Polarization properties during the rising phase of type-I bursts in LMXBs

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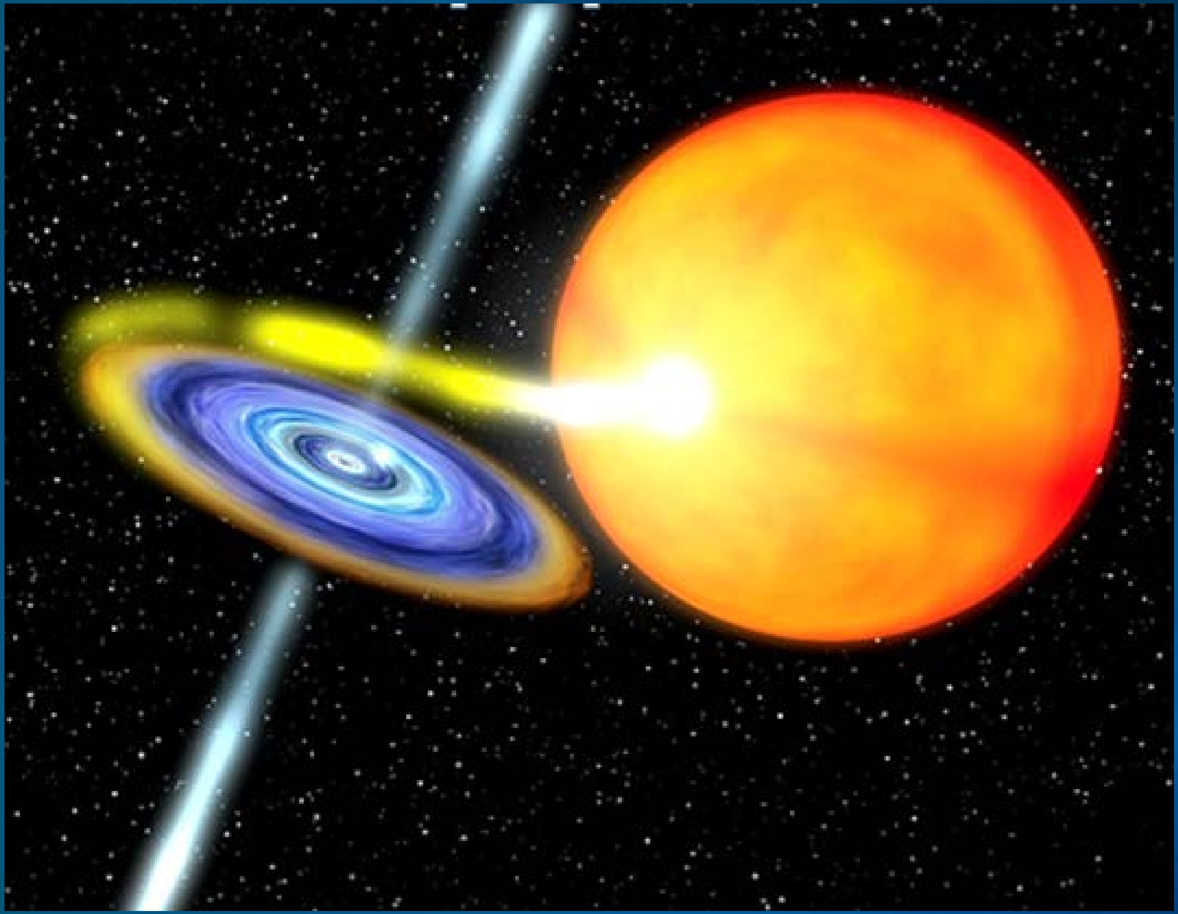
Low-mass X-ray binaries： disk-fed X-ray sources



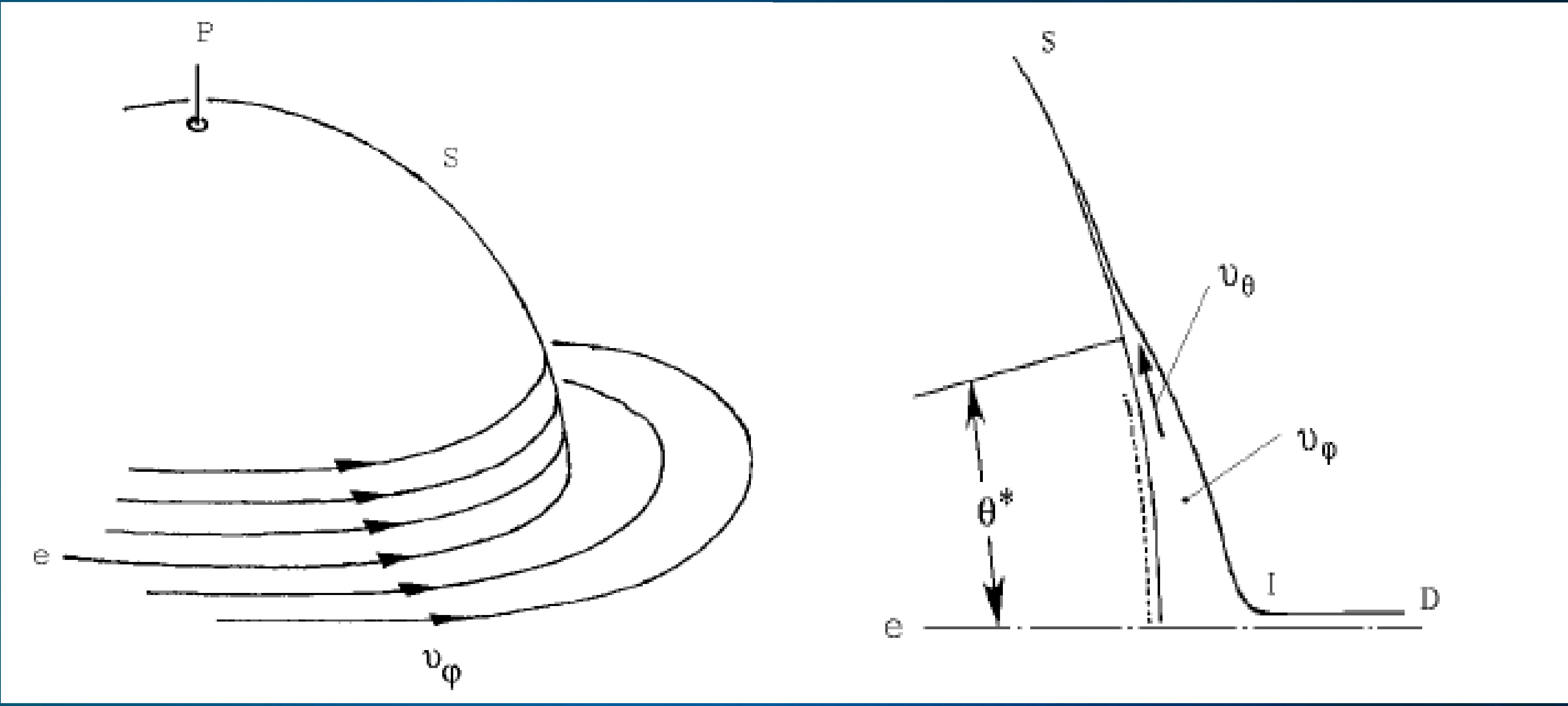
$$L_{acc} = \frac{2\eta G M \dot{M}}{R_*} = \eta \dot{M} c^2$$

$\eta \sim 0.1$

$$R_* = \frac{2GM}{c^2}$$

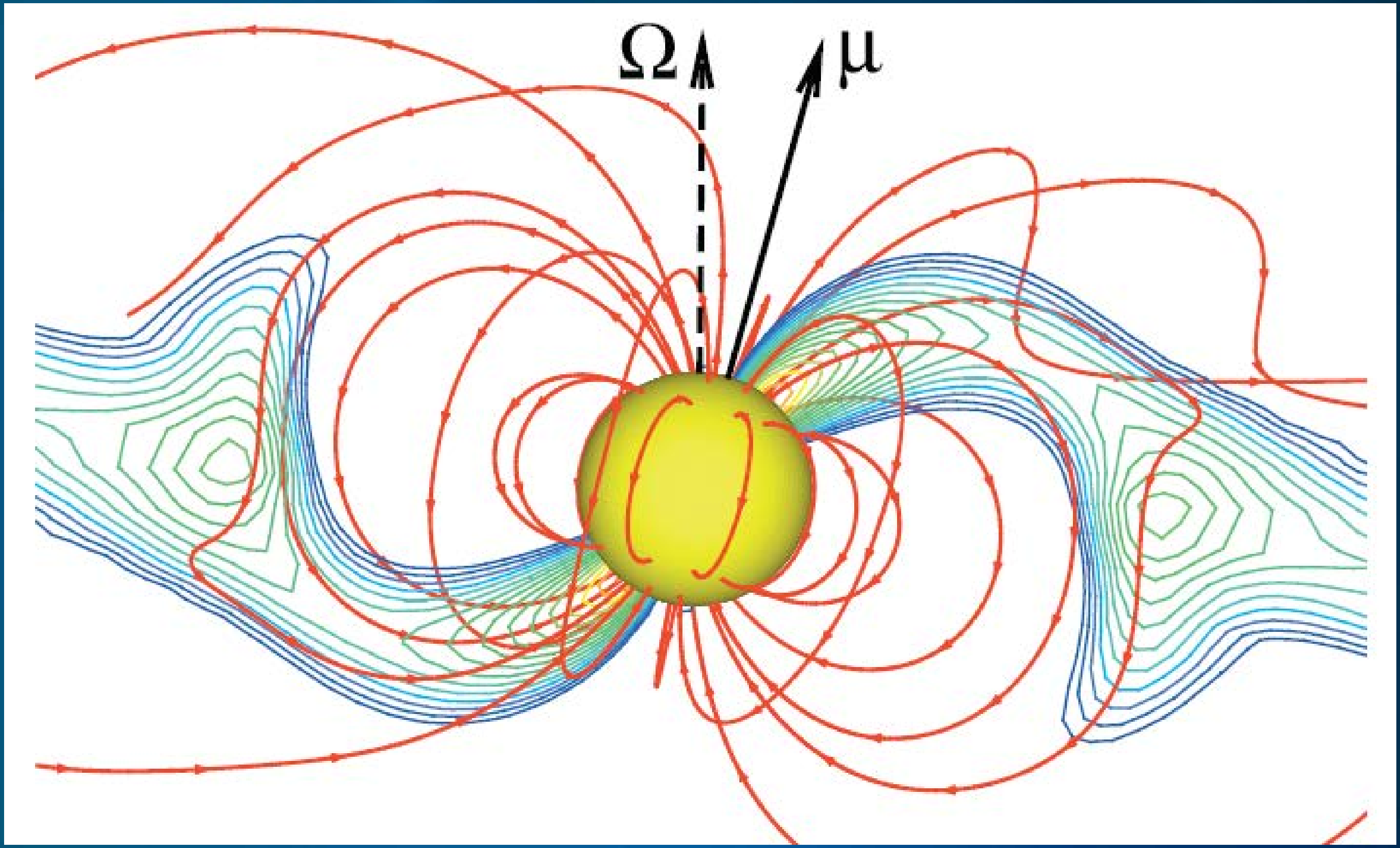
$T_b = (L_{acc} / R_*{}^2 4\pi * \sigma)^{1/4} \sim$ 1keV < **T** < $\frac{3}{2} k T_{th} = GMm_p / 2R_* \sim$100 keV

Accreting mode:



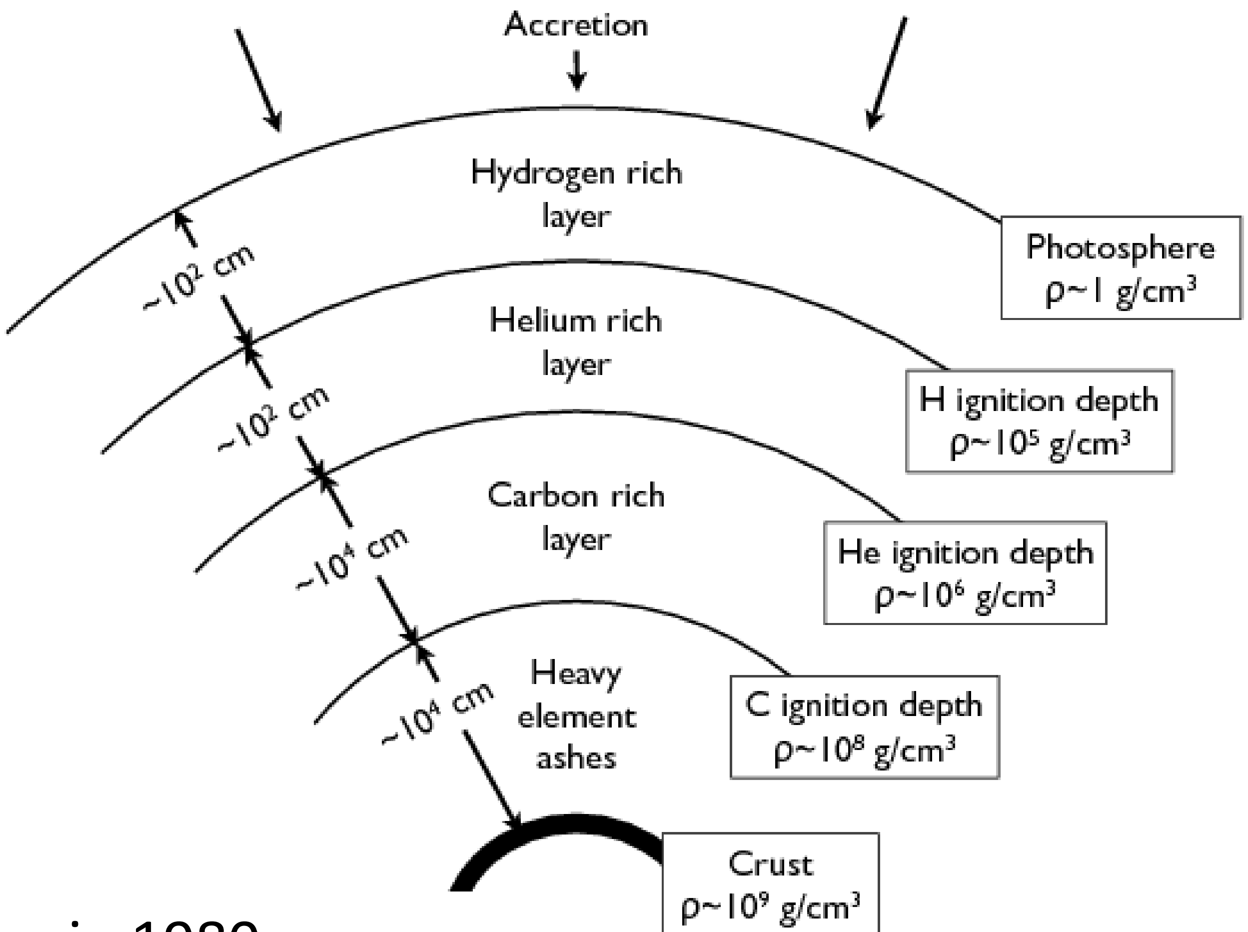
Inogamov & Sunyaev 1999

Channel accretion:



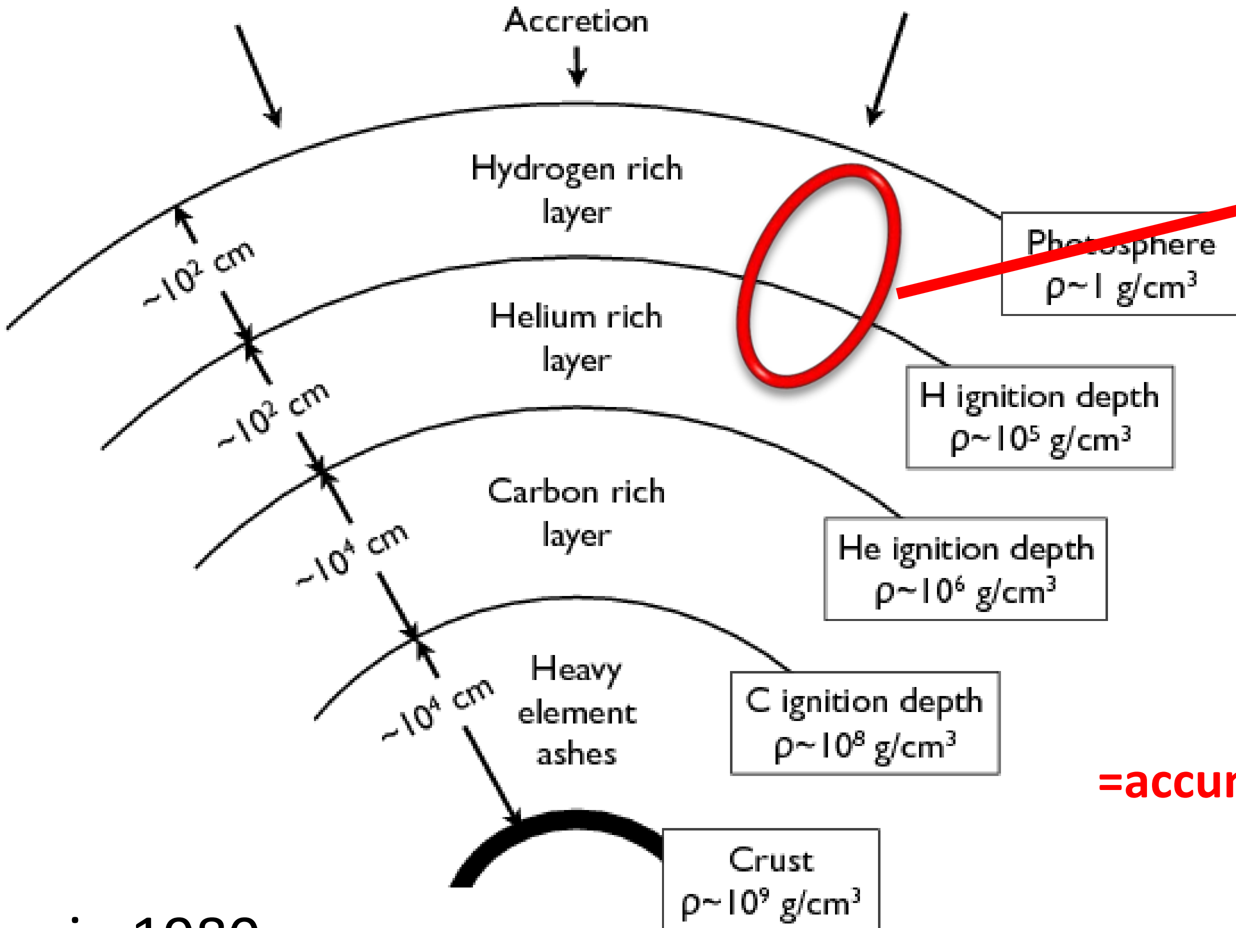
Romanova et al. 2004

How to disentangle the different accretion modes?


Accretion
Hydrogen rich layer
~10^2 cm
Photosphere
ρ~1 g/cm^3
Helium rich layer
~10^2 cm
H ignition depth
ρ~10^5 g/cm^3
Carbon rich layer
~10^4 cm
He ignition depth
ρ~10^6 g/cm^3
Heavy element ashes
~10^4 cm
C ignition depth
ρ~10^8 g/cm^3
Crust
ρ~10^9 g/cm^3

Lewin 1980


Hexane
Water
CCl_4



Lewin 1980

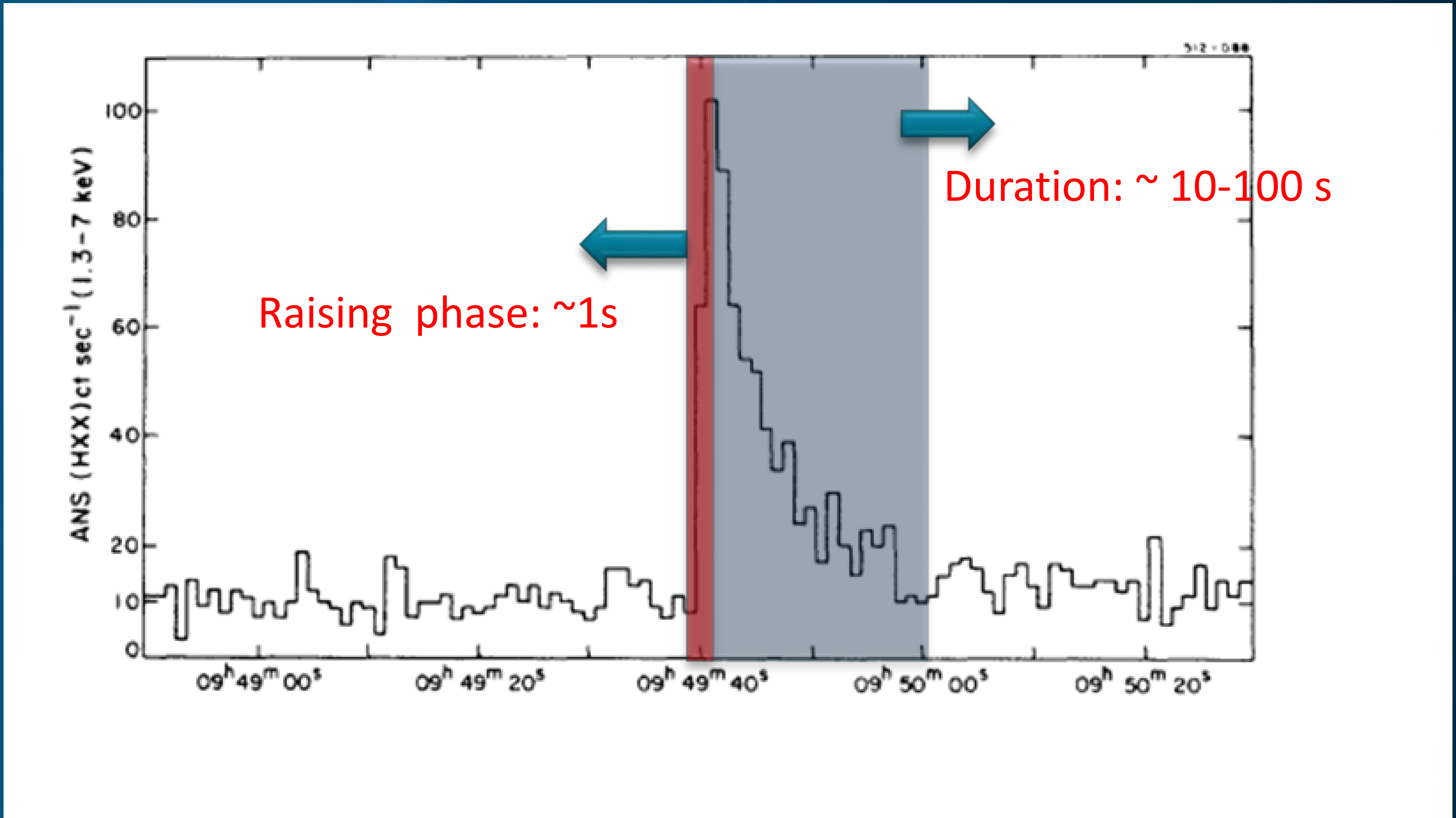
Ignite here

It highly depends on the local **column density**

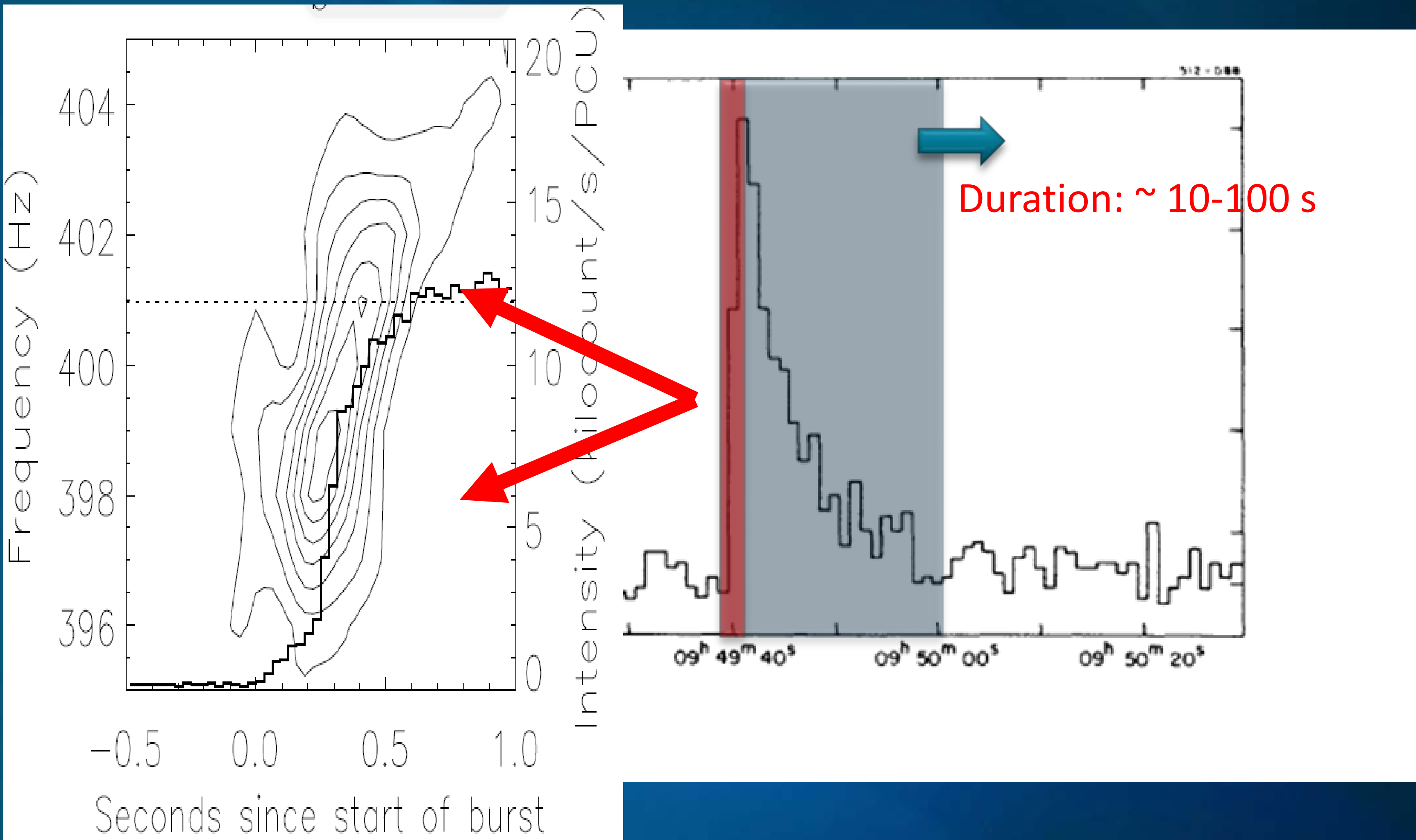
=accumulated accreting materials

"where ignite" is related to "where accrete"

The first observed type-I burst （Grindlay et al， 1976）

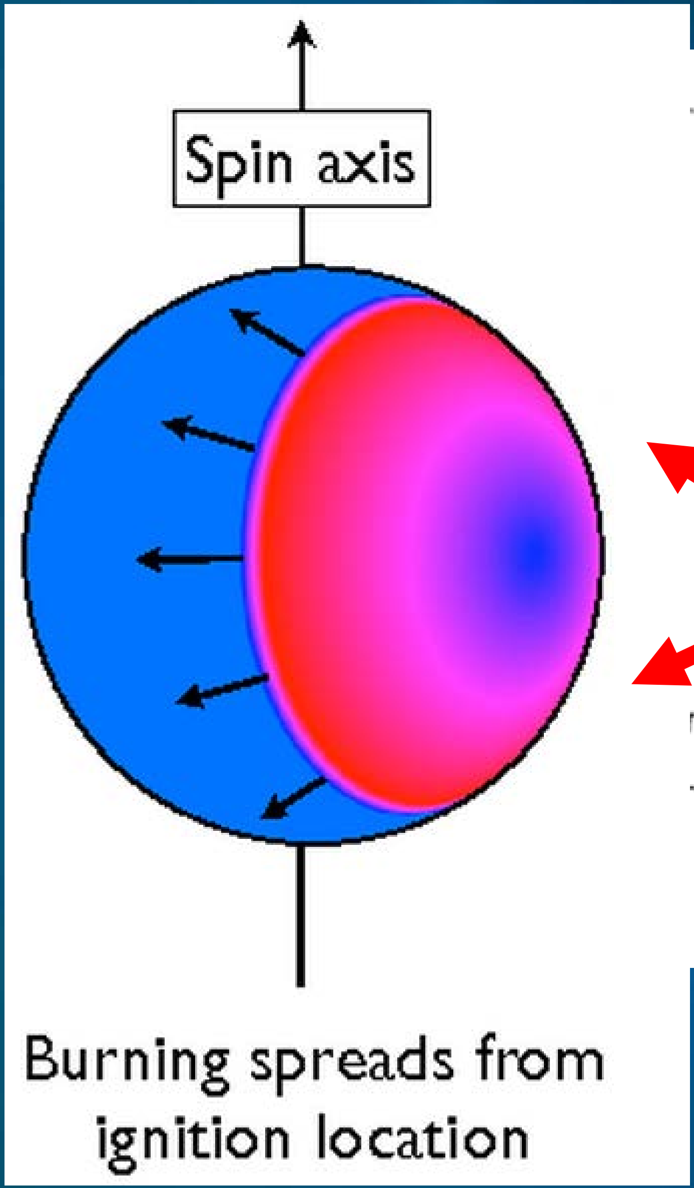


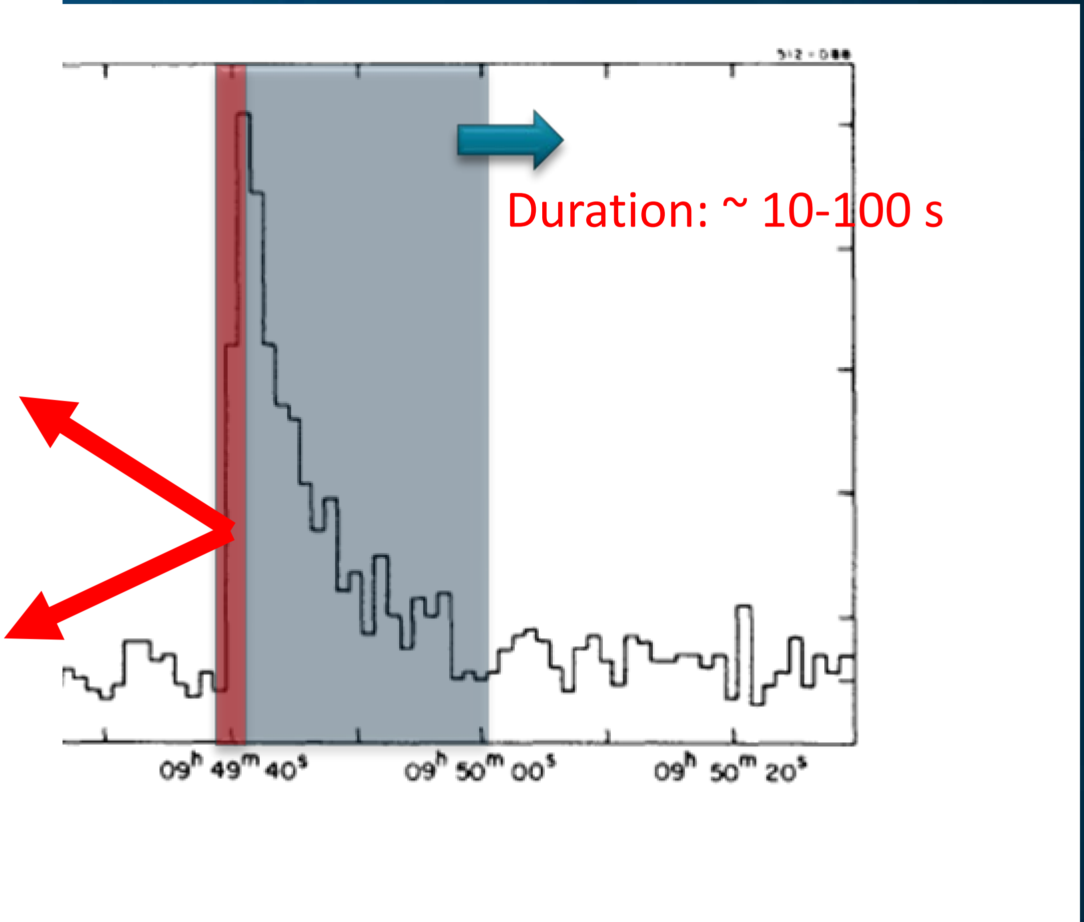
The first observed type-I burst （Grindlay et al， 1976）



Chakrabarty et al 2003

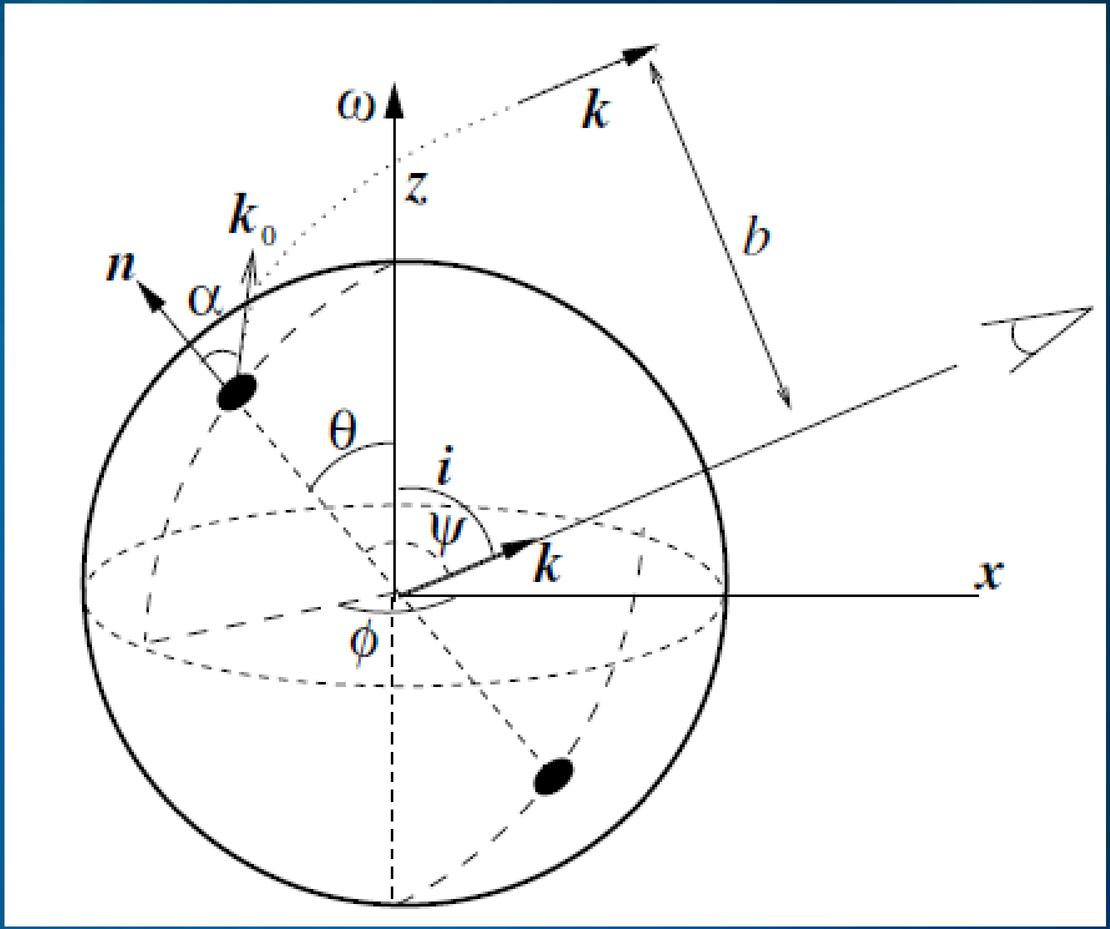
The first observed type-I burst （Grindlay et al， 1976）





Watts, Anna 2012

Hot spots in millisecond pulsars

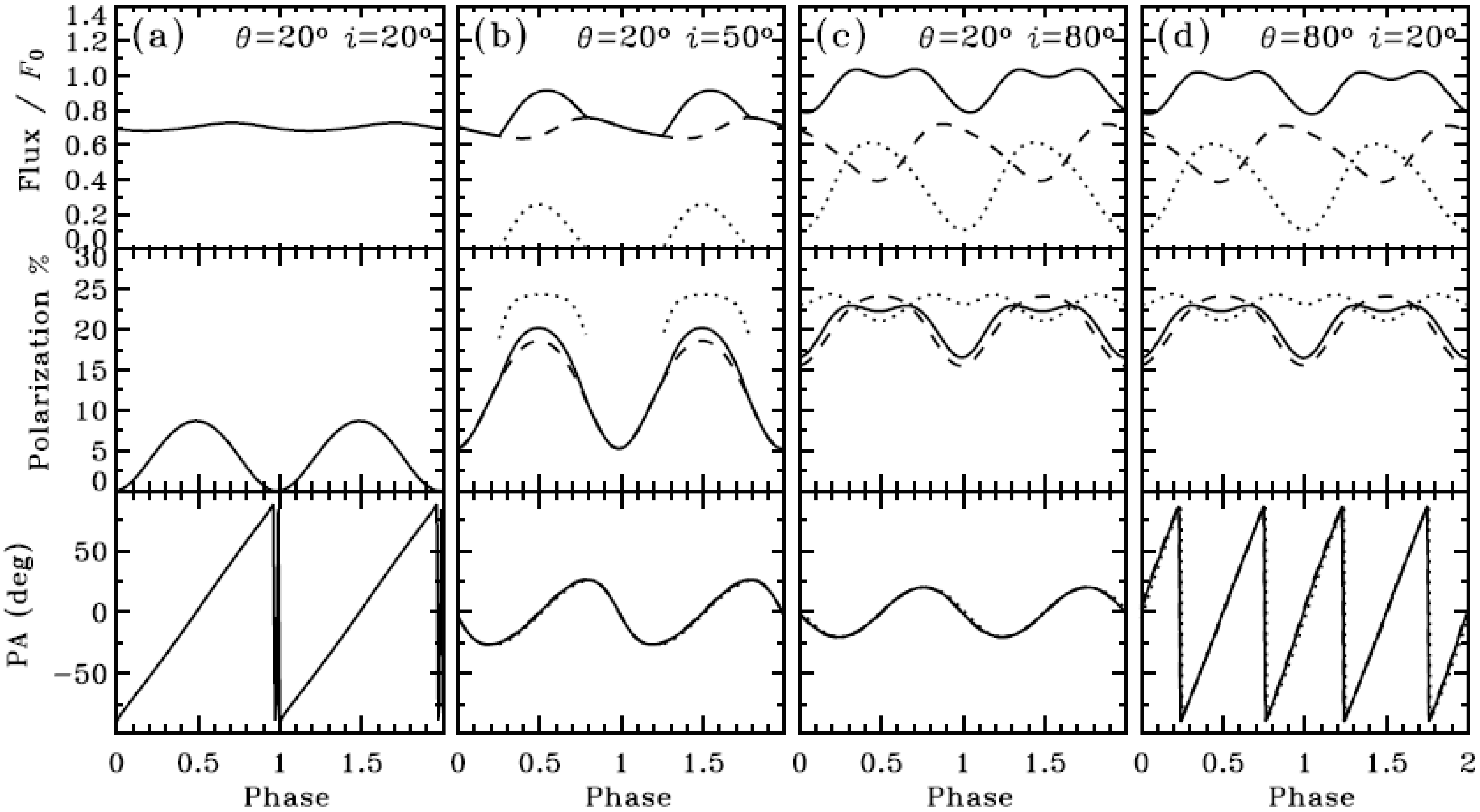


K. Viironen and J. Poutanen 2004

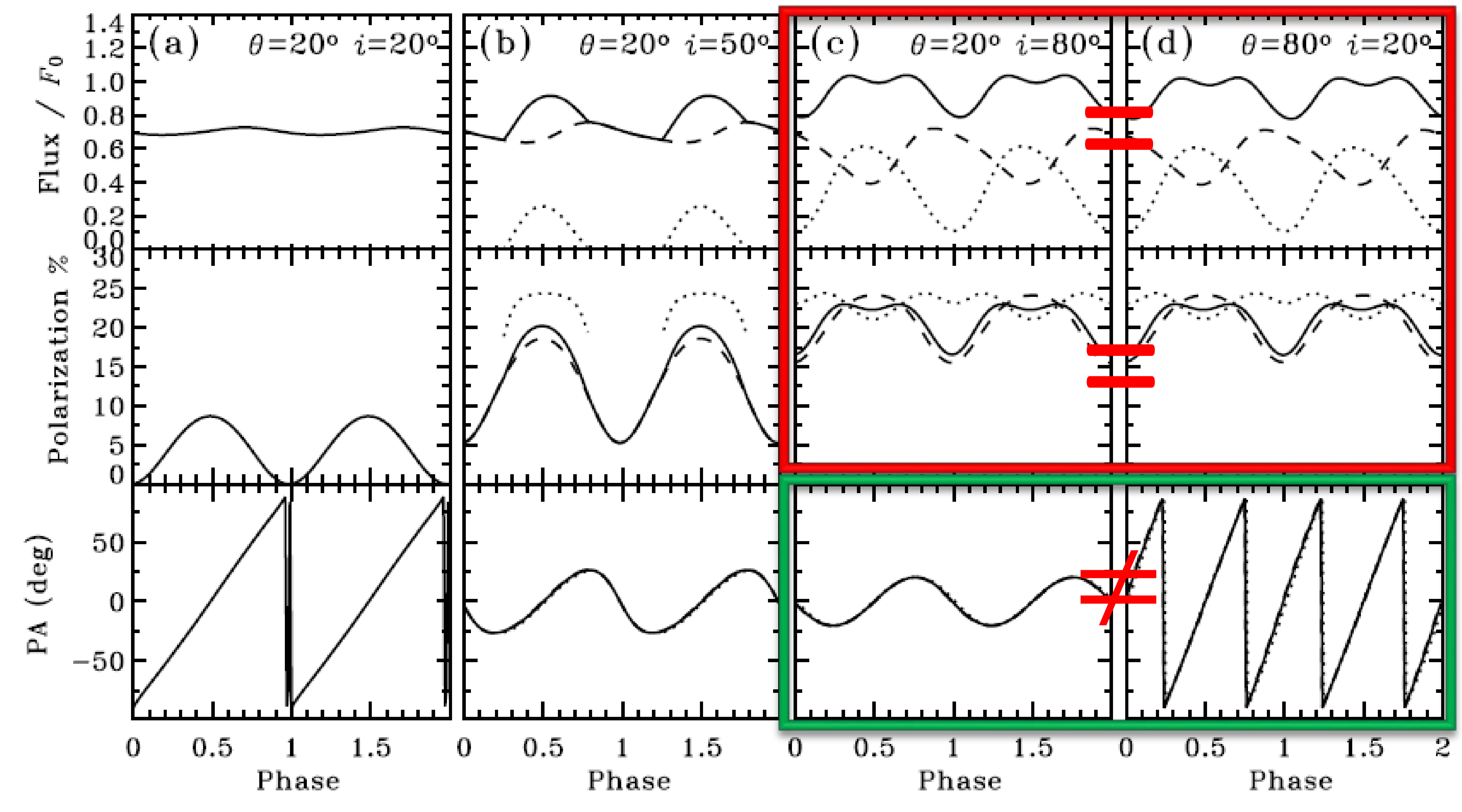
$$\frac{\pi}{2} - \theta = \text{latitude}$$

i ~ the direction we observed

Assuming that what we can see is the north hemisphere

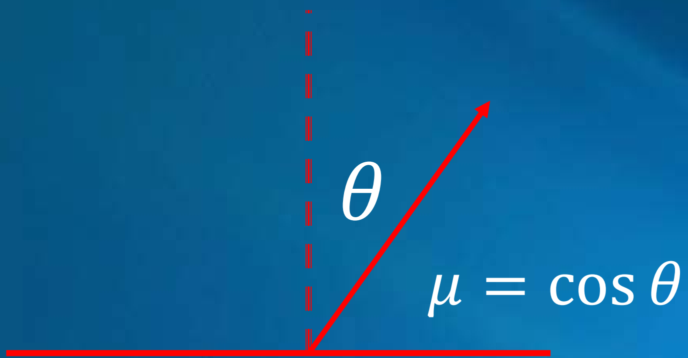


(a) θ=20° i=20°
(b) θ=20° i=50°
(c) θ=20° i=80°
(d) θ=80° i=20°
Flux / F0
Polarization %
PA (deg)
Phase
Phase
Phase
Phase



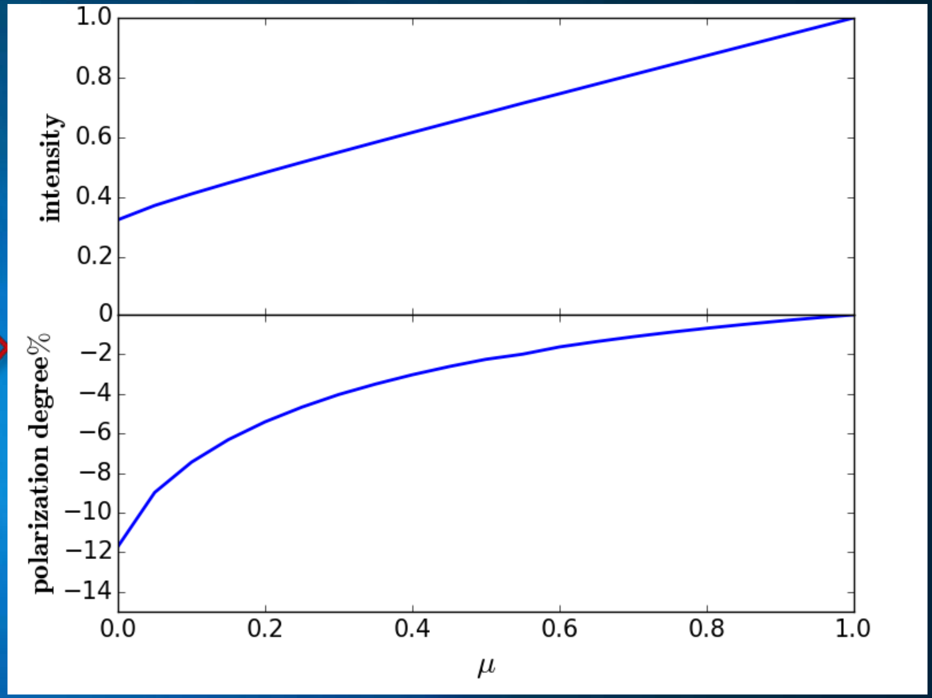
Polarization detection can constrain the position of hot spots on the surface of the neutron star .

For type-I bursts



semi-infinite optical depth

Plane-parallel symmetry

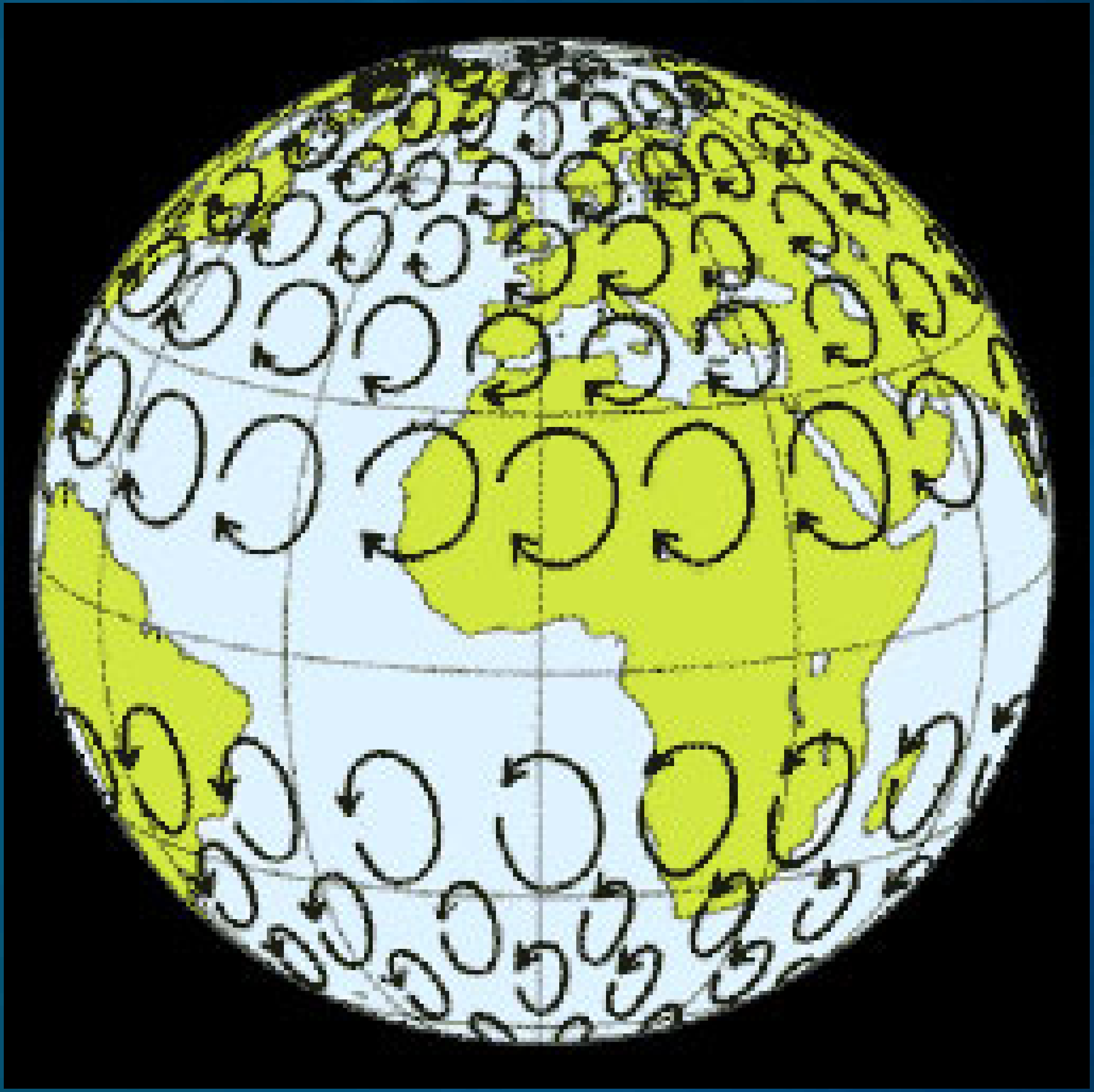


Chandra 1947

An example:

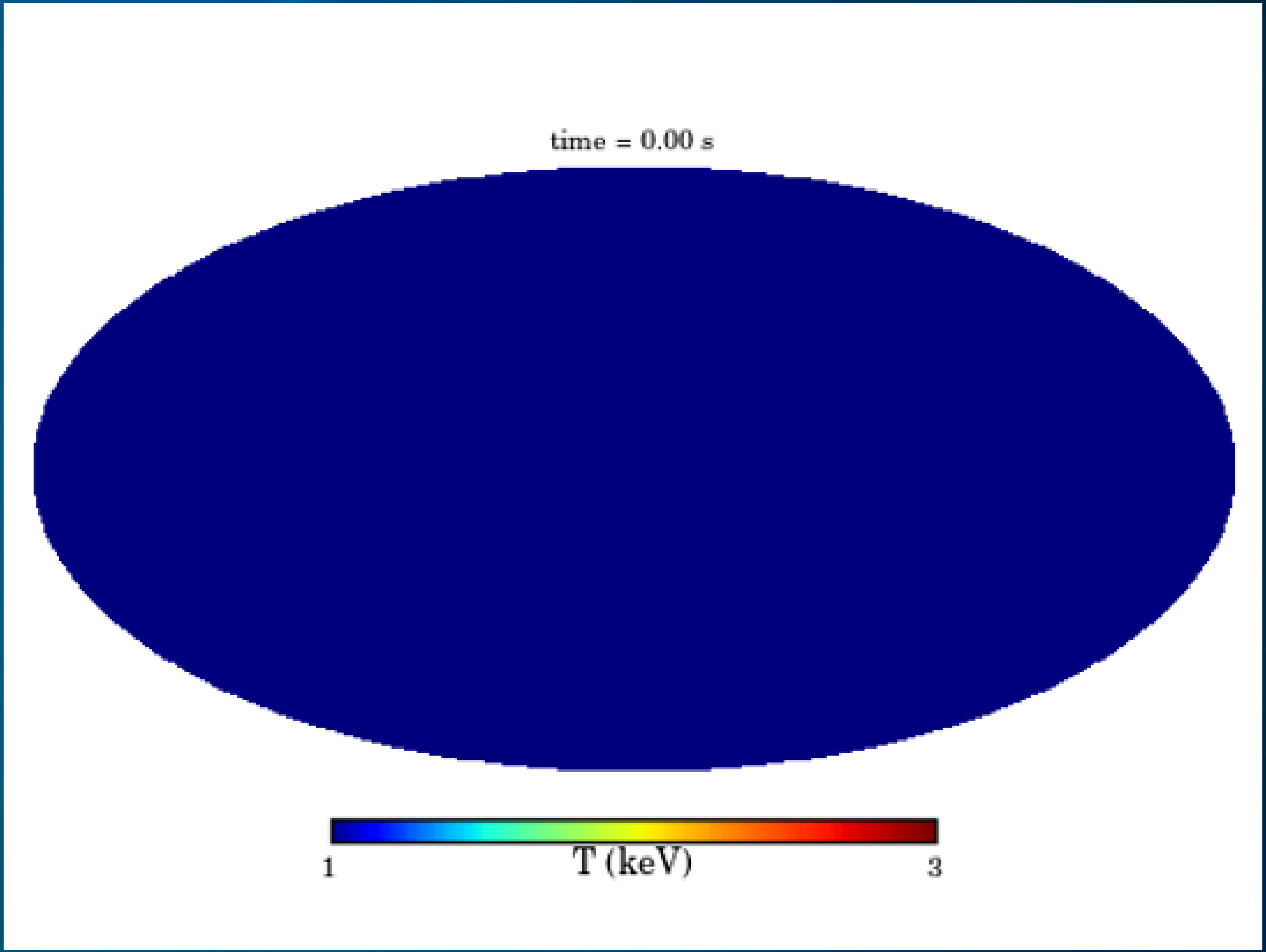
Flux   Polarized flux   Polarization angle

flame spreading

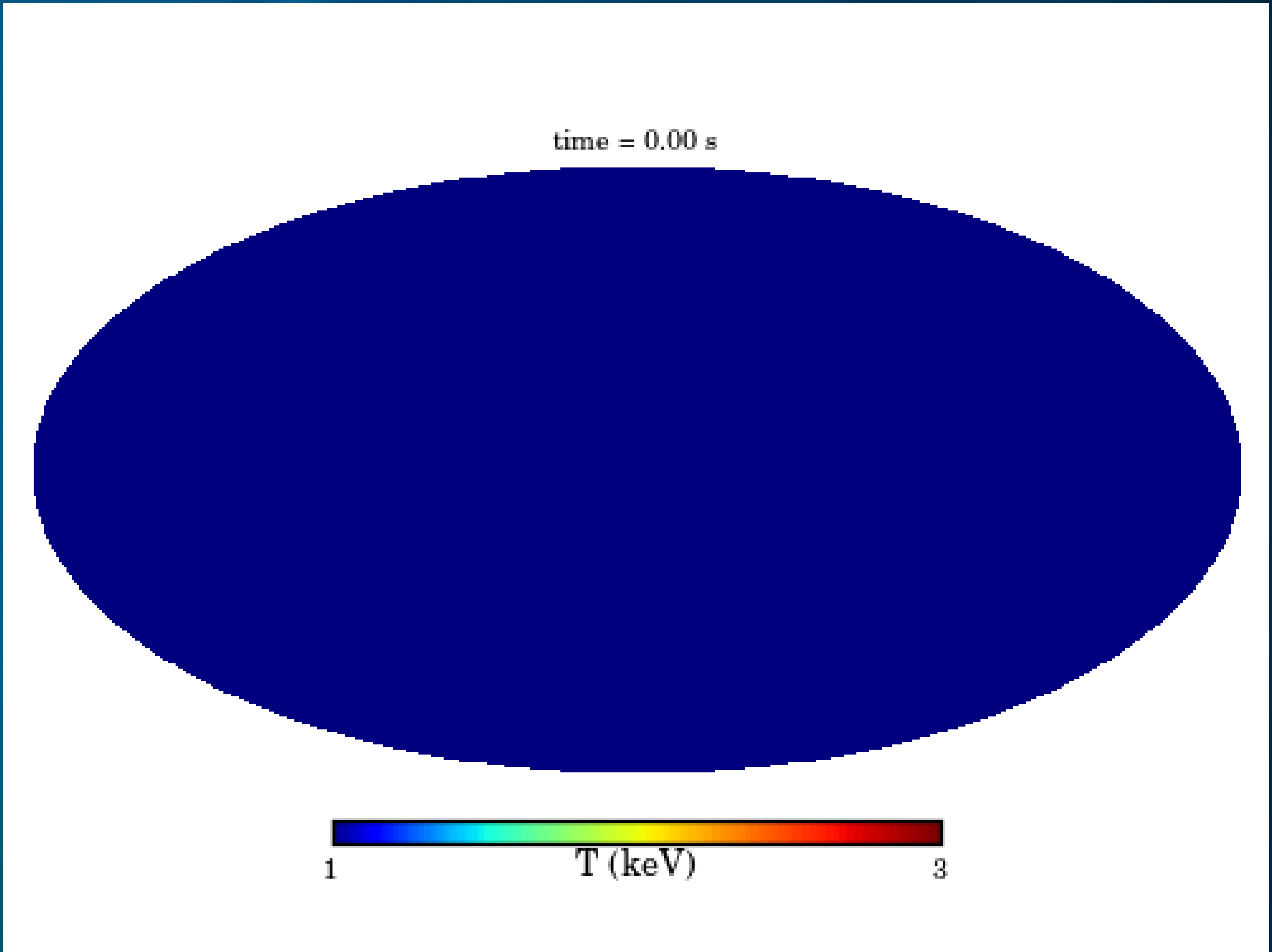


Coriolis force

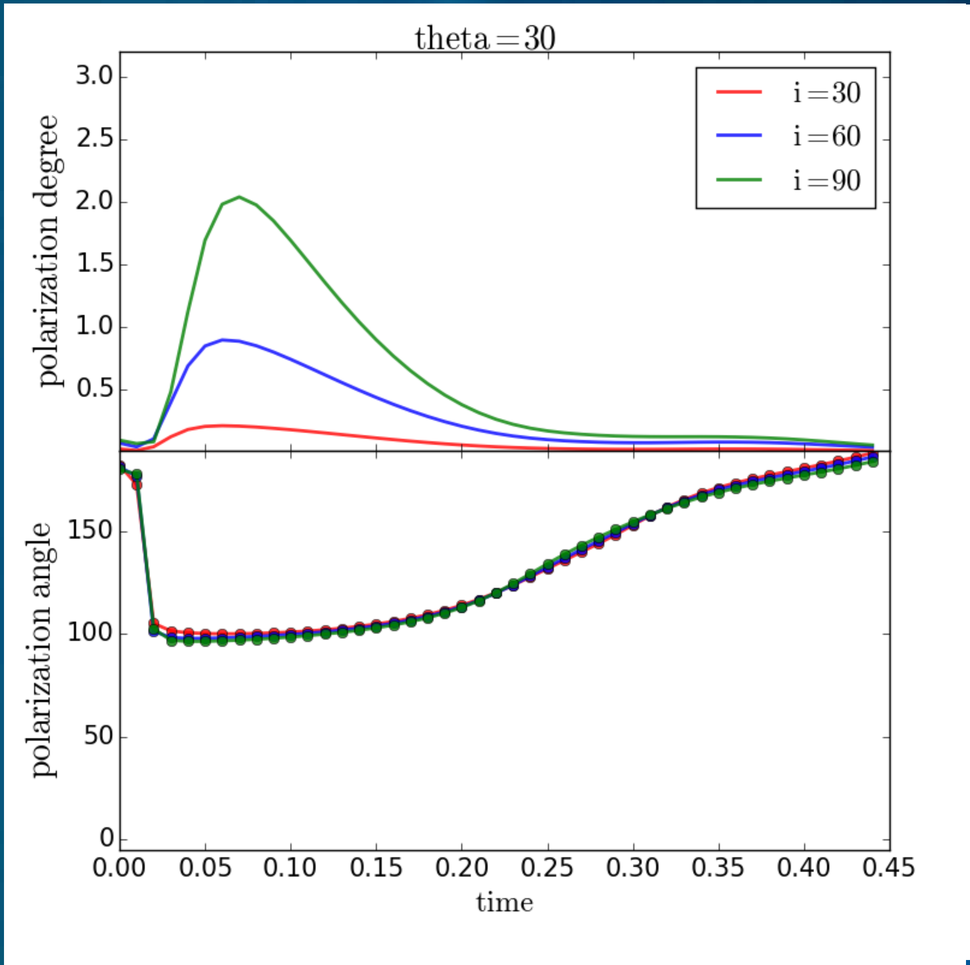
flame spreading



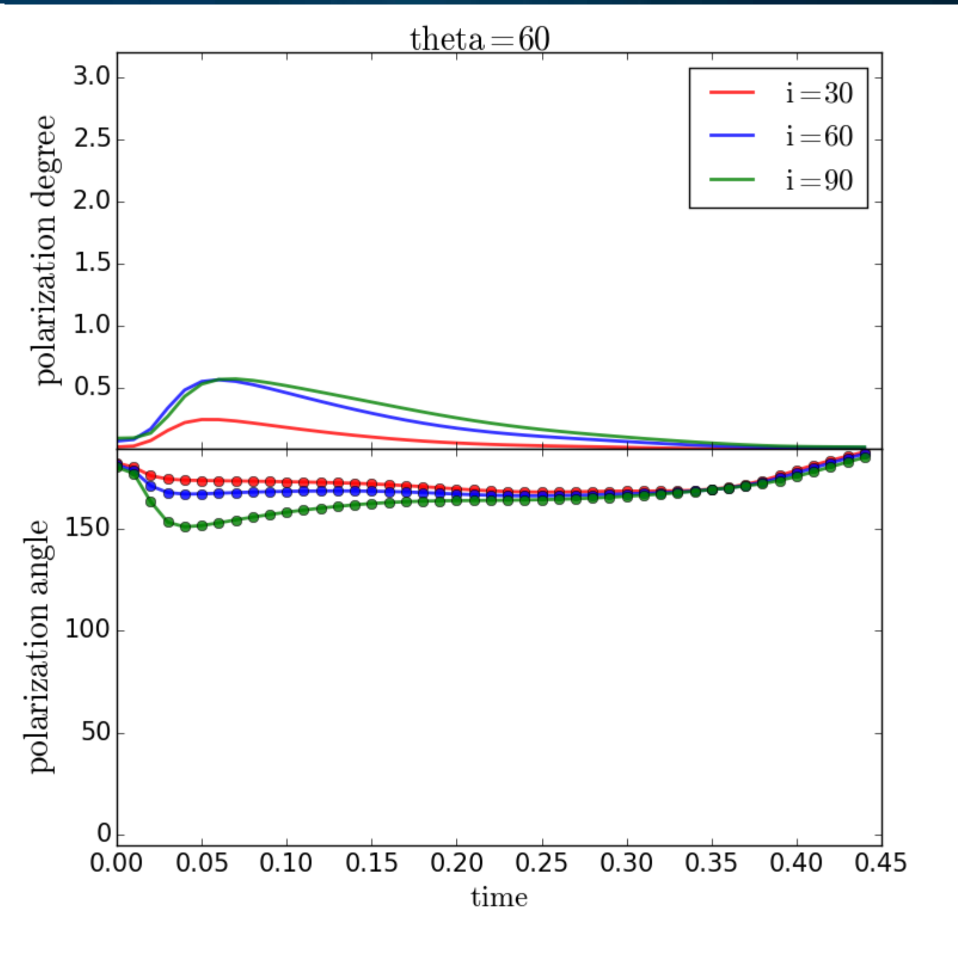
flame spreading



Results:

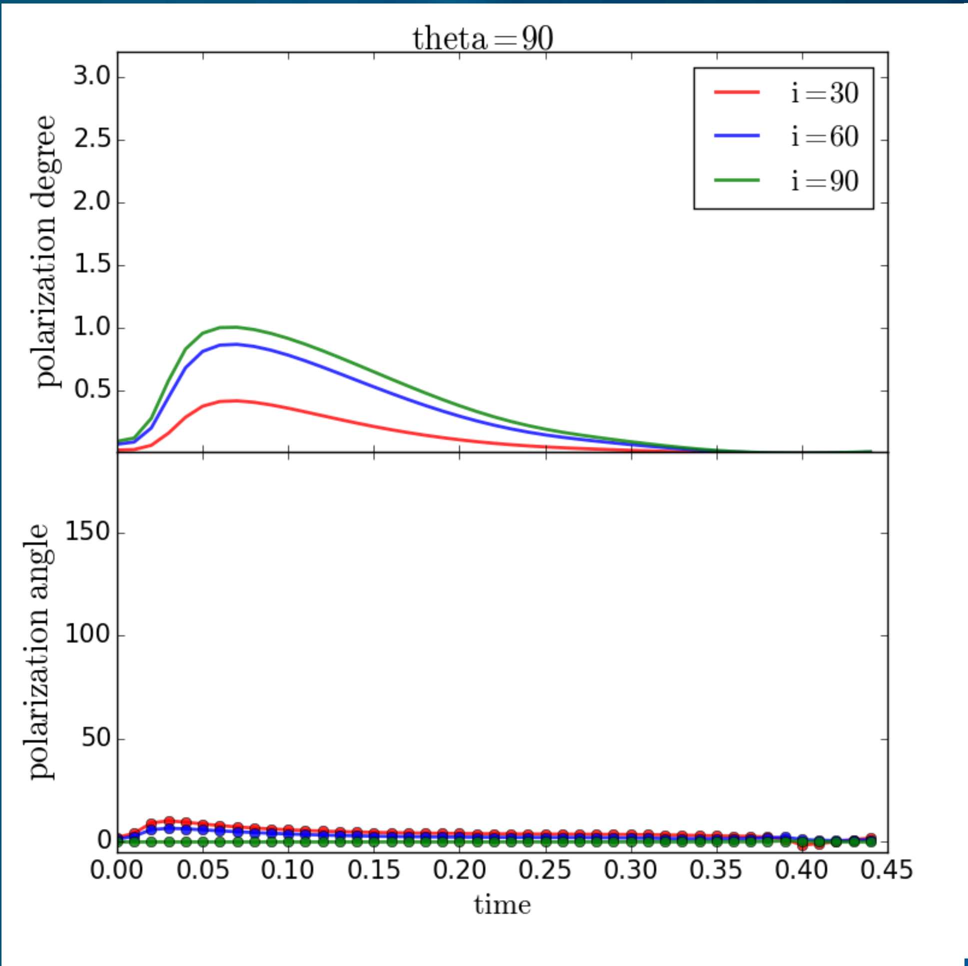


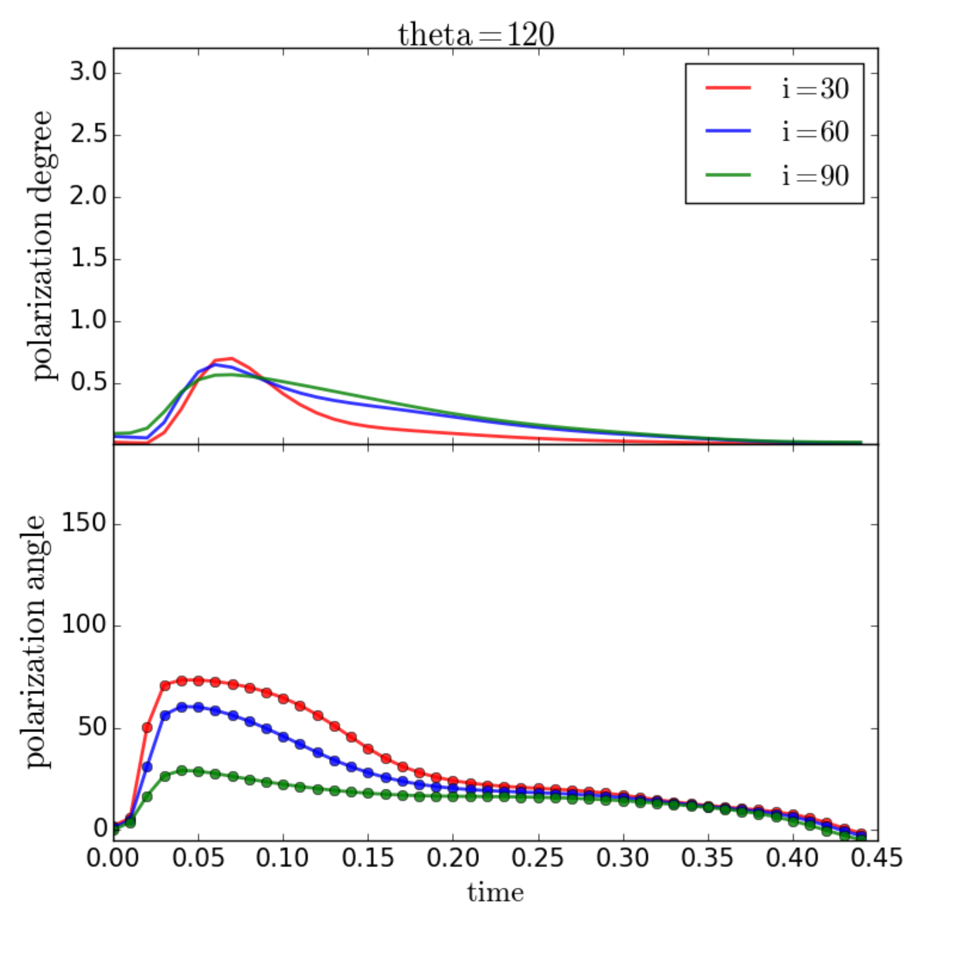
theta = 30
i = 30
i = 60
i = 90
polarization degree
polarization angle
3.0
2.5
2.0
1.5
1.0
0.5
150
100
50
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
time



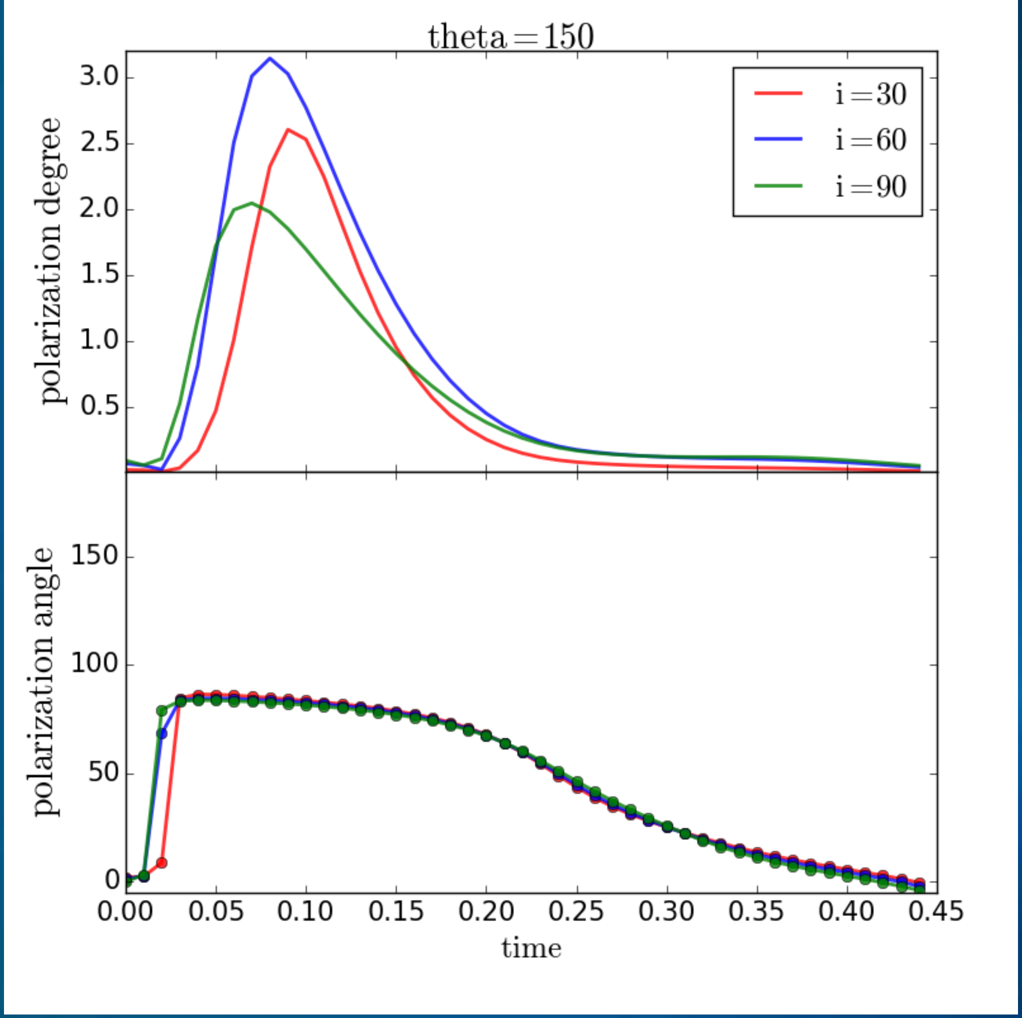
theta = 60
i = 30
i = 60
i = 90
polarization degree
polarization angle
3.0
2.5
2.0
1.5
1.0
0.5
150
100
50
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
time

Results:

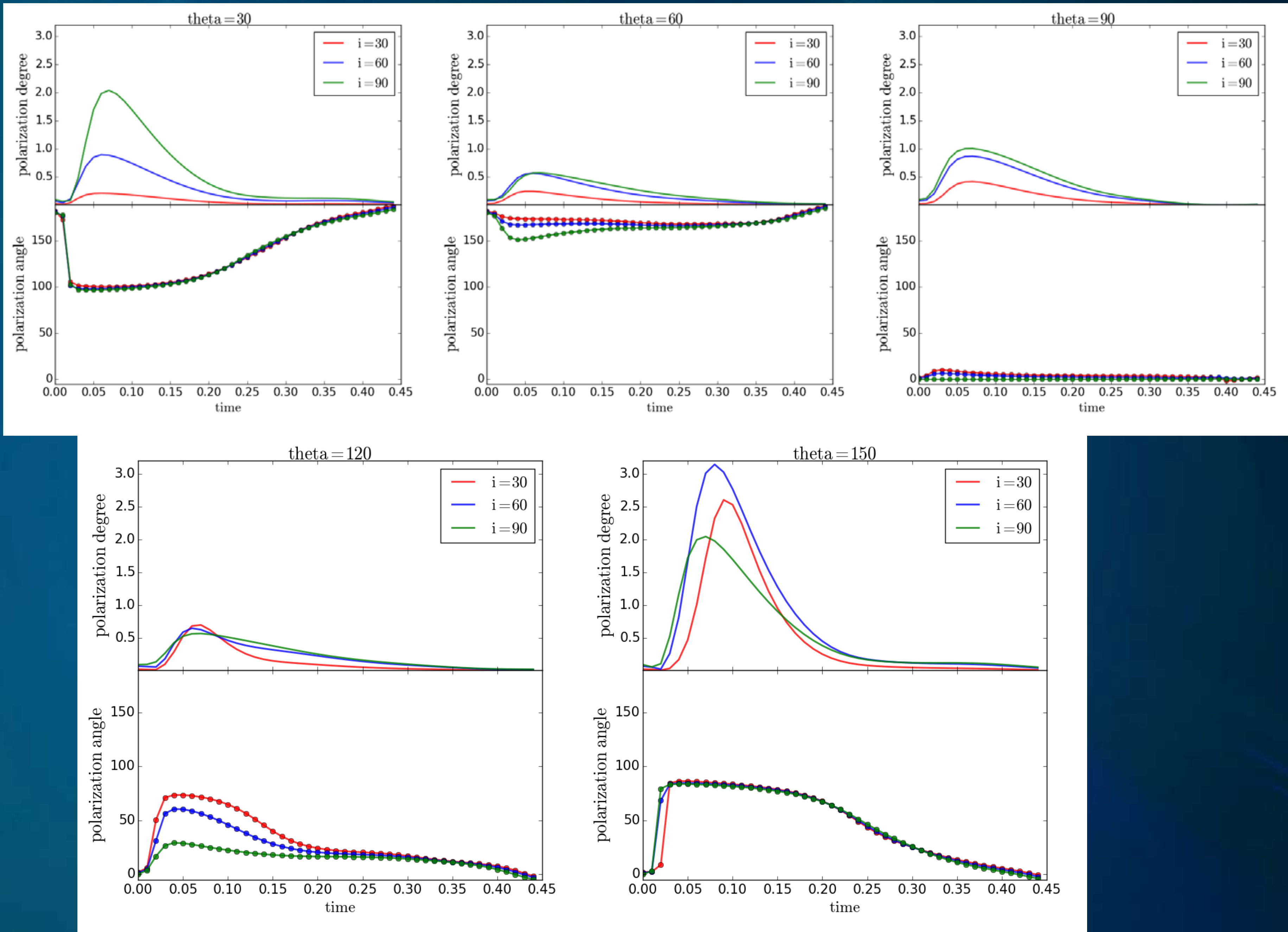

theta = 90
i = 30
i = 60
i = 90
polarization degree
polarization angle
time
3.0
2.5
2.0
1.5
1.0
0.5
150
100
50
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45


theta = 120
i = 30
i = 60
i = 90
polarization degree
polarization angle
time
3.0
2.5
2.0
1.5
1.0
0.5
150
100
50
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

Results:



theta = 150
i = 30
i = 60
i = 90
polarization degree
3.0
2.5
2.0
1.5
1.0
0.5
polarization angle
150
100
50
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
time



theta = 30
theta = 60
theta = 90
theta = 120
theta = 150
i = 30
i = 60
i = 90
polarization degree
polarization angle
time

Summary:

PA	latitude
90°-110°	high latitude (north)
150°-180°	moderate latitude (north)
0°-10°	Equator
20°-70°	moderate latitude (south)
70°-90°	high latitude (south)

Summary:

If PD >2:

$\theta = 30\ or\ 150$ → high latitude

if PD< 0.5:

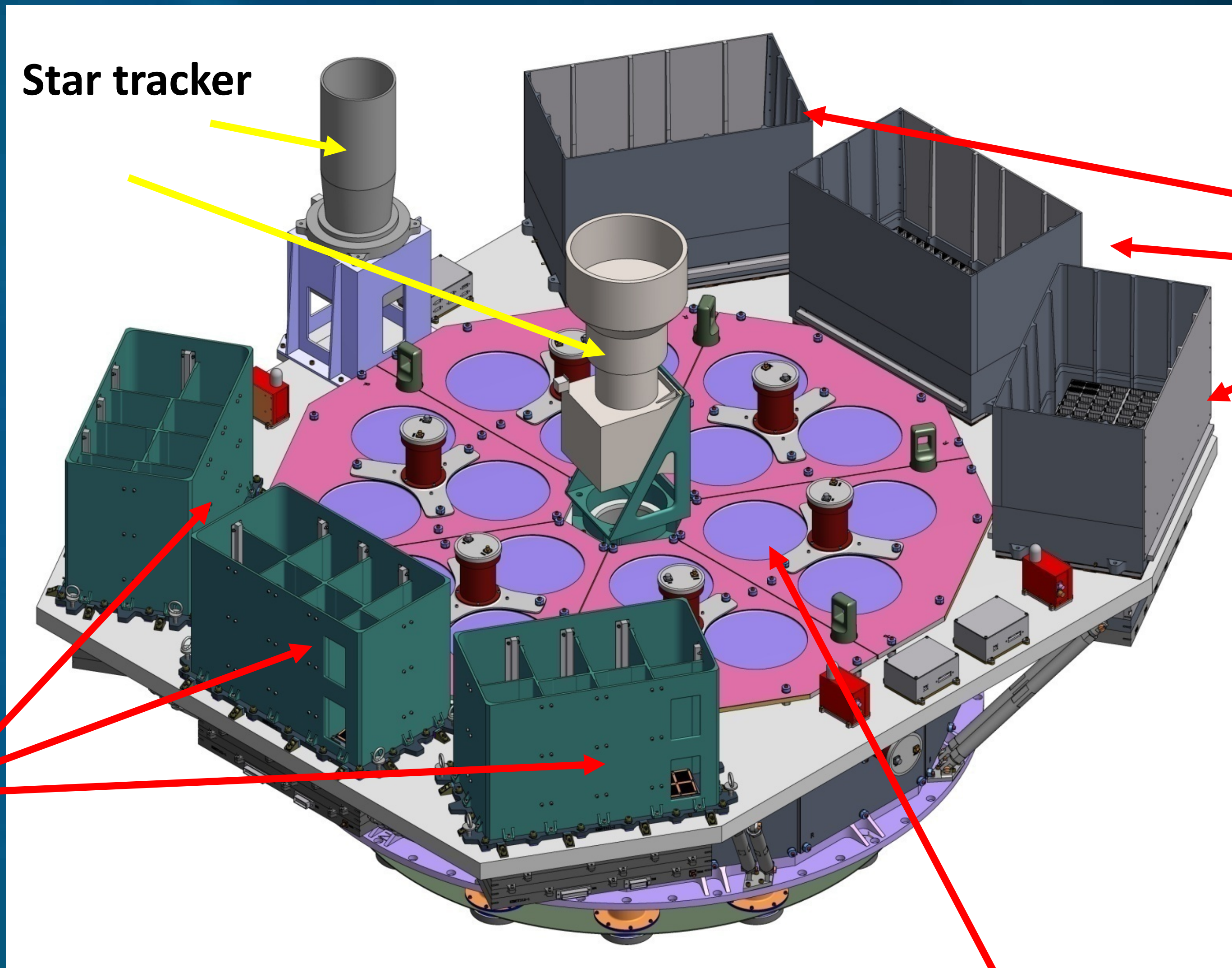
low i angle && north hemisphere

Drawback !

Low polarization degree, which is hard to be detected

HXMT mission

HXMT payloads



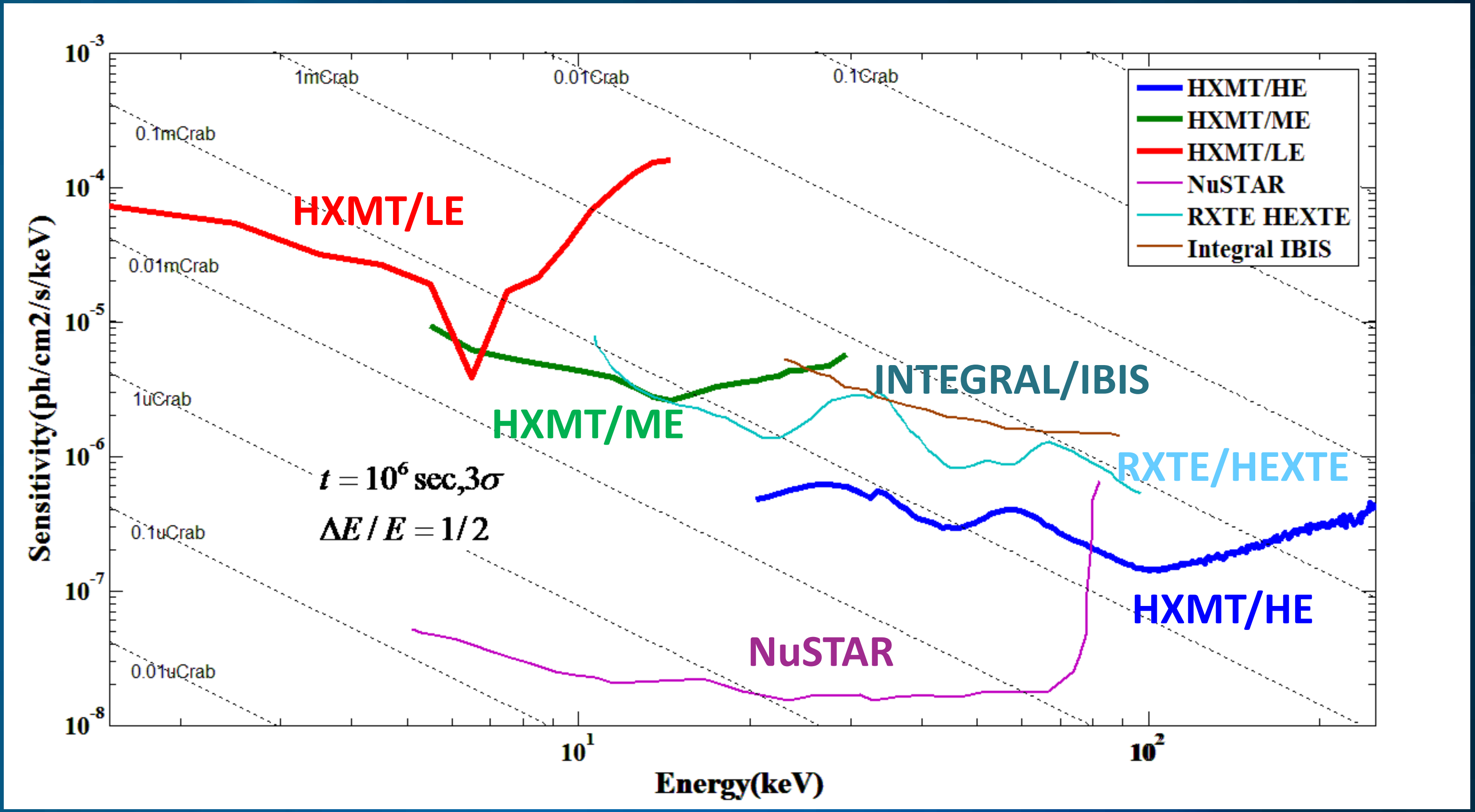
LE:SCD,1-15 keV, 384 cm^2

ME:Si-PIN,5-30 keV, 952 cm^2

Size： 1900×1650×1000 mm

HE: NaI/CsI, 20-250 keV, 5000 cm^2

Sensitivity



The sensitivities of the three telescopes of HXMT. The sensitivities of NuSTAR, INTEGRAL/IBIS and RXTE/HEXTE were reprinted from Koglin et al. (2005)[3].

Comparison between HXMT and other major hard X-ray telescopes

HXMT		RXTE	INTEGRAL/IBIS	SWIFT	NuSTAR
Energy Band (keV)	LE: 0.8-15 ME: 5-30 HE: 15-250	PCA: 2-60 HEXTE: 15-250	15-10000	XRT: 0.5-10 BAT: 10-150	3-79
Detection Area (cm^2)	LE: 384 ME: 950 HE: 5000	PCA: 6000 HEXTE: 1600	2600	XRT: 110 BAT: 5200	847 @ 9 keV 60 @ 78 keV
Energy Resolution (eV)	150@ 6 keV 2500@ 20 keV 10000@60 keV	1200@6keV 10000@60 keV	8000@ 100 keV	150 @ 6 keV 3300 @ 60 keV	900 @ 60 keV
Time Resolution (ms)	LE: 1 ME: 0.18 HE: 0.012	PCA: 0.001 HEXTE: 0.006	0.06	XRT: 0.14, 2.2,2500 BAT: 0.1	0.1
Sensitivity (@100keV, 3σ, 10^5s, mCrab)	0.5	1.5	3.8	9	0.03 @ 20 keV

Sciences with HXMT

Large sky-area scan

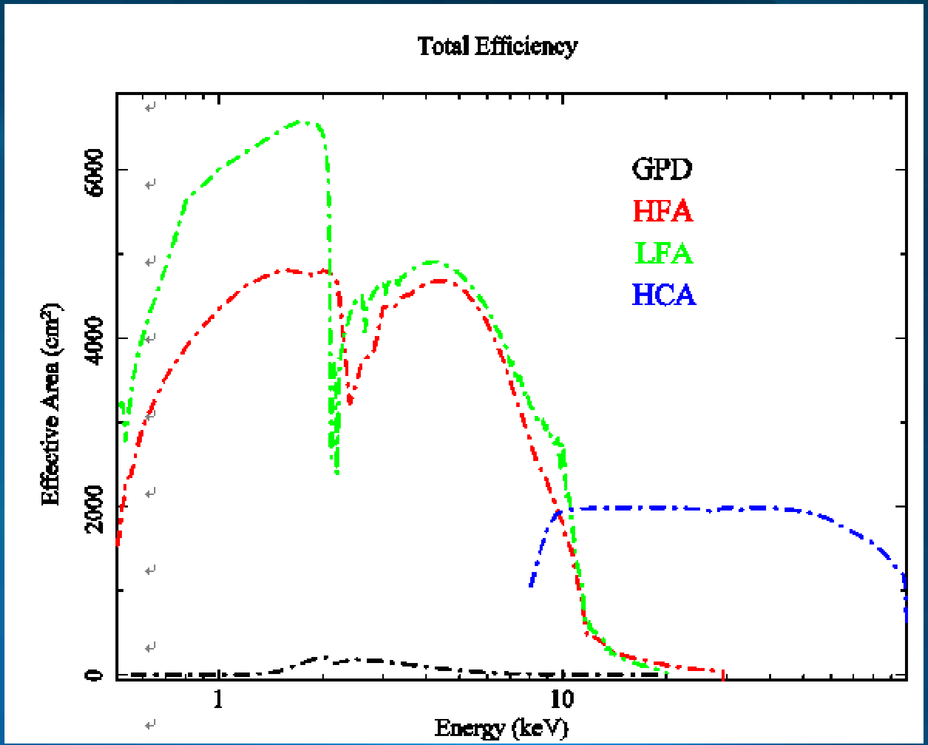
- Diffuse X-ray emission: cosmic X-ray background; X-ray emission from the Galactic ridge and the Galactic center region
- Detection of new (transient) sources and constrain their broad band (1-250 keV) properties
- Follow up observation of gravitational wave bursts

Pointed observations

- X-ray binaries: multiwavelength temporal behaviors, broad band spectra and Fe emission line
- Equation of state in strong magnetic field: AXP, X-ray Bursts
- Monitoring of Blazars and bright AGNs

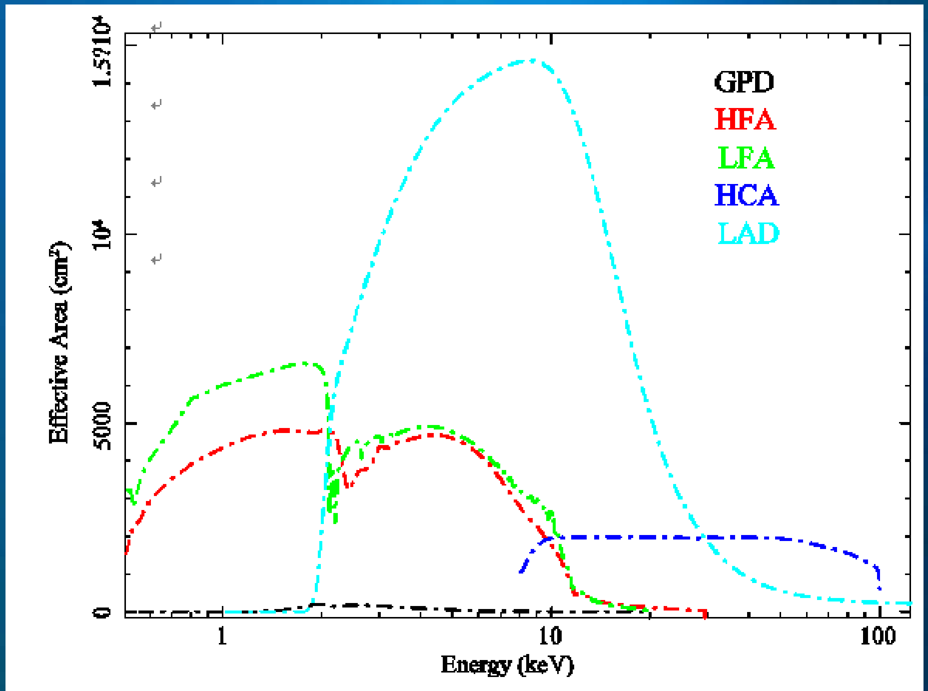
eXTP mission

Detector	Energy range	Area	Energy resolution	FOV
HFA	1~30keV	4000 cm2@2~6keV，300cm2@30 keV	SDD：150 eV@6 keV	16’
LFA	0.5~10 keV	4000 cm2@2~6 keV	150 eV@6 keV	16’
HCA	15-100 keV	CZT：>1000 cm2；LAD：>15000 cm2	≤4 keV@60 keV	1°
PD(Polarization Detector)	2-10 keV	1000cm2@3 keV	1.8 keV@6 keV	12’



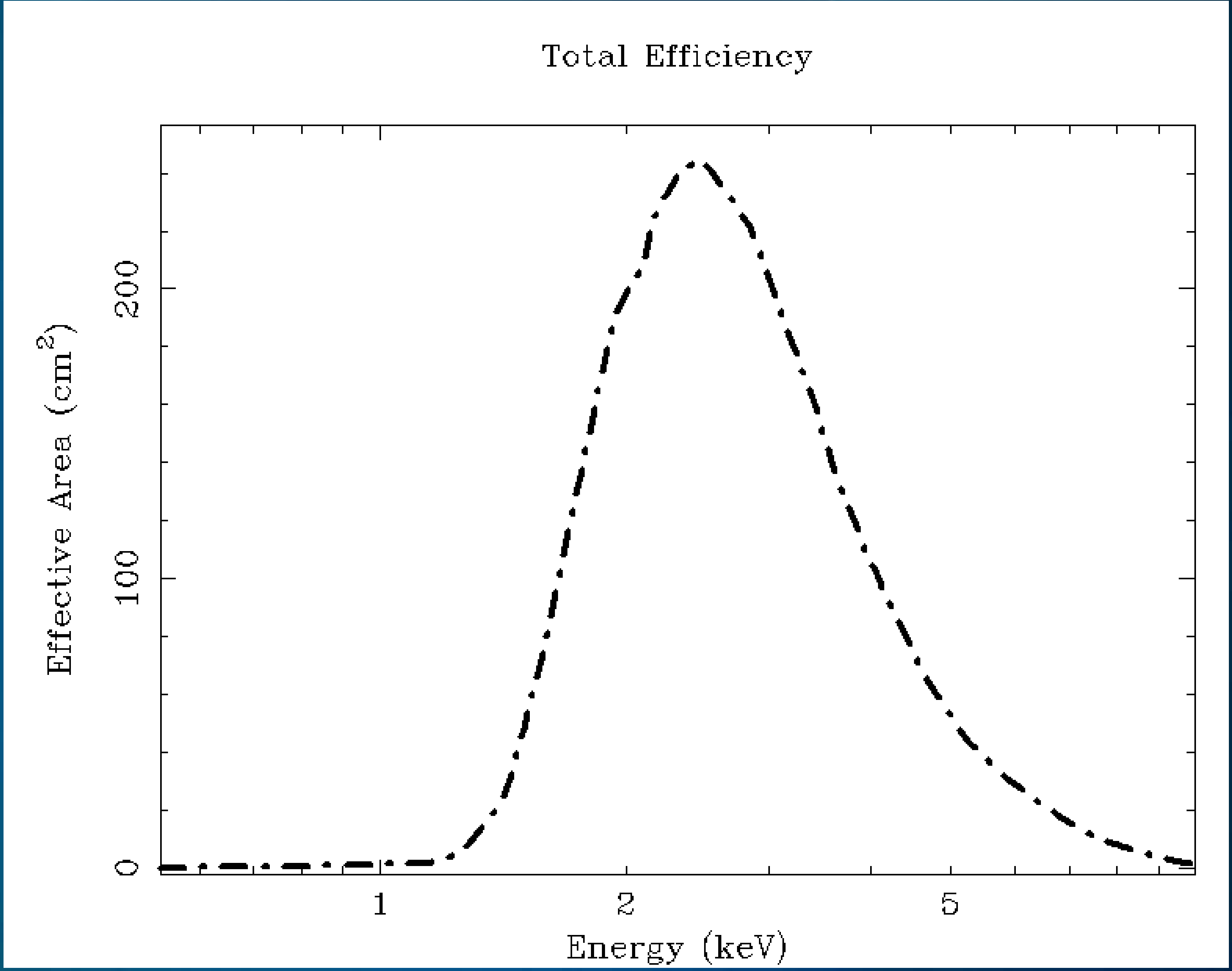
Total Efficiency
GPD
HFA
LFA
HCA
Effective Area (cm^2)
0
2000
4000
6000
1
10
Energy (keV)

XTP



GPD
HFA
LFA
HCA
LAD
Effective Area (cm^2)
0
5000
10^4
1.5?10^4
1
10
100
Energy (keV)

eXTP



Polarization Detector

A simple example：Assuming that PD of crab is 10% with a PA ~ 10

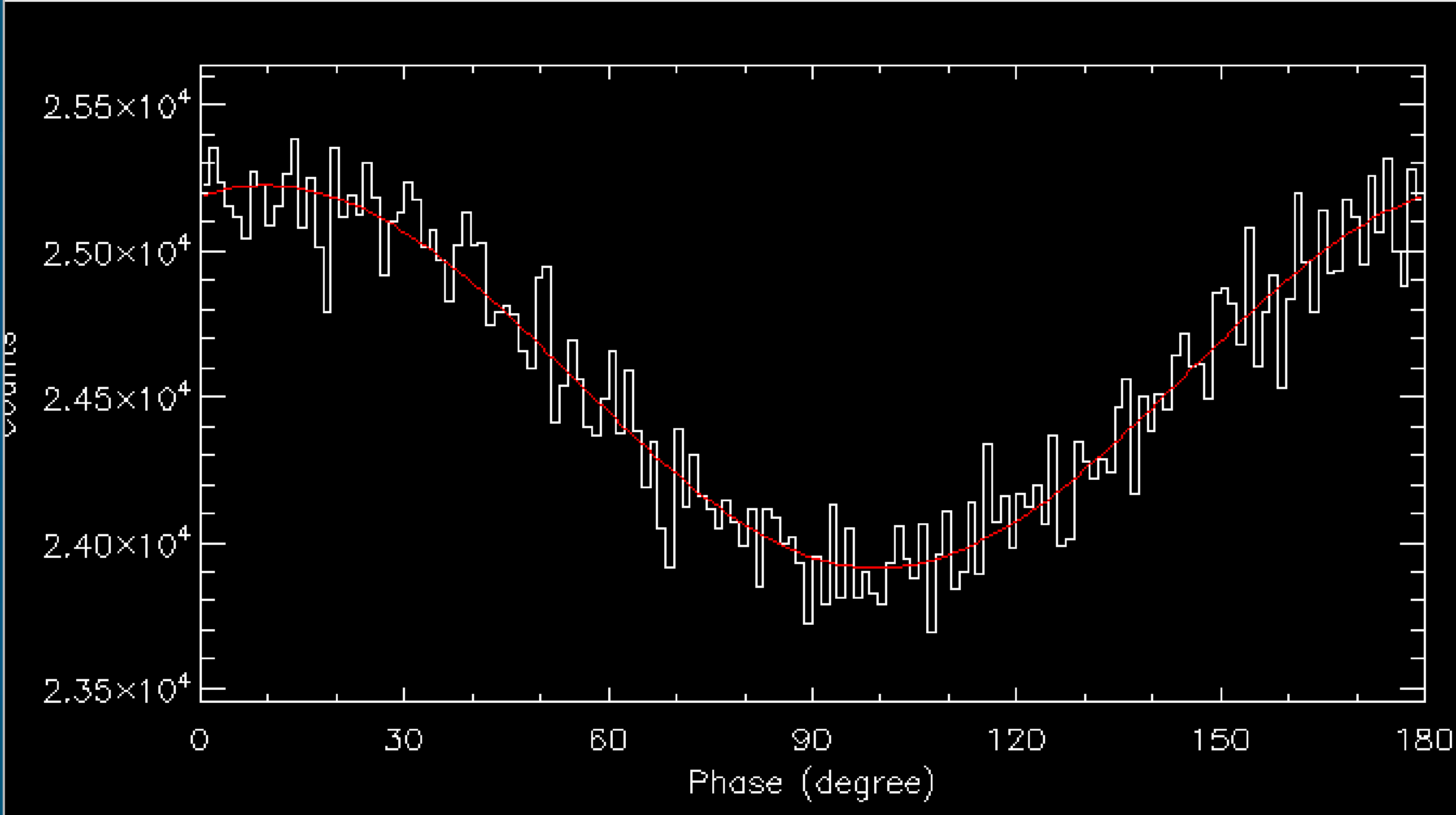
```
========================================================================
Model wabs<1>*powerlaw<2> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   wabs       nH         10^22    0.450000     +/-  5.12254E-04
   2    2   powerlaw   PhoIndex            2.07000      +/-  3.47296E-04
   3    2   powerlaw   norm                8.26000      +/-  3.89294E-03
________________________________________________________________________


Fit statistic : Chi-Squared =          0.0003 using 128 PHA bins.

Test statistic : Chi-Squared =          0.0003 using 128 PHA bins.
 Reduced chi-squared =          2e-06 for    125 degrees of freedom
 Null hypothesis probability =   1.000000e+00
XSPEC12>flux 1 10
 Model Flux    5.2124 photons (2.3883e-08 ergs/cm^2/s) range (1.0000 - 10.000 keV)
```

Detective ability: exposure time: 10^5 s

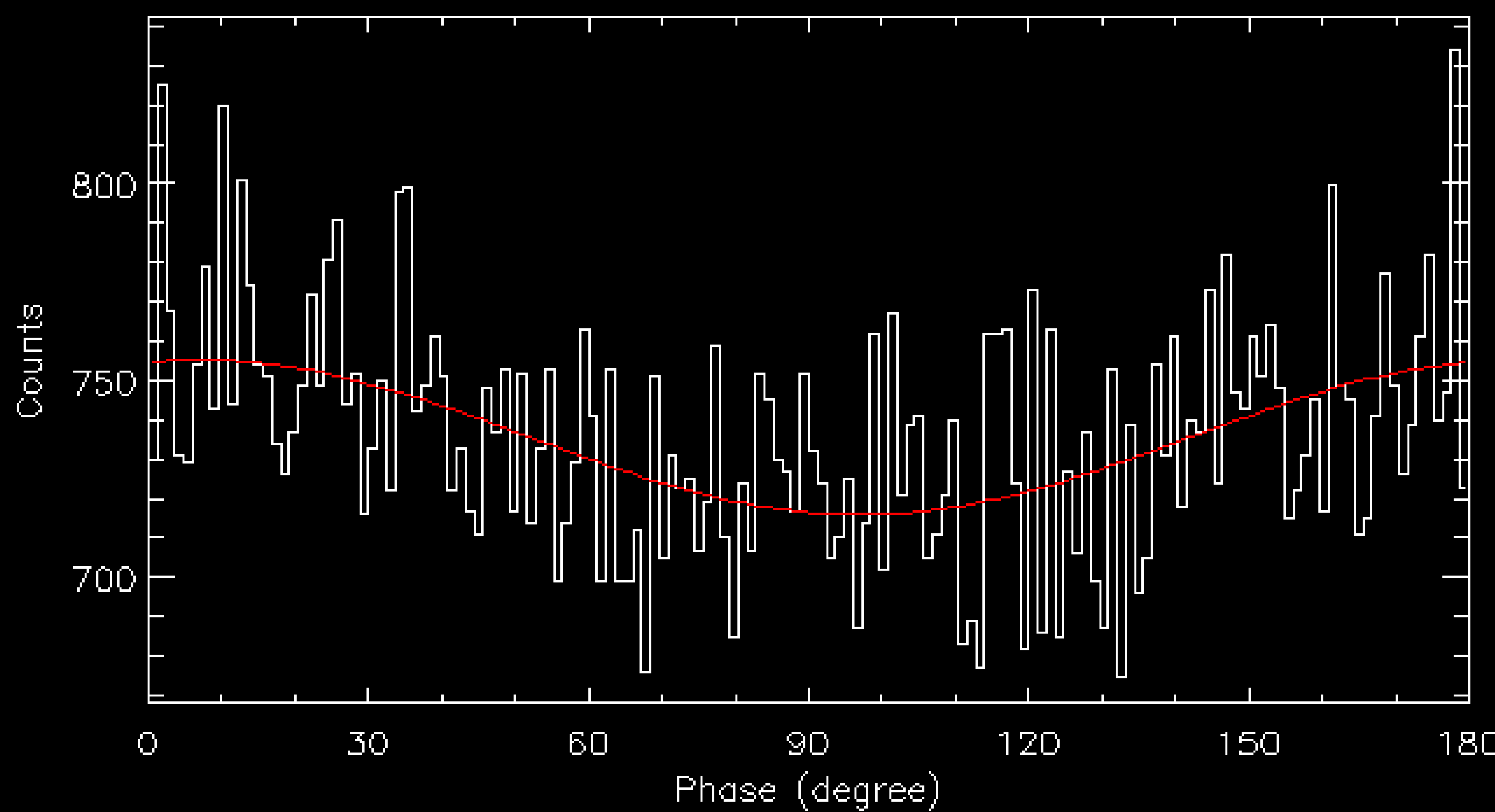
IDL 0




```
Assumed DoP:        0.10
Assumed PA:         10.00
       36.861143    0.0040510000        100000.00       0.27281393      0.100000        0
Success!
Measured DoP:       0.0978 +/- 0.0026
Measured PA:        9.6535 (8.8628, 10.4443)
IDL>
```

Detective ability: exposure time: 3000 s

IDL 0




```
Assumed DoP:          0.10
Assumed PA:           10.00
       36.861143      0.0040510000        3000.0000       0.27281393       0.100000
      0.17453293
Success!
Measured DoP:         0.0980 +/- 0.0152
Measured PA:          7.1001 (2.5285, 11.6666)
IDL>
```

Thank you!