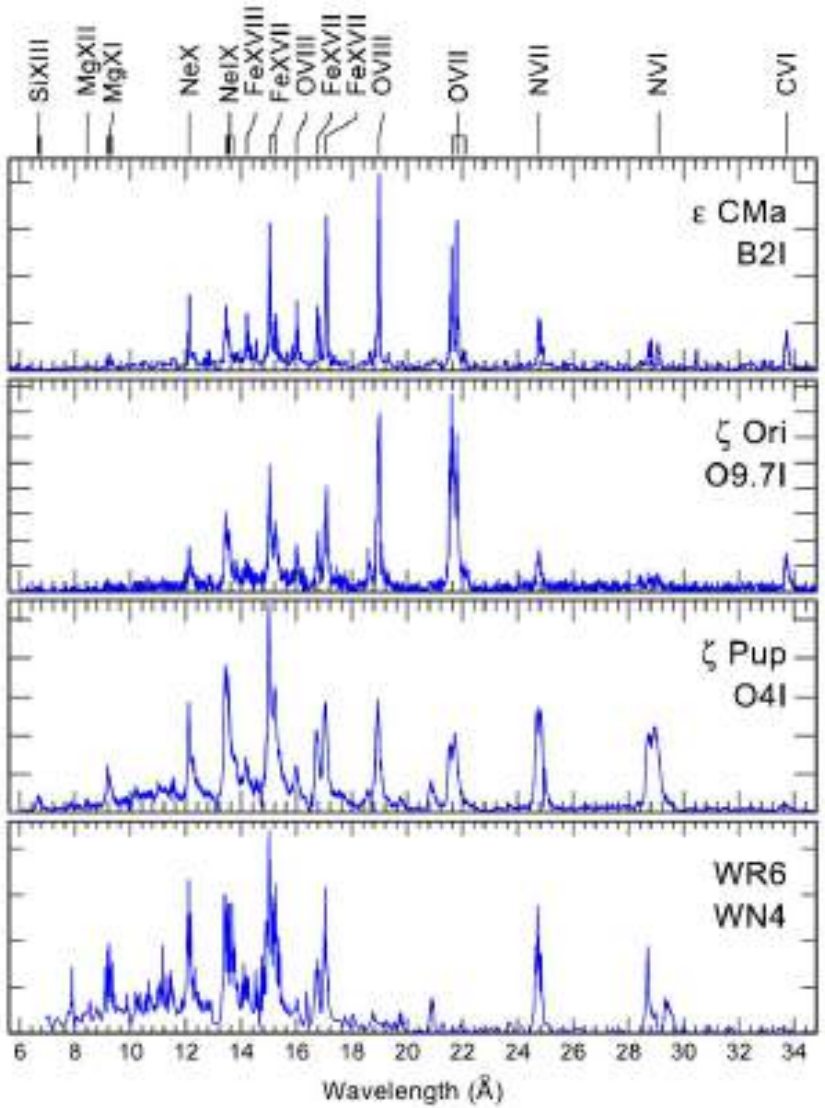


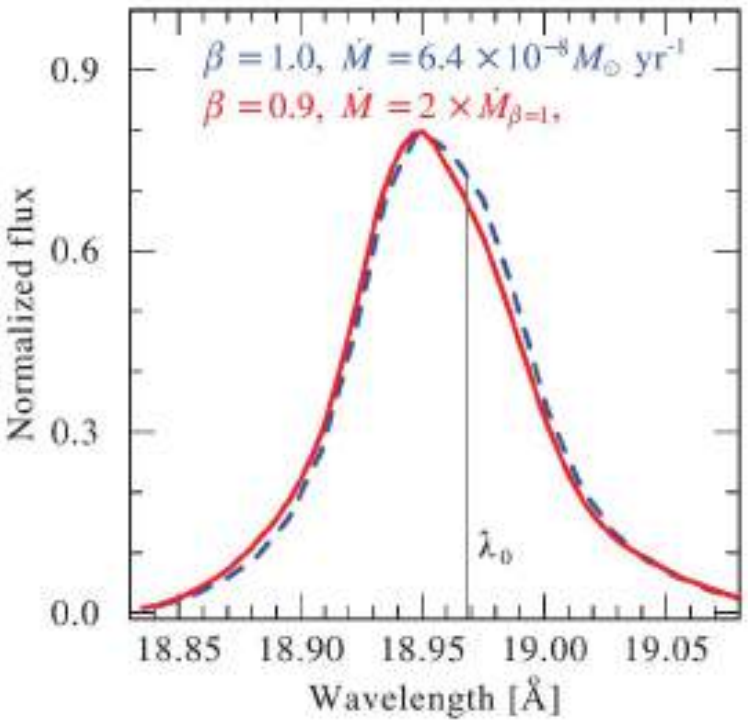
Imagen en rayos X de δ Orionis Creditos: Credits: X-ray: NASA/CXC/GSFC/M. Corcoran et al.; Optical: Eckhard Slawik

Estrellas Masivas

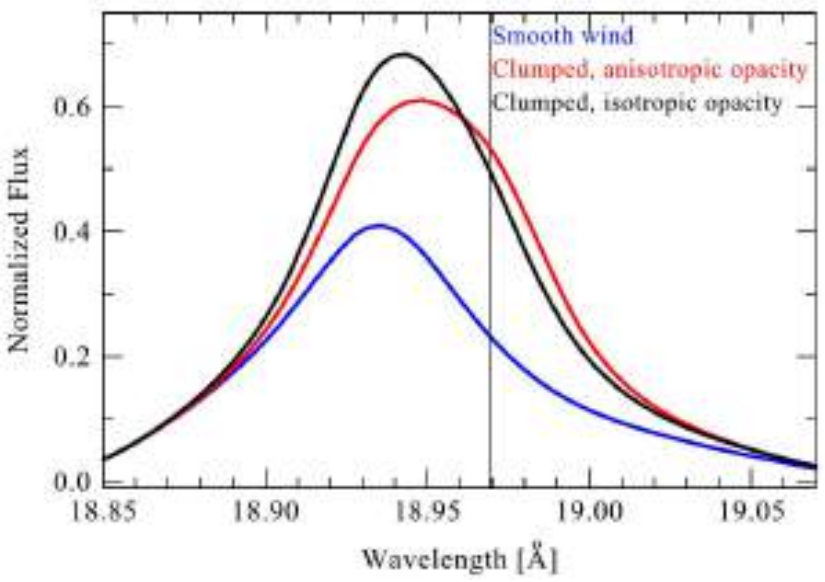


Oskinova 2016

Estrellas Masivas

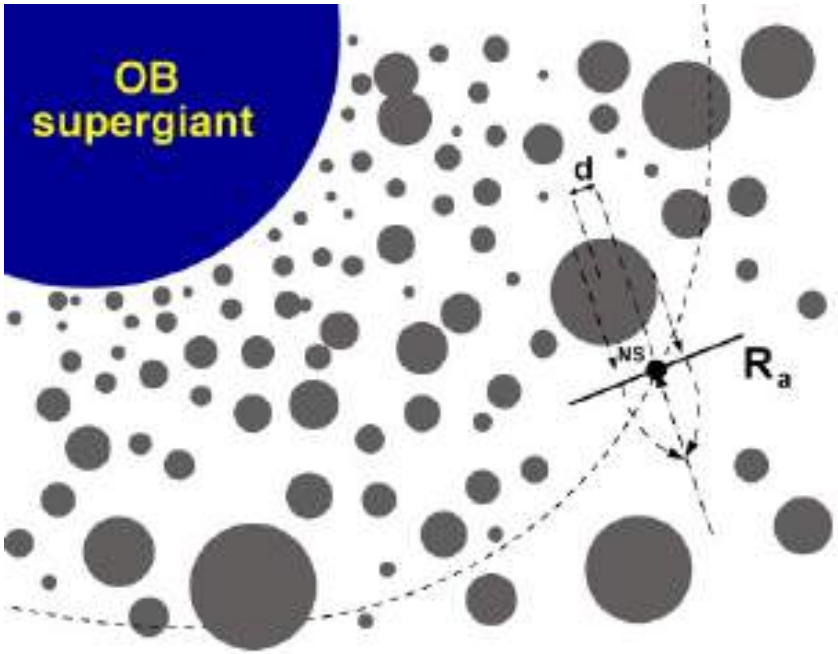


O VIII Lα.

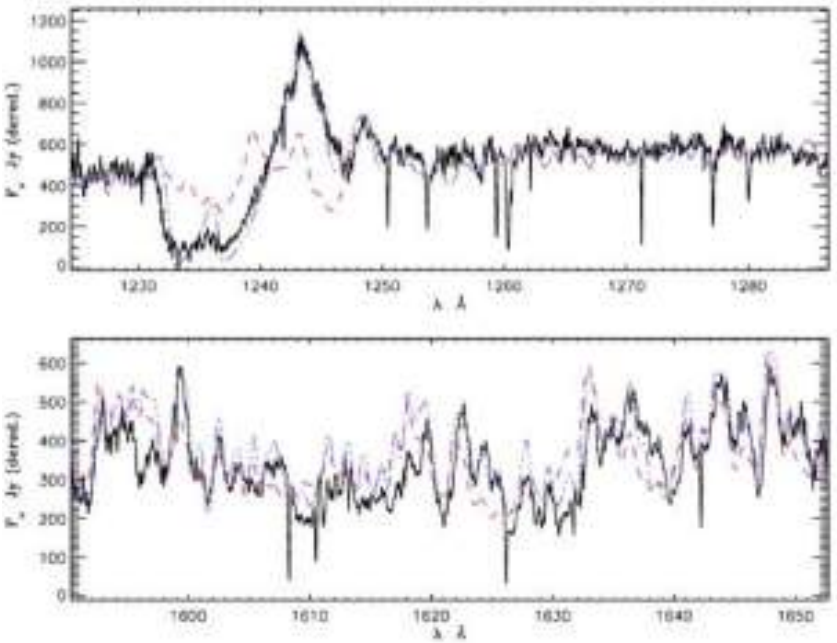


O VIII Lα

Estrellas Masivas



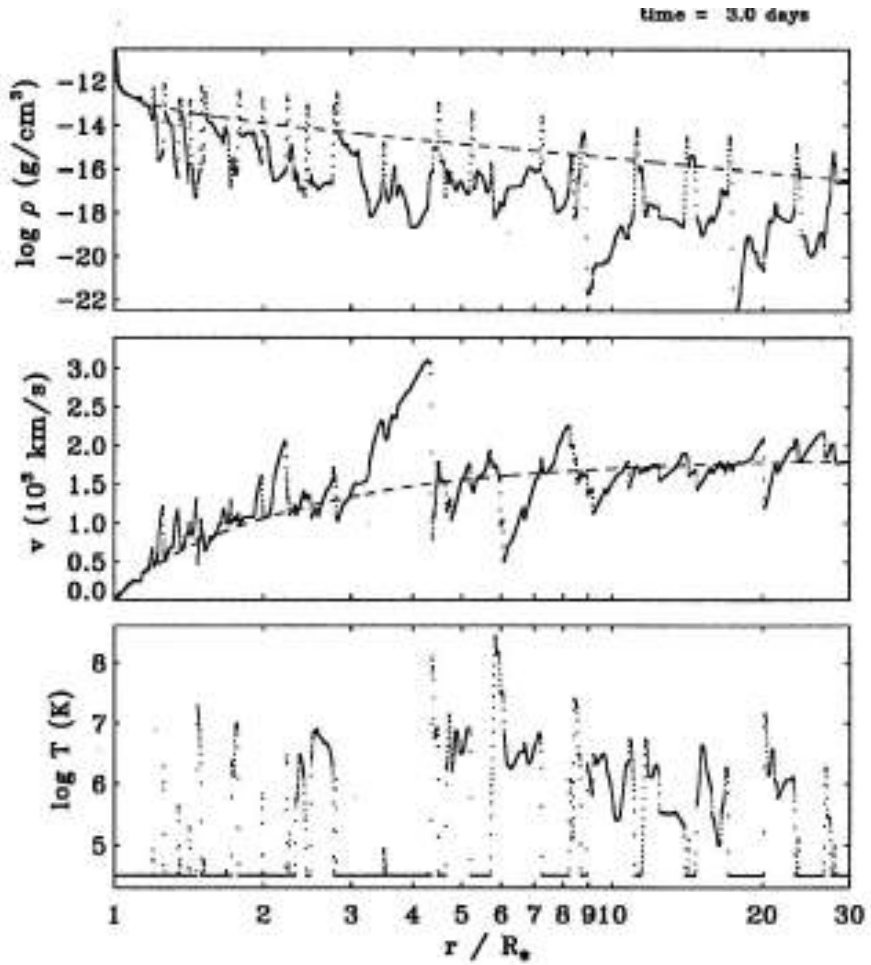
Modelo de viento con condensaciones.



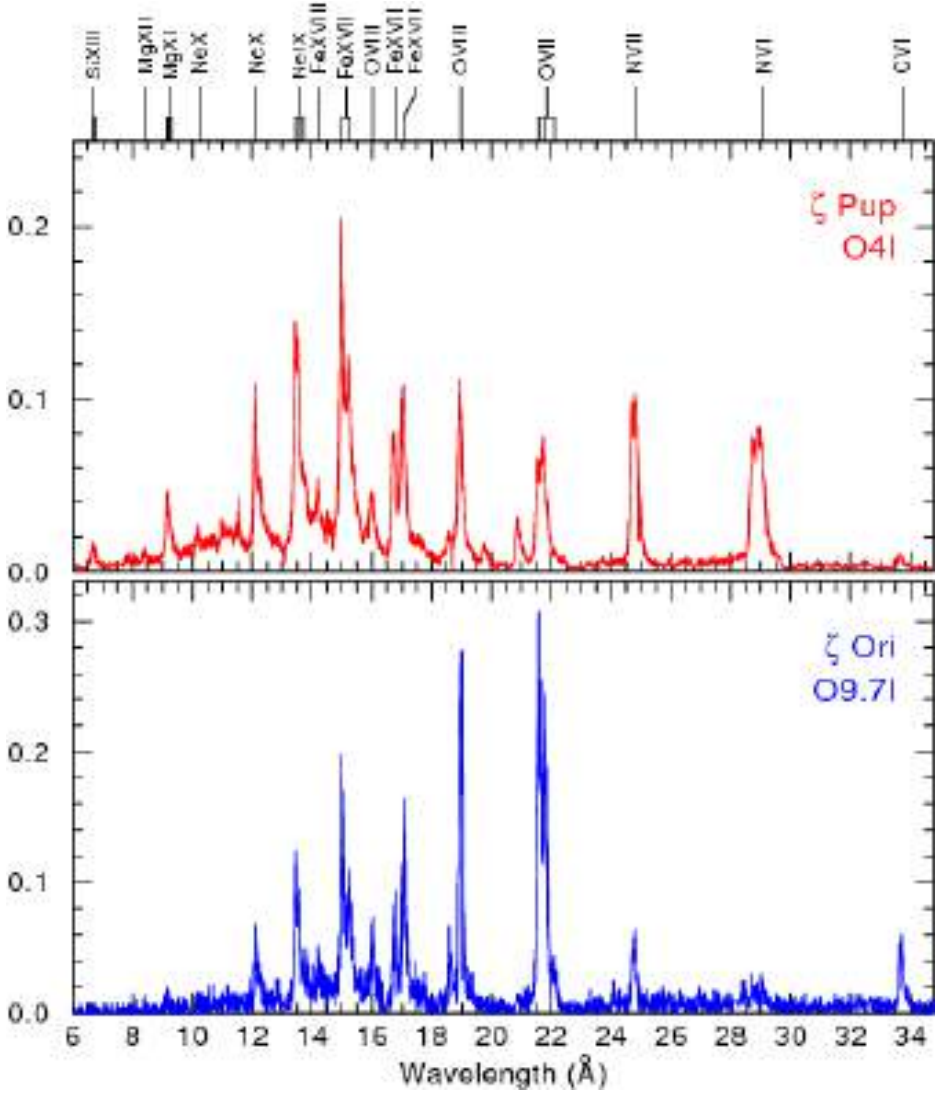
Efecto de rayos X sobre el espectro UV.

Credits: Najarro et al. 2006

Estrellas Masivas

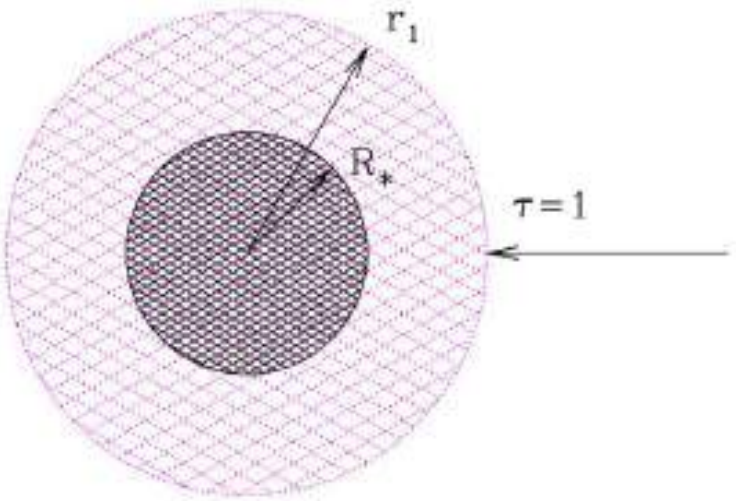


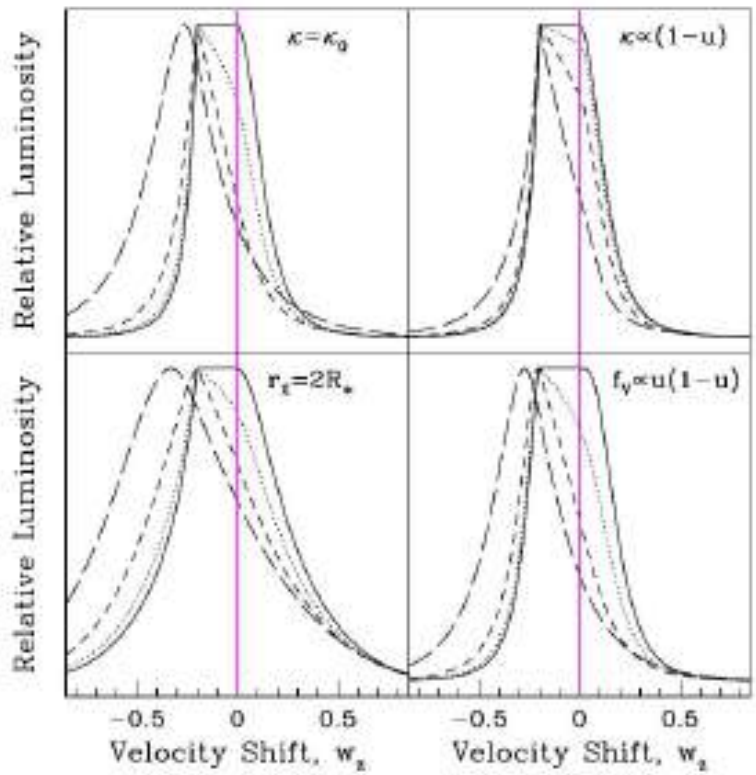
Estrellas Masivas



ζ Pup, T=42000 K. ζ Ori, T=29500 K.

Estrellas Masivas

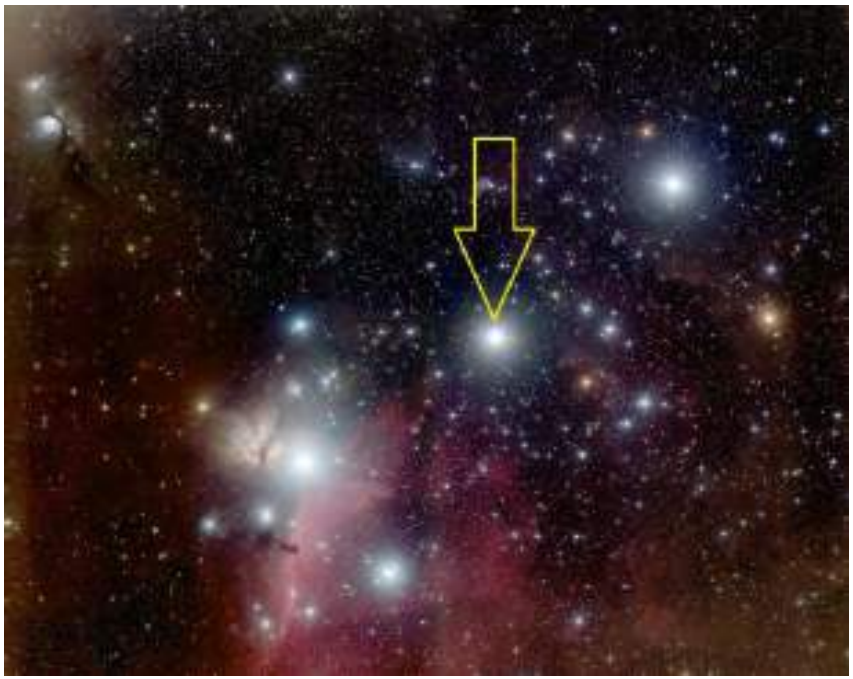




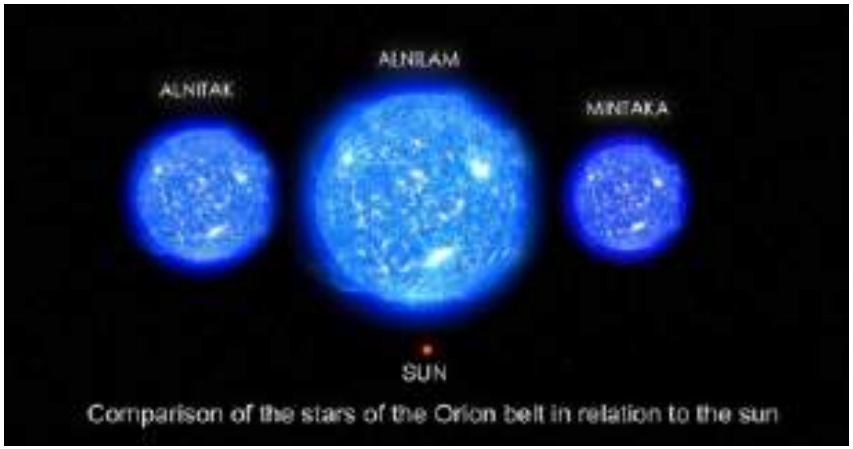
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ϵ Ori



Cinturón de Orión.



Alnilan: Collar de Perlas.

ϵ Ori

Datos:
Optical: NARVAL and ESPANDONS from POLARBASE

UV: IUE, GHRS (HST), Copernicu

X-Rays: Chandra (HETGS), XMM-Newton (RGS1,2)

Table 1. Summary of data of ϵ Ori: optical (NARVAL), ultraviolet (IUE, HST and Copernicus) and X-ray (Chandra and XMM-Newton).

ID Obs.	Date	Julian date	Spectral range (Å)	$\lambda/\Delta\lambda$
		NARVAL (Optical)		
–	Oct-19-2007	245 4392.59607	3606–10000	65 000
		IUE (UV)		
SWP50177	Jan-26-1987	244 6823.37068	1150–1975	10 000
SWP50196	Jan-30-1987	244 6825.36254	1150–1975	10 000
SWP50204	Jan-31-1987	244 6826.54533	1150–1975	10 000
SWP50216	Feb-01-1987	244 6827.37920	1150–1975	10 000
SWP50229	Feb-01-1987	244 6828.47190	1150–1975	10 000
SWP50242	Feb-03-1987	244 6829.64887	1150–1975	10 000
SWP50249	Feb-03-1987	244 6830.47746	1150–1975	10 000
SWP50251	Feb-05-1987	244 6831.64990	1150–1975	10 000
SWP50266	Feb-06-1987	244 6832.66278	1150–1975	10 000
SWP50272	Feb-06-1987	244 6833.47035	1150–1975	10 000
LWR02238	Sept-01-1978	244 3753.35550	1900–3080	14 000
LWR02239	Sept-01-1978	244 3753.48003	1900–3080	14 000
LWR02240	Sept-01-1978	244 3753.42454	1900–3080	14 000

Modelado: CMFGEN

$$\mu \frac{dI_\nu}{dz} - \left[\left(\frac{\mu\nu}{c} \right) \frac{\partial v}{\partial z} \right] \frac{\partial I_\nu}{\partial \nu} = \eta_\nu - \chi_\nu I_\nu$$

$$\frac{dH_\nu}{dz} - \left[\left(\frac{\nu}{c} \right) \frac{\partial v}{\partial z} \right] \frac{dH_\nu}{d\nu} = \eta_\nu - \chi_\nu J_\nu$$

$$\frac{dK_\nu}{dz} - \left[\left(\frac{\nu}{c} \right) \frac{\partial v}{\partial z} \right] \frac{dK_\nu}{d\nu} = -\chi_\nu H_\nu$$

$$\int_0^\infty \chi_\nu \left[J_\nu - S_\nu \right] d\nu = 0$$





Hillier and Miller (1998)

Modelado: CMFGEN

Statistical Equilibrium Equations:

$$\partial \boldsymbol{S}_d \cdot \delta \boldsymbol{N}_d = -\Delta \boldsymbol{S}_d$$

$$(\delta n_{1\mathrm{d}}, \ldots, \delta n_{N\mathrm{d}}, \delta N_{\mathrm{ed}}, \delta T_{\mathrm{d}}, \delta J_{1\mathrm{d}}, \delta J_{2\mathrm{d}}, \ldots, \delta \bar{J}_{1\mathrm{d}}, \delta \bar{J}_{2\mathrm{d}}, \ldots)$$

Radiative Transfer Equations:

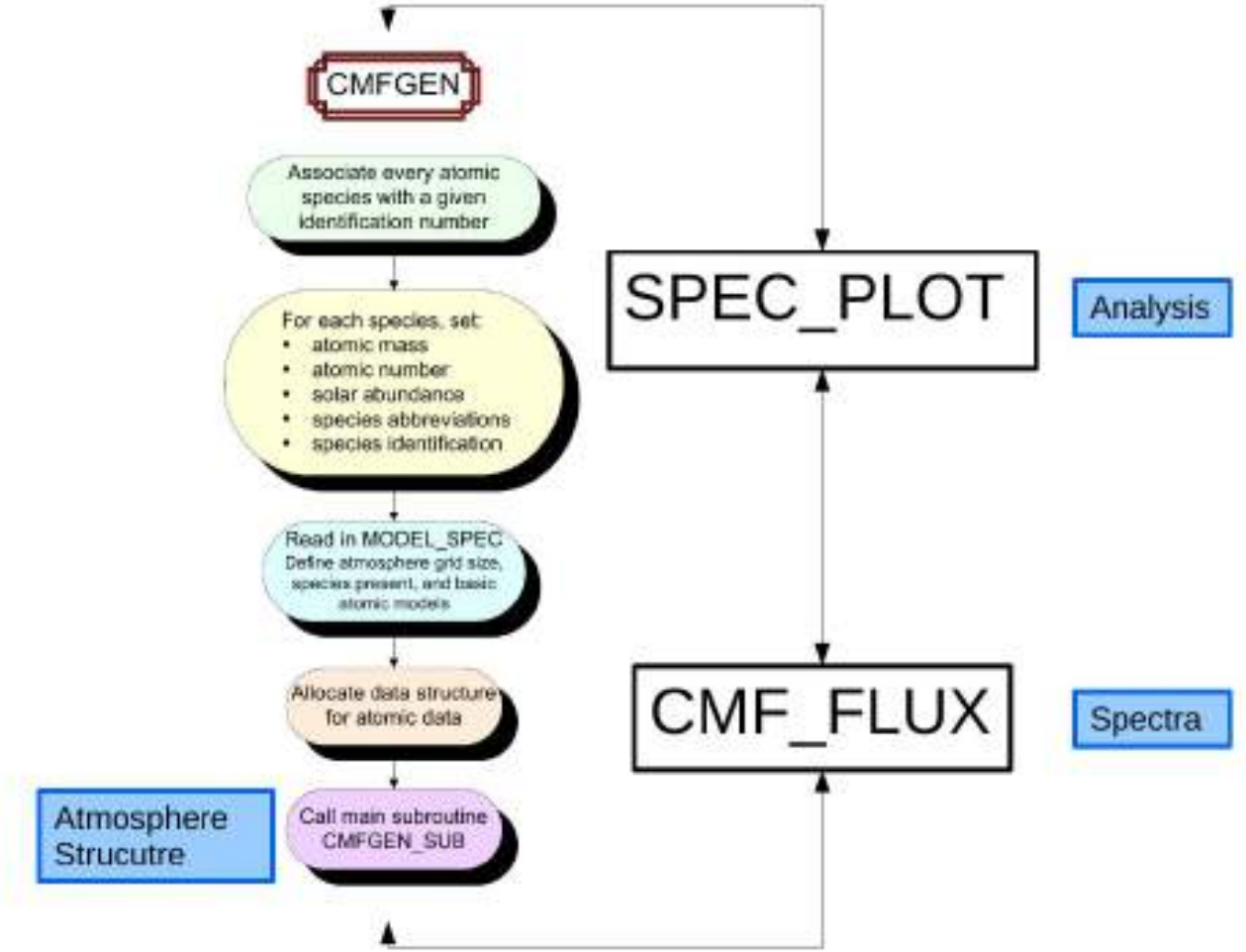
$$\begin{aligned} \boldsymbol{T}_m \cdot \boldsymbol{J}_m &= \boldsymbol{X}_m + \boldsymbol{U}_m \cdot \boldsymbol{J}_{m-1} + \boldsymbol{V}_m \cdot \boldsymbol{H}_{m-1} \\ \boldsymbol{H}_m &= \boldsymbol{A}_m \cdot \boldsymbol{J}_m + \boldsymbol{B}_m \cdot \boldsymbol{H}_{m-1} \end{aligned}$$

Equation system for each m frequency

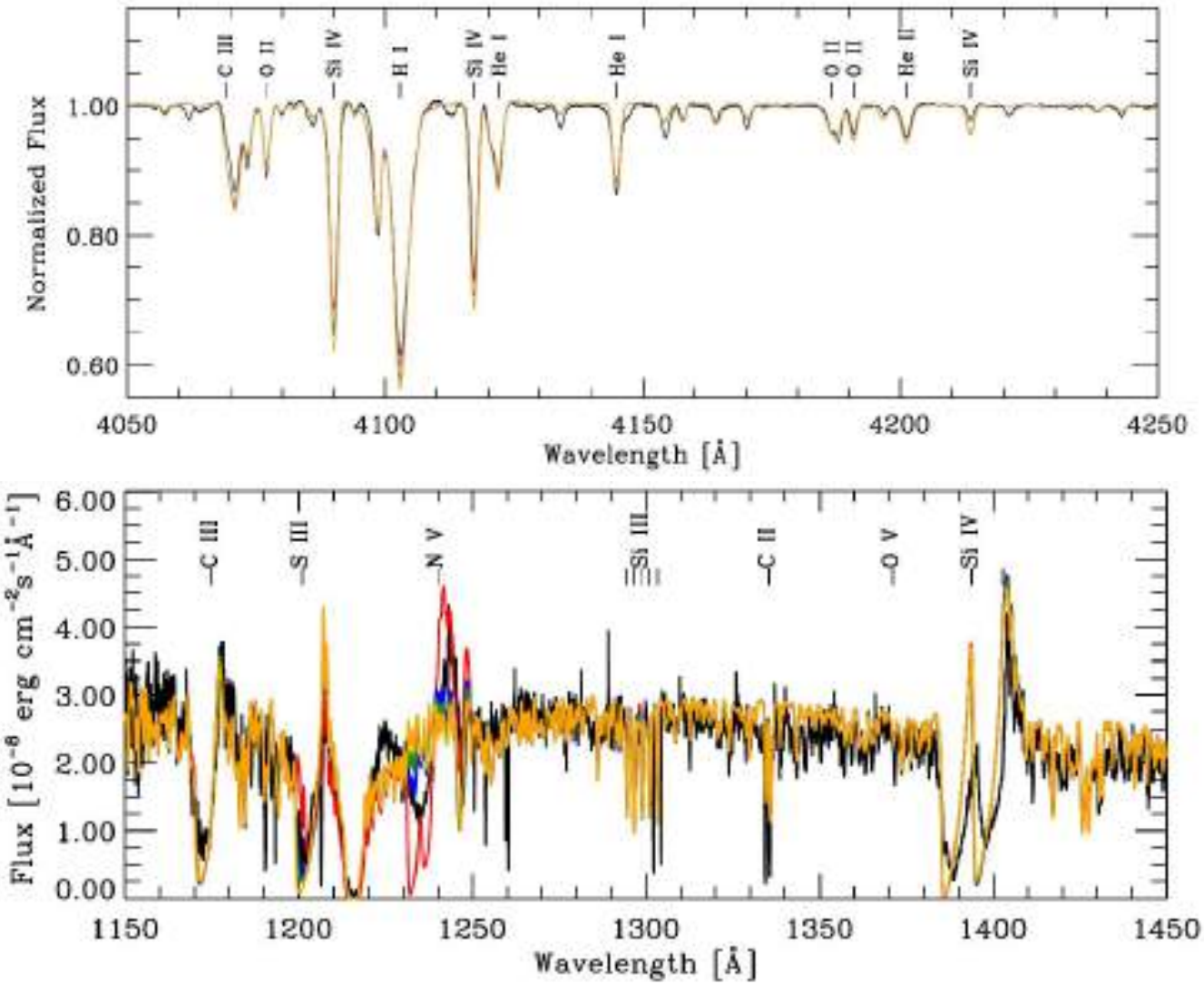


Hillier (1990,1998,2003)

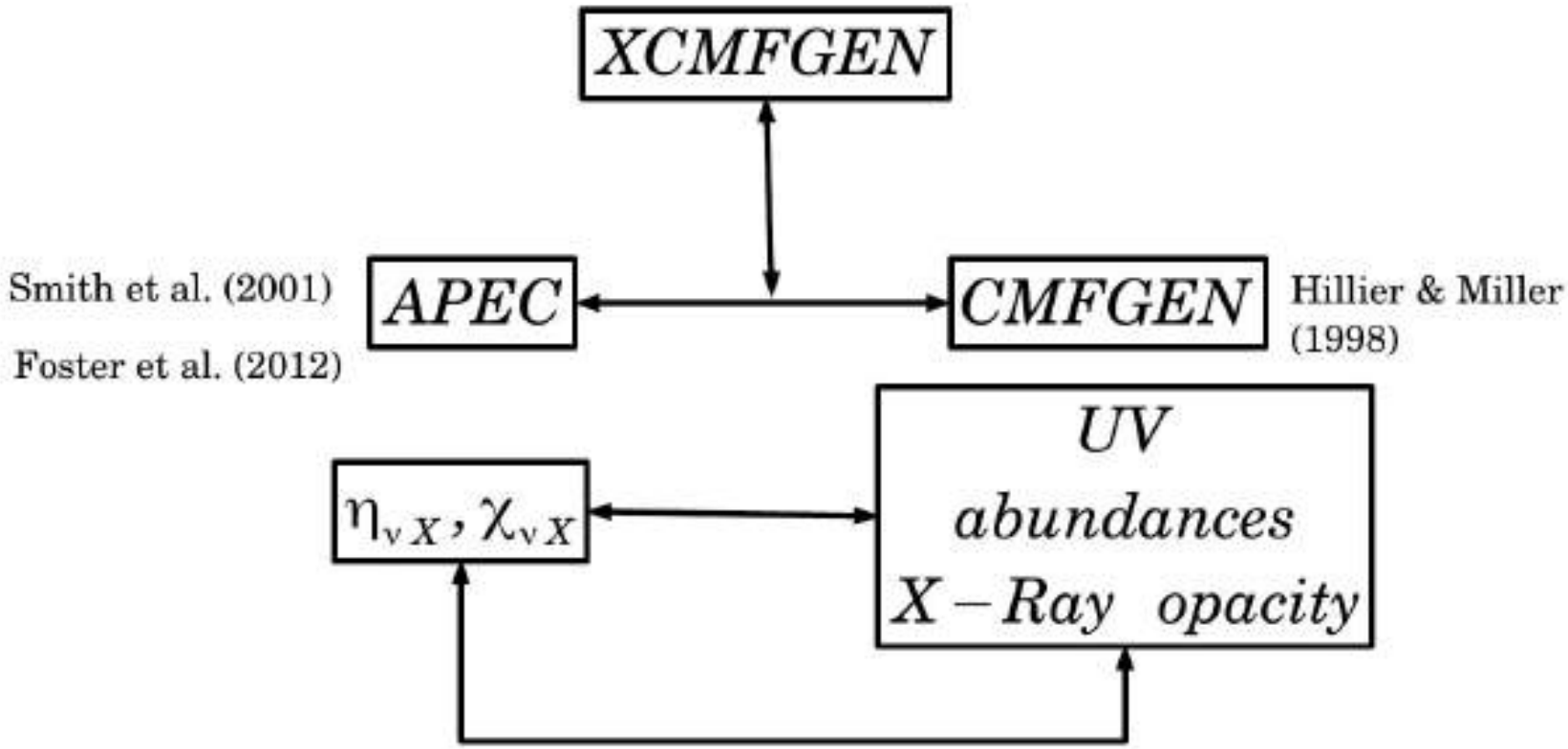
Modelado: CMFGEN



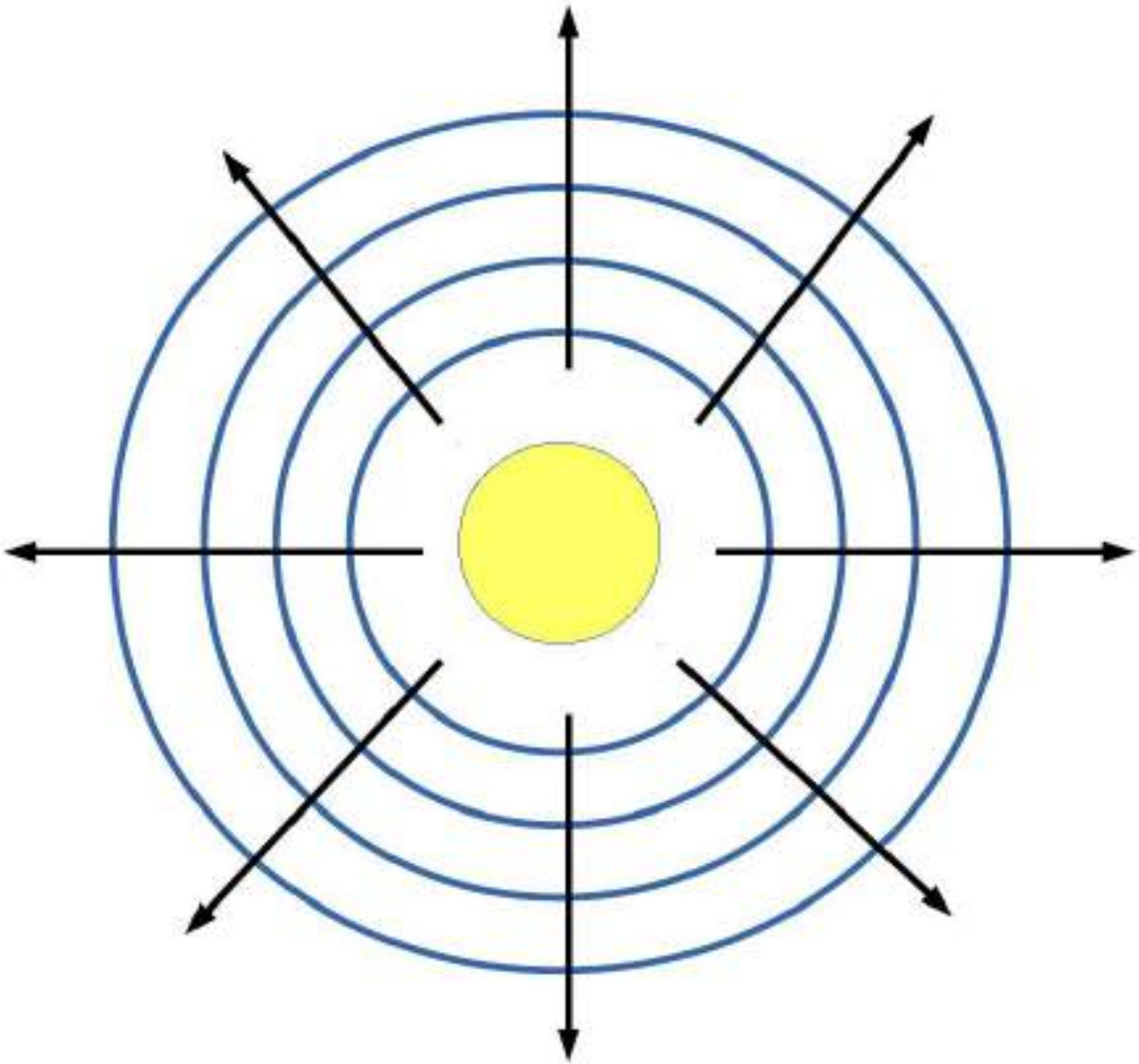
Modelado: CMFGEN



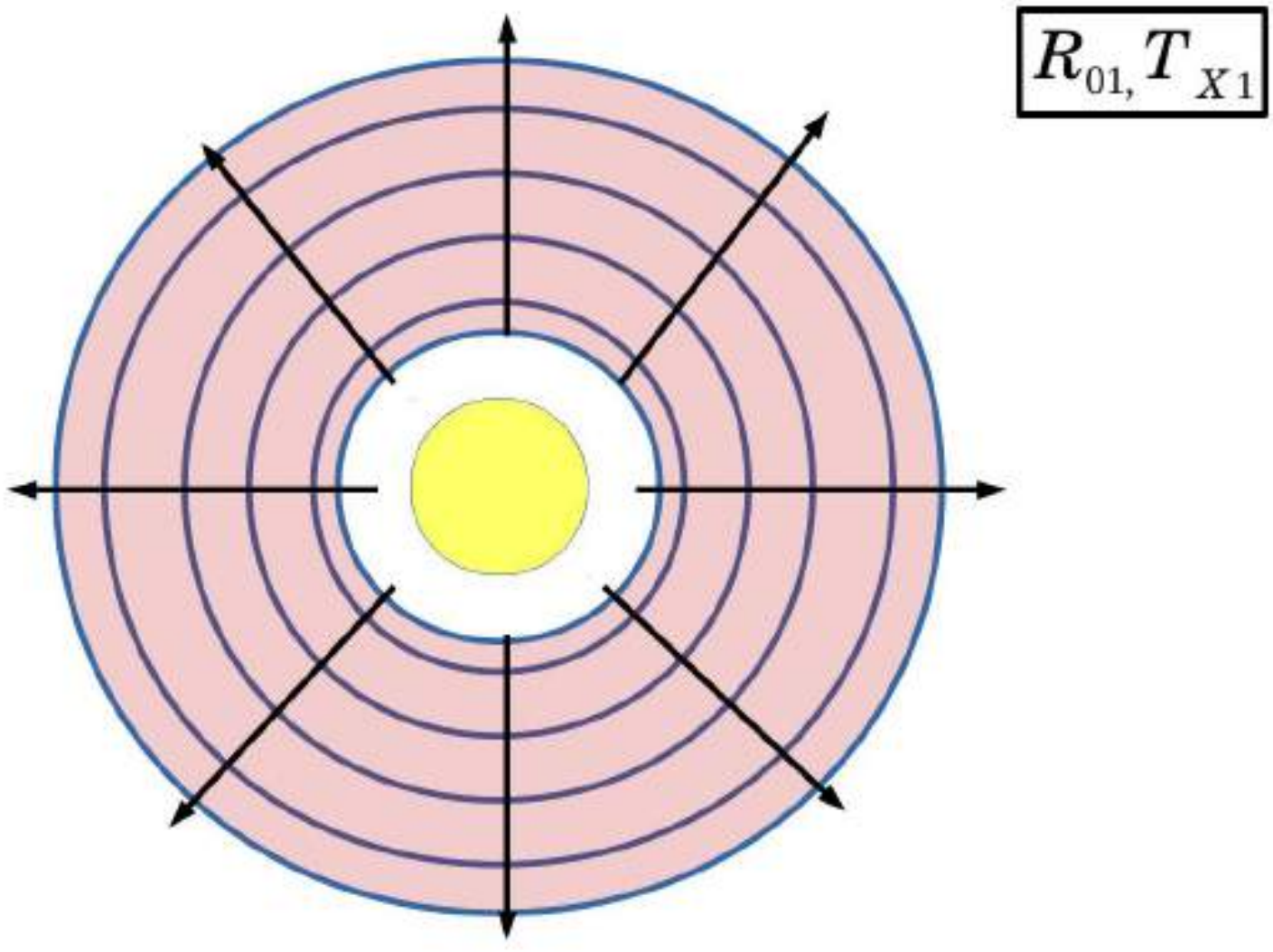
Modelado: XCMFGEN



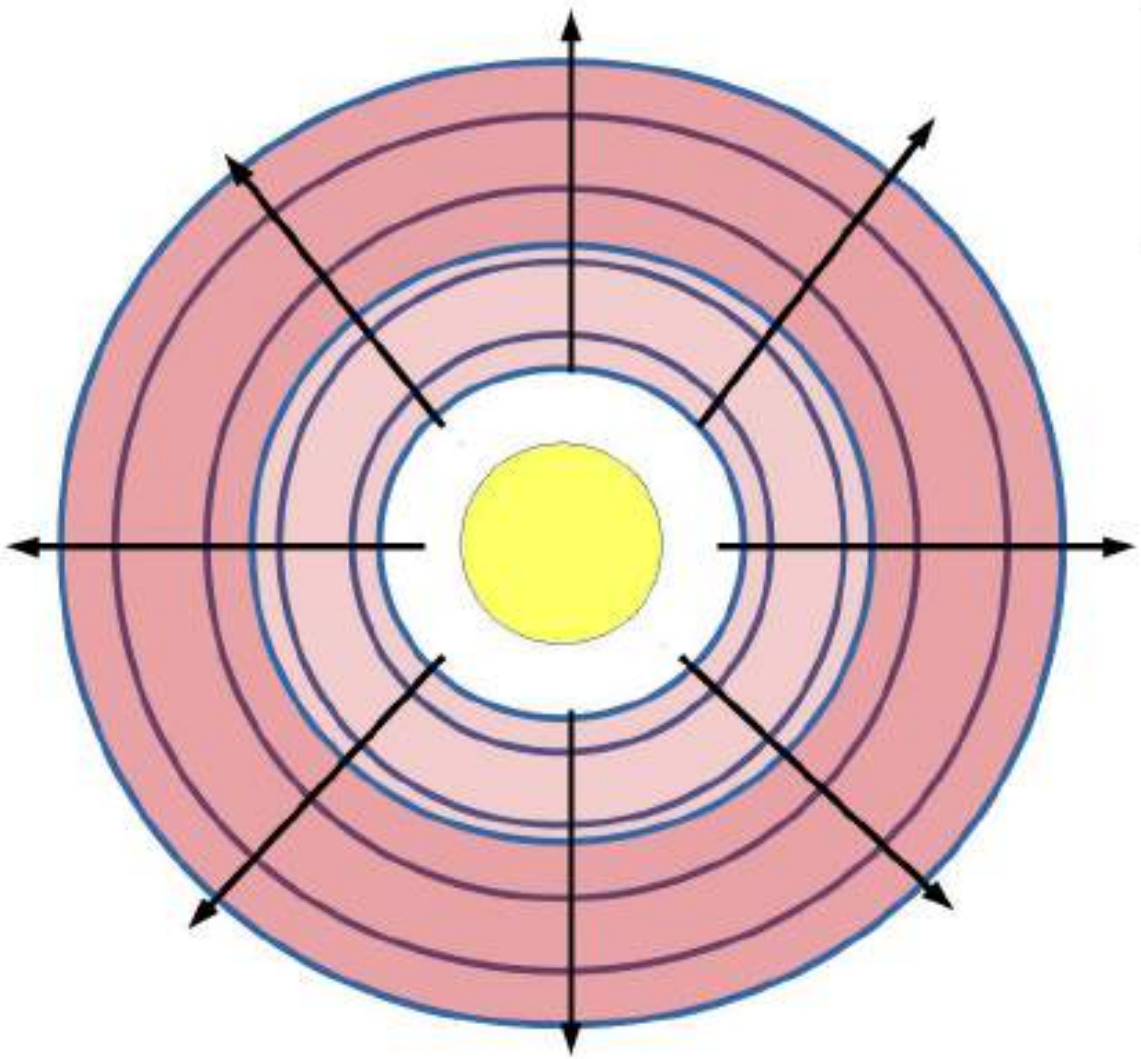
Modelado: XCMFGEN



Modelado: XCMFGEN

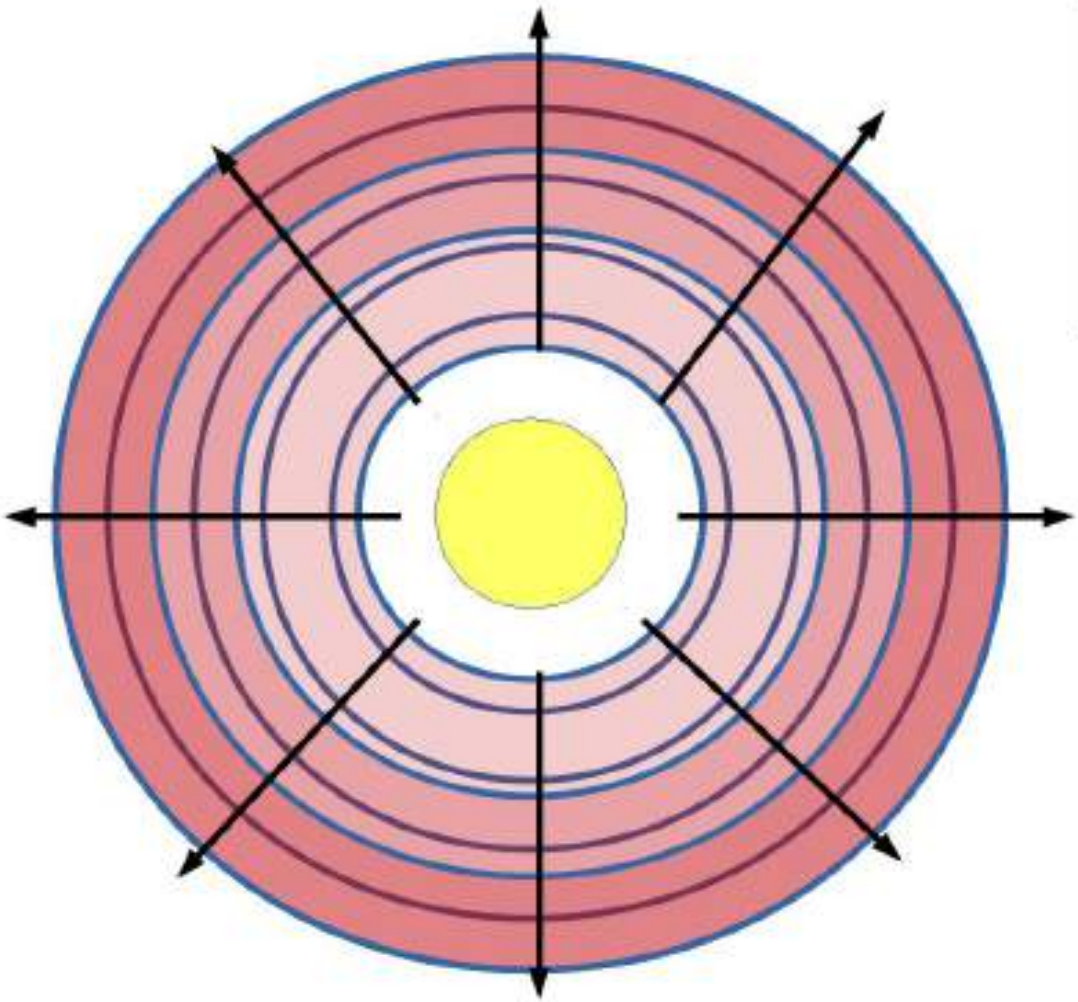


Modelado: XCMFGEN



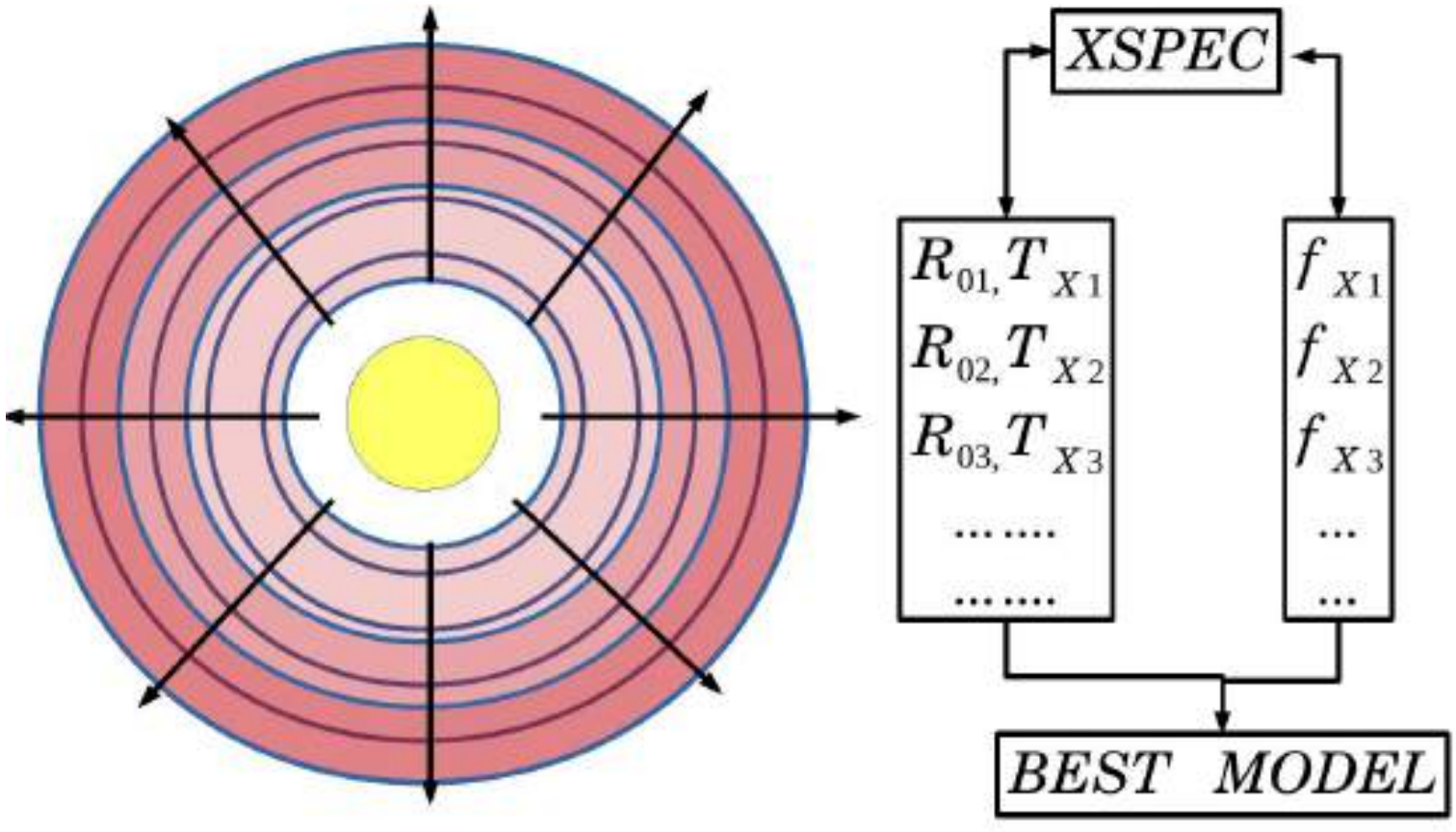
$R_{01,} T_{X1}$
$R_{02,} T_{X2}$

Modelado: XCMFGEN

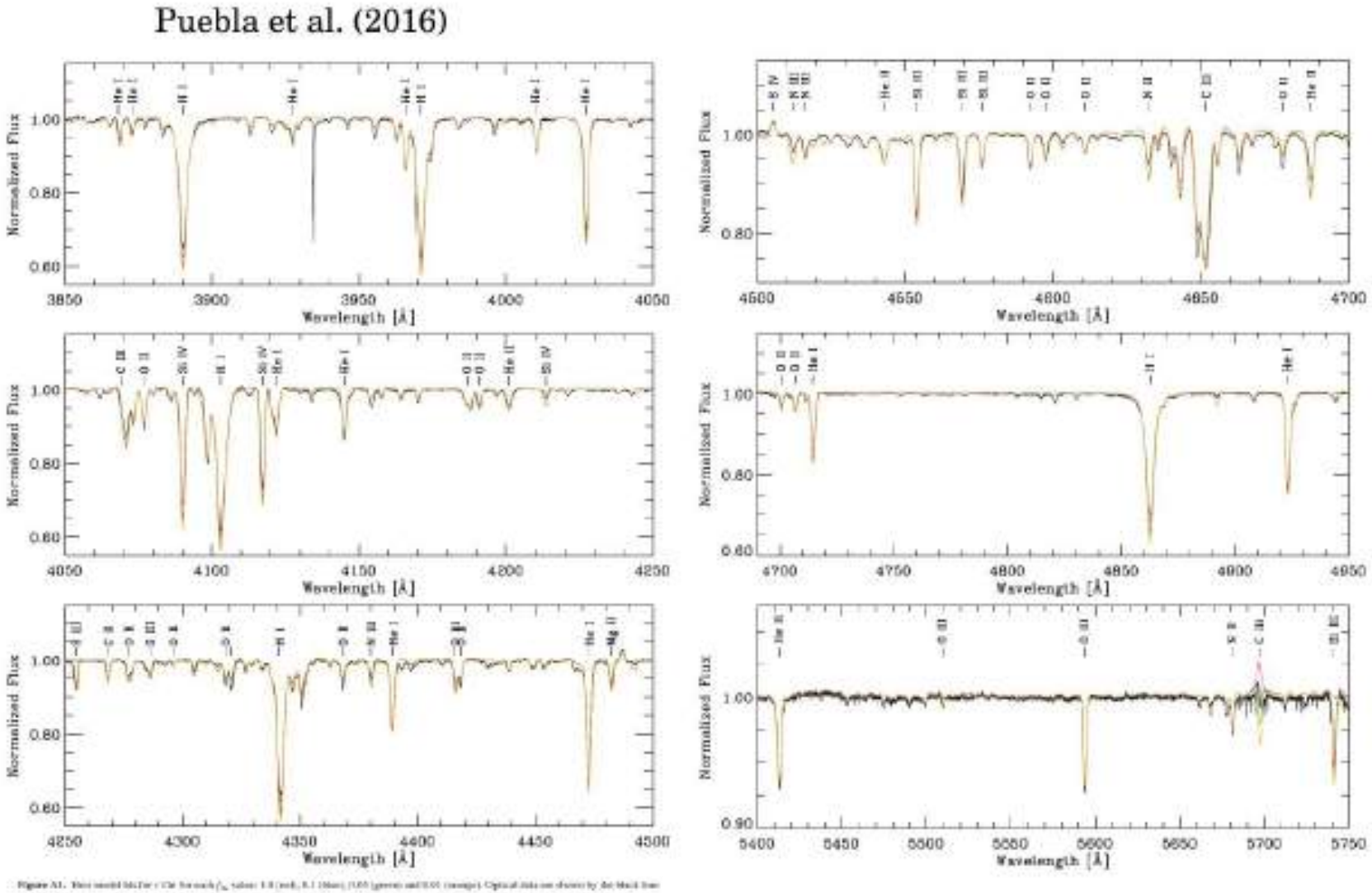


$R_{01,} T_{X1}$
$R_{02,} T_{X2}$
$R_{03,} T_{X3}$

Modelado: XCMFGEN

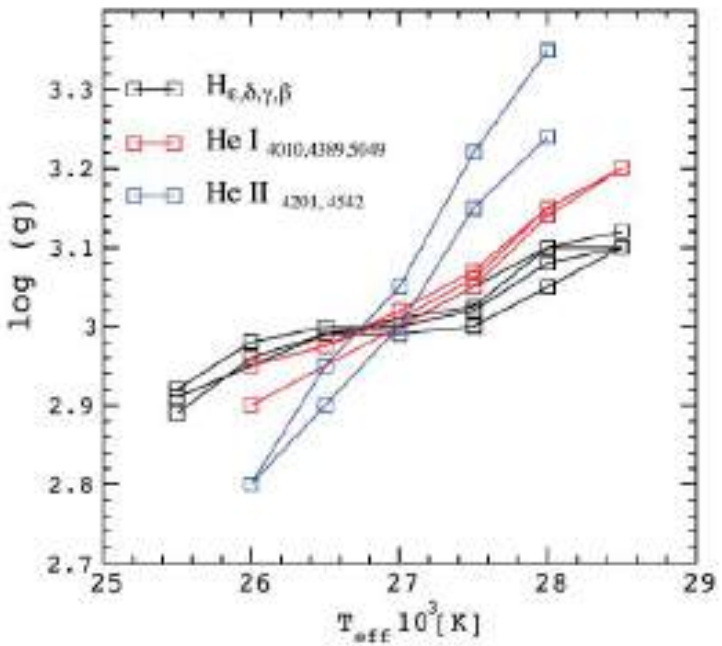


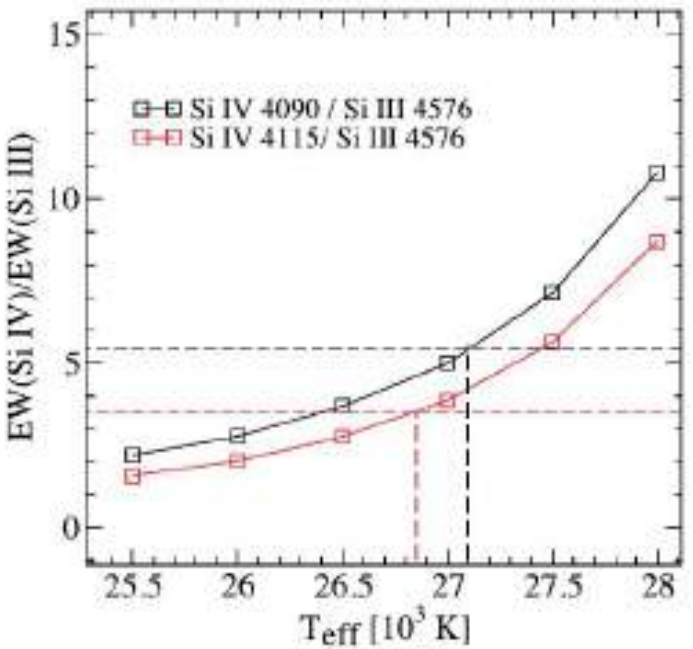
Resultados



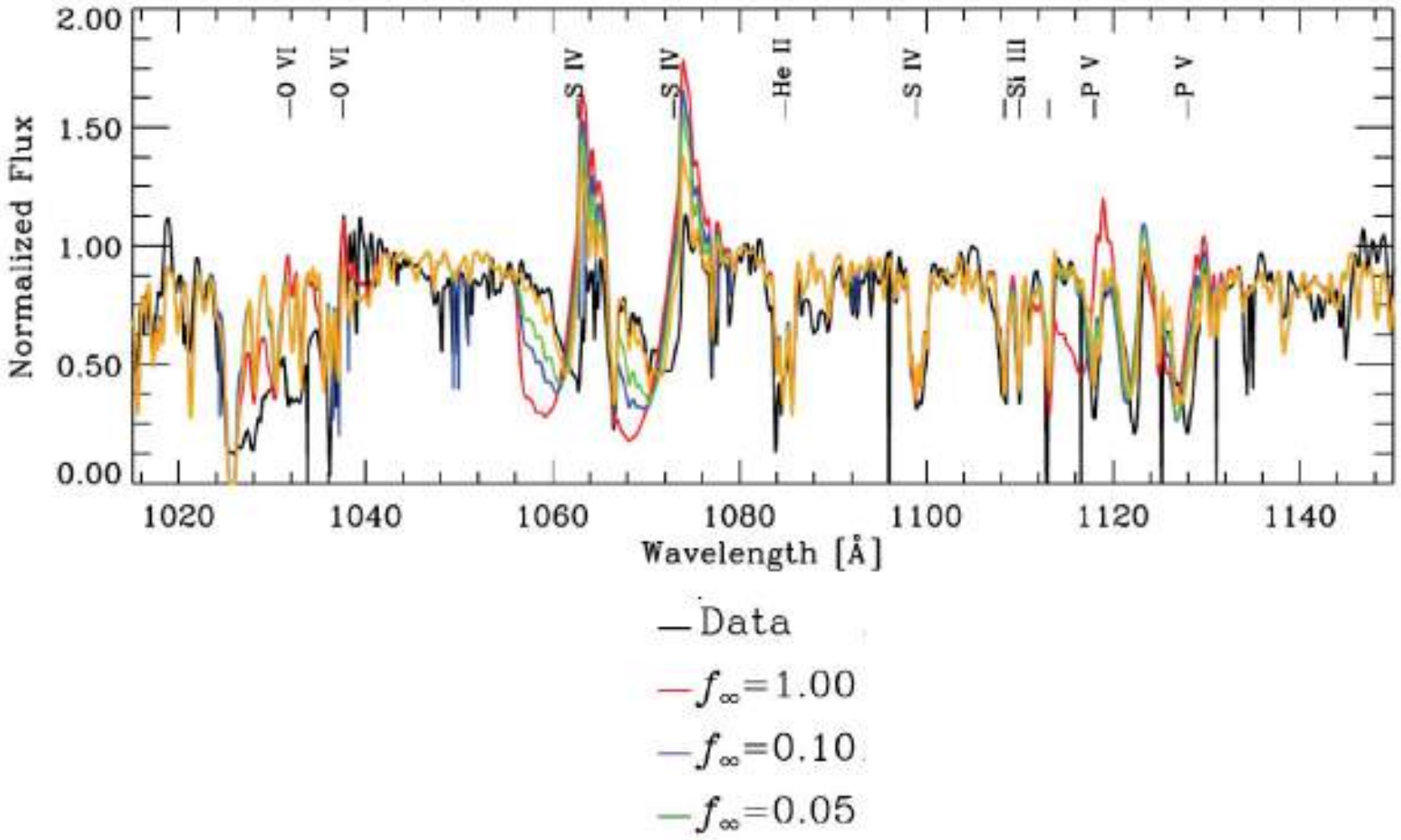
Resultados

Log $(L_*/L_\odot)^a$	$T_{\rm eff}$ 10^3 (K)	log g	R_* $R_\odot$	M_* $M_\odot$	$\xi_{\rm min}$ km s^{-1}	$v \sin i$ km s^{-1}	$v_{\rm macro}$ km s^{-1}	$E(B-V)$ mag	d pc
$5.59^{+0.51}_{-0.20}$	27.0 ± 0.5	3.0 ± 0.05	28.6	30.0	15–20	40–70^b	70–100	0.091 ± 0.01	412^c
$5.92^{+0.32}_{-0.18}$	27.0 ± 0.5	3.0 ± 0.05	42.0	64.5	15–20	40–70^b	70–100	0.091 ± 0.01	606^d

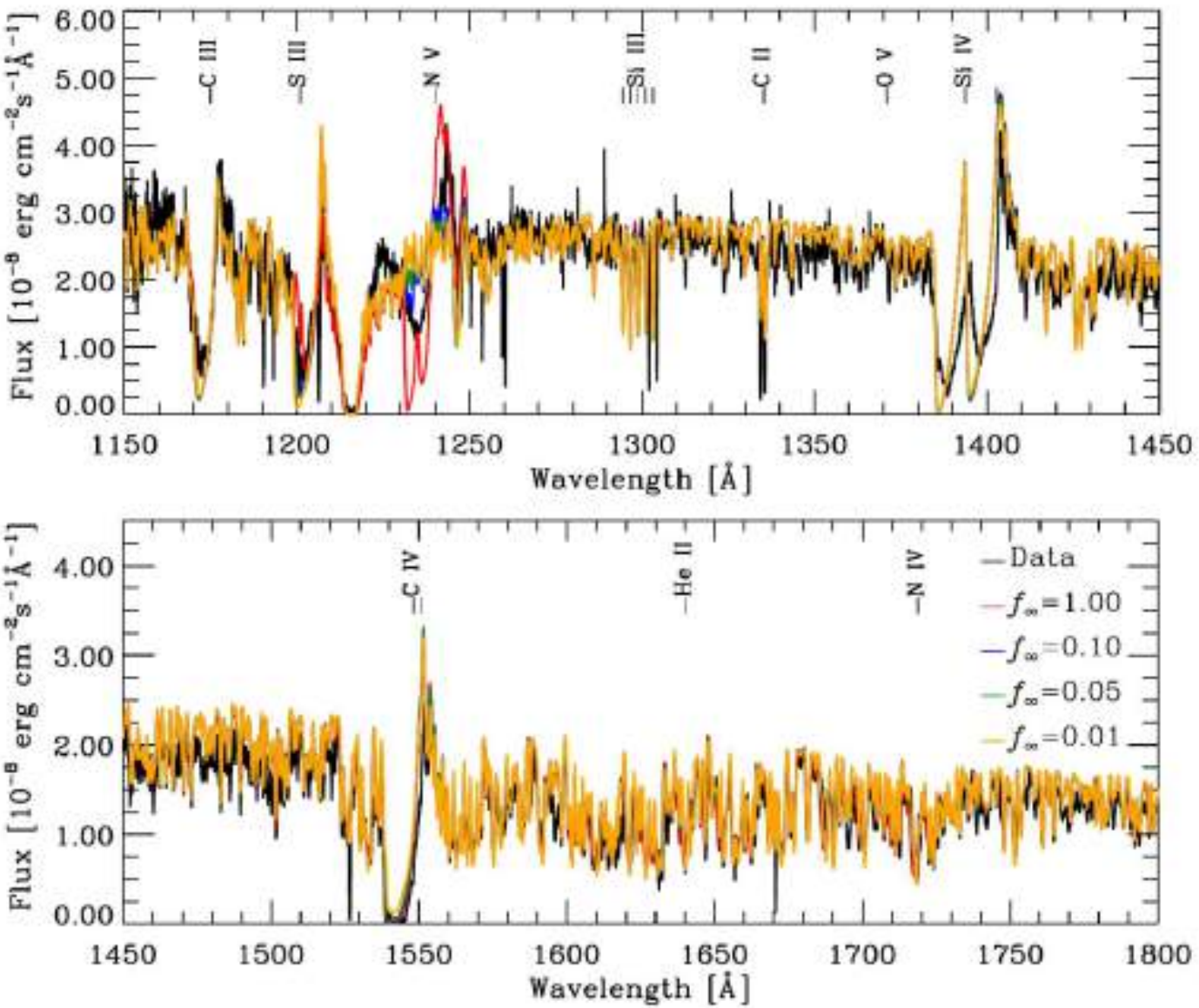




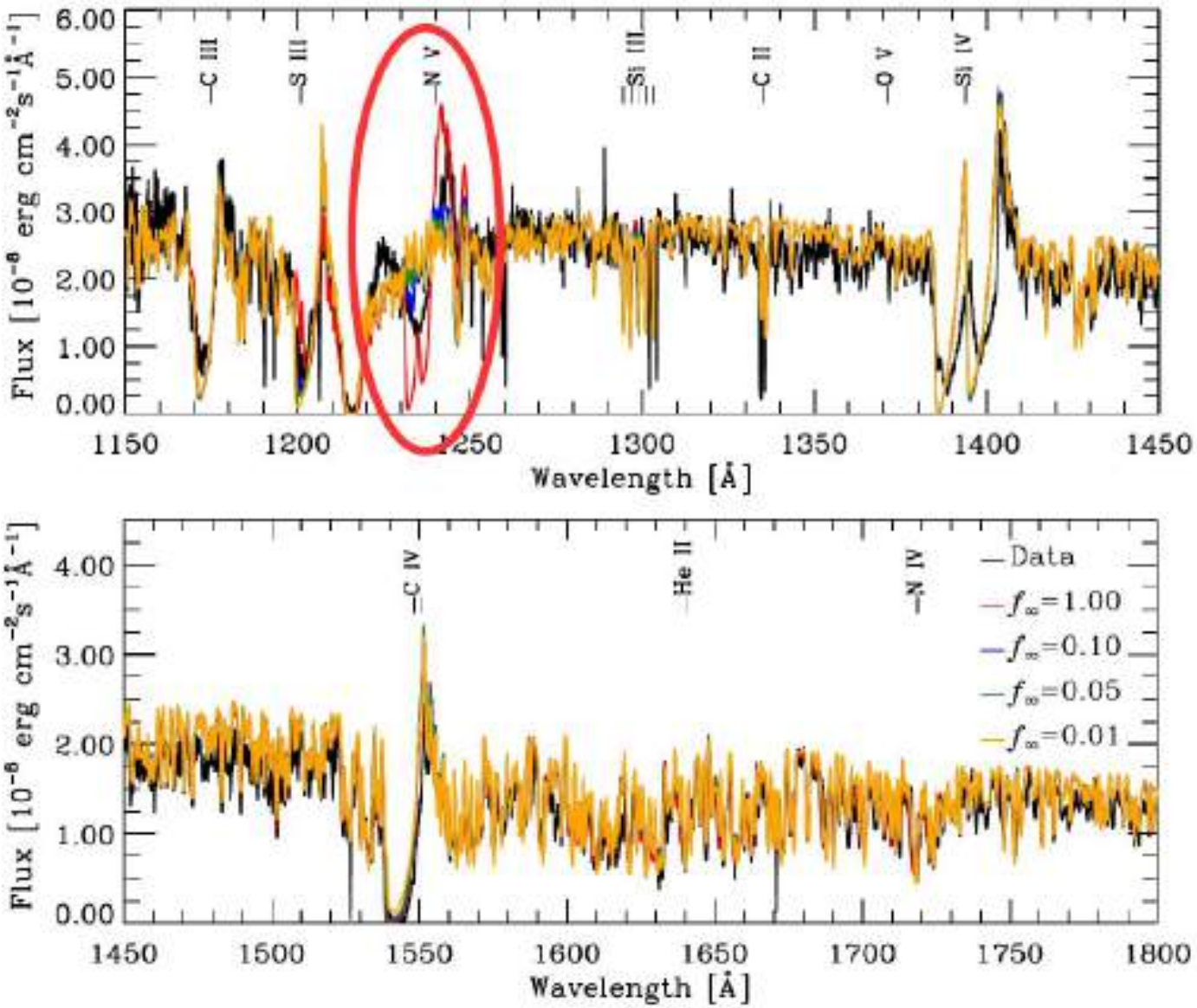
Resultados


2.00
1.50
1.00
0.50
0.00
Normalized Flux
O VI
O VI
S IV
S IV
He II
S IV
Si III
P V
P V
1020
1040
1060
1080
1100
1120
1140
Wavelength [Å]
Data
f_∞=1.00
f_∞=0.10
f_∞=0.05

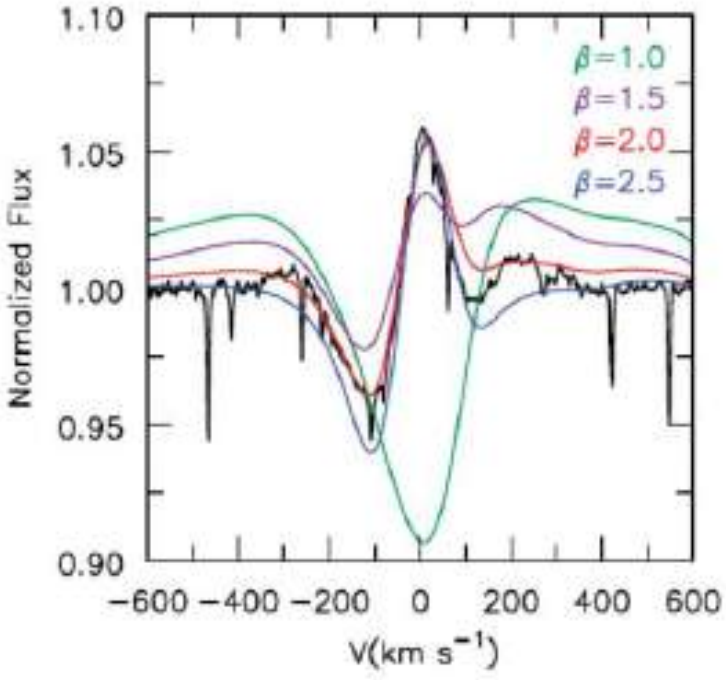
Resultados


C III
S III
N V
Si III
C II
O V
Si IV
Flux [10⁻⁸ erg cm⁻²s⁻¹Å⁻¹]
Wavelength [Å]
C IV
He II
N IV
Data
f_∞=1.00
f_∞=0.10
f_∞=0.05
f_∞=0.01

Resultados


C III
S III
N V
Si III
C II
O V
Si IV
Flux [10⁻⁶ erg cm⁻²s⁻¹Å⁻¹]
Wavelength [Å]
C IV
He II
N IV
Data
f_∞=1.00
f_∞=0.10
f_∞=0.05
f_∞=0.01

Resultados



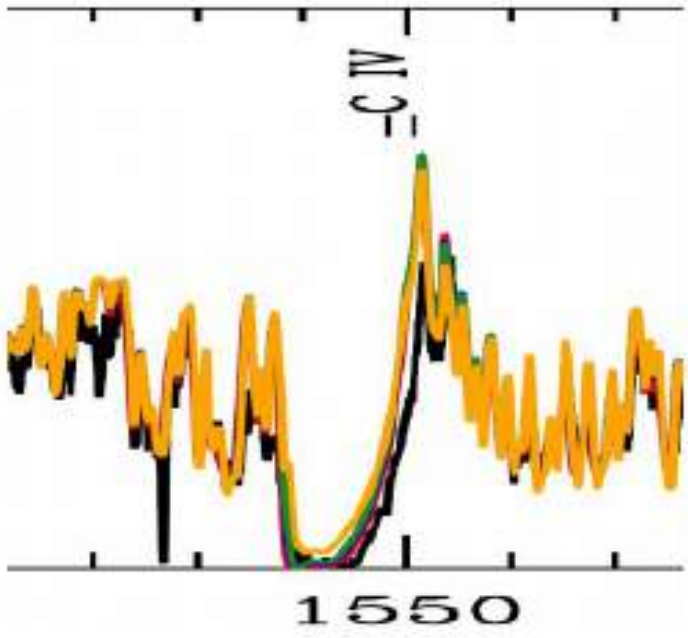
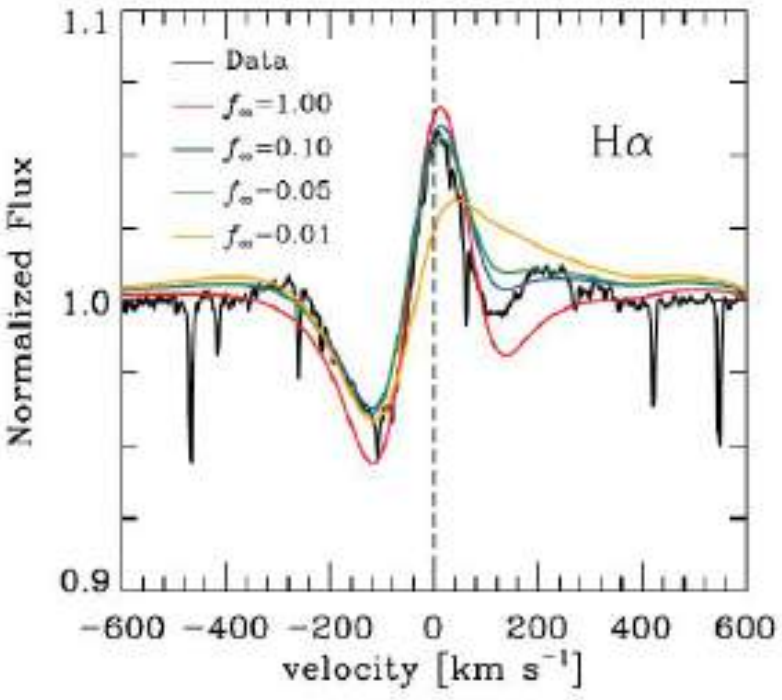


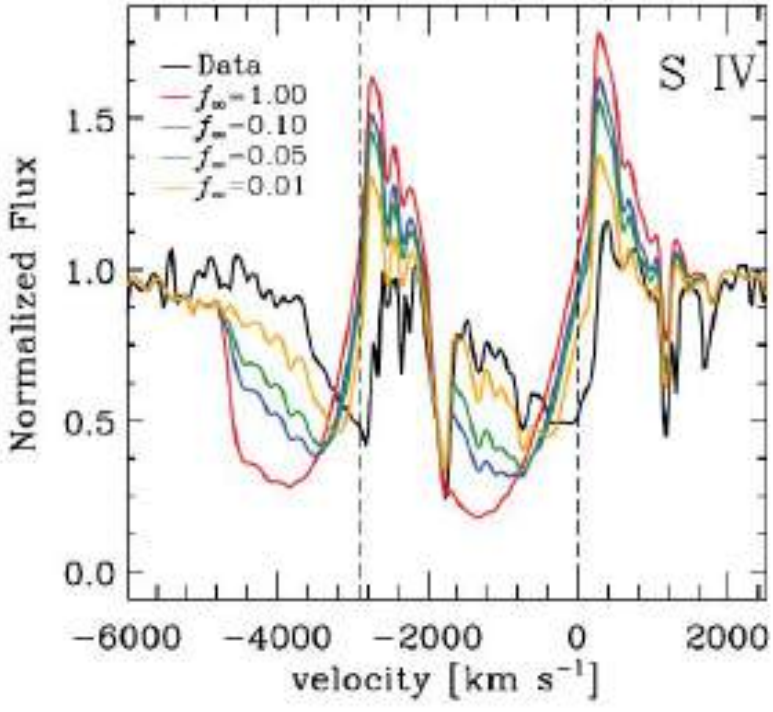
Table 5. Wind parameters of ϵ Ori from optical and UV data. The mass-loss rate for both *Hipparcos* distances is given.

Model	f_∞	$\dot{M}/\sqrt{f_\infty}^a$ $M_\odot yr^{-1}$	$\dot{M}/\sqrt{f_\infty}^b$ $M_\odot yr^{-1}$	v_∞ km s^{-1}	β	ξ_{max} km s^{-1}	v_{cl} km s^{-1}
A	0.1	1.55×10^{-6}	2.70×10^{-6}	1800	2.0	200	40
B	0.05	1.66×10^{-6}	2.80×10^{-6}	1800	2.0	200	30
C	0.01	1.75×10^{-6}	2.90×10^{-6}	1800	2.0	200	20
D	1.0	1.40×10^{-6}	2.55×10^{-6}	1800	2.0	200	–

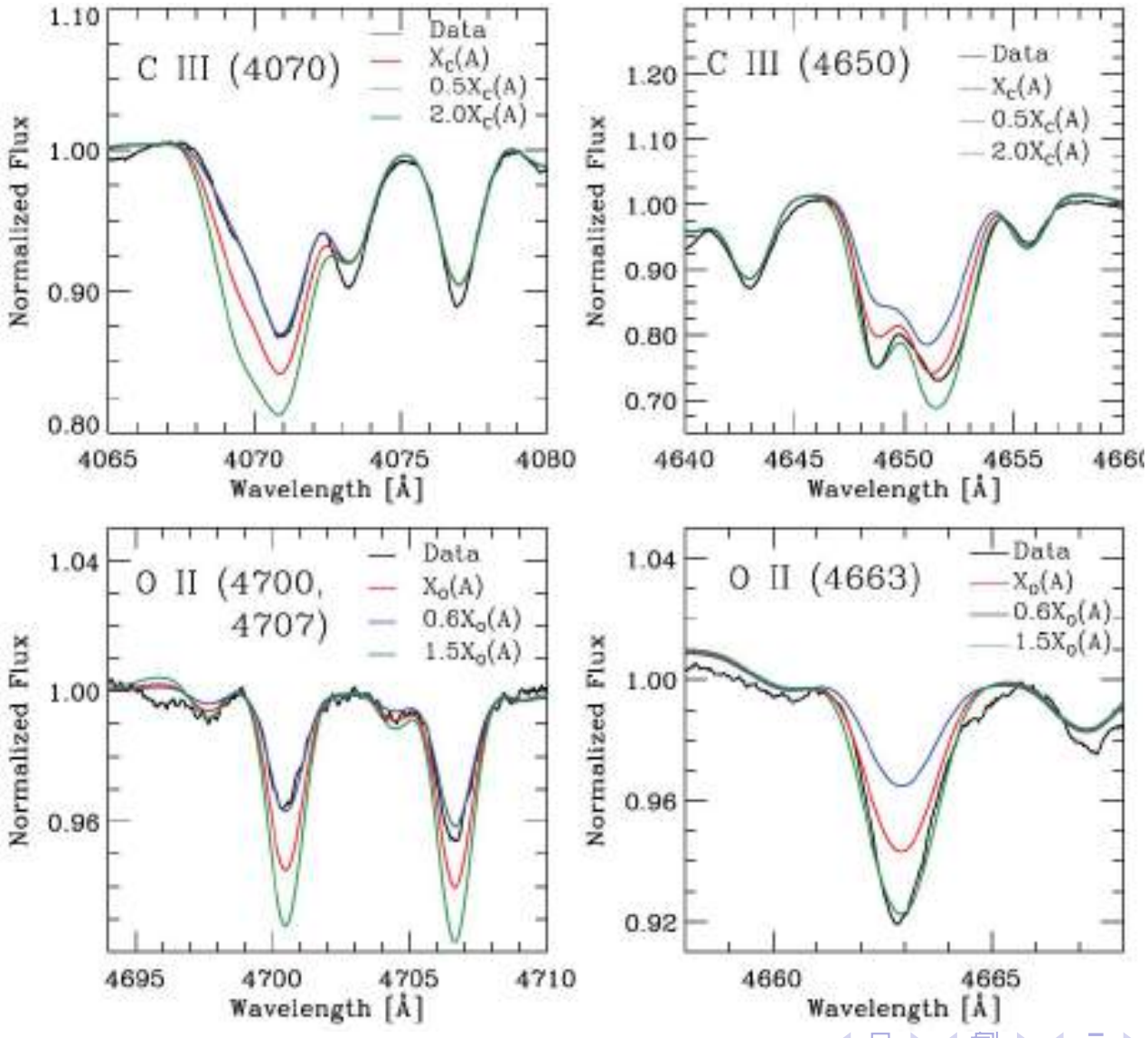
[a] *Hipparcos* catalogue (Perryman et al. 1997) ($d = 412$ pc).
[b] *Hipparcos* catalogue (van Leeuwen 2007) ($d = 606$ pc).

Resultados

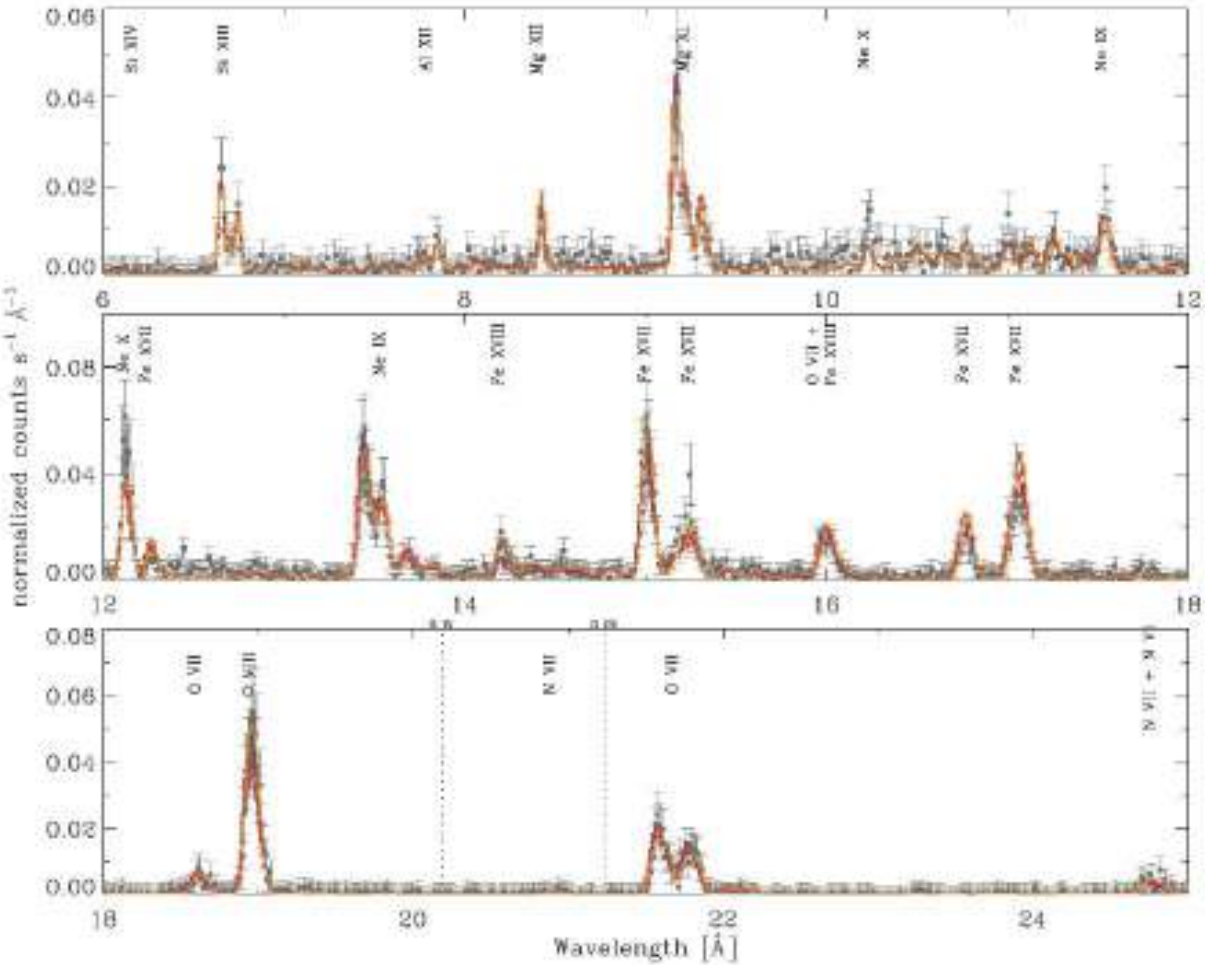

Data
f_∞=1.00
f_∞=0.10
f_∞=0.05
f_∞=0.01
Hα
Normalized Flux
velocity [km s^{-1}]


Data
f_∞=1.00
f_∞=0.10
f_∞=0.05
f_∞=0.01
S IV
Normalized Flux
velocity [km s^{-1}]

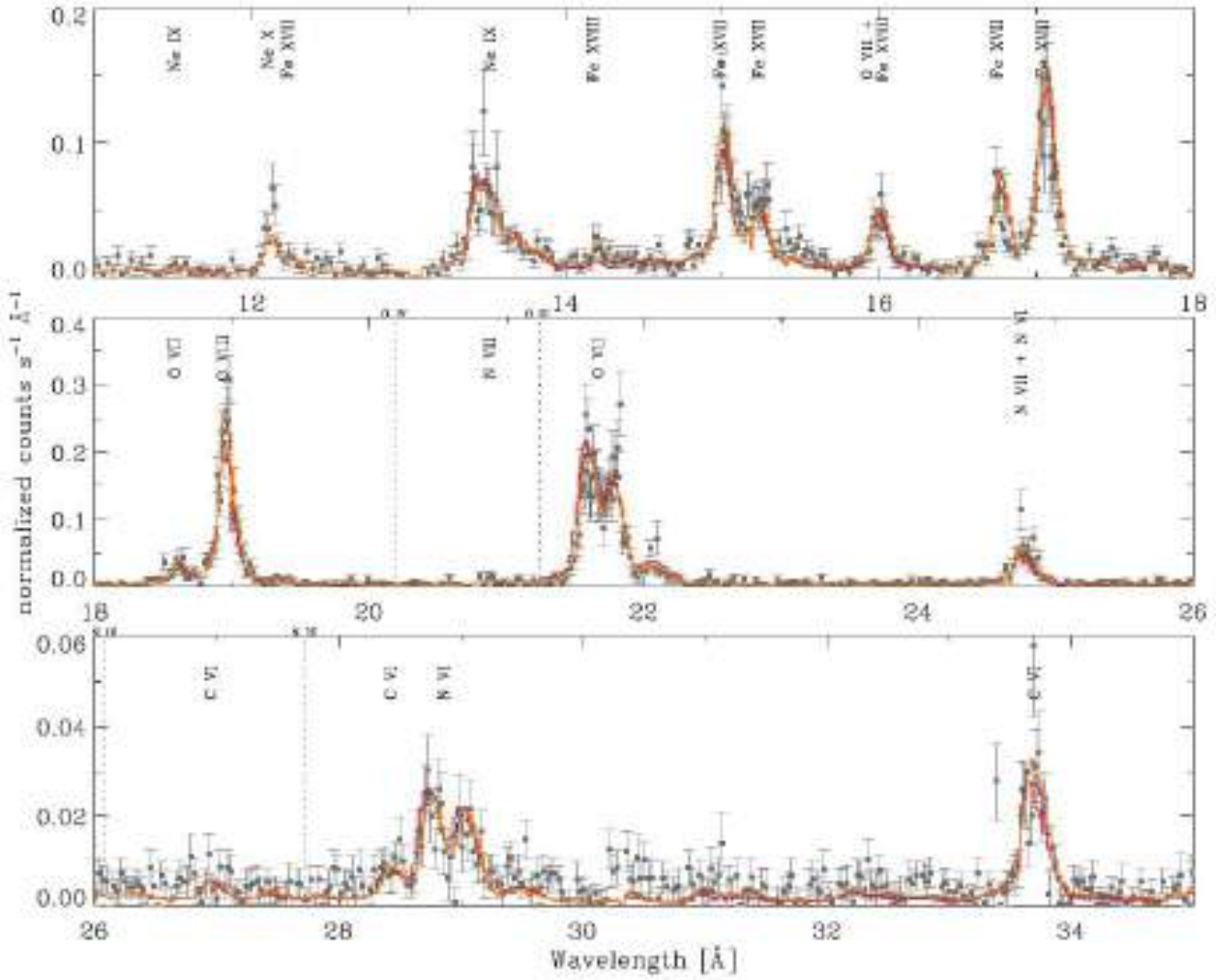
Resultados


C III (4070)
Data
$X_c(A)$
$0.5X_c(A)$
$2.0X_c(A)$
Normalized Flux
Wavelength [Å]
C III (4650)
O II (4700, 4707)
$X_o(A)$
$0.6X_o(A)$
$1.5X_o(A)$
O II (4663)

Resultados


normalized counts s^{-1} Å^{-1}
Wavelength [Å]
Si XIV
Si XIII
Al XII
Mg XII
Mg XI
Ne X
Ne IX
O VII
O VIII
N VII
O VII
N VII + N VI

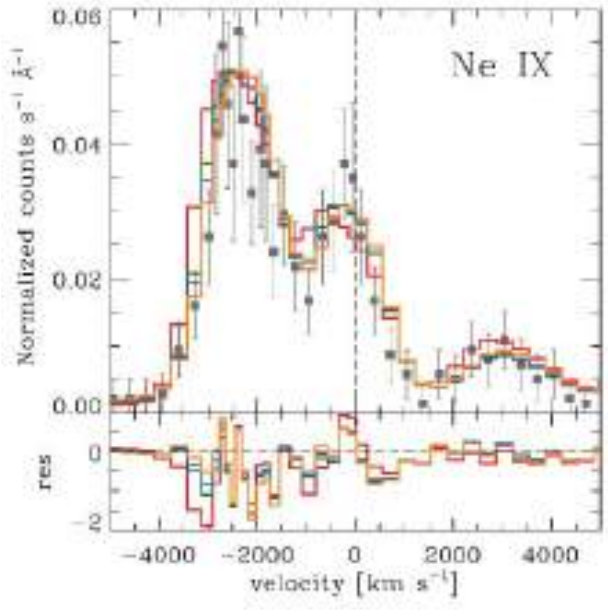
Resultados

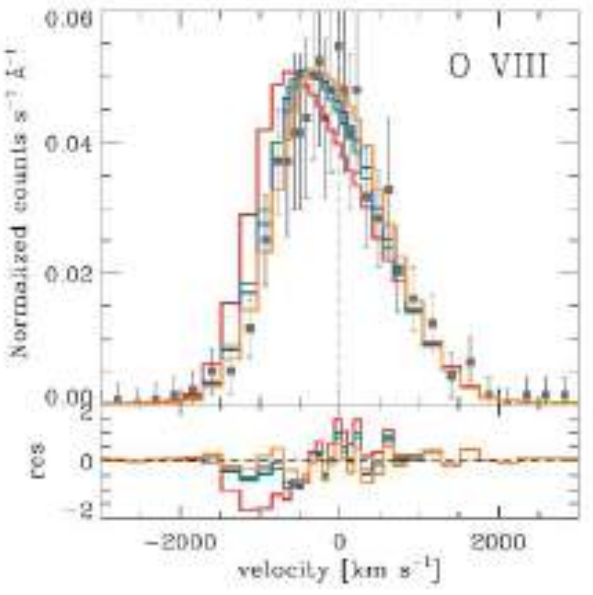

normalized counts s^{-1} Å^{-1}
Wavelength [Å]
Ne IX
Ne X
Fe XVII
Ne IX
Fe XVIII
Fe XVII
Fe XVII + O VIII
Fe XVII
Fe XVII
O VII
O VII
N VII
O VII
N VII + N VII
C VI
C VI
N VII

Resultados

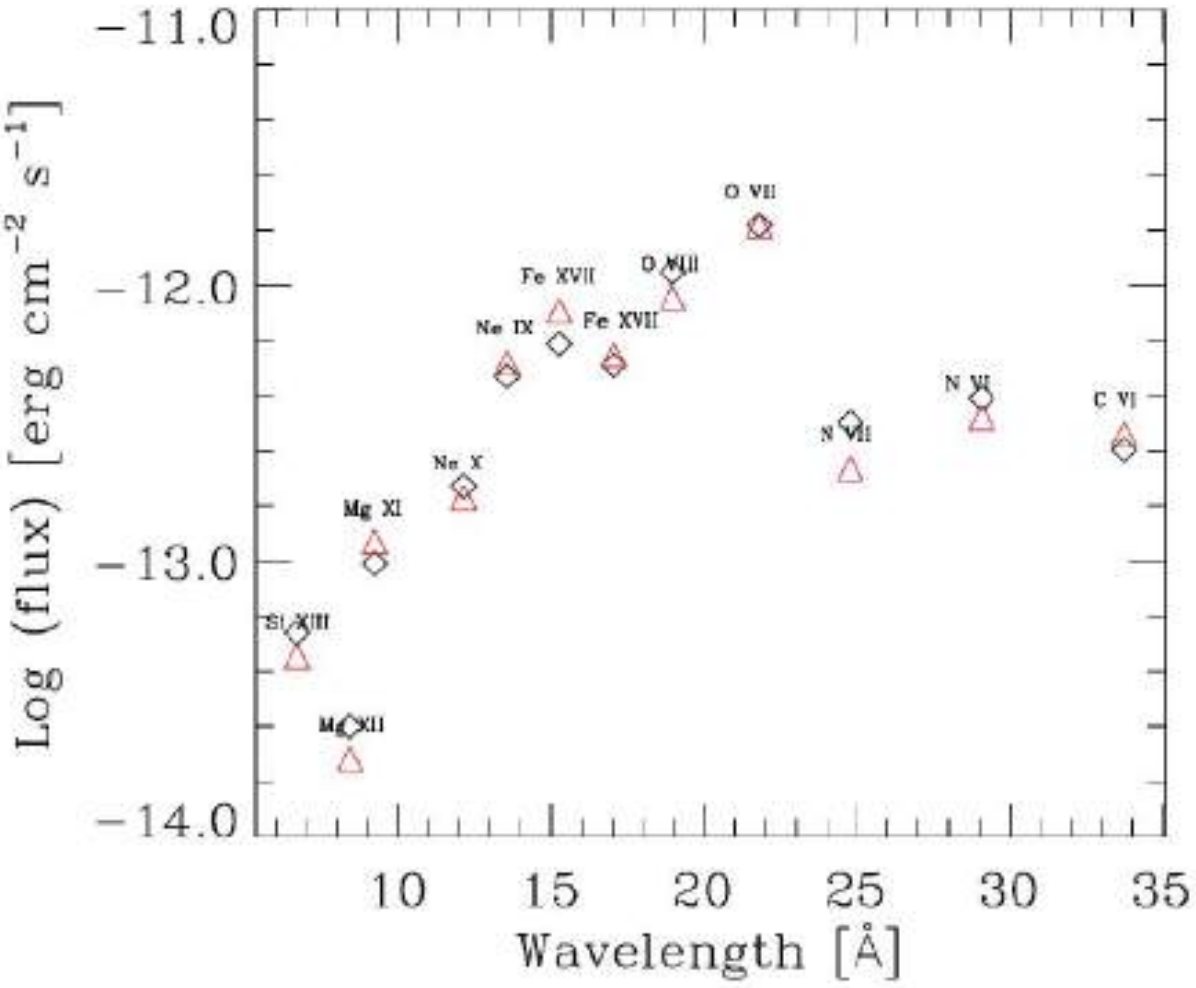
T_X 10^6 K	R_0 R_*	f_X 10^{-3}	T_X 10^6 K	R_0 R_*	f_X 10^{-3}
	Model A			Model B	
1.0	4.84	26.93	1.0	4.45	50.67
2.0	4.56	7.22	2.0	4.73	14.70
3.0	3.05	4.76	3.0	2.95	8.31
7.0	2.60	0.34	7.0	2.63	0.72
	Model C			Model D	
1.0	3.89	123.0	1.0	6.10	12.79
2.0	4.72	62.03	2.0	3.40	1.111
3.0	2.77	24.58	3.0	3.85	1.66
7.0	2.89	4.26	7.0	2.14	0.029

Resultados

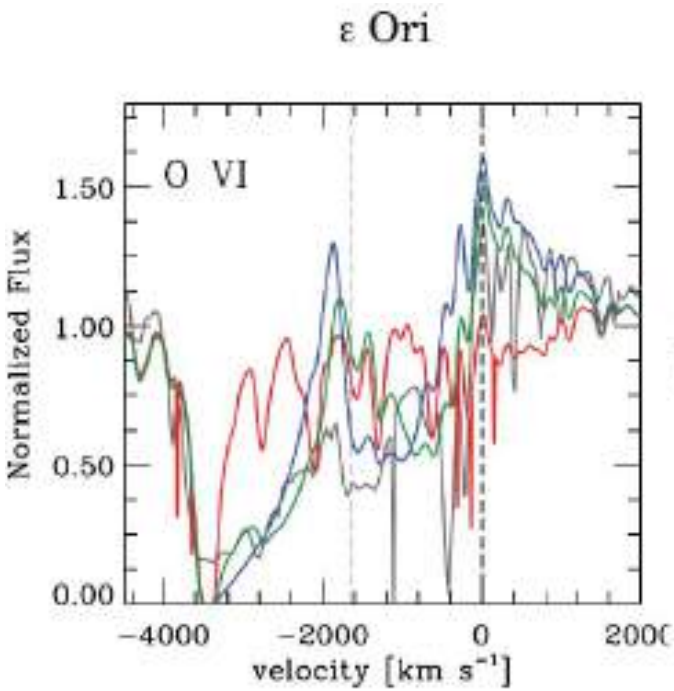

Ne IX
Normalized counts s^{-1} Å^{-1}
0.06
0.04
0.02
0.00
res
0
−2
−4000
−2000
0
2000
4000
velocity [km s^{-1}]


O VIII
Normalized counts s^{-1} Å^{-1}
0.06
0.04
0.02
0.00
res
2
0
−2
−2000
0
2000
velocity [km s^{-1}]

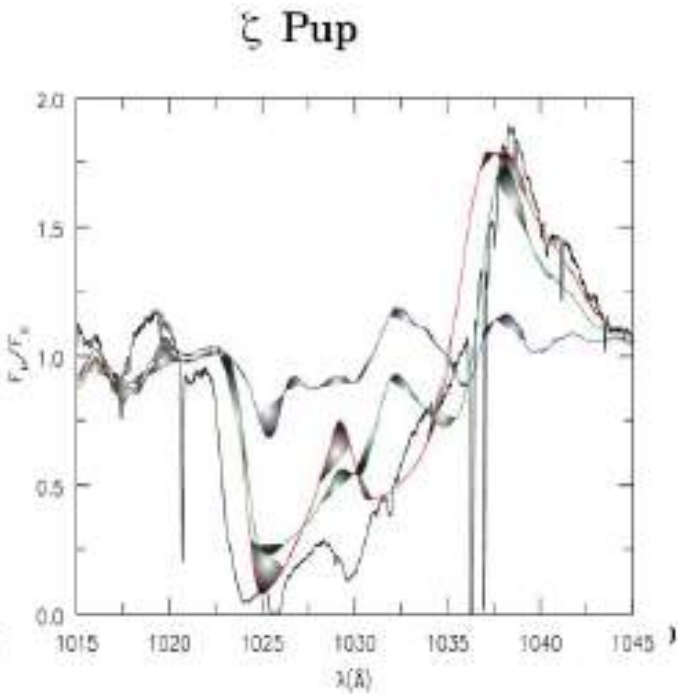
Resultados


−11.0
−12.0
−13.0
−14.0
Log (flux) [erg cm^{-2} s^{-1}]
10
15
20
25
30
35
Wavelength [Å]
O VII
Fe XVII
O VIII
Ne IX
Fe XVII
N VII
N VI
C VI
Ne X
Mg XI
Si XIII
Mg XII

Resultados

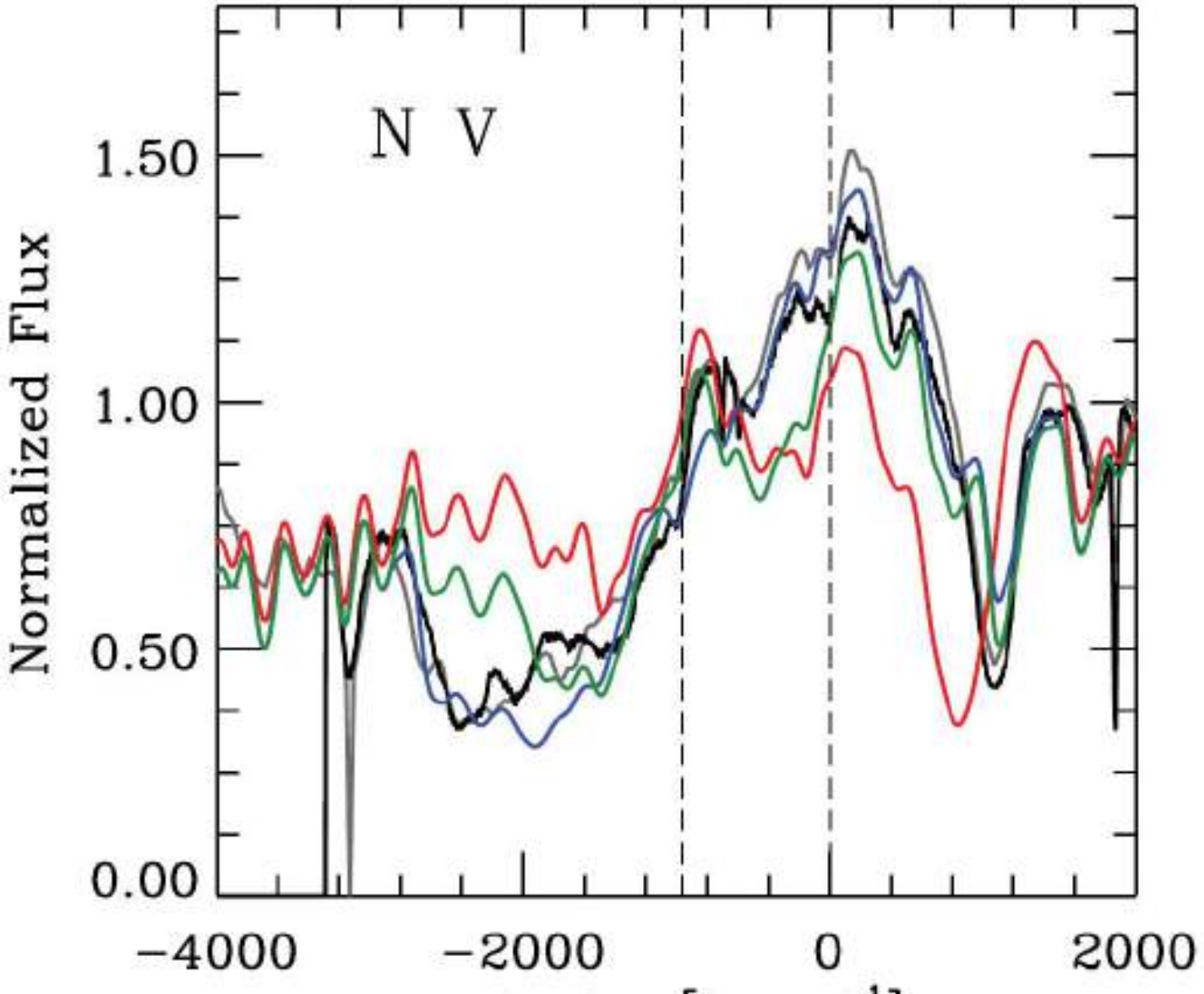


Puebla et al. (2016)
Azul: contrase 100 – Verde: contraste 200

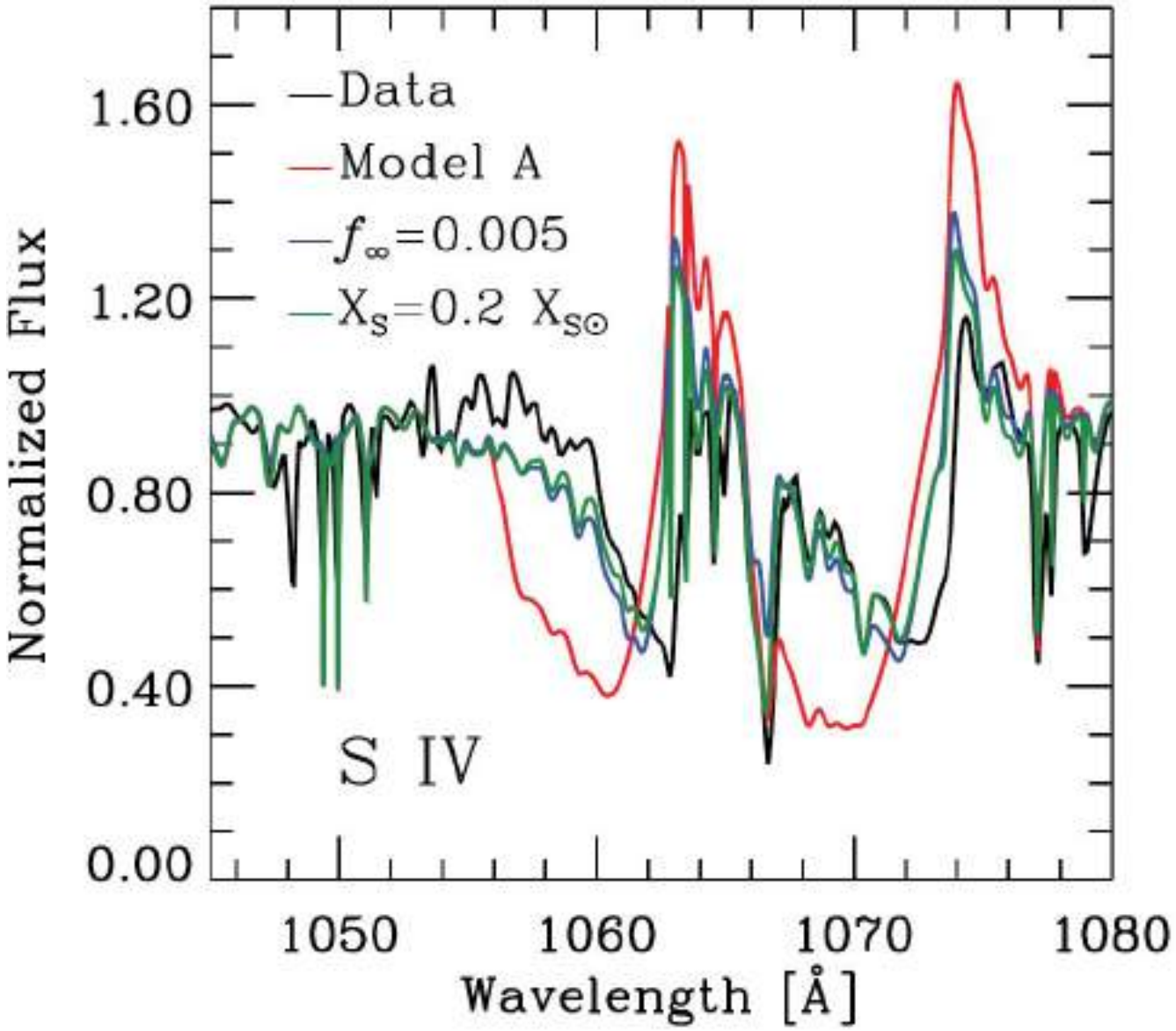


Zsargó et al. (2008)

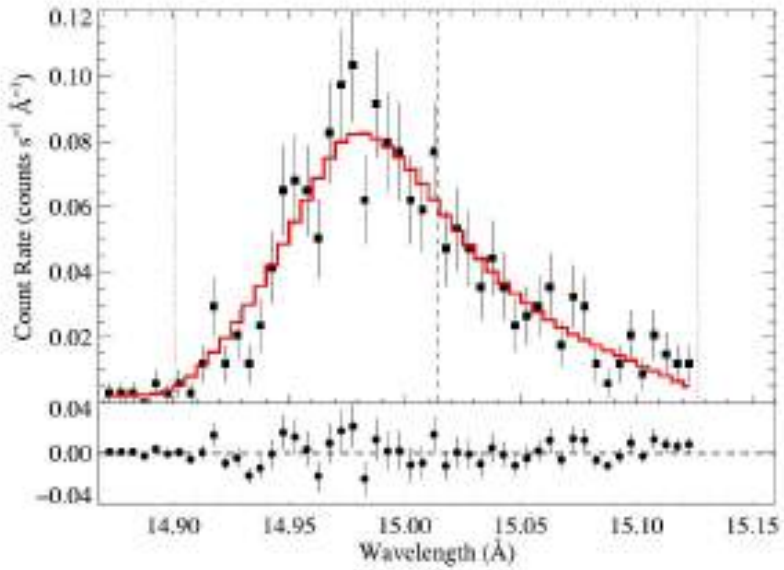
Resultados



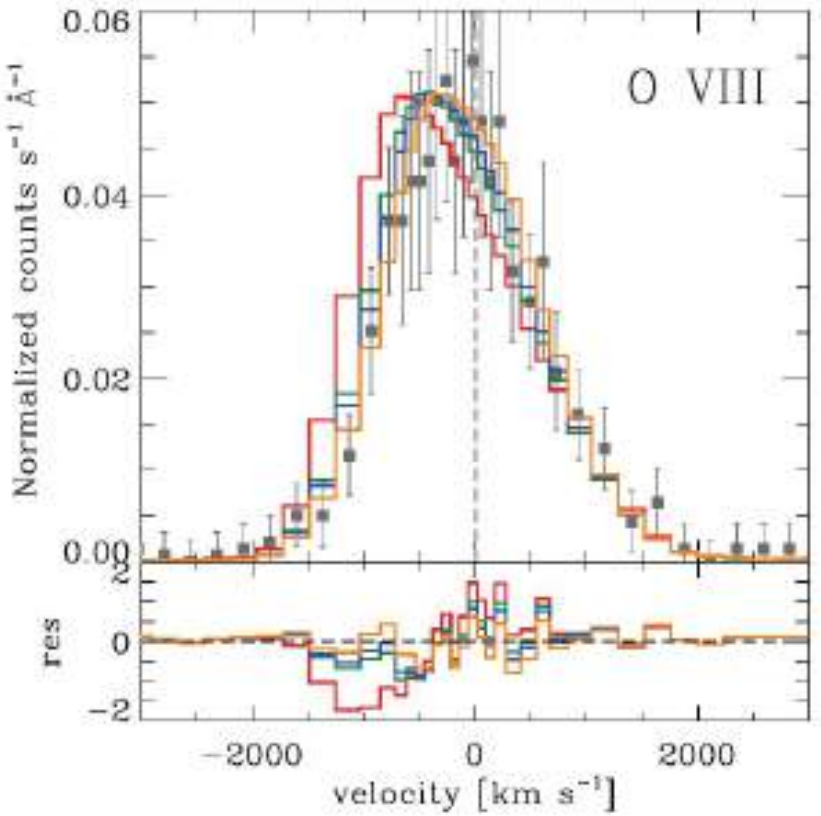
Resultados


Data
Model A
f_∞=0.005
X_S=0.2 $X_{S\odot}$
S IV
Normalized Flux
1.60
1.20
0.80
0.40
0.00
1050
1060
1070
1080
Wavelength [Å]

ϵ Ori

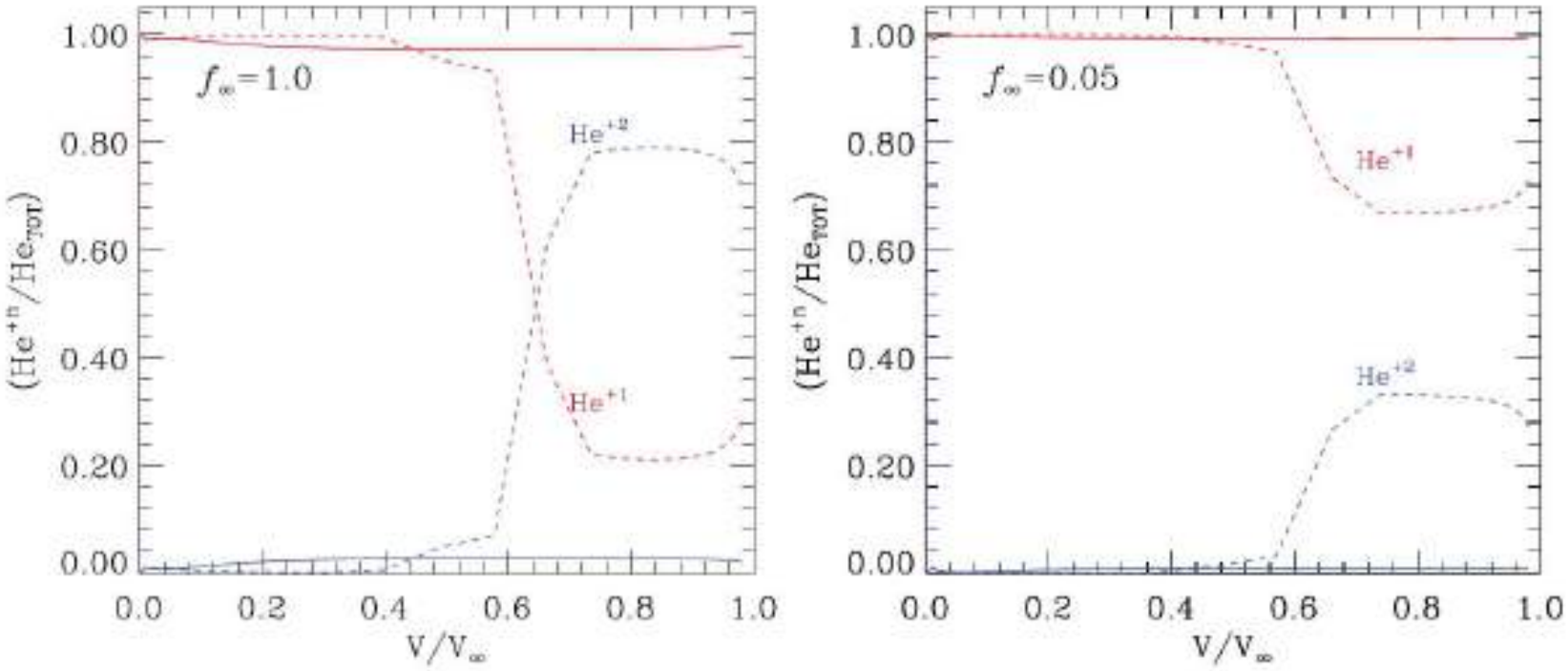


ζ Pup.



ϵ Ori.

Ionización por rayos X



FisLab



GeoLab


GeoLAb
Desarrollo conjunto de:
ESCUELA POLITECNICA NACIONAL

FIN

Muchas Gracias!!!