Motivation

Basic Problem

Inner Acceleration Region (IAR)

**Figure:** Breakdown of the polar gap according to Standard Model (Ruderman & Sutherland 1975)

- Surface overheating:
  \[ \gamma \approx 3 \times 10^6 \]
  \[ h \approx 20 \text{ m} \]
  \[ T = 4 \text{ MK} \]

- Observed hot spot area:
  \[ R_{dp} \approx 128 \text{ m} \]
  \[ R_{hs} \approx 30 \text{ m} \]

Data for PSR B0834+06

- Szary et. al (UZ)
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Cohesive Energy of Condensed Matter

Figure: Maxwell-Boltzmann distribution of particles energy. Black vertical line corresponds to cohesive energy of condensed matter for magnetic field $B_s = 10^{14} \text{ G}$

Standard model (RS75) assumes that ions cannot be extracted from stellar surface

If temperature is high enough density of ions is enough to completely screen the gap ($T_s = T_{\text{crit}} \rightarrow \rho_{\text{ions}} = \rho_{\text{GJ}}$)

Surface temperatures below critical temperature may result in partial screening of the gap ($\rho_{\text{ions}} < \rho_{\text{GJ}}$)
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Surface Overheating Problem

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**The Condition for the Formation of the Gap**

![Graph showing the condition for the formation of a vacuum gap above condensed helium, carbon, and iron neutron star surfaces (Medin & Lai 2008)](image)

**Figure:** The condition for the formation of a vacuum gap above condensed helium, carbon, and iron neutron star surfaces (Medin & Lai 2008)
Motivation

Observed Hot Spot Area

Thermal Emission From Isolated Neutron Star

Three blackbody components

\[ T_s = 0.5 - 1\text{MK} \]
\[ T_{ws} = 2\text{MK} \quad R_{ws} = 2\text{km} \]
\[ T_{hs} = 3\text{MK} \quad R_{hs} = 30\text{m} \]

Surface magnetic field

\[ B_s = A_{dp}/A_{hs} \cdot B_d \sim 2 \times 10^{14}\text{G} \]

PSG model explains two BB components

Szary et. al (UZ) Partially Screened Gap

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Motivation

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Thermal Emission From Isolated Neutron Star

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Warm spot area

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Motivation

Observed Hot Spot Area

Non-dipolar Surface Magnetic Field

Figure: Magnetic field lines of NS with crust anchored local anomalies.
**X-ray Observations**

**Figure:** The surface temperature vs. the surface magnetic field. The red line is the critical temperature evaluated from (Medin & Lai 2008).

\[ T_6 = T_s/10^6 \quad \text{and} \quad B_{14} = B_s/10^{14} \]

| Name          | \( T_6 \)  | \( R_{pc} \) | \( B_{14} \)  |
|---------------|------------|-------------|-------------|
| J0108–1431    | \( 3.2^{+0.41}_{-0.32} \) | \( 6^{+4.5}_{-3.7} \) m | \( 3.87^{+24.31}_{-2.64} \) |
| B0943+10      | \( 3.1^{+1.08}_{-1.07} \) | \( 12^{+41.2}_{-7.7} \) m | \( 4.99^{+30.45}_{-4.72} \) |
| B1929+10      | \( 4.5^{+0.30}_{-0.45} \) | \( 28^{+4.9}_{-3.8} \) m | \( 1.26^{+0.44}_{-0.35} \) |
| B1133+16      | \( 3.2^{+0.46}_{-0.35} \) | \( 14^{+10.5}_{-9.0} \) m | \( 4.07^{+31.82}_{-2.78} \) |
| B0950+08      | \( 2.3^{+0.29}_{-0.29} \) | \( 42^{+26.6}_{-26.6} \) m | \( 0.23^{+1.57}_{-0.15} \) |
| B2224+65      | \( 5.8^{+1.16}_{-1.16} \) | \( 28^{+5.6}_{-18.0} \) m | \( 2.00^{+13.31}_{-0.61} \) |
| J0633+1746    | \( 1.7^{+0.23}_{-0.23} \) | \( 62^{+34.0}_{-34.0} \) m | \( 0.75^{+2.92}_{-0.44} \) |
| B0834+06      | \( 2.0^{+0.75}_{-0.64} \) | \( 30^{+56.4}_{-15.3} \) m | \( 1.05^{+3.19}_{-0.92} \) |
| B0355+54      | \( 3.0^{+1.51}_{-1.06} \) | \( 92^{+122.5}_{-53.6} \) m | \( 0.27^{+1.27}_{-0.22} \) |
| B0628–28      | \( 3.3^{+1.31}_{-0.62} \) | \( 59^{+65.5}_{-46.4} \) m | \( 0.29^{+5.61}_{-0.22} \) |
Our Results

The Model

Partially Screened Gap

Shielding factor

\[ \eta = 1 - \frac{\rho_{\text{ion}}}{\rho_{GJ}} \]

Heating condition

\[ \sigma T_s^4 = \eta e \Delta V_{cnGJ} \]

Acceleration potential drop

\[ \Delta V = \frac{4\pi \eta B_r}{P_c} \cos \alpha h_{\perp}^2 \]
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The Partially Screened Gap Parameters

\[ B_s(T_s), \mathcal{K}_6, P, h_{\perp} \rightarrow \sim h, \eta \leftarrow l_e, l_{\text{acc}}, l_{\text{ph}} \]
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**Graphs**

- **Graph 1**: Dependent variable \( h \) vs. \( B_{14} \) for different \( B_{14} \) values, with two lines representing ICS and CR.
- **Graph 2**: Dependent variable \( \eta \) vs. \( B_{14} \) for different \( B_{14} \) values, with two lines representing ICS and CR.
- **Graph 3**: Dependent variable \( \gamma \) vs. \( B_{14} \) for different \( B_{14} \) values, with two lines representing ICS and CR.
- **Graph 4**: Dependent variable \( h \) vs. \( K_6 \) for different \( K_6 \) values, with two lines representing ICS and CR.

**References**

Szary et. al (UZ)
Drifting Sub-pulse Phenomenon

Figure: Schematic view of the drifting sub-pulse phenomenon showing the periodicities $P_2$ and $P_3$ [Lorimer et al. (2004)].

\[ v_\perp = c \frac{E \times B}{B^2} \]

The existence of IAR in general causes rotation of plasma relative to the NS (drift).

The power spectrum of Radio emission must have a feature due to this plasma rotation.

\[ v_{dr} = \frac{2\pi R_{pc}}{P} \left( \frac{1}{P_3} \frac{P_2^\circ}{360^\circ} \right) \]
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Drift Model

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Our model assumes the existence of plasma columns (sparks) moving (drifting) relative to the NS

Circulation of the electric field

\[ \oint Edl = E_\perp h_\perp + \int_b^c E_\parallel dz + \int_b^c E_\parallel dz = E_\perp h_\perp - V_{cb} = 0 \]

(van Leeuwen & Timokhin 2012)

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Figure: Drifting sparks (sub-pulses). All calculations performed in corotating frame of reference \((E_\perp = 0\) just below the stellar surface).
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Assuming that the spark width and distance between sparks are of the same order ($h_\perp$)

\[
\frac{P_2^\circ}{360^\circ} \approx \frac{2h_\perp}{2\pi R_{pc}}
\]  

**Figure:** Cartoon of spark distribution on polar cap. Spark forms when temperature is slightly below critical temperature.

**Shielding factor**

\[
\eta = \frac{1}{P_3} \frac{1}{2\pi \cos \alpha}
\]

**Heating efficiency**

\[
\xi = \frac{L_{\text{heat}}}{L_{sd}} = 0.74578 \left( \frac{1}{P_3} \frac{P_2^\circ}{360^\circ} \right)^2
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## Our Results

### Drift Observations

| Name          | $P_2^\circ$ (deg) | $P_3$ (P) | $\eta$ | $\xi$ (radio) | $\xi_{bol}$ (x-ray) | $R_{hs}$ (m) | $h_\perp$ (m) |
|---------------|------------------|-----------|--------|---------------|-------------------|--------------|--------------|
| B0950+08      | –                | 6.5       | 0.092  | –             | $1.5 \times 10^{-4}$ | 42           | –            |
| B0943+10      | 18               | 1.8       | 0.088  | $5.5 \times 10^{-4}$ | $2.4 \times 10^{-4}$ | 12           | 1.9          |
| B0834+06      | 20               | 2.2       | 0.148  | $4.8 \times 10^{-4}$ | $3.9 \times 10^{-4}$ | 30           | 5.3          |
| B0628–28      | 30               | 7.0       | 0.023  | $1.1 \times 10^{-4}$ | $1.0 \times 10^{-2}$ | 59           | 15.6         |
| B1929+10      | 90               | 9.8       | 0.020  | $4.9 \times 10^{-4}$ | $2.9 \times 10^{-4}$ | 28           | 21.6         |
| B1133+16      | 130              | 3.0       | 0.085  | $1.1 \times 10^{-2}$ | $4.2 \times 10^{-4}$ | 14           | 15.4         |

**Table:** For both B1929+10 and B1133+16 derived period $P_2^\circ$ is not the actual spacing between sub-pulses (its value is greater than pulse width). Large uncertainty in determination of hot spot radius for B0628–28 affects the observed X-ray efficiency.
Our Results

PSR B0834+06 (Inverse Compton Scattering)

**Figure:** Non-dipolar structure of magnetic field for PSR B0834+06. Green dashed lines show dipolar open lines, while red lines correspond to actual open magnetic field lines. ($\Re_e = 0.5$)

| Parameter | Value |
|-----------|-------|
| $T_s$     | $2.5 \times 10^6$ K |
| $B_s$     | $1.6 \times 10^{14}$ G |
| $b = \frac{B_s}{B_d}$ | 30 |
| $\eta$   | 0.14 |
| $\xi$    | $2 \times 10^{-4}$ |
| $h$      | 52 m |
| $h_\perp$ | 3 m |
| $R_{pc}$ | 25 m |
| $l_{ph}$ | 5 m |
| $l_e$    | 0.5 m |
Our Results

Coherent Curvature Radiation (PSR B0834+06)

Primary particles

\[ \gamma_{pr} = 1000 - 4000 \quad (l_e = 0.5\ m) \]

Secondary particles

\[ \gamma_{sec} = 300 - 1000 \]

Secondary plasma number density

\[ n_{sec} = \eta n_{GJ} M \quad M \approx 10^5 \quad (\text{for } N_{ph} \approx 15) \]
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- PSG model predicts gap dominated by Inverse Compton Scattering

- ICS dominated gap produces secondary particles suitable for generation of coherent Radio Emission
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