



まだ見ぬ世界と生きているうちが華の系外惑星探査  
河原 創 (東大地惑)

Sun, Star



Universe



Galaxy



Cluster



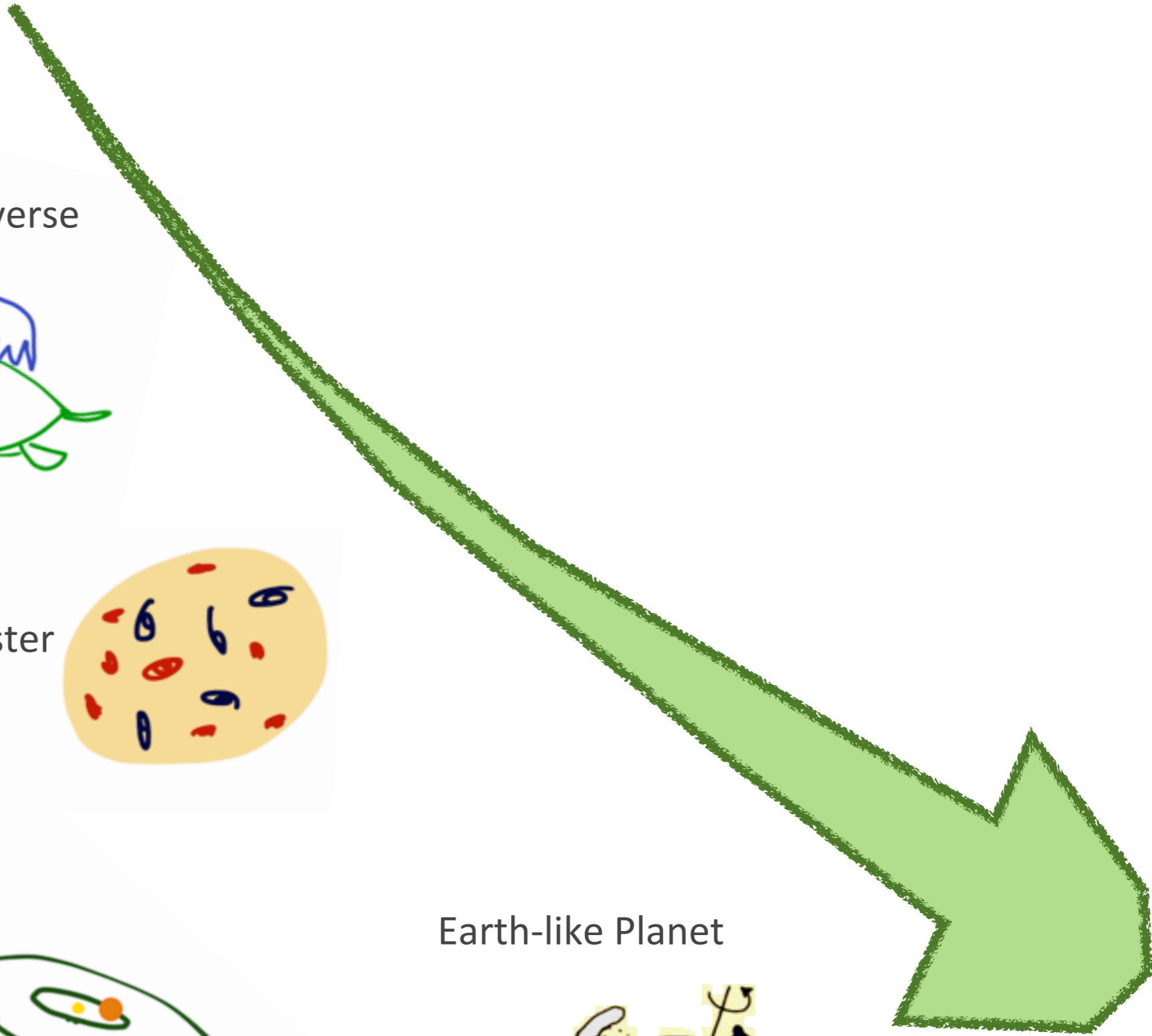
BH, pulser, GRB...



Exoplanet

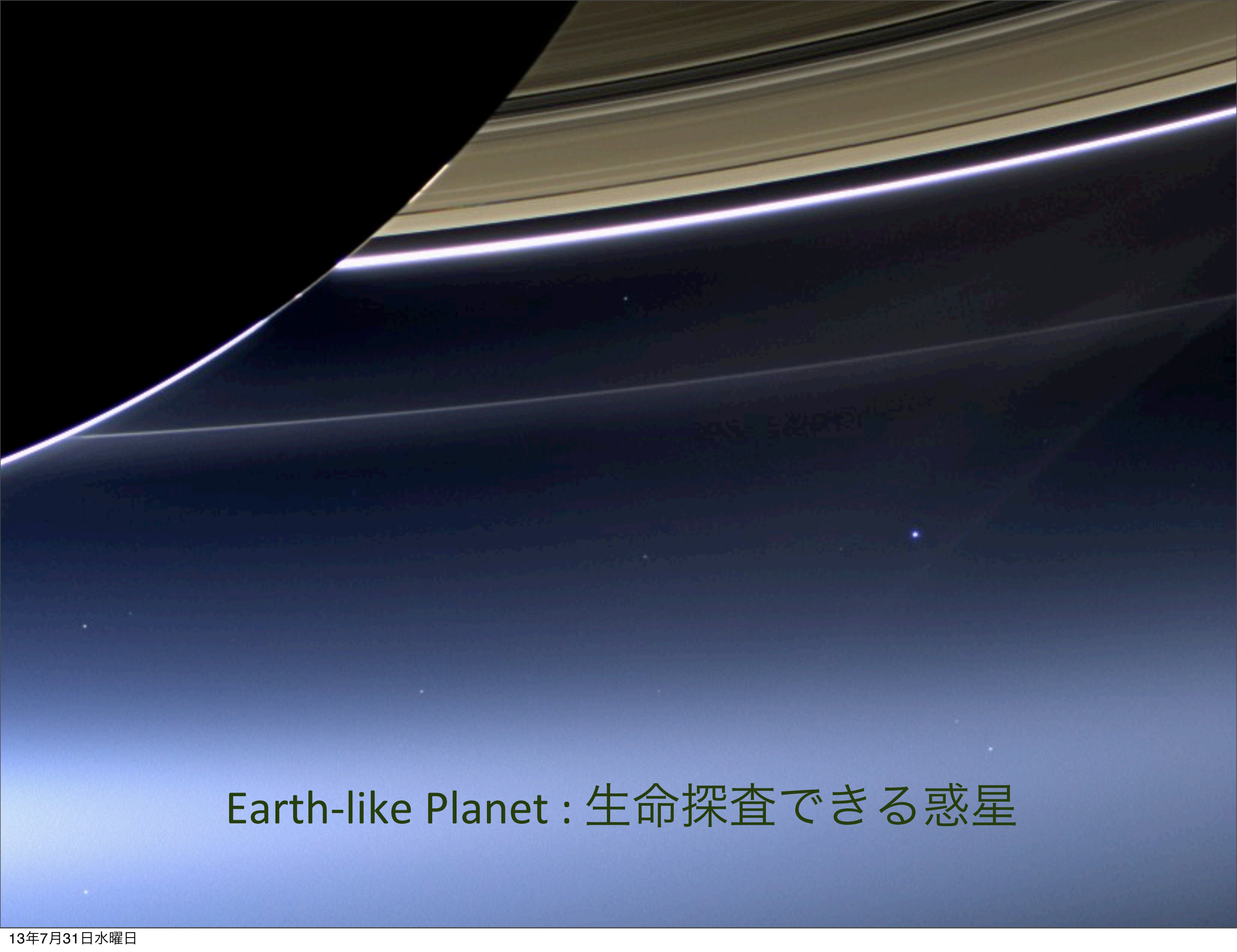


Earth-like Planet

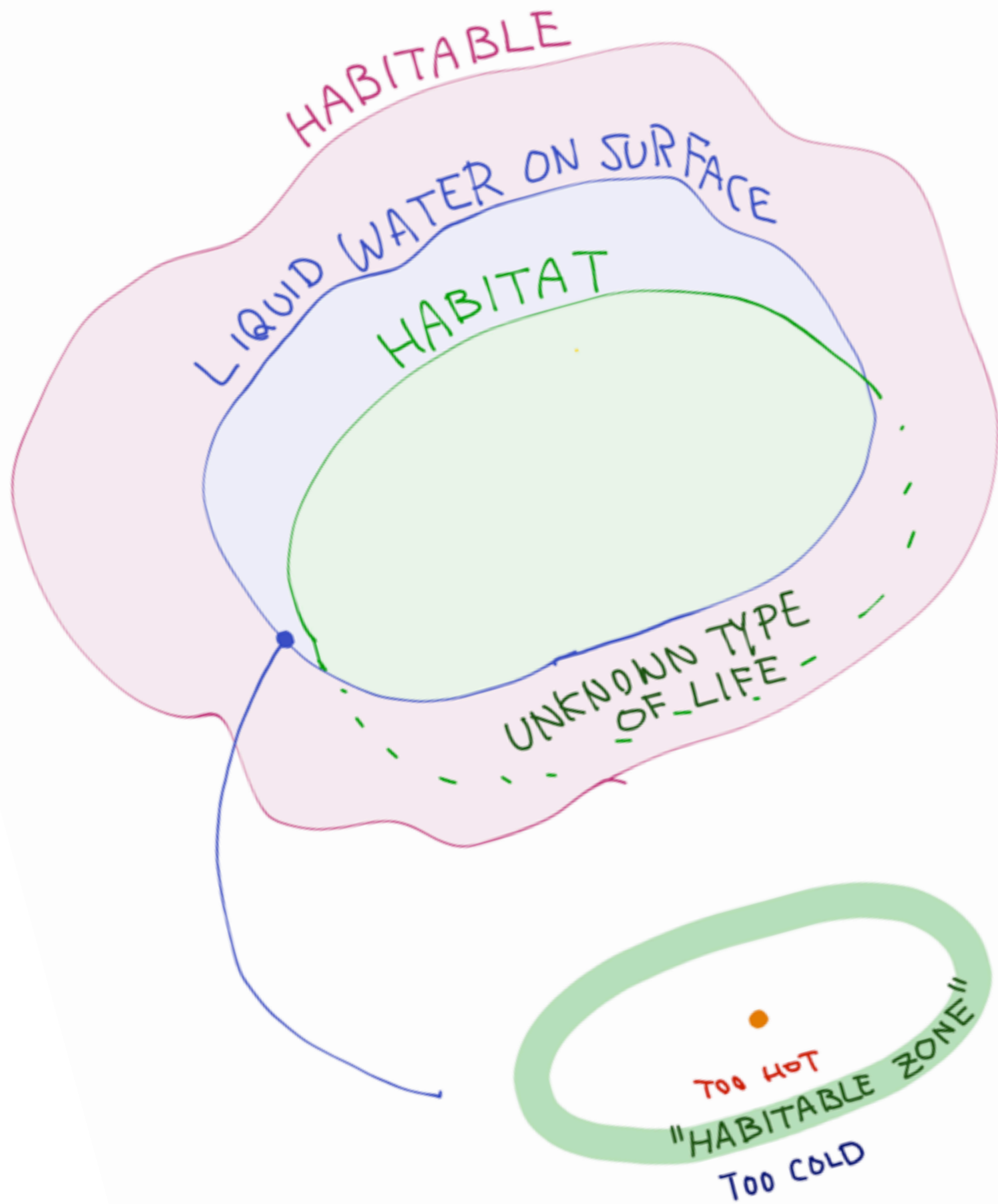




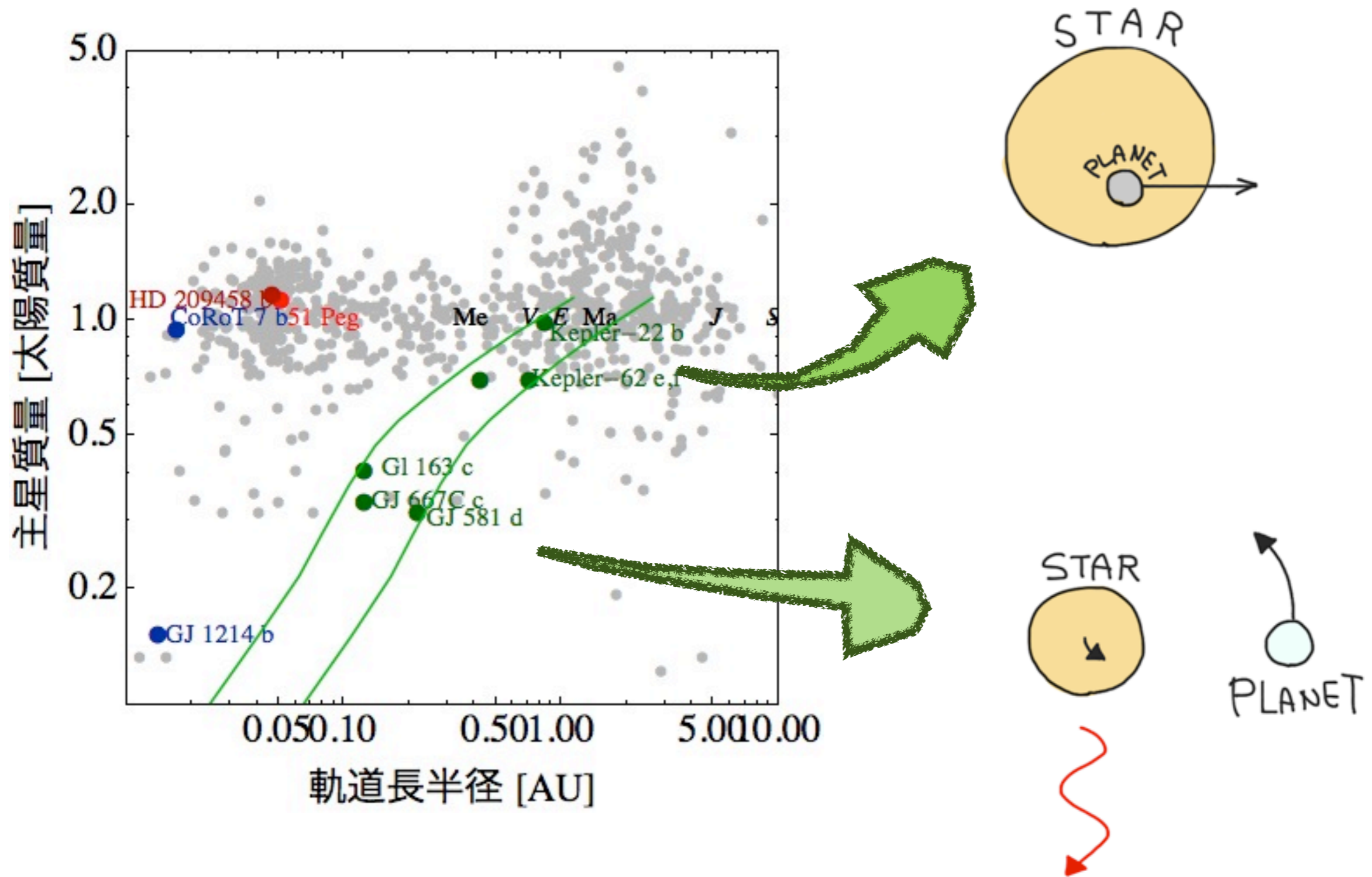
Earth-like Planetを探す



# Earth-like Planet : 生命探査できる惑星

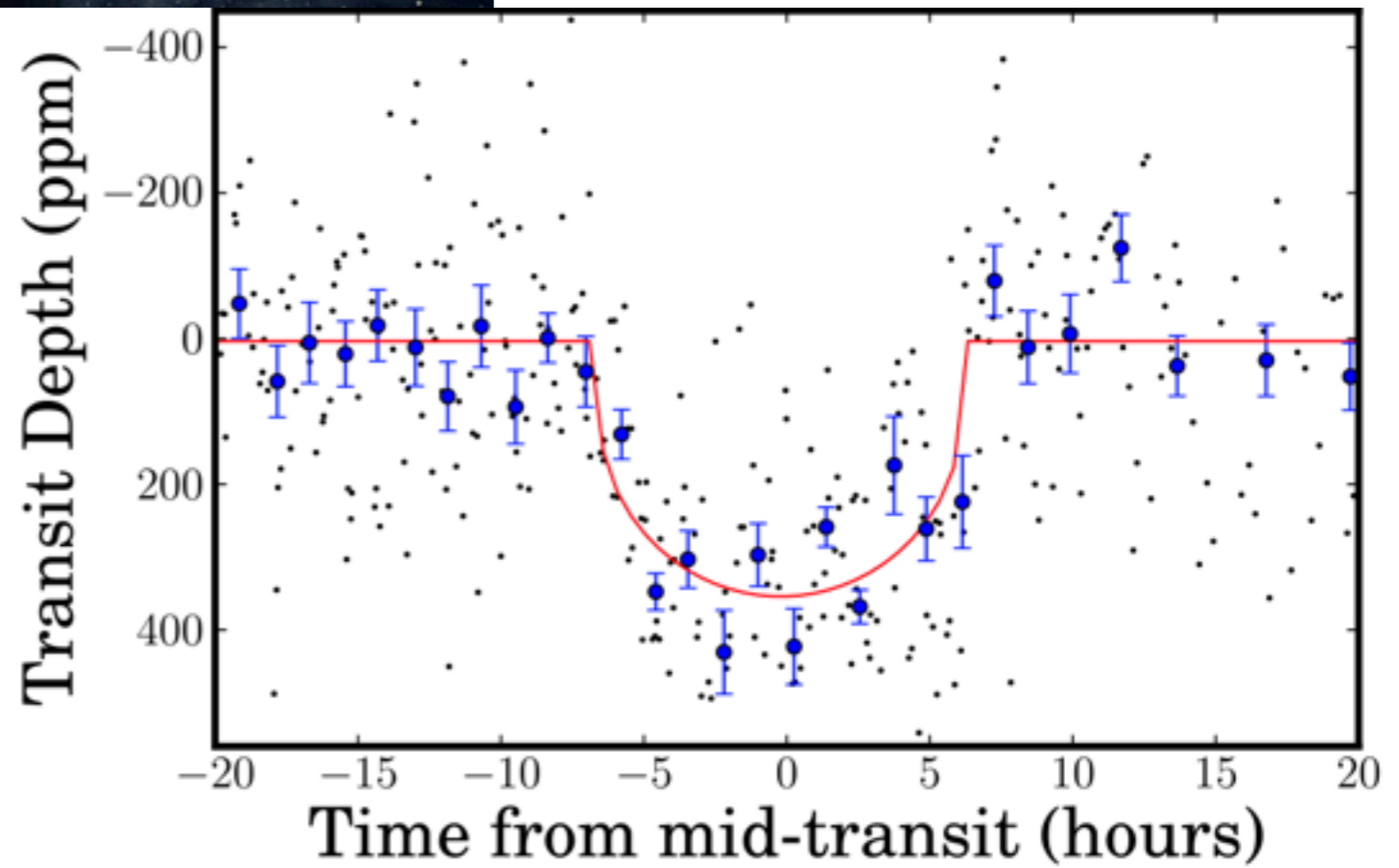


# Earth-like Planetの候補天体



# Kepler 69c announced in April 14 (2013)

イメージ

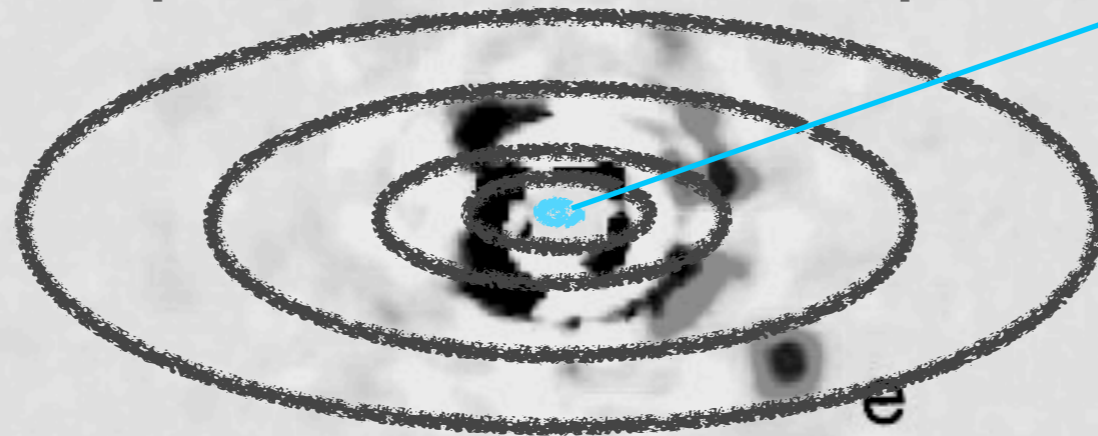


# HR8799 System

b

c

Solar System  
Jupiter, Saturn, Uranus, Neptune



e

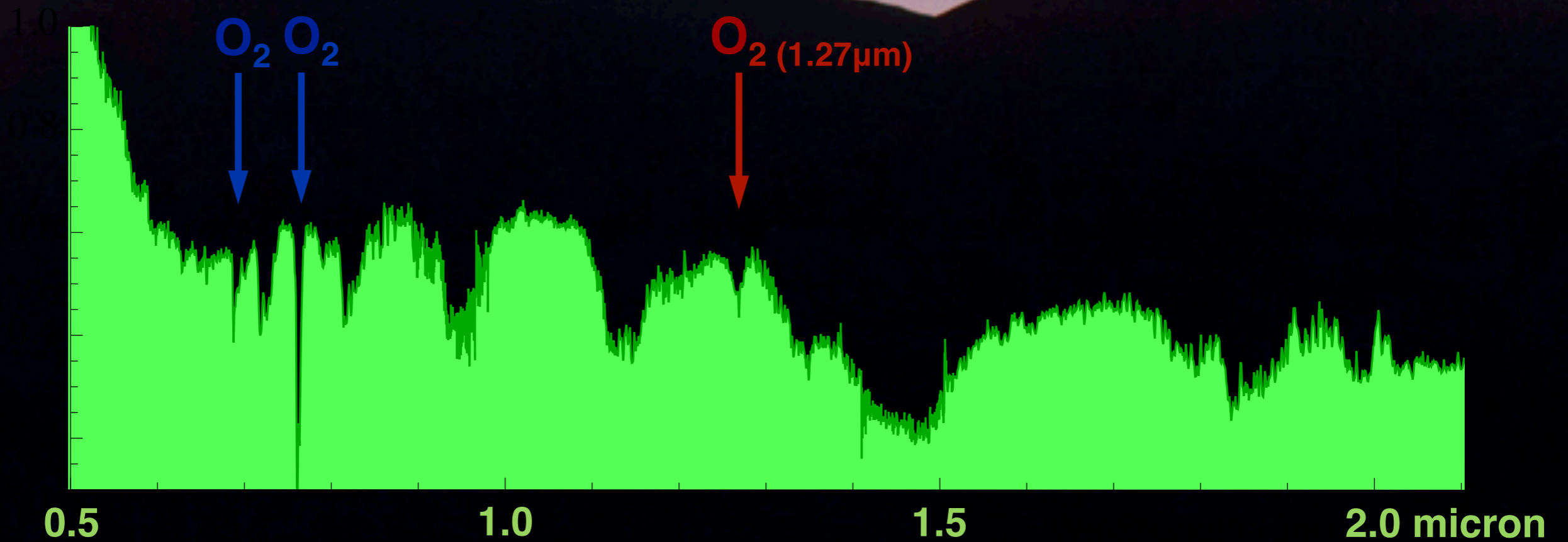
d

20 AU  
—————  
0.5''

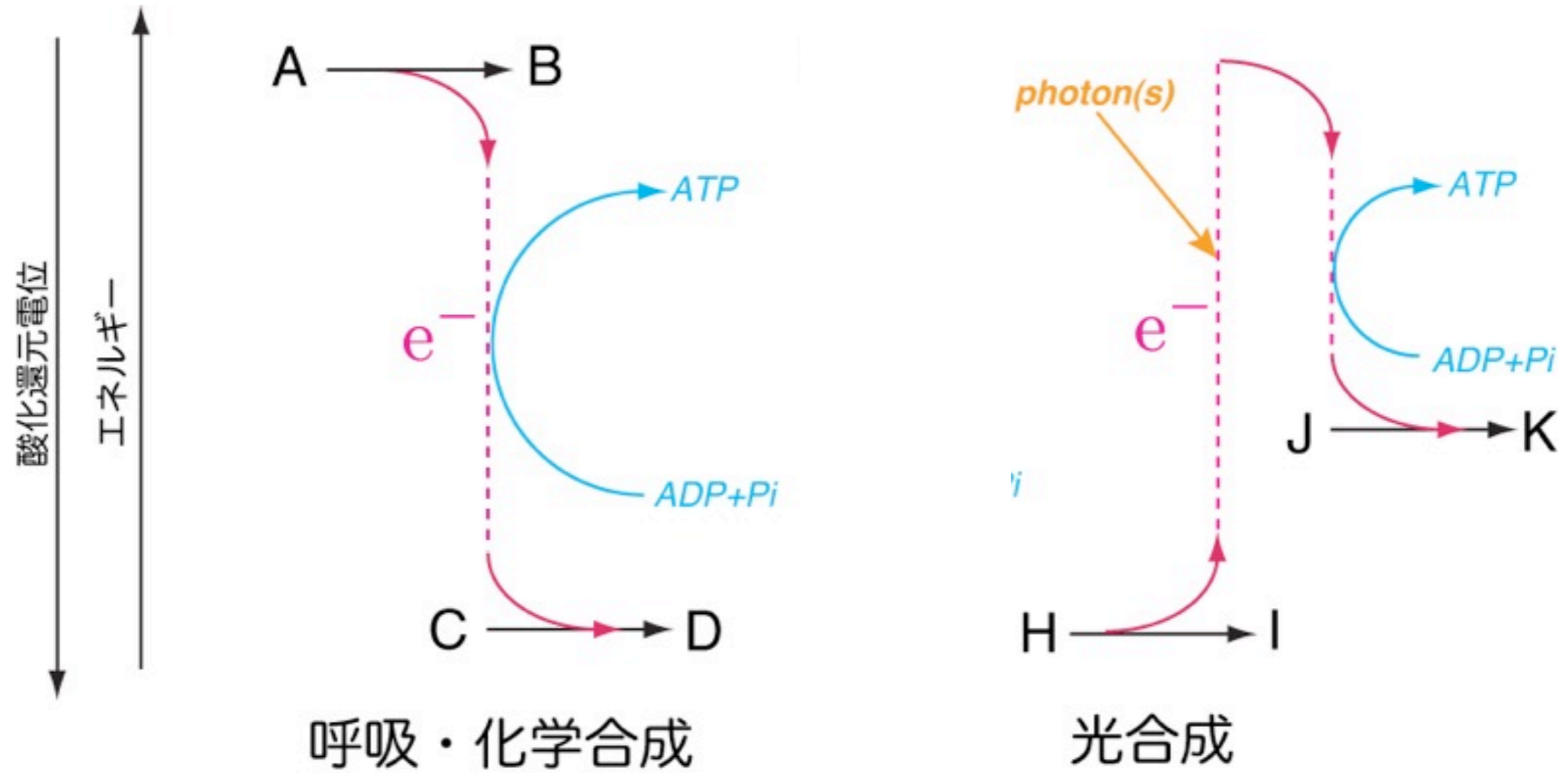


# Reflection Spectra of Earthshine

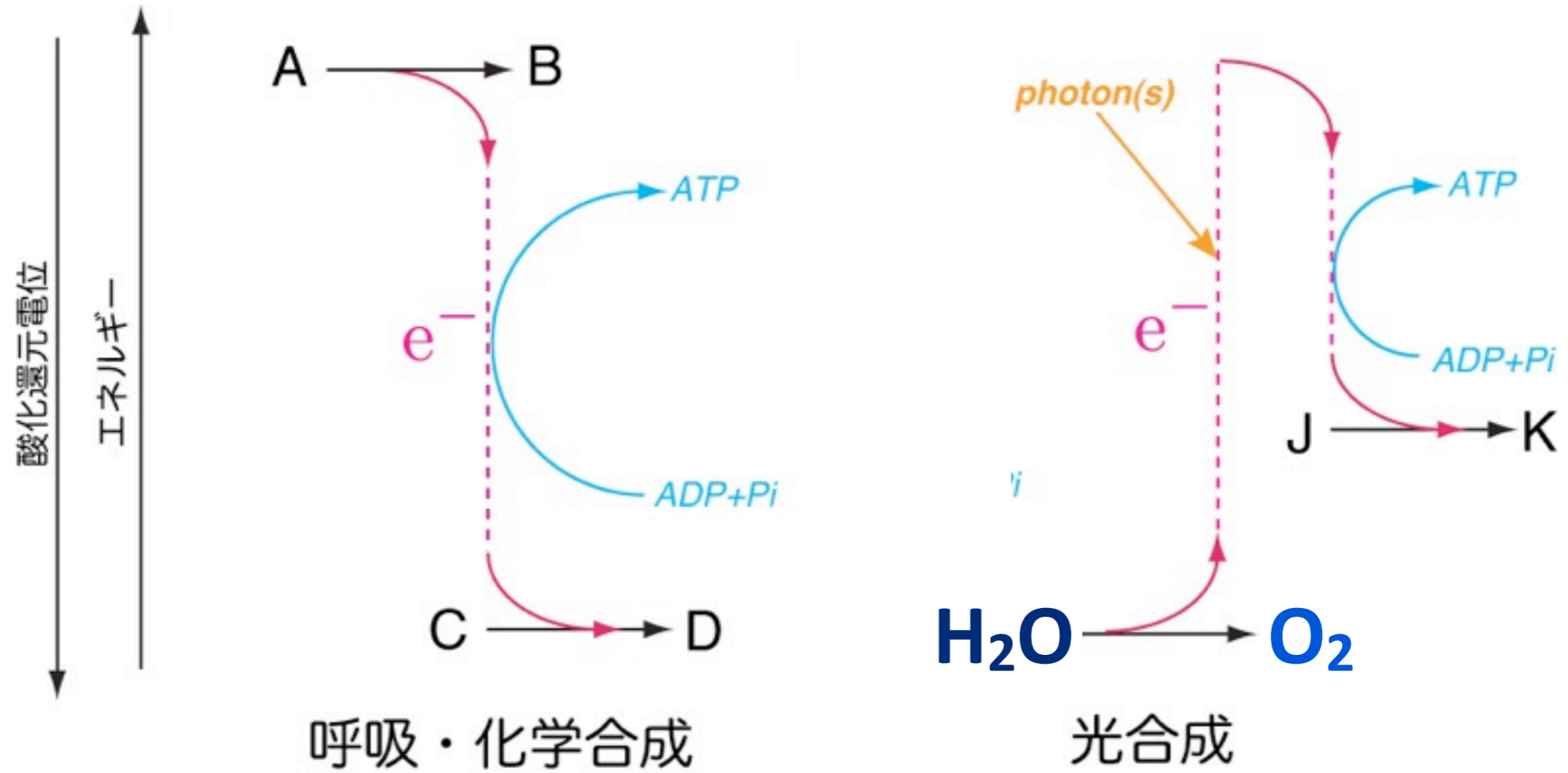
Courtesy of E. Palle

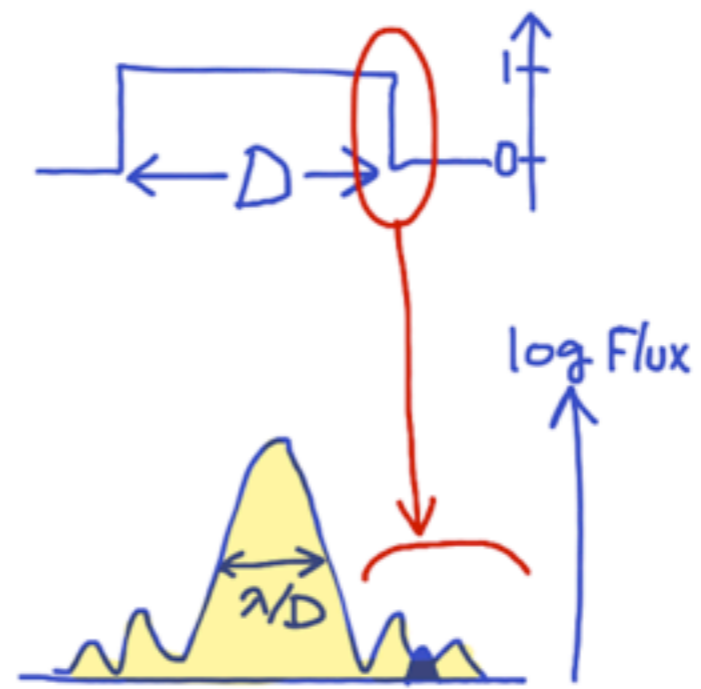
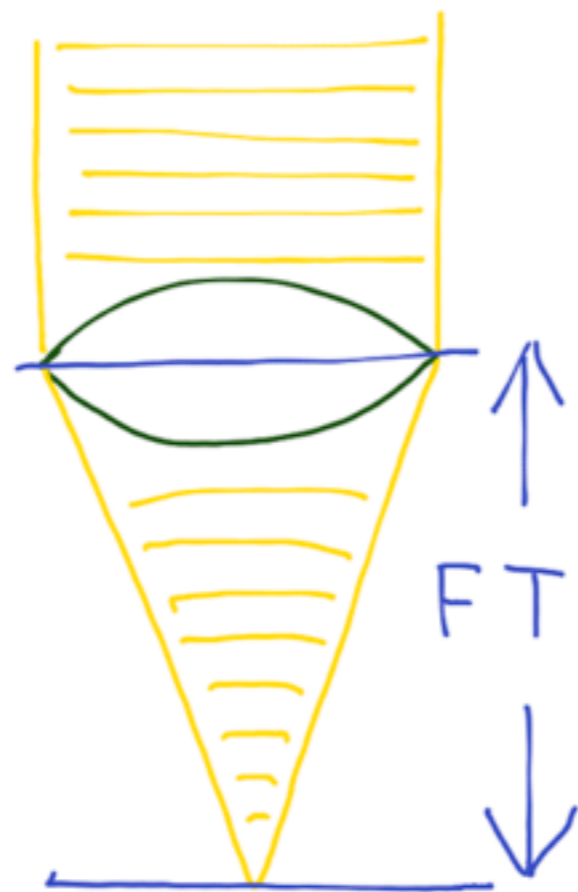


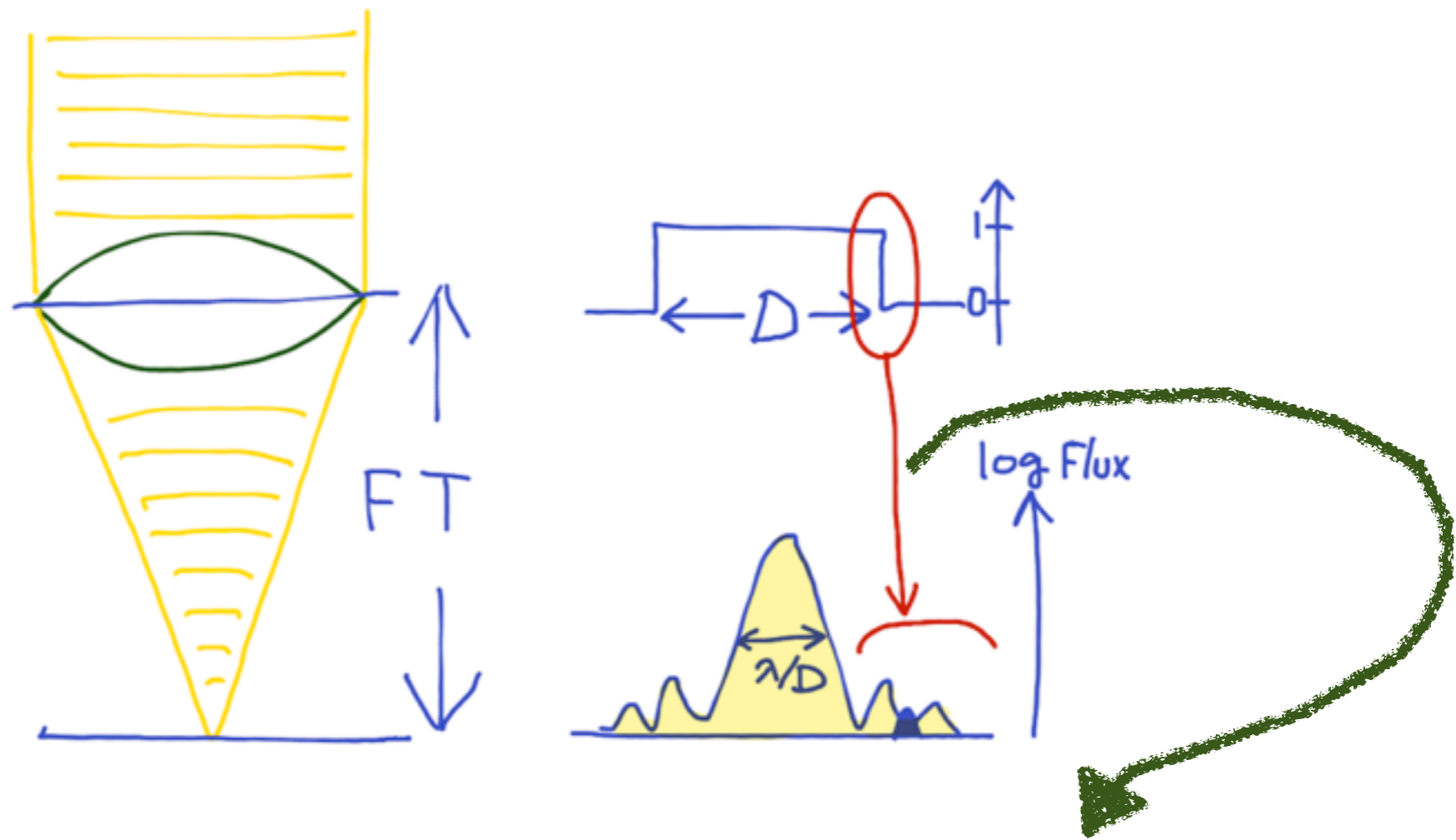
# Metabolic Biomarker



# Metabolic Biomarker

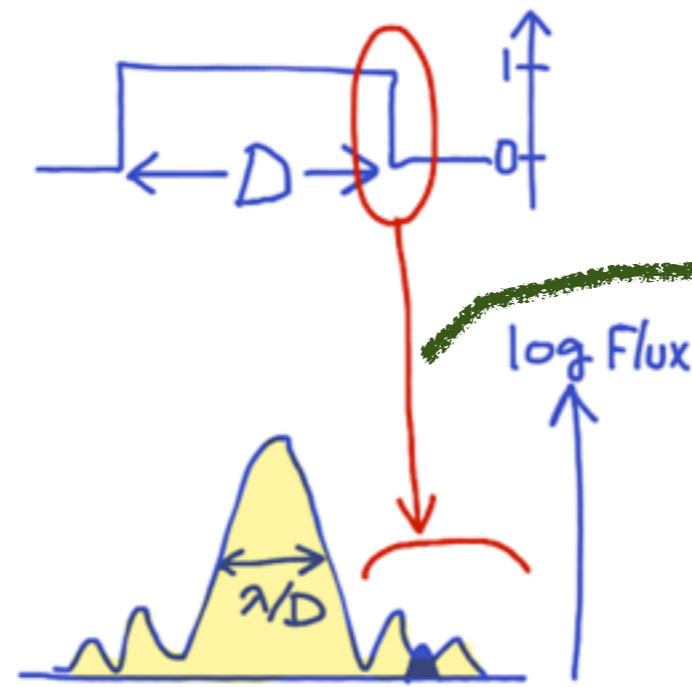
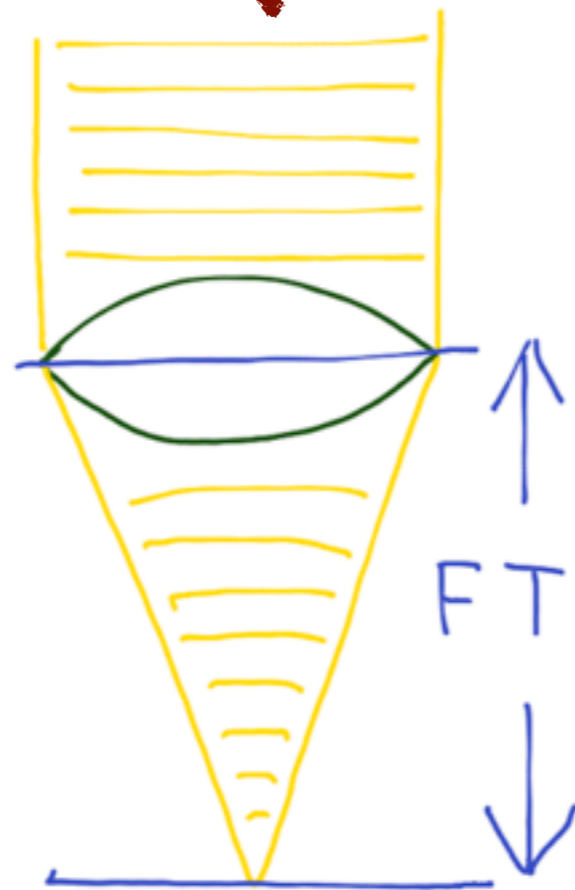
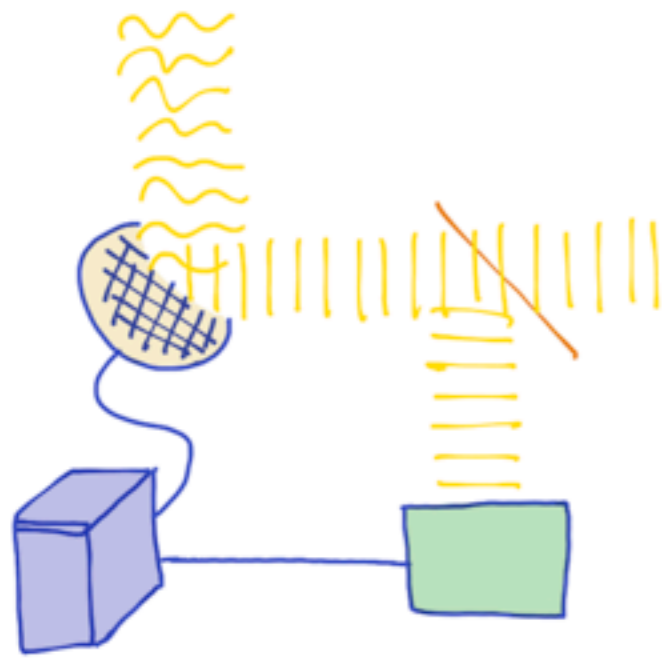






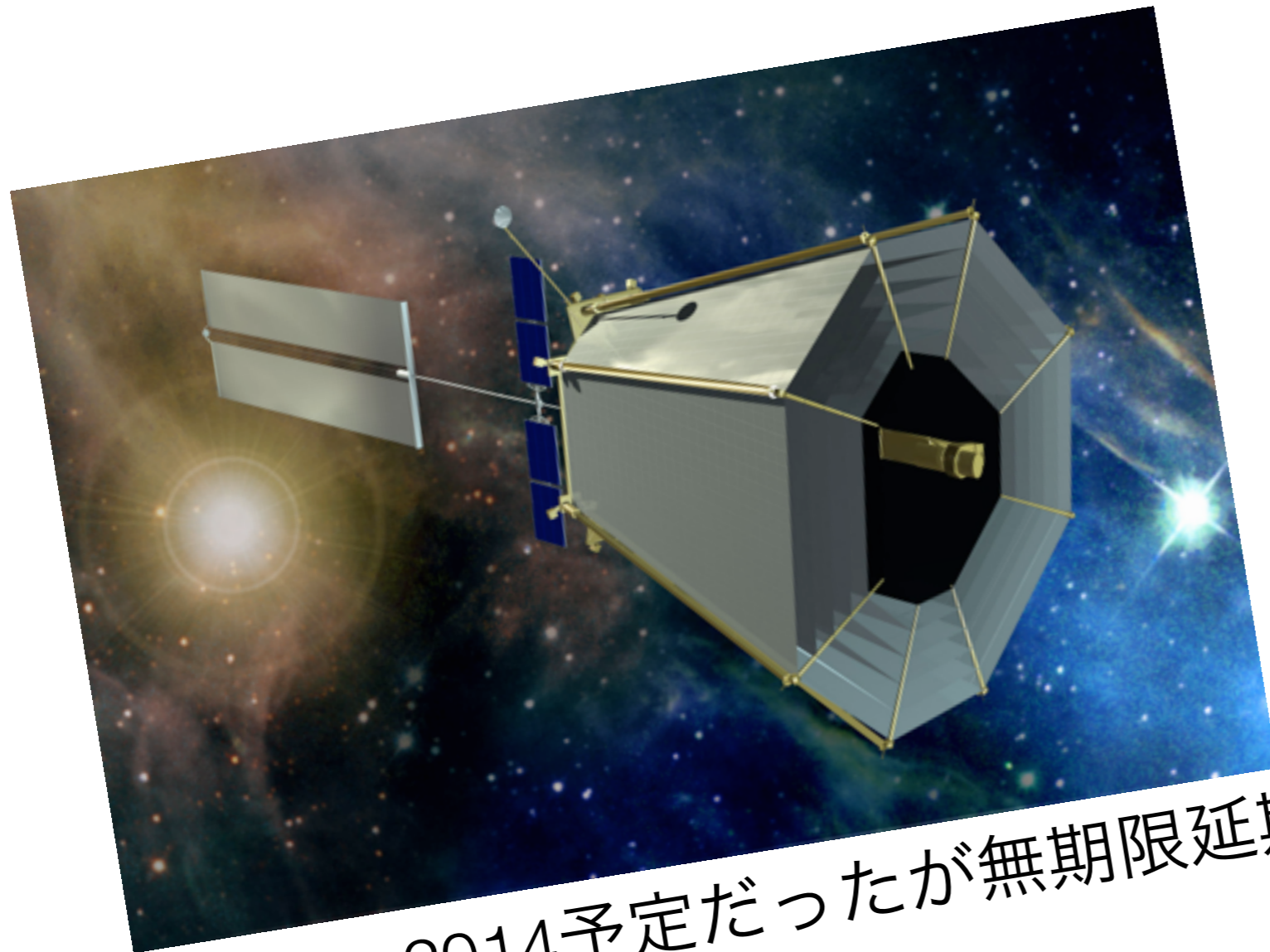
ココをなんとかするのが「コロナグラフ」

揃った波面を作るのが「補償光学装置」



ココをなんとかするのが「コロナグラフ」

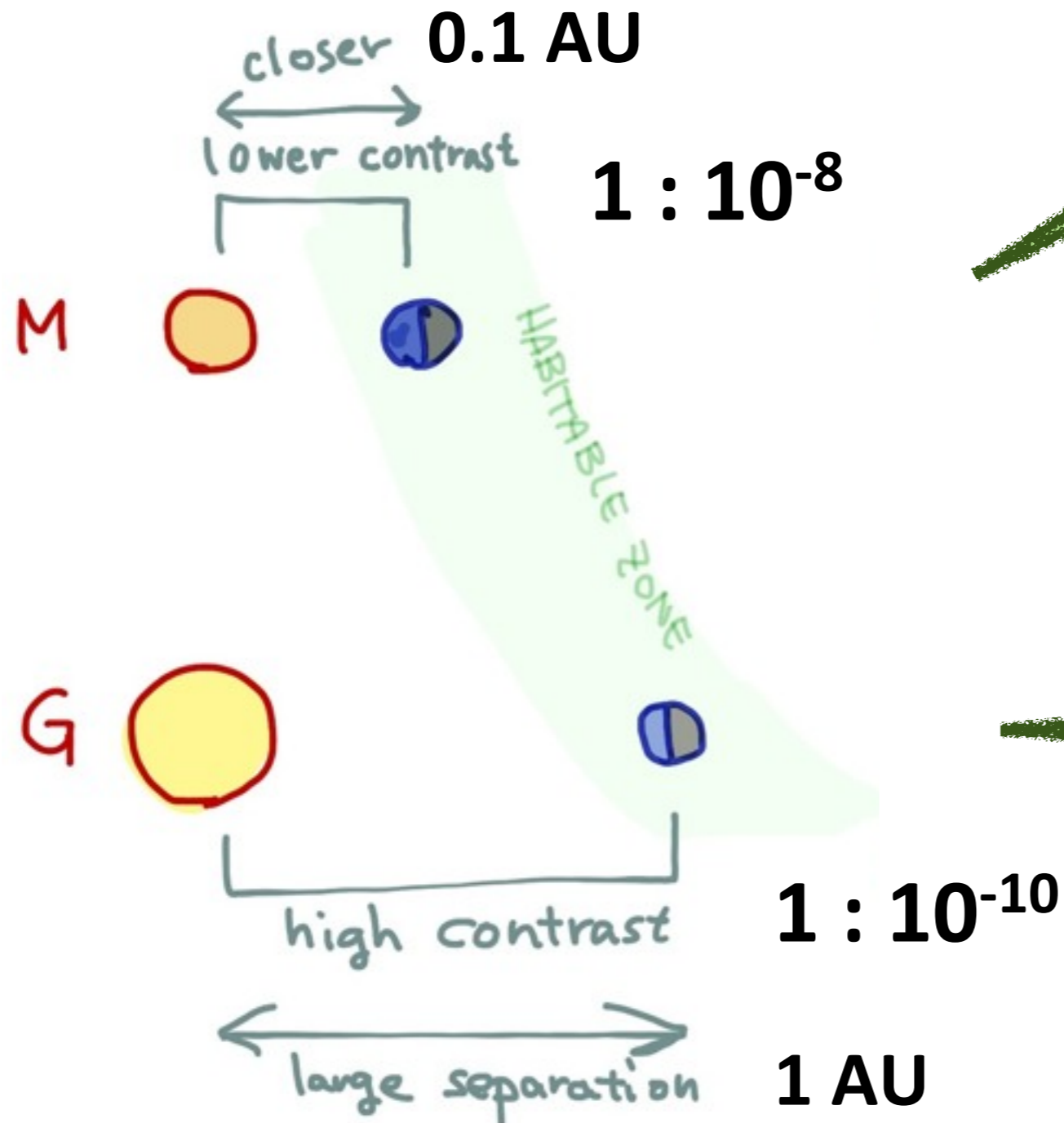
宇宙： $10^{-10}$ =G型星まわりの地球まで狙えるのだが...



TPF-C：2014予定だったが無期限延期

でも30年後にはいけるかも

# Earth-like Planetの直接撮像



大型地上望遠鏡

e.g. PSI (SEIT) for TMT  
EPIC for E-ELT

数m級宇宙望遠鏡

e.g. TPF-C, O3, new world etc



# 地上からのチャレンジ：30m望遠鏡

## Planetary System Imager (PSI)

SEIT Working Group

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成田憲保 (NAOJ)  
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藤井友香 (東工大/ELSI)  
生駒大洋 (東京大学)  
玄田英典 (東工大/ELSI)  
武藤恭之 (工学院大学)  
濱野景子 (東京大学)

観測装置検討班

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木野勝 (名古屋大学)      木田学武 (北海道大学)  
石川久美 (理研)              西田秀哉 (大阪電通大)  
大屋真 (すばる望遠鏡)      岩室史秀 (京都大学)  
入部正継 (大阪電通大)      馬場直志 (北海道大学)  
栗田光樹夫 (京都大学)      西川淳 (NAOJ)  
長田哲也 (京都大学)

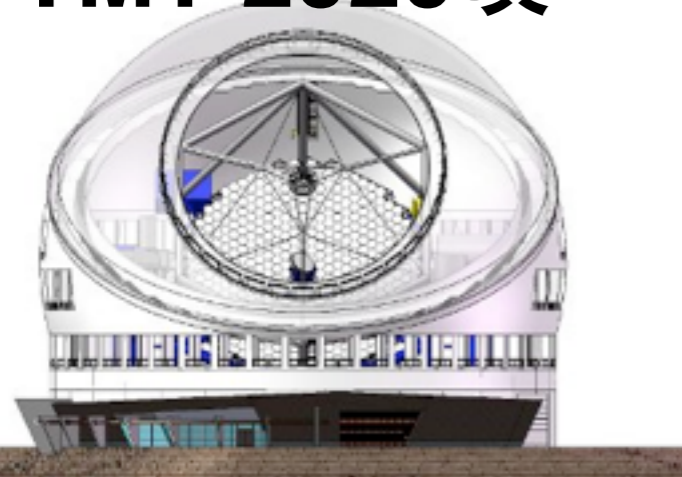
国際協力

Planet Formation Imager  
(Bruce Macintosh (LLNL))

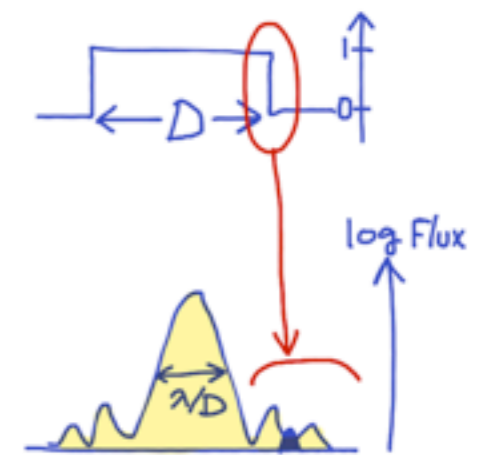
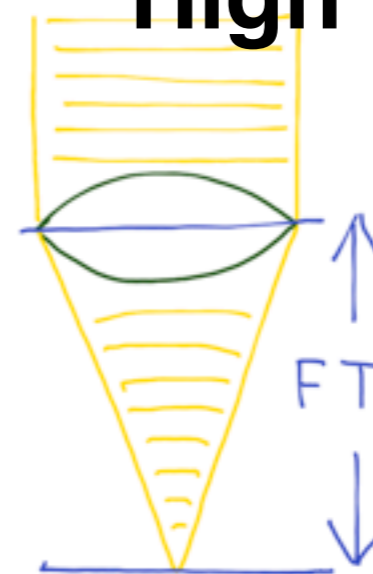
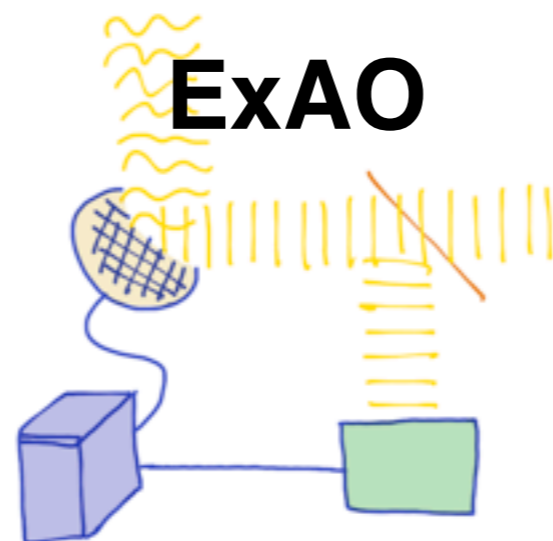
LICK FIRST project  
(Franck Marchis (SETI))

SCEXAO project  
(Olivier Guyon (Arizona))

### TMT 2020頃~

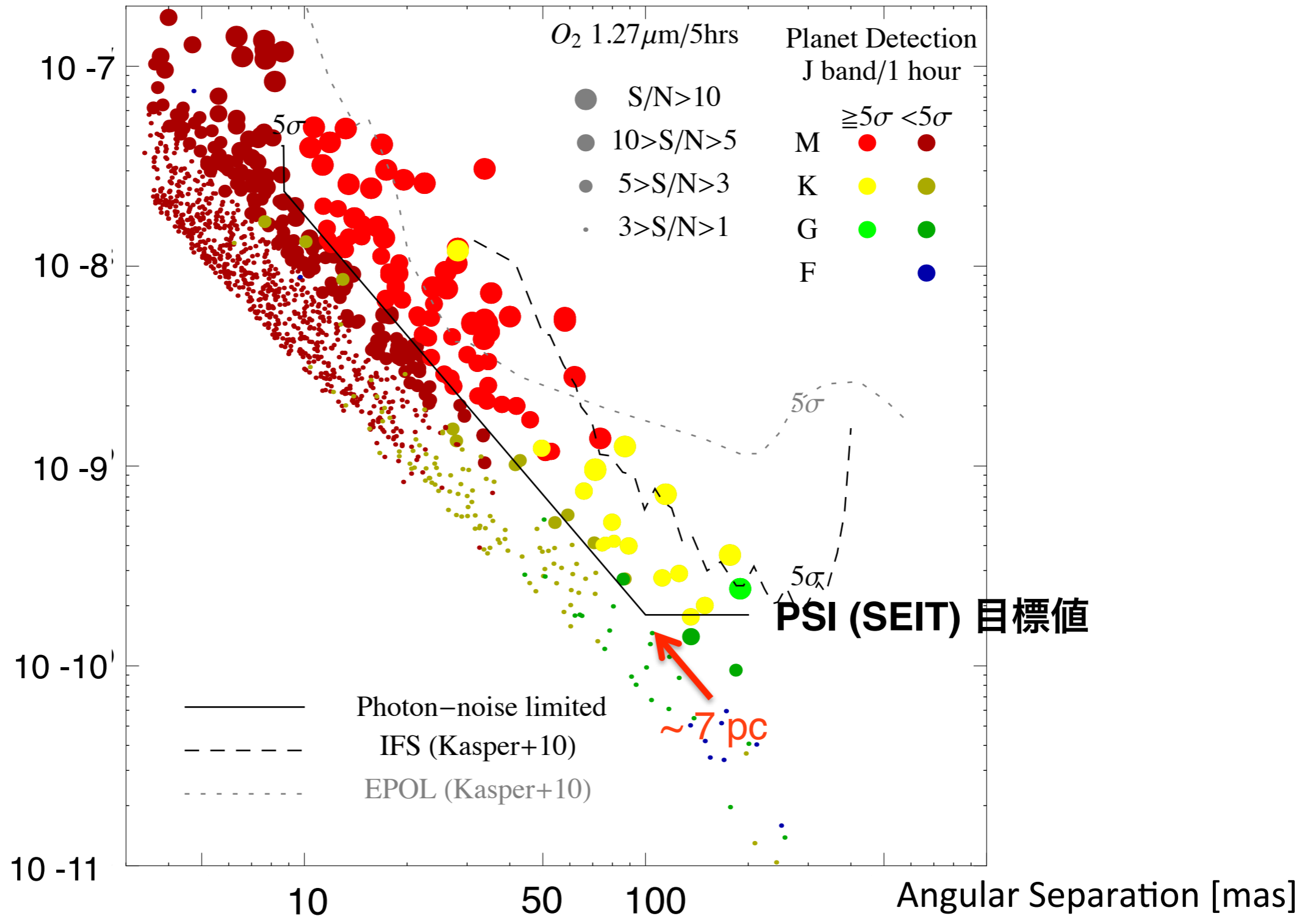


## Coronagraph + High Contrast Inst.



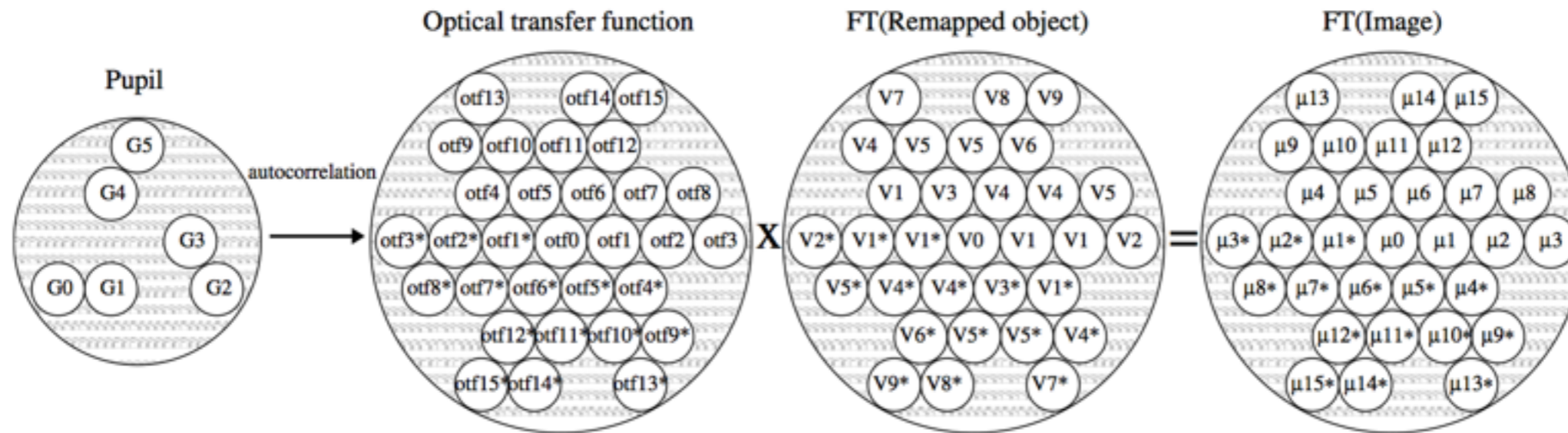
# ハビタブルゾーンにEarth-twinがある時の検出限界

Planet - Star Contrast



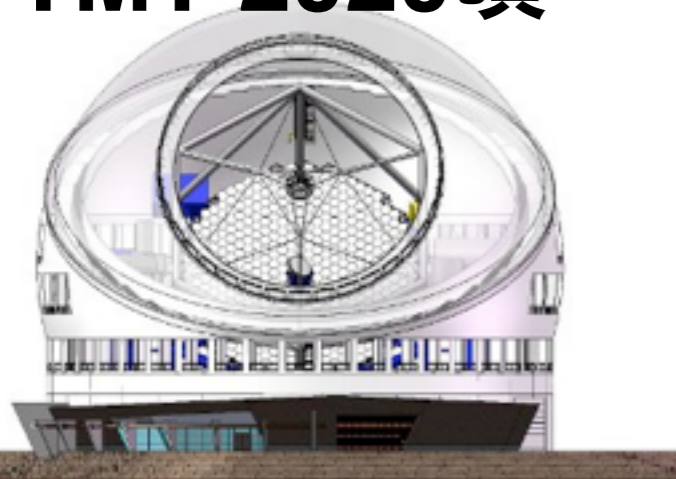
# 地上からのチャレンジ：30m望遠鏡

## Pupil Remapping Imaging

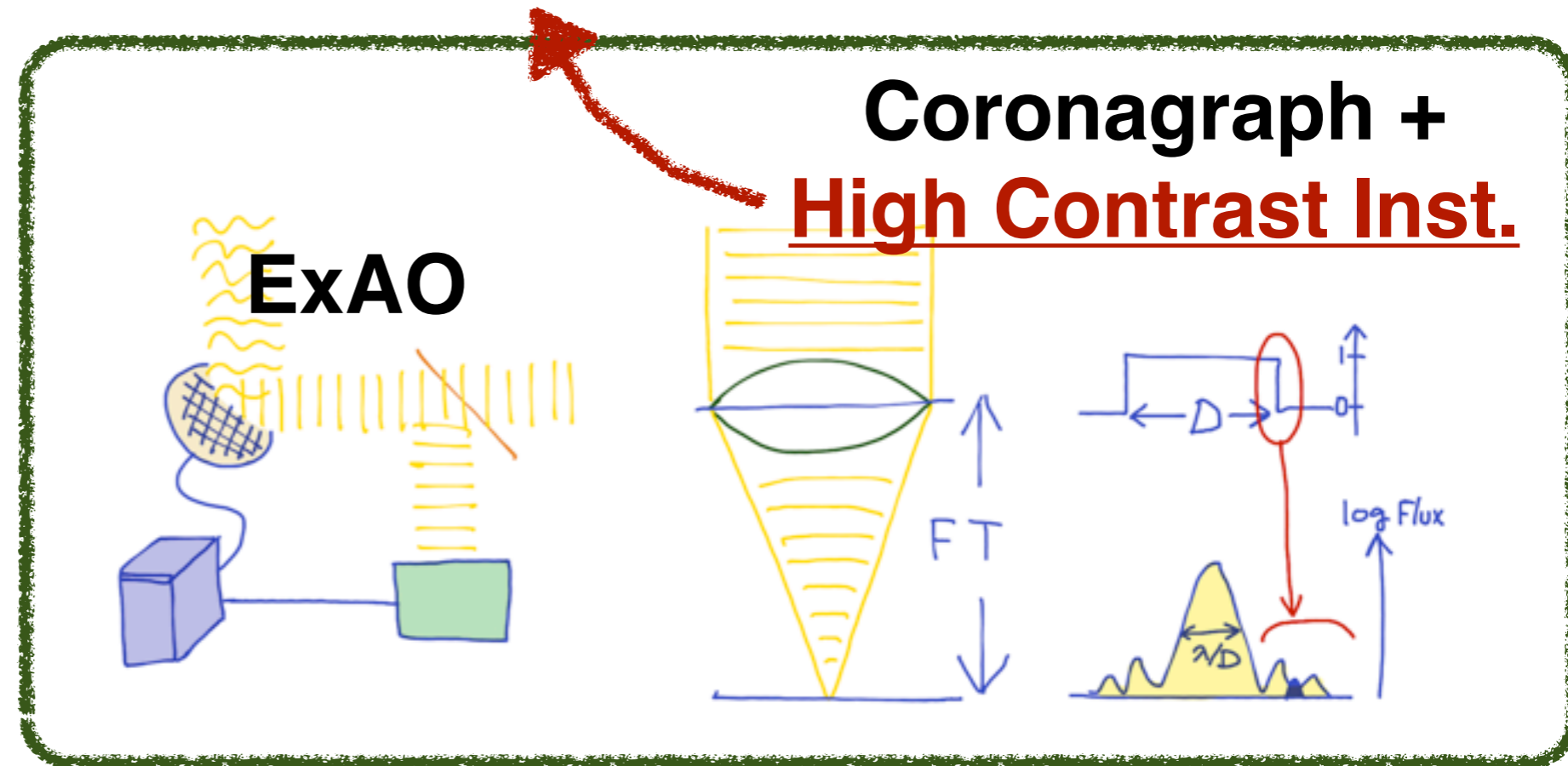


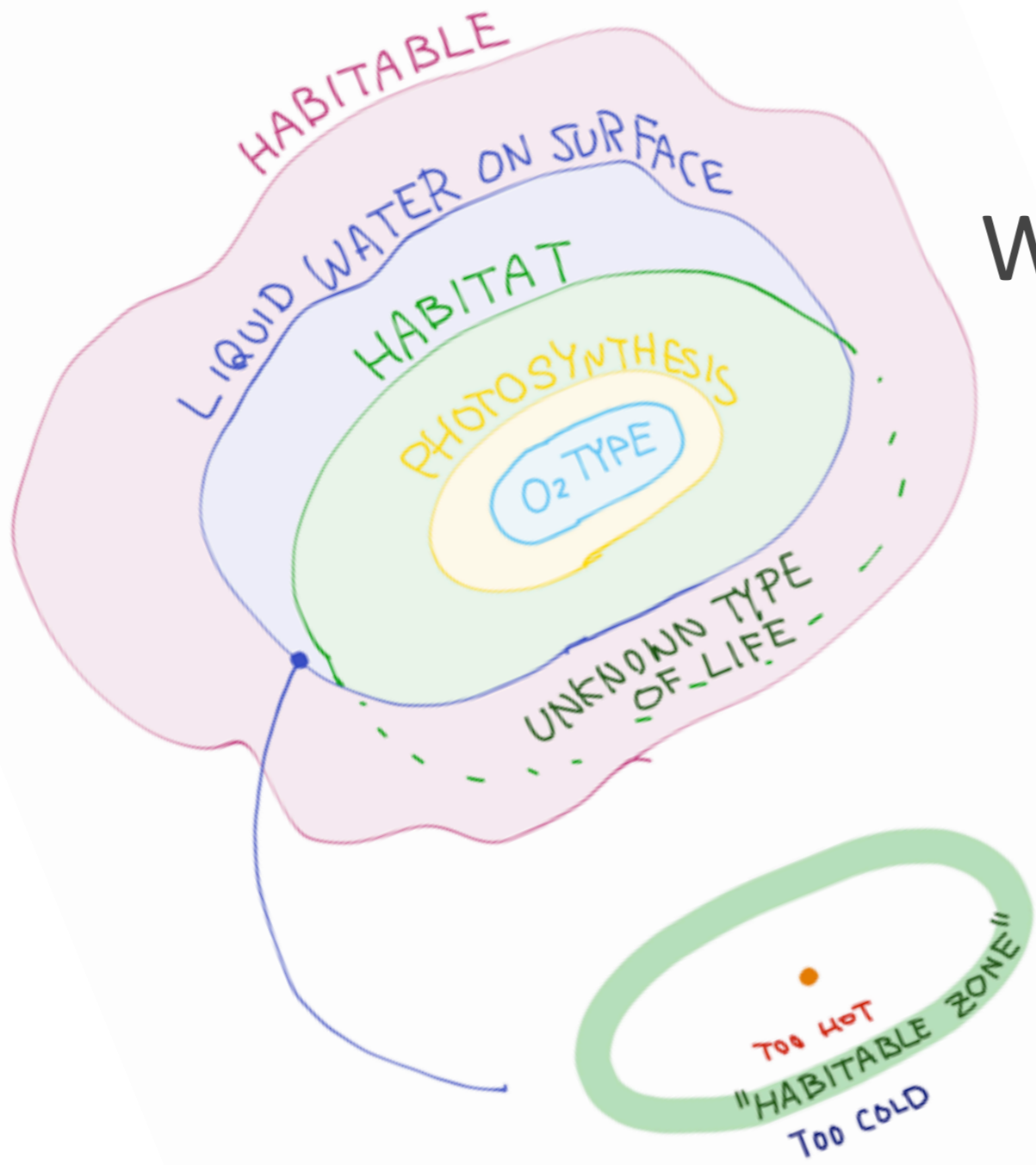
Lacour+07

TMT 2020頃~



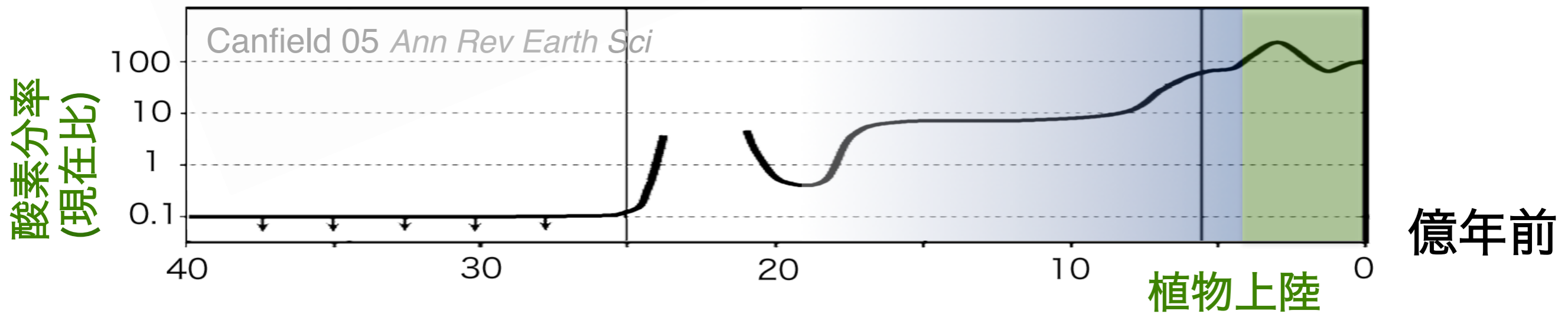
**Coronagraph + High Contrast Inst.**

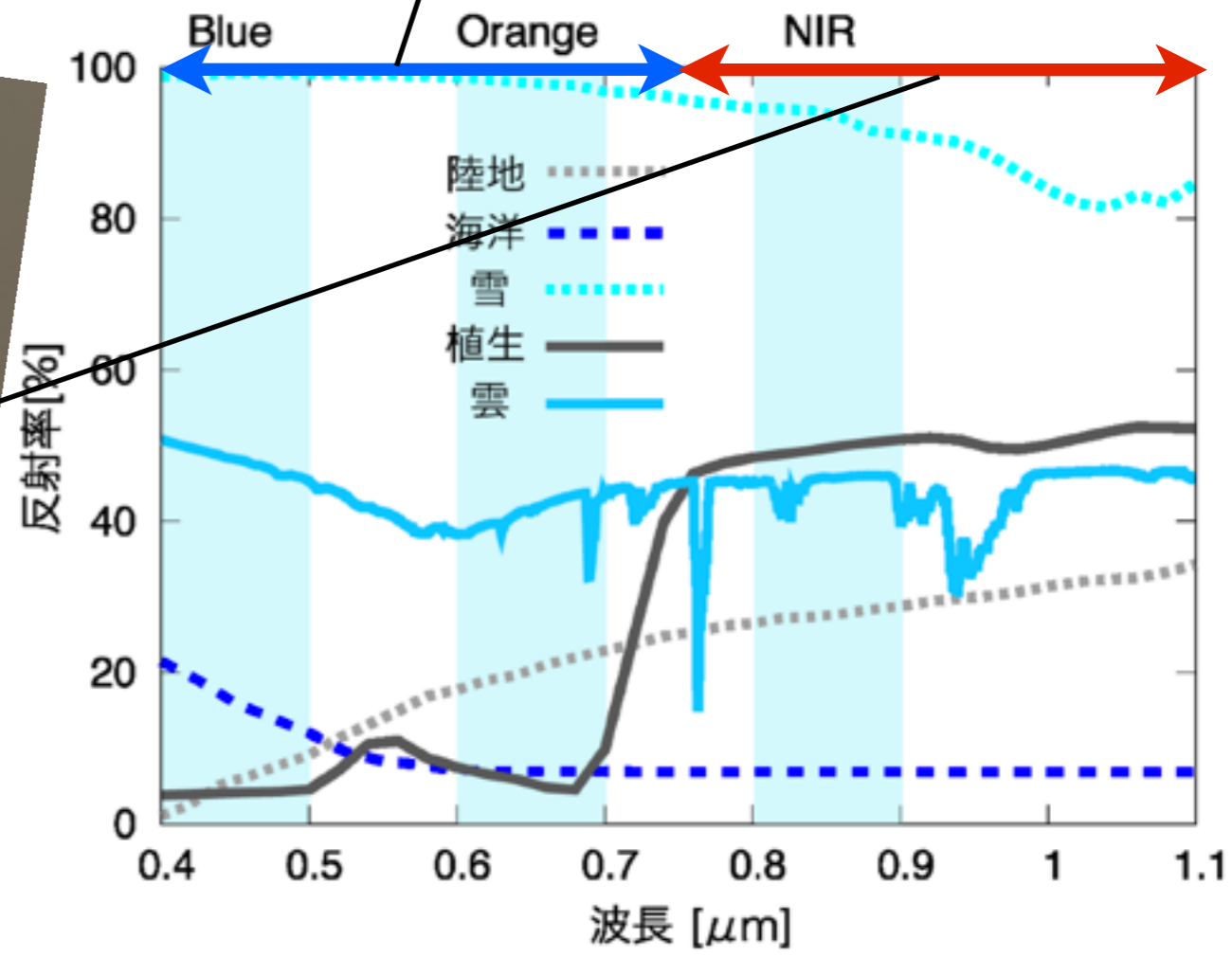
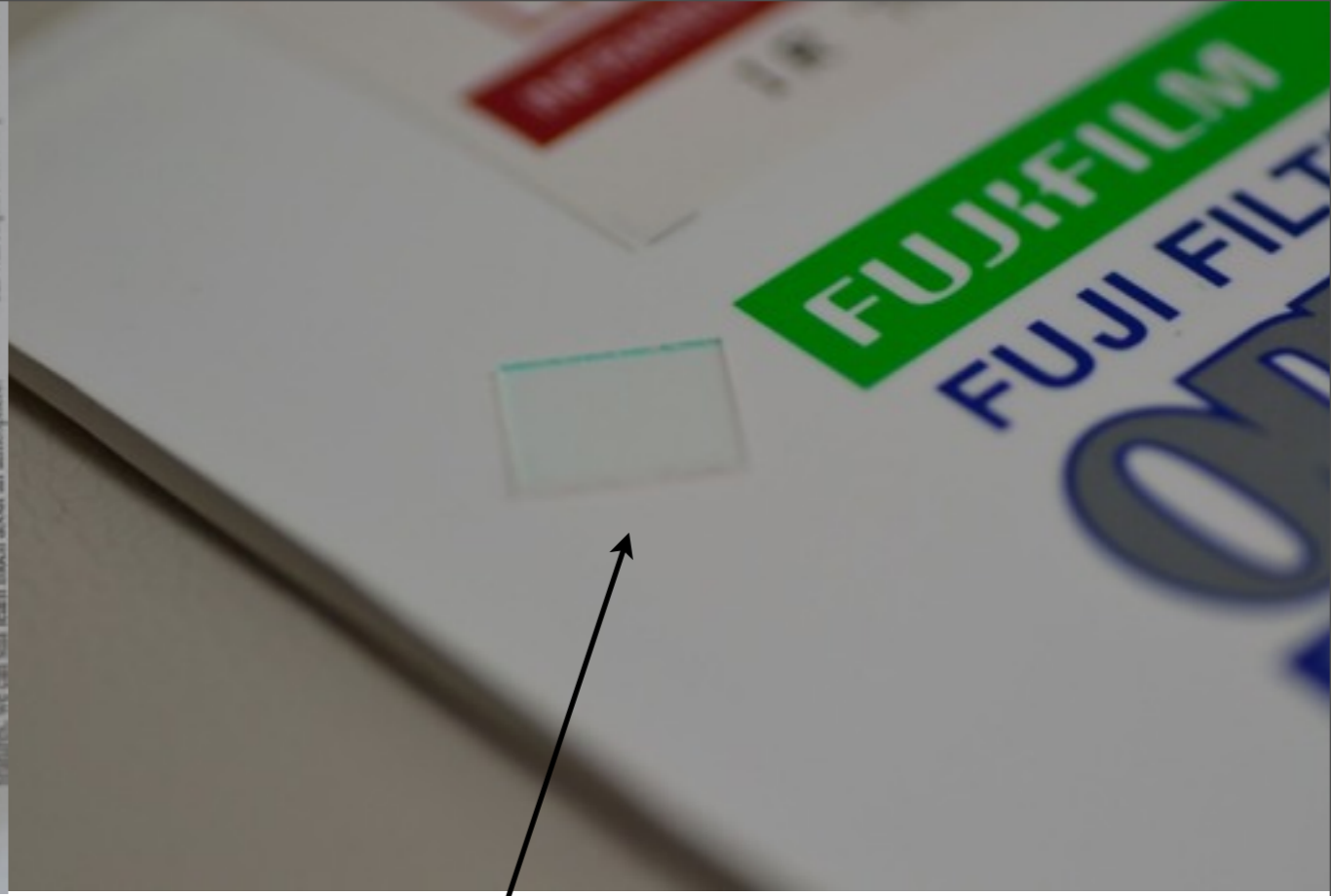
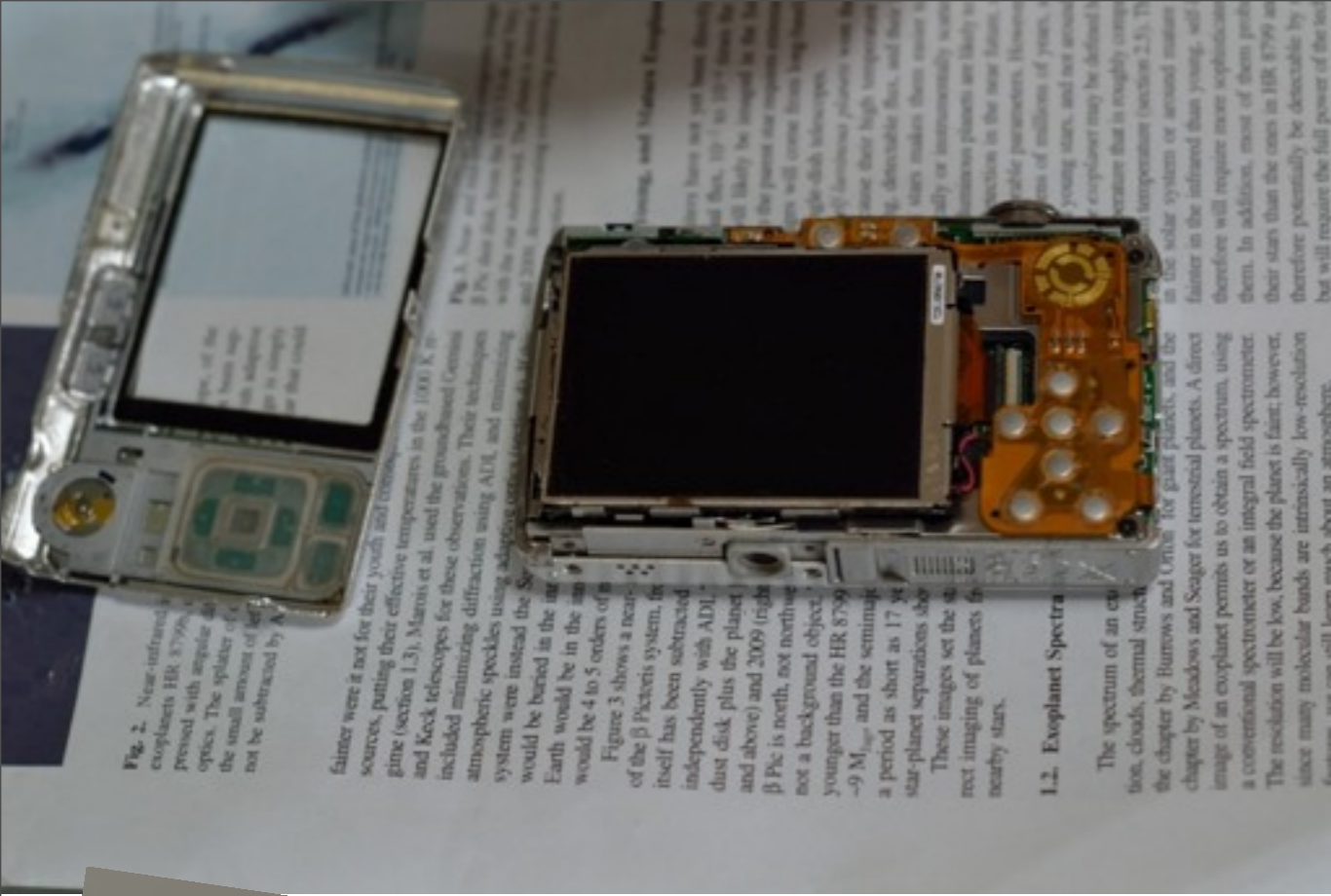




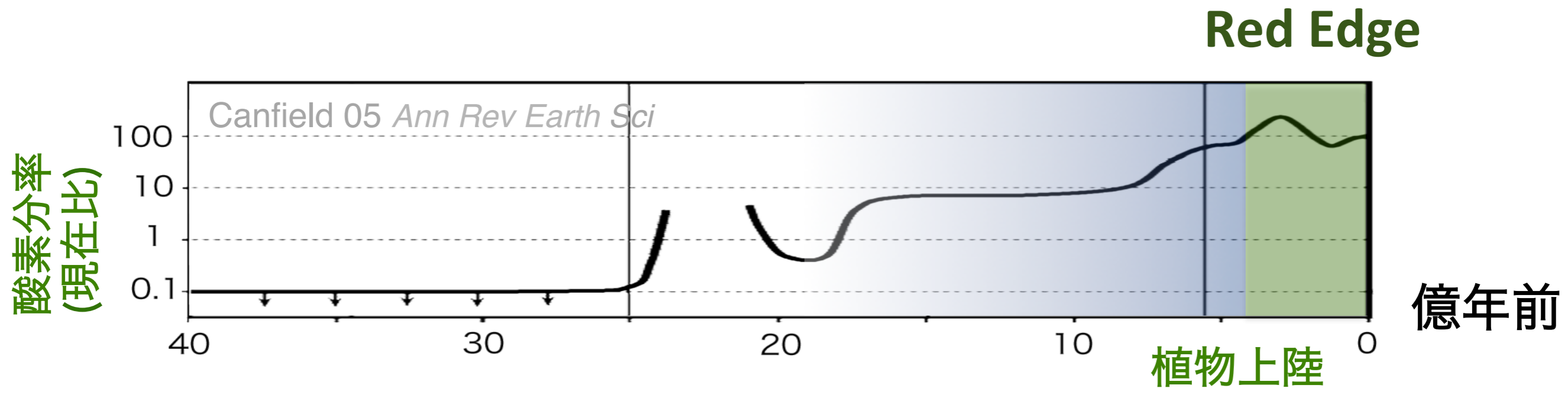
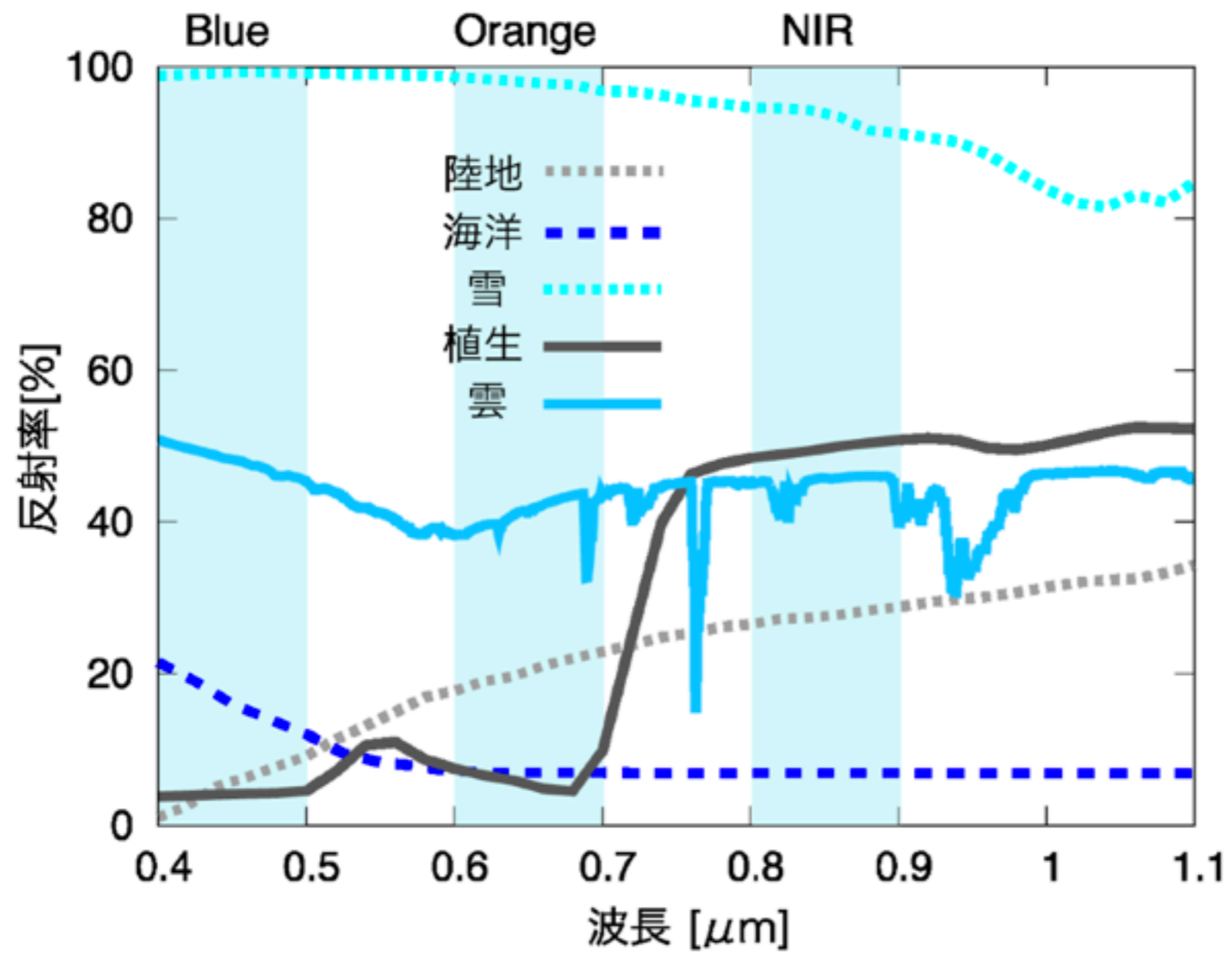
We are (too ?) conservative

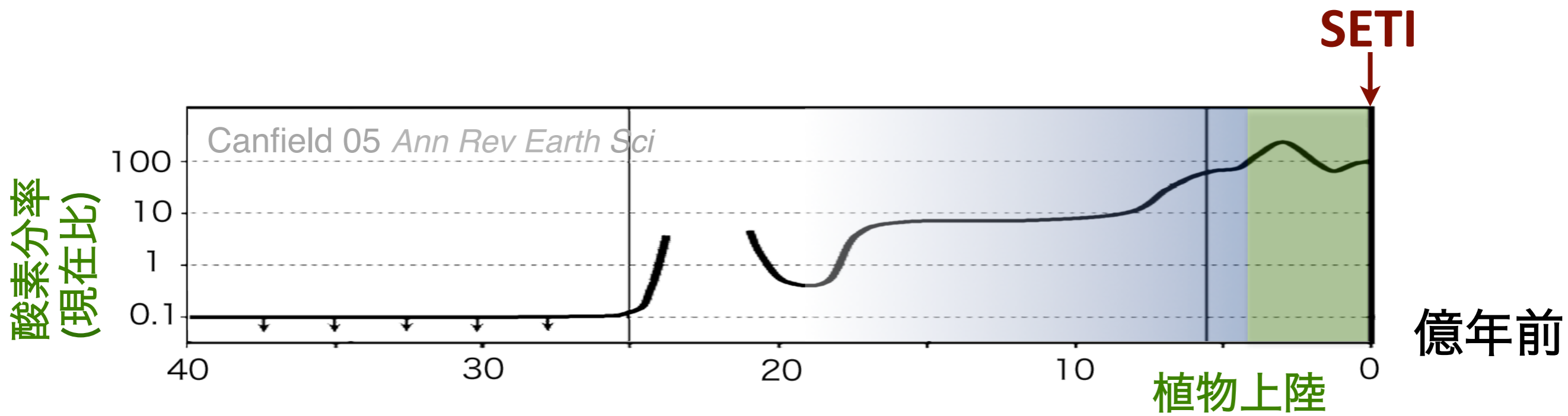
## Oxygen











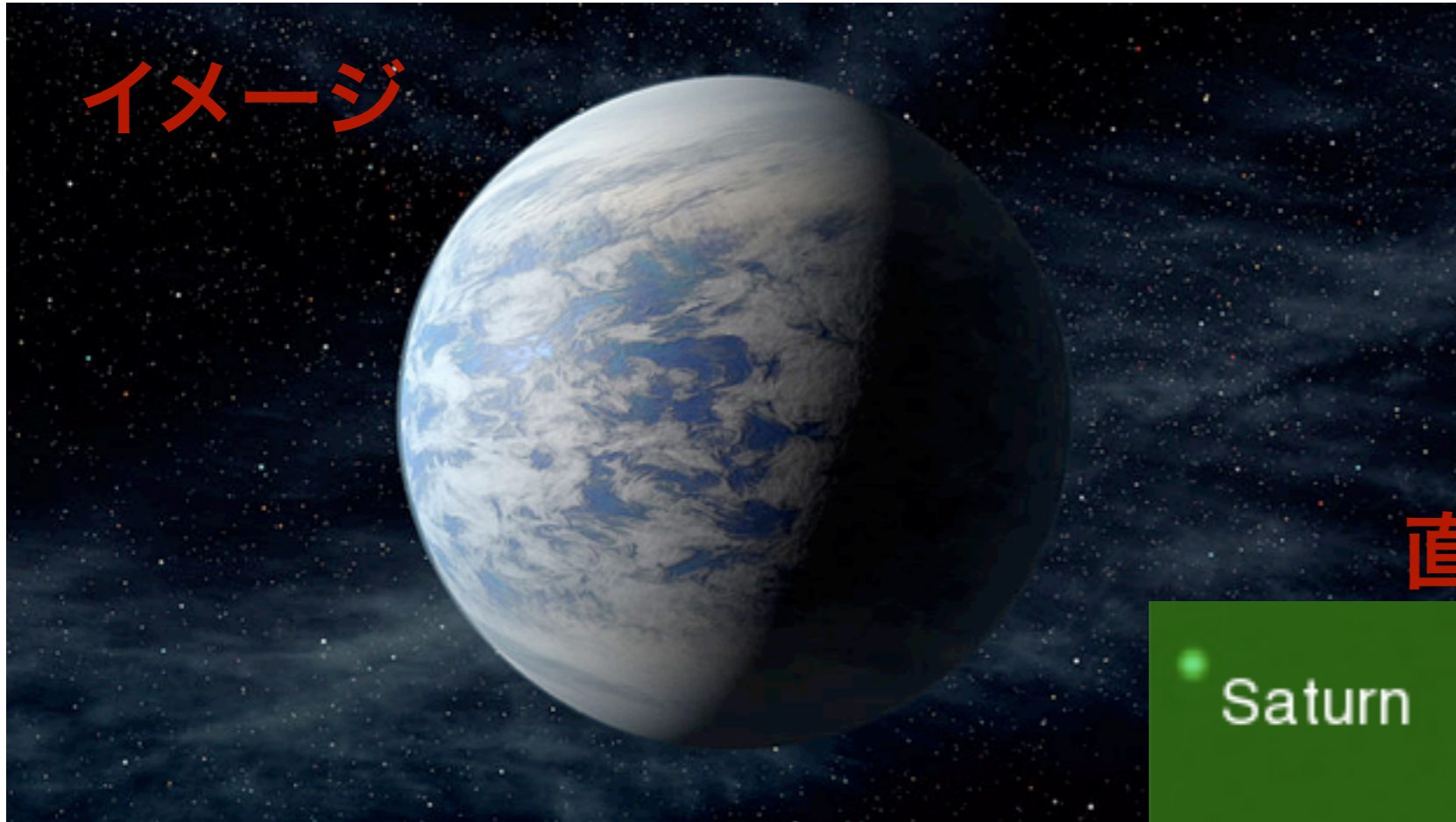




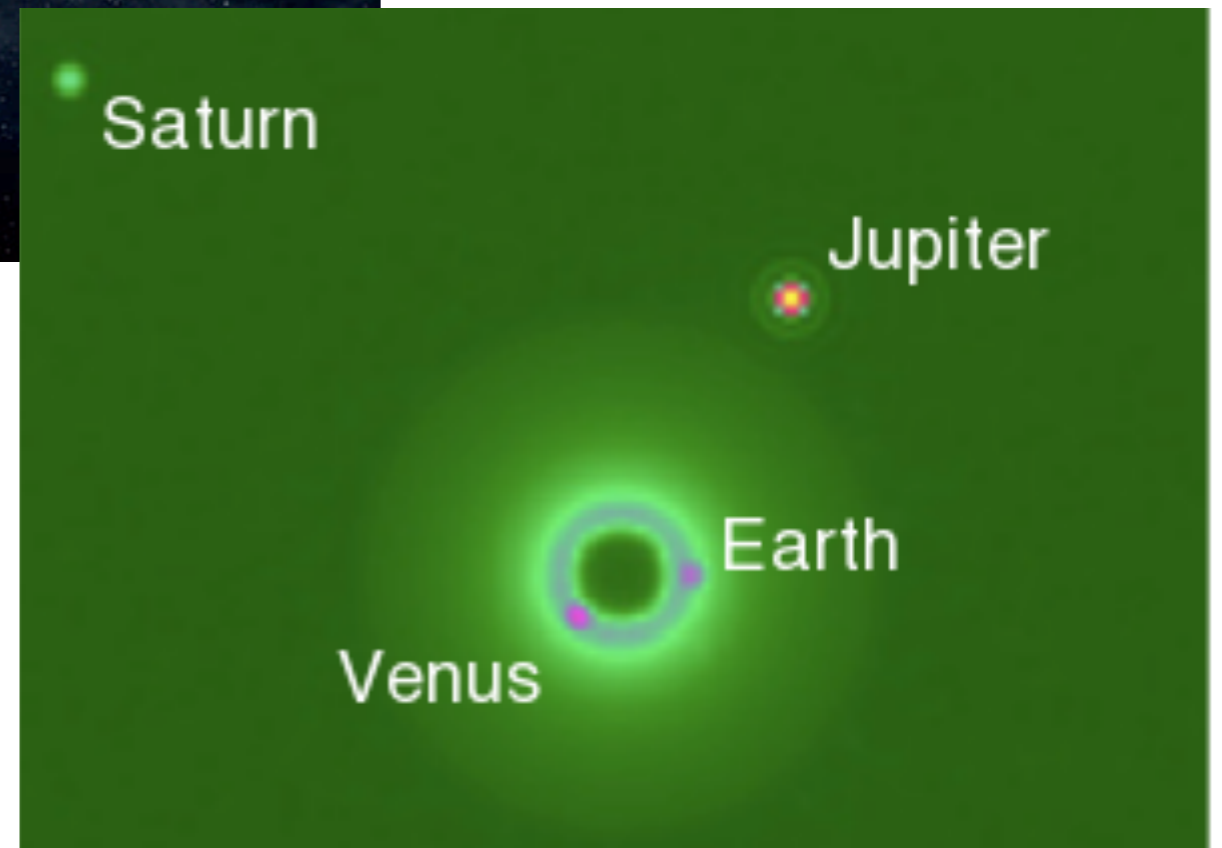
Earth-like Planetをもっと知る

# Kepler 69c announced in April 14 (2013)

イメージ

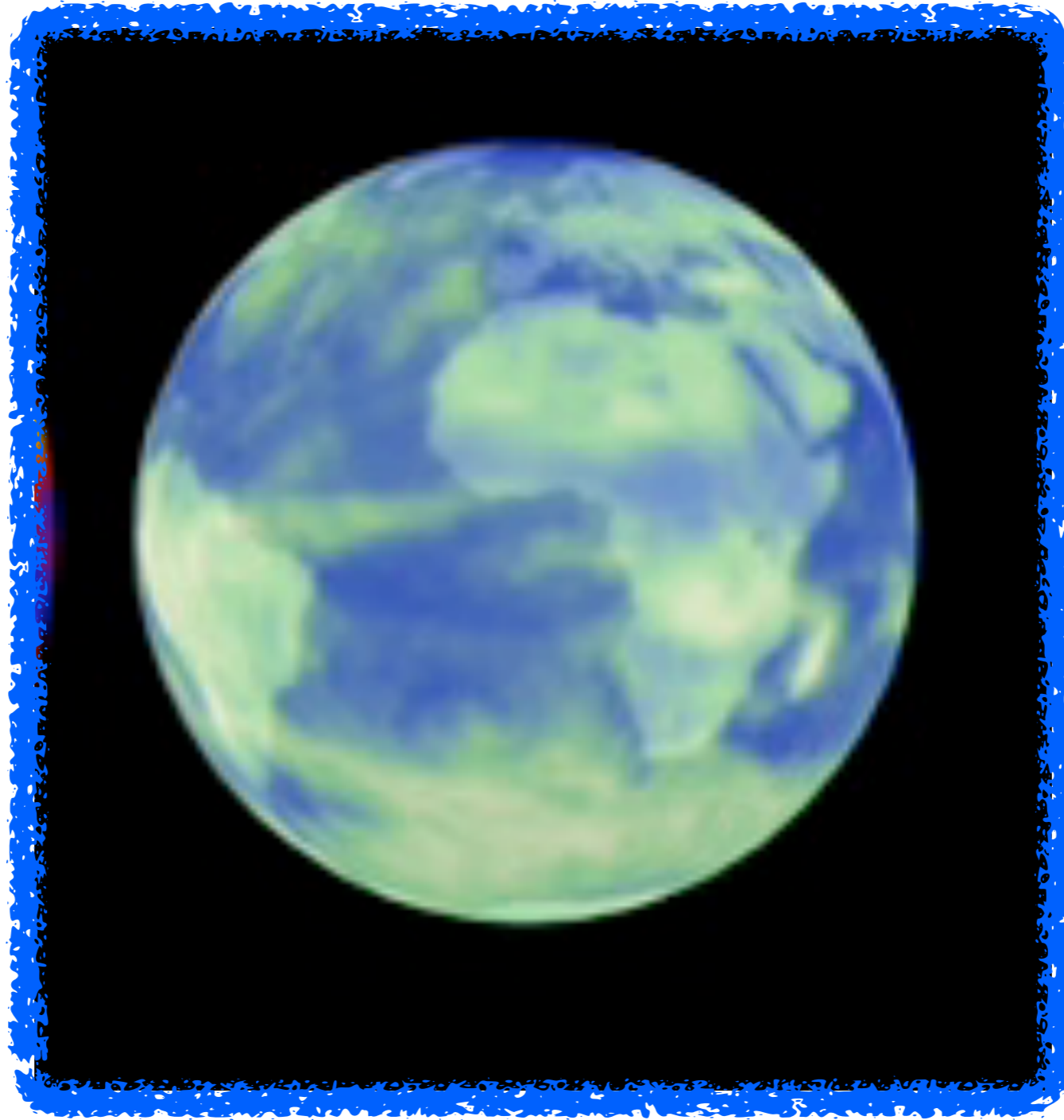


直接撮像の現実

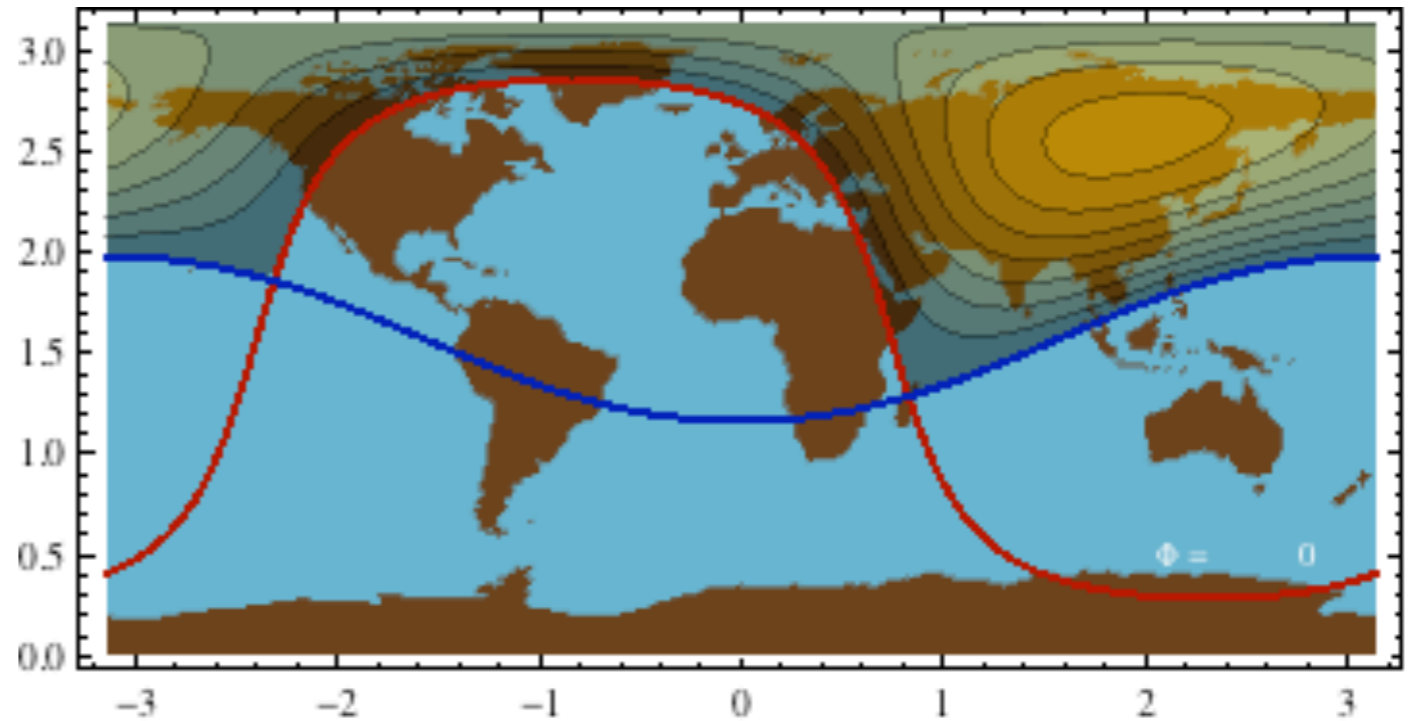
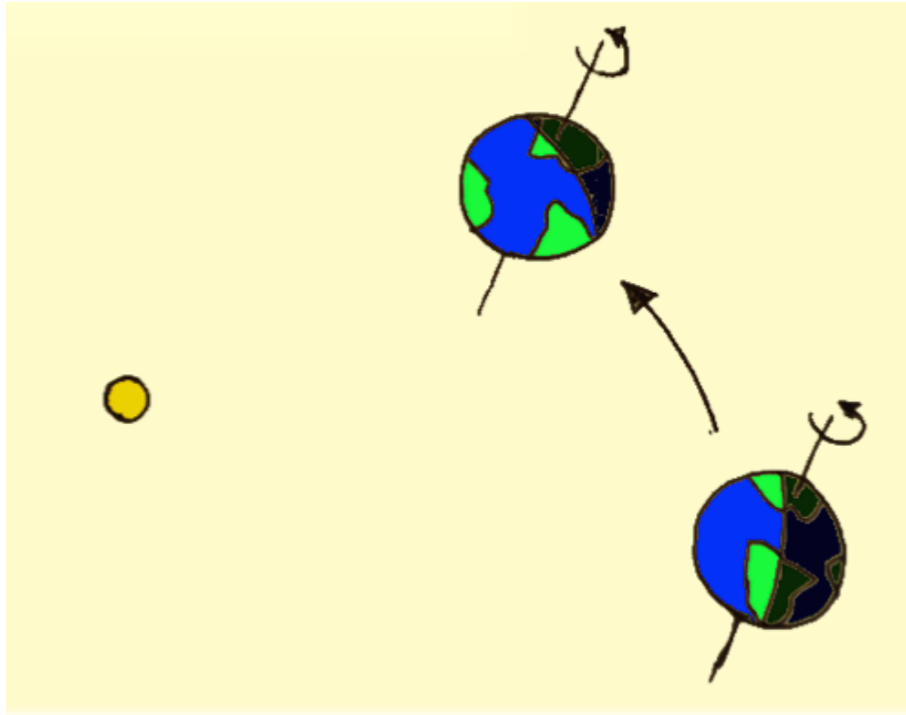


Turnbull+2012

# Photometric Variability



# Spin-Orbit Tomography



Intensity (planet/star)

Reflectivity

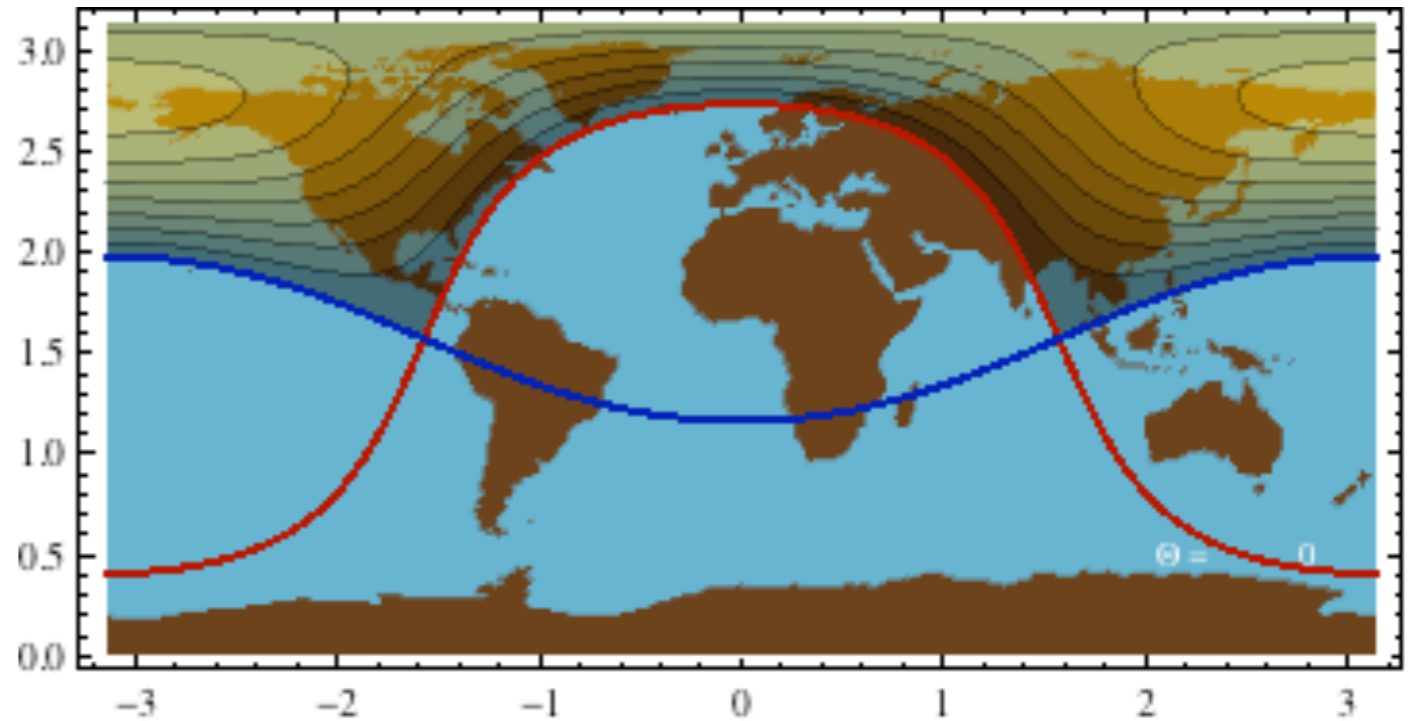
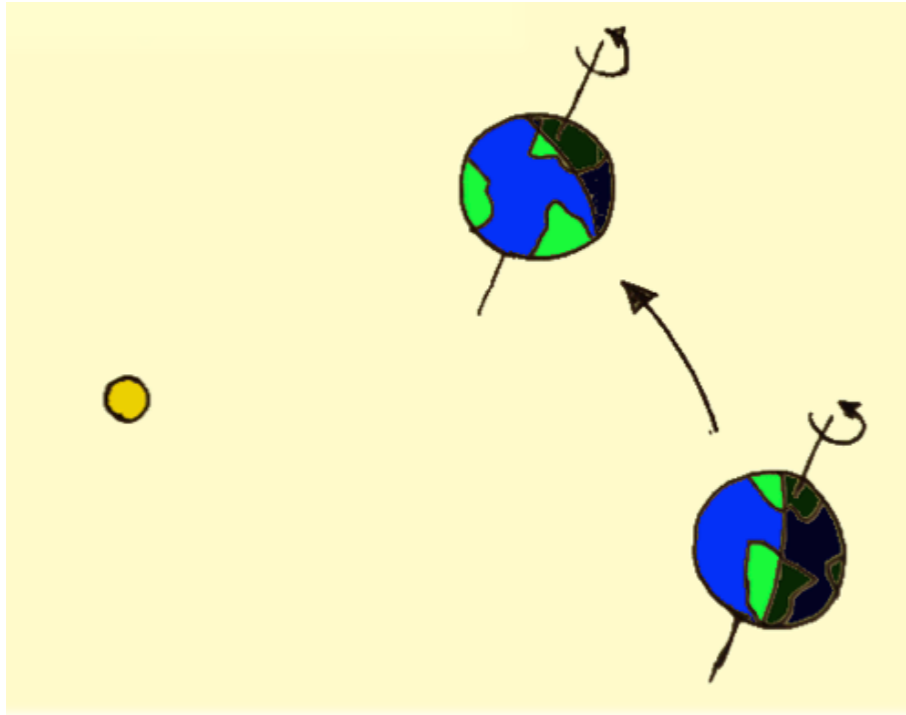
$$d(t) = \int \frac{W(t, \phi, \theta; \mathbf{w})}{m(\phi, \theta)} d\Omega + \epsilon$$

↑
↑
↑

Weight at planetary surface( $\phi, \theta$ )
Noise

1D Mapping : Cowan+2009, Oakley and Cash 2009, Fujii+2010,11  
 2D Mapping : Kawahara & Fujii 2010, 11, Fujii and Kawahara 2012

# Spin-Orbit Tomography



Intensity (planet/star)

Reflectivity

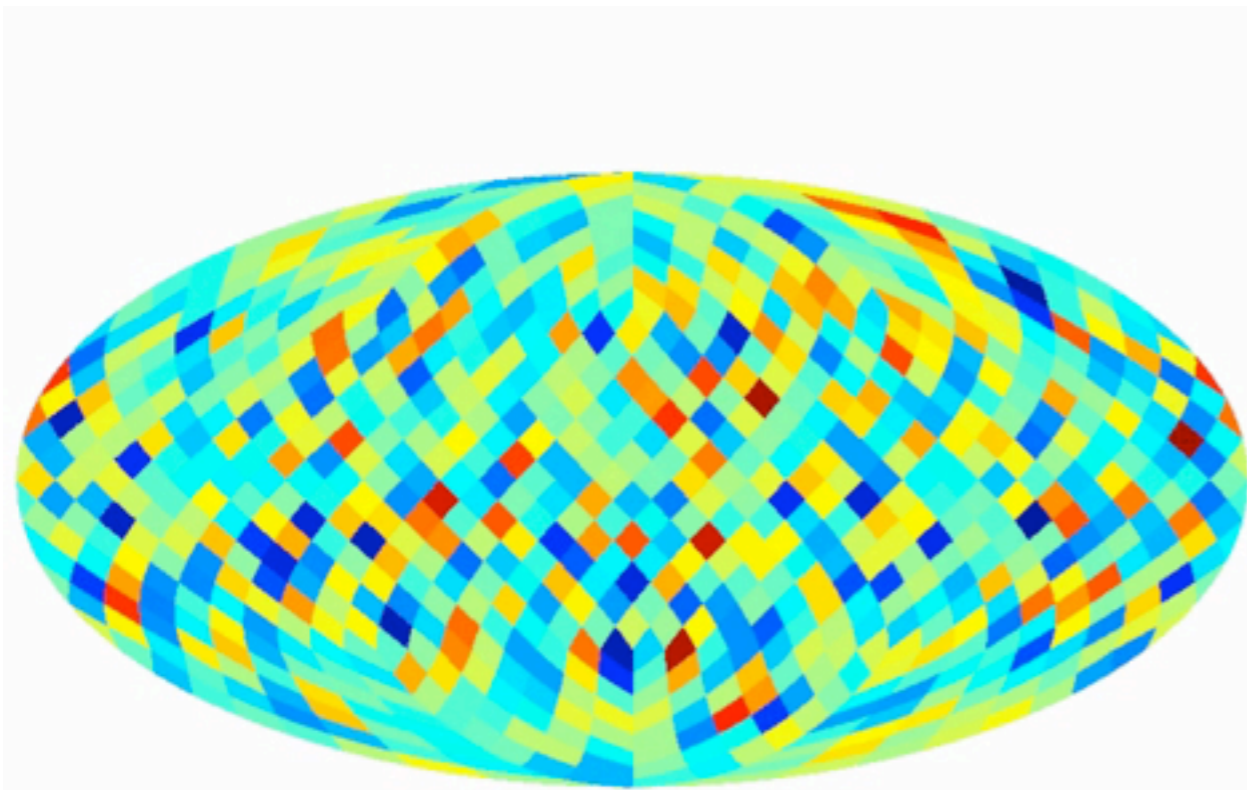
$$d(t) = \int \frac{W(t, \phi, \theta; \mathbf{w})}{m(\phi, \theta)} d\Omega + \epsilon$$

Weight at planetary surface( $\phi, \theta$ )

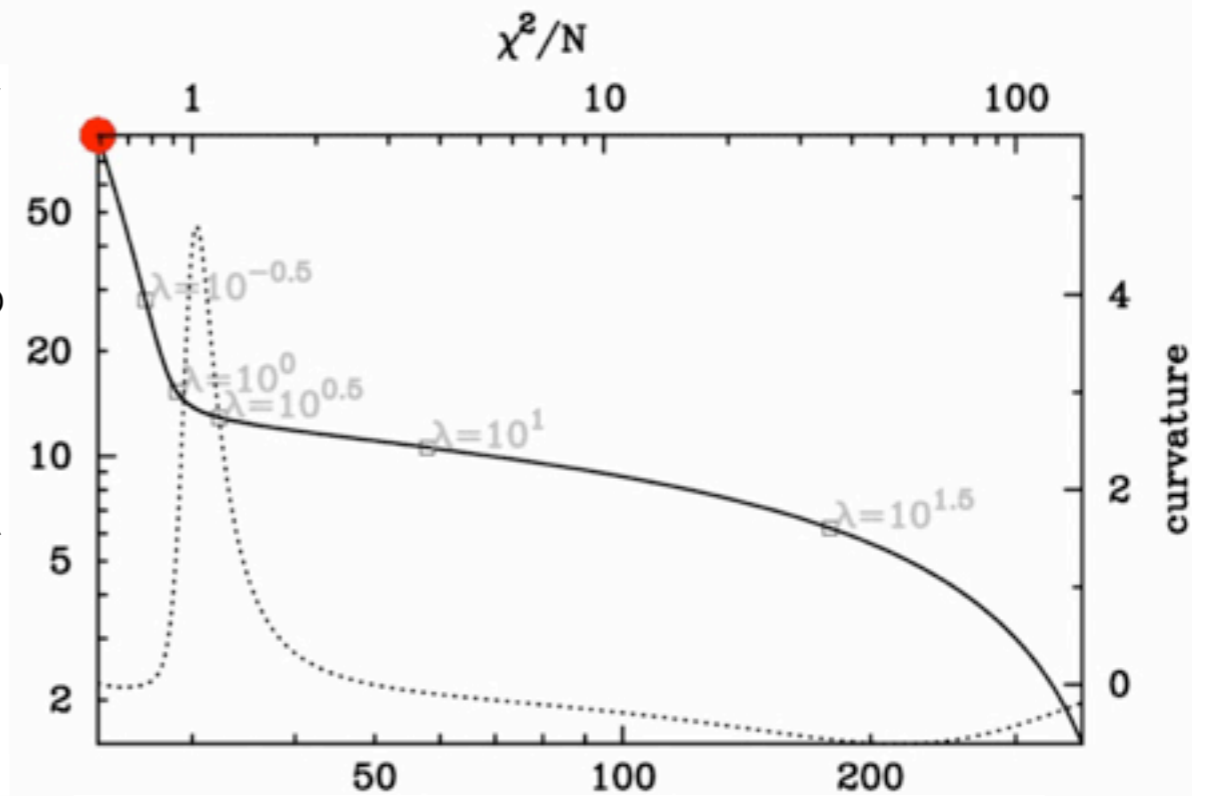
Noise

1D Mapping : Cowan+2009, Oakley and Cash 2009, Fujii+2010,11  
2D Mapping : Kawahara & Fujii 2010, 11, Fujii and Kawahara 2012

# Solving the Inverse Problem



モデル分散(overfittingの度合い)

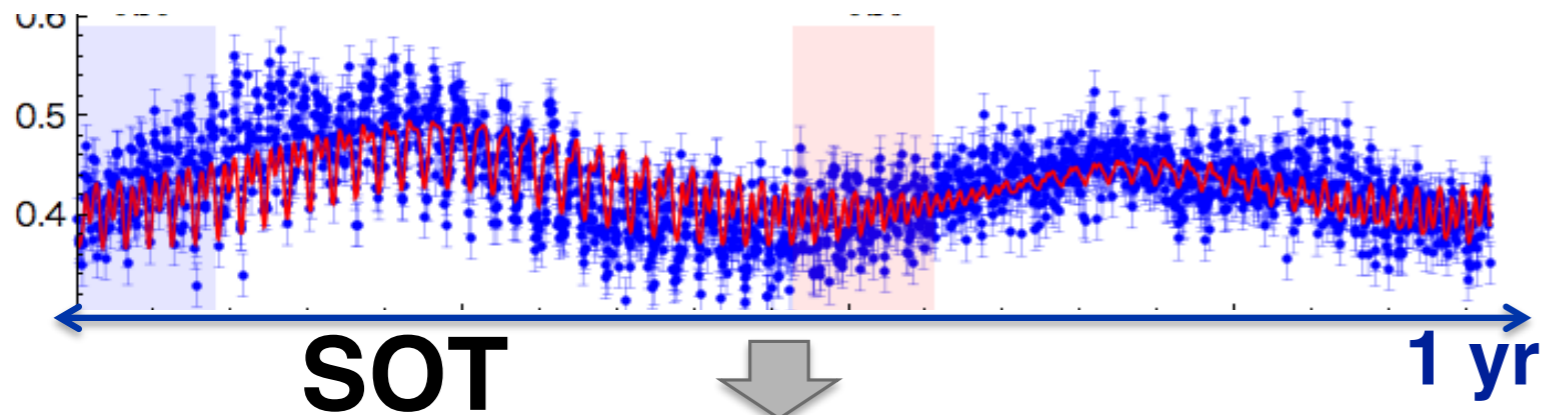


予測誤差(どれだけデータを説明できてるか)

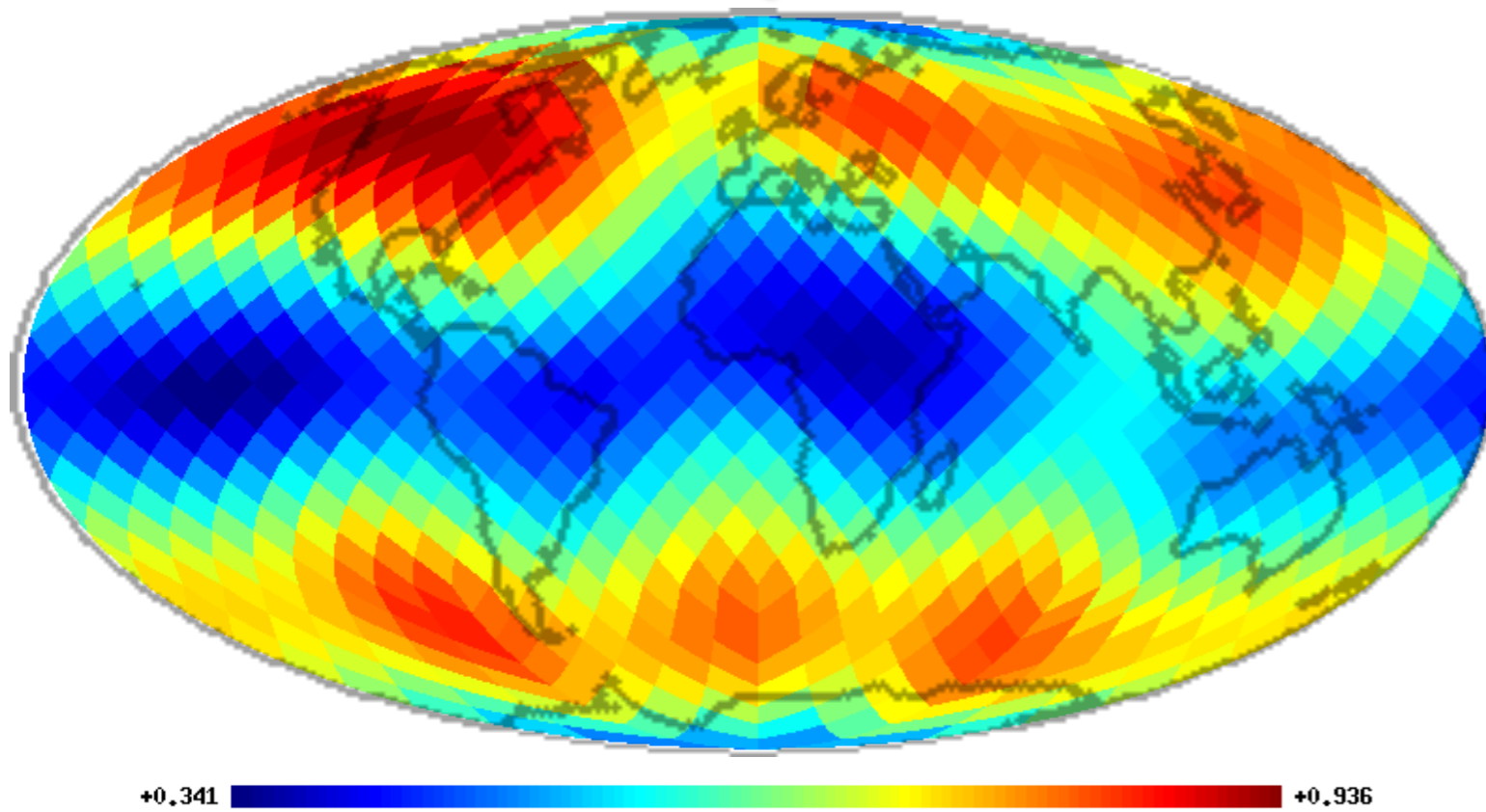
この手の問題はモデルの有効自由度を調節すればよい

# Spin-Orbit Tomography

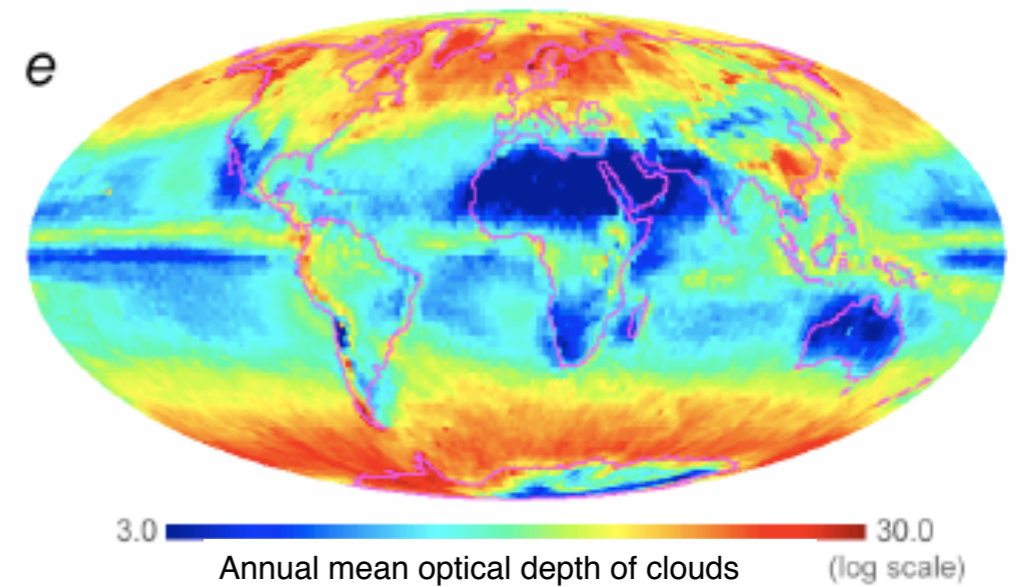
reflectivity



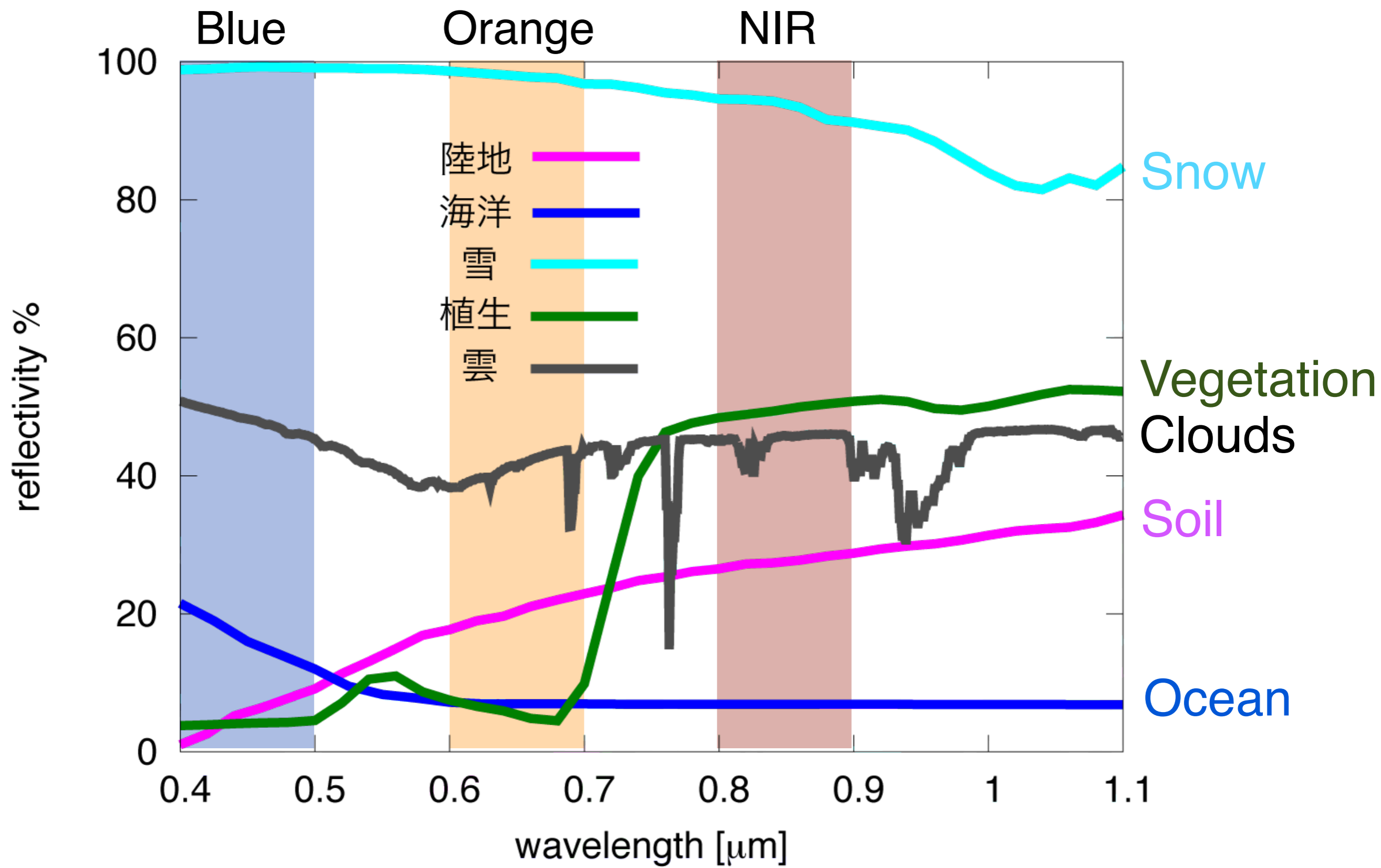
Kawahara and Fujii 2010,2011,  
Fujii and Kawahara 2012



Retrieved map of blue band (0.4-0.5 micron)

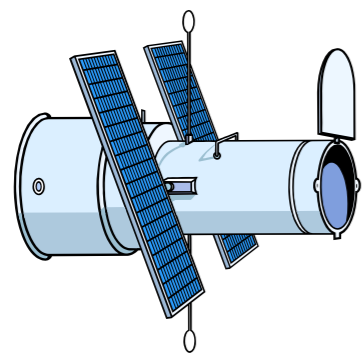


Annual mean optical depth of clouds  
(log scale)

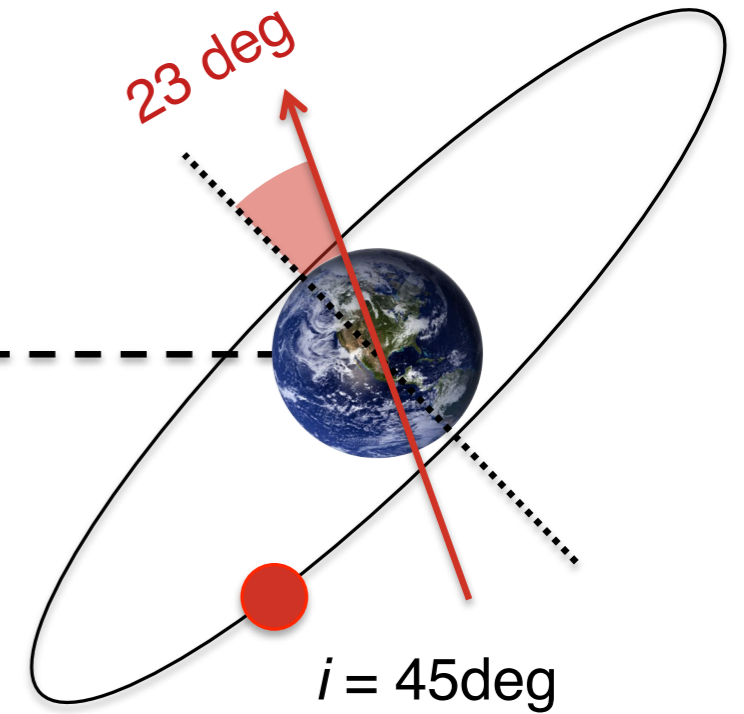




# Earth as a Testbed

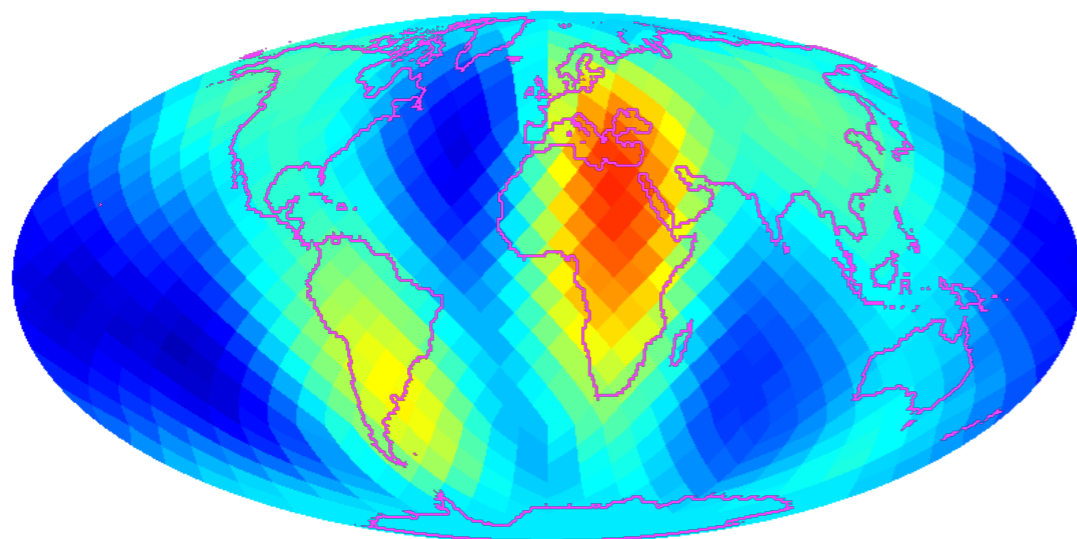


10 pc ~ 30光年



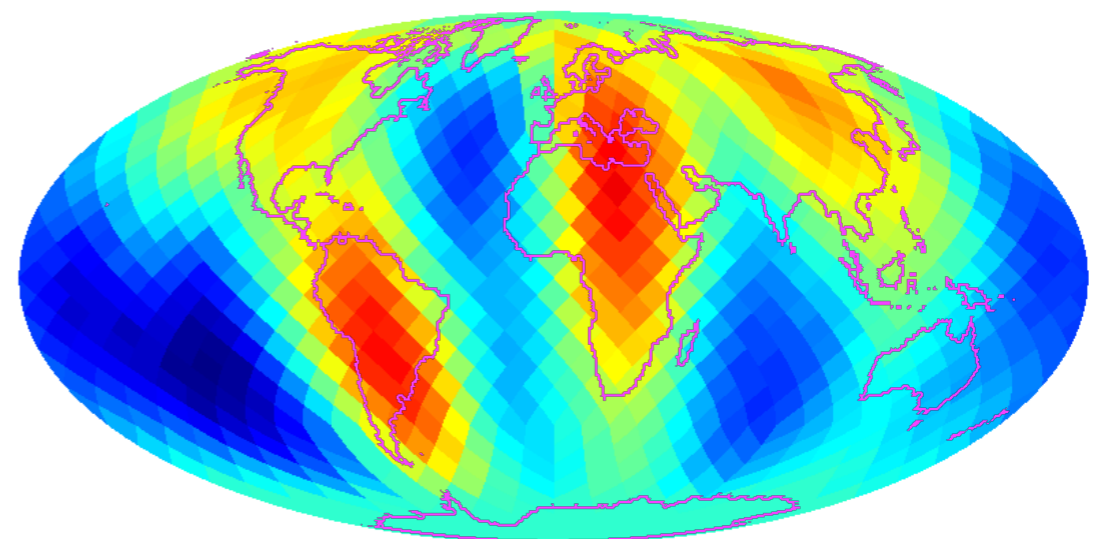
4 - 15 m telescope

NIR-Blue (SN=100)



-0.12 0.12

NIR-Orange (SN=100)

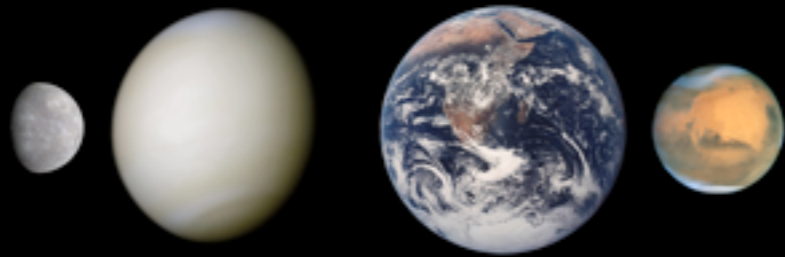


-0.02 0.12

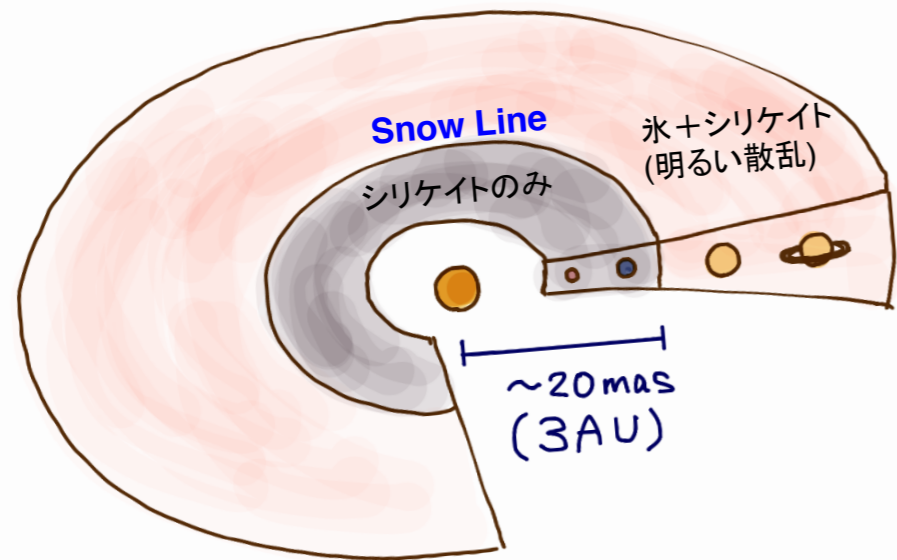


その他諸問題

We don't know terrestrial planets  
except for 4 planets



# Birth and Death of Terrestrial Planets



Snow Line

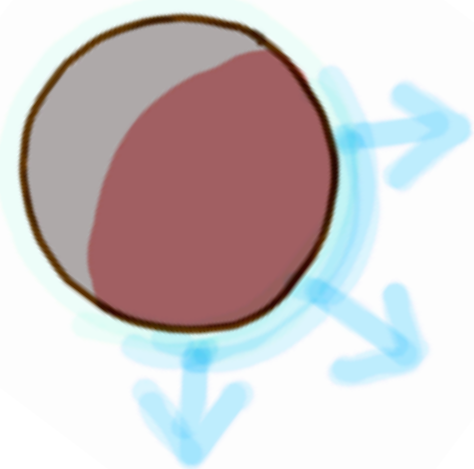
Giant Impactでばらまかれた  
デブリによる強い散乱光を見る

Giant Impact

Magma Ocean

with 武藤、玄田、濱野、他

# Birth and Death of Terrestrial Planets



# どこへいくのか？

30-100m級望遠鏡

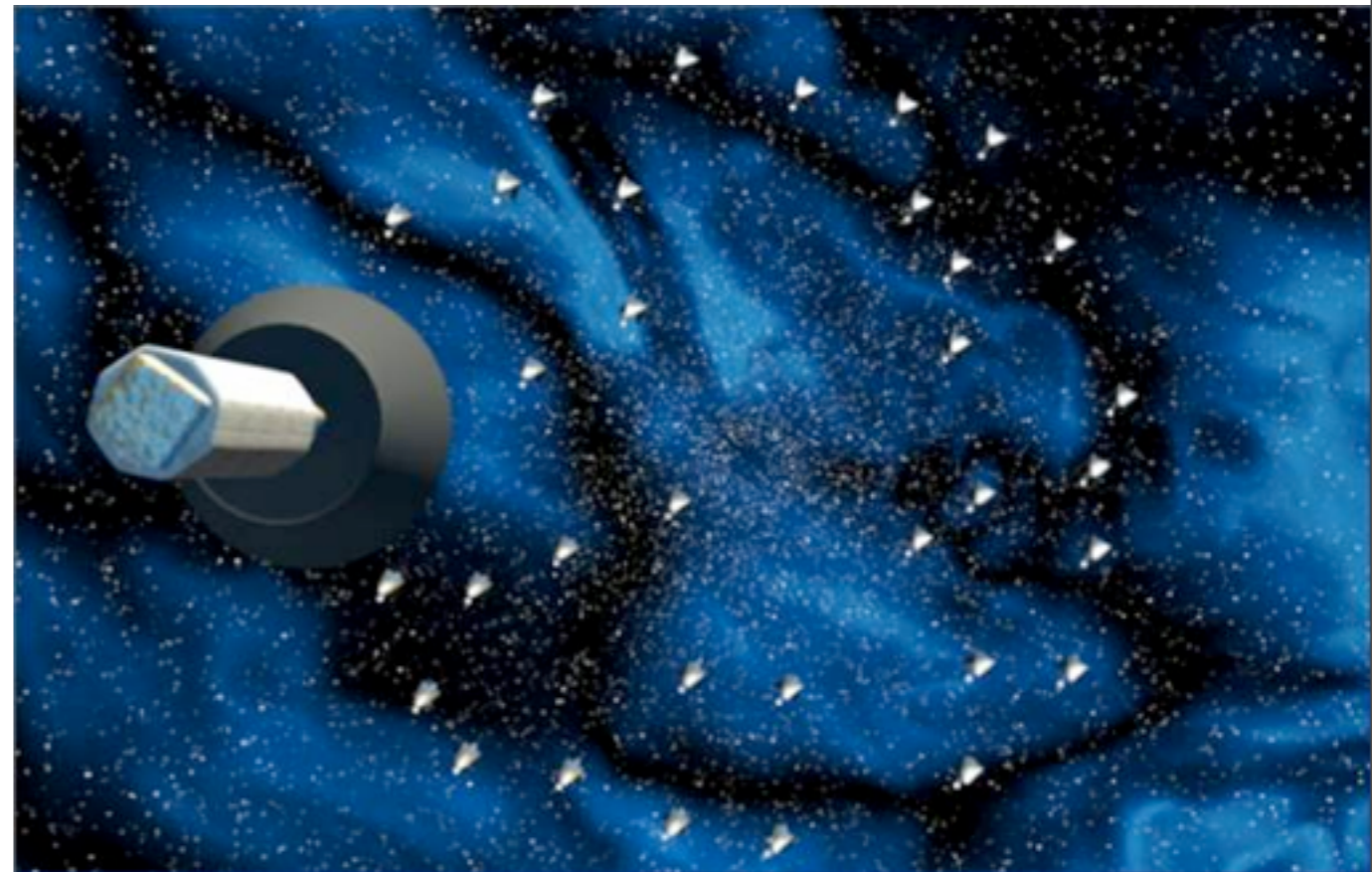
衛星によるEarth-Like Planetモニタリング観測

LabeyrieのHypertelescope

南極望遠鏡 や干渉計

電波 or X線による観測

他には？



# Earth-like Planetの研究

Earth-like Planetなどという天体はまだ存在しない

Earth-like Planetを求める欲求は強まるだろう

短期的な成果競争にはたぶんむかない (情熱の問題)

書を捨て街(装置計画)にでるもよし



まとめ



しままで

市道七  
5-1