Search for gravitational waves associated with the InterPlanetary Network short gamma ray bursts

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Overview

- ✓ Short gamma ray bursts (GRB) and search motivation;
- ✓ The InterPlanetary Network – how it works;
- ✓ Getting the short IPN GRB sample;
- ✓ Future analysis challenges and solutions.

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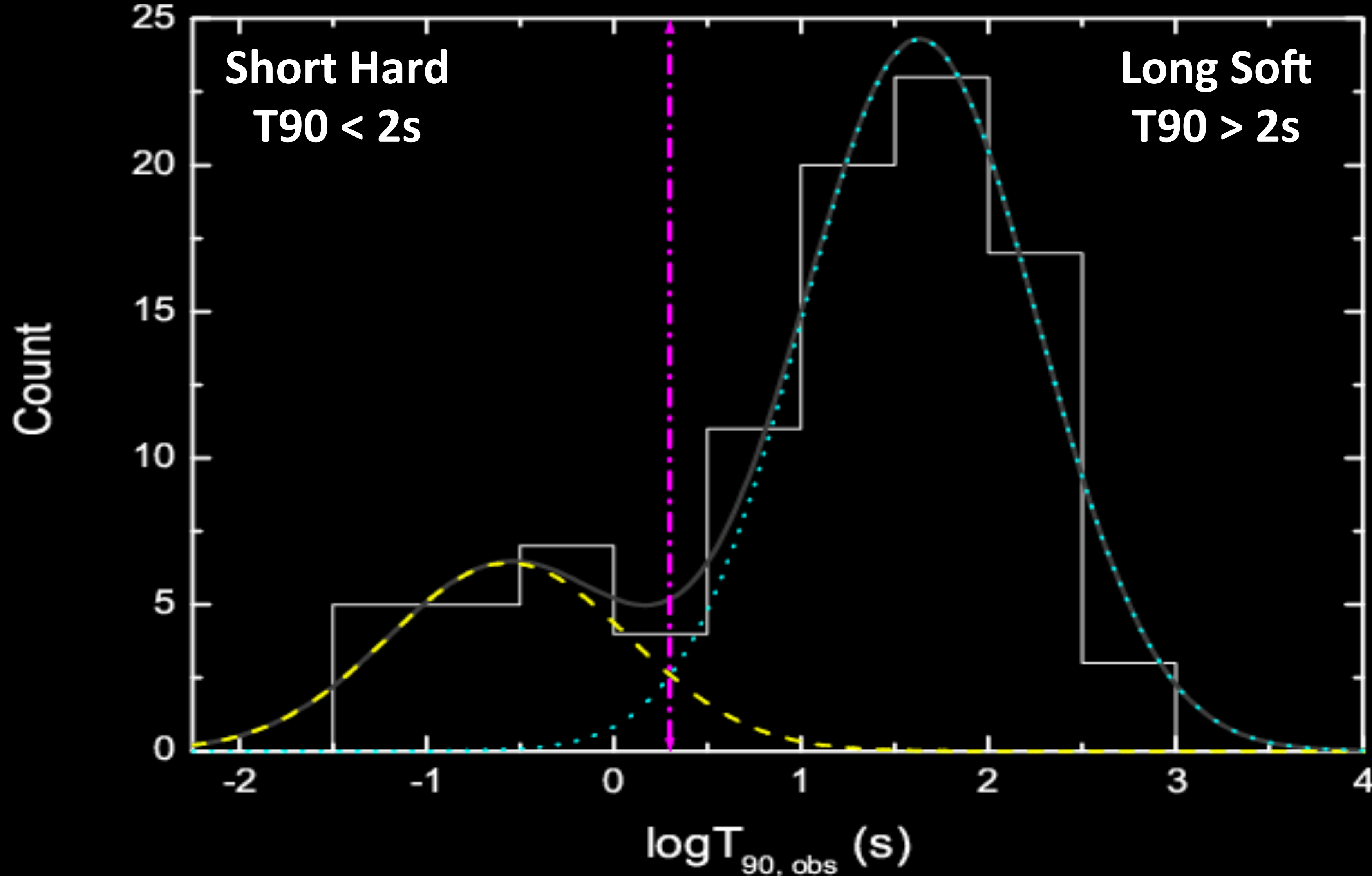
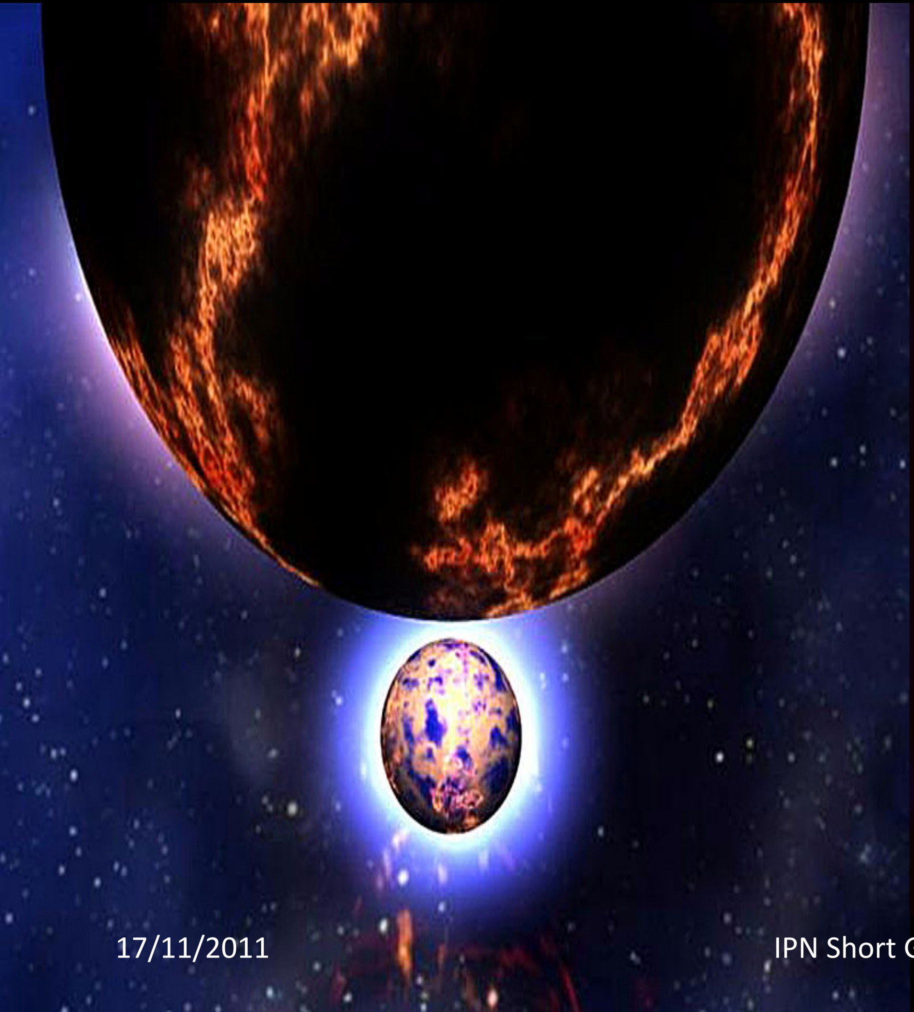
Gamma ray bursts have a bimodal distribution of their durations

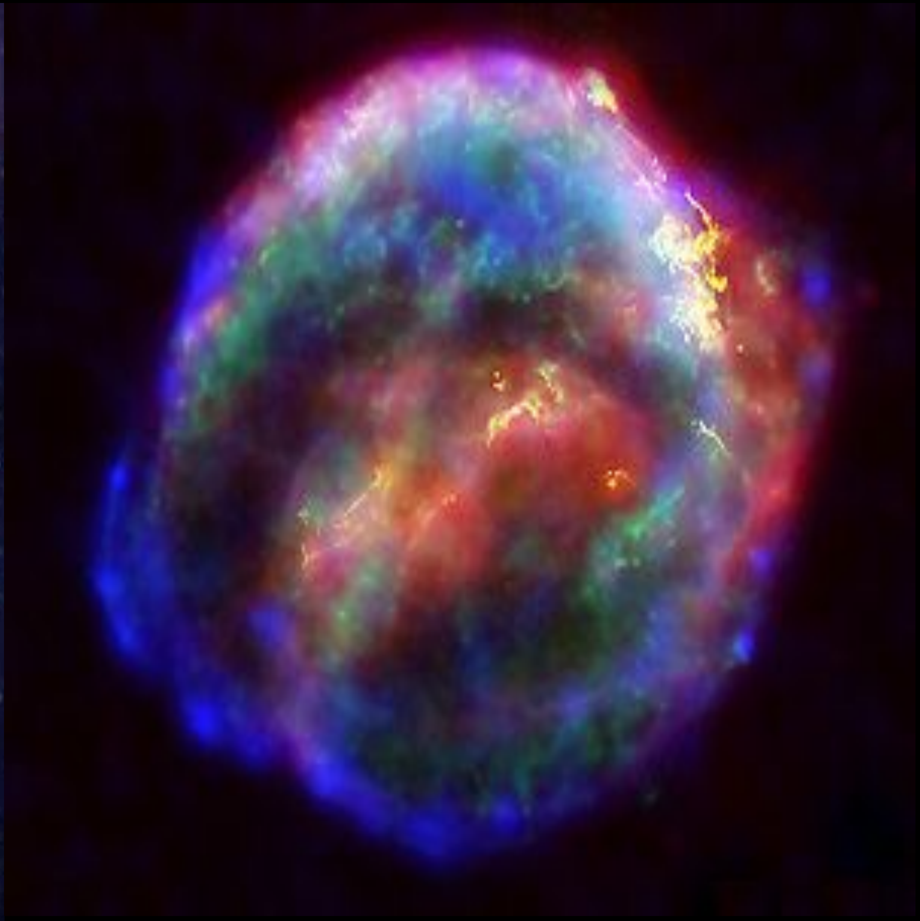


Short Hard and Long Soft Gamma Ray Bursts

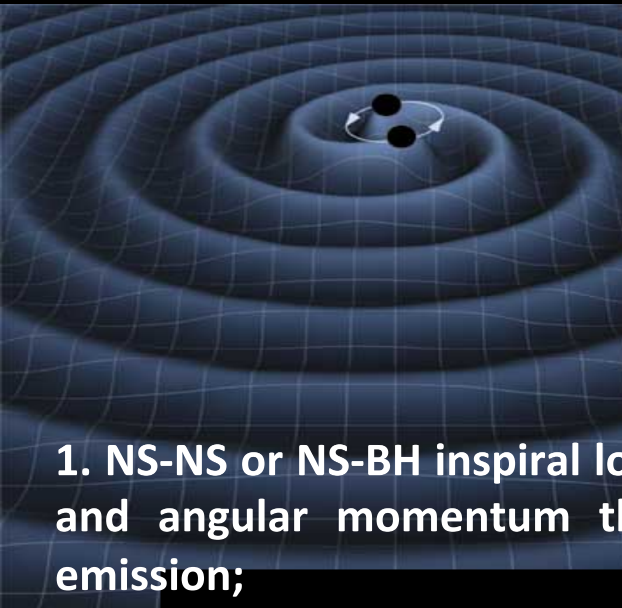
Short Hard GRB
compact binary mergers

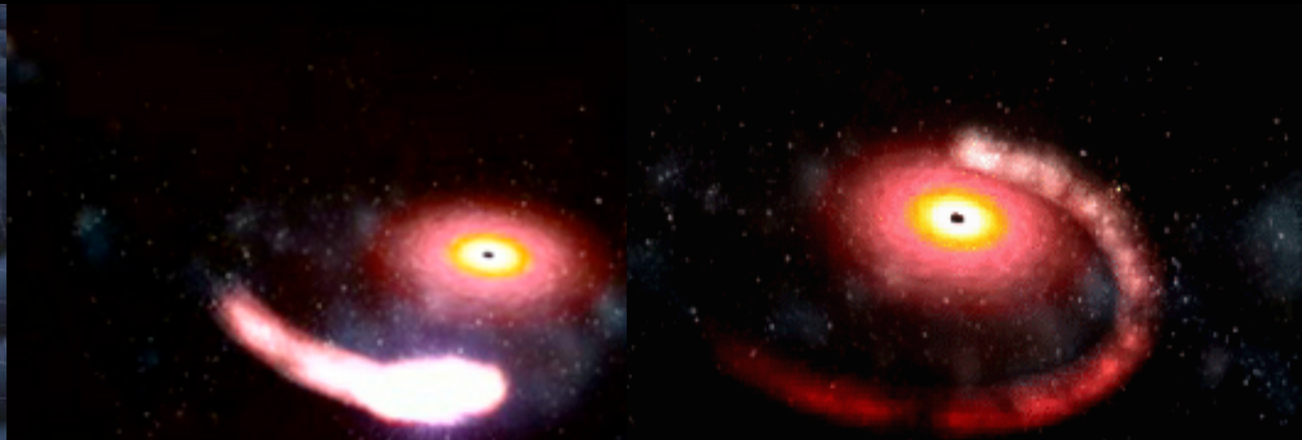


Long Soft GRB
core-collapse SNe



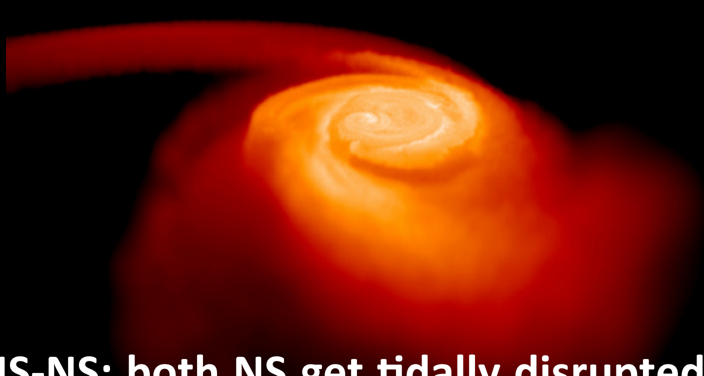
Short Hard Gamma ray bursts: Emission Mechanism

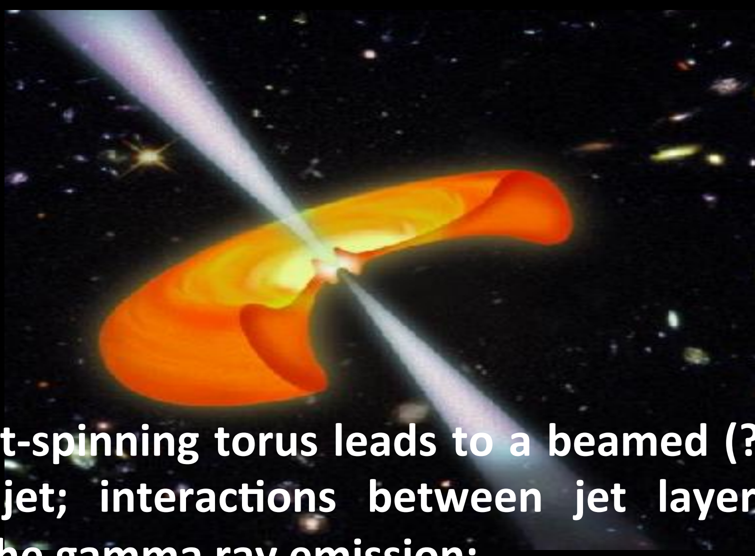




1. NS-NS or NS-BH inspiral losing energy and angular momentum through GW emission;

2a. NS-BH: NS gets tidally disrupted and starts plunging towards the BH creating a dense hot fast-spinning torus ;



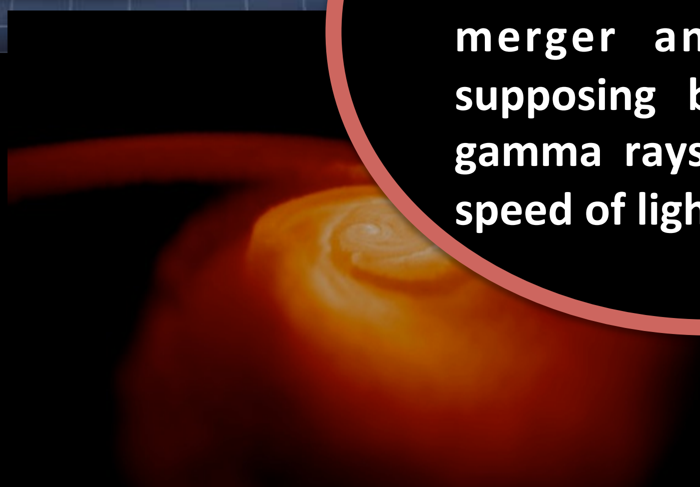


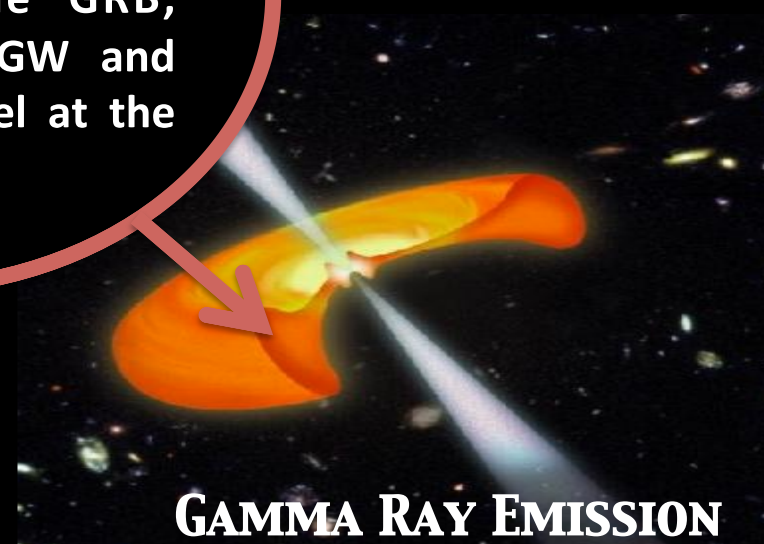
2b. NS-NS: both NS get tidally disrupted and start plunging towards each other creating a dense hot fast-spinning torus;

3. The fast-spinning torus leads to a beamed (?) particles jet; interactions between jet layers produce the gamma ray emission;

Short Hard Gamma ray bursts: Time Delay

There is a time delay of ~ms to a few seconds between the GW burst at merger and the GRB, supposing both GW and gamma rays travel at the speed of light.





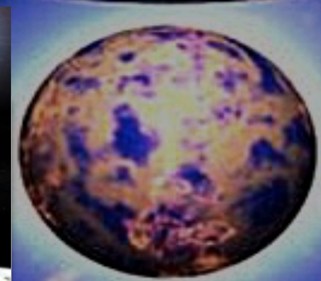
Short Hard Gamma ray bursts: Motivation

- ✓ Widely believed to be mergers of binary neutron stars or of a neutron star and a black hole; this progenitor model has not been confirmed by any observation to date;

- ✓ Compact binary mergers are strong candidates for gravitational waves emission (GW) and the final inspiral waveforms can be theoretically modeled;

- ✓ Hence, a detection of GW associated with a short GRB would confirm the progenitor model and provide us with parameters of the compact binary;

Constant GRB watch



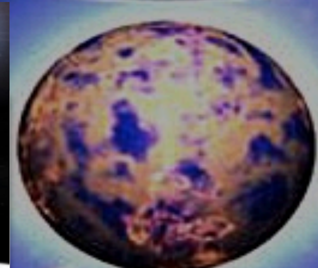
Constant GW watch

Short Hard Gamma ray bursts: Motivation

- We can perform a search in GW data around the time of the GRB and use its sky location, taking into account the delay between the arrival time of GW and the gamma rays (triggered search);
- A GW triggered search buys up to twice in sensitivity compared to all-time all-sky searches;
- In case of a GW detection we can estimate binary masses, spins and get a calibration-free measure of the distance;

It is important to have constant monitoring of both the GRB and GW skies!

Constant GRB watch



Constant GW watch

Overview

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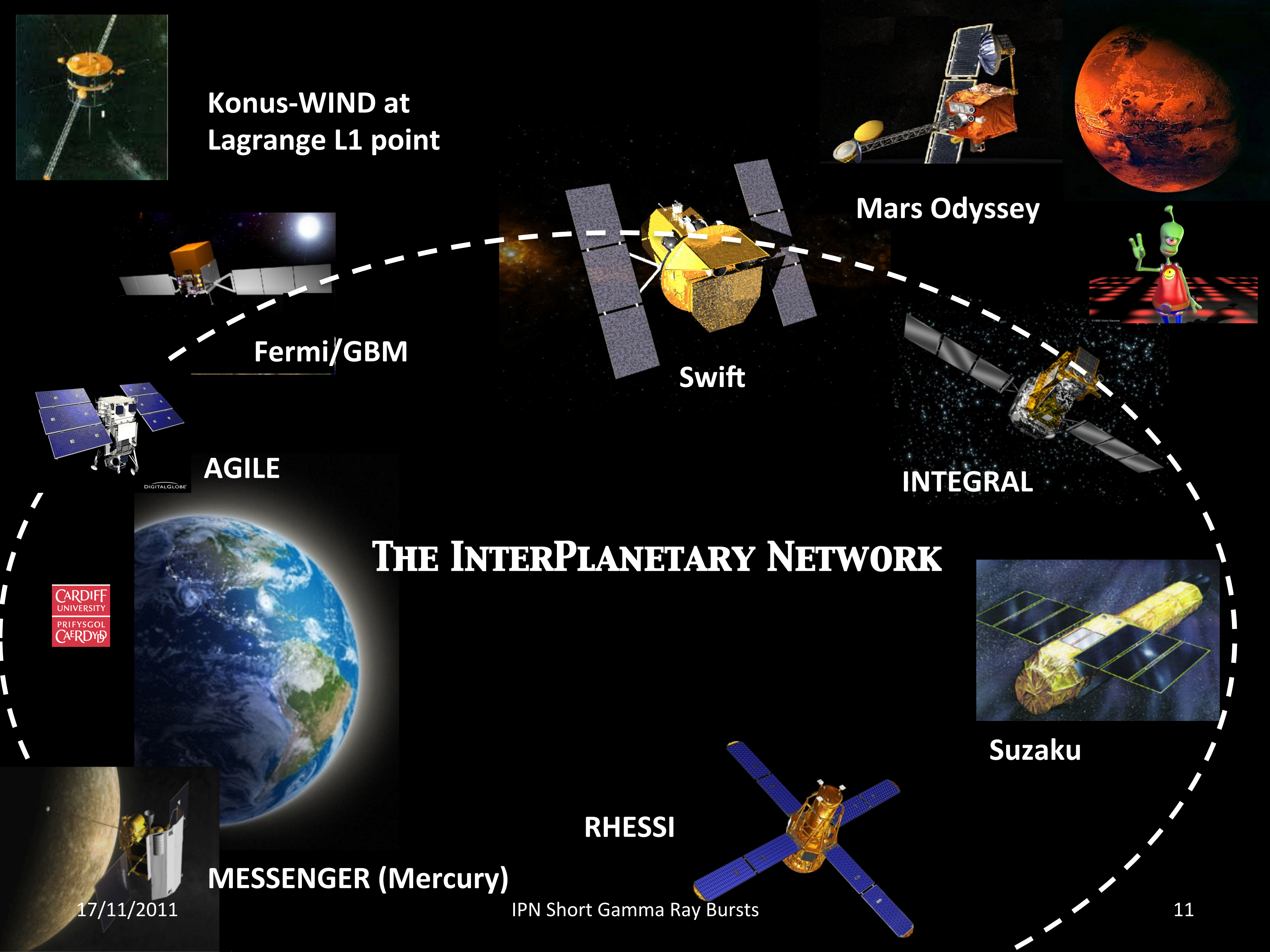
- ✓ The InterPlanetary Network – how it works;
- ✓ Getting the short IPN GRB sample;
- ✓ Future analysis challenges and solutions.

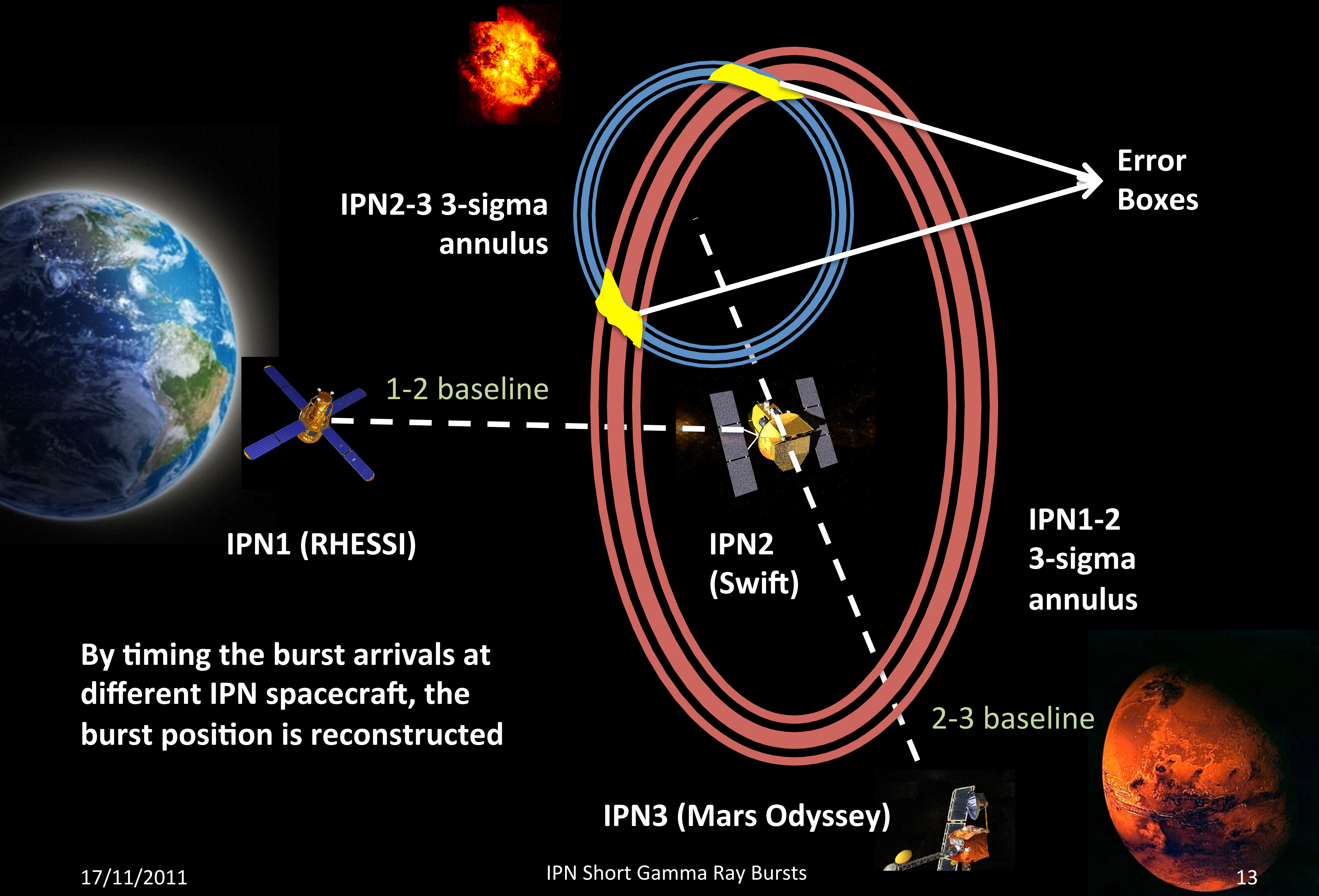
The InterPlanetary Network



The InterPlanetary Network (IPN)

- A group of spacecraft orbiting Earth, Mars and Mercury;
- Third and present generation (IPN3) started in 1990 with the launch of Ulysses;
- Present (main) configuration: Earth orbit (Swift, Fermi/GBM, Suzaku, INTEGRAL, RHESSI, AGILE), Mars orbit (Mars Odyssey), Mercury (MESSENGER), Lagrange L1 point (Konus-WIND); a few other missions contributed to IPN3 in the past but are now retired;
- Each spacecraft has, among other equipment, onboard gamma ray detectors; a few of the spacecraft (e.g. Swift and GBM) are dedicated gamma ray satellites;
- The IPN acts as an <u>all-sky all-time GRB monitor</u>;
- Unfortunately the IPN will suffer from retiring a few of its missions quite soon (e.g. Swift);

The IPN Localization of GRB: Triangulation



By timing the burst arrivals at different IPN spacecraft, the burst position is reconstructed

The IPN Localization of Gamma Ray Bursts

- Uses triangulation as its principle;

- Two independent IPN spacecraft triangulate the position of a GRB to a 3-sigma annulus; three independent spacecraft triangulate the position of a GRB to the intersection of two annuli; and so on…

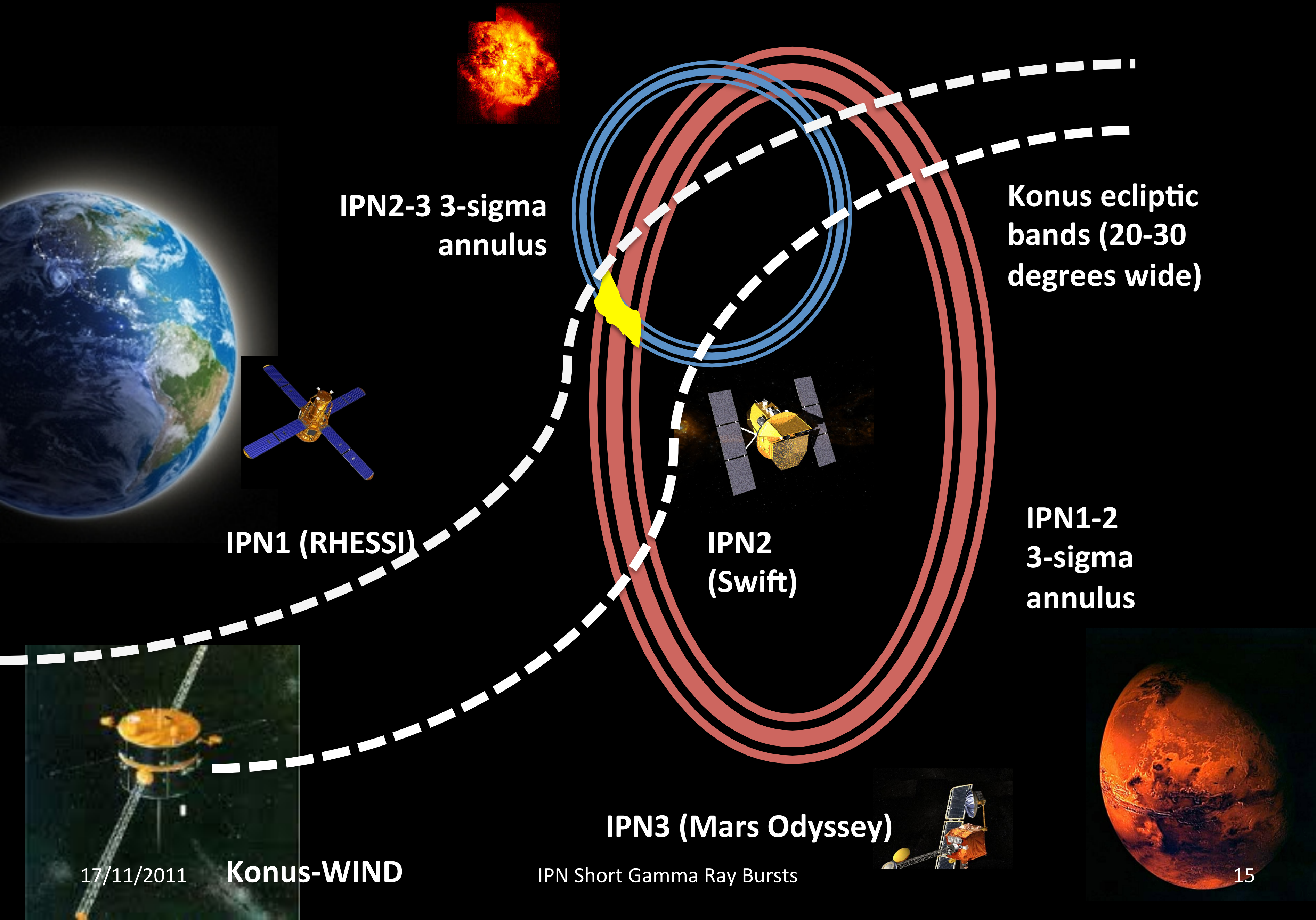
- The longer the separation between spacecraft (baseline) the thinner the annulus;

- The intersection regions of independent annuli form the GRB ERROR BOX regions (3-sigma) hence one wants further separated satellites for thinner annuli and smaller error boxes;

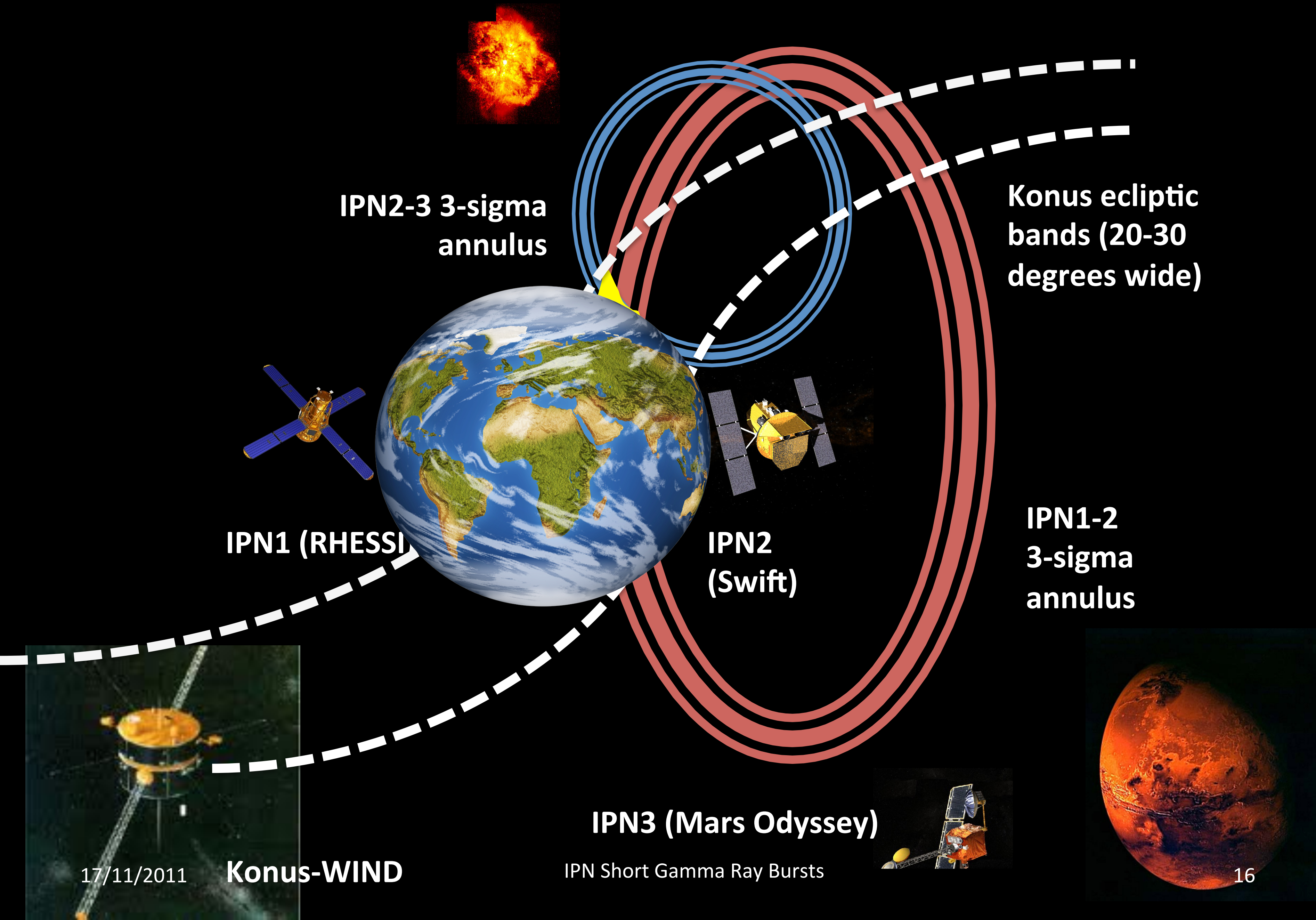
- Konus-WIND is sensitive to a band in the sky (has N-pole and S-pole detectors), this is called the Konus ecliptic band and if we use Konus as a localizing craft, we keep the error boxes within the ecliptic band only;

- The annuli are approximations of the localization regions only;

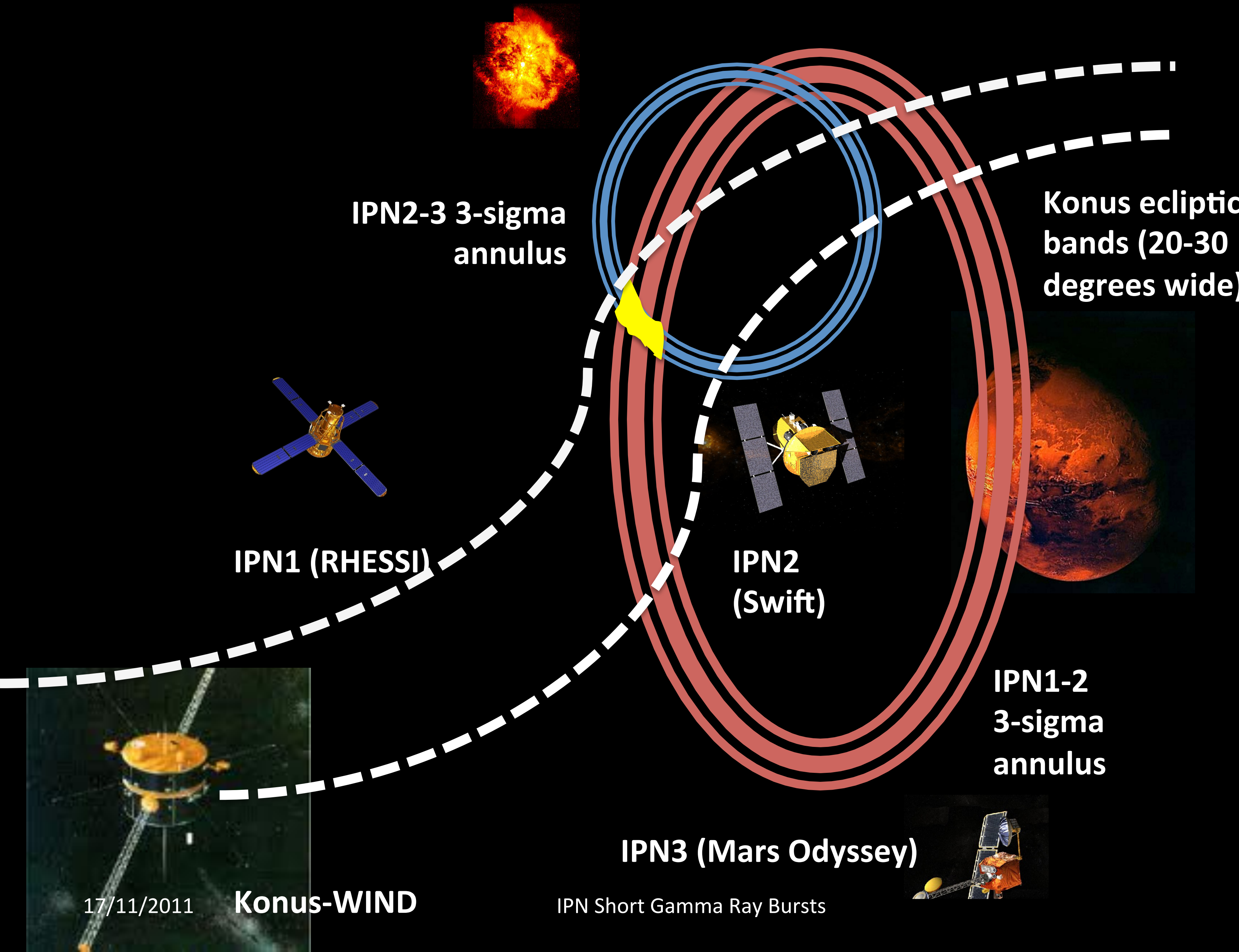
The IPN Localization of GRB: Konus Ecliptic Band



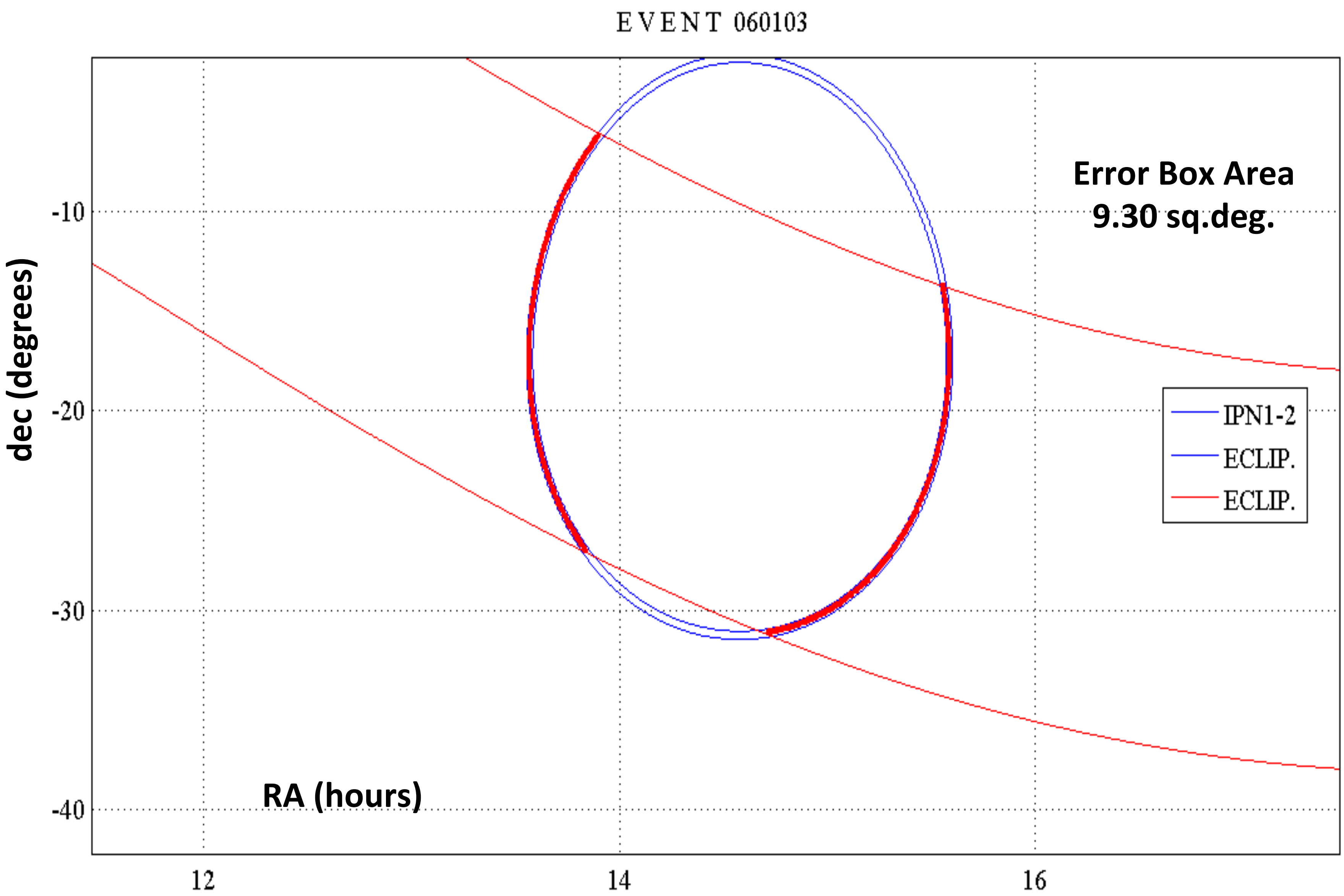
The IPN Localization of GRB: Earth Blocking



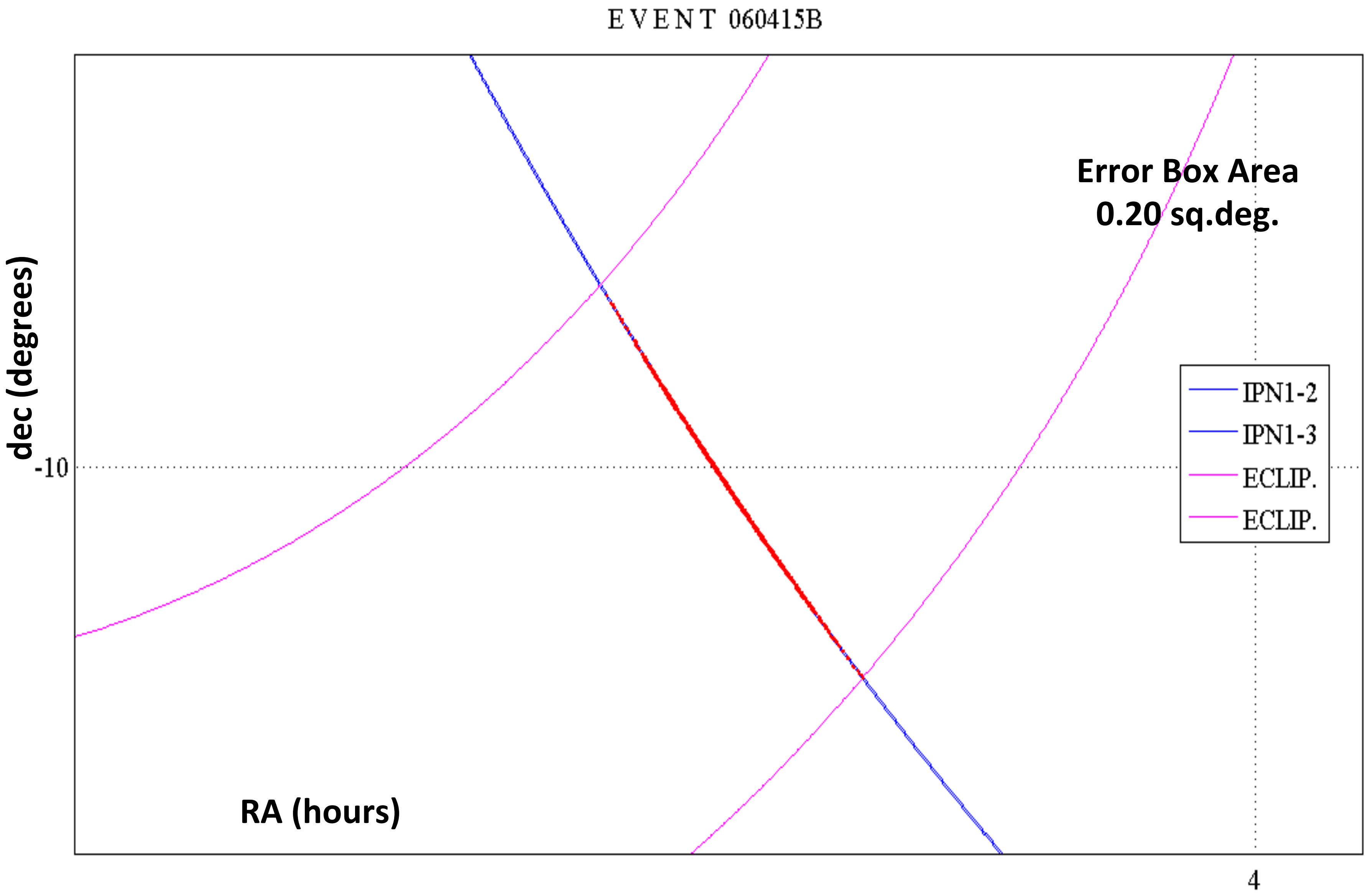
The IPN Localization of GRB: Mars Blocking



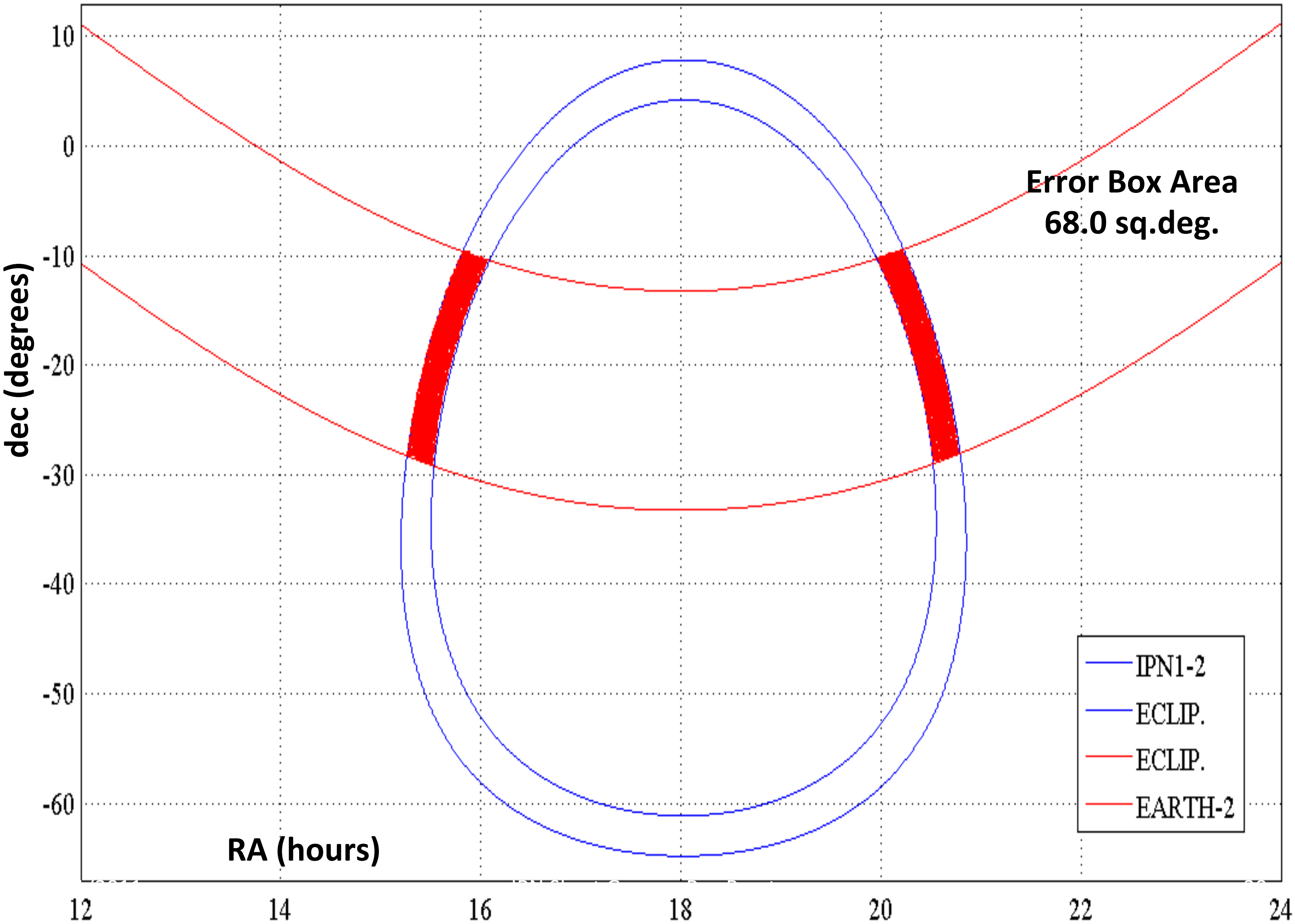
The IPN Localization of GRB: Error Boxes



The IPN Localization of GRB: Error Boxes



The IPN Localization of GRB: Error Boxes



The IPN Localization of GRB: Error Boxes

- ✓ **May be of different sizes (area) and shapes;**

- ✓ **Area may range from fractions of square degrees (usually localized by three or four satellites out of which one is Mars Odyssey or MESSENGER) to thousands of square degrees (usually localized by two nearby satellites only);**

- ✓ **Shapes may be odd or regular, a lot of them are narrow and long regions;**

- ✓ **Shapes are just an approximation of the true contours but it works to 3-sigma precision;**

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The Selection Process

- 302 IPN-localized GRBs during S5/VSR1;
- Three main criteria for choosing the GRB analysis sample:

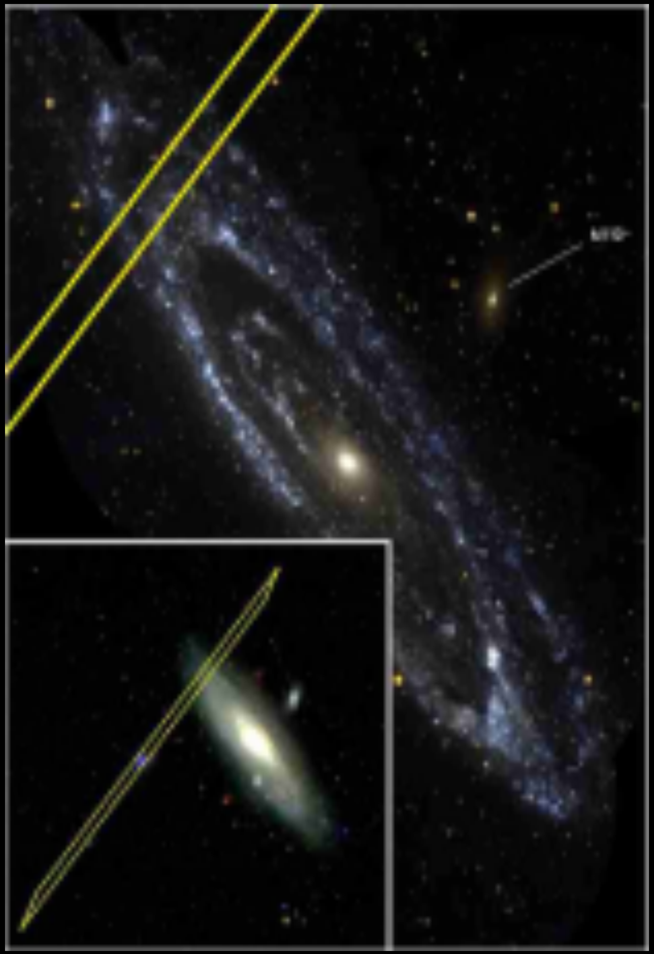
1. They need to be SHORT and not have been analyzed and published before;
2. They need to have decent localization;
3. They need to have available GW data;

EXTRA: The H1H2-only Short Burst Case

1. New SHORT IPN Gamma Ray Bursts

- ✓ **302 IPN-localized GRBs during S5/VSR1;**
- ✓ **29 out of 302 GRBs are confirmed SHORT;**
- ✓ **3 of them have already been analyzed and published, the most notable is GRB070201, its error box overlapped Andromeda M31 at ~4 Mpc:**

  a. The first published in-depth GW analysis of a gamma ray burst;
  b. It was an IPN-localized gamma ray burst.



Ref.: Abbott, B. et. al. Implications for the Origin of GRB 070201 from LIGO Observations, The Astrophysical Journal, No. 681, pp. 1419-1428, 2007.

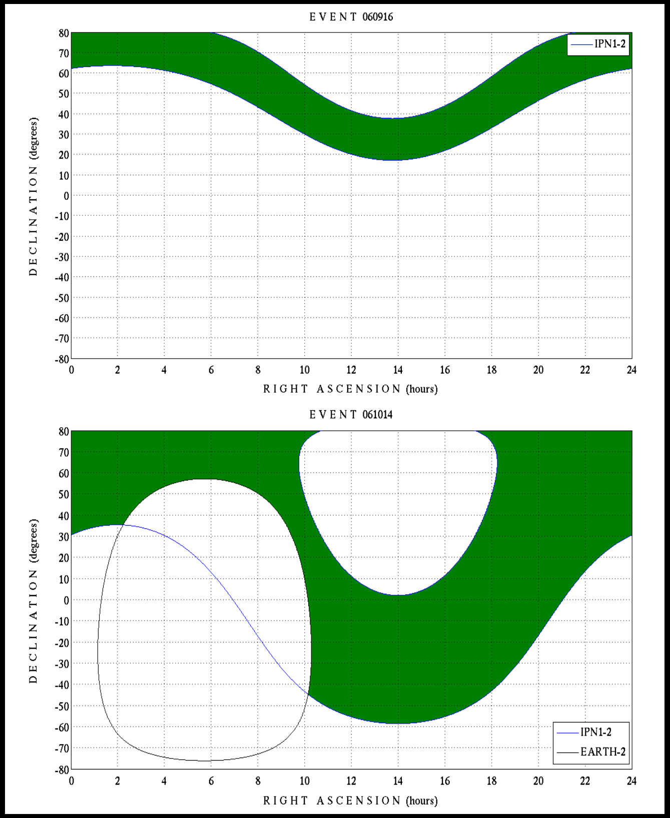
26 short GRB possibly fit for analysis

2. Decently Localized GRB - why?

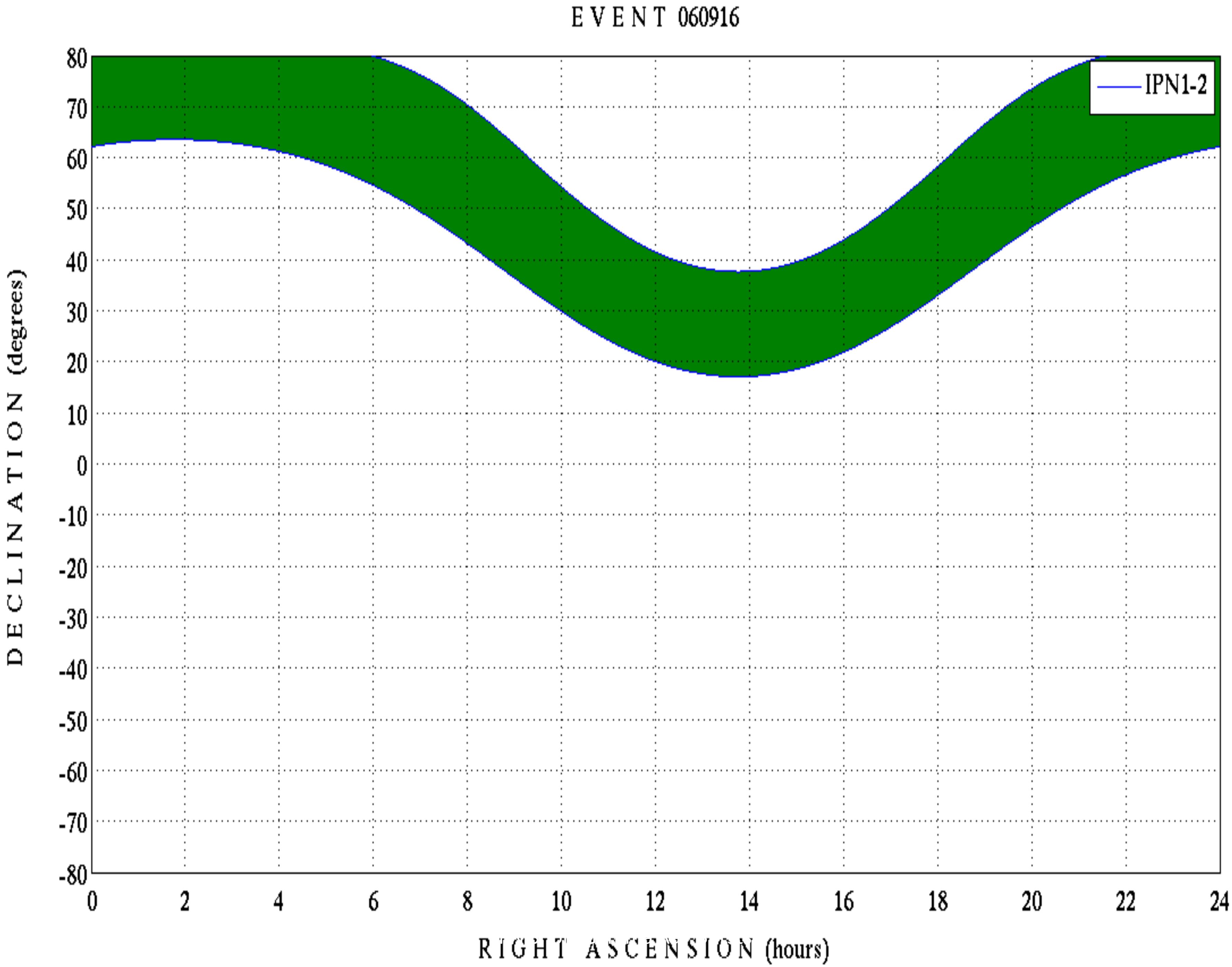
- We are currently doing GW searches over extended GRB error boxes during S6/VSR23 for Fermi/GBM-localized bursts;
- We will do a GW search over each of the IPN GRB error boxes;
- The larger the area of the box the more computationally costly and the less sensitive the search;
- There is no fixed threshold for the size of the error box but a ballpark value of 100 square degrees is chosen;
- This will allow a good balance between sensitivity gain and computational cost (based on the S6/VSR23 Fermi GRB search that we are still performing).

2. Decently Localized GRB

- 302 IPN-localized GRBs during S5/VSR1;
- 29 out of 302 GRBs are confirmed SHORT;
- 3 of them have already been analyzed and published;
- 9 of them have large error boxes (>100 square degrees);
- Despite this, we will still look at the all-time all-sky S5/VSR1 archival data around the times of these GRB…but no analysis for now.



17 short GRB possibly fit for analysis


E V E N T 060916
IPN1-2
D E C L I N A T I O N (degrees)
R I G H T A S C E N S I O N (hours)
80
70
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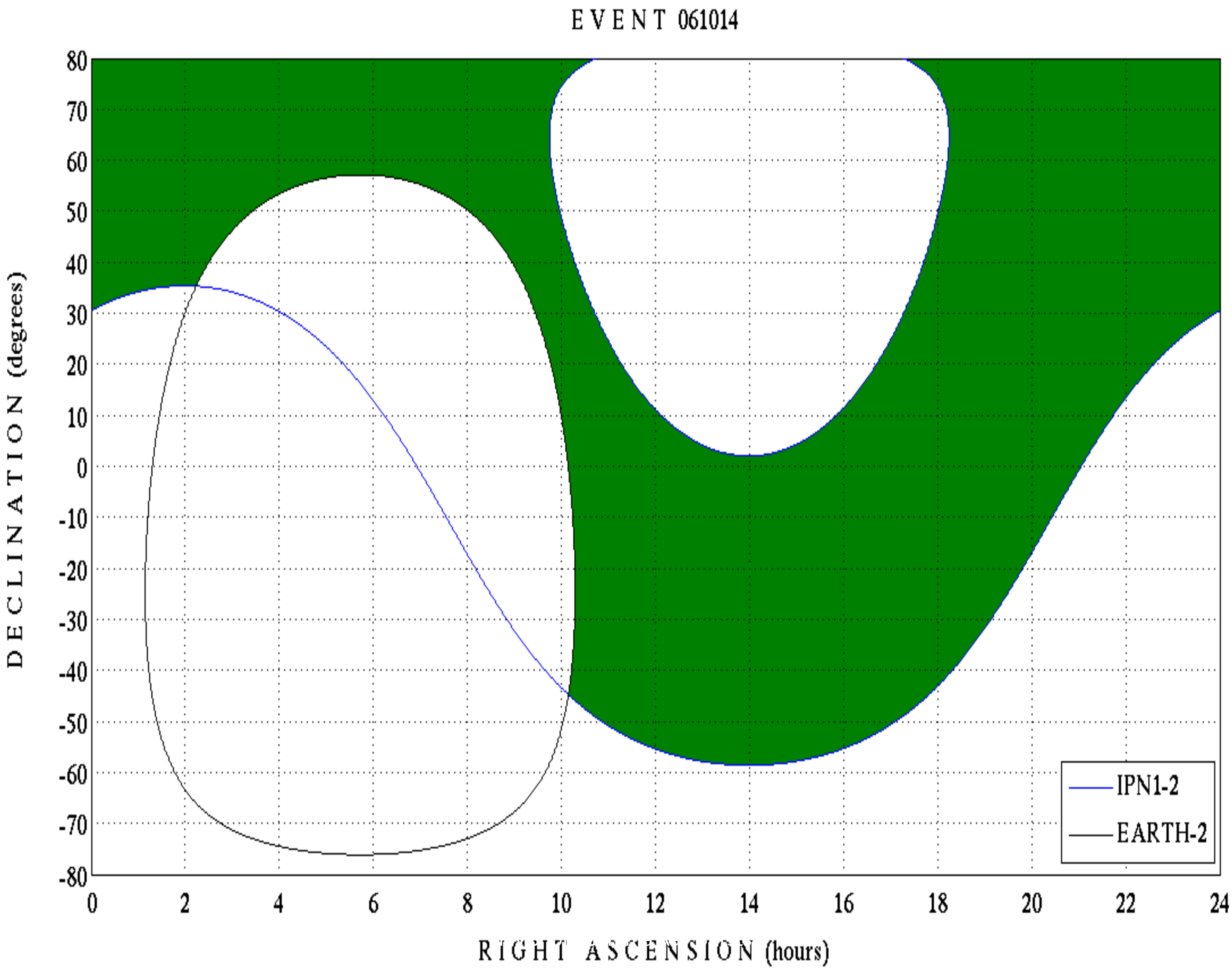
EVENT 061014
DECLINATION (degrees)
RIGHT ASCENSION (hours)
IPN1-2
EARTH-2
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-50
-60
-70
-80
0
2
4
6
8
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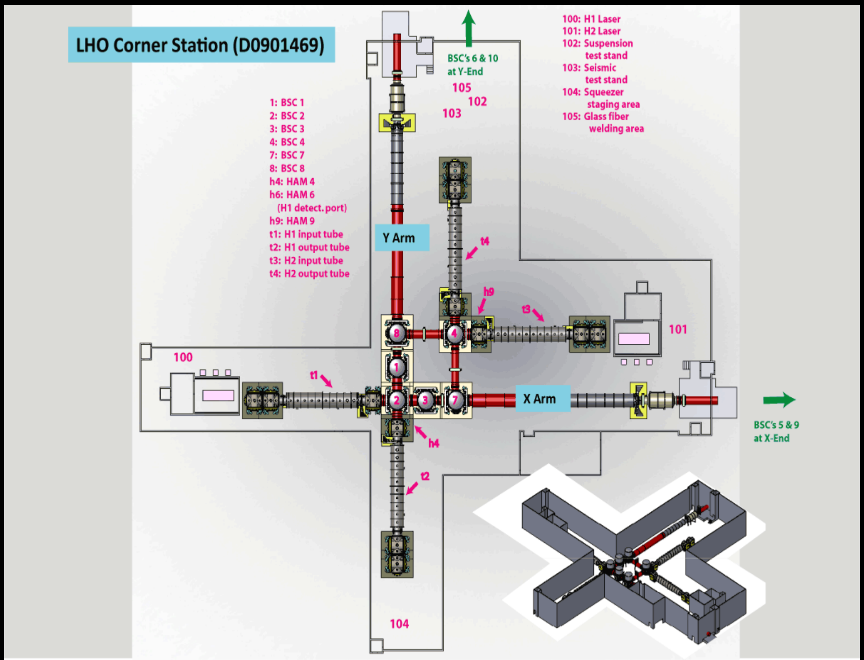
3. GW DATA AVAILABILITY

- 302 IPN-localized GRBs during S5/VSR1;
- 29 out of 302 GRBs are confirmed SHORT;
- 3 of them have already been analyzed and published;
- 9 of them have large error boxes (>100 square degrees);
- **17 SHORT GRB with DECENT LOCALIZATION have available GW data**;

17 SHORT GRB POSSIBLY FIT FOR ANALYSIS

EXTRA. H1H2-ONLY GRBS

- ✓ LIGO Hanford H1 (4km) and LIGO Hanford H2 (km) are co-located and co-aligned;
- ✓ A H1H2-only analysis would not have any sky location sensitivity;
- ✓ A H1H2-only analysis does not need a small error box;
- ✓ Take the short H1H2-only GRBs and analyze them no matter how large their error box;
- ✓ A FIRST for such an analysis; all-sky all-time S5/VSR1 looked at this data but with no means of background estimation, just the few loudest events were investigated.



EXTRA. H1H2-ONLY GRBs

- 302 IPN-localized GRBs during S5/VSR1;
- 29 out of 302 GRBs are confirmed SHORT;
- 3 of them have already been analyzed and published;
- 9 of them have large error boxes (>100 square degrees);
- 17 SHORT GRB with DECENT LOCALIZATION have available GW data;
- +3 extra H1H2-only poorly localized short GRBs.

20 SHORT GRB FIT FOR ANALYSIS

1. Short IPN GRBs with $\Delta A < 100$ deg^2 and data from two or more GW detector sites that will be analysed

GRB	IPN	GW	GRB Date	T_{90}(s)	ΔA(deg^2)	Δt(s)
060103	MO/I	H1H2L1	Jan 03 2006 08:42:17	2.00	9.30	<1
060107	K/MO/S	H1H2L1	Jan 07 2006 01:54:40	3.00	8.20	1.0
060203	K/MO/H	H1H2L1	Feb 03 2006 07:28:58	0.40	0.80	<1
060415B	K/MO/S	H1H2L1	Apr 15 2006 18:14:44	0.44	0.20	<1
060522C	S/K/MO	H1H2L1	May 22 2006 10:10:19	1.10	0.40	<1
060708B	H/K/MO	H1H2L1	Jul 08 2006 04:30:38	1.00	0.06	<1
060930A	K/MO	H1H2L1	Sept 30 2006 02:30:11	1.00	2.40	4.5
061006A	K/MO/S	H1H2L1	Oct 06 2006 08:43:38	1.60	3.20	1.0
070321	I/K/MO/S	H1H2L1	Mar 21 2007 18:52:15	0.34	0.40	<1
070414	S/M	H1H2L1	Apr 14 2007 17:19:52	0.38	0.30	<1
070516	I/K/M/S	H1H2L1	May 16 2007 20:41:24	1.00	7.68	1.0
070614	K/H	H1H2L1V1	Jun 14 2007 05:05:09	0.40	∼68	<1
070915	Sw/I/M/K	H1H2L1V1	Sept 15 2007 08:34:48	0.50	0.10	<1
070927A	Sw/M/I	L1V1	Sept 27 2007 16:27:55	0.70	1.60	<1

2. Short IPN GRBs with data from H1H2-only that will be analysed

GRB	IPN	GW	GRB Date	T_{90}(s)	ΔA(deg^2)	Δt(s)
060317	K/S/I	H1H2	Mar 17 2006 11:17:39	0.70	9.24	<1
060601B	I/S	H1H2	Jun 01 2006 07:55:41	0.50	∼600	<1
061001	I/Sw	H1H2	Oct 01 2006 21:14:28	1.00	∼2000	<1
070129B	S/K	H1H2	Jan 29 2007 22:09:26	0.22	47.50	<1
070222	K/MO	H1H2	Feb 22 2007 07:31:55	1.00	0.45	5.0
070413	I/S	H1H2	Apr 13 2007 20:37:55	0.19	∼350	<1

3. Short IPN GRBs with $\Delta A > 100$ deg^2 and data from two or more GW detector sites for archival data look-up only

GRB	IPN	GW	GRB Date	T_{90}(s)	ΔA(deg^2)	Δt(s)
060916	S/I	H1H2L1	Sept 16 2006 14:33:34	0.13	>3000	<1
061014	I/H	H1L1	Oct 14 2006 06:17:02	1.5	>3000	<1
061111B	K/Sw	H1H2L1	Nov 11 2006 10:54:27	0.6	~700	<1
070203	I/S	H1H2L1	Feb 03 2007 23:06:44	0.69	>2000	<1
070721C	K/I	H1H2V1	Jul 21 2007 14:24:09	1.00	495	<1
070910	K/S	H1H2L1V1	Sept 10 2007 17:33:29	0.38	>200	<1

4. Short IPN GRBs that have already been analysed and published

GRB	IPN	Reference
060427	K/MO/I/Sw	[6, 7]
060429A	S/K/MO	[6, 7]
070201	K/M/I	[35]

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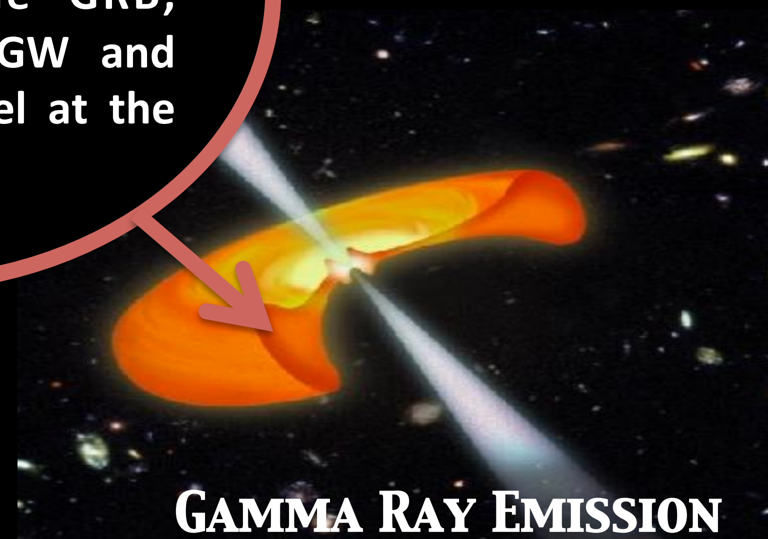
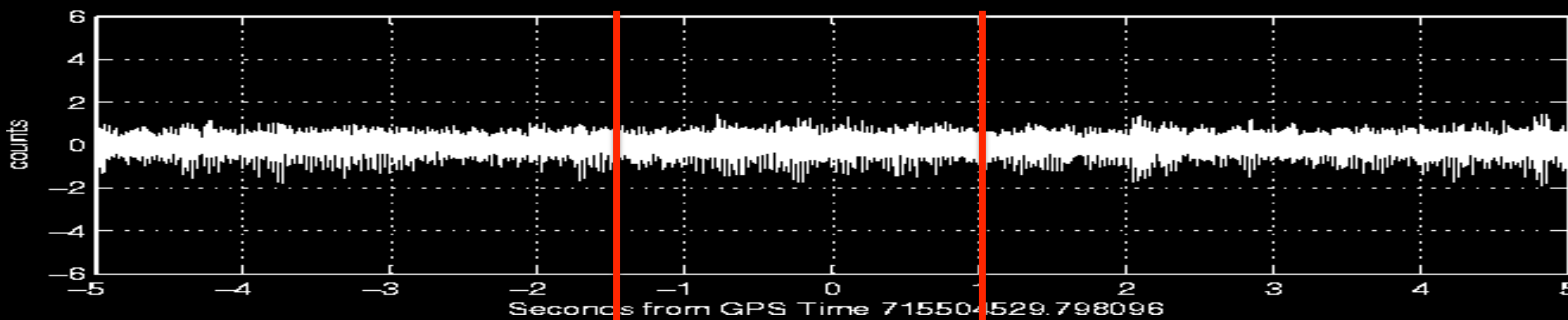


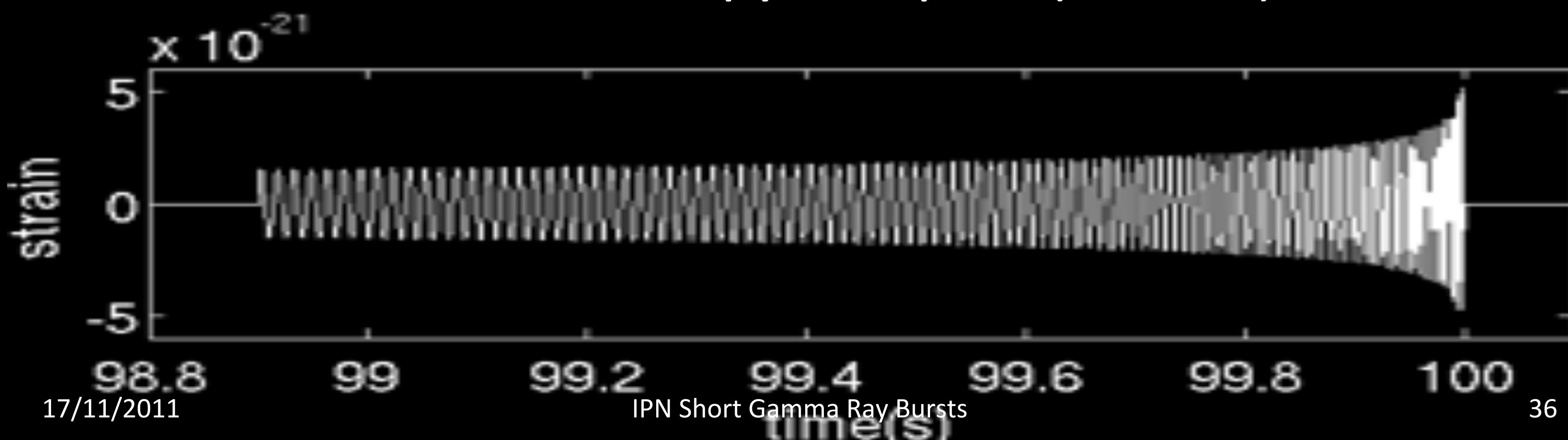
The Search - Match Filtering - Data and Templates



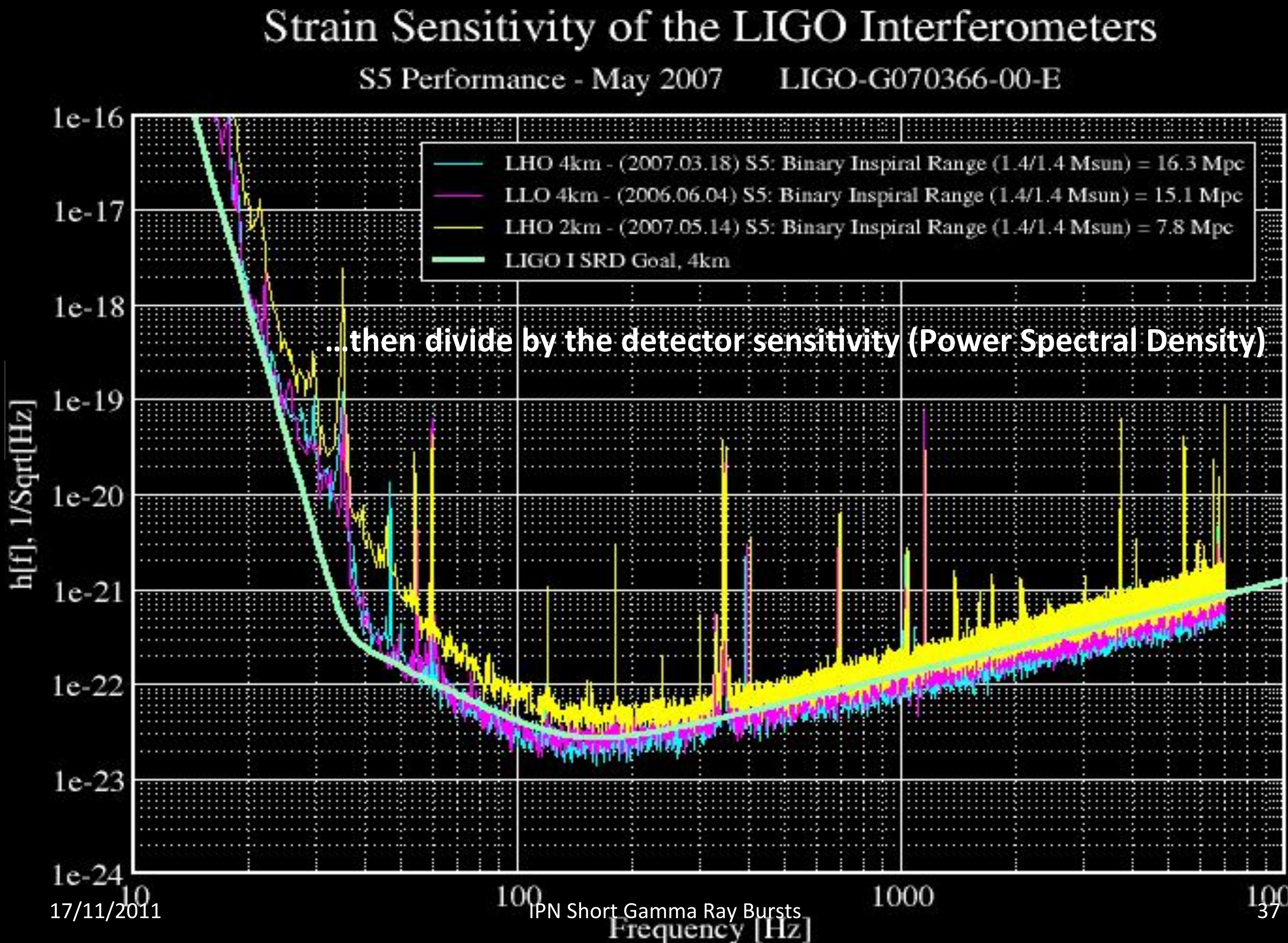
Background (~1000s) | Foreground (6s) | Background (~1000s)

5s **GRB** 1s

Take raw detector data and multiply with expected (theoretical) waveform…

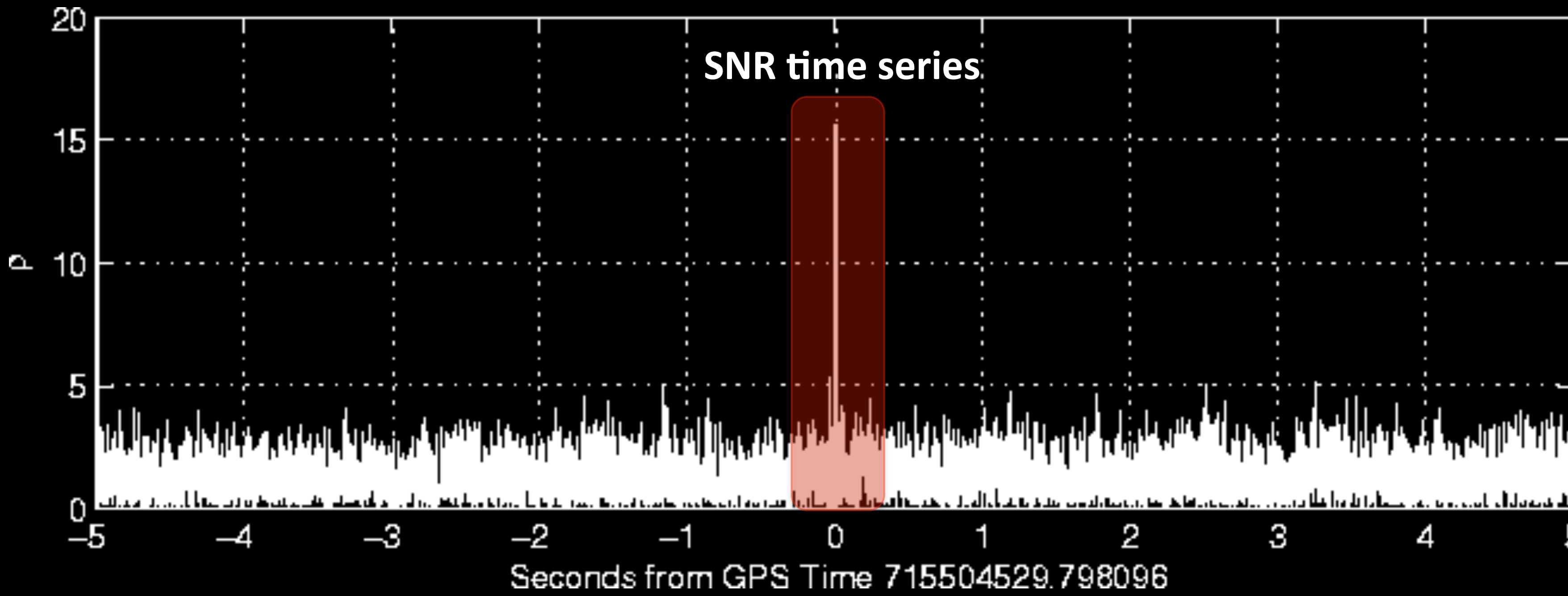


The Search - Match Filtering - Detector Sensitivity



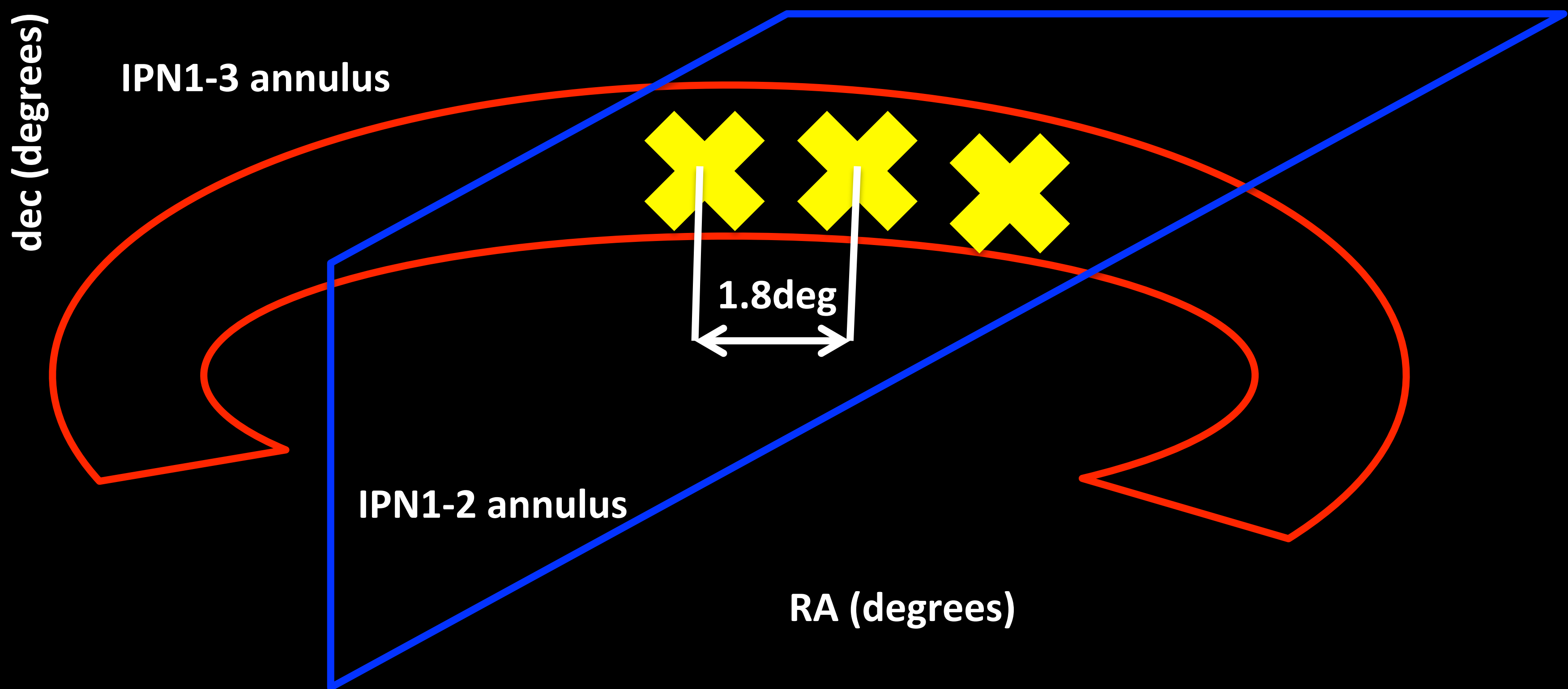
…then divide by the detector sensitivity (Power Spectral Density)

The Search - Match Filtering - SNR

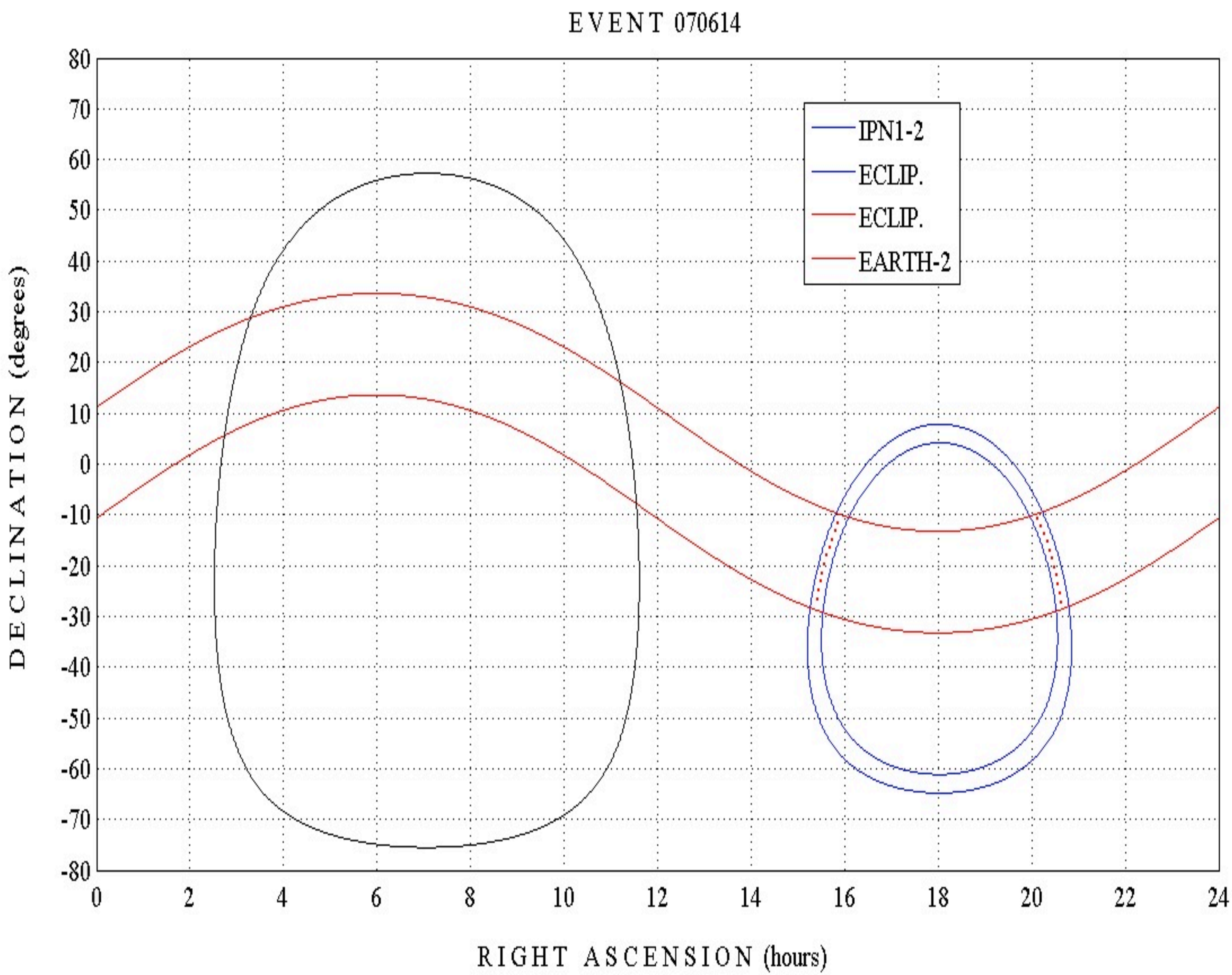


- ✓ **High Signal-to-Noise Ratio is a sign of a GW signal (in an ideal world);**
- ✓ **Coherently combine SNRs from different detectors to get coherent SNR and null streams;**
- ✓ **Apply consistency tests to eliminate glitches since the noise is not stationery.**

The Search - Search Points in the Error Box



- ✓ We pave the error box with SEARCH POINTS equally spaced by 1.8 degrees;
- ✓ The separation between points corresponds to a minimal light travel time difference between the detector sites (roughly 0.5ms);
- ✓ This ensures a thorough search for signals across the whole error box.


EVENT 070614
IPN1-2
ECLIP.
ECLIP.
EARTH-2
DECLINATION (degrees)
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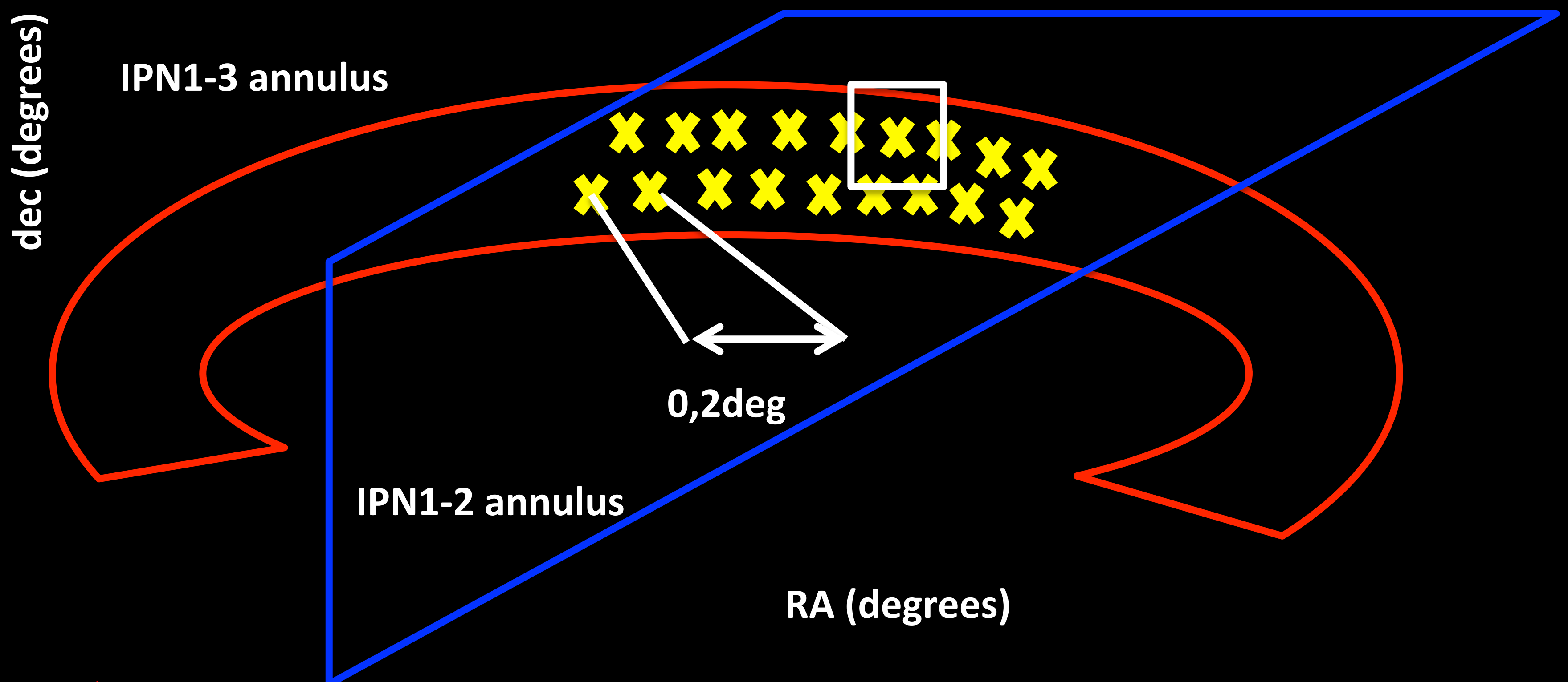
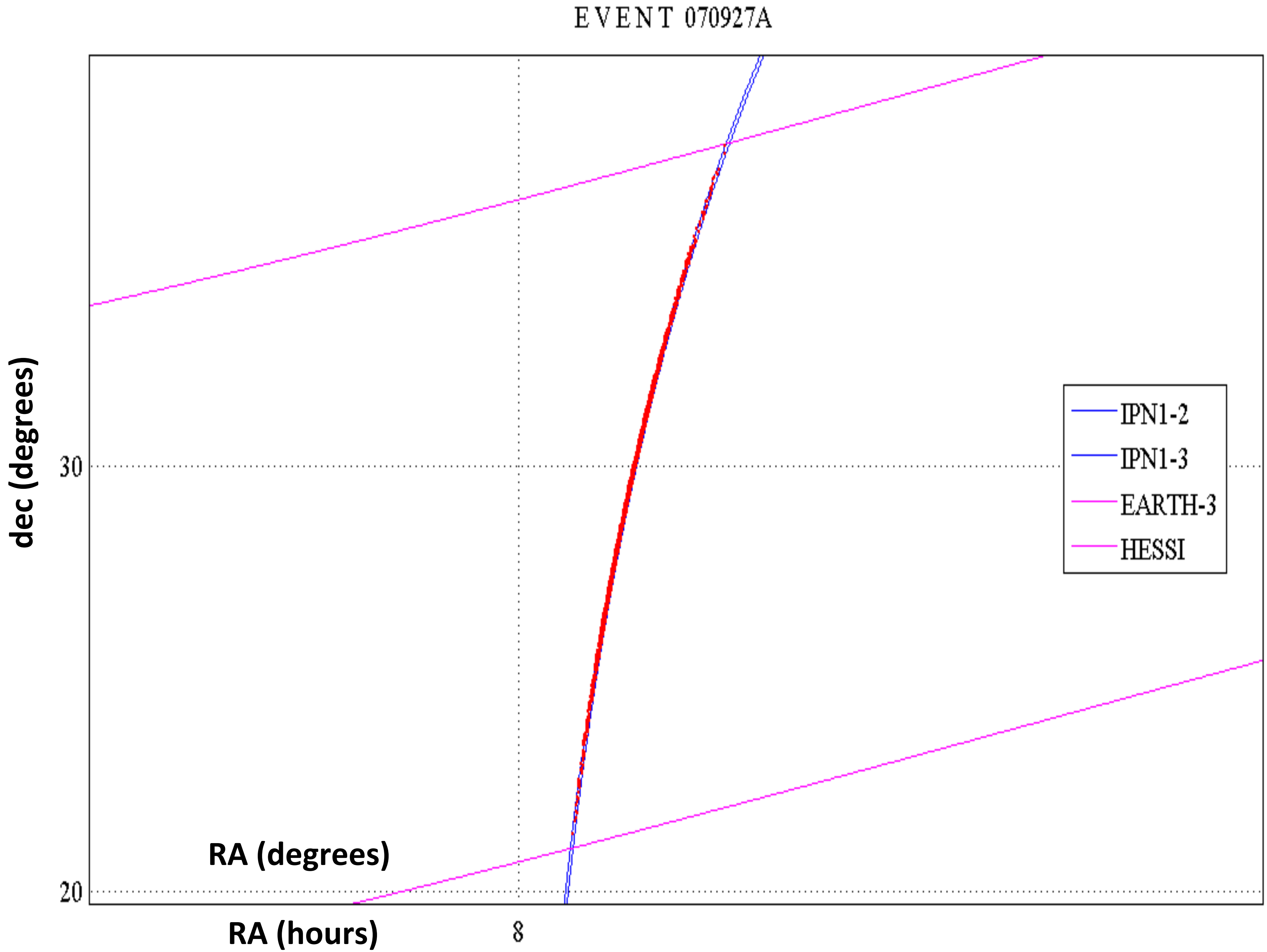
The Search - Simulation Points in the Error Box



- ✓ We pave the error box with denser points equally spaced by 0.2 degrees;
- ✓ We then take a square box centered at each point and throw random SIMULATION POINTS in it;
- ✓ Weighing is done according to a 1-dim Gaussian (one IPN annulus) or 2-dim Gaussian (2 IPN annuli) – more injection points near the 1-sigma radius and less towards 2 and 3-sigma radii.


EVENT 070927A
dec (degrees)
30
20
RA (degrees)
RA (hours)
8
IPN1-2
IPN1-3
EARTH-3
HESSI

Conclusions and Perspectives

- The data analysis will begin very soon (in a week or so..);
- We already have experience running on an S6/VSR23 Fermi+IPN GRB (GRB090802);
- We might be able to have an all-sky coherent search and be able to analyze the short bursts with poor localization (Dunk MacLeod and Ian Harry working on it);
- We are expecting results by next March!
- Thank you for all the work Steve, Duncan and Ian!
- Check the paper that will be on arXiv next week..


THANK YOU!
JIBJAB