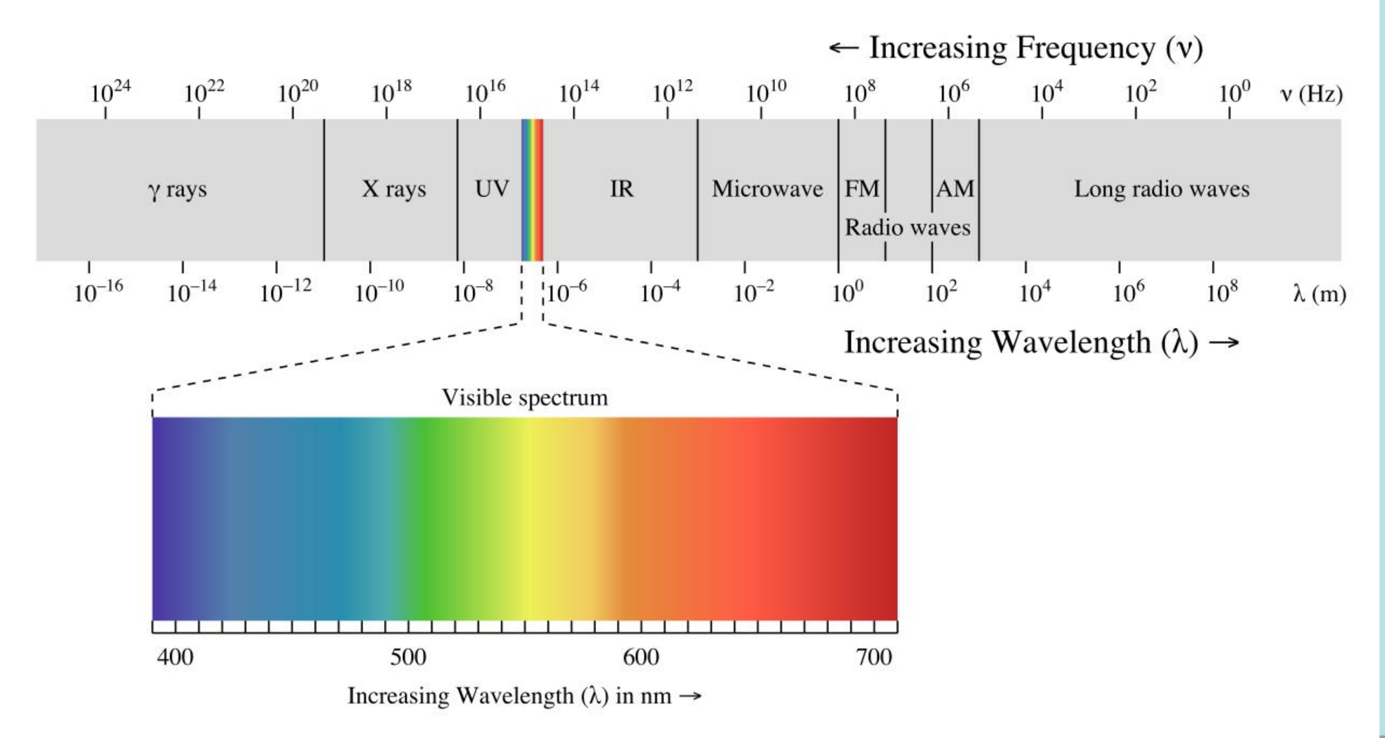
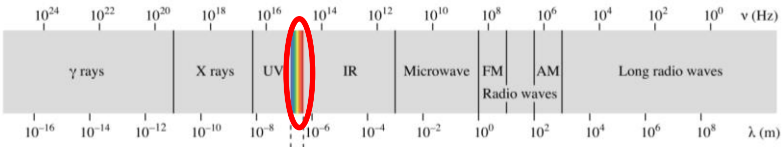
Optical Spectroscopy:
The study absorption and emission of light in nature

Abid Khan (past slides from Virginia Lorenz and Kai Wen Teng)

PHYS 403 Summer 2020

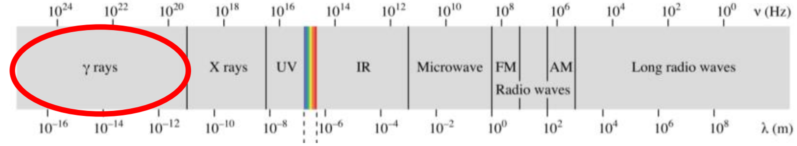


Optical Spectroscopy in Astronomy

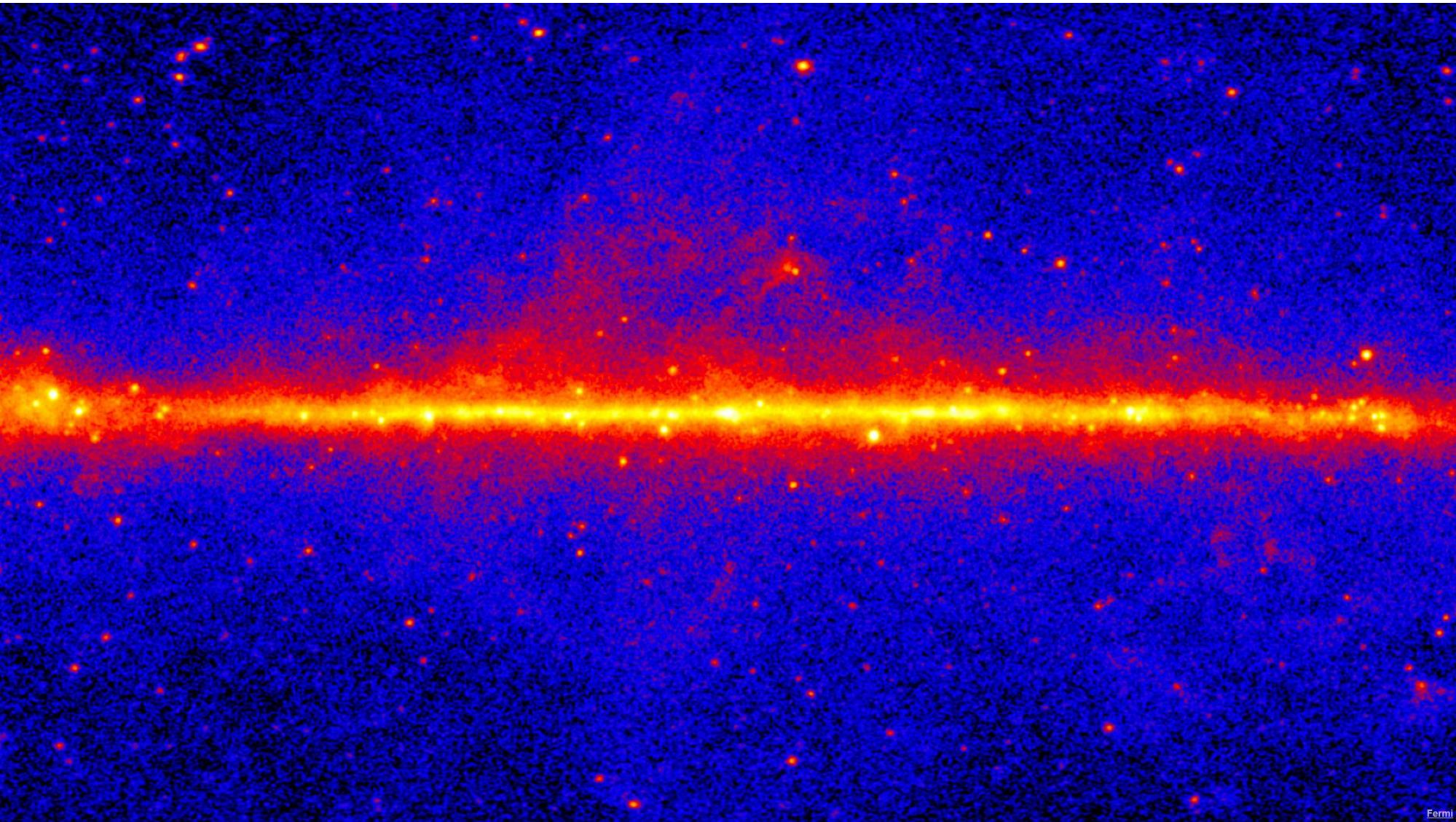


- By looking through a standard telescope, you are observing the night sky at the visible light spectrum

Gamma Rays



10^{24} 10^{22} 10^{20} 10^{18} 10^{16} 10^{14} 10^{12} 10^{10} 10^{8} 10^{6} 10^{4} 10^{2} 10^{0} ν (Hz)
γ rays
X rays
UV
IR
Microwave
FM
AM
Radio waves
Long radio waves
10^{-16} 10^{-14} 10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} 10^{8} λ (m)



Fermi

Black hole binaries in disks of plasma are sources of gamma rays

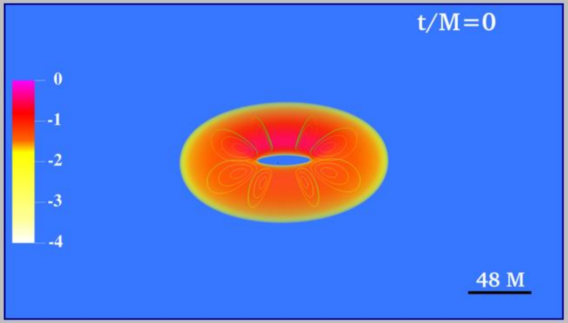


Fig. 2-1: *Inital Configuration*

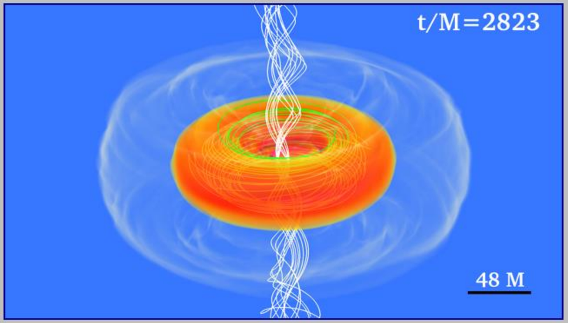


Fig. 2-2: *Twin jets rise from the inspiraling black holes*

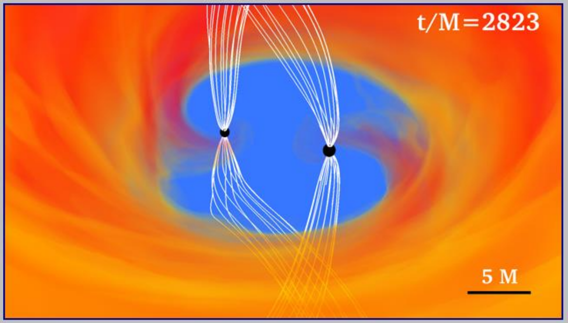


Fig. 2-3: *Zoom in to central cavity*

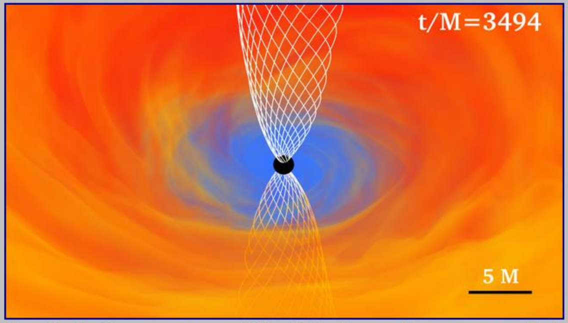


Fig. 2-4: *Post merger black hole and magnetic field*

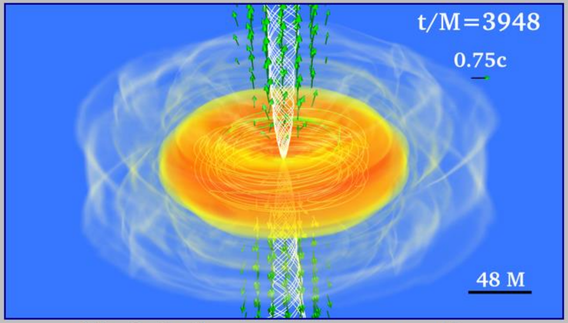
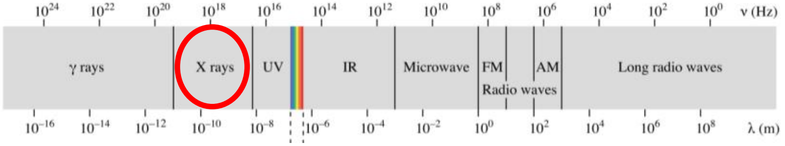
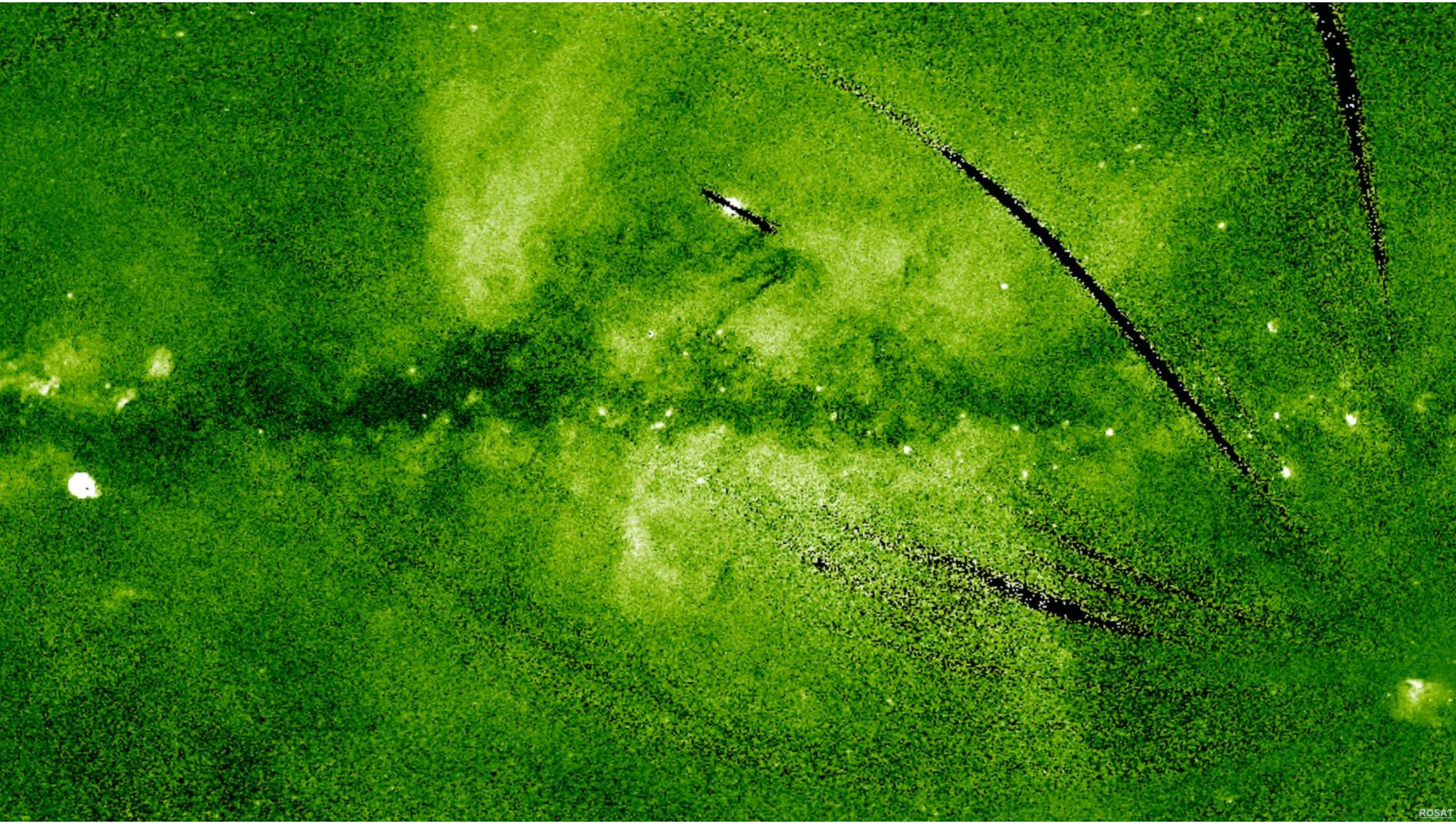


Fig. 2-5: *Quasistationary jet outflow*

Khan, Paschalidis, Ruiz, Shapiro. 2018

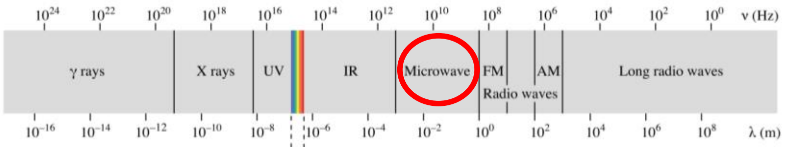
X Rays

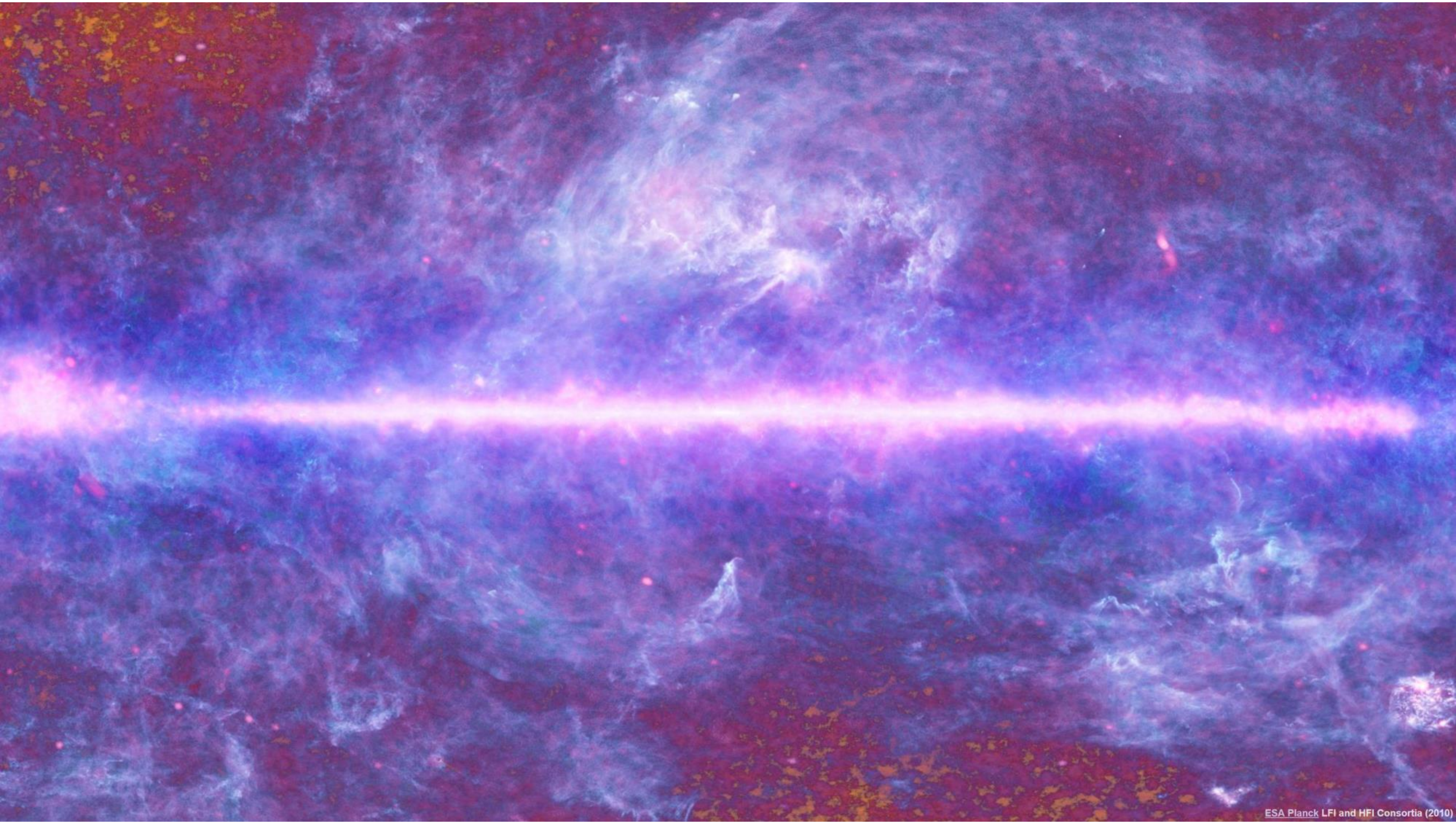




X-ray sources include stars, supernova, gaseous shells ejected during a violent explosion of a dying star, and synchrotron radiation

Microwave





Cosmic microwave background radiation emitted from the big bang and inflation

Luminescence: Emission of light from any substance

- **Fluorescence**: transition from excited state to ground state is **fast (~ns – ms range)**
- **Phosphorescence**: transition from excited state to ground state is **slow (~s – ks range)**

Perrin-Jablonski energy diagram

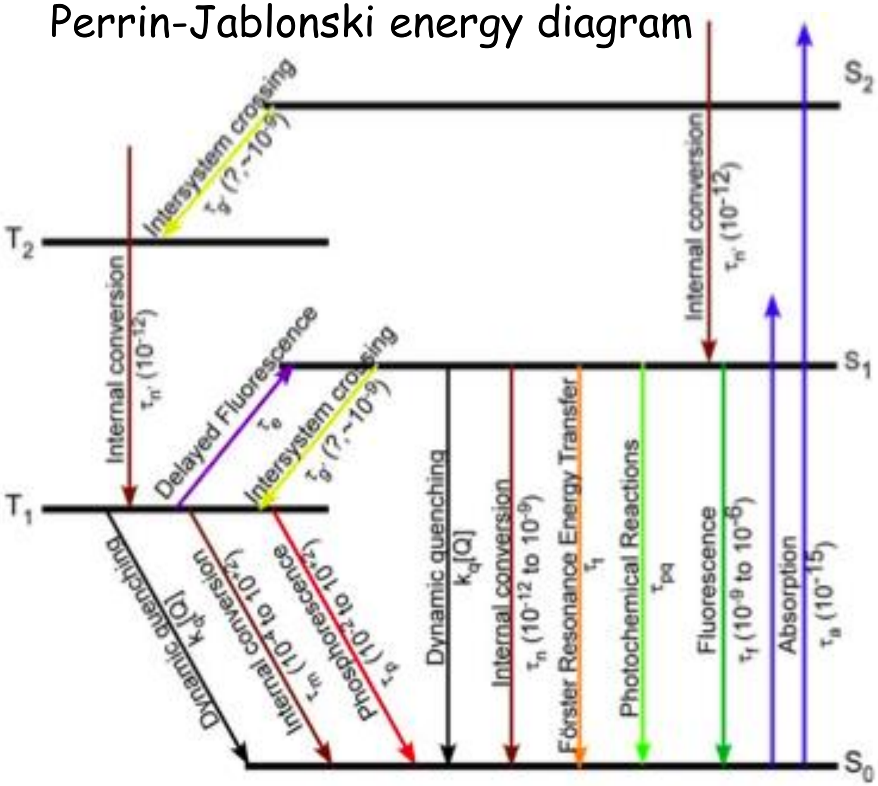


Diagram by Ulai Noomnarm in Photosynth Res. 2009 Aug-Sep;101(2-3):181-94.

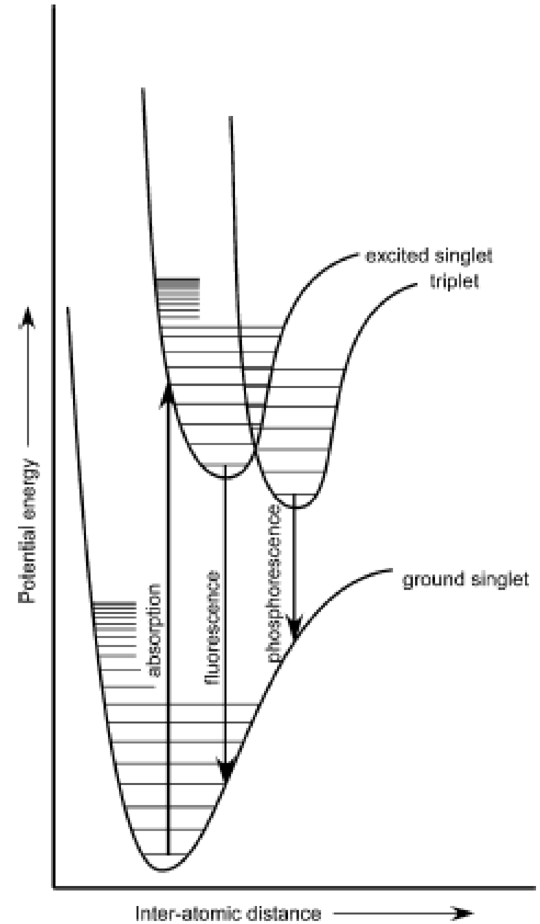
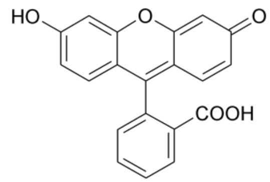


Diagram by Robert Clegg in Photosynth Res. 2009 Aug-Sep;101(2-3):181-94.

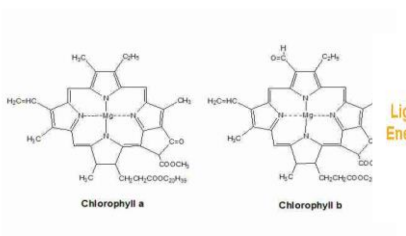
Types of Fluorescent Molecules

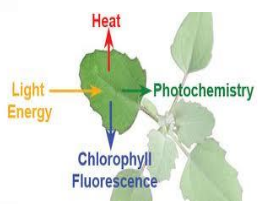
Synthetic Organic:

Fluorescein



Naturally Occuring:

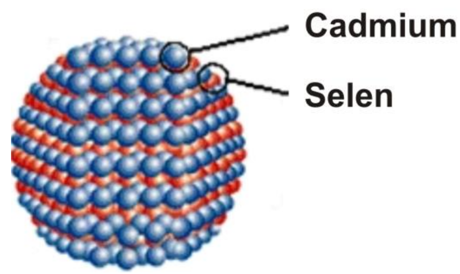


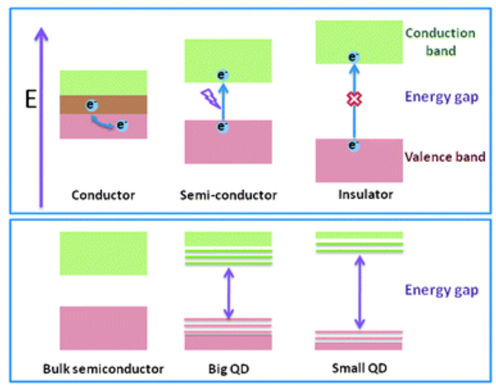


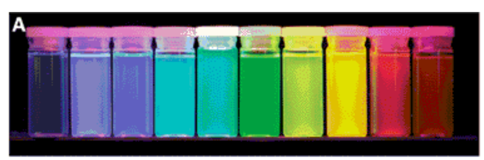
Fluorescent Proteins:

Green Fluorescent Protein

Semiconductor Nanocrystal:







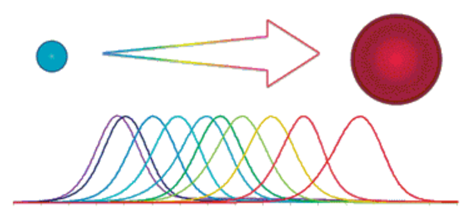
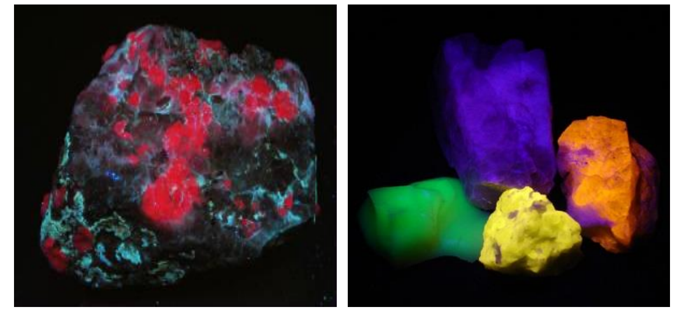


Image from Zrazhevskiy et al. 2010

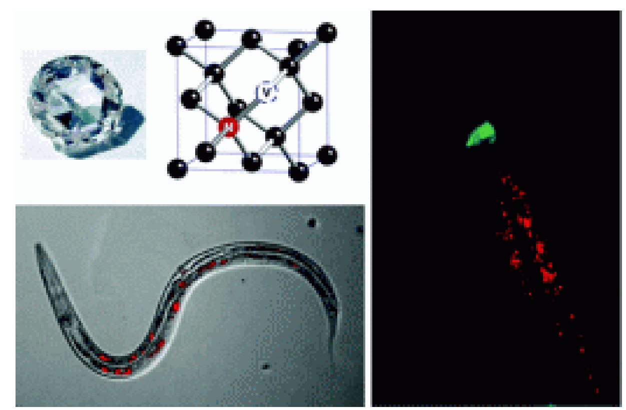
Crystals:



Ruby and assorted minerals

From mineralman.net

Fluorescent Nanodiamonds



Nano Lett., 2010, 10 (9), pp 3692-3699. DOI: 10.1021/nl1021909

Time-Dependent Fluorescence: Fluorescence Lifetime

Fluorescence Lifetime: The average amount of time a molecule stays in excited state

Probability of being in the excited state

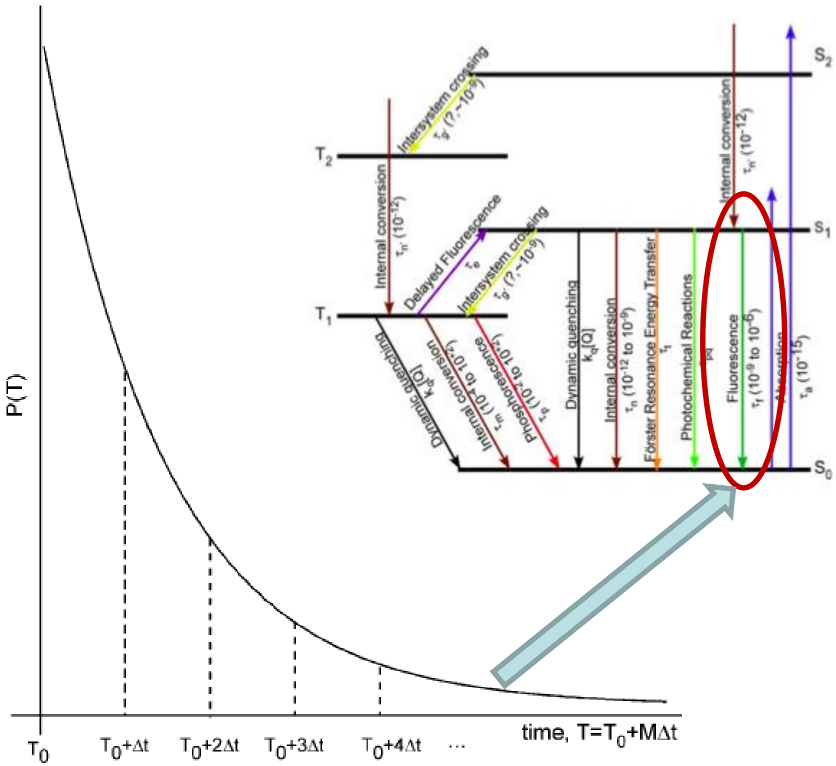
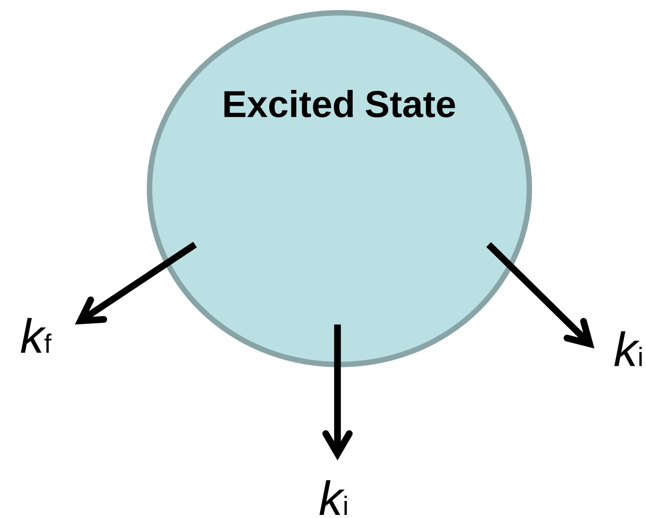


Diagram by Robert Clegg in Photosynth Res. 2009 Aug-Sep;101(2-3):181-94.

k_f = rate constant for leaving excited state while emitting a photon

k_i = rate constant for leaving excited state through other means (ie. Dynamic quenching, Energy Transfer, etc)

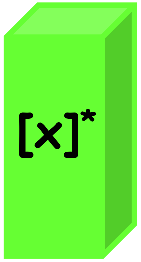


Fluorescence Lifetime: $$\tau = \sum_i \frac{1}{k_i}$$

Lifetime is sensitive to other decaying pathways present!

Measuring the Depletion of the excited state

$$\left[\# x^{*}\right] = \left[\# x_{o}^{*}\right] e^{-\left(k_F + k_t\right)t}$$

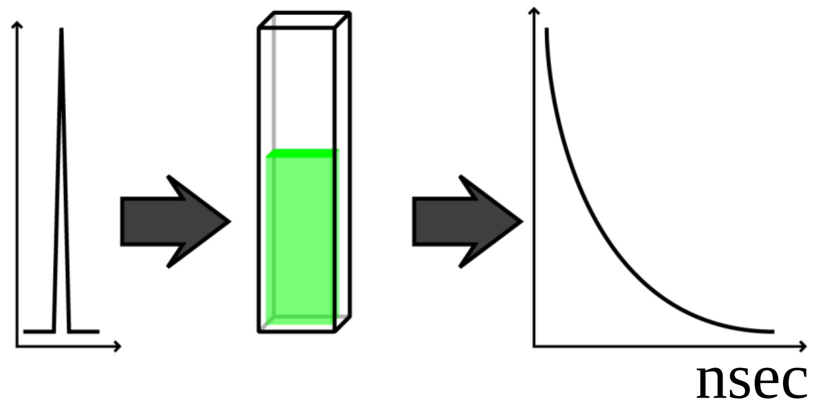


$\left[\# x^{*}\right]\left(k_F\right)$ = Intensity that you measure

K_F is rate constant of fluorescence

Intensity measured is proportional to the # of molecules in the excited state!

Measuring Lifetime: Time Domain



What do you need?

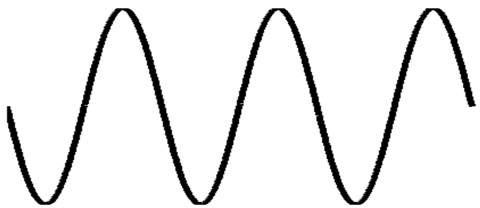
-Collect signal fast enough

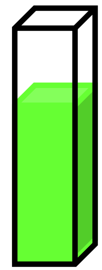
-Fitting

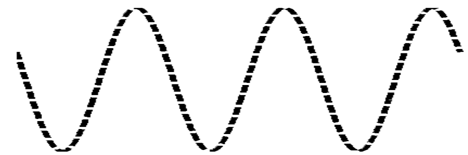
Measuring Lifetime: Frequency Domain

$$E(t) = E_o + E_\omega \cos\left(\omega_E t + \varphi_E\right)$$

$$F(t) = F_o + F_\omega \cos\left(\omega_E t + \varphi_E - \varphi\right)$$



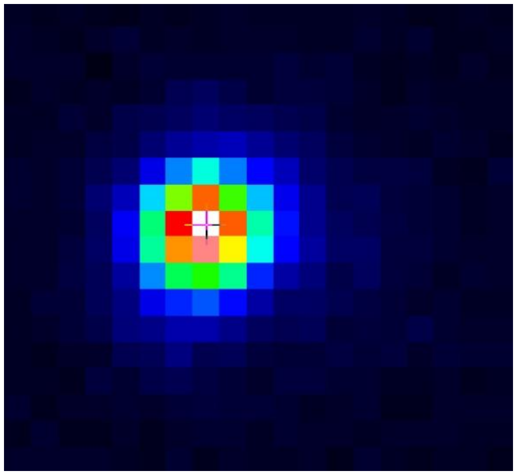


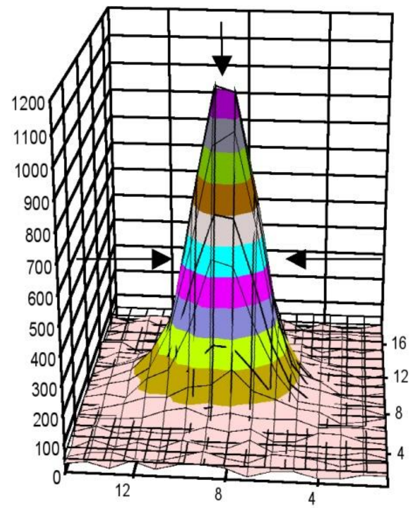


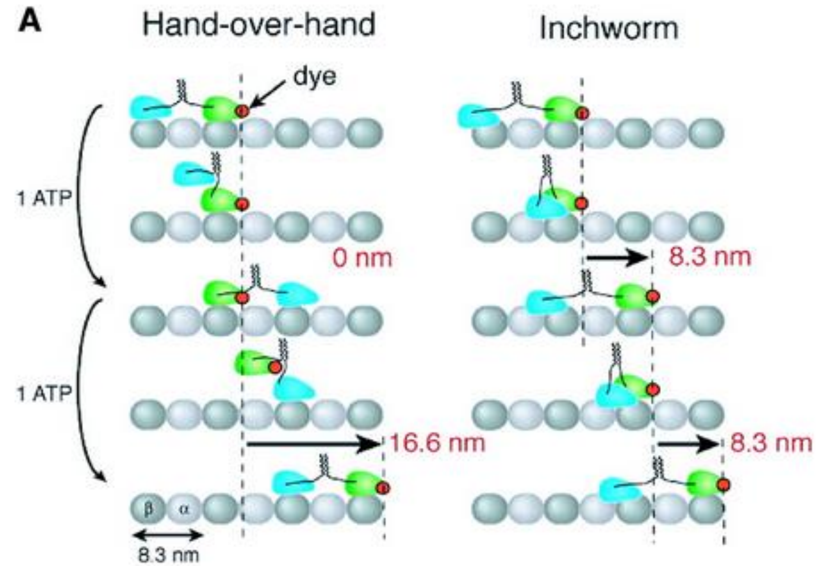
$$\tan\left(\varphi\right) = \omega_E \tau_\varphi$$

$$M = \frac{F_\omega / F_o}{E_\omega / E_o} = \frac{1}{\sqrt{1 + \left(\omega \tau_{Mod}\right)^2}}$$

Single Molecule Fluorescence Imaging (myosin)







$$\sigma_{\mu_i} = \sqrt{\left(\frac{s_i^2}{N} + \frac{a^2/12}{N} + \frac{8\pi s_i^4 b^2}{a^2 N^2}\right)}$$

Center of the distribution can be determined in ~1.5 nm accuracy if #N is more than 10^4