INAF
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Plasmi astrofisici confinati e non: modelli e diagnostica

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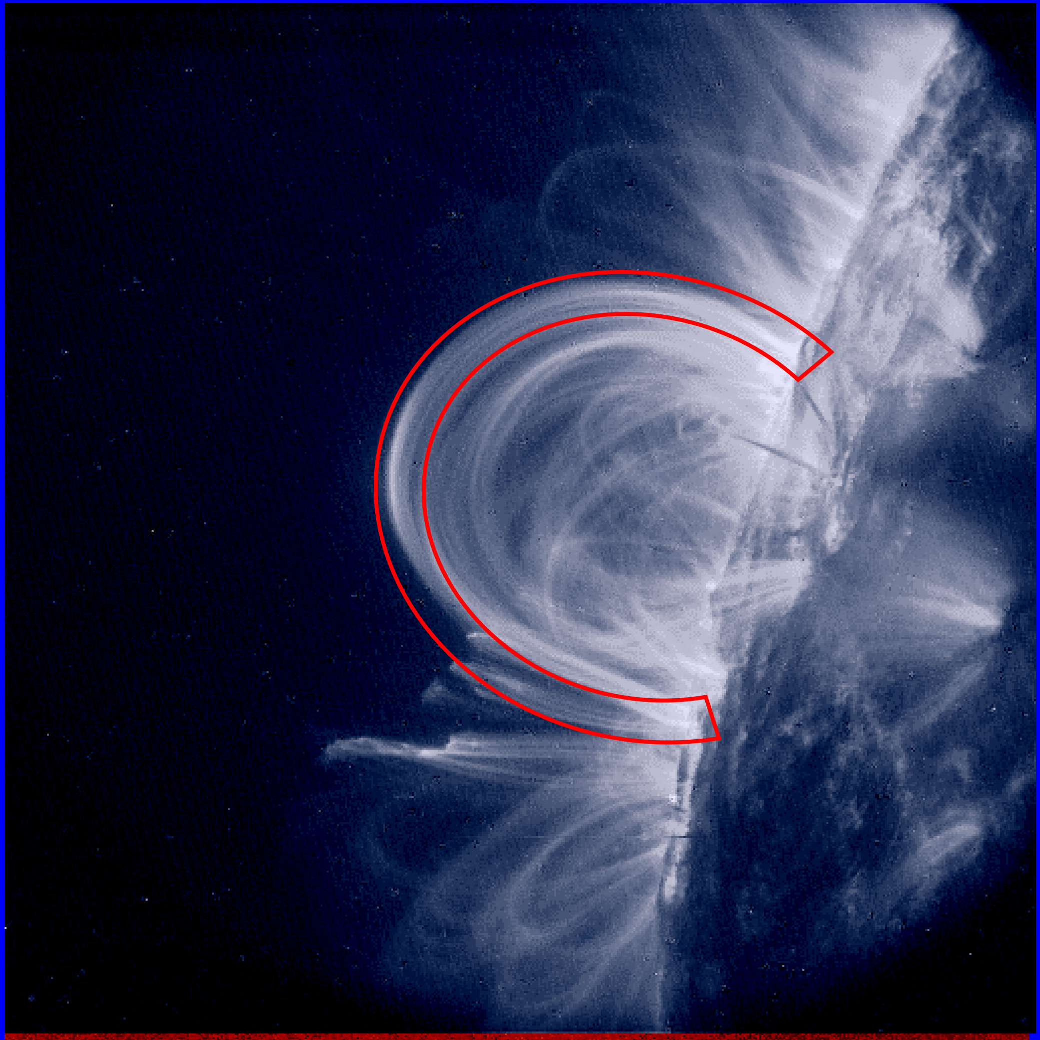
Outline

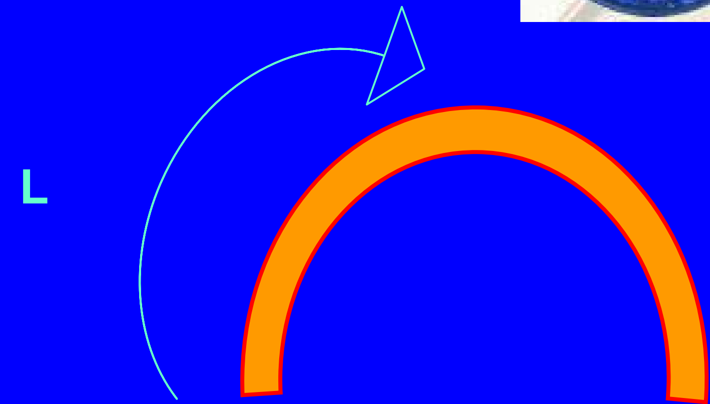
- Overview: Modeling & diagnostics
- The tools: Codes, HPC, data analysis
- The scientific topics:
  – Loop modeling & diagnostics
  – Non-confined plasmas: modeling & diagnostics
  – Coronal plasma diagnostics

Overview:
The solar corona

- X-ray emission from plasma:
  - Optically thin
  - Magnetically confined in loop-like structures
- Loops:
  - Building blocks of the emitting corona
  - Independent miniatmospheres
  - Confined plasma as a fluid
- Hydrodynamic models



Overview:
Hydrodynamic modeling



- Equation of Mass conservation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

- Equation of Momentum conservation

$$\frac{\partial (\rho \mathbf{v})}{\partial t} + \nabla \cdot (\rho \mathbf{v}\, \mathbf{v}) = -\nabla p + \mathbf{F}_{grav} + \mathbf{F}_{Lor} + \mathbf{F}_{visc}$$

- Equation of Energy conservation

$$\frac{\partial u}{\partial t} + \nabla \cdot [(u + p)\mathbf{v}] = P_{grav} + P_{rad} + P_{heat} + P_{cond} + P_{magn} + P_{visc}$$

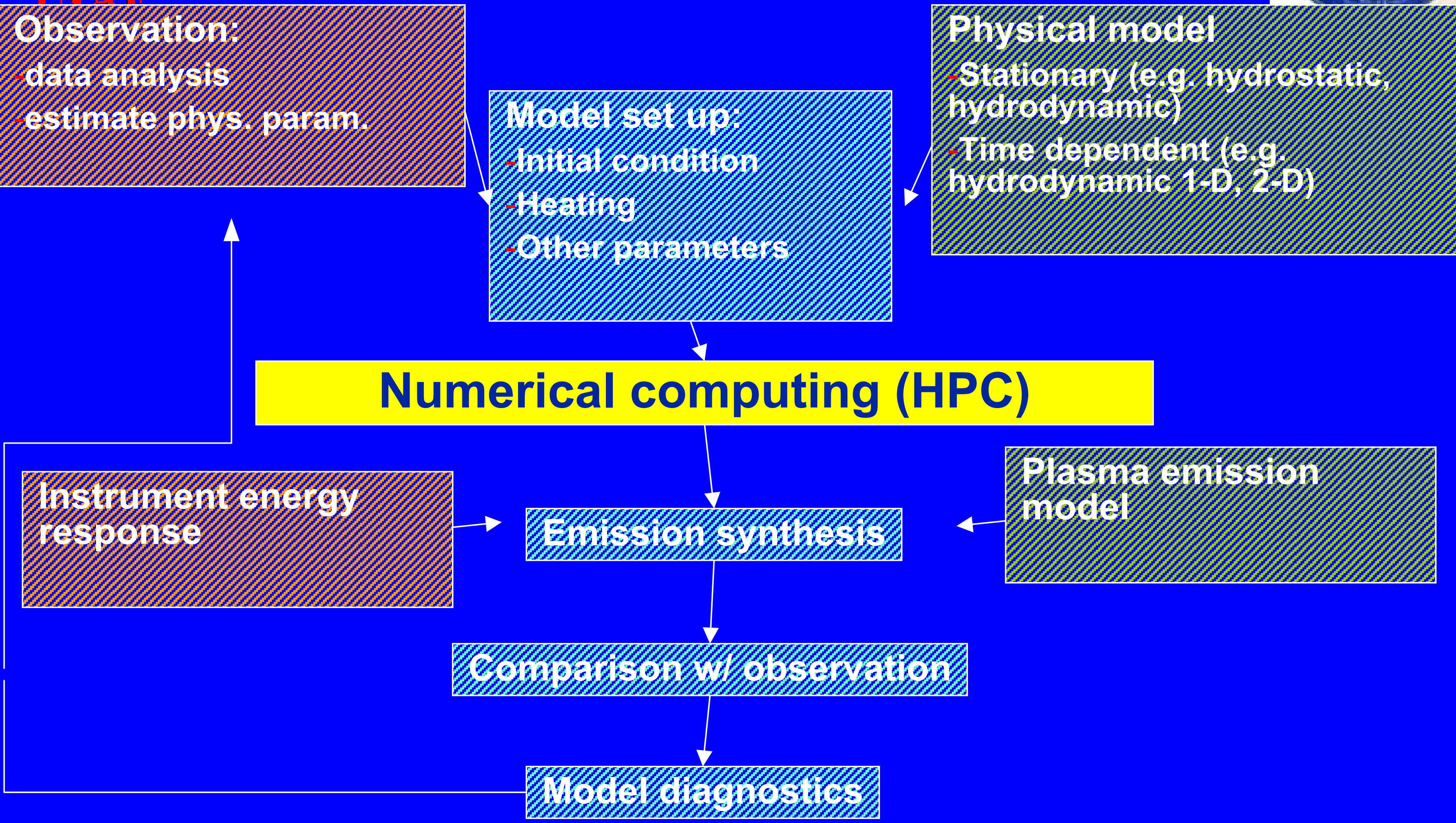
- Maxwell's Equations

$$\nabla \cdot \mathbf{B} = 0$$

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\nabla \times \mathbf{B})$$

$$\mathbf{J} = \frac{c}{4\pi} \nabla \times \mathbf{B} \qquad \mathbf{E} = \frac{4\pi}{\sigma}\mathbf{J} - \frac{1}{c}\mathbf{v} \times \mathbf{B}$$

Overview:
How we do it



Overview: Implications

- Modeling:
  - Theoretical tool for physical insight
  - tool to interpret observations
- Forward modeling: direct link to observations
- Link to data analysis
- Connection to:
  - Space missions and data analysis tools (e.g. solar & stellar X-ray telescopes, telescope simulation & spectral synthesis (ASAP package))
  - Numerical analysis (e.g. Palermo-Harvard code, ASCI/FLASH code)
  - High Performance Computing (OAPa/SCAN, CINECA)

Overview: Funding

Provenienza	Titolo	Anno	kE
ASI	Sole/modelli (PI G. Peres)	00	36
		01	21
		02	35
	SoHO/UVCS (Local PI F. Reale)	00	13
		01	12
		02	20
CoFin	Sole + Stelle (PI Peres)	99	32+7
		00	60+9
		03	43+7
Unipa (ex 60%)	Astrofisica + Storia Astronomia	01	20
		02	25
		03	20
MIUR/EU	Alta formazione – OAPa/SCAN	00-02	516

The tools:
The FLASH Code

- Framework: *Accelerated Strategic Computing Initiative* (ASCI - USA)
- Main site: *FLASH Center* (Univ. of Chicago)
- Main features: Multi-D, adaptive-mesh, parallel code for astroph. flows (e.g. thermonuclear flashes on white dwarfs).
- Collaboration OAPa/FLASH center: test site (HP cluster, application to coronae & SNRs)
- New FLASH modules implemented @OAPa (Non-equilibrium ionization, Thermal conduction & viscosity, Radiative losses)

The tools:
OAPa/SCAN

- Framework: expertise in vector and parallel computing since '80s (*Cray/CINECA, Transputers/IAIF-CNR, MeikoCS/OAPa*)
- Funding: "Alta formazione nel campo del calcolo ad alte prestazioni e problematiche astrofisiche attuali" (MURST/UE, MLit.1000, 2000-2002)
- Scope: high education and HPC
- Facility: Cluster Compaq/HP (16 AlphaEV67)

Loop modeling

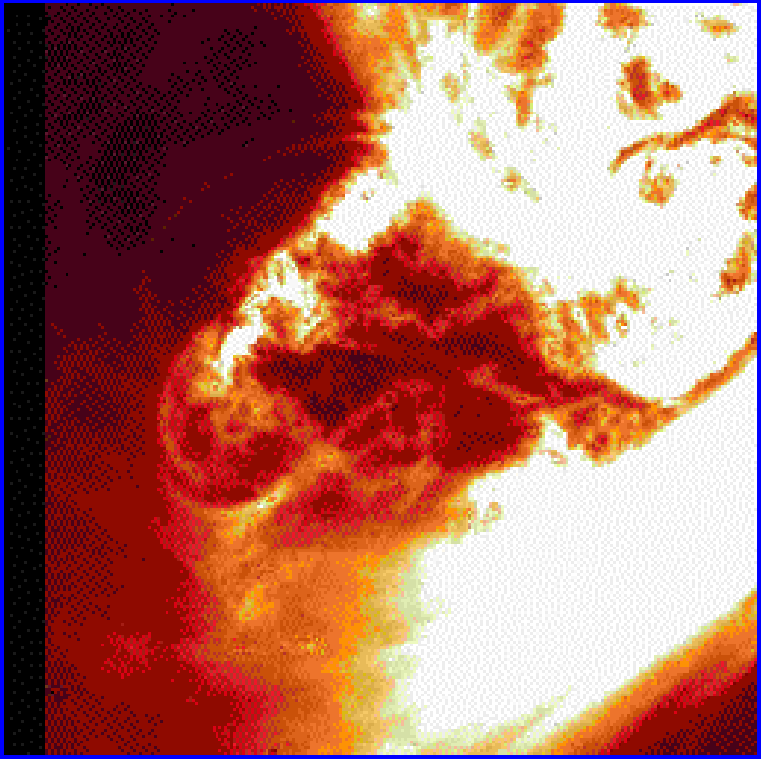
- Participants:
  - DSF&A/UniPa: *S. Serio, G. Peres, F. Reale, P. Testa(Dott.)*
  - INAF/OAPa: *S. Orlando, A. Ciaravella, A. Maggio, G. Micela*
- Main collaborations: *R. Rosner (Chicago/USA), B.&J. Sylwester (Wroklaw/PL), L. Golub (CfA/USA), E. Antonucci (Torino), F. Favata (ESA), M. Güdel (Zurich/CH)*
- Tools: *steady loop codes, wind code, Palermo-Harvard code, ASAP package*

Loop modeling: the scope

- Initiated by the first high resolution X-ray observations (Skylab, 1973)
- “Historic” OAPa-Astro/UniPa research line
- Loop modeling useful for:
  - Insight in loop plasma physics
  - Interpretation of the loop emission
  - Diagnostics of plasma conditions
  - Diagnostics of heating mechanisms and flares

Loop modeling:
A brightening coronal loop observed w/ TRACE

- **The observation (26 June 1998):**
  - **171 A filter band**
  - **Start time: 13:01 UT**
  - **End time: 15:25 UT**
- **213 full frames**
- **Cadence: 30 s (Exposure 23 s)**
- **Six gaps (140 – 568 s)**
- **Region: AR 8253**



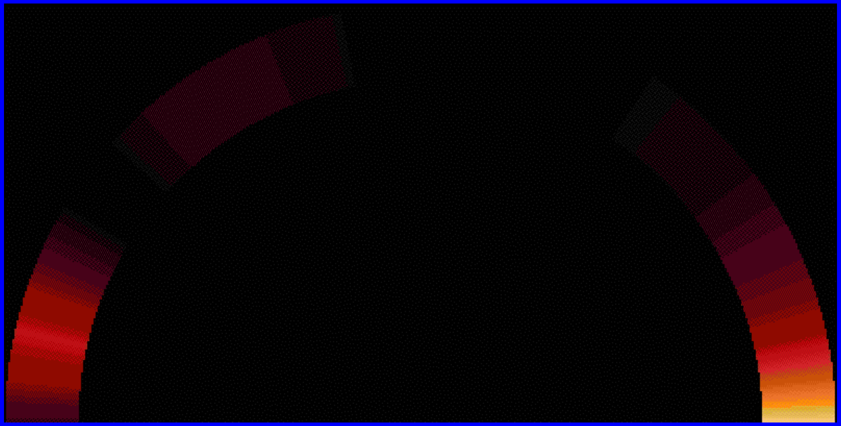
Reale et al. 2000, ApJ, 535, 412 , Reale et al. 2000, ApJ, 535, 423

Loop modeling:
A brightening coronal loop observed w/ TRACE

Heating in corona

Heating at the footpoint

Data (loop model format)



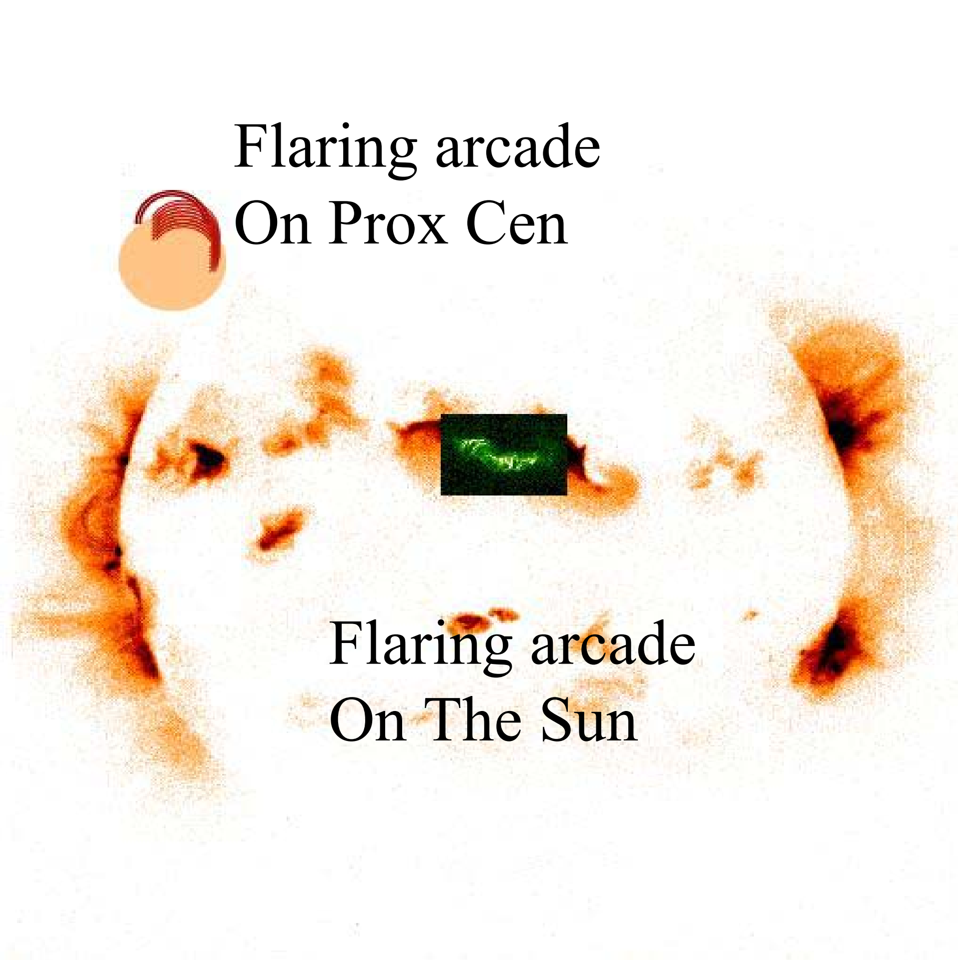
Loop modeling: Overview

- Steady-state modeling:
  - Scaling laws & first numerical models: *SKYLAB* (Rosner et al. 1978, Serio et al. 1981)
  - Loop diagnostics: *NIXT, TRACE, Yohkoh* (Peres et al. 1994, Reale & Peres 2000, Testa et al. 2002, Reale 2002)
  - Stellar loop fitting: *RoSAT* (Maggio et al. 1994)
  - Diagnostics of siphon flows and solar wind: *SoHO* (Orlando et al. 1995, 1996, 1997a,b)
- Modeling of transients and flares:
  - Diagnostics of solar flares: *SMM, Yohkoh* (Peres et al. 1987, Serio et al. 1991, Peres & Reale 1993a, b, Reale & Peres 1995)
  - Loop modeling of stellar flares and diagnostics of the decay phase: *Einstein, RoSAT, ASCA, XMM-Newton* (Reale et al. 1988, 1993, 1997, Reale & Micela 1998, Reale et al. 2004) - *see pres. A. Maggio*
  - Loop stability, transients and microflaring: *SMM, Yohkoh* (Peres et al. 1982, Peres et al. 1992, Reale et al. 2000)

Loop modeling:
Current projects

- Solar loops:
  – Benchmark analysis of coronal loops: *TRACE, Yohkoh, SoHO* (*F. Reale, A. Ciaravella, G. Peres*)
  – Loop heating by microflares: *TRACE, Yohkoh, SoHO* (*G. Peres, P. Testa, F. Reale*)

- Stellar flares: *Chandra, XMM-Newton* (*F. Reale, G. Micela, I. Pillitteri*) – *see pres. G. Micela*



Unconfined plasma modeling

- Participants:
  - DSF&A/UniPa: *G. Peres, F. Reale, S. Bonito(Laur.*)
  - INAF/OAPa: *S. Orlando, F. Bocchino*
- Main collaborations: *R. Rosner (Chicago/USA), J.C. Raymond (CfA/USA), F. Favata (ESA)*
- Tools: *Palermo FCT code, FLASH code, HPC (OAPa/SCAN, CINECA)*

Unconfined plasma modeling

- Hydrodynamics of unconfined plasma
- Last generation hydrodynamic codes and HPC systems
- Topics:
  - SNR/ISM interaction
  - PMS stellar jets
  - CME hydrodynamic modeling
  - Unconfined stellar flares
  - Thermal stability of cluster cooling flows & solar transition region

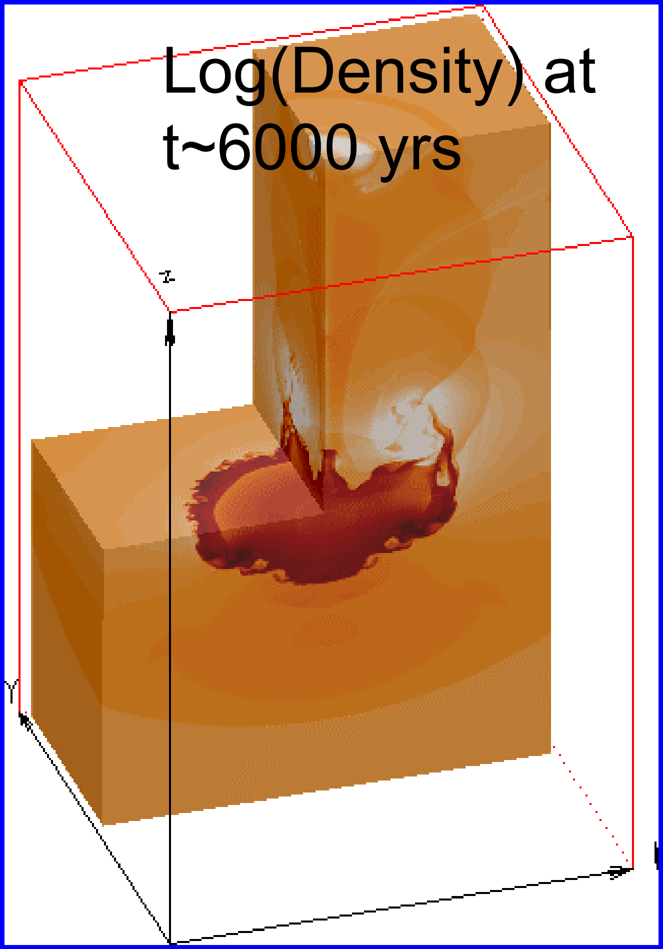
Unconfined plasma modeling

- Completed works:
  – Thermal stability of cooling flows & solar transition region: *RoSAT, SoHO* (Reale et al. 1991, 1994, 1995, 1996)
  – CME hydrodynamic modeling: *SoHO* (Ciaravella et al. 2001)
  – Unconfined coronal flares: *Chandra* (Reale et al. 2002)

- Current projects:
  – SNR/ISM interaction: *Chandra, XMM-Newton* (Key Project INAF/CINECA, Orlando et al., in preparation)
  – PMS star jets: *Chandra, XMM-Newton* (S. Bonito thesis)

Unconfined plasma modeling:
SNR shock onto ISM cloud

- Objectives:
  - compare the role of physical processes: therm. conduction, radiative losses, NEI
  - interpret X-ray observations (Chandra, XMM-Newton) – *see pres. A. Maggio*
- Implementation:
  - 2-D and 3-D hydro-simulations:
    - Key project INAF/CINECA
    - OAPa/SCAN
- Status:
  - Simulations just completed
  - Analysis in progress (*Orlando et al., in preparation*)



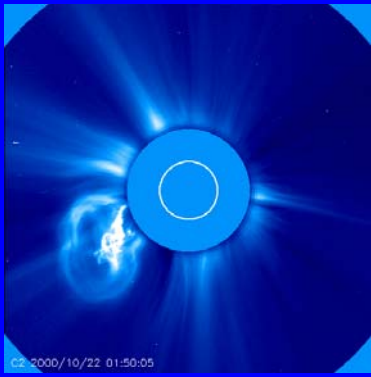
Coronal plasma diagnostics

- Participants:
  - UniPa/DSF&A: *G. Peres, F. Reale*
  - INAF/OAPa: *S. Orlando, A. Ciaravella*
- Main collaborations: *R. Rosner (Chicago), J.C. Raymond, J. Kohl (CfA)*
- Tools: Solar SoftWare (SSW), XSPEC

Coronal plasma diagnostics

- Diagnostics from data analysis
- Topics:
  - Loop diagnostics & Coronal Mass Ejections (*Yohkoh, SoHO, TRACE*)
  - The Sun as an X-ray Star (*Yohkoh, RoSAT, ASCA, Chandra, XMM-Newton*)

Coronal plasma diagnostics:
Coronal Mass Ejections

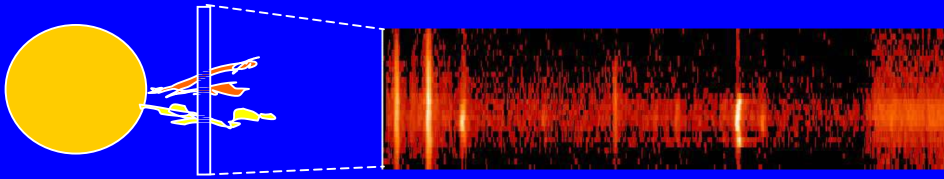


10^{16} g
up to 2000 km/sec } 10^{32} erg

SoHO (*Solar and Heliospheric Observatory*)

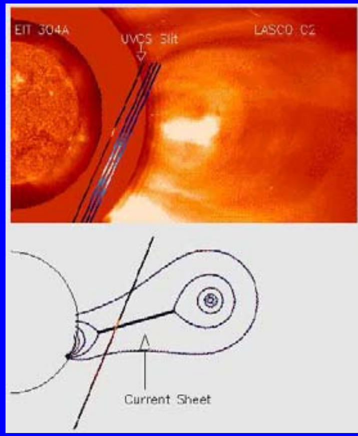
Multiwavelength observations

UV Spectroscopy:



- *Analysis:*
  - *Temperature, density, ionization stage*
  - *Shock diagnostics*
  - *Energetic evolution*
  - *Line of sight speed and 3D reconstruction*
- *Constraints on theoretical Models*:

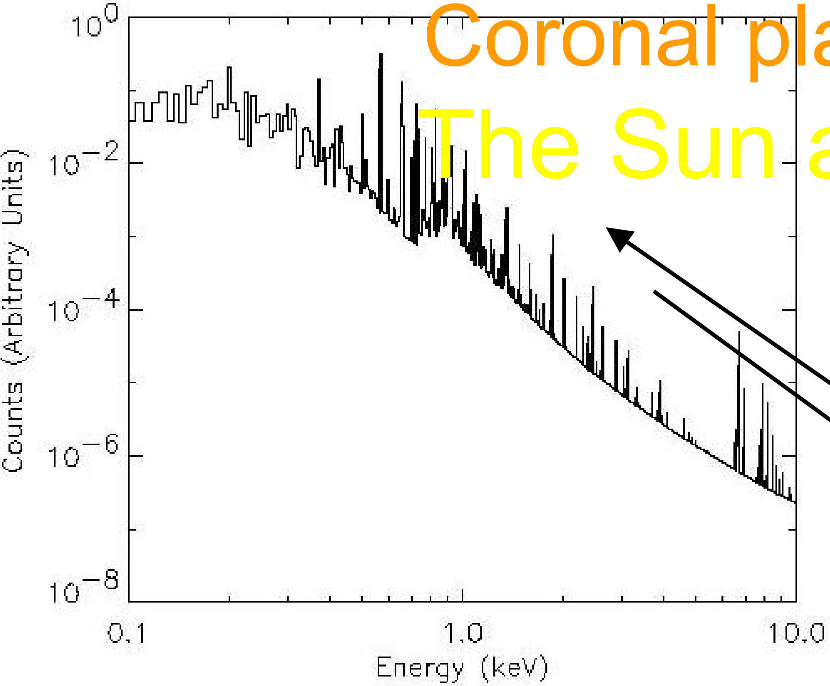
e.g. a narrow hot feature is evidence of a current sheet predicted by some CME models (Ciaravella et al. 2002 ***)***

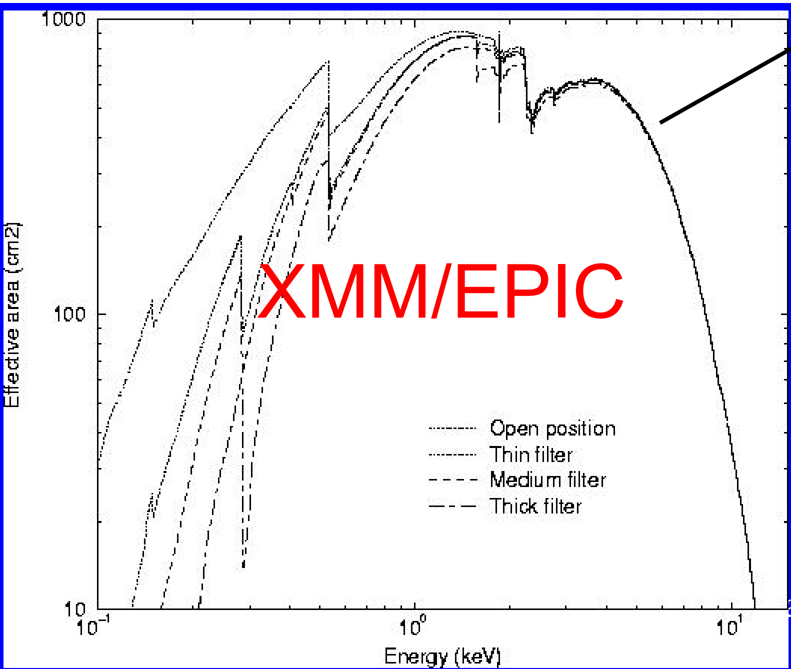


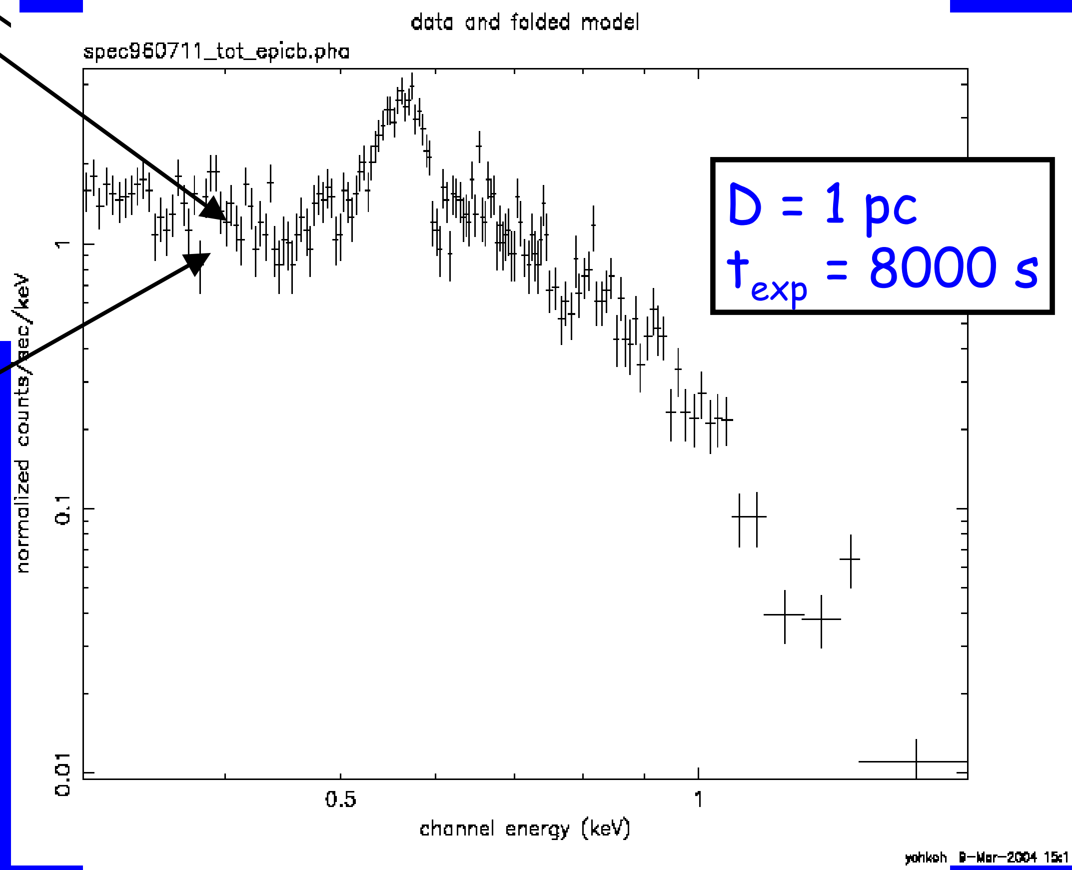
Coronal plasma diagnostics:
The Sun as an X-ray Star

- Link solar & stellar coronal physics
- Use know-how from solar coronal physics
- Analyze solar phenomena in stellar context
- Analyze contribution of coronal building blocks (*flares, active regions, quiet regions*) to stellar coronae
- A template to interpret stellar coronal data

Coronal plasma diagnostics: The Sun as an X-ray Star







$D = 1$ pc
$t_{exp} = 8000$ s

Perspectives

- State-of-art loop plasma modeling & diagnostics (microflares & fine structure)
- Full MHD 3-D modeling (FLASH + HPC)
- Solar-B and Solar Dynamic Observatory missions
- Extensive stellar flares studies (Chandra & XMM-Newton data)

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