

超高解像度の 遠赤外線干渉計を作る

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FIR atomic fine structure lines

- OI
 - 63.185 μm 4.745THz $5.0 \times 10^5 \text{ cm}^{-3}$
 - 145.54 μm 2.060THz $1.5 \times 10^5 \text{ cm}^{-3}$
- OIII 35.1eV
 - 51.815 μm 5.786THz $3.4 \times 10^3 \text{ cm}^{-3}$
 - 88.356 μm 3.393THz $5.0 \times 10^2 \text{ cm}^{-3}$
- NII 14.5eV
 - 121.80 μm 2.461THz $2.8 \times 10^2 \text{ cm}^{-3}$
 - 205.30 μm 1.460THz $4.5 \times 10^1 \text{ cm}^{-3}$
- NIII 29.6eV
 - 57.330 μm 5.229THz $3 \times 10^3 \text{ cm}^{-3}$
- CII 11.3eV
 - 157.68 μm 1.901THz $2.7 \times 10^3 \text{ cm}^{-3}$

Example of [OIII] observations in submillimeter-wave

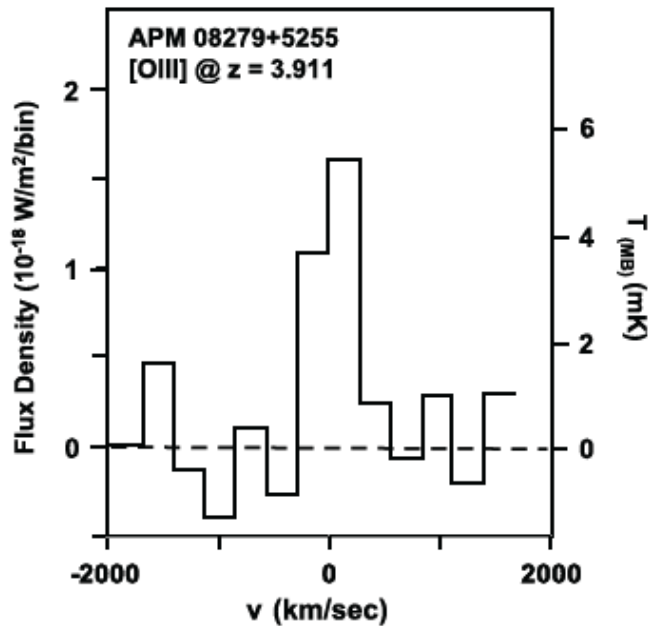


Figure 1. ZEUS/CSO detection of the [O III] $88 \mu\text{m}$ line from APM 08279+5255. Velocity is referenced to $z = 3.911$. The continuum emission has been subtracted off.

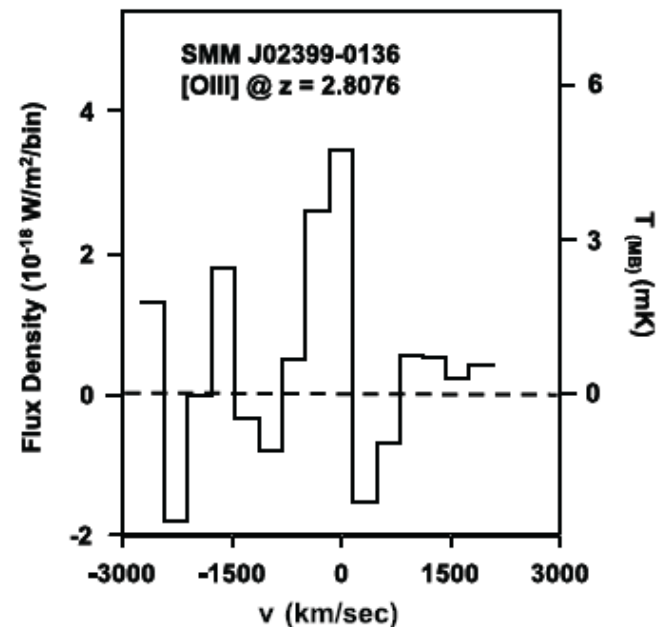
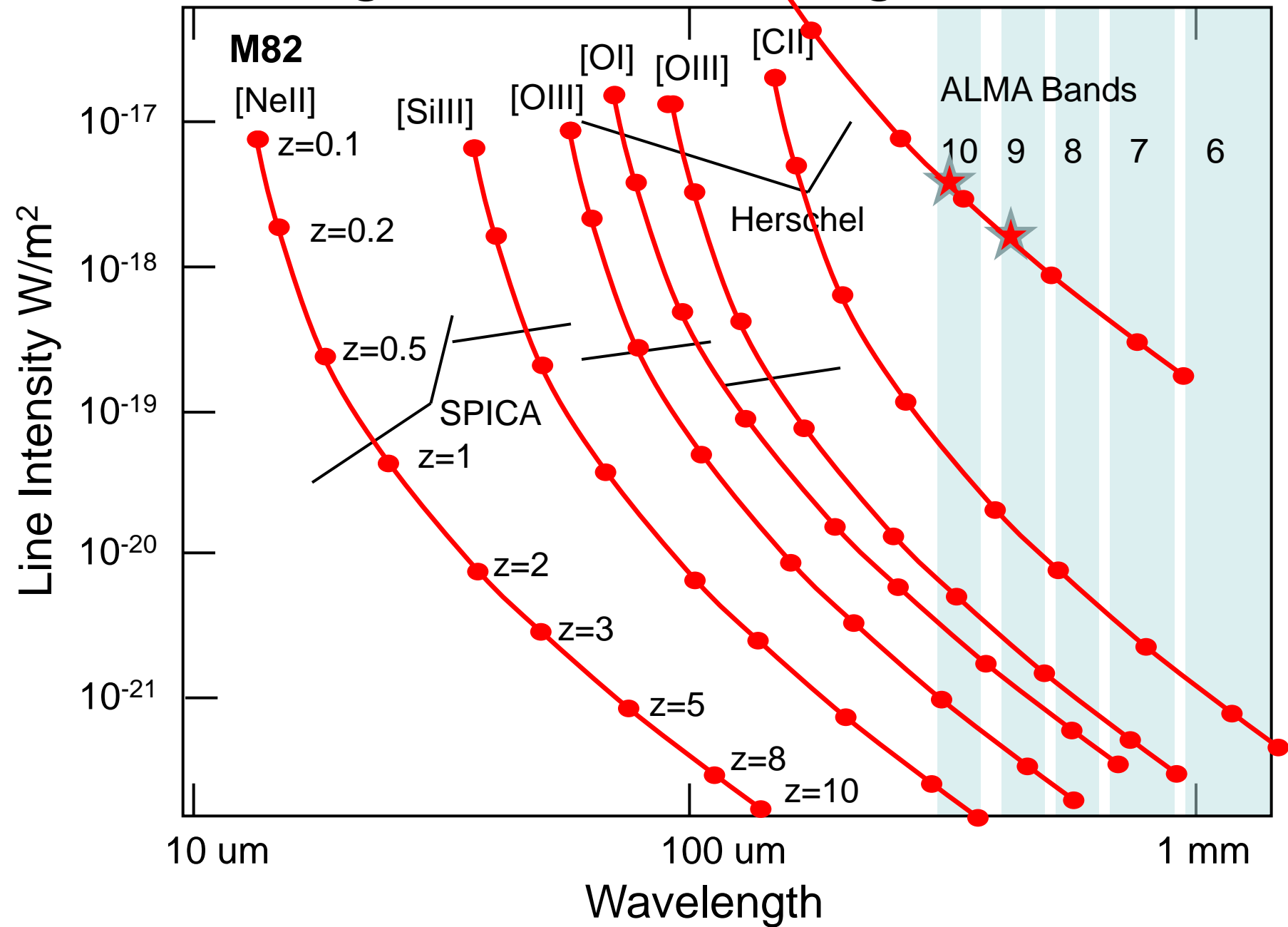


Figure 2. ZEUS/CSO detection of the [O III] $88 \mu\text{m}$ line from SMM J02399-0136. Velocity is referenced to $z = 2.8076$. The continuum emission has been subtracted off.

$\sim 10^{-18}$ W/m²

Ferkinhoff (2010)

High-z Star-Forming Galaxies



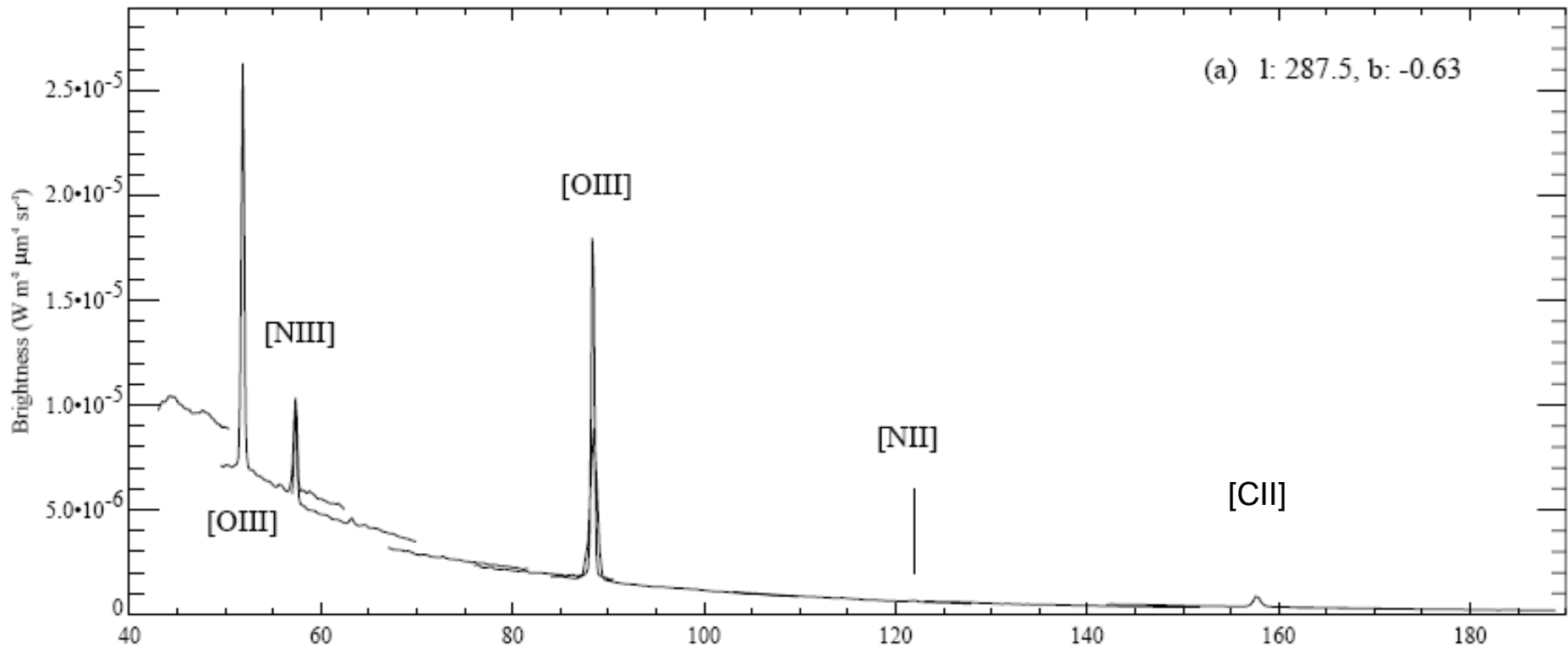
ALMAによる[OIII]の検出？

- [OIII]はどこから出てるのか？
- Our galaxy, nearby galaxy
- High angular resolution observation

To identify sources of cosmic re-ionization

Carina Nebula by ISO LWS

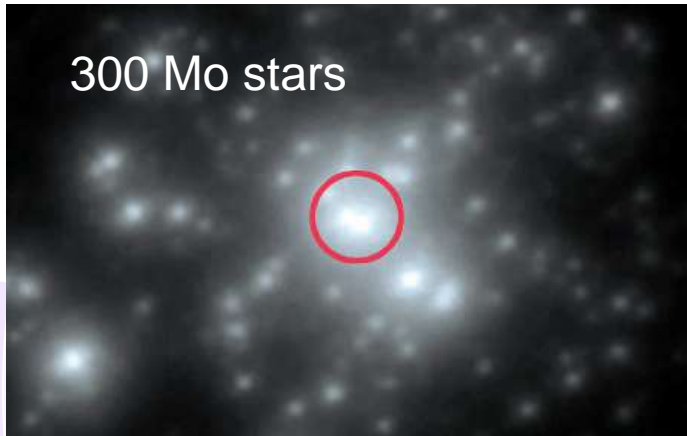
M. Mizutani et al.: Detection of highly-ionized diffuse gas



Mizutani, Onaka, Shibai. (2002)

30Dor region and R136

Low metal, High UV field



◆ [OIII] 88 μ m is observed widely distributed around R136

Contour: MIPS 24 μ m

Kawada et al. (2011)

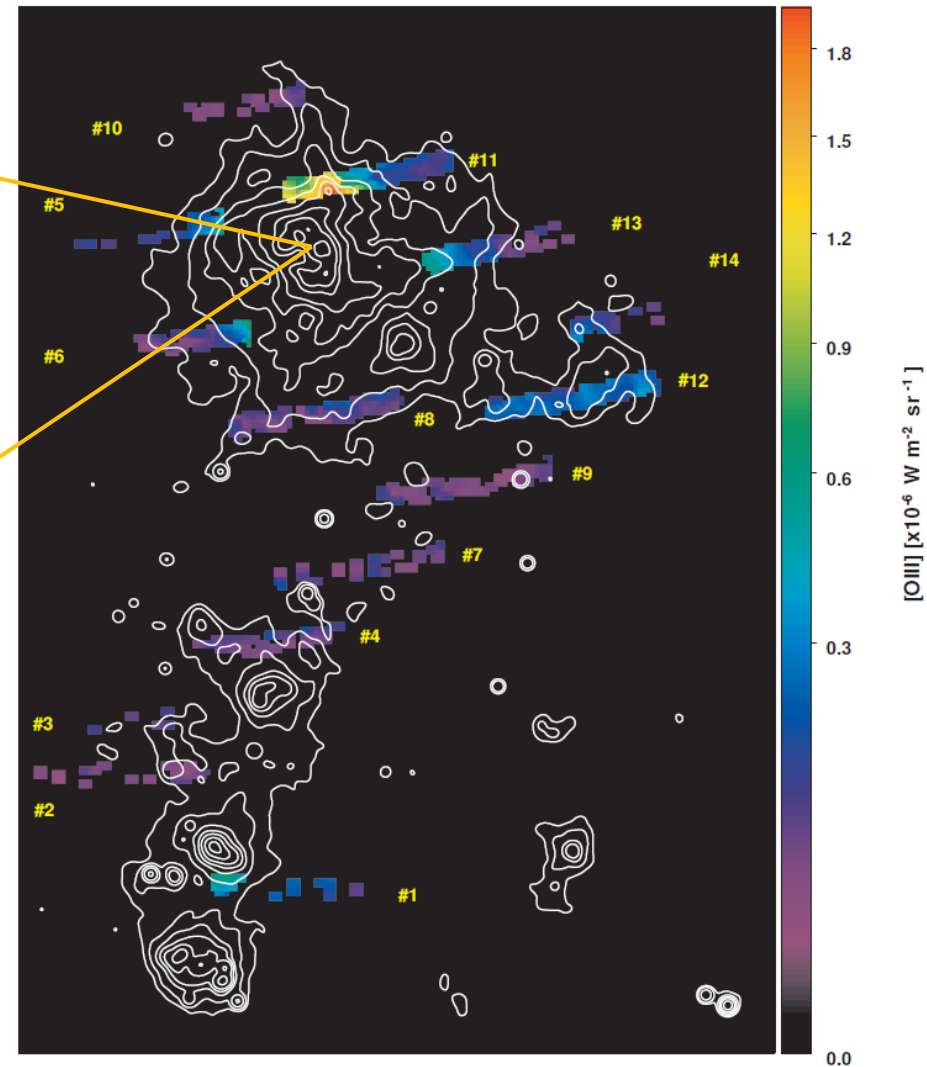
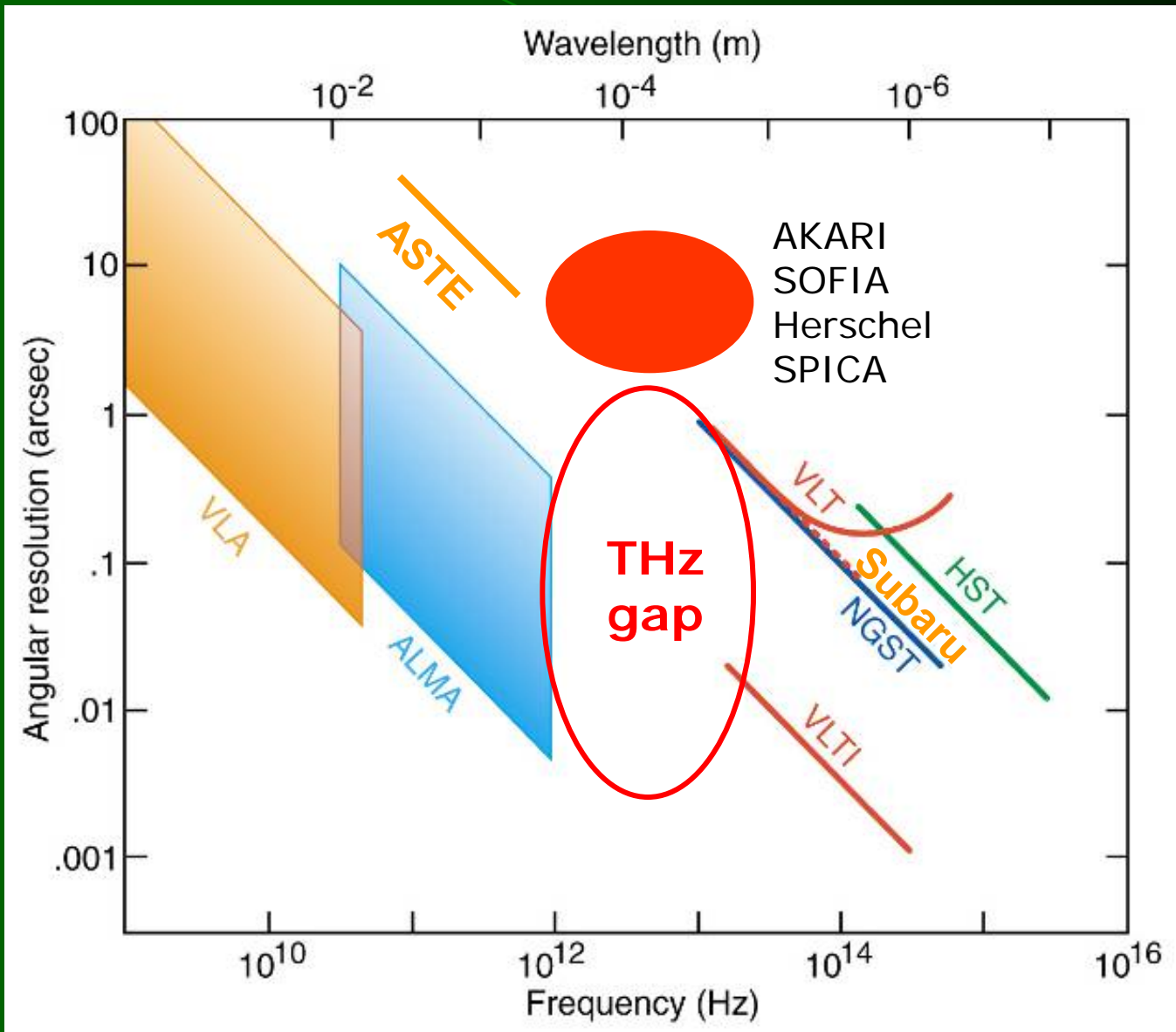


Fig. 3. [OIII] 88 μ m line intensity map, shown together with the MIPS 24 μ m contour map

[OIII] 88 μm line intensities

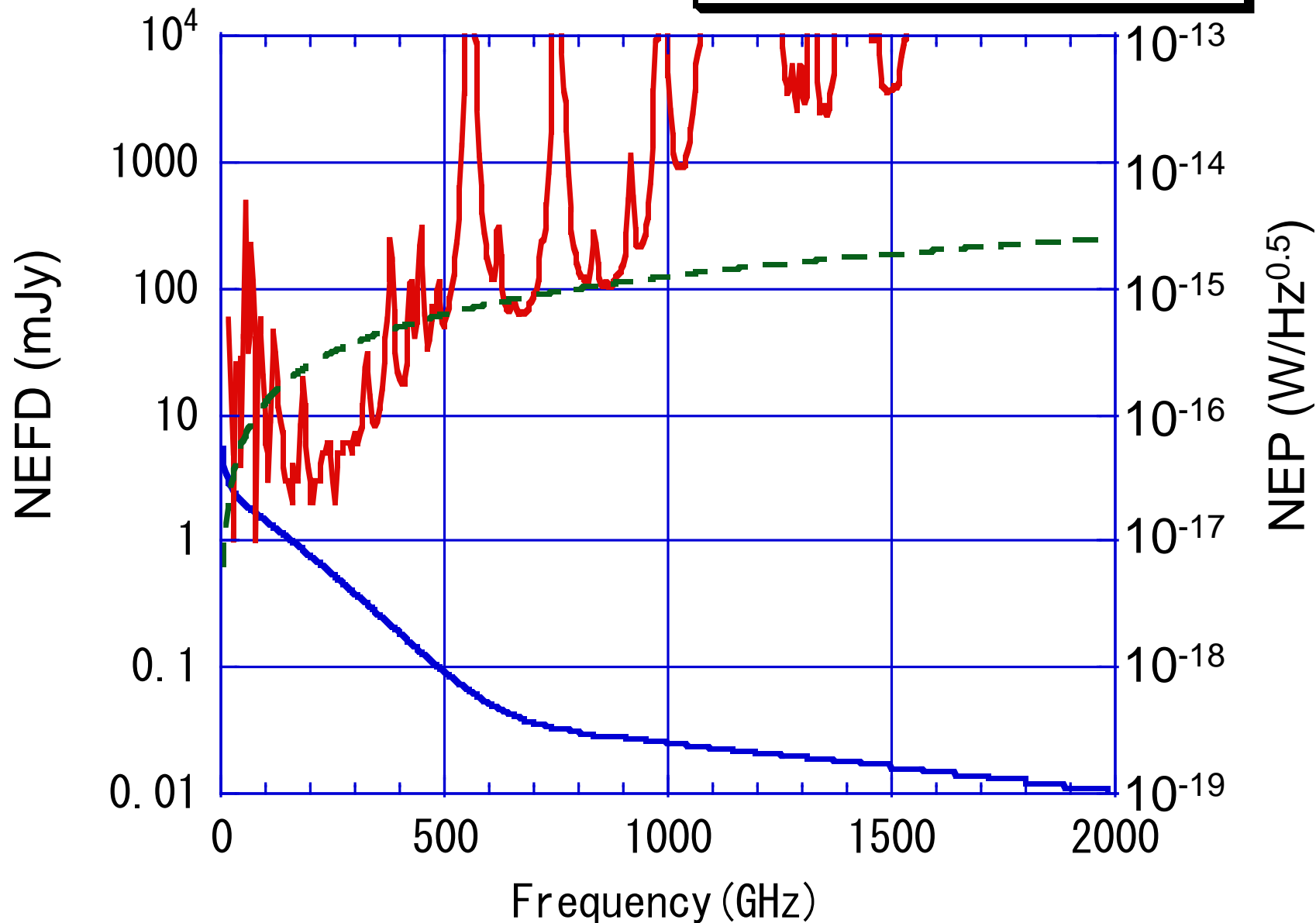
- Single massive cluster
 - $1 \times 10^{-5} \text{ W/m}^2/\text{sr}$ from Carina
 - 10 arcmin in diameter @ 50 kpc from 30 Dor
 - $7 \times 10^{-11} \text{ W/m}^2$ at $z=10^{-5}$
 - $2 \times 10^{-22} \text{ W/m}^2$ at $z=8$
 - 1.7 mJy for 10 km/s @ 350 GHz
 - angular diameter 10 milli-arcsec

THz Gap of Spatial Resolution

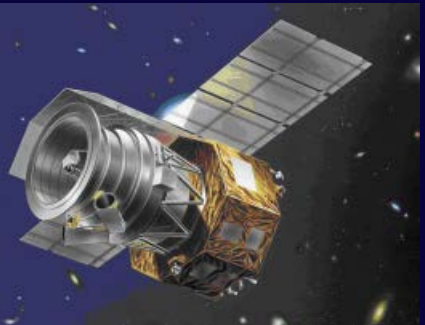


Observing sensitivity using

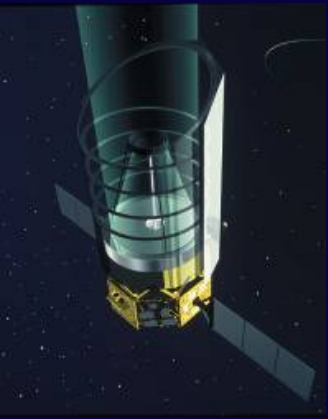
D=10m telescope
NEFD (1sec, 1sigma)



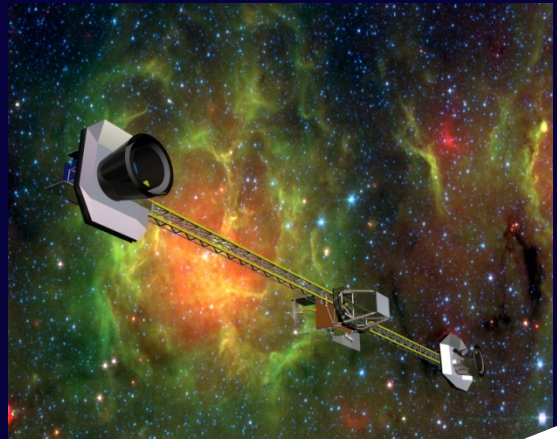
Space THz Interferometer The Road Map



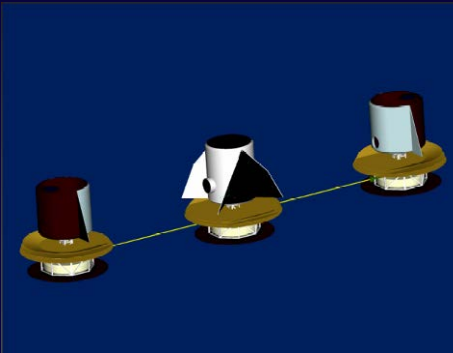
AKARI



SPICA



SPIRIT



SPECS

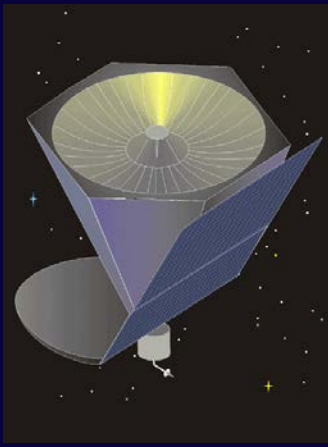


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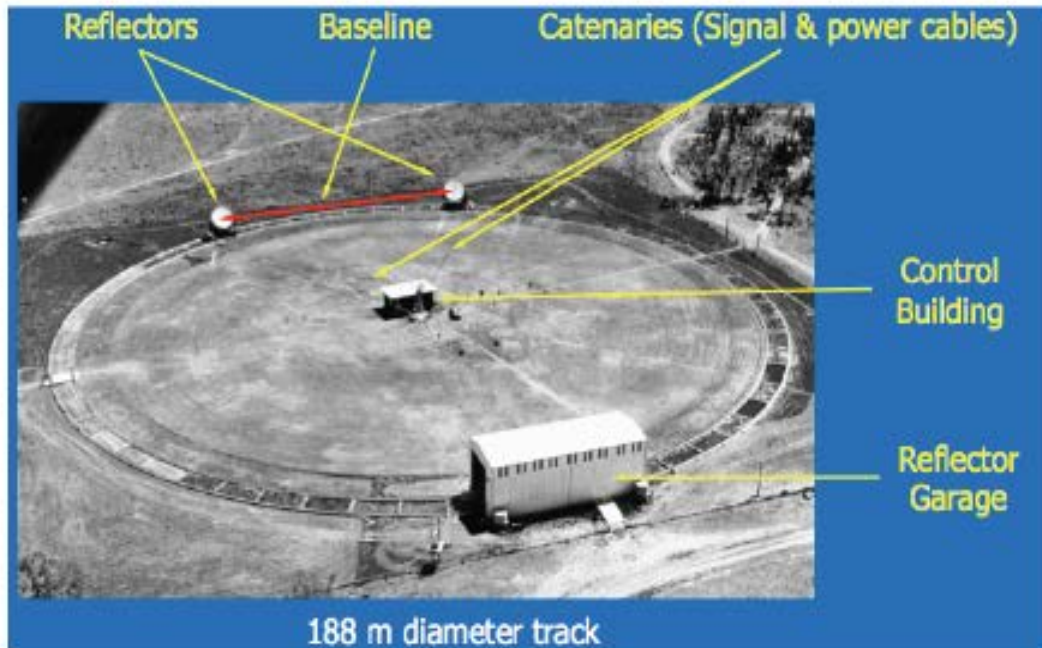
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Narrabri Stellar Intensity Interferometer



Hanbury-Brown et al. (1974)
Diameter of 32 early-type stars were measured.

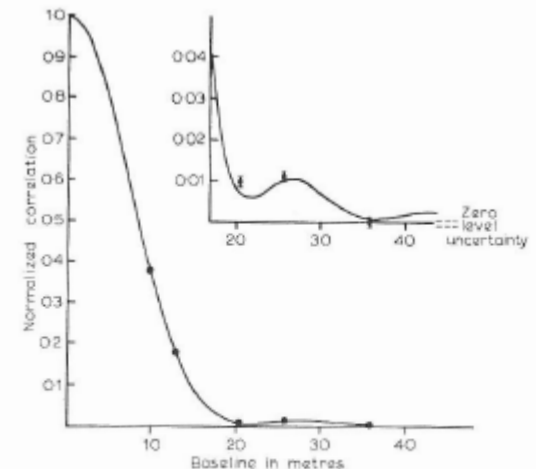


Fig. 11.5. Correlation as a function of baseline for Sirius A ($\approx C Ma$). The points show the observed results; the full line shows the theoretical curve for a model atmosphere ($T_e=10\,000\text{ K}$, $\log g=4$, $\lambda=450\text{ nm}$). Results for three long baselines are shown on an expanded scale together with their r.m.s. uncertainties. (Total exposure 203 hours.)

光子計数型テラヘルツ干渉計 Photon Counting THz Interferometry (PCTI)

- HBT強度干渉計の発展型
 - Hanbury-Brown, Twiss (1956, Nature)
- テラヘルツ帯での光子バンチ測定
 - 高い干渉効率 (輝度温度100 K以上)
- 光子バンチを用いた遅延時間測定
 - 位相情報として使えるか？

熱放射の揺らぎ

$$\Delta n = \sqrt{n + n^2}, \text{ where } n = \frac{1}{e^{h\nu/kT} - 1} \text{ (個/Hz)}$$

n : 光子占有数 (photon occupation number)

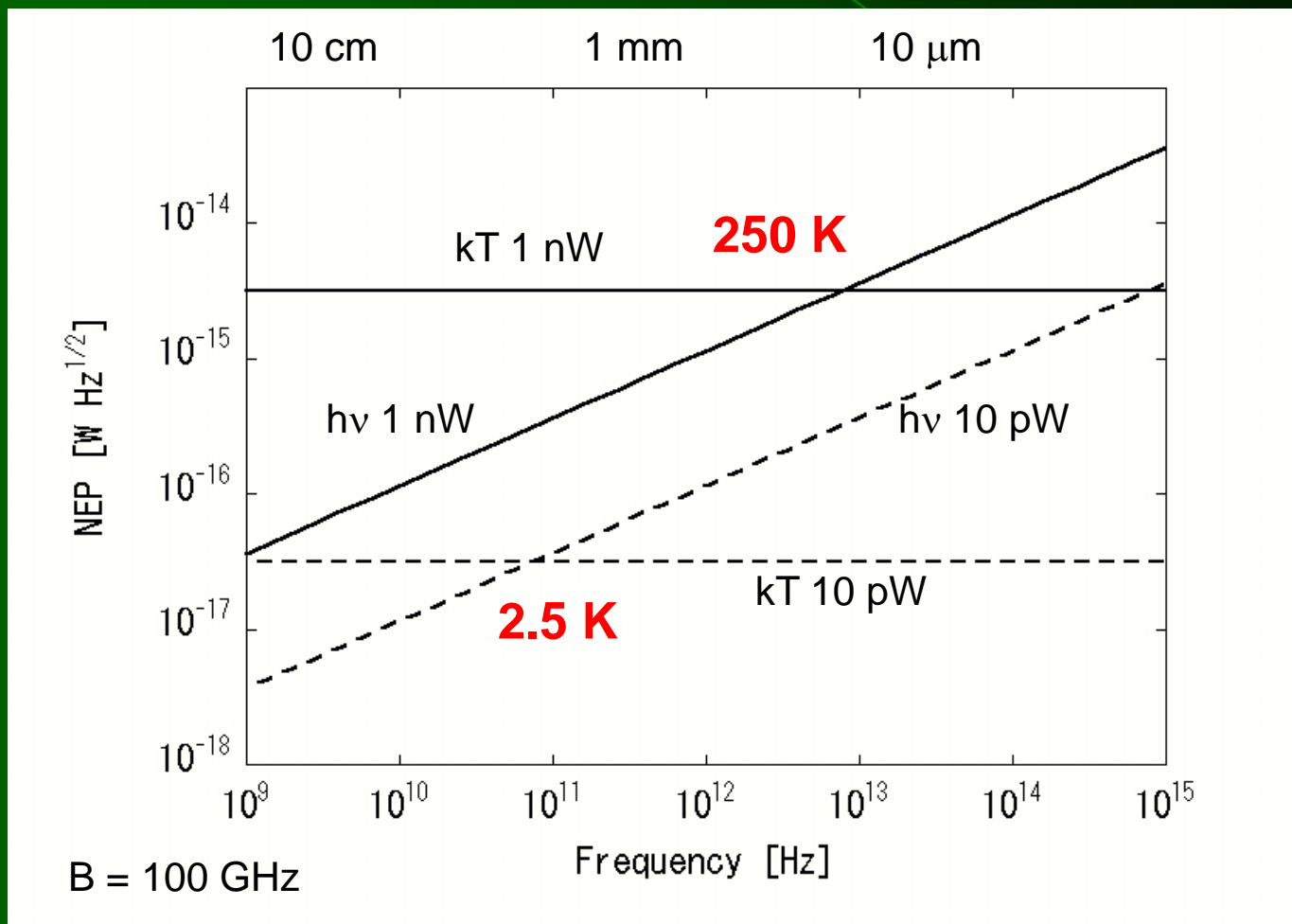
$$A \cdot \Omega = \lambda^2$$

$$\text{NEP} = \sqrt{2P \cdot (h\nu + kT_B)} [\text{W}/\sqrt{\text{Hz}}]$$

References A. Einstein (1909)
 J. Mather (1984)
 J. Zmuidzinas (2003)

テラヘルツ波の粒子性、波動性

$$\text{NEP}_{\text{direct}} = \sqrt{2P \cdot (h\nu + kT_B)} [\text{W}/\sqrt{\text{Hz}}]$$



遅延時間の測定精度は？

- 期待される光子レート 100 MHz
測定時間 100 sec
総光子数 10^{10} 個
- 光子到来時刻の揺らぎは
1光子で $1/100\text{MHz} = 10^{-8}$ sec
100秒積分すると
 $10^{-8} / \text{sqrt}(10^{10}) = 10^{-13}$ sec
- テラヘルツ波長以内で時刻測定が可能！

太陽電波による強度干渉計実験

April 7-15, 2014

野辺山電波ヘリオグラフ

80cm antennas 16台を用いる

HEMT受信機 Trx=360K

RF 17 GHz

IF 200 MHz

BW 100 MHz



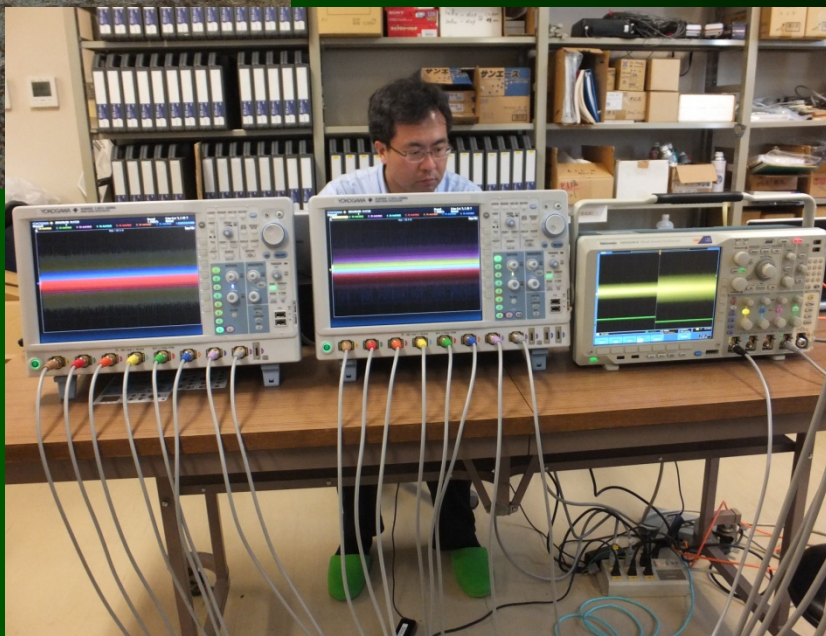
横河電機DLM4058

2x 8ch 1.25 G sample/sec

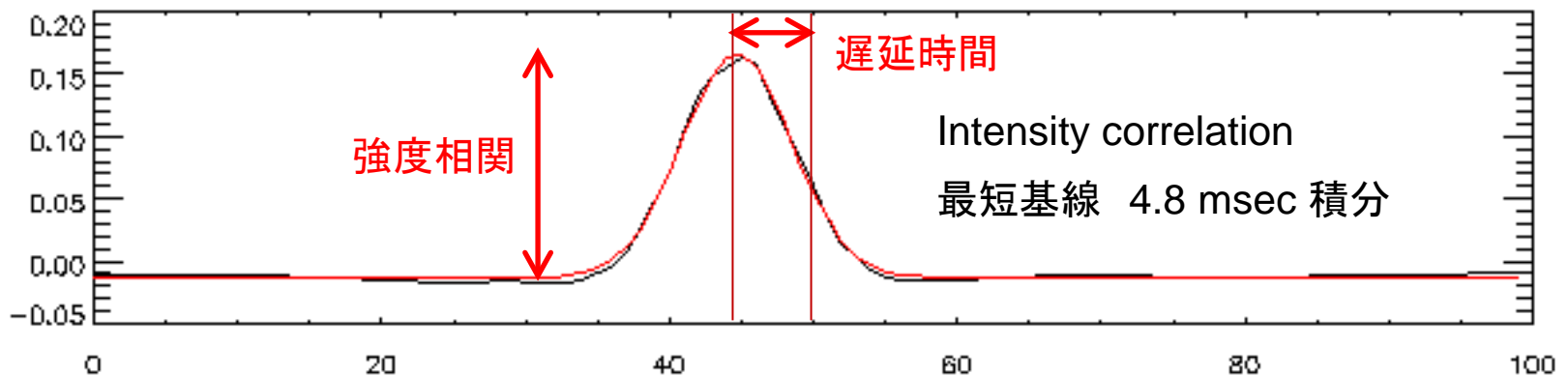
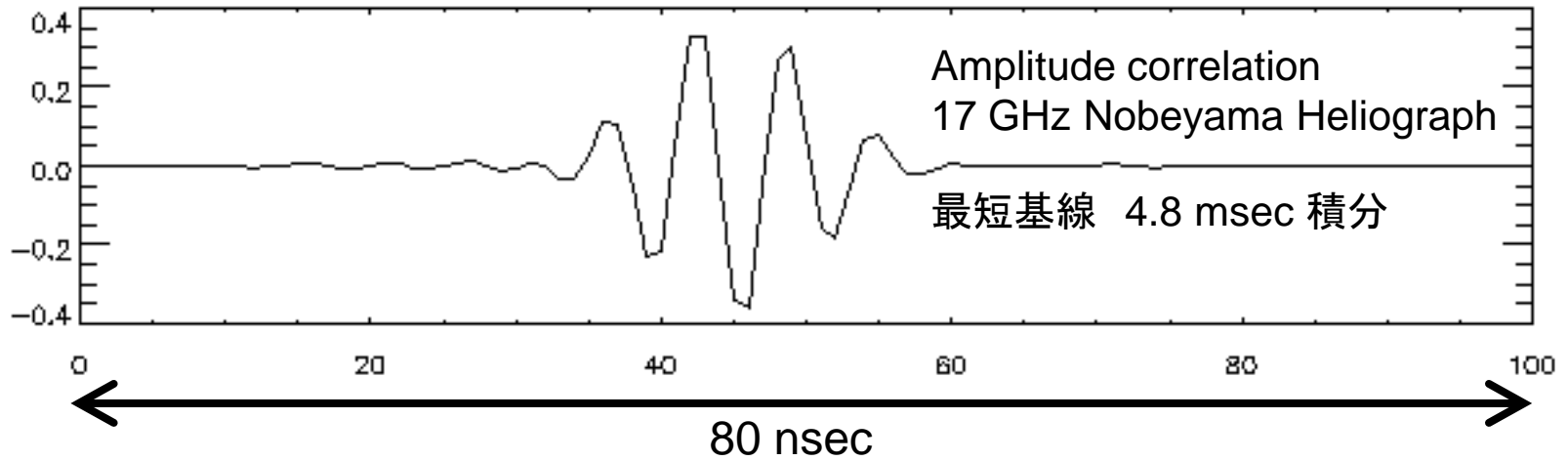
帯域幅 500 MHz

16chの中間周波信号

50 msecの連続データ記録



振幅・強度による相互相関の例



遅延時間測定精度

- 強度相関による遅延時間測定
 - $\Delta t = 3\text{-}10$ psec (BL < 1.5 m, $t = 50$ msec)
 - $c \Delta t = 1\text{-}3$ mm vs. 17 GHz (λ 17 mm)
 - 約1/10波長で遅延時間を測定
- 光子数の推定
 - 太陽のアンテナ温度 約600K
 - $kTB = 800$ fW (B=100MHz)
 - = 70 G photons/sec
 - = 400 photons/bunch ($\tau = 1/2B = 5$ nsec)

量子光学的考察

- コヒーレント時間当たり1光子レベルでの相関強度測定
- 光子バンチによる遅延時間精密測定
- 強度干渉計による複素ビジビリティー取得
- 光子計数型テラヘルツ干渉計への応用

受信機雑音 360 K

量子雑音 $h\nu/k = 0.8$ K

受信機雑音は 400 photons/Hz

太陽からの光子は 400 photons/bunch

積分 50 msecで $S/N \approx 3000$ が期待される

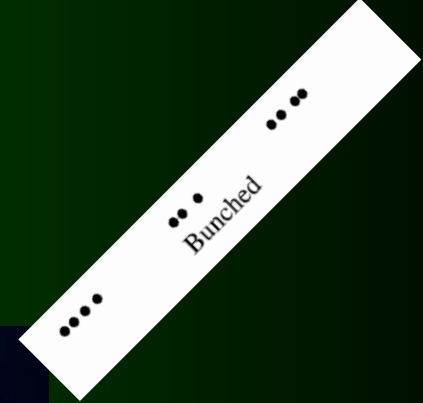
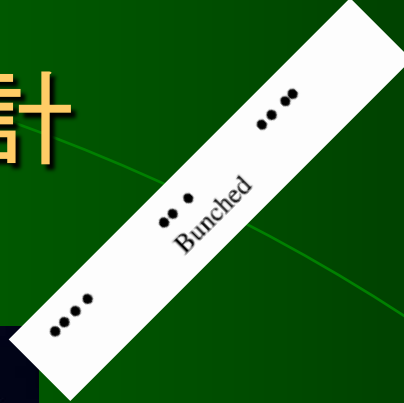
超長基線干渉計 への応用



Recorder
 $B > 1\text{GHz}$

Recorder
 $B > 1\text{GHz}$

Calculate correlation and delay



強度(光子計数型)干渉計の特徴

- 超高感度直接検出器が使える
- 位相雑音の影響を受けない
- 超長基線干渉計が実現可能
- 地上観測では、
 - 高輝度天体の観測
 - FIR lines, BH shadow, stars
- 宇宙空間からは、
 - exo-planet imaging
 - 300 K source with micro-arcsec resolution

南極大陸

Atlantic Ocean

Indian Ocean

South Pole

Dome F

Dome A

Dome C

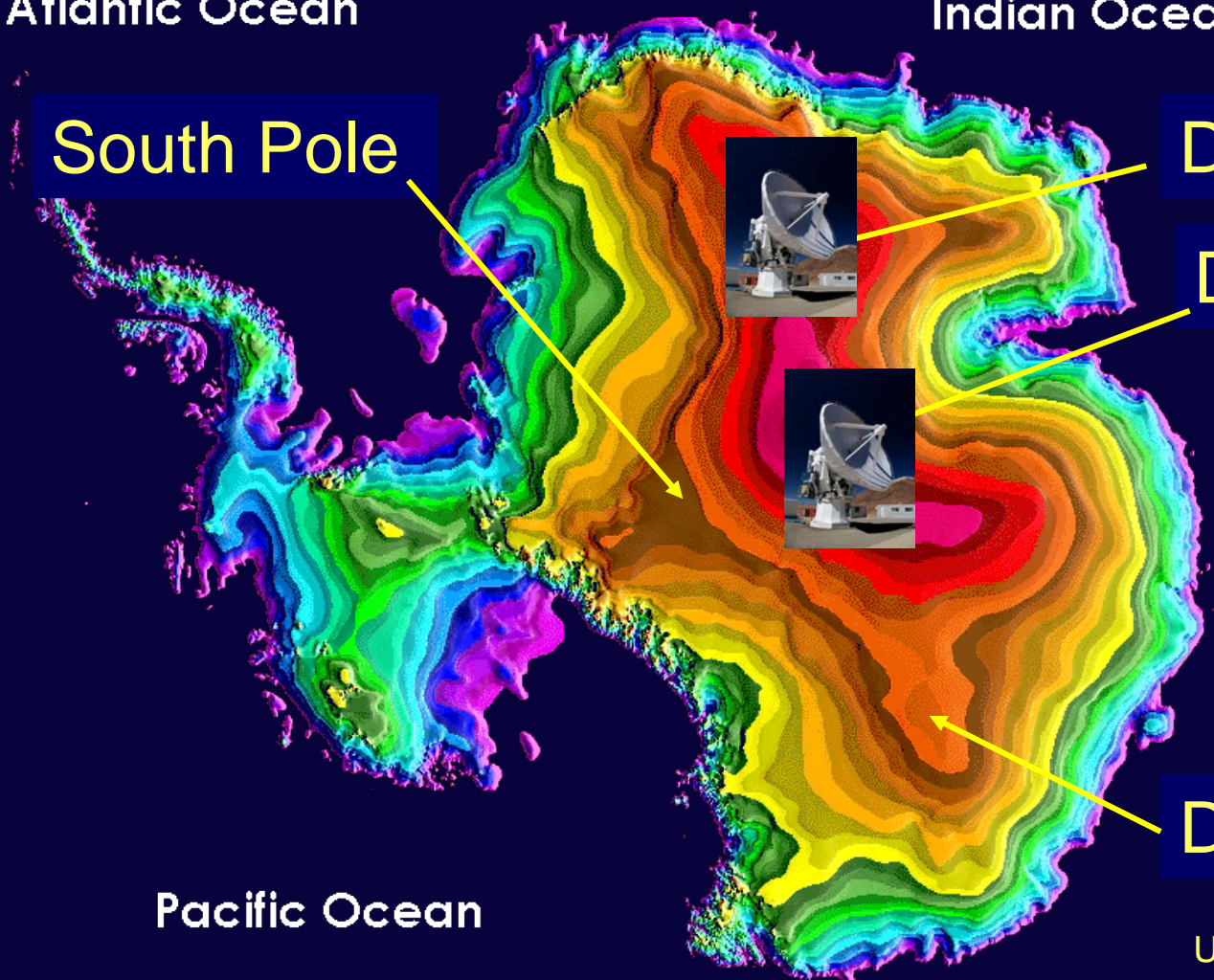
Pacific Ocean

USGS image

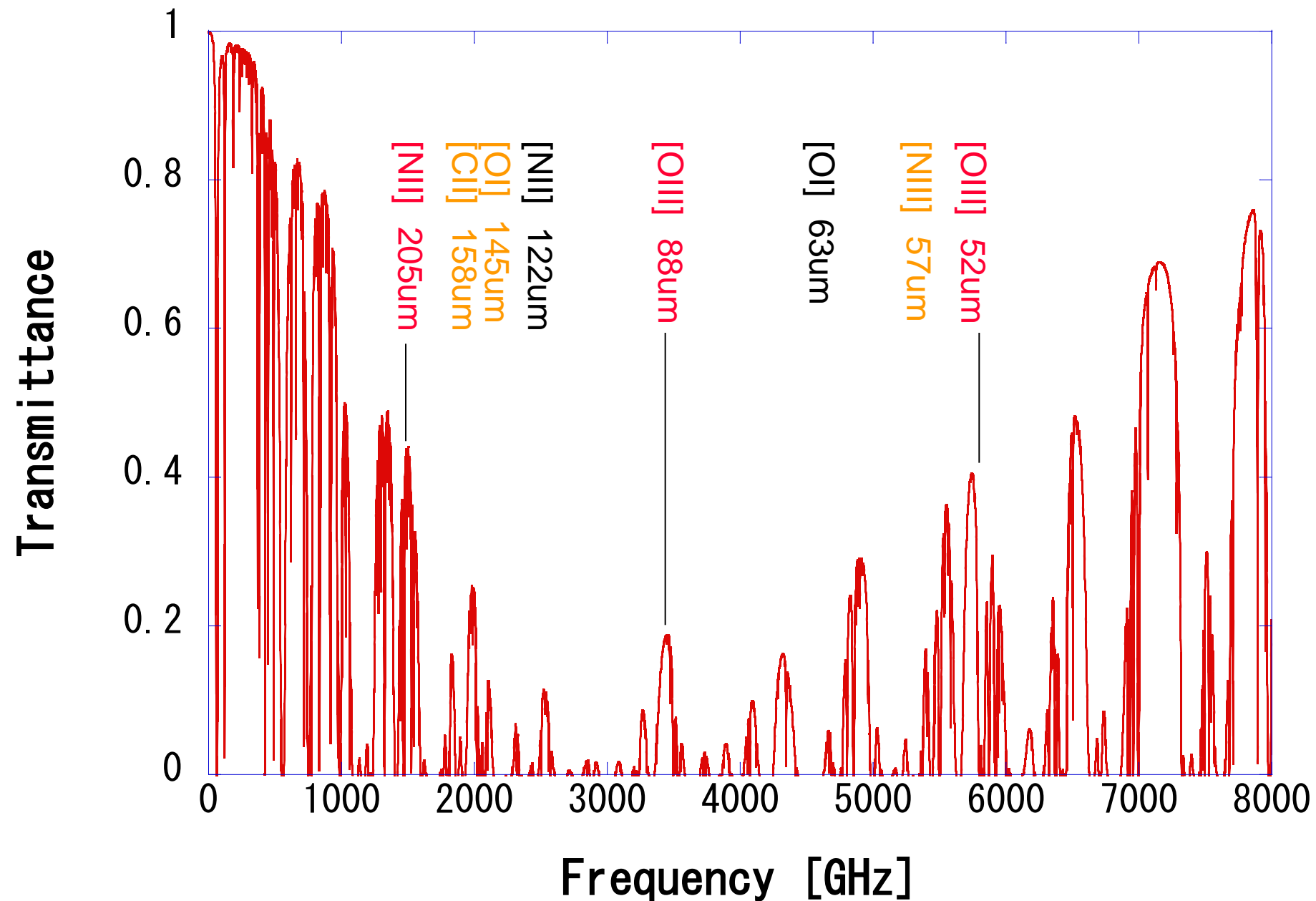
0

Elevation in meters

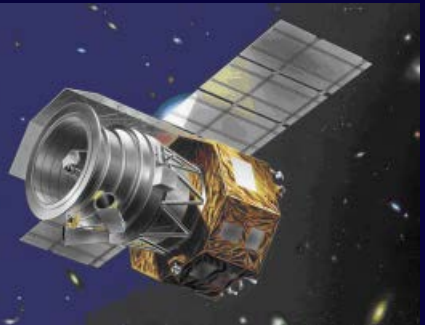
4000



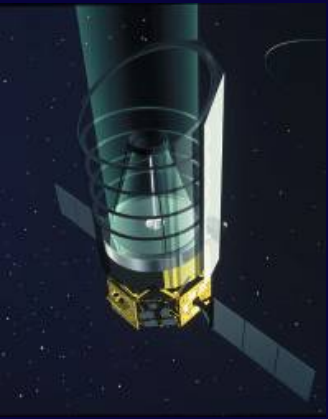
Dome_A_winter_75um



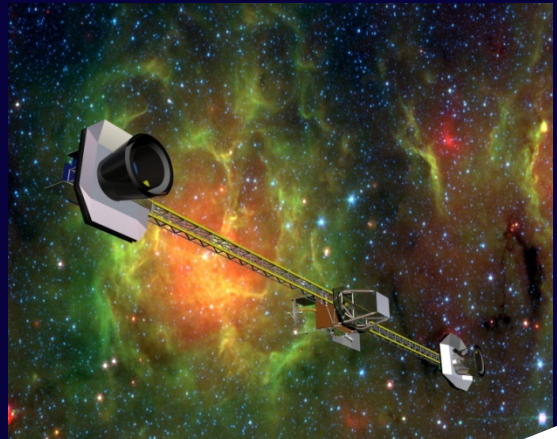
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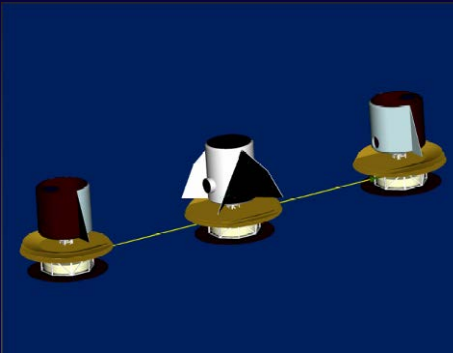
AKARI



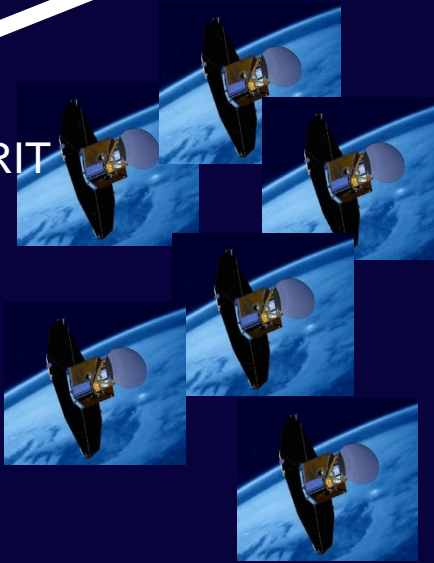
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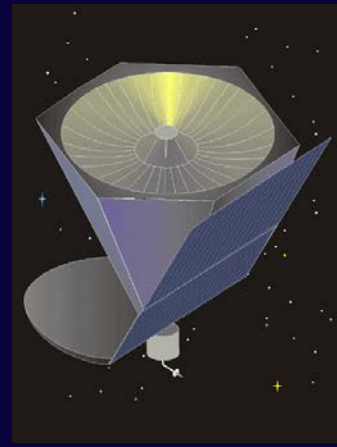


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Herschel



Millimetron



まとめ

- 量子光学的手法による天体観測
- 光子計数型テラヘルツ干渉計 (PCTI)
- 強度干渉計による遅延時間測定
- 将来展望