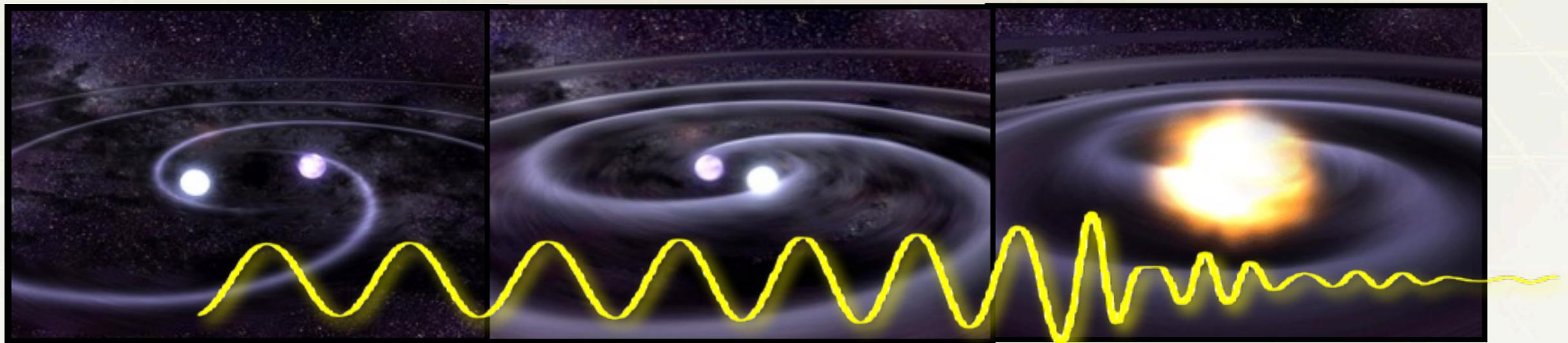


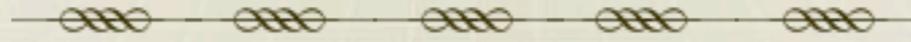
重力波マルチメッセンジャー観測網で ダイナミックな宇宙を捉える



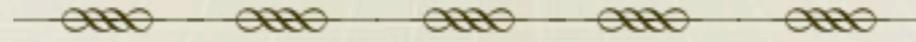
NASA

端山和大 (国立天文台)

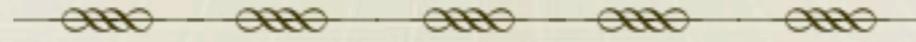
ある森の中の様子

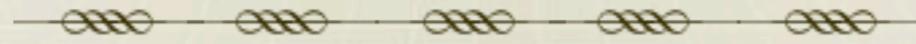


実はにぎやかな森の中



実はにぎやかな森の中





ウグイス

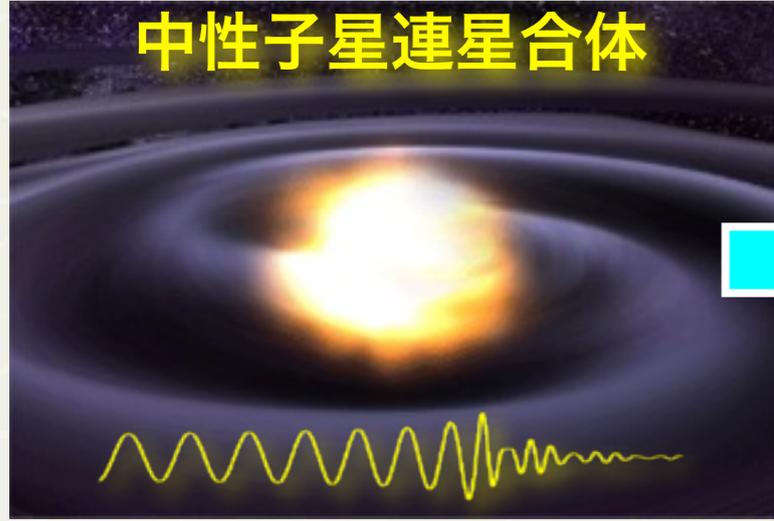
見た目はオスかメスか

見分けるのが困難

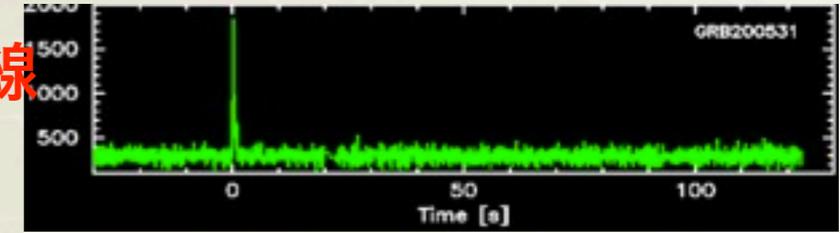
ホーホケキョと鳴けばオス

中性子星連星合体の観測

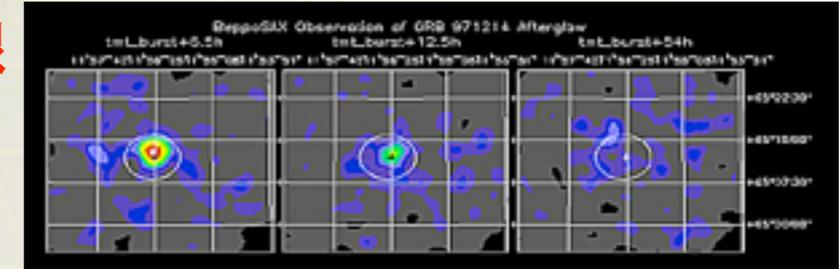
電磁波で合体を見る



ガンマ線



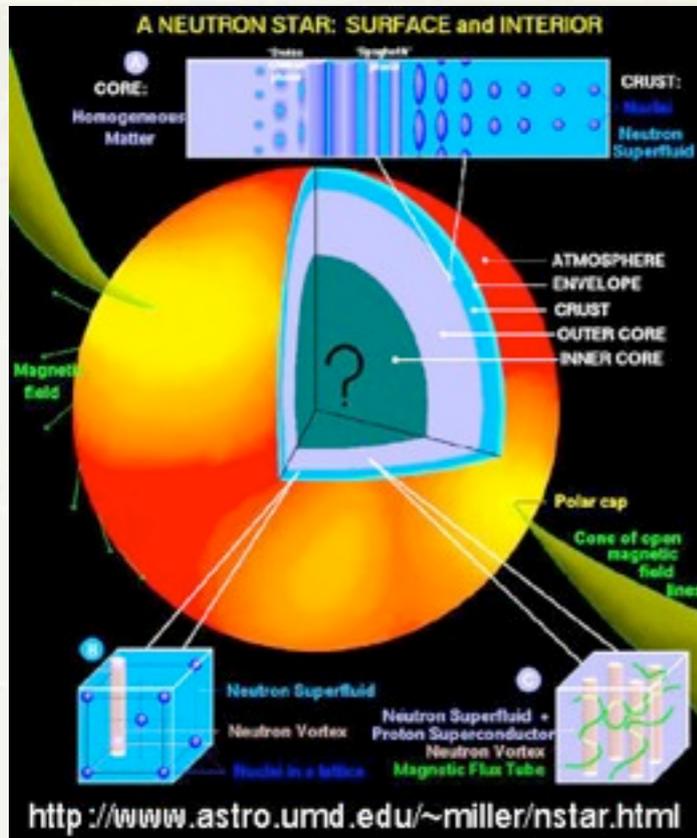
X線



可視光

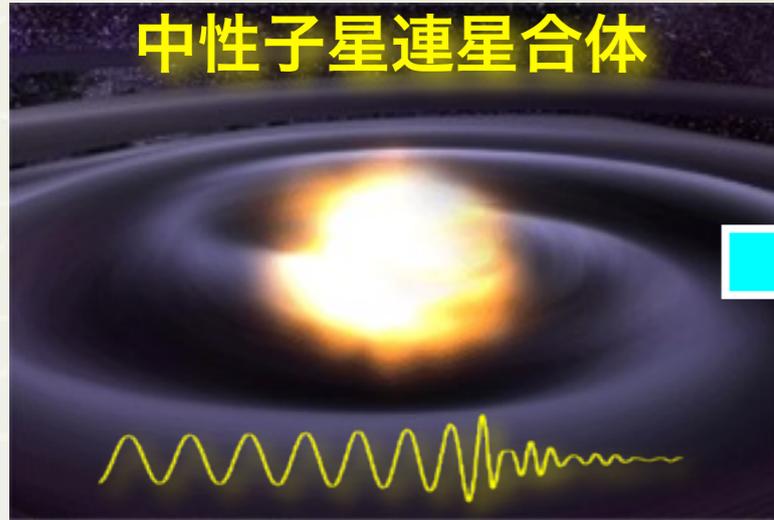


重力波で中性子星の内部の物理を読み取る

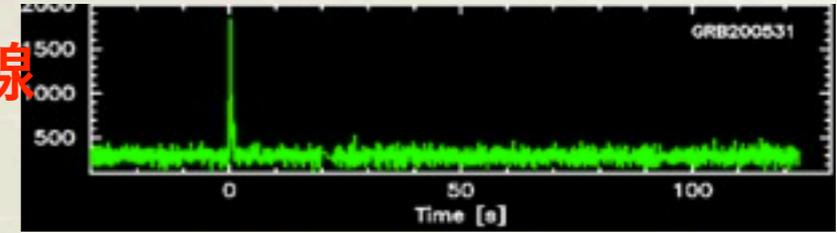


中性子星連星合体の観測

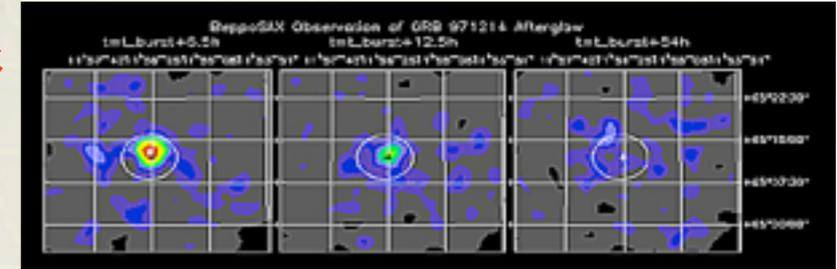
電磁波で合体を見る



ガンマ線



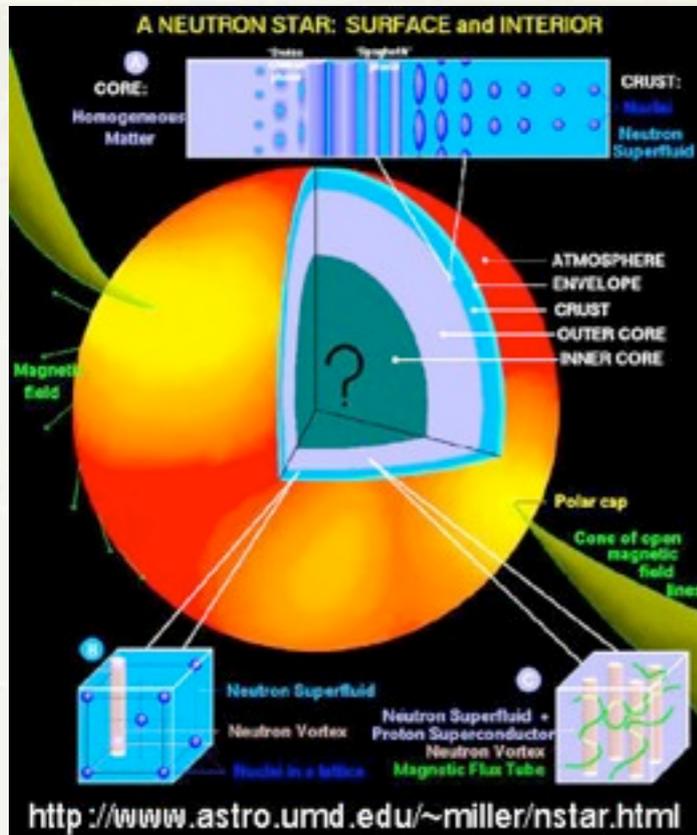
X線



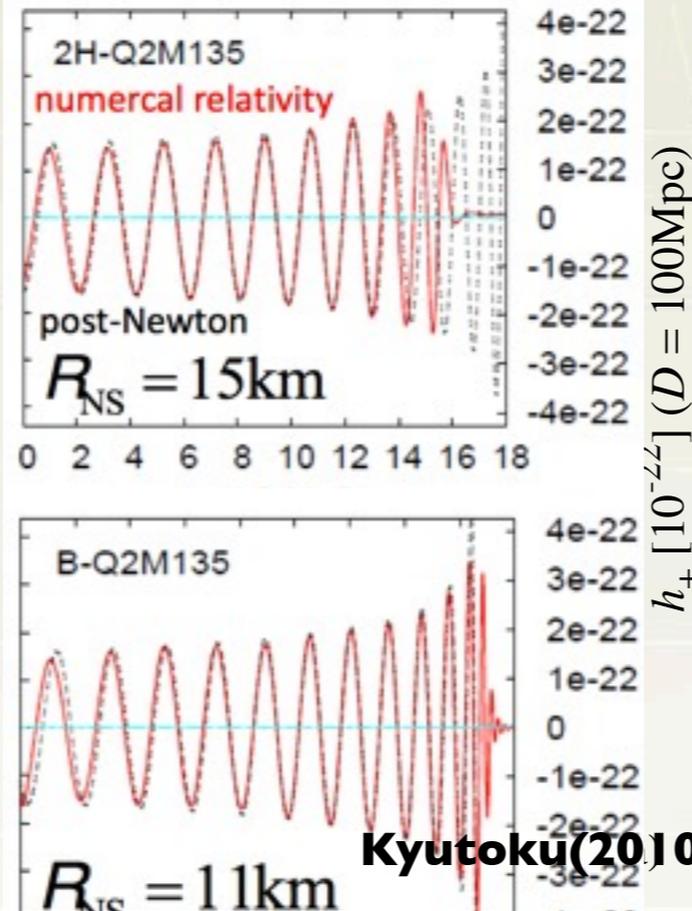
可視光



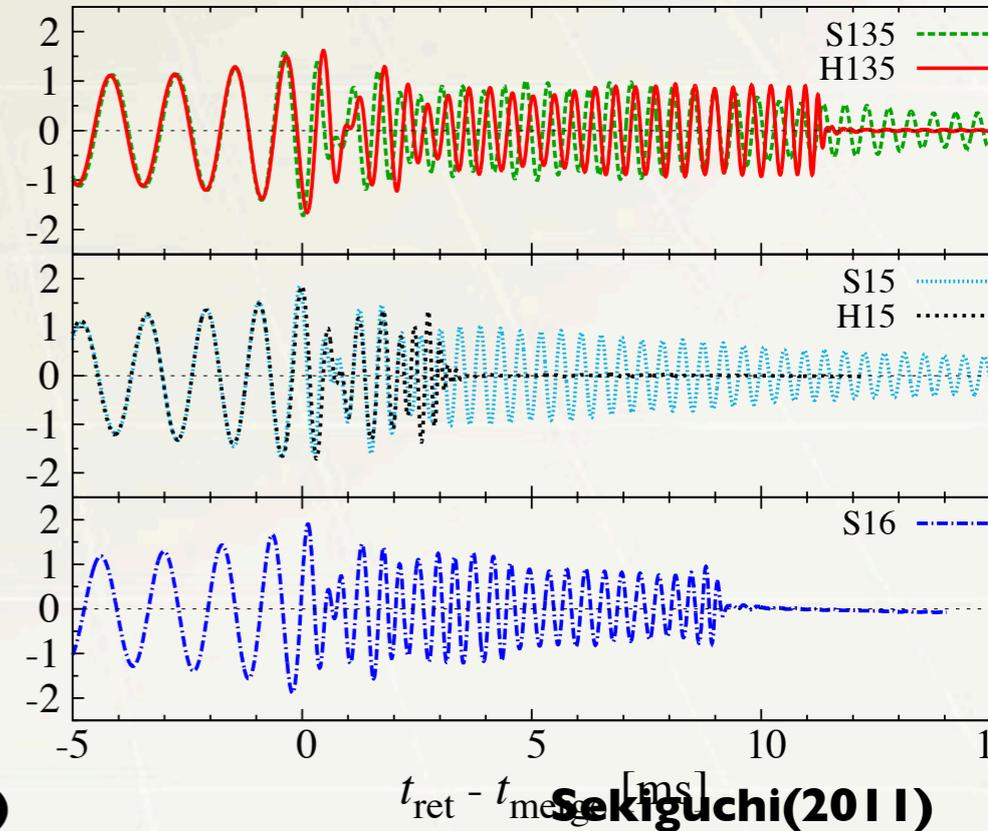
重力波形から中性子星の内部の物理を読み取る

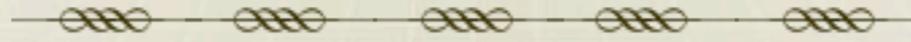


超高密度状態方程式の違い



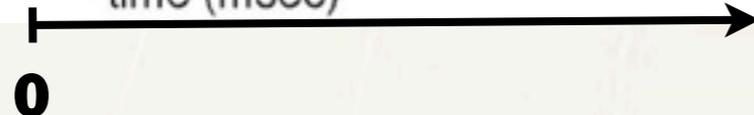
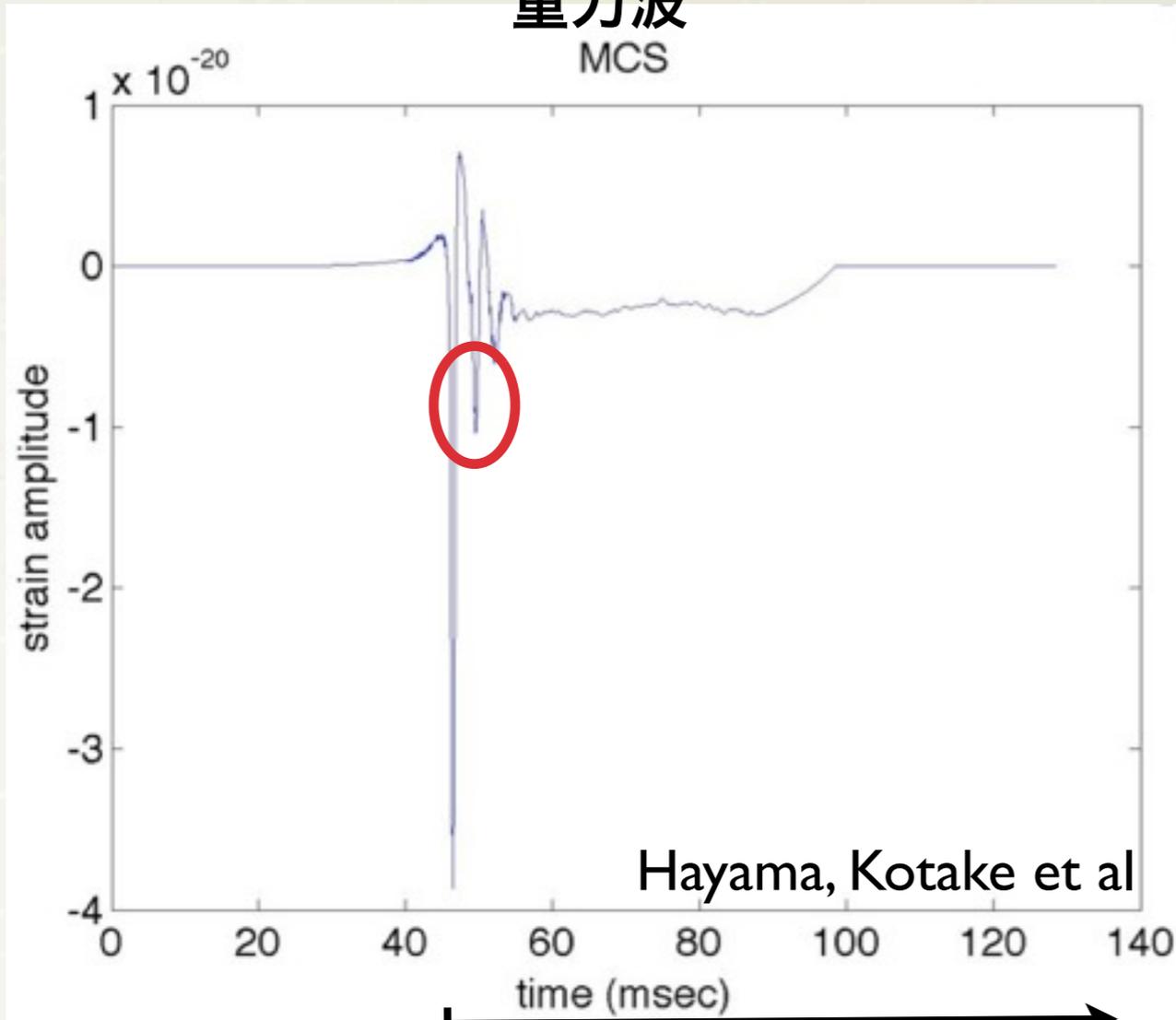
Hyperonの存在



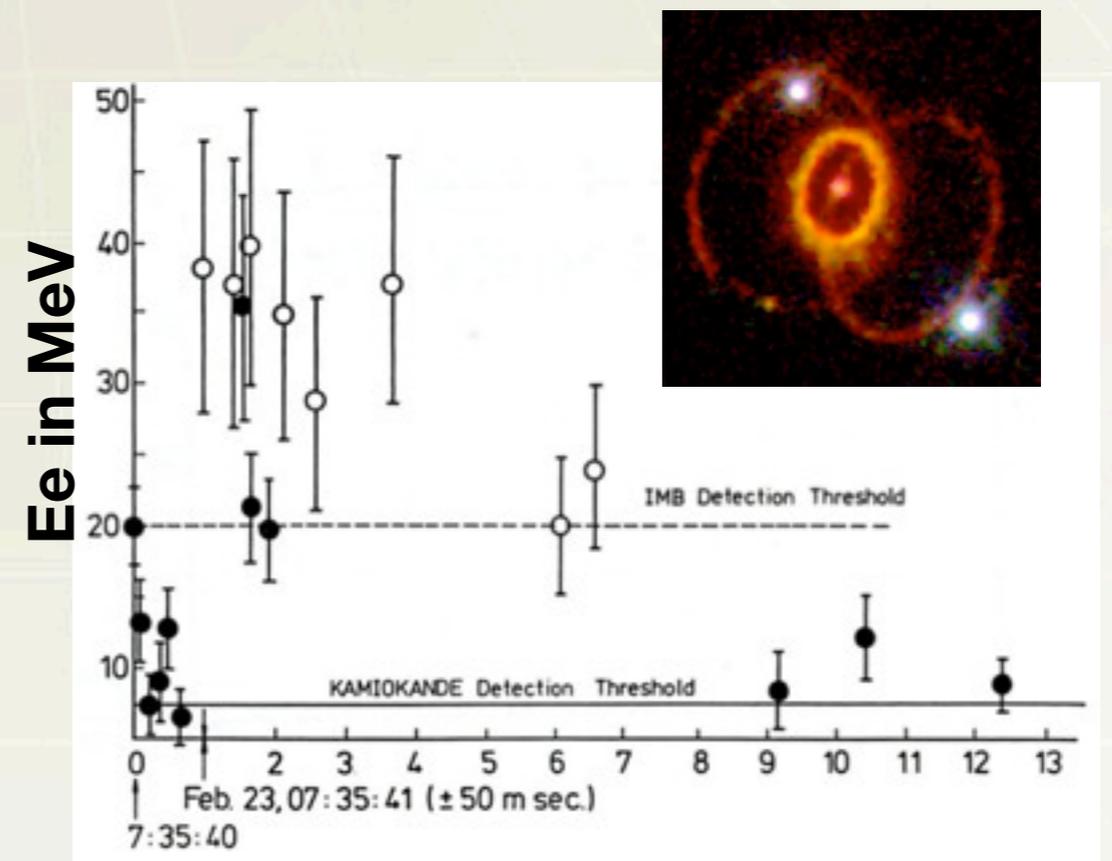


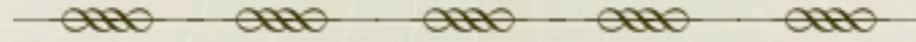
- 超新星爆発からの重力波形から、**progenitor**の微分回転の強さをよむ

重力波
MCS



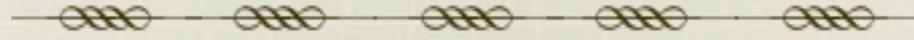
ニュートリノ放射 (SNI987A)



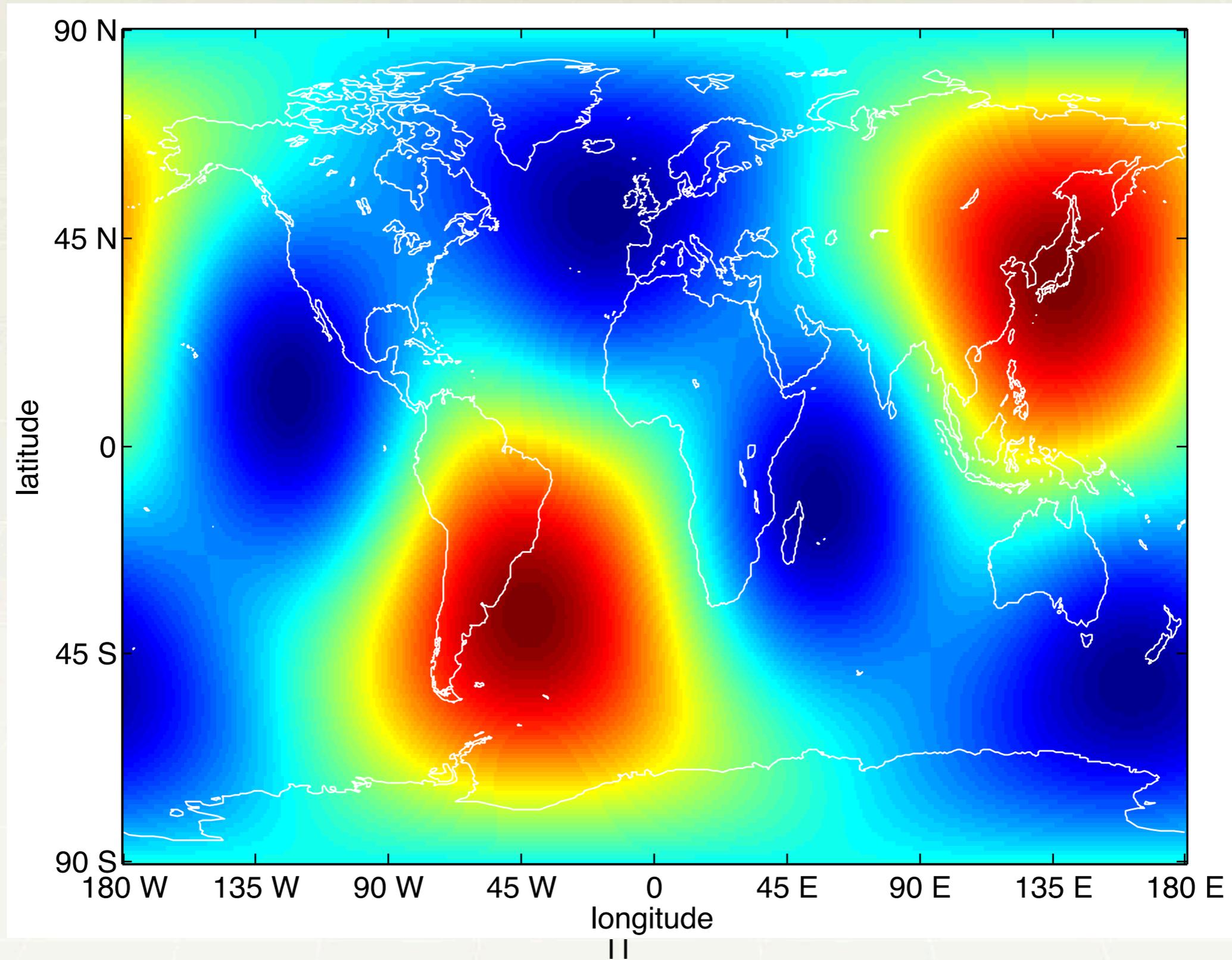
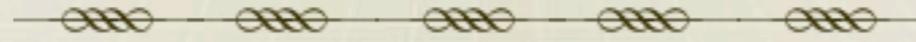


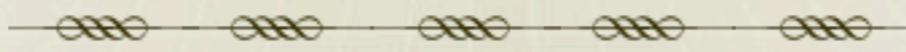
- 天体爆発現象を、起点となる時空のダイナミックな変動からニュートリノ、電磁波などの観測を統合して多角的に理解することが可能になる！
- 複数の観測手段による信頼性の高い初検出が効果的！

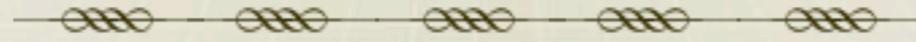
重力波望遠鏡



KAGRAのアンテナパターン

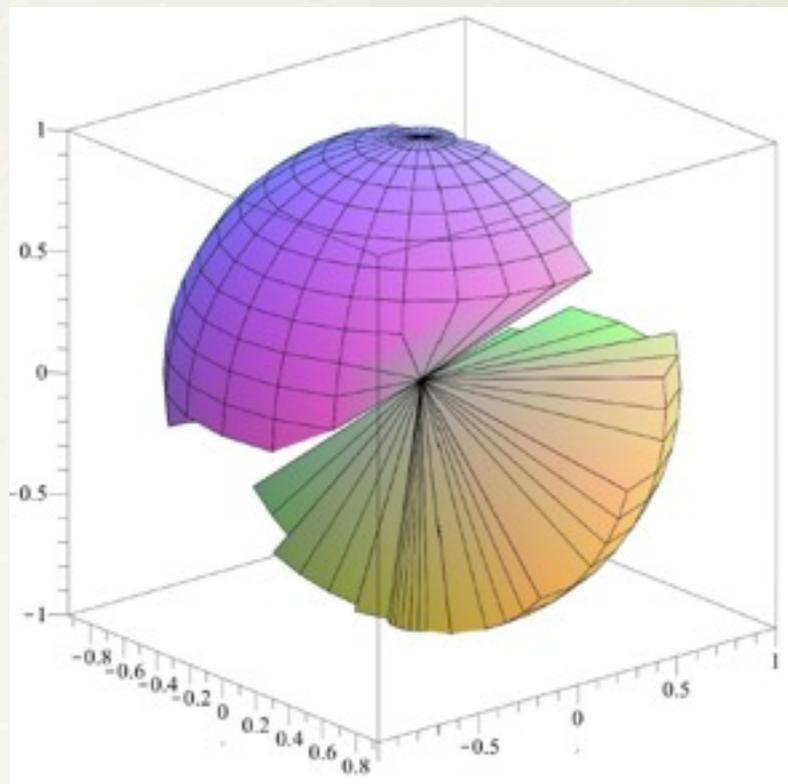




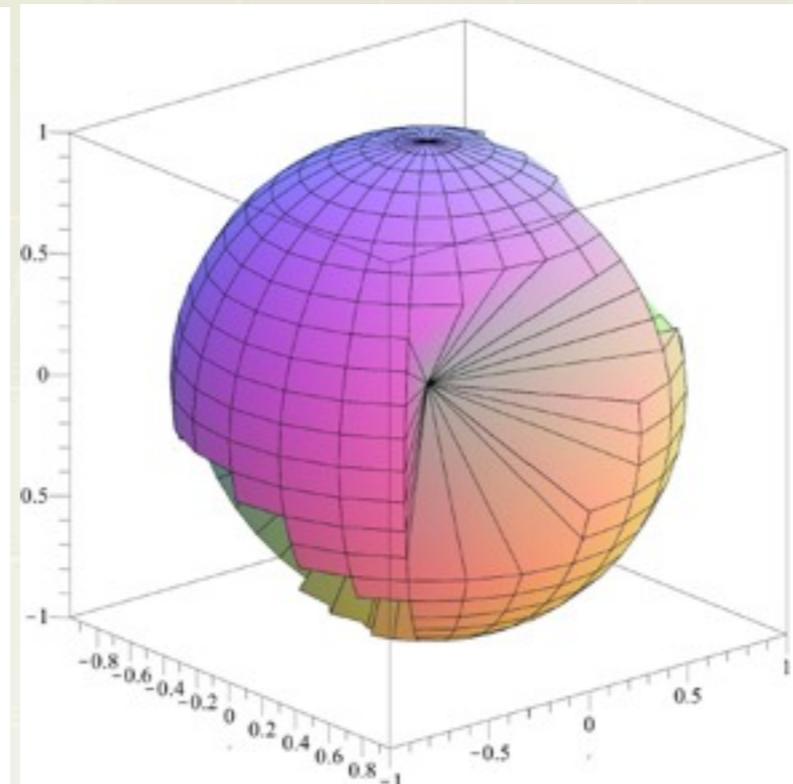


● 望遠鏡ネットワークのアンテナパターン。 ($>1/\sqrt{2}$ のエリア)

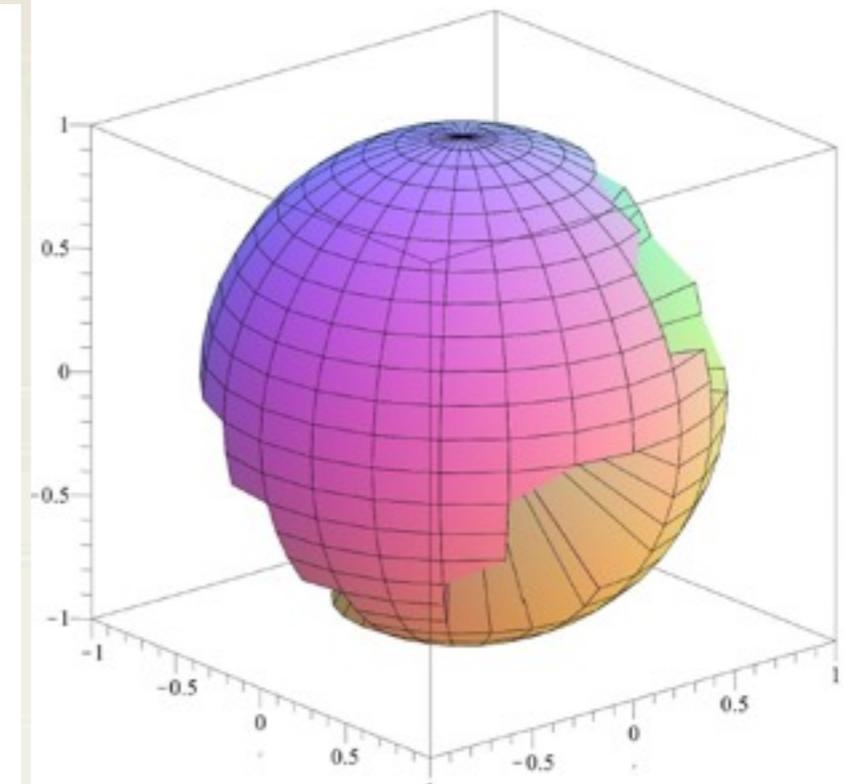
HLV



HLVJ

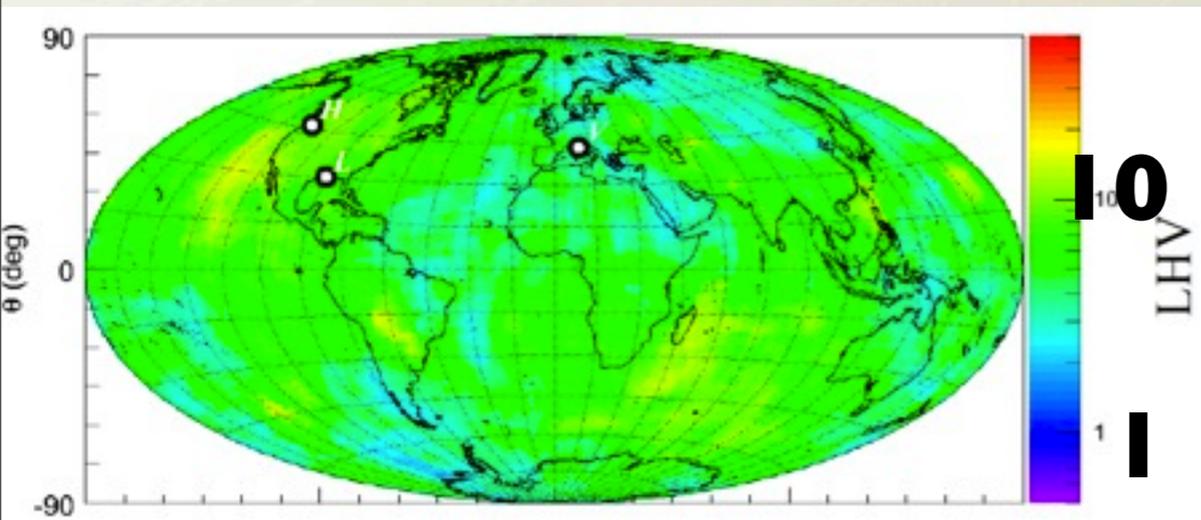
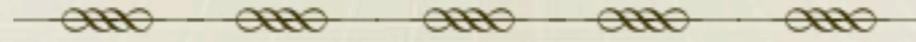


HLVJA

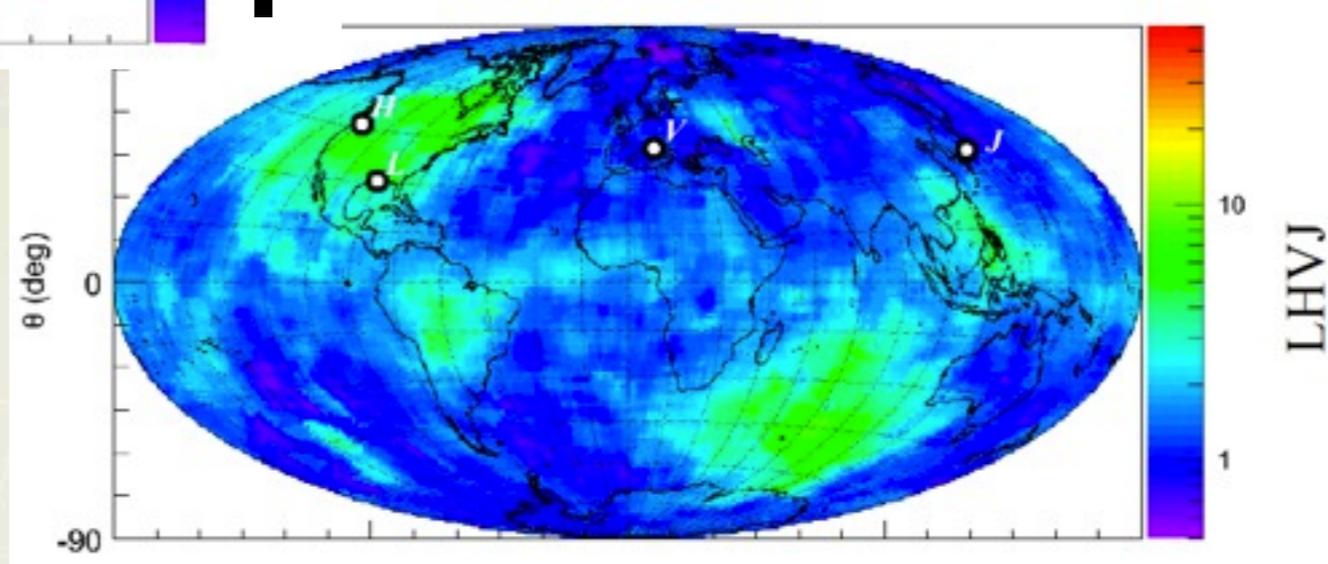


B.Schutz(2011)

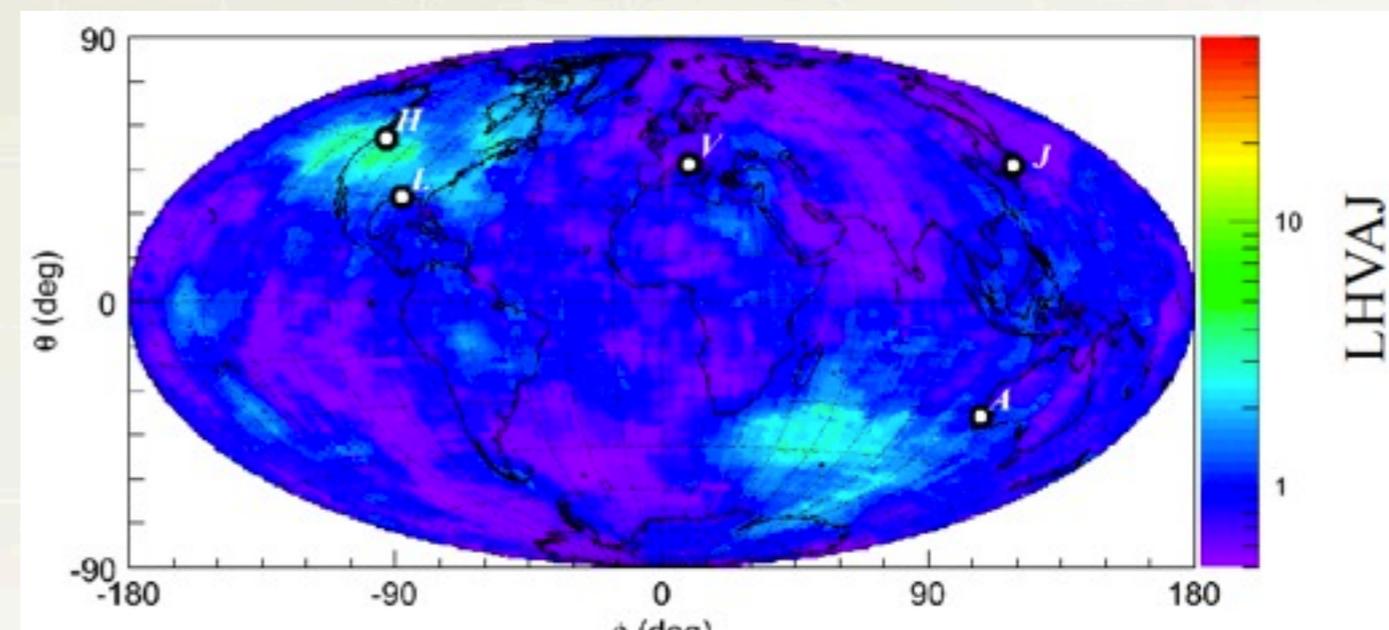
バースト重力波のSky position推定

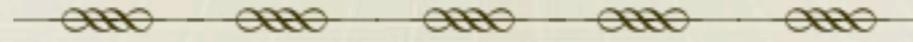


- LHVでは $>10^\circ$ だが、LHVJではほとんどの領域で $\sim 1^\circ$
- マルチメッセンジャー観測に重要！

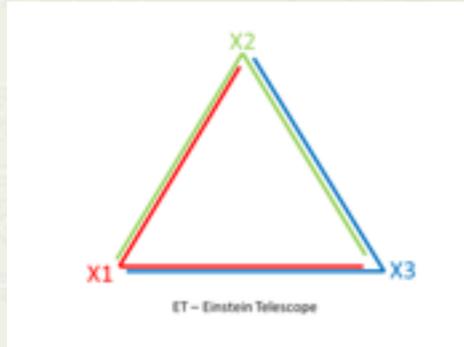


Un-modeled	LHV	LHVA	LHVJ	LHVAJ
WNB LF	4.8° / 0.7°	1.1° / 0.4°	1.8° / 0.4°	0.8° / 0.4°
WNB HF	4.5° / 0.4°	0.6° / 0.4°	0.8° / 0.4°	0.4° / 0.4°
SGQ9 LF	6.4° / 0.7°	1.4° / 0.4°	1.6° / 0.4°	1.0° / 0.4°
SHQ9 HF	4.1° / 0.9°	1.0° / 0.4°	1.0° / 0.4°	0.5° / 0.4°
SGQ3 LF	9.4° / 0.5°	1.1° / 0.5°	1.5° / 0.4°	0.9° / 0.4°
SGQ3 HF	6.3° / 0.4°	0.9° / 0.4°	1.0° / 0.4°	0.5° / 0.4°
SGCQ9 LF	9.3° / 0.8°	1.7° / 0.4°	2.0° / 0.4°	0.9° / 0.4°
SGCQ9 HF	5.5° / 1.1°	1.4° / 0.4°	1.7° / 0.4°	0.9° / 0.4°

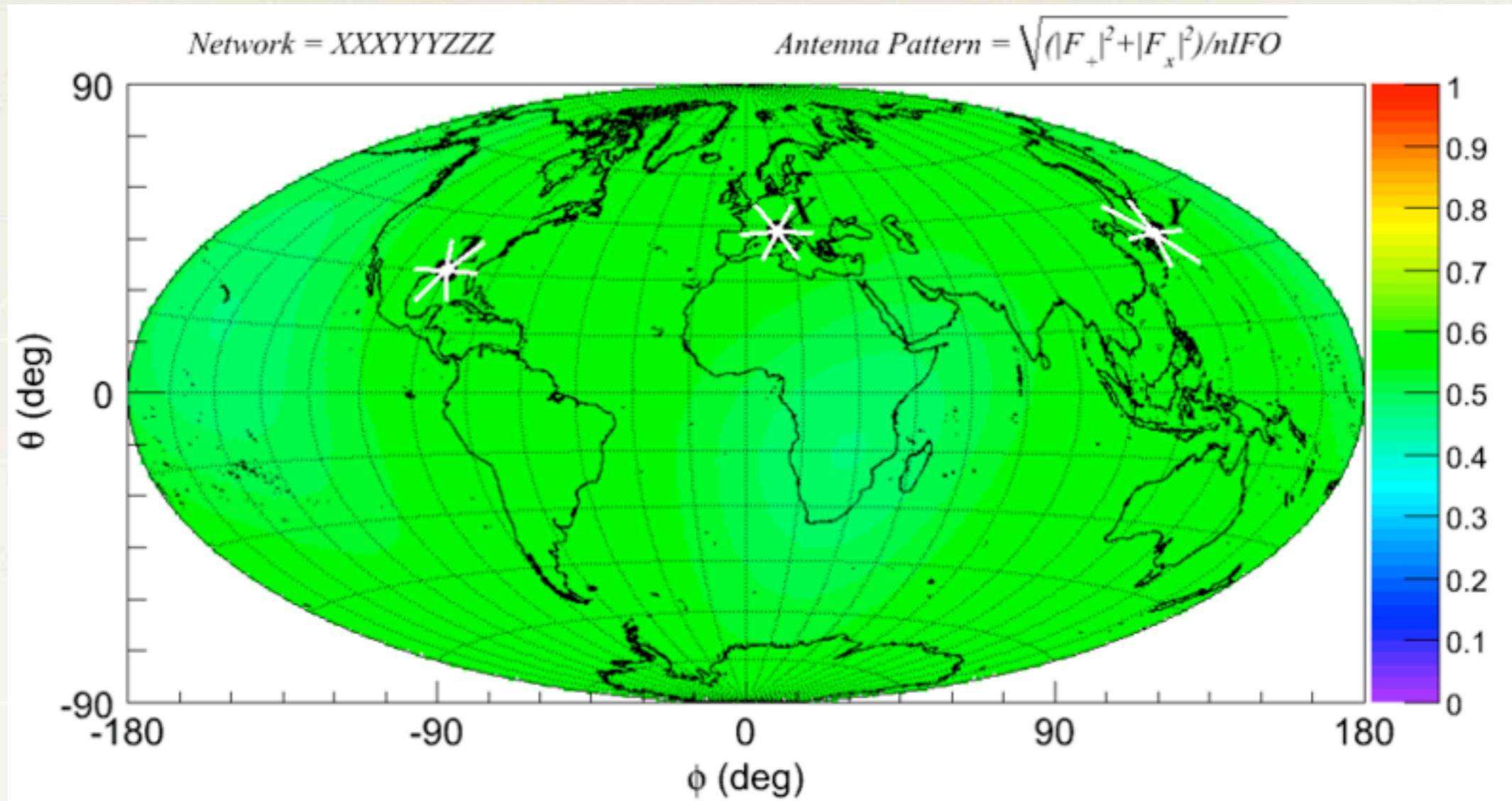


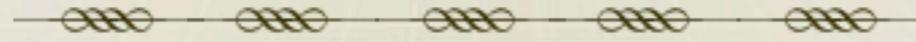


第3世代望遠鏡



- 日本、アメリカ(Livingston)、イタリア(Virgo)の位置がほぼ最適





Milky Way
(~50kpc)

到達年

2002年

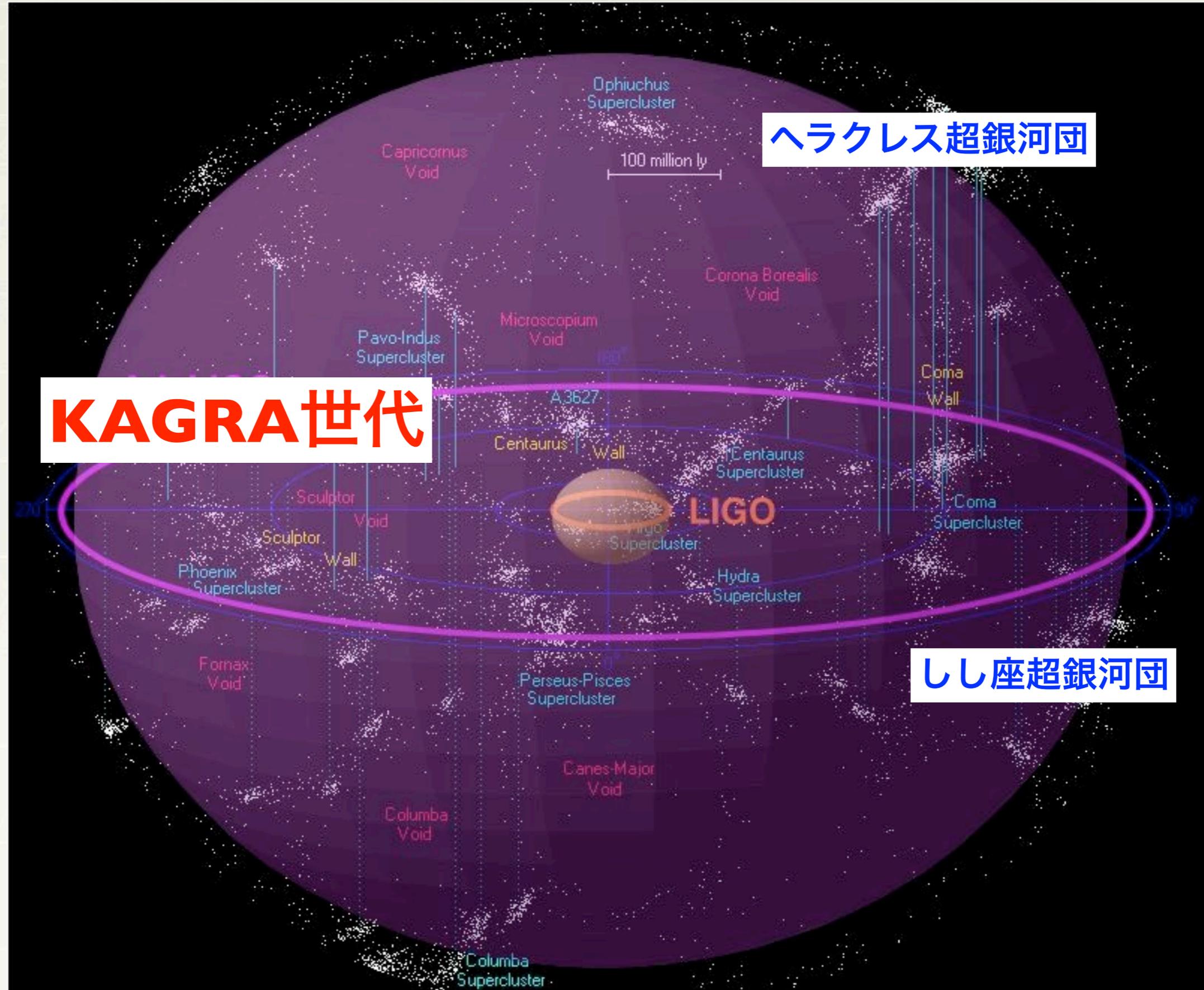
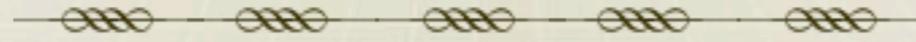
アンドロメダ銀河
(~700kpc)

2003年

乙女座銀河団
(~15Mpc)

2005年

現在40Mpc ---> KAGRA世代で~250-300Mpc



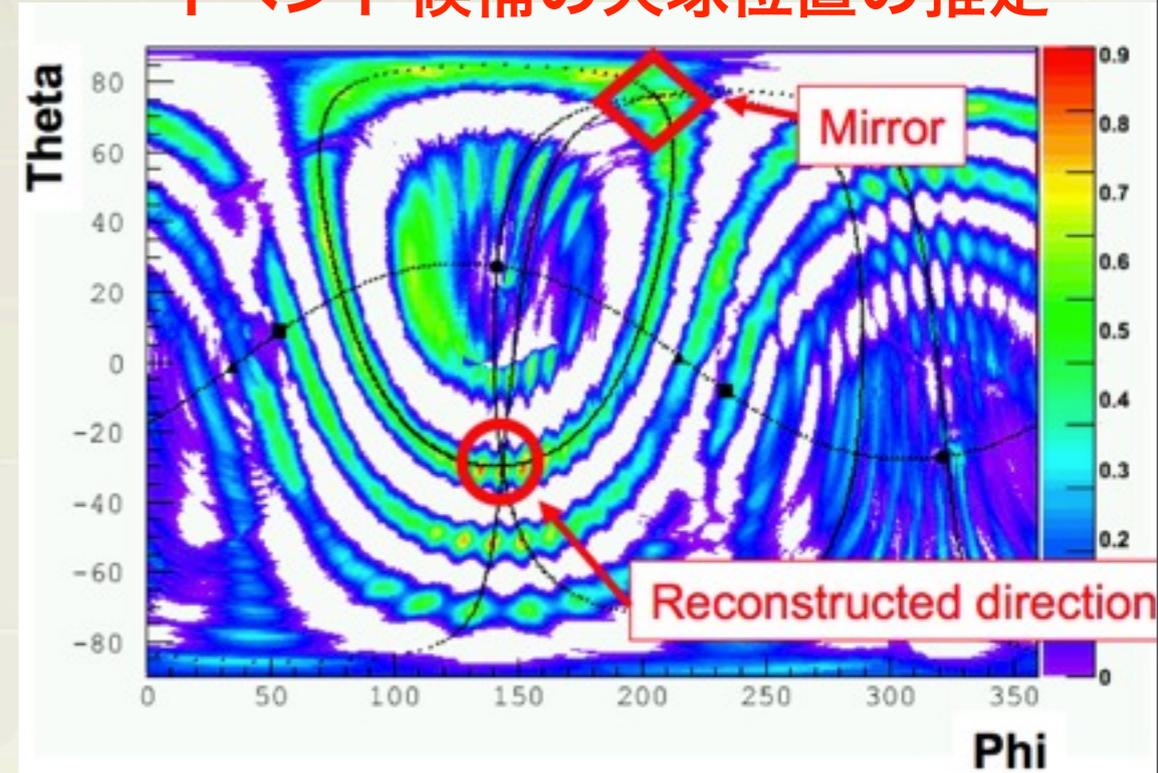
KAGRA世代

しし座超銀河団

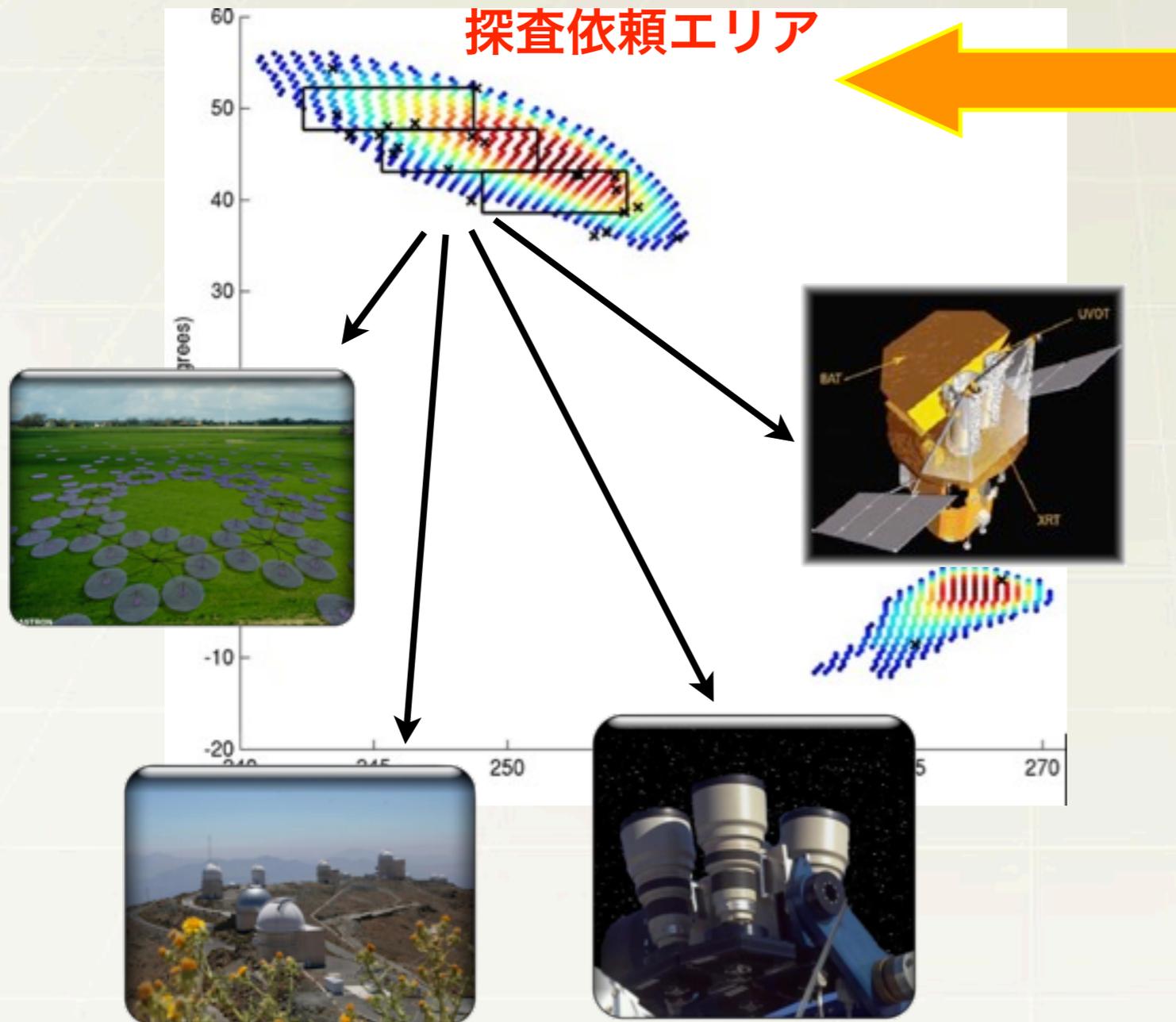
マルチメッセンジャー観測プロセス

- リアルタイムバーストサーチにより、重力波イベント候補の推定天球位置を電磁波望遠鏡に送り、フォローアップ観測を依頼
- 例えば、重力波によるガンマ線バーストの予報なども目指す

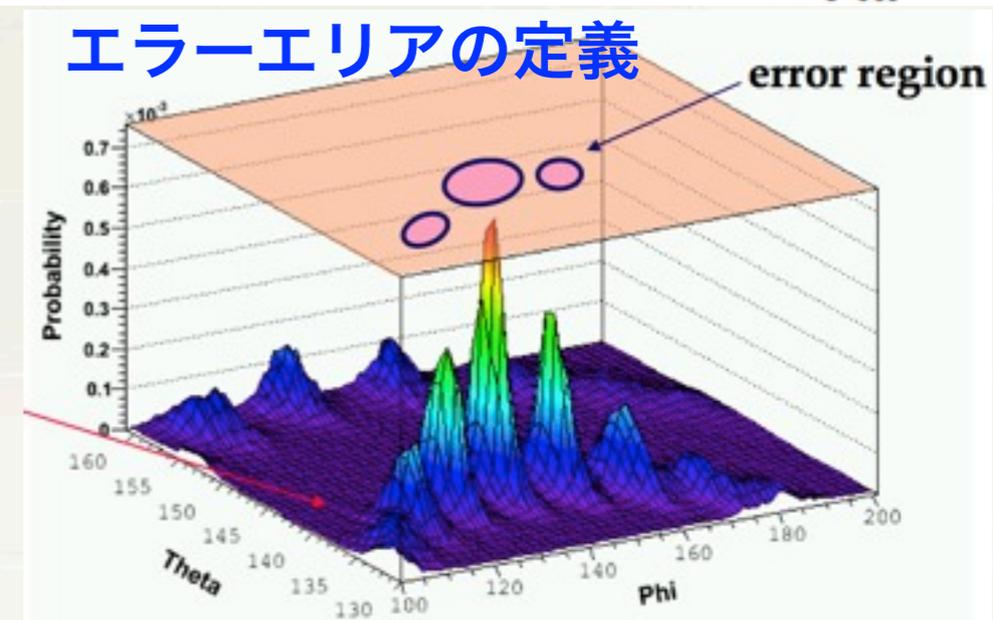
イベント候補の天球位置の推定



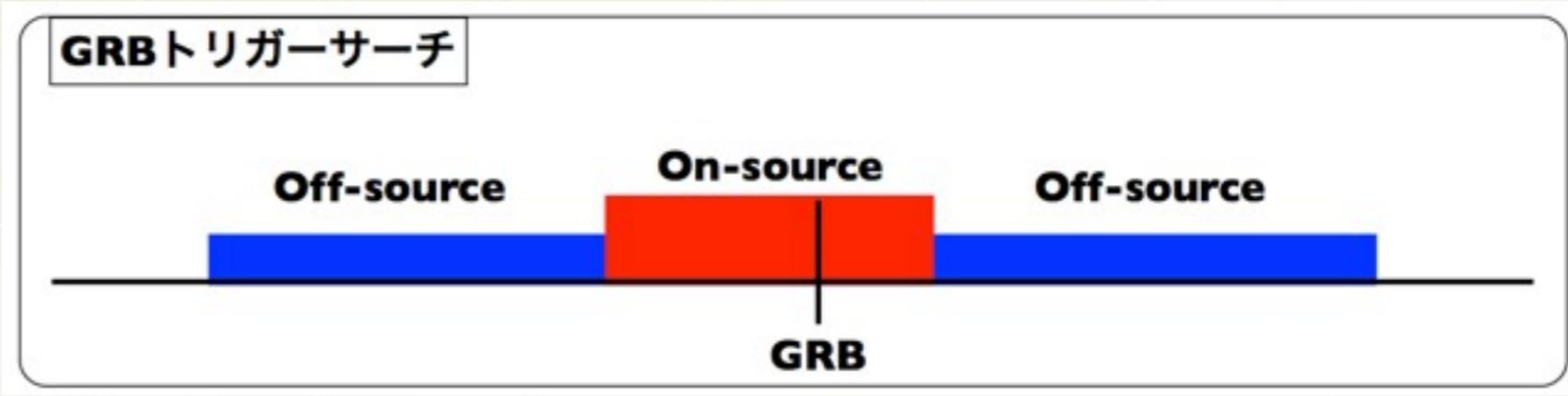
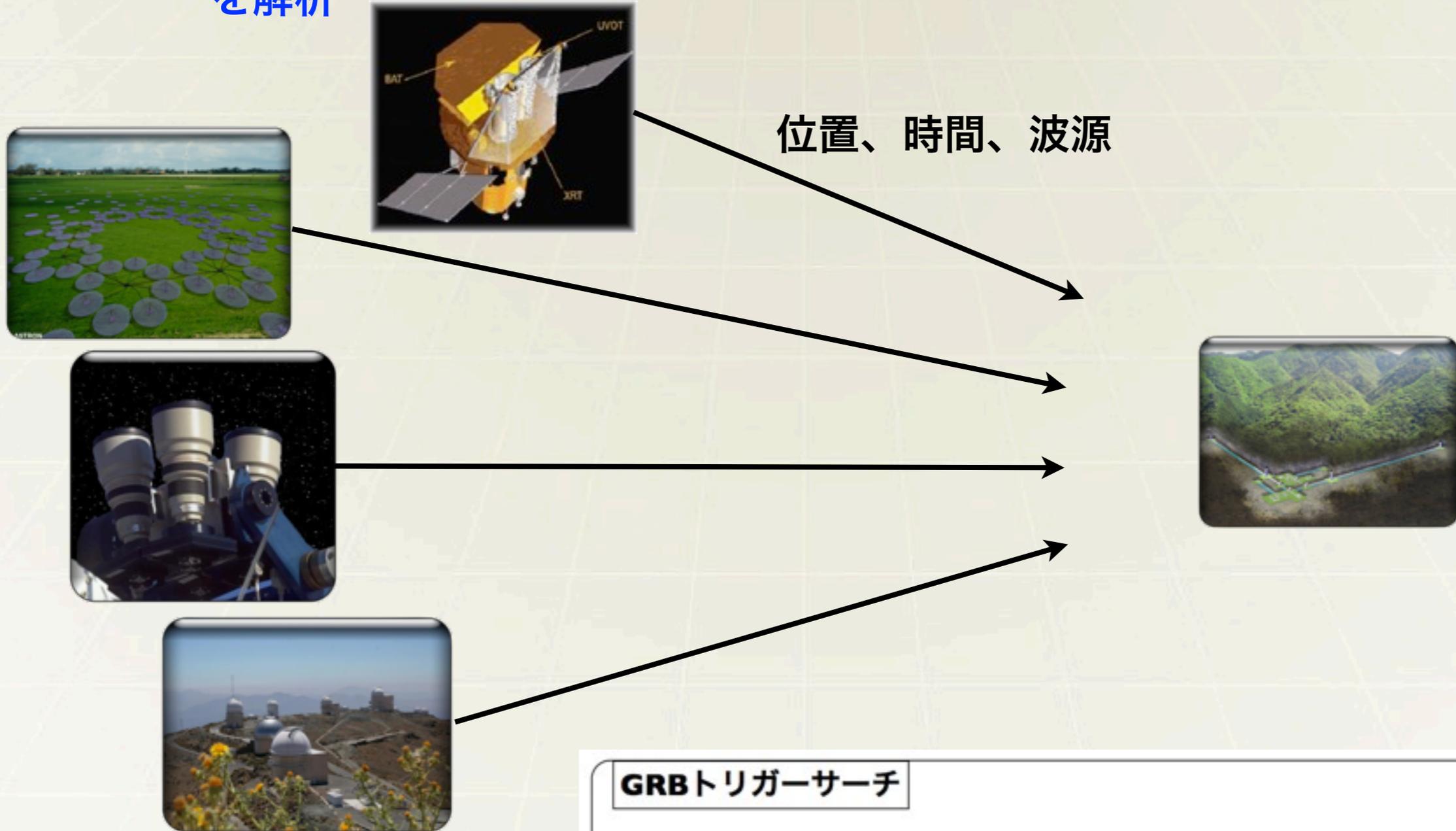
探査依頼エリア

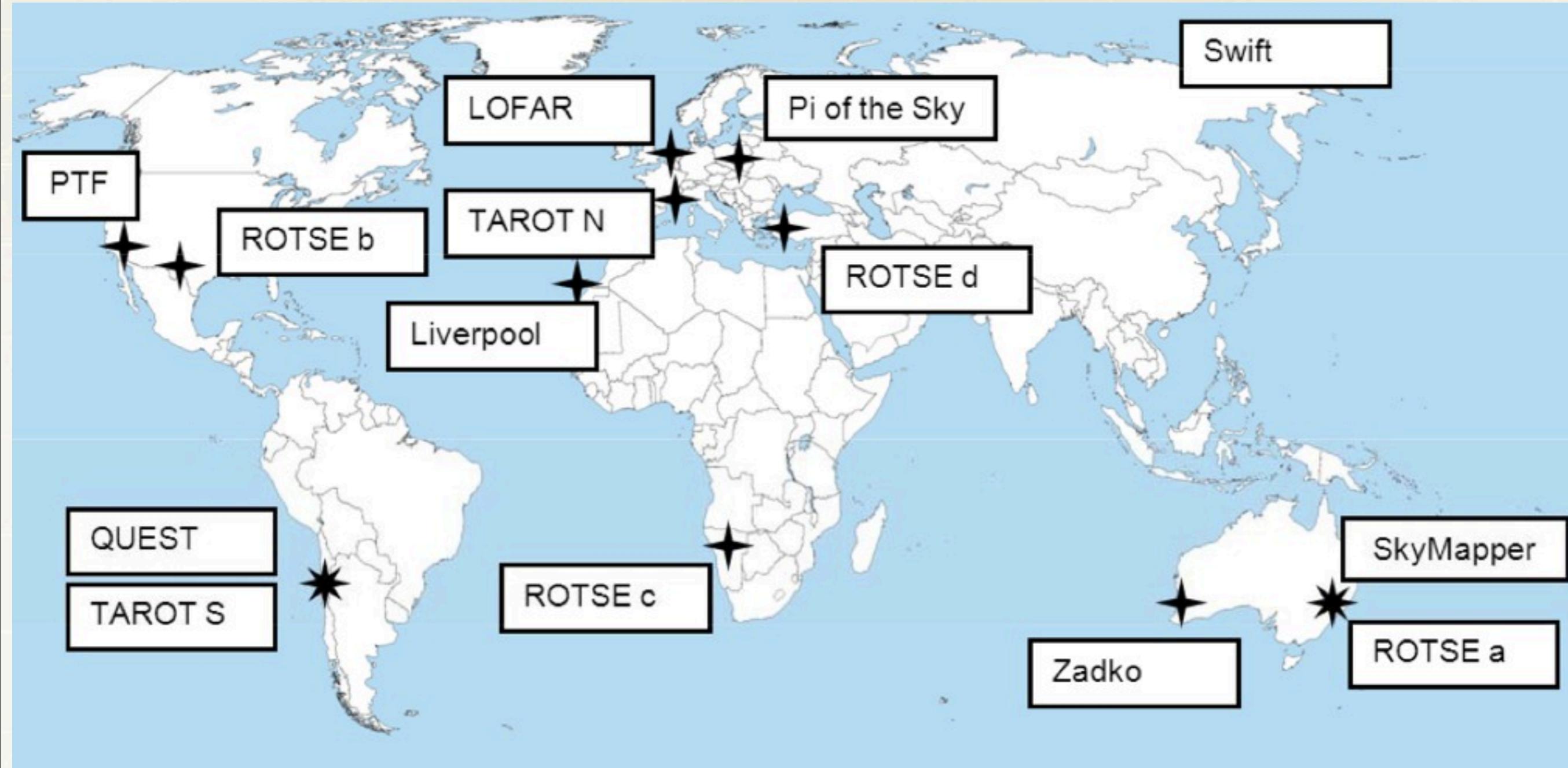
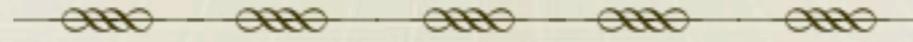


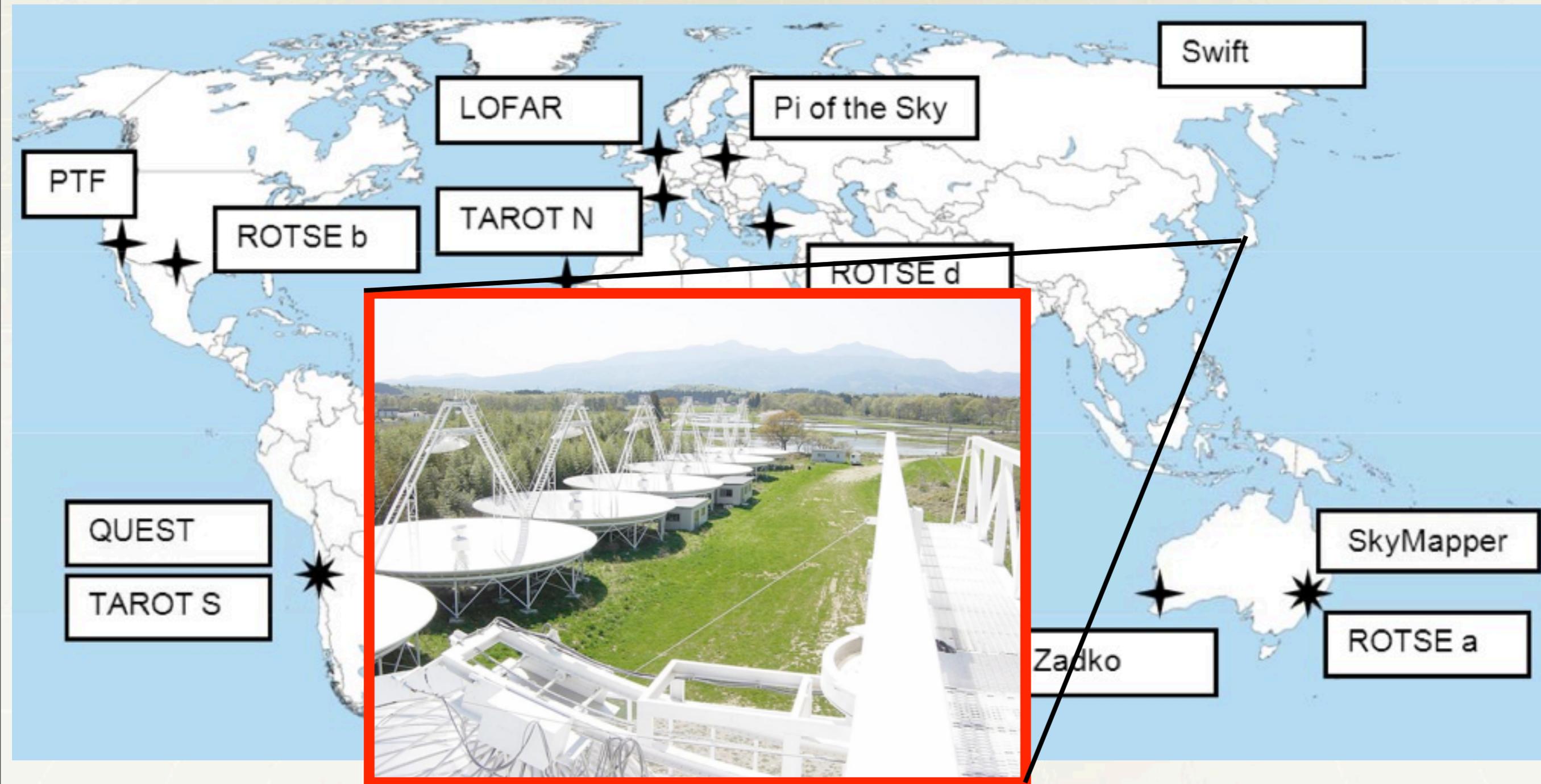
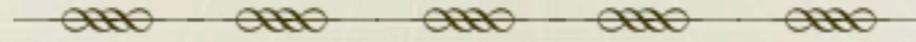
エラーエリアの定義



- 電磁波望遠鏡からのトランジェントアラートを受けて、重力波データを解析を解析







那須パルサー観測所（早稲田 大師堂研）

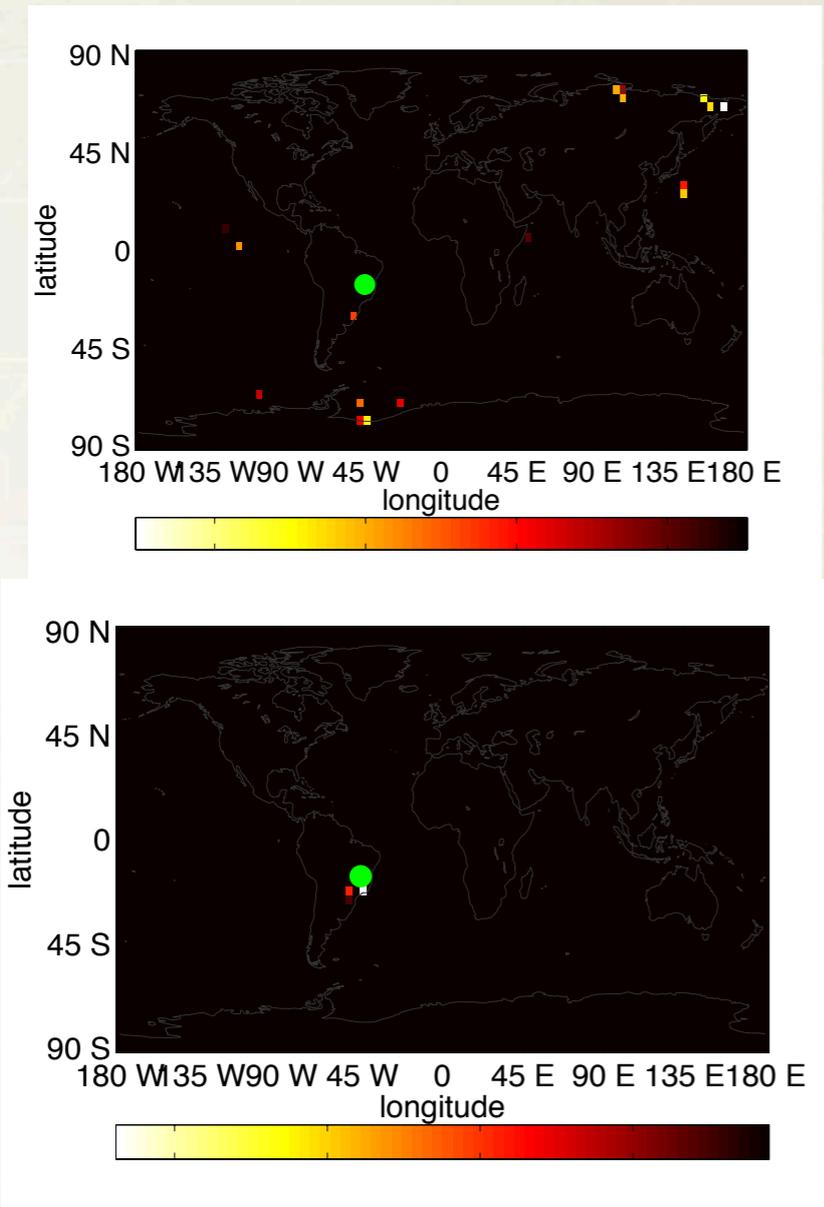
- 重力波の到来方向の推定精度の改善
- 誤検出の改善

今まで理論波形を改善

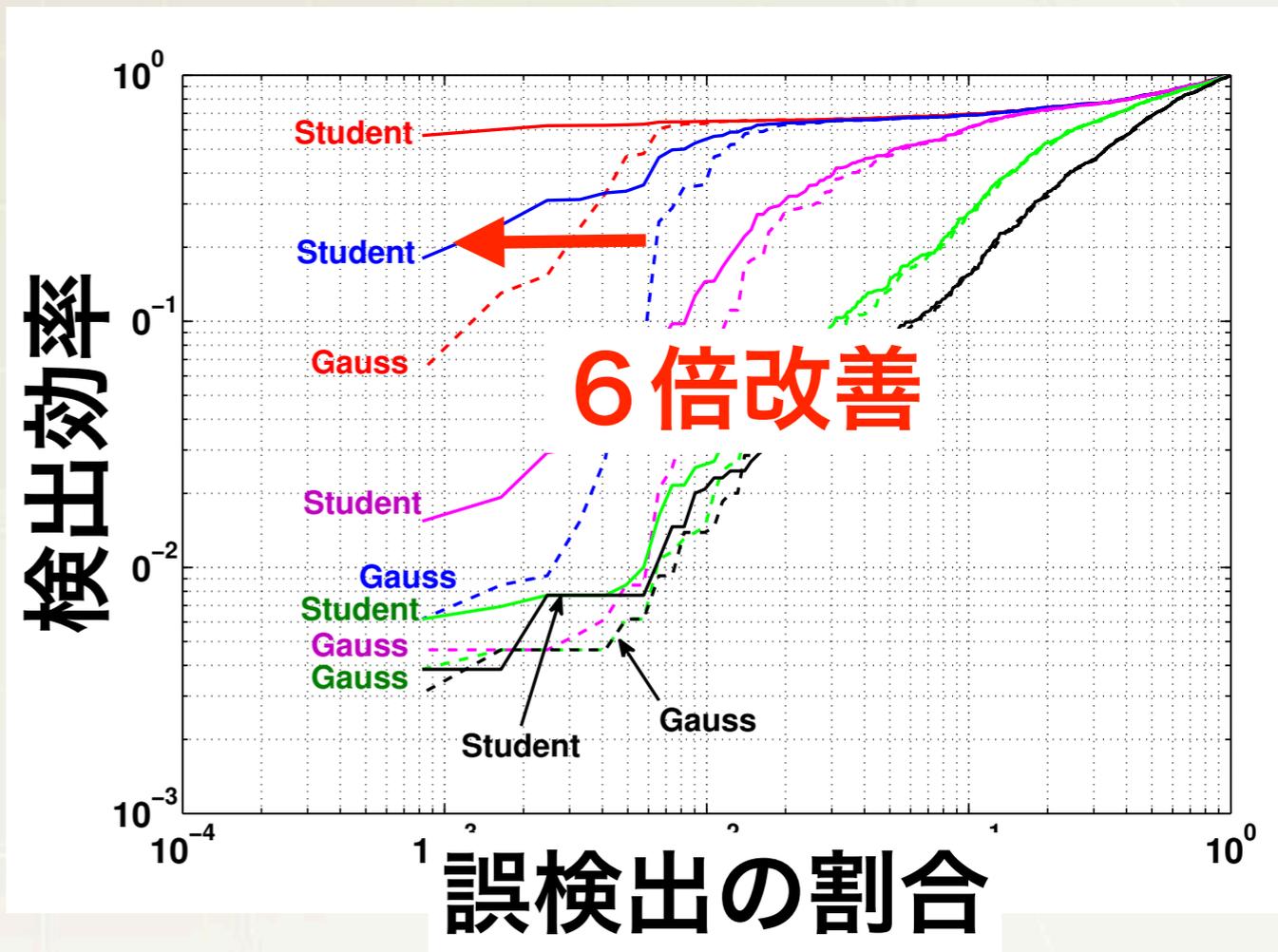
信号雑音比

$$= 4 \operatorname{Re} \int_{f_{\text{low}}}^{f_{\text{high}}} \frac{\tilde{s}(f) \tilde{h}(f)}{S_n(f)} df$$

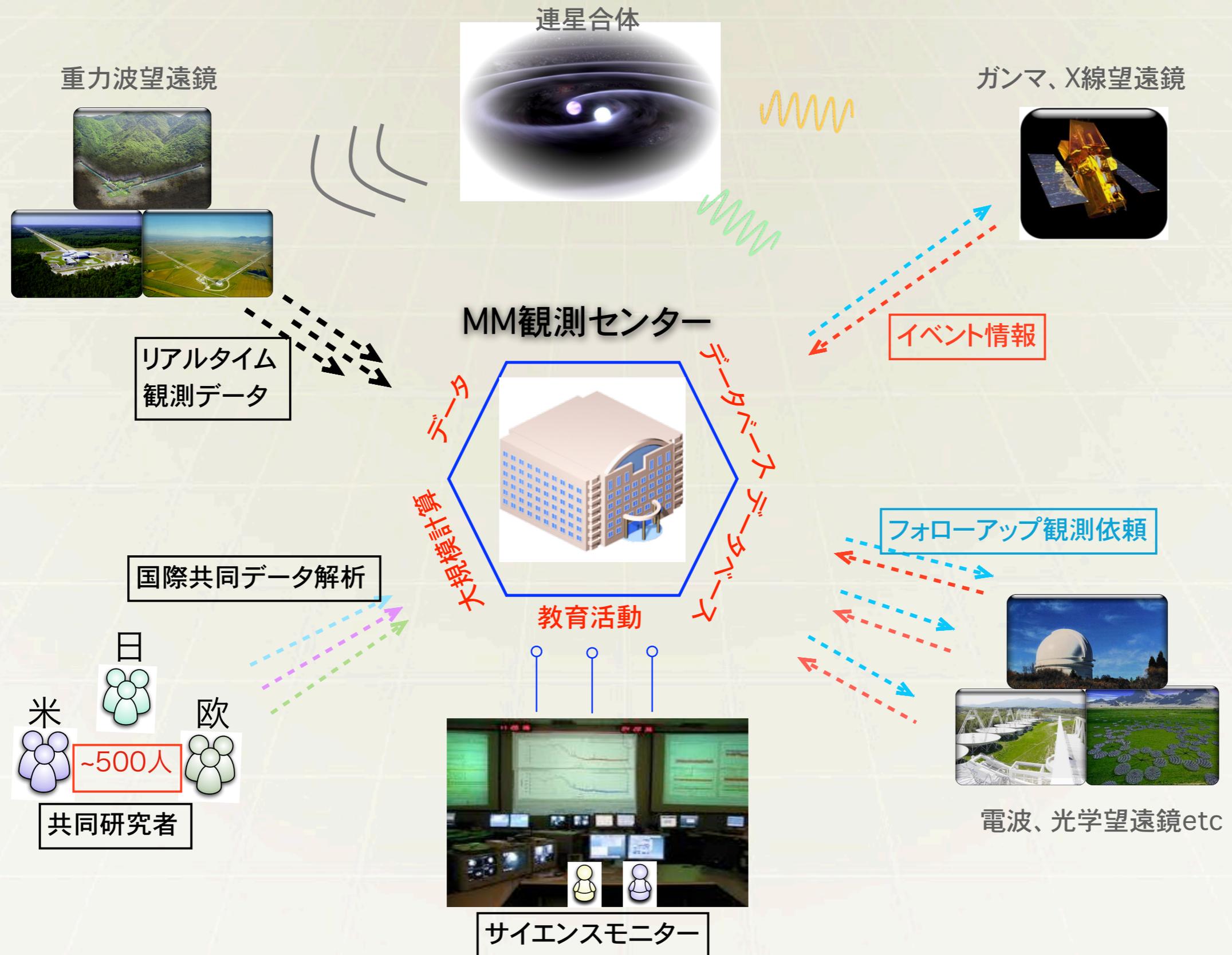
さらにスペクトル推定を改善



Hayama et al



Hayama, Roever

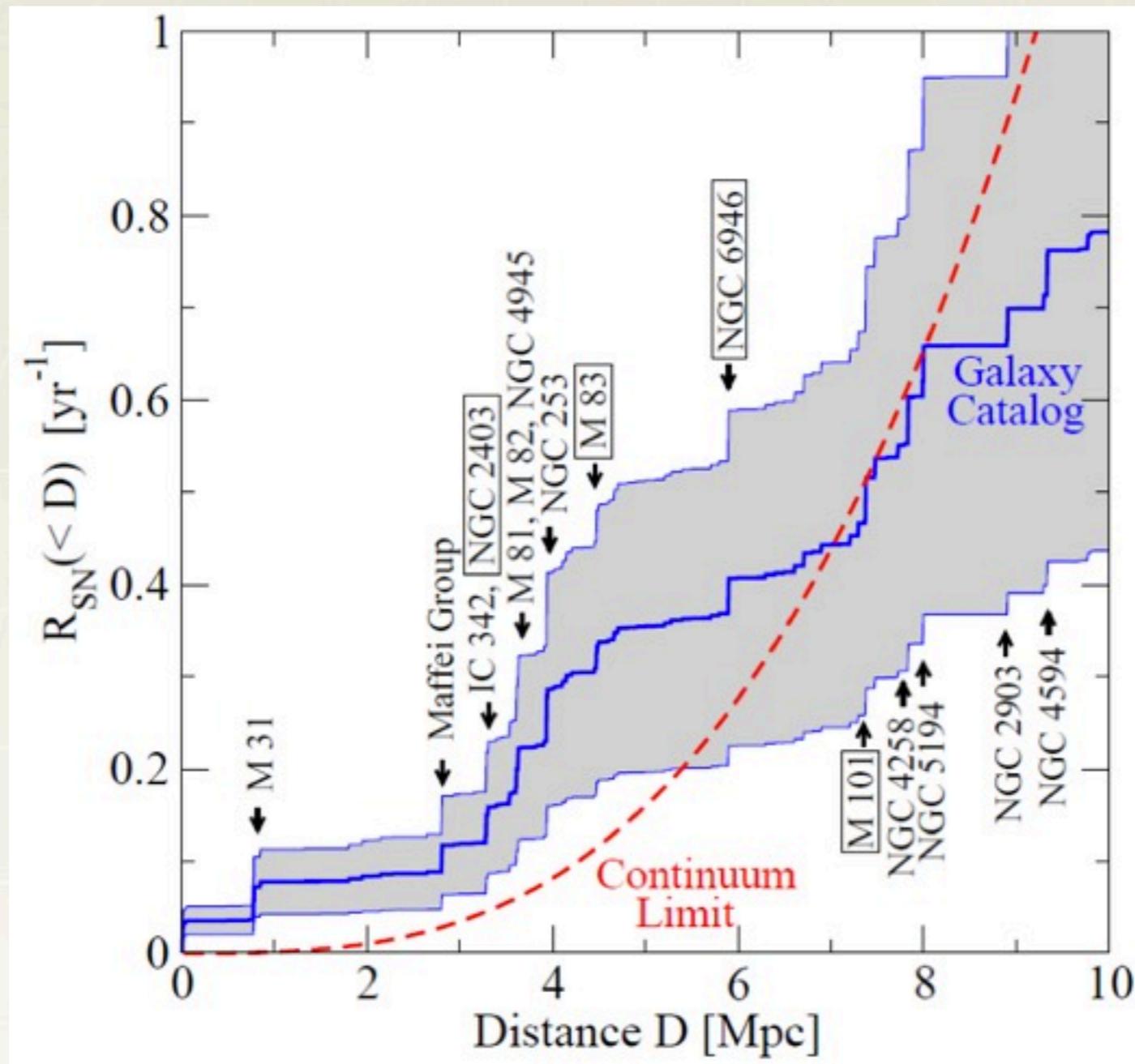


2010年代の日本の天体宇宙物理大型計画

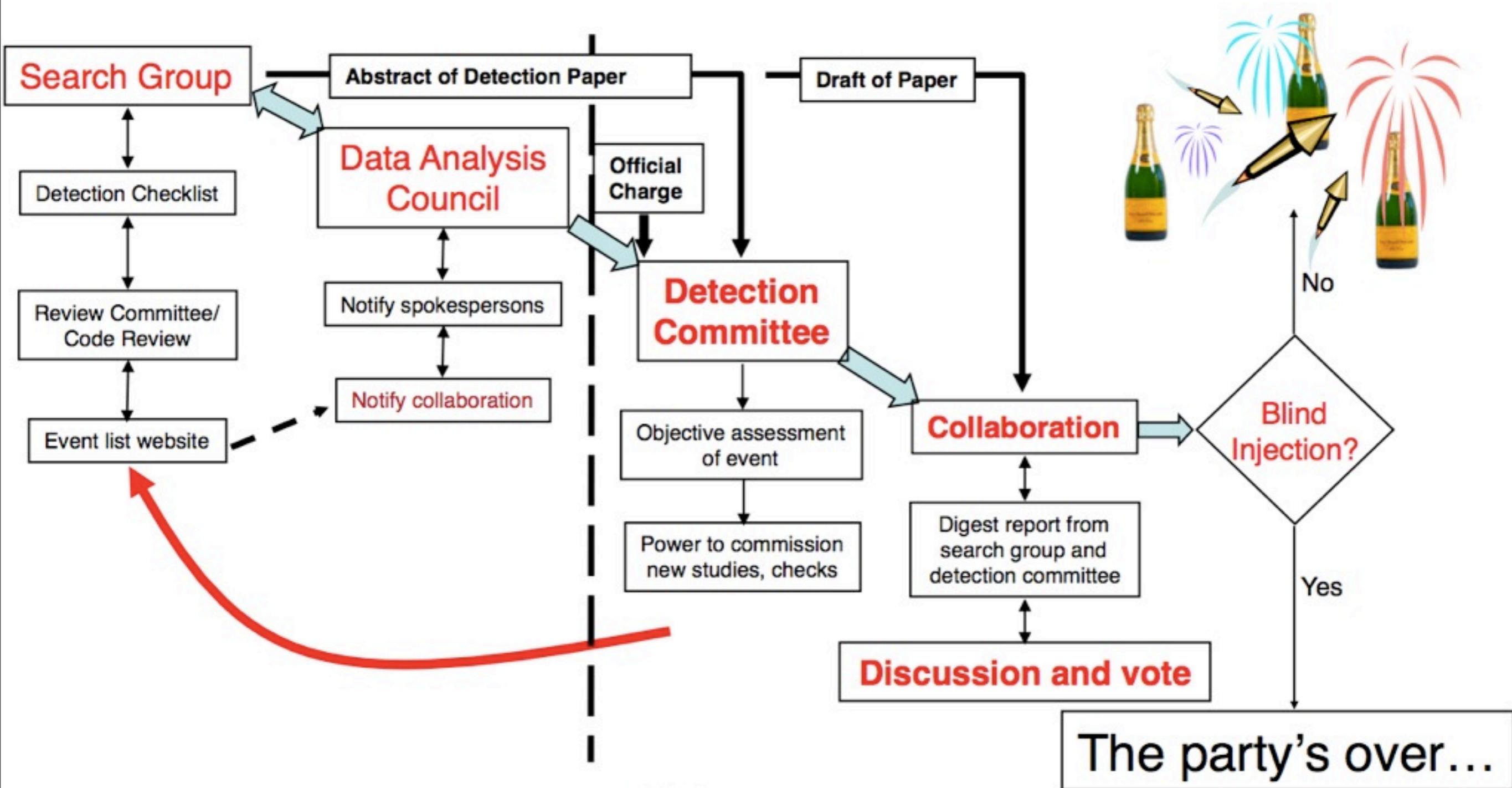


超新星爆発のイベントレート

- Galactic rate ~ 1 per 30–50 years
- Expect one core-collapse SN within 5 Mpc every 2–5 years

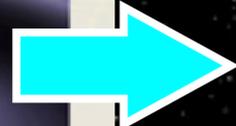
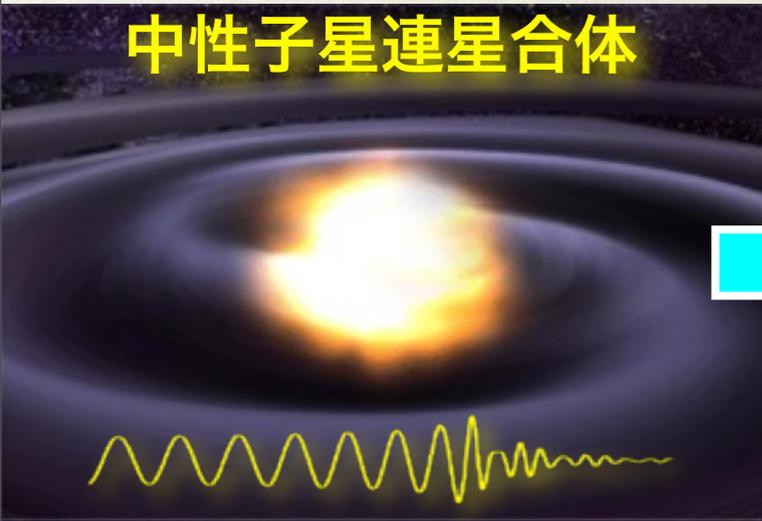
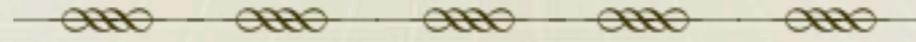


S. Ando et al. 2005 [PRL 95, 171101]

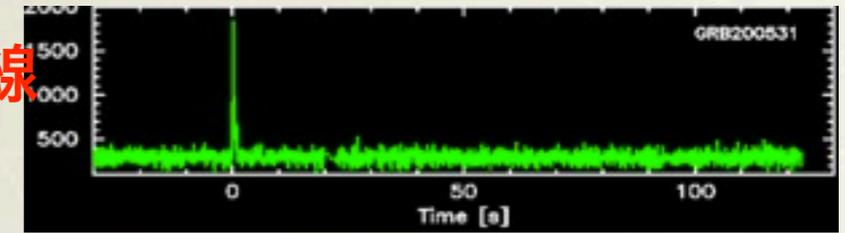


R. Weiss (MIT)

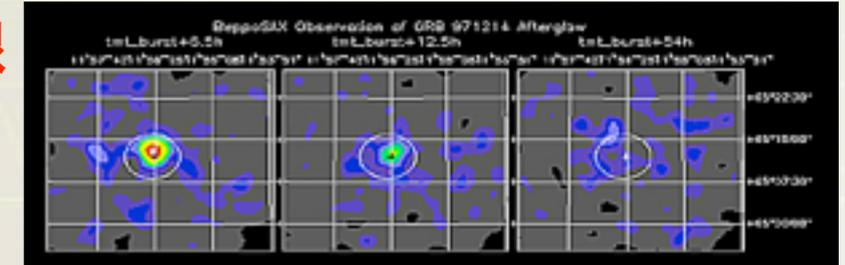
マルチメッセンジャー観測



ガンマ線



X線



可視光



秒

日

週

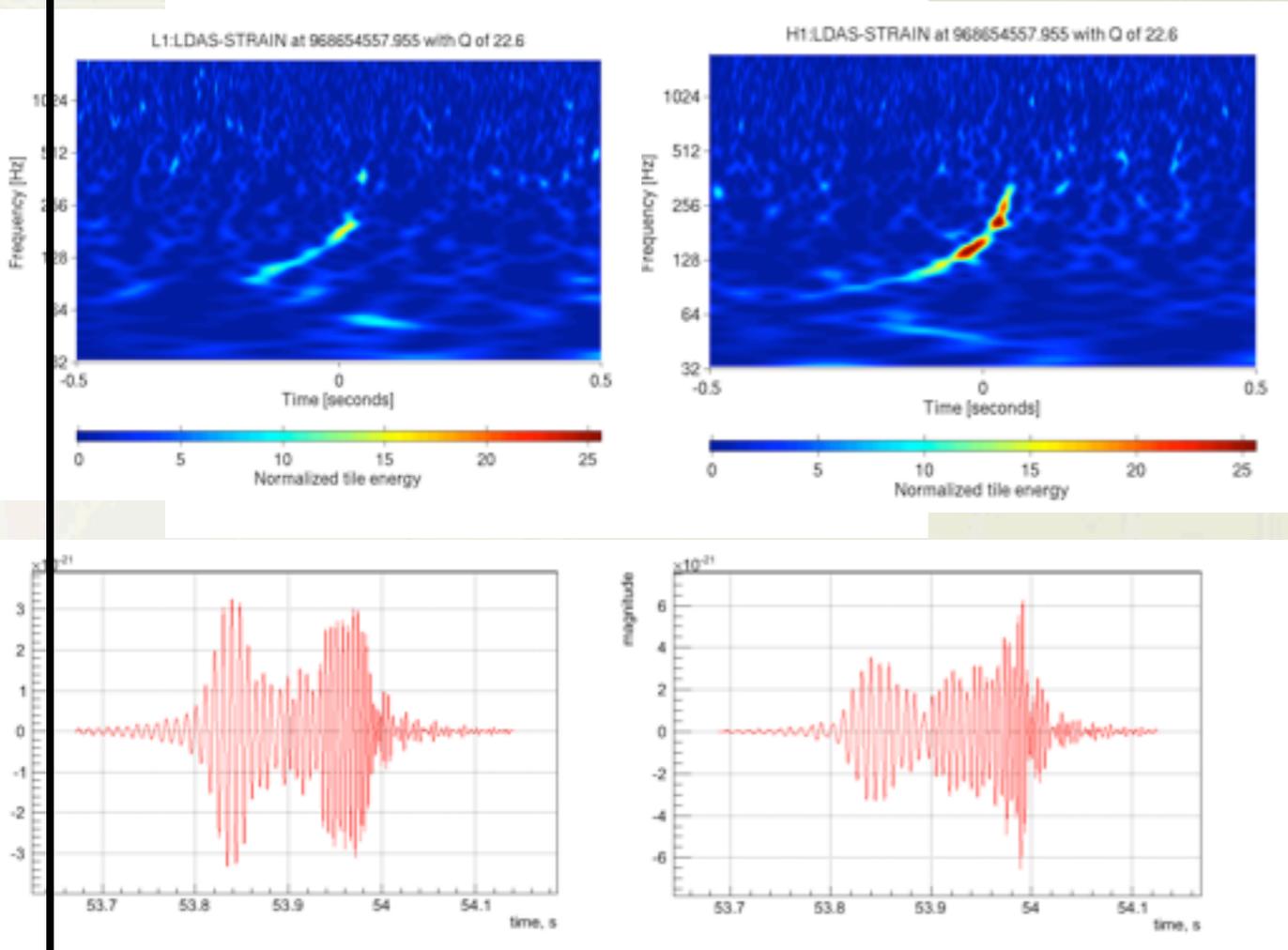


解析パイプライン

オペレータによる環境データチェック

L1

H1



Undefined flags

- Are there any undefined CAT 1 or CAT 2 flags? : No
- If Yes, please include the names of the flags here:
- GO/NOGO: **GO**
- Checked by: Christian Ott
- Comments:

Sanity Checks Script

See sanity check script output - '+' means GO / '!' or '-' means NOGO

- Within detector locks: GO
- DQ Flags: GO
- KleineWelle trigger rate: GO
- GO/NOGO: **GO**
- Checked by: Christian Ott, Peter Shawhan, LLO [SciMon](#)
- Comments: Confusion about error messages concerning Virgo (script says 'ignore')

Control Room Sign-off - Include any notes on Omega grams or FOM here

- H1:
 - Scimon Name: Kiwamu Izumi
 - GO
- L1:
 - Scimon Name: Rahul Kumar
 - GO
- V1:
 - Scimon Name: K.Borkowski
 - GO
- GO/NOGO: **GO**
- Comments:

'gold plated inspiral at first glance' (Igor)

$t_{\text{dog}}+8[\text{m}]$

$t_{\text{dog}}+42[\text{m}]$

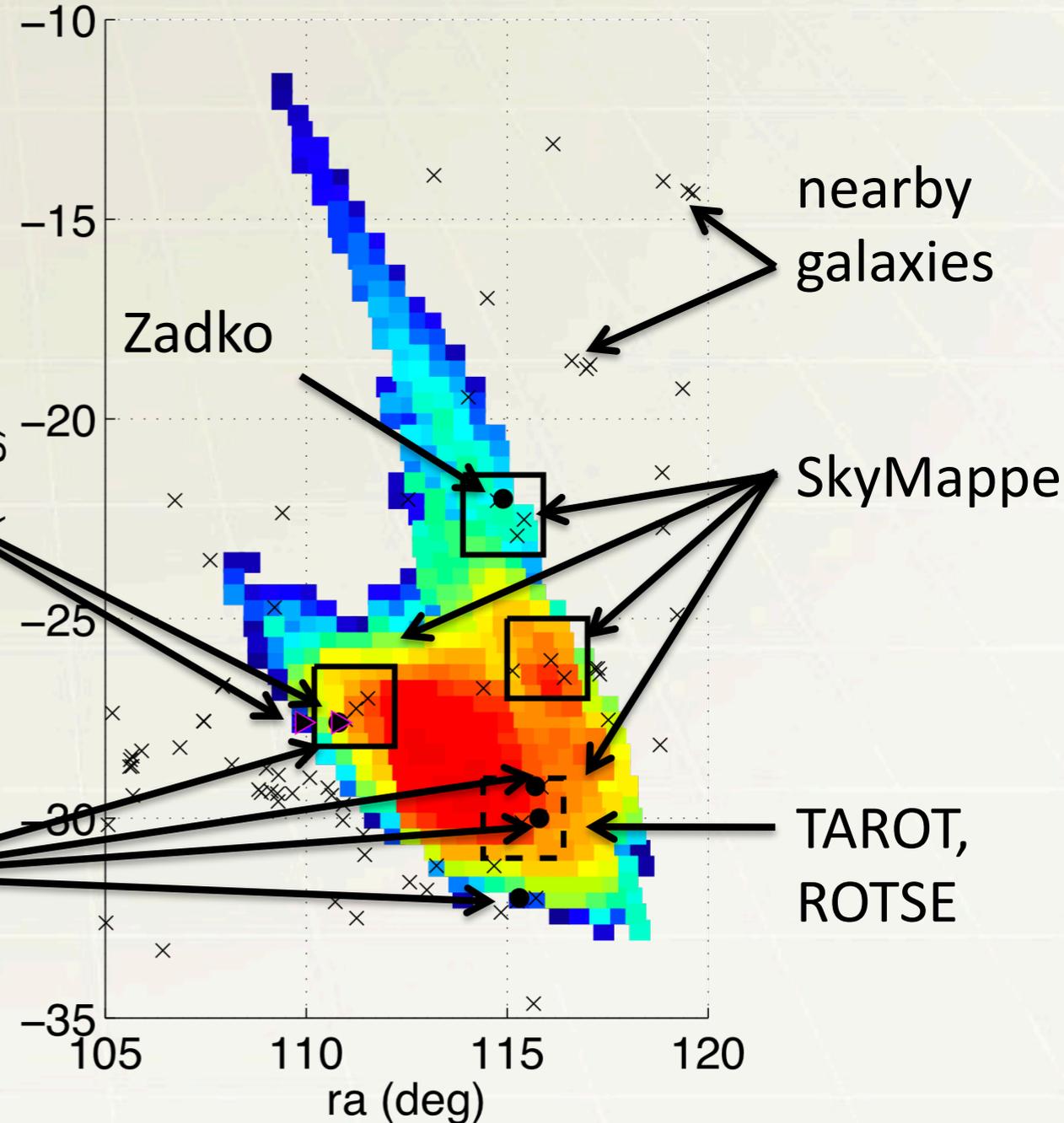
Requested sky region for follow-up

Top 1000 pixels reported
 • total area: 129 sq deg
 • estimated containment: 19%

Telescopes pointed at nearby galaxies (<50 Mpc) in this area

-120 -60 0 60 120 180
 ra (deg)

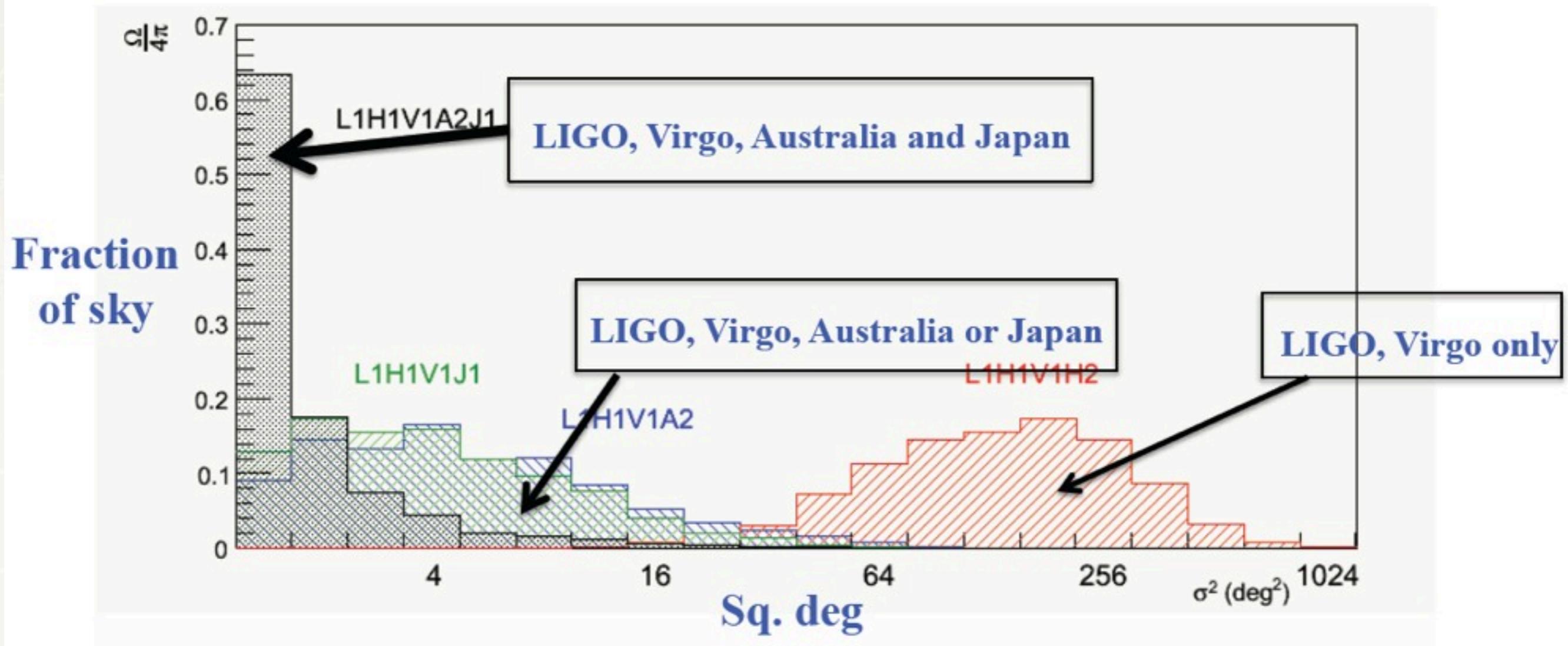
LUMIN pipeline
 銀河カタログを参照して
 こちらの島が選ばれた



Usable images:

- TAROT: 20, + [44 min - 4 day]
- ROTSE: 102, + [0.5 - 29] day
- Zadko: 63, + [1, 160] day
- SkyMapper: 21, + 8 day
- *Swift*: 4, + [0.5, 105] day

中性子星連星合体からの重力波の場合



エラー領域の大きさ

S. Witcomb (2011)