CGWAS 2015 Problem Set - Transient Astronomy
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Useful web tools

- NASA WebPIMMS - `http://heasarc.gsfc.nasa.gov/cgi-bin/Tools/w3pimms/w3pimms.pl`
- Cosmology calculator - `http://www.astro.ucla.edu/~wright/CosmoCalc.html`

EM counterparts of compact binary coalescences

NS-NS and BH-NS mergers are the "golden" sources for ground-based GW detectors such as the advanced LIGO and Virgo. In today's lectures we have discussed several of the possible electromagnetic counterparts that may be associated with these systems: kilonovae, supernovae, and (on- / off-axis) GRBs. For each of these classes of transients:

1. Briefly describe characteristic frequencies(s) and timescale(s) of their EM emission;
2. Based on the answers above, name a few observational facilities you would use to observe them.

Observing short GRB X-ray afterglows

Gamma-ray bursts (GRBs) are observed once per day, somewhere on the sky. The gamma-ray event typically lasts for a few seconds ($< 2\,\mathrm{s}$ for short GRBs). Post-GRB emission (called "afterglow") is thought to result from the deceleration of a relativistic expanding and radiating jet. Let us consider a fiducial short GRB with: on-axis isotropic X-ray (0.3-10 keV) luminosity at 11 hr post-burst of $L_X(11\,\mathrm{hr}) \approx 8.5 \times 10^{43}\,\mathrm{erg\,s^{-1}}$; isotropic kinetic energy $E_{iso} \approx 10^{51}$ erg; jet half-opening $\theta_j \approx 10^{\circ}$; and expanding in an ISM of constant density $n \approx 0.15\,\mathrm{cm^{-3}}$. Assume this fiducial short GRB went off at $d_L \approx 200$ Mpc (the average advanced LIGO-Virgo horizon distance for NS-NS in-spirals):

1. Calculate the on-axis absorption-corrected flux F_X at 2 d after the burst, knowing that $F_X(t) \propto t^{-\alpha_X}$ with $\alpha_x \approx 1.2$ for $t \lesssim t_{break}$ and $\alpha_x \approx 2.2$ for $t > t_{break}$, where $t_{break} \approx 1\,\mathrm{d}(\mathrm{E_{iso}}/10^{51}\,\mathrm{erg})^{1/3}(\theta_\mathrm{j}/10\,\mathrm{deg})^{8/3}(\mathrm{n}/0.15\,\mathrm{cm^{-3}})$. What is t_{break}? Explain.
2. Show that, in the photon-count-limited regime (when the exposure time T_{exp} is small enough that less than one background photon is expected), the limiting (absorption corrected) X-ray flux for a detection with *Swift/XRT-PC* as a function of T_{exp} can be written as: $F_{X,lim} = 1.5\times10^{-12}\mathrm{erg\,cm^{-2}s^{-1}}\left(\frac{290\,\mathrm{s}}{\mathrm{T_{exp}}}\right)$, if 12 source counts are required to claim a detection. (Hint: use WebPIMMS to find the conversion between *Swift/XRT* count rate and flux; assume a

photon spectral index $\Gamma_X \approx 2$ and a typical Hydrogen column density $N_H \approx 10^{20}\,\mathrm{cm}^2$).

3. If we are observing the short GRB slightly off-axis, i.e. $\theta_{obs} \approx 2\theta_j$, we can roughly estimate the off-axis afterglow peak time as $t_{peak} \approx 2 \times t_{break}$, and the off-axis afterglow peak flux as $F_X(\theta_{obs} = 2\theta_j, t_{peak}) \approx 0.1 \times F_X(\theta_{obs} = 0, 2 \times t_{break})$[1]. What exposure time would you need to detect such off-axis X-ray afterglow with *Swift/XRT* at t_{peak}?

4. Assume we want to search for the afterglow from a fiducial short GRB in the large error-box provided by the advanced LIGO-Virgo. Consider a GW-reconstructed position of $\approx 30\,\mathrm{deg}^2$. Knowing that the *Swift/XRT* FOV is $\approx 0.15\,\mathrm{deg}^2$ and that the effective total time available for observing each day is $\approx 30\%$ of the day (mainly due due to Earth occultation during each orbit), what fraction of the GW error-box can you observe within 2 d since the trigger, down to a flux sensitivity sufficient to detect off-axis afterglows with $\theta_{obs} \lesssim 2\theta_j$? (For simplicity, you can neglect the time needed for slewing between fields.)

[1] These are rough estimates based on comparison of analytical models and more accurate numerical simulations.