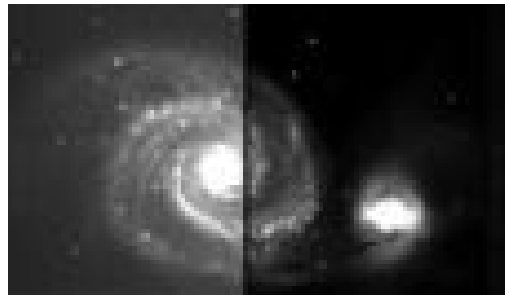
Locating and Observing Optical Counterparts to Unmodeled Pulses in Gravitational Waves



Jonah Kanner, Peter Shawhan, Tracy Huard — Univ. of Maryland
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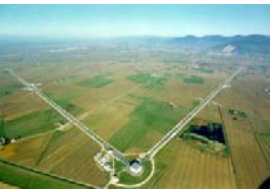
David Murphy — Carnegie Observatories

GW + EM

LOOC UP

What is LOOC UP?



- 1) Analyze GW data in near real-time to seek 3 site coincident “event candidates” (H-L-V)

- 2) Estimate the source location of “candidates”
  - Timing information yields a “triangulation” solution
  - So-called “coherent methods” may do a more careful job

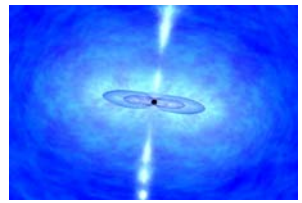
- 3) Image the source location with an optical radio, and/or x-ray telescope
  - A GW producing astrophysical event could produce an EM transient, thus **confirming the event** and **gaining extra astronomical information**

Motivation: Why should we actively seek optical counterparts in this novel and exciting manner?

- Increased GW sensitivity
  - Low-threshold search
- Even at high SNR, would like to confirm first GW detection in independent channel
- More information => better physics
- Prepare for Advanced LIGO era
- Important step toward integrating GW astronomy into greater astronomical community
    - Education/Research opportunity at forefront of GW and EM astronomy

Sample Source Models

- Nuclear fireball of Li and Paczynski
  - Simplified theoretical model
  - NS matter ejected during merger decays
  - Tau ~ 1 day, R ~ 13 at 20 Mpc



- Optical afterglow of short GRB's
  - Empirical
  - Beaming means we may not see gammas
  - Tau ~ 1 hour, bright at 20 Mpc

- Supernovas
  - Tau ~1 week, R~14 at 20 Mpc

Potential Problems: Time and Space

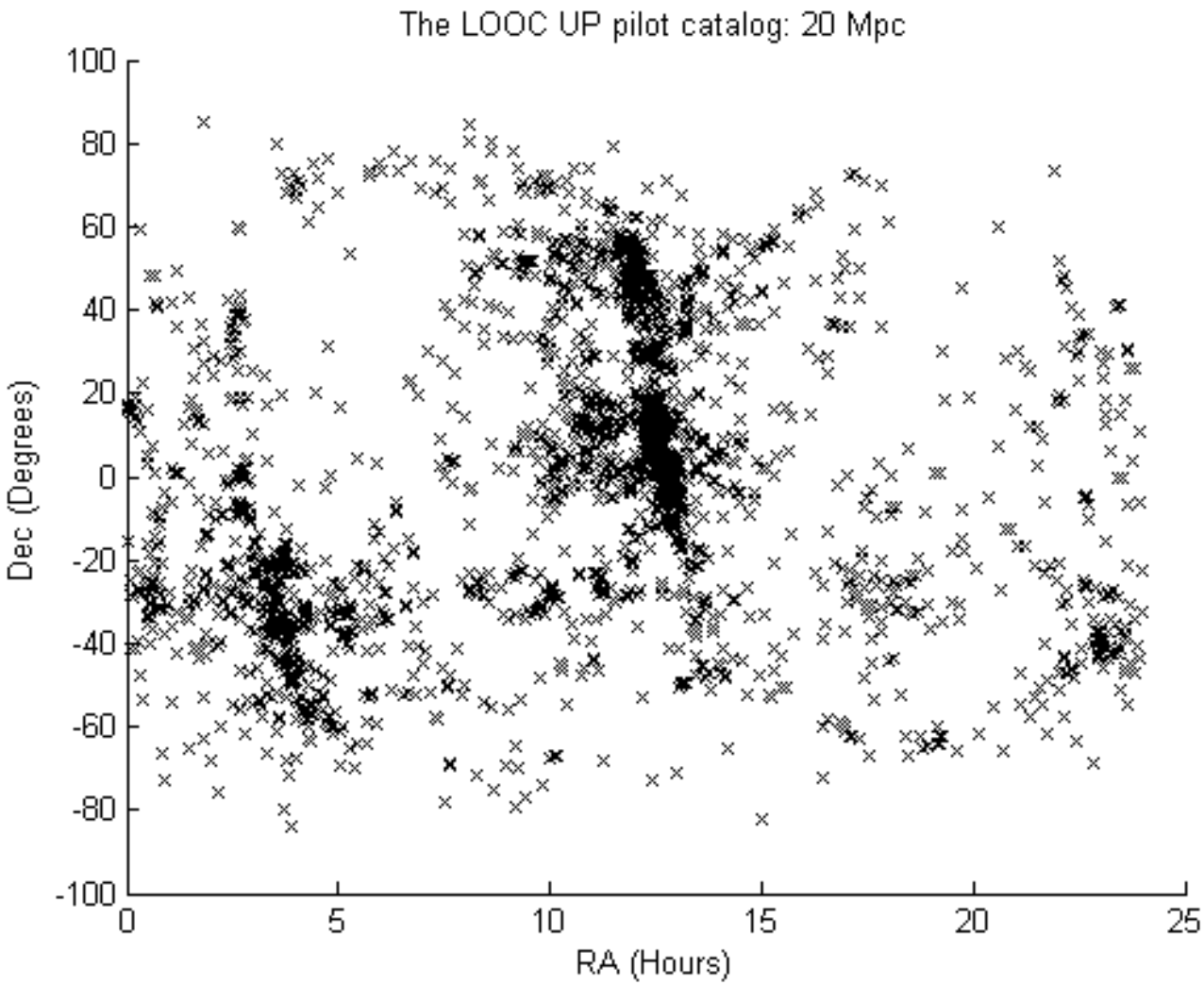
- Space: GW Source reconstruction is hard, and has an “error box” larger than the field of view of most optical telescopes!
    - GW “error box” is a few square degrees at best
- Time: It takes time to analyze gravitational wave data - can it really be done in about an hour?

Solutions: Space

We can take advantage of LIGO's limited range.

For example,
for NS-NS mergers:
S5/VSR1 ~15 Mpc
S6/VSR2 ~30 Mpc

Assemble a catalog* of potential host locations within the target range of our search



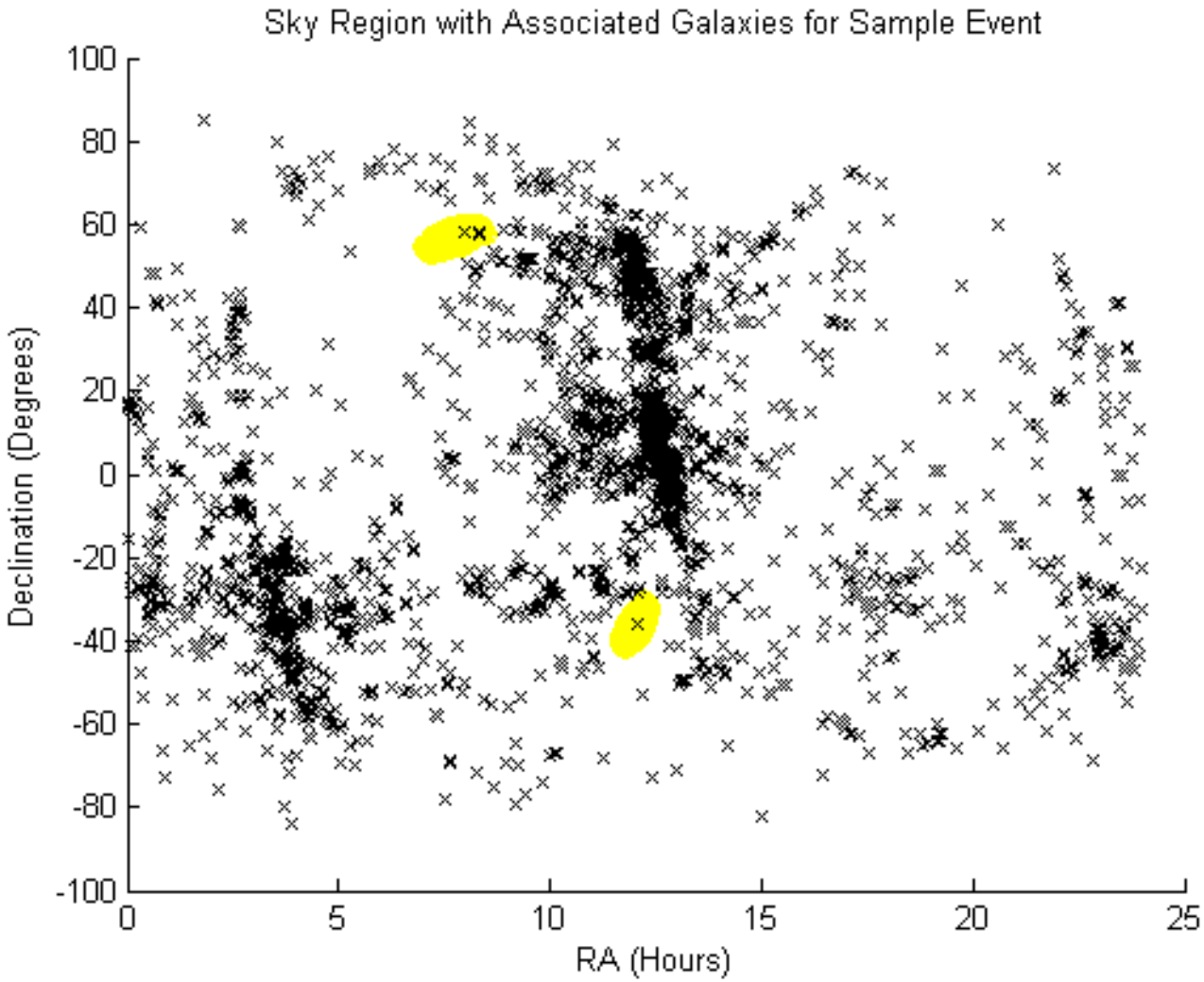
*Thank you CBC group!

Solutions: Space

We can take advantage of LIGO's limited range.

For each candidate event, we seek nearby galaxies within the error box of the estimated source location.

These galaxies are then imaged for transients.

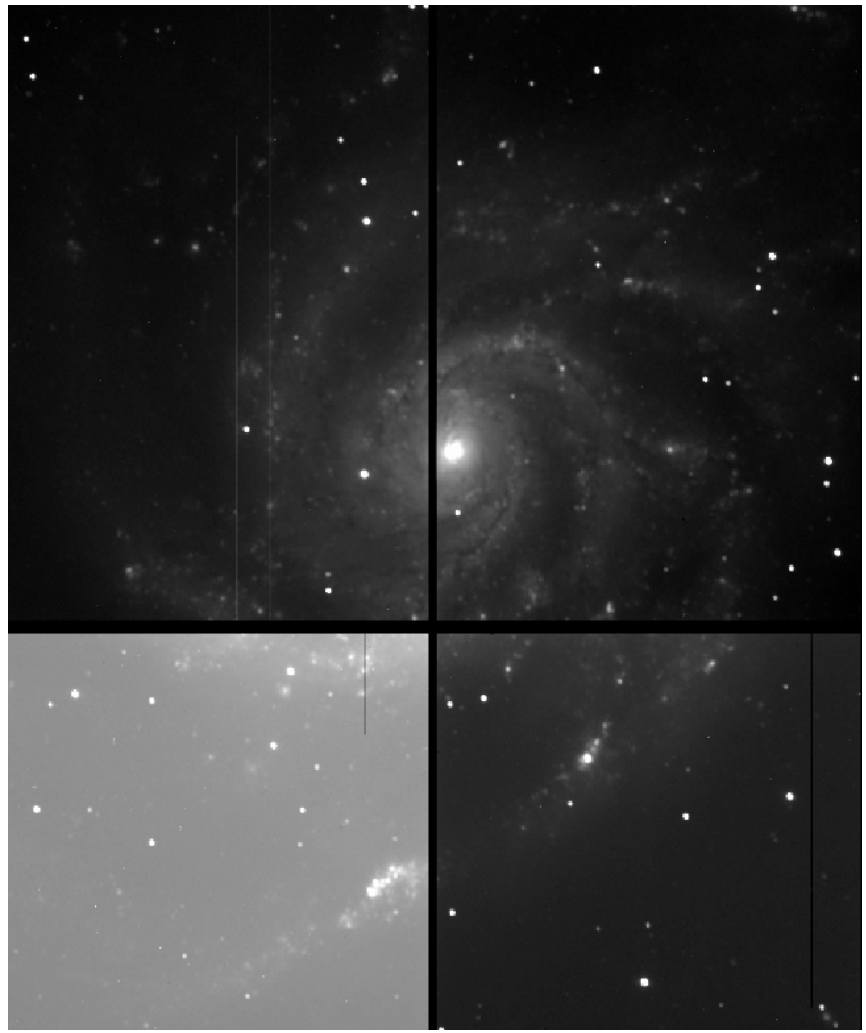


Solutions: Time

- By the end of S5, Q-Online was creating near real-time triggers for the H-L-V network.
  - Typical time lags of 2 to 4 hours
- In pilot studies, our software was able to download lists of Q-triggers, find coincident events, and identify target galaxies in short time scales (10 – 20 minutes).
- While our pilot approach used “timing only” source reconstruction, “coherent methods” are possible as well
  - For example, X-Pipeline currently takes 1 to 3 hours for one event
- All of these algorithms likely have room for optimization: *we have a goal of ~1 hour from IFO event to first EM observation*

Open Issues: Image Processing

- Need to define a data pipeline to reduce images and identify transients. Issues Include:
  - Do we use pre-existing star catalogs or take our own reference images?
  - How dim a transient can we resolve against a galactic background?
  - How much variability do we expect from “normal” stars (or, how high a threshold do we set for variability?)
  - How do we identify known variable objects (Cepheid variables, eclipsing binaries, etc.)



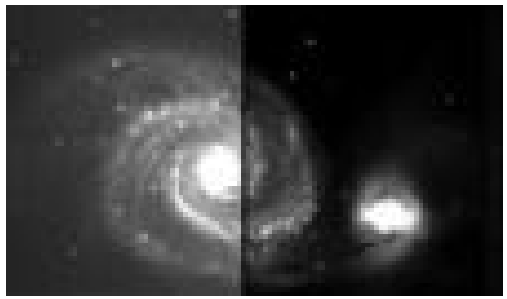
Open Issues: Observational Resources

- We need to identify the observational resources to use for this search.
  - Small robotic telescopes
  - ~2 m telescopes
  - Radio telescopes such as LOFAR
  - Public Alerts, such as VoEvent
  - ToO (SWIFT, etc.)
- Appropriate resources are likely “era dependant”

Proposal: LOOC UP in S6

- Expected NS-NS inspiral range ~30 Mpc. This suggests:
  - About 1 target galaxy per square degree
  - Could meet demands of source models with modest equipment (R ~ 15)
  - With effort, software can be ready by 2009 start date
  - Basic technique has been demonstrated in pilot studies
  - *With a dedicated or semi-dedicated network of robotic telescopes, we could perform a GW search with FAR of a few per day instead of a few per year*
- The S6 run is a crucial opportunity to develop real-time techniques for the Adv. LIGO era, when detection-based GW astronomy will be a reality

LOOC UP



Thank you

Extra Slides

GW triggers in S6/VSR2 ???

Waiting 2 days to image short GRB afterglows allows dimming of perhaps 30x (~ 3 magnitudes) and may miss interesting physics

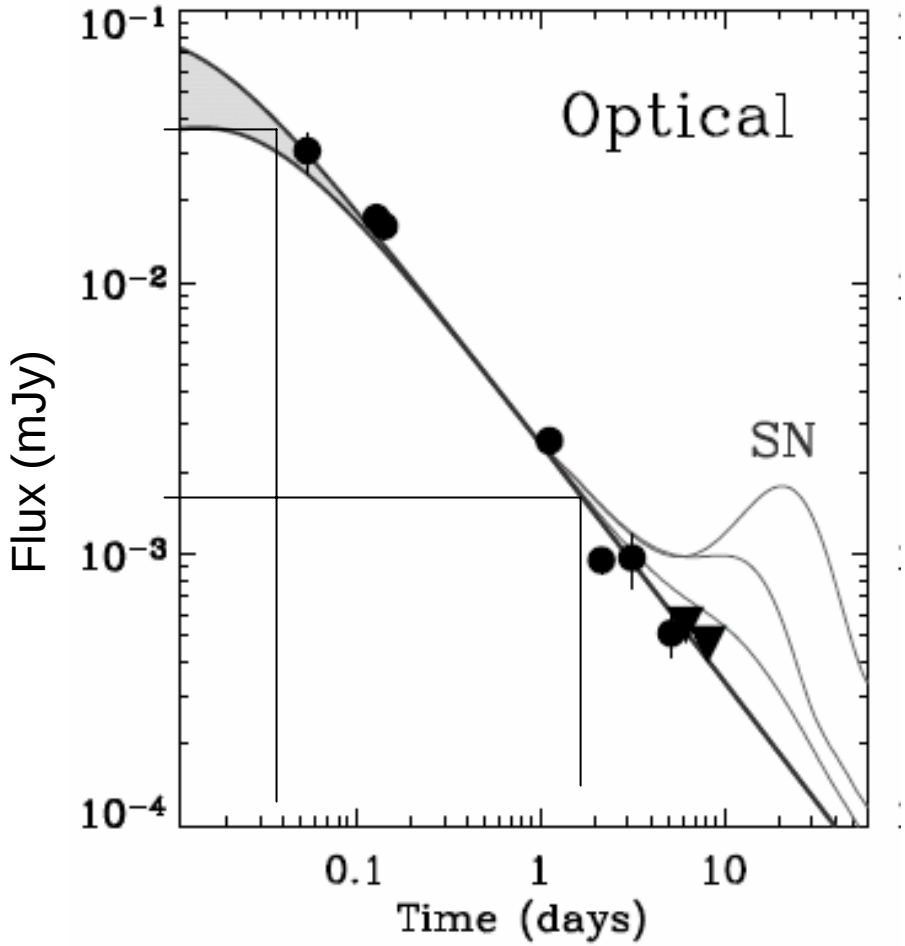
Should we wait that long?

-Could 2009 transient surveys devote a fraction of time to IFO triggers? (a few targets per night?)

-GW triggered searches with "off-the-shelf" telescopes *compliments* all sky surveys *(targeted search* vs. *all-sky scan)*

-Radio band an interesting option as well

Edo Berger

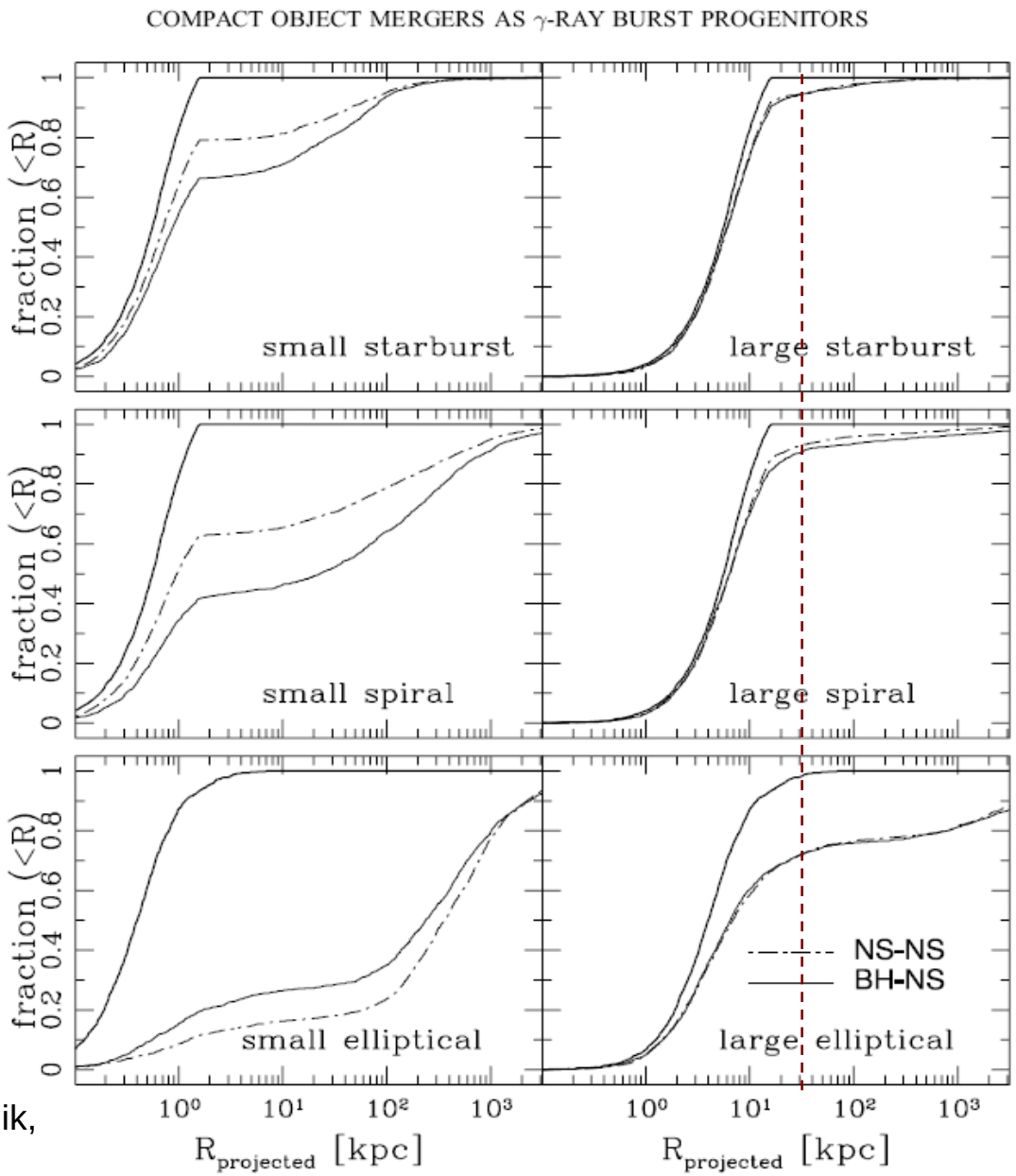


Short GRB051221 - Afterglow

Solutions: Space

Visible matter of the universe is concentrated in galaxies: We don't have to scan the whole GW error box, but only image the galaxies within it.

Here, we see that most compact object mergers, at 10 Mpc, should occur within ~10 arc min of their hosts.



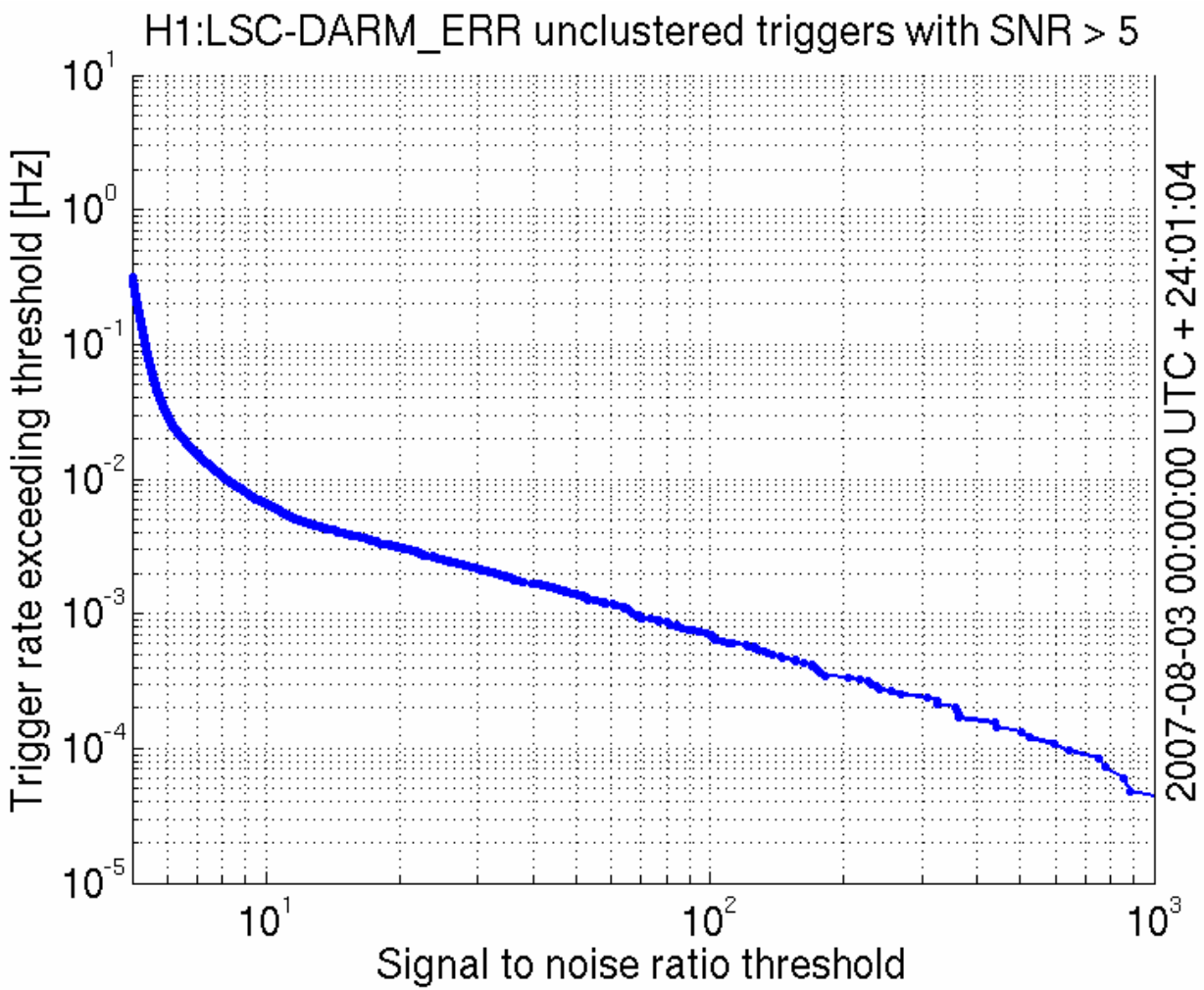
Krzysztof Belczynski, Rosalba Perna,Tomasz Bulik, Vassiliki Kalogera,Natalia Ivanova, Donald Q. Lamb, *The Astrophysical Journal*, 648:1110-1116, 2006 September 10

How low can you go?

Rough estimate
triple coincidence FAR of 1 per year: SNR = 7

Rough estimate
triple coincidence FAR of 1 per day: SNR = 5.5

Low threshold search improves sensitivity by ~20% Increase space of search by ~70%!!



Search Skeleton




IFO 1 Trigger Generator

IFO 2 Trigger Generator

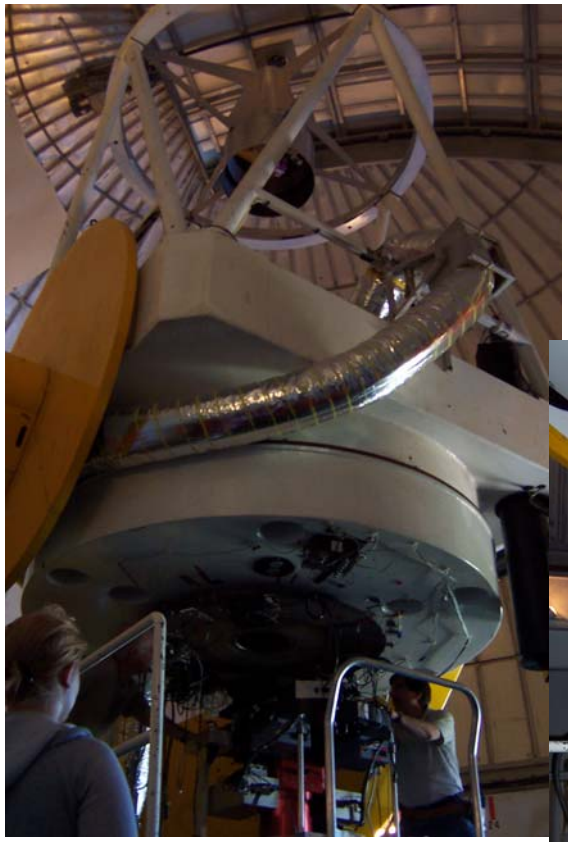
IFO 3 Trigger Generator

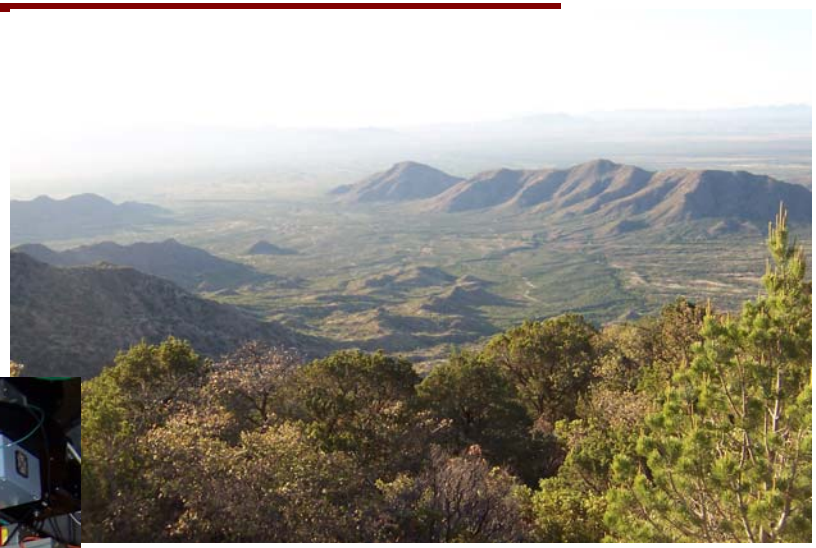
Coincidence and Position

Take Optical Images

Image Processing

Pilot Study: Summer ‘07





Pilot Study: Summer '07

- 3 Runs on 3 different telescopes:
  - MDM 2.4 m June 4-6
  - Swope Telescope July 22 – Aug 1
  - MDM 1.3 m Sept. 4-9
- Incoherent Source Reconstruction
- H-L-V and H-L networks
- I and R-Harris filters
- Imaged targets ~1 to 10 hours after GW trigger