Observatory Science with eXTP

Jean in 't Zand, Xiandong Li, Enrico Bozzo and Jinlu Qu

Thank you D. de Martino, M. Hernanz, A. de Rosa and I. Donnarumma for providing some of the slides

Contributions from L. Amati, S. Bianchi, Y. Chen, V. Doroshenko, S. Drake, Y. Fan, M. Ge, P.A. Jenke, L. Ji, T. Maccarone, S. Mahmoodifar, E. Rossi, G. Sala, G. Stratta, T.E. Strohmayer, J. Wang, S. Weng, J. Wilms, X. Wu, Z. Yan, P. Zhou

+the many other researchers involved in LOFT!

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Netherlands Institute for Space Research

Netherlands Organisation for Scientific Research (NWO)

Why Observatory Science?

- eXTP is a mission with 3 primary goals: SG, DM & SM
- eXTP has 4 instruments with capabilities that go far beyond these goals and can serve a broader community
- eXTP will at some level be open to the community as an observatory
  - as prime facility
  - as secondary facility to observatories at other wavelengths and information messengers

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eXTP excels in..

- Large **effective area** from soft to hard X-rays, combined with **high-throughput** and CCD-like spectral resolution

  → short time-scale phenomena

- **Polarimetry**

  → Geometry of magnetic fields and scattering media

- Large **duty cycle** imaging all-sky monitor in classic X-ray band

  → sub-1 hr bright phenomena

➔ Timing → transients , (q)POs, non-statistical noise..

- X-ray bursts, gamma-ray bursts, flares, fast x-ray SG transients, pulsars, QPOs

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But eXTP is also good at…

- **Fast CCD-like spectroscopy**
  - Fe-K reverberation
  - Cyclotron line phase-resolved

- **Long-term moderate-sensitive (10^{-11} erg/s/cm2) monitoring**
  - WFM collects large amounts of exposure time, much more sensitive than ASMs on RXTE, Astrosat
    - Monitoring AGN and BL Lacs
    - Faint long-term transients (peculiar class of LMXBs)

- **Large effective area and low(er) background at sub-2 keV energies**
  - Short term low-E behavior

- **Deep sensitivity (10^{-14} erg/s/cm2 @ 10^5 s)**
  - Diffuse objects (SNR, clusters)

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Observatory Science touches on many subjects

- **From small/nearby to large/far**: stellar flares, binary stars, cataclysmic variables, x-ray binaries, x-ray bursts, supernova remnants, intermediate-mass black holes, active galactic nuclei, clusters of galaxies, gamma-ray bursts

- **Relevant questions** in Observatory Science WG:
  - What is the importance?
  - What pressing issues can eXTP particularly address?

- Drawing from **12 LOFT White Papers** (arXiV:1501.027[66-77]), plus additional capabilities from SFA and PFA

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Why important?
Use ESA Cosmic Vision context

Do not try to read this!

1. What are the conditions for planet formation and the emergence of life?

1.1 From gas and dust to stars and planets

Map the birth of stars and planets by peering into the highly obscured cocoons where they form

1.2 From exo-planets to biomarkers

Search for planets around stars other than the Sun, looking for biomarkers in their atmospheres, and image them

1.3 Life and habitability in the Solar System

Explore *in situ* the surface and subsurface of the solid bodies in the Solar System most likely to host – or have hosted – life

Explore the environmental conditions that makes life possible

Near-Infrared Nulling Interferometer

Mars Landers + Mars Sample Return (*with Aurora Programme*)

Far-Infrared Observatory

Solar Polar Orbiter

Terrestrial Planet Astrometric Surveyor

Europa Landers

2. How does the Solar System work?

2.1 From the Sun to the edge of the Solar System

Study the plasma and magnetic field environment aro the E th and around Jupiter, over the Sun's poles, and out to the hel pause wh the solar wind meets the interst r m iu

2.2 The giant planets and their nviro ments

In situ studies of Jupit its at osph re, interna structure and satellites

2.3 Astero ds nd o her small bodies

Obtain direct la orator nformation by analysing samples from a Near-Earth Object

arth Ma netospheric Swarm

Solar Polar Orbiter

Jupiter Exploration Programme *including* Europa Orbiter and Jupiter probes

Near-Earth Object Sample Return

Interstellar Heliopause Probe

3. What are the fundamental physical laws of the Universe?

3.1 Explore the limits of contemporary physics

ironment of space to search for tiny deviat n model of fundamental interactions

avitational wave Universe

ecting the gravitational rad atio background erated at the Big Ba g

under ext eme co diti ns

ery st ng fi d en ironment of black holes and he sta of matter at supra-nuclear energies in neutr n stars

Fun amental Physics Explo er Programme

Large-Aperture X-ray Observatory

Deep Space Gravity Probe

Gravitational Wave Cosmic Surveyor

Space Detector for Ultra-High-Energy Cosmic Rays

rse originate and what is it made of?

The early Universe

s that led to the inflationary phase in the early ic expansion supposedly took place. Investigate ark Energy that is accelerating the expansion of the Universe

Universe taking shape

ally-bound structures that were assembled in oday's galaxies, groups and clusters of galaxies ir evolution to the current epoch

volving violent Universe

Trace the formation and evolution of the supermassive black holes at galaxy centres – in relation to galaxy and star formation – and trace the life cycles of matter in the Universe along its history

Large-Aperture X-ray Observatory

Wide-Field Optical-Infrared Imager

All-sky Cosmic Microwave Background Polarisation Mapper

Far-Infrared Observatory

Gravitational Wave Cosmic Surveyor

Gamma-Ray Imager

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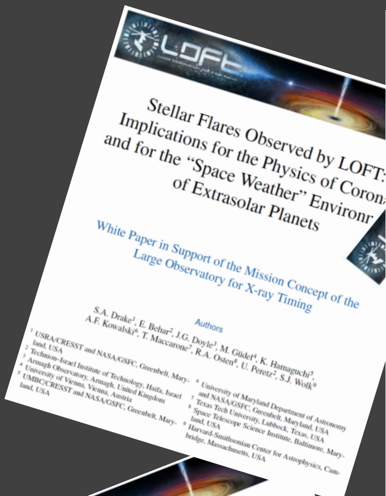
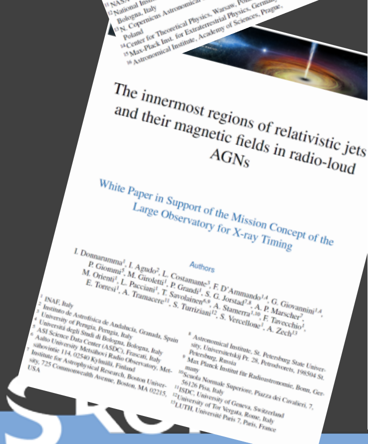
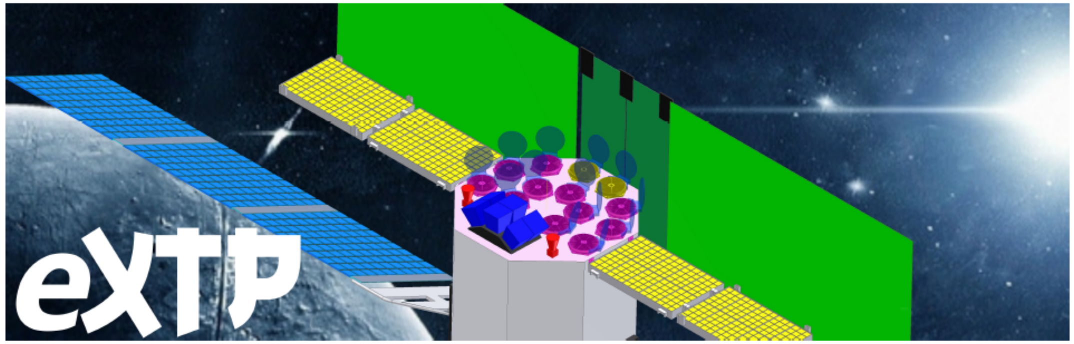






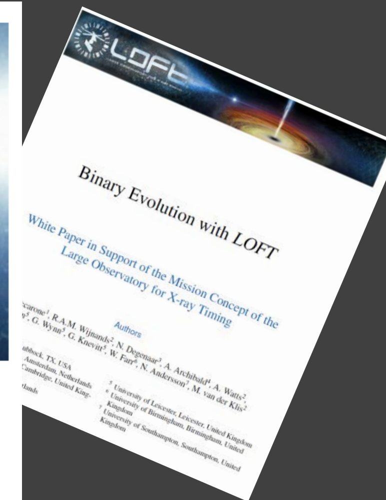
Observatory science with *eXTP*

White Paper in Support of the Mission Concept of the Enhanced X-ray Timing Polarimetry mission

Contributors

L. Amati[1], S. Bianchi[2], E. Bozzo[3], Y. Chen[4], I. Donnarumma[5], V. Doroshenko[6], S. Drake[7], Y. Fan[8], M. Ge[9], M. Hernanz[10], P.A. Jenke[11], L. Ji[9], X. Li[4], T. Maccarone[12], S. Mahmoodifar[13], D. de Martino[14], J. Qu[9], A. de Rosa[15], E. Rossi[16], G. Sala[10], G. Stratta[17], T.E. Strohmayer[13], J. Wang[18], S. Weng[19], J. Wilms[20], X. Wu[7], Z. Yan[21], J.J.M. in 't Zand[22], P. Zhou[4]

[1] Italian National Institute for Astrophysics (INAF), Bologna, Italy
[2] Universitá degli studi Roma Tre, Rome, Italy
[3] ISDC, University of Geneva, Chemin d'Ecogia 16, 1290 Versoix, Switzerland
[4] School of Astronomy and Space Science, Nanjing University, Nanjing 210023, China
[5] Italian National Institute for Astrophysics (INAF), Roma, Italy
[6] Institut für Astronomie und Astrophysik, Sand 1, 72076 Tübingen, Germany
[7] USRA/CRESST and NASA's Goddard Space Flight Center, Greenbelt, Maryland, USA
[8] Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008, China
[9] Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Beijing 100049, China
[10] Institute fo Space Sciences, ICE (CSIC-IEEC), Barcelona, Spain
[11] University of Alabama, Huntsville, AL 35805, USA
[12] Texas Tech University, Lubbock, TX, USA
[13] Astrophysics Science Division and Joint Space-Science Institute, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
[14] Italian National Institute for Astrophysics (INAF) & Osservatorio Astronomico di Capodimonte, Naples, Italy
[15] INAF/Istituto di Astrofisica e Planetologie Spaziali, Roma, Italy
[16] Leiden Observatory, Leiden University, P.O. Box 9513, 2300 RA , Leiden, The Netherlands
[17] University of Urbino, Urbino, Italy
[18] Department of Astronomy, Xiamen University, Xiamen 361005, China
[19] Department of Physics, Nanjing Normal University, Nanjing 210023, China
[20] Friedrich-Alexander University Erlangen-Nürnberg, Bamberg, Germany
[21] Shanghai Astronomical Observatory, Shanghai 200030, China
[22] SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, the Netherlands



Observatory Science subjects in LOFT

- Terrestrial Gamma-ray Flashes
- Stellar flares
- Cataclysmic variables
- LMXBs
- HMXBs
- Accretion and ejection
- Thermonuclear flashes on neutron stars
- Pulsars
- Tidal disruption events
- Flares on AGN and blazars
- Gamma-ray bursts

- eXTP synergy with other messengers

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Observatory Science subjects in eXTP

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Observatory Science subjects / other talks

- Terrestrial Gamma-ray Flashes
- Stellar flares
- Cataclysmic variables
- LMXBs
- HMXBs → Romano
- Accretion and ejection → Feng, Papitto, Liu
- Thermonuclear flashes on neutron stars → 3 Zhangs
- Pulsars → Mignani, Papitto
- Tidal disruption events
- Flares on AGN and blazars
- Gamma-ray bursts → Amati, Wu
- Supernova remnants → Chen

- eXTP synergy with other messengers → Funk, Shearer, Xu

- Magnetars, accreting ms pulsars, SFXTs, specific objects

Observatory Science subjects / this talk

- Terrestrial Gamma-ray Flashes
- Stellar flares
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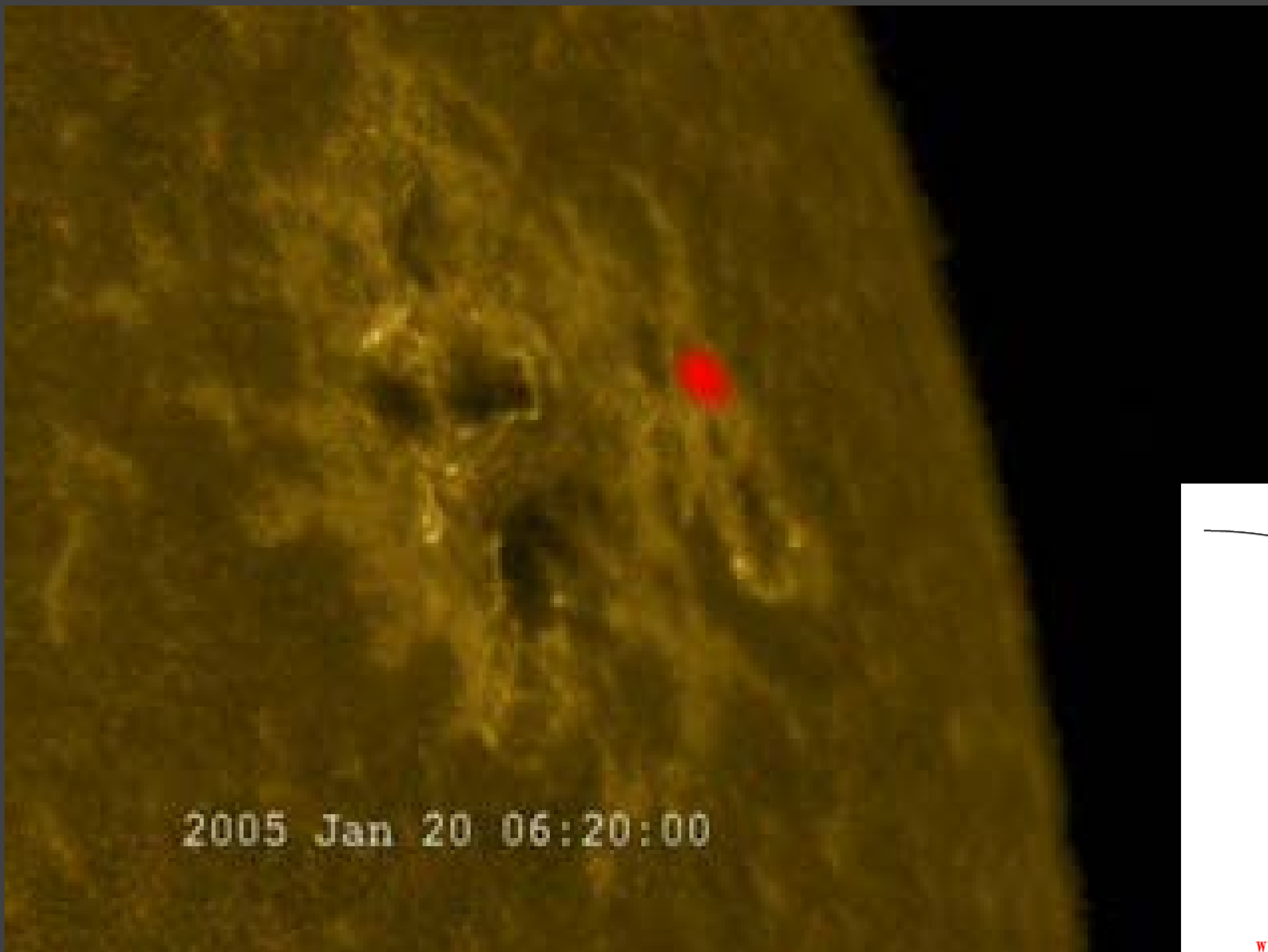
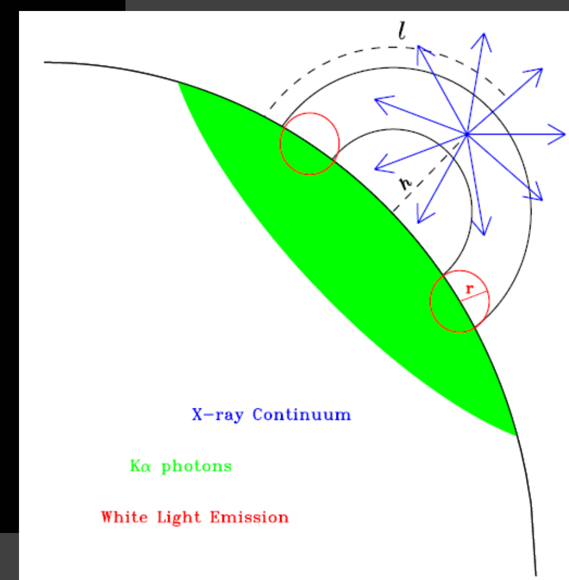
- eXTP symbiosis with other messengers

Stellar flares (<10^{33} erg/s @ ~10 pc)





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Why important?

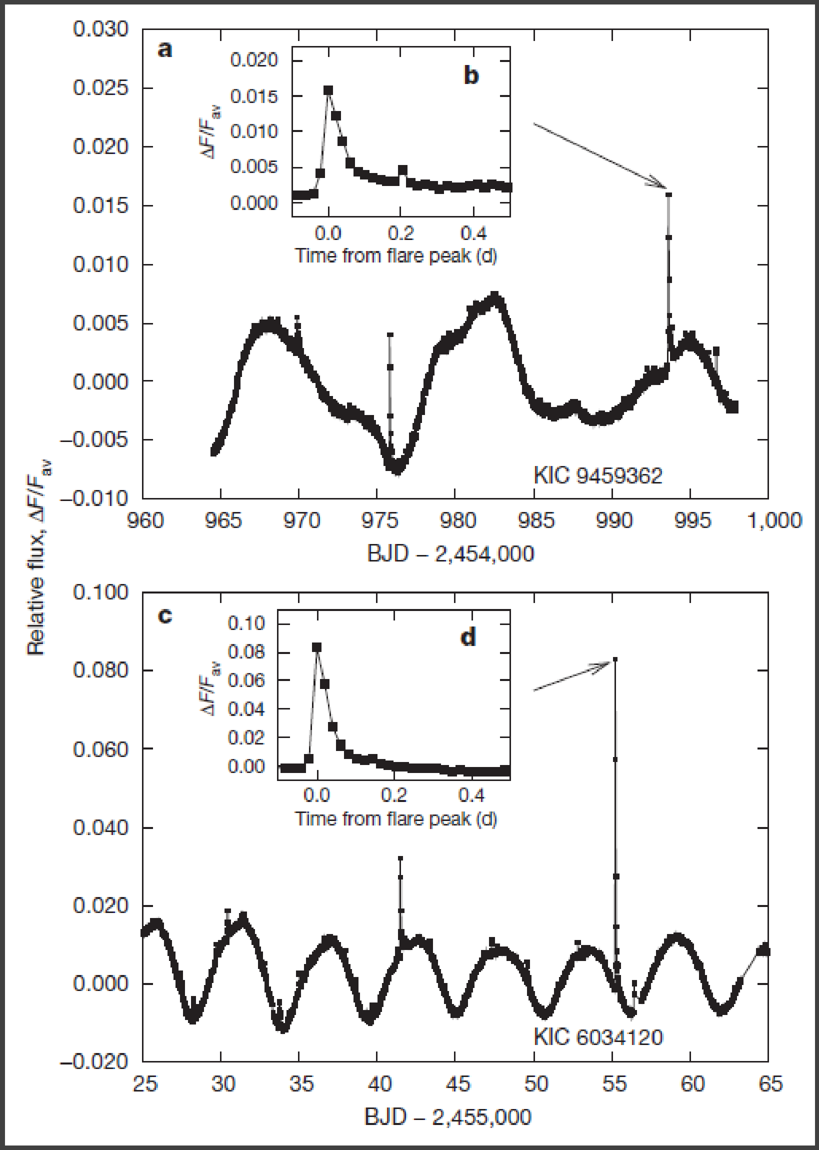
- Stellar (super)flares can influence the environmental conditions that make life possible (CV1.3)

What are pressing issues?

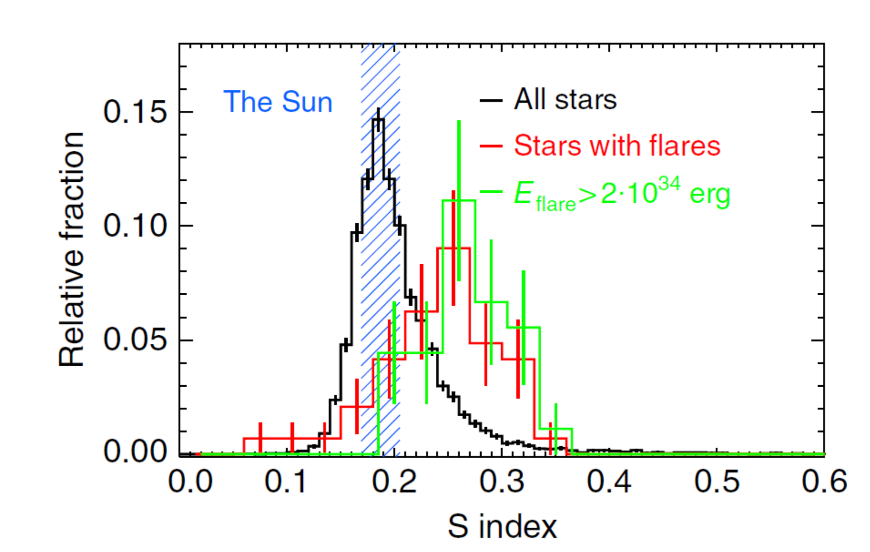
- What are the properties of non-thermal particles responsible for the initial flare input? (LAD)
- What are the physical conditions of the thermal plasma whose emission dominates late stages of stellar flares? (SFA)
- What is the maximum (super)flare energy? (WFM)
- Are there any stars from which unexpected flares occur? (WFM)

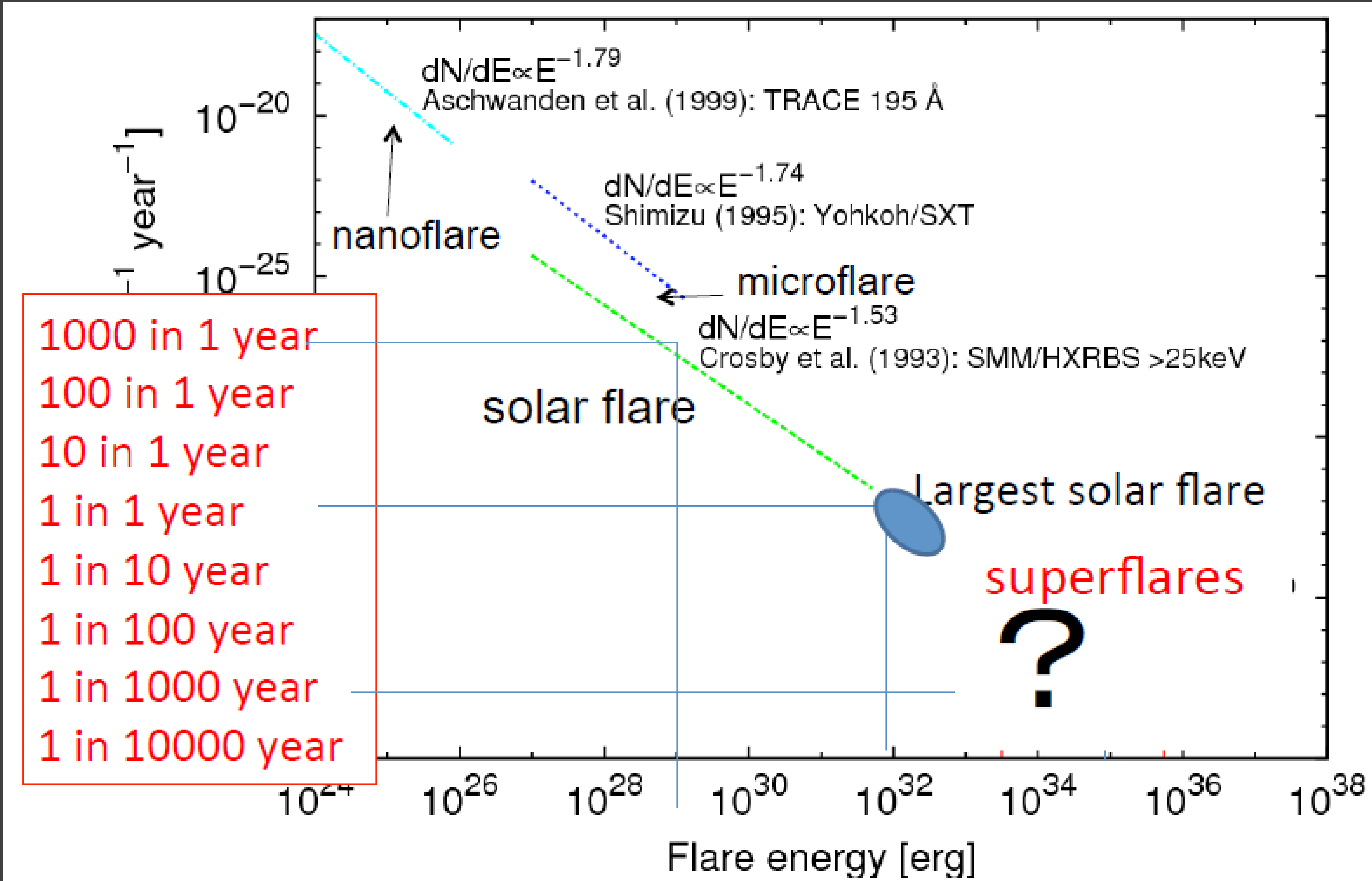
Kepler found 1547 superflares from 279 G-type stars (Maehara+ 2012, Shibayama+ 2013)

- Can happen on slow rotators as well once every 500-5000 yr
- Stronger dependence on magnetic activity than on rotation
- Omnipresent
- May affect biospheres of planets



(Karoff et al. 2015)

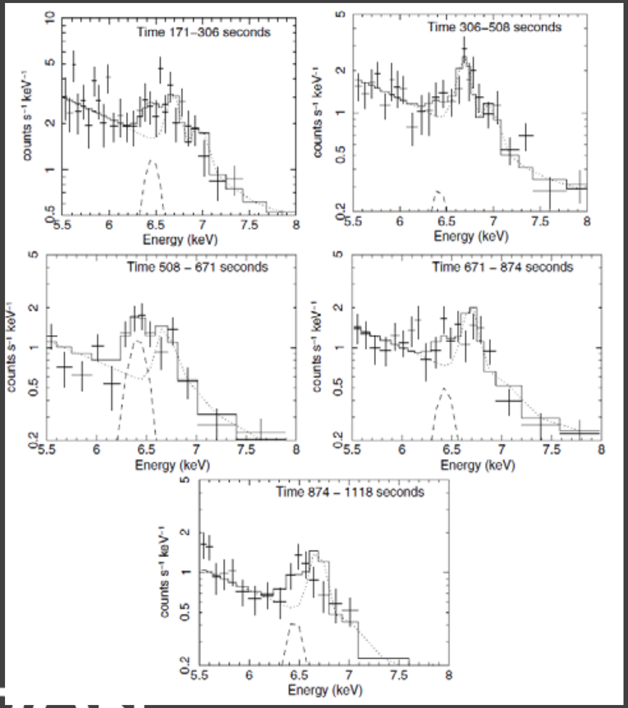


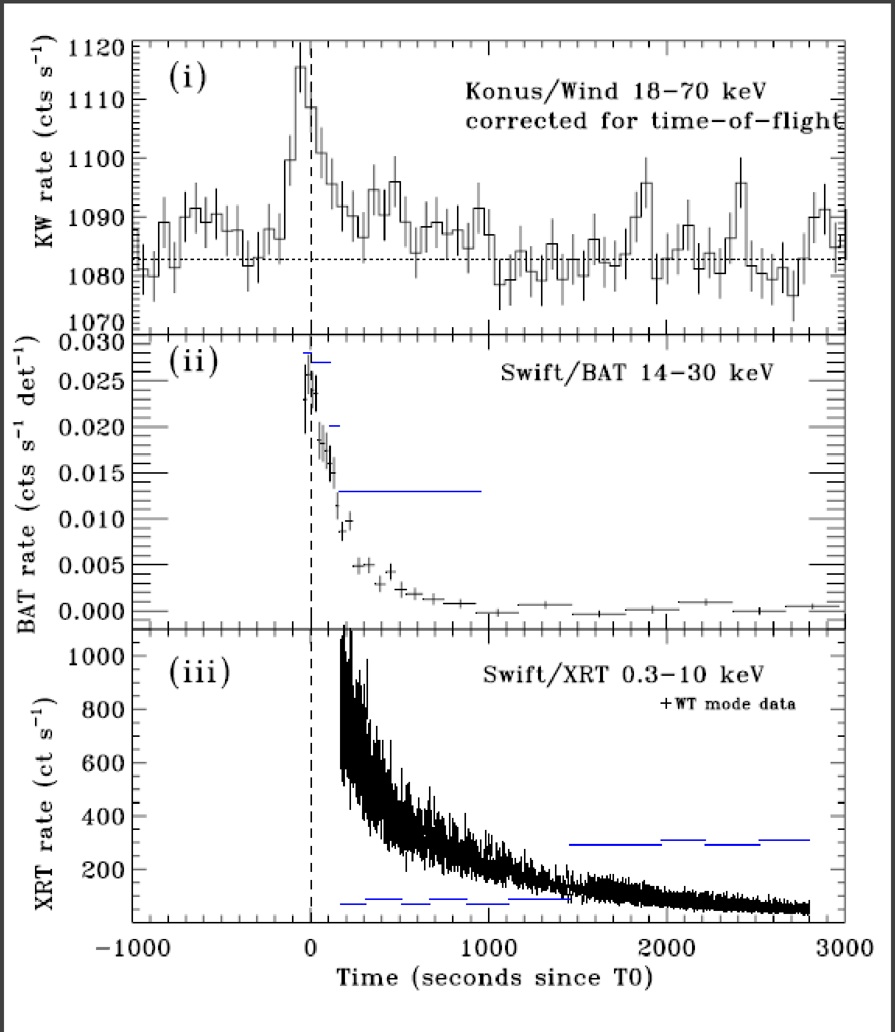


(Shibata 2016)

Superflares

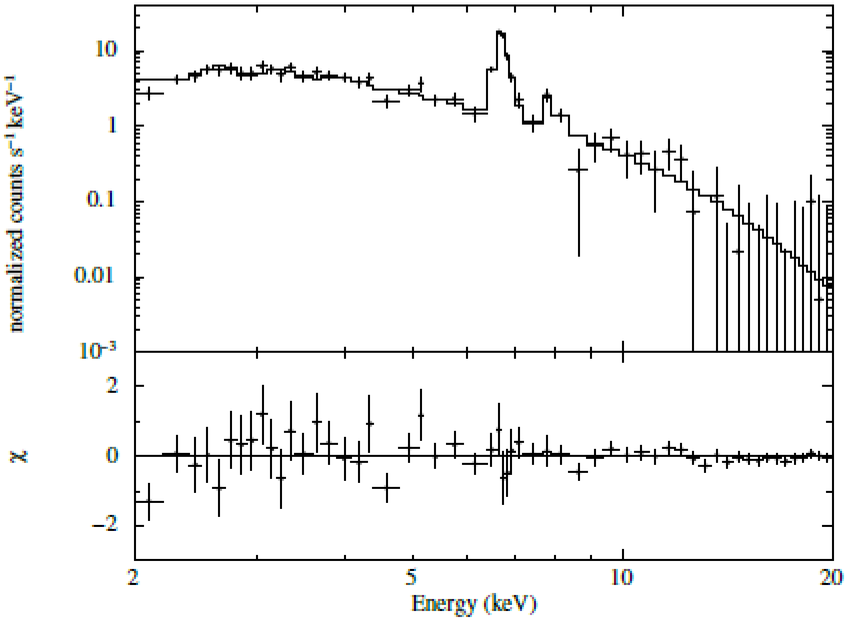
- dMe flare star EV Lac @ 5 pc (Osten et al. 2010)
- Fx~2 Crab (peak)
- Lx/Lbol~3.1 (peak)
- Strong Fe-Kα emission with ill-understood short term changes





(Osten et al. 2010)

Superflare simulation with LAD



(Drake 2016)

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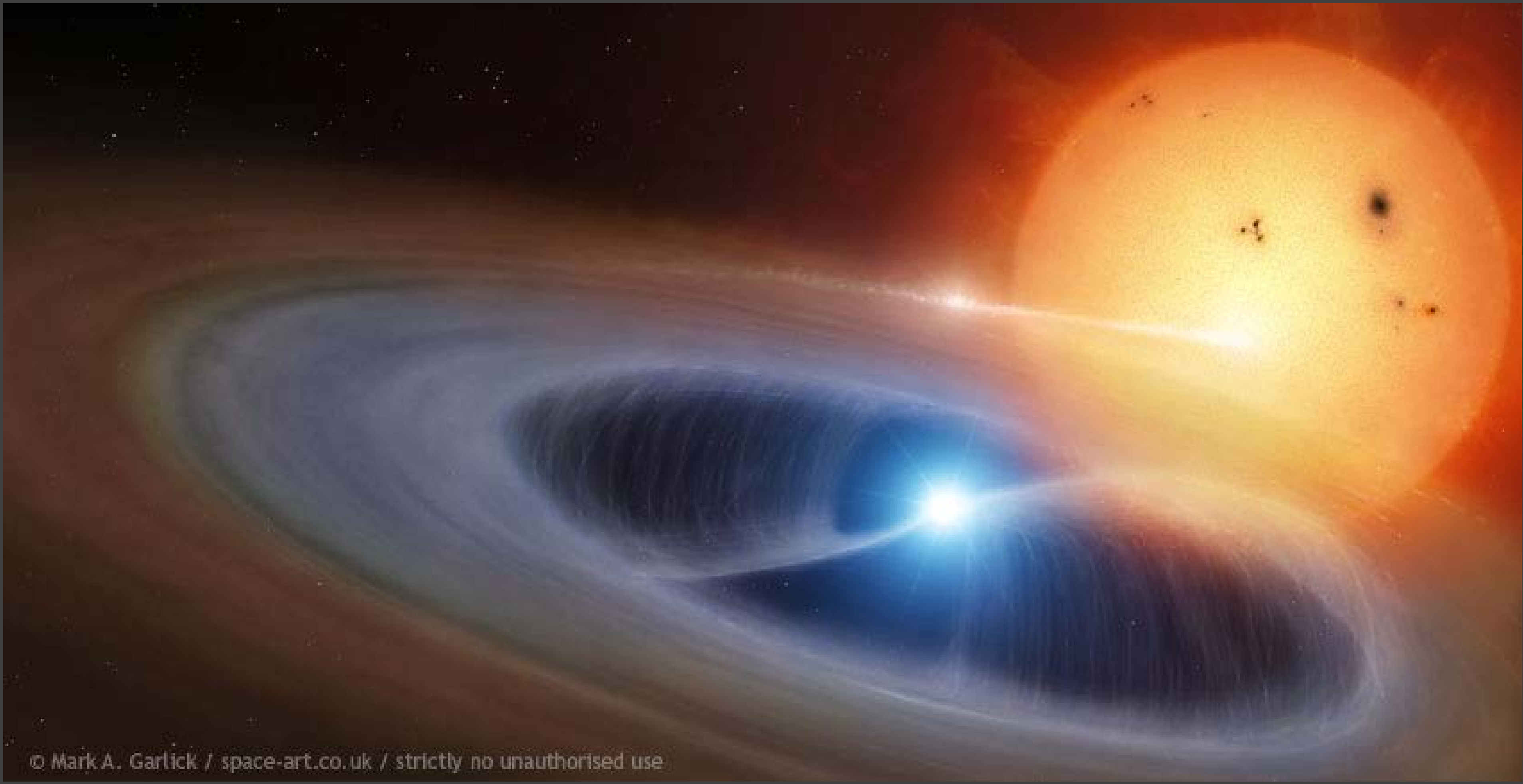
Accreting white dwarfs ($<10^{34}$ erg/s @ ~100 pc)



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Zoo of CVs

- **Dwarf novae**: disc instabilities, optical brightening (2-5) mag)
- **Nova explosions** (classical, recurrent): due to explosive nuclear burning of hydrogen (thermonuclear runaway) on top of the white dwarf - UNPREDICTABLE OUTBURSTS

- **supersoft X-ray emission** from the very hot photosphere, until residual H-burning turns-off (Teff: 1e5 to 1e6 K)
- mass ejection: **hard X-ray emission** related to shocks inside the ejecta and between the ejecta and circumstellar matter
- **high-E gamma-rays** (E>100 MeV, detected with Fermi/LAT:, related to particle acceleration in strong shocks in the ejecta. Early and with very short duration
  - case of symbiotic recurrent novae (Red Giant wind), e.g., RS Oph, but also in classical novae (Main Sequence companion):
- **hard X-rays** also produced when accretion is resumed (CV-like emission) - Lx $\approx 10^{33} – 10^{34}$ erg/s, kT up to 20keV lasting a few yrs

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Why important?

- Growing to Chandrasekhar limit, they are a viable path to type-Ia supernovae which are employed as cosmology probes (CV 4.1)
- They are probes of symbiotics = strong polluters of interstellar medium that gives rise to the birth of new stars and planets (CV 1.1)
- They are a non-relativistic benchmark for accretion/ejection phenomena in LMXBs

What are pressing issues?

- How does mass ejection work in nova explosions? Does it obstruct the path to type-Ia SNe?
- What causes dwarf novae outburst diversity and what are the conditions for disk-jet launch?
- How does matter accrete onto white dwarfs?

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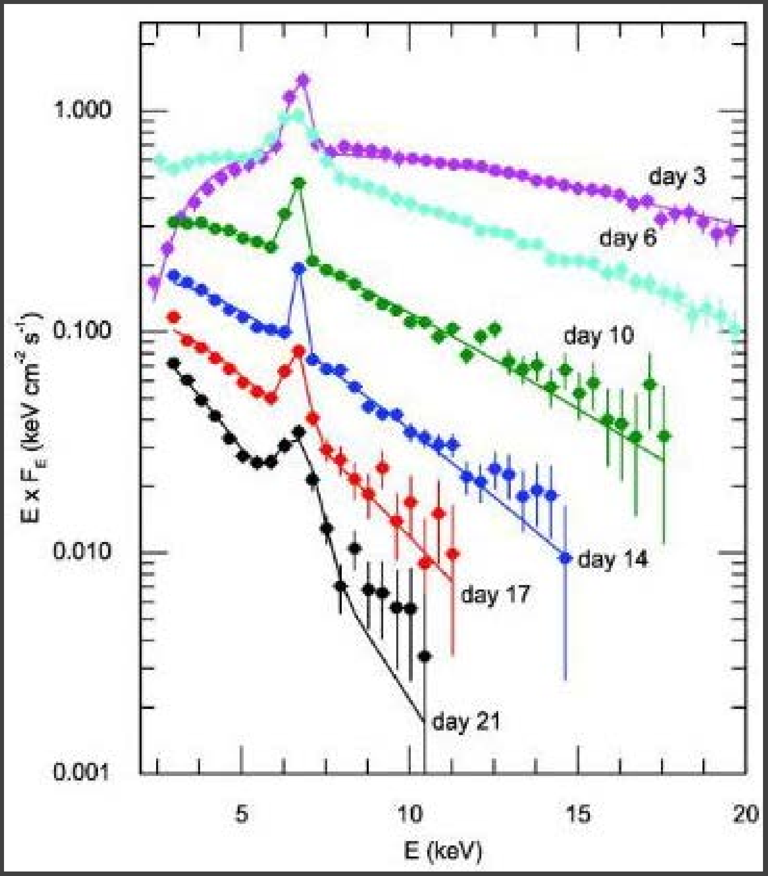
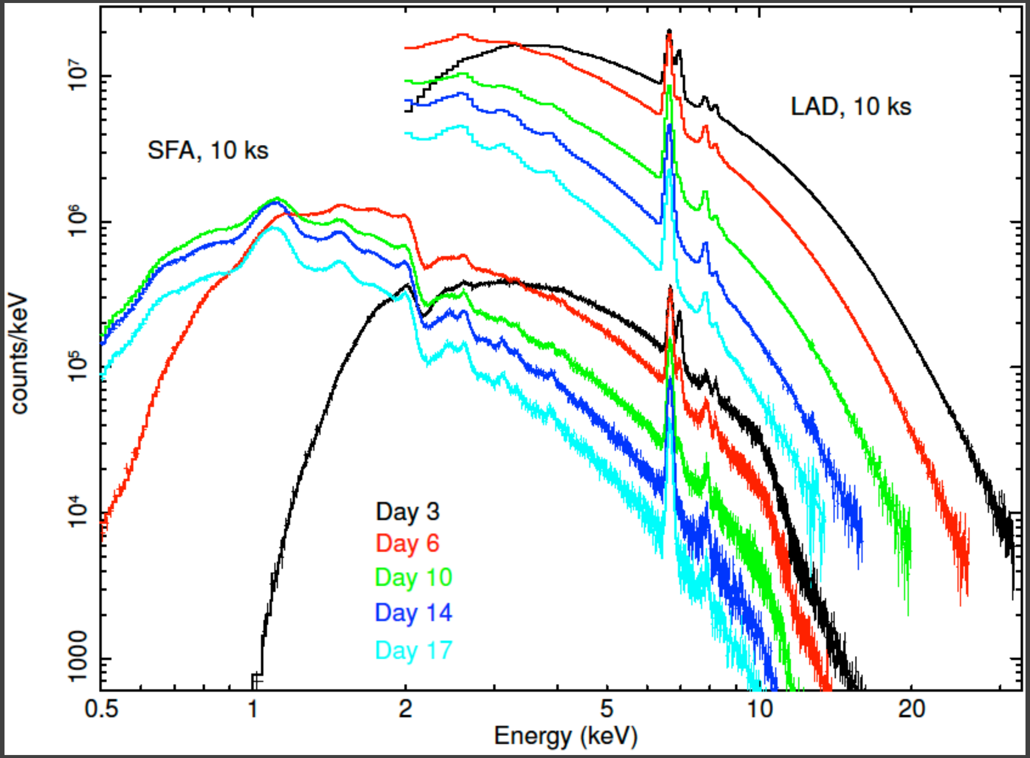
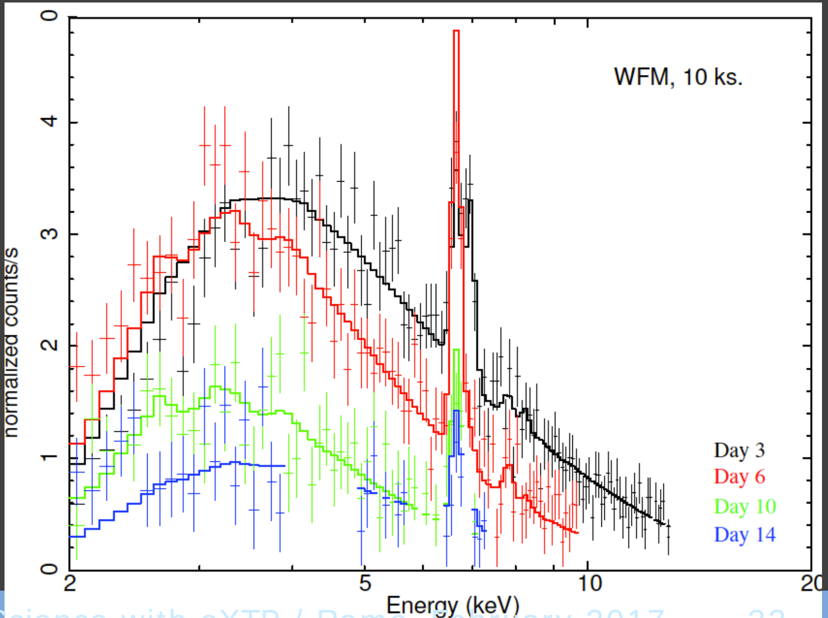
RS Oph: 2006 eruption

RXTE obs., Sokoloski+ 2006







X-ray spectrum at various times ➔ T_{shock} (t)

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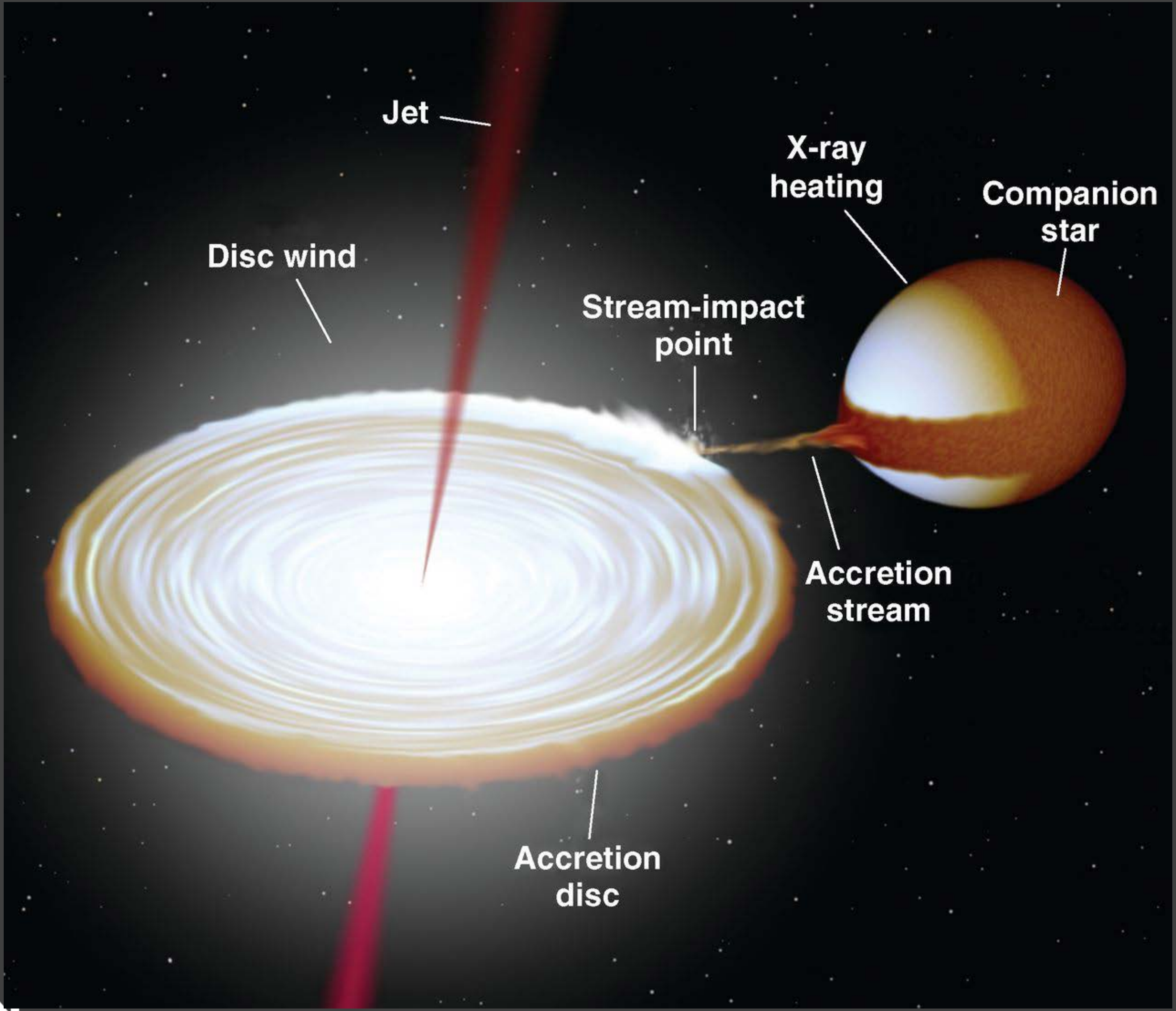
Low-mass X-ray binaries ($<10^{38}$ erg/s @ 10 kpc)

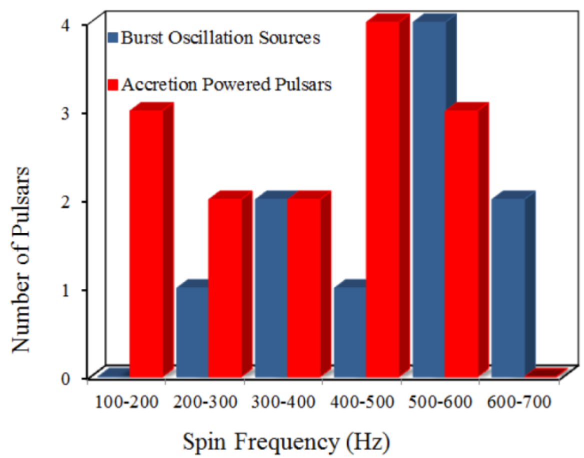


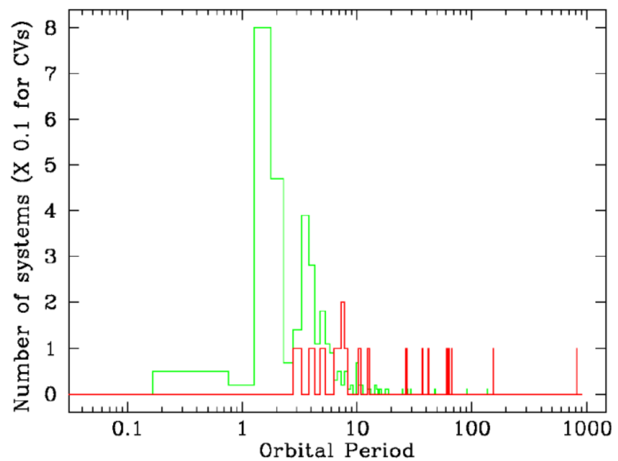
Why important?

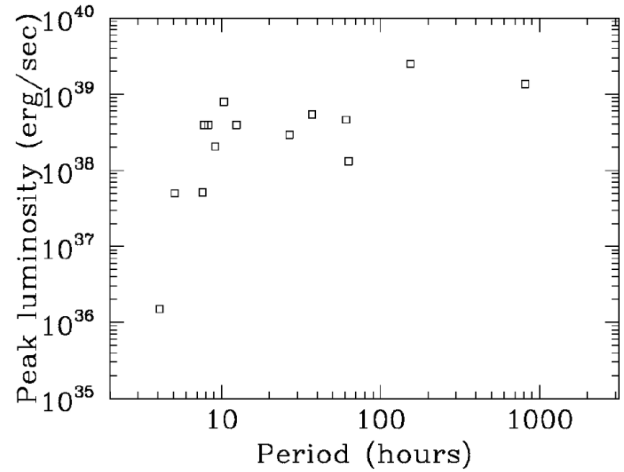
- Prime target of eXTP
- They are production sites of (fast rotating) neutron stars and black holes (CV 3.1 [SG Kerr BHs], CV 3.3 [Dense matter])

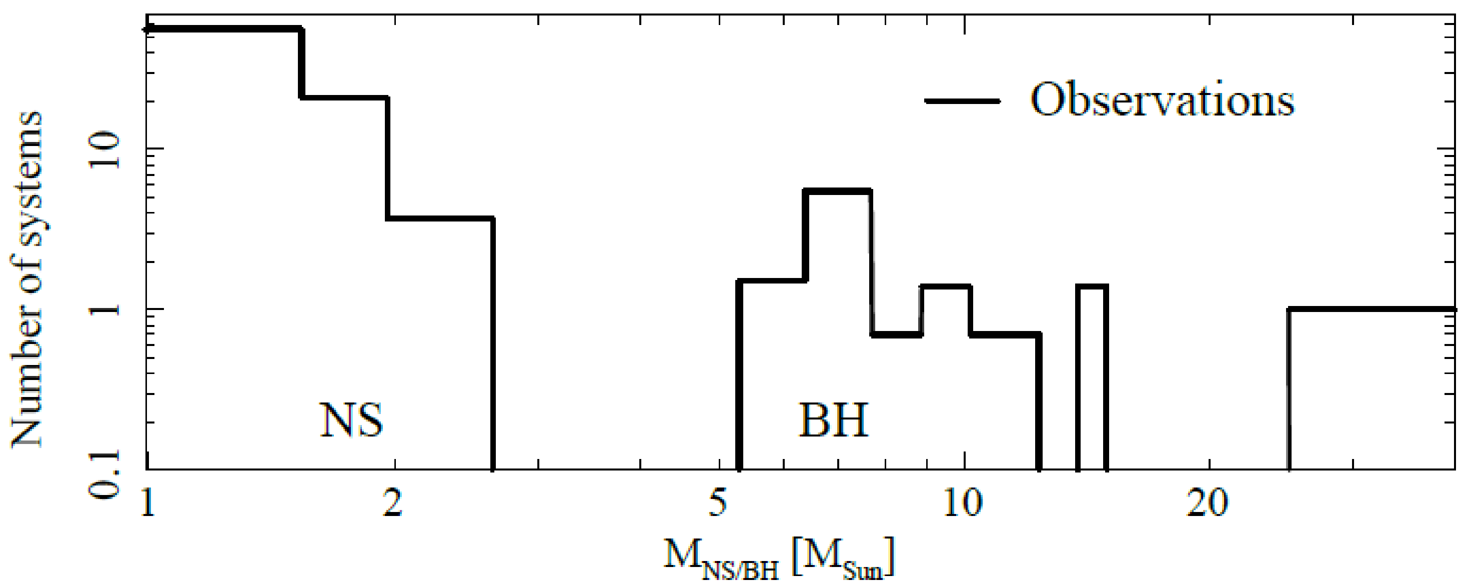
What are pressing issues?

- What is the complete population of LMXBs?
    - Mass gap NSs/BHs?
    - Very faint X-ray transients?
- How efficient is the process of neutron star spin up?


Burst Oscillation Sources
Accretion Powered Pulsars
Number of Pulsars
0
1
2
3
4
100-200
200-300
300-400
400-500
500-600
600-700
Spin Frequency (Hz)


Number of systems (X 0.1 for CVs)
0
1
2
3
4
5
6
7
8
0.1
1
10
100
1000
Orbital Period


Peak luminosity (erg/sec)
10^{35}
10^{36}
10^{37}
10^{38}
10^{39}
10^{40}
10
100
1000
Period (hours)


Observations
Number of systems
0.1
1
10
NS
BH
1
2
5
10
20
$M_{NS/BH}$ [M_{Sun}]

(Abbott + 2016)

Very faint transient LMXBs

- Discovered either
  - with moderately sensitive instruments, through type-I X-ray bursts as typical for NS LMXBs (e.g., in 't Zand et al. 1998, Cornelisse et al. 2002, Wijnands et al. 2009, Degenaar 2011)
  - In large-area surveys (e.g., Wijnands et al. 2006)
- Outside bursts: $L_{peak} < 10^{36}$ erg/s
- Explanation unclear:
  - Ultracompact X-ray sources
  - Stellar wind accretion
  - B-inhibited accretion
- Optical follow-up often difficult (high NH), but when successful usually consistent with ordinary LMXBs (e.g., Degenaar et al. 2010, Kaur et al. 2017)
- Many more? Also BH systems? → WFM

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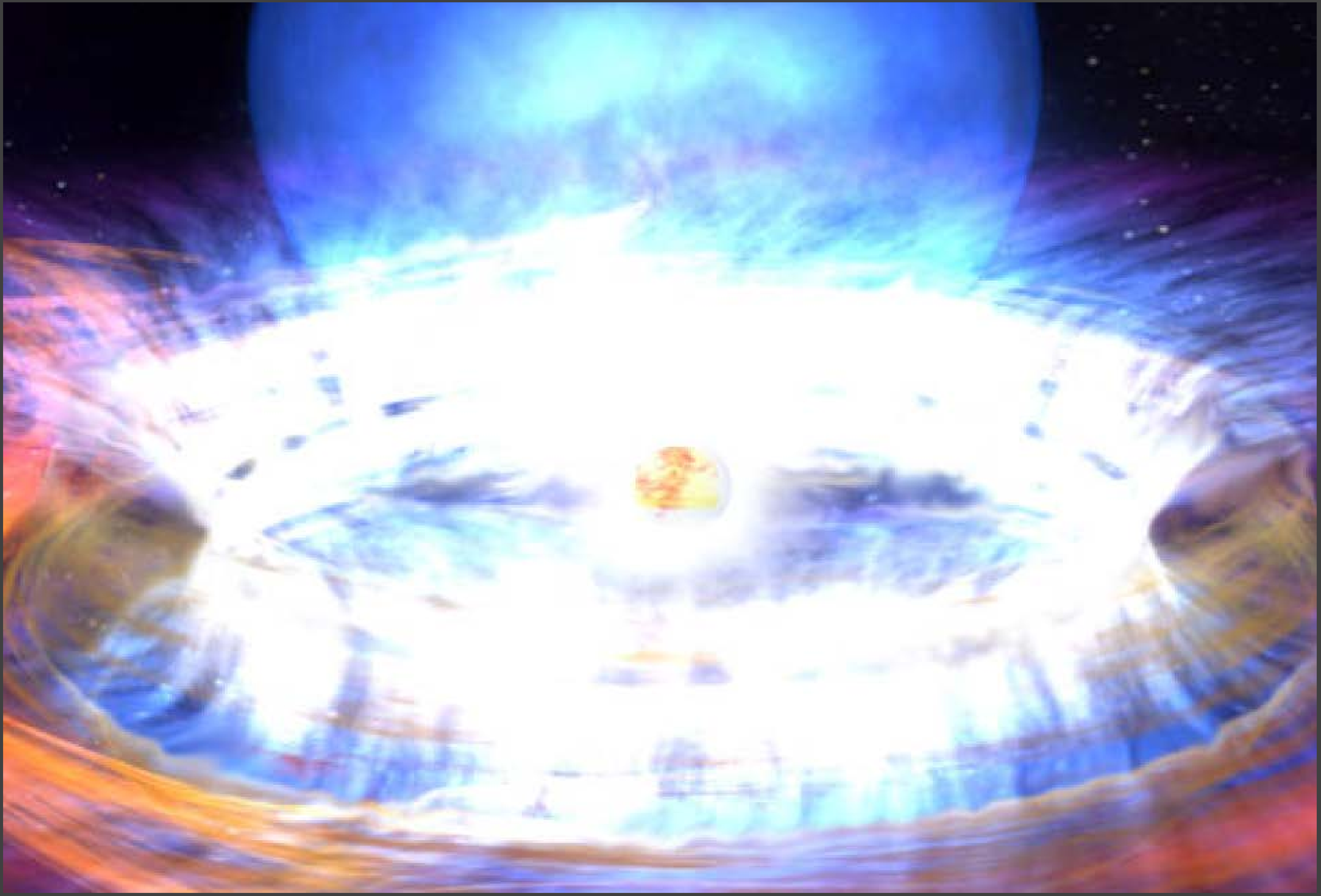
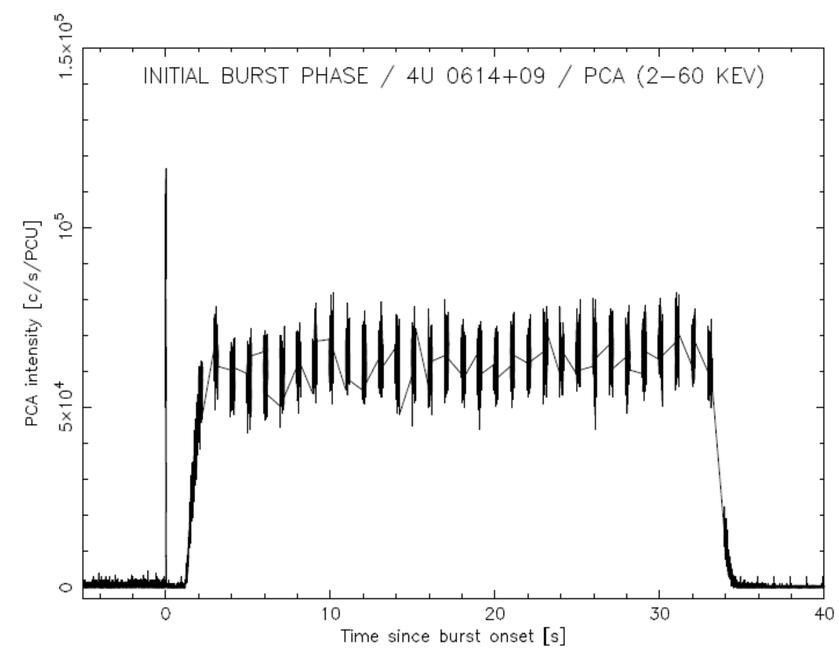
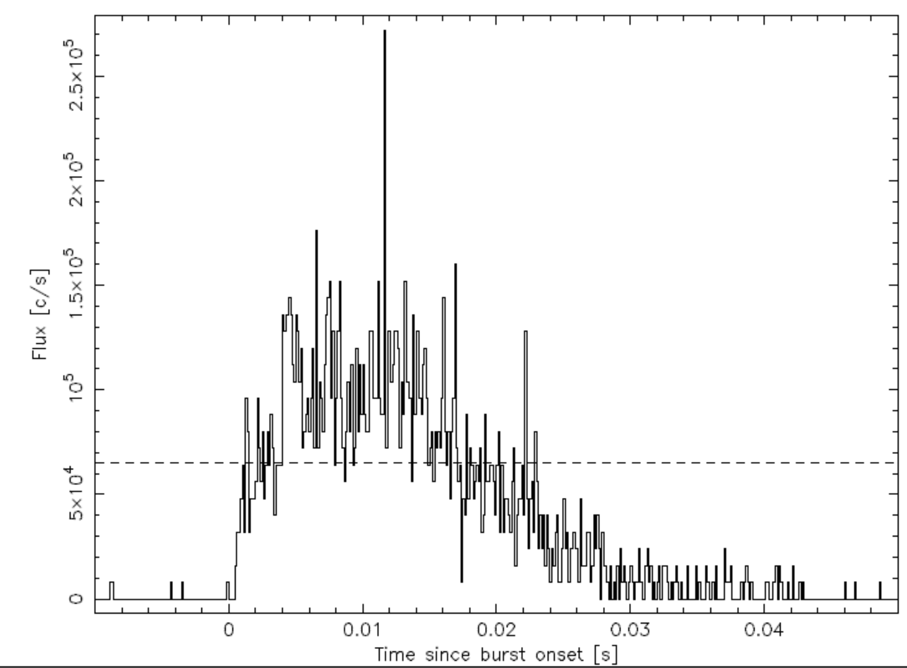
Thermonuclear flashes on neutron stars



Brightest burst in RXTE-PCA from 4U 0614+09 a showcase of high time-resolution science





(in 't Zand+ 2014)

Why important?

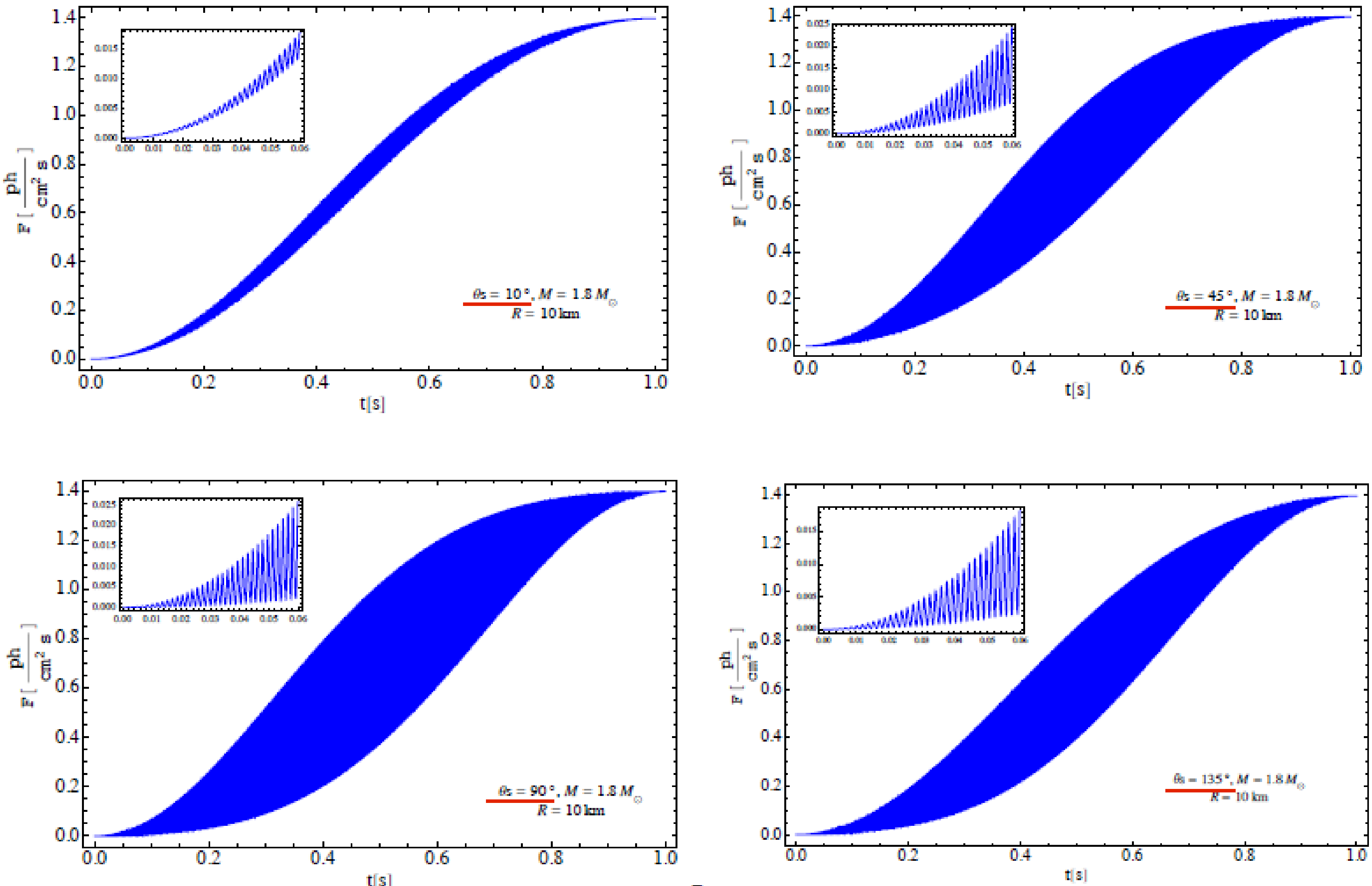
- Brightest phenomenon from NS surface → dense matter probe (CV 3.3)
- Exhibits nuclear reactions seen nowhere else (CV 4.3)

What are pressing issues?

- How does flame spreading work?
- What is the origin of burst oscillations in burst tails?
- Can bursts spread unusual isotopes?
- How do superbursts work?
- What are the circumstances for stable 3α burning on neutron star surface?

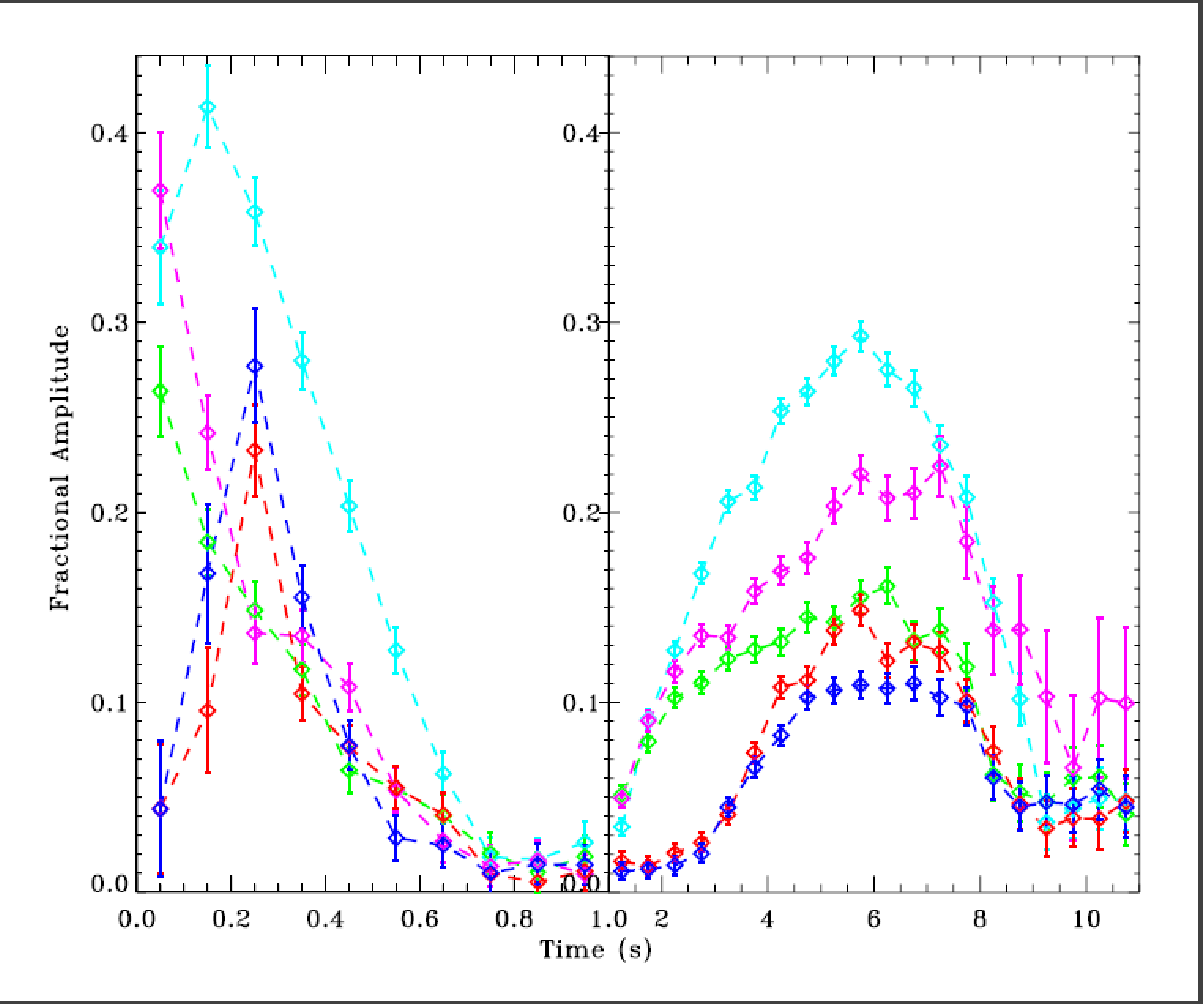
Different ignition latitudes

(Mahmoodifar & Strohmayer 2016)

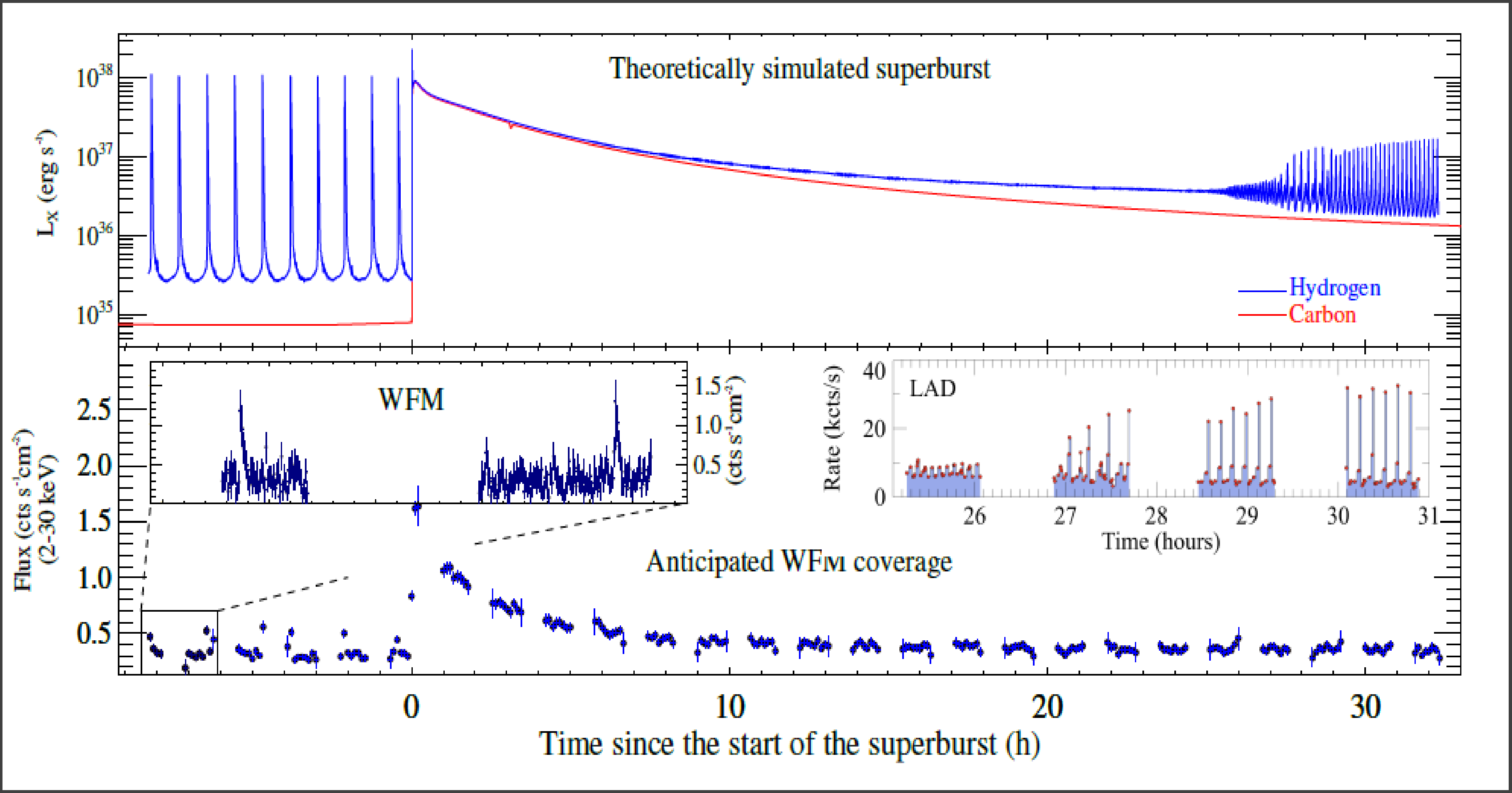


Burst oscillations – answers with eXTP-LAD

- Assume flux as for 4U 1636-536 – a prolific burster
- Viewing inclination angle 70 deg
- Ignition co-latitude
  - Red: 30 deg
  - Green: 85 deg
  - Blue 150 deg
- Magenta: larger delta-*T* (2 instead of 1.5 keV)
- Cyan: slower flame speed

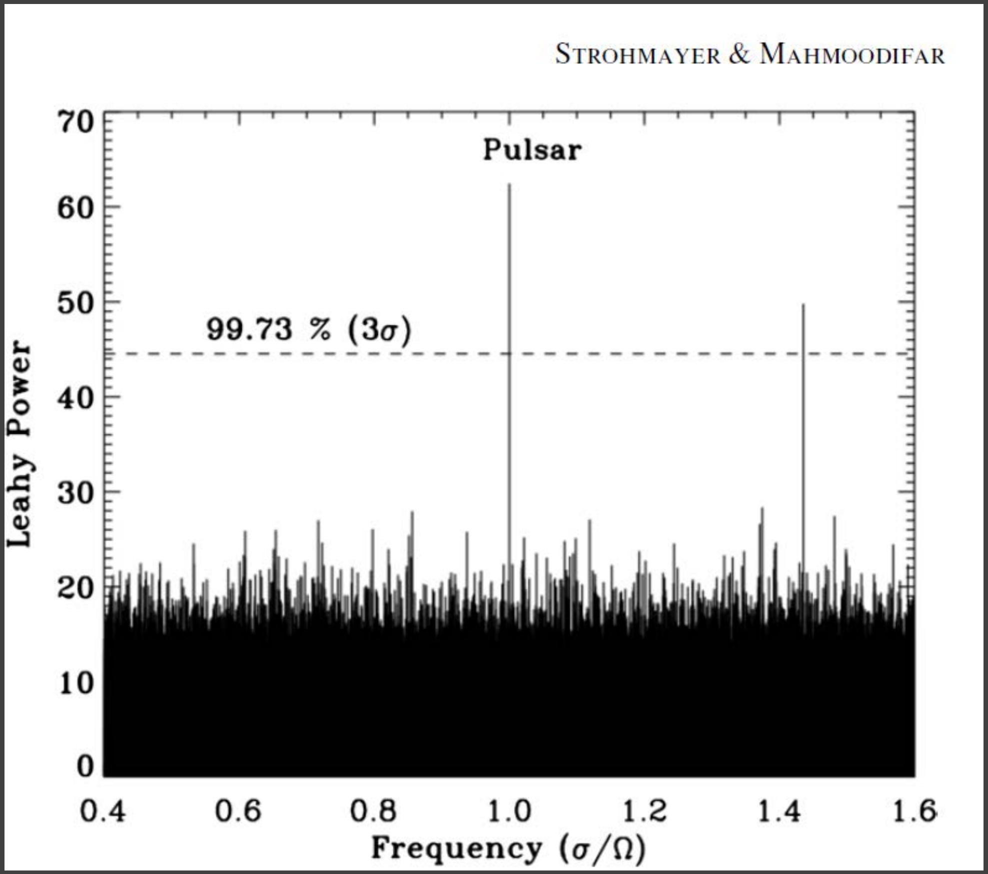


Superburst simulation (Keek et al. 2012)

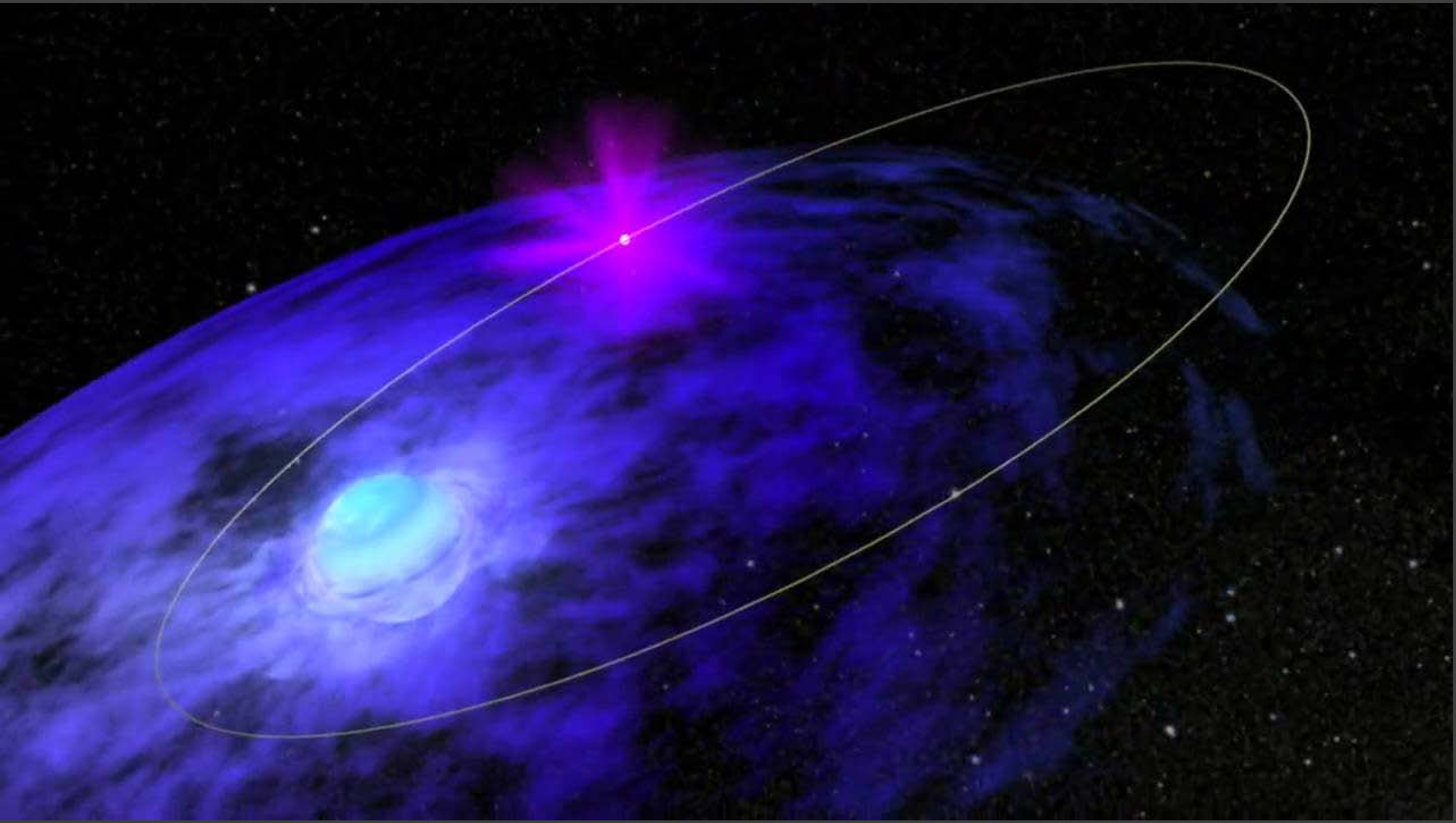


Oscillation modes

- Mode oscillations from superbursts as in Strohmayer & Mahmoodifar (2014) analysis of 1636 superburst
- Can be valuable for DM science



High-mass X-ray binaries (<10^{38} erg/s @ 10 kpc)



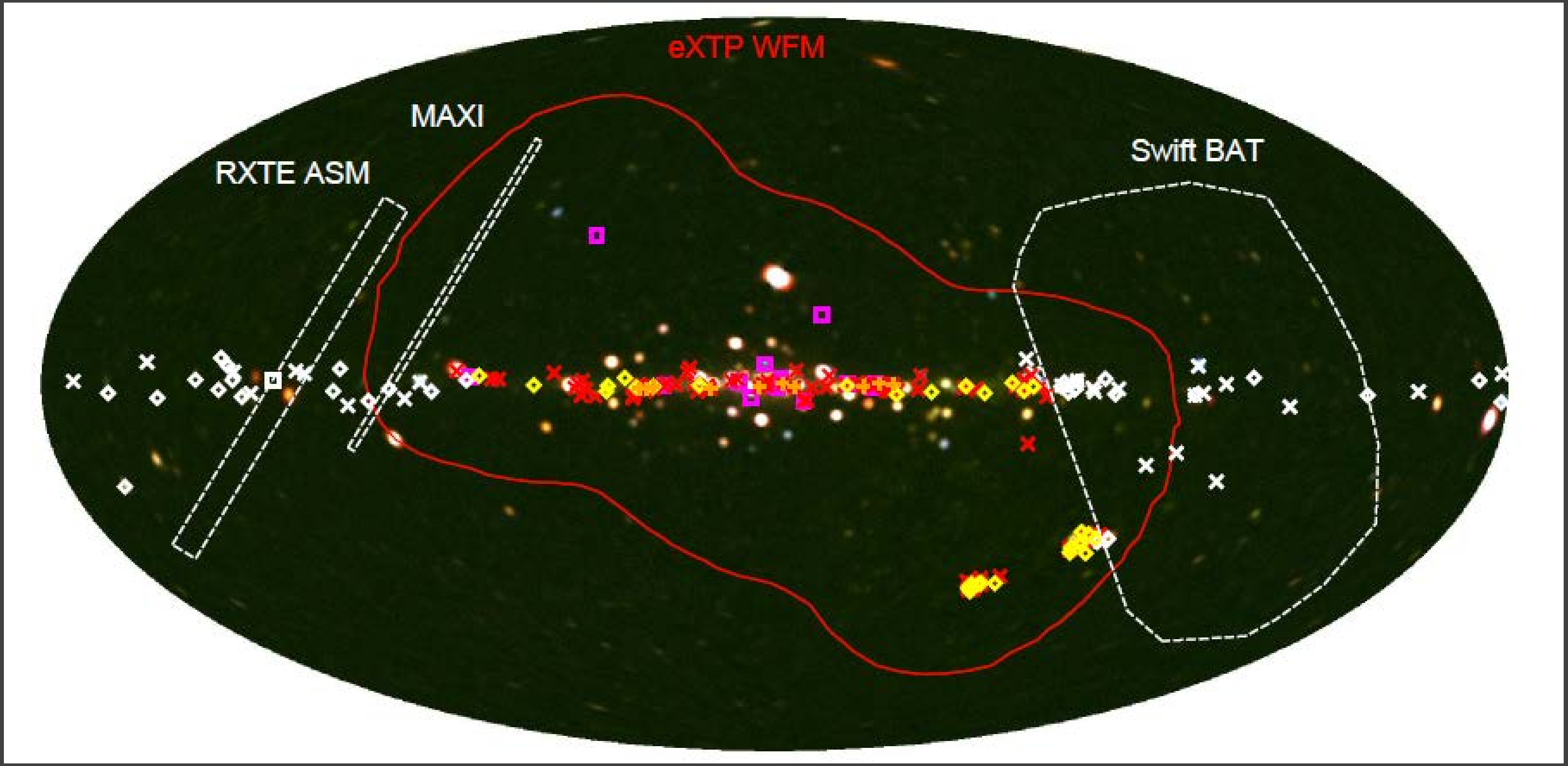
Why important?

- Dominant source of X-ray output of a star-forming region/galaxy
- We do not understand well (super)giant wind structures, mass loss rate, and heavy-mass stars
- They may be origins of (NS,BH)-(NS,BH) mergers → GWs

What are pressing questions?

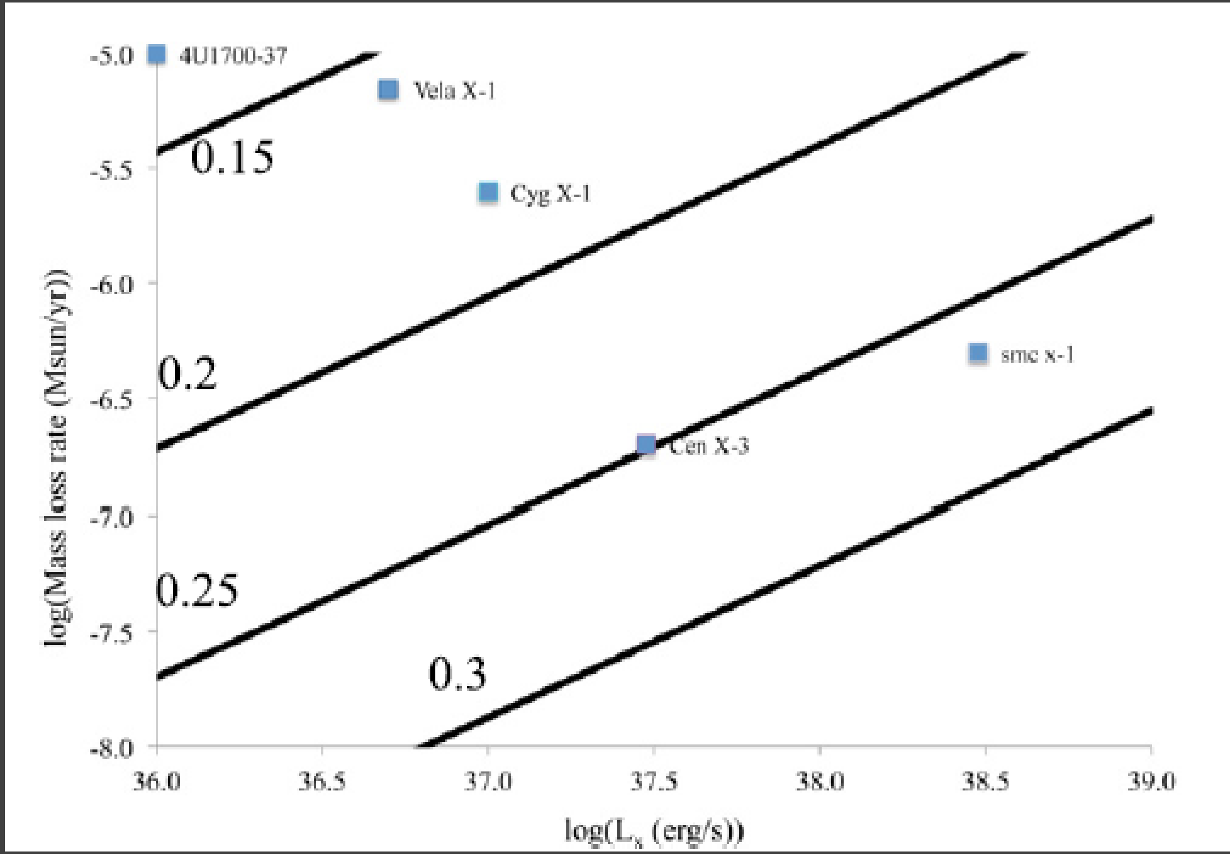
- What is the wind geometry from polarization? (PFA)
- What role do clumps play in the wind? → Romano talk
- How do torque reversals work; how does the wind play this out?
- What is B (cyclotron lines)? (LAD)

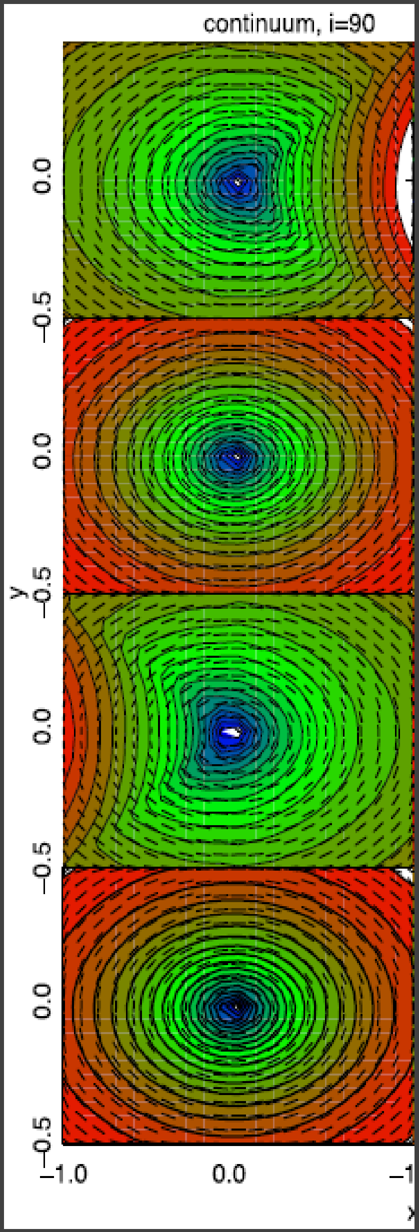
'All-sky / All-the-time' monitoring



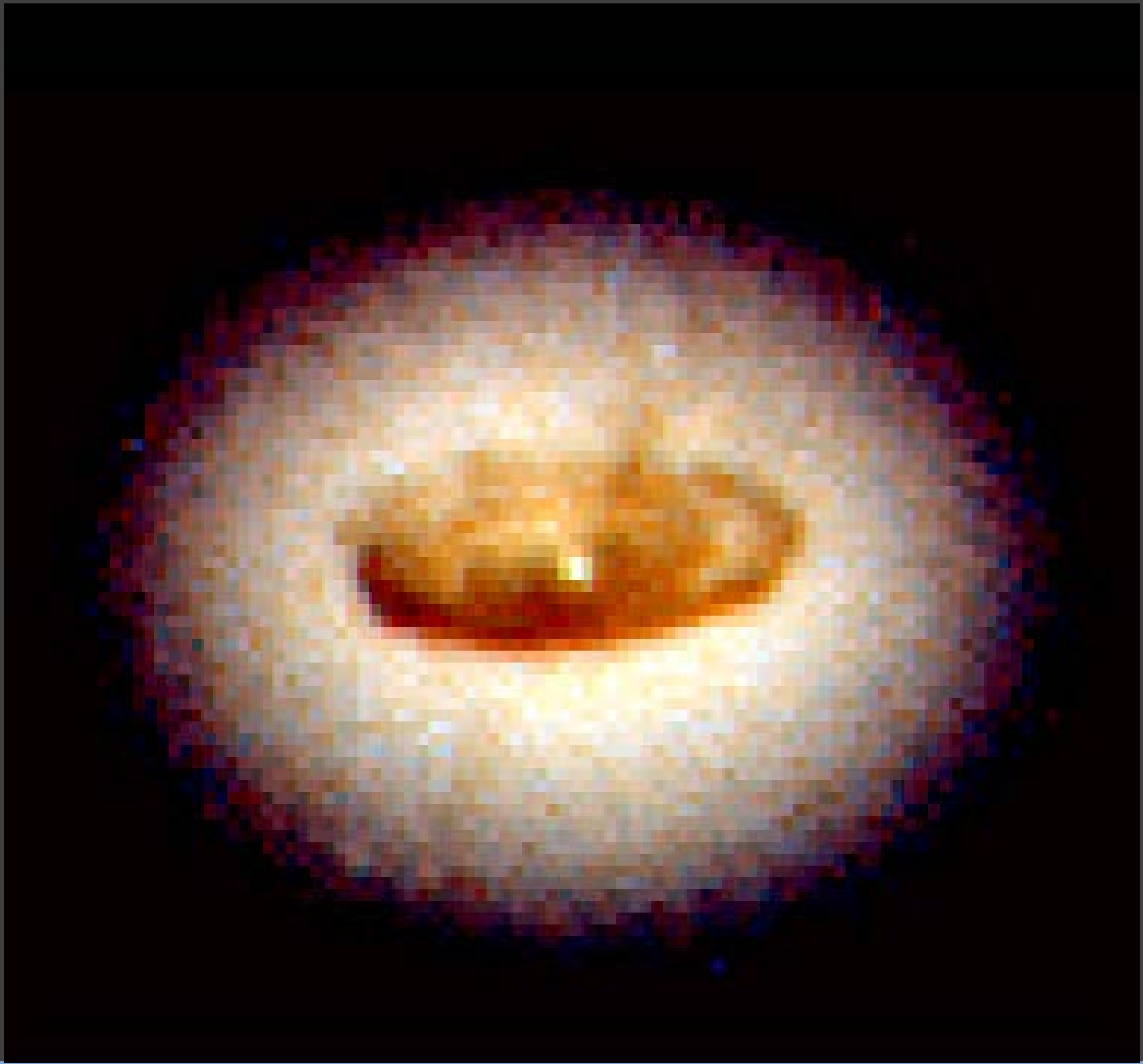
Phase-dependent polarization due to scattering in the wind

- Kallman et al. 2015





Blazars & Active galactic nuclei (<10^{48} erg/s @ ~1 Gpc)



Why important?

- What is the growth of supermassive BHs (CV 4.3)?
- How are TeV photons produced?

What are pressing issues?

- How do fast (~min) gamma-ray flares come about?
- What accelerates highly energetic electrons?

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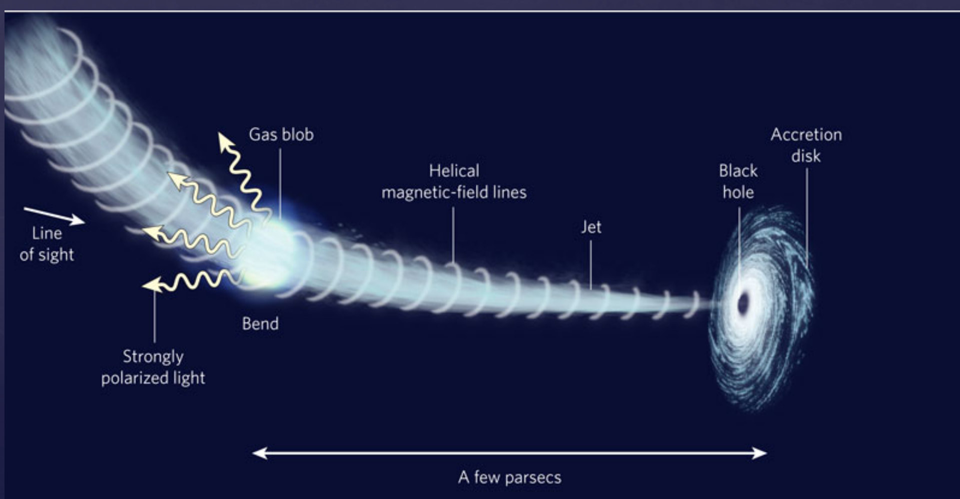
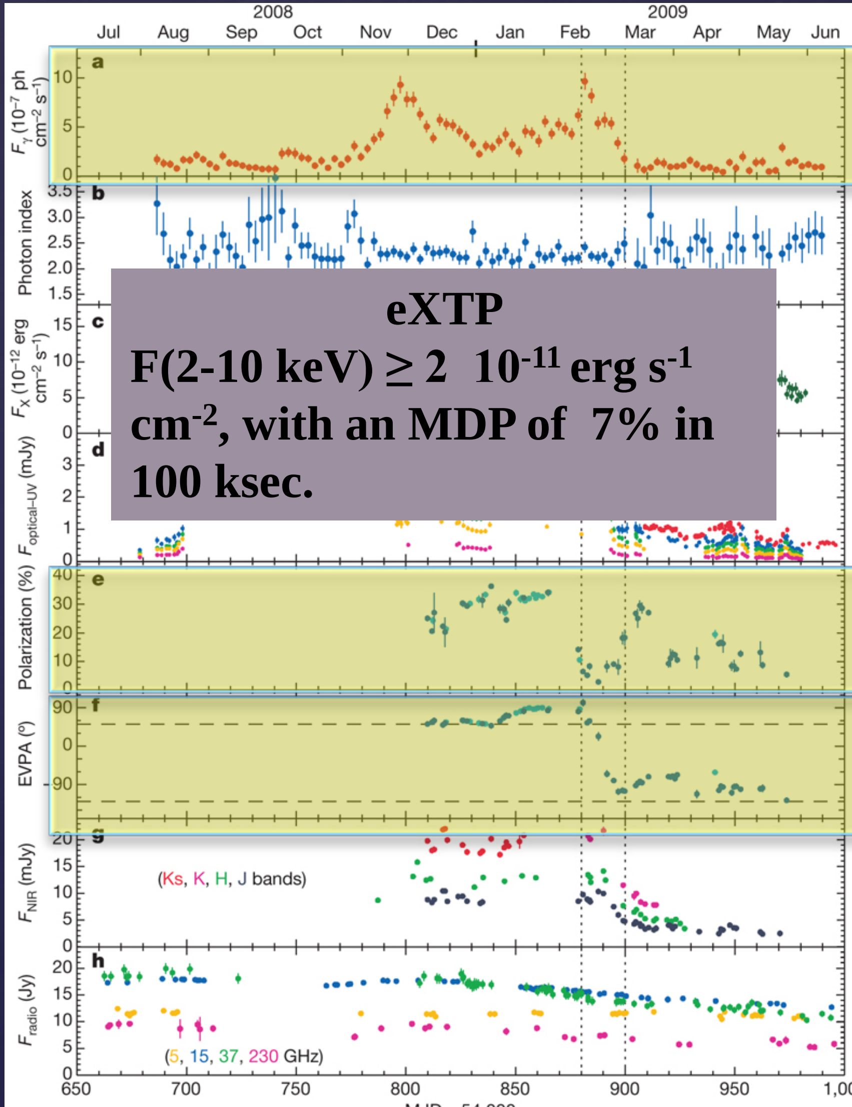
PFA measurements

Abdo et al. 2010, Nature, 463, 919

Topology of the magnetic field lines driving efficient particle acceleration:
<u>Polarization angle rotation leading the γ-ray flare</u>





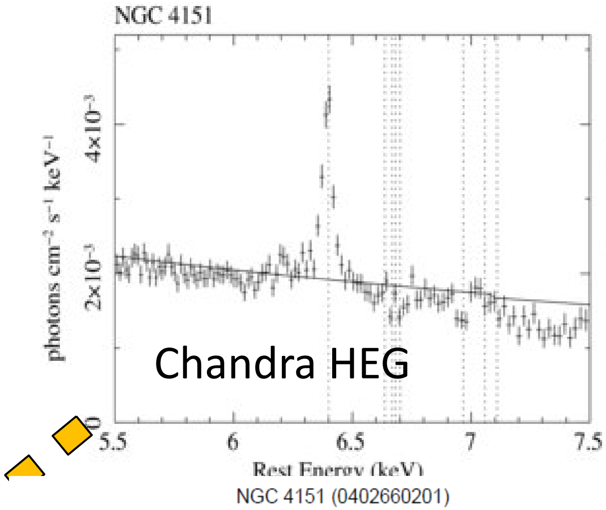
eXTP
F(2-10 keV) ≥ 2 10^{-11} erg s^{-1} cm^{-2}, with an MDP of 7% in 100 ksec.

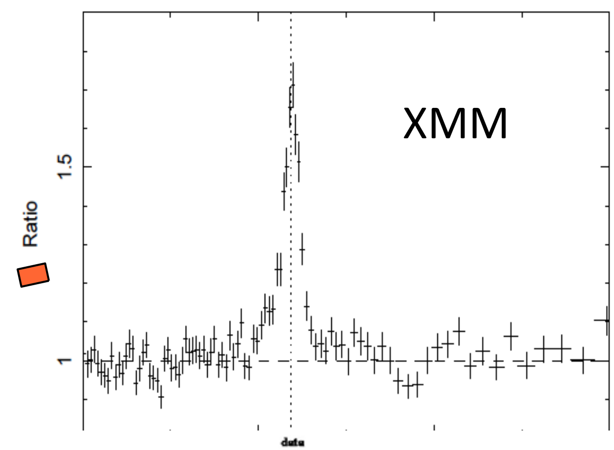
Narrow Fe line Reverberation

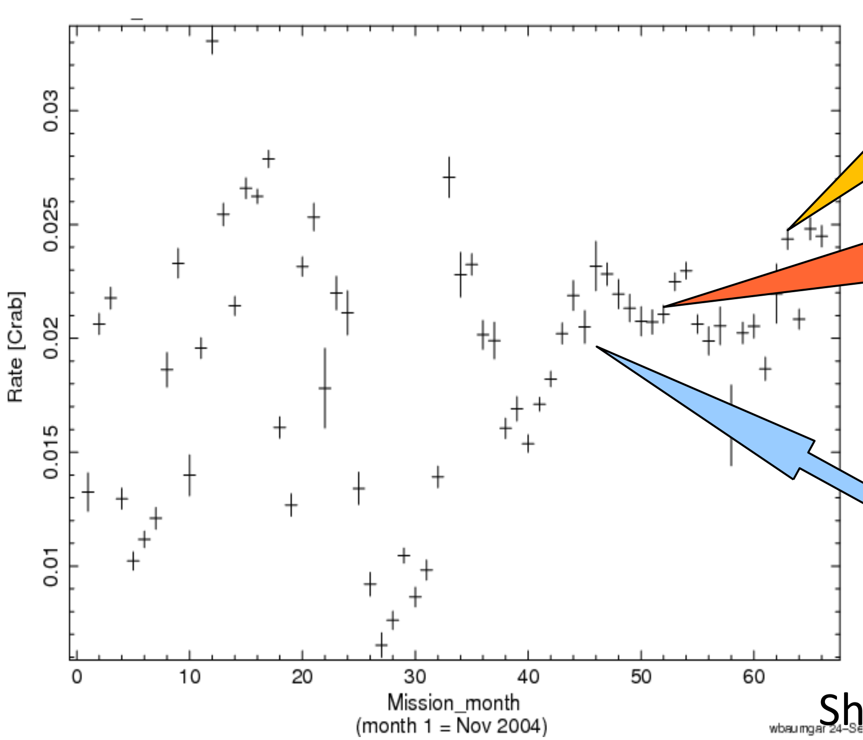
Goal: monitoring the Fe line and the continuum in order to Investigate the geometry and location of the reprocessing material.
Expected time-scales are from weeks to years (BLRs, Torus)

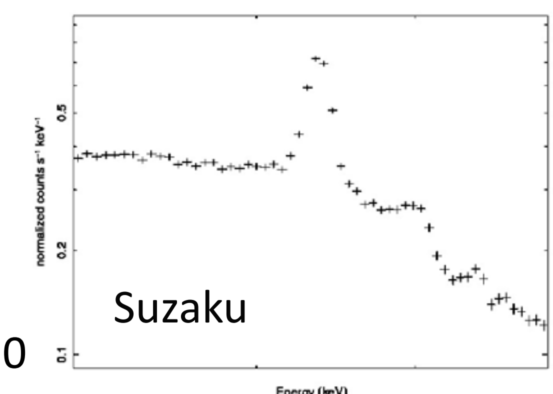
What can be done now?

Swift BAT 'continuous' lightcurves for the continuum
Badly sampled Fe line fluxes from different instruments





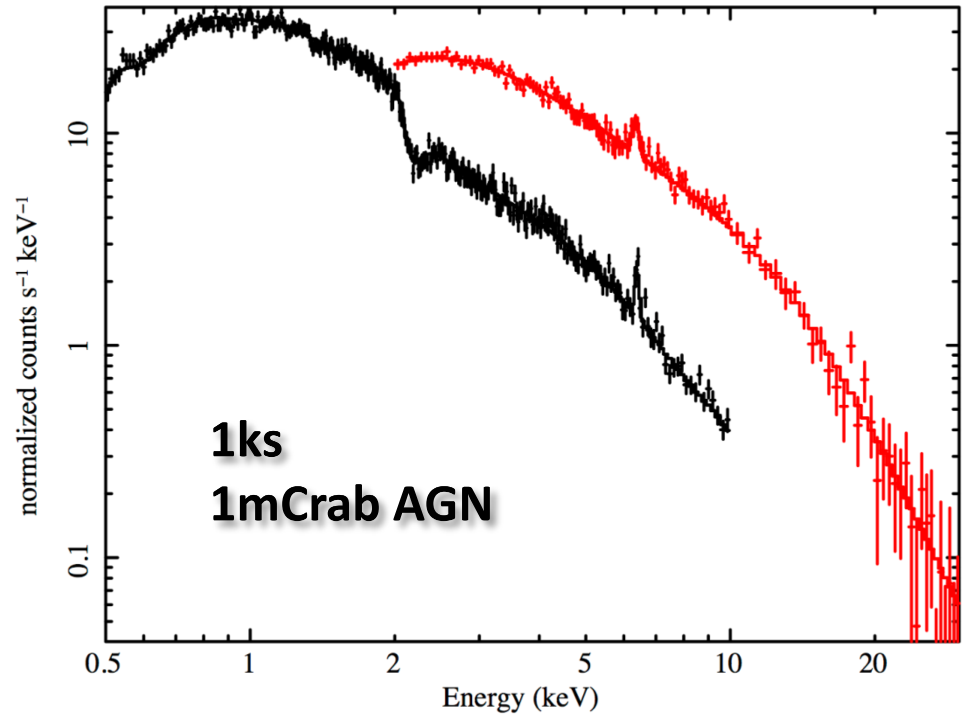




Shu+10, Tombesi+10

Narrow Fe line reverberation with eXTP

- eXTP will perform a well-sampled monitoring for the narrow Fe line (and Compton reflection for the brightest AGN) with short observations
- in 1 ks for 1mCrab AGN the Fe line flux can be recovered with **SFA+LAD** with an uncertainty of ~5-10%
- The **WFM** will produce continuous light-curves with 3σ daily (on average) time-bins for bright sources (10^{-10} cgs in the 7-50 keV band, i.e., above the Fe K edge). Weaker objects (5 $\times 10^{-11}$ cgs) will have 3σ weekly (on average) time-bins
- WFM+SFA+LAD combined capabilities!



These timescales are perfectly suited for the Fe narrow line reverberation analysis, since the expected timescales are from days to weeks to years (external disk, BLRs, Torus)

Credit A. De Rosa

eXTP synergy with other observatories..

IR

exoplanet

X-ray

Gamma

Radio

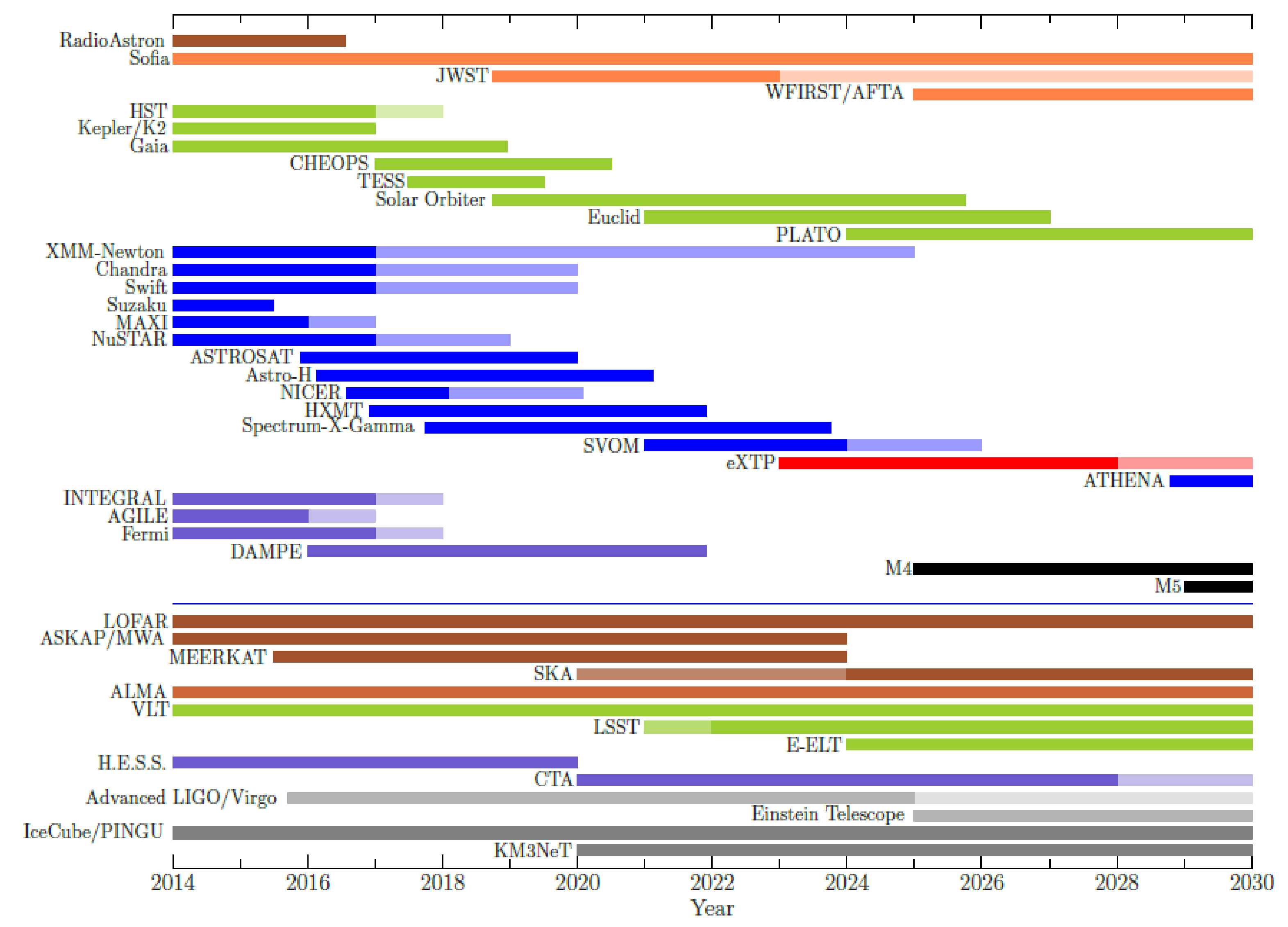
Submm

optical

TeV

GW

Neutrino



(Status January 2016)

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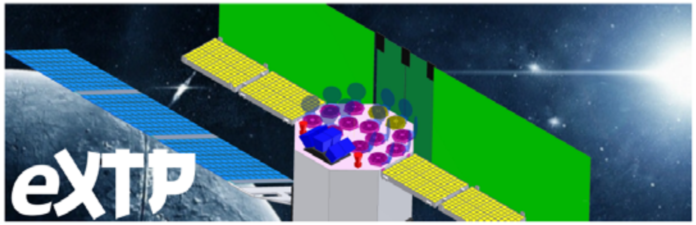
White Paper

- White Paper is for
  - promoting the mission to community
  - show broad interest to national funding agencies and ESA
- 1st version eXTP White Paper ready
  - Used for advancing eXTP in China
  - 30 pages
  - 29 authors
- Based largely on 12 LOFT White Papers
  - 140 pages
  - 277 authors
- Missing important science?
  - Use of polarization capability
  - Low-E science
- Please:
  - Provide further ideas
  - Join us, join the paper (go to eXTP website, click 'SWG registration')



Observatory science with *eXTP*

White Paper in Support of the Mission Concept of the Enhanced X-ray Timing Polarimetry mission

Contributors

L. Amati[1], S. Bianchi[2], E. Bozzo[3], Y. Chen[4], I. Donnarumma[5], V. Doroshenko[6], S. Drake[7], Y. Fan[8], M. Ge[9], M. Hernanz[10], P.A. Jenke[11], L. Ji[9], X. Li[4], T. Maccarone[12], S. Mahmoodifar[13], D. de Martino[14], J. Qu[9], A. de Rosa[15], E. Rossi[16], G. Sala[10], G. Stratta[17], T.E. Strohmayer[13], J. Wang[18], S. Weng[19], J. Wilms[20], X. Wu[7], Z. Yan[21], J.J.M. in 't Zand[22], P. Zhou[4]

[1] Italian National Institute for Astrophysics (INAF), Bologna, Italy
[2] Universitá degli studi Roma Tre, Rome, Italy
[3] ISDC, University of Geneva, Chemin d'Ecogia 16, 1290 Versoix, Switzerland
[4] School of Astronomy and Space Science, Nanjing University, Nanjing 210023, China
[5] Italian National Institute for Astrophysics (INAF), Roma, Italy
[6] Institut für Astronomie und Astrophysik, Sand 1, 72076 Tübingen, Germany
[7] USRA/CRESST and NASA's Goddard Space Flight Center, Greenbelt, Maryland, USA
[8] Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008, China
[9] Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Beijing 100049, China
[10] Institute fo Space Sciences, ICE (CSIC-IEEC), Barcelona, Spain
[11] University of Alabama, Huntsville, AL 35805, USA
[12] Texas Tech University, Lubbock, TX, USA
[13] Astrophysics Science Division and Joint Space-Science Institute, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
[14] Italian National Institute for Astrophysics (INAF) & Osservatorio Astronomico di Capodimonte, Naples, Italy
[15] INAF/Istituto di Astrofisica e Planetologie Spaziali, Roma, Italy
[16] Leiden Observatory, Leiden University, P.O. Box 9513, 2300 RA , Leiden, The Netherlands
[17] University of Urbino, Urbino, Italy
[18] Department of Astronomy, Xiamen University, Xiamen 361005, China
[19] Department of Physics, Nanjing Normal University, Nanjing 210023, China
[20] Friedrich-Alexander University Erlangen-Nürnberg, Bamberg, Germany
[21] Shanghai Astronomical Observatory, Shanghai 200030, China
[22] SRON Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, the Netherlands

Thank you!