XMM-Newton view of eight young open star clusters

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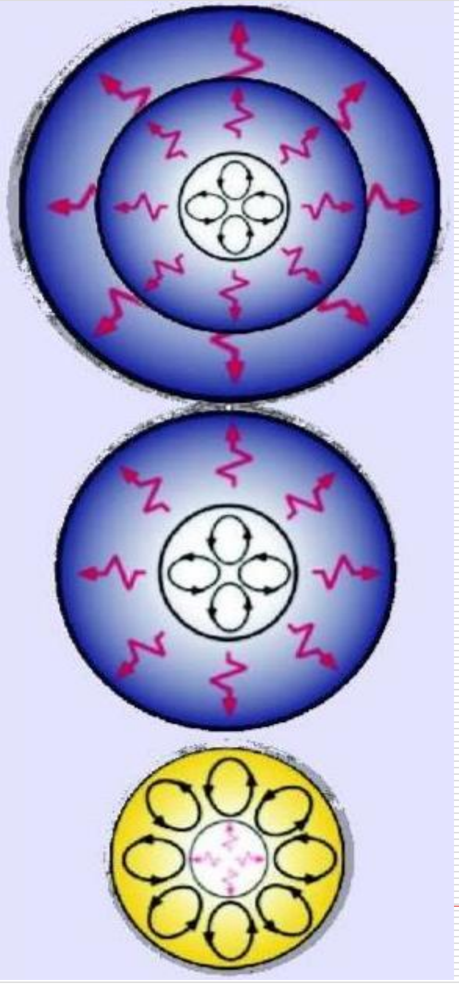
Outline

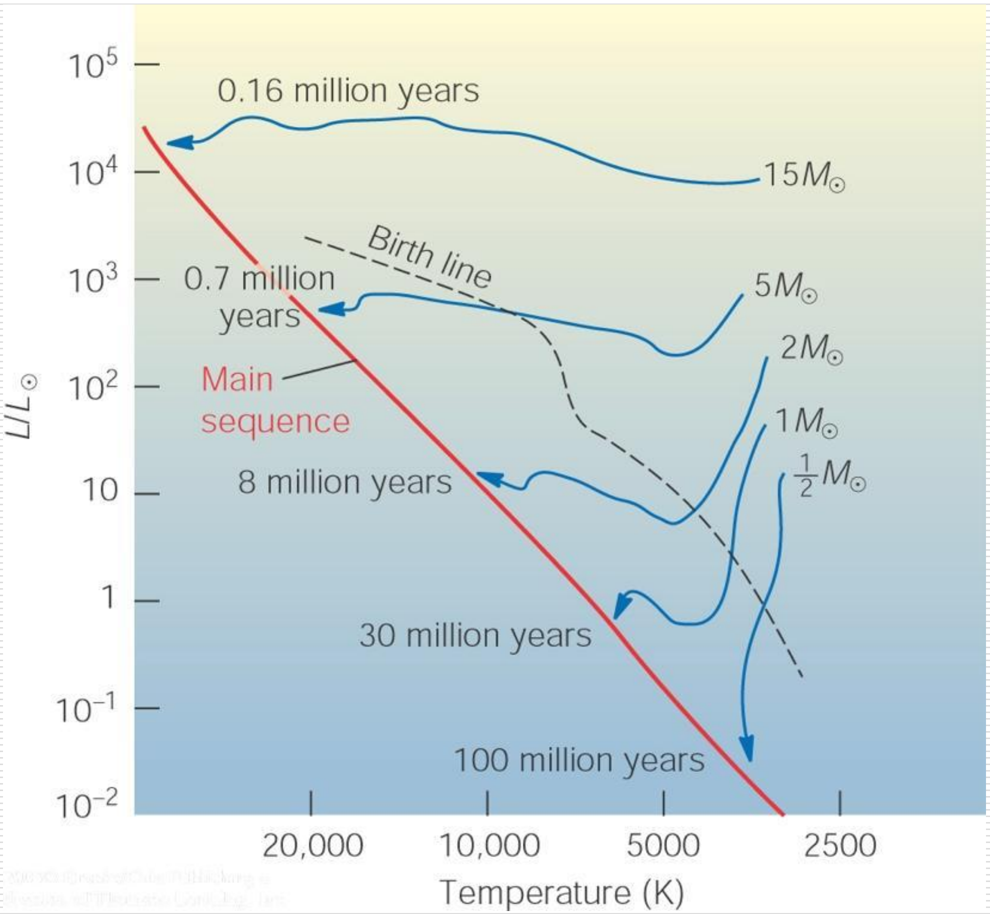
- Introduction
- Sample Selection and classification
- Temporal and Spectral Analysis
- X-ray Characteristics : Massive, Intermediate and Low mass stars
- Conclusions

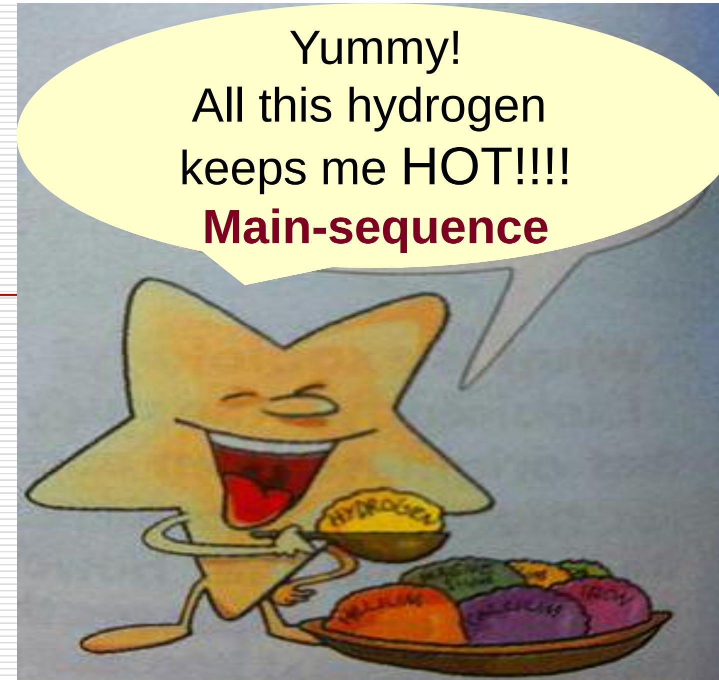
Introduction

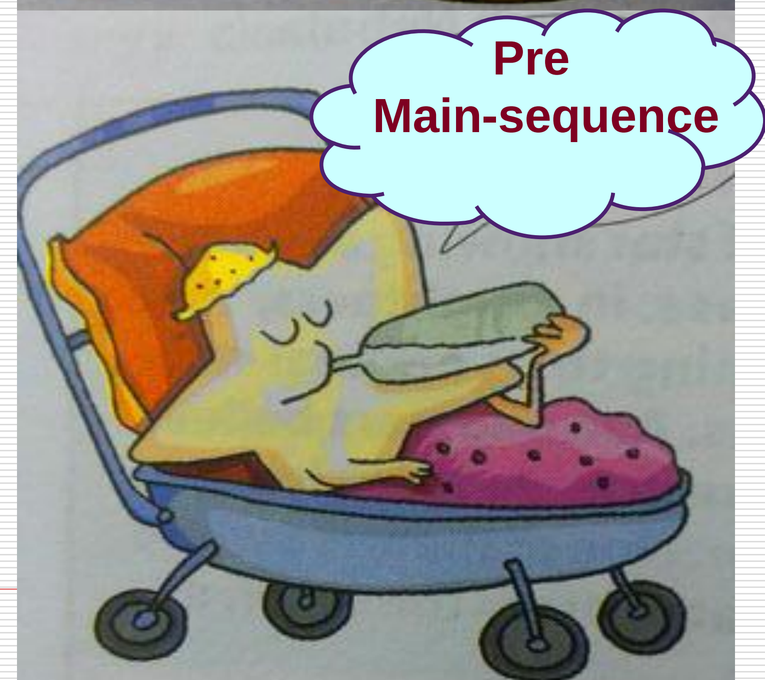
Stars	Structure	X-ray
Massive (M> 10 M_{sun}) O - B Stars		Winds $L_x \sim 10^{-7} L_{bol}$
Intermediate (2<M<10 M_{sun}) A Stars		??? L_x absent ?
Low mass (M<2 M_{sun}) F to M Stars		Dynamo $L_x \sim V_{rot}^2$



Young Clusters
(age<100 Myr)

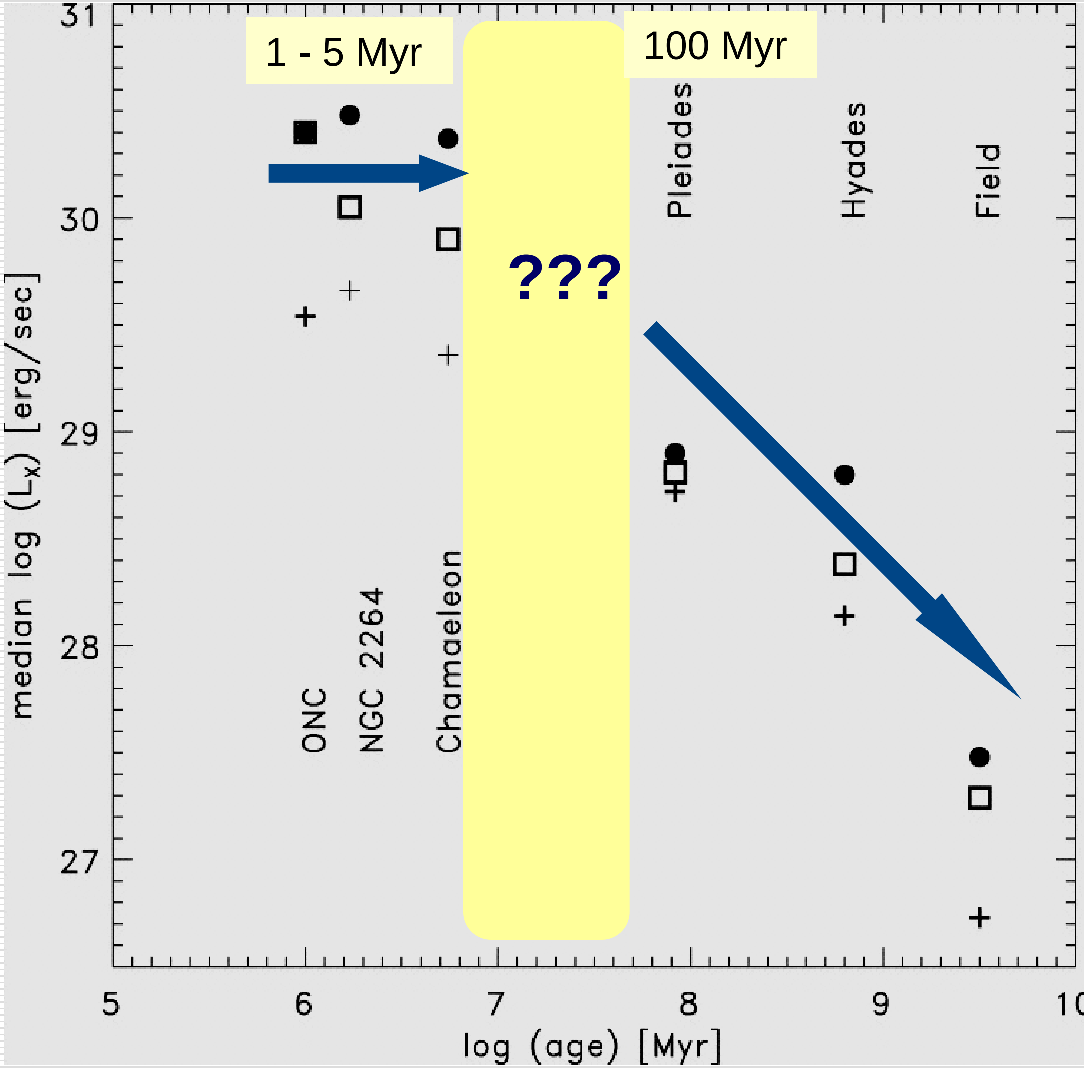






Evolution of X-rays

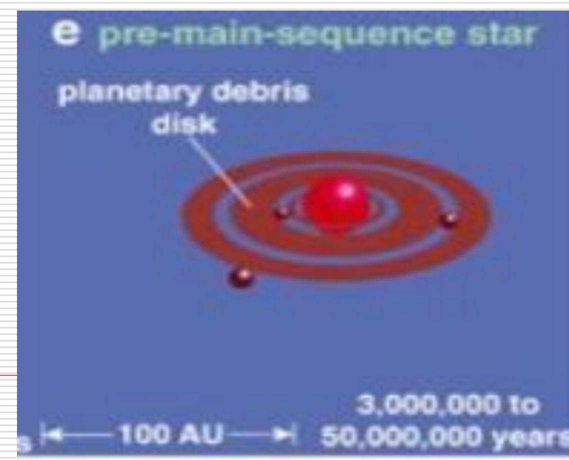
Chandra Orion Ultra deep Project (COUP): 13 days nearly continuous observation in 2003



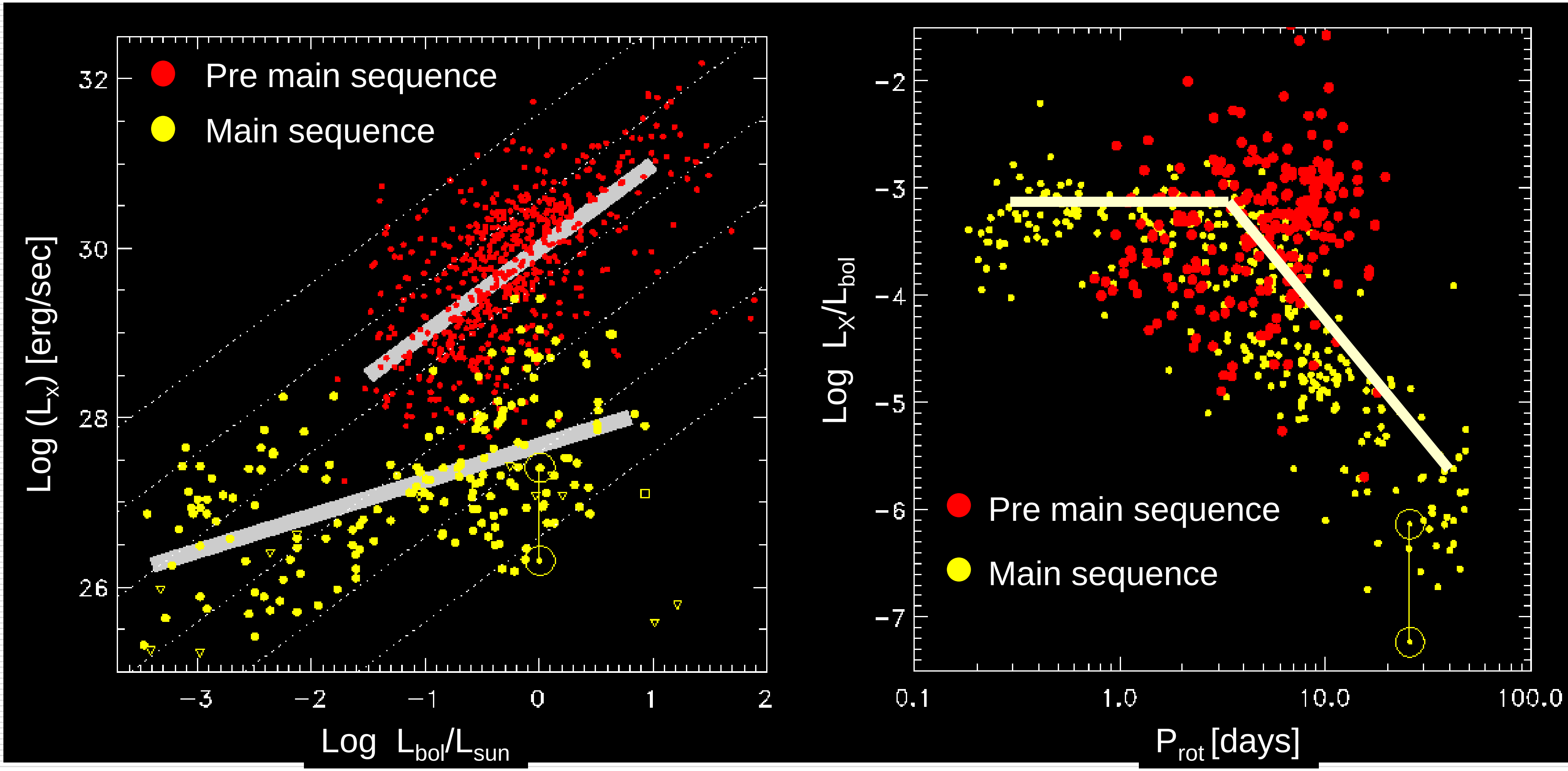
X-ray levels are roughly constant during Class I-II-III phases

…

but drop greatly on the main sequence



Preibisch & Feigelson (2005)



COUP (PMS) : $L_X \propto L_{bol}^{1.0}$

NEXXUS (MS) : $L_X \propto L_{bol}^{0.4}$

Schmitt& Liefke 2004

- **PMS :** **no activity - rotation relation**

even slow rotators are highly active

MS : $L_X \propto P_{rot}^{-2}$

- saturation at **log (L_X / L_{bol}) ~ −3**

for $P_{rot} \leq 3$ days

Thomas Preibisch

http://www.mpifr-bonn.mpg.de/staff/tpreibis/3-02-preibisch.pdf

Open Questions ????

Low Mass Stars

- Not clear exactly at which stage of the PMS stellar evolution, low mass stars deviate from the X-ray saturation level.
- Which fundamental parameters govern their X-ray emission ?
- Flare-disk interaction during 5 to 50 Myr?

Intermediate mass Stars

- Possible mechanism of X-ray emission.
- Companion Hypothesis or presence of magnetic fields?

Sample Selection and Classification

understand the X-ray emission properties of Young Stars

4 – 50 Myr

NGC 7380, Berkeley 86, Hogg 15 : 4-8 Myr

NGC 663, NGC 869, NGC 884 : 12 -15 Myr

Trumpler 18 : 15-30 Myr

IC 2602 : 40-50 Myr

FOV : 30’ x 30’

Science Analysis software (SAS).

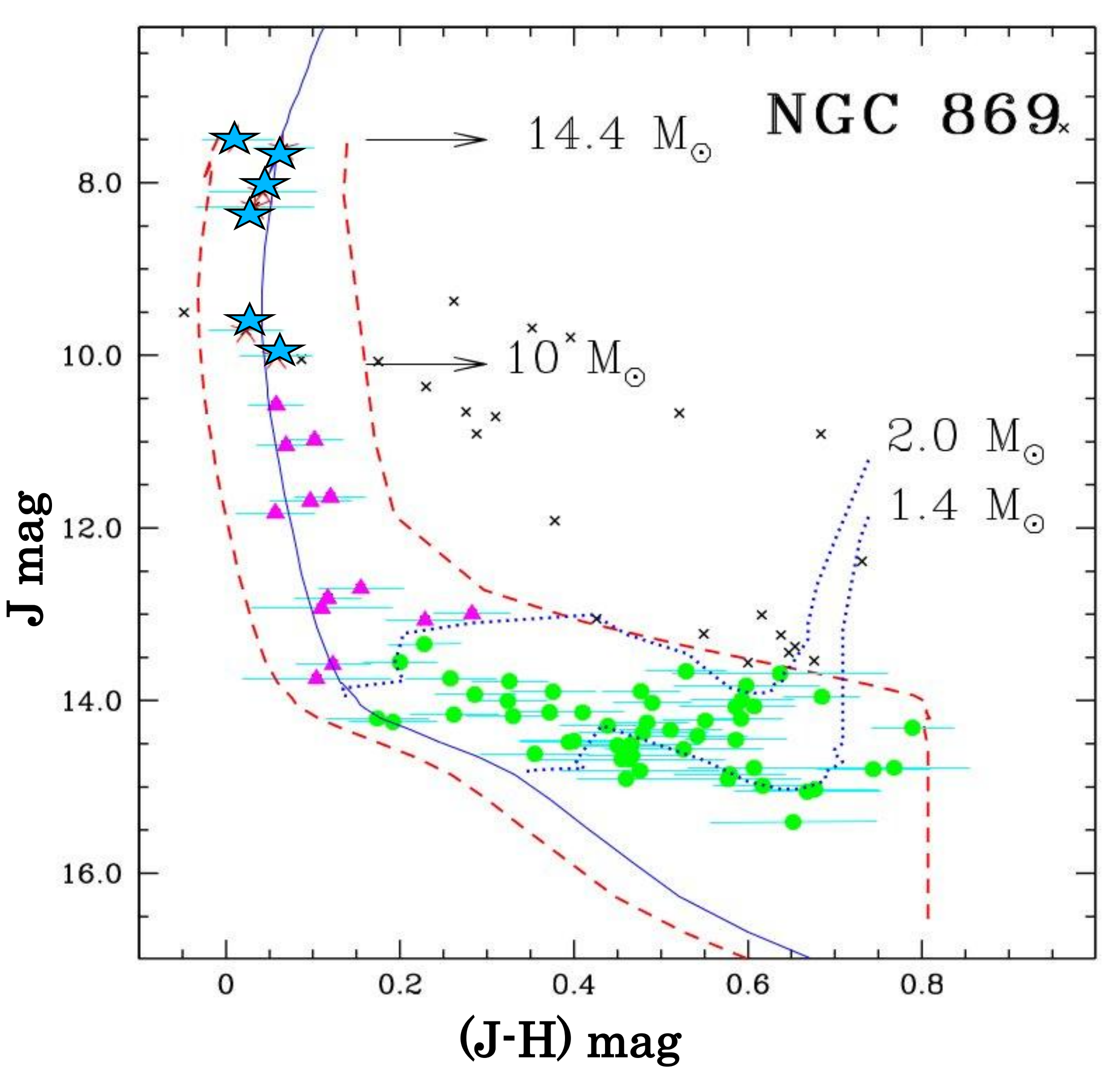
XMM-Newton Mission

Source Detection & Identification (edetect_chain; 0.3-7.5 keV)

Near Infrared (Two micron all sky survey; 2MASS;Cutri et al. 2003)

	Name	X-ray Sources	NIR	Unidentified
1.	NGC 663	85	48	36 (42%)
2.	NGC 869	183	130	70 (38%)
3.	NGC 884	147	61	67 (45%)
4.	NGC 7380	88	60	26 (29%)
5.	Be 86	95	82	8 (8%)
6.	IC 2602	95	55	39 (41%)
7.	Hogg 15	124	88	34 (27%)
8.	Trumpler 18	208	167	38 (18%)

Color-magnitude diagrams : Classification



Sample :

Low mass Stars
($<2M_{sun}$) : 152

Intermediate mass stars
(2-10 M_{sun}) : 36

Massive stars
(>10 M_{sun}) : 16

Analysis

Timing
(for all the stars)

Flares from 6 stars

Intermediate mass : LAV 796 (B7)
LAV 1174 (B9)

Low mass PMS : SHM2002 3734 (A7)
V553 Car (M4)
V557 Car (G0)
2MASS02191082+5707324 (K5)

Spectral
(counts > 40)

The stars with different masses

1T Apec model

N_H is fixed to the extinction for the open cluster.

Massive Stars :

$\mathrm{Log}(L_x) = 31\text{-}35$ erg s^{-1}

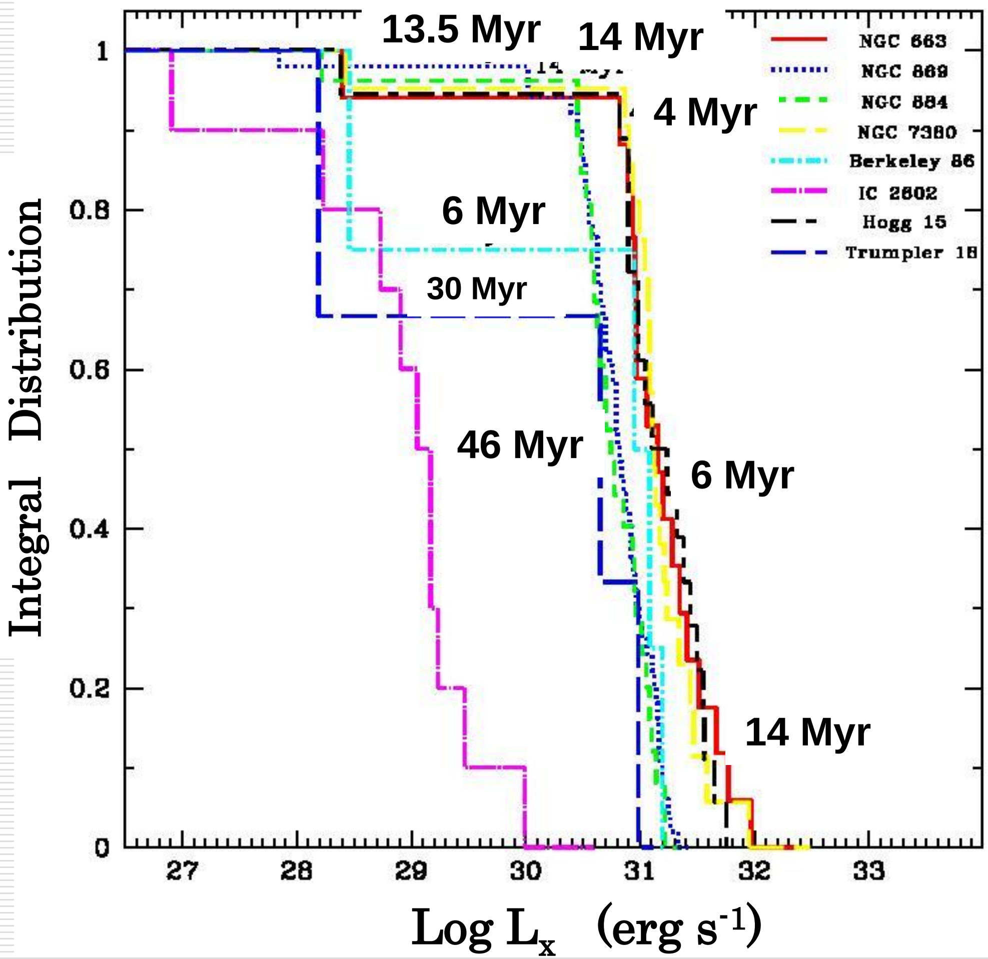
$\mathrm{Log}(L_x/L_{bol}) = -6.9 \pm 0.3$

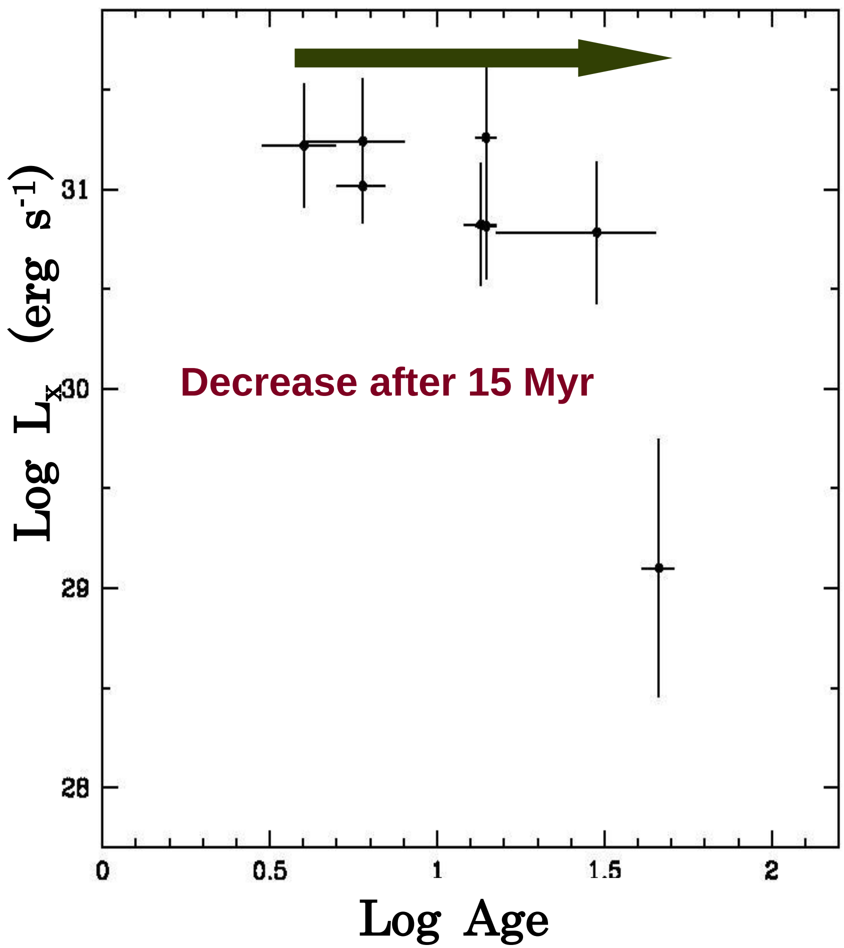
Low mass stars

Quiescent state

Plasma temperatures :
0.2 – 3.0 keV

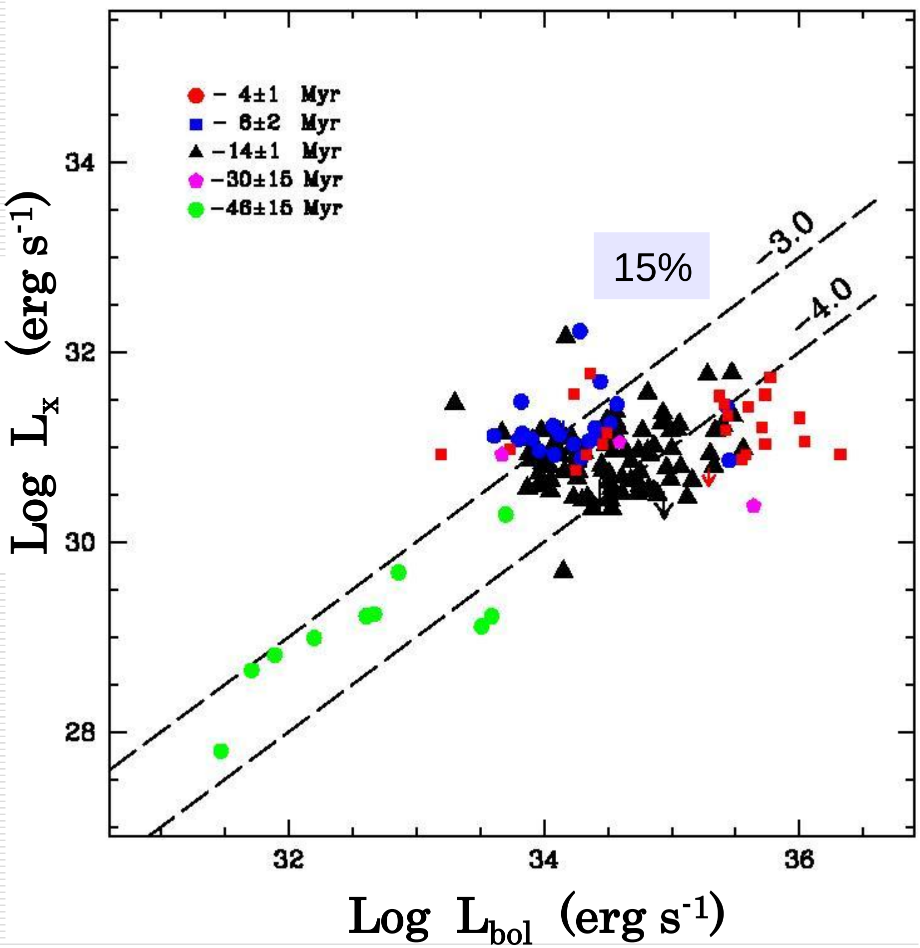
Appears to be constant during 4 to 46 Myr (**median value ~1.3 keV**)



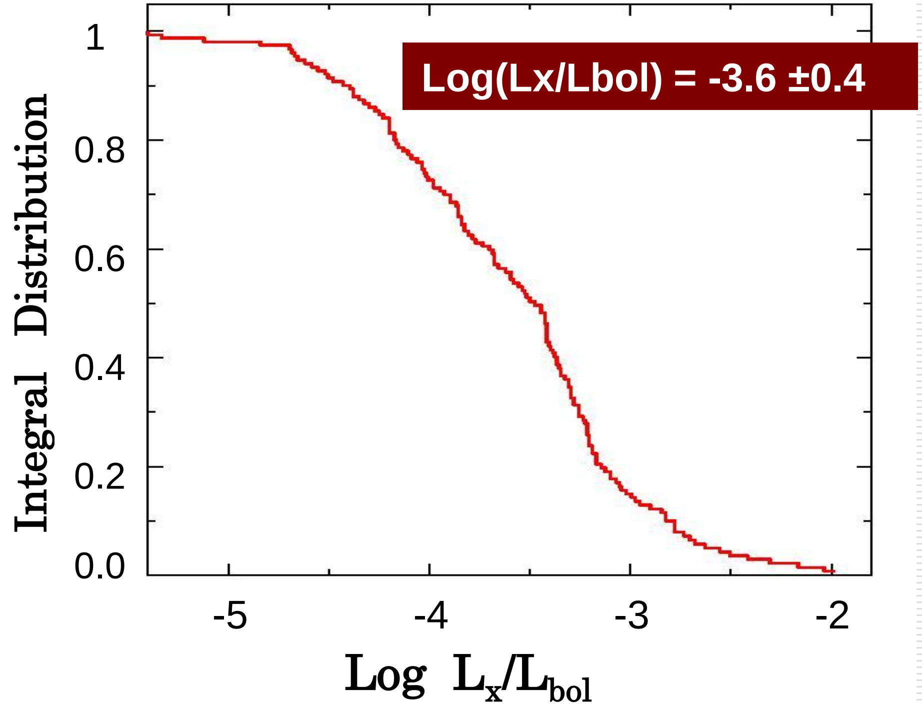


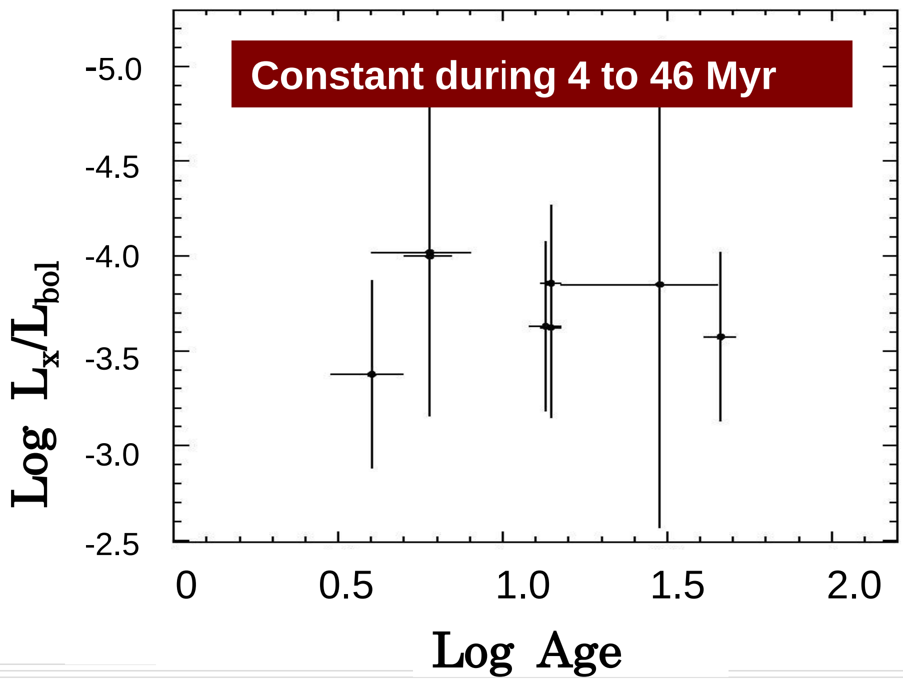
Low mass stars

Quiescent state



Come out from saturation before 4 Myr





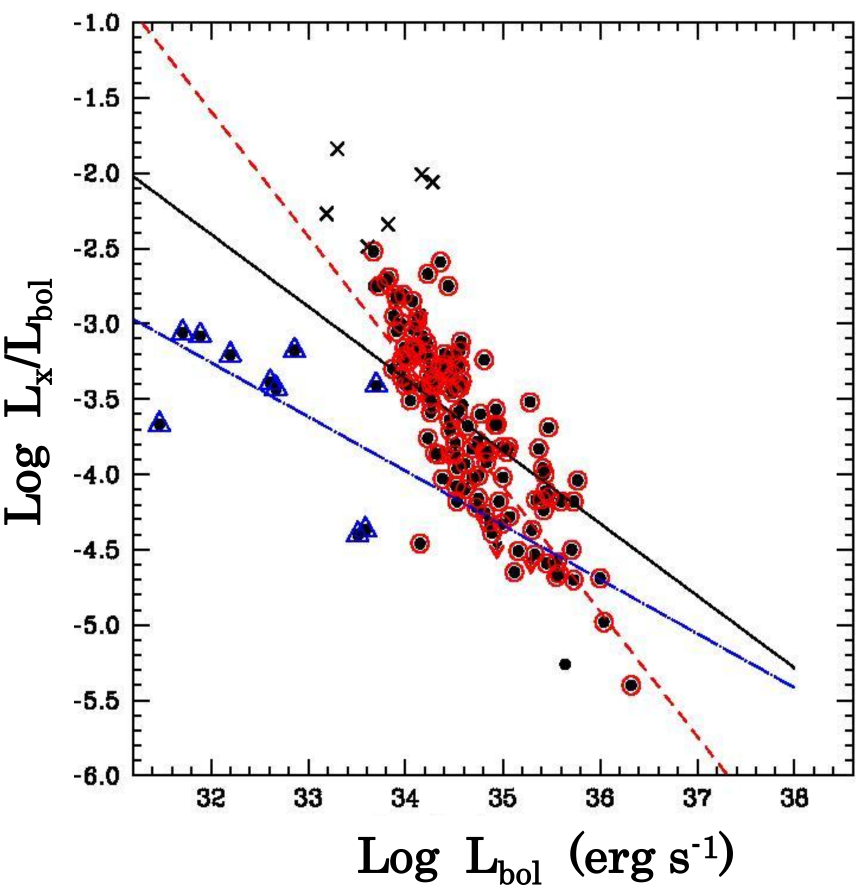
Low mass stars

Quiescent state

$L_x/L_{bol} \propto L_{bol}^{-0.48\pm0.05}$ All stars

$L_x/L_{bol} \propto L_{bol}^{-0.83\pm0.05}$ For 4 to 14 Myr

$L_x/L_{bol} \propto L_{bol}^{-0.36\pm0.17}$ For 46 Myr



Lx/Lbol depends upon Lbol.

As low mass stars evolve to MS, their effective temperatures eventually increase and the depth of their convective envelopes reduce, therefore their L_{bol} changes

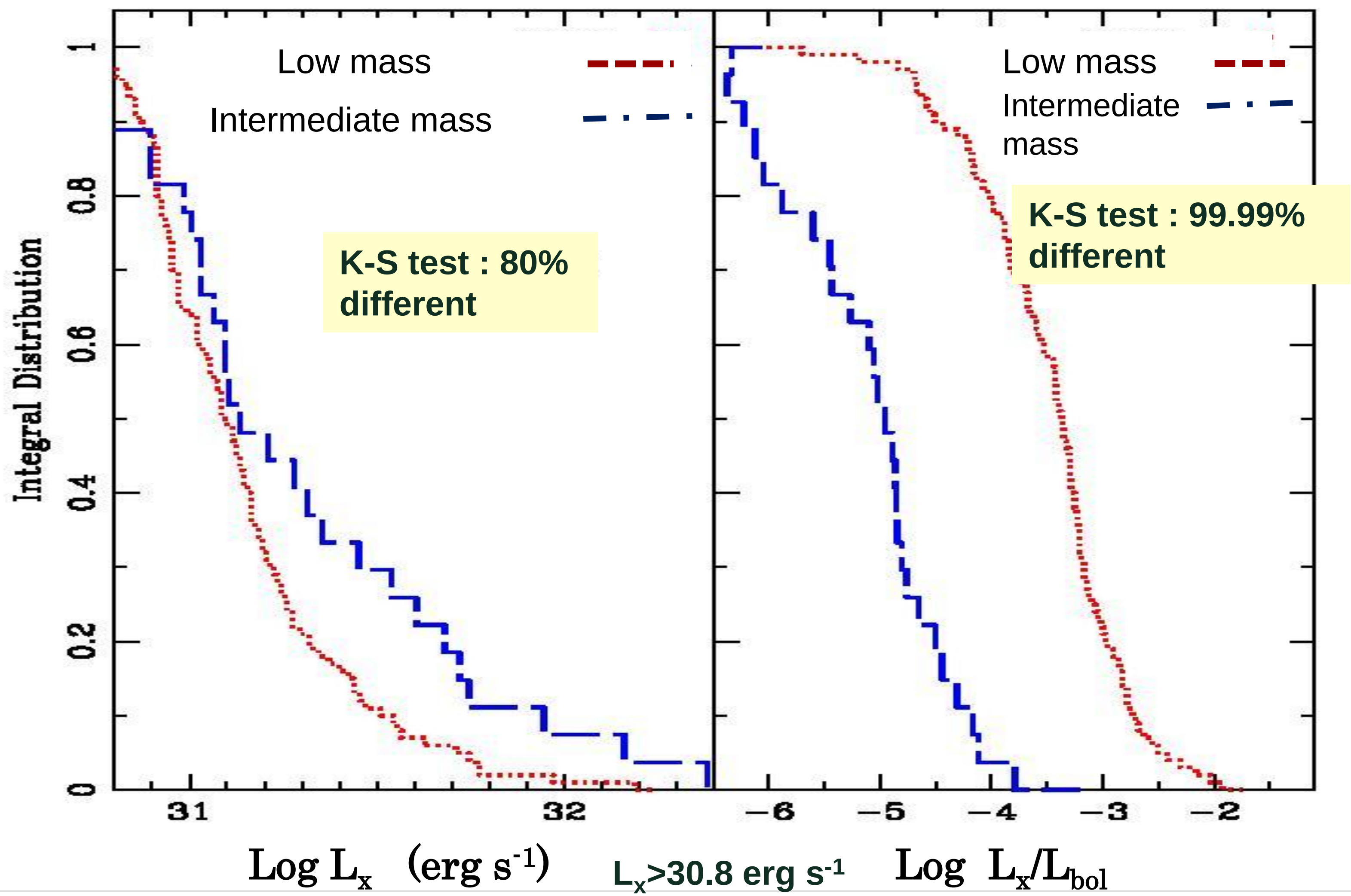
During 4 Myr to 46 Myr, the L_{bol} increases nearly three times.

This increase in L_{bol} can produce a decrease of nearly one third in (L_X/L_{bol}) (0.5 dex in log scale)

Such a variation cannot be distinguished using present data because the standard deviation in log(L_X/L_{bol}) is comparable with the decrease of **0.5 dex.**

Intermediate mass stars

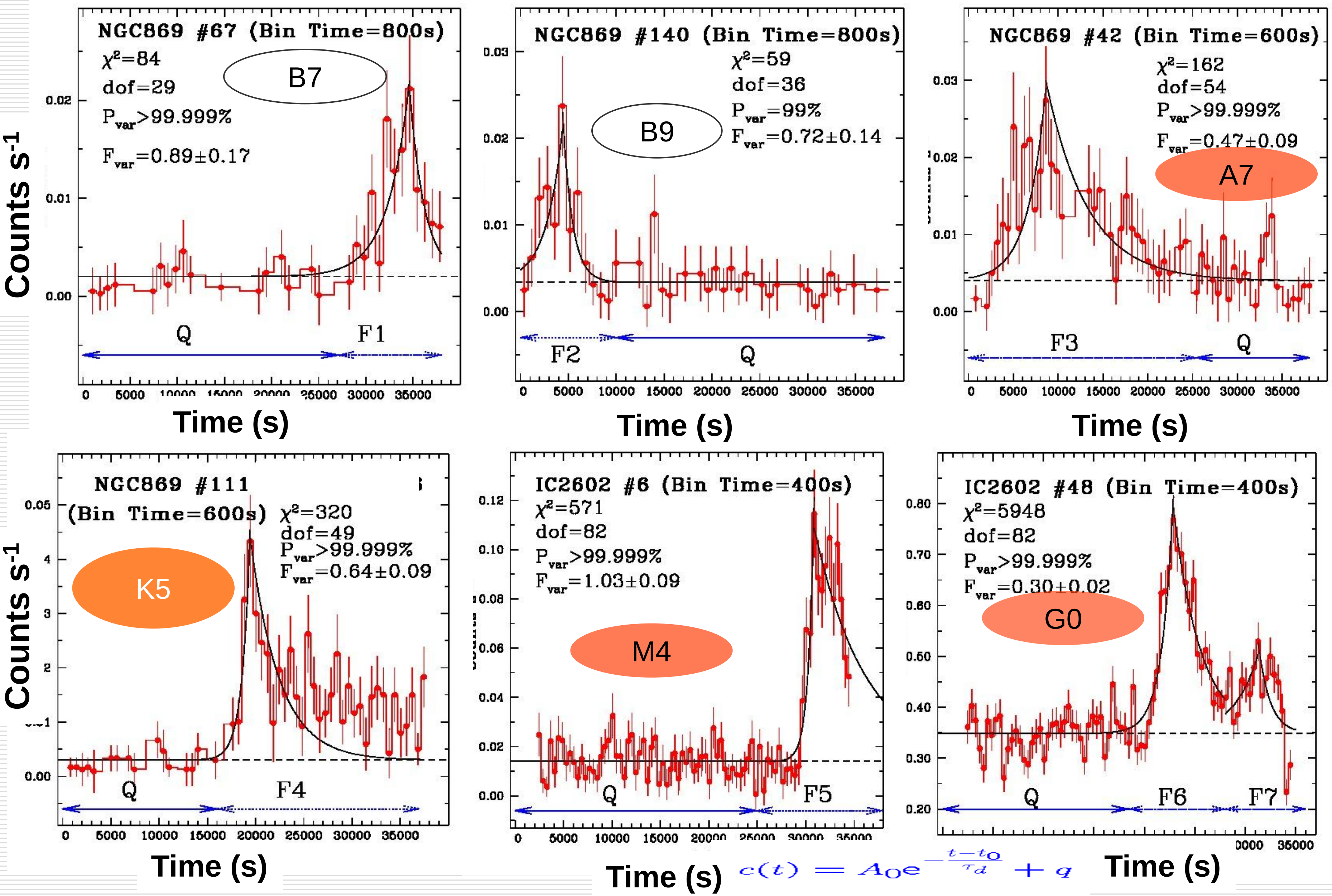
Quiescent state



L_x>30.8 erg s^{-1}

If intermediate mass stars themselves emit X-rays, they possess weaker dynamo

Timing Analysis : Flares



$$c(t) = A_0 e^{-\frac{t-t_0}{\tau_d}} + q$$

X-ray flare characteristics

Rise time in the range of 10-40 minutes

Cluster	ID	Name	FN	Start Time (ks)	Duration (ks)	T_r (ks)	T_d (ks)	Quiescent (cts s^{-1})
NGC 869	67	LAV 796	F1	27.0	11.0	2.3±0.5	1.6±0.4	0.002± 0.001
NGC 869	140	LAV 1174	F2	0.0	10.0	1.7±0.7	1.0± 0.3	0.003± 0.002
NGC 869	42	SHM2002 3734	F3	0.0	25.0	2.0±0.7	4.6± 0.6	0.004± 0.003
NGC 869	111	2MASS 02191082+ 5707324	F4	16.0	21.0	0.8±0.1	3.0± 0.9	0.003± 0.002
IC 2602	6	V553 Car	F5	24.8	13.2	0.6±0.1	5.3± 1.7	0.014± 0.007
IC 2602	48	V557 Car	F6	18.4	9.6	1.1±0.2	2.7± 0.2	0.349± 0.036
IC 2602	48	V557 Car	F7	28.0	8.0	2.3±1.1	1.1± 0.9	0.349± 0.036

Decay time in the range of 20-90 minutes

Spectral characteristics

Temperature

- Flaring state → 1.5 – 7.5 keV
- Quiescent state → 0.5 – 1.3 keV

Temperature increases during flaring state

Luminosity

Log L_X (erg s^{-1})

- Flaring state → 30.0 - 31.7
- Quiescent state → 29.2 – 31.0

An increase of nearly 5 times in X-ray luminosity.
Maximum increase : 16.6 times in F4 flare

These flares are **more powerful than those observed from field stars** but equally powerful as the flares from PMS stars in Orion (Getman et al. 2008)

Loop Parameters :

Haisch (1983) approach

Rise and decay method (Hawley et al. 1995)

Using the spectral parameters during flaring state and estimated values of rising and decay times

Semi Loop lengths : : 2 - 4 (10^{10} cm)

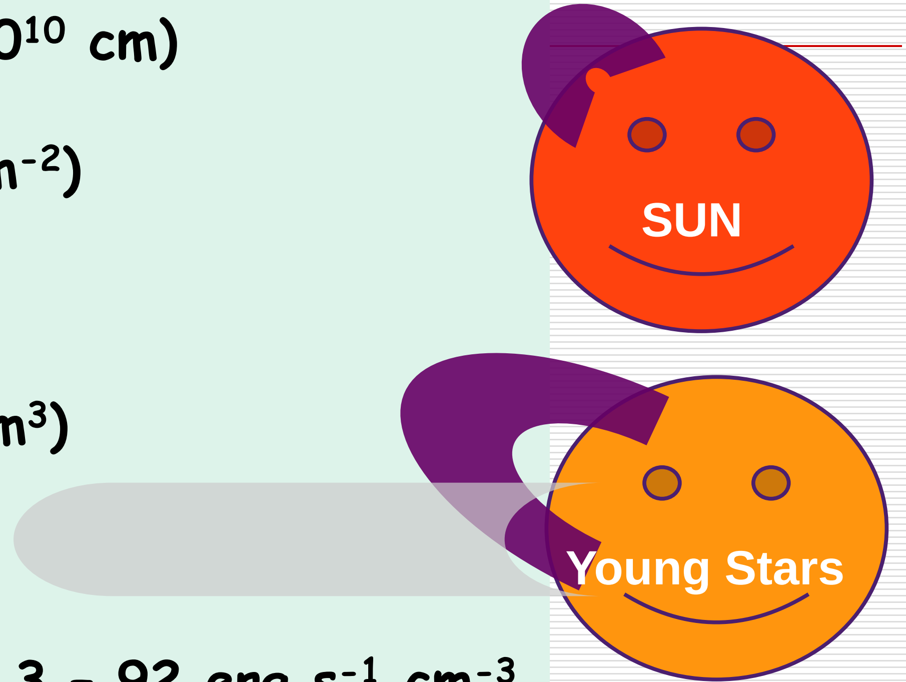
Pressure : 1.5 – 87 (10^{3} dyne cm^{-2})

Density : 0.5 – 15 (10^{11} cm^{-3})

Loop Volume : 1.3 – 570 (10^{30} cm^{3})

Magnetic field : 100 – 1200 (G)

Heating rate per unit volume : 0.3 – 92 erg s^{-1} cm^{-3}
(at flare peak)



- X-ray flares from young stars are enhanced analogs of eruptive solar Flares
- Can interact with Disk around stars
- No significant difference in loop parameters of intermediate & low mass stars.

Conclusions

PMS Low mass

(a) Plasma temperatures in the range of 0.2-3 keV, irrespective of their ages.

(b) The observed XLFs of low mass stars from 4 to 14 Myr appear to be **similar**. **The decrease in Lx may occur during 14 to 100 Myr.**

(c) Nearly 85% of the stellar population deviate from the saturation level, **deviation of low mass stars from X-ray saturation may occur before the age of 4-8 Myr.**

(d) The L_x/L_{bol} correlate with their L_{bol}, shows **its dependence on the internal structure of stars.**

(e) **Semi loop lengths of coronal structure** are found to be of order **of 10^{10} cm**, which may interact with the disk around the PMS stars and may affect the planet formation process during 4 to 50 Myr.

Intermediate mass stars

(a) **No statistically significant difference in Lx from intermediate mass and low mass PMS stars.**

(b) The observed L_x/L_{bol} for intermediate mass stars are found to be significantly lower than that of low mass stars.

(c) But, the possibility of companion hypothesis can not be examined because of the limited resolution of XMM-Newton.

(d) Coronal loops which are involved for the X-ray flares from intermediate mass stars are **similar** to that of low mass stars.

Thanks

This work is recently published in

(1) Himali Bhatt et al., 2013 Journal of Astrophysics & Astronomy, vol. 34, 393-429

(2) Himali Bhatt et al., 2014 Journal of Astrophysics & Astronomy, vol. 35, 39-54