Searches for a stochastic gravitational wave background with pulsar timing arrays:
a data analysis pipeline

Sydney J. Chamberlin

Jolien Creighton, Paul Demorest, Justin Ellis, Larry Price, Joe Romano, Xavier Siemens

Outline

* Search efforts for gravitational waves (GWs)
* Detecting GWs with pulsar timing arrays (PTAs)
* Constructing the optimal detection statistic
* Building a stochastic GW detection pipeline
* (very) preliminary results with upper limits, mock data challenge

Current GW detection efforts

* Ground-based laser interferometers (**L**aser **I**nterferometer **G**ravitational wave **O**bservatory)

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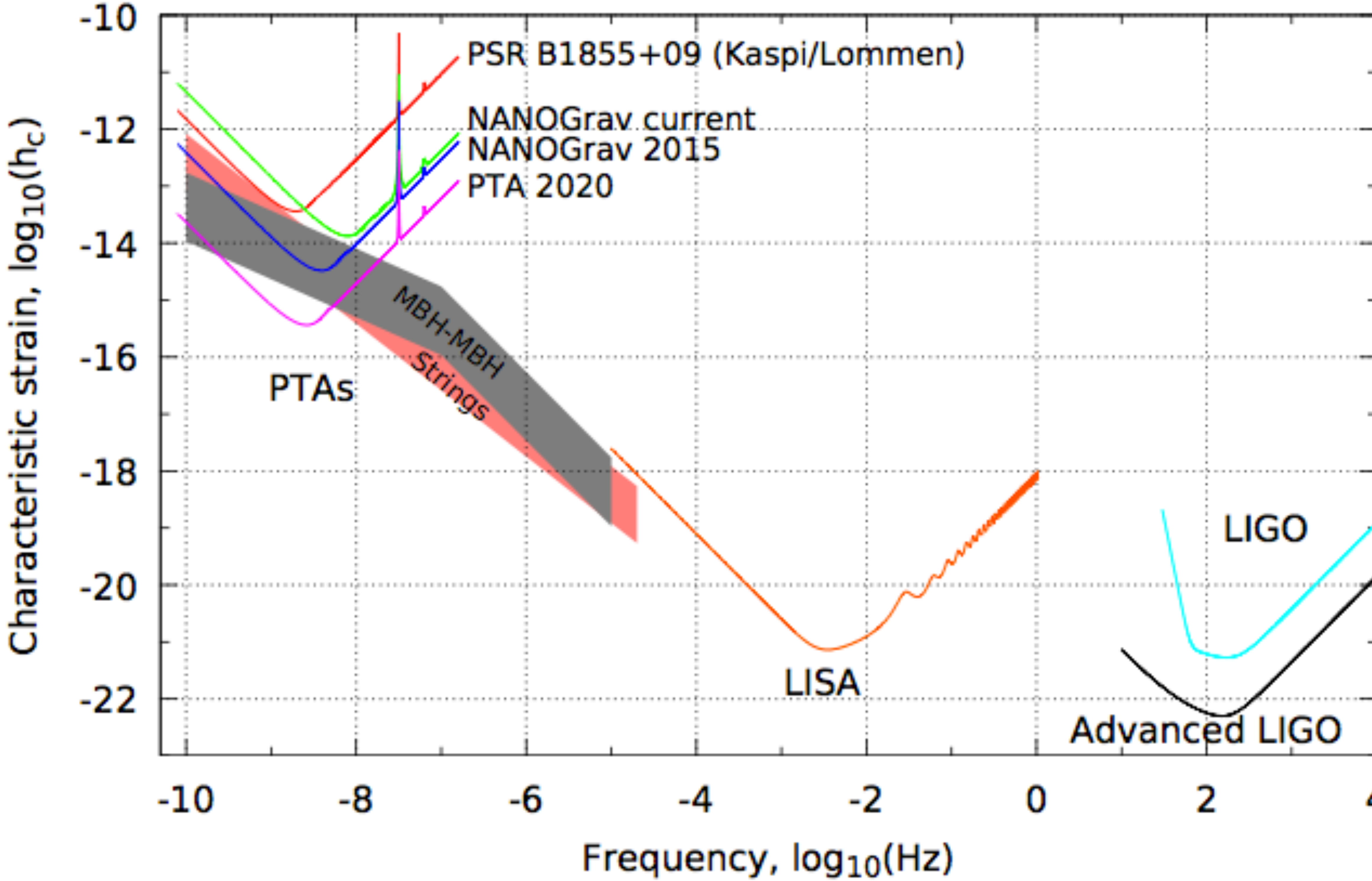
- PTAs (**N**orth **A**merican **N**anohertz **O**bservatory for **Grav**itational Waves, **E**uropean **P**ulsar **T**iming **A**rray, **P**arkes **P**ulsar **T**iming **A**rray)

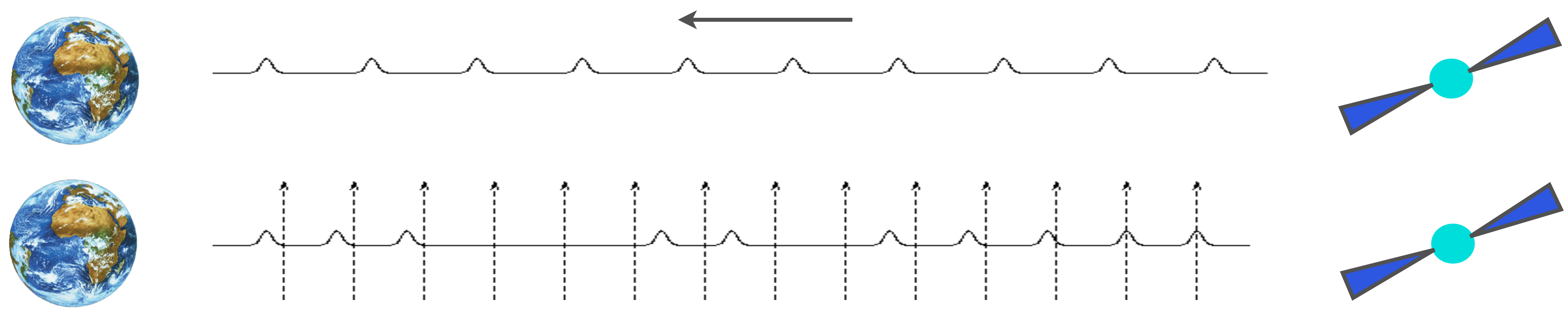
Together, form **I**nternational **P**ulsar **T**iming **A**rray

Current GW detection efforts

Demorest et al. (2009)



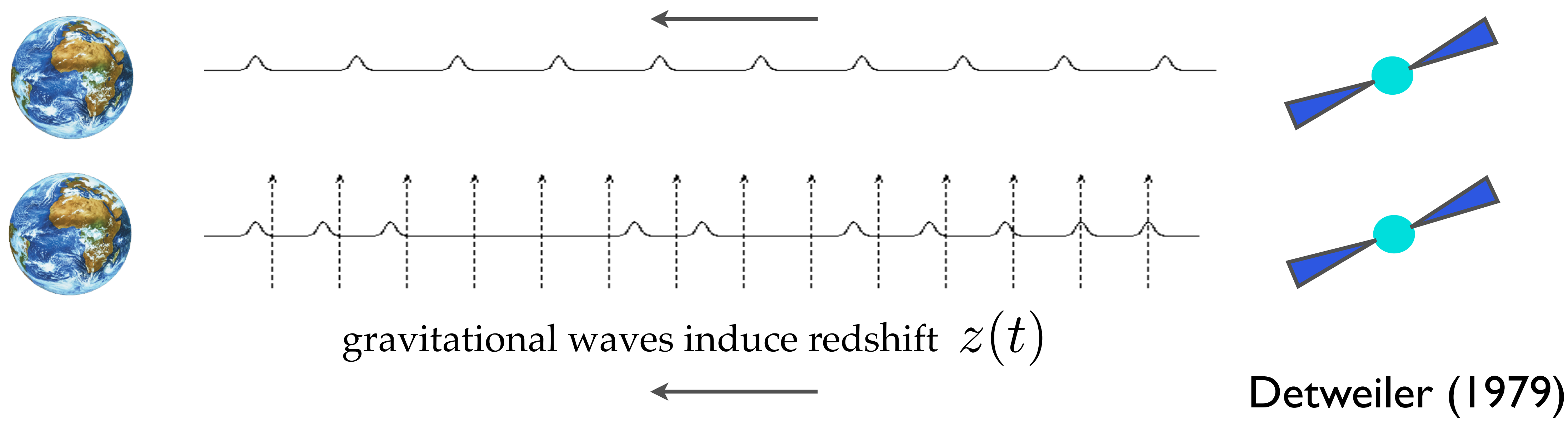
GW searches with PTAs



gravitational waves induce redshift $z(t)$

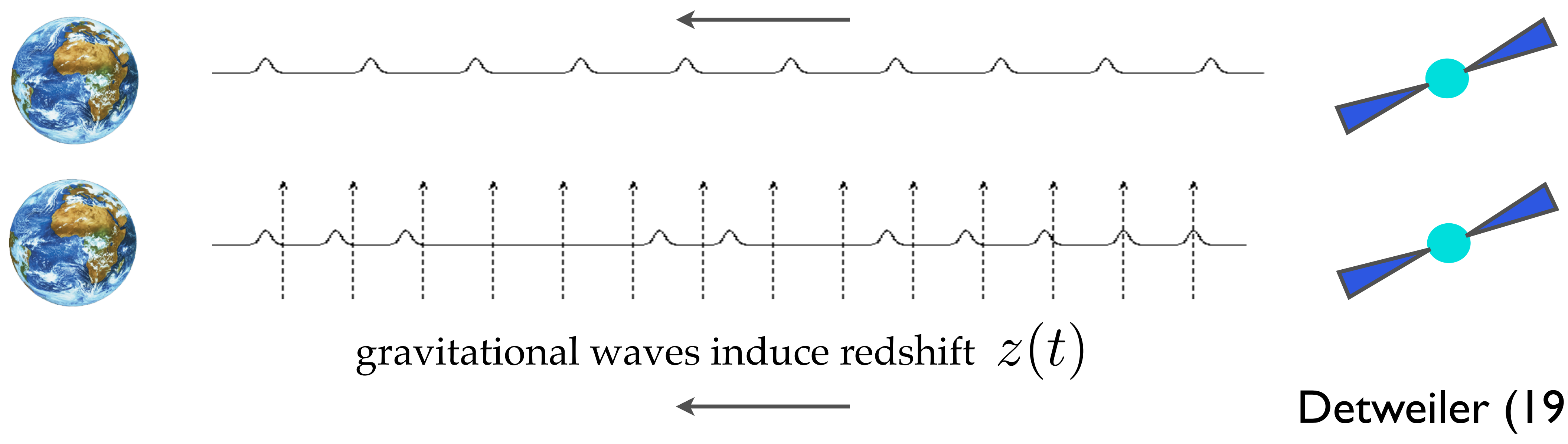
Detweiler (1979)

GW searches with PTAs



* Millisecond pulsars are extremely precise astronomical clocks:

GW searches with PTAs



- Millisecond pulsars are extremely precise astronomical clocks:

  Spin period of PSR B1937+21 at Midnight, December 5, 1998:

  P = 1.5578064688197945 ms +/- 0.0000000000000004 ms !

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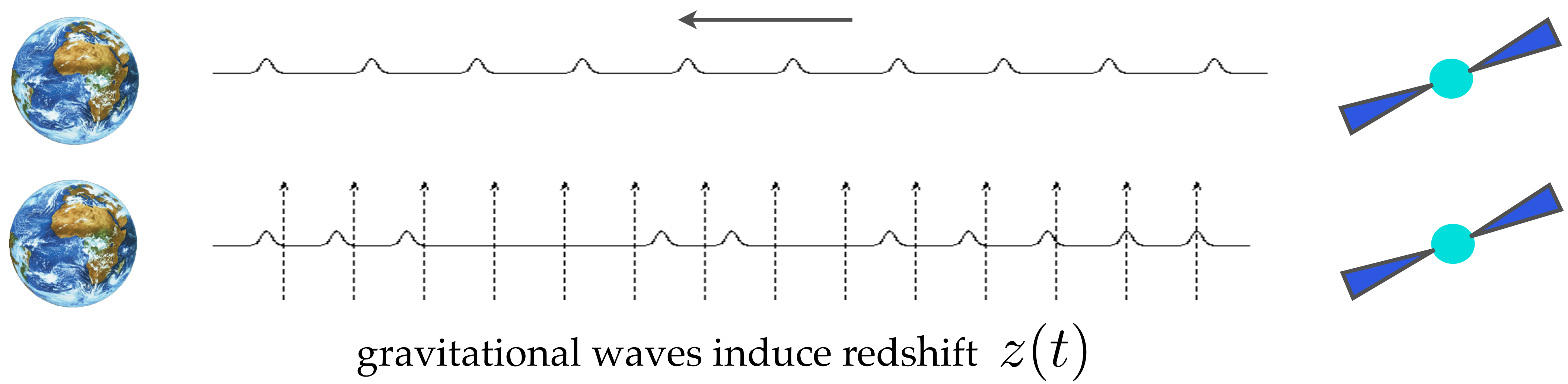

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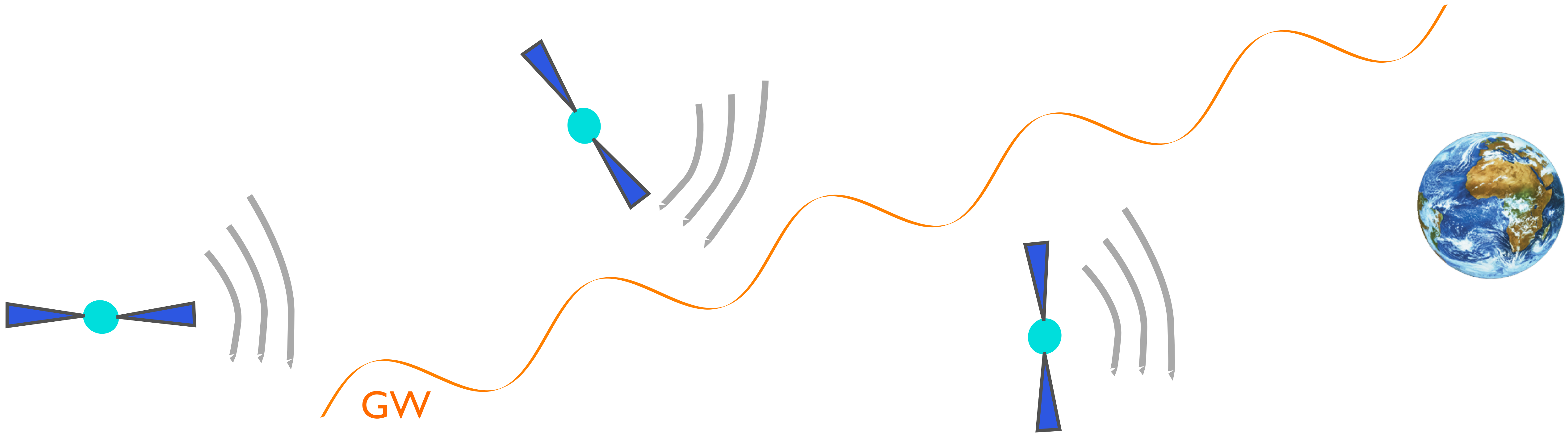
* This gives us an observable quantity, the *timing residual*:

$$r(t) = TOA_{\mathrm{actual}} - TOA_{\mathrm{expected}}$$

$$r(t) = \int_0^t z(t')\,dt'$$

GW searches with PTAs



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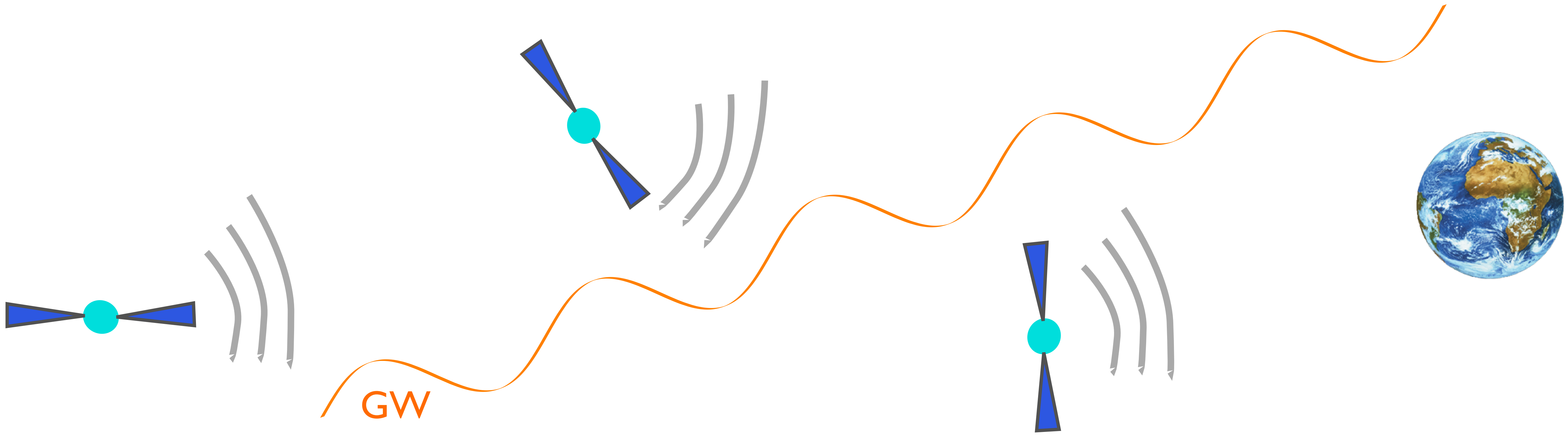

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* To find optimal detection statistic, start with timing residuals:

$$\mathbf{r} = \begin{bmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \\ \vdots \\ \mathbf{r}_l \end{bmatrix}$$

GW searches with PTAs

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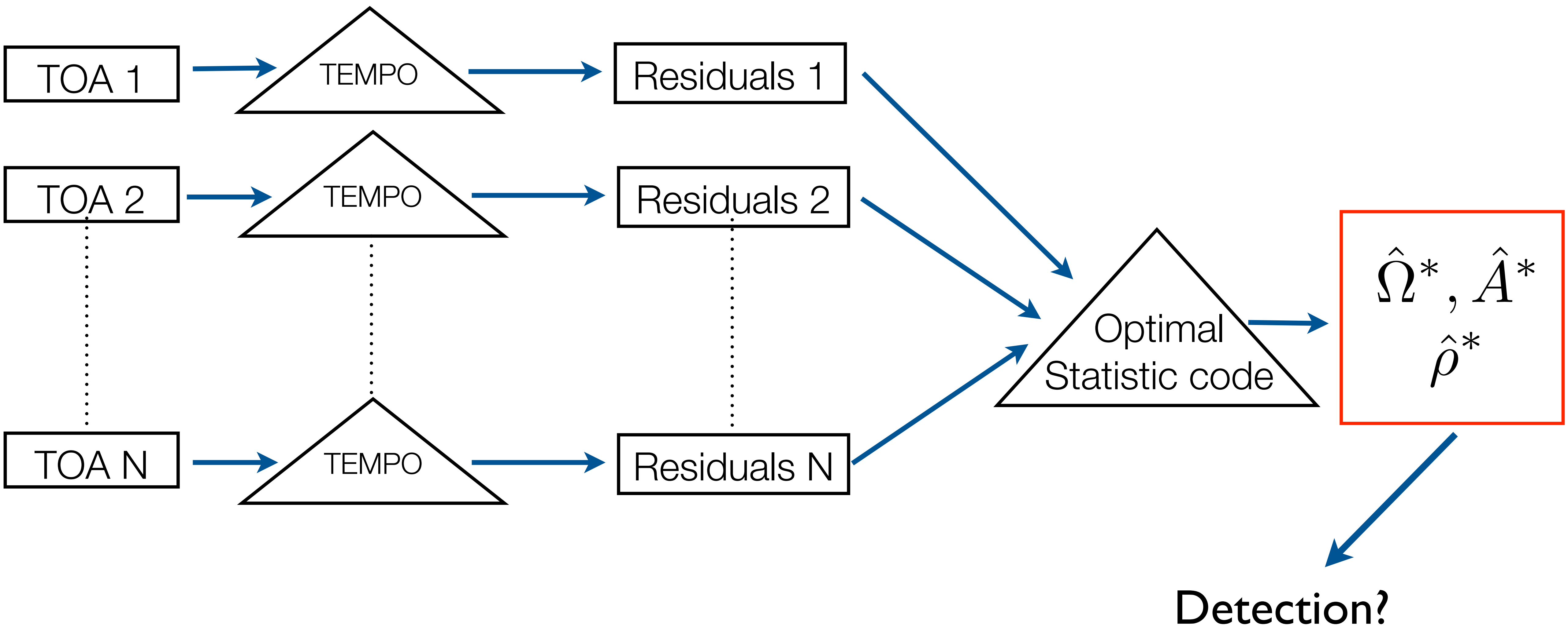
$\hat{\Omega}$	$\hat{\rho}$	A
optimal statistic	SNR	dimensionless amplitude of the power spectrum

and... a working pipeline is born!

<u>Stochastic GW detection pipeline</u>



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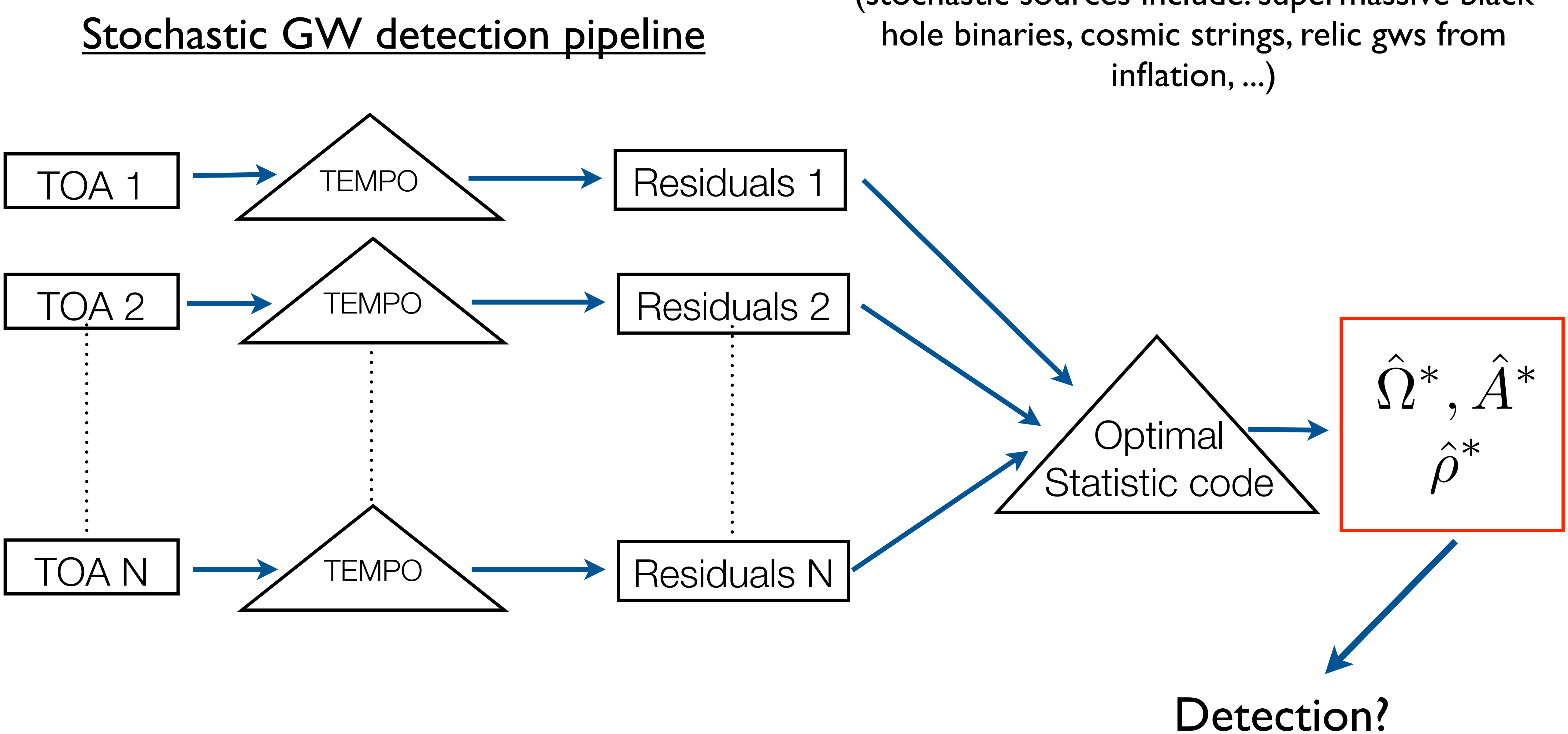

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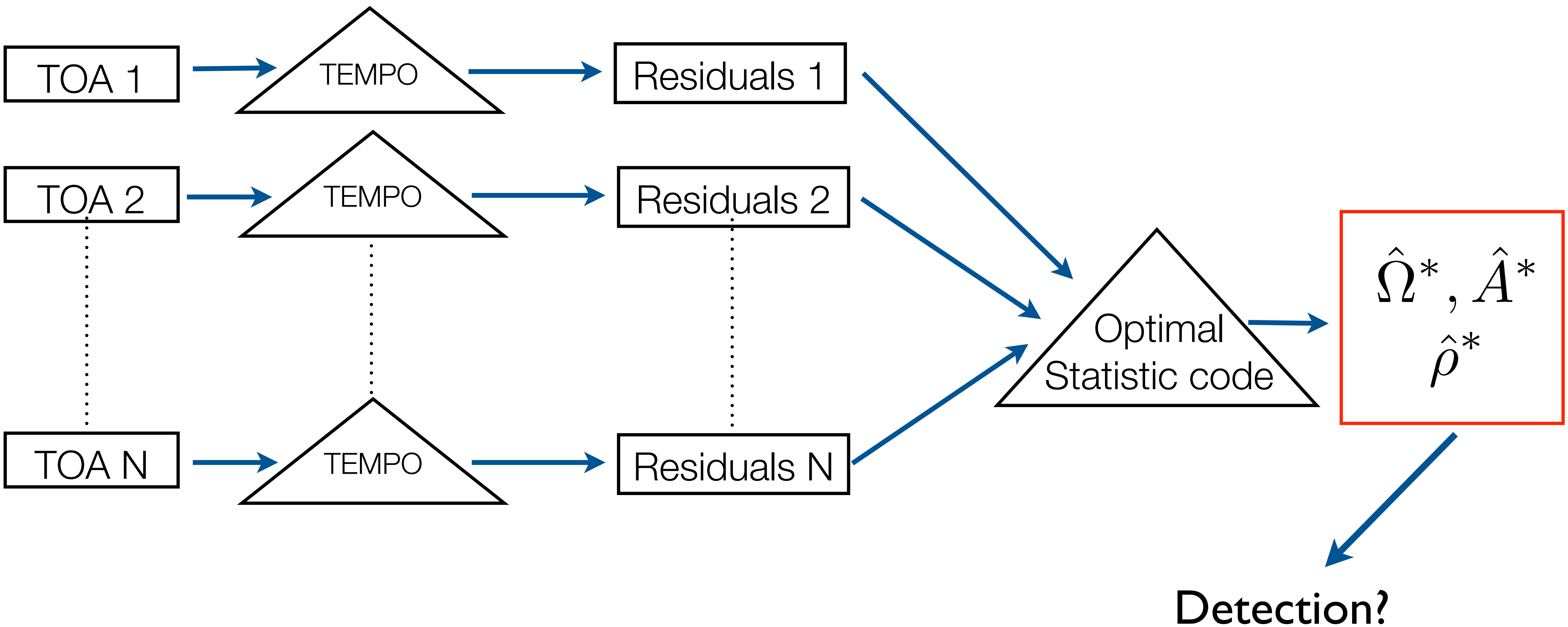

Pipelines for other GW sources also being developed
- stay tuned for Justin Ellis's talk (next)!

Upper limit work

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  van Haasteren et al. 2011 (EPTA): $A = 6 \times 10^{-15}$

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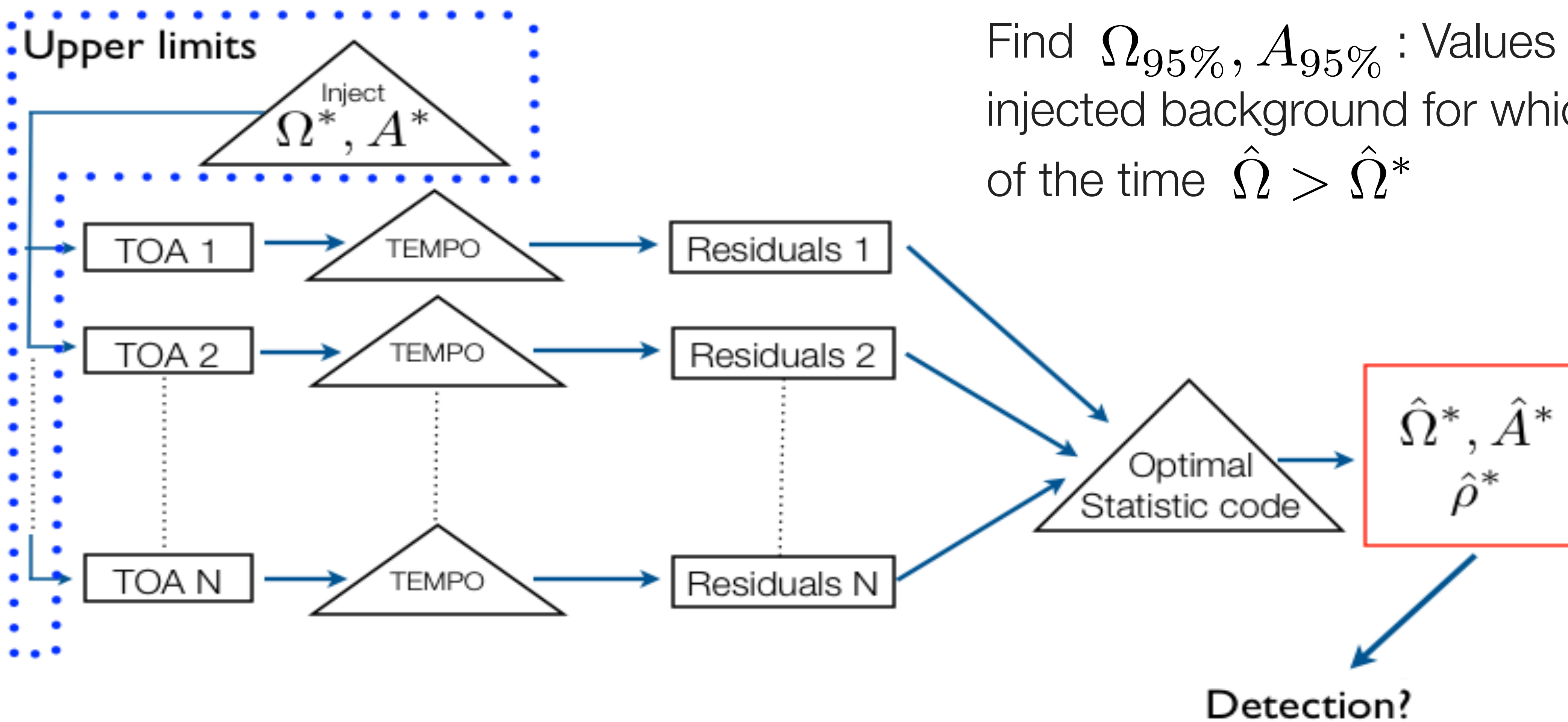
Find $\Omega_{95\%}, A_{95\%}$: Values of injected background for which 95% of the time $\hat{\Omega} > \hat{\Omega}^*$



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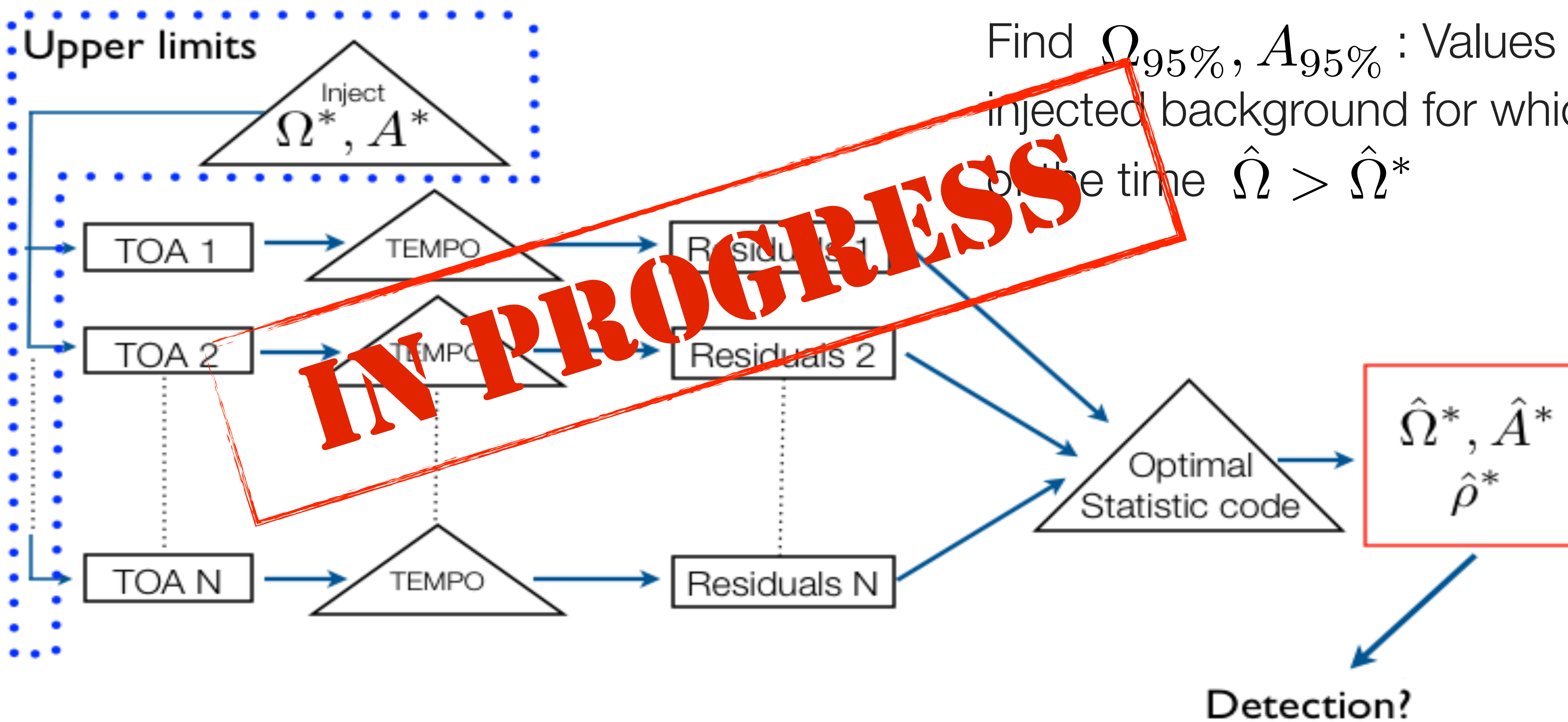

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FOUND: $A = (1.2 \pm 0.07) \times 10^{-14}$

$\mathrm{SNR} = 8.7$

Further steps

* Work on noise estimation (watch for upcoming paper by Ellis et al. 2012)
* Issues with combining data sets from different PTAs
* Need to better characterize timing noise (how much red noise is intrinsic to pulsars, interstellar medium, etc.?)
* Need to develop documentation
* Could generalize pipeline to search for extra GW polarization modes

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