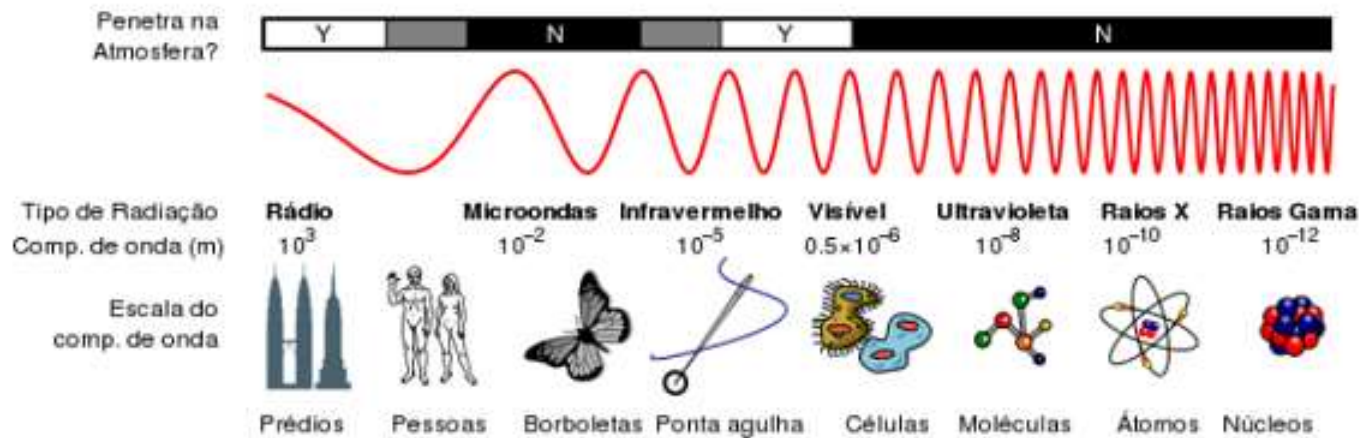


Radioastronomia

Pedro P.B. Beaklini

18/06/2019



Vamos Lembrar??

Poder de resolução

$$\theta \propto \frac{\lambda}{D}$$

λ (rádio) > 10.000 λ (visível)

Diâmetro

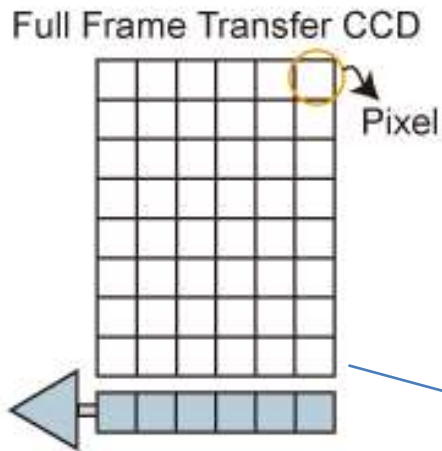


10 km

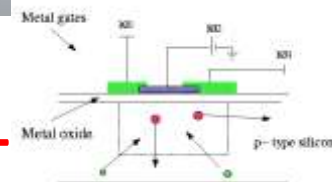
D = 30 m Freqüência 1400 MHz

$$\theta = 30'$$

Uma outra forma de ver

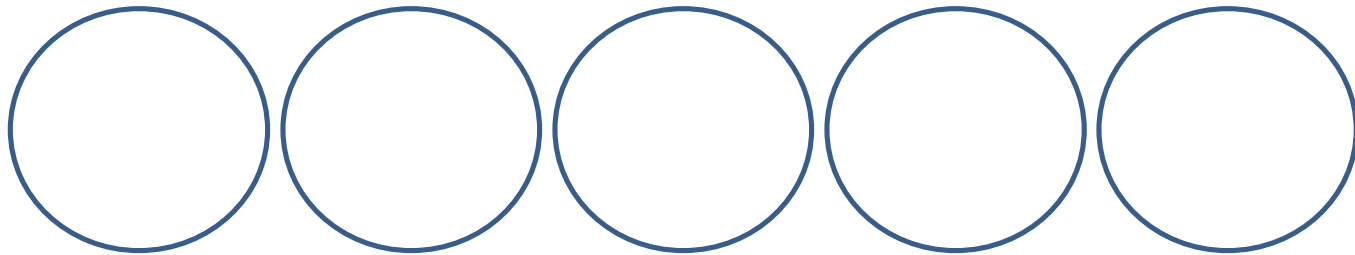


UM PIXEL



Como se olha o mundo com um pixel?

– Com muita paciência!



5volts

7volts

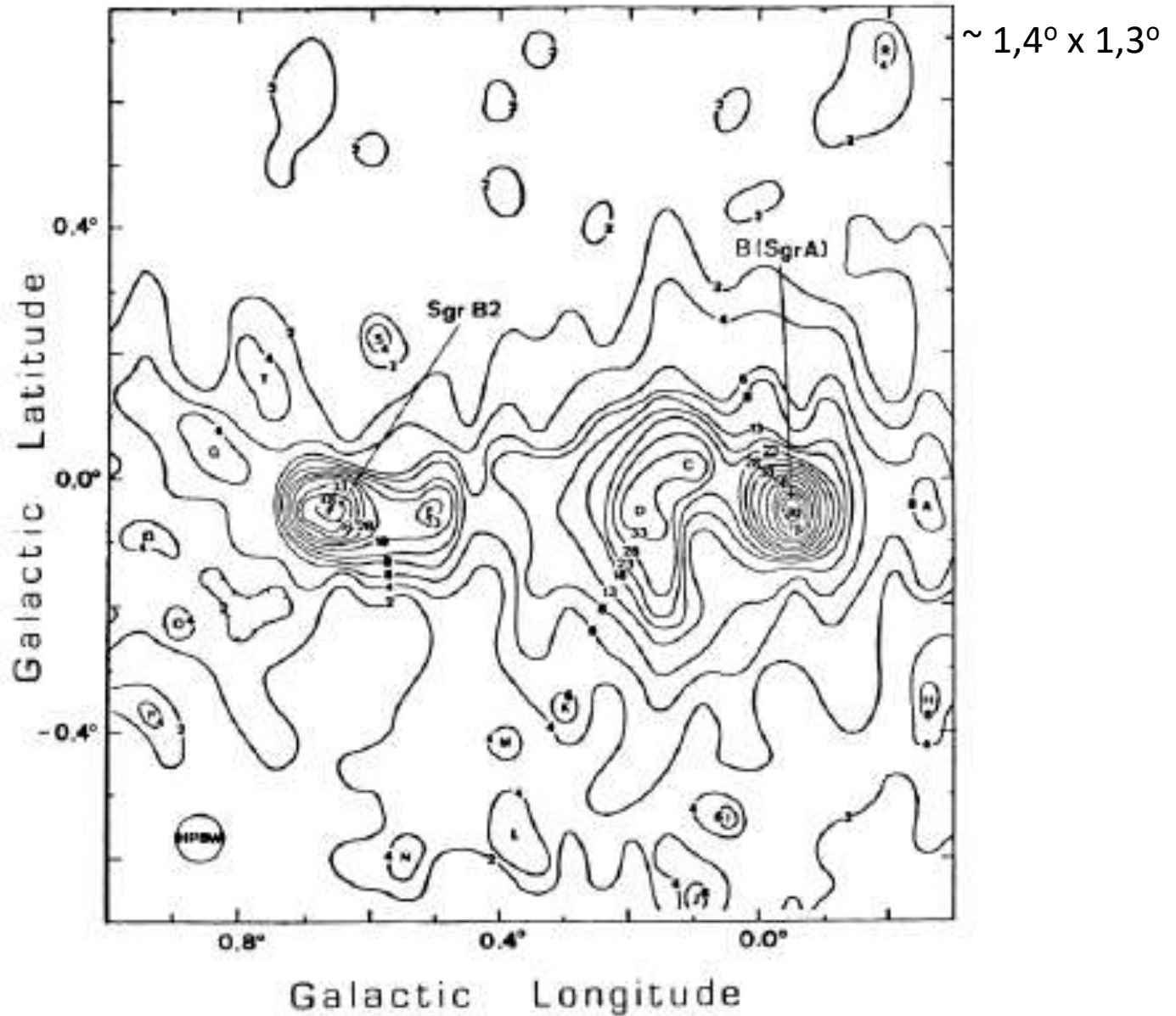
9volts

2volts

3volts

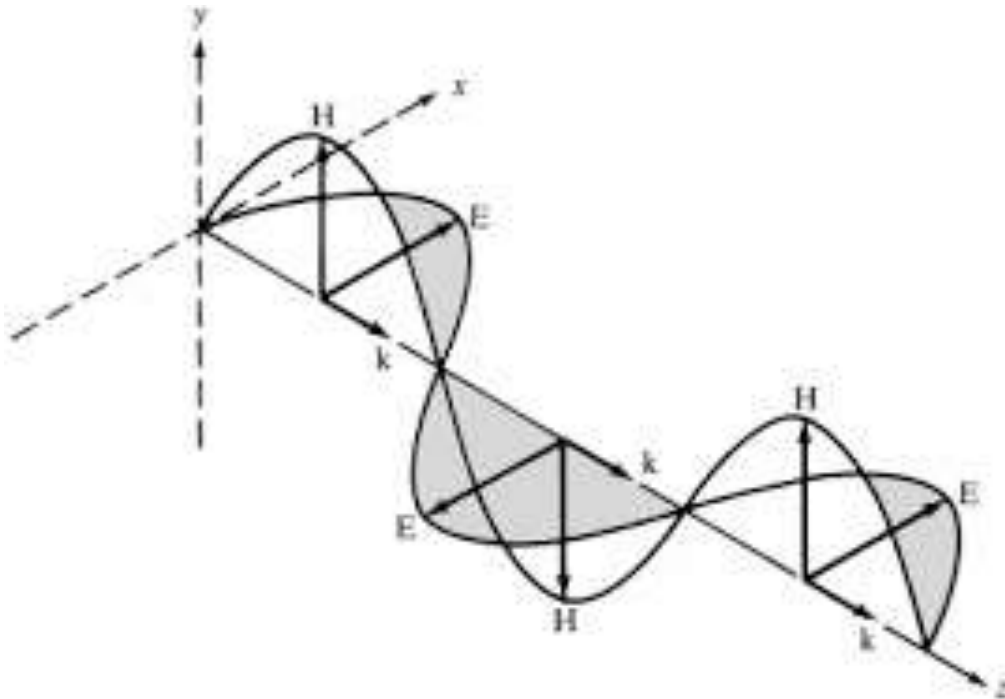
Mapa em 1.3 cm

Tateyama et al.
(1986)



Tratamento de luz como onda!

- Guia de onda!!!
 - Corneta!!
 - Circular ou Quadrada



Do infinito até seus olhos

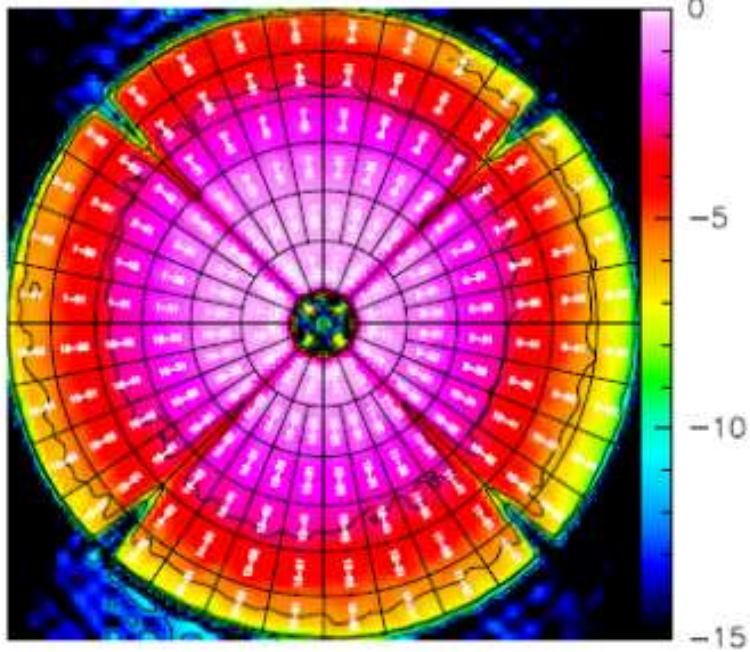
CAMINHO DA RADIAÇÃO

Fontes Típicas

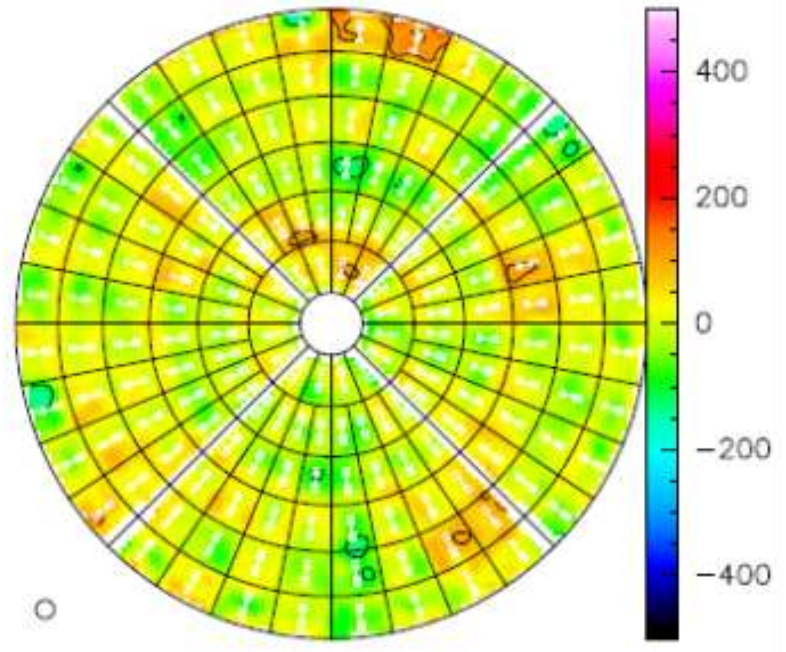
- Regiões HII
- Regiões HI (21cm, 1.42GHz)
- Linhas do CO (110.2 GHz, 230.5 GHz)
- Regiões Moleculares (Astroquímica)
- Remanescentes de Supernova
- Pulsares
- Quasares (AGNs)

PRATO!

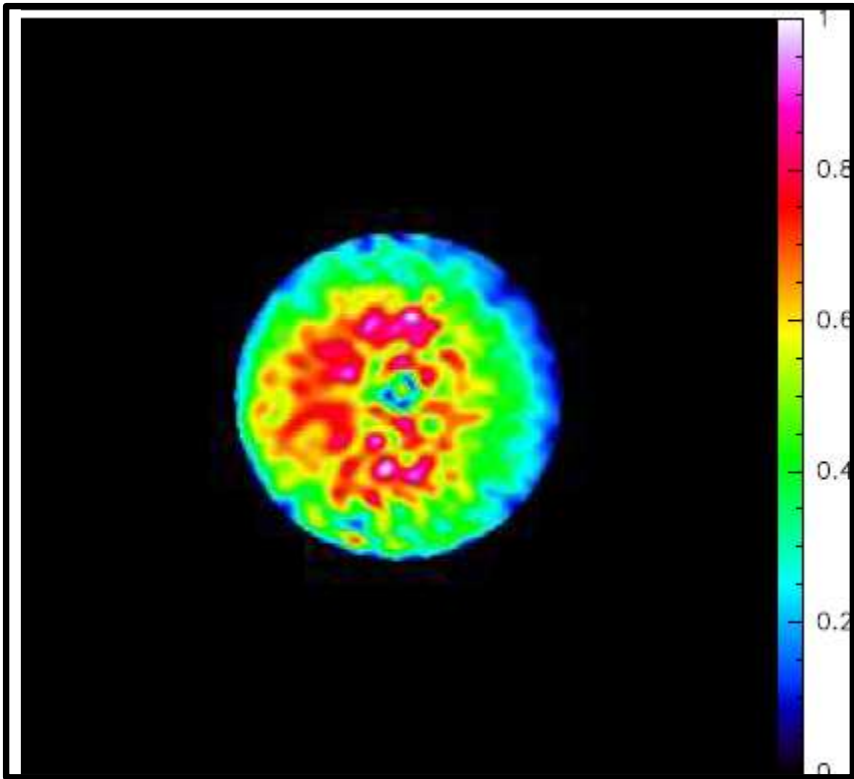
Amplitude (back view)
-15.000 to 0.000 by 3.000



Normal errors (back view)
-500.000 to 500.000 by 100.000



Efficiency



$$\eta_i = \frac{\int (F dA)^2}{\int F^2 dA}$$

Silver 1949, Baars 2007

$$\eta_a \sim \exp\left(\frac{-16\pi^2 \sigma^2}{\lambda^2}\right)$$

Roze equation
(Roze 1966)

Gaussian Fitting

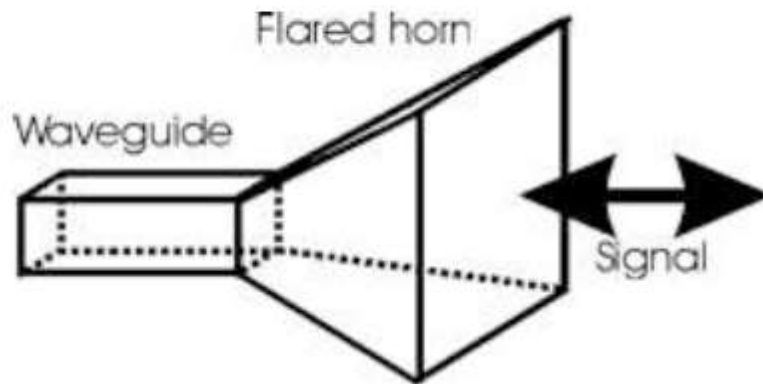
$$F = e^{-\alpha r^2}$$

$$\alpha = \frac{T}{20} \ln(10)$$

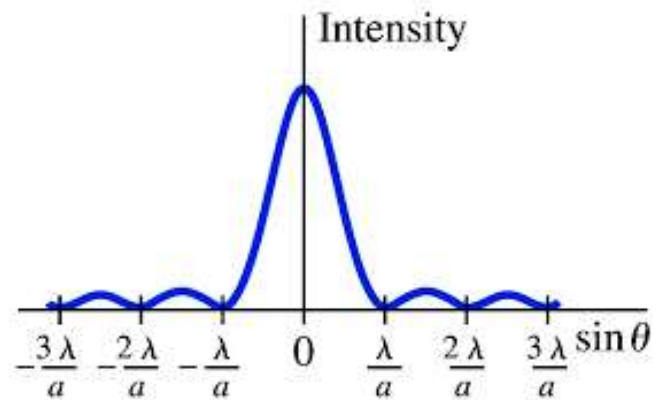
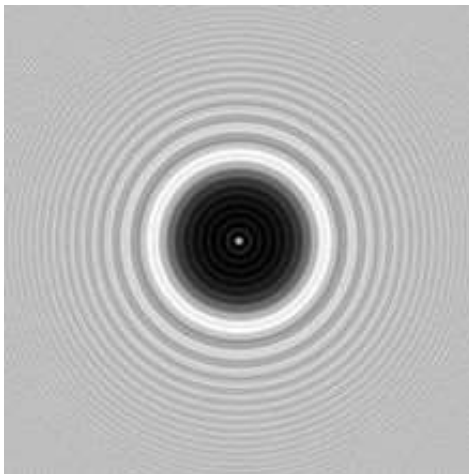
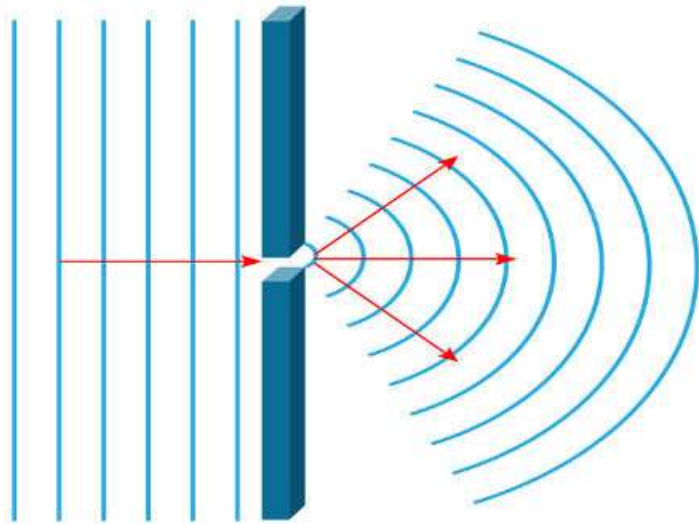
- Receiver Taper (T)
- Receiver Offset
- Surface rms

Receptor

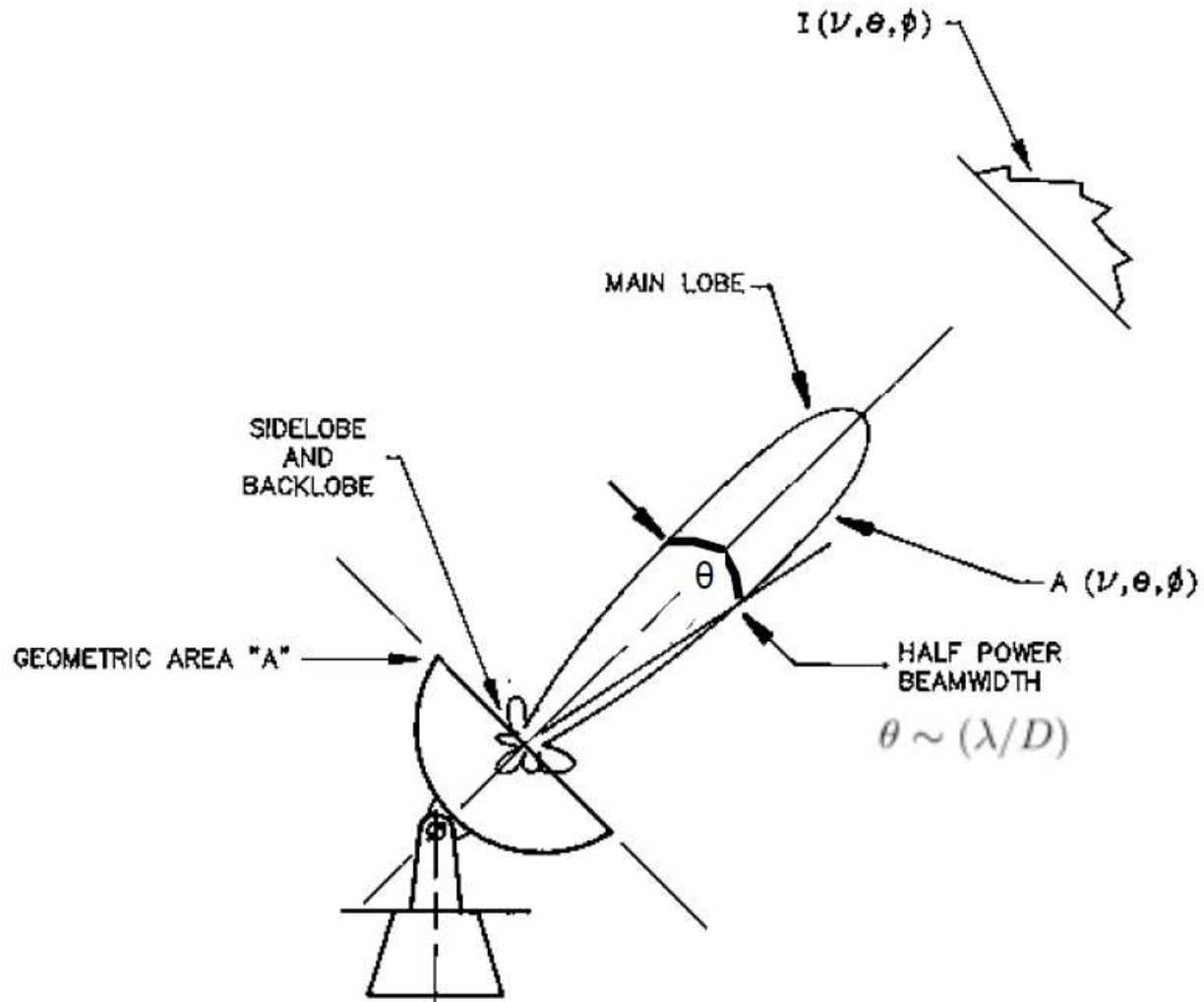
Cornetas e Guias de Onda



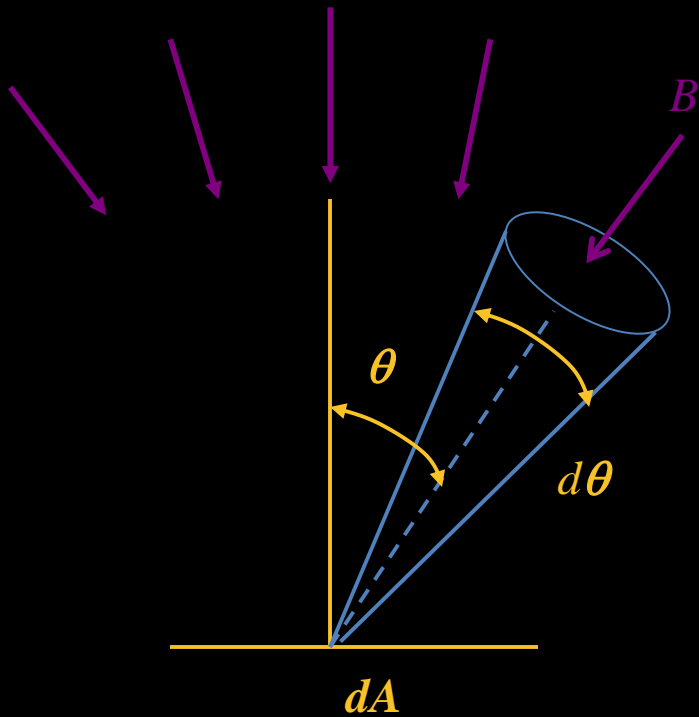
Luz como onda



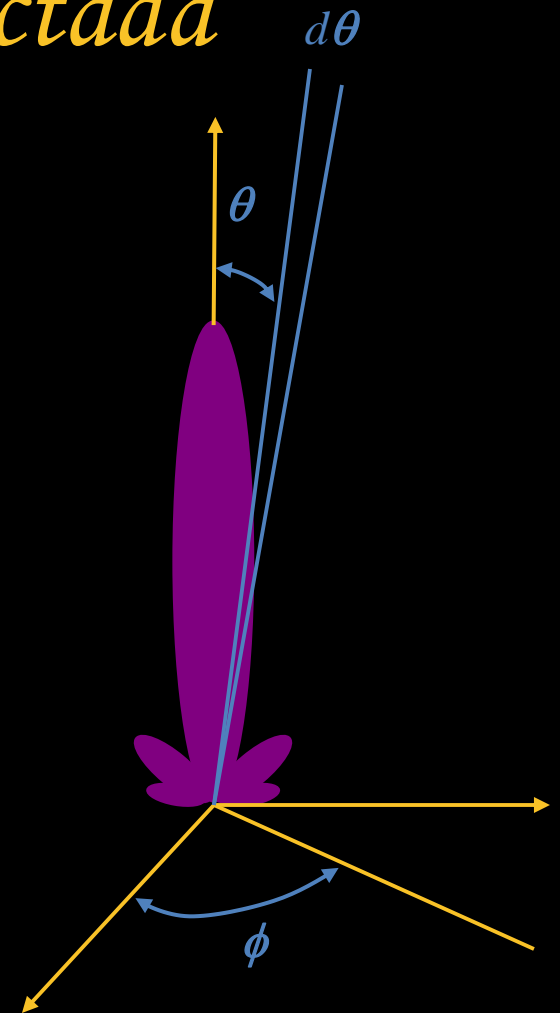
0 Feixe



Potência Espectral Detectada



$$dw = B(\theta, \phi) \cos \theta d\Omega dA$$



$$dw = B(\theta, \phi) P_n(\theta, \phi) d\Omega dA$$

$$W = \int w dv$$

$$dw = B(\theta, \phi) P_n(\theta, \phi) d\Omega dA$$

Se A é a área do radiotelescópio, a potência total detectada é:

$$w = \frac{1}{2} A_e \iint B(\theta, \phi) P_n(\theta, \phi) d\Omega$$

$A_e < A$ área efetiva do radiotelescópio

Se o brilho da fonte é constante

$$w = \frac{1}{2} A_e B_c \iint P_n(\theta, \phi) d\Omega = \frac{1}{2} A_e B_c \Omega_A$$

Ω_A é o tamanho do feixe do radiotelescópio

Densidade de Fluxo de uma fonte

$$S = \int_{\text{fonte}} B(\theta, \phi) d\Omega$$

intrinseca

$$S_0 = \int_{\text{fonte}} B(\theta, \phi) P(\theta, \phi) d\Omega$$

medida

Fontes pontuais ou discretas

$$\Omega \ll \Omega_A$$

Fontes extensas

$$\Omega \gg \Omega_A$$

$$S = \int_{\text{fonte}} B(\theta, \phi) d\Omega$$

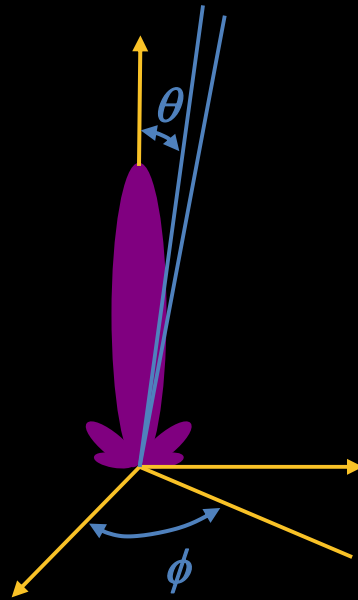
$$S_0 = \int_{\text{fonte}} B(\theta, \phi) P(\theta, \phi) d\Omega$$

Fontes Pontuais

Fontes Extensas

$$P(\theta, \phi) \approx 1$$

$$S = S_0$$



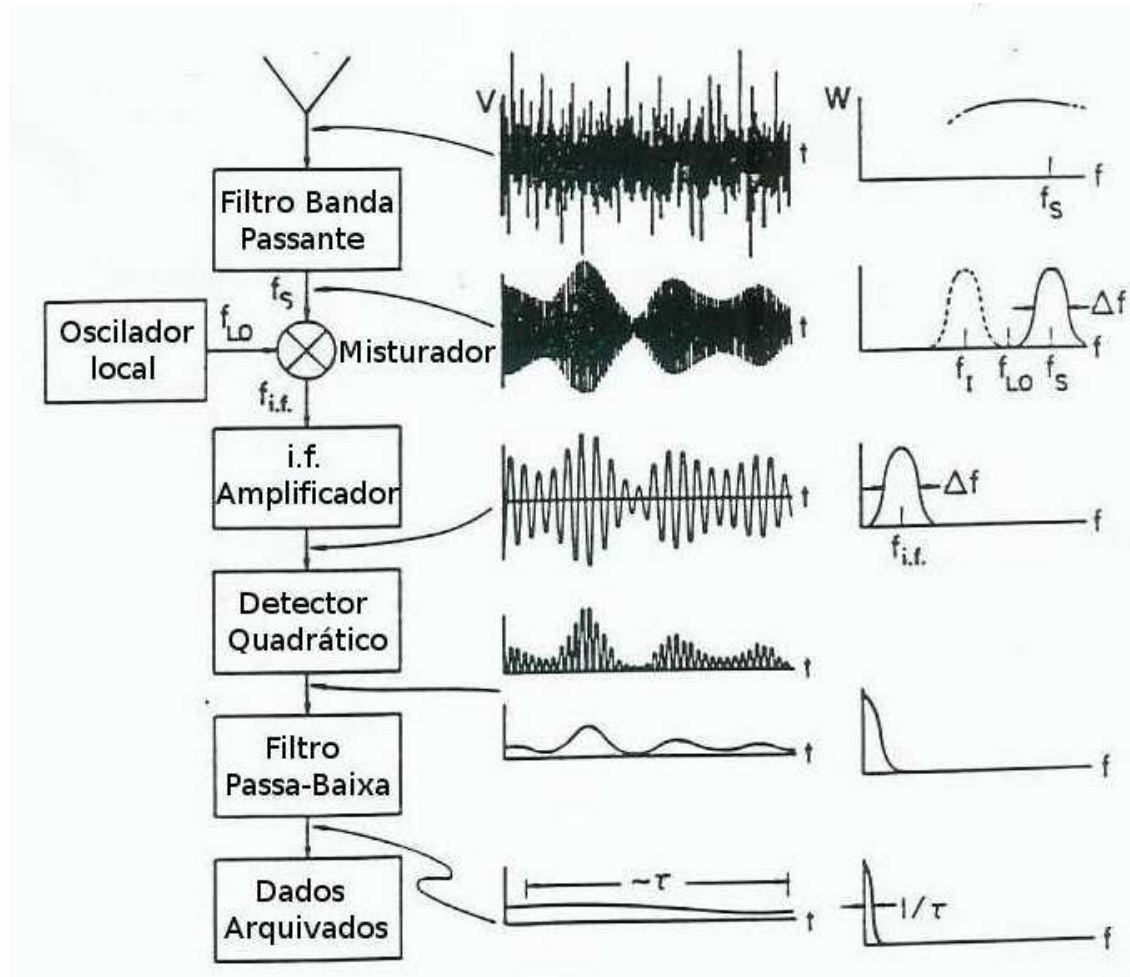
$$B(\theta, \phi) = \text{constante}$$

$$S_0 = B(\theta, \phi) \int_{\text{fonte}} P(\theta, \phi) d\Omega$$

$$S_0 = B(\theta, \phi) \Omega_M$$

Ω_M é o ângulo sólido do feixe principal

O Front-End



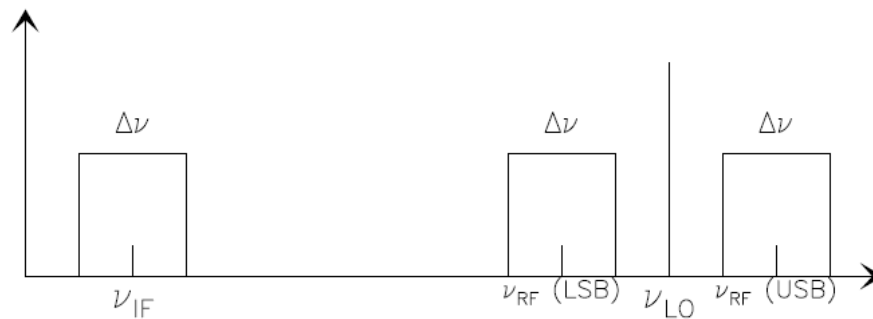
Oscilador Local

Princípio da superposição de ondas:

$$y_r(x, t) = y_1(x, t) + y_2(x, t)$$

Frequência do Oscilador Local Conhecida.

Uma com sinal positivo e outra com o sinal negativo



Receptores

- d.s.b – Double side band
- s.s.b – Single side band
- 2s.b. – both single band – Both sides useful

Back-end

Atenuadores



Voltímetros



GPS -Computadores



Computador
de Aquisição



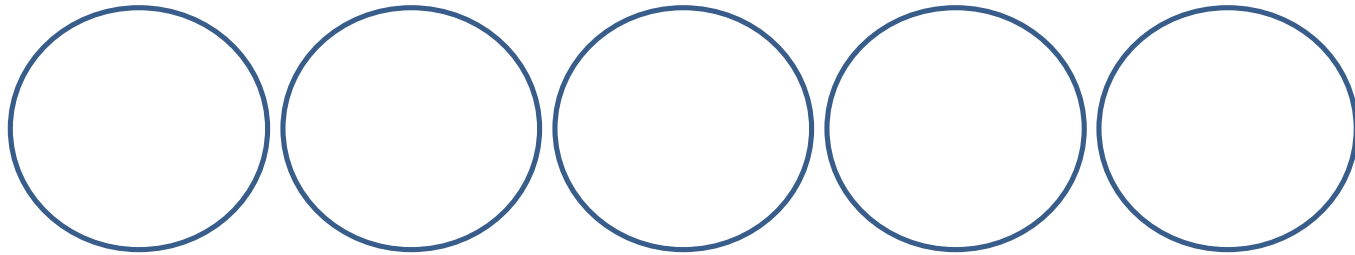
Computador
de Rastreo



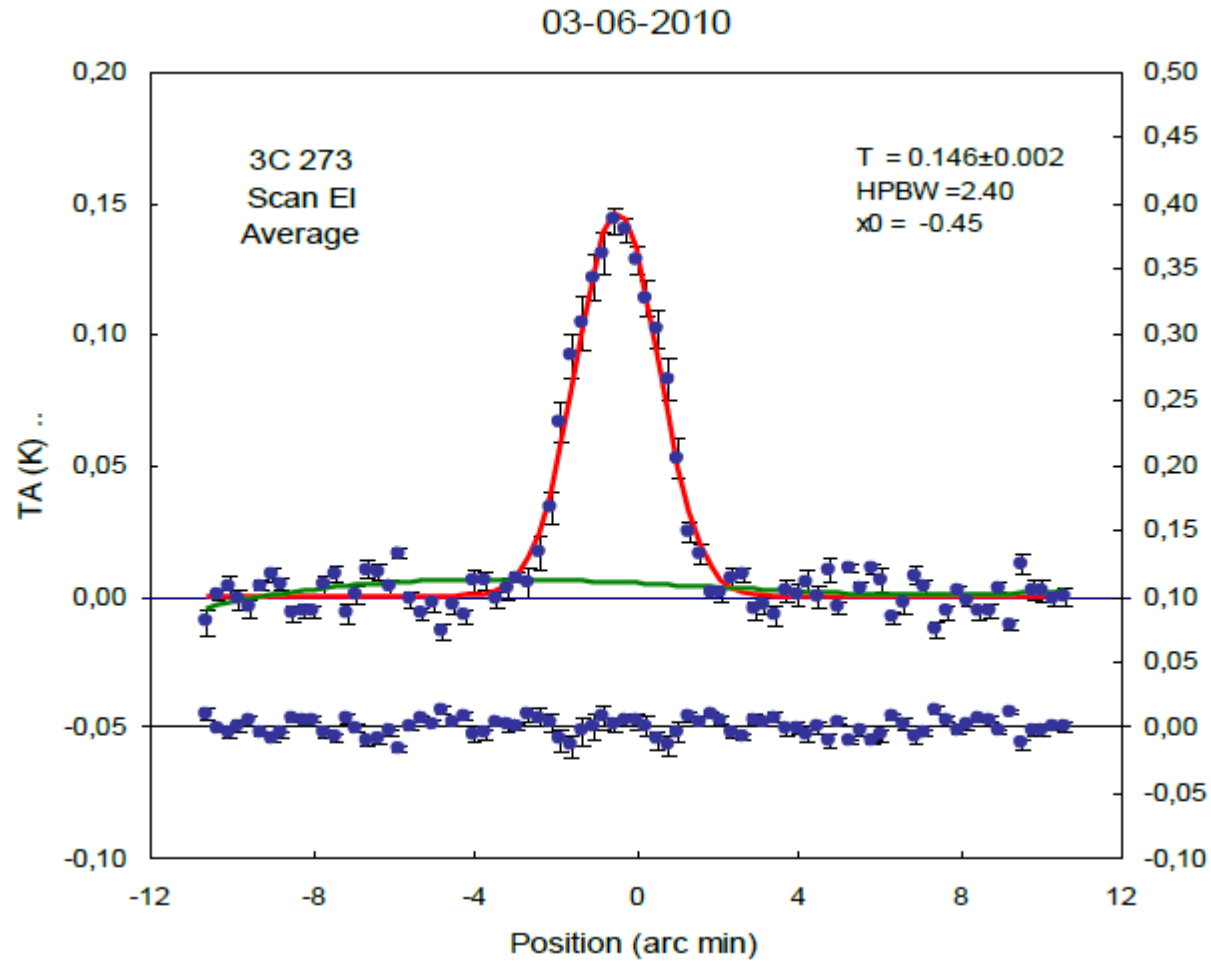
Métodos de Observação

- Vendo o mundo com um pixel!!
- Contínuo
 - Varredura (Scan ou on-the-fly)
- Espectro
 - Acusto-óptico
 - Multi-channel
 - Fourier (Mais moderno, usado em interferômetros)

Varredura



Fonte Pontual – Formato do Feixe



Como Calibrar a Voltagem?

- 1) É realizada uma observação do céu, sendo registrada a voltagem indicada;
- 2) É realizada a medida de uma fonte de ruído com uma temperatura conhecida;
- 3) É realizada uma medida do absorvedor, sendo utilizada uma carga a temperatura ambiente;
- 4) Por fim, é realizada uma nova observação do céu, sendo realizada a média com a primeira medida.

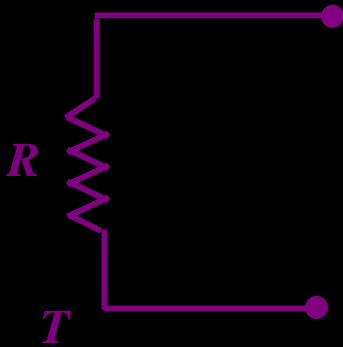


LOAD

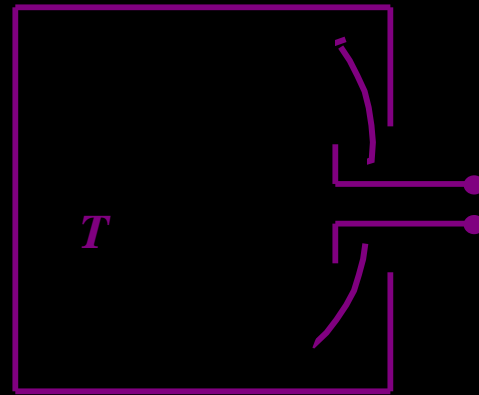
Temperaturas de brilho e de antena

$$T_B = \frac{B\lambda^2}{2k}$$

temperatura de brilho



$$w = kT$$

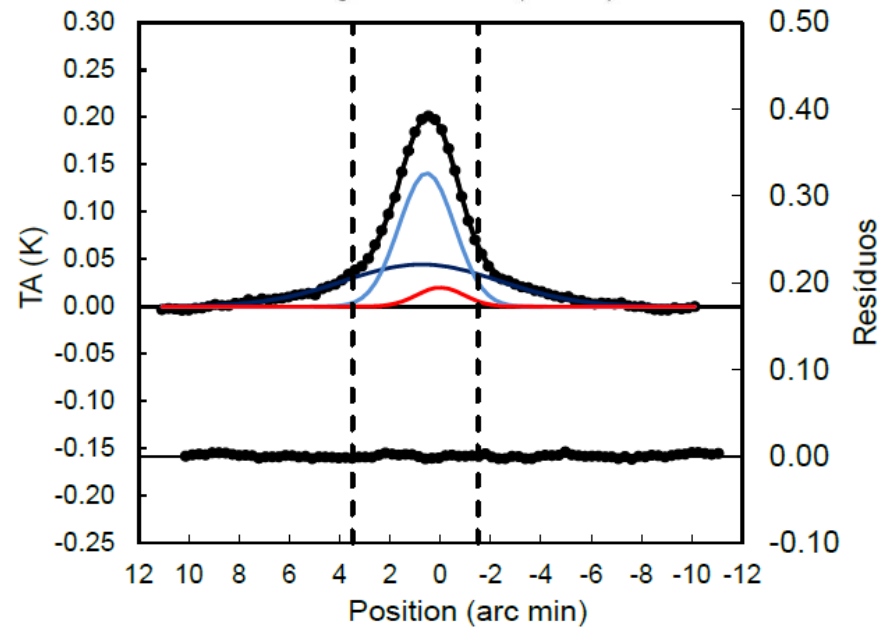
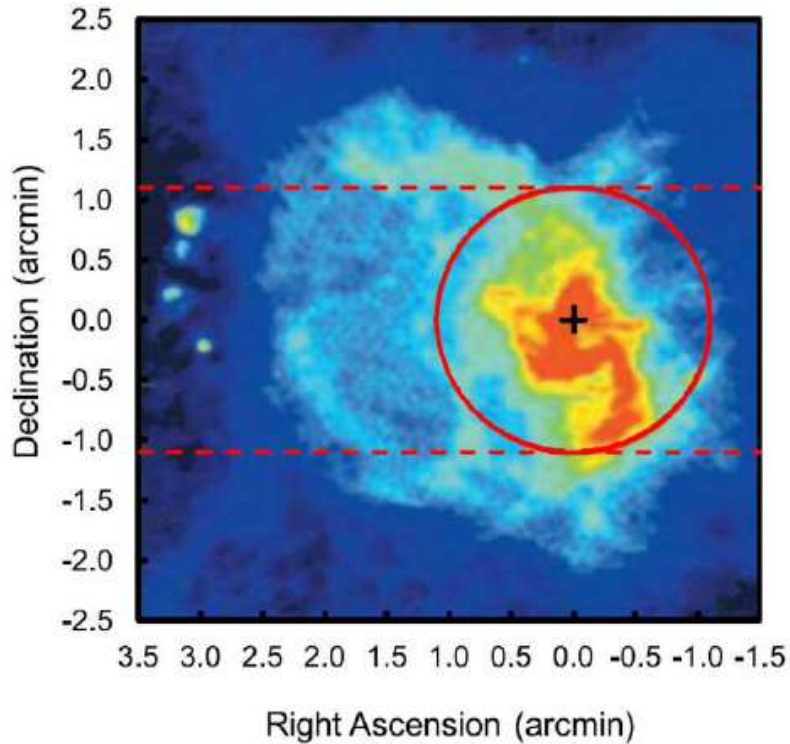


$$B(\theta, \phi) = B_0 = \frac{2kT}{\lambda^2}$$

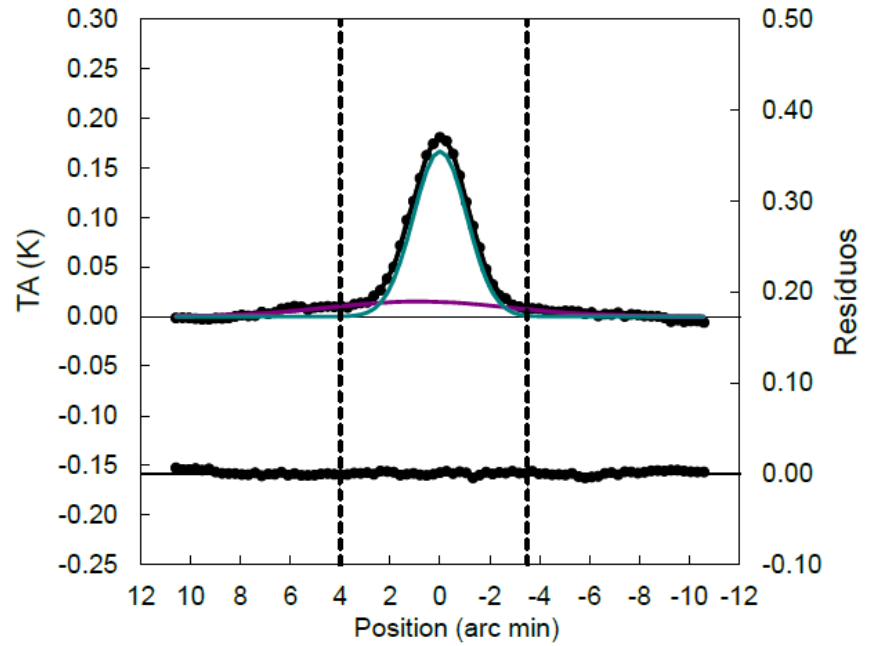
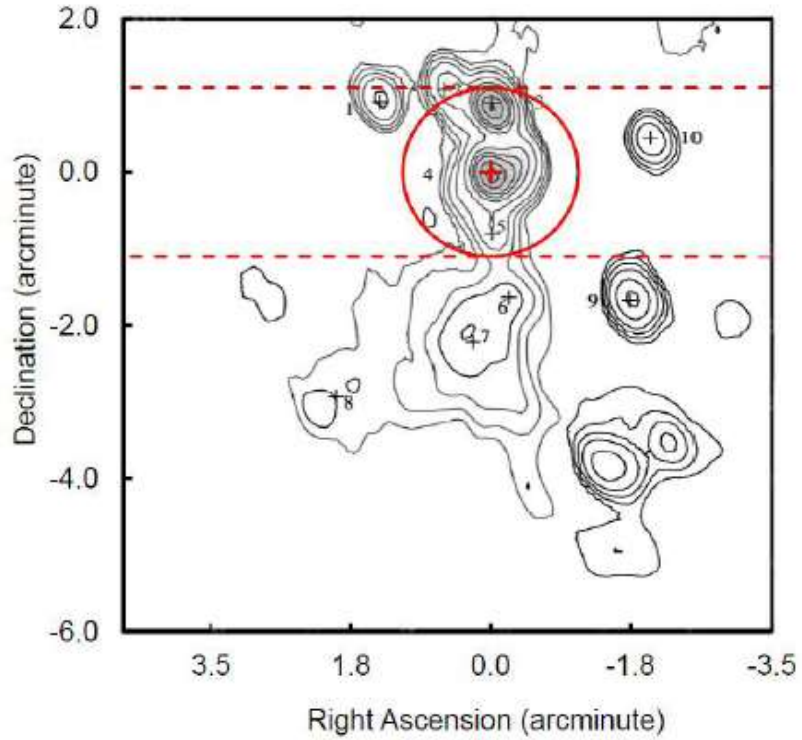
Utilizando uma calibradora

- Primeiro, com a calibração de voltagem passamos para Temperatura de Antena
- Com uma calibradora de fluxo em Jy conhecido, passamos para Jy
- Mas como vemos o mundo para caso de fontes não pontuais???

Centro Galáctico



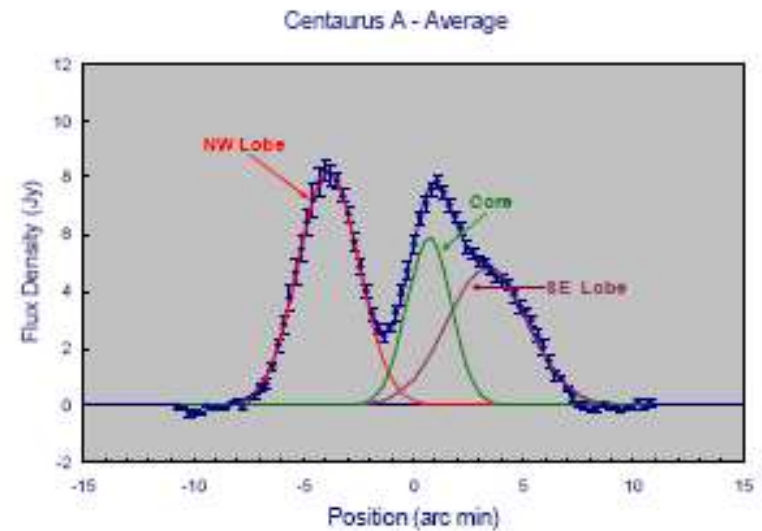
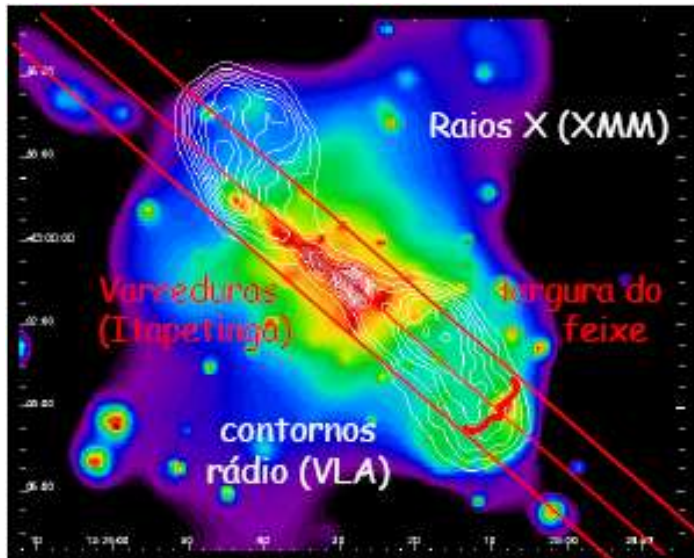
SgrB2 Main



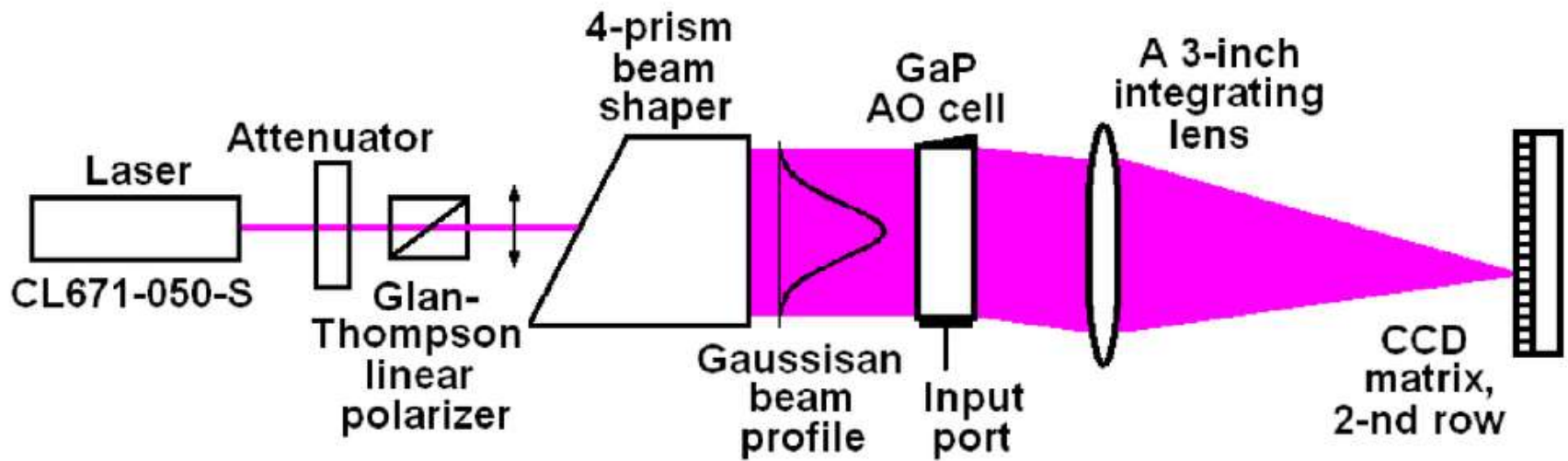
Centaurus A



Centaurus A



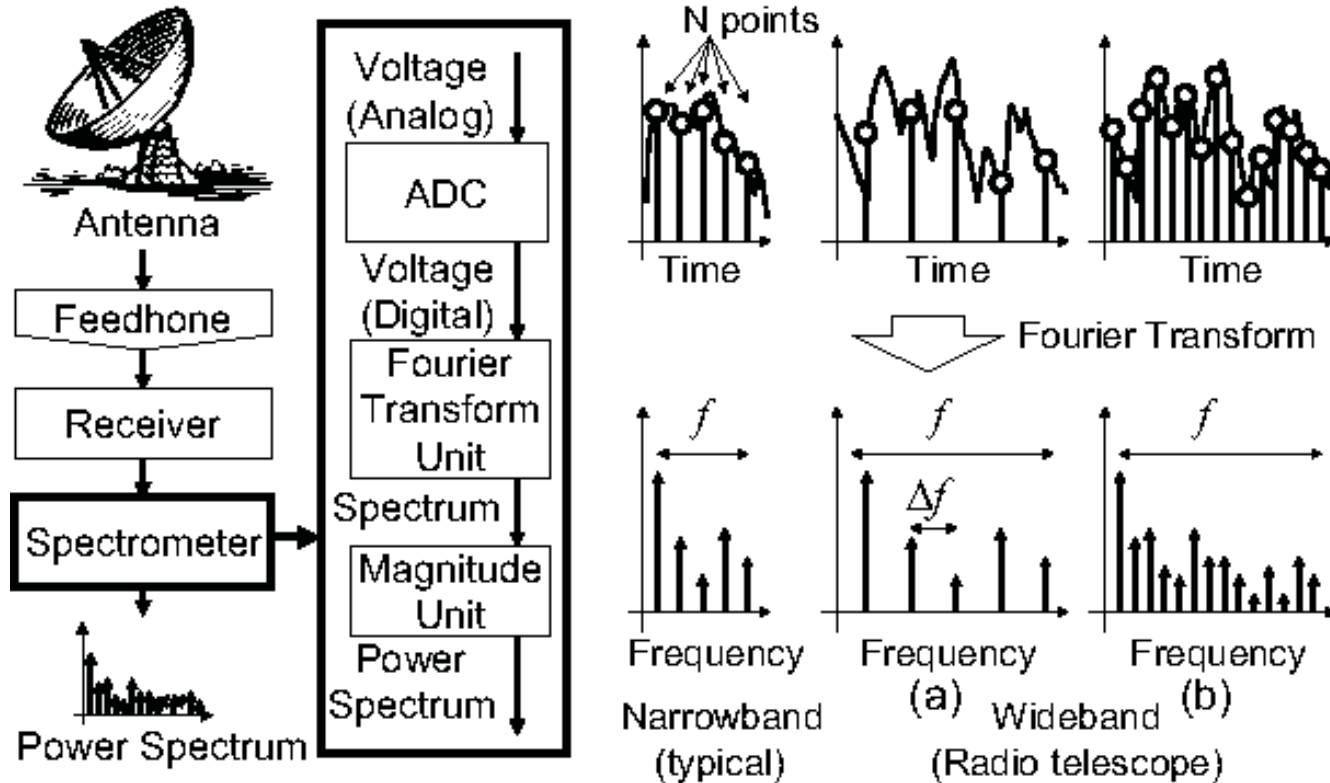
Espectro – Acusto-óptico



Espectro - Multicanais



Fourier



[Hiroki Nakahara](#), [Hiroyuki Nakanishi](#), [Tsutomu Sasao](#)

Published in SIGARCH Computer Architecture News 2012

DOI:[10.1145/2460216.2460225](https://doi.org/10.1145/2460216.2460225)

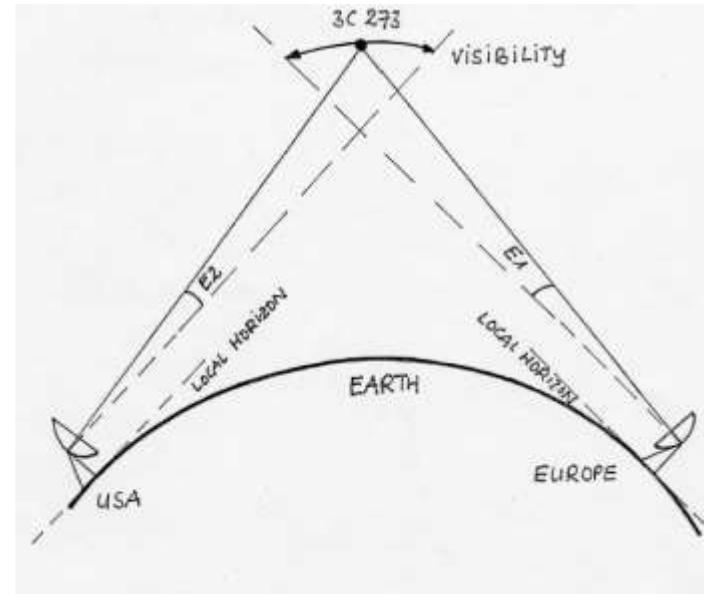
Métodos de Observação

- On-the-fly
- Multi-beam
- On-off
- On-on
- On-off síncronico



Diacho

- Radioastronomia
 - Voltagem – Temperatura de Antena – Fluxo.
- Mas e a imagem?
 - Mapas de baixa resolução usando varredura
- Mas e as imagens lindas que eu vejo????



Quem já ouviu falar??

INTERFEROMETRIA

Vamos Lembrar??

Poder de resolução

$$\theta \propto \frac{\lambda}{D}$$

λ (rádio) > 10.000 λ (visível)

Diâmetro



10 km

D = 30 m Freqüência 1400 MHz

$\theta = 30'$



=



Images: EHT Collaboration, Paper I – The shadow of the SMBH.



Images: EHT Collaboration, Paper I – The Shadow of the SMBH.

Interferometria

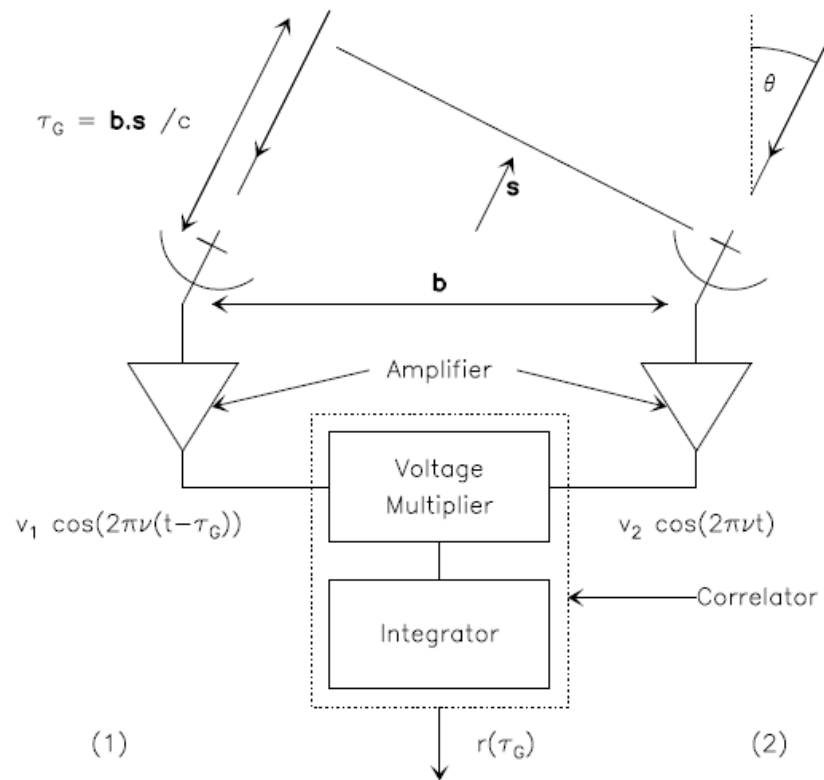


Figure 2.2: Schematic Diagram of a two-element interferometer

Qual o sinal que sai?

$$\begin{aligned} r &= d\nu (\cos(2\pi\nu\mathbf{b}\cdot\mathbf{s}_o/c)|V| \cos(\Phi_V) - \sin(2\pi\nu\mathbf{b}\cdot\mathbf{s}_o/c)|V| \sin(\Phi_V)) \\ &= d\nu|V| \cos(2\pi\nu\tau_G - \Phi_V) \end{aligned}$$

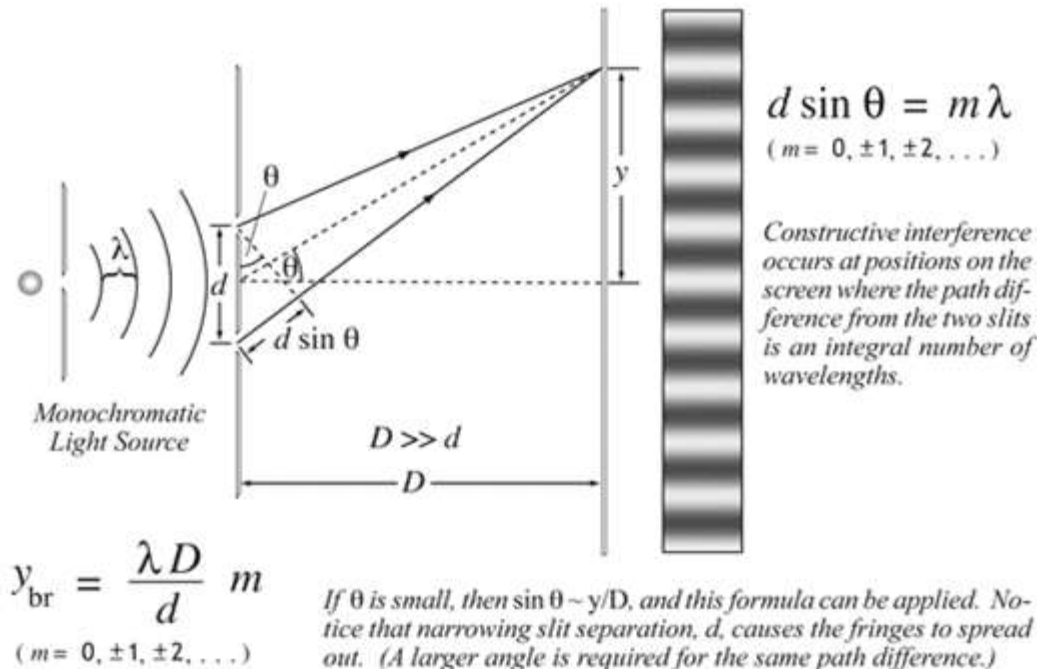
Continua sendo uma voltagem



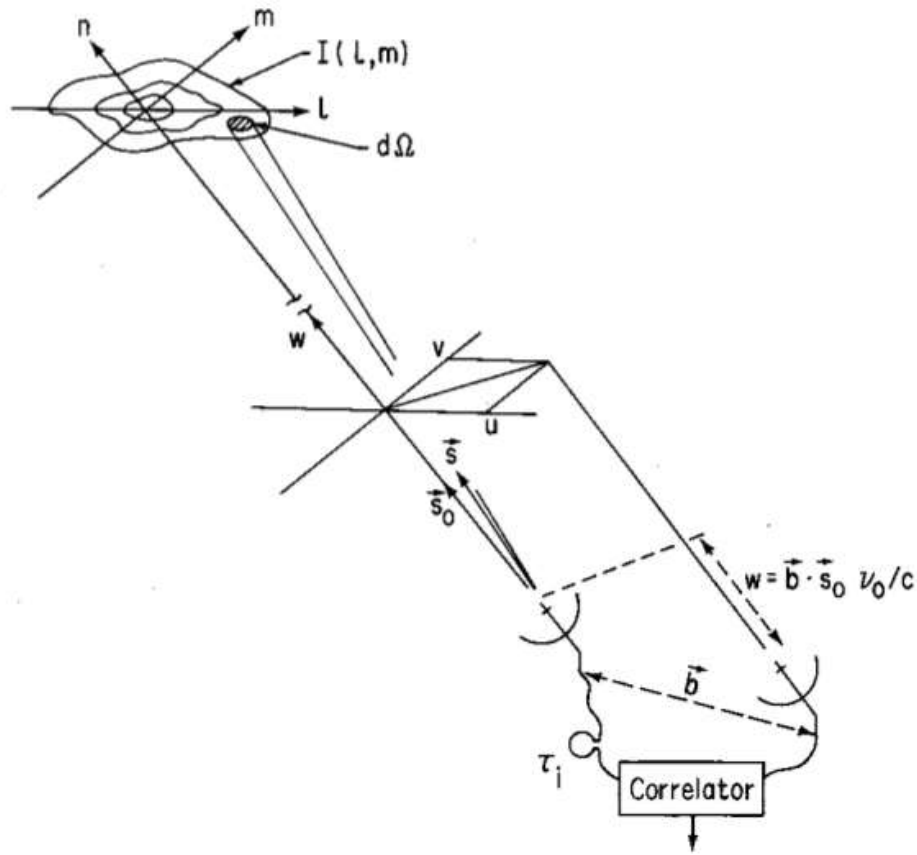
Representa uma franja!



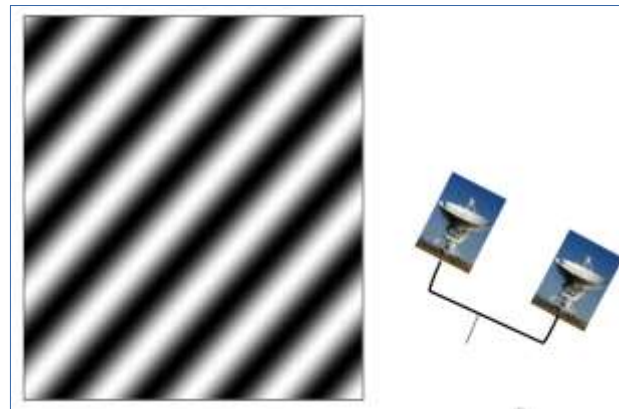
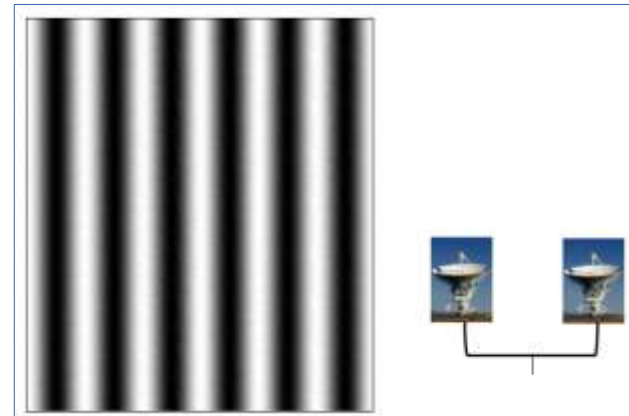
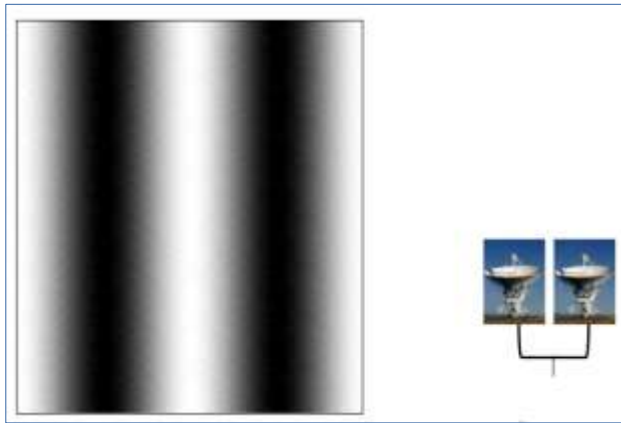
Young's Double Slit Interference



Como produzir uma imagem?

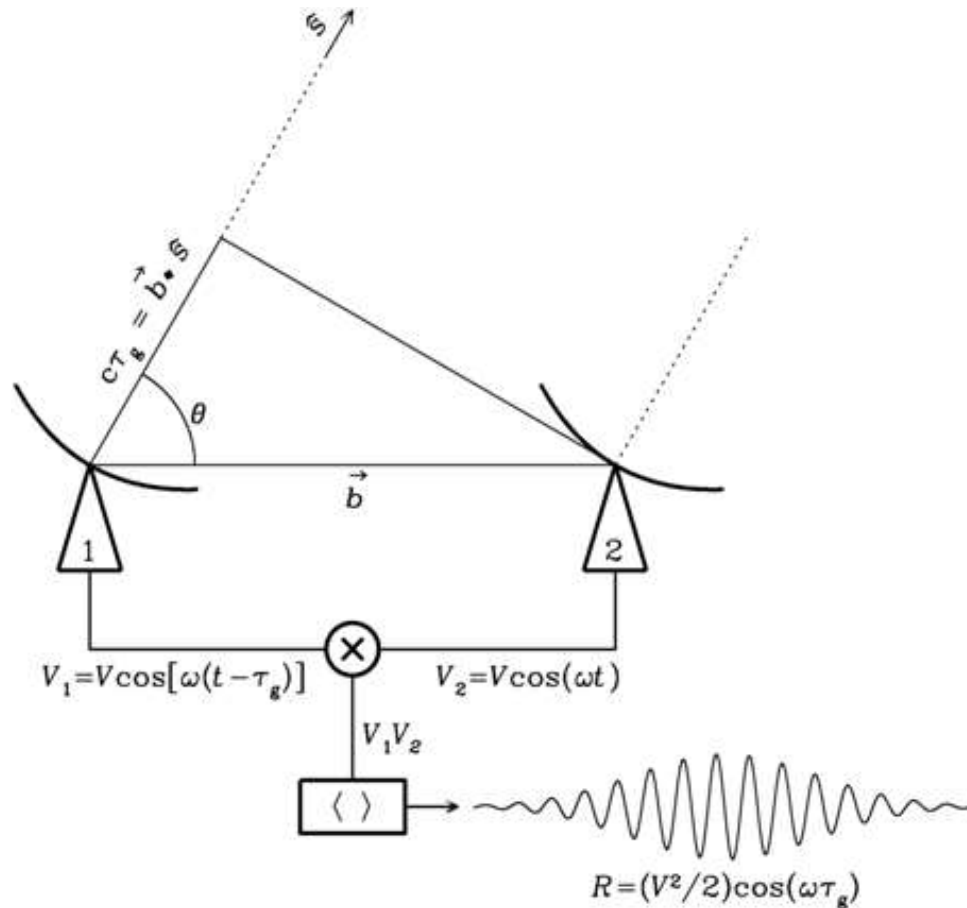


Para cada Par de Antena, uma franja

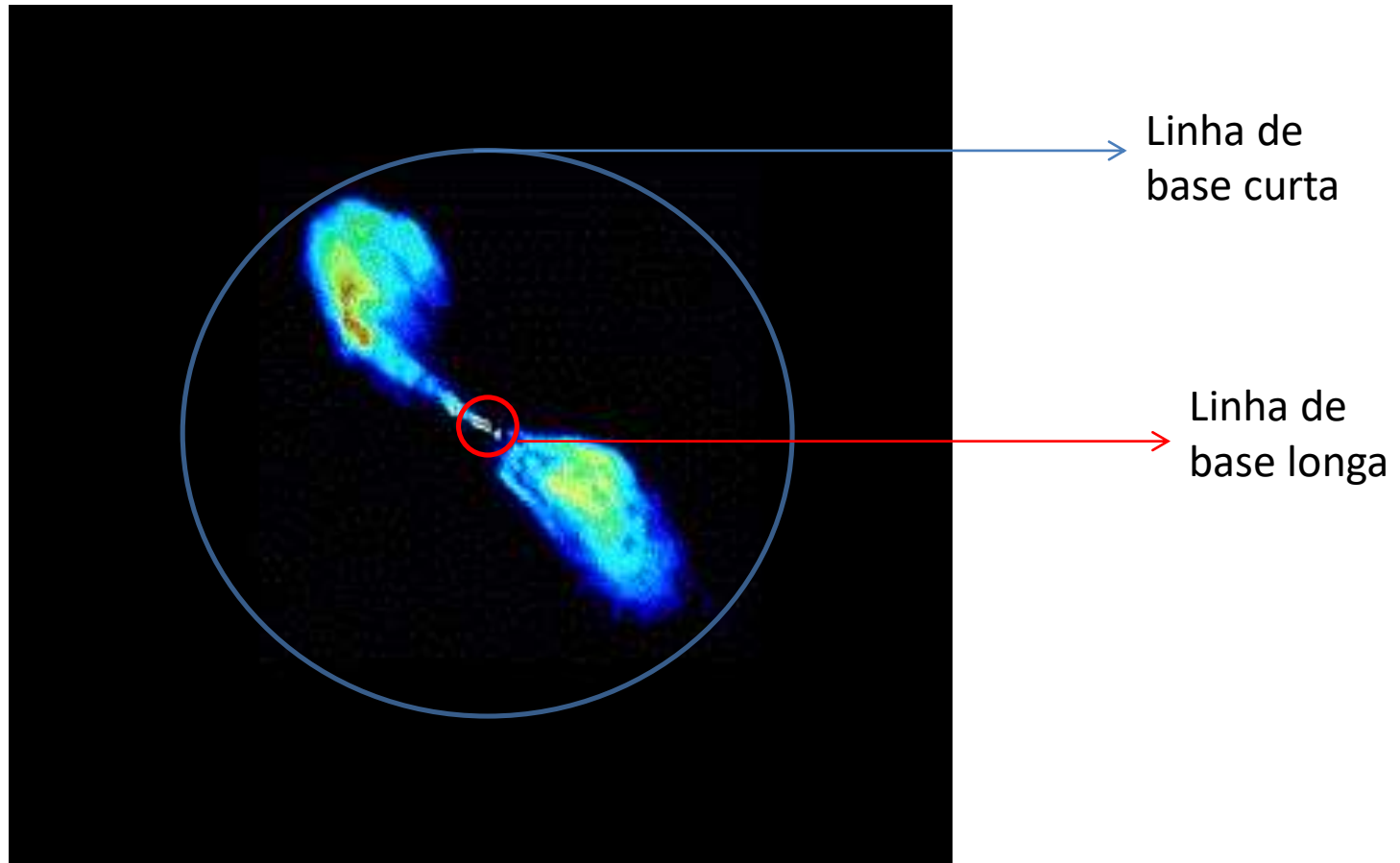


Figuras de Dra. Juliana Motter (IF/UFRGS)

Para cada tempo, uma linha de base diferença

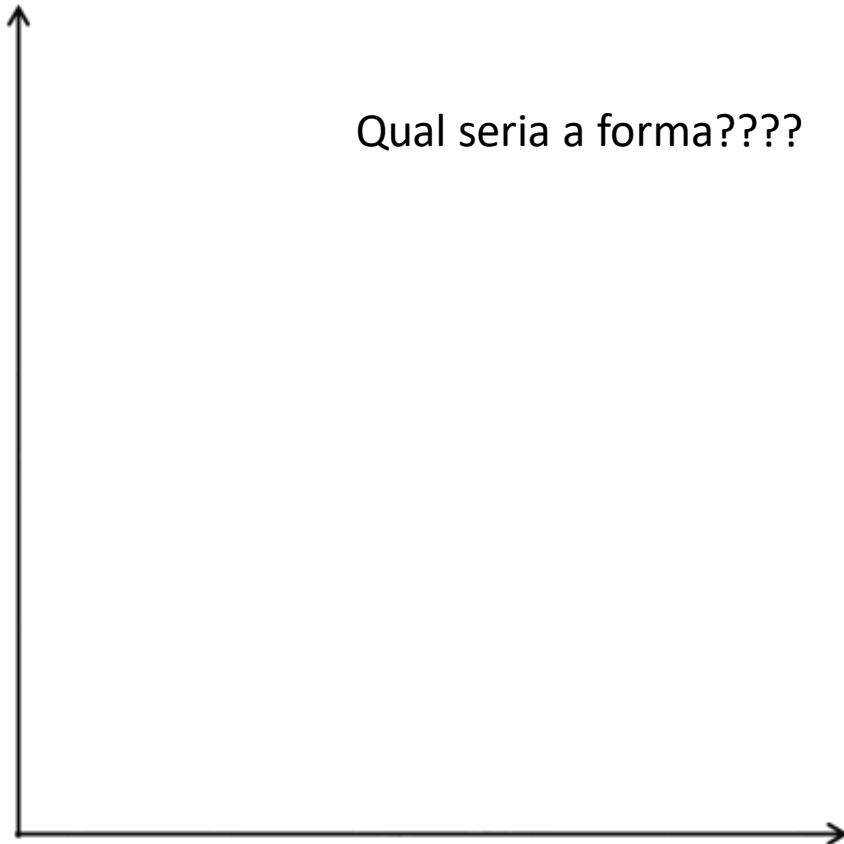


Cada Feixe pra fonte!



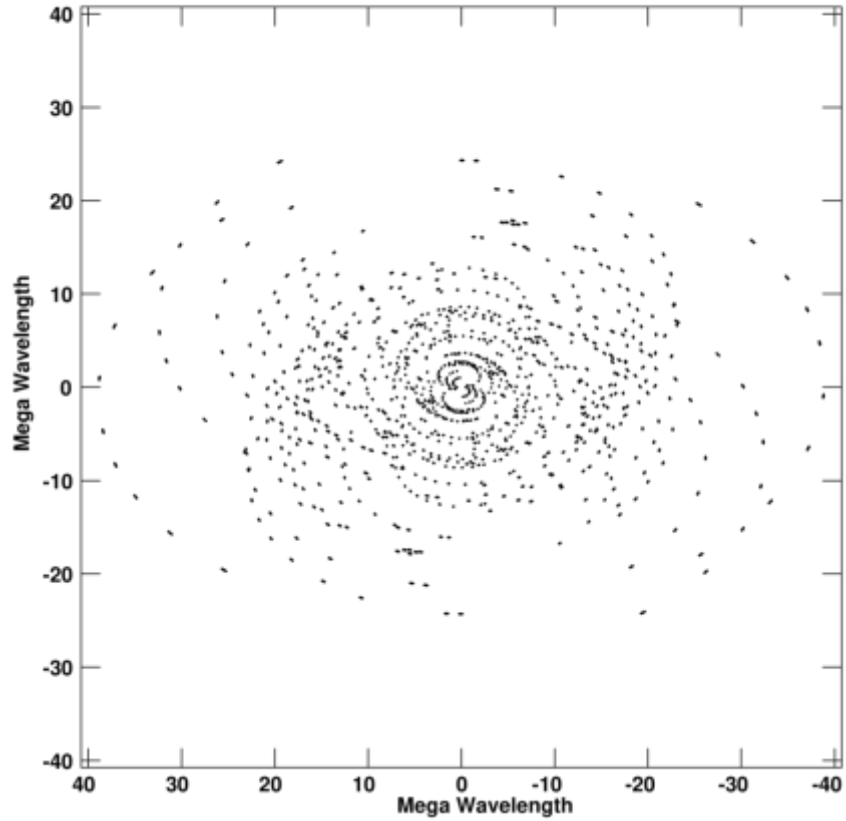
Vamos Fazer o Plot!

Intensidade – Linha de base

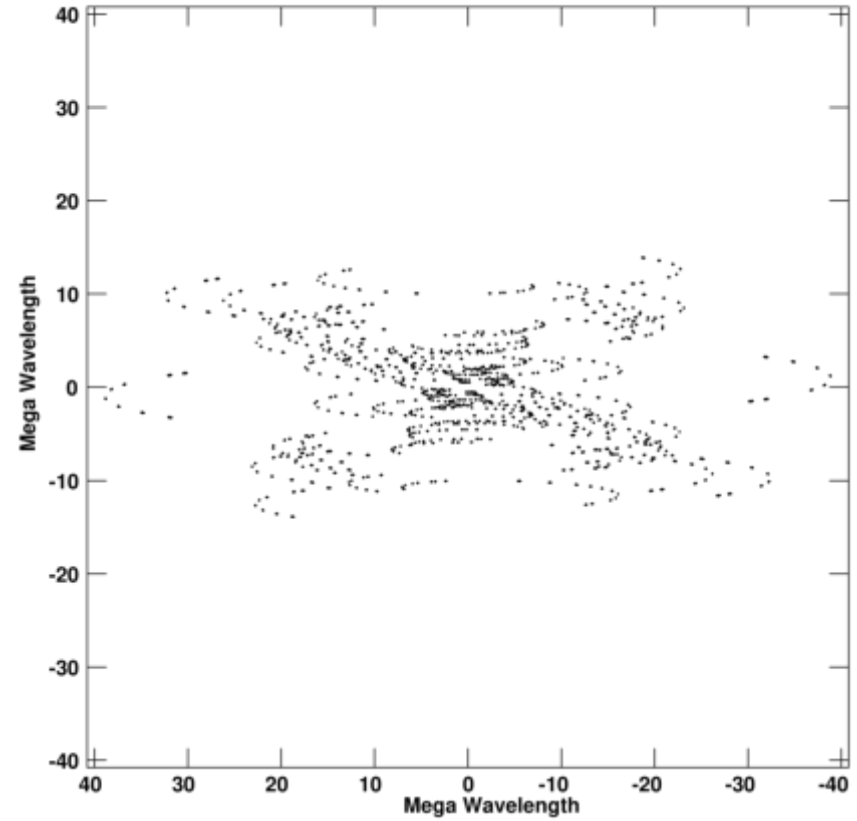


Cobertura uv

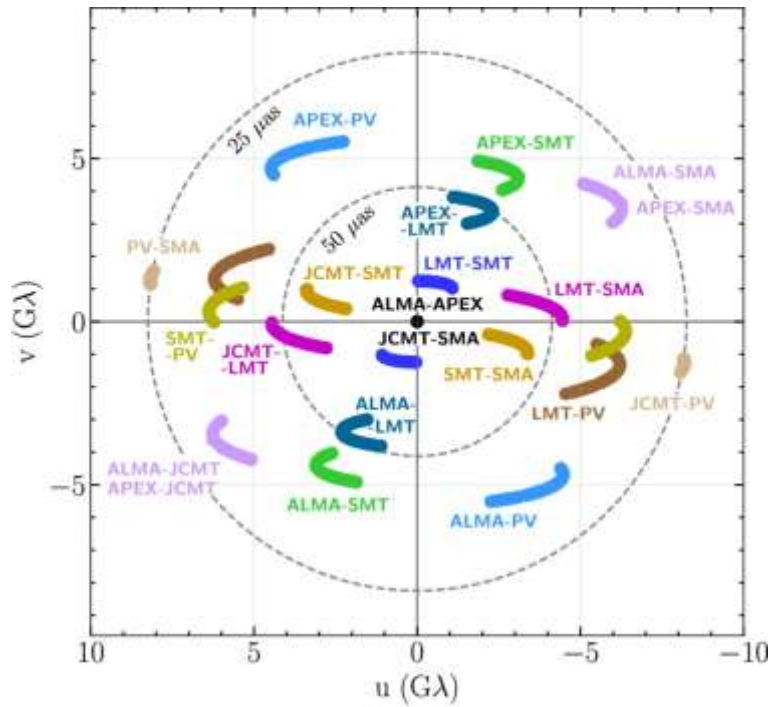
Plot V vs U - Source: 3C 345



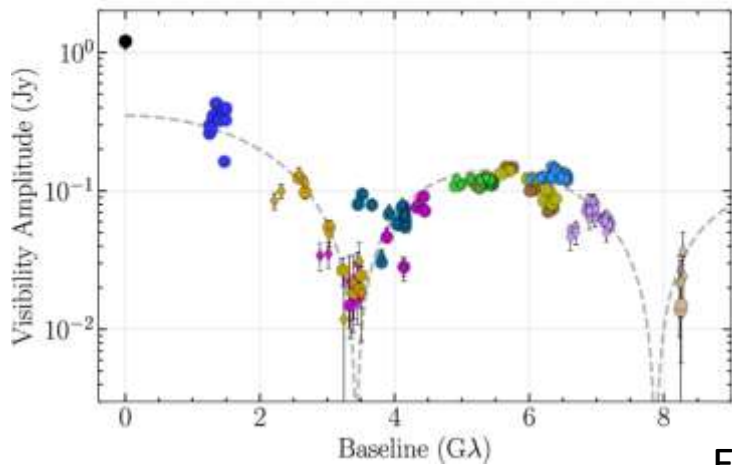
Plot V vs U - Source: 3C 279



Sin x / x

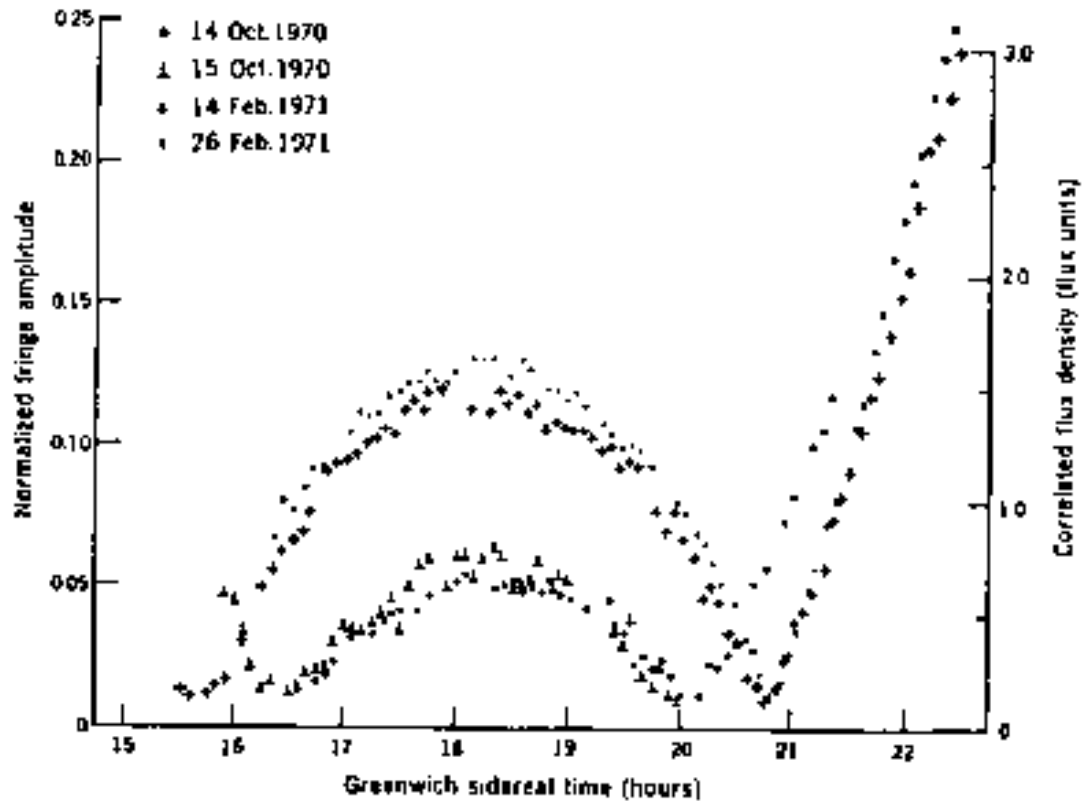


M87 Black Hole Shadow



EHT Collaboration et al. 2019

Precisa image gear?



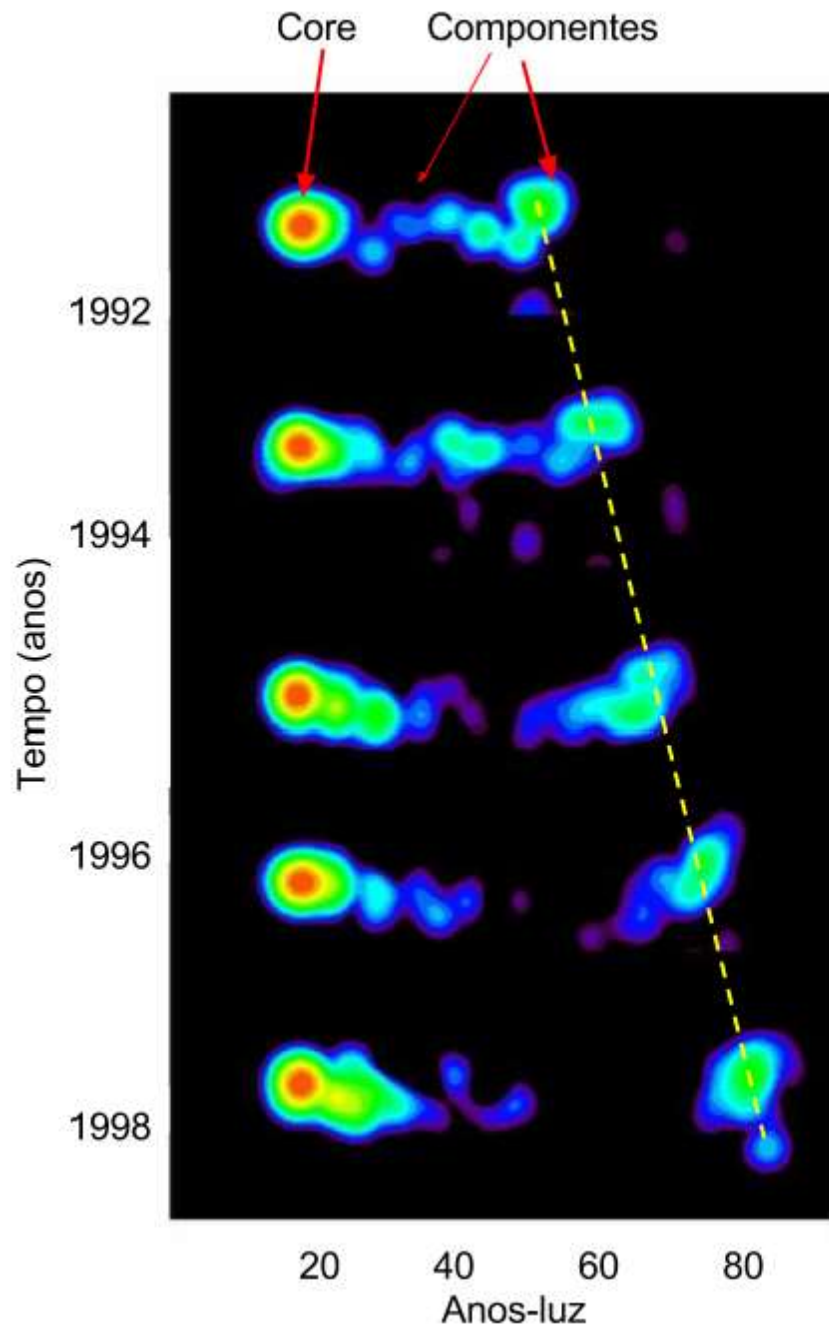
Whitney et al. 1971

Mas como chegar na imagem??

- Imageamento
 - Supõe uma fonte pontual
 - Convolue com o feixe
 - Tenta ajustar sua franja
 - Supõe outra fonte pontual. Veja se melhorou
 - Por aí vai...

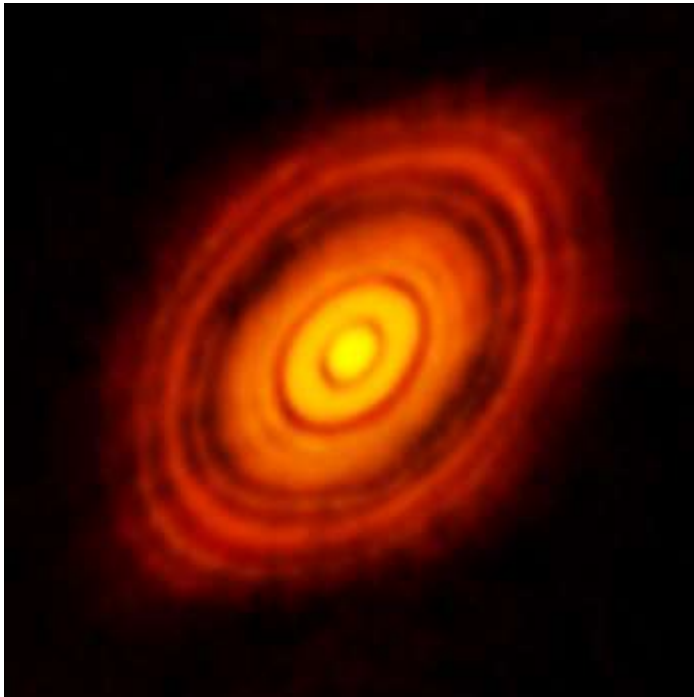
(Hoogbom 1974)

Jato de 3C279

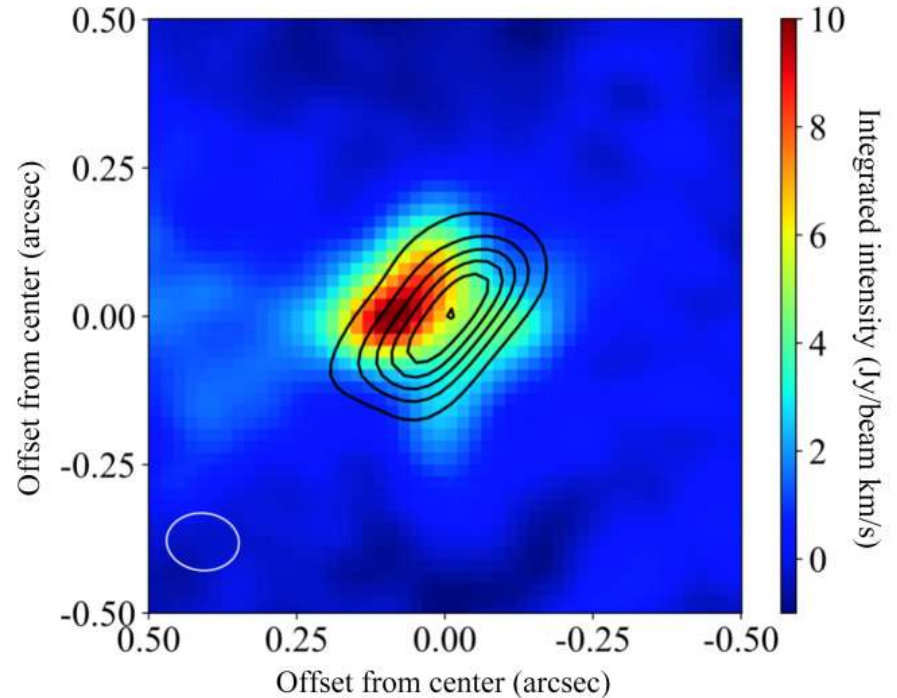


Motter 2017

Imagens em Rádio



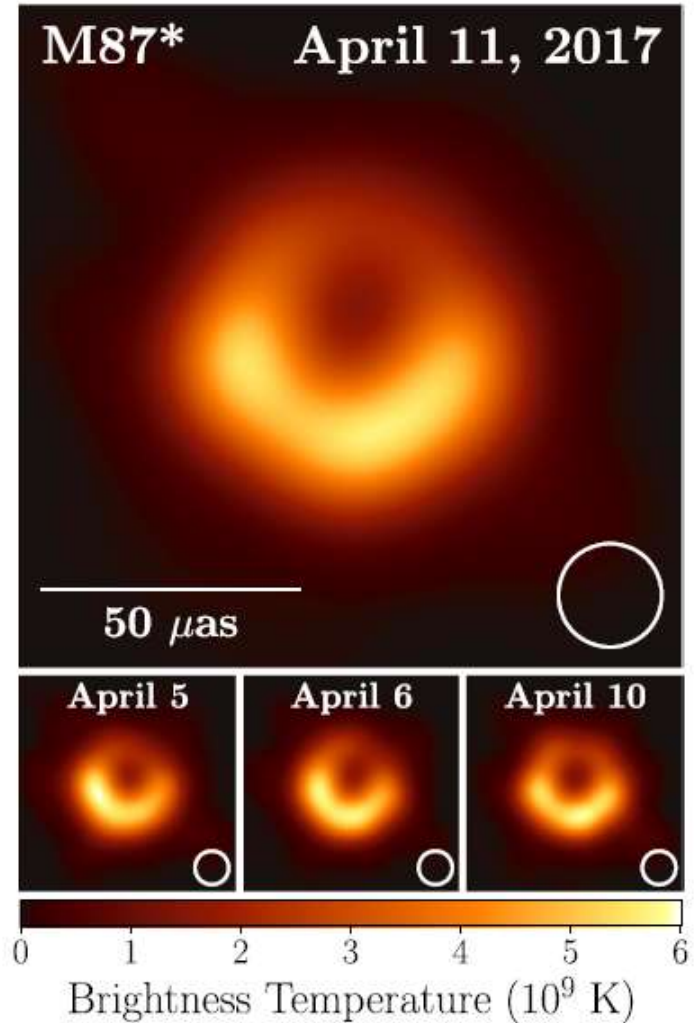
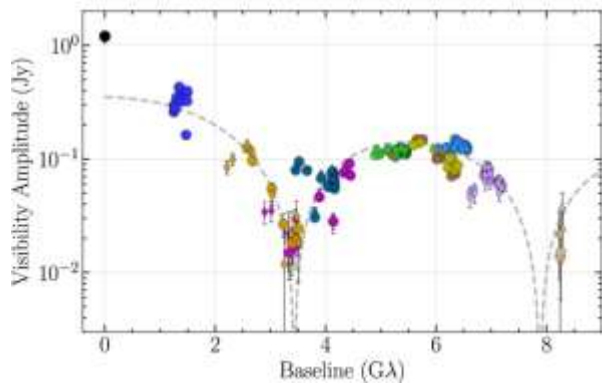
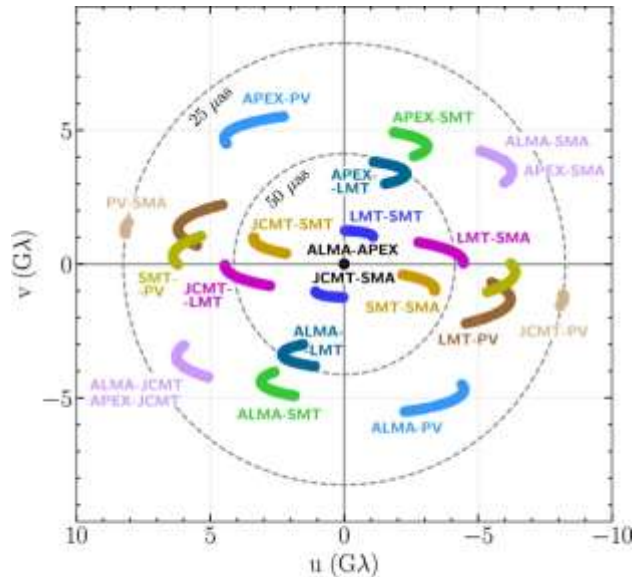
Disco proto-planetário



Alumínio em estrela
jovem

Fonte das imagens: Site do ALMA (press-releases)

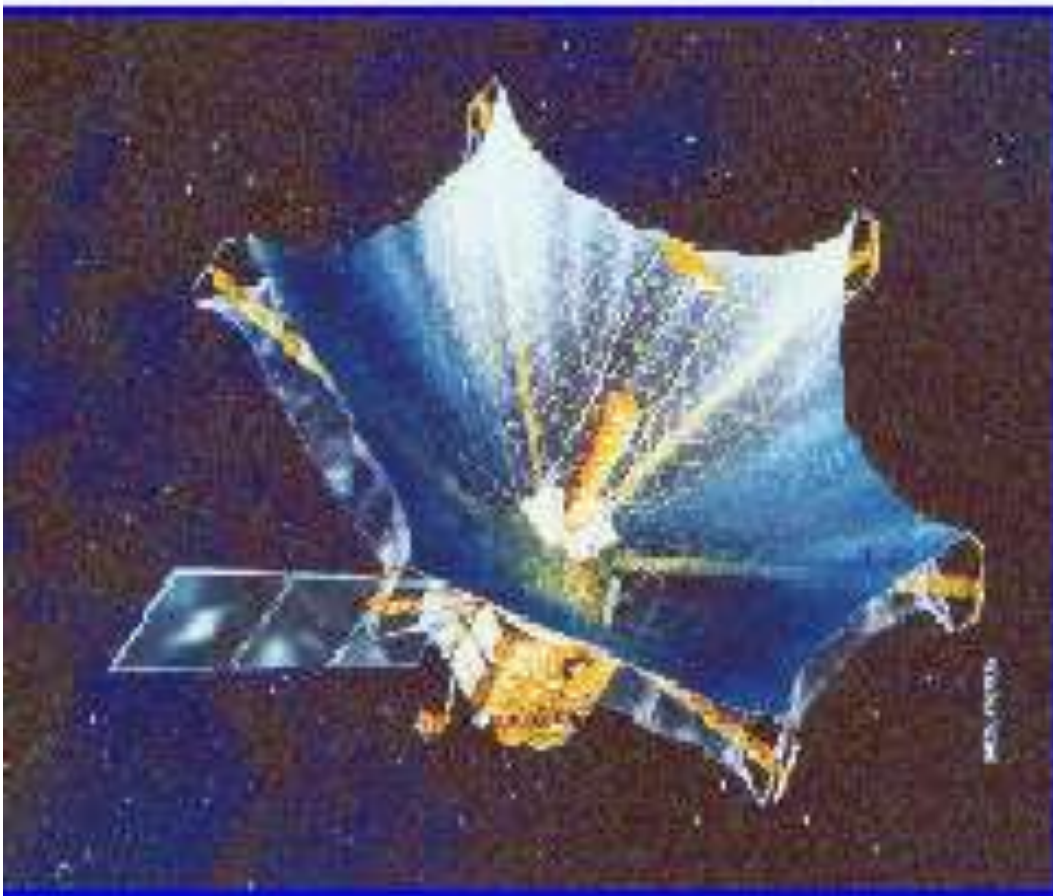
Imagem do Black Hole



O que é VLBI? O que é Interferômetro

- Large
 - Phase cable
 - ALMA
 - VLA
 - NOEMA
- Long
 - Maser Clock – Closure Phase
 - VLBI - Very Long Baseline Interferometer
 - VLBA
 - EHT

E é possível por no Espaço?



VSOP:

Vantagens e
Problemas??

Próximas Fronteiras

- Qual é a próxima fronteira tecnológica?
 - Aumentar a Frequência (10 anos)
 - VLBI espacial (30 anos)
 - Melhorar a cobertura uv (5 anos)

Resumindo

- Baixa frequência
 - Maior comprimento de onda
 - Pior resolução
- Possível técnicas interferométricas
 - Resolução jamais atingida pela humanidade em 1.3 mm (50 μ arcsec)