

射电天文学笔记

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第一章 射电信号的探测方法

射电 (10MHz–1THz) \neq 无线电 (3kHz–3GHz).

白天可测: 波长远大大气尘埃, 无散射; 太阳射电信号少.

排除水汽: 高地, 旱地.

- 镜面精度低 ($\lambda/20$).
- λ 大, 在 λ^3 范围内放很多带点粒子, 形成相干辐射.
- 波长远大星际尘埃, 透明.
- $h\nu/kT \ll 1$, 所有天体都辐射.
- $\theta \sim \lambda/D$, 需要大 D .

第二章 射电辐射基础¹

I_λ : 垂直于单位面积方向的单位立体角内单位时间通过的单位波长的能量. F_λ : 单位面积的所有立体角内单位时间通过的单位波长的能量.

$$I_\lambda = \frac{dE}{\cos \theta d\sigma d\Omega dt d\lambda}. \quad (2.1)$$

$$F_\lambda = \int I_\lambda \cos \theta d\Omega. \quad (2.2)$$

$$1 \text{ Jy} = 10^{-26} \text{ W}/(\text{m}^2 \cdot \text{Hz}), \quad 1 \text{ erg} = 10^{-7} \text{ J}.$$

$$\frac{dI_\nu}{I_\nu} = -\kappa_\nu ds. \quad (2.3)$$

$$\tau_\nu = \int_{s_{\text{in}}}^{s_{\text{out}}} \kappa_\nu ds. \quad (2.4)$$

$$I_\nu(s_{\text{out}}) = I_\nu(s_{\text{in}})e^{-\tau_\nu}. \quad (2.5)$$

$$dI_\nu = j_\nu ds. \quad (2.6)$$

$$\frac{dI_\nu}{ds} = -\kappa_\nu I_\nu + j_\nu. \quad (2.7)$$

局部热动平衡,

$$\frac{j_\nu}{\kappa_\nu} = B_\nu. \quad (2.8)$$

低频 $B_\nu \approx \frac{2kT\nu^2}{c^2}$, 亮温度

$$T_{\text{b}} := \frac{I_\nu c^2}{2k\nu^2}. \quad (2.9)$$

¹梦回天体物理导论.

第三章 天线理论基础

运动电子, Larmor 公式.

短 (尺度远小于波长) 偶极子天线. (Gauss 单位制)

$$E = \frac{q\dot{v} \sin \theta}{rc^2}, \quad (3.1)$$

全天线

$$E = \int_{-l/2}^{+l/2} \frac{dq}{dz} \frac{\dot{v} \sin \theta}{rc^2} dz, \quad (3.2)$$

$\dot{v} = -i\omega v$,

$$E = \frac{-i\omega \sin \theta}{rc^2} \int_{-l/2}^{+l/2} I dz, \quad (3.3)$$

假设 $I = I_0 e^{-i\omega t} \left[1 - \frac{|z|}{l/2}\right]$,

$$E = \frac{-i\omega \sin \theta}{rc^2} \frac{I_0 l}{2} e^{-i\omega t} = \frac{-i\pi \sin \theta}{c} \frac{I_0 l}{\lambda} \frac{e^{-i\omega t}}{r}, \quad (3.4)$$

$$S = \frac{c}{4\pi} E^2 = \frac{c}{4\pi} \left(\frac{I_0 l}{\lambda} \frac{\pi}{c}\right)^2 \frac{\sin^2 \theta}{r^2} \cos^2(\omega t + \frac{\pi}{2}), \quad (3.5)$$

$$\langle S \rangle = \frac{1}{2} \frac{c}{4\pi} \left(\frac{I_0 l}{\lambda} \frac{\pi}{c}\right)^2 \frac{\sin^2 \theta}{r^2} \propto \sin^2 \theta. \quad (3.6)$$

实际一般 $l \approx \lambda/2$, $I = I_0 e^{-i\omega t} \cos(2\pi z/\lambda)$.

辐射电阻 R ,

$$\langle P \rangle := \langle I^2 \rangle R = \frac{1}{2} I_0^2 R. \quad (3.7)$$

功率增益 $G(\theta, \phi)$,

$$G(\theta, \phi) := \frac{P(\theta, \phi)}{\langle P(\theta, \phi) \rangle}. \quad (3.8)$$

$G(\text{dB}) = 10 \log_{10}(G)$.

有效接受面积 A_e ,

$$A_e = \frac{P_\nu}{S_{\text{matched}}}. \quad (3.9)$$

$\langle A_e \rangle = \frac{\lambda^2}{4\pi}$, 短波无方向性则效率低.

$$A_e(\theta, \phi) = \frac{\lambda^2 G(\theta, \phi)}{4\pi}. \quad (3.10)$$

天线温度 T_A ,

$$T_A := \frac{P_\nu}{k}. \quad (3.11)$$

第四章 反射天线

一维反射面, 频率 ω , 强度 $g(x)$ 照射面, 反射到远处, $l := \sin \theta$, 远处强度 $f(l)$, $u := x/\lambda$, 刚好 Fourier 变换

$$f(l) = \int g(u) e^{-2\pi i l u} du. \quad (4.1)$$

反射面效率 $\eta_S = G_{\text{实际}}/G_{\text{完美}}$, 镜面误差 ϵ ,

$$p(\epsilon) = N(0, \sigma^2), \quad (4.2)$$

$$\eta_S = \exp \left[- \left(\frac{4\pi\sigma}{\lambda} \right)^2 \right]. \quad (4.3)$$

第五章 干涉天线

窄带, 假设频率都为 ω , 距离 b , 源方向 \hat{s} , \vec{b} 和 \hat{s} 夹角 θ , 两天线电压 V_1 , V_2 , 时间延迟 τ_g ,

$$V_1 V_2 = \frac{V^2}{2} [\cos(2\omega t + \omega\tau_g) + \cos(\omega\tau_g)], \quad (5.1)$$

$$R := \langle V_1 V_2 \rangle = \frac{V^2}{2} \cos(\omega\tau_g). \quad (5.2)$$

$\phi := \omega\tau_g = \frac{b\omega}{c} \cos \theta$, $\Delta\phi = 2\pi \rightarrow \Delta\theta = \lambda/(b \sin \theta)$, 若 $b \sin \theta \gg \lambda$, 则小 $\Delta\theta$ 得 $\Delta\phi$.

$$R = \frac{V_1(\theta)V_2(\theta)}{2} \cos\left(\frac{b\omega}{c} \cos \theta\right) = \frac{V_1(\theta)V_2(\theta)}{2} \cos\left(\frac{b \cos \theta}{\lambda}\right). \quad (5.3)$$

$\frac{V_1(\theta)V_2(\theta)}{2}$ 一般 Gauss. 多天线, 不同 b 叠加得 Gauss.

非点源,

$$R_c = \int I_\omega(\hat{s}) \cos(\omega\tau_g) d\Omega. \quad (5.4)$$

I 分解为奇偶宇称, \cos 偶宇称, 奇宇称为加 $\frac{\pi}{2}$ 相位,

$$R_s = \int I_\omega(\hat{s}) \sin(\omega\tau_g) d\Omega. \quad (5.5)$$

定义

$$R = \int I_\omega(\hat{s}) \exp(-i\omega\tau_g) d\Omega. \quad (5.6)$$