ACCRETING ISOLATED NEUTRON STARS

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- **"Missing" Accreting Isolated Neutron Stars**

- **Does this challenge the Theory of Accretion ?**

- **No! There is no Problem.**

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The Problem

● Mass Capture Rate	$\dot{\mathfrak{M}}_{\mathrm{c}} \sim 10^{12}\,\mathrm{g/s}$	$N_{\mathrm{ISM}}\, V_6^{-3}\, M_{1.4}^{2}$
● Luminosity	$L_{\mathrm{a}} \sim 10^{32}\,\mathrm{erg/s}$	$N_{\mathrm{ISM}}\, V_6^{-3}\, M_{1.4}^{3}\, R_6^{-1}$
● Energy Range	$\epsilon_\gamma \sim 0.5\,\mathrm{keV}$	$L_{32}^{1/4}\, S_9^{-1/4}$

Predictions:

★ Treves & Colpi (1991, A&A, 241, 107)	$\sim 5 \times 10^3$	(ROSAT, All Sky Survey)
★ Blaes & Madau (1993, ApJ, 403, 690)	$\sim 10^3 - 10^4$	(ROSAT, All Sky Survey)
★ Popov et al. (2000, ApJ, 544, L53)	$\sim 3 \times 10^4$	Chandra & XMM-*Newton*

Observations:

ROSAT, All Sky Survey   a few candidates...

- **An accretion onto the surface of a NS can occur if**

$$\boxed{r_{\rm m} = \left(\frac{\mu^2}{\dot{\mathfrak{M}}_{\rm c}\,\sqrt{2GM}} \right)^{2/7} \quad \lesssim \quad r_{\rm cor} = \left(\frac{GM}{\Omega^2} \right)^{1/3}}$$

$$P_{\rm s} \;\gtrsim\; P_0 \simeq \underline{7000\ {\rm s}}\;\; \mu_{30}^{6/7}\; V_7^{9/7}\; N^{-3/7}\; M_{1.4}^{-11/7}$$

- **The spin-down time scale of a NS is**

$$\tau(P_0) = \tau_{\rm md} + \tau_{\rm p} \sim \;\underline{5 \times 10^9\ {\rm yr}}\;\; \mu_{30}^{-1}\; V_7\; N^{-1/2}\; I_{45}\; M_{1.4}^{-1}$$

$\tau(P_0) \lesssim 10^{10}$ **yr** $\Rightarrow$ **NS is strongly magnetized** $(r_{\rm m} \gg r_{\rm ns})$ **!!!**

Geometry of the Accretion Flow

- Disk Accretion **(in a turbulent ISM)**:

$$V_{\rm rel} \lesssim \underline{10^6 \ {\rm cm/s}} \times \xi^{21/68} \ \mu_{30}^{-3/34} \ N^{3/68} \ M_{1.4}^{25/68} \left(\frac{V_{\rm t}}{10^6 \, {\rm cm/s}}\right)^{21/68} \left(\frac{R_{\rm t}}{10^{20} \, {\rm cm}}\right)^{-7/68}$$

- Spherical (Bondi) Accretion **(Direct Accretion Approximation** $\dot{\mathfrak{M}}_{\rm c} \equiv \dot{\mathfrak{M}}_{\rm a}$**)**:

$$V_{\rm rel} < \underline{300 \ {\rm km/s}} \times N^{1/3} \, R_6^{-1/3} \, M_{1.4} \left(\frac{L_{\rm X}}{10^{28} \, {\rm erg/s}}\right)^{-1/3}$$

- Kick velocity: $V_{\rm rel} \gtrsim \underline{5 \times 10^6 \ \ {\rm cm/s}}$

Basic Conditions (normalization of parameters)

- ★ Strong magnetic field: $\mu \simeq \underline{10^{30}\,\mathrm{G\,cm}^3}$

- ★ Relative velocity: $50\,\mathrm{km/s} \lesssim V_{\mathrm{rel}} \lesssim 300\,\mathrm{km/s}$

- ★ Spherical (Bondi) Accretion: $\dot{\mathfrak{M}}_{\mathrm{c}} \sim \underline{10^9\,\mathrm{g/s}}\ \ N\ \ V_7^{-3}\ \ M_{1.4}^2$

ESTIMATED NUMBER OF OBJECTS WITHIN 140 pc $\sim$ $\mathbf{10^4}$

Flow Parameters at the magnetospheric boundary

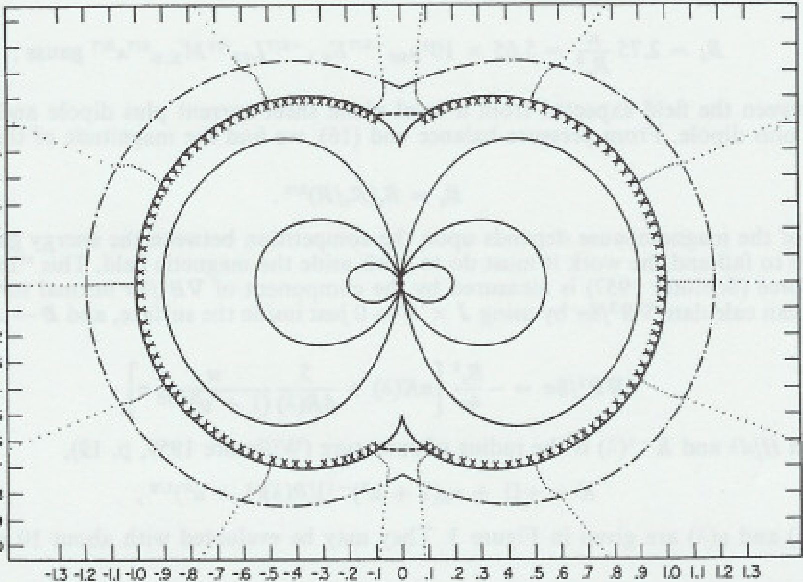
★ Magnetosperic Radius: $r_{\mathrm{m}} \simeq 6 \times 10^{10}\,\mathrm{cm} \quad \mu_{30}^{4/7}\ \dot{\mathfrak{M}}_9^{-2/7}\ M_{1.4}^{-1/7}$

★ Free-fall temperature: $T_{\mathrm{ff}} \simeq 10^{7}\,\mathrm{K} \quad M_{1.4} \left(\frac{r_{\mathrm{m}}}{6 \times 10^{10}\,\mathrm{cm}}\right)^{-1}$

★ Plasma density: $N(r_{\mathrm{m}}) \simeq 300\,\mathrm{cm}^{-3} \quad \mu_{30}^{2}\ T_7^{-1} \left(\frac{r_{\mathrm{m}}}{6 \times 10^{10}\,\mathrm{cm}}\right)^{-6}$

★ Free-fall time scale: $t_{\mathrm{ff}} \simeq 740\,\mathrm{s} \quad M_{1.4}^{-1/2} \left(\frac{r_{\mathrm{m}}}{6 \times 10^{10}\,\mathrm{cm}}\right)^{3/2}$

★ Bremsstrahlung cooling time: $t_{\mathrm{br}} \sim 10^{5}\,\mathrm{yr} \quad T_7^{1/2} \left(\frac{N(r_{\mathrm{m}})}{300\ \mathrm{cm}^{-3}}\right)^{-1}$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PLASMA ENTRY INTO THE MAGNETOSPHERE (I)

Interchange instabilities

(Arons & Lea 1976, ApJ, 207, 914; Elsner & Lamb 1976, Nature, 262, 356)

$$g_{\mathrm{eff}} = \frac{GM_{\mathrm{ns}}}{r_{\mathrm{m}}^2(\lambda)} - \frac{V_{\mathrm{T_i}}^2(r_{\mathrm{m}})}{R_{\mathrm{cur}}(\lambda)} > 0, \quad \longleftrightarrow \quad T(r_{\mathrm{m}}) < 0.3T_{\mathrm{ff}}(r_{\mathrm{m}})$$

A Transient X-ray Source

Recurrent time: $\sim 10^5$ yr

Outburst duration: ~ 15 min.

Luminosity $\sim 10^{29}$ erg/s

(Lamb, Fabian, Pringle, & Lamb 1977, ApJ, 217, 197)

PLASMA ENTRY INTO THE MAGNETOSPHERE (II)

Diffusion

★ Entry Rate:

$$\dot{M}_{\rm in} \simeq \dot{M}_{\rm B} = 2 \times 10^{6}\,{\rm g\,s^{-1}} \quad \alpha_{0.1}^{1/2}\,\mu_{30}^{-1/14}\,M_{1.4}^{11/7}\,N^{11/14}\,V_{7}^{-33/14}$$

★ Persistent Luminosity:

$$L_{\rm a} \simeq \underline{2 \times 10^{26}\,{\rm erg\,s^{-1}}} \quad \alpha_{0.1}^{1/2}\,\mu_{30}^{-1/14}\,N^{11/14}\,V_{7}^{-33/14}\,M_{1.4}^{19/7}\,r_{6}^{-1}$$

The Evolutionary Track of a Neutron Star contains TWO states of *Propeller*

(Davies, Fabian, & Pringle 1979, MNRAS, 186, 779)

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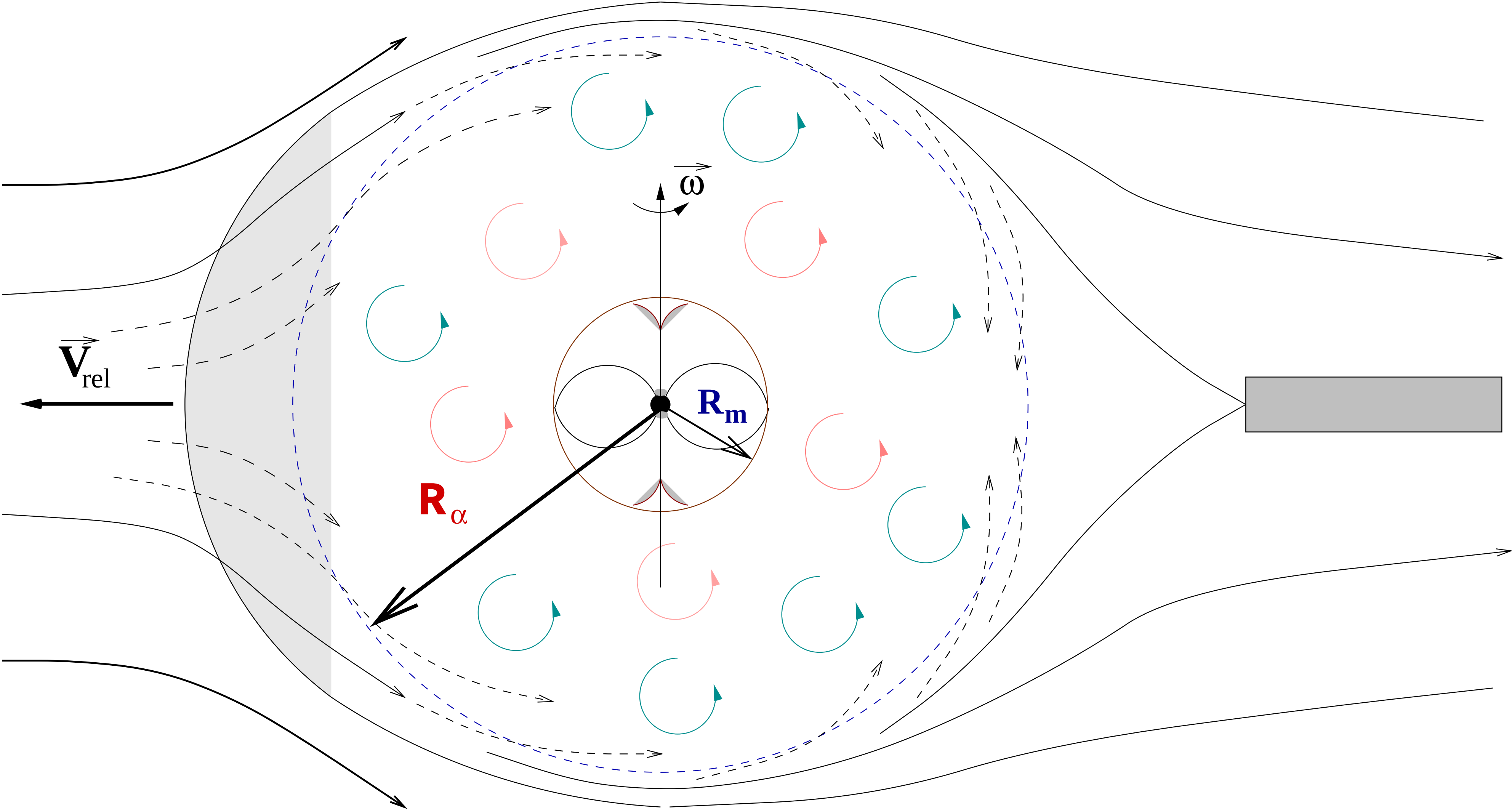
I. EJECTOR (spin-powered pulsar) ⟹

II★. SUPERSONIC PROPELLER ⟹

III★★. *SUBSONIC* **PROPELLER** ⟹

IV. ACCRETOR (direct accretion: $\dot{\mathfrak{M}}_{\rm c} \equiv \dot{\mathfrak{M}}_{\rm a}$)


$\vec{V}_{rel}$
$\vec{\omega}$
R_m
R_α

Subsonic Propeller $\equiv$ Diffusion-driven Accretor

★ Spin-down heating: $P_{\rm s} \lesssim P_{\rm br} \simeq 10^5\ {\rm s} \quad \mu_{30}^{16/21}\, N^{-5/7} V_7^{15/7}\, M_{1.4}^{-34/21}$

$$\tau_{\rm br} \sim 2 \times 10^5\ {\rm yr} \quad \mu_{30}^{-2}\, I_{45}\, P_5\, M_{1.4}$$

★ Heating by Radial Plasma Drift:

$$\boxed{L_{\rm dr} \sim \dot{\mathfrak{M}}_{\rm a} \frac{G M_{\rm ns}}{r}}$$

Heating by the drift dominates cooling ($t_{\rm heat} \lesssim t_{\rm br}$) if

$$\dot{\mathfrak{M}}_{\rm c} \lesssim \dot{\mathfrak{M}}_0 \simeq 10^{14}\,{\rm g\,s}^{-1}\ \alpha_{0.1}^{7/17}\ \mu_{30}^{-1/17}\ V_7^{14/17}\ M_{1.4}^{16/17}$$

Old Isolated NS Accreting Material from ISM can appear as

★ Persistent Sources

$$L_{\rm a} \lesssim \underline{2 \times 10^{26}\ {\rm erg\,s^{-1}}}\ \ \alpha_{0.1}^{1/2}\ \mu_{30}^{-1/14}\ N^{11/14}\ V_7^{-33/14}\ M_{1.4}^{19/7}\ r_6^{-1}$$

$$P_{\rm s} \gtrsim \underline{7000\ {\rm s}}\ \ \mu_{30}^{6/7}\ V_7^{9/7}\ N^{-3/7}\ M_{1.4}^{-11/7}$$

★ Transient Sources

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Outburst duration: $\sim$ 15 min

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