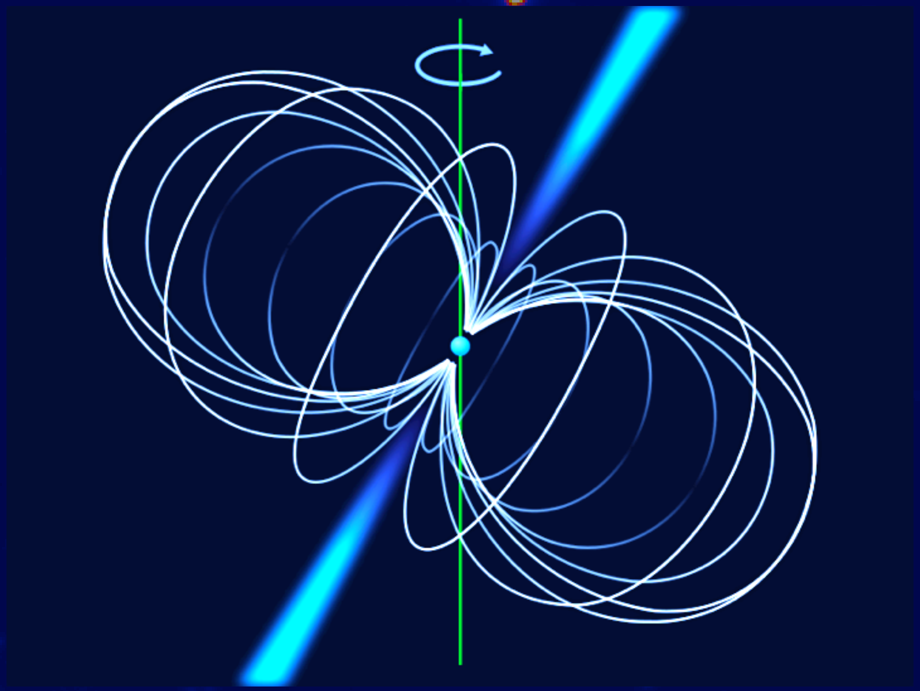
The ESO crucial role in studying isolated neutron stars



Nanda Rea

with the collaboration of Roberto Mignani (UCL-MSSL), Gianluca Israel (INAF-OAR) and the ESO-INS working group

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Institute of Space Science
Ramon y Cajal Fellow

University of Amsterdam
Astronomical Institute "Anton Pannekoek"
NWO Veni Fellow

Isolated neutron stars

•1931 Chandrasekhar argued that WDs collapse at masses > 1.4 $M_{\odot}$. (Chandrasekhar 1931, ApJ)

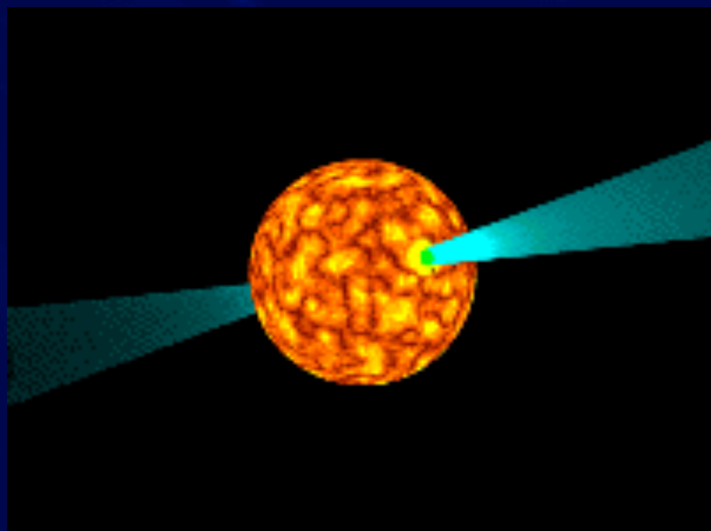
•1934 Baade & Zwicky proposed the existence of NS, they predicted their formation due to supernova explosion and their radius of ~10 km . (Baade & Zwicky 1934, Proc.Nat.Acad.Sci.)

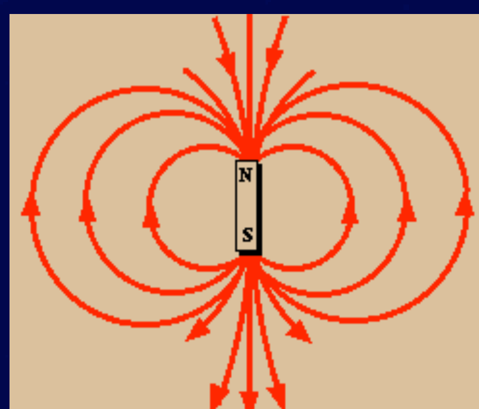
•1939 Oppenheimer & Volkoff delined the first equation of state for a NS of mass ~1.4 $M_{\odot}$, a radius of ~10 km and a density of ~10^{14} gr/cm^3 (Oppenheimer & Volkoff 1939, Phys.Rev)

•1967 Pacini predicted electromagnetic waves from rotating NSs and that such star might be powering the Crab nebula. (Pacini 1967 and 1968, Nature)

•1968 Hewish & Bell studing interplanetary scintillation observed a periodicity of 1.337s, discovering the first pulsar: PSR 1919+21. (Hewish et al. 1968, Nature)

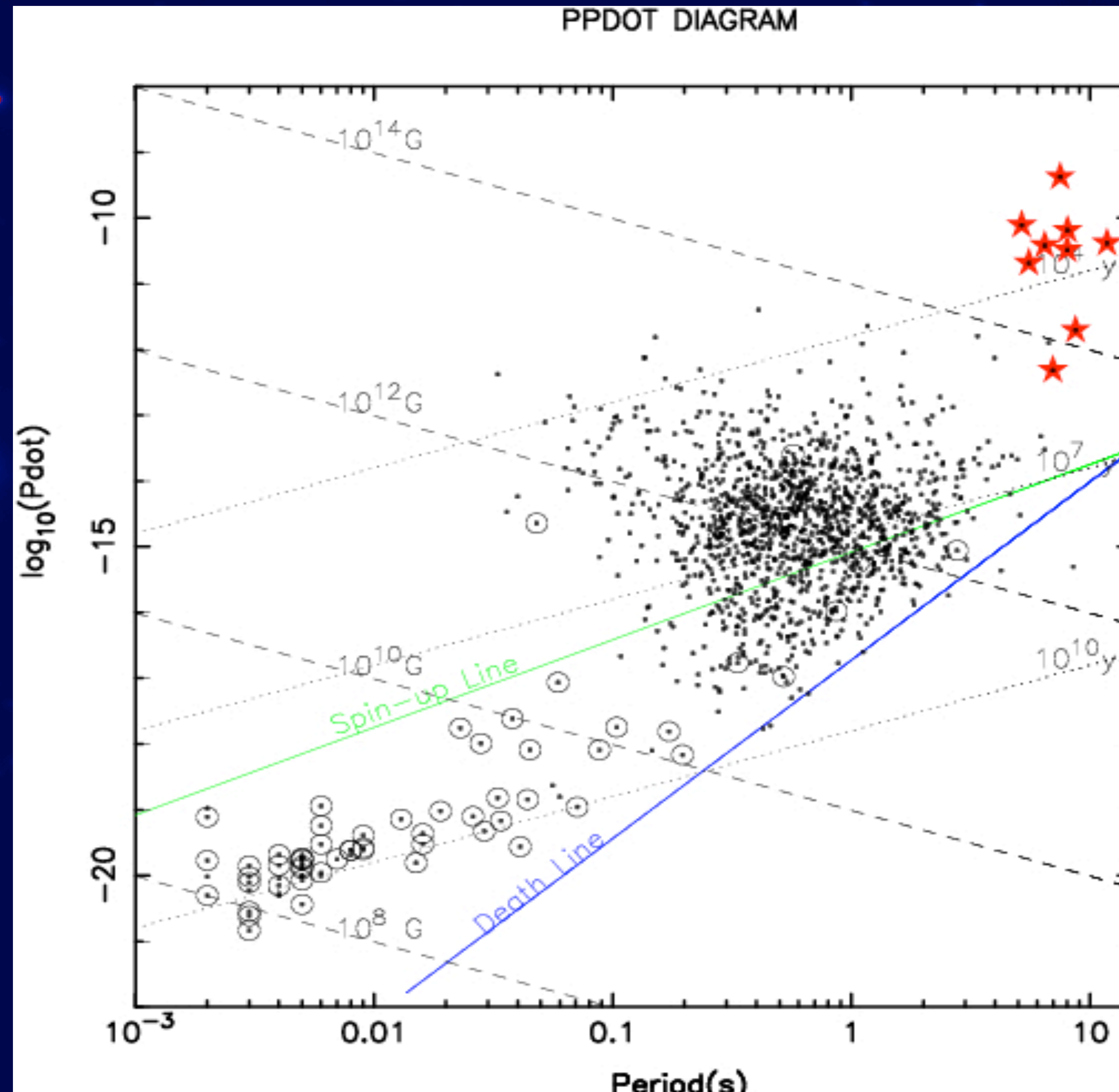
Isolated neutron stars





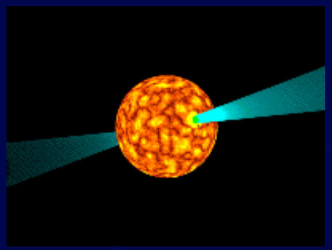
$$\dot{E}_{rot} = -\frac{2}{3c^3}|\ddot{m}|^2 = -\frac{2B^2R^6\Omega^4\sin^2\alpha}{3c^3}$$

$$P\dot{P} = \left(\frac{8\pi^2 R_{ns}^{\ 6}}{3c^3 I}\right) B_0^{\ 2}\sin^2\alpha$$



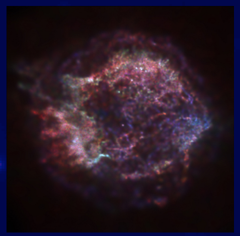
Isolated neutron stars

1- Radio pulsars (PSRs): ~2000



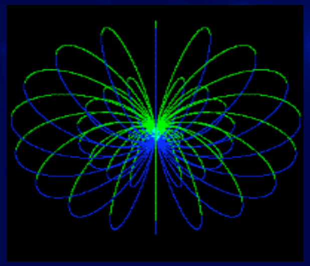
2- X-ray Dim Isolated Neutron Stars (XDINSs): ~7

3- Central Compact Objects (CCO): ~5



4- Rotating RAdio Transients (RRATs): ~11

5- Magnetars (AXPs and SGRs): ~17



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Isolated neutron stars

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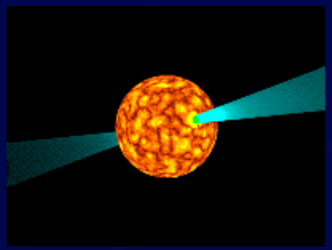

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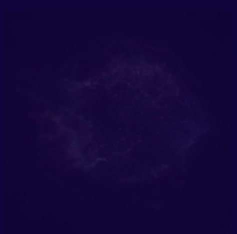

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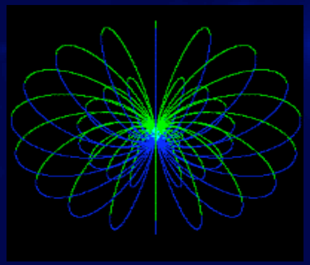

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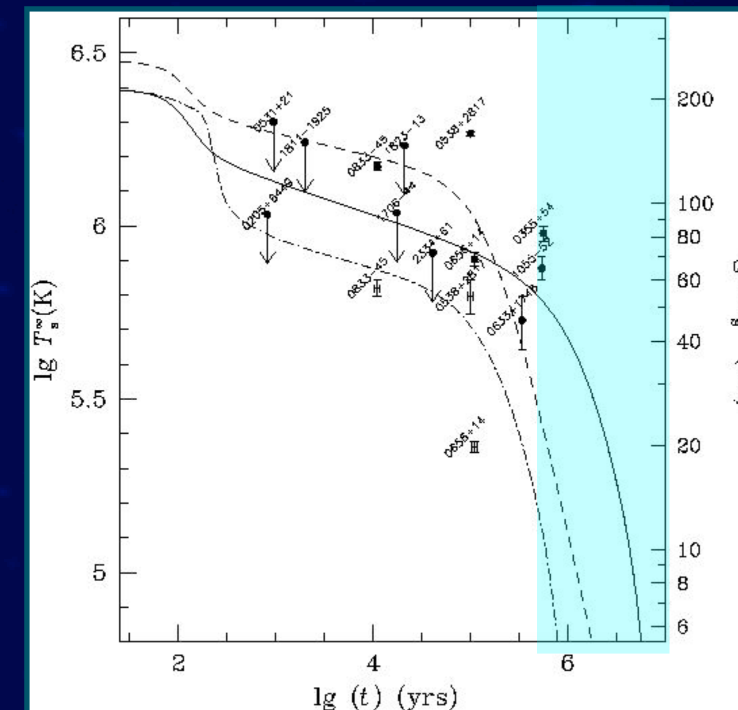
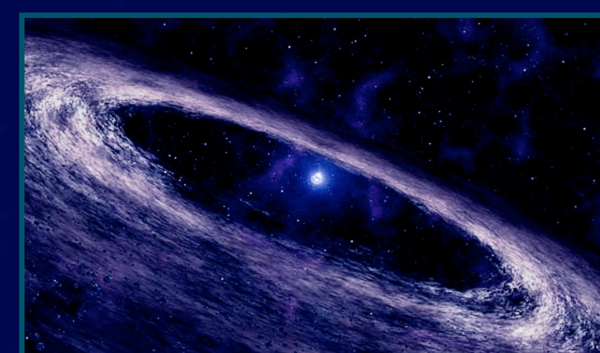
UV-Opt-IR emission of isolated neutron stars



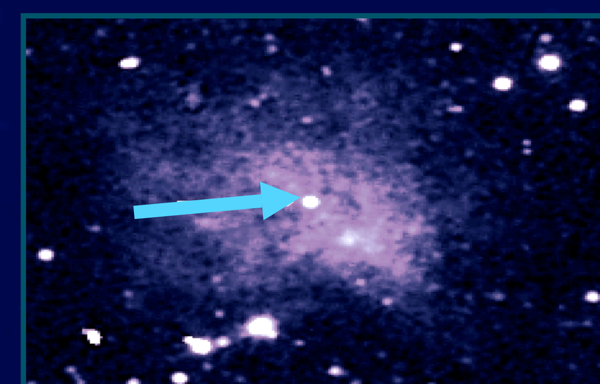
The UV-Opt spectrum yields the neutron star thermal map

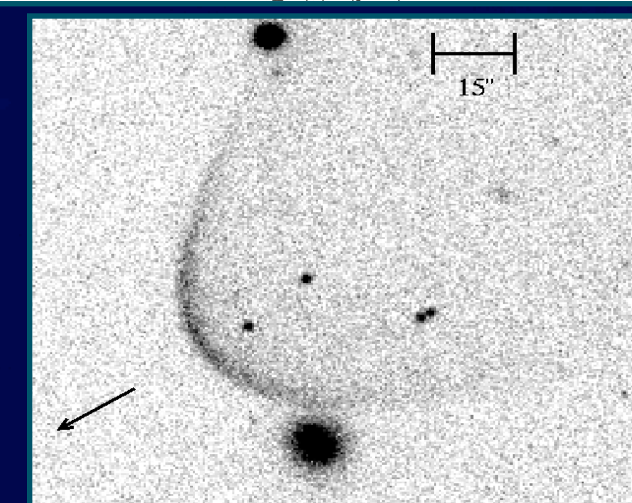
- better <T>, cooling curve models, neutron star conductivy
- UV and Opt are critical @>10^6 yrs (too cold for X-rays)
- Investigate re-heating processes

The Opt-IR spectrum pinpoints disks



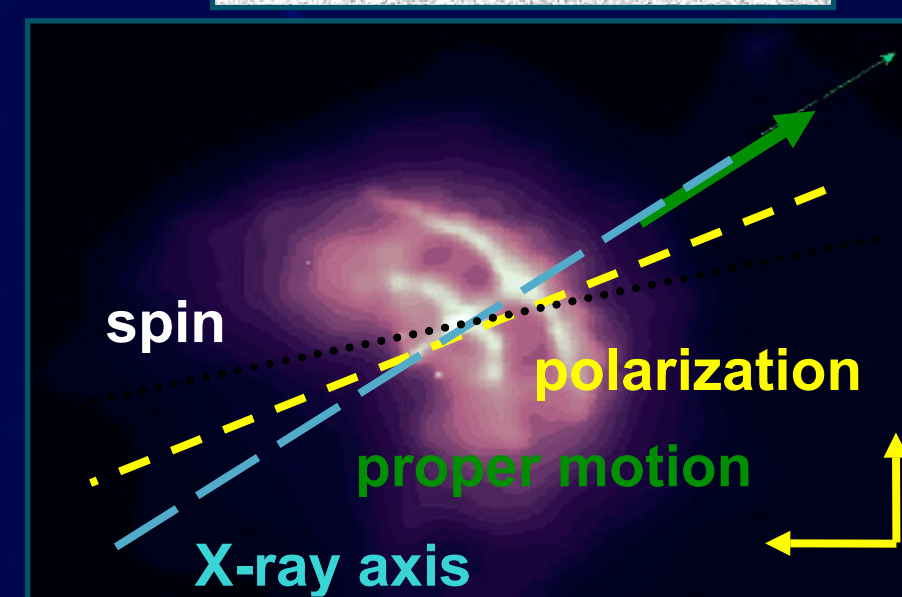
- neutron star accretion
- disks in magnetar and CCO models
- post-SN evolution studies





Optical polarimetry

- test neutron star magnetosphere models
- constrain magnetic field and spin angle
- unveil magneto-dynamical NS/PWN interactions



Optical imaging

- Proper motions and parallaxes
- Bow-shocks, 3D velocity, birth place localization
- PWN morphology and evolution

Radio Pulsars (PSRs): UV-Opt-IR emission

10 radio pulsars identified, mostly by ESO-VLT and HST

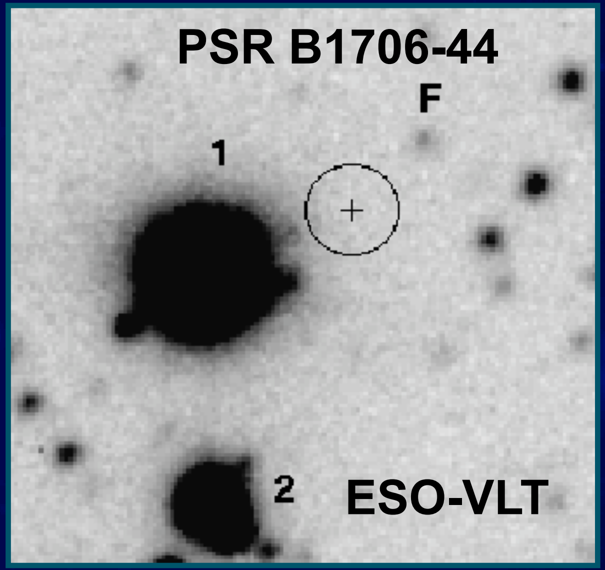
- Identification from radio position, timing, proper motion
- Mostly in optical/UV, only 4 in the IR

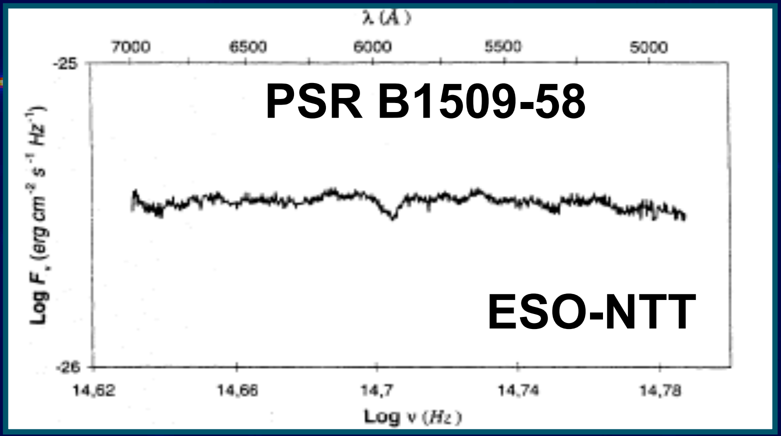
Low. Res. spectroscopy from ESO for 5 pulsars

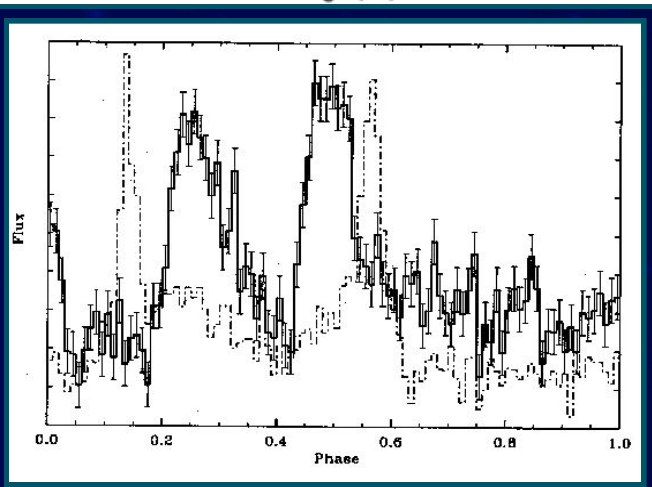
- Synchrotron radiation + thermal radiation
- Relative contributions depend on pulsar age
  but there is no clear spectral evolution

5 optical pulsations have been detected

- about 10% polarization for Crab and Vela

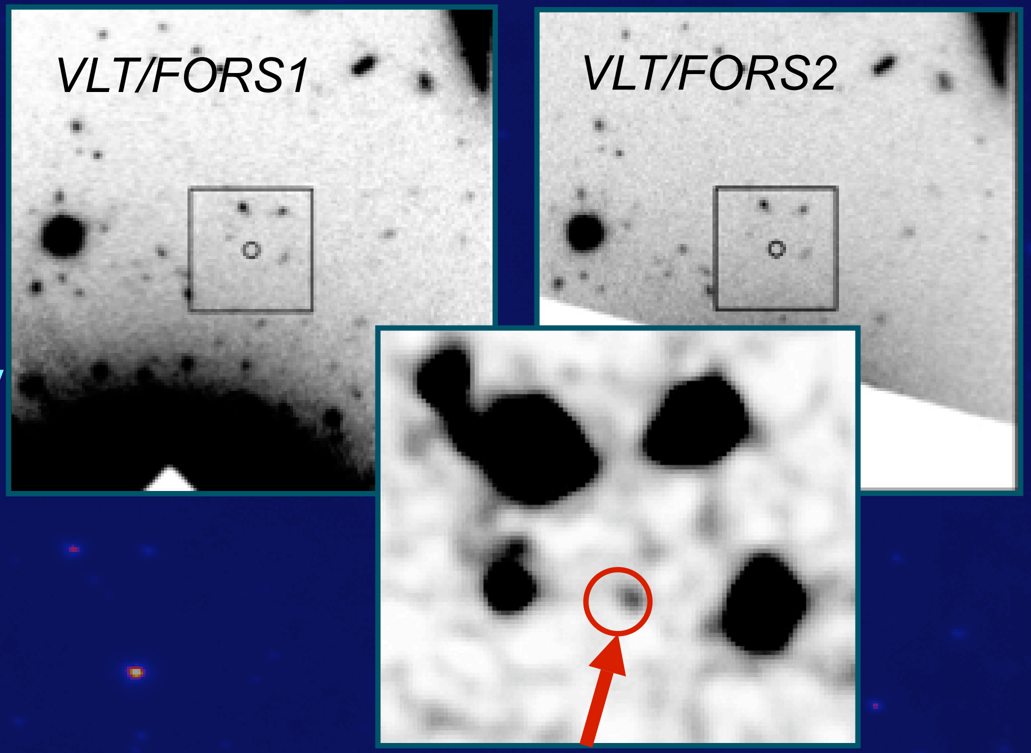






(Zharikov et al. 2008, Mignani et al. 2007a,b, Nasuti et al. 1998)

X-ray Dim Isolated Neutron Stars (XDINSs): Opt emission

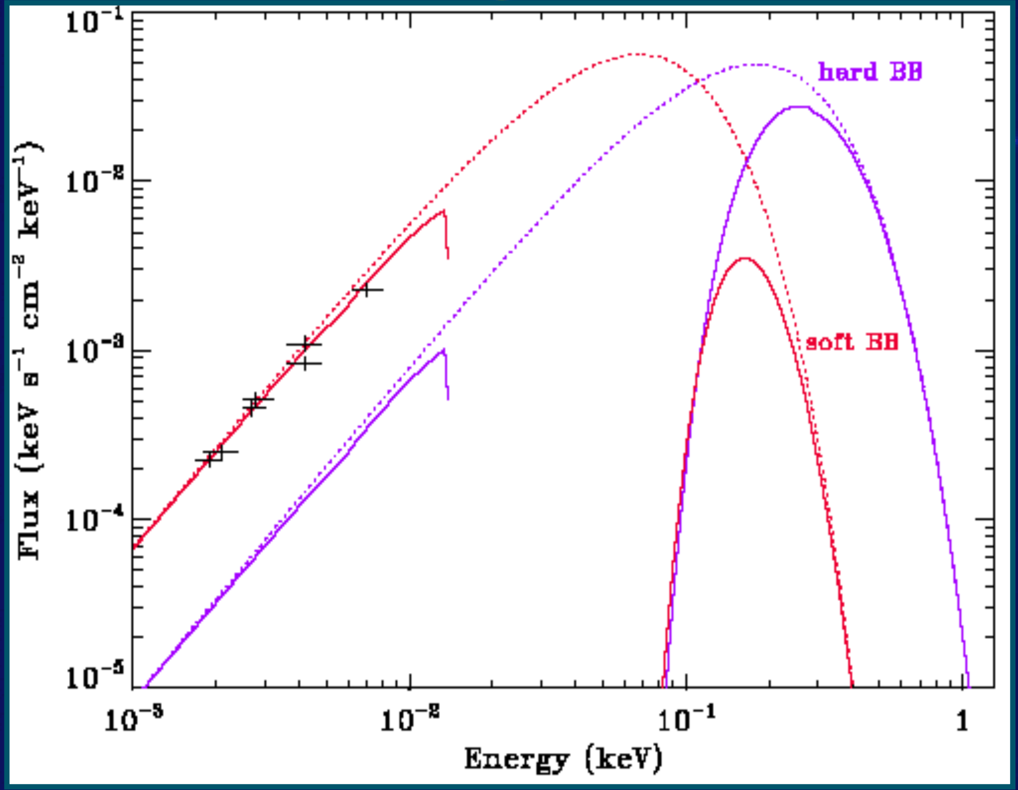


5 out of 7 XDINSs are identified in optical, mostly by ESO-VLT, CFHT, HST

- Identification from colors and F_x/F_{opt}
- Optical, only IR upper limits, no UV

Optical excess with respect to X-ray extrapolation

- Edot~10^{30} erg s^{-1} too low for synchrotron radiation
- Thermal radiation from the NS surface or atmosphere
- No optical pulsations



(Lo Curto et al. 2007, Rea et al. 2007, Mignani et al. 2008)

Magnetars (AXPs and SGRs): Opt-IR emission

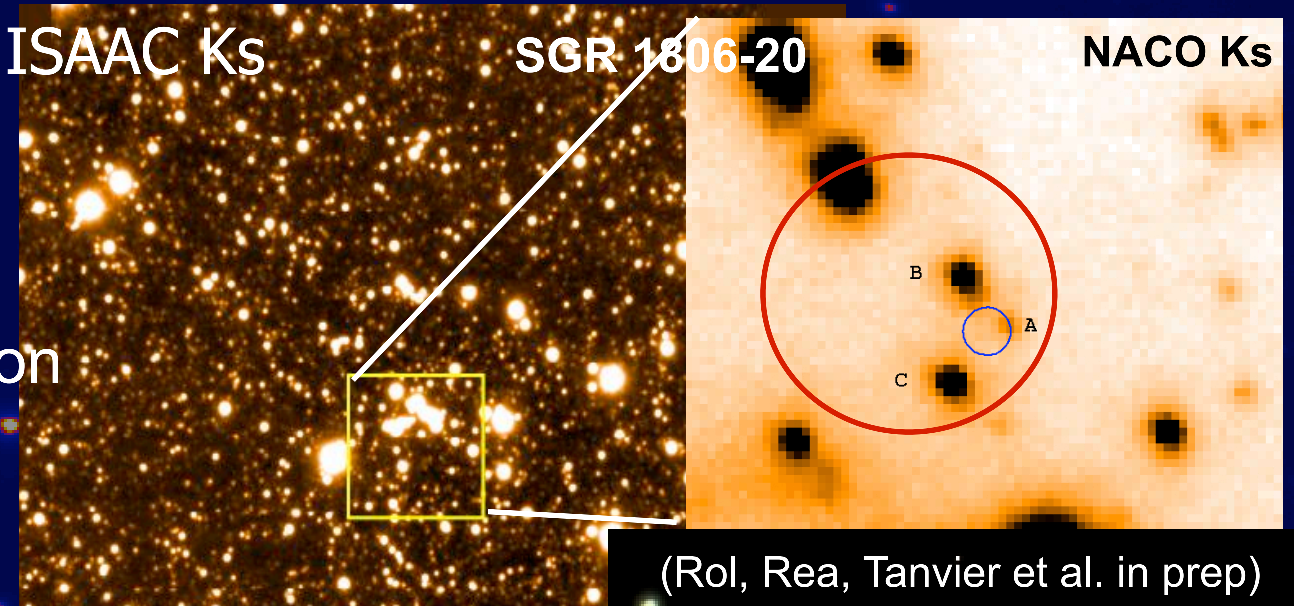
7 out of 17 magnetars have identified nIR counterparts, mostly by ESO- VLT

- Identification from IR variability, Chandra position
- Mostly IR, only two in the optical
- X-ray variability sometimes correlated with the Opt/IR one
- Highly affected by extinction

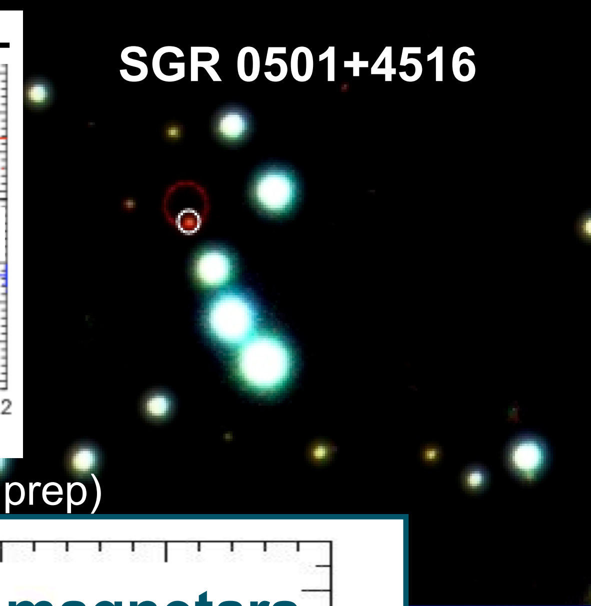
IR excess with respect to the X-ray extrapolation.

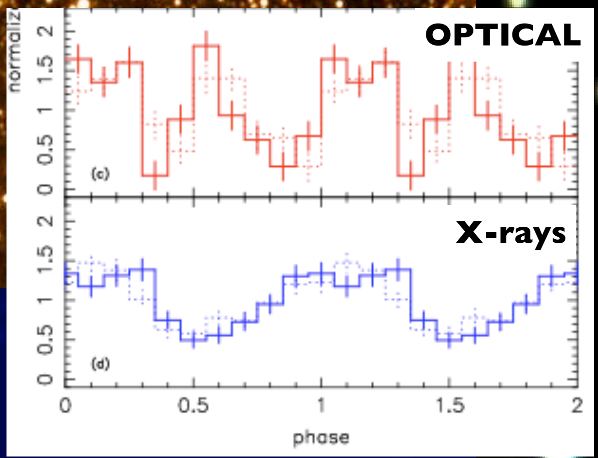
- $(L_{IR}/\dot{E})^{mag} >> (L_{IR}/\dot{E})^{psr}$
- IR powered by the B-field or by a (passive or not) reprocessing (viscous) disc?

3 have optical pulsations observed with UltraCam@VLT, with pulsed fractions higher than the X-ray one (cannot be disk reprocessing then!)

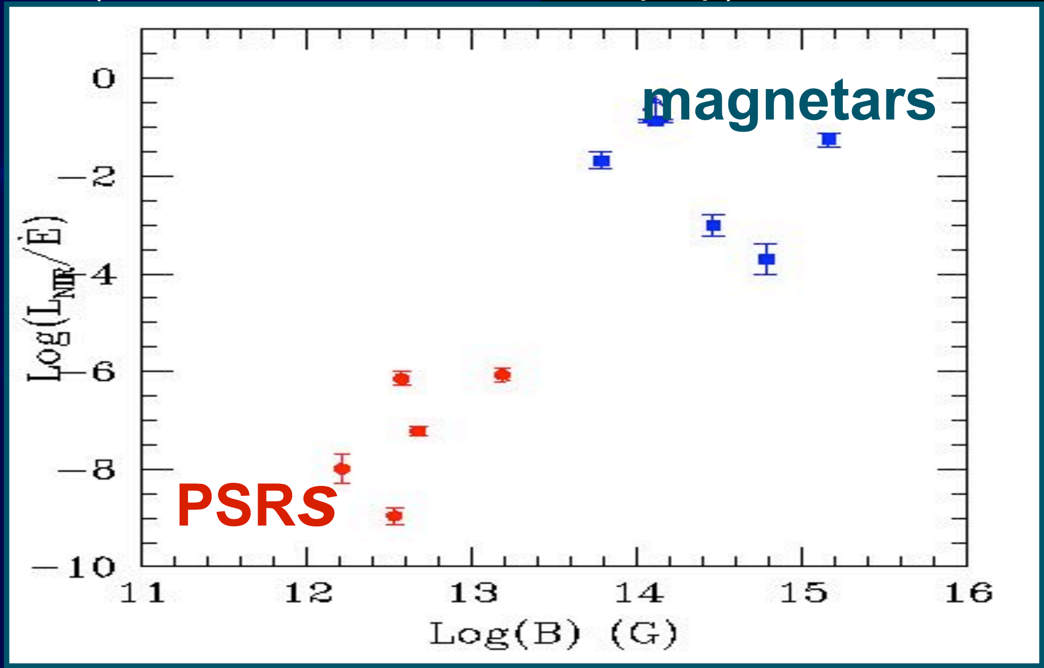


(Rol, Rea, Tanvier et al. in prep)





(Dhillon, Marsh, Rea et al. in prep)



(Israel et al. 2003, Rea et al. 2004, 2007; Durant & vanKerkwijk 2006)

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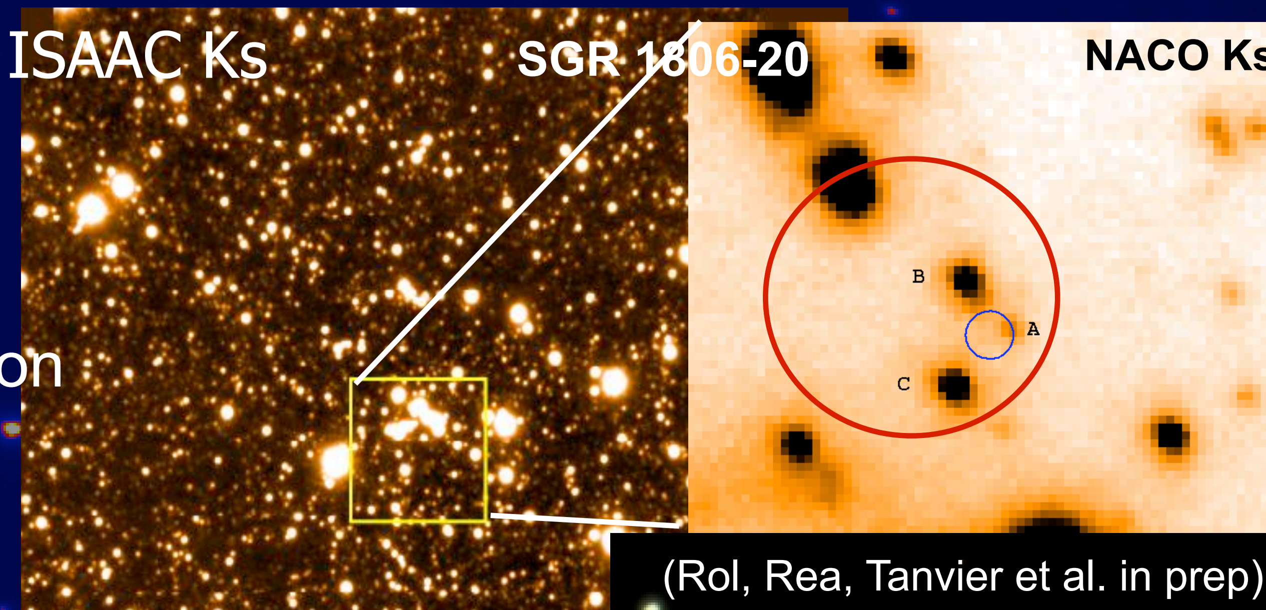

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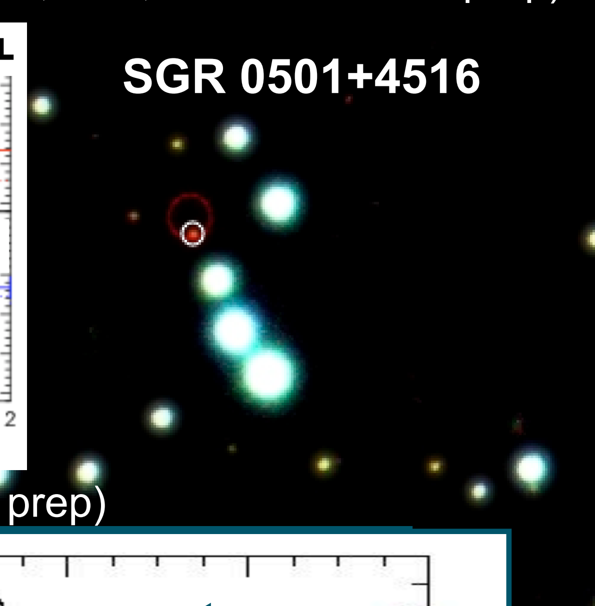

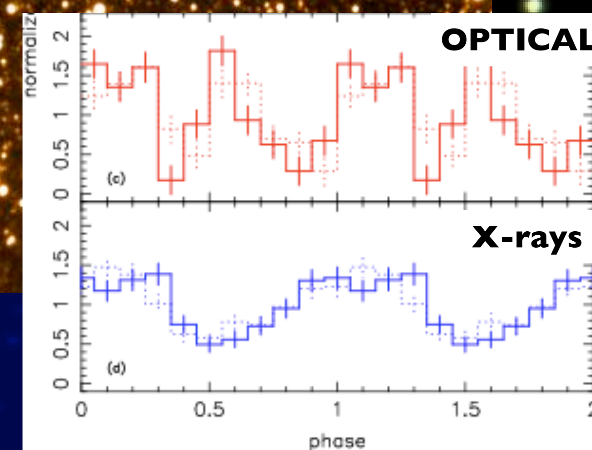

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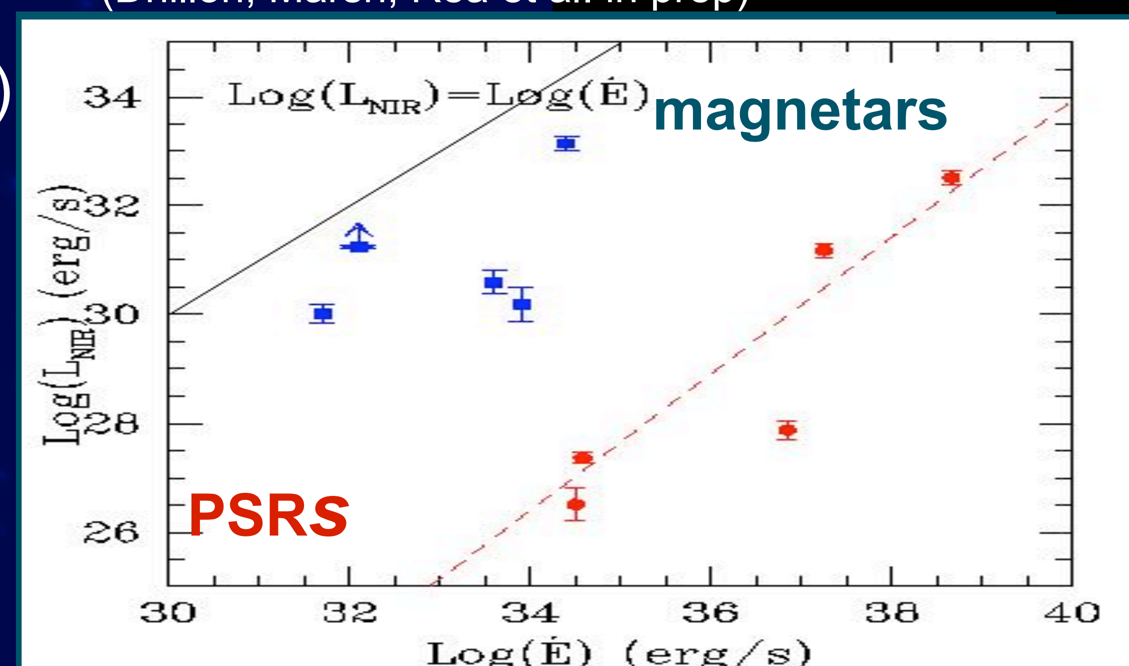


(Israel et al. 2003, Rea et al. 2004, 2007; Durant & vanKerkwijk 2006)

Rotating Radio Transients (RRATs): IR emission

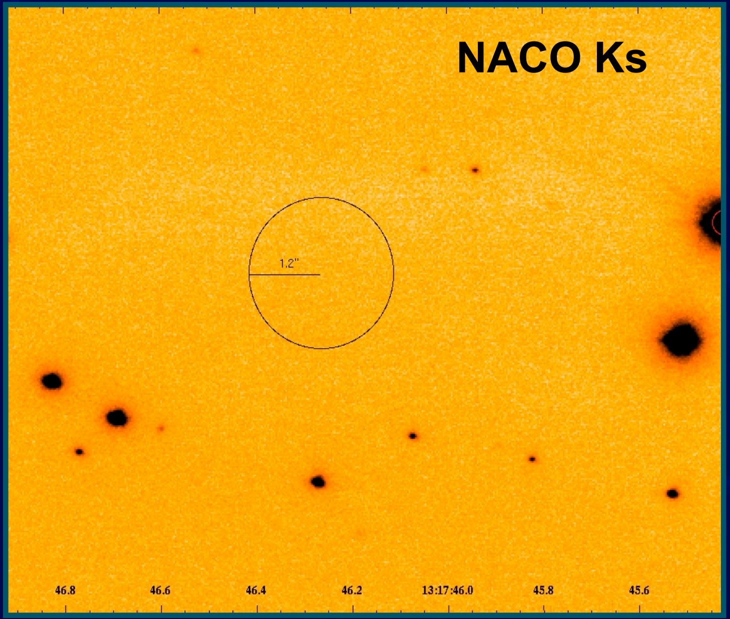
Search for bursts from J1819-1458 with UltraCam@WHT

- no optical bursts or counterparts detected

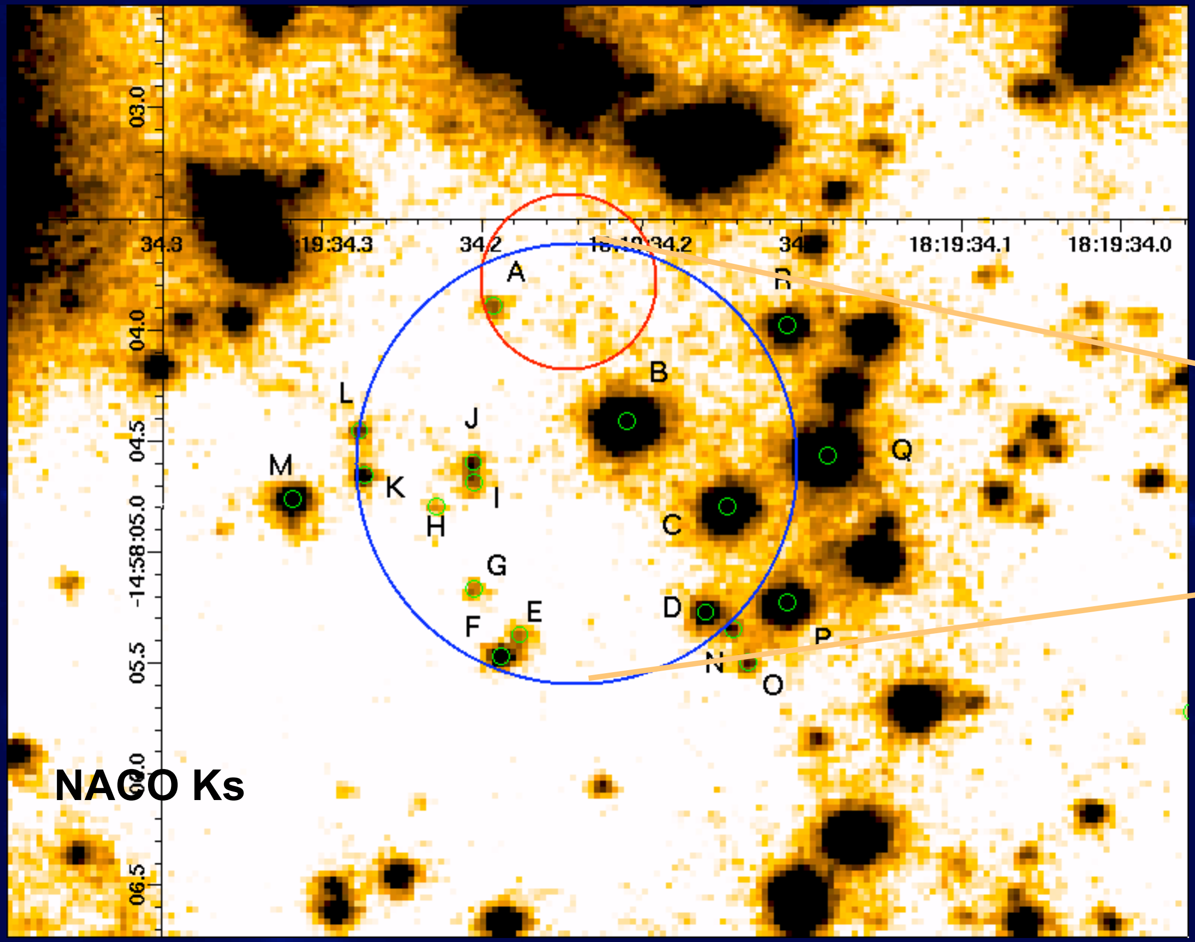
Recent ESO-VLT/NACO JHKs observations of RRATs

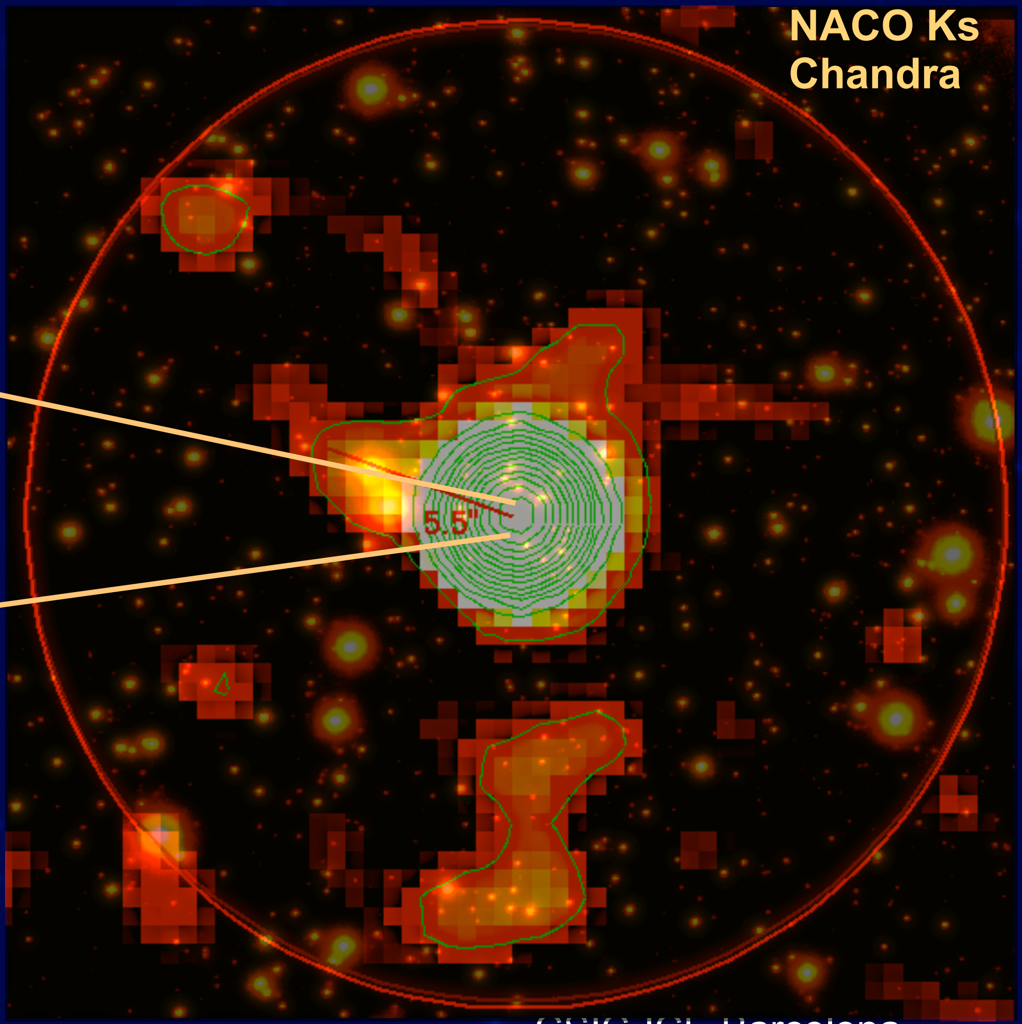
- 1 candidate counterpart for RRAT J1819-1458 (source A), but too dim for color studies
- no IR countarpart to its diffuse emission
- no candidate counterpart for RRAT J1317-5759

RRAT J1317-5759



RRAT J1819-1458





(IDhillon et al. 2006; Rea et al. 2009a, 2009b submitted)

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UV-Opt-IR emission: current census

Pulsars

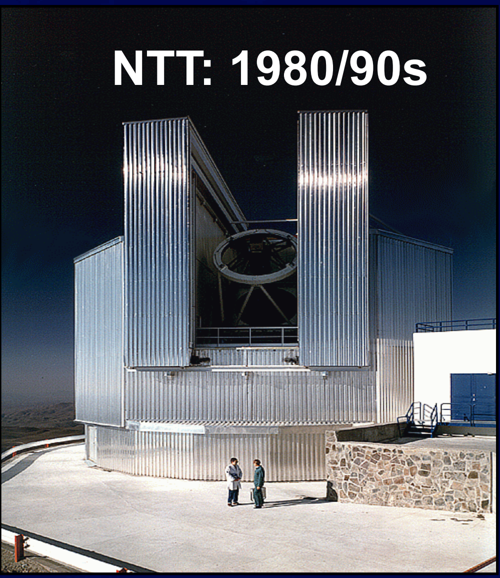
XDINSs

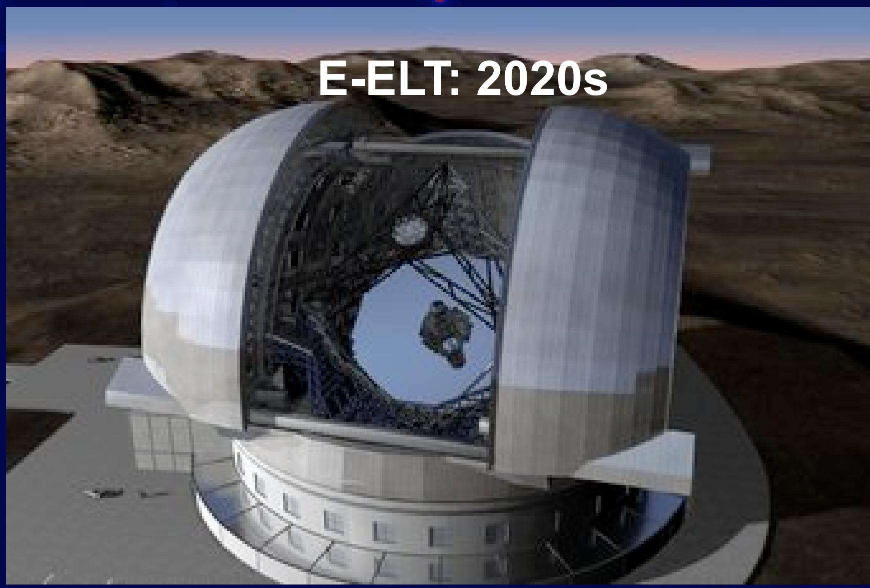
Magnetars

RRATs

Name	log Age	mag	D(kpc)	A_V	Phot	Spec	Pol	Puls
Crab	3.10	16.5	1.73	1.6	UVOIR	Y	Y	P
B1509-58	3.19	26	4.2	5.2	O		Y	
B0540-69	3.22	22	49.4	0.6	O	Y	Y	P
Vela	4.05	23.6	0.23	0.2	UVOIR	Y	Y	P
B0656+14	5.05	25	0.29	0.09	UVOIR	Y	Y	P
Geminga	5.53	25.5	0.16	0.07	UVOIR	Y		P
B1055-52	5.73	24.9	0.72	0.22	UVO			
B1929+10	6.49	25.6	0.33	0.15	UV			
B0950+08	7.24	27.1	0.26	0.03	UVO			
B1133+16	*6.69*	*28*	*0.35*	*0.12*	*O*			
J0108-1431	*8.3*	*27*	*0.3*	*0.1*	*O*			
J0437-471	9.20	26	0.14	0.11	UV	Y		
J1308.6+2127	*6.17*	*28.6*	*<1*	*0.14*	*O*			
J0720-3125	6.27	26.7	0.35	0.10	O			
J1856-3754	6.60	25.7	0.14	0.12	O	Y		
J1605.3+3249	-	26.8	<1	0.06	O			
RBS1774	-	27.4	<0.5	0.2	O			
SGR1806-20	3.14	20.1*	15	29	IR			
1E 1547.0-5408	3.14	20.2*	9	17	IR			
1E 1048.1-5937	3.63	21.3*	3	6.1	OIR		Y	P
XTE J1810-197	3.75	20.8*	4	5.1	IR		Y	
SGR 0501+4516	4.1	19.1*	5	5	OIR			P
4U 0142+61	4.84	20.1*	>5	5.1	OIR			P
1E 2259+586	5.34	21.7*	3	5.7	OIR			
RRAT 1819-5814	5.2	20.8	3	5.4	IR			

Conclusions





- Optical/IR studies are fundamental to address several issue on neutron star physics
- Optical/IR studies are crucial to draw a unified scheme of isolated neutron stars, to investigate their formation and evolution
- 40 years after identification of the Crab, optical astronomy of isolated neutron stars is still a very active field, where ESO marked important milestones with both the *NTT* and the *VLT*
- **Large collective areas and adaptive optics, to overcome crowding, and fast repointing of transient sources (as e.g. magnetars) are crucial ingredients**
- **The E-ELT will provide a unique view to these systems discovering hundreds more in the optical band, and closing long-standing open questions on their emission physics**

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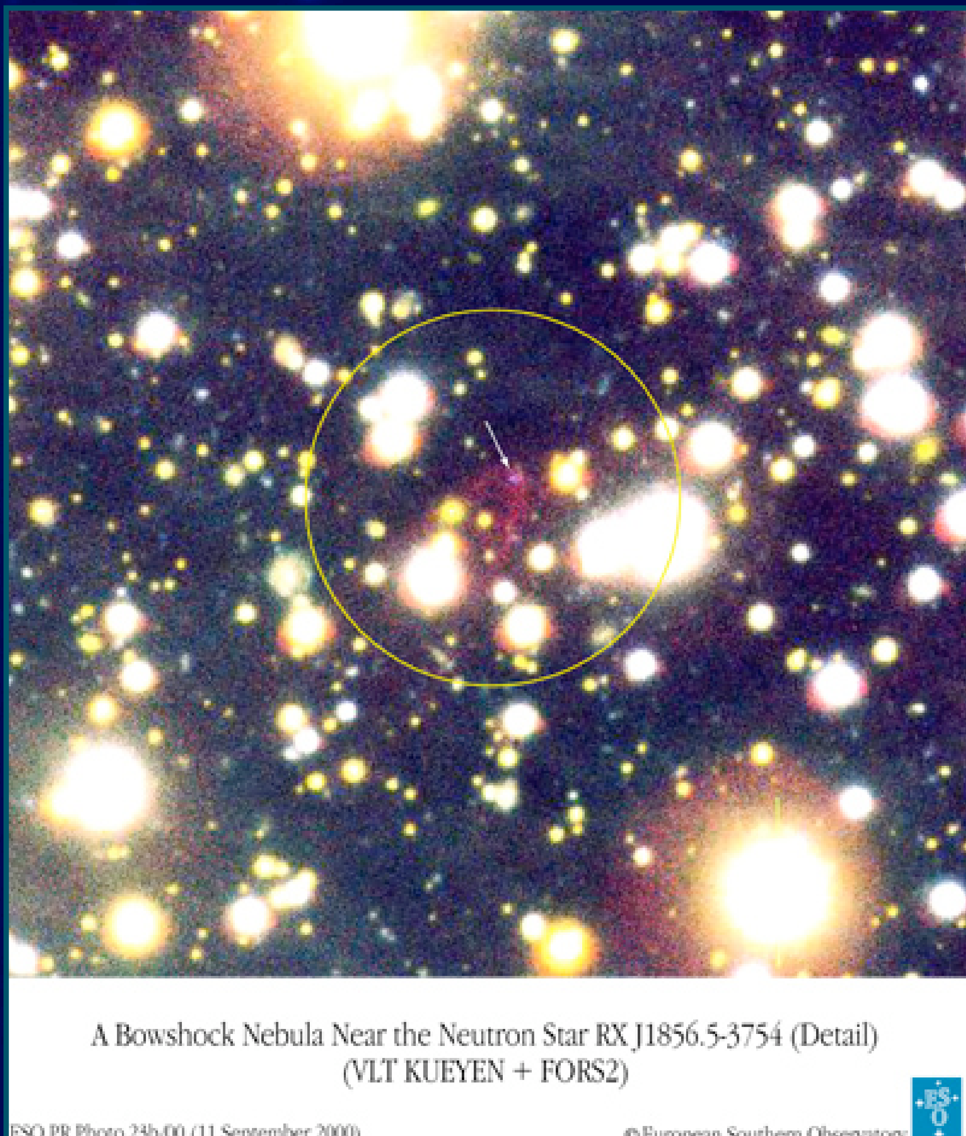
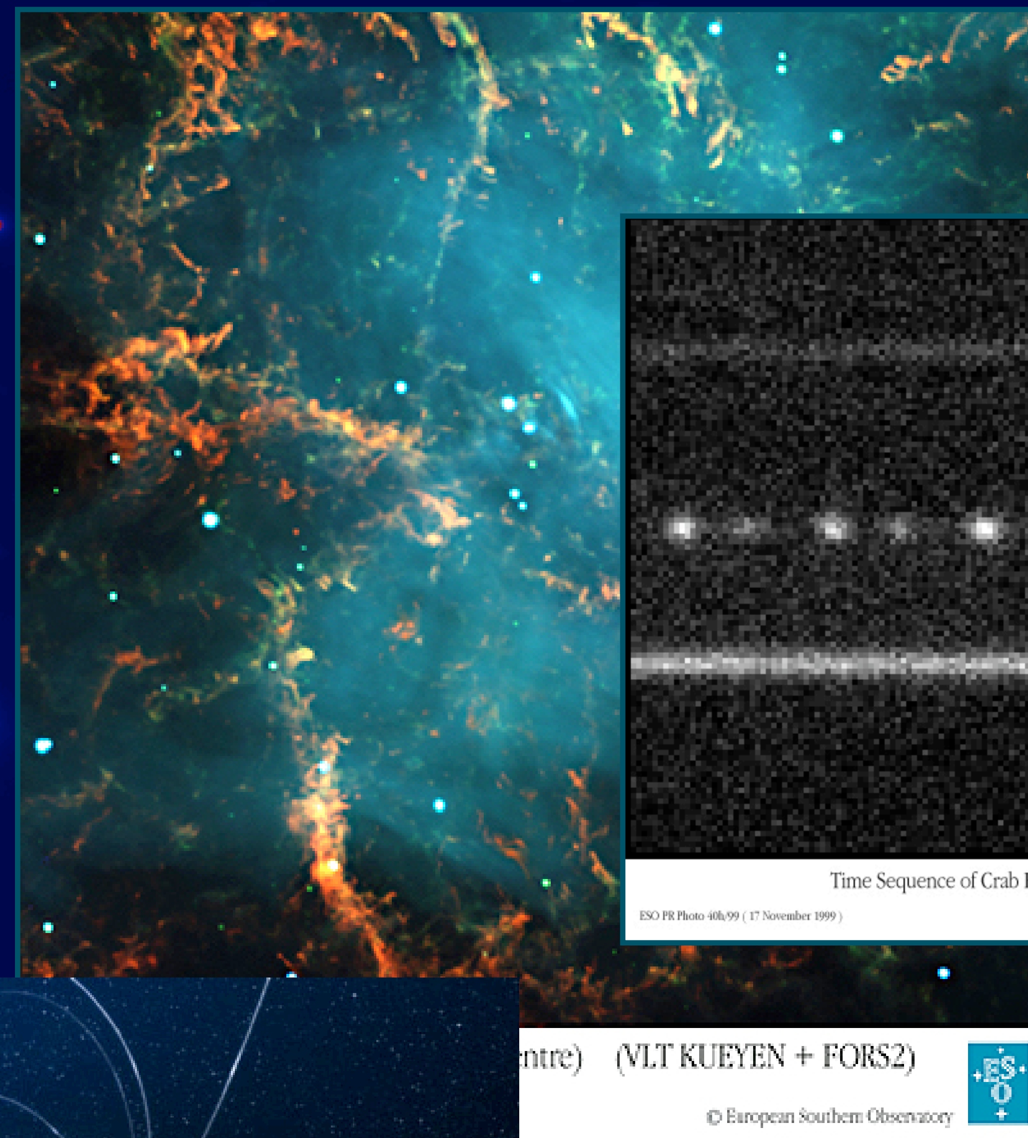
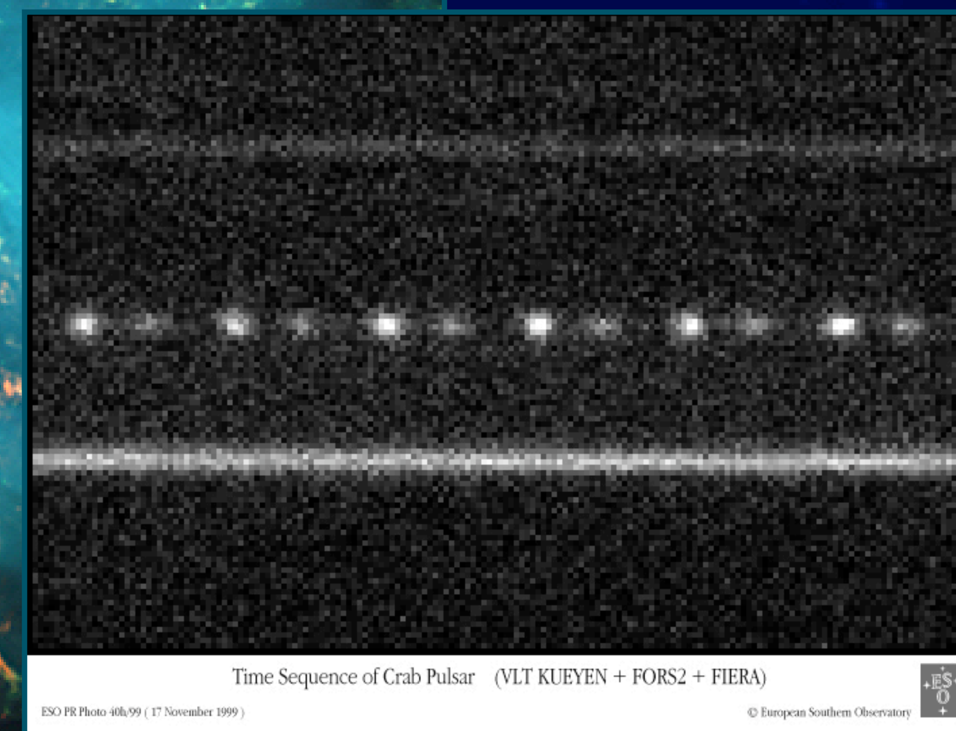
Science Impact of ESO neutron star research







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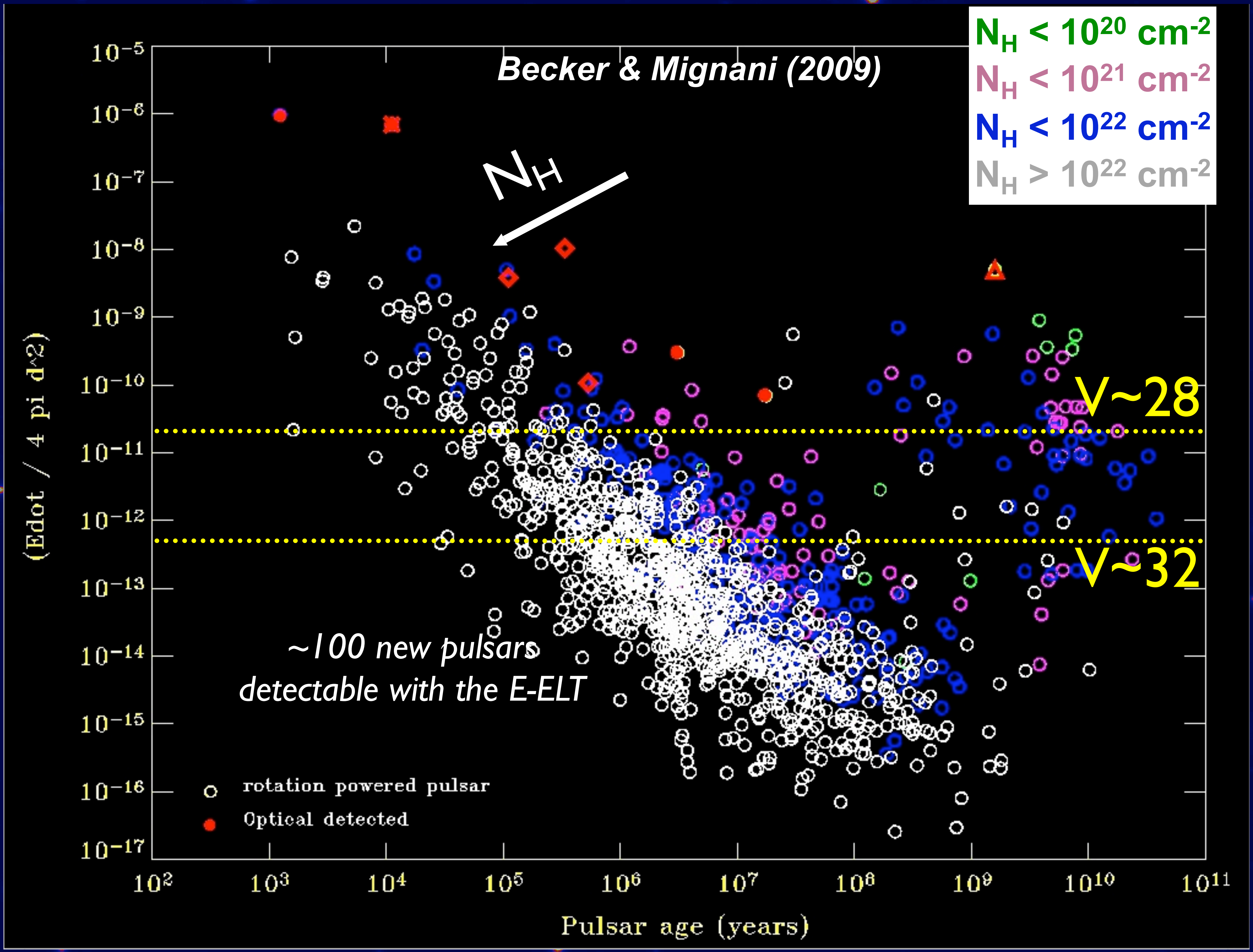
A new era with the E-ELT



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