Flaring activity in accretion flows of Young Stellar Objects

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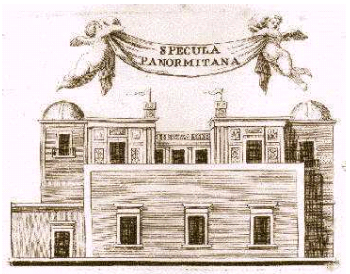

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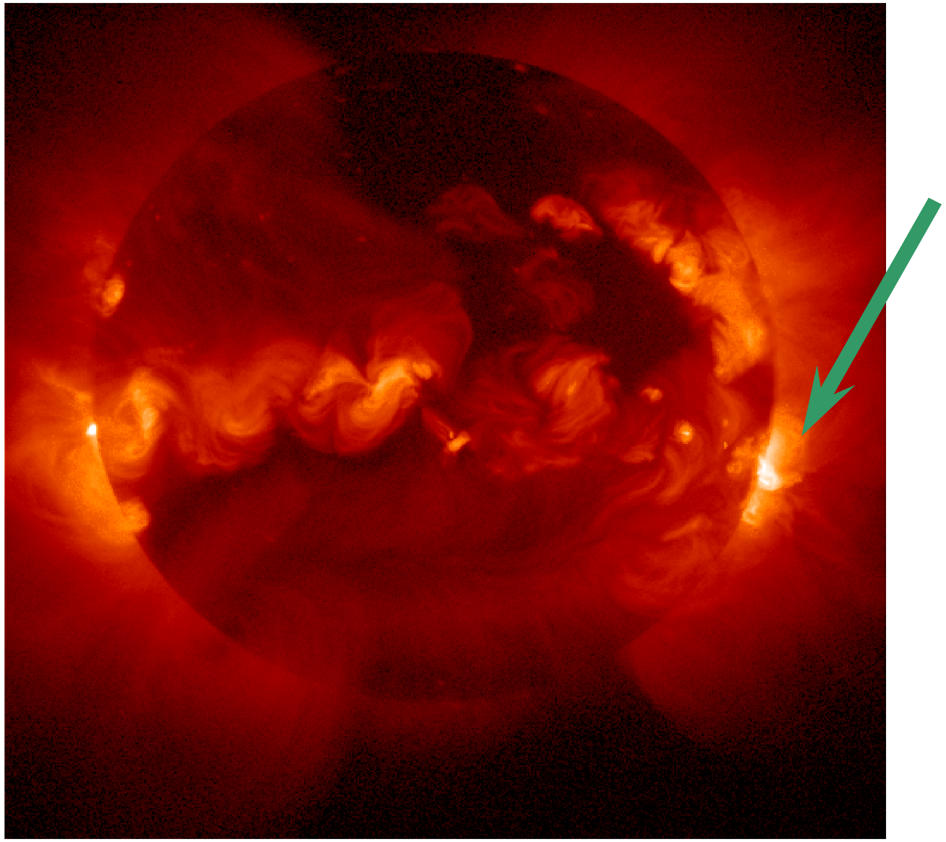
Summary

- Introduction: coronal flares concepts
- Flares in YSO: a case study
- Extension to accreting flow
- Perspectives: accretion vs flaring

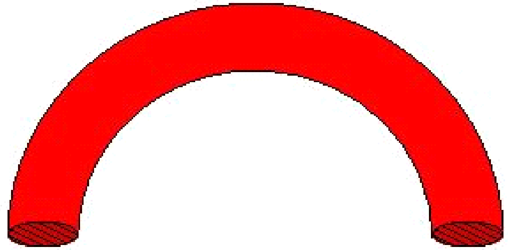
Solar Coronal Flares

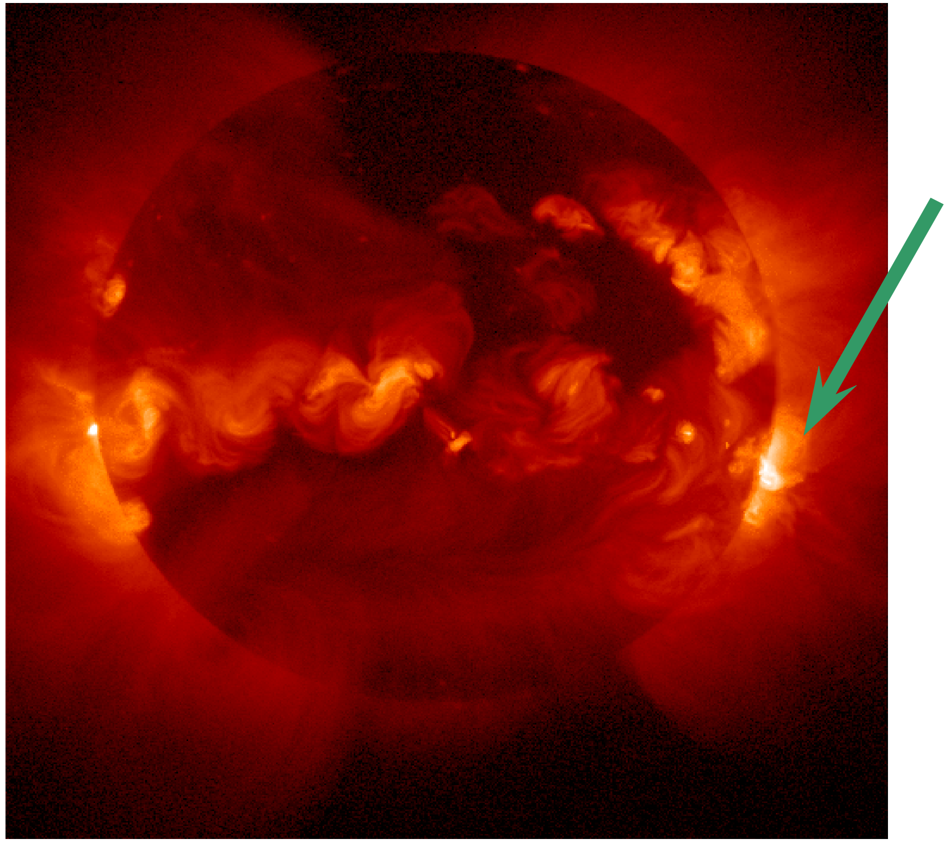
- Soft X-ray observations of coronal flares:
  - Localized regions (loops or arcades)
  - Thermal phase
  - Emission due to hot (x10) and dense (x100) plasma confined in loop(s)



A solar coronal flare

- Yohkoh SXT: high time & space resolution
  - Flare: 12 Jan 1992





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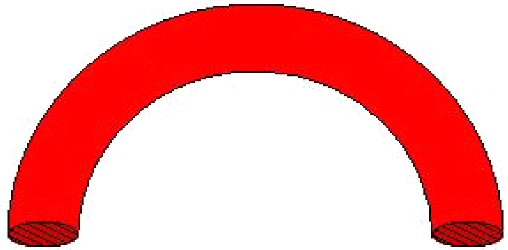
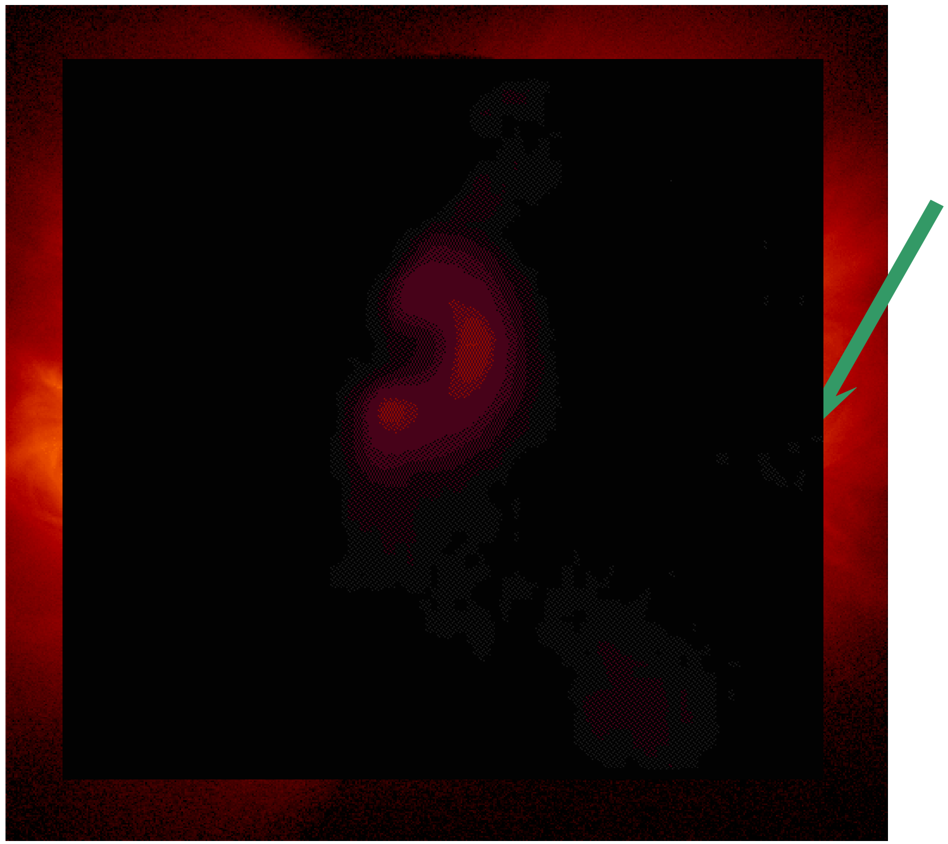




Flare diagnostics

- **Analysis of flare decay**

- **Plasma cooling**
  - **Conduction time**

$$\tau_{cond} = \frac{3nkT}{\kappa T^{7/2} / L^2}$$

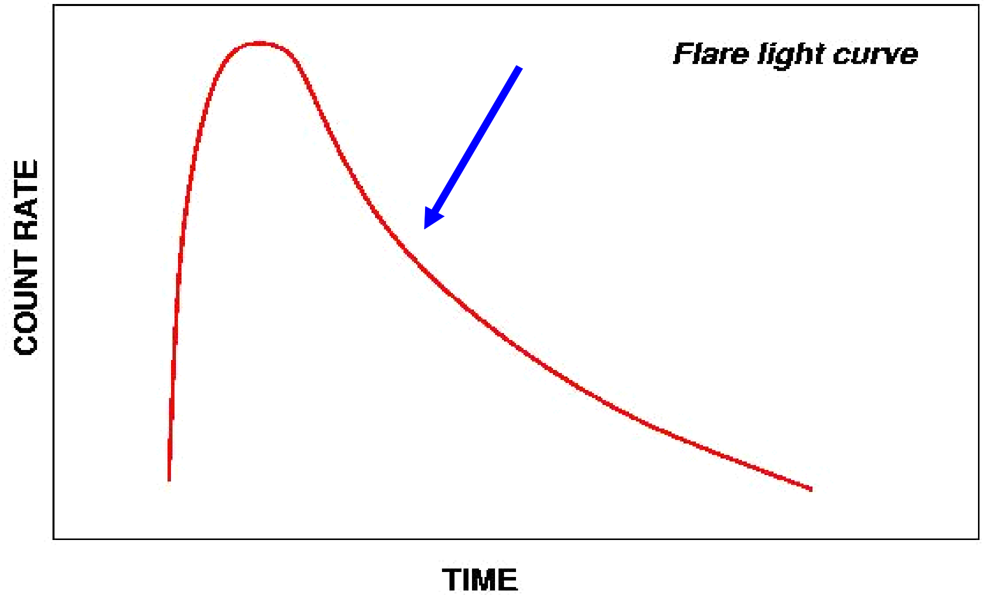
  - **Radiation time**

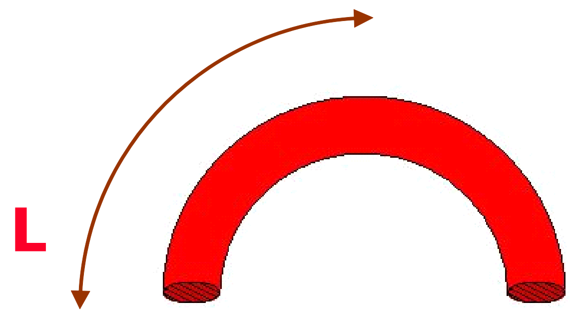
$$\tau_{rad} = \frac{3nkT}{n^2 P(T)}$$

The length enters in the density from loop scaling laws (e.g. Rosner et al. 1978)

  - **Thermodynamic decay time (Serio et al. 1991):**

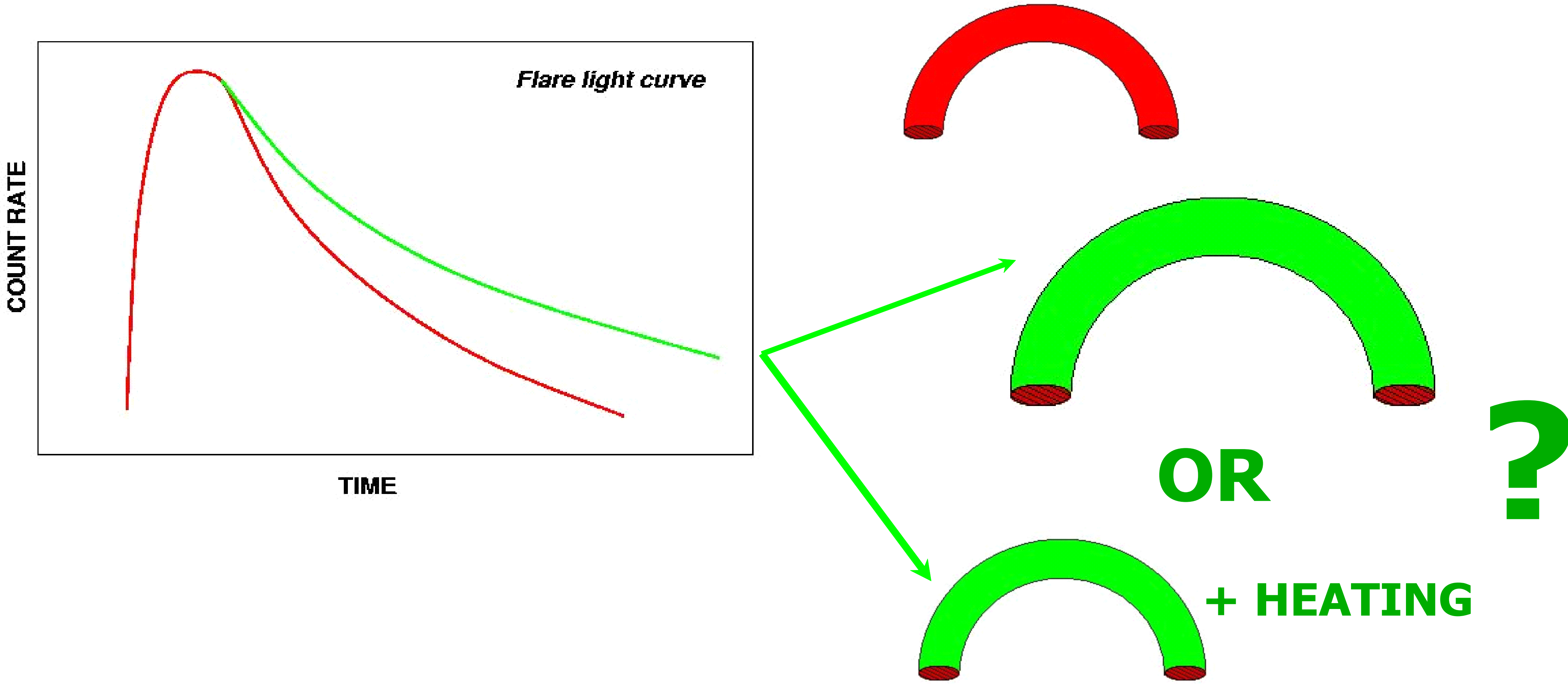
$$\tau_{th} = \frac{120\ L_9}{\sqrt{T_7}} \approx \tau_{total}$$





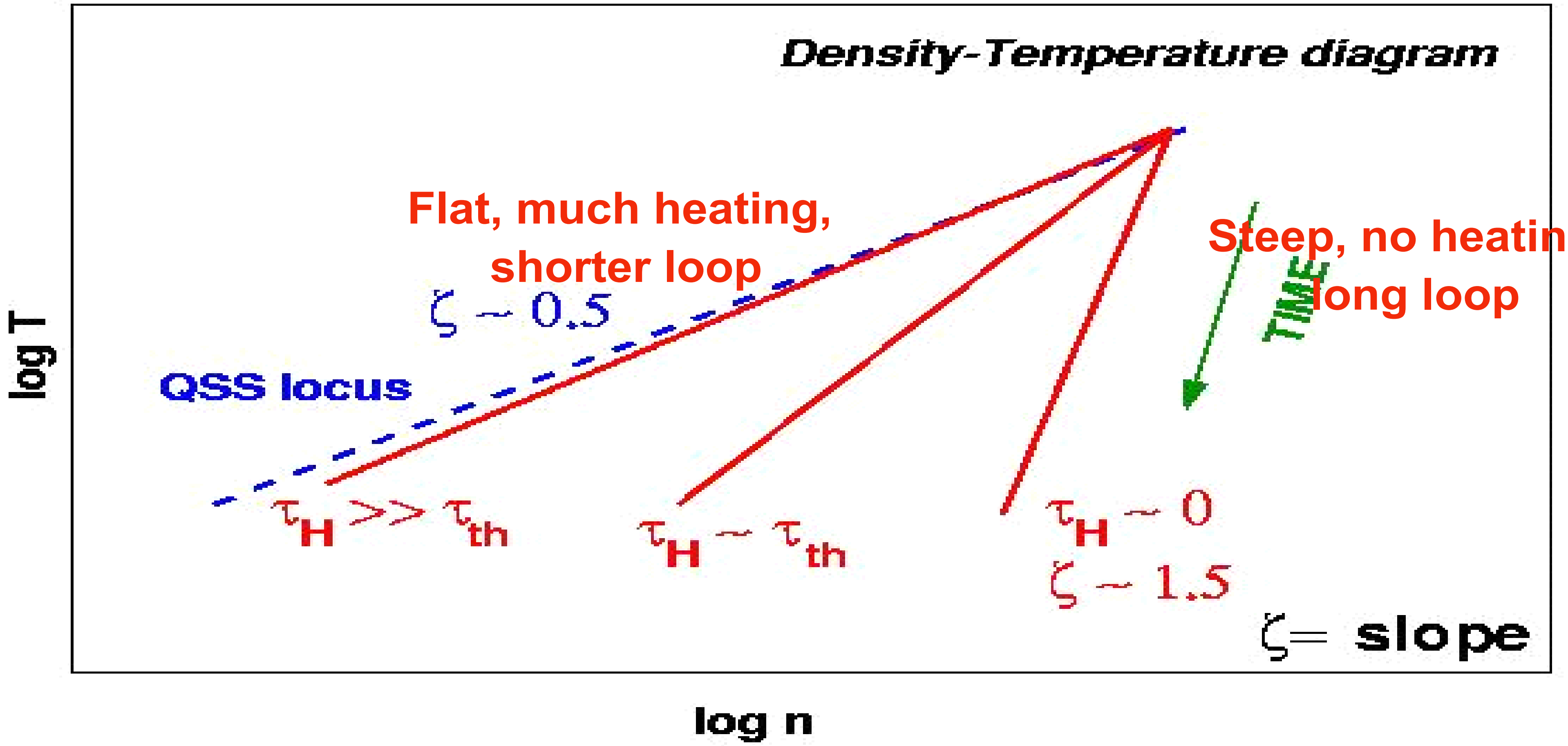
Long flares = long loops?

- Flare decay: the loop length from the decay time



Diagnostics of decay heating
(Sylwester et al. 1993, review and upgrade in Reale 2007)

- Density-temperature diagram: flatter path w/ sustained heating in the decay



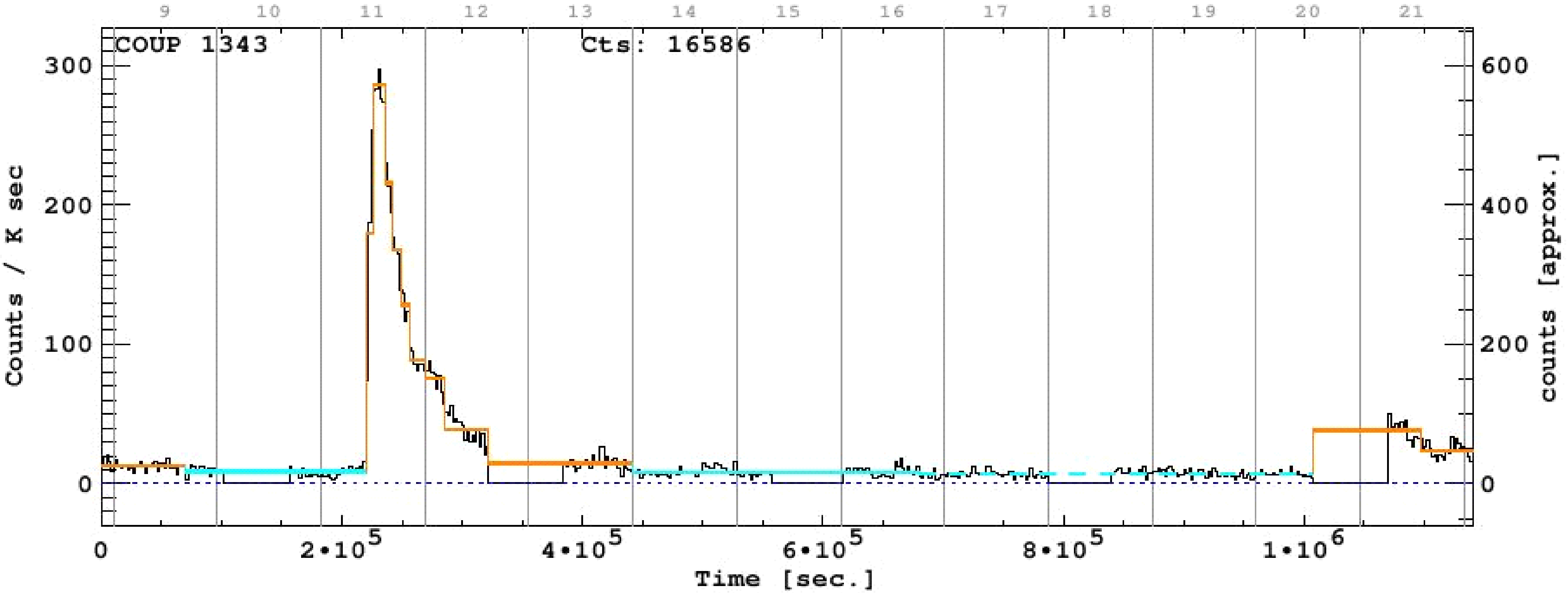
Flares on YSO

- X-ray flares frequently detected in YSO (e.g. Orion Nebula Cluster, RHO Ophiuchi)

- Many flares: strong and long-lasting

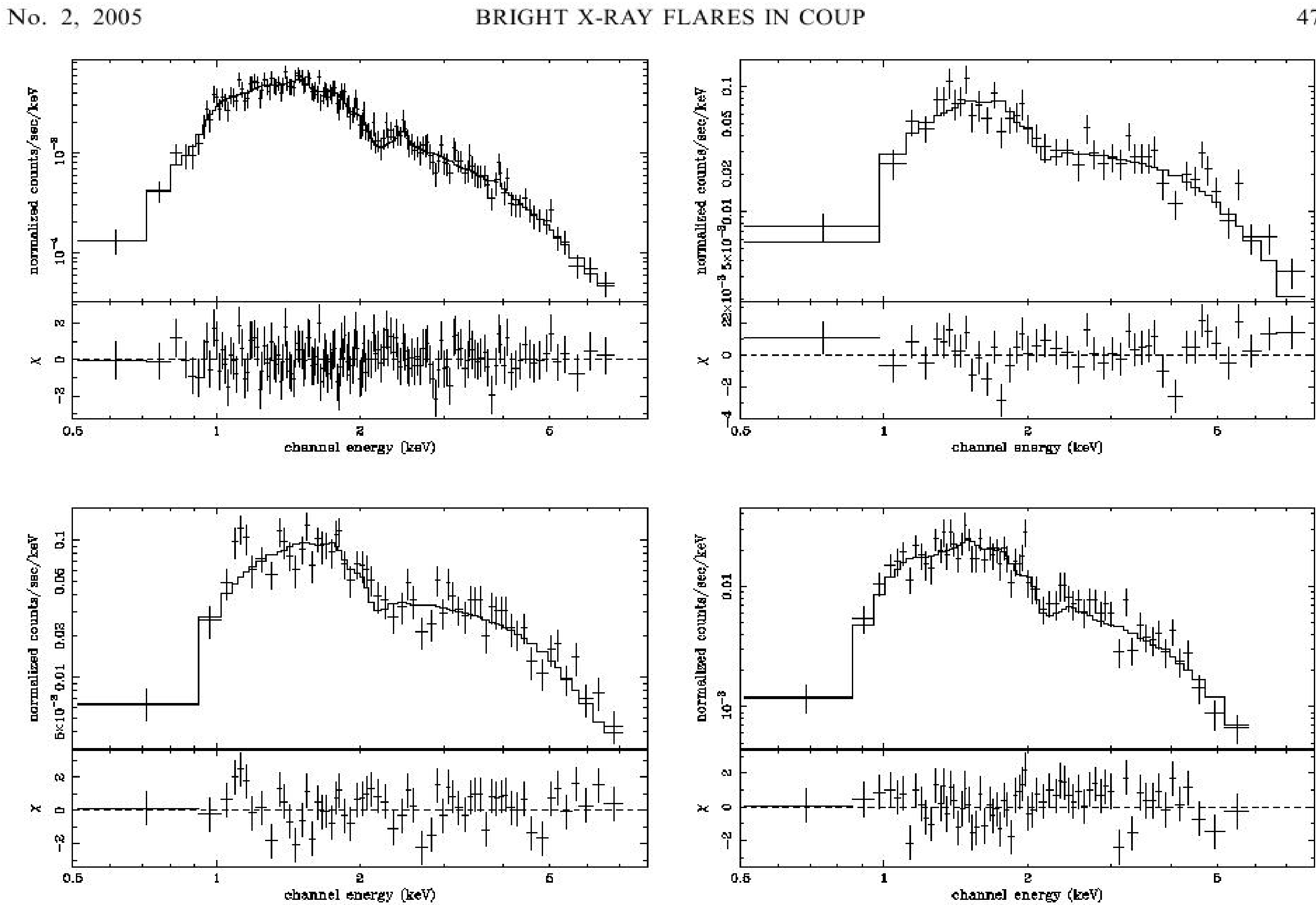
The case of COUP 1343 in Orion Nebula Cluster (*Chandra Orion Ultradeep Project*, Favata et al. 2005)

- Light curve: COUP source 1343, duration: about 1 day



The case of COUP 1343
(Favata, Flaccomio, Reale, Micela, Sciortino, Shang, Stassun, Feigelson 2005, ApJS, 160, 469)

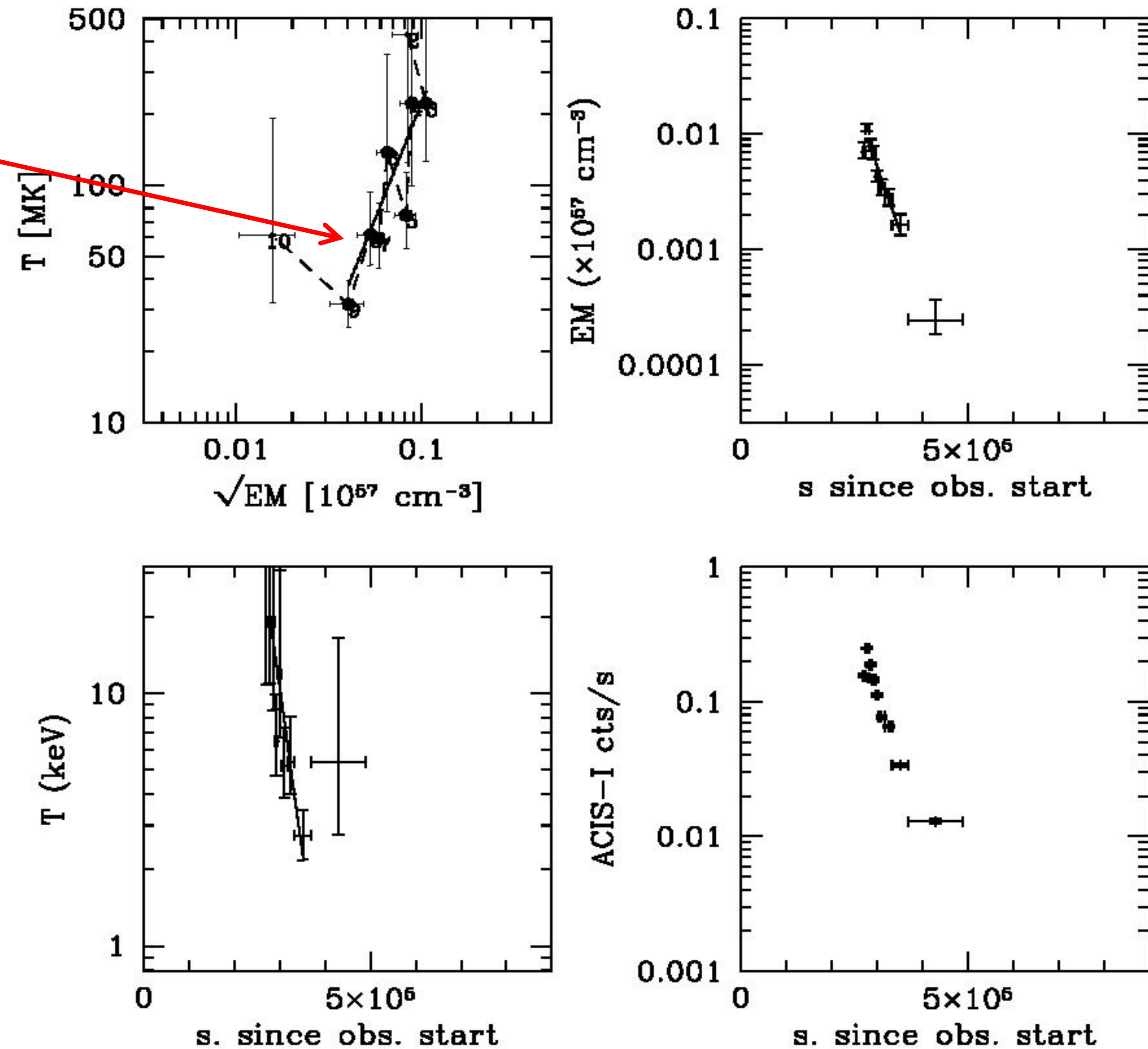
- Chandra/ACIS wide-band X-ray spectra available



The case of COUP 1343
(Favata et al. 2005)

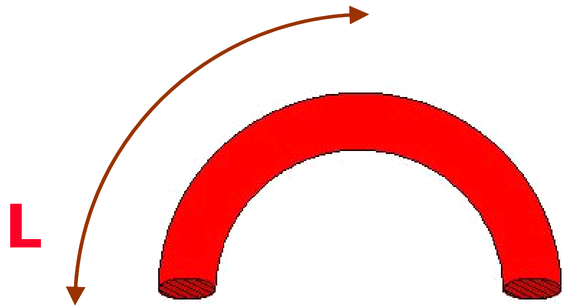
- **Spectral fit results:**
  - **Steep n-T path: no decay heating**
  - **Loop half-length: 10^{12} cm (5-10 R_*)**

- **Hydrodynamic simulation:**
  - **Heat pulse**
  - **Loop aspect**



The case of COUP 1343: Time-dependent hydrodynamic loop model (e.g. Peres et al. 1982)

Flare triggered with a heat pulse



$$\frac{dn}{dt} = -n\frac{\partial v}{\partial s}$$

$$n m_H \frac{dv}{dt} = -\frac{\partial p}{\partial s} + n m_H g + \frac{\partial}{\partial s}\left(\mu \frac{\partial v}{\partial s}\right)$$

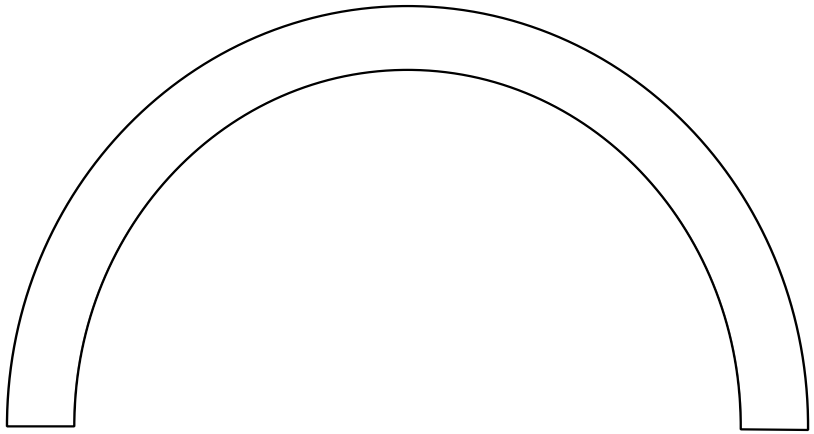
$$\frac{d\mathcal{E}}{dt} + w\frac{\partial v}{\partial s} = Q - n^2 \beta \mathcal{P}(T) + \mu \left(\frac{\partial v}{\partial s}\right)^2 + \frac{\partial}{\partial s}\left(\kappa \frac{\partial T}{\partial s}\right)$$

$$p = (1+\beta) n k_B T \qquad \mathcal{E} = \frac{3}{2}p + n\beta\chi \qquad w = \frac{5}{2}p + n\beta\chi$$

n hydrogen particle density, s coordinate along the loop, v plasma velocity, T temperature, p pressure, g gravity, m_H hydrogen atomic mass, μ viscosity, β ionization fraction, κ thermal conductivity, χ hydrogen ionization potential, k_B Boltzmann constant, $\mathcal{P}(T)$ radiative losses p.u.e.m., $Q(s,t)$ input heating power per unit volume.

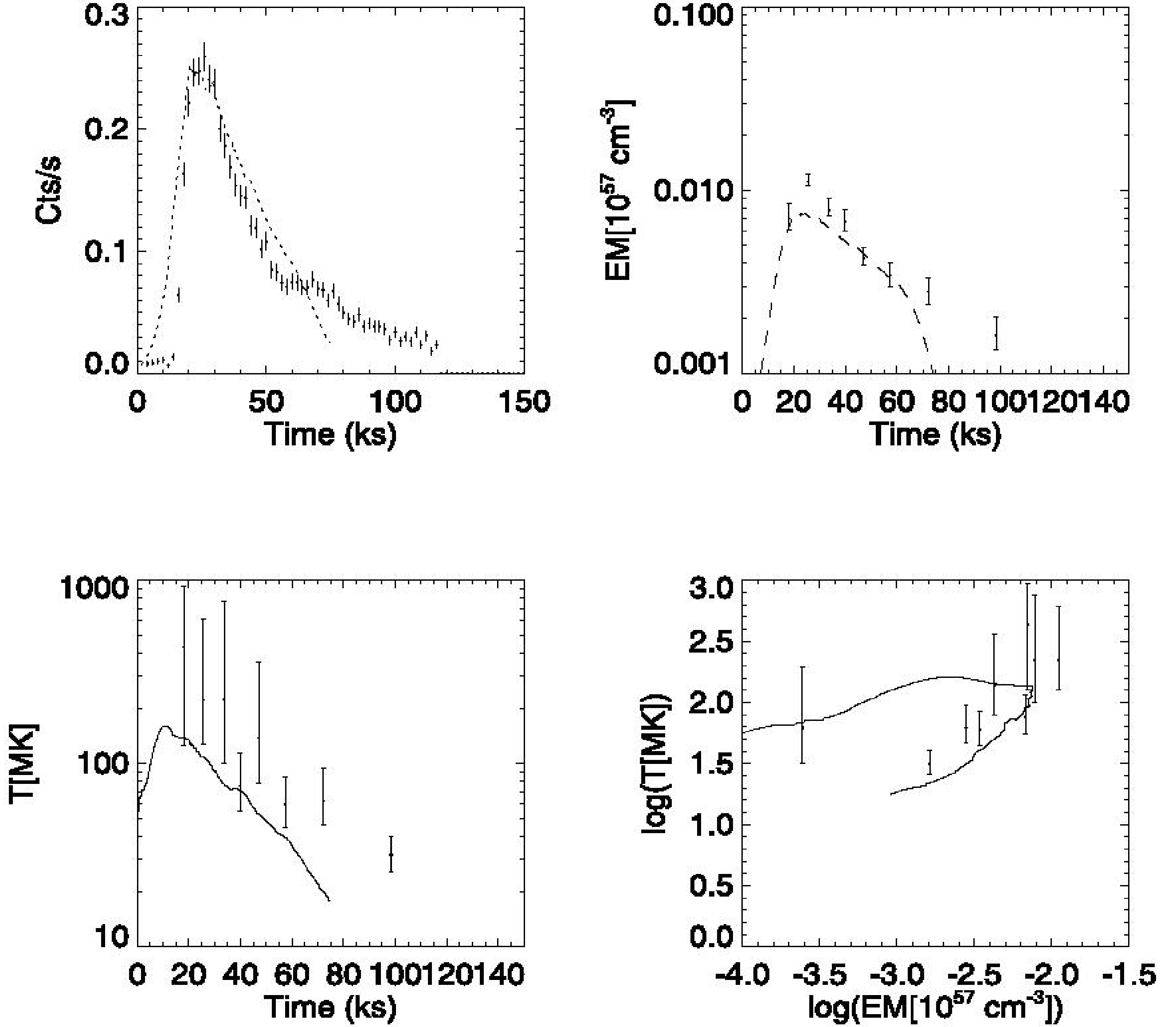
The case of COUP 1343: Hydrodynamic simulation (Favata et al. 2005)

- **Initial solar-like loop:**
  - **Loop half-length: 10^{12} cm**
  - **Density: $\sim 10^{9}$ cm^{-3}**
- **Heat pulse:**
  - **Location: footpoints**
  - **duration: 20000 s**



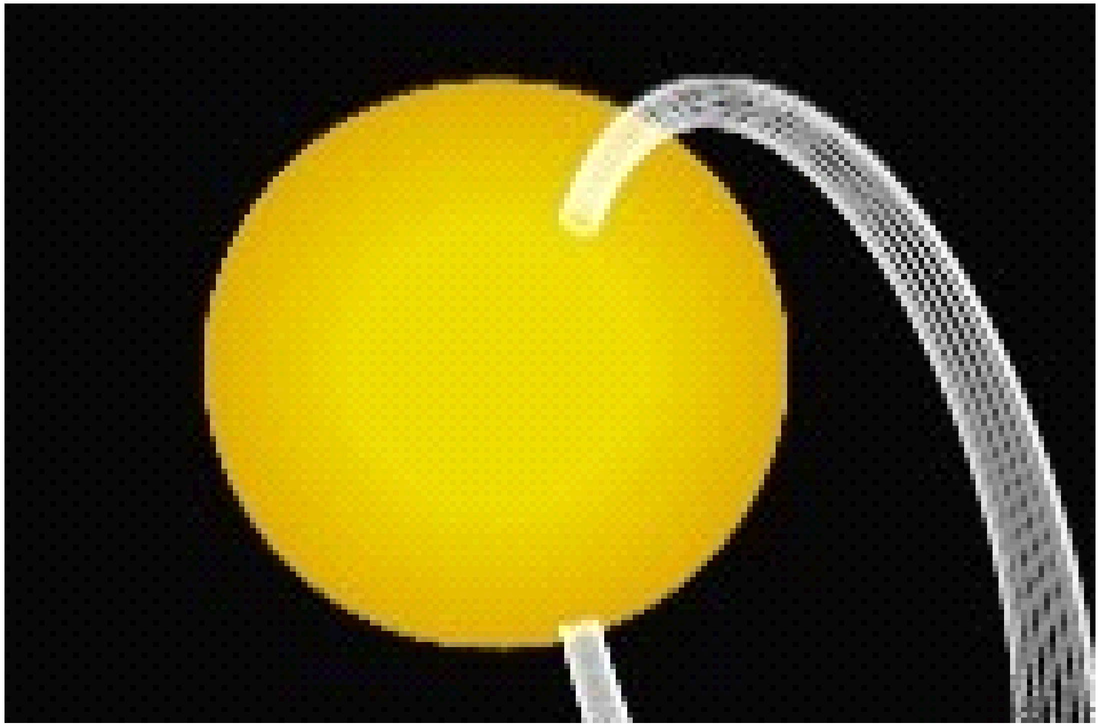
The case of COUP 1343: Simulation results (Favata et al. 2005)

- **Simulation output: density and temperature along the loop**
- **Emission synthesis filtered through Chandra/ACIS eff. Area: count rate**
- **Spectra and integrated light curve**
- **Spectral fit: Temperature and Emission measure**
- **Result:**
  - **Light curve: OK**
  - **n – T slope: OK**



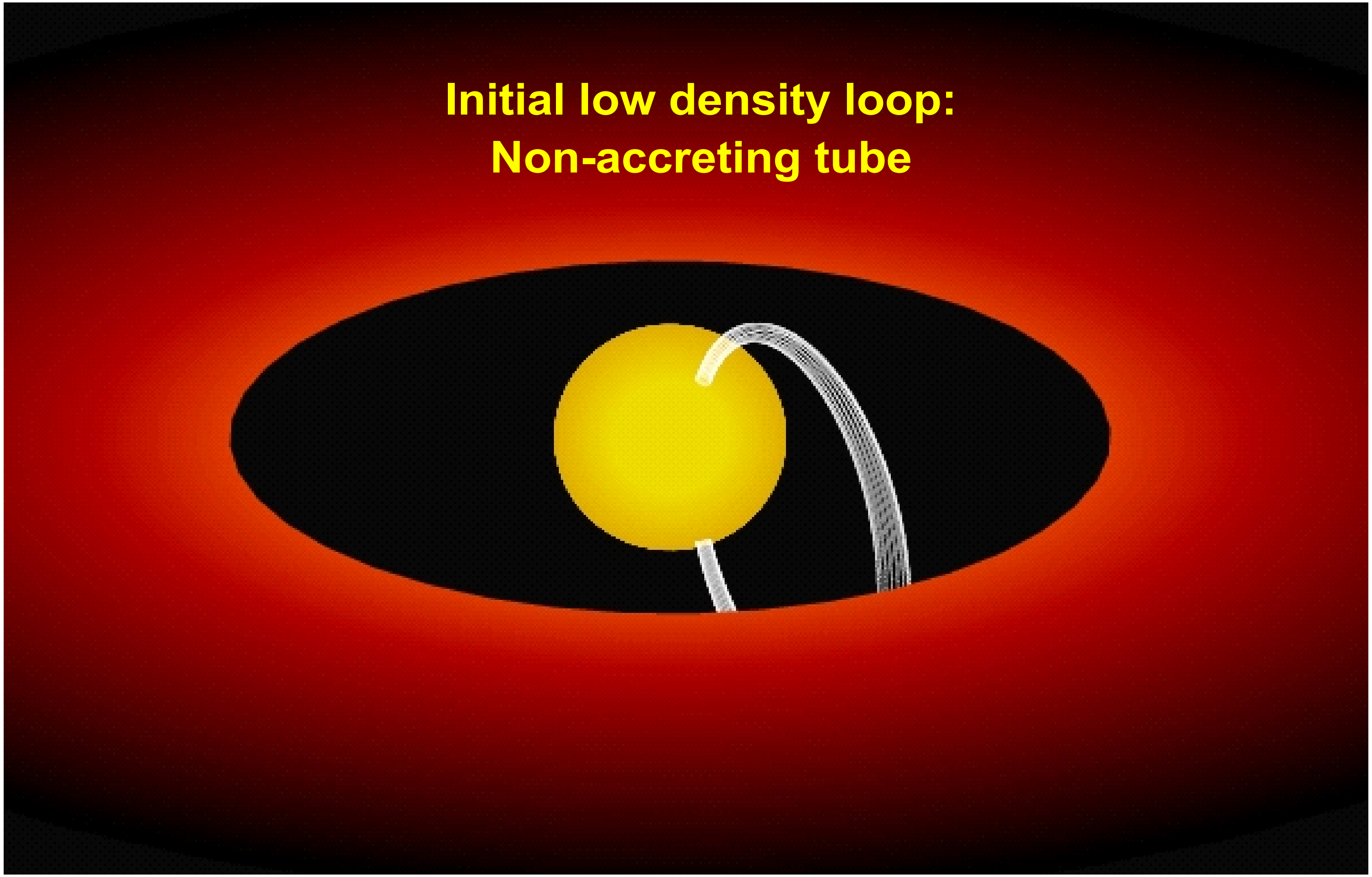
The case of COUP 1343: Loop before flare (not in scale)

- **Good fit with:**
  - **Loop half-length: 10^{12} cm**
  - **Unperturbed density: $\sim 10^9$ cm^{-3} (low)**



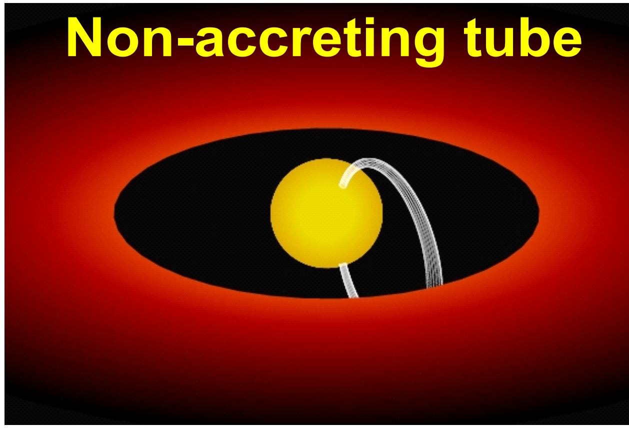
....compatible with....

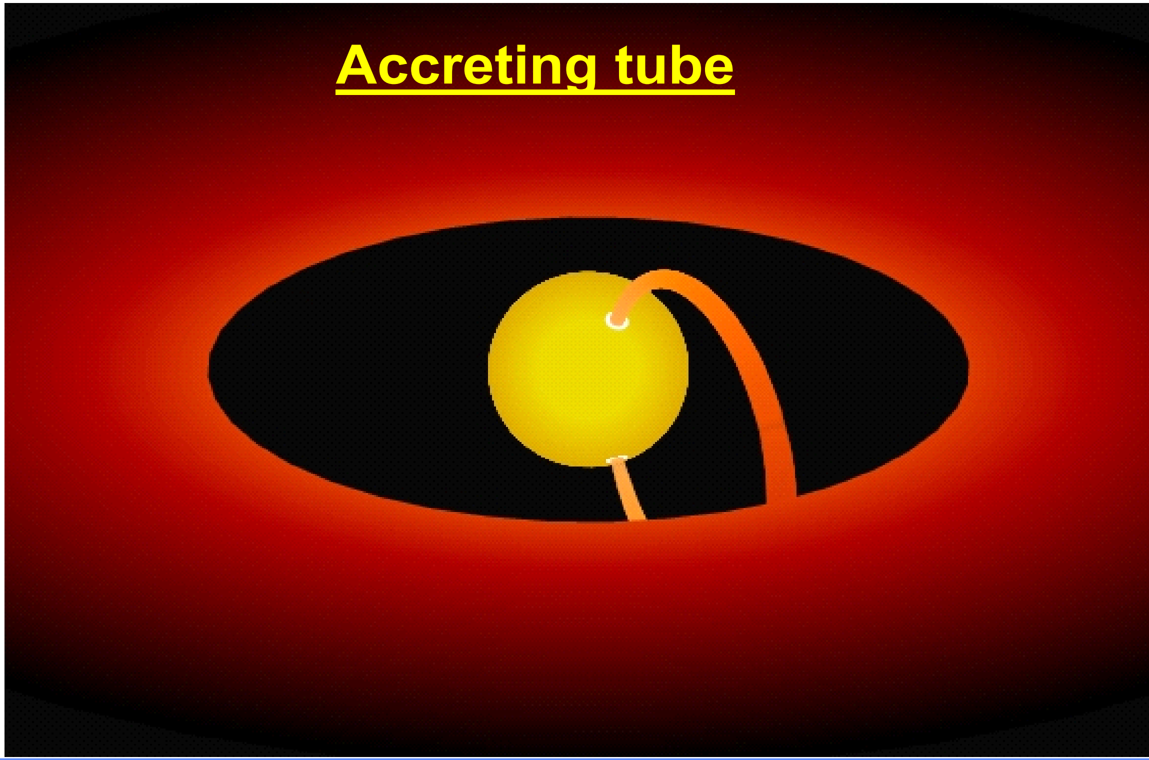
- Star-disk interconnecting tube



The next step: flare in accreting tube?

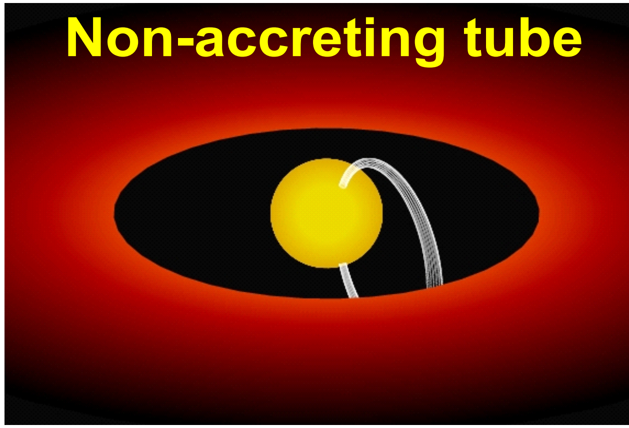
- What happens if we switch to an initial loop with an accretion flow?
- We approximate the accreting flux tube with an initially denser tube

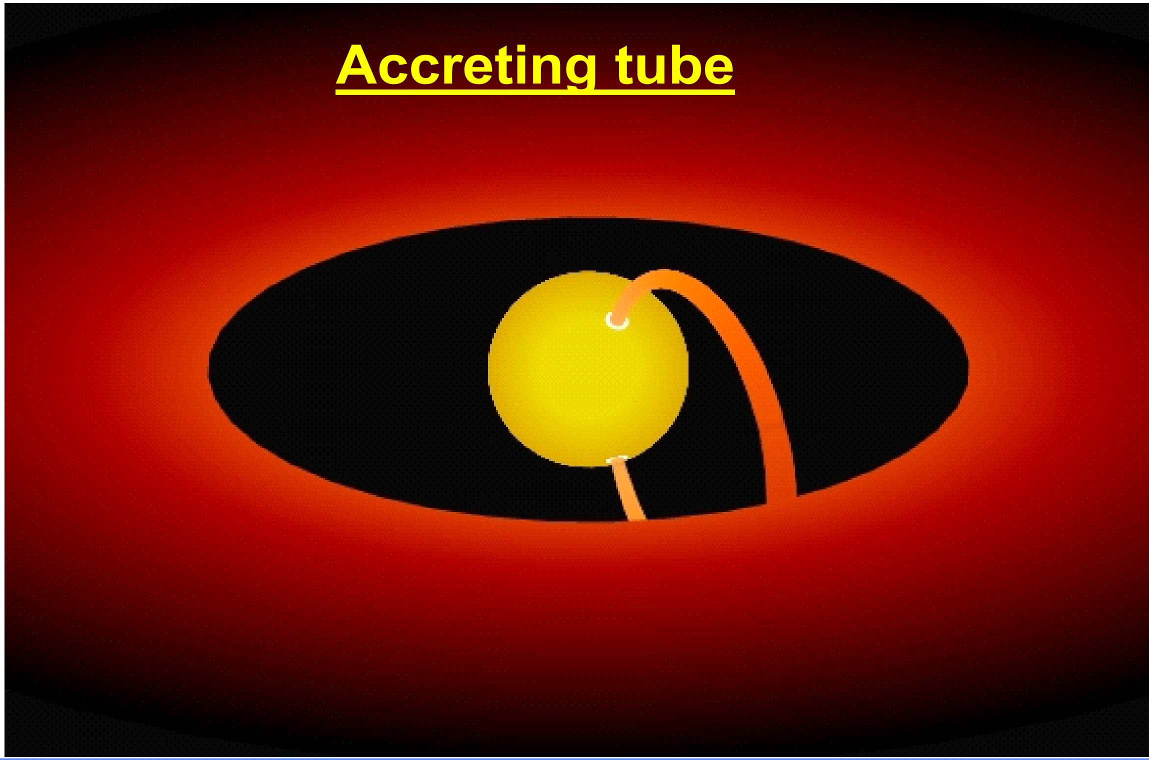




Another hydrodynamic simulation

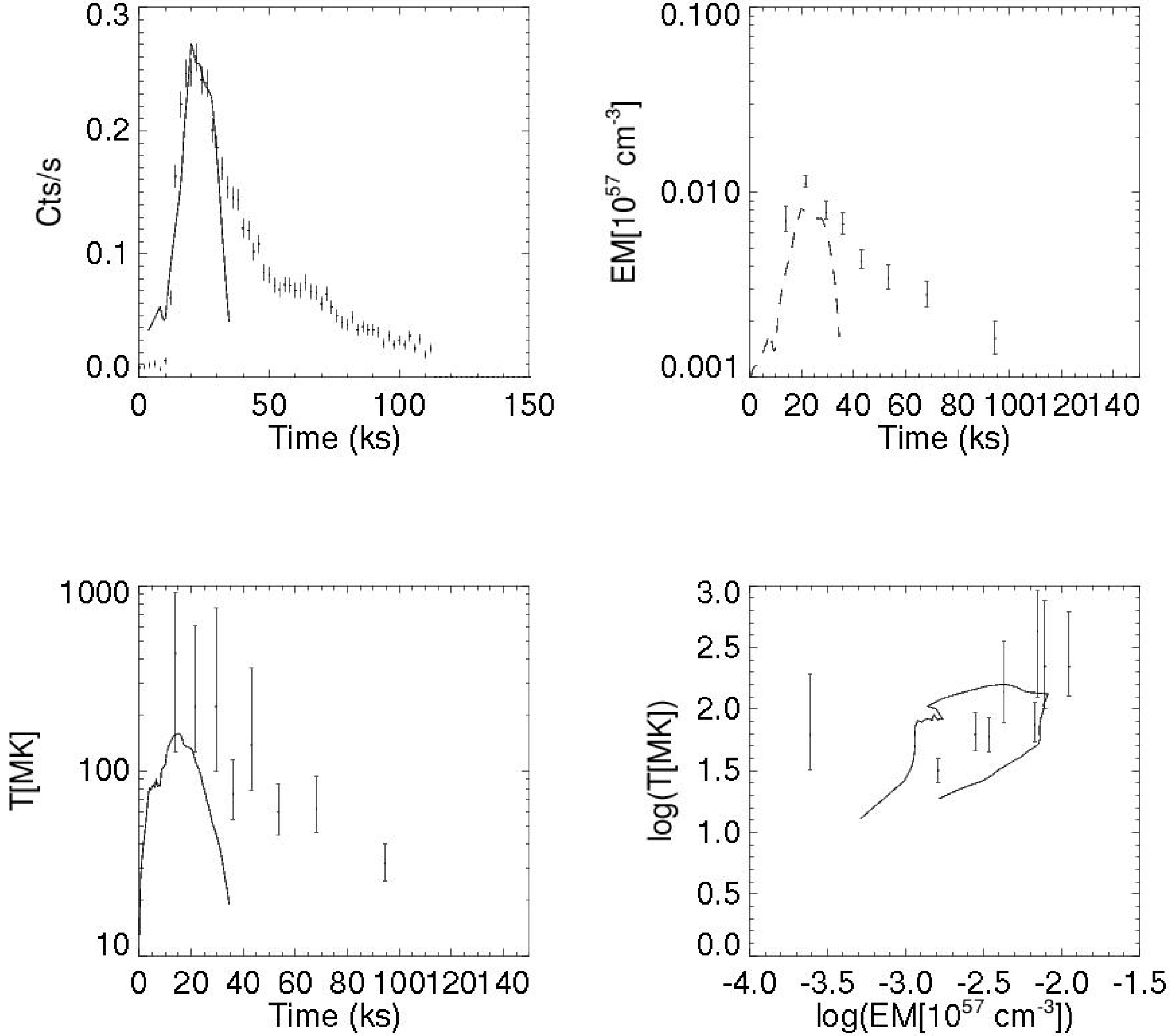
- Same approach, same model, different initial condition: filled loop (w/ accretion flow)
- Accreting plasma density: 10^{11} -10^{12} cm^{-3} (Robrade & Schmitt 2007, Jardine et al. 2008, submitted)
- Our assumption for initial density: ~10^{11} cm^{-3} (100x)





Simulation results

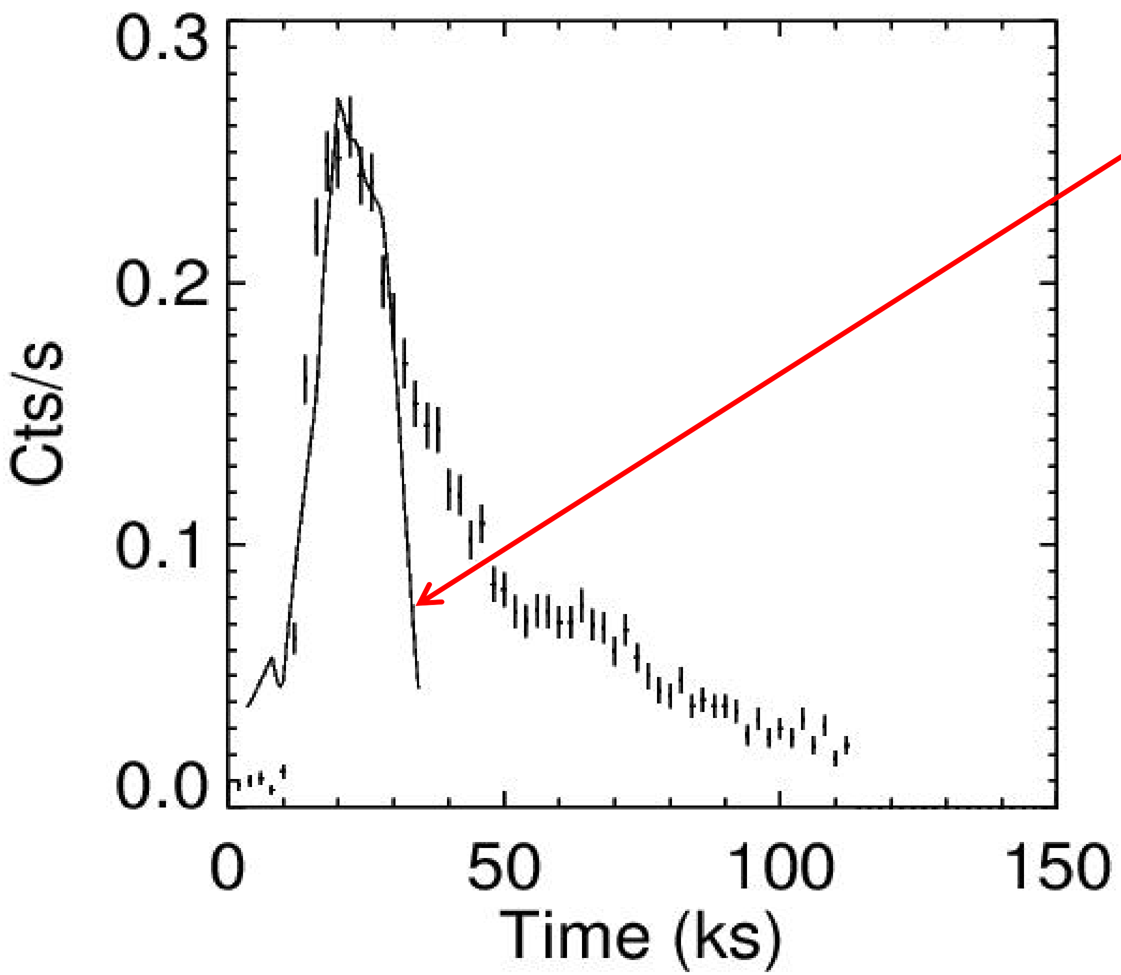
- **Results:**
  - **Light curve: not OK**
  - **n-T diagram: OK**



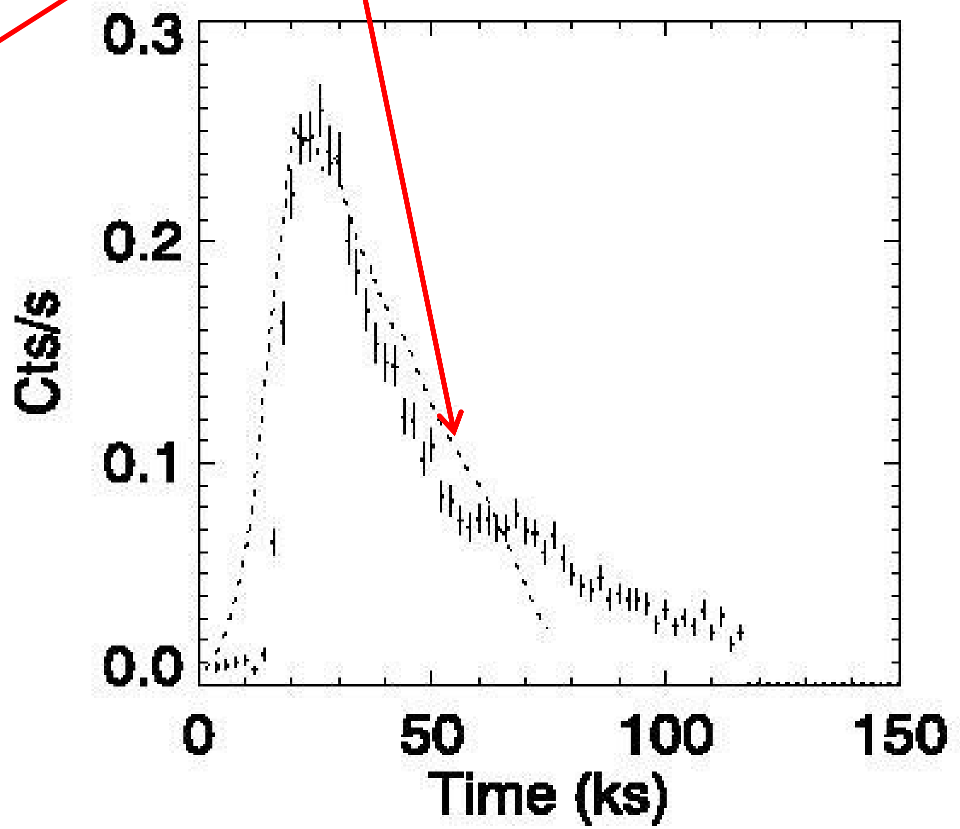
Light curves

- Too fast decay

Accreting tube



Non accreting tube

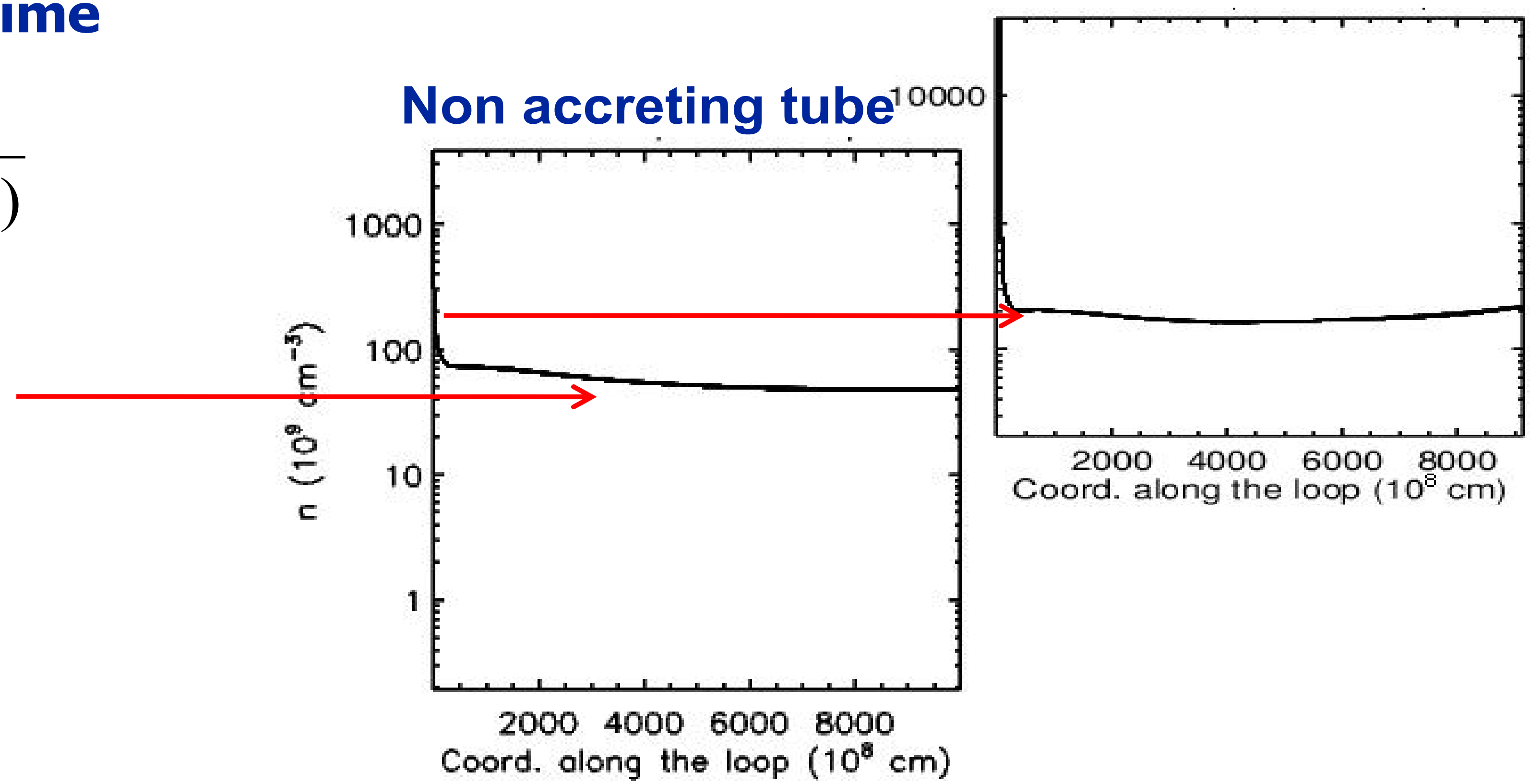


Physical explanation

- At the end of the heat pulse, 4-fold dense: 4-times faster (radiative) cooling
- Longer loop? Unlikely, if radiative cooling dominates

Radiation time

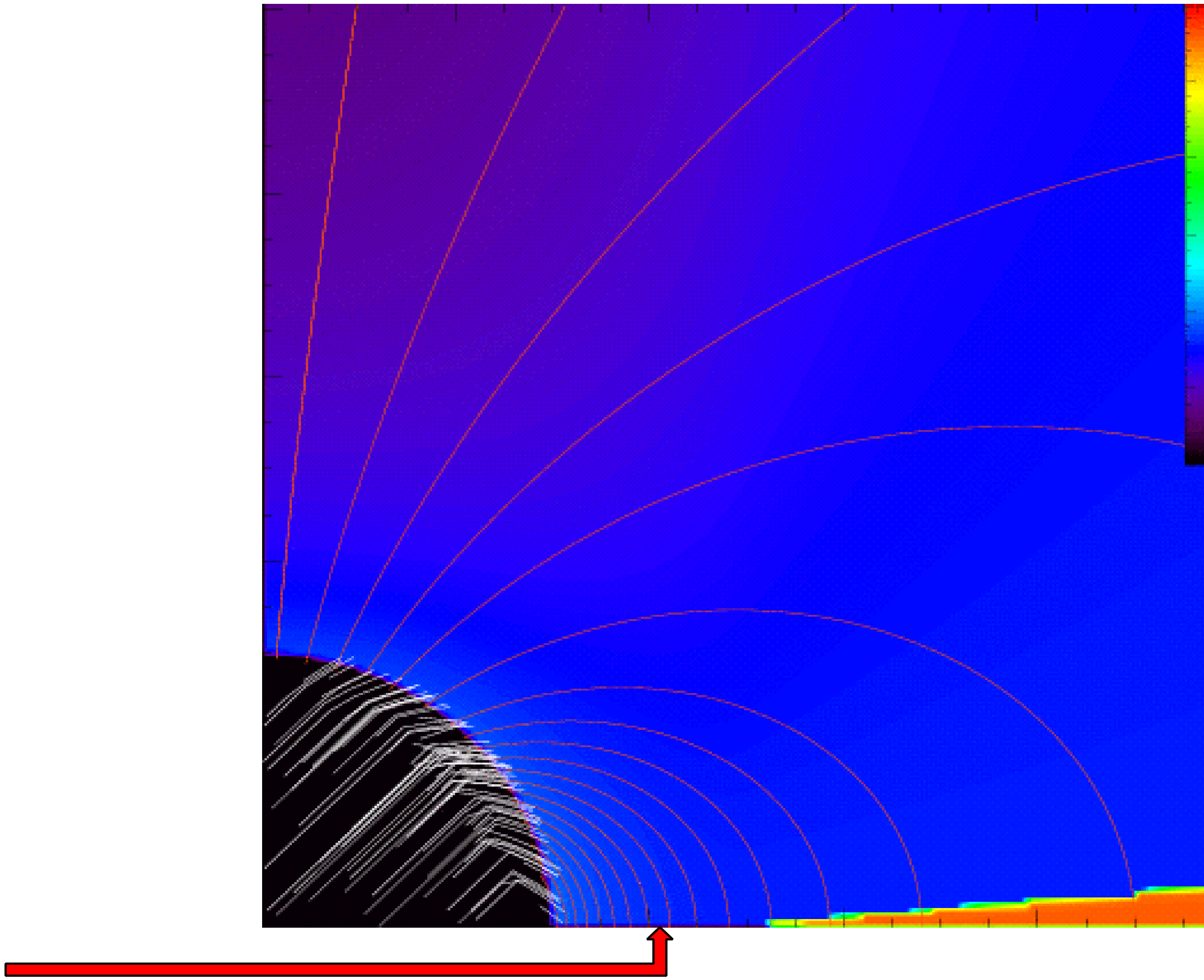
$$\tau_{rad} = \frac{3kT}{n\ P(T)}$$



Time: end of heat pulse (20 ks)

Flare-disk interaction (see poster Yelenina et al.)

- Full MHD simulation of a flare located on the **star**
- **Preliminary results**: accretion episode triggered by the flare



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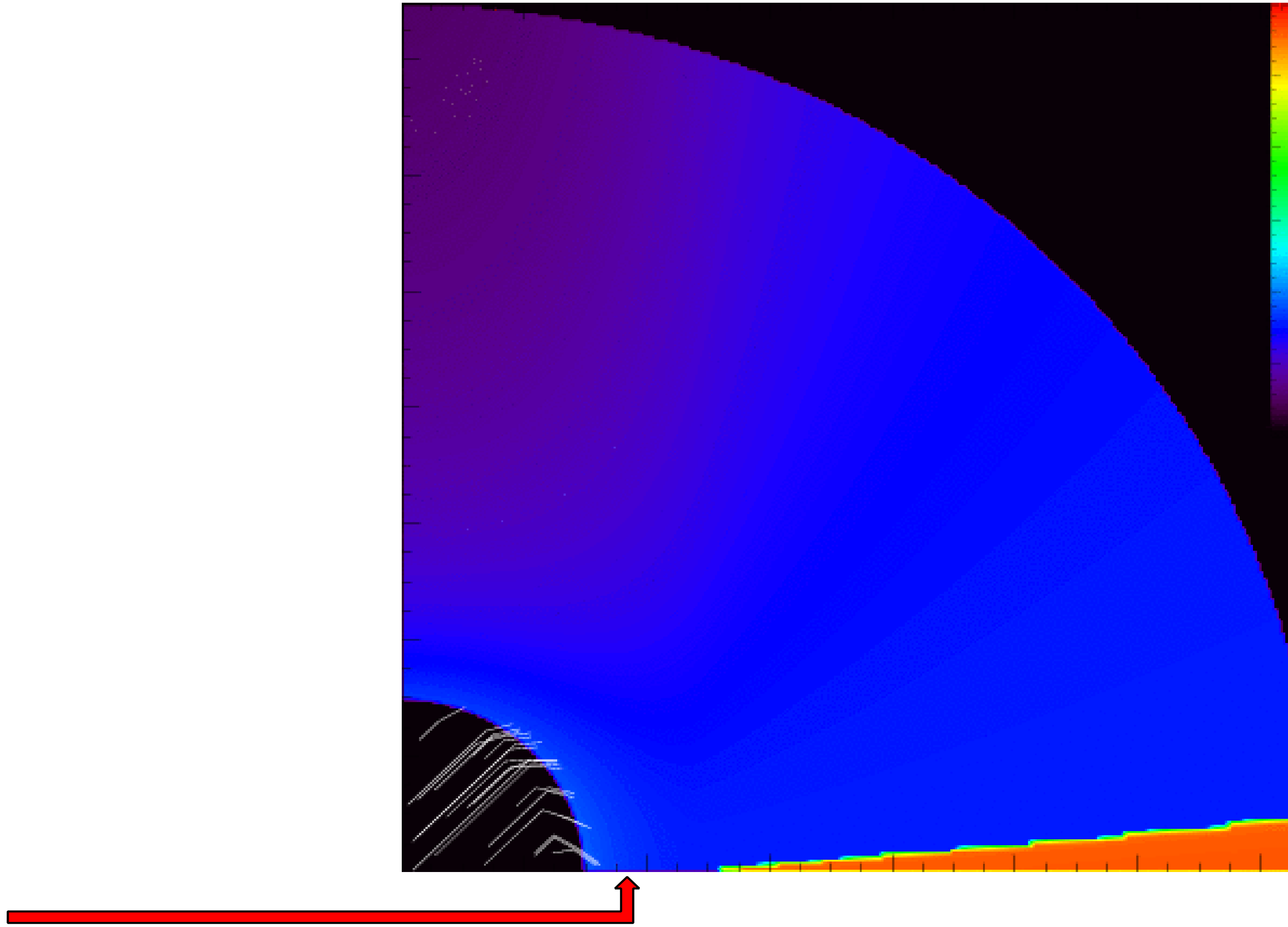

Perspectives

- Flares triggered in accreting tubes: <u>unlikely</u> (but further checks needed, e.g. longer loops?)

- New perspective: accretion triggered by flares? At least occasional important accretion bursts

- New scenario to be explored

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Flare on COUP 1343

- **Flaring region: <u>long loop</u>**
- **Working hypothesis: <u>star-disk interconnecting loops</u>**