第12回 X線放射機構(1)

2021年6月15日　5:03

Radiation process 輻射機構

「Radiative Process in Astrophysics」 Rybicki & Lightman ↑ Bible

1. Optical Depth 光学的厚さ（τ 無次元）

1. Explain concept of the optical depth

$I \rightarrow [\;] \rightarrow Ie^{-\tau_\nu}$

specific intensity $[erg/s/cm^2/Hz/str]$　光学的厚さ（吸収の度合い）

$\tau_\nu \gg 1 \Rightarrow Ie^{-\tau_\nu} \Rightarrow 0$ 光学的に厚い optically thick

$\tau_\nu \ll 1 \Rightarrow I_\nu(1-\tau_\nu)$ 光学的に薄い optically thin

2. Express the optical depth with several different combinations of physical parameters

$\tau = L[cm]\,\alpha[cm^{-1}]$ ← 吸収係数

$= N_H[cm^{-2}] \cdot \sigma_H[cm^2]$ ← 水素原子1個あたりの断面積；水素柱密度 (column density)

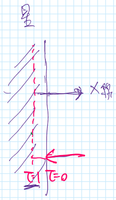
$= \kappa[cm^2/g] \cdot \rho[g/cm^3]\,L[cm]$（opacity，質量密度）

平均自由行程 $l[cm] = \frac{1}{\alpha}$

$\tau = L \cdot \alpha = 1$

$L = \frac{1}{\alpha}$

光学的厚みが1になる距離



3. When photons interact with matter, what will happen? State the **two** fundamental processes.

吸収 absorption と 散乱 scattering

吸収 → 光が吸収される（消滅する）　τ_a 吸収の光学的厚み

散乱 → 光が消滅しない　τ_s 散乱の光学的厚み

2. Radiative Transfer

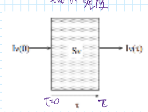
1. Formulate the simplest **radiative transfer equation** in the uniform medium, where the **specific intensity** is Iν [erg/s/cm²/Hz/str] and the **source function** is Sν [erg/s/cm²/Hz/str], and solve it.

輻射強度　源泉関数

プランク関数

$$B_\nu(T) = \frac{2}{c^2}\frac{h\nu^3}{e^{h\nu/kT}-1}\;[\mathrm{ergs/s/cm^2/Hz/str}]$$

同じ単位　覚える！



$$\frac{dI_\nu}{d\tau_\nu} = -I_\nu + S_\nu$$

$\int \frac{dI_\nu}{S_\nu - I_\nu} = \int d\tau_\nu \qquad -\ln(S_\nu - I_\nu) = \tau_\nu + C$

$S_\nu - I_\nu = Ae^{-\tau_\nu} \qquad I_\nu = S_\nu + Ae^{-\tau_\nu}$

$\tau = 0 \quad I_\nu = I_\nu(0) = S_\nu + A$

$A = I_\nu(0) - S_\nu$

$I_\nu = S_\nu + (I_\nu(0) - S_\nu)e^{-\tau_\nu}$

$= I_\nu(0)e^{-\tau_\nu} + S_\nu(1-e^{-\tau_\nu})$

$S_\nu = 0 \Rightarrow I_\nu = I_\nu(0)e^{-\tau_\nu}$

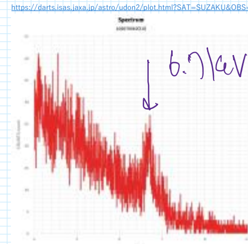
$\tau_\nu \gg 1$（光学的に厚い）$\Rightarrow I_\nu = S_\nu$

2. Explain the physical meaning of the radiative transfer equation *intuitively*. 直感的

$S_\nu > I_\nu \quad \frac{dI_\nu}{d\tau_\nu} > 0 \Rightarrow I_\nu$が増加する

$S_\nu < I_\nu \quad \frac{dI_\nu}{d\tau_\nu} < 0 \Rightarrow I_\nu$が減少する $\Rightarrow I_\nu$はS_νに近づく

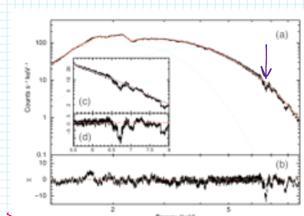
https://darts.isas.jaxa.jp/astro/udon2/plot.html?SAT=SUZAKU&OBS=402070010&REGION=%27circle(748,765,45)%27&VER=3.0



6.7keVの輝線　He-likeの鉄

Cir X-1 when dim (by Suzaku) 暗いとき

https://heasarc.gsfc.nasa.gov/docs/nicer/science_nuggets/20181220.html



6.7keVの吸収線

Cir X-1 when bright (by NICER) 明るいとき

τ_νは $E = 6.7$keVでだけ大きい

3. What will be the solutions of the radiative transfer equation for the optically *thick* limit and the *thin* limit?

$\Rightarrow I_\nu = I_\nu(0)(1-\tau_\nu) + S_\nu\tau_\nu$（光学的に薄い場合）

X射線放射がない場合 $I_\nu \simeq S_\nu\tau_\nu$

X線が強い場合 $I_\nu \simeq I_\nu(0)(1-\tau_\nu)$

6.7keVの輝線

4. Explain the difference of the **thermal emission** and the **blackbody emission**

熱的放射 $S_\nu = B_\nu$ $\xrightarrow{\tau \gg 1}$ 黒体放射 $I_\nu = B_\nu$

光学的に薄い

5. In the optically thin limit, consider the two cases when there is a strong input emission into the medium, and there is no input emission. What do you observe in these two cases?

6. Indicate that intensity of any thermal emission does NOT exceed that of the blackbody emission.

$I_\nu = I_\nu(0)e^{-\tau_\nu} + B_\nu(1-e^{-\tau_\nu}) \le B_\nu$

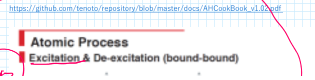
$\tau_\nu \gg 1 \quad I_\nu = B_\nu$

$\tau_\nu \ll 1 \quad I_\nu(0)(1-\tau_\nu) + \tau_\nu B_\nu \ll B_\nu$

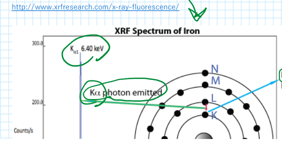
3. Absorption lines and emission lines

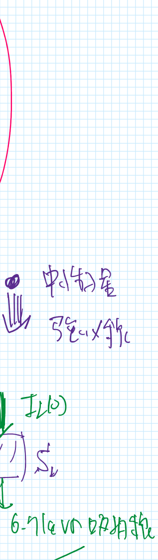
1. Explain the process of producing absorption lines and emission lines

https://github.com/tenoto/repository/blob/master/docs/AHCookBook_v1.0.pdf



http://www.xrfresearch.com/x-ray-fluorescence/

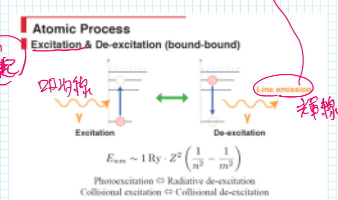


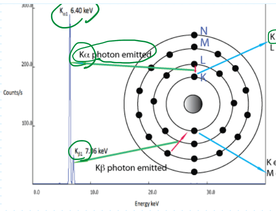

中性子星
強い磁場
$E_L(0)$
S_L
6-7keV 吸収線

3. Absorption lines and emission lines

1. Explain the process of producing absorption lines and emission lines

https://github.com/tenoto/repository/blob/master/docs/AHCookBook_v1.02.pdf





2. Explain the two different mechanisms of producing emission lines

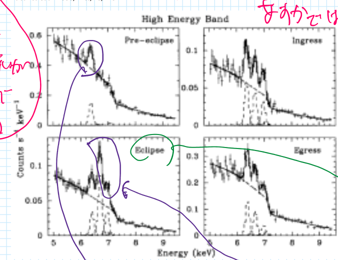
輝線 { recombination line 再結合線 ← 高温電離したプラズマ
fluorescence line (蛍光輝線) ← 冷たい物質

3. What are the energies of the Fe-K emission lines for neutral iron atom (fluorescent line), He-like iron ion, and the H-like iron ion?

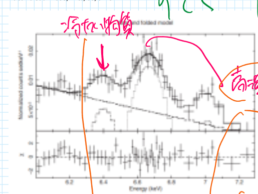
中性 6.4keV
He-like 6.67keV
H-like 6.97keV

4. Show examples of the observations where these three Fe emission lines are detected simultaneously.

Ebisawa et al. 1996, PASJ, 48, 425



Ebisawa et al. 2008, PASJ, 60, S223



4. How to express X-ray energy spectra?

1. Explain different ways of expressing the energy spectra?

エネルギースペクトルの異なる表示方法に慣れて下さい

2. Often "νf_ν plot" (= $E F_E$ plot) is adopted to express energy spectra. What is this? What is the merit of using νf_ν plot?

f_ν [erg/s/cm²/keV]

$$\text{flux} = \int_{E_{min}}^{E_{max}} f_\nu \, d\nu \quad [\text{erg/s/cm}^2] \; E_{min} \sim E_{max}$$

$$= \int \nu f_\nu \frac{d\nu}{\nu}$$

$$= \int \nu f_\nu \, d(\ln \nu)$$

$$\propto \int \nu f_\nu \, d(\log \nu)$$

面積がフラックスになる

https://www.isas.jaxa.jp/home/ebisawalab/ebisawa/TEACHING/2016Note.pdf page 27

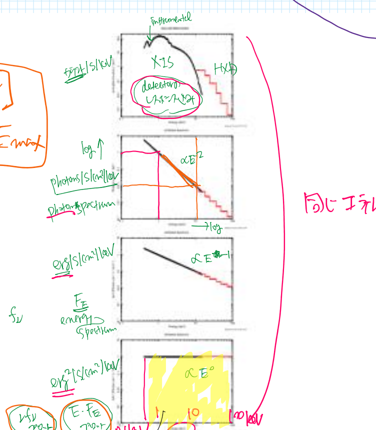


Figure 2.6: Energy spectra displayed in different units. The model is a power-law with E^{-2} [photons/s/cm²/keV]. In the top (counts/s/keV), Suzaku XIS (0.4-12 keV) and PIN (10-80 keV) instrumental responses are adopted.

同じエネルギースペクトル

E^{-2} [photons/s/keV/cm²]
べき関数
power-law

なのか1本の太い
輝線がわからなかった

りなくて エラーが出てなかった)

鉄 複数