Chip-based FAIMS – Triple Quadrupole MS: *Instrumental Studies and Analytical Capabilities*

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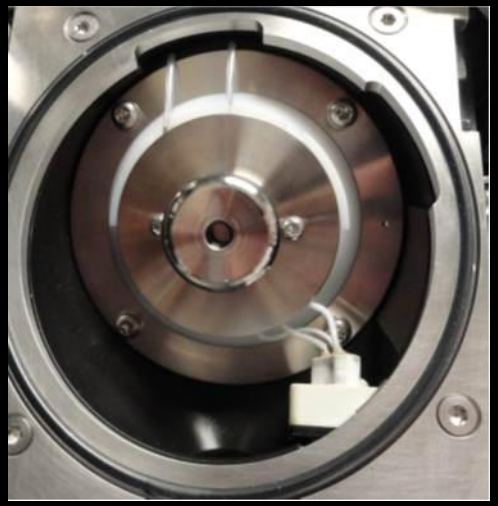
Topics

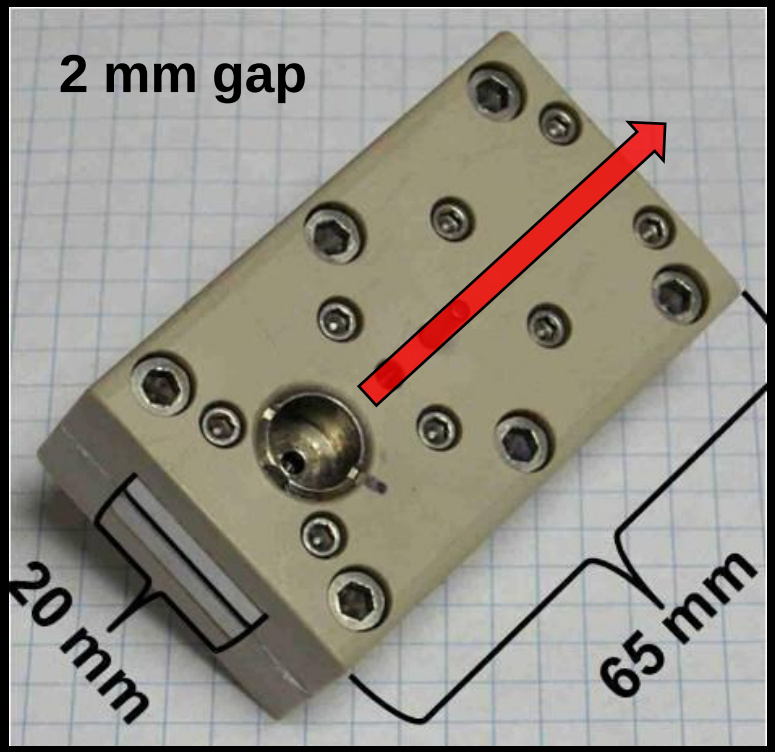
- Instrumentation: Chip FAIMS/Triple Quad
- Chip FAIMS vs. FAIMS
- Rapid CF/DF scans (10-100x faster than with conventional-sized FAIMS cells)
- Effects of modifier gases and solvent vapors on separation of isomeric ions

Instrumentation

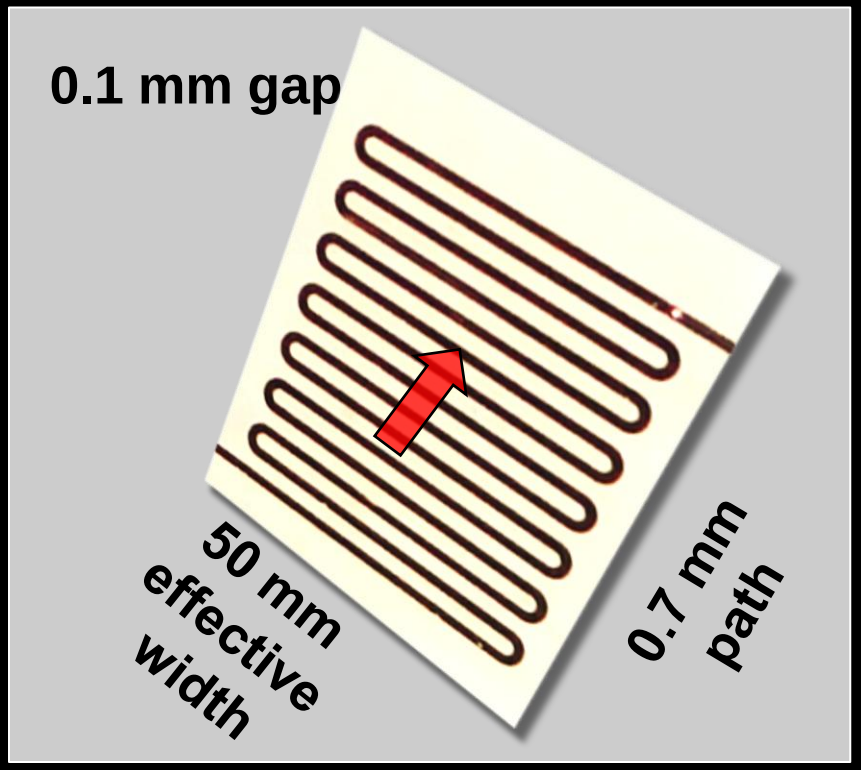
- Custom Owlstone FAIMS chip
- Agilent 6460 triple quadrupole mass spectrometer
- Custom Owlstone FAIMS waveform generator:
  - DF up to 350 Townsends (DV to ~600V_p, 60kV/cm)
  - CF -30 to 30Td (CV -50 to +50V)



Chip FAIMS vs. Conventional FAIMS



FAIMS



Chip FAIMS

20x narrower gap, 2.5x wider channel, 100x shorter path

DV to 5000 V_p @ 2 MHz
$\rightarrow$ 25 kV/cm, 150 Td

DV to 600 V_p @ 27 MHz
$\rightarrow$ 60 kV/cm, 350 Td

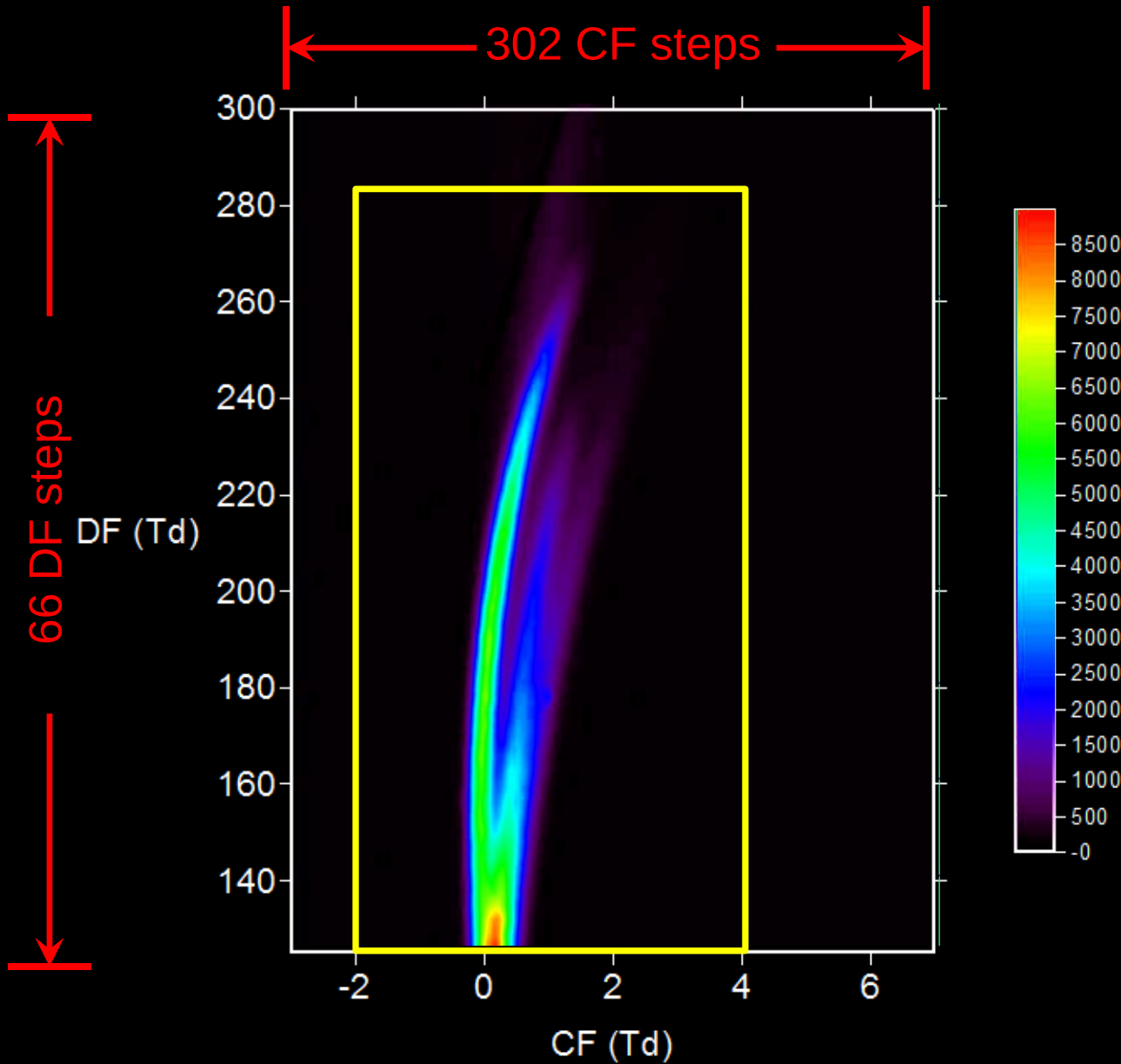
CF/DF Scan: *m*-phthalic acid $[M-H]^-$

Comprehensive CF/DF Scan

SIM mode
20,000 steps
in 11 minutes

What if we want a more rapid CF/DF Scan ?

Limit range, fewer steps

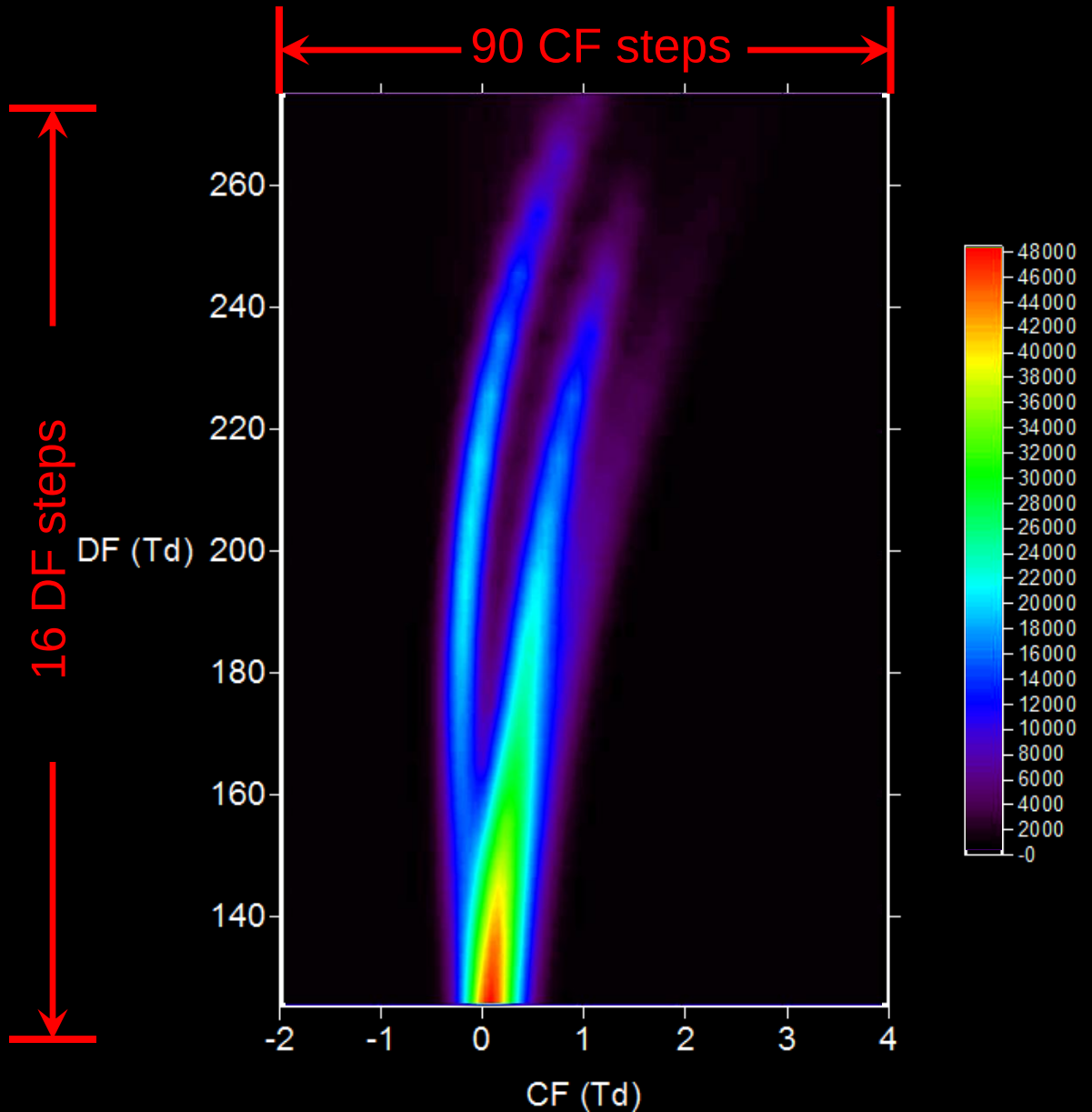


Rapid CF/DF Scan

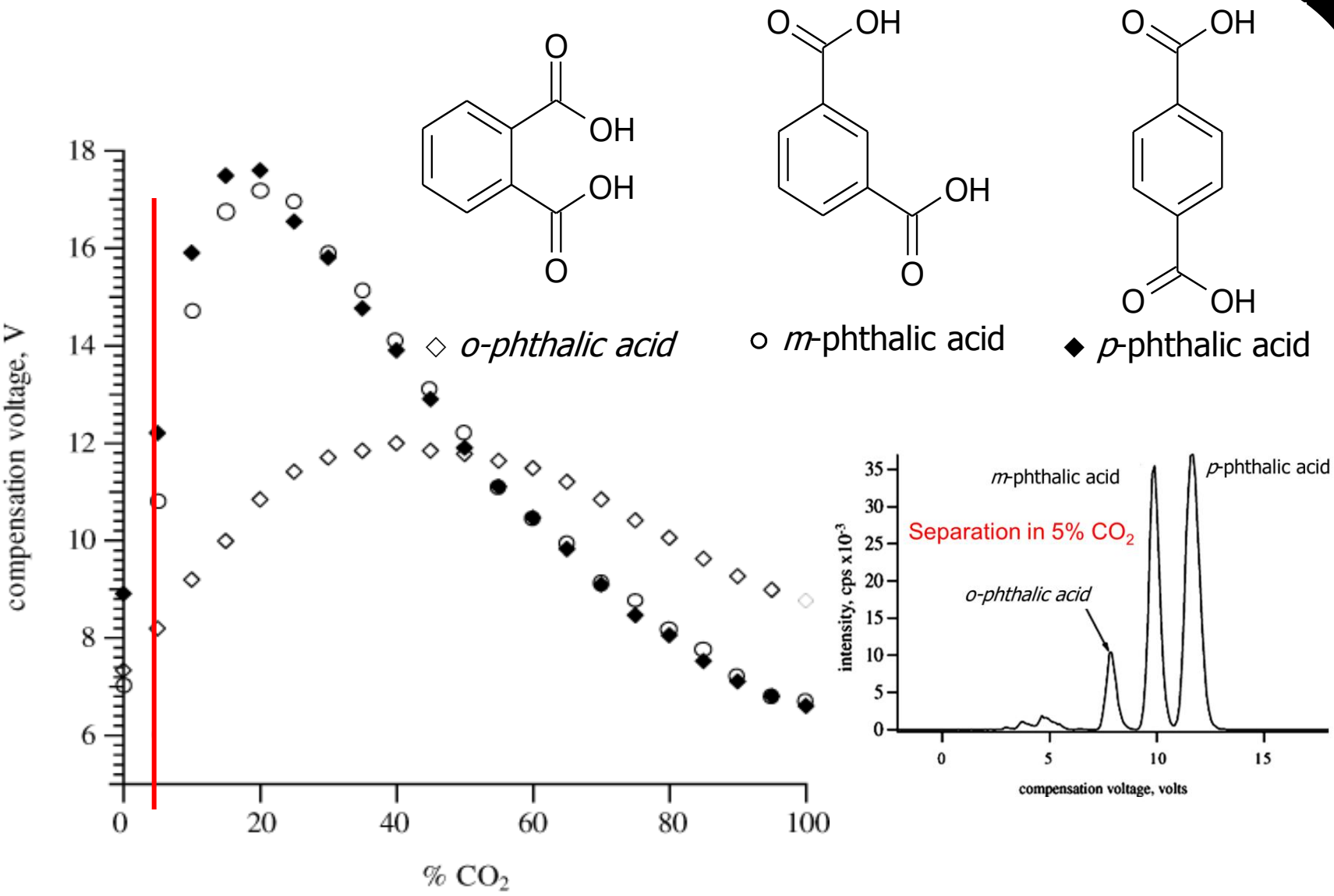
Rapid
CF/DF Scan

SIM mode
1440 steps
in 48 seconds

With reductions in scan overhead, we should be able to reduce this to <10 seconds



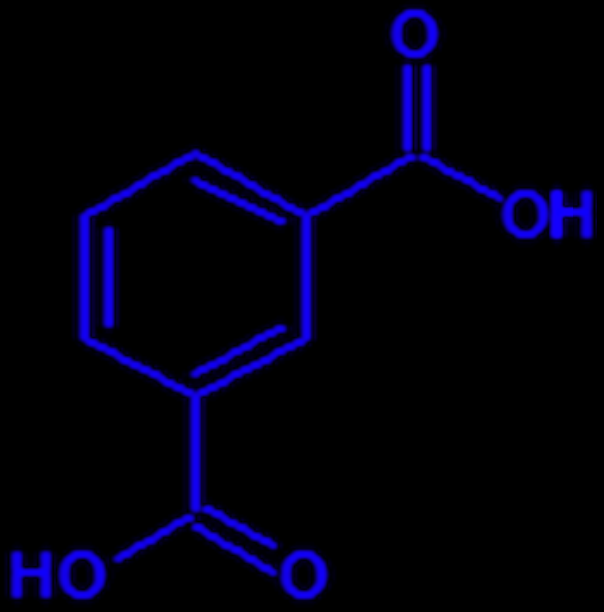
FAIMS w/ Modifier Gases (CO_2)



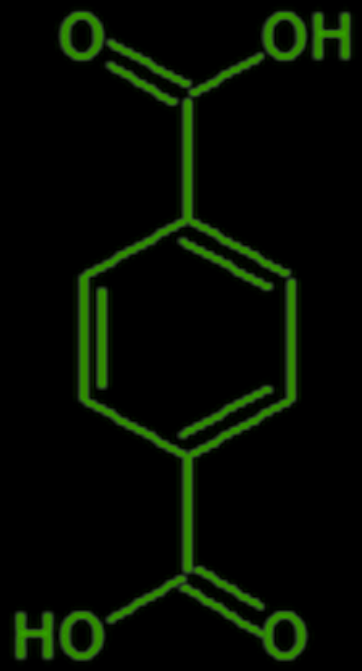
Barnett, D. A.; Ells, B.; Guevremont, R. *J. Am. Soc. Mass Spectrom.* **2000**, *11*, 1125

Chip FAIMS w/ Modifier Gases (CO_2)

o-phthalic acid



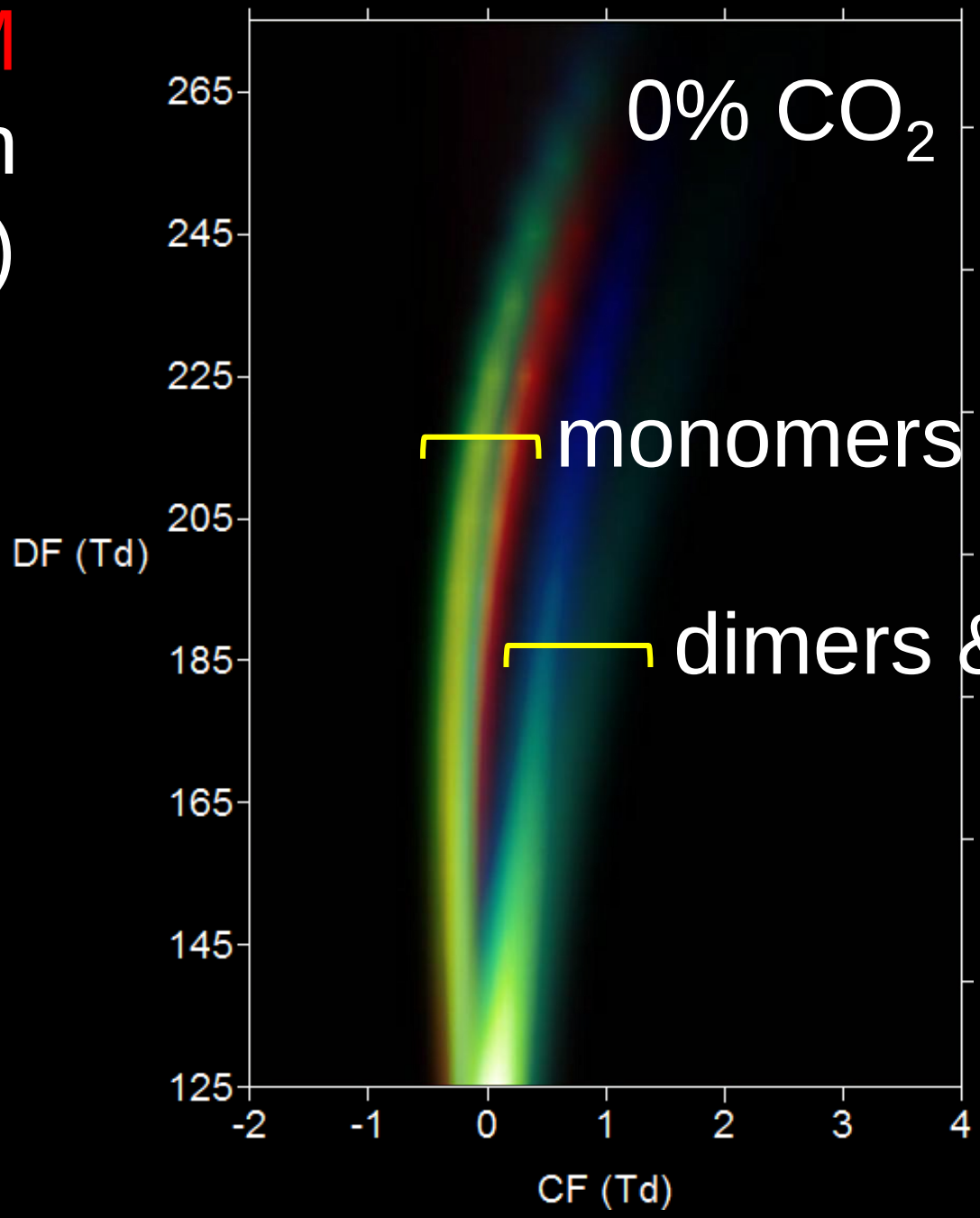
m-phthalic acid



p-phthalic acid

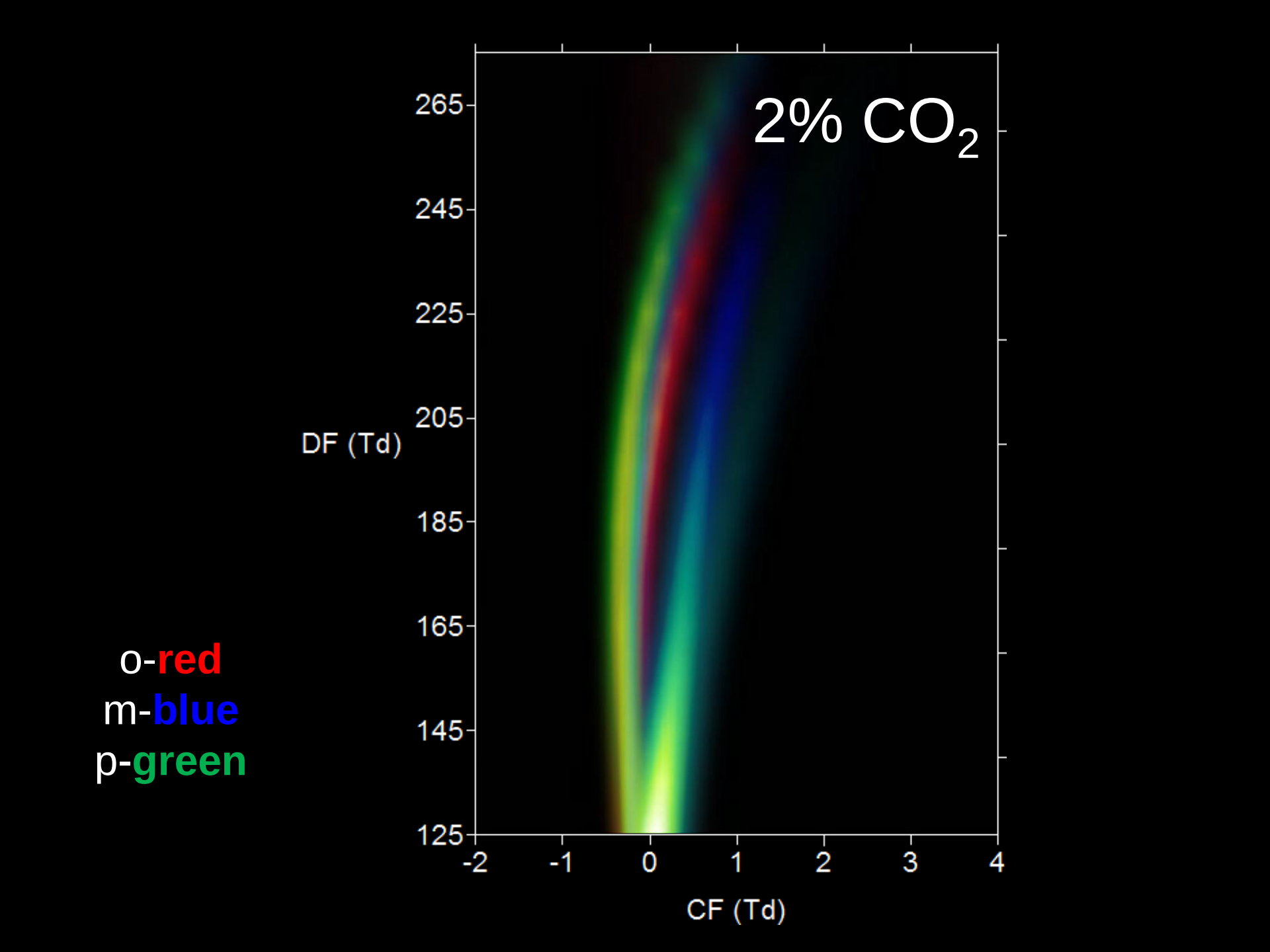
ESI - SIM

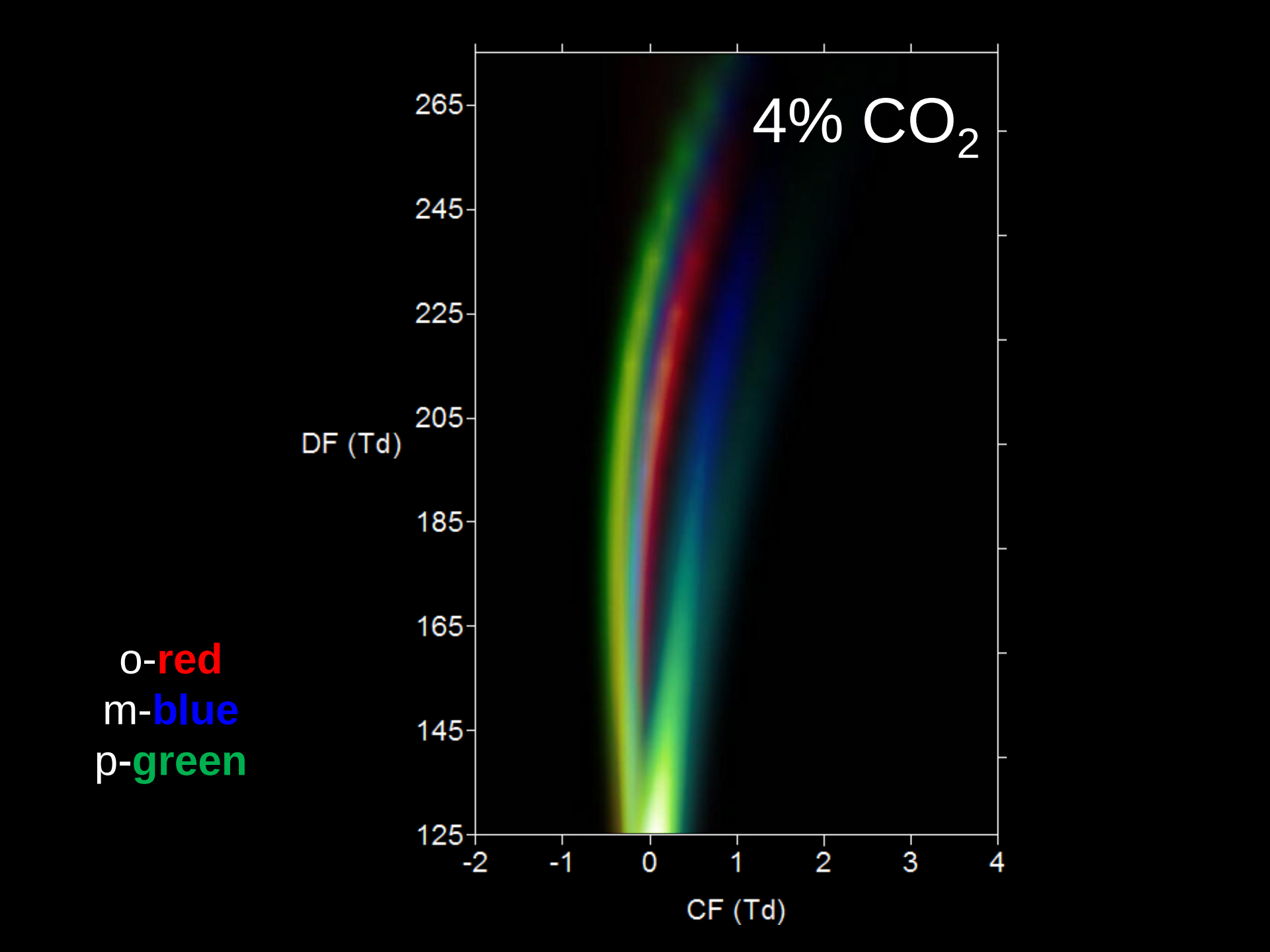
$[M-H]^-$ ion (m/z 165)

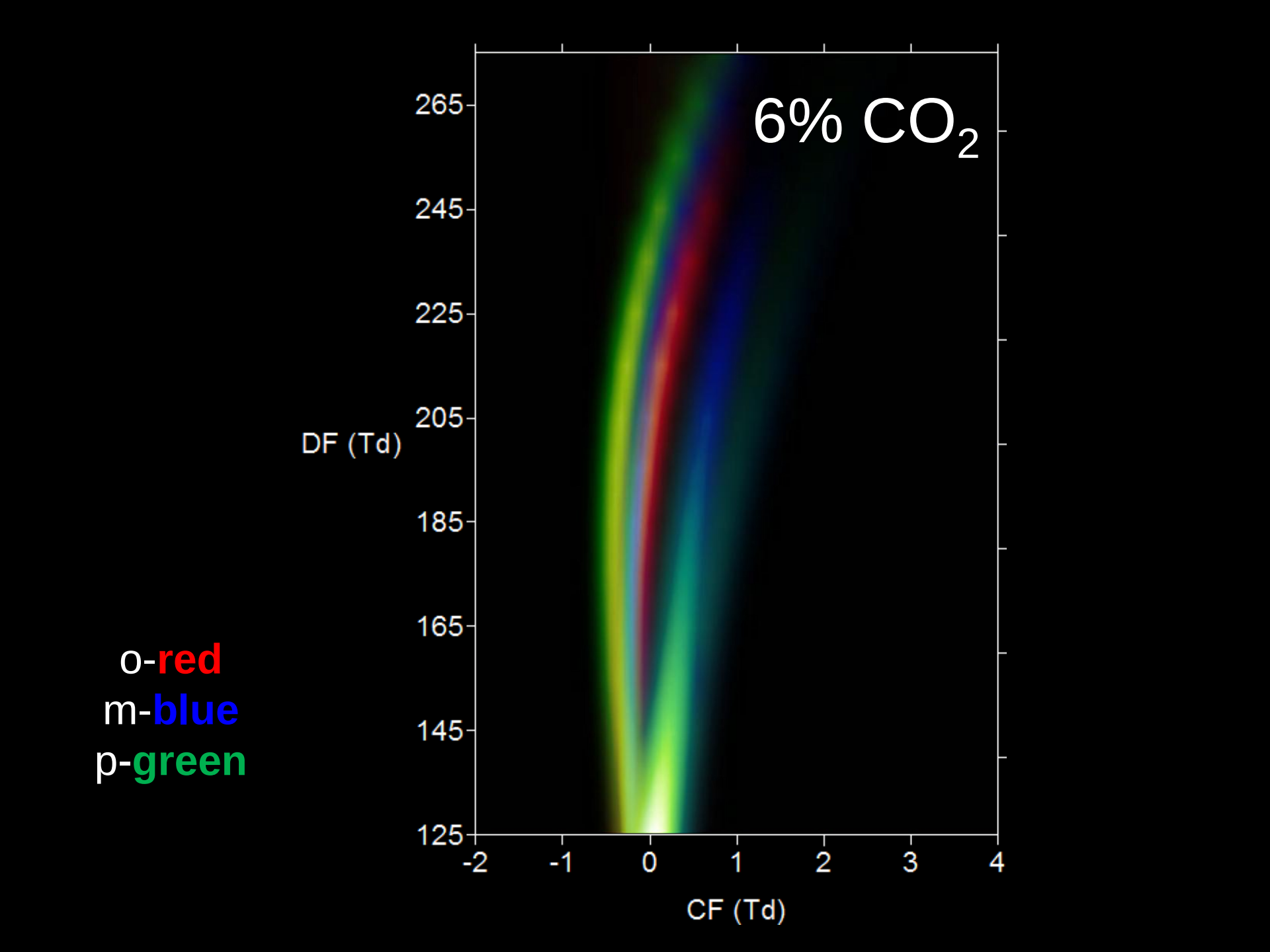


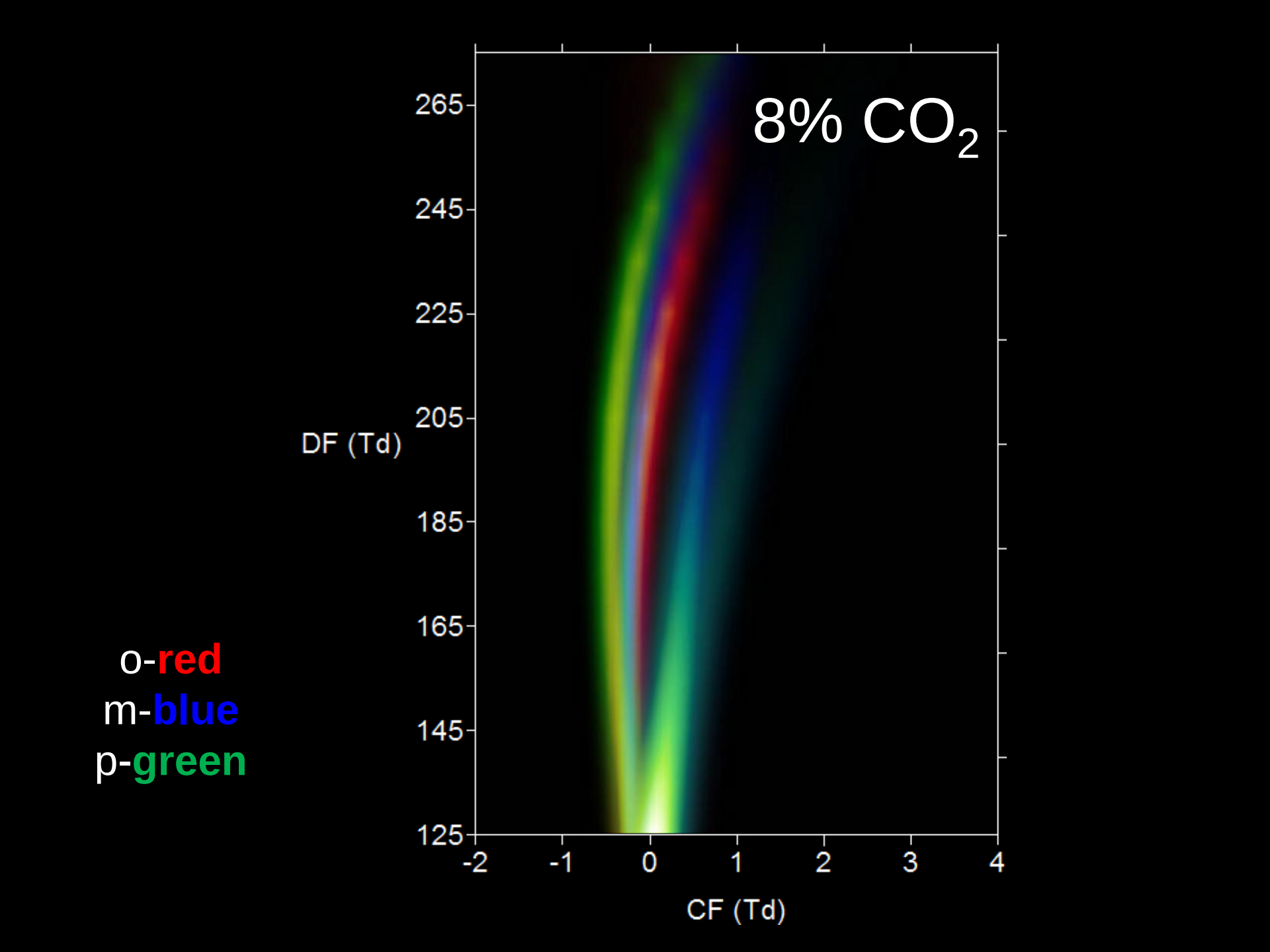
o-**red**
m-**blue**
p-**green**

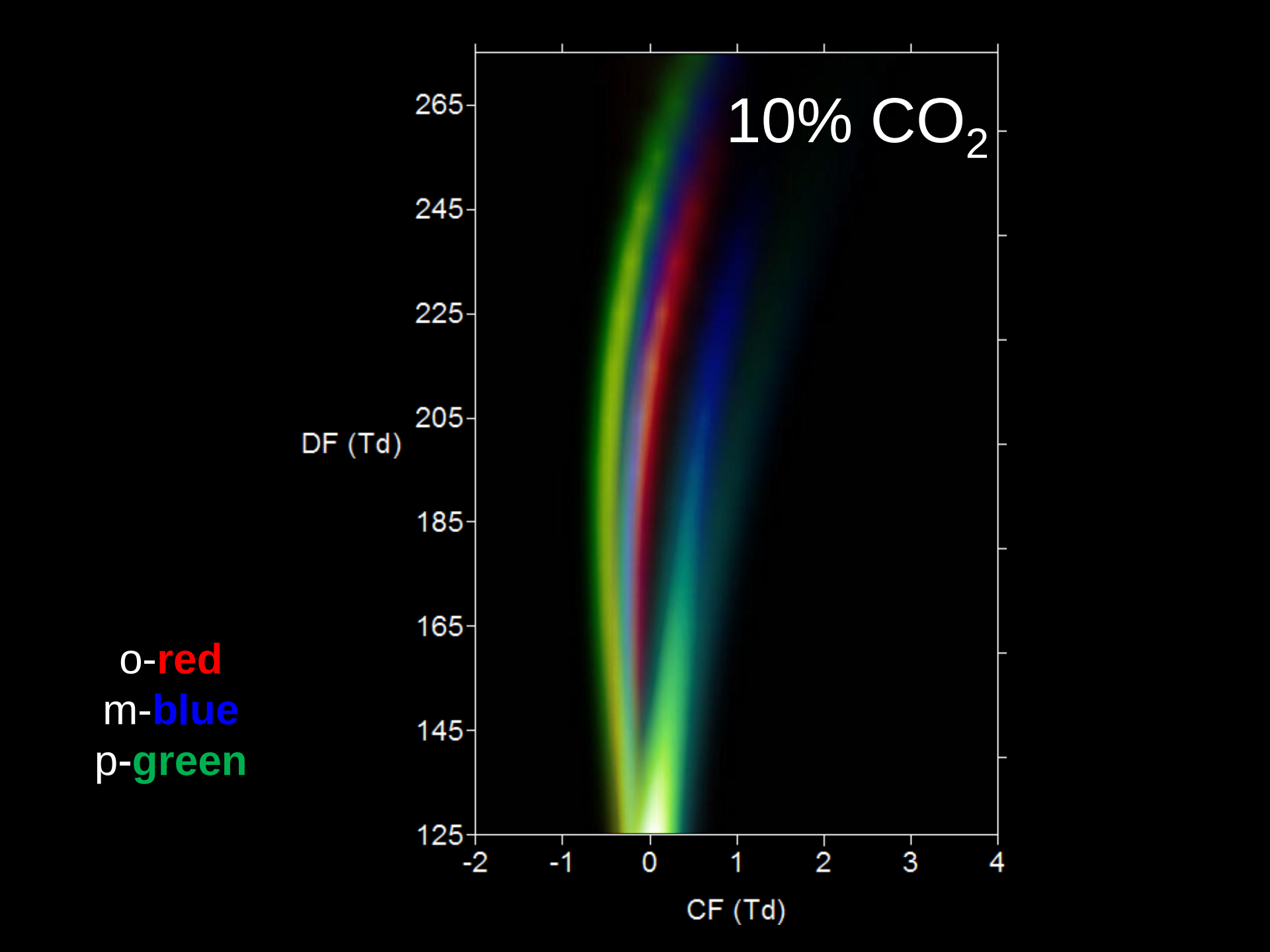
If we increase the % CO_2…

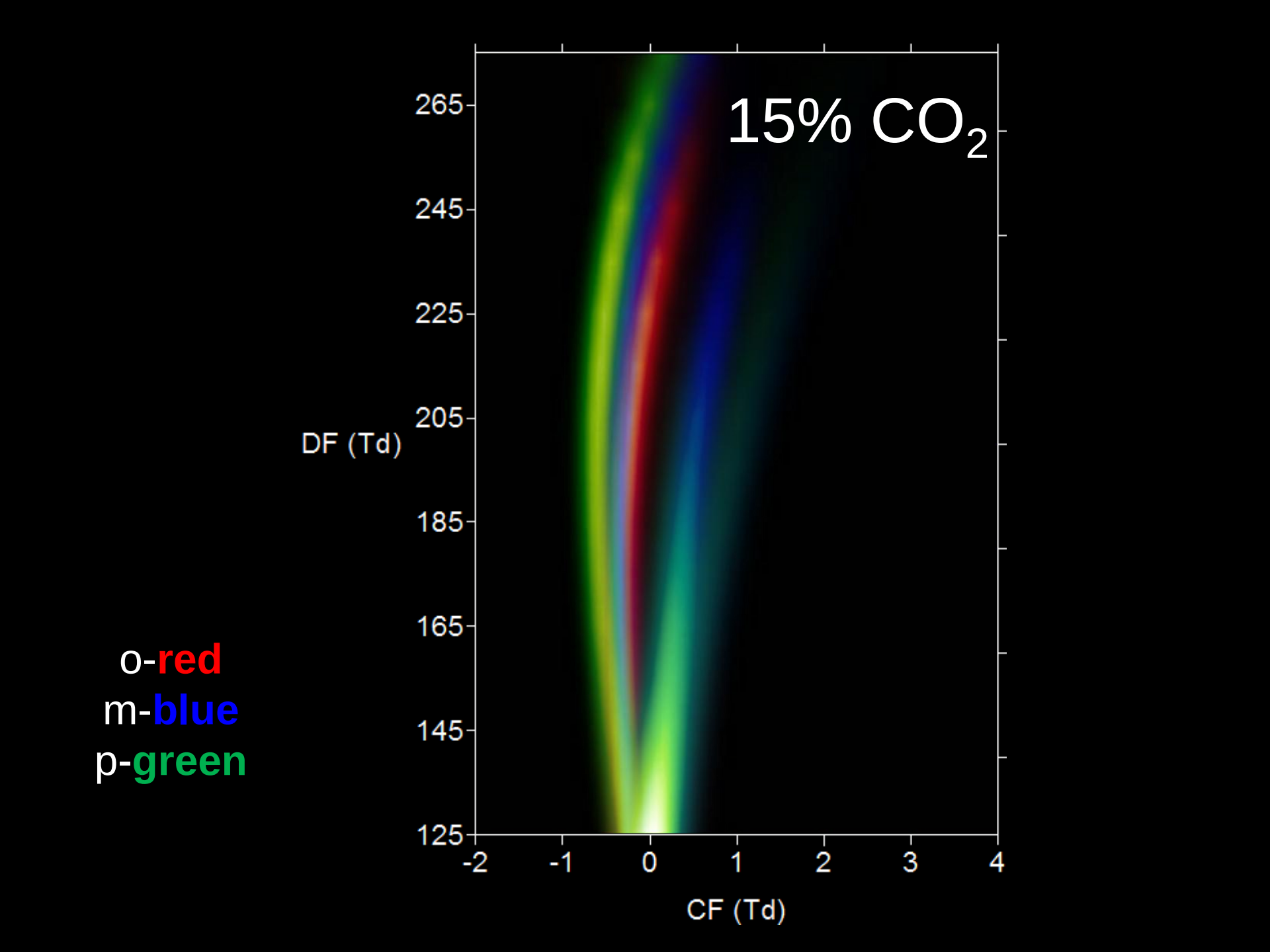

2% CO_2
DF (Td)
265
245
225
205
185
165
145
125
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

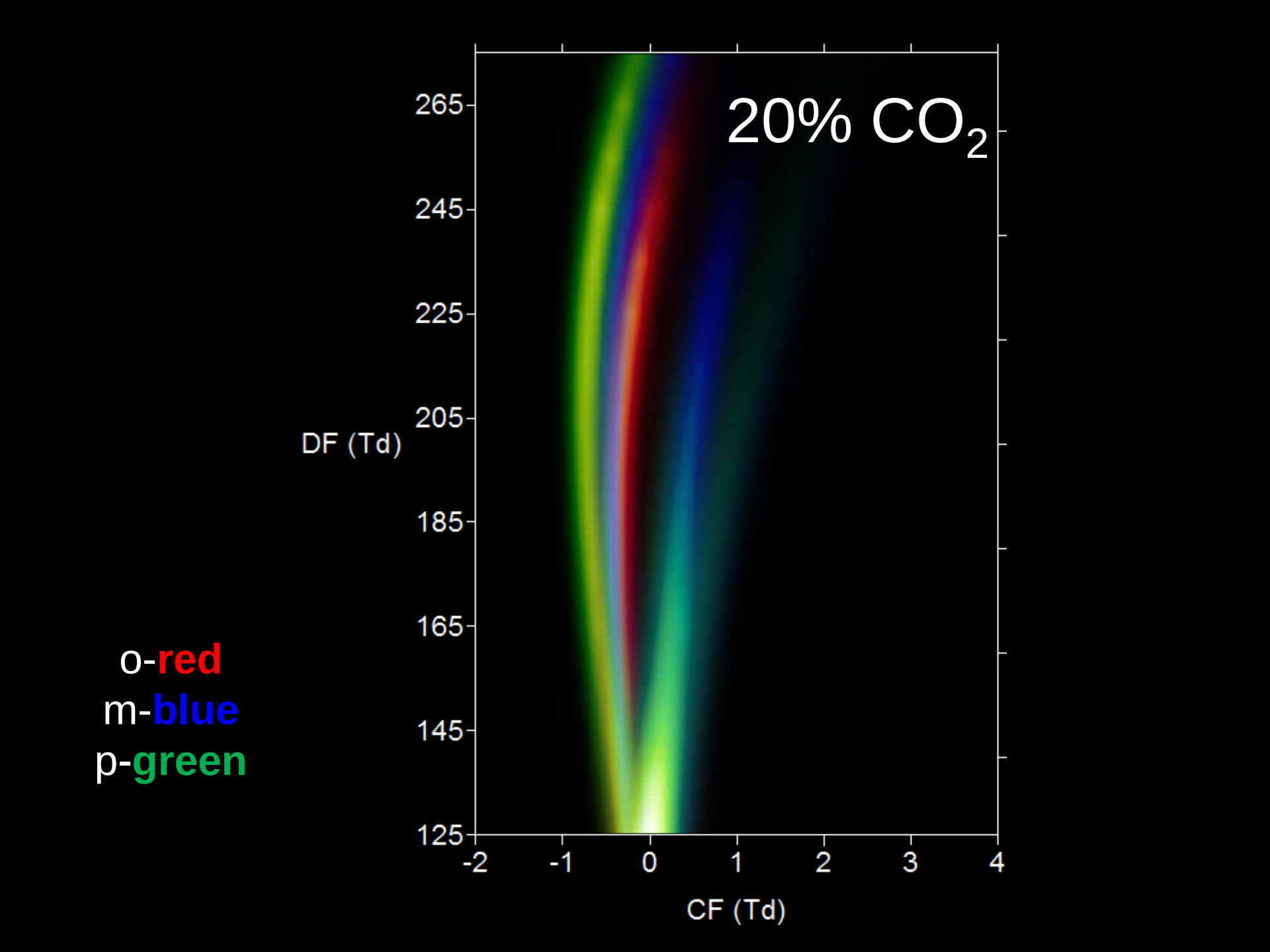

4% CO_2
DF (Td)
265
245
225
205
185
165
145
125
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

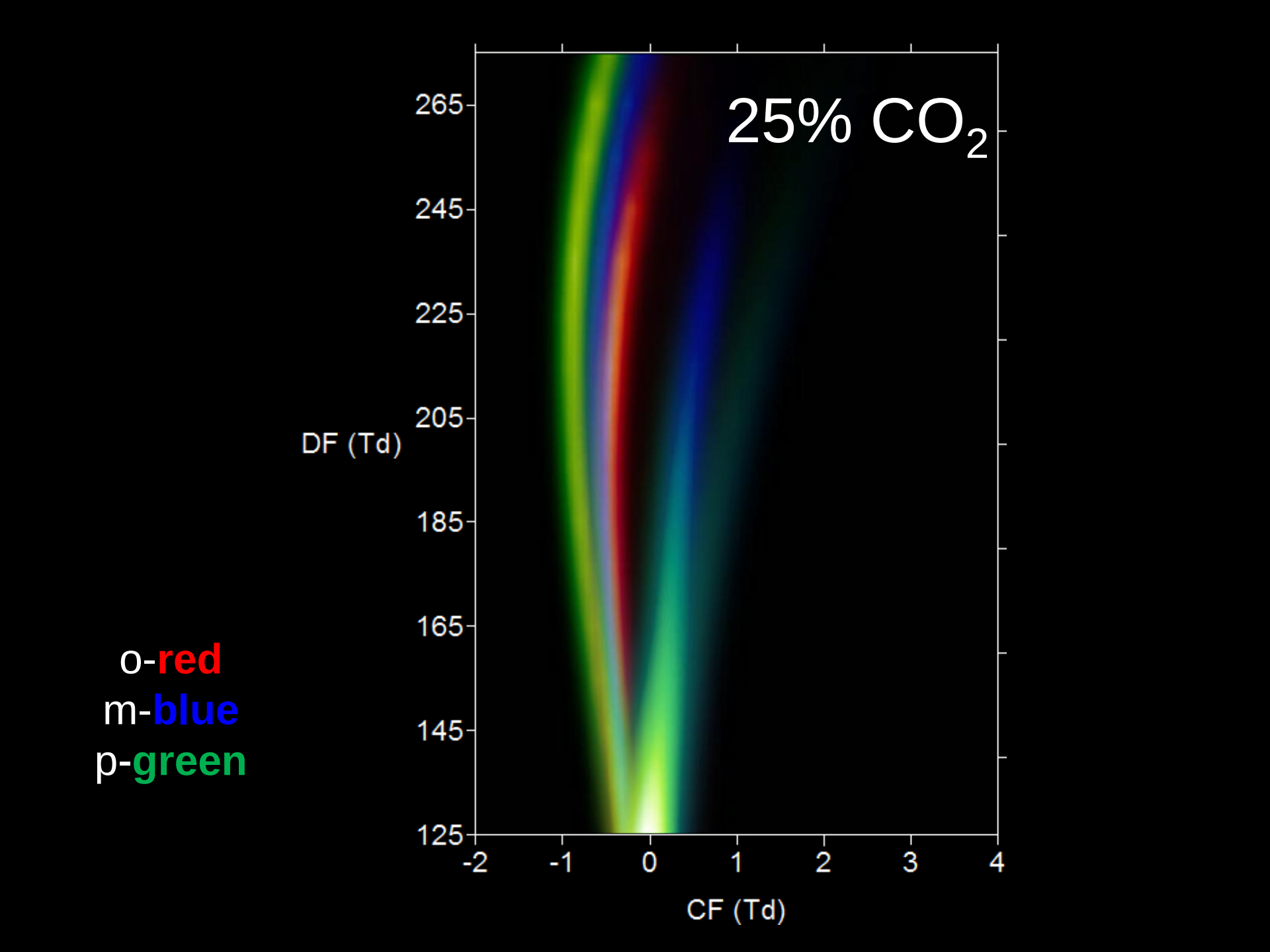

6% CO_2
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

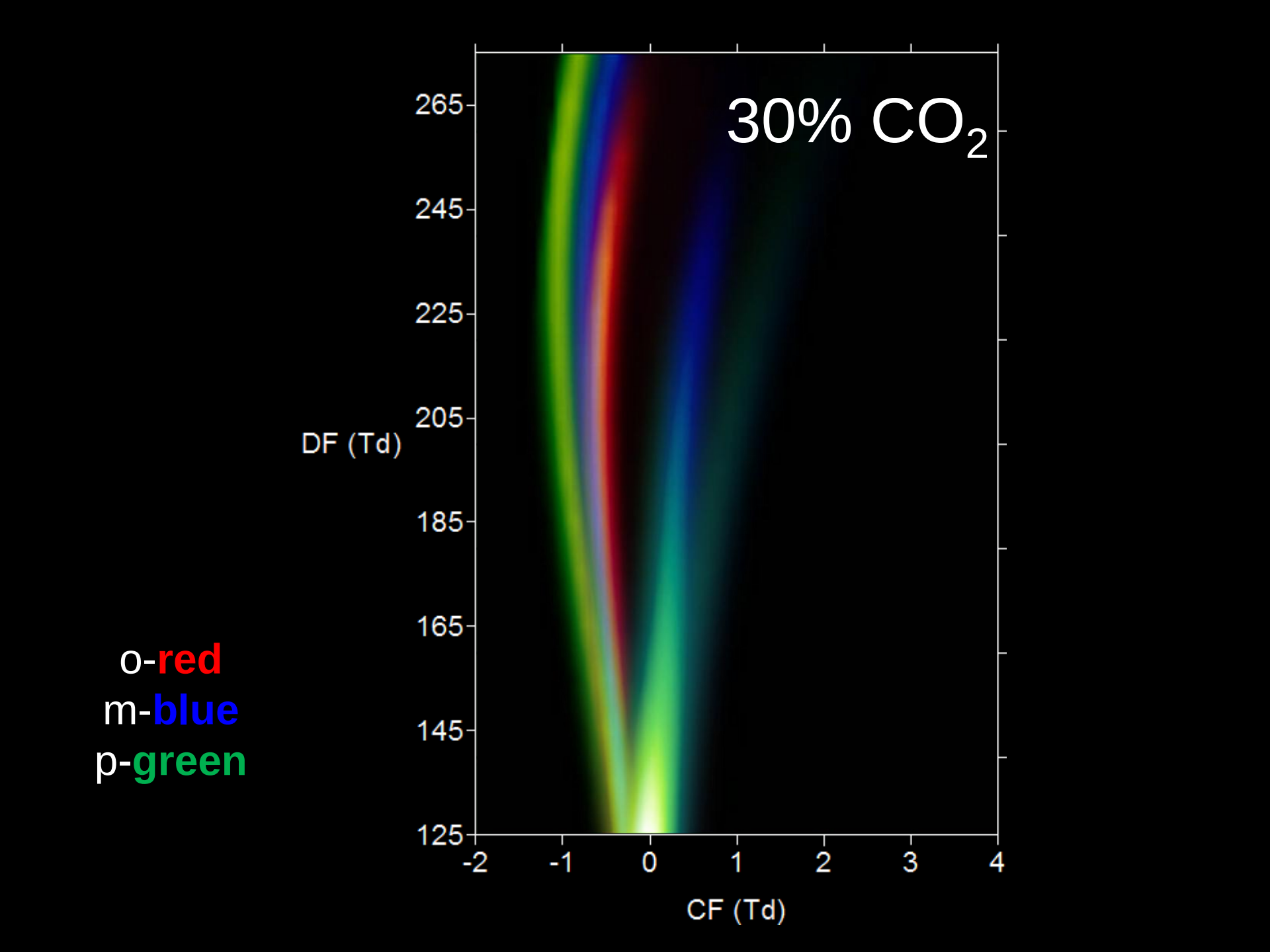

8% CO_2
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

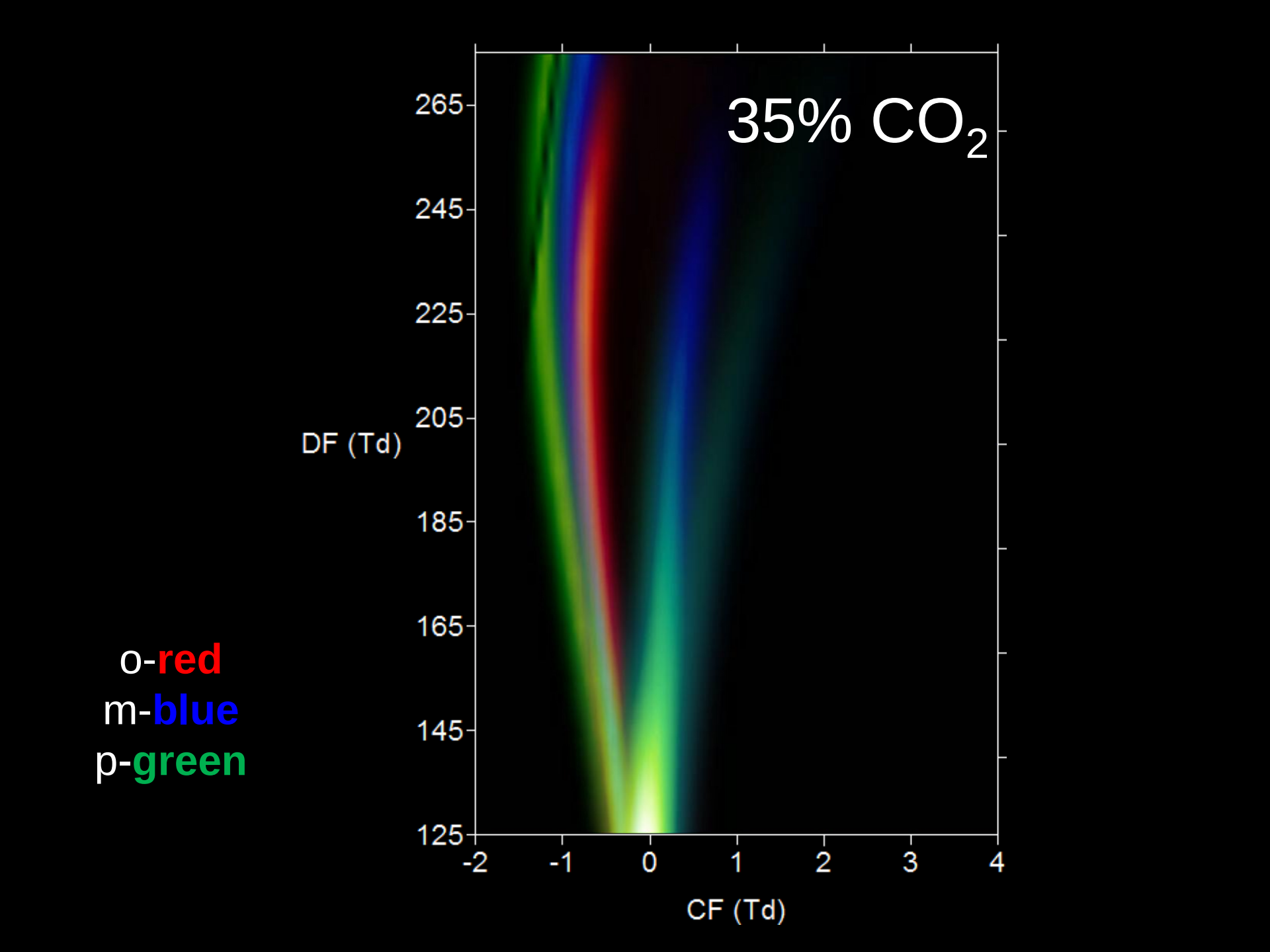

10% CO_2
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

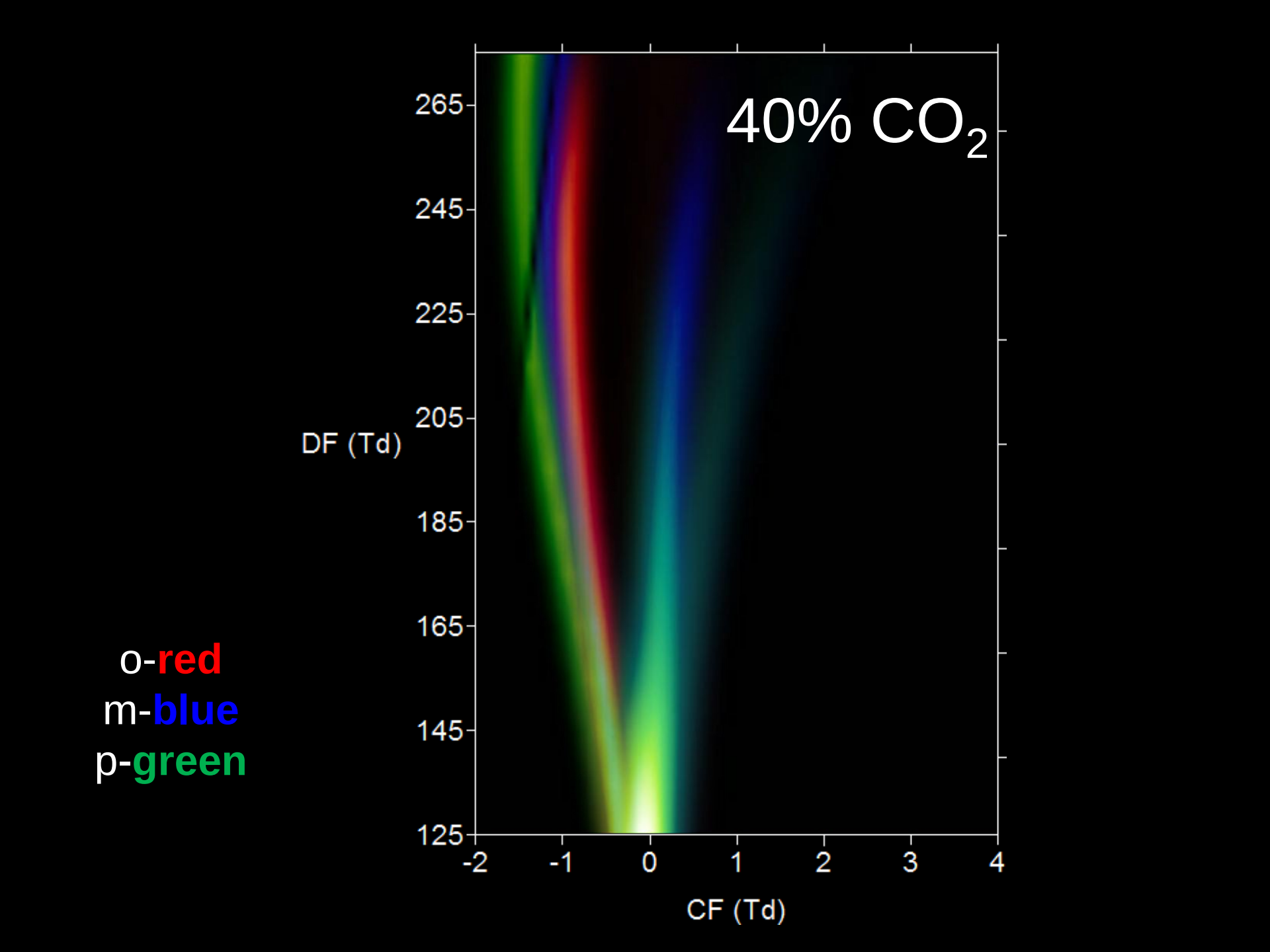

15% CO_2
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

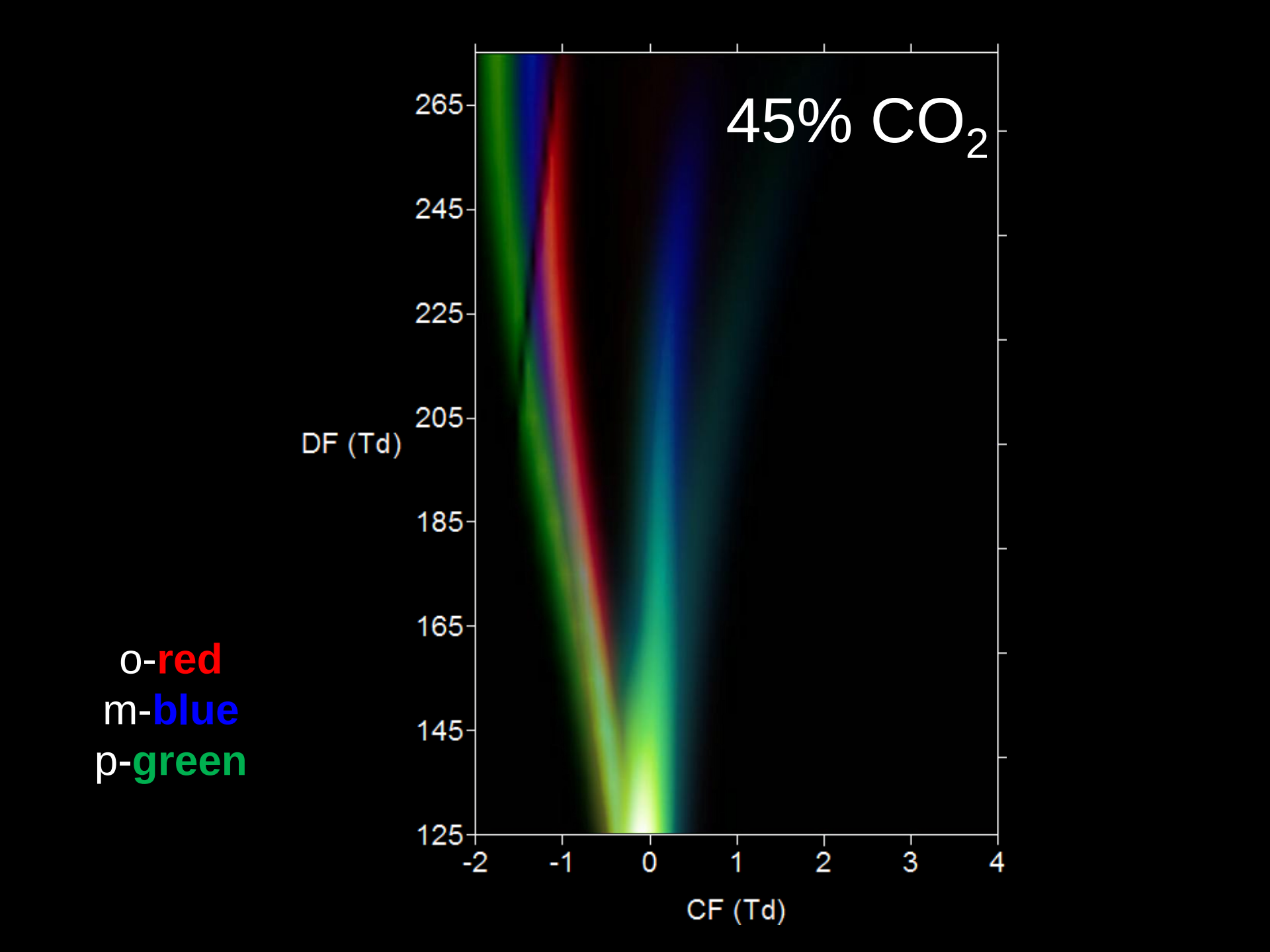

20% CO_2
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

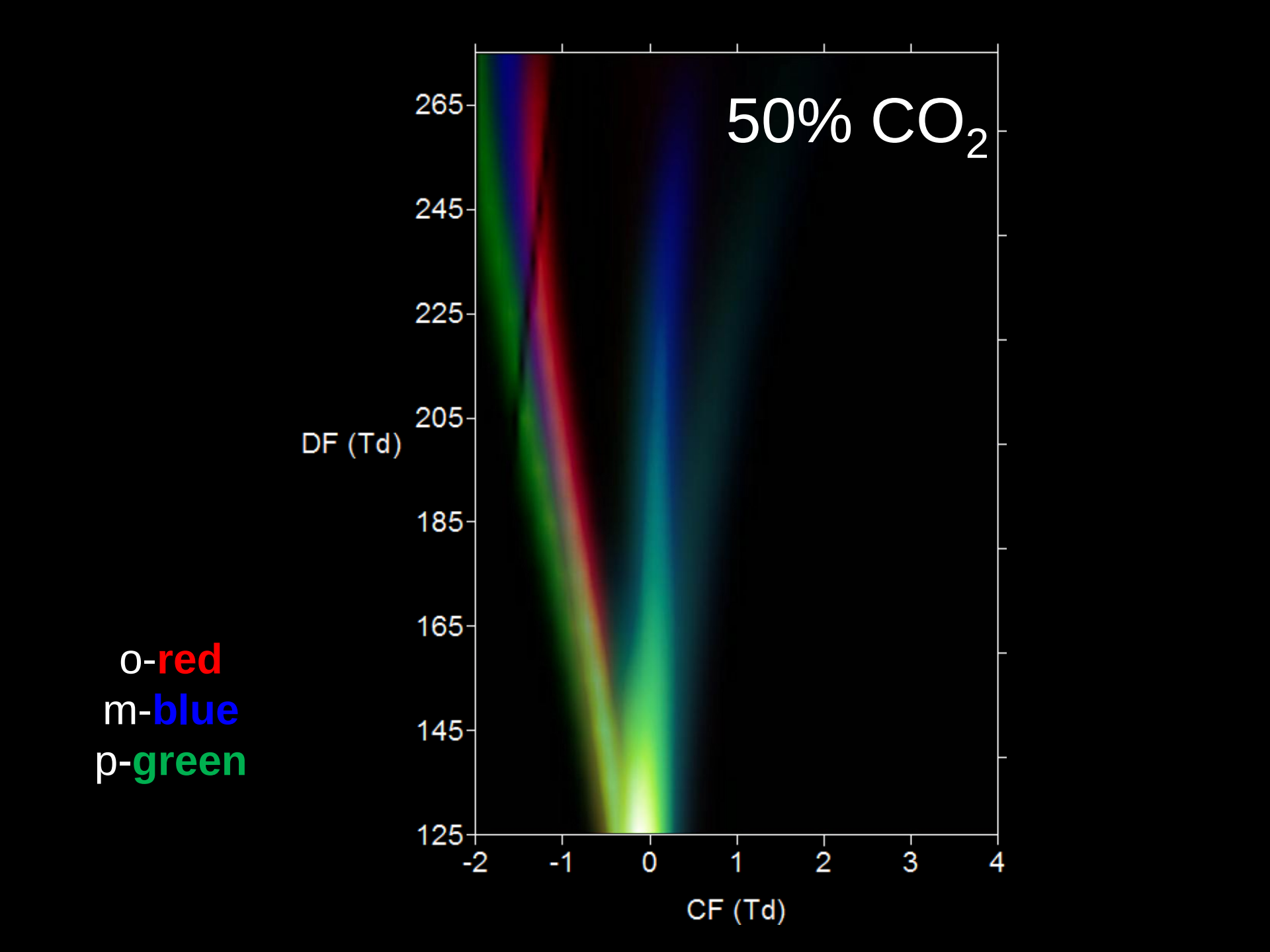

25% CO_2
DF (Td)
265
245
225
205
185
165
145
125
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

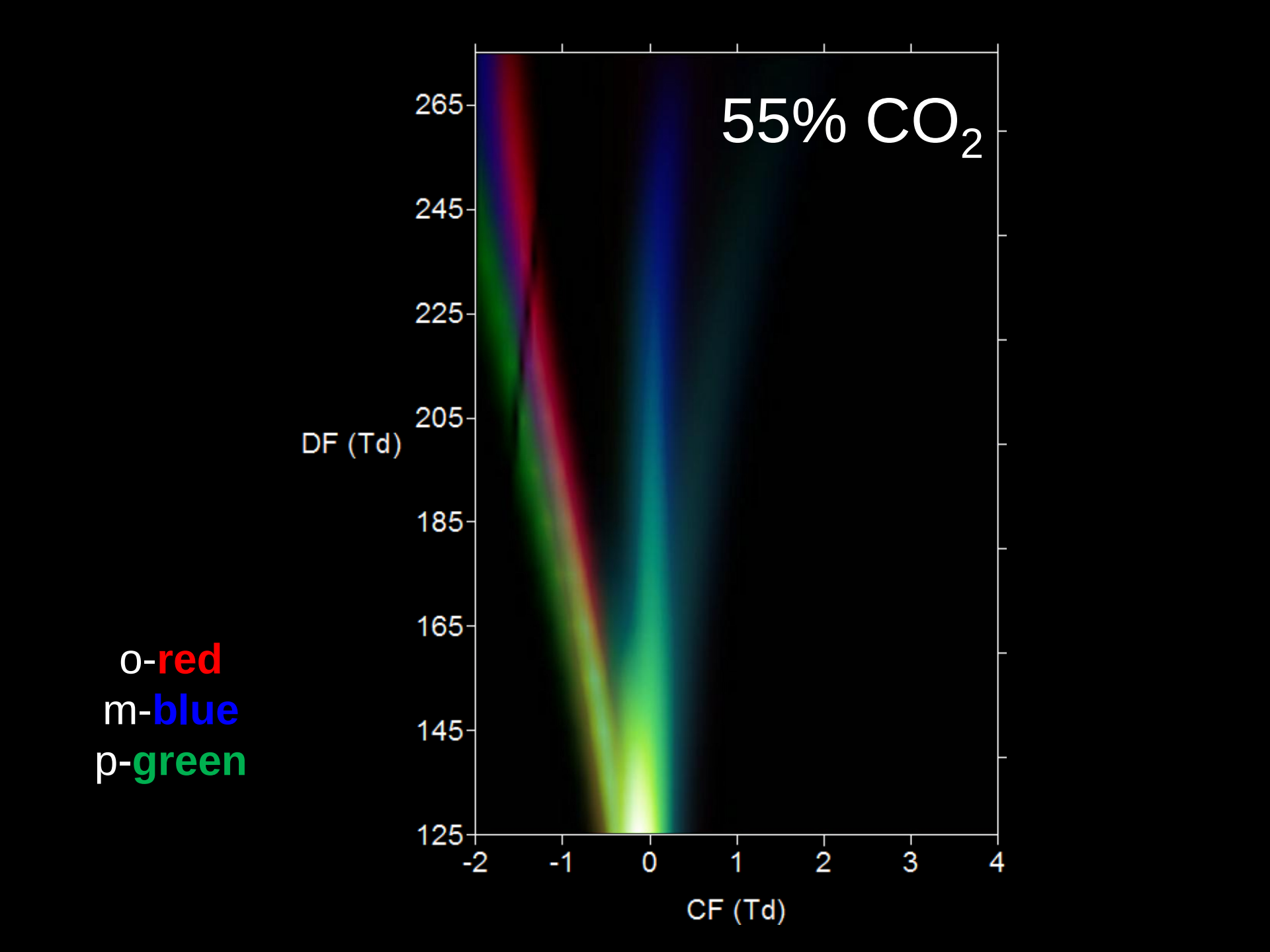

30% CO_2
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

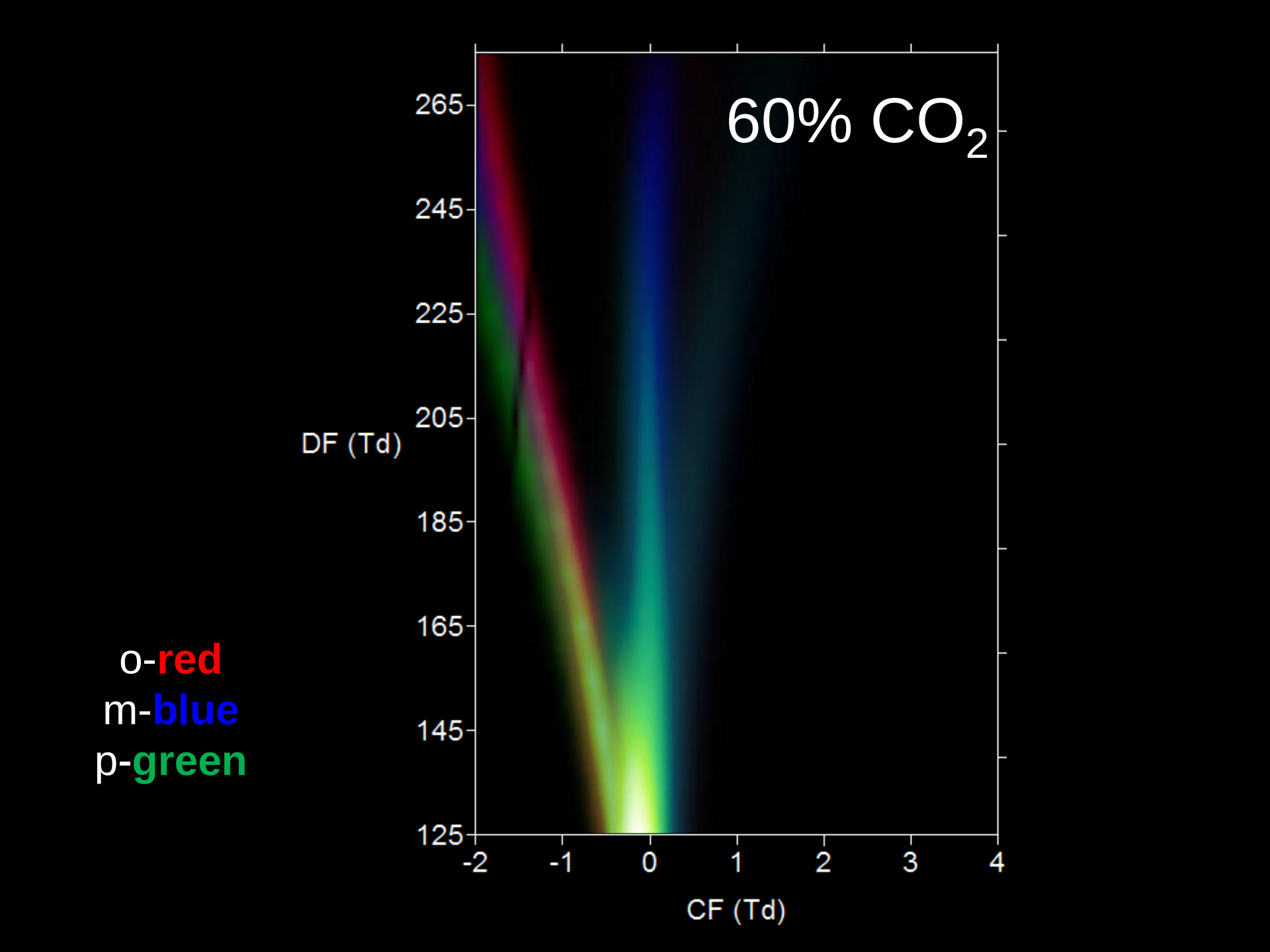

35% CO_2
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

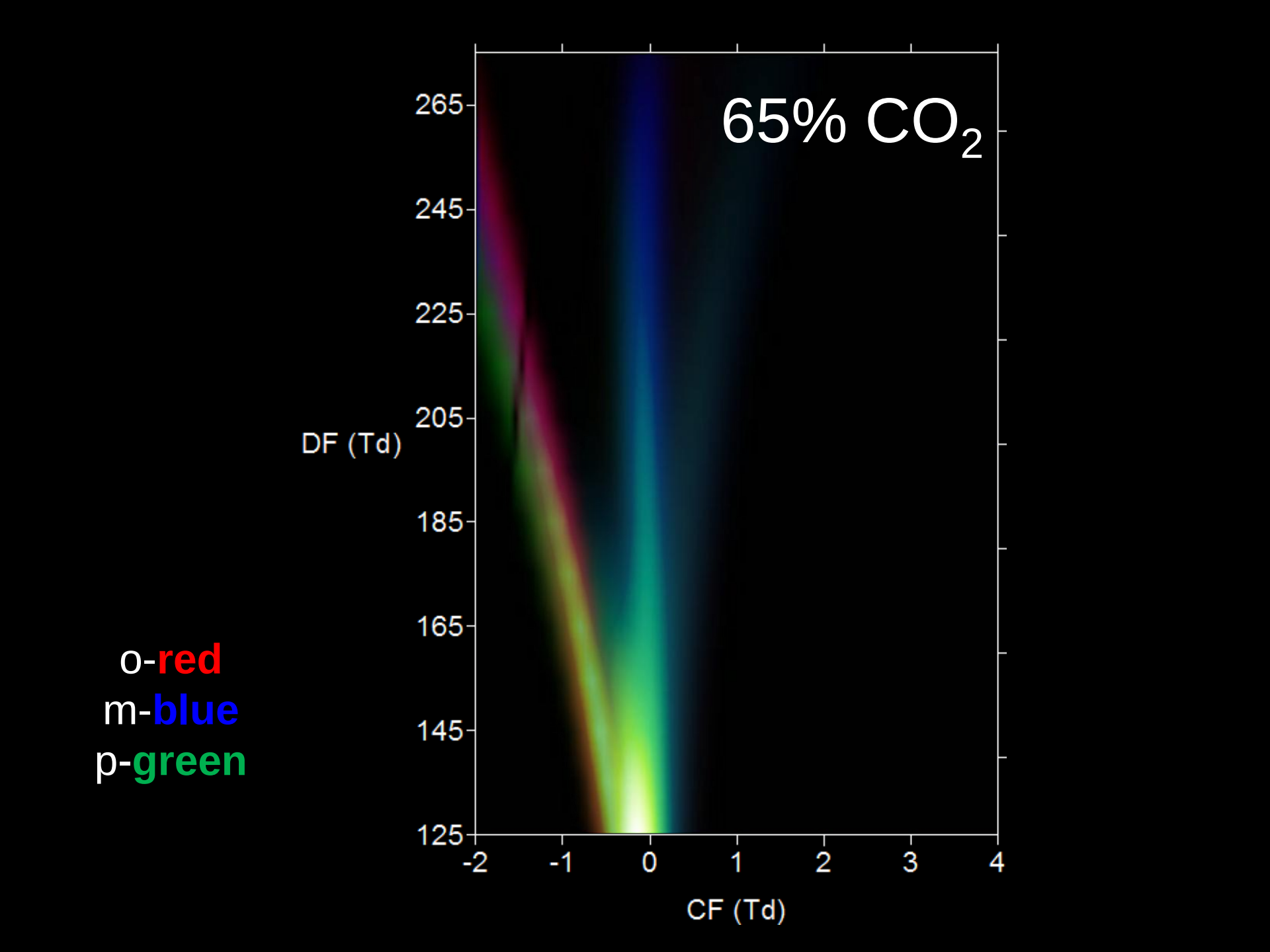

40% CO_2
DF (Td)
265
245
225
205
185
165
145
125
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green


45% CO_2
DF (Td)
265
245
225
205
185
165
145
125
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

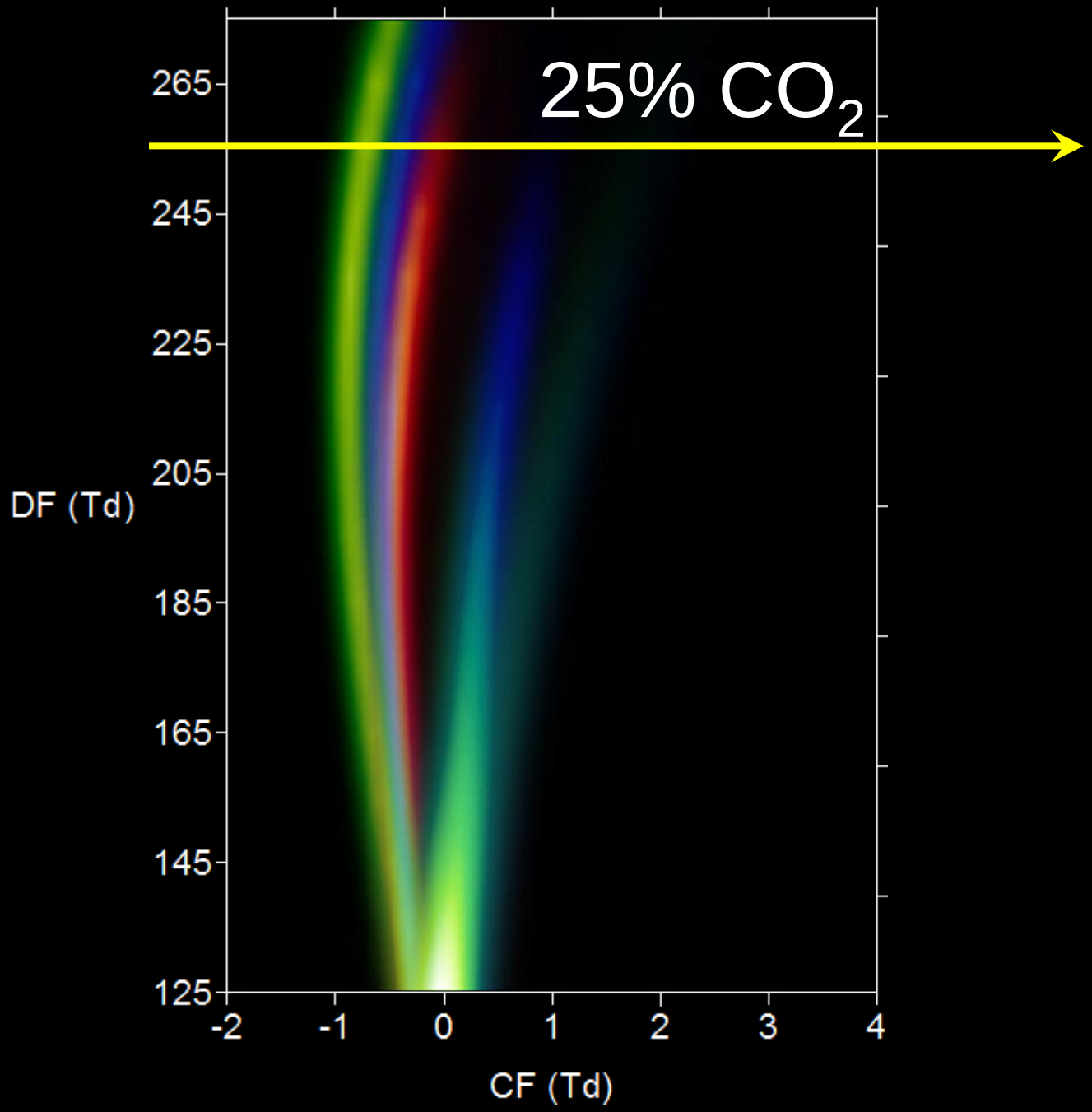

50% CO_2
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green


55% CO_2
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green


60% CO_2
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

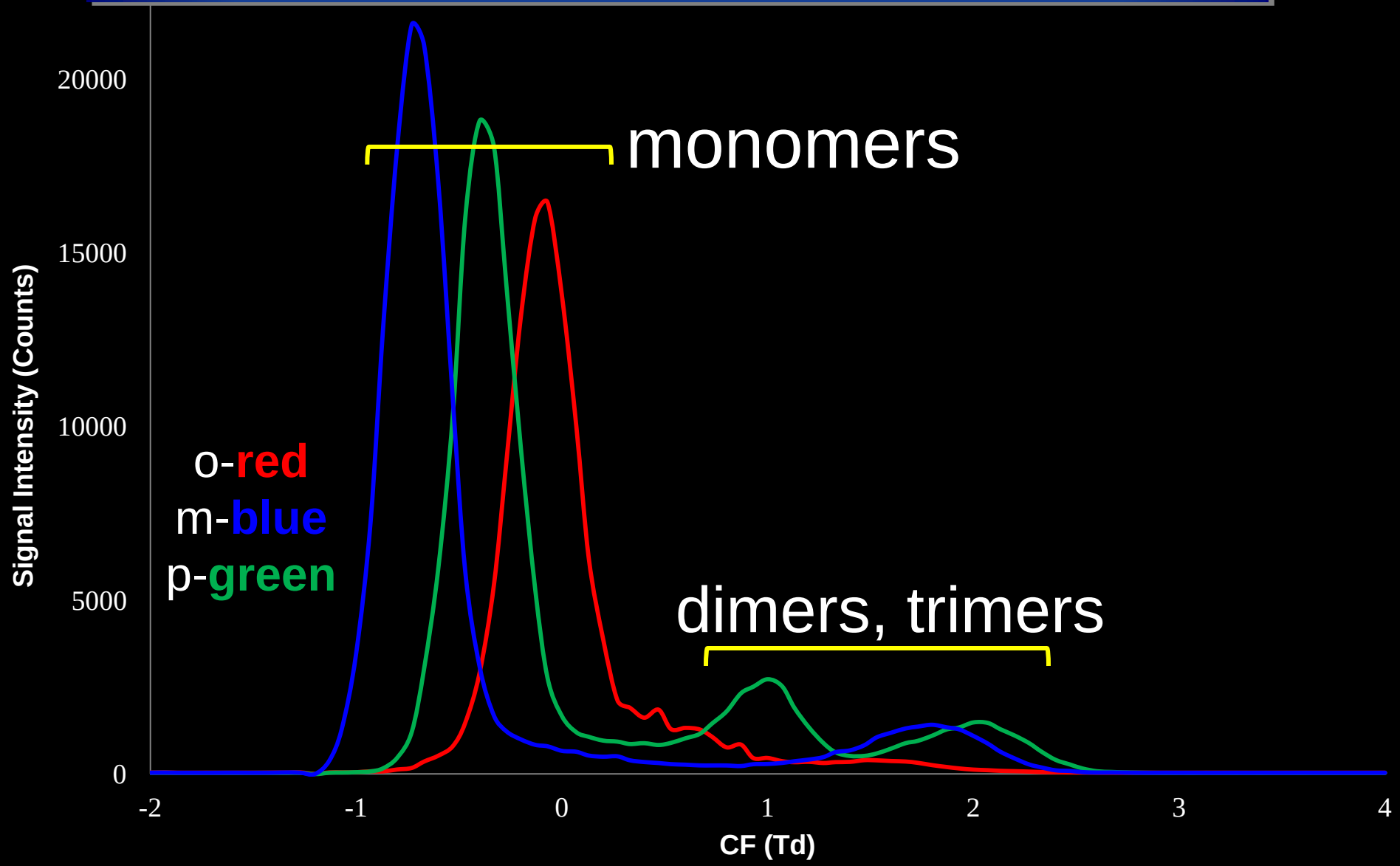

65% CO_2
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

Best Separation?



o-**red**
m-**blue**
p-**green**

Chip FAIMS - 25% CO_2 at DF= 255 Td



Effects of Solvent Vapor on FAIMS

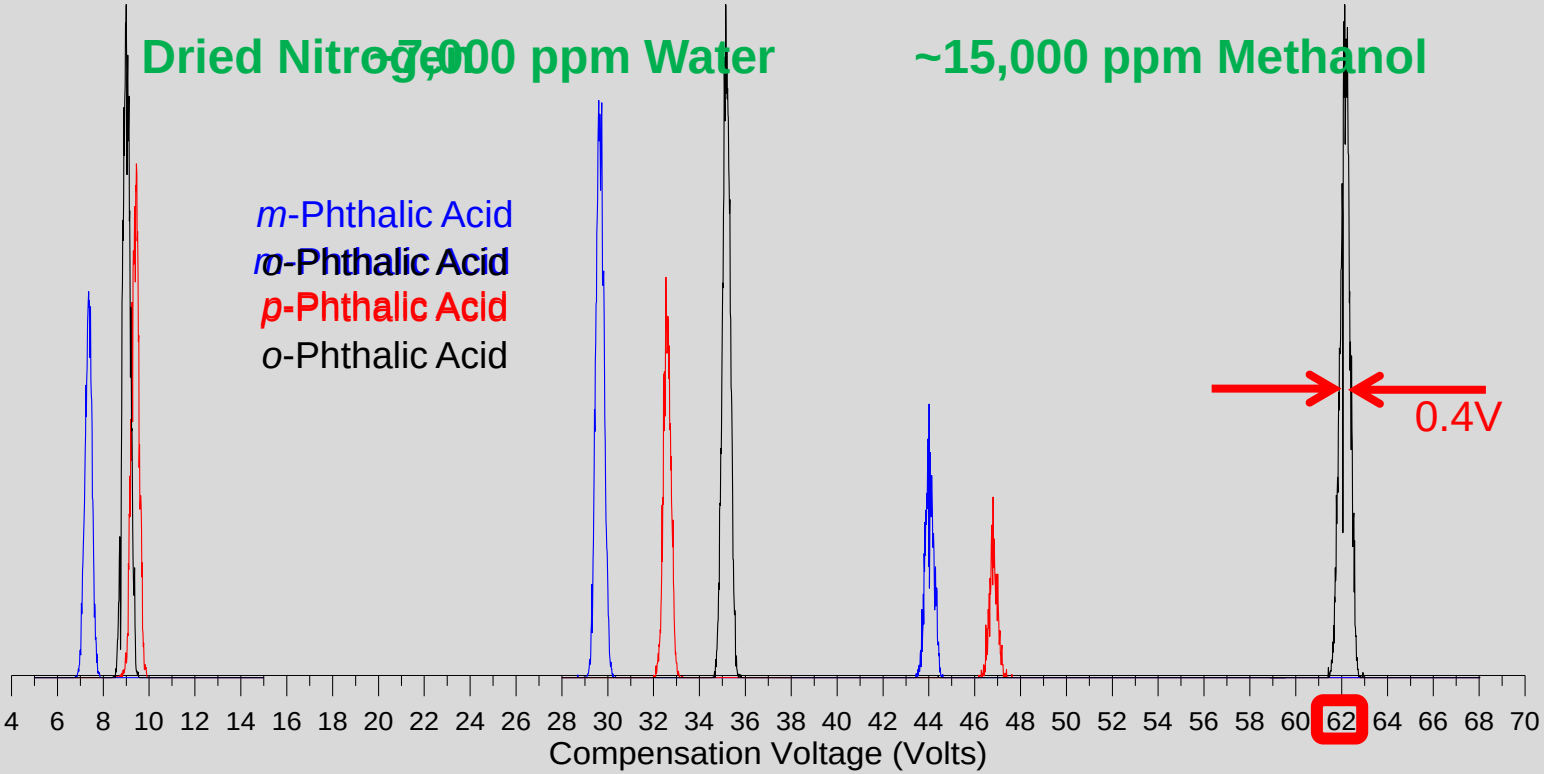
- Ion-neutral molecule clustering
- Differing cluster sizes due to asymmetric field
  - @ Lower field, “cooler” Ions → “clustered” Ion
  - @ Higher field, “hotter” Ions → “bare” Ion

$$\underset{High\ Field}{[Ion]^{\pm}} \xleftrightarrow{K_f} \underset{Low\ Field}{[Ion]^{\pm} \bullet (Solvent)_n}$$

- Different ions may cluster differently
  - Isomers
  - Different ions (M^-, $[M-H]^-$) from same compound

Rorrer, L.C. III; Yost, R.A. *Int. J. Mass Spectrom.* **2011**, *300*, 173

Adding Solvent Vapors – FAIMS



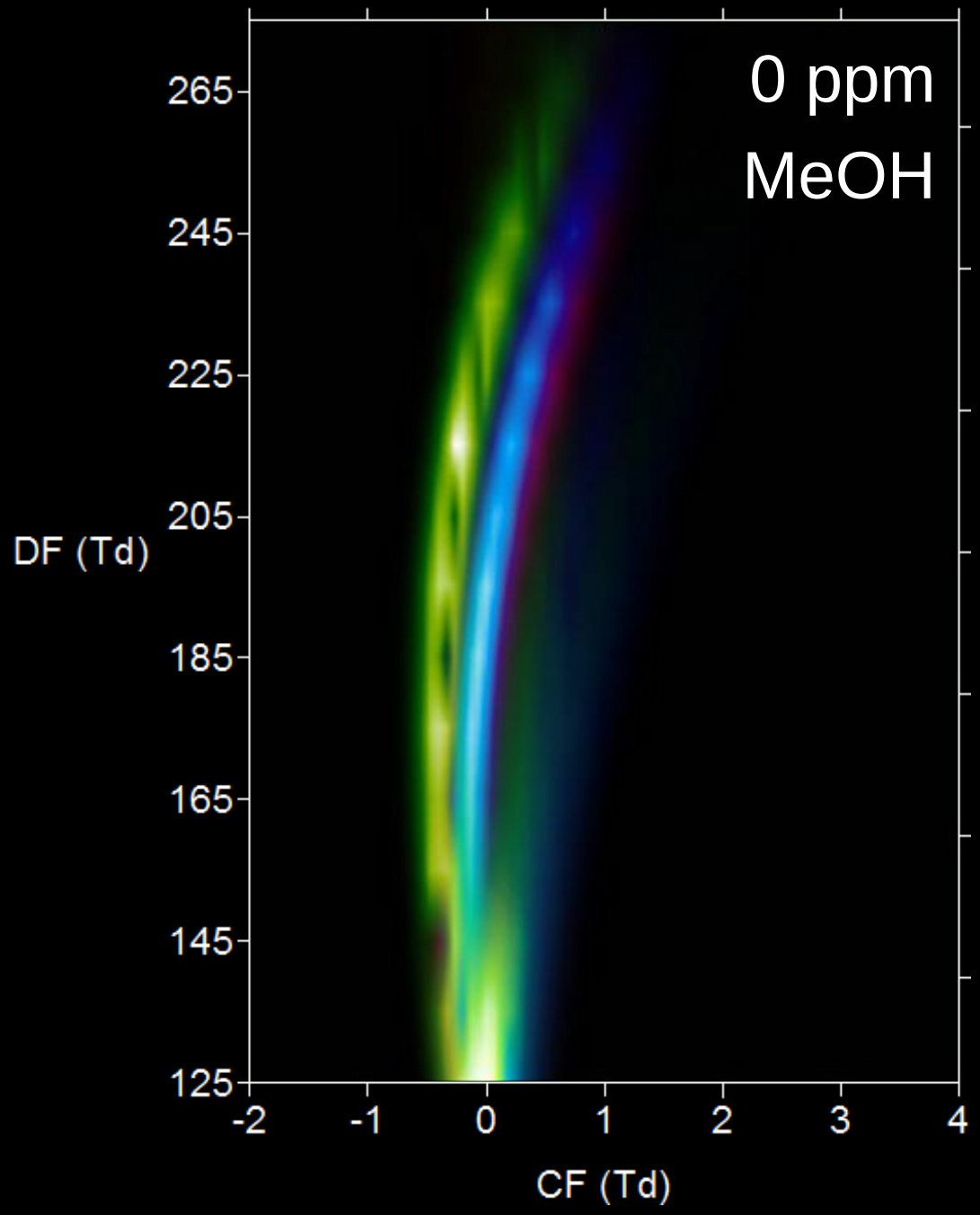
Increased Resolution of $[M-H]^-$ Ions of Phthalic Acid Isomers with Solvent Vapor

Dried Nitrogen			
	CV	R_p	R_s
m-	7.37 V	20.5	
			2.42
o-	8.99 V	22.3	
			0.67
p-	9.45 V	27	

Rorrer, L.C. III; Yost, R.A. *Int. J. Mass Spectrom.* **2011**, *300*, 173

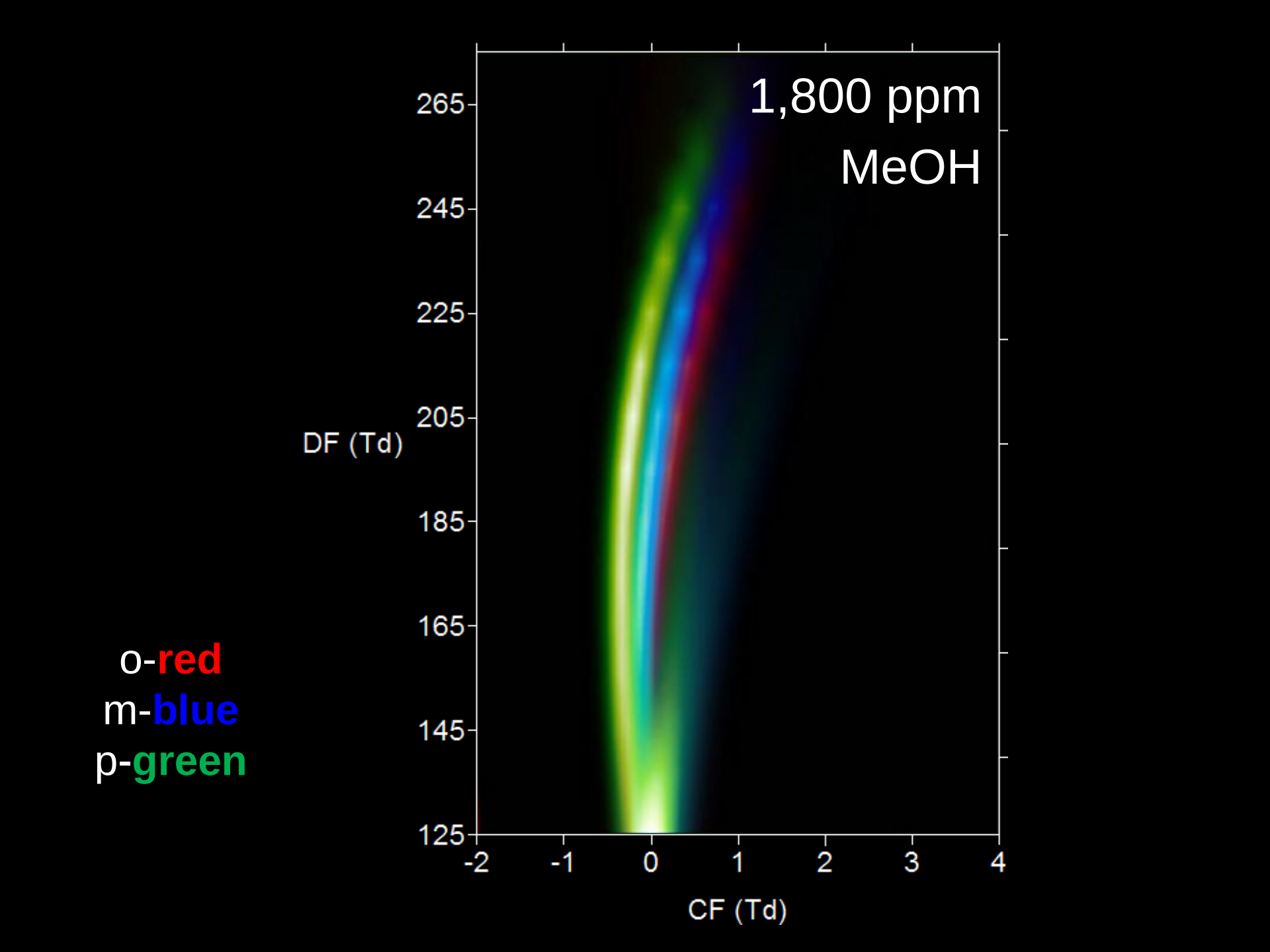
Adding Solvent Vapors – Chip FAIMS

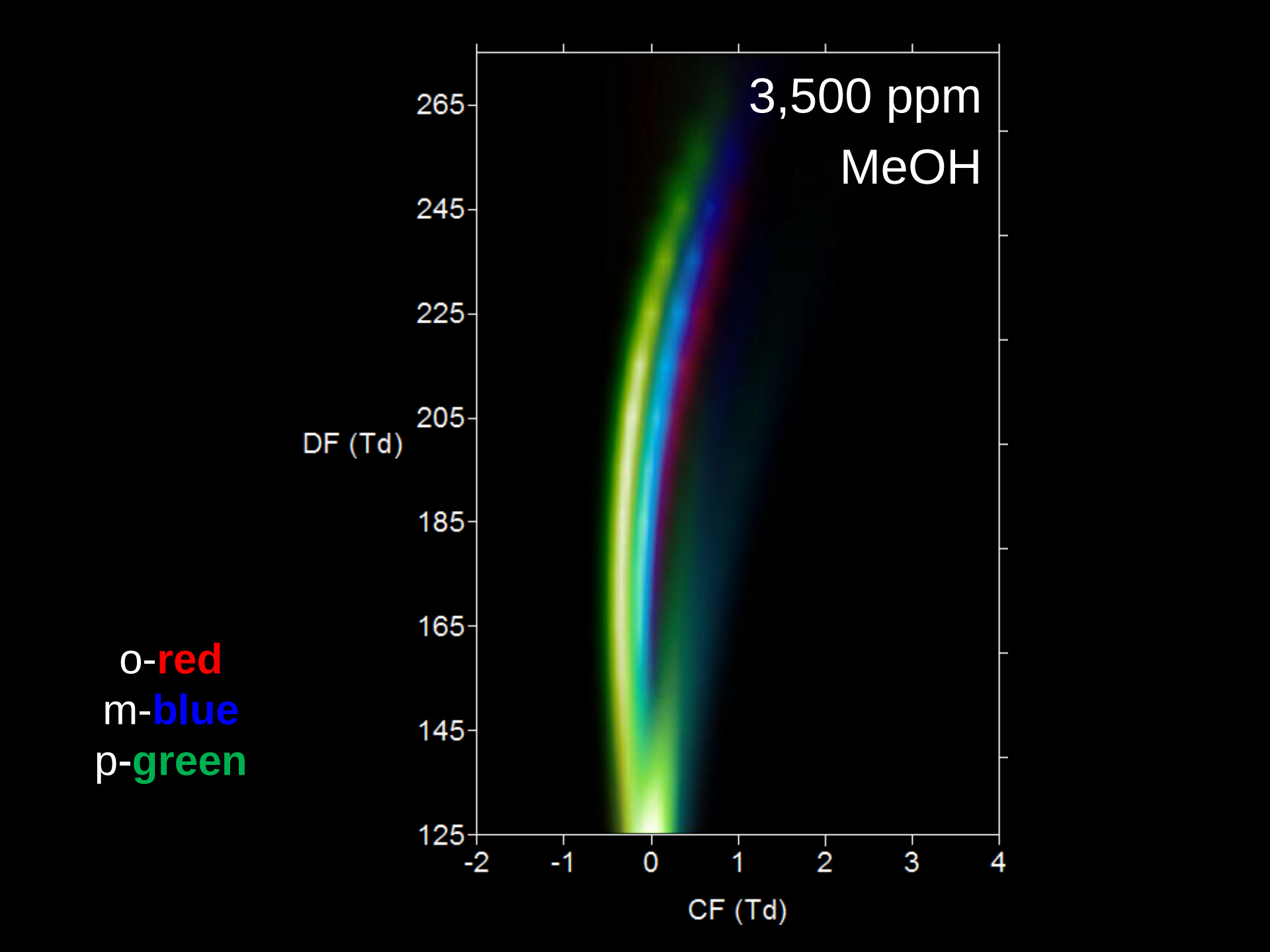
- Consider ion/solvent interactions in chip FAIMS vs. conventional sized FAIMS …
  - 10x higher RF frequency
  - 100x shorter path
  - 20x narrower gap
  - 2 - 4x higher field
- Will we see the same effects?

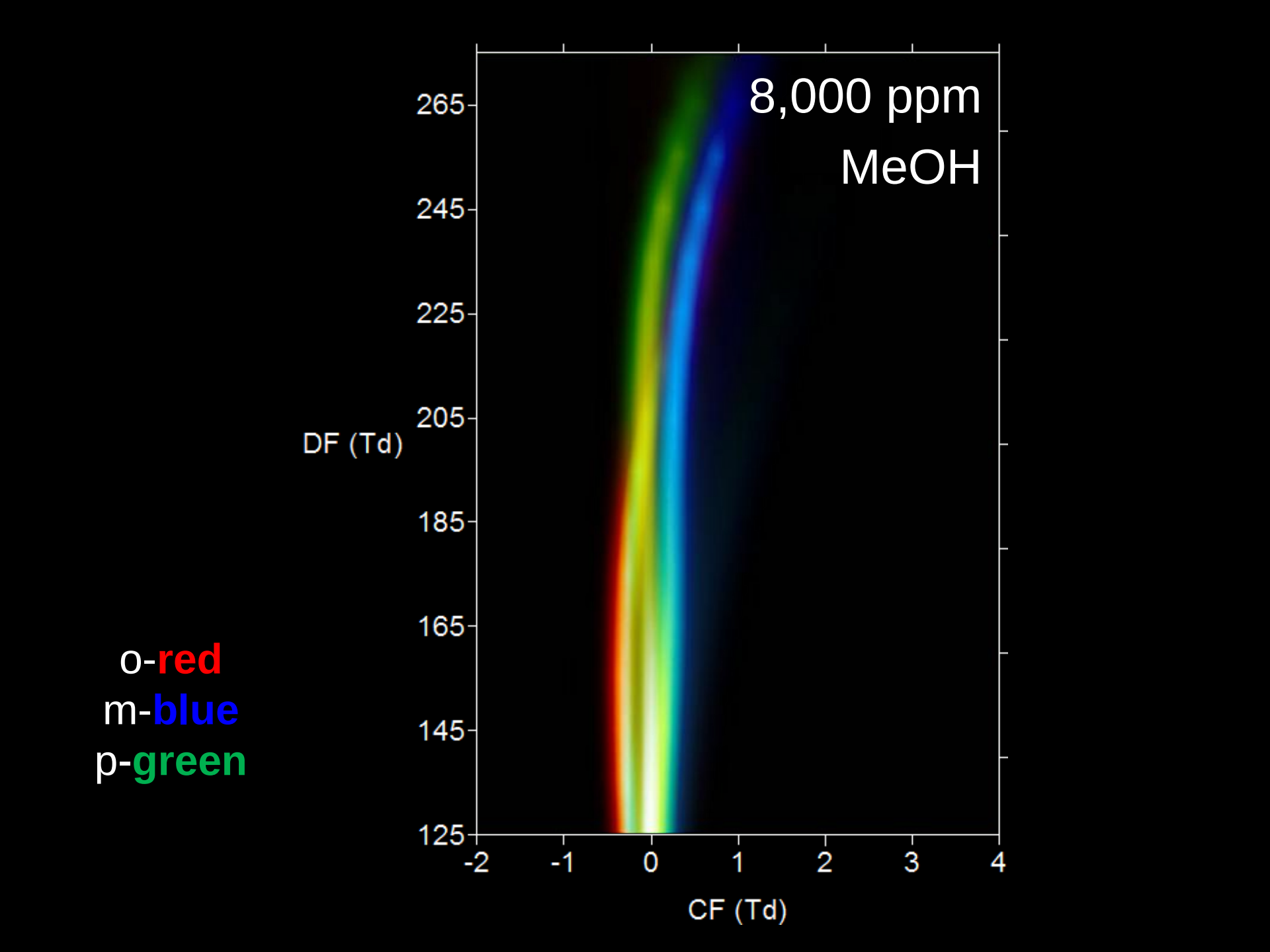


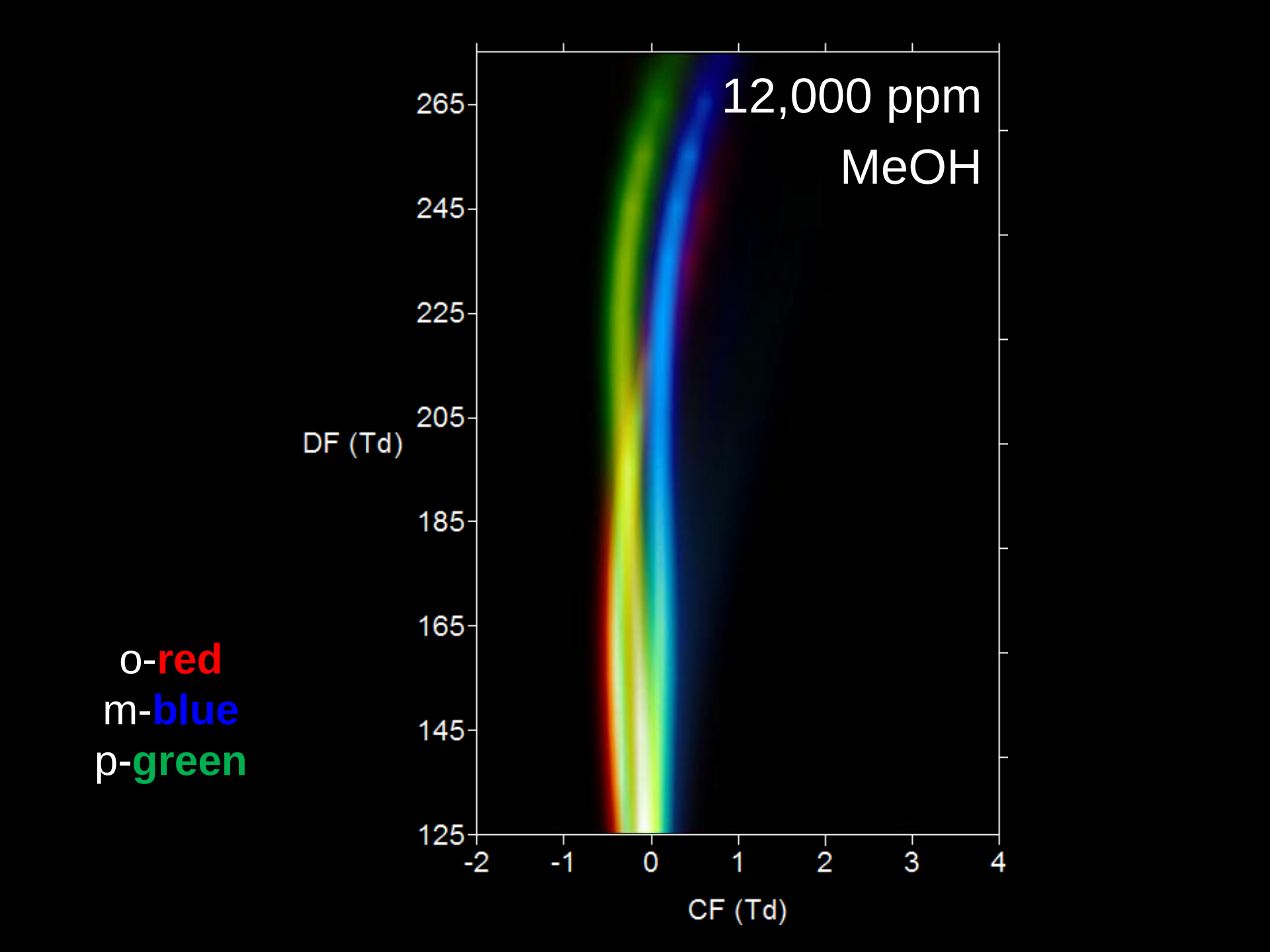
o-**red**
m-**blue**
p-**green**

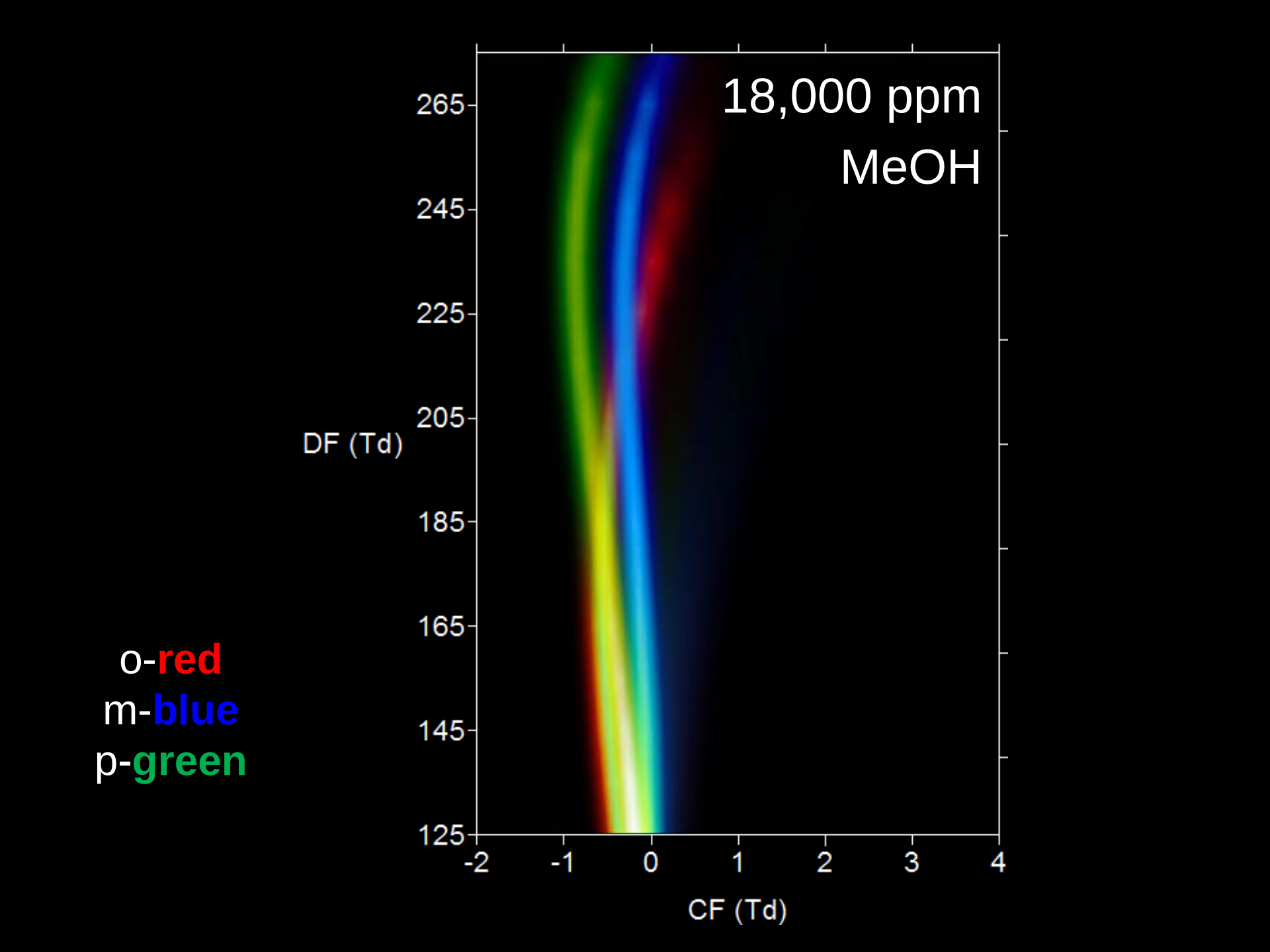
If we increase the ppm MeOH

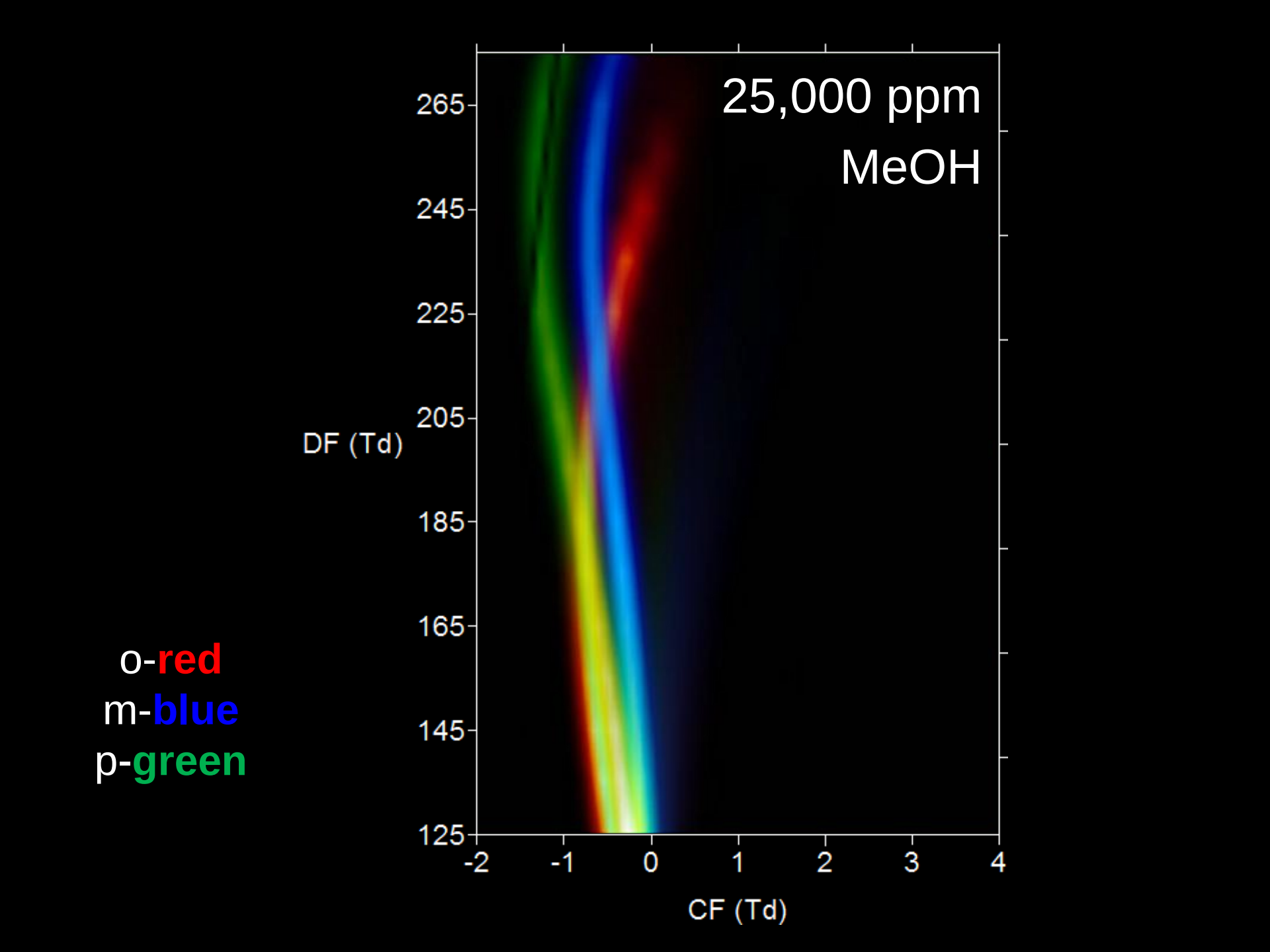

1,800 ppm
MeOH
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

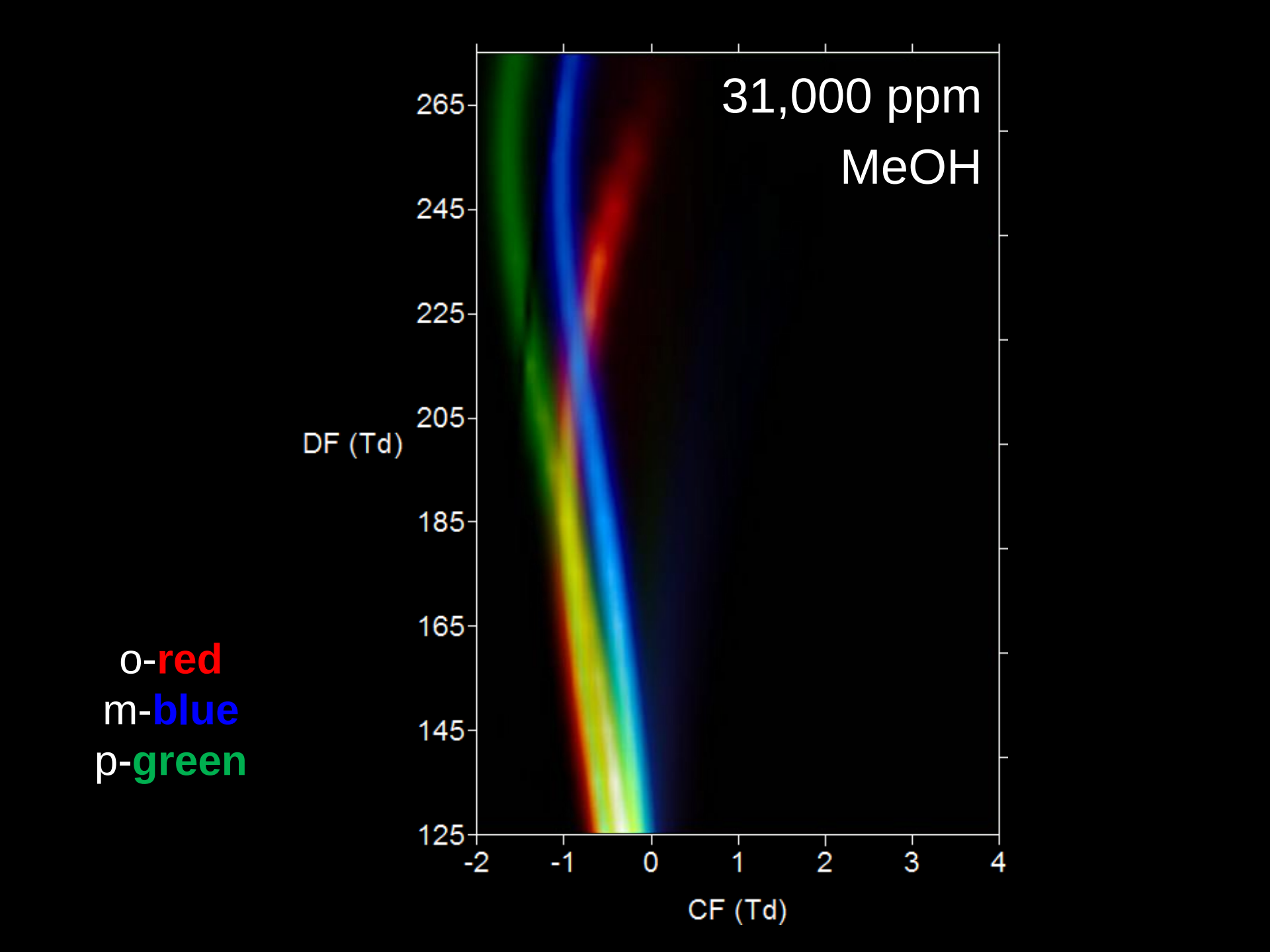

3,500 ppm
MeOH
DF (Td)
265
245
225
205
185
165
145
125
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

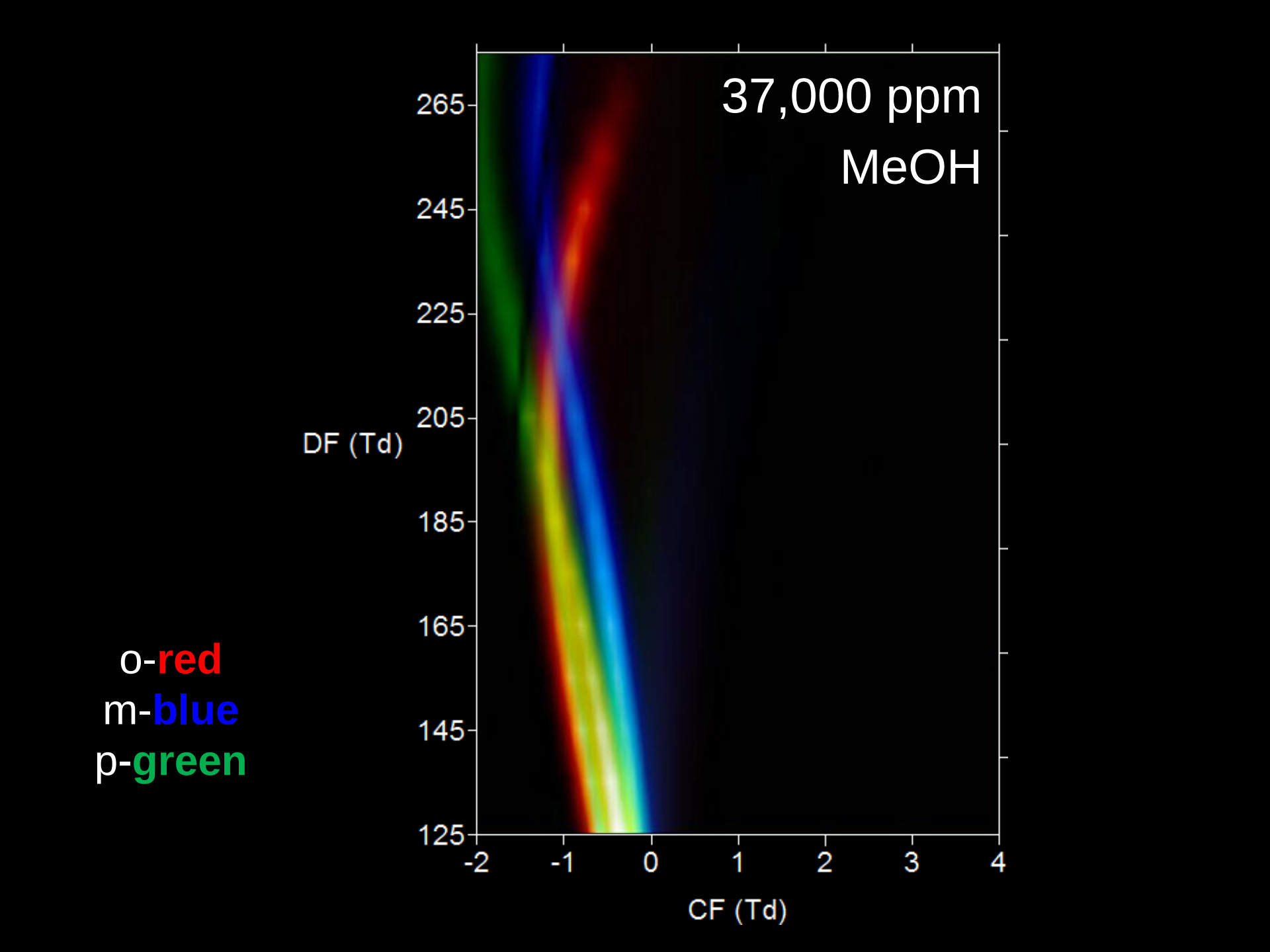

8,000 ppm
MeOH
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

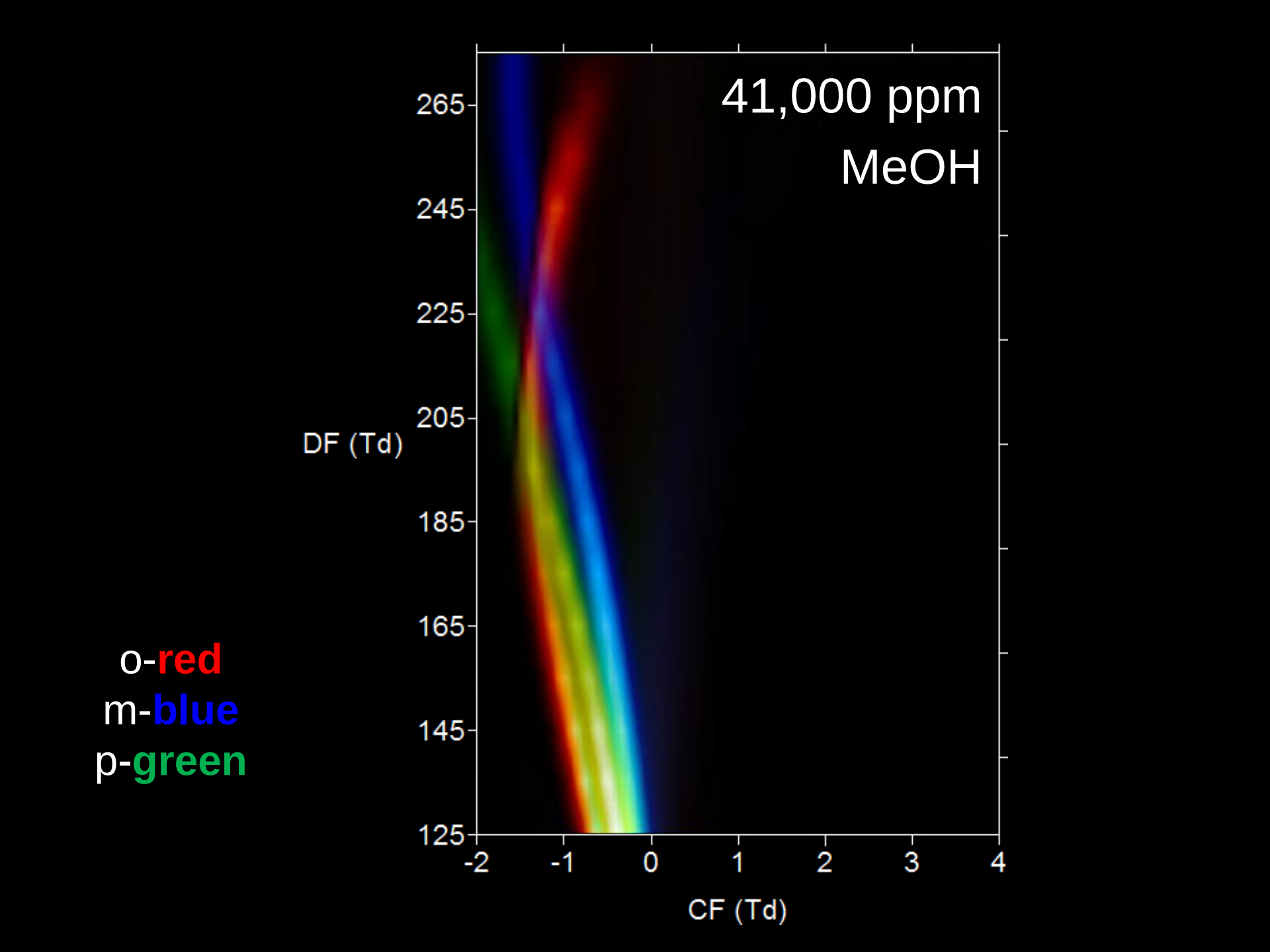

12,000 ppm
MeOH
DF (Td)
265
245
225
205
185
165
145
125
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

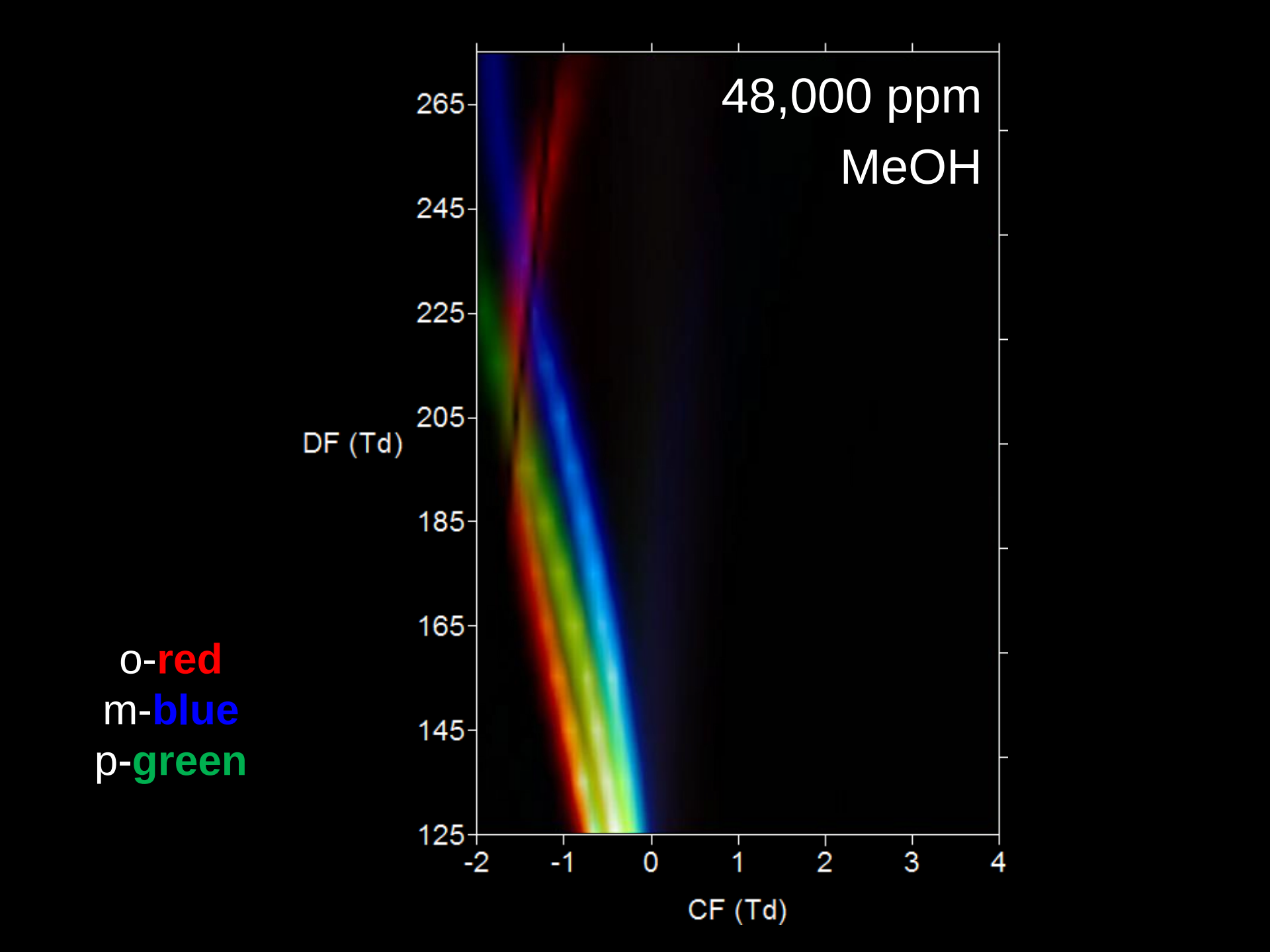

18,000 ppm
MeOH
DF (Td)
265
245
225
205
185
165
145
125
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

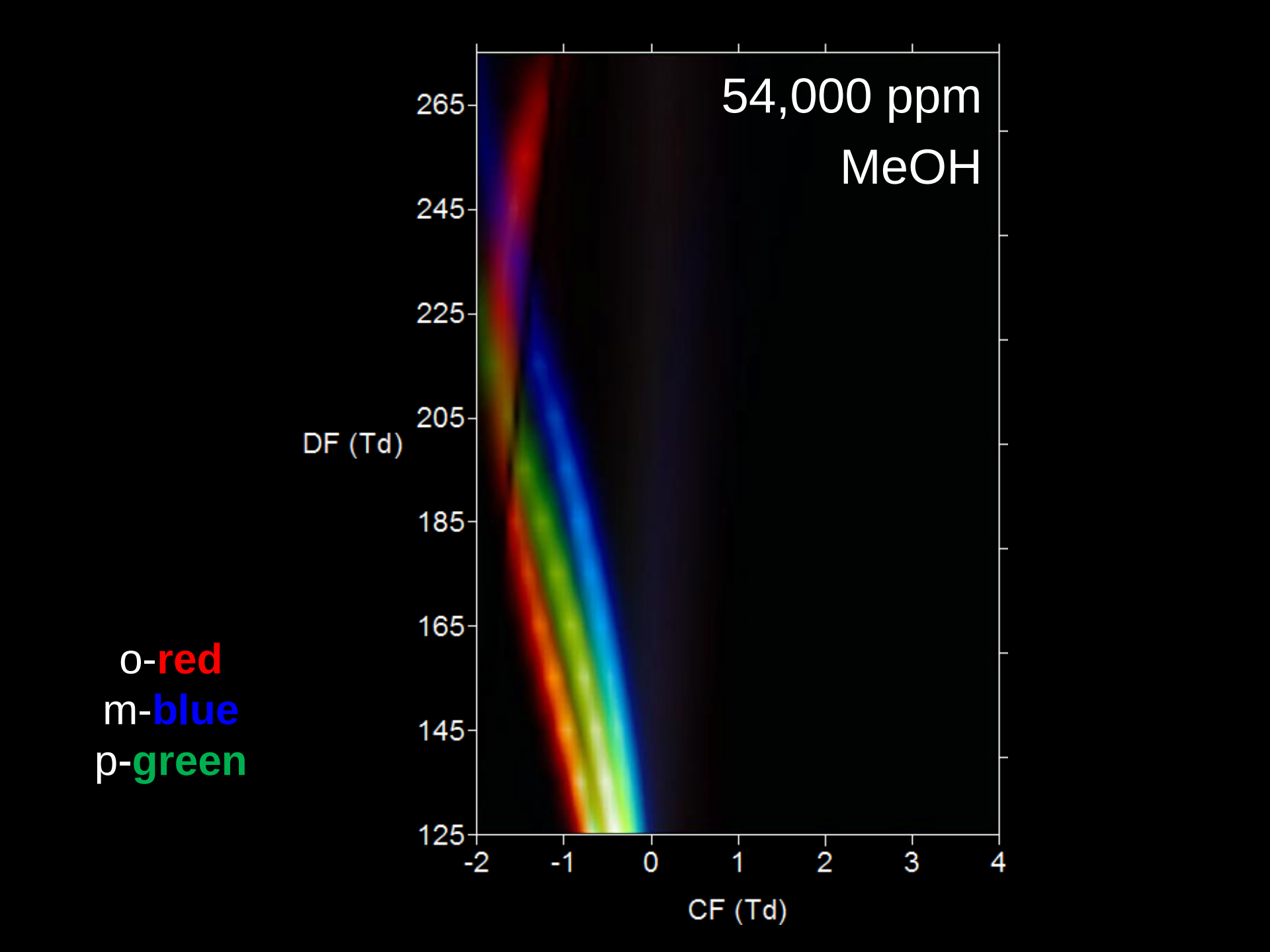

25,000 ppm
MeOH
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

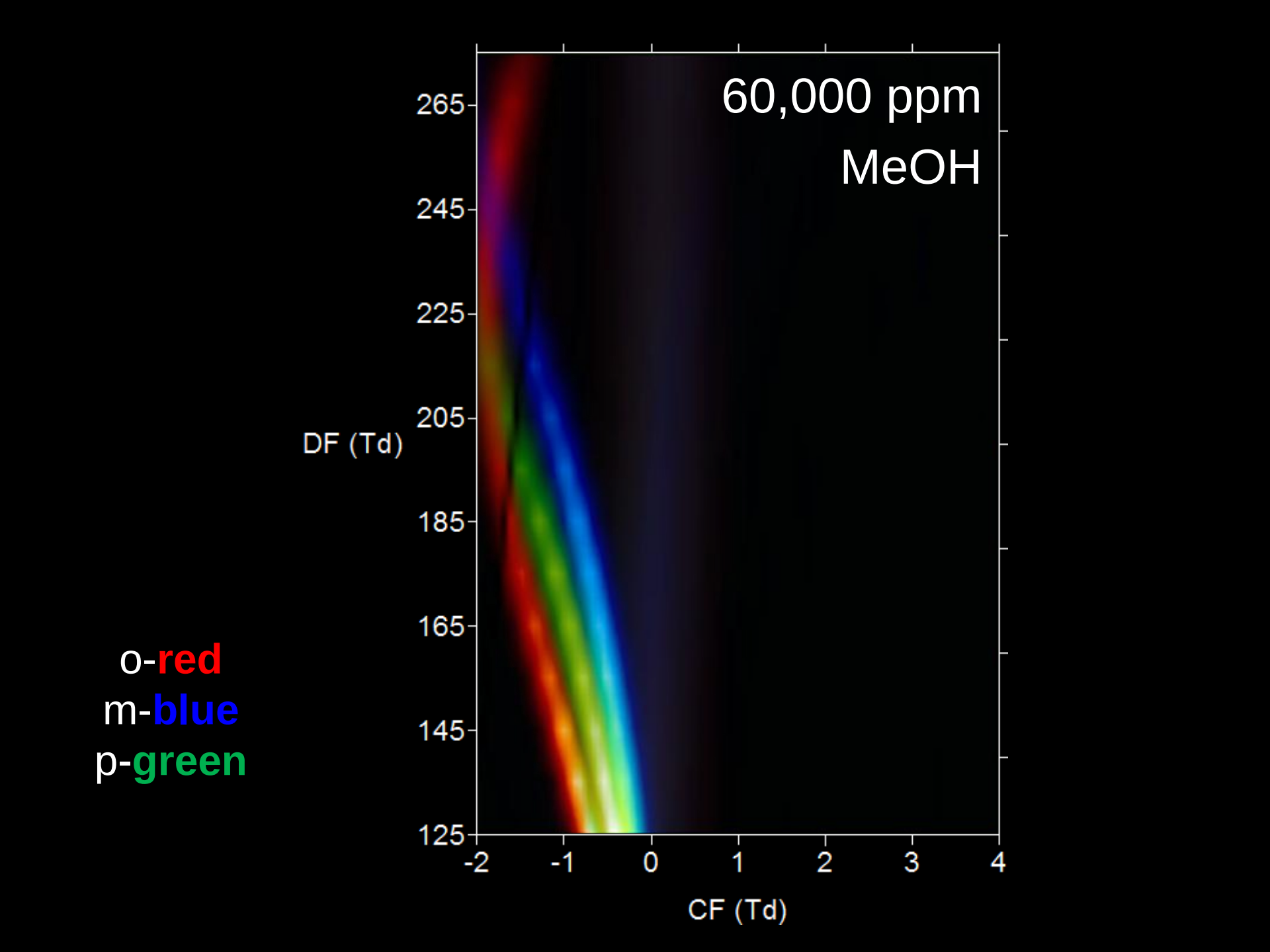

31,000 ppm
MeOH
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

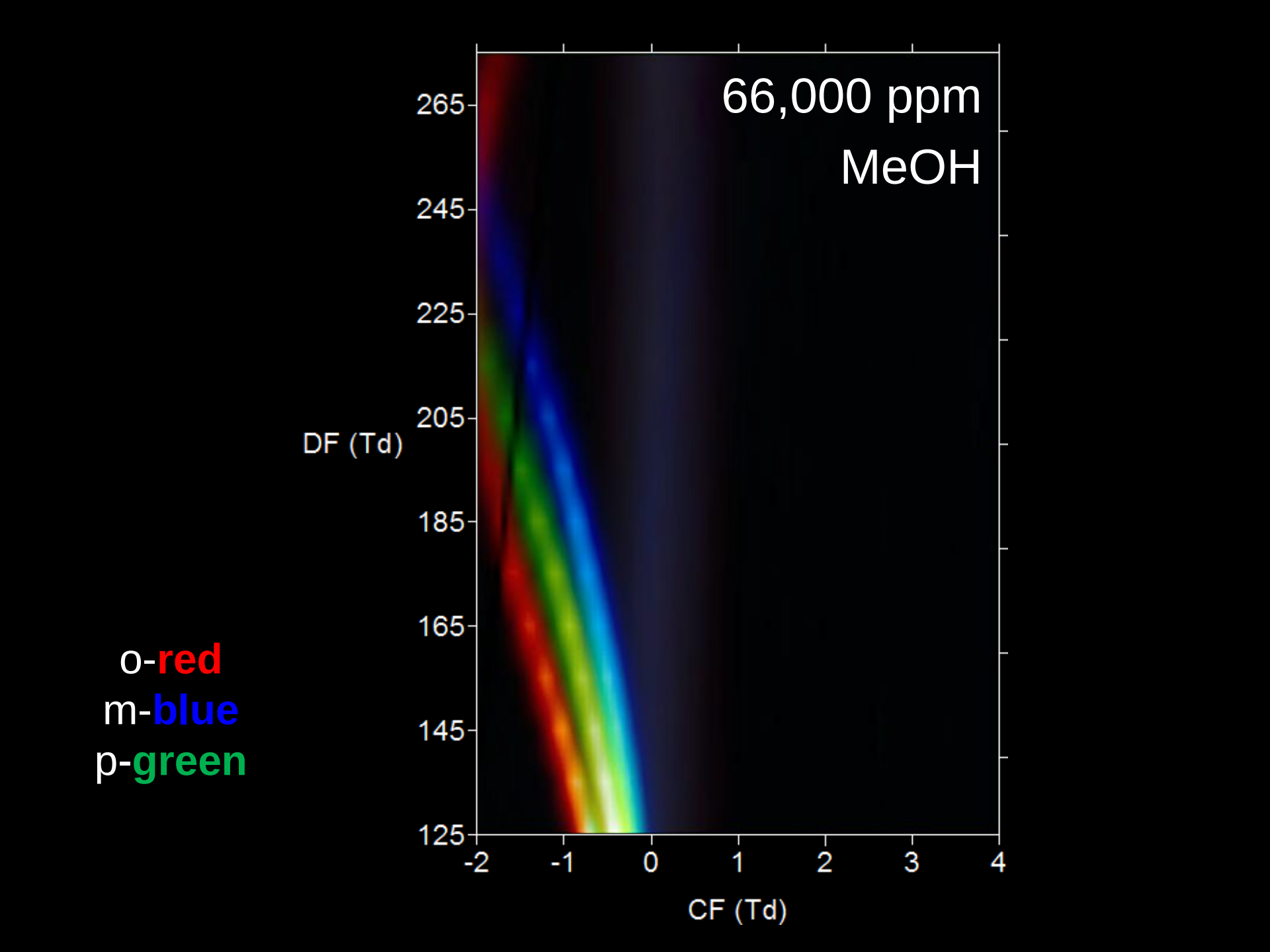

37,000 ppm
MeOH
DF (Td)
265
245
225
205
185
165
145
125
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

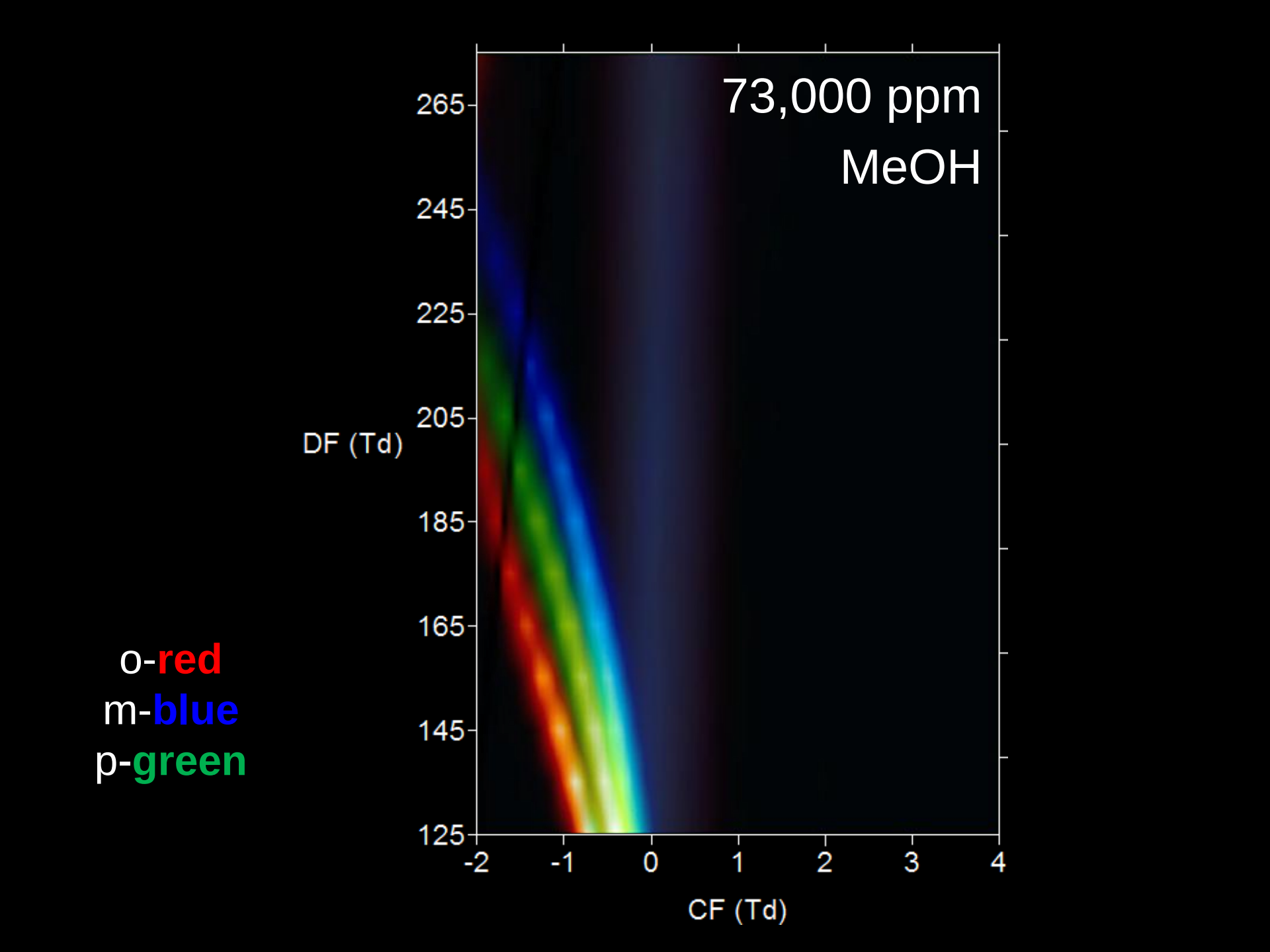

41,000 ppm
MeOH
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

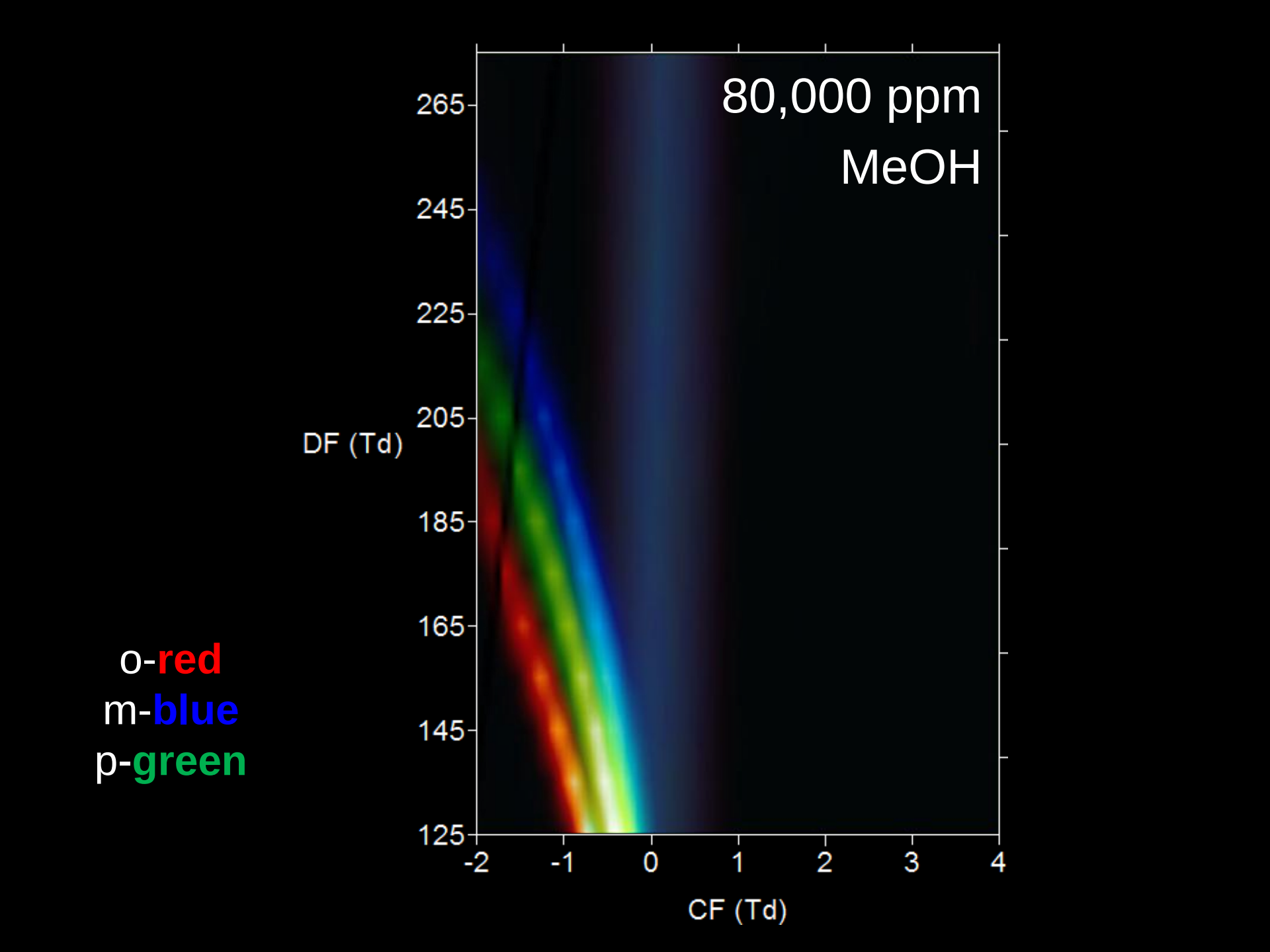

48,000 ppm
MeOH
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green


54,000 ppm
MeOH
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

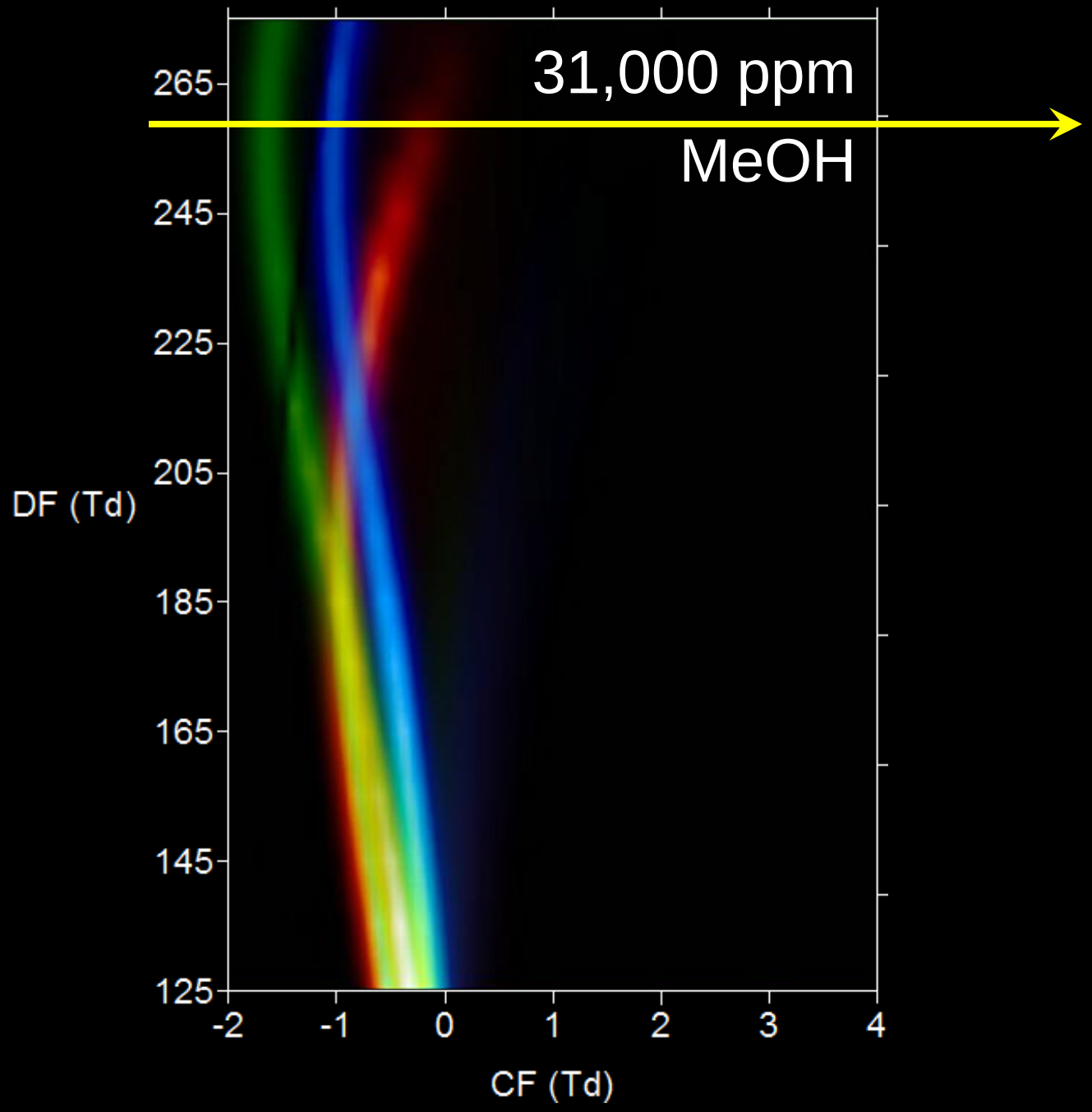

60,000 ppm
MeOH
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green


66,000 ppm
MeOH
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green


73,000 ppm
MeOH
265
245
225
205
185
165
145
125
DF (Td)
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

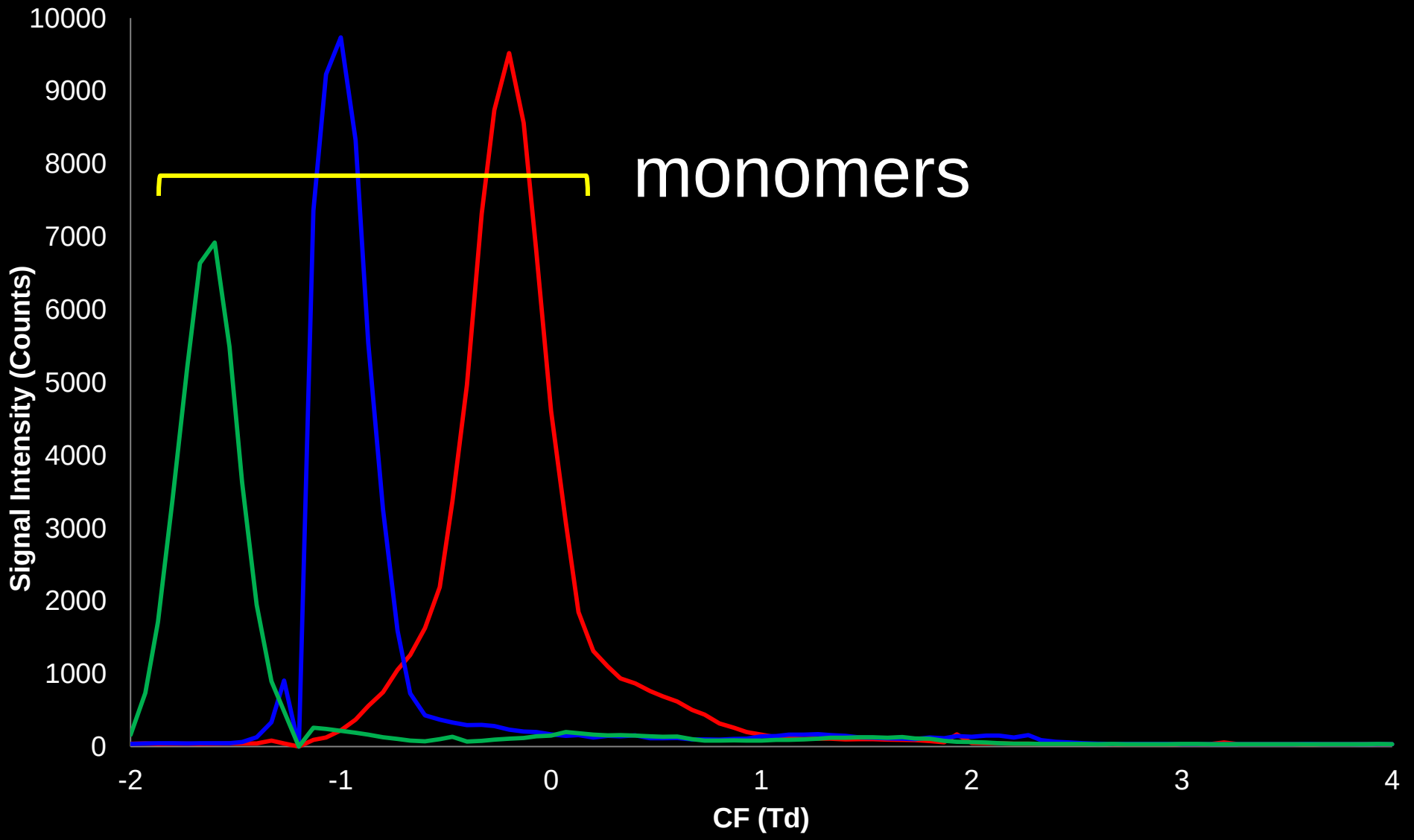

80,000 ppm
MeOH
DF (Td)
265
245
225
205
185
165
145
125
-2
-1
0
1
2
3
4
CF (Td)
o-red
m-blue
p-green

Best Separation?

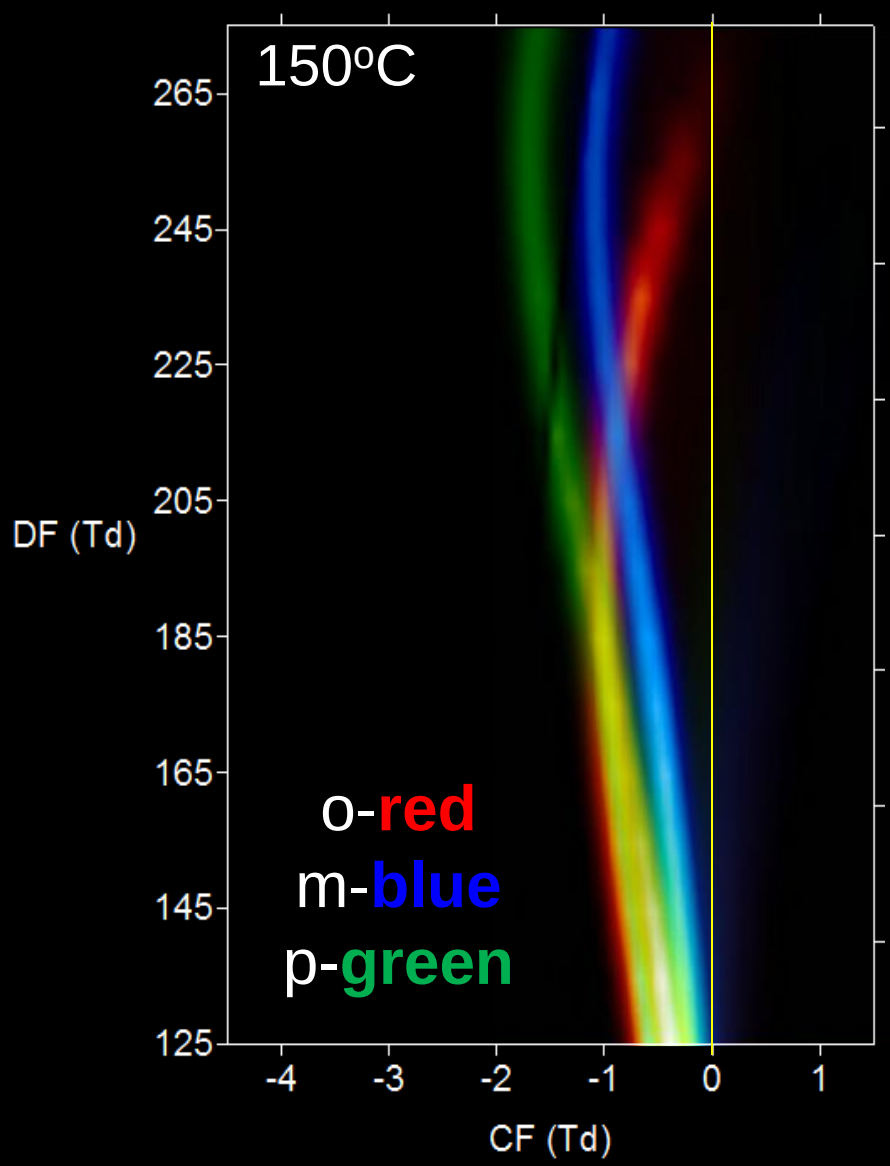


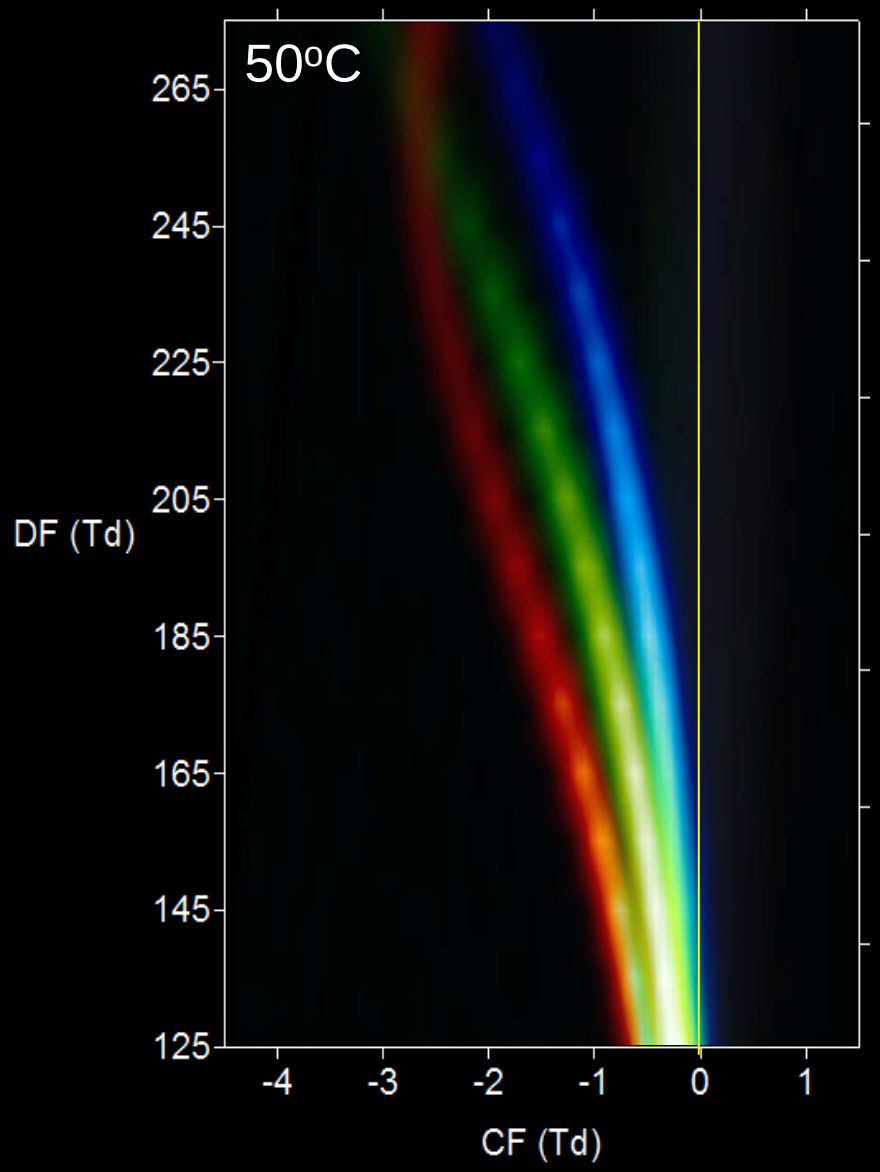
o-**red**
m-**blue**
p-**green**

Chip FAIMS – 31,000 ppm MeOH at DF= 255 Td

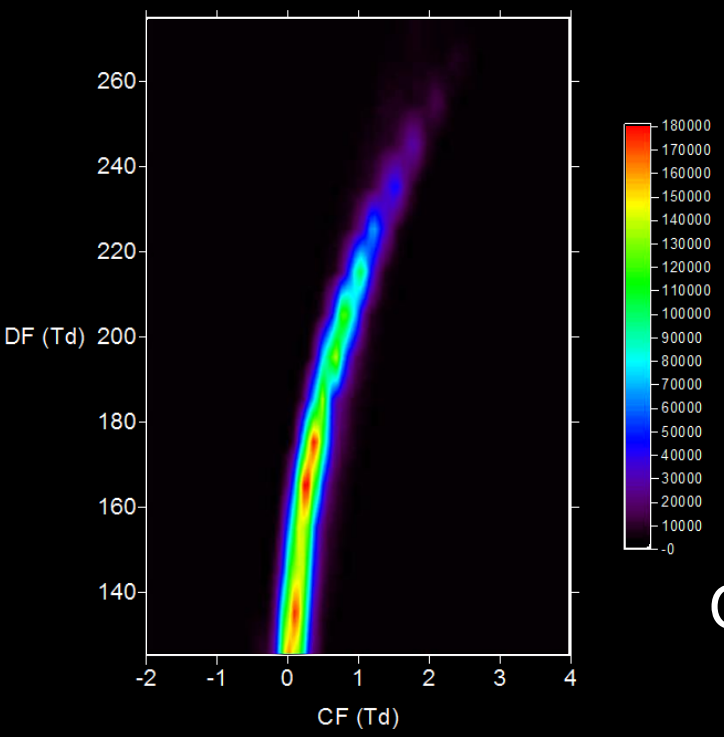


Effect of Temperature – 31,000 ppm MeOH

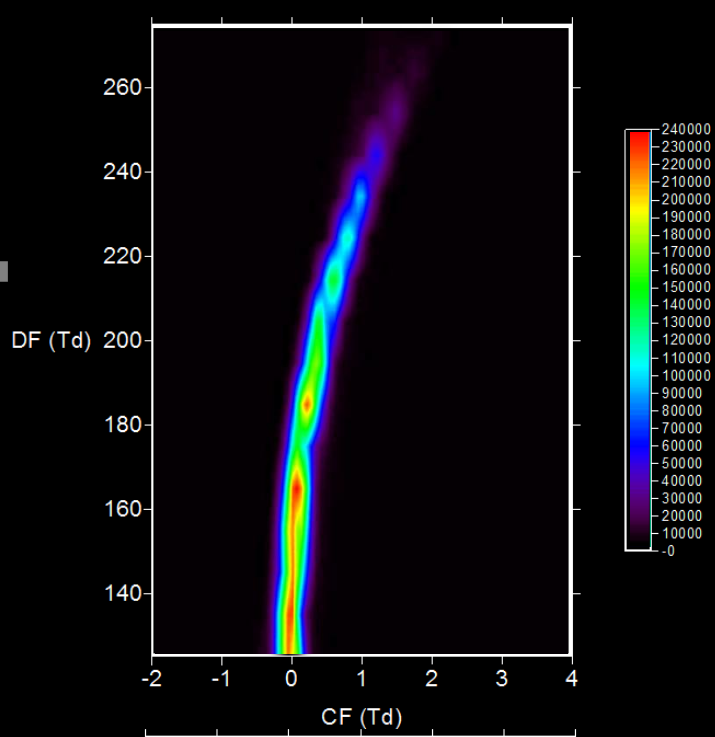




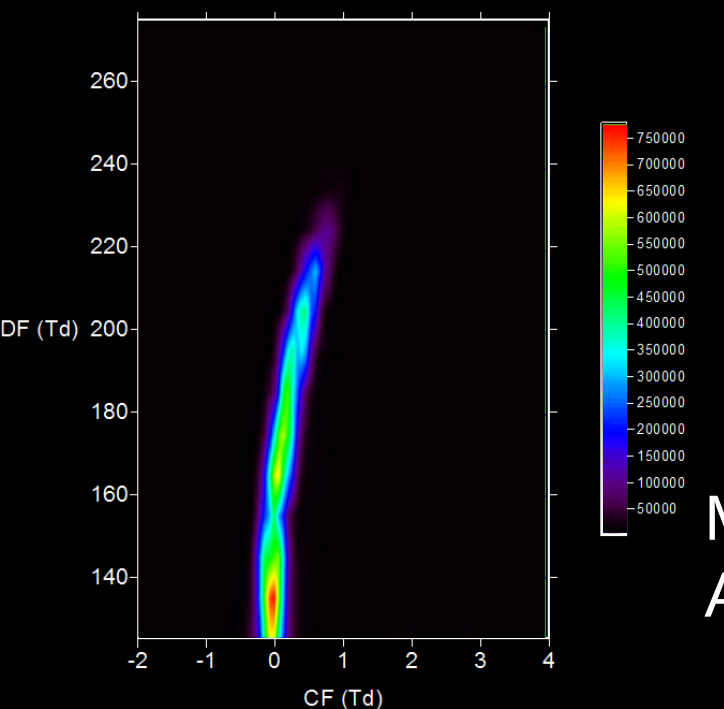
APCI Chip FAIMS



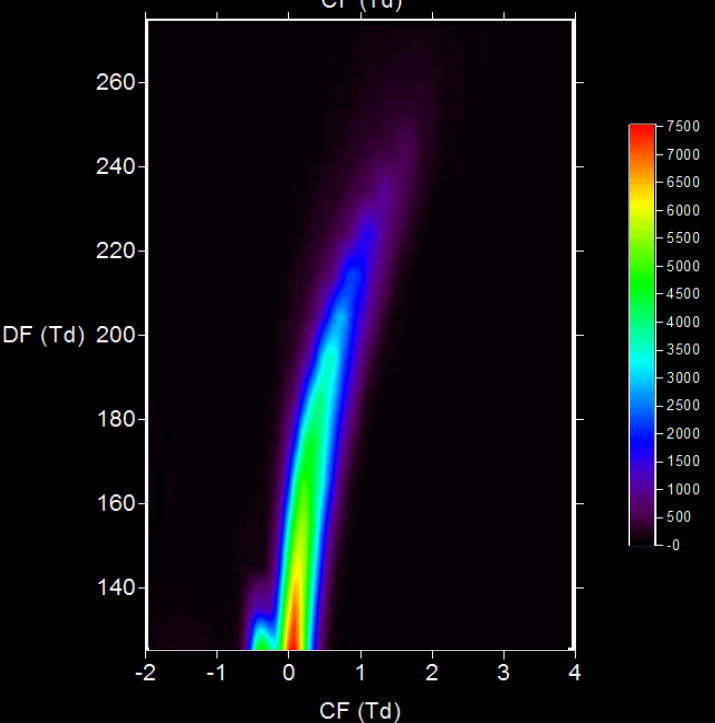
Carvone



Vanillin



Methyl Anthranilate



Methyl Salicylate

Summary

- Chip FAIMS is an ideal combination with a triple quad
- Chip FAIMS vs. FAIMS –
  - 20x narrower gap, 10x lower voltages
  - 100x shorter path, 20x higher frequency
- Provides complete CF/DF scans on the LC/MS time-scale (ultimately <10 sec)
- Adding modifier gases or solvent vapors significantly improves ion separation

Acknowledgements

OWLSTONE

Agilent Technologies