INTERNATIONAL SPACE SCIENCE INSTITUTE

MAURIZIO FALANGA

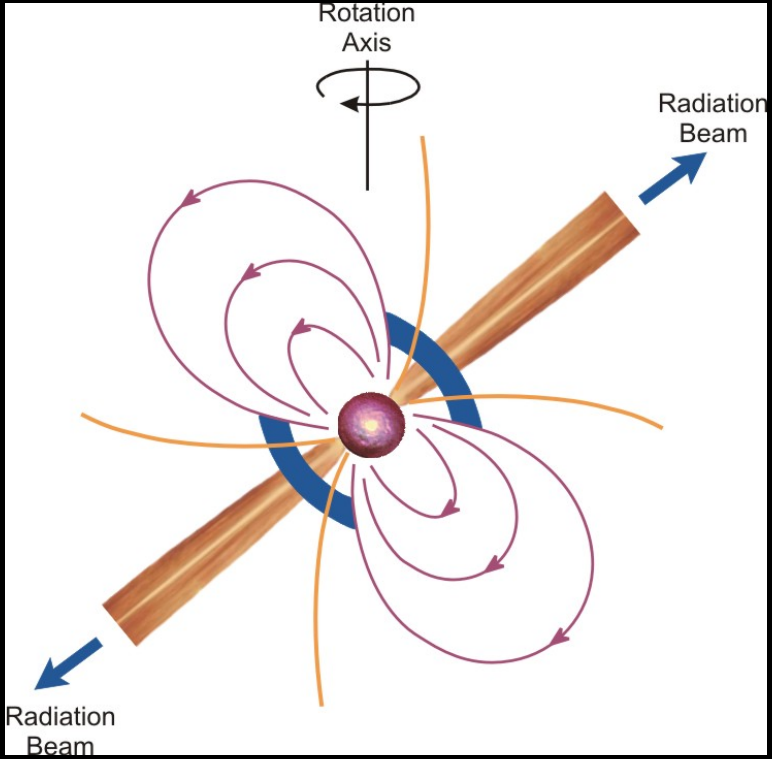
Origin, life, and pulsar evolution to millisecond

Introduction to the International Space Science institute in Bern

J. Bell; 1967 Radio Signales from the sky, 1.3372866576 s

These pulsars were proposed to be rapidly rotating neutron stars. Nobel Prize in Physics 1974.

PULSARS are NEUTRON STARS

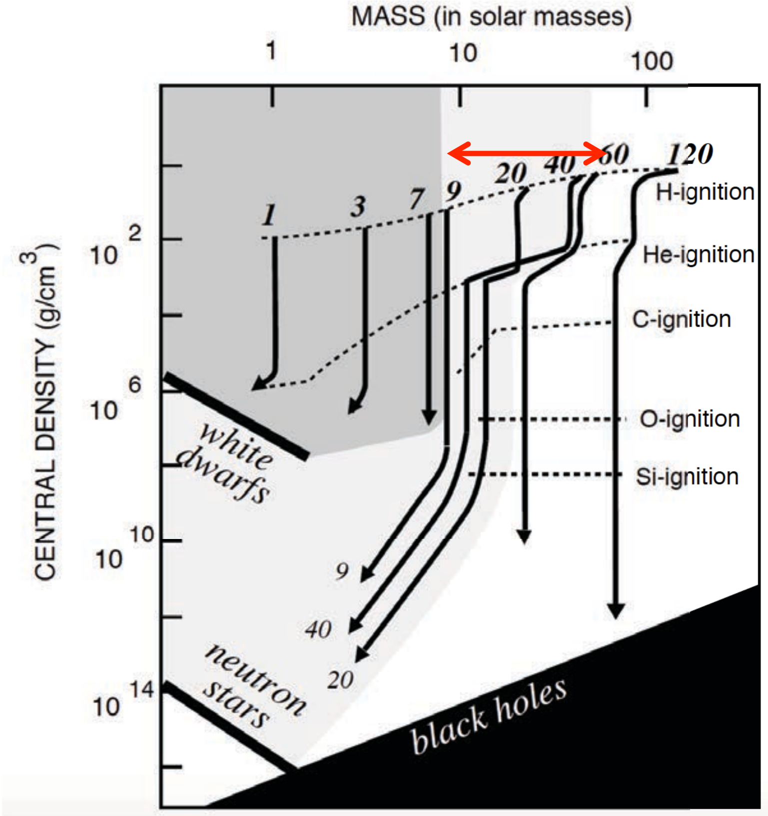


Properties of neutron stars:

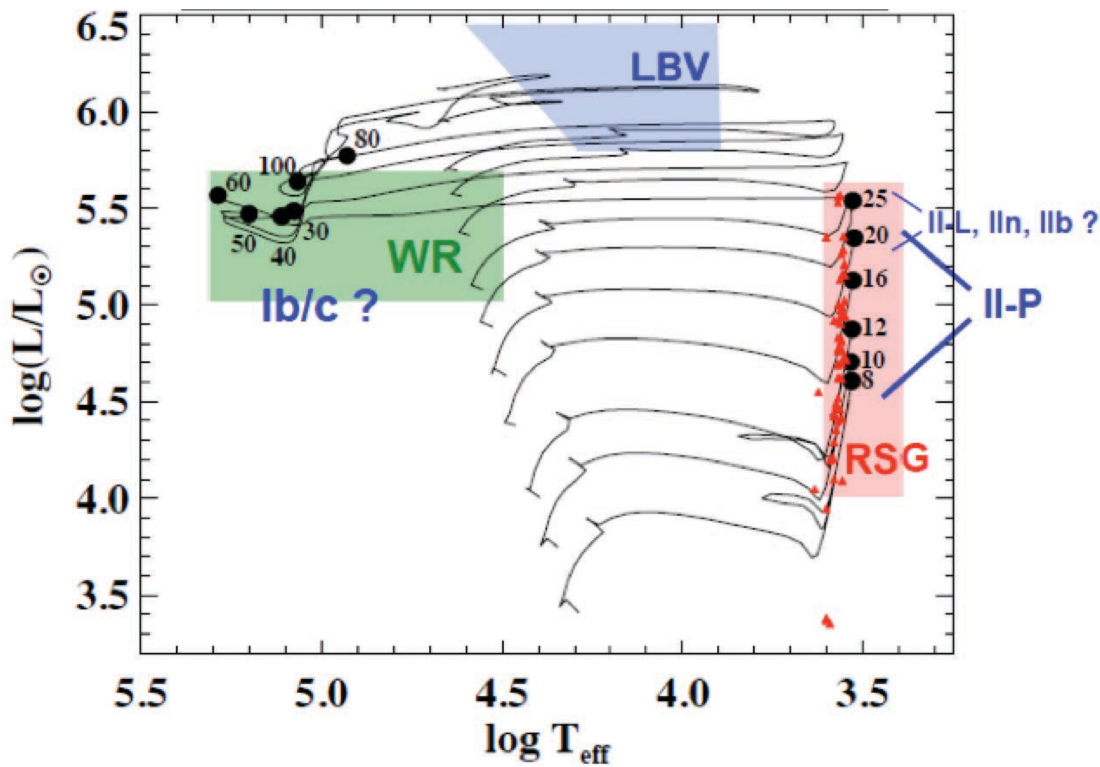
R ~ 10 km
ρ ~10^{14}g/cm^3
M ~ 1.4 M_{sun}

- Magnetic dipole
- Electromagnetic radiation
- Pulsar slowdown

Core-collapse supernova progenitors



A star must have at least 8 times, but no more than 40 to 50 times, the mass of the Sun ($M_{\odot}$) to undergo Core-collapse supernova explosion.



New models predict that most of stars $>18M_{\odot}$ produce BHs (see the review Smartt arXiv: 1504.02635)

Pulsars as Clocks

$R \sim 10$ km
$\rho \sim 10^{14} g/cm^3$
$M \sim 1.4\ M_{sun}$

e.g., PSR J0437-4715 has a period of :

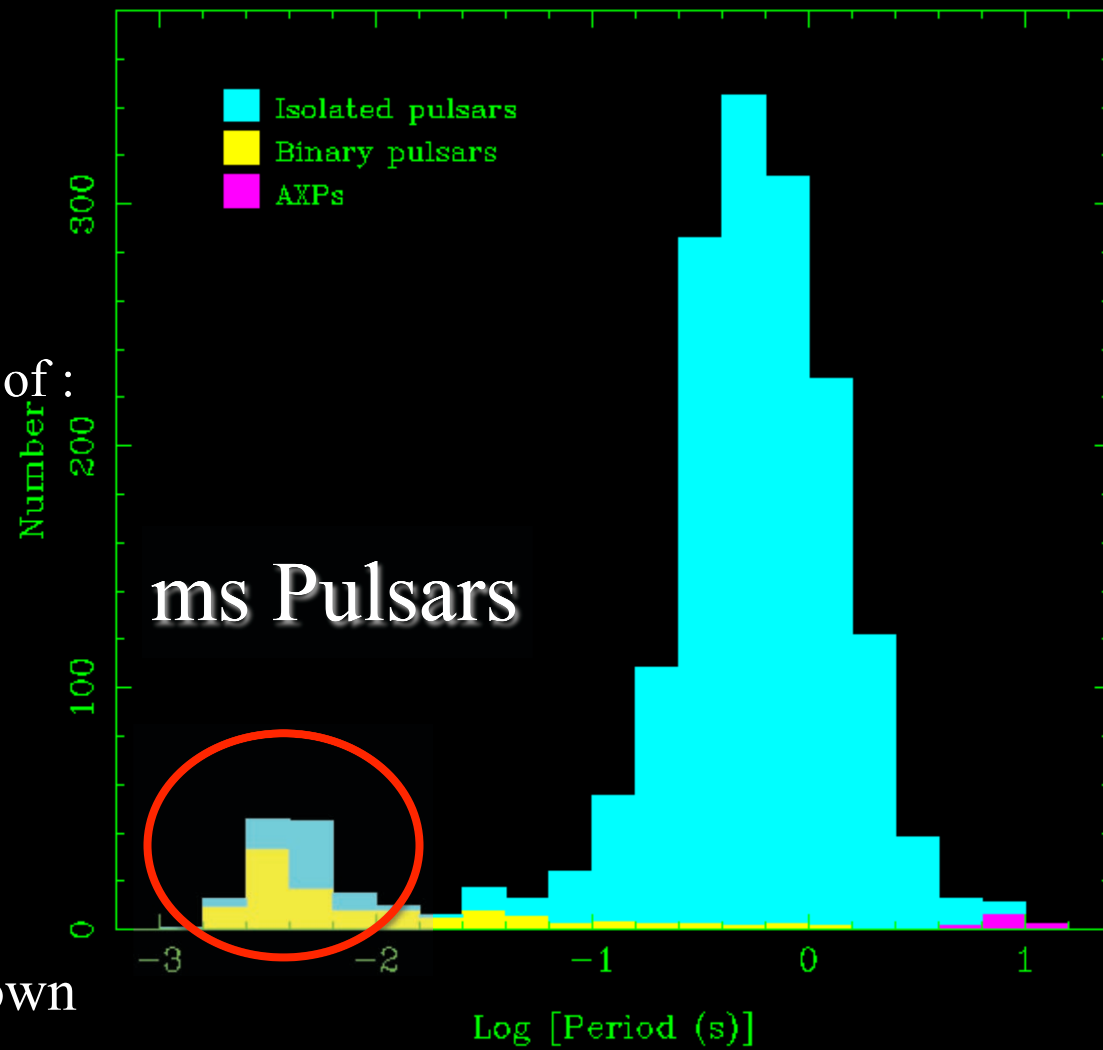
5.757451831072007 ±
0.000000000000008 ms

P_{spin} ~ incredibly stable
but not constant

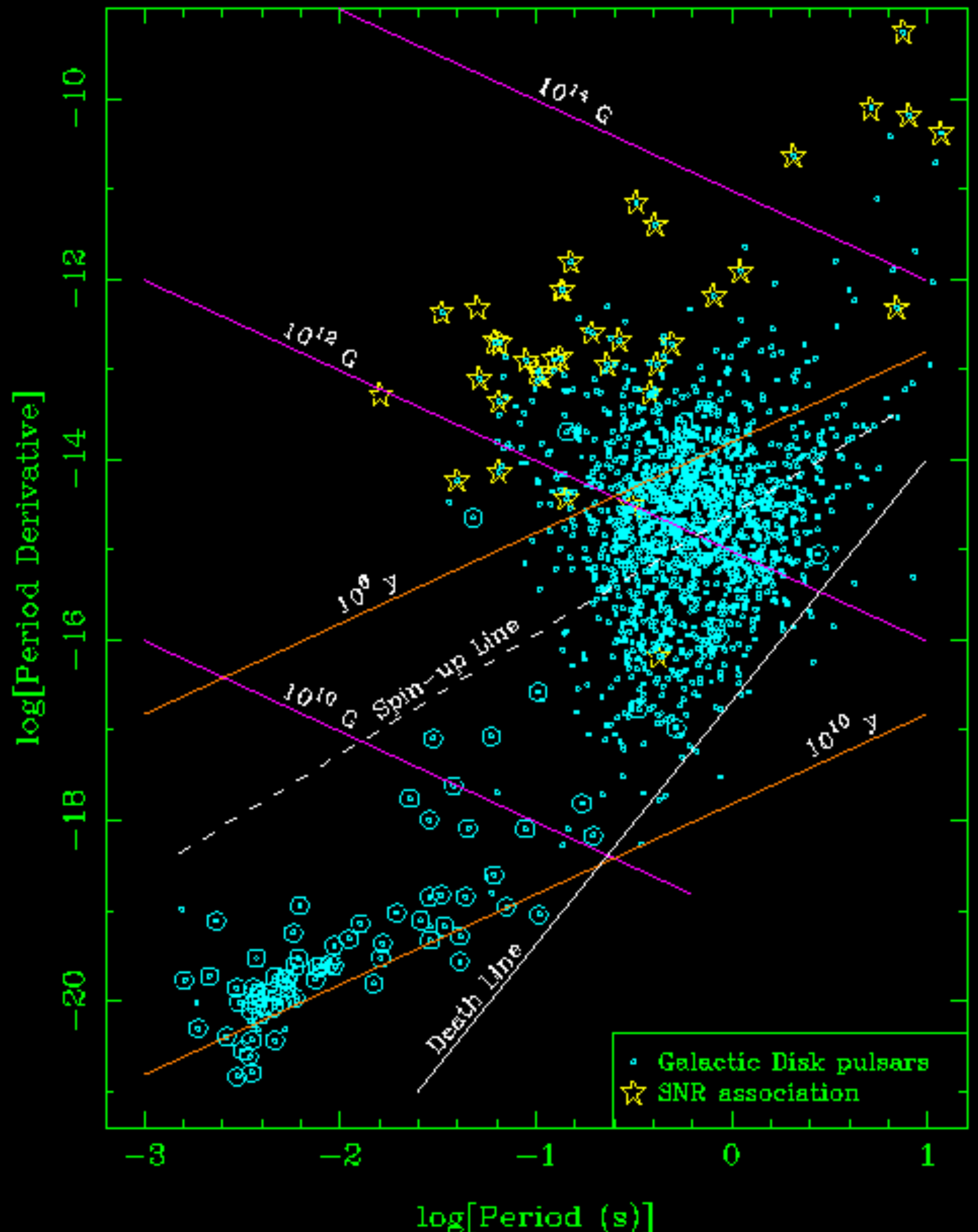
Pulsars lose energy and slow down

$\dot{P}_{spin} < \mu s/yr$

Rotation-Powered Pulsars

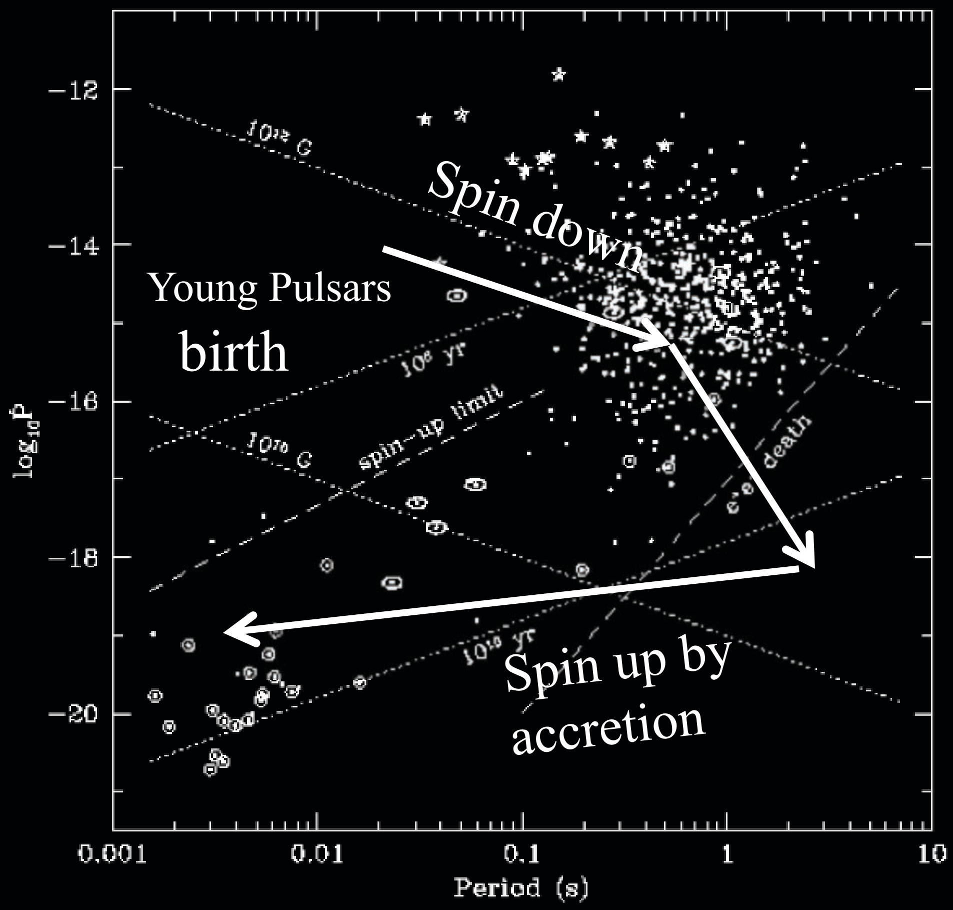


Data from ATNF Pulsar Catalogue, V1.33



log[Period Derivative]
log[Period (s)]
−10
−12
−14
−16
−18
−20
−3
−2
−1
0
1
10^{14} G
10^{12} G
10^{10} G
10^{8} y
10^{10} y
Spin-up Line
Death Line
Galactic Disk pulsars
SNR association

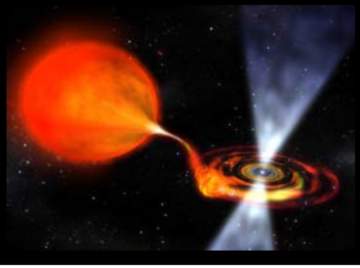
Recycling model for MSPs

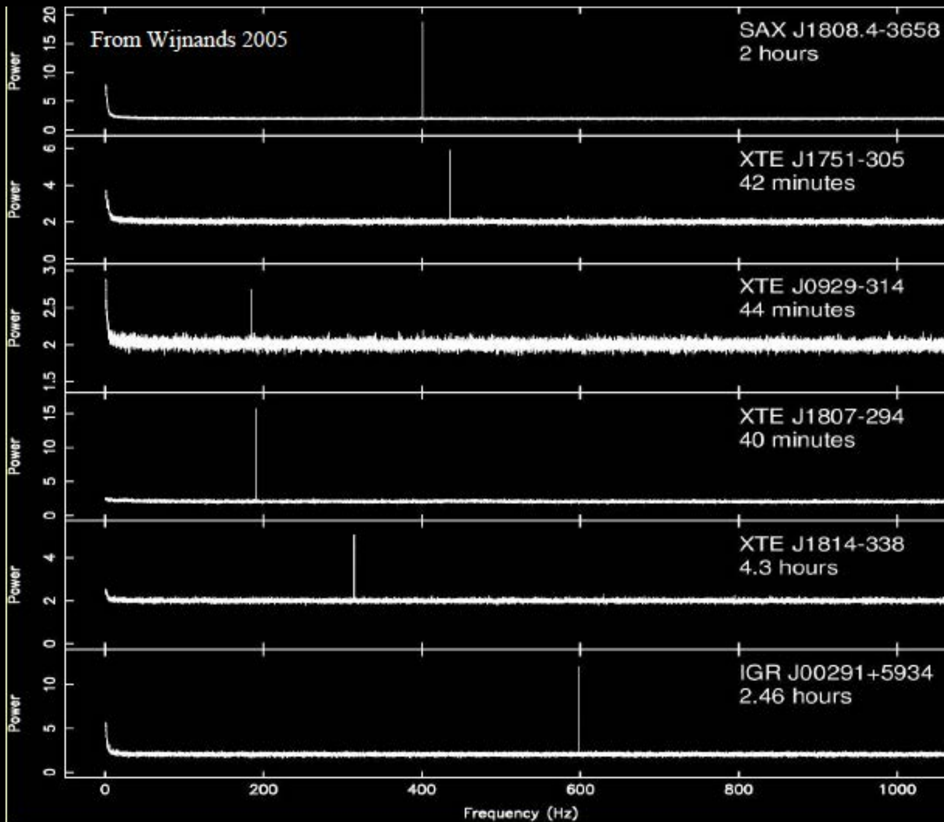


We have to discover the first Accreting Millisecond X-ray Pulsar, 1998

We have to discover an AMXP spinning-up, 2005

2013 the first Accreting Millisecond X-ray Pulsar Swinging between rotation and accretion power in a binary millisecond pulsar





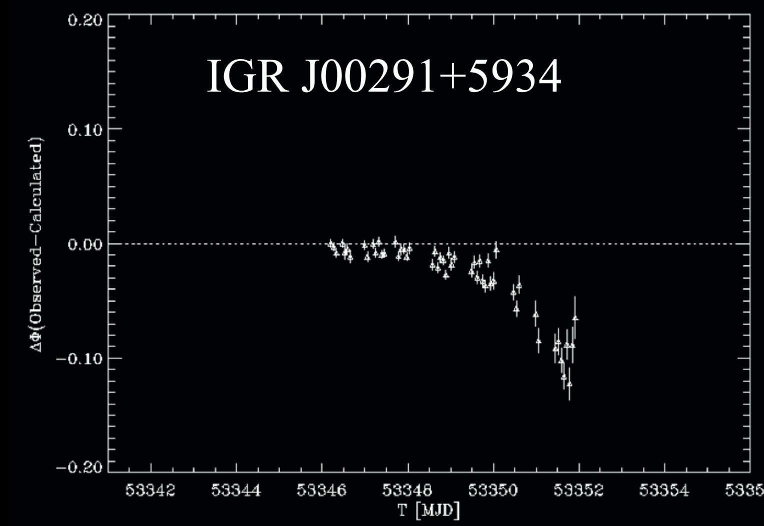
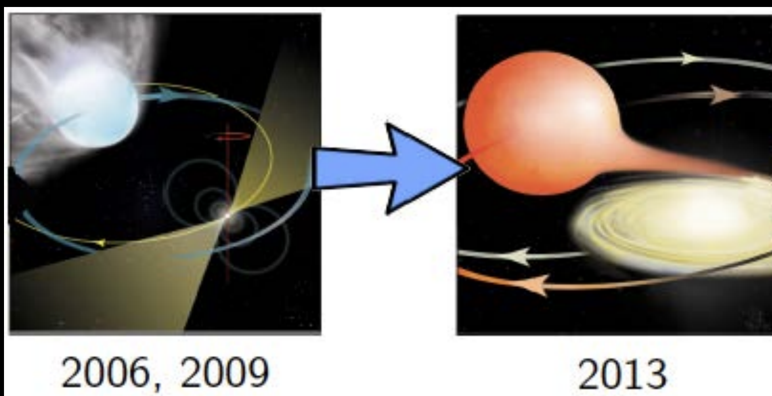
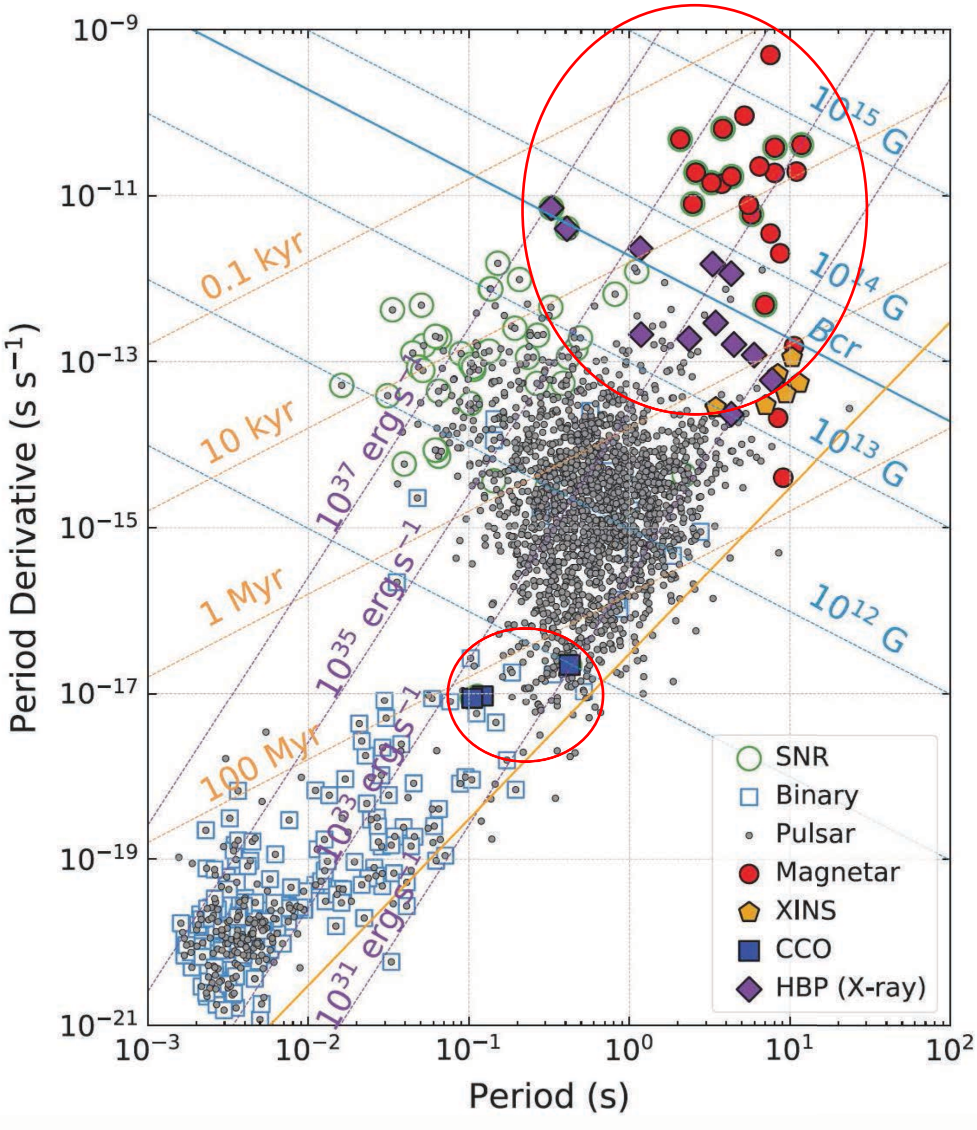


Table 1 | Spin and orbital parameters of IGR J18245–2452 and PSR J1824–2452I

Parameter	IGR J18245–2452	PSR J1824–2452I
Right ascension (J2000)	18 h 24 min 32.53(4) s	
Declination (J2000)	–24° 52′ 08.6(6)″	
Reference epoch (MJD)	56386.0	
Spin period (ms)	3.931852642(2)	3.93185(1)
Spin period derivative	$<1.3 \times 10^{-17}$	
Root mean square of pulse time delays (ms)	0.1	
Orbital period (h)	11.025781(2)	11.0258(2)
Projected semimajor axis (light-seconds)	0.76591(1)	0.7658(1)
Epoch of zero mean anomaly (modified Julian date)	56395.216893(1)	
Eccentricity	$\leq 10^{-4}$	
Pulsar mass function ($M_\odot$)	$2.2831(1) \times 10^{-3}$	$2.282(1) \times 10^{-3}$
Minimum companion mass ($M_\odot$)	0.174(3)	0.17(1)
Median companion mass ($M_\odot$)	0.204(3)	0.20(1)

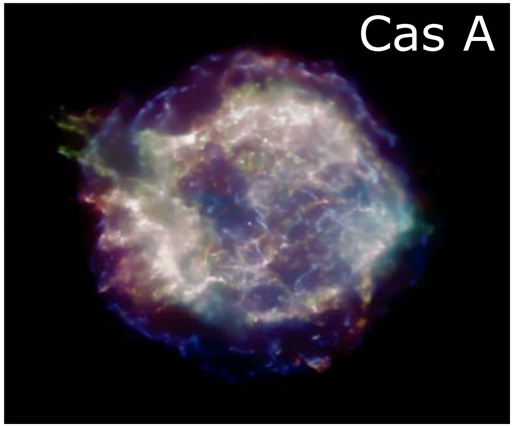




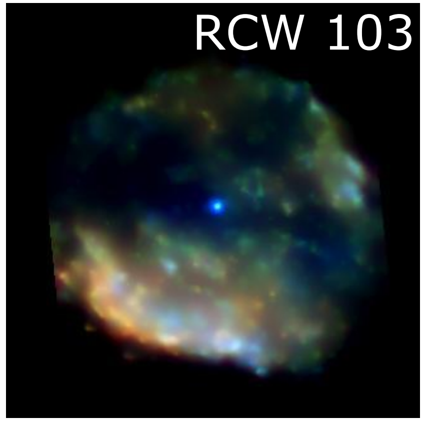
Young Pulsar
high B-field
Why ?

Young Pulsar
low B-field
Why ?

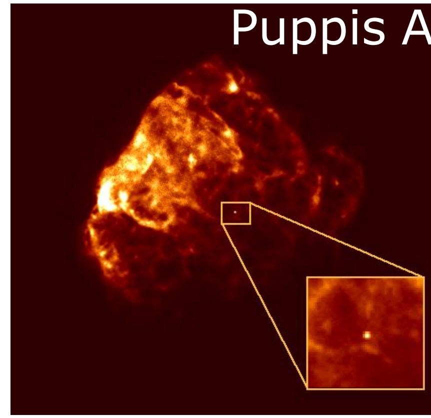
Compact Central (CCOs) X-ray sources in SNR



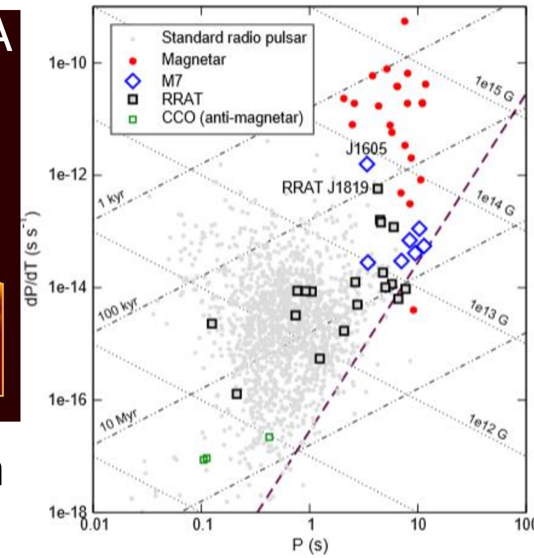
Rapid cooling
(Heinke et al.1007.4719)



6.7 hour period
(de Luca et al. 2006)



High proper motion
Velocity 672 km/s

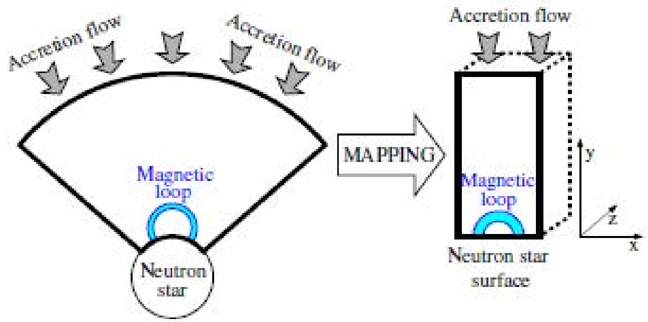


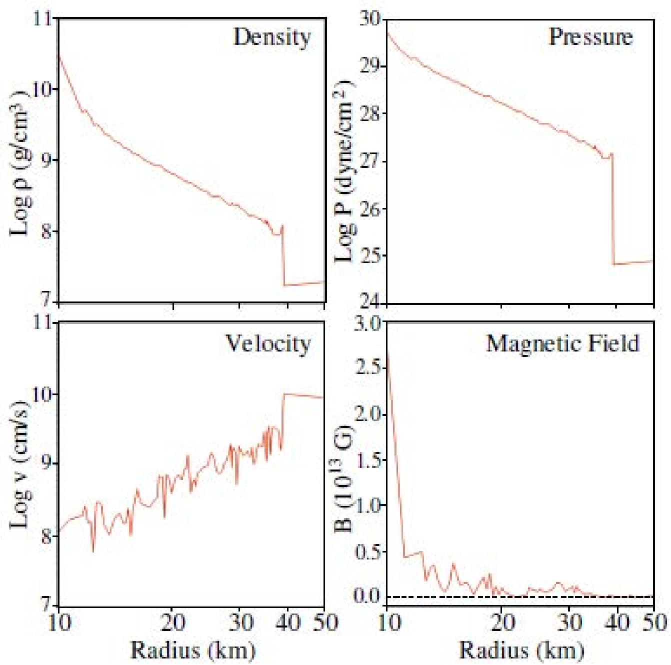
CCO	SNR	Age (kyr)	d (kpc)	P (s)	f_p[a] (%)	B_s (10^{11} G)	$L_{x,\mathrm{bol}}$ (erg s^{-1})	References
RX J0822.0−4300	Puppis A	3.7	2.2	0.112	11	< 9.8	6.5×10^{33}	1,2
CXOU J085201.4−461753	G266.1−1.2	1	1	...	< 7	...	2.5×10^{32}	3,4,5,6,7
1E 1207.4−5209	PKS 1209−51/52	7	2.2	0.424	9	< 3.3	2.5×10^{33}	8,9,10,11,12
CXOU J160103.1−513353	G330.2+1.0	$\gtrsim 3$	5	...	< 40	...	1.5×10^{33}	13,14
1WGA J1713.4−3949	G347.3−0.5	1.6	1.3	...	< 7	...	$\sim 1 \times 10^{33}$	7,15,16
CXOU J185238.6+004020	Kes 79	7	7	0.105	64	0.31	5.3×10^{33}	17,18,19,20
CXOU J232327.9+584842	Cas A	0.33	3.4	...	< 12	...	4.7×10^{33}	20,21,22,23,24
XMMU J172054.5−372652	G350.1−0.3	0.9	4.5	...	...	...	3.4×10^{33}	25
XMMU J173203.3−344518	G353.6−0.7	~ 27	3.2	...	...	...	1.0×10^{34}	26,27,28
CXOU J181852.0−150213	G15.9+0.2	1 − 3	(8.5)	...	...	...	$\sim 1 \times 10^{33}$	29

Anti-magnetars: Young pulsar with very week B-Field

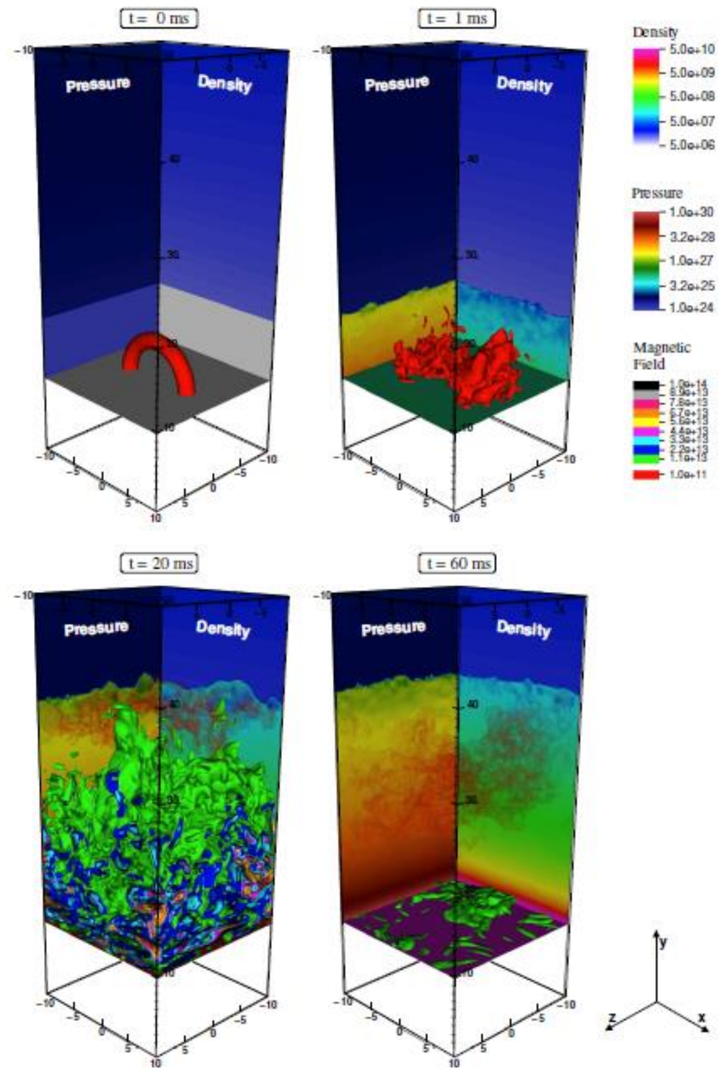
Thermal-like soft X-ray emission (kT_{bb} 0.2 - 0.5 keV) L_x 10^{33} erg/s; radio-quiet INS

How the B-field can be buried





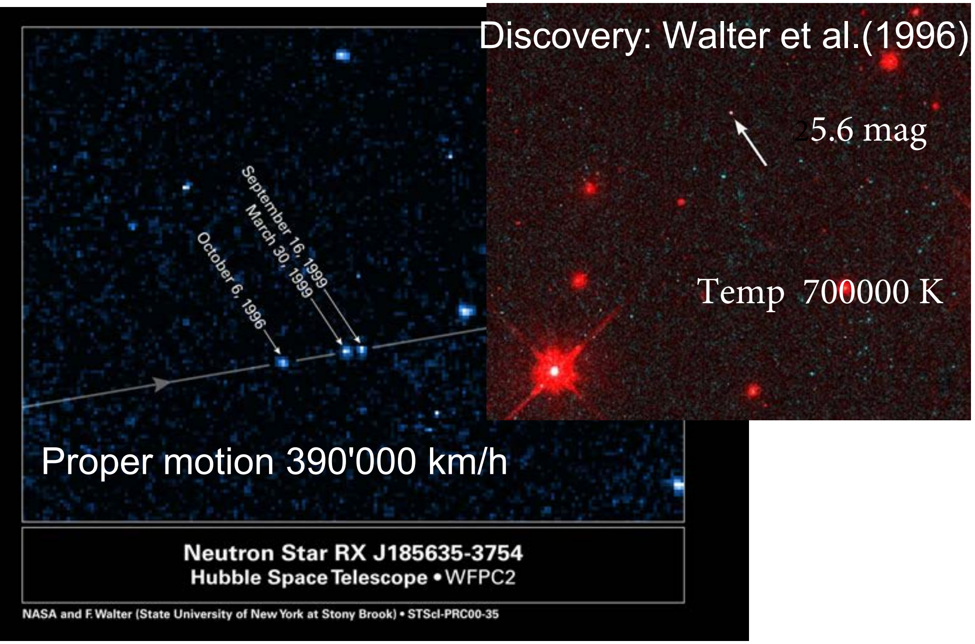
For t=60 msec



1212.0464

See 1210.7112 for a review of CCOs magnetic fields

X-ray Dim Iolated Neutron Star (XDINS)



The first direct observation of a neutron star in visible light.

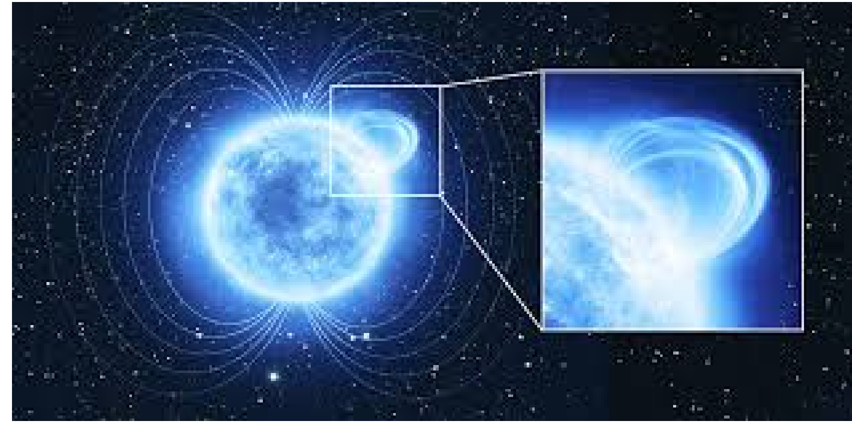
- Close-by radioquiet NSs
- Thermal spectrum

Magnificent Seven

Object	kT_∞ (eV)	P (s)	p_f (%)	$\log(\dot{P})$ (s s^{-1})	$\log(\dot{E})$ (erg s^{-1})	$\log(\tau_{ch})$ (yr)	d (pc)	$\log(B_{dip})$ (10^{13} G)	$\log(B_{cyc})$ (10^{13} G)
RX J1856.5-3754	61	7.06	1	−13.527	30.580	6.58	160	13.17	–
RX J0720.4-3125	84 – 93	8.39	11	−13.156	30.726	6.28	360	13.39	13.75
RX J1605.3+3249	100	3.39	4	−11.796	33.267	4.53	390	13.87	13.92
RX J1308.6+2127	100	10.31	18	−12.951	30.663	6.16	...	13.54	13.60
RX J2143.0+0654	104	9.43	4	−13.398	30.332	6.57	430	13.29	14.15
RX J0806.4-4123	95	11.37	6	−13.260	30.227	6.51	250	13.40	13.96
RX J0420.0-5022	48	3.45	17	−13.553	31.487	6.29	345	13.00	–

In 2008 Rutledge et al. reported the discovery of an enigmatic NS candidated dubbed *Calvera*. It is high above the galactic plane 2XMM J1046-5943

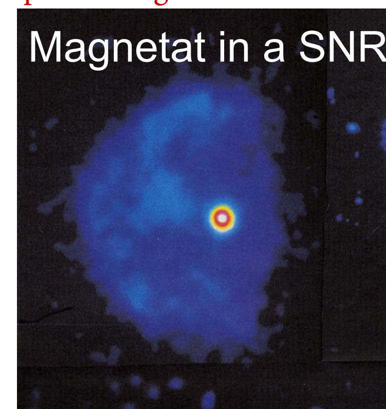
Magnetars



Catalogue: http://www.physics.mcgill.ca/~pulsar/magnetar/main.html

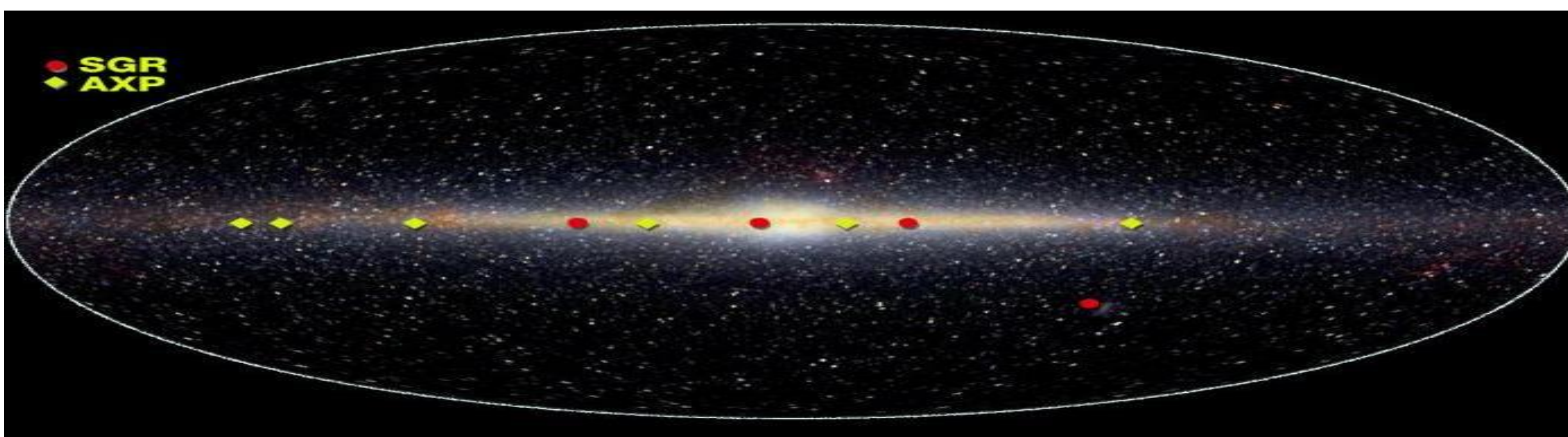
- Young objects (about 10^4 yr).
- Characteristic ages 10^3 - 10^5 yr).
- Magnetic fields 10^{14}–10^{15} G
- $dE/dt > dE_{rot}/dt$

The energy of the magnetic field is released



Magnetars in the Galaxy

(They are in highly absorbed regions in the galactic plane, in spial arms from massive star; SNR, they are young pulsars)



Bursts from SGR

- Concentrated in time ("outbursts")
- Relatively simple profiles (faster rise than decay)
- Broad distribution of wait times (~7 decades) : similar to that of earthaukes: no waiting-time correlations

Clcpew bgqrpg`srgml bL-bC | C+3-1 8 qg k gj_p rm c_prfos_icq
Kmqr `spqrq pcjc_qc | / . 16+/ . 2/ cpeq

Magnetars bursting activity due to decay

In the field decay model it is possible to study burst activity. Bursts occur due to crust cracking. The decaying field produce stresses in the crust that are not compensated by plastic deformations. When the stress level reaches a critical value the crust cracks, and energy can be released.

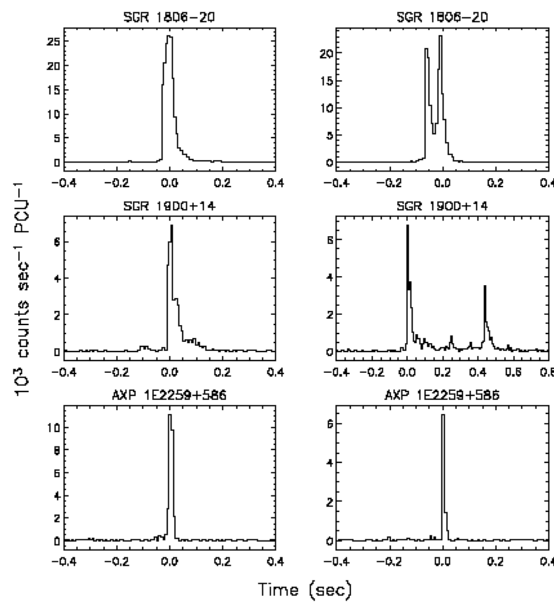


Fig. 14.1. A selection of common burst morphologies recorded from SGR 1806−20, SGR 1900+14 and 1E 2259+586, as observed with the *RXTE* PCA. All light curves display counts in the energy range 2−20 keV, with a time resolution of 7.8 ms. See text for further details.

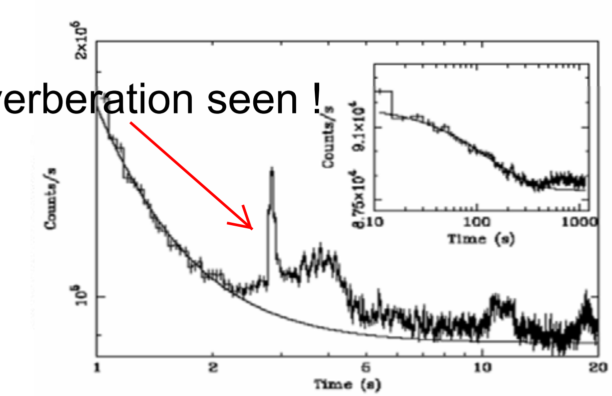
Soft Gamma Repeaters: main properties

Energetic "Giant Flares"
(GFs, L ≈ 10^{45}-10^{47} erg/s)

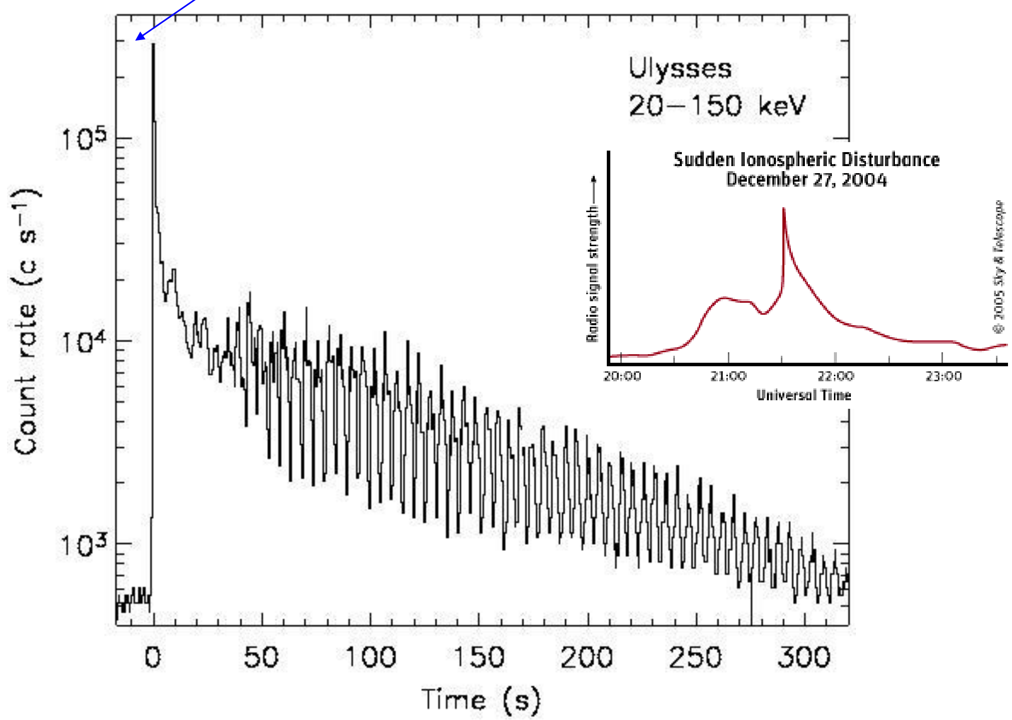
In magnetar model: GFs due to large scale rearrangements of core B-field

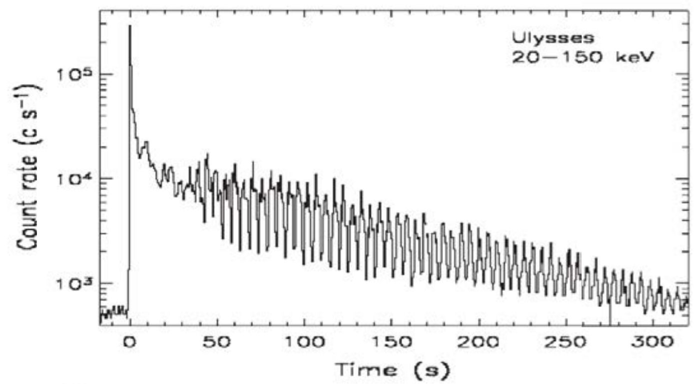
Periodicity is well visbile

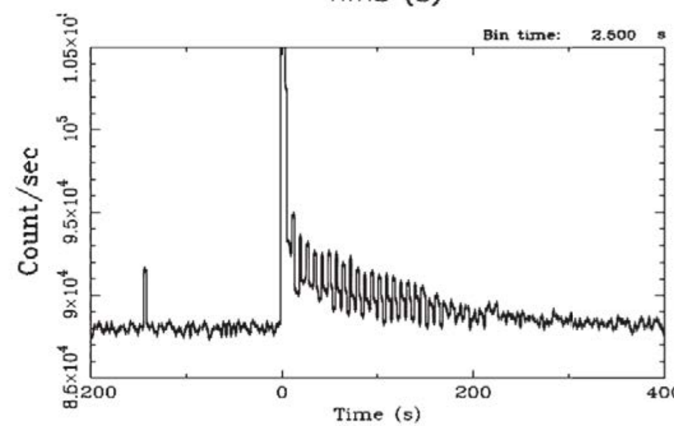
Moon reverberation seen !



Saturation of detectors







Magnetars: Neutron Stars powered by magnetic energy

- "Magnetars" (MAGNEtic sTARS): neutron stars with very high magnetic fields ($B>10^{14}G$)
  Why magnetic energy ? (Magnetic energy propagating through fractures in the crust)

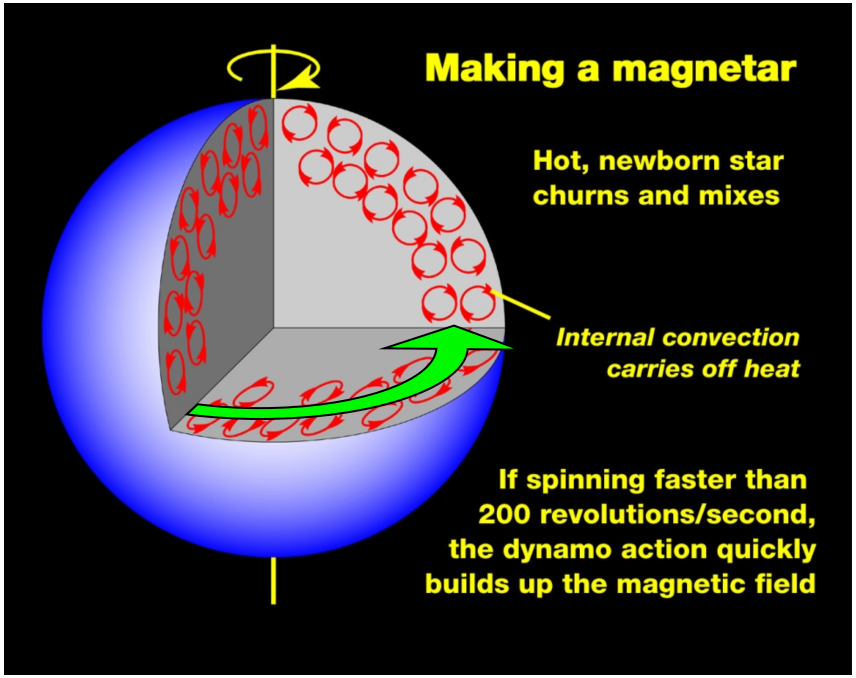
Persistent luminosity 10-100 times higher than spin down power

-> rotational energy ruled out

Recurrent flares/Bursts reach 10^{41} erg/s ~ 1000 L_{Edd} , giant flares 10^{44} erg/s ~ 10^{6} L_{Edd}

-> accretion energy ruled out

Fast spin (few ms) and differential rotation generate internal toroidal field $B > 10^{15}$ G

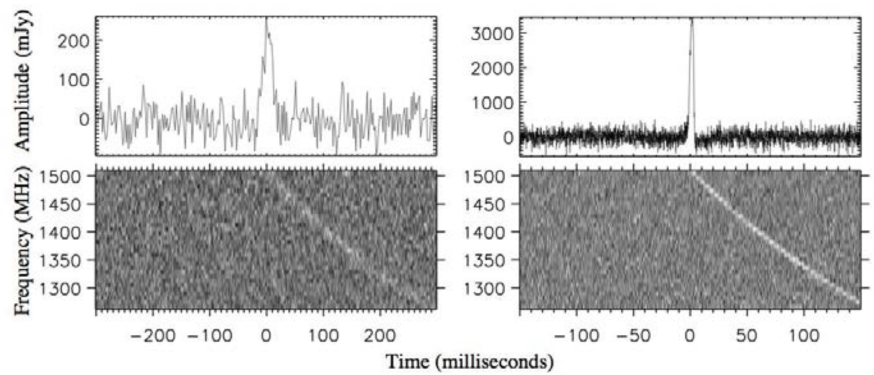


Rotating radio transients (RRATs)

Discovery of radio transients

McLaughlin et al. (2006) discovered a new type of sources– RRATs (Rotating Radio Transients).
For most of the sources (around 100) periods about few seconds were discovered. The result was obtained during the Parkes survey of the Galactic plane.

Burst duration 2-30 ms, interval 4 min-3 hr
Periods in the range 0.4-7 s



See a review in: 1109.6896

Thermal X-rays were observed from one of the RRATs (Reynolds et al. 2006). This one seems to me the youngest.

Catalogue: http://www.as.wvu.edu/~pulsar/rratalog/

Magnetic field evolution in the P - dot P diagram

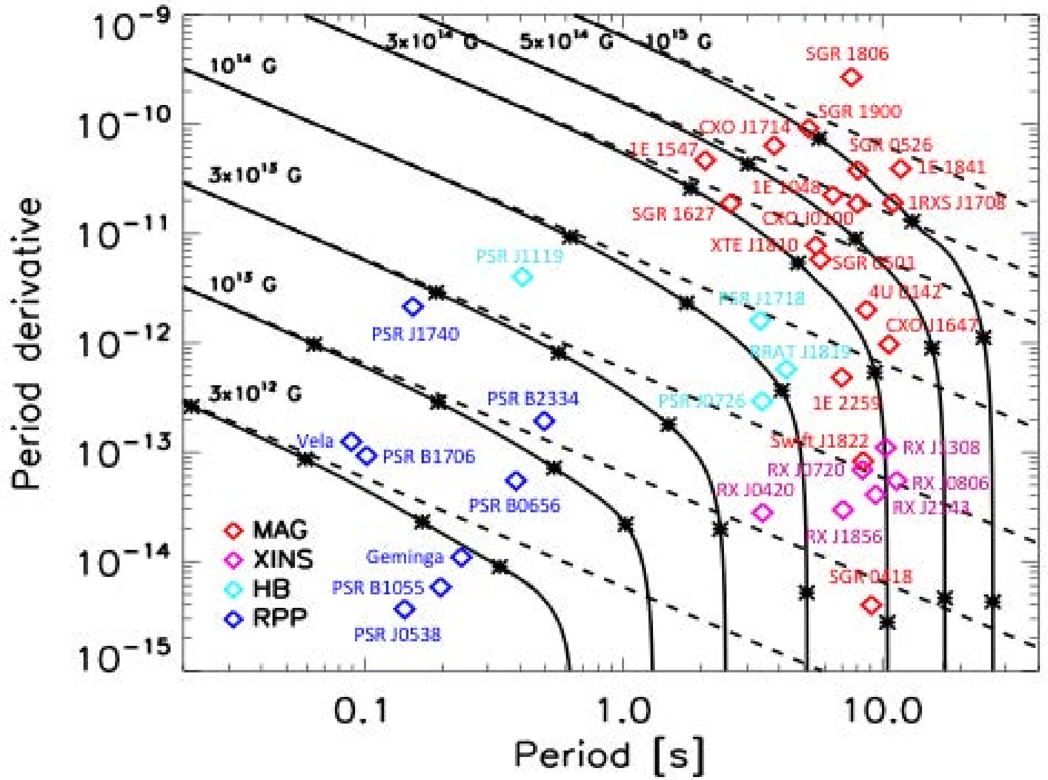
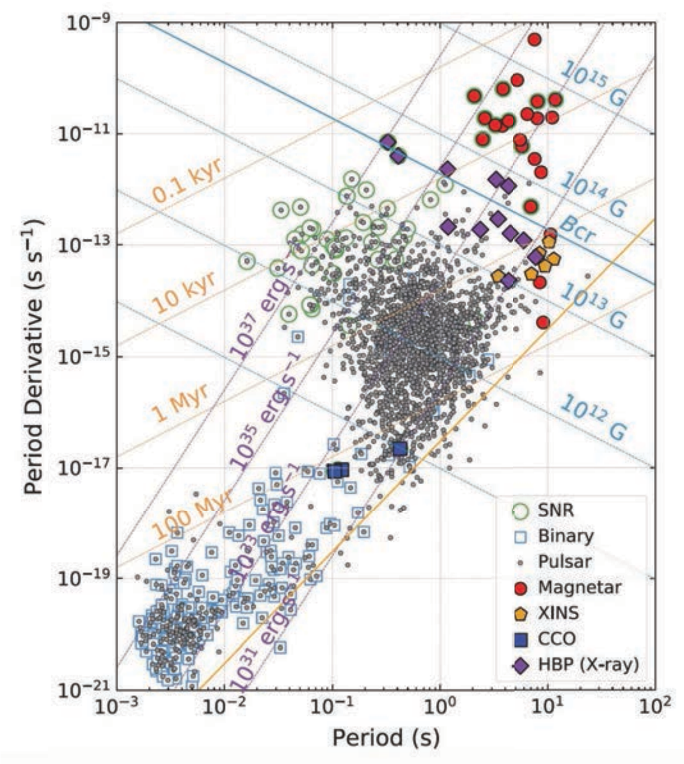


Fig. 8 $P - \dot{P}$ diagram for magnetars and other classes of isolated neutron stars (from Viganò et al. (2013)). The solid lines indicate theoretical evolutionary tracks for different values of the initial magnetic field. The points corresponding to true ages of $10^3, 10^4, 10^5$ and 5×10^5 yrs are indicated by the asterisks on each lines. The dashed lines represent the evolution without magnetic field decay.



Conclusions

- Young isolated NSs appear as a very varied group of sources
- Main types are: radio pulsars, magnetars, CCOs, Magnificent seven, RRATs
- Observational appearances of NSs is significantly determined by their magnetic fields
- The field can have a complicated topology and evolution
- It is necessary to create a unified model of evolution of young NSs
- Magnetic field evolution is one of the main ingredient of such model
- Normally, magnetic field decays
- In some cases external field can increase, if initially it has been ‘’screened’’ due to a fall-back

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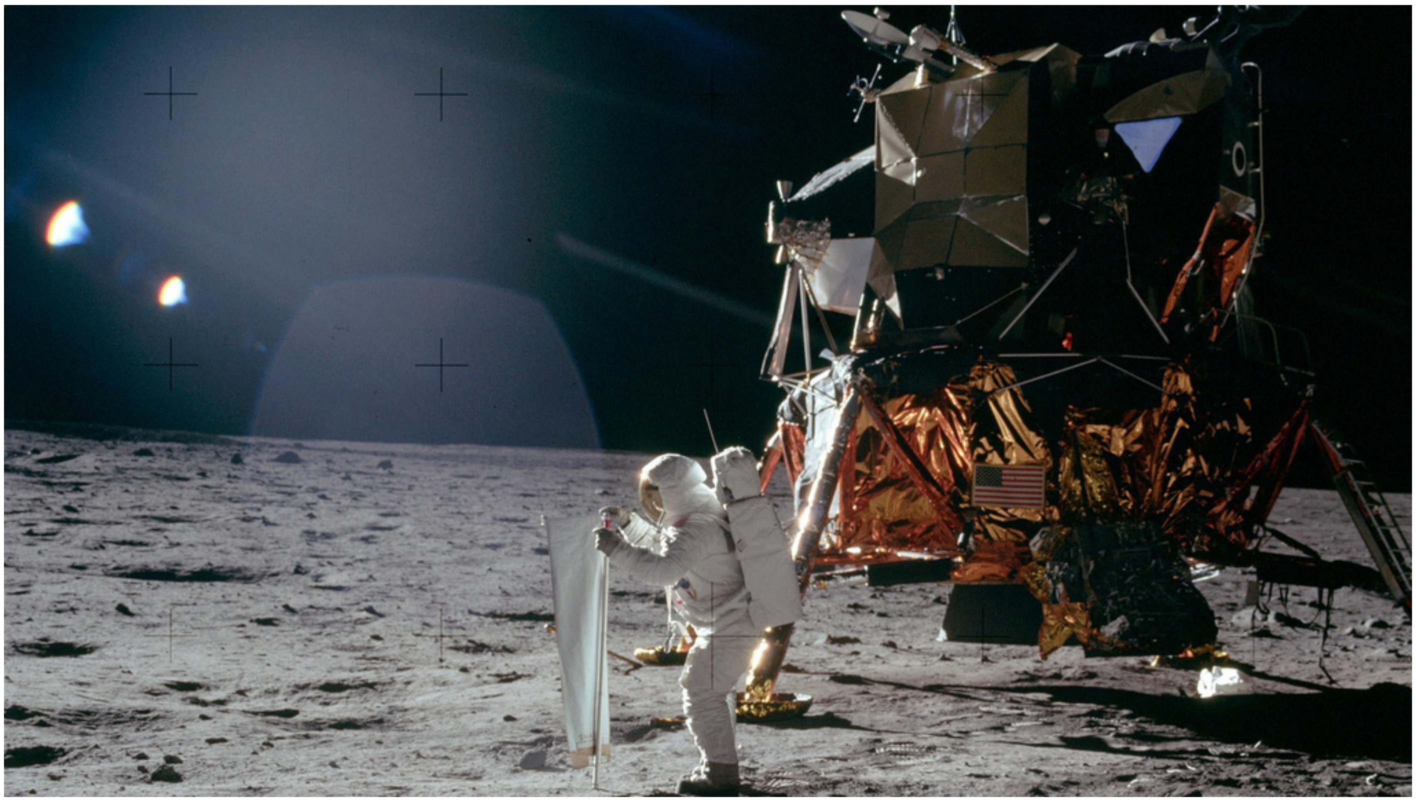
Prof. Johannes Geiss

Solar Wind Composition Experiment

The First “Flag” on the Moon?



Swiss solar sail: One of the only experiments to be carried on every lunar landing mission, and it was the only non-American experiment to be part of the Apollo landings.

History

Late 1980s the idea: An International Space Science Institute to cooperate between Europe (ESA), USA (NASA), Russia (RKA), Japan (JAXA) in the study of the Solar-Terrestrial Physics

1995 Institute founded by Prof. J. Geiss
Since 2003 Honorary Director

2003 International Team Call
Executive Director R.-M. Bonnet

2007 Young Scientists program

2007 Earth-Science from Space ISSI/ESRIN

2010 Russia (RAS) small contribution/year to ISSI

2013 Executive Director R. Rodrigo - 2018 Rudolf von Steiger

esa

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

sc | nat
Swiss Academy of Sciences
Akademie der Naturwissenschaften
Accademia di scienze naturali
Académie des sciences naturelles

u^b UNIVERSITÄT BERN

JAXA

ИКИ

The Staff

ISSI Goals

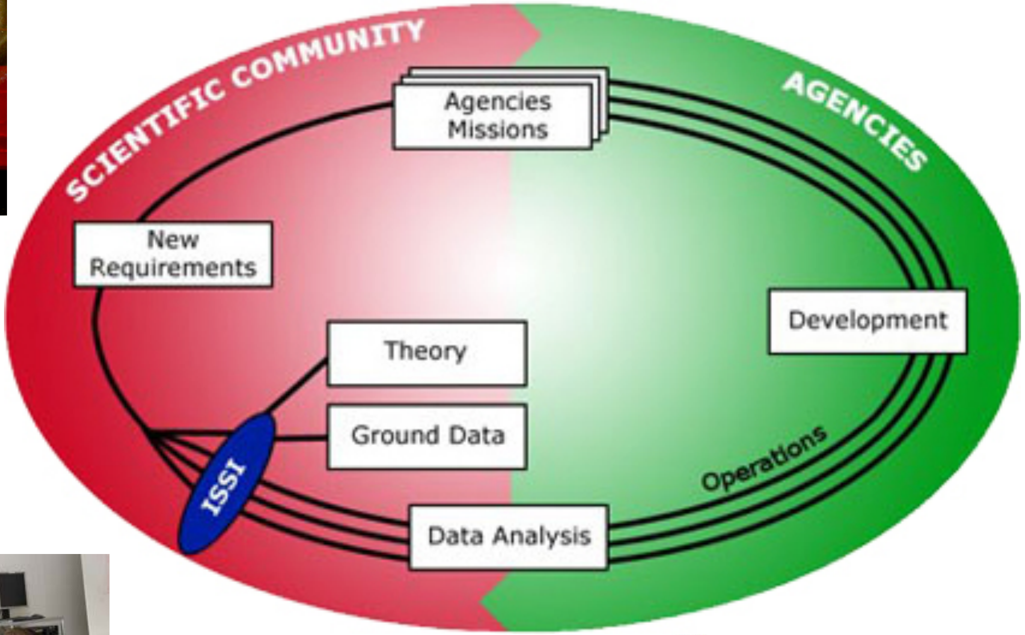
esa

JAXA
Japan Aerospace Exploration Agency

NASA

РОСКОСМОС

Cosmic Vision



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UNIVERSITÀ DI BOLOGNA

HARVARD

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東京大学
THE UNIVERSITY OF TOKYO

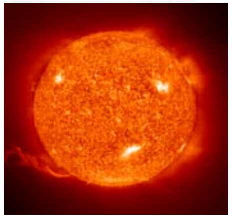
Science Activities

INTERDISCIPLINARY

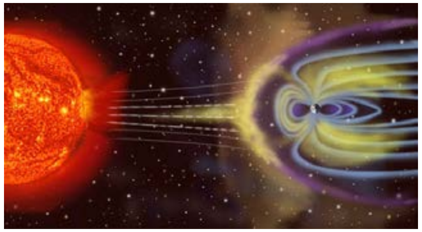
INTERNATIONAL

INFORMAL

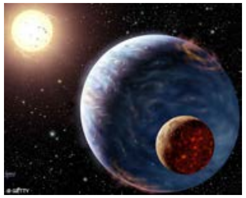
SCIENCE FIERST



Solar Physics



Heliosphere
Magnetosphere
Plasma



Planets

Astrophysics
Astronomy
Fundamental Physics

Earth Science from Space

ISSI Tools

FORUMS

Objectives:	**Open** discussions
Participants:	**20-30** scientists
Duration:	2 days
Output:	**Report**
Support:	Accommodation

INTERNATIONAL TEAMS

Objectives:	Research on **focused** topics
Participants:	**10-15** scientists
Duration:	2 years, 1-2 meetings/year
Output:	**Papers** in scientific journals **Per**
Support:	**diem** + **accommodation**

WORKSHOPS

Objectives:	**Broad** scientific area
Participants:	~**40** scientists One week
Duration:	**Book** (peer reviewed)
Output:	**Per diem** + **accommodation**
Support:	Book **publication cost**

VISITING SCIENTISTS

Objectives:	**Research** (specific to visitor) As
Duration:	necessary
Output:	**Publications / Management** tasks
Support:	**Travel** + **accommodation**

How to use the Tools

FORUMS

- **No annual call**
- May be **suggested any time**
- Submit an idea on max 1 page
- Ideas evaluated by the Science Committee

INTERNATIONAL TEAMS

- **Call** for proposals released every year **on January**
- Proposals evaluated by the Science Committee

WORKSHOPS

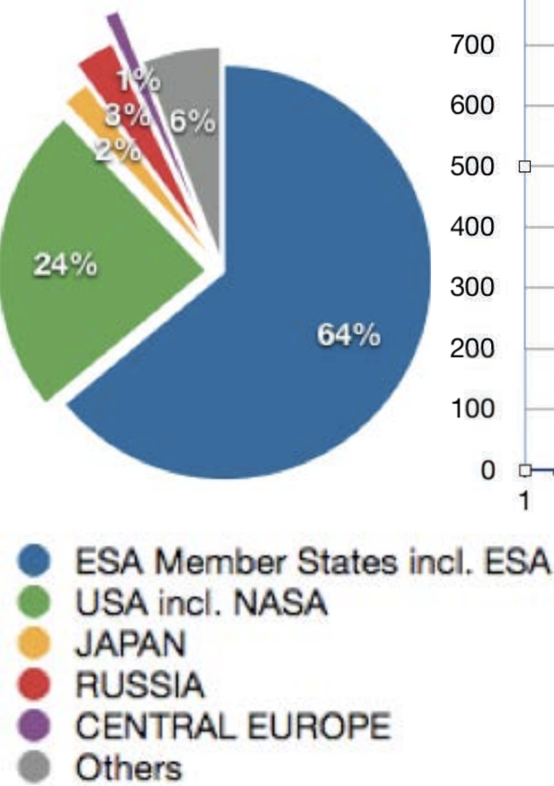
- **No annual call**
- May be **suggested any time**
- Submit an idea on max 1 page
- Ideas evaluated by the Science Committee

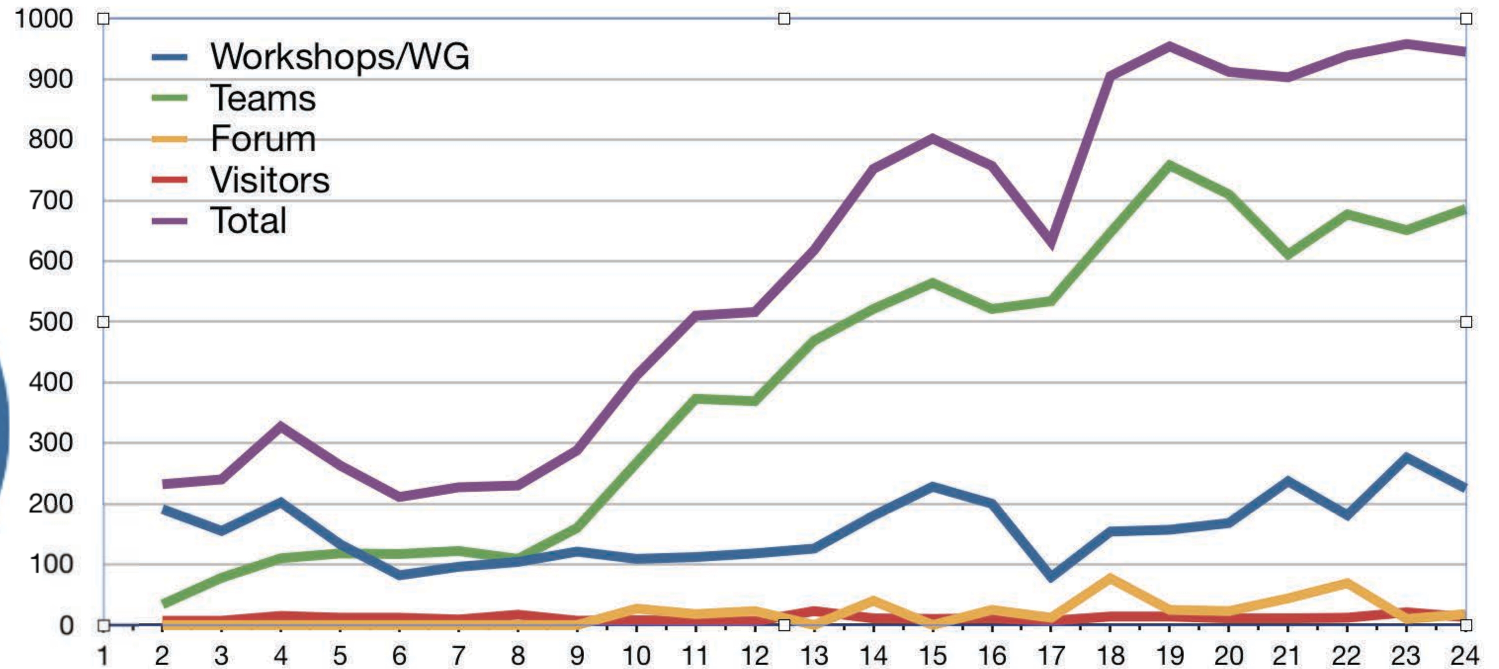
VISITING SCIENTISTS

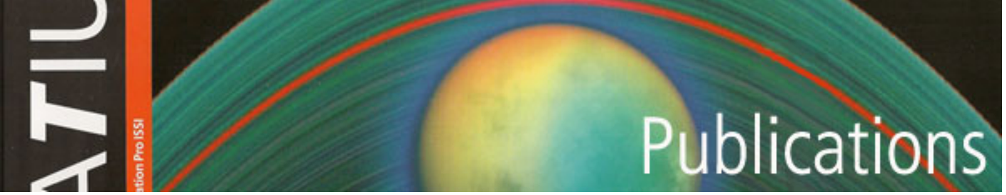
- **Invited** by the Directorate and External Scientists
- Selected by the Directorate

Statistics

- 60 Countries, and
- 6000 Individual Scientists visited ISSI during the first 25rd years







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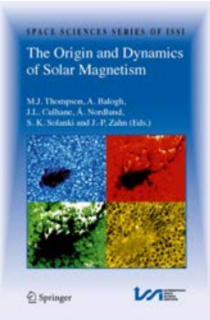

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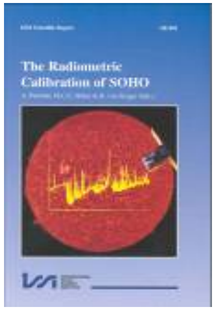

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