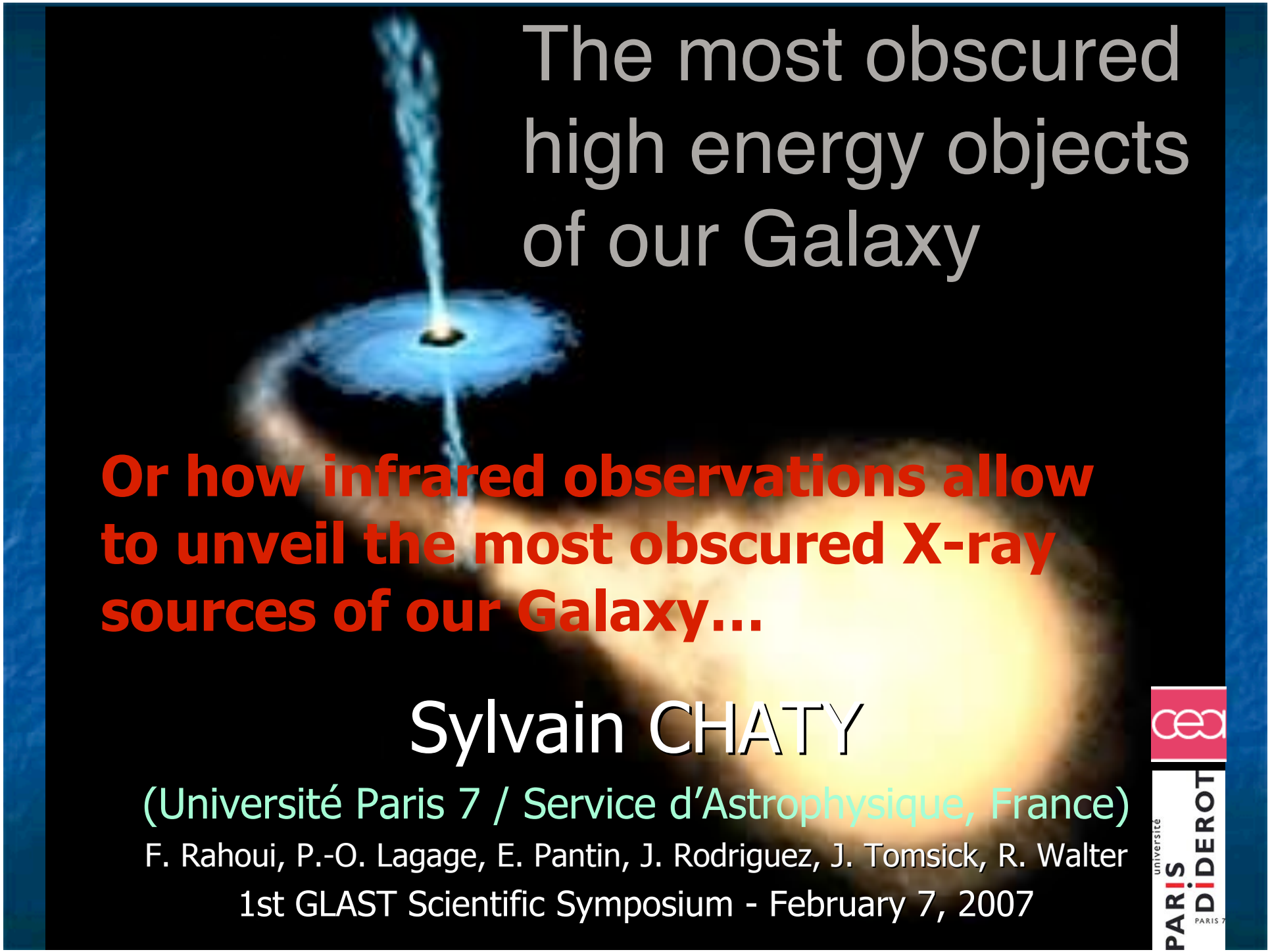


The most obscured high energy objects of our Galaxy

Or how infrared observations allow to unveil the most obscured X-ray sources of our Galaxy…

Sylvain CHATY

(Université Paris 7 / Service d'Astrophysique, France)

F. Rahoui, P.-O. Lagage, E. Pantin, J. Rodriguez, J. Tomsick, R. Walter

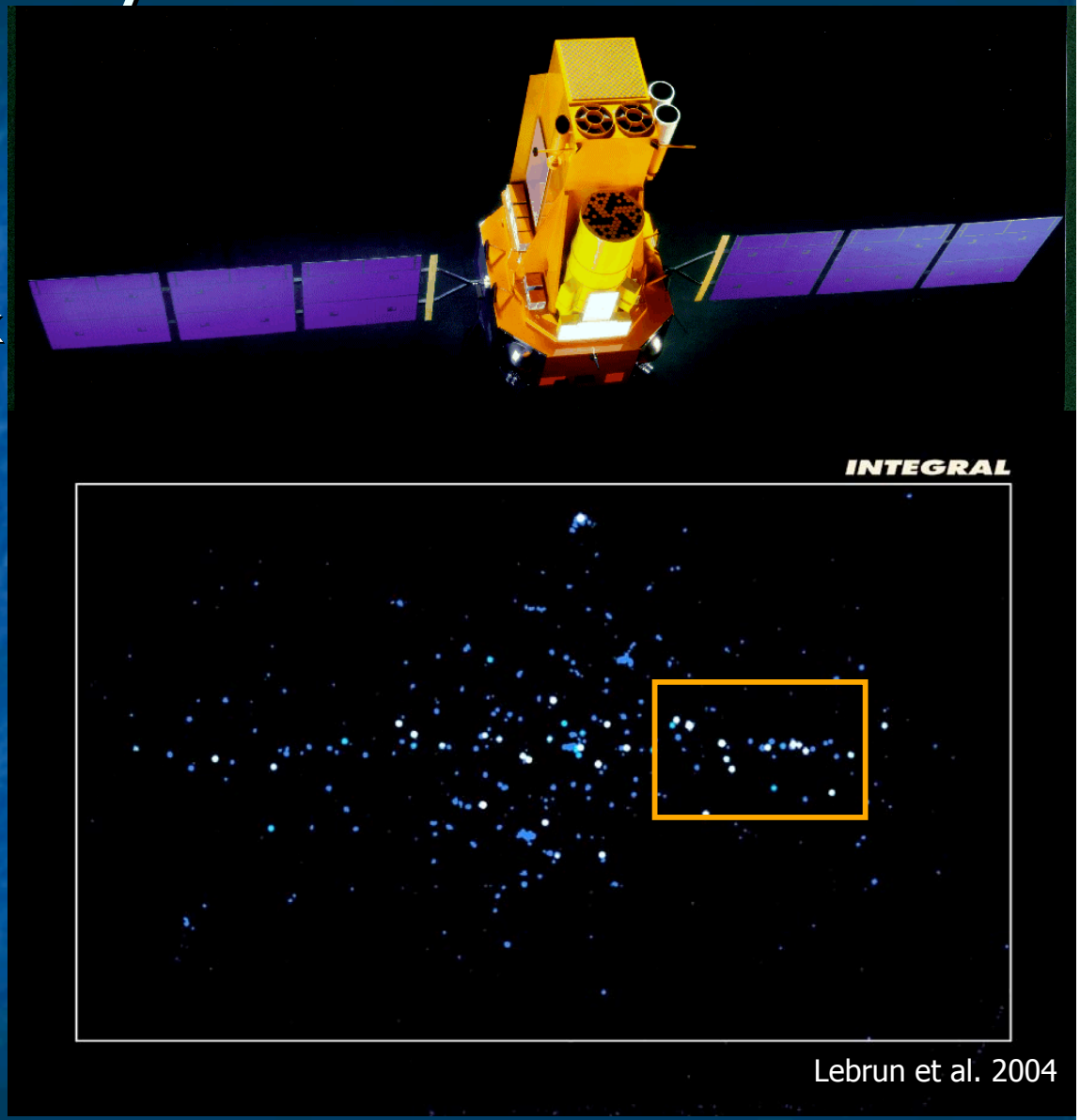
1st GLAST Scientific Symposium - February 7, 2007

Plan

- Discovery of new high energy sources
- Multi-wavelength optical/NIR/MIR observations:
  - Obscured X-ray sources: the archetype IGR J16318-4848
  - New INTEGRAL sources: results and discussion
- The future

The γ-ray sky seen by INTEGRAL

- ESA satellite launched on 17 October 2002 by PROTON rocket on excentric orbit
  - Imager IBIS: coded mask γ telescope: 10keV-4MeV
  - Resolution 12', fov 19°
- Highly obscured high energy objects discovered by INTEGRAL
  - towards the Norma arm of the Galaxy… full of star forming regions!
- How to reveal their nature?

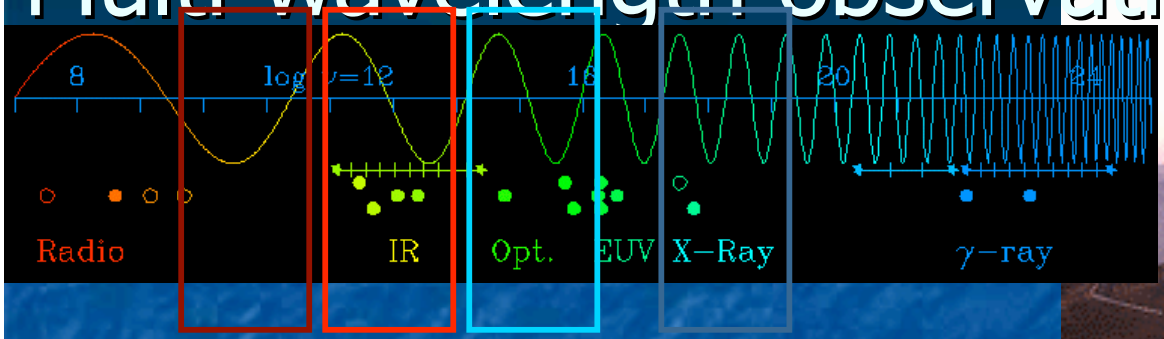


Lebrun et al. 2004

Discovery of new sources

- How to identify all these new INTEGRAL sources?
- To observe in X/γ rays is not enough:
  - ISGRI localisation not enough to identify the counterpart
- To observe in optical is difficult:
  - Sources mainly in the plane (centre) of the Galaxy: too much absorption (interstellar dust and gas)

Multi-wavelength observations



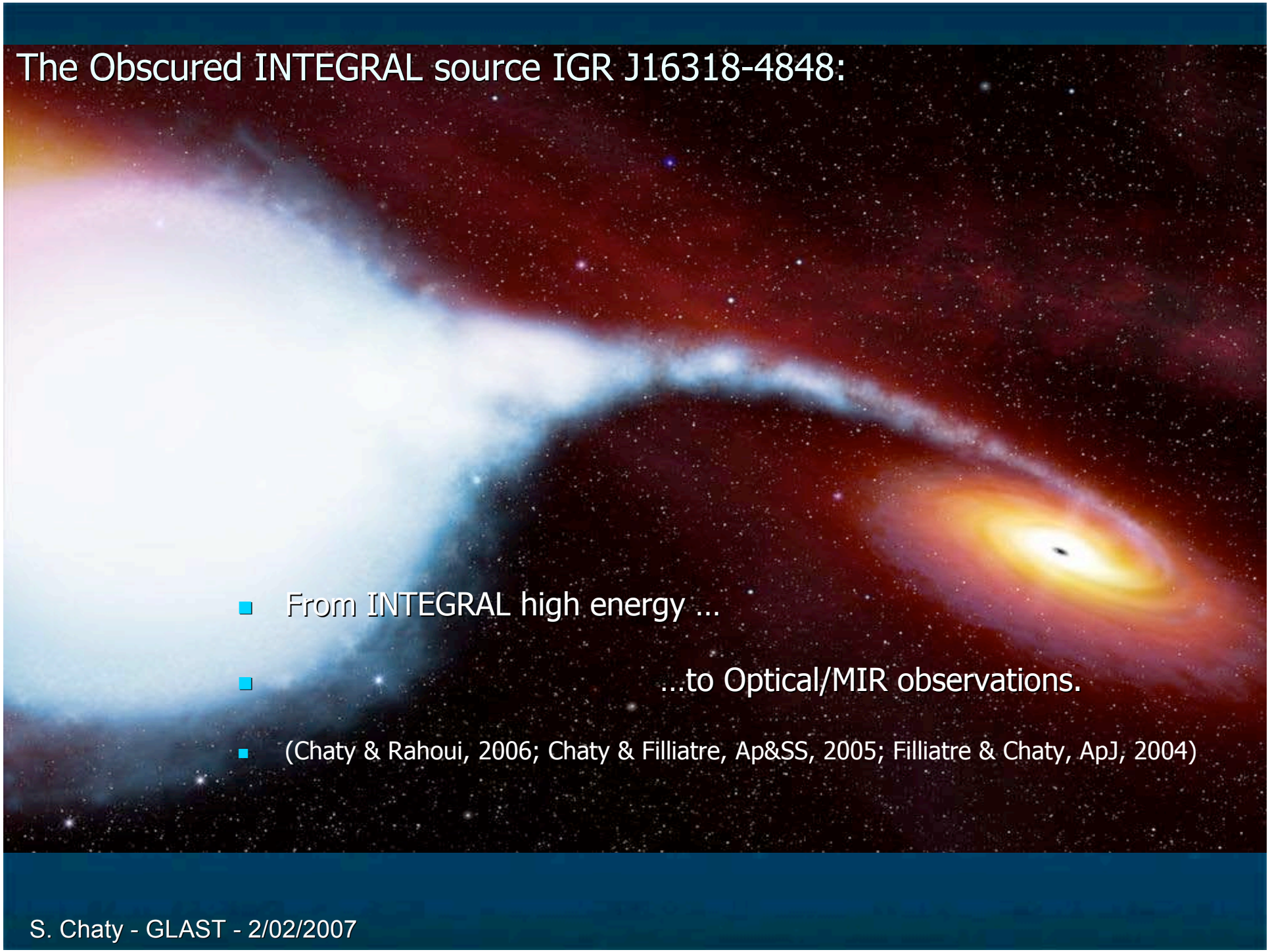
- Study of 20 new INTEGRAL sources at **E**
  Observatory)
  - Identification of counterparts, nature of system
  - Target of Opportunity & Visitor mode (20

- Photometry/Spectroscopy in 3 domains:
  - Optical / Near-infrared (0.4-2.5μm): La S
  - Mid-Infrared (5-20 μm): Paranal (8m-VL

Plan

- Discovery of new high energy sources
- Multi-wavelength optical/NIR/MIR observations:
  - Obscured X-ray sources: the archetype IGR J16318-4848
  - New INTEGRAL sources: results and discussion
- The future

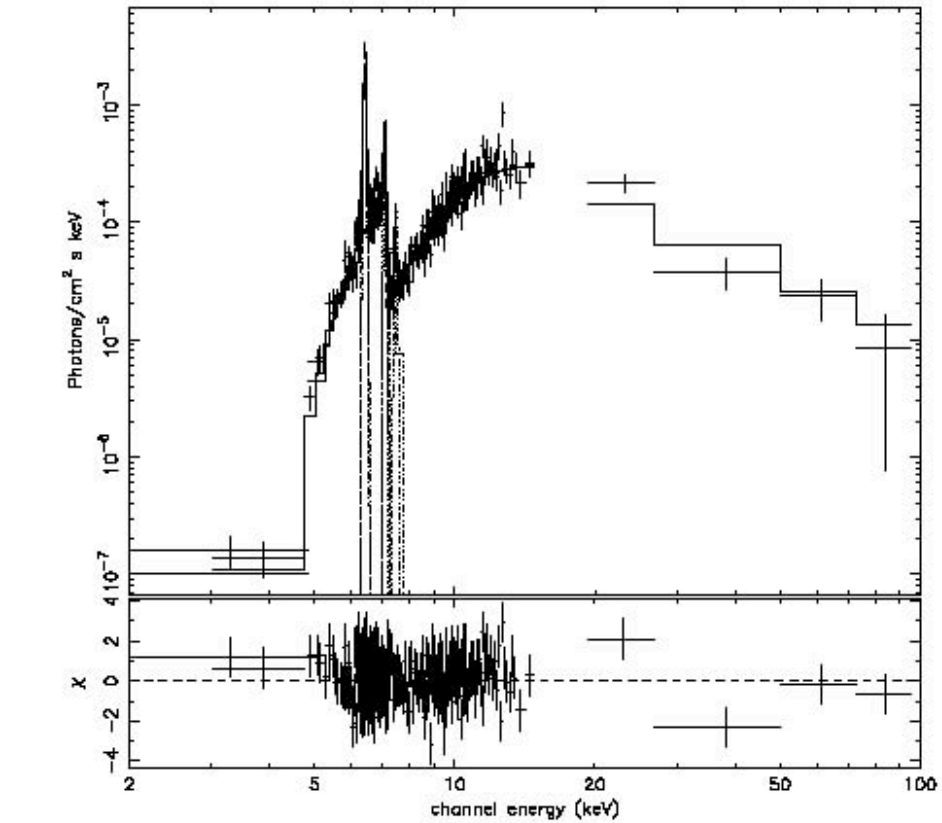
The Obscured INTEGRAL source IGR J16318-4848:



- From INTEGRAL high energy …
- …to Optical/MIR observations.
- (Chaty & Rahoui, 2006; Chaty & Filliatre, Ap&SS, 2005; Filliatre & Chaty, ApJ, 2004)

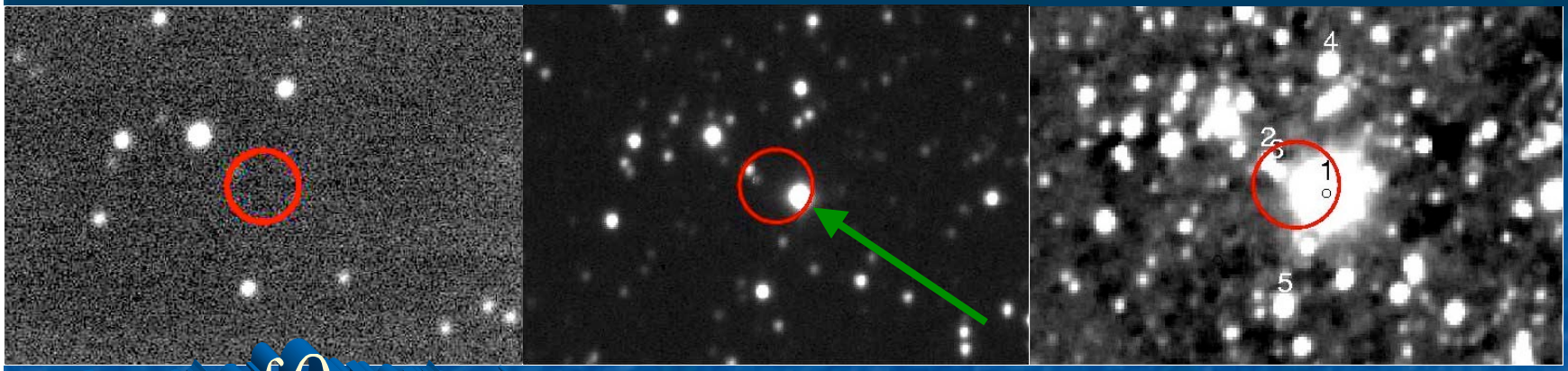
Discovery of IGR J16318-4848

- 1st source discovered by INTEGRAL (IBIS/ISGRI) on 29 January 2003
  - Position: (l,b)~(336°, 0.5°)
  - 2' localisation
  - 15-40 keV Flux: 50-100 mCrab
- ToO observations with XMM-Newton
  - 4" localisation
  - Comptonised spectrum:
    - N_h=1.84x10^{24} cm^{-2}
    - kT = 9±0.5 keV
    - Photon index ~ 2
  - Strong photoelectric absorption



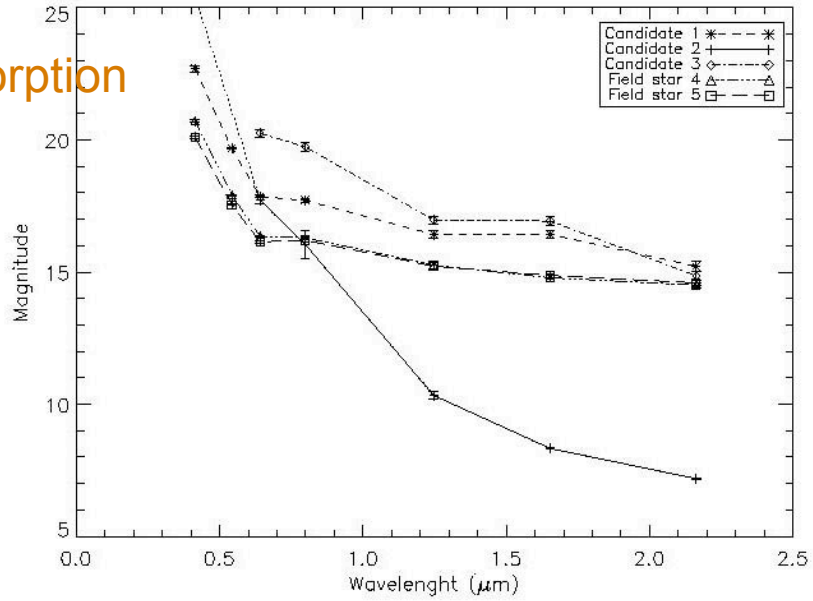
EPIC PN, EPIC MOS2 and ISGRI spectra
(Matt & Guainazzi 2003; Walter et al. 2003)

Photometric observations

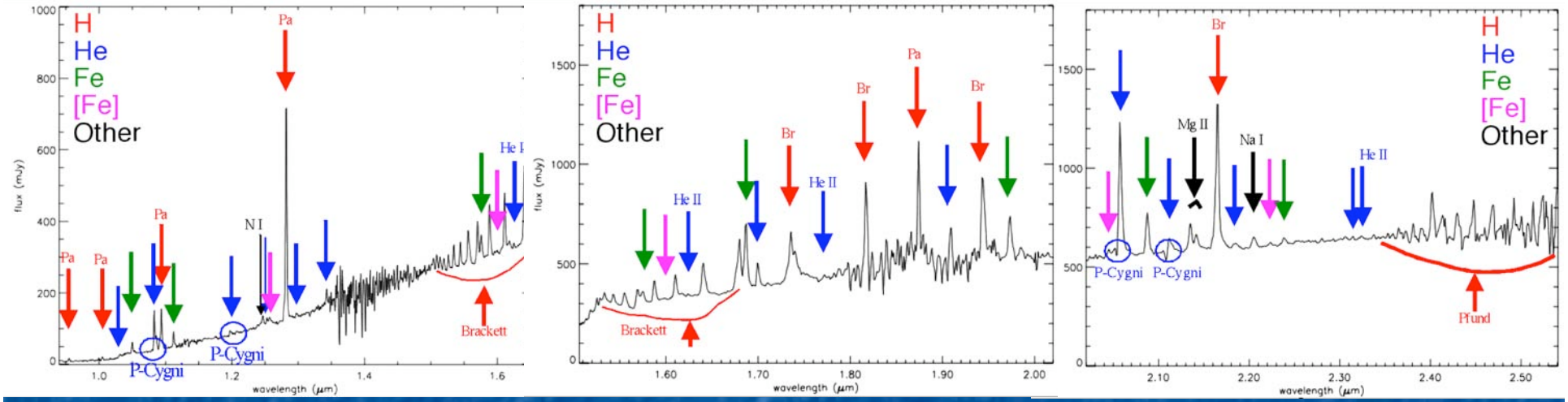


- Target of Opportunity photometric observations on 23-25/02/2003
- Discovery of the optical counterpart, confirmation of NIR counterpart (Walter et al. 2003) B>25.4+/-1; I=16.05+/-0.54, Ks=7.20+/-0.05

- Absorption in opt/NIR:
  - IGR source exhibits unusual 17.4mag absorption
  - 100x stronger than interstellar absorption
  - but 100 x lower than X-rays!!!
  - Material absorbing in X-rays must be concentrated near the compact object



NIR spectroscopy: 0.95-2.5 μm



Unusual spectrum very rich in many strong emission lines

- Strong H (Br, Pa, Pf), HeI (P-Cyg): dense, ionised wind
- He II: highly excited region
- [FeII]: shock heated material
- FeII => densities > 10^5-10^6 cm^{-3}
- NaI: cool/dense regions
- Lines originate from different media (various densities, temperature)

- Highly complex, stratified circumstellar environment + enveloppe, wind…
  - => luminous post main sequence star: sgB[e] star:
    High-mass X-ray binary system

Spectral Energy Distribution

- Fit parameters:
  $L \sim 10^6\ d^2_{6kpc} L_\odot$
  $T = 23\ 500$ K
  $M = 30\ M_\odot$
  High L, T and M:

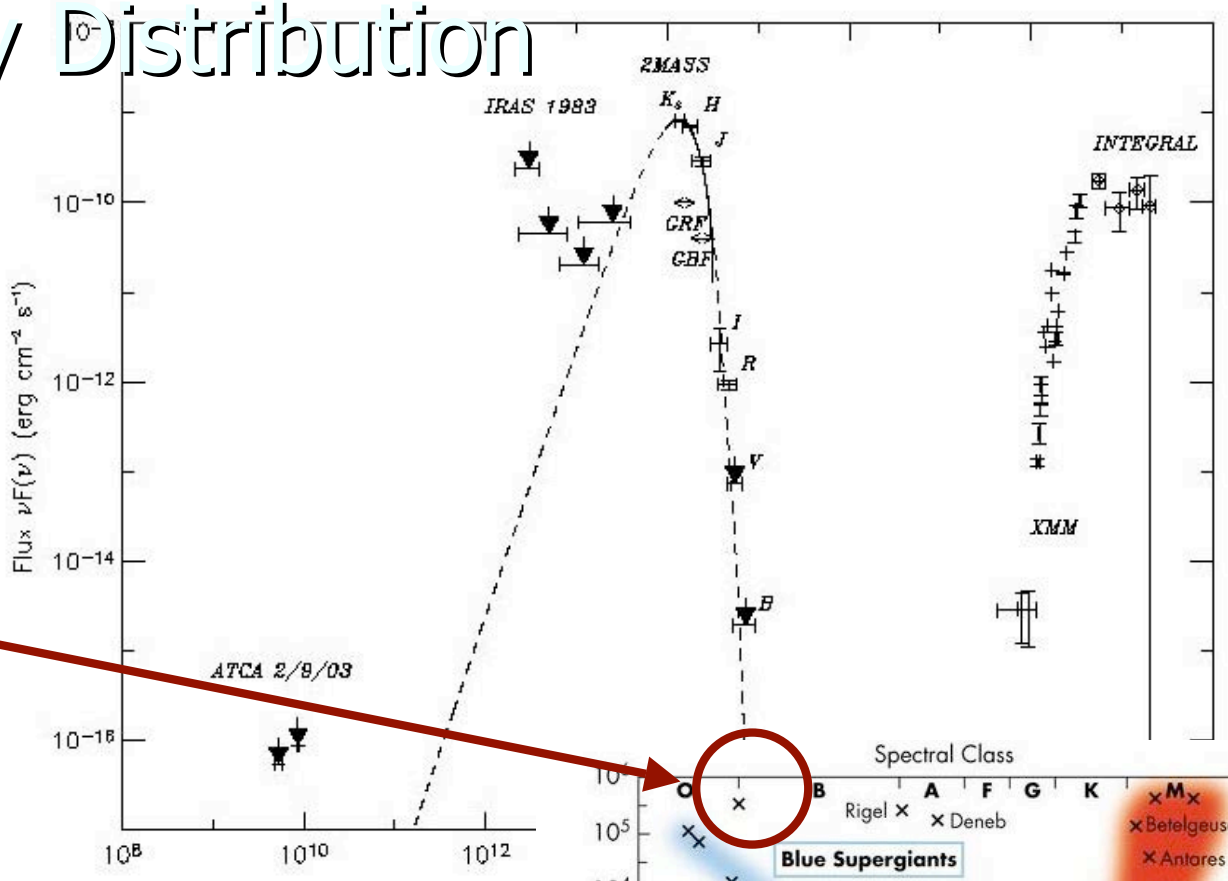
⇒ Supergiant star

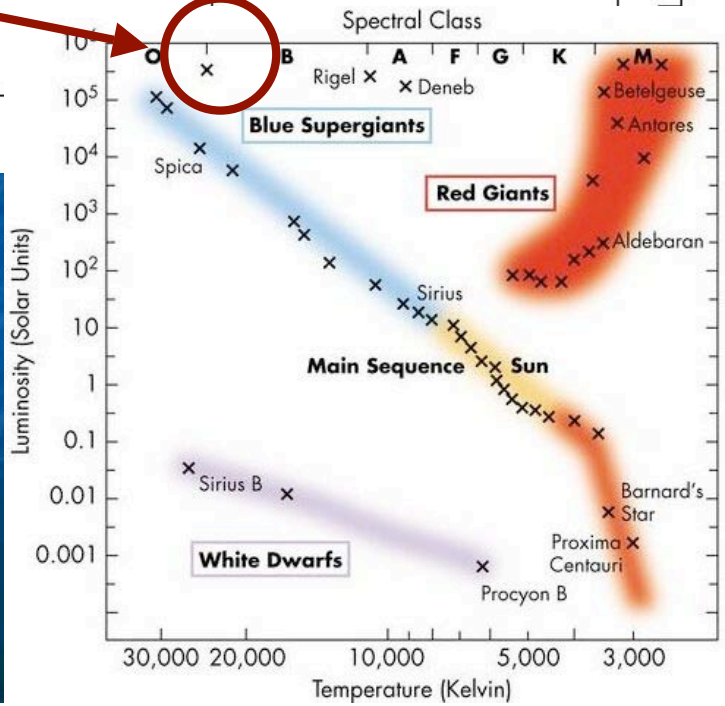
⇒ Distance = 6kpc

⇒ Av = 17.5 mag

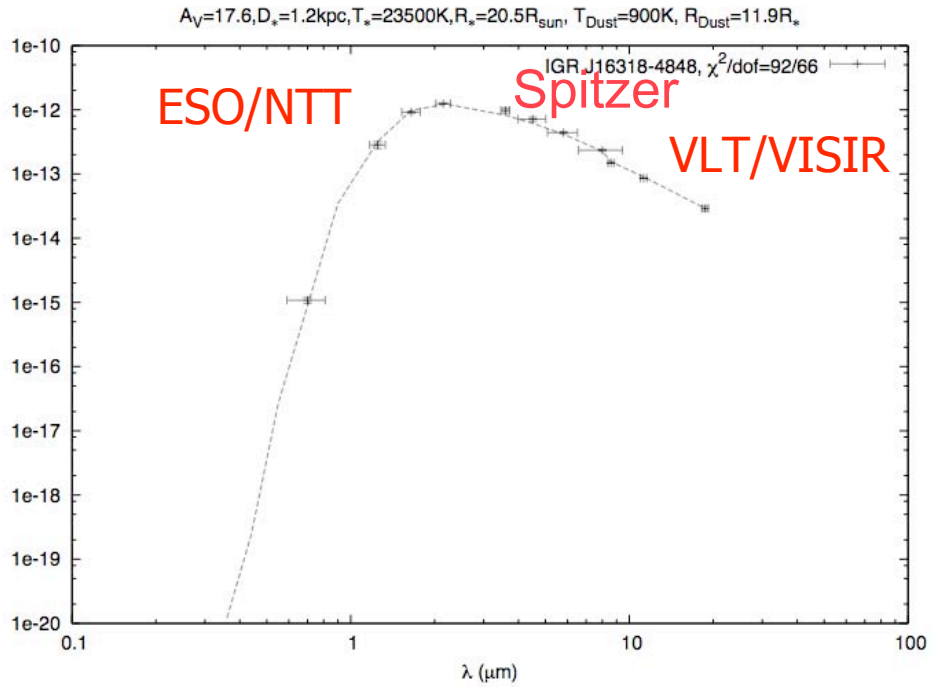
- Unusual absorption:
  cocon of dust?

Hertzprung-Russel Diagram



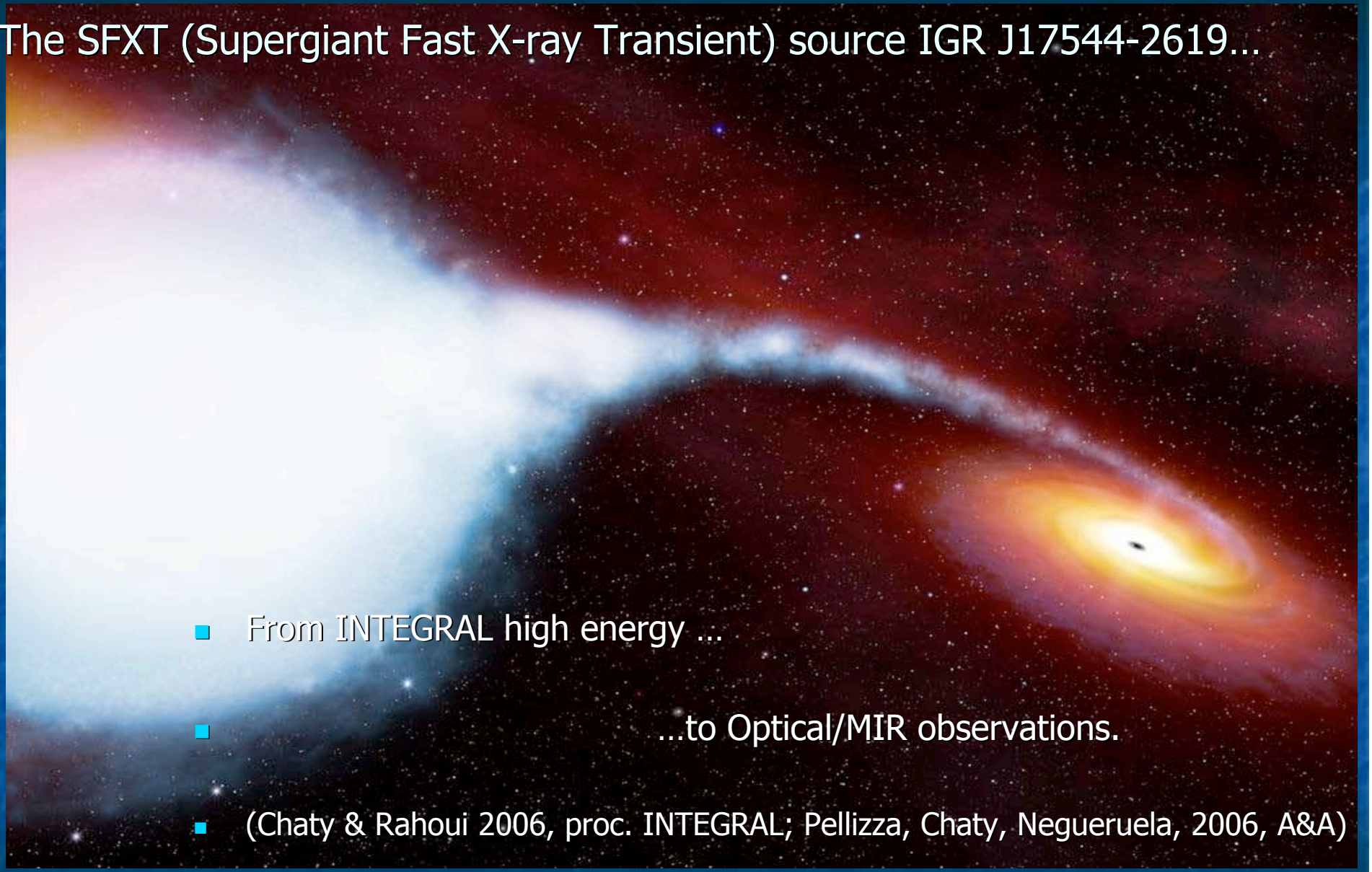


IGR J16318-4848 Optical -> mid-infrared SED



- High Mass X-ray Binary system:
  - Supergiant star: sgB[e], T=23500 K, R=20.5$R_\odot$ = 15x10^6km
  - +Neutron star
  - + Cocoon of Dust/cold gas: T=900K, R=11.9R_* = 1a.u.
- Need for extra (dust) component. Extension of this dust component seems to suggest that it is enshrouding the whole binary system.

The SFXT (Supergiant Fast X-ray Transient) source IGR J17544-2619…



- From INTEGRAL high energy …
- …to Optical/MIR observations.
- (Chaty & Rahoui 2006, proc. INTEGRAL; Pellizza, Chaty, Negueruela, 2006, A&A)

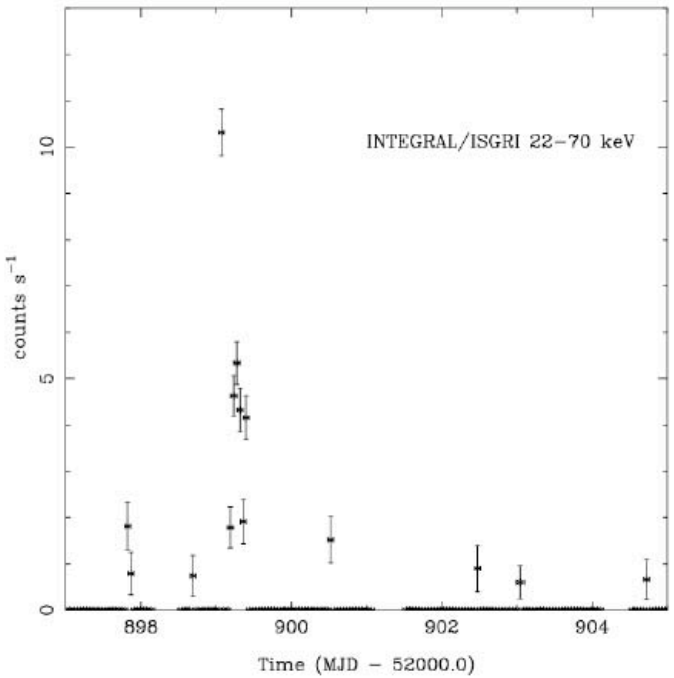


Figure 1. A typical outburst from a SFXT. INTEGRAL lightcurve for IGR J17544−2619 during the flare on 2003 September 17th. The data have been downloaded from the public data archive at the ISDC.

Negueruela, Smith, Reig, Chaty, Torrejon, 2005

IGR J17544-2619

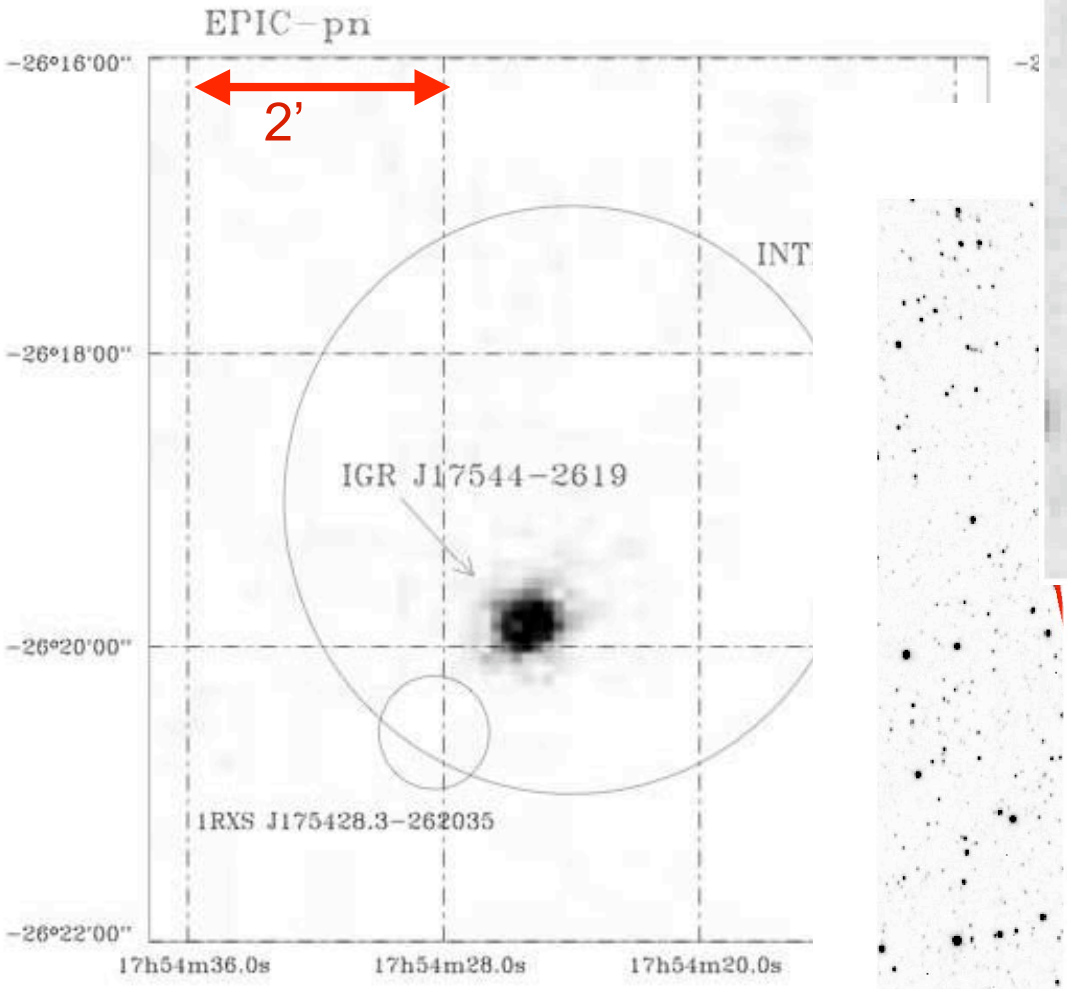
Recurrent transient X-ray source discovered by INTEGRAL (09/2003) near the Galactic center
(Sunyaev et al. 2003, ATel 190)

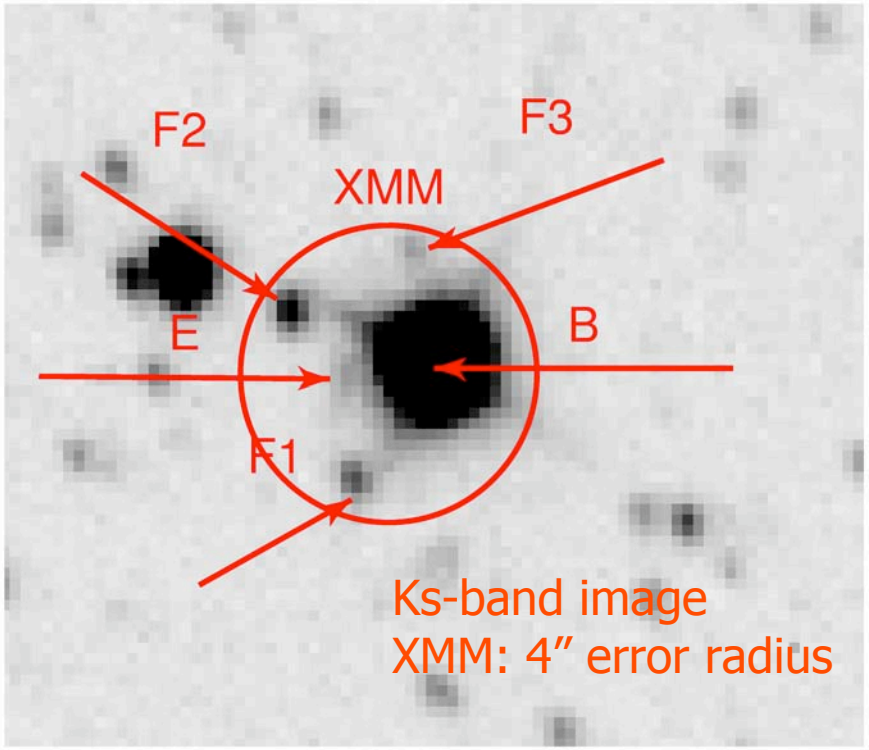
Bursts last ~hours, long quiescence periods, Long $P_{outburst}$=165d, no radio emission reported
(Gonzalez-Riestra et al. 2004, A&A 420, 589)

Very hard X-ray spectrum, Faint intrinsic absorption (Nh~2 10^{22}cm^{-2})
(Gonzalez-Riestra et al. 2004, A&A 420, 589)

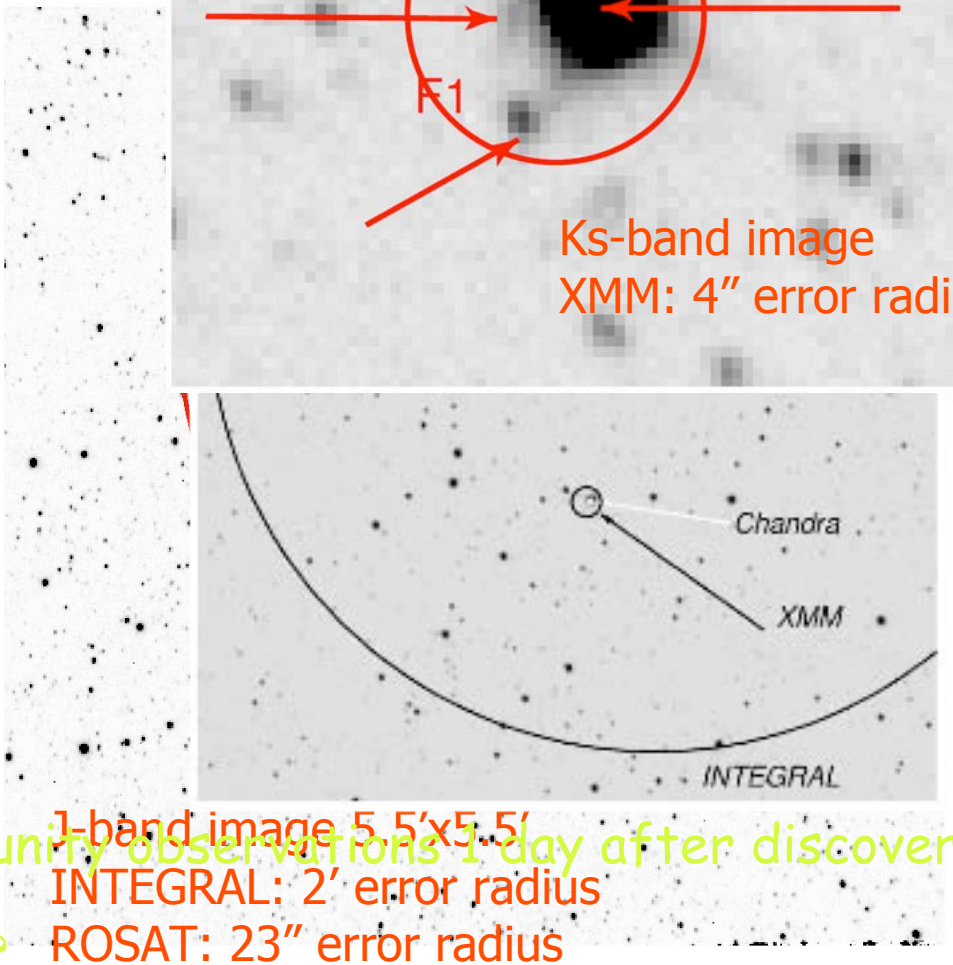
- Compact object: likely Neutron Star (in't zand 2005)
- Distance: 3-4 kpc
- Archetype of "SFXTs": Supergiant Fast X-ray transients:
  - O/B supergiant companions,
  - Compact object = BH or NS,
  - faint quiescent emission, outbursts lasting only hours.

IGR J17544-2619 optic





Ks-band image
XMM: 4" error radius

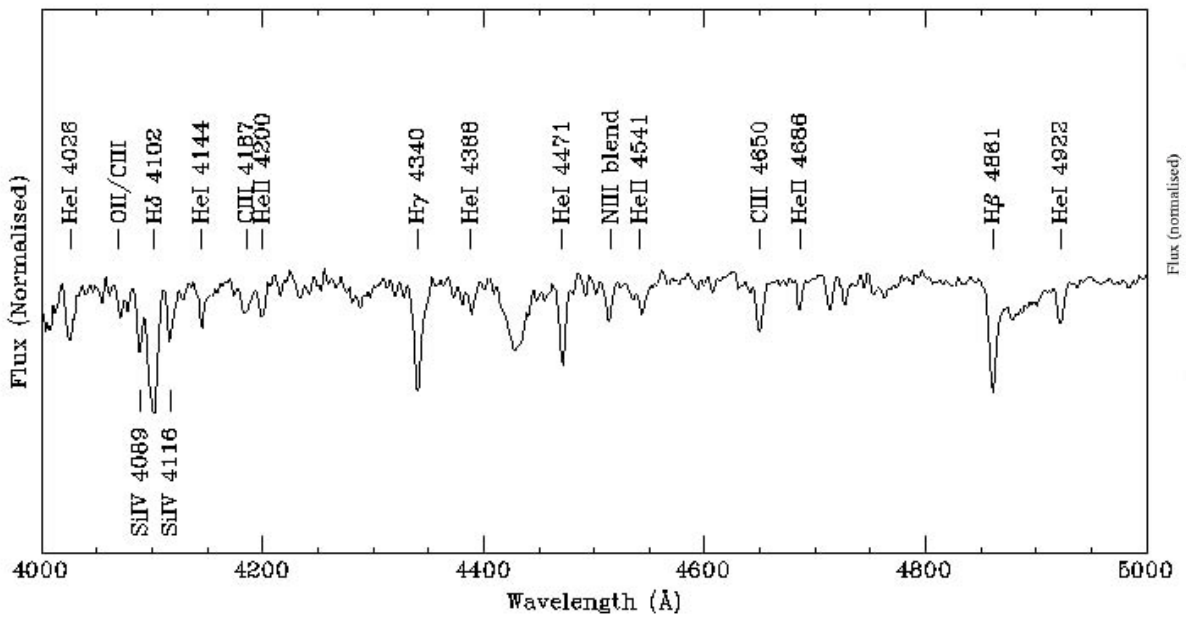


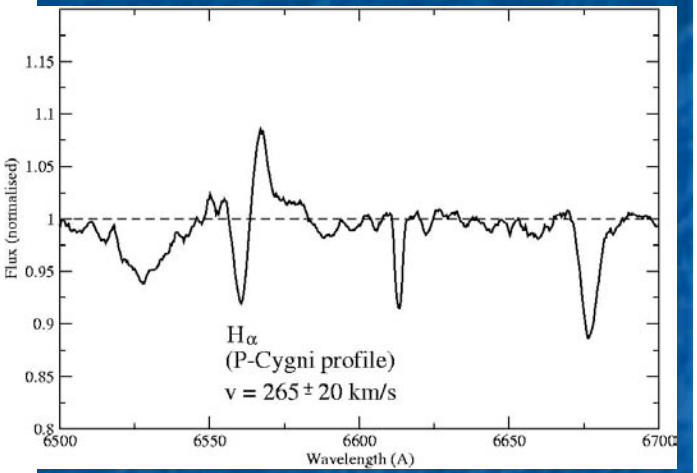
I-band image 5.5'x5.5'
INTEGRAL: 2' error radius
ROSAT: 23" error radius
XMM: 4" error radius
Chandra: 0.4''

Optical/NIR Target of Opportunity observations 1 day after discovery!

1 bright candidate (B) identified in USNO & 2MASS
3 very faint candidates (F1-3): foreground dwarf stars?
1 extended object (E) high-z galaxy?

Candidate B spectrum



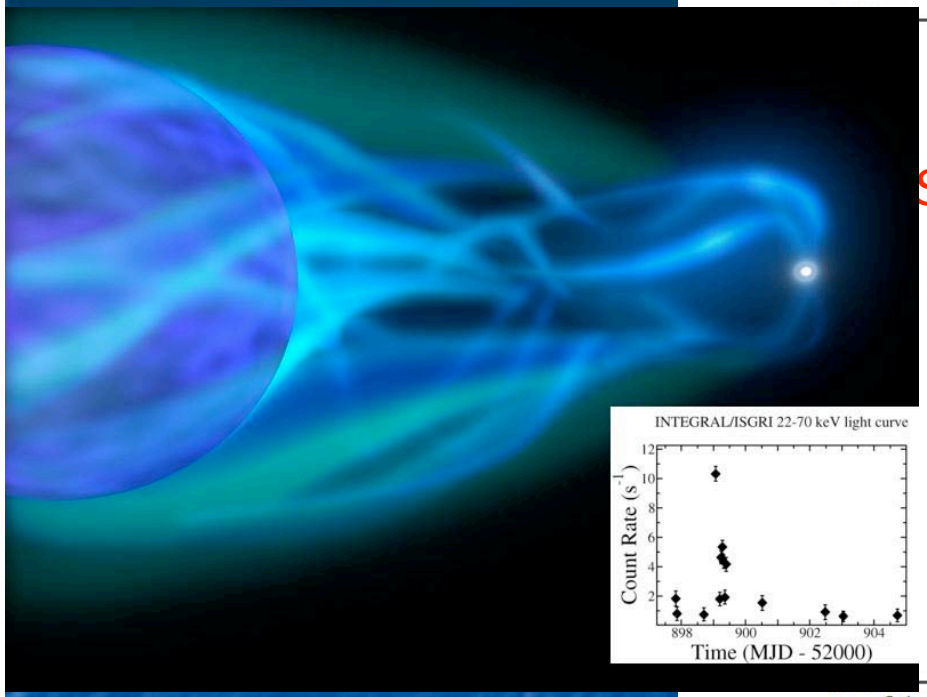


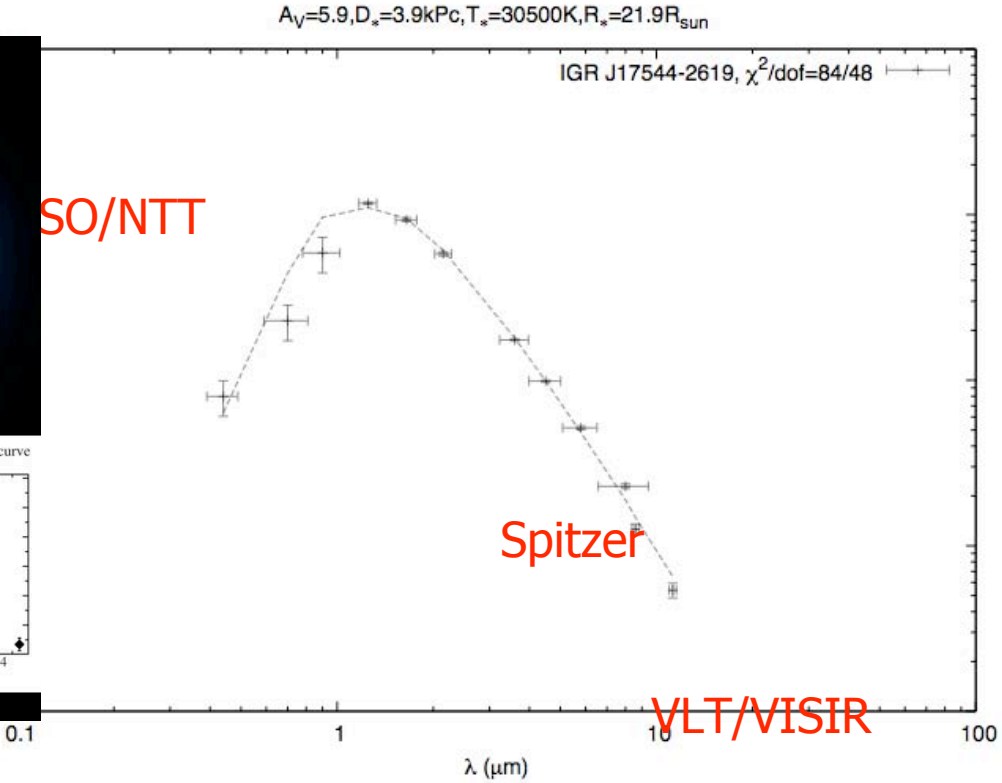
Blue supergiant O9 Ib (25-28 $M_\odot$, T~32000K)

High-mass X-ray binary

Existence of a stellar wind: 265 ± 20 km/s (unusually mild for O stars, cf. 400 km/s in IGR J16318-4848: Filliatre & Chaty 2004, ApJ 616, 469)

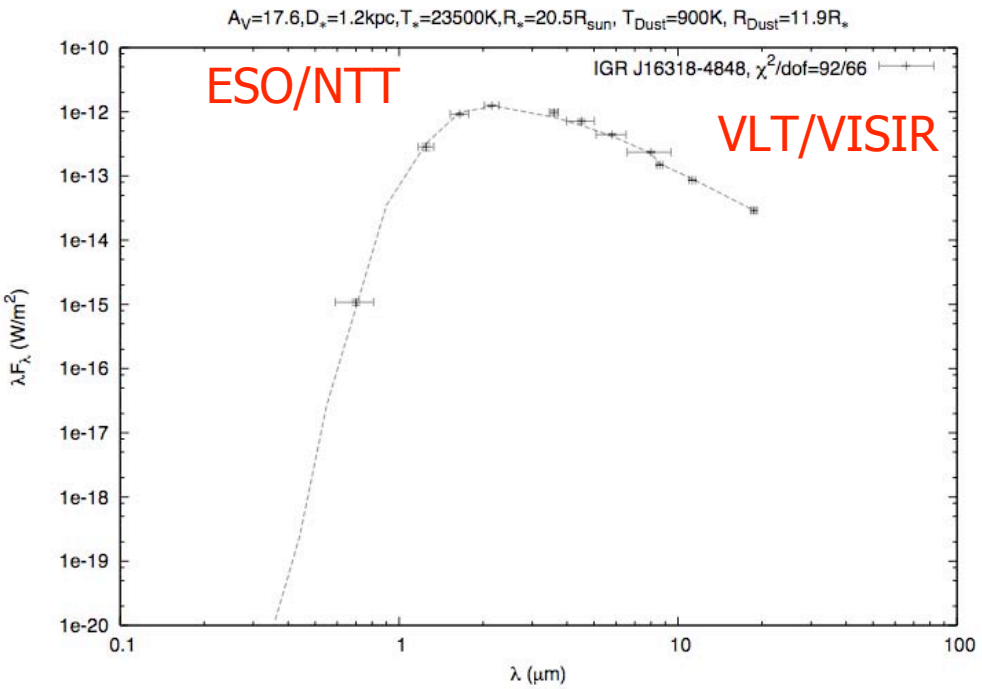
IGR J17544-2619 Optical -> mid-infrared SED

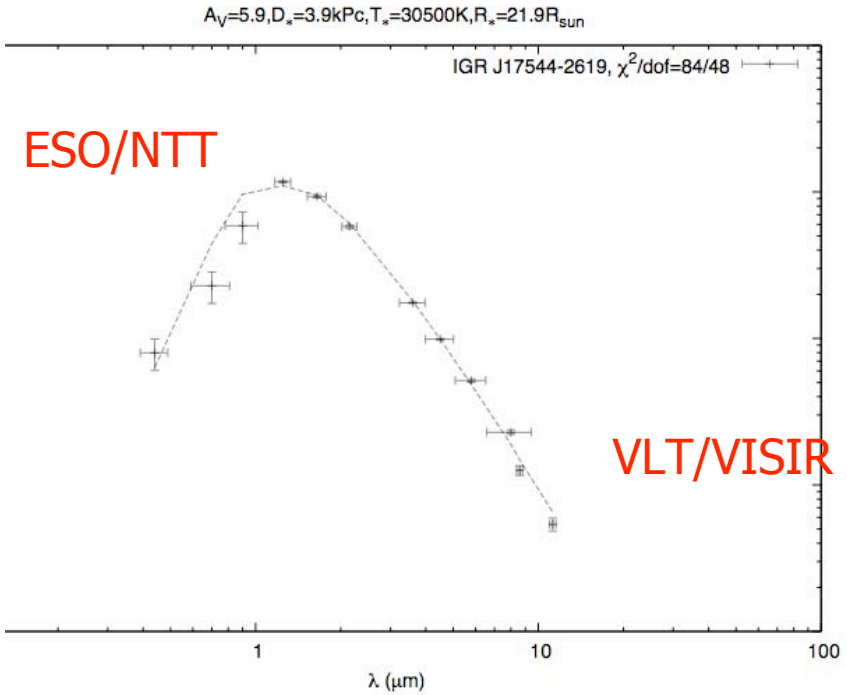




- Model:
  - Companion star: O9Ib, T=30500K, R=21.9 Rsun
  - Av=5.9, D=3.9kpc
  - Fit result: χ^2/dof=84/48
- no need for extra (e.g. dust) component

Dusty or not dusty?





- IGR J16318-4848:
  - Companion star: sgB[e]
    T=23500K, R=20 R_{Sun}
  - + Cocoon of Dust: T=900K, R=12R_*

- IGR J17544-2619:
  (Pellizza, Chaty, Negueruela, 2006, A&A)
  - Companion star: O9Ib
    T=30000K, R=22 R_{Sun}
  - No need for extra component

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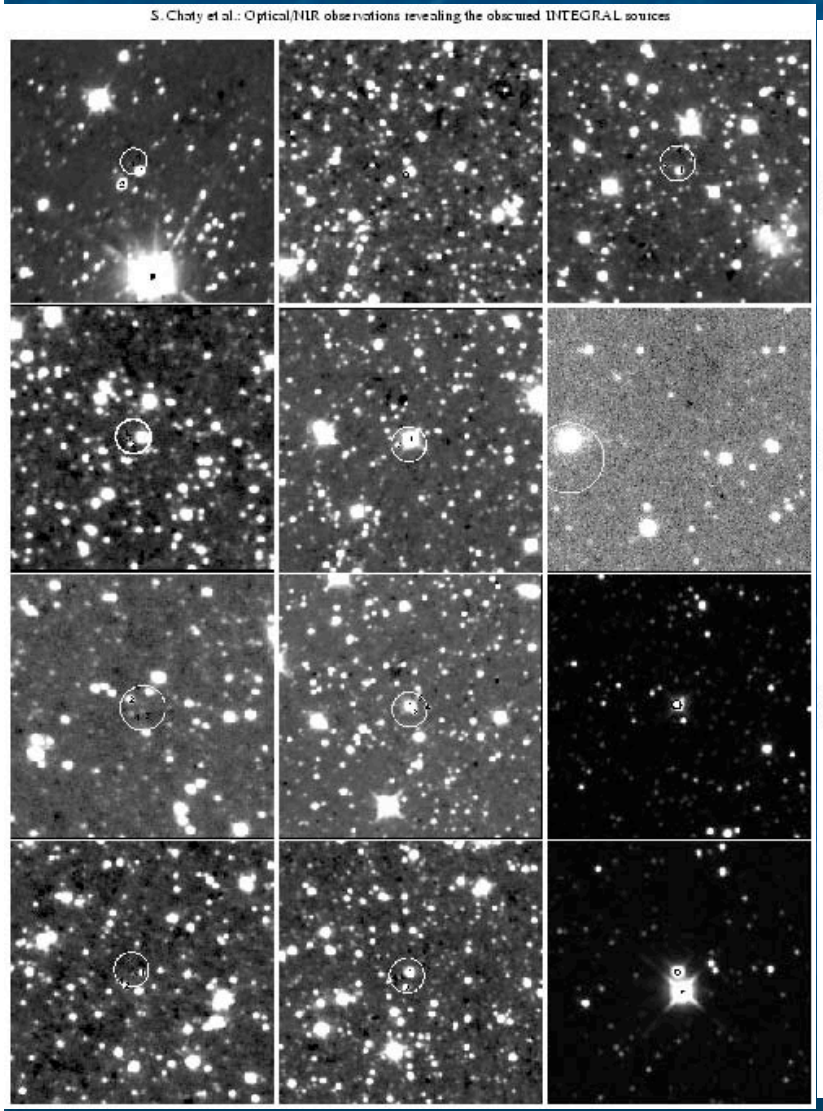
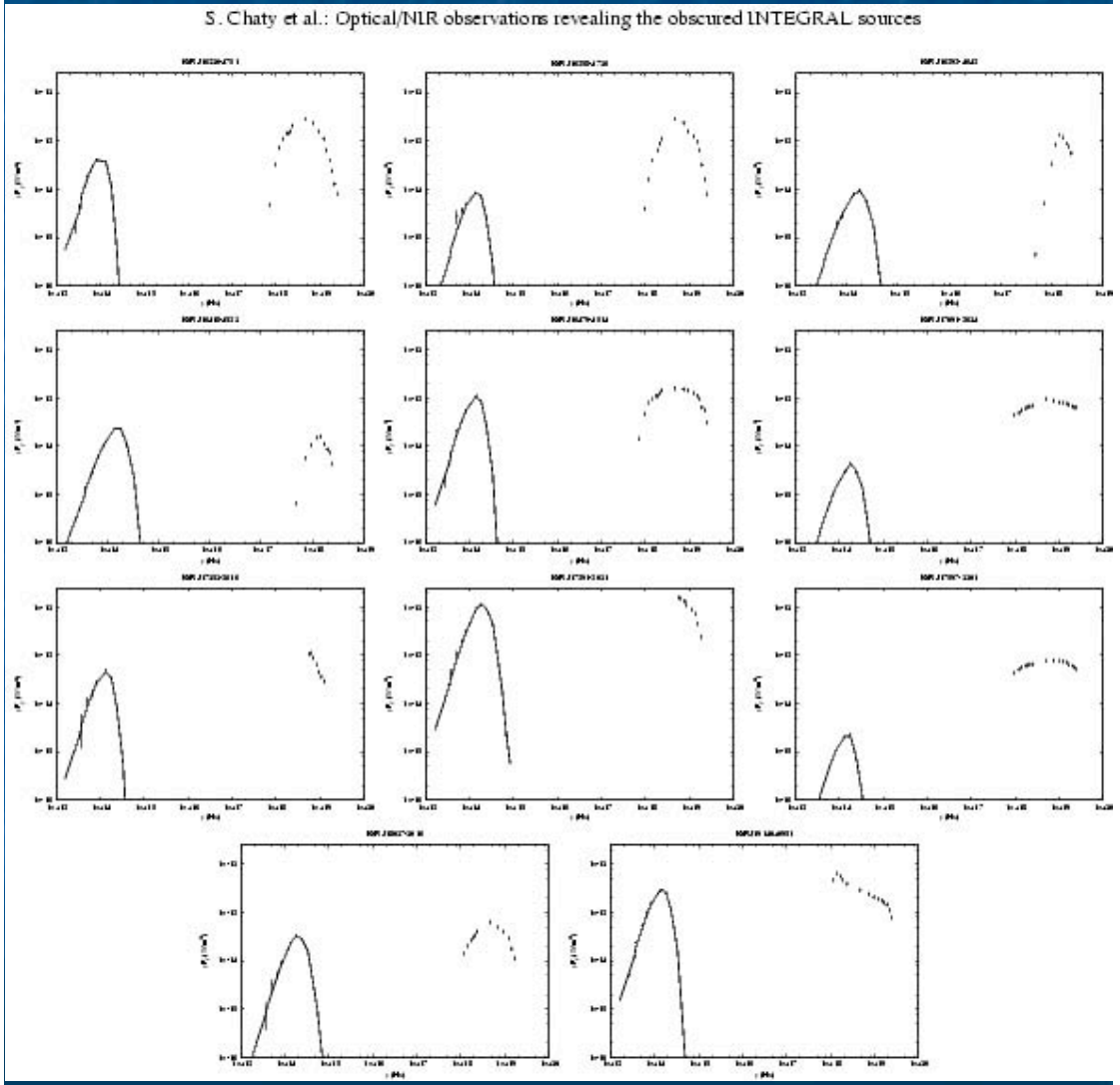
Optical to MIR results





Results of 2004 NTT-SOFI/EMMI and 2005/2006 Paranal UT3-VISIR observations

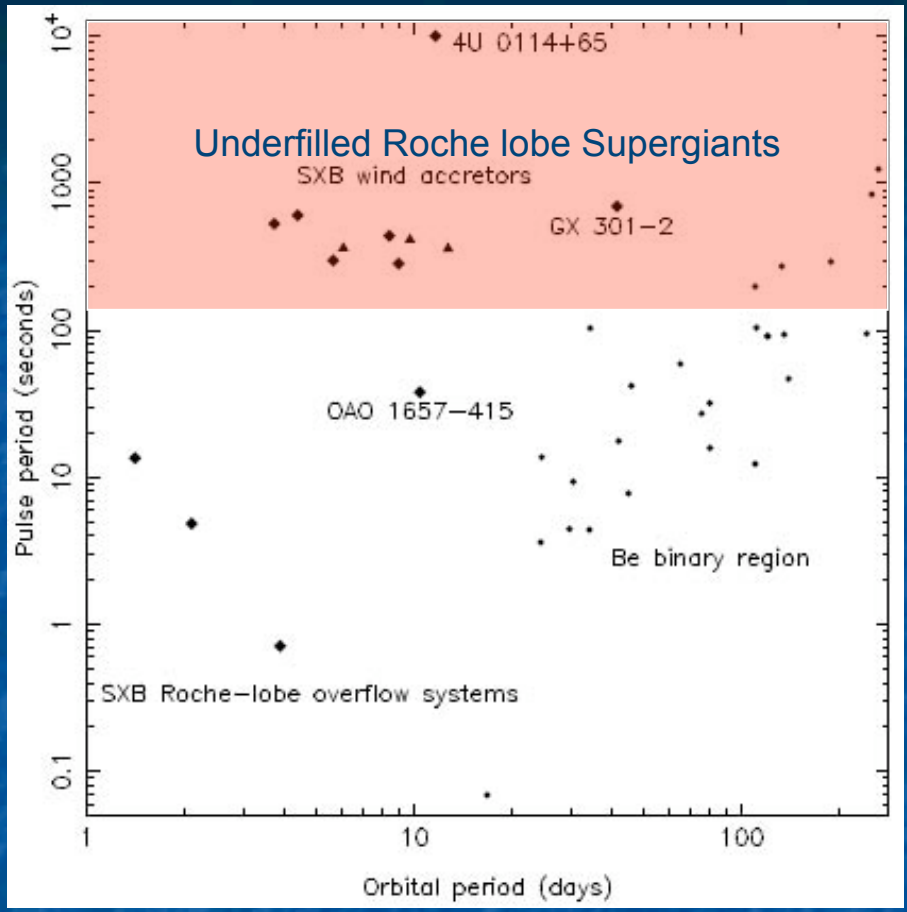
Source	Spectral type	Nhi	NhV	NhX	Star Temp (K)	Star Radius (R*)	Dust Temp (K)	Dust Radius (R*)
IGR J16195-4945	OB	2.18	2.9	7	23100	22.6	950	6.1
IGR J16207-5129	B0I	1.73	2	3.7	32500	21.2		
IGR J16318-4848	sgB[e]	2.06	3.3	200	23500	20.5	900	11.9
IGR J16320-4751	OB	2.14	6.6	21	32600	22.6		
IGR J16358-4726	sgB[e]?	2.20	3.3	33	24800	20.5	820	10
IGR J16393-4641	?	2.2	<2.7	24				
IGR J16418-4532	OB?	1.88	2.7	10	27000	20.2		
IGR J16465-4507	B0.5I	2.12	1.1	60	27500	20.1		
IGR J16479-4514	OB	2.14	3.4	7.7	32000	20.3		
IGR J17252-3616	OB	1.56	3.8	15	30000	20.6		
IGR J17391-3021	O8Iab(f)	1.37	1.7	30	32100	22.9		
IGR J17544-2619	O9Ib	1.44	1.1	1.4	30700	22		
IGR J17597-2201	Late?	1.2	<2.9	5				
IGR J18027-2016	sgOB	1.1	<2.1	9				
IGR J19140+0951	sgB0.5I	1.68	2.9	6	20000	21.2		

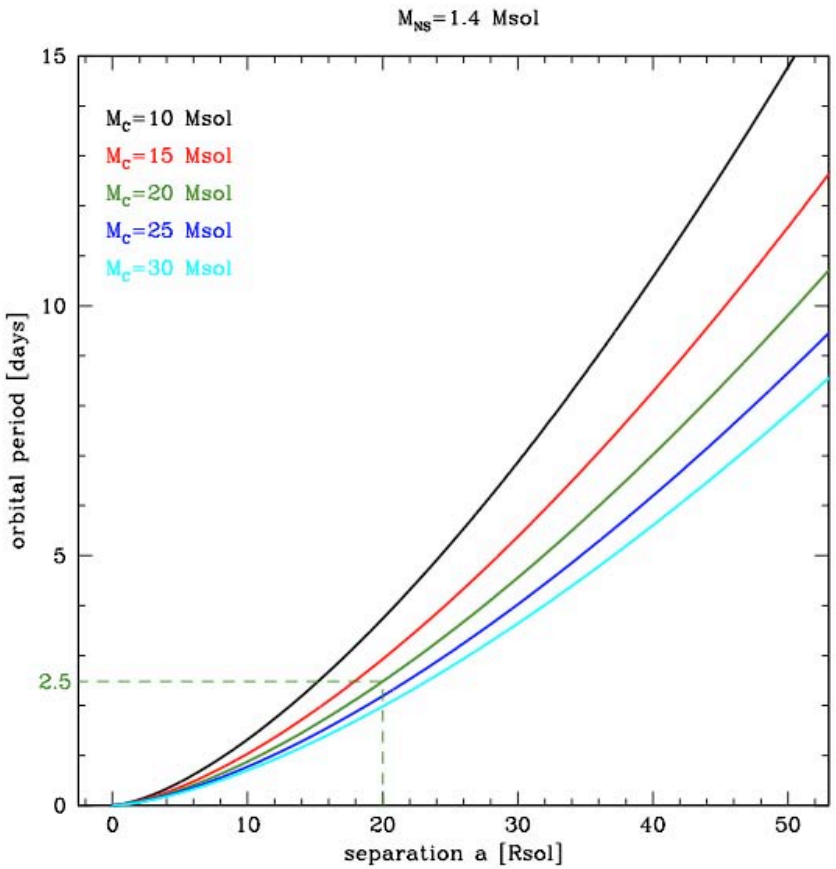
Results of 2004 NTT-SOFI/EMMI and 2005/2006 Paranal UT3-VISIR observations

Source	Region	Type	Pspin	Porb	Spectral type	Dust Temp (K)	Dust Radius (R*)
IGR J16195-4945	Norma	SFXT/OBS			OB	950	6.1
IGR J16207-5129	Norma				B0I		
IGR J16318-4848	Norma	P, OBS			sgB[e]	900	11.9
IGR J16320-4751	Norma	P, OBS	1250	9	OB		
IGR J16358-4726	Norma	T, OBS	5880		sgB[e]?	820	10
IGR J16393-4641	Norma	P	912				
IGR J16418-4532	Norma	SFXT	965		OB?		
IGR J16465-4507	Norma	SFXT/OBS	228		B0.5I		
IGR J16479-4514	Norma	SFXT			OB		
IGR J17252-3616	GC	P, OBS	413	9.7	OB		
IGR J17391-3021	GC	SFXT			O8Iab(f)		
IGR J17544-2619	GC	SFXT	NS	165?	O9Ib		
IGR J17597-2201	GC	P			Late?		
IGR J18027-2016	GC	P	139	4.57	sgOB		
IGR J19140+0951					sgB0.5I		

Nature of systems: Corbet Diagram

- 80% of Norma sources are X-ray pulsars
- High spin periods
- Star P_{orb}=10d, M=20M_{sol}, a=50R_{sol} < R_{dust} (R_{dust}=240$R_{Sun}$for IGR J16318)

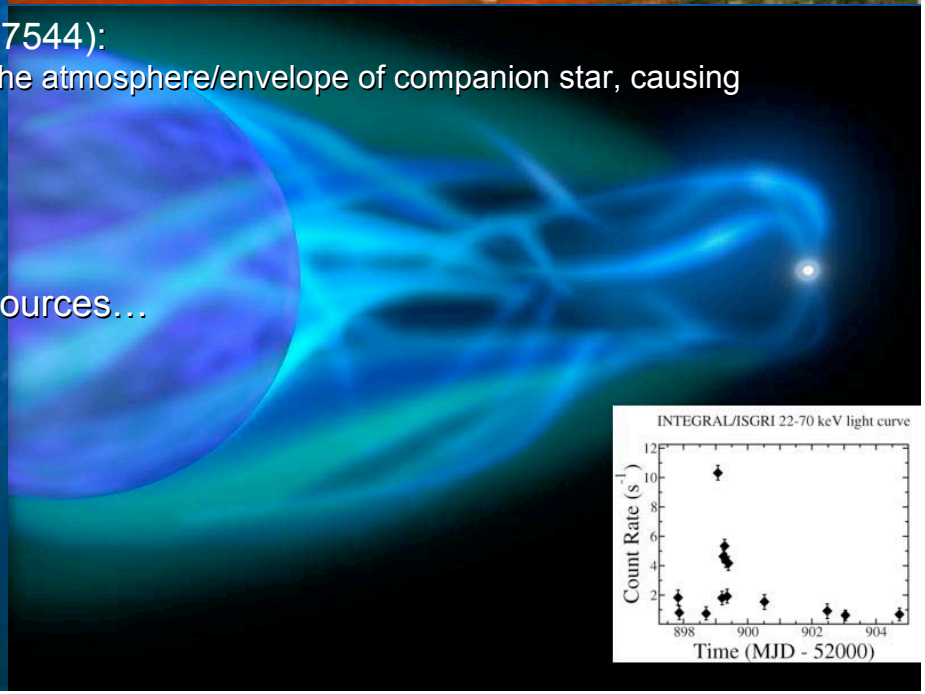


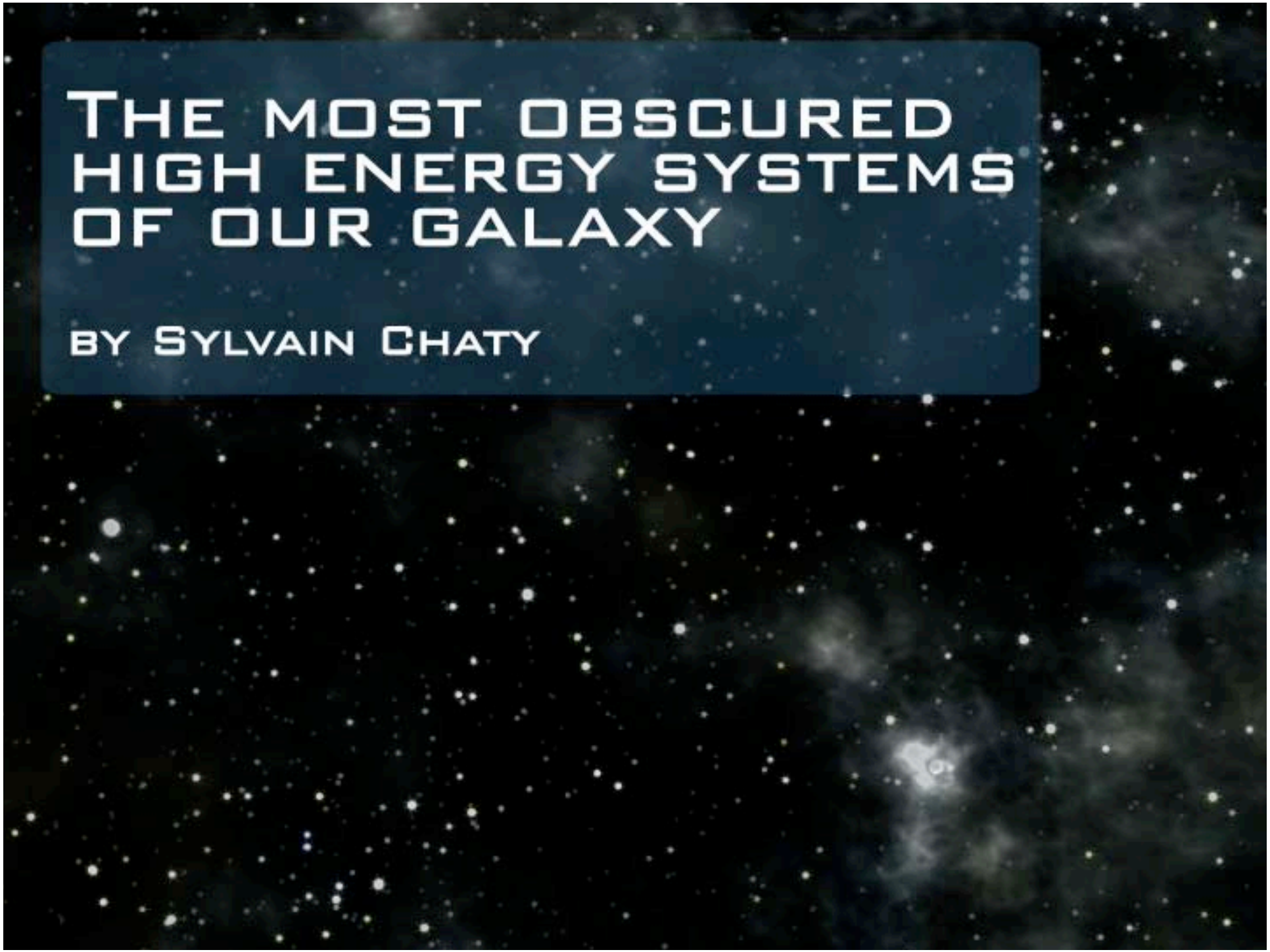


- HMXBs Pspin vs Porb:
  - Be Binaries
  - supergiant Roche lobe overflow systems
  - super-giant wind accretors

So, what are these sources? Different geometries, different scenarii

- Presence of a cocoon of dense and absorbing dust concentrated:
- 1) Around the whole system: obscured sources (~IGR J16318) :
  - neutron star orbits permanently within a dense cocoon: persistent X-ray emission
  - density 10^{11-12} cm^{-3}
  - Disc thickness 10^{12-13} cm (10-100 R_{Sun})
  - Disc radius 10^{13-14} cm (1-10 a.u.)
- 2) Only around the compact object: SFXTs (~IGR J17544):
  - Eccentric orbit, neutron star crosses periodically inside the atmosphere/envelope of companion star, causing transient X-ray outbursts?
- The answer will be given by orbital periods of these sources…




The most obscured high energy systems of our galaxy
by Sylvain Chaty

Conclusions

- INTEGRAL doubled the population of massive binaries with supergiant in our Galaxy, and revealed a class of highly absorbed binaries.

- These INTEGRAL sources exhibit common characteristics:
  - High Mass X-ray Binaries with O/B supergiant secondaries
  - Compact object: mostly neutron star, high Pspin
  - Close to the galactic plane $|b|<1°$
  - No radio emission

- But they are not the same!
  - Intrinsic absorption around the neutron star (X-ray absorption)
  - Cocoon of dust/cold gas enshrouding whole system (MIR excess)
  - Properties, circumstellar environment due to star
  - X-ray transient/persistent

The future…

- This new population constrains our vi
  formation and evolution of HMXBs:
  - dominant population born with two very massive components, in rich star-forming region?
  - Short living systems…
  - What will happen when the supergiant star dies?
    - Primary progenitors of NS/NS or NS/BH mergers,
    - Good candidates of gravitational waves emitters?
    - Link with short/hard gamma-ray bursts?
- GLAST will discover such new and unexpected objects…

Multi-wavelength study decisive to unveil the nature of high-energy objects…