Hubble constant estimation from GW and EM joint measures

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GW170817 EM and GW joint analysis

We use the Bayesian inference to process the gravitational wave (GW) and electromagnetic (EM) data of the **GW170817** event. The EM data set includes the broad-band afterglow (AG, Figure 2, top panel) and the centroid motion (C, Figure 2, bottom panel) of the relativistic jet from HST and VLBI observation. We perform 2 analyses: GW+AG+C and GW+AG, assuming a Gaussian jet for the afterglow. The GW and EM domains can be joined in one analysis as the models describing the two emissions have parameters in common, namely the viewing angle θ_v and the luminosity distance d_L.

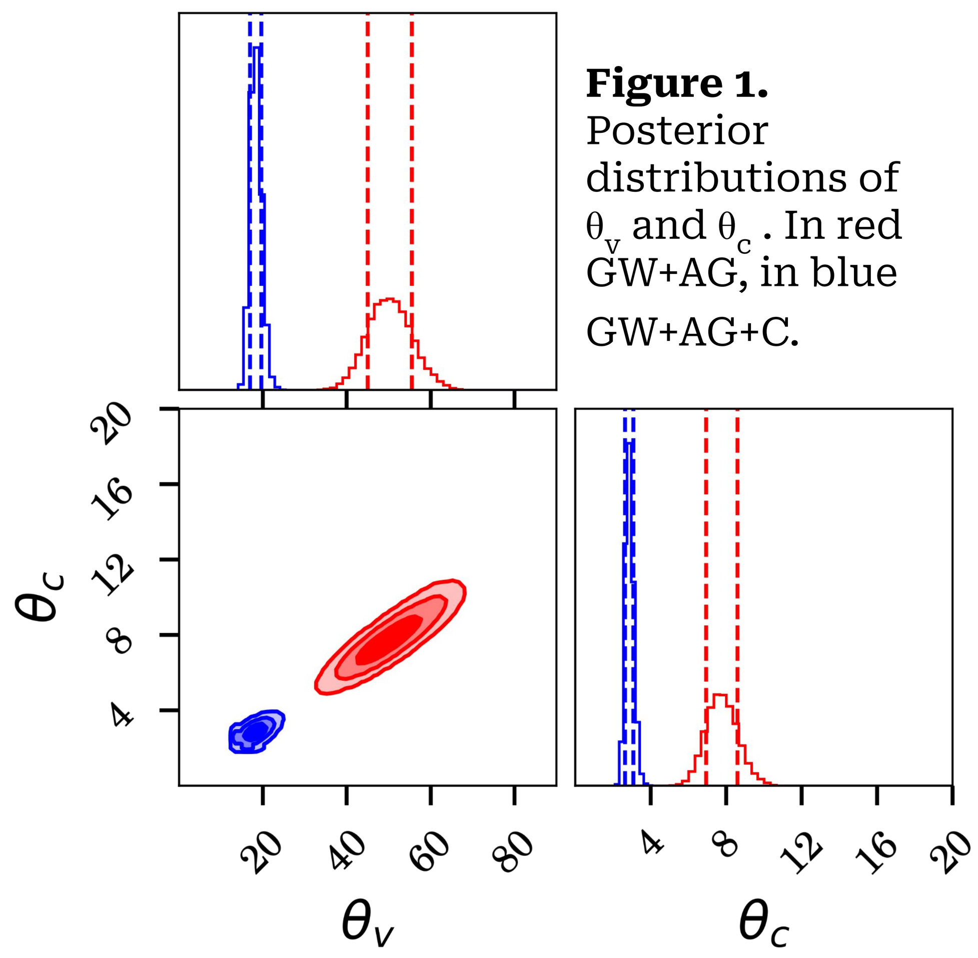

Figure 1. Posterior distributions of θ_v and θ_c. In red GW+AG, in blue GW+AG+C.

- **GW+AG+C**: the centroid motion is able to constrain very well θ_v to 18.2+1.2-1.5°, and the jet opening angle to θ_c = 2.85±0.24°;
- **GW+AG**: there are no specific constraints on θ_v, so we find θ_v= 50±5° and θ_c=7.7±0.7°.

The results are so different because of the light curve data points at late times, well captured by the GW+AG fit, but not by the GW+AG+C fit, see Figure 2 on the top. Moreover, the degeneracy between θ_v and θ_c (see Figure 1), proper of the Gaussian jet model, ties the two angles.

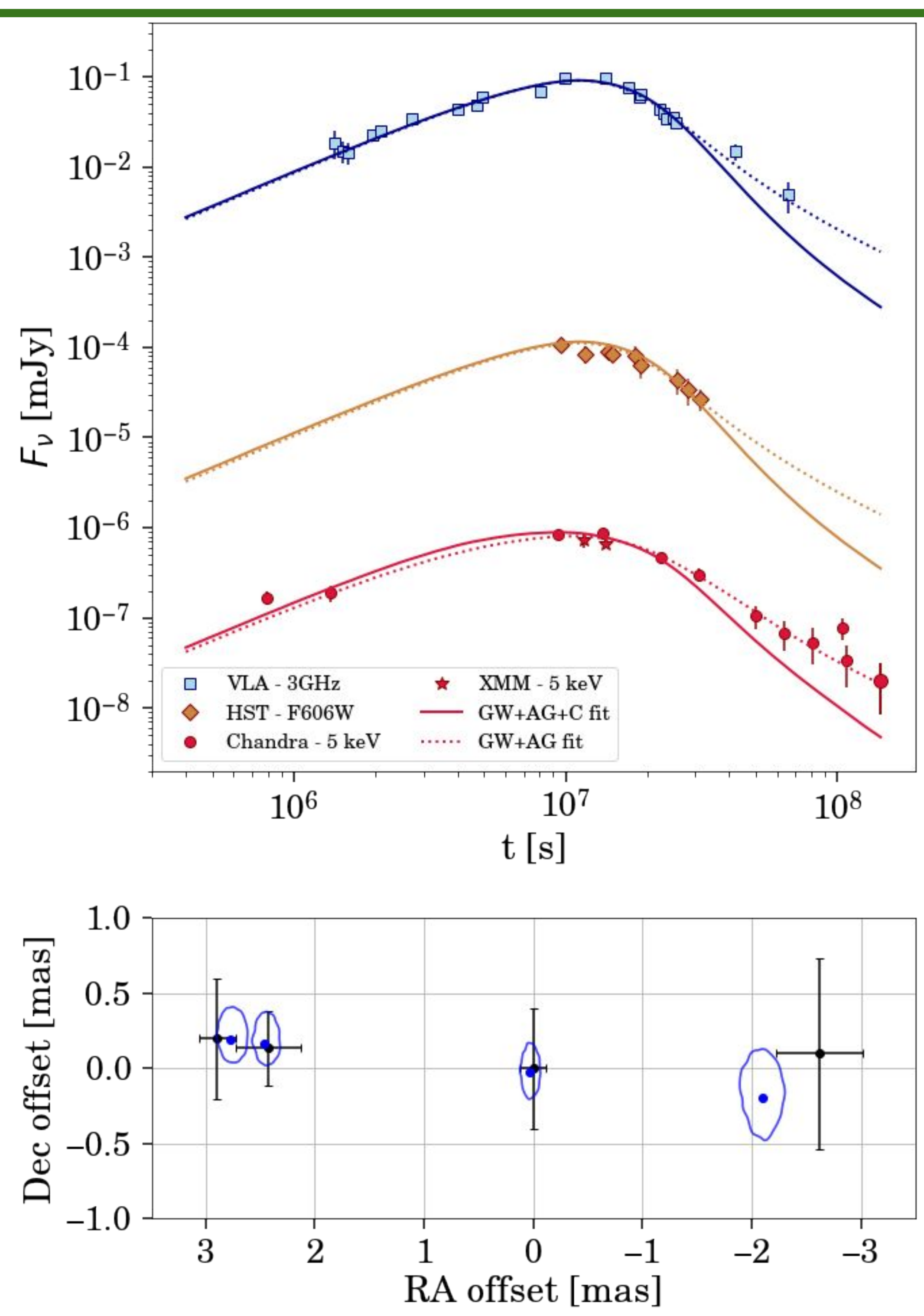

Figure 2. Top: GW170817 broad band light curve. The lines represents the GW+AG and the GW+AG+C fits. Bottom: jet centroid motion. The blue contours represent the fit of the position(GW+AG+C).

Hubble constant

From d_L, we can estimate the Hubble constant H_0 and we test its robustness depending on the data set used and on the presence of a possible late time flux excess. A strong **degeneracy between θ_v and d_L (or H_0)** is present in the GW modeling. It can be broken exploiting the independent EM messengers:

- **GW-only**: the fit leads to an Hubble constant of H_0=77+21−10 km/s/Mpc, light blue contours in the Figure 3. The almost 20% error is due to the degeneracy stated above;
- **GW+AG**: H_0 is quite high: 96+13-10 km/s/Mpc (green filled contours) because of the flux excess at late times, the degeneracy shrinks.
- **GW+AG+C**: H_0 is 69±4 km/s/Mpc. This is a ~3 times more precise H0 measurement than the GW-only standard-siren measurement. The Planck [1] and SHOES [2] (in pink and yellow below) are in agreement within 1 sigma.

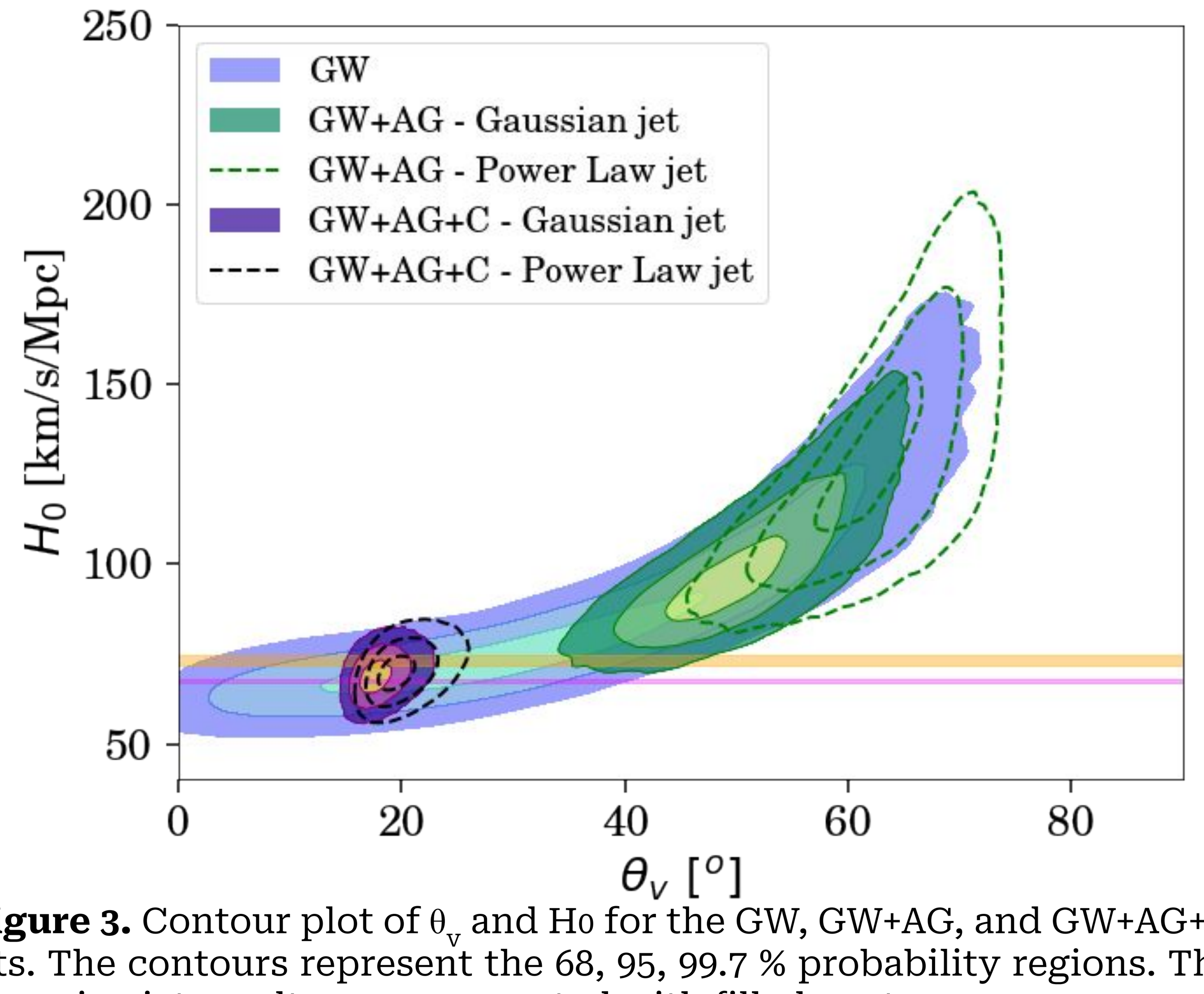

Figure 3. Contour plot of θ_v and H_0 for the GW, GW+AG, and GW+AG+C fits. The contours represent the 68, 95, 99.7 % probability regions. The Gaussian jet results are represented with filled contours.

Flux excess

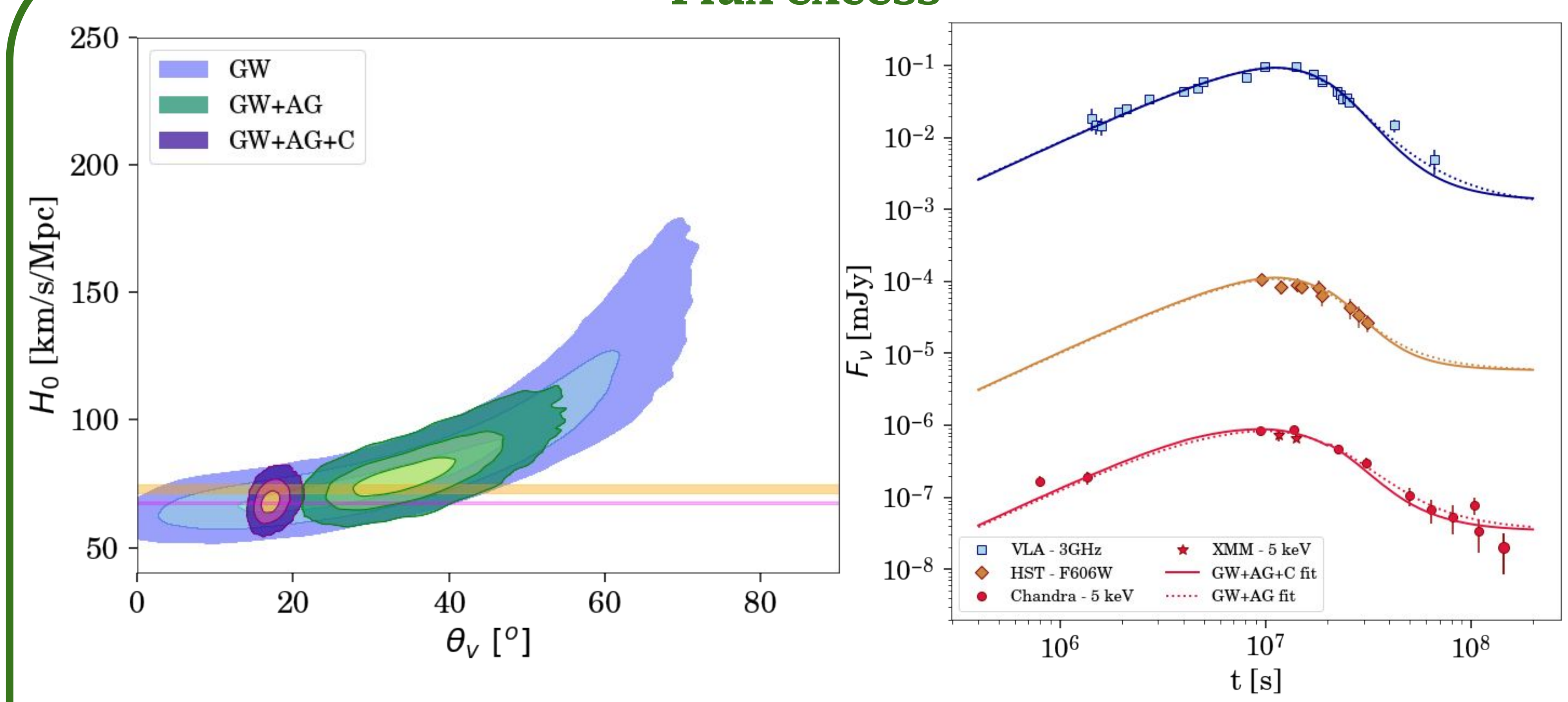

Figure 4. Right and left panels: same as Fig 2 and 3 respectively, but including an additional constant flux component in the model at late times.

In the case of GW170817, the high viewing angle preference mainly arises at late times, where there seem to be a flux excess. This is either due to some missing emission at late times in the jet model itself, or due to a **new component becoming visible**, like a kilonova afterglow or the emission from a long-lived pulsar [4]. To account for this, we fit the same data adding a constant flux component, see Figure 4, right panel.
This model can well fit the afterglow light curve both in the GW+AG and GW+AG+C case. In the **GW+AG** fit we find θ_v= 35±6° and θ_c=5±1°, in agreement with the literature on GW170817. The H_0 that we retrieve in GW+AG case is 78.5+7.9-6.4 km/s/Mpc (see Figure 4, left panel), in agreement with the GW+AG+C analysis.

Conclusions

The best H_0 precision reached here is **4 km/s/Mpc** (GW+AG+C), not good enough to prefer the Planck or SHoES H_0. More events are needed. The centroid motion is hard to detect, therefore, we will need to rely solely on the AG light curve. We estimate that, at the end of O5, we should be able to reach the SH0ES uncertainty level on H_0.

References

Gianfagna et al, 2024, MNRAS, 528, 2600−2613
[1] Planck Collab, 2020, A&A, 641, A6.
[2] Riess et al, 2019, ApJ, 876, 85.
[4] Piro et al., 2019, MNRAS, 483, 1912