Not-So-Little Light: Bringing *Destiny 2* to HDR Displays

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GAME DEVELOPERS CONFERENCE
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Viewer Beware

- Imagery that I’m about to show you isn’t necessarily faithful to the medium.


DISRUPT WEAPONS EXCHANGE
Drive the Fallen away from their weapons caches.
Time Remaining:
4:03
41 m
3
0
|tiger| _


DISRUPT WEAPONS EXCHANGE
Drive the Fallen away from their weapons caches.
Time Remaining:
4:03
41 m
3
0
|tiger|


60
31
499
OMOLON
|tiger| _


60
OMOLON
31
499
91
6
|tiger|

Agenda

- HDR Recap
- Destiny 2 in HDR
  - Goals and Constraints
  - Challenges
    - Tonemapping
    - Color Grading
    - UI
  - Comparison Tool

Agenda

- HDR: The Wild West
- HDR on PC: The *Wild,* Wild West
- And…

Agenda

- But did we do it right?
- We did it well, but maybe not right.
- Does it hold up?
- Well...

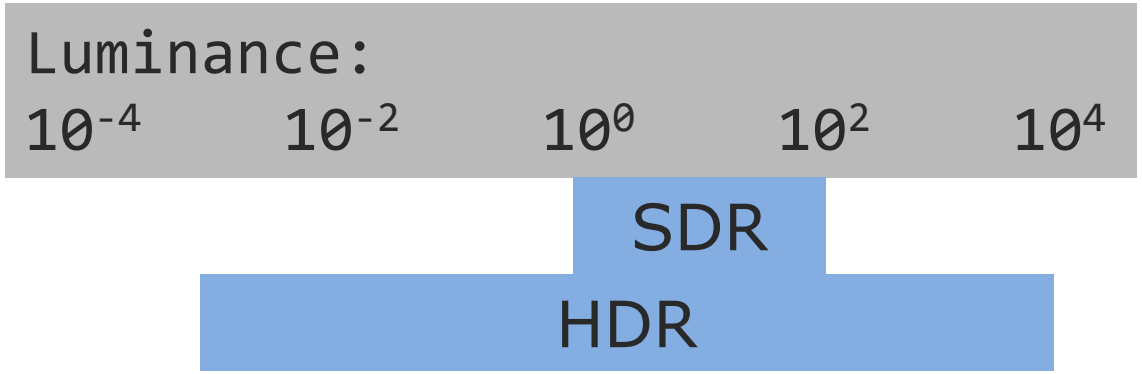

117
15
119
272
6
|tiger| _

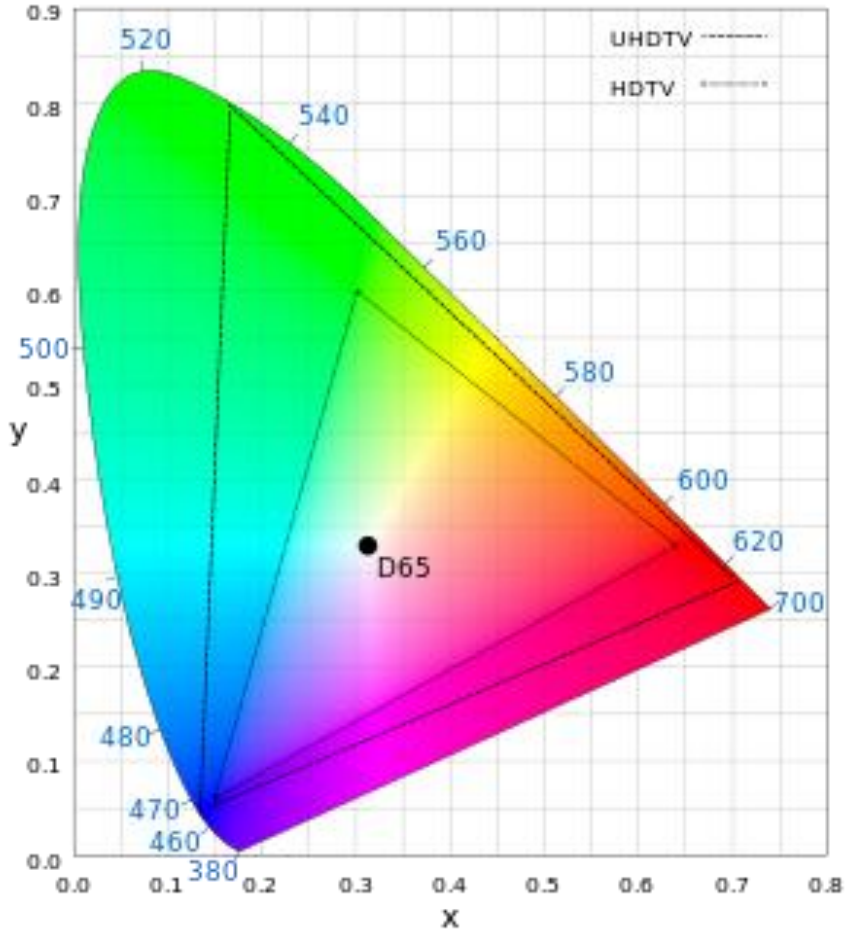

116
15
119
272
6
|tiger| _

What is HDR?

A Whole New World

- More dynamic range.
- More colors.





Luminance

1 nit = 1 candela per m^2

Terminology

- Tonemapping – mapping a set of colors to a more limited range
- LUT – Look-up table, used in color grading
- FP16 – 16-bit per channel floating point
- Gamma – a non-linear transform of image data from the days of the CRT TV
- PQ – Perceptual quantizer, HDR's "gamma" curve

Bringing HDR to Destiny 2

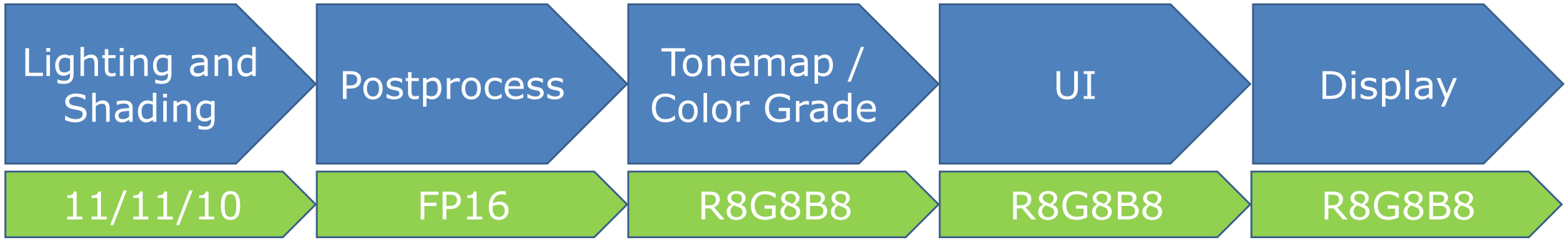
Goals and Constraints

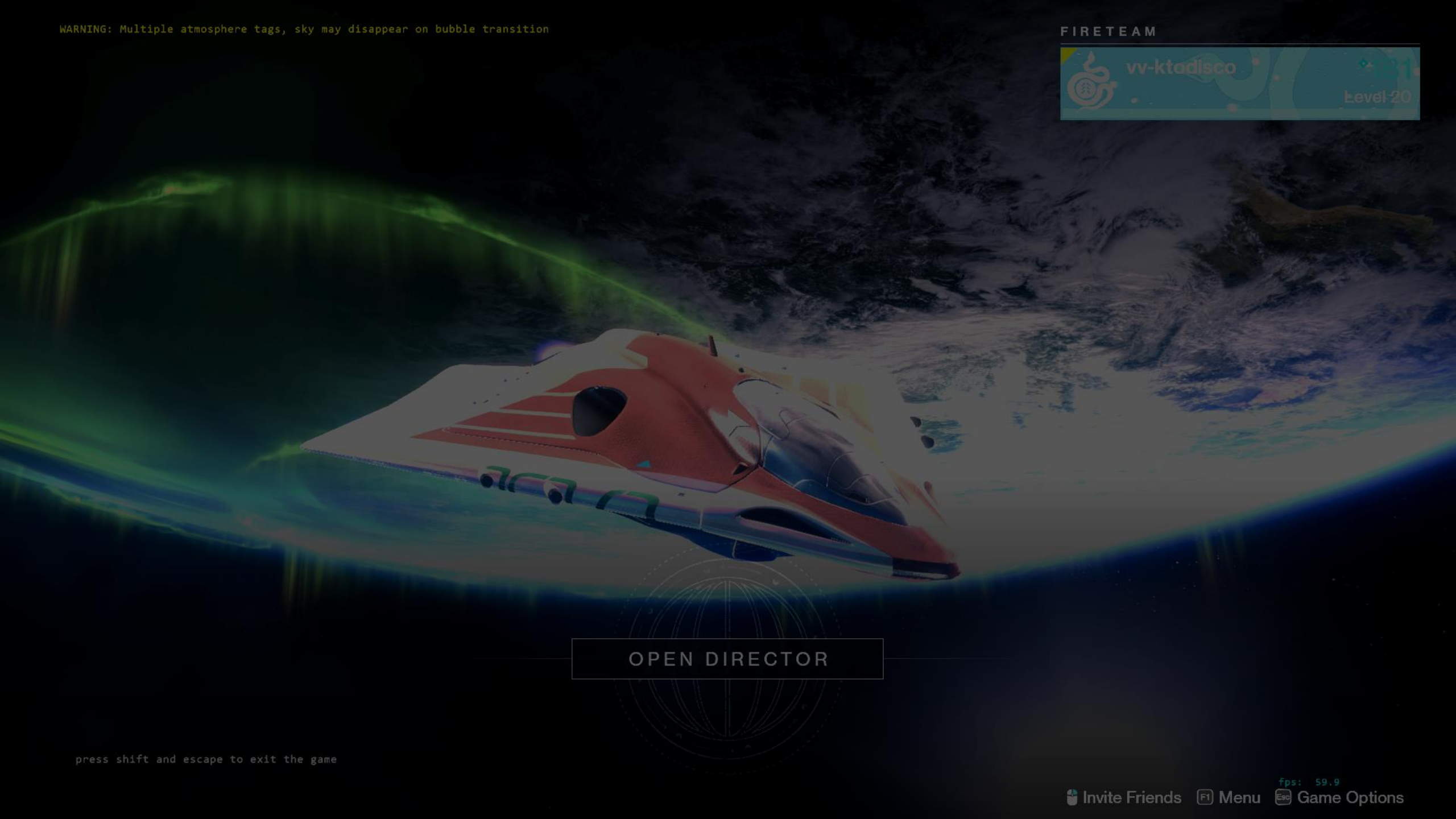
- Visual consistency.
- Visual quality.
- Little extra art support.
- Technical robustness.
- … but only two people.
- Retroactively HDR.

Checklist

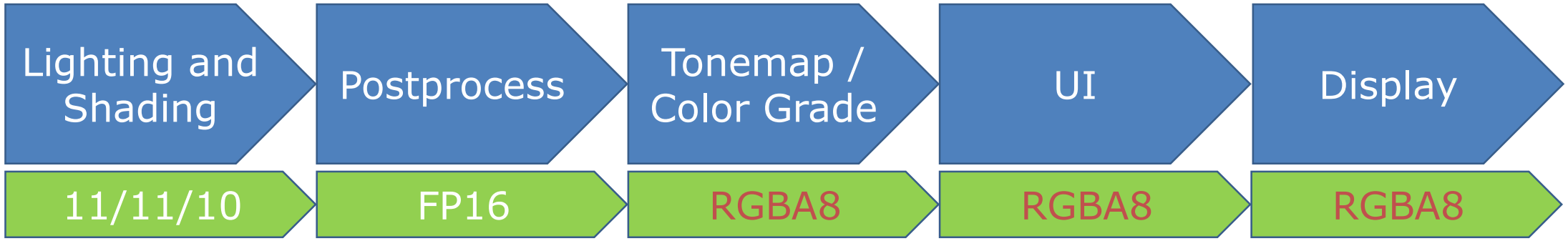
- Enable HDR on the capable display.
- Change backbuffer format.
- Maintain 10 bit-per-channel precision.
- Convert to Rec.2020 color space.
- PQ encode.
- ???
- Profit. … ?

Rendering Pipeline

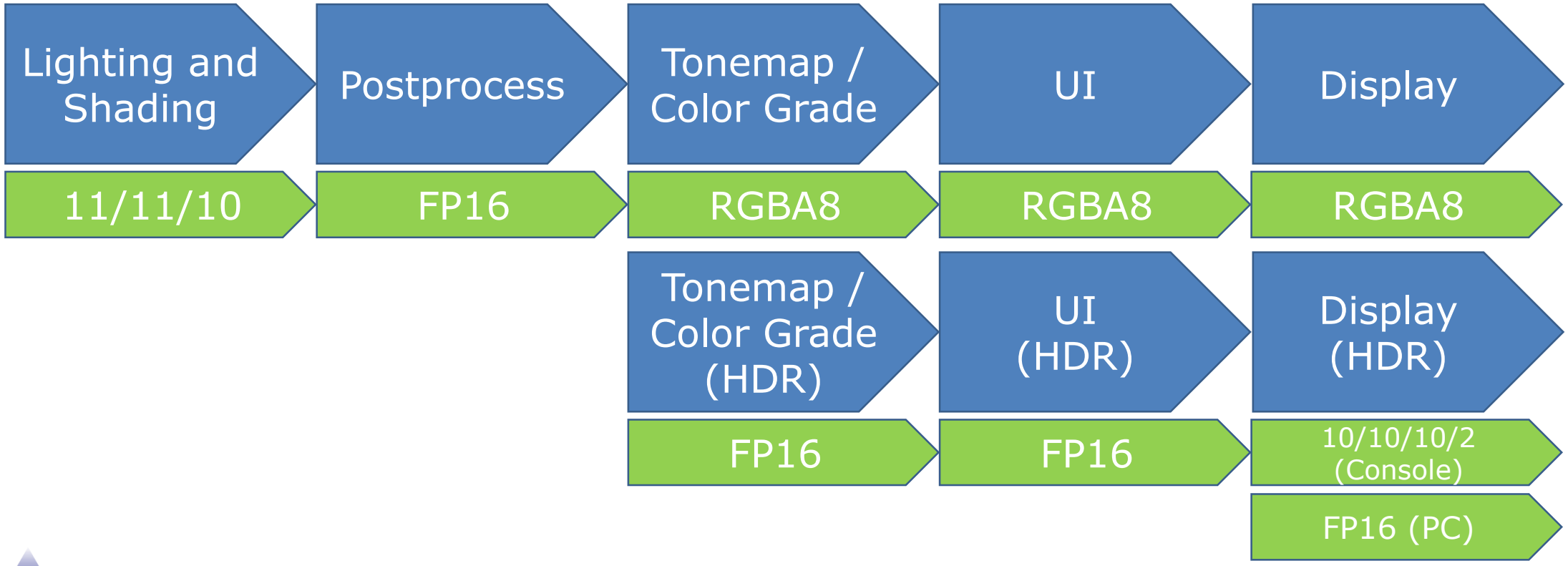


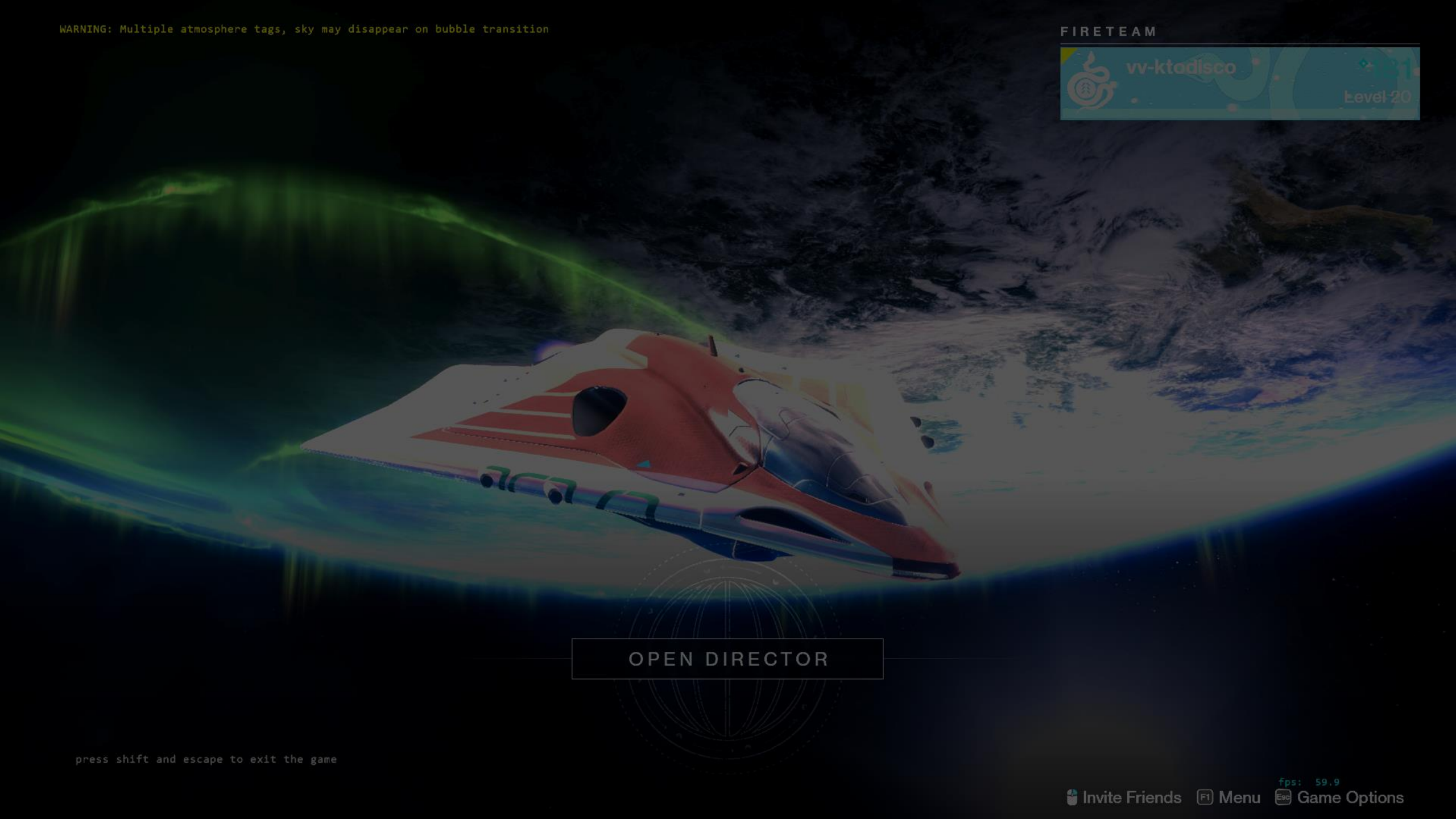

WARNING: Multiple atmosphere tags, sky may disappear on bubble transition
FIRETEAM
vv-ktodisco
Level 20
OPEN DIRECTOR
press shift and escape to exit the game
fps: 59.9
Invite Friends
F1 Menu
Esc Game Options

Rendering Pipeline



Rendering Pipeline

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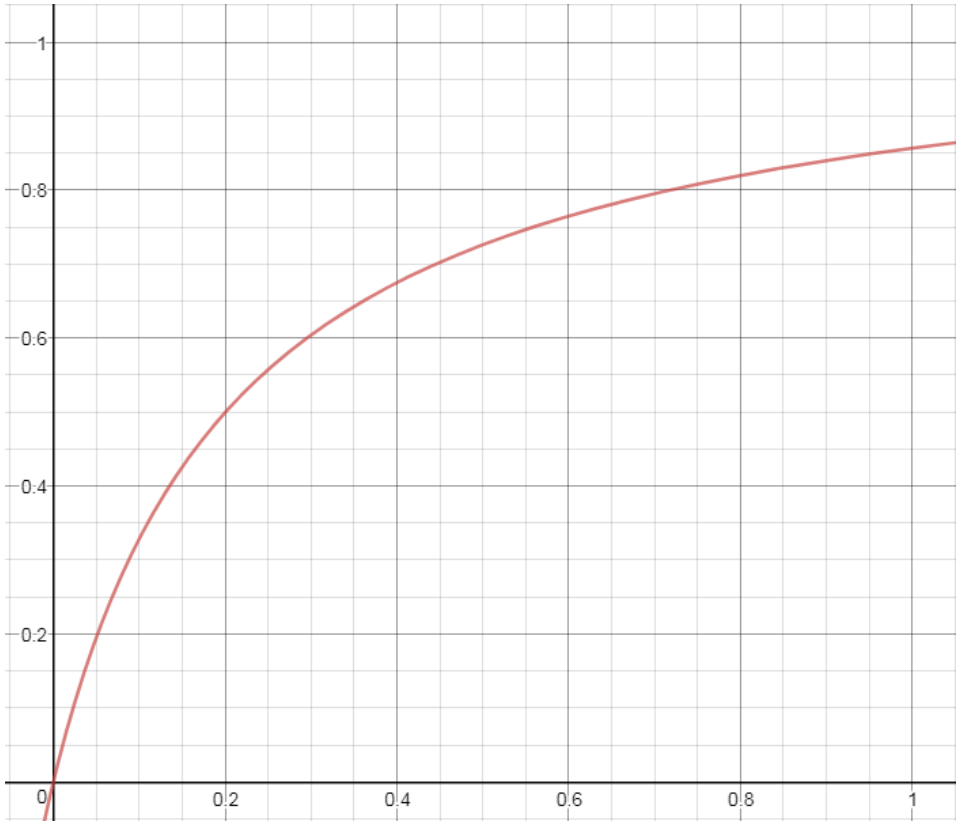
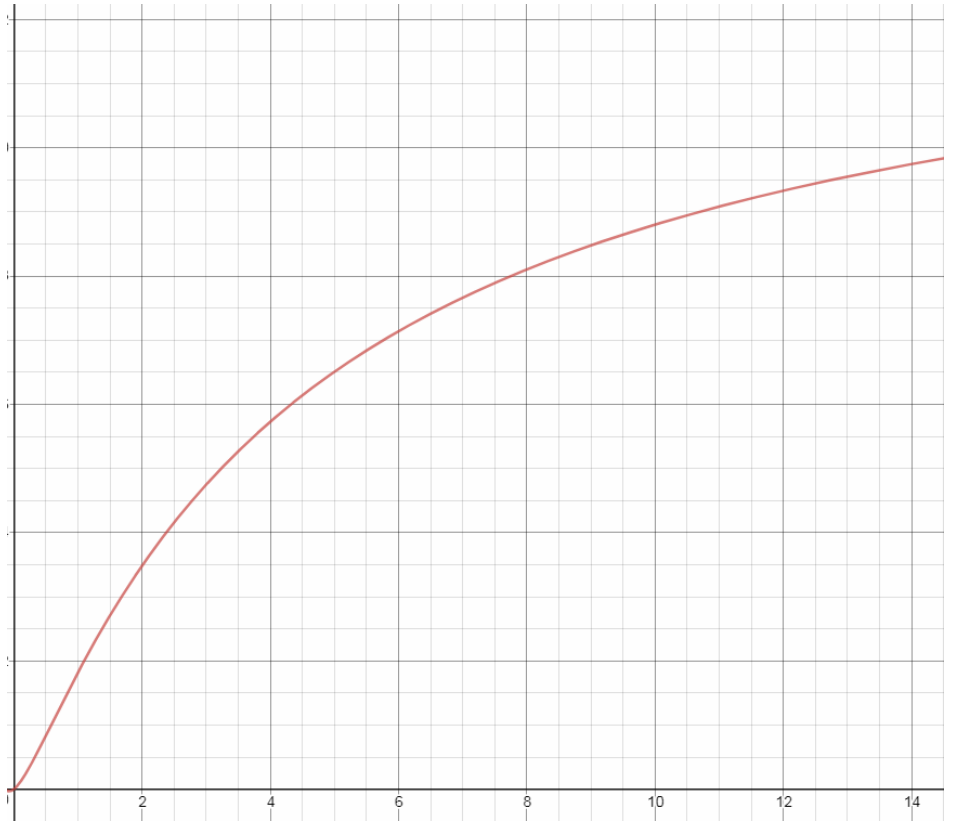
FIRETEAM
vv-ktodisco
181
Level 20
OPEN DIRECTOR
|tiger| _
fps: 59.9
Invite Friends
F1 Menu
Esc Game Options

Tonemapping

Tonemapping





Tonemapping

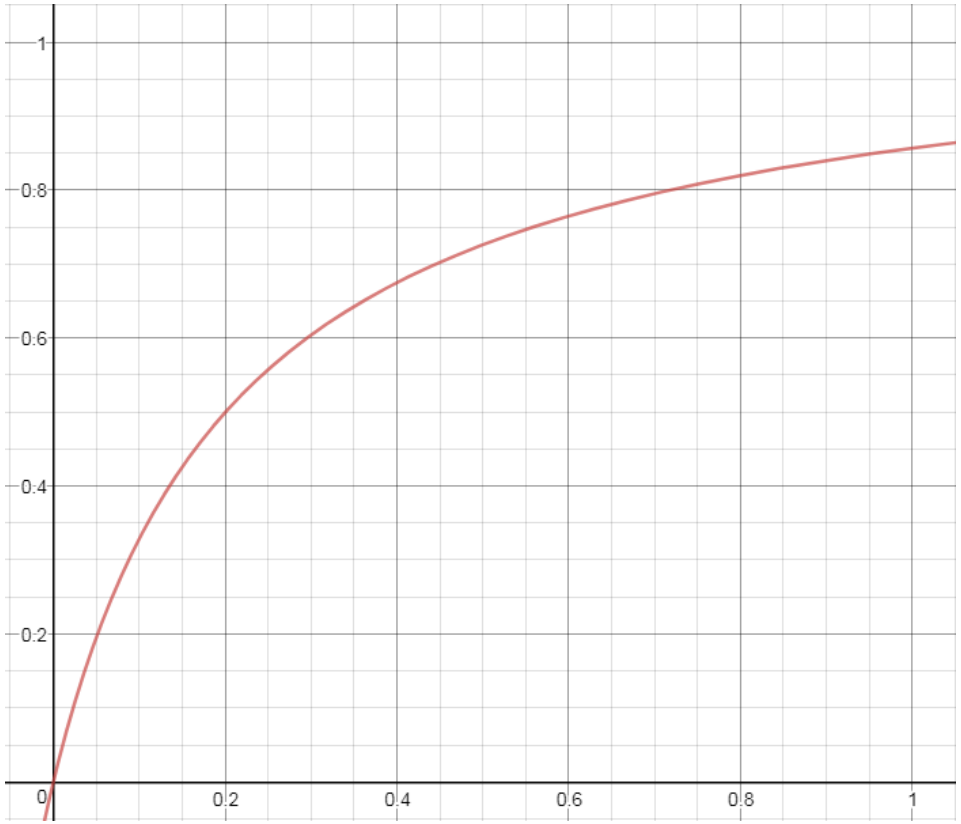
SDR

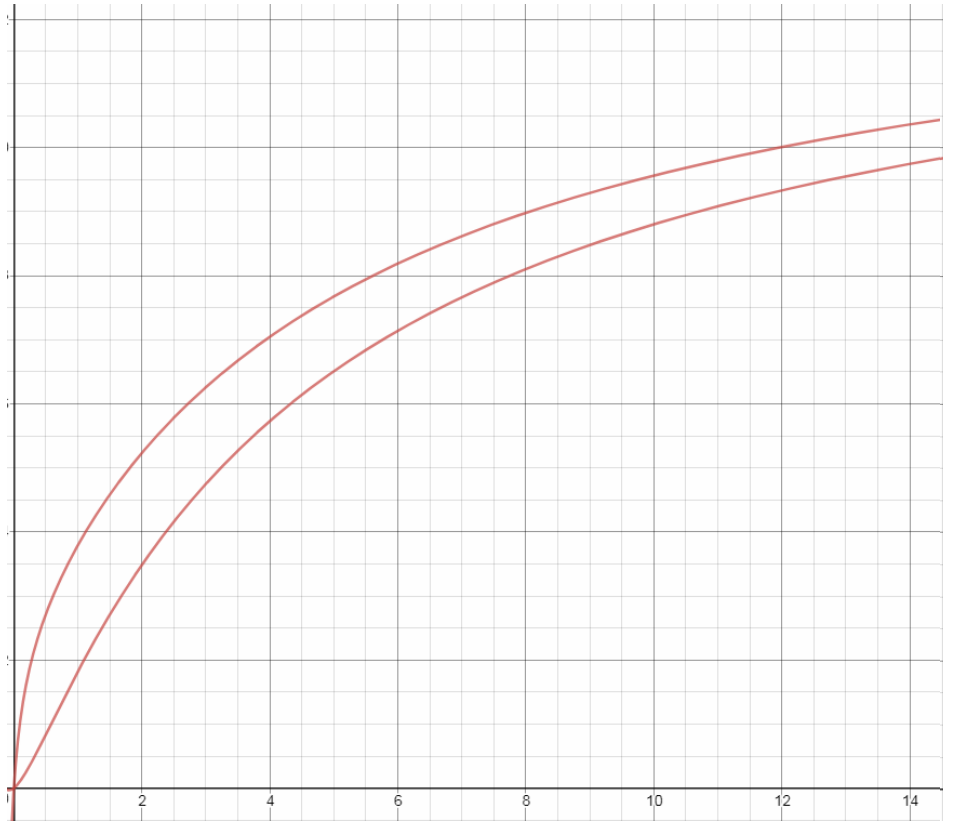
HDR

SDR

HDR

Tonemapping





Color Grading


WARNING: Multiple atmosphere tags, sky may disappear on bubble transition
28
127
71
8
fps: 59.9

Color Grading

- The LUTs are SDR
- Re-author or be clever?
- Math!
  - We always want the linear input.
  - First we tonemap, then we transform.
  - Ignoring transform, this is reversible.

$$y = x$$

$$y = l(s(x))$$

$$y = s(x)\frac{x}{s(x)} = x$$

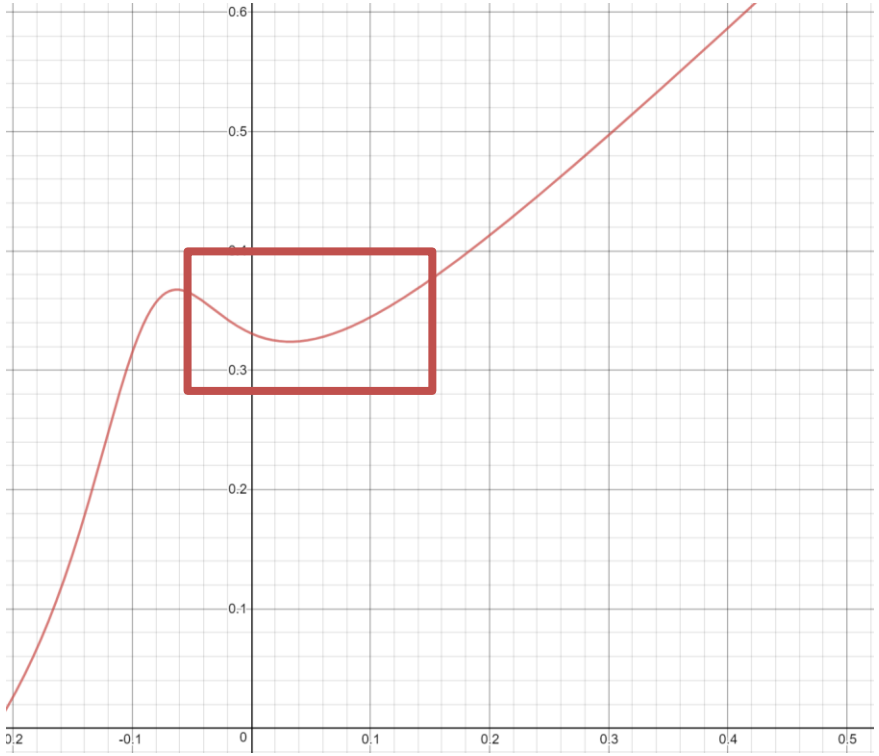
Color Grading

```
SDR Color = TonemapForSDR( Input Color )
LUT Color = LutLookup ( SDR Color )
...
Transform = Input Color / max( SDR Color, 0.001 )
...
LUT Color *= Transform
```

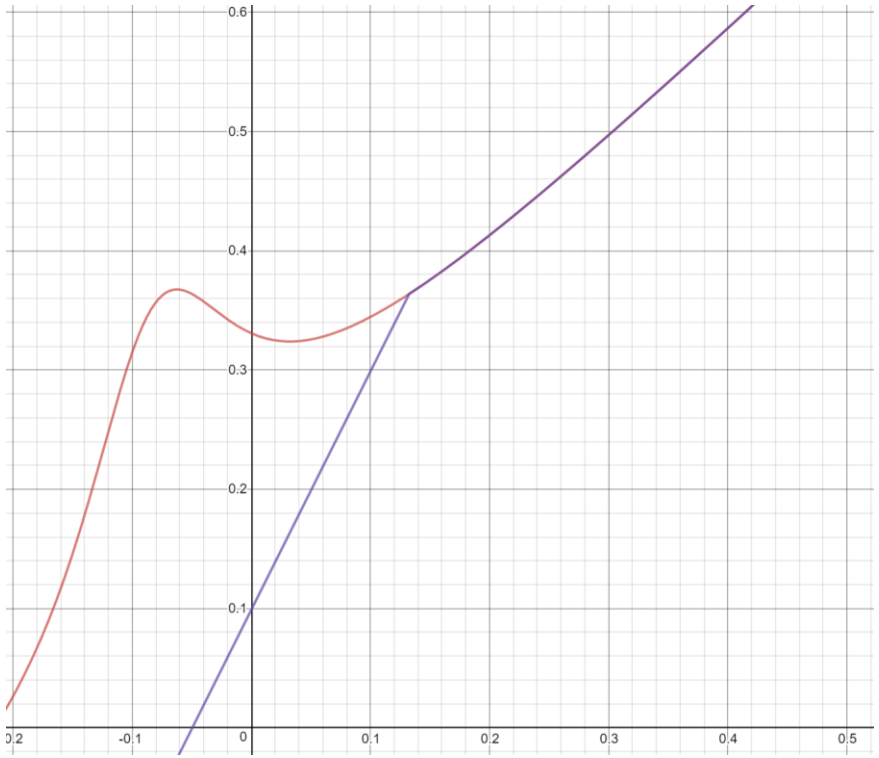
LutColor is 0 when **InputColor** is 0.

Color Grading

```
Transform = Input Color / max( SDR Color, 0.001 )
```



Color Grading

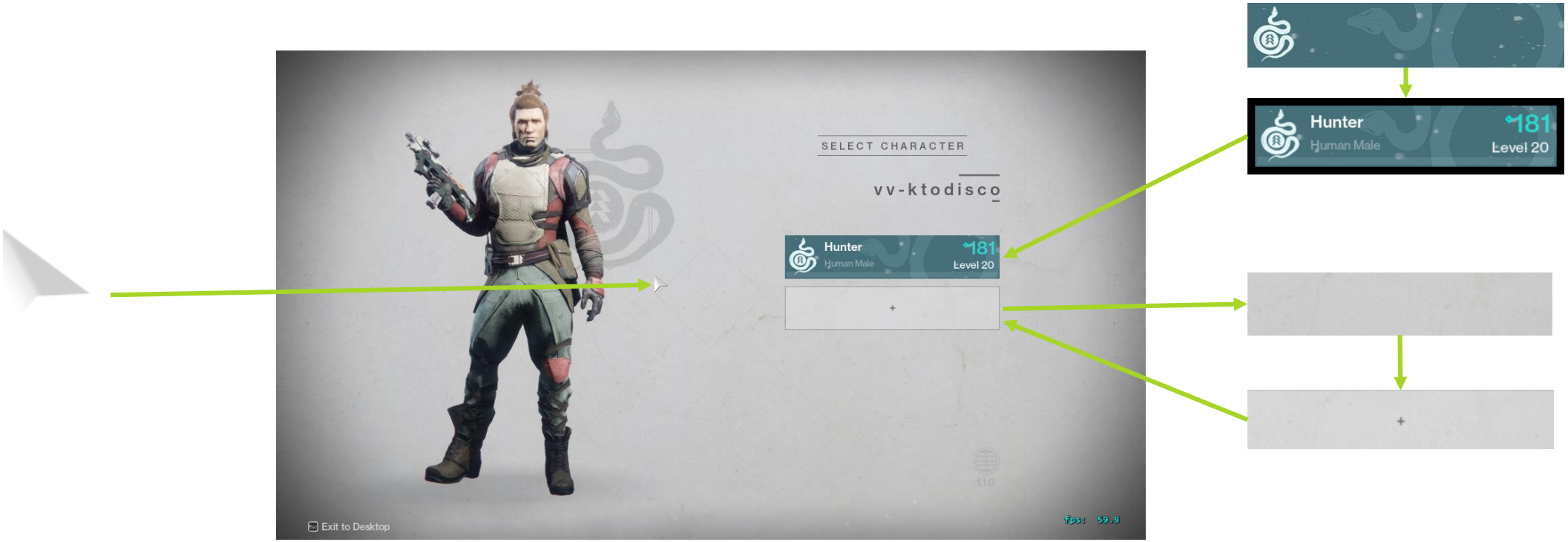


UI

HDR UI

- Definitely the most challenging aspect.
- Tried three distinct approaches.
- Two major hurdles:
  - UI content is inherently SDR.
  - UI blending is expected to occur in SDR.

UI Rendering Preview

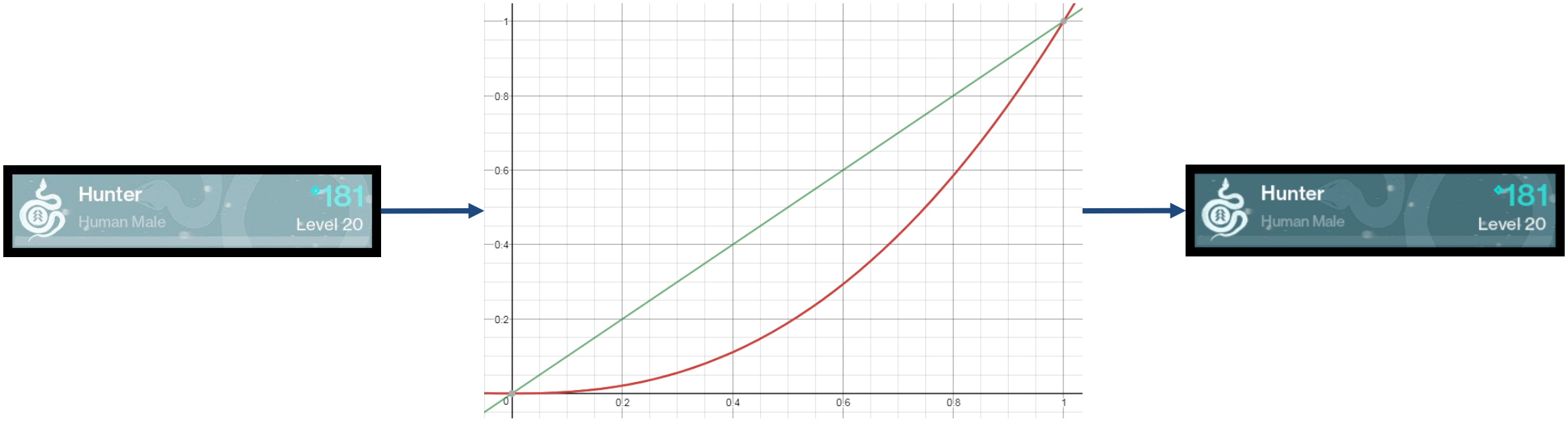


Washed out UI

SDR

HDR

Gamma correction



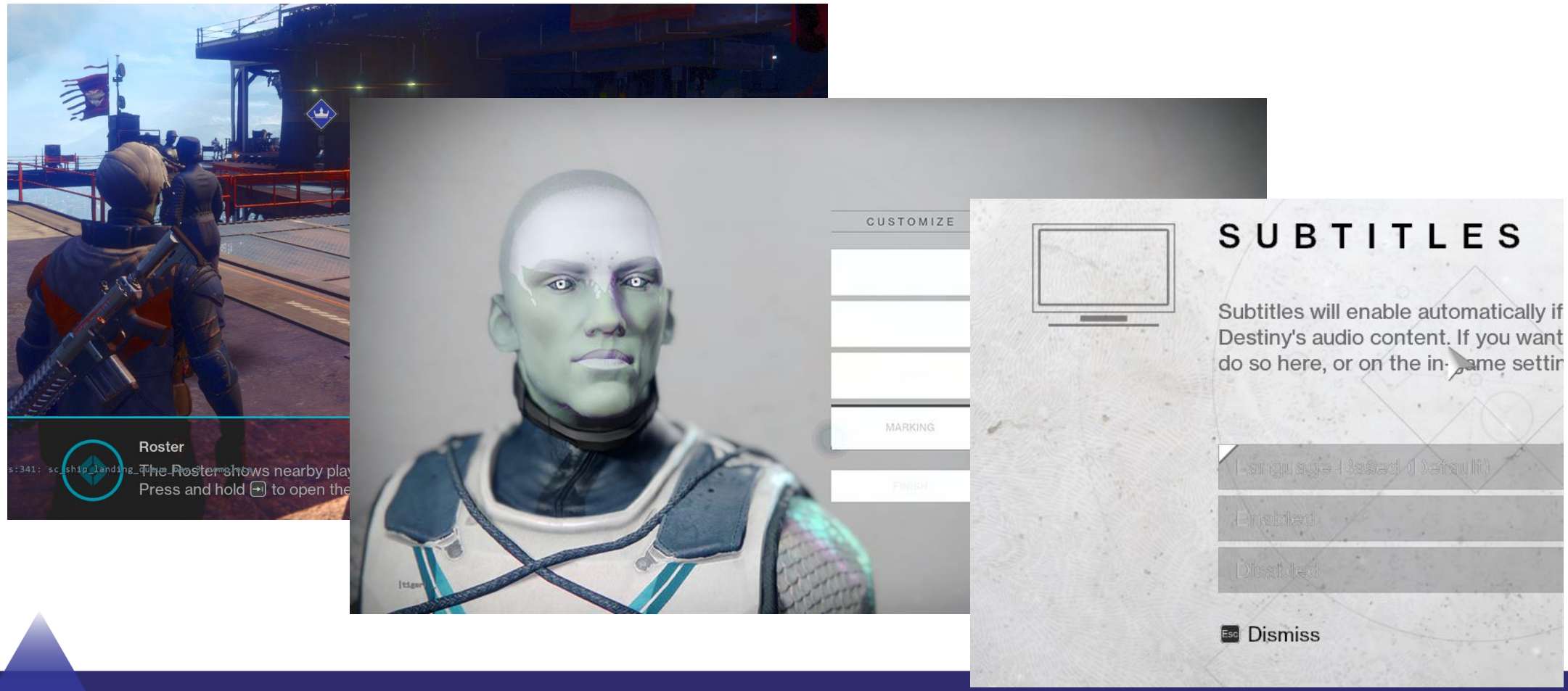
Gamma correction

```
Output = pow( Color, Gamma Exponent ) * HDR Constant
```

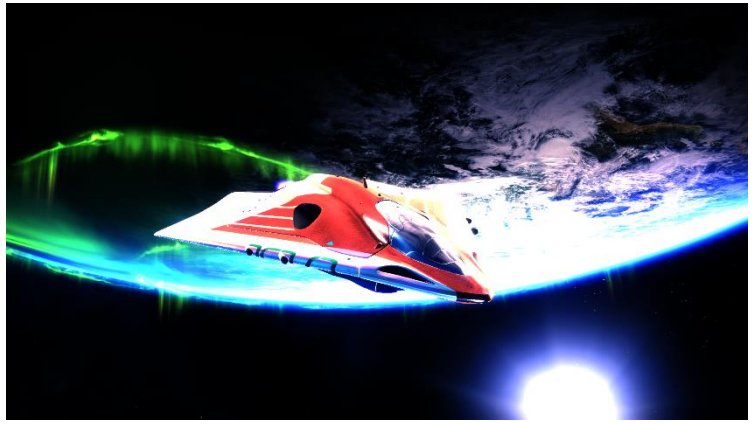
SDR

HDR

99 Problems, and all of them are UI.



On to the next…



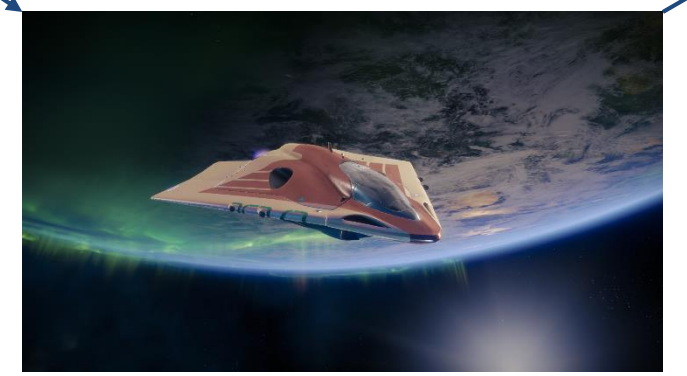
+

=

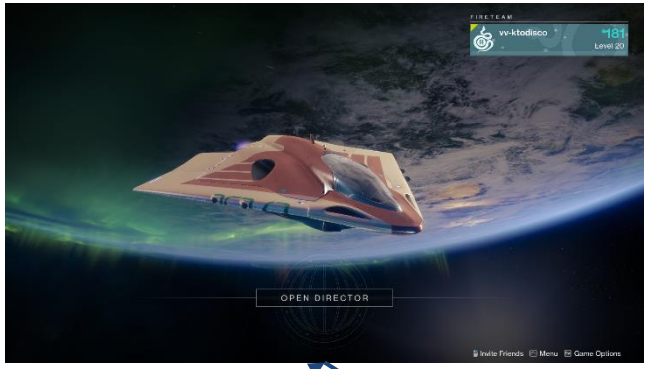
???

Finishing touches

Tonemap

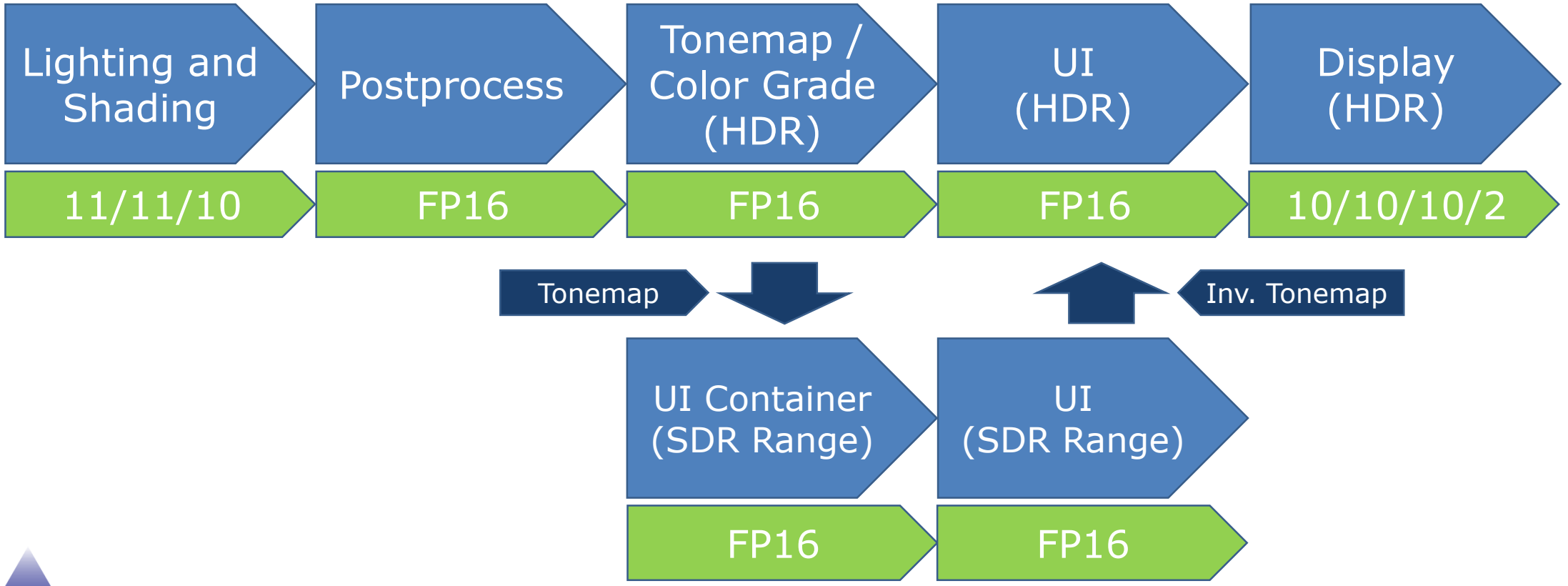


Render UI



Reverse Tonemap

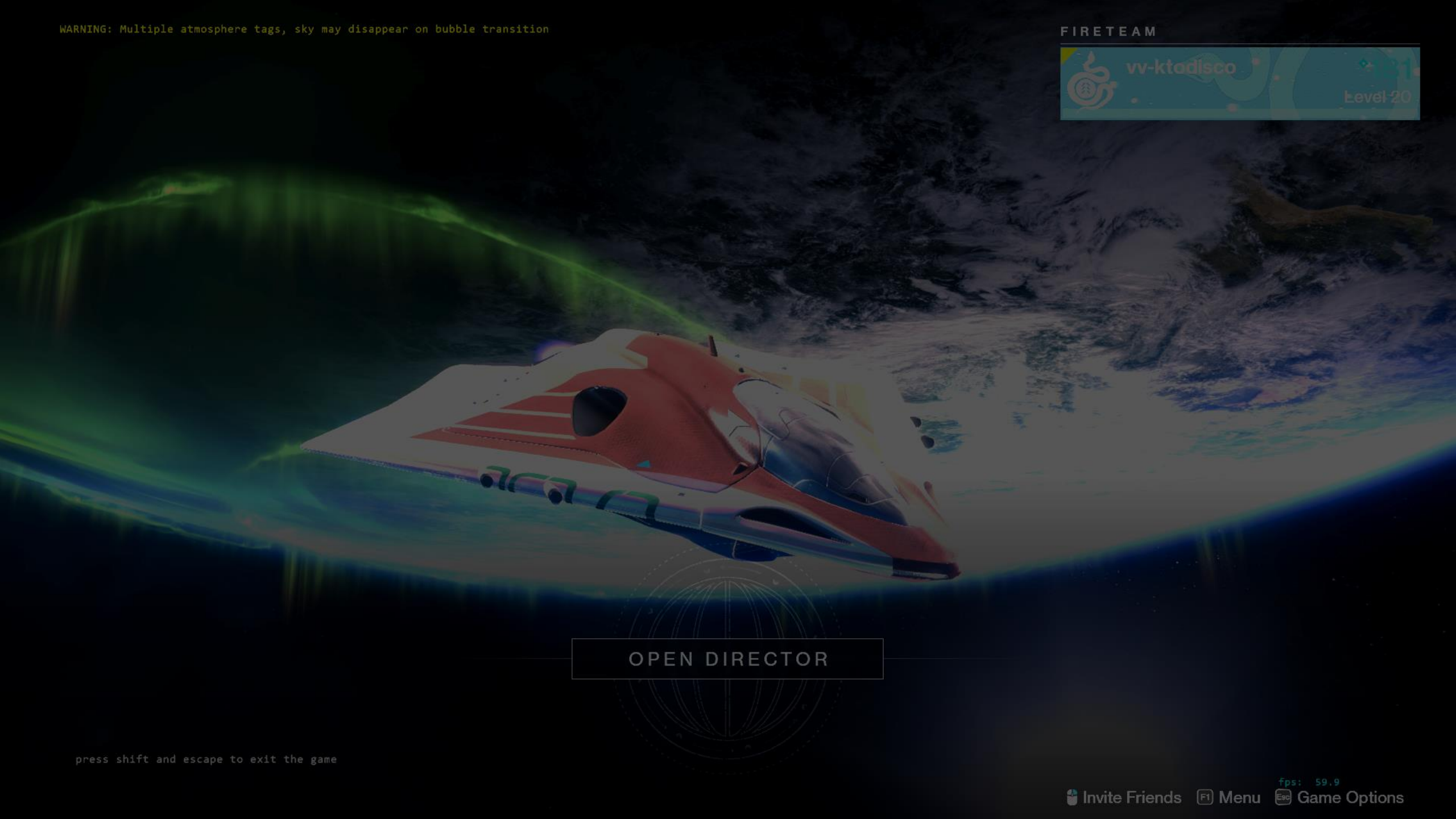
New Pipeline



Comparison Tool

Tech Artist Tools

- Can we have a side-by-side comparison of SDR and HDR?
- On the same screen?
- Challenge accepted.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FIRETEAM
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Level 20
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press shift and escape to exit the game
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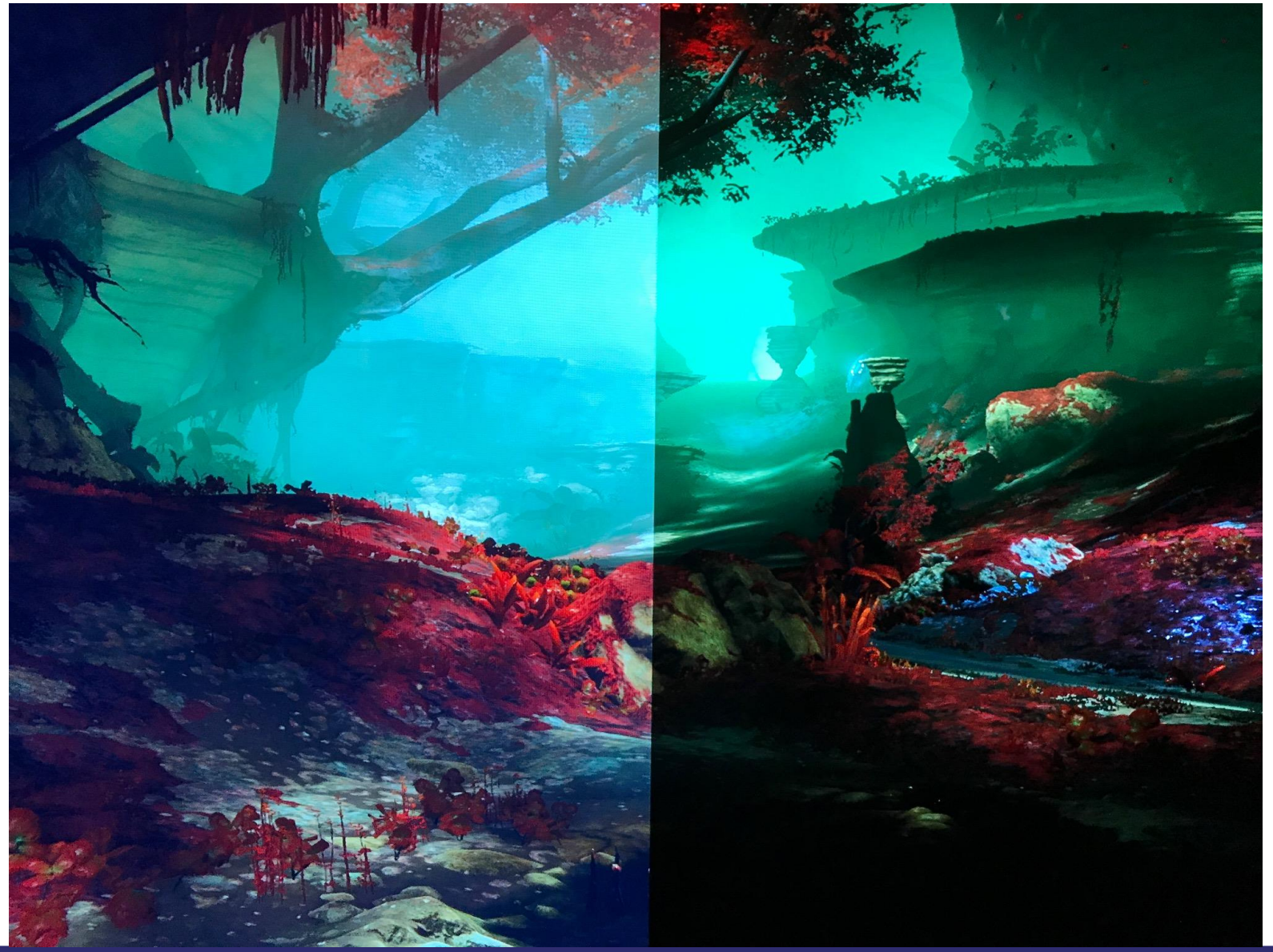
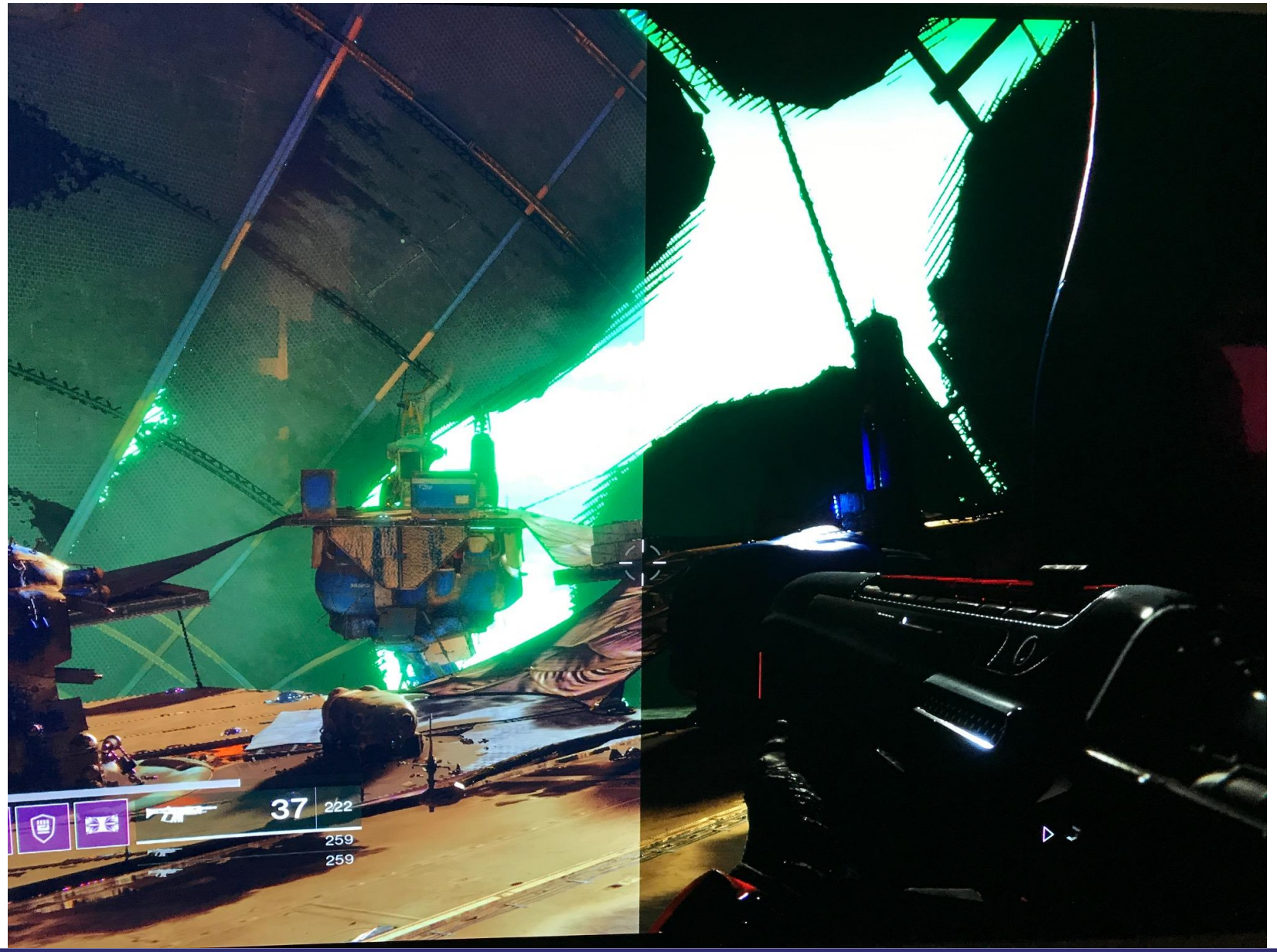
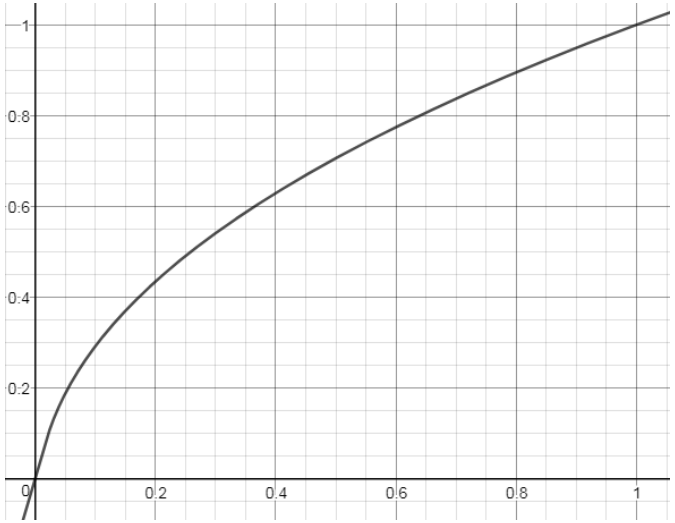



37
222
259
259

Transfer Functions

- EOTF
  - Electro-optical transfer function.
  - From voltage, to optical intensity.
- OETF
  - Opto-electrical transfer function.
  - From optical intensity, to voltage.

Tech Artist Tools



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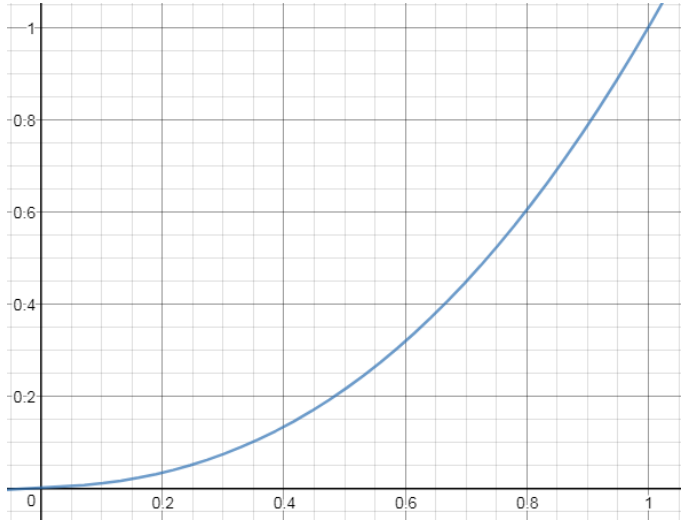
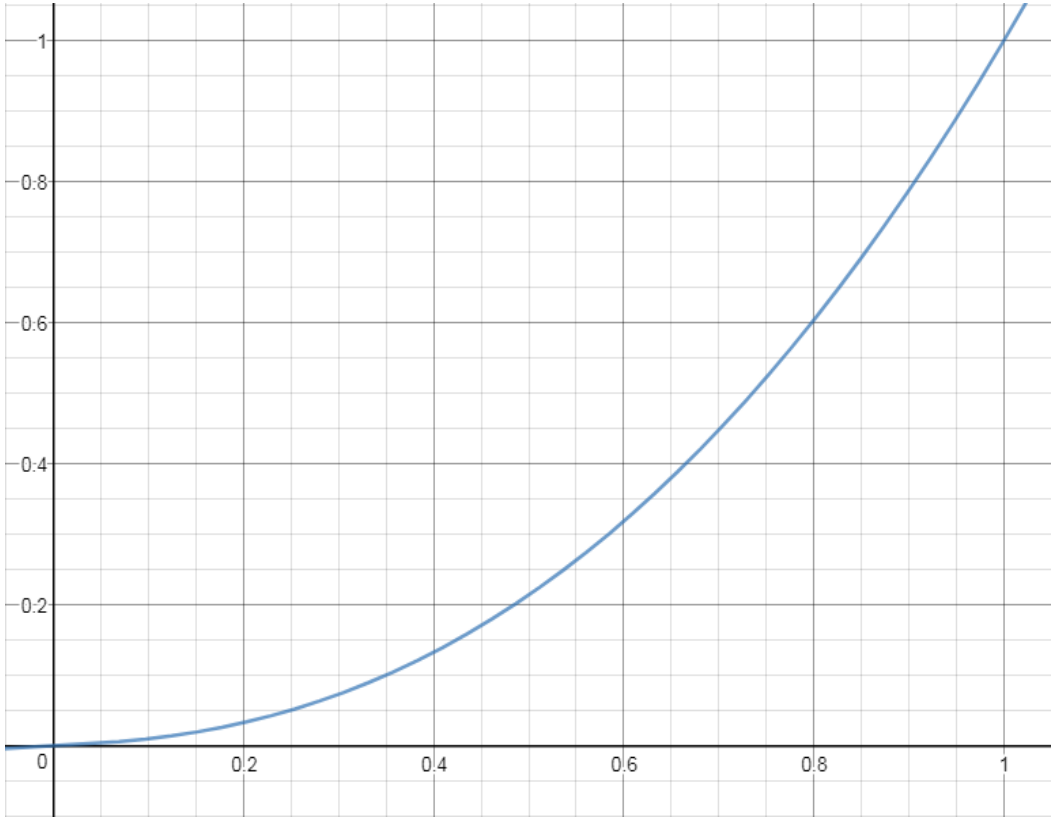


=

sRGB EOTF

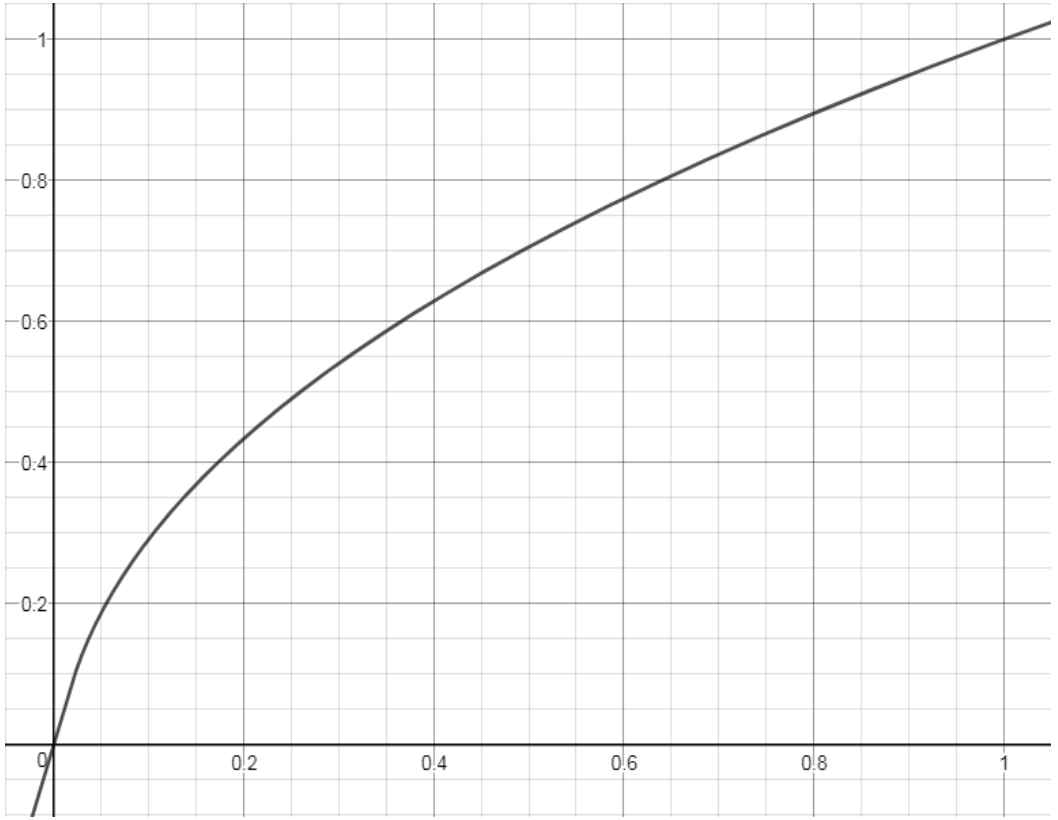
$$L = \frac{x}{12.92} \quad x \leq 0.04045$$

$$L = (\frac{x + 0.055}{1.055})^{2.4} \quad x \leq 0.04045$$



BT.709 OETF

$$V = 4.500L \quad L < 0.018$$
$$V = 1.099L^{0.45} - 0.099 \quad L \geq 0.018$$



Comparison – Final Result

SDR

HDR

Comparison – Final Result

SDR

HDR

The Wild West

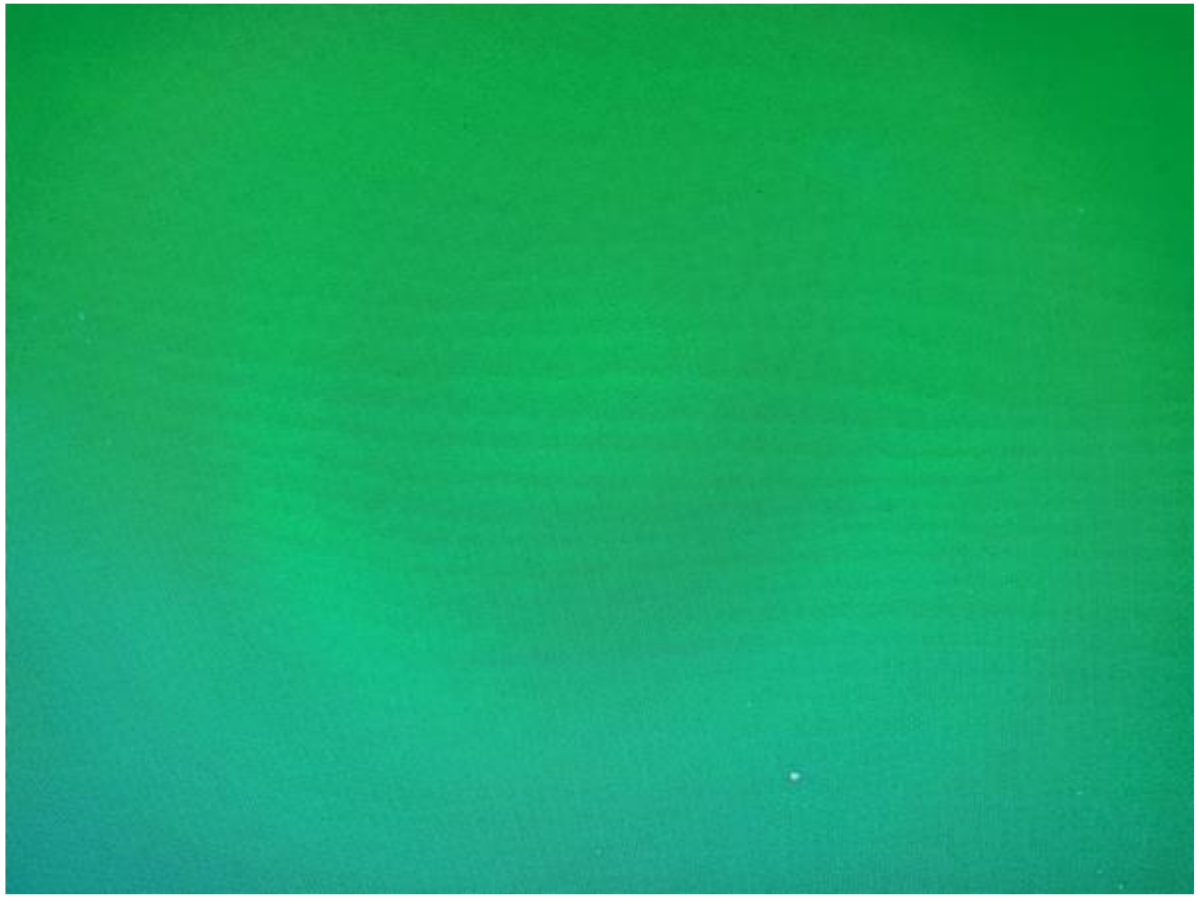
Technical Gotchas

- Enhanced HDMI
- Careful using saturate in shaders.
- fp16 buffers means negative numbers.
- AA in SDR space.
- Deeper blacks accentuate screen noise.

HDR on PC

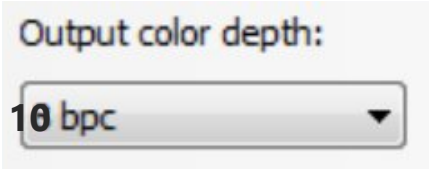
The Wild, *Wild* West

Banding



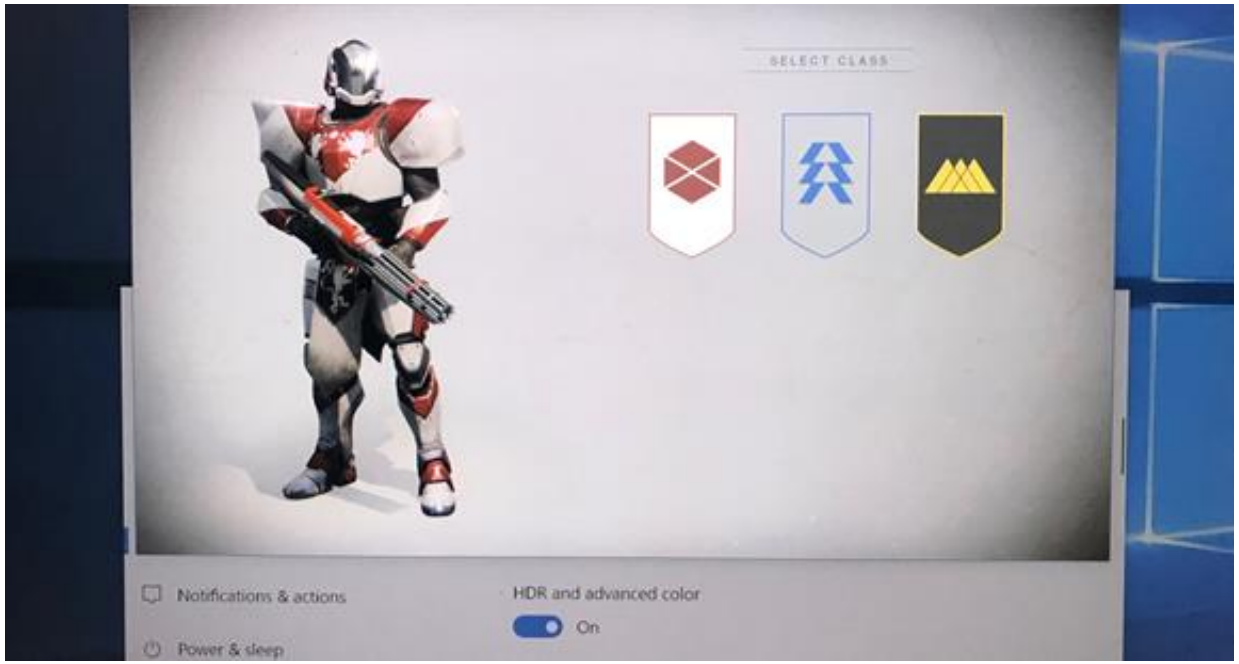
Bandwidth

- Change the output color depth.
- Requirements
  - 4K 10-bit @30fps = 11.14 Gbps
  - 4K 10-bit @60fps = 22.28 Gbps
- HDMI
  - 2.0 = 18 Gbps, 2.1 = 48 Gbps
- DisplayPort
  - 1.4 = 25.92 Gbps



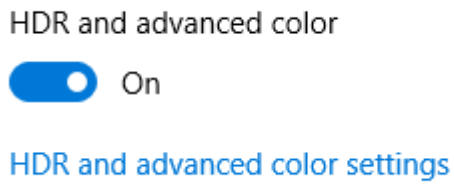
HDR and Windows

- First: "it works and looks great!"
- Make it better: windowed?



HDR and Windows

- If (HDR and Advanced Color)
  - Use SetColorSpace1 and SetHDRMetaData
- Else
  - Use NVAPI or AMD AGS.



- Both use fp16 backbuffer with 709 primaries.

HDR and Windows

- Color spaces are a bit rigid.

Backbuffer Format	Color Space
10/10/10/2	RGB_FULL_G2084_NONE_P2020
FP16	RGB_FULL_G10_NONE_P709

  - Why can’t I have fp16 with 2020 primaries?
- Requires FLIP model.
- DWM expects fp16 backbuffer.

SELECT CLASS

Notifications & actions

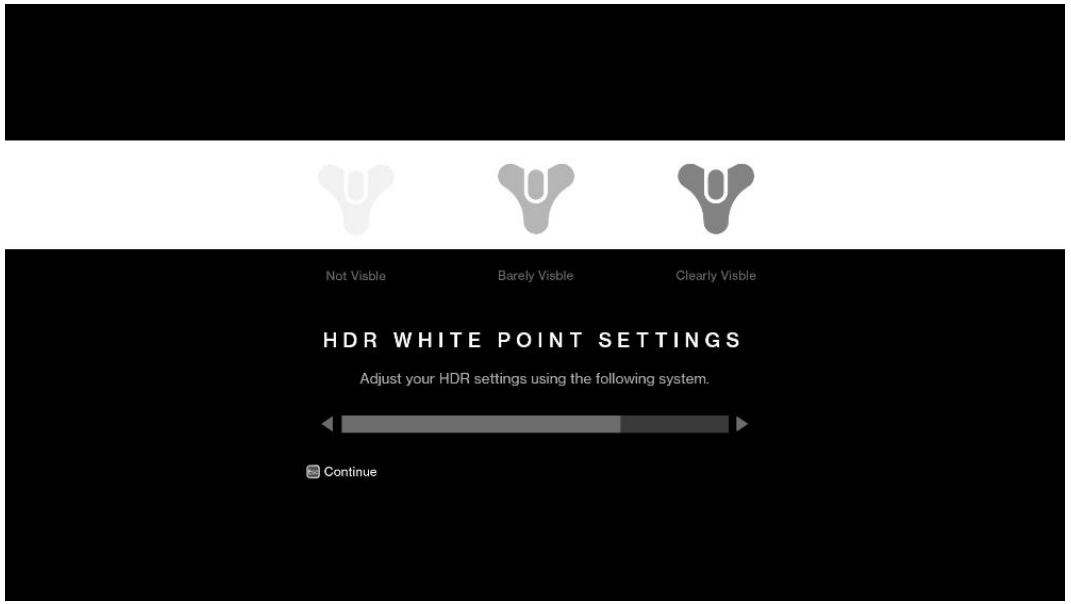
Power & sleep

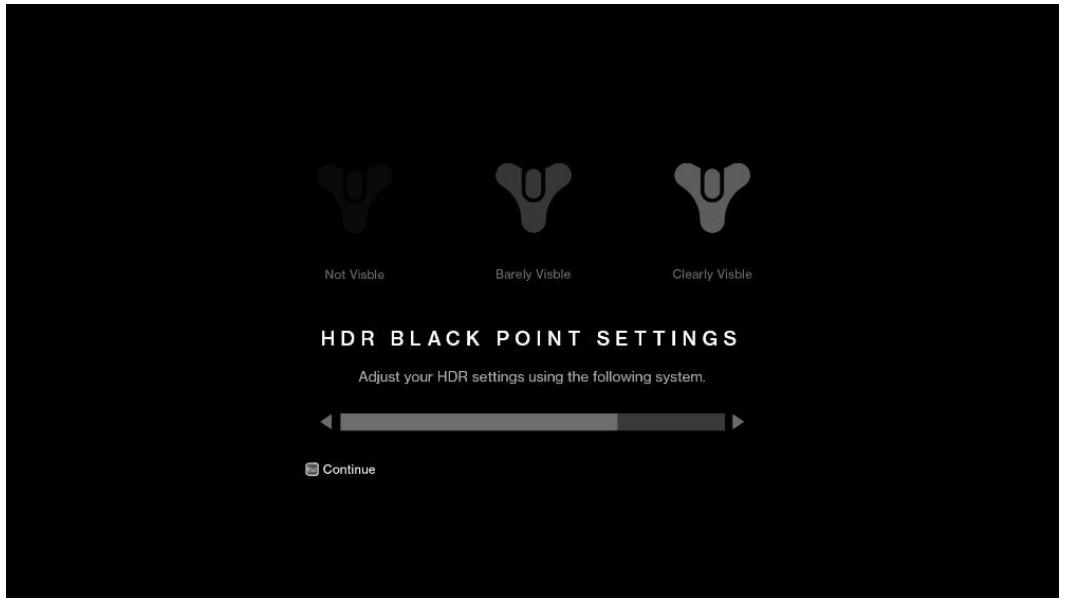
HDR and advanced color

On

Calibrations

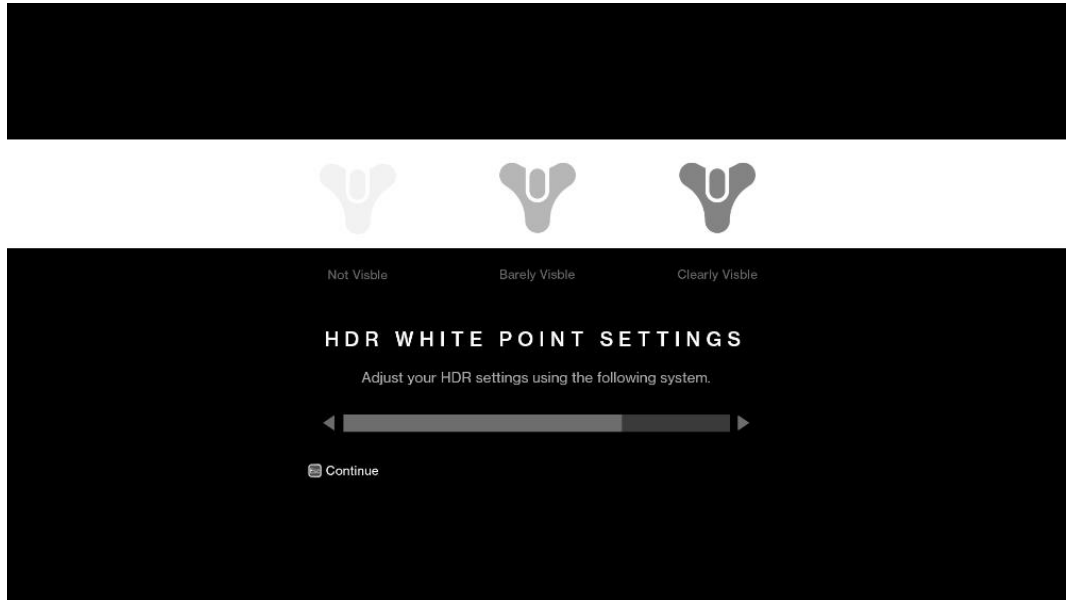
- Scale and bias





White Point Behavior

- HDR and Advanced Color
- Fullscreen vs. Windowed
- Different IHVs
- Multi-monitor
- Monitor auto-correction
  - :(



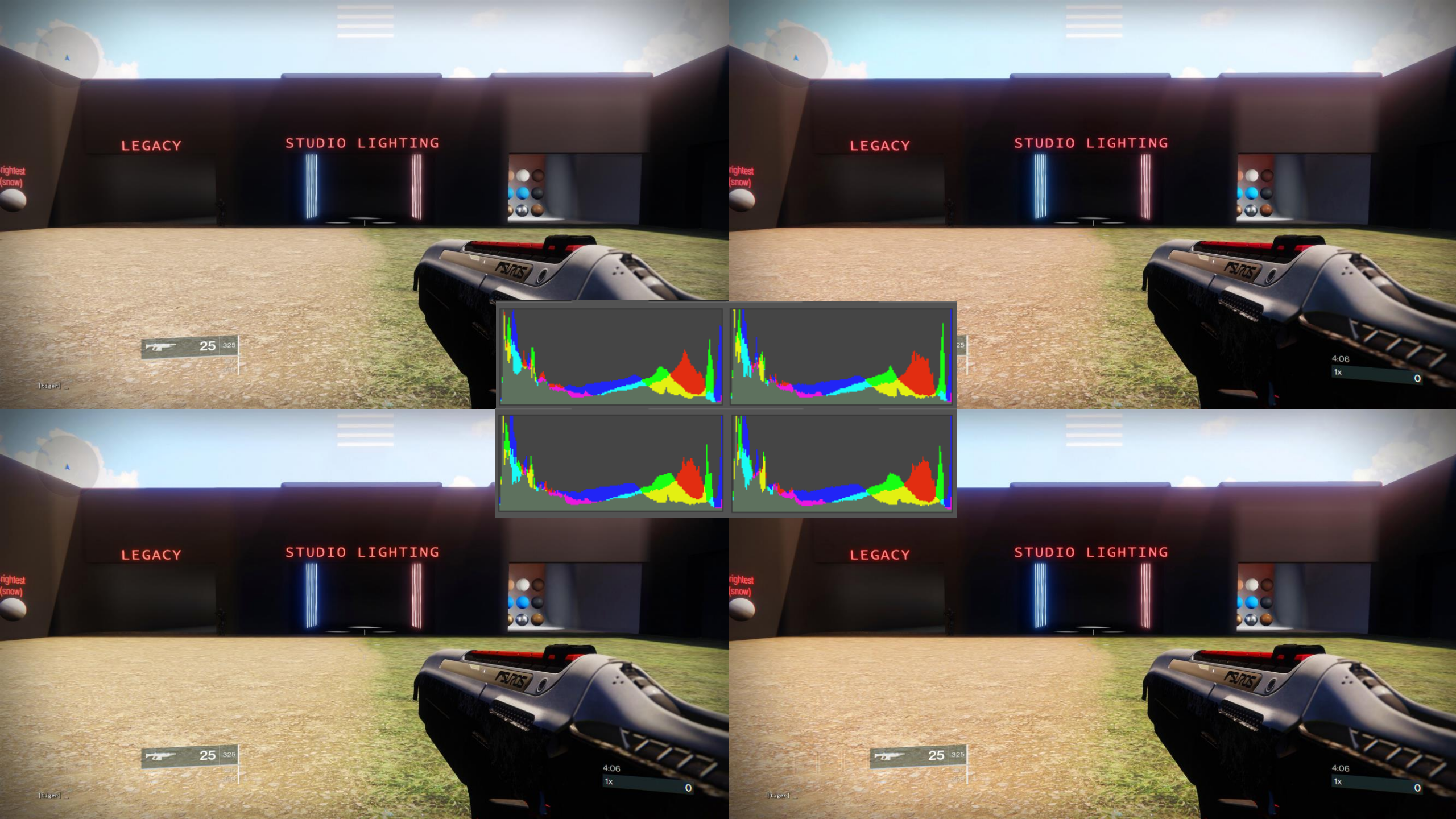
Comparison – Final Result

SDR

HDR

So why is this so hard?

The Wild West of HDR


LEGACY
STUDIO LIGHTING
25
325
4:06
1x
0

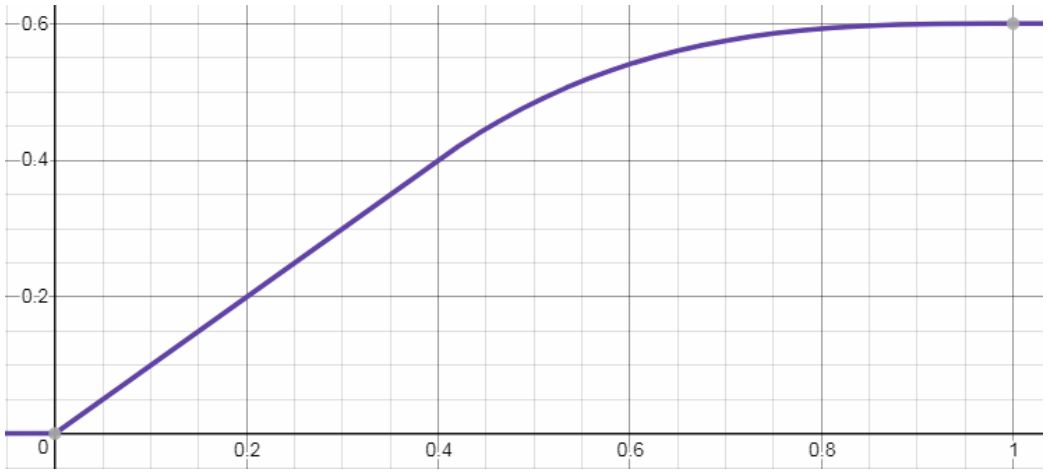
Comparison – Final Result

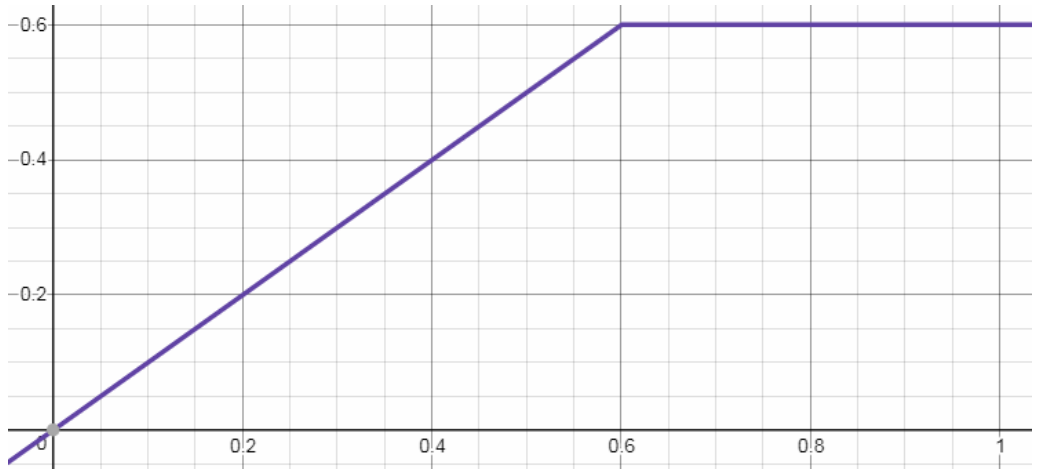
SDR

HDR

HDR is No Exception

- HDR Gaming Interest Group
- Rolloff no, hard-clip yes!





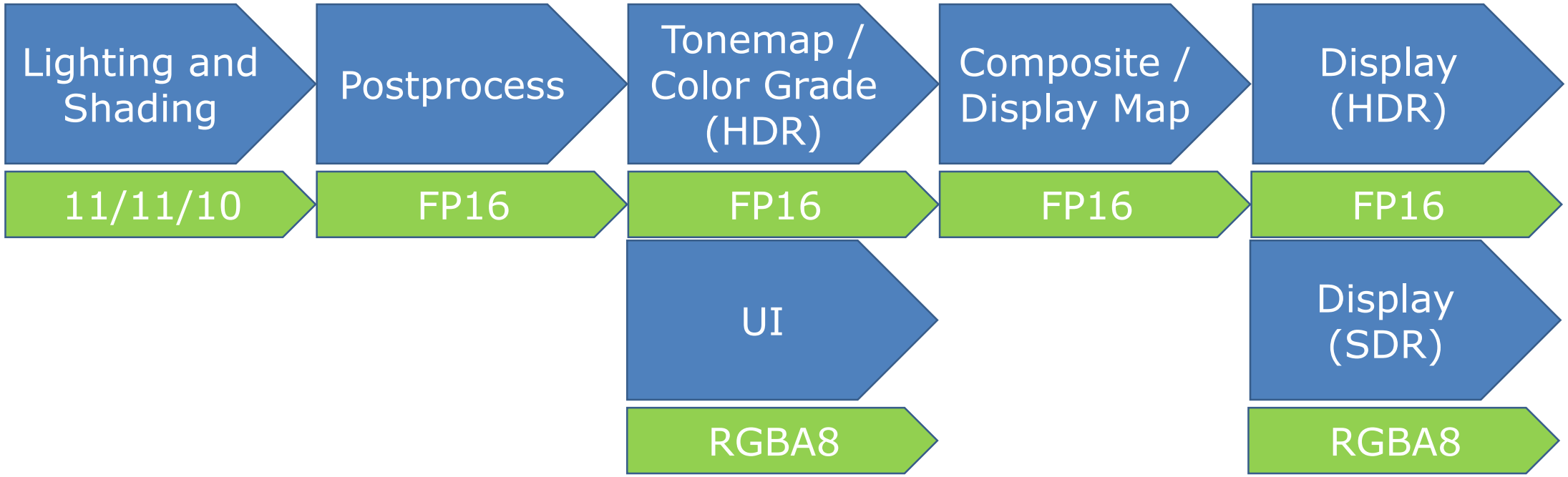
What would I do differently?

A lot.

What I'd Do Differently

- HDR LUTs
- Use chroma/luma for UI
- Utilize ICtCp or other
- Tonemapping as a final step

Ideal HDR Pipeline



Lessons

Lessons

- Content validation.
- Be prepared to change your SDR pipeline.
  - We couldn't.
- Maintain HDR buffers for as long as you can.
- Explore alternatives to RGB.
- Use photometric units.
- Make a comparison tool.

Special Thanks

- Nate Hawbaker
- Acy Stapp
- Brandon Whitley
- Brad Loos
- Tim Healey

Questions?

Kevin Todisco | @kevintodisco | ktodisco@vvisions.com

References

1. Wikipedia. 2012. Retrieved from https://en.wikipedia.org/wiki/Ultra-high-definition_television#/media/File:CIExy1931_Rec_2020_and_Rec_709.svg
2. Melosevic, Petar. 2017. Retrieved from https://commons.wikimedia.org/wiki/File:Candle_(Slava_celebration).jpg
3. Kish, Paul. 2015. Data from https://www.belden.com/blog/smart-building/understanding-4k-necessary-data-rates