Event Horizon Technical Working Group Summary

Event Horizon Telescope Specifications

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and
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10: MIT Haystack, SMA

EHT meeting, CfA, Jun 11 2014

Future mmVLBI

- **Currently: 8 Gb/s** for 2x1 GHz dual-pol
- ALMA aggregate bandwidth per telescope: 16 GHz (64 Gb/s)
  - *upgrade to 32 GHz being studied*

Configuration options and Development path:

1. **16 Gb/s** for 2x2-GHz dual-pol or 1x4-GHz single-pol
2. **32 Gb/s** for 2x4-GHz dual-pol
3. **64 Gb/s** for 2x2x4-GHz dual-pol, dual-sideband
4. **….**

ETWG

Formed about 1 year ago

Objectives:

1. Survey the capabilities at all EHT facilities
2. Establish a set of specifications for future EHT observations
3. Outline a technical developments needed to reach these goals
4. Iterate with science and oversight working groups in formulating a project roadmap with prioritized science objectives and that grounded in technical feasibility with the resources available.

Survey the capabilities for 64 Gb/s VLBI

EHT: Instrument Matrix (~2016)

	BEAMFORMER	INTERNET	MASER	RX230	RX345	VLBI-BACKEND	VLBI-RECORDER	WVR	REVIEWER
SMTO	n/a	24	y	y	2016?	n	n	n	Shep Doeleman + Dan Marrone
SMA	2014	24	y	y but	y	y	y	n	Jonathan Weintroub
CARMA	2015?	24	y	y	n	y	n	n	Dick Plambeck
JCMT	n/a	24	y	n but	n	n	n	y	Remo Tilanus
APEX	n/a	24	y	2015?	y	y	y	y	Alan Roy
LMT	n/a	24	y	n	n	n	n	n	Shep Doeleman
IRAM-PV	n/a	24	y	y	y	y	y	n	Michael Bremer
SPT	n/a	7-11	2015	2015	2016?	n	n	n	Dan Marrone
ALMA	2015	24	y	y	y	y	y	y	Satoki Matsushita/Shep Doeleman
IRAM-PdB	2017	24	y	y	n	y	y	y	Michael Bremer; Vincent Pietu

	red = missing	orange = needs new/upgrade	salmon = missing, but secondary

Survey the capabilities for 64 Gb/s VLBI

EHT: Instrum

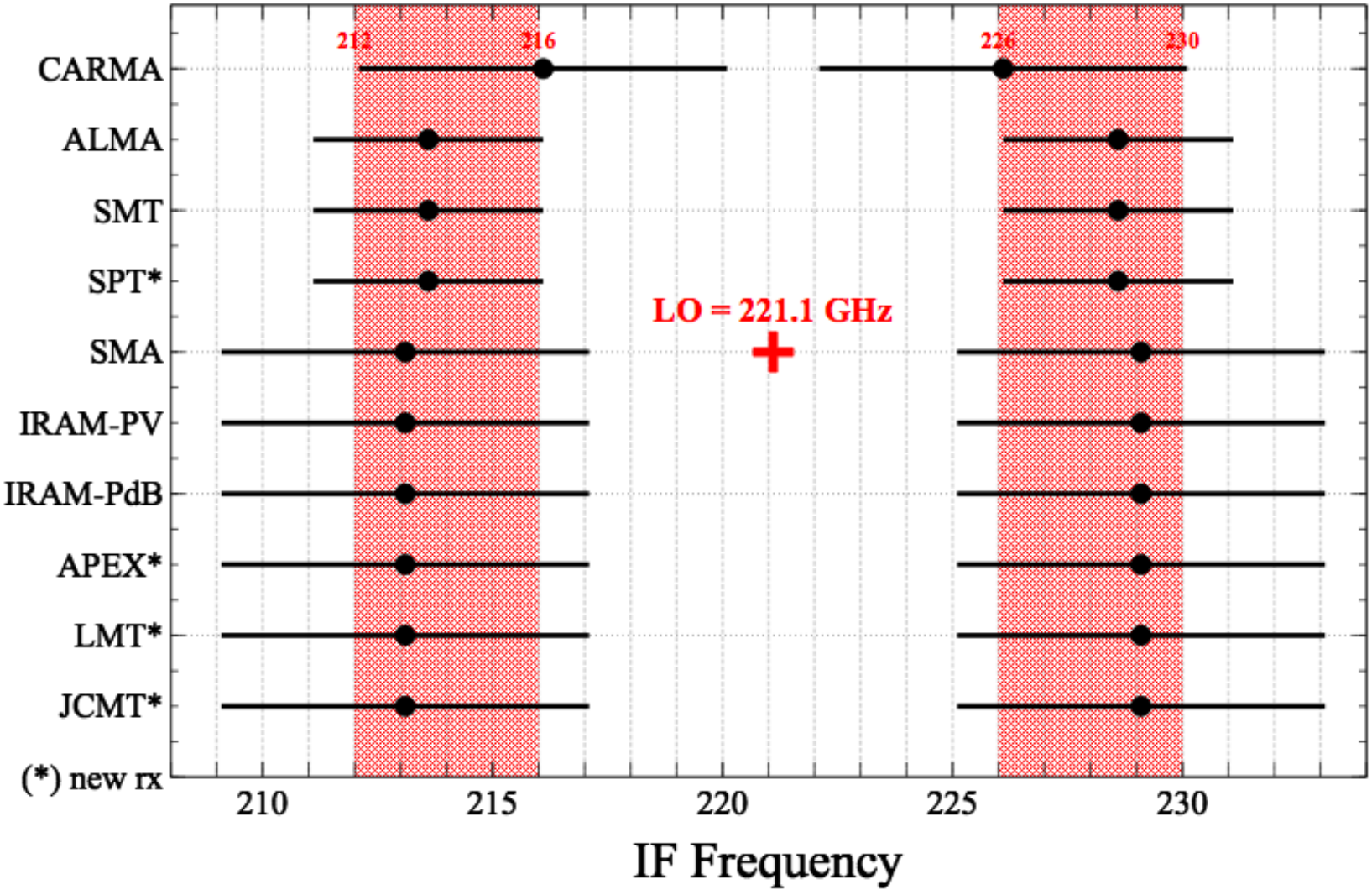
	BEAMFORMER	INTERNET	MASER	RX230	H
SMTO	n/a	24	y	y	
SMA	2014	24	y	y but	
CARMA	2015?	24	y	y	
JCMT	n/a	24	y	n but	
APEX	n/a	24	y	2015?	
LMT	n/a	24	y	n	
IRAM-PV	n/a	24	y	y	
SPT	n/a	7-11	2015	2015	
ALMA	2015	24	y	y	
IRAM-PdB	2017	24	y	y	
	red = missing			orang	

- From start: at most telescopes, (planned) receivers and IFs compatible with 64 Gb/s VLBI (but some dsb i.s.o. 2sb)
- Wide-band beamformers at the various interferometric arrays are on critical path (and often waiting for wide-band correlator upgrades to be completed.
- Compliance matrix focused initiatives towards future upgrades at APEX (new receiver being built) and JCMT (upgrade stalled).

Draft specifications for EHT Observing

1. IF Range for dual-sideband VLBI (i.e. 64 Gb/s):
   - 1.3 mm: 5-9 GHz
   - 0.8 mm: 4-8 GHz
2. LO frequency for observations (SPT not tunable):
   - 1.3 mm: 221.1 GHz
   - 0.8 mm: 342.3 GHz
3. VLBI signal-chain:
   - Downconverter + R2DBE or DBBC3 + Mark 6 recorders
   - 64 or 62.5 MHz channels, VDIF compliant
4. Base-mode: dual-polarization observations.
5. Form polarization products at correlator
   - desirable long term, but default for ALMA and functionality being added to DiFX
6. Semi-turnkey systems with enhanced fringe-checking capabilities (flexible scheduling)

IF-range 1.3 mm: 5-9 GHz (for dual-sideband)



RX230

green = compatible with 221.1 LO and IF 5..9 GHZ

Return

	Available	Min LO	Max LO	Min IF	Max IF	Sideband	Polarization	Handiness	Circ Waveplate	Remote In/Out	Remote rotation	Comments
SMTO	y	210	273	5	10	2sp	dual	linear	y	n	n	
SMA	y	183	245	4	12	dsb	single	linear	y	y	y	Restrictions 5-9; waveplates need installation
CARMA	y	210	270	1	9	dsb	dual	circular	n/a	n/a	n/a	
JCMT	y	210	270	4	8	dsb	single	linear	y	n	y	SMA-style mixer is 4-12 GHz (needs installation)
APEX	2015?	214	267	4	12	2sp	dual	linear	y	n	n	New RX being built
LMT	n											RX being planned
IRAM-PV	y	214	267	4	12	2sp	dual	linear	y	n	n	
SPT	2015	221.1	221.1	5	10	2sp	dual	linear	y	n/a	n	Under construction. Single LO freq.
ALMA	y	221	265	5	10	2sp	dual	linear	n/a	n/a	n/a	
IRAM-PdB	y	214	267	4	12	2sp	dual	linear	y	y	n	IF 4-8+8-12

RX345

green = compatible with 342.3 LO and IF 4..8 GHZ

Return

	Available	Min LO	Max LO	Min IF	Max IF	Sideband	Polarization	Handiness	Circ Waveplate	Remote In/Out	Remote Rotation	Comments
SMTO	2016?	283?	365?	4	8?	2sp	dual	linear	y	n	n	New mixer in progress. Current mixer high-Tsys.
SMA	y	260	354	4	8	dsb	dual	linear	y	y	y	in dual pol mode LO range is 330 to 345 GHz
CARMA	n											
JCMT	n	325	370	4	6	dsb	dual	linear	y	n	y	Mixers removed!
APEX	y	267	378	4	8	2sp	single	linear	n	n	n	
LMT	n											
IRAM-PV	y	289	355?	4	12	2sp	dual	linear	n	n	n	l/4 plate could be built in-house when frequencies are kn
SPT	2016?	342.3	342.3	4	12	2sp	dual	linear	y	n/a	n	Under construction. Single LO freq.
ALMA	y	283	365	4	8	2sp	dual	linear	n/a	n/a	n/a	
IRAM-PdB	n	289	355?	4	12	2sp	dual	linear	y	y	n	First NOEMA extention does not have 345 GHz

LO Frequency for mmVLBI

Dan Marrone, Remo Tilanus, Shep Doeleman

Constraints:

- Avoidance of the Galactic CO
  - 230.5379 ± 300 km/s; i.e. v ~ 230.31 – 230.77 GHz
- Avoidance of Galactic 13CO (to a lesser extent)
  - 220.3987, or 220.18-220.62 GHz
- Atmospheric transmission.
- Access to the SiO maser (215.596 GHz) for VLBI calibration
- Access to specific lines for calibration, etc.:
  - in extended IF range of SPT
- [Performance current wave plates, which are centered on 225 GHz (to a lesser extent)]

(similar for 0.8 mm window)

LO Freq at 1.3mm: 221.1 GHz

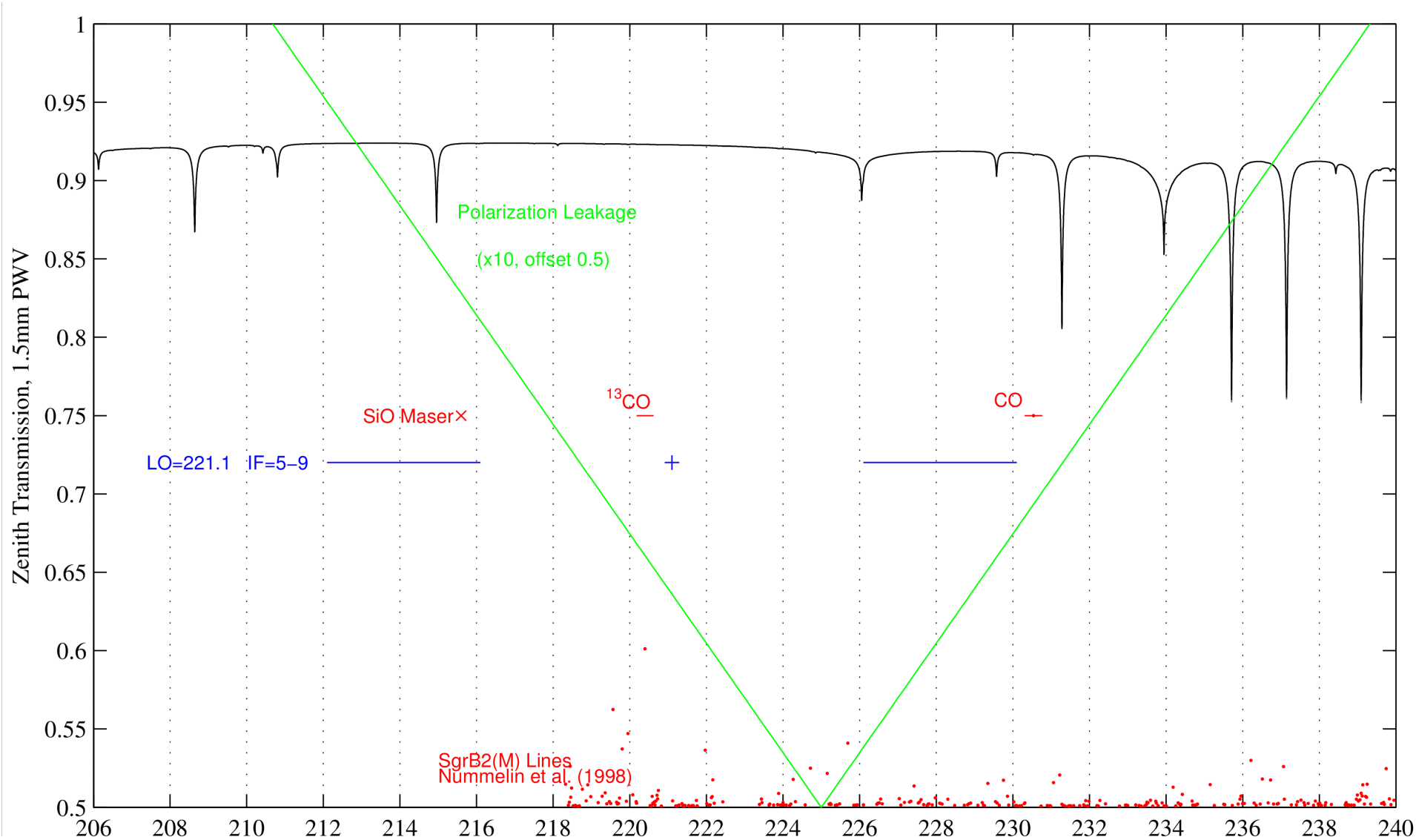


Figure courtesy Dan Marrone

LO Freq at 0.8mm: 342.3 GHz

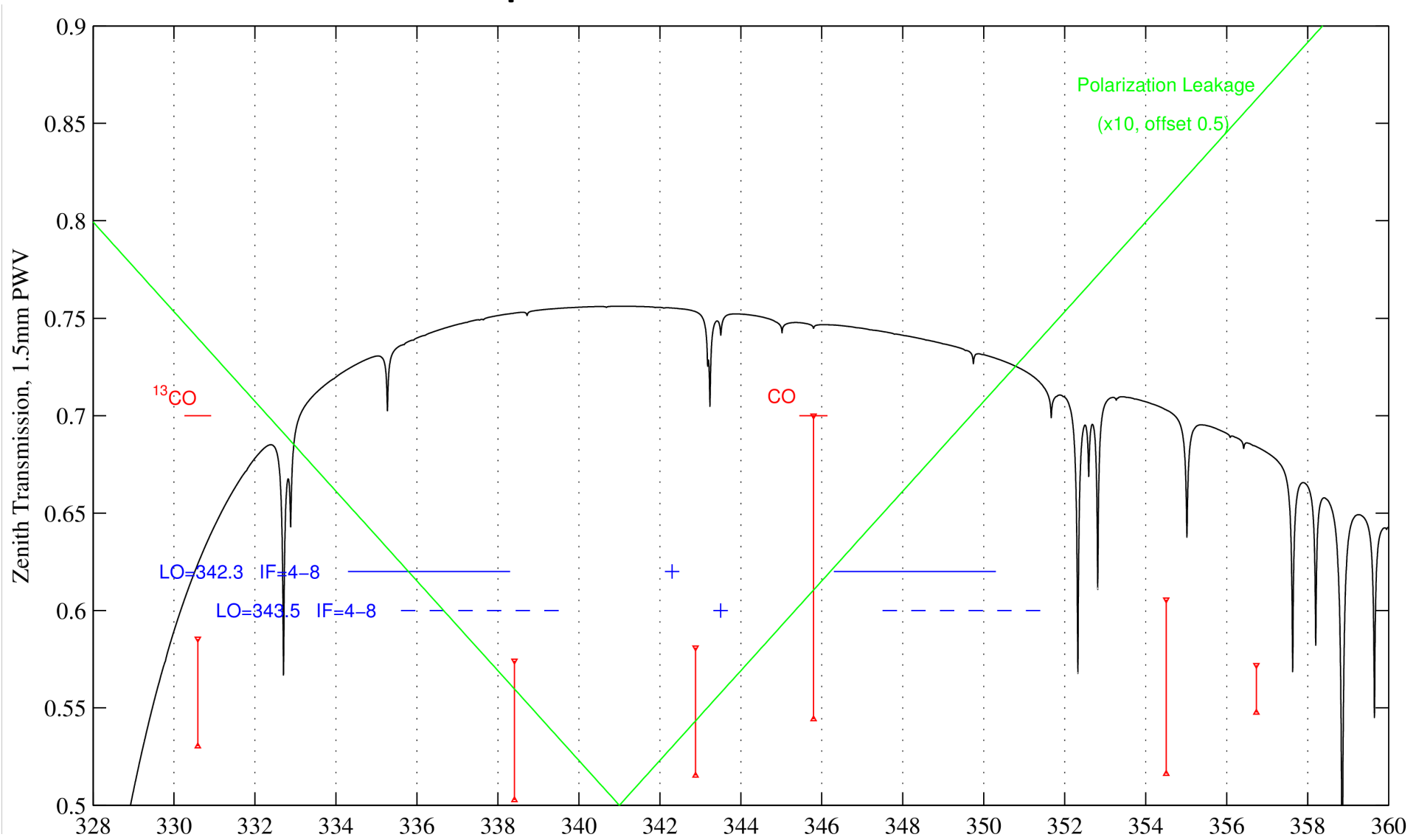
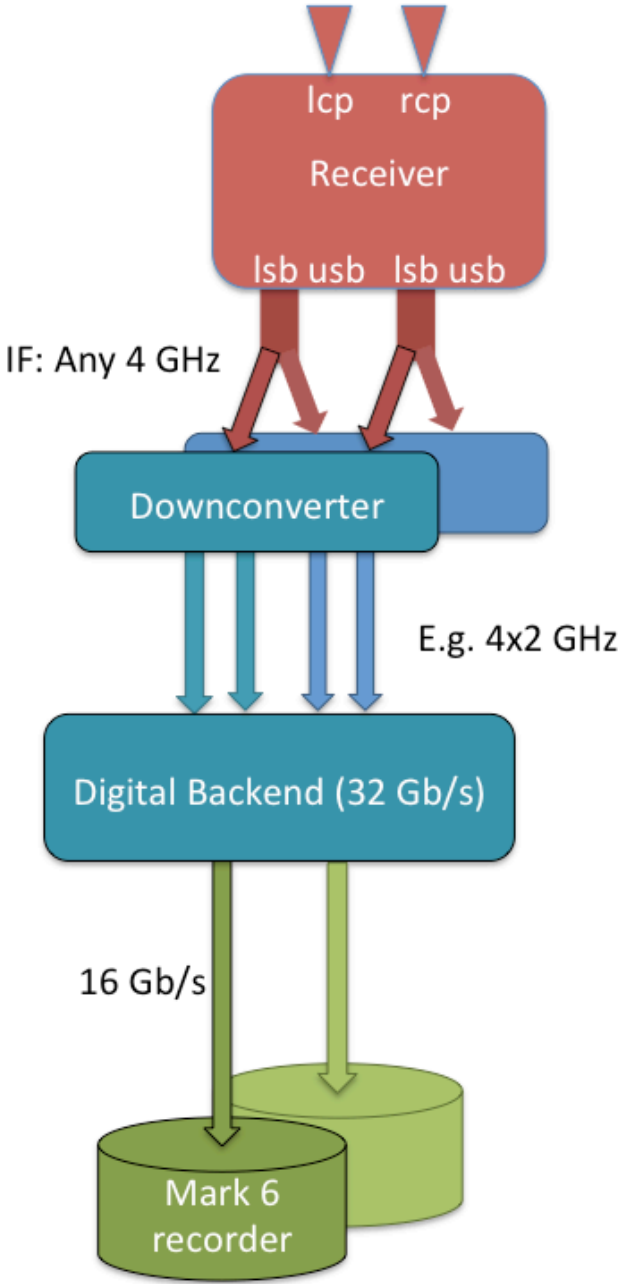


Figure courtesy Dan Marrone

EHT – VLBI Schematic 32 Gb/s: 2x4 GHz 1SB/DSB



Single-dish Equipment:

- Down-converter unit(s)
- Digital backends: 16, 32, or 64 Gb/s versions of R2DBE or DBBC3
- Recorders: 16 Gb/s Mark 6

Ongoing:

- R2DBE takes 2-GHz IF-chunks
- DBBC3-L takes 4-GHz IF chunks

Next step: detailed specifications of the signal chain.

Polarization

Desirable long-term: Form polarization products at correlator.

- Default for ALMA
- Waveplates: semi-turnkey systems would require remotely controlled polarimeters.
- Some existing systems require waveplate swaps between e.g. 1.3 and 0.8 mm.

➔Long-term, waveplates would require development suitable polarimeter

➔This issue requires detailed study

	Circ Waveplate	Remote In/Out	Remote rotation
SMTO	y	n	n
SMA	y	y	y
CARMA	n/a	n/a	n/a
JCMT	y	n	y
APEX	y	n	n
LMT			
IRAM-PV	y	n	n
SPT	y	n/a	n
ALMA	n/a	n/a	n/a
IRAM-PdB	y	y	n

Semi turn-key systems *(ongoing)*

Main technical requirements voiced by telescopes:

- Better integration with standard observing that can be supported by non-expert operators
- Quality assurance: i.e. quick-turnaround fringe verification
  - E.g. port EVN Mark 5 eVLBI "snap-shot" mode to Mark 6 for fringe check on calibrators (may require FILAxx)
  - Pipeline reduction: port VLBI functionality to CASA?
  - Remote monitoring
- "Flexible scheduling" of VLBI i.e. no pre-determined fixed observing dates (but can be within encompassing VLBI blocks).
  - EHT also requires to benefit from best conditions at most sites.
  - New VLBI scheduling software

Data Acquisition *(ongoing)*

Data volumes will be very large!

- 32 Gb/s, per station: two Mark 6s, 8 modules, 64 hard drives
- With 4 Tb drives: 0.25 Petabyte (PB) per station or ~2.5 PB for array
- This provides ~17 hrs of continuous recording i.e. about two/three 12-hr VLBI sessions depending on duty-cycle

Questions:

- Implication for correlation centers? Effective deployment of resources may require data duplication.
- Data integrity issues? Risk mitigation may require data duplication.
- Multiple sessions per year?
- Double requirement for 64 Gb/s.

Next steps…

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Definition and assignments Work Packages (next presentation)