Virgo HoftAR1U02 frames for ER16 and O4b

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This file is from LIGO DCC entry T2500288: https://dcc.ligo.org/LIGO-T2500288/public

The Virgo HoftAR1U02 frame files for ER16 and O4b are available in GWOSC since 26 May 2026.
The data are from GPS 1396458008 (06 Apr 2024 16:59:50 UTC) to GPS 1422118000 (28 Jan 2025 16:46:22 UTC).

The uncertainty information on the Virgo detector strain is stored directly in the frame files along with the detector strain time series. Here we described the content of these frame files, based on the Frame library (the documentation of this software library is available from the GWOSC web page).

- **Frame type: HoftAR1U02**
  - File names: V-HoftAR1U02-xxxxxxxxxxx-2000.gwf
  - Standard file duration is 2,000 s, except a few shorter files.

Times series stored in every frame

- **Strain data channel:**
  - Time series
  - Name: V1:Hrec_hoftRepro1AR_16384Hz
  - Sampling frequency: 16384 Hz
  - Format: float
- **Legacy state vector channel (veto definer files to be used for offline analyses):**
  - Times series
  - Name: V1:DQ_ANALYSIS_STATE_VECTOR
  - Sampling frequency: 1 Hz
  - Format: unsigned int
  - Bit definition: see appendix.
- **Channel storing the GPS time of the frame where the bias/uncertainty information is stored:**
  - Times series
  - Name: V1:Hrec_hoftRepro1AR_U02_lastWriteGPS
  - Sampling frequency: 1 Hz
  - Format: double
  - Values: { gps - gps%1000 }, where gps is the GPS time of the current frame. So that channel is piecewise constant, with its value updated every 1,000 seconds.

Frequency vectors stored every 1,000 frames

The frequency vectors stored every 1,000 frames describe the bias (error) and uncertainties around this bias. The values are valid in the range from 10 Hz to 5 kHz. They are given following the hrec/htrue convention[1]. See the appendix with plots showing the values stored during O4b.

- **V1:Hrec_hoftRepro1AR_U02_mag_bias**
  - frequency vector, giving the h(t) amplitude bias value following the hrec/htrue convention. Its values are hence around 1.
    - For example a value of 1.01 means that the reconstructed detector strain is overestimated by 1%.
- **V1:Hrec_hoftRepro1AR_U02_phase_bias**
  - frequency vector, giving the h(t) phase bias (in radians) value following the hrec/htrue convention. Its values are hence around 0.
    - For example a value of 0.01 means that the phase of the reconstructed detector strain is overestimated by 0.01 rad.
- **V1:Hrec_hoftRepro1AR_U02_mag_plus1sigma**
  - frequency vector, giving the +1 sigma amplitude uncertainty in addition to the amplitude bias, following the hrec/htrue convention. The values are all positive, close to 0 (in general around 0.02, which means 2% relative uncertainties on h(t) amplitude).
- **V1:Hrec_hoftRepro1AR_U02_mag_minus1sigma**
  - frequency vector, giving the -1 sigma amplitude uncertainty below the amplitude bias, following the hrec/htrue convention. The values are all negative, close to 0 (in general around -0.02, which means -2% relative uncertainties on h(t) amplitude).
- **V1:Hrec_hoftRepro1AR_U02_phase_plus1sigma**
  - frequency vector, giving the +1 sigma phase uncertainty in addition to the phase bias, following the hrec/htrue convention. The values are all positive, close to 0 (in general around 0.02, which means 0.02 rad uncertainties on h(t) phase.
- **V1:Hrec_hoftRepro1AR_U02_phase_minus1sigma**
  - frequency vector, giving the -1 sigma phase uncertainty below the phase bias, following the hrec/htrue convention. The values are all negative, close to 0 (in general around -0.02, which means -0.02 rad uncertainties on h(t) phase).

Appendix: definition of the state vector

The state vector is a binary number whose bits are defined in [LIGO-P2000137-v1] and [VIR-0156A-18] . Their definition is reminded here for completeness.

If the bit #n is at 1, then the statement #n is true.

- bit 0: h(t) was successfully computed
- bit 1: science mode button is pushed
- bit 2: observation ready
- bit 3: h(t) was produced by the calibration pipeline
- bit 4: calibration filters settled in

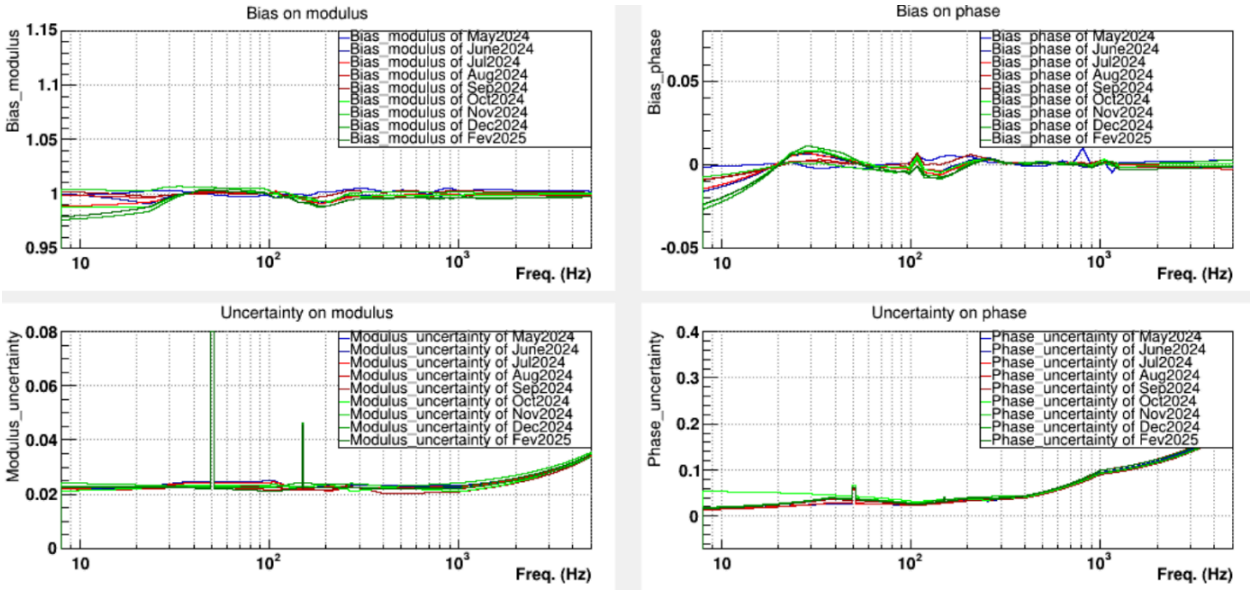
[1] The error and uncertainties provided by LIGO and KAGRA during O4 are following the inverse convention htrue/hrec.

- bit 5: No stochastic HW injections
- bit 6: No CBC HW injection
- bit 7: No burst HW injection
- bit 8: No HW injections for detector characterization
- bit 9: No continuous wave HW injection
- bit 10: good data quality (CAT1 type)
- bit 11: interferometer is locked
- bit 12-32: not used

In practice, the data are good to be analysed if all the first 12 bits are equal to 1 (the equivalent decimal value is 4095).

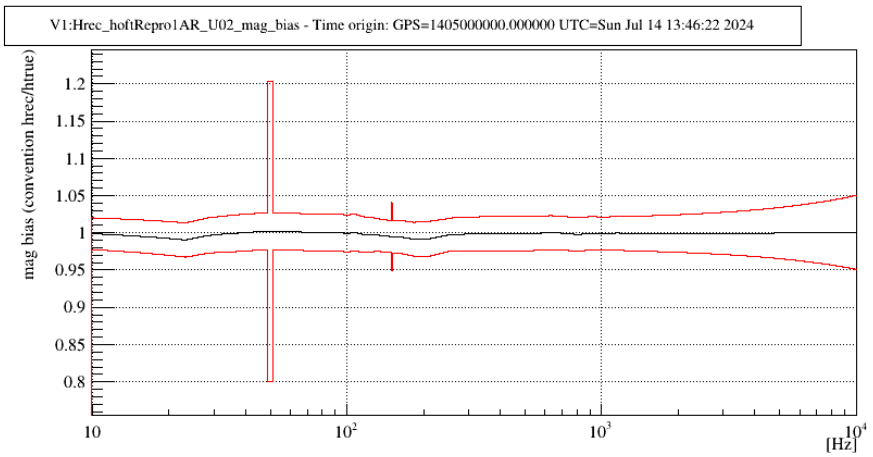
Appendix: bias and uncertainties during O4b

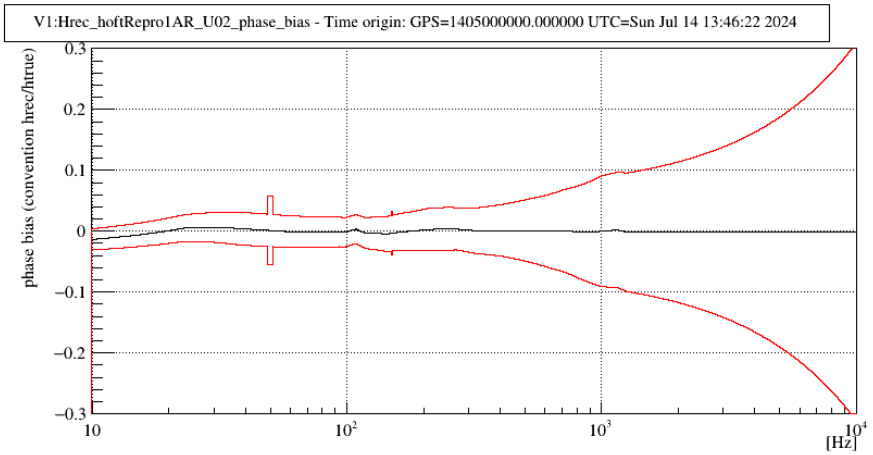
The following figure shows the frequency-dependent bias (top) and uncertainties (bottom) on the strain amplitude (left) and phase (right). They have been computed over nine periods of four to five weeks each (phase given in radians).
They are given following the convention hrec/htrue.



From these values, the bias and uncertainty band around the bias can be reconstructed as shown for example in the following figure (phase in radians). Note that the values from frequencies outside the range 10 Hz-5 kHz are not reliable. For example, the band on the amplitude is estimated as:

- Upper level: mag_bias + mag_plus1sigma (with prefixes V1:Hrec_hoftRepro1AR_U02_)
- Lower level: mag_bias + mag_minus1sigma (with prefixes V1:Hrec_hoftRepro1AR_U02_)





Appendix: list of missing frames

The distributed data are from GPS 1396458008 (06 Apr 2024 16:59:50 UTC) to GPS 1422118000 (28 Jan 2025 16:46:22 UTC). There are some missing frames in the period, which are between frame files and not inside files. All the periods are during segments with the Virgo detector not in Observing Mode:

- From 10 September 2024 09:13:42 UTC: 1409994840 to 1409994862
- From 10 September 2024 09:17:45 UTC: 1409995083 to 1409995099
- From 17 September 2024 06:57:58 UTC: 1410591496 to 1410591671
- From 22 October 2024 06:36:22 UTC: 1413614200 to 1413614287