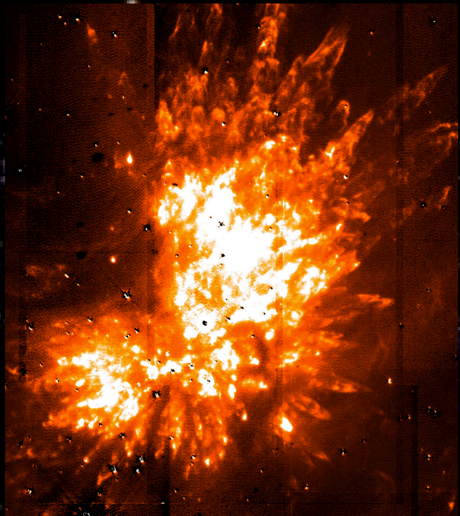


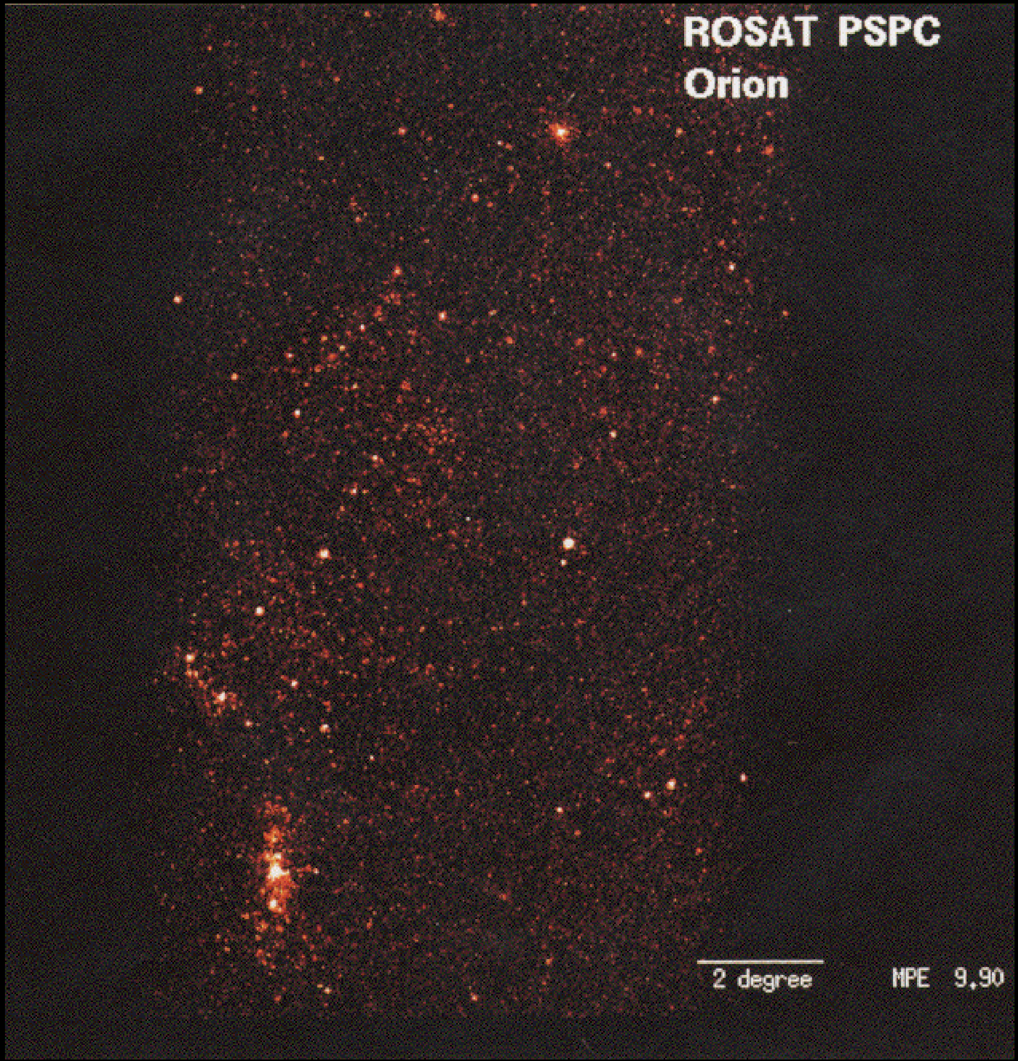
Active stars:
a laboratory for particle acceleration

Thierry Montmerle
Laboratoire d'Astrophysique de Grenoble

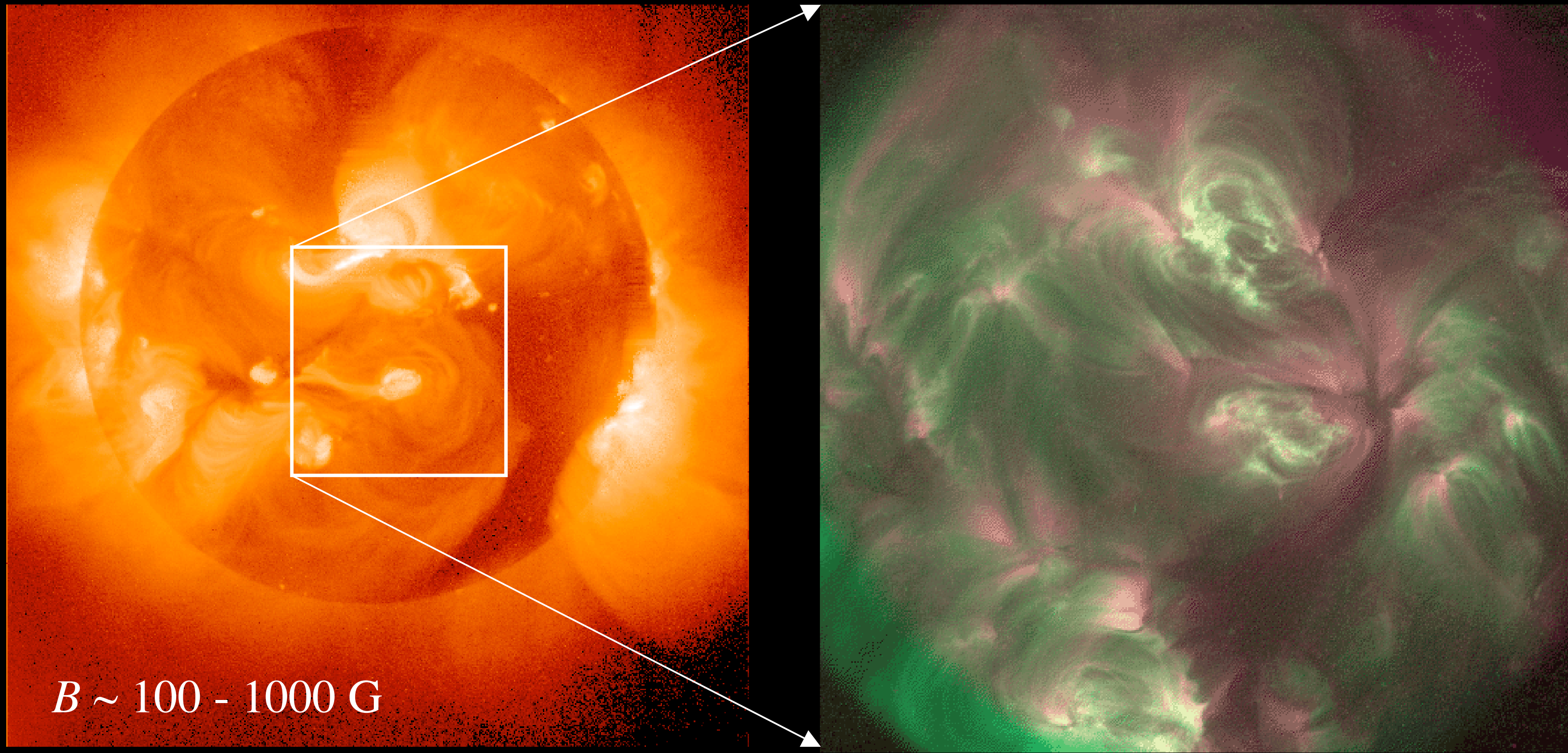
1. Why ?

- *Main tracer of activity: X-rays*
  - Almost all stars in the HR diagram (except A stars), down to brown dwarfs, emit X-rays
  - Hot stars emit X-rays by shocks in massive, fast radiatively driven winds
  - Low-mass (~ solar) stars emit X-rays by plasma heating following magnetic reconnection events (flares) : “magnetic activity”
  - X-rays are *thermal* and soft (~ 1 keV)

The Orion (soft) X-ray sky



The Sun as a template

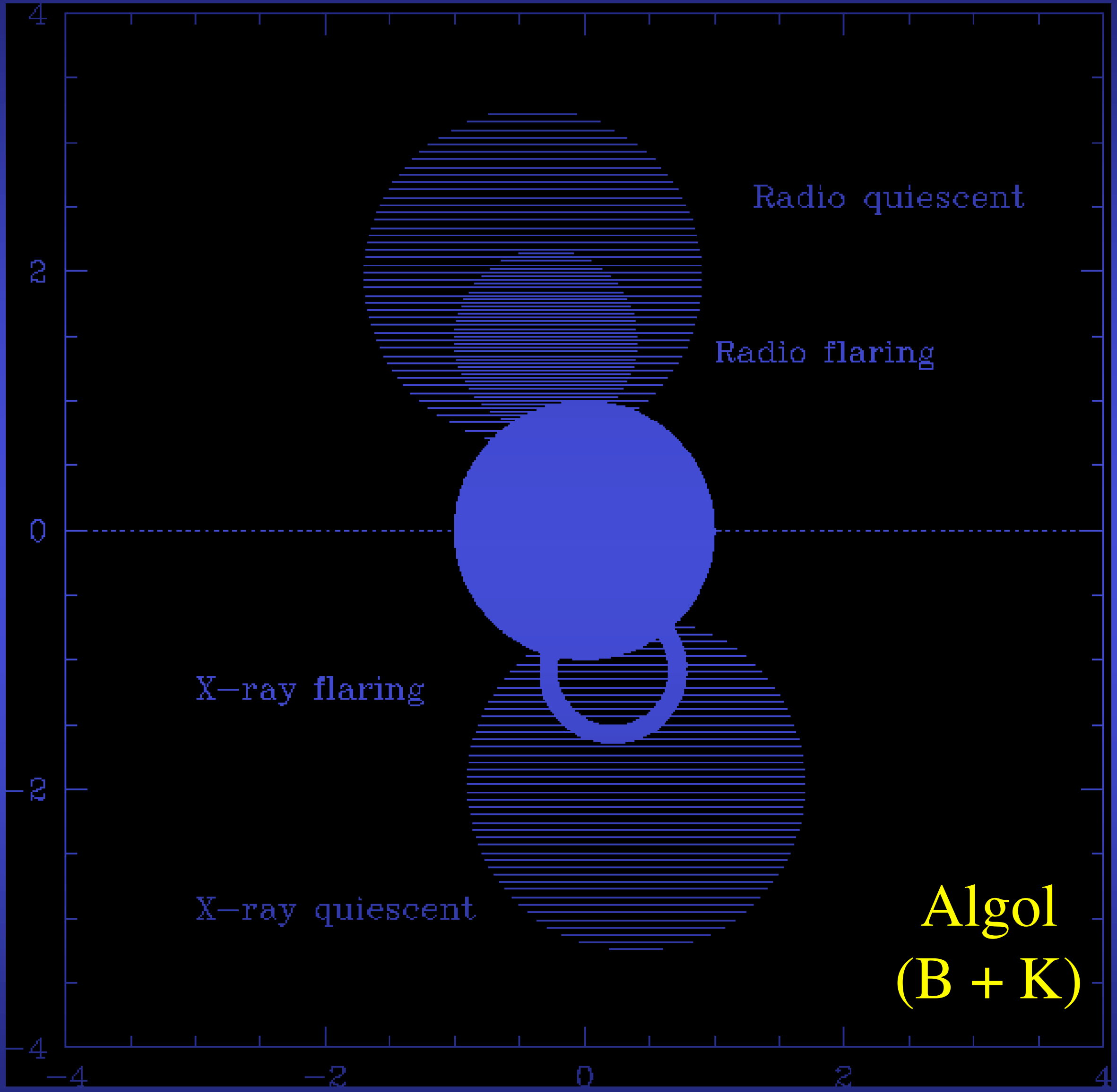


Yohko, soft X-rays

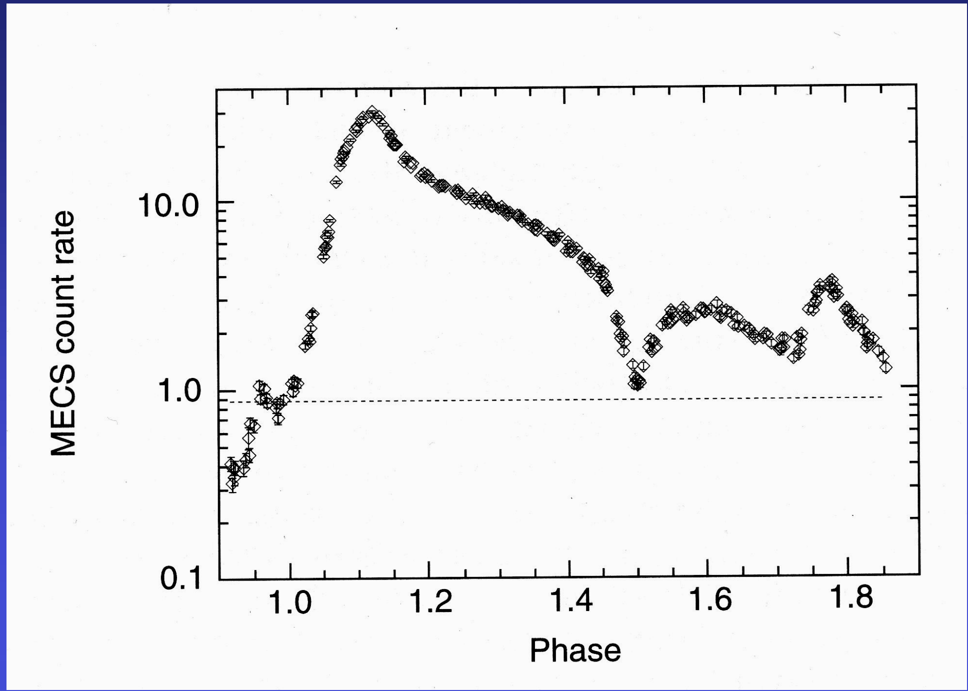
TRACE, far UV

2. Where ?

- *"Active stars" are late-type* and have L_X/L_{bol} up to ~ 10^{-3} (= 10^3 - 10^4 Sun)
  - Close binaries: RS CVn, Algol, etc.
  - Pre-main sequence stars ("T Tauri stars", protostars)
  - Late-type, "emission" stars (dMe)



Radio quiescent
Radio flaring
X−ray flaring
X−ray quiescent
Algol
(B + K)
4
2
0
−2
−4
−4
−2
0
2
4



The X-ray eclipse of Algol *(SAX)*

Schmitt & Favata 1999

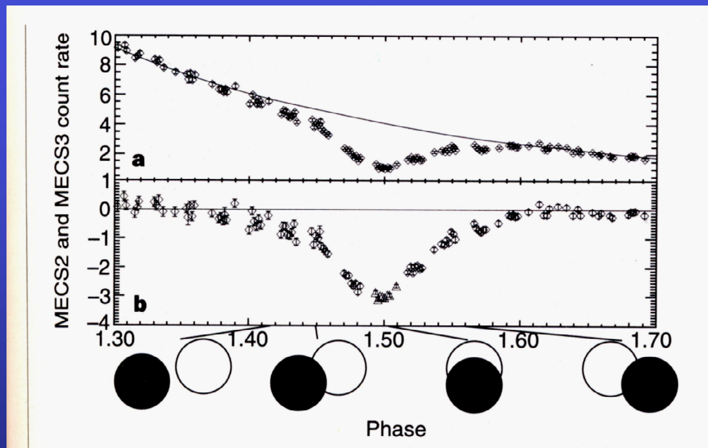
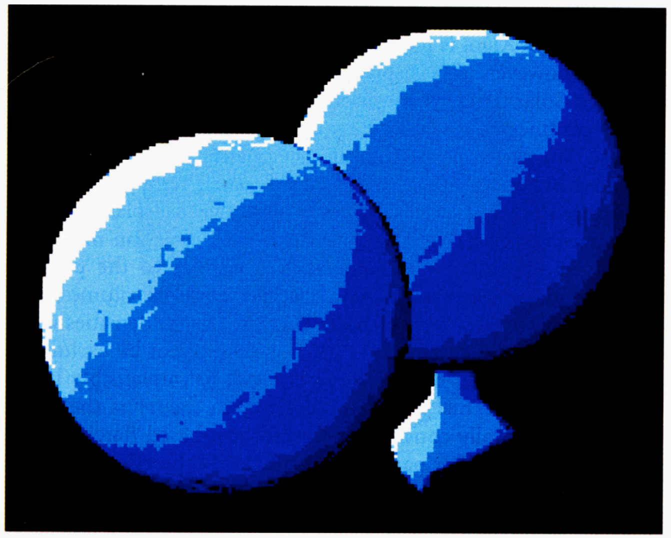
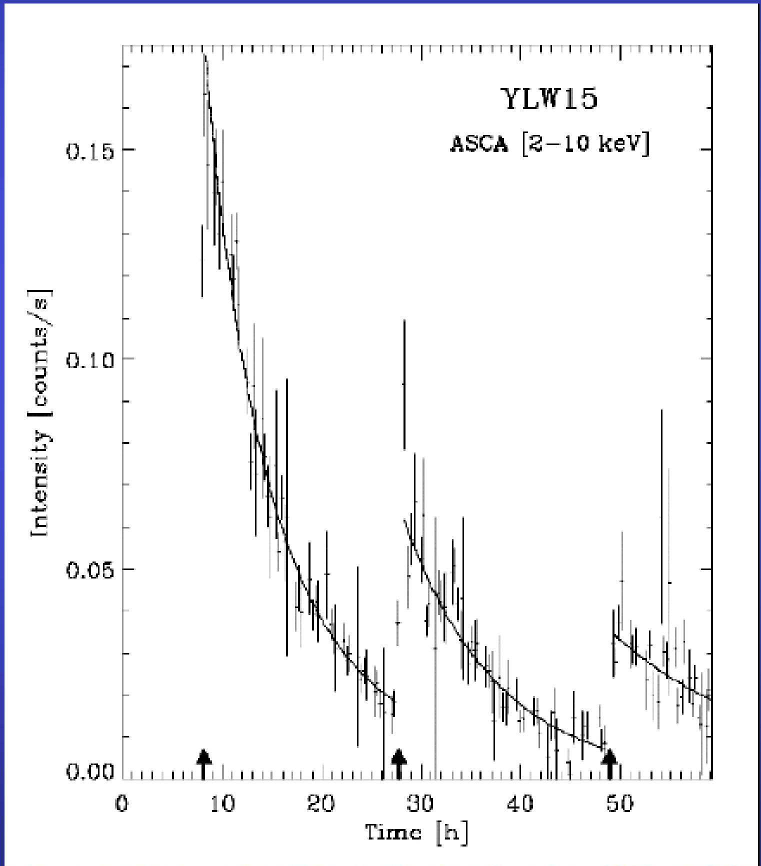
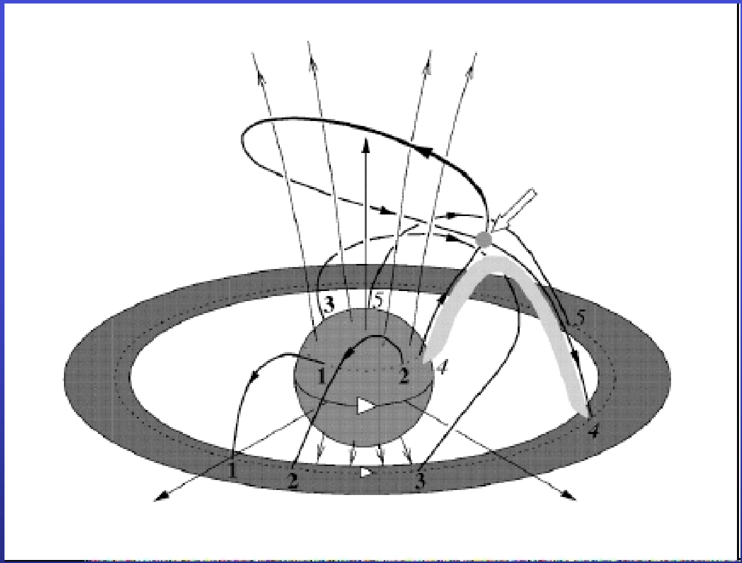


Figure 2 The MECS count rate versus phase in the interval 1.3–1.7. **a**, Count rate versus phase; the solid line represents an exponential fit to the pre- and post-eclipse light curve. **b**, Count rate versus phase in the interval 1.3–1.7 with exponential decay (shown in **a**) removed; the zero line is shown. The flare eclipse starts at $\phi \sim 1.39$ with a somewhat



The triple flare of the YLW15 protostar *(ASCA)*

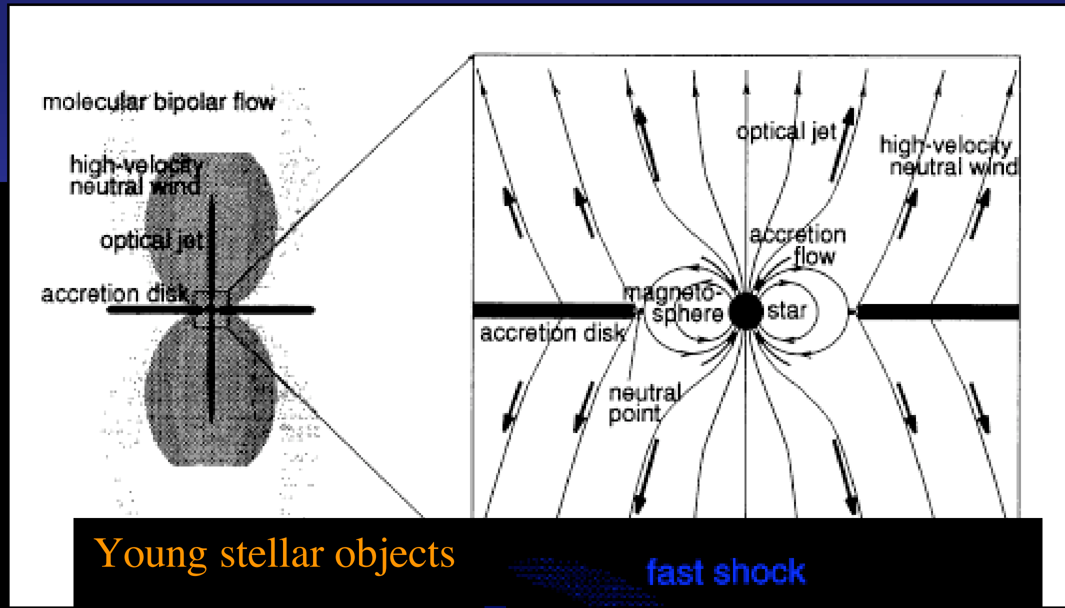


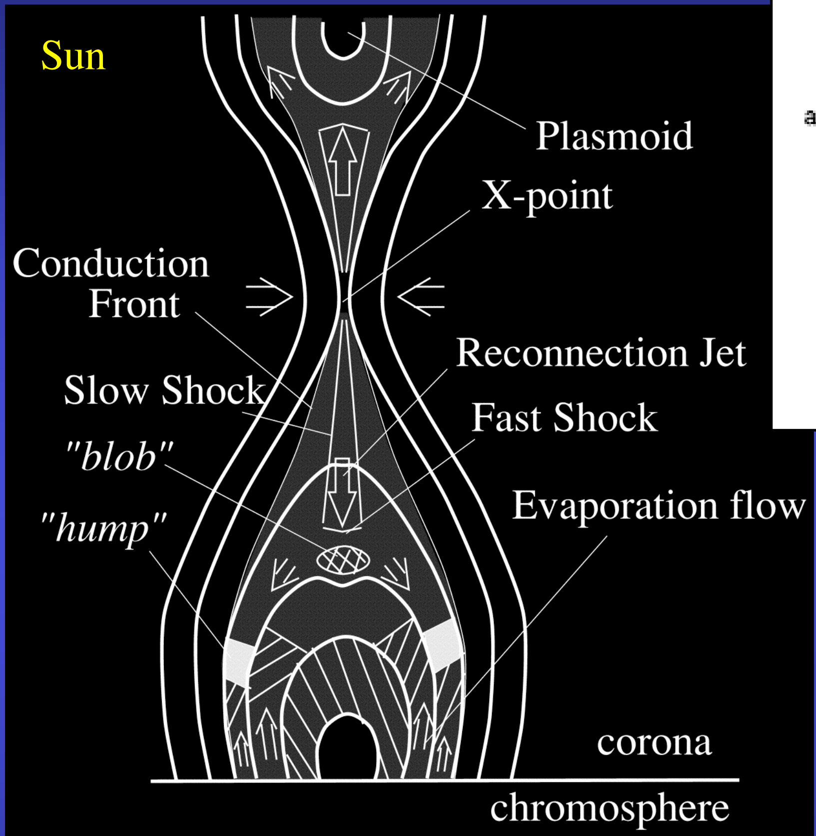


3. How ?

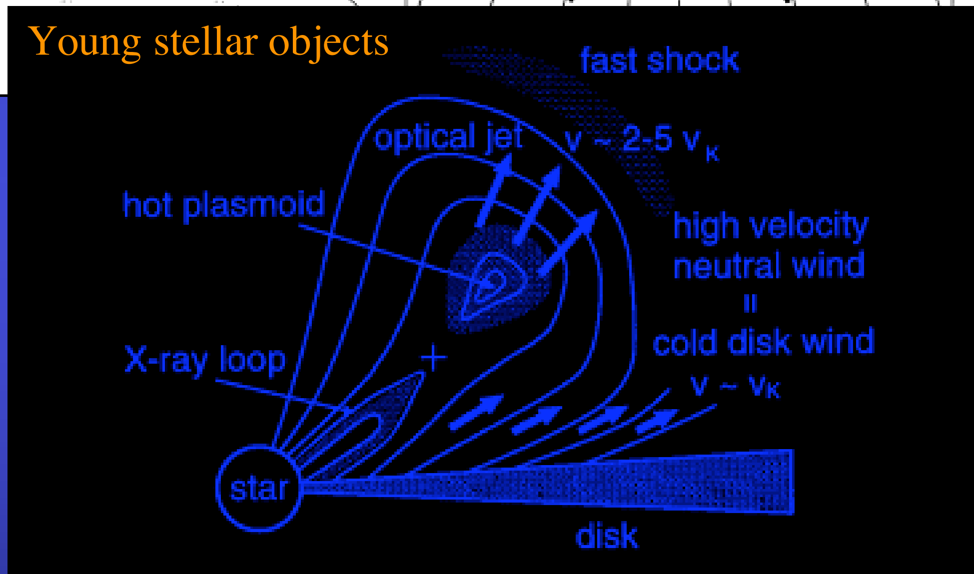
- Magnetic reconnection is the key mechanism for flare triggering
- Plasma heating by MHD-related electron acceleration, confined in magnetic field loops

(Hirose et al. 1997)





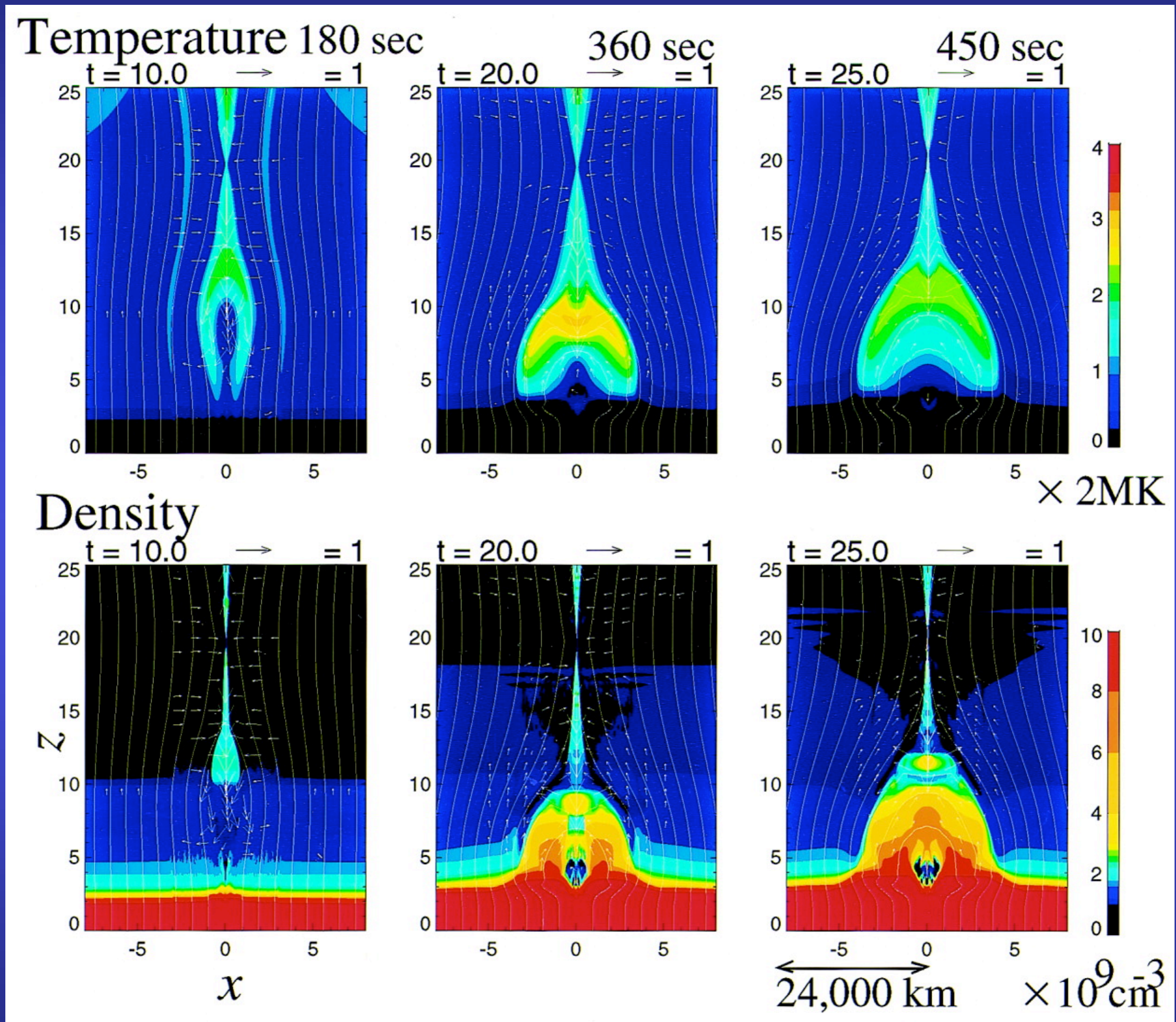
(Yokoyama & Shibata 2001)

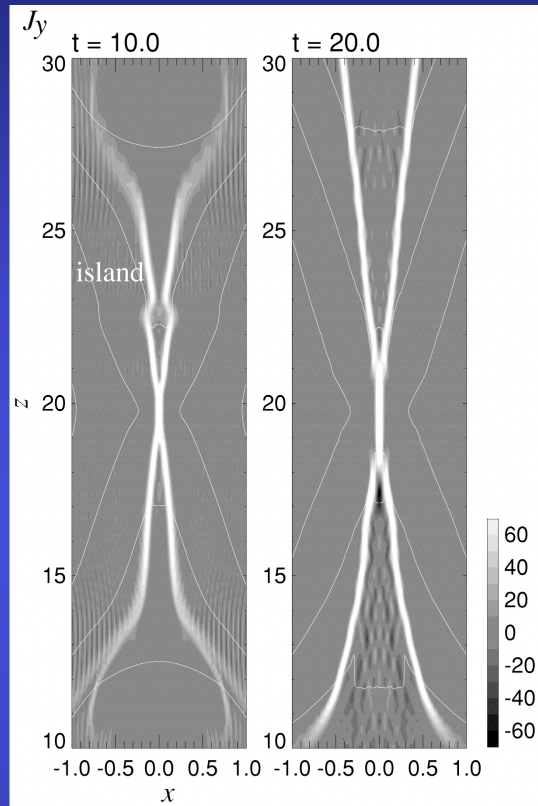


(Hayashi et al. 1996)

From solar models (Yohkoh) : reconnection => X-rays

(anomalous resistivity, + heat conduction & chromospheric evaporation)



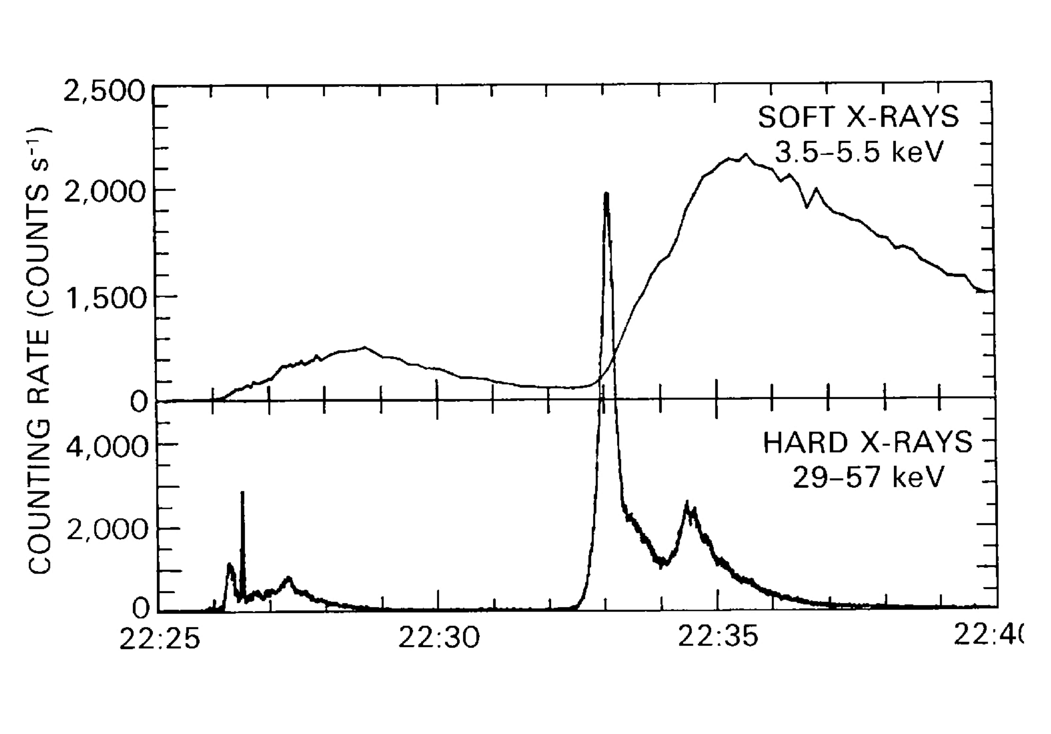


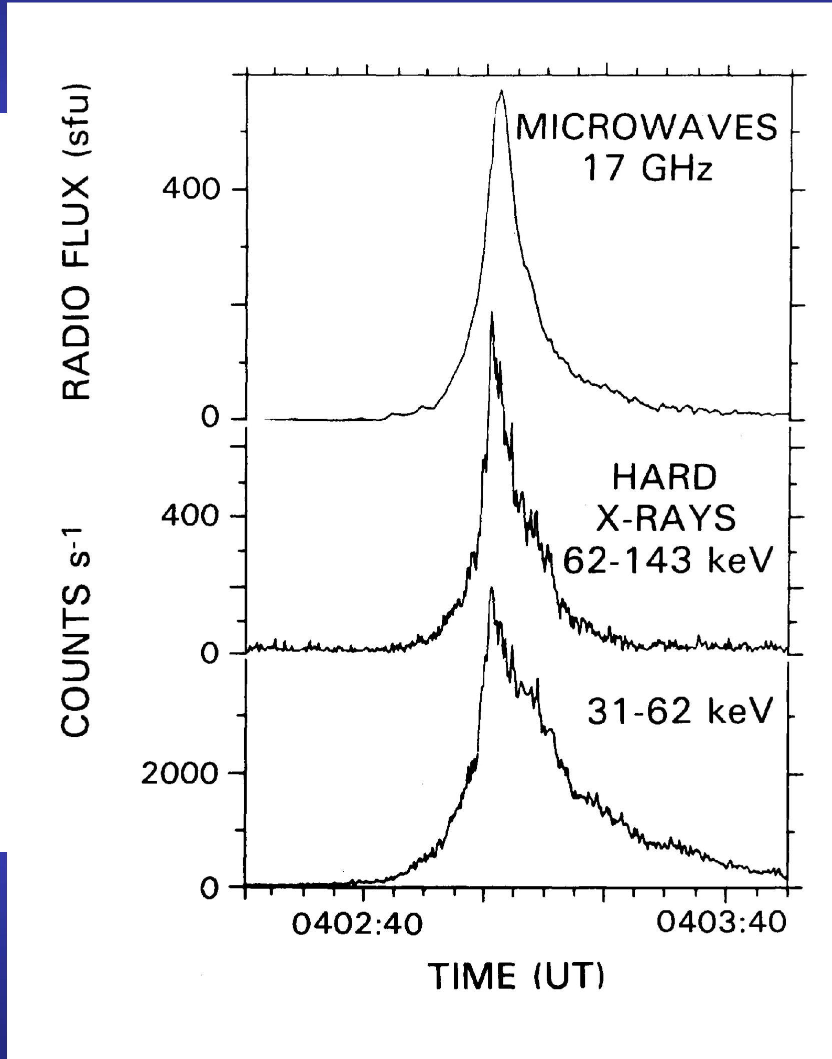
Solar flares

(Yokoyama & Shibata 2001)

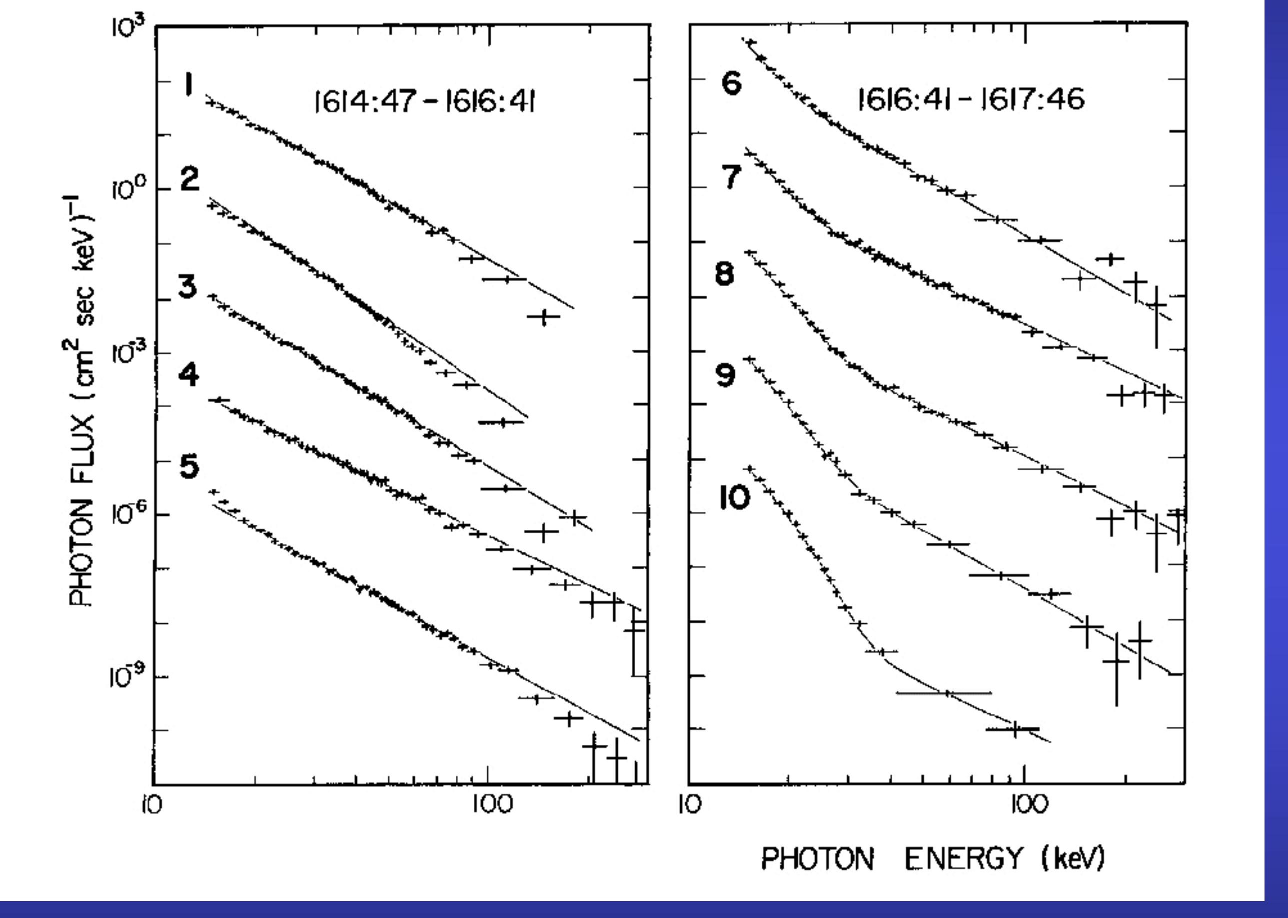
4. Towards Simbol-X

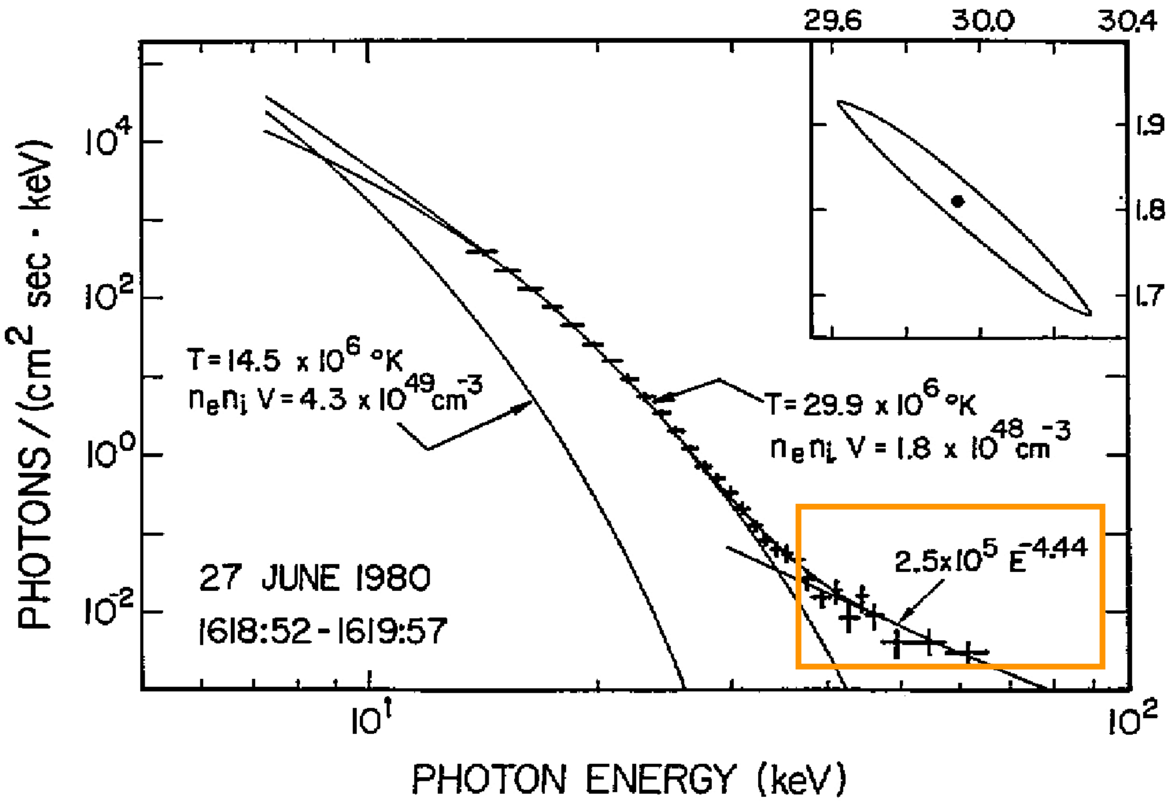
- Finding hard X-rays: direct access to particle acceleration & synchrotron emission
- Again, *solar template*
  - Non-thermal radio emission
  - Hard X-rays


SOFT X-RAYS
3.5–5.5 keV
HARD X-RAYS
29–57 keV
COUNTING RATE (COUNTS s-1)
2,500
2,000
1,500
0
4,000
2,000
0
22:25
22:30
22:35


MICROWAVES
17 GHz
HARD
X-RAYS
62-143 keV
31-62 keV
RADIO FLUX (sfu)
COUNTS s-1
400
0
400
0
2000
0
0402:40
0403:40
TIME (UT)

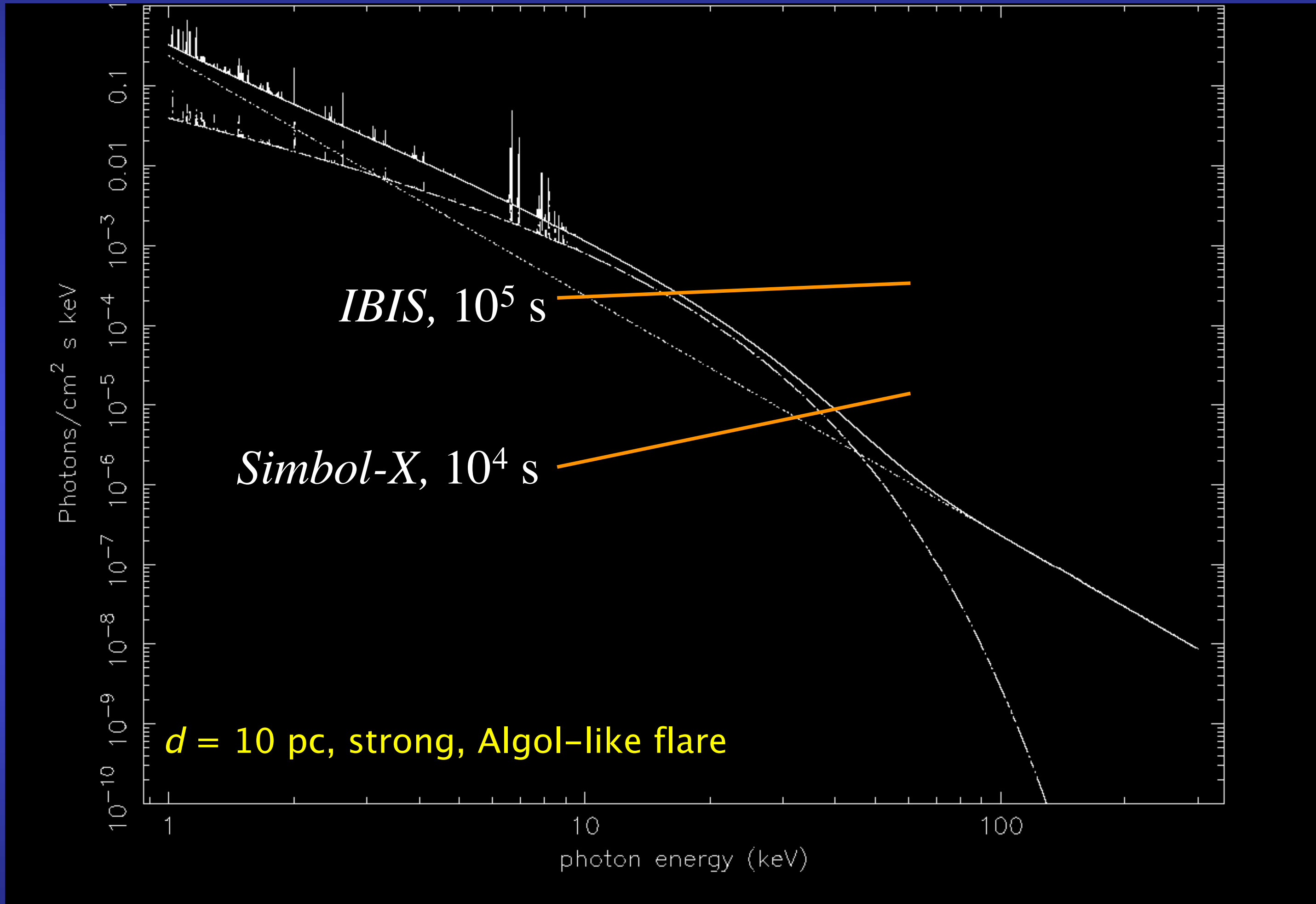
Solar flare spectra



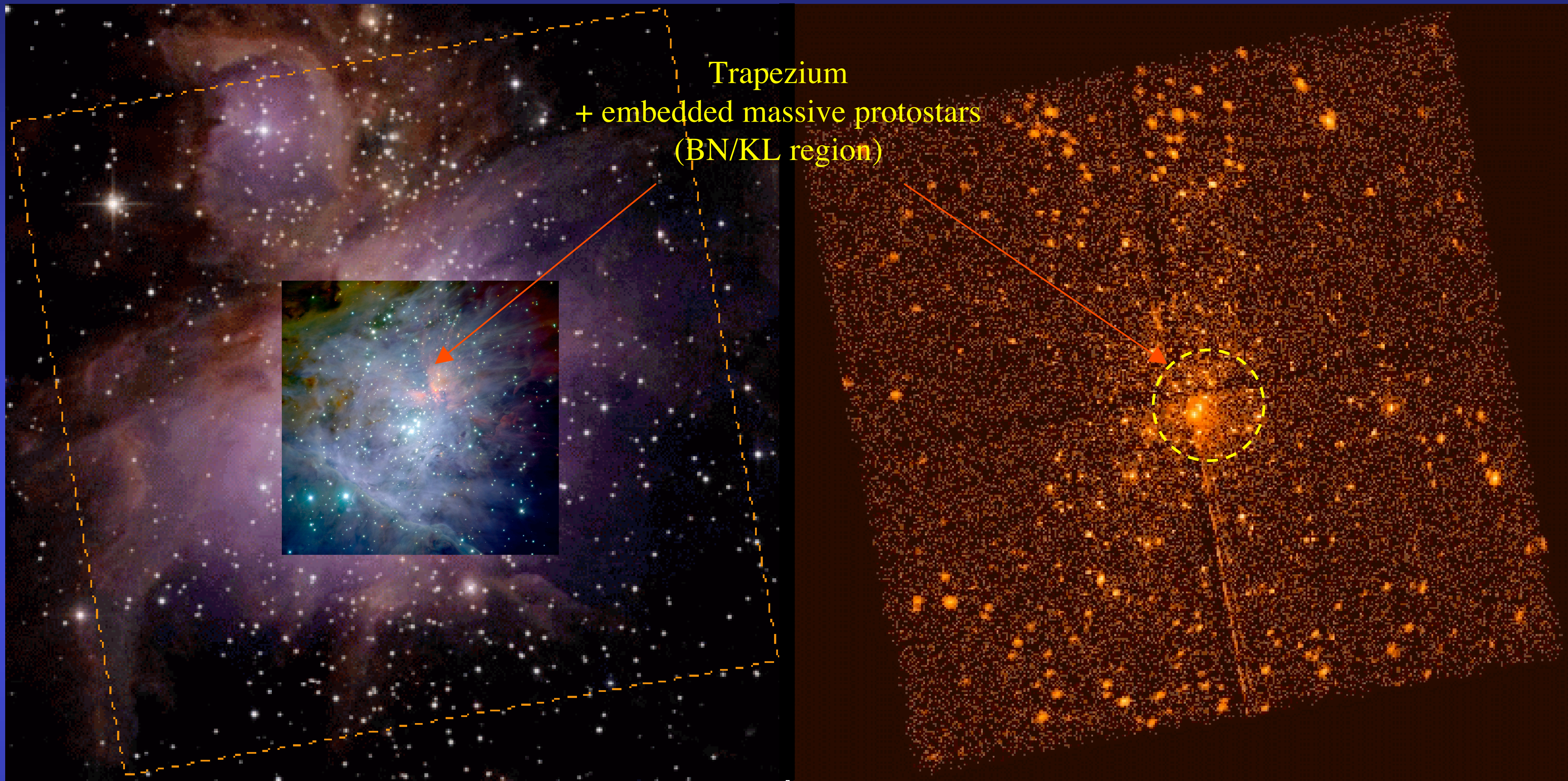


29.6
30.0
30.4
1.9
1.8
1.7
10^4
10^2
10^0
10^{-2}
PHOTONS / (cm^2 sec · keV)
T = 14.5 x 10^6 °K
$n_e n_i$ V = 4.3 x 10^{49} cm^{-3}
T = 29.9 x 10^6 °K
$n_e n_i$ V = 1.8 x 10^{48} cm^{-3}
2.5x10^5 E$^{-4.44}$
27 JUNE 1980
1618:52 - 1619:57
10^1
10^2
PHOTON ENERGY (keV)

Stellar flare model



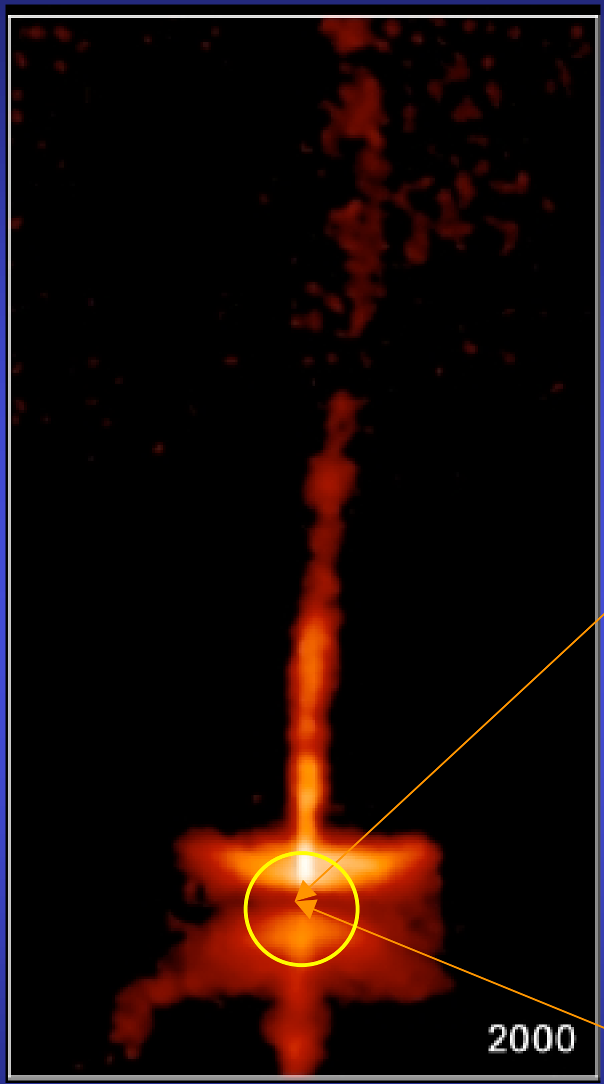
Star forming regions



Near IR image 2MASS + VLT **X-ray image** *Chandra* ACIS I : Garmire et al. 2000

Orion Nebula (M42) and Trapezium region (~ 17' x 17')

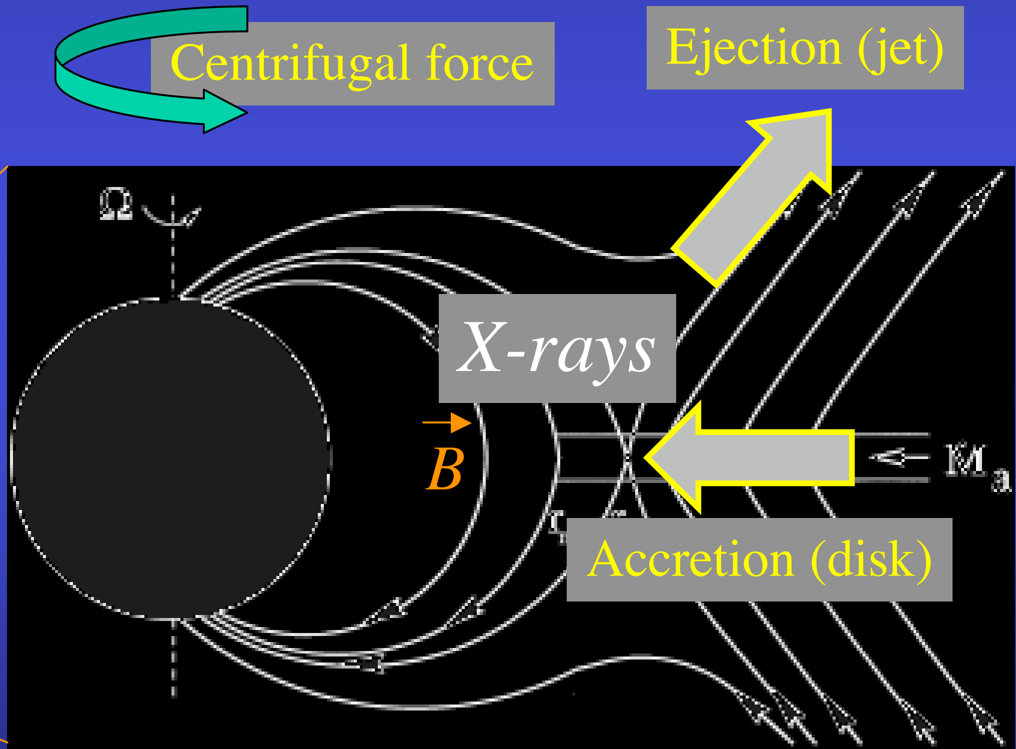
~ 1000 sources, $L_X \sim 10^{28}$ - 10^{32} erg s^{-1} (~ 10 - 10^5 $L_{X,\odot}$)



Protostars:

MHD modelling : coupling with magnetic fields

(e.g., J. Ferreira et al., 2001)



Problem with the youngest protostars (10^4 yrs):
high extinction ($>10^{24}$ cm^{-2}) => hard X-rays (non-thermal ?)

5. Conclusions

- *Simbol-X* has the potential to make detailed studies of *MHD acceleration processes:* stellar activity => laboratory for other magnetic/shock processes
- First opportunity to find whether very young (accreting) protostars actually emit X-rays: *impact on star formation* mechanisms, and even (perhaps) on the earliest stages of *planet* formation (ex.: large grains/planetesimals)