New identifications of young Crab-like pulsars in the optical and infrared

Peter Lundqvist, Natalia Lundqvist, Jesper Sollerman (Stockholm Observatory),

Dima Zyuzin, Andrey Danilenko, Aida Kirichenko

(Ioffe Inst.),

Sergey Zharikov (UNAM),

Ronald Mennickent (Univ. de Concepcion),

Viktoriya Komarova (SAO, N. Arkhyz)

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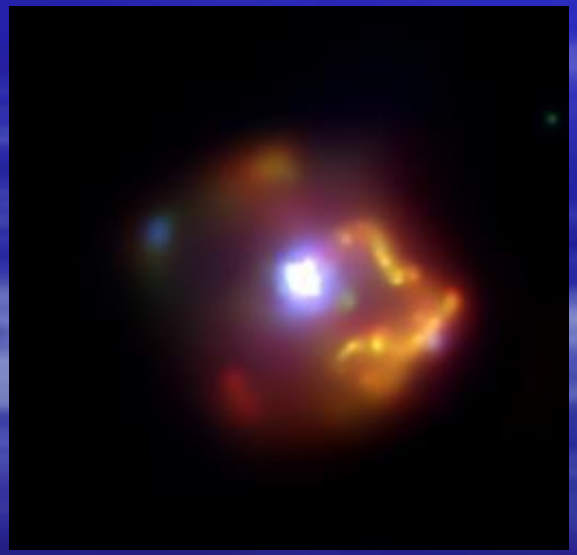
Outline

- Motivation
- Target selection for our optical study
- Results
- Conclusions

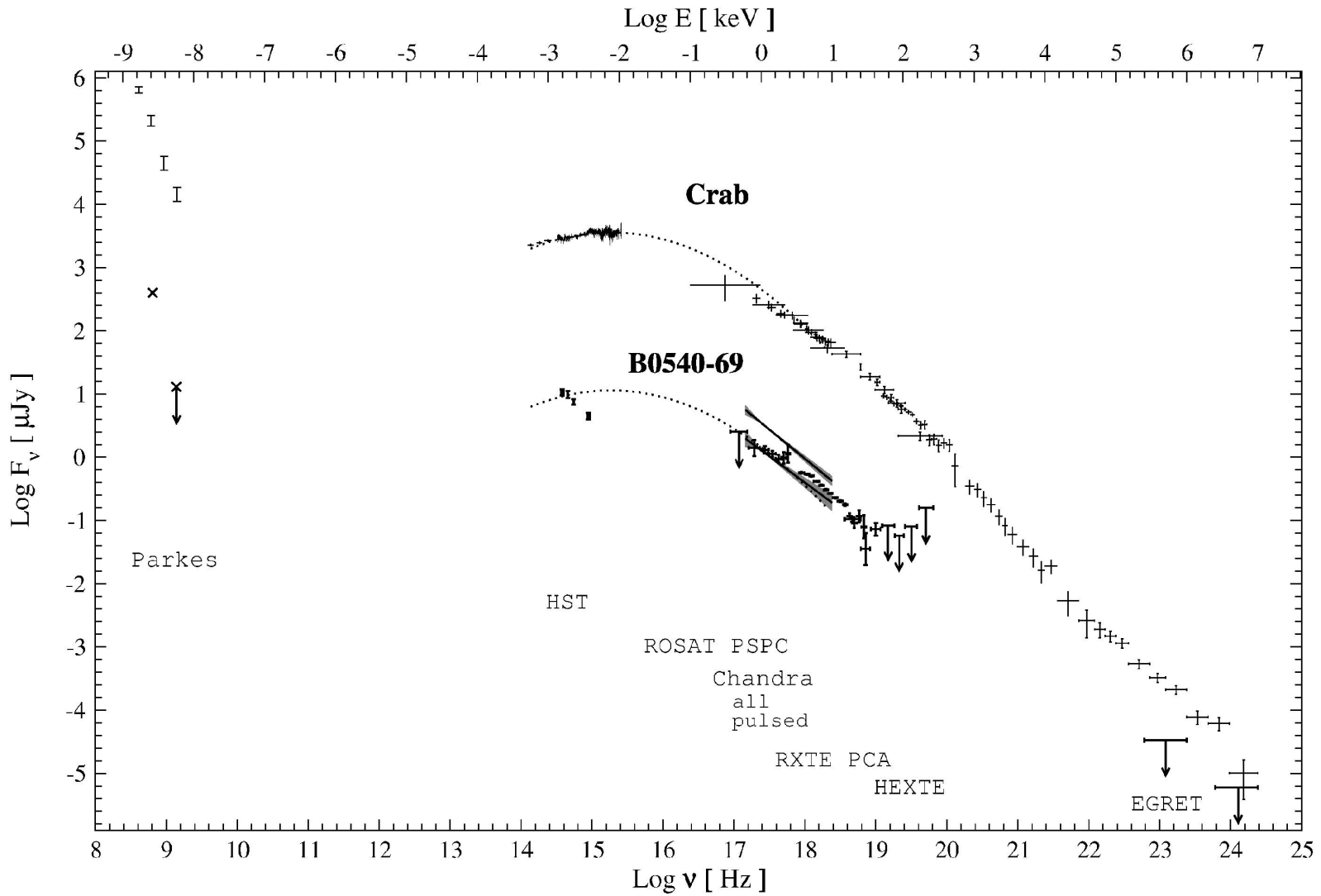
Seven years ago we compared two very similar young pulsars detected with their PWNe in the optical and X-rays

Crab
(opt+ X-rays)

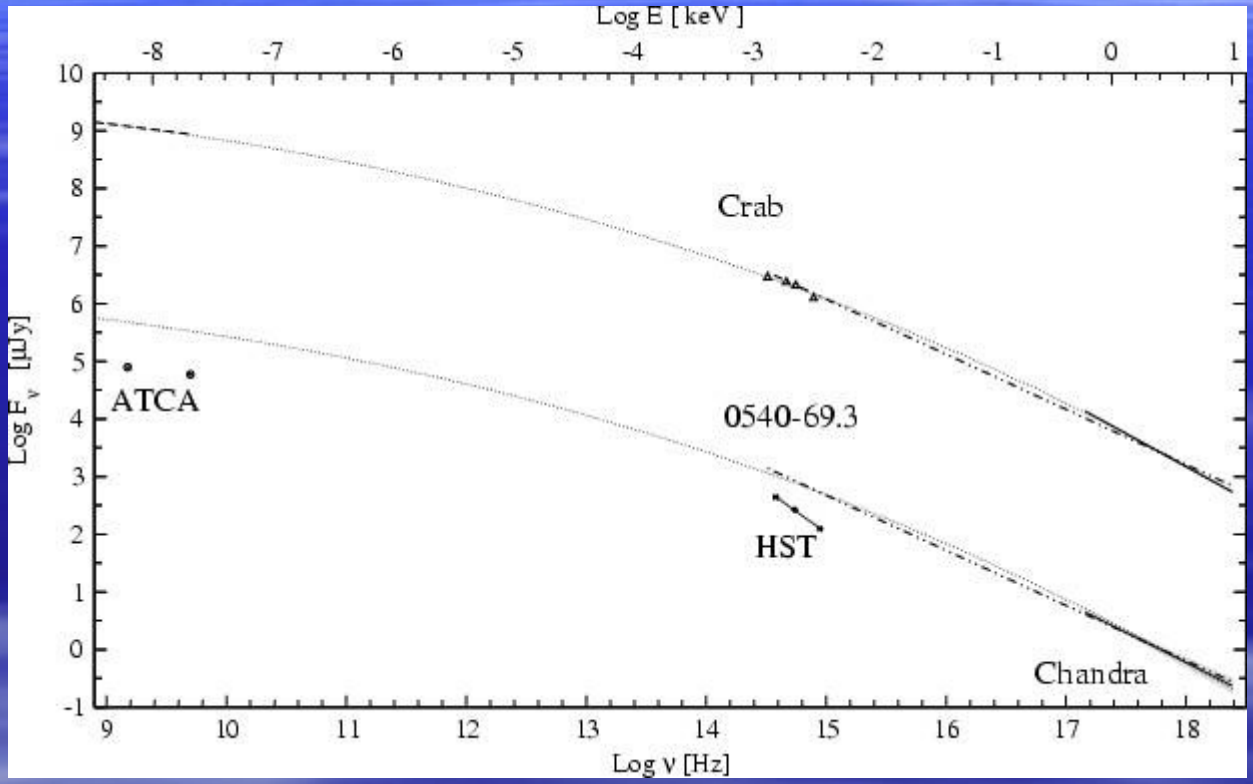
PSR B0540-69.3



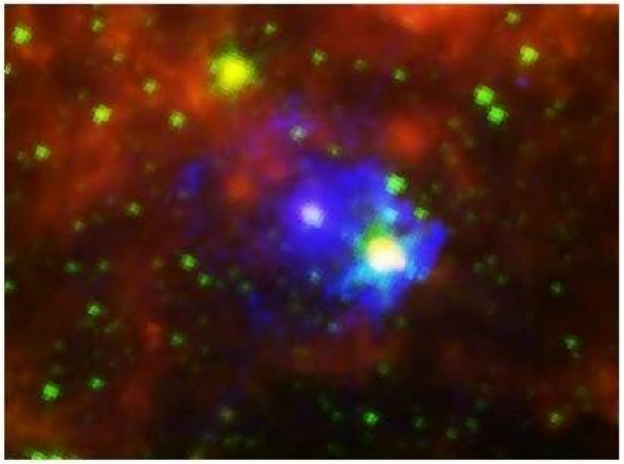
Chandra observation 0.3-10 keV, press release photos.


Log E [keV]
-9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
Log F_ν [μJy]
6 5 4 3 2 1 0 -1 -2 -3 -4 -5
Crab
B0540-69
Parkes
HST
ROSAT PSPC
Chandra
all
pulsed
RXTE PCA
HEXTE
EGRET
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Log ν [Hz]

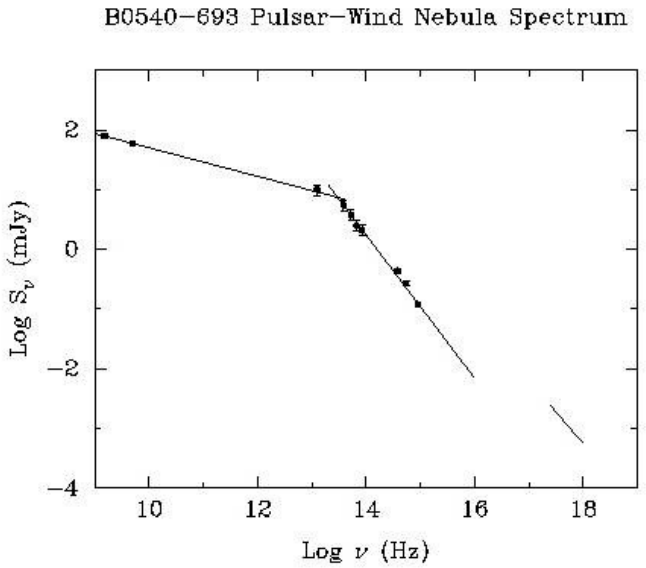
B0540 and Crab PWNe spectra



(Second) Youngest SNR in MCs: 0540-693



Red, 24 μm; green, 3.6 μm;
blue, *Chandra* X-rays



Right: Total spectrum of PWN. Our 24 μm point falls exactly on radio extrapolation; sharp steepening near 20 μm (slope change 0.8 – not synchrotron losses?)

From Williams et al 2008

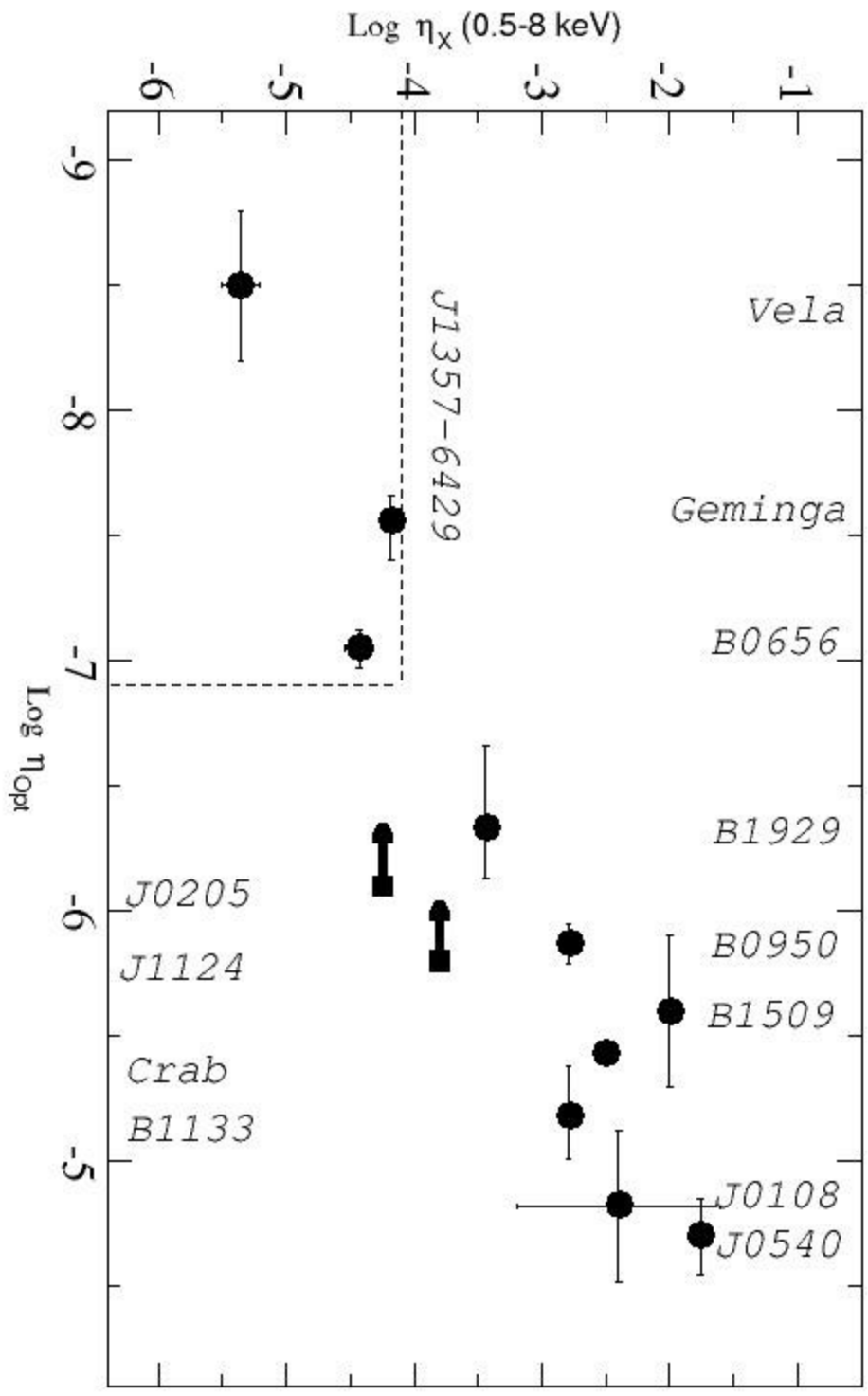
The problem and motivation.

- Most emission models for rotation powered pulsars and their PWNe are constructed to explain the Crab spectrum.
  - However, they cannot not be simple applied to B0540-69 with its
    double knee break between the optical and X-rays.
- What is the situation for other young pulsars?

To answer this questions, one has to increase the number of optically identified young pulsars.

Targets to search for optical counterparts

- Young and energetic nearby pulsars associated with SNRs
- Which are firmly detected in X-rays
- And are expected to be detectable in the optical based on an empirical relationship between the optical and X-ray efficiencies for non-thermal emission found by Zharikov et al. 2006.


Log η_X (0.5-8 keV)
-6
-5
-4
-3
-2
-1
-9
-8
-7
-6
-5
Log η_{Opt}
J1357−6429
Vela
Geminga
B0656
B1929
B0950
B1509
J0205
J1124
Crab
B1133
J0108
J0540

Targets

PSR J0205+6449, associated with SNR 3C 58, P= 65.68 ms, characteristic age τ=5.4 kyr, spindown luminosity É=3.7e37 erg/s, d= 3.2 kpc

PSR J1124-5916, associated with SNR G292.0+1.8, P= 135 ms, characteristic age τ=2.9 kyr, spindown luminosity É=1.2e37 erg/s, d= 6 kpc

PSR J1357-6429, suspected to be associated with SNR candidate G309.8+2.5, P= 166 ms, characteristic age τ=7.3 kyr, spindown luminosity É=3.1e36 erg/s, d= 2 5kpc

All of them have been detected in X-rays and have extended PWNe

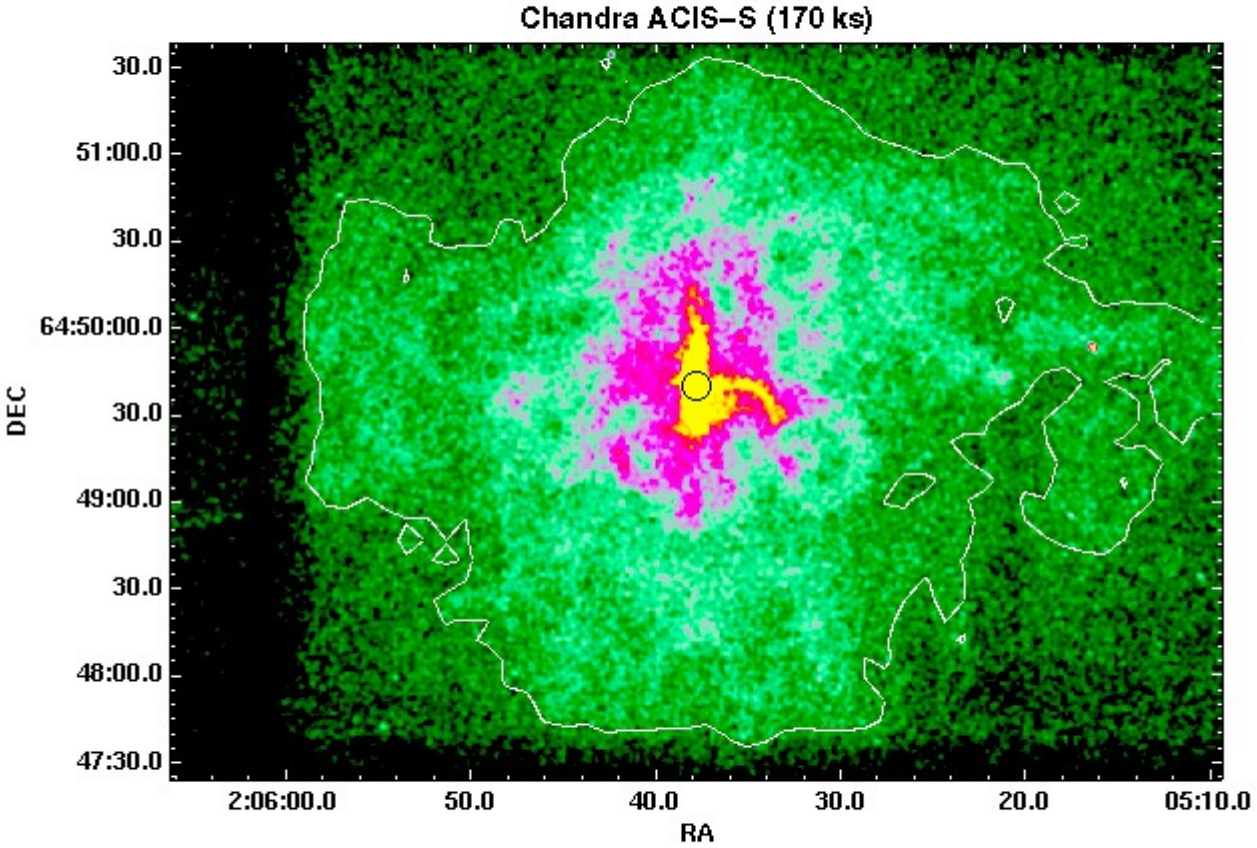
Method

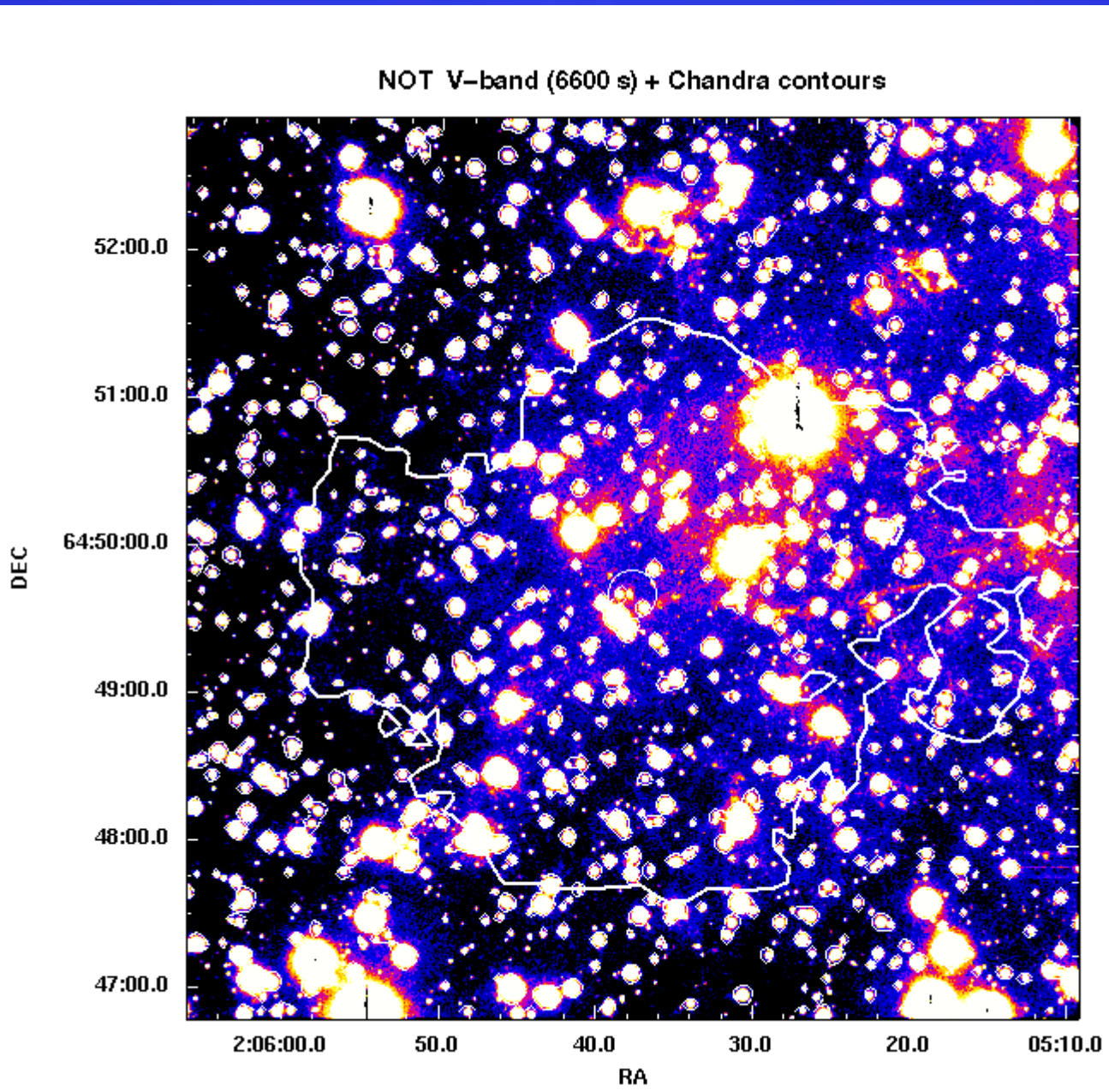
- The fields of the pulsars have not been observed in the optical. As a first step, we did a simple broadband multicolor imaging at a required deepness level of 24-27 mag, depending on the object.
- Accurate astrometry is needed for identification by position.
- And accurate photometry for confirmation of this Identification by a peculiar color of a candidate and its multi-wavelength spectral energy distribution (SED).

3C 58: Nordic Optical Telescope

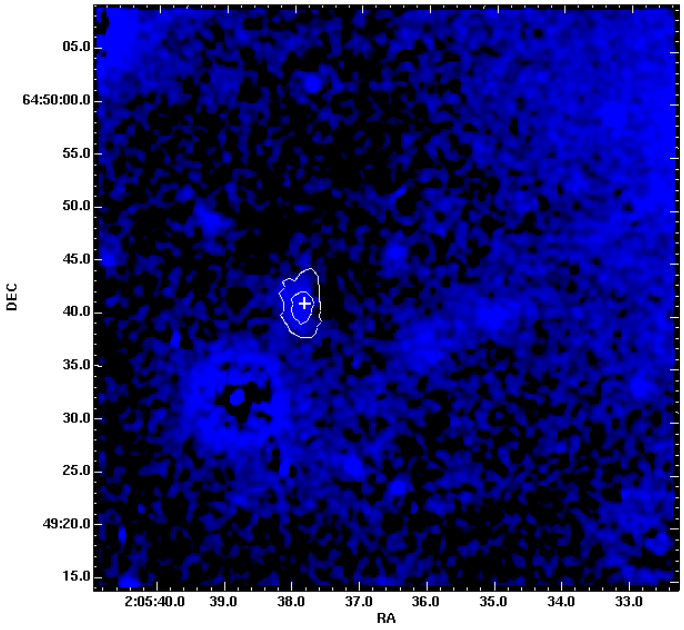
- 2.4 m telescope at La Palma

The field of 3C 58 was observed on Oct 22-23 2006 with Andalucia Fain Object Spectrograph and Camera (ALFOSC) in the B and V bands. FOV - 6'.5x6'.5; pixel scale of the CCD - 0.19"; mean seeing 0.75" with photometric conditions. Total exposure - 5400 s in B and 6600 s in V. Photometric Standard PG0231+051 was taken the same night. Standard data reduction with IRAF tools.

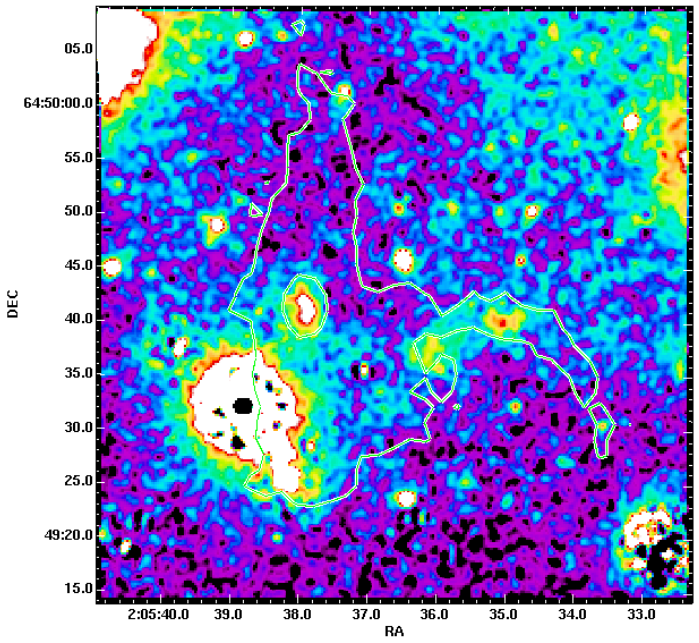

Chandra ACIS–S (170 ks)
30.0
51:00.0
30.0
64:50:00.0
30.0
49:00.0
30.0
48:00.0
47:30.0
DEC
2:06:00.0
50.0
40.0
30.0
20.0
05:10.0
RA


NOT V−band (6600 s) + Chandra contours
52:00.0
51:00.0
64:50:00.0
49:00.0
48:00.0
47:00.0
DEC
2:06:00.0
50.0
40.0
30.0
20.0
05:10.0
RA

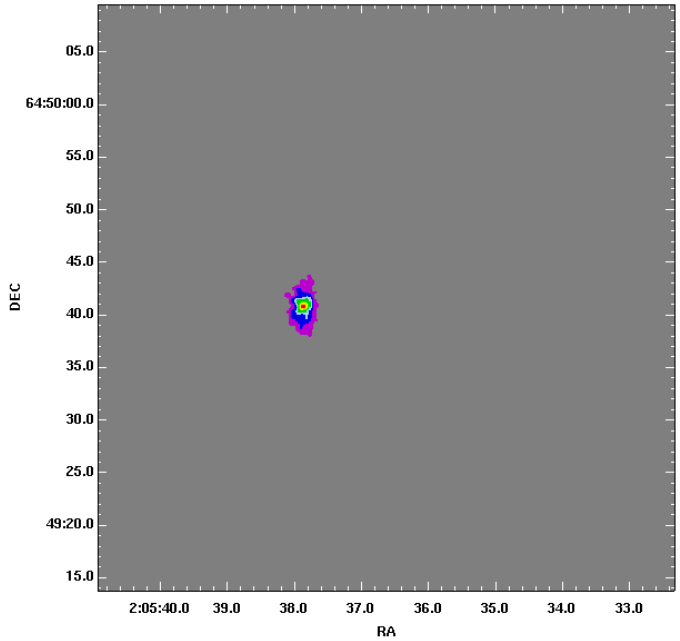
B–band zoomed with HRC X–ray contours



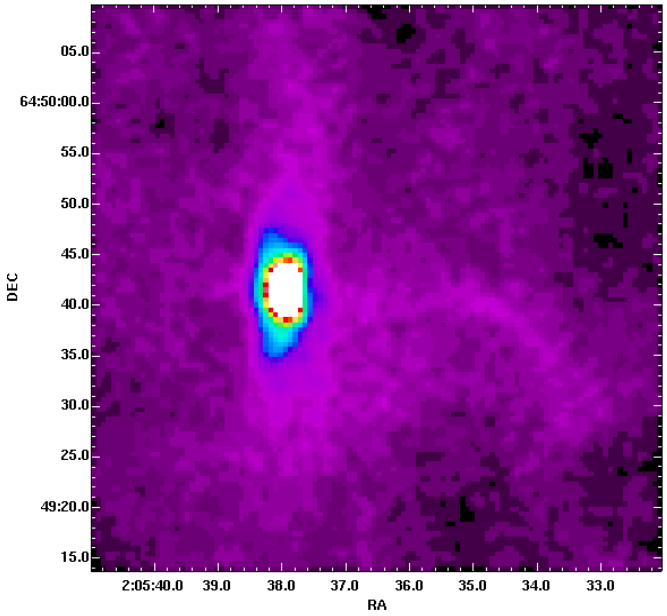
V–band zoomed with ACIS X–ray contours

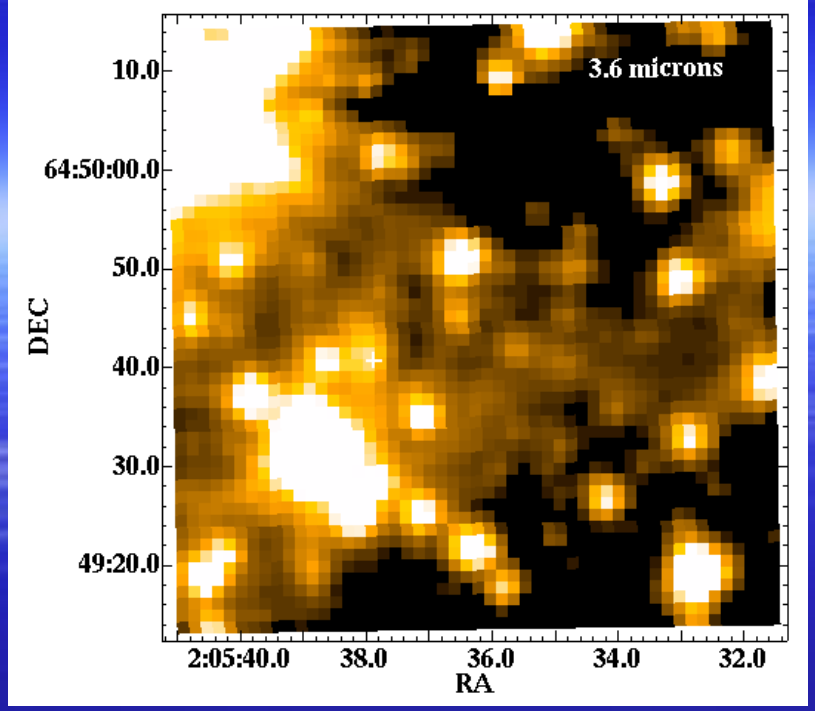


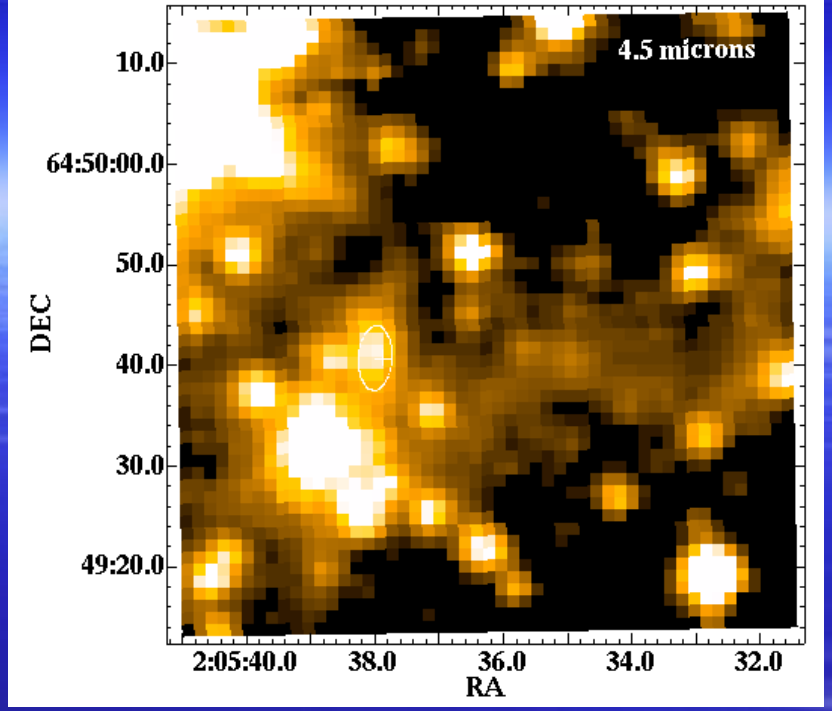
Chandra HRC–S zoomed (33.5 ks)

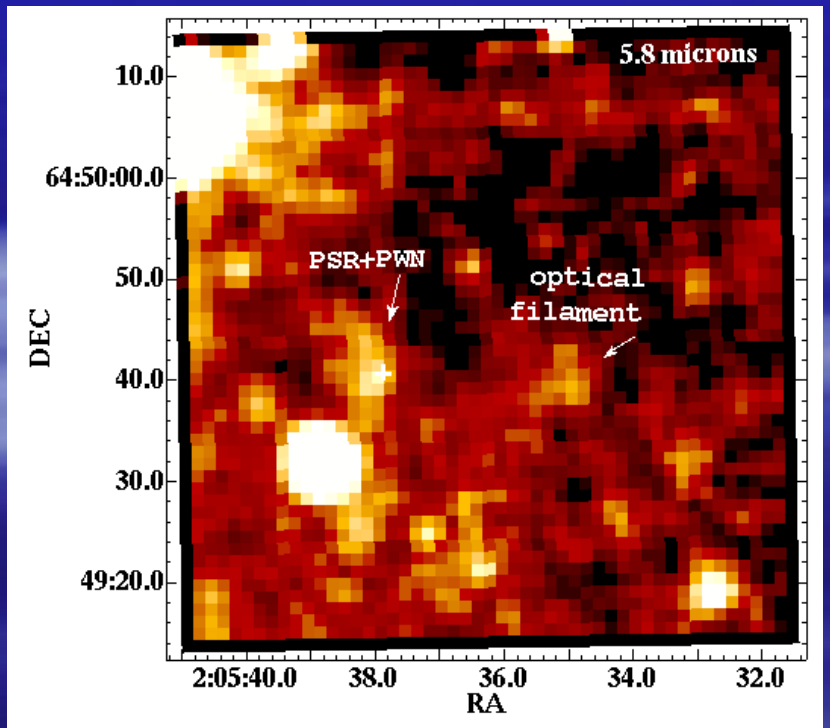


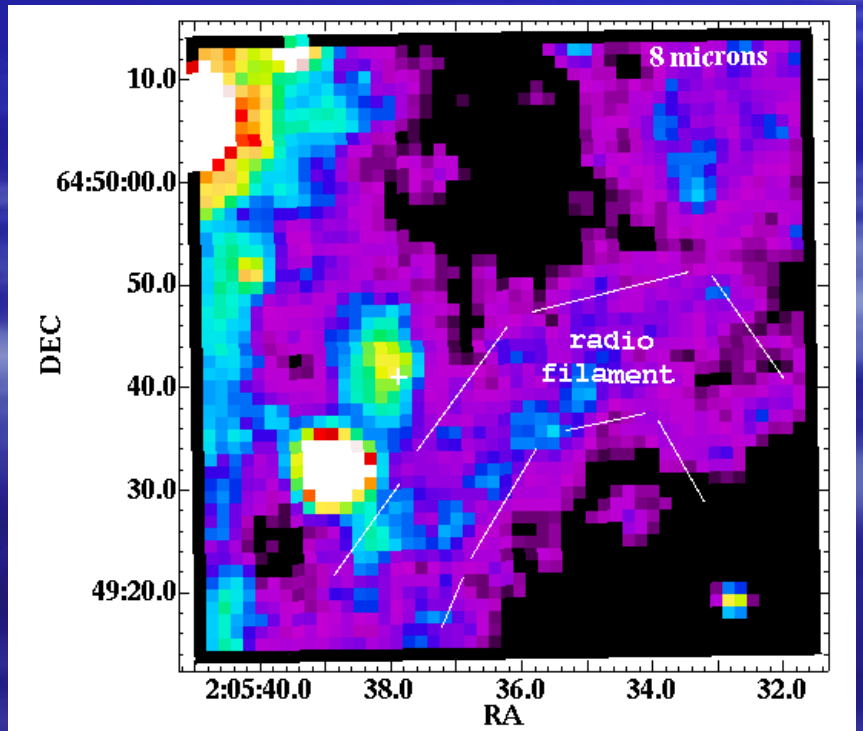
Chandra ACIS–S zoomed

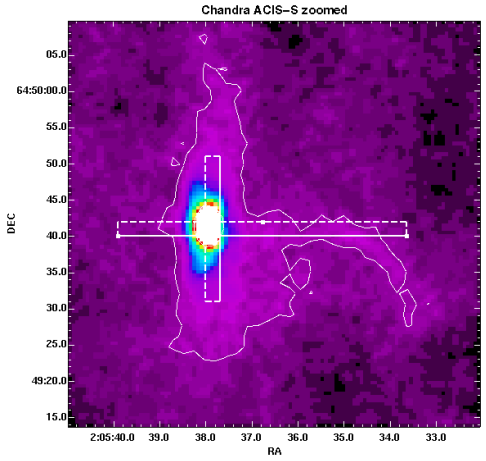


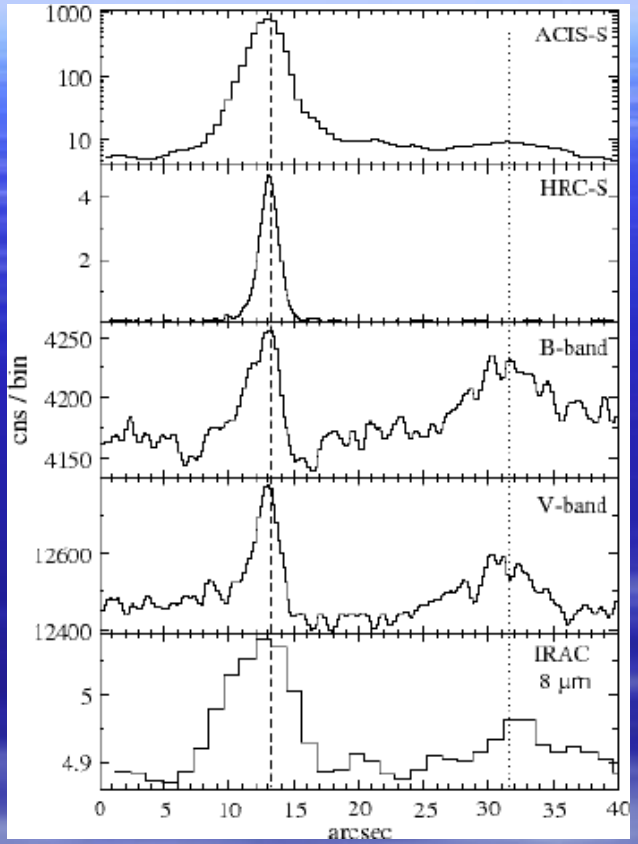

3.6 microns
10.0
64:50:00.0
50.0
40.0
30.0
49:20.0
DEC
2:05:40.0
38.0
36.0
34.0
32.0
RA

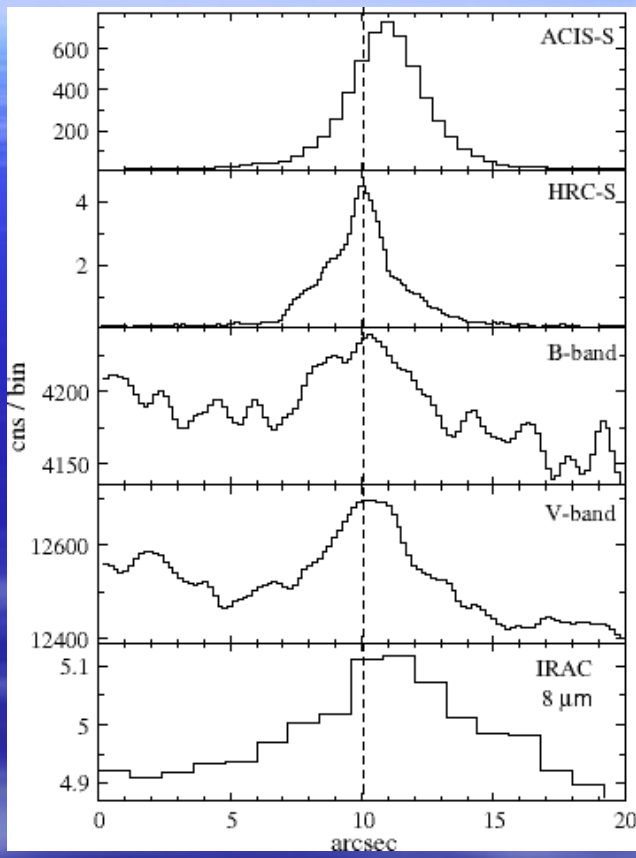

4.5 microns
10.0
64:50:00.0
50.0
40.0
30.0
49:20.0
DEC
2:05:40.0
38.0
36.0
34.0
32.0
RA


5.8 microns
PSR+PWN
optical
filament
10.0
64:50:00.0
50.0
40.0
30.0
49:20.0
DEC
2:05:40.0
38.0
36.0
34.0
32.0
RA


8 microns
radio
filament
10.0
64:50:00.0
50.0
40.0
30.0
49:20.0
DEC
2:05:40.0
38.0
36.0
34.0
32.0
RA

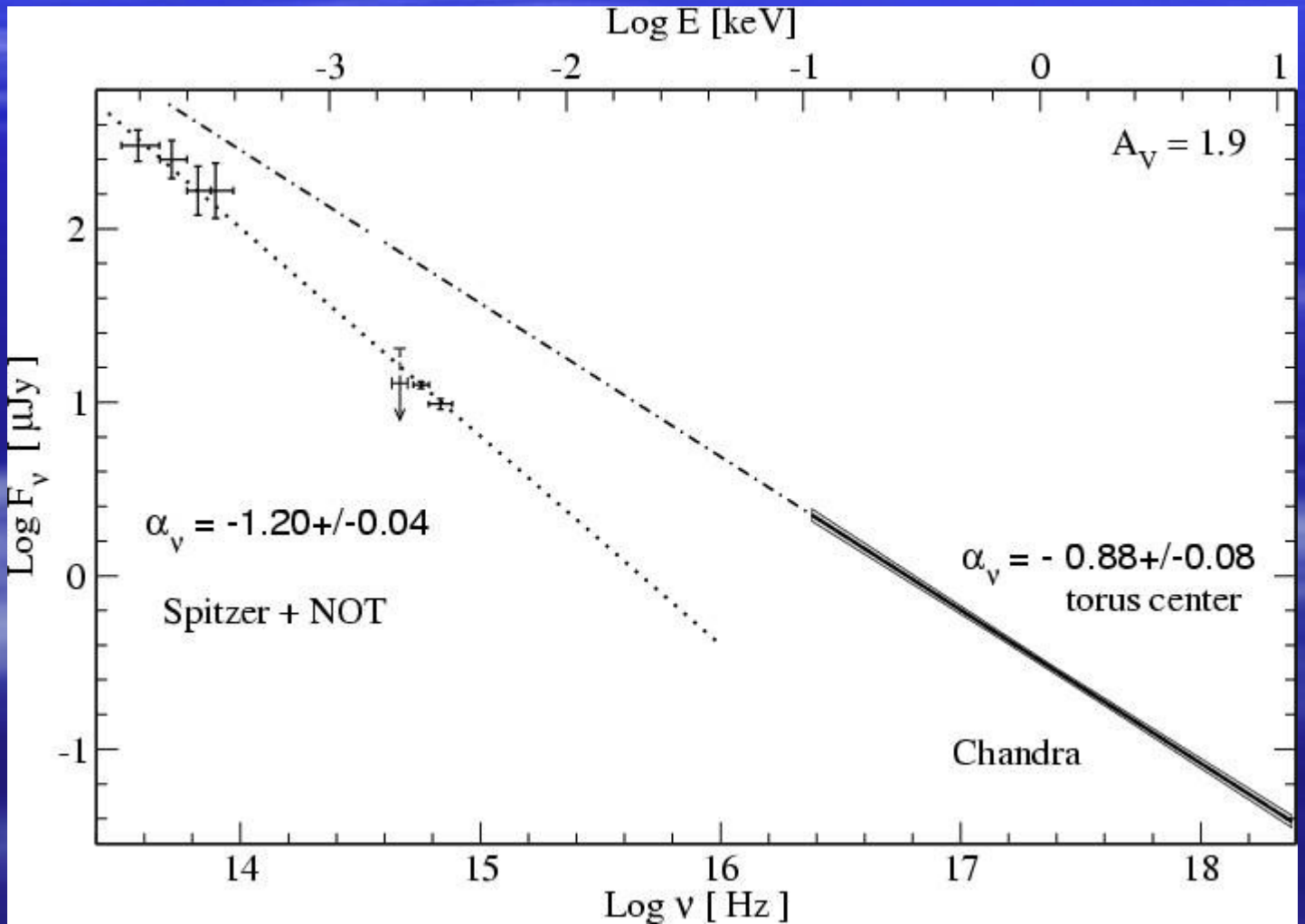




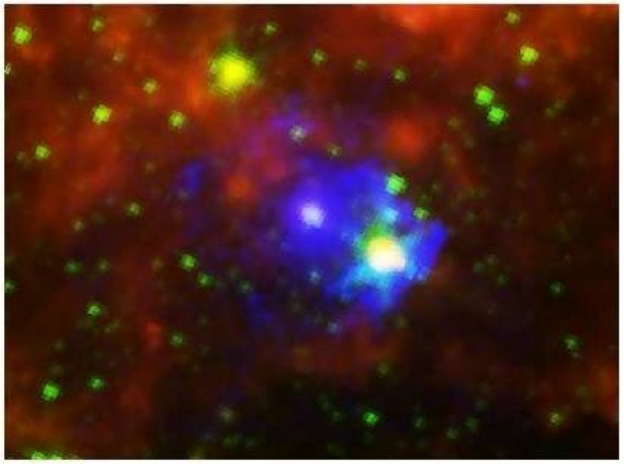


A comparison of spatial profiles of the PSR+PWN candidate in different spectral ranges. HRC pixel-size is 0.13”, NOT – 0.19”, ACIS - 0.5”, Spitzer – 1.2” .

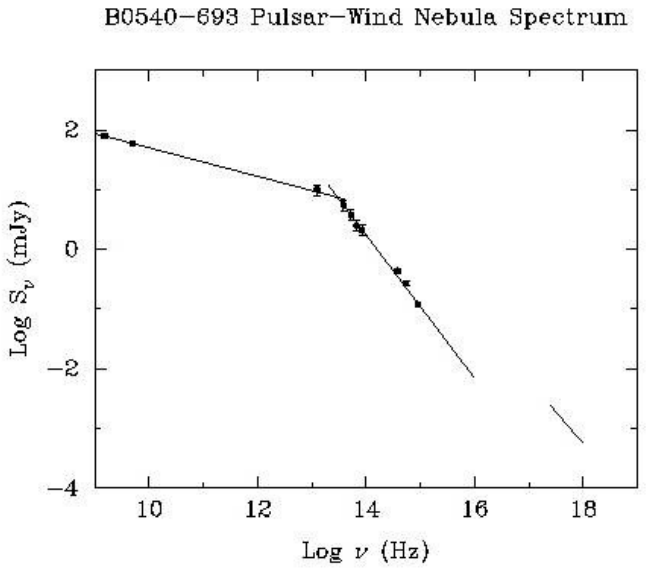
Multiwavelength spectrum of the 3C 58 pulsar+PWN system dereddened with a most plausible Av, estimated from Balmer decrement of the spectral SNR study (Fesen 2007) and NH column density from the X-ray spectral fit. (Shibanov et al. 2008).



(Second) Youngest SNR in MCs: 0540-693

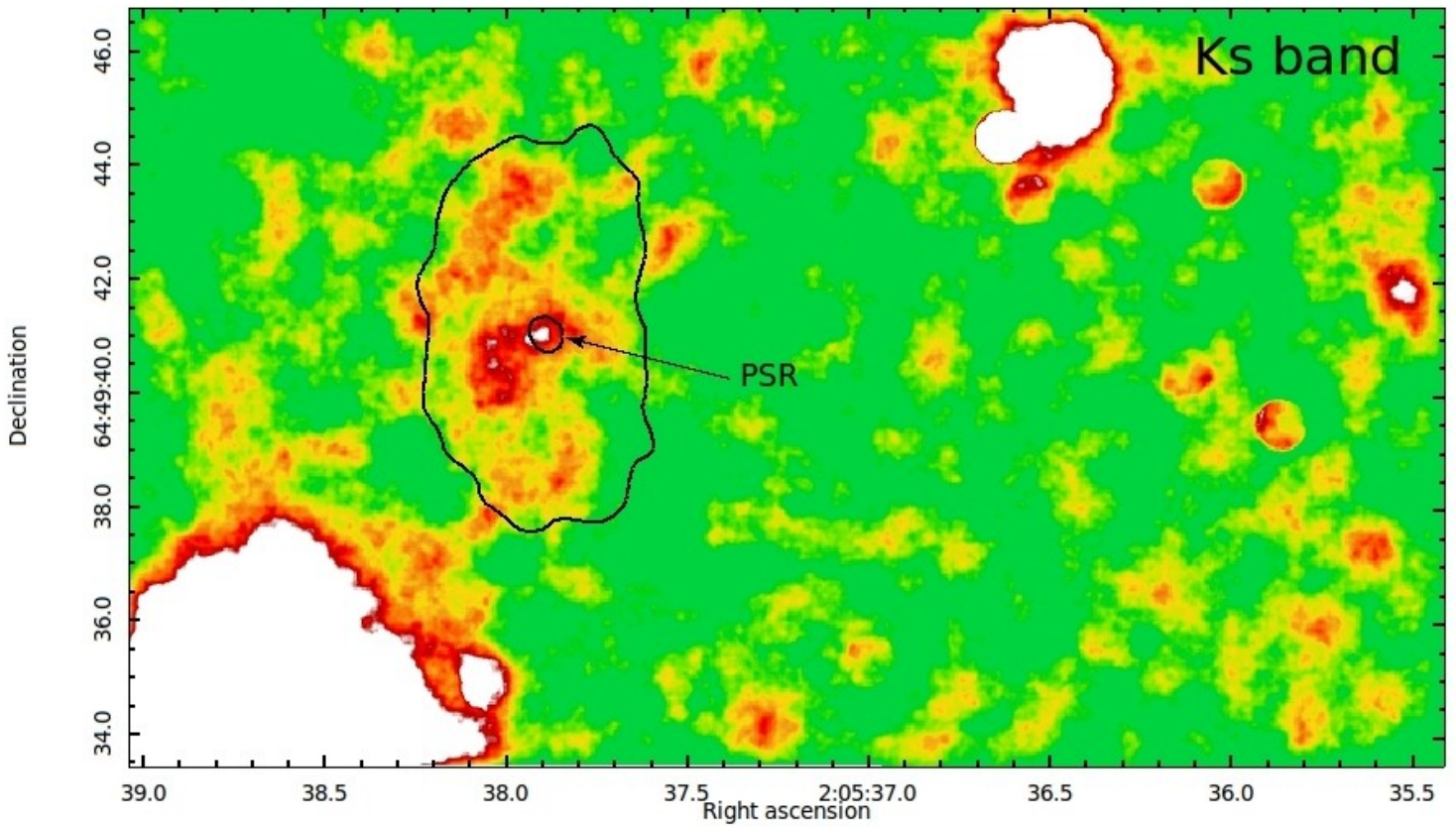


Red, 24 μm; green, 3.6 μm;
blue, *Chandra* X-rays

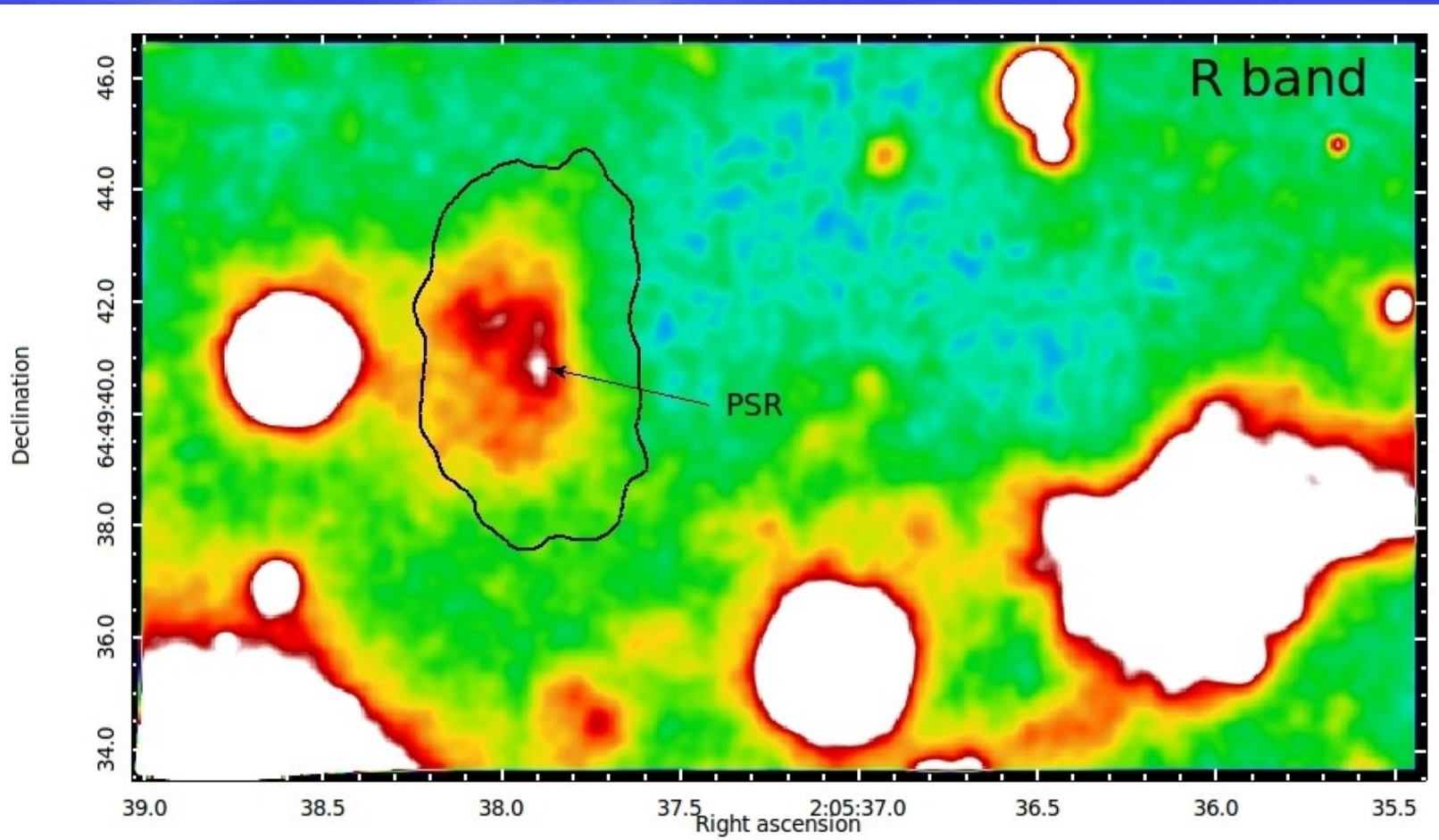


Right: Total spectrum of PWN. Our 24 μm point falls exactly on radio extrapolation; sharp steepening near 20 μm (slope change 0.8 – not synchrotron losses?)

PSR J0205+6449 (3C 58) with the NOT in near-IR

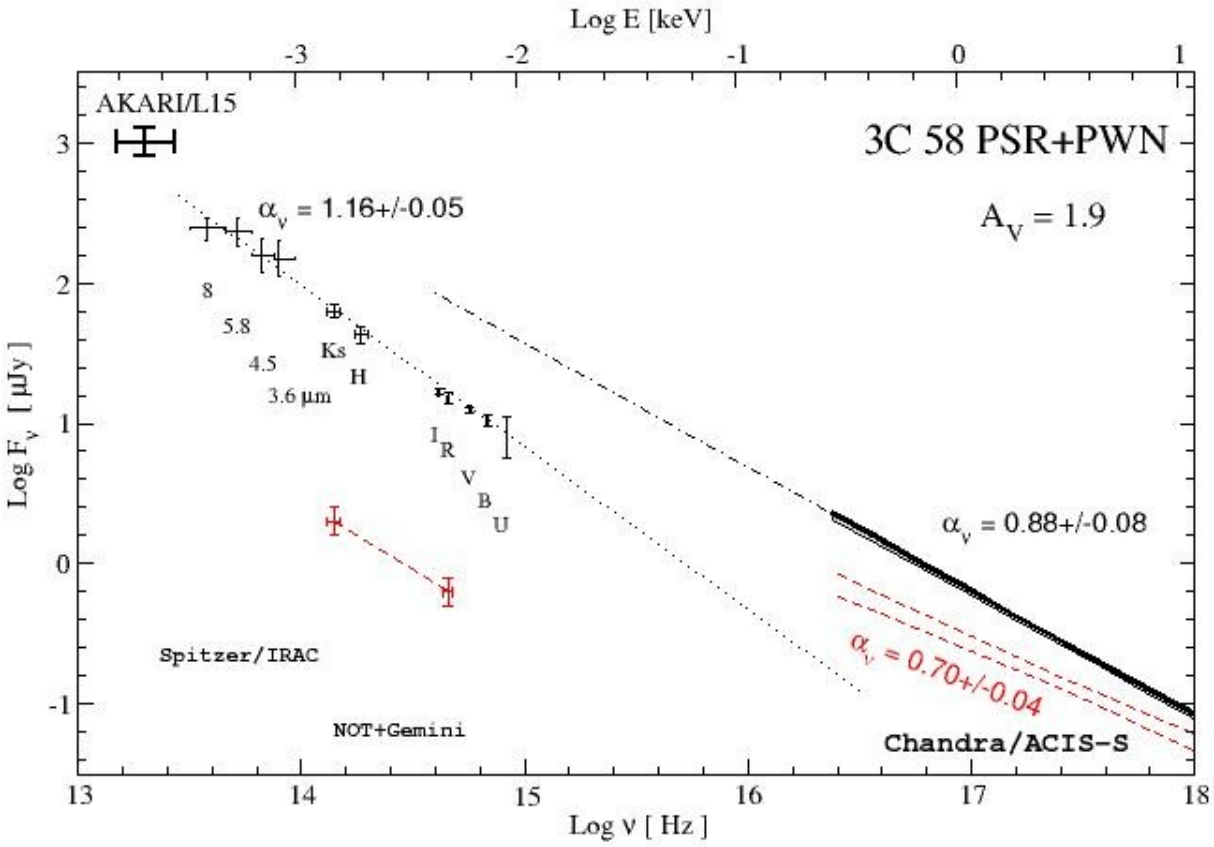


And with Gemini North (2007, archive)



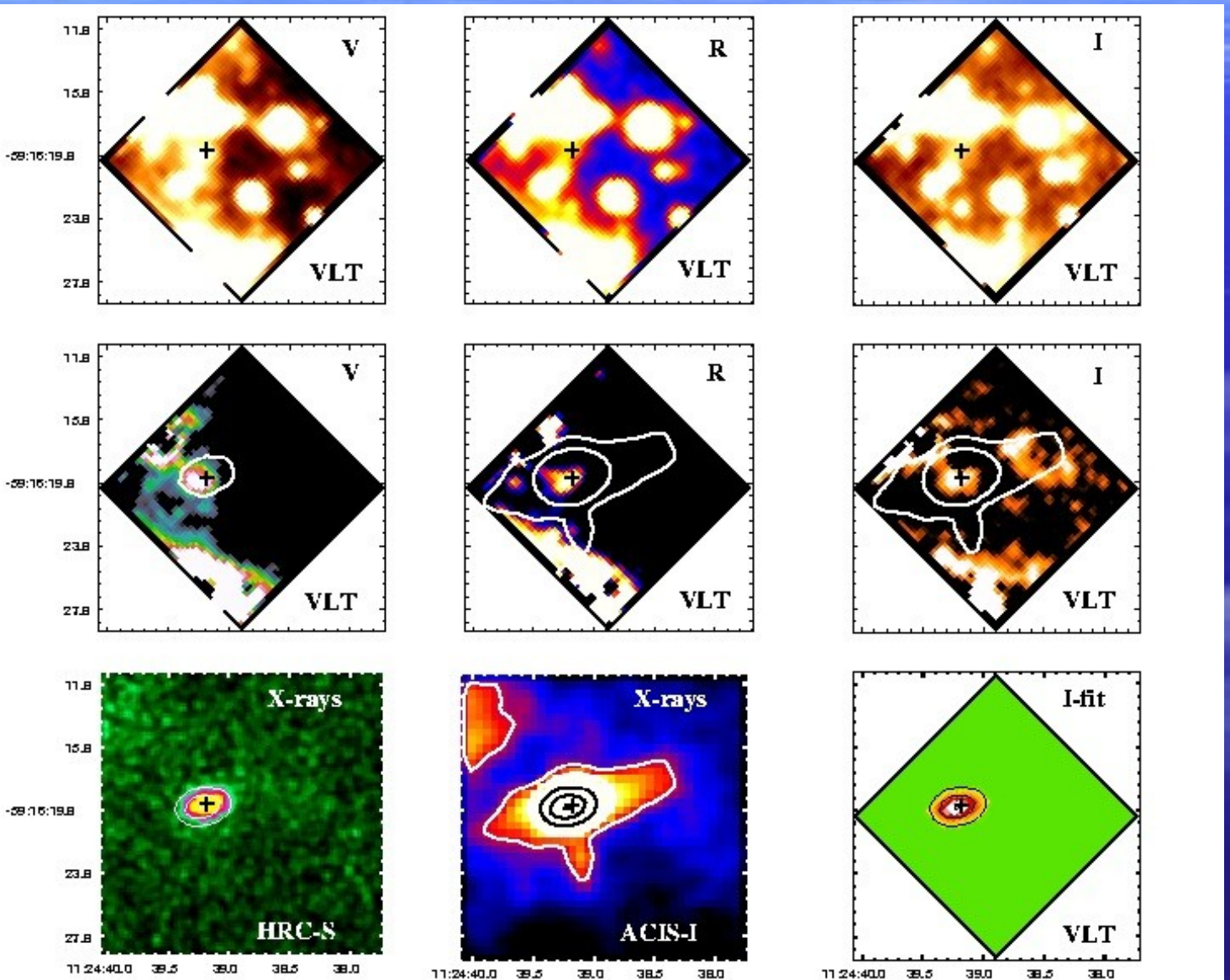
Updated spectrum of 3C 58 pulsar+PWN system (Zyuzin et al. Poster NS2011)

It definitely looks like B0540, but not like the Crab!



V=23.1 Adaptive optics or HST are needed to Better Resolve the Pulsar

PSR J1124-5916 with the ESO VLT

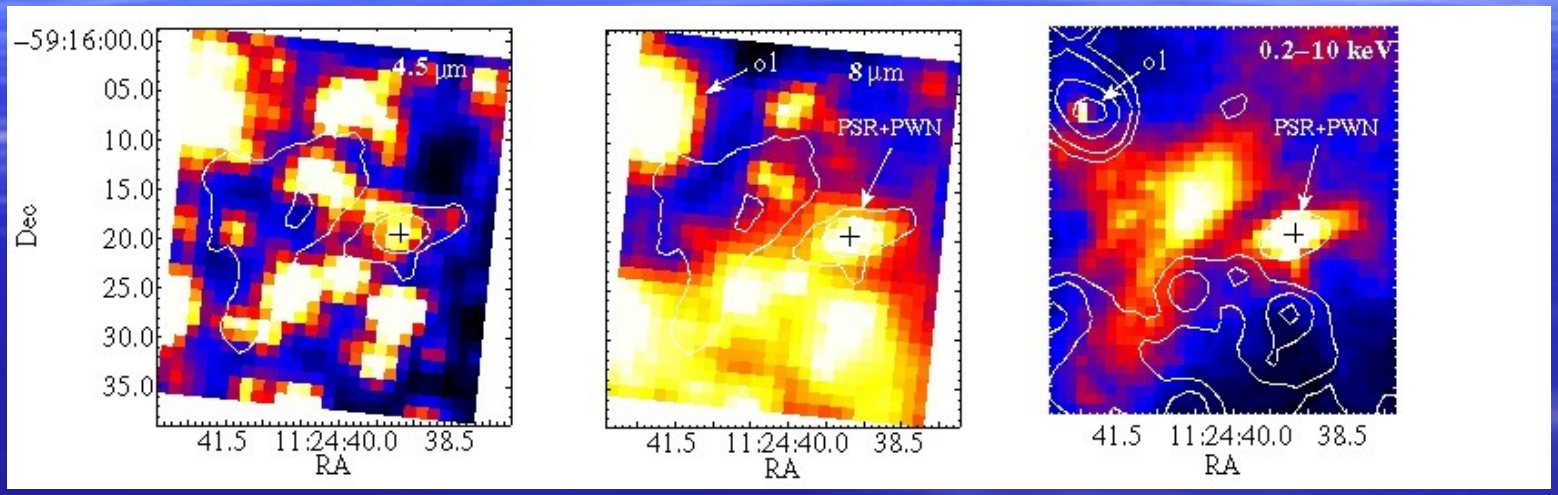


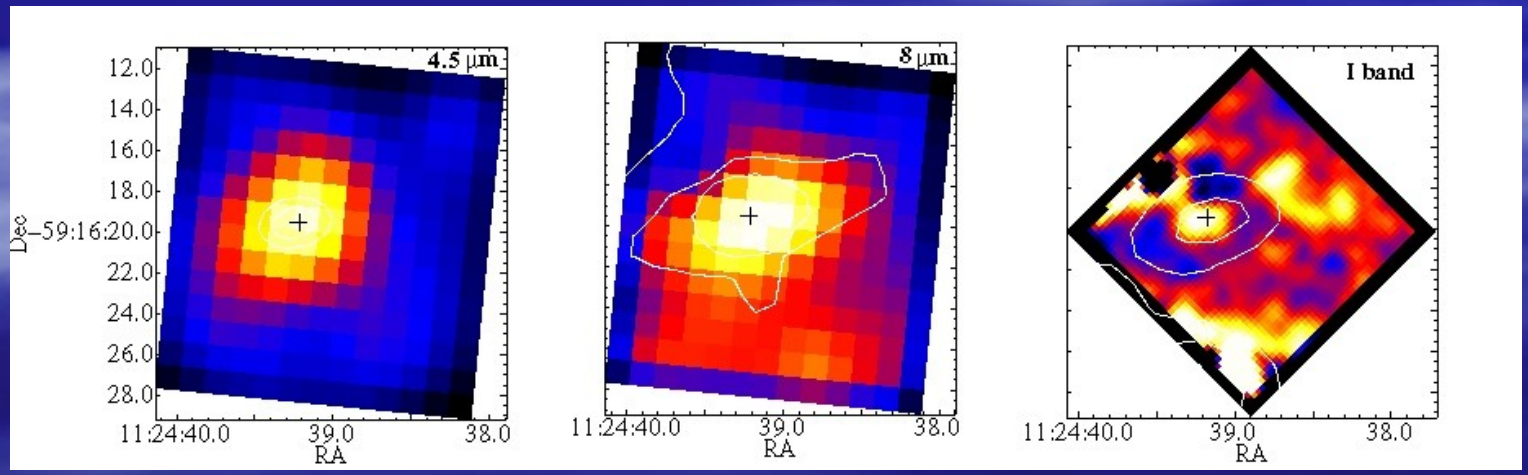
Zharikov et al. 2008

V=24.3
R=24.1,
I=23.1

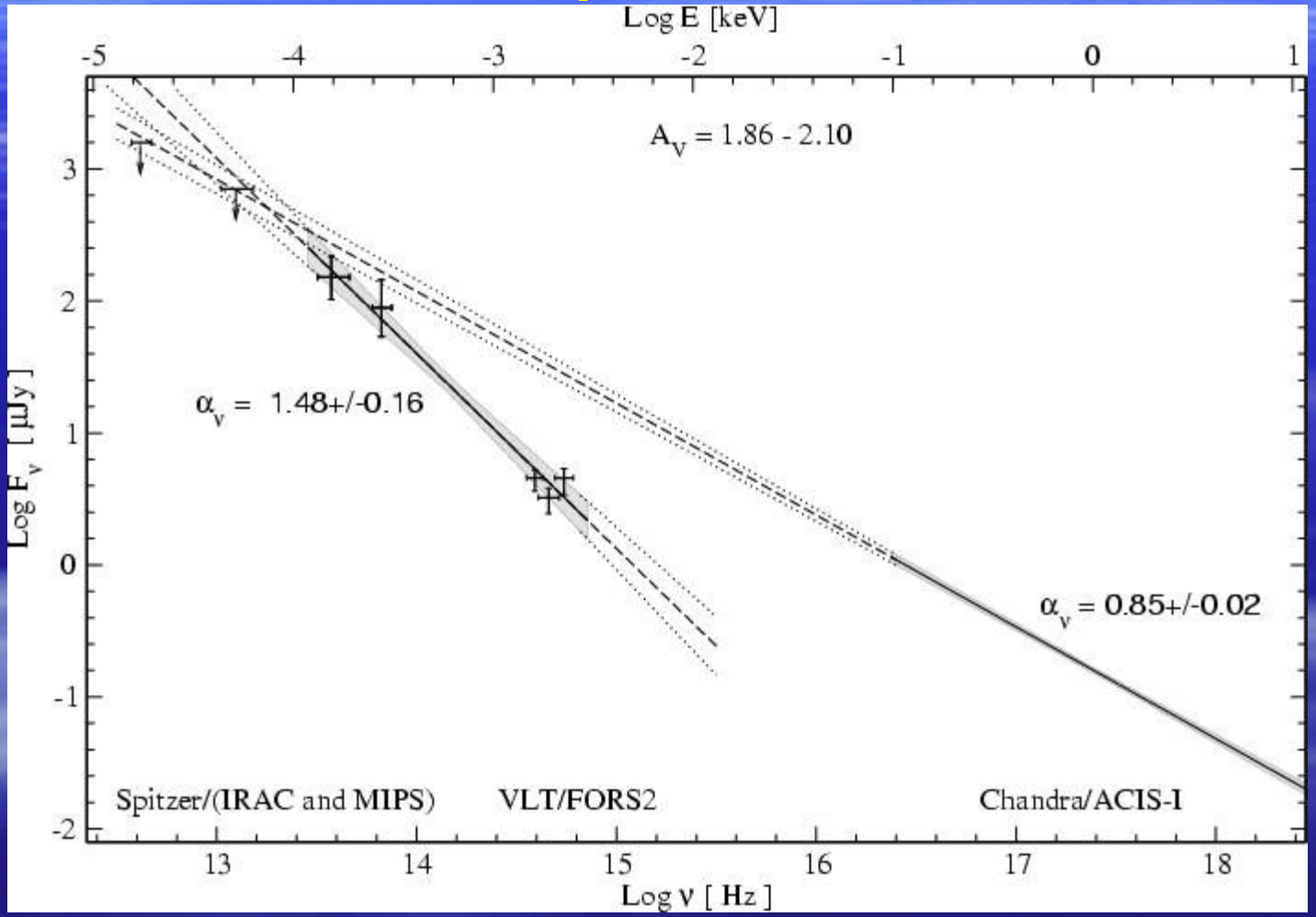
And with Spitzer

Zyuzin et al 2009



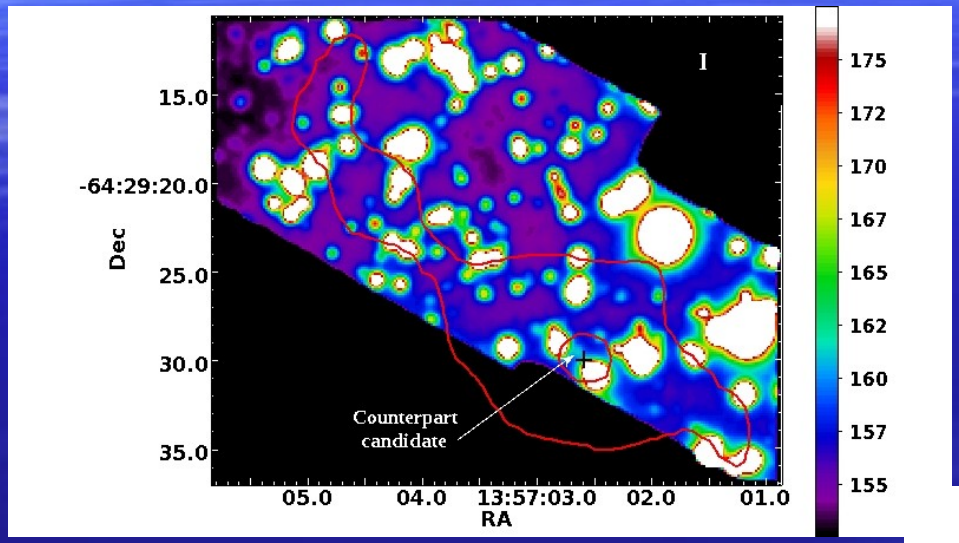


PSR J1124-5916 + its PWN spectrum

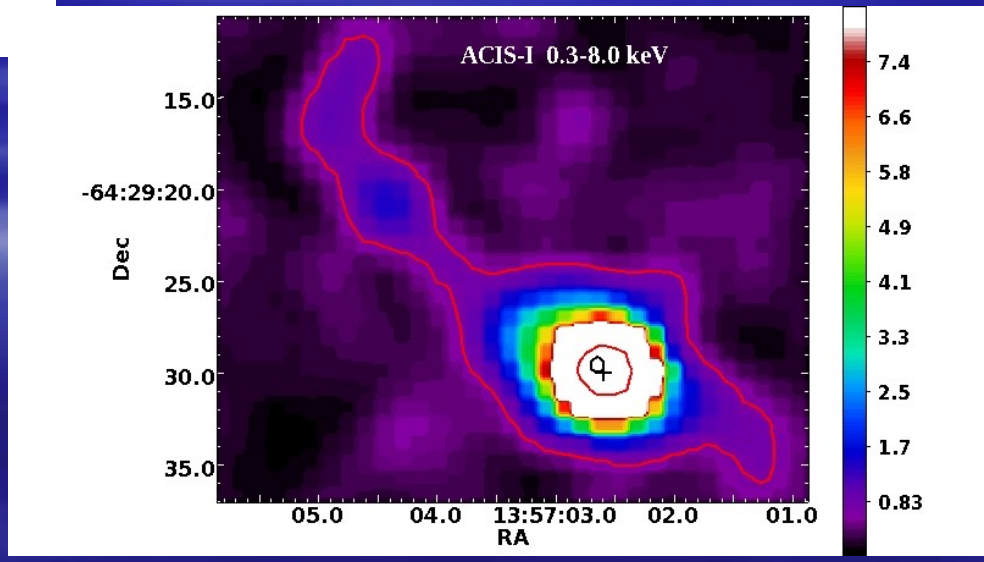


It also looks like those of 3C 58 and B0540 with a double knee break between the optical and X-rays!

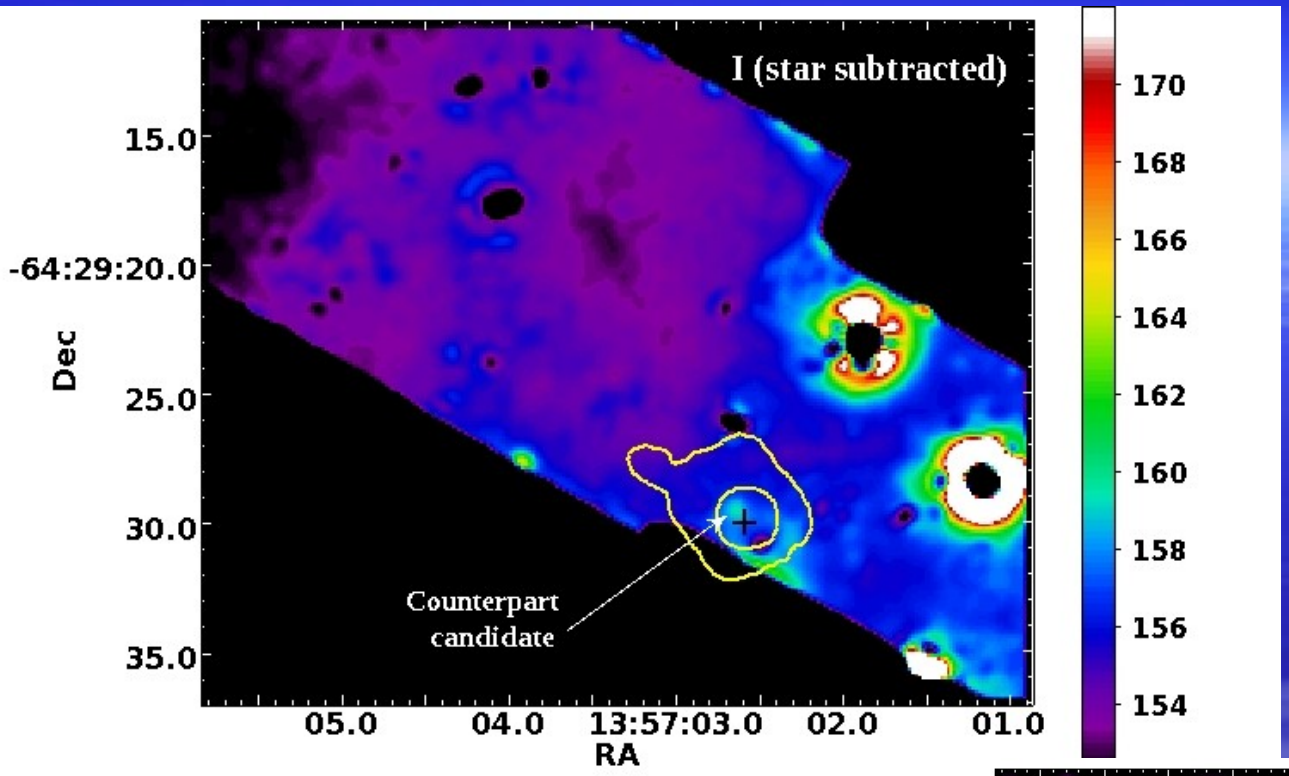
PSR J1357-6429 with the ESO VLT



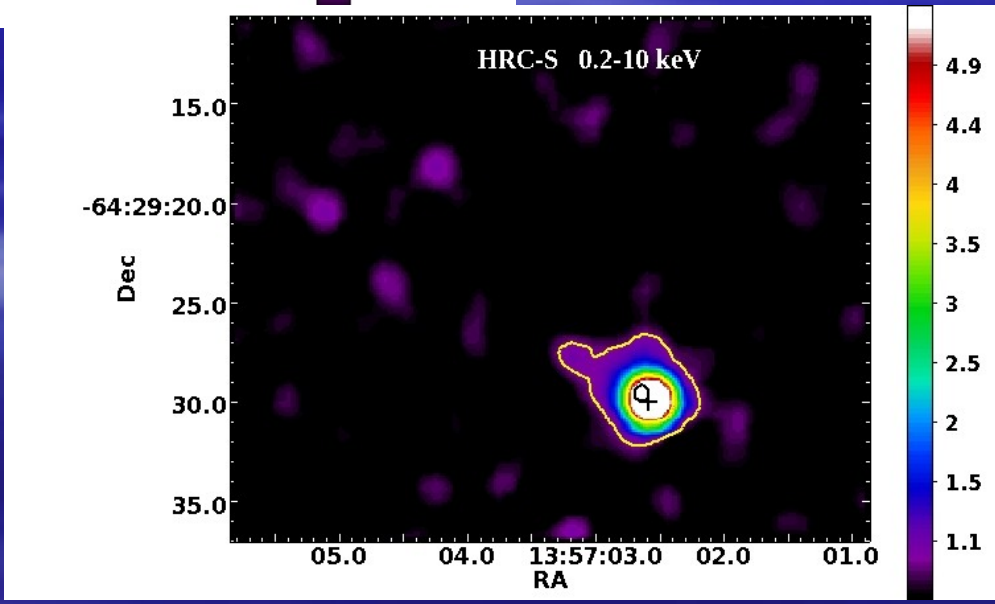
Kirichenko et al. NS2011 Poster



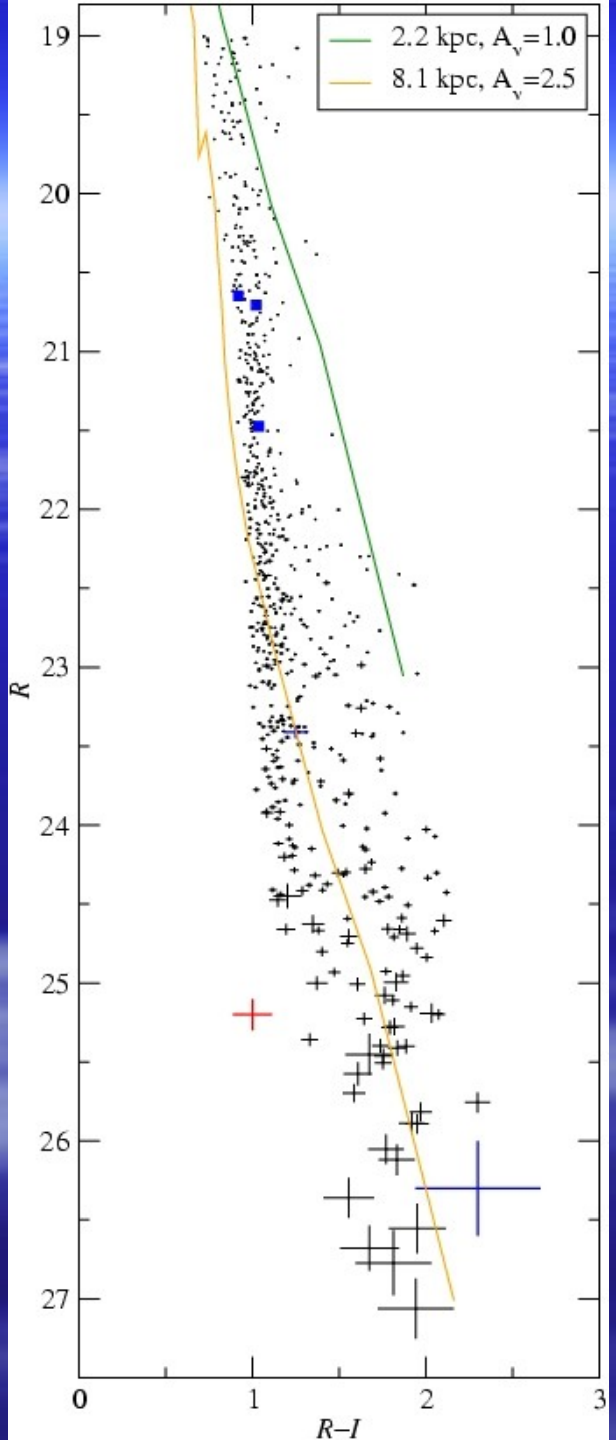
Chang et al. 2011 (ApJ, submitted)

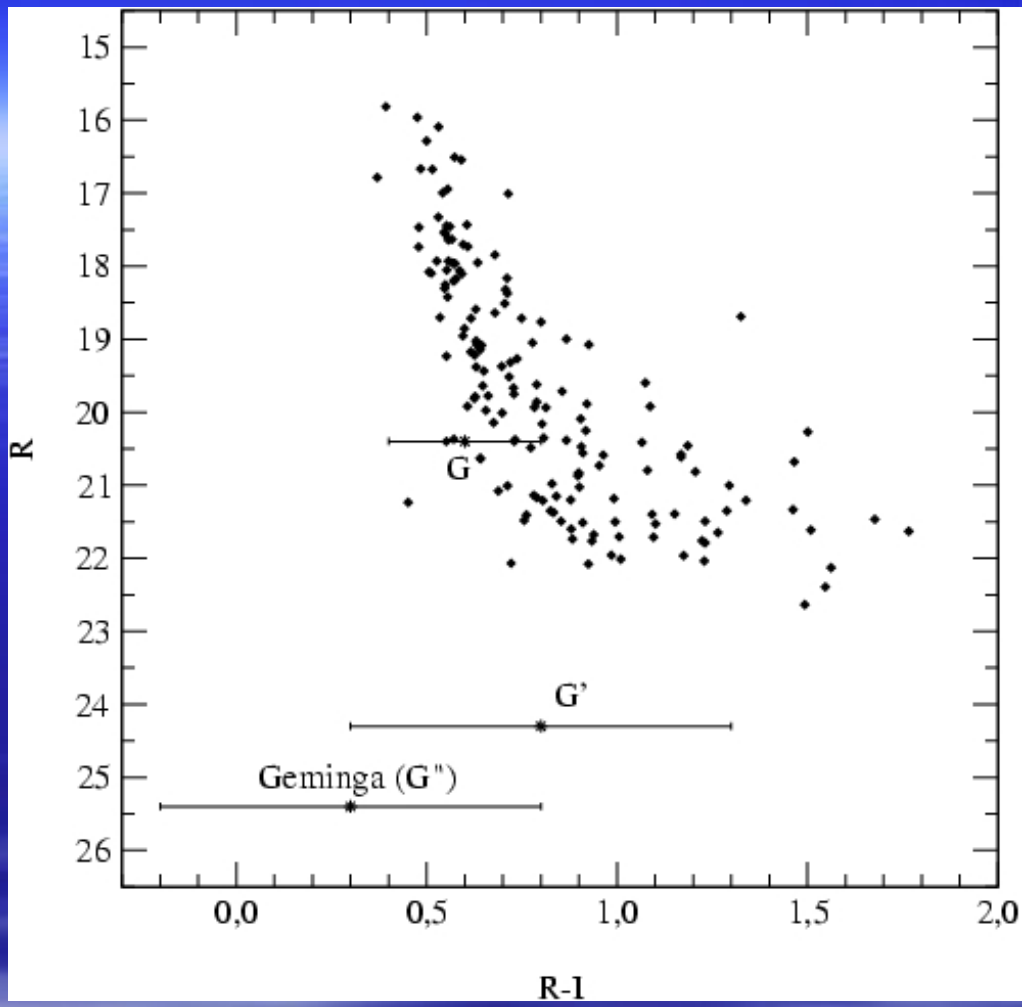

I (star subtracted)
15.0
-64:29:20.0
25.0
30.0
35.0
Dec
Counterpart
candidate
05.0
04.0
13:57:03.0
02.0
01.0
RA
170
168
166
164
162
160
158
156
154

R=25.1
I=24.1

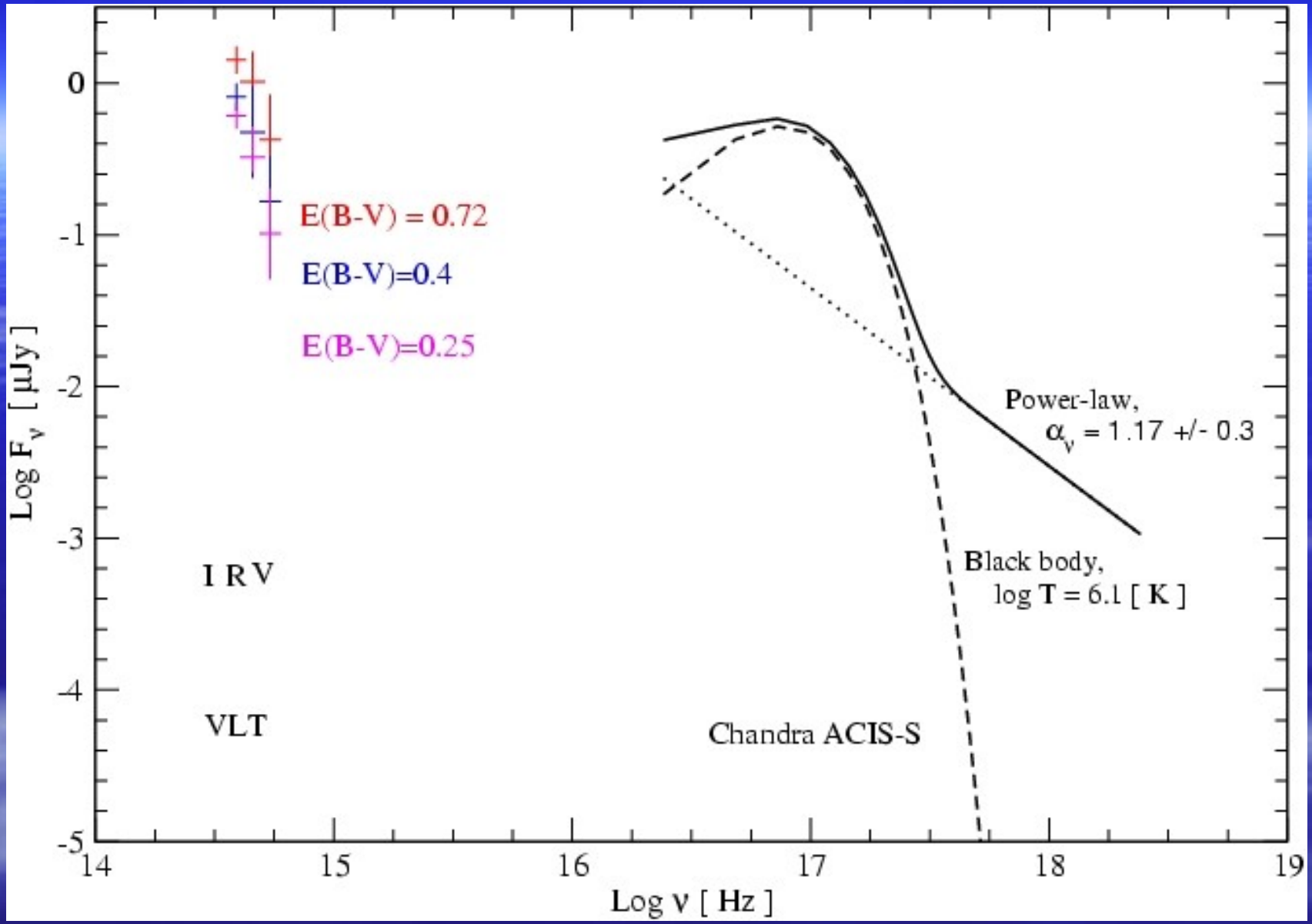

HRC-S 0.2-10 keV
15.0
-64:29:20.0
25.0
30.0
35.0
Dec
05.0
04.0
13:57:03.0
02.0
01.0
RA
4.9
4.4
4
3.5
3
2.5
2
1.5
1.1

J1357



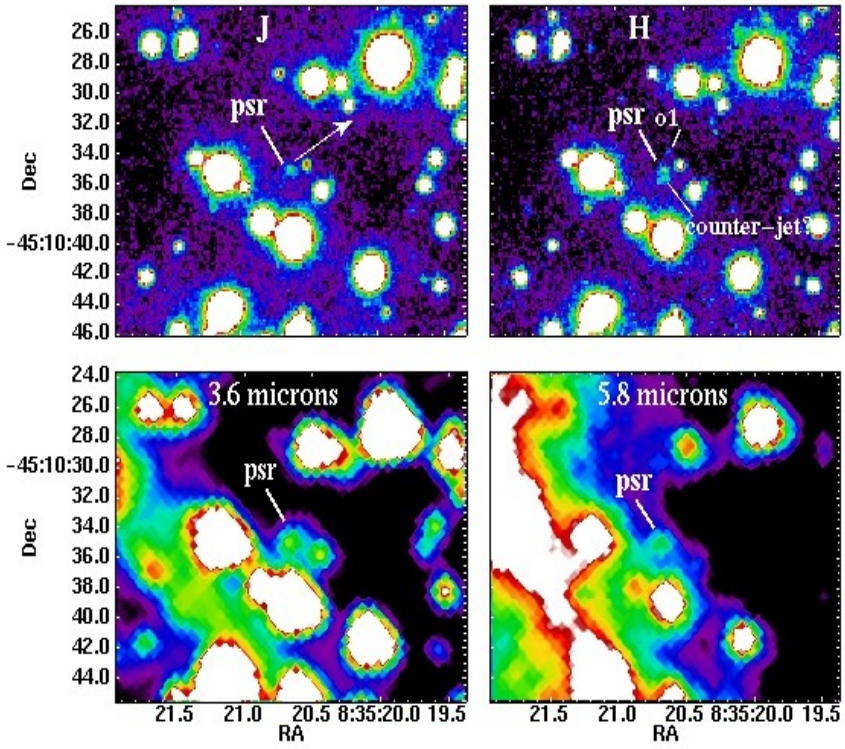


Geminha field, Kurt et al. 2001

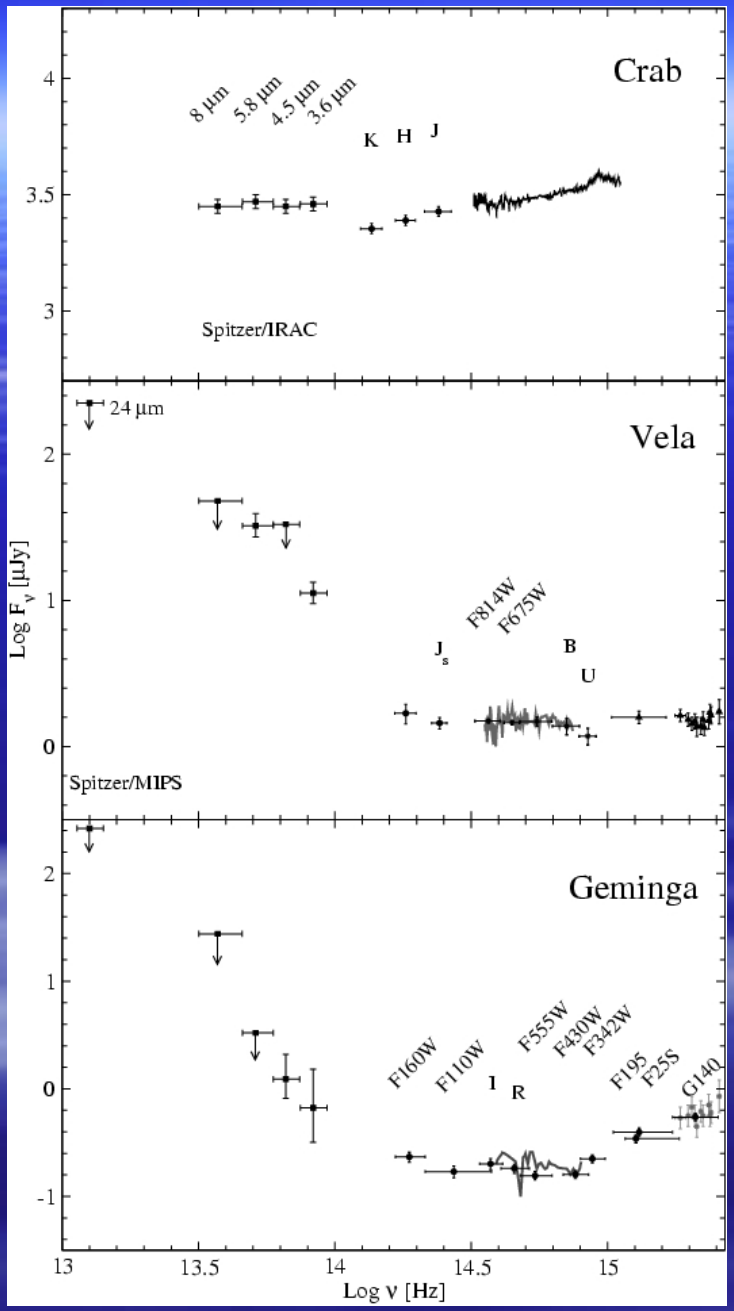


Preliminary: J1357 looks like Vela-pulsar. There are no IR data yet.

The Vela-pulsar in the mid-IR



Danilenko et al. 2011,
See also NS2011 Poster :
Danilenko et al.



The reason of a strong IR Vela excess is not clear yet. It is similar to that of the magnetar 4U 0142 +61 (Wang et al .2006).

A fall-back disk illuminated by X-rays?

For details see Danilenko et al. paper and and NS2011 poster.

Conclusions

- Two new pulsar+PWN systems are firmly identified in the optical-IR, increasing the number of Crab-like systems detected in these ranges from 2 to 4.
- 3 of 4 (B0540, 3C 58, and J1124) have a double knee spectral break between the optical and X-rays making this feature a regular and notable. It is distinct from the Crab and has to be accounted at modeling such systems.
- A likely optical counterpart of PSR J1357 is identified in the optical. Its multi-wavelength spectrum seems to be similar to that of the Vela-pulsar. This needs a confirmation in the IR.
- The Vela pulsar shows a huge flux excess in the IR, that is similar to that of the magnetar 4U 0142+61. It can be a signature of fall-back disk or an unresolved PWN knot.
- All targets are significantly brighter in the IR than in the optical, making this range promising for the study of the pulsars and PWNe.

THANK YOU !