THEME:

"The Underlying Processes Are the Same Across All Scales and Reference Frames"

OUR JOB: Infer Substances and Physics + *Quantify 'Doubt'*

"We can do it right" - Basic Equations --

Model-Based; Computational AstroStatistics

OUTLINE:

- Modeling Astrophysics: Lights + Gratings
- Grand Tour of "Modern Physics"
- Grand Tour of the Skies (Sun Outward)

Additional Thread: History: Women in Astro/Physics/Stat (Boston/Harvard, California, ...)

Thanks to: CBASC; V. Trimble; Lecture/Demo

Example 1: What Do We Mean By:

OUR JOB: Infer Substances and Physics + *Quantify 'Doubt'*

"We can do it right" - Basic Equations --

Model-Based; Computational AstroStatistics

Early Example: Galaxy Clustering as done by UCB Astro-Statisticians Elizabeth Scott and Jerzy Neyman

Used nth-order clustering process to model galaxies attracted to each other into clusters; clusters attracted to each other; etc. I.E. a non-parametric method to distill meaning from 'large' data-sets.

NOW: More explicit physical models

Personal Recollections, from Early Life to Old Age, of Mary Somerville (London: John Murray, 1874, p133-134)

'One bright morning Dr. Wollaston came to pay us a visit in Hanover Square, saying "I have discovered seven dark line crossing the solar spectrum, which I wish to show you;" then, closing the window-shutters so as to leave only a narrow line of light, he put a small glass prism into my hand, telling me how to hold it. I saw them distinctly. I was among the first, if not the very first, to whom he showed these lines, which were the origin of the most wonderful series of cosmic discoveries, and have proved that many of the substances of our globe are also constituents of the sun, the stars, and even the nebulae. Dr. Wollaston gave me the little prism, which is doubly valuable, being of glass manufactured at Munich by Fraunhofer, whose table of dark lines has now become the standard of comparison in that marvellous science, the work of many illustrious men, brough to perfection by Bunsen and Kirchoff.'

OUR JOB: Infer Substances and Physics + *Quantify 'Doubt'*

Part 1: Modeling Astrophysics+Instruments +Inference *Via* Local Lights + Gratings

(Pause while we try to do it)

Part 2: Modeling Astrophysics+Instruments +Inference *Via* Equations

Cecelia Payne (Gaposchkin) - 1st Harvard Astronomy Professor; 1st (Arguably) Full Woman Professor; 1st to put together 'Modern' physics with Astronomy

Modern Physics: Quantum Mechanics Electricity/Magnetism/Atomic Physics

* Black-Body: Thermal+ Optically thick

$I(\nu,T)\, d\nu = (2h\nu^3/c^2)\,(e^{(h\nu/kT)}-1)^{-1}$

-- Sun (roughly)

-- Incandescent bulbs

-- neutron star surfaces, white dwarf surfaces

* Atomic Lines - Simplified 1 electron + 1 nucleus:

Position given by:

$E = h\nu = Ry^*(1/n_1^2 - 1/n_2^2)$

where n_1 and n_2 == diameter of electron orbits in number of wavelengths

Width/Shape (**Lorentzian**) given by:

$\Delta E \sim h/dt$, where "t" ~ time uncertainty

ALSO Density broadening; Doppler Shifts/broadening; electric/magnetic field effects; etc.

Modern Physics: Quantum Mechanics Electricity/Magnetism/Atomic Physics

* Bremsstrahlung+lines / 'Table' Plasma Models:
  Thermal + Optically thin
  $\mathbf{I(\nu,T) \sim a_o\, g(T,\nu)\, Z^2\, n_e n_i T^{-(1/2)}\, e^{-(h\nu/kT)}}$

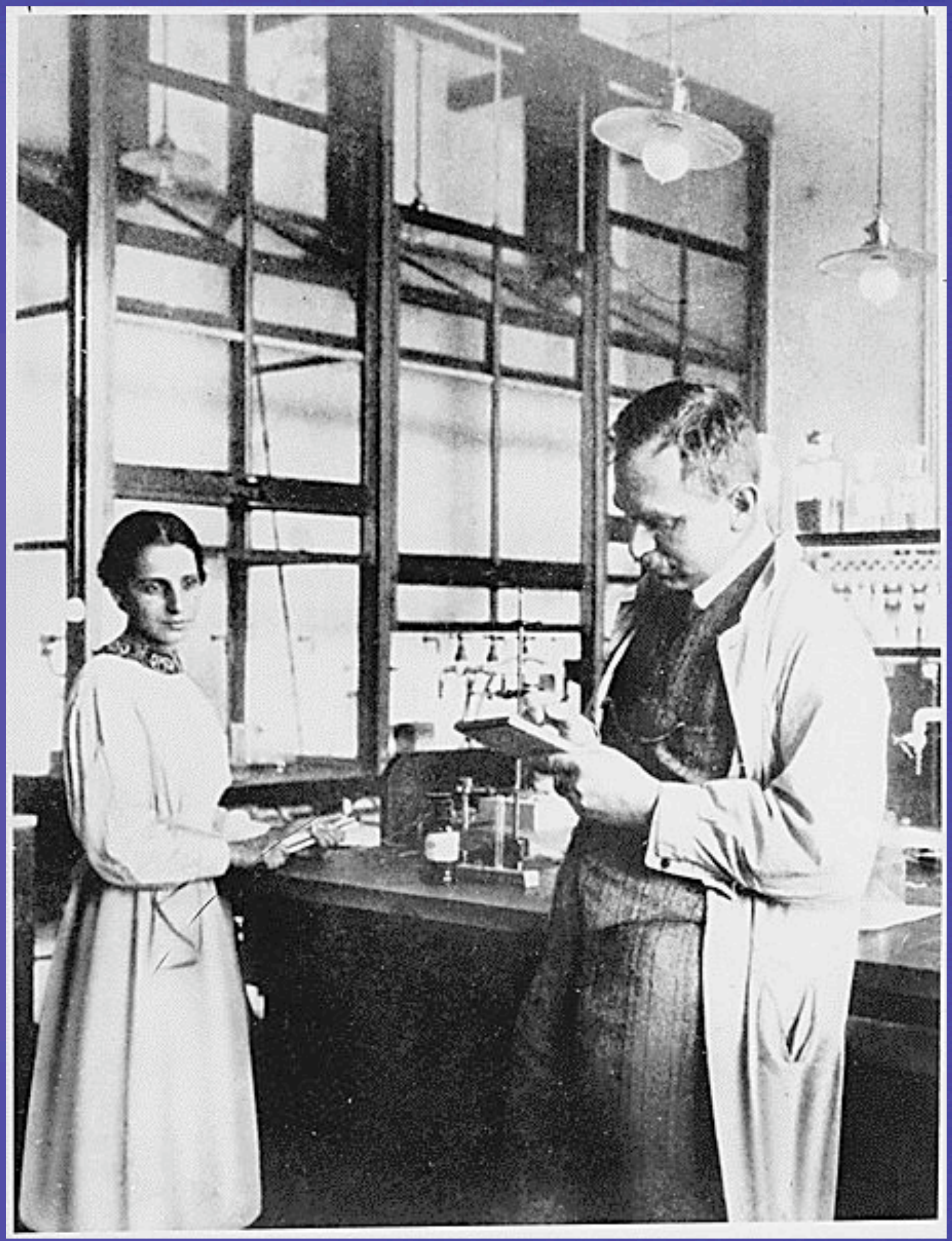
  where n_e and n_i == number density of elecrons and ions, respectively;
  g is the "Gaunt Factor"; Z is the nuclear charge; ao is a constant.

  I(ν,T) <= Atomic Line Tables (VL,VK,NB)

-- Solar / stellar corona (roughly)
-- Fluorescent bulbs
-- Supernova remnant shells, knots

* Power Laws - Simplified shock/nonthermal:
  Position given by:
  $\mathbf{I(\nu,T) = A\, (h\nu)^{-\Gamma}}$

Part 2: Modeling Astrophysics+Instruments +Inference *Via* Equations (nuclear)



Left: Maria Goeppert Mayer - "San Diego Housewife Wins Noble Prize" for elucidating *shells* in Nuclei ~1963 ;
Right: Lise Meitner and Otto Hahn Discovering Fission ~1940's

Modern Physics: Nuclear Physics/ Relativistic Physics

Nuclear Force Analogues: Nuclear lines from 'shells' in the nucleus -- both from burning (strong force - Nova / Supernova, thermonuclear flashes; stellar interiors; solar flares) and weak force (nuclear decay - remnants of old burning - stars, nova); Compton (photon/electron collisions); pions; etc.

Shock physics: magnetic and non, thermal and non-; relativistic and non-; results depend on particle input spectrum.

Relativistic Magnetic Fields

Pulsars and Magnetars pulling particles out of the vacuum

AGAIN from statistics of large numbers of particles.

Taking the Measurements Into Account:

Our Standard Equations for 'True' Intensity, Instrument, Data:

$S(l,b,e,t,\theta)$ = Expected 'True' Source Intensity
(i.e. our physics models)

$E(l,b,e,t,\varphi)$ = 'True' Effective Area
$PSF(x,y \mid l,b,e,t,\xi)$ = 'True' instrument smearing
$\Lambda(x,y,e,t,\theta,\varphi,\xi)$ = 'True' Expected counts in detector
$D(x,y,e,t,\theta,\varphi,\xi)$ = measured counts in detector

$$\Lambda(x,y,e,t,\theta,\varphi,\xi) = PSF(x,y|l,b,e,t,\xi)@E(l,b,e,t,\varphi)*S(l,b,e,t,\theta)$$

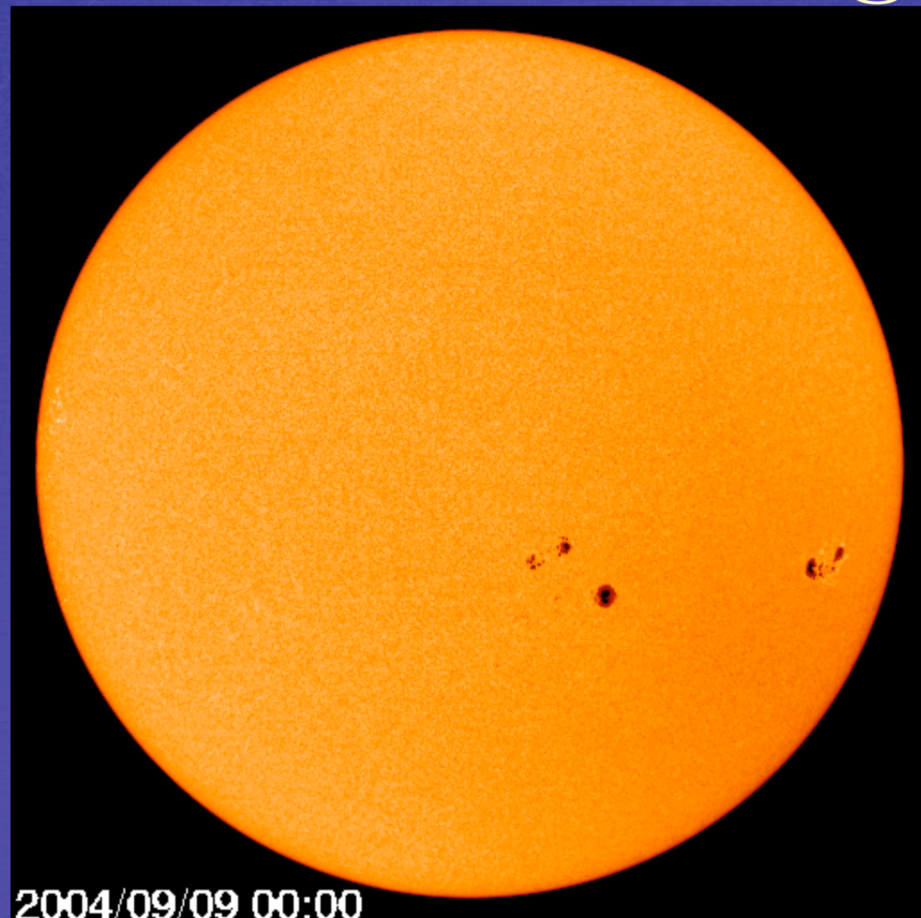
$$D(x,y,e,t,\theta,\varphi,\xi) \sim \text{Poisson}(\Lambda(x,y,e,t,\theta,\varphi,\xi))$$

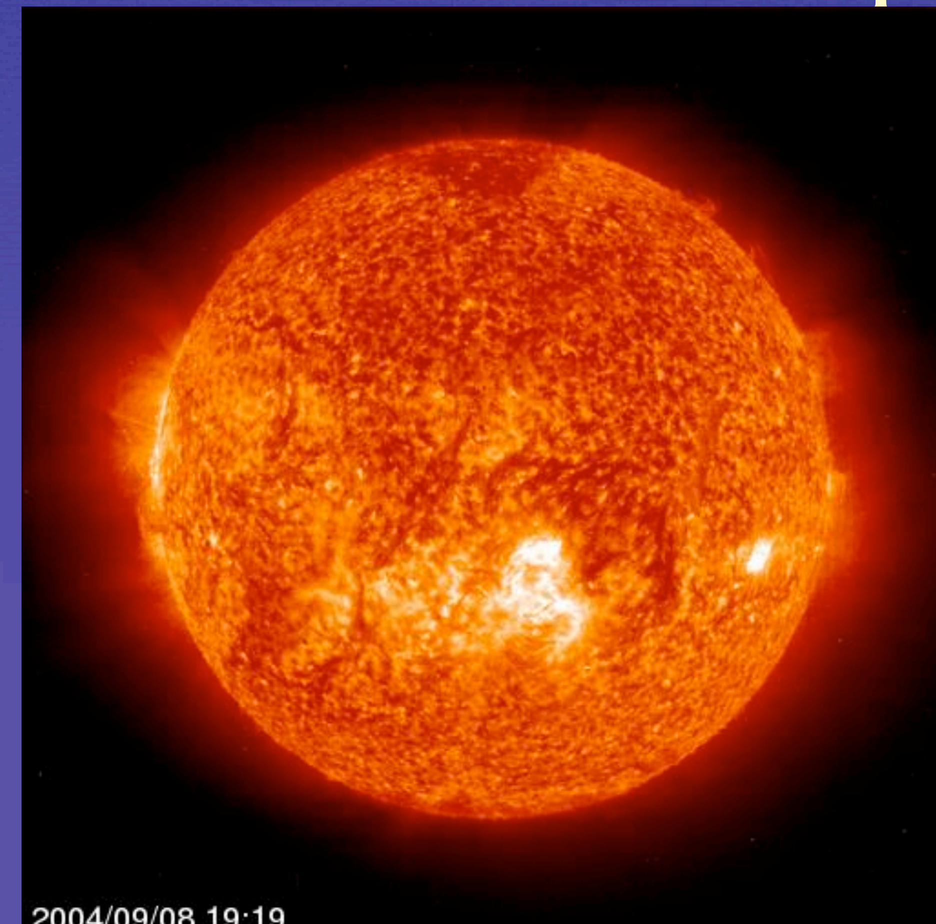
Part 4: Quick Grand Tour of the Sky

* Our Nearest Star in More Detail: The Sun
* Moving Out: Fun Solar System Views
* Stars: What can we learn from Spectra?

SOHO solar images from 2004-sep-08

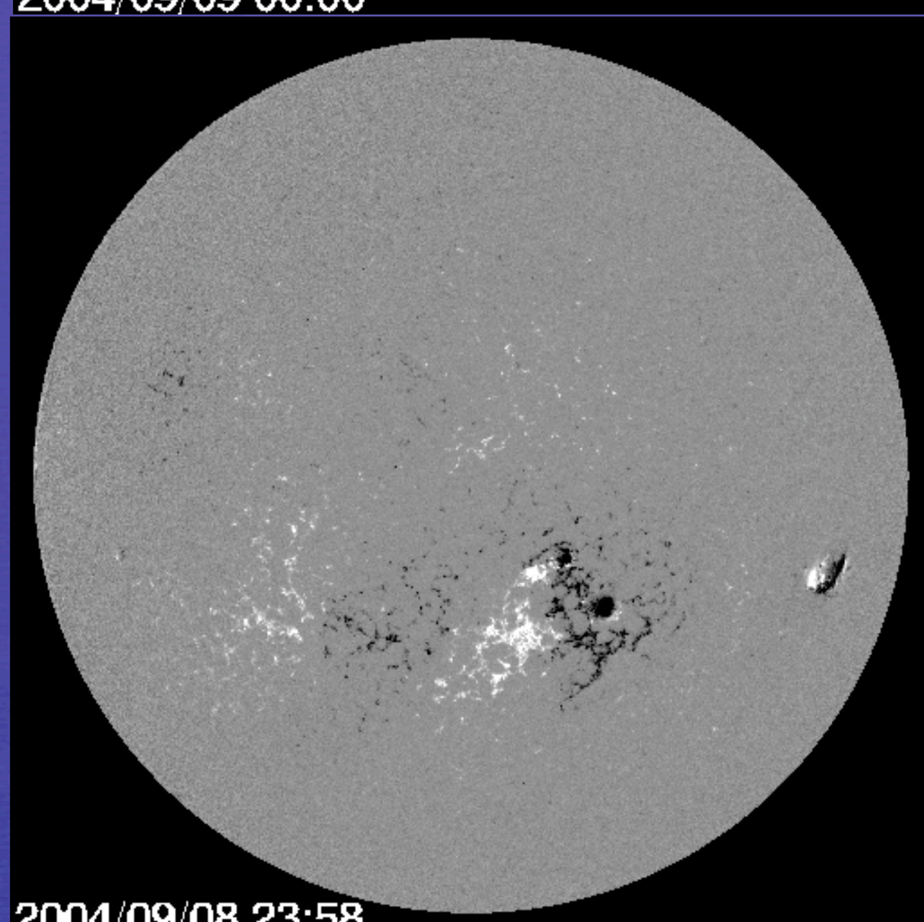
photo-
sphere

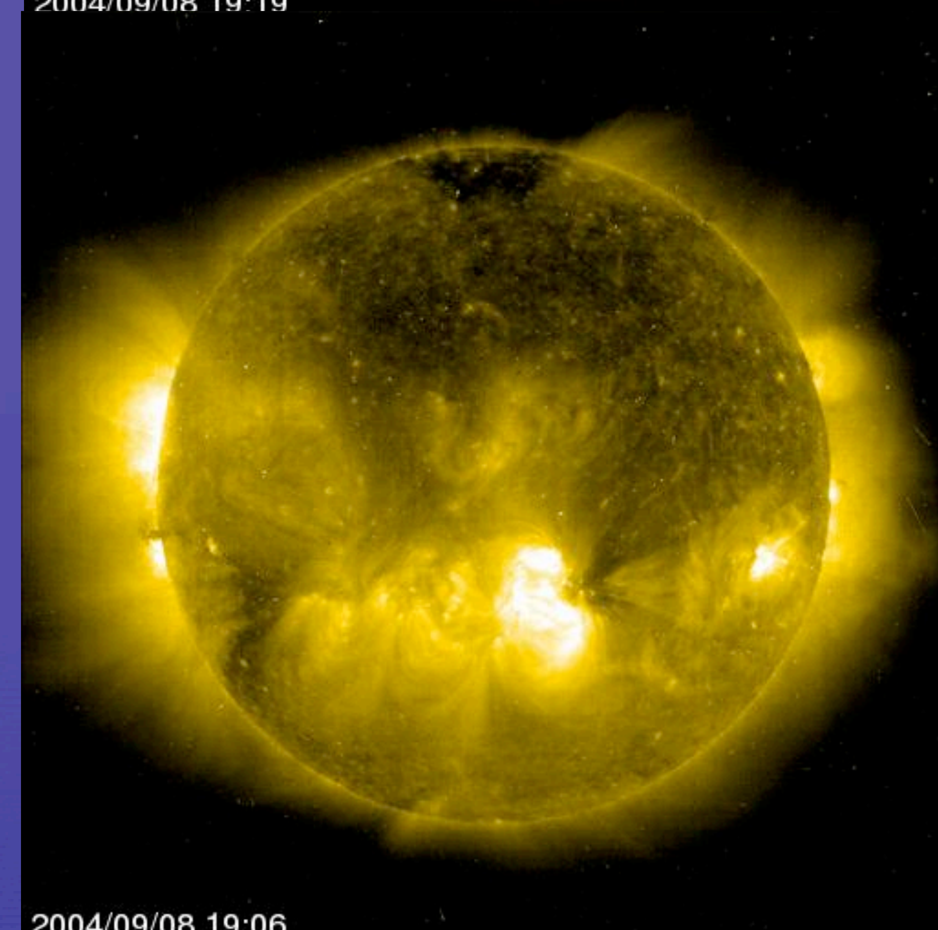




chromo
-sphere

magnet
o-gram

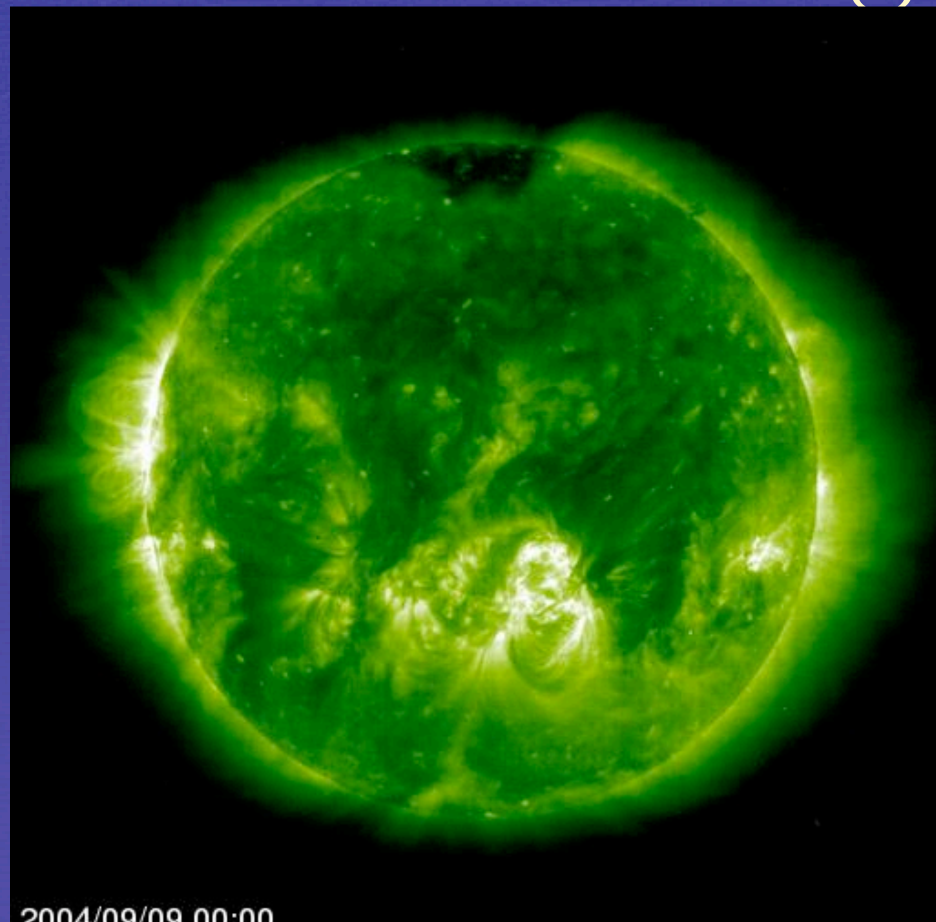


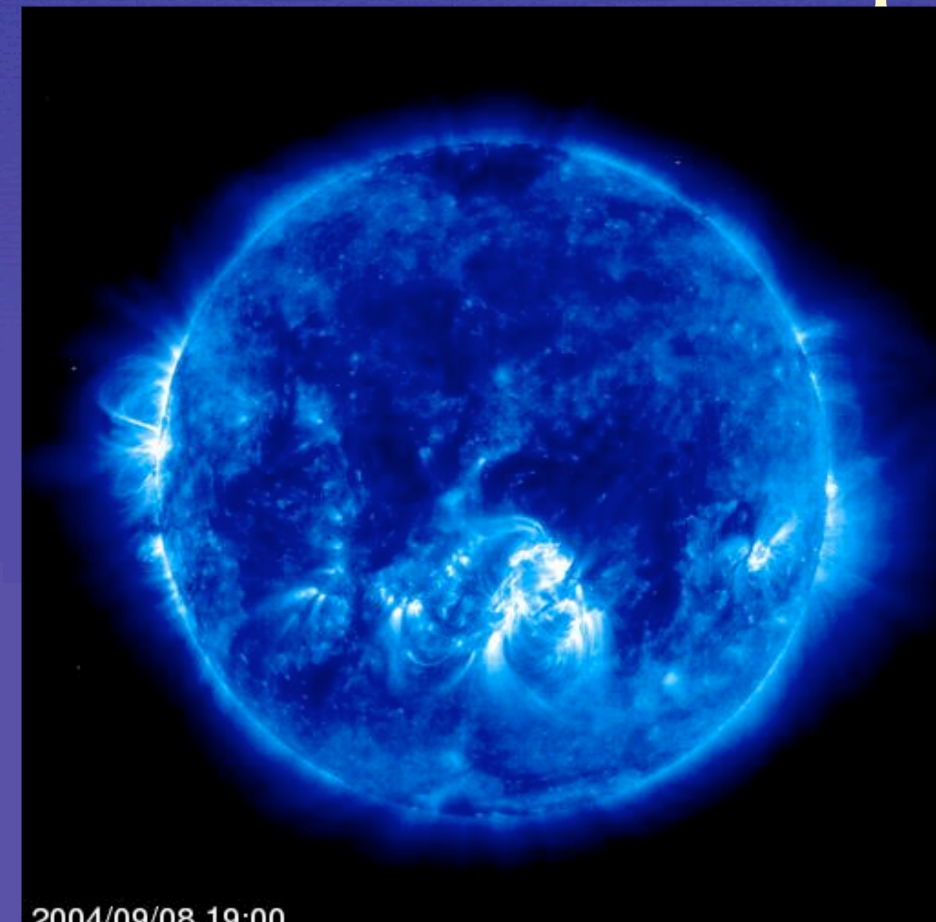


10^6 K
corona

SOHO solar images from 2004-sep-08

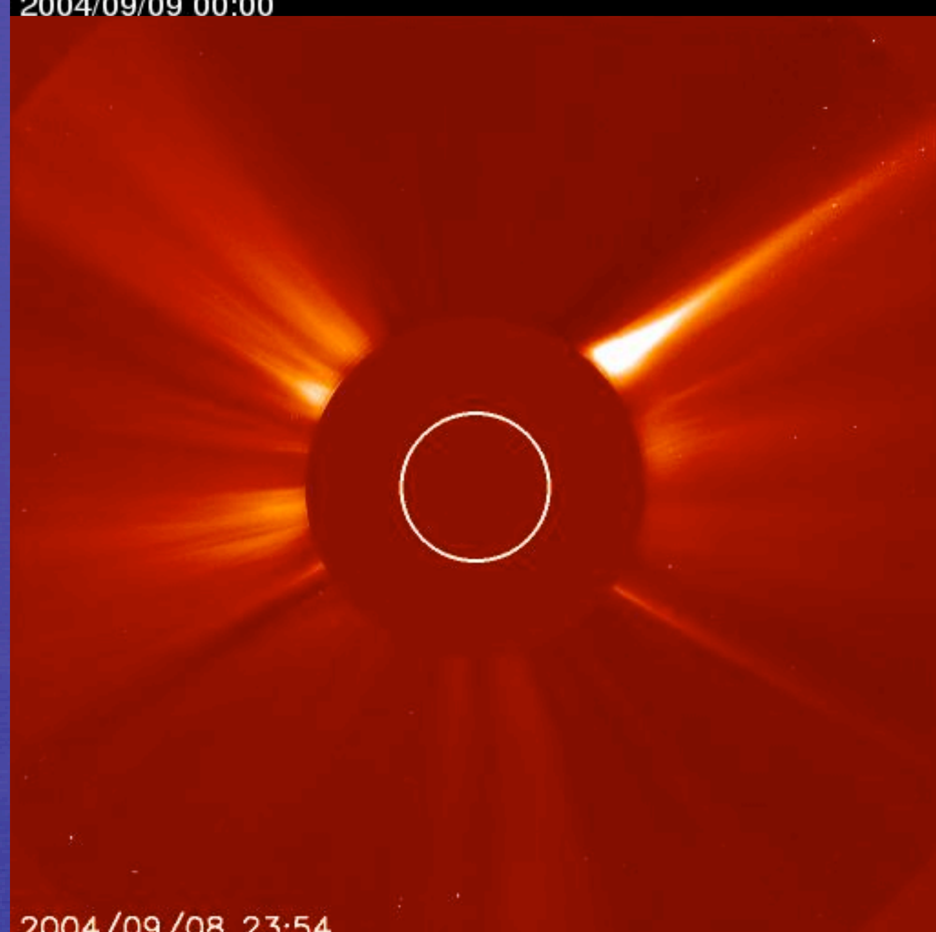
$2\ 10^6$ K corona

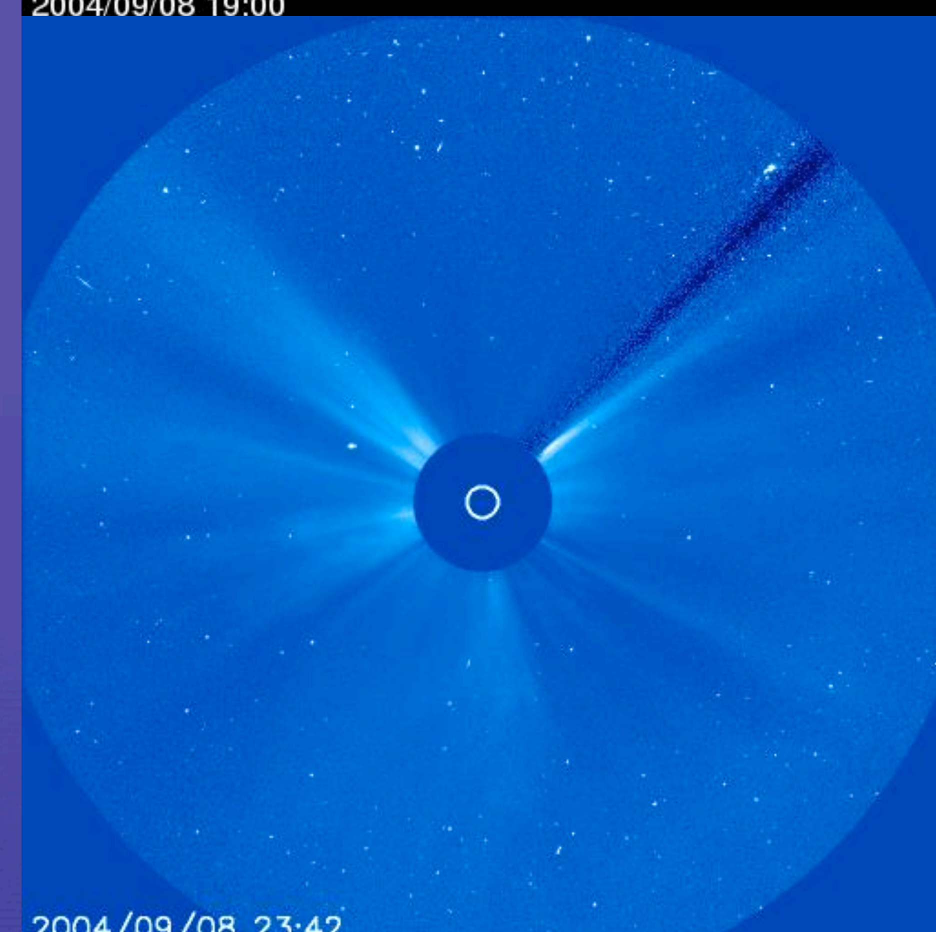




$3\ 10^6$ K corona

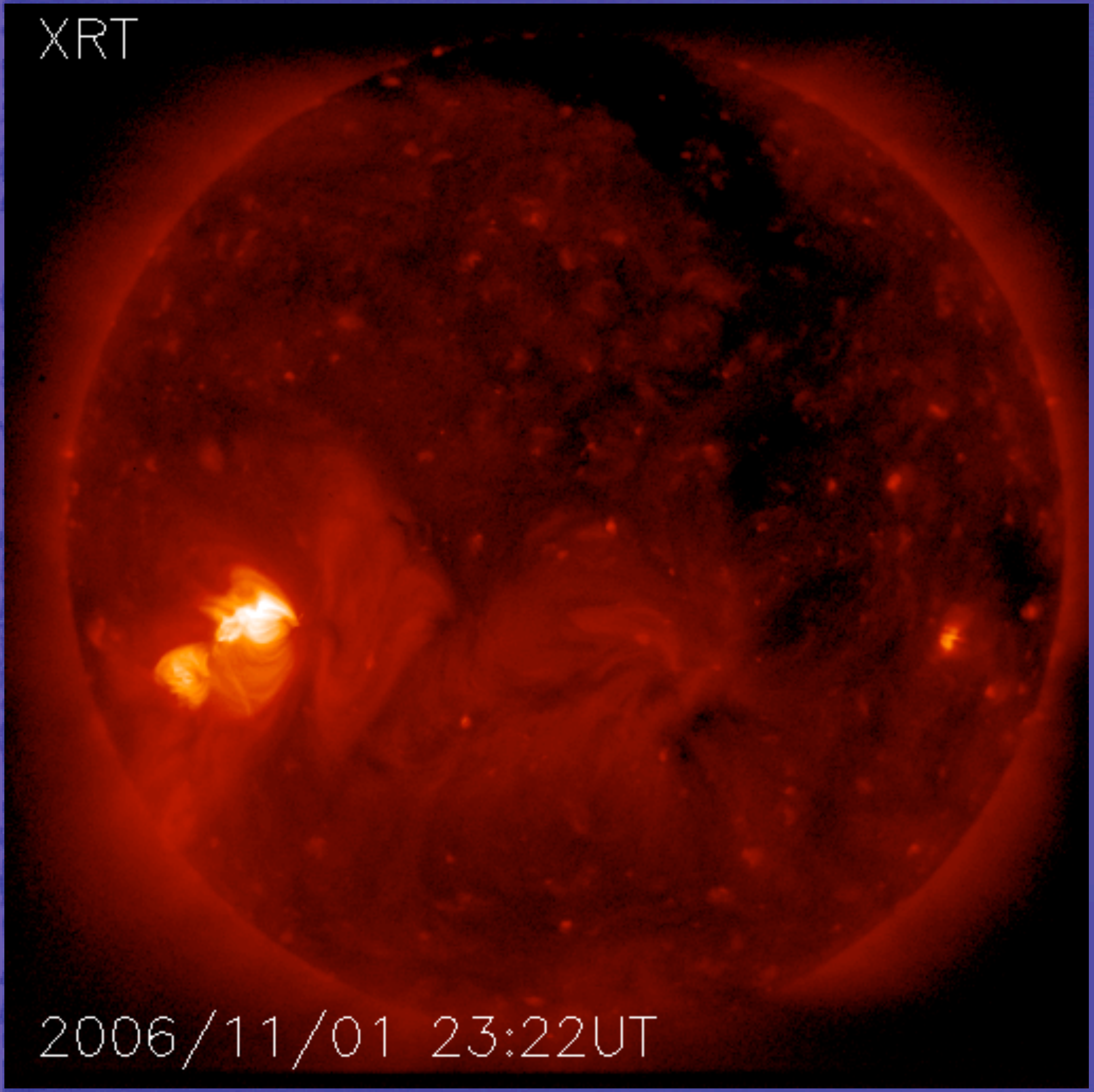
outer corona

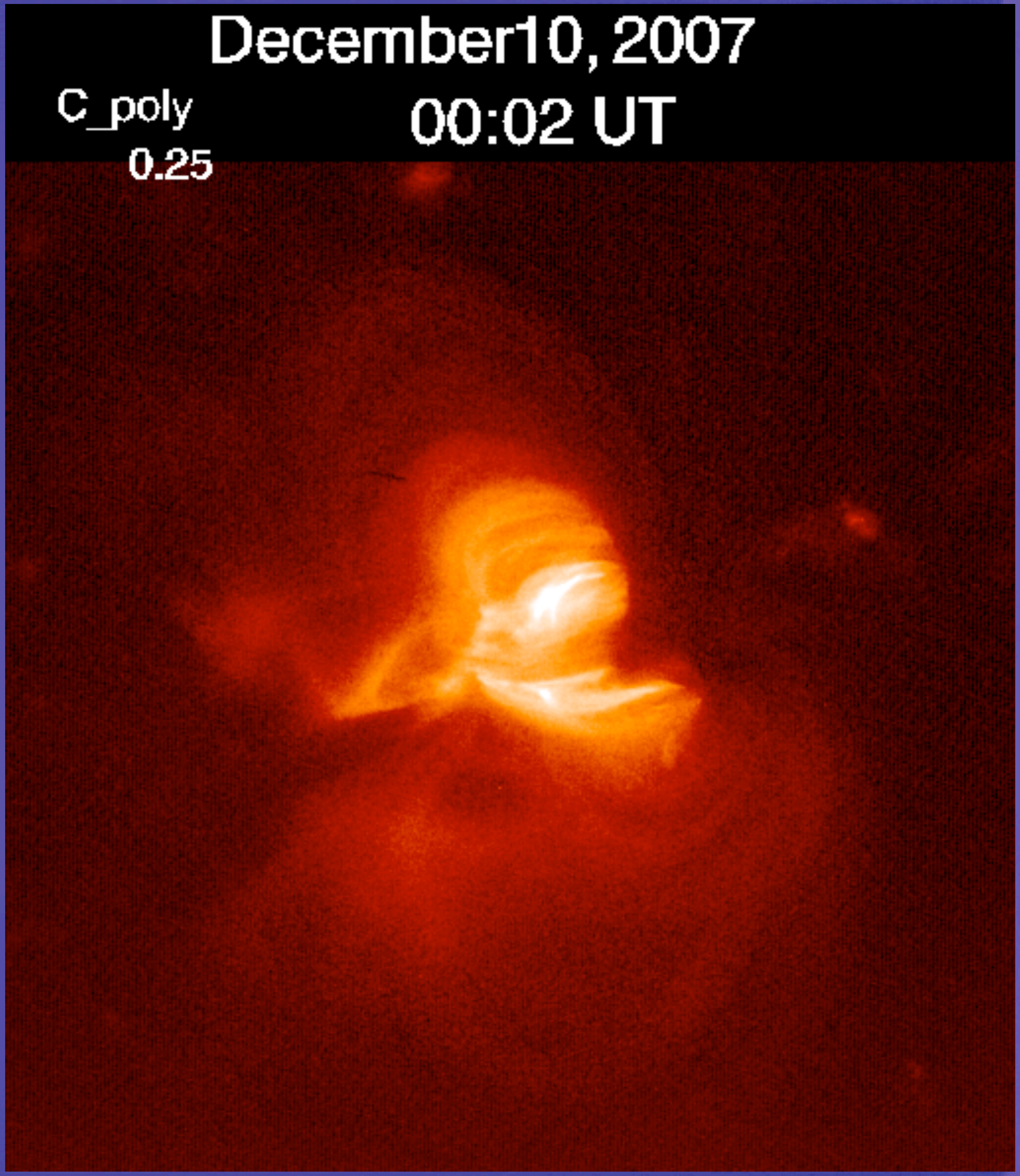




into the wind ...

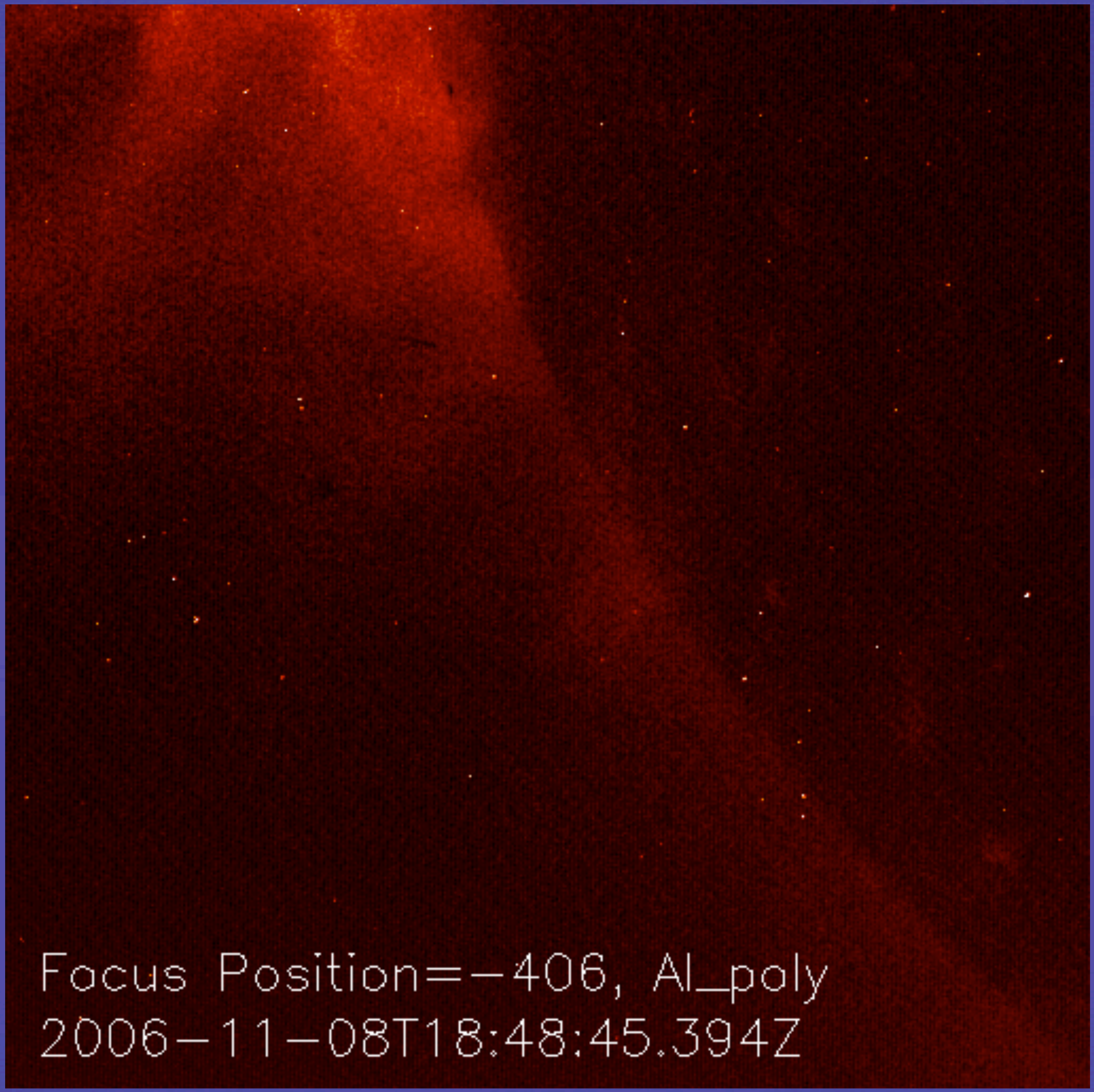
Hinode/XRT movies of our Sun:





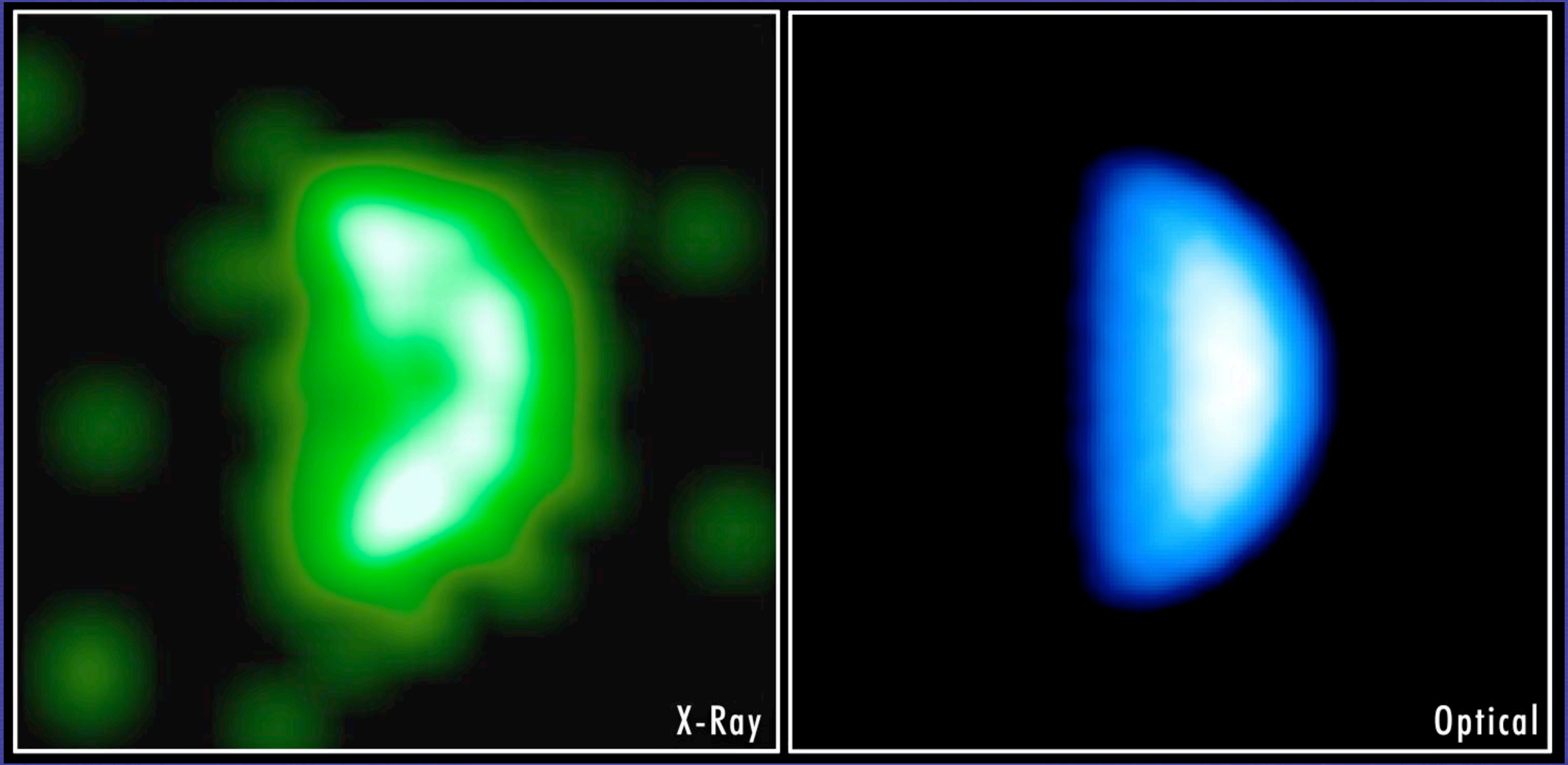
Left: 2006-Nov-25; Right: 2007-Dec-10

Moving Out: Fun Solar System Views



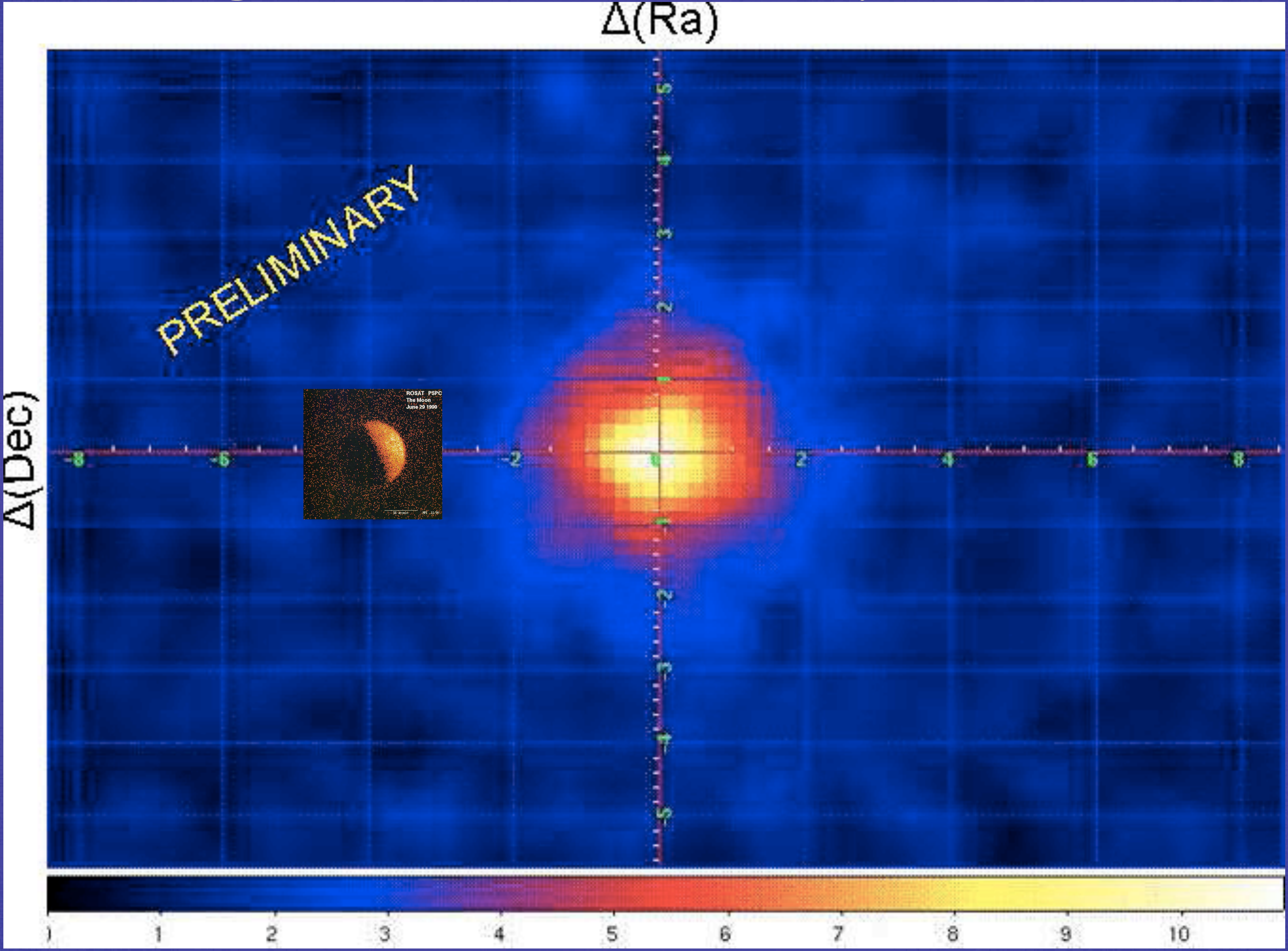
Hinode XRT: Mercury Transit Movie

Moving Out: Fun Solar System Views:



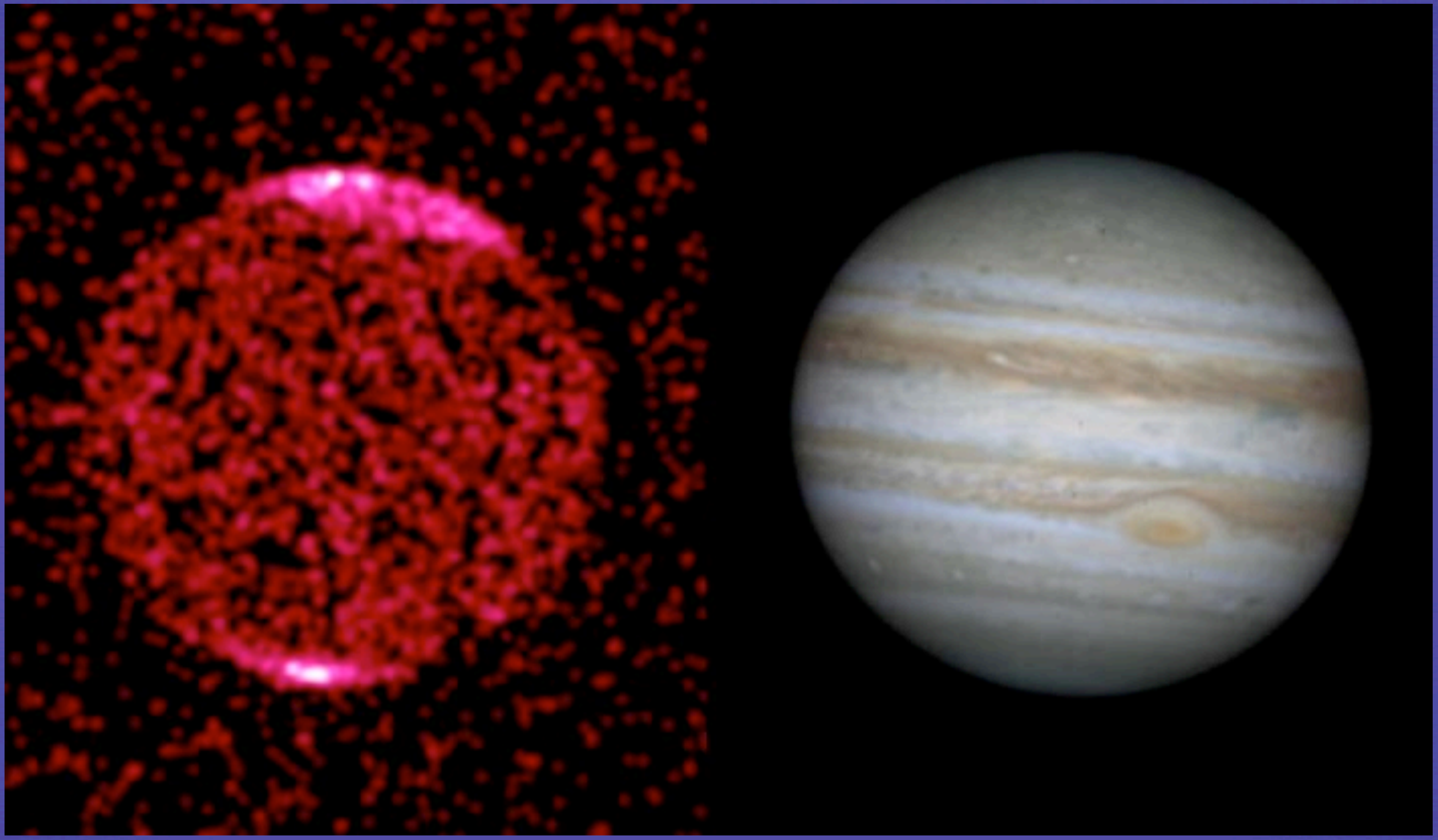
Chandra observation of Venus (flourescence, scattering of solar X-rays)

Moving Out: Fun Solar System Views:



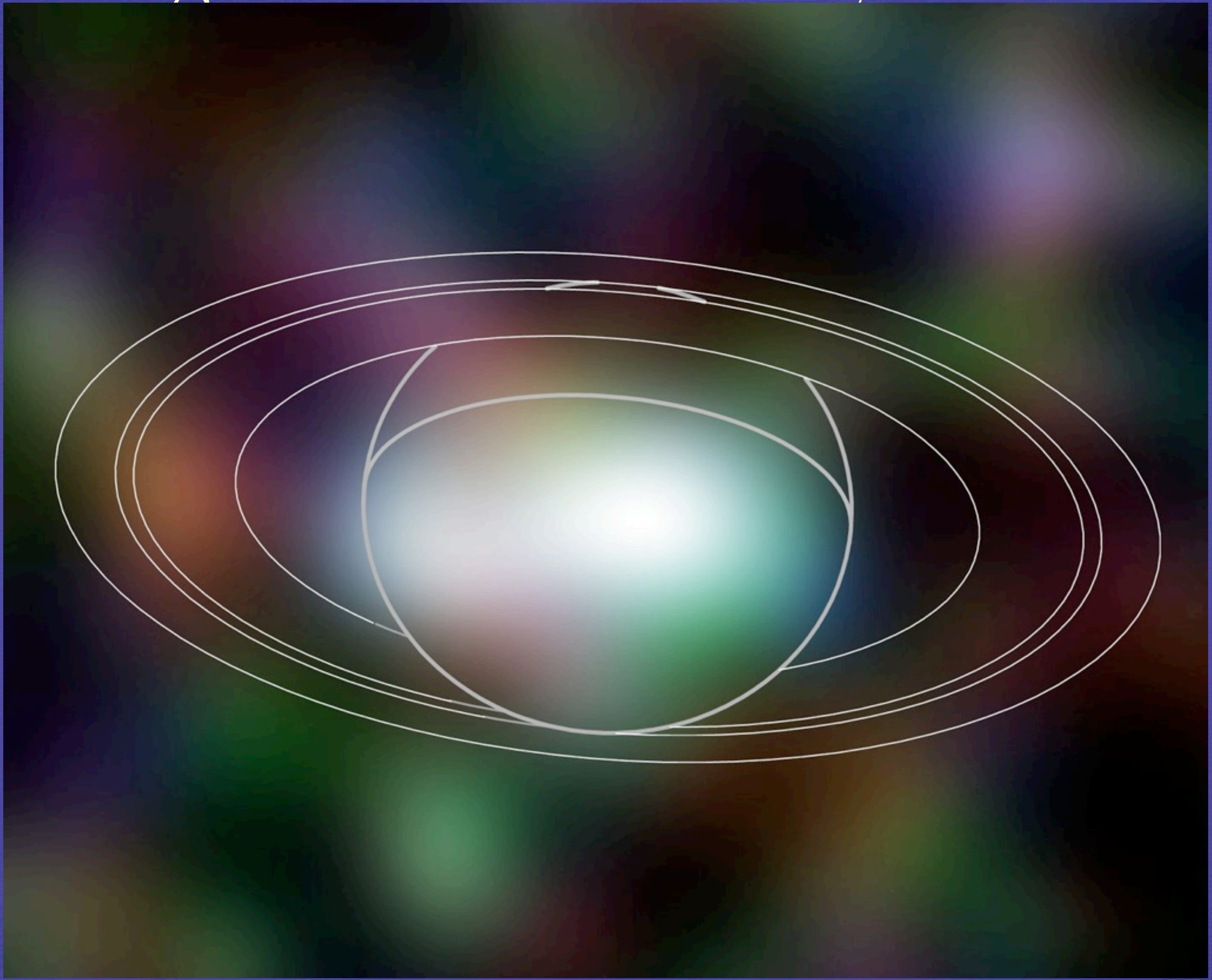
Moon: Rosat X-ray / Fermi γ-ray (cosmic ray activation)

Moving Out: Fun Solar System Views:



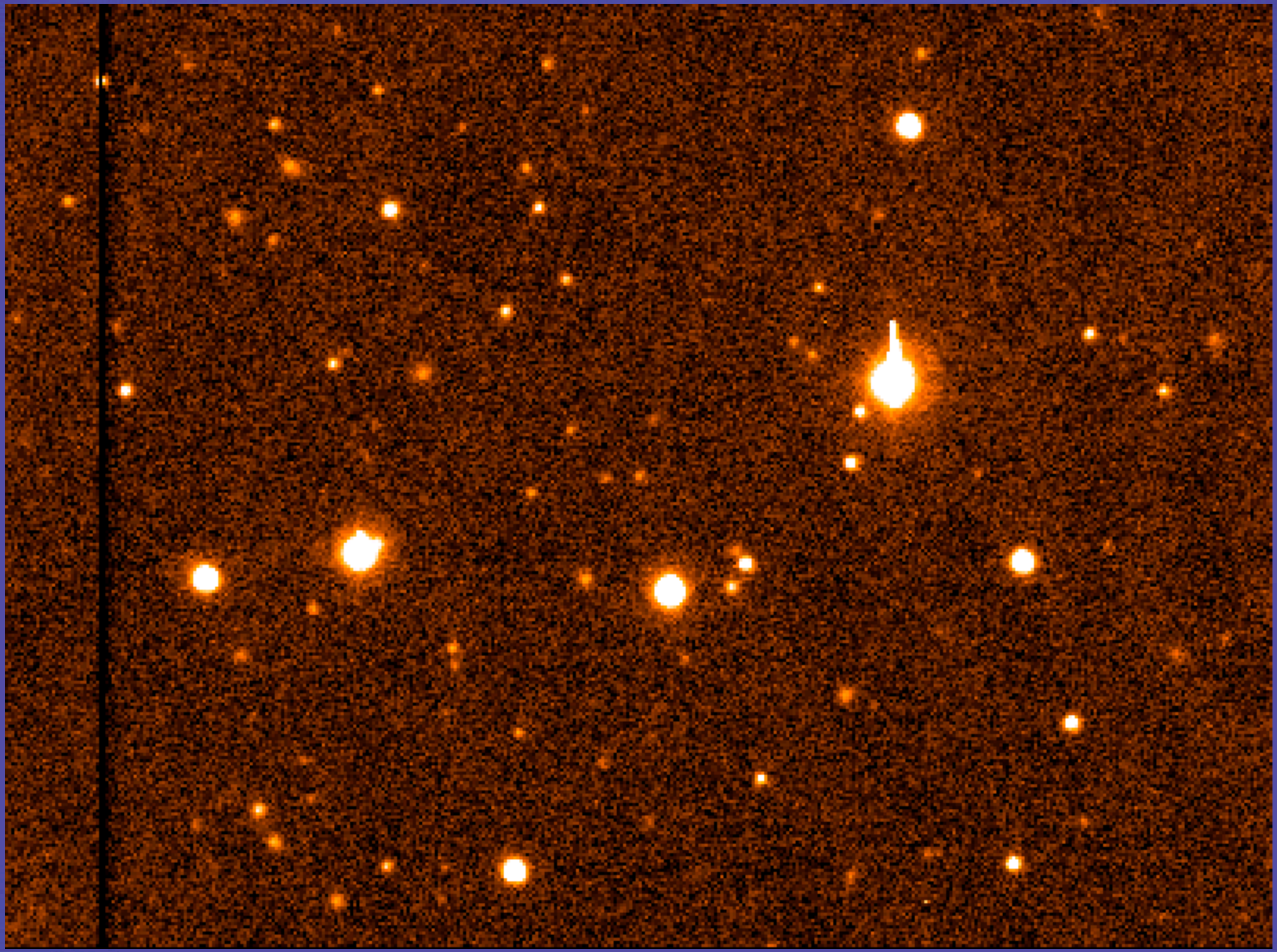
Left: X-rays: Chandra observation of Jupiter (aurorae)
Right: Optical for comparison

Moving Out: Fun Solar Sytem Views:



X-rays: Chandra observation of Saturn

Beyond planets: Kuiper Belt; Oort Cloud;

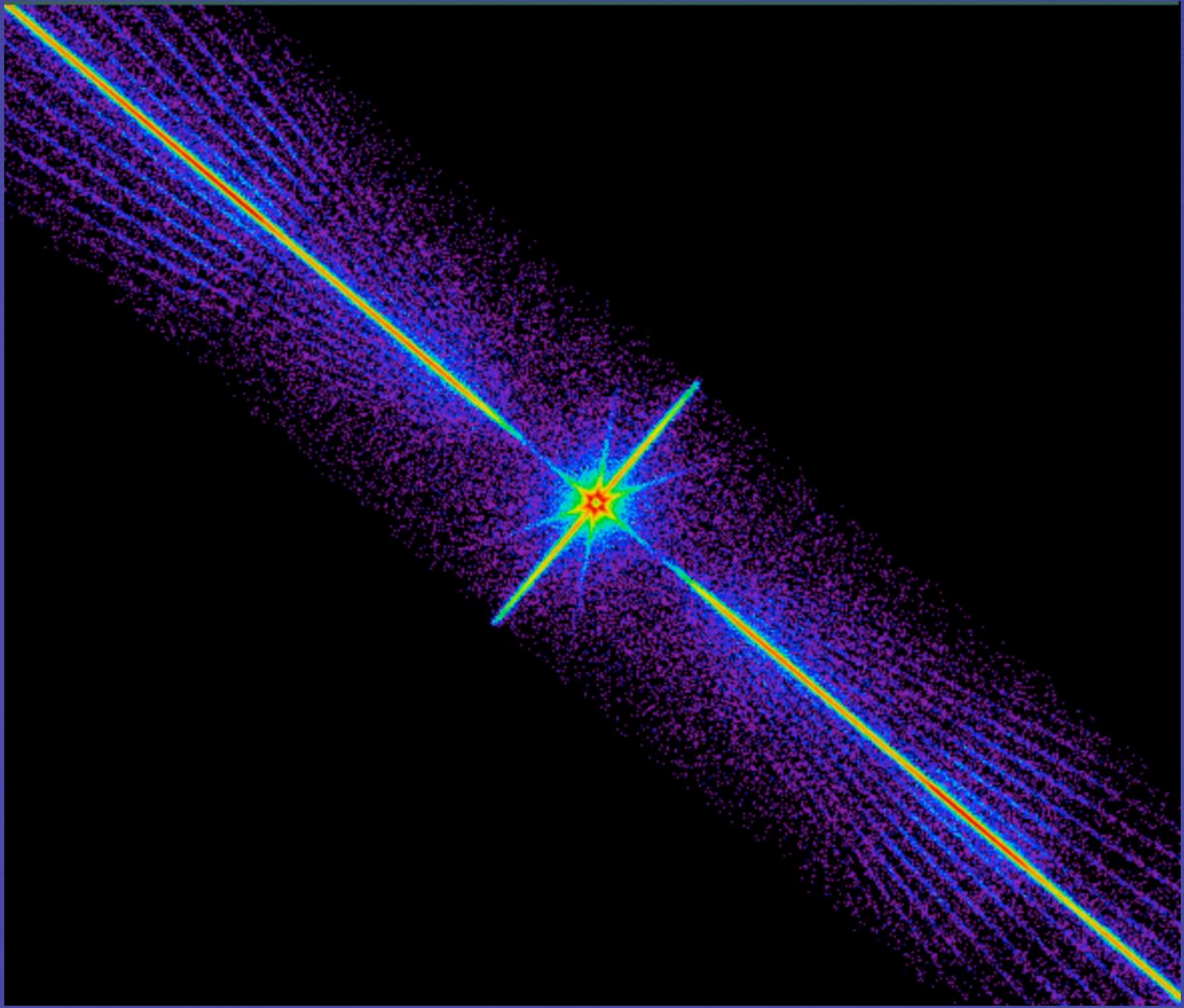


For Later: Ask Pavlos Protopapas and Alex Blocker -- time-domain astronomy!

Stars and Stellar Systems:

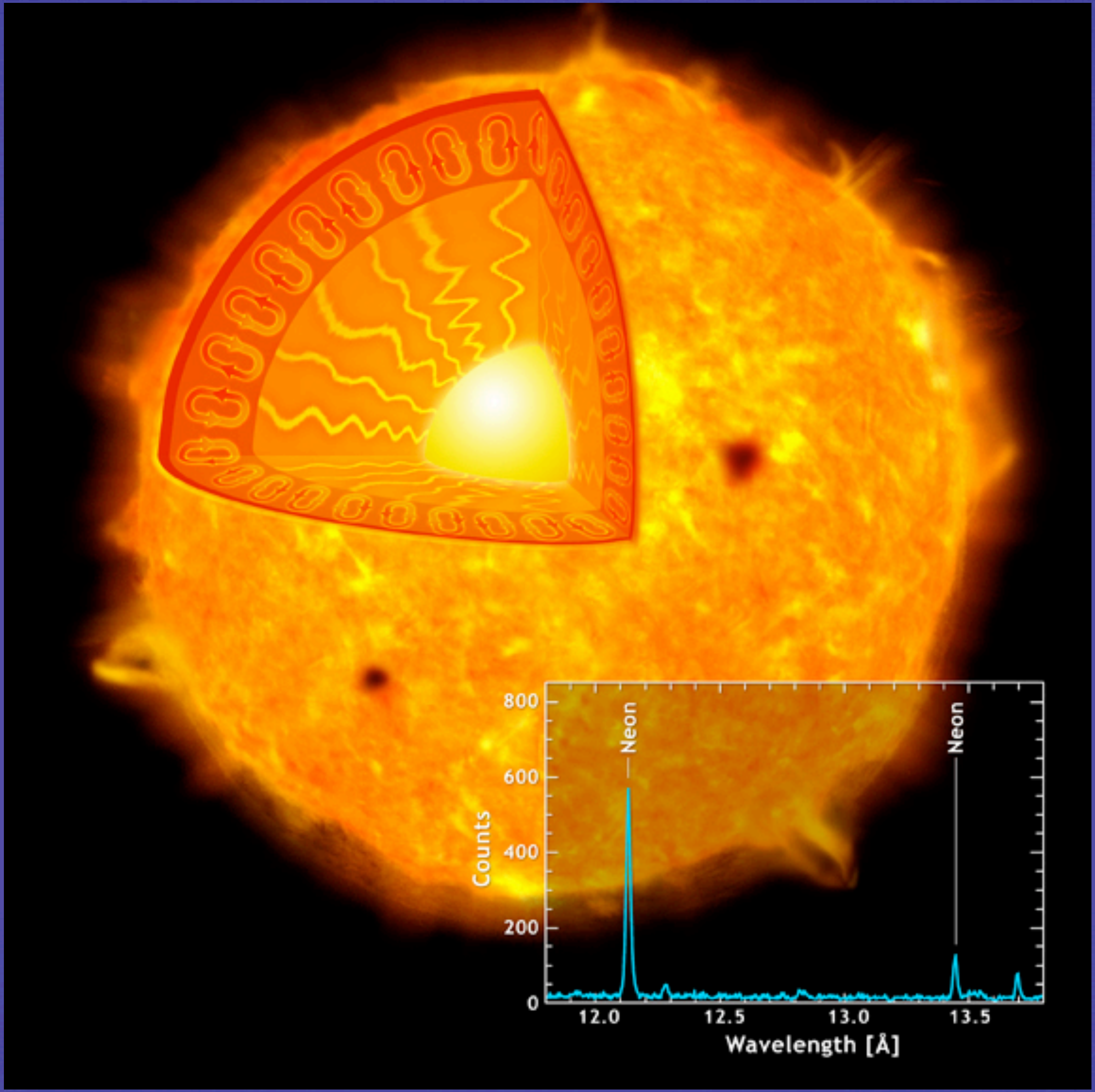
* What can we learn from Spectra?
* Populations / Surveys of Stars

Stars: What can we learn from Spectra?



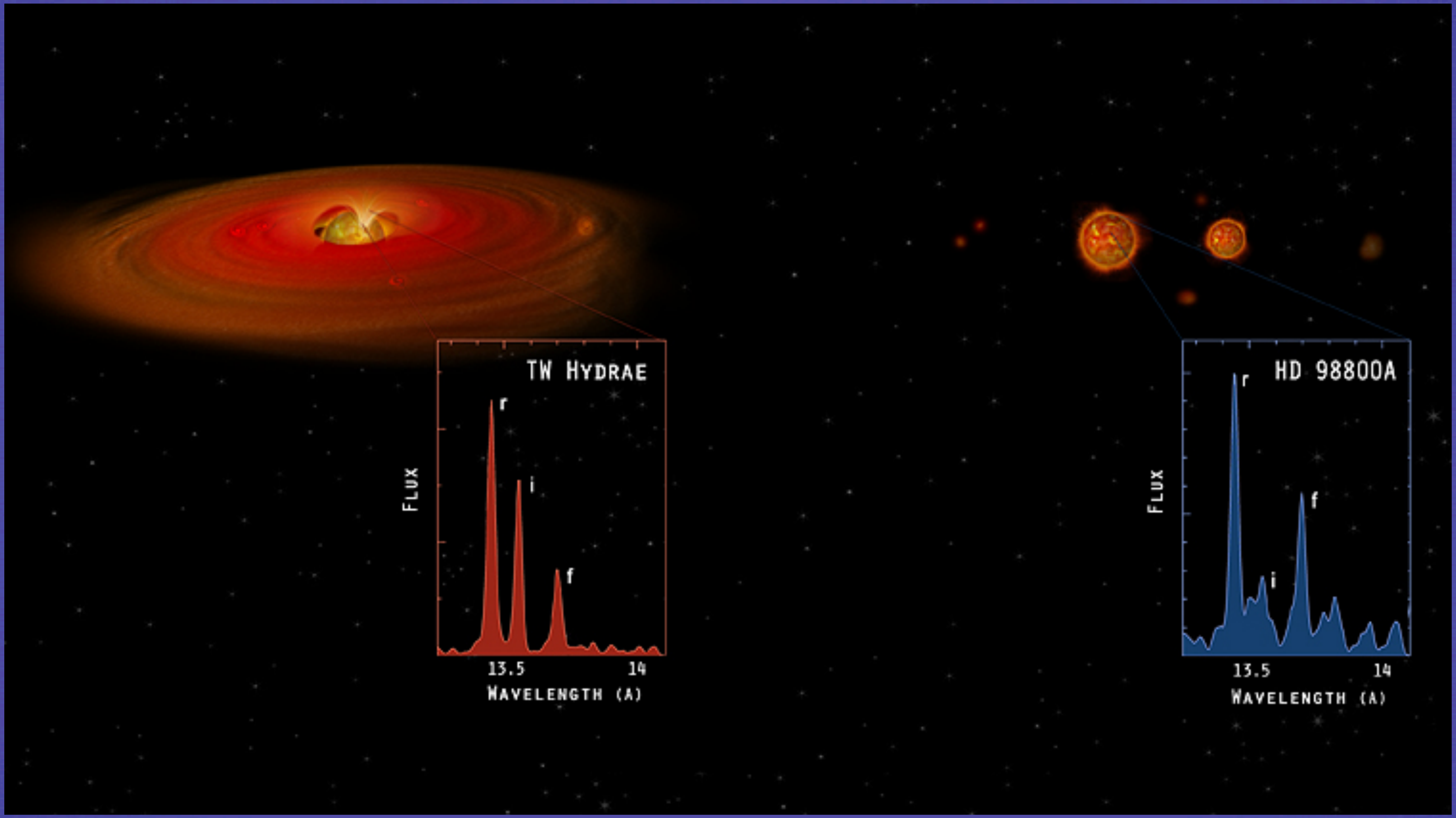
XTEJ1118 CXC grating spectrum

Stars: What can we learn from Spectra?



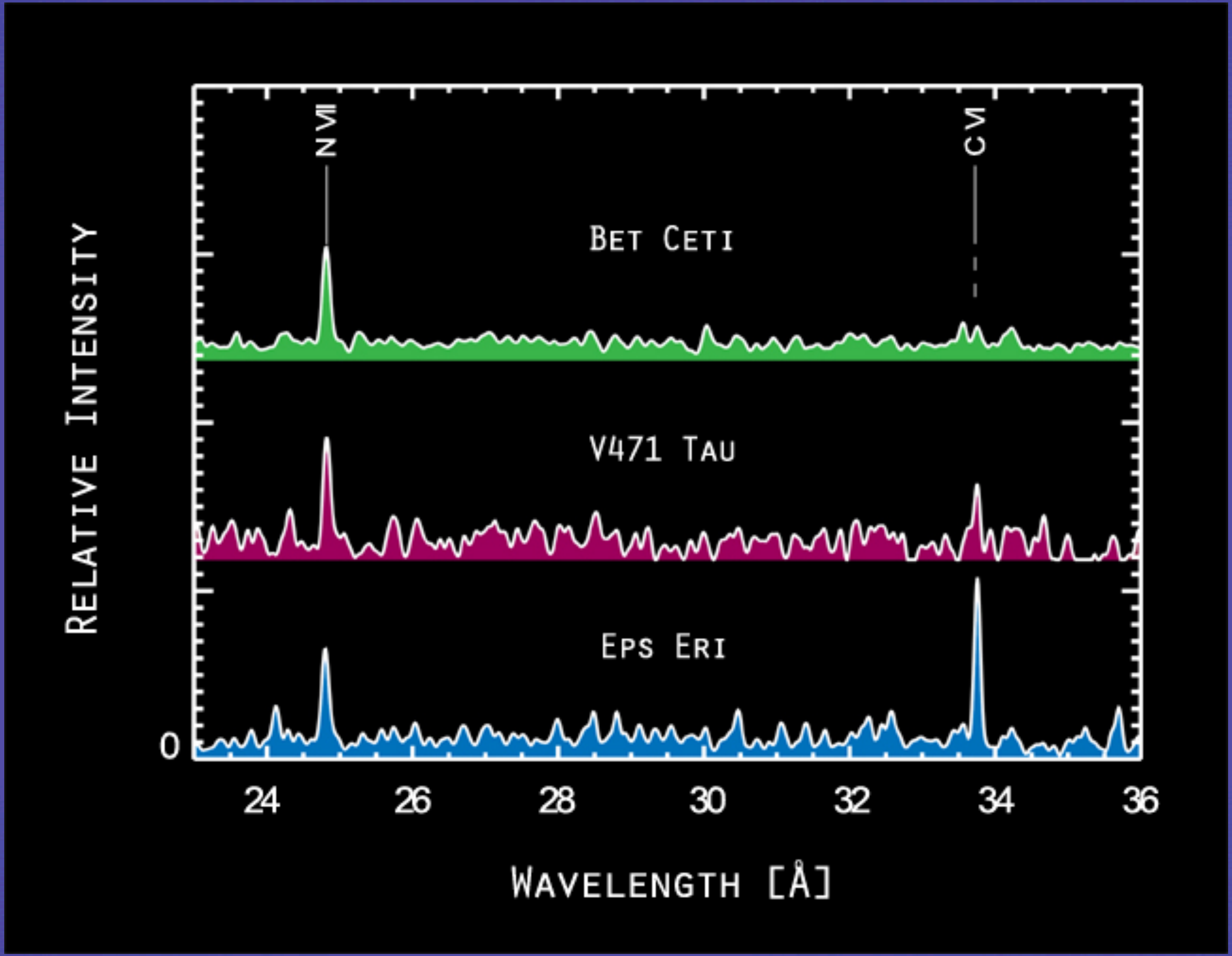
There is too much Neon!

Stars: What can we learn from Spectra?



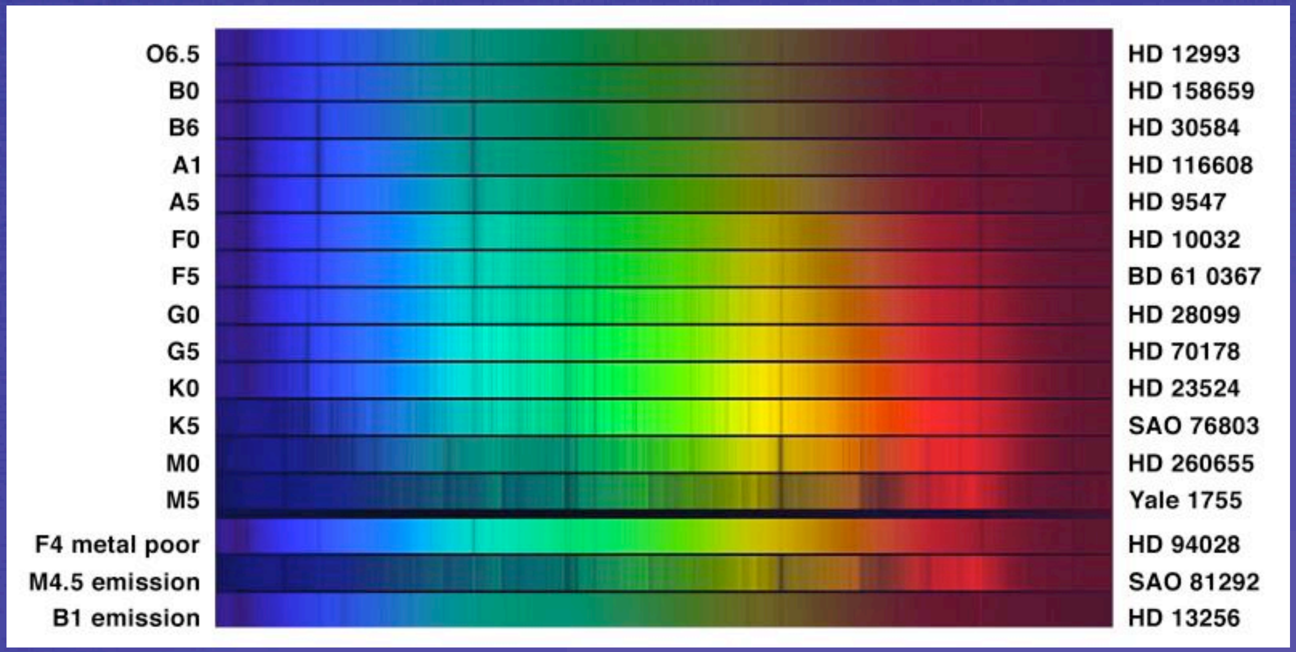
TW Hydrae shows evidence for accretion

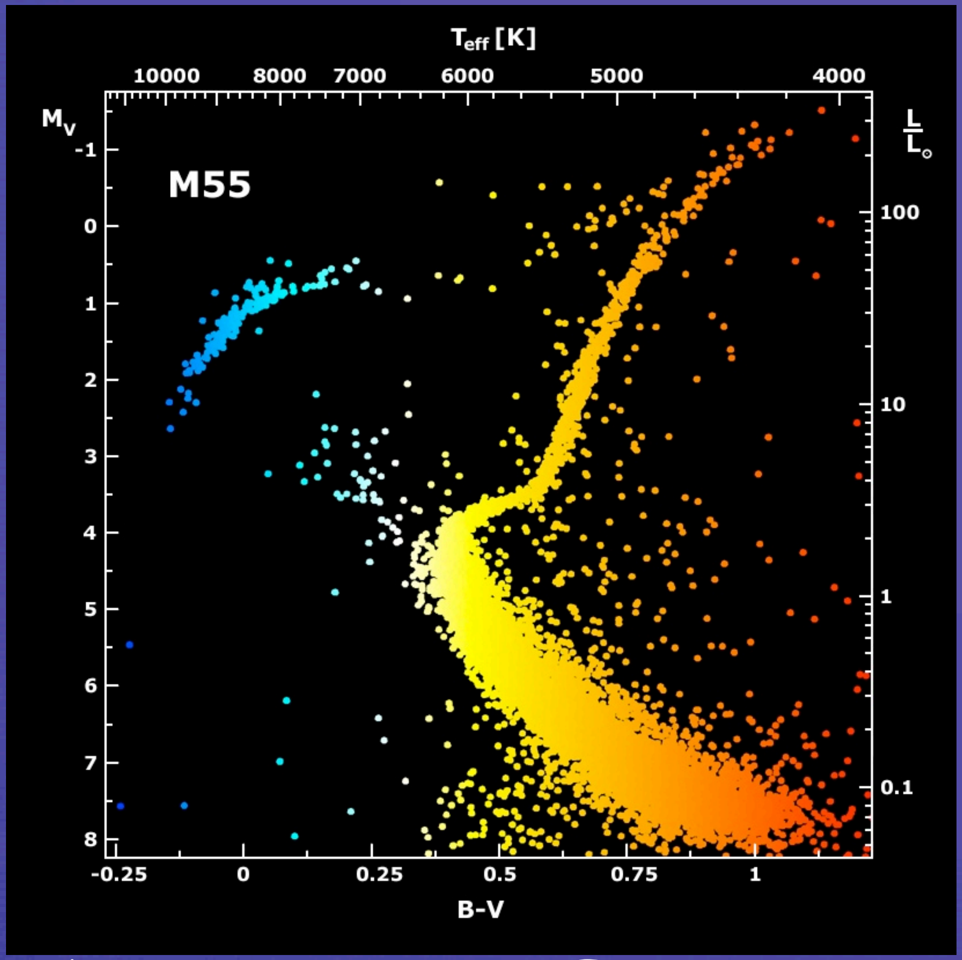
Stars: What can we learn from Spectra?



Evolutionary status of V471 Tau / Beta Ceti / Epsilon Eri

Stars - Within Our Galaxy -- Populations:

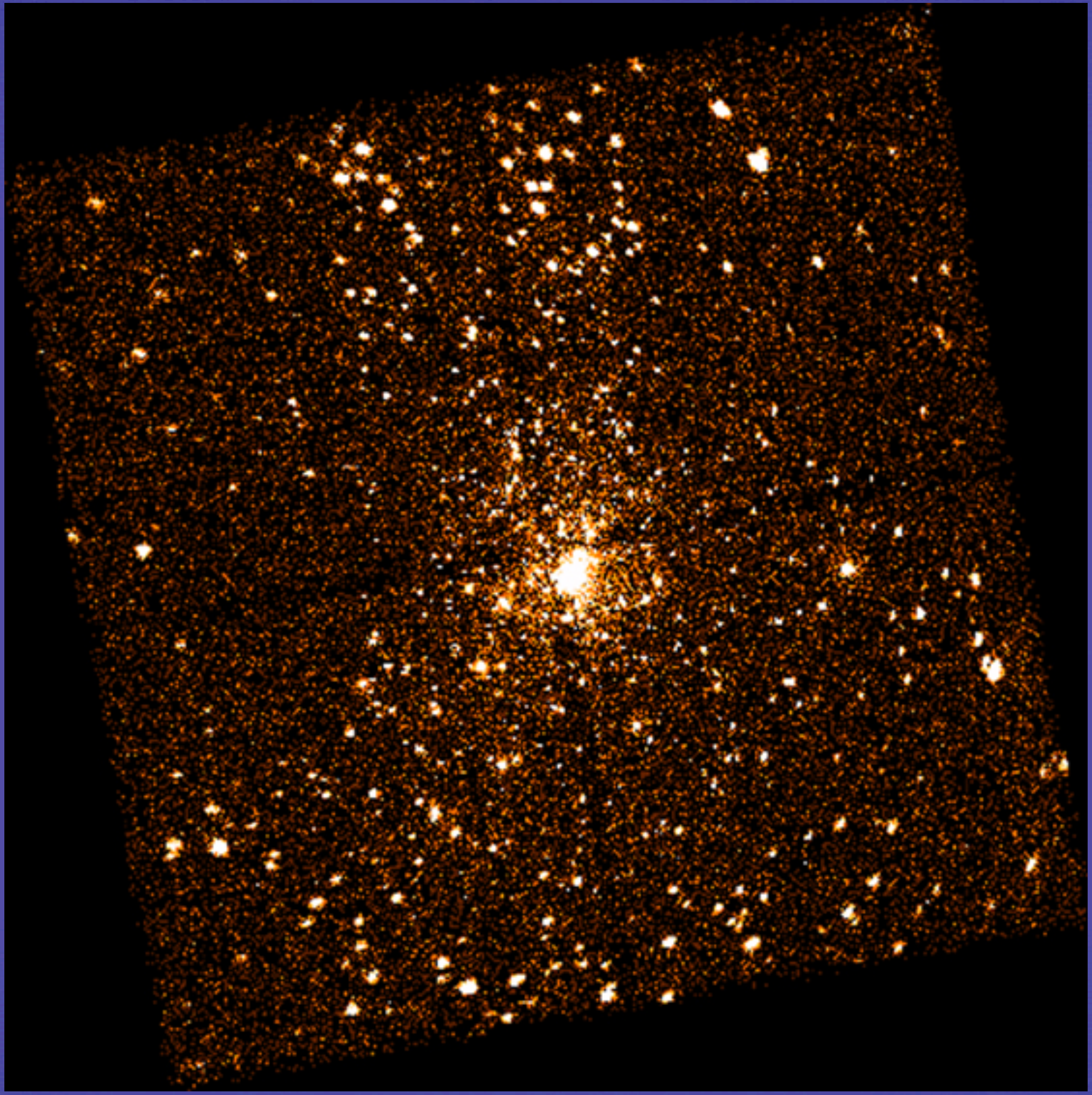




Top: Annie Jump Cannon and Stellar Classification System

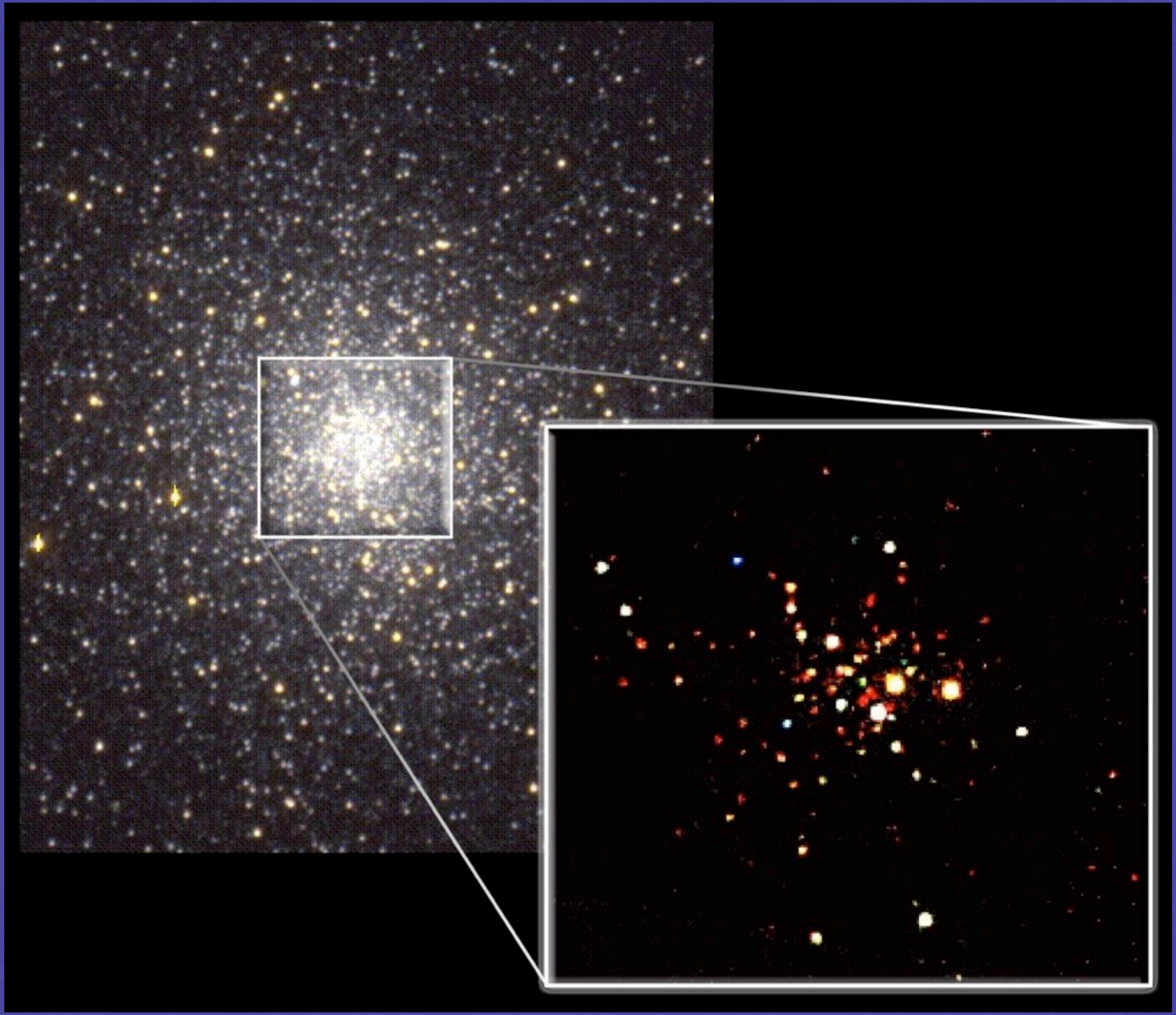
Bottom: Color Magnitude Diagram

Stars - Within Our Galaxy -- Clusters:



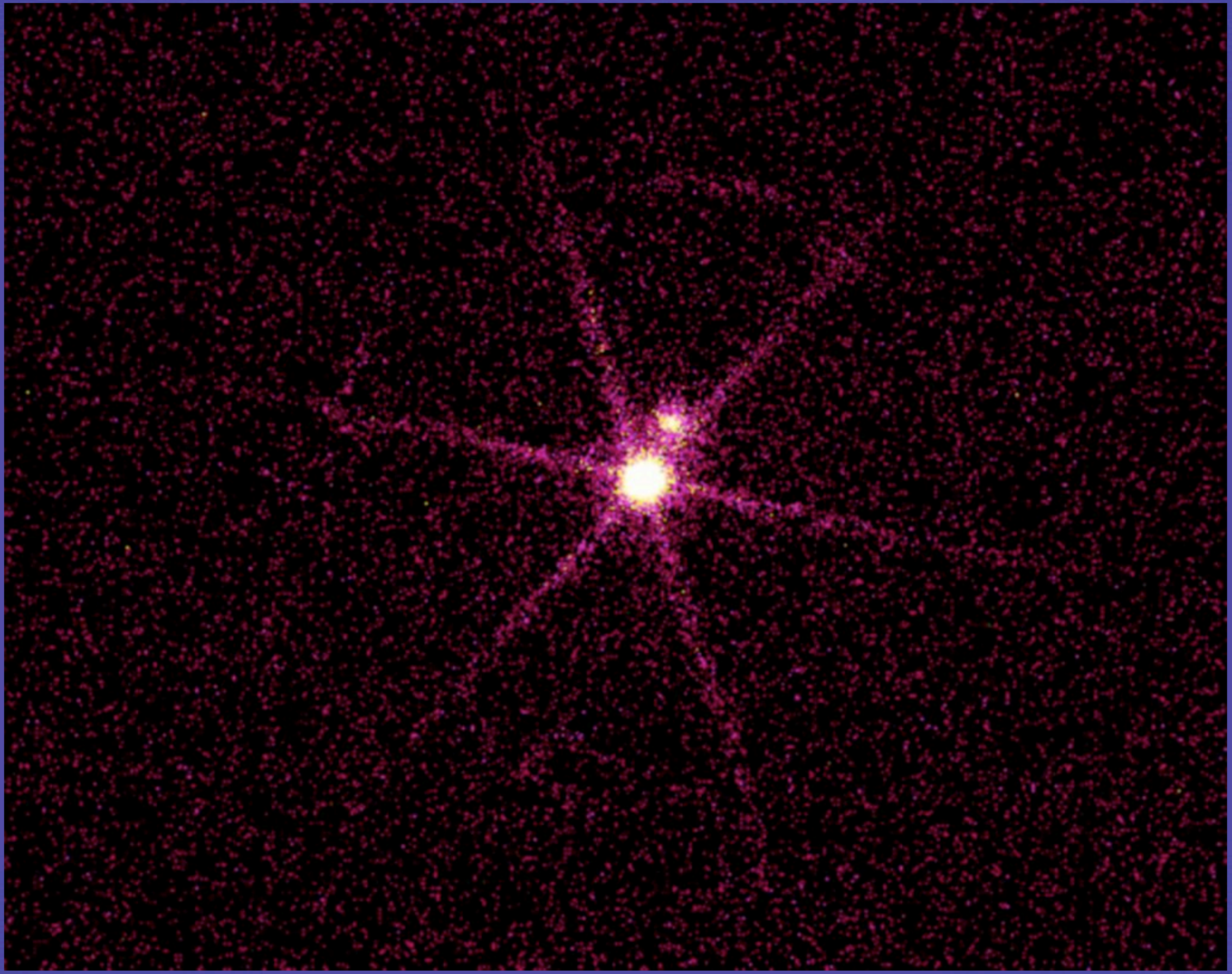
New star forming region in Orion

Stars - Within Our Galaxy - Clusters



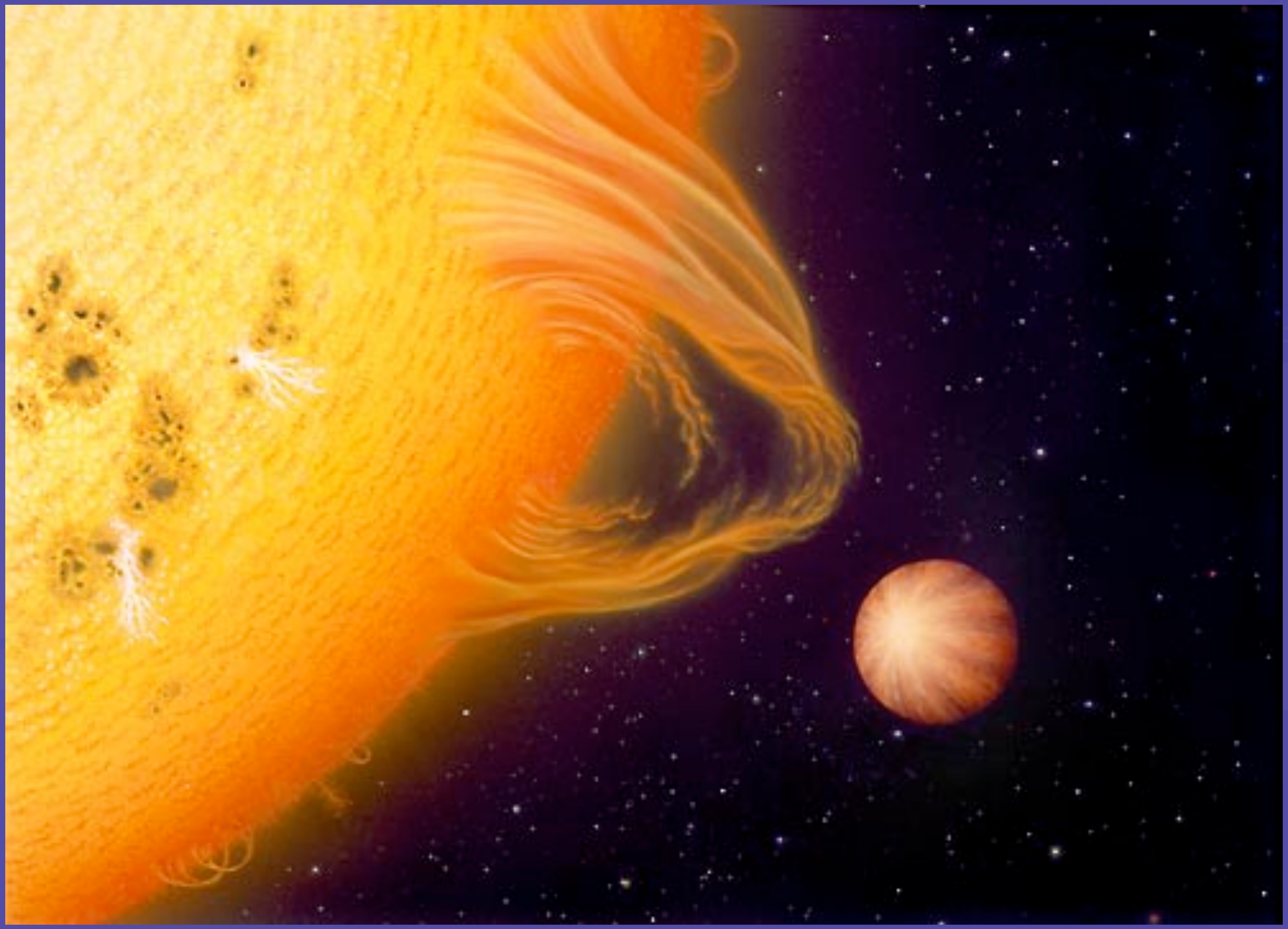
Old globular cluster 47 Tuc: X-ray (binaries?) and optical

Stars - Populations of Compact Objects/ Binaries:



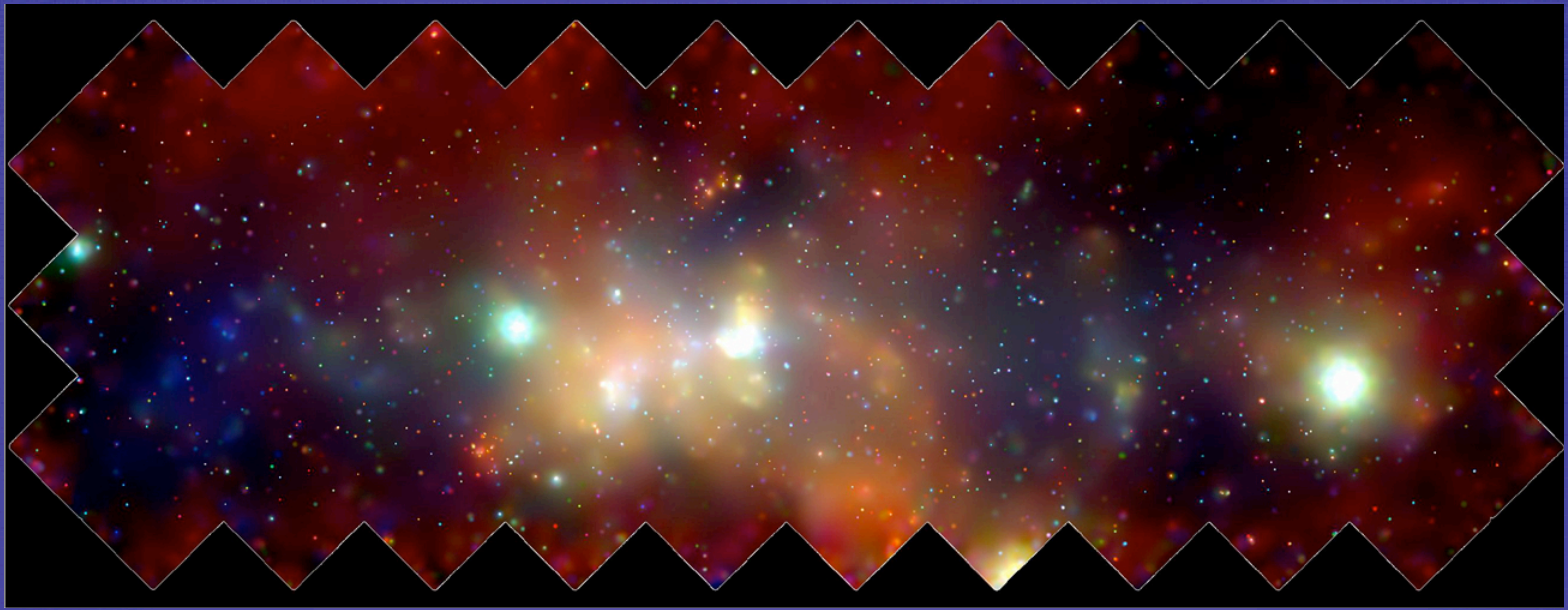
In X-ray : white dwarf shines brighter, Sirius B vs A

THEME:



What might planets do? (ups And and close-in planet)

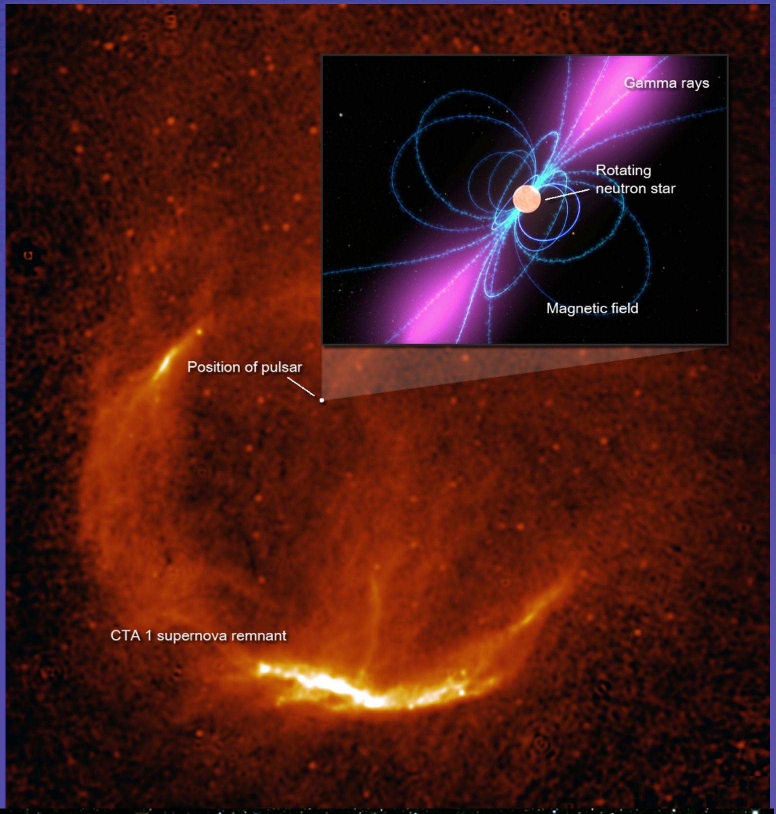
Stars - Within Our Galaxy - Compact/Ends

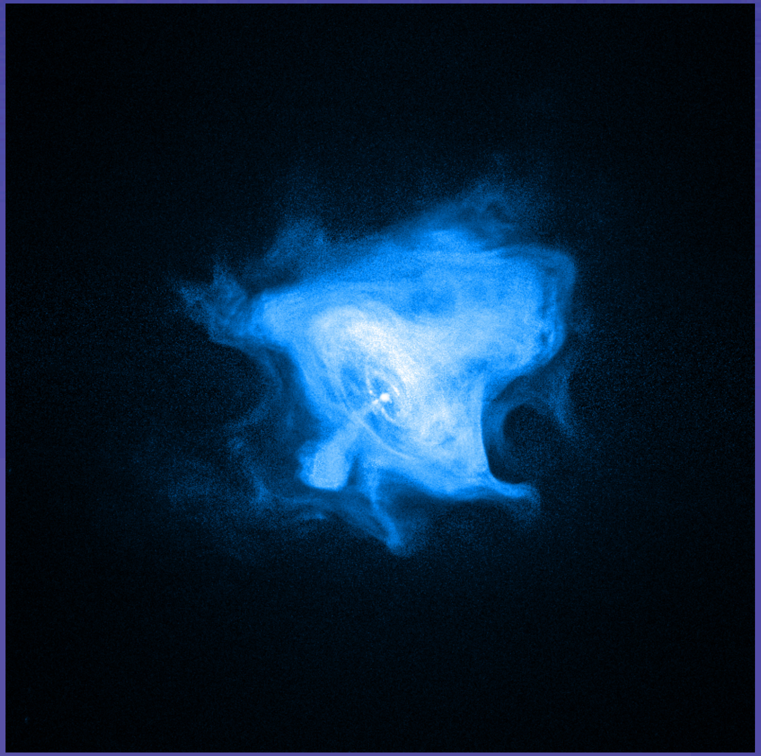


gal center X-ray / gamma-ray

Stars - Within Our Galaxy - Compact/Ends

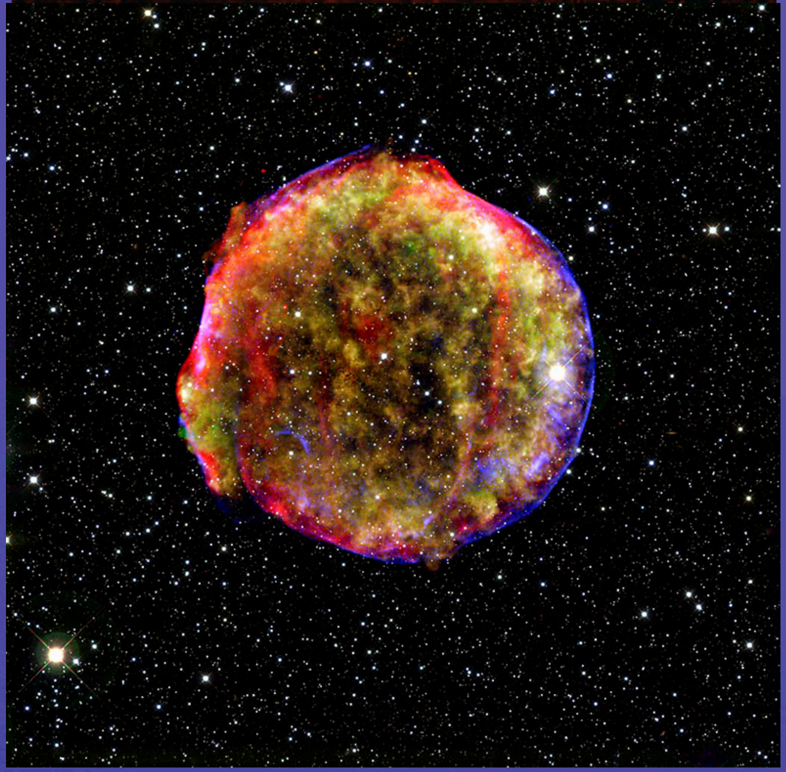
Fermi pulsar in CTA 1





Crab pulsar wind nebula Chandra X-rays

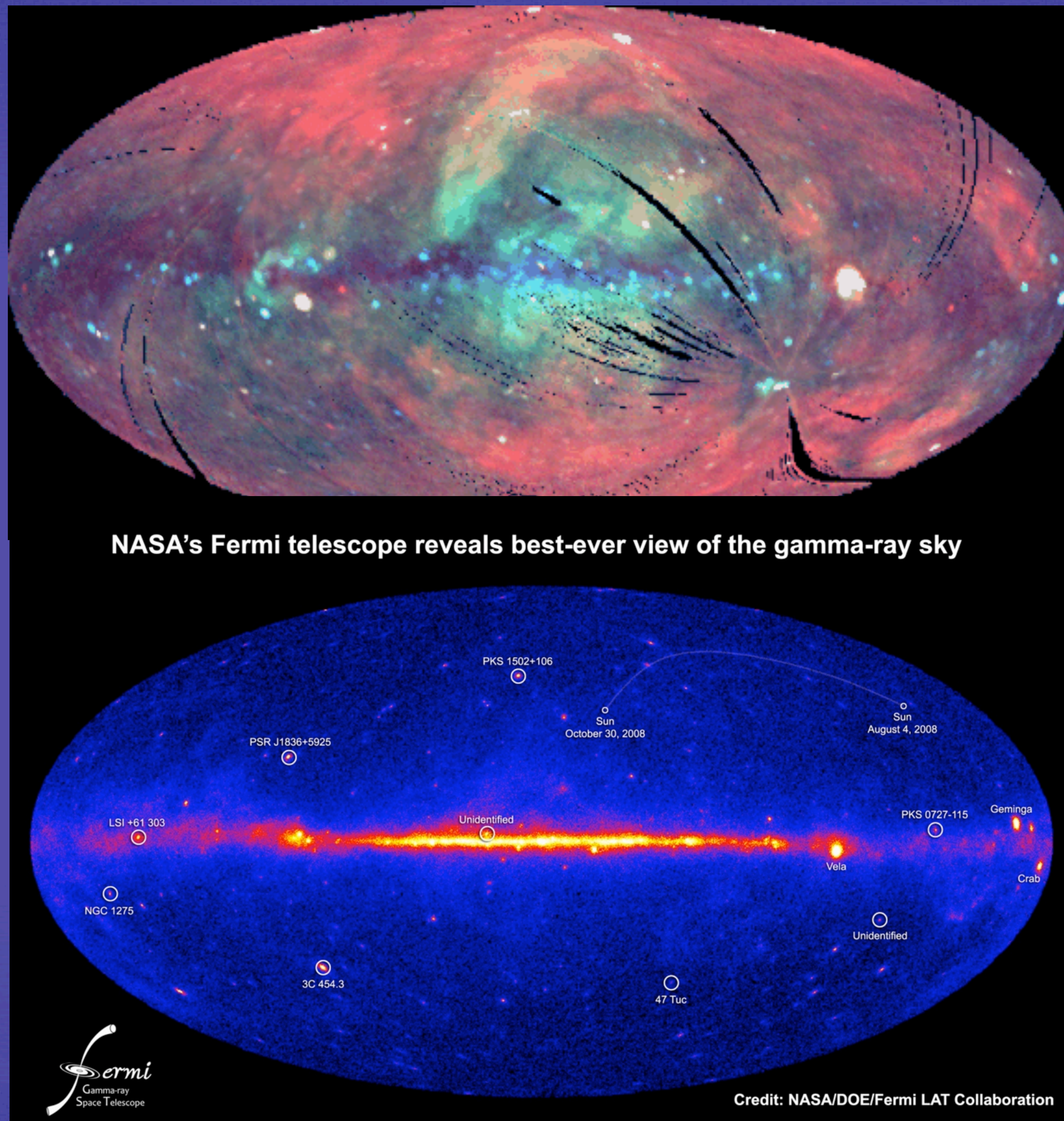
Tycho remnant Chandra X-ray + optical, IR



16 yrs of Galactic center star motions weigh black hole

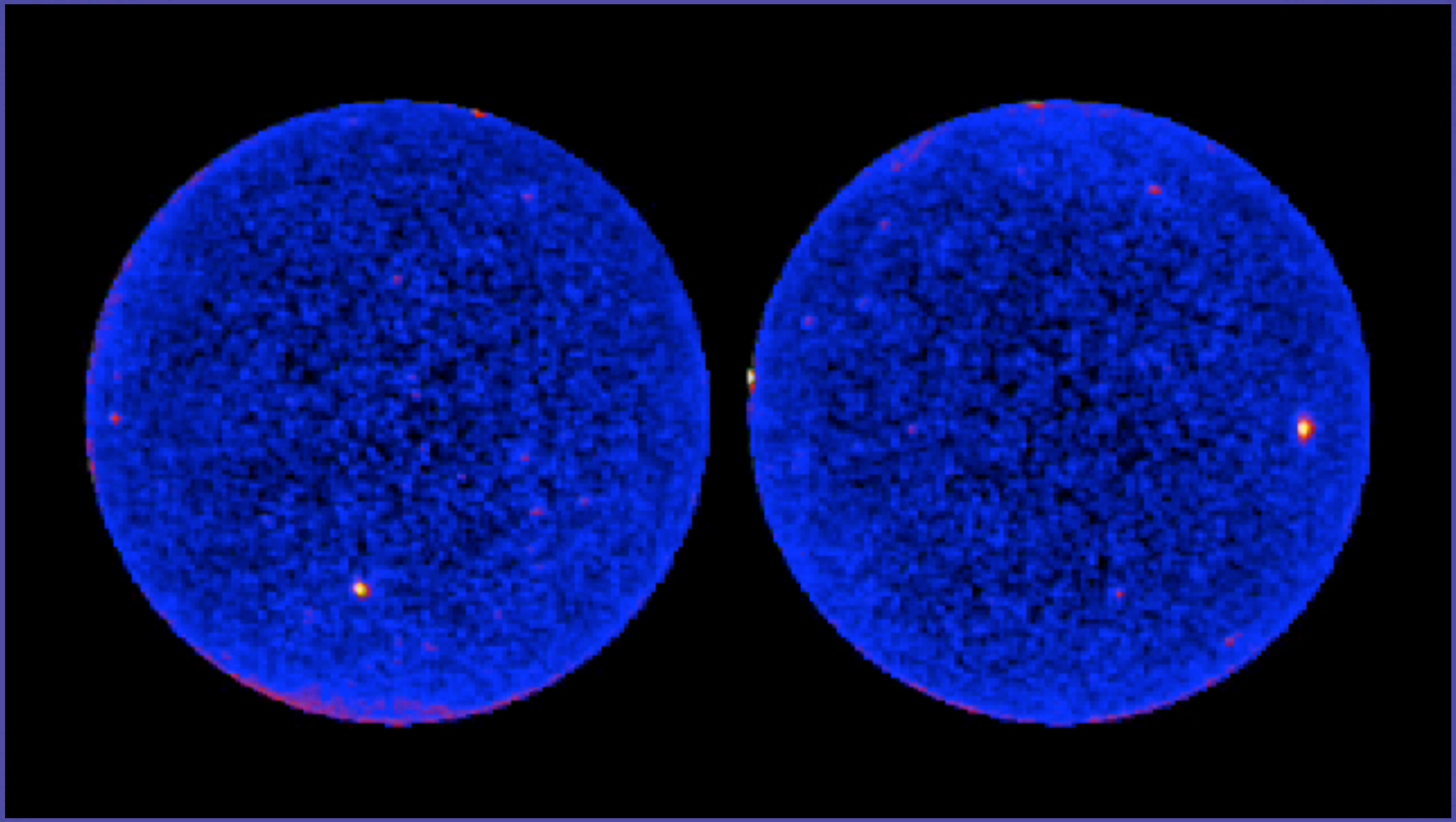
Pulsars, Wind Nebulae, SuperNova Remnants, Black Holes

All-Sky Galactic: Gas Clouds; Compact Objects:



ROSAT X-ray (top) vs Fermi γ-Ray (bottom)

All-Sky Galactic Views - Variable Sky:

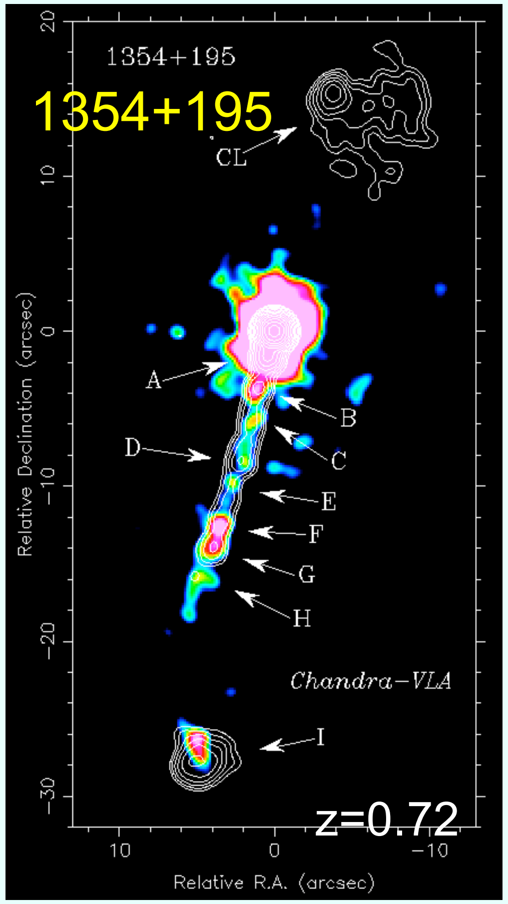


Fermi Gamma-ray all-sky - North/South View/Movie

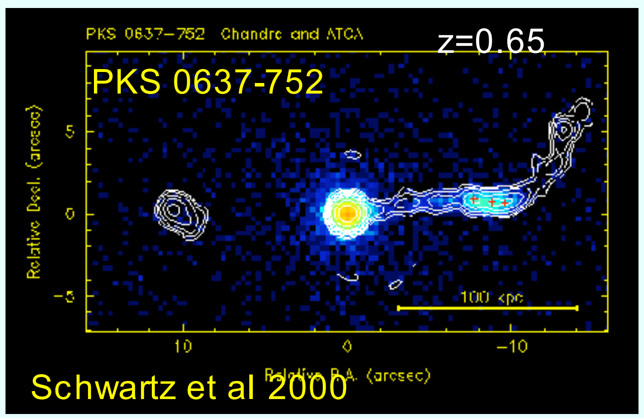
AGNs, AGN surveys, quasars, ...

X-ray Jets in Chandra Era

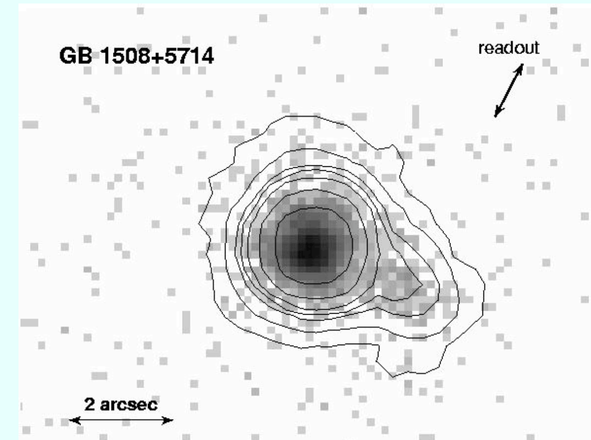
- > 85 X-ray Jets on the XJET Web page (Dan Harris): http://hea-www.harvard.edu/XJET/index.cgi
  FRI/FRII, Lobe Dominated and Compact Quasars
- Highest redshift GB1508 +5714 at z=4.3



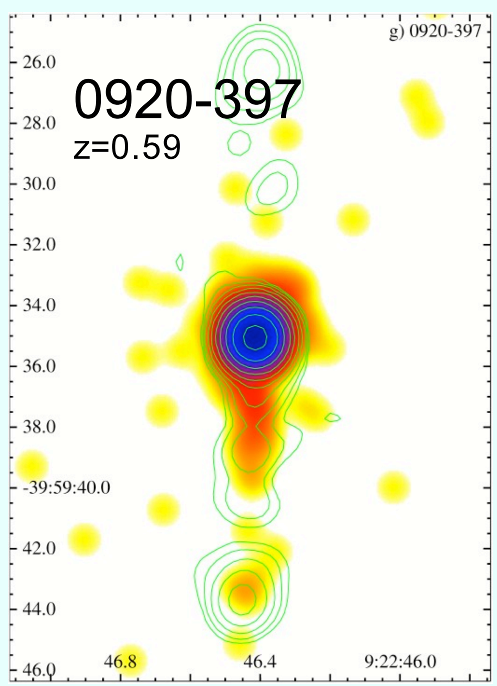
Sambruna et al 2002



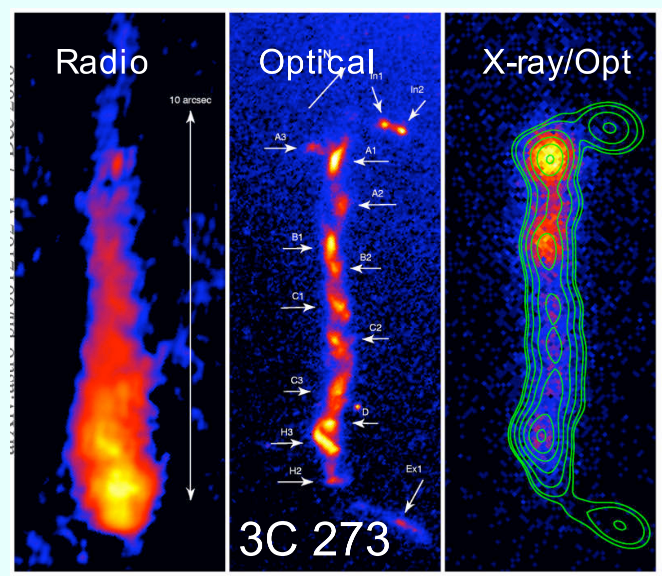
Schwartz et al 2000



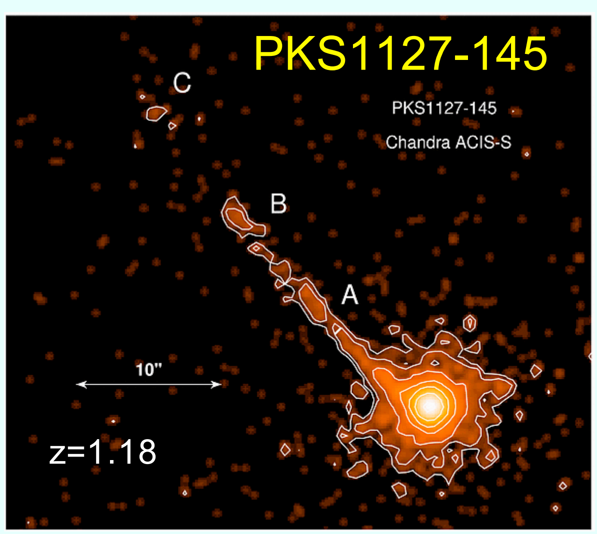
Siemiginowska et al 2003



Marshall et al 2004

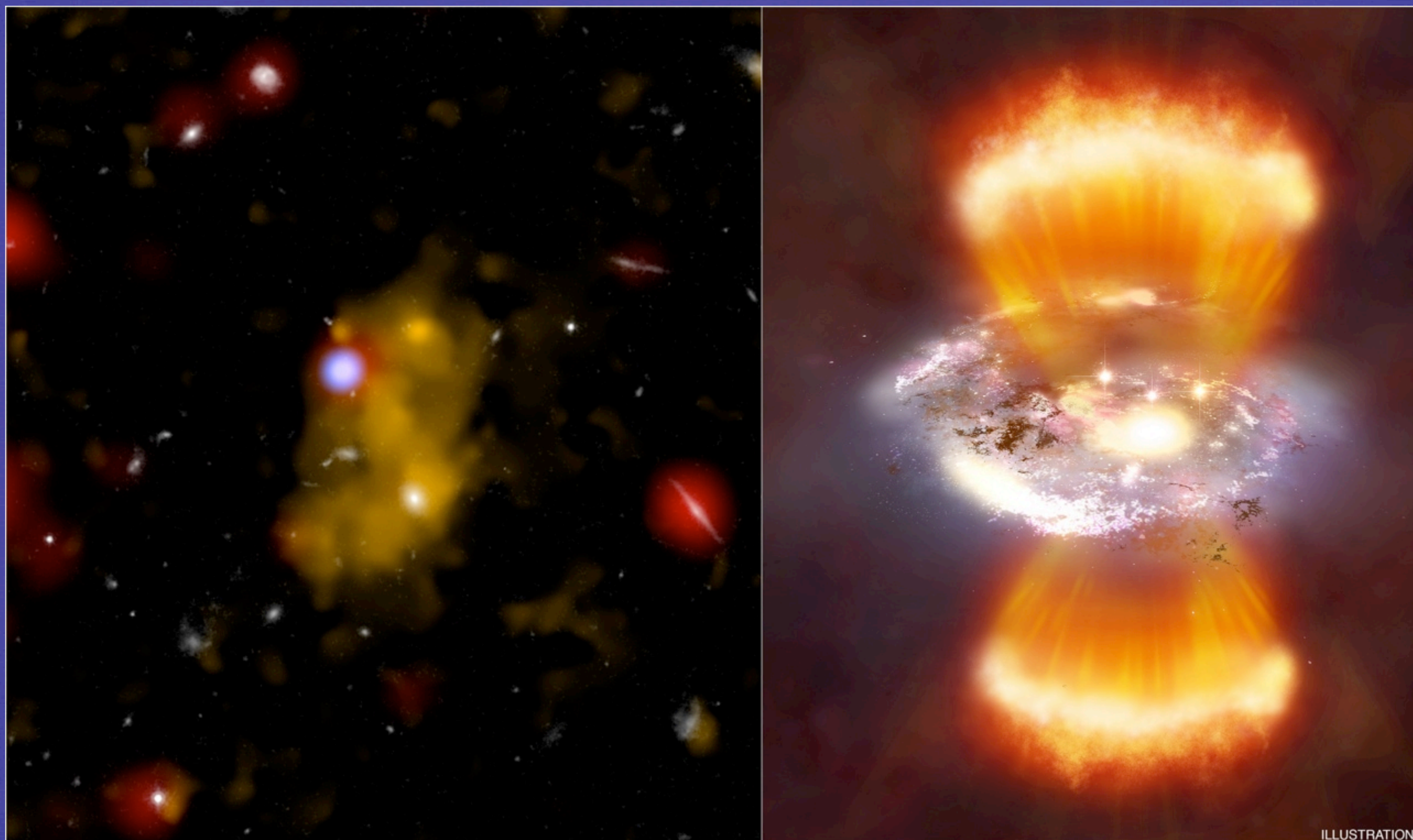


Marshall et al 2001



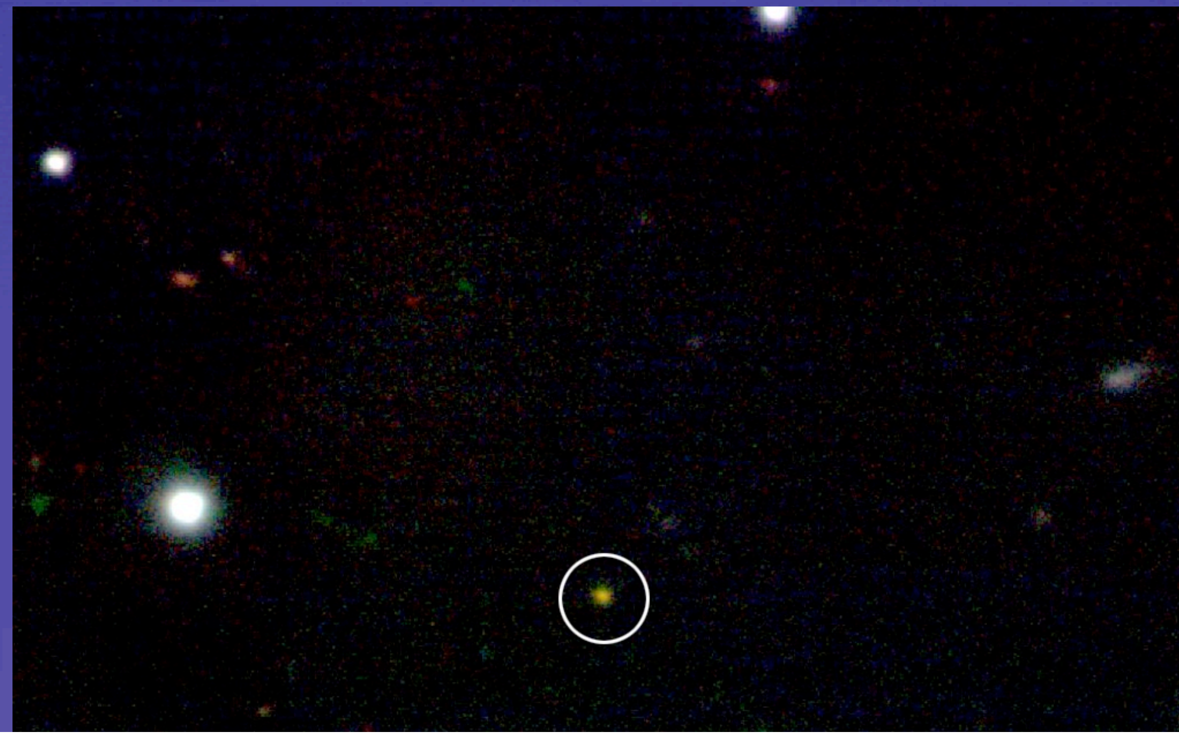
Siemiginowska et al 2002

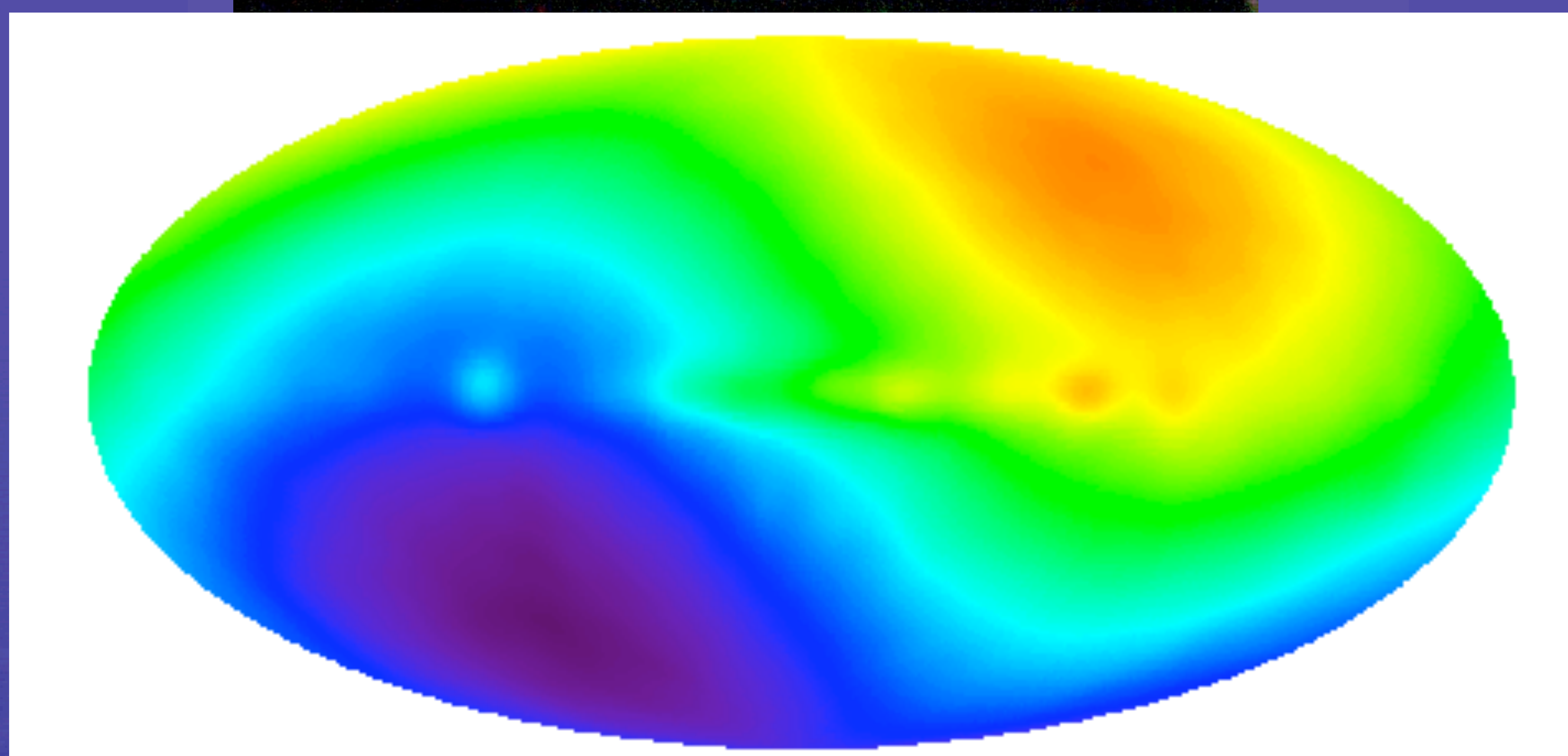
THEME: Put AGNs, AGN surveys, quasars here.



X-rays from black hole in Lyman α ‘Blob’ at 12 billion yrs

END with gamma-ray bursts and CMB:





630 million yrs after big bang (top); CMB (bottom)

END with Scott and Neyman statistics - how far we have come.:

gal center X-ray / gamma-ray

THEME:
"The Underlying Processes Are the Same Across All Scales and Reference Frames"

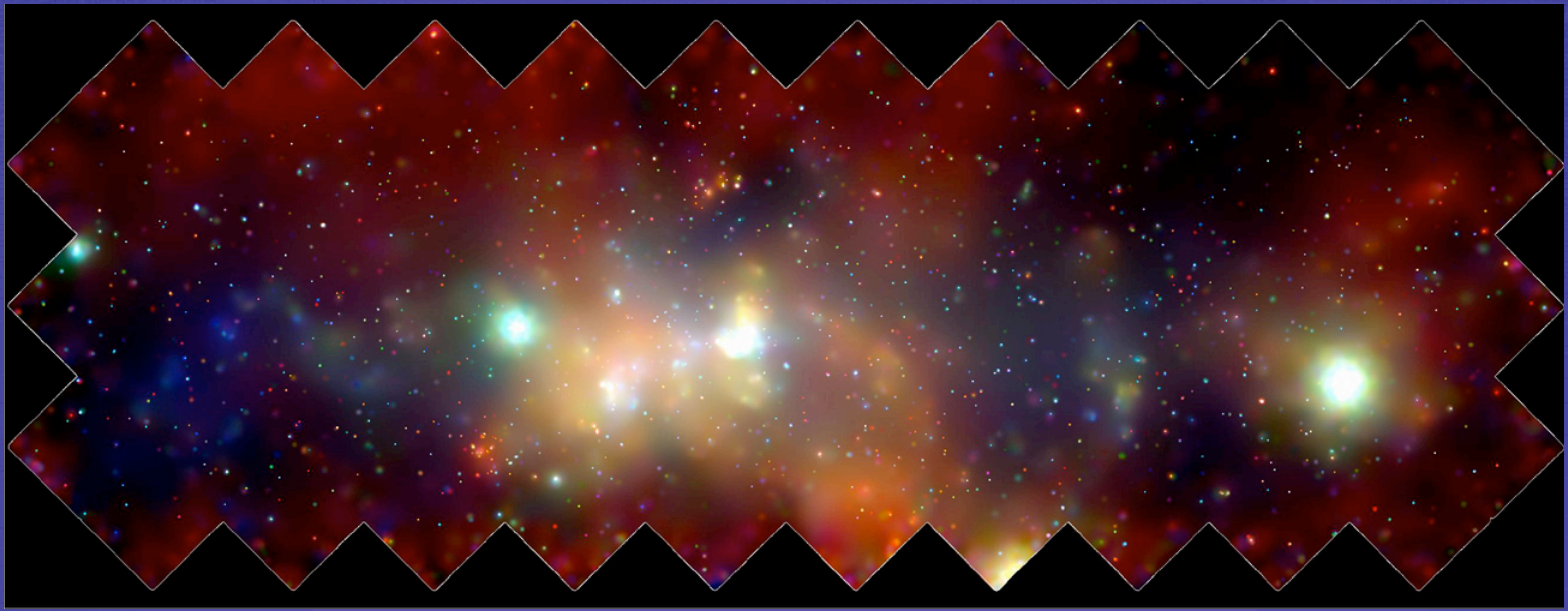
$$\Lambda(x,y,e,t,\theta,\varphi,\xi) = PSF(x,y|l,b,e,t,\xi) @ E(l,b,e,t,\varphi) * S(l,b,e,t,\theta)$$

$$D\,(x,y,e,t,\theta,\varphi,\xi) \sim \text{Poisson}\,(\,\Lambda(x,y,e,t,\theta,\varphi,\xi)\,)$$

OUR JOB: Infer Substances and Physics + *Quantify 'Doubt'*

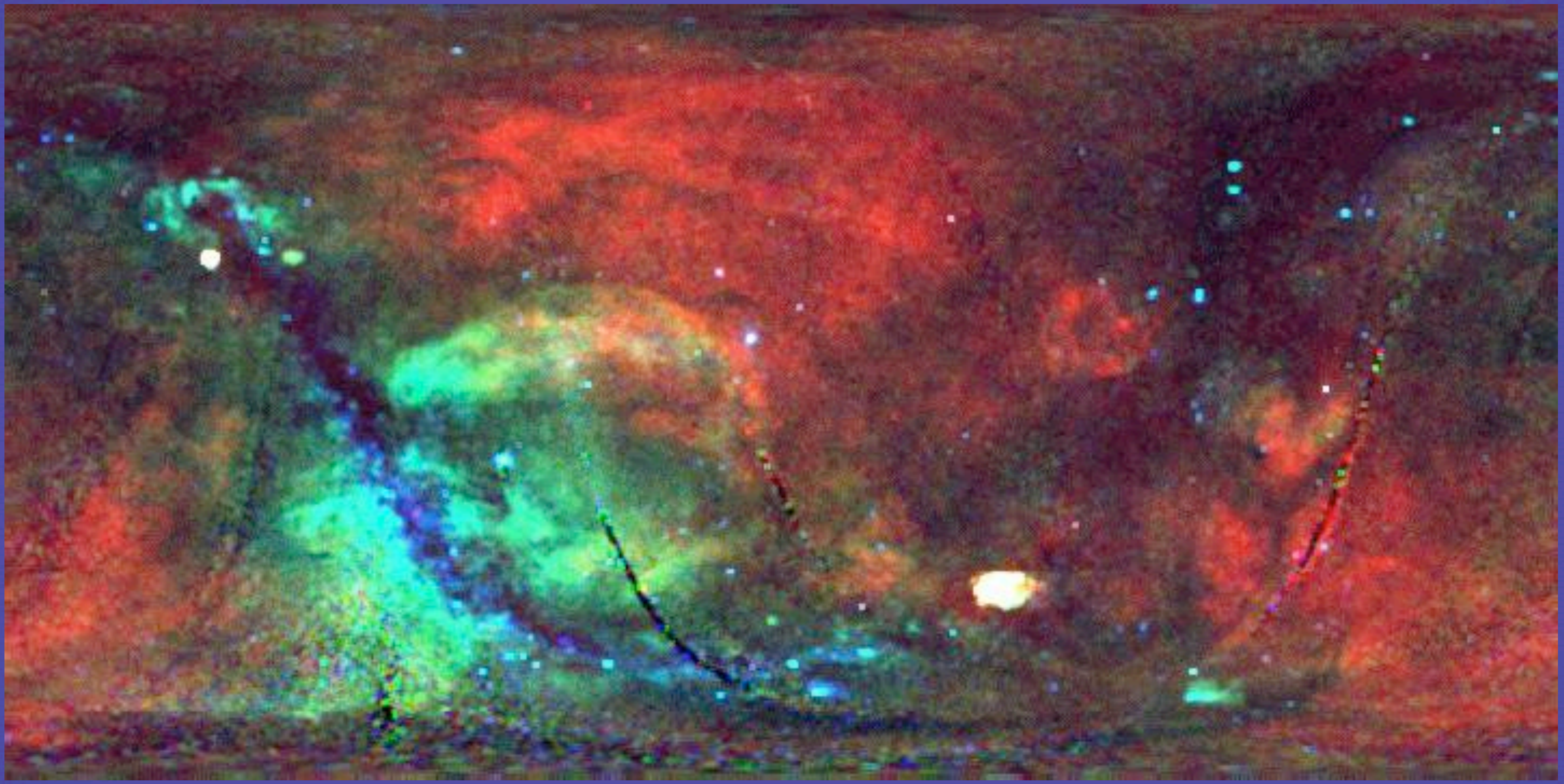
Now, let's *do* it.

Stars - Within Our Galaxy - Compact/Ends



gal center X-ray / gamma-ray

THEME:



gal ras rgb