Homework Assignment1

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1. COMPILE YOUR CODES

Succeed compiling Cosimo's ray tracing codes. Try following different pairs of parameters and plot following two groups of emission lines. (Feel free to use your favorite and most familiar plotting tool.)

plot 1.1

3 lines $a_* = 0$, $i = 10$, 30, 70 deg

plot 1.2

11 lines $a_* = [0.0, 0.9]/0.1$, 0.99, $i = 30$ deg

2. SPECTRUM OUTPUT AND EMISSIVITY INDEX

Read Chap 2.1, 2.2, 2.4 in T. Dauser(2013) and following parts in main.cpp, answer following questions.

/* —– solutions to the fourth-order RKN method —– */

/* — integration - part 1 — */

/* — integration - part 2 — */

/* — print spectrum — */

2.1 Emissivity index

Find out which variable in your code is this so called emissivity index in T. Dauser(2013). Redefine it as a broke powerlaw, replot 1.1 with $q1 = 10$, $r_{break} = 9m$ and explain why when r is very large, the emissivity $q = 3$.

Hint 2.1.1

Broke powerlaw index is defined as

$$q = \begin{cases} q1, & r < r_{break} \\ 3, & r > r_{break} \end{cases} \tag{1}$$

Hint 2.1.2

when r is very large, the spacetime is approximated as flat.

2.2 Spectrum output

Plot an emission line model a_*=0.5, i=45 deg with an energy resolution delta(E)=0.01keV.

Bonus Q 2.2.1

Think about how to add redshift parameter to your line. You may refer to https://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/XSmodelGaussian.html

Bonus Q 2.2.2

Think about how to arrange channels in log scale.(Hint: Redefine $E_{obs}[i]$. This is important as most of reflection models in xspec would prefer to have log channels instead of linear ones.)

3. Kα IRON LINE

3.1 Innermost stable circular orbit(ISCO)

1. Remind /* —– solutions to the fourth-order RKN method —– */part in ”main.cpp”
2. Plot 3.1.1 $ISCOvs.Spin$. Hint: ISCO is returned in ”findisco.cpp”
3. Compare plot 3.1.1 and plot 1.2. Explain the difference among different models with different spin parameters.

3.2 Viewing angle

1. Recall the X-ray emission line you detected in your lab course. Scratch an iron line from a static source in your reference frame.

   Refer to http://phylab.fudan.edu.cn/doku.php?id=exp:xray

2. When the source is moving fast enough in flat spacetime, what the emission line should look like? Scratch an iron line from this source.

3. When the source is moving fast near black hole, what the emission line should look like? Compare your results with plot 1.1 and try to explain the difference.

4. REPRODUCE SPIN-MEASUREMENT PROCESS

4.1 Add powerlaw continuum to iron line model

Add a powerlaw component to your iron line models in 1.1, meeting following requirement. And normalize your spectrum by total photon number $N_{tol} = 10^4$.

1. Fix powerlaw index as 2.

2. Change normalization until the total count of powerlaw photons N_{pl} between $1.0keV$ and $10keV$ is 100 times the number of iron line photons N_{Fe}.

   Powerlaw refer to https://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/XSmodelPowerlaw.html

3. Bonus Q: Calculate the equivalent width of your iron line in all 11 models of 1.1.

   Equivalent width refer to https://en.wikipedia.org/wiki/Equivalent_width

4.2 Constrain spin of one model χ^2

1. Fix emissivity index $q = 3$. Make model $a_* = 0.5, i = 45deg$ with required powerlaw above as your reference and calculate χ^2 between this reference model and each other one in 1.2. Plot 4.1 "χ^2 vs. a_*"

χ^2 is defined in eq4.3 and eq4.5 in J. Jiang et al. (2015).

2. Fix emissivity index $q = 3$. Try to free viewing angle i, by varying it between $43deg$ and $47deg$. Minimize $\chi 2^2$ with varying i and plot 4.2 "χ^2 vs. a_*" again.

3. Bonus Q: What if you free more parameters, such as emissvity index by a broke powerlaw in 2.1.1, normalization of iron line N_{Fe} in your first step and even considering different total photon count N_{tol}.