Multi-wavelength [not radio] Polarimetry of Isolated Neutron Stars

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Alsatian Workshop on X-ray Polarimetry
ISOLATED $\equiv$ NON ACCRETING

Pulsating Neutron Stars

- Radio pulsar
- Magnetar
- X,\(\gamma\)-ray pulsar
- INS
- RRAT
- CCO

The most numerous class of isolated neutron stars (INSs) – ample choice of targets

The only INSs seen across radio, IR, optical, X, γ-rays - multi-wavelength polarisation studies

The only INS class with at least a case of multi-wavelength polarisation measurements

The only INS class with polarisation measurements obtained for a few objects

Polarisation measurements (phase-res & phase-avg) offer unique insights into pulsars’ highly-magnetised relativistic environments and are a prime test for NS magnetosphere models and theory of radiation emission processes.

Besides the radio band, optical observations have been most successful for polarimetry studies [special case, RQ pulsars], exploiting a mature technology.

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Pulsar Polarimetry

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L. C.

P. A.

P. D.

Slowikowska et al. (2009)
Pulsar Optical Polarimetry

- Optical polarization of the Crab pulsar was discovered (Wampler et al. 1969), soon after the discovery of its counterpart (Cocke et al. 1969).

- Being the brightest ($V=16.5$) pulsar the Crab is the only one with both phase-res and avg polarization measurements (linear and circular)

- PD depends on the phase $\langle PD \rangle = 9.8\% \pm 0.1\%$ (Slowikowska et al. 2009)

- Affected by DC component – possibly associated with the highly polarised emission knot at 0.6” from the Crab

HST measurements give $\langle PD \rangle = 5.2\% \pm 0.3\%$

Aligned with the nebula axis and pulsar proper motion

before DC subtraction $9.8\% \pm 0.1\%$

after DC subtraction $5.5\% \pm 0.1\%$
### Pulsar Optical Polarimetry, the Sample

<table>
<thead>
<tr>
<th>Pulsar</th>
<th>$\tau$ (10^3 yr)</th>
<th>$P_s$ (s)</th>
<th>$\dot{P}_s$ (10^{-13} s^{-1})</th>
<th>$\dot{E}$ (10^{38} erg cm^{-2} s^{-1})</th>
<th>$B_S$ (10^{12} G)</th>
<th>$B_{LC}$ (10^6 G)</th>
<th>P.D. (%)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0531+21</td>
<td>1.24</td>
<td>0.033</td>
<td>4.22</td>
<td>4.6</td>
<td>3.78</td>
<td>9.80</td>
<td>5.2±0.3</td>
<td>(1)</td>
</tr>
<tr>
<td>B0540–69</td>
<td>1.67</td>
<td>0.050</td>
<td>4.79</td>
<td>1.5</td>
<td>4.98</td>
<td>3.62</td>
<td>5.5±0.1</td>
<td>(2)</td>
</tr>
<tr>
<td>B1509–58</td>
<td>1.56</td>
<td>0.151</td>
<td>15.3</td>
<td>0.17</td>
<td>15.40</td>
<td>0.42</td>
<td>5.0±2.0</td>
<td>(3)</td>
</tr>
<tr>
<td>B0833–45</td>
<td>11.3</td>
<td>0.089</td>
<td>1.25</td>
<td>0.069</td>
<td>3.38</td>
<td>0.44</td>
<td>16.0±4.0</td>
<td>(4)</td>
</tr>
<tr>
<td>B0656+14</td>
<td>111</td>
<td>0.384</td>
<td>0.55</td>
<td>0.00038</td>
<td>4.66</td>
<td>0.007</td>
<td>10.4</td>
<td>(5)</td>
</tr>
</tbody>
</table>

- **PD values ~5%-10%, below model predictions! And much less than radio.**

- Expand the sample and revisit uncertain cases (**PSR B1509-58**)

- Phase-resolved polarimetry of **PSR B0540-69** and **Vela** – in progress @ 3.6m

- Phase-averaged polarisation of **Geminga** (V\~25.5) - done @ VLT, data analysis in progress

- Phase-resolved polarimetry of the **Crab** continuing – done @WHT; in progress @ 3.6m
Possible anti-correlation between PD and $B_{LC}$ but not with the surface magnetic field $B_S$ (nearly constant).

PD seems to be higher for older and less energetic pulsars.

No apparent correlation btw PD and optical spectrum.
Alignment between pulsar polarisation and proper motion PA (Crab, Vela, B0656+14)

Next obvious target: Geminga. VLT polarimetry observations completed, data analysis in progress
Giant Radio Pulses (GRPs) are erratic variation of the peak-to-peak single pulse intensity (few %)

GP also seen in the optical (GOPs) in the Crab pulsar (Shearer et al. 2003; Collins et al. 2012; Strader et al. 2013)

GOPs occur in time with GRPs (coherent vs. incoherent radiation)

Not yet observed in X (Bilous et al. 2012; Hitomi Collaboration, 2017) and γ-rays (Lewandowska et al. 2011)

Next is to measure changes in pulsar polarisation in coincidence of GOPs/GRPs

ESO observing program (Pl. A. Shearer) approved with the *Galway Astronomical Stokes Polarimeter* (GASP) to carry out phase-res polarisation of the *Crab* and *PSR B0540-69* with parallel GRP monitoring - observations Feb 2018
Pulsar/PWN X-ray Polarimetry

- First attempt to measure the X-ray polarisation of the Crab Nebula back in 1969 with sounding rockets – PD<36% (Wolff et al. 1970)

- First X-ray nebula polarisation measurement:
  PD=15.4%±5.2%, PA=156°±10° (5-20 keV)
  (Novick et al. 1972)

- New nebula polarisation by OSO-8 with:
  PD=15.7%±1.5%, PA=161.1°±2.8° @2.6 keV
  PD=18.3%±4.2%, PA=155.5°±6.6° @5.2 keV
  (Weisskopf et al. 1976)

- After Pulsar subtraction (Weisskopf et al. 1978):
  PD=19.2%±1.0%, PA=156.4°±1.4° @2.6 keV
  PD=19.5%±2.8%, PA=152.6°±4.0° @5.2 keV

- Attempts to measure the pulsar polarisation @ 2.6 and 5.2 keV with OSO-8 (Silver et al. 1978) and at 20-120 keV with PogoLIt (Chauvin et al. 2016) - PD<42.2%

See Martin Weisskopf’s talk
Pulsar/PWN X-ray Polarimetry

**Cadmium Zinc Telluride Imager (CZTI)**
- **Launched:** 2015
- **Duration:** > 5 yrs
- **Angular resolution:** 8 arcmin
- **FoV:** 6x6 deg²
- **Energy Range:** 10-100 keV
- **Effective Area:** 1000 cm²
- **Energy Resolution:** 5% @ 100 keV
- **Time Resolution:** 1 ms

**Phase-resolved X-ray polarimetry of the Crab pulsar with the AstroSat CZT Imager**

Vadawale et al., 2017, Nature Astronomy
20-160 keV phase-res PD and PA from POGO+ (Chauvin et al. 2017)

\[ \langle PD \rangle = 20.9\% \pm 5\% \]
Pulsar Gamma-ray Polarisation

• First measurement of gamma-ray polarisation of the Crab nebula with INTEGRAL/SPI (Dean et al. 2008) – phase resolved

• Off-pulse events only (0.1-1 MeV) → nebula (pulsar localisation within ± 20″)

• Off pulse: PD=46%±10%, PA=123°±11°

• Polarisation P.A. aligned with the pulsar PM

• Gamma-ray polarisation measurement of the Crab pulsar with INTEGRAL/IBIS (Forot et al. 2008) – phase resolved
  ➢ Peaks: PD=42%+30−16, PA=70°±20°
  ➢ Off pulse: PD>72%, PA=120.6°±8.5°
  ➢ OP+Bridge: PD>88%, PA=122°±7.7°
  ➢ Phase-av: PD=47%+19−13, PA=100°±11°

• Like in the optical, peaks are less polarised
Giorgio’s comment: Integral was not designed for polarimetry. Calibration is an issue.

Also:

Optical observations taken with different telescopes/instruments.

Moran et al. (2016)
The azimuthal distribution of planes containing $e^+/e^-$ pairs from high-energy photon materialization is reminiscent, through a quadrupole anisotropy, of the degree and position angle of linear polarization of the incident photons. Data on open pairs in the COS $B$ spark chamber are used in a search for such an effect in $>50$ MeV photons from bright sources, such as Vela, Crab, Geminga, and a reference Galactic plane region in Cygnus. After a description of the method and the related simulations and tests, the analysis of the available data shows no anisotropy for the other sources, but for the Vela pulsar a low chance probability effect is found, apparently implying a high ($\sim 100\%$) degree of linear polarization for the Vela photons. This is discussed in light of the physics of the production mechanisms as well as of their geometry.

We have analyzed the COS $B$ spark chamber telescope observations of the Vela pulsar for gamma-ray polarization. No significant quadrupole moment is found in the azimuthal distribution of the electron-positron pair production planes. However, analysis of the sensitivity indicates that even $100\%$ polarization would not be detected. Therefore, the null result does not constrain the polarization of the Vela pulsar gamma-ray emission. This result contradicts the report of Caraveo et al. of possible evidence for polarization of the Vela pulsar gamma rays.
### Crab Multi-wavelength Polarisation

<table>
<thead>
<tr>
<th>Energy Range</th>
<th>Region</th>
<th>Polarisation (%)</th>
<th>Position Angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>γ-ray (0.1-1 MeV)</td>
<td>OP</td>
<td>46 ± 10</td>
<td>123 ± 11</td>
</tr>
<tr>
<td>γ-ray (0.2-0.8 MeV)</td>
<td>OP</td>
<td>&gt; 72</td>
<td>120.6 ± 8.5</td>
</tr>
<tr>
<td>γ-ray (0.2-0.8 MeV)</td>
<td>OP+B</td>
<td>&gt; 88</td>
<td>122.0 ± 7.7</td>
</tr>
<tr>
<td>γ-ray (0.2-0.8 MeV)</td>
<td>avg</td>
<td>47 ± 19_13</td>
<td>100 ± 11</td>
</tr>
<tr>
<td>γ-ray (0.13-0.44 MeV)</td>
<td>avg</td>
<td>28 ± 6</td>
<td>117 ± 9</td>
</tr>
<tr>
<td>X-ray (20-120 keV)</td>
<td>avg</td>
<td>&lt;42.2</td>
<td>149.2 ± 16</td>
</tr>
<tr>
<td>X-ray (20-120 keV)</td>
<td>avg</td>
<td>20.9 ± 5.0</td>
<td>131.3 ± 6.8</td>
</tr>
<tr>
<td>X-ray (100-380 keV)</td>
<td>avg</td>
<td>33.4 ± 5.8</td>
<td>143 ± 2.8</td>
</tr>
<tr>
<td>X-ray (2.6 keV)</td>
<td>avg</td>
<td>19.2 ± 1.0</td>
<td>156.4 ± 1.4</td>
</tr>
<tr>
<td>Optical (HST)</td>
<td>avg</td>
<td>5.2 ± 0.3</td>
<td>105.1 ± 1.6</td>
</tr>
</tbody>
</table>


#### Comparison between PDs and PAs is scientifically interesting but difficult.
- Different spatial regions - different contribution from the PWN and SNR
- Different off-pulse definitions – is OP+B really not associated with the pulsar?
- Different energies – Is PD energy-dependent?
- Different epochs – Is PD variable (Moran et al. 2016)
Chauvin et al. (2017)

Astrosat
(Vadawale et al. 2017)

Polarization fraction

Phase-integrated

- PoGO 
- PoGOLite Chauvin \textit{et al.} (2016)
- SPI Chauvin \textit{et al.} (2013)
- IBIS Forot \textit{et al.} (2008)

Energy (keV)

Polarization angle (degrees)

Energy (keV)
Polarimetry of Cooling INSs

- Polarisation studies of *pulsars* allow one to derive information on the neutron star magnetosphere, polarisation studies of *Cooling INSs* allow one to peek close to (or at) the star surface.
- Seven targets, dubbed Magnificent Seven (M7).
- Is the thermal emission coming from the bare star surface?
- Is it mediated by an atmosphere?
- What is the atmosphere composition?
- Is the atmosphere magnetised?
- **Polarisation measurements** can provide these answers as well as test QED effects expected to manifest close to the NS surface.
- Vacuum birefringence increases the linear polarisation of the radiation from the NS surface (~few % up to ~100%), depending on the viewing geometry and the surface emission mechanism (Heyl & Shaviv 2000, 2002; Heyl et al. 2003).
• Optical polarisation measurement for RX J1856.5-3754 (Mignani et al. 2017), obtained with the VLT; PD=16.43%±5.26%.

• Faintest INSs with optical polarisation measurement (V=25.5)

• Follow-up VLT observations for a twice as long integration completed – analysis in progress
• All tested emission models consistent with observations BUT ....

• For all of them, measurement not explained without introducing QED vacuum birefringence effects.

• First observational evidence. To be searched for in X-rays, too

• RX J1856.5-3754 is a major target for future soft X-ray polarimetry missions
Polarimetry measurements of magnetars probe the magnetosphere properties and its evolution as a function of the source variability (outburst, flares).

IR phase-averaged polarimetry carried out with VLT/NACO (Ks band) for 1E 1048-5937, XTE J1810-197, 1E1547.0-5408.

First polarimetry measurement ever (Israel et al. in prep)

1E1547.0-5408: PD ~ 4% - right after outburst onset

Large distance and Galactic plane position → Problem of foreground polarisation!

No IR polarimetry for PSRs to compare with. IS 4% LOW OR HIGH?

Dependence of PD on wavelengths unclear (IR spectrum does change)
X-ray Polarimetry Missions

Imaging X-ray Polarimetry Explorer (IXPE)
- NASA SMEX candidate (PI: M. Weisskopf)
- 175 M$
- Pre-selected in 2015 for Phase A study
- Selected as a SMEX mission in January 2017
- Launch Date: **2020**

X-ray Imaging Polarimeter Explorer (XIPE)
- ESA M4 candidate (PI: P. Soffitta)
- 450 M€
- Pre-selected in 2015 for Phase A study
- Down selection Summer/Fall 2017
- Launch Date: **2025**

Enhanced X-ray Timing Polarimetry (eXTP)
- CAS mission candidate (PI. S. Zhang, M. Feroci)
- China+Europe+ESA
- Selected by CAS in December 2016
- Launch Date: **2024**

See Sergio Fabiani’s talk for more

See Roberto Turolla’s talk
# X-ray Polarimetry Missions

<table>
<thead>
<tr>
<th></th>
<th>IXPE</th>
<th>XIPE</th>
<th>eXTP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensitivity</strong></td>
<td>1.8% MDP (2 \times 10^{-10}) erg cm(^{-2}) s(^{-1}) in 300 ks</td>
<td>1.2% MDP (2 \times 10^{-10}) erg cm(^{-2}) s(^{-1}) in 300 ks</td>
<td>1.2% MDP (2 \times 10^{-10}) erg cm(^{-2}) s(^{-1}) in 600 ks</td>
</tr>
<tr>
<td><strong>Spurious polarisation</strong></td>
<td>&lt;0.3%</td>
<td>&lt;0.5% (&lt;0.1%)</td>
<td>&lt;1%</td>
</tr>
<tr>
<td><strong>Telescopes</strong></td>
<td>3</td>
<td>3</td>
<td>2 [4]</td>
</tr>
<tr>
<td><strong>Angular resolution</strong></td>
<td>28”</td>
<td>22”</td>
<td>30” (&lt;15”)</td>
</tr>
<tr>
<td><strong>FoV</strong></td>
<td>12.9x12.9 arcmin(^2)</td>
<td>12.9x12.9 arcmin(^2)</td>
<td>12x12 arcmin(^2)</td>
</tr>
<tr>
<td><strong>Effective Area</strong></td>
<td>854 cm(^2) @ 3 keV</td>
<td>1530 cm(^2) @ 3 keV</td>
<td>1000 cm(^2) @ 3 keV</td>
</tr>
<tr>
<td><strong>Spectral Resolution</strong></td>
<td>16% @ 5.9 keV</td>
<td>16% @ 5.9 keV</td>
<td>16% @ 6 keV</td>
</tr>
<tr>
<td><strong>Time Resolution</strong></td>
<td>&lt;100 µs</td>
<td>&lt;8 µs</td>
<td>500 µs (&lt;100 µs)</td>
</tr>
<tr>
<td><strong>Energy Range</strong></td>
<td>2-8 keV</td>
<td>2-8 keV</td>
<td>2-10 keV</td>
</tr>
<tr>
<td><strong>Launch Date</strong></td>
<td>2020</td>
<td>2025</td>
<td>2024</td>
</tr>
<tr>
<td><strong>Mission Duration</strong></td>
<td>2+1 yrs</td>
<td>3+2 yrs</td>
<td>5 yrs (10)</td>
</tr>
</tbody>
</table>
Target Pulsars for XIPE/eXTP

**Problem 1:** Most bright PSRs are embedded in bright PWNe → background subtraction problem - GPD angular resolution <30"
[much less of a problem for magnetars – no PWN]

**Problem 2:** PWNe are known to be variable in flux, and so is the background

\[
\text{MDP} = 10\% \ (150 \text{ ks}) \text{ down to } F_\chi \sim 5 \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}
\]
The Crab in X-rays

**Caveat:** Variable in flux does not necessarily mean variable in PD. See, e.g. the case of the Crab PWN wisps (Moran et al. 2013)
### Target Pulsars for XIPE/eXTP

**Workaround:** Select PSRs with PWN flux \( \sim 0.1 \) PSR flux within a 30” radius.

**Caveat:** A faint PWN is not necessarily weakly polarised!

All selected targets are X-ray pulsars in the 0.2-12 keV band,

Important to separate pulsed (PSR) and unpulsed (PWN) components – possible thanks to the GPD time resolution (<100\( \mu \)s eXTP and IXPE; <8\( \mu \)s XIPE)

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**Optical polarisation**

<table>
<thead>
<tr>
<th>NAME</th>
<th>P(s)</th>
<th>d(kpc)</th>
<th>( N_H(10^{21}) )</th>
<th>( \Gamma )</th>
<th>PWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>J0534+2200</td>
<td>33</td>
<td>2.0</td>
<td>3.45</td>
<td>1.63</td>
<td>Y</td>
</tr>
<tr>
<td>J0659+1414</td>
<td>384</td>
<td>0.288</td>
<td>0.43</td>
<td>2.1</td>
<td>N</td>
</tr>
<tr>
<td>J0835-4510</td>
<td>89</td>
<td>0.29</td>
<td>0.25</td>
<td>1.64</td>
<td>Y</td>
</tr>
<tr>
<td>J1057-5226</td>
<td>197</td>
<td>0.72</td>
<td>0.27</td>
<td>1.7</td>
<td>N</td>
</tr>
<tr>
<td>J1420-6048</td>
<td>68</td>
<td>5.6</td>
<td>20.2</td>
<td>0.84</td>
<td>Y</td>
</tr>
<tr>
<td>J1513-5908</td>
<td>151</td>
<td>4.2</td>
<td>3.18</td>
<td>2.05</td>
<td>Y</td>
</tr>
<tr>
<td>J1617-5055</td>
<td>69</td>
<td>6.5</td>
<td>34.5</td>
<td>1.14</td>
<td>Y</td>
</tr>
<tr>
<td>J1747-2809</td>
<td>52</td>
<td>8.5</td>
<td>225.0</td>
<td>1.37</td>
<td>Y</td>
</tr>
<tr>
<td>J1747-2958</td>
<td>98</td>
<td>4.8</td>
<td>25.6</td>
<td>1.51</td>
<td>Y</td>
</tr>
<tr>
<td>J1801-2451</td>
<td>124</td>
<td>5.2</td>
<td>37.4</td>
<td>1.54</td>
<td>Y</td>
</tr>
<tr>
<td>J1811-1925</td>
<td>64</td>
<td>5.0</td>
<td>22.2</td>
<td>0.97</td>
<td>Y</td>
</tr>
<tr>
<td>J1813-1246</td>
<td>48</td>
<td>2.5</td>
<td>15.6</td>
<td>0.85</td>
<td>N</td>
</tr>
<tr>
<td>J1813-1749</td>
<td>41</td>
<td>4.8</td>
<td>100.0</td>
<td>2.0</td>
<td>Y</td>
</tr>
<tr>
<td>J1833-1034</td>
<td>61</td>
<td>4.7</td>
<td>21.0</td>
<td>1.52</td>
<td>Y</td>
</tr>
<tr>
<td>J1836+5525</td>
<td>173</td>
<td>0.4</td>
<td>0.07</td>
<td>2.05</td>
<td>N</td>
</tr>
<tr>
<td>J1838-0555</td>
<td>70</td>
<td>6.6</td>
<td>67.0</td>
<td>1.0</td>
<td>Y</td>
</tr>
<tr>
<td>J1846-0258</td>
<td>326</td>
<td>10.0</td>
<td>39.6</td>
<td>1.88</td>
<td>Y</td>
</tr>
<tr>
<td>J1849-0001</td>
<td>38</td>
<td>0.0</td>
<td>43.0</td>
<td>1.1</td>
<td>Y</td>
</tr>
<tr>
<td>J1930+1852</td>
<td>136</td>
<td>5.0</td>
<td>16.0</td>
<td>1.35</td>
<td>Y</td>
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<tr>
<td>J2021+3651</td>
<td>103</td>
<td>2.1</td>
<td>6.38</td>
<td>1.68</td>
<td>Y</td>
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<tr>
<td>J2022+3842</td>
<td>24</td>
<td>10.0</td>
<td>16.0</td>
<td>1.0</td>
<td>Y</td>
</tr>
<tr>
<td>J2229+6114</td>
<td>51</td>
<td>3.65</td>
<td>3.0</td>
<td>1.01</td>
<td>Y</td>
</tr>
</tbody>
</table>
Gamma-ray Polarimetry Missions

- Current ESA M5 candidate

Science with e-ASTROGAM
(A space mission for MeV-GeV γ-ray astrophysics)
De Angelis et al., 2017, arXiv:1711.01265

- Polarisation measurements from pair creation and Compton scattering

- At low energies (0.2 - 2 MeV), e-ASTROGAM will achieve an MDP as low as 0.7% for a Crab-like source in 1 Ms

- Monitor changes in polarisation following γ-ray flaring events in the Crab and verify proposed correlation with optical (Moran et al. 2016)

- PWN contamination problem more severe than in X-rays → Target selection different from X-rays
Summary and Conclusions (I)

- After the radio band, pulsar polarisation mostly done in the optical (Crab, Vela, PSR B0540-69, B0656+14, B1509-58, Geminga ?)
- Optical polarisation measurement for RX J1856.5-3754
- IR polarisation for 1 magnetar (1E 1547.0-5408)

- Main issues for optical/IR polarimetry of INSs:
  1. ~15 pulsars identified in the optical, most fainter than V~25, PWN contamination, phase-res polarisation with guest instruments
  2. All cooling INSs are fainter in the optical than RX J1856.5-3754 (V~25.5)
  3. All magnetars suffer of a large foreground polarisation, variable
  4. No polarimetry instrument planned for next generation ELTs
• In the $X/\gamma$-rays, polarisation measured **only for the Crab** (nebula and pulsar)

  ➢ *IXPE (eXTP, XIPE) and e-ASTROGAM* will make it possible to conduct $X$ and $\gamma$-ray polarisation studies on a larger sample of pulsars

  ➢ First X-ray polarisation studies of magnetars

  ➢ *Need a soft X-ray polarimeter for Cooling INSs (RedSOX-Herman Marshall’s talk)*

• Multi-wavelength polarisation measurements will allow to:

  A. Study pulsar magnetic field and magnetospheres in different energy regimes

  B. Verify dependence of **PD vs energy** (e.g., optical vs X-rays vs $\gamma$-rays)

  C. Verify dependence of **PD vs $X/\gamma$-ray spectrum** (soft/hard vs low/high PD)

  D. Disentangle different emission processes

With IXPE (eXTP, XIPE), e-ASTROGAM, and (hopefully) future optical facilities (ELTs) we will enter the new era of **Multi-wavelength Polarimetry**, adding **a fourth dimension** to the multi-wavelength study of Cosmic Sources

*See Roberto Taverna’s talk*
Special Session 20:

Multi-Wavelength Polarimetry

3 – 6 April 2018

http://eas.unige.ch/EWASS2018/session.jsp?id=SS20

Deadline for abstract submission: 27 November 2017

Scientific organisers
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Session 1: Optical Polarimetry: present and future optical polarimetric science
Session 2: High Energy Polarimetry, from the sun to AGNs
Session 3: Polarimetric Synergies from Radio to Gamma-Rays