MODELING THE REDSHIFT AND ENERGY DISTRIBUTION OF FAST RADIO BURSTS

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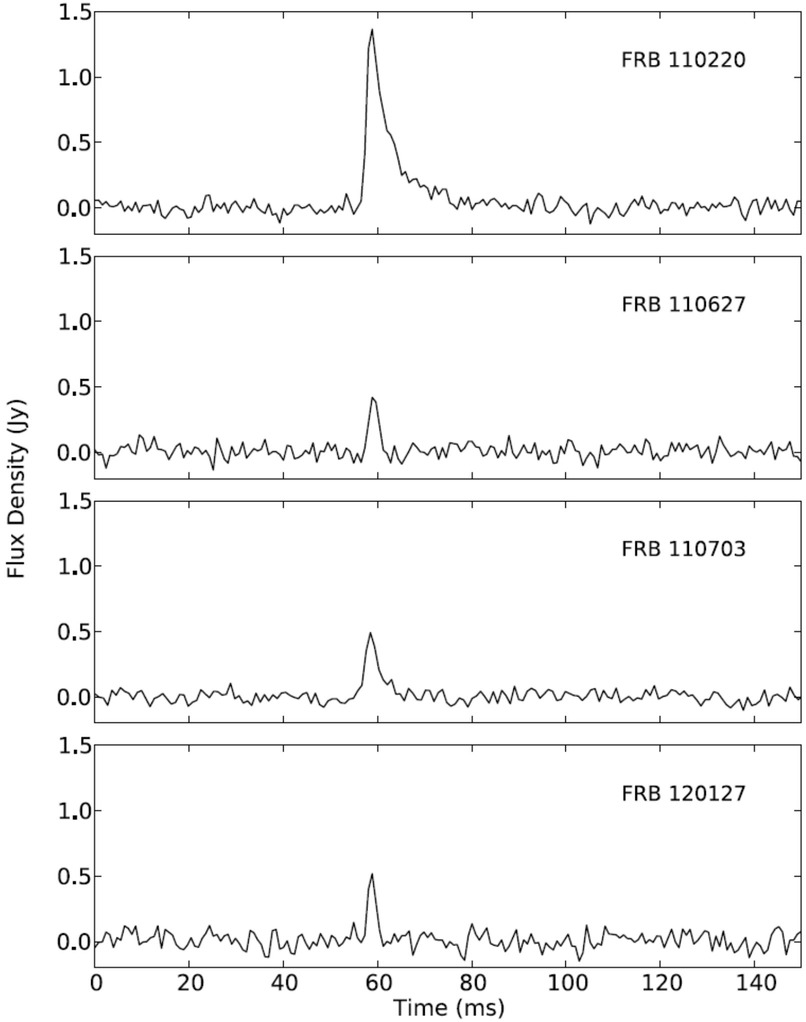
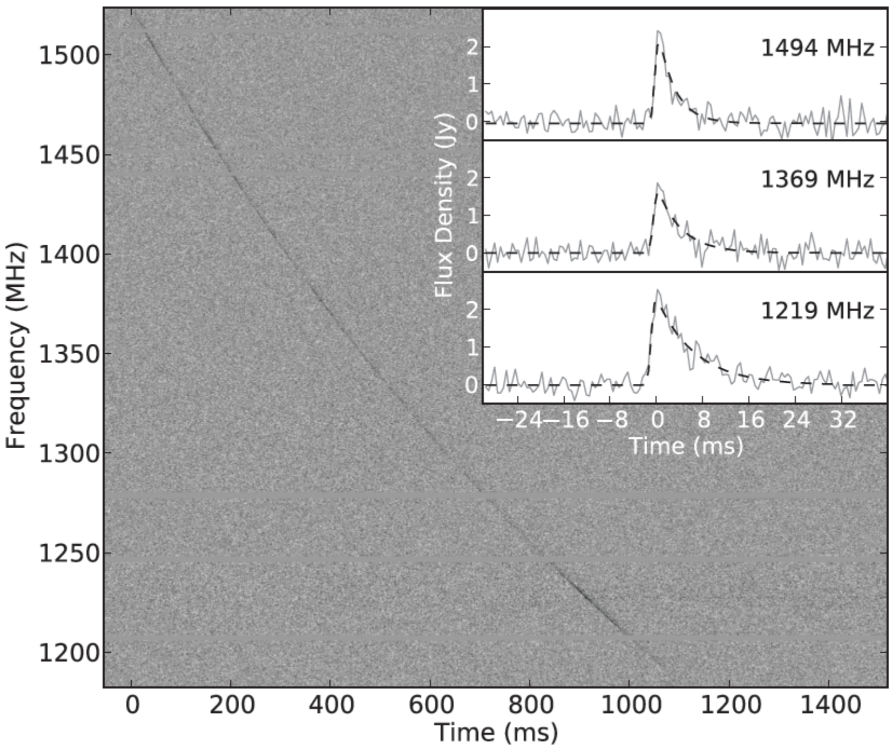
主要内容

- FRBs
- 数据
- FRB模型限制
  - 恒星相关模型
  - 超导宇宙弦模型
- 总结

1. Fast Radio Bursts





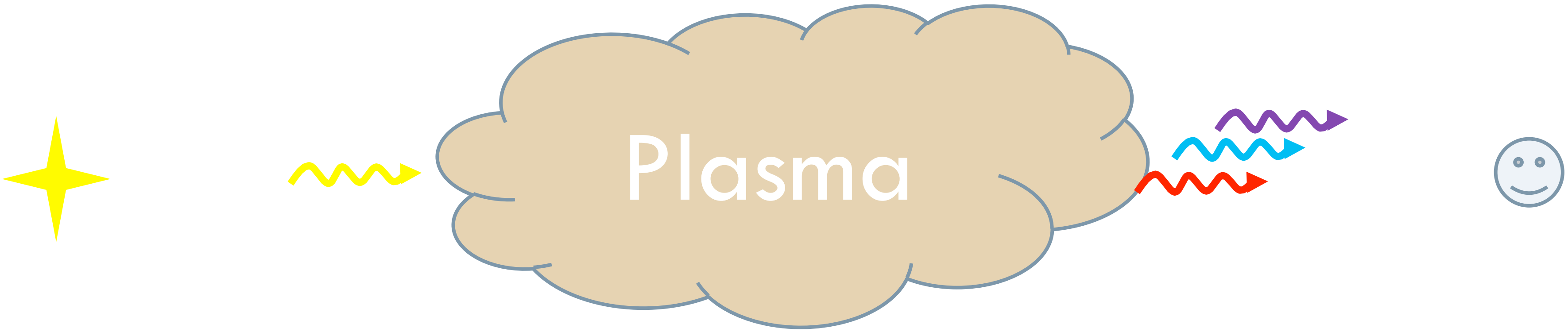
- Anomalously high dispersion measures (DM~*500-1000)*

Thornton et al. 2013

2. 数据

FRB	DM ($pc\,cm^{-3}$)	Pulse width (ms)	Fluence (Jy ms)	Redshift	Energy (10^{40} erg)	Reference
010125	790(3)	$9.40^{+0.20}_{-0.20}$	2.82	0.65	1.22	Burke-Spolaor & Bannister (2014)
010621	745(10)	7	2.87	0.60	1.10	Keane et al. (2011)
010724	375	5	> 150.00	0.24	7.91	Lorimer et al. (2007)
090625	899.55(1)	$1.92^{+0.83}_{-0.77}$	$2.19^{+2.10}_{-1.12}$	0.75	1.24	Champion et al. (2016)
110220	944.38(5)	$5.60^{+0.10}_{-0.10}$	$7.28^{+0.13}_{-0.13}$	0.80	4.58	Thornton et al. (2013)
110626	723.0(3)	1.4	0.56	0.58	0.20	Thornton et al. (2013)
110703	1103.6(7)	4.3	2.15	0.95	2.00	Thornton et al. (2013)
120127	553.3(3)	1.1	0.55	0.42	0.10	Thornton et al. (2013)
121002	1629.18(2)	$5.44^{+3.50}_{-1.20}$	$2.34^{+4.46}_{-0.77}$	1.48	5.01	Champion et al. (2016)
130626	952.4(1)	$1.98^{+1.20}_{-0.44}$	$1.47^{+2.45}_{-0.50}$	0.81	0.94	Champion et al. (2016)
130628	469.88(1)	$0.64^{+0.13}_{-0.13}$	$1.22^{+0.47}_{-0.37}$	0.33	0.13	Champion et al. (2016)
130729	861(2)	$15.61^{+9.98}_{-6.27}$	$3.43+^{6.55}_{-1.81}$	0.72	1.77	Champion et al. (2016)
131104	779(1)	2.08	2.33	0.64	0.98	Ravi et al. (2015)
140514	562.7(6)	$2.80^{+3.50}_{-0.70}$	$1.32^{+2.34}_{-0.50}$	0.43	0.24	Petroff et al. (2015)
150418	776.2(5)	$0.80^{+0.30}_{-0.30}$	$1.76^{+1.32}_{-0.81}$	0.63	0.74	Keane et al. (2016)

2.1 样本红移



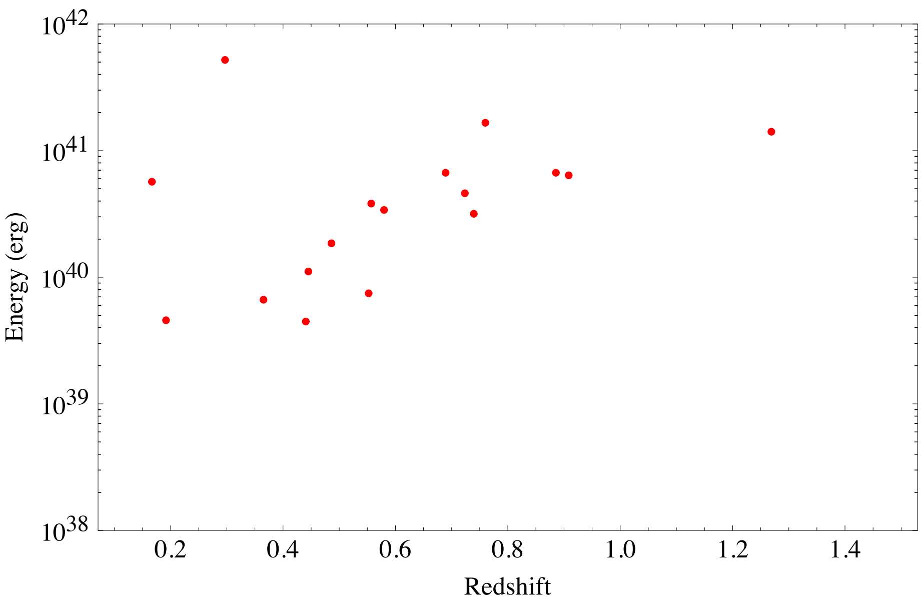
$$DM = DM_{MW} + DM_{IGM} + DM_{Host}$$

$$\mathrm{DM_{IGM}}(z) = \int_0^z \frac{c n_{\mathrm{e}}(z')}{(1+z')^2 H(z')} dz'$$

2.2 样本光度

$$E = 4\pi d_c(z)^2(1+z)\Delta\nu S_\nu \Delta t_{\mathrm{obs}} k(z)$$

✓辐射谱形



$$S_\nu \propto \nu^{-\beta}$$

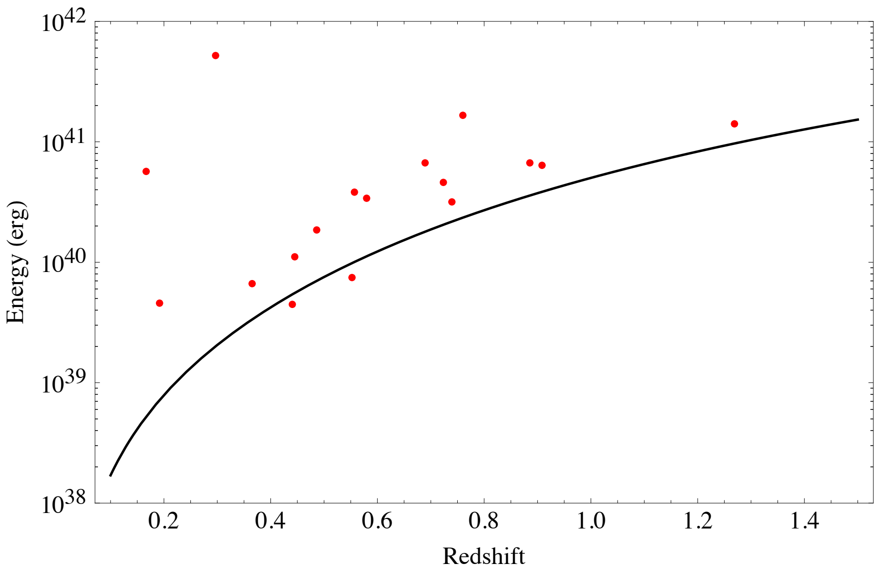
$$k(z) = (1+z)^{\beta-1}\left(\nu_b{}^{1-\beta} - \nu_a{}^{1-\beta}\right)/\left(\nu_2{}^{1-\beta} - \nu_1{}^{1-\beta}\right)$$

2.3 探测阈值

$$E_{\rm th}(z) = 4\pi d_c(z)^2(1+z)\Delta\nu n_{\rm min}\Delta S\Delta t_{\rm obs}k(z)$$

$$\Delta t_{\rm obs}(z) = \sqrt{\Delta t_{\rm burst}^2(1+z)^2 + \Delta t_{\rm DM}^2 + \Delta t_{\rm scat}^2}$$

散射模型



3. FRB模型限制

- FRB的起源：恒星爆发后的新生中子星、双中子星并合、超导宇宙弦、小行星撞击。。。
- 通过对FRB红移分布和光度分布对模型进行限制

$$N_{<z}^{\rm obs} = \mathcal{T}\frac{\mathcal{A}}{4\pi}\int_{z_{\rm min}}^{z}\int_{E_{\rm th}(z)}^{E_{\rm max}}\Phi(E)\dot{R}(z')dE\frac{dV(z')}{1+z'}$$

$$N_{<E}^{\rm obs} = \mathcal{T}\frac{\mathcal{A}}{4\pi}\int_{E_{\rm min}}^{E}\int_{z_{\rm min}}^{z_{\rm max}}\Phi(E)\dot{R}(z')\frac{dV(z')}{1+z'}dE$$

✓辐射谱形
✓本征爆发率
✓光度函数

3.1例如：恒星相关模型

✓本征爆发率

$$\dot{R}(z) \propto (1+z)^{\alpha}\dot{\rho}_*(z)$$

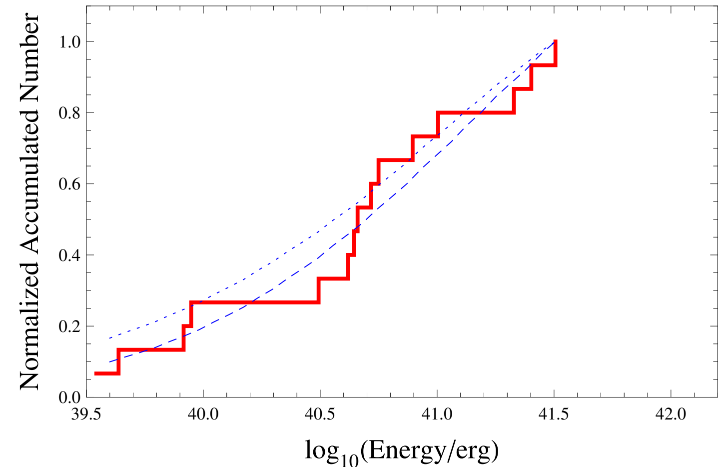
$$\dot{\rho}_*(z) \propto \begin{cases} (1+z)^{3.44}, & z < 0.97, \\ (1+z)^{-0.26}, & 0.97 \leq z < 4 \end{cases}$$

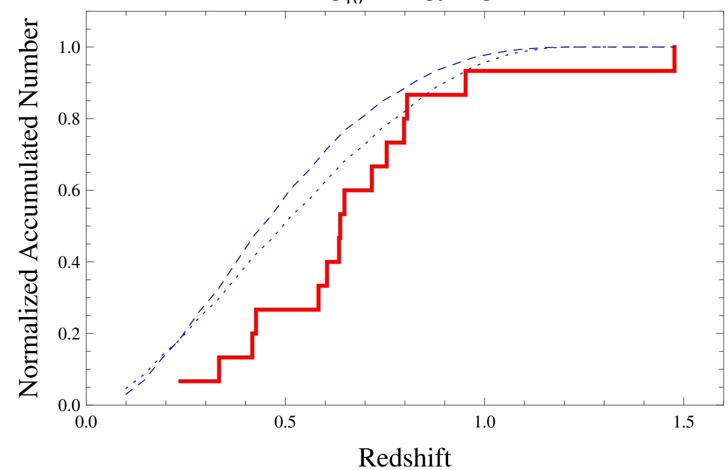
✓辐射谱形

$$S_\nu \propto \nu^{-\beta}$$

✓光度函数

$$\Phi(E) \propto E^{-\gamma}$$

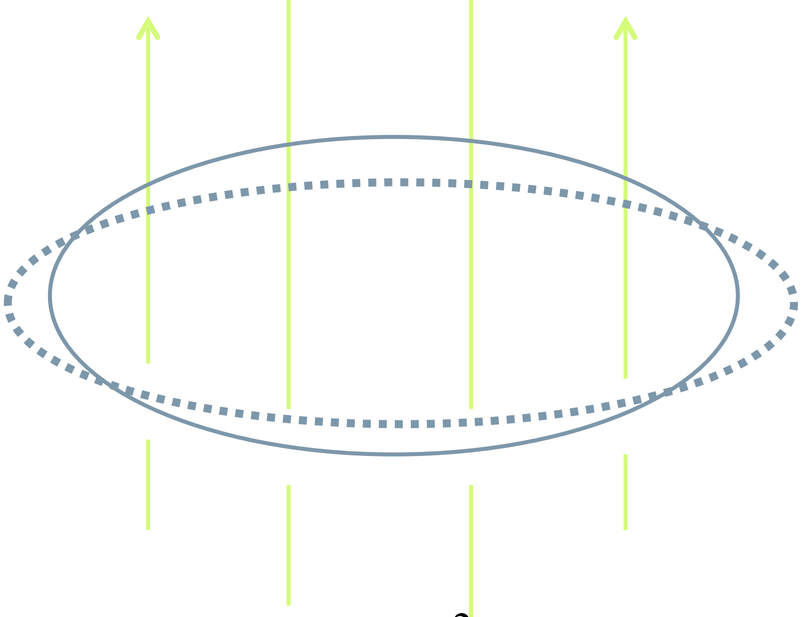




$$\gamma \sim (0.150 - 0.017\beta + 0.001\beta^2)\alpha + (2.117 + 0.193\beta + 0.017\beta^2)$$

3.2 例如：超导宇宙弦模型

Chudnovsky et al. 1986



$$\frac{d^2E}{d\nu d\Omega} \sim \frac{k_{\rm em} I^2 L^2}{c^3}$$

$$\theta \sim \gamma^{-1} \sim (\nu L/c)^{-1/3}$$

$$\Omega = 2\pi(1-\cos\theta) \sim \pi\theta^2$$

✓辐射谱形 $S_\nu \propto \nu^{-2/3}$

$$d\dot{N}(z, E_{\rm iso}) = \frac{\theta^2}{4P_{\rm osc}} \boxed{\frac{dn(z)}{dL}\frac{dL}{dE_{\rm iso}}} dE_{\rm iso} dV_{\rm p}(z)$$

$$d\dot{N}(z,E_{\rm iso}) = \frac{\theta^2}{4P_{\rm osc}}\frac{dn(z)}{dL}\frac{dL}{dE_{\rm iso}}dE_{\rm iso}dV_{\rm p}(z)$$

$$\frac{dn(z)}{dL_i} \sim \left(1+\sqrt{\frac{ct_{eq}}{L_i}}\right)\frac{1}{L_i^2(ct)^2} \sim \sqrt{\frac{ct_{eq}}{L_i}}\frac{1}{L_i^2(ct)^2} \propto t^{-9/2}$$

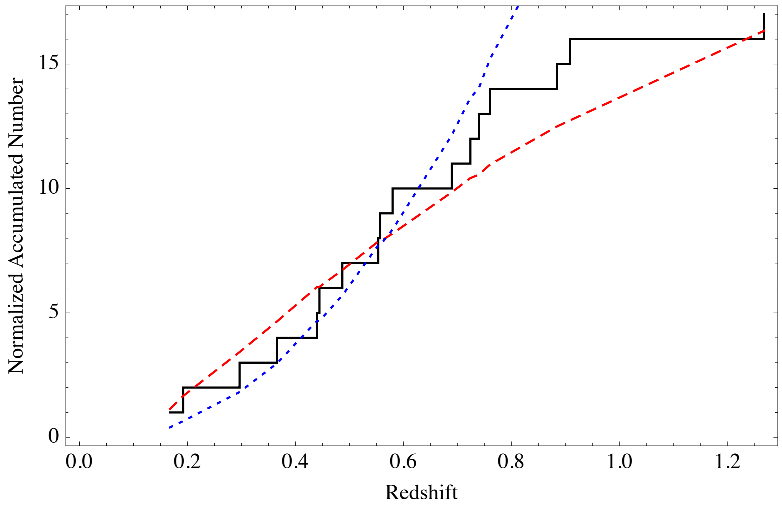
$$\frac{d^2E}{d\nu d\Omega} \sim \frac{k_{\rm em}I^2L^2}{c^3} \Rightarrow E_{\rm iso} \sim 4\pi\nu\frac{d^2E}{d\nu d\Omega} \Rightarrow$$

$$L \sim \left(\frac{c^3E_{\rm iso}}{4\pi k_{\rm em}I^2\nu_{\rm o}f_z}\right)^{1/2}$$

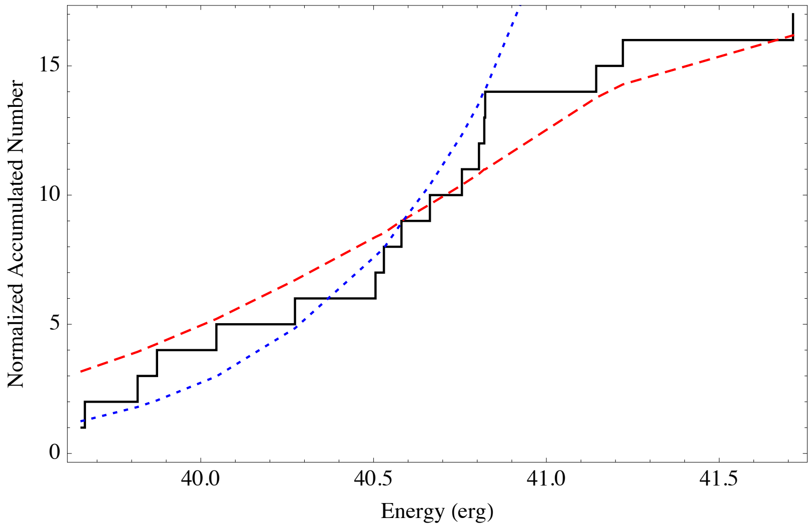
$$L \sim \left(\frac{\hbar^2c^3E_{\rm iso}}{4\pi e^4k_{\rm em}B_0^2\nu_{\rm o}f_z^5}\right)^{1/4}$$

$$\frac{d\dot{N}}{dE_{\rm iso}dV_{\rm p}(z)} \sim 1.1\times10^{-36}I_{16}^{5/3}\mu_{17}^{-3/2}\nu_{\rm o,9}^{1/6} E_{\rm iso,40}^{-11/6}f_{\rm z}^{65/12}{\rm erg}^{-1}{\rm Gpc}^{-3}{\rm yr}^{-1}$$

✓本征爆发率
✓光度函数



Normalized Accumulated Number
Redshift
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
5
10
15



Normalized Accumulated Number
Energy (erg)
40.0
40.5
41.0
41.5
0
5
10
15

4.总结

通过对FRB红移分布和光度分布对模型进行限制

- 观测数据的积累和更新
- 散射效应的红移依赖
- 辐射谱形对流量的k改正
- 本征爆发率
- 光度函数积分