The eXTP Mission

Studying the behavior of matter and light under extreme conditions of density, gravity and magnetism

Luca Latronico
INFN Torino - 23 Giugno 2020

eXTP - enhanced X-ray Timing and Polarimetry Mission

A flagship X-ray astronomy mission led by Chinese Academy of Science

- Launch in late 2027, currently in phase B

Payload concept

- Short focal-length for multiple modules
- Deployable panel for collimated modules
- Polarimeter with imaging capability
- Wide field monitor

A Large China-Italy cooperation opportunity

Parameter	Value
Orbit	550 km, <2.5° inclination
Launcher	Long-March CZ-7 + upper stage, from Wenchang
Mass	4500 kg
Power	3.6 kW
Telemetry	3.2 Tb/day (X-band)
Ground Stations	Sanya, Malindi
Pointing	3-axis stabilized, < 0.01° (3-sigma)
Sky visibility	50% (goal 75%)
Mission Duration	5 years (goal 8 years)
Launch date	2027

- Italy is PI of the LAD (Large Area Detector) instrument, coPI of the PFA (Polarimetry Focusing Array) instrument and co-I of the WFM (Wide Field Monitor) instrument.
- ASI is the lead funding agency in Europe.
- The Italian technology of large-area Silicon Drift Detectors is the enabling technology for both the LAD and the WFM.
- The Italian technology of Gas Pixel Detector is the enabling technology of the PFA (Polarimetry Focusing Array) instrument.

Payload	Parameter	Specification
SFA	Energy range	0.5-10 keV
	Effective area	>7000 cm^2 @1 keV, >5000 cm^2 @6 keV
	Energy resolution	<180 eV FWHM @6 keV
	FoV/HPSD	12 arcmin / 1 arcmin
	Focal plane detector	Pixelated SDD (19 pixels)
LAD	Energy range	2-30 keV (extended: 30-80 keV for out-FoV)
	Effective area	34000 cm^2
	Energy resolution	<240 eV FWHM @6 keV
	FoV	1° (FWHM)
	Detector	Large area SDD (640 units, 40 Modules)
PFA	Energy range	2-10 keV
	Effective area	>900 cm^2 @2 keV (including QE)
	Energy resolution	1.2 keV FWHM @6 keV
	FoV/HPD	12 arcmin / 20 arcsec
	Focal plane detector	GPD (4 units)
WFM	Energy range	2-50 keV
	Energy resolution	300 eV FWHM @6keV
	FoV	>4 sr (at 20% of peak response)
	Angular resolution	<5 arcmin
	Localization accuracy	<1 arcmin
	Detector	Large area SDD

Soft Response — Spectroscopy Focusing Array (Spectroscopy)

Large area — Large-Area Detector (collimated) (Timing)

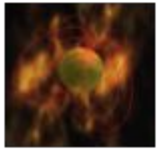
Polarization — Polarimetry Focusing Array (Polarimetry)

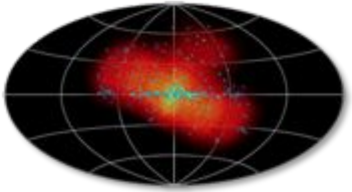
Monitoring — Wide-Field Monitor (Transient Monitoring)

eXTP Science Drivers

Study of matter under extreme conditions of gravity, density and magnetism.
Simultaneous, high-throughput spectral, timing and polarimetry observations.

- Constrain the Equation of state of the supra-nuclear density matter in the interior of neutron stars.
- Accretion physics in the strong-field regime of gravity and tests of General Relativity in neutron stars and black holes over the mass scale.
- Physics of light and matter in the presence of ultra-strong magnetic fields in magnetars and X-ray pulsars.
- Multi-purpose observatory and wide-field monitoring for transients (and e.m. counterparts of GWs). Rapid follow-up.





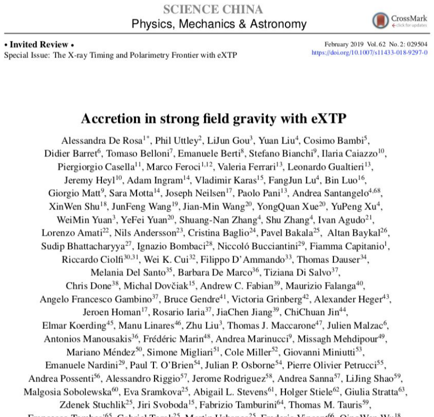
eXTP Science Themes

Dense Matter: which is the state of matter at supranuclear densities?

Strong Gravity: what are space-time properties under extreme gravity?

Strong magnetism: how does light behave with ultra-strong B fields?

Observatory Science: multimessenger astroparticle



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Accretion in strong field gravity with eXTP

Alessandra De Rosa[1*], Phil Uttley[2], LiJun Gou[3], Yuan Liu[4], Cosimo Bambi[5], Didier Barret[6], Tomaso Belloni[7], Emanuele Berti[8], Stefano Bianchi[9], Ilaria Caiazzo[10], Piergiorgio Casella[11], Marco Feroci[1,12], Valeria Ferrari[13], Leonardo Gualtieri[13], Jeremy Heyl[10], Adam Ingram[14], Vladimir Karas[15], FangJun Lu[4], Bin Luo[16], Giorgio Matt[9], Sara Motta[14], Joseph Neilsen[17], Paolo Pani[13], Andrea Santangelo[4,68], XinWen Shu[18], JunFeng Wang[19], Jian-Min Wang[20], YongQuan Xue[20], YuPeng Xu[4], WeiMin Yuan[3], YeFei Yuan[20], Shuang-Nan Zhang[4], Shu Zhang[4], Ivan Agudo[21], Lorenzo Amati[22], Nils Andersson[23], Cristina Baglio[24], Pavel Bakala[25], Altan Baykal[26], Sudip Bhattacharyya[27], Ignazio Bombaci[28], Nicolò Bucciantini[29], Fiamma Capitanio[1], Riccardo Ciolfi[30,31], Wei K. Cui[32], Filippo D'Ammando[33], Thomas Dauser[34], Melania Del Santo[35], Barbara De Marco[36], Tiziana Di Salvo[37], Chris Done[38], Michal Dovčiak[15], Andrew C. Fabian[39], Maurizio Falanga[40], Angelo Francesco Gambino[37], Bruce Gendre[41], Victoria Grinberg[42], Alexander Heger[43], Jeroen Homan[17], Rosario Iaria[37], JiaChen Jiang[39], ChiChuan Jin[44], Elmar Koerding[45], Manu Linares[46], Zhu Liu[3], Thomas J. Maccarone[47], Julien Malzac[6], Antonios Manousakis[36], Frédéric Marin[48], Andrea Marinucci[9], Missagh Mehdipour[49], Mariano Méndez[50], Simone Migliari[51], Cole Miller[52], Giovanni Miniutti[53], Emanuele Nardini[29], Paul T. O'Brien[54], Julian P. Osborne[54], Pierre Olivier Petrucci[55], Andrea Possenti[56], Alessandro Riggio[57], Jerome Rodriguez[58], Andrea Sanna[57], LiJing Shao[59], Malgosia Sobolewska[60], Eva Sramkova[25], Abigail L. Stevens[61], Holger Stiele[62], Giulia Stratta[63], Zdenek Stuchlik[25], Jiri Svoboda[15], Fabrizio Tamburini[64], Thomas M. Tauris[59],

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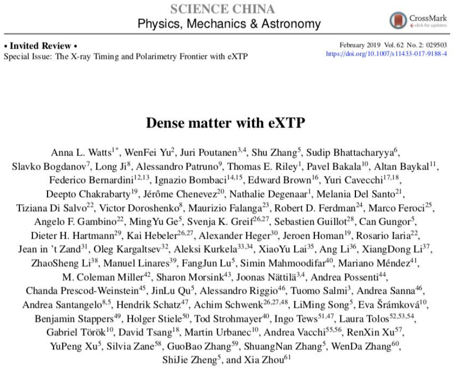
Observatory science with eXTP

Jean J. M. in 't Zand[1*], Enrico Bozzo[2], JinLu Qu[3], Xiang-Dong Li[4], Lorenzo Amati[5], Yang Chen[4], Immacolata Donnarumma[6,7], Victor Doroshenko[8], Stephen A. Drake[9], Margarita Hernanz[10], Peter A. Jenke[11], Thomas J. Maccarone[12], Simin Mahmoodifar[9], Domitilla de Martino[13], Alessandra De Rosa[7], Elena M. Rossi[14], Antonia Rowlinson[15,16], Gloria Sala[17], Giulia Stratta[18], homas M. Tauris[19], Joern Wilms[20], XueFeng Wu[21], Ping Zhou[15,4], Iván Agudo[22], Diego Altamirano[23], Jean-Luc Atteia[24], Nils A. Andersson[25], M. Cristina Baglio[26], David R. Ballantyne[27], Altan Baykal[28], nud Behar[29], Tomaso Belloni[30], Sudip Bhattacharyya[31], Stefano Bianchi[32], Anna Bilous[15], Pere Blay[33], João Braga[34], Søren Brandt[35], Edward F. Brown[36], Niccolò Bucciantini[37], Luciano Burderi[38], dward M. Cackett[39], Riccardo Campana[5], Sergio Campana[30], Piergiorgio Casella[40], Yuri Cavecchi[41,25], Frank Chambers[15], Liang Chen[42], Yu-Peng Chen[3], Jérôme Chenevez[35], Maria Chernyakova[43], ChiChuan Jin[44], Riccardo Ciolfi[45,46], Elisa Costantini[1,15], Andrew Cumming[47], Antonino D'Aì[48], Zi-Gao Dai[4], Filippo D'Ammando[49], Massimiliano De Pasquale[50], Nathalie Degenaar[15], Melania Del Santo[48], Valerio D'Elia[40], Tiziana Di Salvo[51], Gerry Doyle[52], Maurizio Falanga[53], XiLong Fan[54,55], Robert D. Ferdman[56], Marco Feroci[7], Federico Fraschetti[57], Duncan K. Galloway[58], ngelo F. Gambino[51], Poshak Gandhi[59], MingYu Ge[3], Bruce Gendre[60], Ramandeep Gill[61], Diego Götz[62], Christian Gouiffès[62], Paola Grandi[5], Jonathan Granot[61], Manuel Güdel[63], Alexander Heger[58,64,121], Craig O. Heinke[65], Jeroen Homan[66,1], Rosario Iaria[51], Kazushi Iwasawa[67], Luca Izzo[68], Long Ji[8], Peter G. Jonker[1,69], Jordi José[17], Jelle S. Kaastra[1], Emrah Kalemci[70], Oleg Kargaltsev[71], Nobuyuki Kawai[72], Laurens Keek[73], Stefanie Komossa[19], Ingo Kreykenbohm[20], Lucien Kuiper[1], Devaky Kunneriath[74], Gang Li[3], En-Wei Liang[75], Manuel Linares[17], Francesco Longo[76], FangJun Lu[3], Alexander A. Lutovinov[77], Denys Malyshev[8], Julien Malzac[78], Antonios Manousakis[79],



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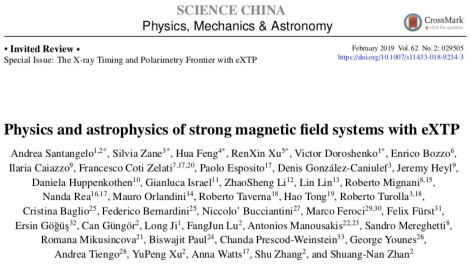
Dense matter with eXTP

Anna L. Watts[1*], WenFei Yu[2], Juri Poutanen[3,4], Shu Zhang[5], Sudip Bhattacharyya[6], Slavko Bogdanov[7], Long Ji[8], Alessandro Patruno[9], Thomas E. Riley[1], Pavel Bakala[10], Altan Baykal[11], Federico Bernardini[12,13], Ignazio Bombaci[14,15], Edward Brown[16], Yuri Cavecchi[17,18], Deepto Chakrabarty[19], Jérôme Chenevez[20], Nathalie Degenaar[1], Melania Del Santo[21], Tiziana Di Salvo[22], Victor Doroshenko[8], Maurizio Falanga[23], Robert D. Ferdman[24], Marco Feroci[25], Angelo F. Gambino[22], MingYu Ge[5], Svenja K. Greif[26,27], Sebastien Guillot[28], Can Gungor[5], Dieter H. Hartmann[29], Kai Hebeler[26,27], Alexander Heger[30], Jeroen Homan[19], Rosario Iaria[22], Jean in 't Zand[31], Oleg Kargaltsev[32], Aleksi Kurkela[33,34], XiaoYu Lai[35], Ang Li[36], XiangDong Li[37], ZhaoSheng Li[38], Manuel Linares[39], FangJun Lu[5], Simin Mahmoodifar[40], Mariano Méndez[41], M. Coleman Miller[42], Sharon Morsink[43], Joonas Nättilä[3,4], Andrea Possenti[44], Chanda Prescod-Weinstein[45], JinLu Qu[5], Alessandro Riggio[46], Tuomo Salmi[3], Andrea Sanna[46], Andrea Santangelo[8,5], Hendrik Schatz[47], Achim Schwenk[26,27,48], LiMing Song[5], Eva Šrámková[10], Benjamin Stappers[49], Holger Stiele[50], Tod Strohmayer[40], Ingo Tews[51,47], Laura Tolos[52,53,54], Gabriel Török[10], David Tsang[18], Martin Urbanec[10], Andrea Vacchi[55,56], RenXin Xu[57], YuPeng Xu[5], Silvia Zane[58], GuoBao Zhang[59], ShuangNan Zhang[5], WenDa Zhang[60], ShiJie Zheng[5], and Xia Zhou[61]



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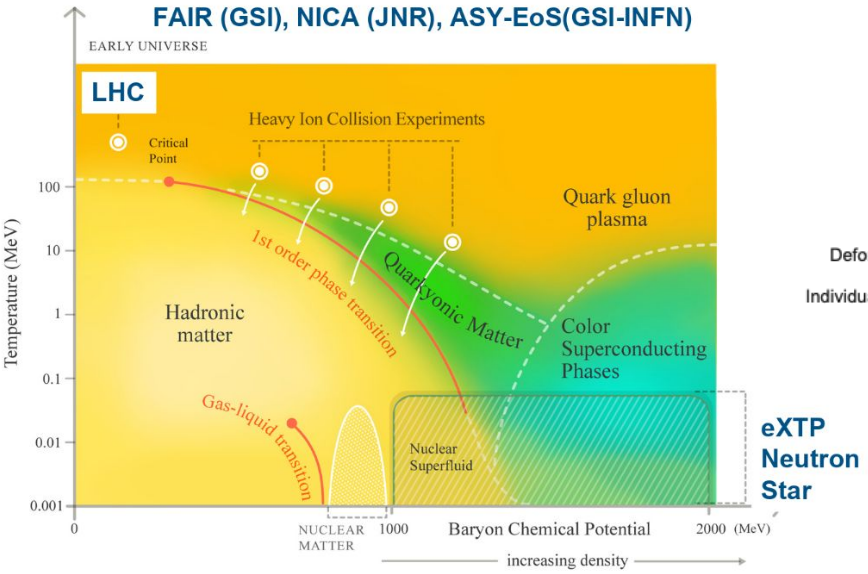
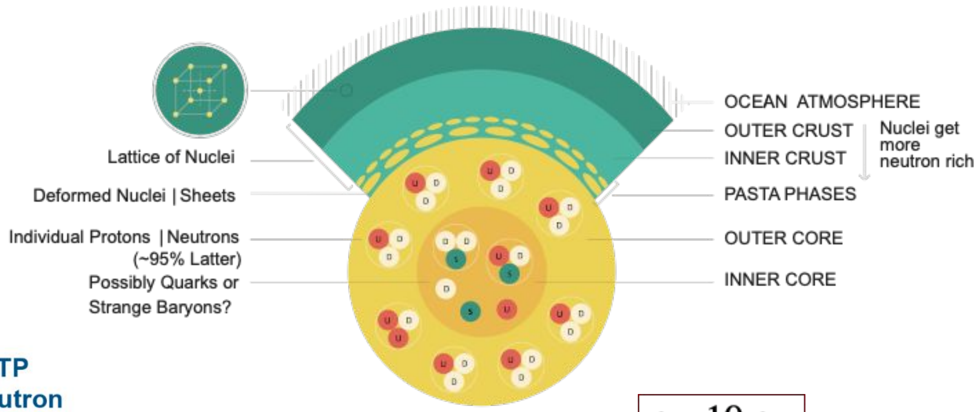
Physics and astrophysics of strong magnetic field systems with eXTP

Andrea Santangelo[1,2*], Silvia Zane[3*], Hua Feng[4*], RenXin Xu[5*], Victor Doroshenko[1*], Enrico Bozzo[6], Ilaria Caiazzo[9], Francesco Coti Zelati[7,17,20], Paolo Esposito[17], Denis González-Caniulef[3], Jeremy Heyl[9], Daniela Huppenkothen[10], Gianluca Israel[11], ZhaoSheng Li[12], Lin Lin[13], Roberto Mignani[8,15], Nanda Rea[16,17], Mauro Orlandini[14], Roberto Taverna[18], Hao Tong[19], Roberto Turolla[3,18], Cristina Baglio[25], Federico Bernardini[25], Niccolo' Bucciantini[27], Marco Feroci[29,30], Felix Fürst[31], Ersin Göğüş[32], Can Güngör[2], Long Ji[1], FangJun Lu[2], Antonios Manousakis[22,23], Sandro Mereghetti[8], Romana Mikusincova[21], Biswajit Paul[24], Chanda Prescod-Weinstein[33], George Younes[26], Andrea Tiengo[28], YuPeng Xu[2], Anna Watts[17], Shu Zhang[2], and Shuang-Nan Zhan[2]

eXTP Science - Dense Matter





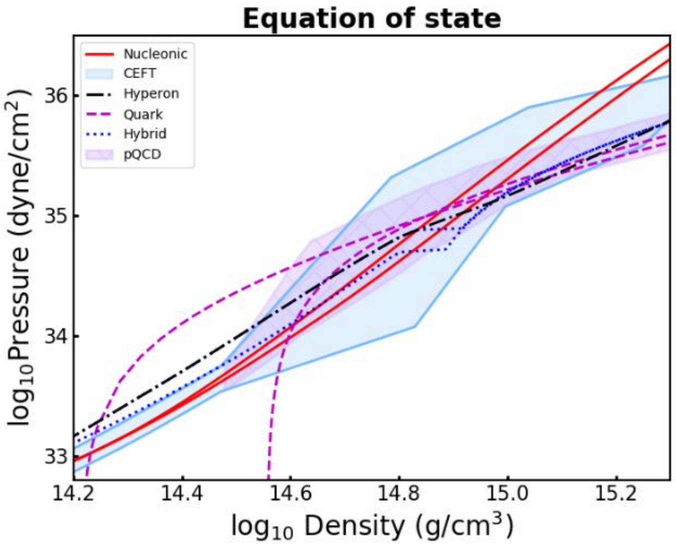
$$\boxed{\rho \approx 10\rho_{sat}}$$

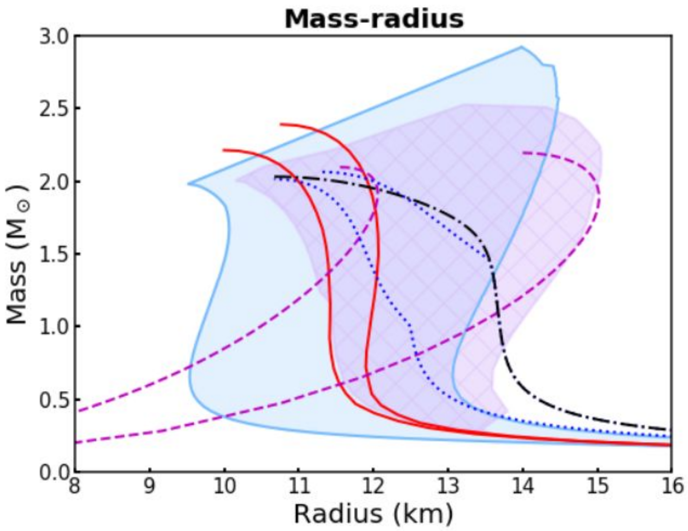
$$\rho_{sat} \approx 2\times10^{14}\,\mathrm{gcm}^{-3}$$

Explore the phase diagram of QCD

- Complementary to lab. experiments through M/R neutron star measurements
- Low temperature, high density (10x the normal density in atomic nuclei)
- Neutron stars offer states of matter inaccessible to ground experiments

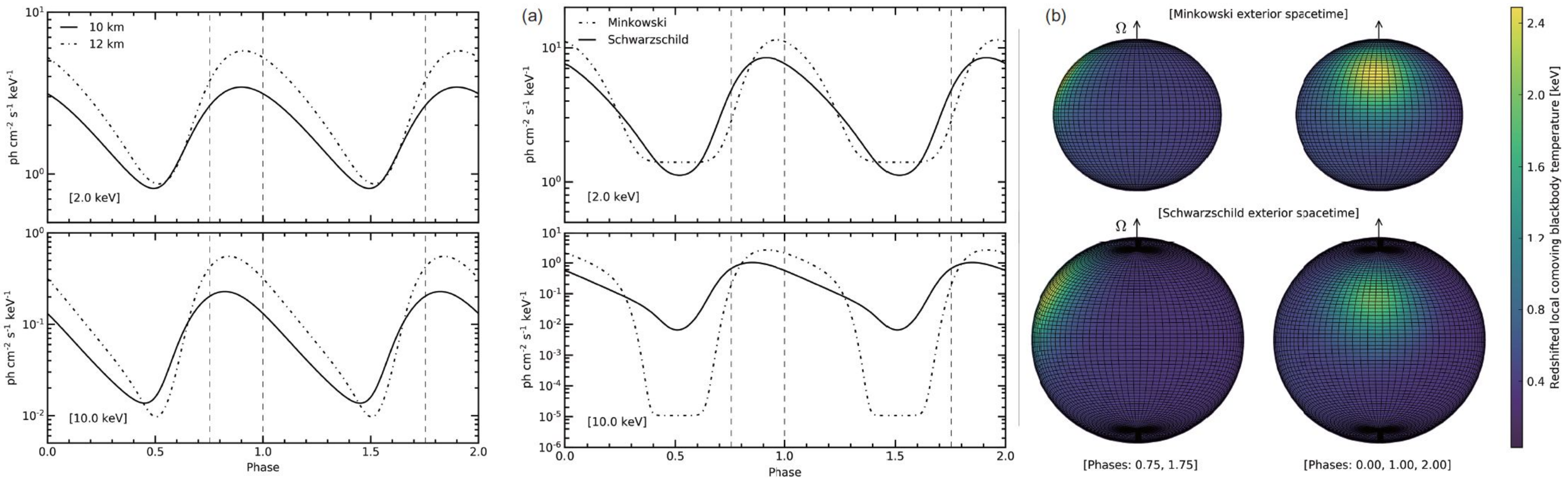
eXTP Science - Dense Matter





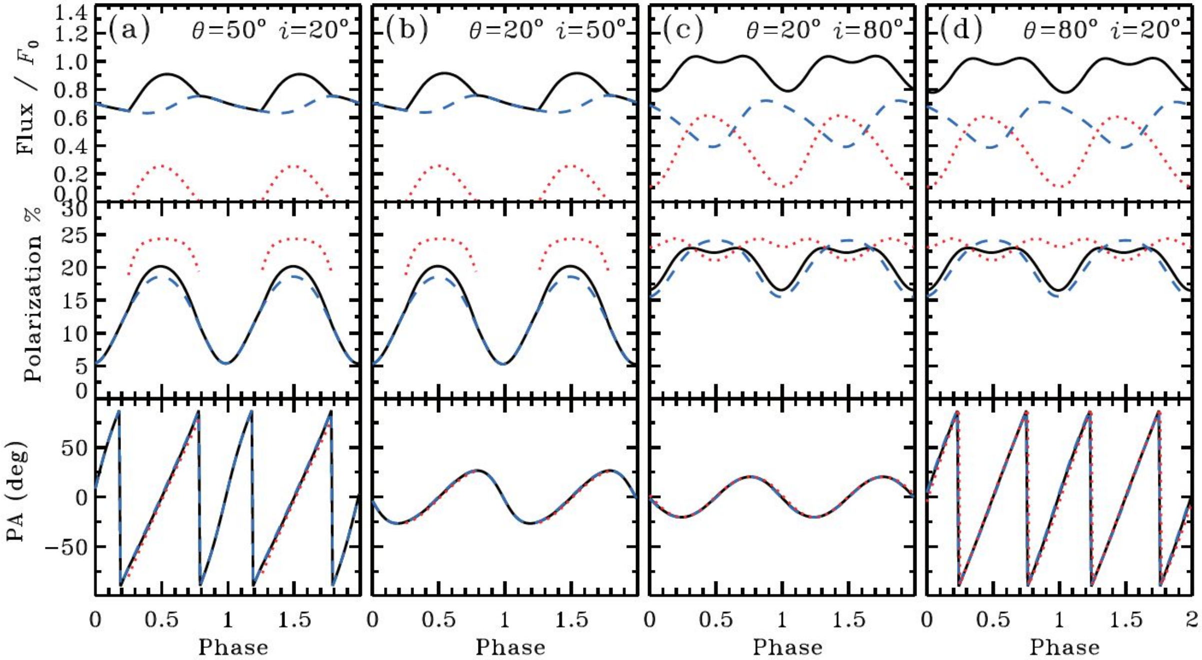
- Explore the QCD phase diagram (complementary to laboratory experiments)
- NS equation of state <-> mass-radius diagram (via the structure equations)
    - Different microphysics give different curves
- Current constraints: spectral modeling / pulsar timing in compact binaries

eXTP Science - Dense Matter



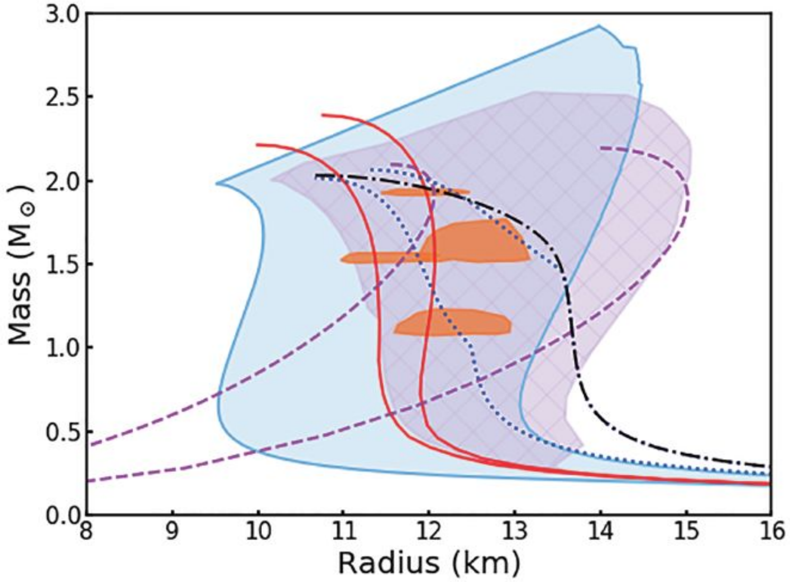
- eXTP will allow pulse-profile modeling (PPM) of neutron stars hot spots
  - Information about M and R in the normalisation and harmonic content of the pulse profile
    - Needs % acuracy on M/R, sets energy and time resolution requirements
  - Relativistic effects affecting the flux modulation can be computed
    - Doppler boosting, gravitational redshifting, time delays, light bending

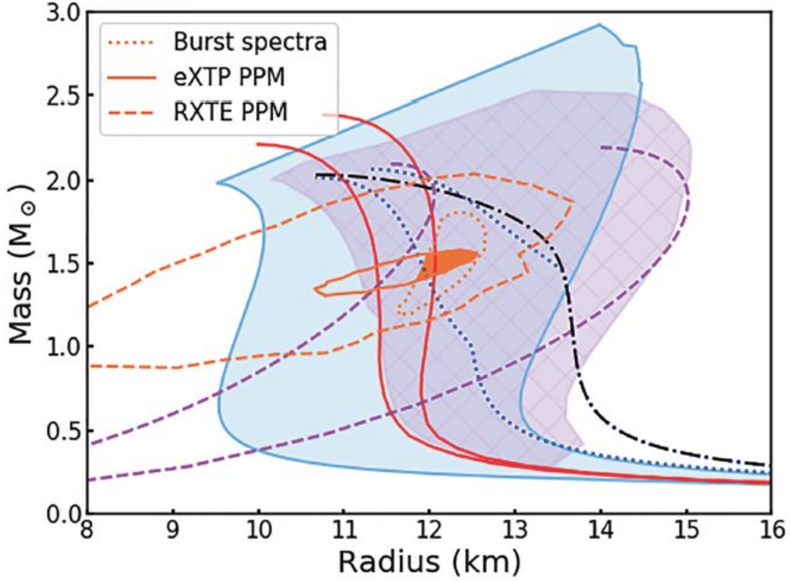
eXTP Science - Dense Matter



- eXTP PPM of accretion-powered pulsars with ~100ks observations
  - Polarization measurements can constraint the geometry and resolve degeneracies
    - MDP and systematics are key instrument performance

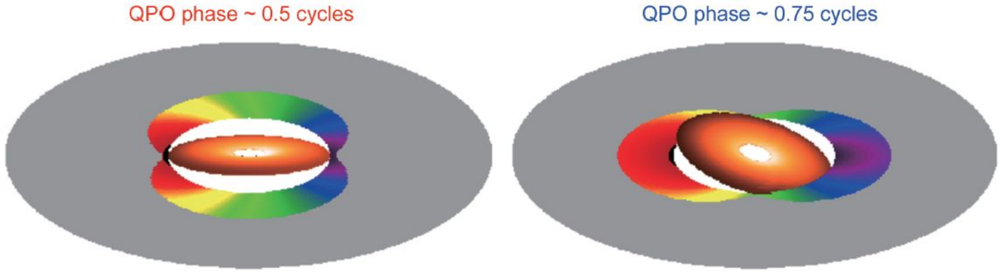
eXTP Science - Dense Matter

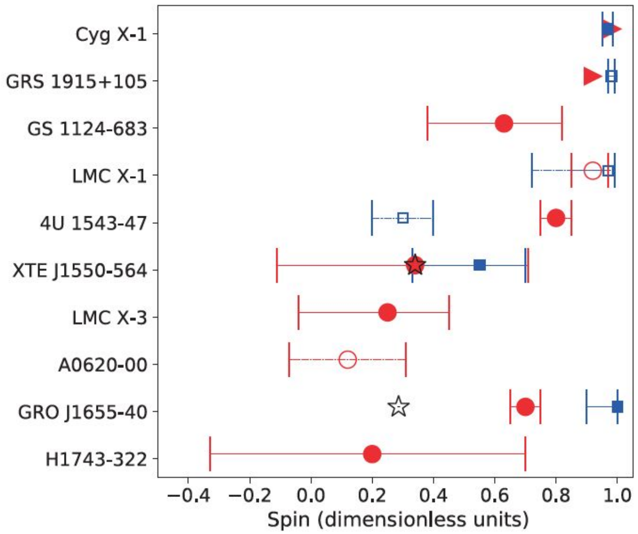




- eXTP PPM of burst oscillation sources and rotation-powered pulsars
  - ~400Ks observation for busts oscillation sources (right)
  - ~1Ms observations for four known-mass rotation-powered pulsars (left)

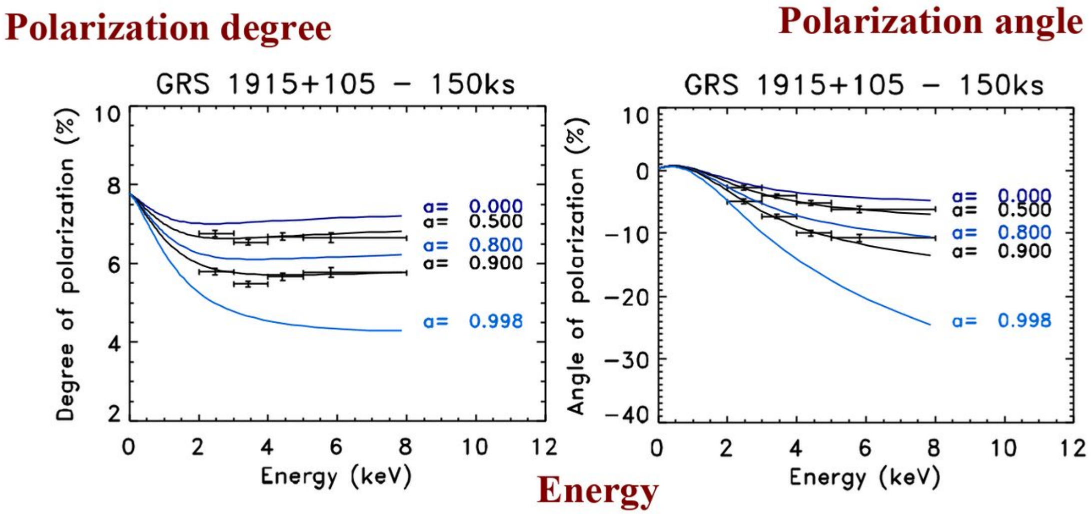
eXTP Science - Accretion in strong field gravity

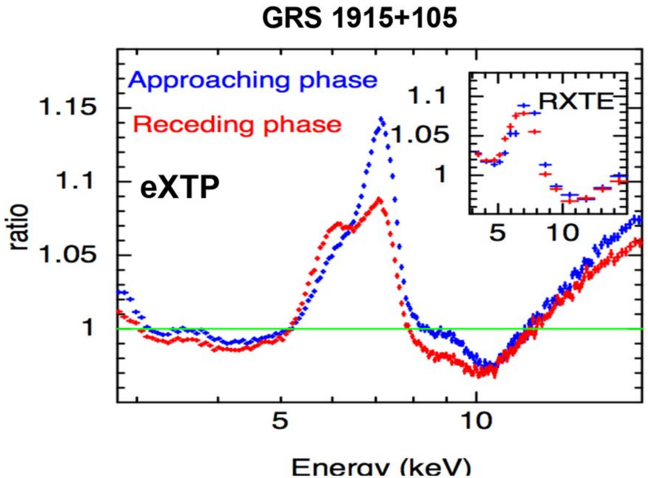




- Black hole spin from
  - Broad Fe lines (enlarged by relativistic effects)
  - Quasi-Periodic Oscillations (QPO from inner disk dynamics)
  - And combination of the two (Fe lines vs QPO phases)
- Current measurements limited by observatories performance, often in tension and affected by large errores

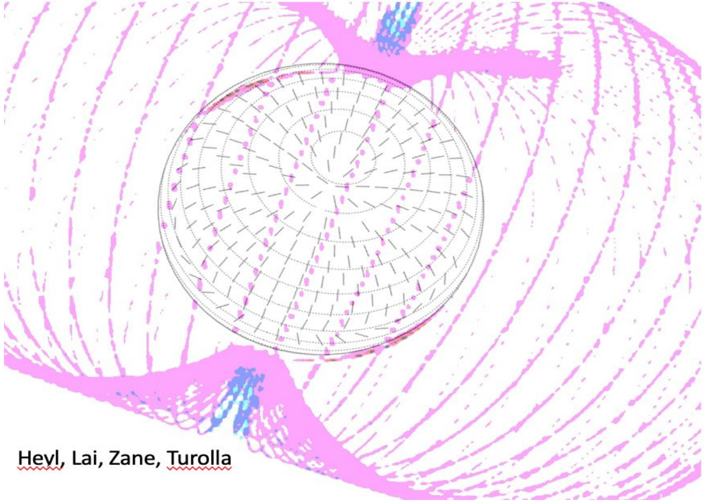
eXTP Science - Accretion in strong field gravity

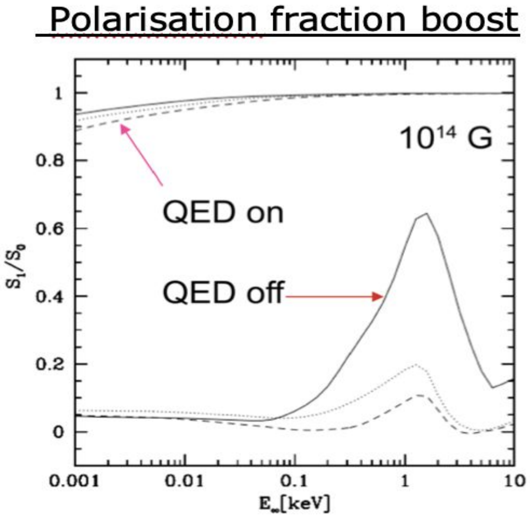




- eXTP will benefit from superior resolution and sentivity to spectrally resolve Fe lines broadening in time and wrt to QPO phases (right with LAD)
- eXTP will benefit from multiple instruments to allow independent black hole spin measurements (left with PFA)

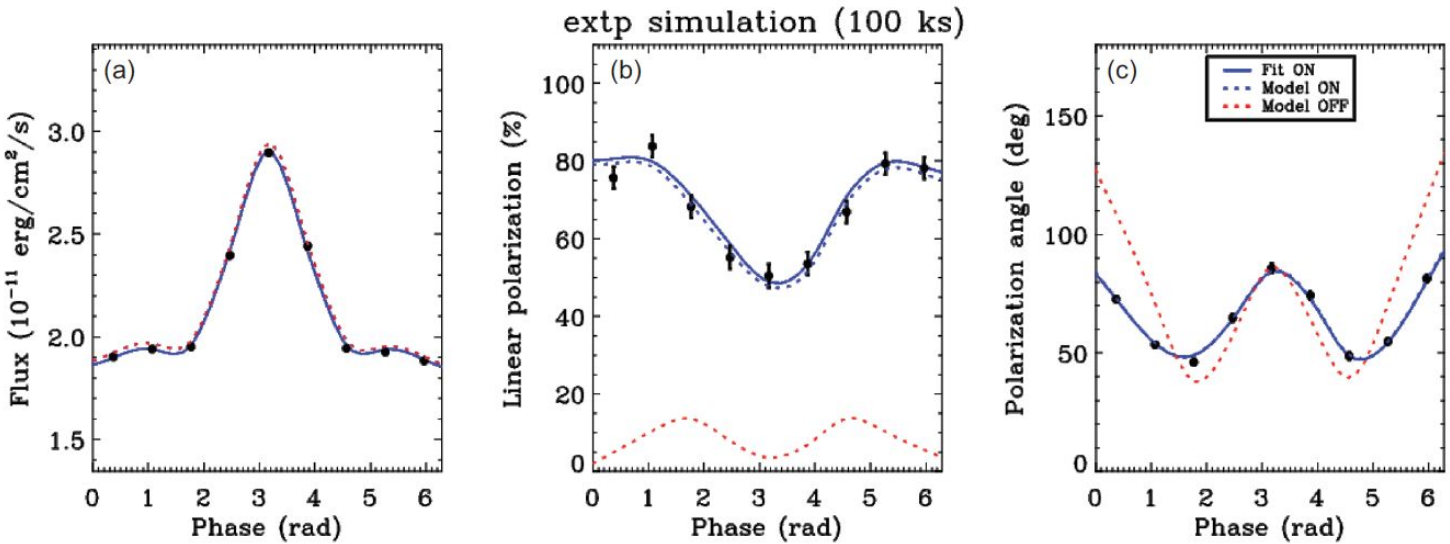
eXTP Science - Strong magnetism





- QED predicts vacuum birifringence in a high-enough magnetic field
  - O and X modes have different indices of refraction
- Magnetars provide an astrophysical environment in which this can be confirmed for the first time
  - Maximal polarization evolution in the NS magnetosphere

eXTP Science - Strong magnetism



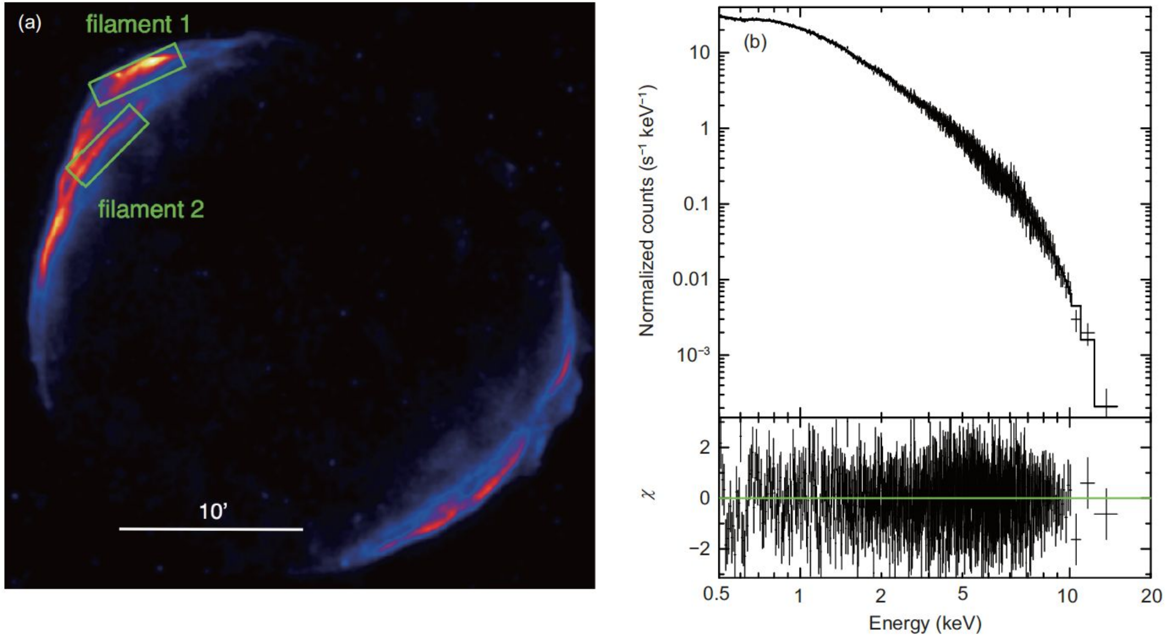
- eXTP sensitivity will allow discovery of many more interesting magnetars
- Spectral-timing-polarization performance will break degeneracy in flux measurements and allow confirmatin of expected QED effect

eXTP Science - Observatory Science

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 Supernova remnants
Galactic Center

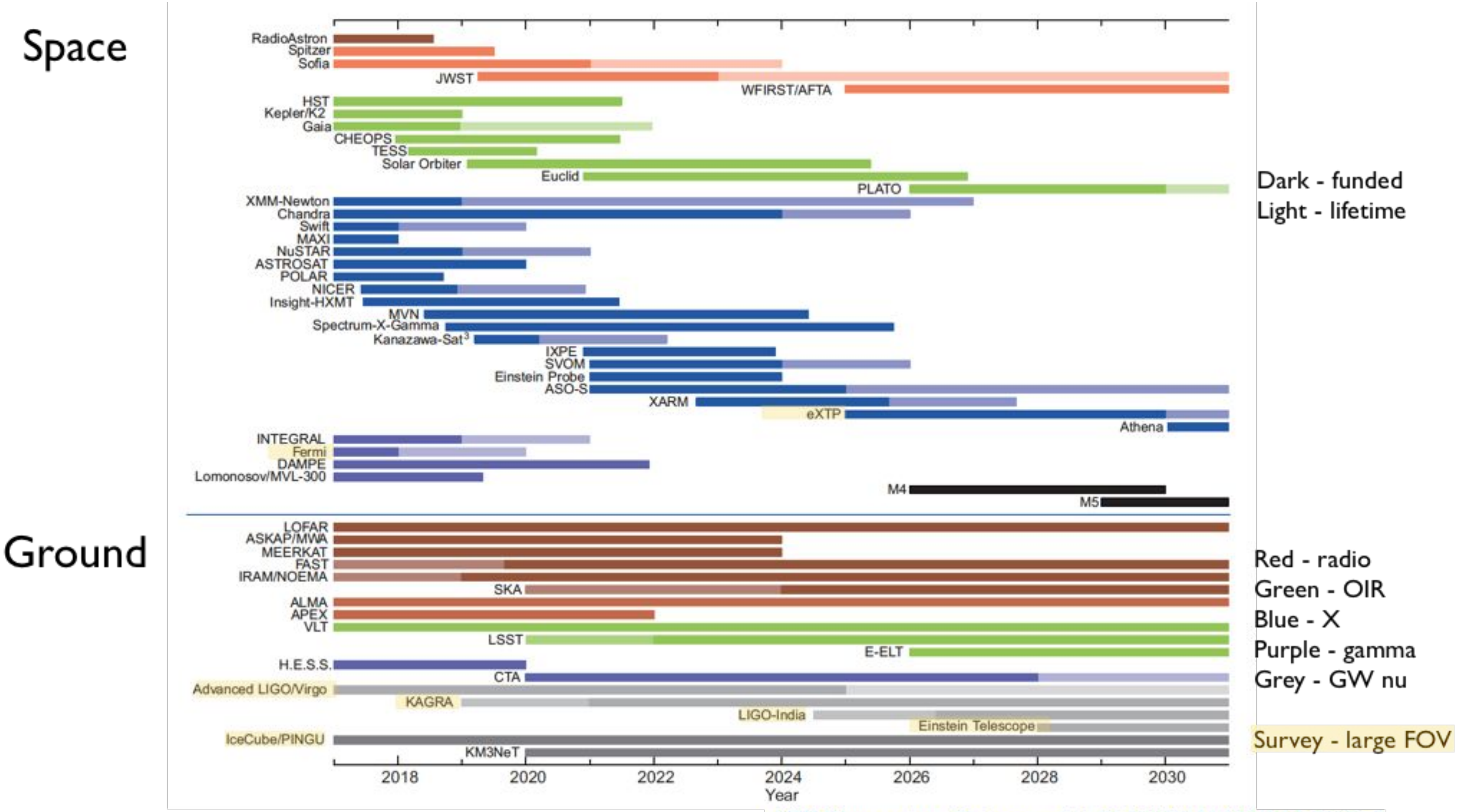
eXTP synergy with other messengers:
Gravitational Waves, TeV, neutrinos

eXTP Science - Observatory Science



- SNR polarization measurement resolved spatially and spectrally

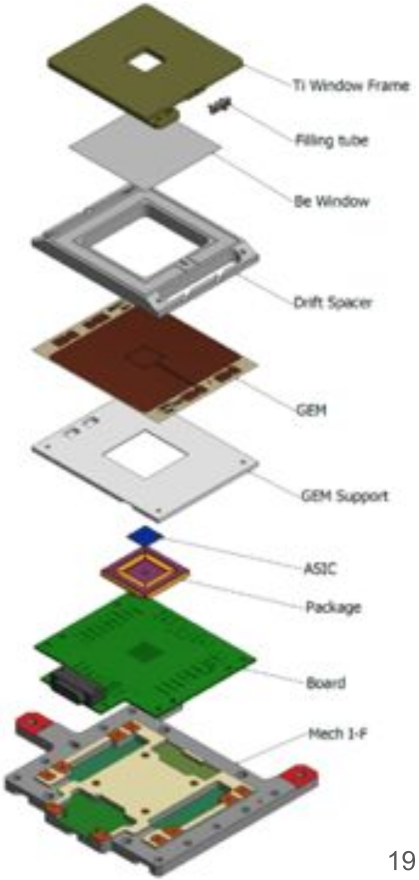
eXTP Science - Observatory Science



eXTP Observatory Science - doi 10.1007/s11433-017-9186-1

INFN Heritage for PFA

1. Established GPD technology at INFN
    a. Proprietary design of enabling ASIC
    b. GPDs integration & qualification line available
        i. IXPE completed with delivery of 17 GPDs + 4 Flight telescopes
    c. Readout Electronics design & implementation capability
        i. w/ technology transfer for outsourcing production
2. Dedicated team with two X-ray polarimetry missions
    a. NASA/SMEX IXPE and PolarLight on chinese Cubesat Tonghuan-1

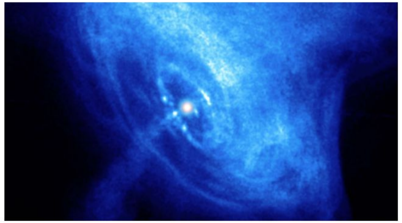


INFN Heritage for PFA

IXPE Flight Models delivered for integration on S/C and planned April 2021 launch

12 MAGGIO 2020

LA PULSAR DEL GRANCHIO AI RAGGI X: POLARLIGHT CONFERMA IL SUCCESSO DELLA TECNOLOGIA TUTTA ITALIANA



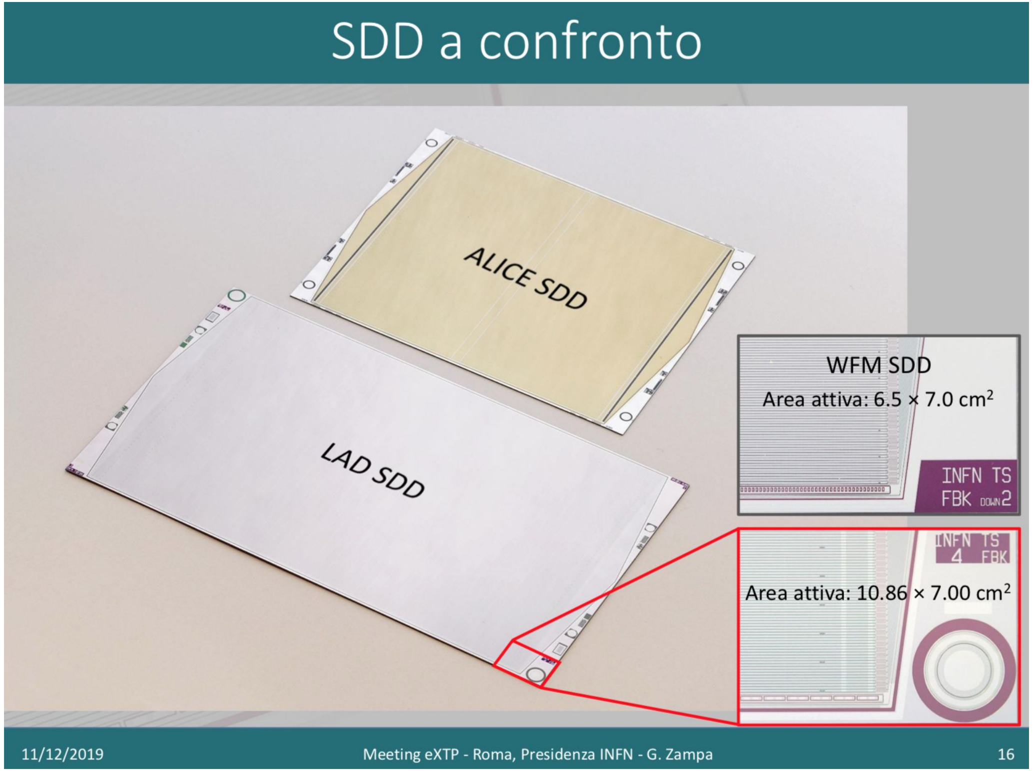
Prendi un nanosatellite, aggiungi dei rivelatori nei raggi X super efficienti di derivazione tecnologica italiana e lancialo in orbita per studiare la più celebre delle pulsar, quella del Granchio. Questa potrebbe essere, in estrema sintesi, la “ricetta” della missione spaziale cinese PolarLight, i cui primi risultati vengono pubblicati in un articolo sulla rivista Nature Astronomy. Il team di PolarLight, guidato da Hua Feng della Tsinghua University di Pechino e a cui partecipano ricercatori dell’Istituto Nazionale di Fisica Nucleare (INFN) e dell’Istituto Nazionale di Astrofisica (INAF), avrebbe registrato una diminuzione del grado di polarizzazione della radiazione emessa dalla pulsar Granchio, a cavallo di un 'glitch' osservato nel luglio del 2019. I 'glitch' sono delle rapide accelerazioni della rotazione della stella di neutroni dovute a un riassestamento repentino del suo nucleo. Questa variazione potrebbe essere legata a un riaggiustamento della magnetosfera della pulsar e alla conseguente variazione col tempo dell’angolo di polarizzazione della radiazione di alta energia emessa. Con questi suoi primi risultati, la missione PolarLight riapre la finestra della polarimetria nei raggi X, dopo 45 anni dal lancio del satellite statunitense OSO-8.

PolarLight measurement of Crab polarization
Nature Astronomy, 2020 may

https://home.infn.it/it/comunicazione/news/4020-la-pulsar-del-granchio-ai-raggi-x-polarlight-conferma-il-successo-della-tecnologia-tutta-italiana

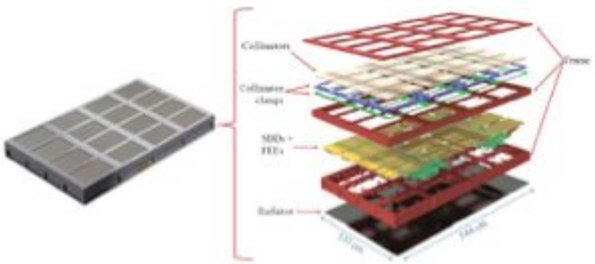
Heritage for Silicon Drift Detector for LAD and WFM

- SDD production for ALICE
- Updates for large-area, low-power, space qualified devices for X-ray missions in space



Heritage for Silicon Drift Detector for LAD and WFM

- Collimated, large-area SDD modules
- Based on LOFT phase-A mission study for ESA



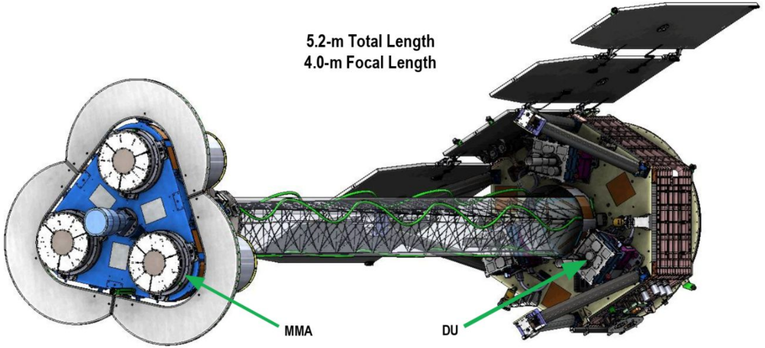
eXTP - schema organizzativo gruppi INFN

- XRO - singola sigla IXPE + eXTP
    - Interessi scientifici comuni e intersezione di comunità esistenti
        - Detector teams: GPD + SDD
        - Astroparticle and multimessenger scientists
    - Proposal in preparazione per CNS2 in luglio
- Gruppi IXPE - almeno 12.5 FTE (9.5 @ Pisa, 3 @ Torino)
- Gruppi SDD - Trieste, Trento, Perugia, Roma2
- Gruppo teorico - in costruzione

X-Ray Observatories @ INFN

IXPE NASA-SMEX

2017-2018 EM - QM → 2019-2020 FM - Integr. → 2021-2024 Launch & Ops



2021-2022 EM - QM → 2023-2026 FM - Integr. → 2027-2032 Launch & Ops

eXTP - CAS

XRO

Nuova sigla CSN2

Rivelatori GPD per polarimetria

Rivelatori SDD per timing / imaging

Fisica fondamentale da raggi-X in astrofisica

eXTP/PFA - schema di finanziamento

- Simile a IXPE, grossomodo:
  - acquisti, personale TD, ~50% missioni a carico ASI
  - facilities, personale TI, metabolismo laboratori e ~50% missioni a carico INFN
- Accordi con ASI
  - ASI-INAF per eXTP (~25k per attivita’ PFA nel 2020)
  - ASI-INFN per IXPE (~2M) - spese in linea con finalita’ accordo esistente per migliorare performance GPD e sistematiche su modulazione spuria e secular pressure changes
  - ASI-INAF per ADAM (~200k) - spese in linea con design e produzione 3a generazione ASIC (10x faster)

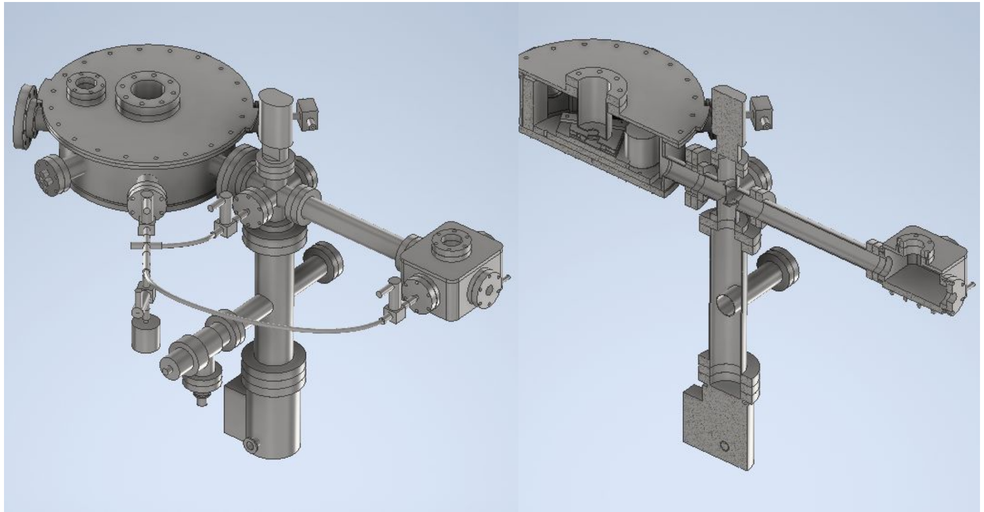
Attivita' PFA - proposte

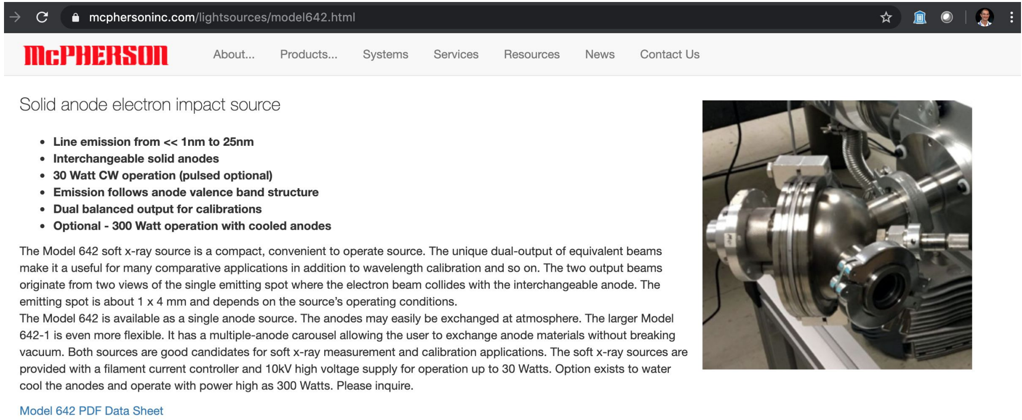
Hardware

- Sistema integrazione GPD
- Sistema per calibrazioni sistematiche con soft X-rays
- Test funzionalita' nuovo ASIC

Analysis Software

- Instrument sim / recon
- Science Analysis sw
  - Science w/ other instruments





mcphersoninc.com/lightsources/model642.html

McPHERSON About... Products... Systems Services Resources News Contact Us

Solid anode electron impact source

- **Line emission from << 1nm to 25nm**
- **Interchangeable solid anodes**
- **30 Watt CW operation (pulsed optional)**
- **Emission follows anode valence band structure**
- **Dual balanced output for calibrations**
- **Optional - 300 Watt operation with cooled anodes**

The Model 642 soft x-ray source is a compact, convenient to operate source. The unique dual-output of equivalent beams make it a useful for many comparative applications in addition to wavelength calibration and so on. The two output beams originate from two views of the single emitting spot where the electron beam collides with the interchangeable anode. The emitting spot is about 1 x 4 mm and depends on the source's operating conditions.
The Model 642 is available as a single anode source. The anodes may easily be exchanged at atmosphere. The larger Model 642-1 is even more flexible. It has a multiple-anode carousel allowing the user to exchange anode materials without breaking vacuum. Both sources are good candidates for soft x-ray measurement and calibration applications. The soft x-ray sources are provided with a filament current controller and 10kV high voltage supply for operation up to 30 Watts. Option exists to water cool the anodes and operate with power high as 300 Watts. Please inquire.

Model 642 PDF Data Sheet

Conclusions

- eXTP will be the next reference X-ray Observatory
  - Synergy of four instruments performing simultaneous observations
  - Open to the worldwide Scientific Community according to the International standards
- Two enabling technologies largely developed within INFN
  - Gas Pixels Detectors
  - Large-area Silicon-Drift Detectors
- Aligned with interests of nuclear theorists and MW/GW community
- New activity in CSN 2
  - Will include IXPE and eXTP
  - Two detector teams: GPD (Pisa, Torino) and SSD (Trieste, Trento, Perugia, Roma2,….)
  - Detailed proposal being prepared for July

References

Mission website and White papers https://www.isdc.unige.ch/extp/

INFN Meeting 11 Dec 2020 https://agenda.infn.it/event/20546

Backup

The eXTP International Consortium

PI Institute: IHEP

CAS	中国科学院 CHINESE ACADEMY OF SCIENCES
CNSA	
IHEP Beijing	Institute of High Energy Physics Chinese Academy of Sciences
Tsinghua University	清华大学 Tsinghua University
Tongji University	同濟大學 TONGJI UNIVERSITY
CAST Beijing	中国空间技术研究院 China Academy of Space Technology 中国航天
Microsat Shanghai	microsat

Italy:	INAF, INFN
Germany:	UNIVERSITÄT TÜBINGEN, MPE, FAU
France:	cea
Spain:	CSIC, IEEC
Switzerland:	UNIVERSITÉ DE GENÈVE
Czech Republic:	asu Astronomical Institute
Poland:	CBK
Denmark:	DTU
The Netherlands:	NOVA, SRON

Programmatic Status Update

- **China** - The mission has started its Phase B study in mid-2019, lasting until December 2021, when the Preliminary Design Review (PDR) is scheduled. This will be the key milestone for the mission adoption. The study is currently funded in China up to the end of Phase C1 (end-2022).

- **ESA and MS** - CAS and the European Member States requested an ESA participation to the mission under a Mission of Opportunity. Although not formally approved yet, eXTP is included in the perspective plan for MoOs. ESA successfully reviewed the status of the LAD and WFM instruments in Summer 2019, assessing their readiness to (officially) enter Phase B. Meeting with MS planned on 30^{th} Jan 2020. Most of the MS have already allocated funds for the Phase B study.

- **ASI** - Funds for Phase B1 already approved: contract to be kicked off in Jan-Feb 2020. Plans for funding for the Phase B2/C1 are being developed jointly with ASI.

The formal decision/commitment on the mission adoption in Europe (both ESA and MS) will be taken after PDR (Dec 2021), when any potential export issues will be cleared out.

Technical Status Update

- **China** - CAS has selected one single Prime Contractor for the spacecraft, the Microsat company/institute in Shanghai (the same as SVOM and SMILE). Interface activities have started in October 2019.
- **ESA** - After the successful Phase A review ESA is expected to allocate a small study team at ESTEC to follow/support the Phase B study, in preparation to their official involvement in Phase C.
- **European MS** - The LAD and WFM got organized as two independent instrument consortia, under the responsibility of Italy and Spain, respectively. Considering the large technical and programmatic overlap (detectors, analog and digital electronics, ..) the two teams work in tight connection.
- **Italy** - The Italian participation involves ASI, INAF, INFN, Universities. The lead institute for the LAD is IAPS, hosting the Project Office. Next milestones are the Instrument System Requirements Review (I-SRR, June 2020) and the Instrument Preliminary Requirements Review (I-PDR, December 2021). These will be key milestones to define the configuration of the science instruments.

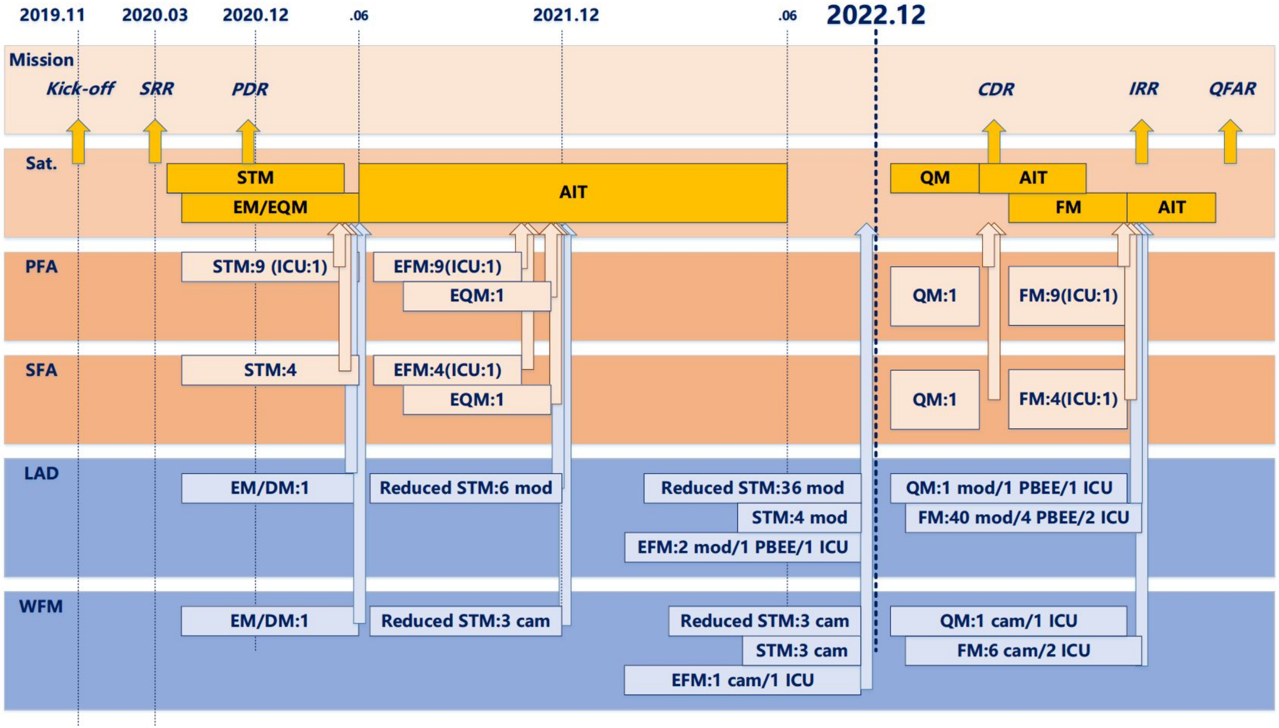
Expected Science Return

- **Observatory Type -** eXTP is designed as an Observatory. The science program will include a Core Program and a Guest Observer Program. All data will become public after the proprietary period. Some data may go public immediately (WFM, TBC).
- **Europe vs China -** The exact share between Europe and China will be defined at agency level at a later stage (MoU). However, the current understanding is in terms of a 40:60 share. The science return is expected to be proportional to that.
- **Italy vs Europe** - Italy is leading the largest instrument and, in Europe, it has the largest share.
- **ESA** - The ESA contribution is parallel to the contribution of the individual Member States. Overall, it will be in the range of 5-10%, that will give science access to a proportional fraction of the observing time. For Europe, this fraction adds on top of the science return of the individual MS.

Participating (H/S/W) Italian Institutes/Institutions

Institution	Institute	eXTP Subsystem	What
INAF	IAPS OAS OAPa OAB IASF-Mi OAR/SSDC	LAD/WFM LAD/WFM LAD SFA/PFA LAD/WFM SGS	PI, PO, AIVT, FEE, Calibrations AIVT, FEE, Calibrations, Simulations Optical filters Optics (design, integration and tests) FEE Science SW, Archive, User support
INFN	Trieste Trento Perugia Pisa Torino Roma2 Roma2/SSDC	LAD/WFM LAD/WFM LAD PFA PFA LAD/WFM SGS	Detectors, FEE, AIVT Detectors, AIVT AIVT GPD, BEE, Tests, Calibrations (TBD) GPD, BEE, Tests, Calibrations (TBD) Detectors, FEE, AIVT, PA Science SW, Archive, User support
FBK	MNF	LAD/WFM	Detectors
Universities	PoliMi UniPv	LAD/WFM LAD/WFM	FEE, Tests FEE, Tests
ASI	EOS SSDC Malindi	ALL SGS ALL	Management Science SW, Archive, User support TM Downlink

Plan of eXTP


2019.11
2020.03
2020.12
.06
2021.12
.06
2022.12
Mission
Kick-off
SRR
PDR
CDR
IRR
QFAR
Sat.
STM
EM/EQM
AIT
QM
AIT
FM
AIT
PFA
STM:9 (ICU:1)
EFM:9(ICU:1)
EQM:1
QM:1
FM:9(ICU:1)
SFA
STM:4
EFM:4(ICU:1)
EQM:1
QM:1
FM:4(ICU:1)
LAD
EM/DM:1
Reduced STM:6 mod
Reduced STM:36 mod
STM:4 mod
EFM:2 mod/1 PBEE/1 ICU
QM:1 mod/1 PBEE/1 ICU
FM:40 mod/4 PBEE/2 ICU
WFM
EM/DM:1
Reduced STM:3 cam
Reduced STM:3 cam
STM:3 cam
EFM:1 cam/1 ICU
QM:1 cam/1 ICU
FM:6 cam/2 ICU

Schedule of PFA

- Phase B (24 months): Jan 2019 – Dec 2020 (funded by CAS)
  - DM/EM development
  - 2020.03 SRR
  - 2020.01 ASIC for DM/EM
  - 2020.06 GPD for DM/EM
  - 2020.07 DM/EM for PFA
  - 2020.11 PDR
- Phase C1 (24 months): Jan 2021 – Dec 2022 (funded by CAS)
  - 2020.07 ASIC for EFM (new version?)
  - 2021.03 GPD for EFM
  - 2021.06 EFM for PFA
  - 2020.10 ASIC for EQM
  - 2021.06 GPD for EQM
  - 2021.12 EQM for PFA
  - 2021.12 Instrument (SFA & PFA) STM & EFM delivery
  - 2022.09 AIT of system STM and AVM
  - 2022.12 KDP for further support
- Phase C2 (21 months): Jan 2023 – Sep 2024
  - QM development and verification
  - 2023.06 CDR
- Phase D (30 months): Oct 2024 – Mar 2027
  - FM delivery, S/C AIT
- Phase E1: Launch (6 months): Apr – Sep 2027
- Phase E2/3 (60 + 60 months): Oct 2027 – Dec 2037

We have completed the SRR and are in the process of EM design.

Collaboration on PFA - Partners and Contributions

Partners

- The Institute of High Energy Physics, Chinese Academy of Sciences (CAS/IHEP)
- Istituto Nazionale di Fisica Nucleare (INFN) - PI, TO
- Tsinghua University

IHEP Contributions

- lead the PFA instrument development and scientific studies.
- PFA mirror assembly developments
- develop the PFA focal plane camera with the GPD module
- conduct PFA instrument assembly integration test (AIT) and calibration

Collaboration on PFA - Contributions

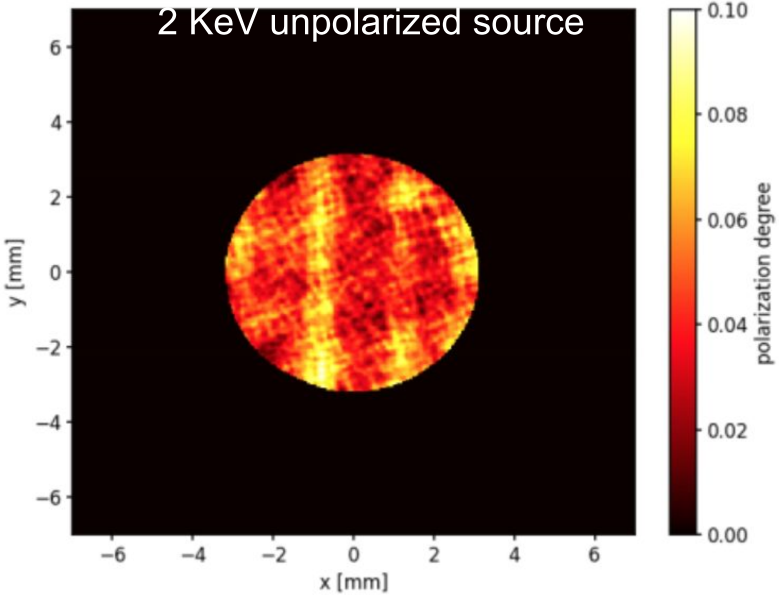
INFN contribution

- develop the new ASIC
- Develop, qualify and define new-design GPD (jointly with China)
- Support to Back End Electronics (BEE)
- Participation in calibrations
- Simulation and analysis packages
- Expertise

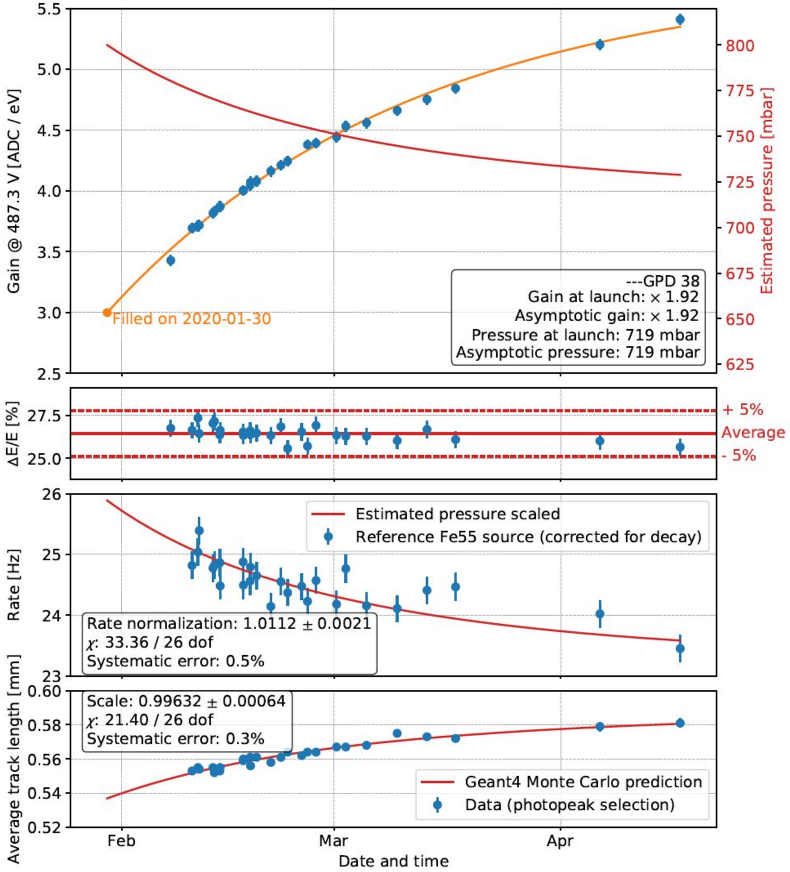
Challenges for PFA - technical and programmatic

1. eXTP science drivers and telescope design require 10x faster new ASIC
2. Minimize known systematics of IXPE GPDs
    a. spurious modulation
    b. performance evolution with pressure (gain and efficiency)
3. Program development
    a. Export control on exchanges with China
    b. eXTP tight schedule

Challenges for PFA systematics



Residual modulation with GEM-related pattern



GPD performance evolution