Filling the fiber:

Factors involved in absolute fiber capacity

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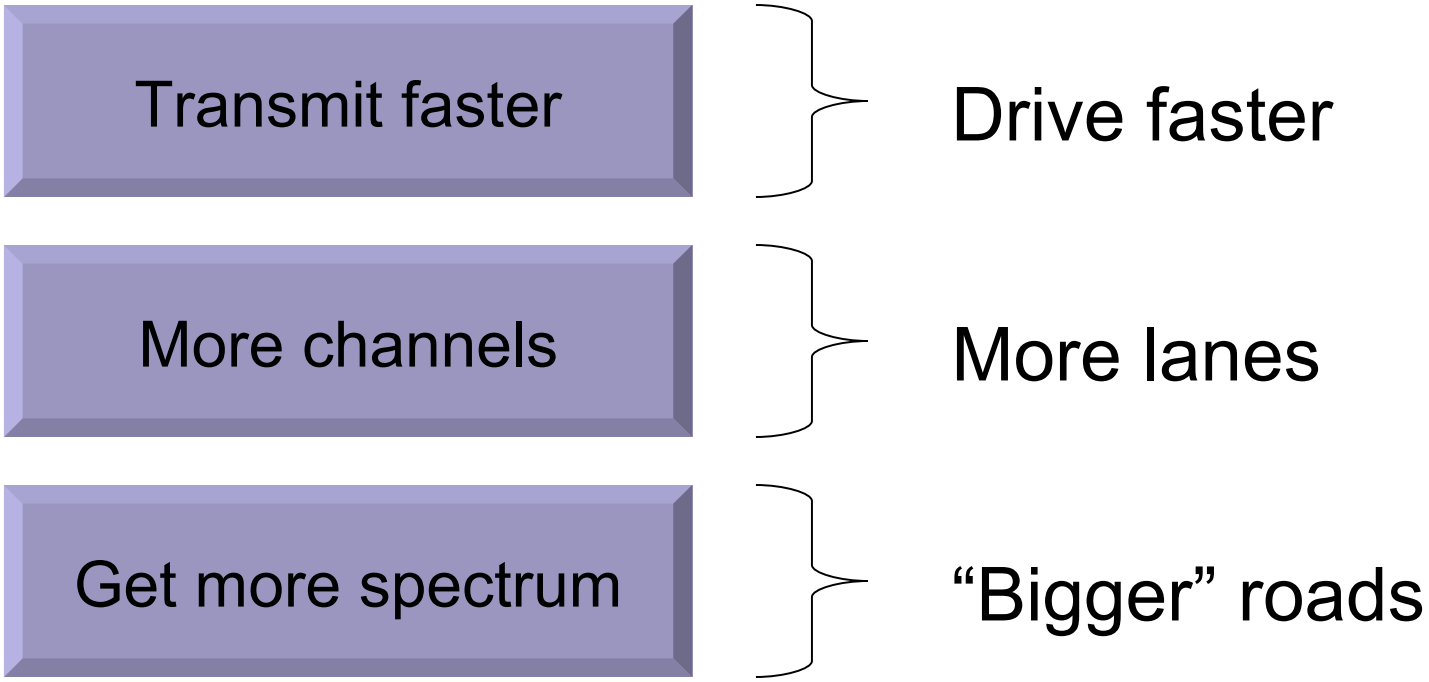
Initial assumption

- We are aiming to achieve the highest possible capacity from an individual fiber
- This tutorial does not consider:
  - The fact that unlit fibers may be available in the same location
  - Or that new fibers could be laid
  - Both of these are obvious options, but will vary dramatically with individual circumstances

Increasing fiber capacity



Let’s consider the road system

- How could we get more volume of traffic along this road?

Option 1: Drive faster

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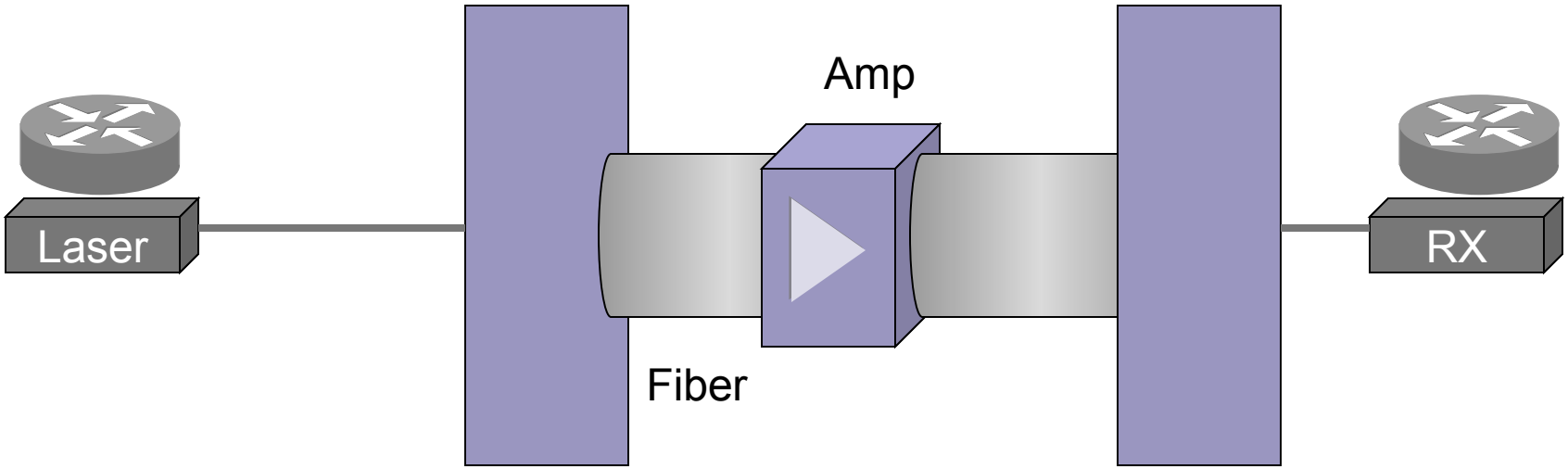
- But speed sometimes brings problems…

"Obstacles" that were OK at 10Gb/s might become a problem at 40Gb/s

Transmitting Faster

- Single wavelength into fiber
  - “Grey” optics
- Transmit as fast as the economics will allow
  - Cost includes Router ports, and amplifiers



What do we learn from this?

- Upgrading speeds will cost money
  - Especially as an early adopter
  - Ultimately higher speed hardware will cost less – both in relative and absolute terms
  - Useful rule of thumb – look for 4 times the speed at only 2.5 times the cost
- Existing obstacles may become important as we increase speed
  - Let's have a short overview of the bulk properties of optical fiber

Bulk Properties of Optical Fiber

Attenuation

- Signal strength “sucked up” by fiber
- Attenuation accumulates with distance
- May require amplification

Dispersion

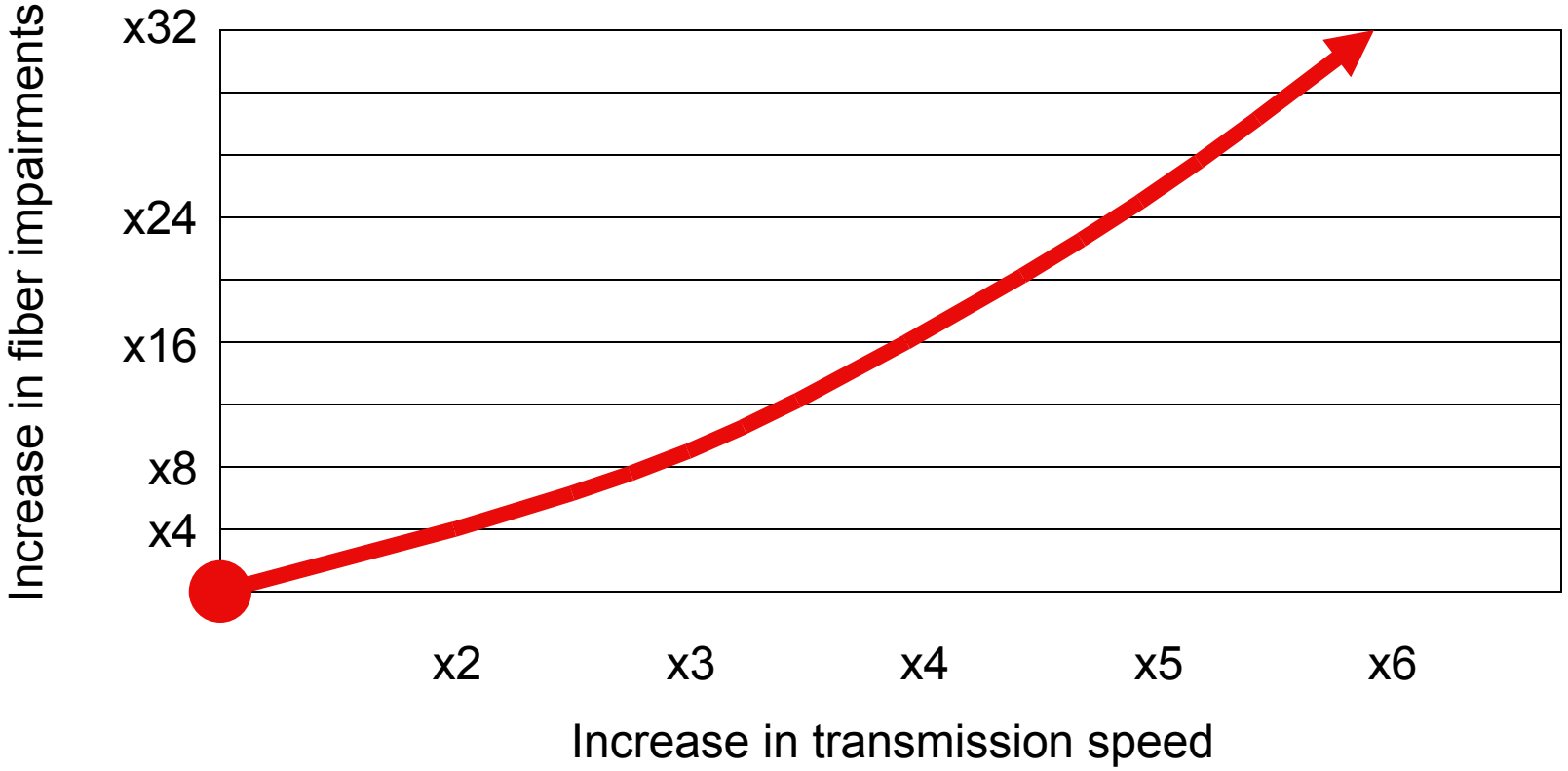
- Signal pulse is “smeared out” by something in the fiber
- Dispersion accumulates with distance
- Three main causes
  - Modal dispersion
  - Chromatic dispersion
  - Polarization mode dispersion

Non-linearities

- Weird stuff that happens at very high signal strengths
  - Typically after the EDFA
- General result is loss of OSNR
- Three broad examples:
  - Self phase modulation
  - Cross phase modulation
  - Four wave mixing
- The cure is often to use chromatic dispersion to help
  - Leads to the concept of “dispersion management”

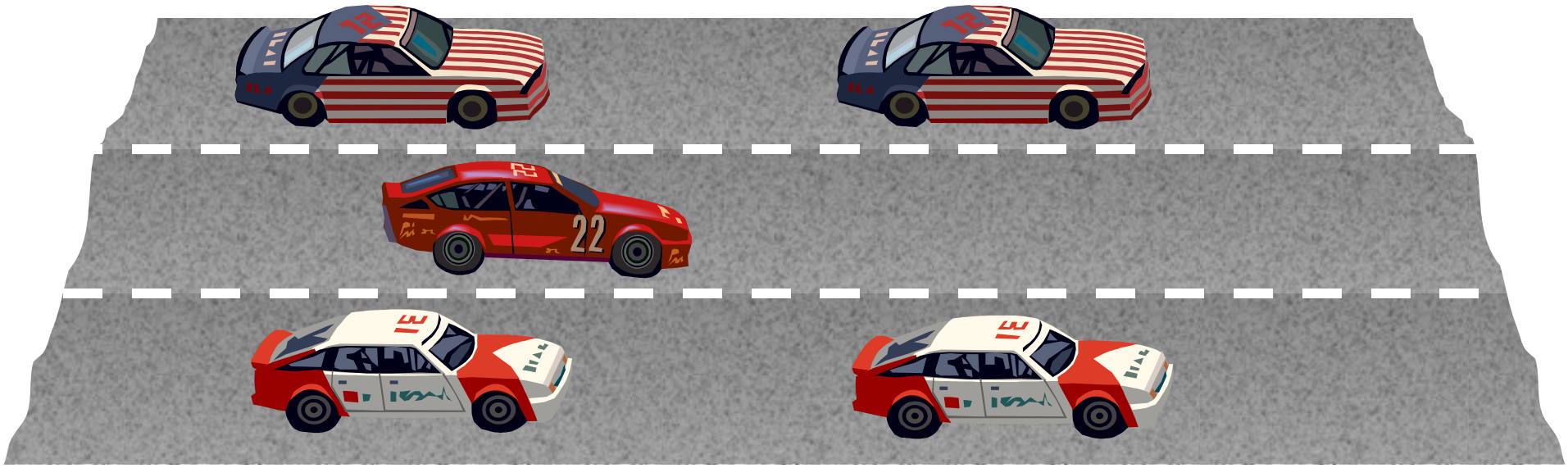
It gets harder to transmit faster…

- Fiber impairments scale with the *square* of transmission speed…



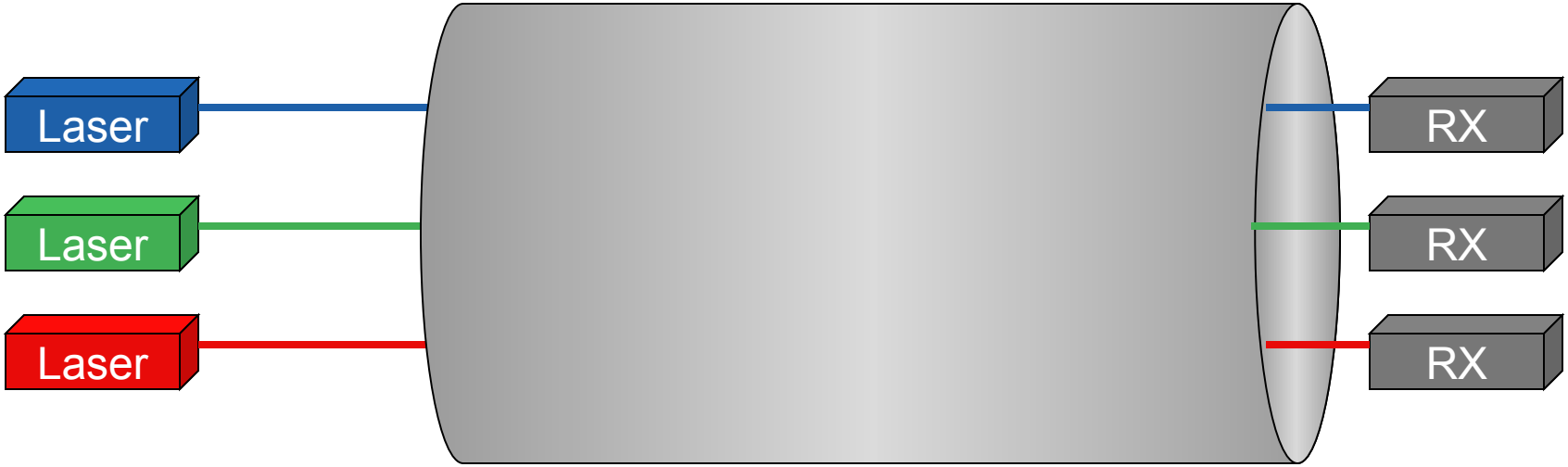
Option 2: More lanes

- Each stream of traffic has its own lane…

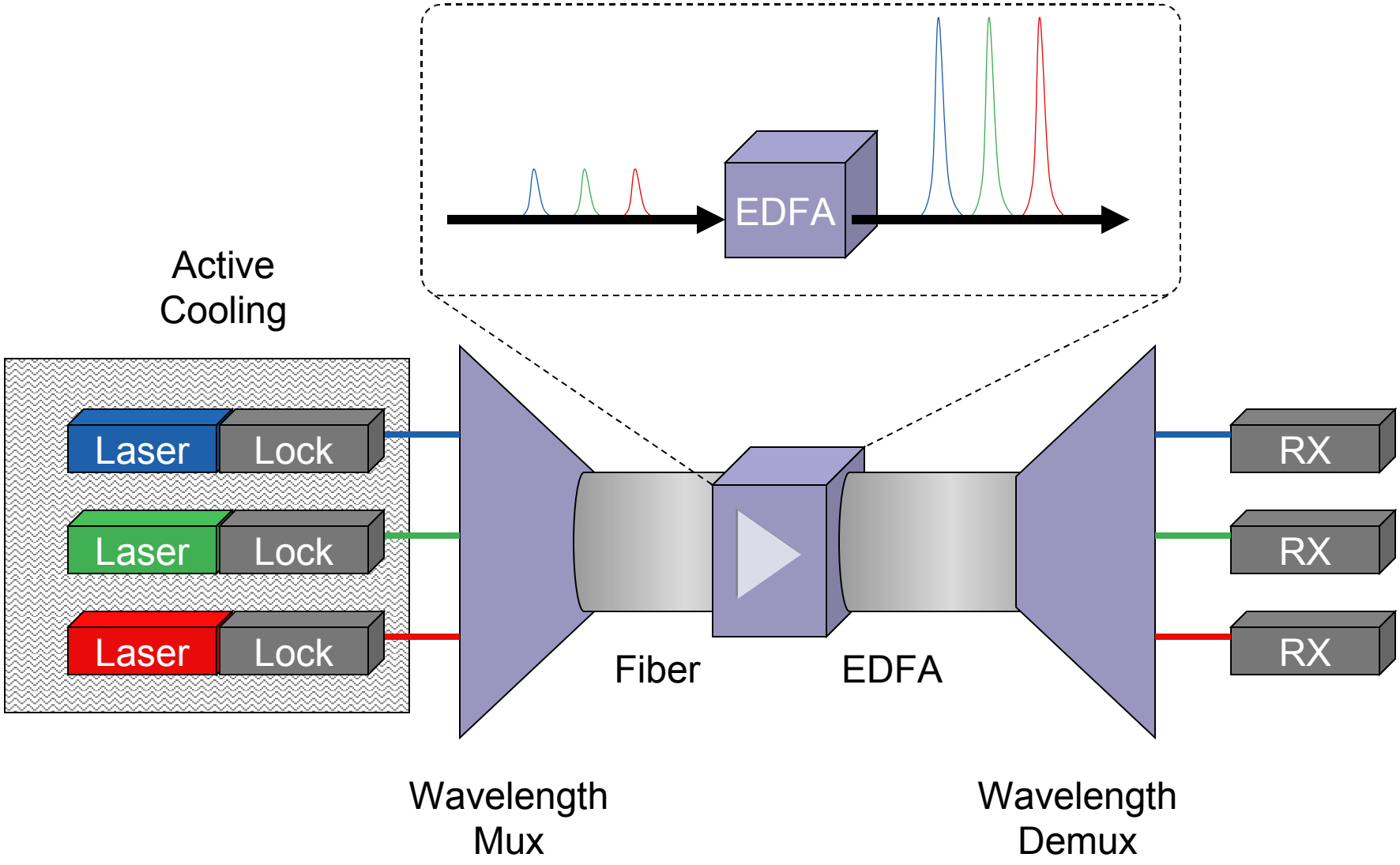


WDM Transmission

- Multiple wavelengths into fiber
- Each wavelength is independent
  - (Not really true)



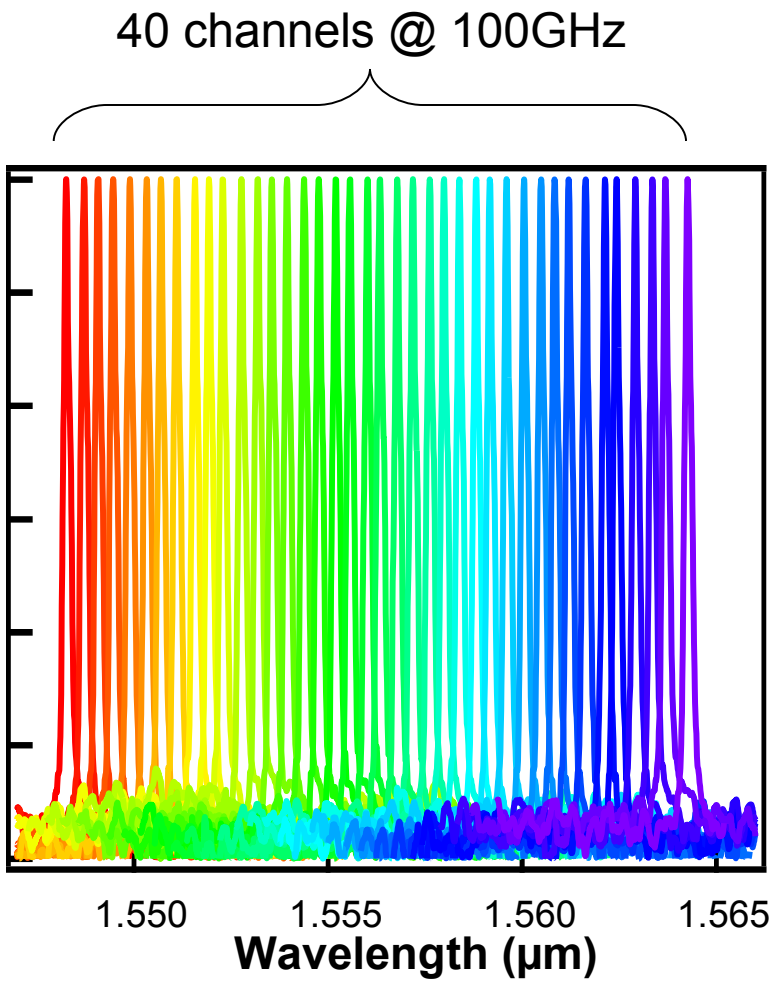
Elements of WDM System



EDFA -> The Conventional Band

- 1530-1565nm
- Defined by minimum attenuation and the EDFA
- Space for:
  - 40 x 100GHz channels
  - 80 x 50GHz channels
  - Typical channel is 10Gb/s

The capacity in the C-band is traditionally quoted as 800Gb/s

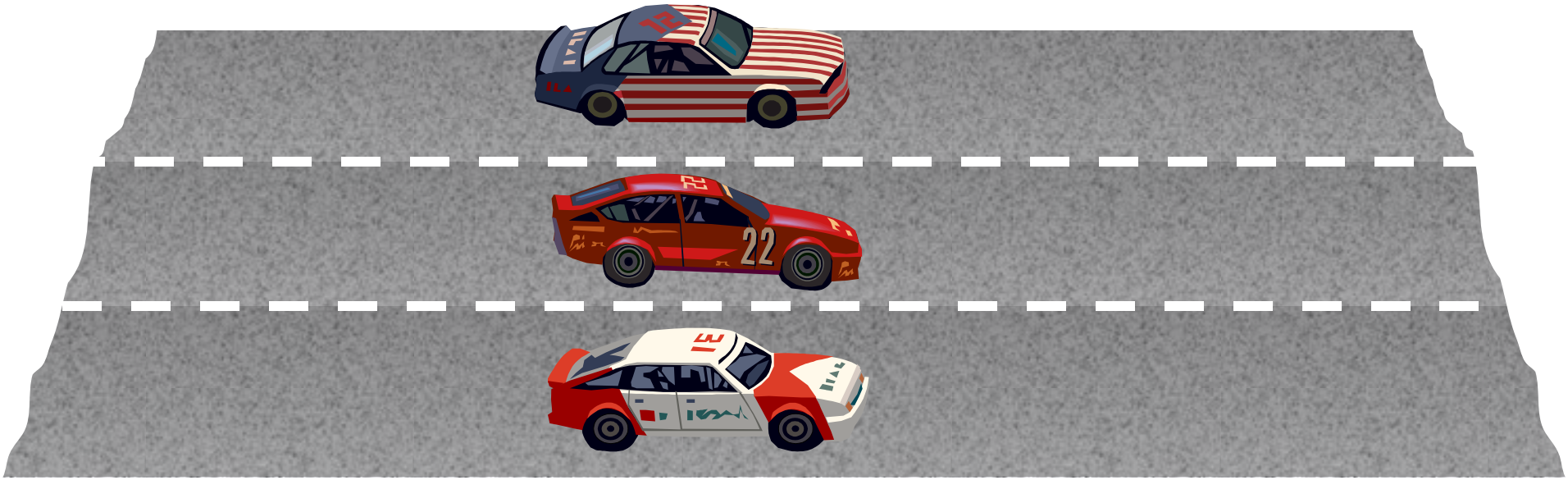


A Quick Word…CWDM vs DWDM

- CWDM uses R E A L L Y W I D E channel spacing ☺
  - 20nm for CWDM
  - 0.2nm (25GHz) for DWDM
- This means we can use uncooled (and therefore much cheaper) lasers
  - Uncooled laser drifts by ±0.06nm/°C
- Cheaper wavelength mux/demux
- 18 channels defined by ITU G.694.2
  - From 1271 – 1611nm
- Assume no amplification needed

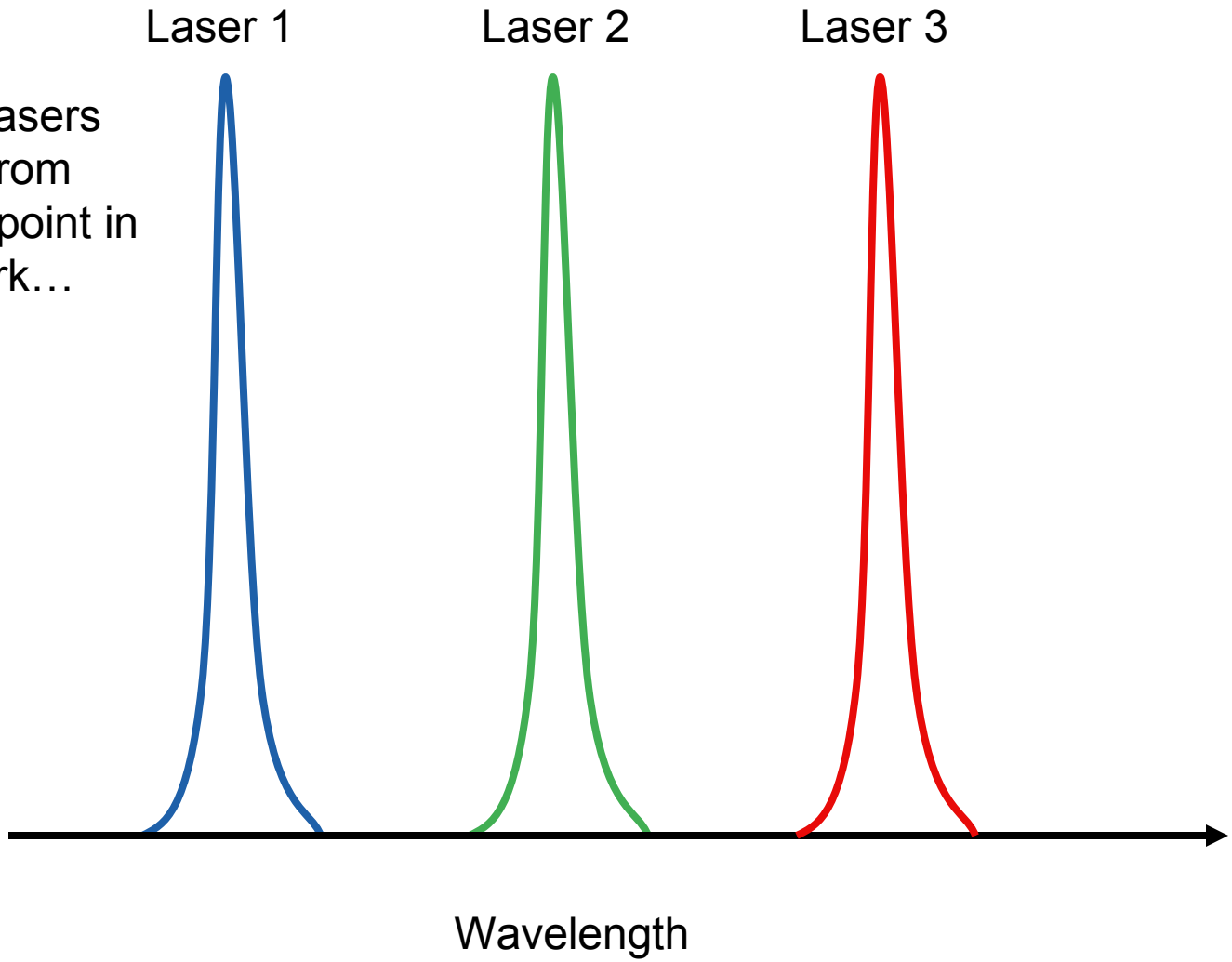
How close can these lanes get?

- What happens if traffic “wobbles about”?
  - What’s the optical equivalent of a “crash”?



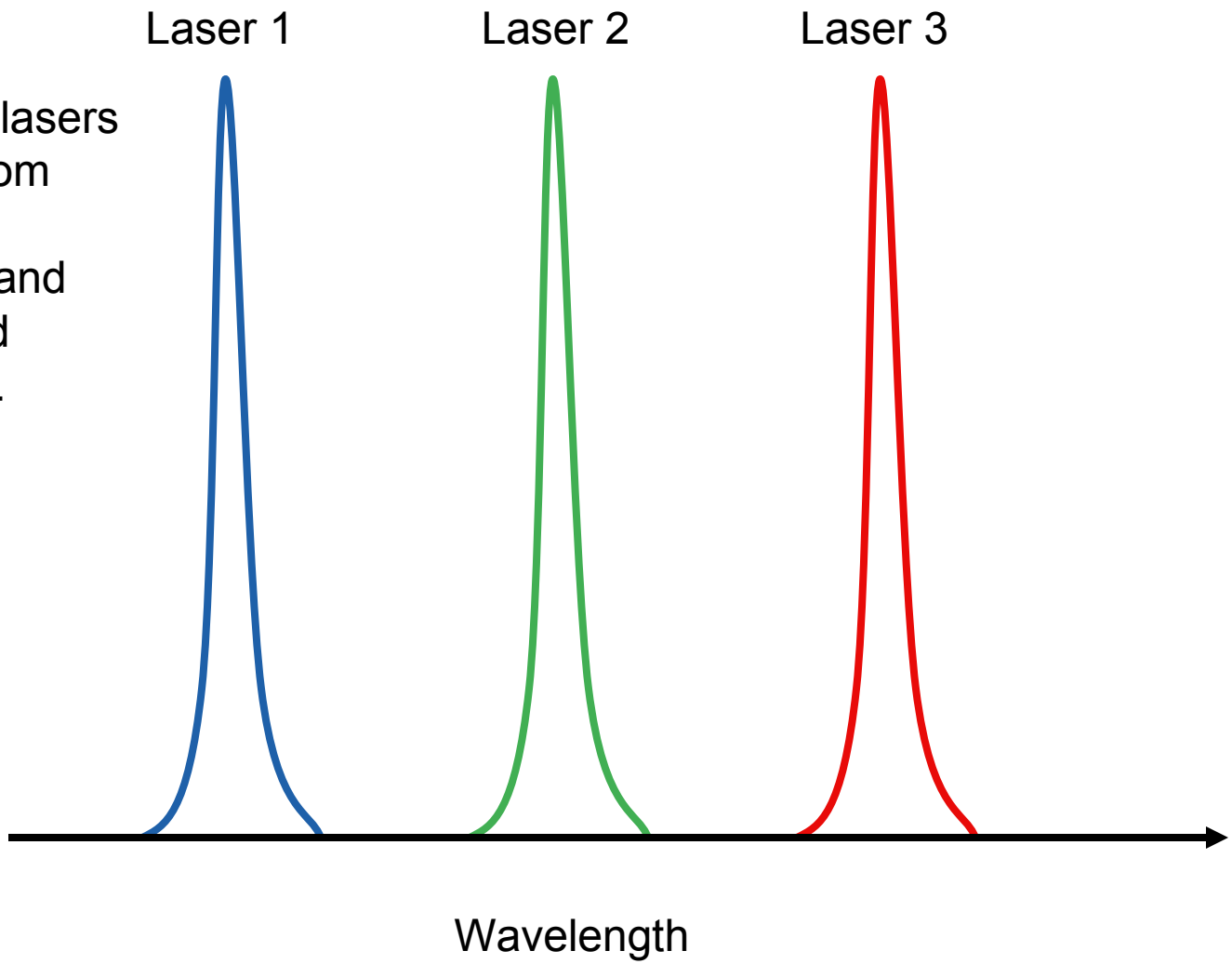
Laser *wavelength* varies with *temperature*

All these lasers originate from the same point in the network…



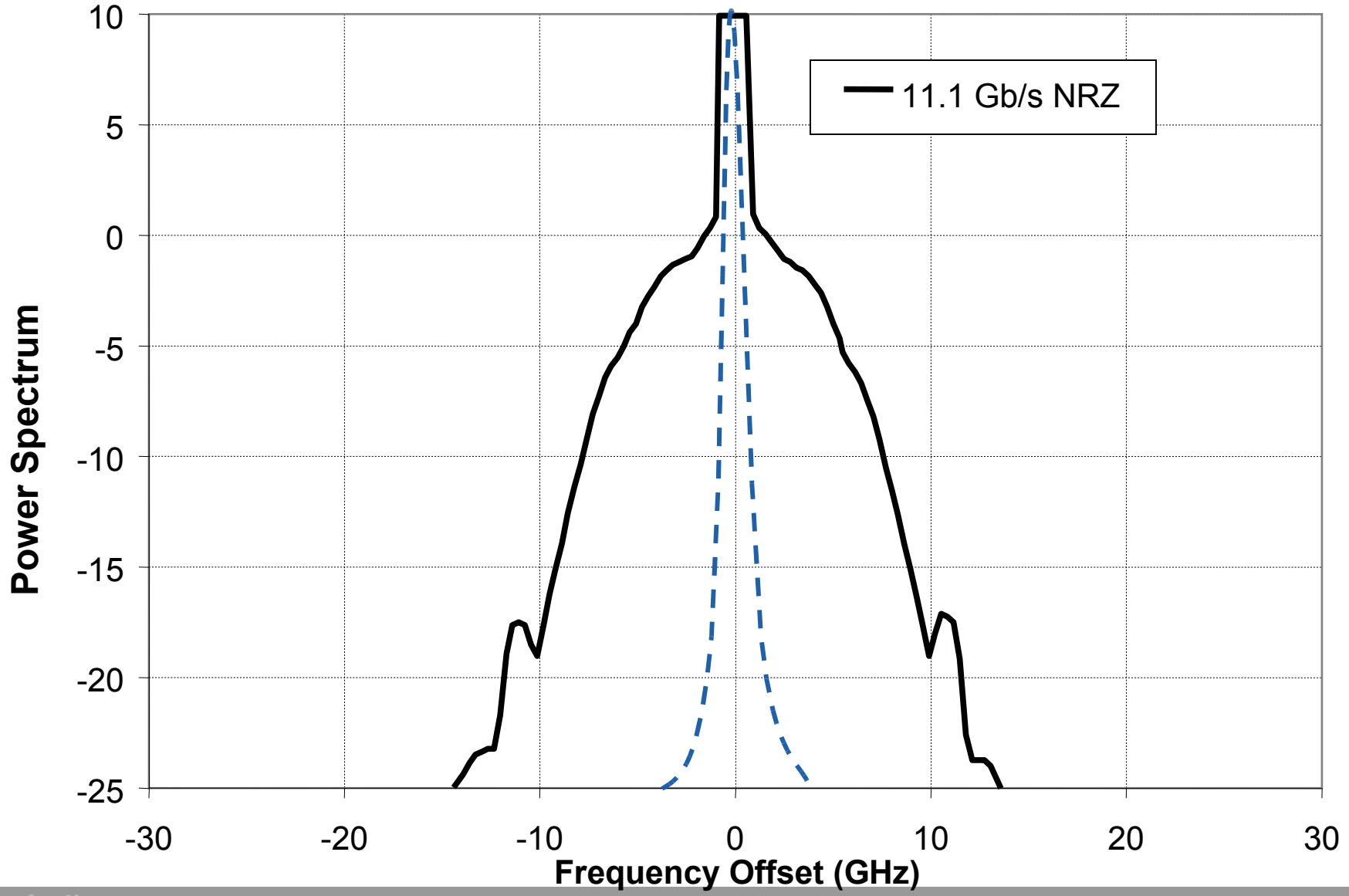
Laser *wavelength* varies with *temperature*

But these lasers start off from different terminals and are muxed together…



Modulation broadening:

Adding a signal to the laser…



Modulation schemes

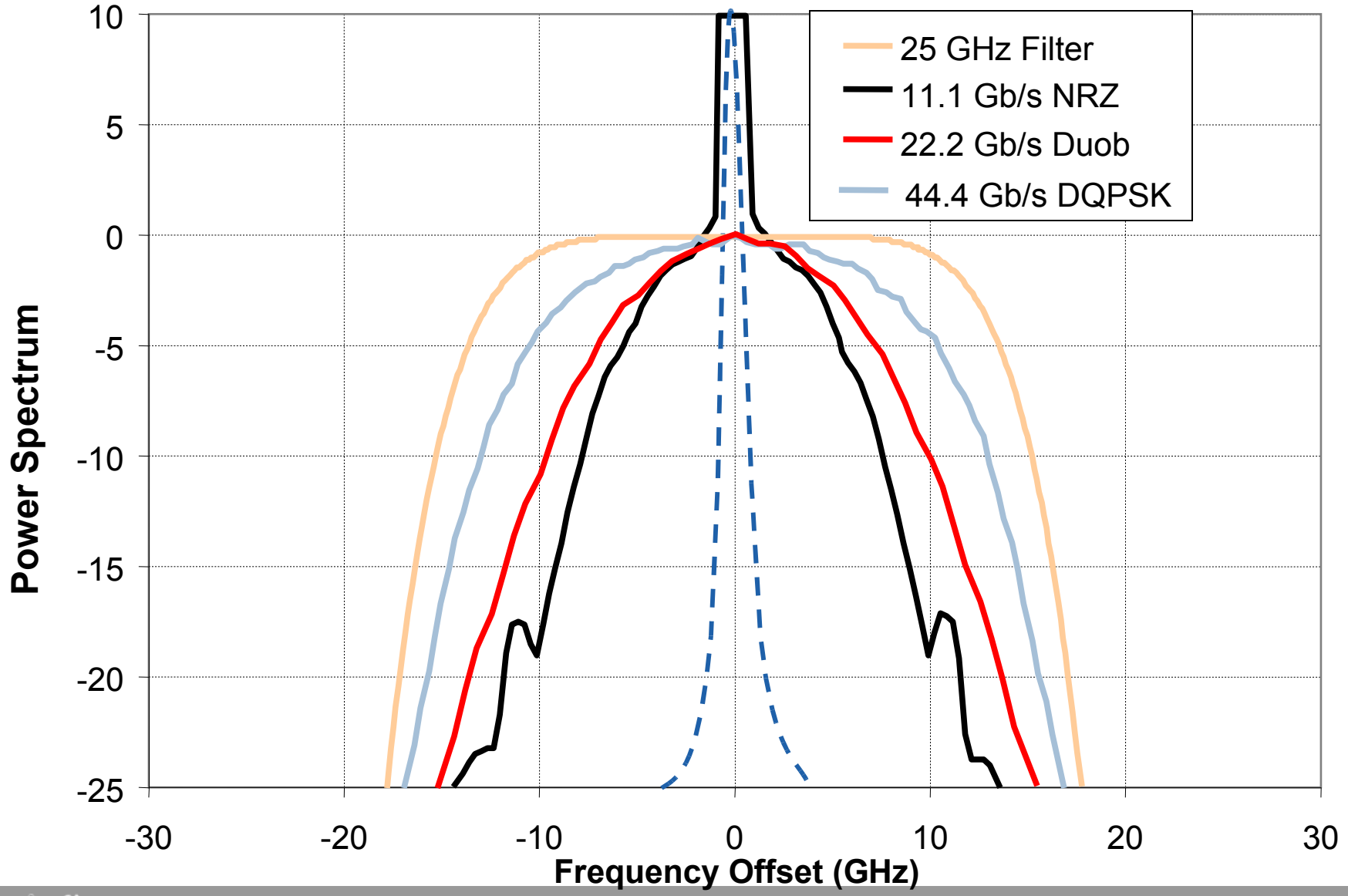
- NRZ: Most common, and easiest to implement
  - Rule of thumb:

Safe channel spacing (GHz)	=	Data rate (Gb/s)	x 2.5

  - 10Gb/s = 25GHz, 40Gb/s = 100GHz
- More complex modulations schemes now available, or in the lab
  - Duobinary
  - DPSK
  - DQPSK
  - 2-pol DQPSK

These techniques show tremendous promise, but it's early days yet

Complex Modulation Schemes



A short recap…

- We know fiber has certain bulk properties
  - Attenuation is one – and we need to amplify signals to overcome attenuation issues
  - EDFAs work really well to amplify all multiple DWDM signals
- WDM: We send multiple signals, on separate wavelengths, down the same fiber
  - There are certain factors that govern the minimum spacing between these channels
    - Laser lock stability
    - Wavelength mux/demux resolution
    - Modulation broadening
- Together these represent the *economic options* to achieve ultimate fiber capacity

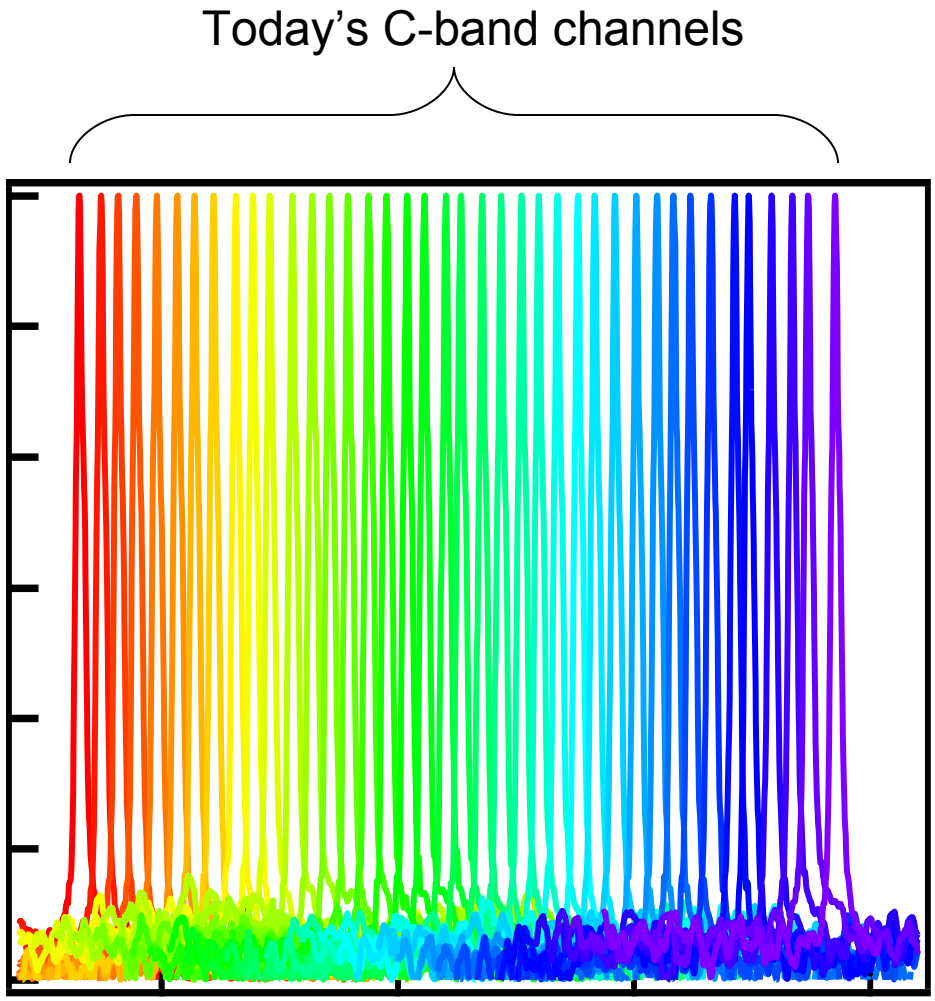
A quick glimpse to the future…

- Transmit faster
  - Including complex modulation
- Adding more channels
  - With closer spacing

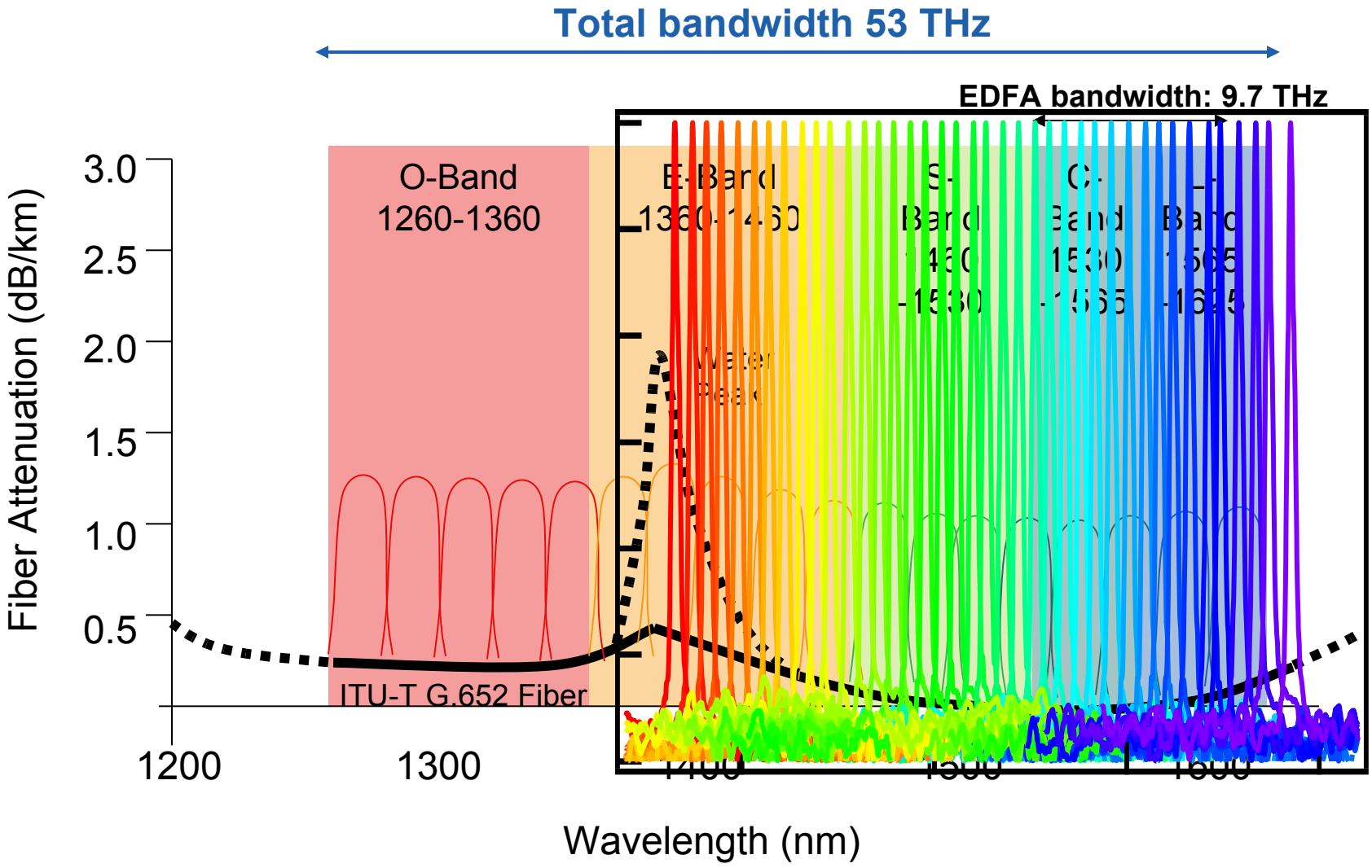
Right now, we are "trapped" by the C-band

How can we access "more highway"?

= Get More Spectrum



= Get More Spectrum



Beyond the C-band

- How can we amplify efficiently outside the C-band?
- How can we manage the enormous number of wavelengths that will become available?
- When?

Watch this space ☺

Thank You

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