

GW/HE ν Coincidences are...

- ...Possible?
 - ⇒ **Common** Sources for GW/HE ν
 - ⇒ **Coincident** signals in GW and HE ν
- ...Observable?
 - ⇒ **Common** Sky Map?
- ...Detectable?
 - ⇒ **Accidentals Coincidence Rate** :
 $R_{\text{coincidence}} \sim R_{\text{Antares}} R_{\text{Virgo}} \Delta t_{\text{coincidence}}$
 - ⇒ Setting $R_{\text{coincidence}}$ constrains detection efficiencies

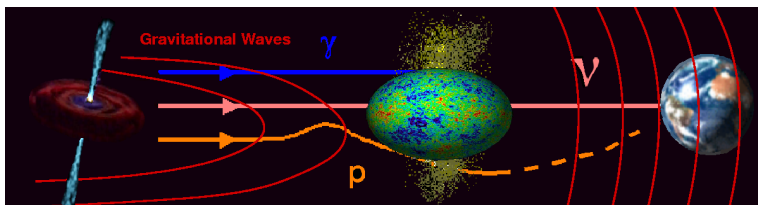
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Why study GW/HE ν Coincidences ?



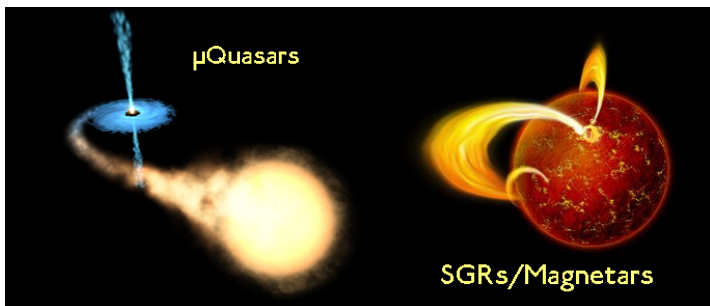
- Sources **invisible** in electromagnetic channels may emit both GW/ ν
- Unique information on internal processes

- **Quantum Gravity** : $c^2 p^2 = E^2 \left[1 + \xi \left(\frac{E}{E_{QG}} \right) + \mathcal{O} \left(\frac{E^2}{E_{QG}^2} \right) + \dots \right]$

$$\Rightarrow |\Delta t_{QG}| \simeq 0.15 ms \left(\frac{d}{10 \text{ kpc}} \right) \left(\frac{E_{\nu}^{HE}}{1 \text{ TeV}} \right) \left(\frac{10^{19} \text{ GeV}}{E_{QG}} \right) \text{ for } z \ll 1$$

S. Choubey & S. F. King, Phys. Rev. D 67, 073005 (2003)

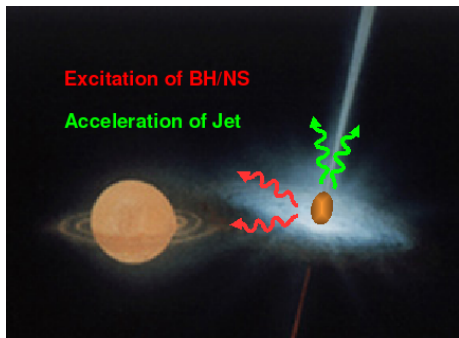
Galactic Sources of GW & ν



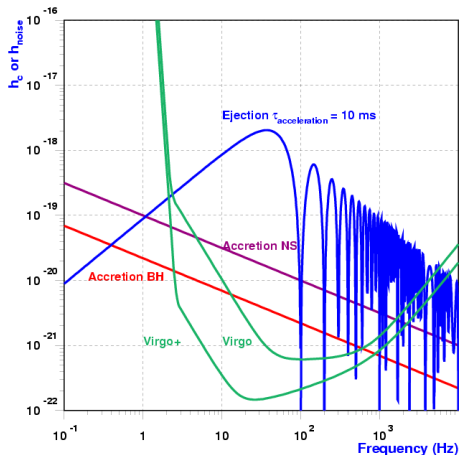
Focus on galactic sources

- Only accessible sources for 1st detectors *Antares & Virgo*?
- Δt_{QG} independent on cosmological models for $z \ll 1$

MicroQuasars : Gravitational Waves



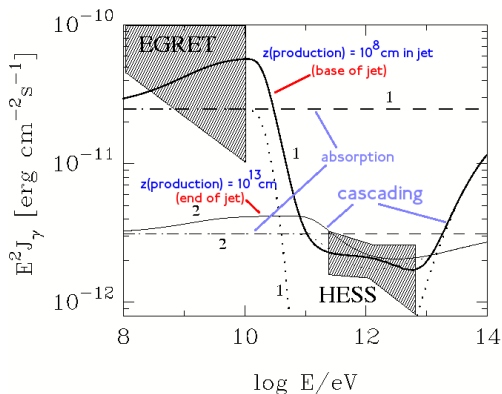
MicroQuasars : Gravitational Waves



- $\delta m \sim 10^{-4} M_{\odot}$ at 1 kpc
- Accretion less favourable
- Ejection more promising if :
 - $\tau_{\text{acceleration}} \lesssim 1 \text{ s}$ - fast!
 - discrete/discontinuous flow

Th. P., A&A, to be submitted

MicroQuasars : Neutrinos from LS 5039



- Production of γ/ν at the base of the jet favoured

F. A. Aharonian, L. A. Anchordoqui, D. Khangulyan & T. Montaruli J.Phys.Conf.Ser. 39, 408-415 (2006)

MicroQuasars : Neutrinos & Flares

Source name	Δt (days)	N_μ
CI Cam	0.6	0.05
XTE J1748-288	20	2.5
Cygnus X-3	3	4.8
LS 5039	persistent	0.2
GRO J1655-40	6	1.8
GRS 1915+105	6	0.5
Circinus X-1	4	0.2
XTE J1550-564	5	0.04
V4641 Sgr	0.3	0.03
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Scorpius X-1	persistent	0.9
SS433	persistent	252
GS 1354-64	2.8	0.02
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Other possible sources...

Soft Gamma Repeaters : NS crust disruption

- GW emission : *J. A. de Freitas Pacheco, A&A 396, 397-401 (1998)*
- HE ν emission : *F. Halzen, H. Landsman & T. Montaruli arXiv : astro-ph/0503348v1*

Gamma-Ray Bursters : Hypernova or Binary Coalescence

Orphan Sources : no electromagnetic counterparts

- γ -Telescopes have discovered a lot of sources not visible before...

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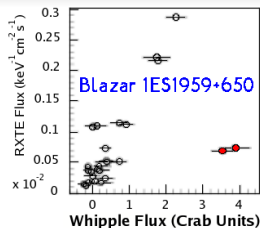
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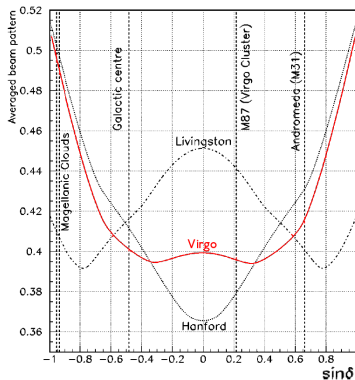
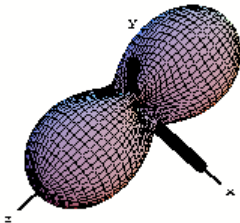
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Source Name	\varnothing ($^{\circ}$)	$N_{\text{src}} - E_{\nu} > 1 \text{ TeV}$ min-max(mean)	N_{atm}
HESS J1303-631	0.3	0.8-2.3(1.6)	11
HESS J1745-303	0.4	0-18(9)	9.0
HESS J1614-518	0.5	1-10(6)	19
HESS J1837-069	0.2	1.2-4.5(3.3)	5.9
HESS J1634-472	0.2	0.0-3.1(1.7)	9.8
HESS J1708-410	0.1	0.1-1.6(1.1)	7.6

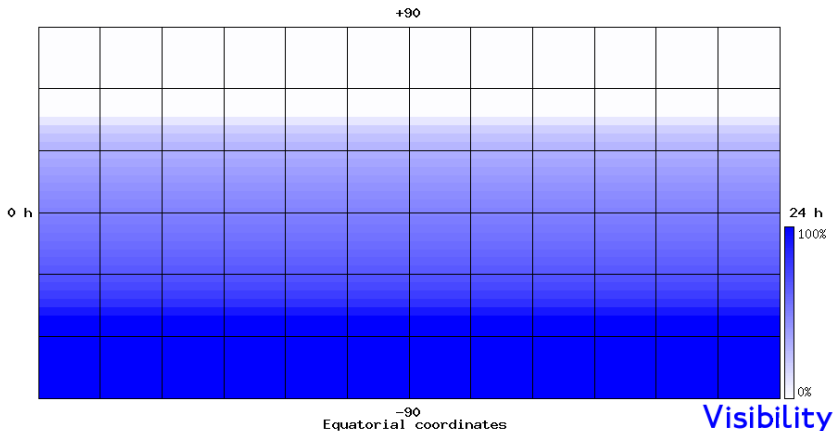
Virgo Beam Pattern, daily averaged



A GW interferometer is an antenna

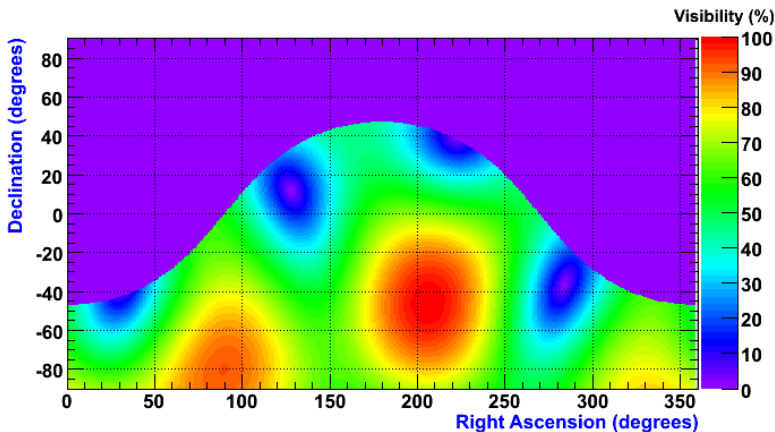
- Beam Pattern depends on Wave Polarization Ψ and (α, δ)

Antares Visibility, daily averaged



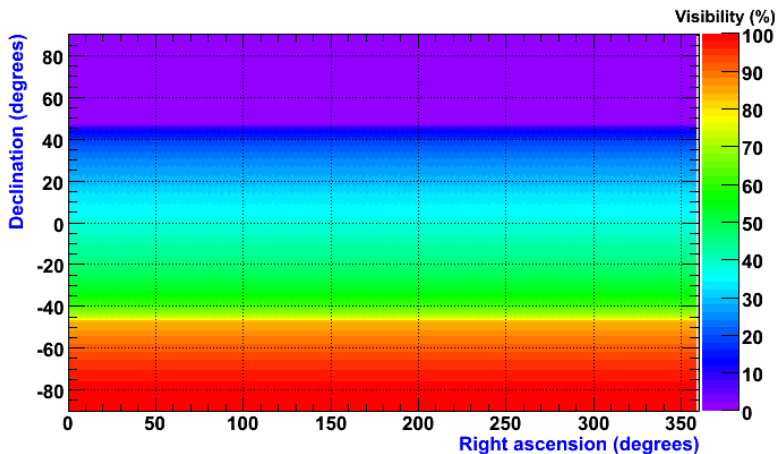
Antares/Virgo common Sky

Antares/Virgo Instantaneous Sky Map

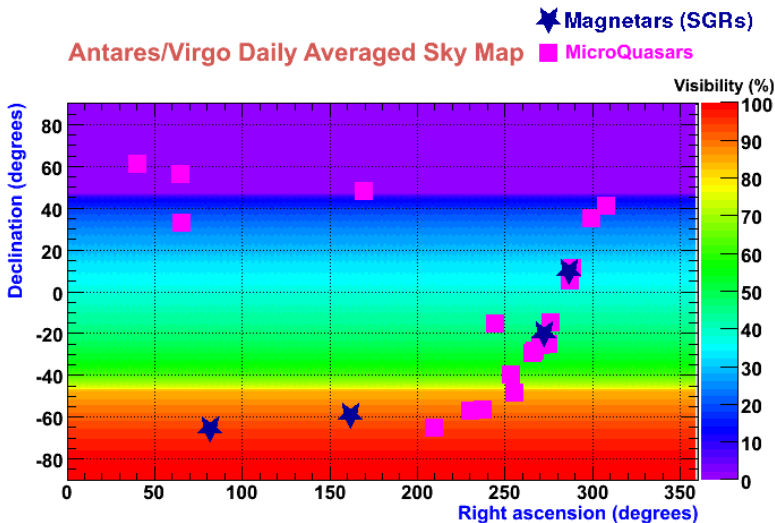


Antares/Virgo common Sky

Antares/Virgo Daily Averaged Sky Map



Antares/Virgo common Sky



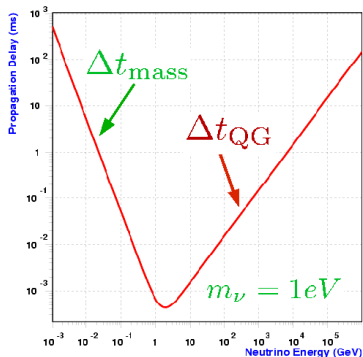
Quantum Gravity effects & coincidence window

- $m_{\text{graviton}} = 0$, and $E_{\text{graviton}} \ll 1 \Rightarrow \Delta t_{QG}^{\text{GW}}$ negligible!
- $\delta t_{\text{mass}}^{\nu} \ll 1$ for $E_{\nu} \sim \text{TeV}$
- Quantum Gravity : Dispersion

$$c^2 p^2 = E^2 \left[1 + \xi \left(\frac{E}{E_{QG}} \right) + \mathcal{O} \left(\frac{E^2}{E_{QG}^2} \right) + \dots \right]$$
- $\xi = -1$ favoured (ν slower than c)
- $z \ll 1 \Rightarrow$ independence from cosmological models
- $\Delta t_{QG}^{\text{GW}-\nu} \simeq 0.15 \text{ms} \left(\frac{d}{10 \text{ kpc}} \right) \left(\frac{E_{\nu}^{\text{HE}}}{1 \text{ TeV}} \right) \left(\frac{10^{19} \text{ GeV}}{E_{QG}} \right)$

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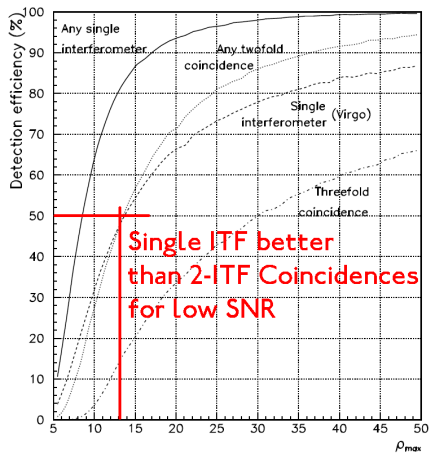
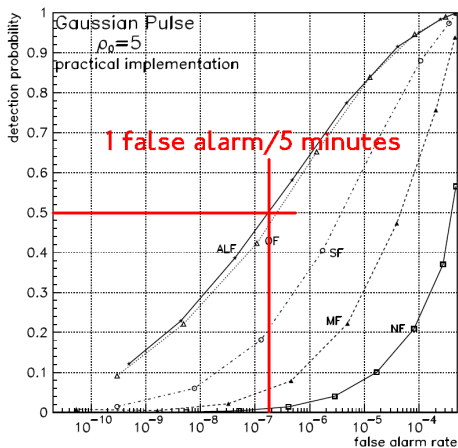
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Maximum QG delay for $E_{\text{QG}} \sim 10^{19}\text{ GeV}$

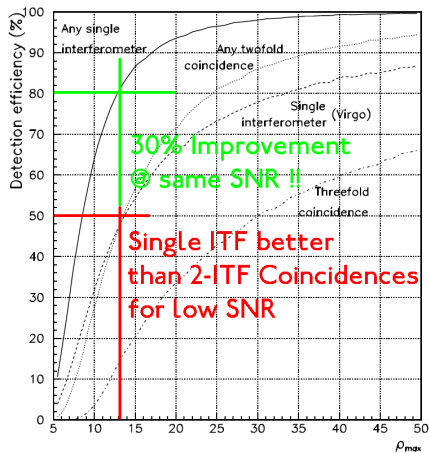
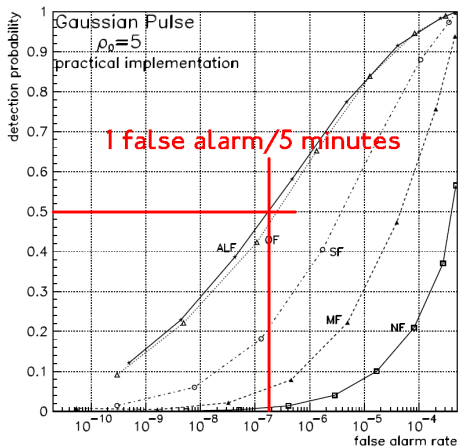
- $\Delta t_{\text{QG}} \lesssim 1\text{ s} : E_\nu \lesssim 1\text{ PeV}, d \lesssim 50\text{ kpc}$ (whole Galaxy + LMC)
- $\Delta t_{\text{QG}} \lesssim 1\text{ s} : E_\nu \lesssim 3\text{ TeV}, d \lesssim 20\text{ Mpc}$ (Virgo Cluster)

Virgo Detection : efficiency



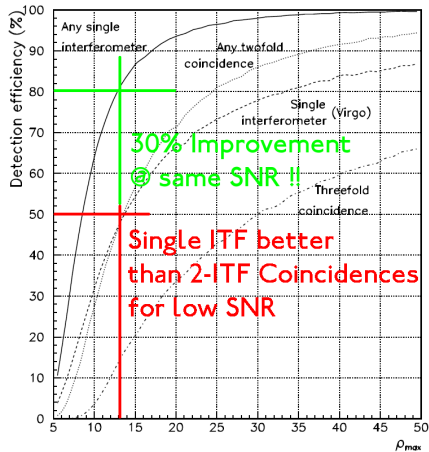
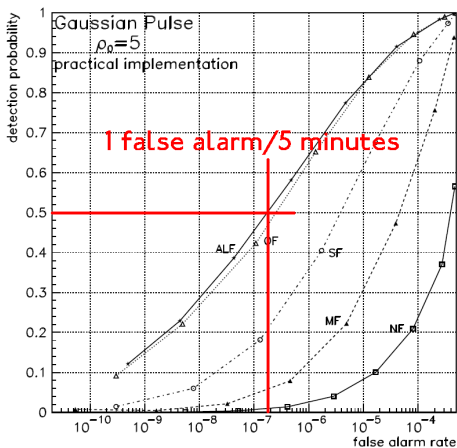
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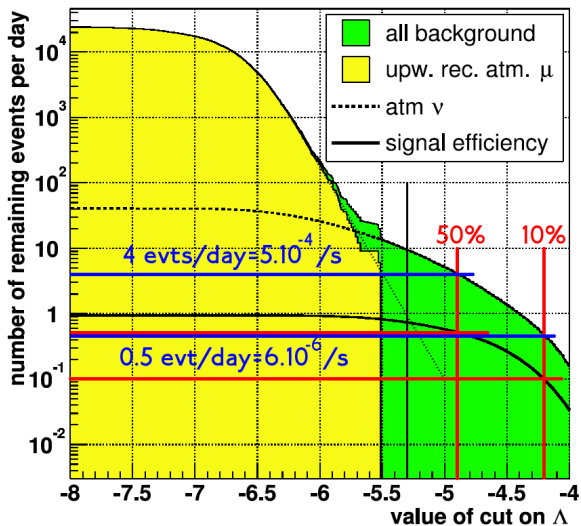
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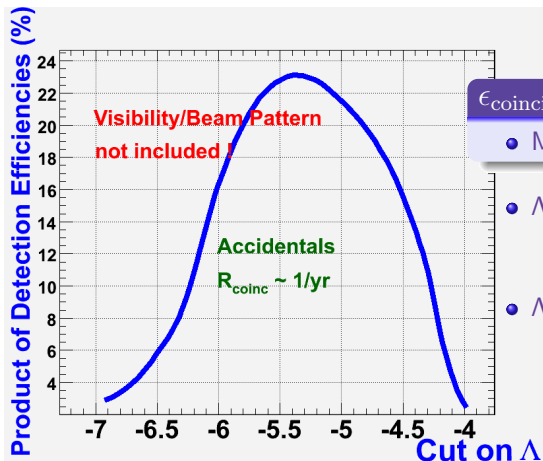
- Case Any single interferometer/Virgo only more probable
- ⇒ Directional information not available!

Antares Detection : efficiency vs background



- $\Lambda \approx \frac{\log(\mathcal{L})}{N_{DOF}}$
- Standard cut : $\Lambda > -5.3$:
 - \Rightarrow Efficiency $\sim 75\%$
 - \Rightarrow Atm. ν : 10/day
- For lower Λ , bkg explodes
- For higher Λ , ϵ drops

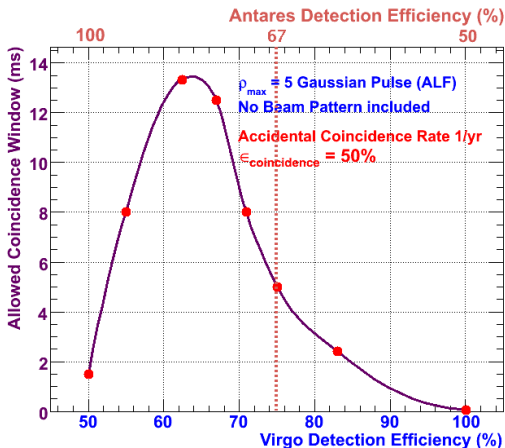
Combined Detection Efficiency : $\Delta t_{\text{coincidence}} = 1 \text{ s}$



$$\epsilon_{\text{coincidences}} \sim \epsilon_{\text{Virgo}} \times \epsilon_{\text{Antares}}$$

- Maximum for $\Lambda \sim -5.5$
- Λ low :
 - \Rightarrow Antares bkg high
 - \Rightarrow Virgo Threshold too high
- Λ high :
 - \Rightarrow Antares efficiency too low

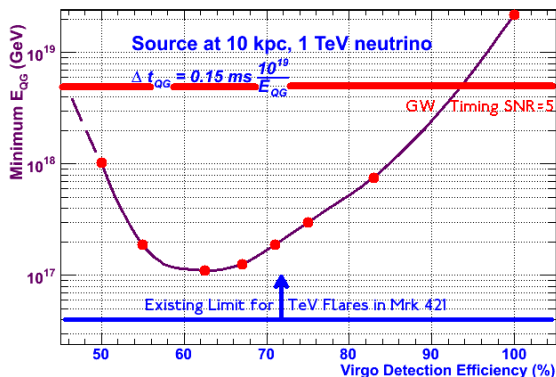
Combined Detection Efficiency : $\epsilon_{\text{coincidence}} = 50\%$



Impose detection probability $\epsilon = 50\%$

• $\Delta t_{\text{max}} \sim 15$ ms

Possible Scientific Output : Minimum accessible E_{QG}

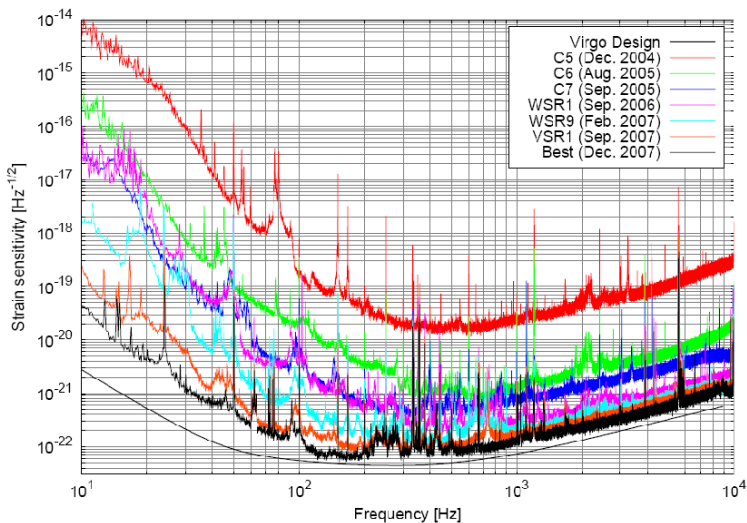


- Limited by GW Timing Resolution
- Here $E_{QG}^{\max} \approx 5 \times 10^{18} \text{ GeV}$

$$\Delta t_{QG} \propto E_{QG}^{-1}$$

- for $\epsilon_{\text{coincidence}} = 50\%$, can go down to 10^{17} GeV !

Antares & Virgo Status : Virgo in 2007

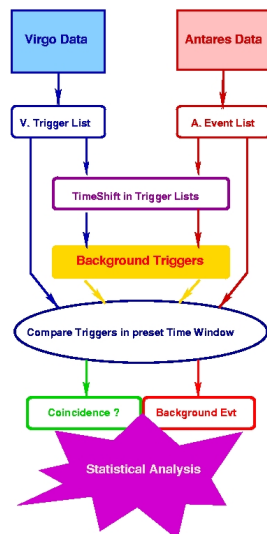


Antares & Virgo Status : common calendar

	ANTARES	VIRGO
SEPTEMBER 2006	2 Lines	WSR 1-2
OCTOBER 2006	2 Lines	WSR 3-4
NOVEMBER 2006	2 Lines	WSR 5
DECEMBER 2006	2 Lines	WSR 6
JANUARY 2007	5 Lines	WSR 7
FEBRUARY 2007	5 Lines	WSR 8-9
MARCH 2007	5 Lines	WSR 10
APRIL 2007	5 Lines	
MAY 2007	5 LINES	VSRI
JUNE 2007	5 LINES	VSRI
JULY 2007	5 LINES	VSRI
AUGUST 2007	5 LINES	VSRI
SEPTEMBER 2007	5 LINES	VSRI
OCTOBER 2007	5 Lines	
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NOVEMBER 2007	5 Lines	
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Conclusions...

- GW/HE ν coincidences are :
 - possible (Galaxy at least)
 - observable : sky maps not \perp !
 - detectable (with a bit of luck...)
- Coincidences *Antares 5 Lines/Virgo Scientific Run* :
 - *Letter of Intent* being written
- 2009 : Full *Antares/Virgo+*
 - *Antares 12 Lines*
 - *Virgo upgrade* \Rightarrow improvement by factor 2 above 1 kHz
- *circa 2015* : km^3 / *Advanced Virgo*
 - km^3 in the Mediterranean...
 - *Advanced Virgo* : enhanced sensitivity above 20 Hz

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