An Introduction to Radio Interferometry

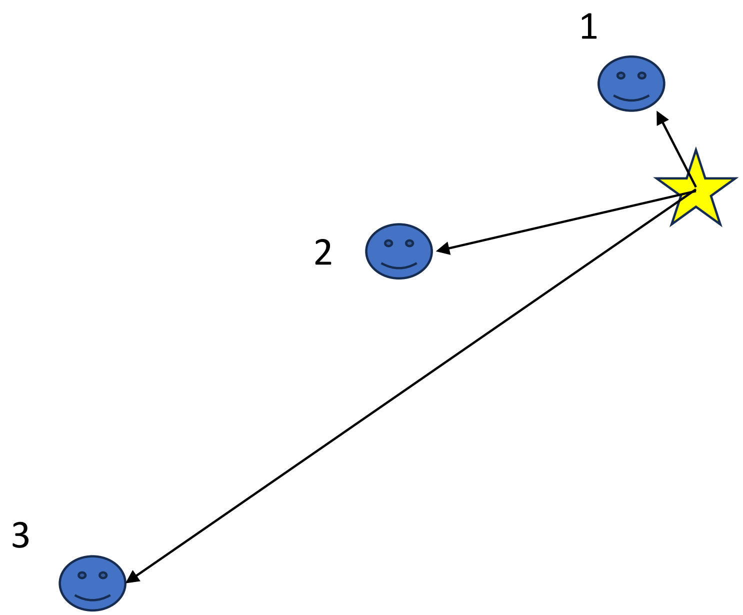
1-2 What is electromagnetic wave

You can find relevant material
on my personal webpage

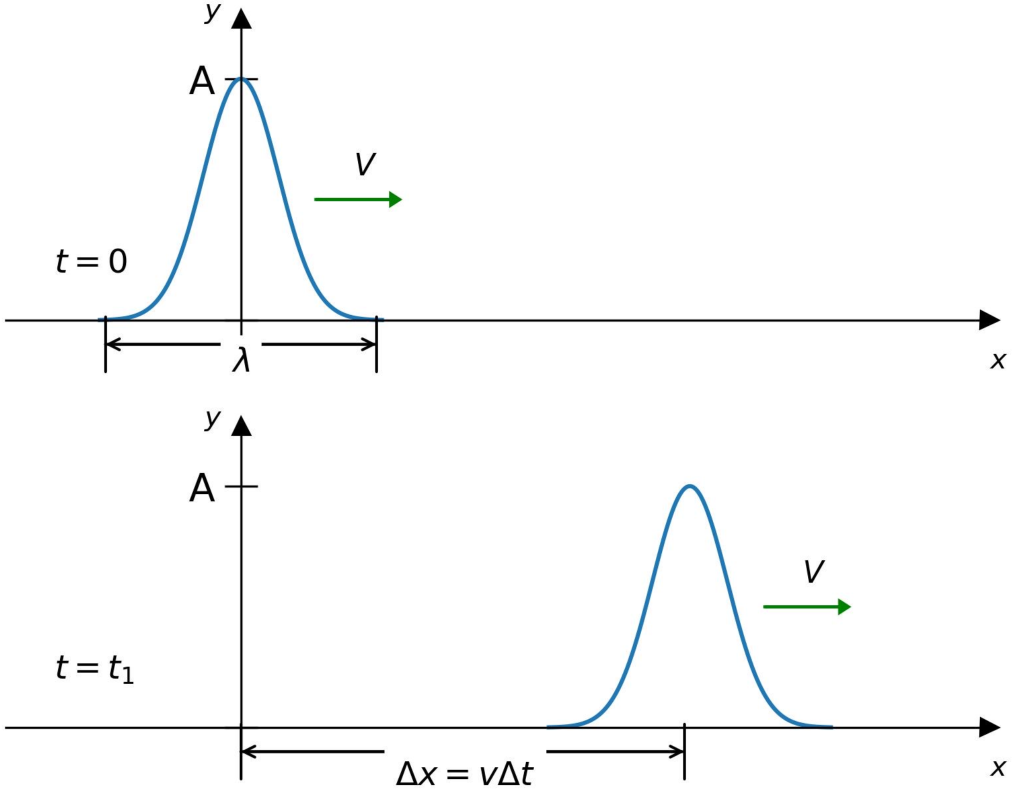
In most cases, astronomers observe light, and then deduce/testify principles based on the observations.

How can light be observed? What is it?

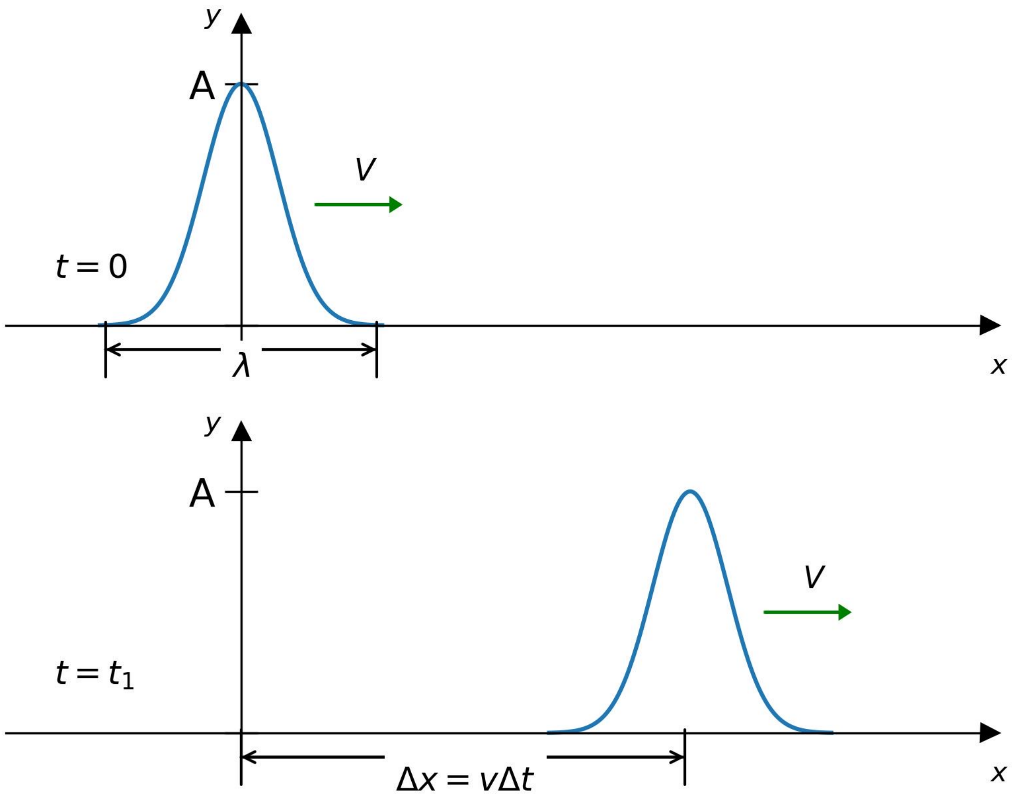
Emergence of electric (and magnetic field) in the observational devices.



Emerged electric (and magnetic field) propagates in the straight lines radiating from the emission source.



Classically, light can be described as electromagnetic waves (EM waves):



Charged particle(s) (e.g., electrons, ions) can perturb the electric and magnetic fields in space and thereby excite the EM waves.

Classically, light can be described as electromagnetic waves (EM waves):

(i) linear perturbations of electric and magnetic fields

(ii) propagation obeys Maxwell's equations

Electric field

Electric charge density

Gauss law ➡ $\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0}$

Magnetic field

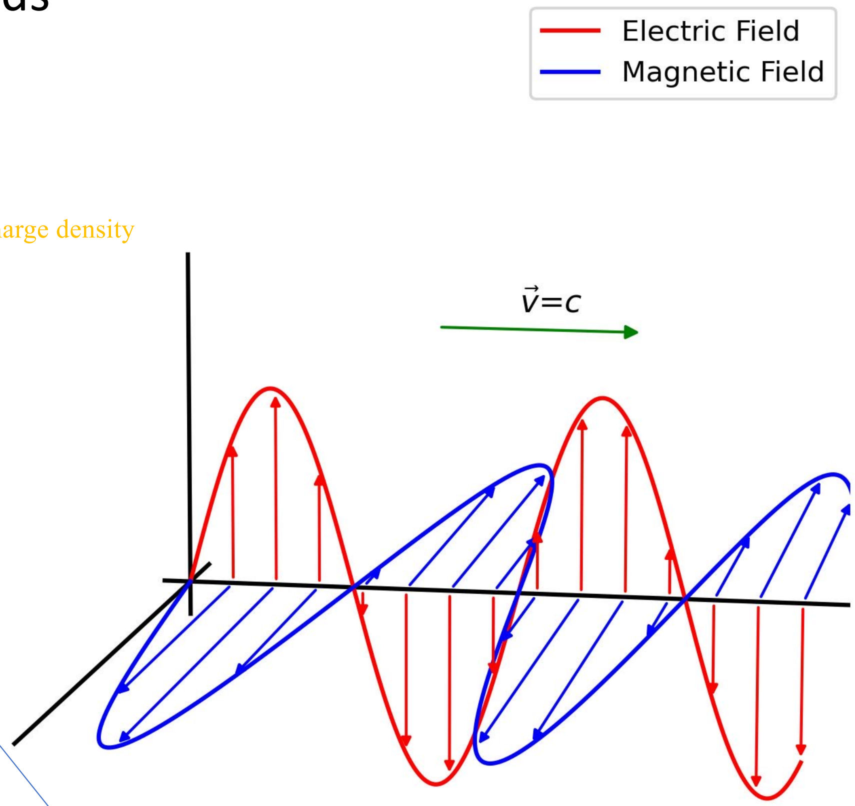
Gauss law ➡ $\nabla \cdot \vec{B} = 0$

Faraday's law ➡ $\nabla \times \vec{E} + \frac{\partial \vec{B}}{\partial t} = 0$

Ampere's law ➡ $\nabla \times \vec{B} - \mu_0 \left(\epsilon_0 \frac{\partial \vec{E}}{\partial t} \right) = \mu_0 \vec{J}$
(with Maxwell's correction)

Vacuum permeability
and permittivity

Current density



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(ii) propagation obeys Maxwell's equations

Enclosed electric charge — Electric field — Electric charge density

$$\oint \vec{E} \cdot d\vec{A} = \frac{1}{\epsilon_0} q_{enc}$$ Gauss law ➡ $$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0}$$

Magnetic field

$$\oint \vec{B} \cdot d\vec{A} = 0$$ Gauss law ➡ $$\nabla \cdot \vec{B} = 0$$

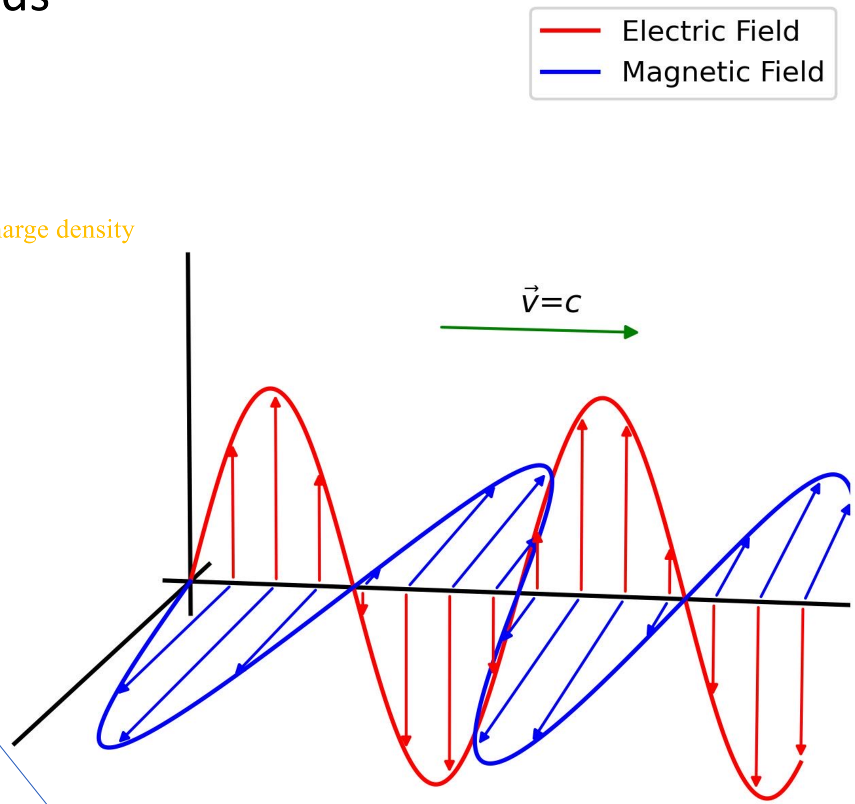
Magnetic flux

$$\oint \vec{E} \cdot \overrightarrow{d\ell} + \frac{\partial \Phi_B}{\partial t} = 0$$ Faraday's law ➡ $$\nabla \times \vec{E} + \frac{\partial \vec{B}}{\partial t} = 0$$

Electric flux

$$\oint \vec{B} \cdot \overrightarrow{d\ell} - \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t} = \mu_0 \mathrm{i}$$ Ampere's law (with Maxwell's correction) ➡ $$\nabla \times \vec{B} - \mu_0 \left(\epsilon_0 \frac{\partial \vec{E}}{\partial t} \right) = \mu_0 \vec{J}$$

Current — Vacuum permeability and permittivity — Current density



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Enclosed electric charge

$$\oint \vec{E} \cdot d\vec{A} = \frac{1}{\epsilon_0} q_{enc} = 0$$

$$\oint \vec{B} \cdot d\vec{A} = 0$$

Magnetic flux

$$\oint \vec{E} \cdot \overrightarrow{d\ell} + \frac{\partial \Phi_B}{\partial t} = 0$$

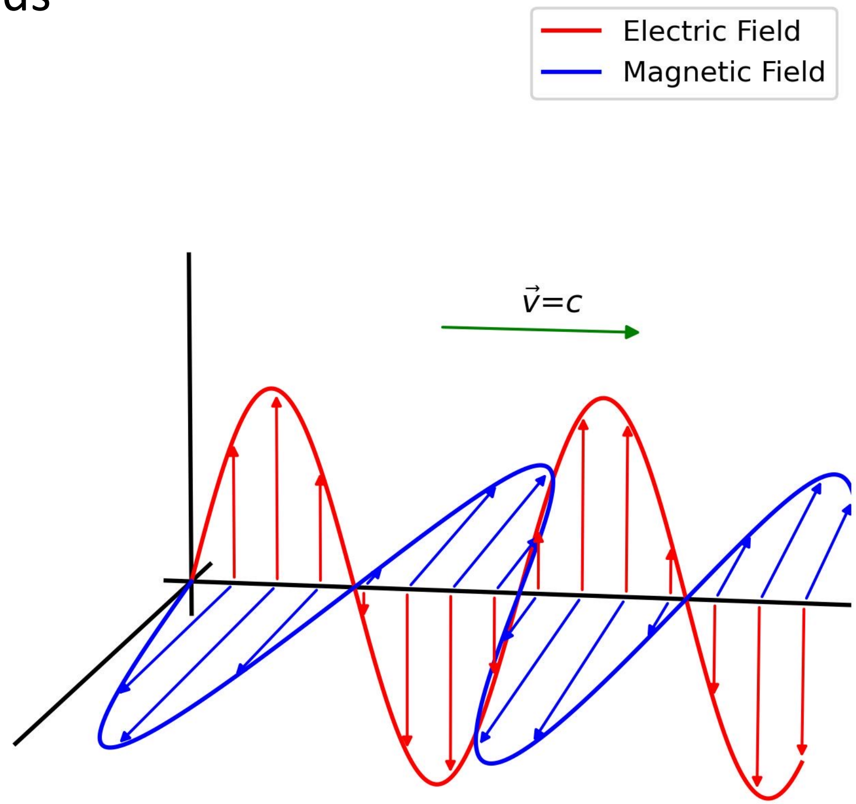
Electric flux

$$\oint \vec{B} \cdot \overrightarrow{d\ell} - \mu_0 \epsilon_0 \frac{\partial \Phi_E}{\partial t} = \mu_0 \mathrm{i} = 0$$

Current

$$\Phi_B \equiv \int \vec{B} \cdot d\vec{A}$$

$$\Phi_E \equiv \int \vec{E} \cdot d\vec{A}$$



Faraday's law

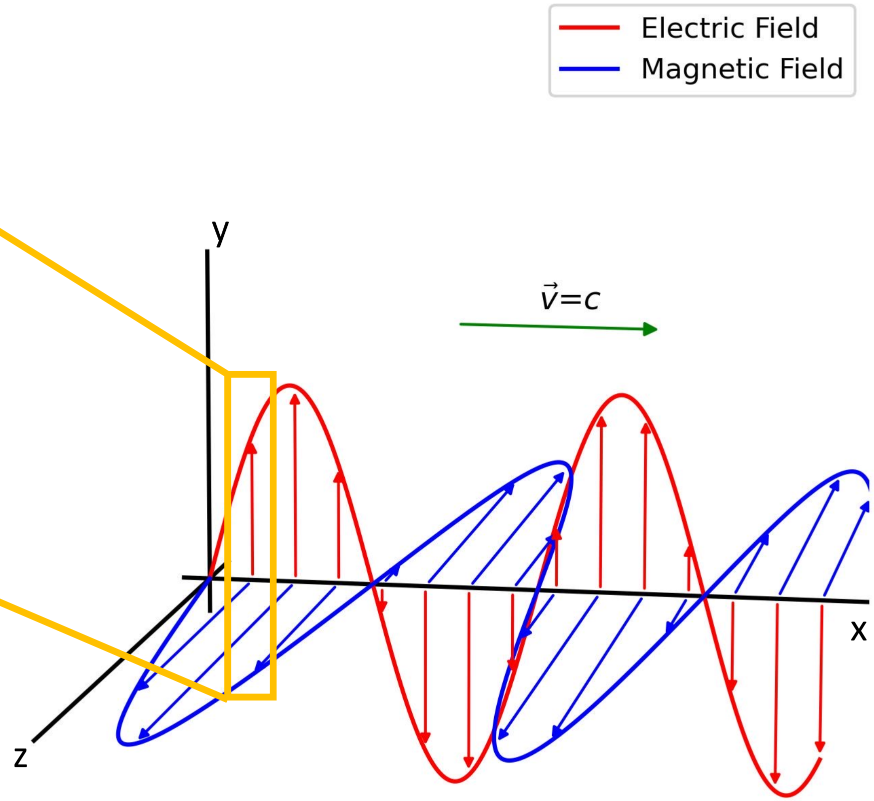
$$\oint \vec{E}\cdot\vec{d\ell} + \frac{\partial \Phi_B}{\partial t} = 0$$

$$\Phi_B \equiv \int \vec{B}\cdot d\vec{A}$$

Ampere's law

$$\oint \vec{B}\cdot\vec{d\ell} - \mu_0\epsilon_0\frac{\partial \Phi_E}{\partial t} = 0$$

$$\Phi_E \equiv \int \vec{E}\cdot d\vec{A}$$



$$(E+dE)h - Eh = \underline{h(dE)} = -\frac{d}{dt}[B(hdx)] = \underline{-hdx\frac{d}{dt}B}$$

$$\boxed{\frac{\partial E}{\partial x} = -\frac{\partial B}{\partial t}}$$

Faraday's law

$$\oint \vec{E}\cdot\vec{d\ell} + \frac{\partial \Phi_B}{\partial t} = 0$$

$$\Phi_B \equiv \int \vec{B}\cdot d\vec{A}$$

Ampere's law

$$\oint \vec{B}\cdot\vec{d\ell} - \mu_0\epsilon_0\frac{\partial \Phi_E}{\partial t}=0$$

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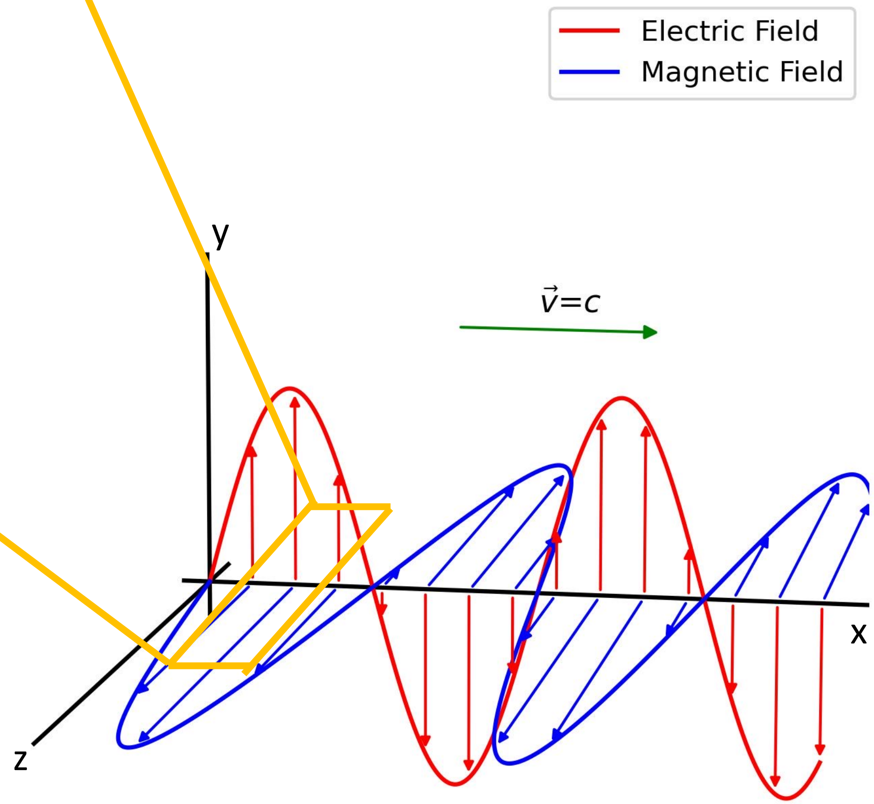

$$-(B + dB)h + Bh = \underline{-h(dB)} = \underline{\mu_0\epsilon_0 h dx\frac{d}{dt}E}$$

$$\boxed{-\frac{\partial B}{\partial x} = \mu_0\epsilon_0\frac{\partial E}{\partial t}}$$

Given by Faraday's law

$$\boxed{\frac{\partial E}{\partial x} = -\frac{\partial B}{\partial t}}$$

Given by Ampere's law

$$\boxed{-\frac{\partial B}{\partial x} = \mu_0 \epsilon_0 \frac{\partial E}{\partial t}}$$

$$\underbrace{\frac{\partial}{\partial x}\left(\frac{\partial E}{\partial x}\right) = -\frac{\partial}{\partial x}\left(\frac{\partial B}{\partial t}\right)} = \frac{\partial}{\partial t}\underbrace{\left(-\frac{\partial B}{\partial x}\right)} = \frac{\partial}{\partial t}\left(\mu_0 \epsilon_0 \frac{\partial E}{\partial t}\right)$$

$$\Rightarrow \frac{\partial^2 E}{\partial x^2} - \mu_0 \epsilon_0 \frac{\partial^2 E}{\partial t^2} = 0$$

$$\begin{cases} E = E_m \sin(kx - \omega t) \\ B = B_m \sin(kx - \omega t) \end{cases}$$

$$\omega = 2\pi\nu$$

$$c = \frac{\omega}{k} = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

$$k = \frac{2\pi}{\lambda}$$

$$\frac{E_m}{B_m} = \frac{1}{\mu_0 \epsilon_0 c}$$

$$\vec{E} = \overrightarrow{E_0} e^{i\vec{k}\cdot\vec{x} - i\omega t}$$

1. Astronomical observations detect EM waves that propagate from (nearly infinitely) distant sources.

2. The (plane) EM waves have a sinusoidal form: $E = E_m \sin(kx - \omega t)$

$$B = B_m \sin(kx - \omega t)$$

$$\frac{E_m}{B_m} = \frac{1}{\mu_0 \epsilon_0 c}$$