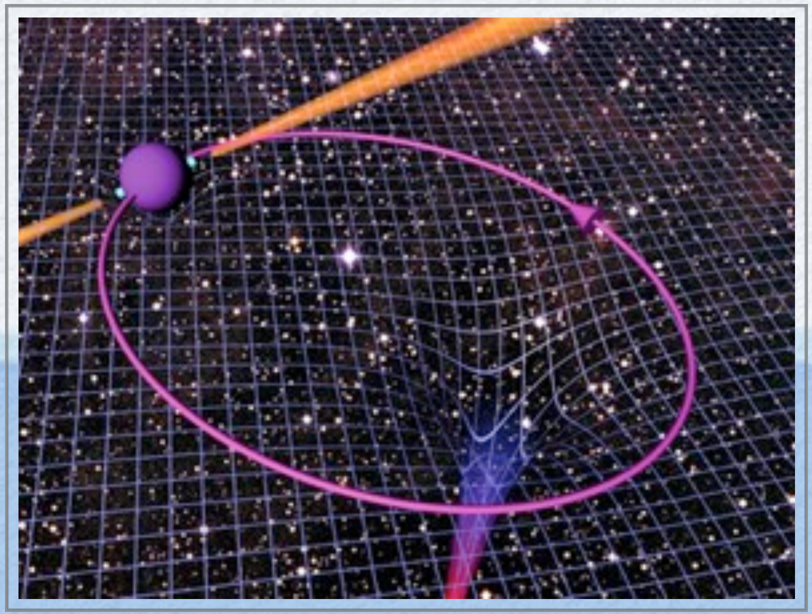
Real-Time Fast Transient Detection with Interferometers

Casey Law
UC Berkeley

The State of the Art

Parkes Observatory:
a fast transients workhorse

The State of the Art



Testing GR

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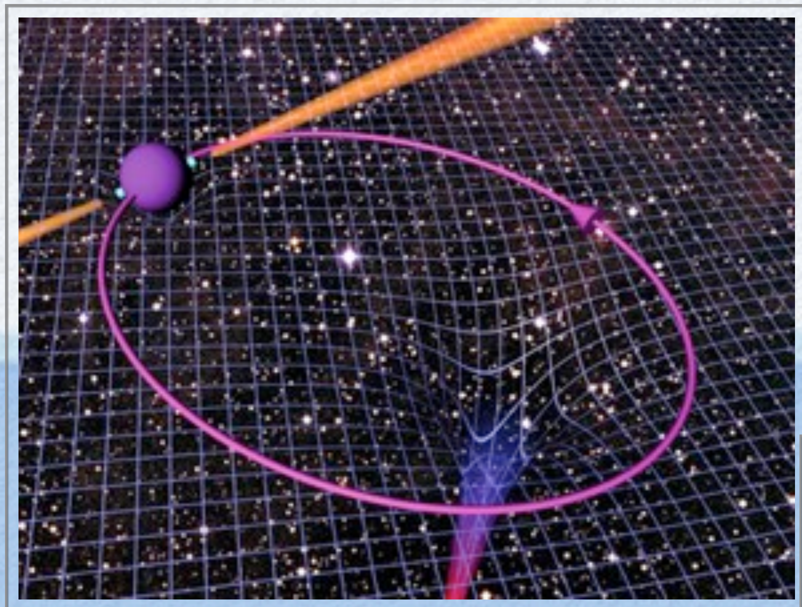

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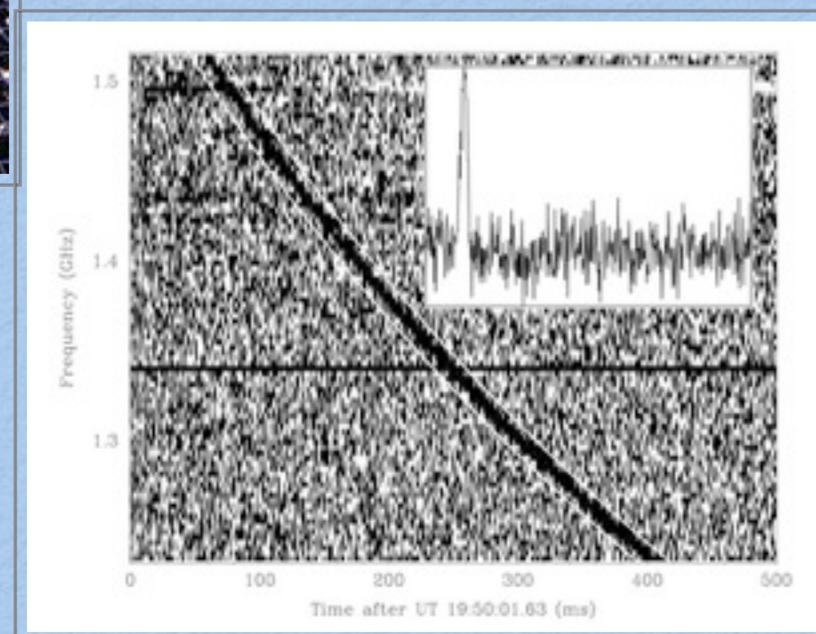

Extragalactic transients

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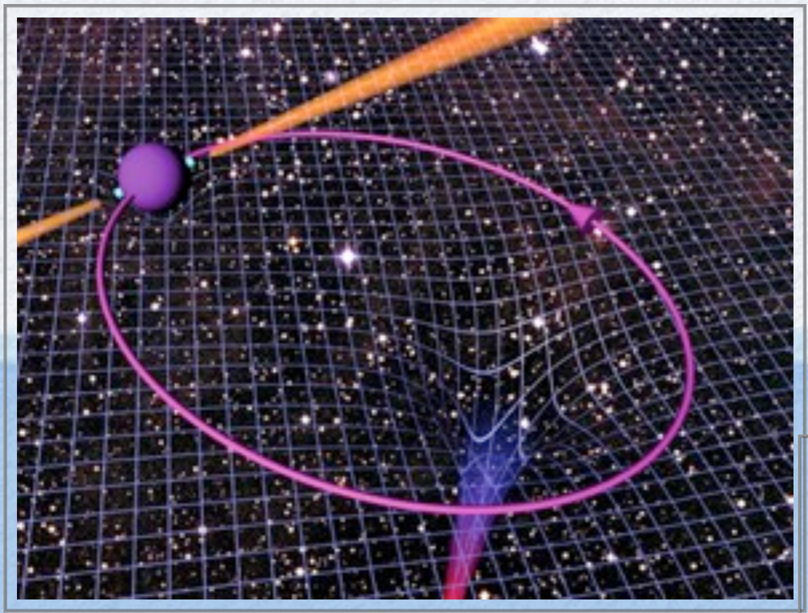

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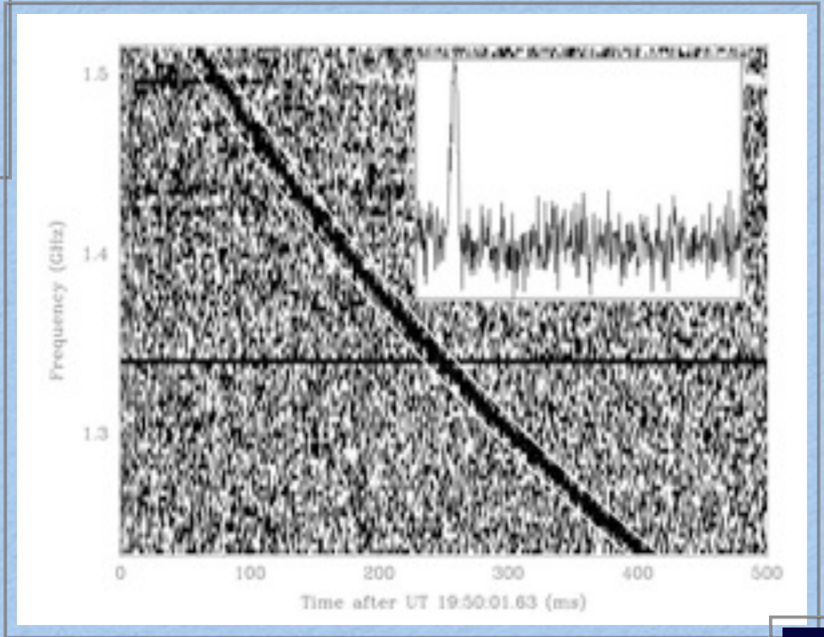
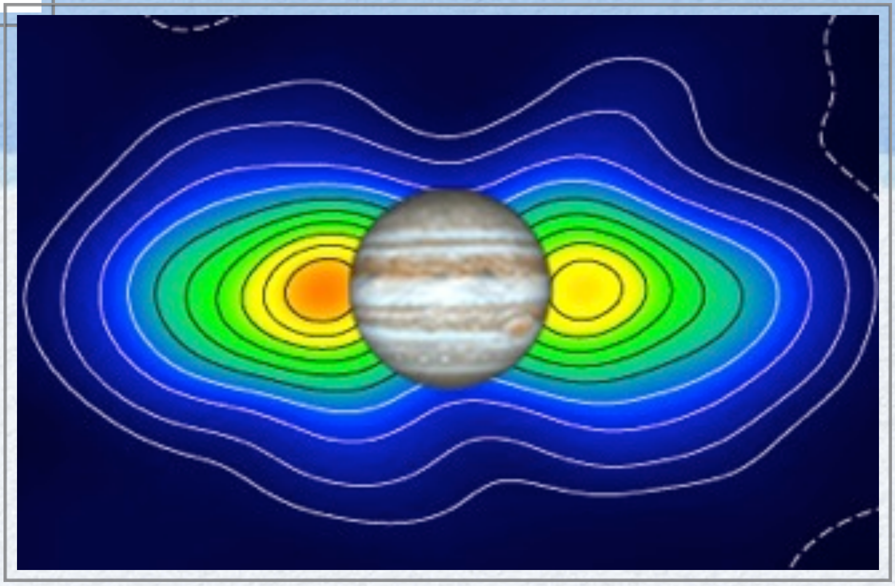
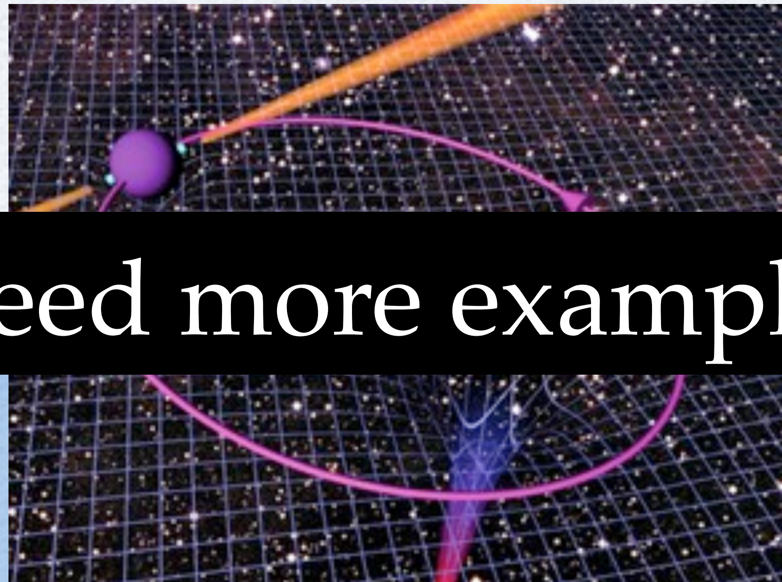


Extragalactic transients



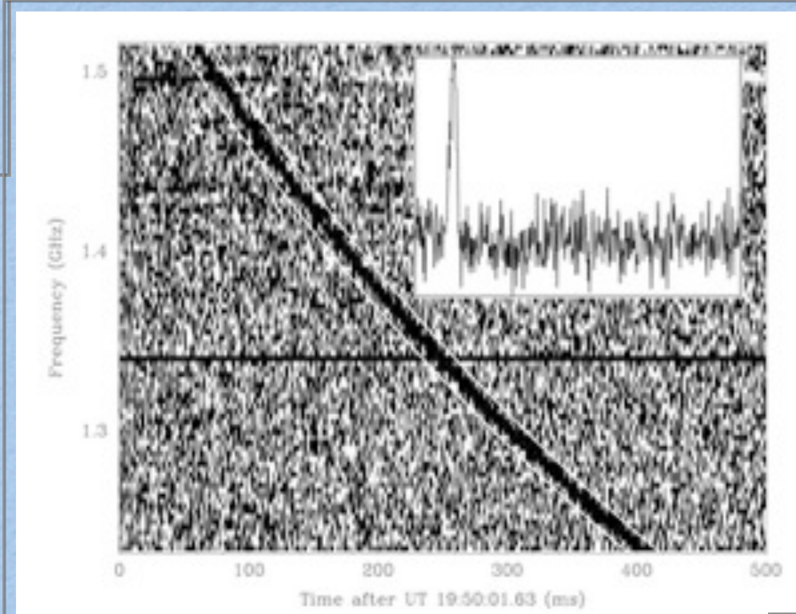
Exoplanets and dwarfs

The State of the Art



Need more examples

Testing GR



Extragalactic transients

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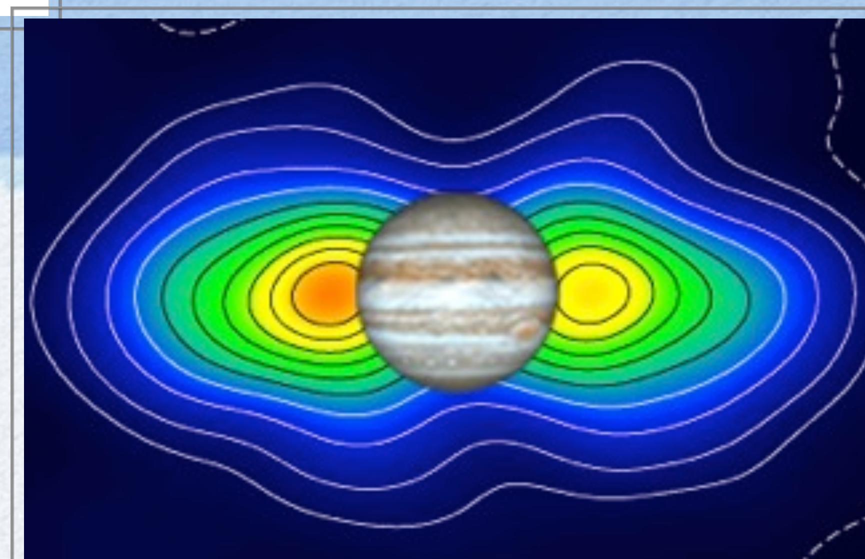

Exoplanets and dwarfs

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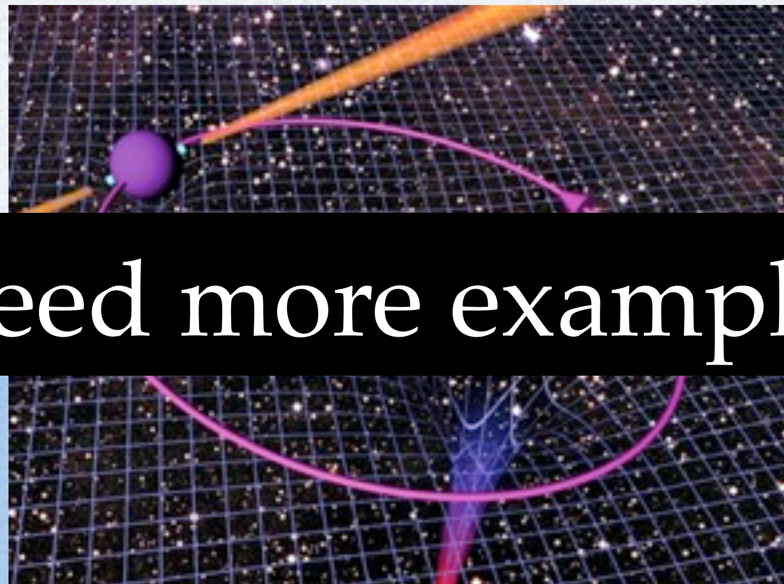
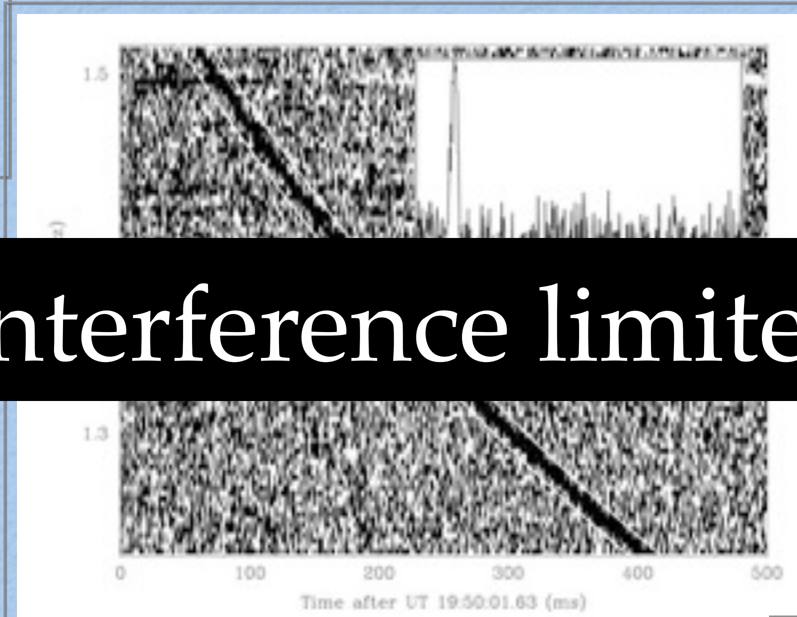


Need more examples

Testing GR



Interference limited

Extragalactic transients

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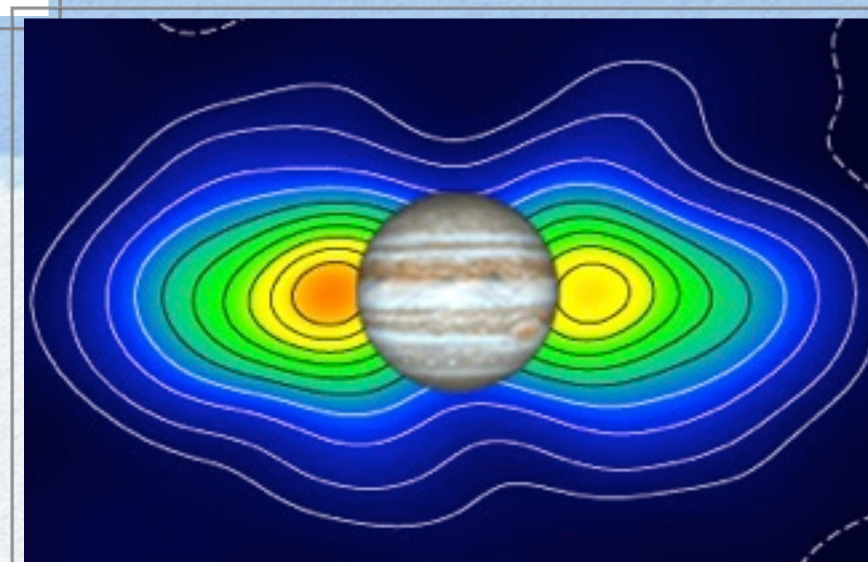

Exoplanets and dwarfs

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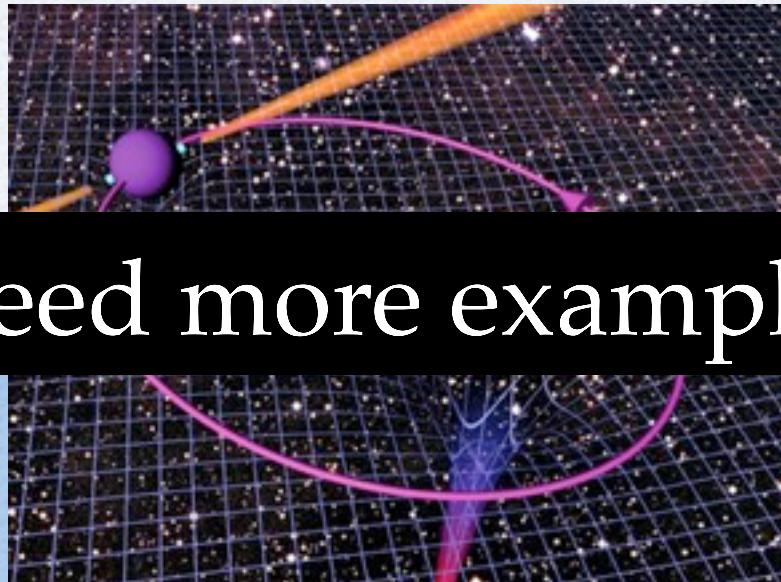
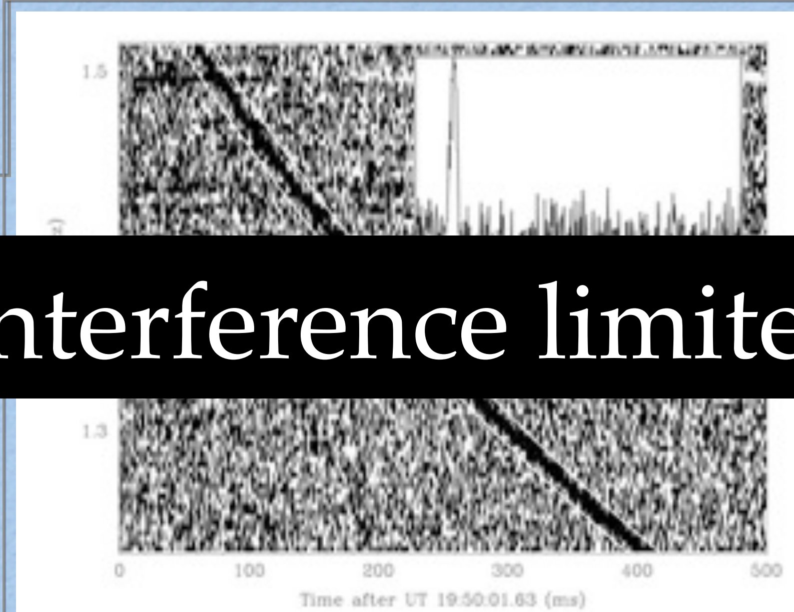


Need more examples

Testing GR



Interference limited

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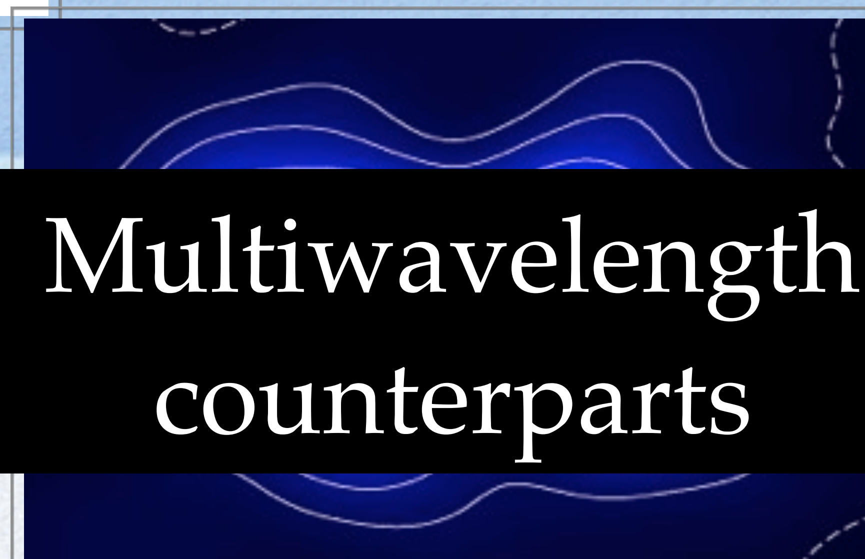


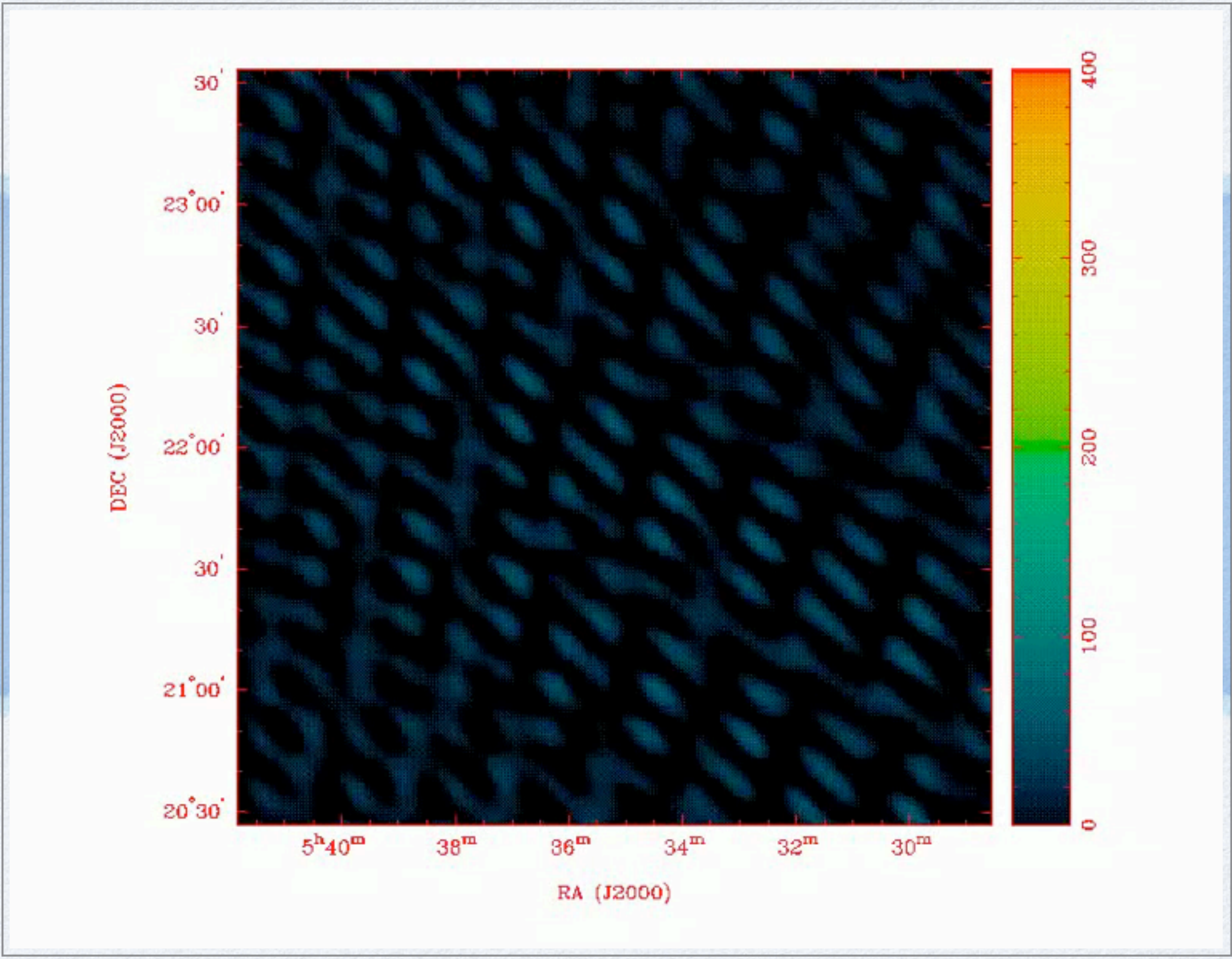
Multiwavelength counterparts

Exoplanets and dwarfs

Fast Imaging

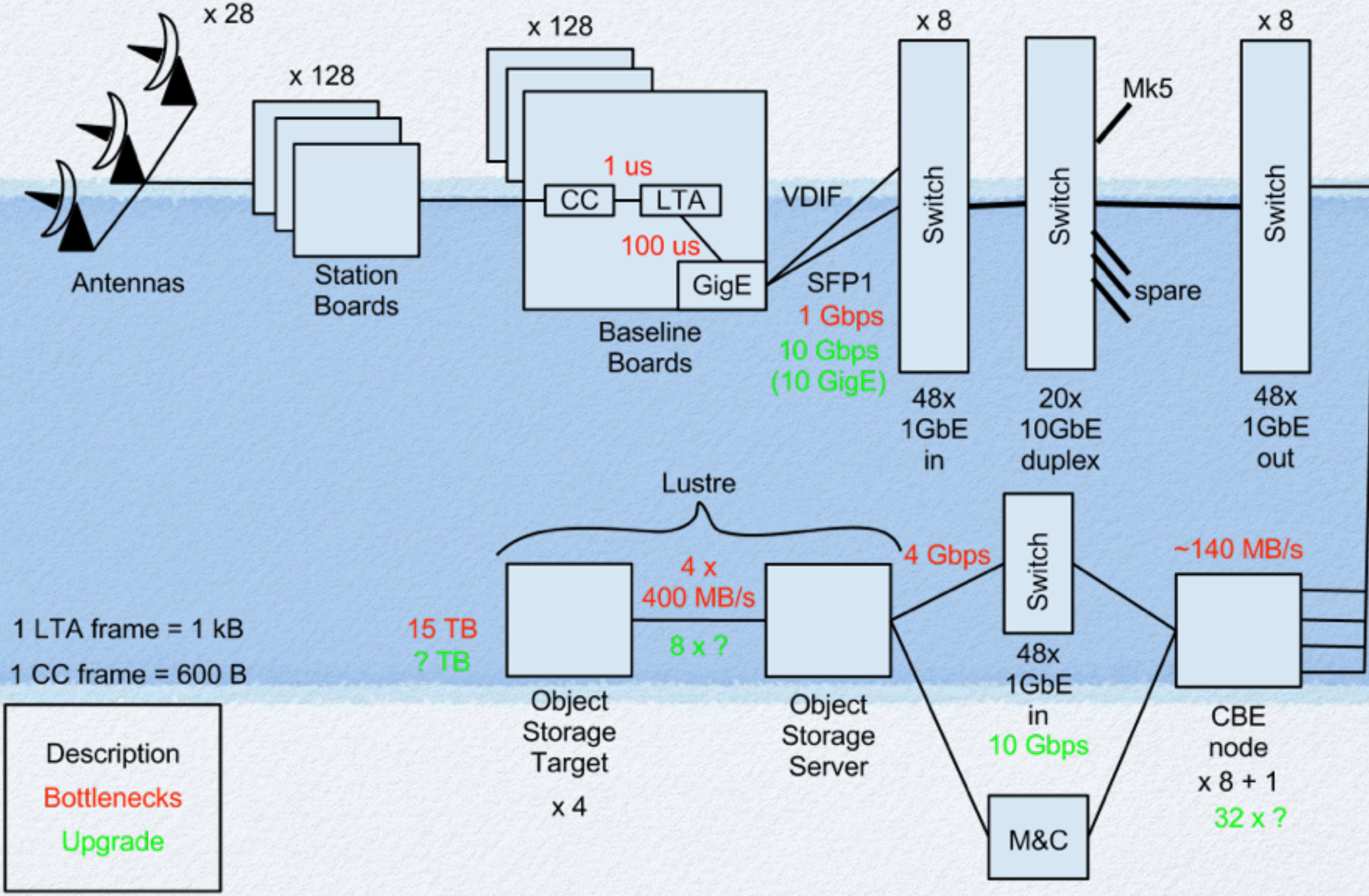
Movie of ATA observation of Crab giant pulse (at 1/40th speed)

Fast Imaging



Movie of ATA observation of Crab giant pulse (at 1/40th speed)

The JVLA Correlator



Success!

- Bottleneck improved from 20 to ~100 MB/s
- Integration time of 10 ms now possible

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Breaking the Data Speed Limit with the Jansky VLA

Casey Law, Geoffrey Bower (UC Berkeley); Martin Pokorny, Michael Rupen, Ken Sowinski (NRAO)

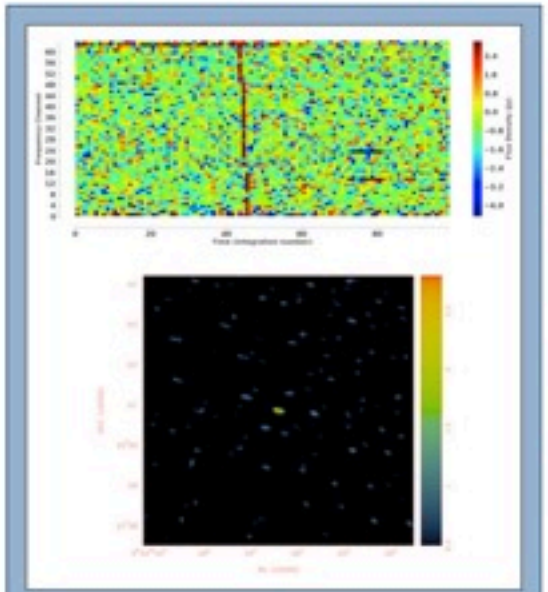


Figure-1: (top) A dynamic spectrum formed from Jansky VLA visibilities at a time resolution of 10 ms. A pulse from the Crab pulsar is seen with its characteristic dispersion. Selecting visibilities for that dispersed pulse, we can use the imaging capabilities of the Jansky VLA to localize the pulse to arcsecond precision (bottom).

Zoom

If you were to drive I-25 in New Mexico, road safety demands that you go no faster than 75 miles per hour. "Driving" the Jansky VLA (JVLA) correlator is also limited, although in this case by networking, computation, and archiving requirements. Coincidentally, the JVLA data speed limit was set at 75 MB/s. In practice, the correlator ran no faster than about 25 MB/s, roughly the speed (in miles per hour) of a fast cyclist. Recently, as part of an experimental observing mode, we broke both of these speed limits by writing data at a rate of 110 MB/s.

This record-breaking speed was set as part of a Resident Shared Risk Observing (RSRO) project to record fast integrations with the JVLA correlator. This optimized mode ran at 1/4 of network capacity to the archive and nearly 1/2 the limit into each compute node of the correlator backend. As this speed test was run in a special mode – the Bonneville Salt Flats of correlator modes, if you will – it is not generally available. However, this work is pioneering high data rate observing modes (e.g., fast integrations, large spectra) that are in demand at the JVLA and will be critical to the development of the SKA.

The goal of this RSRO project is to open the world of millisecond radio transients to interferometers. These fast transients have traditionally been studied with large, single-dish telescopes. Since interferometers correlate signals from all pairs of antennas (the JVLA has 351 such pairs), they tend to produce data at a larger rate than single-dish telescopes. Until recently, that made the study of fast transients with correlated data from an interferometer impossible. The latest speed record means that the JVLA can now write correlated data products as fast as once every 10 ms.

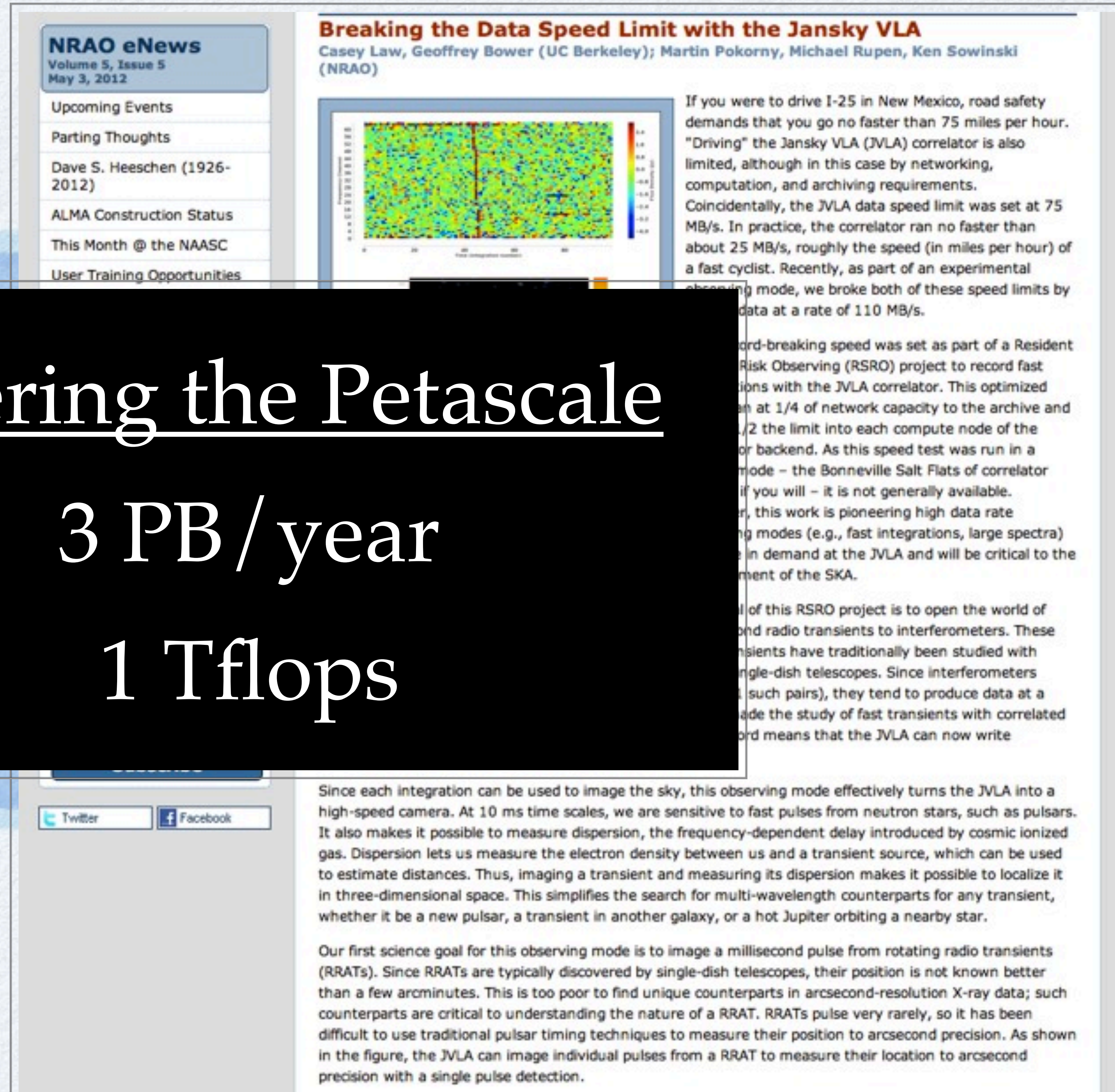
Since each integration can be used to image the sky, this observing mode effectively turns the JVLA into a high-speed camera. At 10 ms time scales, we are sensitive to fast pulses from neutron stars, such as pulsars. It also makes it possible to measure dispersion, the frequency-dependent delay introduced by cosmic ionized gas. Dispersion lets us measure the electron density between us and a transient source, which can be used to estimate distances. Thus, imaging a transient and measuring its dispersion makes it possible to localize it in three-dimensional space. This simplifies the search for multi-wavelength counterparts for any transient, whether it be a new pulsar, a transient in another galaxy, or a hot Jupiter orbiting a nearby star.

Our first science goal for this observing mode is to image a millisecond pulse from rotating radio transients (RRATs). Since RRATs are typically discovered by single-dish telescopes, their position is not known better than a few arcminutes. This is too poor to find unique counterparts in arcsecond-resolution X-ray data; such counterparts are critical to understanding the nature of a RRAT. RRATs pulse very rarely, so it has been difficult to use traditional pulsar timing techniques to measure their position to arcsecond precision. As shown in the figure, the JVLA can image individual pulses from a RRAT to measure their location to arcsecond precision with a single pulse detection.

Success?

- Bottleneck improved fr
~100 MB/s

- Integration
10 ms now p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Volume 5, Issue 5
May 3, 2012

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Breaking the Data Speed Limit with the Jansky VLA

Casey Law, Geoffrey Bower (UC Berkeley); Martin Pokorny, Michael Rupen, Ken Sowinski (NRAO)

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Entering the Petascale

3 PB/year

1 Tflops

Solutions to the Big Data Challenge

- Solution 1:
  Brute Force

Henyey compute cluster at UCB

- Solution 2:
  Real-time Processing...

LHC 10^7:1 compression

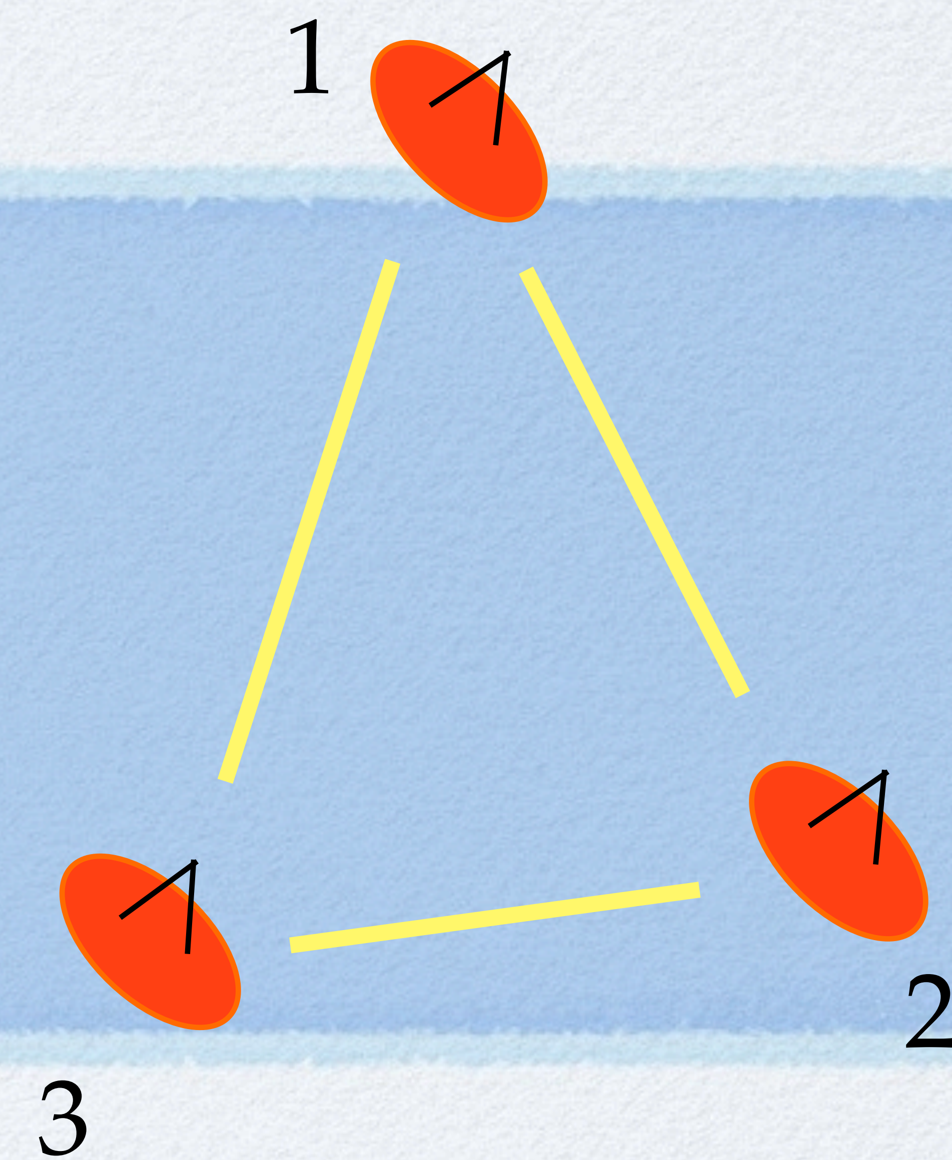
Closure Quantities

- Combine visibilities on closed loop

  $\theta_{12} + \theta_{23} + \theta_{31}$

  $\mathbf{V}_{12} * \mathbf{V}_{23} * \mathbf{V}_{31}$

- Independent of source location and calibration



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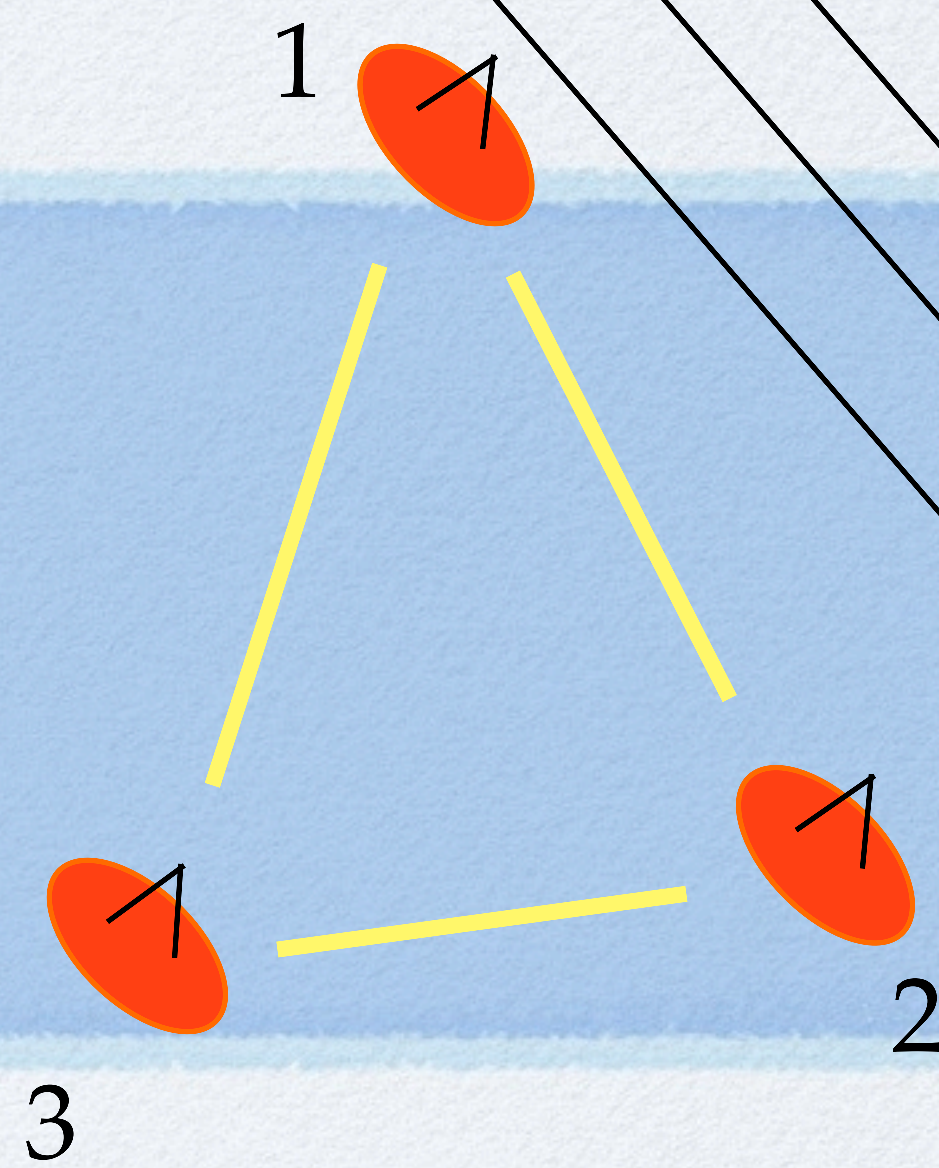
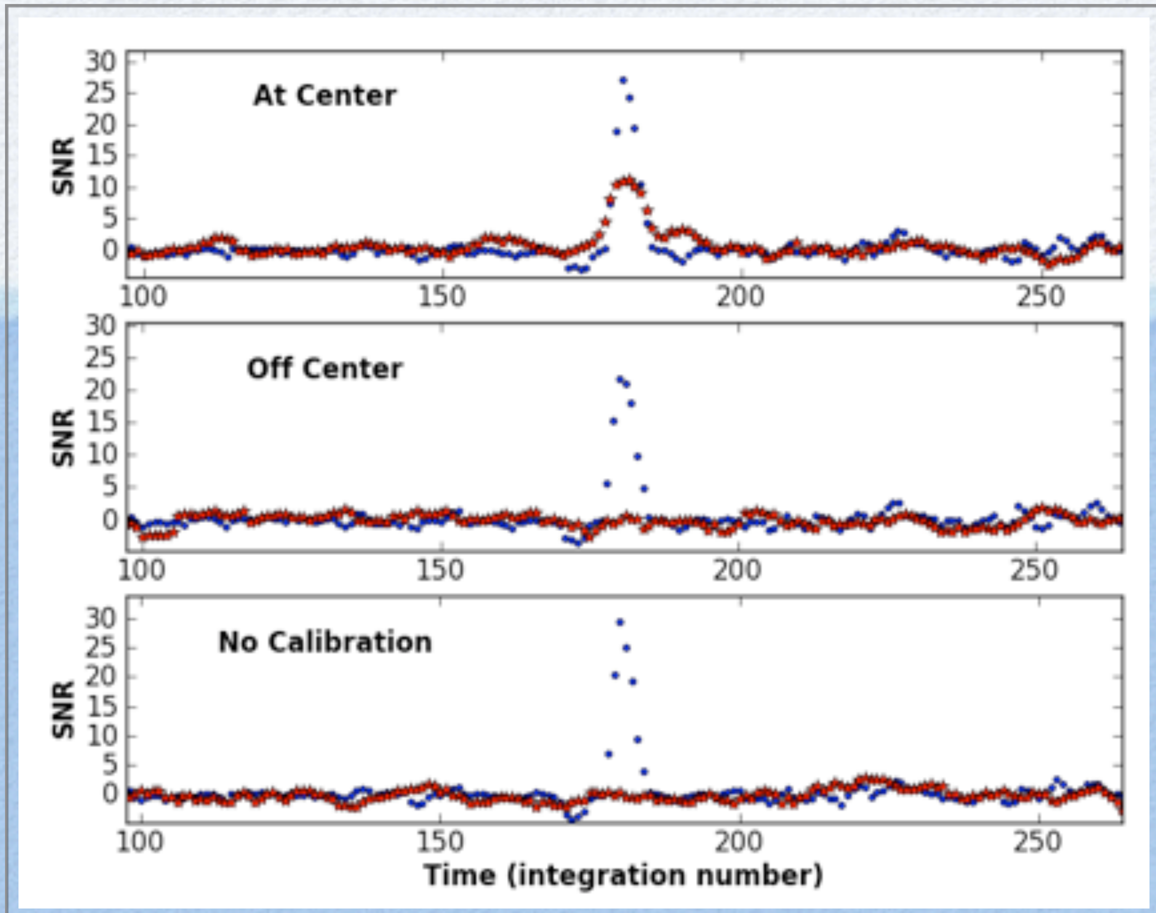


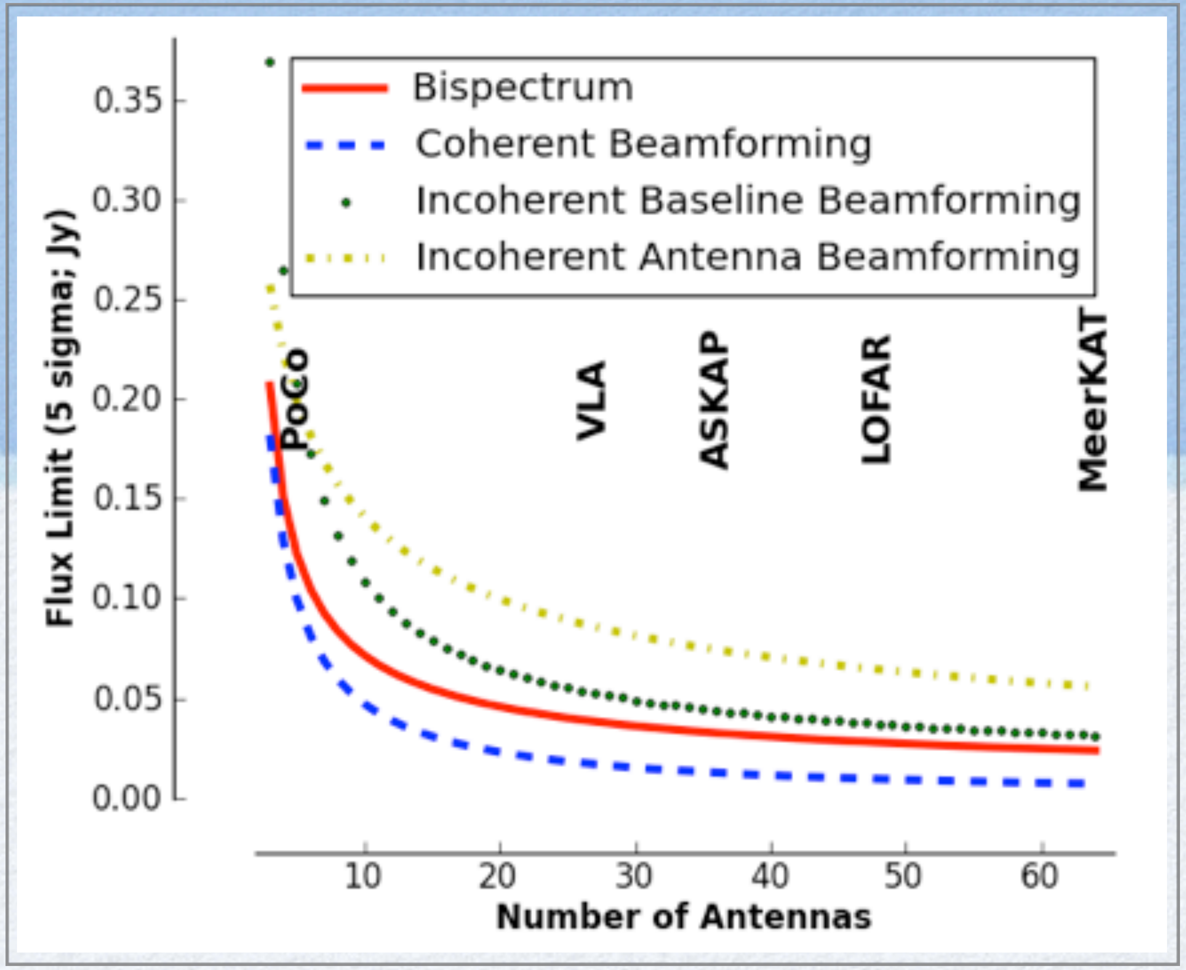
Testing the Theory



ATA lightcurves toward B0329+54

Bispectrum detects regardless of location and calibration

Some sensitivity loss compared to imaging



Simple, Yet Resistant to Interference

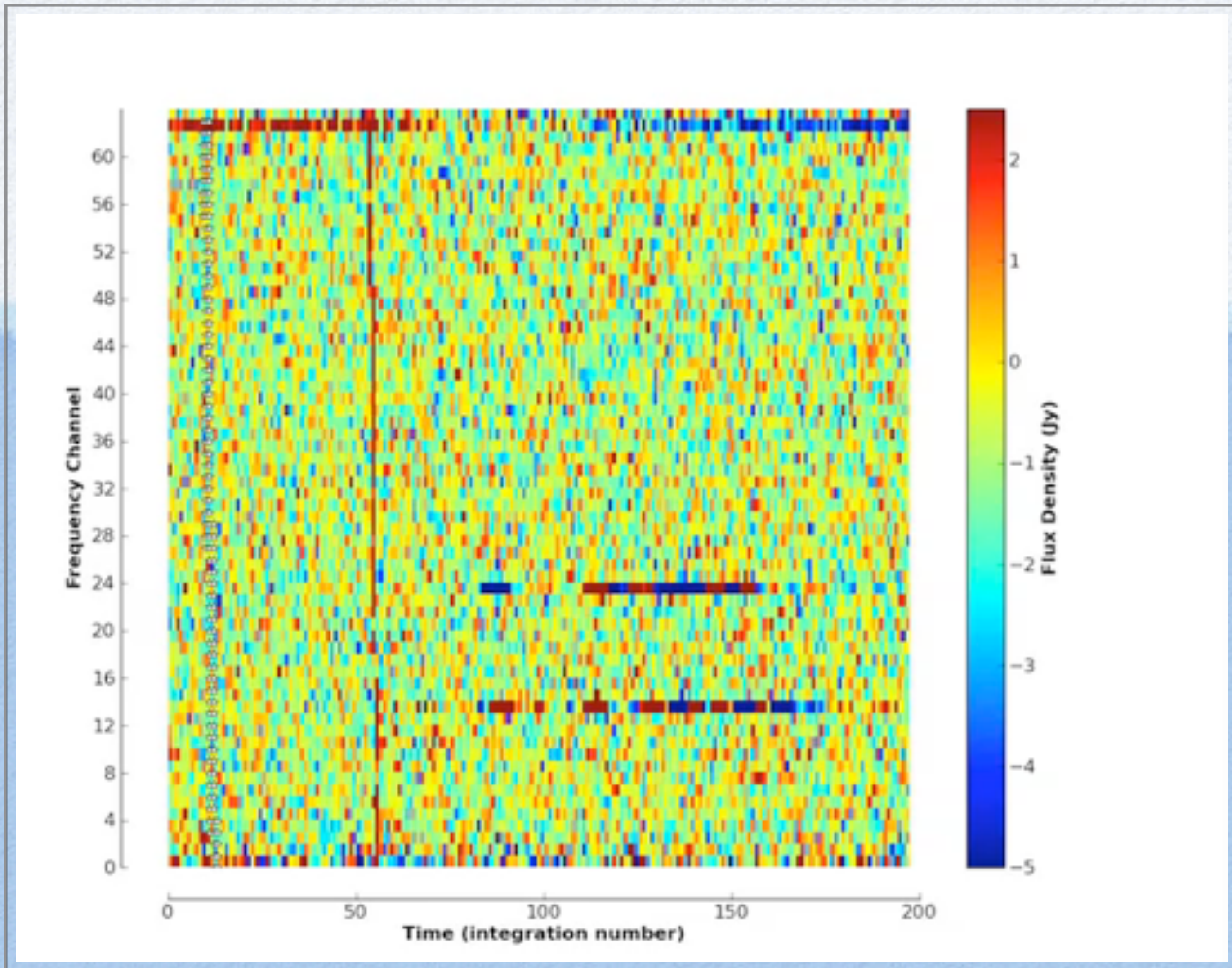
VLA dynamic spectrum of dispersed Crab pulse

Bispectra can distinguish sources from RFI

SNR

sigma_B

Simple, Yet Resistant to Interference



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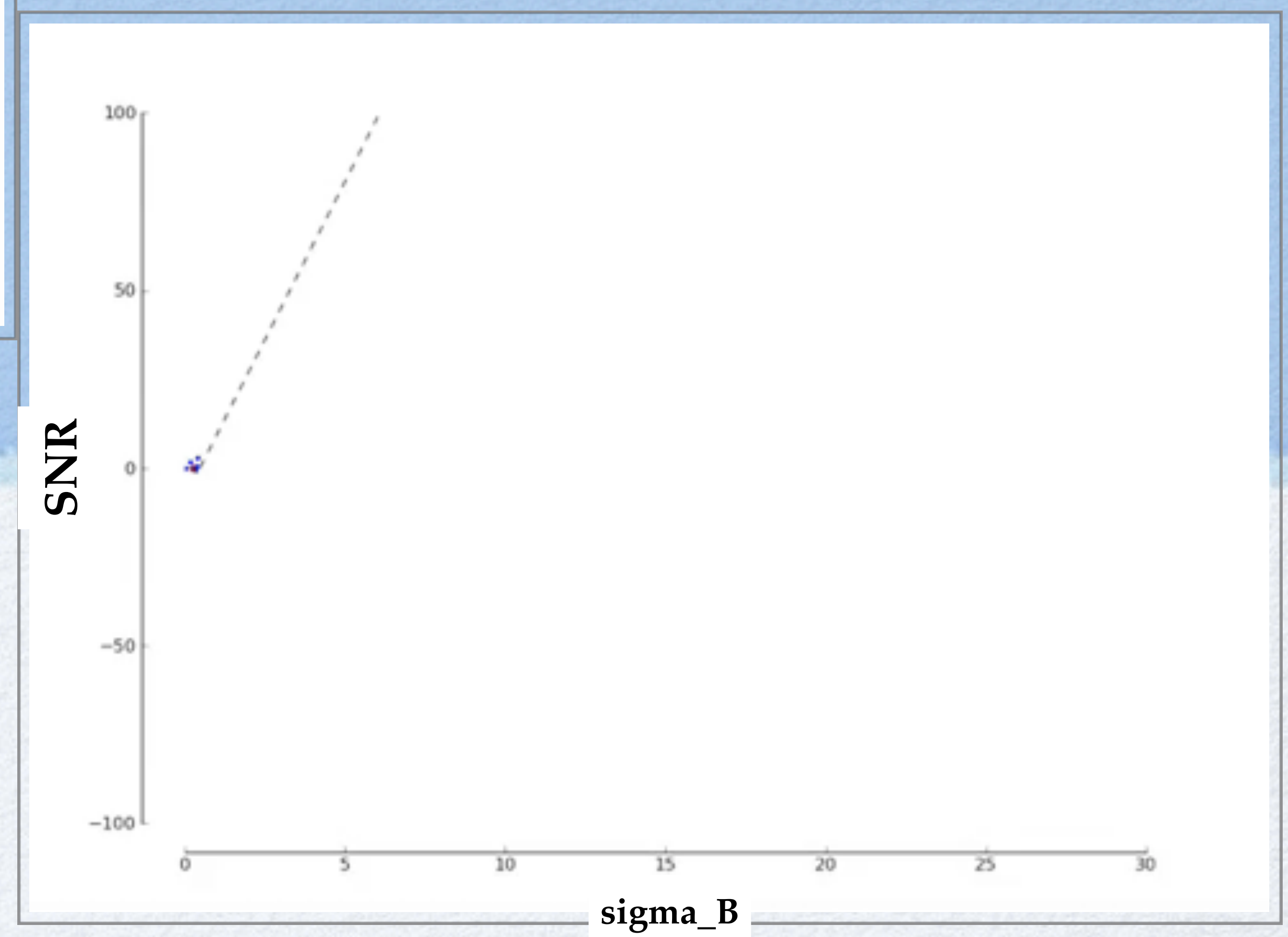
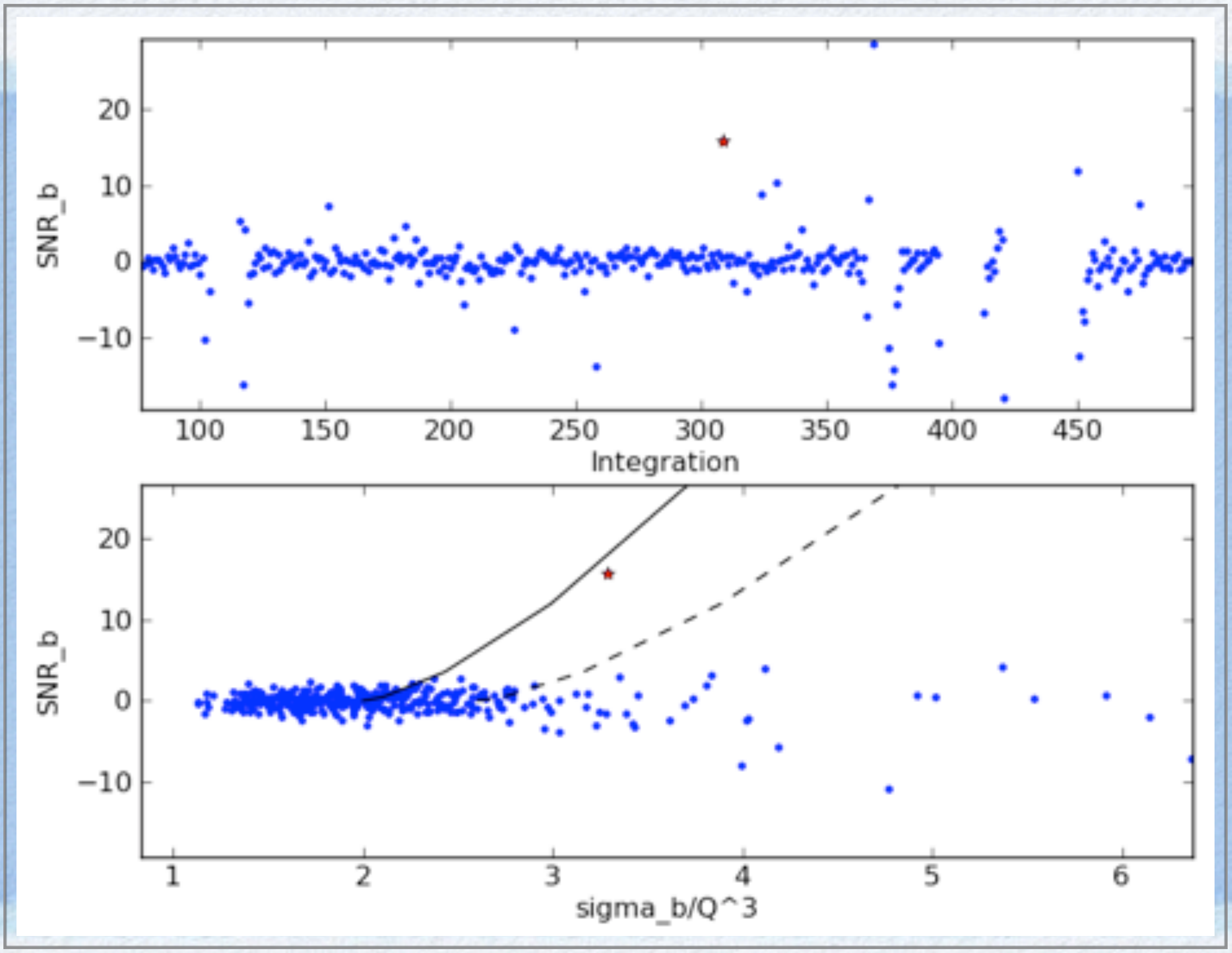


Yeah, but does it work?



Bispectrum lightcurve and diagnostic for VLA data toward J0628+0909

(Law et al. 2012, http://arxiv.org/abs/1208.6056)

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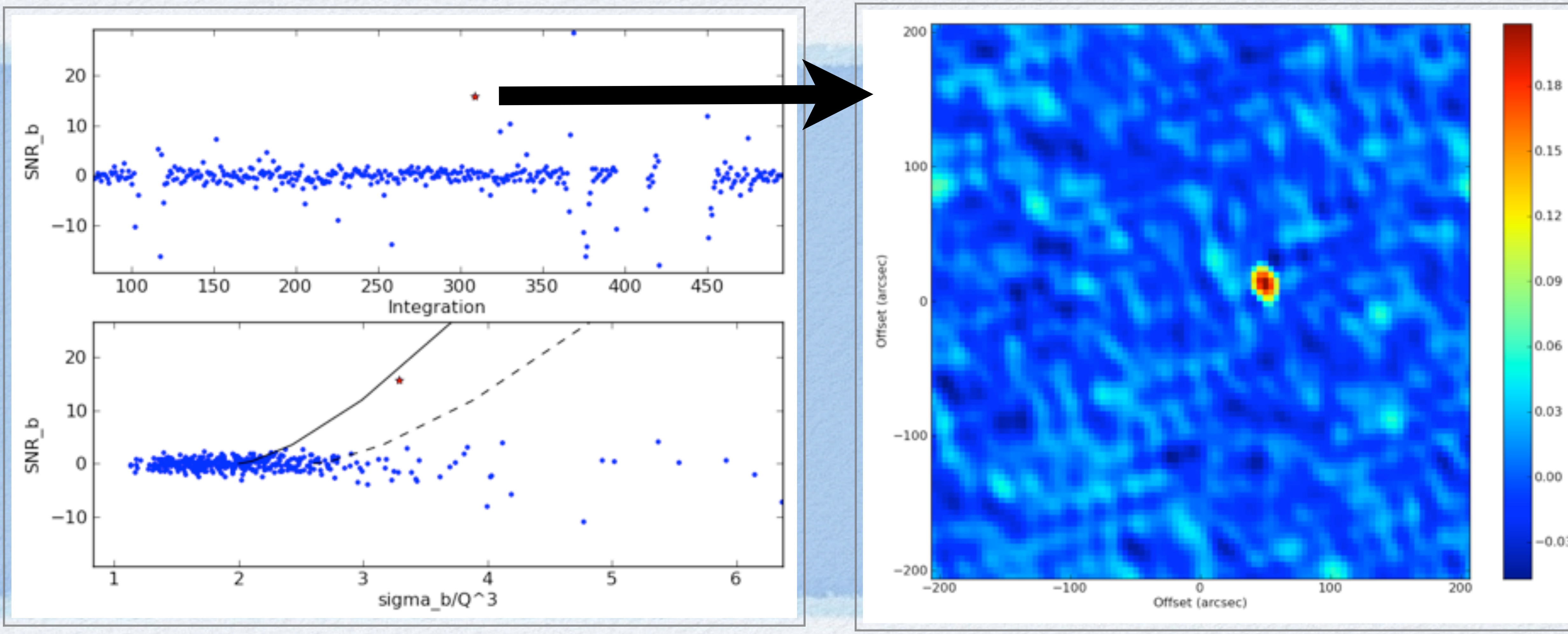
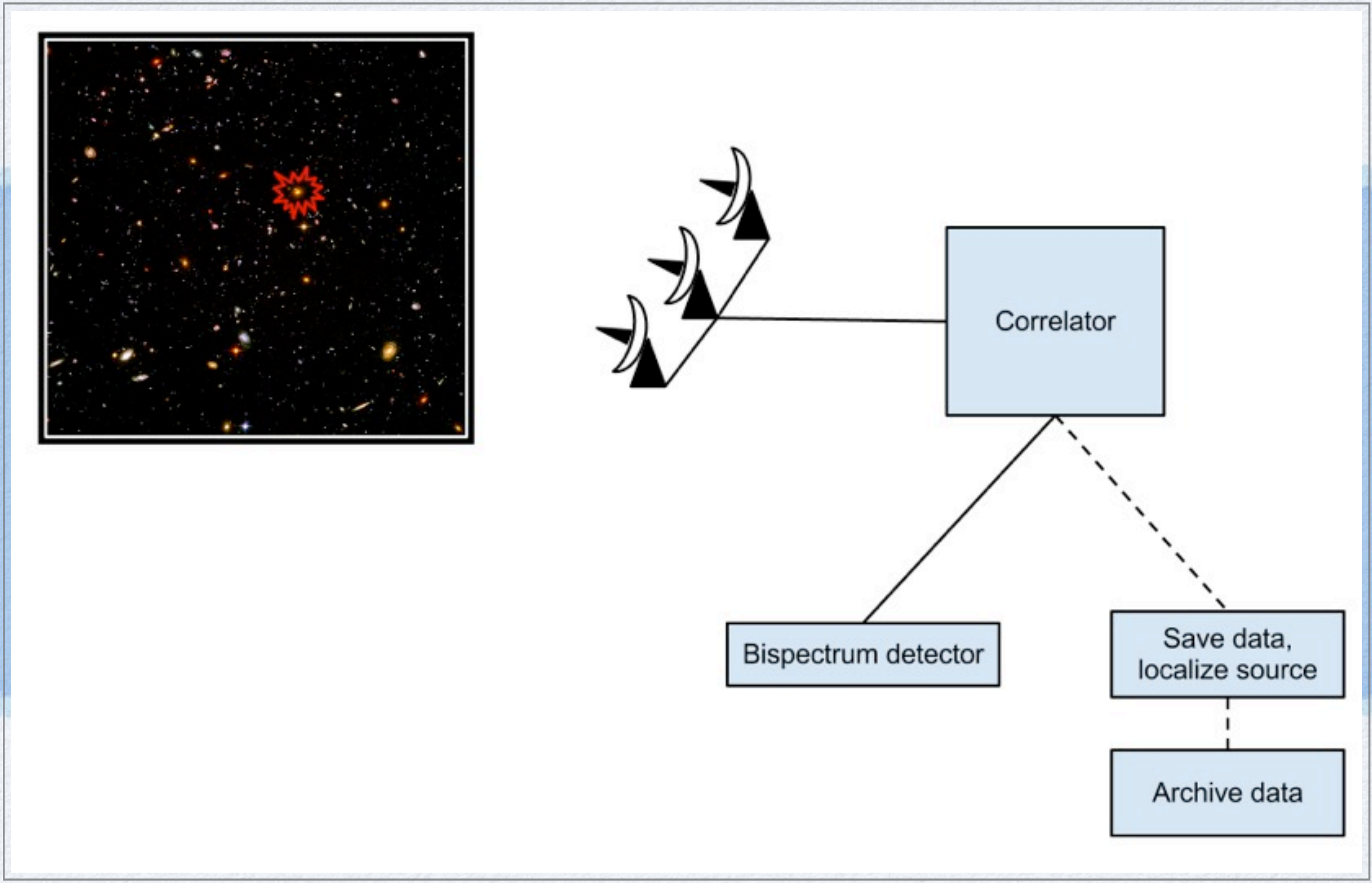


Bispectrum lightcurve and diagnostic for VLA data toward J0628+0909

Pulse localized!

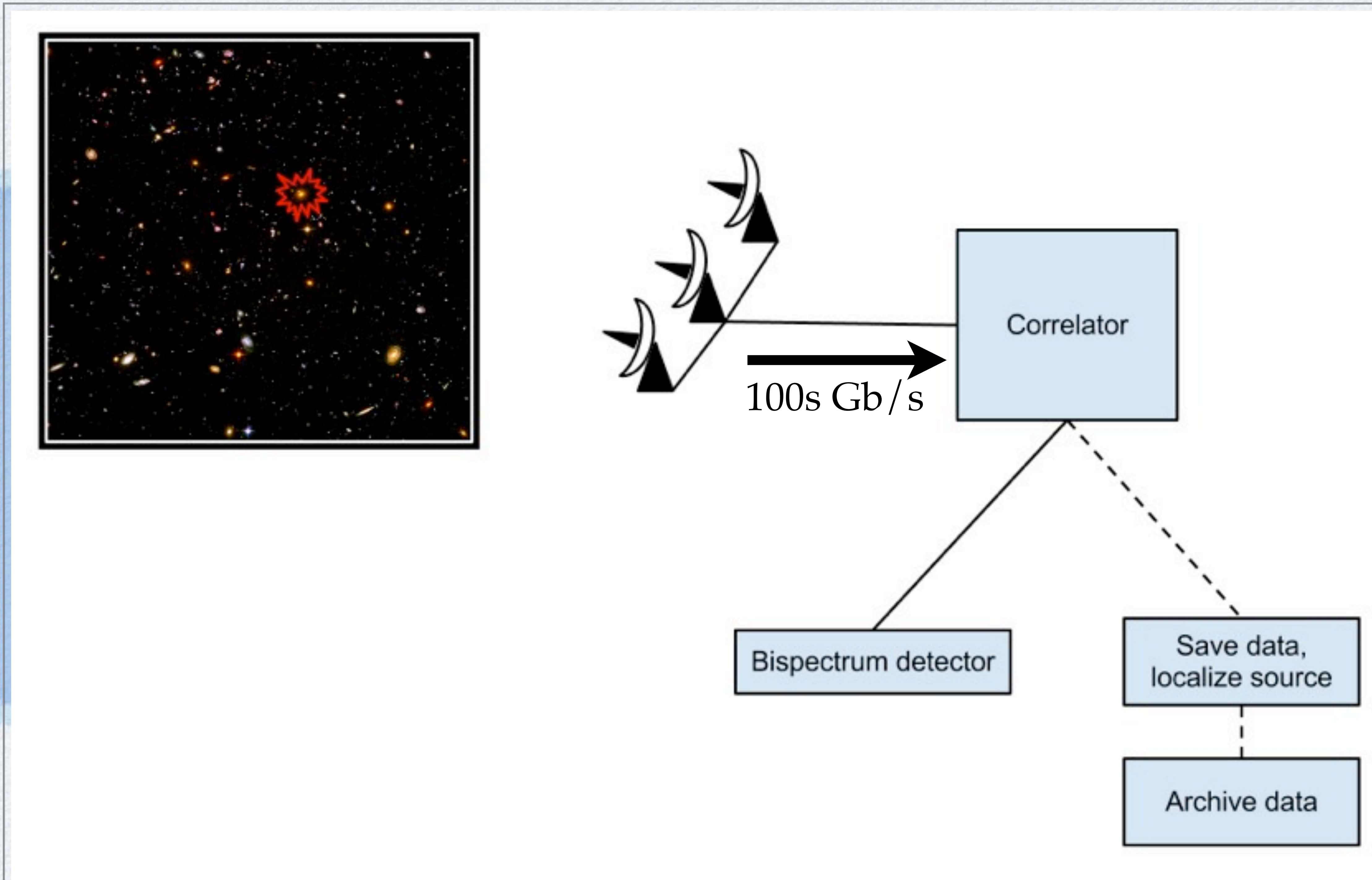
(Law et al. 2012, http://arxiv.org/abs/1208.6056)

Save the Data with the Science!



Conceptual pipeline for bispectrum transient detection

Save the Data with the Science!



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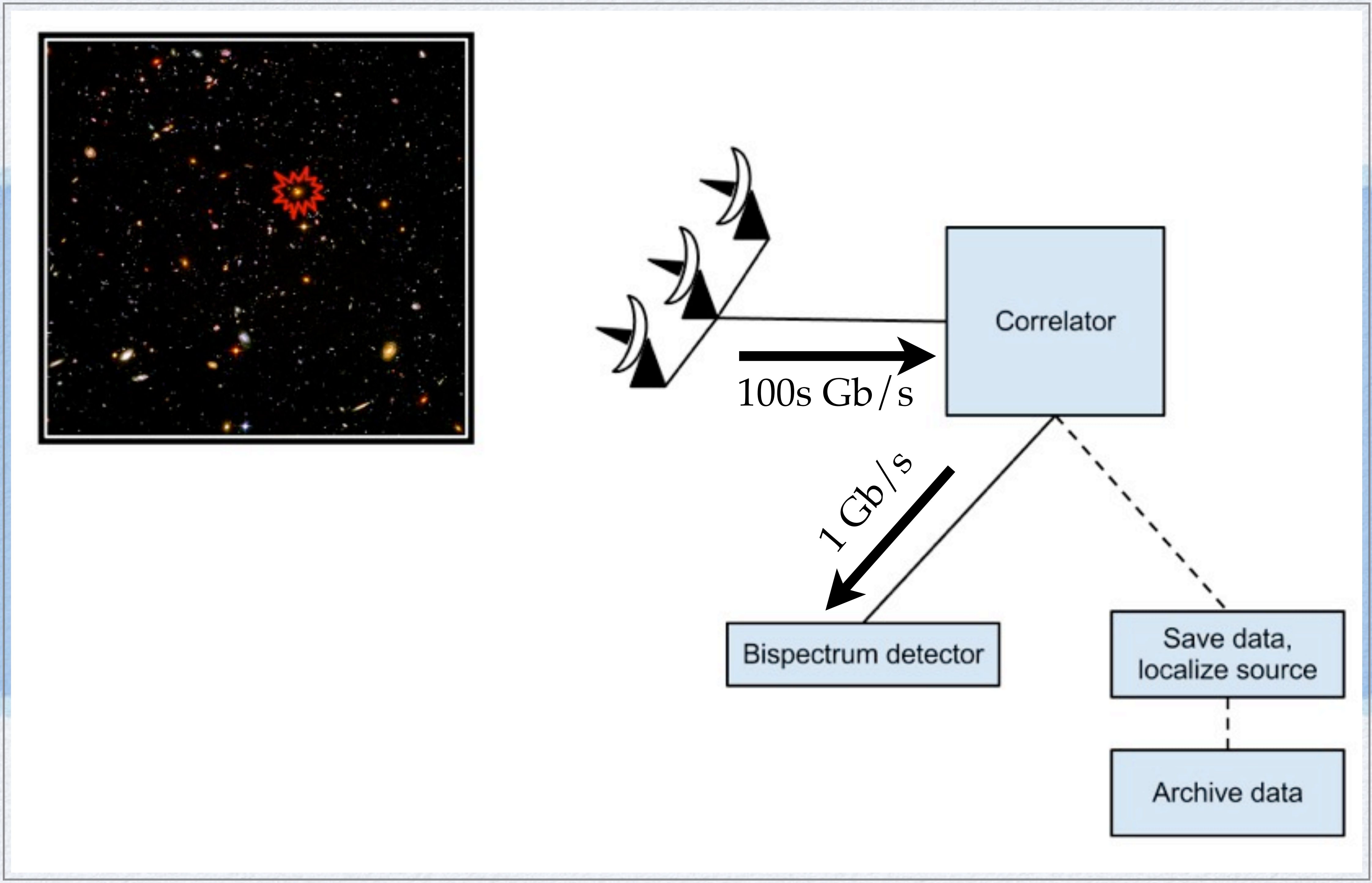

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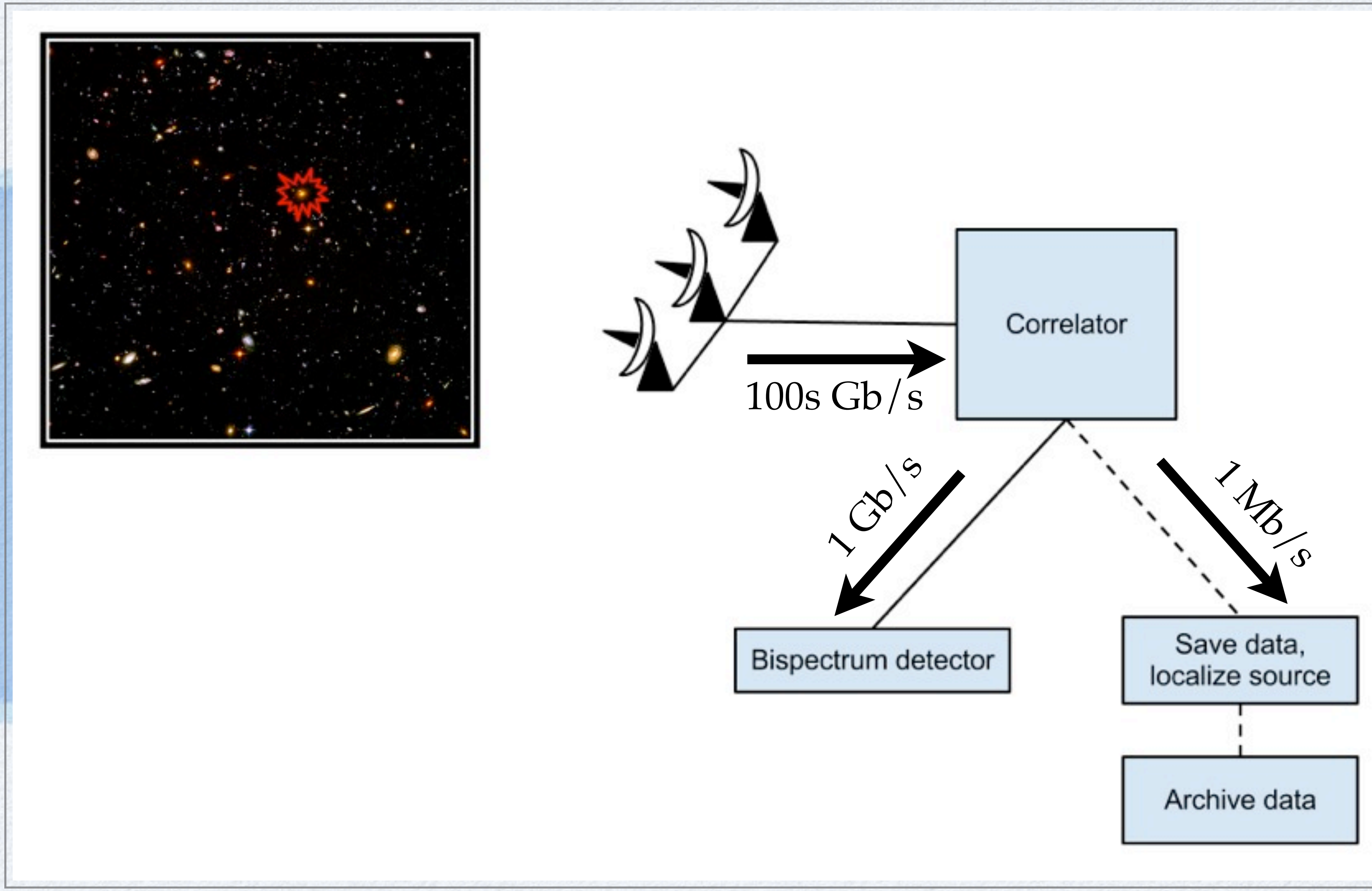

Conceptual pipeline for bispectrum transient detection

Ten Years Later...

Bigger Data!

- Survey machines
- Wide-field, commensal

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Solutions:

Ten Years Later...

Bigger Data!

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- “Triggering”

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Ten Years Later...

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- Survey machines
- Wide-field, commensal

Solutions:

- “Triggering”
- Real-time science detection
- Real-time flagging