# X-rays, Stars & Planets

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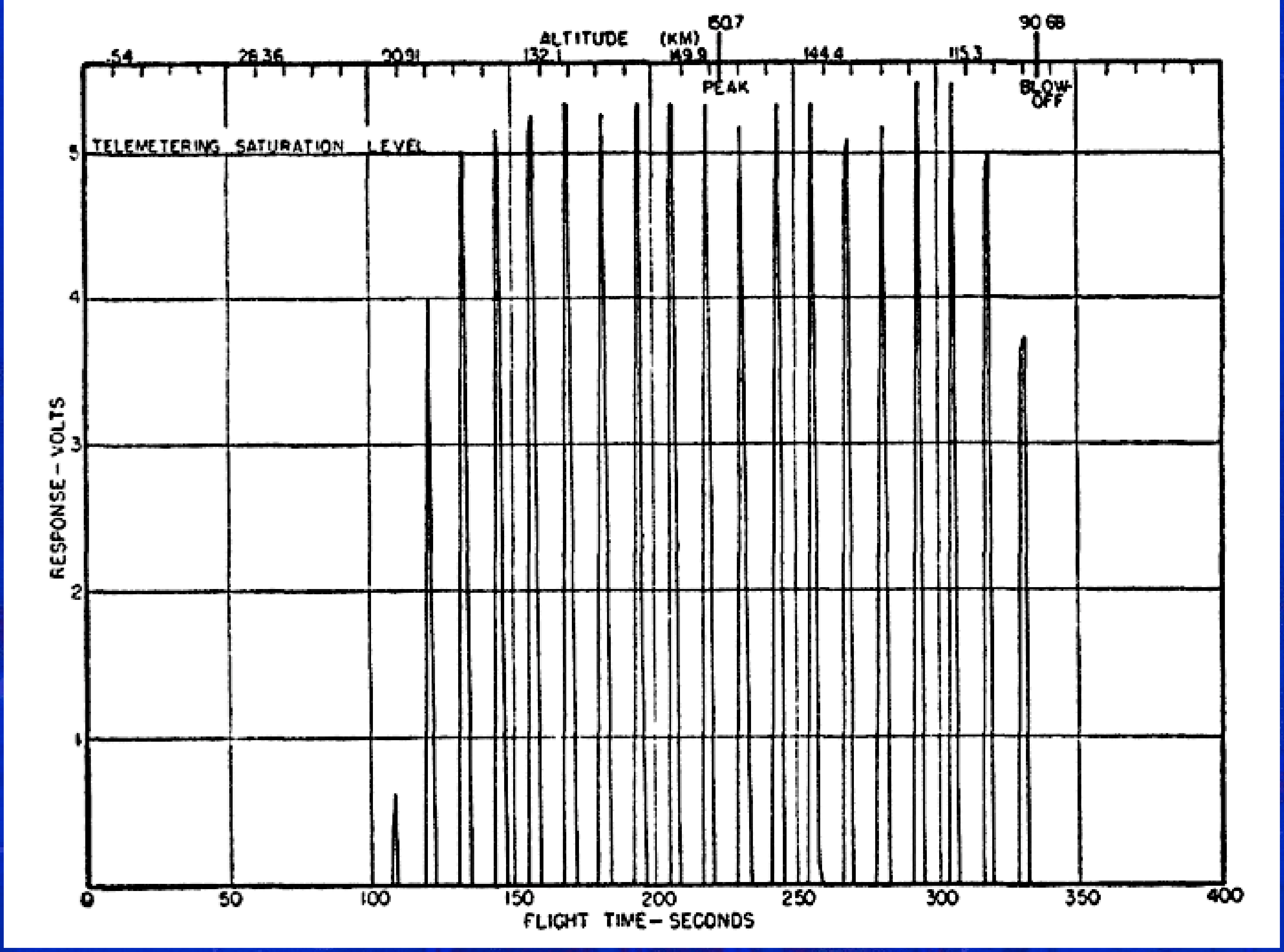
Smithsonian Astrophysical Observatory

# The Silvio Berlusconi Guide to Stellar X-ray Astronomy

# 60th Anniversary of Stellar X-rays

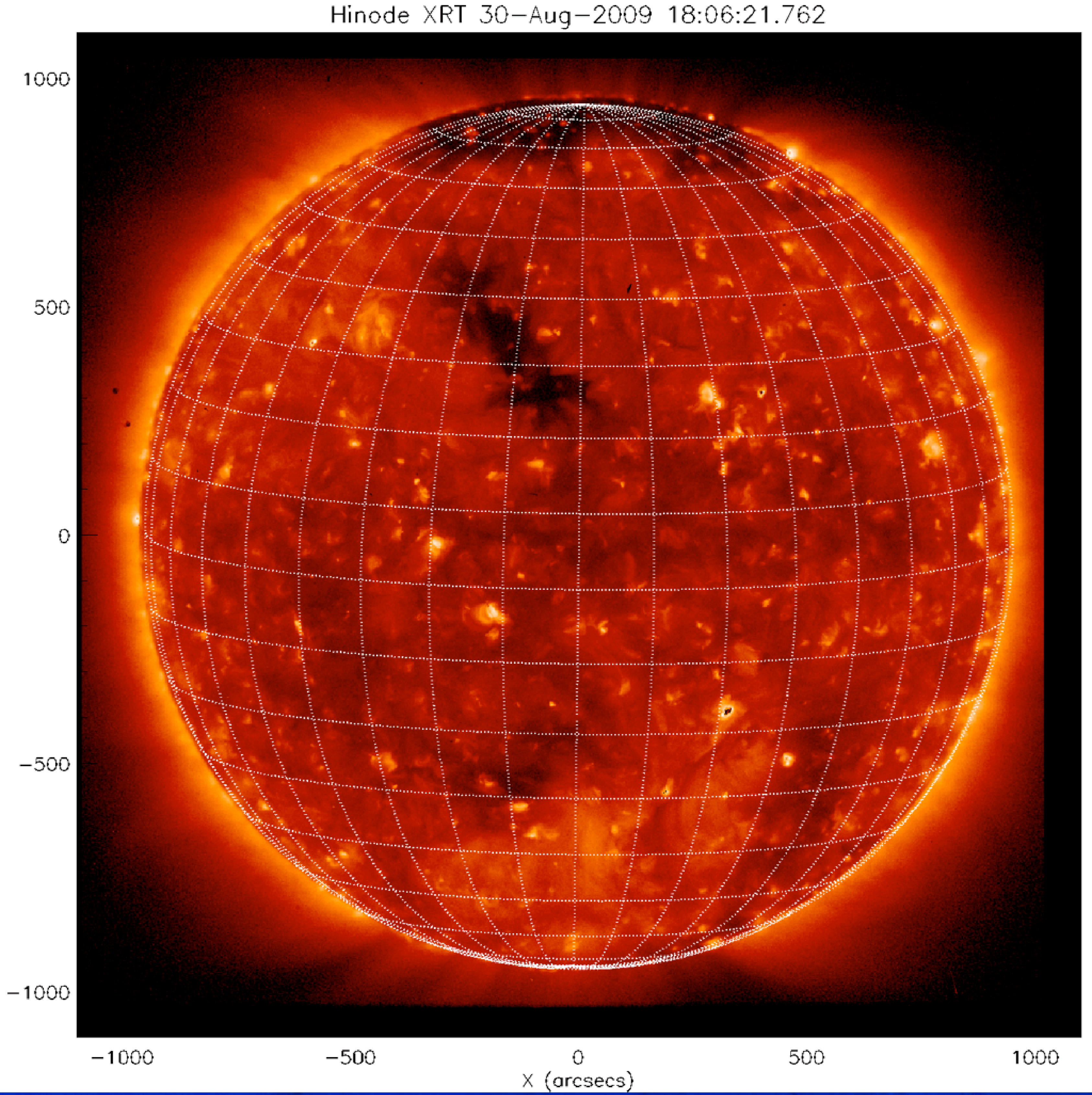
V2 rocket flight September 1949, Friedman et al. (1951)

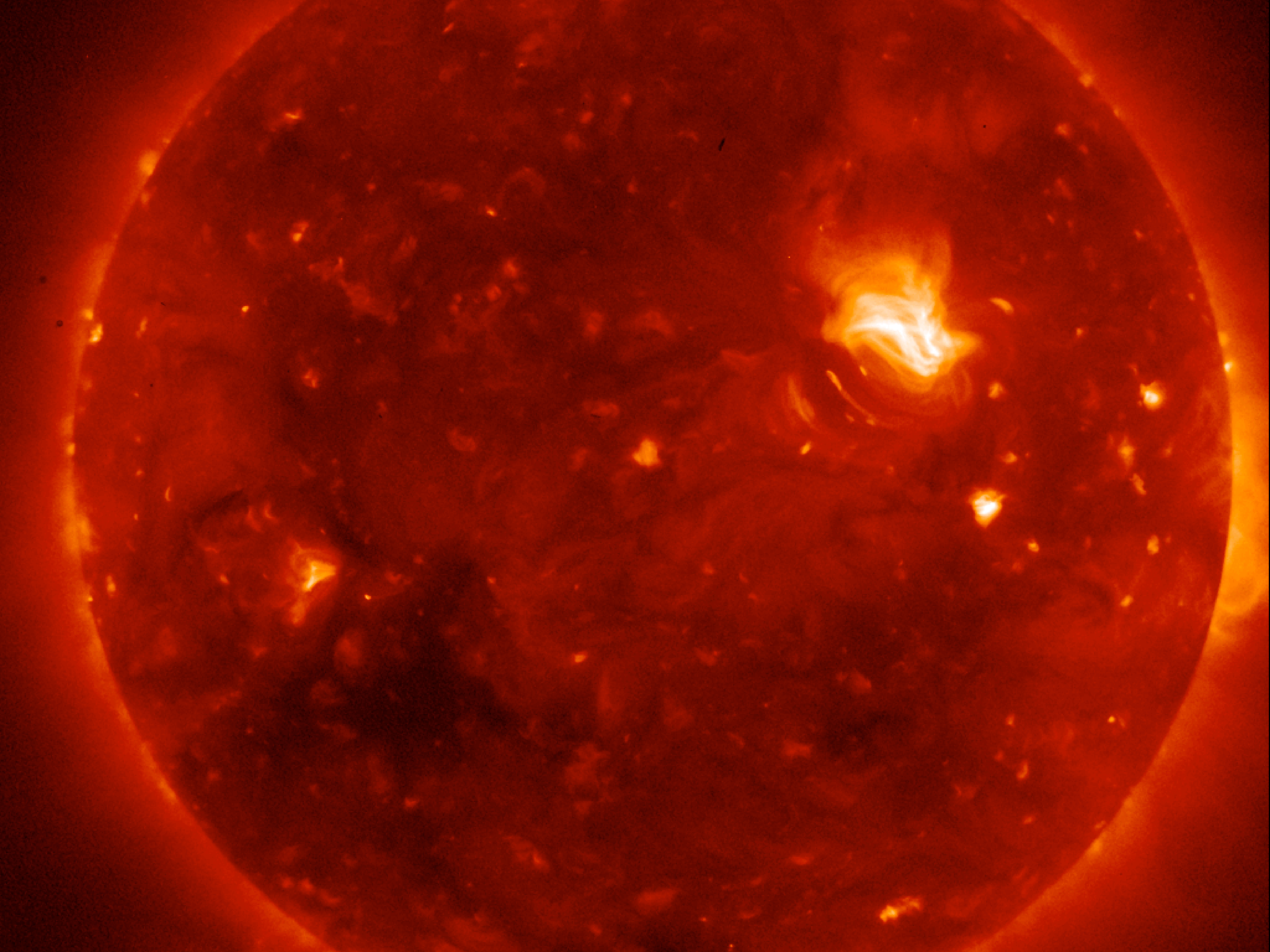
# 60th Anniversary of Stellar X-rays



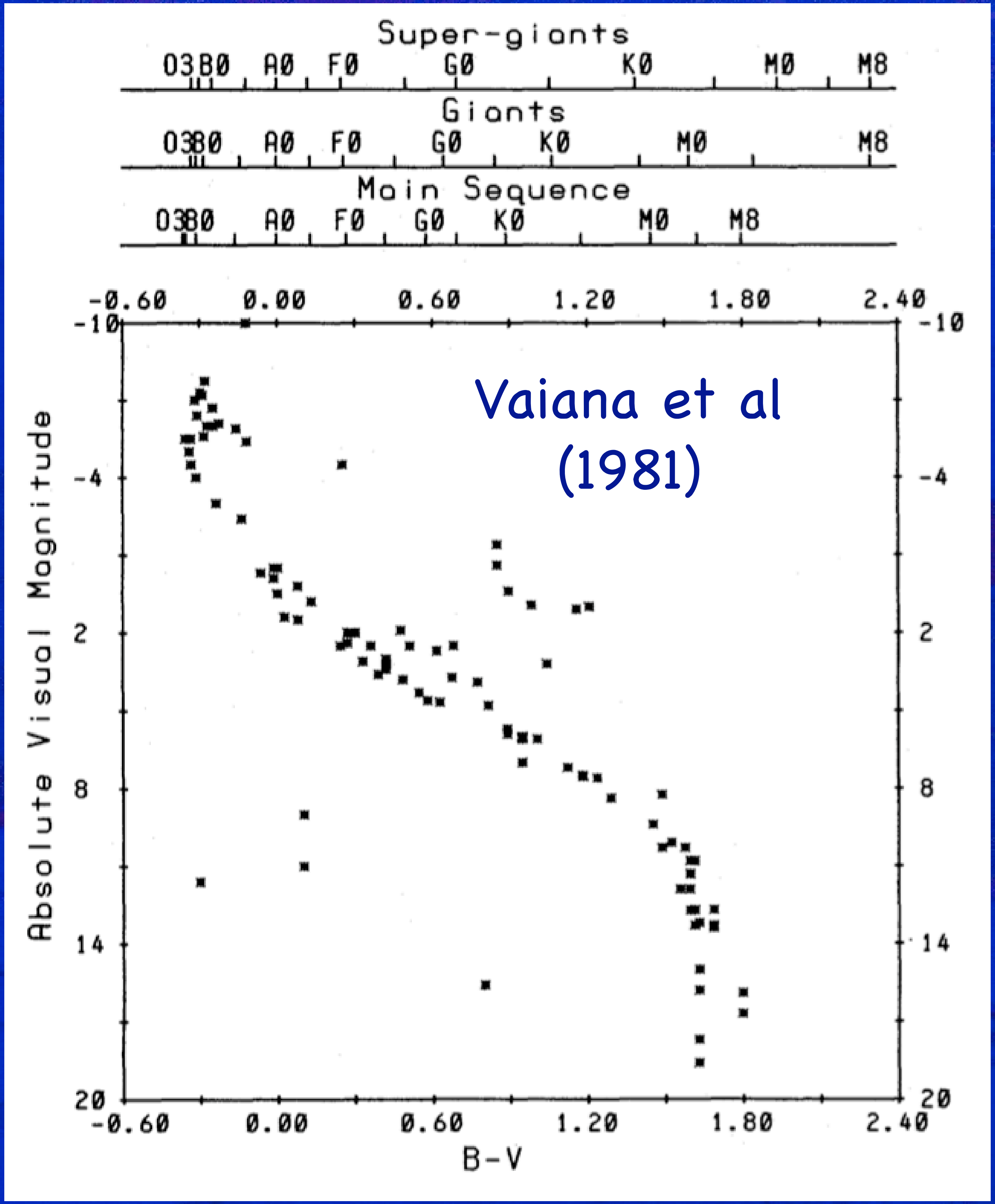

V2 rocket flight September 1949, Friedman et al. (1951)

# The "Quiet" Sun





# XMM+Chandra Legacy (so far...)



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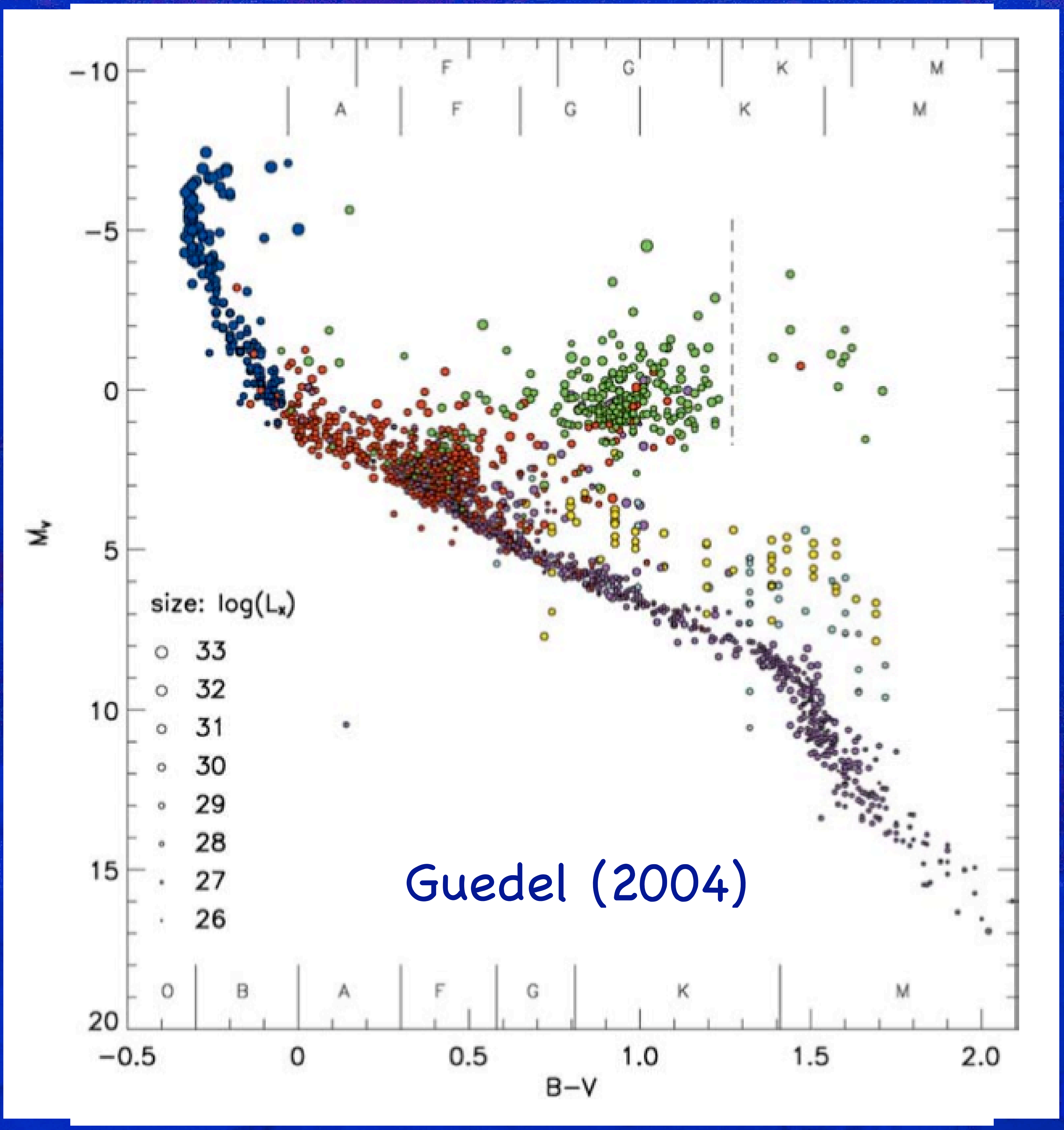

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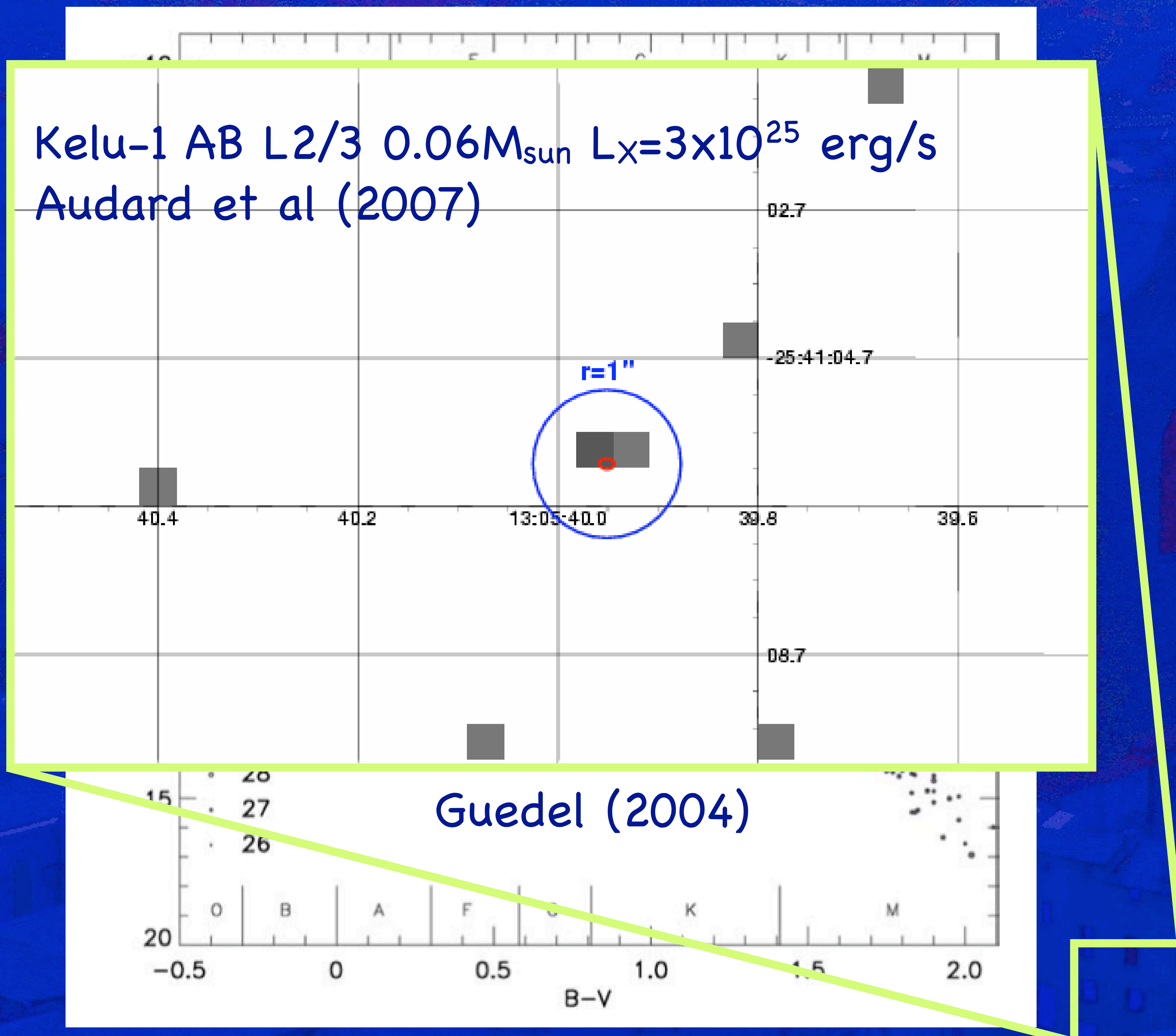

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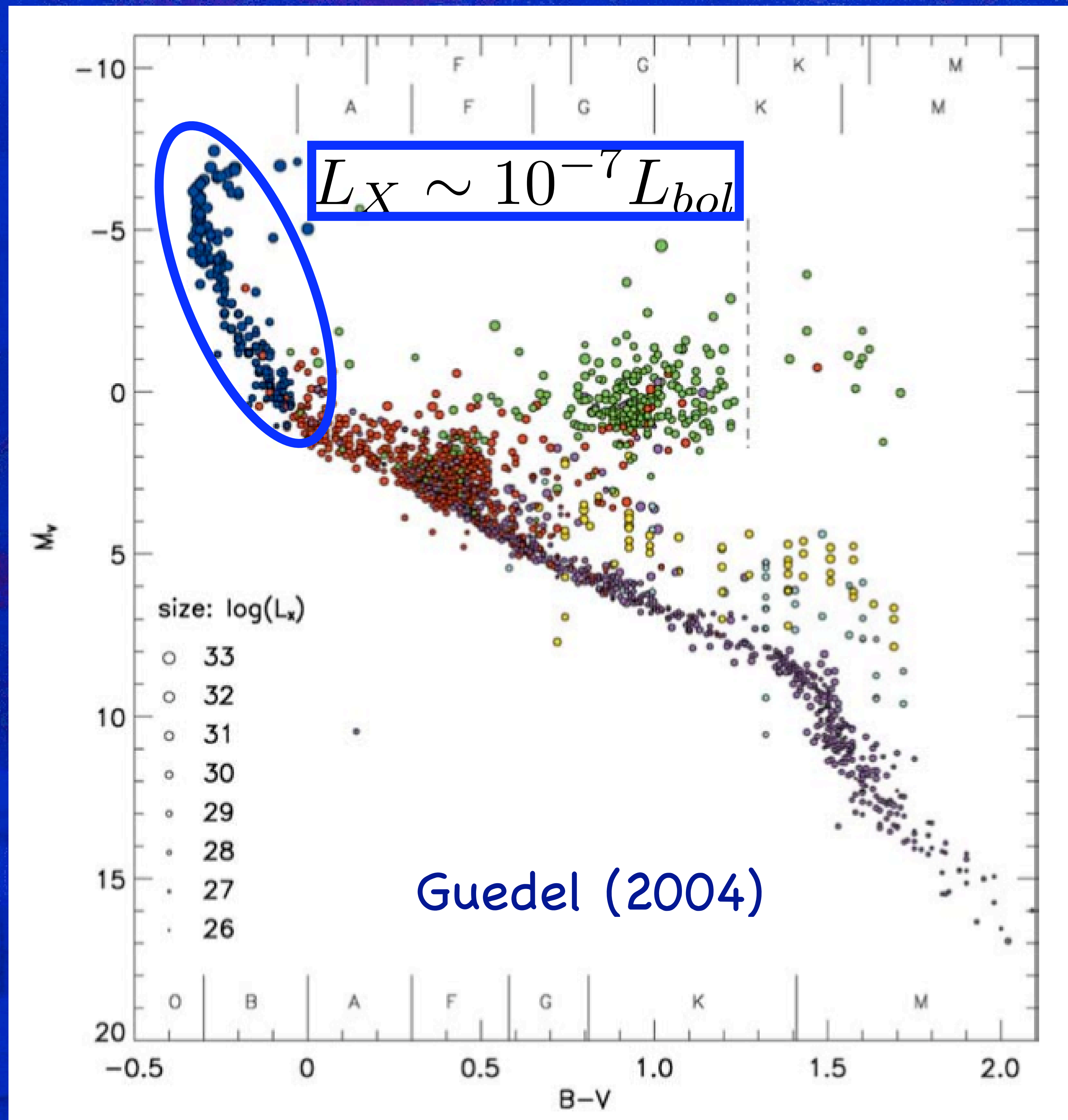


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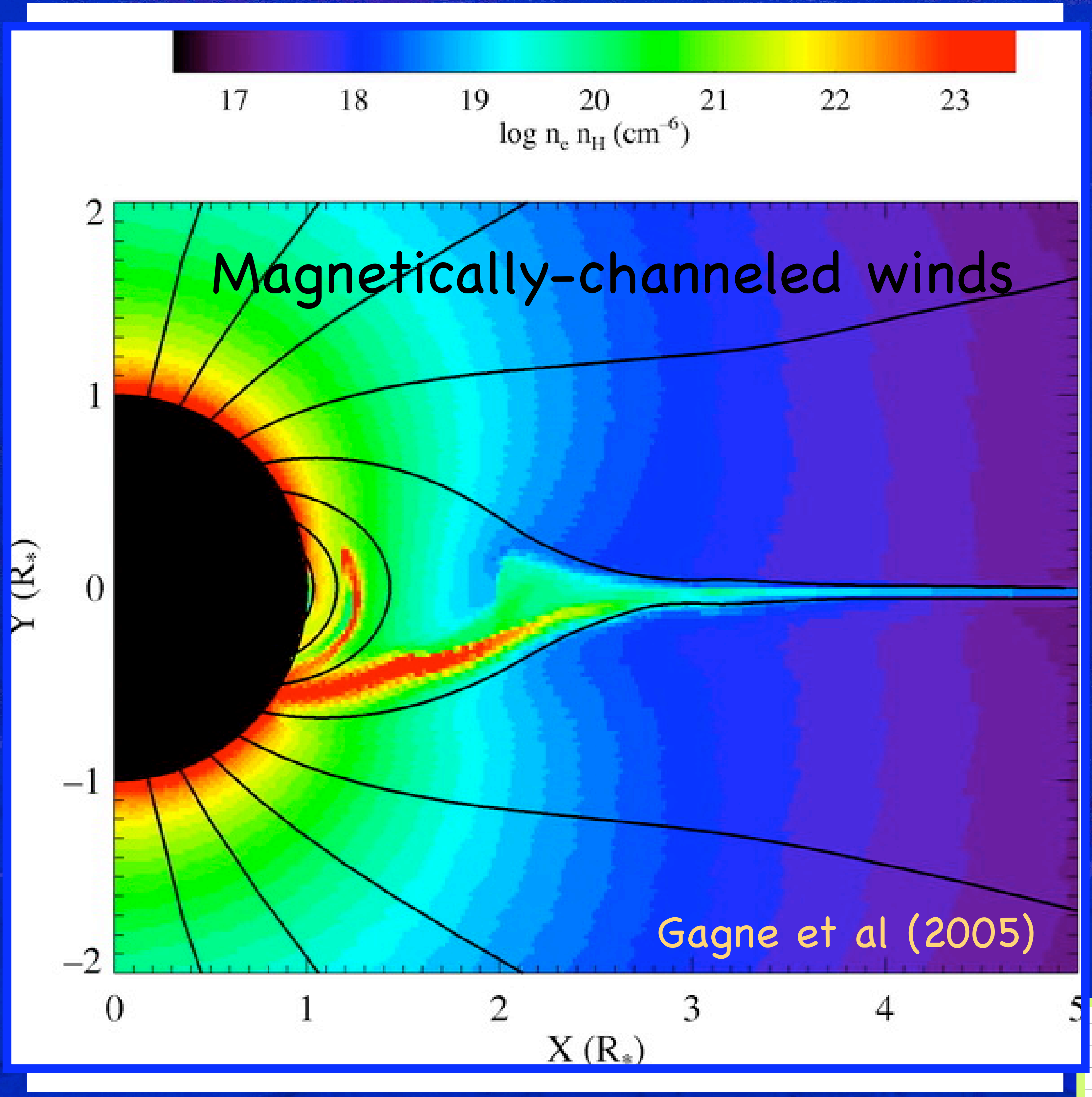

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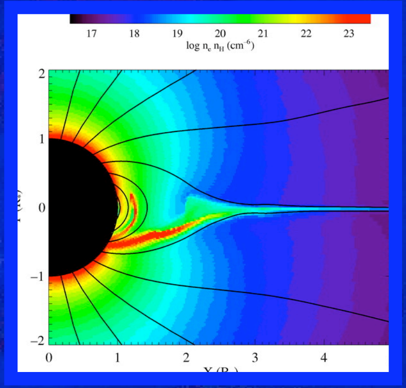

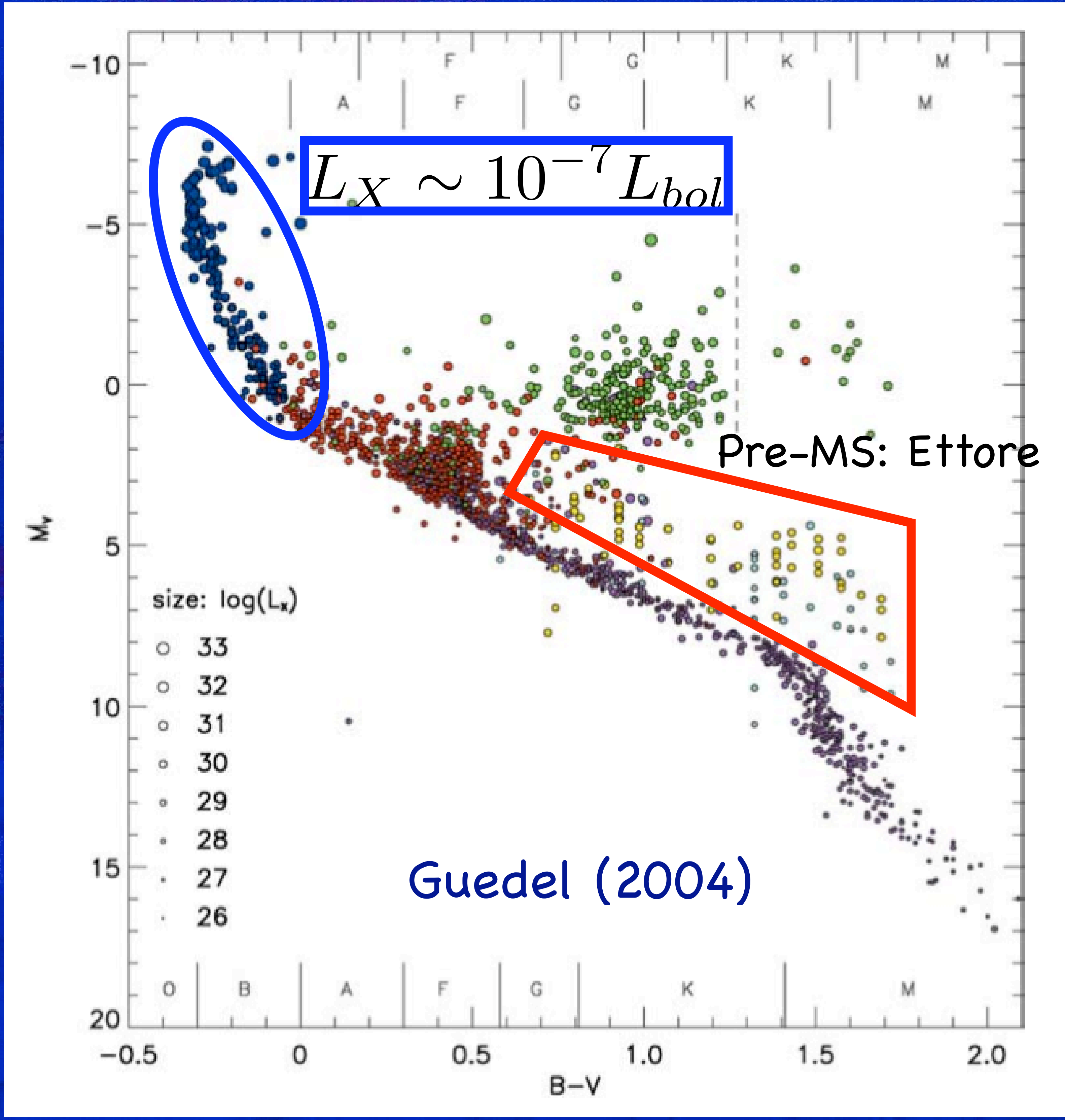


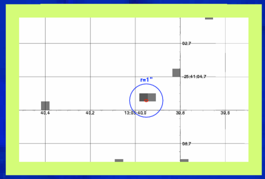

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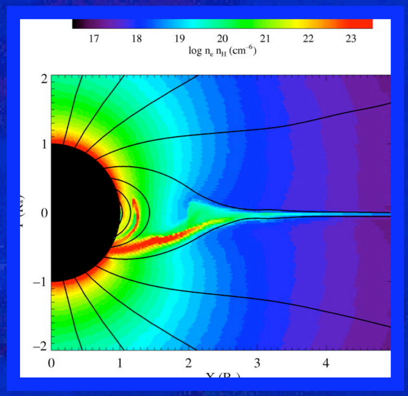
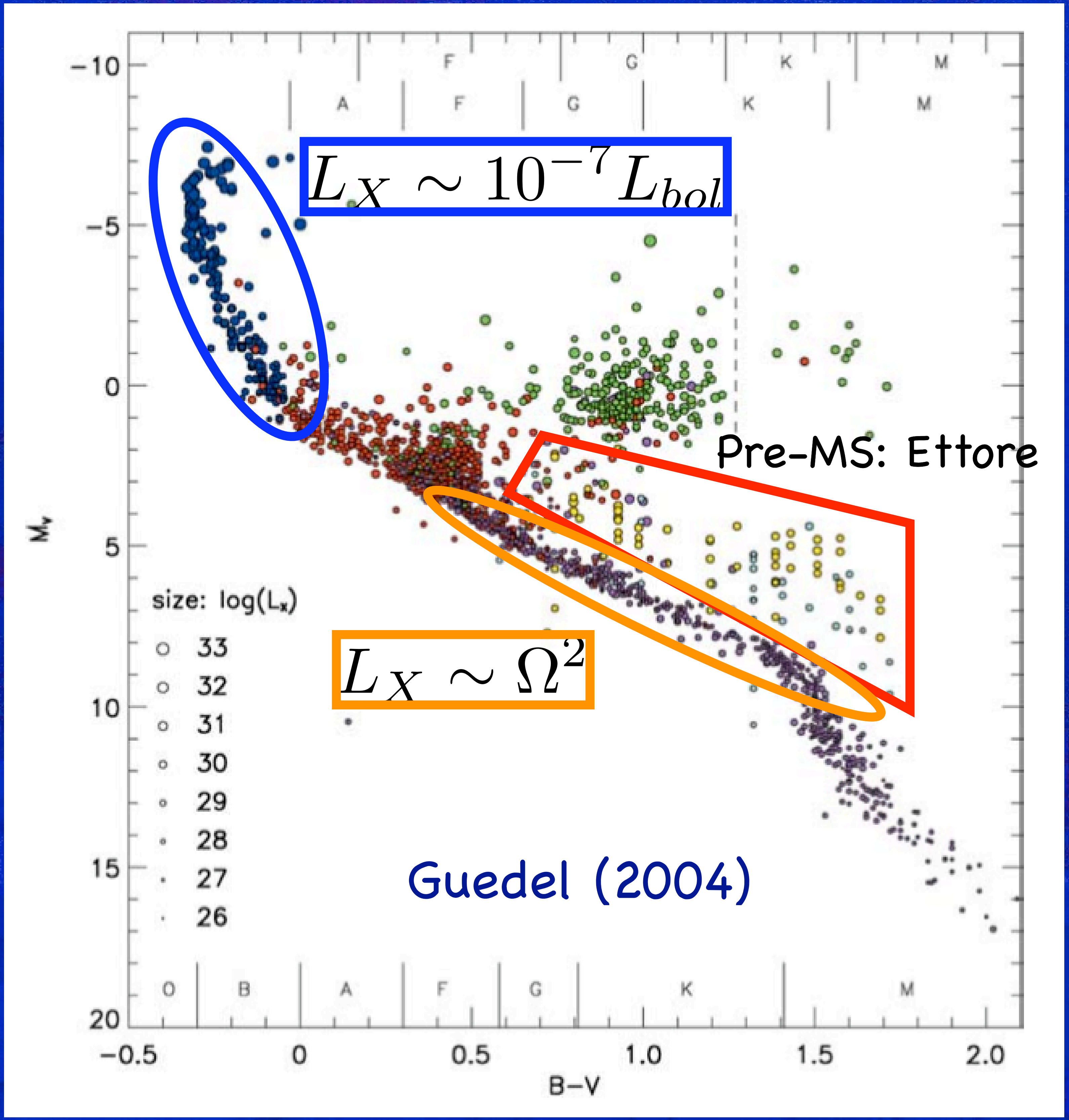
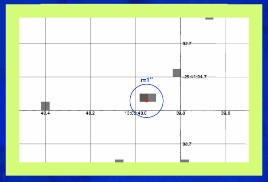
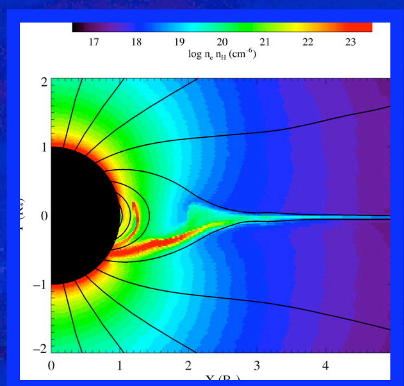
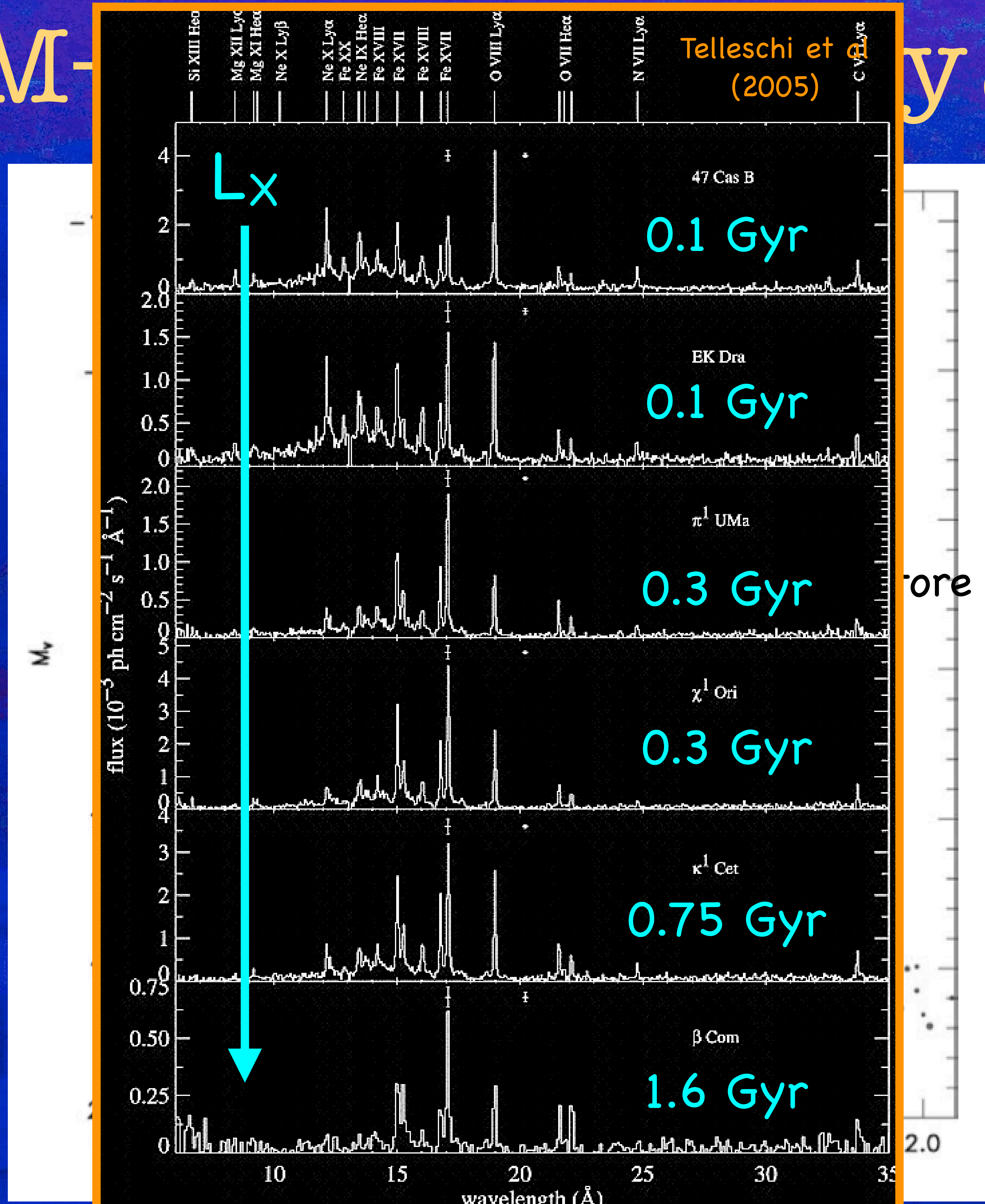




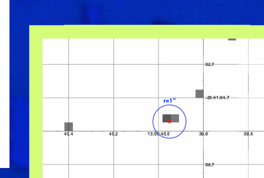



# XMM- ... y (so far...)

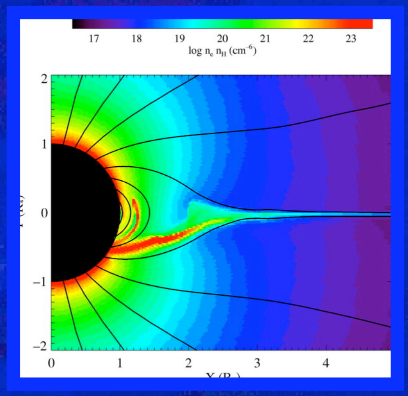


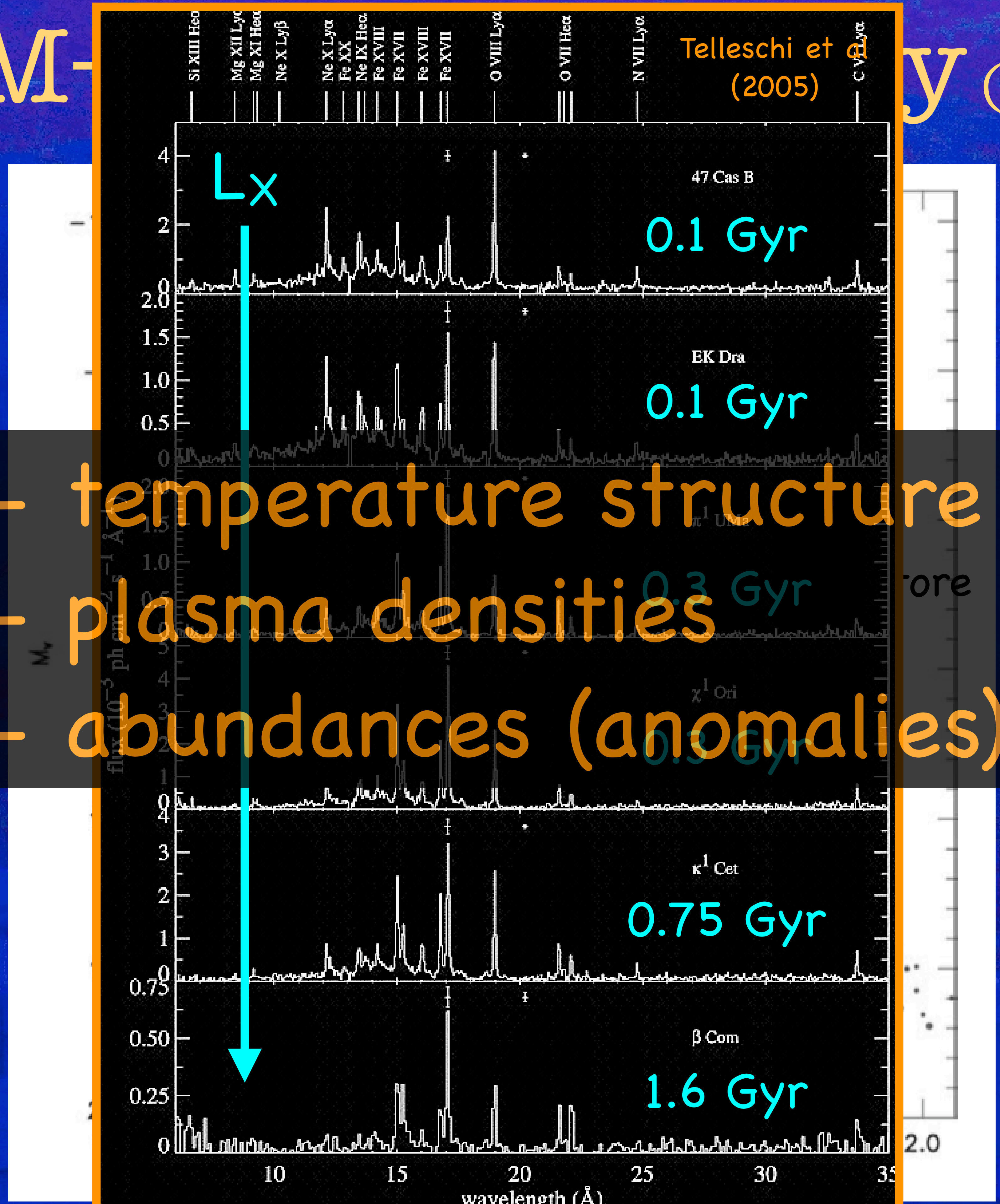


Si XIII Heα
Mg XII Lyα
Mg XI Heα
Ne X Lyβ
Ne X Lyα
Fe XX
Ne IX Heα
Fe XVIII
Fe XVII
Fe XVIII
Fe XVII
O VIII Lyα
O VII Heα
N VII Lyα
C VI Lyα
Telleschi et al
(2005)
Lx
47 Cas B
0.1 Gyr
EK Dra
0.1 Gyr
π¹ UMa
0.3 Gyr
χ¹ Ori
0.3 Gyr
κ¹ Cet
0.75 Gyr
β Com
1.6 Gyr
flux (10⁻⁵ ph cm⁻² s⁻¹ Å⁻¹)
wavelength (Å)
ore
2.0

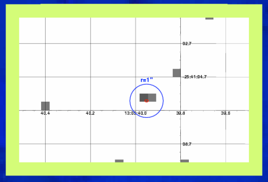



# XMM- … y (so far...)



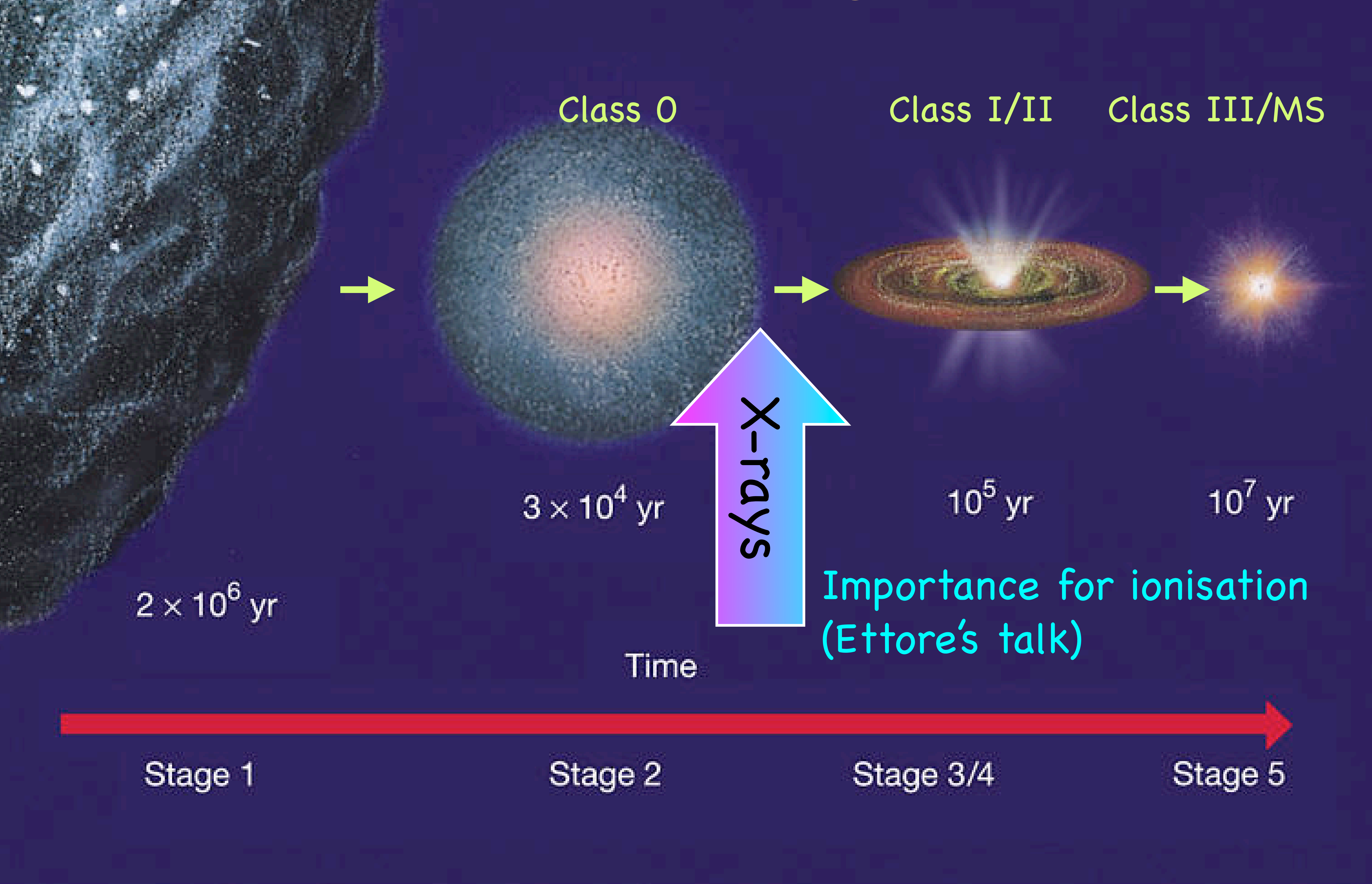




- temperature structure
- plasma densities
- abundances (anomalies)

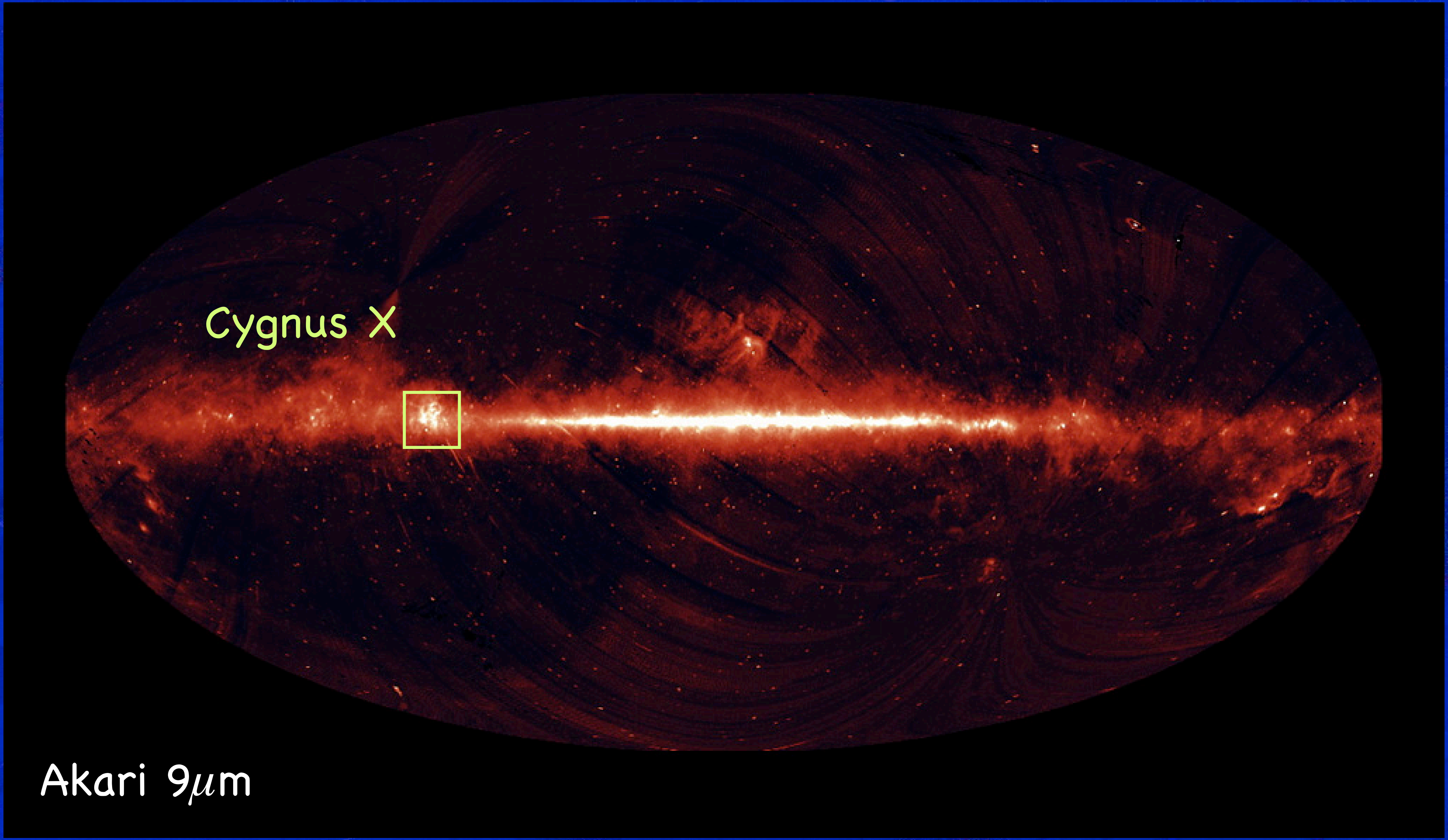


- Stellar outer atmospheres and X-rays are crucial for star and planet formation, solar system evolution and the origin and sustainability of life

# (visible) Stellar X-ray Ignition



# Stellar X-ray Ignition



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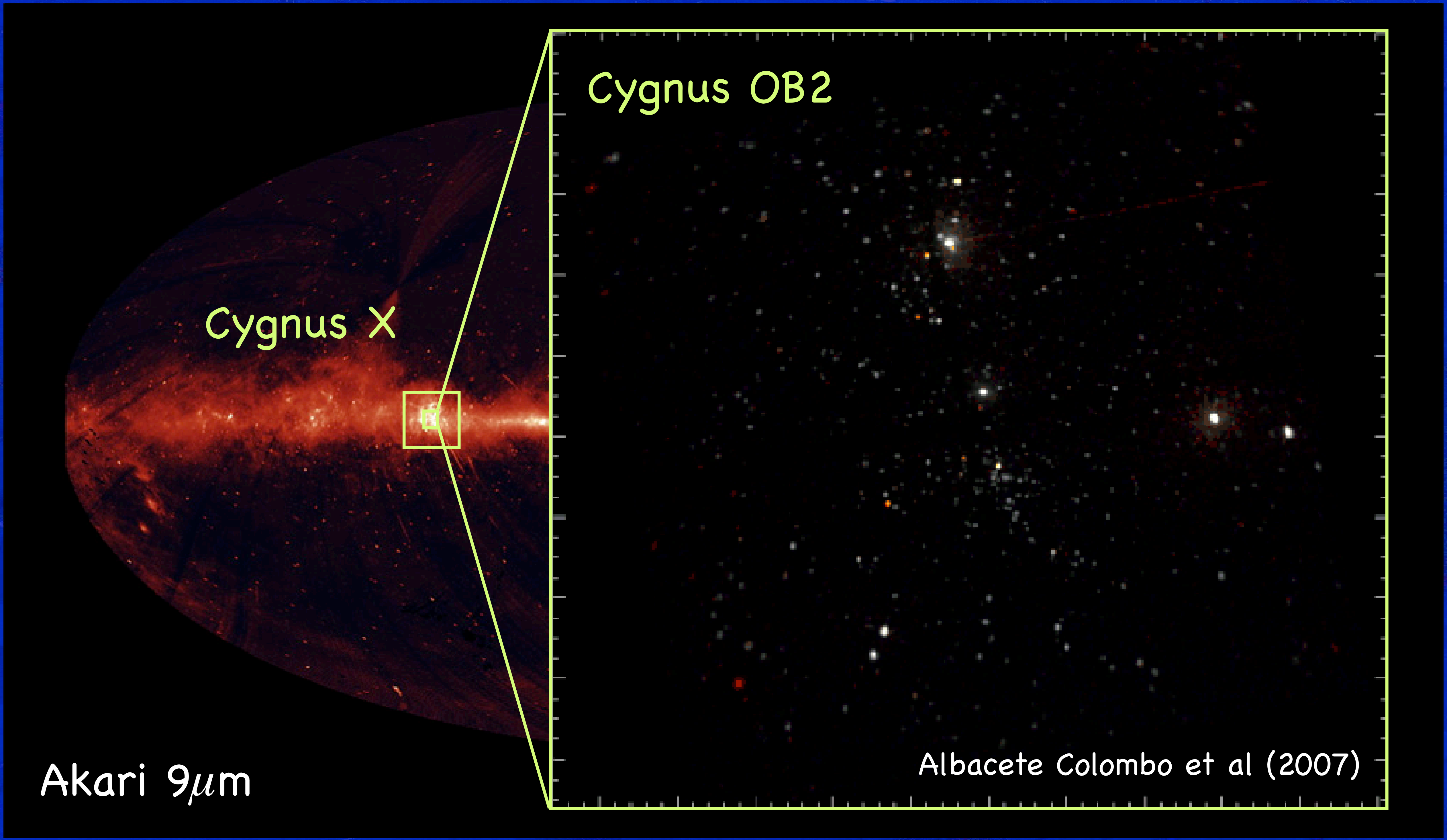
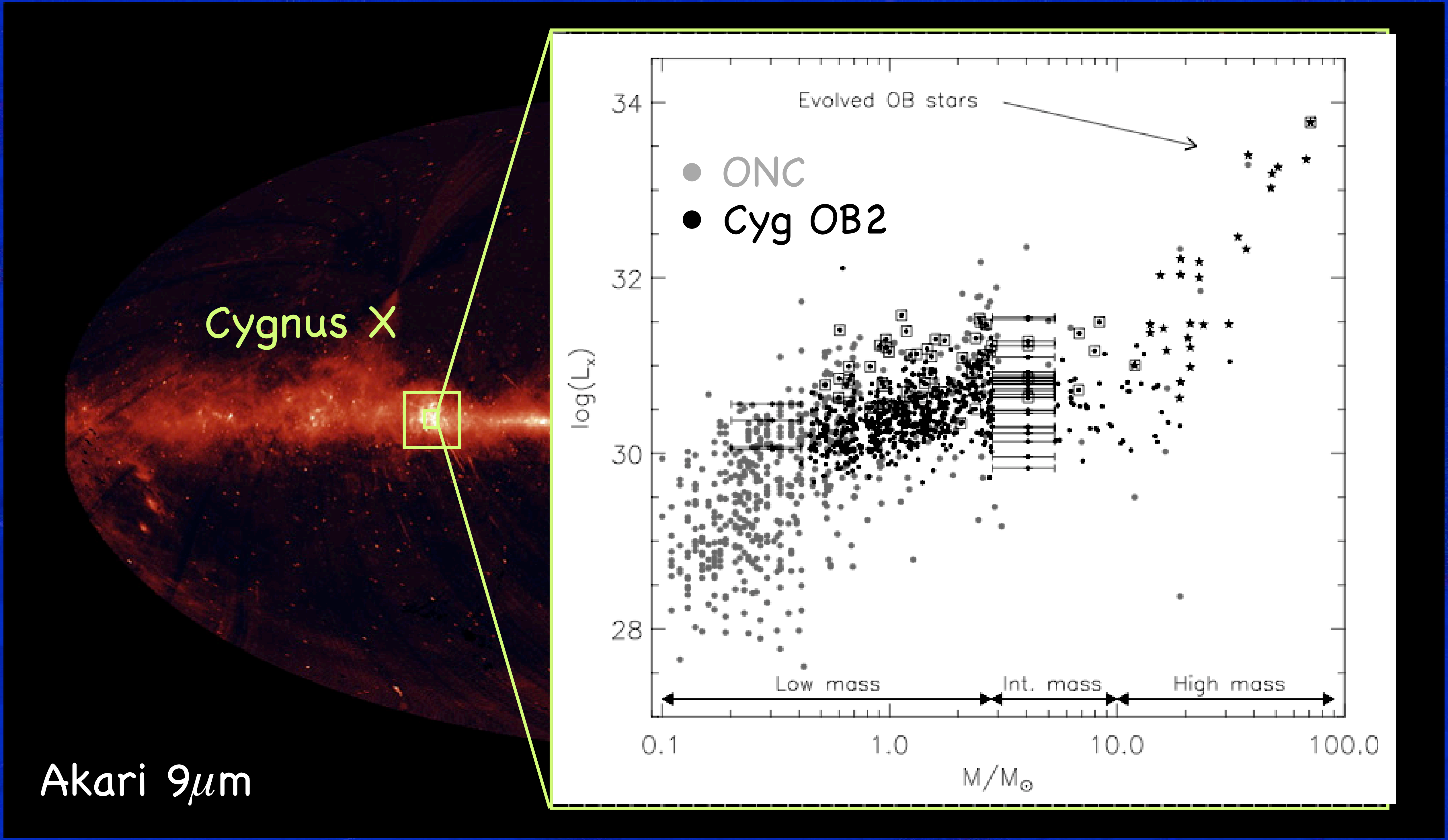
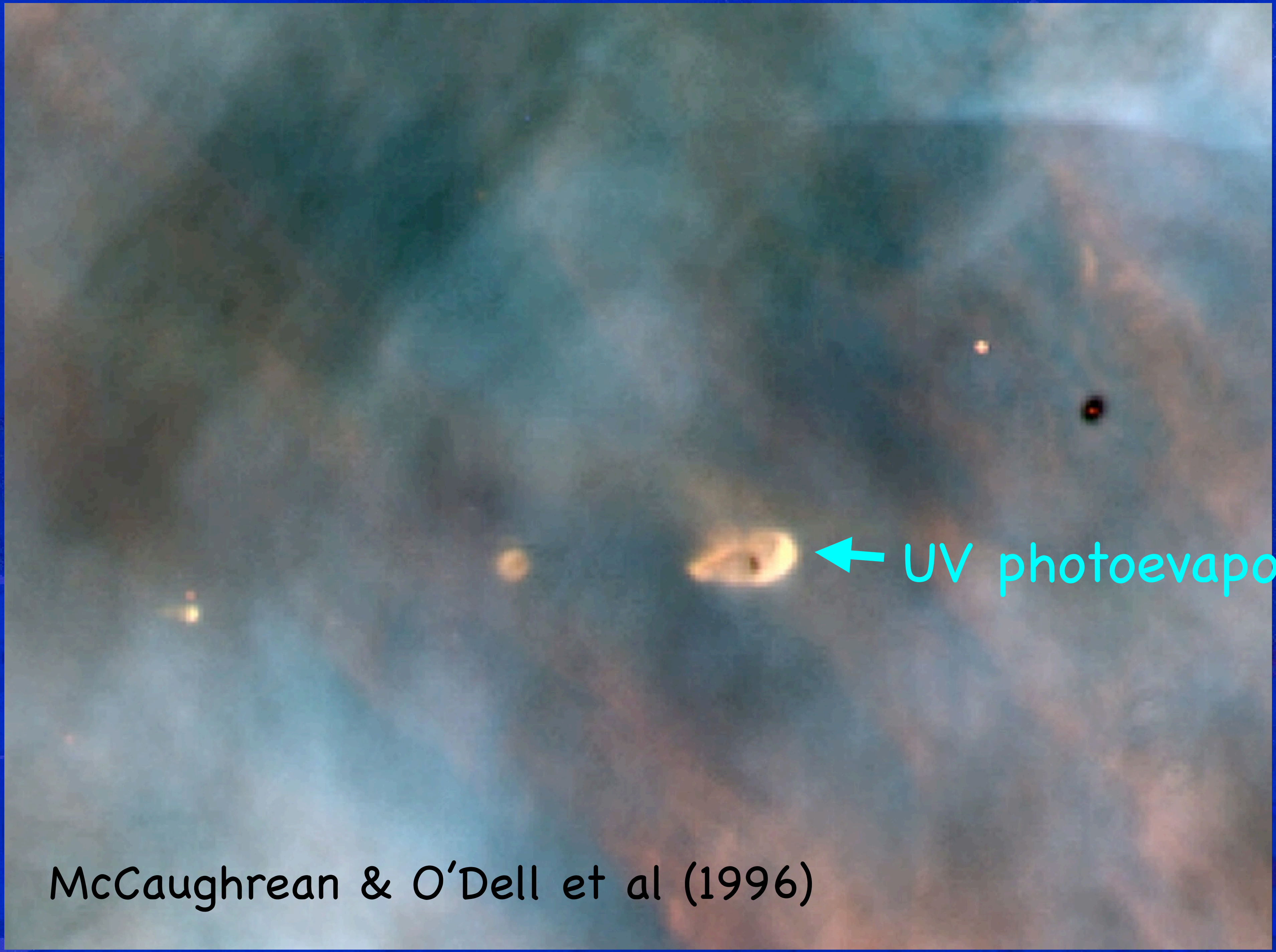


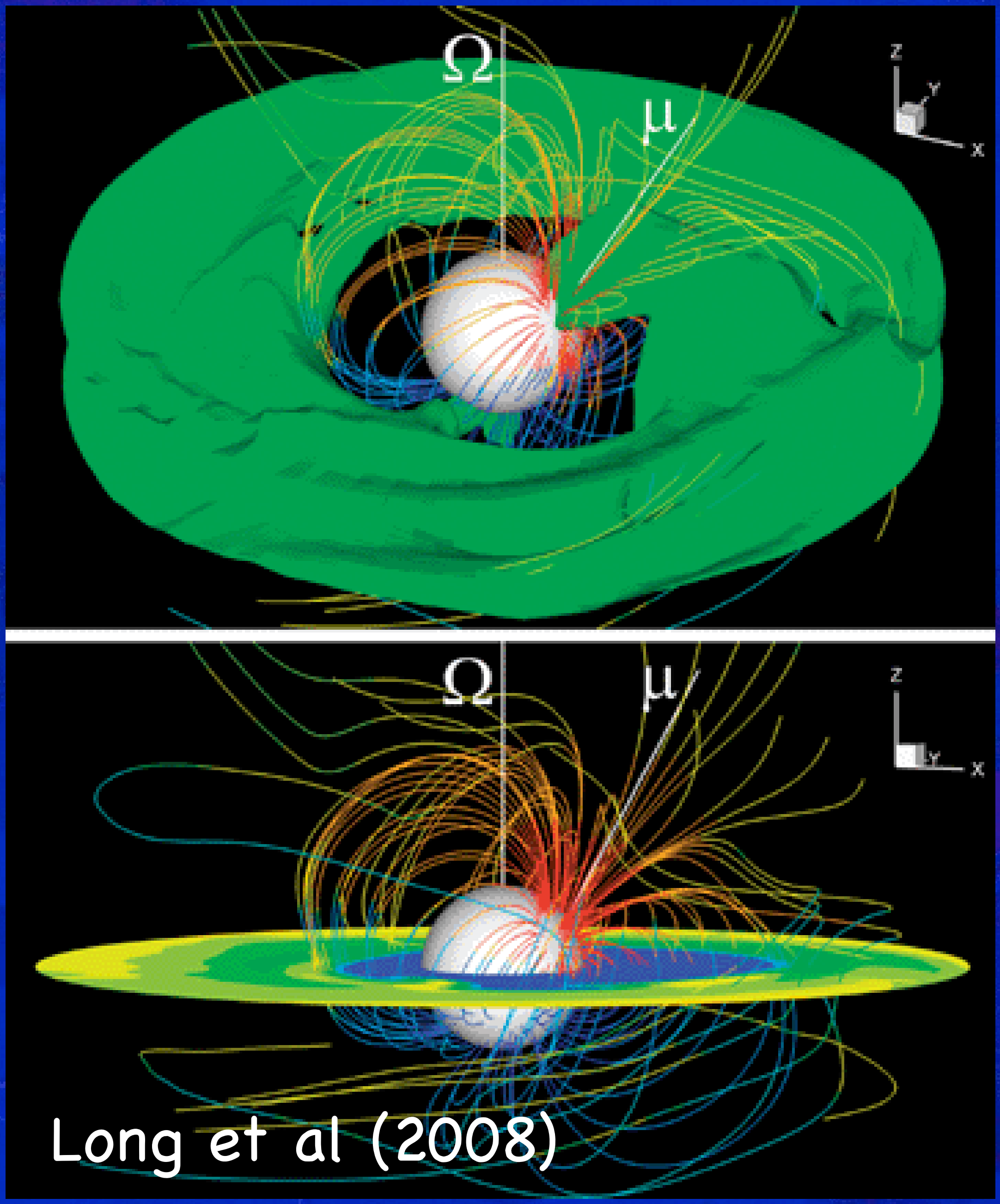
# Stellar X-ray Ignition

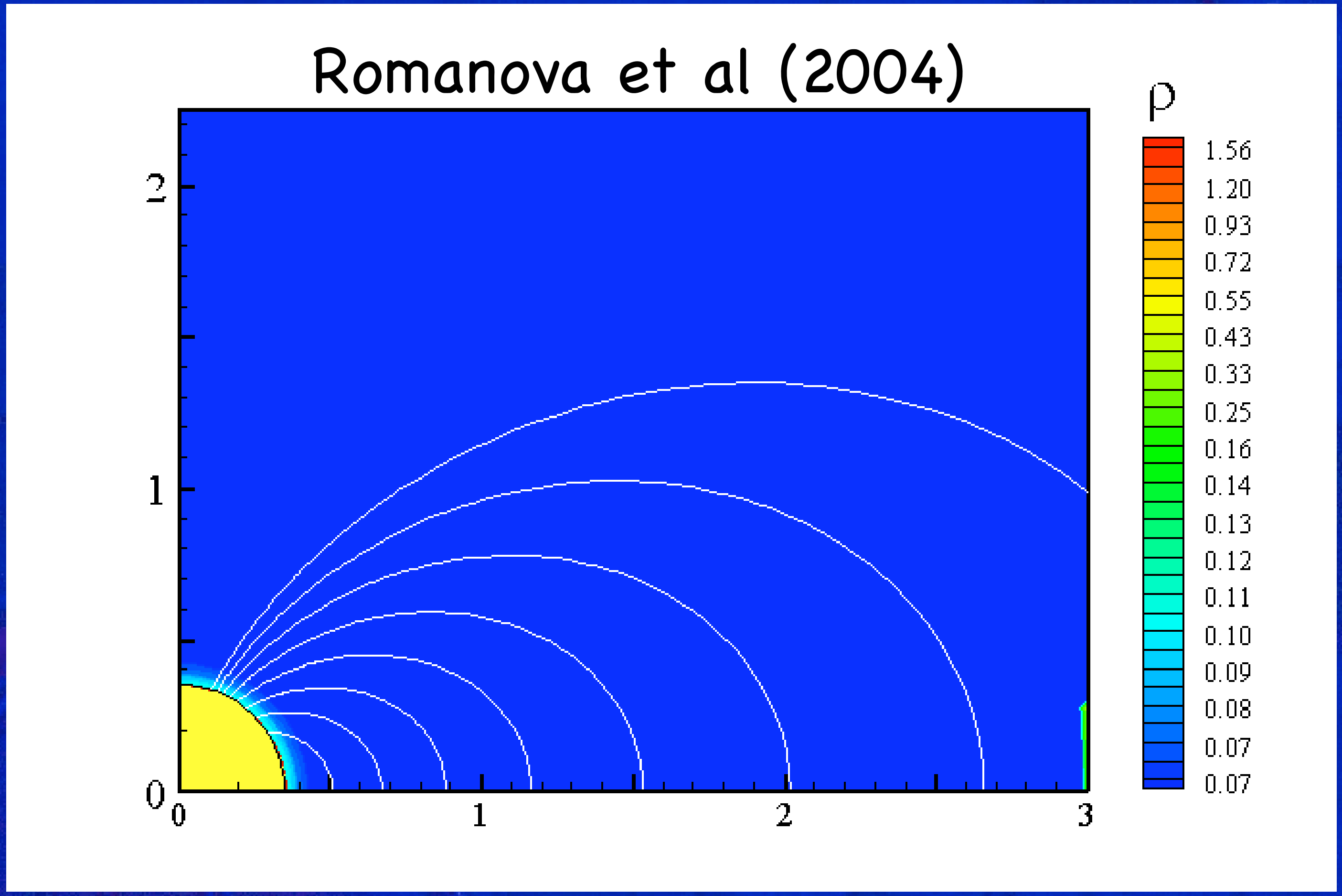


# X-rays and Protoplanetary Disks

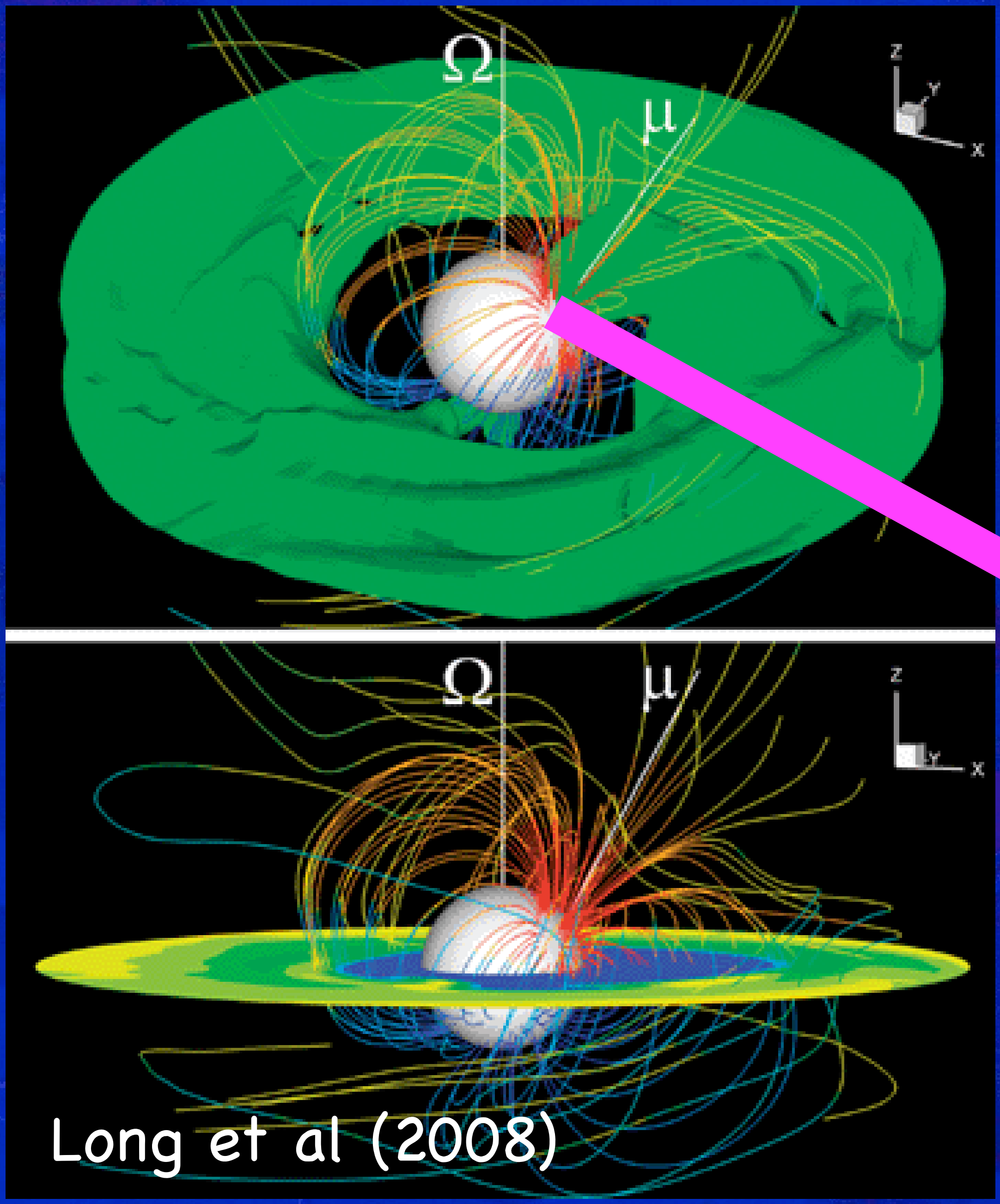


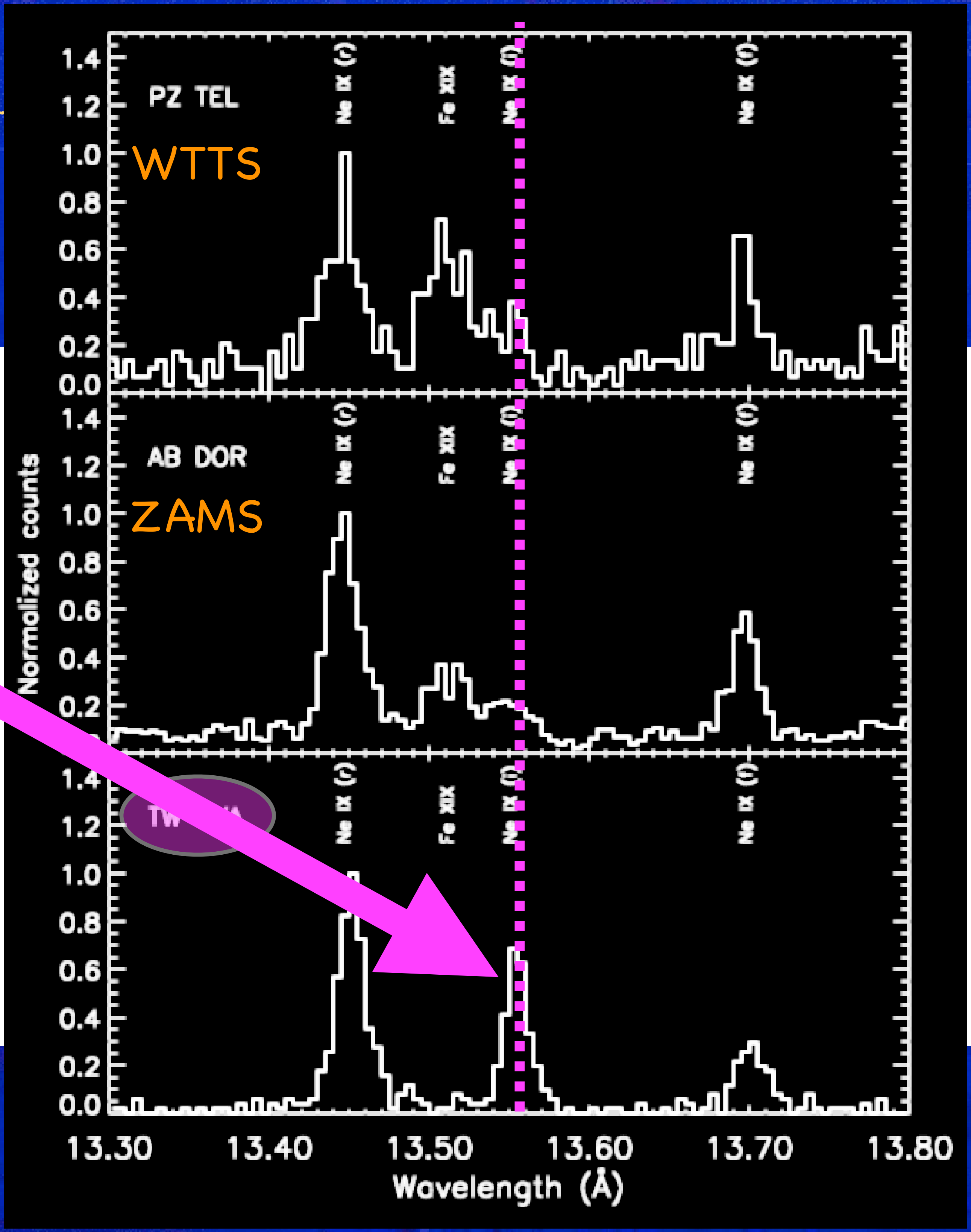
# Magnetospheric Accretion (Uchida & Shibata 1984, Bertout et al 1988...)



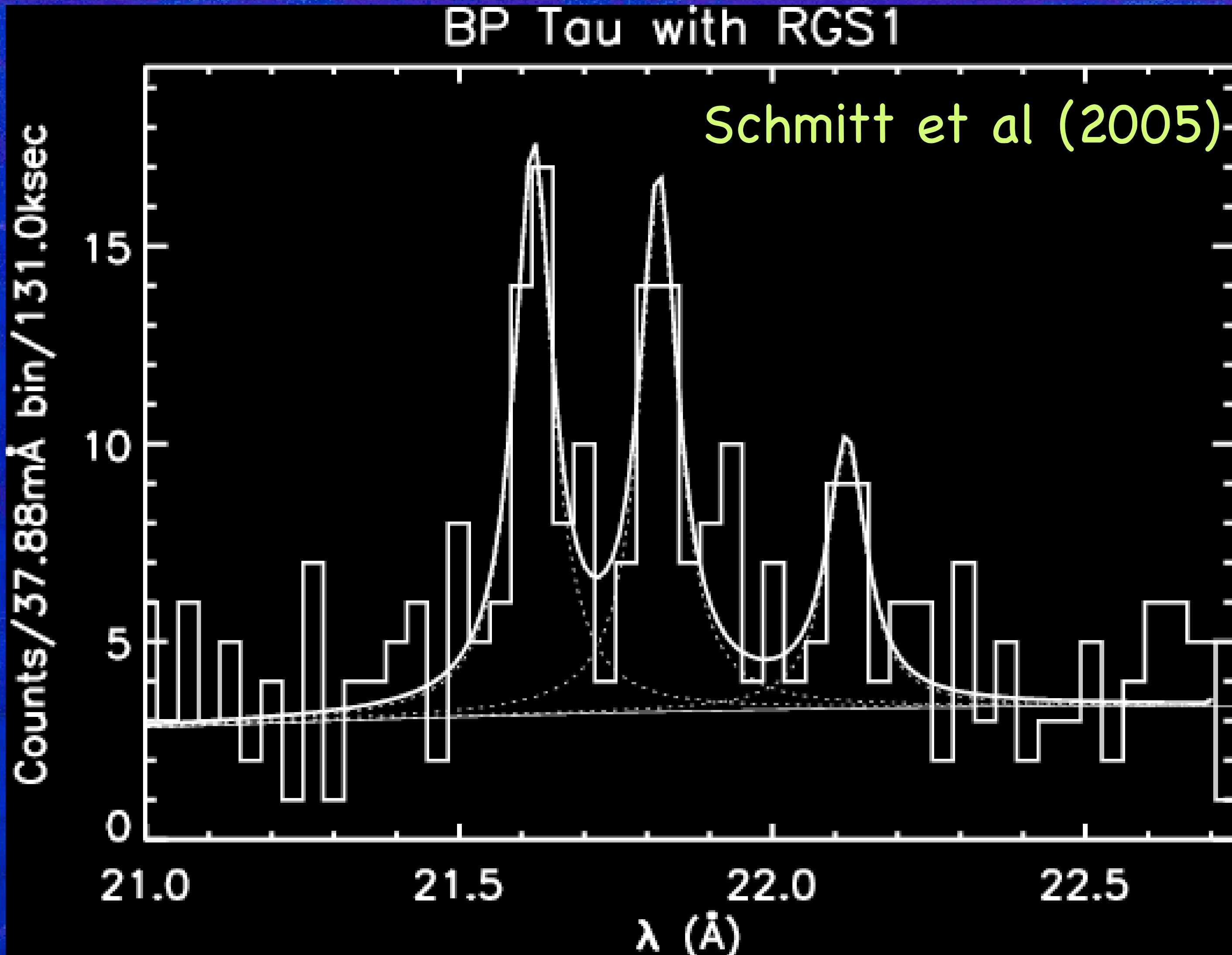



# Magnetospheric Accretion (Uchi

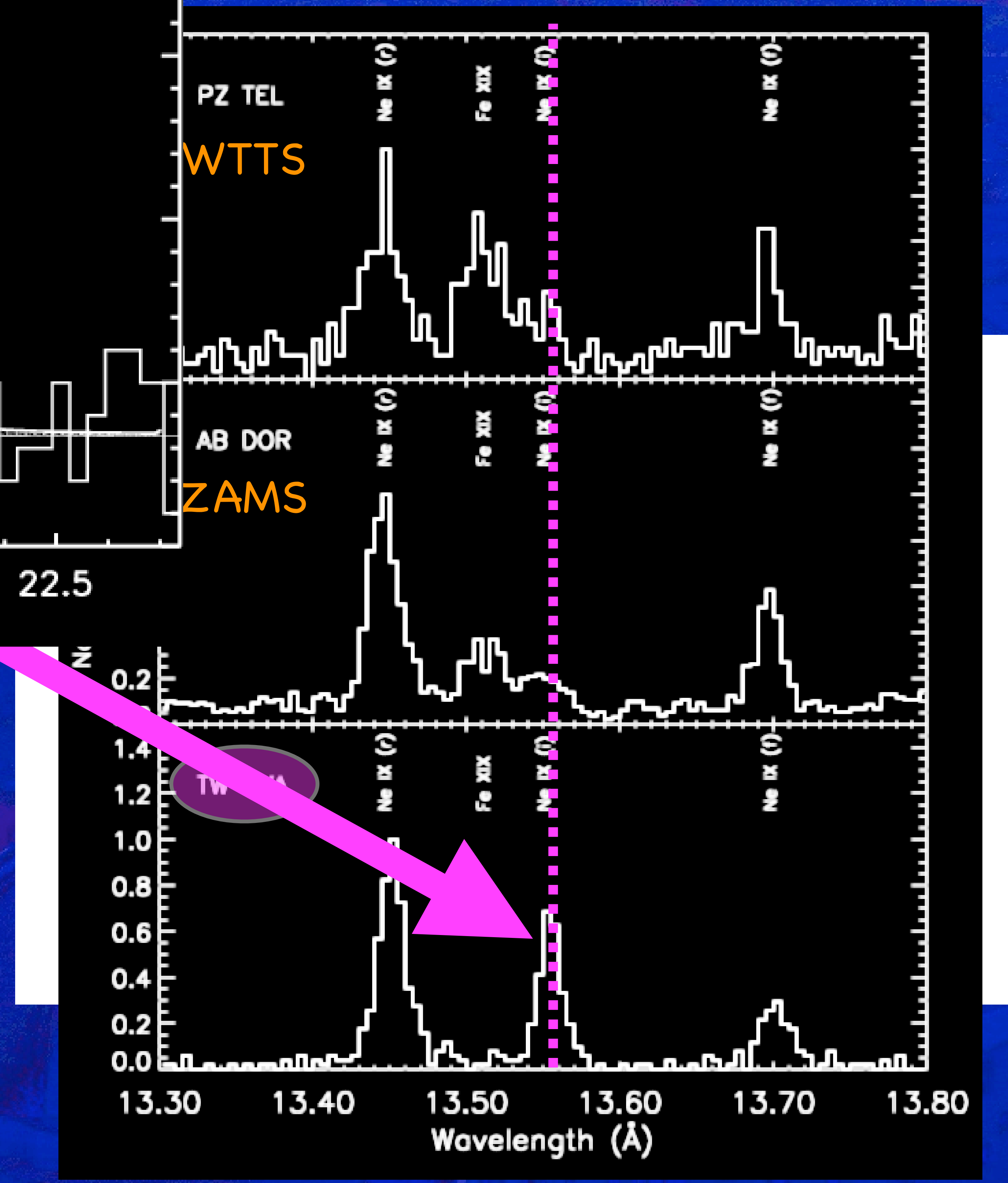


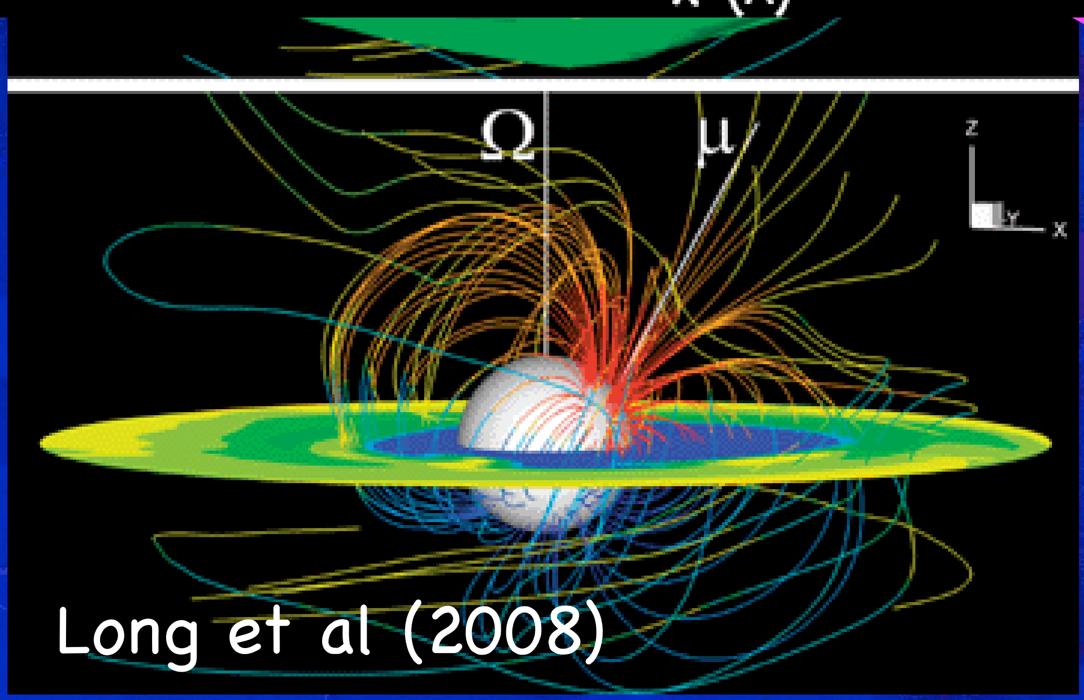
# spheric



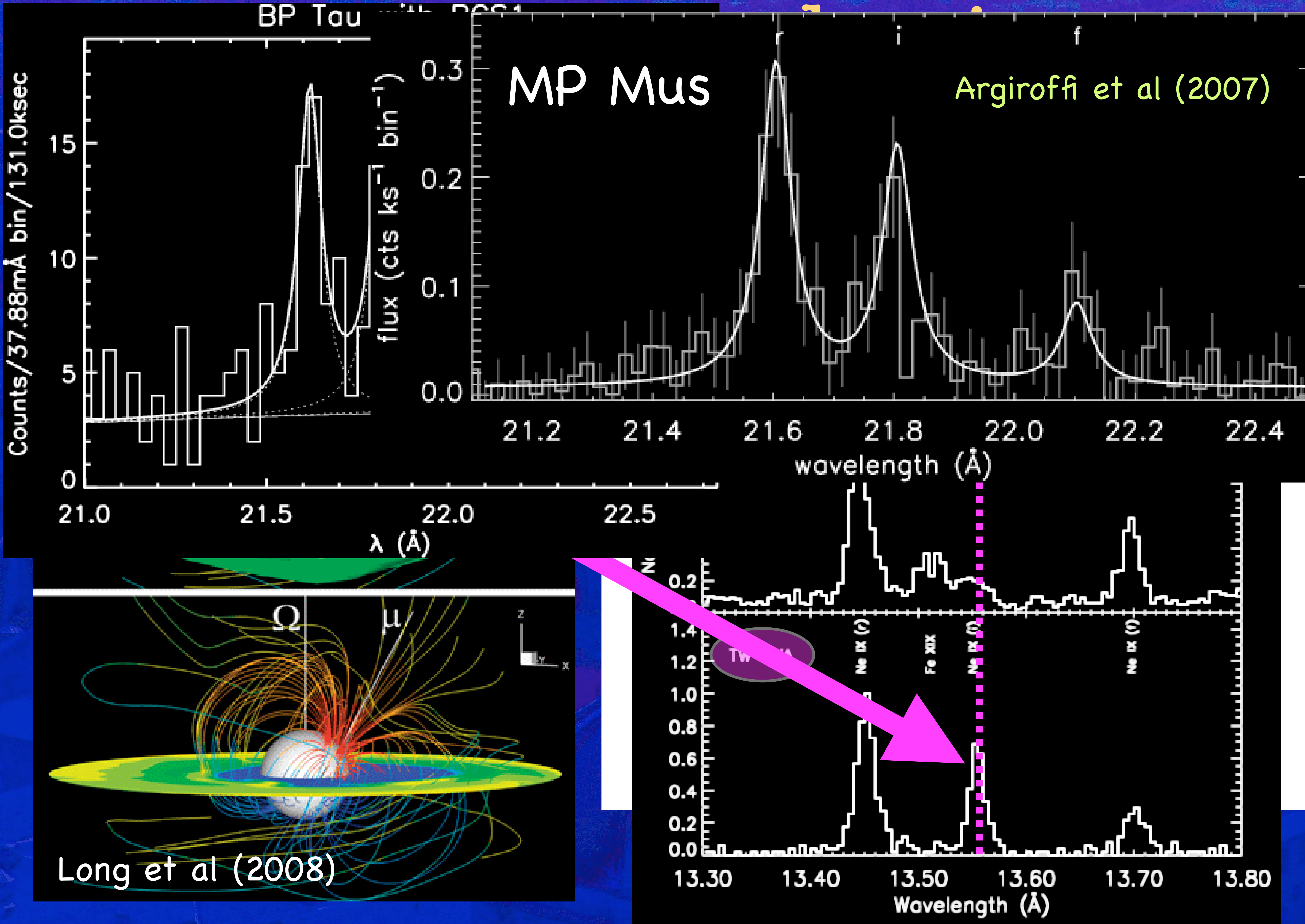
BP Tau with RGS1
Schmitt et al (2005)
Counts/37.88mÅ bin/131.0ksec
0
5
10
15
21.0
21.5
22.0
22.5
λ (Å)

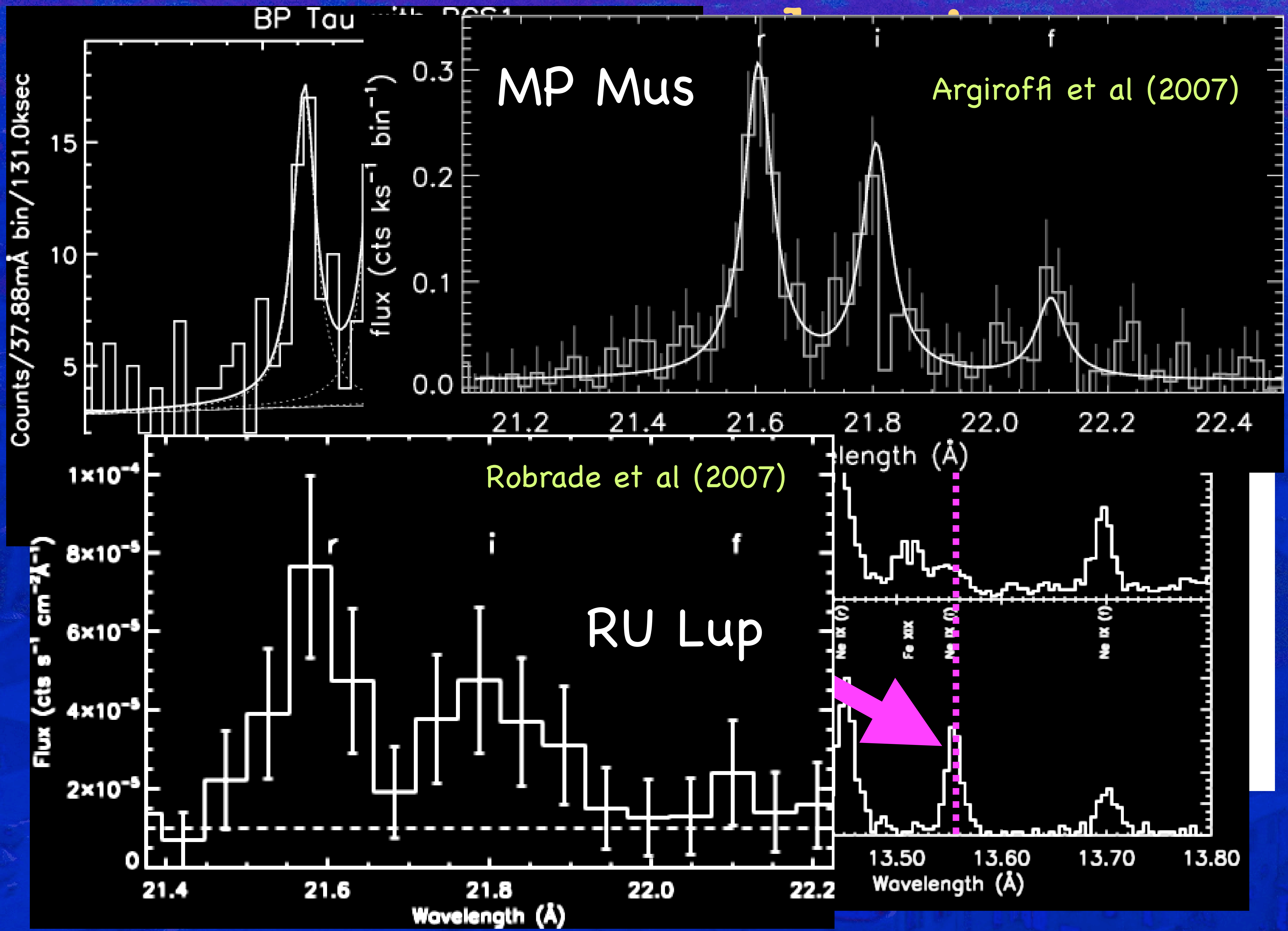



PZ TEL
WTTS
AB DOR
ZAMS
Ne IX (r)
Fe XIX
Ne IX (i)
Ne IX (f)
0.2
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
13.30
13.40
13.50
13.60
13.70
13.80
Wavelength (Å)

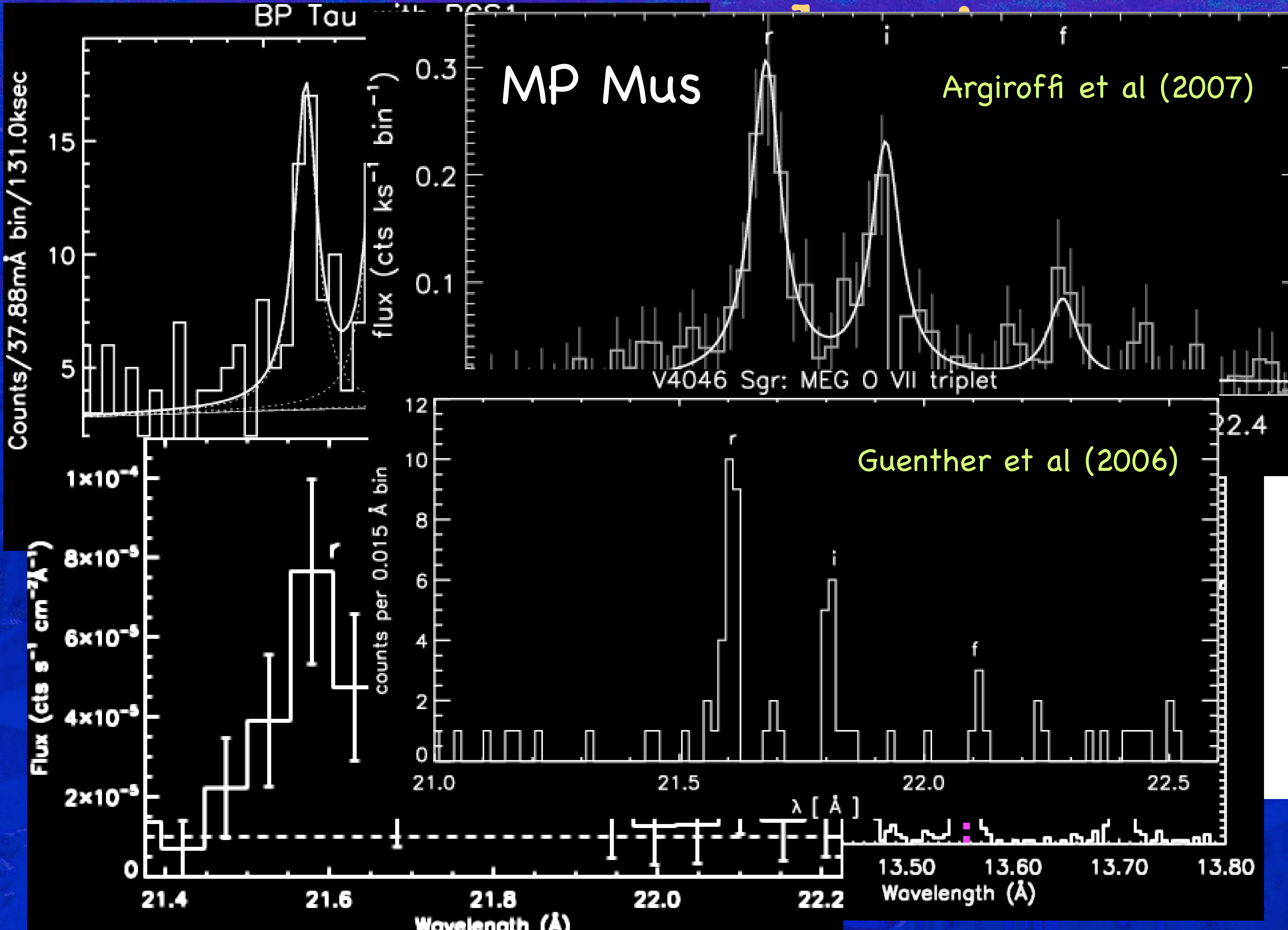



Ω
μ
Long et al (2008)


BP Tau
Counts/37.88mÅ bin/131.0ksec
λ (Å)
MP Mus
Argiroffi et al (2007)
r
i
f
flux (cts ks$^{-1}$ bin$^{-1}$)
wavelength (Å)
Ω
μ
Long et al (2008)
Ne IX (r)
Fe XIX
Ne IX (i)
Ne IX (f)
Wavelength (Å)



BP Tau
Counts/37.88mÅ bin/131.0ksec
15
10
5
MP Mus
Argiroffi et al (2007)
flux (cts ks$^{-1}$ bin$^{-1}$)
0.3
0.2
0.1
0.0
r
i
f
21.2
21.4
21.6
21.8
22.0
22.2
22.4
length (Å)
Robrade et al (2007)
RU Lup
Flux (cts s$^{-1}$ cm$^{-2}$Å$^{-1}$)
1×10$^{-4}$
8×10$^{-5}$
6×10$^{-5}$
4×10$^{-5}$
2×10$^{-5}$
0
r
i
f
21.4
21.6
21.8
22.0
22.2
Wavelength (Å)
Ne IX (r)
Fe XIX
Ne IX (i)
Ne IX (f)
13.50
13.60
13.70
13.80
Wavelength (Å)


BP Tau
MP Mus
Argiroffi et al (2007)
r
i
f
flux (cts ks$^{-1}$ bin$^{-1}$)
0.3
0.2
0.1
22.4
Counts/37.88mÅ bin/131.0ksec
15
10
5
V4046 Sgr: MEG O VII triplet
Guenther et al (2006)
counts per 0.015 Å bin
12
10
8
6
4
2
0
21.0
21.5
22.0
22.5
λ [ Å ]
Flux (cts s$^{-1}$ cm$^{-2}$Å$^{-1}$)
1×10$^{-4}$
8×10$^{-5}$
6×10$^{-5}$
4×10$^{-5}$
2×10$^{-5}$
0
21.4
21.6
21.8
22.0
22.2
Wavelength (Å)
13.50
13.60
13.70
13.80
Wavelength (Å)

# Protoplanetary Disks

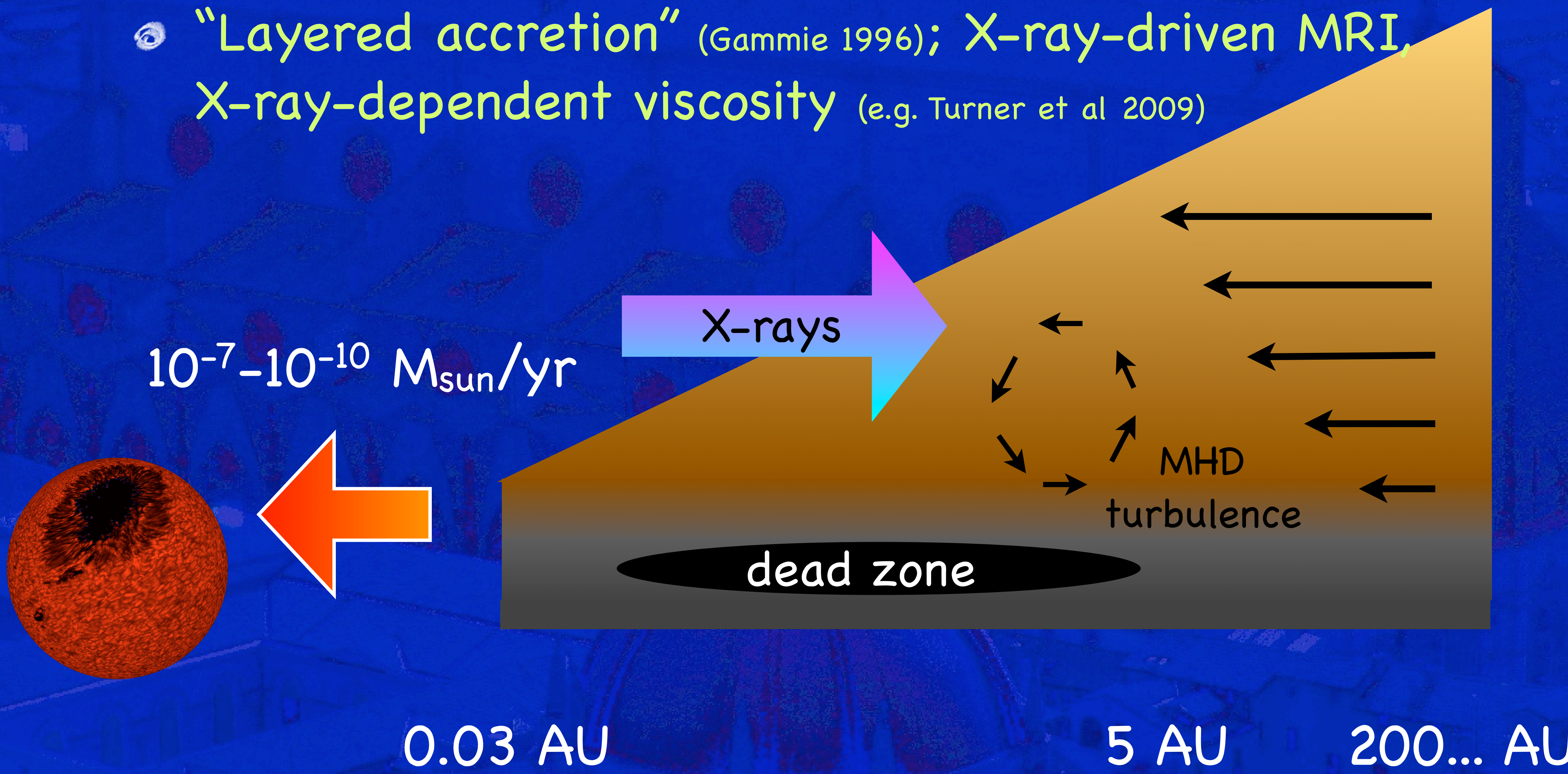
## What's it all about

# $\alpha$

"The most fruitful approach has been the condensation of our uncertainties by Shakura & Sunyaev (1973) into a dimensionless parameter $\alpha$" Pringle (1981)

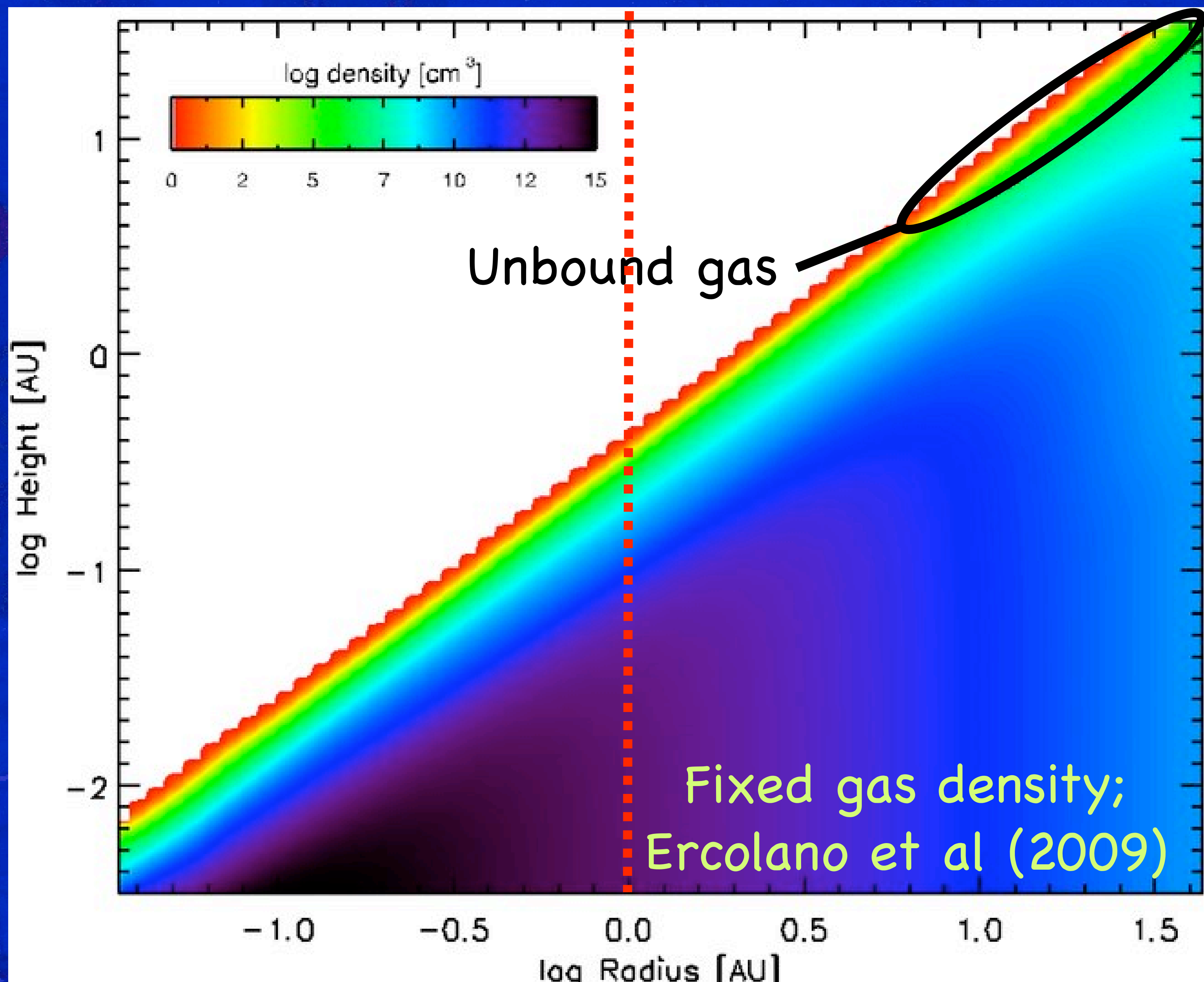
# Protoplanetary Disks

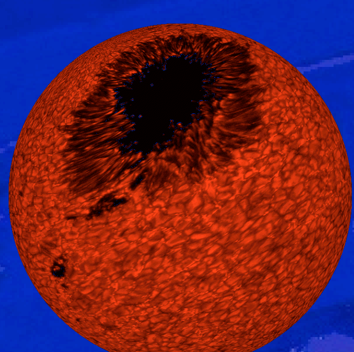
- Importance of X-ray heating/ionization pointed out by Al Glassgold and co-workers (Igea & Glassgold 1999....)
- "Layered accretion" (Gammie 1996); X-ray-driven MRI, X-ray-dependent viscosity (e.g. Turner et al 2009)



# Disk X-ray Heating

(difficult: coupled radiative transfer, hydrodynamics, chemistry...)



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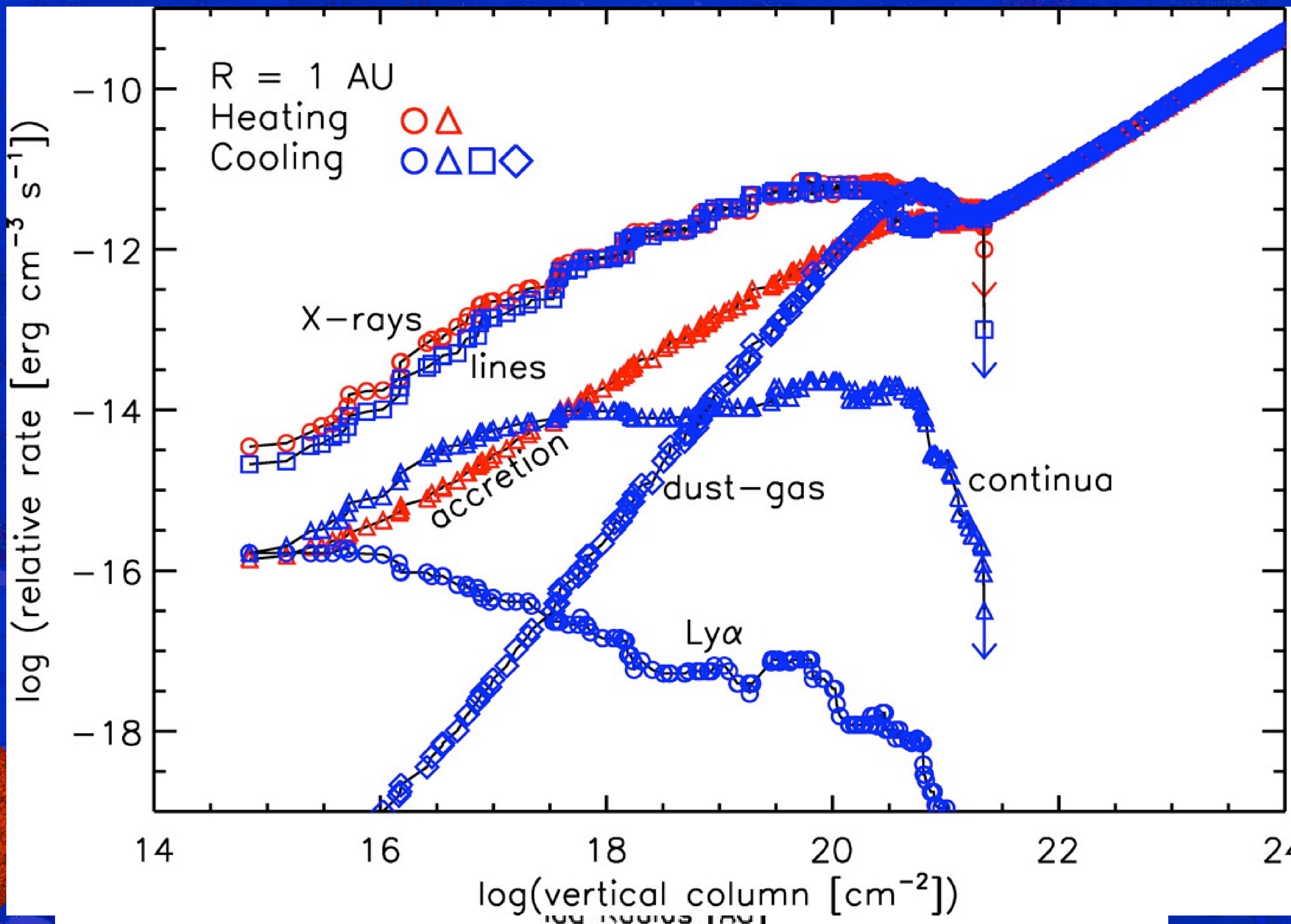


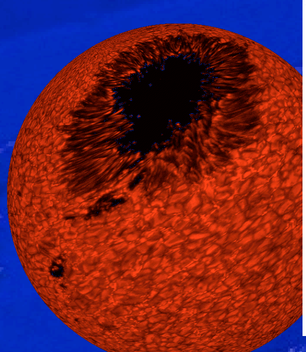

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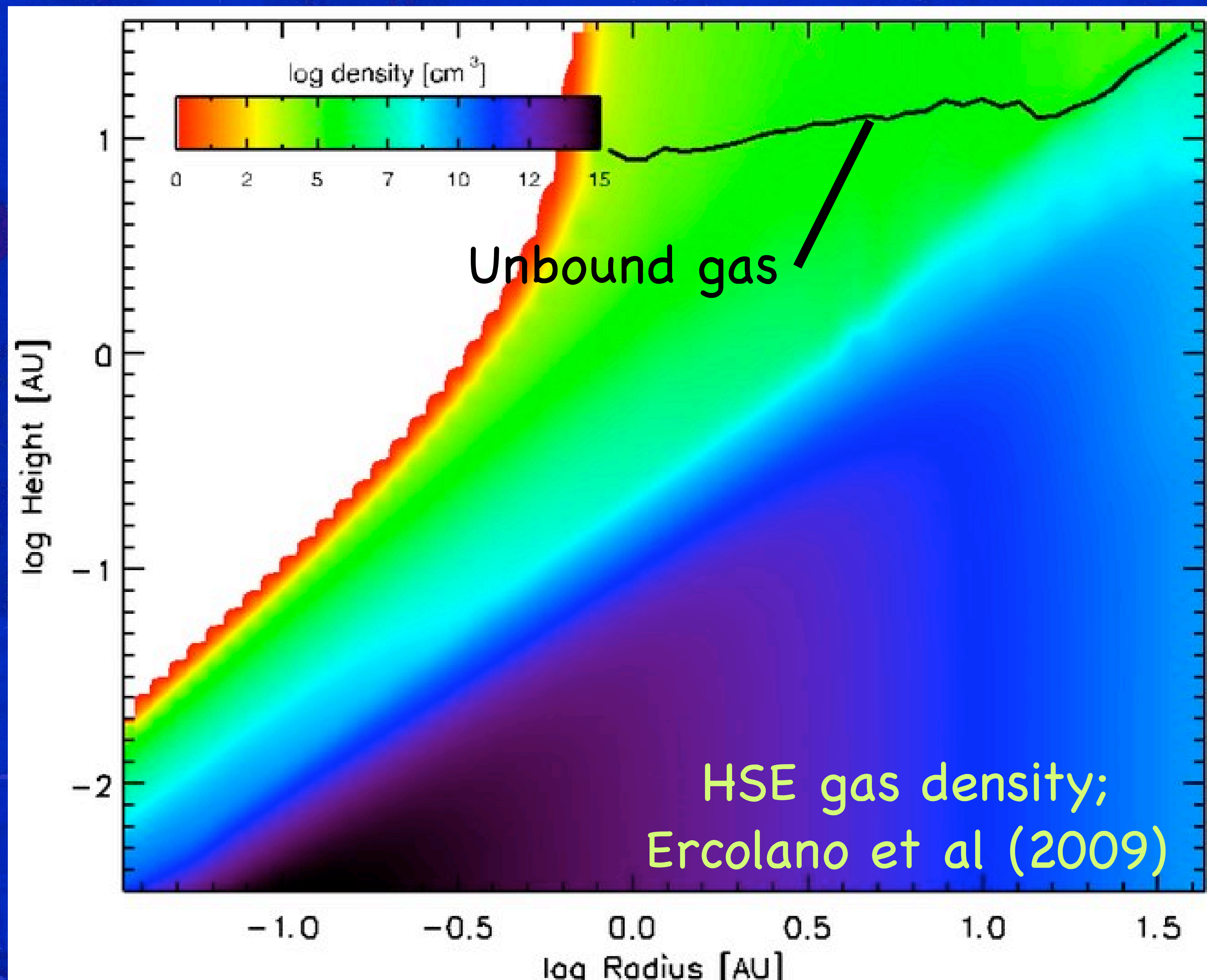
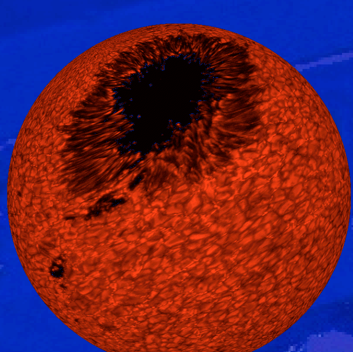
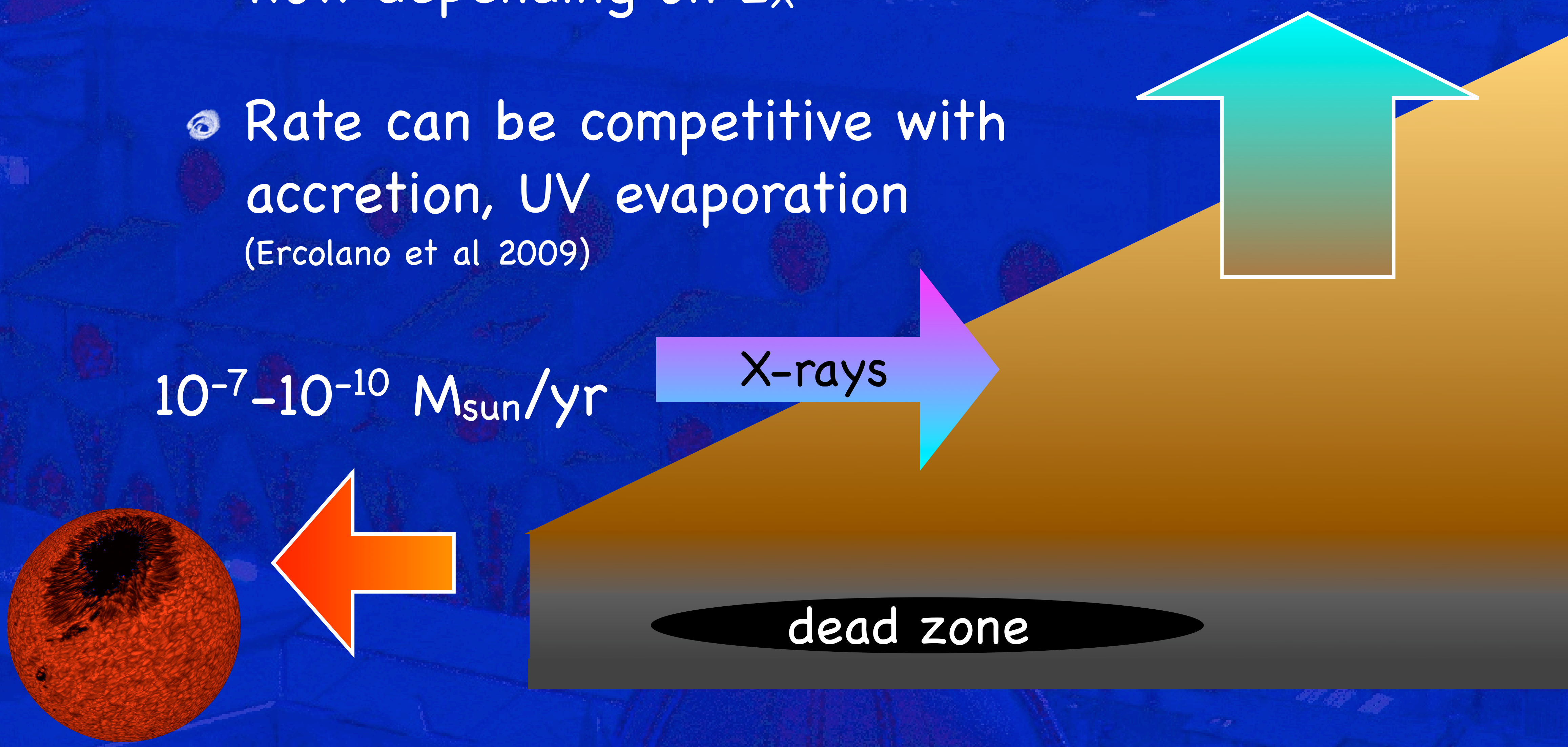


# Protoplanetary Disks

- X-ray driven photoevaporative flow depending on $L_X$
- Rate can be competitive with accretion, UV evaporation (Ercolano et al 2009)



# Protoplanetary Disks

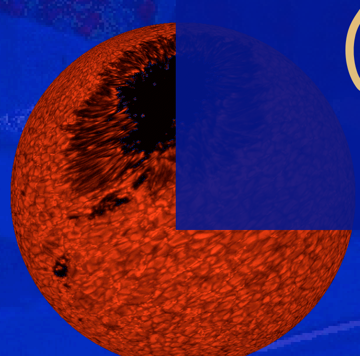
- X-ray driven photoevaporative flow depending on $L_X$

X-ray Photoevaporation

- ~50% of late-type stars emerge with debris disks
- ~6%+ emerge with gas giant planets

Likely controlled largely by X-rays

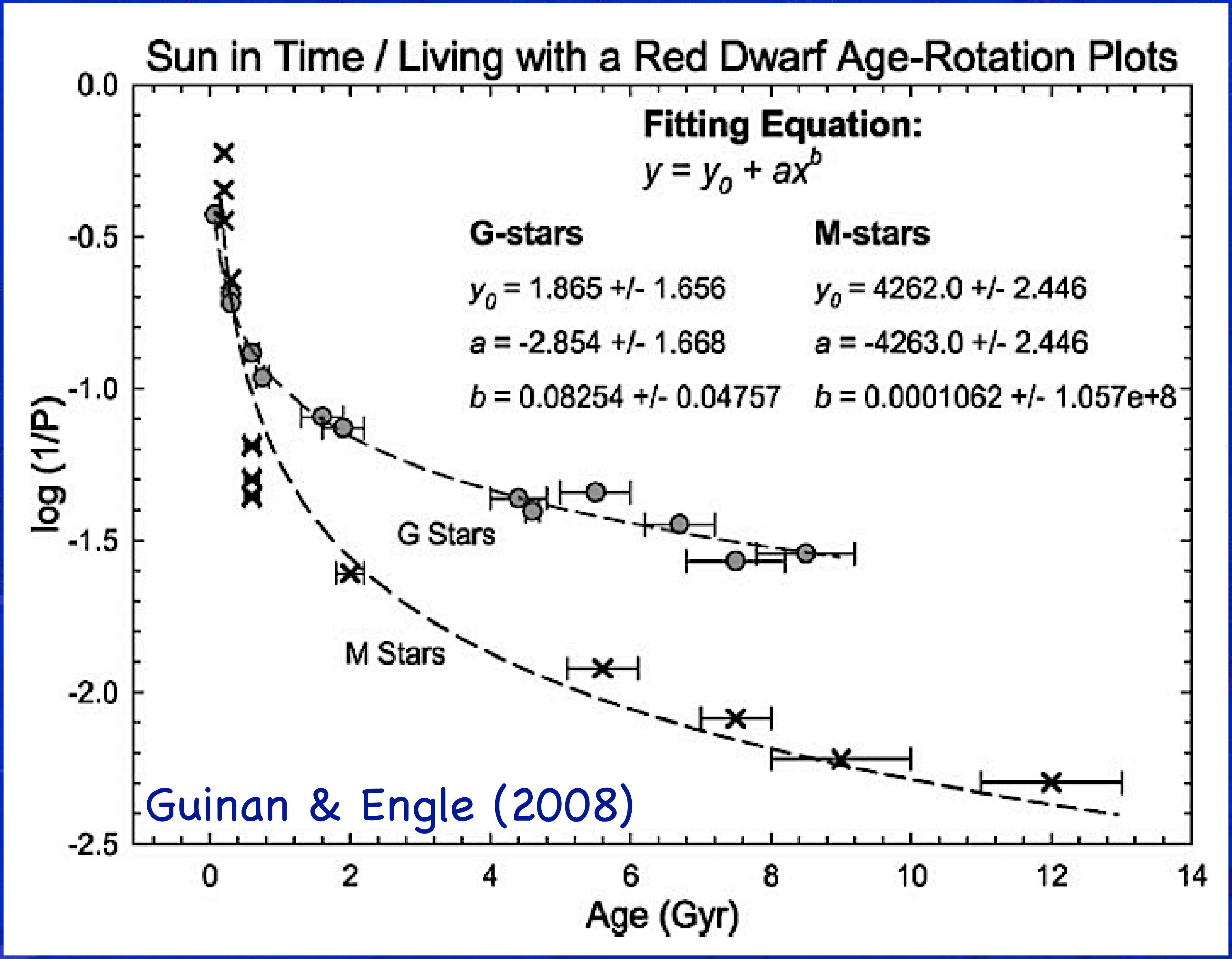
(+initial disk conditions + UV environment: Ettore's talk next)



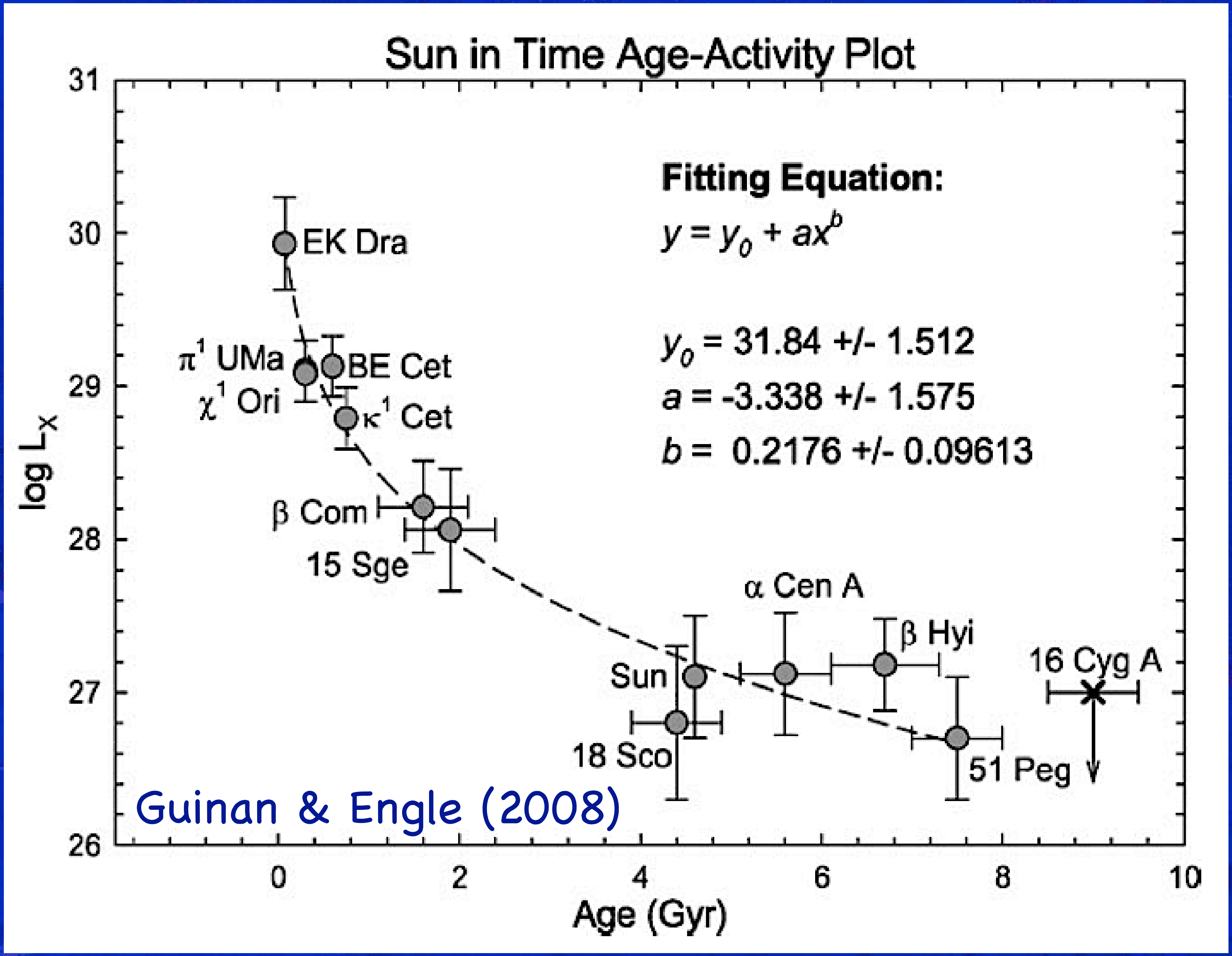
0.03 AU 5 AU 200... AU

# Coronal Structure and the Origin and Evolution of Life

# Age - Rotation - Lx



# Age - Rotation - Lx



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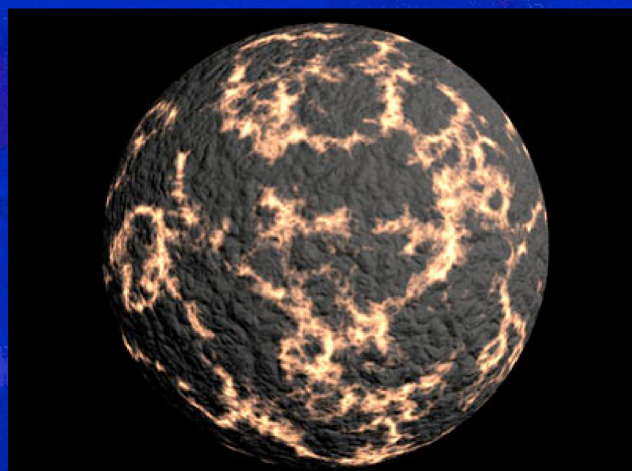
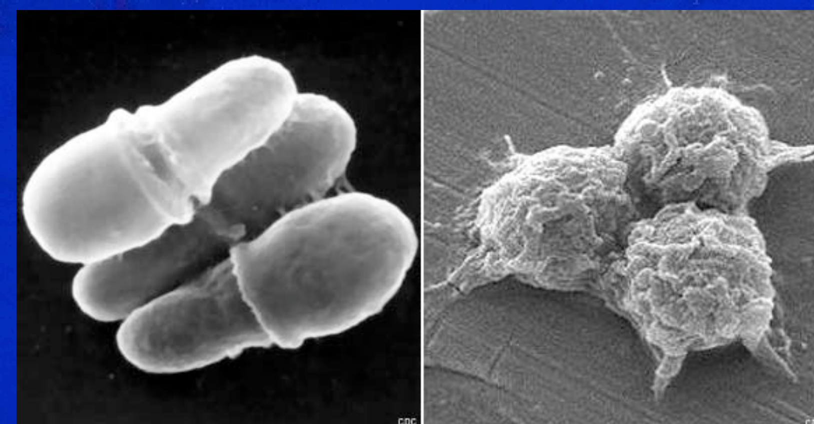


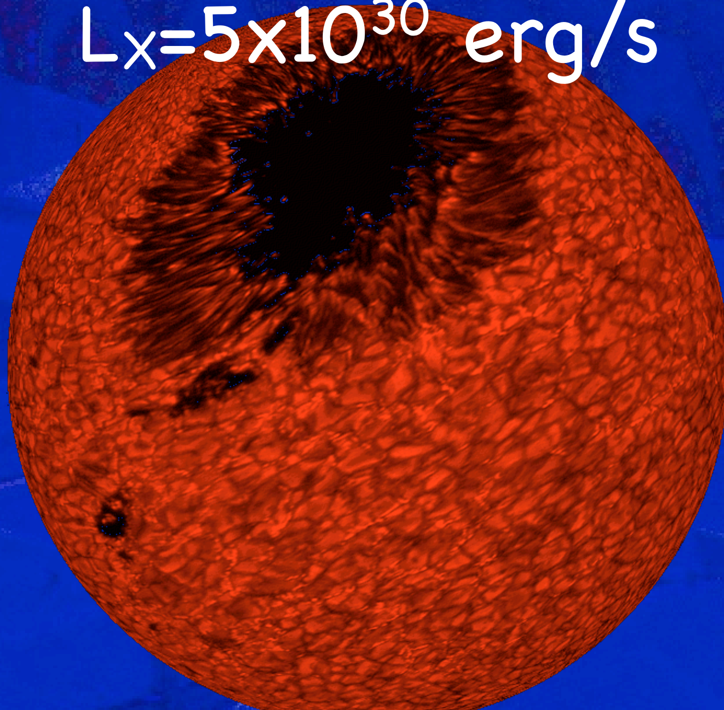


0.01 Gyr

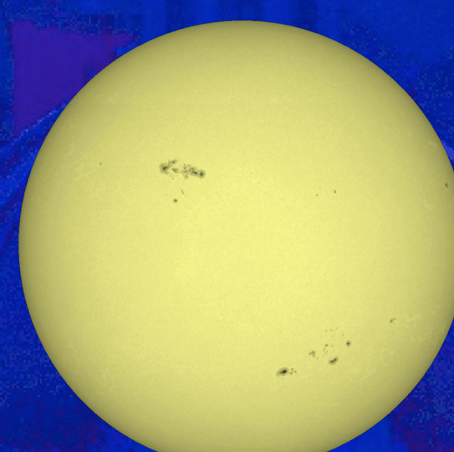
1.0 Gyr

4.5 Gyr

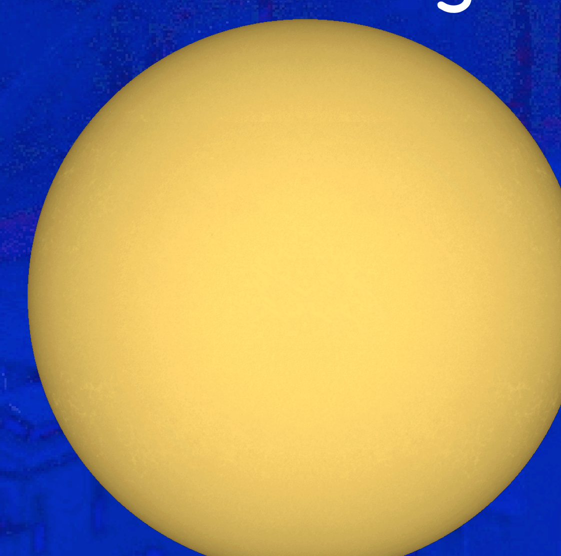
$L_X = 5 \times 10^{30}$ erg/s



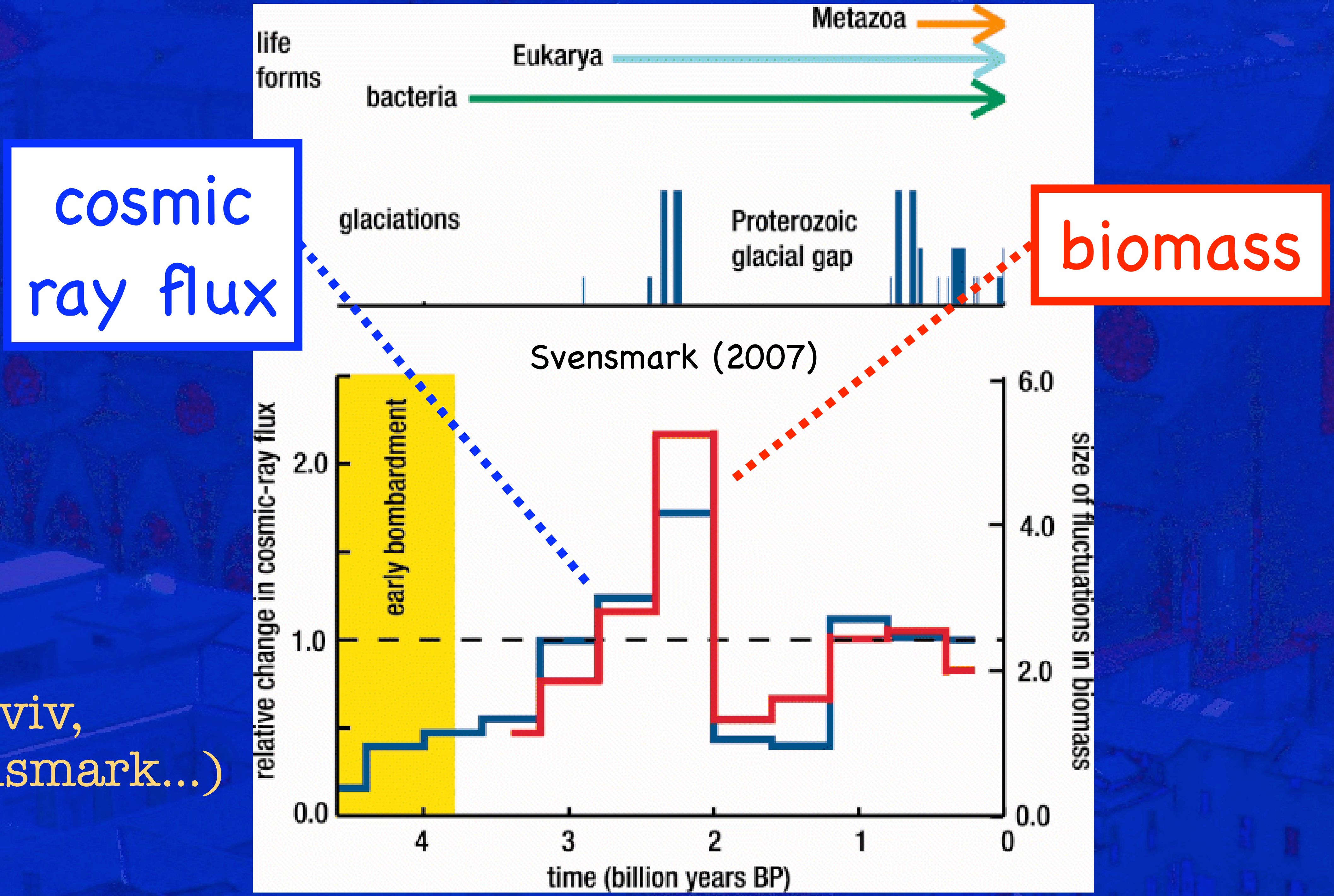
$L_X = 10^{29}$ erg/s



$L_X = 10^{27}$ erg/s

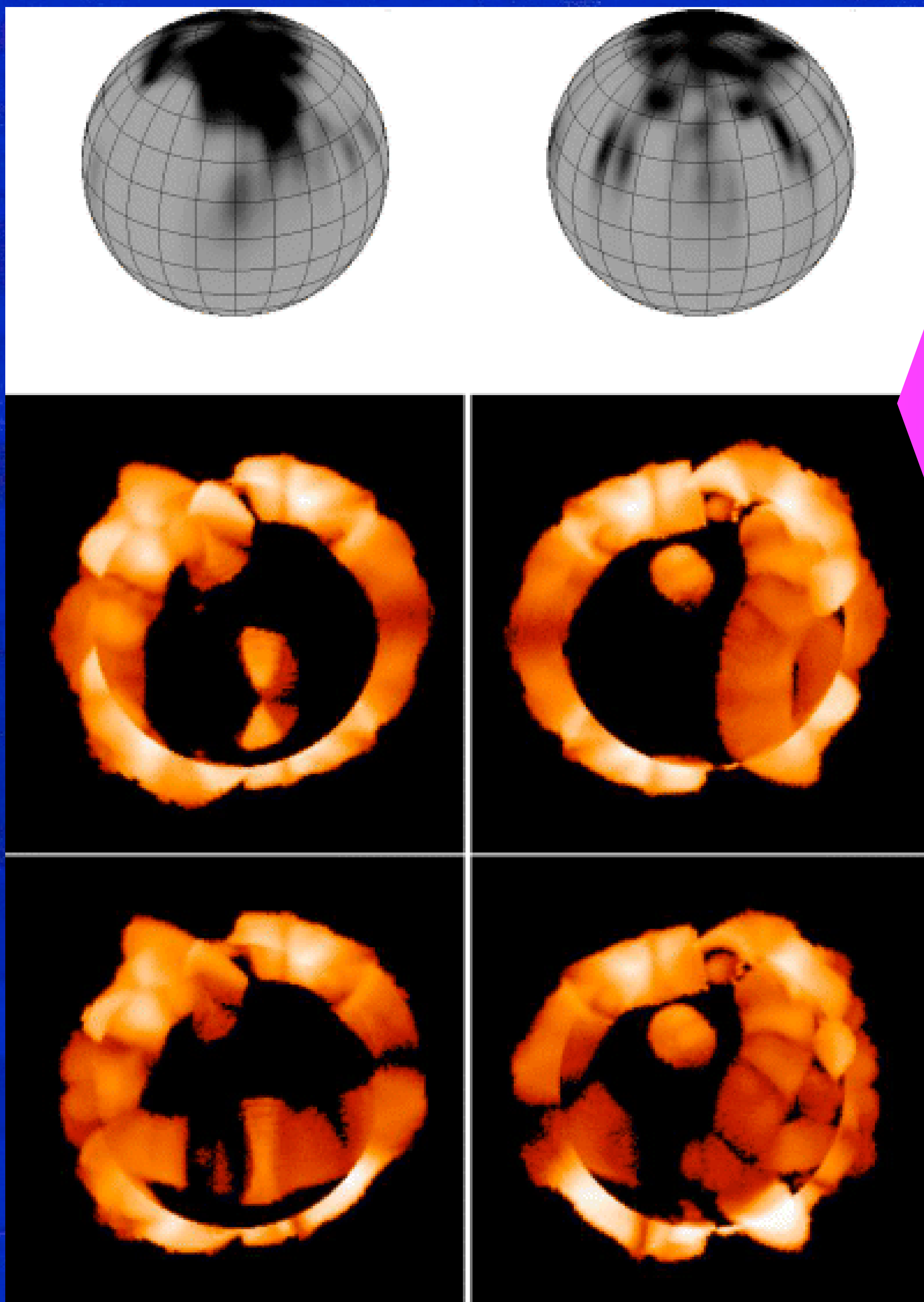


# Paleoclimate Moderated by Solar Wind & Cosmic Rays?



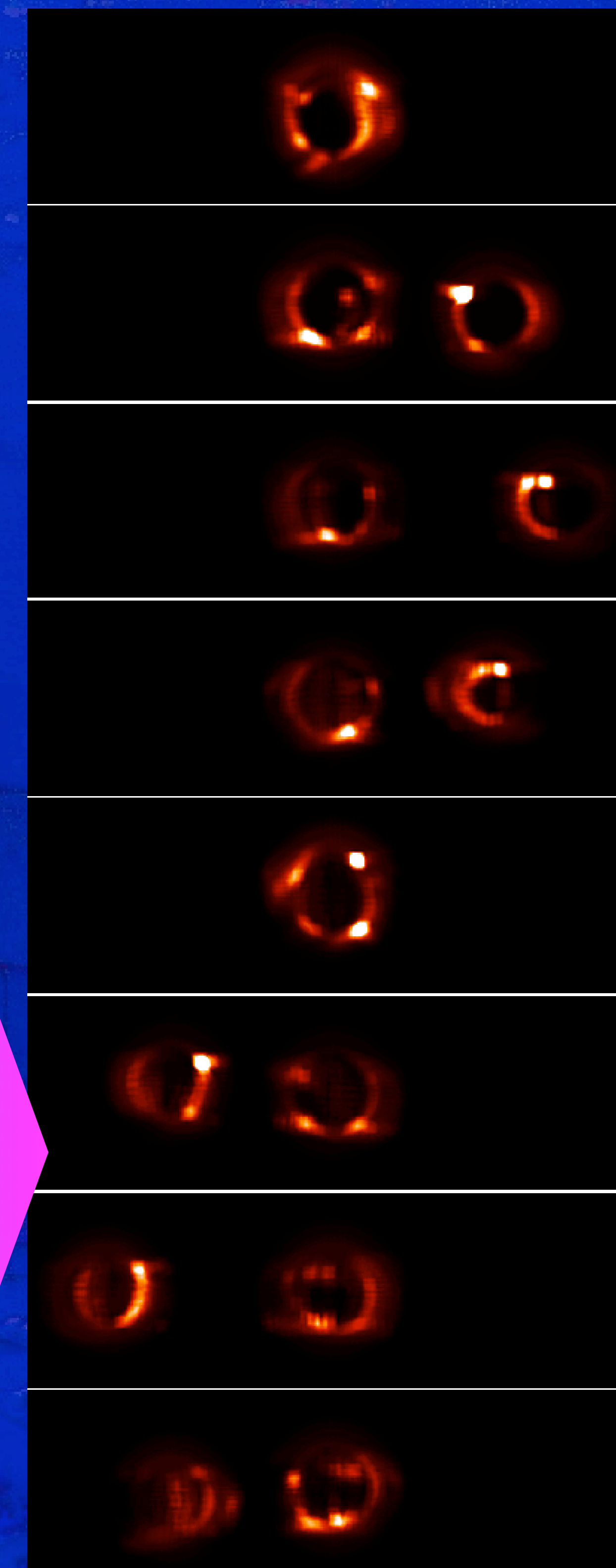

(Shaviv, Svensmark...)

# Inferring Coronal Structure



AB Dor, K0V, P=0.5d, Chandra LETG (Hussain et al 2007)

YY Gem, dM1 +dM1, P=0.8d, XMM EPIC (Guedel et al 2001)



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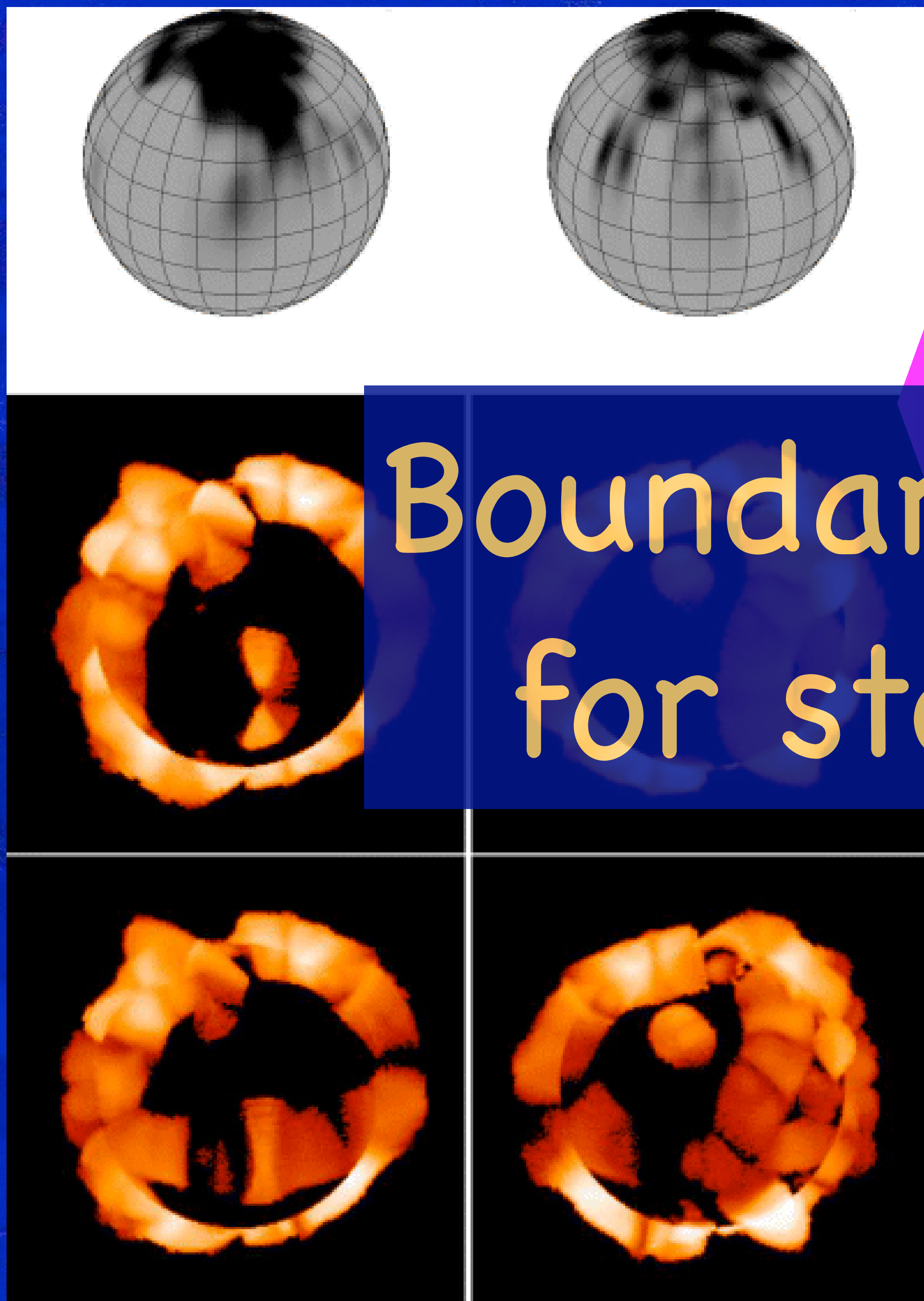
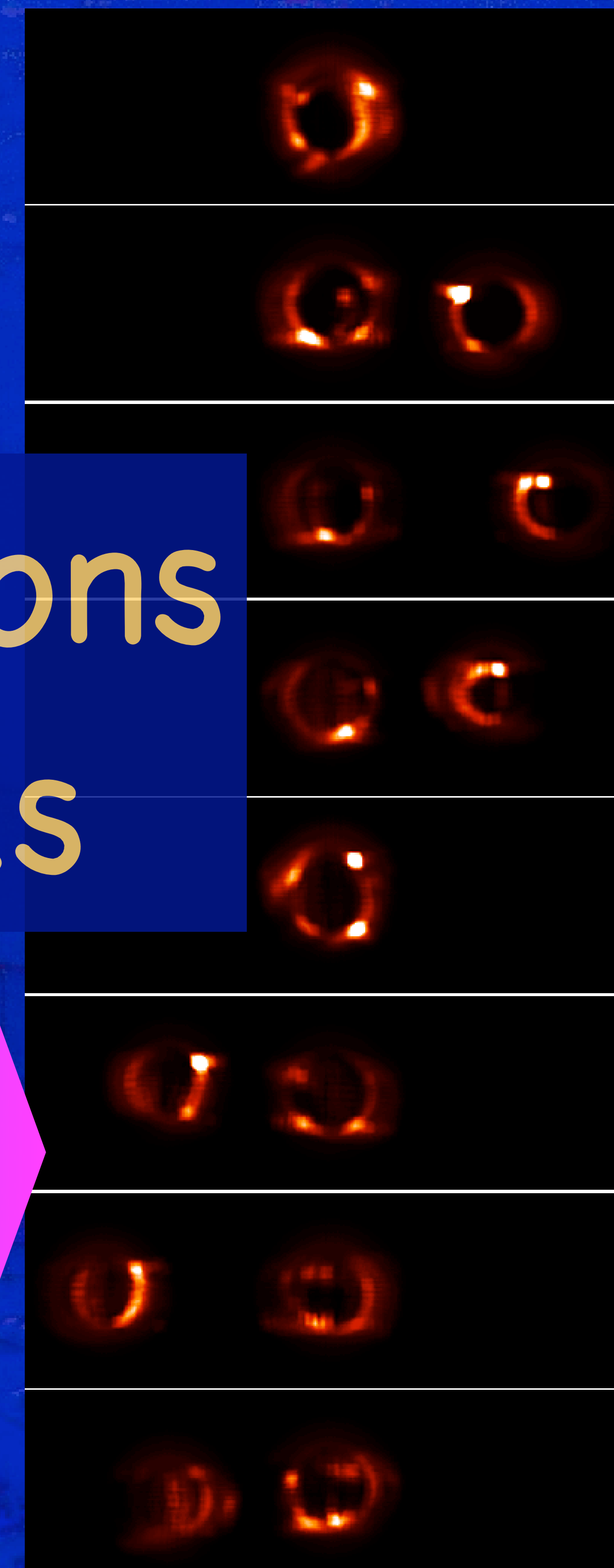


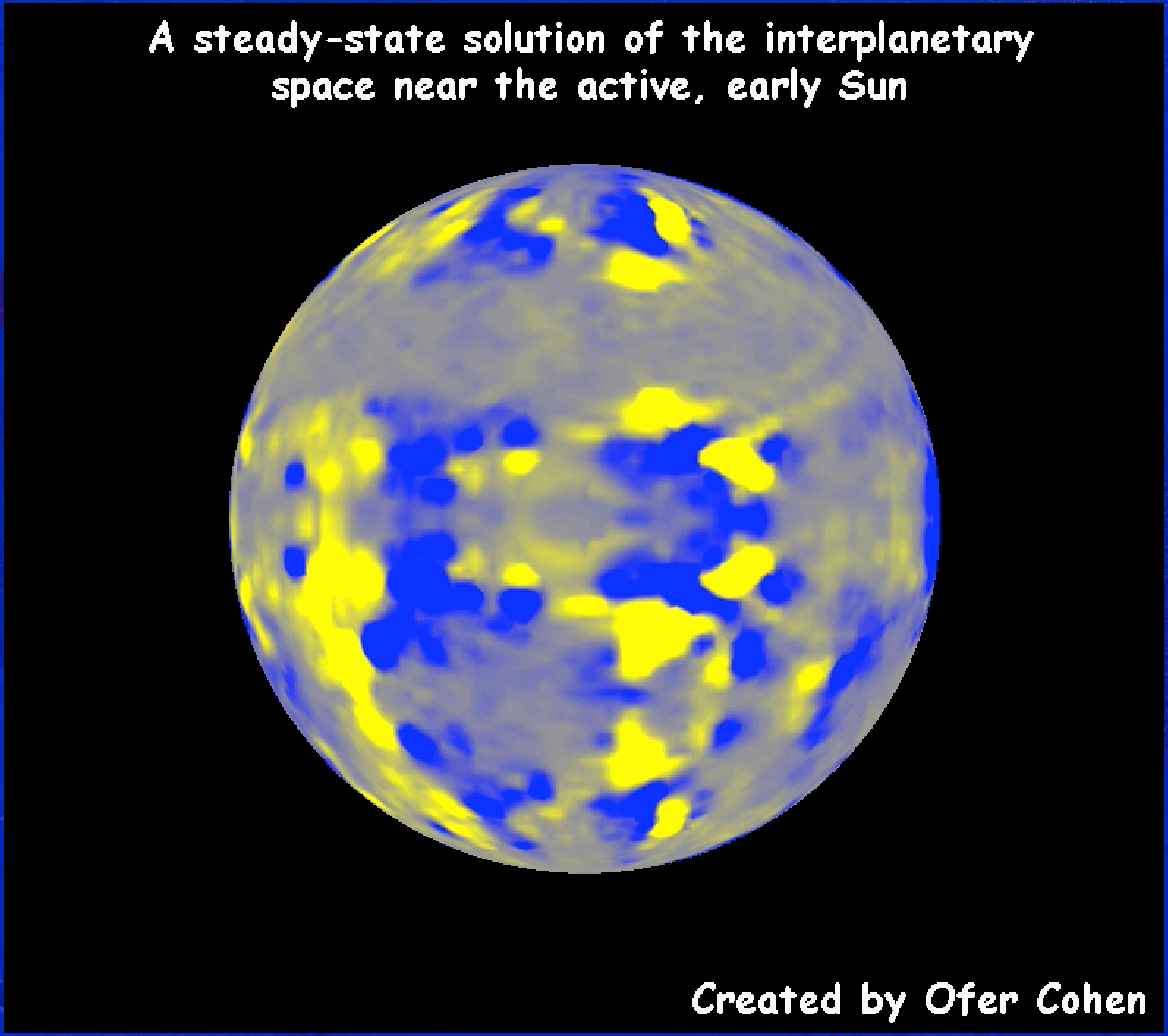
AB Dor, K0V, P=0.5d, Chandra LETG (Hussain et al 2007)

**Boundary conditions for stellar winds**

YY Gem, dM1 +dM1, P=0.8d, XMM EPIC (Guedel et al 2001)



# Simulation using solar wind MHD code (Cohen et al. 2009)



# Future

**X-ray surface layer chemistry**

| | | |
|---|---|---|
| $H_2CO^d$ | → | $H_2CO$ |
| $H_2O^d$ | → | $H_2O$ |
| $C + h\nu_{CR}$ | → | $C^+ + e^-$ |
| $OH + h\nu_{CR}$ | → | $O + H$ |
| $CO + h\nu_{CR}$ | → | $C + O$ |
| $H_2CO + h\nu_{CR}$ | → | $CO + H_2$ |
| H+ CRP, X-ray | → | $H^+ + e^-$ |
| $H_2$+ CRP, X-ray | → | $H_2^+ + e^-$ |
| $H_2^+ + H_2$ | → | $H_3^+ + H$ |
| $H^+ + O$ | → | $O^+ + H$ |
| $H^+ + OH$ | → | $OH^+ + H$ |
| | | |
| $H_3^+ + O$ | → | $OH^+ + H_2$ |
| $H_3^+ + H_2O$ | → | $H_3O^+ + H_2$ |
| $H_3^+ + CO$ | → | $HCO^+ + H_2$ |
| $O^+ + H$ | → | $H^+ + O$ |
| $O^+ + H_2$ | → | $OH^+ + H$ |
| $OH^+ + H_2$ | → | $H_2O^+ + H$ |
| $H_2O^+ + H_2$ | → | $H_3O^+ + H$ |
| $C^+ + H_2O$ | → | $HCO^+ + H$ |
| $C^+ + O_2$ | → | $O^+ + CO$ |
| $O + OH$ | → | $O_2 + H$ |
| $H^+ + e^-$ | → | $H + h\nu$ |
| $H_3^+ + e^-$ | → | $H_2 + H$ |
| $C^+ + e^-$ | → | $C + h\nu$ |
| $H_2O^+ + e^-$ | → | $O + H_2$ |
| $H_3O^+ + e^-$ | → | $OH + H + H$ |
| $HCO^+ + e^-$ | → | $CO + H$ |

**Hot chemistry in midplane**

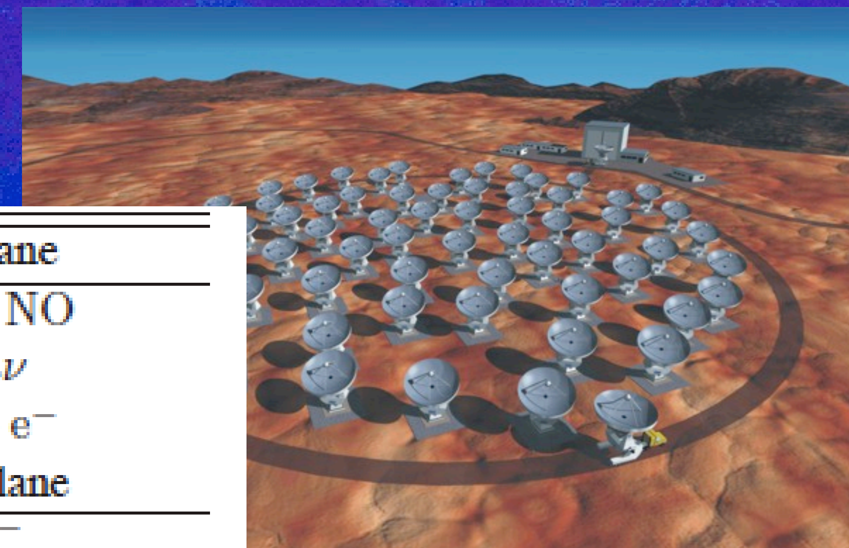
| | | |
|---|---|---|
| $NO^+ + Mg$ | → | $Mg^+ + NO$ |
| $Mg^+ + e^-$ | → | $Mg + h\nu$ |
| $NO + h\nu_{CR}$ | → | $NO^+ + e^-$ |

**Cold chemistry in midplane**

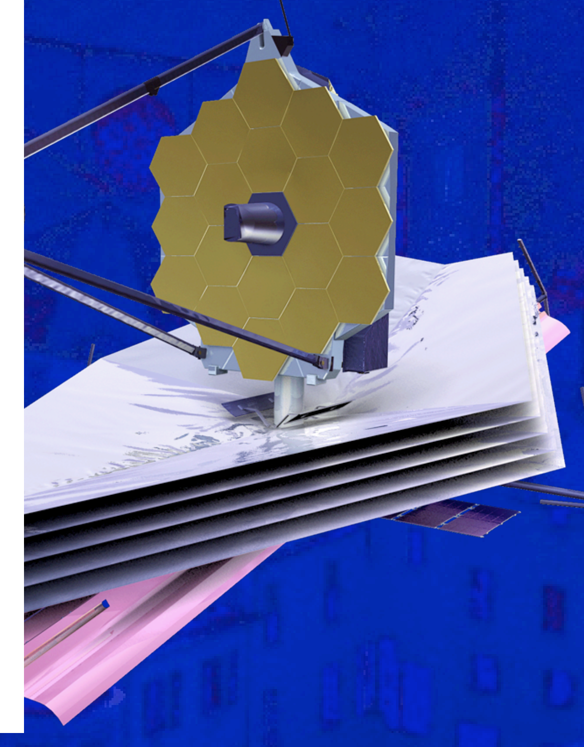
| | | |
|---|---|---|
| $H_2 + CRP$ | → | $H_2^+ + e^-$ |
| $H_2^+ + H_2$ | → | $H_3^+ + H$ |
| $H_3^+ + N_2$ | → | $N_2H^+ + H_2$ |
| $H_3^+ + e^-$ | → | $H_2 + H$ |
| $HCO^+ + e^-$ | → | $CO + H$ |
| $N_2H^+ + e^-$ | → | $N_2 + H$ |
| $Fe^+ + g^-$ | → | $Fe$ |
| $Mg^+ + g^-$ | → | $Mg$ |
| $H_3^+ + g^-$ | → | $H_2 + H$ |
| $HCO^+ + g^-$ | → | $CO + H$ |
| $N_2H^+ + g^-$ | → | $N_2 + H$ |

**UV surface layer chemistry**

| | | |
|---|---|---|
| $H_2CO^d$ | → | $H_2CO$ |
| $C^+ + H_2CO$ | → | $H_2CO^+ + C$ |
| $C^+ + e^-$ | → | $C + h\nu$ |
| $HCO^+ + e^-$ | → | $CO + H$ |
| $H_2CO^+ + e^-$ | → | $CO + H + H$ |
| $H_2CO^+ + e^-$ | → | $H_2CO + h\nu$ |
| $C + h\nu$ | → | $C^+ + e^-$ |
| $CO + h\nu$ | → | $C + O$ |
| $H_2CO + h\nu$ | → | $CO + H_2$ |
| $H_2CO + h\nu$ | → | $CO + H + H$ |
| $H_2CO + h\nu$ | → | $H_2CO^+ + e^-$ |
| $H_2CO + h\nu$ | → | $HCO^+ + e^- + H$ |

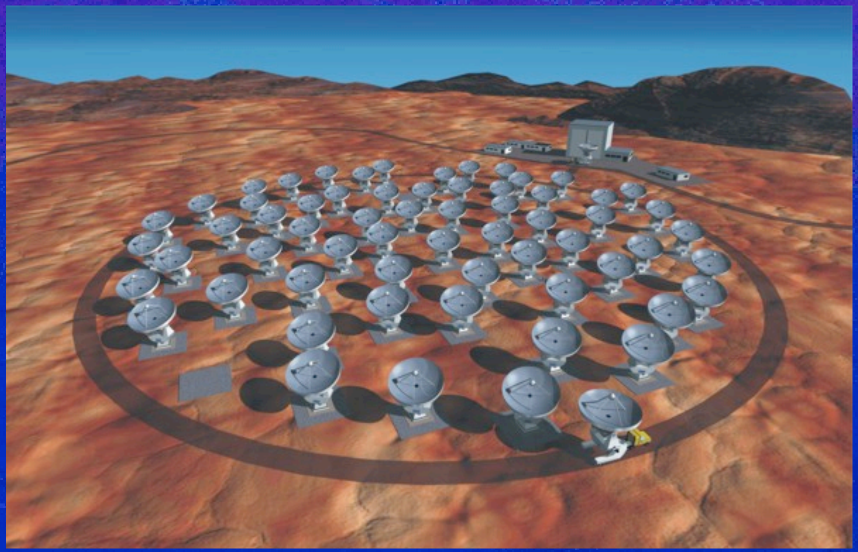
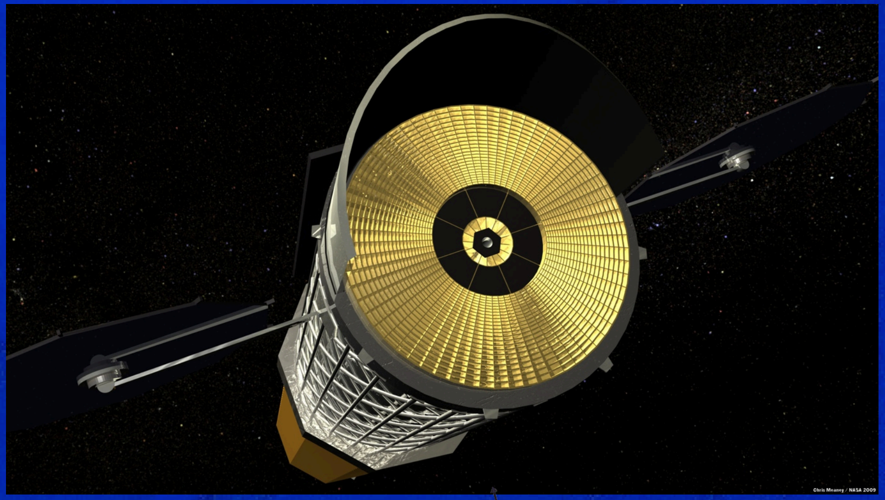
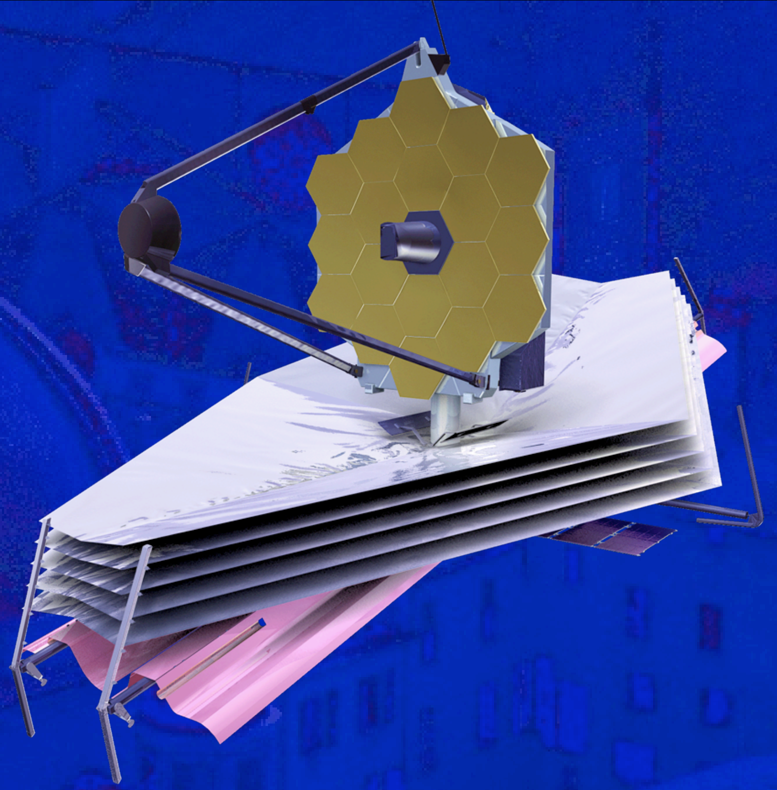


Semenov et al (2004)

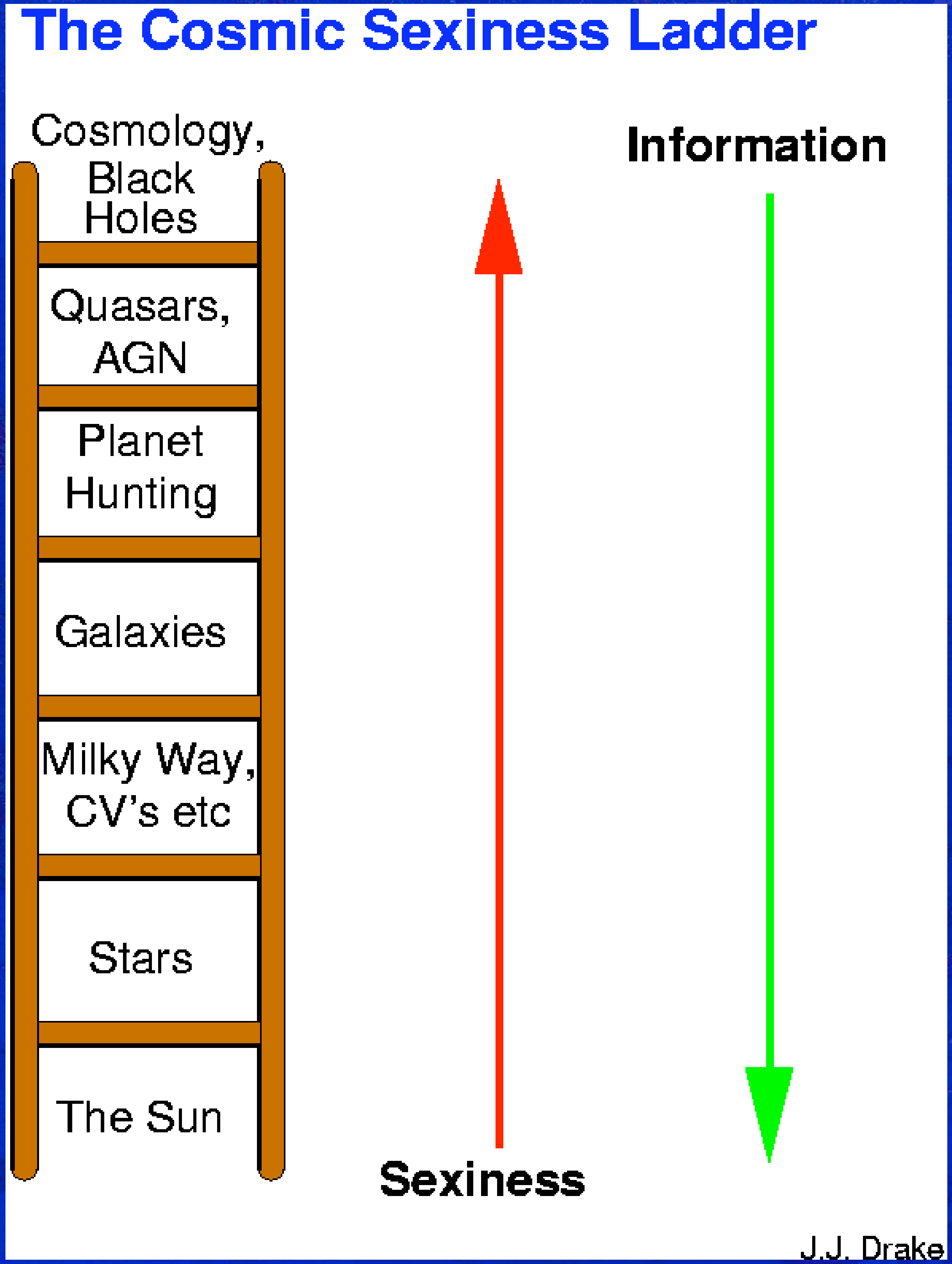


# Future

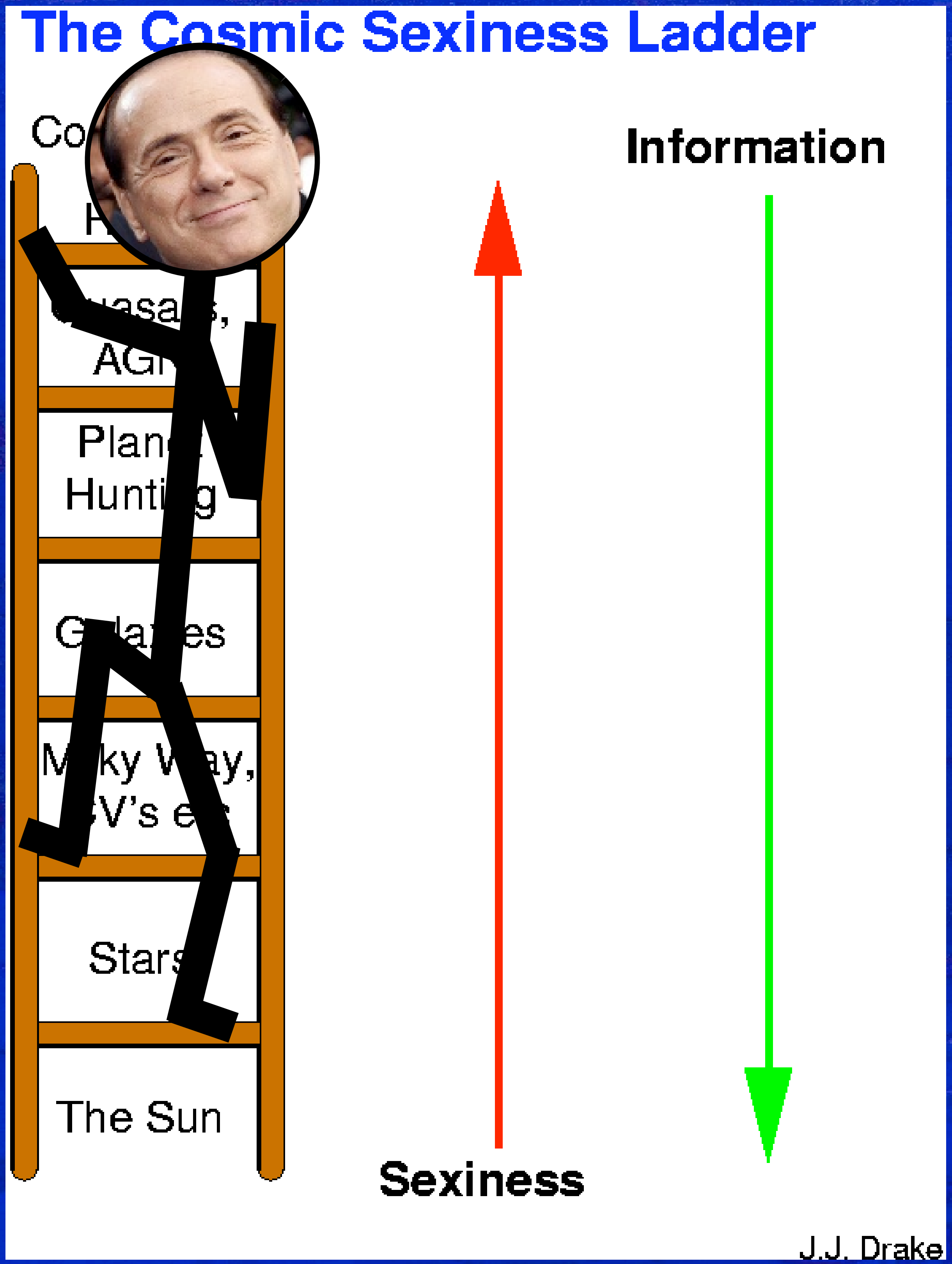
- IXO: more detailed coronal structure, proplyd-hosting TTS, Fe K fluorescence, much wider range of sources...
- ALMA, JWST revolutionise protoplanetary disk studies; X-ray-induced chemstry...

# Summary


The Cosmic Sexiness Ladder
Cosmology, Black Holes
Quasars, AGN
Planet Hunting
Galaxies
Milky Way, CV's etc
Stars
The Sun
Sexiness
Information
J.J. Drake

# Summary


The Cosmic Sexiness Ladder
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