The coincident event search using TAMA300 and LISM data

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Introduction

- TAMA and LISM observed during August 1, 2001 and September 20, 2001(JST) (Data Taking 6)

TAMA

Location : Mitaka campus of NAOJ

Baseline length : 300m

Best sensitivity: $5\times10^{-21}[1/\sqrt{Hz}]$

Observation: 8/1 - 9/20 /2001

Total length of data $\sim 1038\,hours$

LISM

Operated mainly by people in ICRR (Univ. of Tokyo)

Location : Kamioka mine,Gifu

Baseline length : 20m

Best sensitivity: $6.5\times10^{-20}[1/\sqrt{Hz}]$

Observation: 8/1 - 8/23 /2001

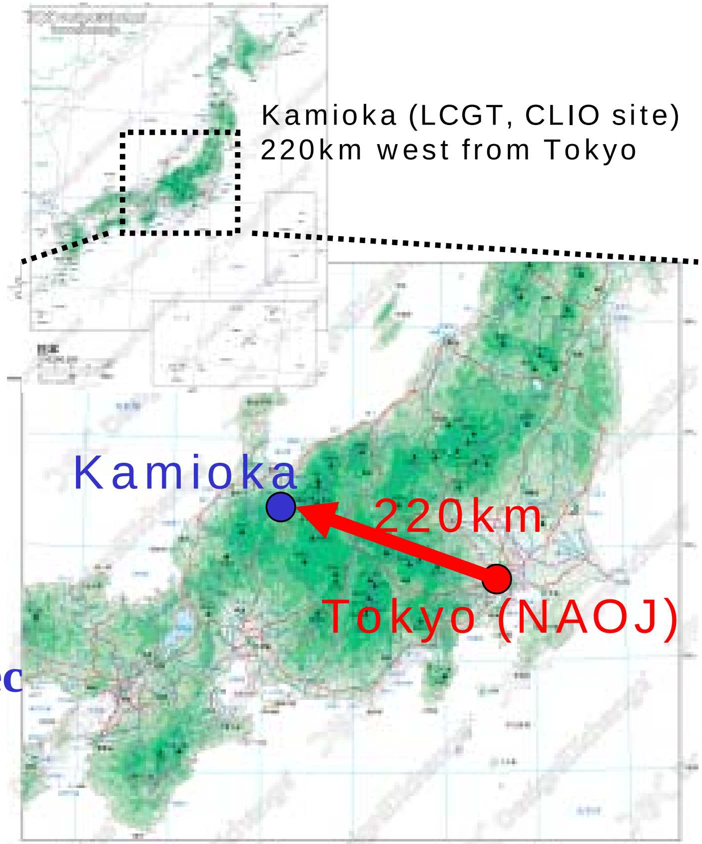
9/3 - 9/17 /2001

Total length of data $\sim 777\,hours$

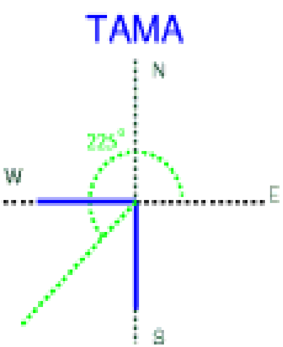
- We have tried a coincident event search for inspiraling compact binaries using TAMA and LISM data.

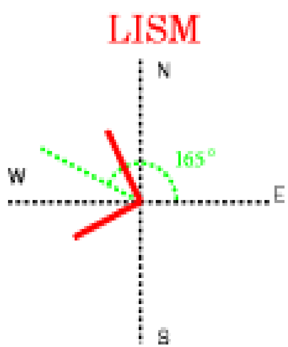
Location of TAMA and LISM

	orientation	latitude	longitude
TAMA	225 °	35.68 ° N	139.54 ° E
LISM	165 °	36.25 ° N	137.18 ° E



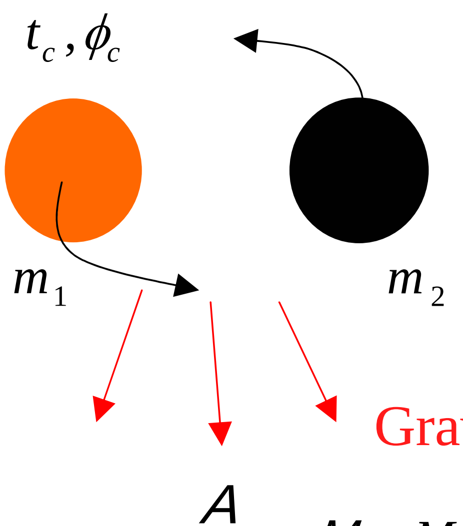
- Distance between TAMA and LISM 〜 220km
- **Maximum delay of signal arrival time〜0.73msec**
- Relation between TAMA and LISM arms direction





Coalescing compact binaries

Inspiral phase of coalescing compact binaries are main target because expected event rate of NS-NS merger
:a few within 200Mpc / year , well known waveform etc.



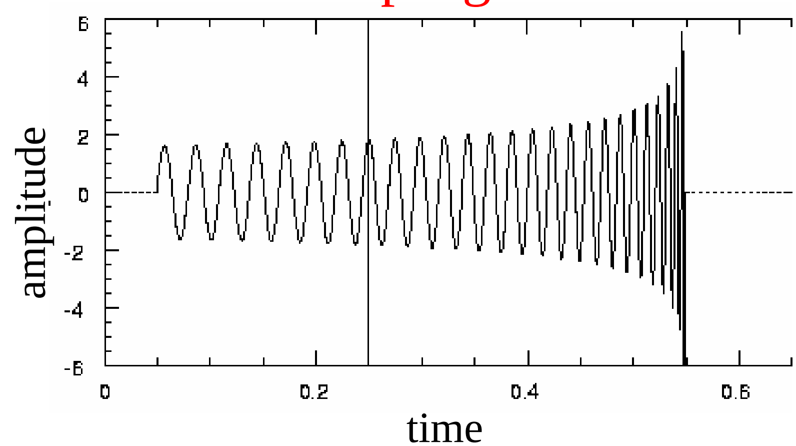
Neutron stars
Black holes

Gravitational Waves

$$\mathcal{M} = M\eta^{3/5}$$ M : total mass
η : reduced mass

Possibility of MACHO black hole

chirp signal



In this search, mass region: $1.0M_{solar} \leq m_1, m_2 \leq 2.0M_{solar}$

Matched Filter

- Detector outputs: $s(t) = Ah(t) + n(t)$

  $h(t)$: known gravitational waveform (template)

  $n(t)$: noise

  2.5Post-Newtonian

- Outputs of matched filter:

$$\rho(m_1, m_2, t_c \ldots) = 2\int \frac{\tilde{s}(f)\tilde{h}^*(f)}{S_h(f)} df = (s \mid h)$$

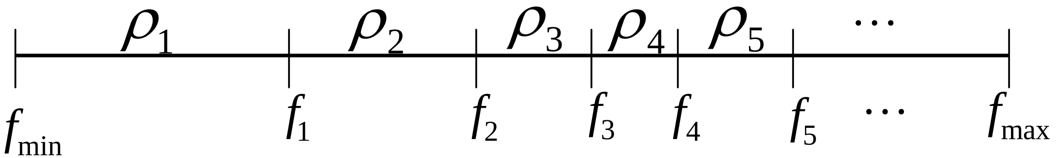
  noise spectrum density : $S_h(f)$

- signal to noise ratio : $SNR = \frac{\rho}{\sqrt{2}}$
- Matched filtering is the process to find the optimal parameters which realize $\max_{m_1, m_2, t_c \ldots} (\rho(m_1, m_2, t_c \ldots))$

χ^2

Ref:B.Allen et al. ,Phys. Rev. Lett. ,83, 1489 (1999)

- Divide frequency region into bins.
- Test whether the contribution to ρ from each bins agree with that expected from chirp signal.



$$\rho \equiv (s,h) = 2\int \frac{\tilde{s}(f)\tilde{h}^*(f)}{S_n(f)}\, df$$

$$\chi^2 \equiv \sum \frac{1}{\sigma_i^{\,2}}(\rho_i - \bar{\rho}_i)^2$$

$$\sigma_i^{\,2} \equiv \left\langle (\rho_i - \bar{\rho}_i)^2 \right\rangle, \; \bar{\rho}_i = \langle \rho_i \rangle$$

TAMA－LISM Analysis Algorithm

TAMA

data reading

Matched filter

$$\max_{m_1,m_2,t_c\cdots}(\rho(m_1,m_2,t_c\ldots))$$

$$t_c - {}^{\Delta t_c}\!/_2 \le t_c \le t_c + {}^{\Delta t_c}\!/_2 \quad (\Delta t_c \simeq 3.2s)$$

TAMA event list

$t_{ctama}, M_{tama}, \eta_{tama}, \rho_{tama}, \chi^2_{tama}$

LISM

data reading

Matched filter

$$\max_{m_1,m_2,t_c\cdots}(\rho(m_1,m_2,t_c\ldots))$$

$$t_c - {}^{\Delta t_c}\!/_2 \le t_c \le t_c + {}^{\Delta t_c}\!/_2 \quad (\Delta t_c \simeq 3.2s)$$

LISM event list

$t_{clism} M_{lism}, \eta_{lism}, \rho_{lism}, \chi^2_{lism}$

keep the events in the common lock parts

TAMA event list for common lock parts

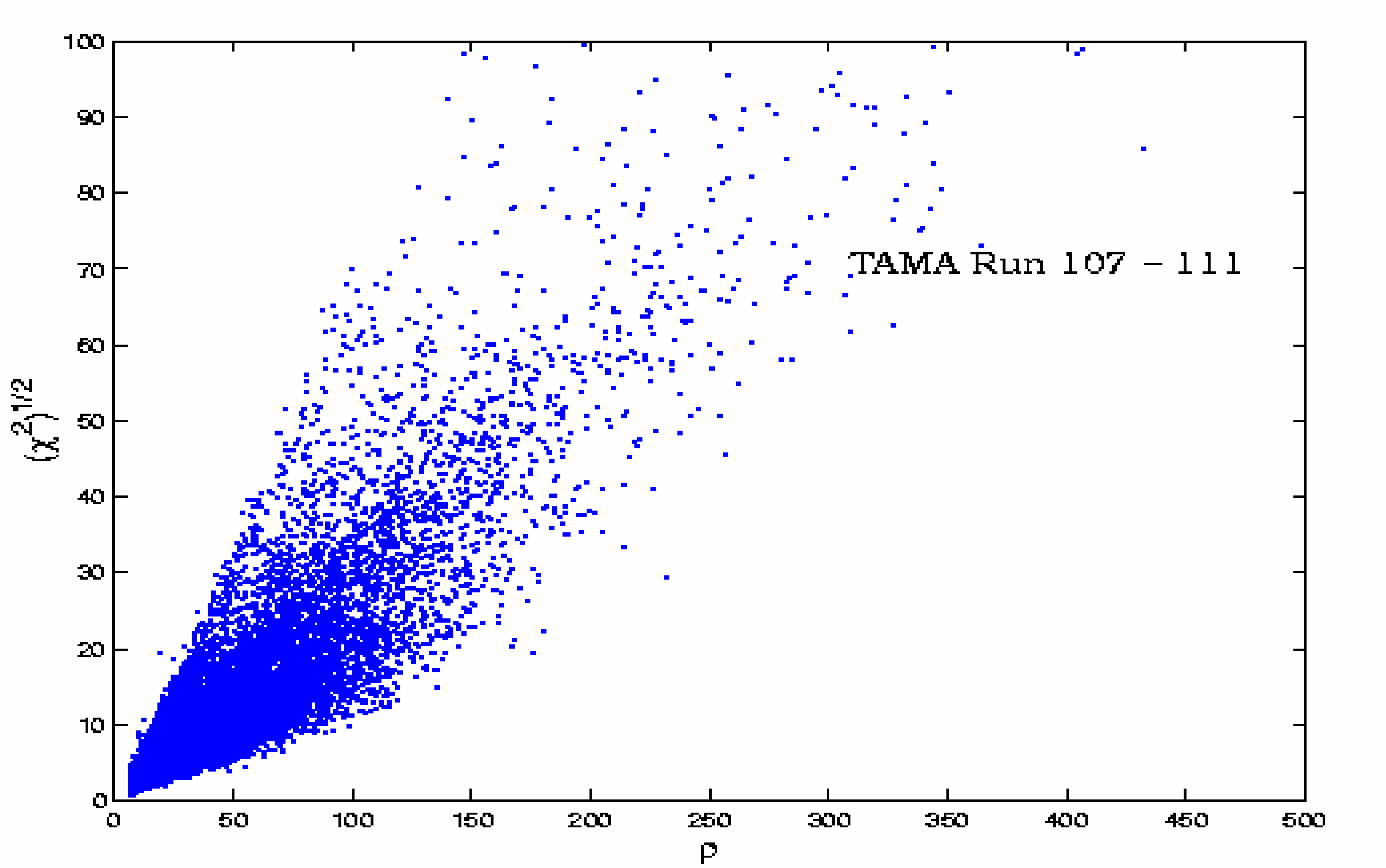
LISM event list for common lock parts

coincident event search

Total length of locked part 〜 322 hours

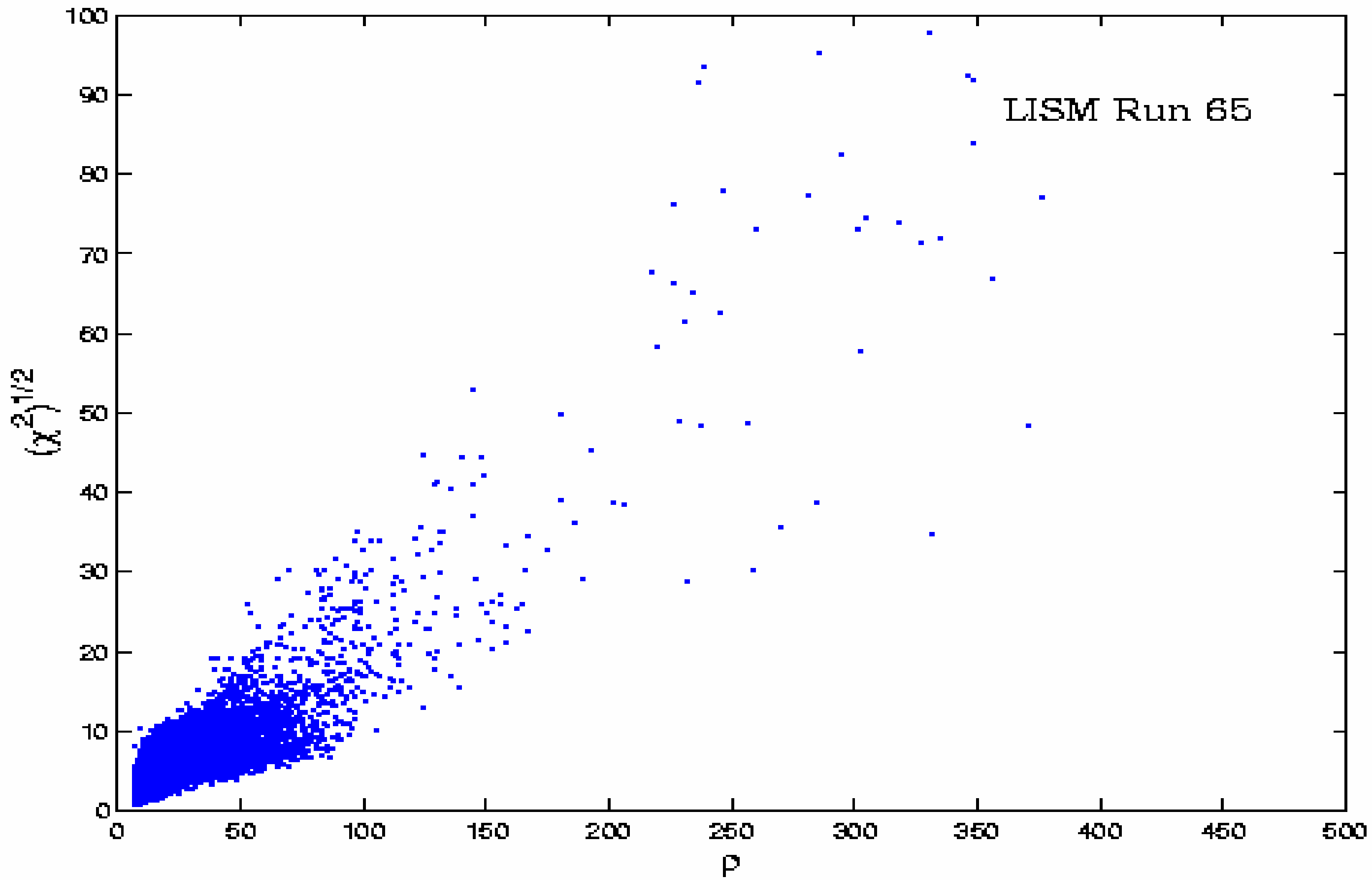
Common locked parts 〜 244 hours

$\rho-\left(\chi^2\right)^{1/2}$ Scatter plots with TAMA for common lock parts



There are 158437 events.

$\rho - \left(\chi^2\right)^{1/2}$ Scatter plots with LISM for common lock parts



There are 142465 events.

Coincident Event Search

- We compared candidate event list and required parameter consistency.

"time" coincidence

Maximal delay for arrival time : $\Delta t_{dis} = 0.73 m\sec$

Parameter-estimation errors of t_c : $\Delta t_{cnoise} \Leftarrow$ Fisher matrix

Time window : $\Delta t_{cwin} = \Delta t_{cnoise} + \Delta t_{dis}$

if $\left| t_c^{tama} - t_c^{lism} \right| < \Delta t_{cwin} \Rightarrow$ candidate events

"mass" coincidence

Mass parameter window : $(\Delta M, \Delta \eta) \Leftarrow$ Fisher matrix

if $\left| M_{tama} - M_{lism} \right| < \Delta M, \left| \eta_{tama} - \eta_{lism} \right| < \Delta \eta \Rightarrow$ candidate events

"amplitude (ρ)" coincidence

if $-\rho_{simu} - \rho_{sen} \le \log(\rho_{tama}) - \log(\rho_{lism}) \le \rho_{simu} - \rho_{sens}$

ρ_{simu} :derived from galactic simulation

ρ_{sens}:derived from difference of detector sensitivity

$\Rightarrow$ candidate events

Results of coincident event search

Results of onestep search for common lock parts

TAMA	LISM
158437 events	142465 events

After t_c -coincidence

70 events

After t_c, M, η -coincidence

18 events

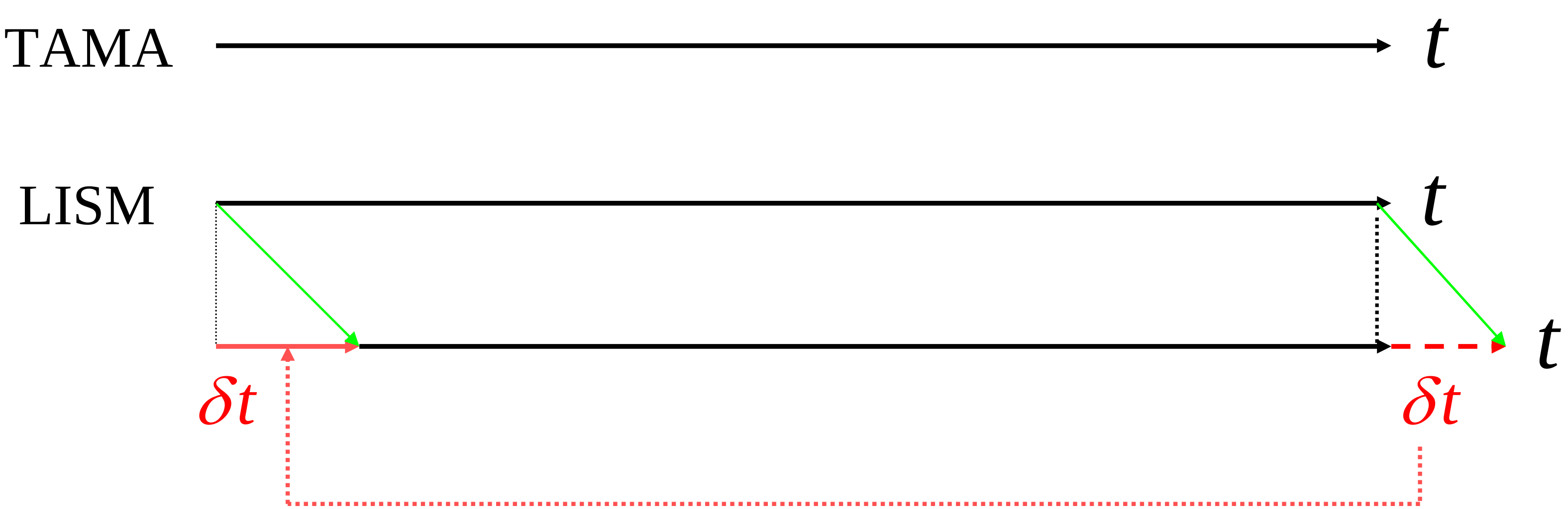
After t_c, M, η, ρ -coincidence

13 events

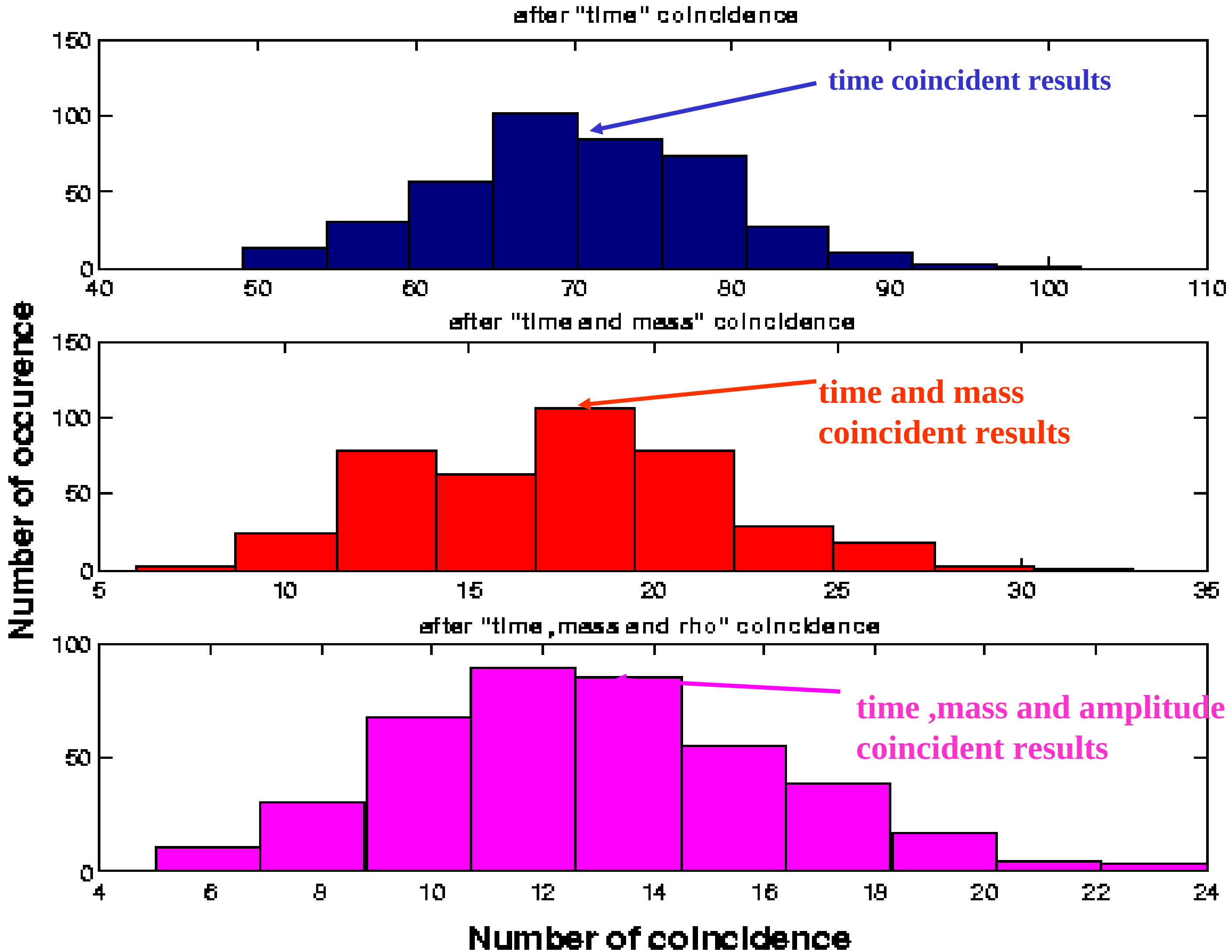
A technique to evaluate the average number of accidental coincidences

Ref:E.Amaldi et al. ,A&A. ,216, 325 (1989)
Ref:P.Astone et al. ,Phtys Rev.D ,59, 122001 (1999)

- It is possible to measure the number of accidental coincidences experimentally by usual procedure of shifting one of the two sets of data by a time δt and determining the number of coincidences $n(\delta t)$. δt is usually referred "time delay"



The accidental distribution derived from time delay histogram



Results of coincident event search

Results of onestep search for common lock parts

TAMA	LISM
158437 events	142465 events

After t_c-coincidence — 70 events

accidental coincidence $(\bar{n}_{acc} \pm \sigma_c)$ — 70.45 ± 8.53

After t_c, M, η-coincidence — 18 events

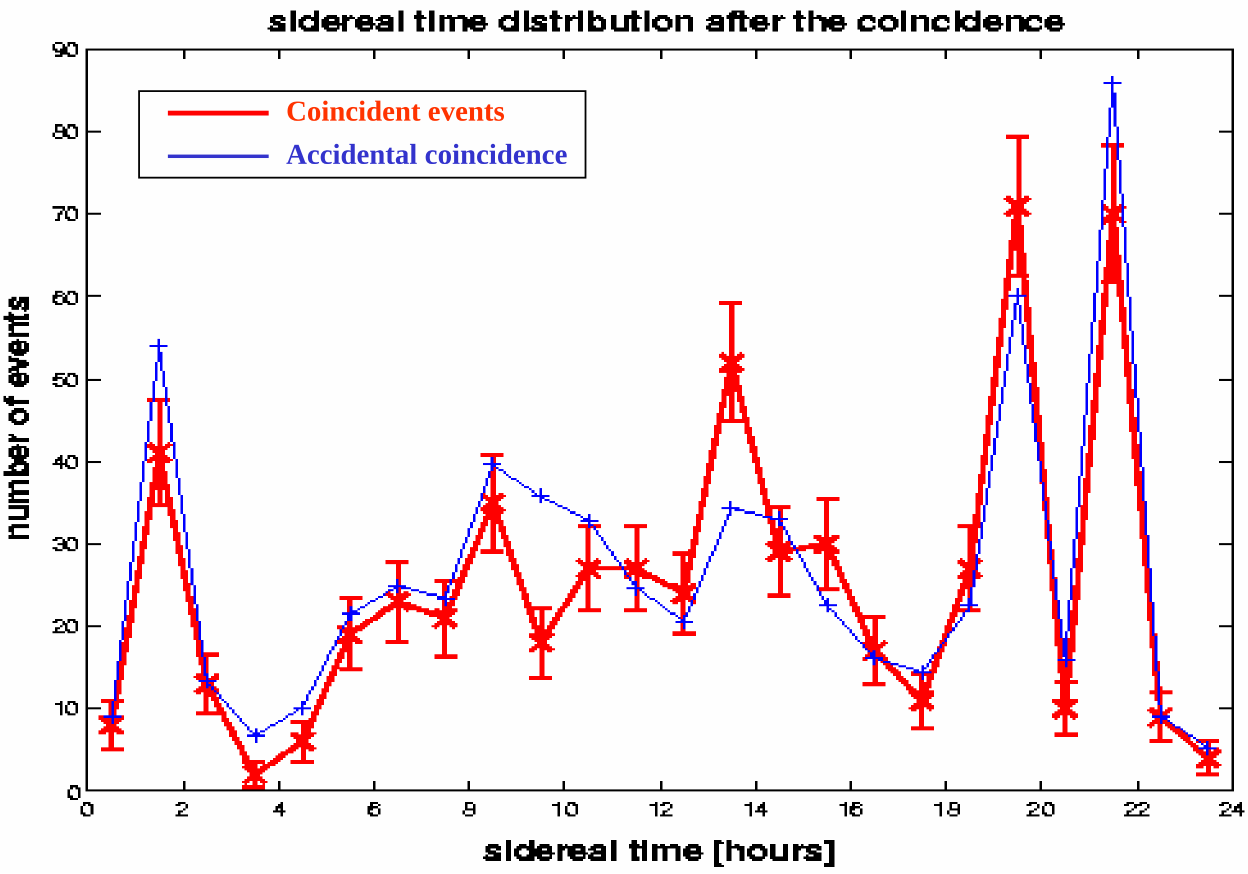
accidental coincidence $(\bar{n}_{acc} \pm \sigma_c)$ — 17.55 ± 4.08

After t_c, M, η, ρ-coincidence — 13 event

accidental coincidence $(\bar{n}_{acc} \pm \sigma_c)$ — 12.76 ± 3.51

Sidereal time analysis for TAMA–LISM coincidence

• Over the events survived time , mass and amplitude coincidence, we plot 24-hours histogram of coincidence events versus sidereal time.



Coincident event search upper limit (1)

We propose a method to evaluate the upper limit to the Galactic event rate for coincidence analysis.

- Since LISM's sensitivity does not cover all of Galactic events, we evaluate upper limit to the galactic event rate using the results of the TAMA-LISM coincidence analysis for the purpose of a test for this method.

- Since LISM's sensitivity is one order lower than TAMA, we only consider Galactic events within 1kpc.

Coincident event search upper limit (2)

Upper limit to the Galactic event rate is given by

$$\frac{N}{T\varepsilon}$$

- N：upper limit to the average number of real events over certain threshold
- T：length of data [hours]
- **ε** : detection efficiency

Coincident event search upper limit (3)

- The first, we evaluated **upper limit to the average number N of real events over certain threshold**.

Assuming Poisson distribution for the number of real/fake events over threshold, we can obtain the average number **N** by

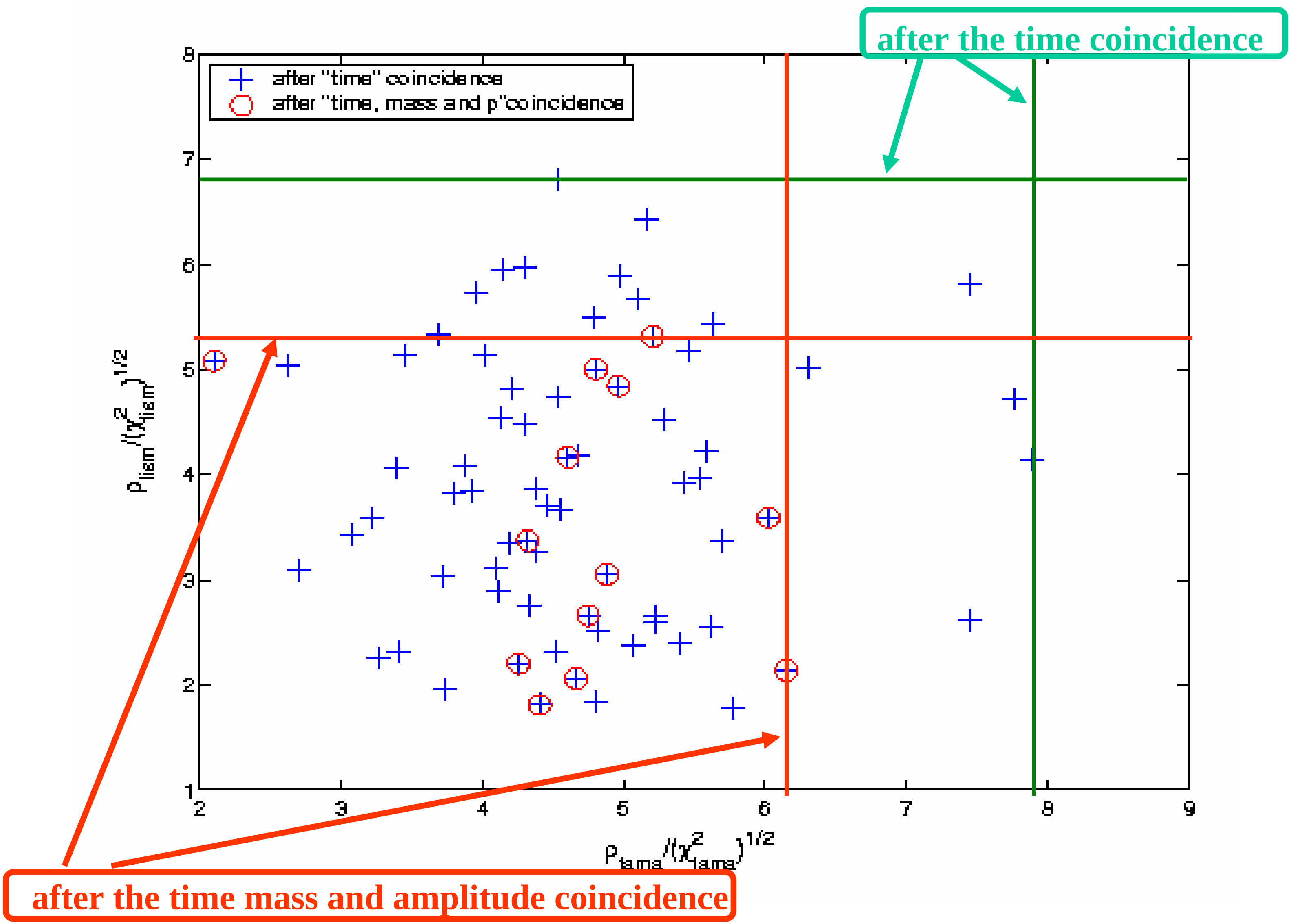
$$\frac{e^{-(N+N_{bg})}\sum_{n=0}^{n=N_{obs}}\frac{(N+N_{bg})^n}{n!}}{e^{-N_{bg}}\sum_{n=0}^{n=N_{obs}}\frac{(N_{bg})^n}{n!}}=1-CL$$

ref :e.g. Particle Data Group,*Review of Particle Physics*,Phys.Lett.**B204,**81(1998)

N_{obs} **: observed number of events over threshold**
N_{bg} **: expected number of fake events over threshold**

In order to set the threshold, we draw a $\rho_{tama}/\sqrt{\chi^2_{tama}} - \rho_{lism}/\sqrt{\chi^2_{lism}}$ scatter plots.

TAMA – LISM coincident results



Coincident event search upper limit (4)

From above figure, we set threshold for each detector,

TAMA threshold : $\rho_{tama} / \sqrt{\chi^2_{tama}} = 6.2$

LISM threshold : $\rho_{lism} / \sqrt{\chi^2_{lism}} = 5.3$

Observed number of events over threshold: Nobs=0

Expected number of fake events over threshold : N_{bg}=0.72

We can obtain **the average number of events over threshold N=2.3 (C.L.=90%)**

- The second, we evaluated **detection efficiency ε**

we performed a Galactic event simulation (within 1kpc) .

Setting above thresholds, we can obtain the probability that we observe events over the each detector's threshold **(namely detection efficiency)** ⟹ **ε = 0.22**

- Length of data : **T=244 hours**

TAMA + LISM case

Upper limit to the Galactic (within 1kpc) event rate :

N/T ε = 0.042 events/hour (C.L. 90%)

c.f. : TAMA only case :
0.0094 events/hour (C.L. 90%)
c.f. : LISM only case :
0.096 events/hour (C.L. 90%)

Conclusion & Discussion

1.We performed a coincident event search for inspiraling compact star binaries using TAMA300 and LISM data.
(mass range : $1.0M_{solar} \le m_1, m_2 \le 2.0M_{solar}$)
No significant coincidence excess was observed.
Our results are consistent with accidental coincidence.

2. We proposed a method to evaluate the upper limit to the Galactic event rate from coincidence analysis.
This method can be applied even in the multiple detector coincidence case straightforwardly.