The H.E.S.S rapid Gravitational Wave follow-up program

H. Ashkar[1,*], F. Brun[1], M. Füßling[2], C. Hoischen[3], S. Ohm[2], H. Prokoph[2], P. Reichherzer[1,4], F. Schüssler[1] and M. Seglar-Arroyo[1,5]

[1] IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
[2] DESY, D-15738 Zeuthen, Germany
[3] Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Strasse 24/25, D 14476 Potsdam, Germany
[4] Plasma-Astroparticle Physics, Faculty for Physics & Astronomy, Ruhr-Universität Bochum, 44780 Bochum, Germany
[5] Univ. Savoie Mont Blanc, CNRS, Laboratoire d'Annecy de Physique des Particules - IN2P3, 74000 Annecy, France

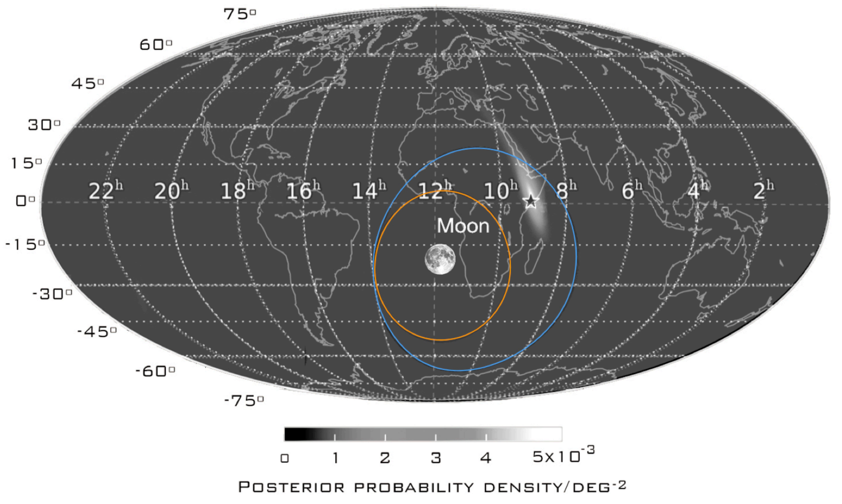
* Speaker

GW event localization problem

One of the main issues with Gravitational Waves (GW) follow-up astronomy is the poor localization of the GW events in the sky. In the following, the techniques used by the High Energy Stereoscopic System (H.E.S.S.) in order to facilitate follow-up observations and maximize the probability of the VHE counterpart detection are presented [1].

Ingredients for the solution

- **Localization maps:** containing 2D information on the probability of finding the event in the sky and 3D information on its distance.
- **Galaxy catalogs**: containing information on the local distribution of the matter in the Universe [2].
- **Telescope constraints**: In the case of H.E.S.S. the constraints are observations at low zenith angle (< 60 deg) and under moderate background light from the moon. The H.E.S.S. Field of View (FoV) used has a 1.5 deg radius.



H.E.S.S. located in Namibia can only observe the parts that fall between the orange line that represent the minimum required moon-source separation and the blue line that represent the telescopes visibility at a given time. The simulated GW localization from [3] is represented in white. The star represents the true location of the GW event. From [4].

Solution: GW follow-up strategies

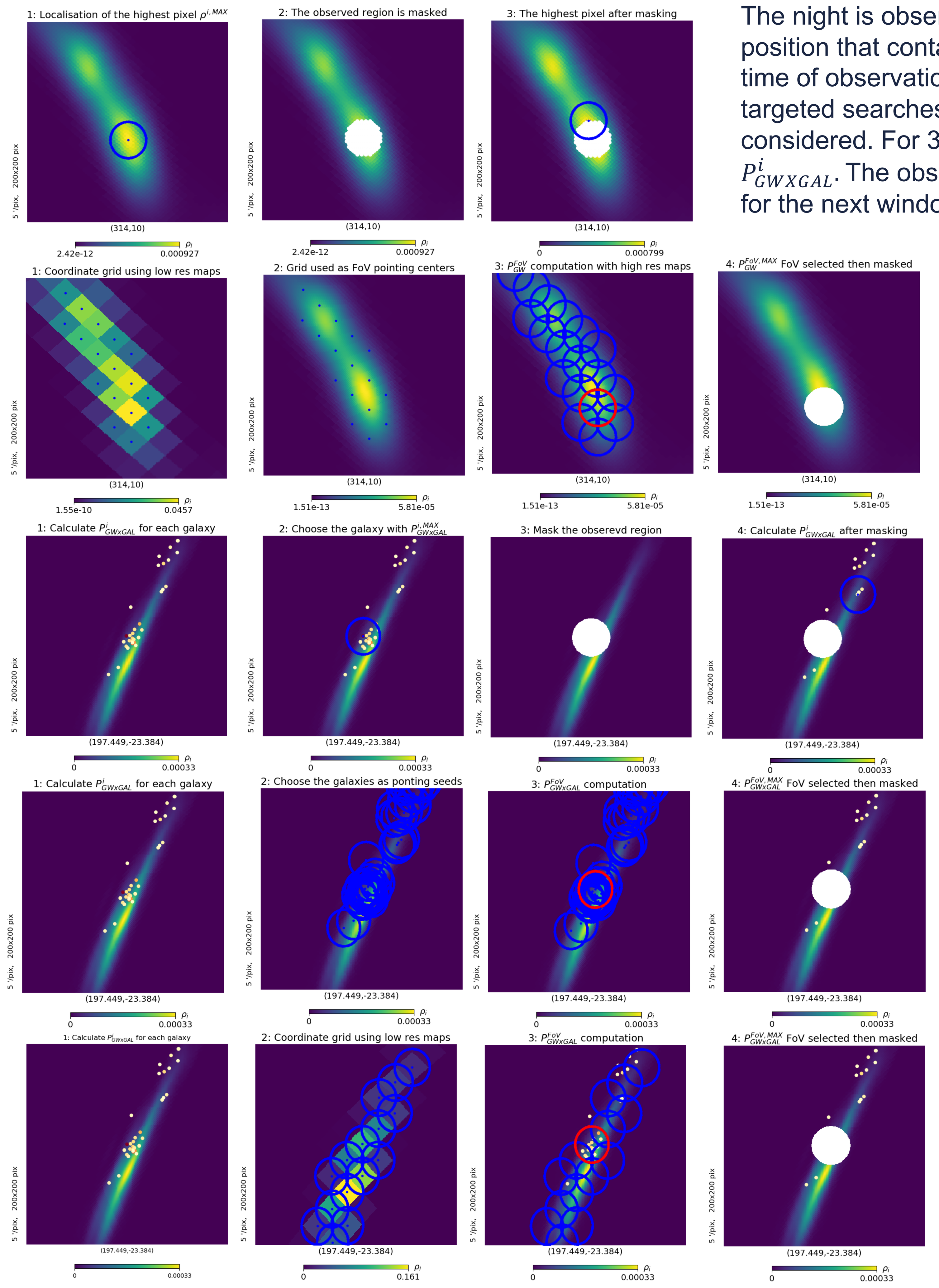
Strategy 1: 2D pixel-targeted search

Strategy 2: 2D FoV-targeted search with coordinate grid

Strategy 3: 3D galaxy-targeted search

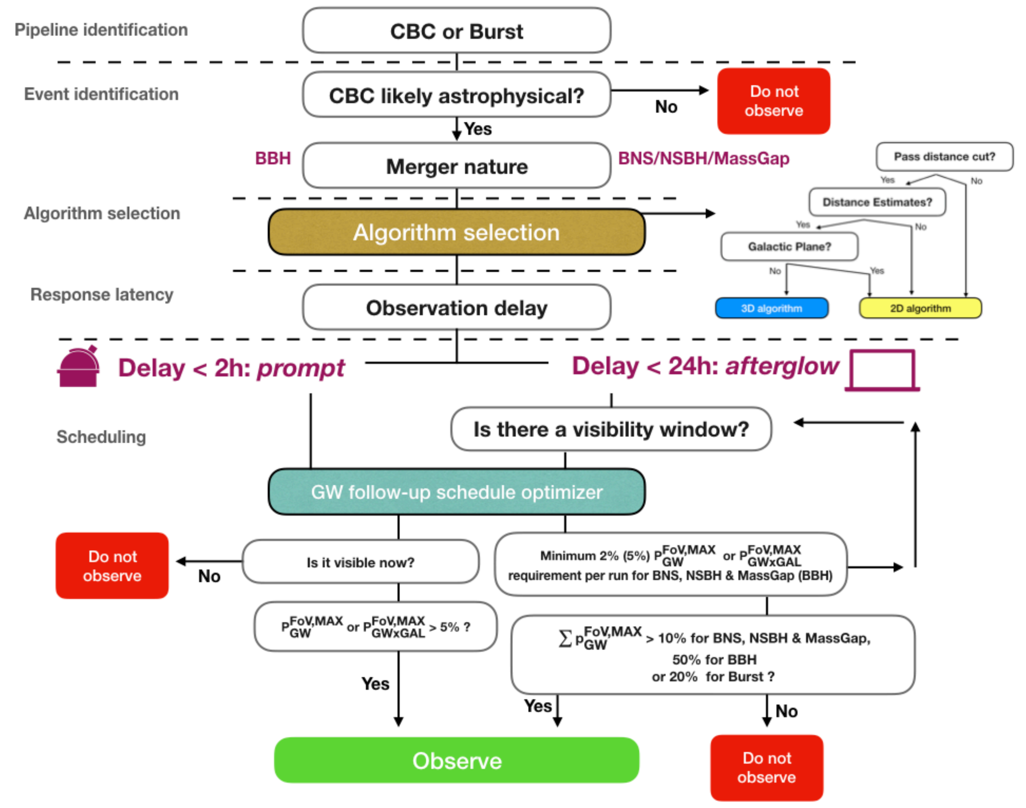
Strategy 4: 3D FoV-targeted search with galaxies as seeds

Strategy 5: 3D FoV-targeted search with coordinate grid



The night is observation time windows. For each observation window the best position that contains the highest probability P of finding the GW event at the time of observations is determined using one of the strategies. For the FoV-targeted searches, the integrated probability inside the telescope's FoV is considered. For 3D strategies, each galaxy is assigned a probability P^{i}_{GWXGAL}. The observed parts are masked and the procedure is performed again for the next window until the end of observations.

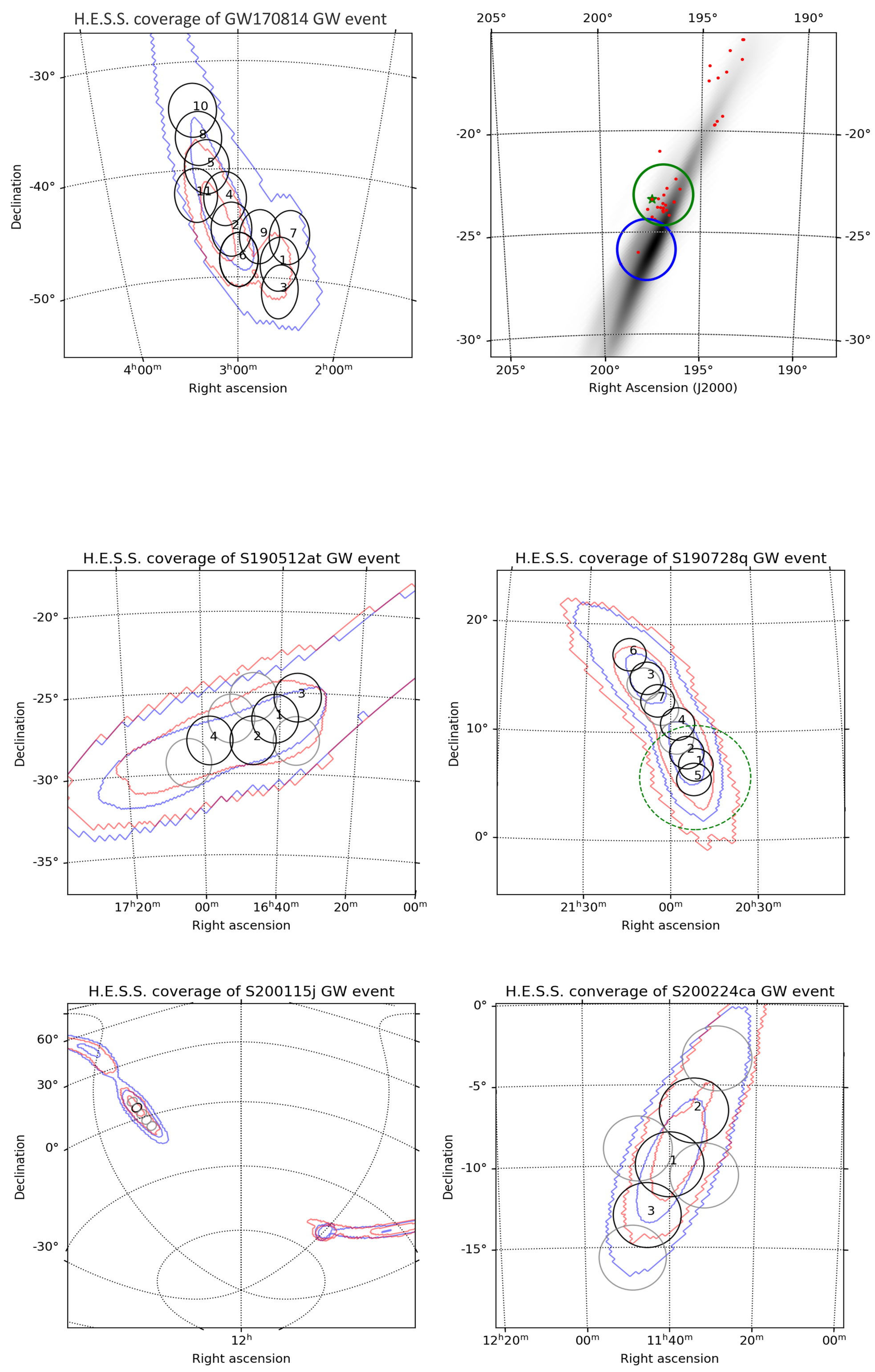
H.E.S.S. automatic GW follow-up module



The GW follow-up strategies are fully implemented in the H.E.S.S. transient system. Depending on the GW event information received, the GW follow-up module automatically filters out the non-interesting events, chooses a 2D or 3D strategy, and prepares an observation schedule depending on a series of selection cuts. If the GW alert is received during the night, prompt observations are automatically scheduled. The latency of the H.E.S.S. prompt response is estimated to be less than 1 minute for most cases (including telescope slewing). From [1].

H.E.S.S. follow-up of GW events during O2 & O3

H.E.S.S. observed 2 events during O2 and 4 events during O3 [10]. Except for GW170817 [5], the observed GW event maps lie in regions where galaxy information are not complete, therefore 2D strategies were used. In both cases the coverage achieved allowed to get valuable data in the VHE domain. From [1].



H.E.S.S.

References:
[1] Ashkar, H., et al. 2021, *JCAP*, 2021, 045
[2] Dálya, G., et al. 2018, *MNRAS*, **479**, 2374
[3] Patricelli, B. et al. 2018, GW COSMoS: Gravitational Wave COmpact binary SysteM Simulations, https://doi.org/10.6084/m9.figshare.c.4243595.v1
[4] Seglar-Arroyo, M., et al. 2019, (ICRC2019), 36, 790
[5] Abbott, B. P., et al. 2017, *ApJL*, 848, L13

Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers