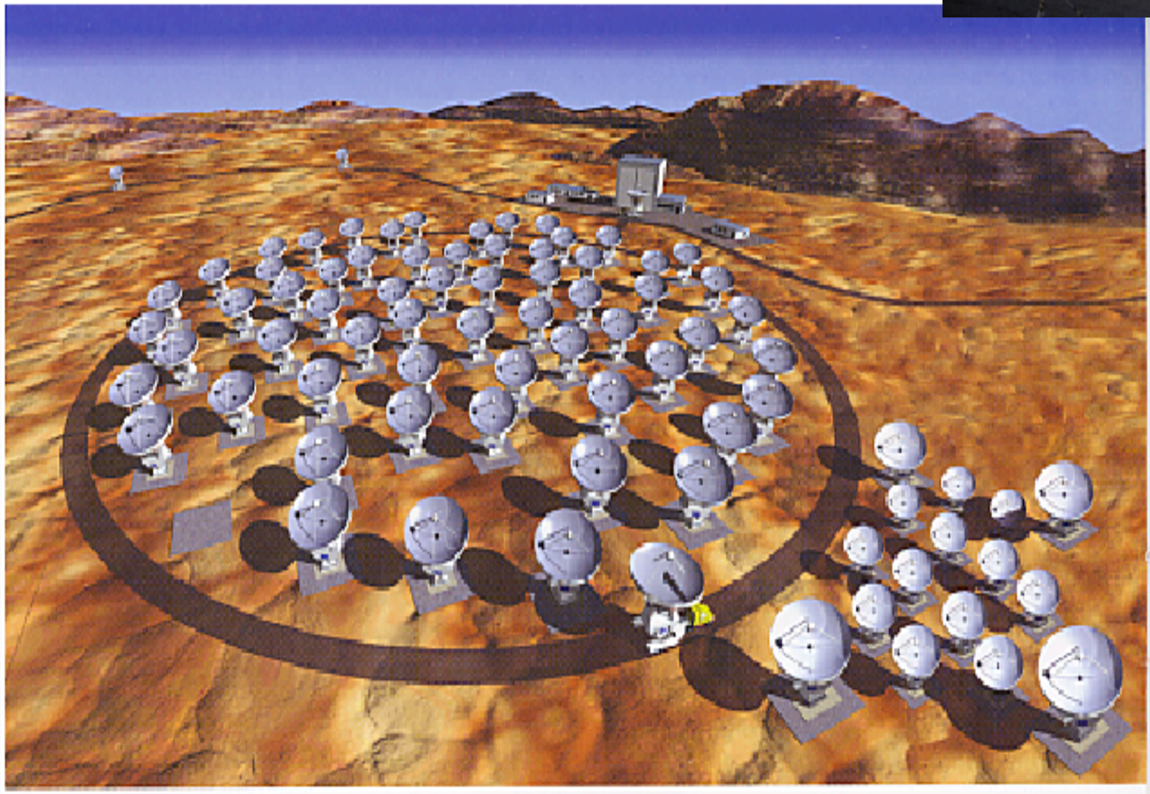
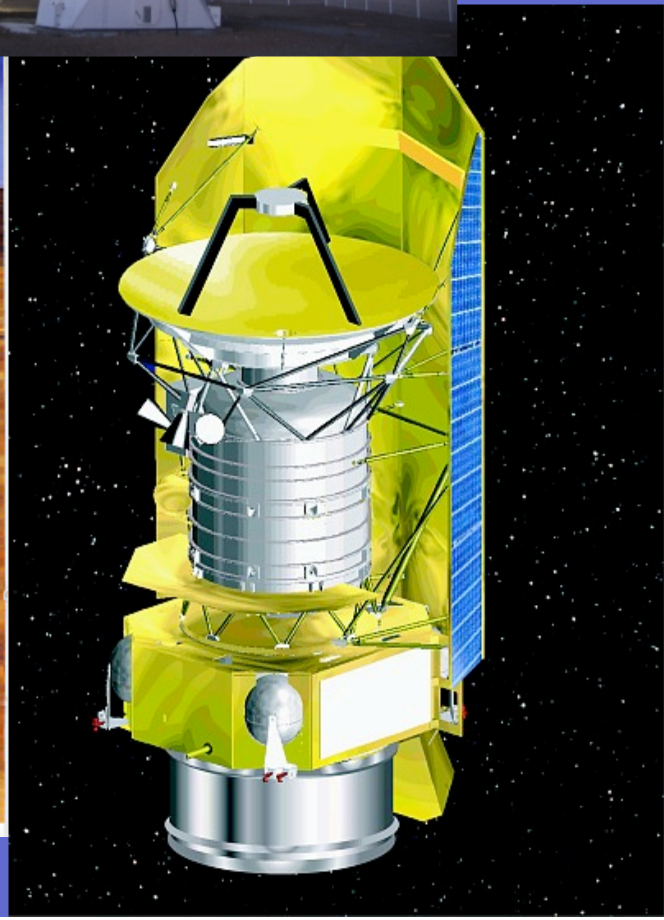
ALMA SYNERGIES
APEX, HERSCHEL, CMB experiments





Paola Andreani

TALK OUTLINE

- Synergies?
- Explore the 'cool' Universe: the origins of planets, stars and galaxies.
- ALMA, APEX, HERSCHEL+others

  'complementary' instruments
- Common Scientific Projects
  - ✓ Stars and planets formation

  Spectral line surveys
  - ✓ Nearby spirals, LSBGs, DGs, local AGN
  - ✓ CIRB, high-z sources/AGN

  the primordial Universe (CMB, dark energy)

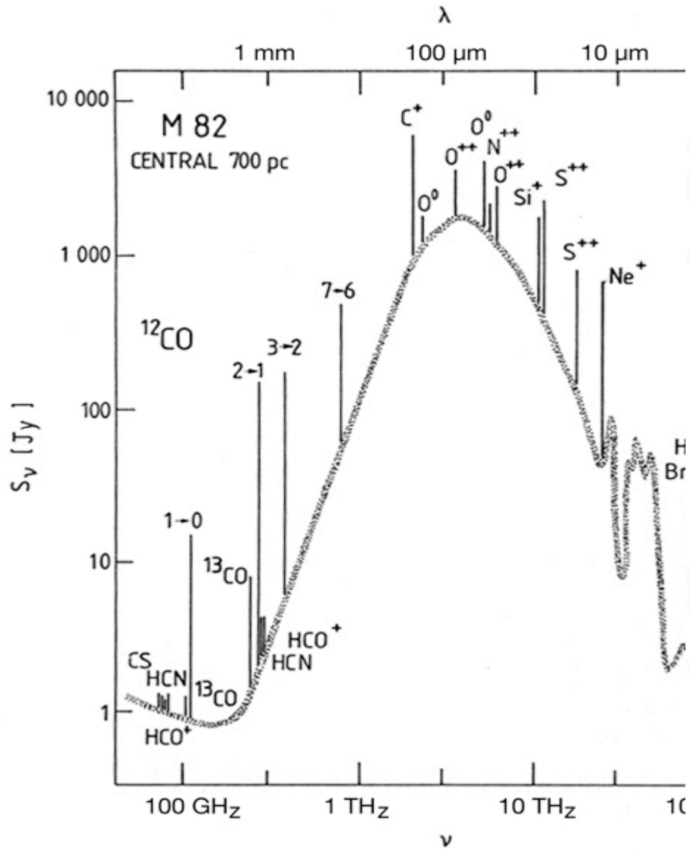
Synergies

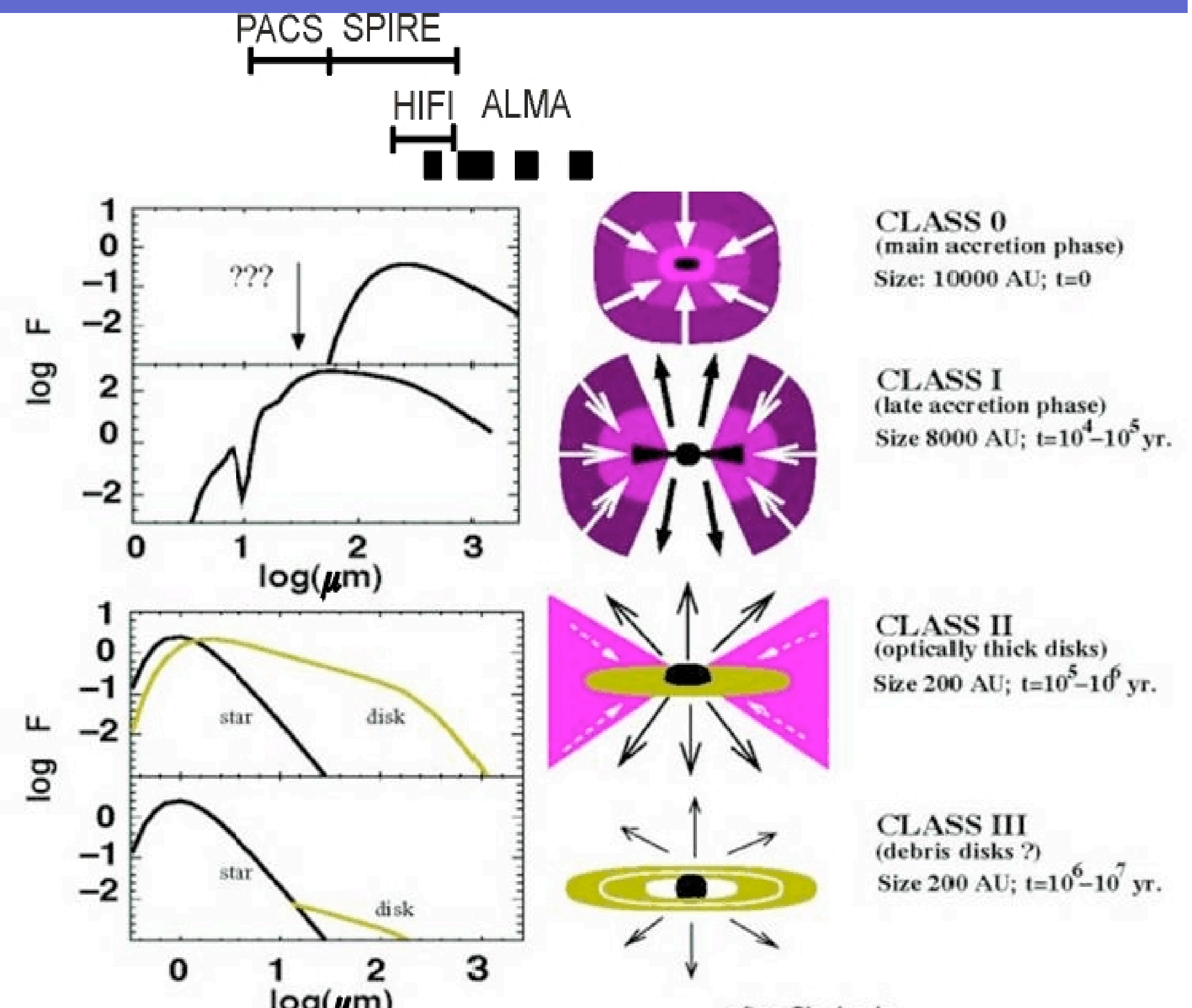
- Survey of the scientific areas covered by these instruments
- Survey of the use of these instruments in those areas and how these compete/complement each other
- Time allocation
- Supporting observations
- Supporting data and model
- Calibration
- Data Archive

FIR+submm: explore the 'cool' Universe

Protostar development

SB spectrum

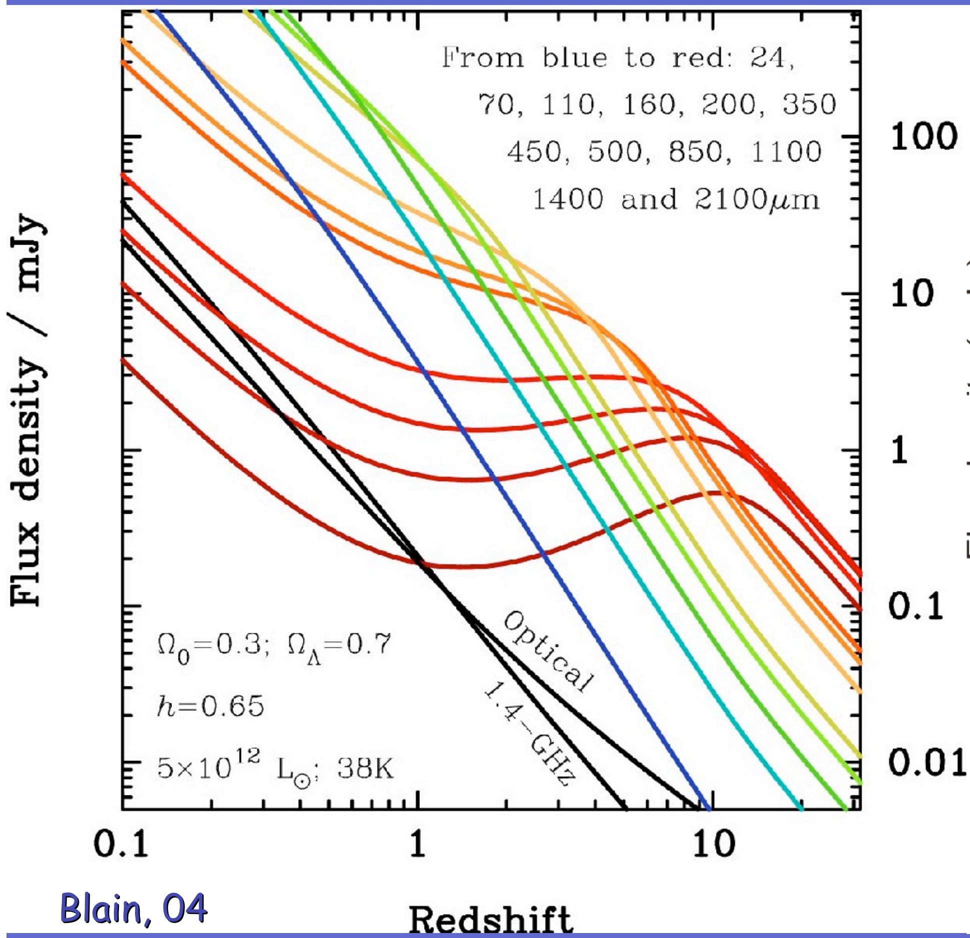




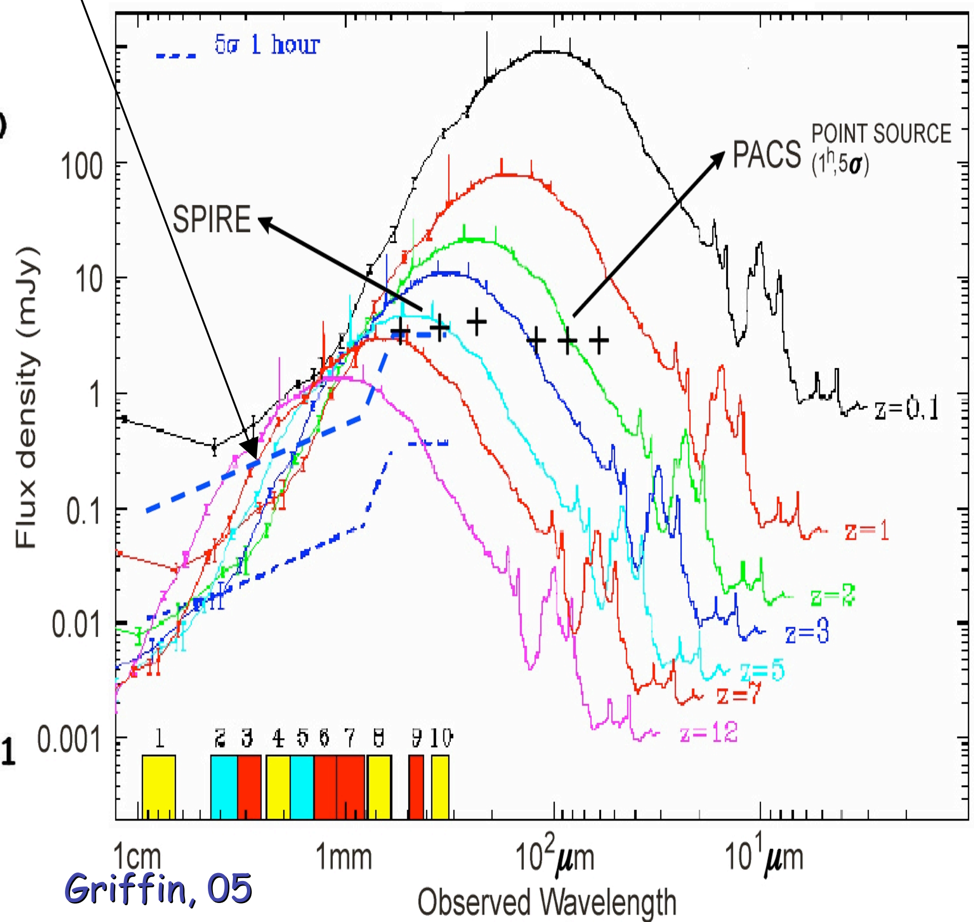
after Ch. Lada,
figs: M. Hogerheijde

K-correction

Sensitivity
with
6 antennas

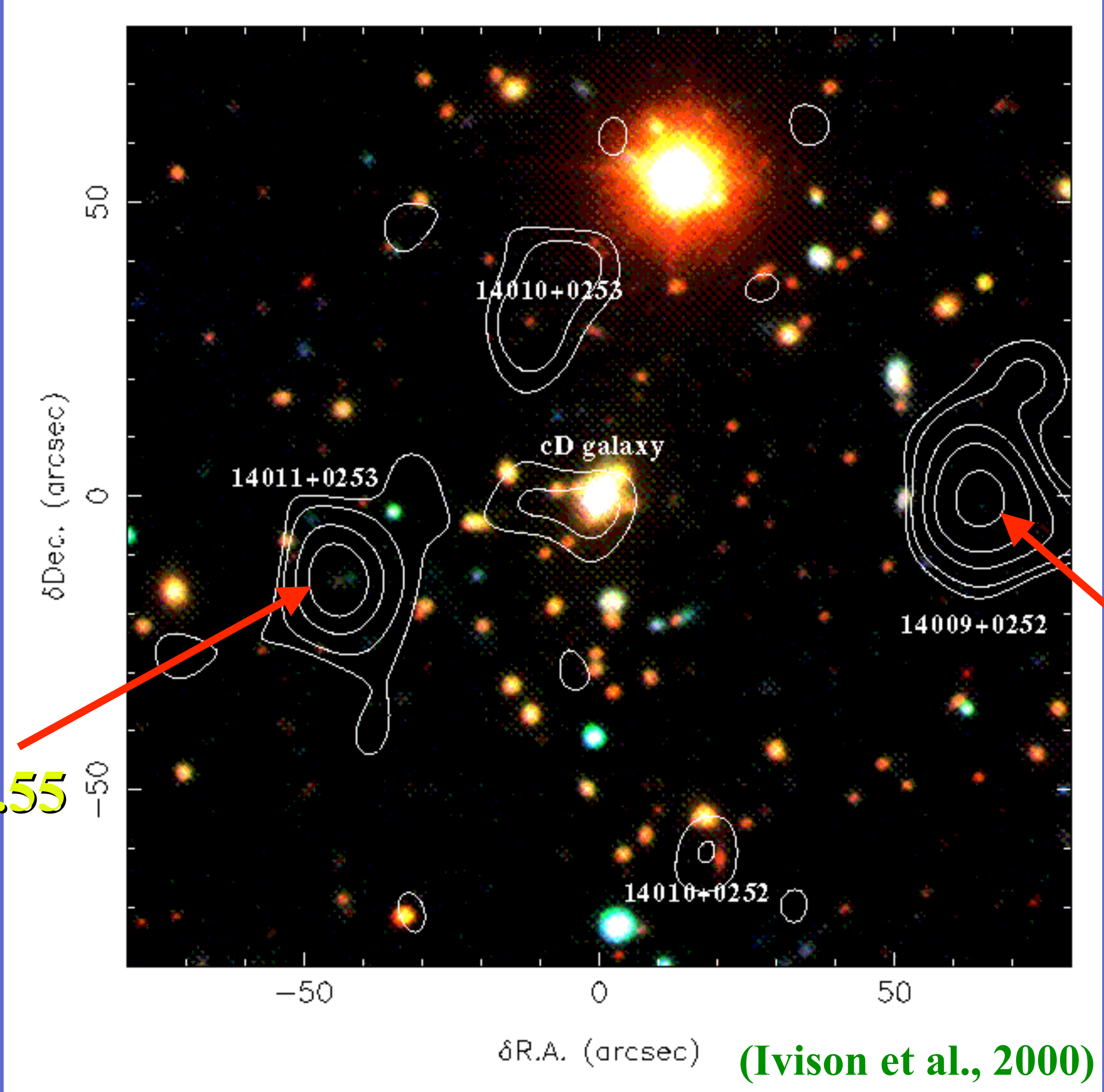


Blain, 04



Griffin, 05

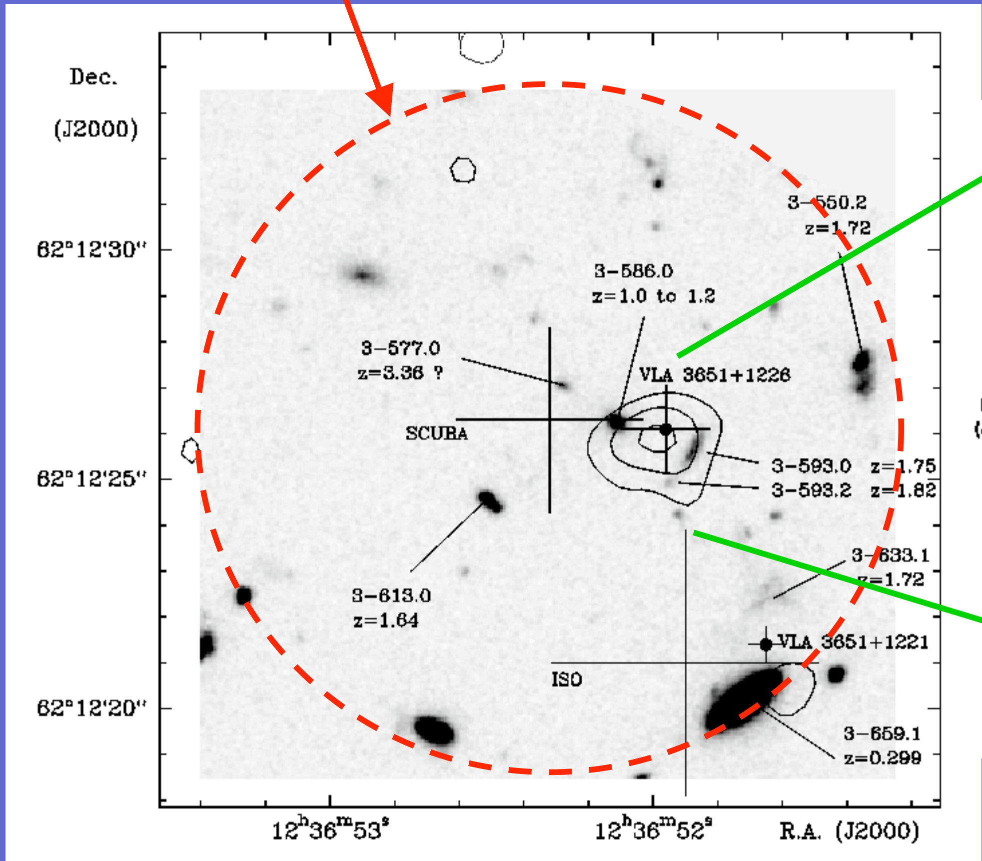
Cluster A1835 Obscured sources



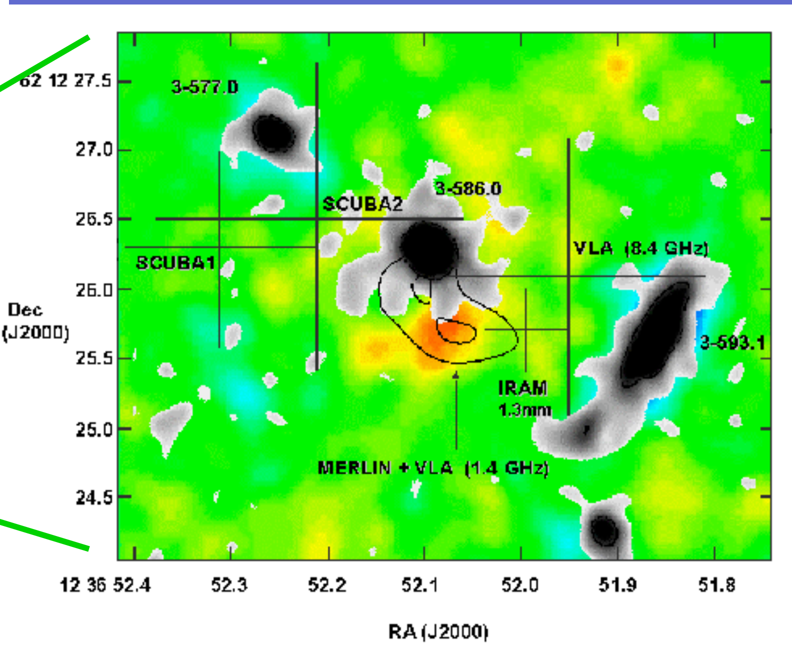
(Ivison et al., 2000)

Source Identification

SCUBA beam



The case of HDF 850.1



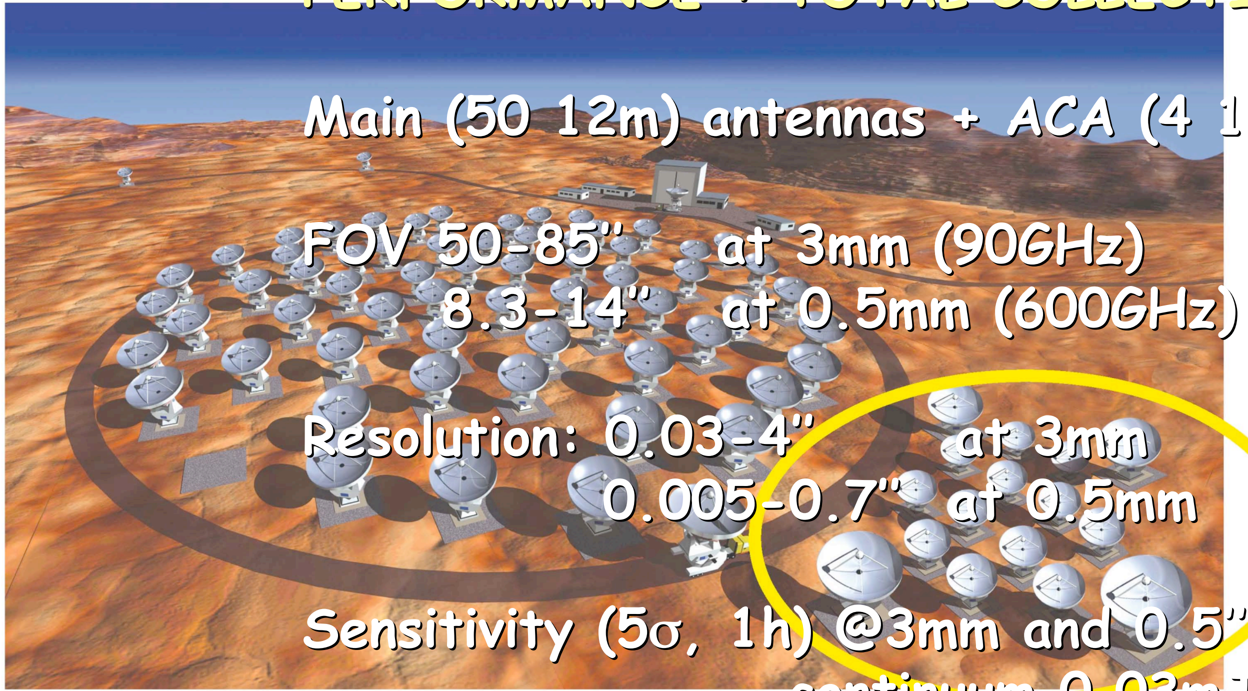
Dunlop et al. (2002)

Downes et al. (1999)

ALMA, APEX, Herschel in a snapshot

ALMA Main + Compact Array

ATMOSPHERIC TRANSPARENCY + DETECTOR NOISE PERFORMANCE + TOTAL COLLECTING AREA:



Main (50 12m) antennas + ACA (4 12m + 12 7m)

FOV 50-85" at 3mm (90GHz)
8.3-14" at 0.5mm (600GHz)

Resolution: 0.03-4" at 3mm
0.005-0.7" at 0.5mm

Sensitivity (5σ, 1h) @3mm and 0.5" resol (1km baseline)
continuum 0.03mJy
line 3mJy

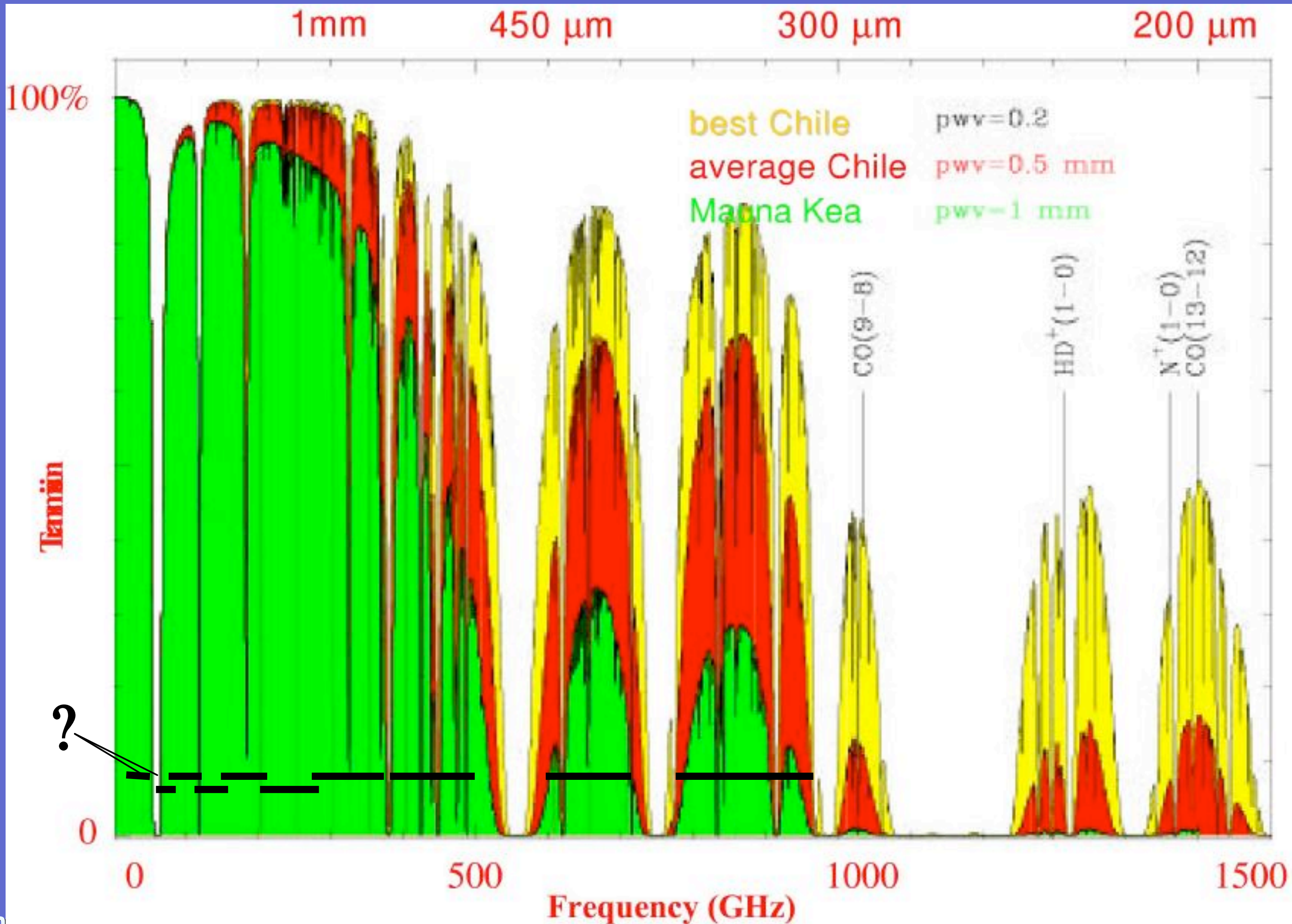
The ACA System

- Twelve (12) 7-meter diameter antennas (18 stations)
- Four (4) 12-meter diameter antennas (4 stations)
- ACA Correlator in AOS building

$$\theta('') = 0.2\ \lambda(mm) / B(km)$$

$$S = 2k/A_{eff}\ T_{sys}/\sqrt{N(N-1)\ \Delta\nu t_{int}}$$

Band3: 84-116 Band4: 125-163 Band5: 163-211 Band6: 211-275
Band7: 275-373 Band8: 385-500 Band9: 602-702 Band10: 787-950 GHz



Band1: 31.3-45
Band2: 67-90 GHz

Paola Andreani

ALMA Receivers

ALMA Band	Frequency Range	Receiver noise temperature		Mixing scheme	Receiver technology
		T_{Rx} over 80% of the RF band	T_{Rx} at any RF frequency		
1	31.3 – 45 GHz	17 K	28 K	USB	HEMT
2	67 – 90 GHz	30 K	50 K	LSB	HEMT
3	84 – 116 GHz	37 K	62 K	2SB	SIS
4	125 – 169 GHz	51 K	85 K	2SB	SIS
5	163 - 211 GHz	65 K	108 K	2SB	SIS
6	211 – 275 GHz	83 K	138 K	2SB	SIS
7	275 – 373 GHz*	147 K	221 K	2SB	SIS
8	385 – 500 GHz	98 K	147 K	DSB	SIS
9	602 – 720 GHz	175 K	263 K	DSB	SIS
10	787 – 950 GHz	230 K	345 K	DSB	SIS

?

* - between 370 – 373 GHz T_{rx} is less then 300 K

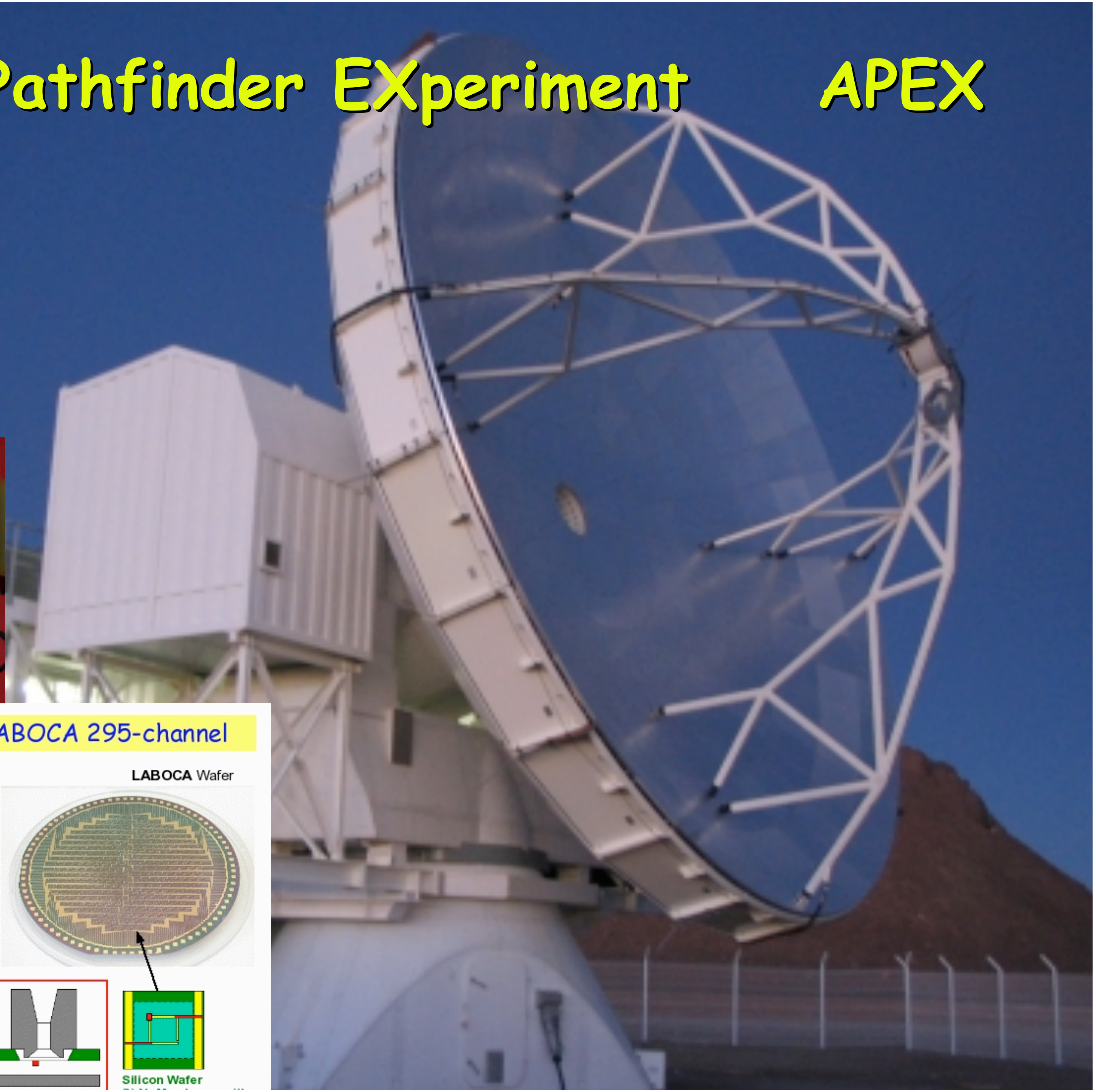
•Dual, linear polarization channels:
- •Increased sensitivity
- •Measurement of 4 Stokes parameters

•183 GHz water vapour radiometer:
- •Used for atmospheric path length correction

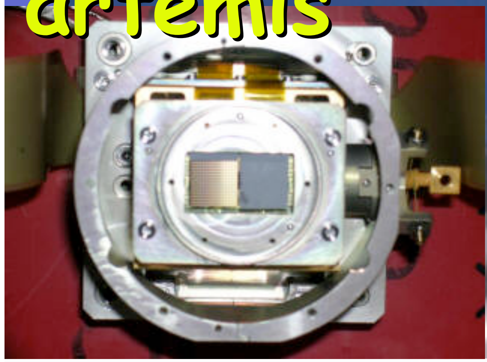
★ **Japanese contribution all telescopes plus ACA**

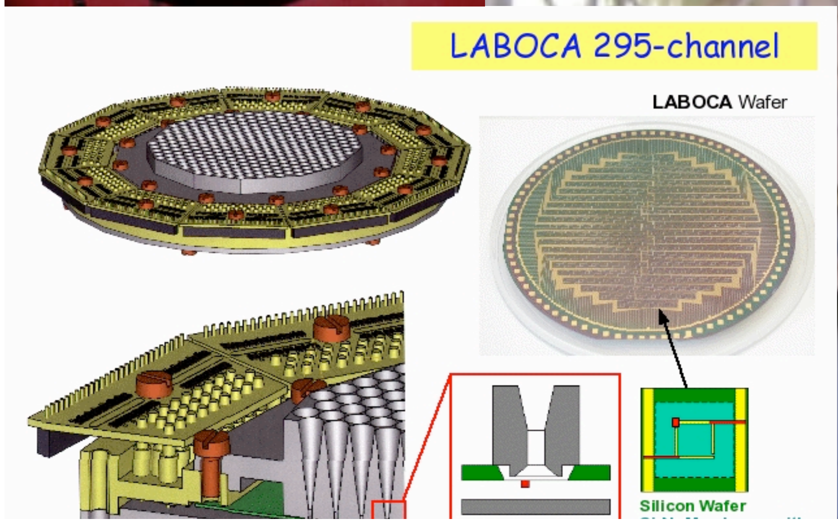
★ **EC funded 8 receivers ALMA-Herschel synergy**

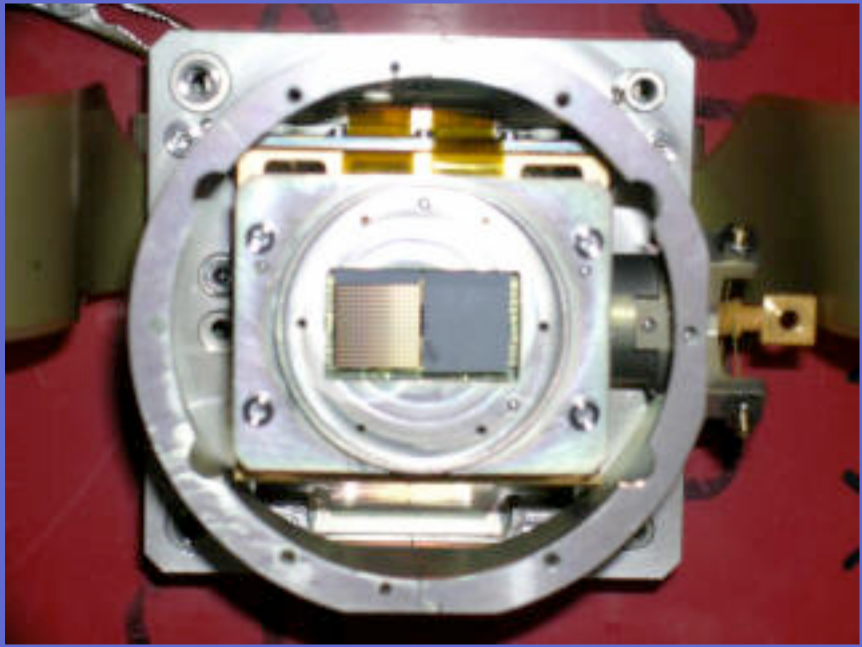
Atacama Pathfinder EXperiment APEX



artemis



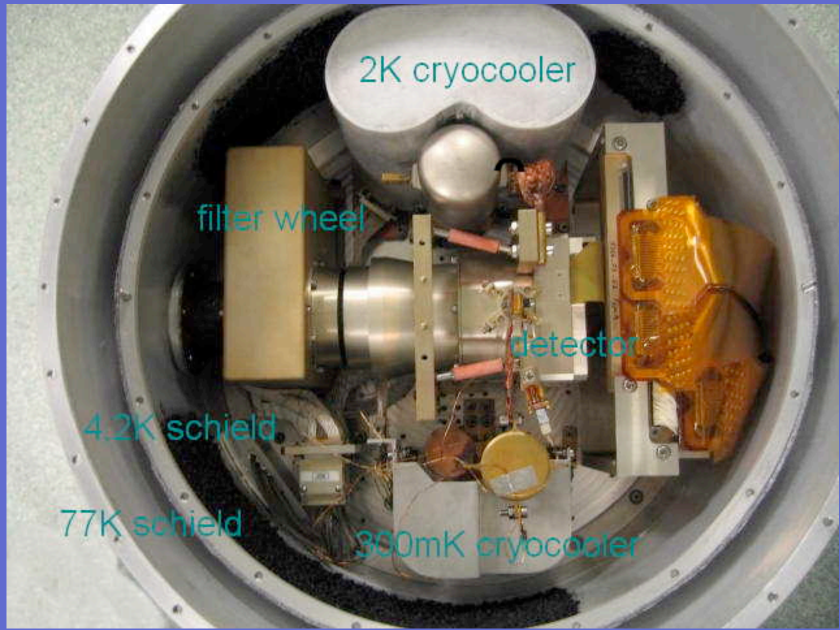




artemis

APEX

200-450μm
800-1200μm

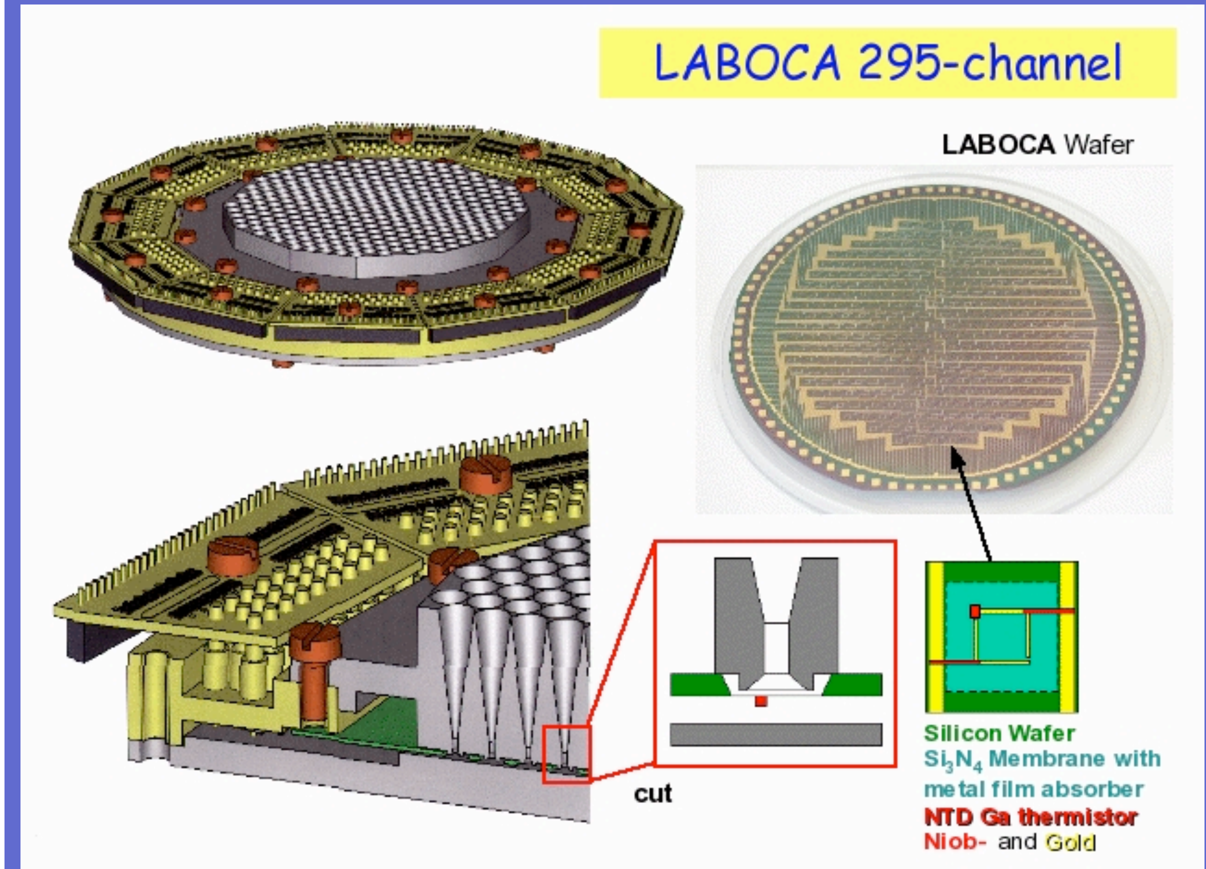


cooled at 300mK
dichroic filter to split
the frequency channels
antireflection dielectric sheet

to improve absorption at 450/850μm

APEX

LABOCA



Neutron Transmutation Doped (NTD)
semiconductor thermistors fabricated from Ge

λ=870μm ≅ 345GHz
$\Delta\lambda$=100μm ≅ 322-364 GHz

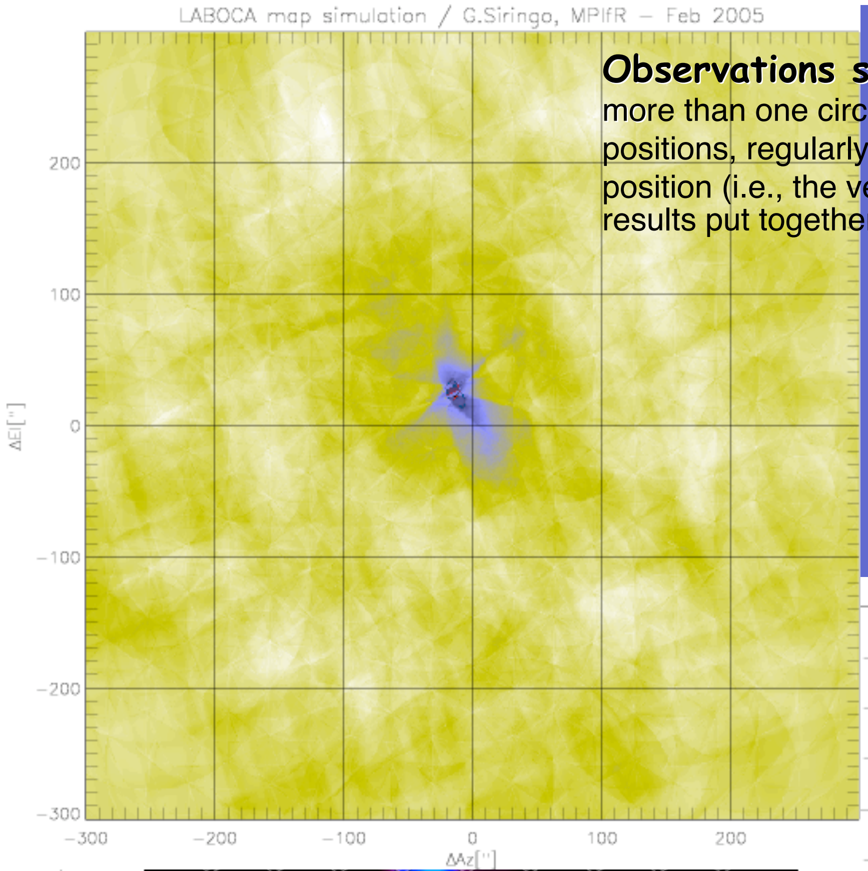
FOV=11'.4

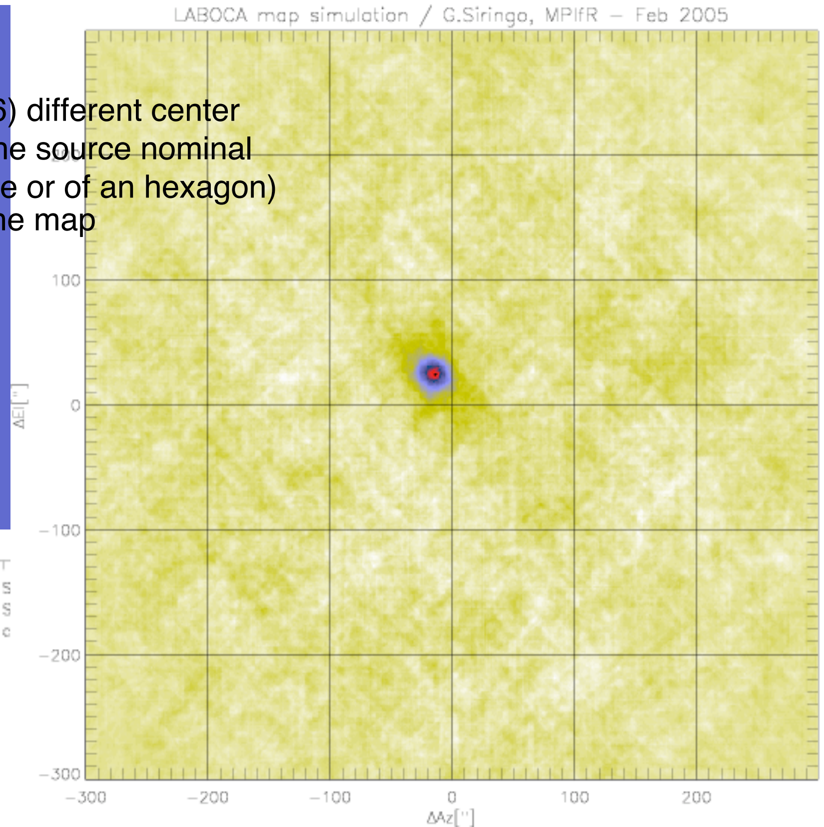
Res=18"

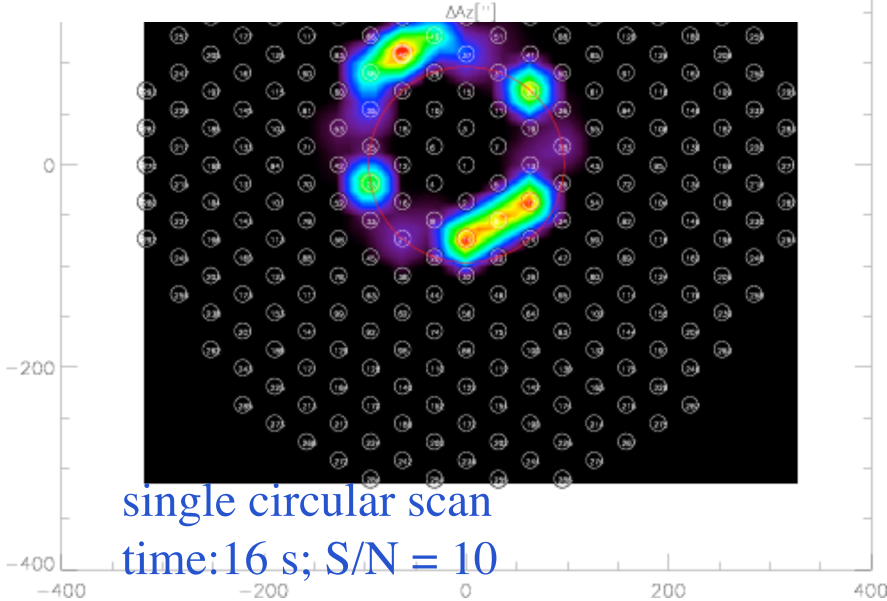
No chopping
atmospheric contribution in the signals of the 295 bolometers correlated and removed with appropriate data reduction algorithms.

Observations simulations:

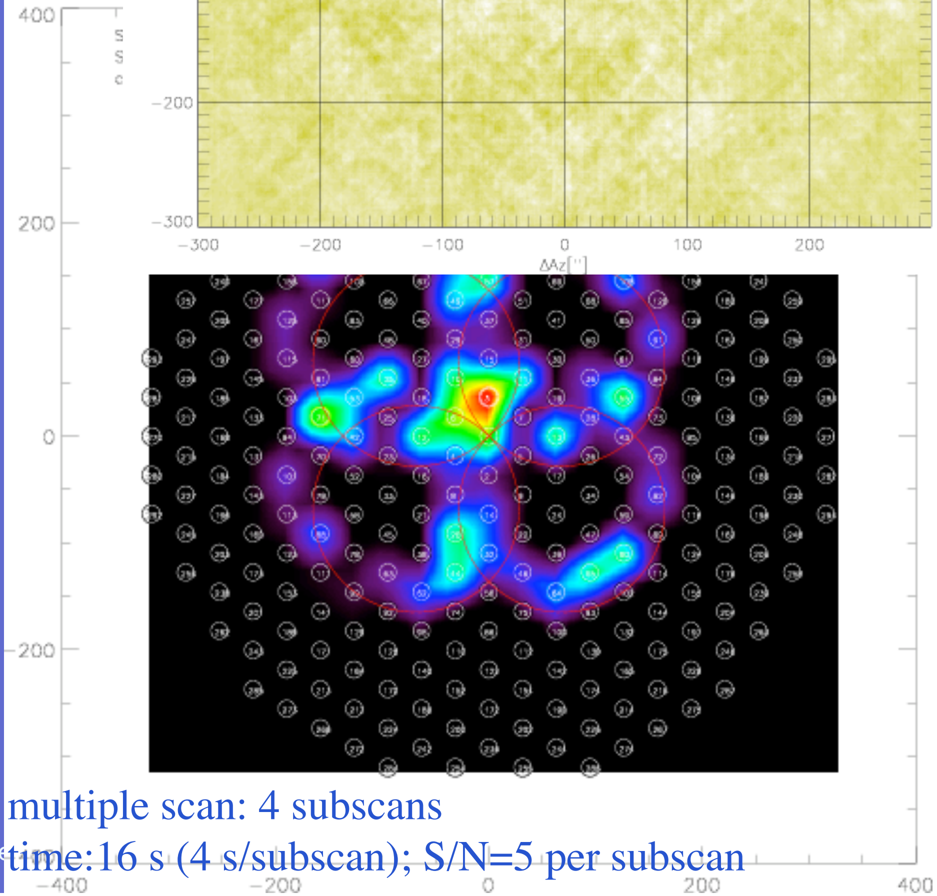
more than one circle scan, at 4 (or 6) different center positions, regularly placed around the source nominal position (i.e., the vertices of a square or of an hexagon)
results put together to reconstruct the map







single circular scan
time:16 s; S/N = 10



multiple scan: 4 subscans
time:16 s (4 s/subscan); S/N=5 per subscan

rschel syn

Herschel

fourth cornerstone mission in ESA's Horizon 2000 programme

launch End 2008

3.5 m passively cooled to 80 K

3 cold focal plan instruments

photometry and spectroscopy in the 60 – 670 µm range

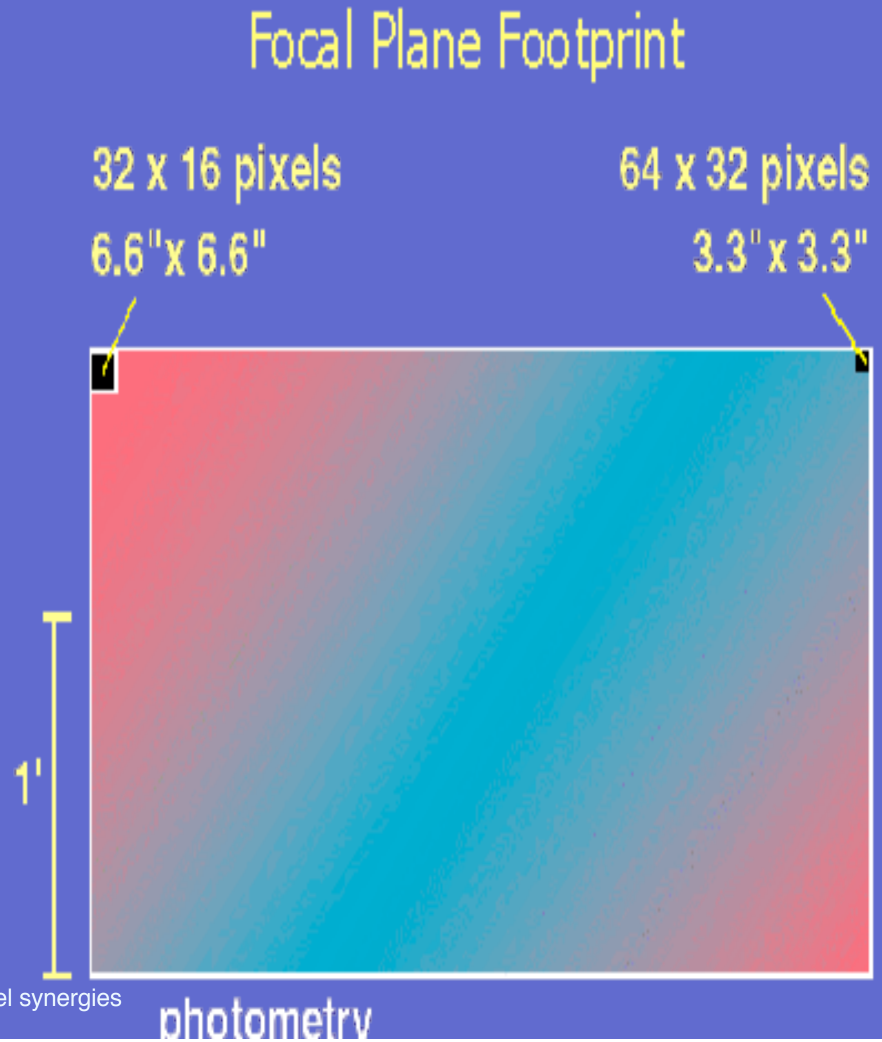
liquid helium cryostat

operational lifetime of at least 3 years

PHOTODETECTOR ARRAY CAMERA AND SPECTROMETER (PACS)

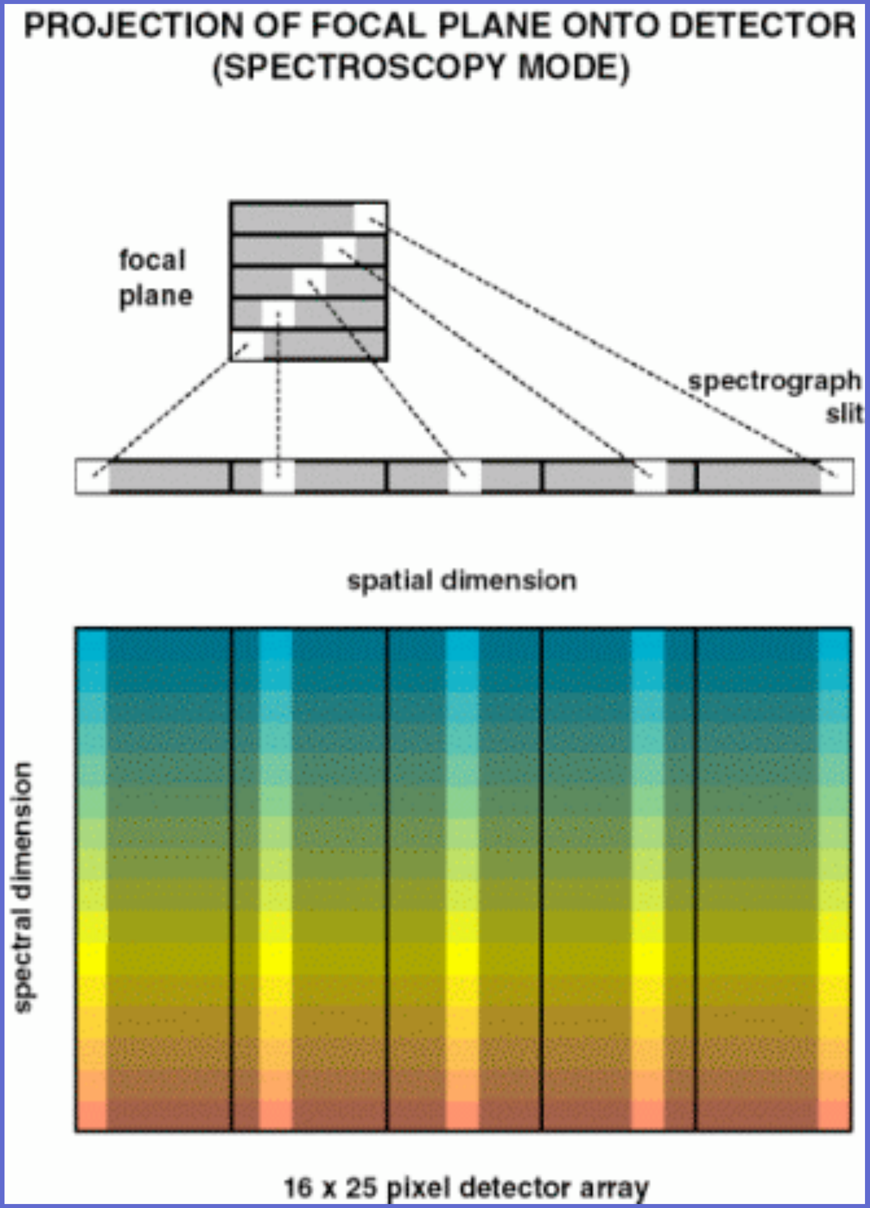
Imaging Photometry

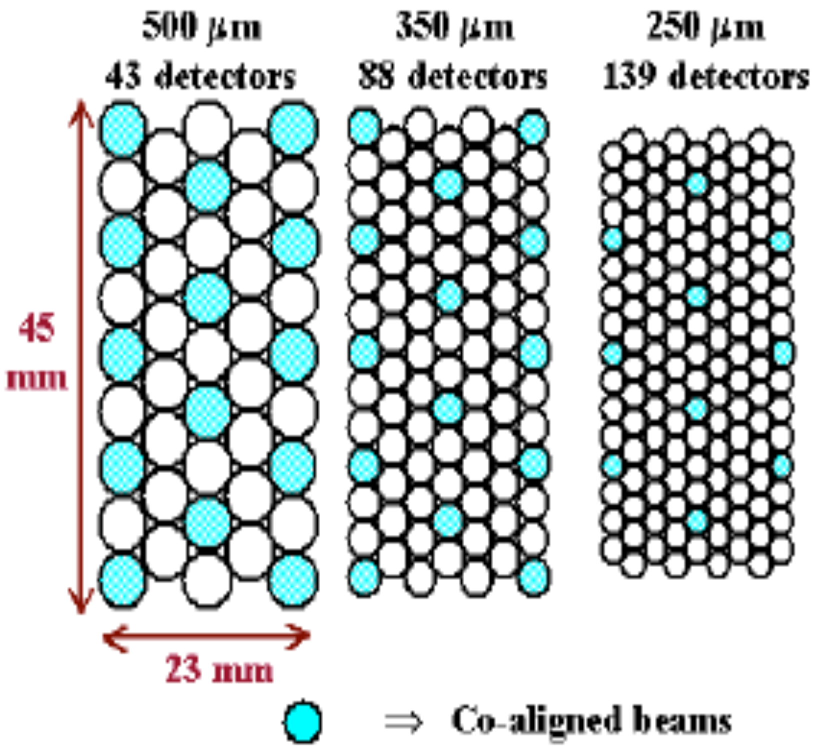
- Two bands simultaneously (60-90 μm or 90-130 μm and 130-210 μm) with dichroic beam splitter
- two filled **bolometer** arrays (32x16 and 64x32 pixels)
- point source detection limit ~ 3 mJy (5σ, 1h)

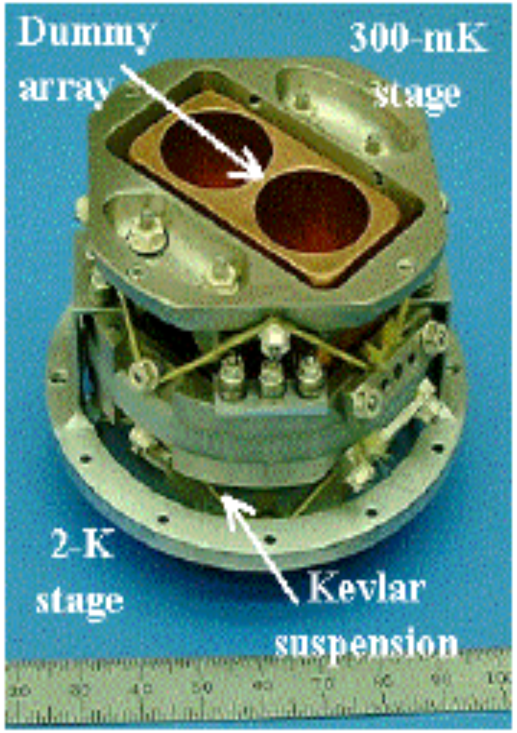


Integral Field Line Spectroscopy

– wavelength range 57-210 μm
– optical image slicer rearranges 2-D field of view (5x5 pixels) along 1-D slit (1x25 pixels)
– long-slit grating spectrograph (R ~ 1500) disperses light
– dispersed slit image is projected on 16x25 pixel Ge:Ga Photoconductor arrays (stressed/unstressed)
– 16 spectral channels recorded simultaneously for each spatial element
– point source detection limit $2.5 – 8 \times 10^{-18}$ W/m^2 (5 sigma, 1h)

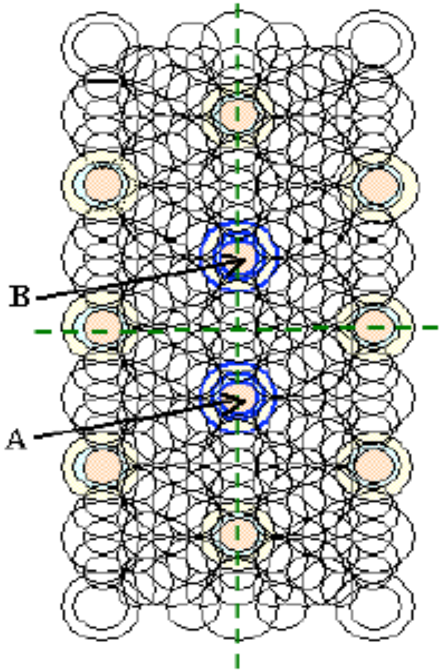






SPIRE IMAGER

The bolometer arrays (spider-web bol.with Ge-microthermometers)



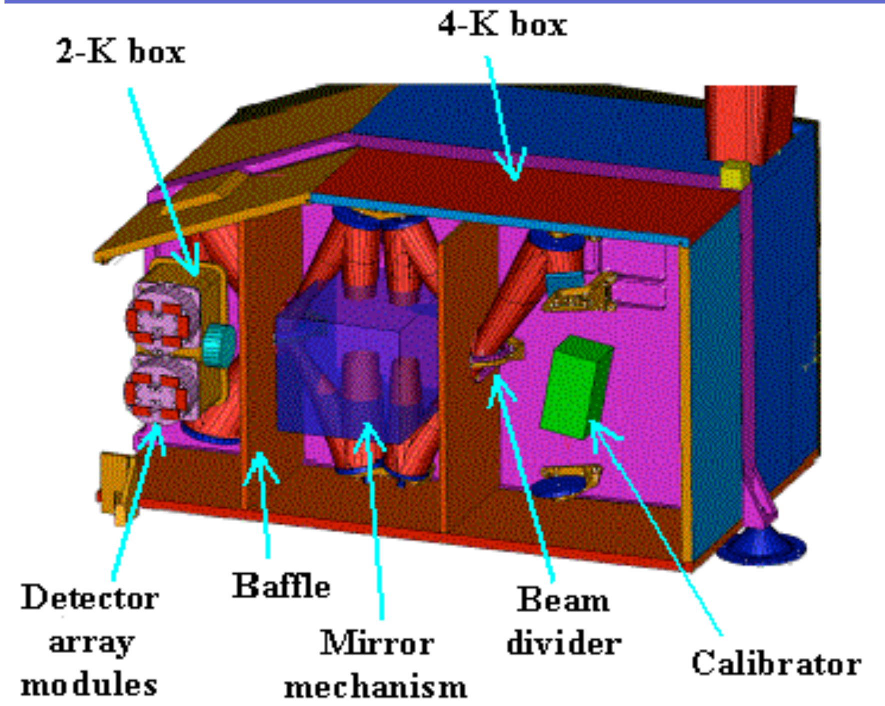
Point source observation
- ± 63" chop between A and B
- No jiggle (reliable pointing)
- 7-point jiggle (unreliable pointing)

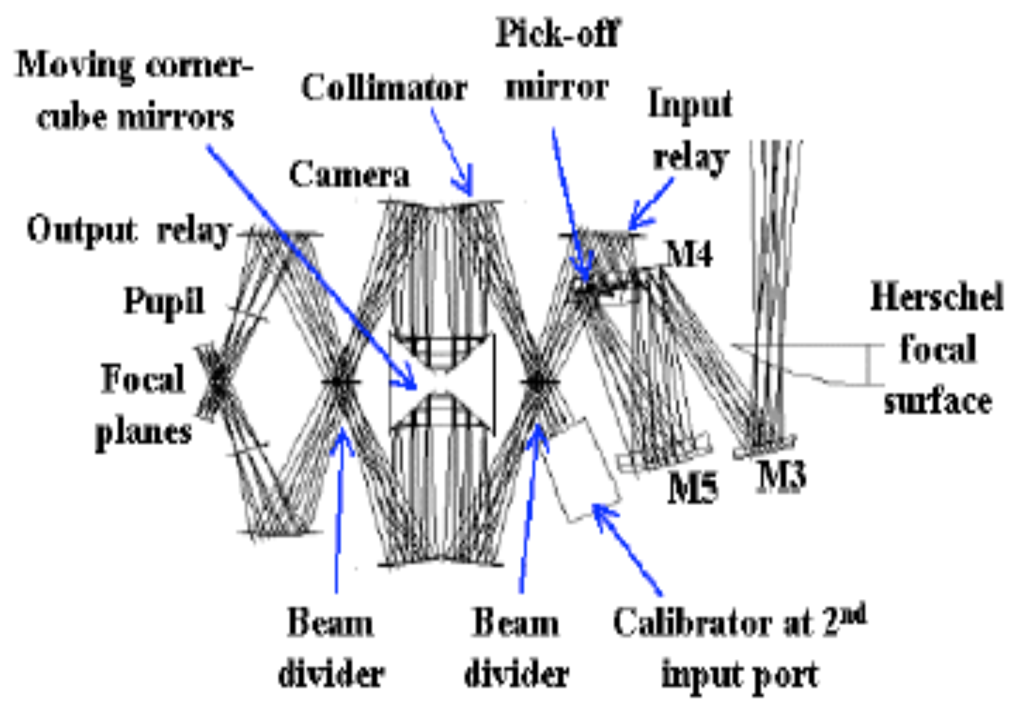
Field map (4 x 4 arcmin.)
- ± 120" chop
- 64-point jiggle

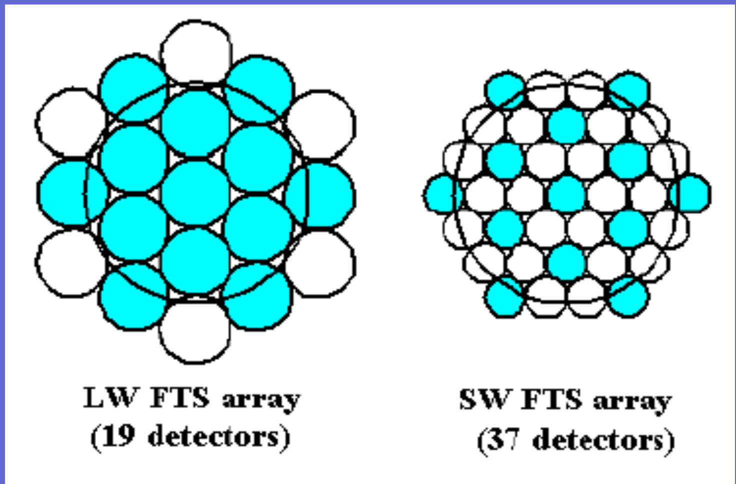
Scan map
- 4 x 8 arcmin. fov
- No chop or jiggle
- Telescope scanned at 14.5° wrt either of the array axes

Photometer observing modes

SPIRE Imaging Spectrometer (highly-optimized 2-band FTS)

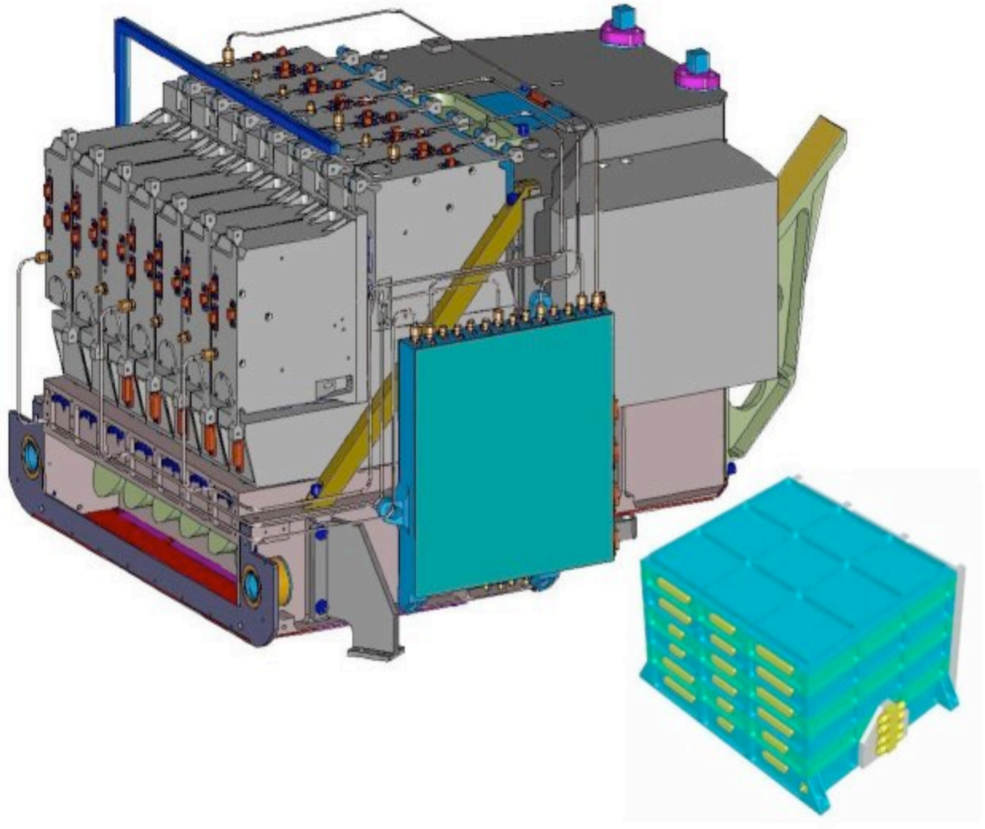






300-670μm 200-300μm

HIFI: heterodyne receiver



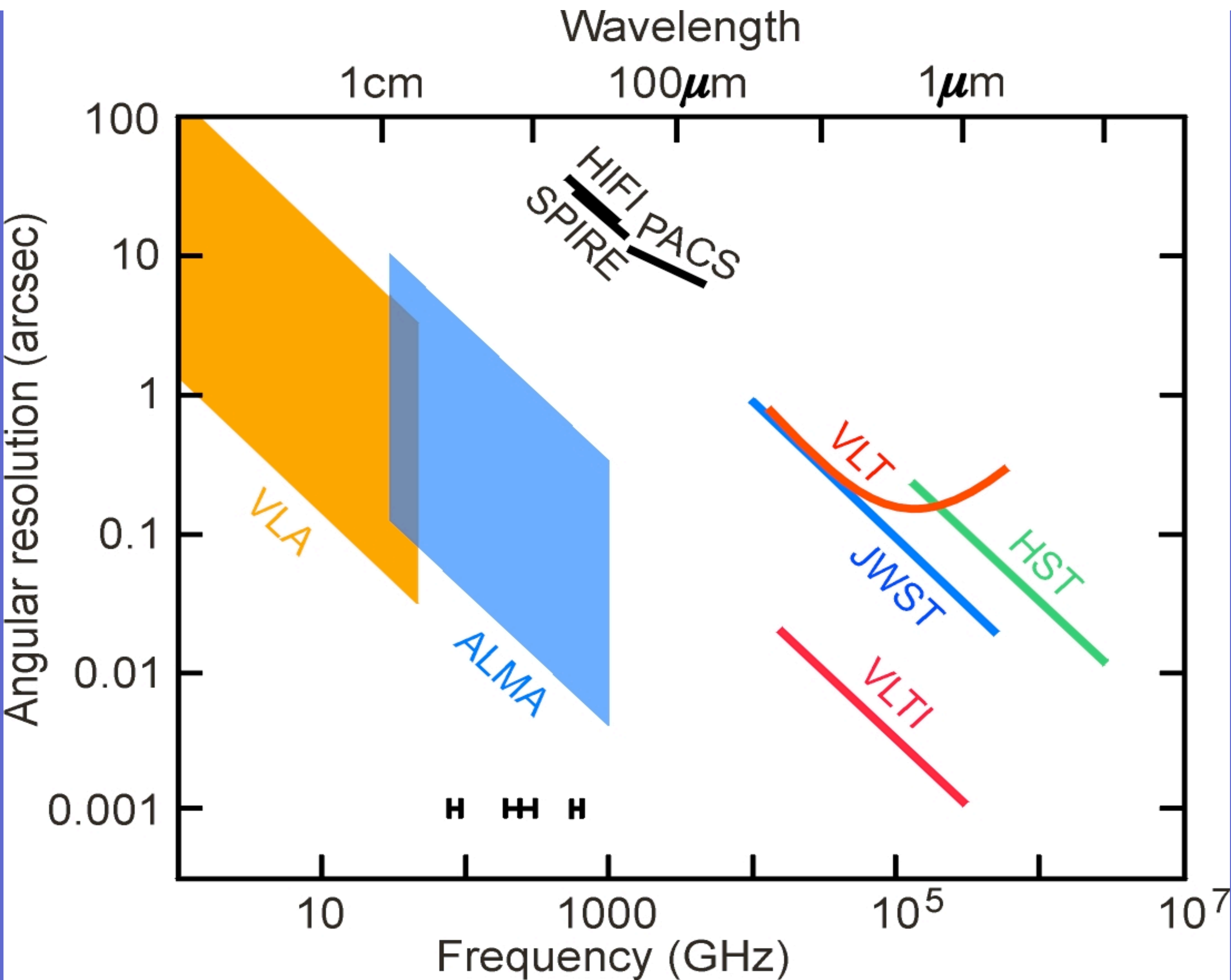
- Single pixel receiver
- 480-1250 GHz
- 1414 - 1910 GHz
- FWHP beams 12-45"
- Very high spectral resolution (140-280 kHz-0.5/1MHz)
- quantum sensitivity limit
- Instantaneous IF bw 4GHz

Photometry with Herschel

		PACS			SPIRE	
λ_{cent}	75μm	110μm	170μm	250μm	350μm	500μm
$\Delta\lambda$(μm)	60-90	90-130	130-210	210-290	290-400	410-580
Sensitivity mJy,5σ,1h	3	3	3	1.1	1.2	1.5
FOV (arcmin)	1.8x3.5	1.8x3.5	1.8x3.5	4x8	4x8	4x8
Angular res.	5″	8″	12″	17″	24″	35″

Spectroscopy with Herschel

	HIFI	PACS	SPIRE
Spectral range	480-1250GHz (240-625μm) 1410-1910GHz(157-212μm)	1426-4997GHz (60-210μm)	447-1499GHz (200-670μm)
Sp band	WBS: 4GHz HRS: 1/0.5GHz	---------	---------
Spectral res	WBS(1MHz) 0.2-0.6km/s HRS(100/200kHz) 0.03-0.06/0.13km/s R=2 10^6-10^7	100-250 km/s R=1200-3000	300-15000km/s R=20-1000
Flux limit	R=10^3 1.1-3.2 mK (0.5-1.5Jy) R=10^6 34-100 mK (15-46 Jy)	R=10^3 0.16-0.21 (0.11-0.14 Jy)	R=10^3 2.9-3.2 Jy PS 7.2-8.4Jy
Line flux limit 10^{-18}W/m^2	0.9-7	7.8 (60μm) PS 2.5 (180μm)	38 (200-300μm) PS 35 (300-400μm) 35-70 (400-670μm)
FOV	12", 48"	47"x47"	2.6'x2.6'
HPBW	46-12"	9.4"	18", 25"

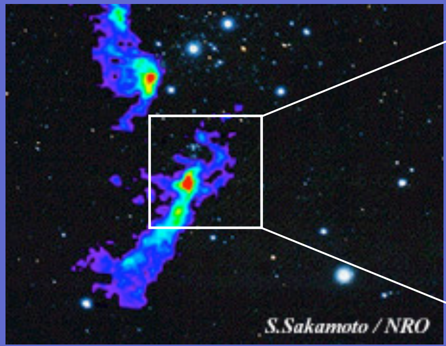

Wavelength
1cm
100μm
1μm
100
10
1
0.1
0.01
0.001
Angular resolution (arcsec)
HIFI
SPIRE
PACS
VLA
ALMA
VLT
JWST
HST
VLTI
10
1000
10^5
10^7
Frequency (GHz)

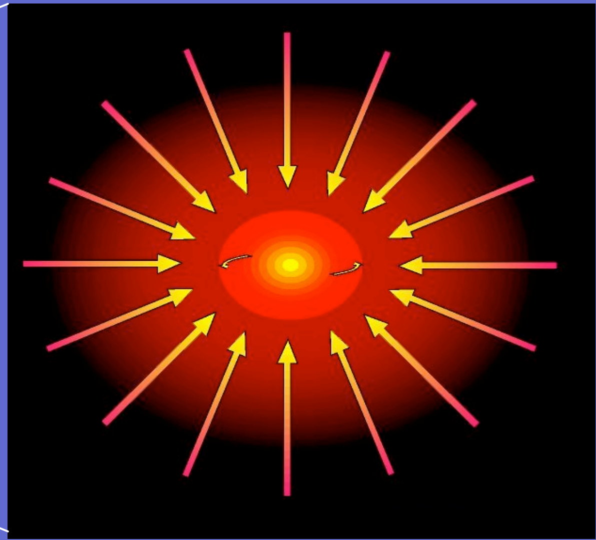
Common scientific projects

- Star formation
- Planetary system formation
- Nearby galaxies
- Galaxy formation
- AGN-Host joint formation/BH formation
- Dark energy constraints

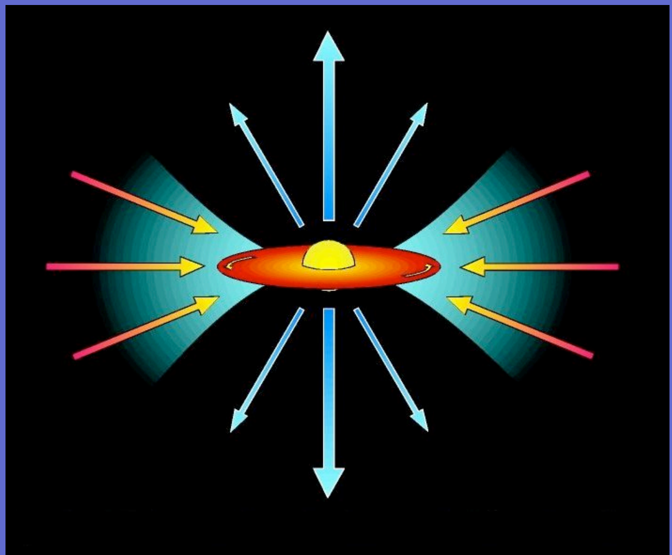
Standard model of star formatior

1. Formation of pre-stellar clumps in molecular clouds.

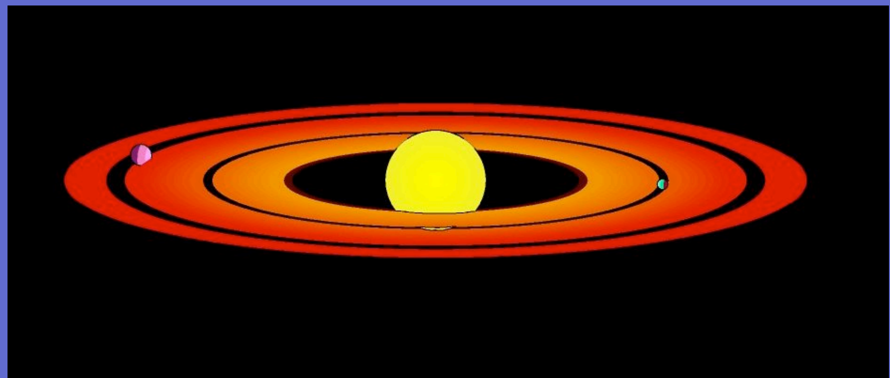




2. The pre-stellar clump collapses



3. Protostar (infall and outflow coexists)

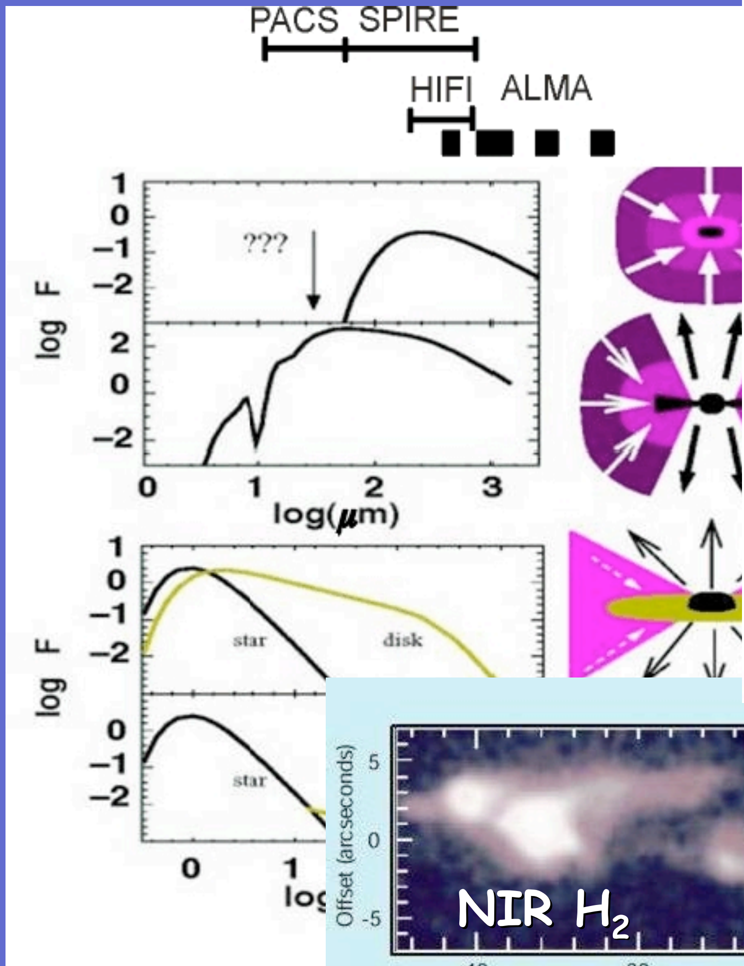


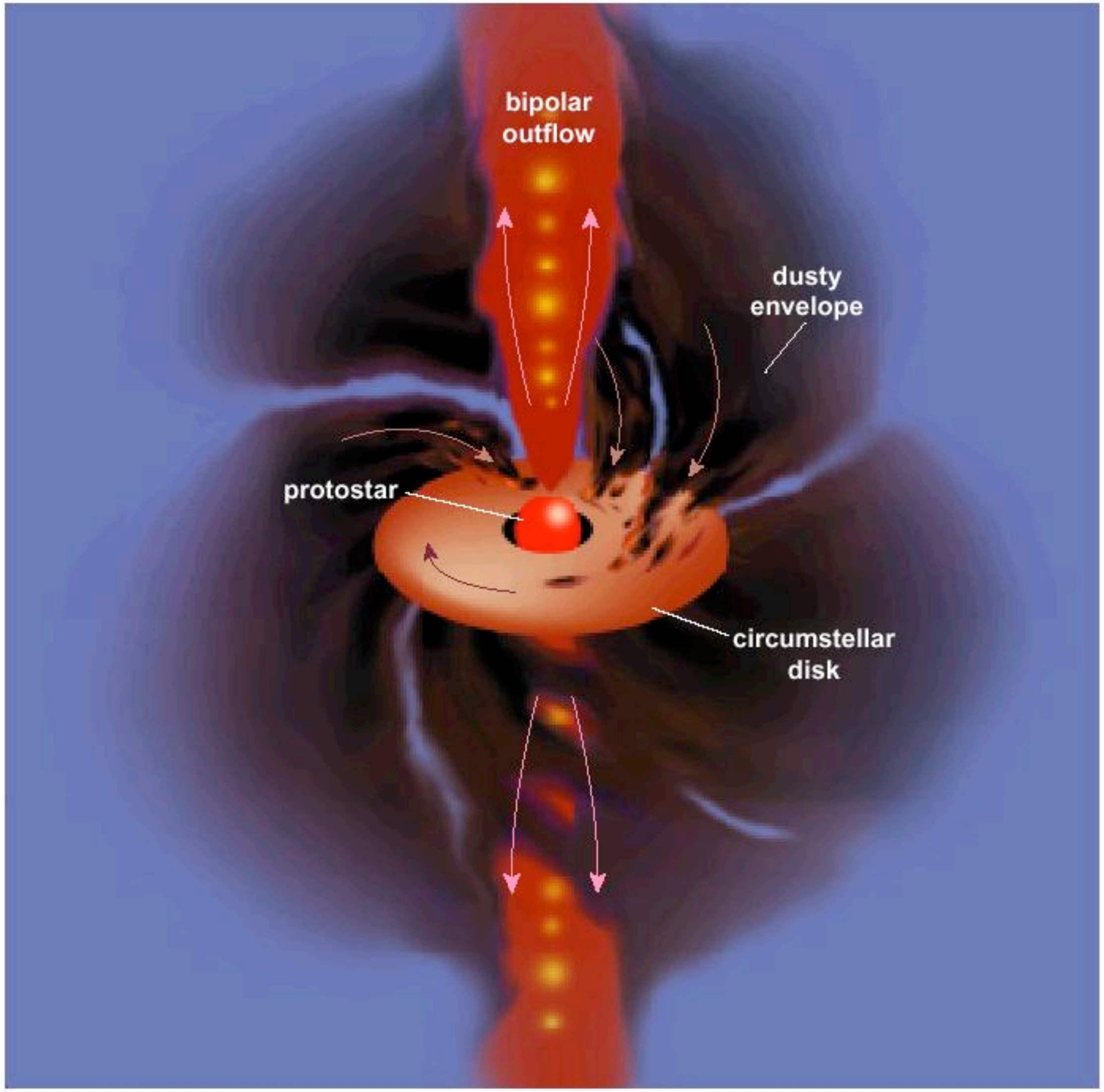
4. Formation of a planetary system

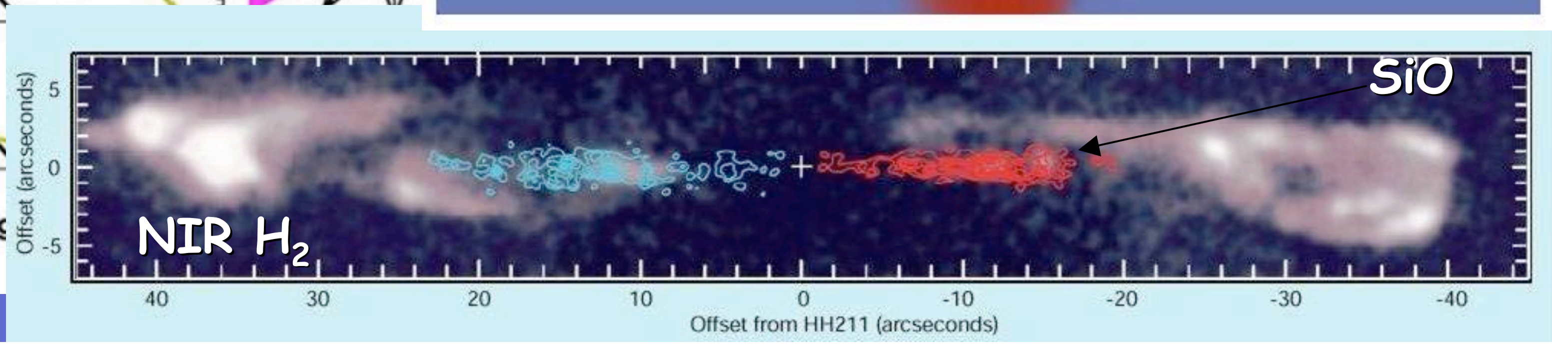
Fig. from McCaughrean

Star for

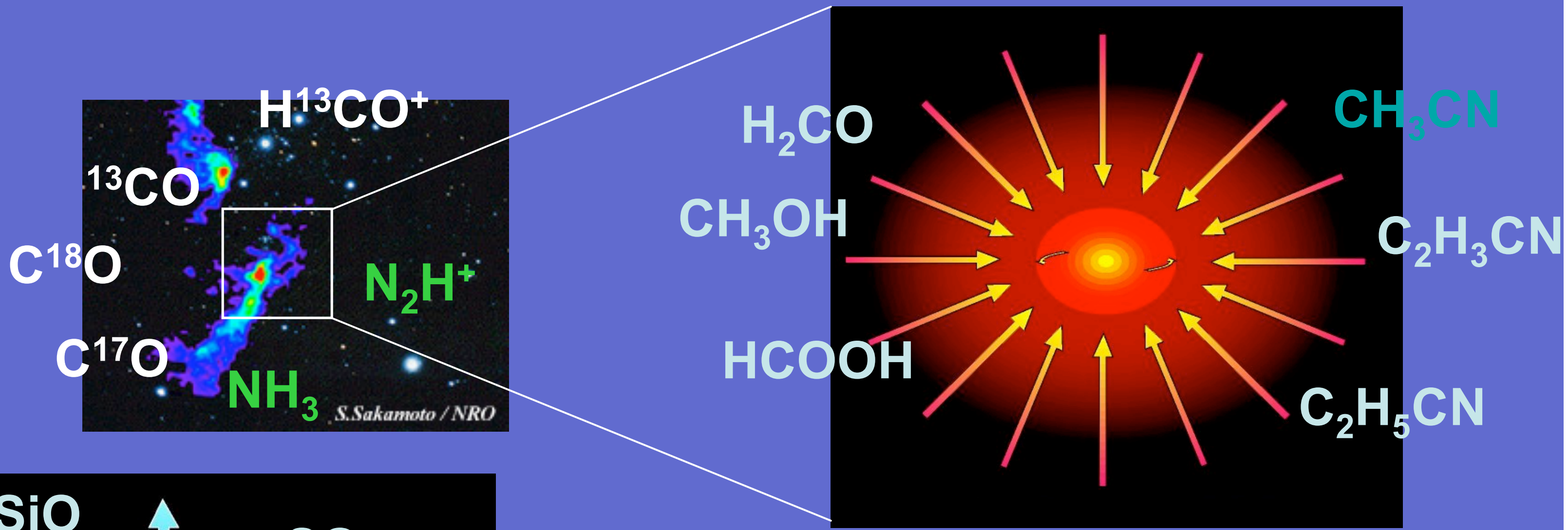
Fo

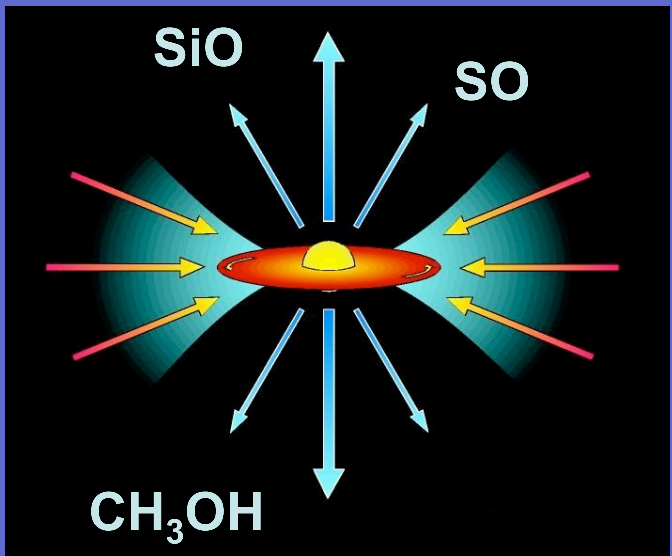

PACS SPIRE
HIFI ALMA
???
log F
log(μm)
star
disk
star
log

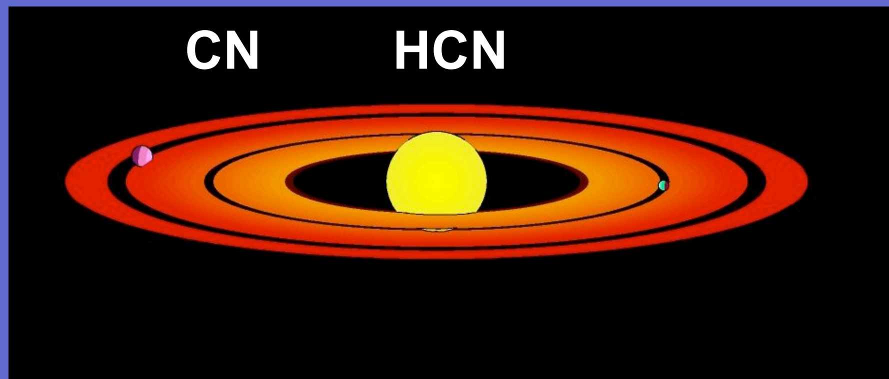

bipolar outflow
dusty envelope
protostar
circumstellar disk


SiO
NIR H2
Offset (arcseconds)
Offset from HH211 (arcseconds)

Chemistry as a clock for YSOs





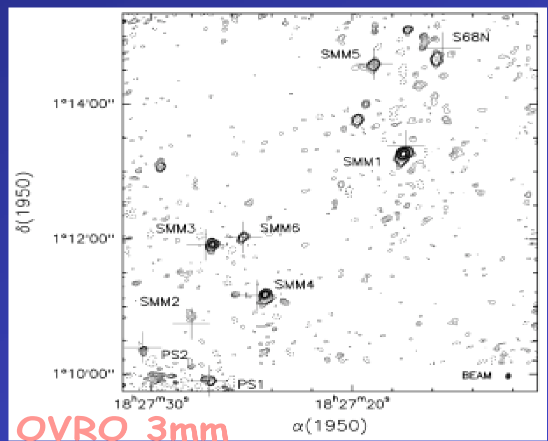


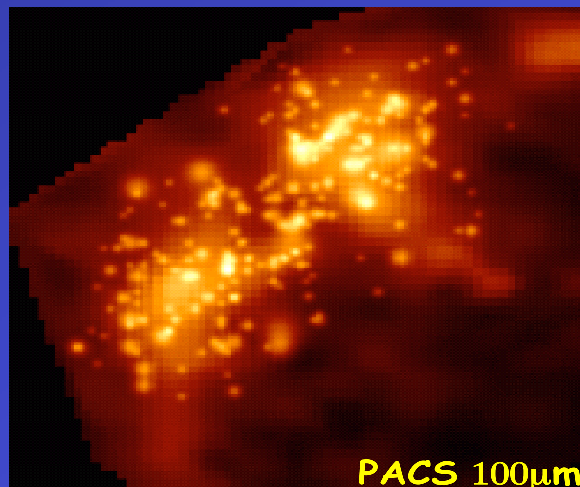
Star formation

- **PACS+SPIRE+ARTEMIS:** grain properties, maps of star forming regions in continuum, mass spectrum for small masses (IMF) + OI 63 μm line maps on the large scale
- **HIFI:** molecules (mainly H_2O) + detailed kinematics of star forming regions
- **ALMA:** molecules at higher spatial resolution + outflows

Serpens

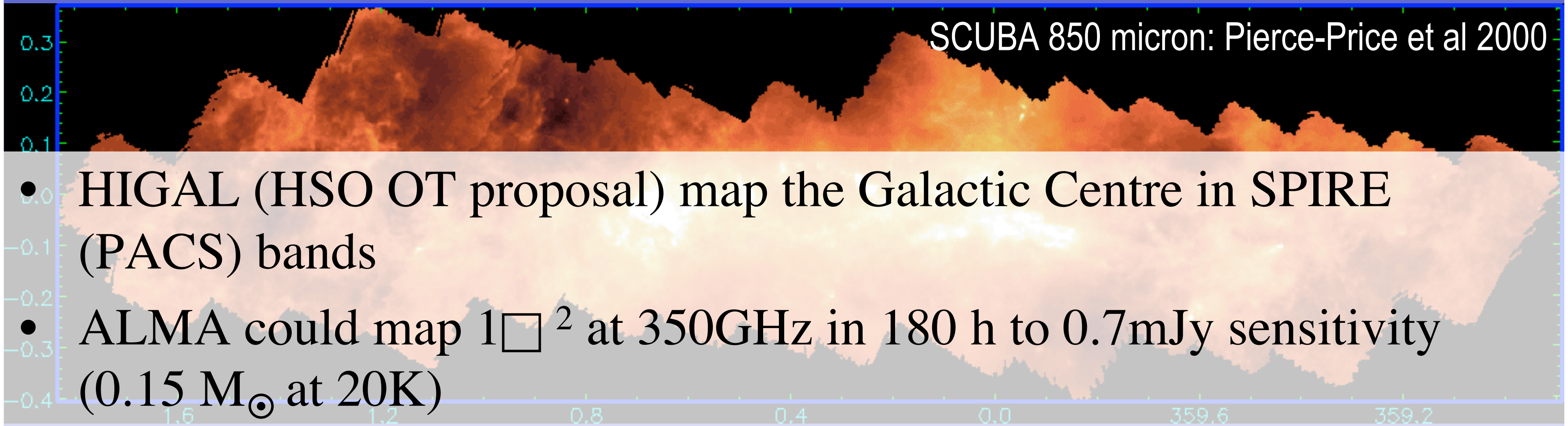
High spatial res at SED max of most SF regions separate the main sources of luminosity





Testi

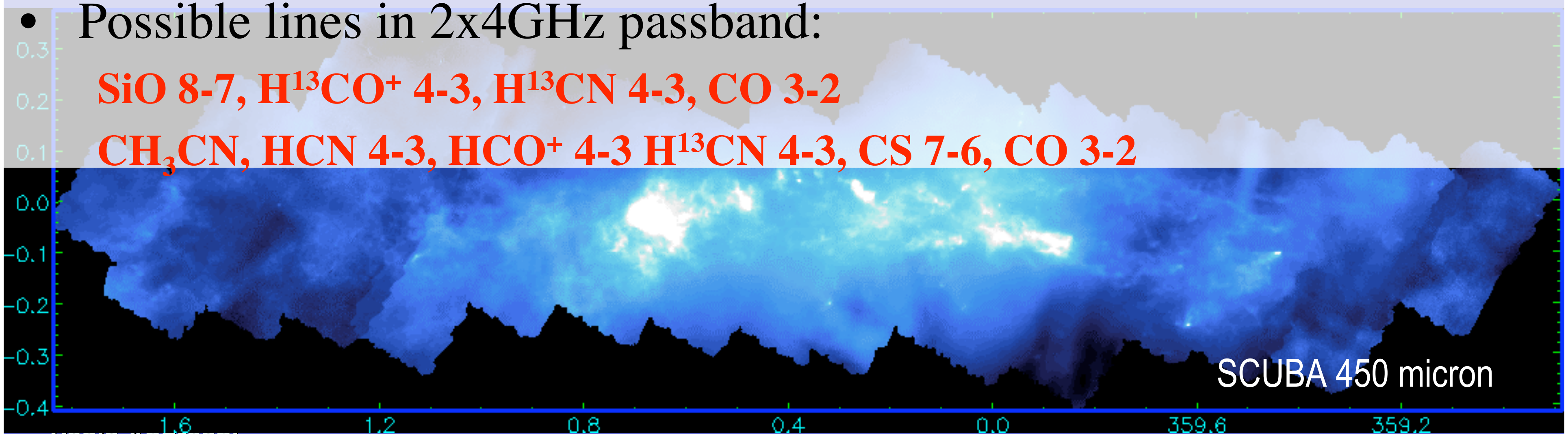
Star Formation at the Galactic Centre



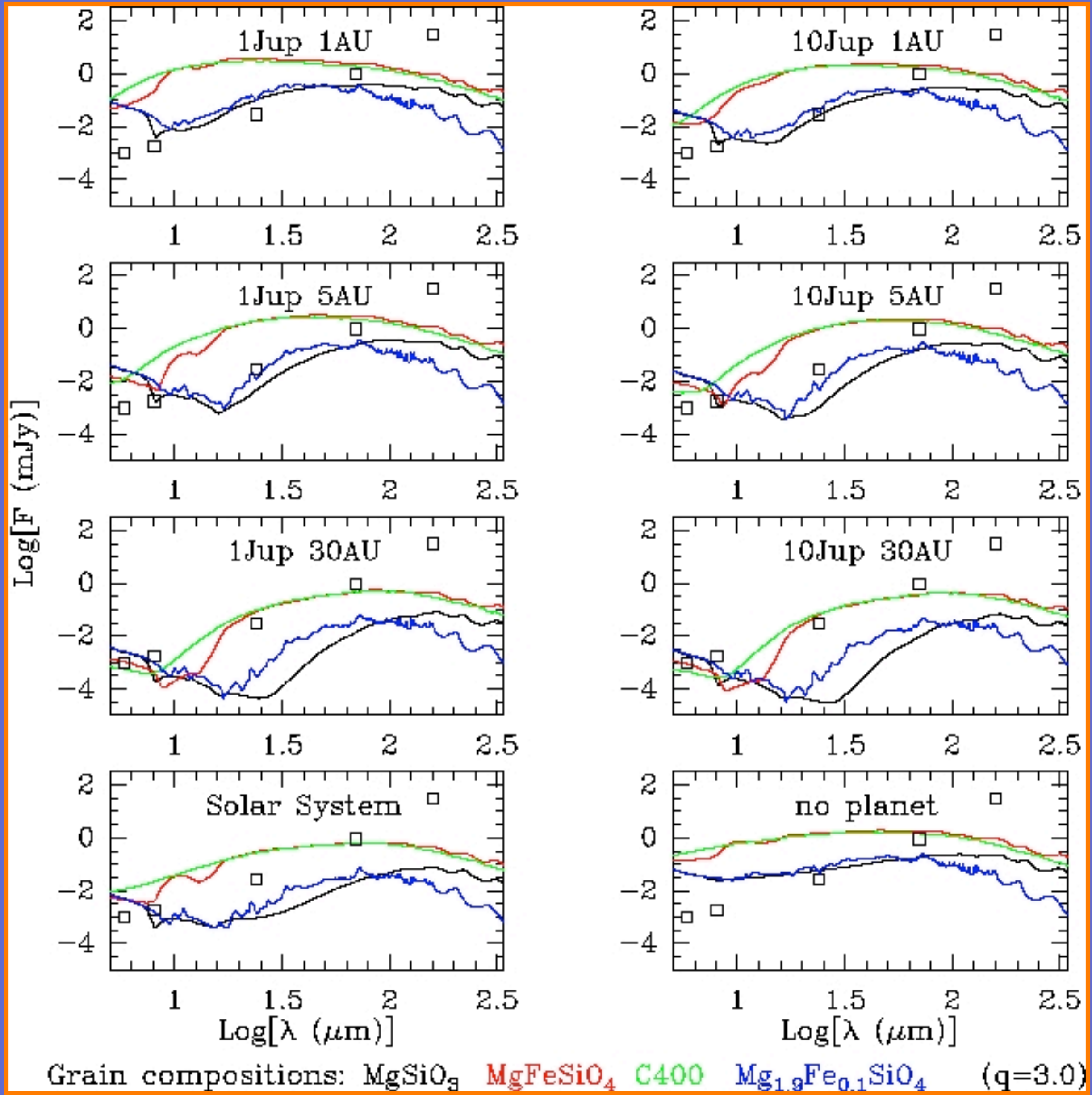
- HIGAL (HSO OT proposal) map the Galactic Centre in SPIRE (PACS) bands
- ALMA could map 1□ ^{2} at 350GHz in 180 h to 0.7mJy sensitivity (0.15 $M_\odot$ at 20K)
- 1" beam (8500AU) would give ΔT=0.6K at 1 km/s resolution
- Possible lines in 2x4GHz passband:

  SiO 8-7, $H^{13}CO^+$ 4-3, $H^{13}CN$ 4-3, CO 3-2

  CH_3CN, HCN 4-3, HCO^+ 4-3 $H^{13}CN$ 4-3, CS 7-6, CO 3-2



Debris discs + planet formation

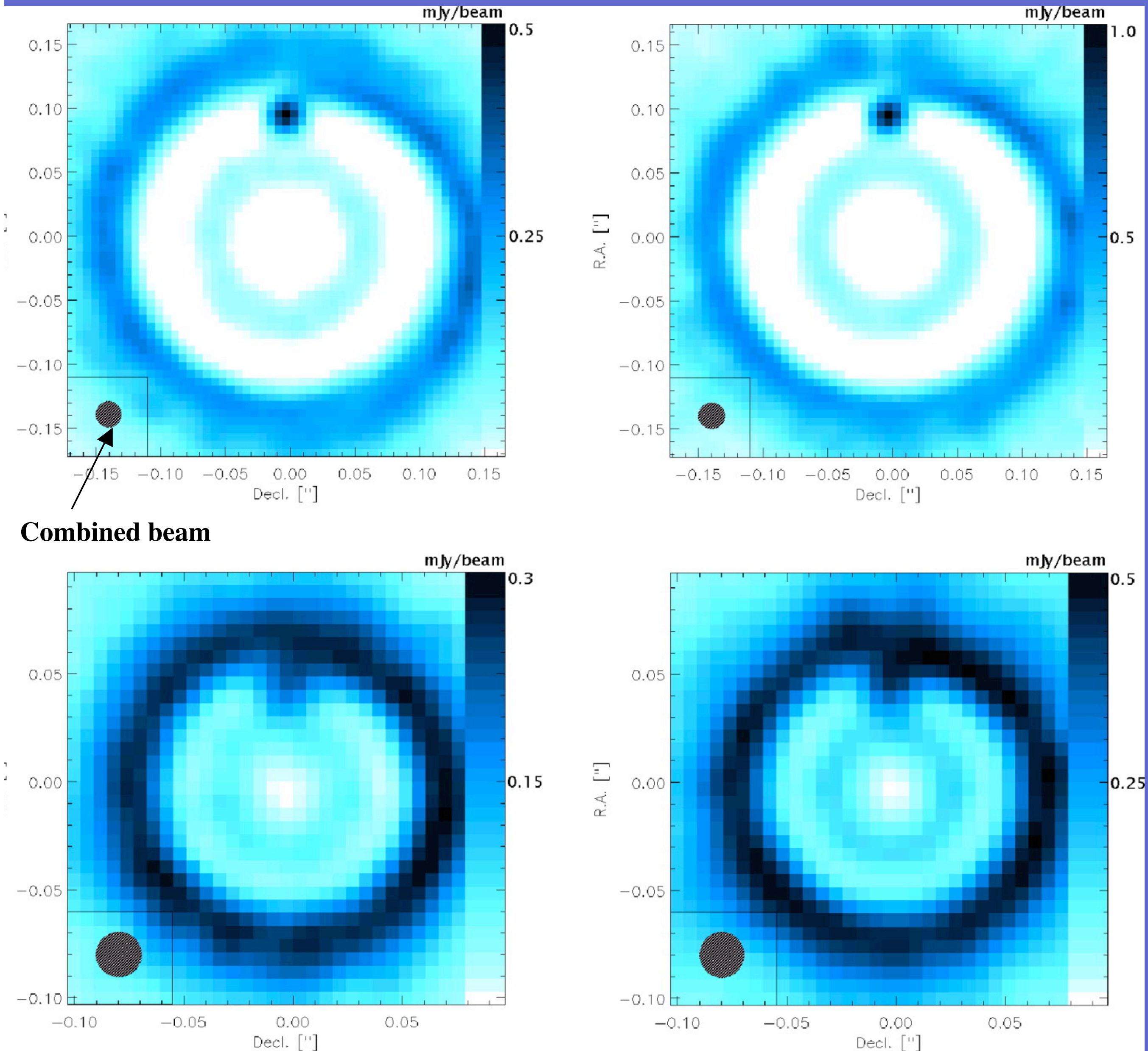


SED of dust discs in presence of different planetary configurations, 4 grain chemistry

same particle size distribution $n(b)db=n_0b^{-q}$, distance 50pc, total mass 10^{-10} $M_\odot$

Final Disk SED

$1\ M_{Jup}$ $0.5\ M_\odot$ $5\ M_{Jup}$ $2.5\ M_\odot$



dust emission from a face-on disc with a planet
ALMA 900GHz simulations

Integration time 8 hours;
10 km baselines;
30 degrees phase noise

Detection of the warm dust in the vicinity of the planet only for distance 50-100pc

orbital radius 5 AU
distance 50pc,
total disc mass $10^{-2}\ M_\odot$

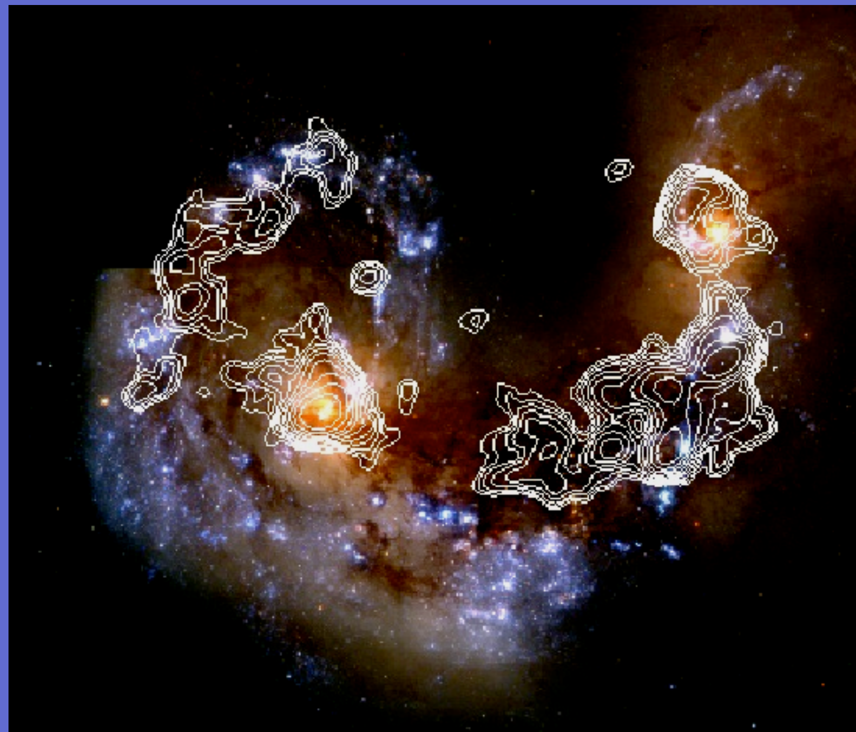
orbital radius 5 AU
distance 100pc,
total disc mass $10^{-2}\ M_\odot$

Disc + planet

(Wolf & D'Angelo 2005)

Dust and molecular emission from optically obscured regions

HST optical image **HST optical image + CO contours**



The "Antennae"

(CO : Wilson et al. 2000)
(HST: Whitmore et al. 1999)

Star formation in nearby galaxies

Obscured galaxy formation at low redshift

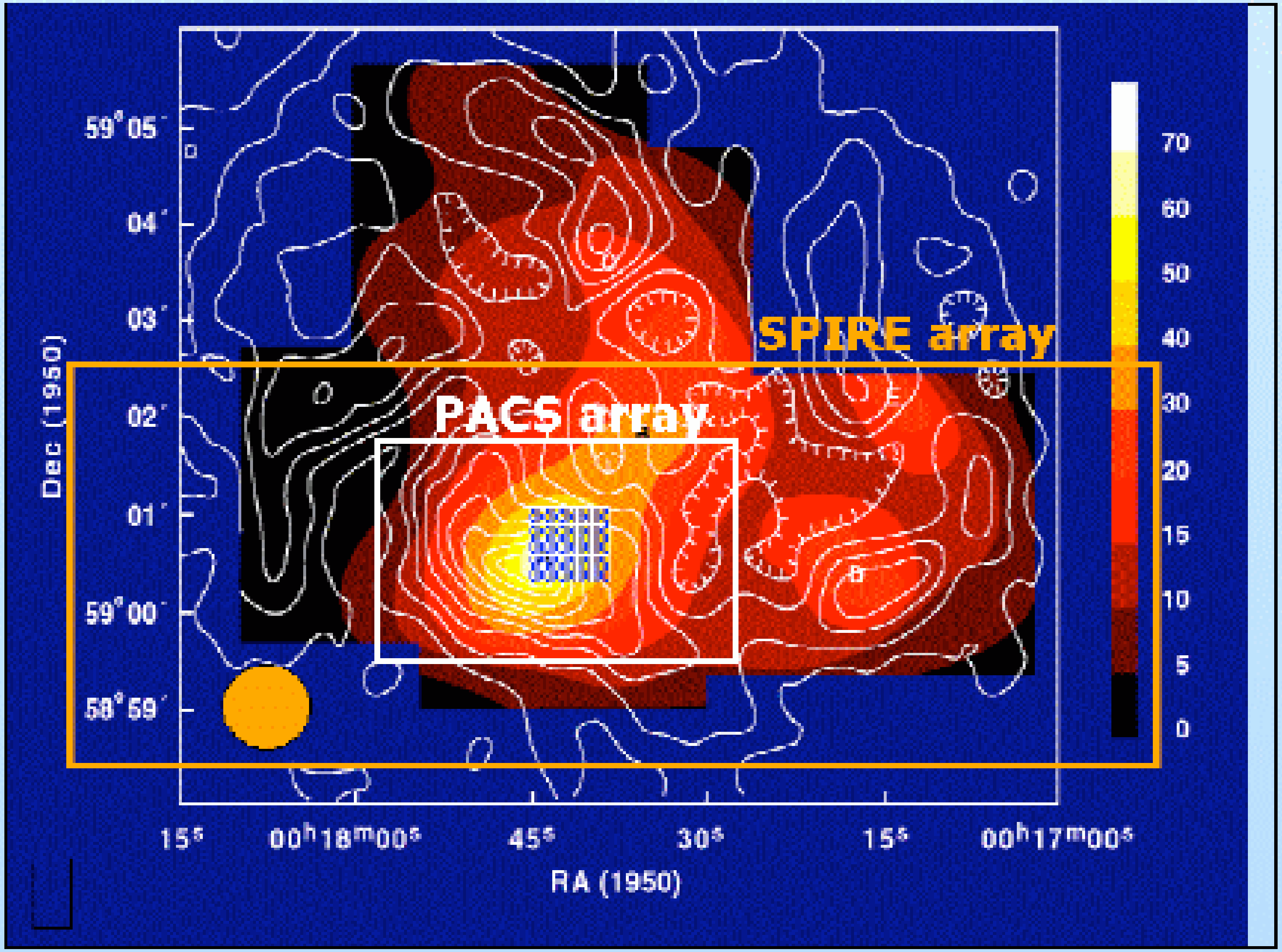
(Meier & Turner 2004)

IC342

- distance = 2 Mpc
- $M_{gas} = 4\ 10^7\ M_\odot$
- SFR = 0.1 M⊙/yr
- Starburst age = 10^7 yrs

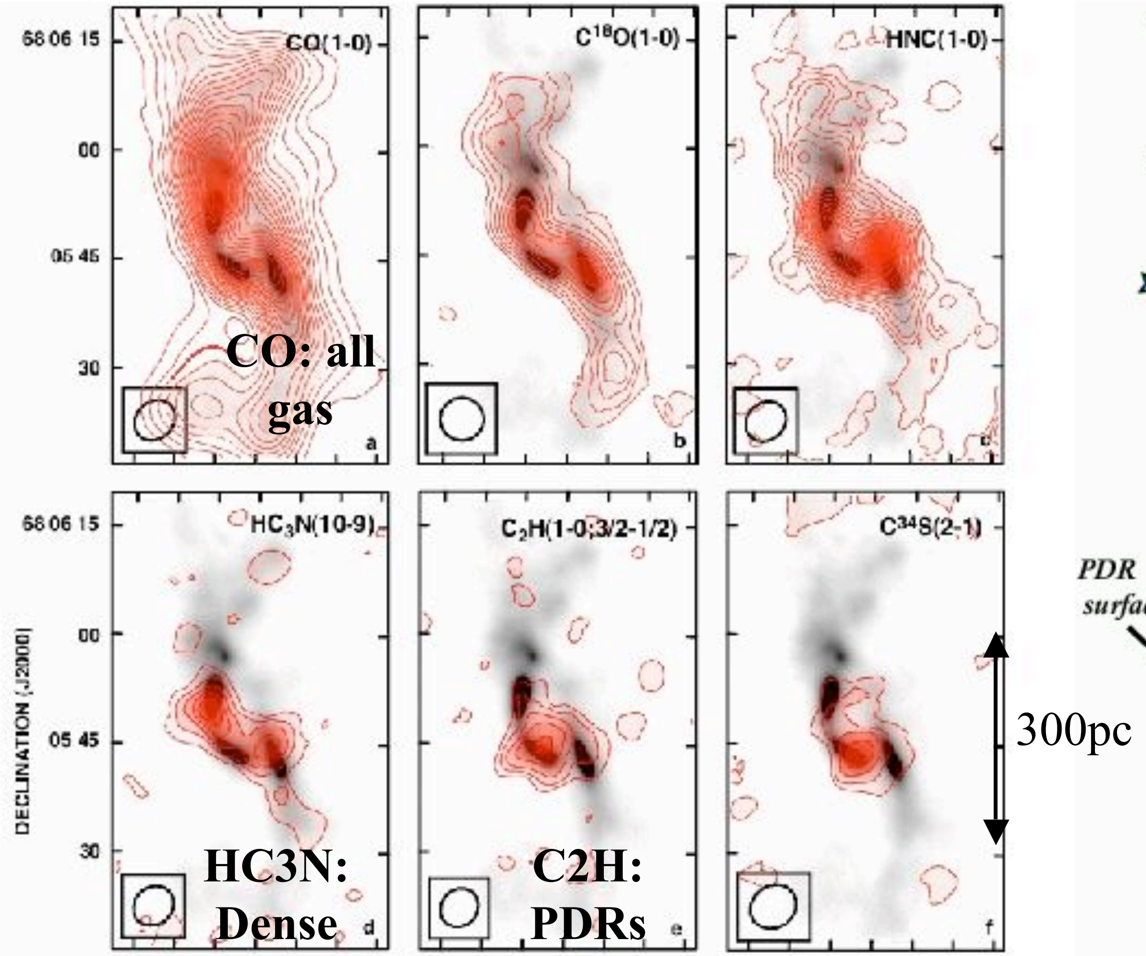
Star formation in nearby galaxies

- SED from IR to mm: active nucleus + SF activity + metallicity
- ISM structure
- Heating and cooling of the gas in different metallicity environment
- Effect on SF from environments
- Templates for high-z studies

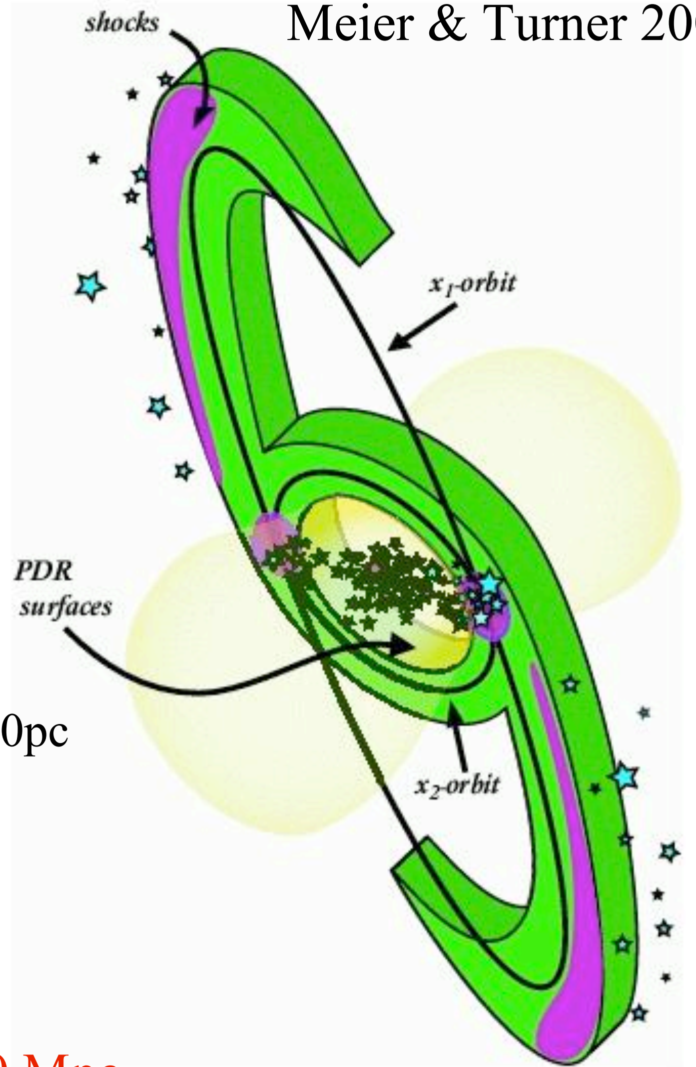


Contours: HI; Color 158 mu CII Madden et al 1997

Nearby star forming Galaxies – Chemistry/Physics: IC342, D=2Mpc



Meier & Turner 2004



ALMA: Image with GMC resolution (50pc) to 250 Mpc

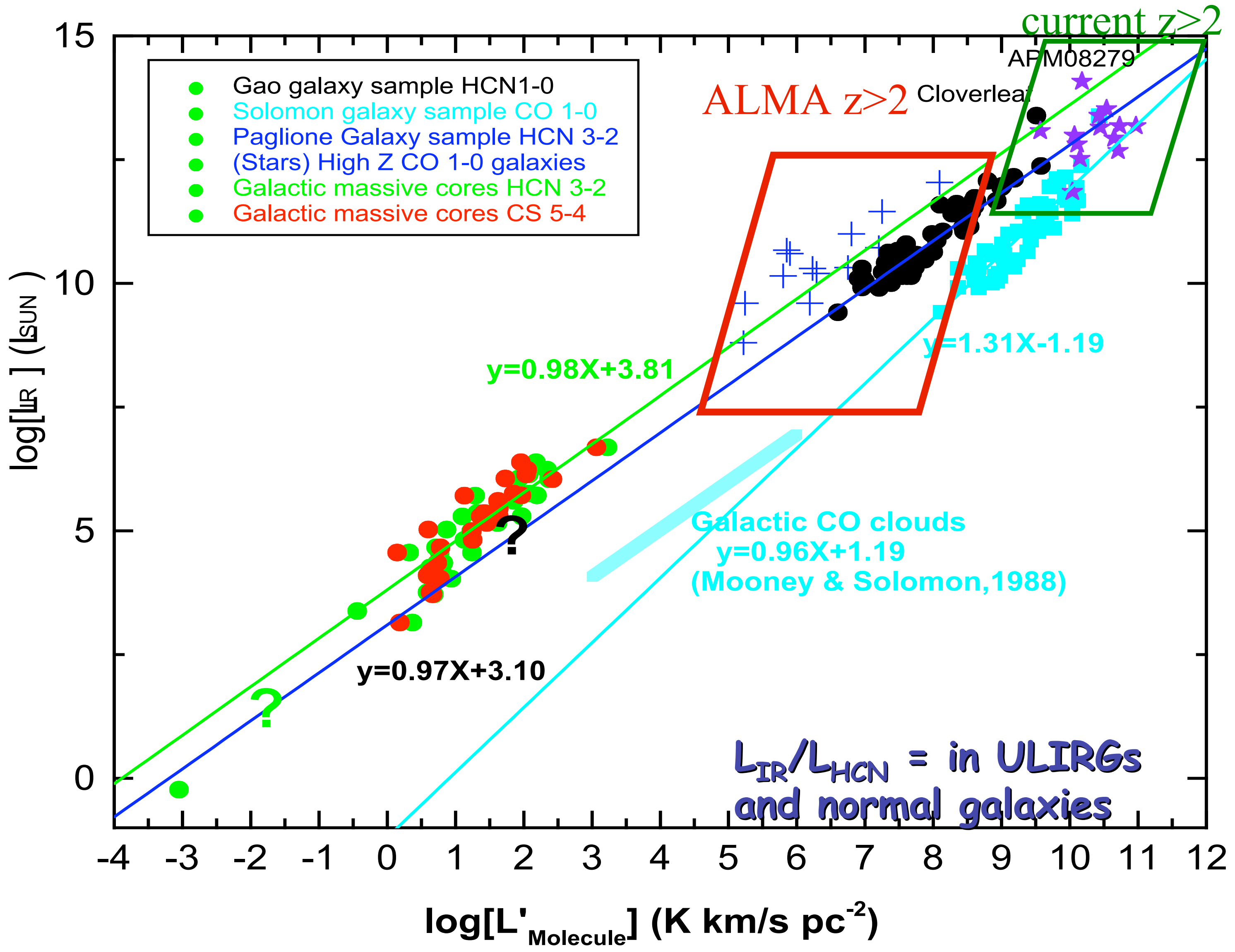
- Rich clusters: Virgo = 16 Mpc,   Coma = 100 Mpc
- ULIRGs: Arp 220 = 75 Mpc, Mrk 273 = 160 Mpc

Line diagnostics at low/high-z

is SF responsible for most of L_{FIR}?

- [OI]63μm + [CII]158μm 1-2% of L_{bol}
- Accurate SFR estimate + Metallicity
- Produced in PDR (not affected by AGN)
- ([OI]+[CII])/FIR → obscured AGN contribution ([CII] weaker in ULIRGs)
- HCN (dense gas, MC core) is a measure of the mass of SF cores
- CO traces the total molecular mass + gas dynamics

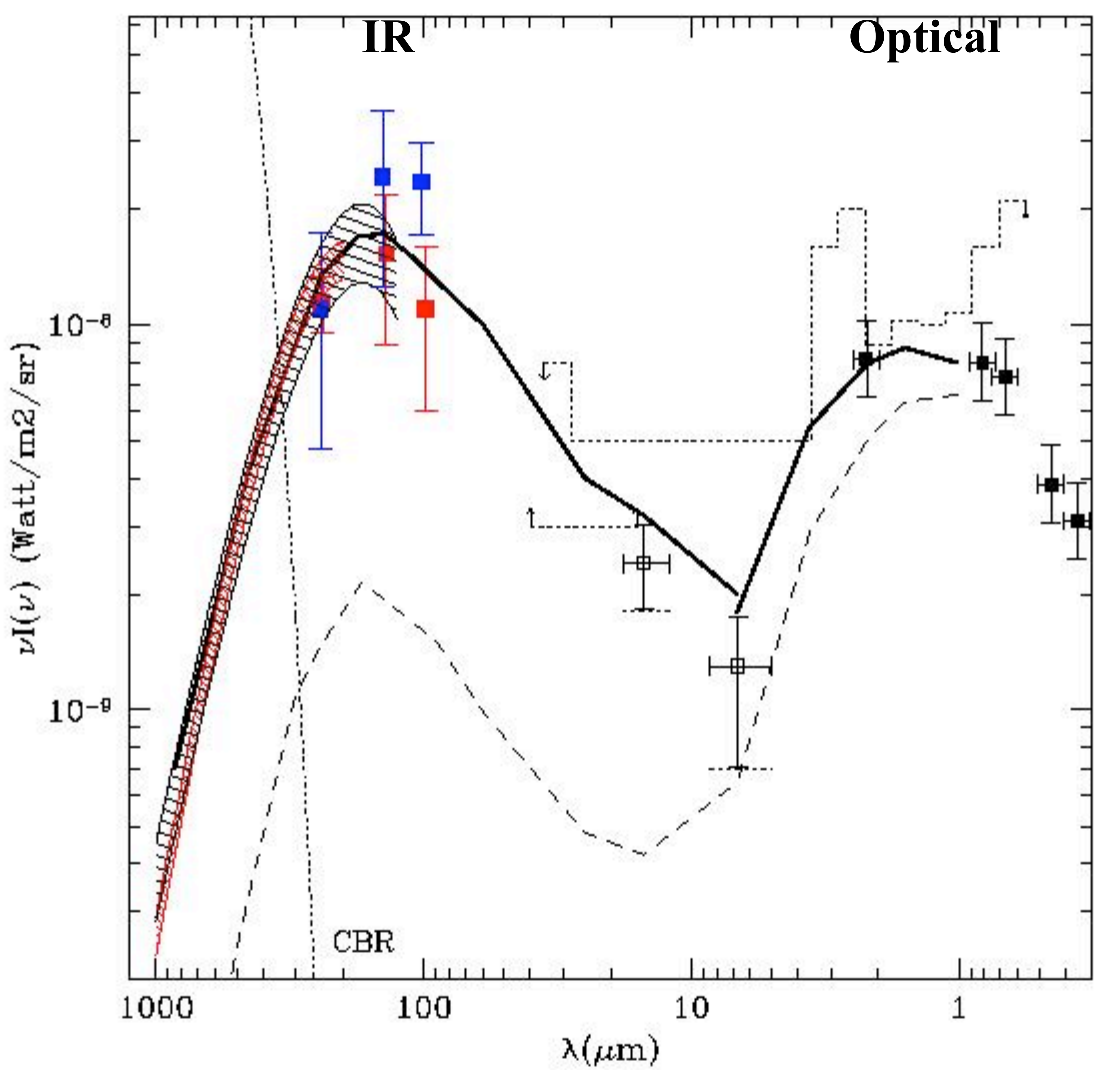
Line diagnostics at low/high-z



L_{IR}/L_{HCN} = in ULIRGs and normal galaxies

Wu et al., 2005

The Cosmic Extragalactic Background



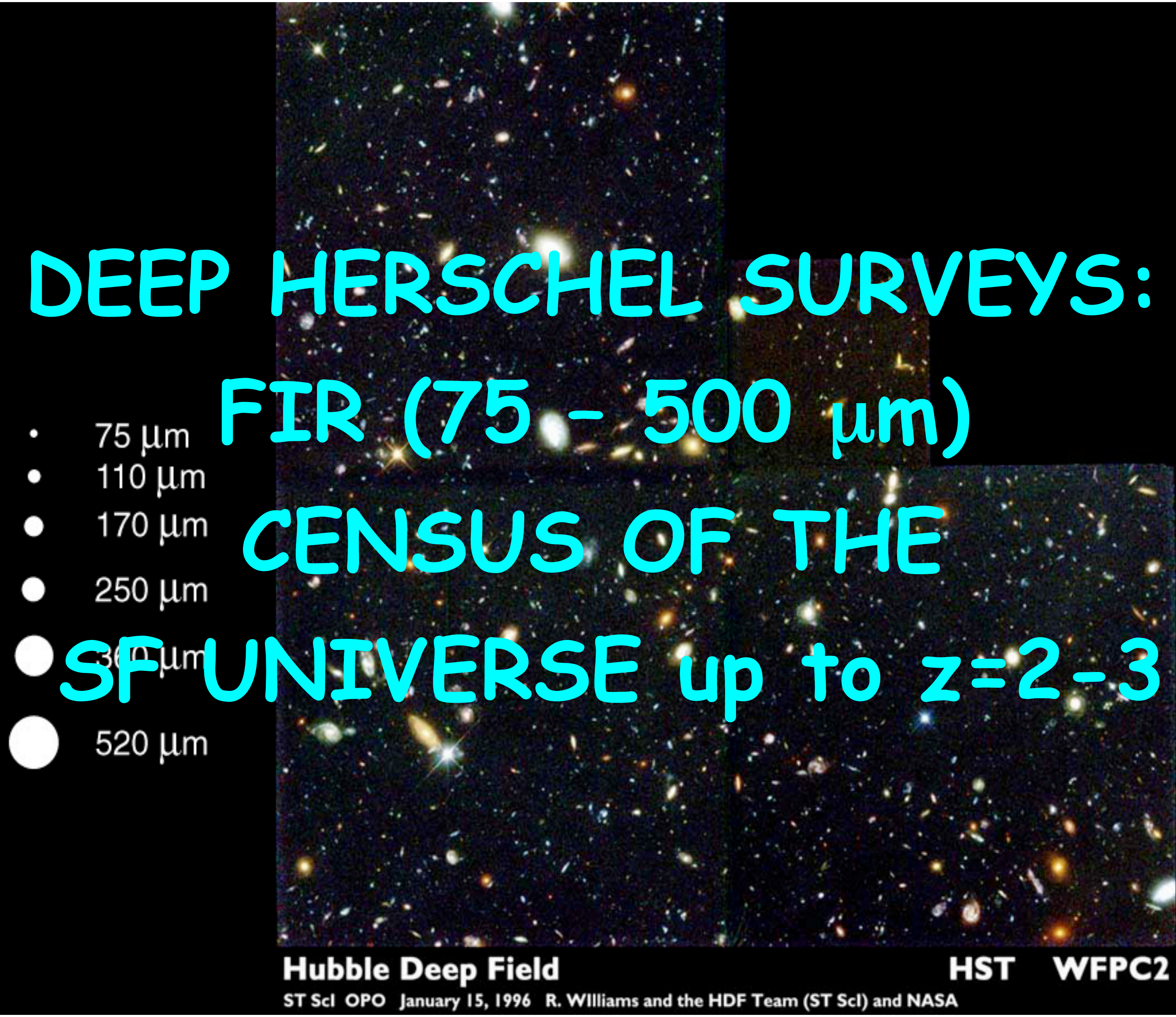
Franceschini 2000

$$\int_{100\mu m}^{1000\mu m} I(\nu)d\nu = 30nW/m^2/sr$$

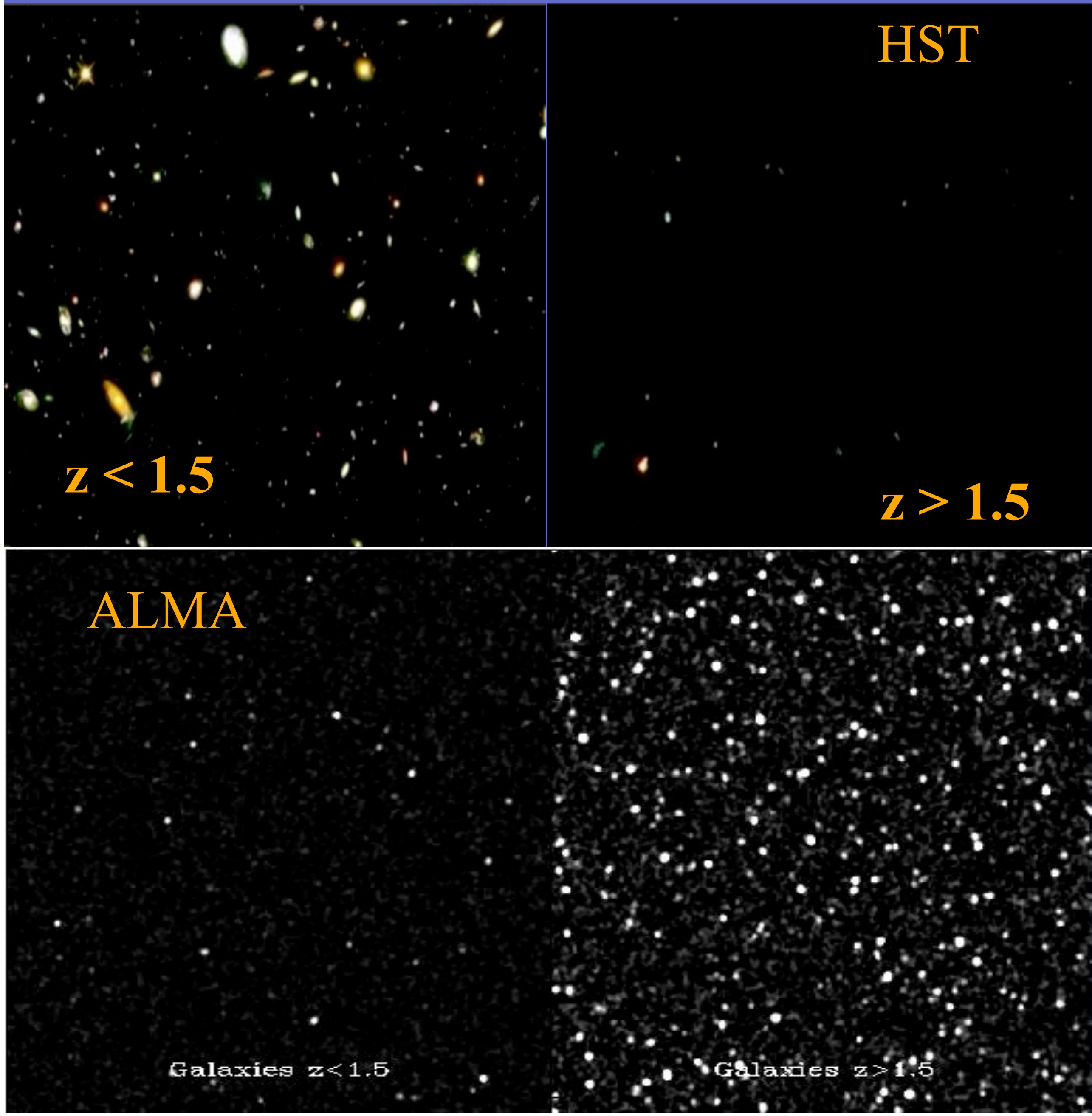
$$\int_{0.3\mu m}^{30\mu m} I(\nu)d\nu = 17nW/m^2/sr$$

Its origin revealed detecting those galaxies responsible for the 100-1000μm radiation

DEEP HERSCHEL SURVEYS: FIR (75 - 500 μm) CENSUS OF THE SF UNIVERSE up to z=2-3

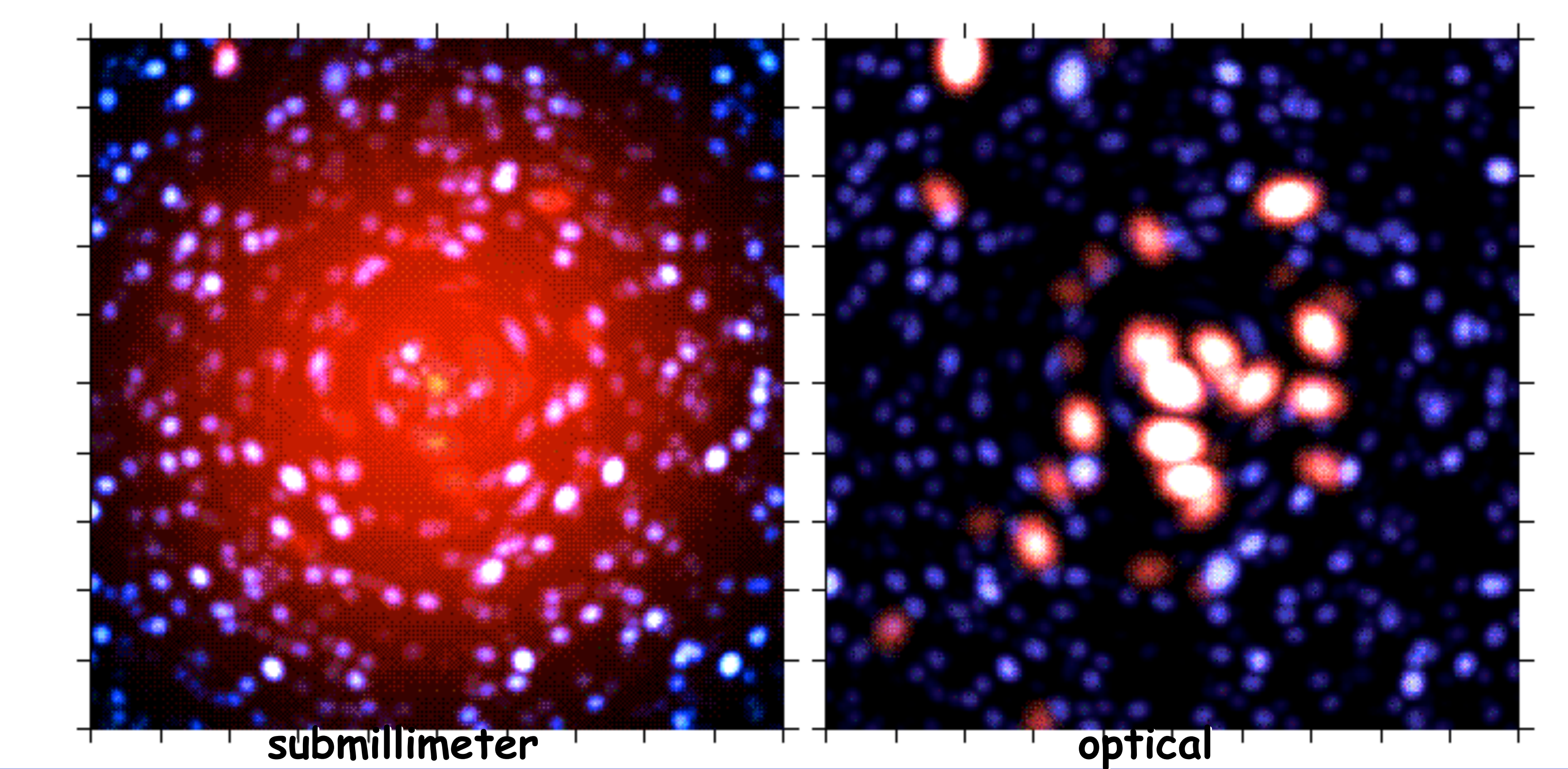


ALMA Deep field: 'normal' galaxies at high z



- Detect current submm gal in seconds!
- ALMA deep survey: 3days, 0.1 mJy (5σ), 4'
- HST: few 1000 Gal, most at z<1.5
- ALMA: few 100 Gal, most at z>1.5
- Parallel spectroscopic surveys, 100 and 200 GHz: CO/other lines in majority of sources
- Redshifts, dust, gas masses, plus high res. images of gas dynamics, star formation

Gravitational lensing by a cluster of galaxies



Blain 2001

Surface density with steep/shallow counts N(S) increased/decreased by gravitational lensing magnification (μ): $N'(S)=N(S/\mu)/\mu^2$

For $N(S)\propto S^{\alpha}$ bias factor $B=N'/N = \mu^{-(2+\alpha)} > 1$ if $\mu > 1$ source counts increase if $\alpha < -2$. If $\mu < 1$ $\alpha > -2$ positive magnification bias.

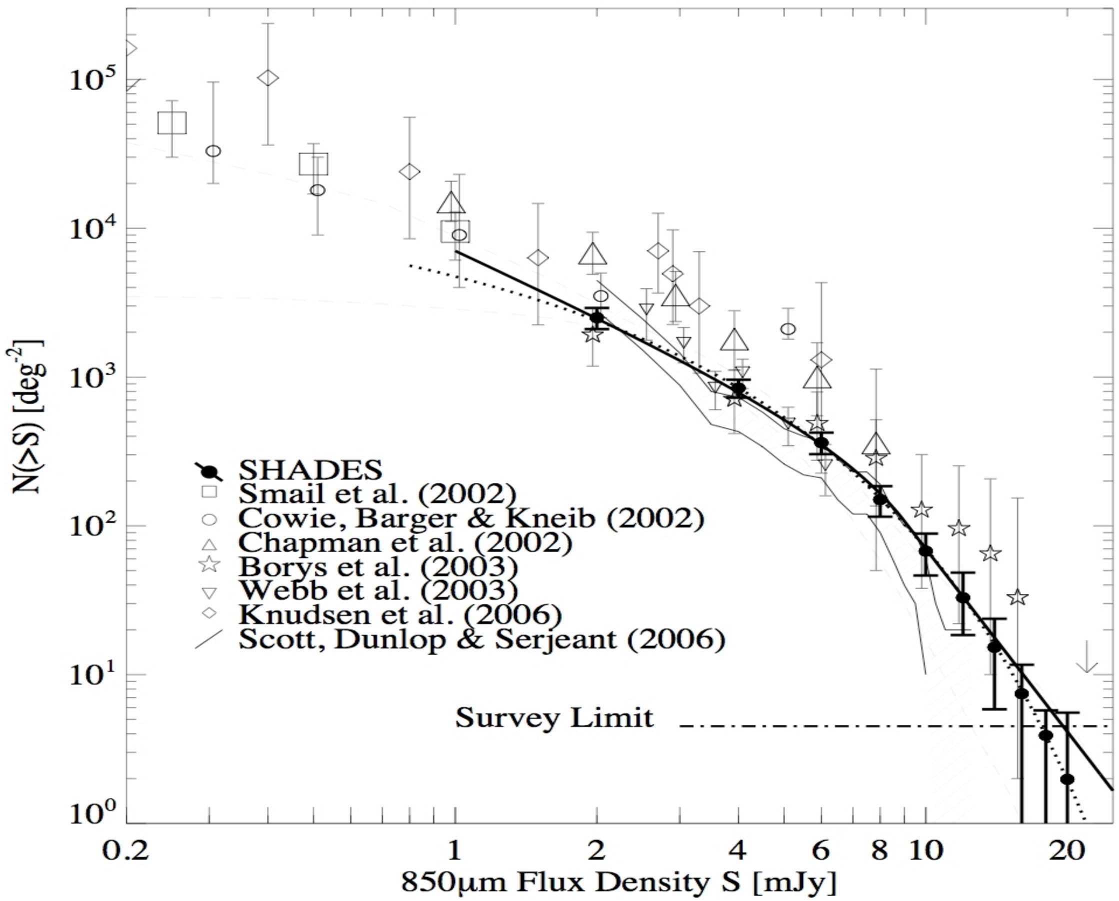
Sources otherwise too faint can be detected and resolved.

FOV increased

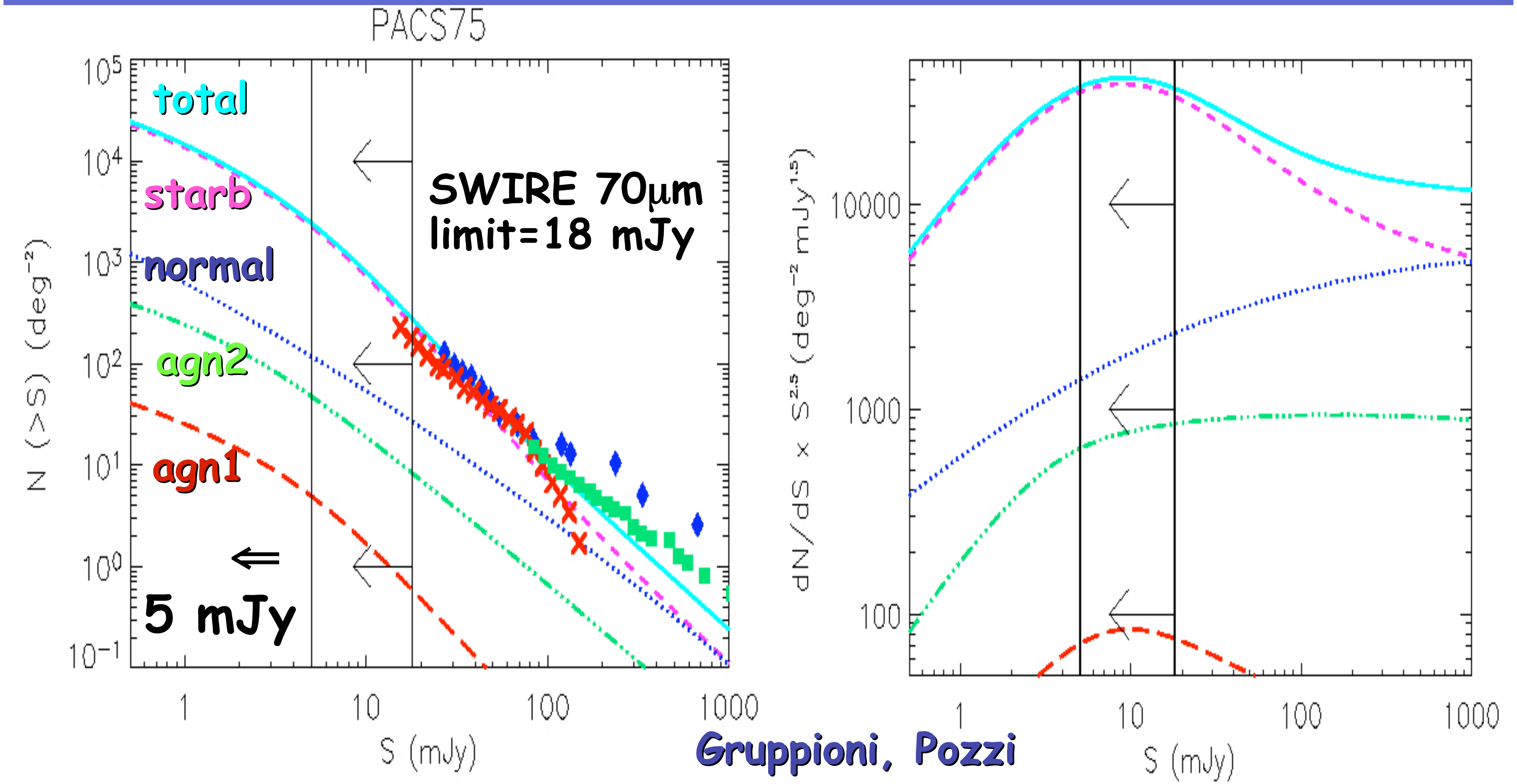
Gravi

Exploit ALMA to image the densely packed demagnified counterimages of background galaxies in the cluster core

1μJy 1 source/30 0.1" beam

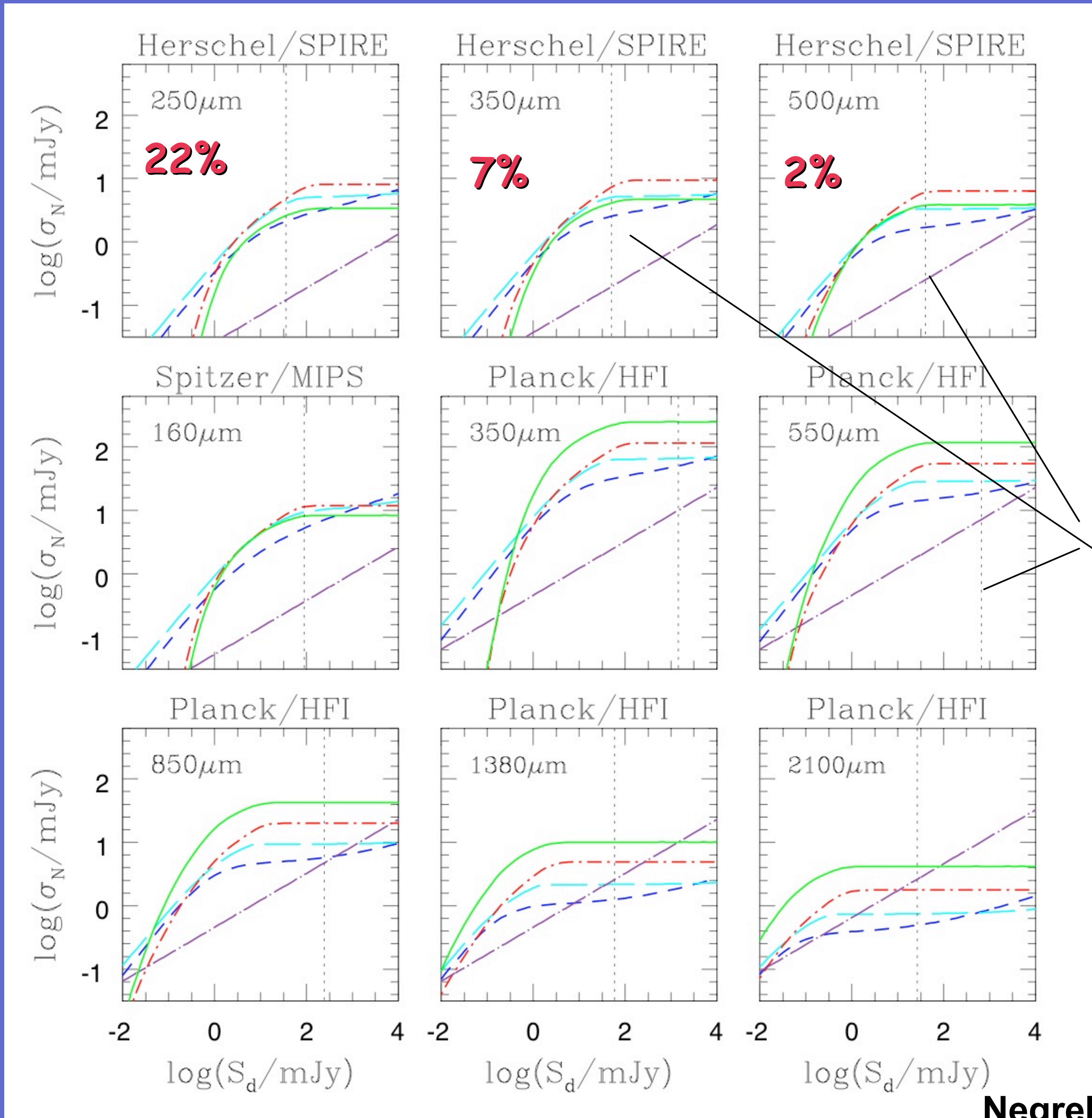


We will detect at 75 μm and characterize all the star-forming galaxies making up the peak of the differential counts



Gruppioni, Pozzi

Confusion noise estimates



Detection limits (poisson+clustering)

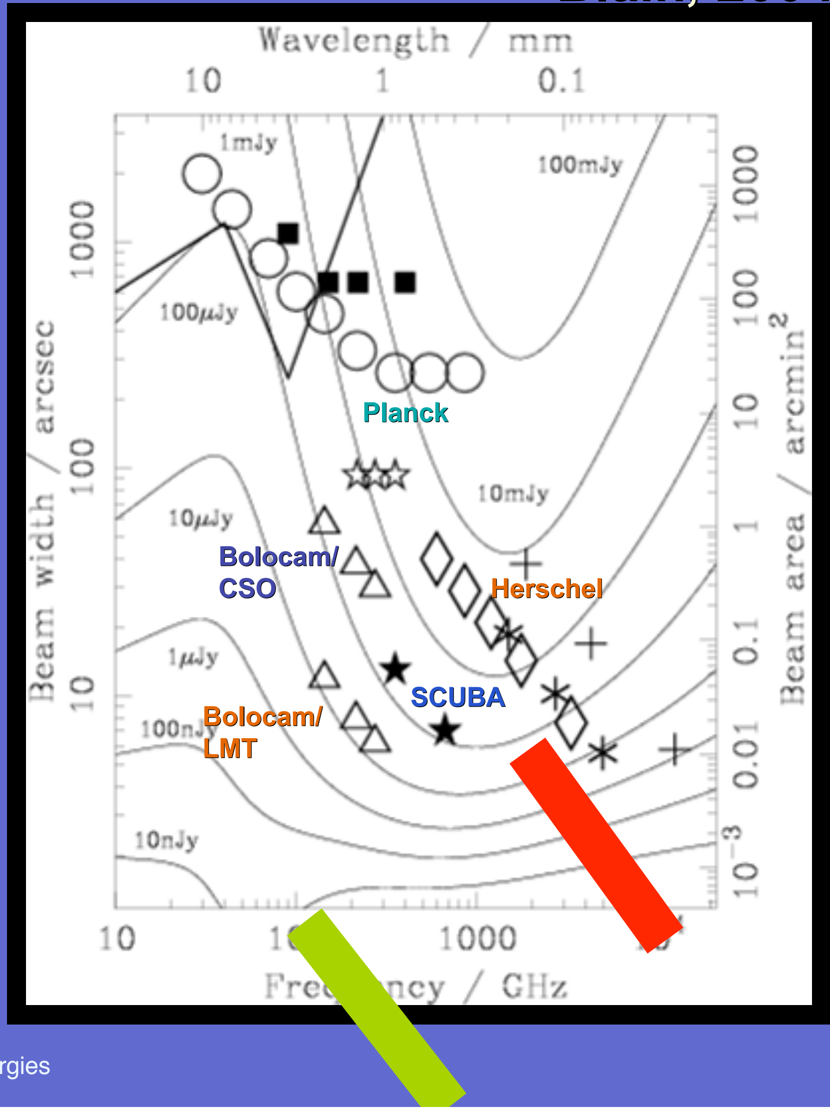
Blue: spirals
Cyan: SB
Violet: Radio sources
Red: SF spheroids
Green: clustered SF spheroids

Negrello et al., 2004

Confusion is avoided with ALMA

Blain, 2004

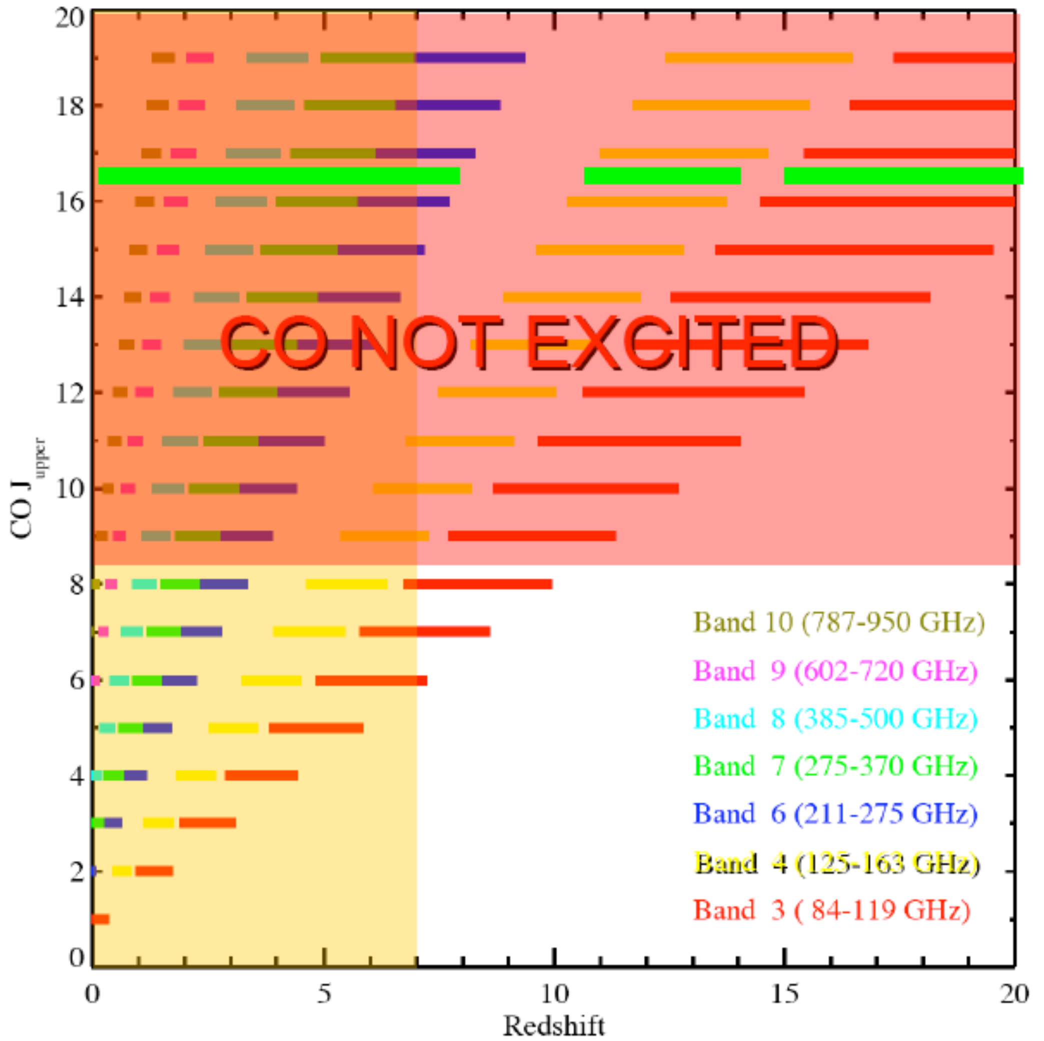
- Current missions in black
  - Spitzer is +\
- Green bar is just a 500m baseline ALMA
- Red bar is 10-m SAFIR
  - Confusion from galaxies not met for many minutes or hours
  - At shortest wavelengths very deep observations are possible
- Factor of 10 in resolution over existing facilities is very powerful



Confusion noise: square root of the variance $\sigma^2_N(S_d)$ of intensity fluctuations within the telescope beam

Detection limit: $S_d = q\ \sigma_N(S_d)$

ALMA as a redshift machine

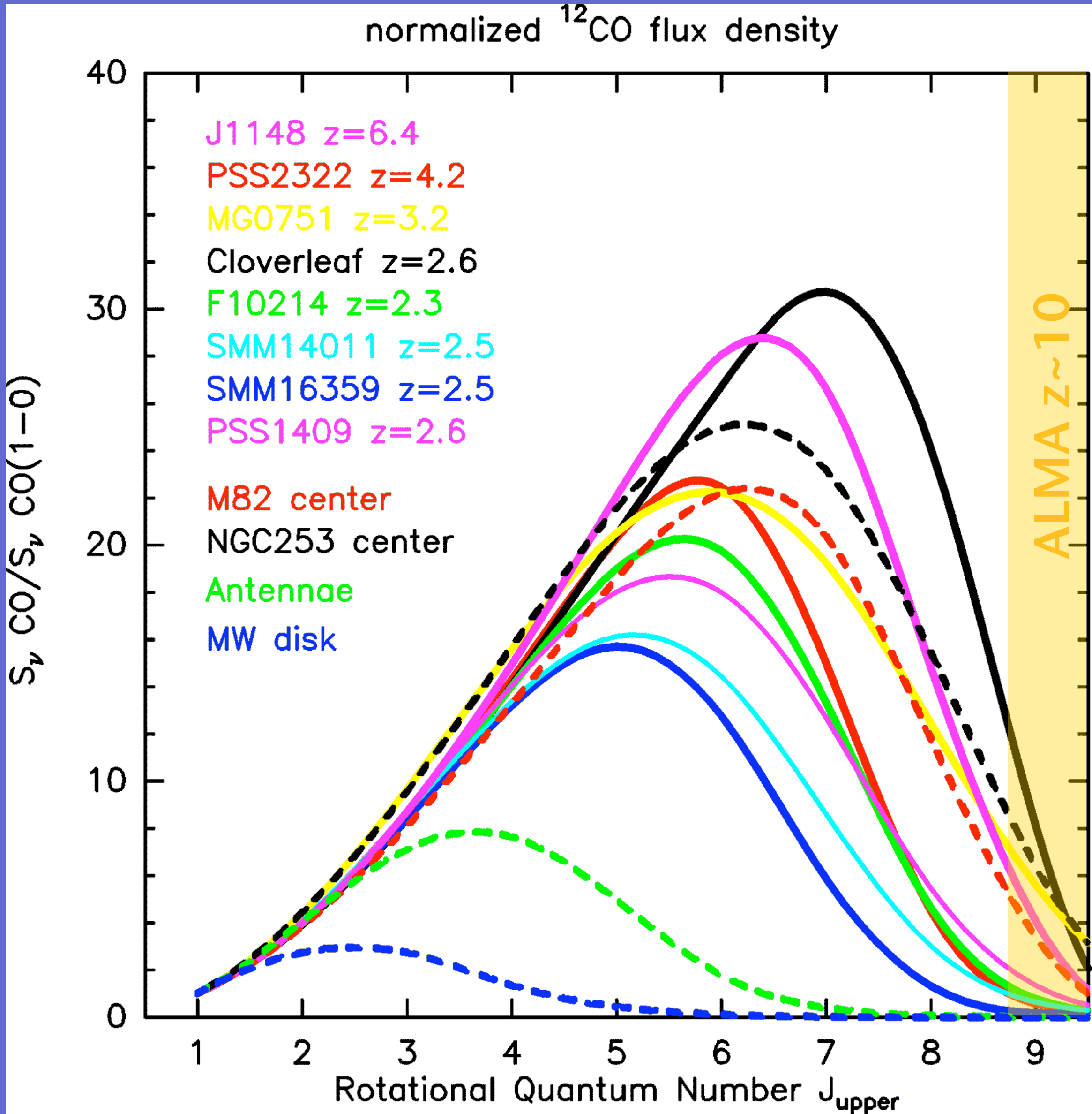


CII – line of choice for
EoR studies
Case for Band 5

CO transitions for
z < 7

F Walter, 2006

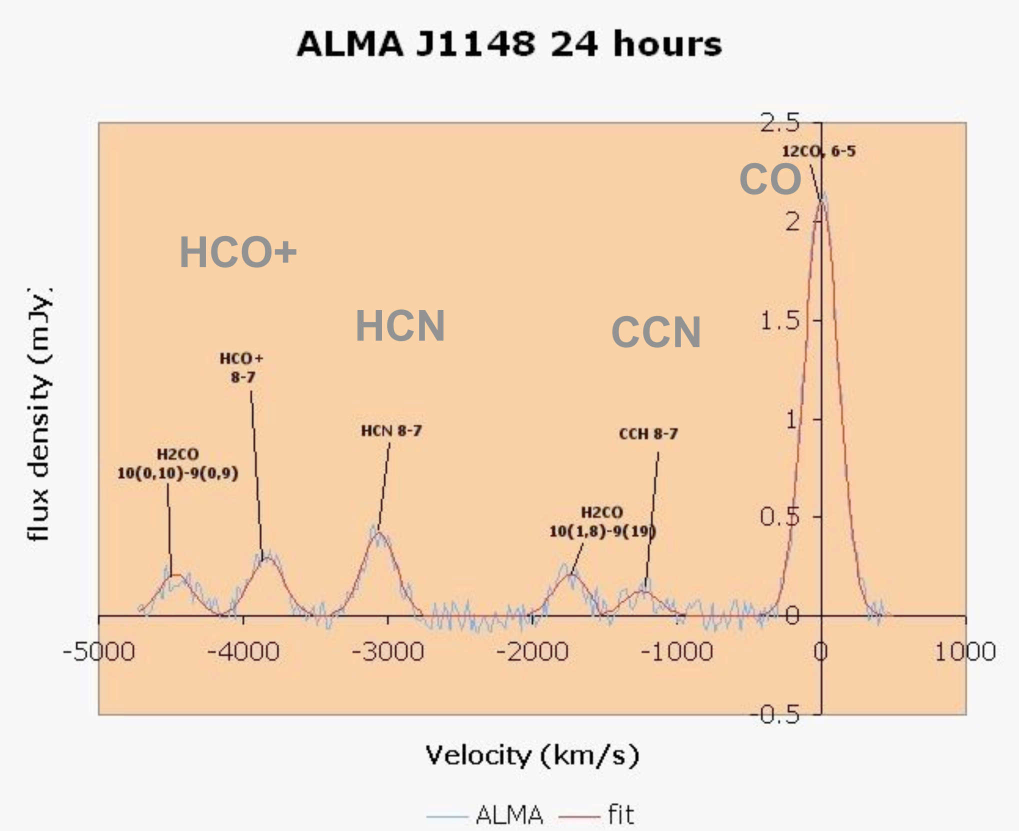
CO Line SEDs



@ z~10
CO lines not detectable

Weiss, Walter, Downes, Henkel, in prep

ALMA into the Epoch of Reionization

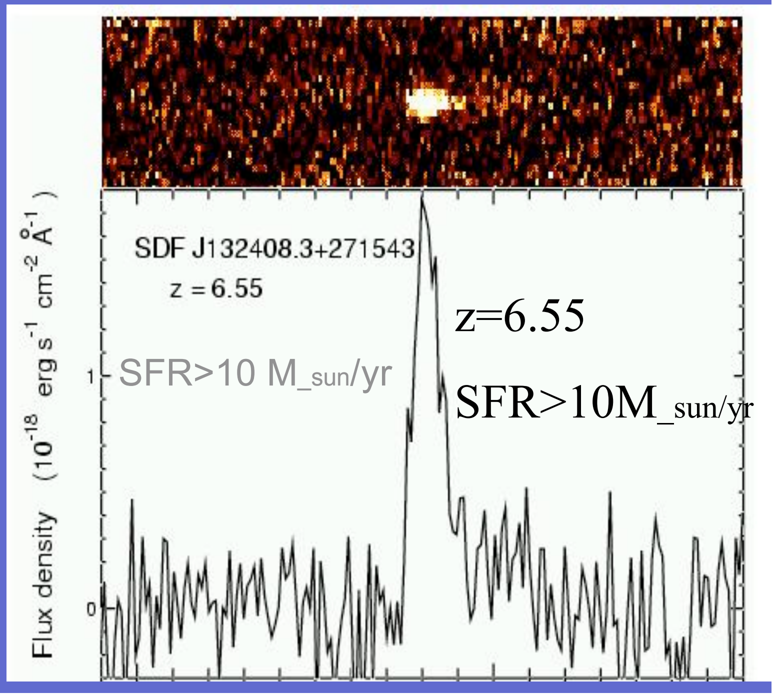


Spectral simulation of J1148+5251

- Detect dust emission in 1s (5σ) @ 250 GHz
- Detect multiple lines, molecules per band => detailed astrochemistry
- Image dust and gas at sub-kpc resolution – gas dynamics!

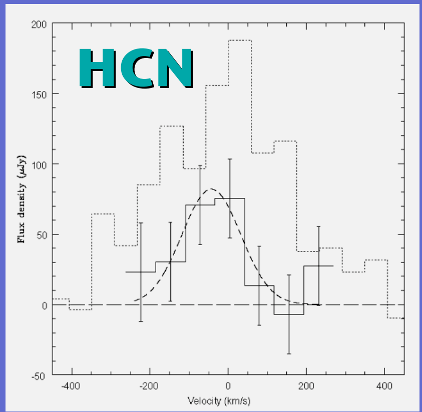
Studying 1st galaxies

- Detect 'normal' (eg. Ly α), star forming galaxies, like M51, at z>6, in few hours
- Determine redshifts directly from mm spectroscopy

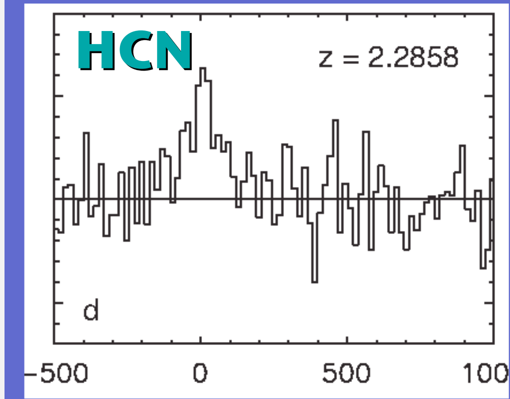


High Density Tracers: HCN & HCO^+

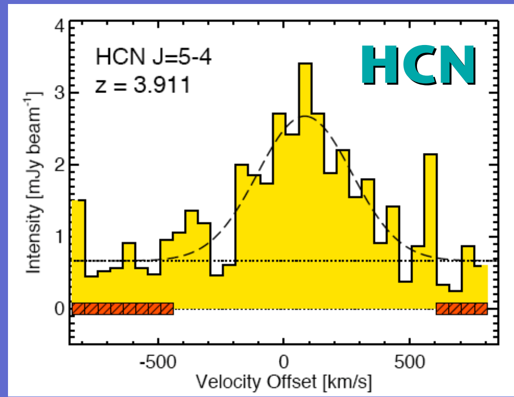
J1409 - Carilli ea '04



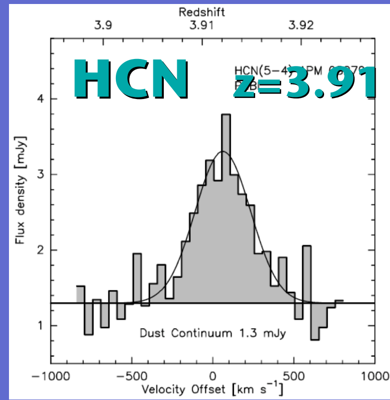
F10214- Solomon ea '04

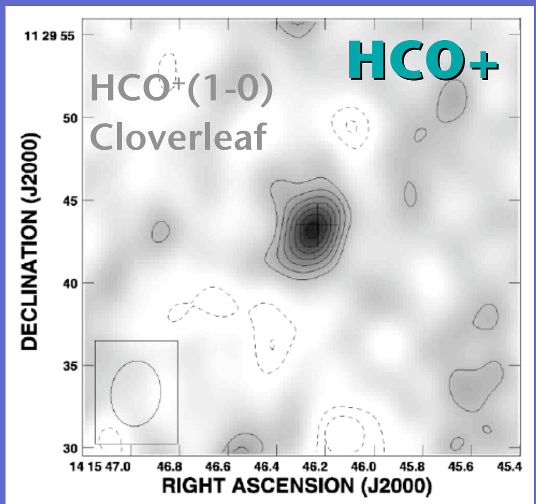


APM08279 - Wagg ea. '05

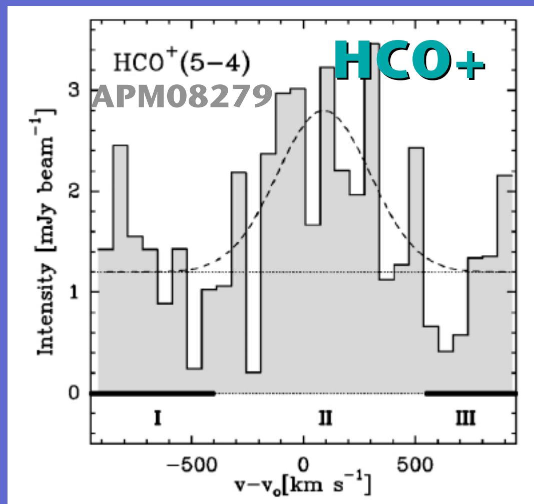


Weiss ea. '06





Riechers, Walter ea 2006



Garcia Burillo ea 2006

...lines 5-10 fainter than CO lines...

Paola Andreani

[CII] (ionized carbon): major cooling line of the ISM

$^2P_{3/2}$-$^2P_{1/2}$ fine-structure line -- PDR / SF tracer

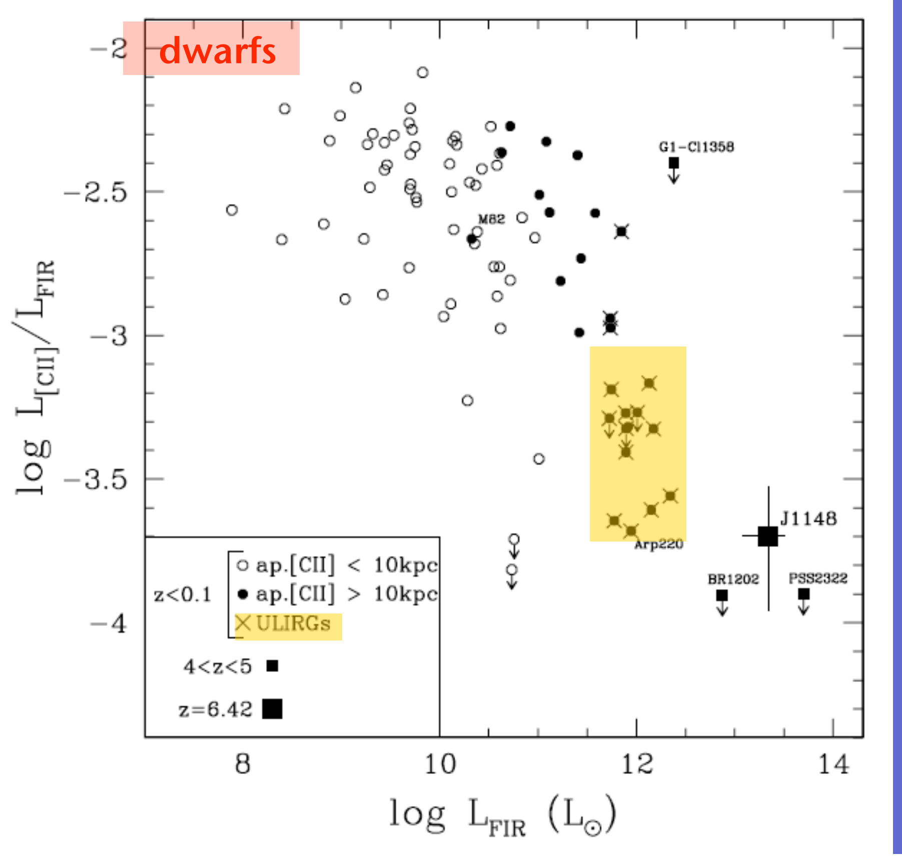
Rest frequency: 1900 GHz (158 microns)
-> z=0 observations from ground prohibitive

ISO observations:
[CII] carries high fraction of L_{FIR} !

Low-metallicity dwarfs: ~1 %
Starforming galaxies: ~0.5 %
ULIRGS: ~0.05 %

Why? A) self-absorbed/optically thick [CII]
B) saturation due to high UV flux
C) others

[e.g., Stacey 91, Israel 96, Malhotra 97, Madden 97, Gerin 00 Luhmann 03]



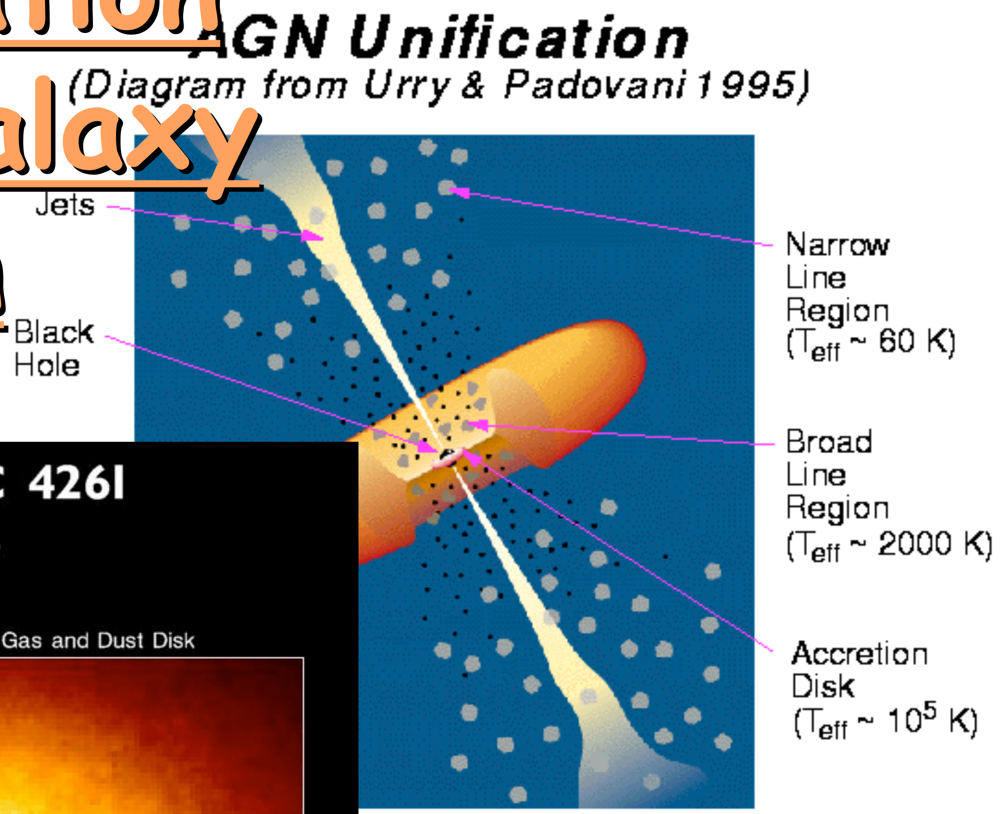
adopted from Maiolino et al 05

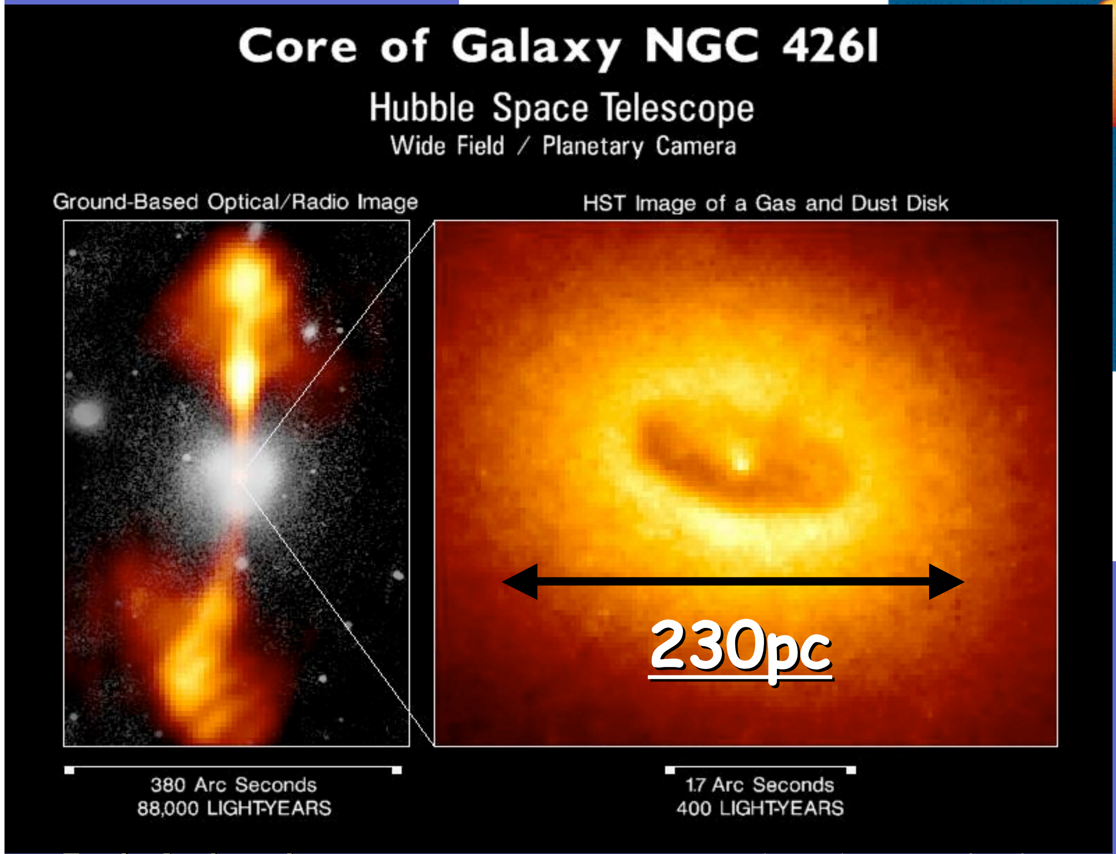
ALMA, APEX, Herschel

Finding z >> 2 galaxies

- Blind Herschel/APEX surveys trace heavily obscured star-forming galaxies up to z=2-3
- Optical/near-IR identification very difficult.
- ALMA images individual Herschel/APEX source, separates different galaxies in 1 beam
- ALMA will resolve and detect a galaxy at z=6 with L_{CO} = that of M51
- ALMA will provide redshifts for all obscured source with CO spectroscopy.
- But ALMA blind surveys needed to detect the highest-z ones!

Coeval formation
BH - host galaxy
BH accretion

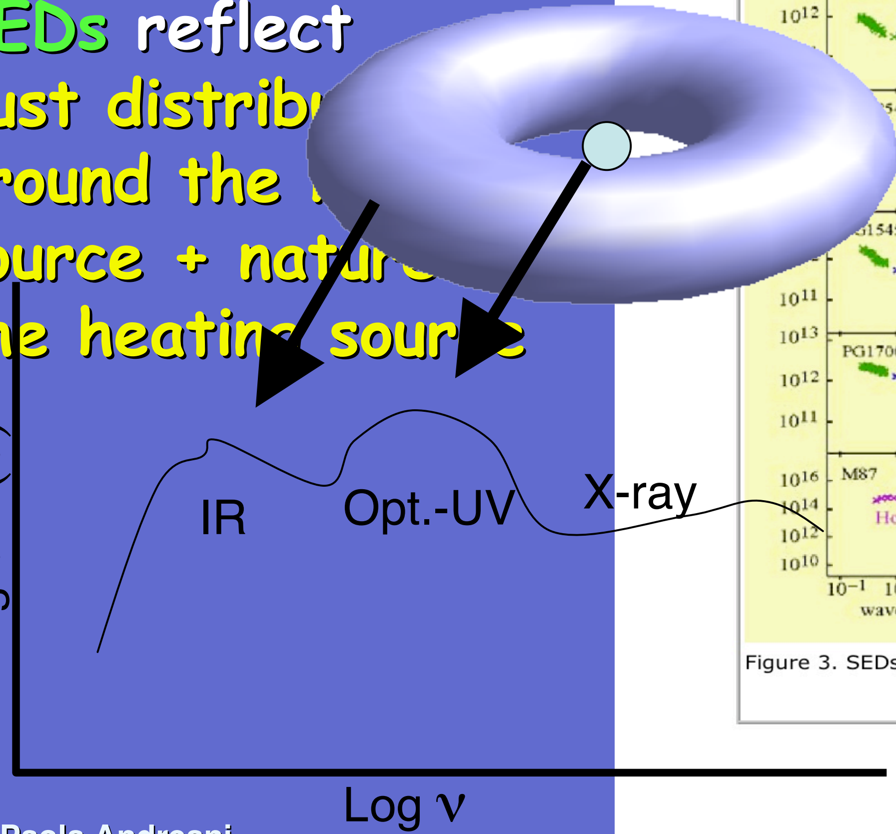




SEDs of QSOs and RGs

ISO+MAMBO+ SCUBA

SEDs reflect dust distrib[…] around the […] source + natur[…] the heatin[…] sour[…]



http://www.journals.cambridge.org/action/displayFulltext?type=6&...

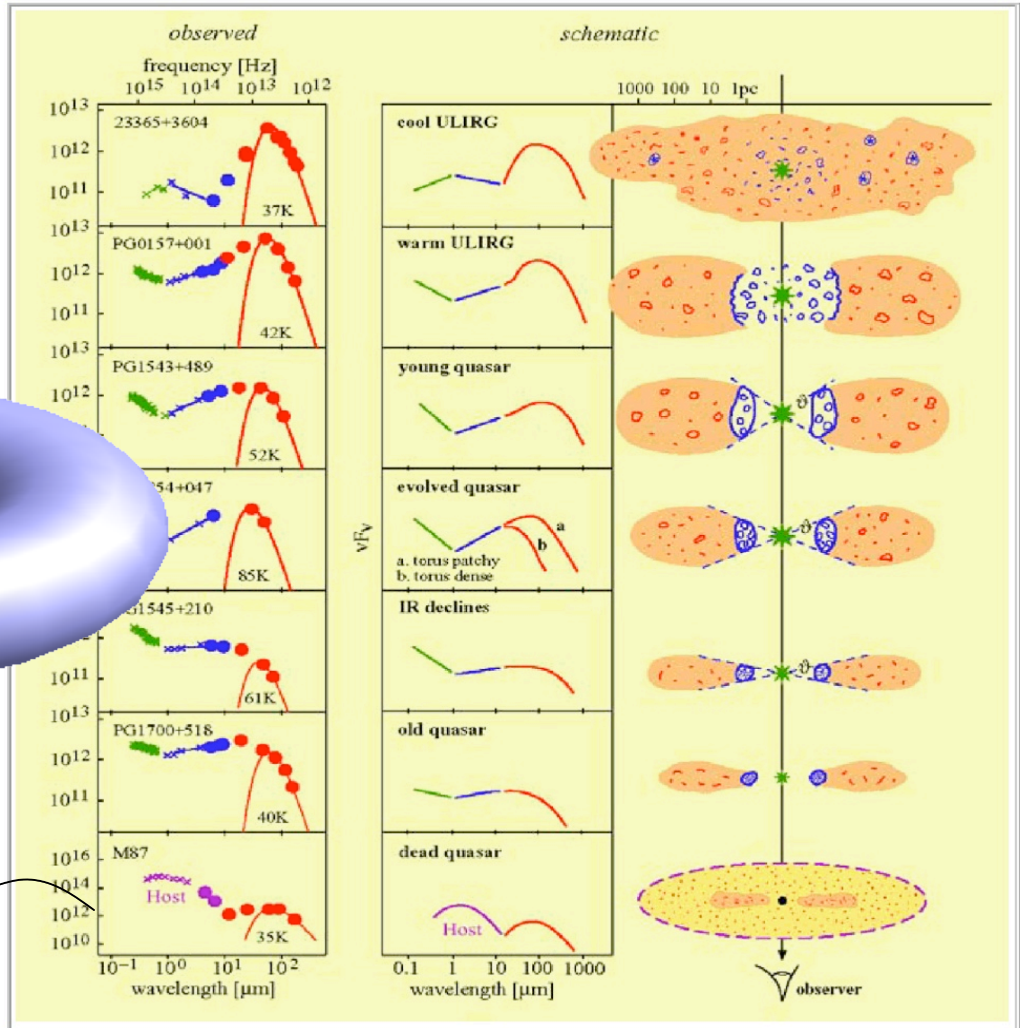


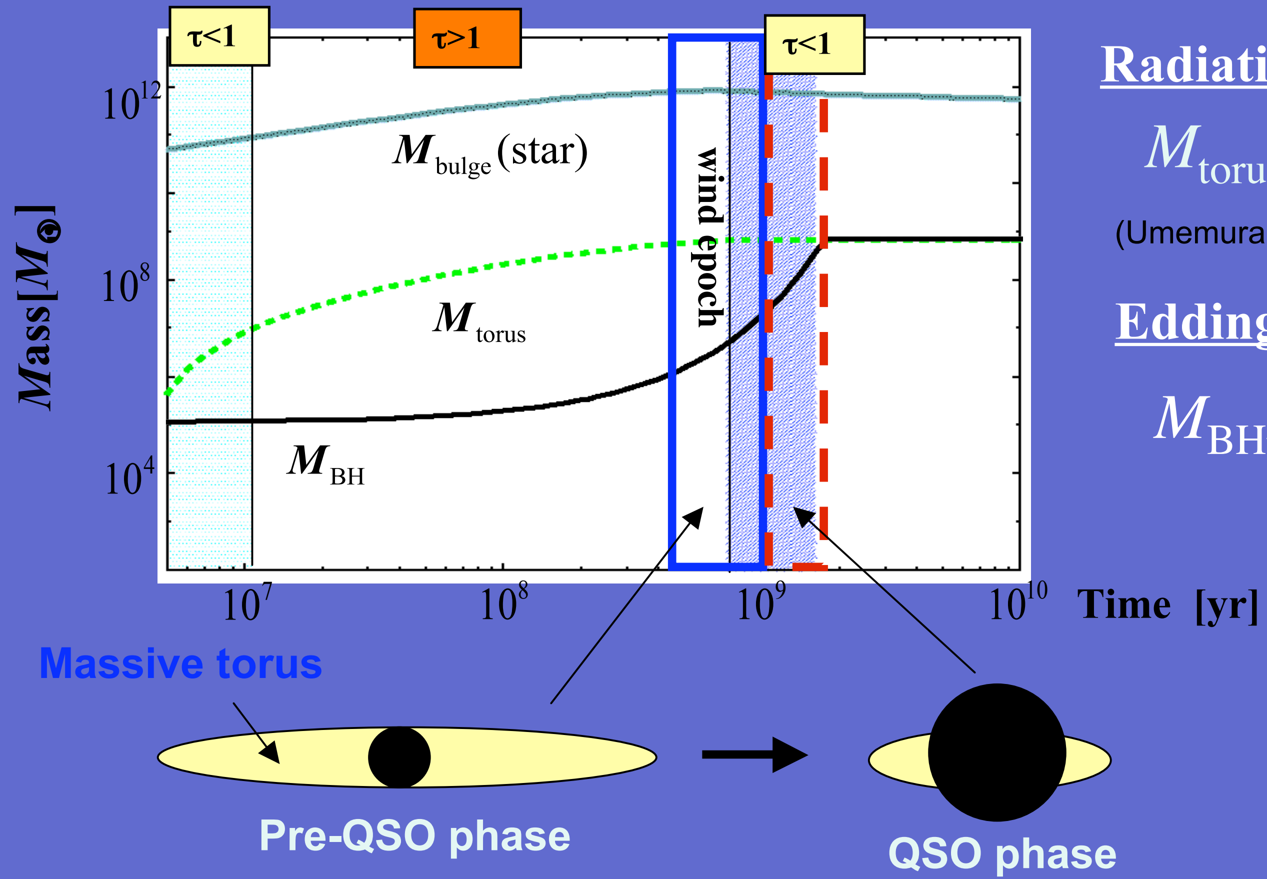
Figure 3. SEDs and scheme of dust distribution surrounding the AGN.

close

Haas et al., 2005

Which is the physical process of BH growth?

Coevolution of SMBHs and galactic bulges



Radiation drag growth

$$M_{torus} = \int L_{bulge}/c^2 \, dt$$

(Umemura 2001; Kawakatu & Umemura 2002)

Eddington growth

$$M_{BH}/M_0 = e^{\nu t/t_{Edd}}$$

$t_{Edd} = \eta_{BH} M_{BH} c^2 / L_{edd}$
$\nu = dM_{BH} / dM_{Edd}$
($\nu = 1$: $M_0 = 10^5 M_\odot$)

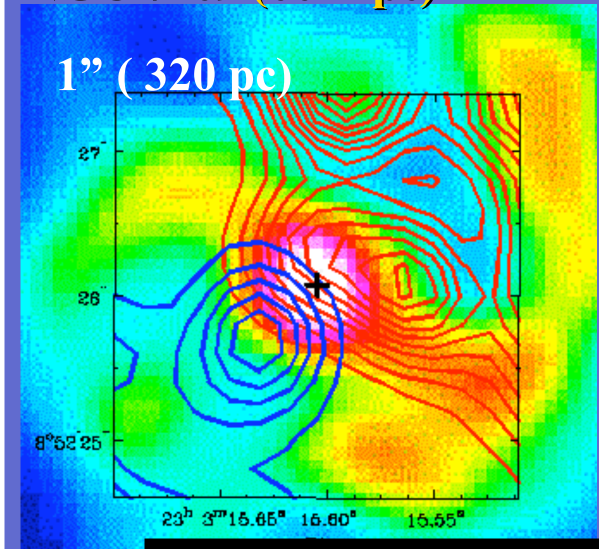
prediction

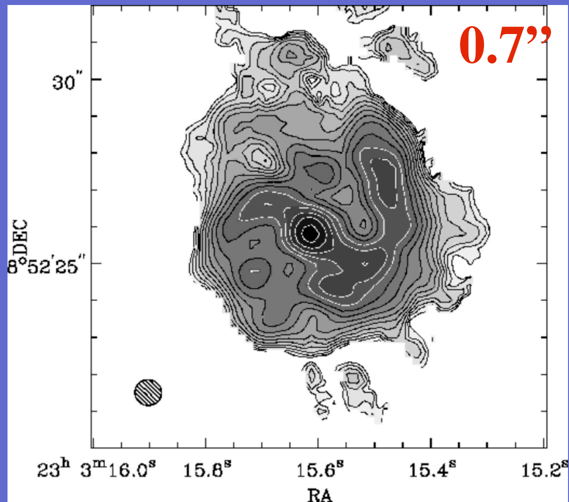
In pre-QSO phase, a massive dusty torus ($M_{BH} << M_{torus}$) exists around BH.

(Kawakatu, Umemura & Mori 2003)

Nearby Seyfert 1s

NGC 7469 (66 Mpc)



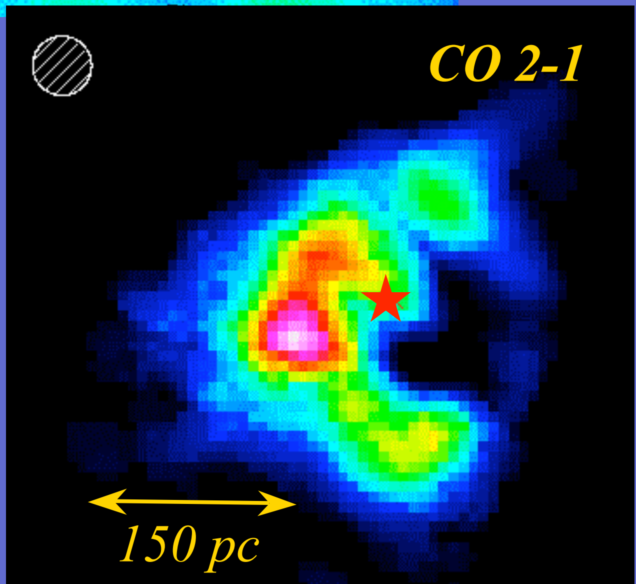


M_{CO}/M_{BH} ~ 400

Davies, Tacconi Genzel, 2003

M_{CO}/M_{BH} ~ 90

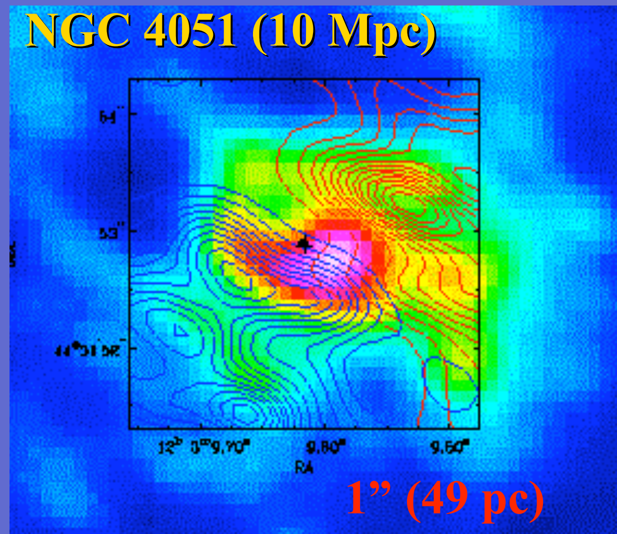
BLS1



N 3227 (16 Mpc)

NLS1

NGC 4051 (10 Mpc)



M_{CO}/M_{BH} ~ 15

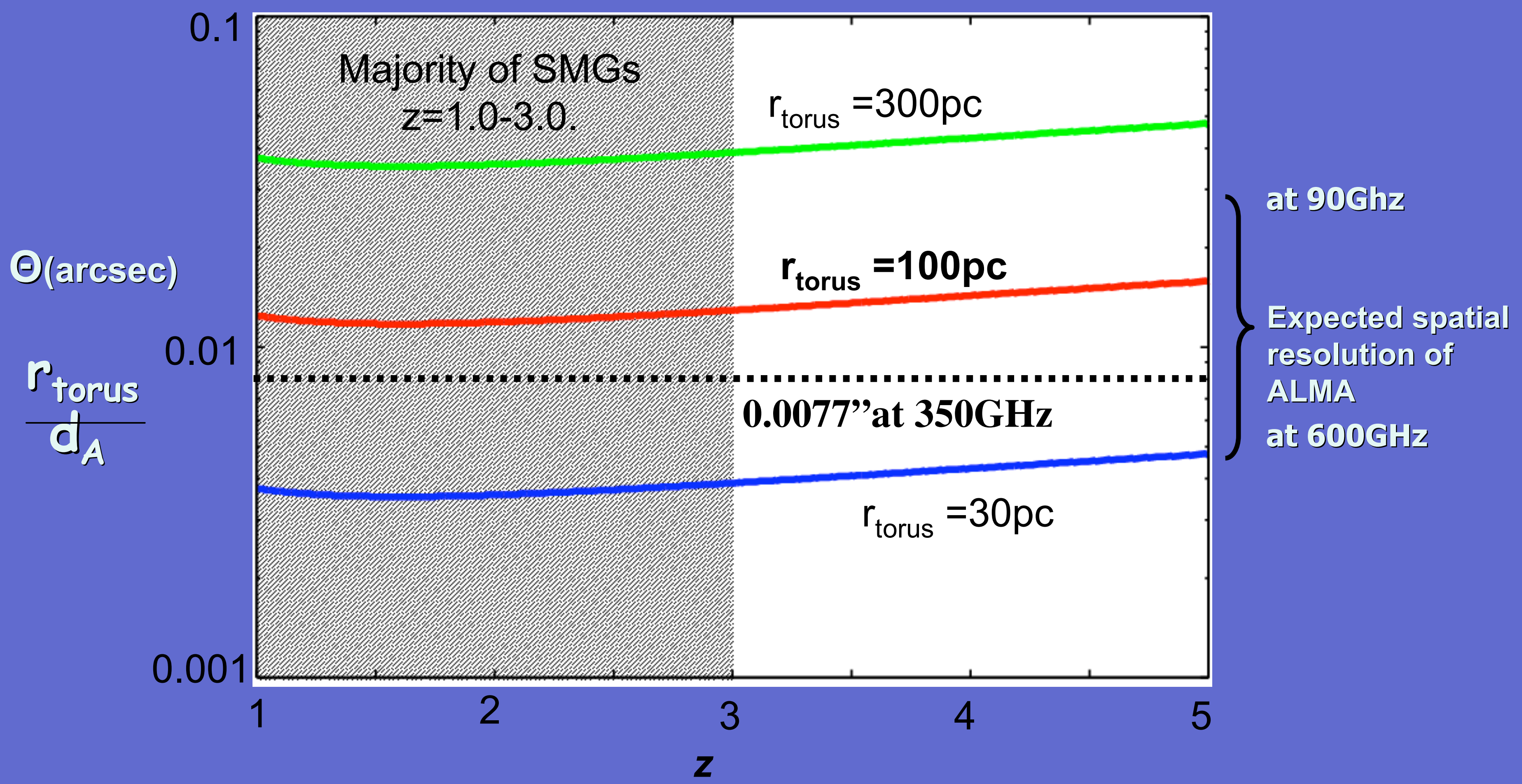
Schinnerer et al., 2000

Looney et al., 2002

Requested spatial resolution

(H_0=70 km s^{-1} Mpc $^{-1}$ Ω_m =0.3, Ω_Λ =0.7)

PdBI (Max: 0.6'')



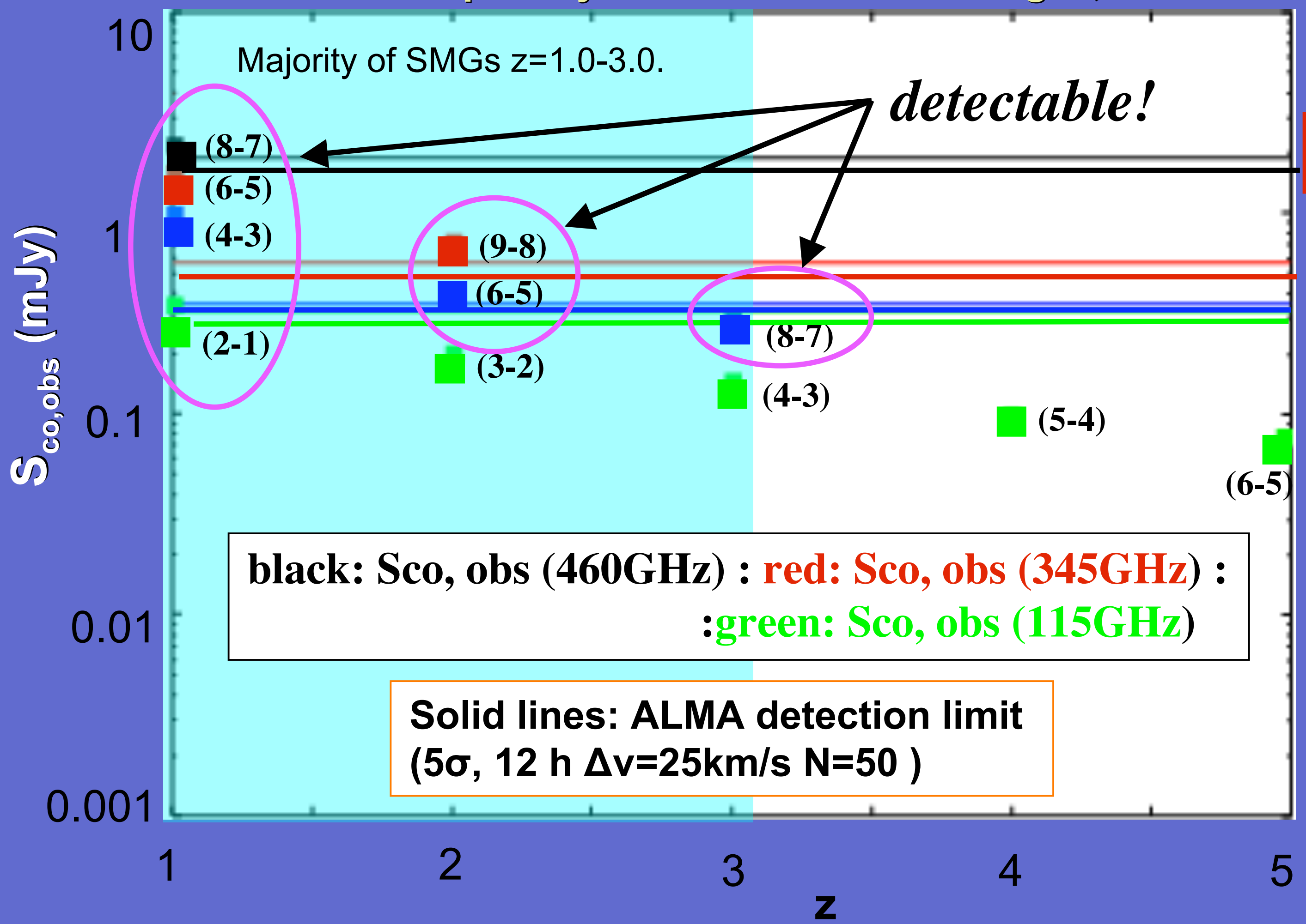
We can resolve a massive torus (~100pc) with ALMA

High spatial resolution (0.01'') is required!

Expected CO emission flux

Assumption: L(J+1-J)/L(1-0)=1 for 1<J<9, Xco=0.8 (K km s^{-1} pc^2) $M_\odot$

optically thick and thermalized gas, size of torus =100pc



M_{torus} =3 $10^8 M_\odot$

($S_{co,obs} \propto M^{1.5}_{torus}$)

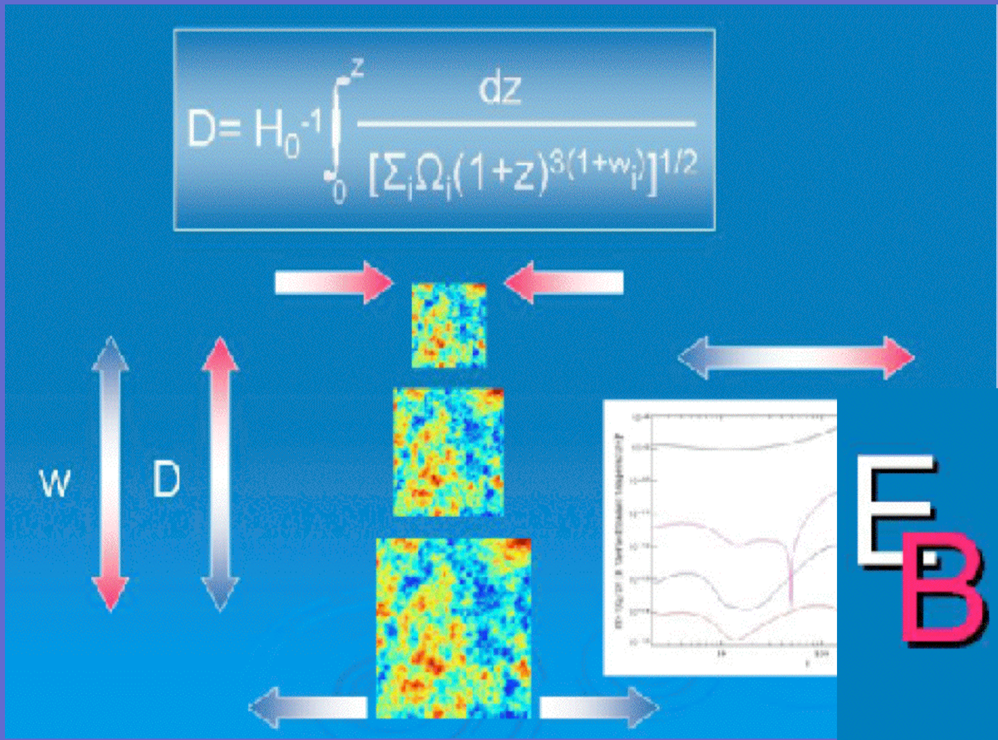
It is possible to detect a massive torus with more than $10^8 M_\odot$ with ALMA.

CMB BB polarization modes in presence of DE

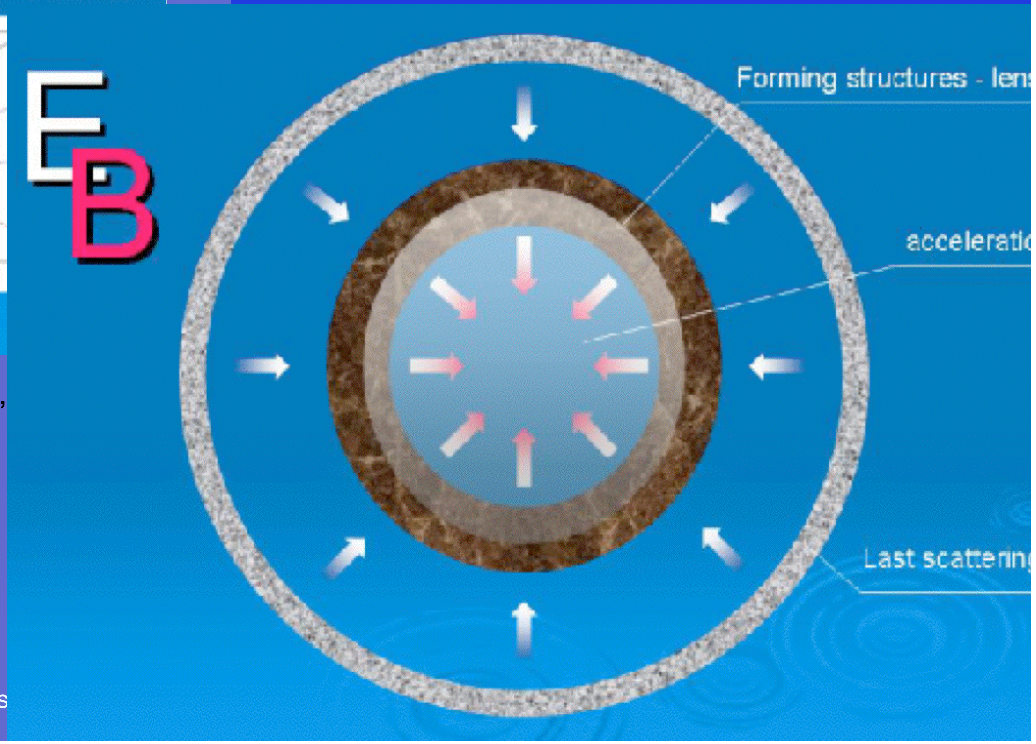
additional effect in polarization:
leaking of EE polarization modes into BB

DE dynamics affect the cosmological expansion rate modifying the power of the lensing and the magnitude of BB modes

BB modes are sensitive to the dark energy abundance at the epoch when the lensing is effective on CMB (z ~1)



(Acquaviva & Baccigalupi,



The generation of lensing BB modes in the CMB polarization anisotropies occurs at the onset of acceleration and is sensitive to the dark energy abundance at that epoch.
The expected BB signal is dominated by lensing on arcminute angular scales.

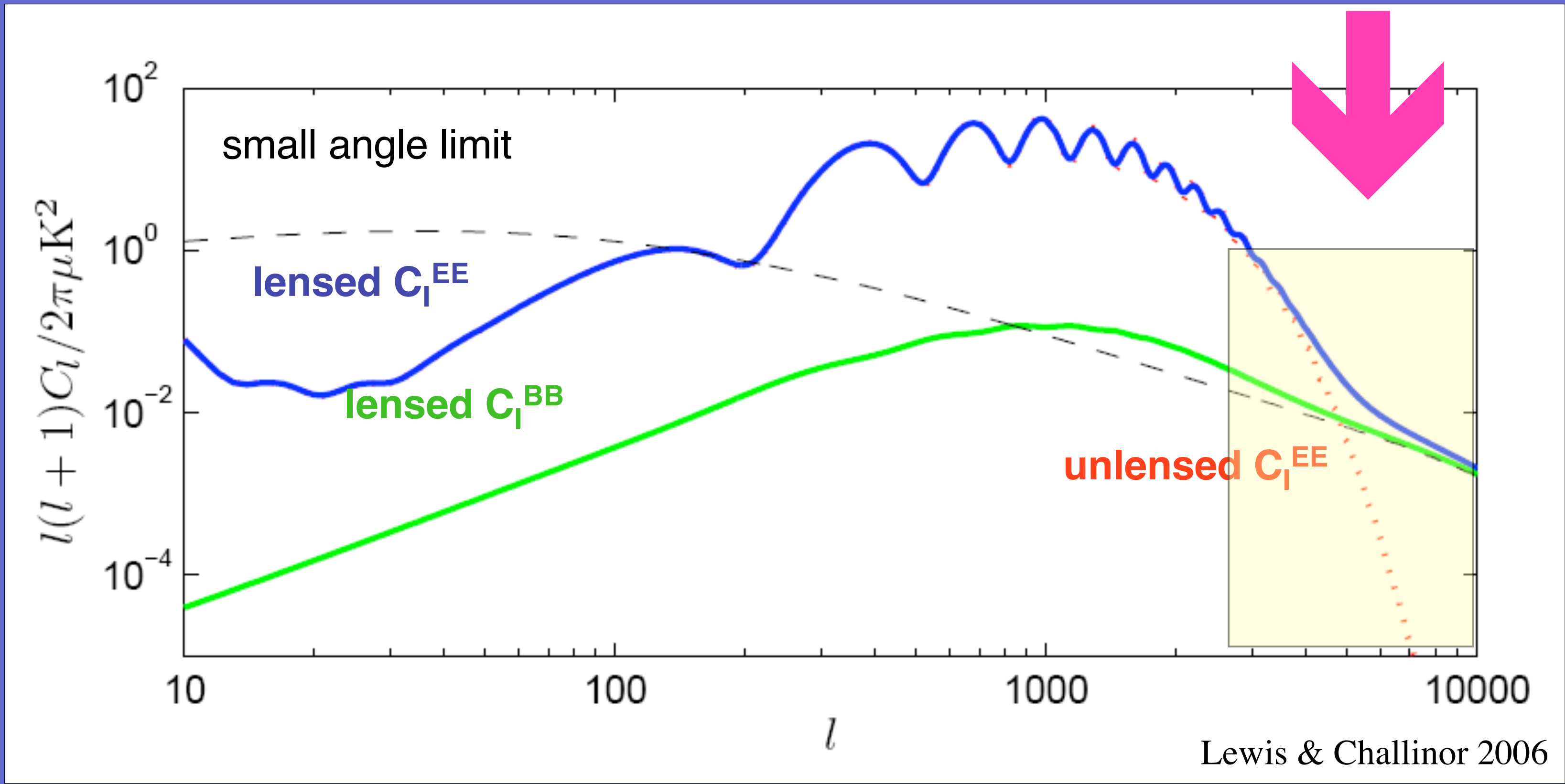
ALMA, APEX, Hers

Expected signals

polarization anisotropy spectrum

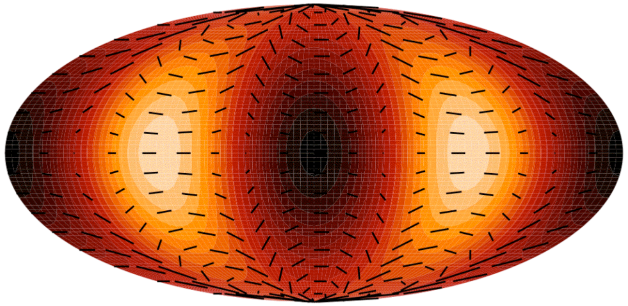
EE and BB: polarization tensor components

on very small scales ($l \geq 3000$, i.e. ALMA) the lensed power spectrum is much larger than the unlensed



Polarization induced by CMB quadrupole

temperature quadrupole



(Baumann & Cooray, 2003)

The redshift evolution of the quadrupole has a rise at low z as the Universe becomes DE-dominated

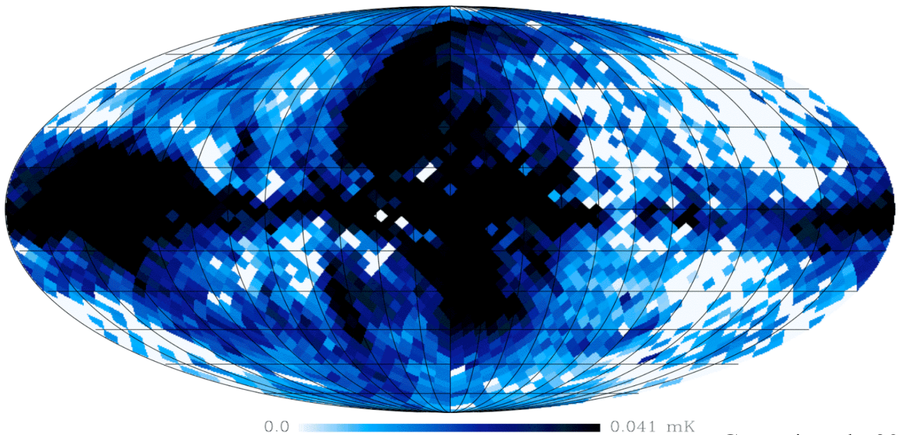
CMB polarization due to galaxy clusters.

- **CMB polarization towards clusters is generated when the incident radiation has nonzero quadrupole moment.**
- **The quadrupole has two components: the projection of the primordial CMB quadrupole to the cluster location and a local kinematic quadrupole from the cluster peculiar motion.**

(Sazanov & Sunyaev, 1999)

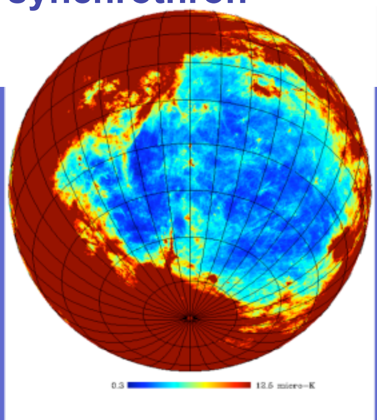
Foregrounds: point sources + Galaxy

WMAP polarization map at 22.5GHz

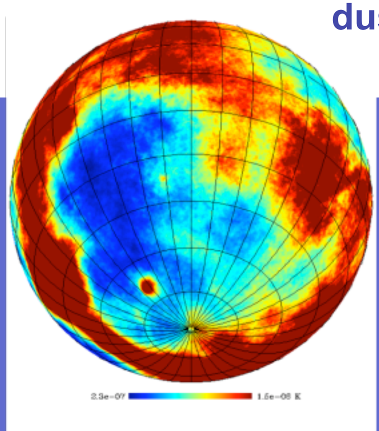


Carretti et al., 2006

synchrothron



dust



- **Contamination from point sources:**
- **compact flat spectrum radio sources**
- **submm? Arp220 (<1.54%)**

(Baccigalupi et al., 2001; Tucci et al., 2004; Seiffert et al., 2006)

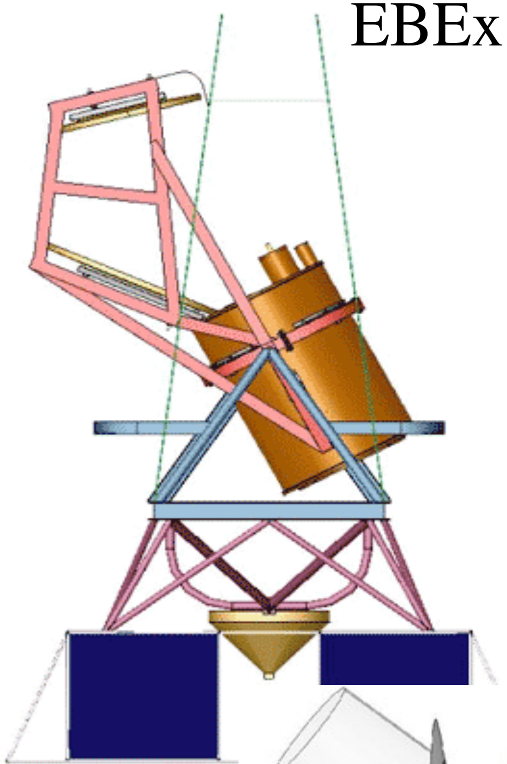
- **Galaxy:**
- **Dust emission polarized, increases with λ**
- **Overall polarization on average decreases wrt individual clouds**
- **Diffuse synchrothron emission dominant at $\nu < 70$ GHz.**

Synergies with CMB Experiments

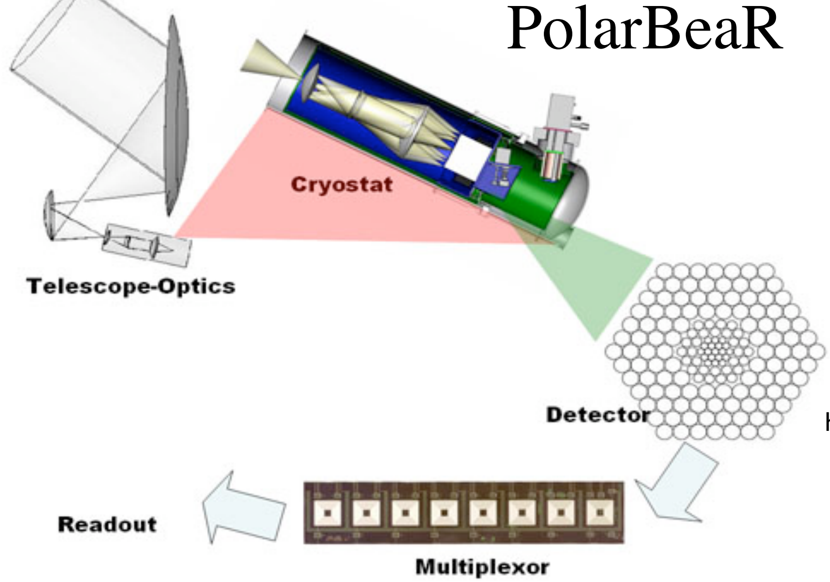
EBEx, CAPMAP, Clover, MBI-B

PolarBeaR, Polatron, QUAD, QUIET

EBEx



PolarBeaR



QUAD

http://lambda.gsfc.nasa.gov/product/suborbit/su_experiments.cfm

Conclusions for common projects

- HSO/PACS + SPIRE + APEX/Artemis+LABOCA: suited to surveying large regions and SED in the FIR
- ALMA: high sensitivity, high ang. Resolution in spectral line and continuum and SED @ long-λ
- HSO+APEX extragalactic/Galactic survey driver
- ALMA follow up (z, size, physical conditions)
- ALMA - HSO: complementary because of different frequency range and resolving power
- HSO/HIFI + ALMA: complementary in spectral line surveys and studies (i.e. H_2O)

Synergies

Herschel / APEX

- bolometres suited to survey large regions of sky
- Take the lead in initiating projects
- PACS+SPIRE+LABOCA+ ARTEMIS: finding surveys
- HIFI: water vapour + other molecules not observable from ground

ALMA

- high sensitivity, high spatial resolution
- Quick reactions to followup (redshifts, longer-λ SEDs)
- Redshift machine + identification
- Complementary lines

(3_{13}-2_{20} H_2O transition @183GHz) and H_2O^{18} @203GHz) + high resolution

Paola Andreani

Supporting Observations and Data

- Lower angular resolution preparatory surveys (APEX+LABOCA, SCUBA2, LMT, APEX+Artemis, SCELT+ELT?, Spitzer) larger single dishes+large bolometer cameras: higher mapping speed+lower source confusion
- Single dishes very wideband spectroscopy up to 32GHz: spectra with multiple transitions: suitable for redshift.
- Molecular collision rates, radiative transfer algorithms, chemical reaction rates
- Completely automated form of data reductions (huge datacube) automated comparison with models

Calibration

- **Accurate calibration: measurement and modeling programmes, including time variation**
- **Different limitations of ALMA and Herschel: PACS and SPIRE are quickly saturated and large bandwidths**
- **Less bright, smaller outer planets and asteroids**
- **HIFI+ALMA: common bands**

  small spectral line sources unresolved by ALMA but bright enough for HIFI (S/N small)

  Complete ALMA imaging of slightly extended calibration sources (large investment of time)

Conclusions

- Synergies between ALMA and other experiments: Herschel, APEX+LABOCA, SCUBA2, LMT, APEX+Artemis, SCELT+ELT?, JSWT
- Common scientific projects: competion vs complementarity
- Data model
- Preparatory observations (surveys) see workshop
- Calibration (steering committee)
- Data archive (VO compliant)