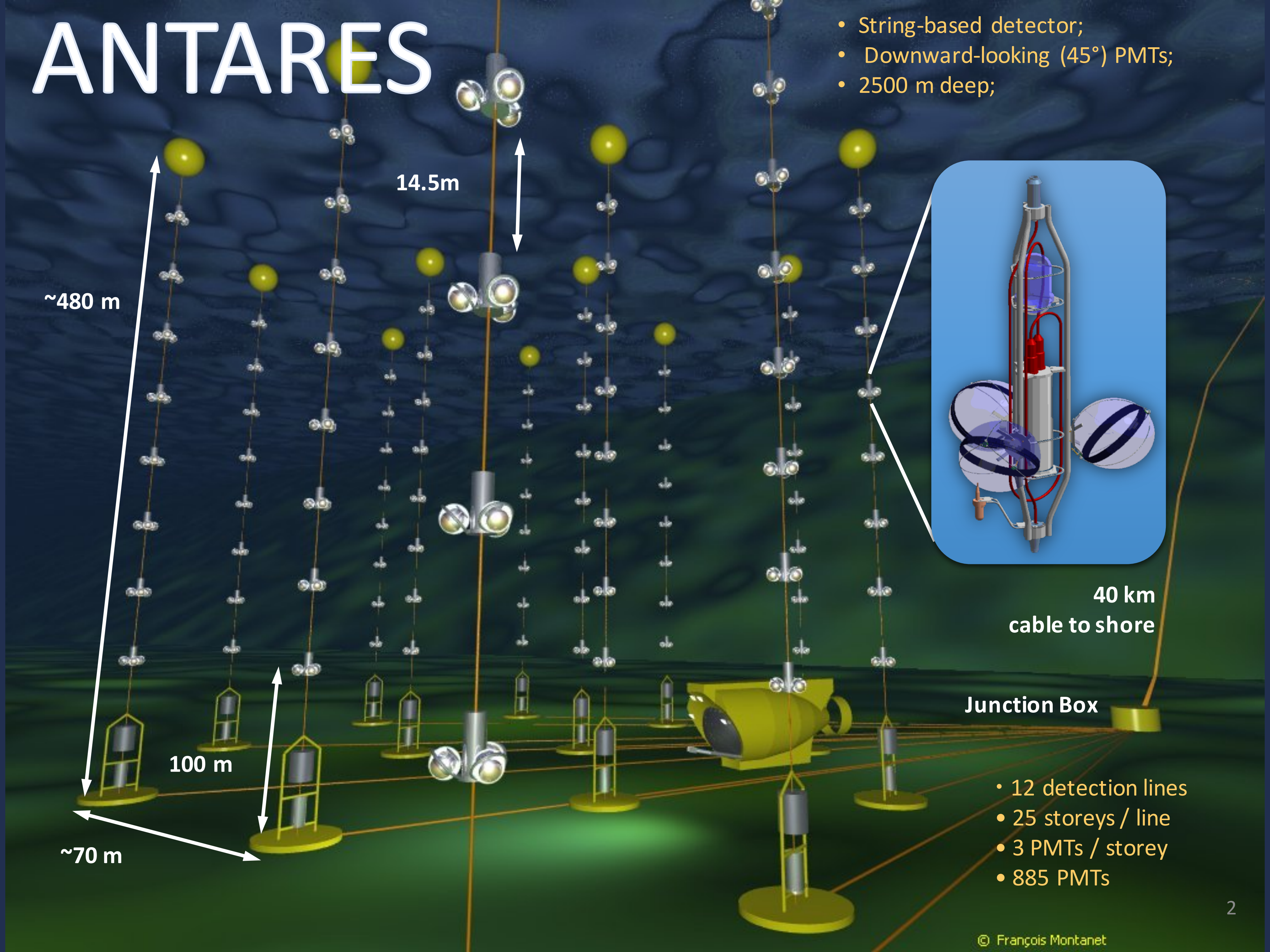
ANTARES neutrino telescope


ANTARES
• String-based detector;
• Downward-looking (45°) PMTs;
• 2500 m deep;
14.5m
~480 m
40 km
cable to shore
Junction Box
100 m
~70 m
• 12 detection lines
• 25 storeys / line
• 3 PMTs / storey
• 885 PMTs
© François Montanet

XRB, γRB: hadronic ?

$\sigma(\nu p)/\sigma(\gamma p) = 10^{-7}$ at 1 TeV

GeV-TeV γ-ray detections => emission of outflow containing particles accelerated away from the compact object up to relativistic speeds.
HE radiations -> interaction of this outflow with wind/raditation of the companion star.

Cosmic rays can also be accelerated together with the electrons but are more difficult to see (less radiation, longer accelration time…).

The non-thermal emission of the system is surely dominated by leptonic processes but a hadronic component could also be present (not necessary to have jets).

As usual only few indications of hadronic component in XRB, only few cases:

- SS433: Migliari et al. , Science (2002)
- 4U 1630-472: Trigo et al. , Nature (2013)
- Cyg X-1: population of cold baryons supposed. Heinz et al, ApJ (2005)

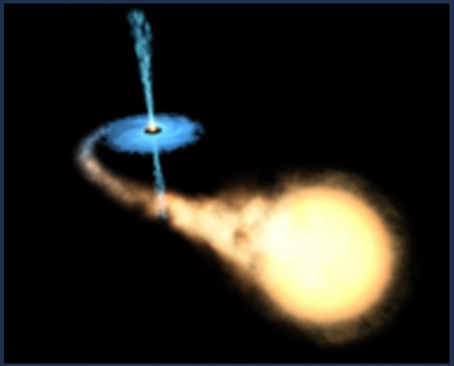
Detection of neutrinos => smoking gun for the presence of hadronic processes

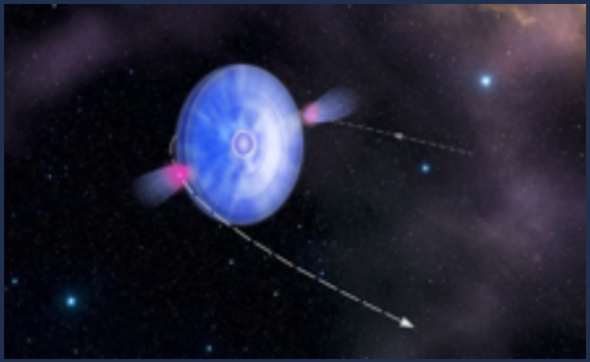
Neutrinos from XRB

Hadronic models

⇒ In the presence of jets, neutrinos produced in p-γ interactions in the jet and/or p-p interactions with thermal protons from dense stellar wind (HMXB)

(Levinson et al, PRL 2001, Distefano et al, ApJ 2002, Romero et al, A&A 2008, Romero et al, A&A 2003, Christiansen et al, PRD 2006, Torres et al, A&A 2007, Vila et al, 2012, Vieyro et al, A&A 2012, Pepe et al, 2015)



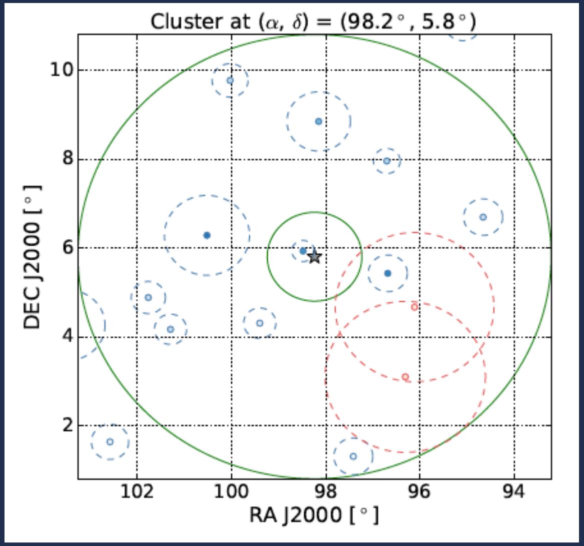


⇒ In the absence of jets (HMXB_NS), p-p processes between the accelerated protons in the rotation-driven relativistic wind from the young neutron star and the circumstellar disk in the case of Be type stars

(Bartosik et al, 2003, Neronov et al, PRD 2009, Sahakyan et al, A&A 2014, Bednarek et al, PRD 2009, Anchordoqui et al, ApJ 2003)

Neutrinos from XRB, γRB

1st analysis: Looking for a point-like source signal using 9 years of data [2007-2015, 2423.6 days]
- all-flavour neutrino search (ν_e+ν_μ+ν_τ)



Name	$\delta[°]$	$\alpha[°]$	μ_{sig}	$\Phi_0^{90\%}$
CirX-1	-57.17	230.17	–	0.84
GX339-4	-48.79	255.70	–	0.63
LS5039	-14.83	276.56	–	1.19
SS433	4.98	287.96	–	0.99
HESSJ0632+057	5.81	98.24	2.7	2.40

<= small fluctuation <2σ

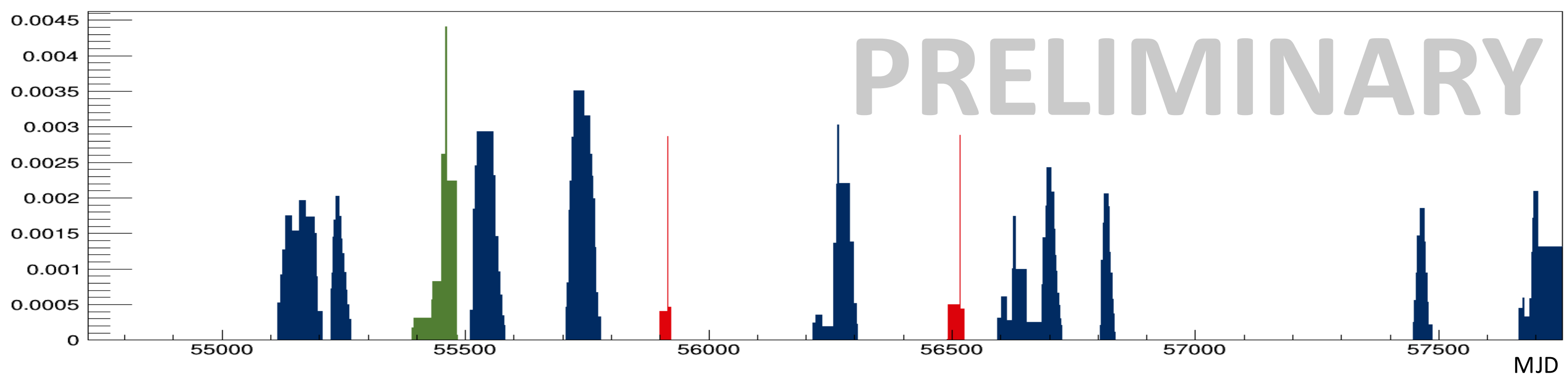
(in units of 10^{-8} GeV cm^{-2} s^{-1})

Source and flare selection: XRBs

⇒ Gain in sensitivity by looking at space/time correlation (~2-3)
⇒ Choose the more appropriate periods to look for neutrinos
Neutrino emission is assumed to be correlated with hard X-ray outbursts (natural in the case of μ-quasars).

⇒ Selection of 36 XRBs exhibiting outburst periods between 2008-2016 from the Swift and MAXI catalogues, extended with RXTE/ASM data when available.

⇒ In Transition State periods, even more favourable conditions but difficult to be identified. So, we have used ATels and papers as references.



$P_{sg}(t)$ sample for GX 1+4, made up with flares registered by **SWIFT**, **Rossi** and **MAXI**

Source and flare selection: γRBs

HE emission due to interaction of pulsar wind with the intense stellar wind of the companion massive star.

Four γ-RBs compatible with ANTARES up-going visibility selected:

- **1FGL J1018.6−5856**: M.J. Coe et al. , Science (2012) [astro-ph/1202.3164]
- **HESS J0632+057**: S. Bongiorno et al. , ApJL (2011) [astro-ph/1104.4519]
- **LS 5039−63**: J. Casares et al. , MNRAS (2005) [astro-ph/0507549]
- **PSR B1259−63**: A. Abramowski et al. , A&A (2013) [astro-ph/1301.3930]

Name	RA (°)	DEC (°)	Period (days)	Flaring phase	Periastron (MJD)
1FGL J1018.6−5856	154.7	−58.9	16.58±0.02	0.70–0.40	55387.5±0.4
HESS J0632+057	98.2	+5.8	315±5	0.20–0.45	54587.0±0.5
LS 5039−63	276.6	−14.8	$3.91\pm8\cdot10^{-5}$	0.45–0.95	51942.59±0.05
PSR B1259−63	195.7	−63.8	$1236.7\pm2\cdot10^{-5}$	0.92–0.08	55545.0±0.5

(TeV measurements for **LS 5039−63**)

Cyg X−3 XRB detected outbursting at γ-ray energies by Fermi-LAT(A. Bodaghee et al. ,ApJ 2013). Flaring periods: ON/OFF periods Y+ and Y− reported in the reference + #ATel 8591 and 9502.

Preliminary sensitivities

All-flavour time-dependent point-like source search using 2008-2016 data (2412 days).

=> Preliminary sensitivities using only muon neutrino sample (+30% including all-flavour neutrinos)

$$dN/dE = \Phi_0^{90\%}\,(E/GeV)^{-2}$$

$$F^{90\%} = \Delta t \int_{E_{5\%}}^{E_{95\%}} E \cdot dN/dE \cdot dE$$

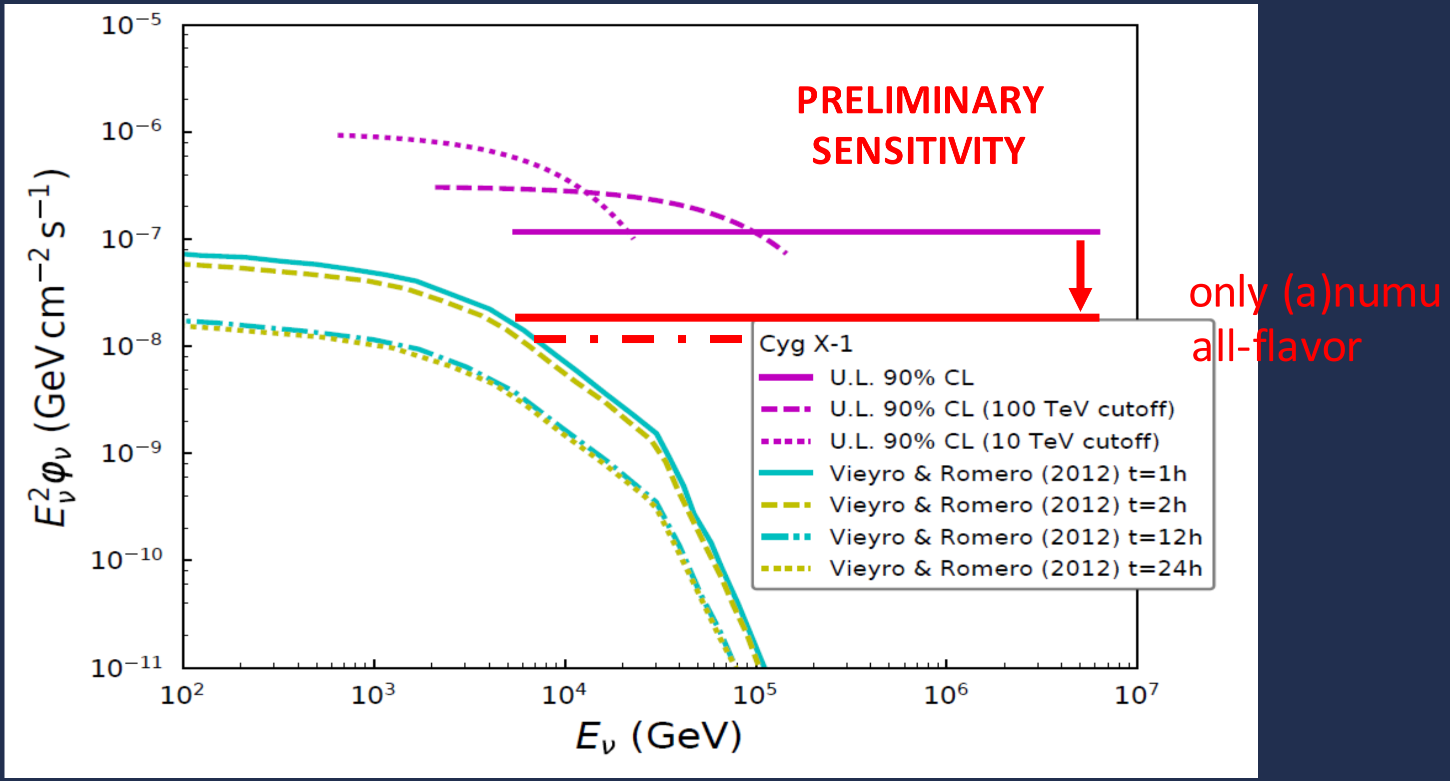
Name	RA (°)	DEC (°)	$\Phi_0^{90\%}$ 10^{-8} GeV^{-1} cm^{-2} s^{-1}	$F^{90\%}$ GeV cm^{-2}
1FGL J1018.6−5856	154.7	−58.9	0.5	6.8
HESS J0632+057	98.2	+5.8	1.6	12
LS 5039−63	276.6	−14.8	1.1	10
PSR B1259−63	195.7	−63.8	3.0	6.5
Cyg X−3	308.1	+41.0	146	18

Name	RA (°)	DEC (°)	Satellite (#flares|days)	$\Phi_0^{90\%}$ 10^{-8} GeV^{-1} cm^{-2} s^{-1}	$F^{90\%}$ GeV cm^{-2}
1A 0535+262	84.7	+26.3	S(#11|417)+M(#2|30)	8.6	14
1A 1118−61	170.2	−61.9	S(#1|141)	16	6.6
1A 1742−294	266.5	−29.5	S(#1|3)+M(#5|284)	5.7	9.2
4U 1630−472	248.5	−47.4	S(#6|437)+M(#3|278)	2.0	7.1
Aql X−1	287.8	+0.6	S(#7|460)+M(#10|95)	3.9	11
AX J1749.1−2639	267.3	−26.6	S(#1|85)	19	9.6
Cir X−1	230.2	−57.2	S(#10|205)+M(#18|478)	2.0	6.8
Cyg X−1	299.6	35.2	S(#9|1965)	1.8	17
EXO 1745−248	267.0	−24.8	S(#3|191)+M(#4|237)	3.9	9.6
GRO J1008−57	152.4	−58.3	S(#12|614)	2.2	6.8
GRS 1739−278	265.7	−27.8	S(#1|143)+M(#2|264)	4.5	9.5
GS 0834−430	129.0	−43.2	S(#1|1427)+M(#2|13)	1.2	7.1
GS 1354−64	209.5	−64.7	S(#1|136)+M(#3|16)	7.9	6.4
GX 1+4	263.0	−24.7	S(#9|661)+M(#2|58)+R(#1|93)	2.2	9.6
GX 304−1	195.3	−61.6	S(#16|579)+M(#1|10)	2.9	6.7
GX 339−4	255.7	−48.8	S(#5|525)+M(#5|121)	2.5	7.1
H 1417−624	215.3	−62.7	S(#1|107)	15	6.6
H 1608−522	243.2	−52.4	S(#7|967)+M(#12|384)	1.1	7.1
H 1743−322	266.6	−32.2	S(#12|772)+M(#3|33)	2.1	8.9
IGR J17473−2721	266.8	−27.3	S(#1|9)+R(#1|61)	34	9.6
KS 1947+300	297.4	30.2	S(#4|324)+M(#10|242)	4.9	16
MAXI J0556−332	89.2	−33.2	M(#2|475)	3.8	8.8
MAXI J1543−564	235.8	−56.4	M(#3|131)	11	6.9
MAXI J1659−152	254.8	−15.3	S(#2|125)+R(#2|96)	11	10
MAXI J1836−194	278.9	−19.3	S(#1|83)+M(#2|18)	18	10
MXB 0656−072	104.6	−7.2	S(#1|37)+M(#1|2)+R(#1|4)	53	11
SAX J1747.0−2853	266.8	−28.9	M(#6|382)	4.4	9.3
SMC X−3	13.0	−72.4	S(#1|90)+M(#1|3)	13	6.3
SWIFT J1539.2−6227	234.8	−62.5	S(#1|46)	50	6.6
SWIFT J1745.1−2624	266.3	−26.4	S(#1|198)	10	9.6
SWIFT J1842.5−1124	280.6	−11.4	S(#1|133)+R(#1|356)	4.8	10
SWIFT J1910.2−0546	287.6	−5.8	S(#2|52)+M(#2|14)	29	11
V404 Cyg	306.0	33.9	S(#2|89)+M(#1|28)+R(#4|19)	22	17
XTE J1752−223	268.1	−22.3	S(#2|210)+M(#12|229)	5.3	9.9
XTE J1810−189	272.6	−19.1	M(#2|277)	9.2	10
XTE J1946+274	296.4	27.4	S(#1|61)+M(#1|12)	48	15

Preliminary sensitivities

In the case of Cyg X-1, non-thermal emission of Cyg X-1 comes from static corona model without presence of relativistic outflows (Romero et al, A&A 2010).

=> Vieyro et al, A&A 2012: neutrinos produced by the interactions of CR in the strongly magnetized corona.



Preliminary sensitivities

In the case of µ-quasar: we use the model of Levinson et al, PRL 2001, Distefano et al, ApJ 2002, to constrain the parameter space
=> Prediction of the neutrino energy flux based on the radio luminosity of the jets observed in radio during flares.

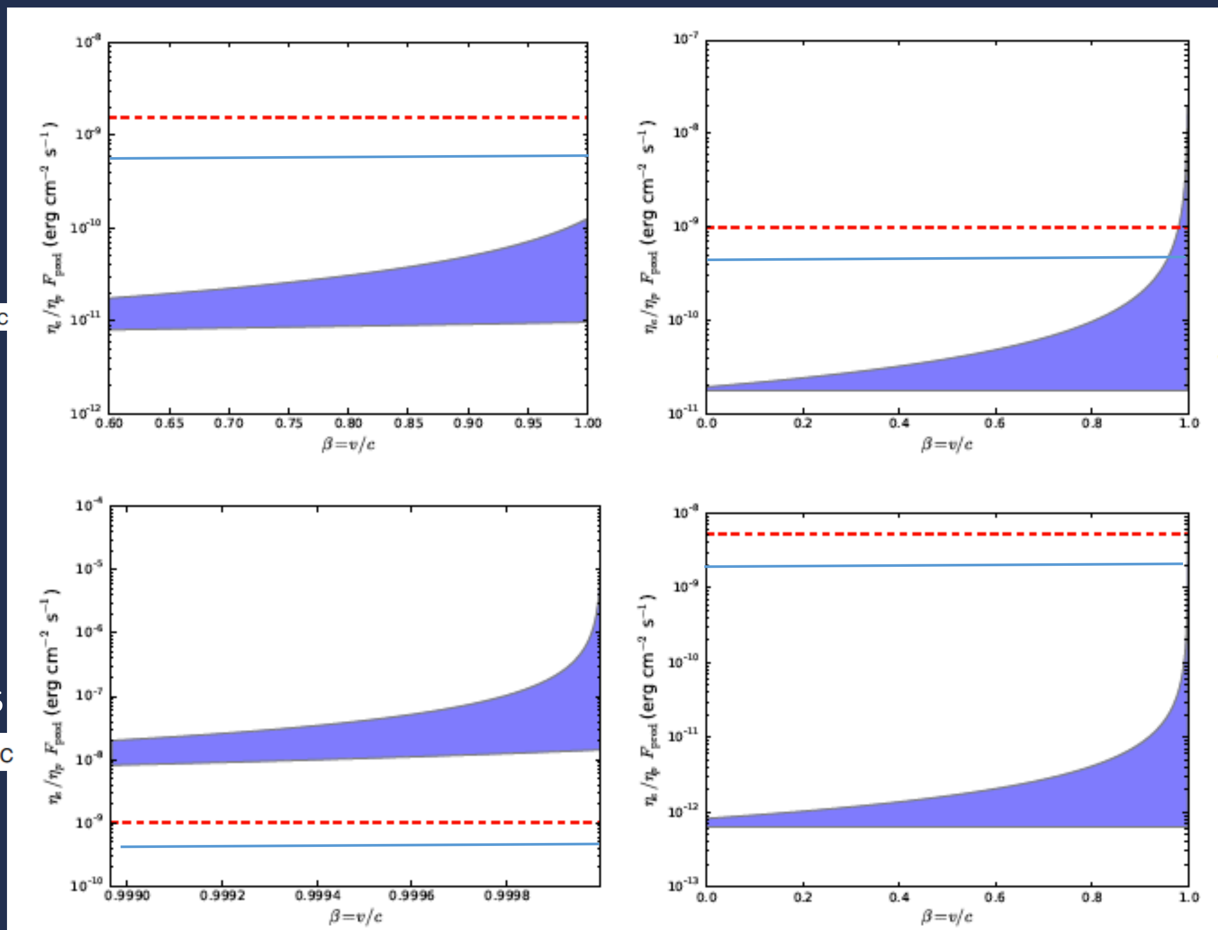
Cyg X-1

0.6<**β**<0.97, **θ** = 40°, D=1.8 kpc

Circ X-1

Miller-Jones et al, MNRAS 2012

1.076<**Γ**<5, **θ** < 20°, D=7.8 kpc



Circ X-1

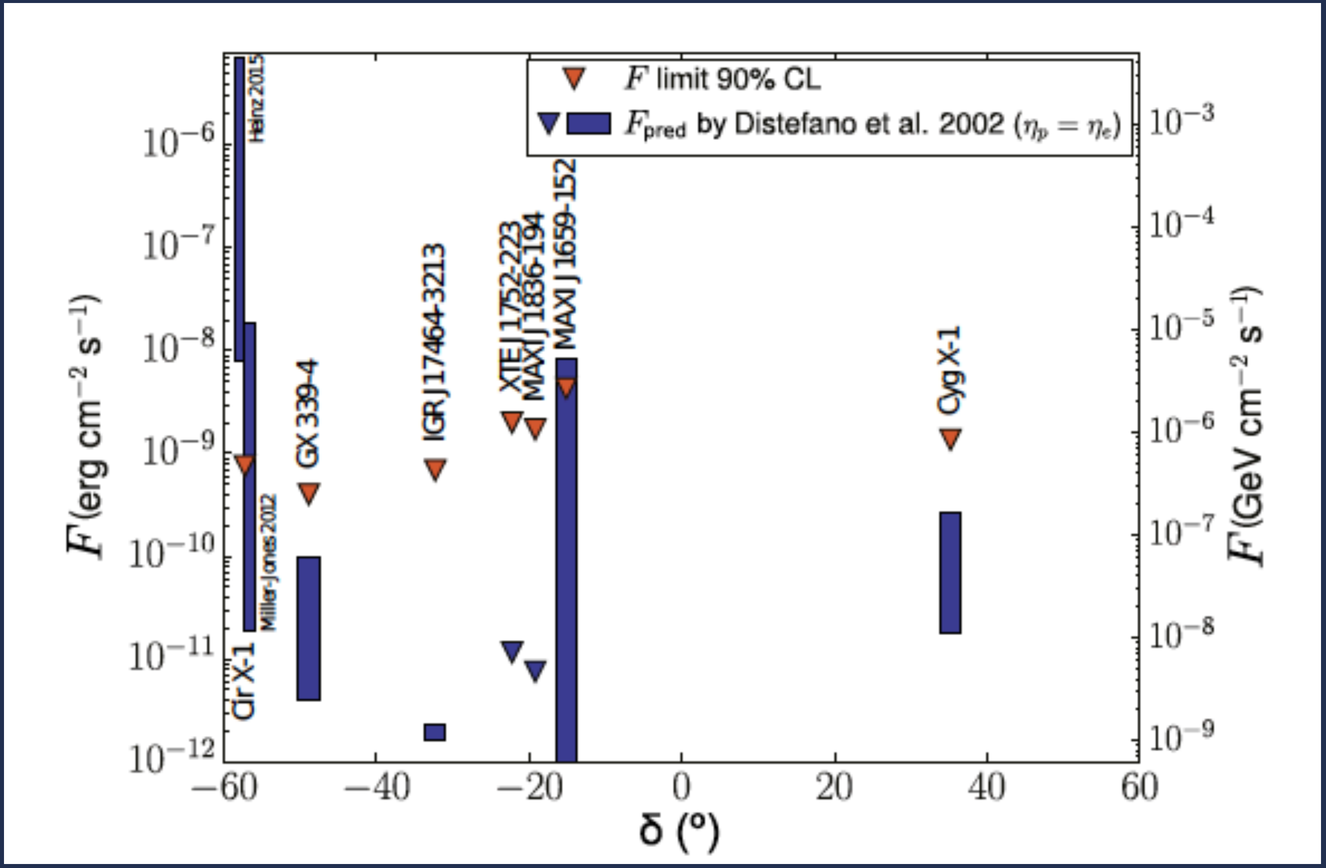
Heinz et al, ApJ 2015

Γ > 22, **θ** < 3°, D=9.4 kpc

MAXI J1659-152

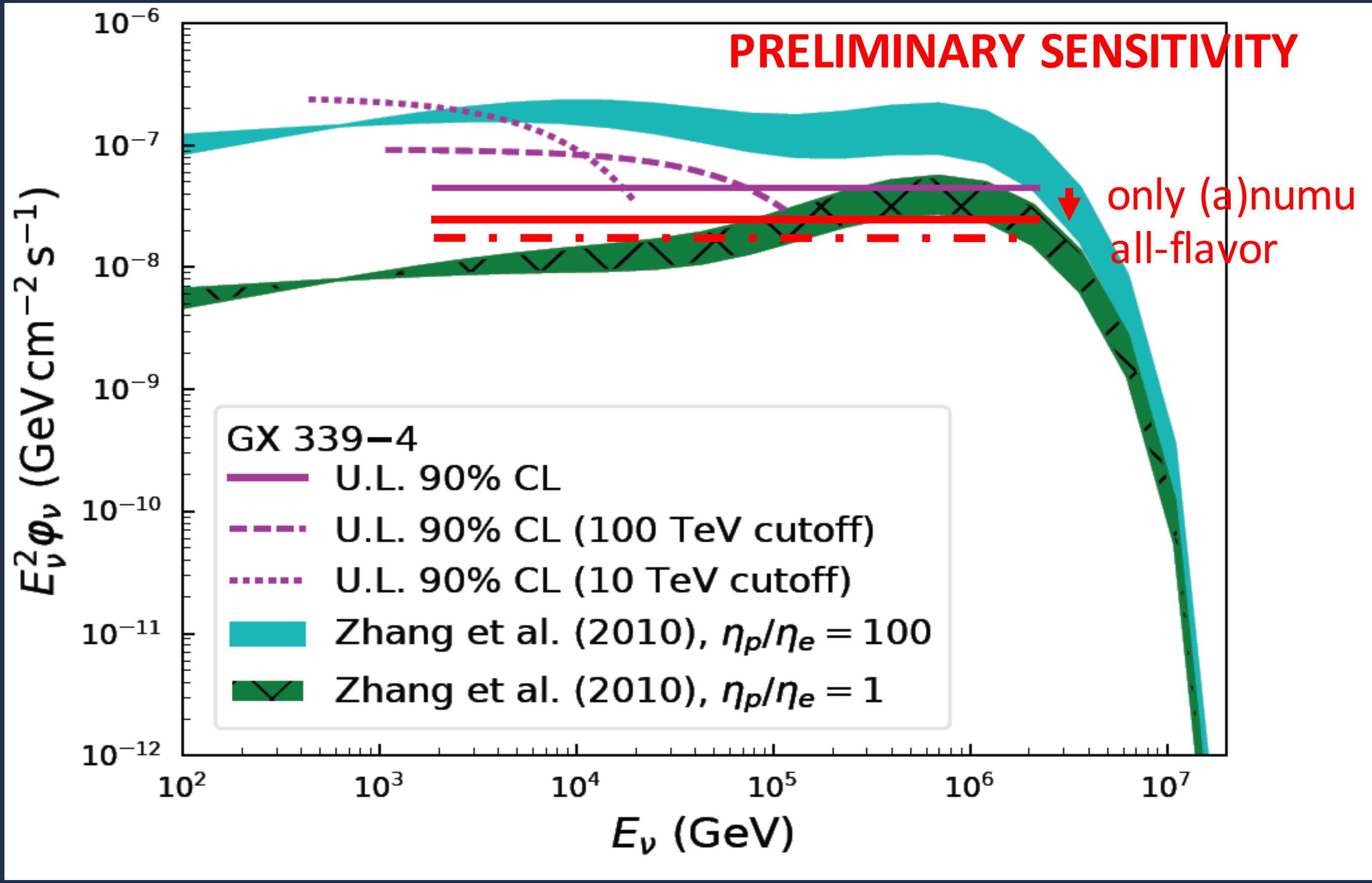
Preliminary sensitivities

In the case of μ-quasar: we use the model of Levinson et al, PRL 2001, Distefano et al, ApJ 2002, to constrain the parameter space
=> Prediction of the neutrino energy flux based on the radio luminosity of the jets observed in radio during flares.



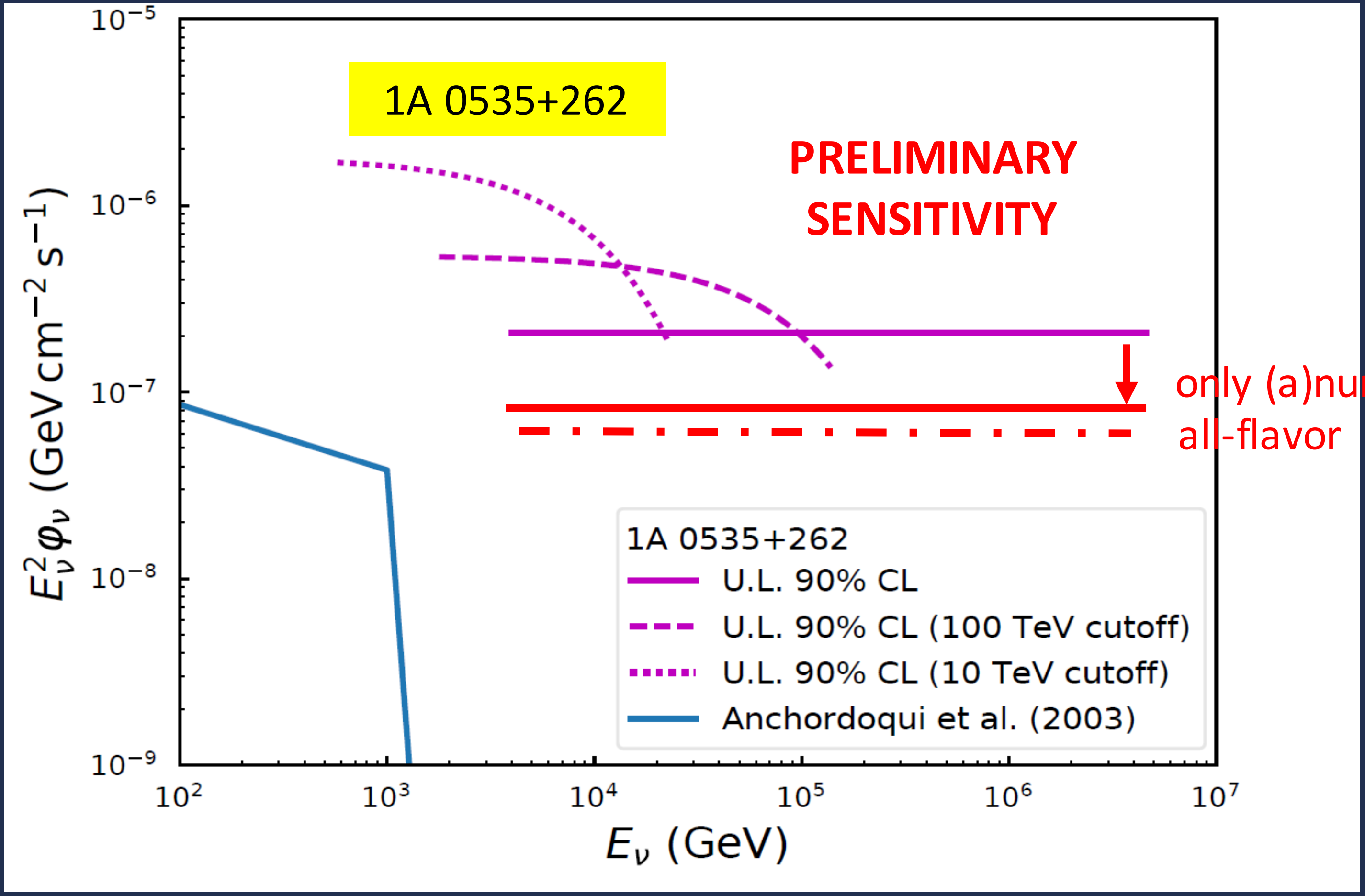
Preliminary sensitivities

In Zhang et al. MNRAS (2010), neutrinos are produced in p-γ interactions assuming primary spectrum of the injected particles in the jets has spectral indexes -1.8 > α > -2:0 and that the ratio between proton and electron energy is equal to 1 and 100



Preliminary sensitivities

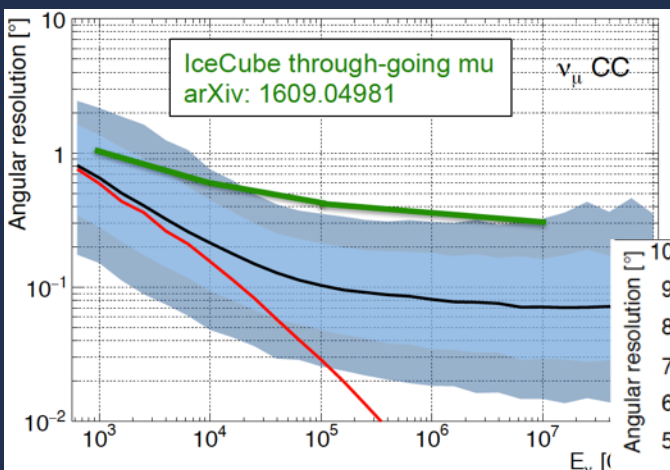
In the case of XRB without relativistic jets, Anchordoqui et al. ApJ (2003) predict that protons can be accelerated in the gaps in the magnetosphere of accreting NS and can impact onto the accretion disk, finally producing high-energy neutrinos under specic conditions of disk density

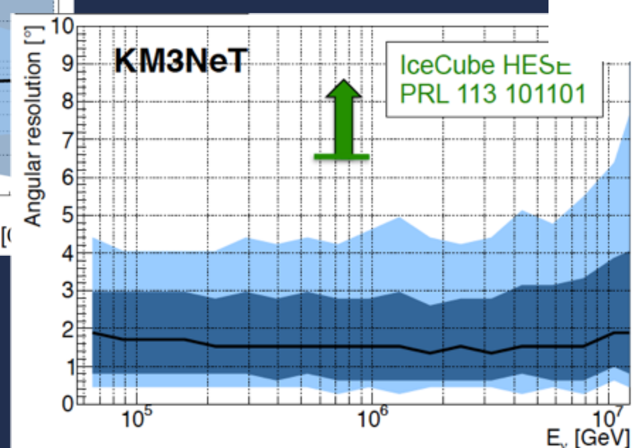


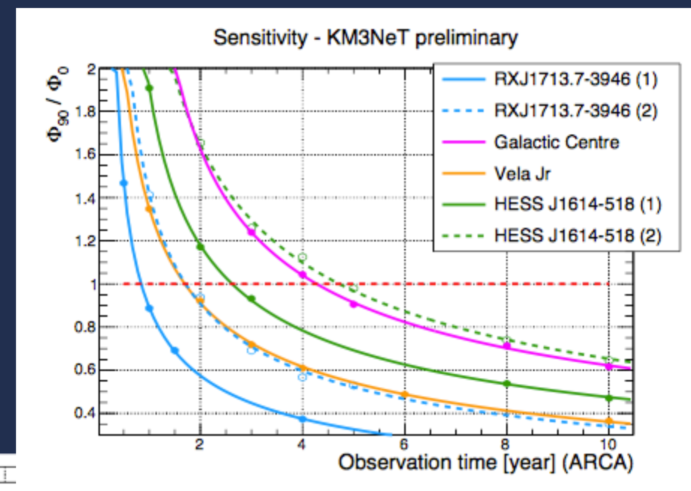
2^{nd} generation KM3NeT telescope

ORCA: South of Toulon [construction 2017-2020]: Low-energy array 3-300 GeV => Neutrino oscillation properties (mass hierarchy), dark matter, low-energy astro…

ARCA: South of Sicily [construction 2016-2023]: High-energy array 300 GeV-30 PeV => Astronomy, dark matter…







~30-50 better than ANTARES at high-energy

Conclusions

- ANTARES: 11 years of continuous data-taking. Still the best neutrino observatory to study the southern sky (GC region)

- Search for all-flavour neutrinos in space/time correlation with XRB and γRB.

⇒ The limits start to arrive to the level where we can constrain the "optimistic" hadronic models

- The construction of KM3NeT has started in Italy (ARCA) and in France (ORCA).