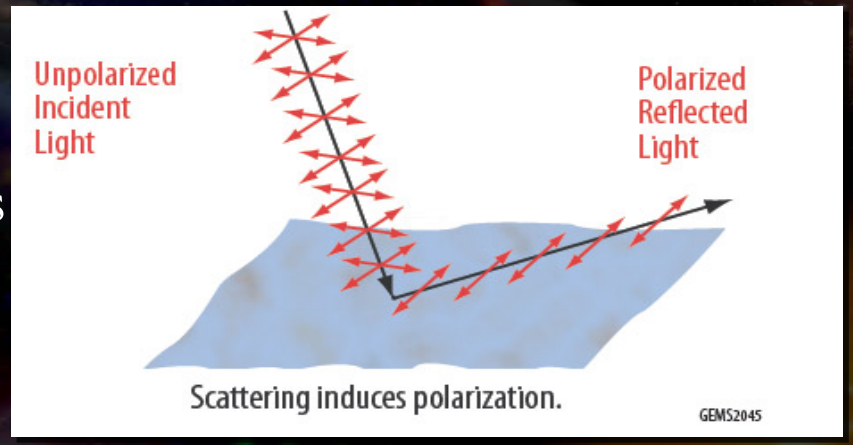
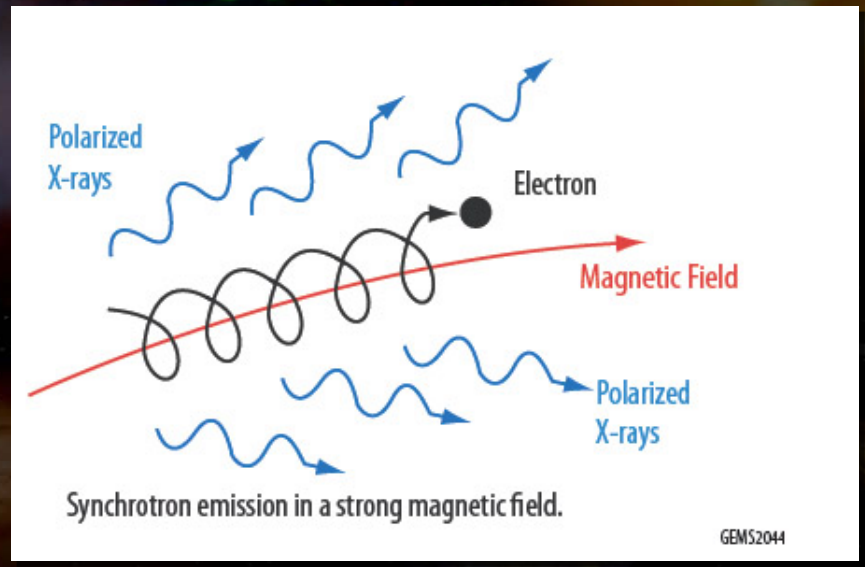
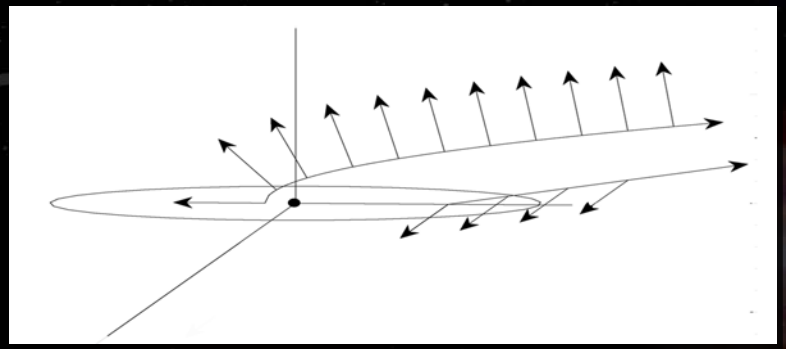
The fourth dimension: Polarimetry

- Polarimetry probes physics of photon emission and propagation
- Polarization measurements allow us to study:
  - ✓ Scattering geometry
  - ✓ Magnetic fields
  - ✓ Strong gravity







Observational status (I)

- Insofar only Crab in X-rays (OSO 8), other results from hard X-rays (Integral, GRB GAP)
- Crab Nebula:
  - X-rays from nebula 19.2%±1.0% ; (Weisskopf et al. 1978)
  - γ-rays (INTEGRAL IBIS&SPI): (46 ±10) % (Forot et al. 2008)
  - High-energy electrons responsible for the γ-rays polarized photons are produced in a highly ordered structure close to the pulsar while X-rays sample larger region (thus lower fraction)
- Cyg X-1: a polarized jet component dominating >300keV (INTEGRAL)
- GRBs: polarization in the prompt: nature of the relativistic jet. INTEGRAL GRB 041219A 96%+-40% (Kalemci et al 2007), Ikarus GAP (Yonetoku et al 2013): GRB110301A 70%±22%, GRB110721A:84(+16,-28)%

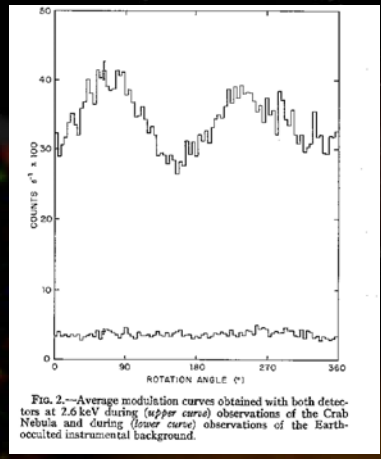
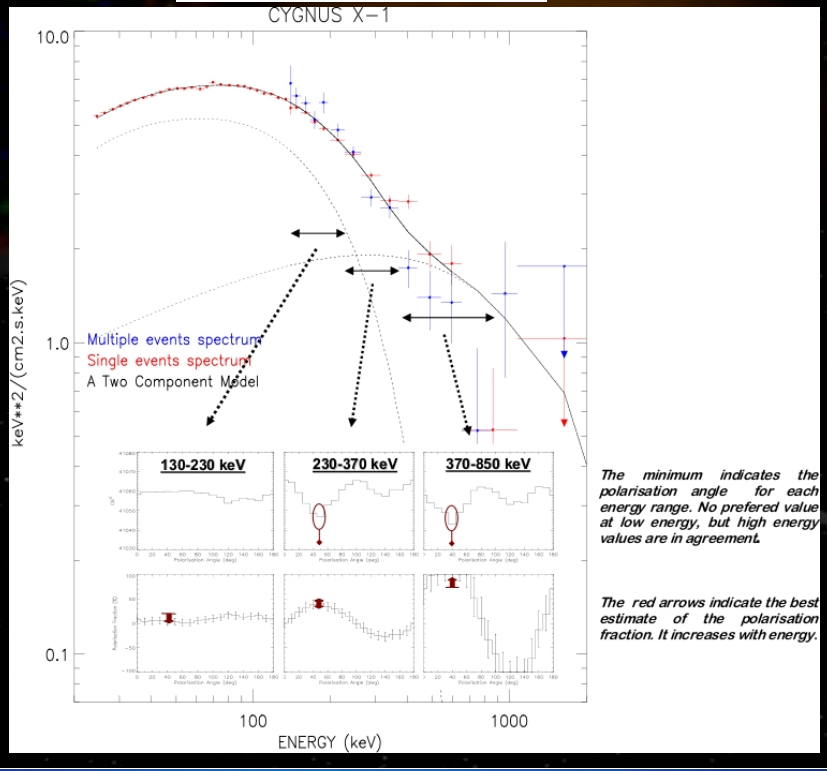
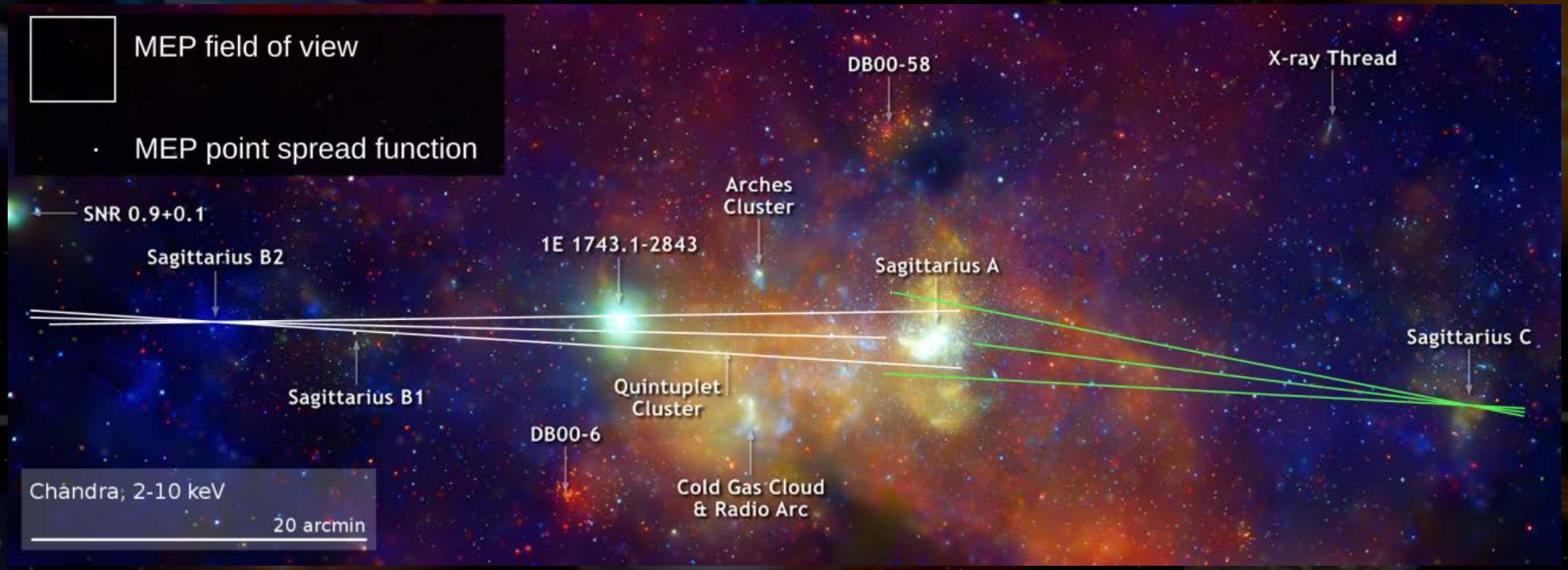


FIG. 2.—Average modulation curves obtained with both detectors at 2.6 keV during (*upper curve*) observations of the Crab Nebula and during (*lower curve*) observations of the Earth-occulted instrumental background.



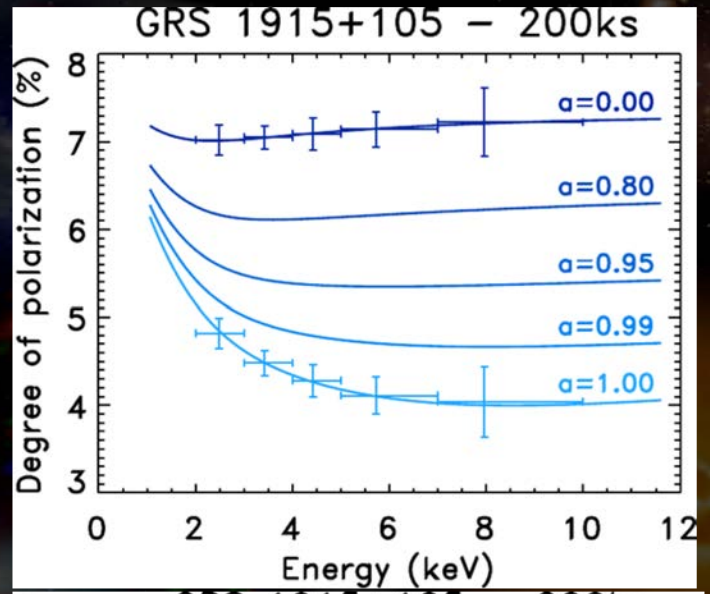
X-Ray Polarimetry: key drivers

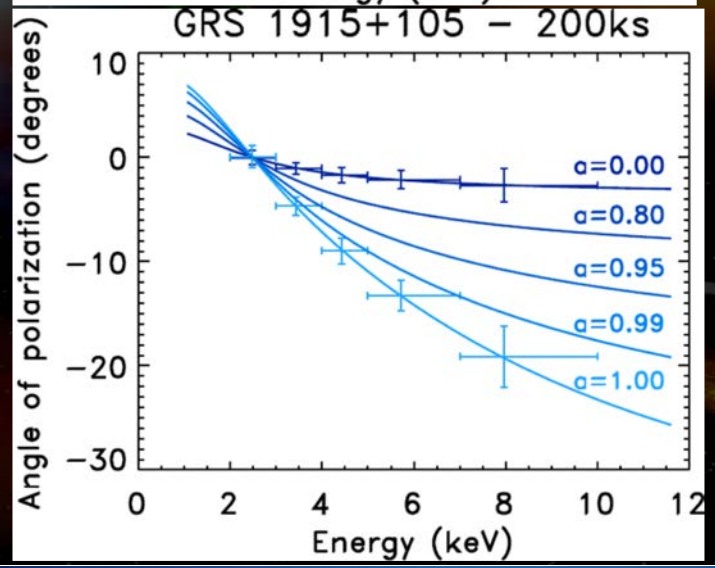
- **Astrophysical measurements** (radiation processes, source geometry)



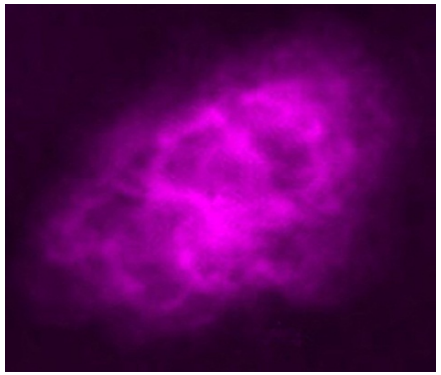
X-Ray Polarimetry: key drivers

- **Strong Gravity:** Effects of General and Special Relativity on X-ray polarization in BH & NS. Measure of BH spin
- Quantum Electro Dynamics : Vacuum Polarization & Birefringence in strong magnetic fields. Measure of B field in magnetar

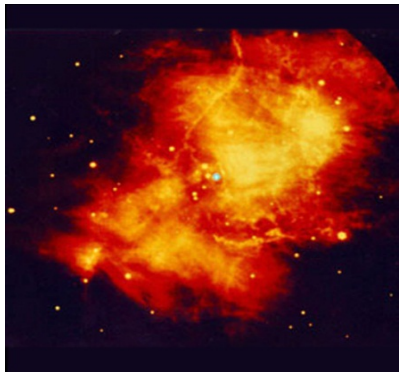




THE CRAB NEBULA OR THE IMPORTANCE OF IMAGING X-RAY POLARIMETRY



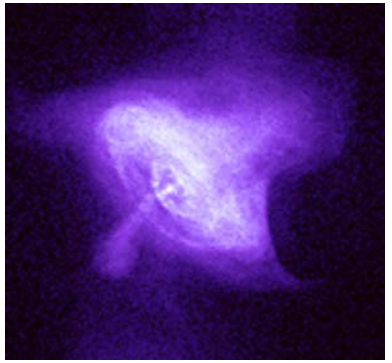
Radio (VLA)



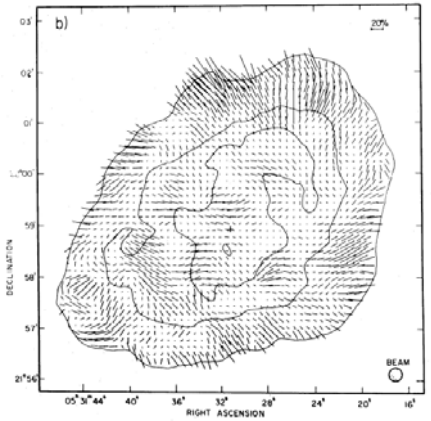
Infrared (Keck)



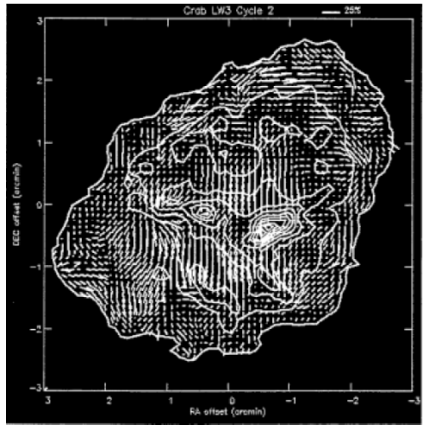
Optical (Palomar)



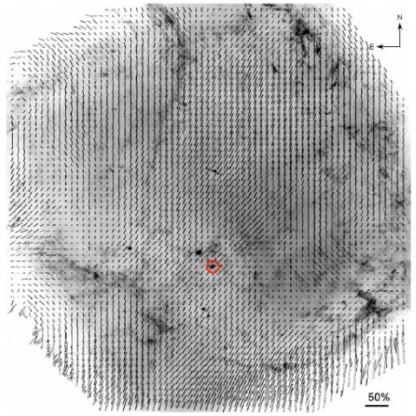
X-rays (Chandra)



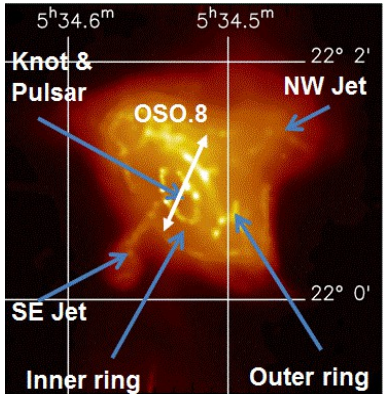
Radio polarisation



IR polarisation



Optical polarisation



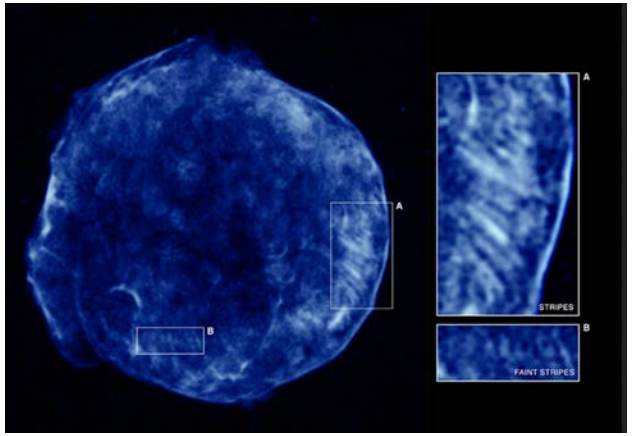
X-ray polarisation

X-rays probe **freshly accelerated** electrons and their acceleration site.

TYCHO, ENHANCEMENT OF 4-6 keV EMISSION: SIMULATION – 500 ks

IXPE Field of View is 12.9 arcmin. Tycho size is 8 arcmin: a single stared observation is sufficient

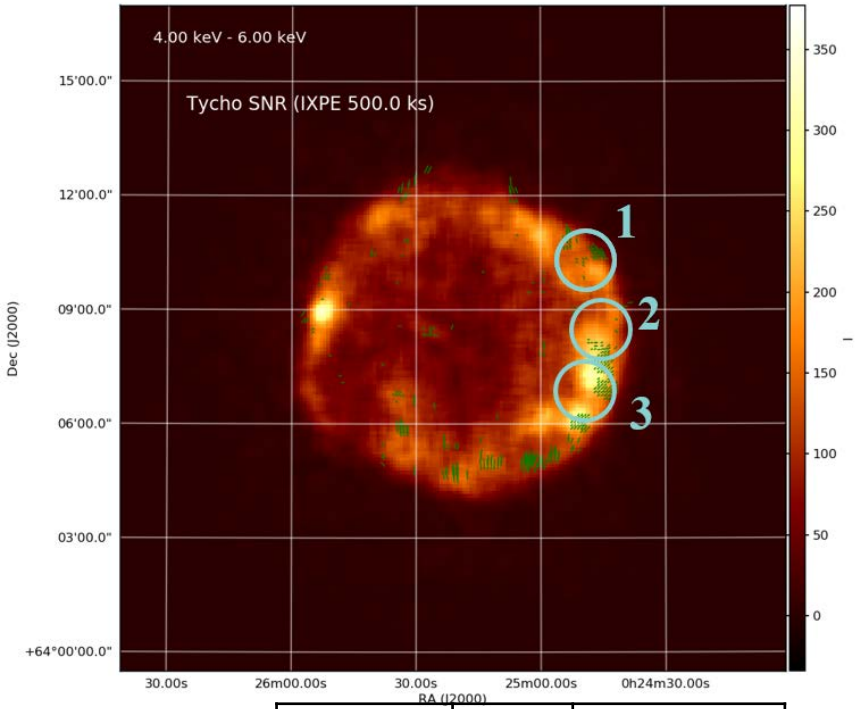
Chandra image with strip close view



Strips seen by Chandra could be the site of collective acceleration of cosmic rays because non-linear diffusive acceleration. Due to the ordered orientation they are expected to be polarized (Bychov et al., 2009, 2011).

Courtesy of Riccardo Ferrazzoli

Chandra image IXPE blurred



Region	MDP	P
1	28.3	42.3+/-9.2
2	28.8	58.0+/-9.2
3	23.3	41.1+/-7.6

§ 6

BLAZARS

Synchrotron-dominated

Blazars, multi-λ polarimetry probes **the structure** of the jet and of its **magnetic field**

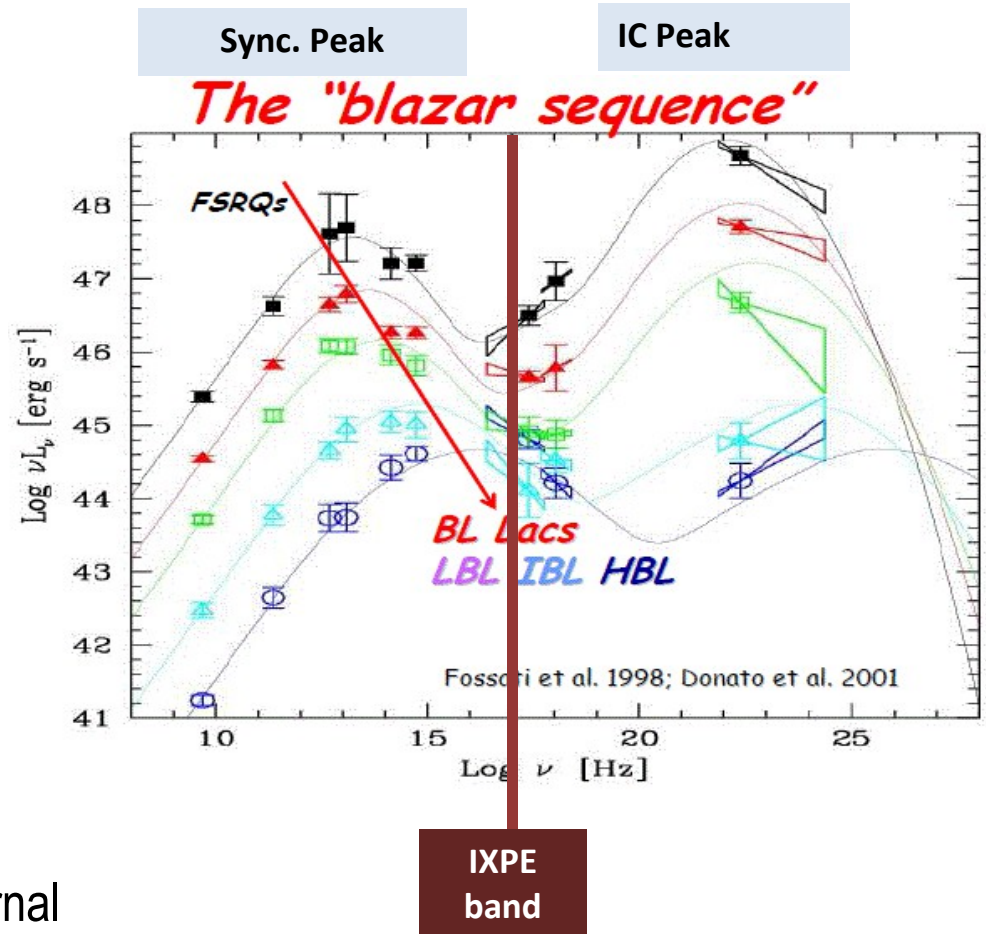
Inverse Compton dominated

Blazars, multi-λ polarimetry observations can determine:

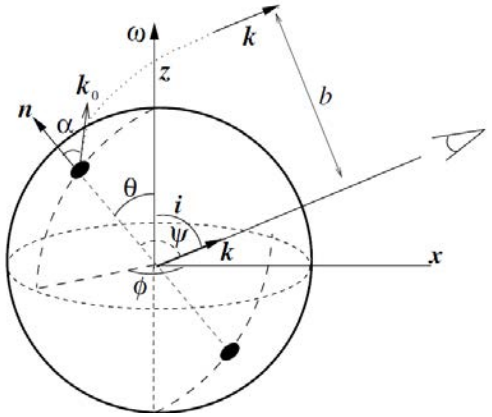
- **the composition of the jet** (hadronic vs. leptonic, Zhang & Bottcher, 2013)
- **the origin of the seed photons**

Synchrotron-Self Compton (SSC) or External Compton (EC)

(Celotti & Matt, 1994; Poutanen 1994)

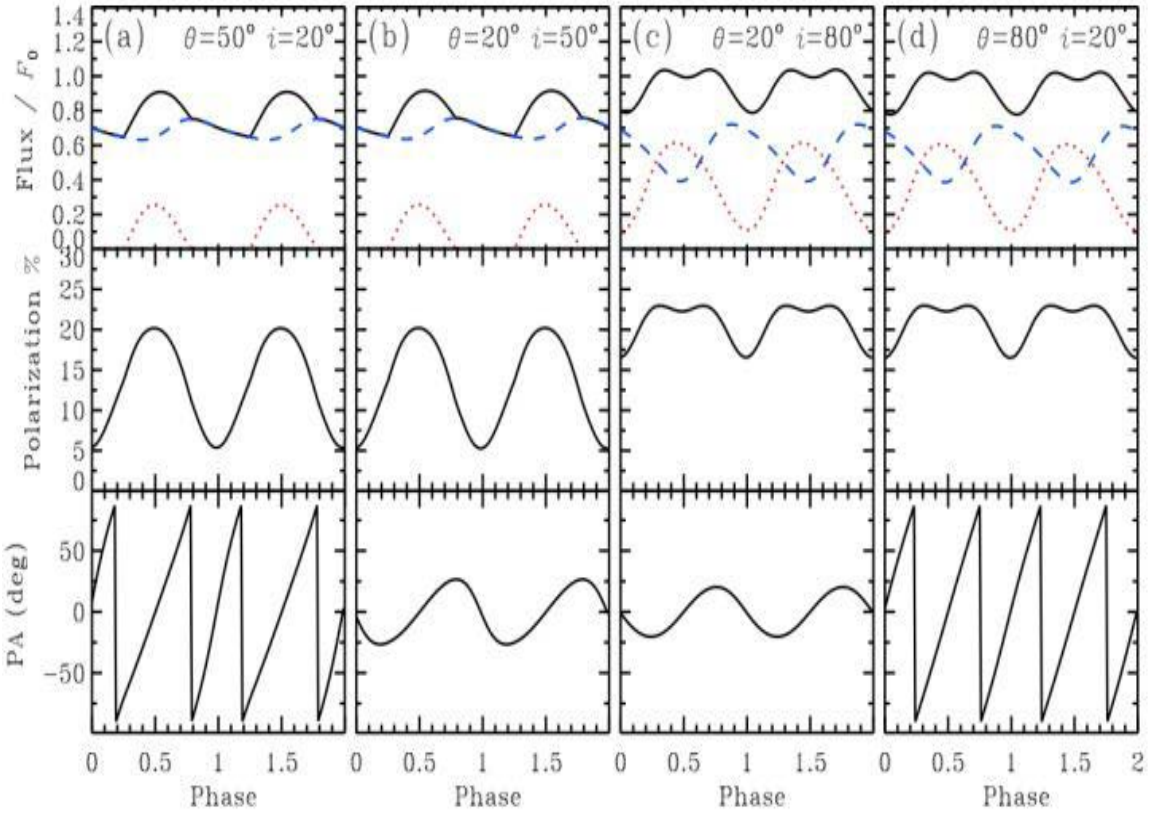


ACCRETING MILLISECOND PULSARS



B = 10^8 Gauss

Viironen & Poutanen 2004



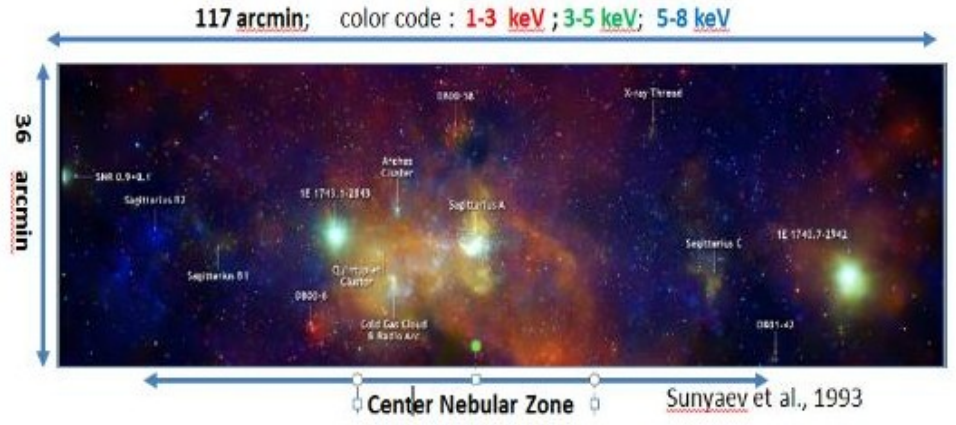
Emission due to scattering in
hot spots ⇒

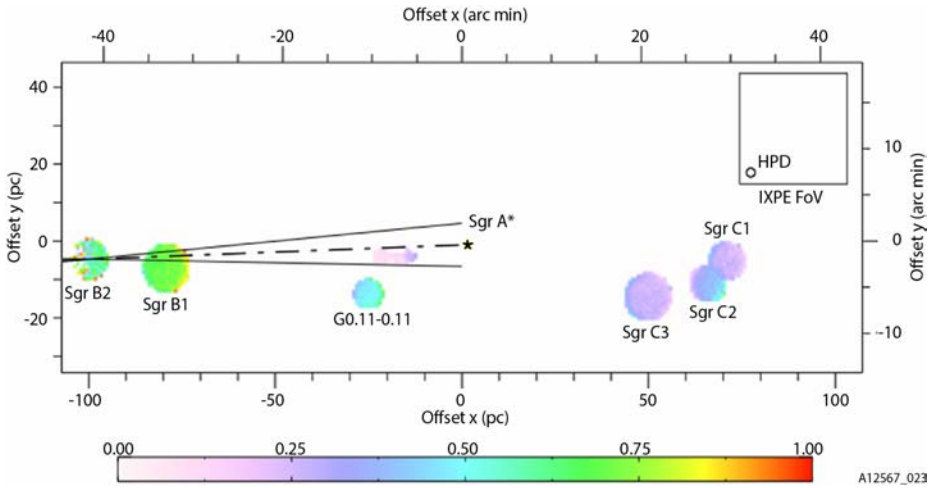
Phase-dependent linear polarization

Polarization measurements determine the geometrical parameters of the system. When combined with spectral and timing measurements from e.g. NICER, the EoS of the NS can be better constrained.

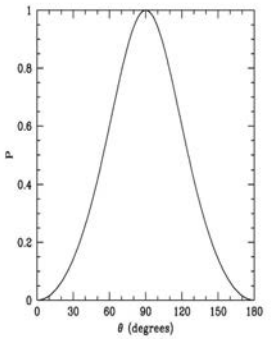
WAS THE GC ACTIVE A FEW CENTURIES AGO?

- **Galactic Center molecular clouds (MC are known X-ray sources**
  - Are MCs reflecting X-rays from Sgr A (supermassive black hole in the GC)
    - X-radiation would be *highly polarized* perpendicular to plane of reflection and indicates the direction back to Sgr A*
    - Sgr A* X-ray luminosity was 10^6 larger ≈ 300 years ago



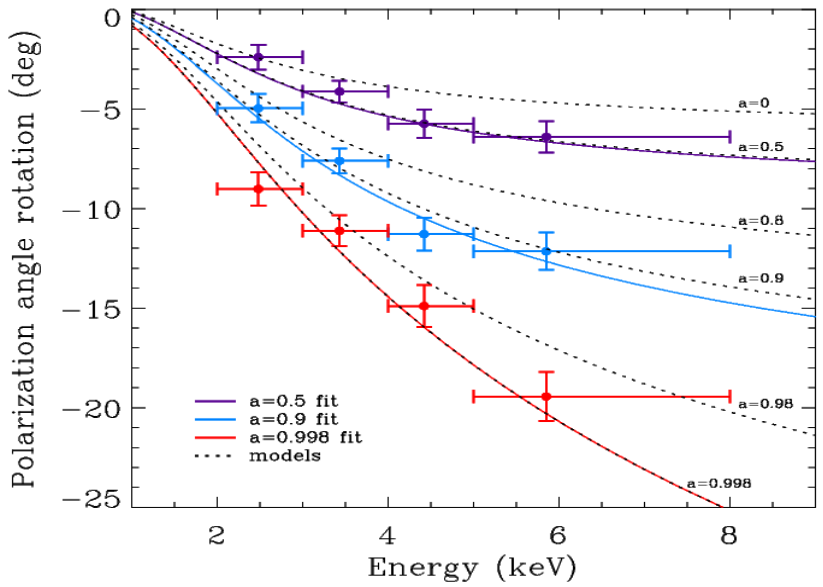






THE SPIN OF THE BLACK HOLE IN MICROQUASARS

- **For an accreting Galactic BH in the soft state**
  - Scattering polarizes the thermal disk emission
  - Polarization angle rotates due to GR effects
    - Polarization rotation is greatest for emission from inner disk
    - Inner disk is hotter, producing higher energy X-rays



200 ks IXPE observation of GRS1915+105